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Impacts of Severe Weather, Climate Zone, and Energy Factors on Base Realignment and Closure (BRAC)

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THESIS

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Abstract

The Air Force is in a period of downsizing, both aircraft and personnel. In recent years, the service has cut hundreds of aircraft from its fleet and decreased military end-strength, but has not substantially reduced its infrastructure. Consequently, the cost to operate and maintain Air Force Bases is not decreasing. Mitigation methods are needed to manage the costly burden of excess infrastructure. A new Base Realignment and Closure (BRAC) round will help the Air Force reduce unnecessary infrastructure and alleviate precious resources necessary for weapon modernization and improved readiness. Cost savings through BRAC can help the Air Force achieve reduced spending and realign itself to post-war budget reductions and a constrained fiscal environment.

This research analyzed new severe weather and energy factors at 62 major Air Force Bases in the United States. Adding these new factors should better account for other potential costs and savings associated with BRAC. To estimate these costs, a Monte Carlo simulation is used to forecast annual costs and account for uncertainty with tornado and hurricane risks, along with annual electricity and natural gas costs. Annual cost estimates of these four factors range from approximately $1-million to $100-million dollars. Each base is ranked in a *1-to-n* list, according to the total annual cost of the four factors, from highest to lowest. The base with highest annual cost is the best candidate, according to the new proposed criteria, to be eligible for a future BRAC round. If a base is selected for closure, forecasted costs are avoided and ultimately become savings that help offset other expenses in a BRAC scenario.

To my wife and daughter – AFIT has put us all through a lot, but we survived together!

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IMPACTS OF SEVERE WEATHER, CLIMATE ZONE, AND ENERGY FACTORS ON BASE REALIGNMENT AND CLOSURE (BRAC)

Chapter 1 – Introduction

The purpose of chapter 1 is to provide a foundation of knowledge on the background and problems addressed in this research. This chapter begins with a brief examination of the background of Base Realignment and Closure (BRAC), severe weather in the United States (U.S.), climate zone, U.S. energy use, U.S. energy policy, energy reporting mechanisms, and utility rates. The problem statement, research and investigative questions, hypotheses, assumptions and scope, methodology, and the significance of the study are then addressed. The chapter concludes with a brief overview of the remaining chapters. The introduction establishes the groundwork for how severe weather, climate zone, energy use, and utility rates can influence future BRAC and basing decisions. Ultimately, these critical factors may help identify the most risky and costly locations to maintain Air Force installations and provide valid closure or realignment recommendations to future BRAC efforts.

1.1 – Background

1.1.1 – BRAC

BRAC is the congressionally authorized process that the Department of Defense (DOD) uses to reorganize its bases and infrastructure to more efficiently and effectively support its forces, increase operational readiness, and facilitate new ways of doing business (DOD, 2005c). Under a closure scenario, all installation missions cease or relocate, and all military, civilian, and contractor personnel relocate or are eliminated. Likewise, realignment includes any action that both reduces and relocates military functions and civilian personnel positions, but does not include a reduction in force resulting from workload adjustments, reduced personnel or funding levels, or skill imbalances (DOD, 2005e).

The DOD administered the BRAC process through five rounds of realignment and closure during the years of 1989, 1991, 1993, 1995, and most recently in 2005 (GAO, 2010). The current BRAC process takes into account many factors for realignment or closure, but one of the leading purposes of BRAC is the reduction of costs through elimination of infrastructure. As of Fiscal Year 2014, the DOD maintains a total of 4,855 locations worldwide while the Air Force maintains a total of 1,732 locations, ranging from large installations to small sites, with a total plant replacement value exceeding $850 billion dollars. Furthermore, 523 of the DOD and 185 Air Force locations are considered major or large installations (DOD, 2013). Many of these major bases have been active or used since the 1940s or earlier. While each installation served an important purpose at some point during its lifespan, some locations became less important or obsolete as mission needs changed.

Over the last 70 years or so, the DOD and Air Force have evolved from a large force requiring numerous personnel, equipment, vehicles, ships, and airplanes to a much leaner force. The evolution was necessary to shift from a post-World War and Cold War mentality to a much more modular, mobile, and agile force designed to confront smaller multi-state conflicts and Global War on Terrorism style engagements (Anderson, 2009; OMB, 2014a). During World War II and the Cold War, an expansive build-up occurred from the 1940s through the 1980s, which created an overabundance of dispersed installations (Sorenson, 1998). Although the vast framework of bases served its purpose to counter the threat at the time, a considerable amount of the infrastructure became excess, obsolete, and a burden to maintain. As stated in the *Fiscal Year 2015 Budget* request, the DOD wants to develop a smaller force, by reducing military end-strength and force structure, to build a technologically superior and more agile force (OMB, 2014a). A central focus of DOD's Fiscal Year 2015 budget is also to align infrastructure with its current mission and force structure needs. To meet this goal, defense officials requested authorization for a new BRAC round in 2017 (OMB, 2014a). According to a February 2014 speech by Defense Secretary Chuck Hagel, "We cannot fully achieve our goals for overhead reductions without cutting unnecessary and costly infrastructure." Hagel goes on to say, "I am mindful that Congress has not agreed to [our] BRAC requests of the last two years. But if Congress continues to block these requests even as they slash the overall budget, we will have to consider every tool at our disposal to reduce infrastructure" (DOD, 2014a).

Following the Secretary's 2017 BRAC request, Congress sought to restrict the DOD's efforts in conducting future BRAC rounds. The Fiscal Year 2014 National Defense Authorization Act (NDAA) "would prohibit funds, appropriated pursuant to an authorization of appropriations contained in this Act, to be used to propose, plan for, or execute an additional Base Realignment and Closure (BRAC) round" (HASC, 2013). The Senate committee also included a provision that would "establish, as a precondition for the authorization of a future BRAC round, a requirement for the Department of Defense to submit to Congress a formal review of overseas military facility structure" (HASC, 2013).

However, language in the NDAA does not completely prohibit DOD from conducting some forms of analysis. Legal authority still exists for the DOD to conduct infrastructure capacity analysis. According to the United States House of Representatives and Senate Armed Services Committee's Joint Explanatory Statement for the Fiscal Year 2015 NDAA:

> Due to the force structure changes and infrastructure investments and management strategies that have occurred since the 2005 BRAC round, we believe that excess infrastructure capacity assessments should be based on current infrastructure data and informed by current force structure projections. We believe the Department of Defense

has the authority to provide such an updated analysis but to date has not provided such an assessment (HASC, 2014).

Furthermore, the DOD has legal authority, granted under Title 10 of the U.S. Code, Section 2687, "Base closures and realignments," that states it can plan for base realignments based on current force structure and capacity analyses (Code, U.S., 2011). Conducting capacity analyses and determining requirements based upon force structure are considered routine activities. The services should conduct these activities to ensure proper use of installations and to justify basing decisions and validate funding strategies (J. Webb, personal communication, December 29, 2014).

Although the Fiscal Year 2014 NDAA is a setback for the proposed 2017 DOD BRAC efforts, the DOD plans to submit future BRAC proposals to Congress. If BRAC proves to be too large of a political hurdle, the DOD has other tools at its disposal to reduce or manage infrastructure. Some tools the DOD can pursue are alternative privatization strategies, such as Public-Public Public-Private Partnerships (P4) and City Base agreements, that can mitigate the costly burden of excess infrastructure (Meurer, Morris, Bonner, Zgabay, & Rowe, n.d.). Another tool employs the concept of "warm basing," which keeps a base open in a limited, less costly way while avoiding opposition to a full BRAC closure action (Everstine, 2014). Furthermore, the nonpartisan Congressional Research Service said in a 2012 report, "while base closures and realignments often create socioeconomic distress in communities initially, research has shown that they generally have not had the dire effects that many communities expected. For rural areas, however, the impacts can be greater and the economic recovery slower" (Cowan, 2012).

The DOD contends that considerable excess infrastructure capacity remains for all branches of the military with estimates at or above 25 percent excess (Garamone, 2013). In April 2014, Kathleen Ferguson, Assistant Secretary of the Air Force (Installations, Environment,

& Logistics), testified to a Senate Armed Services Committee that capacity estimates show the Air Force has about 24 percent excess infrastructure (Ferguson, 2014). This estimate is based on the most recent capacity analysis completed in 2004 (prior to the 2005 BRAC). Since that analysis, the service has cut more than 500 aircraft and reduced military end-strength by nearly 8 percent (Ferguson, 2014). Consequently, without a new BRAC round, the DOD will be forced to maintain unnecessary infrastructure with precious resources that could otherwise be used to modernize and field needed military capabilities (OMB, 2014a). To illustrate this magnitude of excess, a 20 percent targeted reduction in installation infrastructure could generate approximately $7-billion dollars in annual savings, based on similar costs and savings experiences of the most recent BRAC round in 2005 (DOD, 2005c). By reducing the cost burden of excess capacity at Air Force installations, the DOD can reallocate resources currently being spent on infrastructure to higher priority requirements, such as weapon modernization and improved readiness (Anderson, 2009). Additional BRAC cost savings can also help the DOD achieve reduced spending and realign itself to budget reductions and a more constrained fiscal environment.

1.1.2 – Severe Weather in the United States

Severe weather has been prominently featured in the news over the past 10 to 15 years. Major storms and severe weather events such as Hurricane Katrina, Superstorm Sandy, and tornadoes in Joplin, MO, and Moore, OK, have captured the headlines, costing the United States billions of dollars in losses (Smith & Katz, 2013). History has shown many examples of major severe weather events and their impact to Air Force bases. Recent examples include Hurricane Katrina's impact on Keesler Air Force Base in 2005. Keesler Air Force Base suffered nearly $1 billion dollars in damages from Hurricane Katrina alone (Keesler AFB website, n.d.). In addition, Hurricane Isabel caused major storm surge and flooding at Langley Air Force Base in

September 2003, costing an estimated $147 million dollars in damage (Langley AFB History Office, 2003). Two destructive tornadoes struck Tinker AFB in March 1948. The tornadoes hit on 20 and 25 March 1948, within five days of each other, producing in excess of $10 and $6 million dollars in damage to the base, respectively (Maddox & Crisp, 1999). Multiple tornadoes hitting a military installation within the course of five days was a historical event in itself. More importantly, however, base weather-detachment officers, Major E. J. Fawbush and Captain R. C. Miller, accurately forecasted the recurrence of the second tornado. Weather pattern recognition techniques used in the officers' analysis led to the evolution and methodologies used in severe weather forecasting in the U.S. (Doswell, Weiss, & Johns, 1993).

The most notable disaster to strike a major Air Force base in recent history was Hurricane Andrew in August of 1992. Homestead Air Force Base suffered a nearly direct hit from Andrew, which was one of only a handful storms in United States history that made landfall as a Category 5 hurricane (Homestead ARB website, 2012). The widespread devastation of Hurricane Andrew caused nearly a total destruction of the base. Initial reconstruction efforts cost the Department of Defense in excess of $100 million dollars. Ironically, after DOD invested such a large sum of money for reconstruction, the base made the initial 1995 list of BRAC closure recommendations. However, the BRAC committee ultimately withdrew Homestead from the BRAC closure list and subsequently realigned the base mission to the Air Force Reserve (Homestead ARB website, 2012).

1.1.3 – Climate Zone and Weather Impacts on Energy Consumption

Climate zone and weather variations have a major impact on energy consumption at Air Force installations. Energy consumption is influenced by many external factors to include outside air temperature and relative humidity (Eto, 1988). Outdoor air temperature has the largest impact on climate or weather induced facility energy consumption (Eto, 1988; Sailor & Munoz, 1997). Since temperature is the most influential weather factor, it is the standard basis of comparison for climatic impacts at Air Force Bases. See Section 2.5 in Chapter 2 – Literature Review for a more in-depth review of climate zone.

1.1.4 – Energy Reporting Mechanisms

The Defense Energy Information System (DEIS) was initiated in February of 1974 to report energy usage in federal facilities. The DOD designed this system to monitor all energy consumption data and to manage energy reduction goals. Since its introduction in 1974, a variety of legislation exists mandating the reporting and tracking of energy in the DOD. Executive Orders, the Energy Policy Act (EPAct) of 2005, and the Energy Independence and Security Act (EISA) of 2007 all require the Air Force to reduce energy consumption, water consumption, use renewable energy wherever practicable, and report on progress towards meeting mandated conservation goals (HQ AFCESA, 2011). The DEIS was later renamed the Defense Utility Energy Reporting System (DUERS) and as of 4 April 2011, DUERS transitioned to the Air Force Energy Reporting System (AFERS) for all fiscal year 2011 and later reporting (DOD, 1993; HQ AFCESA, 2011). AFERS is currently the service's software platform used to track and analyze energy data and it produces information and statistics for the Annual Energy Management Report (AEMR). Each fiscal year, Headquarters United States Air Force submits the AEMR through the Office of the Secretary of Defense to the Department of Energy and Congress (DOD, 2014b; HQ AFCESA, 2011).

The AFERS provides valuable information to energy policy makers to assist in the development and execution of DOD energy programs. AFERS data collected by Civil Engineer Energy Managers is used by the Air Staff to budget for energy costs, to track consumption trends, and measure progress towards energy goals (DOD, 2005b). In addition, AFERS data helps validate energy efficiency initiatives and develops long-term energy policy (HQ AFCESA, 2011). Data gathered since Fiscal Year (FY) 1985 (baseline year) from all Air Force installations are maintained at the Air Force Civil Engineer Center (AFCEC). The data are presented annually to the Office of the Secretary of Defense and used to assess DOD energy policy. In past BRACs, energy was not a major focus area and the DOD or Air Force did not fully leverage this wealth of historical energy data in their BRAC analysis. Further examination of the available energy data may help guide better BRAC decision-making by identifying installations with excessive energy usage and costly energy bills.

1.1.5 – Utility Rates

Utility rates play an important role in the overall cost to operate DOD infrastructure. Utility rate data for this research are obtained through the Energy Information Agency's (EIA) website and AFERS. EIA state-by-state data and AFERS installation-by-installation data are collected and are the basis for average annual utility rates of both electricity (in units of dollars per kilowatt-hour, $/kWh) and natural gas (in units of dollars per thousand cubic feet, $/Mcf). The most recent, complete, and available EIA utility rate data utilized for this report are a state-by-state average from 2013 for electricity and a state-by-state average for the 2012 calendar year for natural gas. For the installation-by-installation energy analysis, this research applied energy data from Fiscal Year (FY) 2012 through 2014, as the data were the most recent three-year installation-level energy-usage and cost data available from AFERS. For the analysis, utility-rates are derived from the raw AFERS data. AFCEC does not publish or report actual installation-by-installation utility rates.

1.2 – Problem Statement

The Air Force is in a period of downsizing its workforce, both military and civilian, because of budgetary constraints and congressional funding issues. To further exacerbate this problem, service members' medical costs are on the rise, while retirement and pension obligations are increasingly difficult to fund. This demand on resources creates a cash flow problem for the Air Force and limits its effort to recapitalize its number one priority, an aging fleet of airplanes. Furthermore, the Air Force is fighting for operations and maintenance dollars to deal with its old and decaying base infrastructure. With so many concurrent issues on the table fighting for funding, new and innovative ways to address budgetary concerns must be explored.

The Air Force has entered a new era of increased budgetary constraints. These budgetary constraints are largely due to major post-war drawdowns following conflicts in Iraq and a planned withdrawal from Afghanistan. Other major constraining budget factors include a sluggish economy in the United States and the congressional *Budget Control Act of 2011* (Heniff, Rybicki, & Mahan, 2011). The *Budget Control Act of 2011* contained elements that led to budget sequestration, also known as the "Sequester," within the Department of Defense. Budget sequestration will continue to have a profound direct impact on the Air Force's operations and maintenance budget for base infrastructure in the years to come.

According to the *Air Force Times*, in September 2013, "Chief of Staff Gen. Mark Welsh told Congress that the Air Force could be forced to cut up to 25,000 airmen over the next five years if the sequester continues" (Losey, 2013). This reality came to light in January 2014, when the Headquarters Air Force Personnel Center (AFPC) announced major Fiscal Year (FY) 2014 programs that would trim the active duty force, both on the enlisted and officer side. Personnel Services Delivery Memorandum(s) (PSDM) announced plans for cutting the force which included major programs such as a Force Shaping Board, Officer Reduction in Force (RIF) Board, Voluntary Separation Pay (VSP), and Temporary Early Retirement Authority (TERA) (HQ AFPC, 2014). Although cutting these programs will curtail a vast majority of the excess personnel costs, it is still not enough to address all the budgetary issues facing the Air Force.

Active duty members of the Air Force are often told that they *have to do more with less* or *keep doing the same with less.* This concept succeeds up to a point, until the maximum productivity of personnel or resources has been reached. Eventually, Air Force leaders will realize that mission and base requirements must be cut along with personnel. Historically, the best and most cost effective way to cut and consolidate base and infrastructure requirements is through the congressionally authorized BRAC process (DOD, 2005c).

In order to address budgetary problems, this research explores the cost of severe weather occurrences and climate zone and their relation to major Continental United States (CONUS) Air Force installations. Specifically, this research applies historical weather and climate data to conduct a geospatial analysis of impacts from severe weather. Additionally, the research analyzes and maps average energy consumption and average utility costs (natural gas and electric) by state and at the Air Force installation level. Geospatial representations contained in this research are intended to display the impacts of all these major factors on the location of major CONUS Air Force installations. A successful analysis of available Geographic Information System (GIS) information should help answer the basic questions of how and where severe weather, climate zone, energy use, and utility rates, positively or negatively impact the United States the most. Answers to these basic questions should help identify the riskiest and costliest locations to maintain Air Force installations and provide valid recommendations for future BRAC efforts. In Chapter 4, thematic maps are presented to help pictorially answer these questions and enhance visualization of the geospatial data analyzed.

1.3 – Research and Investigative Questions

This research attempts to answer the following research and investigative questions. The scope of this report focuses on how and where severe weather, climate zone, energy use, and utility rates, either negatively or positively impact regions of the United States where major Air Force installations are located.

Primary Research Questions:

1. *What impact does severe weather, climate zone, energy use, and utility rates have on the cost to maintain base infrastructure?*

2. *Which factors in Research Question 1 are the most appropriate and applicable to be used in future BRAC and basing decisions?*

Investigative Questions:

1. *Which severe weather factor is more influential on cost in a BRAC decision – tornadoes or hurricanes?*

2. *Is frequency of severe weather occurrence or magnitude of severe weather occurrence more costly to base infrastructure?*

3. *For each installation, what is the average return period for tornadoes and hurricanes and how large of an impact does each event type have on cost?*

4. *Which energy factor is more influential on cost in a BRAC decision – electricity or natural gas?*

1.4 – Research Model

The following section is an overview of the basic research model. Figure 1 graphically represents the relationships of the new proposed factors. The five proposed new factors influence the BRAC Cost of Base Realignment Actions (COBRA) model. For a more in-depth explanation and detailed overview of COBRA, and how it influences BRAC, see Chapter 2.

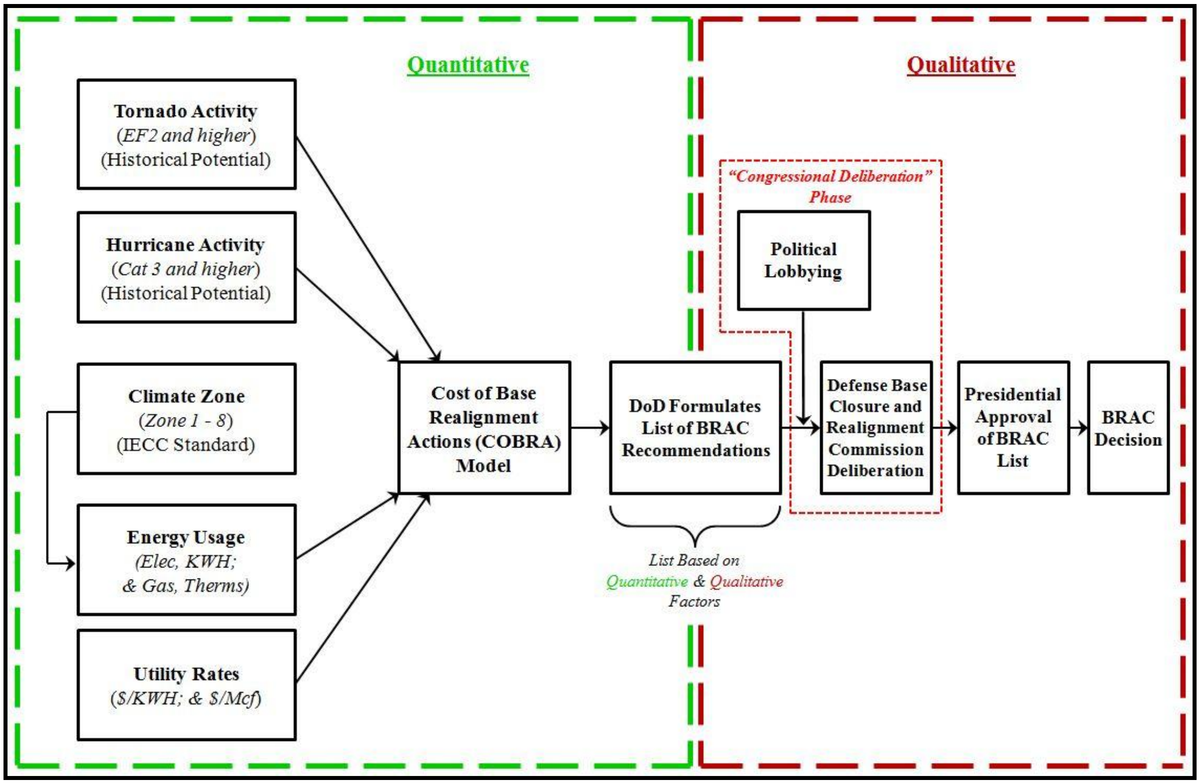


Figure 1: Proposed Relationships of New BRAC Factors

As shown in Figure 1, *Congressional Deliberation* moderates the BRAC process. The Defense Department formulates its recommended BRAC list based on output from the COBRA model, which Congress deliberates into the final BRAC decision. The Congressional Deliberation moderating effect is subjective and not easily quantifiable and is beyond the scope of this research. Nonetheless, the proposed relationships diagram illustrates this factor to inform the reader that the congressional deliberation process does and will play a significant role in influencing the final base selections and BRAC decision.

1.5 – Assumptions and Scope

Several major assumptions must be made in the development of this research. First, since the analysis focused on severe weather occurrences, the researcher must assume that future weather patterns will follow the same statistical occurrence rate and patterns of existing historical data. For all severe weather types analyzed, this is a valid statistical assumption because historical weather data used for this analysis span 50 years or more. The second major assumption is that overall energy use for an installation is tied mainly to energy consumed by facilities and infrastructure (as it related to climate zone), rather than energy consumed by mission related activities, such as radar equipment, computer server banks, or large scale equipment maintenance operations. Wherever practical and when available, energy use data are collected and analyzed for only those facility and infrastructure consumers and omitted for mission related activities.

The scope of this research focuses on how and where severe weather, climate zone, energy use, and utility rates, either negatively or positively impact regions of the United States where major Air Force installations are located. The scope of analysis includes all major CONUS Air Force installations in addition to any joint-base locations where the Air Force is the lead DOD service operating the base. All other Air Force Reserve and Air National Guard installations; range, annex, or auxiliary airfields; radar or air defense missile sites; along with sister service installations (Army, Navy, Marine Corps, and Coast Guard), are excluded from the analysis. Additionally, the study includes select major CONUS Air Stations (AS) and Geographically Separated Units (GSUs), but does not include installations Outside of Continental United States (OCONUS). Limiting the scope to these Air Force installations generates a list of actionable recommendations, within the DOD's congressionally authorized latitude of the BRAC program that could be used for a future round of base realignments or closures.

1.6 – Methodology

The overall analysis for this project will focus on patterns of severe weather, climate zone, energy usage, and utility rates. Once complete, the analysis should help visualize any patterns or concentrations of areas of concern and installations that may be closely affected by severe weather patterns, climate zone influence (extreme temperatures), excessive energy usage, and high regional energy rates.

The main method employed to examine and display the data is geospatial analysis (mapping). Chapter 3 details the actual geospatial techniques used in the analysis. Based on the geospatial analysis, data is tabulated into rank-matrices. This data is put into a Monte Carlo simulation to forecast annual costs. Annual costs for each factor evaluated translates into a ranked *1-to-n* list for all major CONUS Air Force installations.

1.7 – Overview

The following chapters provide more extensive analysis of the main research and investigative questions presented in section 1.3. Chapter 2 is a comprehensive analysis of the pertinent literature, reports, and past efforts associated with BRAC. The literature review will help the reader gain a better understanding of the history of BRAC and the science behind severe weather occurrences and climate zone. Chapter 3 further details the methodology used in the analysis and sets the stage for the results presented in Chapter 4. Finally, Chapter 5 wraps up the analysis with an in-depth discussion of the pertinent results followed by major conclusions and recommendations drawn from this research.

Chapter 2 – Literature Review

Chapter 2 further describes the background of Base Realignment and Closure (BRAC) and the additional severe weather and energy factors proposed for consideration in the BRAC process. Chapter 2 aims to provide a detailed background to inform the reader about relevant research areas presented. First, a review of the current BRAC process and COBRA is presented. Second, historical severe weather events affecting major Air Force bases are discussed followed by a review of specific severe weather terminology. It is important to understand the definitions and terminology behind major severe weather phenomenon, to fully comprehend how these additional factors could affect BRAC. Last, the effects of climate zone and energy factors are examined.

2.1 – BRAC

The DOD has implemented five BRAC rounds since 1988. The Defense Department administered the BRAC process in 1989, 1991, 1993, 1995, and most recently in 2005 (GAO, 2010). The 2005 BRAC was the biggest, most complex, and costliest BRAC round ever. According to DOD's fiscal year 2011 update, the BRAC 2005 budget submission to Congress shows one-time implementation costs grew from $21 billion, originally estimated by the BRAC Commission in 2005, to approximately $35.1 billion. This increase of about $14.1 billion, or 67 percent, is largely due to increased construction costs (GAO, 2012). The most recent BRAC administered in 2005, generally followed the legislative framework of previous BRAC rounds, providing for an independent Defense Base Closure and Realignment Commission to review the Secretary of Defense and DOD's realignment and closure recommendations. Under the authority of the Defense Base Closure and Realignment Act of 1990 (commonly referred to as

“The BRAC Statute”), the Commission assesses the Defense Secretary’s recommendations and can approve, modify, reject, or add closure or realignment recommendations. The Commission then reports its own recommendations to the President. Once the President approves the Commission’s recommendations, the list is forwarded to Congress and the recommendations are final (GAO, 2013a). As depicted in Figure 1, the DOD’s in-depth BRAC analysis and COBRA Model data provides objective criteria and recommendations to aid in the creation of the Defense Secretary’s recommended realignment and closure list. The Defense Base Closure and Realignment Commission deliberates this list and submits its final BRAC list and decision for presidential approval. Political lobbying activities moderate the Defense Base Closure and Realignment Commission step and are lumped together and collectively represented as “Congressional Deliberation” throughout this research.

During the last BRAC in 2005, the DOD’s goals emphasized transformation and jointness (GAO, 2013b). Moreover, the Air Force based its final selection criteria for the 2005 BRAC primarily on *Military Value* (Wynne, 2005). *Military Value* focused on four main subcategories: current and future mission capabilities and their impact on operational readiness of the total force; availability and condition of land, facilities, and associated airspace; ability to accommodate contingency, mobilization, surge, and future total force requirements; and the cost of operations and manpower implications (Wynne, 2005).

Other considerations taken into account in 2005 included the extent and timing of costs and savings, the number of years for savings to exceed costs (i.e., *simple payback*), the economic impact on surrounding communities, and the ability of infrastructure and surrounding communities to support increased mission and personnel (realignment scenario). Additionally, other considerations included the environmental impact of closure actions to include environmental restoration, waste management, and compliance (Wynne, 2005).

One of the major political concerns in a BRAC is the effect on local communities after a closure. The closure of a major installation can have a direct financial impact on the surrounding community, because of the loss in jobs and base-generated revenue in the local economy. Some lawmakers allege that BRAC can also reduce real estate and property values in the areas surrounding a major base closure. One 2006 study concluded that BRAC has no significant effect on real estate values following a closure, and the impact is not statistically different from zero (Mantovani, 2006). However, Mantovani completed the study prior to the start of the 2007 economic recession and housing market crash in the United States. A new study taking into consideration the effect of the rapid rise in home values, from 2000-2007 (AKA *the Housing Bubble*), may reveal a decline in property values attributed to a BRAC. Consequently, lawmakers' concerns of a decline in property values following a BRAC may have merit. Nevertheless, previous BRACs have shown that surrounding areas can thrive after a closure if proper planning occurs and the community reutilizes the closed Air Force Base effectively. One example of an effective closure is Bergstrom Air Force Base in Austin, TX, which closed under the 1995 round of BRAC. Although Bergstrom was originally located on the fringe of town, proactive aviation planning for the old base created a high demand for cargo and passenger flights (Cidell, 2003). The proactive planning fueled new economic growth and prevented future problems caused by sprawl and encroachment issues near the airfield. In this example, the BRAC closure turned out to be a winning scenario for the city of Austin.

The Government Accountability Office's (GAO) most recent report on BRAC titled, "Military Bases: Opportunities Exist to Improve Future Base Realignment and Closure Rounds," did not address any of the additional proposed factors of severe weather occurrences, climate zone, energy use, and utility rates and how they relate to major CONUS Air Force installations (GAO, 2013b). The GAO's report discusses lessons learned from all previous BRAC rounds, but focuses mainly on the 2005 BRAC and how recent lessons could be applied if Congress authorizes future BRAC rounds. Aside from recommended changes to leadership and oversight in the BRAC process, the GAO's report focused mainly on how the DOD estimated BRAC realignment and construction costs and savings and ways it could improve its methodology (GAO, 2013b).

2.2 – COBRA

COBRA is the economic analysis model used in the BRAC process. COBRA is an analytical tool used to estimate and calculate all costs, savings, and return on investment attributed to a proposed BRAC action. COBRA is not a budgeting tool; rather, it is a tool to provide an auditable and consistent method to evaluate the costs and savings, and the resulting economic impacts of a BRAC decision (DOD, 2005d). The United States Air Force Cost Center and Logistics Management Institute jointly developed the first COBRA model in early 1988 to evaluate the cost of stationing actions (DOD, 2005d). The 1988 BRAC Commission subsequently adopted the Lotus spreadsheet-based model to evaluate and compare stationing alternatives. The BRAC Commission revised the spreadsheet throughout 1988 so it could apply the model to all military services for the upcoming BRAC. By mid-1989, the GAO reviewed and evaluated the COBRA Model tool and concluded that it "is a conceptually sound tool for evaluating costs, savings, and payback periods" (DOD, 2005d). Consequently, the COBRA Model spreadsheet produced all cost estimates for the first BRAC in 1989 (DOD, 2005d). Figure 2 shows the key inputs and outputs of the current COBRA Model (GAO, 2013a).

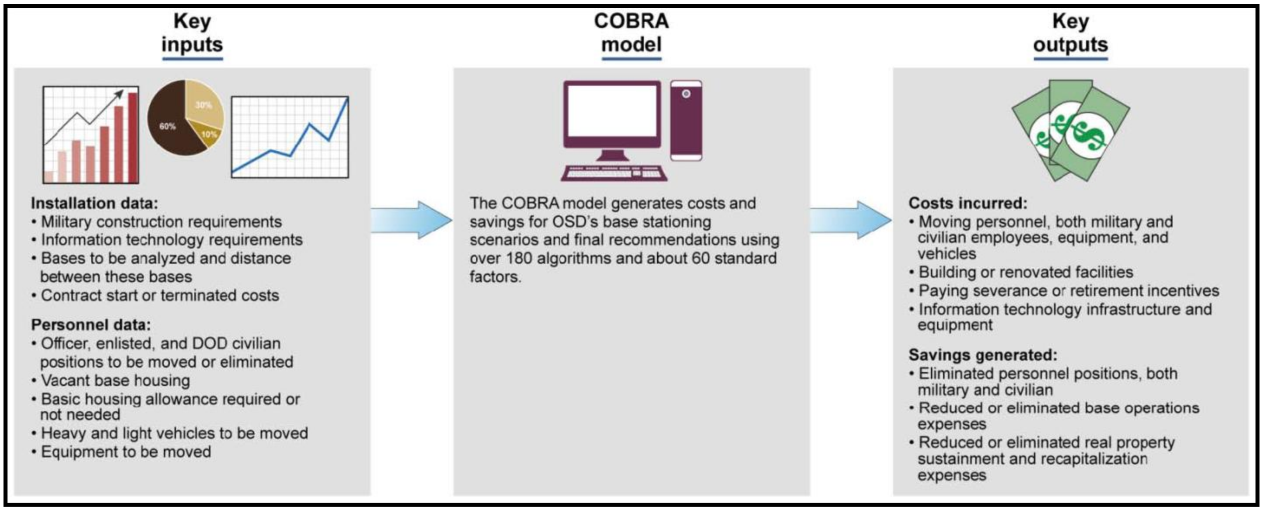


Figure 2: Key Inputs and Outputs of the COBRA Model

The output of the COBRA model allows for a baseline economic comparison of the costs and benefits associated with all proposed closures and realignments. The COBRA Model calculates the net present value (NPV) of all associated costs or savings generated from closure and realignment scenarios over a 20-year planning period. The NPV is the present value of future costs and savings discounted back to the present at the appropriate rate. Discount rates are based on standards published in the Office of Management and Budget's (OMB) Circular No. A-94 titled, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" (OMB, 2014b).

The COBRA model also assumes that all actions involving closure or realignment happen within the first six years, during the BRAC Implementation Period (DOD, 2005a). These actions include, but are not limited to, the costs associated with all permanent and local personnel moves, construction, procurement, sales, transfer of military students, Homeowner Assistance Program (HAP), and closures (DOD, 2005d). All costs and savings incurred over this six-year implementation period are considered steady-state for economic purposes (DOD, 2005a). The baseline for comparison, known as time zero, starts once the six-year BRAC Implementation

Period is over. A key component of the COBRA output is the payback year. The payback year is the point in time where all accumulated savings equal accumulated costs. The difference in the payback year and the end of the closure or realignment period is considered the payback period. This is where the BRAC action has paid for itself. This procedure is based on a simple-payback and not a discounted-payback method.

The Department of Defense's report on "Base Closure Account - Air Force, Fiscal Year 2015 Budget Estimates," outlines all the one-time implementation costs, net implementation costs, and total savings for all Air Force locations identified in all five BRAC rounds (DOD, 2014b). Recent examples of full base closures under BRAC include Lowry AFB, CO (1991); Bergstrom AFB, TX (1995); and Castle AFB, CA (1995). No major Air Force installations closed under the 2005 BRAC (Sorenson, 2007). Lowry AFB, for example, closed under the 1991 Commission, had a net (BRAC) implementation cost of $12.180 million dollars and a total savings of $170.872 million dollars, spanning Fiscal Years 1992-1997 (DOD, 2014b). Using COBRA's previously defined simple payback method, Fiscal Year 1996 was the payback year for BRAC closure actions at Lowry. This date is when the accumulated savings equaled the accumulated costs for all BRAC actions at Lowry AFB, thus creating a payback period of five years, inclusive of Fiscal Years 1992 through 1996 (DOD, 2014b).

2.3 – Proposed Relationships and Research Hypotheses Overview

The following section breaks down and depicts how each new proposed BRAC factor relates to the COBRA Model. The five main independent factors include tornado activity, hurricane activity, climate zone, energy use, and utility rates. Each new factor has an associated hypothesis shown in the relationship diagram in Figure 3. The end of each factor's respective section or subsection in Chapter 2 presents and further explains Hypotheses 1 through 5. Each hypothesis relates the independent factor to its impact on the BRAC Cost of Base Realignment Actions (COBRA) Model. The costs (or savings) associated with BRAC, otherwise known as the COBRA Model output, assists in the formulation of the DOD's list of BRAC recommendations. In turn, the Defense Base Closure and Realignment Commission (formed by members of Congress), deliberates this interim list of DOD recommendations to generate the final BRAC list for presidential approval.

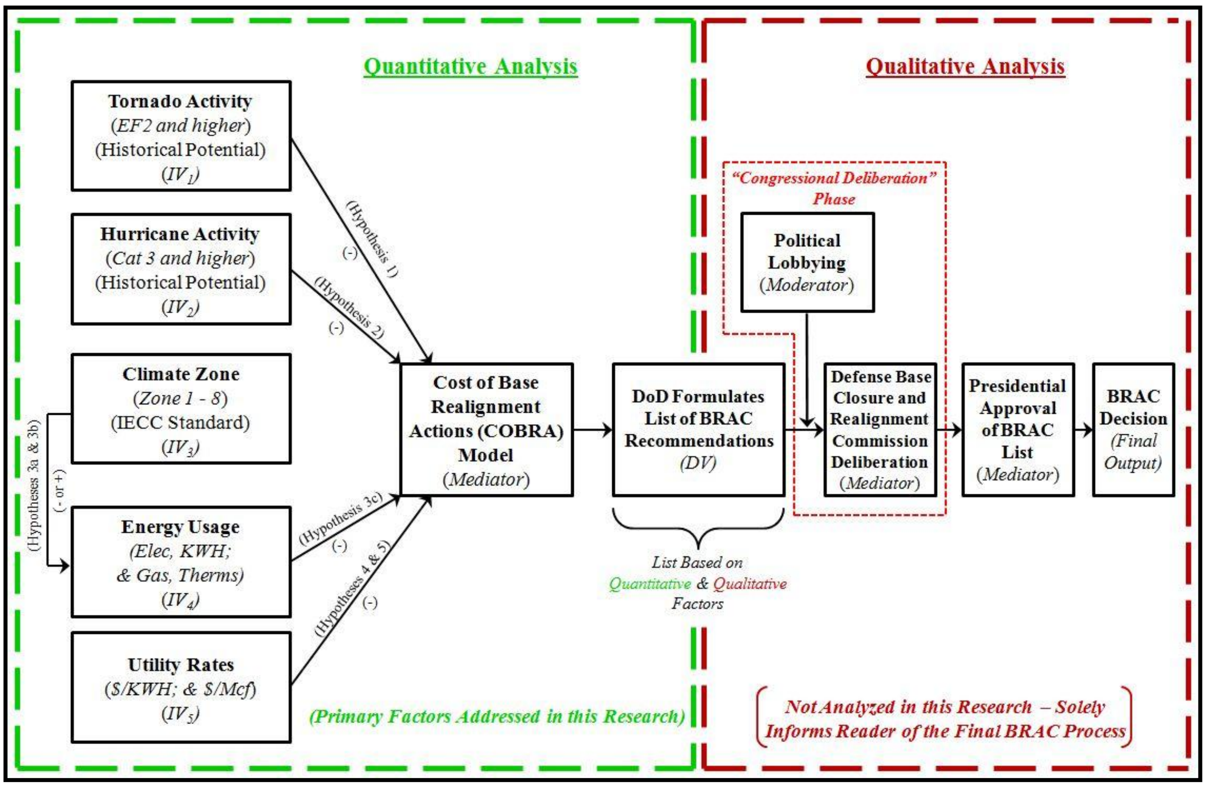


Figure 3: Proposed Relationships of New BRAC Factors with Correlation Values

2.4 – Severe Weather

Severe weather refers to any dangerous meteorological phenomena that have potential to cause monetary loss, property damage, social disruption, or loss of human life (NOAA, 2014b). According to the National Oceanic and Atmospheric Administration's (NOAA) National Severe

Storms Laboratory, the term *severe weather* differs from *extreme weather*. Extreme weather describes abnormal weather events that fall at the extreme ends of the historical distribution for a specified location or region. The statistical range of magnitude of a particular weather phenomenon increases for a given area due to extreme events. Extreme events normally lie in the outermost ten percent of a location's weather history distribution and NOAA considers them the most unusual (NOAA, 2014a). Not all extreme weather events are considered severe and not all severe events are considered extreme. For example, the Florida Keys can experience a one-day cold weather snap where temperatures dip below the thirties. This cold-weather event is considered extreme but not severe, as there is no major damage or loss imposed. Conversely, if Joplin, MO experiences an EF-3 tornado (considered *severe weather*) that inflicts massive amounts of damage and loss to the affected area, this tornado may not be considered an extreme event, because the city previously experienced an EF-5 tornado. The severe weather definition is favored in this research as it is more inclusive of all weather events and phenomena that have potential for great destruction and monetary loss.

Severe weather manifests itself in many forms. Types of severe weather include tornadoes, hurricanes, thunderstorms, lightning, high winds, large hail, excessive precipitation, and floods. Seasonal and regional weather phenomena include winter storms, blizzards, snowstorms, ice storms, and dust storms. Some of the severe weather events can lead to other second order effects. For example, high temperatures, high winds, lightning, and a prolonged drought can lead to wildfires. Wildfire is an effect of other contributing severe weather factors, and is not considered severe weather by itself. Earthquakes are another large natural disaster that can inflict monetary loss, property damage, social disruption, or loss of human life. However, earthquakes do not fall under the severe weather, as they are classified a geological event.

Although earthquakes, high winds, large hail, and floods are initially considered for analysis in this research, they are inconsequential from a monetary impact standpoint compared to tornadoes and hurricanes (Lott & Ross, 2003; USAA, 2014). Figure 4 is a comparison of inflation adjusted U.S. catastrophe losses, which highlights the disproportionate financial impact that hurricanes and tornadoes make compared to other natural disasters. Additionally, a review of historical storm damage occurrences indicates that most major flood impacts at Air Force bases are the result of a storm surge from a passing hurricane and not an individual flood event.

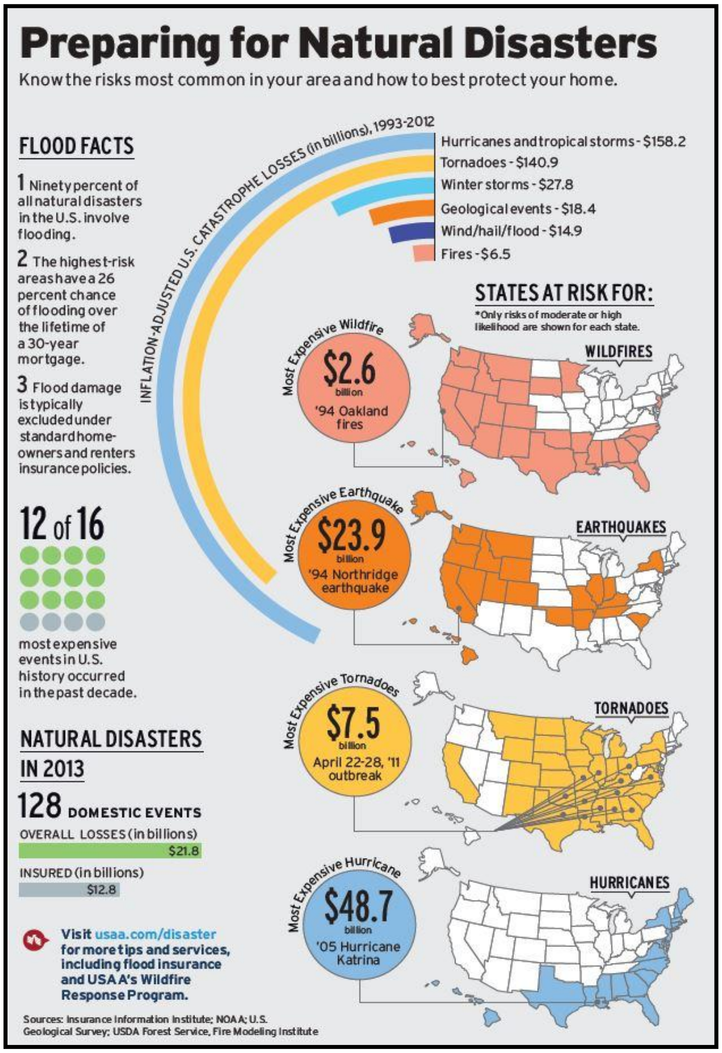


Figure 4: Costliest Natural Disaster Risks (USAA, 2014)

Similar to Figure 4, Figure 5 is data from the Insurance Information Institute (III) and the Property Claim Services (PCS) unit of ISO, representing the inflation adjusted percentage of monetary losses by cause, for major U.S. catastrophes from 1994 to 2013 (III, 2015). Both figures highlight how much more influence hurricanes and tornadoes have on infrastructure damage cost, as compared to other major natural disasters. Based on these facts and statistics, tornadoes and hurricanes are the focus of the severe weather analysis in this research.

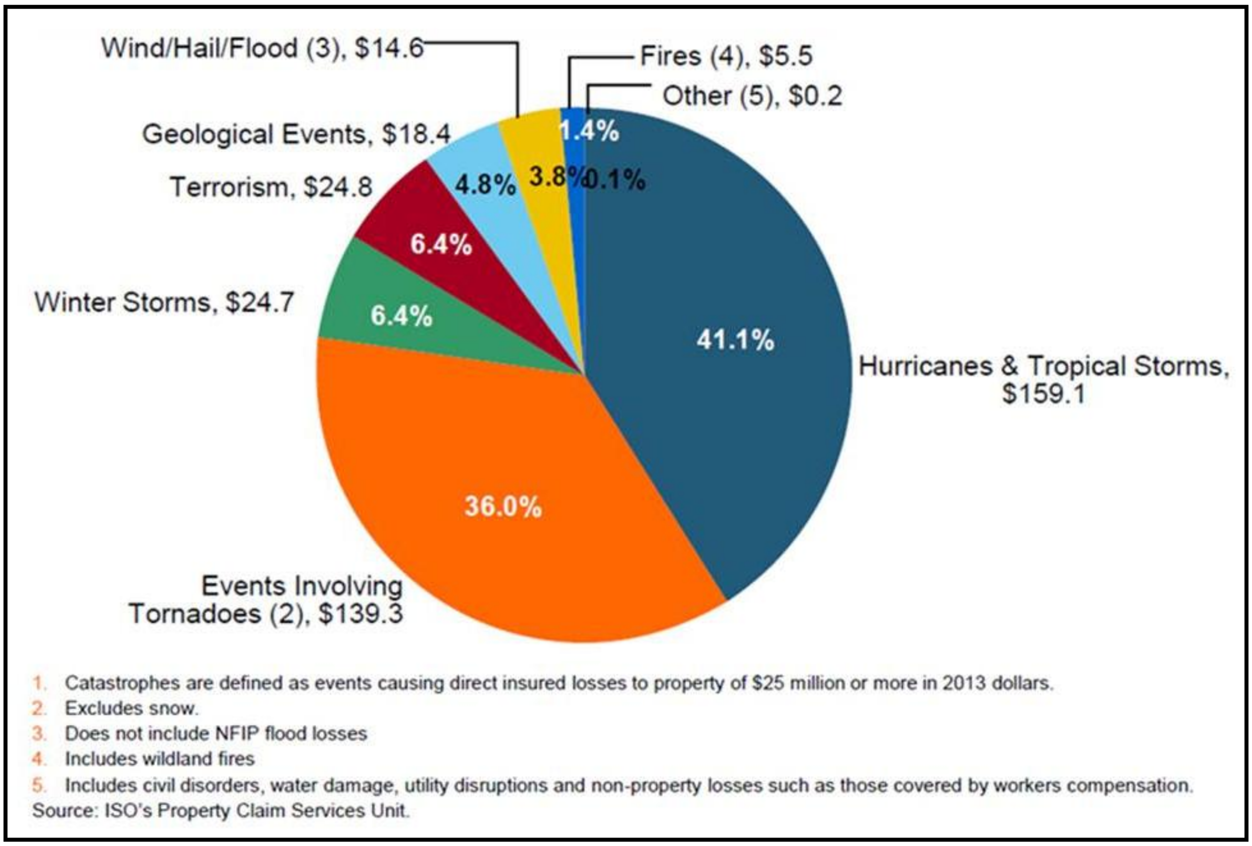


Figure 5: Inflation Adjusted U.S. Catastrophe Losses by Cause, 1994–2013 (III, 2015)

2.4.1 – Tornadoes

A tornado is a violent narrow rotating column of air that extends from a bank of clouds or the base of a thunderstorm to the ground (NOAA, 2014b). Tornadoes are ranked in size according to the Enhanced Fujita (EF) Scale, with a range of EF-0 to EF-5. One major important item to note about the new EF Scale adopted in 2007 is that wind magnitude estimates are based on post-storm assessed damage and not actual wind speed. According to NOAA, the EF Scale "uses three-second gusts estimated at the point of damage based on a judgment of 8 levels of damage" to 28 different indicators (NOAA, 2014b). These indicators focus mainly on damage to certain building types such as residences, barns, mobile homes, strip malls, and office buildings, along with natural features such as trees. The wind estimates vary with height and exposure. Moreover, the three-second wind gust measurement is not the same wind measurement as in a *standard* surface observation. "*Standard* measurements are taken by weather stations in open exposures, using a directly measured, "one minute mile" speed" (NOAA, 2014b). Table 1 represents both the previous Fujita Tornado Scale used prior to 2007, along with the current Enhanced Fujita (EF) Scale adopted in 2007 (Tennessee.gov, 2014).

Table 1: Fujita Tornado Scale Comparison

Fujita Scale		Enhanced Fujita Scale* * In use since 2007	
F–0	40–72 mph winds	EF–0	65–85 mph winds
F–1	73–112 mph	EF–1	86–110 mph
F–2	113–157 mph	EF–2	111–135 mph
F–3	158–206 mph	EF–3	136–165 mph
F–4	207–260 mph	EF–4	166–200 mph
F–5	261–318 mph	EF–5	>200 mph

Table 2 breaks down the Enhanced Fujita Scale in more detail to include damage descriptions and a comparison with hurricane categories. EF-2 and higher tornadoes create the majority of financial losses and property destruction to commercial style buildings (Pinelli &

O'Neill, 2000; Brooks & Doswell, 2001; Yazdani, Green, & Haroon, 2006). Most Air Force installations construct facilities to this commercial-grade standard and are not as susceptible to costly damage stemming from EF-0 to EF-1 tornadoes. Therefore, this research focuses on EF-2 and larger tornadoes using geospatial analysis to examine and quantify the potential damage and monetary impacts from strong to violent, EF-2 and larger tornado events. Excluding EF-0 through EF-1 tornadoes focuses on the financial impacts of the most devastating and catastrophic events that affect Air Force base infrastructure. These strong-violent tornadoes have the largest cost impacts and hold the most influence in a BRAC analysis.

Tornado damage differs in scale from damage done by hurricanes. Although winds are typically much stronger in a severe tornado event, one hurricane event typically causes more damage than one tornado event. Hurricanes tend to create more destruction than tornadoes because their size is so much larger, they persist over an area for a much longer time, and hurricanes inflict wind and water related property-damage, versus just wind for tornadoes. As opposed to tornadoes, hurricanes have a destructive core that can be 50 to over 100 miles wide, endure many hours longer, and damage structures through storm surge and localized flooding from rainfall, as well as from wind. On the contrary, tornadoes average a few hundred yards to two miles in diameter and last for only a few minutes, and damage is primarily caused by extreme winds (NOAA, 2014b).

Table 2: Enhanced Fujita Scale with Damage Descriptions

EF Scale	Wind Speed (mph)	Comparable Hurricane Category (Wind Only)	Types of Damage Due to Tornado Winds
0 (Weak)	65–85	Severe Tropical Storm – Category 1	**Light Damage**: Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over.
1 (Weak)	86–110	Category 1-2	**Moderate Damage:** Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.
2 (Strong)	**111–135**	**Category 3**	**Considerable Damage:** Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
3 (Strong)	**136–165**	**Category 4-5**	**Severe Damage:** Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations blown away some distance.
4 (Violent)	**166–200**	**Strong Category 5**	**Devastating Damage:** Well-constructed houses and whole frame houses completely leveled; cars thrown and small missiles generated.
5 (Violent)	**>200**	**None**	**Explosive Damage:** Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 300 ft; steel reinforced concrete structures badly damaged; high-rise buildings have significant structural deformation; incredible phenomena will occur.

For more detailed information on what factors into the EF-Scale rating, see Appendix F for a description of the 28 Damage Indicators (DIs) and Appendix G for more information on the Degrees of Damage (DoD).

Infrastructure damage costs increase with higher frequency of occurrence and greater intensity of tornadoes. Geospatial analysis of tornado data can yield results of the frequency and size of these recorded historical events. Tornado-path width also factors in to the magnitude of property destruction. The EF-Scale rating of a tornado strongly correlates to the average tornado-path width (Brooks & Doswell, 2001). An EF rating, along with its average swath-width, is used to forecast damage estimates to tornado prone Air Force bases. High potential for tornado activity puts an installation at greater risk for damage and financial loss. Therefore, if an installation with historically high tornado activity is closed under BRAC, a future savings (not cost) can be applied to the COBRA Model, based on the avoidance of future infrastructure damage. This theory leads to Hypothesis #1.

Hypothesis #1: EF-2 and higher tornadoes are negatively related to COBRA Model Cost (*Tornadoes can cause damage and create costs to a base, but generate a savings in the COBRA model if base is selected for closure*).

2.4.2 – Hurricanes

The categorization of a hurricane is similar to that of a tornado, in terms of its intensity and wind speed. A hurricane is characterized as a large rotating storm system with a low-pressure center, also known as the eye. According to NOAA's National Hurricane Center (NHC), depending on their location and strength, hurricanes can also be referred to as tropical cyclones, typhoons, tropical storms, or tropical depressions (NOAA, 2014b). The Saffir-Simpson Hurricane Wind Scale (SSHWS), shown in Table 3, provides specific sustained wind speed values for each hurricane category. Since 1990, the NHC has assigned the SSHWS category based solely on the maximum one-minute sustained wind speed (Blake, Rappaport, & Landsea, 2007). As shown in Table 3, the term *major hurricane* is defined as a Category 3 or larger storm. This research focuses on Category 3 and larger storms using geospatial analysis to examine and quantify the potential damage and monetary impacts from major hurricanes. Similar to EF-3 and larger tornadoes, Category 3 and higher hurricanes cause the majority of financial loses, deaths, and property destruction to well-built commercial buildings (Blake et al., 2007). The Air Force constructs most its facilities to a higher commercial-grade standard, which exceeds residential construction standards. Consequently, commercial-grade Air Force facilities are not as susceptible as light-duty home construction, which can experience costly damage stemming from Category 1 and 2 hurricanes. Excluding Category 1 and 2 storms focuses on the financial impacts of the most devastating and catastrophic hurricanes that affect Air Force base infrastructure, which is central to a strong justification of future cost savings in the COBRA model.

Table 3: Saffir-Simpson Hurricane Wind Scale (NWS, 2012)

Category	Sustained Wind Speed	Types of Damage Due to Hurricane Winds
1	74-95 mph 64-82 kt 119-153 km/h	**Very Dangerous Winds Will Produce Some Damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 kt 154-177 km/h	**Extremely Dangerous Winds Will Cause Extensive Damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (Major)	**111-129 mph** 96-112 kt 178-208 km/h	**Devastating Damage Will Occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (Major)	**130-156 mph** 113-136 kt 209-251 km/h	**Catastrophic Damage Will Occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (Major)	**157 mph or higher** 137 kt or higher 252 km/h or higher	**Catastrophic Damage Will Occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

The costs of infrastructure damage increases with higher hurricane intensity and occurrence rates. Geospatial analysis of hurricane data can generate the frequency and magnitude of these recorded historical events. Storm-path width also factors into the magnitude of property destruction. The size and category of a hurricane strongly correlates to the average storm-path width. Hurricane width varies considerably, but a typical hurricane is approximately 300 miles wide (NOAA, 1999).

For any specific location, the National Weather Service's National Hurricane Center defines a hurricane strike as any hurricane path that passes through the "Strike Circle" shown in Figure 6 (NWS, 2014b). If a specific location, such as an Air Force Base, lies within the hurricane's strike circle, one hurricane strike occurrence is counted for that location. The National Hurricane Center defines the strike circle as a circle with a diameter of 125 nautical miles, centered 12.5 nautical miles to the right of the hurricane center, relative to the direction of travel. This 125 nautical-mile circle depicts the typical extent of hurricane force winds. On average, hurricane force winds exist approximately 75 nautical miles to the right of the center and 50 nautical miles to the left (NWS, 2014b). Figure 6 illustrates the strike circle in detail. To simplify the data analysis, hurricane occurrences are counted at each base if the eye of a storm passes within 75 nautical miles on any side of the base centroid. This definition ignores the storm's direction of travel relative to the position of the base. Consequently, this definition does not put the base within range of the 50 nautical mile "Strike Circle" of a hurricane's radius of maximum winds for a hurricane tracking to the right of a base. Nevertheless, with a hurricane path located 50 to 75 nautical miles to the right of a base, relative to the storm's direction of travel, the installation would still experience an indirect hit from the hurricane. Most major hurricanes (Cat 3-5) are well in excess of 125 nautical miles wide. Therefore, significant damage still occurs in a right-tracking hurricane scenario, although damage from wind and storm surge are not as severe as a hurricane tracking to the left of the base's location (NWS, 2014b).

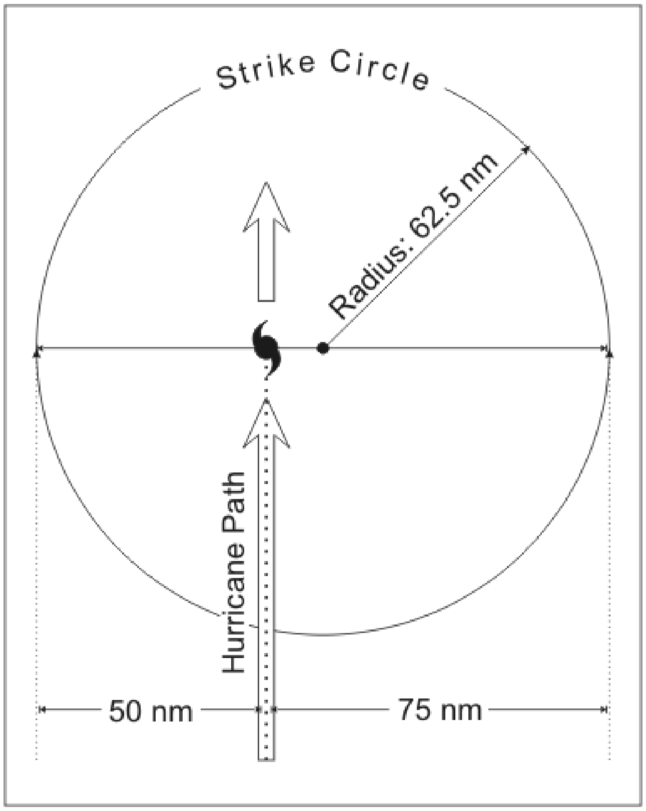


Figure 6: Hurricane Strike Circle (NWS, 2014b)

The category and average swath-width of a hurricane is used to forecast damage estimates to hurricane prone Air Force bases. High potential for hurricane activity puts an installation at greater risk for damage and financial loss. Therefore, if an installation with historically high hurricane activity is closed under BRAC, a future savings (not cost) can be applied to the COBRA Model, based on the avoidance of future infrastructure damage. This theory leads to Hypothesis #2.

Hypothesis #2: Cat-3 and higher hurricanes are negatively related to the COBRA Model Cost *(Hurricanes can cause damage and create costs to a base, but generate a savings in the COBRA model if base is selected for closure*).

2.4.3 – Hurricane Storm Surge

Beyond the impacts of wind, storm surge plays a major role in damage created by hurricanes. Storm surge is created when a hurricane pushes a mound of water ashore. Figure 7 illustrates this phenomenon. The forces a hurricane exerts on the ocean causes the water to pile up from both wind and pressure. These factors combine to create a deadly storm surge.

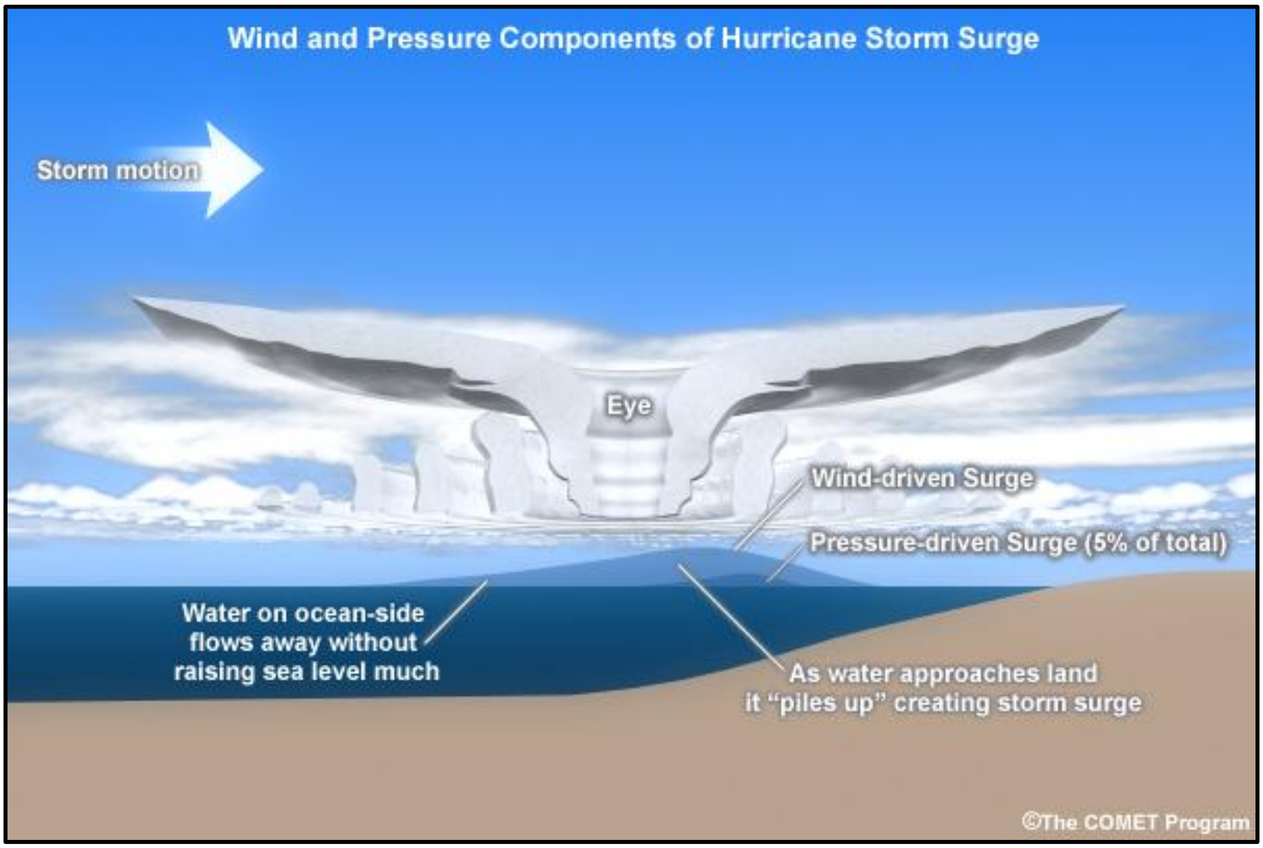


Figure 7: Hurricanes and Storm Surge (NOAA, 2014c)

Subsequently, hurricane force winds combine with astronomical tides to create a storm tide. The storm tide's mound of water, shown in Figure 8, inundates low-lying coastal areas. The cumulative effects of storm tide and astronomical tide lead to large changes in mean sea level.

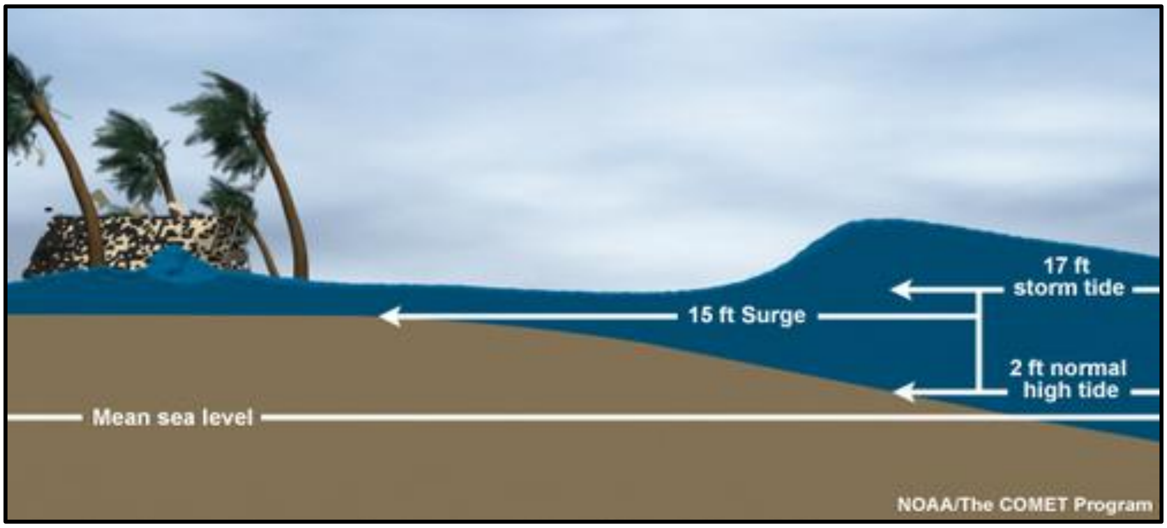


Figure 8: Storm Tide

Storm surge levels generally range from a few feet to upwards of 28 feet (NOAA, 2014c). However, hurricane Category alone is not an accurate predictor of storm surge levels. Hurricane Charley, a Category 4 storm, created a storm surge of about 7 feet, yet Hurricane Katrina, a smaller Category 3 storm, created a storm surge of 25 to 28 feet (NOAA, 2014c). Other major factors that contribute to the magnitude of storm surge are high winds, low-pressure inside the hurricane, astronomical tides, the hurricane's forward speed and angle to the coast, and the slope of the continental shelf and local bathymetry (NOAA, 2014c). The slope and relative depth of the continental shelf for the Gulf Coast, Florida peninsula, and southern east coast of the United States is shown in Figure 9. Areas with a shallow gently sloping continental shelf, such as the Texas, Louisiana, and Florida gulf coasts, are more prone to large storm surge than areas with deeper offshore waters, such as the east coast of Florida (NOAA, 2014c).

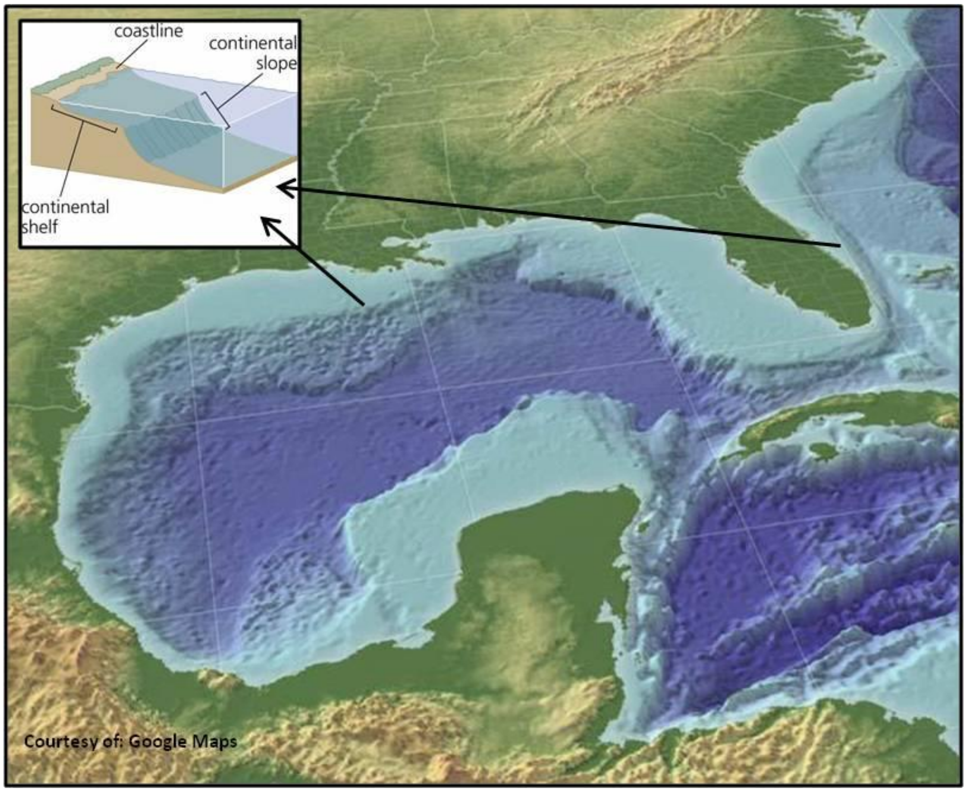


Figure 9: Continental Shelf Map of the Southeastern United States

In addition, due to the counterclockwise rotation of hurricanes, storm surge is much greater to the right-hand side of the storm, relative to its direction of travel. Figure 10 illustrates this phenomenon for Hurricane Ike, a Category 2 storm that made landfall on the upper Texas gulf coast in 2008 (Berg, 2009). In Figure 10, the solid line crossing Galveston Bay is the track from Hurricane Ike. As the figure shows, the storm surge is much greater on the right-hand side of the storm's track, denoted with shaded areas of yellow and red. Areas of the Bolivar Peninsula (shaded in red) to the northeast of Galveston, Texas, saw upwards of 17 to 20 feet of storm surge.

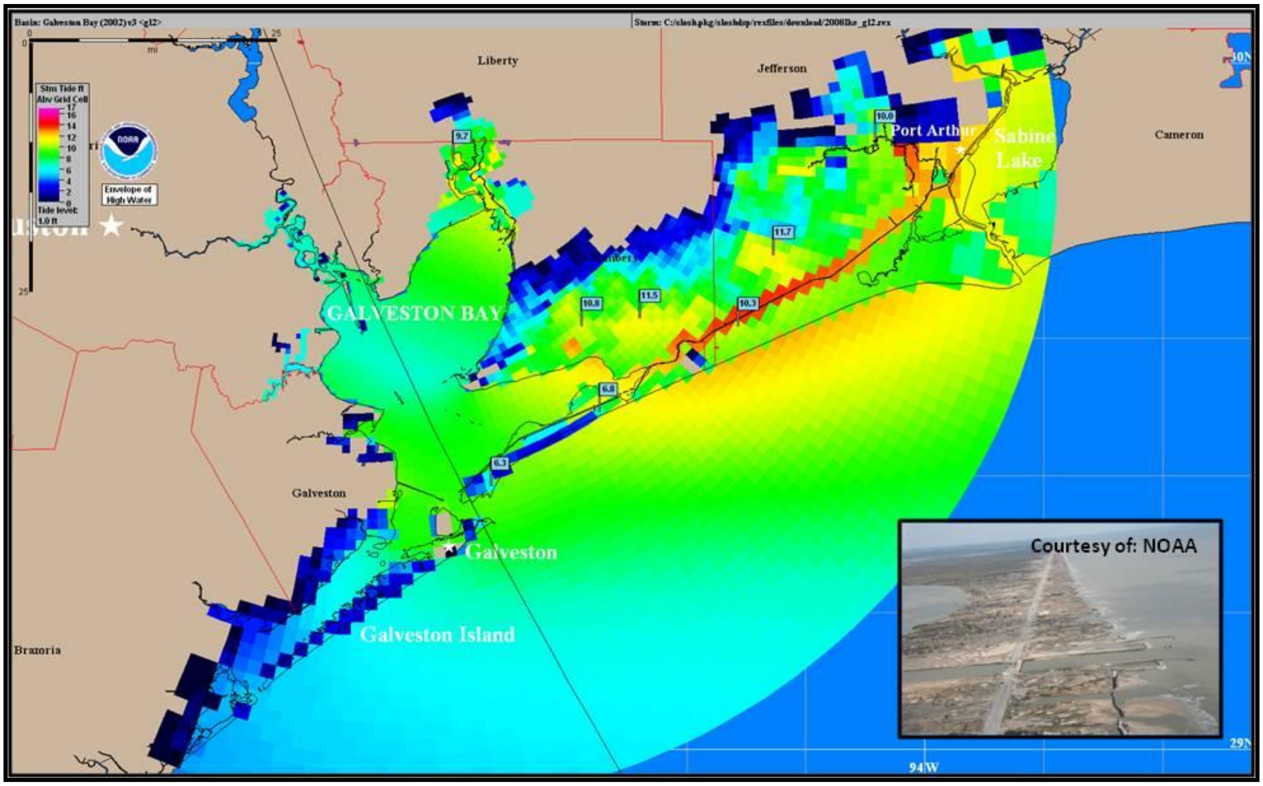


Figure 10: Hurricane Ike Track and Storm Surge (Berg, 2009)

Finally, since Hurricane Category is not the primary driver of storm surge depth, the National Weather Service's National Hurricane Center put together a vulnerability map to highlight storm-surge threats in the United States. Figure 11 is one particular storm surge vulnerability map created specifically for Category 4 hurricanes (NOAA, 2014c). Highly vulnerable areas on the map include the upper Texas gulf coast, the Louisiana and Mississippi gulf coasts, the eastern Florida panhandle, and the Florida gulf coast near Tampa Bay. These areas prone to severe levels of storm-surge include Keesler AFB, MS; Hurlburt Field, FL; Eglin AFB, FL; Tyndall AFB, FL; and MacDill AFB, FL. These five bases are at the greatest risk for not only wind damage, but also storm surge damage from hurricanes.

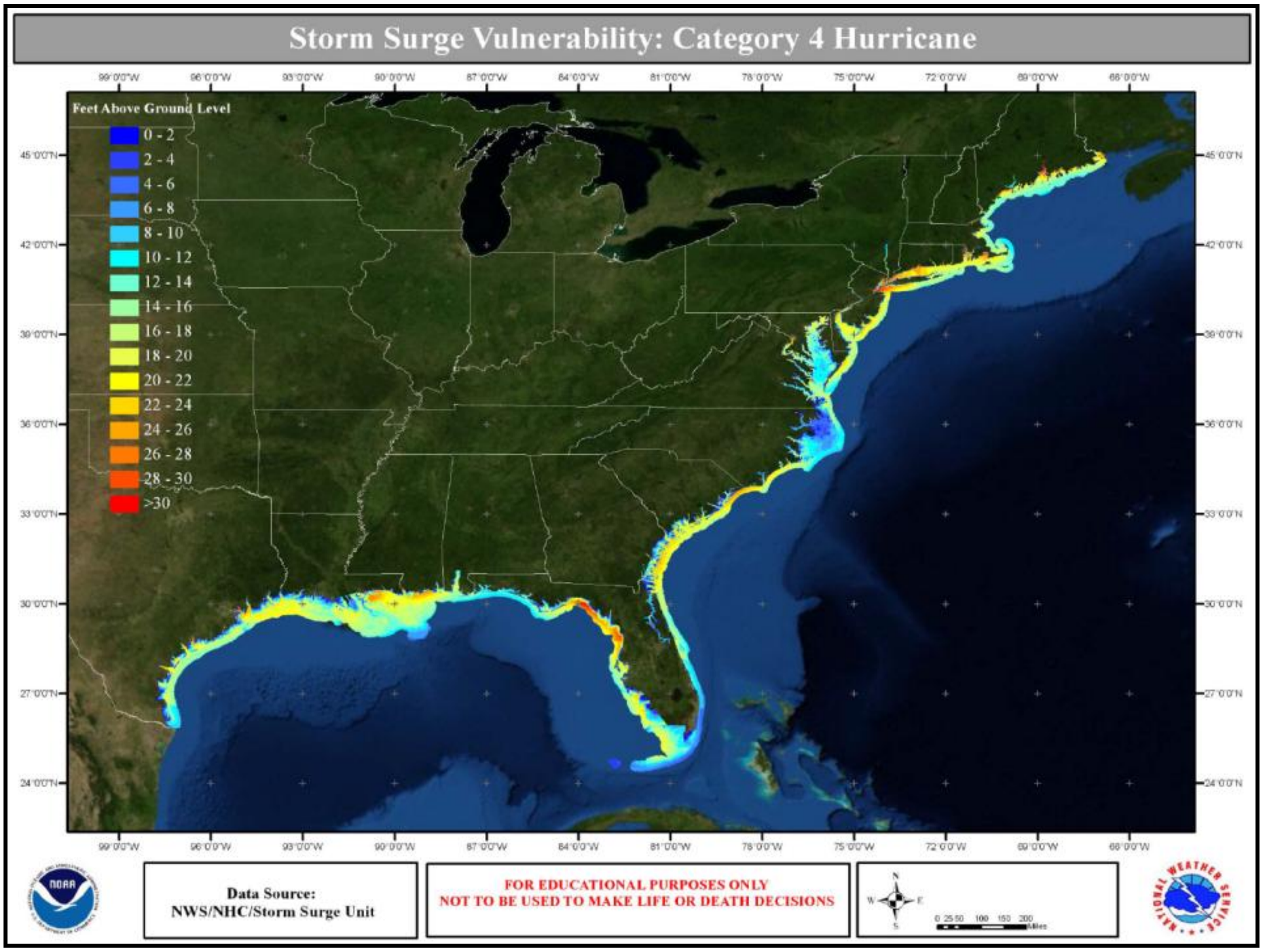


Figure 11: CONUS Storm Surge Vulnerability from a Category 4 Hurricane

2.5 – Climate Zone

Climate zone can have a large impact on operations and maintenance costs of buildings, especially in terms of energy use. Facility construction codes and standards within the Air Force also vary largely based on where and when a facility is built. It was not until the early 21st century that many jurisdictions even considered adopting an energy code (Makela, 2011). As of early 2014, many federal, state, and local building-code enforcement-agencies have adopted new energy codes developed by the International Code Council (ICC). These new energy codes fall under the International Energy Conservation Code (IECC) published by the ICC. Figure 12 is a graphical representation of the climate zones established in the current 2012 IECC (ICC, 2012).

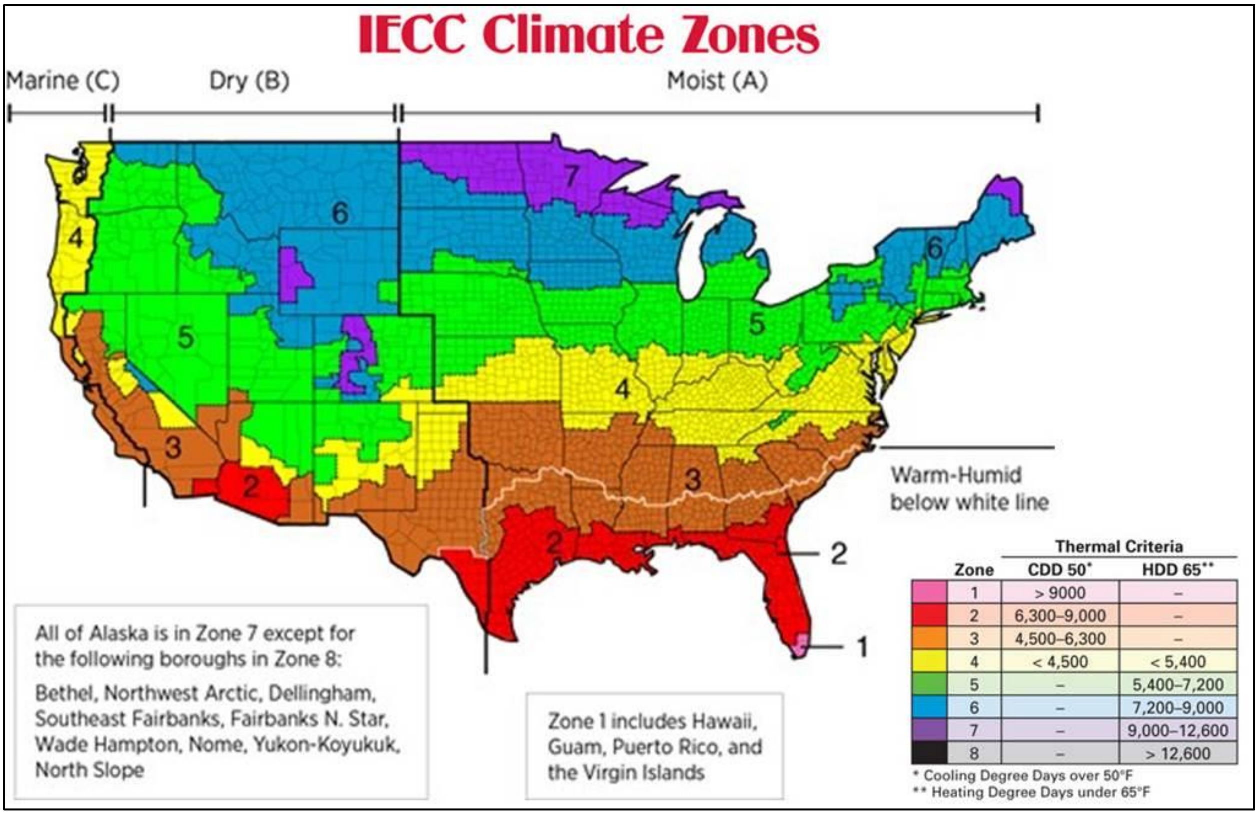


Figure 12: 2012 IECC Climate Zones

According to the IECC, there are eight major temperature-oriented climate zones within the United States (ICC, 2012). These zones are further divided into three moisture-oriented subcategories designated by the letters A, moist; B, dry; and C, marine. As a result, the IECC map allows for up to 24 potential climate combinations and designations. Although moisture categories are important for building construction, material choices, heating, ventilation, and air conditioning equipment, this research focuses solely on the temperature aspect of climate zones. The climate zones vary in temperature and humidity, and exhibit distinctly different quantities of Cooling Degree Days (CDD) and Heating Degree Days (HDD). CDD and HDD are calculated by averaging the daily high and low temperature and comparing the temperatures to a baseline value, usually 50° or 65° degrees Fahrenheit, respectively. A difference in the average and the baseline temperature that exceeds 50° degrees is considered a CDD; while a difference in the average and the baseline temperature that is below 65° degrees, is considered an HDD (Quayle & Diaz, 1980). Climate zone, and more specifically CDD and HDD, are important factors to consider when determining energy use for an installation. Installation energy usage is largely based on physical location, so a base's climate zone is a primary factor affecting the quantity of energy consumed.

This research evaluates climate zone as a major influential factor in a base's energy use. Due to the cost implications, this research penalizes bases located in either extremely hot or cold climates. Maintaining an Air Force base in one of these extreme climates increases energy usage, costs, and creates a greater financial burden. Therefore, if an installation located in an extreme climate is closed under BRAC, a future savings (not cost) can be applied to the COBRA Model, based on a reduction in energy usage. This theory leads to Hypothesis #3a and 3b.

Hypothesis #3a: IECC Climate Zone 3 positively effects Energy Usage (*Bases use less energy in Climate Zone 3, are considered the most neutral climate zone, and least costly to operate and thus are favored to retain under BRAC*)

Hypothesis #3b: IECC Climate Zones 1, 2, 4, 5, 6, 7, and 8 are negatively related to Energy Usage (*the further above or below (numerically) a base's climate zone is from Zone 3, the more energy it uses and the more costly it is to operate. Extremely cold or hot or climate zones or climate zones with highly variable temperatures are less favorable to retain under BRAC*)

2.6 – Energy Use and Utility Rates

The DOD is the single largest consumer of energy in the United States, with consumption comparable to the State of West Virginia (DOD, 2014c). Operational energy (including aircraft and vehicle fuel) and facility energy account for about 80 percent of total Federal energy consumption (DOD, 2014c). The DOD consumes a little over four times the facility-related energy than the next closest Federal government agencies, which is the U.S. Postal Service (DOD, 2014c). As shown in Figure 13, the DOD spent over $18.9 billion dollars on energy in FY 2013; $4.1 billion dollars of that money was spent on facility energy, with buildings consuming 207,232 billion BTU's of energy and $3.8 billion dollars going directly to heat, cool, and power them (DOD, 2014c). The Air Force is the second largest energy consumer in the DOD, following close behind the Army. According to the DOD's Annual Energy Management Report, electricity and natural gas account for more than eighty-one percent of DOD's facility energy usage. Fuel oil, coal, and liquefied petroleum gas account for the remaining portion of the DOD's facility energy consumption (DOD, 2014c).

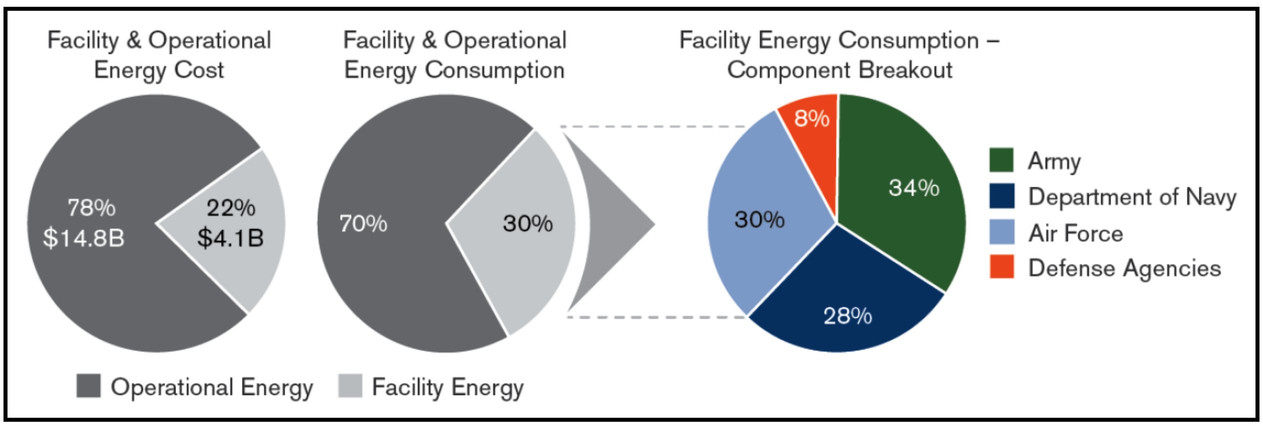


Figure 13: DOD FY 2013 Facility Energy Consumption & Cost (DOD, 2014c)

This research partially expands upon conclusions of a previous Air Force Institute of Technology graduate, James S. Griffin. Griffin published a thesis in 2008 titled, "Impacts of Weather Variations on Energy Consumption Efforts at U.S. Air Force Installations." Within this report, he concluded that:

> Trend analysis conducted over the 22-year period (October 1985 to September 2006, 22 fiscal years of data) provided insight into the significant use of heating load requirements during the winter months as compared to cooling load requirements in summer months. This information should encourage energy policy makers to allocate more resources into heating system requirements than into cooling requirements, taking advantage of major opportunities to reduce energy consumption (Griffin, 2008).

Griffin's analysis concluded that monetary resources should focus more on heating load requirements rather than cooling load, as cooling loads demand less overall energy than heating loads. In addition, the more harsh and extreme the climate zone, either hot or cold, the greater the amount of energy the base will consume. To reduce energy use, he mainly recommends improvements to Heating Ventilation and Air Conditioning (HVAC) systems (Griffin, 2008).

However, for the purposes of guiding a BRAC decision and reducing infrastructure operation costs to the Air Force, a slightly different approach will be followed. This research ignores potential improvements to HVAC systems and focuses on factors that are mostly out of the Air Force's control. Climate related energy usage and utility rates are generally out of the control of the Air Force. Therefore, this research focuses on climate related energy usage and utility rates as the primary uncontrollable energy factors to be used in a BRAC round.

As a result, if an installation located in an area with high natural gas and electric rates is closed under BRAC, a future savings (not cost) can be applied to the COBRA Model, based on relocating a base's mission elsewhere, where utility rates are cheaper. This theory leads to Hypothesis #3c, Hypothesis #4, and Hypothesis #5.

<u>Hypothesis #3c:</u> Energy usage is negatively related to the COBRA Model Cost

Hypothesis #4: Electric rates are negatively related to the COBRA Model Cost

Hypothesis #5: Natural gas rates are negatively related to the COBRA Model Cost

(Bases with lower energy usage and utility rates are less costly to operate and are favorable to retain under BRAC. If a base is considered for BRAC, annual electricity and natural gas costs (usage x rates) generate a savings in the COBRA model and not a cost. If a do nothing approach is selected, these factors remain costs to a base.)

2.7 – Conclusion

Following a thorough review of BRAC literature, one basic conclusion emerges. Previous BRAC efforts have adequately addressed military value in the process, but none of the previous rounds accounted for severe weather, climate zone, or energy related factors such as usage and utility rates. With the addition of these factors to the COBRA model, this research should help improve risk evaluation and the estimation of associated future costs of retaining major Air Force installations. Evaluating the additional aspects of severe weather, climate zone, energy usage, and utility rates, should help Air Force and DOD decision-makers establish an enhanced framework so Congress can make better-informed risk-based BRAC decisions in the future.

Chapter 3 – Methodology

The analysis for this research focuses on patterns of severe weather, climate zone, energy use, and utility rates. The results of the evaluation should help visualize patterns or concentrations of areas of concern and installations that may be affected by severe weather patterns, climate zone influence (extreme temperatures), excessive energy usage, and high regional energy rates.

This chapter provides an overview of the methodology used to develop new criteria and help better define the costs and savings in a BRAC decision. The chapter will begin with a detailed description of the sample selection and data collection processes, followed by an explanation of the procedures and tools used for the mapping and geospatial data analyses. Next, a detailed description is provided outlining the process to create the rank matrices for each factor evaluated. Finally, the chapter concludes by explaining the process of applying key attributes from select rank-matrices to a Monte Carlo simulation. The Monte Carlo simulation is an analysis tool used to quantify the overall annual costs of tornadoes, hurricanes, and energy usage (electricity and natural gas) at each installation. Chapter 4 presents and explains the outcome from this methodology.

As in previous BRAC rounds, geographical importance to the mission and transferability to another location will not be taken into consideration for this analysis. For example, C-130s from the 53rd Weather Reconnaissance Squadron, commonly known as the "Hurricane Hunters," are located near the Gulf Coast Region at Keesler Air Force Base, MS. Although this squadron's mission has a strategic military necessity to be stationed near the coast, geographic necessity will not be taken into consideration for this analysis. The new BRAC factors presented in this research may rank Keesler Air Force Base high on the list of BRAC candidates because of its vulnerability to hurricanes and the associated damage from storm surge, flooding, and high winds. For the purposes of this analysis, consideration of mission importance and transferability to another location is redundant. The BRAC process already accounts for and factors in separately these two factors (GAO, 2013b).

3.1 – Data Collection

Section 3.1 lays the foundation for the overall analysis plan. This section is described in two basic steps. These steps include the sample selection process and the data collection methods.

3.1.1 – Sample Selection Process

In an effort to improve the BRAC process, evaluating additional factors such as severe weather, climate zone, energy use, and utility rates, should assist Congress in making better-informed BRAC decisions in the future. To effectively perform this analysis, sample data must be constrained to a geographic region where DOD and Congress have the legal authority to conduct BRAC.

The sample used for this analysis includes all major CONUS Air Force installations in addition to any joint-bases where the Air Force is the lead service. Under this definition, Joint Base Anacostia-Bolling (Bolling Air Force Base), Joint Base Lewis-McChord (McChord Air Force Base), and Fort Bragg (includes former Pope Air Force Base, now Pope Field) are not included in the analysis; the Navy or Army has the lead for these three major installations. All other Air Force Reserve and Air National Guard installations, along with sister service installations such as Army, Navy, Marine Corps, and Coast Guard, are excluded from the analysis. Additionally, the study includes select major CONUS Air Stations (AS) and Geographically Separated Units (GSUs), to include Cavalier, Cape Cod, and New Boston Air

Stations. Cheyenne Mountain Air Force Station is excluded from the analysis because it is a unique, one-of-a-kind Air Force asset, and has no exposure to the severe weather factors identified in this research. According to this definition, the sample size used in this analysis is 62 CONUS Air Force installations. See Appendix A for a full list of all 62 bases selected for this analysis.

Because the indicated sample size includes all data points within the defined population, inferential statistical analysis tools such as test statistics, confidence intervals, analysis of variance, and regression are not applicable for this analysis. Basic descriptive statistics are the primary tool to evaluate quantitative aspects of the data sets. In addition, all historical severe-weather occurrence data are assumed to be captured and recorded for the period of study identified for each factor in the analysis.

3.1.2 – Data Collection

The data collected and used for this analysis came directly from various Air Force civil engineer databases maintained by the Air Force Civil Engineer Center (AFCEC) or readily available online sources. For energy usage, cost, utility rate data and historical trends, available sources such as the Air Force Energy Reporting System (AFERS), United States Energy Information Administration (EIA), Department of Energy (DOE), and National Renewable Energy Laboratory (NREL) are used for the analysis. Data from the National Weather Service (NWS), the National Oceanic and Atmospheric Administration (NOAA), the 14th Weather Squadron (14th WS) (formerly known as the Air Force Combat Climatology Center, AFCCC), and National Center for Atmospheric Research (NCAR) served as the basis of analysis for historical severe-weather information and trends. Weather and energy related data sets from the listed agencies, in particular the NWS and EIA, are used primarily in the geospatial analysis in this research.

Miscellaneous pertinent GIS data sets used in this analysis are readily available through online sources to include data pertaining to city, county, and state boundaries; topographical info; transportation networks and roads; natural disasters; and other built infrastructure or jurisdictional boundaries. Other GIS resources used include Environmental Systems Research Institute's (ESRI) ArcMap software's preloaded base-map data, National Atlas.gov, data.gov, US Census Bureau, and the Federal Emergency Management Agency (FEMA). All applicable GIS data collected are compatible for use in ESRI's ArcGIS software. The data include but are not limited to shape files, layer files, geodatabases, geotiffs, MrSID images, and other pertinent raster, vector, images, or geo-datasets.

3.2 – Geospatial Analysis Plan

Severe weather, climate zone, energy use, and utility rates all have a major impact on the cost to maintain and operate major Air Force installations. The most efficient way to analyze these factors is through a geospatial analysis of available data. An in-depth analysis of this data will highlight and identify Air Force installations with the highest rate of historical severe-weather occurrences and unfavorable climate and energy factors.

3.2.1 – Severe Weather Occurrences

Severe weather has a sizeable influence on the cost to maintain and operate a major Air Force installation. One of the tools and techniques to analyze severe-weather GIS data is buffering. Buffering is used to assess impact within a region based on historical weather data. To assess the potential for tornado damage, a 25 statute-mile buffer is established from the centroid of each base. This definition captures historical tornado occurrences with enough granularity to evaluate the financial impact to a base. This process is repeated with hurricanes, but instead used a 75 nautical-mile buffer from the base centroid. The buffered layer is queried in ArcMap or other online GIS viewers, such as NOAA's online historical hurricane-track viewer (NOAA, 2015a), to quantify the total number of severe weather occurrences that intersect and are contained within those buffers. The intersection of a tornado with a base buffer is used to determine the total count of severe weather occurrences in relation to a particular Air Force base. As previously mentioned, buffering techniques can also be applied to other severe weather data such as hurricane paths.

To display severe weather data effectively, the total count or average annual number of occurrences of severe weather is displayed using a shaded density map. For this style of map, the frequency of occurrence is normalized based on the area of the region of interest. The area of interest for this research is primarily Air Force installations and state boundaries. Visual depictions from this shaded density mapping technique are presented in Chapter 4.

3.2.2 – Mapping and Symbology Methods

Map symbology is adjusted to best reflect size, density, or intensity of the severe weather patterns. Symbology choices are important to help the end-user understand what is depicted on a thematic map. The data classification technique of Jenks Natural Breaks is used to establish each of the shaded density maps (Jenks, 1967). The total number of data classes varies based on the type of information displayed, ranging from six to ten classes. Total Jenks Natural-Breaks classes is adjusted until the map appears to display the optimum theme and message that is most understandable to a reader. A standard yellow-to-dark-red graduated color scheme is employed to ensure that the density or distribution of major weather events is clearly and accurately depicted on the map. These mapping and symbology techniques are also be used to enhance the visual representation of the utility-rate geospatial data.

3.2.3 – Climate Zone

According to the International Energy Conservation Code (IECC), there are eight major climate zones within the United States (ICC, 2012). Figure 14 shows the IECC's eight climate zones and their respective CDDs and/or HDDs. Just because there is a dash in a cell, does not mean that heating or cooling degree-days are not possible in that climate zone. In fact, focusing on the extreme ends, Zone 1 can still have HDDs and Zone 8 can still have CDDs. The cells without values are often times negligible compared to the other values listed. CDDs and HDDs vary widely across each climate zone, so it is important to focus on the actual observed days by location versus the average for the entire zone.

	Thermal Criteria	
Zone	CDD 50*	HDD 65**
1	> 9000	–
2	6,300–9,000	–
3	4,500–6,300	–
4	< 4,500	< 5,400
5	–	5,400–7,200
6	–	7,200–9,000
7	–	9,000–12,600
8	–	> 12,600

* Cooling Degree Days over 50°F
** Heating Degree Days under 65°F

Figure 14: IECC Climate Zone Scale

Bases typically consume more energy at the extreme ends of the climate scale, so for the purposes of defining the costs and savings in a BRAC decision, increased energy consumption from extreme climates penalizes bases located in either hot or cold locations. In general, the harsher and more extreme the climate zone, either hot or cold but especially cold, the greater the amount of energy the base will consume (Griffin, 2008). Table 4 depicts the eight IECC Climate Zones, from hottest to coldest.

Table 4: Climate Zone Categories (Hottest-Coldest)

IECC Climate Zone	
1	Hottest
2	
3	*(Baseline)*
4	
5	
6	
7	
8	Cold

IECC Climate Zone 3 is the most *neutral* climate zone, which for this analysis, is defined as having the lowest amount of combined cooling-degree and heating-degree days. For all IECC climate zones, Zone 3's temperature is the most neutral and it generally has the lowest energy consumption (ICC, 2012); therefore, it is considered the baseline or ideal climate zone for this analysis.

3.2.4 – Energy Use

Energy use data is not mapped in this analysis, because an energy usage map has minimal practical significance because climate-zone and mission-related energy usage cannot easily be separated and depicted. As a result, a tabular method to display data is used. See section 3.3.5 for a detailed description of this tabular rank-matrix method.

3.2.5 – Utility Rates

Utility rate data for this research are obtained through the Energy Information Agency's (EIA) website. Data are collected on a state-by-state basis for average annual utility rates of both electricity (in units of dollars per kilowatt-hour, $/kWh) and natural gas (in units of dollars per thousand cubic feet, $/Mcf). At the time of publication, the most recent and complete data utilized for the utility rate mapping was a 2013 calendar-year state-by-state average for electricity and a 2012 calendar-year state-by-state average for natural gas. The data are downloaded from the EIA website in spreadsheet form and subsequently joined with the state layer in ArcMap. The visual state-by-state representation of electric and natural gas rates is shown in section 4.5.1 and 4.5.3, respectively, in Chapter 4.

3.3 – Rank Matrices

Rank matrices are created for each significant factor, following tabulation of severe weather occurrences, energy use, and utility rate data. The subsequent sections summarize the steps required for data collection and rank-matrix creation.

3.3.1 – PRV Rank Matrix

The data for the PRV rank-matrix comes from a DOD report titled, "Base Structure Report – Fiscal Year 2014 Baseline, A Summary of the Real Property Inventory" (DOD, 2013). This report provides a snapshot of all of DOD's real property stateside and abroad. The report used for this analysis was published on 30 September 2013. The data contained in the Base Structure Report serves as a baseline for the start of the following Fiscal Year, in this case, 2014 (DOD, 2013).

In order to be listed in the Base Structure Report, CONUS DOD or Air Force installations must be larger than 10 acres and have a PRV of more than $10 million dollars (DOD, 2013).

The PRV is defined as the total replacement value for all facilities to include buildings and linear structures (examples: roadways, airfields, and utilities) and represents the total cost of physical plant replacement using current construction costs, methods, and standards. The PRV does not include the cost of land that the installation occupies. Loss of land and its associated replacement value is not a consideration in this analysis. Land damage is not quantified or accounted for in this research, only damage to facilities and infrastructure. According to the Base Structure Report, the formula for calculating PRV is:

Plant Replacement Value = Facility Quantity[1] X Construction Cost Factor[2] X Area Cost Factor[3] X Historical Records Adjustment[4] X Planning and Design Factor[5] X Supervision Inspection and Overhead Factor[6] X Contingency Factor[7]

1 Quantity of assets from the real property inventory database.
2 Construction cost as published in the DoD Cost Factor Handbook.
3 A geographic location adjustment for costs of labor, material, and equipment.
4 An adjustment to account for increased costs for replacement of historical facilities or for construction in a historic district; the current value of the factor is 1.05.
5 A factor to account for the planning and design of a facility; the current value of this factor is 1.09 for all but medical facilities and 1.13 for medical facilities.
6 A factor to account for the supervision, inspection, and overhead activities associated with the management of a construction project; the current value of the factor is 1.06 for facilities in the continental US (CONUS) and 1.065 for facilities outside of the continental US (OCONUS).
7 A factor to account for construction contingencies; the current value of the factor is 1.05.

Figure 15: Standard DOD formula for calculating PRV (DOD, 2013)

The PRV is a central element in this research, as it quantifies the current cost to replace facilities and infrastructure. This value is important because the Monte Carlo simulation, described step-by-step in section 3.4, estimates facility damage and a percentage of total PRV destroyed during a tornado or hurricane. This estimated damage ultimately determines the Equivalent Annual Cost (EAC) of the forecasted severe-weather events. The PRV values are ranked in descending order in the PRV rank matrix, in section 4.1.2.

3.3.2 – Tornado Risk Rank-Matrix

The Air Force Weather Agency's (AFWA) 14th Weather Squadron (14th WS) is the source of all tornado occurrence data used in the tornado risk rank-matrix (AFWA, 2014a). At the request of the researcher, the 14th WS supplied tabulated tornado event data for all 62 Air Force installations. This data, provided in spreadsheet form, contains details for each tornado event occurring within a 25 mile radius of each base, over a period of 30 years, from 1984 to 2013. Tornado events are counted in both the first and last years of this period. Even though a simple subtraction (2013-1984) yields 29 years, the data accounts for 30 years of actual observations. It is not necessary to go back further in the records than 1984, because this 30-year period shows enough variation in tornado counts and reveals differences in tornado threats between installations. Moreover, tornado reports prior to the 1980s are more sporadic and less accurate. This is largely due to the fact the Doppler weather radar did not come in to wide use until the 1970s and weather observations and storm reports generally occur less frequently in sparsely populated areas (Doswell et al., 1993; NOAA, 2014b). However, even with Doppler weather radar, some tornado events still go unaccounted for without eyewitness confirmation or actual damage reports. Prior to the 1970s, many tornadoes are not reported at all because they occurred in an area where nobody witnessed them and there was no reported damage (NOAA, 2014b). As a result, due to the accuracy of these early reports, the later period spanning 1984 to 2013 is used for the analysis.

Each specific tornado event at a given installation includes the date and time of occurrence, the EF scale, number of injuries and fatalities, location of event (latitude and longitude), and the approximate tornado-path length and width. The average return period is calculated by taking the reciprocal of the total number of occurrences for strong-violent tornadoes (EF 2-5) and dividing it by the 30 time-period. Total tornado counts (EF 0-5), strong-violent tornado counts (EF 2-5), and average return periods are derived from this data and applied to the tornado risk rank-matrix in section 4.2.4.

Additionally, the 14th WS provided all the tornado occurrence maps by base, featured in Appendix E. Figure 16 is a sample tornado-occurrence map for Tinker AFB, OK. As shown in the figure, Tinker experienced 101 tornado events from 1984 to 2013. Twenty-nine of the total occurrences at Tinker AFB are rated EF 2-5 during this 30-year period.

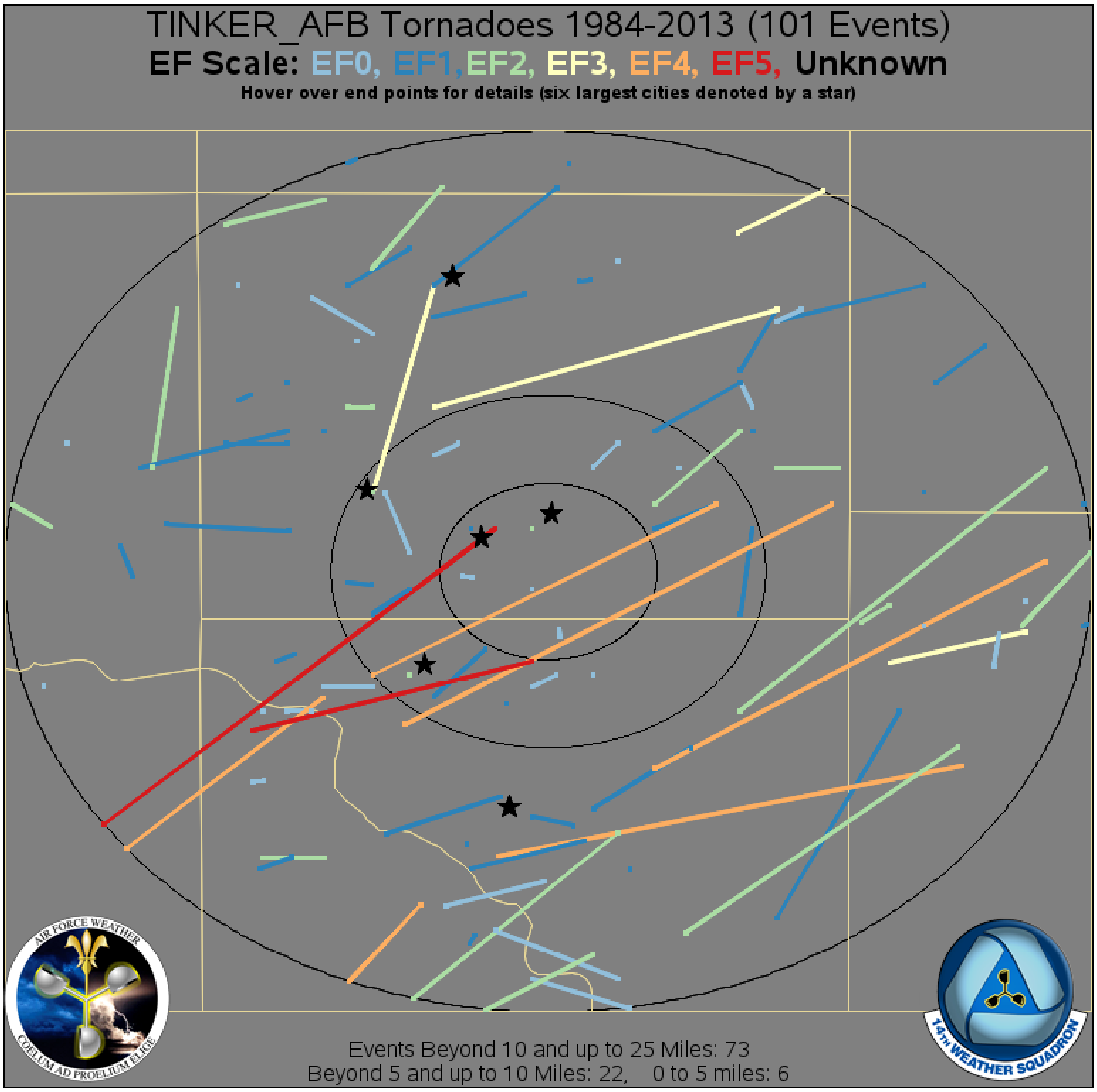


Figure 16: Tornado Occurrence Map – Tinker AFB, OK

To help better understand the likelihood of a tornado impacting an Air Force base, and the variable nature of tornado risk throughout the year, Appendix D contains tornado probability maps, organized temporally by month (four weeks each month) and type (all tornadoes, EF 0-5; and strong-violent tornadoes, EF 2-5). These probability maps are created from the NOAA Storm Prediction Center's online severe-weather viewer (NOAA, 2015b). Figure 17 contains two sample tornado-probability maps, which break down the probability of occurrence for each severity level (EF 0-5 or EF 2-5) in the final week of May.

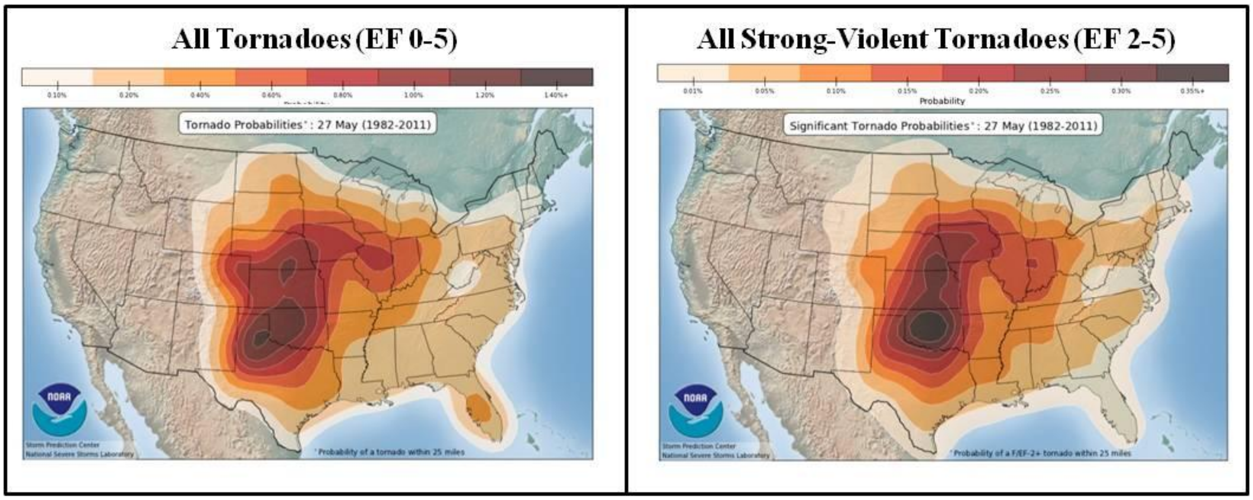


Figure 17: Tornado Probability Maps – Last Week of May

The map on the left side in Figure 17 represents the probability of a tornado occurrence (EF 0-5), within a 25 mile radius, during the final week of May. The right side map in Figure 17 represents the probability of a strong-violent tornado occurrence (EF 2-5), within a 25 mile radius, during the same final week of May. NOAA's Storm Prediction Center estimates these probabilities from severe weather reports covering a 30-year period, from 1982 to 2011. According to NOAA, the procedure to create these maps is (NOAA, 2015b):

1. Reports for each day are put onto a grid 80 kilometer x 80 kilometer.
2. If one or more reports occur in a grid box, that box is assigned the value "1" for the day. If no reports occur, it is a zero.
3. The raw frequency for each day at each grid location is found for the period (number of "1" values divided by number of years) to get a raw annual cycle.

4. The raw annual cycle at each point is smoothed in time, using a Gaussian filter with a standard deviation of 15 days.
5. The smoothed time series are then smoothed in space with a 2-D Gaussian filter (standard deviation = 120 kilometers in each direction).

As a final point, the word *Risk* is added to the title of this matrix to inform the reader of the negative consequences of this type of event, because bases with a higher tornado occurrence rate are at greater risk for damage and financial loss. The traditional definition of *risk* involves the combination of likelihood and consequence of an event (Ang & Tang, 2007). The Monte Carlo simulation accounts for this traditionally defined tornado *risk* in the form of predicted equivalent annual cost (EAC), which is the outcome of the product of likelihood (tornado occurrence probability and return period) and consequence (the damage a tornado causes to a base). Section 3.4 details the Monte Carlo simulation method and assumptions in-depth.

3.3.3 – Hurricane Risk Rank-Matrix

The National Oceanic and Atmospheric Administration's (NOAA) online "Historical Hurricane Tracks" viewer is the source of all maps in Appendix H and hurricane occurrence data used in the hurricane risk rank-matrix (NOAA, 2015a). Hurricane occurrences are mapped and tabulated for all 62 Air Force installations, using data contained in NOAA's Hurricane Tracks viewer. By definition, one occurrence is counted if a hurricane passes within 75 nautical miles of the base centroid. Data is analyzed over a period of 163 years, spanning 1851 to 2013. Hurricane events are counted in both the first and last years of this period, which yields 163 years of actual observations. The period of study for hurricanes is much longer than tornadoes, because the accuracy and span of hurricane records is much better. Furthermore, a hurricane is a much rarer event than a tornado, so a longer time-period is necessary to establish granularity for hurricane threats among all the bases.

Using NOAA's Historical Hurricane Track viewer, all applicable hurricane events for each installation are counted for each severity range to include all hurricanes, Category 1-5; and major hurricanes, Category 3-5. The inclusion of all hurricanes, Category 1-5, serves primarily as a tie-breaker in the risk rank-matrix for bases with identical major hurricane counts. However, for the Monte Carlo simulation, major hurricane occurrences (Category 3-5) is the only metric used to assess damage and predict hurricane costs. Figure 18 is a sample hurricane-occurrence map for MacDill AFB, FL, used to establish event counts for the risk rank-matrix in section 4.2.6. See Appendix H for all hurricane occurrence maps by base.

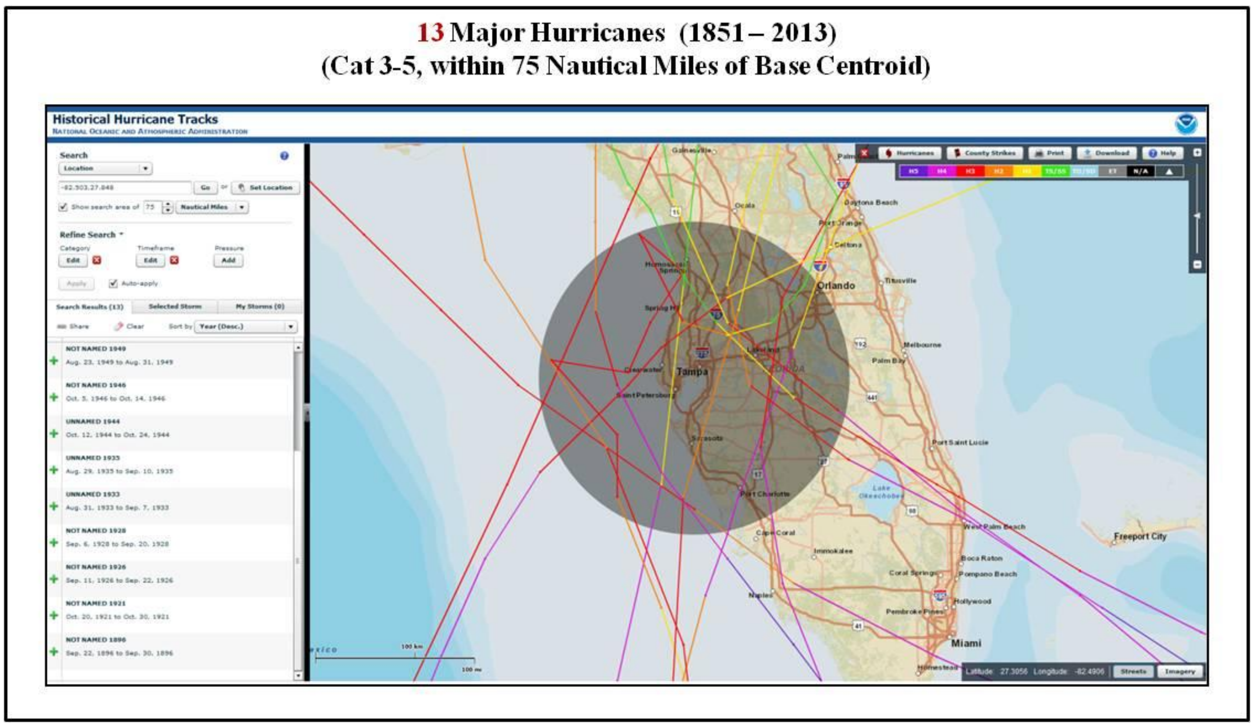


Figure 18: Major Hurricane Occurrence Map – MacDill AFB, FL

After tabulation of occurrences, the average return period is calculated by taking the reciprocal of the total number of major hurricane occurrences (Category 3-5) and dividing it by the 163 year time-period. Total hurricane occurrences and average return period by base are shown in the risk rank-matrix in section 4.2.6.

As described in the tornado section, the word *Risk* is added to the title of this matrix to inform the reader of the negative consequences of this type of event, because bases with a higher hurricane occurrence rate are at greater risk for damage and financial loss. The traditional definition of *risk* involves the combination of likelihood and consequence of an event (Ang & Tang, 2007). The Monte Carlo simulation accounts for this traditionally defined hurricane *risk* by taking into account both likelihood and consequence. Section 3.4 provides more in-depth details on the methodology behind the Monte Carlo simulation used to assess hurricane damage and predict costs.

3.3.4 – Climate Zone Matrix

The climate zone matrix is compiled using published "Engineering Weather Data" reports from the 14th WS (AFWA, 2014b). Cooling-degree day (CDD) and heating-degree day (HDD) information is pulled from the Engineering Weather Data reports for all 62 Air Force Bases. The CDD and HDD denoted in the climate zone matrix are yearly averages covering a 30-year period-of-record from 1984 to 2013 or 1985 to 2014, depending on the base's report. CDD and HDD are an important metric as they are major contributing factors affecting energy use on a base. To determine the IECC climate zone, the base's county is inputted into an online program hosted by the U.S. Department of Energy. Once the county information is entered, the IECC Climate Zone is determined (DOE, 2014). This climate zone data is then entered in to the climate zone matrix.

3.3.5 – Energy Usage Rank-Matrix

Energy use is a major component affecting Air Force base operation costs that could shape future BRAC decisions. As detailed in the section 3.2.3, climate zone is a major factor that affects energy consumption at Air Force installations, but it does not drive all usage. Mission-related use, including energy loads such as space radar systems, large network server-banks or computer systems, or industrial processes such as depot maintenance, is another main component driving facility and infrastructure energy usage. Climate zone and energy-intensive mission-processes are two similar energy usage factors affecting Air Force bases. However, to assess variations on energy use with respect to a base's location, the climate and mission-related energy factors must be separated, which is impracticable in this analysis. As a result, these two contributing factors are lumped together and are henceforth collectively referred to as total energy-usage or simply – energy usage.

To evaluate energy usage, data for this research are obtained through the AFCEC's AFERS database. Fiscal Year (FY) 2012 through 2014 data are the most recent installation-level energy usage information available for analysis from AFERS. Data are analyzed on an installation-by-installation basis to compute average annual energy consumption, for a three-year period from Fiscal Year 2012 through Fiscal Year 2014, for both electricity (in units of kilowatt-hour, kWh) and natural gas (in units of thousand cubic feet, Mcf). Additionally, the standard deviation of the energy usage for each commodity is calculated. This standard deviation is applied in a subsequent section in the Monte Carlo simulation.

AFCEC provided AFERS data in spreadsheet form, which is used to create the energy usage and intensity rank-matrices. For a given commodity, all sources of energy data are combined into one value. For example, total electricity usage is a combined total of electricity (derived from nuclear, natural gas, or coal-fired power plants), hydroelectric, solar photovoltaic, and wind power. Aside from locations and facilities that use electricity to heat, natural gas is the only heating fuel that is evaluated. Other common raw fuel sources such as coal and heating-oil are not analyzed in this research, as natural gas constitutes the largest heating fuel source in the DOD and Air Force (DOD, 2014c). Additionally, for each major installation, energy usage is combined and consolidated for all local auxiliary sites assigned under the main installation. For example, at Vandenberg AFB, CA, energy usage is totaled for Vandenberg main-base, along with Pillar Point Air Force Station and a small communication annex transmitter. In addition, at many of the Air Mobility Command bases, such as McConnell AFB, KS, or Scott AFB, IL, installation energy usage for both AMC and Air National Guard (ANG) tenants are combined. ANG energy usage is included at the AMC bases because if the installation is closed under BRAC, both the AMC and ANG missions would be required to close or relocate.

Section 4.4.1 break down energy usage by base and bases are ranked in descending order by total energy usage. Each table lists energy usage by commodity (electricity and natural gas) along with the combined total, average-annual energy usage. Electricity usage is quantified using kilowatt-hours (kWh), natural gas usage is shown in thousand cubic feet (Mcf), and total energy usage is displayed in million British Thermal Units (MBTU).

3.3.6 – Energy Intensity Rank-Matrix

The energy intensity metric is simply a combination of previously described datasets. For each base, energy intensity is calculated by taking the total Fiscal Year 2013 energy usage in millions of British Thermal Units (MBTU), converting it to BTUs, and dividing the value by the total Fiscal Year 2013 gross square-footage. Fiscal Year 2013 is chosen because it is the most current year of data available for facility square footage. Choosing one specific Fiscal Year's data, allows equal comparison of same-year energy usage with same-year facility square-footage, thus matching the correct usage with the correct real-property records. Cross-year comparisons lead to errors and inaccuracy in the calculations, as facility square-footage changes each year as facilities are built or demolished.

Energy intensity is reported only as a value of total site-delivered energy divided by gross square-footage. Total site-delivered energy (MBTU) is a common unit-of-measure, which combines all electricity (kWh) and natural gas (Mcf) energy delivered to the base into one common value. This metric is not sub-divided into individual energy-intensity categories for electricity or natural gas. In a BRAC analysis, the energy-intensity metric is valuable because it highlights bases that are extremely energy-intensive and costly to operate. The results of the energy-intensity calculations, ranked in descending order, are featured section 4.4.2.

3.3.7 – Energy Cost-Intensity Rank-Matrix

Similar to energy intensity, the energy cost-intensity metric is a combination of available datasets. For each base, energy cost-intensity is calculated by taking the total Fiscal Year 2013 energy cost (in dollars, $) and dividing this value by the Fiscal Year 2013 gross square-footage. Fiscal Year 2013 is chosen because it is the most current real property data. Choosing only Fiscal Year 2013 data, allows equal comparison of same-year energy cost with same-year facility square-footage, thus matching the correct cost with the correct real-property records. Cross-year comparisons lead to errors and inaccuracy in the calculations, as facility square-footage changes each year.

In the end, energy cost-intensity can be used to compare bases on the cost of energy usage per unit of total area (gross square footage). In a BRAC analysis, this metric is valuable because it highlights bases that are extremely cost-intensive to operate. The results of the energy cost-intensity calculations are ranked in descending order and are shown in section 4.4.3.

3.3.8 – Electric Rate Rank-Matrix

Energy usage is not the only factor of concern influencing the cost to operate Air Force Bases. Utility rates play a significant role in the cost of energy. Specifically, electric rates are an important factor to evaluate for Air Force Bases. For all 62 bases, overall average electric rates are computed by taking the rate for all 12 months during a 3-year period from Fiscal Year 2012 through Fiscal Year 2014. This method yields an overall average rate of 36 individual monthly rates. This average electricity rate is in dollars per kilowatt-hour ($/kWh). Additionally, the standard deviation of this rate is calculated. This standard deviation is applied in a subsequent section in the Monte Carlo simulation. The average rate is ranked in descending order to create the electric rate rank-matrix found in section 4.5.2.

3.3.9 – Natural Gas Rate Rank-Matrix

Natural gas rates are an important factor to evaluate for Air Force Bases. For all 62 bases, overall average natural gas rates are computed by taking the rate for all 12 months during a 3-year period from Fiscal Year 2012 through Fiscal Year 2014. This method yields an overall average rate of 36 individual monthly rates. This average natural gas rate is in dollars per thousand cubic feet ($/Mcf). Additionally, the standard deviation of this rate is calculated. The standard deviation is applied later in the Monte Carlo simulation. The average rate is ranked in descending order to create the natural gas rate rank-matrix found in section 4.5.4.

3.4 – Monte Carlo Simulation & Determination of Equivalent Annual Costs (EACs)

A Monte Carlo simulation is used to help analyze risk and model the future probabilities of occurrence for severe weather events, along with energy use and utility rate fluctuations. Monte Carlo simulation allows the researcher to evaluate multiple possible outcomes of the variables and to assess the impact of risk. This technique allows for a better decision-making process given future uncertainty in areas such as tornado and hurricane occurrences, yearly and climatic variations in energy use, and utility rates.

Major severe weather occurrences are modeled in the Monte Carlo simulation using various distributions. Return periods for both tornadoes and hurricanes follow a Poisson process and are modeled using an exponential distribution (Ang & Tang, 2007; Huang, Rosowsky, & Sparks, 2001). A Weibull distribution is used to model the damage caused by tornado occurrences, by focusing specifically on the tornado path length and width within the 25 mile radius of interest surrounding a base (Meyer, Brooks, & Kay, 2002; Chu & Wang, 1998). Due to the sheer size and width of a major hurricane, damage to a base is assumed to occur (to varying degrees) every time a hurricane enters the 75 nautical-mile radius surrounding a base. Based on this assumption, a uniform distribution is used to model the damaged caused by each category of major hurricanes. This uniform distribution is adapted from building vulnerabilities and damage estimates shown in the Florida Public Hurricane Loss Model along with published research on predicted hurricane losses for varying structure types (Hamid, 2013; Pinelli, Subramanian, Zhang, Gurley, Cope, Simiu, Diniz, & Hamid, 2003; Huang et al., 2001). Fluctuations in energy usage, electric rates, and natural gas rates use due to yearly climatic variations, seasonal trends, and mission needs are modeled using the normal distribution (McClave, Benson, & Sincich, 2011). Each variable's unique parameters, such as probability (created using Excel's random number generator), average, standard deviation (σ), alpha (α), beta (β), and its respective distribution are entered into the Monte Carlo simulation and evaluated using 10,000 trials. See section 4.6 for final Monte Carlo simulation risk-analysis results.

The Monte Carlo simulation yields a list of forecasted equivalent annual costs, which translates into a *1-to-n* ranked list for all 62 major CONUS Air Force installations. The list ranks EAC in descending order, to prioritize the costliest bases for entry into the BRAC COBRA model. Bases ranked high on the list are the best candidates, according to the new proposed factors, to be eligible for a round of BRAC.

The following subsections outline the step-by-step process to create the Monte Carlo simulation in Excel. Seymour Johnson AFB, NC, is used as one specific example to explain the methodology to create the Monte Carlo, because tornadoes and hurricanes each pose a risk to this base, thus creating expected annual costs for these two severe weather factors. The following eight steps repeat for all 62 bases. For a summary of the final Monte Carlo results, see section 4.6.

<u>Step 1: Define Installation Specific Inputs</u>

To set-up the Monte Carlo, installation specific inputs must be first defined. Each base has twelve unique inputs that enter the Monte Carlo. The installation and severe-weather specific input-values are highlighted in yellow in Table 5. Installation specific energy usage, electricity rate, and natural-gas rate averages and standard deviations are highlighted in yellow in Table 6. These twelve unique values are the inputs that define each base's final EAC value.

As mentioned in section 3.3.1, the PRV value in Table 5 comes from the DOD report "Base Structure Report – Fiscal Year 2014 Baseline, A Summary of the Real Property Inventory" (DOD, 2013). In the bottom portion of Table 5 is the 2014 Discount Rate. Per the COBRA User's Manual, the discount rate used for BRAC is the average of the 10 and 30-year

"Real Discount Rates" published in the Office of Management and Budget (OMB) Circular A-94 (DOD, 2005d).

Table 5: Monte Carlo Inputs – Installation & Severe Weather Data

Installation Data		Severe Weather	
Installation Name	**Plant Replacement Value**[1] (PRV) ($)	**Tornado Occurrences** (EF-2 to EF-5) (1984-2013) (w/in 25 mi radius)	**Hurricane Occurrences** (Cat 3-5) (1851-2013) (w/in 75 naut. mi radius of base centroid)
Seymour Johnson AFB	**$ 1,321,700,000**	**16**	**3**
Time Period *(Includes 1st Year; Max Yr - Min Yr + 1)* =		**30**	**163**
Probability, "p" *(Avg # Events/yr)* =		**0.533**	**0.018**
Average Return Period (1/p) *(Yrs)* =		**1.9**	**54.3**
2014 Discount Rate (OMB Circular A-94)[2] ("rate" for EAC Calcs") =		**1.45%**	

Table 6: Monte Carlo Inputs – Energy Usage, Electricity, & Natural Gas

Energy Usage				Electricity		Natural Gas	
Average Annual Electricity Usage (FY12-14) (kWh)	**Std Dev of Annual Electricity Usage** (FY12-14) (kWh)	**Average Annual Natural Gas Usage** (FY12-14) (Mcf)	**Std Dev of Annual Natural Gas Usage** (FY12-14) (Mcf)	**Average Electric Rate** (FY 12-14) ($/kWh)	**Standard Deviation of Electric Rates** (FY 12-14)	**Average Natural Gas Rate** (FY 12-14) ($/Mcf)	**Standard Deviation of Natural Gas Rates** (FY 12-14)
59,373,916	**3,334,361**	**114,725**	**8,827**	**$0.06605**	**$0.00737**	**$8.667**	**$1.383**

Figure 19 shows the Real Discount Rates used in the Monte Carlo simulation, which are extracted from Appendix C of OMB Circular A-94, published in February of 2014 and valid for the 2014 calendar year (OMB, 2014b). The average of the 10-year and 30-year rates listed in Figure 19, yield a discount rate for the BRAC analysis of 1.45%. This discount rate is the interest rate used to calculate the EAC for tornado and hurricane damage. Subsequent steps will further define the EAC formula and how the rate is applied.

Real Discount Rates. A forecast of real interest rates from which the inflation premium has been removed and based on the economic assumptions from the 2015 Budget is presented below. These real rates are to be used for discounting constant-dollar flows, as is often required in cost-effectiveness analysis.

Real Interest Rates on Treasury Notes and Bonds of Specified Maturities (in percent)

3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
-0.7	0.0	0.5	1.0	1.6	1.9

Figure 19: Real Discount Rates – OMB Circular A-94 (OMB, 2014b)

Step 2: Define Total U.S. Tornado Occurrences

To establish the average tornado occurrence rates by EF-Rating and estimate its associated probability, total tornado occurrences are counted for the entire United States. Table 7 is a summary of the total CONUS tornado counts by EF-Rating from 1950 to 2013 (NWS, 2014a). The far right column of Table 7 displays the percentage of strong-violent tornado occurrences (EF 2-5). These occurrence percentages become the tornado probabilities entered into Table 8. The probabilities in Table 8 are used to determine the EF-Rating of a tornado event in the Monte Carlo. Step 4 of the Monte Carlo process explains in full detail the determination of tornado damage costs.

Table 7: CONUS Tornadoes (1950-2013)

CONUS Tornadoes 1950-2013 (EF-Rating)	Occurrences	% of Total Occurrences	% of Strong-Violent Occurrences
0	27,124	46.7%	
1	18,846	32.5%	
2	8,934	15.4%	73.9%
3	2,458	4.2%	20.3%
4	619	1.1%	5.1%
5	76	0.1%	0.6%
Total (EF 0-5)	58,057	Strong-Violent Tornadoes (% of Total):	20.8%
Strong-Violent (EF 2-5)	12,087		

Table 8: Strong-Violent (EF 2-5) Tornado Probabilities

Strong-Violent Tornadoes (EF 2-5)	Probability (Calculated)
2	0.739
3	0.203
4	0.051
5	0.006
Probabilities Applied to Tornado EF-Rating Distribution	

Step 3: Define Total U.S. Hurricane Occurrences

To establish the average hurricane occurrence-rates by Category and estimate its associated probability, total hurricane occurrences are counted for the entire United States. Table 9 is a summary of the total CONUS hurricane counts by Category rating from 1851 to 2013 (Blake et al., 2011; NOAA, 2015a). The far right column of Table 9 displays the percentage of strong-violent hurricane occurrences (EF 2-5). These occurrence percentages become the hurricane probabilities entered into Table 10. The probabilities in Table 10 are used to determine the Category rating of a hurricane event in the Monte Carlo.

Table 9: CONUS Hurricanes (1851-2013)

CONUS Hurricanes 1851-2013 (Category)	Strikes	% of Total Strikes	% of Major Strikes
1	115	40.1%	
2	76	26.5%	
3	75	26.1%	78.1%
4	18	6.3%	18.8%
5	3	1.0%	3.1%
Total (Cat 1-5)	287	Major Hurricanes (% of Total):	33.4%
Major (Cat 3-5)	96		

Table 10: Major Hurricane (Cat 3-5) Probabilities & Damage Estimate Matrix

Major Hurricane (Cat 3-5)	Probability (Calculated)	% Facilities Damaged (Estimated)					
		Low End Damage Estimate			High End Damage Estimate		
		Wind Only	Storm Surge & Flooding	**Total Low Estimate**	Wind Only	Storm Surge & Flooding	**Total High Estimate**
3	0.781	2%	0%	**2%**	28%	10%	**38%**
4	0.188	5%	0%	**5%**	39%	10%	**49%**
5	0.031	17%	0%	**17%**	83%	10%	**93%**

Hurricane Damage Estimates Used for Uniform Distribution of Base Damage Assessment

The damage estimates in Table 10 are derived from values shown in Figure 20. Figure 20 shows the vulnerabilities of masonry buildings in the central wind-borne debris region of a hurricane. Figure 20 is a product of the Florida Public Hurricane Loss Model, which bases its damage ratios versus wind speeds for masonry buildings on post-hurricane damage observations and laboratory tests (Hamid, 2013). Wind-damage ratio percentages in Figure 20 are estimated for four levels of masonry building strength: weak, medium, strong, and age-weighted. The masonry building-type best describes the average facility type found on an Air Force base, which is why the masonry type is selected. In addition to the hurricane wind-damage estimates derived from Figure 20, a 10 percent plus-up for storm-surge above and beyond wind damage is added to the high-end damage estimates for all three categories of major hurricanes. The highlighted low-end and high-end damage estimates derived from Figure 20 and shown in Table 10, establish the upper and lower bounds of the uniform distribution for the Base Damage Assessment. Step 5 of the Monte Carlo process explains in full detail the determination of hurricane damage costs.

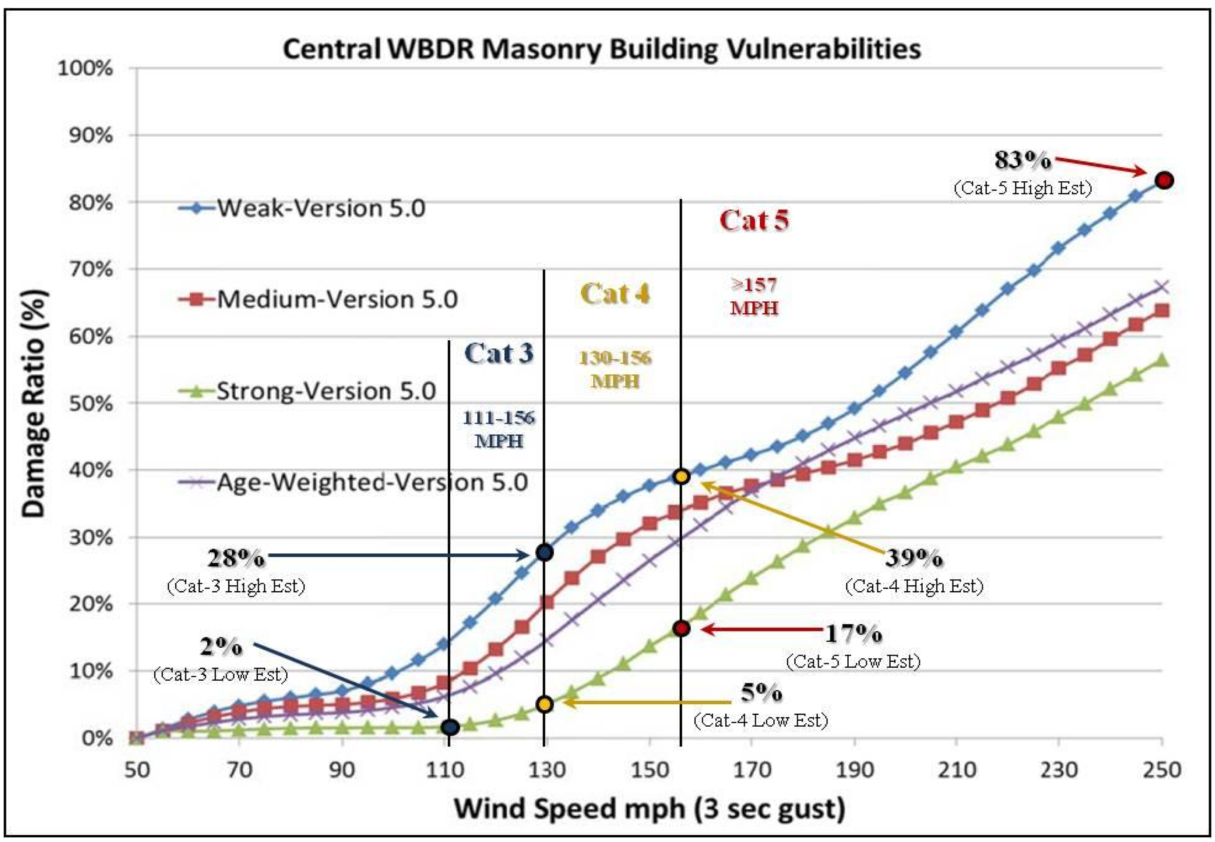


Figure 20: Masonry Building Vulnerabilities and Damage Ratios (%)

Step 4: Define Monte-Carlo Tornado Parameters

To set-up and run the Monte Carlo simulation for tornadoes, a number of different steps and input parameters are required. First, as shown in Table 12, the tornado return period is calculated for each trial. The return period is calculated using a probability value from Excel's random number generator and applying that value to the formula for the Exponential distribution. The return period is calculated in Excel using Equation 1:

$$= -\text{LN}\ (\text{Rand}())*(\text{Avg Return Period}) \tag{1}$$

Where:

Rand() = a random number generated in Excel from 0 to 1
Avg Return Period = 1/p
p = probability (average number of tornado events per year)

Second, the EF-Rating is calculated for each trial. As shown in Table 12, the EF-Rating (2-5) is generated by associating the adjacent random number column with the tornado probabilities listed in Table 8. All random number values from 0.000 < [Rand # (0-1)] ≤ 0.739, are assigned an EF-Rating of 2; all values from 0.739 < [Rand # (0-1)] ≤ 0.942, are assigned an EF-Rating of 3; all values from 0.942 < [Rand # (0-1)] ≤ 0.993, are assigned an EF-Rating of 4; and all values from 0.993 < [Rand # (0-1)] ≤ 1.000, are assigned an EF-Rating of 5. This process yields a distribution of tornado severity (EF 2-5) that matches the percentage distribution of historical strong-violent tornado occurrences shown in Table 7.

Third, the Base Damage Assessment is calculated using a Weibull distribution. The percent facilities damaged column in Table 12 is calculated by taking one minus the Weibull cumulative distribution function in Excel. The "% Facilities Damaged" is calculated in Excel using Equation 2:

$$=1-\text{WEIBULL}\ (x,\alpha,\beta,\text{cumulative}) \quad (2)$$

Where:

x = a random number generated in Excel from 0 to 1, “Rand # (0-1)”
α = shape parameter > 0
β = scale parameter > 0
cumulative = determines the form of the function (“TRUE” is entered for for all equations to use the Weibull cumulative distribution function)

Table 11: Weibull Parameters for Tornado Damage Distribution

% Facilities Damaged Equation		
	Weibull Parameters	
Tornado Rating	**α**	**β**
EF-2	**1.6052**	**0.15**
EF-3	**1.6052**	**0.15**
EF-4	**1.6052**	**0.20**
EF-5	**1.6052**	**0.25**

Next, cost of damage is calculated by taking the “% Facilities Damaged” value and multiplying it by 80% of the PRV. Decreasing the percentage of PRV damaged by a tornado by 20% is necessary because a tornado cannot destroy all facilities and infrastructure included in the total PRV. Table 13 shows a breakdown of 1-digit Category Codes (CATCODES). These CATCODES define the different categories that make up the PRV. Codes 1-7 account for 80% of all PRV. As shown in Table 13, Code 8 – Utility and Ground Improvements and Code 9 – Land, account for the remaining 20% of PRV and are excluded from the analysis because tornadoes generally do not damage these categories of property. Example Subsets of Code 8 infrastructure include water, sewage and waste, roads and other pavements, and railroad facilities. The final tornado damage cost is shown in present value dollars (pv, $).

Last, the present value (pv) of the tornado damage cost must be converted into an Equivalent Annual Cost of Damage, EAC ($). EAC is calculated using the payment, “PMT,” function in Excel, by spreading out the present-value costs over the tornado return period (nper) for each trial, at the given interest rate (). The EAC is calculated in Excel using Equation 3:

$$= \text{PMT (rate,nper,pv,fv,type)} \qquad (3)$$

Where:

rate = Discount Rate (1.45%), discussed in Step 1 and shown in Figure 19
nper = number of payments in years, where “nper = (ROUNDUP(return period)).” The return period value is rounded up to the nearest year – because tornado costs are accounted for at the end of the year in which they occur.
pv = the present value of tornado damage cost shown in Table 12
~~fv~~ & ~~type~~ = (omitted) – not required for payment calculation in Excel

Table 12: Sample Monte-Carlo Tornado Analysis

Trial #	Tornadoes							
	Return Period (Exponential Distribution)		Strong-Violent Tornadoes (Historic Distributions)		Base Damage Assessment (Weibull Dist)		Cost of Damage (% Damaged * 80% of PRV)[3]	Equivalent Annual Cost (EAC) EAC = -PMT[4] (rate,nper,pv,~~fv~~,~~type~~)
	Rand # (0-1)	Return Period of EF 2-5 Tornado (nper)	Rand # (0-1)	EF-Rating (2-5)	Rand # (0-1)	% Facilities Damaged	Tornado Damage Cost (pv, $)	Tornado Damage EAC ($)
1	0.24739	2.6	0.76561	3	0.33123	2.8%	$ 29,872,295	$ 10,247,583
2	0.81103	0.4	0.05063	2	0.6656	0.0%	$ 18,873	$ 19,146
3	0.17489	3.3	0.34241	2	0.22694	14.3%	$ 151,375,716	$ 39,225,645
4	0.2098	2.9	0.97478	4	0.35366	8.2%	$ 87,074,059	$ 29,870,441
5	0.32946	2.1	0.06028	2	0.28687	5.9%	$ 62,304,985	$ 21,373,500
6	0.71812	0.6	0.00532	2	0.43138	0.4%	$ 4,541,626	$ 4,607,480
7	0.60246	1.0	0.73672	2	0.27616	7.0%	$ 73,682,935	$ 74,751,338
8	0.78994	0.4	0.54569	2	0.70398	0.0%	$ 6,741	$ 6,838
9	0.854	0.3	0.53806	2	0.5737	0.0%	$ 192,068	$ 194,853
10	0.35029	2.0	0.14174	2	0.72067	0.0%	$ 4,262	$ 2,178
11	0.14376	3.6	0.02366	2	0.67217	0.0%	$ 15,863	$ 4,111
12	0.78928	0.4	0.4884	2	0.86512	0.0%	$ 62	$ 63
13	0.47477	1.4	0.88857	3	0.9232	0.0%	$ 10	$ 5
14	0.86268	0.3	0.82646	3	0.555	0.0%	$ 300,061	$ 304,412
15	0.30236	2.2	0.58505	2	0.02804	93.4%	$ 988,100,729	$ 338,964,383
16	0.9266	0.1	0.71598	2	0.39794	0.8%	$ 8,806,163	$ 8,933,852
17	0.49274	1.3	0.59044	2	0.01152	98.4%	$ 1,040,328,899	$ 531,505,171
18	0.43244	1.6	0.35693	2	0.92857	0.0%	$ 8	$ 4
19	0.42019	1.6	0.22167	2	0.99135	0.0%	$ 1	$ 1
20	0.94146	0.1	0.54026	2	0.69643	0.0%	$ 8,277	$ 8,397

Table 13: 1-Digit CATCODES

	DOD Facility Classes (1-digit) "CATCODES"	
	Code	**Title**
Accounts for ~80% of Total PRV	**1**	Operation & Training
	2	Maintenance & Production
	3	Research, Development, Test, and Evaluation
	4	Supply
	5	Hospital & Medical
	6	Administrative
	7	Housing & Community
CATCODES Excluded	8	Utility & Ground Improvements
	9	Land

Step 5: Define Monte-Carlo Hurricane Parameters

To set-up and run the Monte Carlo simulation for hurricanes, a number of different steps and input parameters are required. First, as shown in Table 14, the hurricane return period is calculated for each trial. The return period is calculated using a probability value from Excel's random number generator and applying that value to the formula for the Exponential distribution. The return period is calculated in Excel using Equation 4:

$$= -\text{LN}\ (\text{Rand}())*(\text{Avg Return Period}) \tag{4}$$

Where:

Rand() = a random number generated in Excel from 0 to 1
Avg Return Period = 1/p
p = probability (average number of hurricane events per year)

Second, the hurricane category is calculated for each trial. As shown in Table 14, the Category rating (3-5) is generated by associating the adjacent random number column with the hurricane probabilities listed in Table 10. All random number values from 0.000 < [Rand # (0-1)] ≤ 0.781, are assigned a Category 3 hurricane; all values from 0.781 < [Rand # (0-1)] ≤ 0.969, are assigned a Category 4 hurricane; and all values from 0.969 < [Rand # (0-1)] ≤ 1.000, are assigned a Category 5 hurricane. This process yields a distribution of major-hurricane categories (3-5), that match the percentage distribution of historical major-hurricane occurrences shown in Table 9.

Third, the Base Damage Assessment is calculated using a Uniform distribution. The percent facilities damaged column in Table 14 is calculated by taking the adjacent random number column and multiplying it by the range between the high and low estimate for the corresponding hurricane Category for each trial and then adding that value to the low estimate. The "% Facilities Damaged" is calculated in Excel using Equation 5:

=IF(Cat=3,(Rand()*(High Est Cat 3-Low Est Cat 3)+Low Est Cat 3),
IF(Cat=4,(Rand()*(High Est Cat 4-Low Est Cat 4)+Low Est Cat 4), (5)
IF(Cat=5,(Rand()*(High Est Cat 5-Low Est Cat 5)+Low Est Cat 5))))

Where:

"Cat=3" = Category 3 Hurricane
"Cat=4" = Category 4 Hurricane
"Cat=5" = Category 5 Hurricane
Rand() = Excel generated random number between 0 and 1 (shown in column labeled "Rand # (0-1)")
High & Low Est for Cat 3-5 = See Table 10 for High and Low End Damage Estimates for each category of major hurricane (3-5)

Next, cost of damage is calculated by taking the "% Facilities Damaged" value and multiplying it by 85% of the PRV. Decreasing the percentage of PRV damaged by a hurricane by 15% is necessary because a hurricane cannot destroy all facilities and infrastructure included in the total PRV. As shown in Table 13, CATCODE Codes 1-7 account for 80% of all PRV. Differing slightly from tornadoes, hurricanes have a slightly greater potential to damage some surface-level and underground infrastructure due to the added threat of flooding. Because of the additional risk, hurricanes are assumed to damage an additional 5% of total PRV, due to flooding damage of select Code 8 infrastructure shown in Table 13. The final hurricane damage cost is shown in present value dollars (pv, $).

Last, the present value (pv) of the hurricane damage cost must be converted into an Equivalent Annual Cost of Damage, EAC ($). EAC is calculated using the payment, “PMT,” function in Excel, by spreading out the present-value costs over the hurricane return period (nper) for each trial, at the given interest rate (rate). The EAC is calculated in Excel using Equation 6:

$$= \text{PMT}\ (\text{rate},\text{nper},\text{pv},\text{fv},\text{type}) \tag{6}$$

Where:

rate = Discount Rate (1.45%), discussed in Step 1 and shown in Figure 19
nper = number of payments in years, where “nper = (ROUNDUP(return period)).” The return period value is rounded up to the nearest year – because hurricane costs are accounted for at the end of the year in which they occur.
pv = the present value of hurricane damage cost shown in Table 14Table 12
~~fv~~ & ~~type~~ = (omitted) – not required for payment calculation in Excel

Table 14: Sample Monte-Carlo Hurricane Analysis

Trial #	Hurricanes							
	Return Period (Exponential Distribution)		Major Hurricanes (Historic Distributions)		Base Damage Assessment (Uniform Distribution)		Cost of Damage (% Damaged * 85% of PRV)[3]	Equivalent Annual Cost (EAC) EAC = -PMT[4] (rate,nper,pv,~~fv,type~~)
	Rand # (0-1)	Return Period of Cat 3-5 Hurricane (nper)	Rand # (0-1)	Cat-Rating (3-5)	Rand # (0-1)	% Facilities Damaged	Hurricane Damage Cost (pv, $)	Hurricane Damage EAC ($)
1	0.53937	33.5	0.94516	4	0.61273	32.0%	$ 359,054,576	$ 13,451,467
2	0.16007	99.5	0.48163	3	0.03637	3.3%	$ 37,180,063	$ 706,591
3	0.67454	21.4	0.26801	3	0.23503	10.5%	$ 117,524,323	$ 6,277,603
4	0.49398	38.3	0.68432	3	0.31408	13.3%	$ 149,495,722	$ 5,045,682
5	0.48777	39.0	0.84676	4	0.31125	18.7%	$ 210,027,971	$ 6,956,715
6	0.32202	61.6	0.97077	5	0.80152	77.9%	$ 875,341,884	$ 21,498,506
7	0.40419	49.2	0.54293	3	0.31041	13.2%	$ 148,010,996	$ 4,182,344
8	0.53808	33.7	0.39701	3	0.2544	11.2%	$ 125,356,721	$ 4,696,310
9	0.85342	8.6	0.79234	4	0.05033	7.2%	$ 81,050,541	$ 9,671,051
10	0.13446	109.0	0.50745	3	0.80609	31.0%	$ 348,483,672	$ 6,357,958
11	0.82152	10.7	0.70768	3	0.19831	9.1%	$ 102,673,075	$ 10,165,442
12	0.97036	1.6	0.33908	3	0.71728	27.8%	$ 312,564,555	$ 159,689,572
13	0.72835	17.2	0.51254	3	0.50019	20.0%	$ 224,763,830	$ 14,277,027
14	0.33265	59.8	0.41677	3	0.38543	15.9%	$ 178,352,194	$ 4,470,961
15	0.50883	36.7	0.44794	3	0.41236	16.8%	$ 189,242,285	$ 6,644,882
16	0.55462	32.0	0.24531	3	0.01861	2.7%	$ 29,994,021	$ 1,150,093
17	0.10888	120.5	0.73179	3	0.50224	20.1%	$ 225,594,275	$ 3,965,889
18	0.33798	58.9	0.0773	3	0.94461	36.0%	$ 404,507,786	$ 10,248,574
19	0.18553	91.5	0.38816	3	0.23814	10.6%	$ 118,781,579	$ 2,346,365
20	0.95009	2.8	0.08197	3	0.21693	9.8%	$ 110,206,125	$ 37,805,813

Step 6: Define Monte-Carlo Electricity Parameters

In order to set-up and run the Monte Carlo simulation for electricity, a few steps and input parameters are required. First, as shown in Table 15, average annual electricity usage (kWh) and average electricity rates ($/kWh) are modeled for each trial according to the normal distribution. Each of these parameters are estimated in Excel using the "NORMINV" function, which returns the inverse of the normal cumulative distribution after specifying a mean (average) and a standard deviation. Once annual electricity usage and electricity rate is calculated for each trial, the two values can be multiplied together to produce the Equivalent Annual Cost (EAC, $) of electricity. First, the average annual electricity usage (kWh) shown in Table 15 is calculated in Excel using Equation 7:

=NORMINV(probability, mean, standard dev) (7)

Where:

NORMINV = Excel function for the inverse of the normal cumulative distribution
probability = probability corresponding to the normal distribution – use Excel generated random number between 0 and 1 (shown in column labeled "Rand # (0-1)")
mean = arithmetic mean of the distribution (see Monte Carlo Inputs in Table 6)
standard dev = the standard deviation of the distribution (see Monte Carlo Inputs in Table 6)

Second, the average electricity rate ($/kWh) shown in Table 15 is calculated in Excel using Equation 8:

=NORMINV(probability, mean, standard dev) (8)

Where:

NORMINV = Excel function for the inverse of the normal cumulative distribution
probability = probability corresponding to the normal distribution – use Excel generated random number between 0 and 1 (shown in column labeled "Rand # (0-1)")
mean = arithmetic mean of the distribution (see Monte Carlo Inputs in Table 6)
standard dev = the standard deviation of the distribution (see Monte Carlo Inputs in Table 6)

Last, the Equivalent Annual Cost (EAC, $) of electricity shown in Table 15 is calculated in Excel using Equation 9:

$$EAC = \text{Average Annual Usage (kWh)} \times \text{Average Rate (\$/kWh)} \quad (9)$$

Table 15: Sample Monte-Carlo Electricity Analysis

Trial #	Electricity Annual Electricity Cost Calculation Electricity Usage (kWh) x Rate ($/kWh) = Cost ($) (Normal Distribution) (=NORMINV(RAND(0-1),MEAN,STD DEV)				
	Rand # (0-1)	Average Annual Electricity Usage (kWh)	Rand # (0-1)	Average Rate ($/kWh)	EAC ($)
1	0.29391	57,566,659	0.32848	$ 0.06277	$ 3,613,733
2	0.12347	55,513,280	0.94224	$ 0.07764	$ 4,310,038
3	0.23022	56,912,774	0.45769	$ 0.06526	$ 3,714,325
4	0.01476	52,116,385	0.60312	$ 0.06797	$ 3,542,457
5	0.80385	62,226,342	0.92897	$ 0.07686	$ 4,782,802
6	0.13811	55,743,372	0.61945	$ 0.06829	$ 3,806,486
7	0.52079	59,547,761	0.36758	$ 0.06355	$ 3,784,527
8	0.0882	54,866,140	0.67071	$ 0.06930	$ 3,802,289
9	0.60652	60,275,057	0.21354	$ 0.06020	$ 3,628,309
10	0.32374	57,849,215	0.86889	$ 0.07430	$ 4,298,480
11	0.60005	60,219,116	0.33936	$ 0.06300	$ 3,793,510
12	0.11082	55,298,737	0.3742	$ 0.06368	$ 3,521,620
13	0.7349	61,466,861	0.68156	$ 0.06952	$ 4,273,394
14	0.93905	64,531,705	0.44417	$ 0.06501	$ 4,195,336
15	0.77573	61,900,854	0.72661	$ 0.07049	$ 4,363,092
16	0.57215	59,980,250	0.20826	$ 0.06006	$ 3,602,492
17	0.01511	52,147,929	0.69186	$ 0.06974	$ 3,636,682
18	0.97943	66,183,044	0.94653	$ 0.07792	$ 5,157,091
19	0.88818	63,431,456	0.66313	$ 0.06915	$ 4,386,129
20	0.6771	60,906,389	0.65913	$ 0.06907	$ 4,206,628

Step 7: Define Monte-Carlo Natural Gas Parameters

In order to set-up and run the Monte Carlo simulation for natural gas, a few steps and input parameters are required. First, as shown in Table 16, average annual natural gas usage (Mcf) and average natural gas rates ($/Mcf) are modeled for each trial according to the normal distribution. Each of these parameters are estimated in Excel using the "NORMINV" function, which returns the inverse of the normal cumulative distribution after specifying a mean (average) and a standard deviation. Once annual natural gas usage and natural gas rate is calculated for each trial, the two values can be multiplied together to produce the Equivalent Annual Cost (EAC, $) of natural gas. First, the average annual natural gas usage (Mcf) shown in Table 16 is calculated in Excel using Equation 10:

=NORMINV(probability, mean, standard dev) (10)

Where:

NORMINV = Excel function for the inverse of the normal cumulative distribution
probability = probability corresponding to the normal distribution – use Excel generated random number between 0 and 1 (shown in column labeled "Rand # (0-1)")
mean = arithmetic mean of the distribution (see Monte Carlo Inputs in Table 6)
standard dev = the standard deviation of the distribution (see Monte Carlo Inputs in Table 6)

Second, the average natural gas rate ($/Mcf) shown in Table 16 is calculated in Excel using Equation 11:

=NORMINV(probability, mean, standard dev) (11)

Where:

NORMINV = Excel function for the inverse of the normal cumulative distribution

probability = probability corresponding to the normal distribution – use Excel generated random number between 0 and 1 (shown in column labeled "Rand # (0-1)")
mean = arithmetic mean of the distribution (see Monte Carlo Inputs in Table 6)
standard dev = the standard deviation of the distribution (see Monte Carlo Inputs in Table 6)

Last, the Equivalent Annual Cost (EAC, $) of natural gas shown in Table 16 is calculated in Excel using Equation 12:

$$\text{EAC} = \text{Average Annual Usage (kWh)} \times \text{Average Rate (\$/kWh)} \qquad (12)$$

Table 12, Table 14, Table 15, and Table 16 are snapshots of only the first 20 trials in the Monte Carlo simulation for each of the four factors: tornadoes, hurricanes, electricity, and natural gas respectively. The full Monte Carlo simulation and spreadsheet calculates EAC for each of the four factors for 10,000 individual trials. Final results for all 10,000 Monte Carlo trials, showing each factor's EAC, for all 62 bases evaluated can be found in Chapter 4, section 4.6.

Table 16: Sample Monte-Carlo Natural Gas Analysis

Trial #	Natural Gas				
	Annual Natural Gas Cost Calculation Natural Gas Usage (Mcf) x Rate ($/Mcf) = Cost ($) **(Normal Distribution)** *(=NORMINV(RAND(0-1),MEAN,STD DEV)*				
	Rand # (0-1)	**Average Annual Natural Gas Usage (Mcf)**	**Rand # (0-1)**	**Average Rate ($/Mcf)**	**EAC ($)**
1	0.63448	117,759	0.65543	$ 9.220	$ 1,085,782
2	0.64263	117,951	0.03426	$ 6.147	$ 725,049
3	0.82828	123,087	0.6626	$ 9.247	$ 1,138,237
4	0.52337	115,243	0.42289	$ 8.398	$ 967,795
5	0.14111	105,234	0.87072	$ 10.230	$ 1,076,526
6	0.76824	121,196	0.12326	$ 7.064	$ 856,109
7	0.00049	85,633	0.54198	$ 8.813	$ 754,667
8	0.23889	108,459	0.17922	$ 7.397	$ 802,224
9	0.14352	105,328	0.37377	$ 8.222	$ 865,975
10	0.42339	113,020	0.16786	$ 7.335	$ 829,028
11	0.05398	100,537	0.1176	$ 7.025	$ 706,254
12	0.26978	109,310	0.77491	$ 9.712	$ 1,061,571
13	0.12323	104,495	0.72596	$ 9.498	$ 992,482
14	0.16768	106,222	0.28252	$ 7.871	$ 836,074
15	0.14122	105,238	0.31836	$ 8.014	$ 843,337
16	0.64887	118,099	0.5299	$ 8.771	$ 1,035,817
17	0.5503	115,841	0.38831	$ 8.274	$ 958,523
18	0.55645	115,978	0.08997	$ 6.812	$ 790,044
19	0.37988	112,026	0.28505	$ 7.881	$ 882,914
20	0.66459	118,477	0.43807	$ 8.451	$ 1,001,289

Step 8: Calculate Equivalent Annual Cost (EAC) for Each Factor and Total EAC

The final step in the Monte Carlo process summarizes the EACs for the four main cost factors, which are tornadoes, hurricanes, electricity, and natural gas. Table 17 is a sample summary output table from the Monte Carlo simulation of all the EACs for Seymour Johnson AFB, NC. It is important to note that the median of all 10,000 values of EAC is used for the severe weather factors (tornadoes and hurricanes), while the mean or average of all 10,000 values of EAC is used for the energy factors (electricity and natural gas). Using the median as a measure of central tendency is necessary and more accurate because the distribution of the severe weather EACs is highly skewed and not normally distributed. On the other hand, using the mean as a measure of central tendency for the energy factors is accurate and reliable because the electricity and natural gas EACs are normally distributed.

In summary, the eight-step Monte Carlo process is repeated 62 times to account for the unique parameters at each base considered in the analysis. The values created in Table 17 for each base are consolidated into one complete EAC matrix and ranked in descending order of total EAC. The final EAC rank-matrix is shown in Chapter 4, section 4.6.

Table 17: Sample Monte-Carlo Summary EAC Table

Summary of Equivalent Annual Cost (EAC) of Tornado, Hurricane, Electricity, & Natural Gas For BRAC - Enter Total EAC into COBRA Model to Account for Severe Weather & Energy Costs								
Tornadoes		Hurricanes		Electricity		Natural Gas		
Median Tornado EAC ($)	Tornado Cost (% of Total EAC)	Median Hurricane EAC ($)	Hurricane Cost (% of Total EAC)	Mean Electricity EAC ($)	Electricity Cost (% of Total EAC)	Mean Natural Gas EAC ($)	Natural Gas Cost (% of Total EAC)	Total EAC (Amount *Entered into COBRA Model*) ($)
$722,142	5.24%	$8,137,709	59.07%	$3,921,213	28.46%	$994,967	7.22%	$13,776,032

3.5 – Analysis Tools

Various tools and software are used for the analysis. The most frequently used analysis tools in the research are ESRI's GIS software called ArcMAP 10.2 and Microsoft Excel for the rank-matrices and Monte Carlo simulation. Although these tools comprised the bulk of the analysis and mapping, the following also aided the investigation:

- Microsoft Office 2007
- Electronic Publications, Papers, and Journal Articles
- World-Wide Web

3.6 – Conclusion

This chapter presented the methodology used to analyze and rank Air Force installations for a potential BRAC recommendation based on new proposed factors including severe weather, climate zone, energy use, and utility rates. First, the sample selection and the data collection processes are described. Next, the process of analyzing geospatial data related to the new proposed BRAC factors was explained. Then, the creation of the rank matrices was detailed, as it is unique to each factor. Additionally, a step-by-step methodology for risk analysis was provided through the utilization of a Monte Carlo simulation. Lastly, the Monte Carlo methodology yields a final 1-n list of all installations ranked 1 to 62. The list identifies the best candidate bases, based on equivalent annual costs of the new proposed factors, that rank high on the list for a BRAC closure recommendation. This chapter establishes the roadmap for Chapter 4, where the actual severe weather, climate zone, energy use, and utility rate data is analyzed and presented.

Chapter 4 – Results

Chapter 4 represents the outcome of all the results produced by the methods described in Chapter 3. Using ESRI's ArcMap GIS software, thematic and density maps are created for major Air Force installations in the CONUS, including tornado activity and density map, major hurricane strike map, and electric and natural gas rate maps. In addition, the climate zone map displayed throughout this research is a product of the IECC (ICC, 2012).

Additionally, each section contains a rank-matrix relevant to the specific data set under discussion. Each rank-matrix organizes Air Force installations in descending order from the largest number of occurrences, quantity or cost, down to the lowest. The raw climate zone data matrix is sorted from hottest climate, with the highest amount of CDDs, down to the coldest climate, with the highest amount of HDDs. A higher overall rank in each of these matrices indicates a greater potential for BRAC eligibility under the new proposed criteria.

The final section of Chapter 4 contains the Monte Carlo simulation results and the predicted Equivalent Annual Cost (EAC) of tornadoes, hurricanes, electricity, and natural gas by base. The total EAC represents the total amount that would apply to the COBRA Model during a BRAC, to account for the annual costs associated with localized tornado and hurricane activity, along with annual electricity and natural gas costs.

4.1 – Major Air Force Installations in the Continental United States

4.1.1 – Map of Major CONUS Air Force Installations

Based on the research scope, the analysis focused on 62 major CONUS Air Force installations. These bases are shown in Figure 21 and exhibit a reasonably even distribution of Air Force installations across the United States, with some states having a higher concentration than others, and a few states with no major Air Force bases. This distribution yields a good mix of bases located in tornado and hurricane prone areas of the country, along with bases that experience minimal to no tornado and hurricane threats. In addition, bases are distributed in hot, mild, and cold climates, all with varying energy usage and utility rates. Each subsequent section of the results chapter details these factors for each of the 62 bases shown in Figure 21.

Figure 21: 62 Major CONUS Air Force Bases

4.1.2 – Facility Count, Square Footage, Acreage, & Plant Replacement Value

The DOD is one of the federal government's largest owners of real estate. The DOD manages a collection of real property across the globe consisting of over 562,000 facilities, located on 4,800 sites worldwide and covering more than 24.7 million acres (DOD, 2013). Figure 22 summarizes the breakdown of facility type within the DOD as a percentage of PRV.

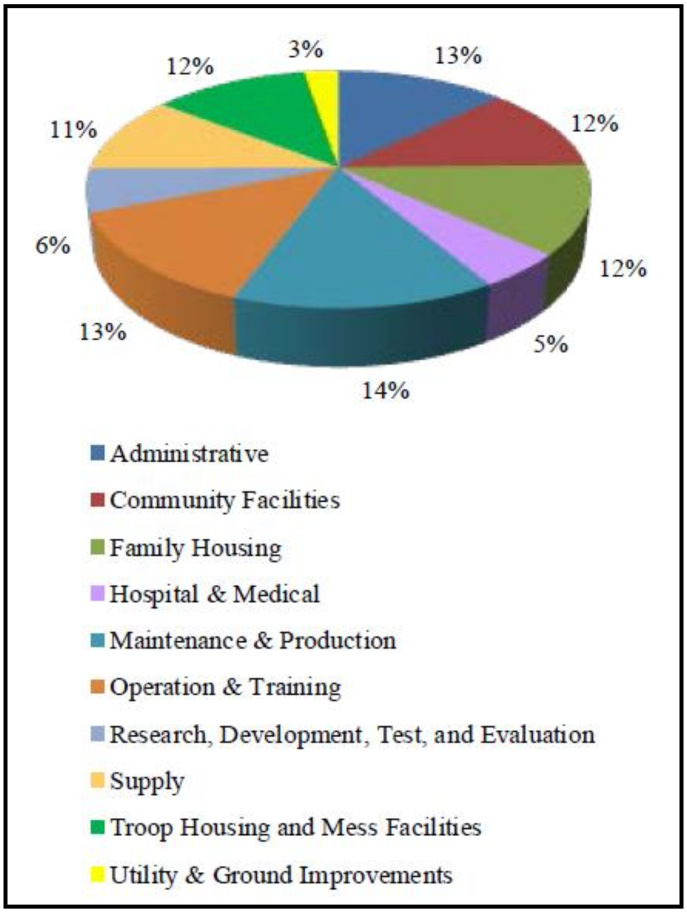


Figure 22: PRV by Facility Type (DOD, 2013)

The Air Force maintains a sizeable piece of this global DOD real-property portfolio, but the CONUS portion is the focus of this analysis. Table 18 summarizes building count, square-footage, acres owned, and ranks the top twenty Air Force bases by PRV. Arnold AFB, TN, ranks the highest for PRV, even though it is not the largest base by any definition. The base is home to the Arnold Engineering Development Complex (AEDC), which houses unique, one-of-a-kind, and expensive test and evaluation facilities and equipment. By comparison, Arnold AFB has 22.6% of the total buildings and 9.7% of the total facility square-footage as Joint Base

Antonio, ranked number two on the list. Yet Arnold has 2.3% greater PRV than Joint Base San Antonio, an amalgamation of three major installations including Lackland AFB, Randolph AFB, the Army's Fort Sam Houston (Defense Base Closure and Realignment Commission, 2005). Other installations with high PRV values include Air Force Materiel Command's (AFMC) three large Air Logistics Centers located at Tinker AFB, OK; Robins AFB, GA; and Hill AFB, UT; along with the major test and evaluation bases of Eglin AFB, FL; Edwards AFB, CA; and Wright-Patterson AFB, OH (AFMC, 2014). In addition, it is no surprise that all of the large Air Force controlled joint-base conglomerations, created in the 2005 BRAC, make the list of top 20 bases by PRV. For a complete list of all 62 installations, see "PRV Rank Matrix" in Appendix I.

Table 18: Plant Replacement Value (PRV) Rank by Base – Top 20

PRV Rank by Base - Top 20 CONUS Air Force Bases							
Installation Name	State	Buildings Totals		Acres Owned	Total Acres	PRV ($)	PRV Rank
		Count	SQFT				
Arnold AFB	TN	334	2,837,855	38,861	38,862	$ 7,802,100,000	1
JB San Antonio	TX	1,478	29,351,739	14,497	15,418	$ 7,629,100,000	2
JB McGuire-Dix-Lakehurst	NJ	1,189	14,015,273	41,688	41,745	$ 7,289,300,000	3
Wright-Patterson AFB	OH	595	16,798,409	7,680	8,189	$ 5,968,000,000	4
Edwards AFB	CA	741	7,249,229	288,997	307,517	$ 5,719,800,000	5
Eglin AFB	FL	1,671	11,563,202	449,290	449,415	$ 4,726,700,000	6
Hill AFB	UT	767	12,813,276	517	6,946	$ 4,165,100,000	7
Tinker AFB	OK	414	14,587,790	3,945	4,842	$ 4,153,500,000	8
Vandenberg AFB	CA	640	6,415,839	98,415	118,312	$ 3,920,700,000	9
Travis AFB	CA	370	6,406,042	5,130	6,445	$ 3,684,200,000	10
Robins AFB	GA	530	13,943,133	6,779	6,935	$ 3,679,200,000	11
JB Langley-Eustis	VA	701	12,116,506	11,698	11,925	$ 3,625,400,000	12
Nellis AFB	NV	617	6,311,226	5,214	14,160	$ 3,185,900,000	13
Joint Base Charleston	SC	894	8,629,056	20,864	23,077	$ 3,098,100,000	14
Kirtland AFB	NM	754	7,538,562	25,473	43,842	$ 2,981,000,000	15
US Air Force Academy	CO	264	5,910,086	44,230	53,276	$ 2,873,300,000	16
Holloman AFB	NM	494	6,028,378	10,601	53,603	$ 2,795,500,000	17
Joint Base Andrews	MD	355	6,658,924	4,996	5,008	$ 2,589,900,000	18
Minot AFB	ND	1,242	8,084,075	4,965	5,616	$ 2,520,600,000	19
Whiteman AFB	MO	879	5,230,677	4,478	6,026	$ 2,245,000,000	20

4.2 – Maps & Rank Matrices of Severe Weather Factors

4.2.1 – Severe Weather Occurrences in the Continental United States

Table 19 is a summary of severe weather impacts and the total number of tornado and hurricane occurrences for the entire continental United States (NWS, 2014a). Spatial locations of these occurrences, such as state or latitude/longitude coordinate, are contained in the underlying GIS data. Tornado and hurricane activity or density maps can be found within each of their respective sections.

Table 19: CONUS Severe Weather Impacts

Severe Weather Impacts in the Continental United States				
	Tornadoes (EF1 & Higher)	**Tornadoes (EF-2 & Higher)**	**All Hurricanes Making Landfall (Cat 1 & Higher)**	**Major Hurricanes Making Landfall (Cat 3 & Higher)**
Total # of Occurences for the Entire US	**58,057**	**12,087**	**287**	**96**
Time Span	1950-2013		1851-2013	
Total Years of Data	63		163	
Average # of Occurences per Year	**922**	**192**	**1.761**	**0.589**

4.2.2 – Tornado Activity Map

Figure 23 shows all recorded tornado activity in the United States from 1950 to 2012. The large concentration of tornado activity in the central portion of the country is what is commonly known as *tornado alley*. Air Force bases located within tornado alley are at high risk for tornado activity and prone to high future rates of occurrence. In addition, one major item to note is the large concentration of historical tornado paths in the central region of Florida. A larger scale representation of the Florida region is shown in Figure 24.

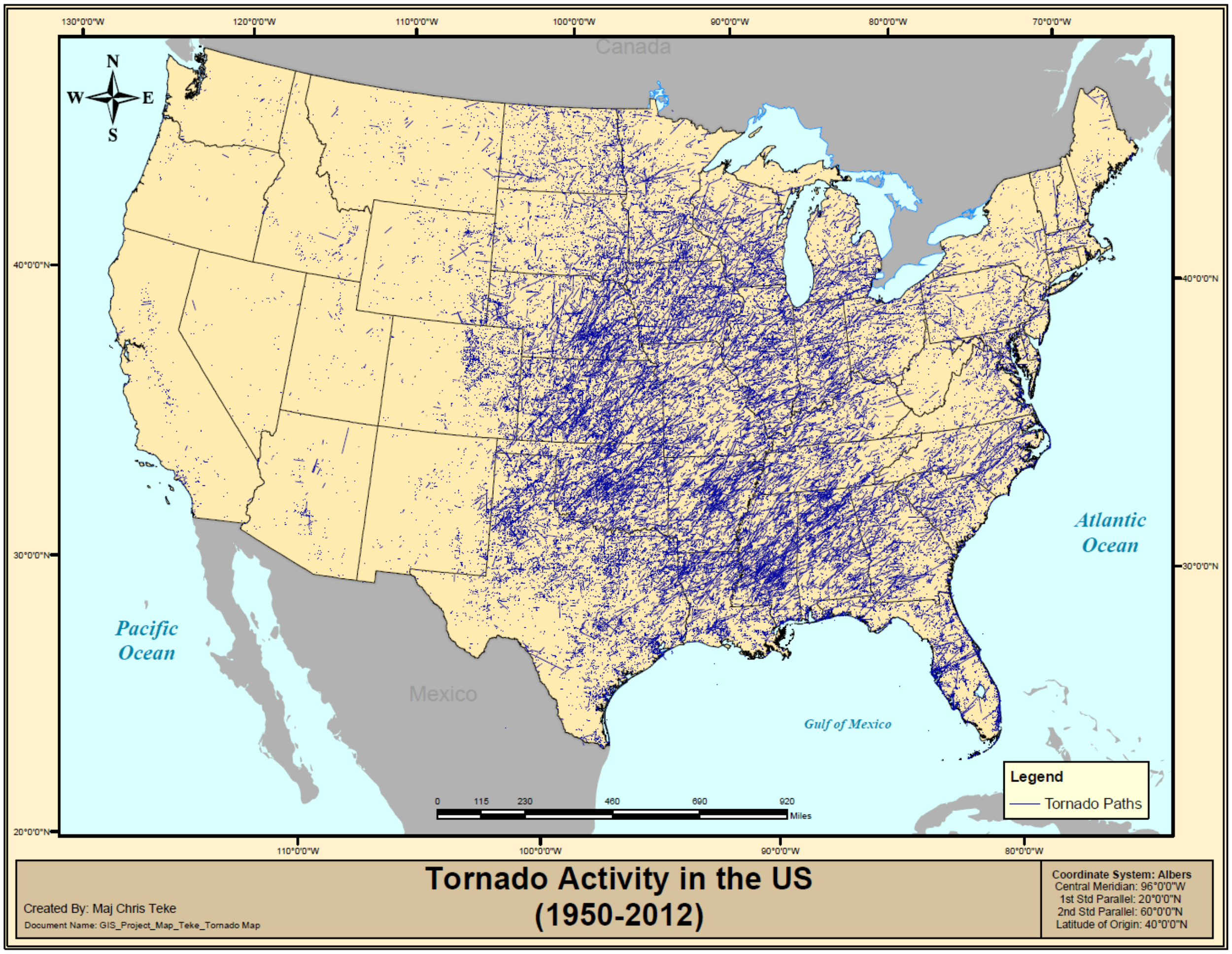


Figure 23: Tornado Activity in the US (1950-2012)

Figure 24 highlights the historical tornado paths in Florida. Not all of Florida's tornadoes are individual events, spurred on by severe thunderstorms. Sizable quantities of Florida's tornadoes are produced as a second-order effect from hurricane activity. To the researcher's surprise, a major sub-level *tornado alley* appeared in the central region of Florida. Ironically, Florida's mini tornado alley crosses over or very close to three major Air Force installations (see Figure 24). These installations are MacDill and Patrick Air Force Bases along with Cape

Canaveral Air Force Station. As indicated in Figure 25, Florida has a significant statewide tornado density. Florida's tornado density is further broken down and quantified in the base-specific tornado counts listed in Table 20.

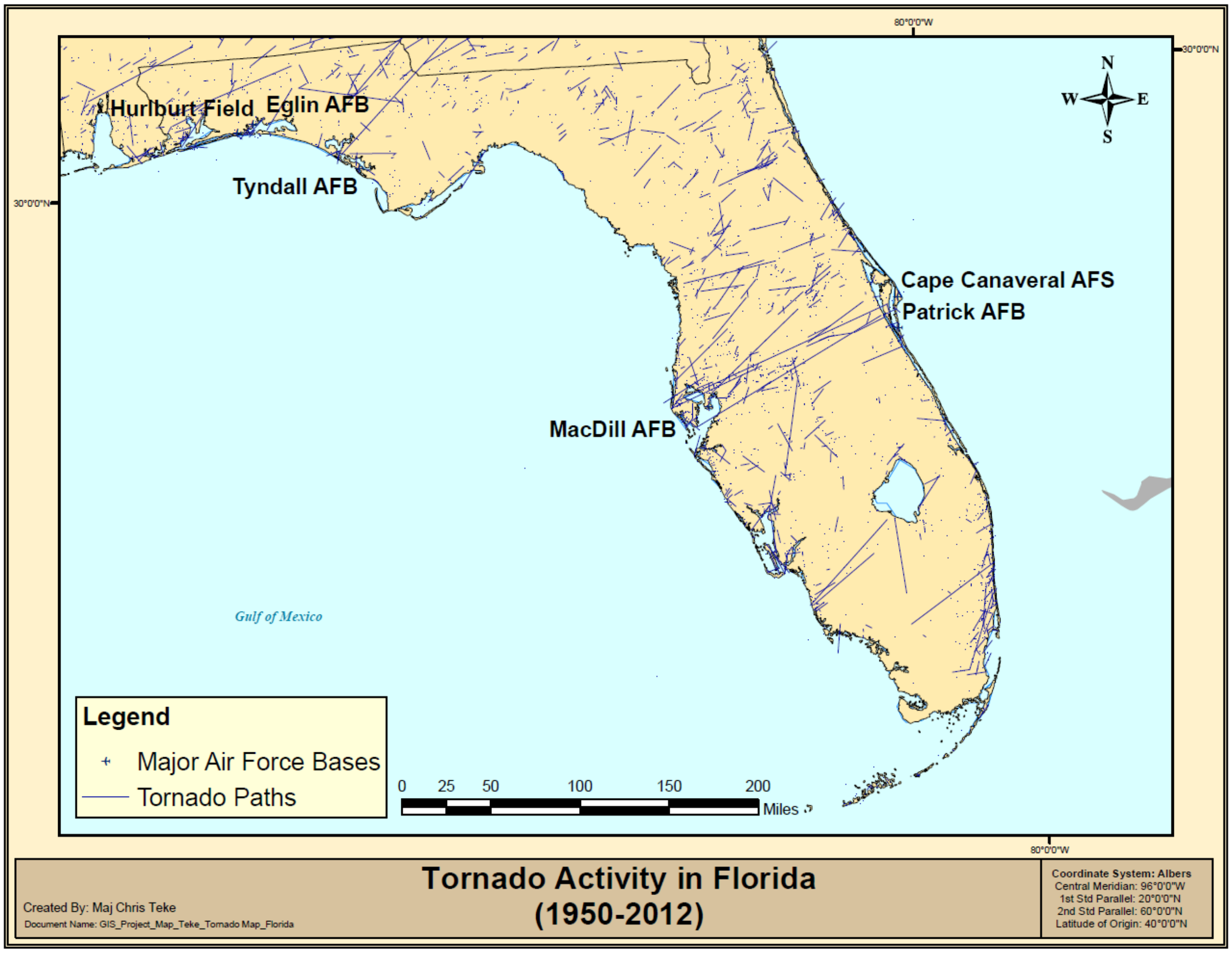


Figure 24: Tornado Activity in Florida (1950-2012)

4.2.3 – Tornado Density Map

Figure 25 represents the state-by-state tornado density. Tornado density is calculated by taking the average annual rate of tornado occurrence for each state and normalizing it by the state's area (in square miles). According to the map, Oklahoma, Louisiana, Mississippi, and Alabama ranked the highest for overall tornado density. Based on historical state-specific occurrence rates (not installation specific), seven major Air Force installations are bounded within these states and have a greater likelihood of tornado impacts and damage. These Air Force Bases include Altus, OK; Tinker, OK; Vance, OK; Barksdale, LA; Columbus, MS; Keesler, MS; and Maxwell, AL.

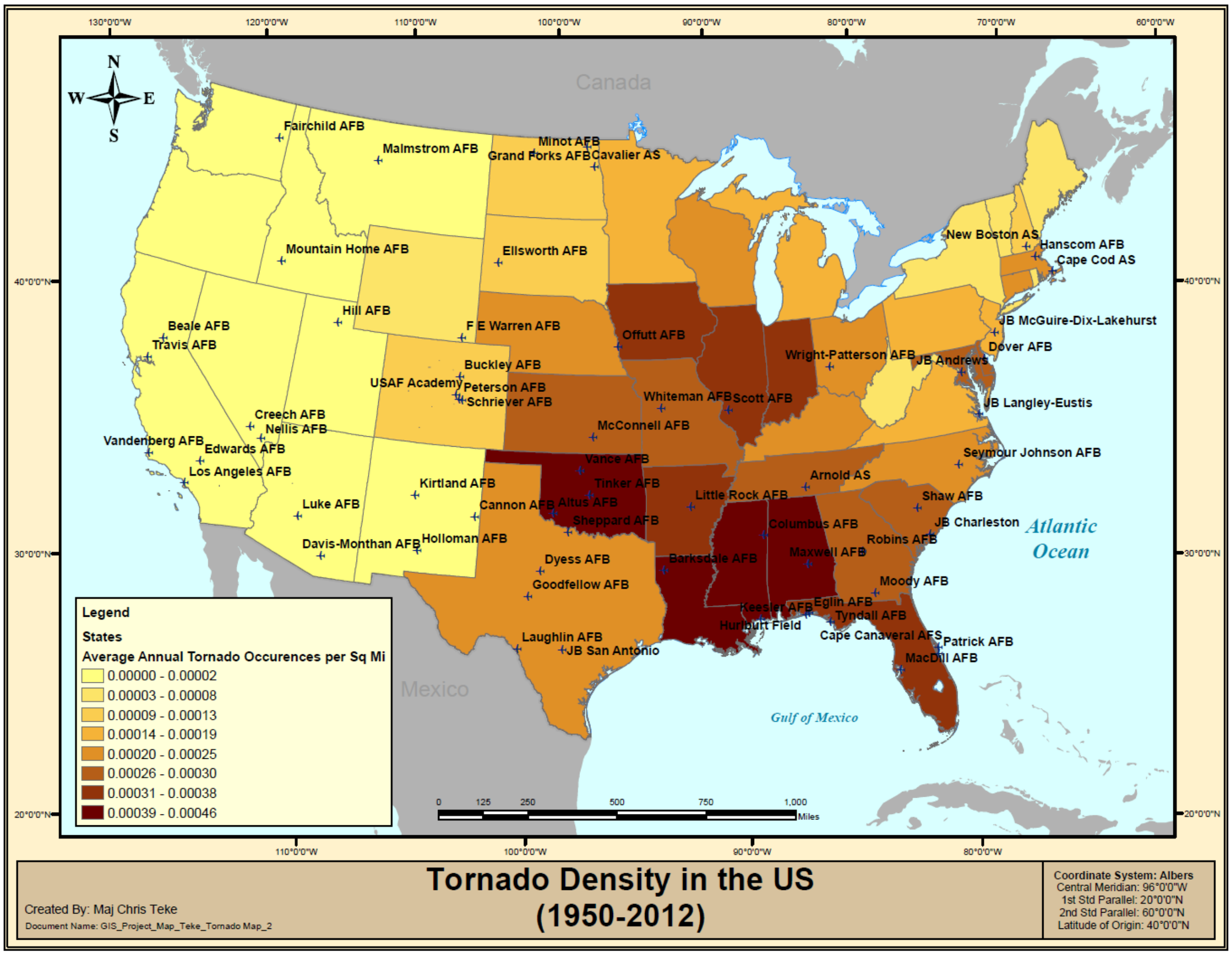


Figure 25: Tornado Density in the US by State

However, the tornado density map does not tell the whole story. The tornado threat can be broken down in more detail. Appendix D contains tornado probability maps by month. The tornado probability maps in Appendix D are broken down by four weeks in each of the twelve months of the year. These maps are further broken down into severity groups, consisting of all tornadoes, EF 0-5, and all strong-violent tornadoes, EF 2-5. The maps in Appendix D show the temporal relationship that tornadoes have as climatic conditions vary throughout the year.

Appendix E contains tornado occurrence maps for each Air Force installation, for the period from 1984 through 2013. These maps depict all tornado occurrences within a 5, 10, and 25-mile radius of the base. The underlying data used to produce these base specific tornado maps is used to establish the tornado event counts shown in the tornado risk-rank matrix. The following section provides a detailed ranking of tornado occurrences for each base included in this study.

4.2.4 – Tornado Risk Rank-Matrix

Table 20 shows the 44 CONUS bases with strong-violent tornado occurrences in the 30-year period, from 1984 to 2013. Tinker AFB, OK, and Little Rock AFB, AR, rank number one and two on the list with 29 strong-violent (EF 2-5) tornado occurrences. Tinker edges out Little Rock for the top spot because it has a slightly higher count of total tornadoes. Tinker's rank is no surprise as this base is at the heart of tornado alley. Additionally, Tinker AFB is centered in the highest probability of strong-violent (EF 2-5) tornadoes throughout much of the Spring, but especially in the month of May (see Appendix D). In addition to Oklahoma and Arkansas, bases located in Mississippi, Louisiana, Illinois, North Carolina, Alabama, Nebraska, Tennessee, and Kansas all have a significant threat of occurrence of an EF-2 to EF-5 tornado. The top-ten ranked bases all had 12 or more strong-violent tornado occurrences during the 30-year period.

Buckley AFB, CO, ranked number twelve on the list, is unique because it has ten strong-violent tornado occurrences, but it also has the highest count of total tornadoes, with 189. According to Mr. Mike Hunsucker, Chief, Climate Analysis Section at the 14th WS, Buckley AFB's high total tornado count is likely based on a few simple explanations. Hunsucker states that some of the apparent quandary is explained by population areas – the bigger the population the more likely an event will be recorded. This may explain why Altus AFB, OK, located not far away from top-ranked Tinker, may have a lower tornado count. Hunsucker goes on to explain that remote areas, such as Altus AFB, see less tornado counts than highly-populated areas such as Tinker AFB, near Oklahoma City, OK, and Buckley AFB, located in Aurora, CO, near the Denver metro area. Additionally, Hunsucker indicates that Buckley AFB, CO, has a National Weather Service site located within a few miles, which leads to more weather observations (M. Hunsucker, personal communication, January 30, 2015). The good news for Buckley AFB is even though the base has the highest total tornado count (EF 0-5), many of these occurrences are mere blips on the radar (see small light-blue dots on center map, Figure 26). Very few of these EF-0 and EF-1 storms near Buckley AFB touch the ground for long. Most of the EF-0 tornadoes near Buckley have very short paths and do little to no destructive damage. Figure 26 shows the major difference between tornado occurrences at Altus AFB, OK; Buckley AFB, CO; and Tinker AFB, OK. To study these differences in greater detail and to compare with other installations, see Appendix E for full-size base tornado maps.

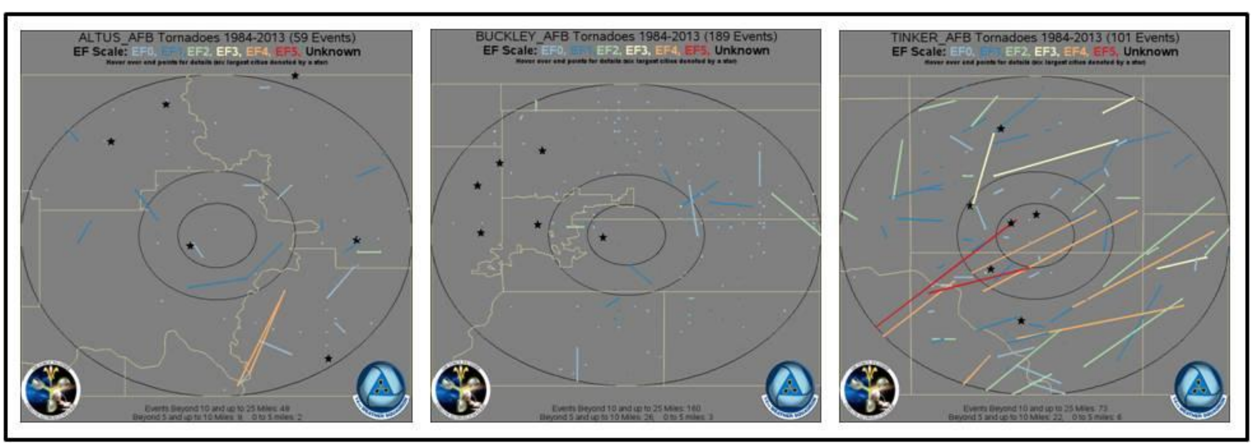


Figure 26: Tornado Occurrence Maps – Altus, Buckley, & Tinker AFBs

As exposed in the Florida tornado activity map in Figure 24, all six major Florida Air Force Bases made the list of top 44 installations with strong-violent tornado threats. Sheppard AFB, TX, narrowly missed inclusion on the risk rank-matrix because it had no recorded EF 2-5 tornado events; however, it did have 47 EF-0 to EF-1 tornadoes. Table 20 details the remaining CONUS Air Force installations with strong-violent tornado risk. For a complete list of all 62 installations, see "Tornado Risk Rank-Matrix" in Appendix I.

Table 20: Strong-Violent Tornado (EF 2-5) Risk-Rank by Base

Tornado Risk-Rank by Base (1984-2013; 30 Year Period) 44 CONUS Air Force Bases with EF 2-5 Tornado Occurrences					
Installation Name	**State**	**Tornado Occurrences** (EF-0 to EF-5) (w/in 25 mile radius)	**Tornado Occurrences** (EF-2 to EF-5) (w/in 25 mile radius)	**Average Return Period** (EF-2 to EF-5) (Years)	**Tornado Risk Rank** (Ranked by EF 2-5 First, Tie-Breaker = EF 0-5)
Tinker AFB	OK	101	29	1.0	1
Little Rock AFB	AR	98	29	1.0	2
Columbus AFB	MS	71	27	1.1	3
Barksdale AFB	LA	99	23	1.3	4
Scott AFB	IL	86	20	1.5	5
Seymour Johnson AFB	NC	68	16	1.9	6
Vance AFB	OK	50	15	2.0	7
Maxwell AFB	AL	77	13	2.3	8
Offutt AFB	NE	60	13	2.3	9
Arnold AS	TN	58	12	2.5	10
McConnell AFB	KS	97	11	2.7	11
Buckley AFB	CO	189	10	3.0	12
Grand Forks AFB	ND	60	8	3.8	13
Shaw AFB	SC	45	8	3.8	14
Dyess AFB	TX	57	7	4.3	15
Whiteman AFB	MO	45	7	4.3	16
Joint Base Andrews	MD	67	6	5.0	17
Keesler AFB	MS	54	6	5.0	18
Joint Base Langley-Eustis	VA	40	5	6.0	19
Wright-Patterson AFB	OH	36	5	6.0	20
MacDill AFB	FL	144	4	7.5	21
Hurlburt Field	FL	63	4	7.5	22
Schriever AFB	CO	49	4	7.5	23
Robins AFB	GA	18	4	7.5	24
Eglin AFB	FL	66	3	10.0	25
Peterson AFB	CO	64	3	10.0	26
Altus AFB	OK	59	3	10.0	27
Cavalier AS	ND	43	3	10.0	28
Joint Base San Antonio	TX	43	3	10.0	28
Joint Base Charleston	SC	37	3	10.0	29
Laughlin AFB	TX	26	3	10.0	30
New Boston AS	NH	6	3	10.0	31
Patrick AFB	FL	58	2	15.0	32
US Air Force Academy	CO	52	2	15.0	33
Tyndall AFB	FL	48	2	15.0	34
Cannon AFB	NM	35	2	15.0	35
JB McGuire-Dix-Lakehurst	NJ	26	2	15.0	36
Ellsworth AFB	SD	22	2	15.0	37
Moody AFB	GA	17	2	15.0	38
Dover AFB	DE	16	2	15.0	39
Cape Canaveral AFS	FL	43	1	30.0	40
Minot AFB	ND	37	1	30.0	41
F. E. Warren AFB	WY	34	1	30.0	42
Goodfellow AFB	TX	26	1	30.0	43
Davis-Monthan AFB	AZ	8	1	30.0	44

4.2.5 – Hurricane Map

Hurricanes are analyzed by examining only their historical paths and where they made landfall within the United States. Table 21 reveals all hurricane strikes in the United States from 1851 to 2010. Ninety-six total major hurricanes, Category 3-5, made landfall in the United States from 1851 to 2010. No major hurricanes made landfall in the United States from 2011 to 2013. Two additional Category 1 hurricanes and one Category 2 made landfall in the United States from 2011 through 2014; these are Hurricane Irene (2011), Hurricane Isaac (2012), Hurricane (AKA "Superstorm Sandy") Sandy (2012), and Hurricane Arthur (2014) (NOAA, 2015a).

Sandy started life as a hurricane, but "Superstorm Sandy" as it is more commonly known, makes an interesting case study. Although not officially categorized as a hurricane or included in the analysis, Superstorm Sandy was one of the most destructive storms and second-costliest hurricanes in United States history (NOAA, 2013b). At its peak, Superstorm Sandy had tropical-storm strength winds spanning over 1,000 miles in diameter. Although wind damage was not a big factor from Hurricane Sandy, storm surge and localized flooding damage estimates exceeded 50 billion dollars (NOAA, 2013b). Even though Category 1 storms such as Hurricane Sandy can cause costly destruction, Category 3 and higher storms are the focus of the hurricane analysis, as they represent the majority of financial loses and deaths from hurricanes (Blake, Landsea, & Gibney, 2011). These major storms are the basis of the Monte Carlo simulation to determine the future cost impact of hurricanes.

Table 21: Hurricane Strikes 1851-2010, Mainland U.S. Coast (Blake et al., 2011)

AREA	CATEGORY NUMBER 1	2	3	4	5	ALL	MAJOR HURRICANES
U.S. (Texas to Maine)	113	75	75	18	3	284	96
Texas	27	18	12	7	0	64	19
(North)	14	8	3	4	0	29	7
(Central)	9	4	3	2	0	18	5
(South)	9	7	7	1	0	24	8
Louisiana	21	16	16	3	1	57	20
Mississippi	4	6	8	0	1	19	9
Alabama	17	5	5	0	0	27	5
(Inland only)	6	0	0	0	0	6	0
Florida	43	34	29	6	2	114	37
(Northwest)	27	18	14	0	0	59	14
(Northeast)	15	6	1	0	0	22	1
(Southwest)	17	10	10	4	1	42	15
(Southeast)	16	14	11	3	1	45	15
Georgia	15	5	2	1	0	23	3
(Inland only)	9	0	0	0	0	9	0
South Carolina	17	7	4	2	0	30	6
North Carolina	25	14	11	1	0	51	12
(Inland only)	3	0	0	0	0	3	0
Virginia	7	2	1	0	0	10	1
(Inland only)	2	0	0	0	0	2	0
Maryland	1	1	0	0	0	2	0
Delaware	2	0	0	0	0	2	0
New Jersey	2	0	0	0	0	2	0
Pennsylvania (Inland)	1	0	0	0	0	1	0
New York	6	1	5	0	0	12	5
Connecticut	5	3	3	0	0	11	3
Rhode Island	3	2	4	0	0	9	4
Massachusetts	6	2	3	0	0	11	3
New Hampshire	1	1	0	0	0	2	0
Maine	5	1	0	0	0	6	0

Notes:

*State totals will not equal U.S. totals, and Texas or Florida totals will not necessarily equal sum of sectional totals. Regional definitions are found in Appendix A
*Gulf Coast state totals will likely be underestimated because of lack of coastal population before 1900

The 96 total major hurricanes, Category 3-5, that made landfall in the United States, are shown in Figure 27. Florida and the Gulf Coast regions generally suffered the greatest quantity and highest intensity hurricanes. Historically intense Gulf Coast storms such as Hurricane Camille in 1969 and Katrina and Rita in 2005 (Blake et al., 2011) have devastating potential capable of wiping out entire Air Force Bases.

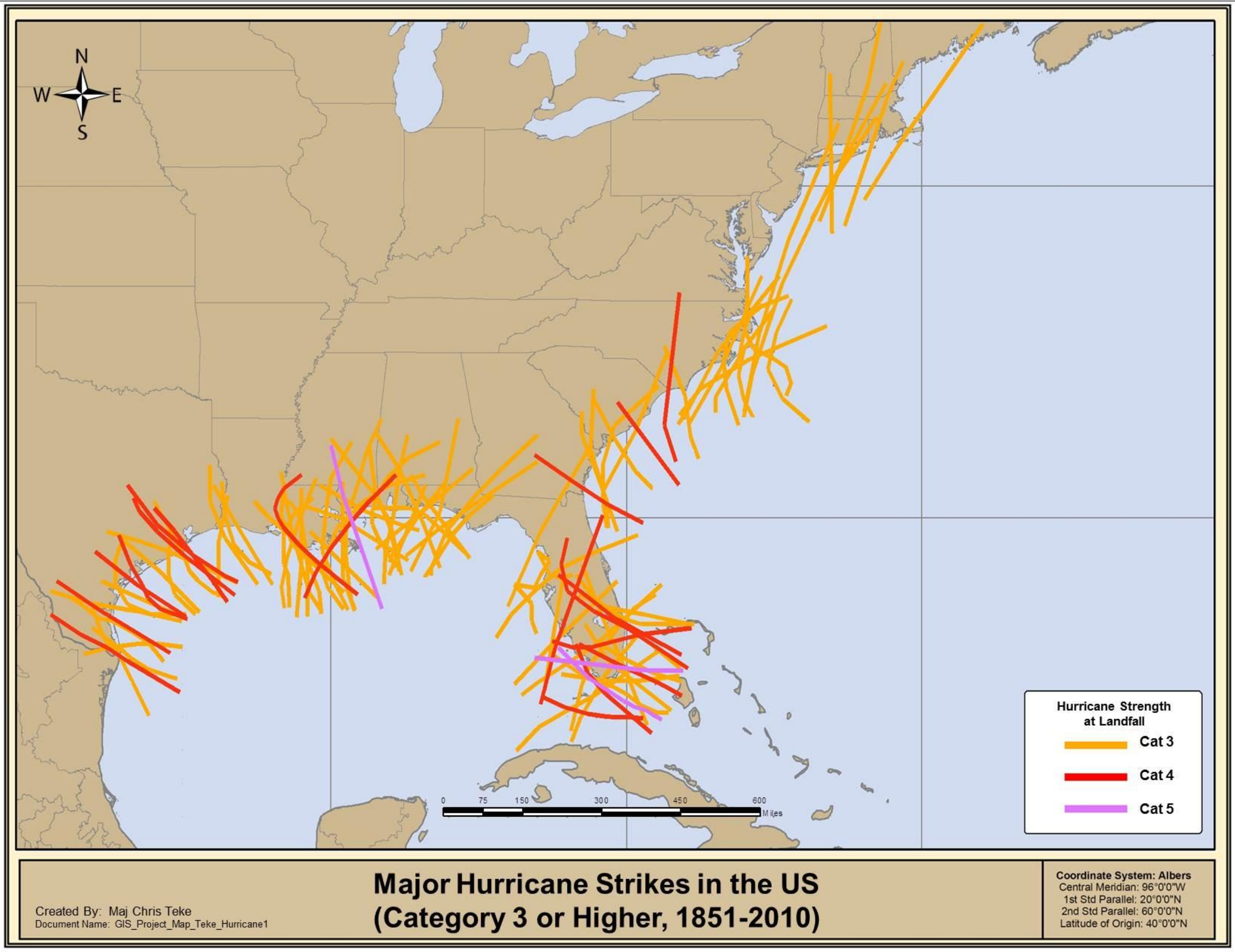


Figure 27: United States Major Hurricane Strikes (Category 3 or Higher), 1851-2010

Gulf Coast Air Force Bases at the greatest risk from the impacts of a hurricane are: Keesler, MS; Hurlburt Field, FL; Eglin, FL; and Tyndall, FL. Additionally, the lower and upper east coast of the United States is not immune. A repeat of a major Category 4 storm such as Hurricane Hazel in 1954 or Hurricane Hugo in 1989 would greatly affect Air Force Bases in the Carolinas such as Charleston, SC; Shaw; SC; and Seymour Johnson, NC (Blake et al., 2011). Furthermore, Joint Base Langley-Eustis, VA, is at great risk for hurricanes and storm surge, as was the case in 2003, when Hurricane Isabel caused major storm surge and flooding damage at Langley (Langley AFB History Office, 2003).

Appendix H contains hurricane occurrences maps by base, for each of the 24 installations that experienced any hurricane activity, Category 1-5, from 1851 through 2013. The maps in Appendix H provide a good representation of the actual hurricane threat at each installation, based on past occurrences. Each hurricane track represented in the Appendix H maps exists within a 75 nautical-mile radius of the centroid of the base. The underlying data, from NOAA's National Hurricane Center, used to produce the base specific hurricane maps, established the hurricane event counts shown in the hurricane risk-rank matrix. The following section provides a detailed ranking of hurricane occurrences for each base included in this study.

4.2.6 – Hurricane Risk Rank-Matrix

Table 22 shows the risk of hurricane occurrence and damage from major hurricanes is the greatest at all six Florida bases and at Keesler AFB, MS. MacDill AFB, FL, ranks at the top of the list for the most total and major hurricanes, 35 and 13, respectively. Keesler AFB, MS, and Patrick AFB, FL, nearly tie for the second rank position. Following closely behind and tied for the fourth ranked position is Eglin AFB, FL, and Hurlburt Field, FL. The tie in rank should come as no surprise as these two installations sit less than 15 miles apart. On the contrary, on the Atlantic-side of Florida, Patrick AFB and Cape Canaveral AFS also sit less than 15 miles apart. However, the number of hurricane occurrences at these two installations is significantly different. Patrick AFB had eleven major hurricanes while Cape Canaveral AFS had only seven. This is not an error in the data. Patrick AFB is situated just enough further south than Cape Canaveral AFS that the 75 nautical-mile radius surrounding Patrick includes four additional major hurricane tracks. These four hurricane tracks cut through the Florida mainland just outside the 75 nautical-mile radius of Cape Canaveral, AFS. See Appendix H, Map of Hurricane Occurrences by Base, for detailed hurricane-track maps depicting this geographical distinction.

Installations situated along the Eastern seaboard of the United States account for the majority of the remaining bases with one or more major hurricane occurrences. A select number of inland bases, such as Joint Base San Antonio, Shaw, Moody, Hanscom, Maxwell, and New Boston had one major hurricane occurrence during the 163-year period. For a complete list of all 62 installations, see “Hurricane Risk Rank-Matrix” in Appendix I.

Table 22: Major Hurricane (Cat 3-5) Risk-Rank by Base

Hurricane Risk-Rank by Base (1851-2013; 163 Year Period) **21 CONUS Air Force Bases with Cat 1-5 & 16 Bases with Cat 3-5 Hurricanes**					
Installation Name	**State**	**All Hurricane Occurrences** (Cat 1-5) (w/in 75 nautical mile radius)	**Major Hurricane Occurrences** (Cat 3-5) (w/in 75 nautical mile radius)	**Average Return Period** (Cat 3-5) (Years)	**Hurricane Risk Rank** (Ranked by Cat 3-5 1st, Tie-Breaker = Cat 1-5)
MacDill AFB	FL	35	13	12.5	1
Keesler AFB	MS	32	11	14.8	2
Patrick AFB	FL	31	11	14.8	3
Eglin AFB	FL	31	10	16.3	4
Hurlburt Field	FL	31	10	16.3	4
Tyndall AFB	FL	34	8	20.4	5
Cape Canaveral AFS	FL	30	7	23.3	6
Joint Base Charleston	SC	30	4	40.8	7
Seymour Johnson AFB	NC	23	3	54.3	8
Shaw AFB	SC	16	2	81.5	9
Cape Cod AS	MA	13	2	81.5	10
Moody AFB	GA	18	1	163.0	11
Joint Base Langley-Eustis	VA	14	1	163.0	12
Hanscom AFB	MA	10	1	163.0	13
Joint Base San Antonio	TX	8	1	163.0	14
Maxwell AFB	AL	7	1	163.0	15
New Boston AS	NH	6	1	163.0	16
Robins AFB	GA	11	0	N/A	17
JB McGuire-Dix-Lakehurst	NJ	6	0	N/A	18
Barksdale AFB	LA	4	0	N/A	19
Dover AFB	DE	4	0	N/A	19
Joint Base Andrews	MD	4	0	N/A	19
Columbus AFB	MS	2	0	N/A	20
Laughlin AFB	TX	1	0	N/A	21

4.3 – Climate Zone Map & Rank Matrix

4.3.1 – Climate Zone Map

As discussed in section 3.2.3, climate zone can have a major impact on energy use. There are eight major climate zones within the United States (ICC, 2012). These climate zones vary in both temperature and humidity and exhibit distinctly different quantities of Cooling Degree Days (CDD) and Heating Degree Days (HDD). The eight major climate zones are displayed in Figure 28.

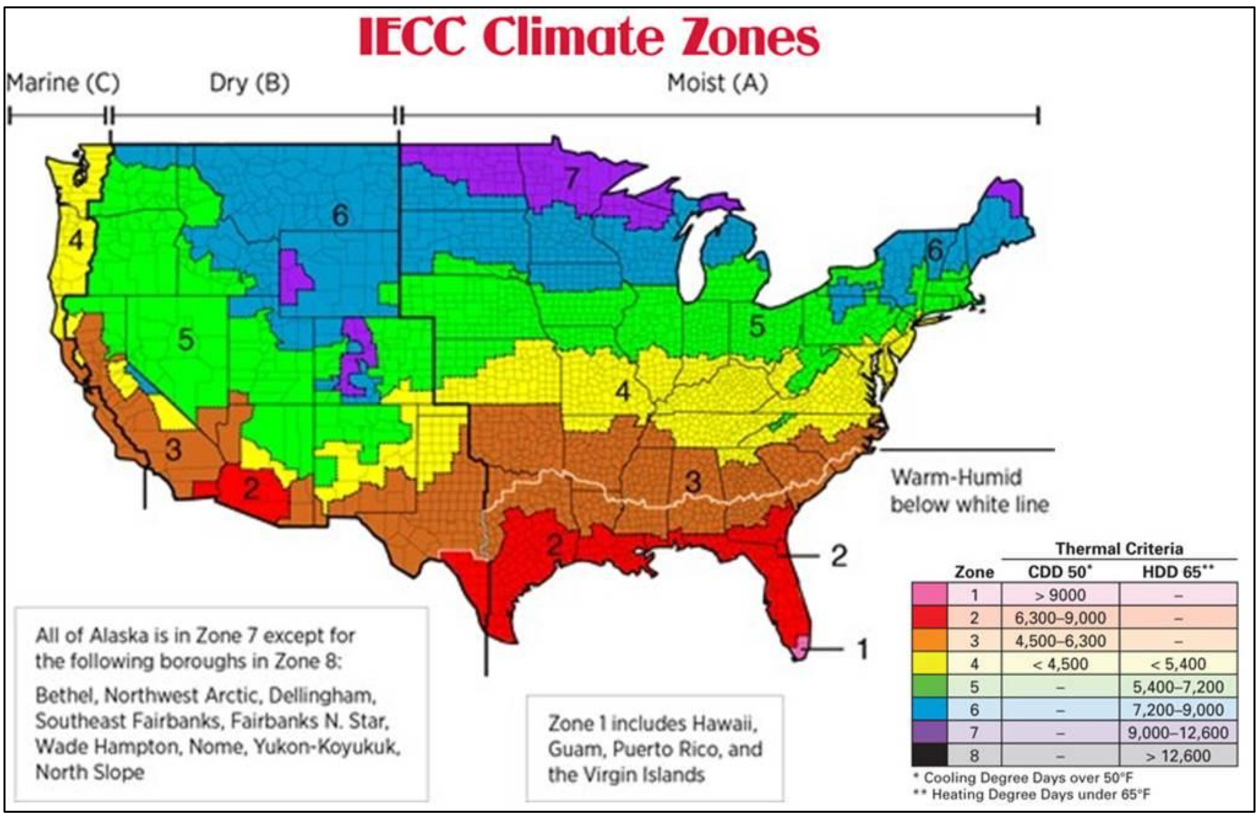


Figure 28: IECC Climate Zone Map

Climate zones in this analysis are assessed based on CDD and HDD. A low combination of CDDs and HDDs indicate an Air Force installation is located in a *neutral* climate zone, in which bases require less energy to operate. For the IECC climate zones, the most neutral climate is Zone 3, which is considered the baseline in this analysis. A large combination of CDDs and HDDs at an Air Force installation indicates the base is likely to consume more energy. The worst-case scenario for a climate zone, in terms of energy use, is zone 8. Although no major Air Force Bases in the CONUS fall within IECC Climate Zone 8, the three major bases in North Dakota fall within climate zone 7. These Air Force Bases include Minot and Grand Forks along with Cavalier Air Station. A final tabulation of CDDs and HDDs by base is shown in Table 23 and Table 24.

4.3.2 – Climate Zone Rank-Matrix

Climate zone is a major factor influencing a base's energy usage, because it costs a lot to heat and cool millions of square-feet of facilities on a typical base. As shown in Table 23, MacDill AFB, FL, tops the list of bases with the warmest climate, with 8,353 cooling-degree days, while Table 24 shows that Cavalier AS, ND, ranks the coldest with 10,071 heating-degree days. Cavalier AS, ND, is the most energy-intensive base in terms of climate-zone induced energy use. Furthermore, Cavalier tops the list of most energy-intensive bases (see Table 28) because it is not only located in a cold harsh climate, requiring a lot of energy, but it also uses large quantities of mission-related energy to operate its radar site.

Table 23: Raw Climate Data (Zones 2 & 3)

Climate Zone Data 34 Major CONUS Air Force Bases (Zones 2 & 3)					
Installation Data				IECC Climate Zone	
Installation Name	State	CDD 50	HDD 65		
MacDill AFB	FL	8,353	664	2	Hot
Cape Canaveral AFS	FL	8,348	385	2	
Patrick AFB	FL	8,334	411	2	
Laughlin AFB	TX	7,521	1,497	2	
Joint Base San Antonio	TX	7,389	1,660	2	
Luke AFB	AZ	7,224	1,688	2	
Keesler AFB	MS	7,000	1,536	2	
Tyndall AFB	FL	6,995	1,447	2	
Eglin AFB	FL	6,723	1,657	2	
Hurlburt Field	FL	6,699	1,681	2	
Davis-Monthan AFB	AZ	6,619	1,936	2	
Moody AFB	GA	6,421	1,571	2	
Nellis AFB	NV	7,431	2,349	3	
Creech AFB	NV	7,366	2,408	3	
Maxwell AFB	AL	6,416	2,255	3	
Joint Base Charleston	SC	6,263	2,123	3	
Goodfellow AFB	TX	6,076	2,672	3	
Barksdale AFB	LA	6,035	2,506	3	
Robins AFB	GA	6,005	2,507	3	
Columbus AFB	MS	5,656	2,888	3	
Shaw AFB	SC	5,637	2,745	3	
Holloman AFB	NM	5,426	3,530	3	
Altus AFB	OK	5,365	3,434	3	
Edwards AFB	CA	5,241	3,262	3	
Vance AFB	OK	5,124	4,182	3	
Tinker AFB	OK	4,906	3,741	3	
Sheppard AFB	TX	4,899	3,264	3	
Little Rock AFB	AR	4,836	3,361	3	
Dyess AFB	TX	4,759	2,842	3	
Beale AFB	CA	4,694	2,779	3	
Seymour Johnson AFB	NC	4,137	3,093	3	
Travis AFB	CA	4,062	3,160	3	
Los Angeles AFB	CA	2,457	1,587	3	
Vandenberg AFB	CA	2,275	2,497	3	Mild

As shown in Table 24, Cavalier Air Station and all North Dakota bases are by far the coldest bases and require the most natural gas for heating and are the most energy intensive in terms of climate (not mission related) energy use.

Table 24: Raw Climate Data (Zones 4, 5, 6, & 7)

Climate Zone Data 28 Major CONUS Air Force Bases (Zones 4, 5, 6, & 7)					
Installation Data				IECC Climate Zone	
Installation Name	State	CDD 50	HDD 65		
Joint Base Langley-Eustis	VA	4,720	3,582	4	Mild
Arnold AS	TN	4,296	3,873	4	
Cannon AFB	NM	4,002	4,283	4	
Kirtland AFB	NM	4,131	4,482	4	
Joint Base Andrews	MD	4,096	4,555	4	
McConnell AFB	KS	4,716	4,557	4	
Dover AFB	DE	3,868	4,696	4	
Scott AFB	IL	4,258	4,944	4	
Whiteman AFB	MO	4,225	5,069	4	
JB McGuire-Dix-Lakehurst	NJ	3,638	5,121	4	
Wright-Patterson AFB	OH	3,624	5,551	5	
Hanscom AFB	MA	2,139	5,679	5	
Cape Cod AS	MA	2,785	5,773	5	
Offutt AFB	NE	3,751	6,121	5	
Mountain Home AFB	ID	3,097	6,194	5	
Hill AFB	UT	2,964	6,322	5	
Buckley AFB	CO	2,951	6,498	5	
New Boston AS	NH	2,805	6,515	5	
Peterson AFB	CO	2,276	6,679	5	
Schriever AFB	CO	2,483	6,703	5	
US Air Force Academy	CO	2,179	6,811	5	
Fairchild AFB	WA	2,186	7,032	5	
Ellsworth AFB	SD	2,700	7,279	6	
F. E. Warren AFB	WY	2,157	7,558	6	
Malmstrom AFB	MT	2,001	7,657	6	
Minot AFB	ND	2,288	9,262	7	
Grand Forks AFB	ND	2,308	9,457	7	
Cavalier AS	ND	2,136	10,071	7	Cold

Another major factor of climate zone to consider is the combination of both CDD and HDD at a base. Large values of combined CDD and HDD increase an installation's energy use and energy intensity. As shown in Table 25, bases with a large combination of both CDD and HDD are Cavalier AS, ND; Grand Forks AFB, ND; and Minot AFB, ND. These northern-tier installations consume a lot of energy, primarily to heat in the winter. Nellis AFB and Creech AFB, located in Nevada, rank number six and seven for combined CDD and HDD (see Table

25). The two bases' high rankings are somewhat of a surprise, given that they are both in IECC Climate Zone 3. However, the large combination of CDD and HDD for these Nevada bases is likely due to their unique desert climate. Nellis and Creech AFBs require a great deal of energy to cool facilities in the hot summer and a moderate amount of energy to heat in cool desert winter. Large quantities of cooling and heating days at the top-ten ranked bases in Table 25, are a major factor contributing to high levels of energy usage, because it is energy intensive to heat and cool facilities at these ten bases. On the other hand, Los Angeles AFB, CA, and Vandenberg AFB, CA, are the most neutral bases in terms of energy intensity stemming from climate zone (see Table 25). These two bases have the lowest combination of CDD and HDD. As previously theorized, the two California bases, both located in IECC Climate Zone 3, define the most neutral climate, yielding the smallest overall climate-induced energy-use per year.

Table 25: Climate Zone Data, Ranked by Combined CDD & HDD

Ranked Climate Zone Data						
Installation Data				IECC Climate Zone	CDD+HDD	Combined CDD+HDD Rank
Installation Name	State	CDD 50	HDD 65			
Top 10 Bases - Combined CDD+HDD						
Cavalier AS	ND	2,136	10,071	7	12,207	1
Grand Forks AFB	ND	2,308	9,457	7	11,765	2
Minot AFB	ND	2,288	9,262	7	11,550	3
Ellsworth AFB	SD	2,700	7,279	6	9,979	4
Offutt AFB	NE	3,751	6,121	5	9,872	5
Nellis AFB	NV	7,431	2,349	3	9,780	6
Creech AFB	NV	7,366	2,408	3	9,774	7
F. E. Warren AFB	WY	2,157	7,558	6	9,715	8
Malmstrom AFB	MT	2,001	7,657	6	9,658	9
Buckley AFB	CO	2,951	6,498	5	9,449	10
Bottom 5 Bases - Combined CDD+HDD						
Beale AFB	CA	4,694	2,779	3	7,473	58
Seymour Johnson AFB	NC	4,137	3,093	3	7,230	59
Travis AFB	CA	4,062	3,160	3	7,222	60
Vandenberg AFB	CA	2,275	2,497	3	4,772	61
Los Angeles AFB	CA	2,457	1,587	3	4,044	62

To help better visualize the raw climate zone data, Figure 29 is a graphical depiction of CDD and HDD for each base. Bases located on the warmer end of the spectrum are on the left, while those located in the colder climates are on the right. As previously discussed, the major drop in CDD and HDD in the middle of Figure 29 is Los Angeles AFB, CA, and Vandenberg AFB, CA. This drop demonstrates that California's coastal climate is very mild, with minimal swings in temperature. The mild climate is beneficial because it reduces costs to heat and cool facilities. The mild coastal climate is also a significant reason why 22,680,010 people called Southern California home in 2010 (US Census, 2010).

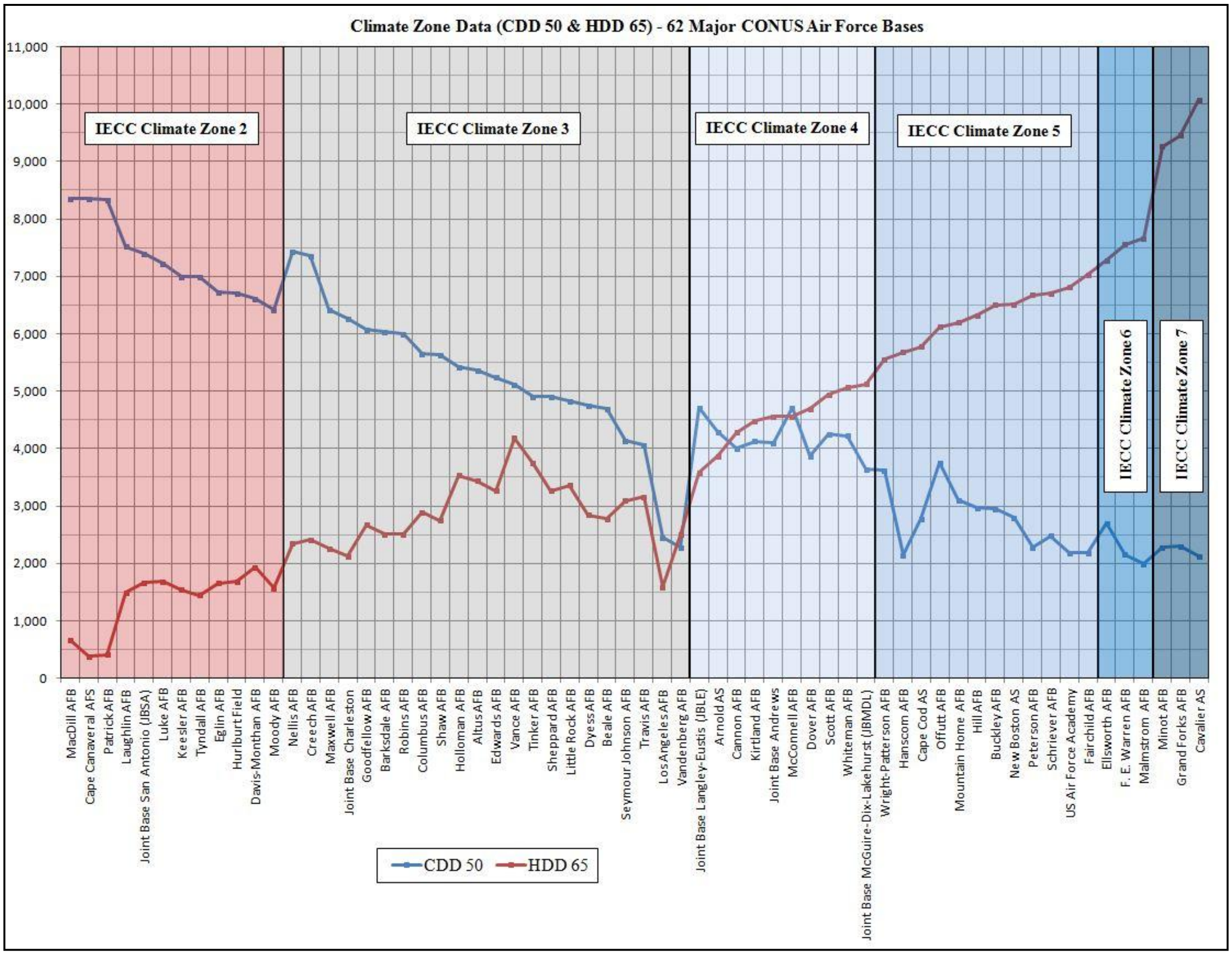


Figure 29: Climate Zones, CDDs, & HDDs by Base

Figure 30 is another graphical depiction of CDD and HDD, but it is broken out by month. The CDD and HDD data in Figure 30 comes from the 14th WS's "Engineering Weather Data" reports (AFWA, 2014b). Figure 30 shows the warmest and coldest bases in the analysis, MacDill AFB, FL, and Cavalier AS, ND, respectively. The figure shows for these two bases the large groupings of degree-days, both on the warm and cold ends of the scale. Similarly, the bottom-right chart in Figure 30 shows the monthly degree-days for Vance AFB, OK. Vance AFB is an installation with a higher degree of variability from the summer to the winter months. The variability is shown by the large fluctuations in the graph from hot to cold.

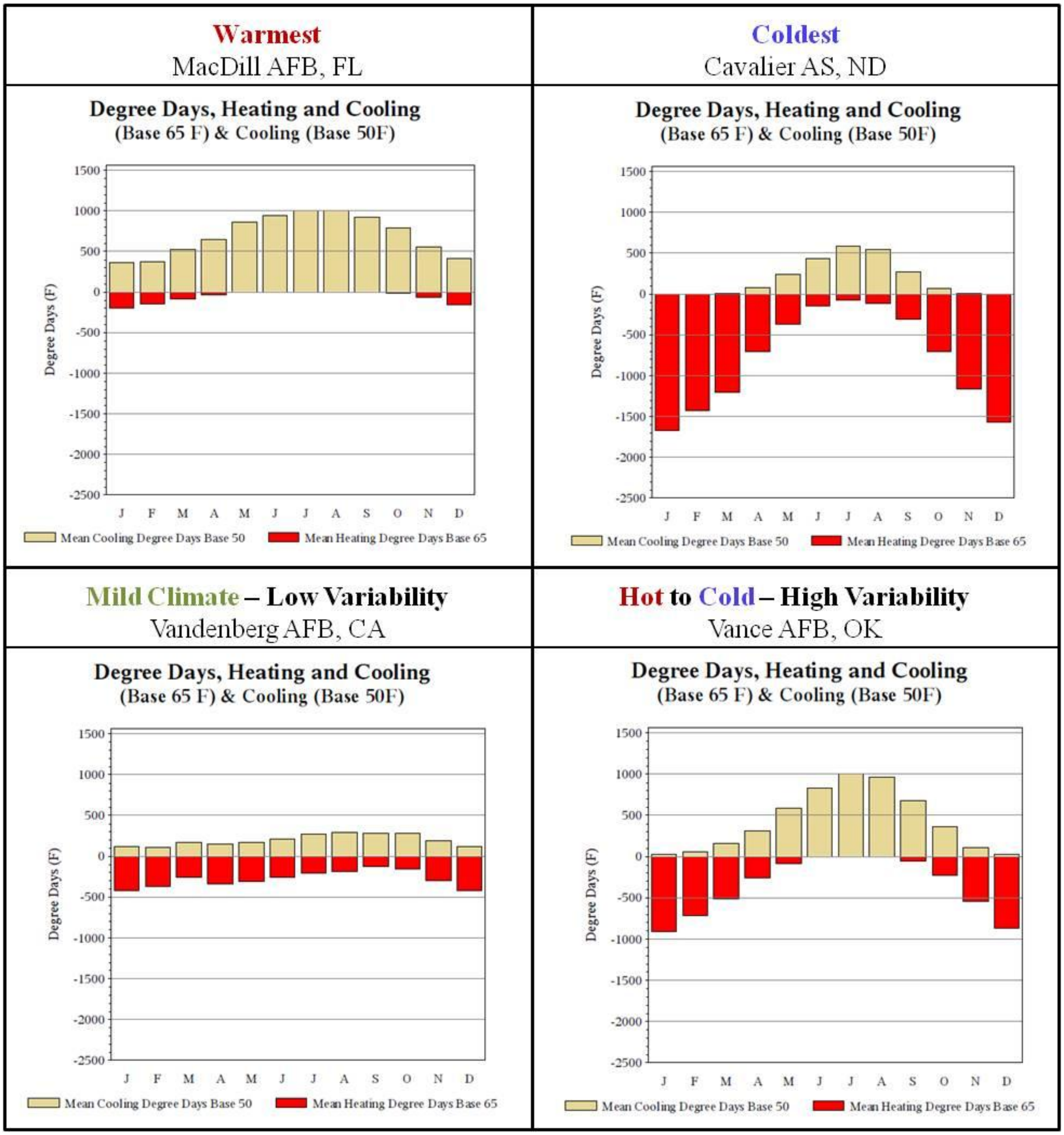


Figure 30: CDD & HDD by Month – 4 Divergent Examples (AFWA, 2014b)

Contrary to the large patterns of temperature fluctuation at Vance AFB, OK, Vandenberg AFB, CA, has one of the mildest climates, exhibiting the lowest variability in degree-days month-to-month (see lower-left graph in Figure 30). The neutrality of Vandenberg AFB's climate is easily seen on this graph, which is why it shares the top spot with Los Angeles AFB for the mildest climate. Energy use, along with cooling and heating costs, are greatly minimized when a base resides in a neutral climate such as Vandenberg's. The three other installations besides Vandenberg AFB, represented in Figure 30, all have greater climate-zone driven energy usage, and are thus more costly to operate.

4.4 – Energy Usage and Intensity Rank-Matrices

4.4.1 – Energy Usage Rank-Matrix by Base

Table 26 and Table 27 break down energy usage by base. Each table lists energy usage by commodity (electricity and natural gas) along with the combined total-average-annual energy usage. Electricity usage is represented in kilowatt-hours (kWh), natural gas usage is in thousand cubic feet (Mcf), and total energy usage is displayed in million British Thermal Units (MBTU).

Large installations rank high on the list with elevated levels of energy usage. These rankings are no surprise, as a greater number of facilities generally require more energy to operate. For that reason, the total site-delivered energy does not tell the whole story. Energy usage can be broken down in more detail, by focusing on the total energy usage per square-foot. This ratio of an installation's total energy usage per total square-foot of facility space is defined as energy intensity. Section 4.4.2 breaks down energy intensity by base.

As previously discussed, infrastructure energy loads related to mission include large radar systems, large network server-banks, industrial processes such as depot maintenance, and space launch and control systems. Installations with large mission loads include but are not limited to Tinker AFB, Robins AFB, and Hill AFB (Air Logistics Centers/depot maintenance); Wright-Patterson and Arnold AFBs (large test laboratories and equipment); Cape Cod, Cavalier, and New Boston Air Stations (radar sites); and Buckley, Cape Canaveral, Patrick, Schriever, and Vandenberg AFBs (launch, recovery, and ground control for space assets).

Table 26: Energy Usage by Base (Upper Half)

Energy Usage by Base (3-Year Average, FY12-14) Top 31 Major CONUS Air Force Bases								
Installation Name	Energy Usage by Commodity						Total Site Delivered Energy (Combined BTUs)	
	Electricity			Natural Gas			Electricity & Natural Gas	
	Average Annual Usage (kWh)	Std Dev Annual Usage (kWh)	Average Annual Usage Rank	Average Annual Usage (Mcf)	Std Dev Annual Usage (Mcf)	Average Annual Usage Rank	Average Annual Energy Usage (MBTU)	Average Annual Total Energy Usage Rank
Joint Base San Antonio	651,884,213	2,932,134	1	1,637,677	50,218	1	3,912,674	1
Tinker AFB	435,276,506	19,844,051	2	1,623,661	56,540	2	3,159,158	2
Wright-Patterson AFB	406,836,333	11,184,491	3	522,437	159,905	6	1,926,758	3
Robins AFB	317,216,487	16,628,011	4	775,520	41,745	4	1,881,904	4
Hill AFB	235,033,000	13,976,522	7	1,018,887	43,080	3	1,852,406	5
Arnold AS	267,465,333	62,611,672	6	506,221	57,042	8	1,434,505	6
JB McGuire-Dix-Lakehurst	179,030,260	6,937,530	9	763,308	96,479	5	1,397,822	7
Eglin AFB	282,449,623	4,131,670	5	385,243	7,251	11	1,360,904	8
Joint Base Langley-Eustis	233,060,977	696,706	8	430,587	89,383	9	1,239,140	9
Edwards AFB	147,232,150	11,984,182	13	404,105	77,930	10	918,988	10
US Air Force Academy	91,451,321	9,989,755	24	509,278	11,997	7	837,098	11
Offutt AFB	152,579,709	6,619,514	12	302,851	8,274	16	832,841	12
Kirtland AFB	132,335,296	7,896,165	14	344,152	9,954	13	806,348	13
Joint Base Charleston	178,572,857	5,946,226	10	135,323	15,543	40	748,808	14
Maxwell AFB	131,681,093	15,702,184	15	281,430	5,102	19	739,450	15
Keesler AFB	124,053,234	7,653,023	16	262,773	6,211	23	694,188	16
Sheppard AFB	104,838,190	5,341,839	19	313,189	38,683	15	680,605	17
Vandenberg AFB	97,280,476	3,001,236	22	267,488	45,688	21	607,701	18
Scott AFB	120,328,647	975,002	17	186,022	10,483	32	602,350	19
Holloman AFB	80,917,124	1,483,672	31	296,562	23,140	17	581,845	20
MacDill AFB	163,478,333	2,189,208	11	21,957	4,427	59	580,426	21
Joint Base Andrews	102,286,901	4,184,394	21	221,979	47,331	27	577,864	22
Nellis AFB	117,809,256	1,591,287	18	169,825	2,788	34	577,055	23
Whiteman AFB	68,345,000	2,222,406	37	329,723	26,913	14	573,137	24
Minot AFB	85,634,014	2,711,455	27	245,377	31,839	24	545,167	25
Cannon AFB	84,935,284	3,895,056	28	244,796	35,087	25	542,184	26
Hurlburt Field	103,612,926	869,198	20	149,414	6,163	39	507,573	27
Peterson AFB	90,619,554	4,055,068	26	191,945	6,483	30	507,089	28
Dover AFB	63,688,200	1,386,805	39	266,934	52,773	22	492,513	29
Travis AFB	92,066,312	3,902,110	23	169,263	6,218	35	488,640	30
Ellsworth AFB	54,010,464	2,491,632	45	290,777	28,927	18	484,075	31

Table 27: Energy Usage by Base (Lower Half)

Energy Usage by Base (3-Year Average, FY12-14) Bottom 31 Major CONUS Air Force Bases								
Installation Name	Energy Usage by Commodity						Total Site Delivered Energy (Combined BTUs)	
	Electricity			Natural Gas			Electricity & Natural Gas	
	Average Annual Usage (kWh)	Std Dev Annual Usage (kWh)	Average Annual Usage Rank	Average Annual Usage (Mcf)	Std Dev Annual Usage (Mcf)	Average Annual Usage Rank	Average Annual Energy Usage (MBTU)	Average Annual Total Energy Usage Rank
Hanscom AFB	35,853,365	8,044,270	55	344,913	84,583	12	477,936	32
Little Rock AFB	74,141,082	2,042,789	34	209,465	26,718	29	468,928	33
Fairchild AFB	50,491,969	1,092,854	46	276,846	18,607	20	457,707	34
Schriever AFB	82,572,411	1,991,299	30	151,735	2,094	38	438,176	35
Barksdale AFB	79,211,000	6,358,855	32	152,837	24,467	37	427,843	36
McConnell AFB	62,923,146	884,321	40	170,452	19,751	33	390,430	37
Malmstrom AFB	62,717,094	2,007,012	41	163,947	68,982	36	383,020	38
F. E. Warren AFB	42,635,901	15,399,925	50	225,461	9,966	26	377,924	39
Davis-Monthan AFB	73,473,588	848,324	35	113,681	17,173	43	367,897	40
Grand Forks AFB	41,610,091	1,554,943	52	214,548	33,107	28	363,173	41
Tyndall AFB	84,000,188	2,574,862	29	71,138	8,133	48	359,952	42
Cape Canaveral AFS	90,735,445	2,607,936	25	46,652	3,881	54	357,687	43
Shaw AFB	71,020,090	3,197,131	36	89,876	18,147	46	334,982	44
Mountain Home AFB	40,941,227	508,470	54	187,384	39,799	31	332,884	45
Seymour Johnson AFB	59,373,916	3,334,361	43	114,725	8,827	42	320,866	46
Dyess AFB	54,145,888	2,627,218	44	129,423	3,726	41	318,181	47
Patrick AFB	77,096,201	3,945,960	33	30,618	5,399	57	294,619	48
Beale AFB	61,973,566	14,845,732	42	65,817	9,896	49	279,311	49
Luke AFB	66,701,665	3,295,719	38	50,089	6,411	53	279,227	50
Altus AFB	42,033,090	1,753,648	51	111,112	29,040	44	257,974	51
Buckley AFB	41,075,077	881,862	53	92,971	16,204	45	236,001	52
Goodfellow AFB	49,880,833	1,058,159	47	61,479	9,454	50	233,579	53
Cavalier AS	46,148,899	4,733,340	49	73,699	30,198	47	233,444	54
Moody AFB	47,438,413	1,321,031	48	45,792	4,287	55	209,072	55
Columbus AFB	30,514,667	520,531	56	56,747	8,876	51	162,622	56
Vance AFB	22,974,817	105,871	59	52,573	7,971	52	132,593	57
Laughlin AFB	27,676,235	645,057	58	34,065	6,414	56	129,552	58
Los Angeles AFB	20,586,430	784,052	60	26,489	182	58	97,551	59
Creech AFB	27,789,217	2,320,826	57	N/A	N/A	N/A	94,817	60
Cape Cod AS	9,393,804	2,401,968	61	N/A	N/A	N/A	32,052	61
New Boston AS	5,075,333	56,083	62	N/A	N/A	N/A	17,317	62

4.4.2 – Energy Intensity Rank-Matrix by Base

Bases that top the list for energy intensity are the radar or space early-warning sites, such as Cavalier AS, ND; Cape Cod AS, MA; and New Boston AS, NH. Again, the bases with heavy mission-related energy-intensities top the list. These bases include Arnold AS, TN, and Tinker

AFB, OK. Additionally, Schriever AFB, CO, ranks number five on the list of most energy-intensive bases because it has a relatively small footprint, but it operates energy-intensive ground control equipment. Schriever's power-intensive equipment is used to operate and control satellites for the Global Positioning System, Defense Meteorological Satellite Program, Space Based Surveillance, and various other secure satellite communication systems (AFSPC, 2014).

Table 28: Energy Intensity by Base (Upper Half)

Ranked Energy-Intensity by Base (FY13 Data Only) **Top 31 Major CONUS Air Force Bases**					
Installation Name	**Total Annual Energy Usage** (MBTU)	**Total Facility Count**	**Gross Square Footage** (Ft^2)	**Energy Intensity** (BTU/Ft^2)	**Energy-Intensity Rank**
Cavalier AS	232,966	33	411,335	566,365	1
Arnold AS	1,393,935	334	2,837,855	491,193	2
Cape Cod AS	36,713	16	109,722	334,601	3
Tinker AFB	3,179,289	414	14,587,790	217,942	4
Schriever AFB	447,586	71	2,062,819	216,978	5
New Boston AS	17,538	25	96,075	182,542	6
Maxwell AFB	744,072	217	4,612,524	161,316	7
US Air Force Academy	872,009	264	5,910,086	147,546	8
Peterson AFB	517,101	203	3,539,467	146,096	9
Hill AFB	1,841,509	767	12,813,276	143,719	10
Offutt AFB	821,743	212	5,887,038	139,585	11
Joint Base San Antonio	3,940,589	1,478	29,351,739	134,254	12
Robins AFB	1,838,179	530	13,943,133	131,834	13
Edwards AFB	929,560	741	7,249,229	128,229	14
McConnell AFB	396,652	208	3,193,432	124,209	15
Scott AFB	603,240	286	4,913,640	122,769	16
F. E. Warren AFB	408,640	249	3,342,460	122,257	17
Hanscom AFB	489,822	139	4,045,153	121,089	18
Wright-Patterson AFB	2,023,829	595	16,798,409	120,477	19
MacDill AFB	582,961	302	4,902,311	118,916	20
Little Rock AFB	482,764	354	4,113,665	117,356	21
Eglin AFB	1,352,293	1,671	11,563,202	116,948	22
Dover AFB	458,958	217	4,030,292	113,877	23
Kirtland AFB	825,838	754	7,538,562	109,548	24
Malmstrom AFB	426,478	516	3,925,102	108,654	25
Beale AFB	311,244	256	2,874,438	108,280	26
Joint Base Langley-Eustis	1,290,067	701	12,116,506	106,472	27
Creech AFB	95,002	128	898,766	105,703	28
Whiteman AFB	551,662	879	5,230,677	105,467	29
Altus AFB	268,622	162	2,631,914	102,063	30
Los Angeles AFB	95,946	20	943,450	101,697	31

Table 29: Energy Intensity by Base (Lower Half)

Ranked Energy-Intensity by Base (FY13 Data Only) **Bottom 31 Major CONUS Air Force Bases**					
Installation Name	**Total Annual Energy Usage** (MBTU)	**Total Facility Count**	**Gross Square Footage** (Ft^2)	**Energy Intensity** (BTU/Ft^2)	**Energy-Intensity Rank**
Columbus AFB	166,102	175	1,658,149	100,173	32
Holloman AFB	599,203	494	6,028,378	99,397	33
Keesler AFB	693,082	231	6,989,842	99,156	34
JB McGuire-Dix-Lakehurst	1,389,323	1,189	14,015,273	99,129	35
Fairchild AFB	435,671	285	4,448,752	97,931	36
Hurlburt Field	507,664	567	5,213,156	97,381	37
Mountain Home AFB	328,381	451	3,406,306	96,404	38
Cape Canaveral AFS	358,242	532	3,730,079	96,041	39
Nellis AFB	584,013	617	6,311,226	92,536	40
Shaw AFB	324,647	298	3,528,295	92,012	41
Joint Base Andrews	604,044	355	6,658,924	90,712	42
Sheppard AFB	666,663	350	7,434,061	89,677	43
Vance AFB	133,234	127	1,487,793	89,551	44
Patrick AFB	276,791	279	3,119,905	88,718	45
Vandenberg AFB	562,106	640	6,415,839	87,612	46
Tyndall AFB	360,141	469	4,125,160	87,304	47
Barksdale AFB	437,755	436	5,021,944	87,168	48
Grand Forks AFB	403,711	603	4,652,792	86,767	49
Goodfellow AFB	224,193	155	2,596,632	86,340	50
Cannon AFB	338,239	652	3,925,694	86,160	51
Joint Base Charleston	743,133	894	8,629,056	86,120	52
Ellsworth AFB	482,446	729	5,976,862	80,719	53
Davis-Monthan AFB	375,531	511	4,854,245	77,361	54
Travis AFB	486,803	370	6,406,042	75,991	55
Buckley AFB	252,910	198	3,387,152	74,667	56
Luke AFB	269,998	349	3,716,392	72,651	57
Seymour Johnson AFB	319,005	820	4,506,956	70,781	58
Minot AFB	567,511	1,242	8,084,075	70,201	59
Dyess AFB	316,503	747	4,711,125	67,182	60
Moody AFB	199,735	329	2,987,464	66,858	61
Laughlin AFB	124,398	190	1,939,871	64,127	62

The least energy-intense bases in Table 29 are generally single-mission flying bases located in milder climates. Minot AFB, ND, is the only exception to this generalization, as it is a missile base located in a cold climate. To help avoid a BRAC action, energy-intensive bases make good candidates to explore efficiency measures to reduce overall energy use and consequently reduce energy costs. A reduction in operational cost lessens the impact of energy usage cost in the COBRA Model.

4.4.3 – Energy Cost-Intensity Rank-Matrix by Base

As shown in Table 30, all four Air Stations along with Schriever and Los Angeles Air Force Bases top the list of most energy cost-intensive bases. Some of the cost-intensity may be attributed to higher utility rates, but again, the majority of the top-ranked bases have very intensive mission-related energy needs, thus making it very cost-intensive too. Most of the bases in Table 30, with a cost-intensity of greater than two dollars per square-foot and ranked tenth or higher, exist in states with higher than normal electricity rates. This relationship can be seen by comparing the rates listed in Table 30 with the shaded-density electric rate maps in Figure 31and Figure 32.

Table 31 shows the lower ranked half of bases for energy cost-intensity. The bottom-eight ranked bases, all with less than one dollar per square-foot of cost intensity, are again single-flying mission or missile bases. The data indicates these mission sets may require less energy to operate and are thus, less cost-intensive too. Furthermore, by comparing the rates listed in Table 31 with the shaded-density electric rate maps in Figure 31and Figure 32, the eight bottom-ranked bases in Table 31, generally reside in states with lower electricity rates. Travis AFB, CA, is the single exception to this theory. However, Travis AFB, CA, and Dyess AFB, TX, get a sizable share of their electricity through locally generated wind power. Travis' wind power and reasonably mild climate may offset and reduce the cost of energy to this base, and help explain the lower energy cost-intensity.

Based on the discussion of some of the previous results, energy cost-intensive bases make good realignment or closure candidates in a BRAC. Bases with high energy-cost-intensity should be explored for realignment to areas with lower utility rates or milder climates. Otherwise, if mission permits and realignment is not an option, high energy-cost-intensive bases can be closed altogether through BRAC, as a cost-savings measure for the Air Force.

Table 30: Energy Cost-Intensity by Base (Upper Half)

Ranked Energy Cost-Intensity by Base (FY13 Data Only)
Top 31 Major CONUS Air Force Bases

Installation Name	Total Annual Energy Cost ($) (Elect & Nat Gas)	Total Facility Count	Gross Square Footage (Ft^2)	Energy Cost-Intensity ($\$/Ft^2$)	Energy Cost-Intensity Rank
Cape Cod AS	$ 1,348,265	16	109,722	$12.288	1
Arnold AS	$ 19,658,481	334	2,837,855	$6.927	2
Cavalier AS	$ 2,529,687	33	411,335	$6.150	3
New Boston AS	$ 540,352	25	96,075	$5.624	4
Schriever AFB	$ 6,664,342	71	2,062,819	$3.231	5
Los Angeles AFB	$ 2,549,914	20	943,450	$2.703	6
MacDill AFB	$ 12,811,017	302	4,902,311	$2.613	7
Creech AFB	$ 2,103,141	128	898,766	$2.340	8
Maxwell AFB	$ 10,724,561	217	4,612,524	$2.325	9
Eglin AFB	$ 23,382,584	1,671	11,563,202	$2.022	10
Hanscom AFB	$ 7,856,686	139	4,045,153	$1.942	11
Joint Base San Antonio	$ 56,385,020	1,478	29,351,739	$1.921	12
Dover AFB	$ 7,722,769	217	4,030,292	$1.916	13
Cannon AFB	$ 7,130,369	652	3,925,694	$1.816	14
Peterson AFB	$ 6,393,198	203	3,539,467	$1.806	15
Tinker AFB	$ 25,145,245	414	14,587,790	$1.724	16
Edwards AFB	$ 12,464,172	741	7,249,229	$1.719	17
Joint Base Charleston	$ 14,586,327	894	8,629,056	$1.690	18
Robins AFB	$ 23,474,428	530	13,943,133	$1.684	19
Hurlburt Field	$ 8,701,732	567	5,213,156	$1.669	20
Columbus AFB	$ 2,762,896	175	1,658,149	$1.666	21
Wright-Patterson AFB	$ 27,923,186	595	16,798,409	$1.662	22
Tyndall AFB	$ 6,697,575	469	4,125,160	$1.624	23
Malmstrom AFB	$ 6,294,721	516	3,925,102	$1.604	24
Shaw AFB	$ 5,570,745	298	3,528,295	$1.579	25
JB McGuire-Dix-Lakehurst	$ 21,596,497	1,189	14,015,273	$1.541	26
Davis-Monthan AFB	$ 7,311,552	511	4,854,245	$1.506	27
McConnell AFB	$ 4,762,507	208	3,193,432	$1.491	28
Joint Base Langley-Eustis	$ 18,000,019	701	12,116,506	$1.486	29
Patrick AFB	$ 4,609,127	279	3,119,905	$1.477	30
Beale AFB	$ 4,223,217	256	2,874,438	$1.469	31

Table 31: Energy Cost-Intensity by Base (Lower Half)

Ranked Energy Cost-Intensity by Base (FY13 Data Only) Bottom 31 Major CONUS Air Force Bases					
Installation Name	Total Annual Energy Cost ($) (Elect & Nat Gas)	Total Facility Count	Gross Square Footage (Ft^2)	Energy Cost-Intensity ($\$/Ft^2$)	Energy Cost-Intensity Rank
Joint Base Andrews	$ 9,729,588	355	6,658,924	$1.461	32
F. E. Warren AFB	$ 4,765,776	249	3,342,460	$1.426	33
Kirtland AFB	$ 10,709,381	754	7,538,562	$1.421	34
Cape Canaveral AFS	$ 5,162,508	532	3,730,079	$1.384	35
Keesler AFB	$ 9,598,032	231	6,989,842	$1.373	36
US Air Force Academy	$ 7,825,958	264	5,910,086	$1.324	37
Goodfellow AFB	$ 3,363,700	155	2,596,632	$1.295	38
Luke AFB	$ 4,745,633	349	3,716,392	$1.277	39
Hill AFB	$ 16,046,968	767	12,813,276	$1.252	40
Little Rock AFB	$ 5,109,392	354	4,113,665	$1.242	41
Altus AFB	$ 3,210,903	162	2,631,914	$1.220	42
Moody AFB	$ 3,644,566	329	2,987,464	$1.220	43
Barksdale AFB	$ 6,098,865	436	5,021,944	$1.214	44
Scott AFB	$ 5,947,052	286	4,913,640	$1.210	45
Laughlin AFB	$ 2,341,134	190	1,939,871	$1.207	46
Holloman AFB	$ 6,800,375	494	6,028,378	$1.128	47
Offutt AFB	$ 6,637,509	212	5,887,038	$1.127	48
Mountain Home AFB	$ 3,818,238	451	3,406,306	$1.121	49
Vandenberg AFB	$ 7,084,286	640	6,415,839	$1.104	50
Nellis AFB	$ 6,966,823	617	6,311,226	$1.104	51
Sheppard AFB	$ 8,158,169	350	7,434,061	$1.097	52
Buckley AFB	$ 3,576,644	198	3,387,152	$1.056	53
Seymour Johnson AFB	$ 4,649,922	820	4,506,956	$1.032	54
Whiteman AFB	$ 5,169,952	879	5,230,677	$0.988	55
Travis AFB	$ 5,958,080	370	6,406,042	$0.930	56
Grand Forks AFB	$ 4,010,480	603	4,652,792	$0.862	57
Vance AFB	$ 1,265,269	127	1,487,793	$0.850	58
Minot AFB	$ 6,230,857	1,242	8,084,075	$0.771	59
Dyess AFB	$ 3,604,343	747	4,711,125	$0.765	60
Fairchild AFB	$ 3,286,089	285	4,448,752	$0.739	61
Ellsworth AFB	$ 3,325,842	729	5,976,862	$0.556	62

4.5 – Utility Rate Maps & Rank Matrices

4.5.1 – Electric Rates Map

The electric rates map in Figure 31 reveals no major surprises. Average annual electric rates are the highest in California and the upper northeast. It also appears that electric rates are driven less by geographical location and demand and more by electricity production methods and fuel source type. Politics and environmental regulation also both play a major role in the price of electricity. States with relatively loose regulation and easy access to fuel sources tended to have the lowest electric rates. These states included Idaho, Utah, West Virginia, and Virginia. The Pacific Northwest enjoys relatively low electric rates due to the abundance of available hydroelectric dams, which provide cheap and renewable electricity. On the contrary, areas that have to generate electricity that are far away from a potential fuel source, such as coal or natural gas, tended to have higher rates (Hong, Chang, & Lin, 2013).

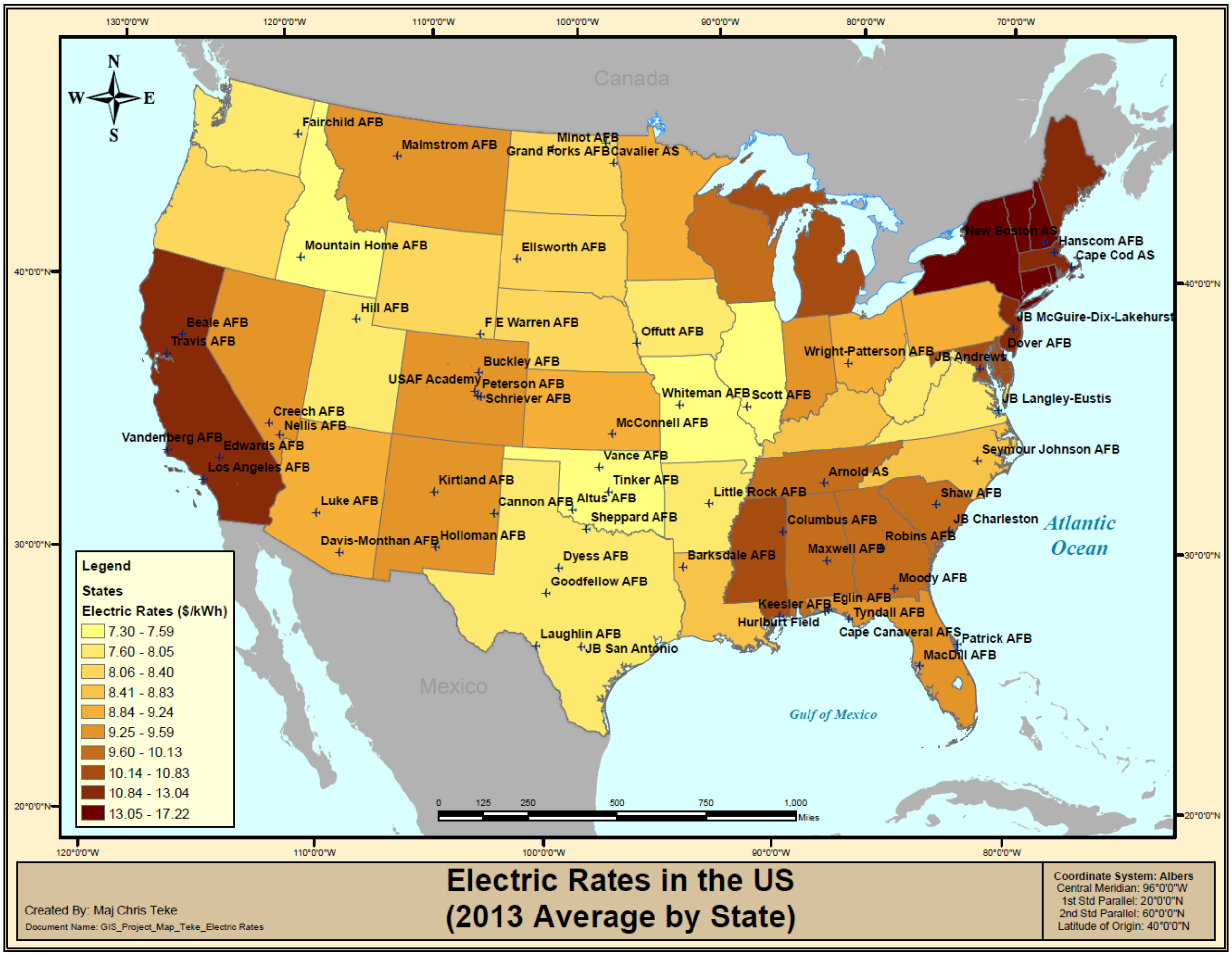


Figure 31: Electric Rates in the US (2013)

Figure 32 is a product of the U.S. Department of Energy's National Renewable Energy Laboratory. The map in Figure 32 breaks down nationwide electricity rates in more detail than the statewide averages, shown in Figure 31 (Roberts, 2012). A map with finer details is often times more helpful than the statewide averages featured in Figure 31. One example where the additional detail is helpful is in Colorado. The substantial changes in shading density around the Pikes Peak Region of Colorado Springs, CO, might help explain why the three Air Force Bases (Peterson, Schriever, and U.S. Air Force Academy) located in this region have highly variable rates. The difference in the electric rates for these three bases, all located within about 30 miles of each other, can be seen in Table 32 and Table 33.

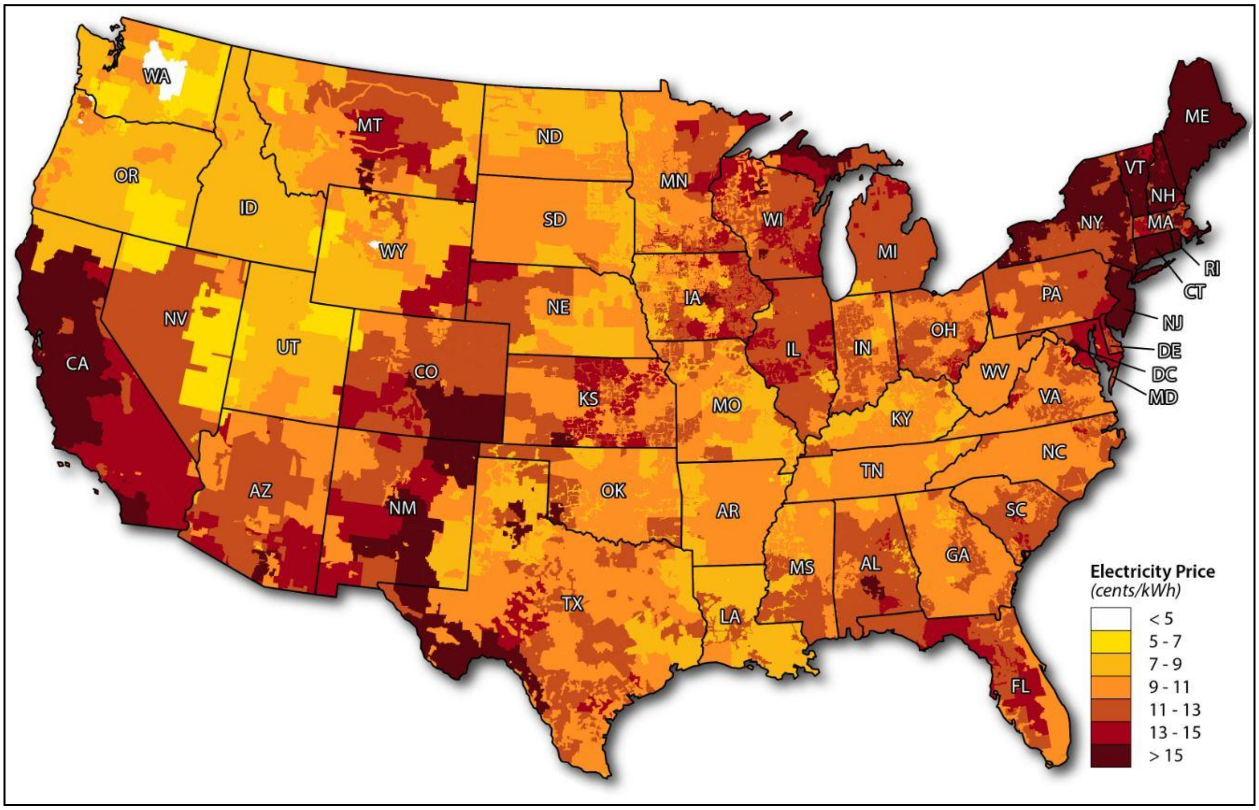


Figure 32: Electric Rates in the US (2012)

4.5.2 – Electric Rate Rank-Matrix by Base

A base-by-base ranking for electric rates is shown in Table 32 and Table 33. Hanscom AFB and Cape Cod AS, MA, lead the way with the highest electric rates along with Los Angeles AFB, CA. A comparison of the rates in Figure 31 with the rates in Table 32 and Table 33 reveal that the actual rates the Air Force pays for electricity differs significantly in some cases than its statewide average. In many instances, the Air Force negotiates a better rate than what regular commercial customers pay in the surrounding area. For example, Travis and Beale AFBs, CA, both rank relatively low on the list at the 42nd and 47th positions, respectively, on the electric rate rank-matrix shown in Table 33. However, Figure 31 and Figure 32 show the State of California has a relatively high electricity rate compared to all other states. These are two instances where the Air Force likely benefits from paying a lower negotiated rate. In contrast, New Boston AS, NH; Joint-Base McGuire-Dix-Lakehurst, NJ; and Dover AFB, DE; all pay between nine and ten-and-a-half cents per kilowatt-hour for electricity and are located in states which generally pay high electric rates. This information coincides with the state's dark shaded-density in Figure 31 and Figure 32.

Other bases listed on Table 33 that rank lower on the list than what the state-wide average on the maps indicate are Nellis AFB, NV, and the U.S. Air Force Academy, CO. These two bases have large photovoltaic solar arrays with unique buy-back contracts or power-purchase agreements. These renewable energy projects benefit primarily the base and not the surrounding communities or electric grid and may help explain the reduced rates that differ from the maps.

Furthermore, bases with high variability and a larger standard deviation among its electric rates are Hanscom AFB, MA; Los Angeles AFB, CA; Vandenberg AFB, CA; Cape Cod AS, MA; and Creech AFB, NV. The states that top the list with high variability of electric rates are Massachusetts, California, and Nevada (See Appendix I for the complete rate rank-matrix showing average and standard deviation of electric rates by base). Ultimately, highly variable electric rates can yield highly variable electricity costs, which makes it difficult for bases to budget for future energy costs. The Monte Carlo simulation results in section 4.6 account for this variability in cost.

Table 32: Electric Rates by Base (Upper Half)

Ranked Electric Rates by Base (FY 12-14) Top 31 Major CONUS Air Force Bases			
Installation Name	**State**	**Average Electric Rate ($/kWh)**	**Electric Rate Rank**
Hanscom AFB	MA	$0.15399	1
Cape Cod AS	MA	$0.11883	2
Los Angeles AFB	CA	$0.11696	3
New Boston AS	NH	$0.10532	4
JB McGuire-Dix-Lakehurst	NJ	$0.09196	5
Dover AFB	DE	$0.09080	6
Davis-Monthan AFB	AZ	$0.08394	7
Columbus AFB	MS	$0.08269	8
Malmstrom AFB	MT	$0.08261	9
Tyndall AFB	FL	$0.08129	10
Eglin AFB	FL	$0.07986	11
Hurlburt Field	FL	$0.07865	12
MacDill AFB	FL	$0.07853	13
Edwards AFB	CA	$0.07841	14
Creech AFB	NV	$0.07783	15
Joint Base Charleston	SC	$0.07753	16
Joint Base Andrews	MD	$0.07674	17
Laughlin AFB	TX	$0.07649	18
Moody AFB	GA	$0.07420	19
Shaw AFB	SC	$0.07401	20
Vandenberg AFB	CA	$0.07399	21
Joint Base San Antonio	TX	$0.07253	22
Keesler AFB	MS	$0.07116	23
Grand Forks AFB	ND	$0.07111	24
Buckley AFB	CO	$0.06981	25
F. E. Warren AFB	WY	$0.06897	26
Schriever AFB	CO	$0.06831	27
Robins AFB	GA	$0.06729	28
Luke AFB	AZ	$0.06697	29
Arnold AS	TN	$0.06638	30
Seymour Johnson AFB	NC	$0.06605	31

Table 33: Electric Rates by Base (Lower Half)

Ranked Electric Rates by Base (FY 12-14) Bottom 31 Major CONUS Air Force Bases			
Installation Name	State	Average Electric Rate ($/kWh)	Electric Rate Rank
McConnell AFB	KS	$0.06601	32
Holloman AFB	NM	$0.06400	33
Joint Base Langley-Eustis	VA	$0.06388	34
Sheppard AFB	TX	$0.06384	35
Altus AFB	OK	$0.06273	36
Kirtland AFB	NM	$0.06210	37
Minot AFB	ND	$0.06175	38
Goodfellow AFB	TX	$0.06173	39
Barksdale AFB	LA	$0.06160	40
Patrick AFB	FL	$0.06068	41
Travis AFB	CA	$0.06058	42
Maxwell AFB	AL	$0.05994	43
Wright-Patterson AFB	OH	$0.05968	44
Cannon AFB	NM	$0.05889	45
Whiteman AFB	MO	$0.05885	46
Beale AFB	CA	$0.05739	47
Dyess AFB	TX	$0.05606	48
Peterson AFB	CO	$0.05602	49
Mountain Home AFB	ID	$0.05602	50
Little Rock AFB	AR	$0.05449	51
Hill AFB	UT	$0.05269	52
Cape Canaveral AFS	FL	$0.05208	53
Nellis AFB	NV	$0.05095	54
US Air Force Academy	CO	$0.04907	55
Cavalier AS	ND	$0.04881	56
Vance AFB	OK	$0.04676	57
Tinker AFB	OK	$0.04514	58
Ellsworth AFB	SD	$0.04354	59
Fairchild AFB	WA	$0.04071	60
Scott AFB	IL	$0.04053	61
Offutt AFB	NE	$0.03427	62

4.5.3 – Natural-Gas Rates Map

The natural gas rates map is shown in Figure 33. Average annual natural gas rates are the highest in the states of Washington, Arizona, Alabama, and the upper northeast. It also appeared that natural gas rates are driven less by geographical location and demand and more by production methods and proximity to the well heads and the fuel source. The northern central plain states such as Wyoming, Nebraska, South Dakota, North Dakota, and Minnesota all had the lowest average annual natural gas rates. In the south, Texas and New Mexico also had very low average annual natural gas rates. On the contrary, areas far away from a potential natural gas well, source, or pipeline, tended to have higher rates (EIA, 2014). As with electric rates, politics and environmental regulation also both play a major role in the price and availability of natural gas. States with relatively loose regulation and easy access to sources tended to have the lowest natural gas rates. In contrast to electricity, natural gas has traditionally not always been available in all regions, especially more rural ones. Since the early days of infrastructure development in the United States, programs such as the Tennessee Valley Authority (TVA) made it a priority to provide electricity to the masses, especially in rural areas (EIA, 2014). However, natural gas has not been afforded the same treatment. Therefore, many areas of the United States have electricity, but not natural gas. In those areas, heating requirements are resolved through other resources such as heating oil, propane, and electricity.

The states with the lowest natural gas rates included Wyoming, Nebraska, South Dakota, North Dakota, Minnesota, Texas, and New Mexico. Therefore, on the basis of natural gas rates alone, the case could be made to keep or realign major Air Force missions to bases in these states. One major trend that appears to benefit the Air Force is that the price of natural gas is currently most expensive in warmer areas of the country, with the exception of the upper northeast. Therefore, although facilities are consuming more natural gas for heat in the colder regions such as North Dakota, these regions are also appear to pay a lesser rate to purchase that gas. On the contrary, states with warmer or more mild climates such as Arizona, Florida, Alabama, and Washington, where they tend to heat less and consume less natural gas, pay a higher rate. In the end, this trend generally benefits the Air Force along with the rest of the United States. The only states that do not appear to benefit from this trend are Missouri, West Virginia, Pennsylvania, Rhode Island, Vermont, New Hampshire, and Maine. These states tend to consume more natural gas for heating, but pay a higher rate.

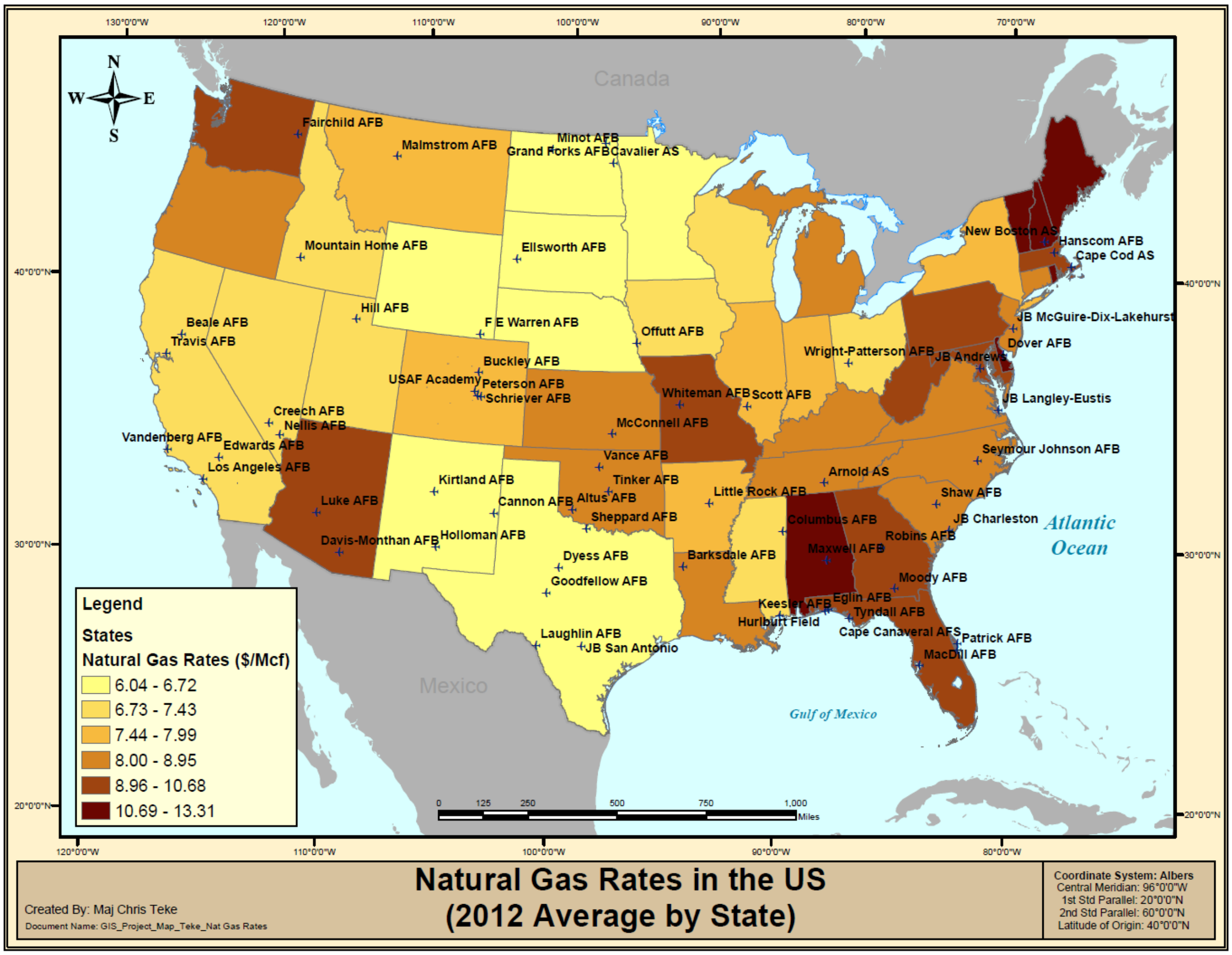


Figure 33: Natural Gas Rates in the US (2012 Average by State)

4.5.4 – Natural-Gas Rate Rank-Matrix by Base

To further break down the state-wide averages, a base-by-base ranking for natural gas rates is shown in Table 34 and Table 35. Altus, Luke, Scott, Davis-Monthan, and Malmstrom Air Force Bases lead the way with the highest natural gas rates. A comparison of the rates in

Figure 33 with Table 34 and Table 35 reveal that the actual rates the Air Force pays for natural gas differ significantly in some cases than its statewide average. In many instances, the Air Force negotiates a better rate than what regular commercial customers pay in the area surrounding the base. For example, Fairchild AFB, WA, ranks 30th on the natural-gas rate rank-matrix shown in Table 34. However, Figure 33 shows Washington State has a relatively high natural-gas rate. This is one instance where the Air Force benefits from paying a lower negotiated rate. In contrast, Luke and Davis-Monthan AFBs located in the State of Arizona both pay high natural-gas rates, which coincide with the state's dark shaded-density in Figure 33.

Furthermore, bases with high variability and standard deviation among its natural gas rates are Altus AFB, OK, and Malmstrom AFB, MT (See Appendix I for the complete rate rank-matrix showing average and standard deviation of natural-gas rates by base). For Fiscal Years 2012 through 2014, Altus AFB's natural gas rates ranged from $4.06 - $48.75 dollars per Mcf. Altus AFB has the highest variability for natural gas costs of all bases. The natural gas rates at Altus AFB plummeted during the colder winter months, averaging $6.21 dollars per Mcf from November through April. The reduced rates in winter benefit the base because heating requirements are more intensive during these months when the highest usage occurs. However, during the same time-period (FY 2012-2014), natural gas rates skyrocketed during the warmer months, averaging $24.97 dollars per Mcf from May to October, when heating requirements are less intensive and usage dropped. Malmstrom AFB, MT, experienced similar natural-gas rate behavior as Altus AFB, but not nearly as pronounced. For Fiscal Years 2012 through 2014, Malmstrom AFB's natural gas rates ranged from $4.27 - $19.83 dollars per Mcf. The average monthly natural-gas rate for Malmstrom during the cooler months, October through May, was $5.86 dollars per Mcf; while Malmstrom's average rate for June through September was $15.44

dollars per Mcf. All other natural gas data analyzed for the 60 remaining installations behaved less erratically with no extreme fluctuations. These highly variable natural gas rates yield highly variable natural gas costs, which make it difficult for the bases to budget for future energy costs. The Monte Carlo simulation results in section 4.6 account for this variability in cost.

Table 34: Natural Gas Rates by Base (Upper Half)

Ranked Natural Gas Rates by Base (FY 12-14) Top 31 Major CONUS Air Force Bases			
Installation Name	**State**	**Average Natural Gas Rate ($/Mcf)**	**Natural Gas Rate Rank**
Altus AFB	OK	$15.591	1
Luke AFB	AZ	$11.054	2
Scott AFB	IL	$9.345	3
Davis-Monthan AFB	AZ	$9.260	4
Malmstrom AFB	MT	$9.055	5
Dover AFB	DE	$9.011	6
JB McGuire-Dix-Lakehurst	NJ	$8.949	7
Buckley AFB	CO	$8.903	8
Maxwell AFB	AL	$8.716	9
Joint Base Andrews	MD	$8.701	10
Seymour Johnson AFB	NC	$8.667	11
Joint Base Charleston	SC	$8.422	12
Patrick AFB	FL	$8.293	13
Joint Base Langley-Eustis	VA	$8.249	14
Cape Canaveral AFS	FL	$8.007	15
Beale AFB	CA	$7.950	16
Peterson AFB	CO	$7.897	17
Shaw AFB	SC	$7.805	18
Barksdale AFB	LA	$7.288	19
Vance AFB	OK	$7.232	20
Mountain Home AFB	ID	$7.023	21
Columbus AFB	MS	$6.868	22
Hanscom AFB	MA	$6.866	23
Eglin AFB	FL	$6.786	24
MacDill AFB	FL	$6.762	25
Hurlburt Field	FL	$6.707	26
Los Angeles AFB	CA	$6.424	27
Arnold AS	TN	$6.065	28
Edwards AFB	CA	$6.051	29
Fairchild AFB	WA	$5.978	30
Dyess AFB	TX	$5.636	31

Table 35: Natural Gas Rates by Base (Lower Half)

Ranked Natural Gas Rates by Base (FY 12-14) Bottom 31 Major CONUS Air Force Bases			
Installation Name	**State**	**Average Natural Gas Rate** ($/Mcf)	**Natural Gas Rate Rank**
Nellis AFB	NV	$5.590	32
Offutt AFB	NE	$5.576	33
Goodfellow AFB	TX	$5.576	34
US Air Force Academy	CO	$5.570	35
Joint Base San Antonio	TX	$5.537	36
F. E. Warren AFB	WY	$5.443	37
Holloman AFB	NM	$5.255	38
Sheppard AFB	TX	$5.187	39
Laughlin AFB	TX	$5.179	40
Moody AFB	GA	$5.128	41
Wright-Patterson AFB	OH	$5.107	42
Cannon AFB	NM	$5.092	43
Little Rock AFB	AR	$5.017	44
Tyndall AFB	FL	$5.016	45
Vandenberg AFB	CA	$4.899	46
Schriever AFB	CO	$4.795	47
Grand Forks AFB	ND	$4.652	48
Keesler AFB	MS	$4.428	49
Tinker AFB	OK	$4.365	50
Kirtland AFB	NM	$4.324	51
Travis AFB	CA	$4.294	52
Whiteman AFB	MO	$4.155	53
Hill AFB	UT	$4.147	54
Minot AFB	ND	$4.141	55
Cavalier AS	ND	$4.039	56
Robins AFB	GA	$3.970	57
Ellsworth AFB	SD	$3.951	58
McConnell AFB	KS	$3.932	59
Cape Cod AS	MA	N/A	N/A
Creech AFB	NV	N/A	N/A
New Boston AS	NH	N/A	N/A

4.6 – Monte Carlo Simulation Results

This section summarizes the Monte Carlo simulation results and the forecasted Equivalent Annual Cost (EAC) of tornadoes, hurricanes, electricity, and natural gas by base. The total EAC listed in Table 36 and Table 37 is the total amount that would enter the COBRA

Model during BRAC to account for the annual costs associated with localized tornado and hurricane activity, along with annual electricity and natural gas costs. Annual cost estimates of these four factors range from approximately $1-million to $100-million dollars. These factors affect operating and base maintenance costs, with electricity and hurricane damage accounting for the largest share. For all 62 bases, the percentage of the total annual cost for each of these four factors is 51% for electricity, 35% for hurricanes, 11% for natural gas, and 3% for tornadoes. The total EAC translates into a ranked list, from *1-to-n*, for all 62 major CONUS Air Force installations. The predicted severe weather and annual energy costs determine the final rank order.

4.6.1 – EAC of Tornado, Hurricane, Electricity, & Natural Gas by Base (Upper Half)

The final results of the Monte Carlo simulation are shown in Table 36 and Table 37. Table 36 summarizes the first half of the 62 major Air Force installations assessed. Mainland Florida, Gulf Coast, and eastern-seaboard coastal bases fared the worst in the Monte Carlo simulation. These bases experience high total EAC and high overall ranks. The top seven bases generally gain their top-ranked positions by having a combination of high probability for hurricane and electricity costs. Many Gulf Coast bases also fared poorly in the rankings due to high hurricane potential and increased tornado potential for the States of Louisiana, Mississippi, and Alabama. Joint Base San Antonio is an unexpected top-five candidate on the list. This ranking is largely due to Joint Base San Antonio having the second highest PRV of all installations included in the analysis. Joint Base San Antonio also had both tornado and hurricane costs along with high consumption of electricity and natural gas. Other bases in the top 15 that rank high on the list due to their large PRV, tornado, electricity, and natural gas costs are Tinker AFB, OK; Wright-Patterson AFB, OH; Robins AFB, GA; Arnold AFB, TN; and

Joint-Base McGuire-Dix-Lakehurst, NJ. To sum up, the COBRA Model calculates and reports the net present value (NPV) of all associated costs or savings generated from closure and realignment scenarios over a 20-year planning period. Consequently, the EAC costs in Table 36 and Table 37, become savings in a closure scenario, and are entered into the COBRA model and converted to NPV for a 20-year period (DOD, 2005d).

Table 36: EAC of Tornado, Hurricane, Electricity, & Natural Gas by Base (Upper Half)

Equivalent Annual Cost (EAC) of Tornado, Hurricane, & Energy Factors by Base - 62 Major CONUS Air Force Bases - Ranked by Total EAC

For BRAC - Enter Total EAC into COBRA Model to Account for Annual Tornado, Hurricane, & Energy Costs

Installation Data		Tornadoes			Hurricanes			Electricity			Natural Gas			Total EAC ($)	Total EAC Rank
Name	PRV ($M)	Median EAC ($)	% of Total	EAC Rank	Median EAC ($)	% of Total	EAC Rank	Mean EAC ($)	% of Total	EAC Rank	Mean EAC ($)	% of Total	EAC Rank		
Eglin AFB	$ 4,726.7	$788,112	0.8%	11	$74,051,189	74.0%	1	$22,561,526	22.6%	3	$2,614,765	2.6%	10	**$100,015,593**	**1**
Joint Base San Antonio	$ 7,629.1	$1,272,048	1.5%	4	$28,630,009	33.2%	4	$47,283,106	54.8%	1	$9,071,602	10.5%	1	**$86,256,764**	**2**
MacDill AFB	$ 1,837.4	$389,723	0.8%	25	$36,033,213	72.9%	2	$12,837,441	26.0%	10	$148,643	0.3%	59	**$49,409,021**	**3**
Keesler AFB	$ 1,831.4	$521,884	1.2%	20	$31,250,829	74.8%	3	$8,826,557	21.1%	13	$1,164,147	2.8%	30	**$41,763,417**	**4**
Joint Base Charleston	$ 3,098.1	$516,566	1.3%	21	$23,311,753	60.1%	5	$13,844,260	35.7%	9	$1,140,477	2.9%	32	**$38,813,056**	**5**
Joint Base Langley-Eustis	$ 3,625.4	$914,997	2.8%	8	$13,605,174	41.3%	10	$14,890,019	45.2%	8	$3,556,450	10.8%	5	**$32,966,640**	**6**
Hurlburt Field	$ 1,482.3	$314,405	1.0%	28	$23,222,561	71.0%	6	$8,150,290	24.9%	15	$1,002,489	3.1%	37	**$32,689,745**	**7**
Tinker AFB	$ 4,153.5	$3,156,226	10.6%	2	$0	0.0%	18	$19,649,799	65.7%	5	$7,090,833	23.7%	2	**$29,896,858**	**8**
Wright-Patterson AFB	$ 5,968.0	$1,506,235	5.3%	3	$0	0.0%	18	$24,281,571	85.3%	2	$2,672,846	9.4%	9	**$28,460,652**	**9**
Tyndall AFB	$ 1,556.3	$188,878	0.7%	33	$20,265,308	73.3%	7	$6,828,991	24.7%	19	$357,164	1.3%	52	**$27,640,341**	**10**
Robins AFB	$ 3,679.2	$780,380	3.1%	12	$0	0.0%	18	$21,342,615	84.7%	4	$3,080,446	12.2%	6	**$25,203,441**	**11**
Arnold AS	$ 7,802.1	$3,733,003	15.2%	1	$0	0.0%	18	$17,737,166	72.3%	6	$3,072,330	12.5%	7	**$24,542,500**	**12**
JB McGuire-Dix-Lakehurst	$ 7,289.3	$884,655	3.7%	10	$0	0.0%	18	$16,465,773	68.1%	7	$6,837,761	28.3%	3	**$24,188,190**	**13**
Patrick AFB	$ 1,063.7	$129,094	0.6%	38	$18,150,872	78.2%	8	$4,677,311	20.2%	37	$254,181	1.1%	55	**$23,211,458**	**14**
Cape Canaveral AFS	$ 1,516.1	$105,154	0.5%	41	$17,680,095	77.3%	9	$4,726,522	20.7%	36	$373,791	1.6%	51	**$22,885,562**	**15**
Hill AFB	$ 4,165.1	$0	0.0%	46	$0	0.0%	18	$12,383,455	74.5%	11	$4,229,714	25.5%	4	**$16,613,169**	**16**
Maxwell AFB	$ 1,297.2	$639,488	4.0%	16	$4,868,051	30.7%	14	$7,891,154	49.8%	16	$2,453,533	15.5%	11	**$15,852,226**	**17**
Hanscom AFB	$ 1,782.8	$0	0.0%	46	$6,690,380	45.9%	12	$5,516,675	37.8%	26	$2,372,743	16.3%	14	**$14,579,799**	**18**
Edwards AFB	$ 5,719.8	$0	0.0%	46	$0	0.0%	18	$11,543,338	82.5%	12	$2,448,834	17.5%	12	**$13,992,172**	**19**
Seymour Johnson AFB	$ 1,321.7	$721,566	5.2%	14	$8,137,709	59.1%	11	$3,921,213	28.5%	43	$994,967	7.2%	39	**$13,775,456**	**20**
Shaw AFB	$ 1,223.1	$440,678	3.6%	24	$5,974,263	48.3%	13	$5,255,067	42.5%	28	$702,566	5.7%	45	**$12,372,574**	**21**
Joint Base Andrews	$ 2,589.9	$738,030	7.0%	13	$0	0.0%	18	$7,850,813	74.6%	17	$1,934,174	18.4%	15	**$10,523,017**	**22**
Kirtland AFB	$ 2,981.0	$0	0.0%	46	$0	0.0%	18	$8,218,817	84.7%	14	$1,489,306	15.3%	23	**$9,708,123**	**23**
Vandenberg AFB	$ 3,920.7	$0	0.0%	46	$0	0.0%	18	$7,202,492	84.6%	18	$1,312,610	15.4%	27	**$8,515,103**	**24**
Dover AFB	$ 1,782.1	$216,282	2.6%	30	$0	0.0%	18	$5,782,955	68.8%	23	$2,408,745	28.6%	13	**$8,407,983**	**25**
Sheppard AFB	$ 2,102.6	$0	0.0%	46	$0	0.0%	18	$6,692,735	80.5%	20	$1,626,287	19.5%	20	**$8,319,022**	**26**
Offutt AFB	$ 1,822.3	$898,350	11.5%	9	$0	0.0%	18	$5,227,427	66.9%	29	$1,689,210	21.6%	18	**$7,814,987**	**27**
Scott AFB	$ 1,911.5	$1,163,571	15.0%	5	$0	0.0%	18	$4,878,481	62.7%	35	$1,739,454	22.4%	16	**$7,781,506**	**28**
US Air Force Academy	$ 2,873.3	$348,714	4.5%	26	$0	0.0%	18	$4,486,818	58.5%	38	$2,837,518	37.0%	8	**$7,673,051**	**29**
Davis-Monthan AFB	$ 2,053.8	$142,447	1.9%	37	$0	0.0%	18	$6,168,133	83.8%	21	$1,053,907	14.3%	34	**$7,364,488**	**30**
Moody AFB	$ 916.1	$111,181	1.5%	40	$3,437,883	47.1%	15	$3,519,994	48.2%	45	$235,159	3.2%	56	**$7,304,216**	**31**

4.6.2 – EAC of Tornado, Hurricane, Electricity, & Natural Gas by Base (Lower Half)

Table 37 summarizes the second half of the 62 major Air Force installations assessed. As shown in the bottom portion of the table, the central mountains, desert southwest, Washington State, and low tornado prone areas of the Midwest generally fared the best, with the lowest overall EAC. Specifically, large bases located in Texas, Wyoming, Colorado, California, South Dakota, Washington, and Idaho proved less costly, in terms of total EAC. Bases having zero hurricane occurrences within the past 163 years and no measurable hurricane threat ultimately help their ranking, yielding a lower overall EAC. Major installations (with more than one billion in PRV) with relatively low EAC are Dyess AFB, TX; F.E. Warren AFB, WY; Buckley AFB, CO; Beale AFB, CA; Ellsworth AFB, SD; Fairchild AFB, WA; and Mountain Home AFB, ID.

Table 37: EAC of Tornado, Hurricane, Electricity, & Natural Gas by Base (Lower Half)

Equivalent Annual Cost (EAC) of Tornado, Hurricane, & Energy Factors by Base - 62 Major CONUS Air Force Bases - Ranked by Total EAC

For BRAC - Enter Total EAC into COBRA Model to Account for Annual Tornado, Hurricane, & Energy Costs

Installation Data		Tornadoes			Hurricanes			Electricity			Natural Gas			Total EAC ($)	Total EAC Rank
Name	PRV ($M)	Median EAC ($)	% of Total	EAC Rank	Median EAC ($)	% of Total	EAC Rank	Mean EAC ($)	% of Total	EAC Rank	Mean EAC ($)	% of Total	EAC Rank		
Barksdale AFB	$ 1,569.2	$1,062,657	15.1%	7	$0	0.0%	18	$4,878,659	69.1%	34	$1,115,174	15.8%	33	**$7,056,490**	**32**
Nellis AFB	$ 3,185.9	$0	0.0%	46	$0	0.0%	18	$6,005,913	86.3%	22	$949,767	13.7%	40	**$6,955,680**	**33**
Peterson AFB	$ 1,217.2	$202,951	3.0%	31	$0	0.0%	18	$5,076,489	74.7%	32	$1,516,381	22.3%	22	**$6,795,822**	**34**
Holloman AFB	$ 2,795.5	$0	0.0%	46	$0	0.0%	18	$5,179,439	76.9%	31	$1,559,323	23.1%	21	**$6,738,762**	**35**
Malmstrom AFB	$ 1,752.0	$0	0.0%	46	$0	0.0%	18	$5,180,689	77.7%	30	$1,489,029	22.3%	24	**$6,669,718**	**36**
Schriever AFB	$ 741.6	$157,298	2.4%	36	$0	0.0%	18	$5,641,101	86.4%	24	$727,853	11.2%	43	**$6,526,252**	**37**
Minot AFB	$ 2,520.6	$174,824	2.7%	35	$0	0.0%	18	$5,287,773	81.6%	27	$1,017,207	15.7%	36	**$6,479,804**	**38**
Cannon AFB	$ 1,462.0	$177,434	2.8%	34	$0	0.0%	18	$5,002,534	77.8%	33	$1,248,002	19.4%	28	**$6,427,970**	**39**
Travis AFB	$ 3,684.2	$0	0.0%	46	$0	0.0%	18	$5,577,970	88.5%	25	$727,278	11.5%	44	**$6,305,247**	**40**
Little Rock AFB	$ 1,457.7	$1,107,700	17.9%	6	$0	0.0%	18	$4,040,774	65.2%	41	$1,051,888	17.0%	35	**$6,200,362**	**41**
Whiteman AFB	$ 2,245.0	$720,384	11.8%	15	$0	0.0%	18	$4,023,298	65.8%	42	$1,371,133	22.4%	25	**$6,114,815**	**42**
McConnell AFB	$ 1,238.8	$557,193	10.4%	17	$0	0.0%	18	$4,154,169	77.2%	40	$670,814	12.5%	46	**$5,382,176**	**43**
Luke AFB	$ 1,336.9	$0	0.0%	46	$0	0.0%	18	$4,466,495	89.0%	39	$554,207	11.0%	47	**$5,020,702**	**44**
Altus AFB	$ 1,169.2	$194,948	4.3%	32	$0	0.0%	18	$2,636,529	57.7%	51	$1,736,958	38.0%	17	**$4,568,435**	**45**
Grand Forks AFB	$ 1,515.7	$546,101	12.1%	18	$0	0.0%	18	$2,959,114	65.7%	48	$999,219	22.2%	38	**$4,504,434**	**46**
Dyess AFB	$ 1,584.8	$508,536	11.9%	22	$0	0.0%	18	$3,036,050	71.0%	47	$729,978	17.1%	42	**$4,274,564**	**47**
F. E. Warren AFB	$ 1,164.7	$80,781	1.9%	42	$0	0.0%	18	$2,935,941	69.2%	49	$1,228,115	28.9%	29	**$4,244,838**	**48**
Buckley AFB	$ 1,139.8	$476,728	11.4%	23	$0	0.0%	18	$2,867,769	68.7%	50	$828,946	19.9%	41	**$4,173,442**	**49**
Beale AFB	$ 2,038.1	$0	0.0%	46	$0	0.0%	18	$3,553,813	87.2%	44	$523,856	12.8%	48	**$4,077,669**	**50**
Ellsworth AFB	$ 2,065.8	$250,713	6.7%	29	$0	0.0%	18	$2,352,045	62.7%	54	$1,149,868	30.6%	31	**$3,752,626**	**51**
Fairchild AFB	$ 1,852.9	$0	0.0%	46	$0	0.0%	18	$2,056,127	55.4%	59	$1,656,526	44.6%	19	**$3,712,653**	**52**
Mountain Home AFB	$ 1,909.2	$0	0.0%	46	$0	0.0%	18	$2,294,221	63.5%	55	$1,317,805	36.5%	26	**$3,612,026**	**53**
Goodfellow AFB	$ 607.7	$42,149	1.2%	43	$0	0.0%	18	$3,079,588	88.9%	46	$343,175	9.9%	53	**$3,464,912**	**54**
Columbus AFB	$ 736.1	$538,718	15.6%	19	$0	0.0%	18	$2,523,984	73.1%	52	$390,188	11.3%	49	**$3,452,891**	**55**
Los Angeles AFB	$ 317.8	$0	0.0%	46	$0	0.0%	18	$2,408,650	93.4%	53	$170,213	6.6%	58	**$2,578,863**	**56**
Cavalier AS	$ 153.2	$25,544	1.0%	44	$0	0.0%	18	$2,251,682	87.4%	56	$298,366	11.6%	54	**$2,575,592**	**57**
Laughlin AFB	$ 741.1	$123,568	5.1%	39	$0	0.0%	18	$2,117,506	87.6%	58	$176,658	7.3%	57	**$2,417,733**	**58**
Creech AFB	$ 574.9	$0	0.0%	46	$0	0.0%	18	$2,162,999	100.0%	57	N/A	N/A	N/A	**$2,162,999**	**59**
Vance AFB	$ 624.8	$335,067	18.7%	27	$0	0.0%	18	$1,074,630	60.0%	61	$380,795	21.3%	50	**$1,790,493**	**60**
Cape Cod AS	$ 53.8	$0	0.0%	46	$262,787	19.1%	17	$1,115,165	80.9%	60	N/A	N/A	N/A	**$1,377,953**	**61**
New Boston AS	$ 70.6	$11,772	1.5%	45	$264,943	32.7%	16	$534,599	65.9%	62	N/A	N/A	N/A	**$811,313**	**62**

Chapter 5 – Discussion, Conclusion, and Recommendations

This chapter summarizes the findings detailed in Chapter 4. It discusses the expected outcome of the analysis, provides a short summary and discussion of the associated findings and their practical significance and a review of the research and investigative questions, as well as addresses the limitations of the source data and research. Finally, the chapter concludes with suggested areas of further research, final recommendations, and conclusion.

5.1 – Expected Outcome

The expected outcome for this project is to introduce and provide innovative new ideas and methods to help Air Force and DOD decision-makers establish a more detailed cost analysis for factors not previously considered in BRAC. This more in-depth analysis is accomplished by evaluating aspects of severe weather, climate zone, energy use, and utility rates. The analysis is intended to evaluate and clarify risks and associated future costs of retaining major Air Force installations that have been historically affected or possess a potential to be affected by severe weather patterns, extreme temperatures, excessive energy usage, or high energy rates.

The results of the research yield a final ranked-list of the costliest major CONUS Air Force installations with regards to forecasted annual tornado and hurricane costs, and electricity and natural gas costs. The end result is a *1-to-n* list, of all 62 major CONUS Air Force installations, where the highest EAC equals the best candidate, according to the new proposed BRAC criteria, to be eligible for a future BRAC round. All or part of this methodology could be applied to future BRAC analysis or other basing decisions.

5.2 – Discussion

The top ranked candidates in Table 36 are the most costly installations to operate and maintain, in terms of forecasted tornado and hurricane risks, and ongoing electricity and natural gas costs. These top-ranked installations are the best candidates, according to the new criteria, to be eligible for closure or realignment in BRAC. To assist comprehension of the results, the median tornado and hurricane EAC values are best understood as insurance premiums. Since the DOD essentially self-insures for catastrophic events such as tornadoes and hurricanes, the EAC values are actuarial estimates and should be thought of as insurance premiums, and ought to remain a budgeted cost if a base stays open. In contrast, if a base is selected for closure, these "insurance premiums" become avoided costs and ultimately become savings in the COBRA model.

Additionally, it is important to understand when the EAC values represent costs or savings. If a decision is made not to close or realign the bases listed, the four categories of EAC (tornado, hurricane, electricity, and natural gas) remain costs to a base. Yet, these costs ultimately become savings in the COBRA model if a base is selected for closure. The savings generated in a BRAC by these four factors help to offset the costs associated with BRAC, such as personnel relocation or environmental remediation. If the realignment option is selected for an entire base, then the difference in total EAC from the old base to the new base should be applied to the COBRA model. This cost adjustment is necessary because there still might be forecasted tornado and hurricane costs, along with electricity and natural gas costs at the new installation. However, if the process works as intended, those costs should be lower at the new base and yield an overall savings in the end.

Analysis of weather and energy can be very complex with many possible variables. Slight modifications to severe weather definitions and radius of impact can drastically change the outcome of the analysis. The results would differ greatly if a 50 nautical-mile radius is used to determine hurricane occurrences. Moreover, California bases ranked numerically low on the list are considered more retainable, due to a low hurricane and tornado threat, a very mild climate, and low natural gas rates. However, California bases could easily rise up the rankings if costs are forecasted for earthquake potential, an even rarer event than tornadoes and hurricanes. Likewise, the high cost and variability of electricity in California could easily increase total EAC and push the state's bases higher up the list.

Furthermore, if the effects of climate zone are removed from the total energy usage, the mission related energy-usage can be quantified. If the overall percentage of mission related energy is high, and the purpose of that function is easily transferable, the mission could be a candidate for relocation to an area where utility rates are cheaper. The bed-down or realignment of a major computer server-bank is one example of mission related energy. If the Air Force considered consolidating its numerous computer server-banks to a few larger locations, it would benefit the service monetarily to locate these server-banks in an area with low severe-weather potential, a cool and mild climate, and low electric rates. Because the mission-related hardware itself consumes the same quantity of energy, no matter where it is located, the cost-benefit of this basing decision could yield major cost savings to the DOD and the Air Force in the long run. Otherwise, if a mission is so restricted that it must reside in a geographic region or specific physical location, such as an early warning radar system overlooking the polar region, then other local sources of cheaper energy should be explored or energy rate contracts renegotiated.

It is also important to note, energy usage driven by climate is out of our control, yet energy usage driven by mission or processes is within our control. Since a base cannot control the climate or weather, the only practical way to achieve a reduction in energy use due to climate zone is through a base closure and mission realignment to a milder climate using the BRAC process. Otherwise, if a base's physical location or mission cannot be changed through a BRAC action, improvements to HVAC systems or building envelopes are practical ways to decrease a base's energy use (Griffin, 2008; Li, Yang, & Lam, 2012; Teke, 2014).

Finally, major installations (with more than one billion in PRV) listed in Table 37 with relatively low EAC are Dyess AFB, TX; F.E. Warren AFB, WY; Buckley AFB, CO; Beale AFB, CA; Ellsworth AFB, SD; Fairchild AFB, WA; and Mountain Home AFB, ID. These bases are considered ideal candidates, according to the new proposed criteria, to gain new missions in a realignment scenario. Realignment to these specific bases assumes that they have the capacity and characteristics, such as a runway or ramp space, to support new missions.

5.3 – Review of Research & Investigative Questions

Two primary research and four investigative questions are identified in Chapter 1. The detailed analysis in the preceding chapters should address each primary research and investigative question, but the following section provides a summary response for each.

Primary Research Questions:

1. *What impact does severe weather, climate zone, energy use, and utility rates have on the cost to maintain base infrastructure?*

   The four main factors in Research Question 1 have a large impact on the cost to operate and maintain base infrastructure; however, each factor has varying degree of influence at each base. The impact of these factors is quantified in the rank-matrices and EAC Tables in Chapter 4.

2. *Which factors in Research Question 1 are the most appropriate and applicable to be used in future BRAC and basing decisions?*

   All the factors identified in Research Question 1 are relevant, but to varying degrees. Severe weather and energy factors each have considerable cost implications and should all be considered in future BRAC and basing decisions. Hurricane, electricity, and natural gas costs are probably the most important and applicable. Tornado costs estimated in this research are probably the least beneficial and accurate, because the chance of a tornado touching down within the base perimeter is so rare. Although hurricanes are a much rarer event, they are more likely to cause large-scale future damage at Air Force Bases than tornadoes.

<u>Investigative Questions:</u>

1. *Which severe weather factor is more influential on cost in a BRAC decision – tornadoes or hurricanes?*

   In this analysis, hurricanes are exceedingly more damaging than tornadoes and have the greatest monetary impact to Air Force installations. For these two severe weather factors, the total EAC is generally much greater for hurricanes than tornadoes. Tornado EACs do not amount to a large percentage of total EAC at each base, unless an installation has a high number of tornadoes and no hurricane occurrences, such as Tinker AFB. For all 62 bases considered, equivalent annual hurricane costs amounted to 35.1% of total EAC, while equivalent annual tornado costs accounted only for 3.1% of total EAC (see complete "Equivalent Annual Cost (EAC) of Tornado, Hurricane, & Energy Factors by Base" matrix in Appendix I). Therefore, according to the factors analyzed in this research, hurricane damage influences BRAC COBRA-model costs/savings 11.3 times more than tornado damage costs. Thus, this research concludes that predicted hurricane costs are far more influential than predicted tornado costs.

2. *Is frequency of severe weather occurrence or magnitude of severe weather occurrence more costly to base infrastructure?*

   The results show that magnitude is more costly than frequency. The large swath-width and magnitude of a hurricane causes much more damage than a similar intensity tornado. Although tornadoes generally had a much shorter return period than hurricanes, tornadoes cause less damage and each unique tornado event is generally less costly than a hurricane event. Additionally, even though hurricanes have a much longer average return-period than tornadoes, the magnitude of damage caused by hurricanes is much greater. Table 36 and Table 37 highlight these facts and reveal that hurricane EACs are much greater than tornado EACs.

3. *For each installation, what is the average return period for tornadoes and hurricanes and how large of an impact does each event type have on cost?*

   In Chapter 4, Table 20 and Table 22 show the average return periods at each base for tornadoes and hurricanes, respectively. In addition, Table 36 and Table 37 reveal the degree of financial impact that these severe weather events have on each installation. This financial impact is standardized to an equivalent annual cost (EAC) to enable equal and easy cost comparison across all bases.

4. *Which energy factor is more influential on cost in a BRAC decision – electricity or natural gas?*

Electricity is more influential on cost. For all 62 bases considered, equivalent annual electricity costs totaled 50.9% of total EAC, while equivalent annual natural gas costs accounted only for 10.9% of total EAC (see complete "Equivalent Annual Cost (EAC) of Tornado, Hurricane, & Energy Factors by Base" matrix in Appendix I). Therefore, according to the factors analyzed in this research, electricity influences BRAC COBRA-model costs/savings 4.67 times more than natural gas costs. Thus, electricity is far more influential on the cost to operate an Air Force base than natural gas.

5.4 – Limitations

One major limitation of this study is the effect of climate change. The analysis methods employed in this research assume that an installation's climate zone will not change over time. However, it is safe to assume only that the climate zone assigned to each installation represents the climatic conditions which existed at the time of the analysis (years 2014 to 2015). Follow-on climate analyses should be performed if major climatic conditions change in the years that follow this research. Based on the new proposed BRAC criteria for weather and climate conditions, major future climate changes may affect whether a specific installation is more or less favorable to retain under BRAC and should be re-analyzed at that time.

Another limitation is the interrelatedness of some of the bases. Some installations cannot close through BRAC without considering what unit or base they are assigned. For example, the 21st Space Wing at Peterson Air Force Base owns and controls the three major Geographically Separated Units (GSUs) identified in this research. These GSUs include Cavalier, Cape Cod, and New Boston Air Stations. The GSUs should be considered interdependent when making a BRAC recommendation. For instance, the Air Force can choose to close Cavalier Air Station under BRAC without closing its parent installation, Peterson Air Force Base. This scenario assumes the mission of the 21st Space Wing can continue without Cavalier or that the Air Force realigns Cavalier's mission elsewhere. Consequently, even if the high cost of severe weather or energy factors identified in this research favor the closure of only one of the interdependent installations, this scenario may not be feasible. The Air Force could not solely close Peterson AFB under BRAC without also closing or realigning the missions at its three major CONUS GSUs – Cavalier, Cape Cod, and New Boston Air Stations.

Other limitations in this research surround the raw source data. First, tornado and hurricane probabilities distributions used in the Monte Carlo simulation are based on averages for the entire continental United States. These probability distributions are not location specific. For example, Tinker AFB, OK should have a higher historical concentration of strong-violent tornadoes than Buckley AFB, CO. However, for simplicity sake, the CONUS averages are applied for all bases in the Monte Carlo simulations. Second, tornado reporting is highly variable by location and time, and in general, tornado data is less accurate and reliable than hurricane data. Lastly, estimating damage and associated costs for low-probability high-consequence events, such as tornadoes and hurricanes, is more difficult and less reliable than high-probability low-consequence events, such as winter storms.

The results of this research are still valid given the assumptions of the model, even with the limitations discussed. Future opportunities exist to refine the data and methods developed in this research, which could give way to more accurate damage and cost estimates. The following section addresses future research opportunities related to the topics presented in this research.

5.5 – Opportunities for Additional Research

Other factors to take into consideration for future BRAC decisions could be earthquake potential and flooding. Further research could also focus on the cost of temporary base closures from high-probability low-impact events such as severe winter weather, ice storms, and high winds that limit or ground flying operations. Each of these factors indirectly cost the base money to maintain and operate. Beyond the costs and savings associated with BRAC, additional research could be beneficial in how capacity analysis is done to justify whether a DOD agency is maintaining excess infrastructure. Congress requires solid justification of excess infrastructure to consider a BRAC, so better tools and techniques may exist to validate this position.

Separate from additional BRAC factors or cost analysis, another area for additional research is climate change and its effect on Air Force Bases or national security. If sea levels continue to rise at their current rate, many Air Force and DOD installations could be inundated by seawater (GAO, 2014). Quantifying the relocation costs due rises in sea levels, may also prove to be a valuable research stream.

5.6 – Recommendations

First, due to the severe-weather threats and risks established in this research, most importantly hurricanes, close consideration should be given to consolidate, realign, or close some Florida, Gulf Coast, or eastern-seaboard coastal bases in a future round of BRAC. Potential bases fitting this description include Eglin AFB, FL; MacDill AFB, FL; Keesler AFB, MS; Joint Base Charleston, SC; Hurlburt Field, FL; Tyndall AFB, FL; Patrick AFB, FL; and Cape Canaveral AFS, FL. Second, focusing solely on the cost to operate, careful consideration should also be given to consolidate, realign, or close bases with high annual electricity bills or high energy-intensity. Potential bases in this category include Joint Base San Antonio, TX; Wright-Patterson AFB, OH; Eglin AFB, FL; Robins AFB, GA; Tinker AFB, OK; and Arnold AS, TN. Finally, based solely on the new factors proposed in this research, bases best suited to be retained and receive realigned missions include Dyess AFB, TX; F.E. Warren AFB, WY; Buckley AFB, CO; Beale AFB, CA; Ellsworth AFB, SD; Fairchild AFB, WA; and Mountain Home AFB, ID.

5.7 – Conclusion

The Monte Carlo process applied in this analysis is flexible and scalable and can be used to analyze other factors beyond the four main ones presented in this research. These risk and cost assessment methods can also be applied beyond a BRAC analysis. First and foremost, new-mission beddown and basing decisions should analyze and account for the risk and cost of severe weather and energy. The Air Force's strategic basing process does use criteria analogous to the factors proposed in this research. Common strategic basing criteria include mission type, capacity of a base to support a new mission, environmental, and some cost factors (USAF, 2010; USAF, 2013; & USAF, 2014).

Examples of recent new-mission beddowns where these specific factors could have influenced final basing locations are the KC-46 aerial-refueling tanker and the F-35 Joint-Strike Fighter missions. Additionally, locating the Air Force Installation and Mission Support Center (AFIMSC) was another recent opportunity to influence a basing decision (USAF, 2014), by including in the analysis the risks and costs associated with severe weather and energy.

In the end, if Congressional approval for another round of BRAC proves too politically challenging to overcome, alternative methods and tools to manage or reduce excess infrastructure must be considered. Some alternative methods include the continued use of Public-Public Public-Private Partnerships (P4), the application of Enhanced Use Leases (EULs), and City Base Agreements. Additionally, other methods to reduce excess infrastructure comprise funding of demolition and consolidation projects. In recent years, the Air Force used a demolition and consolidation program, driven under the adage "*20/20 by 2020*," to reduce excess and unneeded infrastructure. The "*20/20 by 2020"* program used by Air Force Civil Engineers, seeks to offset a twenty-percent reduction in installation support funding by achieving a twenty-percent reduction in the Air Force's physical plant by the year 2020 (USAF, 2012). In the absence of BRAC, a combination of some or all of these alternative cost-reducing or cost-sharing programs must be explored. Otherwise, the DOD and Air Force will be forced to continue operating, maintaining, and repairing unneeded and excess infrastructure.

In conclusion, active duty Air Force members are often told to *do more with less* or *keep doing the same with less.* This concept must also apply to surplus bases and facilities. The Air Force must develop a solid case to strongly justify to Congress that excess installations or infrastructure must be cut along with excess personnel and aging aircraft fleets. The best and most effective way to reduce and consolidate excess bases are through another round of BRAC. Careful consideration of these additional severe weather and energy factors presented in this research should help better define the costs and savings in BRAC and lead to more objective and effective decision-making.

Appendix A – List of Major CONUS Air Force Bases Used for Analysis

62 Major CONUS Air Force Bases Top Half (Altus - Keesler)	
Installation Name	**State**
Altus AFB	OK
Arnold AS	TN
Barksdale AFB	LA
Beale AFB	CA
Buckley AFB	CO
Cannon AFB	NM
Cape Canaveral AFS	FL
Cape Cod AS	MA
Cavalier AS	ND
Columbus AFB	MS
Creech AFB	NV
Davis-Monthan AFB	AZ
Dover AFB	DE
Dyess AFB	TX
Edwards AFB	CA
Eglin AFB	FL
Ellsworth AFB	SD
F. E. Warren AFB	WY
Fairchild AFB	WA
Goodfellow AFB	TX
Grand Forks AFB	ND
Hanscom AFB	MA
Hill AFB	UT
Holloman AFB	NM
Hurlburt Field	FL
Joint Base Andrews	MD
Joint Base Charleston	SC
Joint Base Langley-Eustis (JBLE)	VA
Joint Base McGuire-Dix-Lakehurst (JBMDL)	NJ
Joint Base San Antonio (JBSA)	TX
Keesler AFB	MS

62 Major CONUS Air Force Bases Bottom Half (Kirtland - Wright-Patterson)	
Installation Name	**State**
Kirtland AFB	NM
Laughlin AFB	TX
Little Rock AFB	AR
Los Angeles AFB	CA
Luke AFB	AZ
MacDill AFB	FL
Malmstrom AFB	MT
Maxwell AFB	AL
McConnell AFB	KS
Minot AFB	ND
Moody AFB	GA
Mountain Home AFB	ID
Nellis AFB	NV
New Boston AS	NH
Offutt AFB	NE
Patrick AFB	FL
Peterson AFB	CO
Robins AFB	GA
Schriever AFB	CO
Scott AFB	IL
Seymour Johnson AFB	NC
Shaw AFB	SC
Sheppard AFB	TX
Tinker AFB	OK
Travis AFB	CA
Tyndall AFB	FL
US Air Force Academy	CO
Vance AFB	OK
Vandenberg AFB	CA
Whiteman AFB	MO
Wright-Patterson AFB	OH

Appendix B – List of Acronyms

ACC	Air Combat Command
AEDC	Arnold Engineering Development Complex
AEMR	Annual Energy Management Report
AETC	Air Education and Training Command
AFB	Air Force Base
AFCCC	Air Force Combat Climatology Center
AFCEC	Air Force Civil Engineer Center
AFERS	Air Force Energy Reporting System
AFIT	Air Force Institute of Technology
AFMC	Air Force Materiel Command
AFS	Air Force Station
AFSPC	Air Force Space Command
AFWA	Air Force Weather Agency
ALC	Air Logistics Centers
AMC	Air Mobility Command
ANG	Air National Guard
ARB	Air Reserve Base
AS	Air Station
BBTU	billion British Thermal Units (unit of energy usage)
BRAC	Base Realignment and Closure
BTU	British Thermal Units (unit of energy usage)
CATCODE	Category Code (Air Force real property)
CDD	Cooling Degree Days
COBRA	Cost of Base Realignment Actions
CONUS	Continental United States
DEIS	Defense Energy Information System
DI	Damage Indicators (tornado)
DoD	Degree of Damage (tornado)
DOD	Department of Defense
DOE	Department of Energy
DUERS	Defense Utility Energy Reporting System
DV	Dependent Variable
EAC	Equivalent Annual Cost
EF	Enhanced Fujita (tornado scale)
EIA	Energy Information Agency
ESRI	Environmental Systems Research Institute
EUL	Enhanced Use Lease
EWD	Engineering Weather Data
FEMA	Federal Emergency Management Agency
FPHLM	Florida Public Hurricane Loss Model
FY	Fiscal Year
GAO	Government Accountability Office
GEM	(Graduate) Engineering Management
GIS	Geographic Information System

GSU	Geographically Separated Unit
HAP	Homeowner Assistance Program
HASC	House Armed Services Committee
HDD	Heating Degree Days
HQ AFCESA	Headquarters Air Force Civil Engineer Support Agency
HQ AFPC	Headquarters Air Force Personnel Center
HVAC	Heating Ventilation and Air Conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IV	Independent Variable
JB	Joint Base
kWh	kilowatt-hours (unit of electricity usage)
MBTU	million British Thermal Units (unit of energy usage)
Mcf	thousand cubic feet (unit of natural gas usage)
NCAR	National Center for Atmospheric Research
NDAA	National Defense Authorization Act
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NPV	Net-Present Value
NREL	National Renewable Energy Laboratory
NWS	National Weather Service
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
P4	Public-Public Public-Private Partnerships
PRV	Plant Replacement Value
PRV	Plant Replacement Value
PSDM	Personnel Services Delivery Memorandum
PV	Present Value
RIF	Reduction in Force
SAF/IEI	Secretary of the Air Force (Installations)
SASC	Senate Armed Services Committee
SPC	Storm Prediction Center
SSHWS	Saffir-Simpson Hurricane Wind Scale (hurricane scale)
TERA	Temporary Early Retirement Authority
TVA	Tennessee Valley Authority
USAA	United States Automobile Association
USAF	United States Air Force
VSP	Voluntary Separation Pay
WS	Weather Squadron

Appendix C – Links to Base Closure and Realignment Reports

1989 Base Closure and Realignment Report:
http://www.defense.gov/brac/docs/1988.pdf

1991 Base Closure and Realignment Report:
http://www.defense.gov/brac/docs/1991dod.pdf

1993 Base Closure and Realignment Report:
http://www.defense.gov/brac/docs/1993dod.pdf

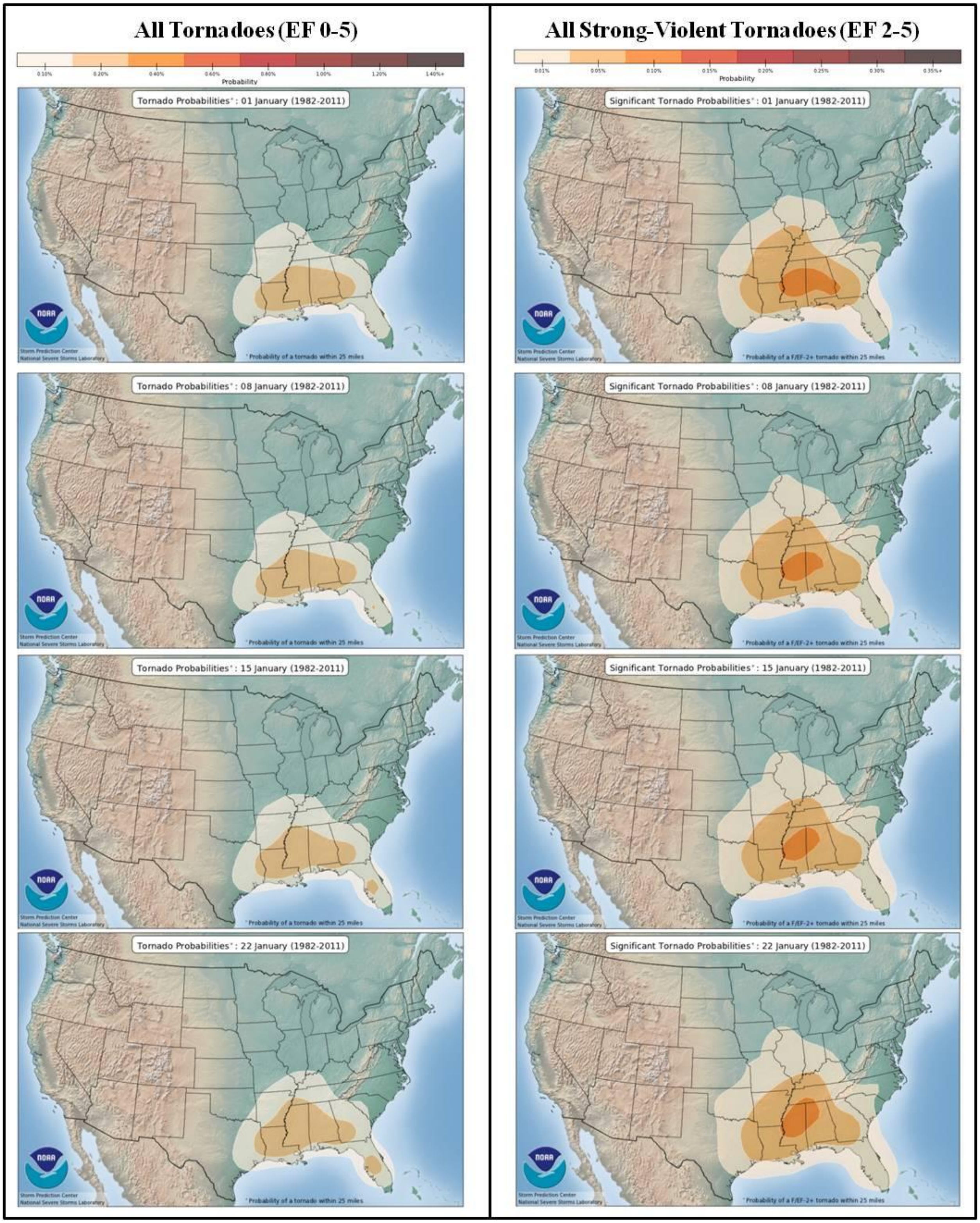
1995 Base Closure and Realignment Report:
http://www.defense.gov/brac/docs/1995dod.pdf

1998 Report of the Department of Defense on Base Realignment and Closure (*request and justification for a new BRAC round*):
http://www.defense.gov/brac/docs/98dodbrac.pdf

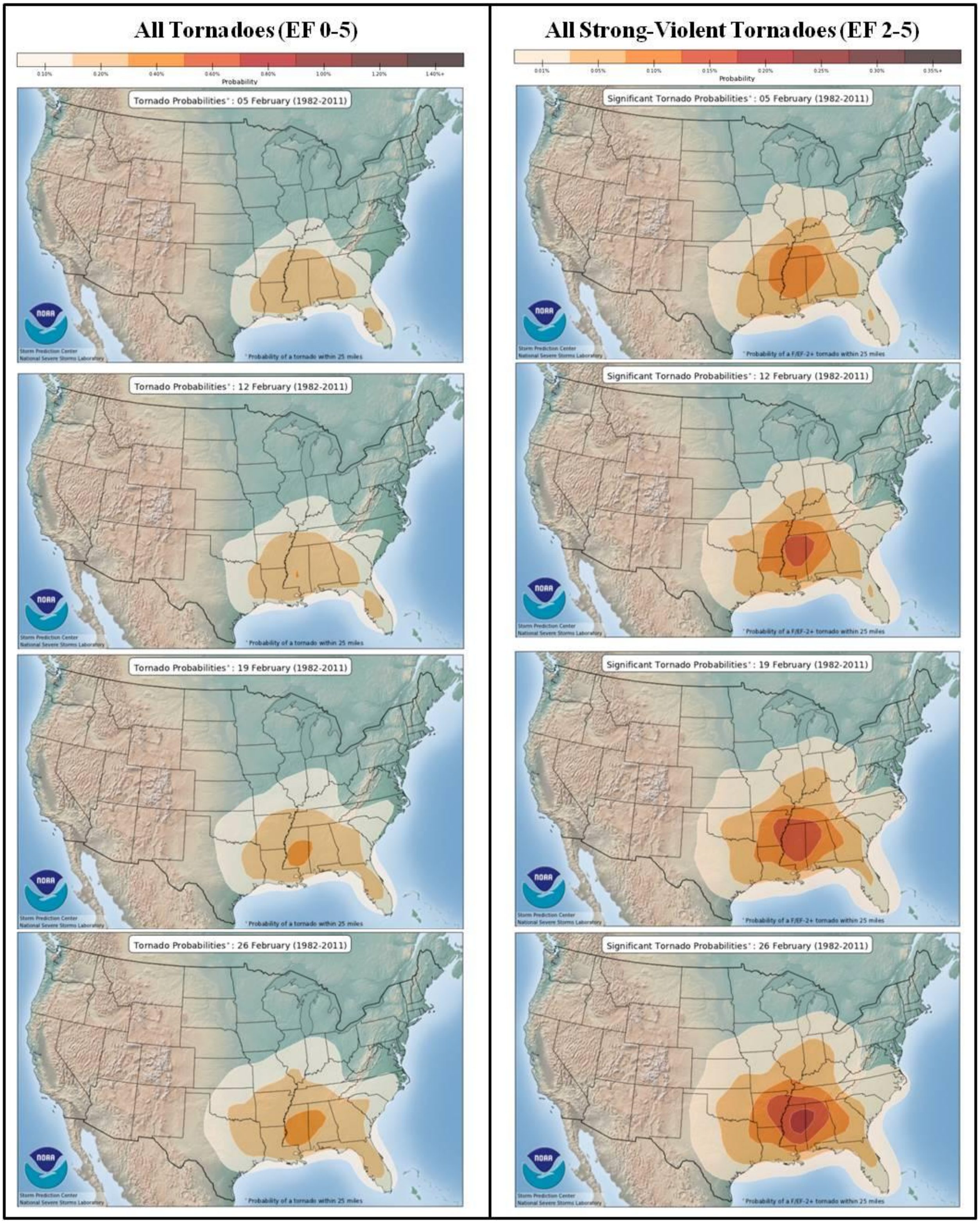
2005 Base Closure and Realignment Report(s):
http://www.defense.gov/brac/pdf/Vol_I_Part_1_DOD_BRAC.pdf
http://www.defense.gov/brac/pdf/Vol_I_Part_2_DOD_BRAC.pdf

Appendix D – Tornado Probability Maps by Month

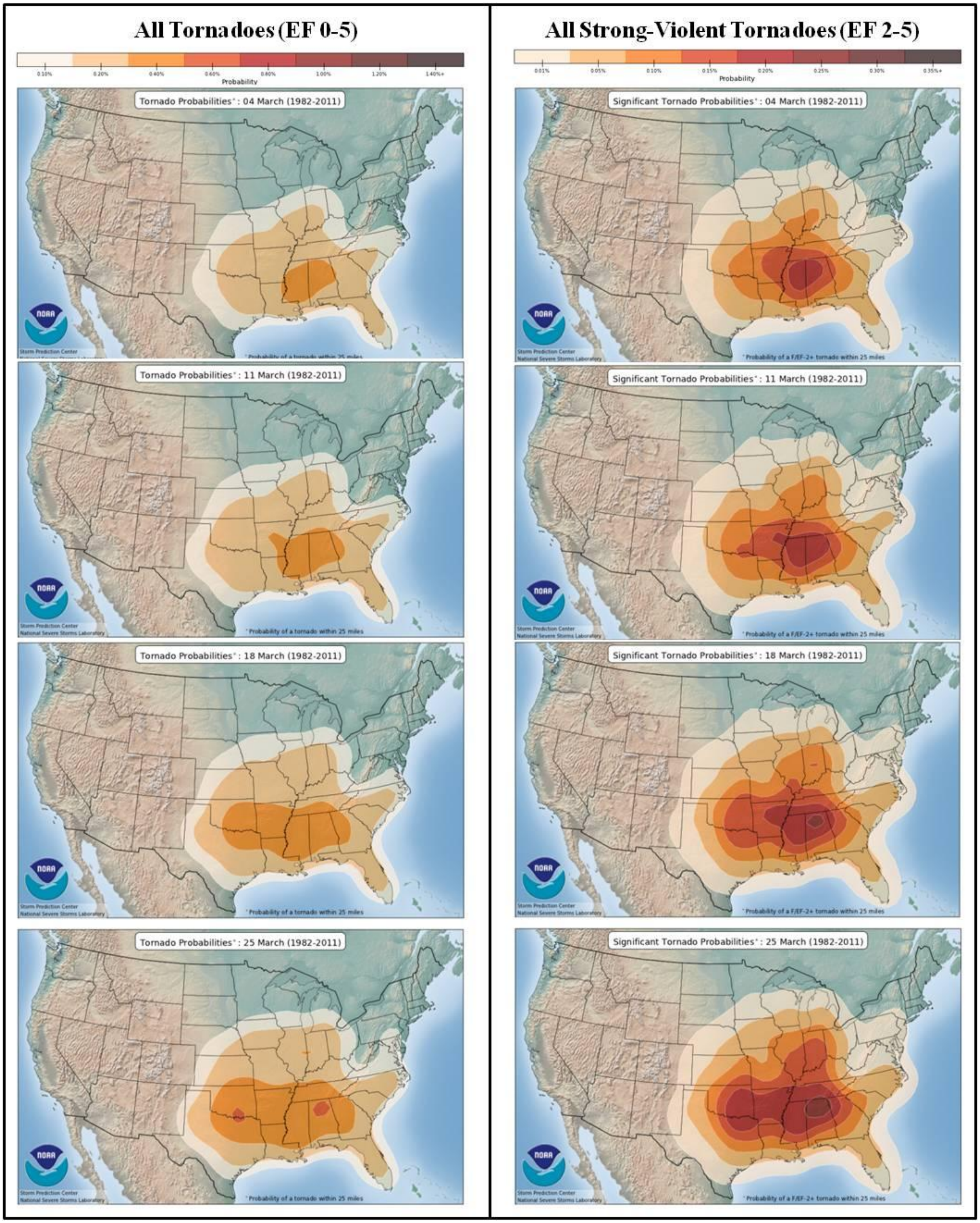
January



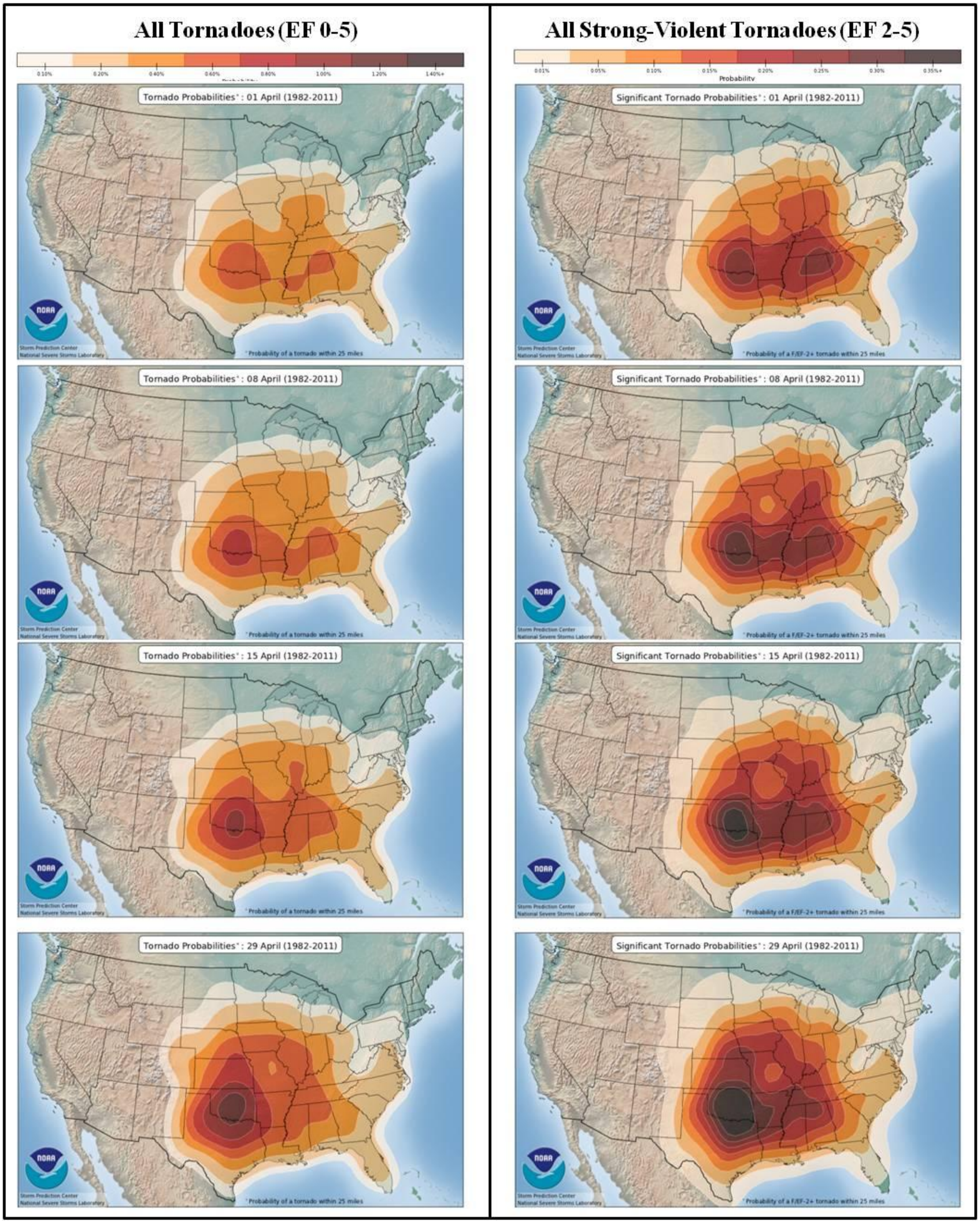
February


All Tornadoes (EF 0-5)
0.10% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40%+
Probability
Tornado Probabilities* : 05 February (1982-2011)
Tornado Probabilities* : 12 February (1982-2011)
Tornado Probabilities* : 19 February (1982-2011)
Tornado Probabilities* : 26 February (1982-2011)
* Probability of a tornado within 25 miles
All Strong-Violent Tornadoes (EF 2-5)
0.01% 0.05% 0.10% 0.15% 0.20% 0.25% 0.30% 0.35%+
Probability
Significant Tornado Probabilities* : 05 February (1982-2011)
Significant Tornado Probabilities* : 12 February (1982-2011)
Significant Tornado Probabilities* : 19 February (1982-2011)
Significant Tornado Probabilities* : 26 February (1982-2011)
* Probability of a F/EF-2+ tornado within 25 miles
Storm Prediction Center
National Severe Storms Laboratory

March

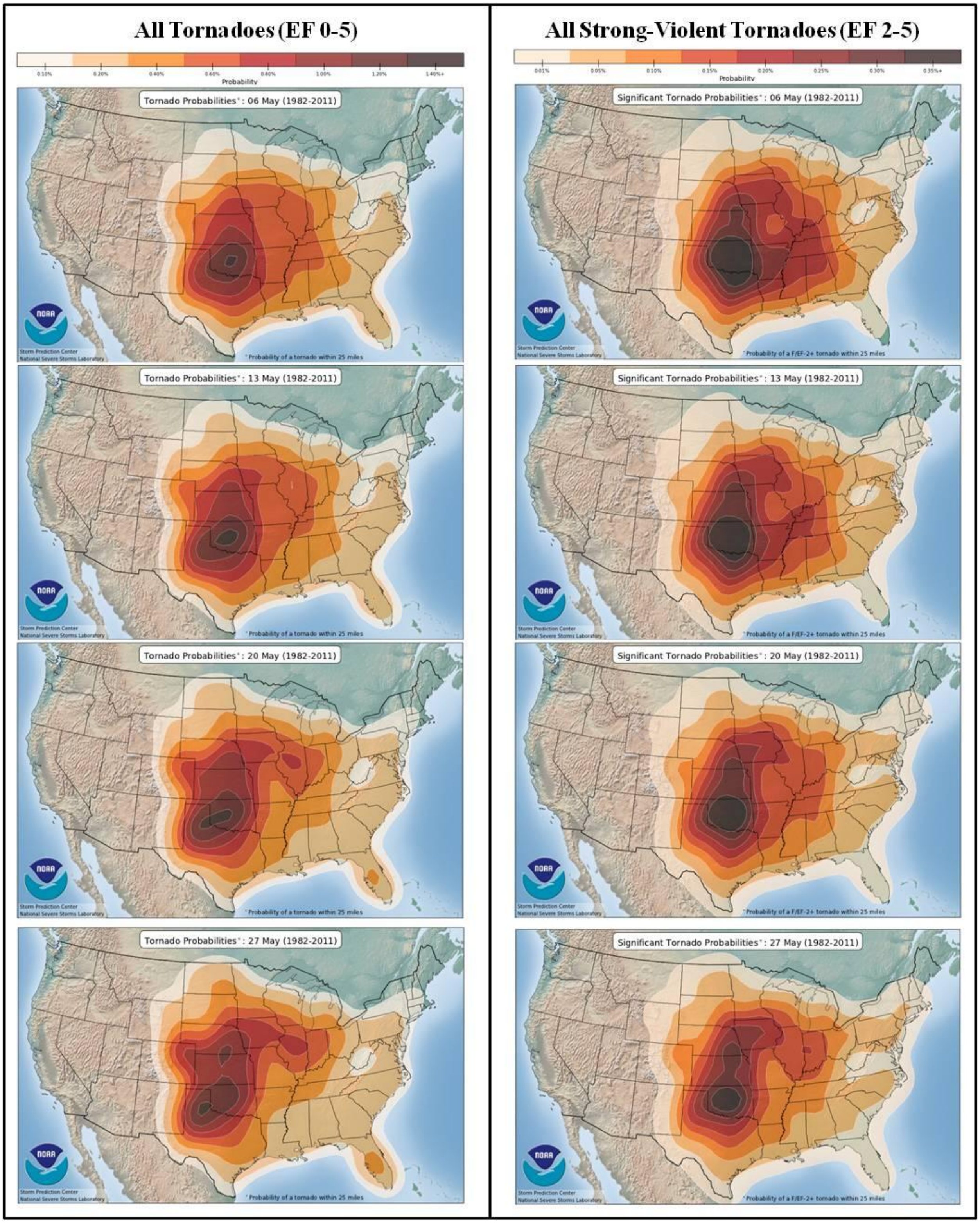

All Tornadoes (EF 0-5)
Probability
Tornado Probabilities*: 04 March (1982-2011)
Tornado Probabilities*: 11 March (1982-2011)
Tornado Probabilities*: 18 March (1982-2011)
Tornado Probabilities*: 25 March (1982-2011)
* Probability of a tornado within 25 miles
All Strong-Violent Tornadoes (EF 2-5)
Significant Tornado Probabilities*: 04 March (1982-2011)
Significant Tornado Probabilities*: 11 March (1982-2011)
Significant Tornado Probabilities*: 18 March (1982-2011)
Significant Tornado Probabilities*: 25 March (1982-2011)
* Probability of a F/EF-2+ tornado within 25 miles
NOAA
Storm Prediction Center
National Severe Storms Laboratory

April

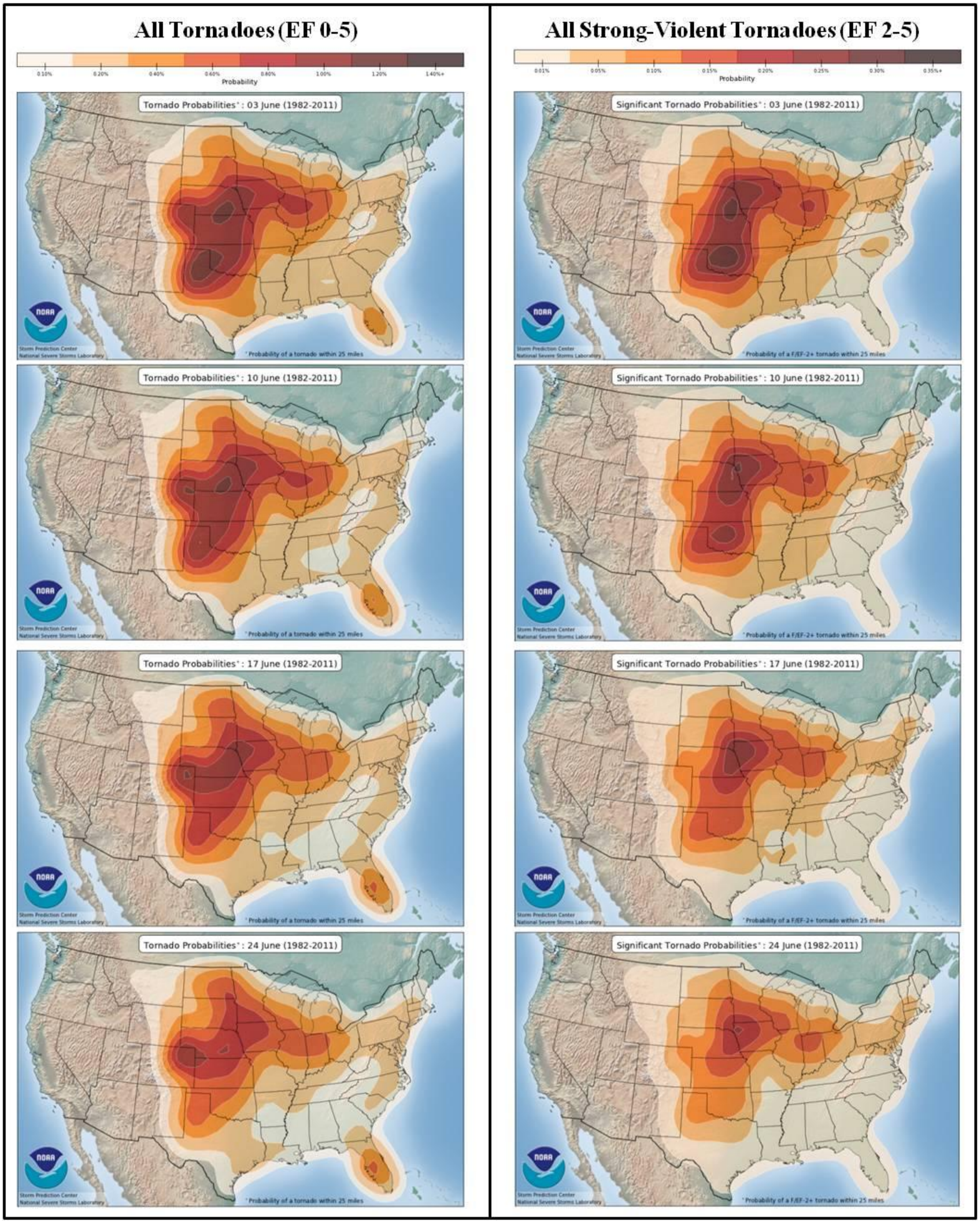


All Tornadoes (EF 0-5)
0.10% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40%+
Tornado Probabilities* : 01 April (1982-2011)
Tornado Probabilities* : 08 April (1982-2011)
Tornado Probabilities* : 15 April (1982-2011)
Tornado Probabilities* : 29 April (1982-2011)
* Probability of a tornado within 25 miles
All Strong-Violent Tornadoes (EF 2-5)
0.01% 0.05% 0.10% 0.15% 0.20% 0.25% 0.30% 0.35%+
Probability
Significant Tornado Probabilities* : 01 April (1982-2011)
Significant Tornado Probabilities* : 08 April (1982-2011)
Significant Tornado Probabilities* : 15 April (1982-2011)
Significant Tornado Probabilities* : 29 April (1982-2011)
* Probability of a F/EF-2+ tornado within 25 miles
NOAA
Storm Prediction Center
National Severe Storms Laboratory

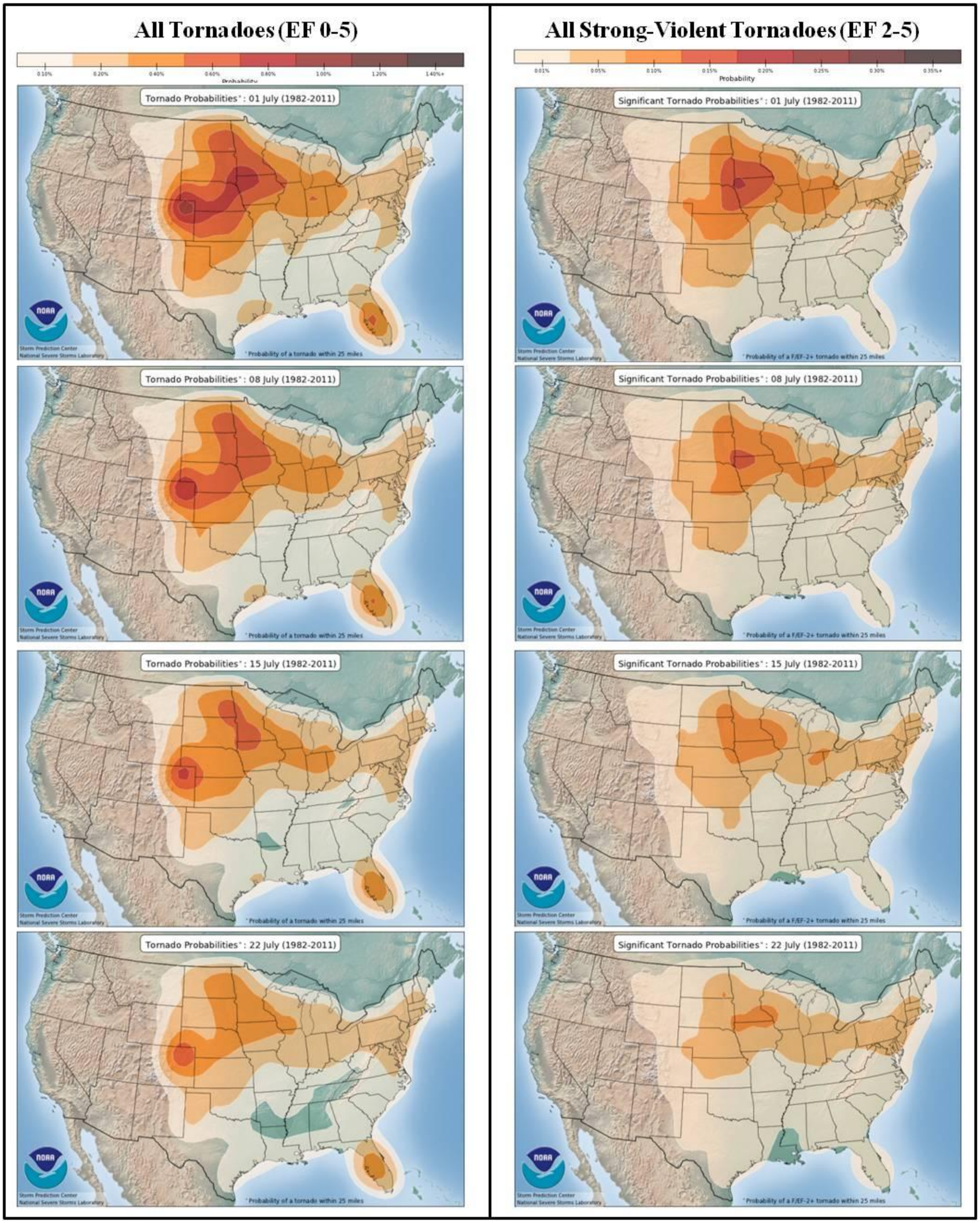
May


All Tornadoes (EF 0-5)
0.10% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40%+
Probability
Tornado Probabilities*: 06 May (1982-2011)
Tornado Probabilities*: 13 May (1982-2011)
Tornado Probabilities*: 20 May (1982-2011)
Tornado Probabilities*: 27 May (1982-2011)
* Probability of a tornado within 25 miles
NOAA
Storm Prediction Center
National Severe Storms Laboratory
All Strong-Violent Tornadoes (EF 2-5)
0.01% 0.05% 0.10% 0.15% 0.20% 0.25% 0.30% 0.35%+
Probability
Significant Tornado Probabilities*: 06 May (1982-2011)
Significant Tornado Probabilities*: 13 May (1982-2011)
Significant Tornado Probabilities*: 20 May (1982-2011)
Significant Tornado Probabilities*: 27 May (1982-2011)
* Probability of a F/EF-2+ tornado within 25 miles

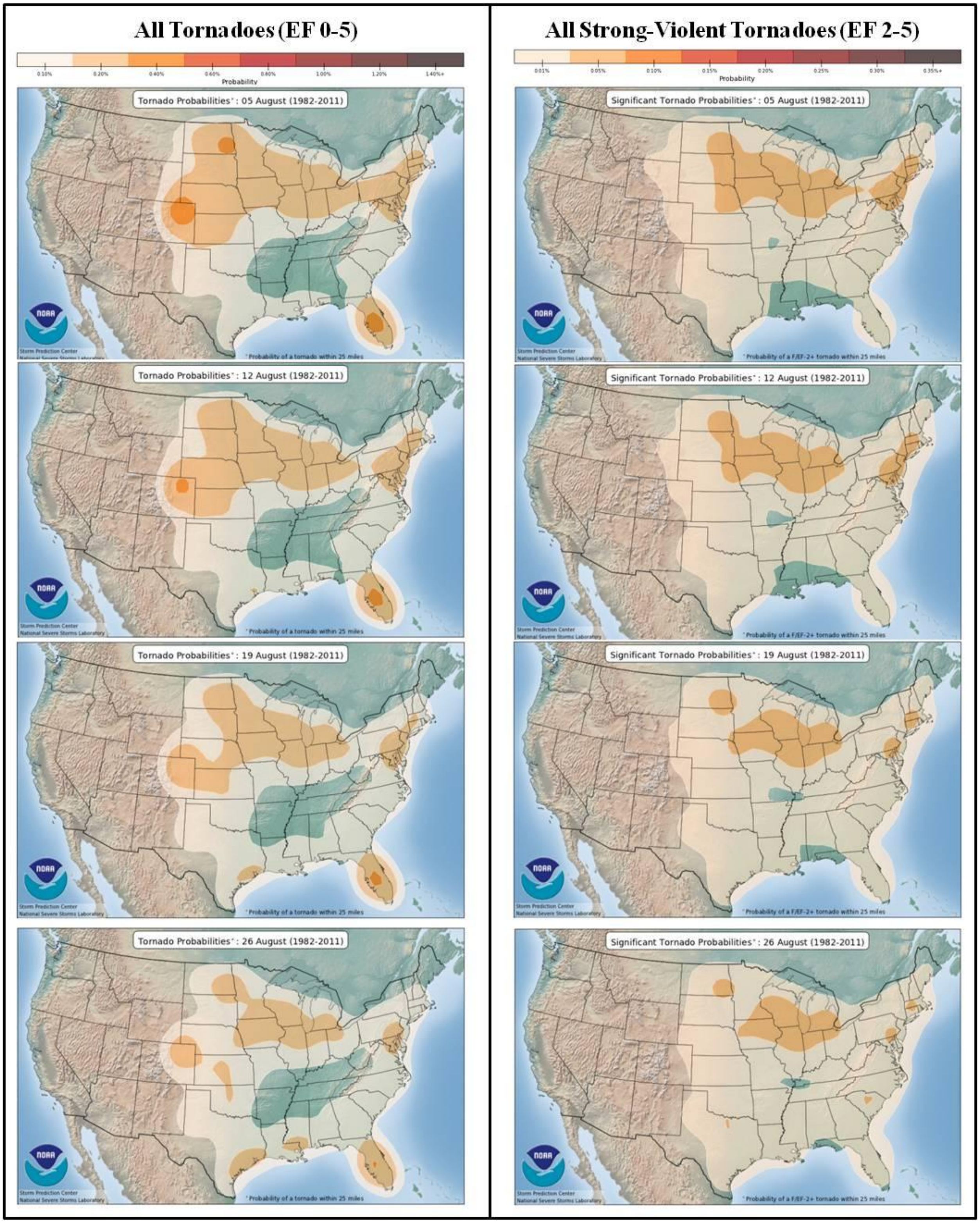
June


All Tornadoes (EF 0-5)
0.10% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40%+
Probability
Tornado Probabilities* : 03 June (1982-2011)
Tornado Probabilities* : 10 June (1982-2011)
Tornado Probabilities* : 17 June (1982-2011)
Tornado Probabilities* : 24 June (1982-2011)
All Strong-Violent Tornadoes (EF 2-5)
0.01% 0.05% 0.10% 0.15% 0.20% 0.25% 0.30% 0.35%+
Probability
Significant Tornado Probabilities* : 03 June (1982-2011)
Significant Tornado Probabilities* : 10 June (1982-2011)
Significant Tornado Probabilities* : 17 June (1982-2011)
Significant Tornado Probabilities* : 24 June (1982-2011)

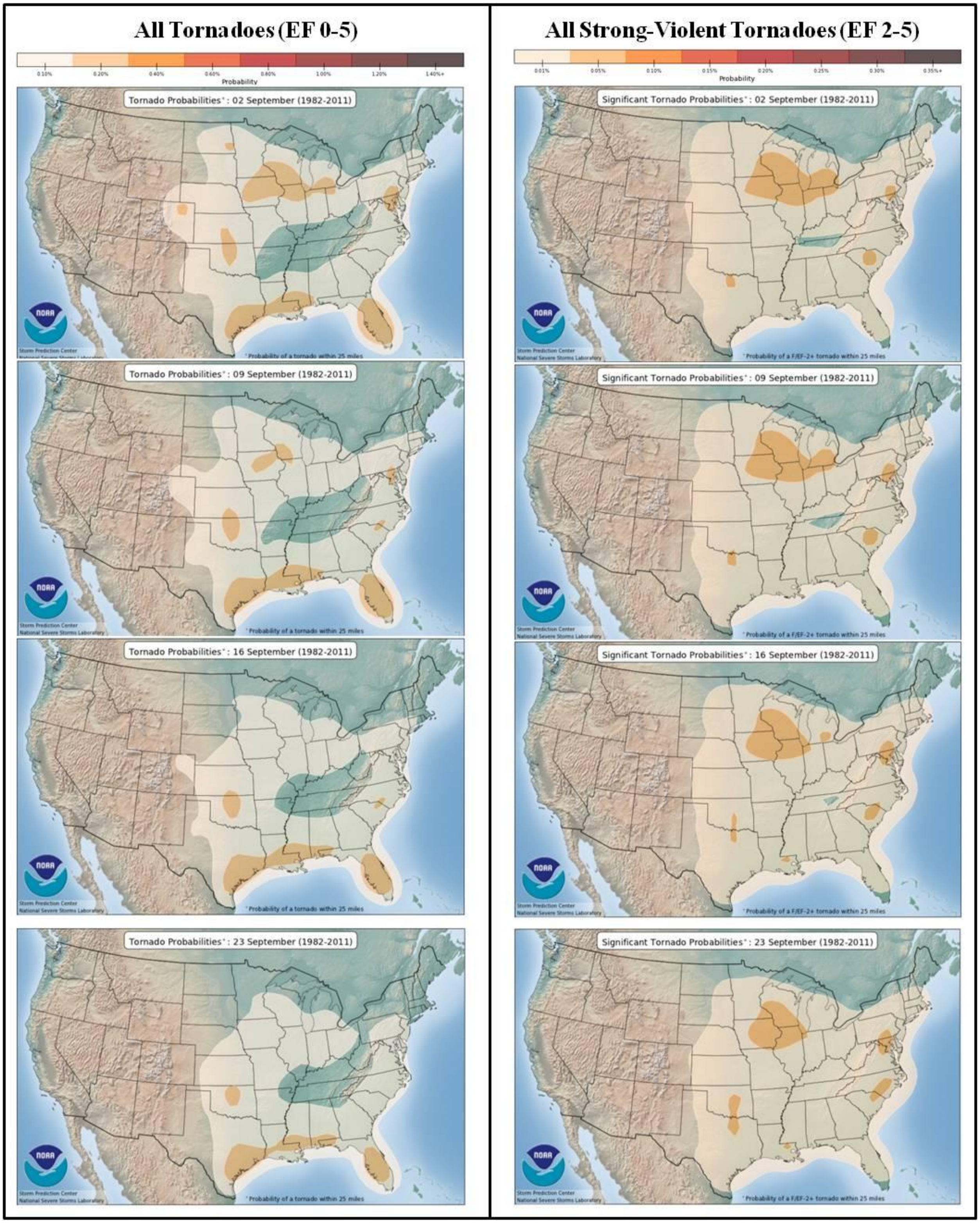
July


All Tornadoes (EF 0-5)
All Strong-Violent Tornadoes (EF 2-5)
Tornado Probabilities* : 01 July (1982-2011)
Significant Tornado Probabilities* : 01 July (1982-2011)
Tornado Probabilities* : 08 July (1982-2011)
Significant Tornado Probabilities* : 08 July (1982-2011)
Tornado Probabilities* : 15 July (1982-2011)
Significant Tornado Probabilities* : 15 July (1982-2011)
Tornado Probabilities* : 22 July (1982-2011)
Significant Tornado Probabilities* : 22 July (1982-2011)
Probability
* Probability of a tornado within 25 miles
* Probability of a F/EF-2+ tornado within 25 miles
Storm Prediction Center
National Severe Storms Laboratory

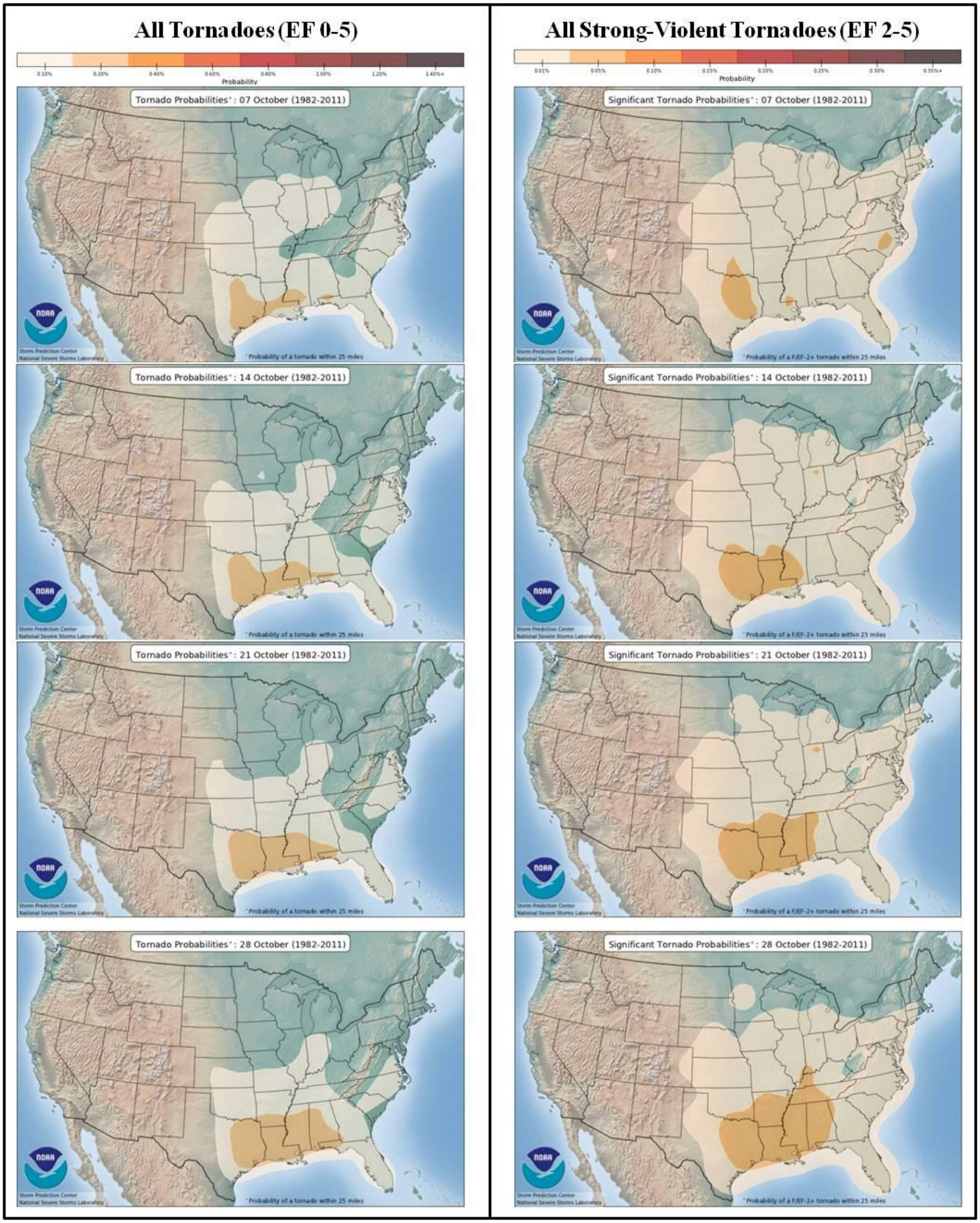
August


All Tornadoes (EF 0-5)
Probability
Tornado Probabilities* : 05 August (1982-2011)
Tornado Probabilities* : 12 August (1982-2011)
Tornado Probabilities* : 19 August (1982-2011)
Tornado Probabilities* : 26 August (1982-2011)
* Probability of a tornado within 25 miles
All Strong-Violent Tornadoes (EF 2-5)
Probability
Significant Tornado Probabilities* : 05 August (1982-2011)
Significant Tornado Probabilities* : 12 August (1982-2011)
Significant Tornado Probabilities* : 19 August (1982-2011)
Significant Tornado Probabilities* : 26 August (1982-2011)
* Probability of a F/EF-2+ tornado within 25 miles
NOAA
Storm Prediction Center
National Severe Storms Laboratory

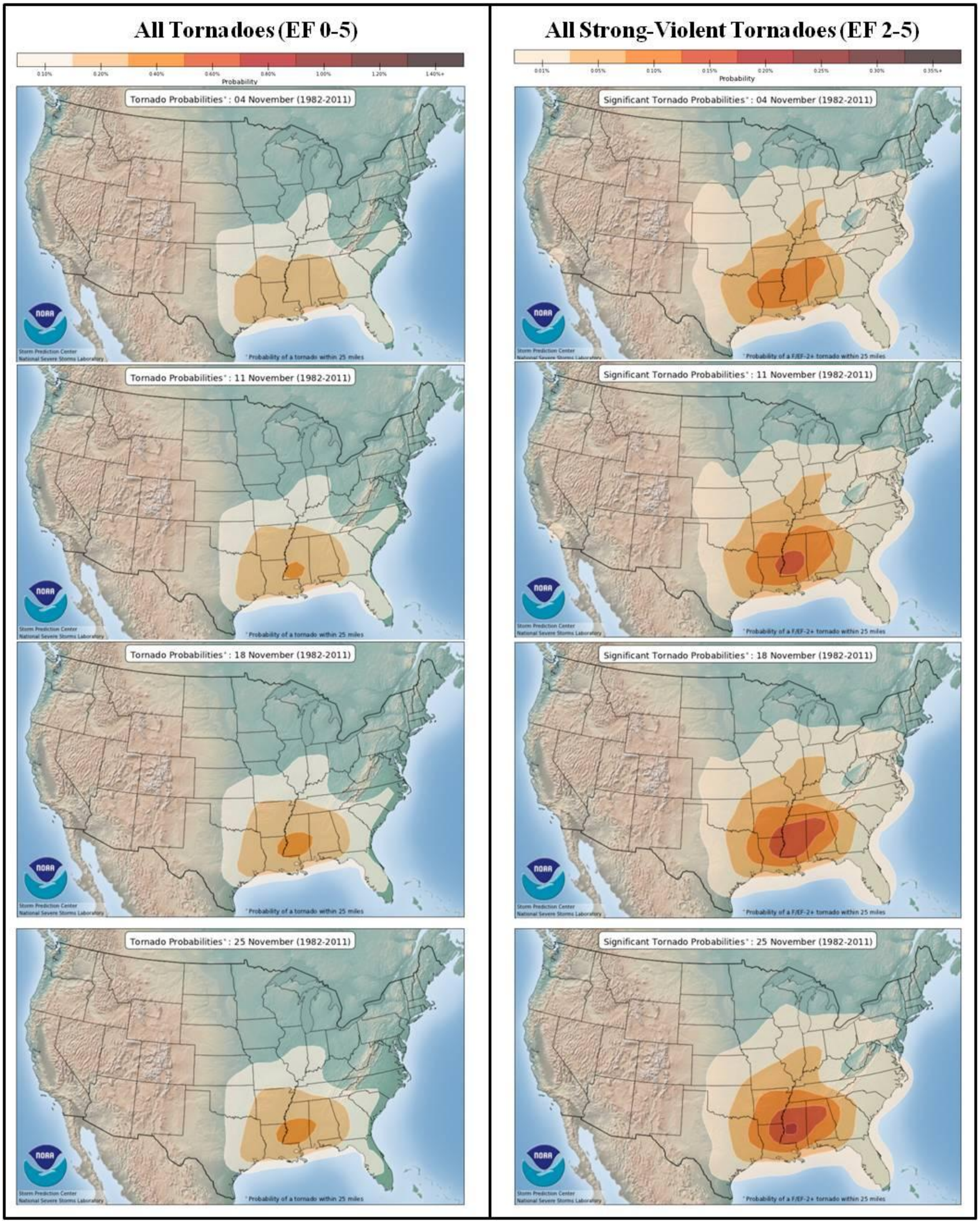
September


All Tornadoes (EF 0-5)
0.10% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40%+
Probability
Tornado Probabilities* : 02 September (1982-2011)
Tornado Probabilities* : 09 September (1982-2011)
Tornado Probabilities* : 16 September (1982-2011)
Tornado Probabilities* : 23 September (1982-2011)
All Strong-Violent Tornadoes (EF 2-5)
0.01% 0.05% 0.10% 0.15% 0.20% 0.25% 0.30% 0.35%+
Probability
Significant Tornado Probabilities* : 02 September (1982-2011)
Significant Tornado Probabilities* : 09 September (1982-2011)
Significant Tornado Probabilities* : 16 September (1982-2011)
Significant Tornado Probabilities* : 23 September (1982-2011)

October

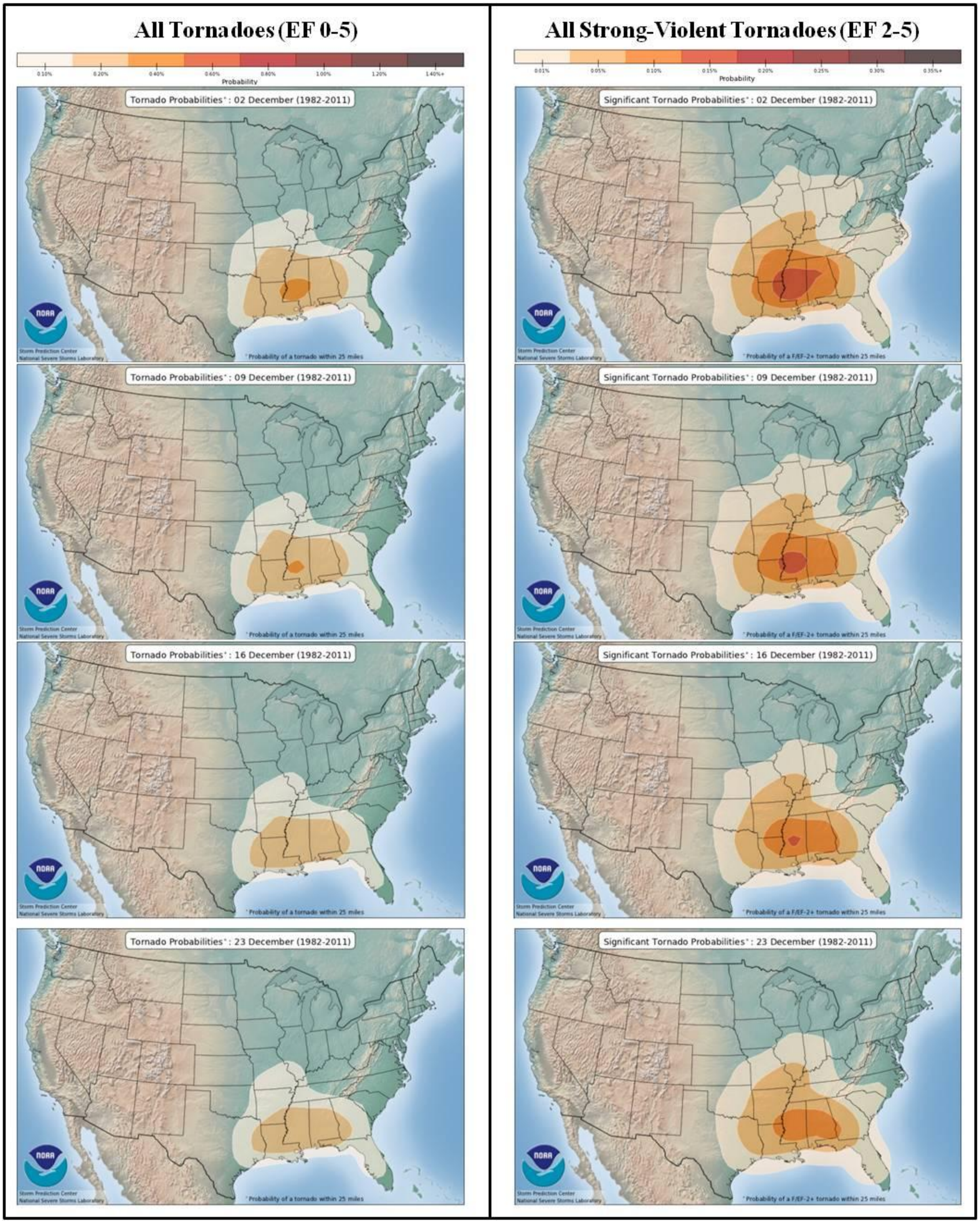

All Tornadoes (EF 0-5)
0.10% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40%+
Probability
Tornado Probabilities*: 07 October (1982-2011)
Tornado Probabilities*: 14 October (1982-2011)
Tornado Probabilities*: 21 October (1982-2011)
Tornado Probabilities*: 28 October (1982-2011)
*Probability of a tornado within 25 miles
All Strong-Violent Tornadoes (EF 2-5)
0.01% 0.05% 0.10% 0.15% 0.20% 0.25% 0.30% 0.35%+
Probability
Significant Tornado Probabilities*: 07 October (1982-2011)
Significant Tornado Probabilities*: 14 October (1982-2011)
Significant Tornado Probabilities*: 21 October (1982-2011)
Significant Tornado Probabilities*: 28 October (1982-2011)
*Probability of a F/EF-2+ tornado within 25 miles
NOAA
Storm Prediction Center
National Severe Storms Laboratory

November



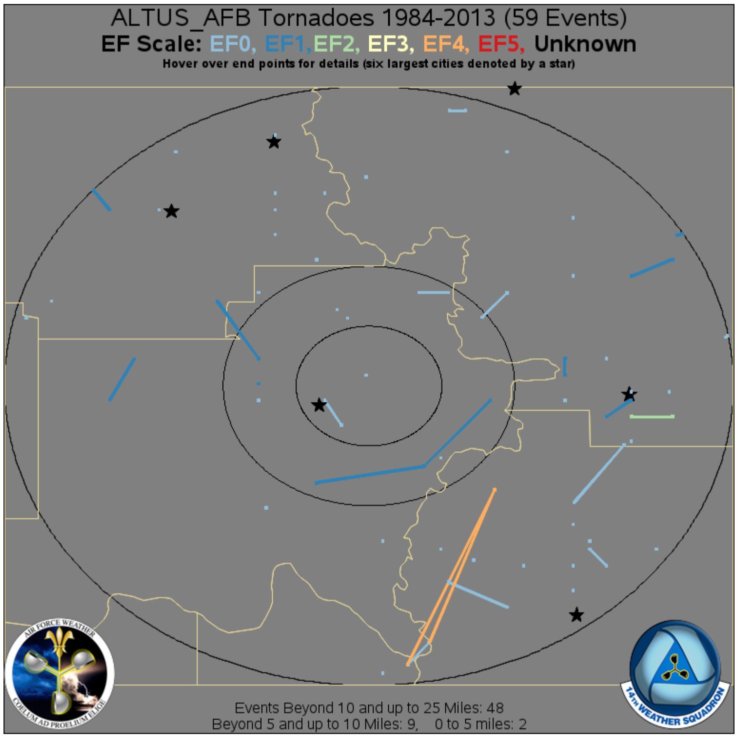
All Tornadoes (EF 0-5)
0.10% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40%+
Probability
Tornado Probabilities*: 04 November (1982-2011)
Tornado Probabilities*: 11 November (1982-2011)
Tornado Probabilities*: 18 November (1982-2011)
Tornado Probabilities*: 25 November (1982-2011)
*Probability of a tornado within 25 miles
All Strong-Violent Tornadoes (EF 2-5)
0.01% 0.05% 0.10% 0.15% 0.20% 0.25% 0.30% 0.35%+
Probability
Significant Tornado Probabilities*: 04 November (1982-2011)
Significant Tornado Probabilities*: 11 November (1982-2011)
Significant Tornado Probabilities*: 18 November (1982-2011)
Significant Tornado Probabilities*: 25 November (1982-2011)
*Probability of a F/EF-2+ tornado within 25 miles
NOAA
Storm Prediction Center
National Severe Storms Laboratory

December

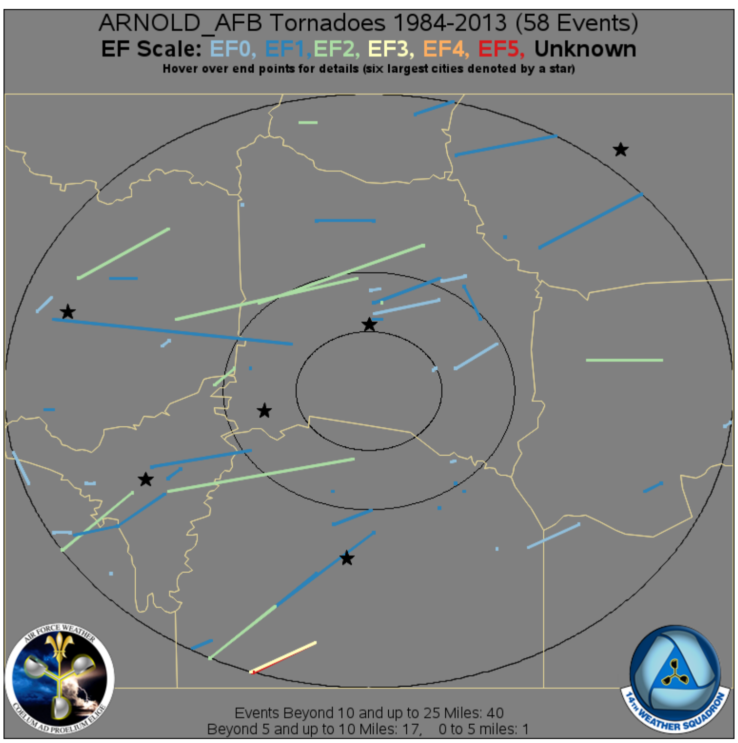


All Tornadoes (EF 0-5)
0.10% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40%+
Probability
Tornado Probabilities*: 02 December (1982-2011)
Tornado Probabilities*: 09 December (1982-2011)
Tornado Probabilities*: 16 December (1982-2011)
Tornado Probabilities*: 23 December (1982-2011)
*Probability of a tornado within 25 miles
All Strong-Violent Tornadoes (EF 2-5)
0.01% 0.05% 0.10% 0.15% 0.20% 0.25% 0.30% 0.35%+
Probability
Significant Tornado Probabilities*: 02 December (1982-2011)
Significant Tornado Probabilities*: 09 December (1982-2011)
Significant Tornado Probabilities*: 16 December (1982-2011)
Significant Tornado Probabilities*: 23 December (1982-2011)
*Probability of a F/EF-2+ tornado within 25 miles
NOAA
Storm Prediction Center
National Severe Storms Laboratory

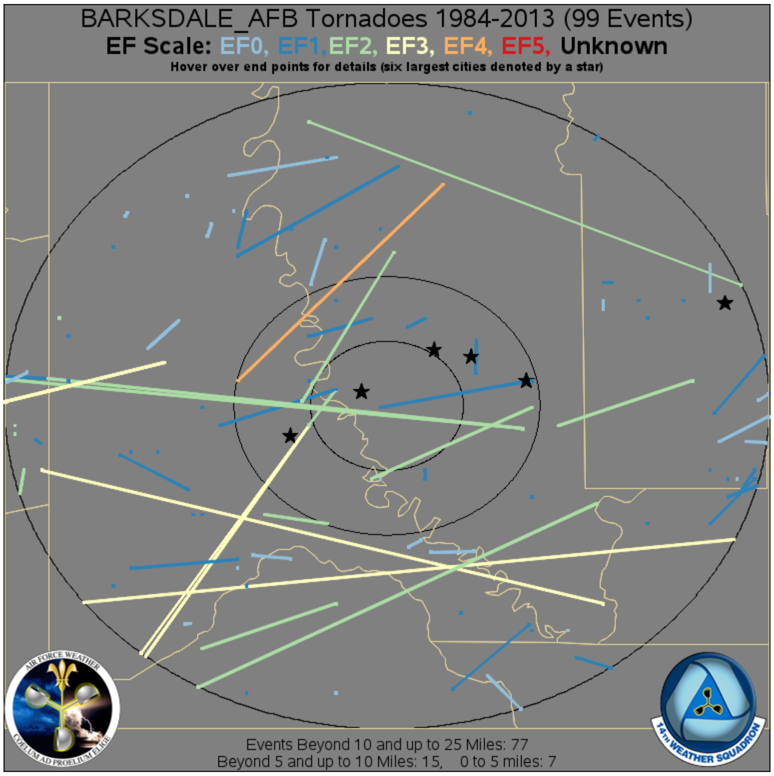
Appendix E – Tornado Occurrence Maps by Base (1984 – 2013)



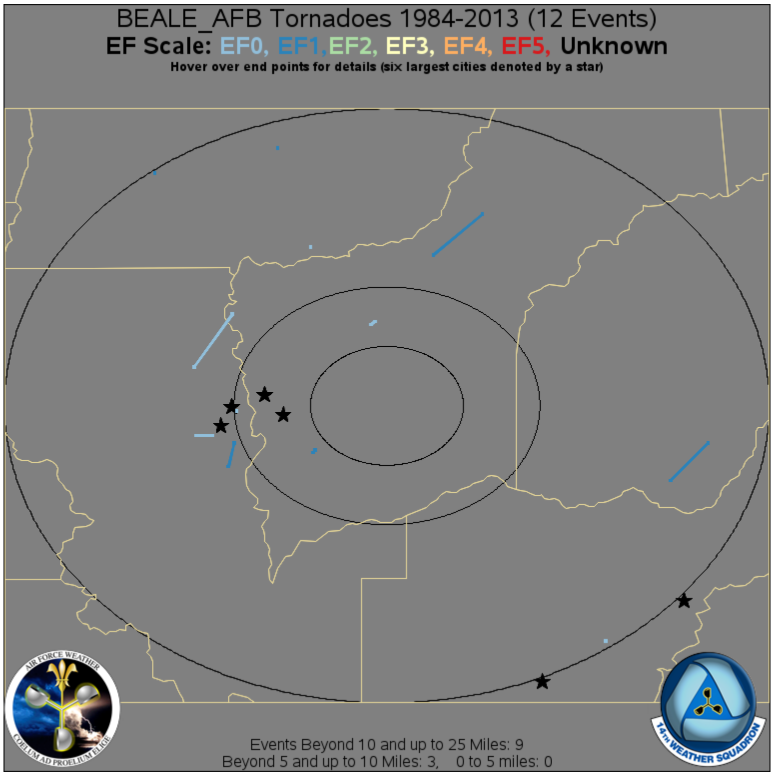
Altus AFB, OK



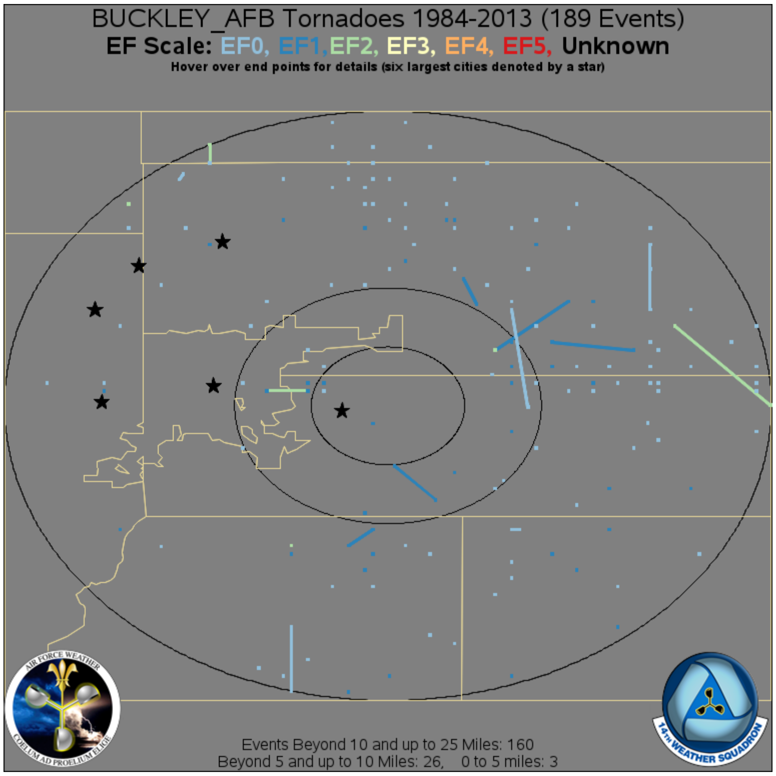
Arnold AFB, TN



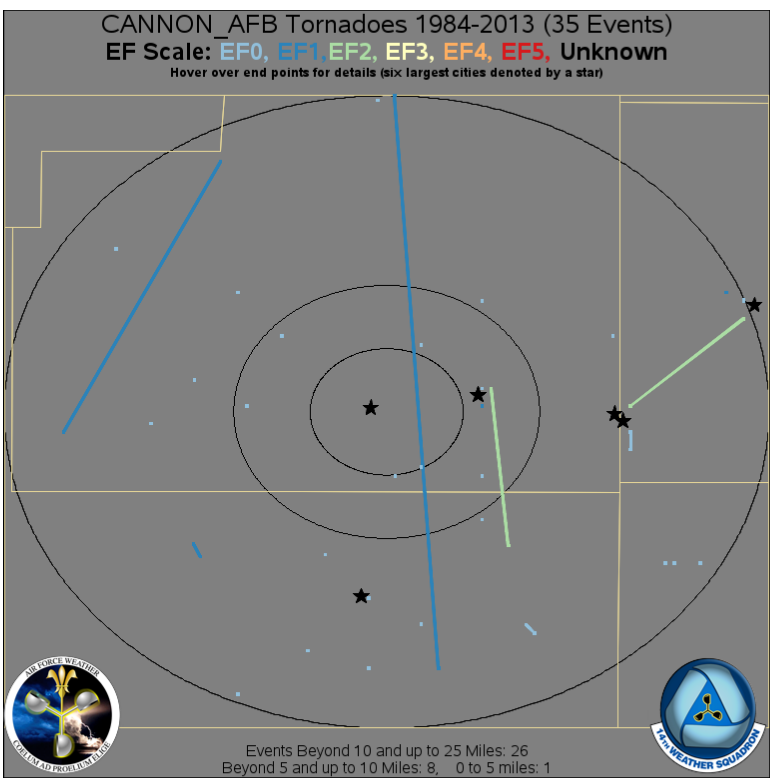
Barksdale AFB, LA



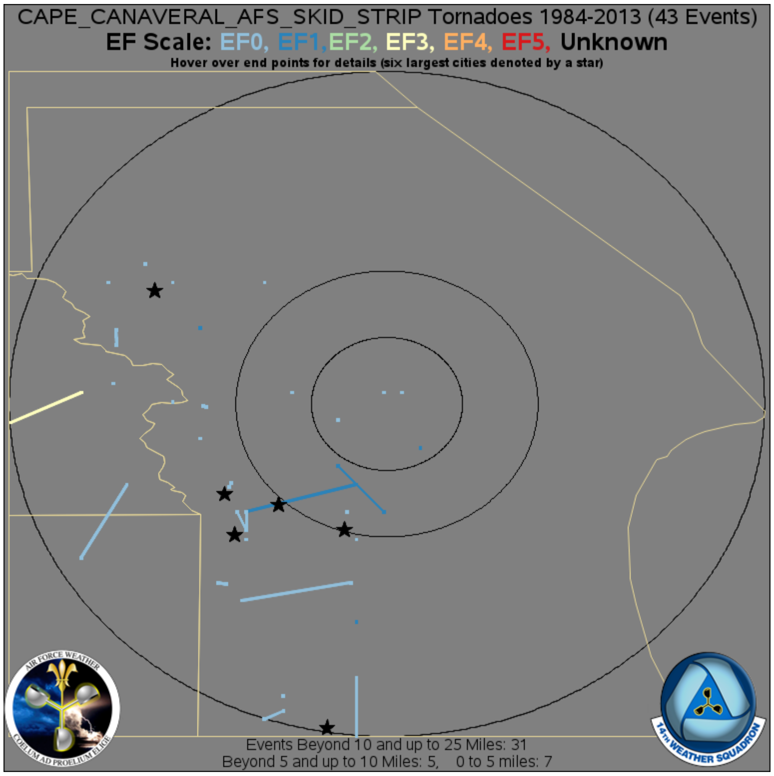
Beale AFB, CA



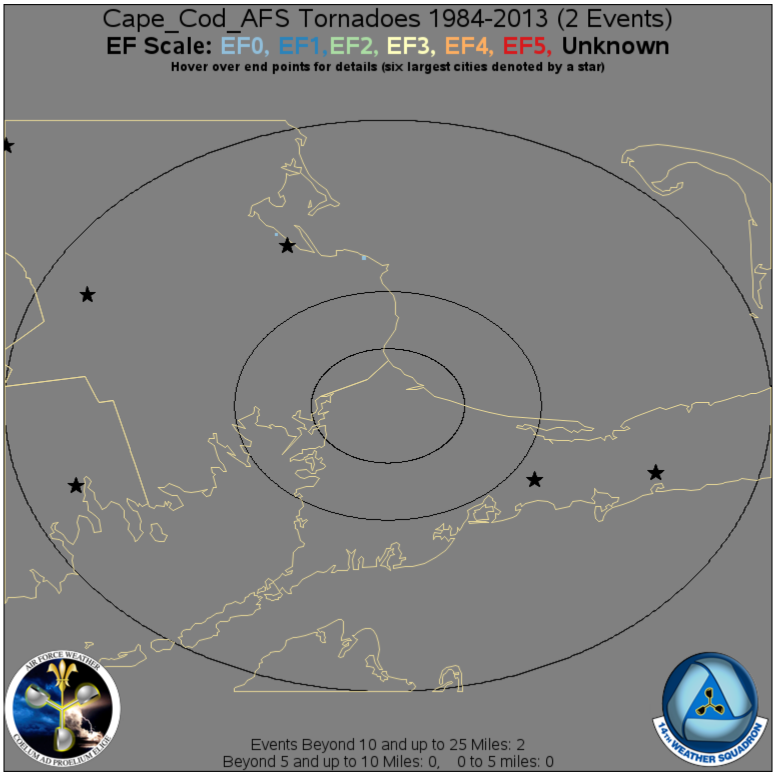
Buckley AFB, CO



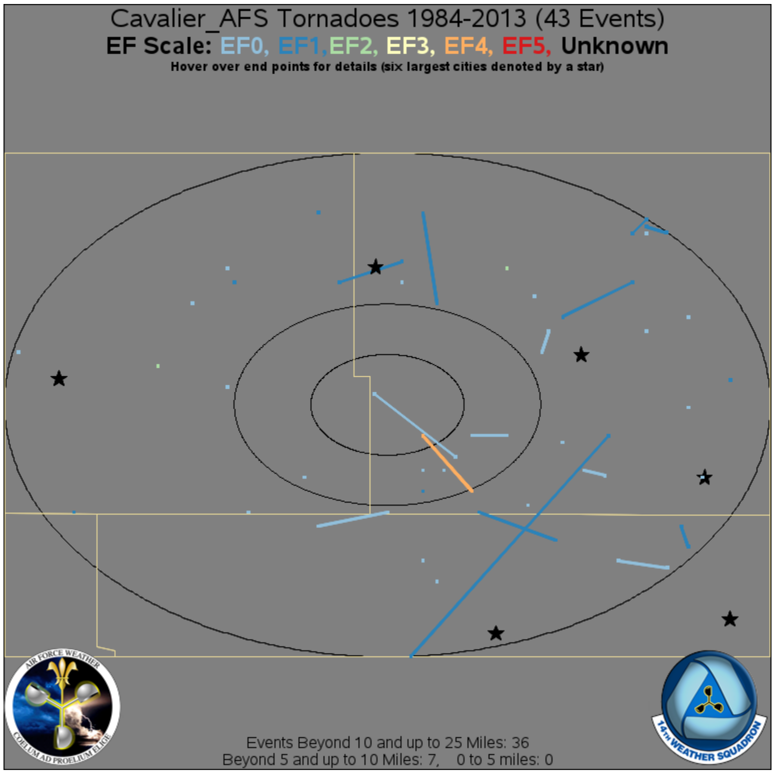
Cannon AFB, NM



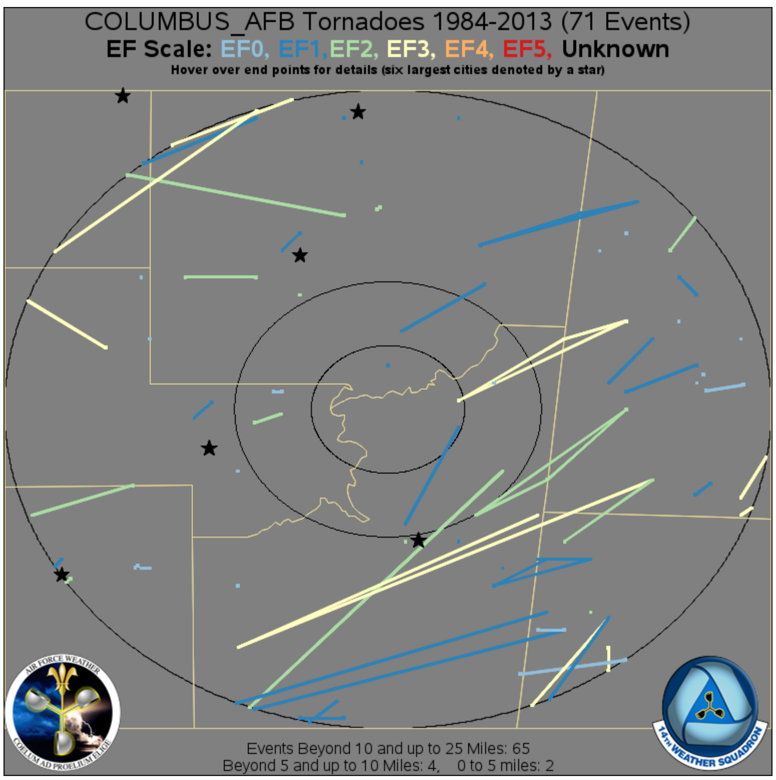
Cape Canaveral AFS, FL



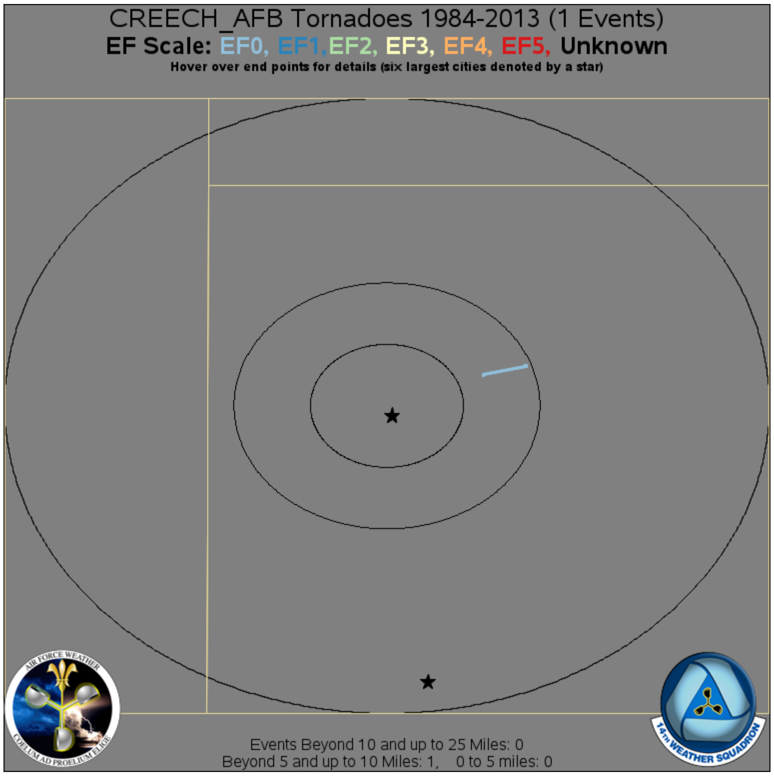
Cape Cod AFS, MA



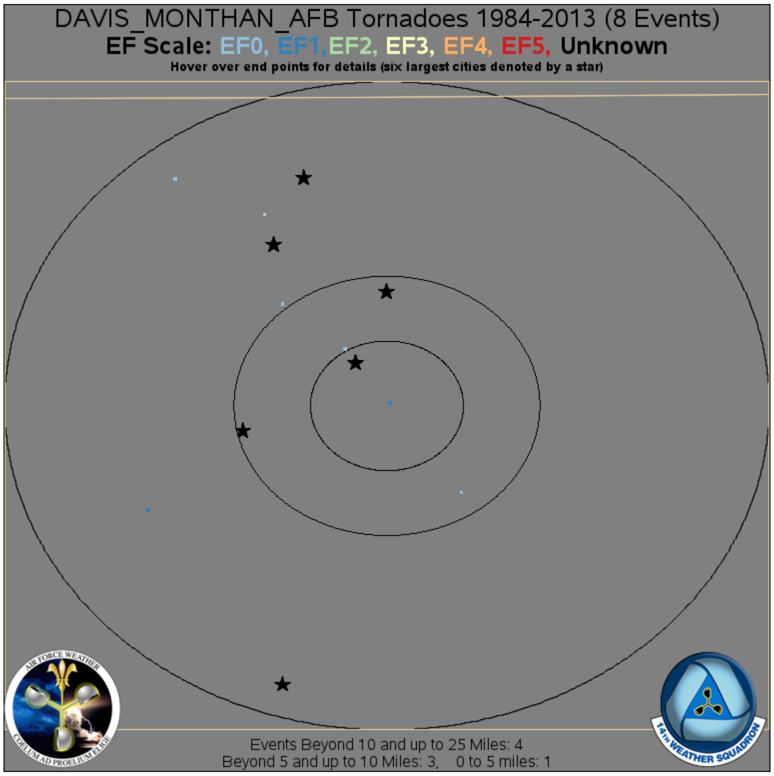
Cavalier AFS, ND



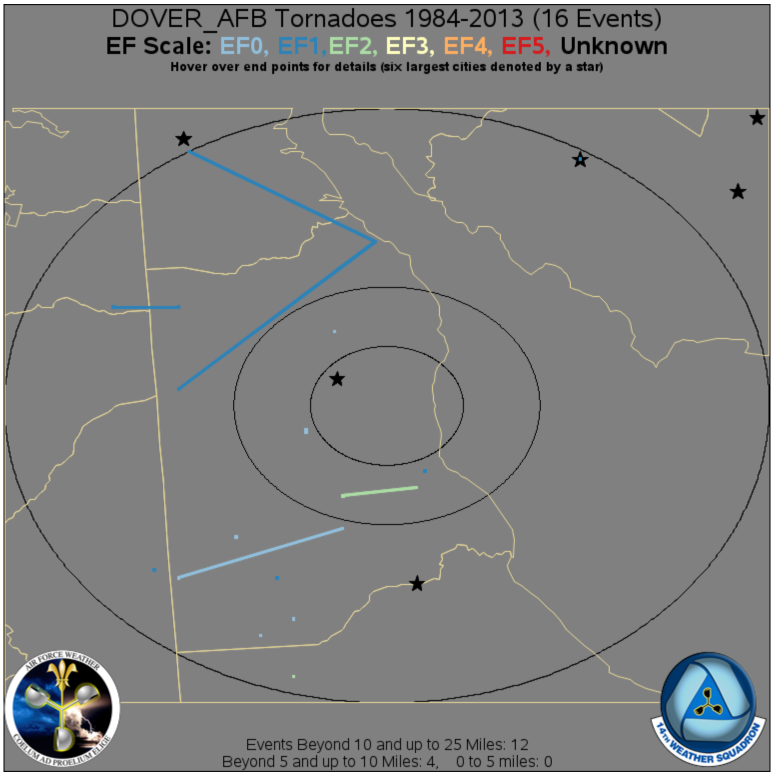
Columbus AFB, MS



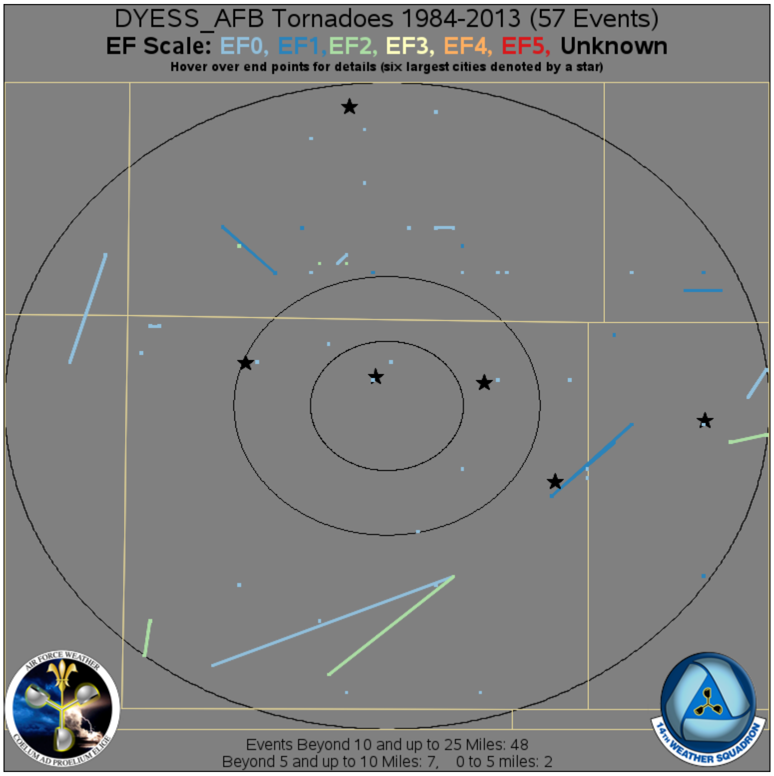
Creech AFB, NV



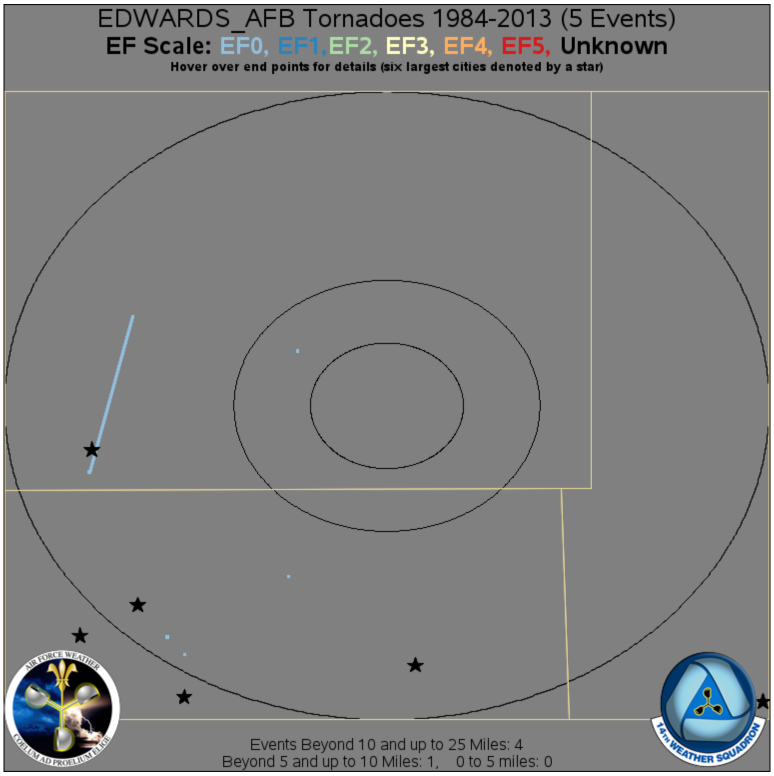
Davis Monthan AFB, AZ



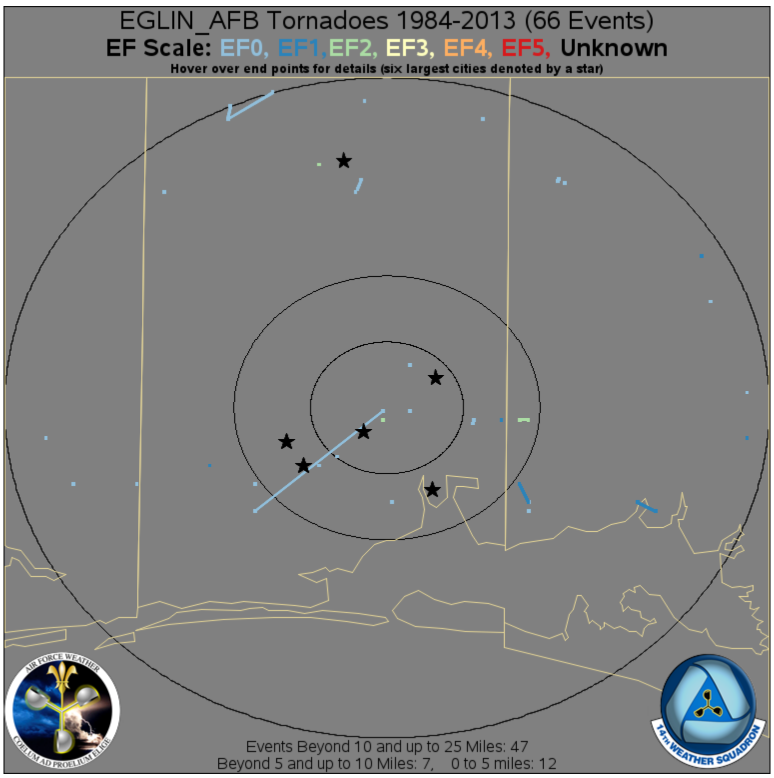
Dover AFB, DE



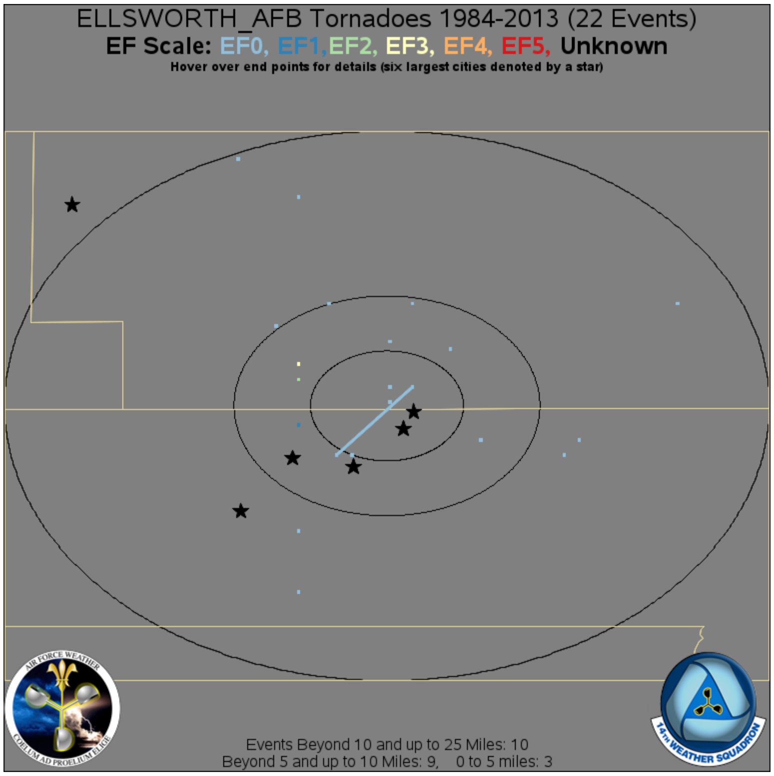
Dyess AFB, TX



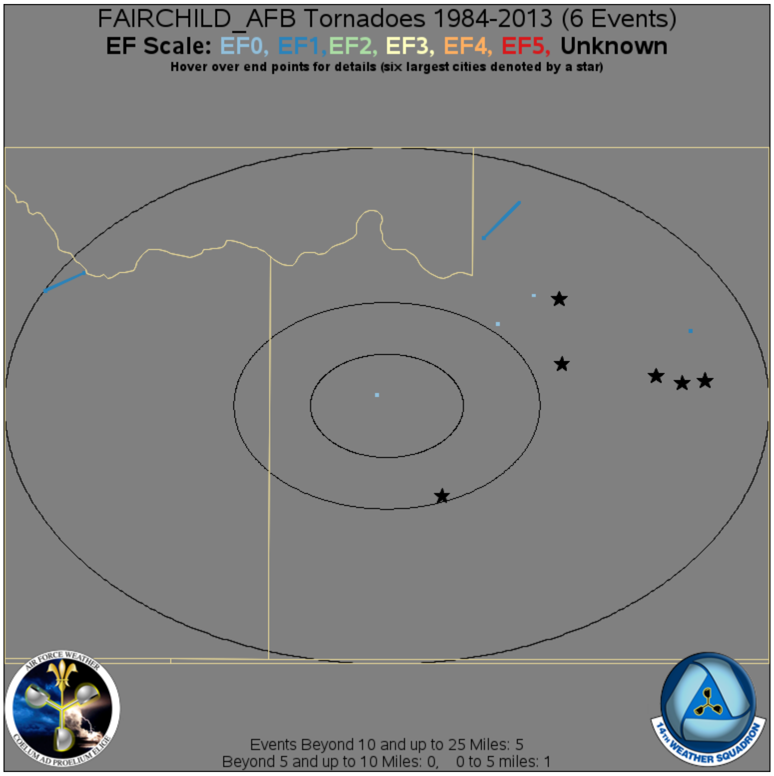
Edwards AFB, CA



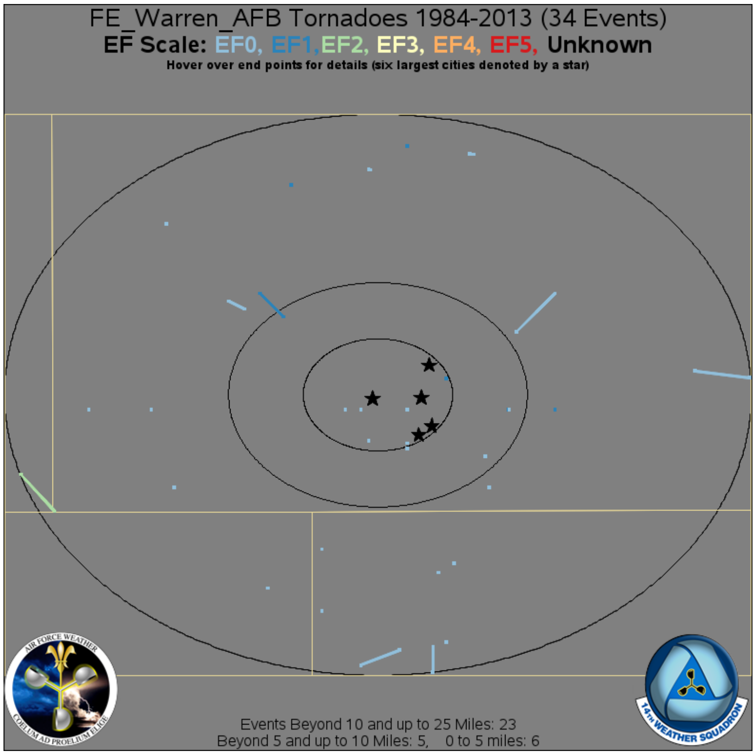
Eglin AFB, FL



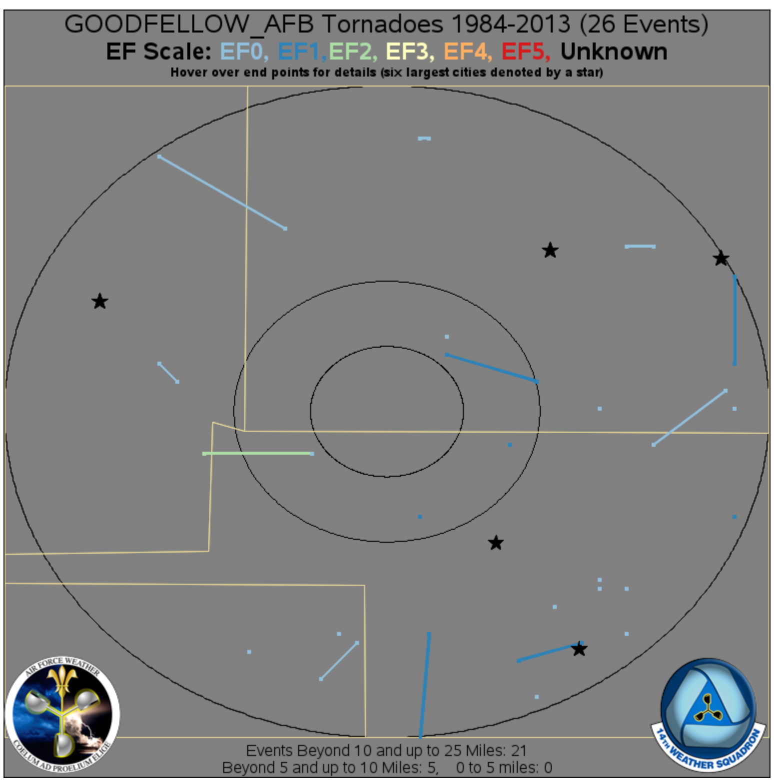
Ellsworth AFB, SD



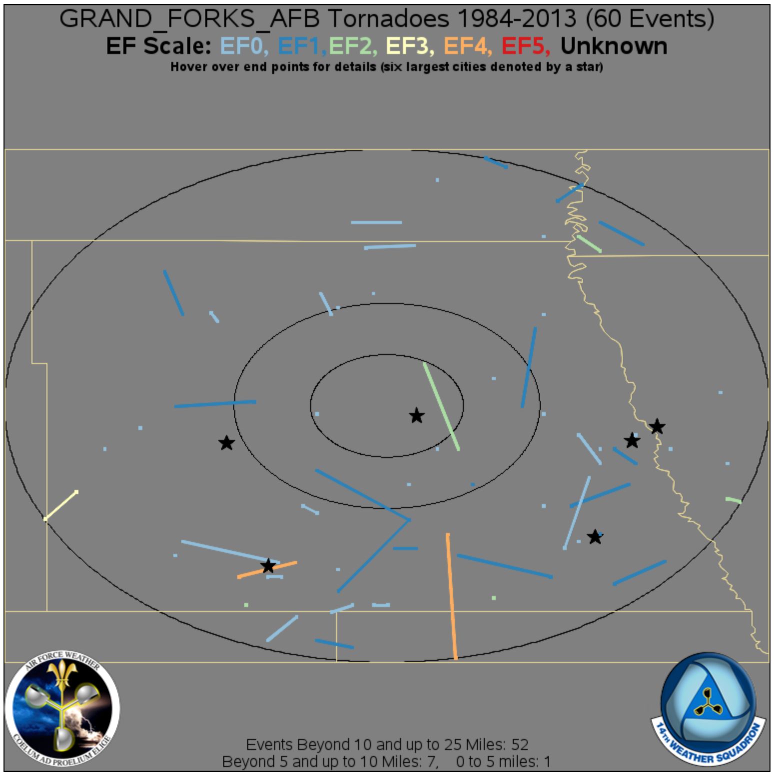
Fairchild AFB, WA



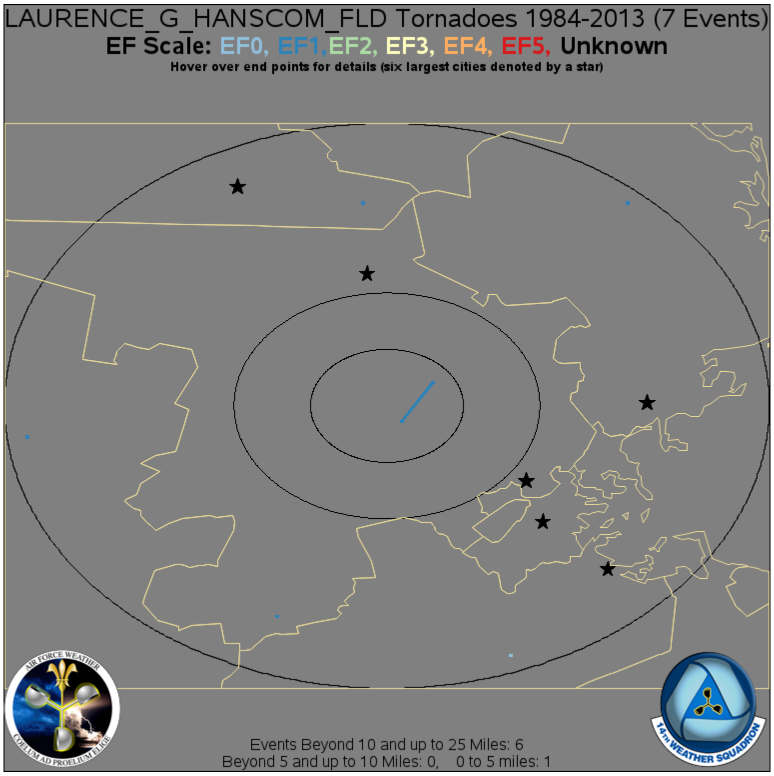
F.E. Warren AFB, WY



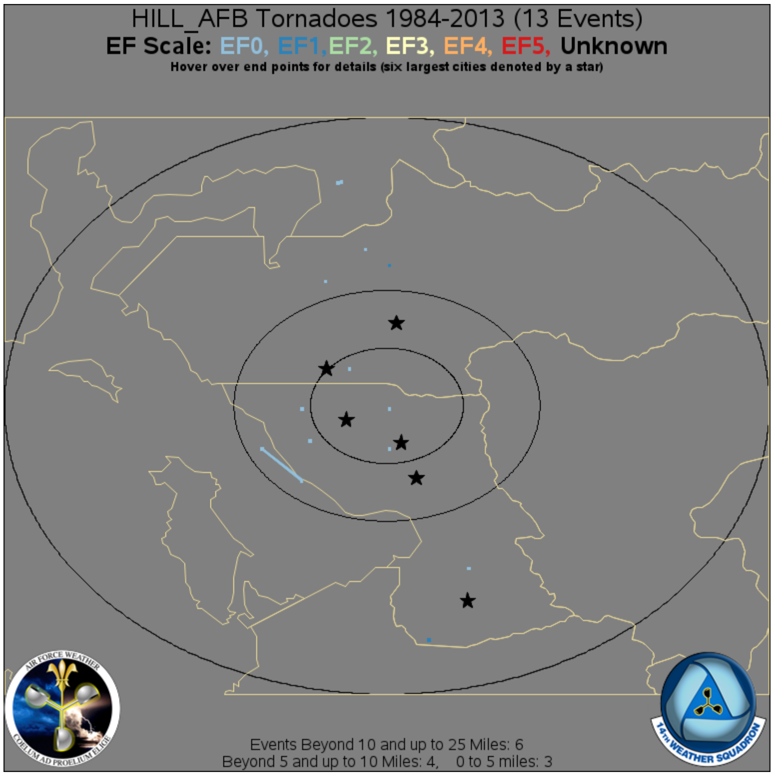
Goodfellow AFB, TX



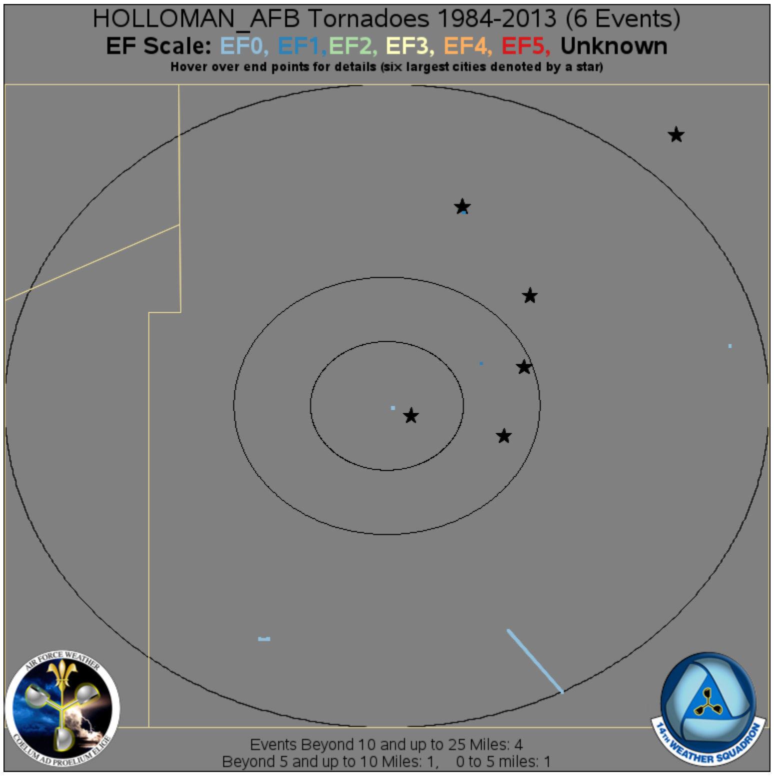
Grand Forks AFB, ND



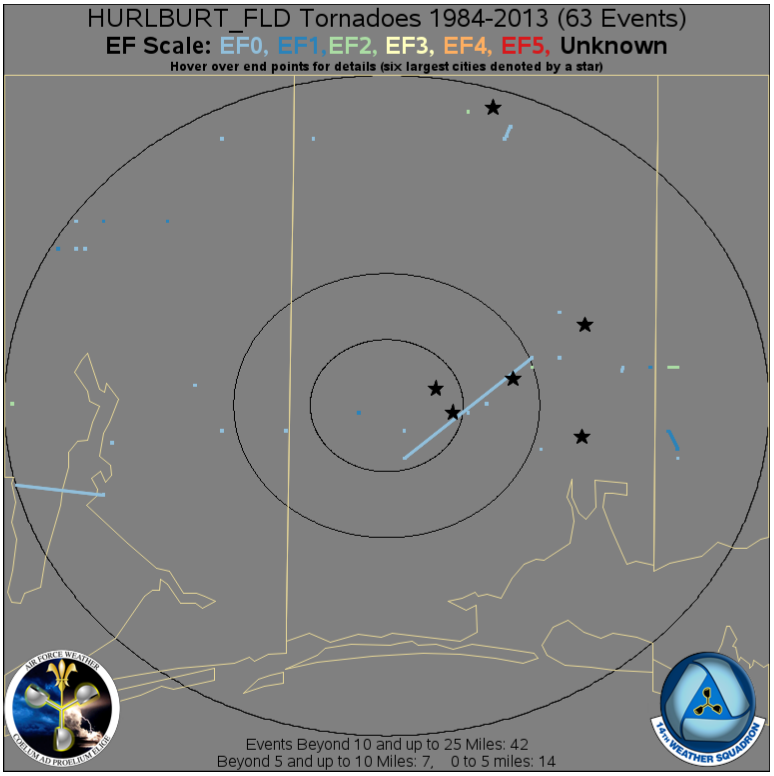
Hanscom AFB, MA



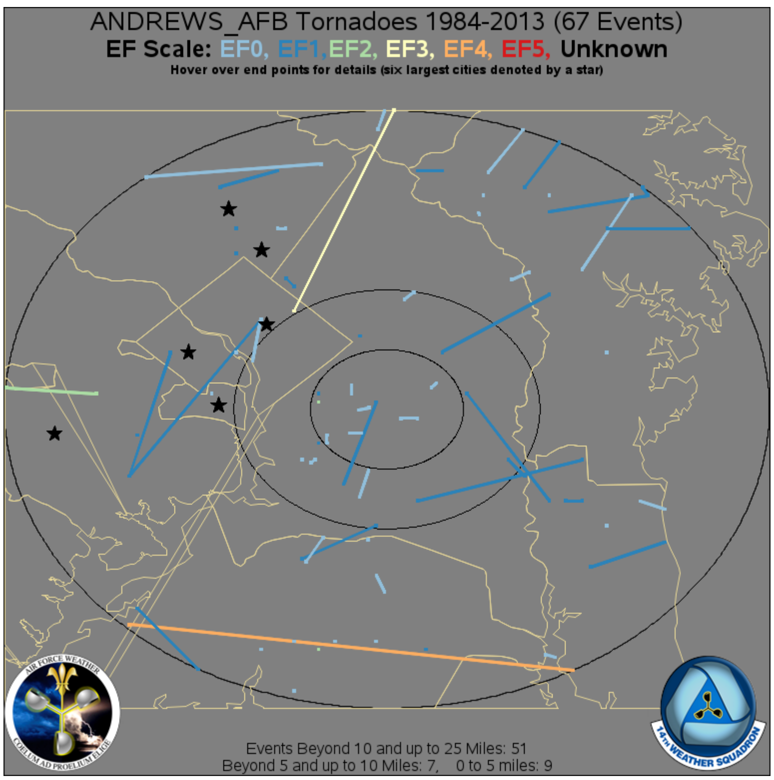
Hill AFB, UT



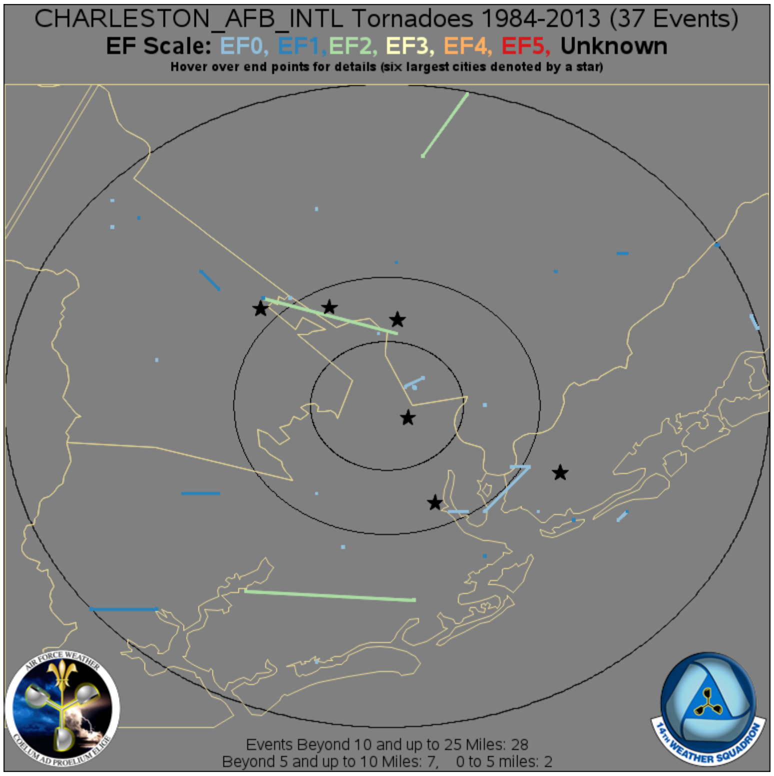
Holloman AFB, NM



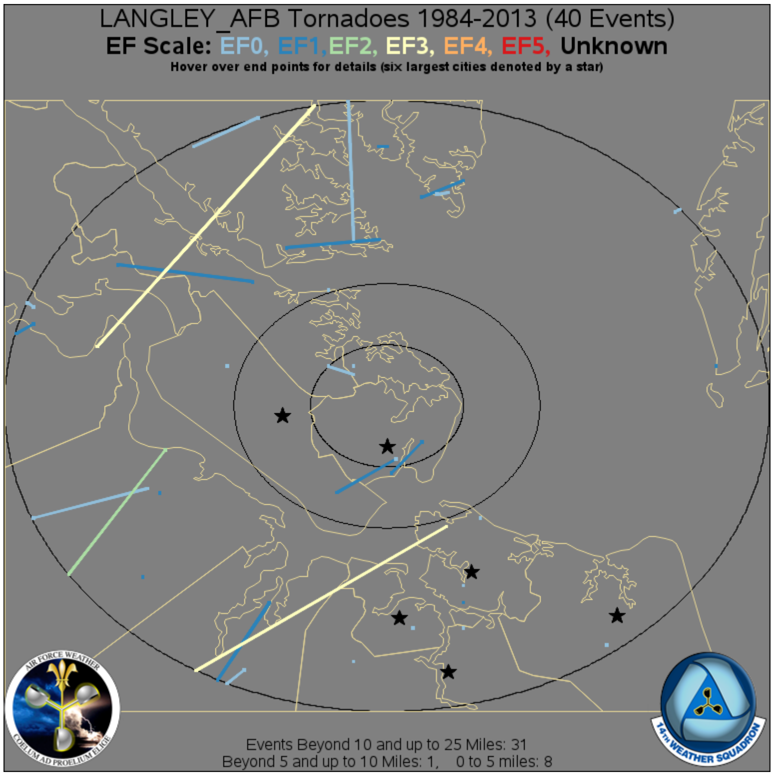
Hurlburt Field, FL



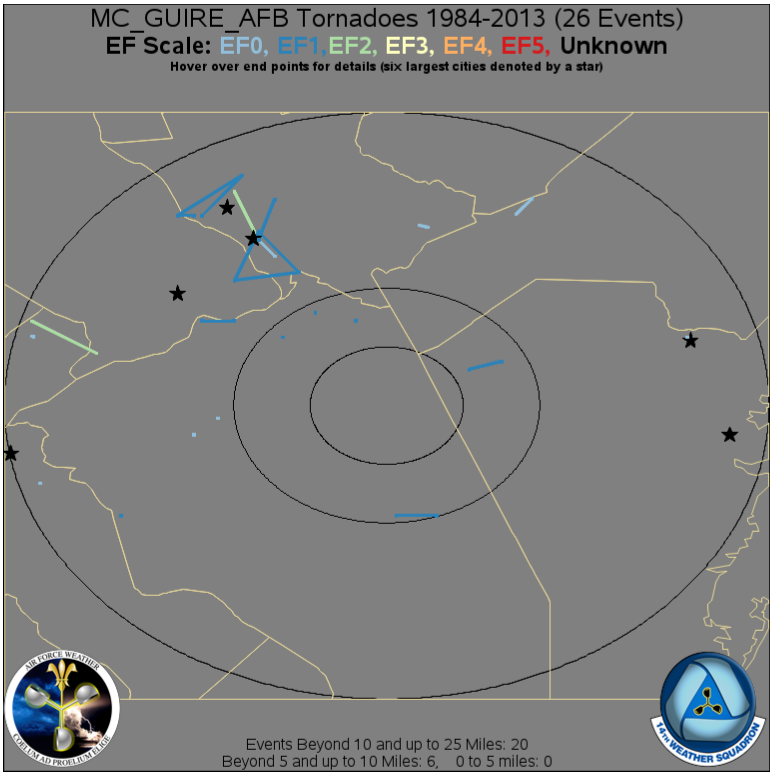
Joint Base Andrews, MD



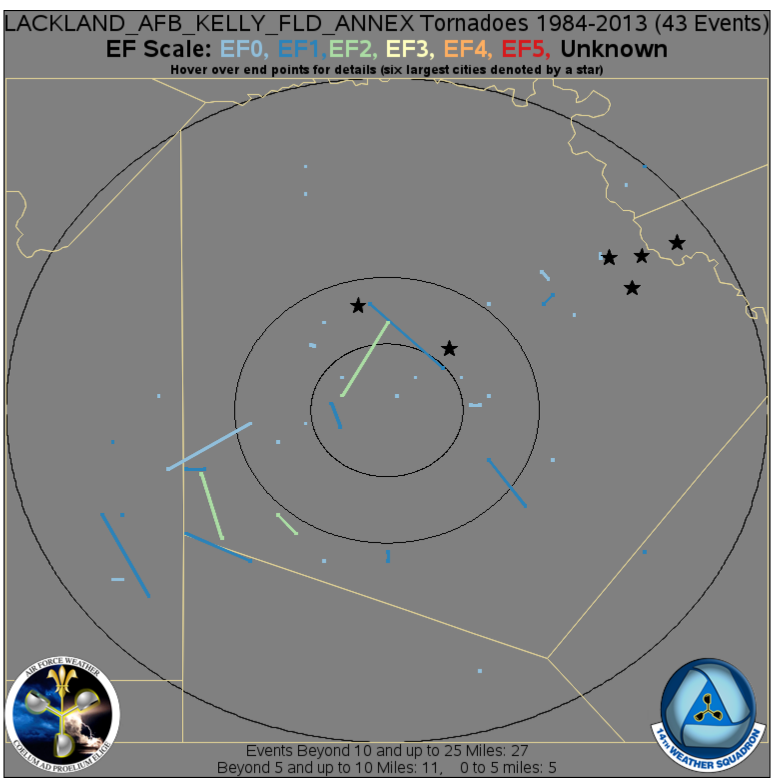
Joint Base Charleston, SC



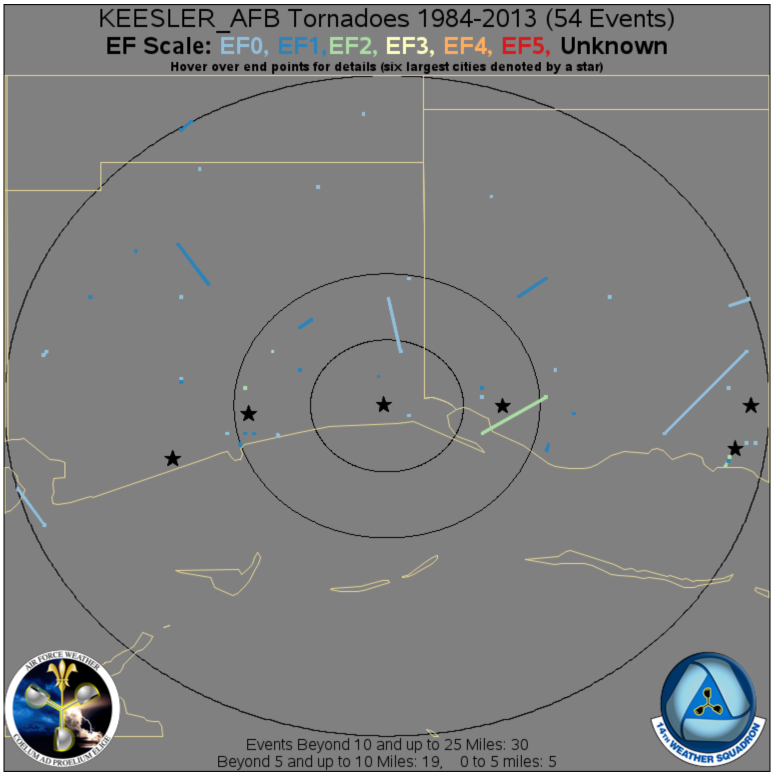
Joint Base Langley-Eustis (JBLE), VA



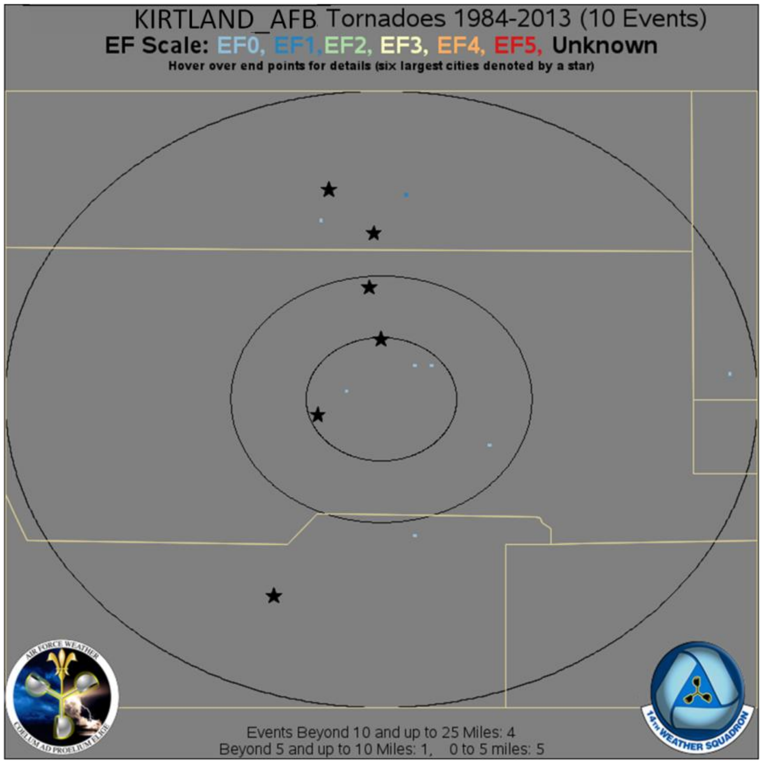
Joint Base McGuire-Dix-Lakehurst (JBMDL), NJ



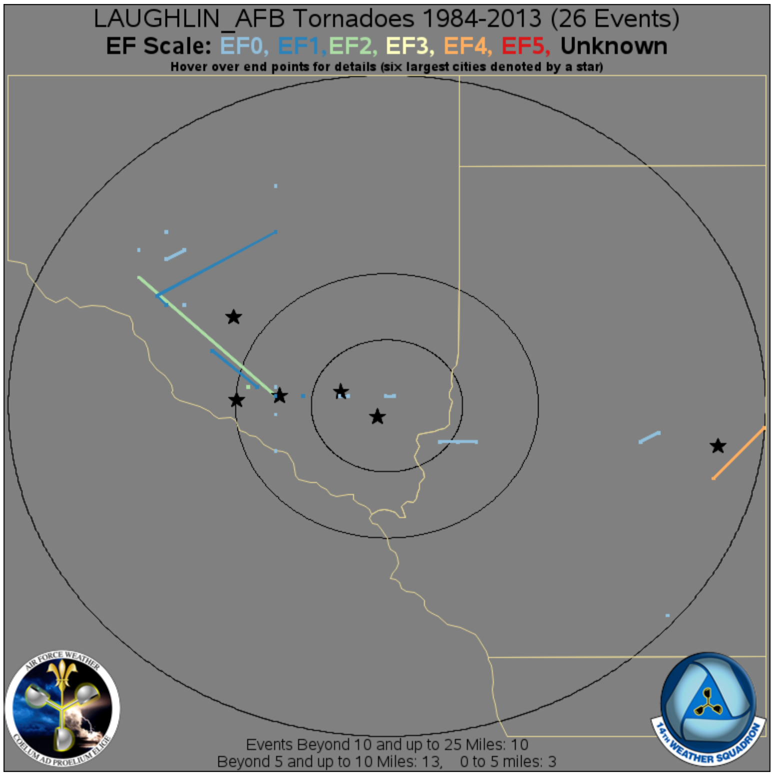
Joint Base San Antonio (JBSA), TX



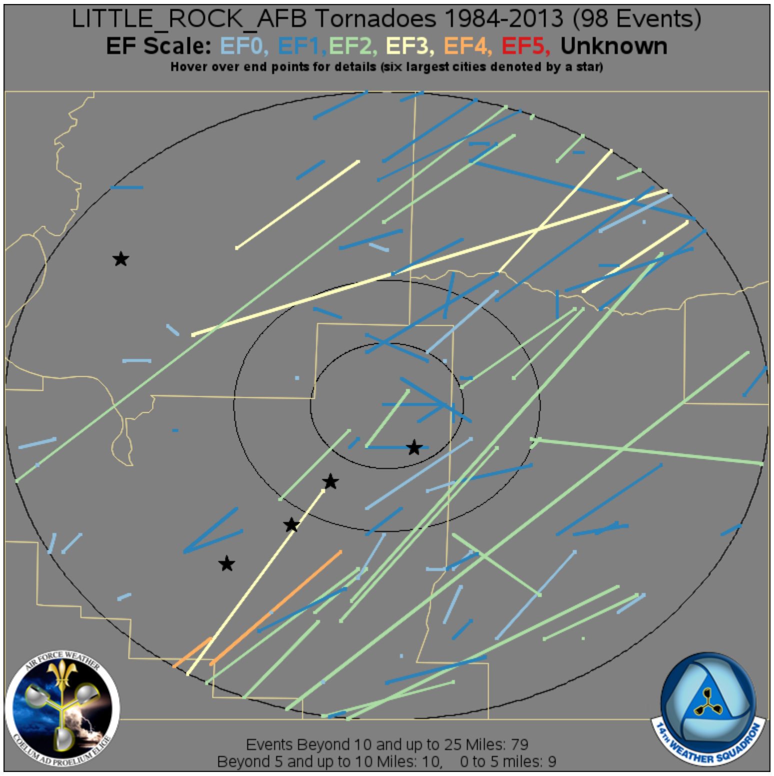
Keesler AFB, MS



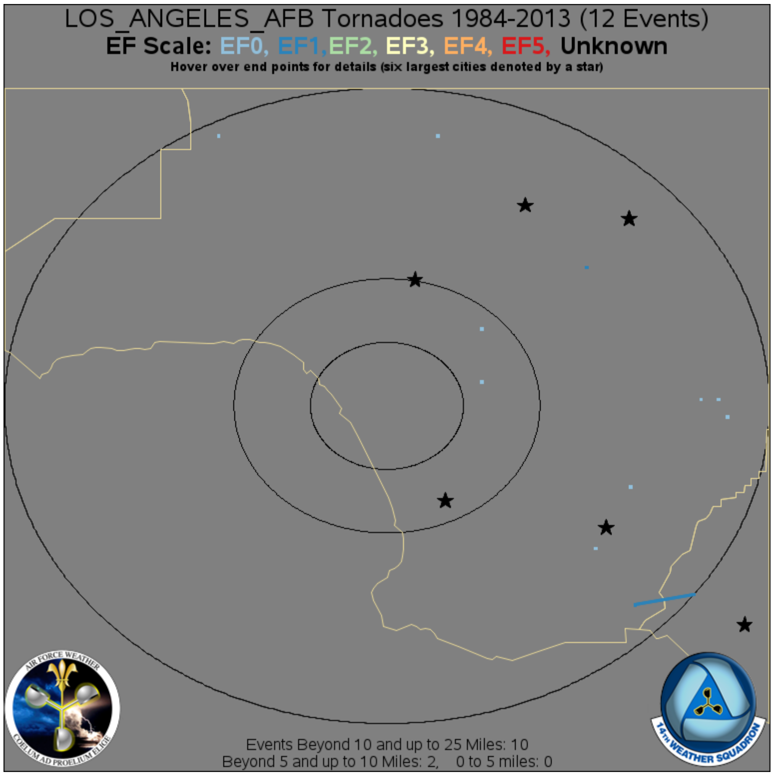
Kirtland AFB, NM



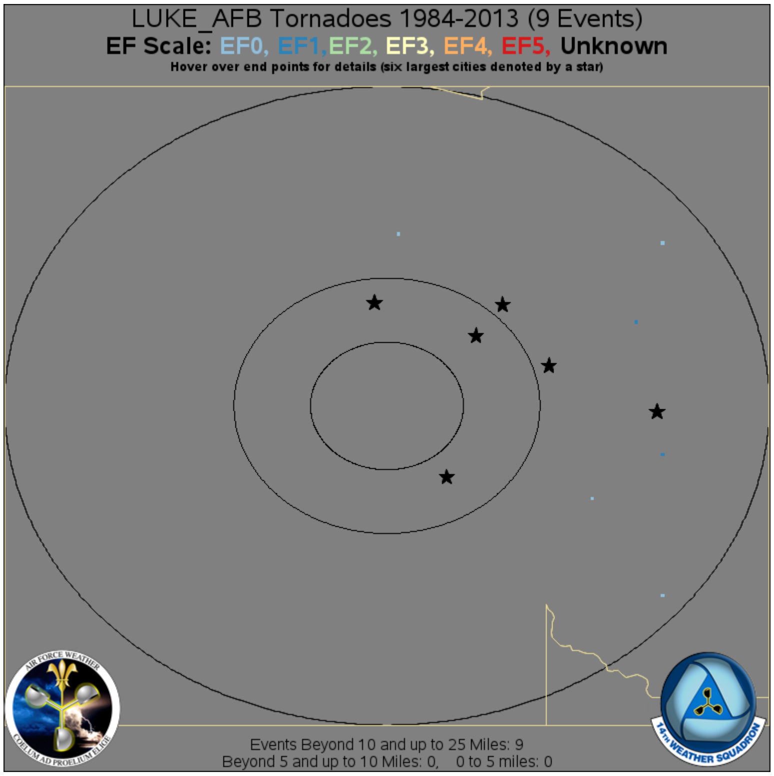
Laughlin AFB, TX



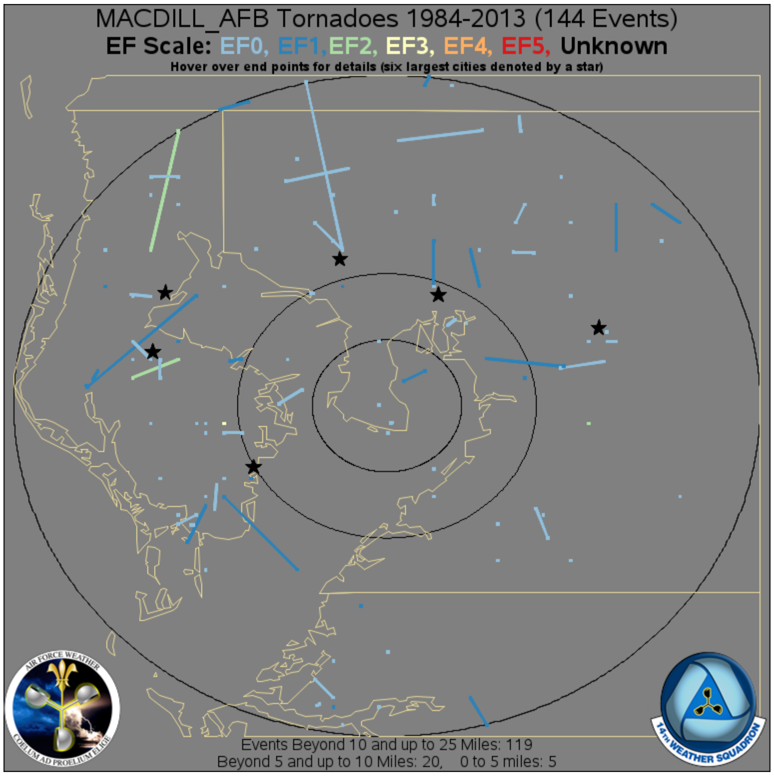
Little Rock AFB, AR



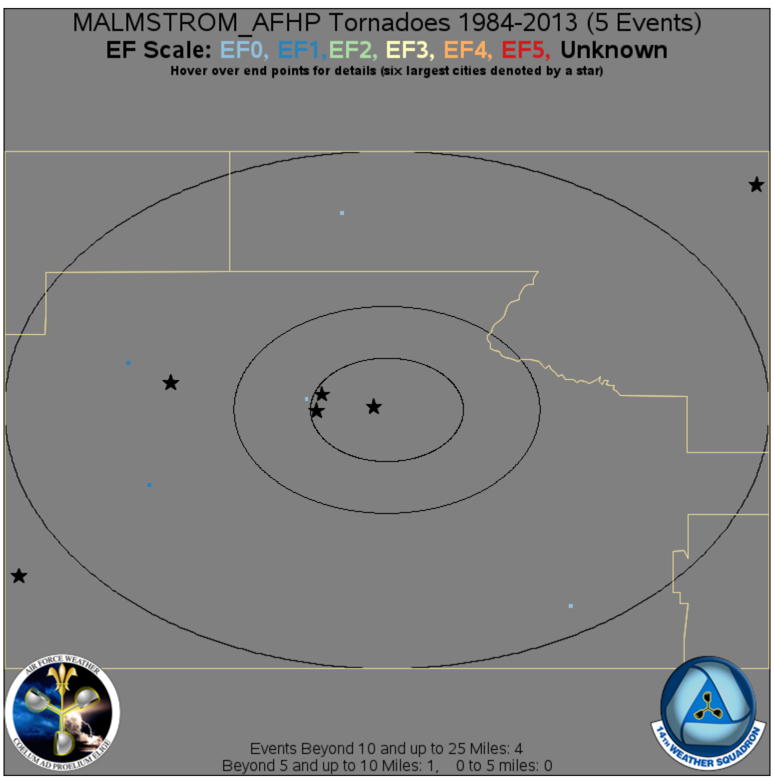
Los Angeles AFB, CA



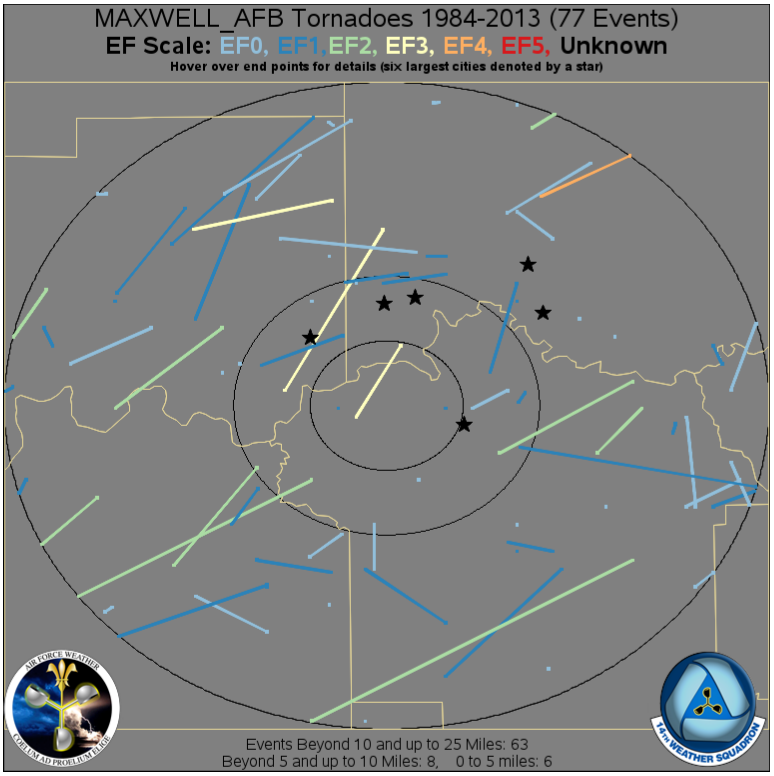
Luke AFB, AZ



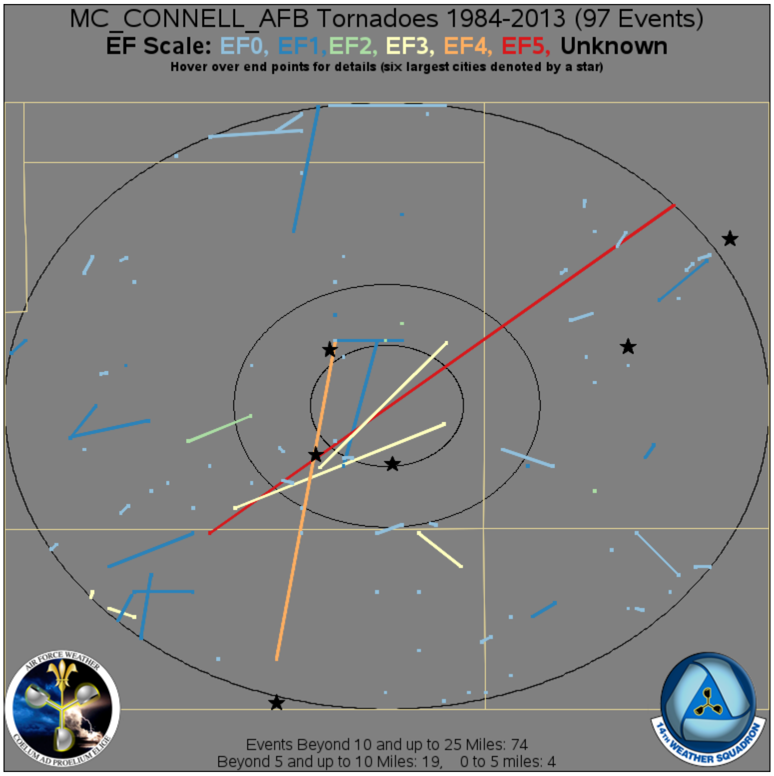
MacDill AFB, FL



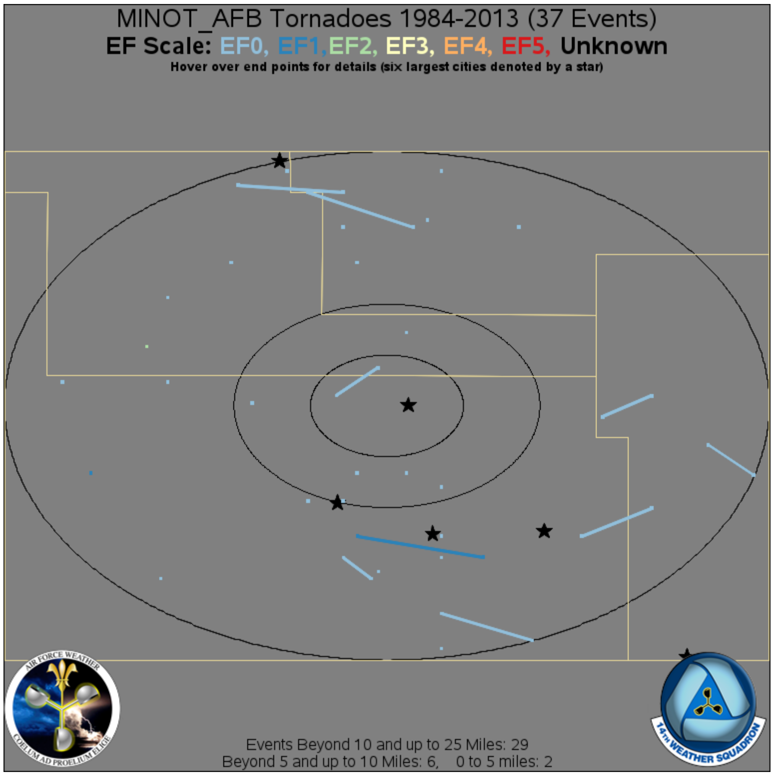
Malmstrom AFB, MT



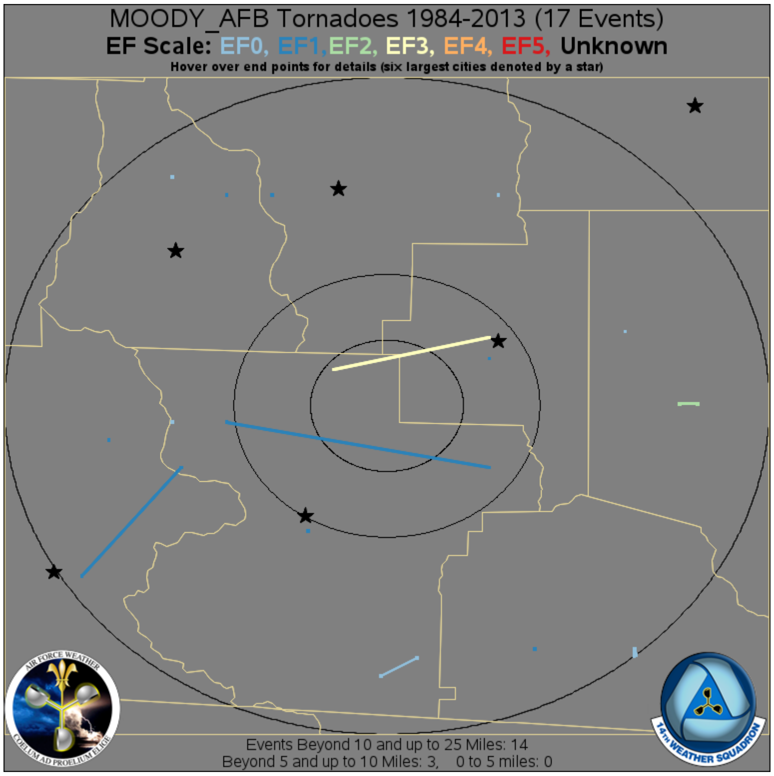
Maxwell AFB, AL



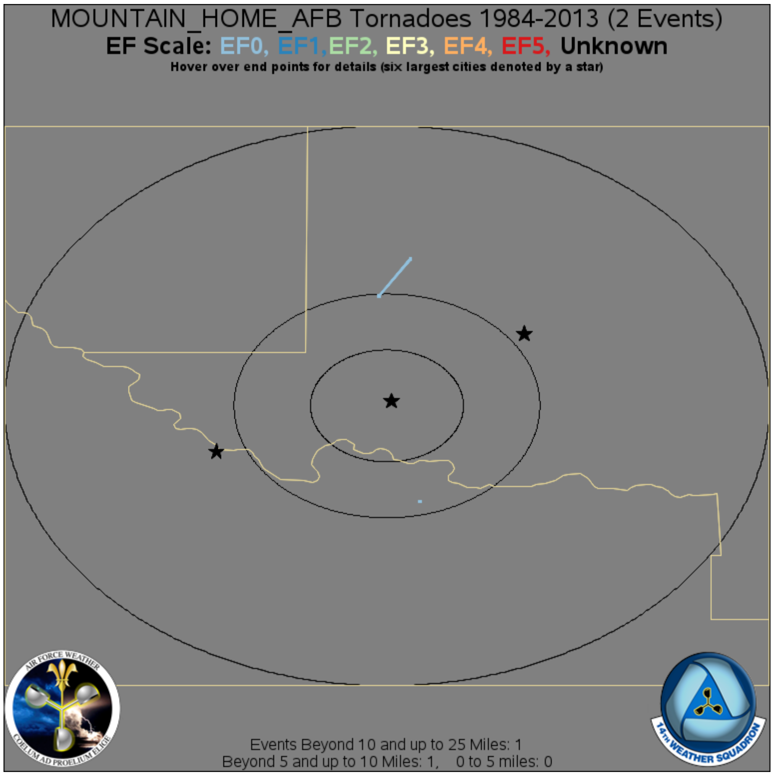
McConnell AFB, KS



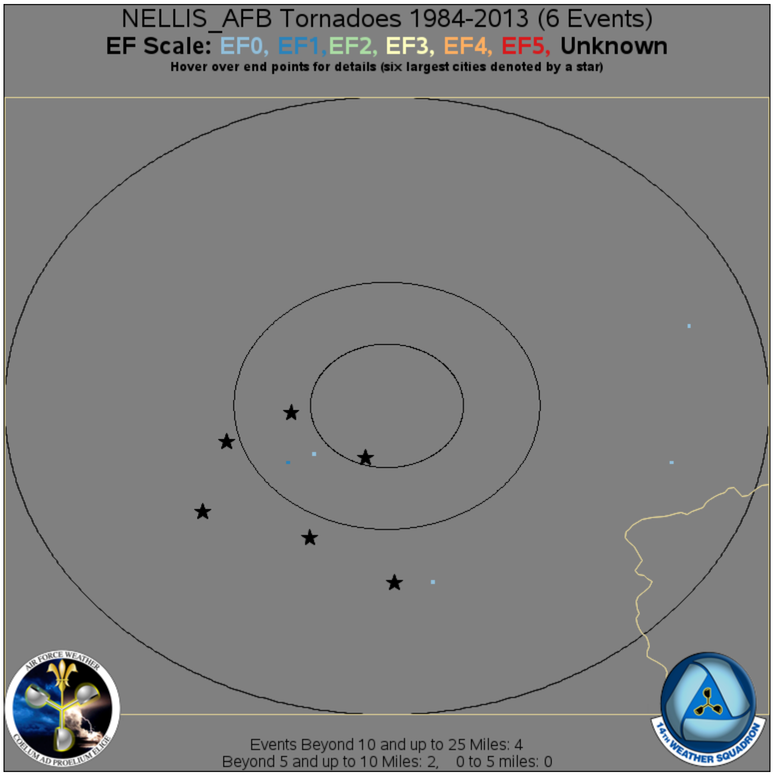
Minot AFB, ND



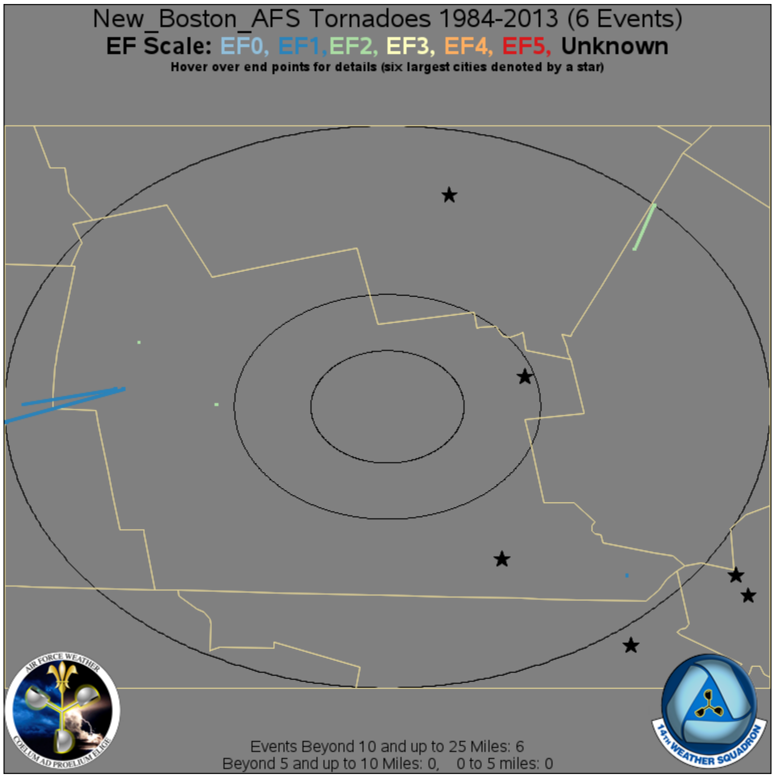
Moody AFB, GA



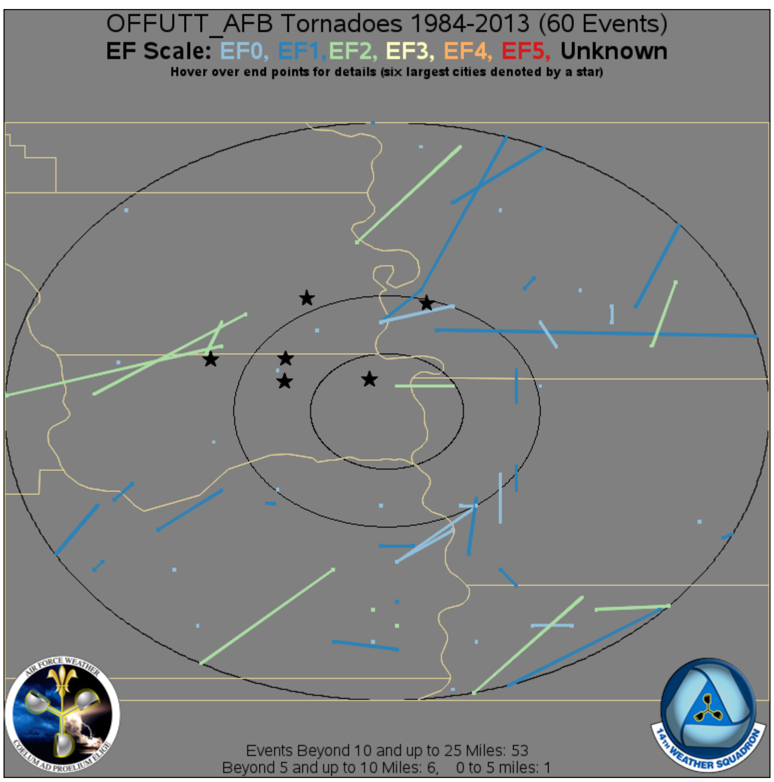
Mountain Home AFB, ID



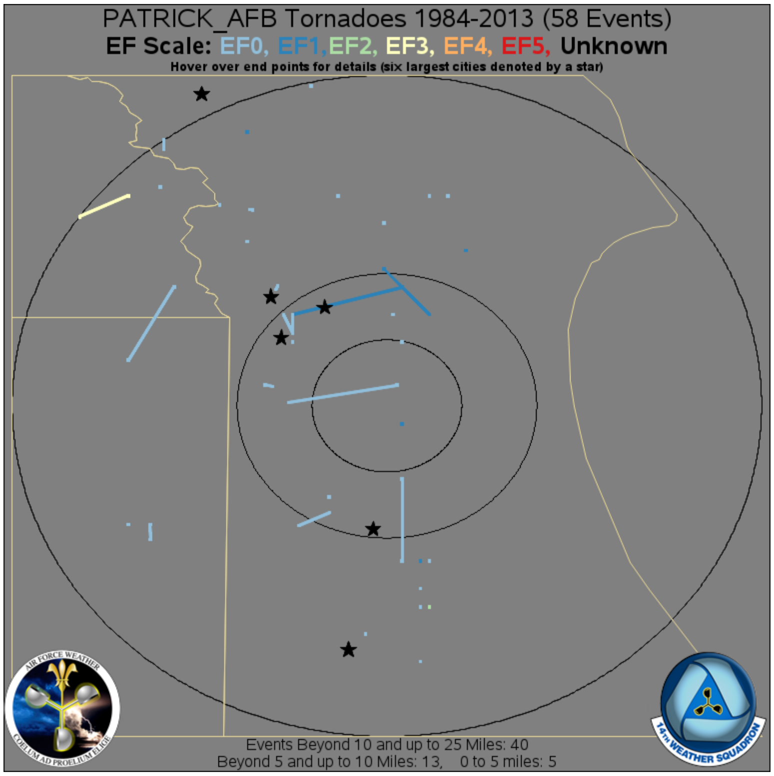
Nellis AFB, NV



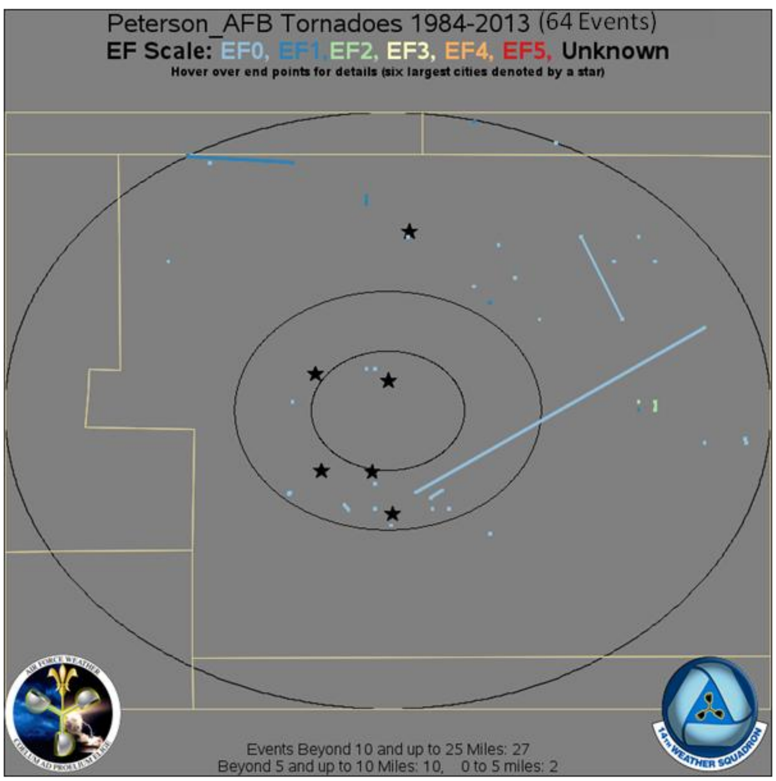
New Boston AFS, NH



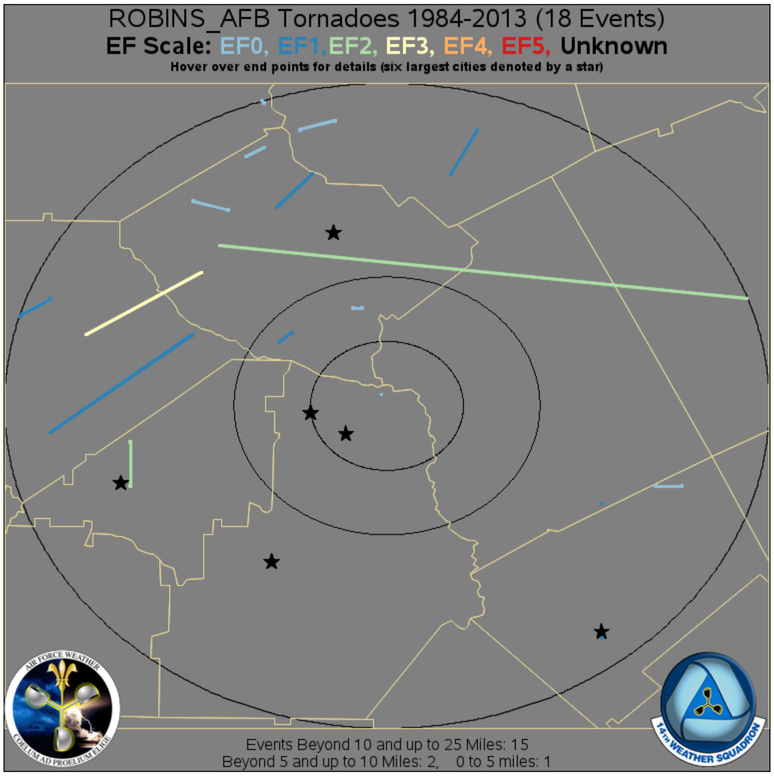
Offutt AFB, NE



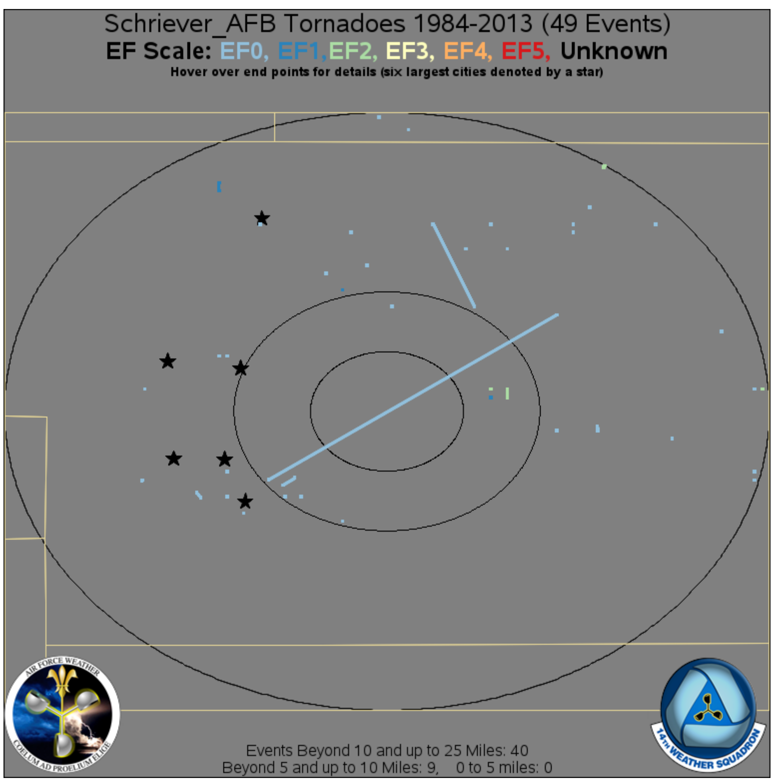
Patrick AFB, FL



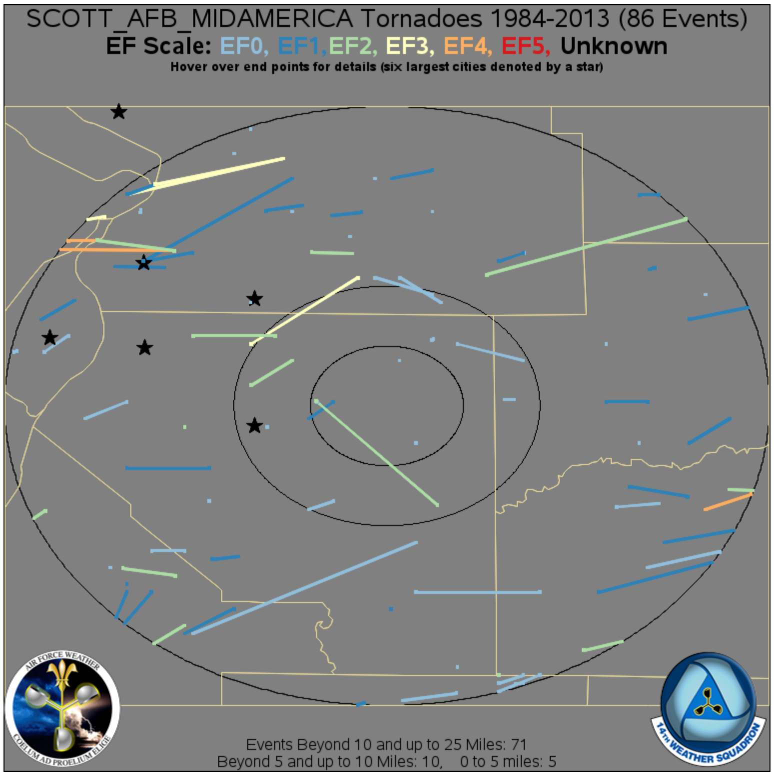
Peterson AFB, CO



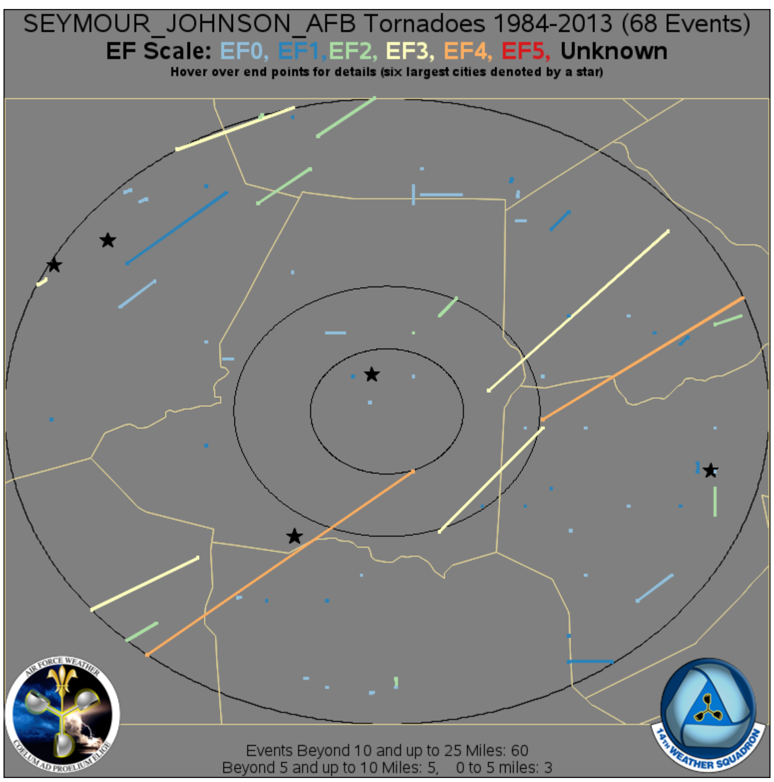
Robins AFB, GA



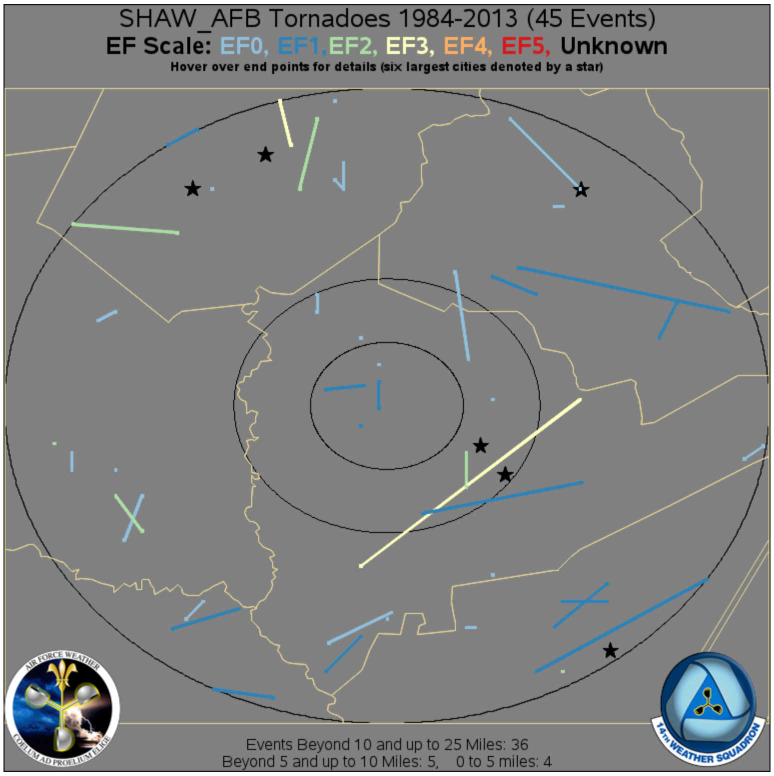
Schriever AFB, CO



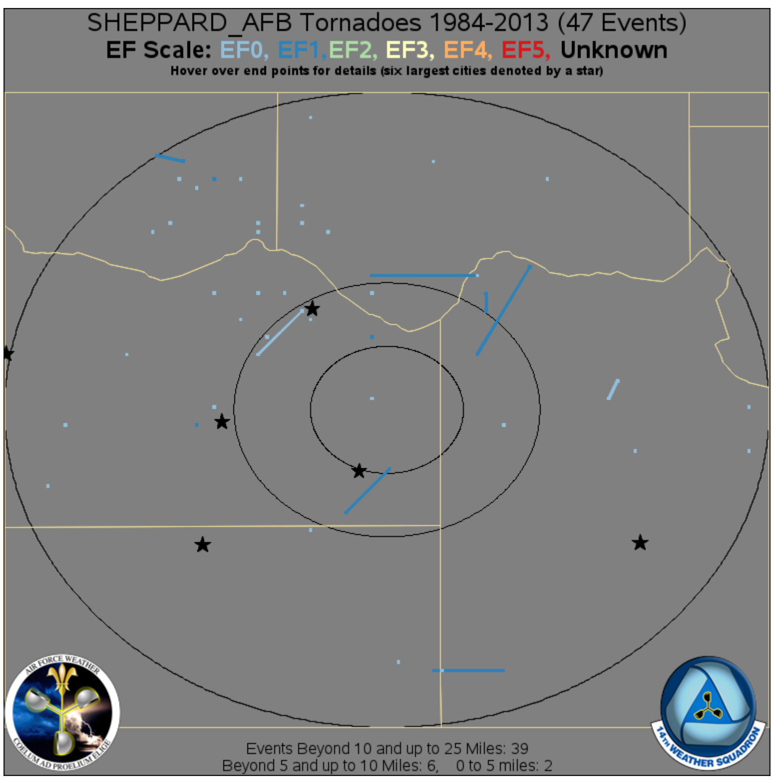
Scott AFB, IL



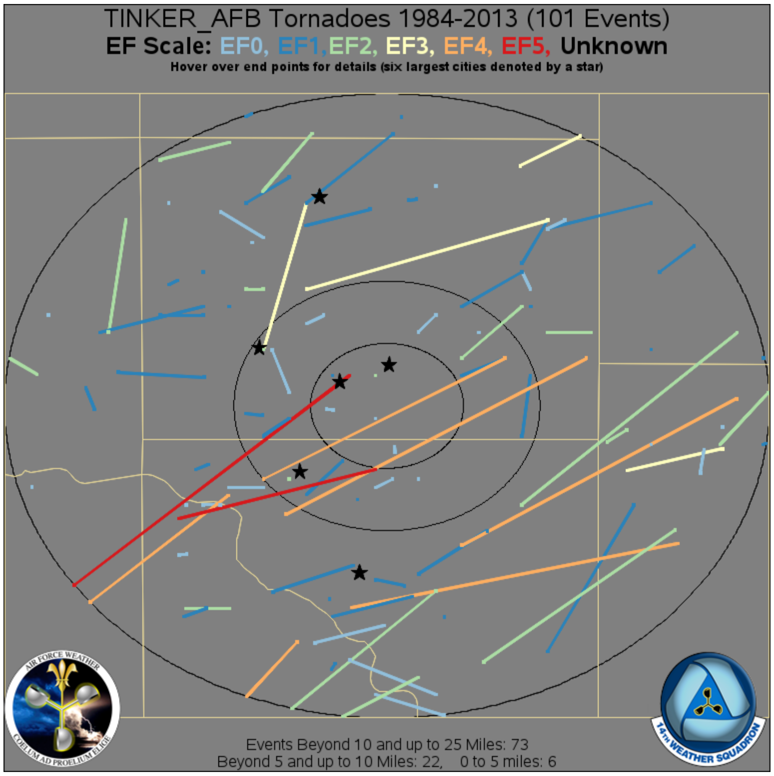
Seymour Johnson AFB, NC



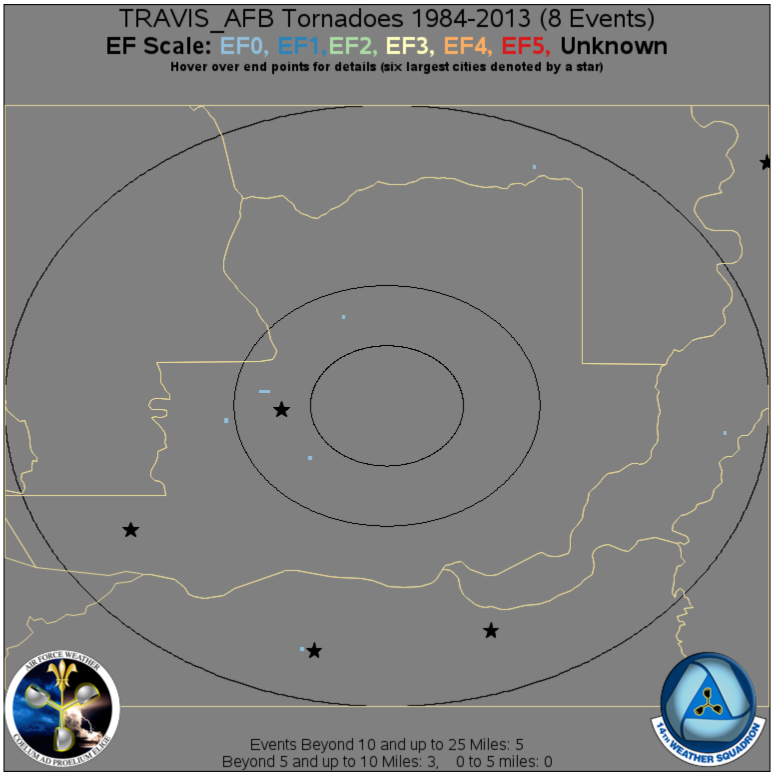
Shaw AFB, SC



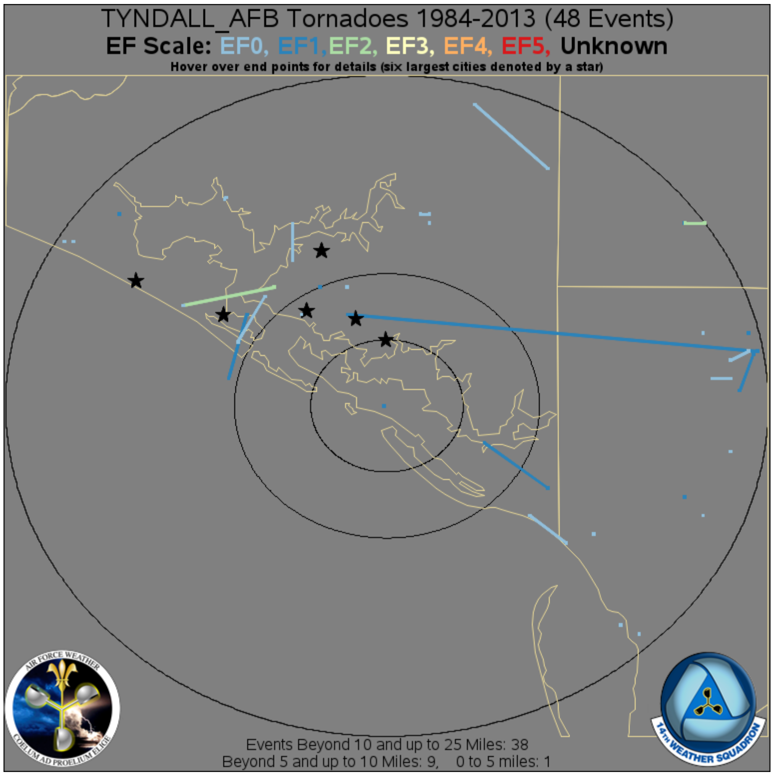
Sheppard AFB, TX



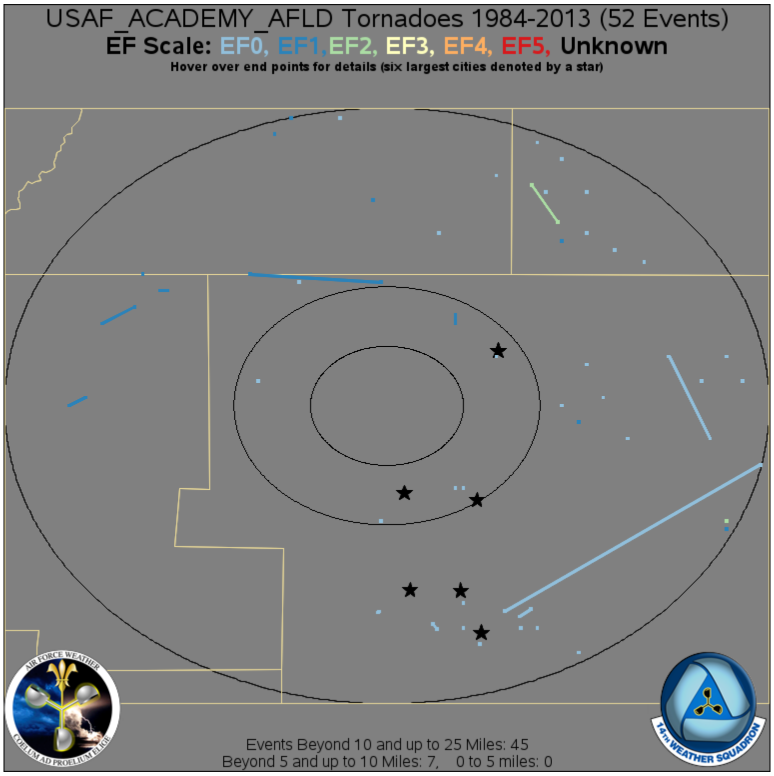
Tinker AFB, OK



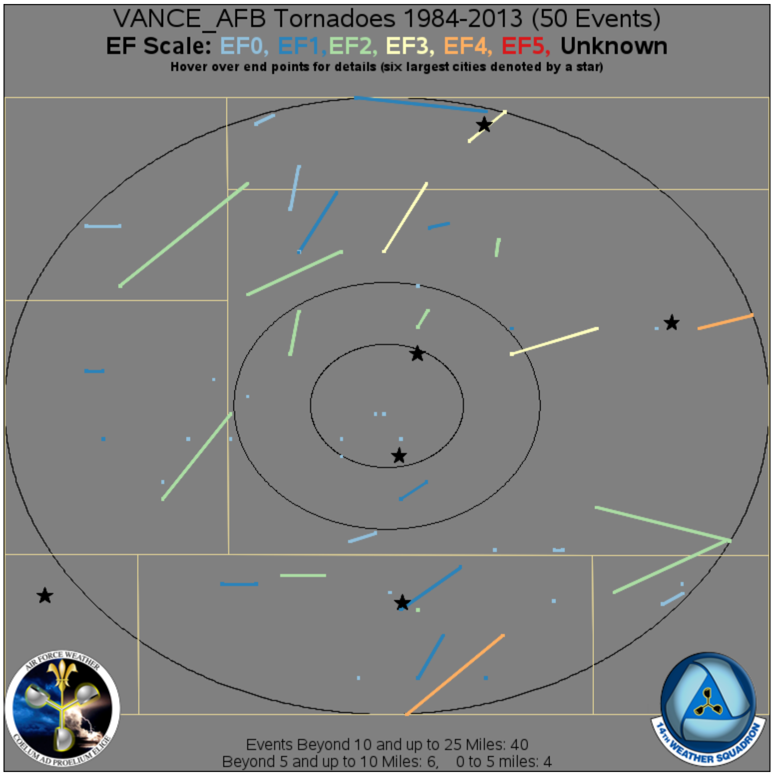
Travis AFB, CA



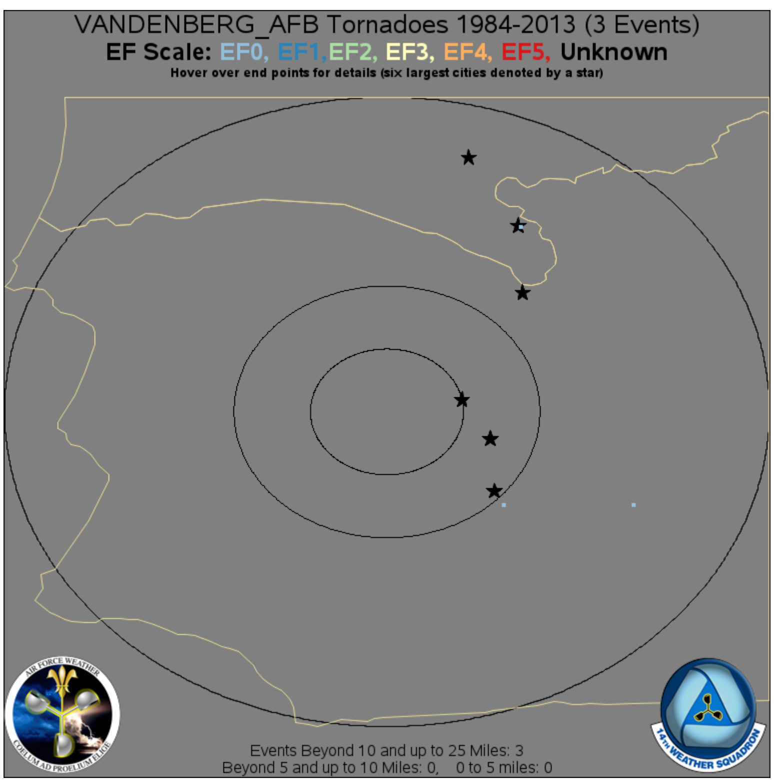
Tyndall AFB, FL



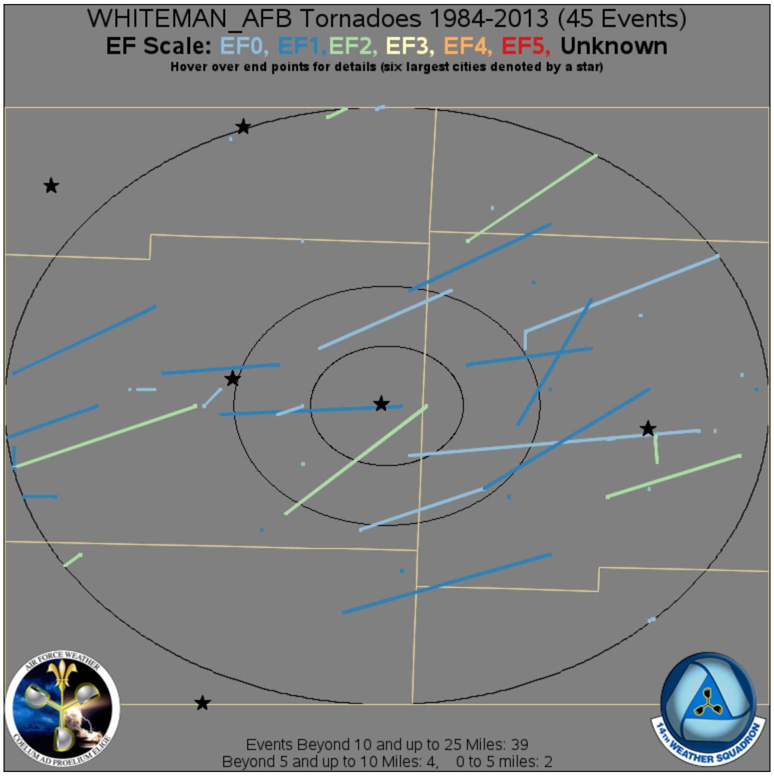
US Air Force Academy, CO



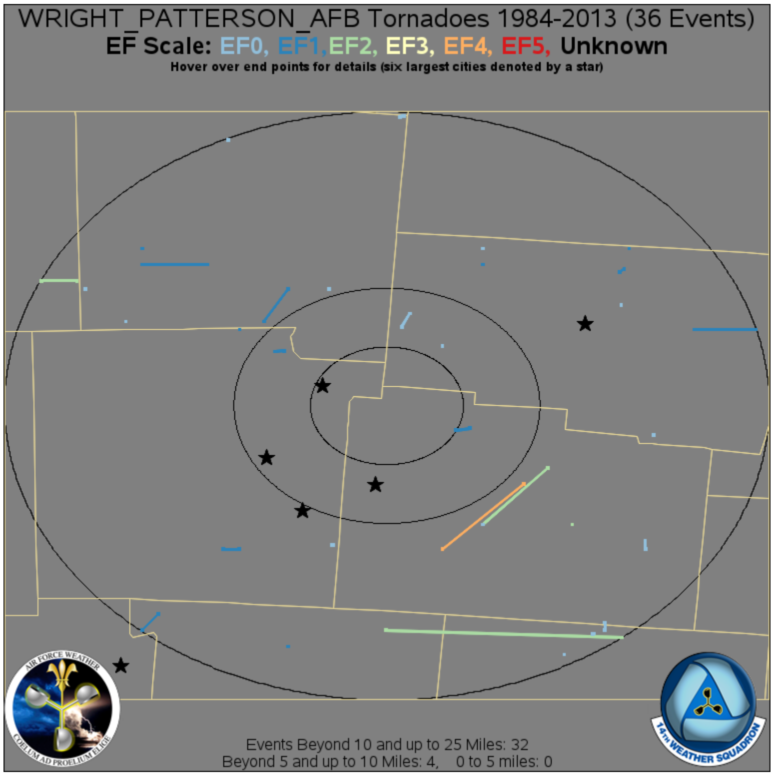
Vance AFB, OK



Vandenberg AFB, CA



Whiteman AFB, MO



Wright-Patterson AFB, OH

Appendix F – Tornado Damage Indicators (DIs) for EF Scale

According to the National Weather Service's Storm Prediction Center, to rate a tornado using the EF-Scale, begin with the 28 Damage Indicators (DIs) listed below (NWS, 2007). Each DI listed has a corresponding description of the type of building or style of construction. Next, once the correct DI is chosen, the next step is to assign a Degree of Damage (DoD). A sample DoD for DI No. 17 is shown in Appendix G. For each DoD within a given DI, there is an expected wind speed and a lower and upper bound of wind speed. The final EF rating comes from a set of wind estimates based on damage, not actual wind-speed readings (NWS, 2007).

DI No.	Damage Indicator (DI)
1	Small Barns or Farm Outbuildings (SBO)
2	One- or Two-Family Residences (FR12)
3	Manufactured Home – Single Wide (MHSW)
4	Manufactured Home – Double Wide (MHDW)
5	Apartments, Condos, Townhouses [3 stories or less] (ACT)
6	Motel (M)
7	Masonry Apartment or Motel Building (MAM)
8	Small Retail Building [Fast Food Restaurants] (SRB)
9	Small Professional Building [Doctor's Office, Branch Banks] (SPB)
10	Strip Mall (SM)
11	Large Shopping Mall (LSM)
12	Large, Isolated Retail Building [K-Mart, Wal-Mart] (LIRB)
13	Automobile Showroom (ASR)
14	Automobile Service Building (ASB)
15	Elementary School [Single Story; Interior or Exterior Hallways] (ES)
16	Junior or Senior High School (JHSH)
17	Low-Rise Building [1-4 Stories] (LRB)
18	Mid-Rise Building [5-20 Stories] (MRB)
19	High-Rise Building [More than 20 Stories] (HRB)
20	Institutional Building [Hospital, Government or University Building] (IB)
21	Metal Building System (MBS)
22	Service Station Canopy (SSC)
23	Warehouse Building [Tilt-up Walls or Heavy-Timber Construction](WHB)
24	Electrical Transmission Lines (ETL)
25	Free-Standing Towers (FST)
26	Free-Standing Light Poles, Luminary Poles, Flag Poles (FSP)
27	Trees: Hardwood (TH)
28	Trees: Softwood (TS)

(NWS, 2007)

Appendix G – Tornado Degrees of Damage (DoD)

17. LOW-RISE BUILDING: 1–4 STORIES (LRB)

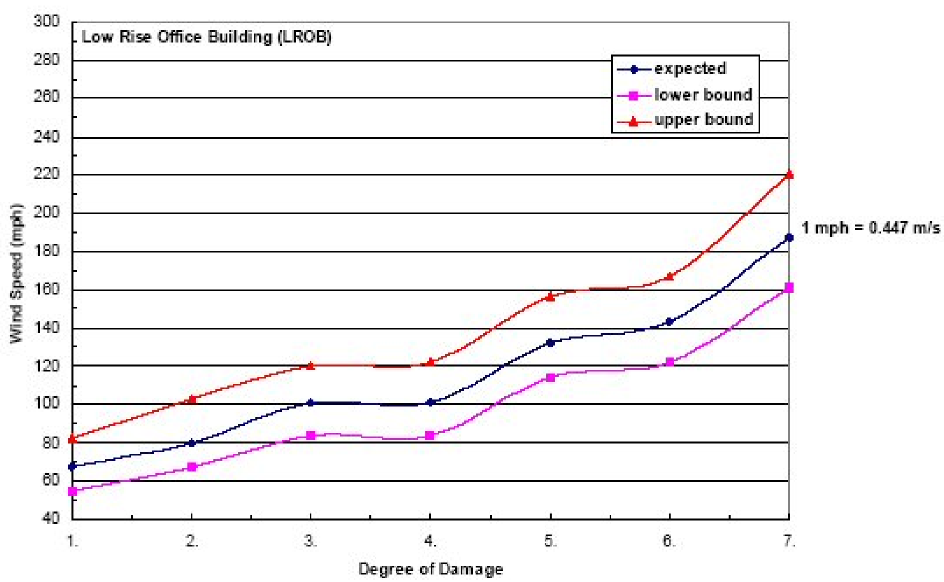
(NWS, 2007)

General Description

- Generally consist of rectangular modules but can be "odd shaped" in plan
- Most will have flat roofs but can have gable, hip, or mansard shapes
- Roofing materials include BUR, single-ply membrane, metal panels, or standing seam
- Roof deck is wood or metal deck, poured gypsum deck, or concrete slab
- Steel or reinforced concrete structural frame
- Glass and metal curtain walls, metal studs with EIFS, non-bearing masonry walls with stucco, or brick veneer
- Examples are office buildings, medical facilities, and bank buildings.

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	68	55	83
2	Loss of roof covering (<20%)	80	67	103
3	Uplift of metal roof decking at eaves and roof corners: significant loss of roofing material (>20%)	101	83	120
4	Broken glass in windows, entryways or atriums	101	83	122
5	Uplift of lightweight roof structure	133	114	157
6	Significant damage to exterior walls and some interior walls	143	122	167
7	Complete destruction of all or a large section of building	188	161	221

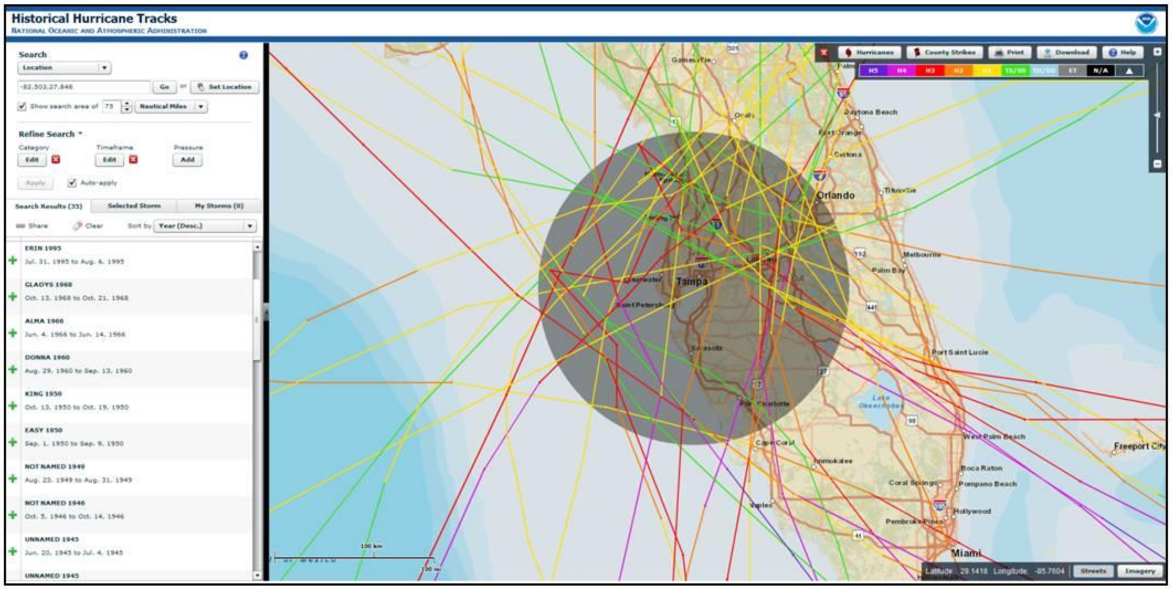
* Degree of Damage



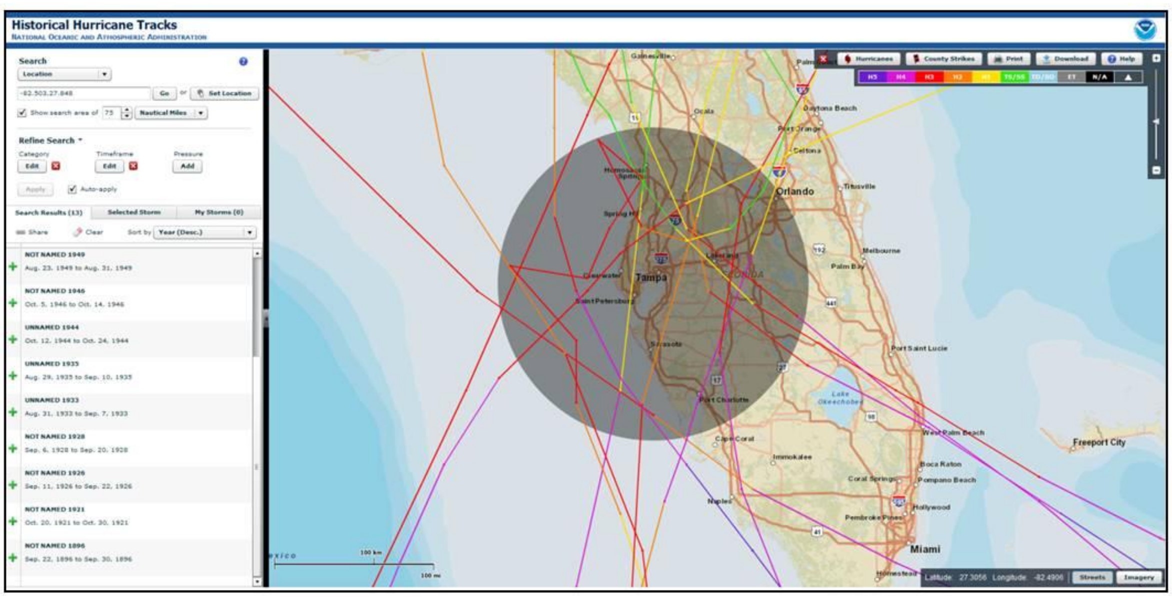
Appendix H – Map of Hurricane Occurrences by Base

Hurricane Rank #1 – MacDill AFB, FL

35 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

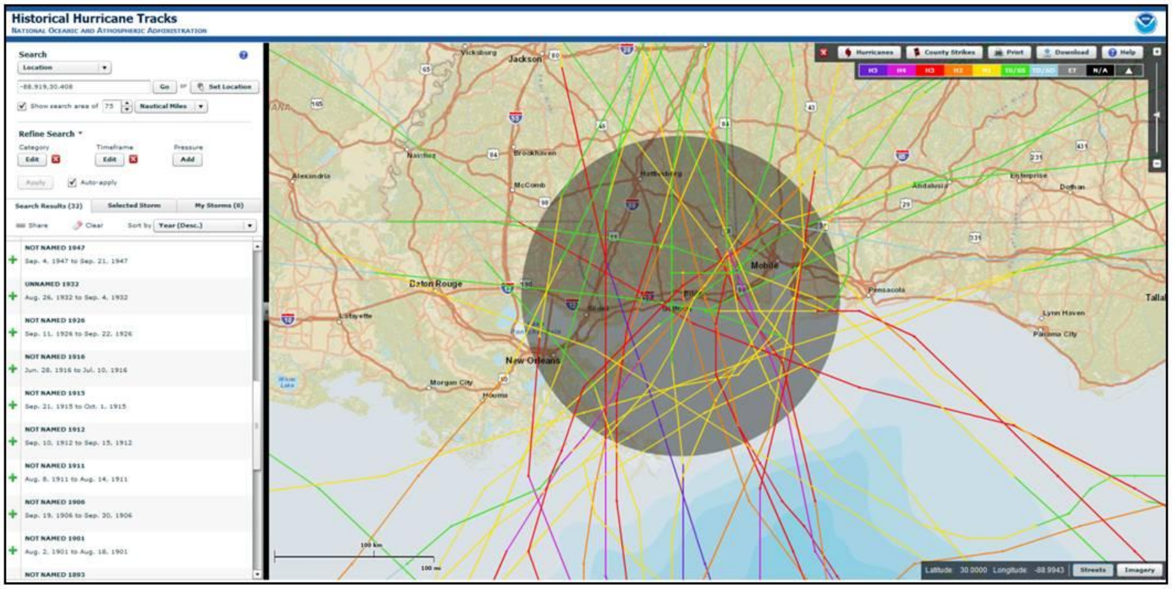


13 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

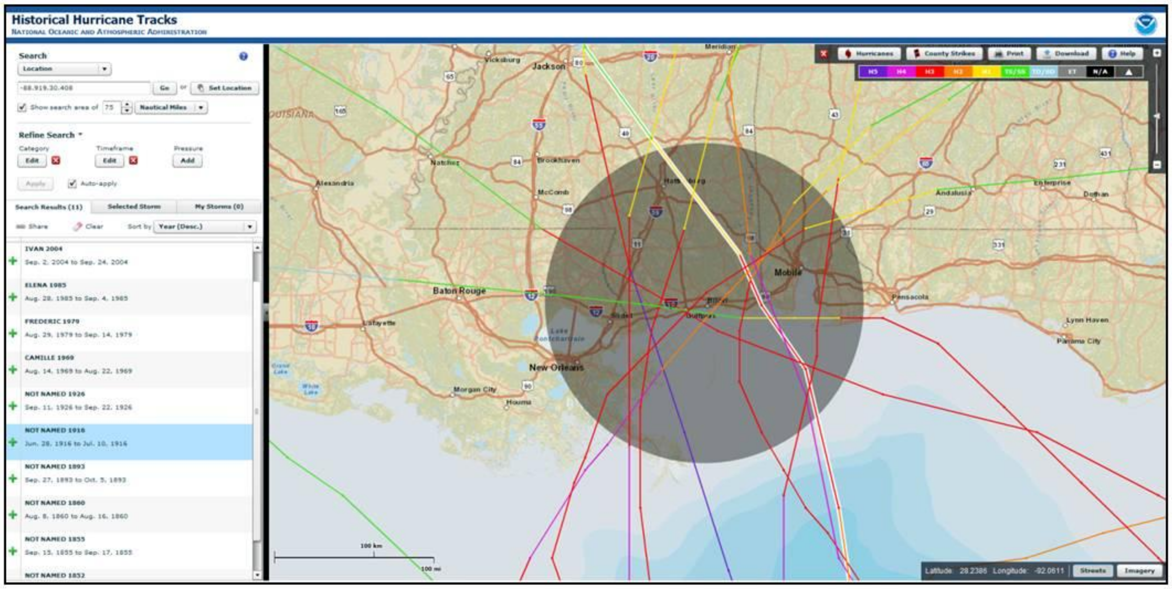


Hurricane Rank #2 –Keesler AFB, MS

32 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

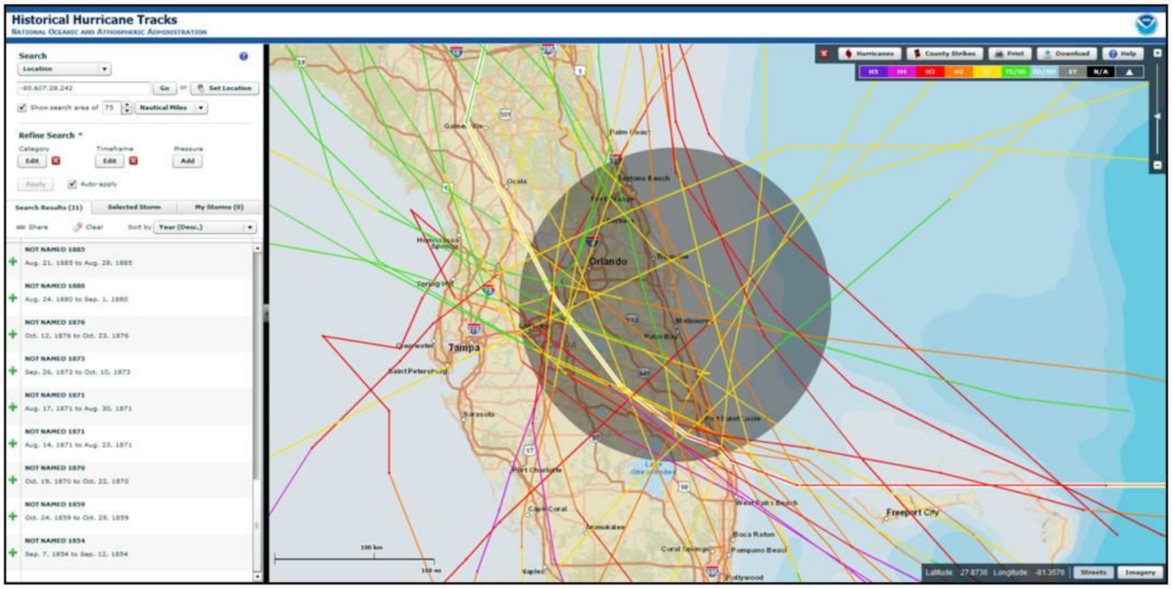


11 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

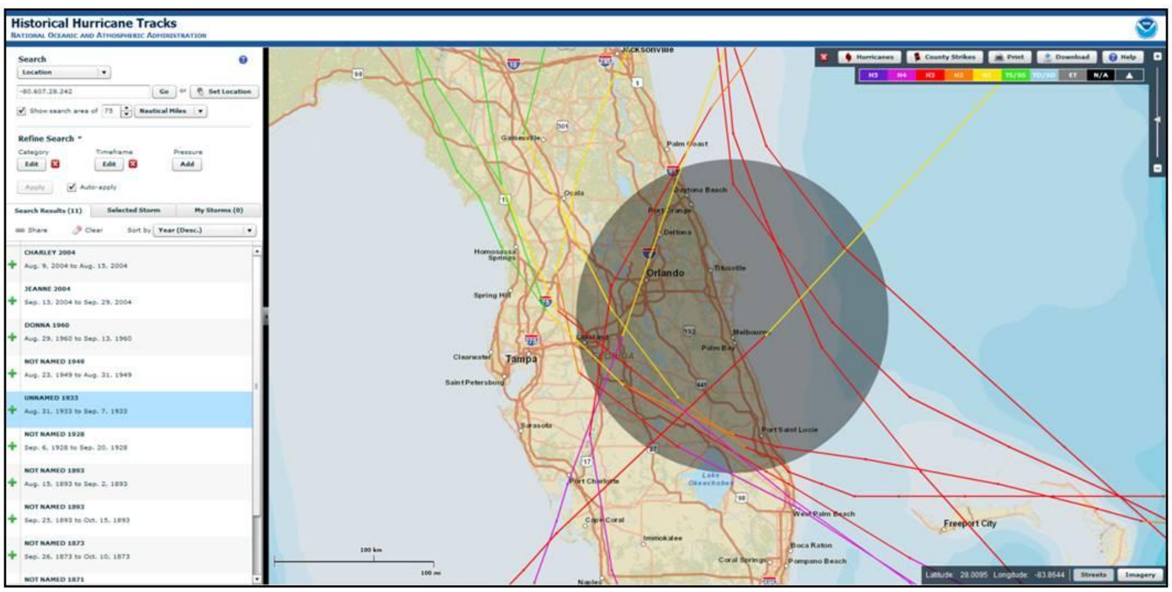


Hurricane Rank #3 – Patrick AFB, FL

31 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

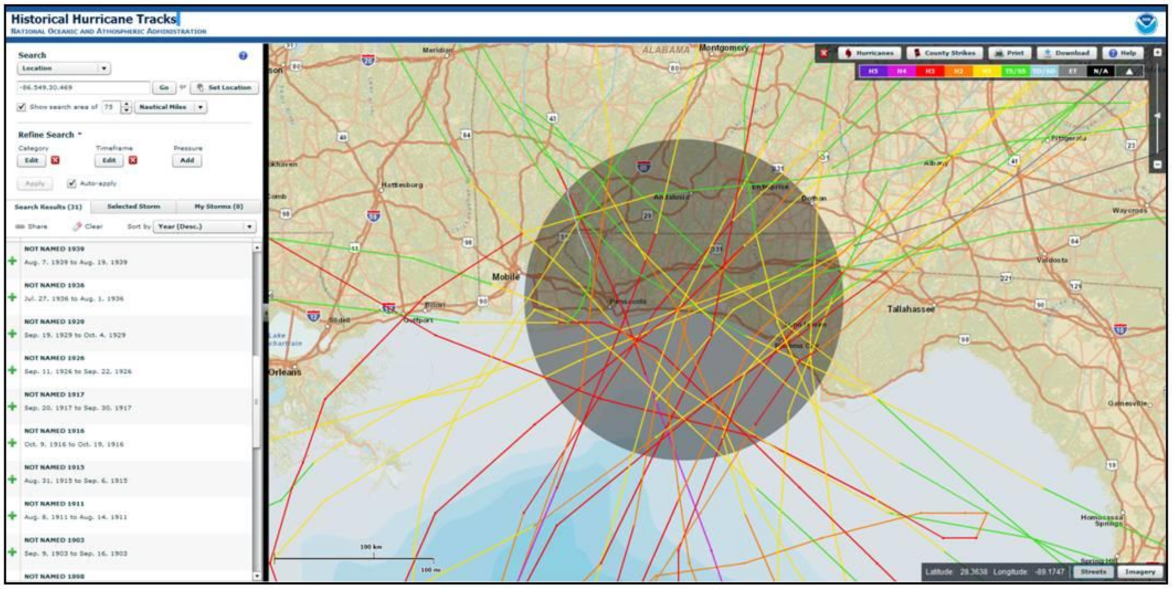


11 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

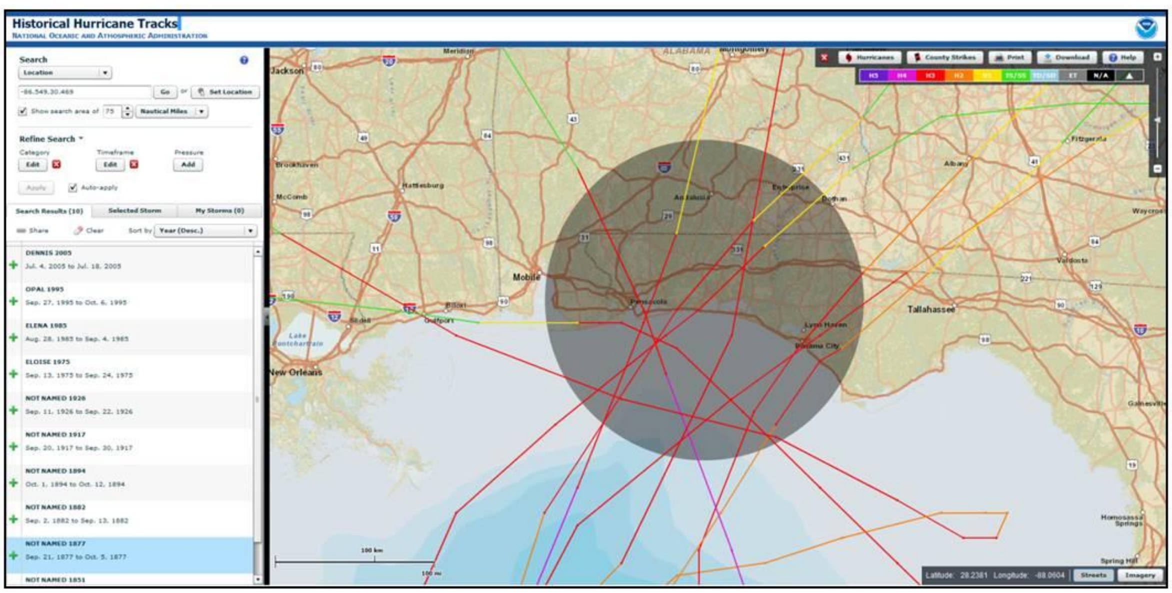


Hurricane Rank #4 (Tie) – Eglin AFB, FL

31 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

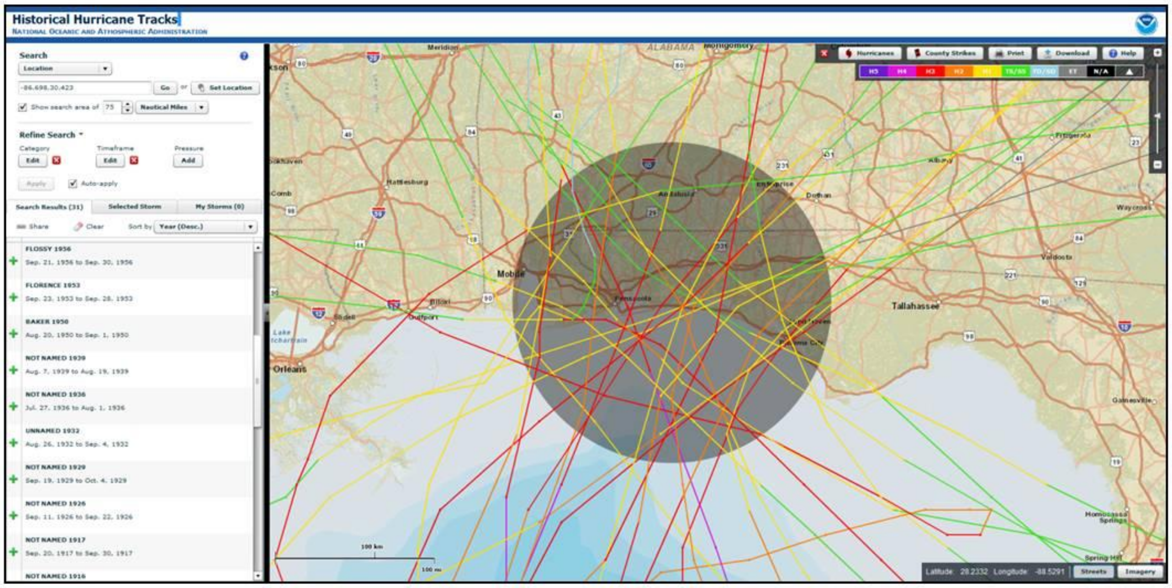


10 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

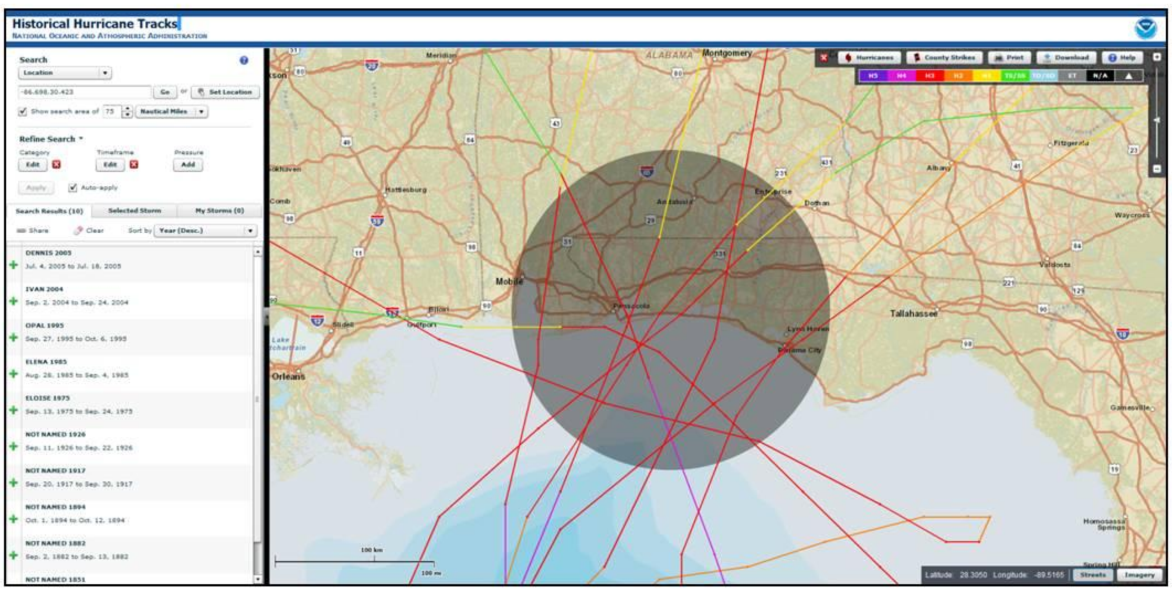


Hurricane Rank #4 (Tie) – Hurlburt Field, FL

31 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

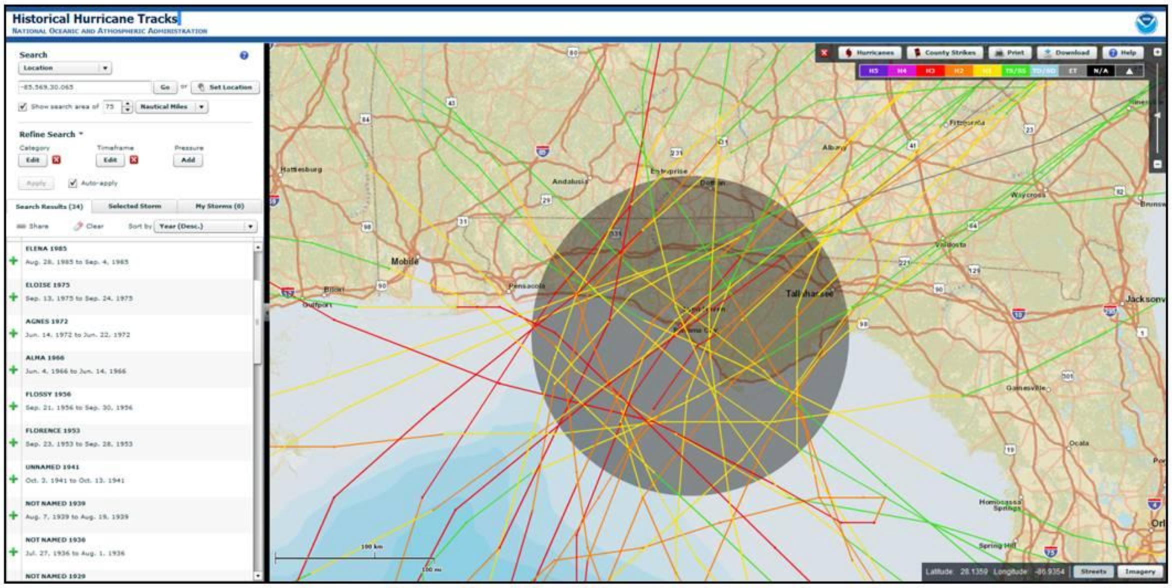


10 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

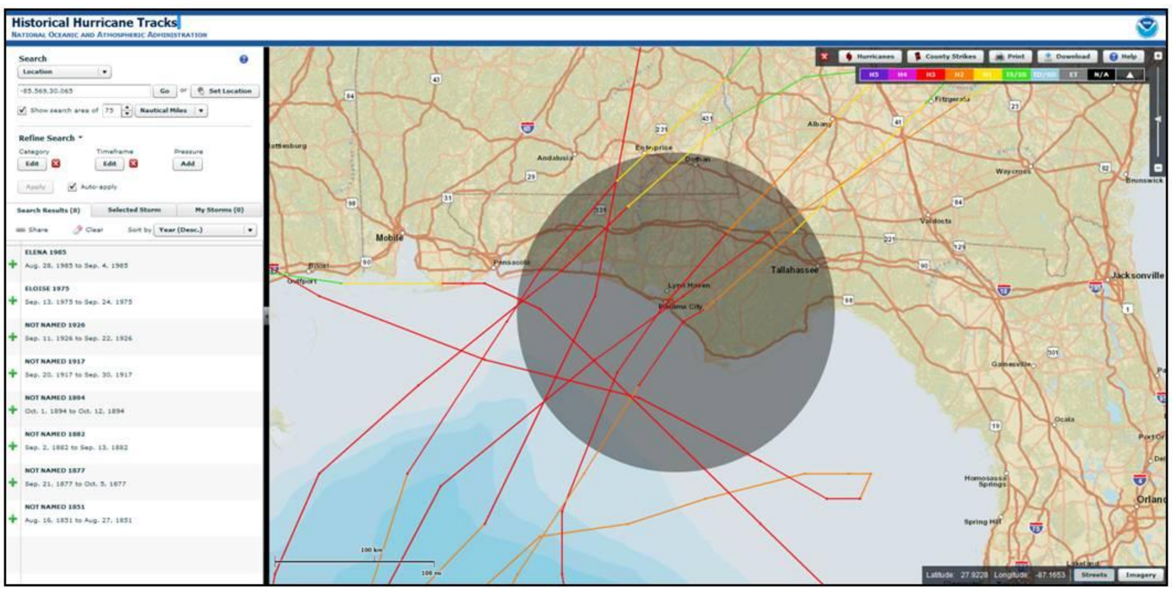


Hurricane Rank #5 – Tyndall AFB, FL

34 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

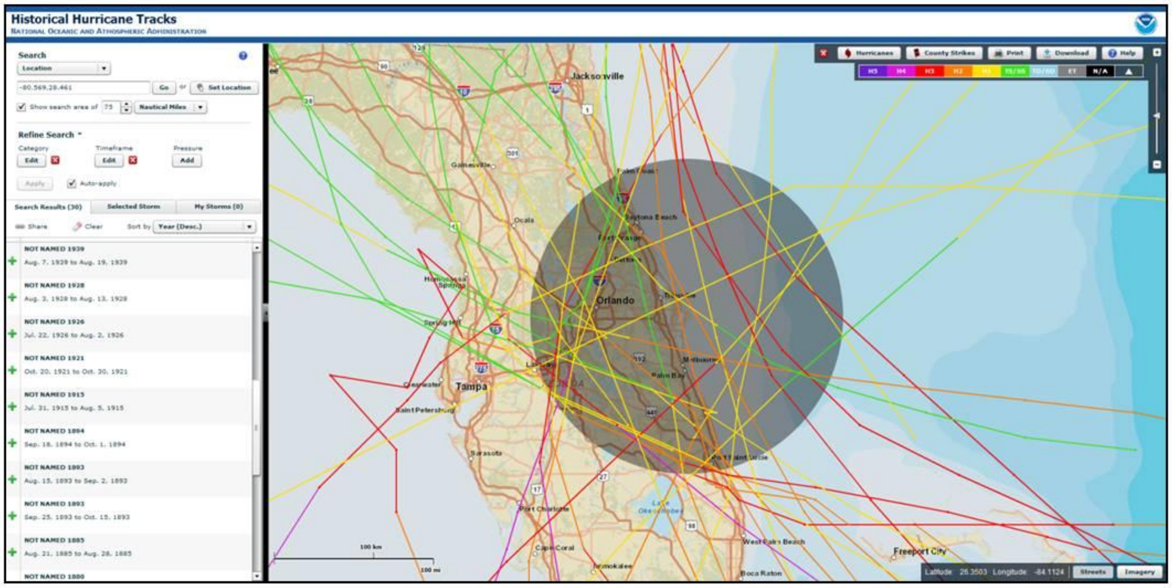


8 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

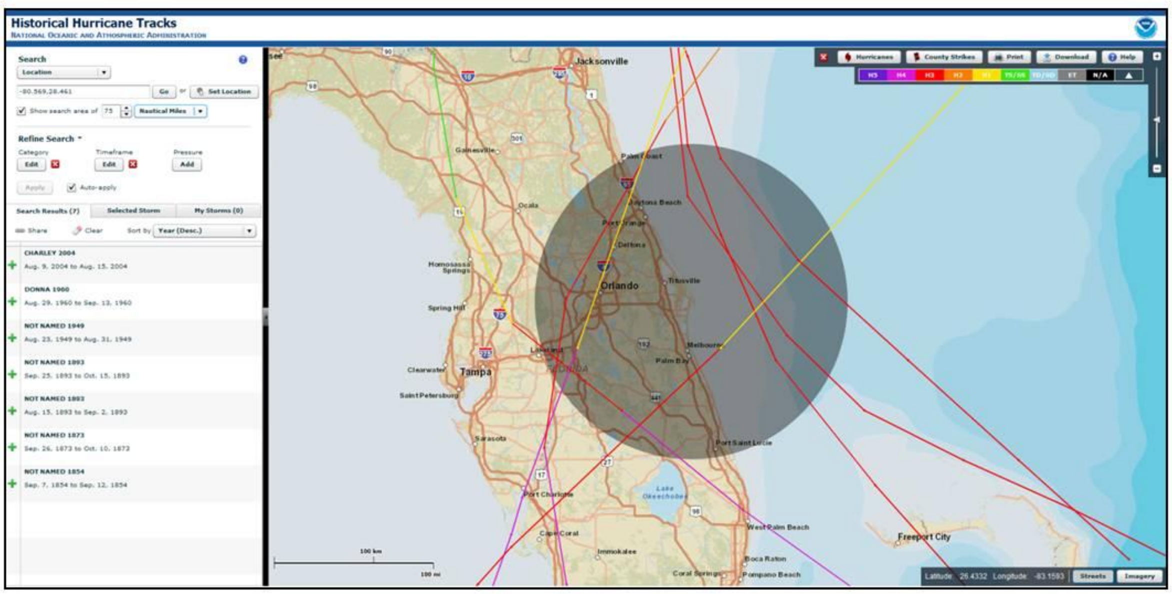


Hurricane Rank #6 – Cape Canaveral AFS, FL

30 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

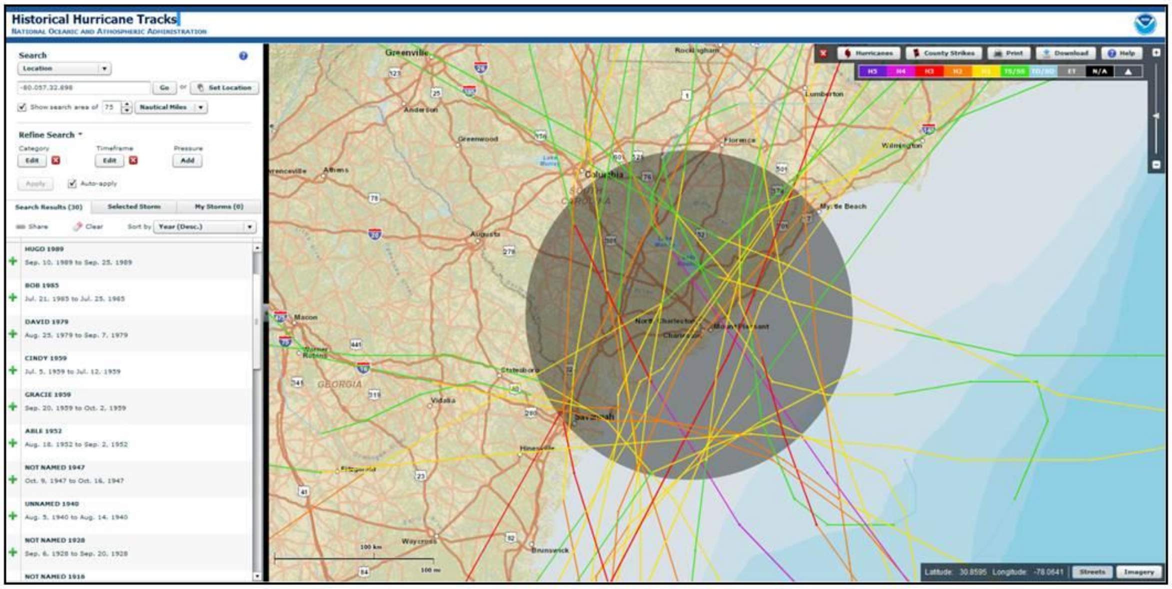


7 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

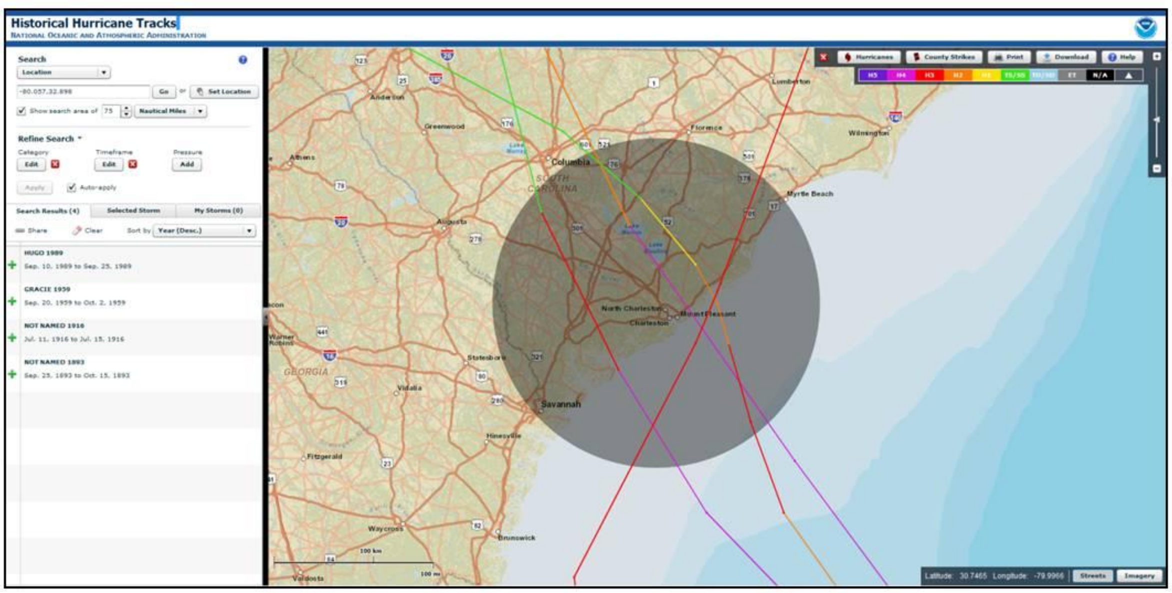


Hurricane Rank #7 – Joint Base Charleston, SC

30 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

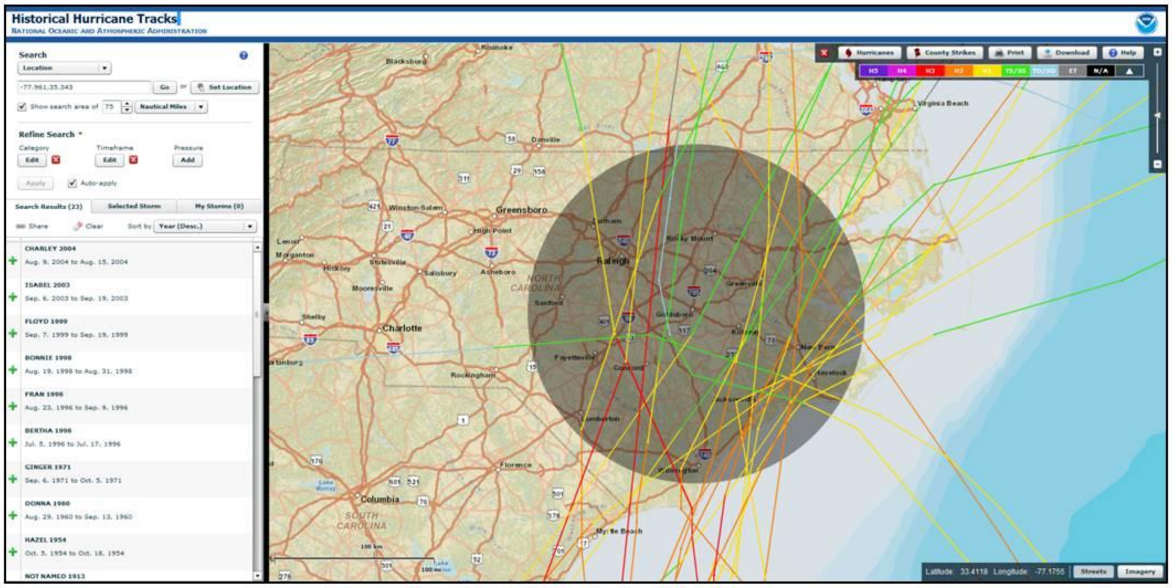


4 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

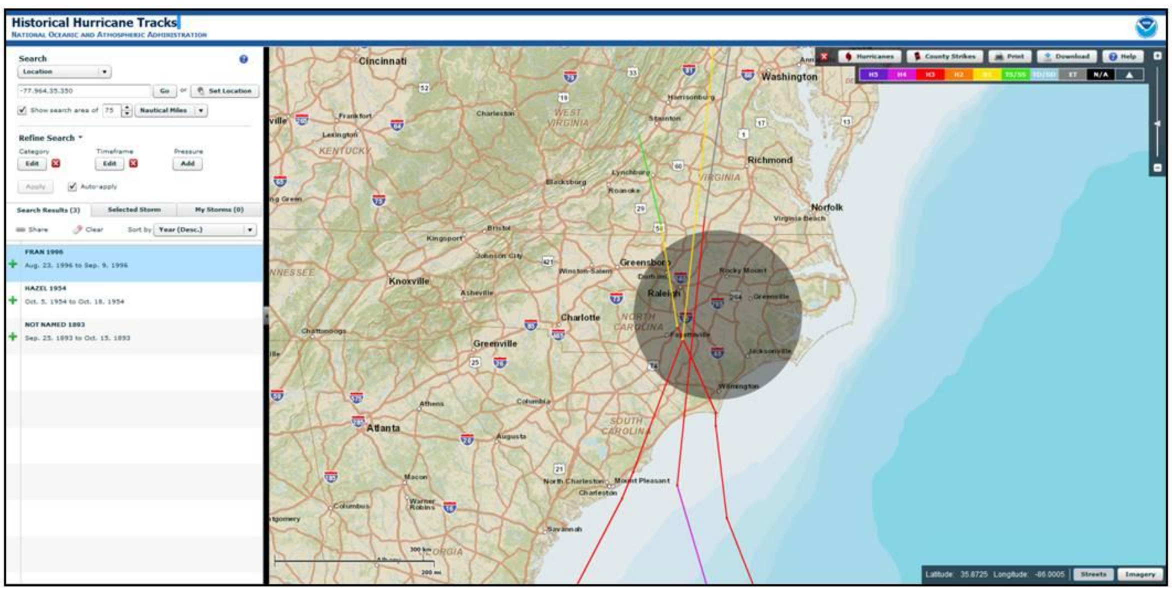


Hurricane Rank #8 – Seymour Johnson AFB, NC

23 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

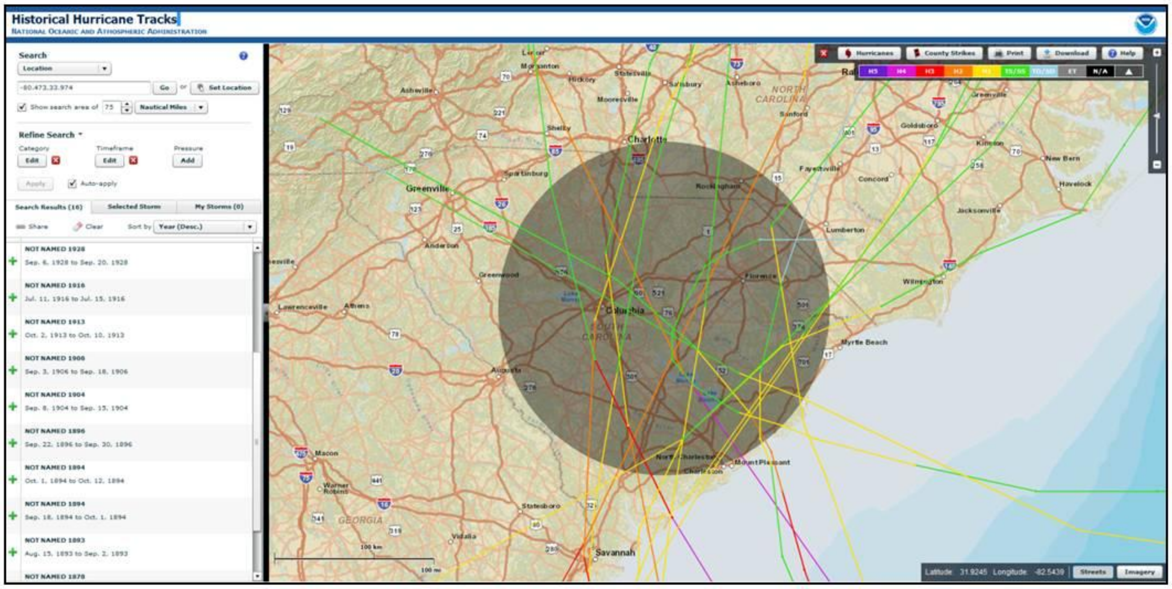


3 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

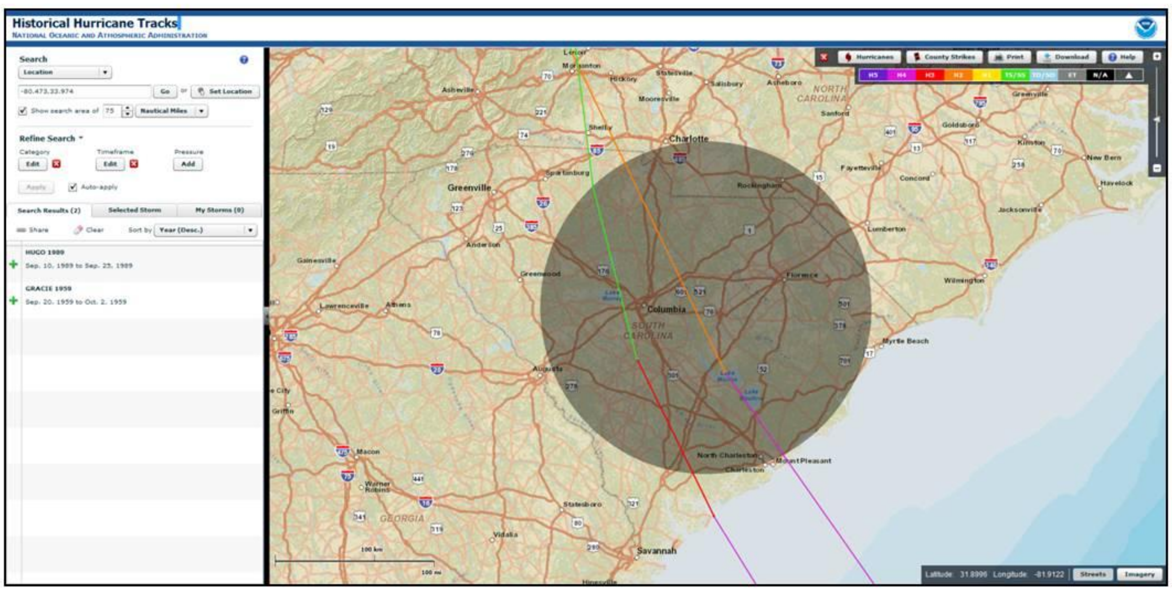


Hurricane Rank #9 – Shaw AFB, SC

16 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

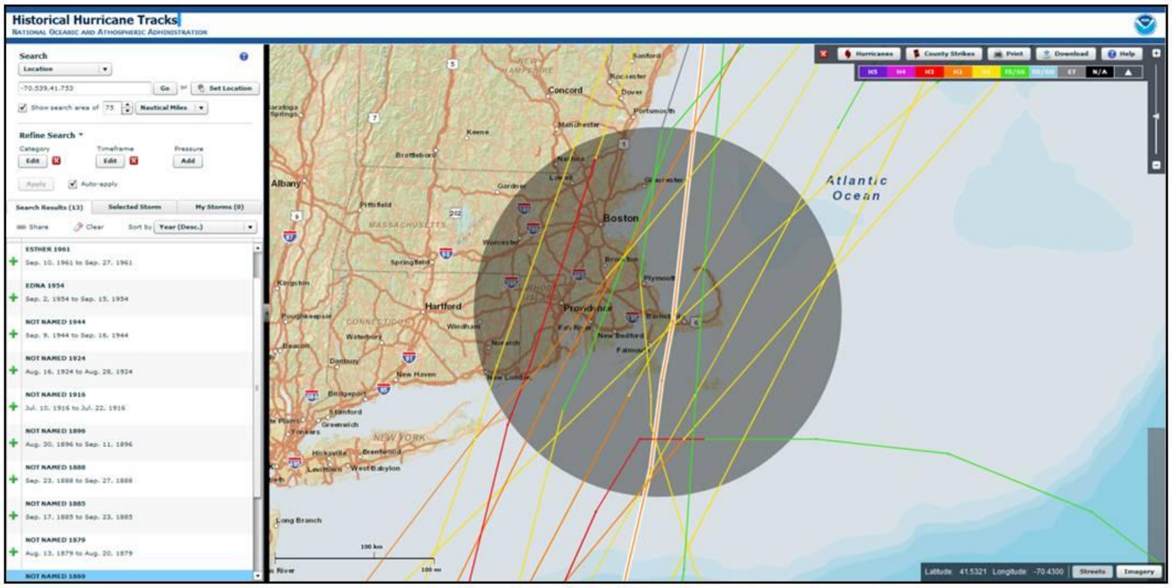


2 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

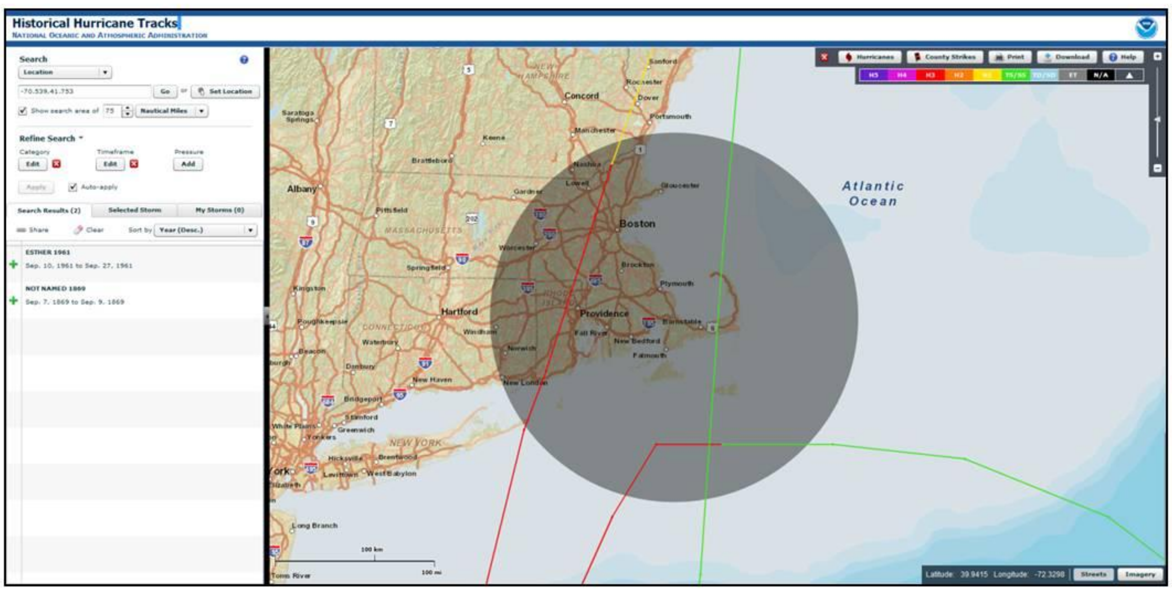


Hurricane Rank #10 – Cape Cod AS, MA

13 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

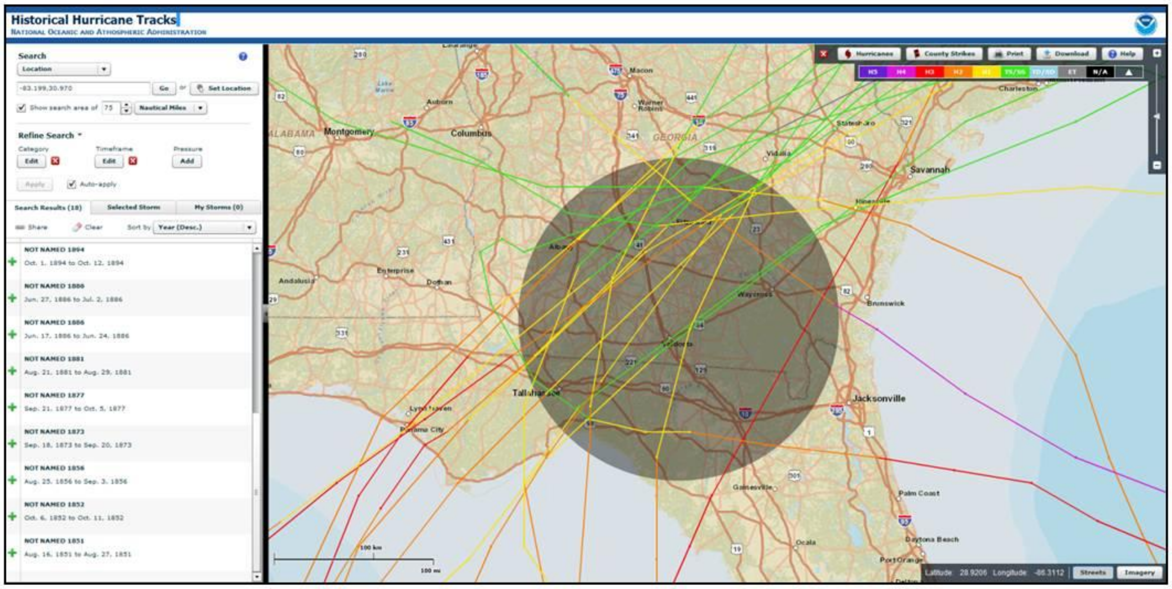


2 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

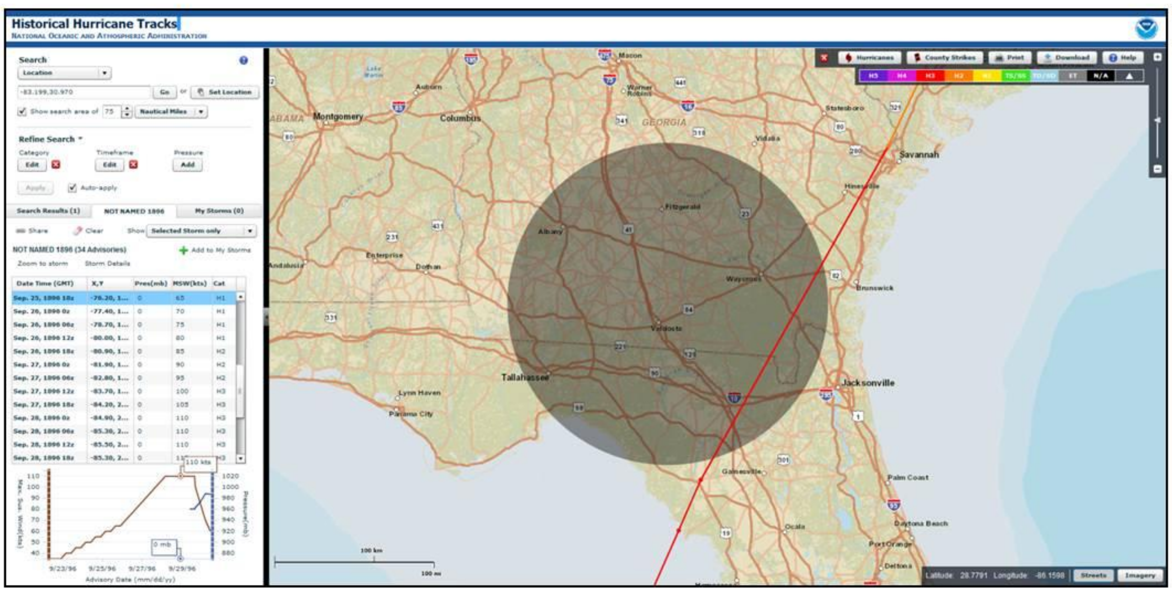


Hurricane Rank #11 – Moody AFB, GA

18 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

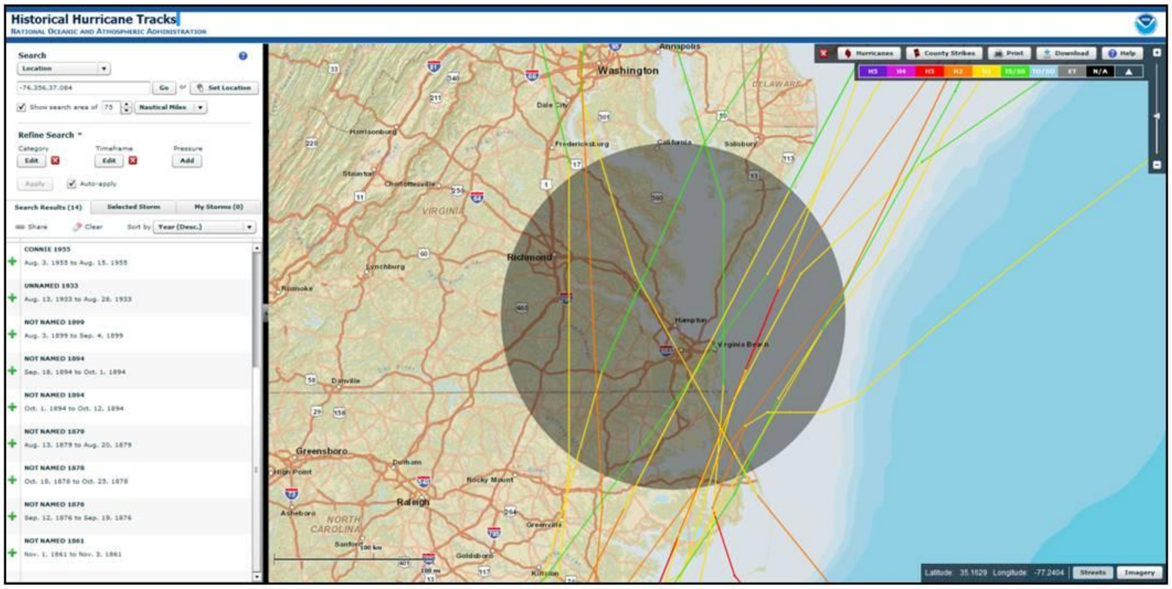


1 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

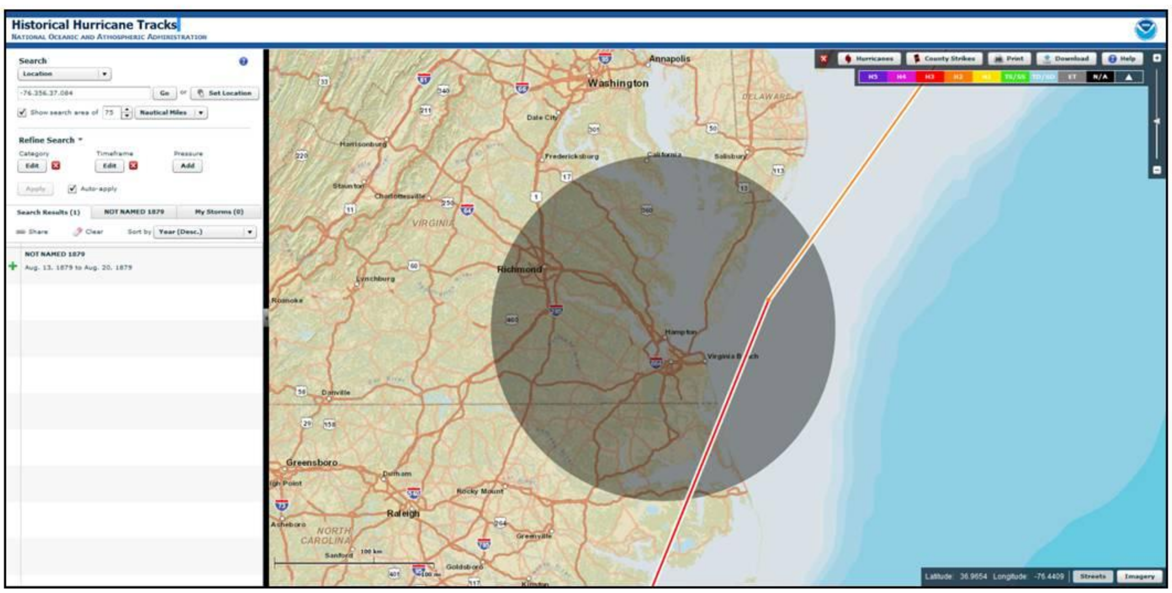


Hurricane Rank #12 – Joint Base Langley-Eustis (JBLE), VA

14 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

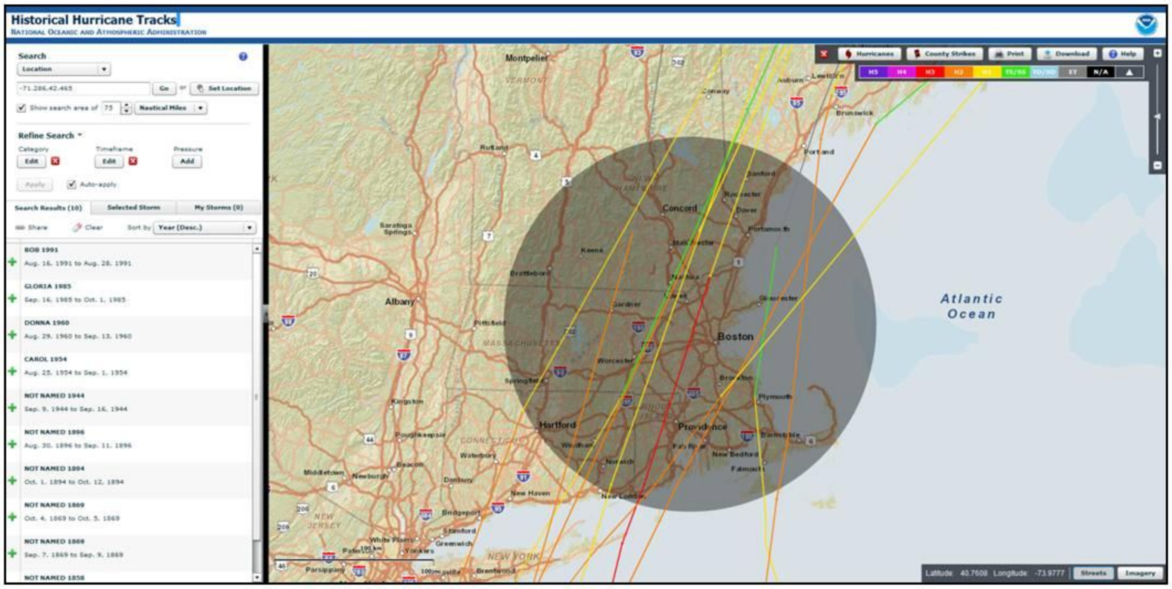


1 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

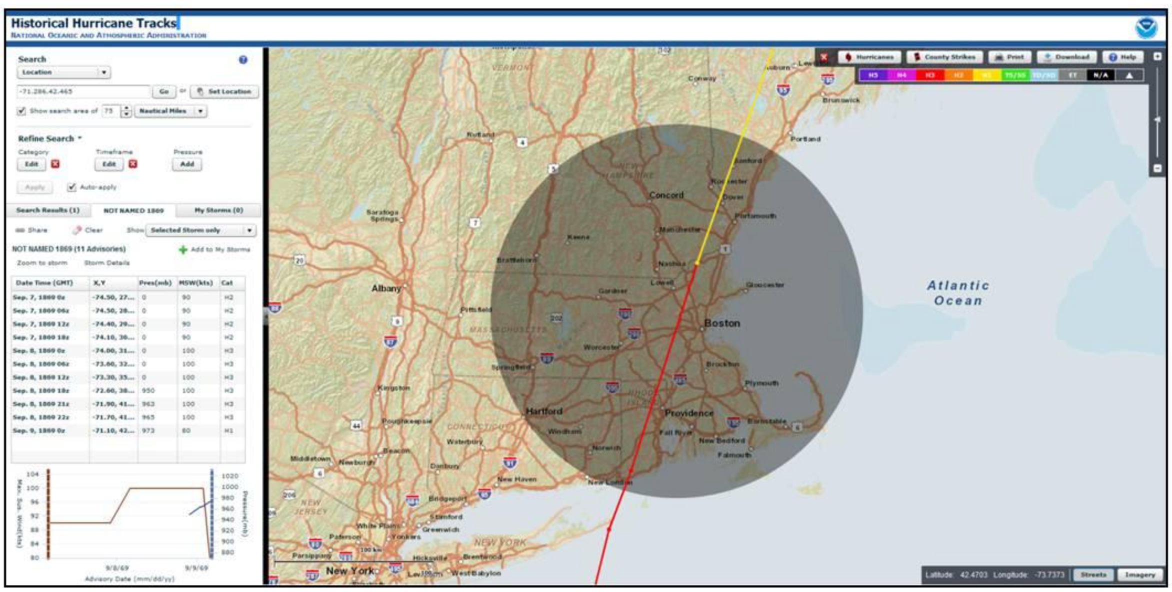


Hurricane Rank #13 – Hanscom AFB, MA

10 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

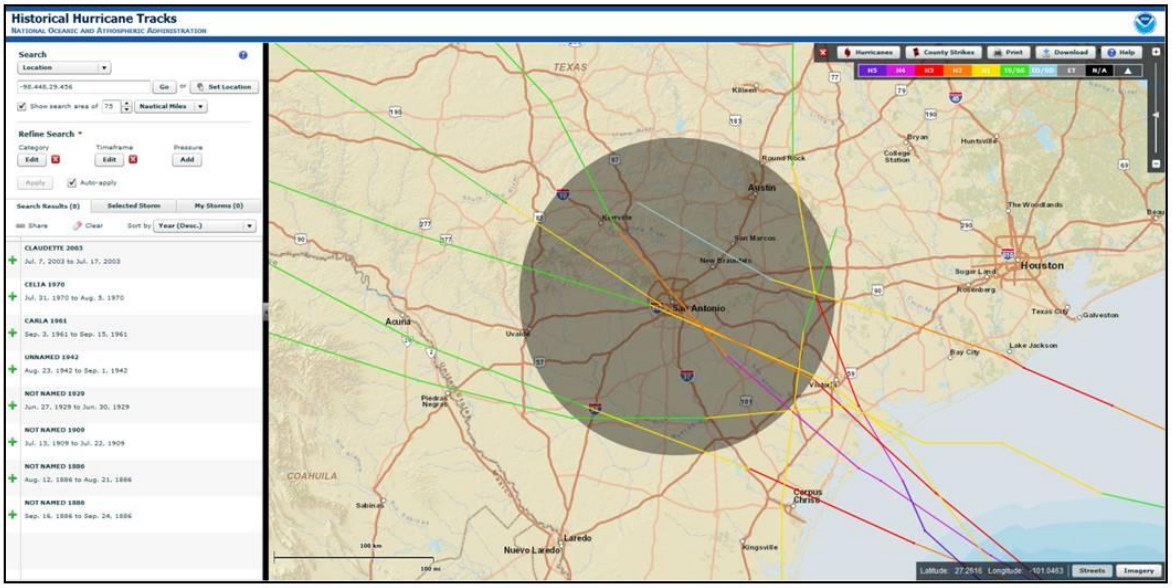


1 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

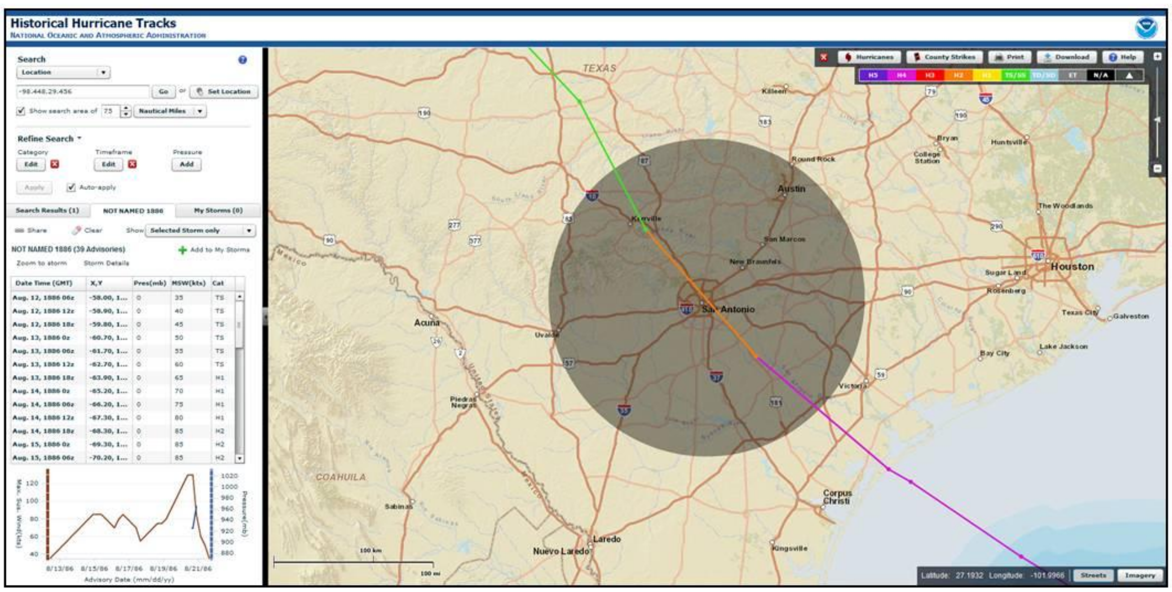


Hurricane Rank #14 – Joint Base San Antonio (JBSA), TX

8 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

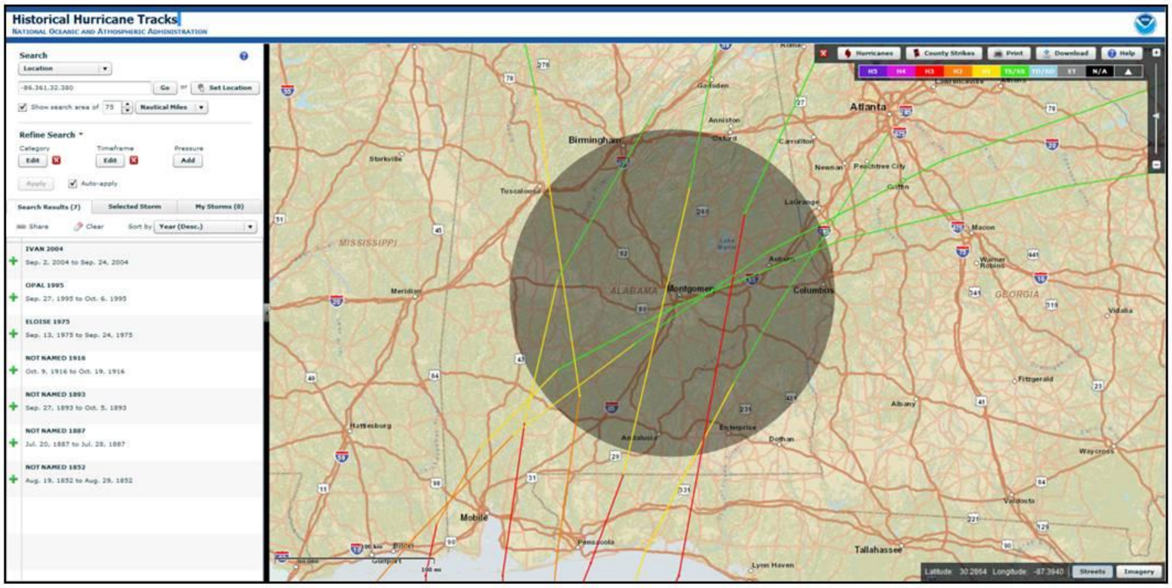


1 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

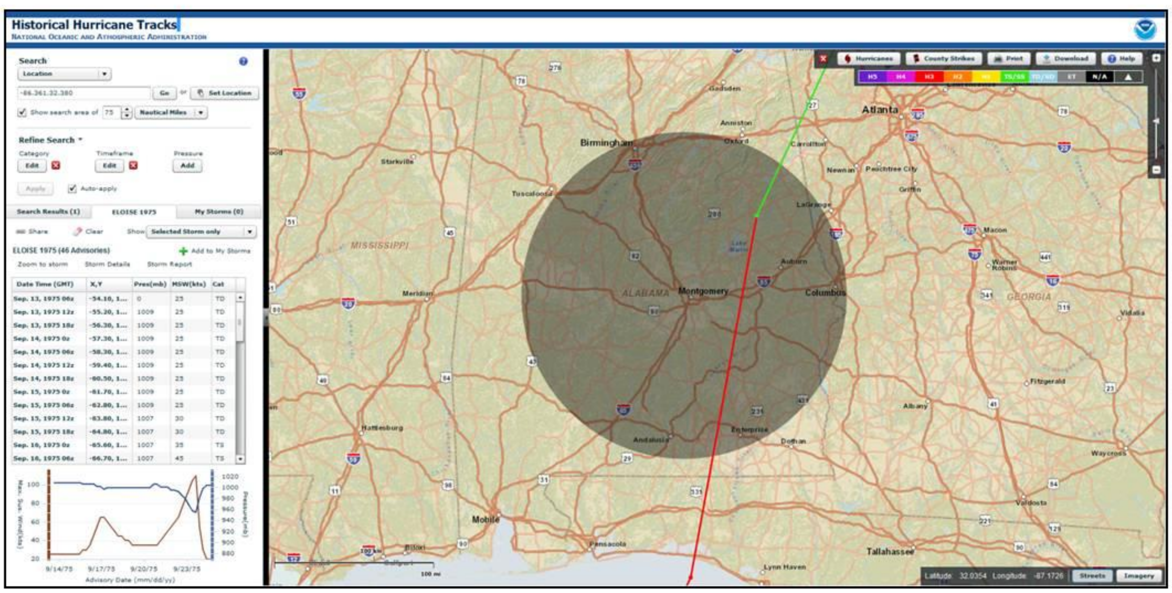


Hurricane Rank #15 – Maxwell AFB, GA

7 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

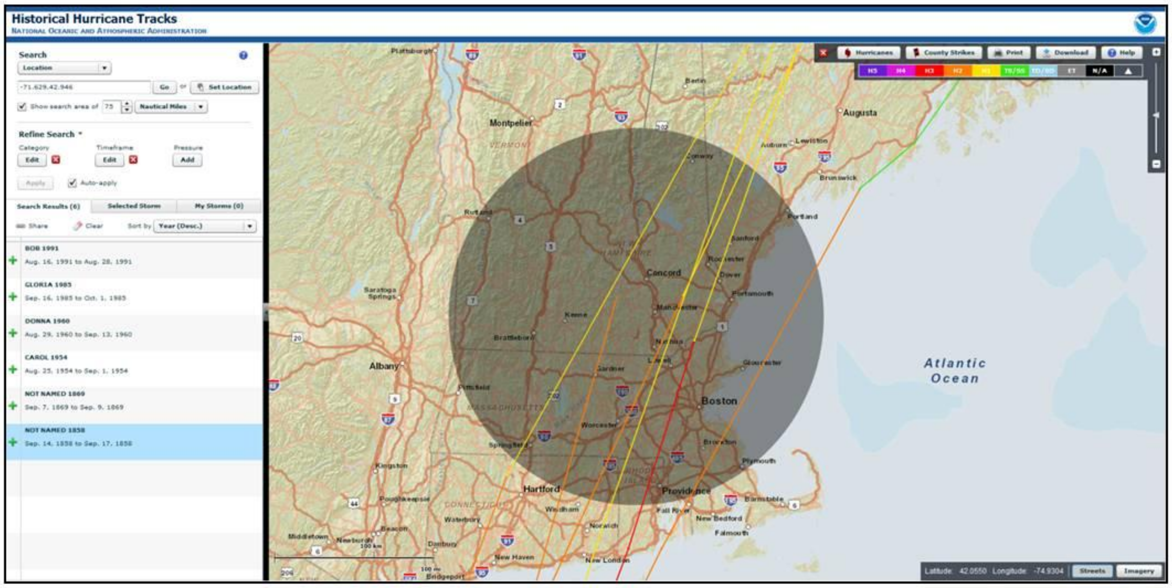


1 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

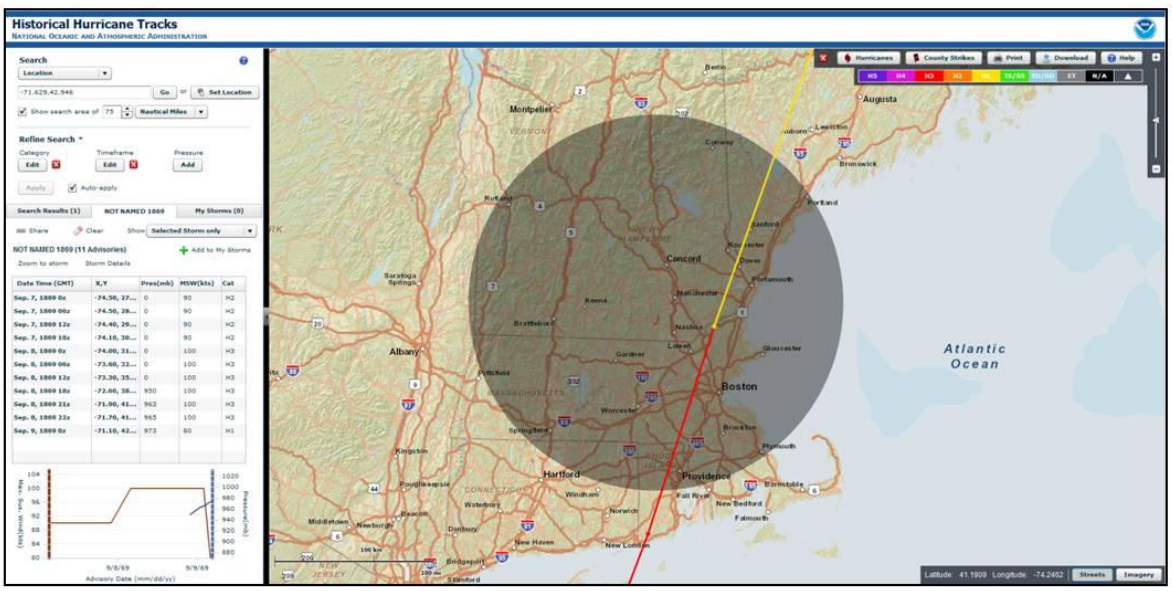


Hurricane Rank #16 – New Boston AS, NH

6 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

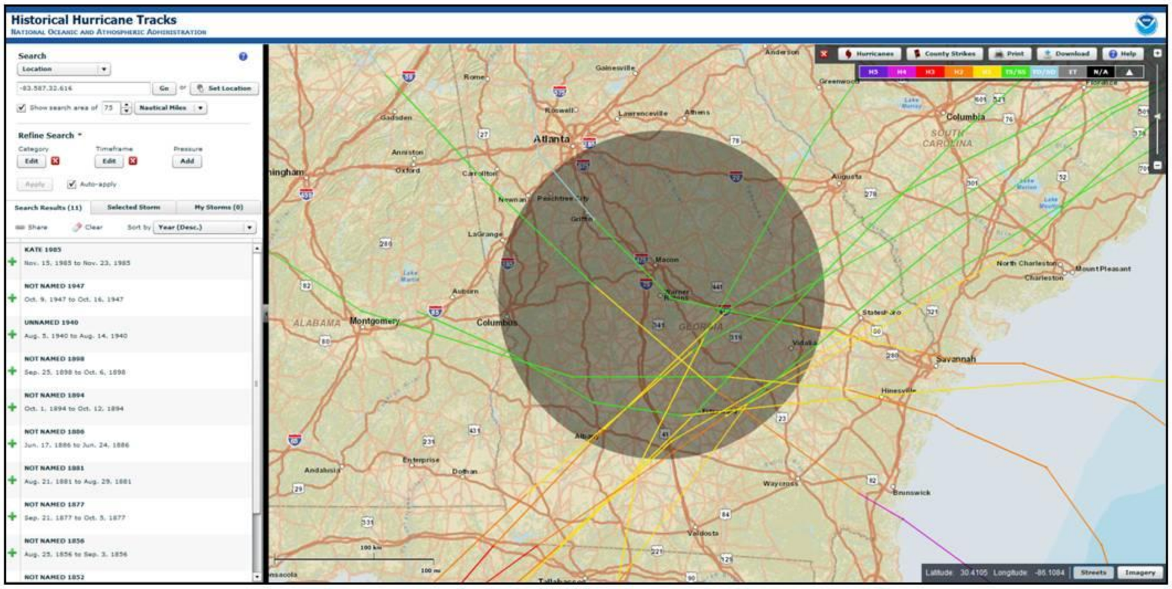


1 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

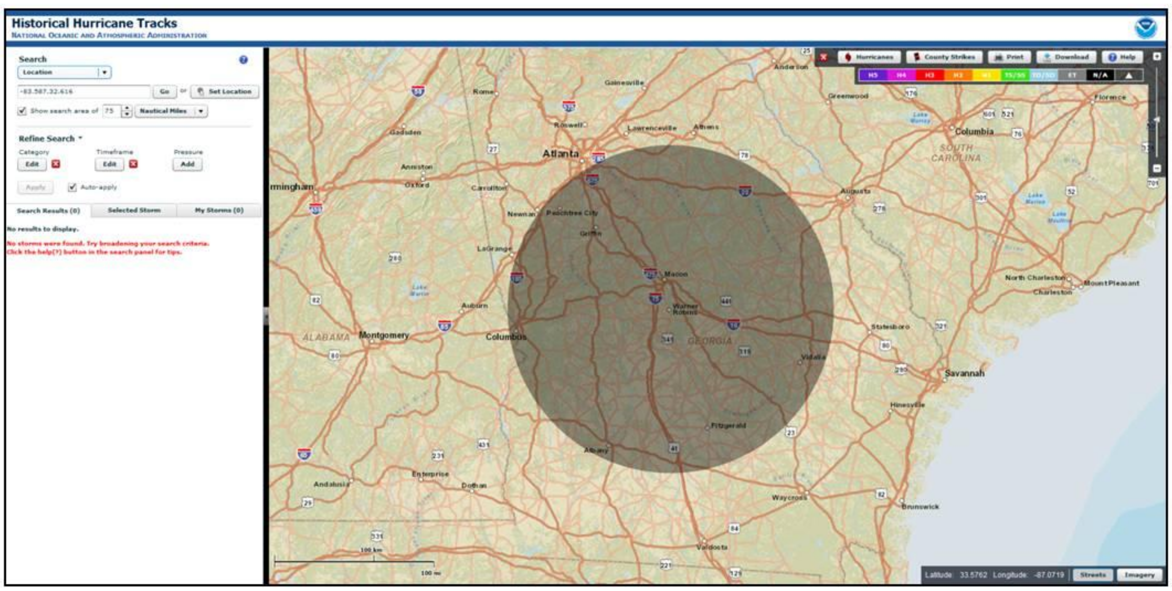


Hurricane Rank #17 – Robins AFB, GA

11 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

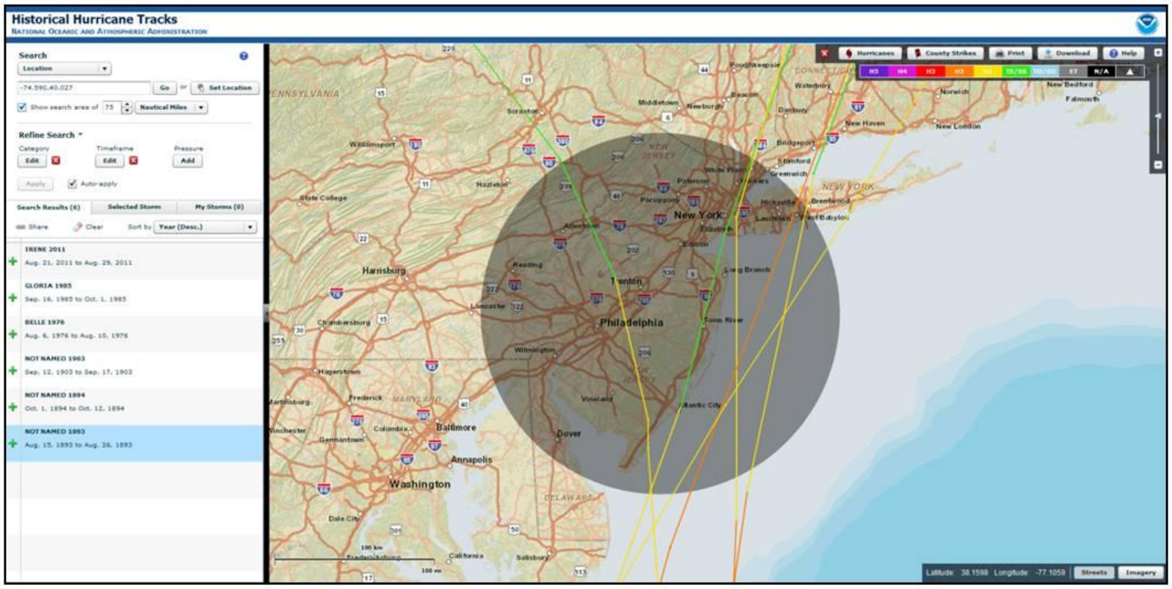


0 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

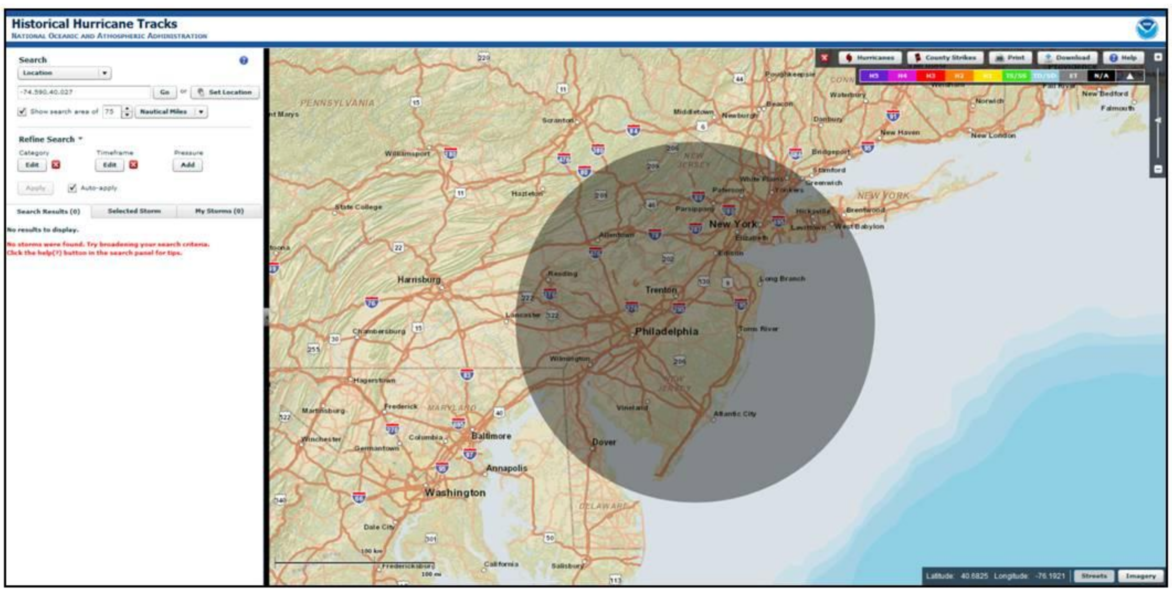


Hurricane Rank #18 – Joint Base McGuire-Dix-Lakehurst (JBMDL), NJ

6 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

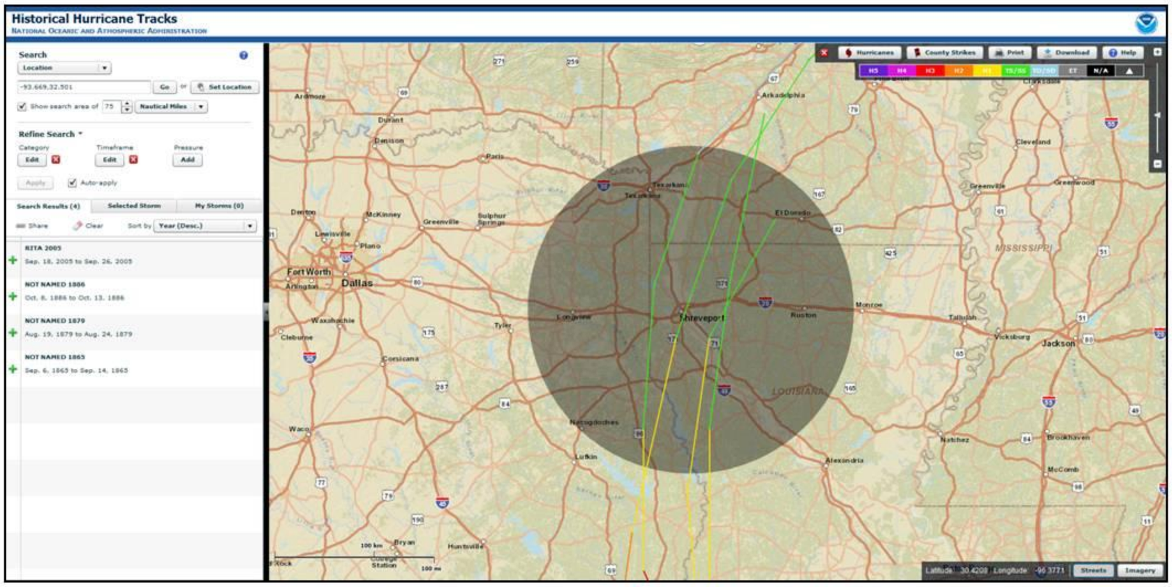


0 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

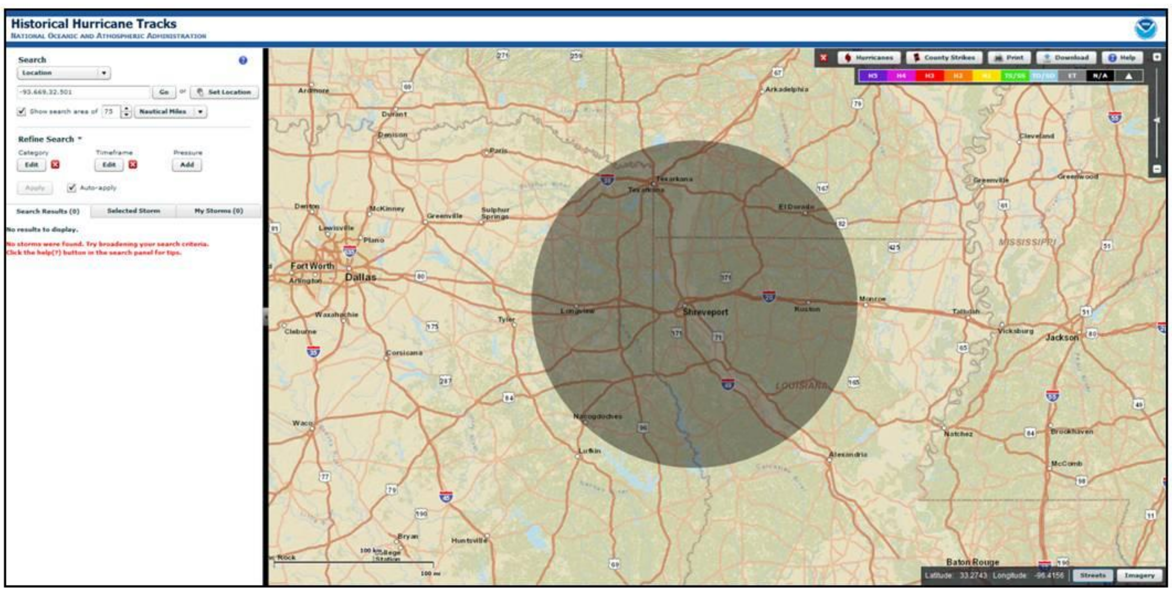


Hurricane Rank #19 (Tie) – Barksdale AFB, LA

4 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

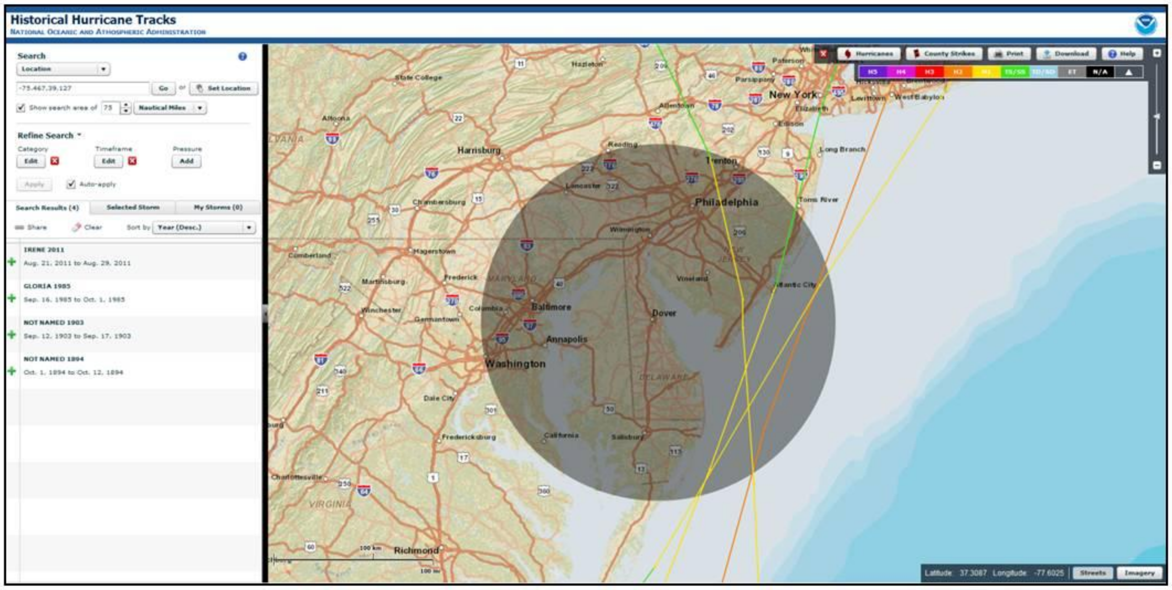


0 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

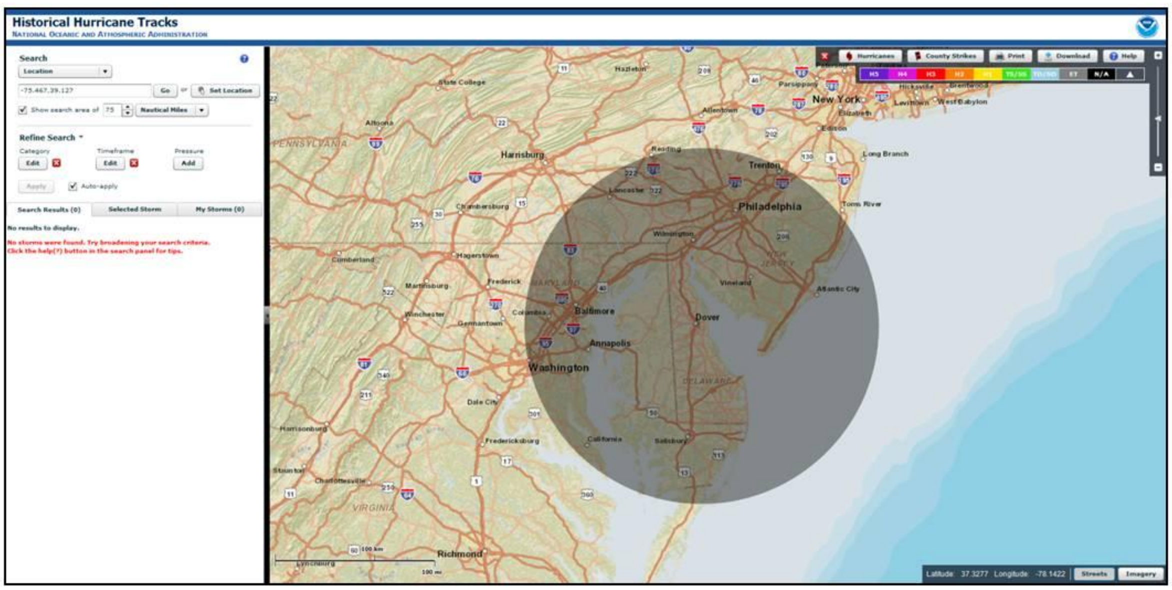


Hurricane Rank #19 (Tie) – Dover AFB, DE

4 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

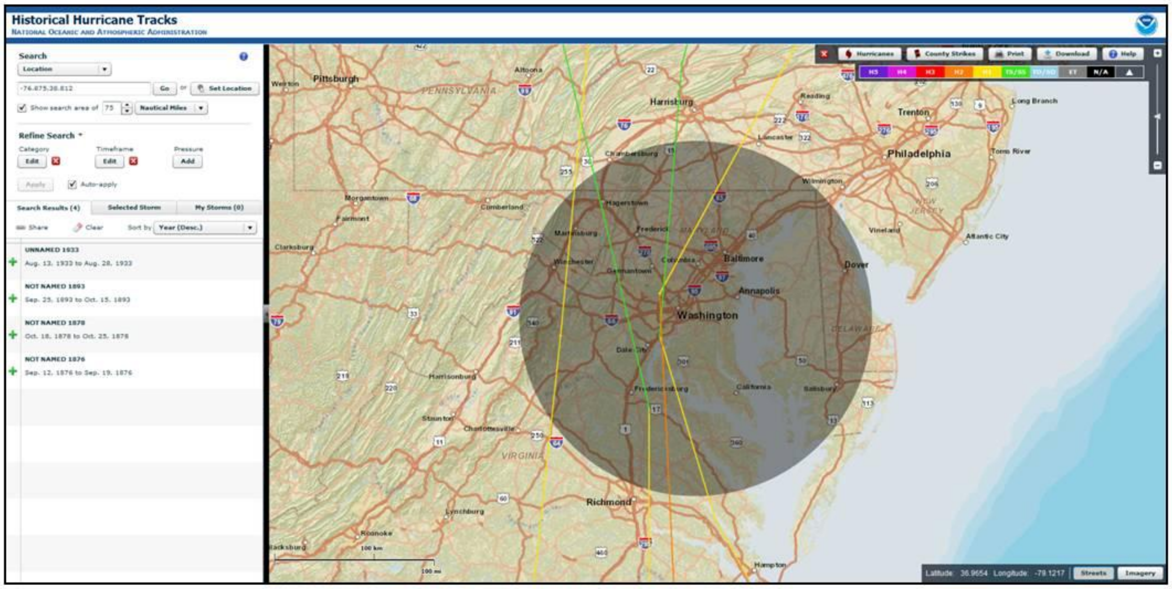


0 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

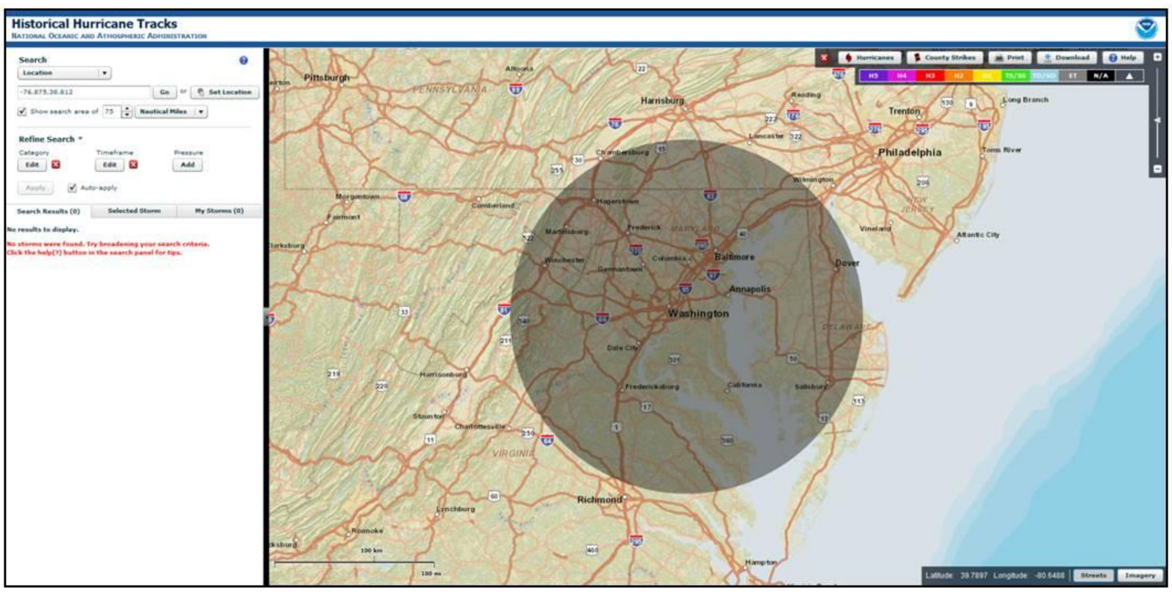


Hurricane Rank #19 (Tie) – Joint Base Andrews, MD

4 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

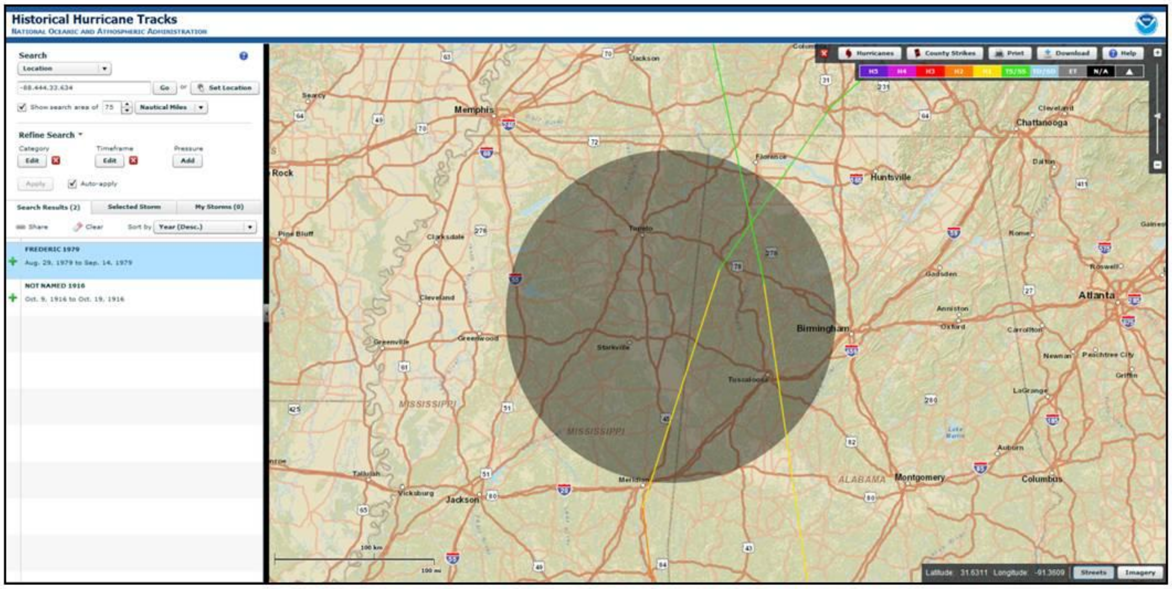


0 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

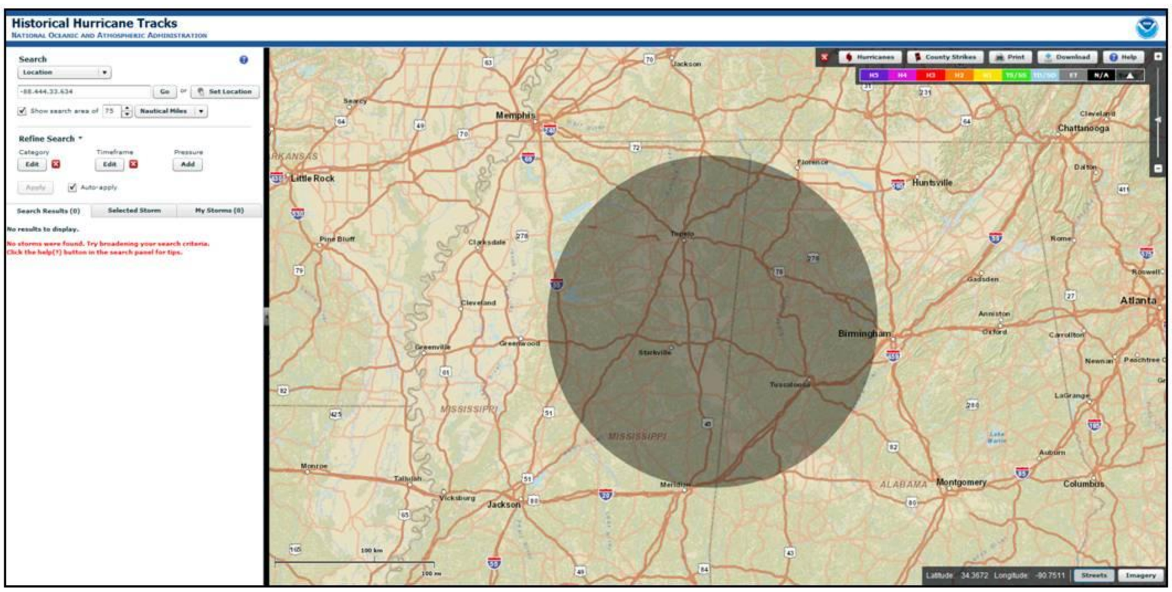


Hurricane Rank #20 – Columbus AFB, MS

2 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)

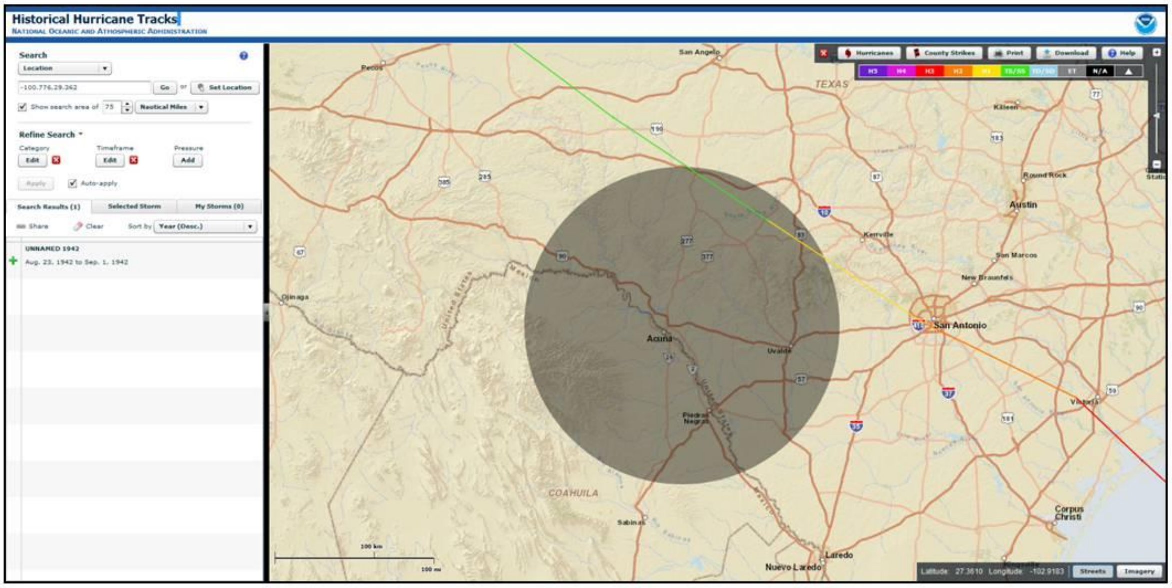


0 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)

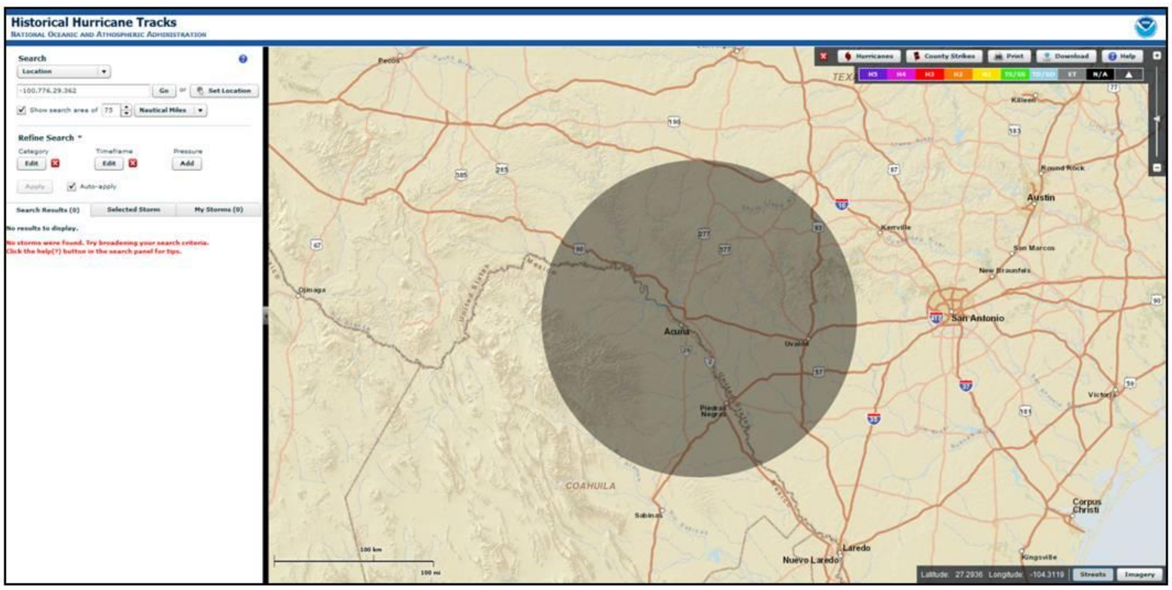


Hurricane Rank #21 – Laughlin AFB, TX

1 Total Hurricanes (1851 – 2013)
(Cat 1-5, within 75 Nautical Miles of Base Centroid)



0 Major Hurricanes (1851 – 2013)
(Cat 3-5, within 75 Nautical Miles of Base Centroid)



Appendix I – Rank Matrices (Complete Tables – All 62 Bases)

PRV Rank by Base - 62 Major CONUS Air Force Bases

Installation Name	State	Buildings								Acres Owned	Total Acres	PRV ($)	PRV Rank
		Owned		Leased		Other		Totals					
		Count	SQFT	Count	SQFT	Count	SQFT	Count	SQFT				
Arnold AFB	TN	332	2,821,835	0	0	2	16,020	334	2,837,855	38,861	38,862	$ 7,802,100,000	1
Joint Base San Antonio (JBSA)	TX	1473	29,332,703	0	0	5	19,036	1,478	29,351,739	14,497	15,418	$ 7,629,100,000	2
JB McGuire-Dix-Lakehurst (JBMDL)	NJ	1186	13,978,249	0	0	3	37,024	1,189	14,015,273	41,688	41,745	$ 7,289,300,000	3
Wright-Patterson AFB	OH	595	16,798,409	0	0	0	0	595	16,798,409	7,680	8,189	$ 5,968,000,000	4
Edwards AFB	CA	737	7,213,316	1	25,913	3	10,000	741	7,249,229	288,997	307,517	$ 5,719,800,000	5
Eglin AFB	FL	1651	11,351,187	0	0	20	212,015	1,671	11,563,202	449,290	449,415	$ 4,726,700,000	6
Hill AFB	UT	767	12,813,276	0	0	0	0	767	12,813,276	517	6,946	$ 4,165,100,000	7
Tinker AFB	OK	414	14,587,790	0	0	0	0	414	14,587,790	3,945	4,842	$ 4,153,500,000	8
Vandenberg AFB	CA	637	6,400,333	0	0	3	15,506	640	6,415,839	98,415	118,312	$ 3,920,700,000	9
Travis AFB	CA	370	6,406,042	0	0	0	0	370	6,406,042	5,130	6,445	$ 3,684,200,000	10
Robins AFB	GA	528	13,740,105	0	0	2	203,028	530	13,943,133	6,779	6,935	$ 3,679,200,000	11
Joint Base Langley-Eustis (JBLE)	VA	701	12,116,506	0	0	0	0	701	12,116,506	11,698	11,925	$ 3,625,400,000	12
Nellis AFB	NV	616	6,199,973	0	0	1	111,253	617	6,311,226	5,214	14,160	$ 3,185,900,000	13
Joint Base Charleston	SC	889	8,599,204	0	0	5	29,852	894	8,629,056	20,864	23,077	$ 3,098,100,000	14
Kirtland AFB	NM	754	7,538,562	0	0	0	0	754	7,538,562	25,473	43,842	$ 2,981,000,000	15
US Air Force Academy	CO	254	5,873,646	0	0	10	36,440	264	5,910,086	44,230	53,276	$ 2,873,300,000	16
Holloman AFB	NM	474	5,448,988	0	0	20	579,390	494	6,028,378	10,601	53,603	$ 2,795,500,000	17
Joint Base Andrews	MD	354	6,656,124	0	0	1	2,800	355	6,658,924	4,996	5,008	$ 2,589,900,000	18
Minot AFB	ND	1242	8,084,075	0	0	0	0	1,242	8,084,075	4,965	5,616	$ 2,520,600,000	19
Whiteman AFB	MO	878	5,228,713	0	0	1	1,964	879	5,230,677	4,478	6,026	$ 2,245,000,000	20
Sheppard AFB	TX	350	7,434,061	0	0	0	0	350	7,434,061	4,598	5,297	$ 2,102,600,000	21
Ellsworth	SD	478	4,799,019	251	1,177,843	0	0	729	5,976,862	5,356	6,179	$ 2,065,800,000	22
Davis-Monthan AFB	AZ	510	4,835,541	0	0	1	18,704	511	4,854,245	5,131	10,668	$ 2,053,800,000	23
Beale AFB	CA	256	2,874,438	0	0	0	0	256	2,874,438	22,439	22,451	$ 2,038,100,000	24
Scott AFB	IL	283	4,897,823	0	0	3	15,817	286	4,913,640	2,881	3,638	$ 1,911,500,000	25
Mountain Home AFB	ID	450	3,350,656	0	0	1	55,650	451	3,406,306	2,250	6,850	$ 1,909,200,000	26
Fairchild AFB	WA	285	4,448,752	0	0	0	0	285	4,448,752	4,343	5,197	$ 1,852,900,000	27
MacDill AFB	FL	297	4,825,255	0	0	5	77,056	302	4,902,311	5,633	5,866	$ 1,837,400,000	28
Keesler AFB	MS	229	6,984,972	0	0	2	4,870	231	6,989,842	1,597	1,670	$ 1,831,400,000	29
Offutt AFB	NE	212	5,887,038	0	0	0	0	212	5,887,038	1,908	1,923	$ 1,822,300,000	30
Hanscom AFB	MA	137	3,833,977	0	0	2	211,176	139	4,045,153	527	846	$ 1,782,800,000	31
Dover AFB	DE	208	3,803,933	0	0	9	226,359	217	4,030,292	3,218	3,824	$ 1,782,100,000	32
Malmstrom AFB	MT	516	3,925,102	0	0	0	0	516	3,925,102	3,189	3,628	$ 1,752,000,000	33
Dyess AFB	TX	747	4,711,125	0	0	0	0	747	4,711,125	3,120	6,320	$ 1,584,800,000	34
Barksdale AFB	LA	436	5,021,944	0	0	0	0	436	5,021,944	21,945	22,504	$ 1,569,200,000	35
Tyndall AFB	FL	444	3,990,677	0	0	25	134,483	469	4,125,160	27,348	28,824	$ 1,556,300,000	36
Cape Canaveral AFS	FL	532	3,730,079	0	0	0	0	532	3,730,079	15,383	16,239	$ 1,516,100,000	37
Grand Forks AFB	ND	603	4,652,792	0	0	0	0	603	4,652,792	4,830	5,420	$ 1,515,700,000	38
Hurlburt Field	FL	567	5,213,156	0	0	0	0	567	5,213,156	6,341	6,341	$ 1,482,300,000	39
Cannon AFB	NM	652	3,925,694	0	0	0	0	652	3,925,694	3,769	4,522	$ 1,462,000,000	40
Little Rock AFB	AR	354	4,113,665	0	0	0	0	354	4,113,665	6,772	6,929	$ 1,457,700,000	41
Luke AFB	AZ	349	3,716,392	0	0	0	0	349	3,716,392	2,933	4,833	$ 1,336,900,000	42
Seymour Johnson AFB	NC	820	4,506,956	0	0	0	0	820	4,506,956	3,232	4,118	$ 1,321,700,000	43
Maxwell AFB	AL	217	4,612,524	0	0	0	0	217	4,612,524	2,528	3,543	$ 1,297,200,000	44
McConnell AFB	KS	208	3,193,432	0	0	0	0	208	3,193,432	2,682	3,606	$ 1,238,800,000	45
Shaw AFB	SC	298	3,528,295	0	0	0	0	298	3,528,295	3,377	3,476	$ 1,223,100,000	46
Peterson AFB	CO	169	3,216,508	34	322,959	0	0	203	3,539,467	218	1,457	$ 1,217,200,000	47
Altus AFB	OK	162	2,631,914	0	0	0	0	162	2,631,914	2,424	6,830	$ 1,169,200,000	48
F.E. Warren AFB	WY	248	3,337,460	0	0	1	5,000	249	3,342,460	6,834	6,834	$ 1,164,700,000	49
Buckley AFB	CO	198	3,387,152	0	0	0	0	198	3,387,152	3,399	4,224	$ 1,139,800,000	50
Patrick AFB	FL	278	3,119,295	0	0	1	610	279	3,119,905	2,089	2,324	$ 1,063,700,000	51
Moody AFB	GA	329	2,987,464	0	0	0	0	329	2,987,464	5,118	5,521	$ 916,100,000	52
Schriever AFB	CO	71	2,062,819	0	0	0	0	71	2,062,819	3,202	5,634	$ 741,600,000	53
Laughlin AFB	TX	190	1,939,871	0	0	0	0	190	1,939,871	4,355	4,692	$ 741,100,000	54
Columbus AFB	MS	175	1,658,149	0	0	0	0	175	1,658,149	4,411	4,919	$ 736,100,000	55
Vance AFB	OK	127	1,487,793	0	0	0	0	127	1,487,793	2,121	3,738	$ 624,800,000	56
Goodfellow AFB	TX	155	2,596,632	0	0	0	0	155	2,596,632	1,183	1,218	$ 607,700,000	57
Creech AFB	NV	128	898,766	0	0	0	0	128	898,766	2,300	2,300	$ 574,900,000	58
Los Angeles AFB	CA	20	943,450	0	0	0	0	20	943,450	54	56	$ 317,800,000	59
Cavalier AS	ND	32	410,951	0	0	1	384	33	411,335	278	295	$ 153,200,000	60
New Boston AS	NH	25	96,075	0	0	0	0	25	96,075	2,826	2,873	$ 70,600,000	61
Cape Cod AS	MA	16	109,722	0	0	0	0	16	109,722	0	101	$ 53,800,000	62
TOTALS:		27,613	348,890,355	286	1,526,715	127	2,024,437	28,026	352,441,507	1,296,460	1,468,887	$ 139,248,400,000	

PRV Rank Matrix

Tornado Risk-Rank by Base (1984-2013; 30 Year Period) - 62 Major CONUS Air Force Bases				
Installation Name	State	Tornado Occurrences (EF-0 to EF-5) (w/in 25 mile radius)	Tornado Occurrences (EF-2 to EF-5) (w/in 25 mile radius)	Tornado Risk Rank (Ranked by EF 2-5 First, Tie-Breaker = EF 0-5)
Tinker AFB	OK	101	29	1
Little Rock AFB	AR	98	29	2
Columbus AFB	MS	71	27	3
Barksdale AFB	LA	99	23	4
Scott AFB	IL	86	20	5
Seymour Johnson AFB	NC	68	16	6
Vance AFB	OK	50	15	7
Maxwell AFB	AL	77	13	8
Offutt AFB	NE	60	13	9
Arnold AS	TN	58	12	10
McConnell AFB	KS	97	11	11
Buckley AFB	CO	189	10	12
Grand Forks AFB	ND	60	8	13
Shaw AFB	SC	45	8	14
Dyess AFB	TX	57	7	15
Whiteman AFB	MO	45	7	16
Joint Base Andrews	MD	67	6	17
Keesler AFB	MS	54	6	18
Joint Base Langley-Eustis (JBLE)	VA	40	5	19
Wright-Patterson AFB	OH	36	5	20
MacDill AFB	FL	144	4	21
Hurlburt Field	FL	63	4	22
Schriever AFB	CO	49	4	23
Robins AFB	GA	18	4	24
Eglin AFB	FL	66	3	25
Peterson AFB	CO	64	3	26
Altus AFB	OK	59	3	27
Cavalier AS	ND	43	3	28
Joint Base San Antonio (JBSA)	TX	43	3	28
Joint Base Charleston	SC	37	3	29
Laughlin AFB	TX	26	3	30
New Boston AS	NH	6	3	31
Patrick AFB	FL	58	2	32
US Air Force Academy	CO	52	2	33
Tyndall AFB	FL	48	2	34
Cannon AFB	NM	35	2	35
JB McGuire-Dix-Lakehurst (JBMDL)	NJ	26	2	36
Ellsworth AFB	SD	22	2	37
Moody AFB	GA	17	2	38
Dover AFB	DE	16	2	39
Cape Canaveral AFS	FL	43	1	40
Minot AFB	ND	37	1	41
F. E. Warren AFB	WY	34	1	42
Goodfellow AFB	TX	26	1	43
Davis-Monthan AFB	AZ	8	1	44
Sheppard AFB	TX	47	0	45
Hill AFB	UT	13	0	46
Beale AFB	CA	12	0	47
Los Angeles AFB	CA	12	0	47
Kirtland AFB	NM	10	0	48
Luke AFB	AZ	9	0	49
Travis AFB	CA	8	0	50
Hanscom AFB	MA	7	0	51
Fairchild AFB	WA	6	0	52
Holloman AFB	NM	6	0	52
Nellis AFB	NV	6	0	52
Edwards AFB	CA	5	0	53
Malmstrom AFB	MT	5	0	53
Vandenberg AFB	CA	3	0	54
Cape Cod AS	MA	2	0	55
Mountain Home AFB	ID	2	0	55
Creech AFB	NV	1	0	56

Tornado Risk Rank-Matrix

Hurricane Risk-Rank by Base (1851-2013; 163 Year Period) **- 62 Major CONUS Air Force Bases**				
Installation Name	**State**	**All Hurricane Occurrences** (Cat 1-5) (w/in 75 nautical mi radius)	**Major Hurricane Occurrences** (Cat 3-5) (w/in 75 nautical mi radius)	**Hurricane Risk Rank** (Ranked by Cat 3-5 First, Tie-Breaker = Cat 1-5)
MacDill AFB	FL	35	13	1
Keesler AFB	MS	32	11	2
Patrick AFB	FL	31	11	3
Eglin AFB	FL	31	10	4
Hurlburt Field	FL	31	10	4
Tyndall AFB	FL	34	8	5
Cape Canaveral AFS	FL	30	7	6
Joint Base Charleston	SC	30	4	7
Seymour Johnson AFB	NC	23	3	8
Shaw AFB	SC	16	2	9
Cape Cod AS	MA	13	2	10
Moody AFB	GA	18	1	11
Joint Base Langley-Eustis (JBLE)	VA	14	1	12
Hanscom AFB	MA	10	1	13
Joint Base San Antonio (JBSA)	TX	8	1	14
Maxwell AFB	AL	7	1	15
New Boston AS	NH	6	1	16
Robins AFB	GA	11	0	17
JB McGuire-Dix-Lakehurst (JBMDL)	NJ	6	0	18
Barksdale AFB	LA	4	0	19
Dover AFB	DE	4	0	19
Joint Base Andrews	MD	4	0	19
Columbus AFB	MS	2	0	20
Laughlin AFB	TX	1	0	21
Altus AFB	OK	0	0	22
Arnold AS	TN	0	0	22
Beale AFB	CA	0	0	22
Buckley AFB	CO	0	0	22
Cannon AFB	NM	0	0	22
Cavalier AS	ND	0	0	22
Creech AFB	NV	0	0	22
Davis-Monthan AFB	AZ	0	0	22
Dyess AFB	TX	0	0	22
Edwards AFB	CA	0	0	22
Ellsworth AFB	SD	0	0	22
F. E. Warren AFB	WY	0	0	22
Fairchild AFB	WA	0	0	22
Goodfellow AFB	TX	0	0	22
Grand Forks AFB	ND	0	0	22
Hill AFB	UT	0	0	22
Holloman AFB	NM	0	0	22
Kirtland AFB	NM	0	0	22
Little Rock AFB	AR	0	0	22
Los Angeles AFB	CA	0	0	22
Luke AFB	AZ	0	0	22
Malmstrom AFB	MT	0	0	22
McConnell AFB	KS	0	0	22
Minot AFB	ND	0	0	22
Mountain Home AFB	ID	0	0	22
Nellis AFB	NV	0	0	22
Offutt AFB	NE	0	0	22
Peterson AFB	CO	0	0	22
Schriever AFB	CO	0	0	22
Scott AFB	IL	0	0	22
Sheppard AFB	TX	0	0	22
Tinker AFB	OK	0	0	22
Travis AFB	CA	0	0	22
US Air Force Academy	CO	0	0	22
Vance AFB	OK	0	0	22
Vandenberg AFB	CA	0	0	22
Whiteman AFB	MO	0	0	22
Wright-Patterson AFB	OH	0	0	22

Hurricane Risk Rank-Matrix

Ranked Climate Zone Data - 62 Major CONUS Air Force Bases				
Installation Data				IECC Climate Zone
Installation Name	State	CDD 50	HDD 65	
MacDill AFB	FL	8,353	664	2
Cape Canaveral AFS	FL	8,348	385	2
Patrick AFB	FL	8,334	411	2
Laughlin AFB	TX	7,521	1,497	2
Joint Base San Antonio (JBSA)	TX	7,389	1,660	2
Luke AFB	AZ	7,224	1,688	2
Keesler AFB	MS	7,000	1,536	2
Tyndall AFB	FL	6,995	1,447	2
Eglin AFB	FL	6,723	1,657	2
Hurlburt Field	FL	6,699	1,681	2
Davis-Monthan AFB	AZ	6,619	1,936	2
Moody AFB	GA	6,421	1,571	2
Nellis AFB	NV	7,431	2,349	3
Creech AFB	NV	7,366	2,408	3
Maxwell AFB	AL	6,416	2,255	3
Joint Base Charleston	SC	6,263	2,123	3
Goodfellow AFB	TX	6,076	2,672	3
Barksdale AFB	LA	6,035	2,506	3
Robins AFB	GA	6,005	2,507	3
Columbus AFB	MS	5,656	2,888	3
Shaw AFB	SC	5,637	2,745	3
Holloman AFB	NM	5,426	3,530	3
Altus AFB	OK	5,365	3,434	3
Edwards AFB	CA	5,241	3,262	3
Vance AFB	OK	5,124	4,182	3
Tinker AFB	OK	4,906	3,741	3
Sheppard AFB	TX	4,899	3,264	3
Little Rock AFB	AR	4,836	3,361	3
Dyess AFB	TX	4,759	2,842	3
Beale AFB	CA	4,694	2,779	3
Seymour Johnson AFB	NC	4,137	3,093	3
Travis AFB	CA	4,062	3,160	3
Los Angeles AFB	CA	2,457	1,587	3
Vandenberg AFB	CA	2,275	2,497	3
Joint Base Langley-Eustis (JBLE)	VA	4,720	3,582	4
Arnold AS	TN	4,296	3,873	4
Cannon AFB	NM	4,002	4,283	4
Kirtland AFB	NM	4,131	4,482	4
Joint Base Andrews	MD	4,096	4,555	4
McConnell AFB	KS	4,716	4,557	4
Dover AFB	DE	3,868	4,696	4
Scott AFB	IL	4,258	4,944	4
Whiteman AFB	MO	4,225	5,069	4
Joint Base McGuire-Dix-Lakehurst (JBMDL)	NJ	3,638	5,121	4
Wright-Patterson AFB	OH	3,624	5,551	5
Hanscom AFB	MA	2,139	5,679	5
Cape Cod AS	MA	2,785	5,773	5
Offutt AFB	NE	3,751	6,121	5
Mountain Home AFB	ID	3,097	6,194	5
Hill AFB	UT	2,964	6,322	5
Buckley AFB	CO	2,951	6,498	5
New Boston AS	NH	2,805	6,515	5
Peterson AFB	CO	2,276	6,679	5
Schriever AFB	CO	2,483	6,703	5
US Air Force Academy	CO	2,179	6,811	5
Fairchild AFB	WA	2,186	7,032	5
Ellsworth AFB	SD	2,700	7,279	6
F. E. Warren AFB	WY	2,157	7,558	6
Malmstrom AFB	MT	2,001	7,657	6
Minot AFB	ND	2,288	9,262	7
Grand Forks AFB	ND	2,308	9,457	7
Cavalier AS	ND	2,136	10,071	7

Hot
More Electricity Used for A/C
Baseline Climate Zone (Most Energy Neutral)
Increasing Natural Gas Usage for Heating
Cold

Climate Zone Matrix

Energy Usage by Base (3-Year Average, FY12-14) - 62 Major CONUS Air Force Bases									
Installation Name	State	Energy Usage by Commodity						Total Site Delivered Energy (Combined BTUs)	
		Electricity			Natural Gas			Electricity & Natural Gas	
		Average Annual Usage (kWh)	Std Dev Annual Usage (kWh)	Average Annual Usage Rank	Average Annual Usage (Mcf)	Std Dev Annual Usage (Mcf)	Average Annual Usage Rank	Average Annual Energy Usage (MBTU)	Average Annual Total Energy Usage Rank
Joint Base San Antonio (JBSA)	TX	651,884,213	2,932,134	1	1,637,677	50,218	1	3,912,674	1
Tinker AFB	OK	435,276,506	19,844,051	2	1,623,661	56,540	2	3,159,158	2
Wright-Patterson AFB	OH	406,836,333	11,184,491	3	522,437	159,905	6	1,926,758	3
Robins AFB	GA	317,216,487	16,628,011	4	775,520	41,745	4	1,881,904	4
Hill AFB	UT	235,033,000	13,976,522	7	1,018,887	43,080	3	1,852,406	5
Arnold AS	TN	267,465,333	62,611,672	6	506,221	57,042	8	1,434,505	6
Joint Base McGuire-Dix-Lakehurst (JBMDL)	NJ	179,030,260	6,937,530	9	763,308	96,479	5	1,397,822	7
Eglin AFB	FL	282,449,623	4,131,670	5	385,243	7,251	11	1,360,904	8
Joint Base Langley-Eustis (JBLE)	VA	233,060,977	696,706	8	430,587	89,383	9	1,239,140	9
Edwards AFB	CA	147,232,150	11,984,182	13	404,105	77,930	10	918,988	10
US Air Force Academy	CO	91,451,321	9,989,755	24	509,278	11,997	7	837,098	11
Offutt AFB	NE	152,579,709	6,619,514	12	302,851	8,274	16	832,841	12
Kirtland AFB	NM	132,335,296	7,896,165	14	344,152	9,954	13	806,348	13
Joint Base Charleston	SC	178,572,857	5,946,226	10	135,323	15,543	40	748,808	14
Maxwell AFB	AL	131,681,093	15,702,184	15	281,430	5,102	19	739,450	15
Keesler AFB	MS	124,053,234	7,653,023	16	262,773	6,211	23	694,188	16
Sheppard AFB	TX	104,838,190	5,341,839	19	313,189	38,683	15	680,605	17
Vandenberg AFB	CA	97,280,476	3,001,236	22	267,488	45,688	21	607,701	18
Scott AFB	IL	120,328,647	975,002	17	186,022	10,483	32	602,350	19
Holloman AFB	NM	80,917,124	1,483,672	31	296,562	23,140	17	581,845	20
MacDill AFB	FL	163,478,333	2,189,208	11	21,957	4,427	59	580,426	21
Joint Base Andrews	MD	102,286,901	4,184,394	21	221,979	47,331	27	577,864	22
Nellis AFB	NV	117,809,256	1,591,287	18	169,825	2,788	34	577,055	23
Whiteman AFB	MO	68,345,000	2,222,406	37	329,723	26,913	14	573,137	24
Minot AFB	ND	85,634,014	2,711,455	27	245,377	31,839	24	545,167	25
Cannon AFB	NM	84,935,284	3,895,056	28	244,796	35,087	25	542,184	26
Hurlburt Field	FL	103,612,926	869,198	20	149,414	6,163	39	507,573	27
Peterson AFB	CO	90,619,554	4,055,068	26	191,945	6,483	30	507,089	28
Dover AFB	DE	63,688,200	1,386,805	39	266,934	52,773	22	492,513	29
Travis AFB	CA	92,066,312	3,902,110	23	169,263	6,218	35	488,640	30
Ellsworth AFB	SD	54,010,464	2,491,632	45	290,777	28,927	18	484,075	31
Hanscom AFB	MA	35,853,365	8,044,270	55	344,913	84,583	12	477,936	32
Little Rock AFB	AR	74,141,082	2,042,789	34	209,465	26,718	29	468,928	33
Fairchild AFB	WA	50,491,969	1,092,854	46	276,846	18,607	20	457,707	34
Schriever AFB	CO	82,572,411	1,991,299	30	151,735	2,094	38	438,176	35
Barksdale AFB	LA	79,211,000	6,358,855	32	152,837	24,467	37	427,843	36
McConnell AFB	KS	62,923,146	884,321	40	170,452	19,751	33	390,430	37
Malmstrom AFB	MT	62,717,094	2,007,012	41	163,947	68,982	36	383,020	38
F. E. Warren AFB	WY	42,635,901	15,399,925	50	225,461	9,966	26	377,924	39
Davis-Monthan AFB	AZ	73,473,588	848,324	35	113,681	17,173	43	367,897	40
Grand Forks AFB	ND	41,610,091	1,554,943	52	214,548	33,107	28	363,173	41
Tyndall AFB	FL	84,000,188	2,574,862	29	71,138	8,133	48	359,952	42
Cape Canaveral AFS	FL	90,735,445	2,607,936	25	46,652	3,881	54	357,687	43
Shaw AFB	SC	71,020,090	3,197,131	36	89,876	18,147	46	334,982	44
Mountain Home AFB	ID	40,941,227	508,470	54	187,384	39,799	31	332,884	45
Seymour Johnson AFB	NC	59,373,916	3,334,361	43	114,725	8,827	42	320,866	46
Dyess AFB	TX	54,145,888	2,627,218	44	129,423	3,726	41	318,181	47
Patrick AFB	FL	77,096,201	3,945,960	33	30,618	5,399	57	294,619	48
Beale AFB	CA	61,973,566	14,845,732	42	65,817	9,896	49	279,311	49
Luke AFB	AZ	66,701,665	3,295,719	38	50,089	6,411	53	279,227	50
Altus AFB	OK	42,033,090	1,753,648	51	111,112	29,040	44	257,974	51
Buckley AFB	CO	41,075,077	881,862	53	92,971	16,204	45	236,001	52
Goodfellow AFB	TX	49,880,833	1,058,159	47	61,479	9,454	50	233,579	53
Cavalier AS	ND	46,148,899	4,733,340	49	73,699	30,198	47	233,444	54
Moody AFB	GA	47,438,413	1,321,031	48	45,792	4,287	55	209,072	55
Columbus AFB	MS	30,514,667	520,531	56	56,747	8,876	51	162,622	56
Vance AFB	OK	22,974,817	105,871	59	52,573	7,971	52	132,593	57
Laughlin AFB	TX	27,676,235	645,057	58	34,065	6,414	56	129,552	58
Los Angeles AFB	CA	20,586,430	784,052	60	26,489	182	58	97,551	59
Creech AFB	NV	27,789,217	2,320,826	57	N/A	N/A	N/A	94,817	60
Cape Cod AS	MA	9,393,804	2,401,968	61	N/A	N/A	N/A	32,052	61
New Boston AS	NH	5,075,333	56,083	62	N/A	N/A	N/A	17,317	62

Energy Usage Rank-Matrix

Ranked Energy-Intensity by Base (FY13 Data Only) - 62 Major CONUS Air Force Bases						
Installation Name	**State**	**Total Annual Energy Usage** (MBTU)	**Total Facility Count**	**Gross Square Footage** (Ft^2)	**Energy Intensity** (BTU/Ft^2)	**Energy-Intensity Rank**
Cavalier AS	ND	232,966	33	411,335	566,365	1
Arnold AS	TN	1,393,935	334	2,837,855	491,193	2
Cape Cod AS	MA	36,713	16	109,722	334,601	3
Tinker AFB	OK	3,179,289	414	14,587,790	217,942	4
Schriever AFB	CO	447,586	71	2,062,819	216,978	5
New Boston AS	NH	17,538	25	96,075	182,542	6
Maxwell AFB	AL	744,072	217	4,612,524	161,316	7
US Air Force Academy	CO	872,009	264	5,910,086	147,546	8
Peterson AFB	CO	517,101	203	3,539,467	146,096	9
Hill AFB	UT	1,841,509	767	12,813,276	143,719	10
Offutt AFB	NE	821,743	212	5,887,038	139,585	11
Joint Base San Antonio (JBSA)	TX	3,940,589	1,478	29,351,739	134,254	12
Robins AFB	GA	1,838,179	530	13,943,133	131,834	13
Edwards AFB	CA	929,560	741	7,249,229	128,229	14
McConnell AFB	KS	396,652	208	3,193,432	124,209	15
Scott AFB	IL	603,240	286	4,913,640	122,769	16
F. E. Warren AFB	WY	408,640	249	3,342,460	122,257	17
Hanscom AFB	MA	489,822	139	4,045,153	121,089	18
Wright-Patterson AFB	OH	2,023,829	595	16,798,409	120,477	19
MacDill AFB	FL	582,961	302	4,902,311	118,916	20
Little Rock AFB	AR	482,764	354	4,113,665	117,356	21
Eglin AFB	FL	1,352,293	1,671	11,563,202	116,948	22
Dover AFB	DE	458,958	217	4,030,292	113,877	23
Kirtland AFB	NM	825,838	754	7,538,562	109,548	24
Malmstrom AFB	MT	426,478	516	3,925,102	108,654	25
Beale AFB	CA	311,244	256	2,874,438	108,280	26
Joint Base Langley-Eustis (JBLE)	VA	1,290,067	701	12,116,506	106,472	27
Creech AFB	NV	95,002	128	898,766	105,703	28
Whiteman AFB	MO	551,662	879	5,230,677	105,467	29
Altus AFB	OK	268,622	162	2,631,914	102,063	30
Los Angeles AFB	CA	95,946	20	943,450	101,697	31
Columbus AFB	MS	166,102	175	1,658,149	100,173	32
Holloman AFB	NM	599,203	494	6,028,378	99,397	33
Keesler AFB	MS	693,082	231	6,989,842	99,156	34
Joint Base McGuire-Dix-Lakehurst (JBMDL)	NJ	1,389,323	1,189	14,015,273	99,129	35
Fairchild AFB	WA	435,671	285	4,448,752	97,931	36
Hurlburt Field	FL	507,664	567	5,213,156	97,381	37
Mountain Home AFB	ID	328,381	451	3,406,306	96,404	38
Cape Canaveral AFS	FL	358,242	532	3,730,079	96,041	39
Nellis AFB	NV	584,013	617	6,311,226	92,536	40
Shaw AFB	SC	324,647	298	3,528,295	92,012	41
Joint Base Andrews	MD	604,044	355	6,658,924	90,712	42
Sheppard AFB	TX	666,663	350	7,434,061	89,677	43
Vance AFB	OK	133,234	127	1,487,793	89,551	44
Patrick AFB	FL	276,791	279	3,119,905	88,718	45
Vandenberg AFB	CA	562,106	640	6,415,839	87,612	46
Tyndall AFB	FL	360,141	469	4,125,160	87,304	47
Barksdale AFB	LA	437,755	436	5,021,944	87,168	48
Grand Forks AFB	ND	403,711	603	4,652,792	86,767	49
Goodfellow AFB	TX	224,193	155	2,596,632	86,340	50
Cannon AFB	NM	338,239	652	3,925,694	86,160	51
Joint Base Charleston	SC	743,133	894	8,629,056	86,120	52
Ellsworth AFB	SD	482,446	729	5,976,862	80,719	53
Davis-Monthan AFB	AZ	375,531	511	4,854,245	77,361	54
Travis AFB	CA	486,803	370	6,406,042	75,991	55
Buckley AFB	CO	252,910	198	3,387,152	74,667	56
Luke AFB	AZ	269,998	349	3,716,392	72,651	57
Seymour Johnson AFB	NC	319,005	820	4,506,956	70,781	58
Minot AFB	ND	567,511	1,242	8,084,075	70,201	59
Dyess AFB	TX	316,503	747	4,711,125	67,182	60
Moody AFB	GA	199,735	329	2,987,464	66,858	61
Laughlin AFB	TX	124,398	190	1,939,871	64,127	62

Energy Intensity Rank-Matrix

Ranked Energy Cost-Intensity by Base (FY13 Data Only) - 62 Major CONUS Air Force Bases						
Installation Name	State	Total Annual Energy Cost (Electricity & Natural Gas) ($)	Total Facility Count	Gross Square Footage (Ft^2)	Energy Cost-Intensity ($/$Ft^2$)	Energy Cost-Intensity Rank
Cape Cod AS	MA	$ 1,348,265	16	109,722	$12.288	1
Arnold AS	TN	$ 19,658,481	334	2,837,855	$6.927	2
Cavalier AS	ND	$ 2,529,687	33	411,335	$6.150	3
New Boston AS	NH	$ 540,352	25	96,075	$5.624	4
Schriever AFB	CO	$ 6,664,342	71	2,062,819	$3.231	5
Los Angeles AFB	CA	$ 2,549,914	20	943,450	$2.703	6
MacDill AFB	FL	$ 12,811,017	302	4,902,311	$2.613	7
Creech AFB	NV	$ 2,103,141	128	898,766	$2.340	8
Maxwell AFB	AL	$ 10,724,561	217	4,612,524	$2.325	9
Eglin AFB	FL	$ 23,382,584	1,671	11,563,202	$2.022	10
Hanscom AFB	MA	$ 7,856,686	139	4,045,153	$1.942	11
Joint Base San Antonio (JBSA)	TX	$ 56,385,020	1,478	29,351,739	$1.921	12
Dover AFB	DE	$ 7,722,769	217	4,030,292	$1.916	13
Cannon AFB	NM	$ 7,130,369	652	3,925,694	$1.816	14
Peterson AFB	CO	$ 6,393,198	203	3,539,467	$1.806	15
Tinker AFB	OK	$ 25,145,245	414	14,587,790	$1.724	16
Edwards AFB	CA	$ 12,464,172	741	7,249,229	$1.719	17
Joint Base Charleston	SC	$ 14,586,327	894	8,629,056	$1.690	18
Robins AFB	GA	$ 23,474,428	530	13,943,133	$1.684	19
Hurlburt Field	FL	$ 8,701,732	567	5,213,156	$1.669	20
Columbus AFB	MS	$ 2,762,896	175	1,658,149	$1.666	21
Wright-Patterson AFB	OH	$ 27,923,186	595	16,798,409	$1.662	22
Tyndall AFB	FL	$ 6,697,575	469	4,125,160	$1.624	23
Malmstrom AFB	MT	$ 6,294,721	516	3,925,102	$1.604	24
Shaw AFB	SC	$ 5,570,745	298	3,528,295	$1.579	25
Joint Base McGuire-Dix-Lakehurst (JBMDL)	NJ	$ 21,596,497	1,189	14,015,273	$1.541	26
Davis-Monthan AFB	AZ	$ 7,311,552	511	4,854,245	$1.506	27
McConnell AFB	KS	$ 4,762,507	208	3,193,432	$1.491	28
Joint Base Langley-Eustis (JBLE)	VA	$ 18,000,019	701	12,116,506	$1.486	29
Patrick AFB	FL	$ 4,609,127	279	3,119,905	$1.477	30
Beale AFB	CA	$ 4,223,217	256	2,874,438	$1.469	31
Joint Base Andrews	MD	$ 9,729,588	355	6,658,924	$1.461	32
F. E. Warren AFB	WY	$ 4,765,776	249	3,342,460	$1.426	33
Kirtland AFB	NM	$ 10,709,381	754	7,538,562	$1.421	34
Cape Canaveral AFS	FL	$ 5,162,508	532	3,730,079	$1.384	35
Keesler AFB	MS	$ 9,598,032	231	6,989,842	$1.373	36
US Air Force Academy	CO	$ 7,825,958	264	5,910,086	$1.324	37
Goodfellow AFB	TX	$ 3,363,700	155	2,596,632	$1.295	38
Luke AFB	AZ	$ 4,745,633	349	3,716,392	$1.277	39
Hill AFB	UT	$ 16,046,968	767	12,813,276	$1.252	40
Little Rock AFB	AR	$ 5,109,392	354	4,113,665	$1.242	41
Altus AFB	OK	$ 3,210,903	162	2,631,914	$1.220	42
Moody AFB	GA	$ 3,644,566	329	2,987,464	$1.220	43
Barksdale AFB	LA	$ 6,098,865	436	5,021,944	$1.214	44
Scott AFB	IL	$ 5,947,052	286	4,913,640	$1.210	45
Laughlin AFB	TX	$ 2,341,134	190	1,939,871	$1.207	46
Holloman AFB	NM	$ 6,800,375	494	6,028,378	$1.128	47
Offutt AFB	NE	$ 6,637,509	212	5,887,038	$1.127	48
Mountain Home AFB	ID	$ 3,818,238	451	3,406,306	$1.121	49
Vandenberg AFB	CA	$ 7,084,286	640	6,415,839	$1.104	50
Nellis AFB	NV	$ 6,966,823	617	6,311,226	$1.104	51
Sheppard AFB	TX	$ 8,158,169	350	7,434,061	$1.097	52
Buckley AFB	CO	$ 3,576,644	198	3,387,152	$1.056	53
Seymour Johnson AFB	NC	$ 4,649,922	820	4,506,956	$1.032	54
Whiteman AFB	MO	$ 5,169,952	879	5,230,677	$0.988	55
Travis AFB	CA	$ 5,958,080	370	6,406,042	$0.930	56
Grand Forks AFB	ND	$ 4,010,480	603	4,652,792	$0.862	57
Vance AFB	OK	$ 1,265,269	127	1,487,793	$0.850	58
Minot AFB	ND	$ 6,230,857	1,242	8,084,075	$0.771	59
Dyess AFB	TX	$ 3,604,343	747	4,711,125	$0.765	60
Fairchild AFB	WA	$ 3,286,089	285	4,448,752	$0.739	61
Ellsworth AFB	SD	$ 3,325,842	729	5,976,862	$0.556	62

Energy Cost-Intensity Rank-Matrix

Ranked Electric Rates by Base (FY 12-14) - 62 Major CONUS Air Force Bases				
Installation Name	State	Average Electric Rate ($/kWh)	Std Dev Electric Rate ($/kWh)	Electric Rate Rank
Hanscom AFB	MA	$0.15399	$0.03415	1
Cape Cod AS	MA	$0.11883	$0.02878	2
Los Angeles AFB	CA	$0.11696	$0.03210	3
New Boston AS	NH	$0.10532	$0.00700	4
Joint Base McGuire-Dix-Lakehurst (JBMDL)	NJ	$0.09196	$0.01576	5
Dover AFB	DE	$0.09080	$0.00734	6
Davis-Monthan AFB	AZ	$0.08394	$0.00685	7
Columbus AFB	MS	$0.08269	$0.01741	8
Malmstrom AFB	MT	$0.08261	$0.00382	9
Tyndall AFB	FL	$0.08129	$0.00896	10
Eglin AFB	FL	$0.07986	$0.01214	11
Hurlburt Field	FL	$0.07865	$0.00732	12
MacDill AFB	FL	$0.07853	$0.00254	13
Edwards AFB	CA	$0.07841	$0.01571	14
Creech AFB	NV	$0.07783	$0.02192	15
Joint Base Charleston	SC	$0.07753	$0.00508	16
Joint Base Andrews	MD	$0.07674	$0.01660	17
Laughlin AFB	TX	$0.07649	$0.01343	18
Moody AFB	GA	$0.07420	$0.00294	19
Shaw AFB	SC	$0.07401	$0.00207	20
Vandenberg AFB	CA	$0.07399	$0.03058	21
Joint Base San Antonio (JBSA)	TX	$0.07253	$0.00461	22
Keesler AFB	MS	$0.07116	$0.00678	23
Grand Forks AFB	ND	$0.07111	$0.00745	24
Buckley AFB	CO	$0.06981	$0.00986	25
F. E. Warren AFB	WY	$0.06897	$0.01575	26
Schriever AFB	CO	$0.06831	$0.00738	27
Robins AFB	GA	$0.06729	$0.00505	28
Luke AFB	AZ	$0.06697	$0.00660	29
Arnold AS	TN	$0.06638	$0.00712	30
Seymour Johnson AFB	NC	$0.06605	$0.00737	31
McConnell AFB	KS	$0.06601	$0.00462	32
Holloman AFB	NM	$0.06400	$0.00749	33
Joint Base Langley-Eustis (JBLE)	VA	$0.06388	$0.00334	34
Sheppard AFB	TX	$0.06384	$0.00893	35
Altus AFB	OK	$0.06273	$0.00478	36
Kirtland AFB	NM	$0.06210	$0.01211	37
Minot AFB	ND	$0.06175	$0.00377	38
Goodfellow AFB	TX	$0.06173	$0.00850	39
Barksdale AFB	LA	$0.06160	$0.00512	40
Patrick AFB	FL	$0.06068	$0.00307	41
Travis AFB	CA	$0.06058	$0.01093	42
Maxwell AFB	AL	$0.05994	$0.01063	43
Wright-Patterson AFB	OH	$0.05968	$0.00466	44
Cannon AFB	NM	$0.05889	$0.01074	45
Whiteman AFB	MO	$0.05885	$0.01176	46
Beale AFB	CA	$0.05739	$0.01329	47
Dyess AFB	TX	$0.05606	$0.01334	48
Peterson AFB	CO	$0.05602	$0.00483	49
Mountain Home AFB	ID	$0.05602	$0.00942	50
Little Rock AFB	AR	$0.05449	$0.00753	51
Hill AFB	UT	$0.05269	$0.00747	52
Cape Canaveral AFS	FL	$0.05208	$0.01162	53
Nellis AFB	NV	$0.05095	$0.01618	54
US Air Force Academy	CO	$0.04907	$0.00860	55
Cavalier AS	ND	$0.04881	$0.00412	56
Vance AFB	OK	$0.04676	$0.00762	57
Tinker AFB	OK	$0.04514	$0.00893	58
Ellsworth AFB	SD	$0.04354	$0.01091	59
Fairchild AFB	WA	$0.04071	$0.00577	60
Scott AFB	IL	$0.04053	$0.00601	61
Offutt AFB	NE	$0.03427	$0.00103	62

Electric Rate Rank-Matrix

Ranked Natural Gas Rates by Base (FY 12-14) - 62 Major CONUS Air Force Bases				
Installation Name	State	Average Natural Gas Rate ($/Mcf)	Std Dev Natural Gas Rate ($/Mcf)	Natural Gas Rate Rank
Altus AFB	OK	$15.591	$11.961	1
Luke AFB	AZ	$11.054	$2.370	2
Scott AFB	IL	$9.345	$2.073	3
Davis-Monthan AFB	AZ	$9.260	$2.204	4
Malmstrom AFB	MT	$9.055	$5.277	5
Dover AFB	DE	$9.011	$2.594	6
Joint Base McGuire-Dix-Lakehurst (JBMDL)	NJ	$8.949	$1.859	7
Buckley AFB	CO	$8.903	$3.271	8
Maxwell AFB	AL	$8.716	$0.940	9
Joint Base Andrews	MD	$8.701	$1.929	10
Seymour Johnson AFB	NC	$8.667	$1.383	11
Joint Base Charleston	SC	$8.422	$0.766	12
Patrick AFB	FL	$8.293	$0.792	13
Joint Base Langley-Eustis (JBLE)	VA	$8.249	$1.459	14
Cape Canaveral AFS	FL	$8.007	$1.042	15
Beale AFB	CA	$7.950	$1.776	16
Peterson AFB	CO	$7.897	$0.852	17
Shaw AFB	SC	$7.805	$2.513	18
Barksdale AFB	LA	$7.288	$1.549	19
Vance AFB	OK	$7.232	$3.230	20
Mountain Home AFB	ID	$7.023	$1.438	21
Columbus AFB	MS	$6.868	$1.794	22
Hanscom AFB	MA	$6.866	$3.004	23
Eglin AFB	FL	$6.786	$0.361	24
MacDill AFB	FL	$6.762	$0.743	25
Hurlburt Field	FL	$6.707	$0.454	26
Los Angeles AFB	CA	$6.424	$0.912	27
Arnold AS	TN	$6.065	$0.776	28
Edwards AFB	CA	$6.051	$1.985	29
Fairchild AFB	WA	$5.978	$1.764	30
Dyess AFB	TX	$5.636	$2.138	31
Nellis AFB	NV	$5.590	$1.385	32
Offutt AFB	NE	$5.576	$0.809	33
Goodfellow AFB	TX	$5.576	$1.319	34
US Air Force Academy	CO	$5.570	$0.771	35
Joint Base San Antonio (JBSA)	TX	$5.537	$0.874	36
F. E. Warren AFB	WY	$5.443	$1.590	37
Holloman AFB	NM	$5.255	$0.859	38
Sheppard AFB	TX	$5.187	$1.217	39
Laughlin AFB	TX	$5.179	$1.441	40
Moody AFB	GA	$5.128	$2.876	41
Wright-Patterson AFB	OH	$5.107	$0.812	42
Cannon AFB	NM	$5.092	$1.268	43
Little Rock AFB	AR	$5.017	$1.080	44
Tyndall AFB	FL	$5.016	$1.277	45
Vandenberg AFB	CA	$4.899	$2.343	46
Schriever AFB	CO	$4.795	$0.813	47
Grand Forks AFB	ND	$4.652	$0.999	48
Keesler AFB	MS	$4.428	$0.958	49
Tinker AFB	OK	$4.365	$0.965	50
Kirtland AFB	NM	$4.324	$1.546	51
Travis AFB	CA	$4.294	$1.199	52
Whiteman AFB	MO	$4.155	$0.883	53
Hill AFB	UT	$4.147	$1.711	54
Minot AFB	ND	$4.141	$0.989	55
Cavalier AS	ND	$4.039	$1.114	56
Robins AFB	GA	$3.970	$0.789	57
Ellsworth AFB	SD	$3.951	$0.888	58
McConnell AFB	KS	$3.932	$0.998	59
Cape Cod AS	MA	N/A	N/A	N/A
Creech AFB	NV	N/A	N/A	N/A
New Boston AS	NH	N/A	N/A	N/A

Natural Gas Rate Rank-Matrix

Equivalent Annual Cost (EAC) of Tornado, Hurricane, & Energy Factors by Base - 62 Major CONUS Air Force Bases - Ranked by Total EAC

For BRAC - Enter Total EAC into COBRA Model to Account for Annual Tornado, Hurricane, & Energy Costs

Installation Data		Tornadoes			Hurricanes			Electricity			Natural Gas			Total EAC ($)	Total EAC Rank
Name	PRV ($M)	Median EAC ($)	% of Total	EAC Rank	Median EAC ($)	% of Total	EAC Rank	Mean EAC ($)	% of Total	EAC Rank	Mean EAC ($)	% of Total	EAC Rank		
Eglin AFB	$ 4,726.7	$788,112	0.8%	11	$74,051,189	74.0%	1	$22,561,526	22.6%	3	$2,614,765	2.6%	10	**$100,015,593**	**1**
Joint Base San Antonio	$ 7,629.1	$1,272,048	1.5%	4	$28,630,009	33.2%	4	$47,283,106	54.8%	1	$9,071,602	10.5%	1	**$86,256,764**	**2**
MacDill AFB	$ 1,837.4	$389,723	0.8%	25	$36,033,213	72.9%	2	$12,837,441	26.0%	10	$148,643	0.3%	59	**$49,409,021**	**3**
Keesler AFB	$ 1,831.4	$521,884	1.2%	20	$31,250,829	74.8%	3	$8,826,557	21.1%	13	$1,164,147	2.8%	30	**$41,763,417**	**4**
Joint Base Charleston	$ 3,098.1	$516,566	1.3%	21	$23,311,753	60.1%	5	$13,844,260	35.7%	9	$1,140,477	2.9%	32	**$38,813,056**	**5**
Joint Base Langley-Eustis	$ 3,625.4	$914,997	2.8%	8	$13,605,174	41.3%	10	$14,890,019	45.2%	8	$3,556,450	10.8%	5	**$32,966,640**	**6**
Hurlburt Field	$ 1,482.3	$314,405	1.0%	28	$23,222,561	71.0%	6	$8,150,290	24.9%	15	$1,002,489	3.1%	37	**$32,689,745**	**7**
Tinker AFB	$ 4,153.5	$3,156,226	10.6%	2	$0	0.0%	18	$19,649,799	65.7%	5	$7,090,833	23.7%	2	**$29,896,858**	**8**
Wright-Patterson AFB	$ 5,968.0	$1,506,235	5.3%	3	$0	0.0%	18	$24,281,571	85.3%	2	$2,672,846	9.4%	9	**$28,460,652**	**9**
Tyndall AFB	$ 1,556.3	$188,878	0.7%	33	$20,265,308	73.3%	7	$6,828,991	24.7%	19	$357,164	1.3%	52	**$27,640,341**	**10**
Robins AFB	$ 3,679.2	$780,380	3.1%	12	$0	0.0%	18	$21,342,615	84.7%	4	$3,080,446	12.2%	6	**$25,203,441**	**11**
Arnold AS	$ 7,802.1	$3,733,003	15.2%	1	$0	0.0%	18	$17,737,166	72.3%	6	$3,072,330	12.5%	7	**$24,542,500**	**12**
JB McGuire-Dix-Lakehurst	$ 7,289.3	$884,655	3.7%	10	$0	0.0%	18	$16,465,773	68.1%	7	$6,837,761	28.3%	3	**$24,188,190**	**13**
Patrick AFB	$ 1,063.7	$129,094	0.6%	38	$18,150,872	78.2%	8	$4,677,311	20.2%	37	$254,181	1.1%	55	**$23,211,458**	**14**
Cape Canaveral AFS	$ 1,516.1	$105,154	0.5%	41	$17,680,095	77.3%	9	$4,726,522	20.7%	36	$373,791	1.6%	51	**$22,885,562**	**15**
Hill AFB	$ 4,165.1	$0	0.0%	46	$0	0.0%	18	$12,383,455	74.5%	11	$4,229,714	25.5%	4	**$16,613,169**	**16**
Maxwell AFB	$ 1,297.2	$639,488	4.0%	16	$4,868,051	30.7%	14	$7,891,154	49.8%	16	$2,453,533	15.5%	11	**$15,852,226**	**17**
Hanscom AFB	$ 1,782.8	$0	0.0%	46	$6,690,380	45.9%	12	$5,516,675	37.8%	26	$2,372,743	16.3%	14	**$14,579,799**	**18**
Edwards AFB	$ 5,719.8	$0	0.0%	46	$0	0.0%	18	$11,543,338	82.5%	12	$2,448,834	17.5%	12	**$13,992,172**	**19**
Seymour Johnson AFB	$ 1,321.7	$721,566	5.2%	14	$8,137,709	59.1%	11	$3,921,213	28.5%	43	$994,967	7.2%	39	**$13,775,456**	**20**
Shaw AFB	$ 1,223.1	$440,678	3.6%	24	$5,974,263	48.3%	13	$5,255,067	42.5%	28	$702,566	5.7%	45	**$12,372,574**	**21**
Joint Base Andrews	$ 2,589.9	$738,030	7.0%	13	$0	0.0%	18	$7,850,813	74.6%	17	$1,934,174	18.4%	15	**$10,523,017**	**22**
Kirtland AFB	$ 2,981.0	$0	0.0%	46	$0	0.0%	18	$8,218,817	84.7%	14	$1,489,306	15.3%	23	**$9,708,123**	**23**
Vandenberg AFB	$ 3,920.7	$0	0.0%	46	$0	0.0%	18	$7,202,492	84.6%	18	$1,312,610	15.4%	27	**$8,515,103**	**24**
Dover AFB	$ 1,782.1	$216,282	2.6%	30	$0	0.0%	18	$5,782,955	68.8%	23	$2,408,745	28.6%	13	**$8,407,983**	**25**
Sheppard AFB	$ 2,102.6	$0	0.0%	46	$0	0.0%	18	$6,692,735	80.5%	20	$1,626,287	19.5%	20	**$8,319,022**	**26**
Offutt AFB	$ 1,822.3	$898,350	11.5%	9	$0	0.0%	18	$5,227,427	66.9%	29	$1,689,210	21.6%	18	**$7,814,987**	**27**
Scott AFB	$ 1,911.5	$1,163,571	15.0%	5	$0	0.0%	18	$4,878,481	62.7%	35	$1,739,454	22.4%	16	**$7,781,506**	**28**
US Air Force Academy	$ 2,873.3	$348,714	4.5%	26	$0	0.0%	18	$4,486,818	58.5%	38	$2,837,518	37.0%	8	**$7,673,051**	**29**
Davis-Monthan AFB	$ 2,053.8	$142,447	1.9%	37	$0	0.0%	18	$6,168,133	83.8%	21	$1,053,907	14.3%	34	**$7,364,488**	**30**
Moody AFB	$ 916.1	$111,181	1.5%	40	$3,437,883	47.1%	15	$3,519,994	48.2%	45	$235,159	3.2%	56	**$7,304,216**	**31**
Barksdale AFB	$ 1,569.2	$1,062,657	15.1%	7	$0	0.0%	18	$4,878,659	69.1%	34	$1,115,174	15.8%	33	**$7,056,490**	**32**
Nellis AFB	$ 3,185.9	$0	0.0%	46	$0	0.0%	18	$6,005,913	86.3%	22	$949,767	13.7%	40	**$6,955,680**	**33**
Peterson AFB	$ 1,217.2	$202,951	3.0%	31	$0	0.0%	18	$5,076,489	74.7%	32	$1,516,381	22.3%	22	**$6,795,822**	**34**
Holloman AFB	$ 2,795.5	$0	0.0%	46	$0	0.0%	18	$5,179,439	76.9%	31	$1,559,323	23.1%	21	**$6,738,762**	**35**
Malmstrom AFB	$ 1,752.0	$0	0.0%	46	$0	0.0%	18	$5,180,689	77.7%	30	$1,489,029	22.3%	24	**$6,669,718**	**36**
Schriever AFB	$ 741.6	$157,298	2.4%	36	$0	0.0%	18	$5,641,101	86.4%	24	$727,853	11.2%	43	**$6,526,252**	**37**
Minot AFB	$ 2,520.6	$174,824	2.7%	35	$0	0.0%	18	$5,287,773	81.6%	27	$1,017,207	15.7%	36	**$6,479,804**	**38**
Cannon AFB	$ 1,462.0	$177,434	2.8%	34	$0	0.0%	18	$5,002,534	77.8%	33	$1,248,002	19.4%	28	**$6,427,970**	**39**
Travis AFB	$ 3,684.2	$0	0.0%	46	$0	0.0%	18	$5,577,970	88.5%	25	$727,278	11.5%	44	**$6,305,247**	**40**
Little Rock AFB	$ 1,457.7	$1,107,700	17.9%	6	$0	0.0%	18	$4,040,774	65.2%	41	$1,051,888	17.0%	35	**$6,200,362**	**41**
Whiteman AFB	$ 2,245.0	$720,384	11.8%	15	$0	0.0%	18	$4,023,298	65.8%	42	$1,371,133	22.4%	25	**$6,114,815**	**42**
McConnell AFB	$ 1,238.8	$557,193	10.4%	17	$0	0.0%	18	$4,154,169	77.2%	40	$670,814	12.5%	46	**$5,382,176**	**43**
Luke AFB	$ 1,336.9	$0	0.0%	46	$0	0.0%	18	$4,466,495	89.0%	39	$554,207	11.0%	47	**$5,020,702**	**44**
Altus AFB	$ 1,169.2	$194,948	4.3%	32	$0	0.0%	18	$2,636,529	57.7%	51	$1,736,958	38.0%	17	**$4,568,435**	**45**
Grand Forks AFB	$ 1,515.7	$546,101	12.1%	18	$0	0.0%	18	$2,959,114	65.7%	48	$999,219	22.2%	38	**$4,504,434**	**46**
Dyess AFB	$ 1,584.8	$508,536	11.9%	22	$0	0.0%	18	$3,036,050	71.0%	47	$729,978	17.1%	42	**$4,274,564**	**47**
F. E. Warren AFB	$ 1,164.7	$80,781	1.9%	42	$0	0.0%	18	$2,935,941	69.2%	49	$1,228,115	28.9%	29	**$4,244,838**	**48**
Buckley AFB	$ 1,139.8	$476,728	11.4%	23	$0	0.0%	18	$2,867,769	68.7%	50	$828,946	19.9%	41	**$4,173,442**	**49**
Beale AFB	$ 2,038.1	$0	0.0%	46	$0	0.0%	18	$3,553,813	87.2%	44	$523,856	12.8%	48	**$4,077,669**	**50**
Ellsworth AFB	$ 2,065.8	$250,713	6.7%	29	$0	0.0%	18	$2,352,045	62.7%	54	$1,149,868	30.6%	31	**$3,752,626**	**51**
Fairchild AFB	$ 1,852.9	$0	0.0%	46	$0	0.0%	18	$2,056,127	55.4%	59	$1,656,526	44.6%	19	**$3,712,653**	**52**
Mountain Home AFB	$ 1,909.2	$0	0.0%	46	$0	0.0%	18	$2,294,221	63.5%	55	$1,317,805	36.5%	26	**$3,612,026**	**53**
Goodfellow AFB	$ 607.7	$42,149	1.2%	43	$0	0.0%	18	$3,079,588	88.9%	46	$343,175	9.9%	53	**$3,464,912**	**54**
Columbus AFB	$ 736.1	$538,718	15.6%	19	$0	0.0%	18	$2,523,984	73.1%	52	$390,188	11.3%	49	**$3,452,891**	**55**
Los Angeles AFB	$ 317.8	$0	0.0%	46	$0	0.0%	18	$2,408,650	93.4%	53	$170,213	6.6%	58	**$2,578,863**	**56**
Cavalier AS	$ 153.2	$25,544	1.0%	44	$0	0.0%	18	$2,251,682	87.4%	56	$298,366	11.6%	54	**$2,575,592**	**57**
Laughlin AFB	$ 741.1	$123,568	5.1%	39	$0	0.0%	18	$2,117,506	87.6%	58	$176,658	7.3%	57	**$2,417,733**	**58**
Creech AFB	$ 574.9	$0	0.0%	46	$0	0.0%	18	$2,162,999	100.0%	57	N/A	N/A	N/A	**$2,162,999**	**59**
Vance AFB	$ 624.8	$335,067	18.7%	27	$0	0.0%	18	$1,074,630	60.0%	61	$380,795	21.3%	50	**$1,790,493**	**60**
Cape Cod AS	$ 53.8	$0	0.0%	46	$262,787	19.1%	17	$1,115,165	80.9%	60	N/A	N/A	N/A	**$1,377,953**	**61**
New Boston AS	$ 70.6	$11,772	1.5%	45	$264,943	32.7%	16	$534,599	65.9%	62	N/A	N/A	N/A	**$811,313**	**62**
	TOTALS:	$27,916,735	3.1%		$315,837,019	35.1%		$457,118,230	50.9%		$97,895,378	10.9%		$898,767,362	

Equivalent Annual Cost (EAC) of Tornado, Hurricane, & Energy Factors by Base

Appendix J – List of Major U.S. Hurricanes (1851-2013)

Most Intense (3, 4, 5) Continental United States Hurricanes: 1851 - 1950, 1969 (Camille), and 1983-2013

(Revised in April 2014 to reflect the 1946-1950 and Hurricane Camille revisions) (NOAA, 2013a)

#	Date	Time	Latitude	Longitude	Max Winds (kt)	SS HWS	RMW nm	Central Pressure (mb)	States Affected	Name
3	9/3/1935	0200Z	24.8N	80.8W	160	5	5	892	CFL5,BFL5	"Labor Day"
9	8/18/1969	0400Z	30.3N	89.4W	150	5	10	900	MS5,LA5,AL1	Camille
2	8/26/1992	0905Z	25.5N	80.3W	145	5	10	922	CFL5,BFL4	Andrew
1	8/10/1856$	1800Z	29.2N	91.1W	130	4	10	934	LA4	"Last Island"
5	8/20/1886	1300Z	28.1N	96.8W	130	4	15	925	BTX4	"Indianola"
2	9/10/1919	0700Z	24.6N	82.9W	130	4	15	927	BFL4,CFL2	---------
2	8/14/1932	0400Z	29.0N	95.2W	130	4	10	935	CTX4,BTX1	"Freeport"
3	8/13/2004	1945Z	26.6N	82.2W	130	4	---	941	BFL4,CFL1,DFL1	Charley
7	9/18/1926	1200Z	25.7N	80.3W	125	4	20	930	CFL4,BFL3	"Great Miami"
4	9/17/1928	0000Z	26.7N	80.0W	125	4	30	929	CFL4,BFL3,AFL1,DFL1	"Lake Okeechobee"
1	9/9/1900	0200Z	29.1N	95.1W	120	4	15	936	CTX4	"Galveston"
8	9/22/1989	0400Z	32.8N	79.8W	120	4	---	934	SC4,INC1	Hugo
10	10/2/1893	0800Z	29.3N	89.8W	115	4	10	948	LA4	"Chenier Caminanda"
7	10/2/1898	1600Z	30.9N	81.4W	115	4	20	938	GA4,DFL2	----------
2	8/17/1915	0700Z	29.2N	95.1W	115	4	25	940	CTX4,BTX1,LA1	"Galveston"
6	8/18/1916	2200Z	27.0N	97.4W	115	4	25	932	ATX4	----------
9	9/15/1945	1930Z	25.3N	80.3W	115	4	10	949	CFL4,BFL2,DFL1	----------
4	9/16/1947	1630Z	26.1N	80.1W	115	4	15	943	CFL4,BFL2	----------
8	9/22/1948	0500Z	25.8N	81.3W	115	4	10	940	BFL4,CFL2	----------
2	8/26/1949	2300Z	26.6N	80.0W	115	4	20	954	CFL4,BFL1,AFL1,DFL1,GA1	----------
11	10/18/1950	0500Z	25.7N	80.2W	115	4	5	955	CFL4,DFL1	King
6	9/16/1855$	0300Z	29.2N	89.5W	110	3	---	945	LA3,MS3	"Middle Gulf Shore"
1	8/11/1860$	2000Z	29.2N	90.0W	110	3	---	945	LA3,MS3,AL2	----------
4	9/1/1879$	1600Z	29.5N	91.4W	110	3	---	945	LA3	----------
2	8/13/1880#	0100Z	25.8N	97.0W	110	3	10	931	ATX3	----------
2	9/10/1882	0200Z	30.4N	86.8W	110	3	---	949	AFL3,AL1	----------
3	8/16/1888$	1900Z	25.8N	80.1W	110	3	---	945	CFL3,BFL1	----------
4	9/29/1896	1100Z	29.2N	83.1W	110	3	15	960	AFL3,DFL3,GA2,SC1,NC1,VA1	----------
6	9/29/1915	1800Z	29.1N	90.3W	110	3	20	944	LA3,MS2	"New Orleans"
10	9/5/1933	0400Z	26.1N	97.2W	110	3	20	940	ATX3	----------
11	9/4/1933	0500Z	26.9N	80.1W	110	3	15	948	CF3	----------
2	9/23/1941	2200Z	28.8N	95.6W	110	3	20	942	CTX3,BTX2	----------

(NOAA, 2013a)

#	Date	Time	Latitude	Longitude	Max Winds (kt)	SS HWS	RMW nm	Central Pressure (mb)	States Affected	Name
11	8/29/2005	1110Z	29.3N	89.6W	110	3	---	920	LA3,MS3,AL1	Katrina
10	10/12/1886	2200Z	29.8N	93.5W	105	3	---	950	LA3,CTX2	
9	10/13/1893	1300Z	33.0N	79.5W	105	3	15	955	SC3,NC2,VA1	---------
5	10/9/1894	0300Z	30.2N	85.5W	105	3	---	950	AFL3,GA1	---------
3	8/18/1899	0100Z	35.2N	75.8W	105	3	---	945	NC3	---------
8	10/18/1906	0900Z	24.7N	81.1W	105	3	10	953	BFL3,CFL3	---------
2	7/5/1916	2100Z	30.4N	88.4W	105	3	20	950	MS3,AL2,AFL2	---------
1	8/6/1918	1800Z	29.8N	93.2W	105	3	10	955	LA3,CTX1	---------
6	/9/21/1938	2000Z	40.7N	72.9W	105	3	40	941	NY3,CT3,RI3,MA2	"Great New England"
13	10/18/1944	2100Z	24.6N	82.9W	105	3	30	949	BFL3	---------
5	9/5/1950	1700Z	29.1N	82.8W	105	3	15	960	AFL3,BFL1	Easy
9	9/16/2004	0650Z	30.2N	87.9W	105	3	---	946	AL3,AFL3	Ivan
10	9/26/2004	0400Z	27.2N	80.2W	105	3	---	950	CFL3,BFL1,AFL1	Jeanne
4	7/10/2005	1930Z	30.4N	87.1W	105	3	---	946	AFL3,IAL1	Dennis
21	10/24/2005	1030Z	25.9N	81.7W	105	3	---	950	BFL3,CFL2	Wilma
4	8/23/1851$	2100Z	30.1N	85.7W	100	3	---	955	AFL3,GA1	"Great Middle Florida"
1	8/26/1852	0600Z	30.2N	88.6W	100	3	10	961	AL3,MS3,LA2,AFL1	"Great Mobile"
2	9/8/1854	2000Z	31.7N	81.1W	100	3	40	950	GA3,SC2,DFL1	"Great Carolina"
6	9/8/1869	2200Z	41.4N	71.7W	100	3	30	965	RI3,MA3,CT1	"Eastern New England"
3	8/17/1871$	0200Z	27.1N	80.2W	100	3	30	955	CFL3,DFL1,AFL1	----------
5	10/7/1873$	0100Z	26.5N	82.2W	100	3	25	959	BFL3,CFL2,DFL1	----------
3	9/16/1875	2100Z	27.7N	97.2W	100	3	---	955	BTX3,ATX2	----------
4	10/3/1877$	0500Z	30.0N	85.5W	100	3	---	955	AFL3,GA1	----------
2	8/18/1879	1200Z	34.7N	76.7W	100	3	15	971	NC3,VA2	----------
6	8/28/1893	0500Z	31.7N	81.1W	100	3	25	954	GA3,SC3,NC1,DFL1	"Sea Island"
4	7/21/1909	1700Z	28.9N	95.3W	100	3	20	959	CTX3	"Velasco"
9	9/21/1909	0000Z	29.5N	91.3W	100	3	30	952	LA3,MS2	"Grand Isle"
11	10/11/1909	1800Z	24.7N	81.0W	100	3	20	957	BFL3,CFL3	----------
4	9/29/1917	0200Z	30.4N	86.6W	100	3	40	949	AFL3,LA2,AL1	----------
2	9/14/1919	2100Z	27.2N	97.3W	100	3	35	950	ATX3,BTX3	----------
6	10/25/1921	2000Z	28.1N	82.8W	100	3	20	958	BFL3,AFL2,DFL1	"Tampa Bay"
3	8/25/1926	2300Z	29.2N	90.9W	100	3	15	967	LA3	----------
7	9/20/1926	2200Z	30.3N	87.5W	100	3	15	955	AFL3,AL3,MS1	----------
2	9/28/1929	1300Z	25.0N	80.5W	100	3	30	948	BFL3,CFL3	----------
3	8/30/1942	0900Z	28.3N	96.6W	100	3	20	950	BTX3,CTX2	----------
5	8/27/1945	1200Z	28.2N	96.7W	100	3	10	963	BTX3,ATX1,CTX1	----------
1	8/18/1983	0700Z	29.1N	95.1W	100	3	---	962	CTX3	Alicia
5	9/2/1985	1300Z	30.4N	89.2W	100	3	---	959	AL3,MS3,AFL3	Elena

#	Date	Time	Latitude	Longitude	Max Winds (kt)	SS HWS	RMW nm	Central Pressure (mb)	States Affected	Name
2	8/26/1992	0830Z	29.6N	91.5W	100	3	---	956	LA3	Andrew
5	8/31/1993	2100Z	35.2N	75.1W	100	3	---	961	NC3	Emily
15	10/4/1995	2200Z	30.3N	87.1W	100	3	---	942	AFL3,IAL1	Opal
6	9/6/1996	0030Z	33.9N	78.0W	100	3	---	954	NC3	Fran
2	8/23/1999	0000Z	26.9N	97.4W	100	3	---	951	ATX3	Bret
17	9/24/2005	0740Z	29.7N	93.7W	100	3	---	937	LA3,CTX2	Rita

Notes:

(NOAA, 2013a)

Date/Time: Date and time when the circulation center crosses the U.S. coastline (including barrier islands). Time is estimated to the nearest hour.

Lat/Lon: Location is estimated to the nearest 0.1 degrees latitude and longitude (about 6 nm).

Max Winds: Estimated maximum sustained (1 min) surface (10 m) winds to occur along the U. S. coast.

SSHWS: The estimated Saffir-Simpson Hurricane Wind Scale at landfall based upon maximum 1-min surface winds.

RMW: The radius of maximum winds (primarily for the right front quadrant of the hurricane), if available.

Cent Press: The central pressure of the hurricane at landfall. Central pressure values in parentheses indicate that the value is a simple estimation (based upon a wind-pressure relationship), not directly measured or calculated.

States Affected: The impact of the hurricane upon individual U.S. states by Saffir-Simpson Scale (again through the estimate of the maximum 1-min surface winds at each state). (ATX-South Texas, BTX-Central Texas, CTX-North Texas, LA-Louisiana, MS-Mississippi, AL-Alabama, AFL-Northwest Florida, BFL-Southwest Florida, CFL-Southeast Florida, DFL-Northeast Florida, GA-Georgia, SC-South Carolina, NC-North Carolina, VA-Virginia, MD-Maryland, DE-Delaware, NJ-New Jersey, NY-New York, PA-Pennsylvania, CT-Connecticut, RI-Rhode Island, MA-Massachusetts, NH-New Hampshire, ME-Maine. In Texas, south is roughly from the Mexico border to Corpus Christi; central is from north of Corpus Christi to Matagorda Bay and north is from Matagorda Bay to the Louisiana border. In Florida, the north-south dividing line is from Cape Canaveral [28.45N] to Tarpon Springs [28.17N]. The dividing line between west-east Florida goes from 82.69W at the north Florida border with Georgia, to Lake Okeechobee and due south along longitude 80.85W.)

$ - Indicates that the hurricane may not have been reliably estimated for intensity (both central pressure and maximum 1-min windspeed) because of landfall in a relatively uninhabited region. Errors in intensity are likely to be underestimates of the true intensity.

- Indicates that hurricane made landfall first over Mexico, but caused hurricane winds in Texas. The position given is that of Mexican landfall. The strongest winds impacted Mexico. The winds indicated here are lower than in HURDAT and are lower than they were over Mexico. Central pressure given is that at Mexican landfall.

Appendix K – Sample Monte Carlo Data & Distributions – Seymour-Johnson AFB, NC

Maj Chris Teke
Thesis Monte Carlo Simulation
Final Version - February 2015

CONUS Tornadoes 1950-2013 (EF-Rating)	Occurrences	% of Total Occurrences	% of Strong-Violent Occurrences
0	27,124	46.7%	
1	18,846	32.5%	
2	8,934	15.4%	73.9%
3	2,458	4.2%	20.3%
4	619	1.1%	5.1%
5	76	0.1%	0.6%
Total (EF 0-5)	58,057	Strong-Violent Tornadoes (% of Total):	20.8%
Strong-Violent (EF 2-5)	12,087		

Strong-Violent Tornadoes (EF 2-5)	Probability (Calculated)
2	0.739
3	0.203
4	0.051
5	0.006

Probabilities Applied to Tornado EF-Rating Distribution Below

CONUS Hurricanes 1851-2013 (Category)	Strikes	% of Total Strikes	% of Major Strikes
1	115	40.1%	
2	76	26.5%	
3	75	26.1%	78.1%
4	18	6.3%	18.8%
5	3	1.0%	3.1%
Total (Cat 1-5)	287	Major Hurricanes (% of Total):	33.4%
Major (Cat 3-5)	96		

Major Hurricane (Cat 3-5)	Probability (Calculated)	% Facilities Damaged (Estimated) – Low End Damage Estimate: Wind Only	Storm Surge & Flooding Only	Total Low Estimate	High End Damage Estimate: Wind Only	Storm Surge & Flooding Only	Total High Estimate
3	0.781	2%	0%	2%	28%	10%	38%
4	0.188	5%	0%	5%	39%	10%	49%
5	0.031	17%	0%	17%	83%	10%	93%

Hurricane Damage Estimates Used for Uniform Distribution of Base Damage Assessment Below

Summary Information of Total EAC (FYI Only - Not Used in Thesis)	
Min =	$ 5,390,039
Max =	$1,079,913,576
Mean (Expected Value) =	$ 124,591,444
Median =	$ 26,639,055
Std Dev =	$ 221,929,509

Installation Data: Installation Name	Plant Replacement Value[1] (PRV) ($)	Severe Weather: Tornado Occurrences (EF-2 to EF-5) (1984-2013) (w/in 25 mi radius)	Hurricane Occurrences (Cat 3-5) (1851-2013) (w/in 75 naut. mi radius of base centroid)	Energy Usage: Average Annual Electricity Usage (FY12-14) (kWh)	Std Dev of Annual Electricity Usage (FY12-14) (kWh)	Average Annual Natural Gas Usage (FY12-14) (Mcf)	Std Dev of Annual Natural Gas Usage (FY12-14) (Mcf)	Electricity: Average Electric Rate (FY 12-14) ($/kWh)	Standard Deviation of Electric Rates (FY 12-14)	Natural Gas: Average Natural Gas Rate (FY 12-14) ($/Mcf)	Standard Deviation of Natural Gas Rates (FY 12-14)	Median Tornado EAC ($)	Tornado Cost (% of Total EAC)	Median Hurricane EAC ($)	Hurricane Cost (% of Total EAC)	Mean Electric EAC ($)	Electricity Cost (% of Total EAC)	Mean Natural Gas EAC ($)	Natural Gas Cost (% of Total EAC)	Total EAC (Amount Entered into COBRA Model) ($)
Seymour Johnson AFB	$ 1,321,700,000	16	3	59,373,916	3,334,361	114,725	8,827	$0.06605	$0.00737	$8.667	$1.383	$722,142	5.24%	$8,137,709	59.07%	$3,921,213	28.46%	$994,967	7.22%	$13,776,032
Time Period (Includes 1st Year; Max Yr - Min Yr + 1) =		30	163																	
Probability, "p" (Avg # Events/yr) =		0.533	0.018																	
Average Return Period (1/p) (Yrs) =		1.9	54.3																	
2014 Discount Rate (OMB Circular A-94)[2] ("rate" for EAC Calcs") =	1.45%																			

Summary of Equivalent Annual Cost (EAC) of Tornado, Hurricane, & Energy Cost Factors (THIS IS ONLY INFO TRANSFERRED TO FINAL RESULTS SPREADSHEET (Total EAC will be sorted in final data table to rank bases for BRAC))

Yellow Cells = User Entered Values (These Vary for Each Base)

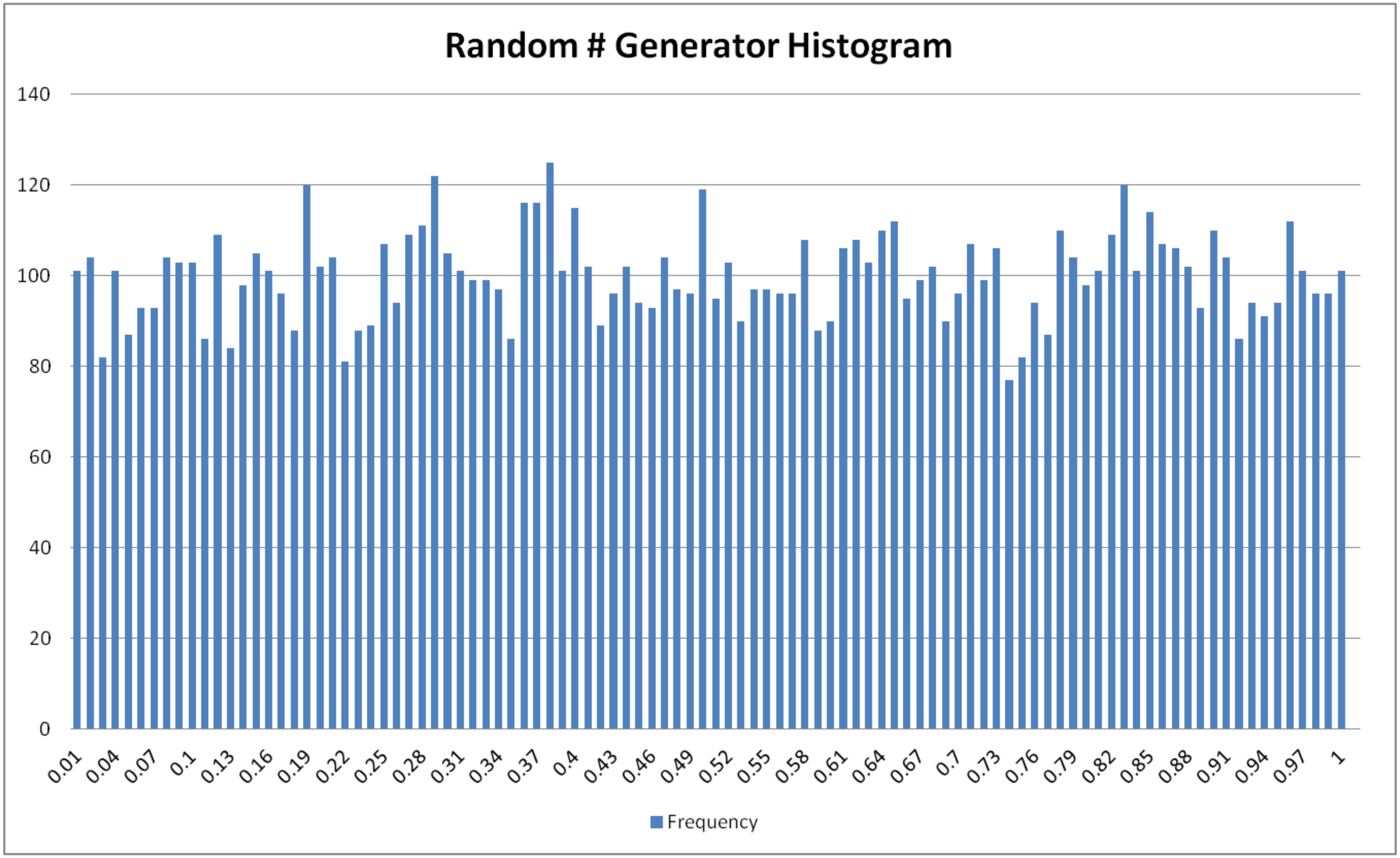
Footnotes:

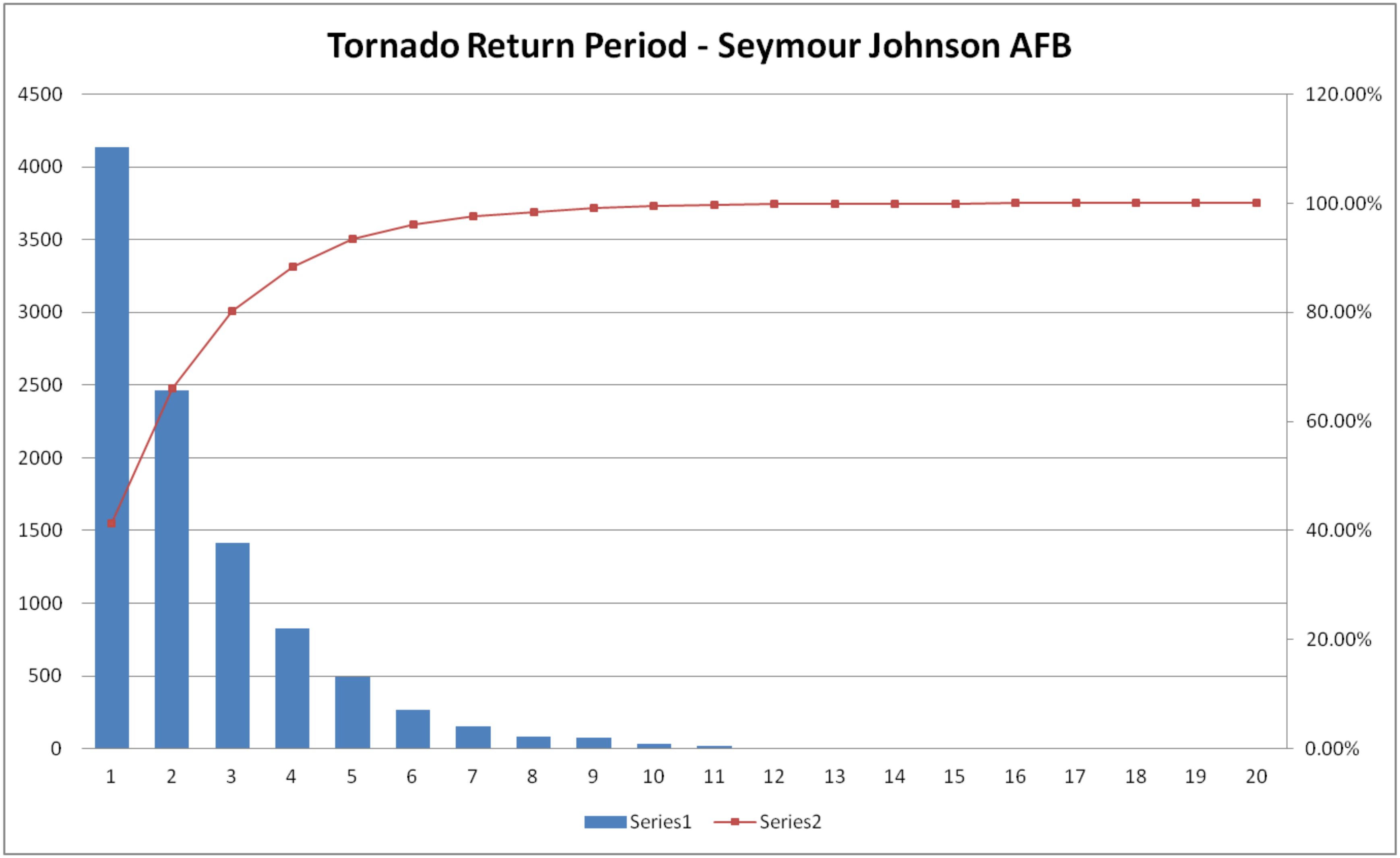
[1] Current as of 30 Sept 2013, *DOD Base Structure Report – FY 14 Baseline*

[2] *Per COBRA User's Manual, the discount rate used for BRAC is the average of the 10 & 30 yr Real Discount Rate published in the current OMB Circular A-94 = (1.0+1.9)/2 =* **1.45%**

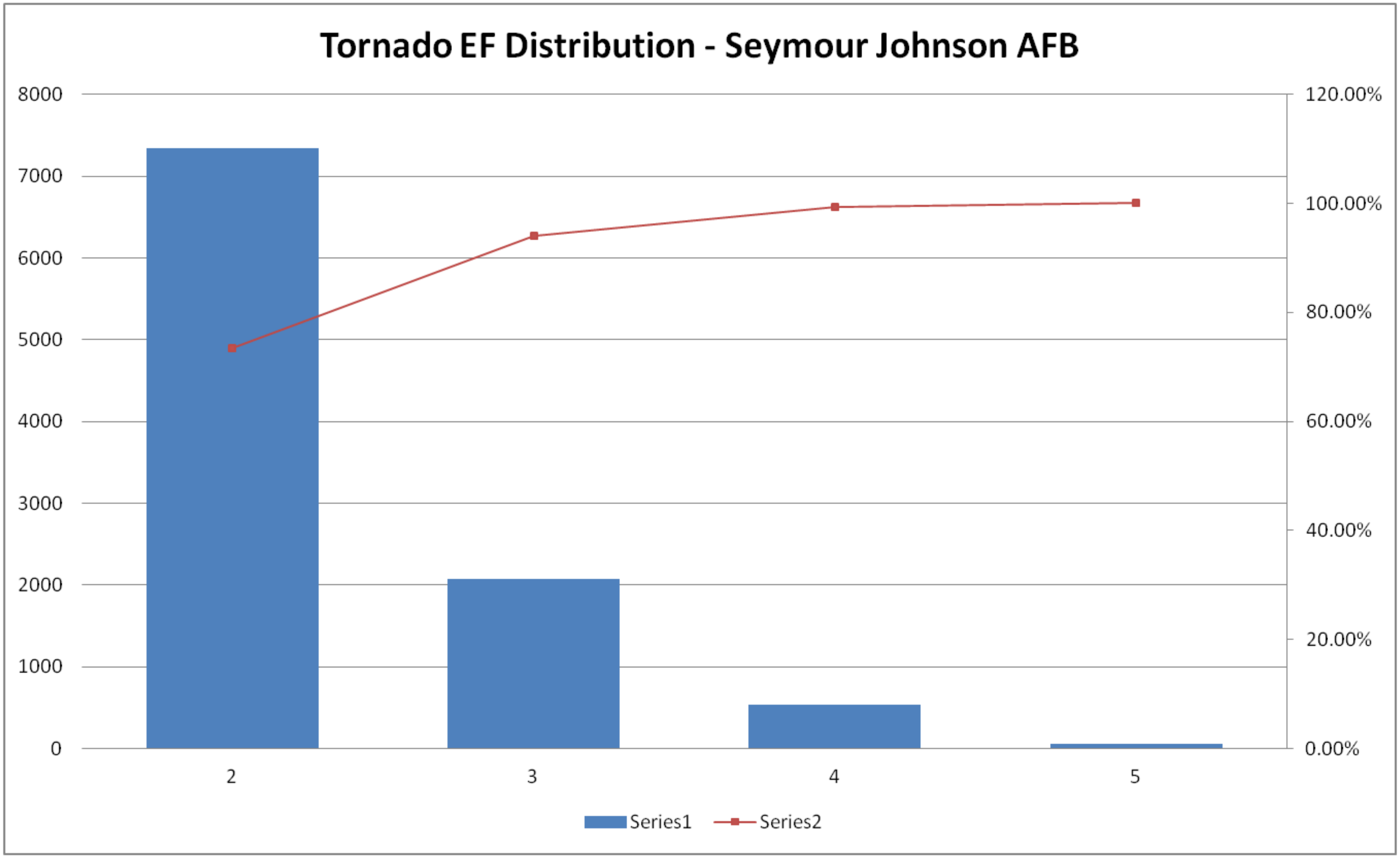
[3] All Return Periods, for each trial, for all Tornado and Hurricane events are rounded up in the "=PMT (rate,nper,pv,fv,type)" equation, where nper = (ROUNDUP(return period)) - ***All severe weather costs are accounted for at the end of the year which they occur***

Trial #	Tornadoes (Exponential Distribution): Random # (0-1)	Return Period of EF 2-5 Tornado (nper)	Strong-Violent Tornadoes (Historic Distributions) (EF-2, 74%; EF-3, 20%; EF-4, 5%; EF-5, 1%): Random # (0-1)	EF-Rating (2-5)	Base Damage Assessment (Weibull Dist): Random # (0-1)	% Facilities Damaged	(% Damaged * 80% of PRV) (Less Infrastructure damage than Hurricane - No Floods, Wind Hazard Only): Tornado Damage Cost (pv, $)	EAC = -PMT[3] (rate,nper,pv,fv,type): Equivalent Annual Cost of Tornado Damage, EAC ($)	Hurricanes (Exponential Distribution): Random # (0-1)	Return Period of Cat 3-5 Hurricane (nper)	Major Hurricanes (Historic Distributions) (Cat-3, 78%; Cat-4, 19%; Cat-5, 3%): Random # (0-1)	Cat-Rating (3-5)	Base Damage Assessment (Uniform Distribution): Random # (0-1)	% Facilities Damaged	(% Damaged * 85% of PRV) (More Infrastructure damage than Tornado - Wind & Flood Hazards): Hurricane Damage Cost (pv, $)	EAC = -PMT[3] (rate,nper,pv,fv,type): Equivalent Annual Cost of Hurricane Damage, EAC ($)	Electricity (Normal Dist) (=NORMINV(RAND(0-1),MEAN,STD DEV)): Random # (0-1)	Average Annual Electricity Usage (kWh)	Random # (0-1)	Average Rate ($/kWh)	EAC ($)	Natural Gas (Normal Dist) (=NORMINV(RAND(0-1),MEAN,STD DEV)): Random # (0-1)	Average Annual Natural Gas Usage (Mcf)	Random # (0-1)	Average Rate ($/Mcf)	EAC ($)	Total EAC ($)	
Min =	0	0	4.73E-06	2	4.89766E-06	0.0%	$ 1	$0	0	0	7.71732E-05	3	8.17504E-06	2.0%	$ 22,472,206	$356,230		47,602,359		$ 0.03869	$ 2,103,992		83,081		$ 3.387	$ 357,791	$ 4,042,601	Min
Max =	1	16	0.999612074	5	0.999664097	100.0%	$ 1,057,359,933	$1,072,622,131	1	569	0.999974604	5	0.999940992	92.9%	$ 1,043,855,469	$841,235,568		71,166,673		$ 0.09591	$ 5,764,175		153,499		$ 14.103	$ 1,782,735	$ 1,435,448,894	Max
Mean =	1	1.9	0.499474415	2	0.497824637	14.0%	$ 148,295,619	$94,100,230	0	54.5	0.497563969	3.25	0.496498687	22.3%	$ 250,432,805	$20,853,677		59,359,138		$ 0.06606	$ 3,921,213		114,767		$ 8.669	$ 994,967	$ 119,870,088	Mean
Median =	0	1.3	0.497064475	2	0.498418067	0.1%	$ 1,360,767	$722,142	1	37.7	0.498172259	3	0.497631361	21.5%	$ 241,542,400	$8,137,709		59,362,264		$ 0.06605	$ 3,914,492		114,638		$ 8.679	$ 989,468	$ 24,788,716	Median
Std Dev =	0	2	0.290582991	0.60386	0.288879246	26.9%	$ 284,901,508	$209,393,270	0	54.327	0.290394654	0.50356	0.289276272	13.1%	$ 146,913,656	$46,726,274		3,301,357		$ 0.00741	$ 490,864		8,845		$ 1.386	$ 177,229	$ 213,986,912	Std Dev
1	0.247393534	2.6	0.765612868	3	0.331231826	2.8%	$ 29,872,295	$10,247,583	0.539373853	33.5	0.945158167	4	0.612730416	32.0%	$ 359,054,576	$13,451,467	0.293905816	57,566,659	0.328478445	$ 0.06277	$ 3,613,733	0.634480607	117,759	0.655434331	$ 9.220	$ 1,085,782	$ 28,398,564	
2	0.811032297	0.4	0.050629557	2	0.665601891	0.0%	$ 18,873	$19,146	0.160067731	99.5	0.481634715	3	0.036374137	3.3%	$ 37,180,063	$706,591	0.12346593	55,513,280	0.942240573	$ 0.07764	$ 4,310,038	0.642630262	117,951	0.034256739	$ 6.147	$ 725,049	$ 5,760,824	
3	0.174890713	3.3	0.342414214	2	0.226939075	14.3%	$ 151,375,716	$39,225,645	0.674542455	21.4	0.268006056	3	0.235029612	10.5%	$ 117,524,323	$6,277,603	0.230222239	56,912,774	0.457685168	$ 0.06526	$ 3,714,325	0.828276871	123,087	0.662604399	$ 9.247	$ 1,138,237	$ 50,355,810	
4	0.209795993	2.9	0.974778208	4	0.353661011	8.2%	$ 87,074,059	$29,870,441	0.493981749	38.3	0.684316437	3	0.314080602	13.3%	$ 149,495,722	$5,045,682	0.01475564	52,116,385	0.603121049	$ 0.06797	$ 3,542,457	0.52336741	115,243	0.422893375	$ 8.398	$ 967,795	$ 39,426,376	
5	0.329457077	2.1	0.060279582	2	0.286870166	5.9%	$ 62,304,985	$21,373,500	0.487767183	39.0	0.846764557	4	0.311249855	18.7%	$ 210,027,971	$6,956,715	0.803852918	62,226,342	0.928974295	$ 0.07686	$ 4,782,802	0.14111159	105,234	0.870718959	$ 10.230	$ 1,076,526	$ 34,189,543	
6	0.718121829	0.6	0.005315373	2	0.431380285	0.4%	$ 4,541,626	$4,607,480	0.322016989	61.6	0.970765359	5	0.801524533	77.9%	$ 875,341,884	$21,498,506	0.138114992	55,743,372	0.619451193	$ 0.06829	$ 3,806,486	0.768235424	121,196	0.123259092	$ 7.064	$ 856,109	$ 30,768,581	
7	0.602456176	1.0	0.736721067	2	0.276162135	7.0%	$ 73,682,935	$74,751,338	0.404186394	49.2	0.542927749	3	0.310409538	13.2%	$ 148,010,996	$4,182,344	0.520790452	59,547,761	0.367580874	$ 0.06355	$ 3,784,527	0.000490442	85,633	0.541975402	$ 8.813	$ 754,667	$ 83,472,876	
8	0.789938644	0.4	0.545689182	2	0.703982863	0.0%	$ 6,741	$6,838	0.538080725	33.7	0.39701382	3	0.254395634	11.2%	$ 125,356,721	$4,696,310	0.088201083	54,866,140	0.670708267	$ 0.06930	$ 3,802,289	0.238886012	108,459	0.179215783	$ 7.397	$ 802,224	$ 9,307,662	
9	0.854000716	0.3	0.538064475	2	0.573697722	0.0%	$ 192,068	$194,853	0.853420381	8.6	0.79233622	4	0.050328738	7.2%	$ 81,050,541	$9,671,051	0.606519538	60,275,057	0.21353539	$ 0.06020	$ 3,628,309	0.143519702	105,328	0.373772079	$ 8.222	$ 865,975	$ 14,360,188	
10	0.350285427	2.0	0.141741289	2	0.720665372	0.0%	$ 4,262	$2,178	0.134457162	109.0	0.507450792	3	0.806088939	31.0%	$ 348,483,672	$6,357,958	0.323738796	57,849,215	0.86888668	$ 0.07430	$ 4,298,480	0.423391754	113,020	0.167857704	$ 7.335	$ 829,028	$ 11,487,644	
11	0.14376474	3.6	0.023657772	2	0.672169913	0.0%	$ 15,863	$4,111	0.821515562	10.7	0.70767833	3	0.198309107	9.1%	$ 102,673,075	$10,165,442	0.600052156	60,219,116	0.339362369	$ 0.06300	$ 3,793,510	0.053982568	100,537	0.11759693	$ 7.025	$ 706,254	$ 14,669,317	
12	0.789281578	0.4	0.488400646	2	0.865124621	0.0%	$ 62	$63	0.970364247	1.6	0.339076489	3	0.717277004	27.8%	$ 312,564,555	$159,689,572	0.110820369	55,298,737	0.374201448	$ 0.06368	$ 3,521,620	0.269775772	109,310	0.774908733	$ 9.712	$ 1,061,571	$ 164,272,826	
13	0.474767725	1.4	0.888569908	3	0.923201388	0.0%	$ 10	$5	0.728353401	17.2	0.512539553	3	0.50018502	20.0%	$ 224,763,830	$14,277,027	0.73489656	61,466,861	0.681556467	$ 0.06952	$ 4,273,394	0.123229396	104,495	0.725962064	$ 9.498	$ 992,482	$ 19,542,908	
14	0.862680093	0.3	0.826459935	3	0.555000891	0.0%	$ 300,061	$304,412	0.332652825	59.8	0.416768161	3	0.385429773	15.9%	$ 178,352,194	$4,470,961	0.939051507	64,531,705	0.444171195	$ 0.06501	$ 4,195,336	0.167683557	106,222	0.28251769	$ 7.871	$ 836,074	$ 9,806,784	
15	0.302361558	2.2	0.585054383	2	0.028038844	93.4%	$ 988,100,729	$338,964,383	0.508831423	36.7	0.447940192	3	0.412356104	16.8%	$ 189,242,285	$6,644,882	0.775729038	61,900,854	0.726612386	$ 0.07049	$ 4,363,092	0.141224733	105,238	0.318359157	$ 8.014	$ 843,337	$ 350,815,695	
16	0.926595482	0.1	0.715981242	2	0.397937582	0.8%	$ 8,806,163	$8,933,852	0.55461696	32.0	0.24530983	3	0.018606263	2.7%	$ 29,994,021	$1,150,093	0.572147528	59,980,250	0.208257973	$ 0.06006	$ 3,602,492	0.64886563	118,099	0.529898049	$ 8.771	$ 1,035,817	$ 14,722,255	
17	0.492736441	1.3	0.59044144	2	0.011516024	98.4%	$ 1,040,328,899	$531,505,171	0.108876579	120.5	0.731791279	3	0.502238342	20.1%	$ 225,594,275	$3,965,889	0.015112538	52,147,929	0.691864397	$ 0.06974	$ 3,636,682	0.550295191	115,841	0.388311439	$ 8.274	$ 958,523	$ 540,066,264	
18	0.432436709	1.6	0.35692538	2	0.928566932	0.0%	$ 8	$4	0.337982256	58.9	0.077304732	3	0.944611554	36.0%	$ 404,507,786	$10,248,574	0.979429654	66,183,044	0.94653308	$ 0.07792	$ 5,157,091	0.556454029	115,978	0.089972314	$ 6.812	$ 790,044	$ 16,195,713	
19	0.420192377	1.6	0.221670603	2	0.991350693	0.0%	$ 1	$1	0.185525911	91.5	0.388163558	3	0.238138244	10.6%	$ 118,781,579	$2,346,365	0.888176441	63,431,456	0.663126782	$ 0.06915	$ 4,386,129	0.379877611	112,026	0.285045971	$ 7.881	$ 882,914	$ 7,615,409	
20	0.941456907	0.1	0.540264359	2	0.69642918	0.0%	$ 8,277	$8,397	0.950091541	2.8	0.081971534	3	0.216934977	9.8%	$ 110,206,125	$37,805,813	0.6770985	60,906,389	0.6591306	$ 0.06907	$ 4,206,628	0.664594993	118,477	0.43807043	$ 8.451	$ 1,001,289	$ 43,022,127	
21	0.713833192	0.6	0.651253925	2	0.120630463	49.4%	$ 522,532,091	$530,108,806	0.381836662	52.3	0.2624015	3	0.603242914	23.7%	$ 266,444,585	$7,238,634	0.412078964	58,633,020	0.279951005	$ 0.06175	$ 3,620,695	0.736296819	120,303	0.35916093	$ 8.168	$ 982,636	$ 541,950,771	
22	0.784483878	0.5	0.648611022	2	0.33808875	2.5%	$ 26,514,030	$26,898,483	0.25598645	74.0	0.973440003	5	0.229560169	34.4%	$ 386,988,300	$8,498,159	0.91599675	63,970,791	0.316133072	$ 0.06252	$ 3,999,531	0.163030809	106,057	0.64323395	$ 9.175	$ 973,051	$ 40,369,224	
23	0.949088633	0.1	0.938561826	3	0.744487194	0.0%	$ 2,191	$2,222	0.224974051	81.1	0.621341332	3	0.115341281	6.2%	$ 69,117,551	$1,446,468	0.340962797	58,007,372	0.535787754	$ 0.06671	$ 3,869,553	0.59161415	116,770	0.559280518	$ 8.873	$ 1,036,136	$ 6,354,379	
24	0.105258563	4.2	0.5924969	2	0.05691165	81.0%	$ 856,179,115	$178,756,063	0.434219576	45.3	0.6163251	3	0.563085495	22.3%	$ 250,203,310	$7,491,273	0.737892486	61,497,442	0.882616818	$ 0.07480	$ 4,599,925	0.71410152	119,716	0.591262986	$ 8.986	$ 1,075,794	$ 191,923,055	
25	0.134942157	3.8	0.197966353	2	0.5449158	0.0%	$ 380,277	$98,540	0.817466819	11.0	0.416263214	3	0.140815153	7.1%	$ 79,420,209	$7,863,225	0.380669775	58,361,196	0.258981858	$ 0.06128	$ 3,576,611	0.484231886	114,376	0.926875463	$ 10.677	$ 1,221,178	$ 12,759,554	
26	0.030923723	6.5	0.816537666	3	0.776488906	0.0%	$ 878	$133	0.487588622	39.0	0.846598179	4	0.120967827	10.3%	$ 115,968,558	$3,841,203	0.729780898	61,415,046	0.752637881	$ 0.07108	$ 4,365,139	0.663181376	118,443	0.053309036	$ 6.435	$ 762,155	$ 8,968,630	
27	0.002933205	10.9	0.119939207	2	0.196563339	21.4%	$ 225,916,584	$22,367,519	0.333765774	59.6	0.255711912	3	0.29294166	12.5%	$ 140,946,284	$3,533,264	0.535518841	59,671,176	0.93417012	$ 0.07715	$ 4,603,724	0.894656731	125,773	0.562331237	$ 8.884	$ 1,117,368	$ 31,621,875	
28	0.00431616	10.2	0.341751605	2	0.313574845	3.8%	$ 40,332,663	$3,993,251	0.090662319	130.4	0.766111015	3	0.04974471	3.8%	$ 42,587,661	$727,950	0.727426634	61,391,366	0.581837527	$ 0.06757	$ 4,148,098	0.372029737	111,844	0.67265638	$ 9.286	$ 1,038,543	$ 9,907,842	
29	0.467974098	1.4	0.454972081	2	0.075816436	71.6%	$ 756,784,094	$386,641,820	0.04765779	165.4	0.602193741	3	0.572314088	22.6%	$ 253,935,724	$4,053,604	0.31978456	57,812,430	0.534409235	$ 0.06668	$ 3,855,071	0.609751037	117,185	0.592484237	$ 8.991	$ 1,053,561	$ 395,604,056	
30	0.68871561	0.7	0.880389774	3	0.294967485	5.2%	$ 54,743,442	$55,537,222	0.287658102	67.7	0.093638438	3	0.390874266	16.1%	$ 180,554,166	$4,193,666	0.861913427	63,004,889	0.968576634	$ 0.07975	$ 5,024,611	0.913861678	126,773	0.866272707	$ 10.201	$ 1,293,213	$ 66,048,711	
31	0.362998934	1.9	0.573402286	2	0.942775092	0.0%	$ 5	$3	0.243841157	76.7	0.92725112	4	0.832007925	41.6%	$ 467,446,913	$10,117,285	0.751791708	61,641,744	0.307402268	$ 0.06234	$ 3,842,706	0.715591931	119,755	0.720952159	$ 9.477	$ 1,134,932	$ 15,094,926	
32	0.423540557	1.6	0.380634922	2	0.011703055	98.3%	$ 1,039,886,428	$531,279,112	0.006666657	272.2	0.853150689	4	0.831253744	41.6%	$ 467,074,110	$6,908,268	0.342820916	58,024,245	0.604575787	$ 0.06800	$ 3,945,640	0.303948626	110,197	0.302982091	$ 7.953	$ 876,433	$ 543,009,453	
33	0.831386099	0.3	0.576576621	2	0.023417919	95.1%	$ 1,005,049,488	$1,019,622,705	0.697993929	19.5	0.732245554	3	0.134375535	6.8%	$ 76,815,768	$4,452,169	0.514938034	59,498,797	0.10175834	$ 0.05668	$ 3,372,352	0.364806748	111,674	0.546462168	$ 8.828	$ 985,910	$ 1,028,433,137	
34	0.446349168	1.5	0.318330996	2	0.88197022	0.0%	$ 37	$19	0.48658569	39.1	0.208584417	3	0.220705265	9.9%	$ 111,730,982	$3,700,843	0.917597463	64,005,646	0.199785016	$ 0.05984	$ 3,830,161	0.765894801	121,128	0.006234787	$ 5.211	$ 631,144	$ 8,162,167	
35	0.820191922	0.4	0.302270794	2	0.101018506	58.9%	$ 622,271,010	$631,293,940	0.182524955	92.4	0.775866801	3	0.526842706	21.0%	$ 235,545,270	$4,628,898	0.8165741	62,382,796	0.019314026	$ 0.05081	$ 3,169,787	0.400212991	112,494	0.616964242	$ 9.079	$ 1,021,279	$ 640,113,904	
36	0.899832496	0.2	0.407920838	2	0.969961363	0.0%	$ 2	$2	0.175421114	94.6	0.189873751	3	0.017298076	2.6%	$ 29,464,937	$573,260	0.319395617	57,808,802	0.656553723	$ 0.06902	$ 3,989,699	0.756039109	120,848	0.790771993	$ 9.786	$ 1,182,642	$ 5,745,603	
37	0.138543354	3.7	0.357019085	2	0.848227359	0.0%	$ 104	$27	0.341917959	58.3	0.48821932	3	0.726907172	28.2%	$ 316,459,382	$8,017,788	0.573100663	59,988,351	0.326135453	$ 0.06273	$ 3,762,886	0.563336216	116,132	0.113294887	$ 6.994	$ 812,256	$ 12,592,957	
38	0.649206459	0.8	0.650570023	2	0.092180231	63.3%	$ 669,035,321	$678,736,333	0.616375436	26.3	0.123461909	3	0.674984466	26.3%	$ 295,459,752	$13,302,602	0.568693655	59,950,924	0.521323733	$ 0.06644	$ 3,983,150	0.111512496	103,970	0.169736019	$ 7.346	$ 763,717	$ 696,785,802	
39	0.860642461	0.3	0.636102181	2	0.491877574	0.1%	$ 1,265,164	$1,283,509	0.242960548	76.9	0.937893248	4	0.060069552	7.6%	$ 85,865,579	$1,858,450	0.499778477	59,372,064	0.363990608	$ 0.06348	$ 3,769,187	0.163956341	106,090	0.864793262	$ 10.192	$ 1,081,223	$ 7,992,368	
40	0.050405964	5.6	0.886961724	3	0.392999021	0.9%	$ 9,684,020	$1,696,897	0.037688322	178.1	0.067169525	3	0.832913811	32.0%	$ 359,332,728	$5,638,953	0.613863616	60,338,891	0.308955755	$ 0.06237	$ 3,763,449	0.721885658	119,919	0.991677934	$ 11.979	$ 1,436,557	$ 12,535,856	
41	0.829117919	0.4	0.259021838	2	0.095373719	61.7%	$ 652,048,321	$661,503,022	0.312465383	63.2	0.194109746	3	0.569935944	22.5%	$ 252,973,907	$6,093,092	0.425861068	58,750,652	0.857739006	$ 0.07393	$ 4,343,421	0.917760224	126,996	0.945213212	$ 10.880	$ 1,381,774	$ 673,321,309	
42	0.356478559	1.9	0.044623064	2	0.612266728	0.0%	$ 74,409	$38,016	0.316305858	62.5	0.032891368	3	0.066128451	4.4%	$ 49,213,904	$1,196,831	0.716610637	61,283,844	0.083325211	$ 0.05586	$ 3,423,215	0.561593482	116,093	0.620616289	$ 9.092	$ 1,055,497	$ 5,713,559	
43	0.236632486	2.7	0.001795017	2	0.405368776	0.7%	$ 7,622,585	$2,614,900	0.508050585	36.8	0.861870137	4	0.816307581	40.9%	$ 459,685,985	$16,140,998	0.161689297	56,081,105	0.775157133	$ 0.07161	$ 4,016,232	0.124209033	104,538	0.965479293	$ 11.182	$ 1,168,950	$ 23,941,080	
44	0.687955748	0.7	0.337642124	2	0.437903708	0.4%	$ 3,976,415	$4,034,073	0.937950638	3.5	0.753314836	3	0.033306307	3.2%	$ 35,939,309	$9,312,872	0.671589095	60,855,390	0.242234213	$ 0.06090	$ 3,705,865	0.012606128	94,970	0.448237286	$ 8.487	$ 806,008	$ 17,858,818	
45	0.360188334	1.9	0.976509508	4	0.059527585	86.7%	$ 916,522,865	$468,252,533	0.137253678	107.9	0.828289881	4	0.574030146	30.3%	$ 339,924,421	$6,248,936	0.442591203	58,892,425	0.215992564	$ 0.06026	$ 3,548,731	0.953914605	129,590	0.380004521	$ 8.244	$ 1,068,388	$ 479,118,588	
46	0.022858928	7.1	0.279048729	2	0.303340679	4.5%	$ 47,778,999	$6,368,616	0.253908369	74.5	0.153877352	3	0.232507372	10.4%	$ 116,504,228	$2,558,401	0.265353983	57,283,519	0.379288183	$ 0.06378	$ 3,653,670	0.779963724	121,540	0.362668833	$ 8.181	$ 994,311	$ 13,574,999	
47	0.851429274	0.3	0.671814925	2	0.943988567	0.0%	$ 5	$5	0.263209135	72.5	0.992365214	5	0.015008056	18.1%	$ 203,799,802	$4,543,669	0.748983248	61,612,251	0.411840173	$ 0.06440	$ 3,968,134	0.256287295	108,945	0.181192033	$ 7.407	$ 806,953	$ 9,318,761	
48	0.141625391	3.7	0.058743253	2	0.531194057	0.0%	$ 522,699	$135,446	0.103336569	123.3	0.860867041	4	0.37142381	21.3%	$ 239,772,908	$4,177,640	0.390795653	58,449,478	0.064753044	$ 0.05488	$ 3,207,626	0.919586036	127,103	0.284380012	$ 7.879	$ 1,001,393	$ 8,522,105	
49	0.94660763	0.1	0.915202816	3	0.623096188	0.0%	$ 56,636	$57,458	0.958363616	2.3	0.482308414	3	0.257099476	11.3%	$ 126,450,263	$43,378,306	0.52630791	59,593,957	0.727809398	$ 0.07051	$ 4,202,071	0.462325968	113,890	0.254899697	$ 7.755	$ 883,234	$ 48,521,069	
50	0.752272293	0.5	0.114705649	2	0.232489209	13.3%	$ 140,175,402	$142,207,946	0.972256288	1.5	0.969696946	5	0.11934242	26.1%	$ 292,882,380	$149,633,928	0.780884501	61,958,658	0.644719752	$ 0.06878	$ 4,261,510	0.311504764	110,386	0.003876616	$ 4.984	$ 550,120	$ 296,653,504	
51	0.504746523	1.3	0.742891224	3	0.376971923	1.2%	$ 13,116,674	$6,701,323	0.748562905	15.7	0.867866689	4	0.839195528	41.9%	$ 470,999,859	$33,196,123	0.069473528	54,439,984	0.792398565	$ 0.07205	$ 3,922,297	0.722384836	119,932	0.71440929	$ 9.450	$ 1,133,406	$ 44,953,148	
52	0.289858378	2.3	0.540942163	2	0.804584377	0.0%	$ 386	$132	0.446188156	43.8	0.504664181	3	0.53925923	21.4%	$ 240,567,011	$7,433,992	0.713115327	61,249,523	0.196685641	$ 0.05976	$ 3,660,210	0.763850896	121,069	0.449118817	$ 8.490	$ 1,027,884	$ 12,122,219	
53	0.182870929	3.2	0.925785082	3	0.773576718	0.0%	$ 955	$247	0.391633171	50.9	0.576799935	3	0.783281105	30.2%	$ 339,259,267	$9,458,187	0.737604202	61,494,491	0.045906954	$ 0.05363	$ 3,297,791	0.474703402	114,165	0.619934311	$ 9.089	$ 1,037,682	$ 13,793,908	
54	0.325426761	2.1	0.044332821	2	0.717585968	0.0%	$ 4,641	$1,592	0.324684157	61.1	0.29899437	3	0.409585539	16.7%	$ 188,121,757	$4,620,294	0.646687937	60,628,948	0.018837354	$ 0.05074	$ 3,076,093	0.13681225	105,062	0.532506905	$ 8.780	$ 922,426	$ 8,620,405	
55	0.16974685	3.3	0.60545429	2	0.755249971	0.0%	$ 1,615	$418	0.266542743	71.8	0.139320776	3	0.791661036	30.5%	$ 342,648,448	$7,699,282	0.724923307	61,366,297	0.287836566	$ 0.06192	$ 3,800,000	0.338293596	111,043	0.39045185	$ 8.282	$ 919,683	$ 12,419,383	
56	0.486552485	1.4	0.767737137	3	0.420887978	0.5%	$ 5,609,750	$2,866,028	0.241183339	77.3	0.185612995	3	0.096516658	5.5%	$ 61,504,117	$1,321,869	0.640413349	60,572,831	0.157431104	$ 0.05864	$ 3,552,150	0.626784662	117,579	0.880335862	$ 10.295	$ 1,210,444	$ 8,950,491	
57	0.250196374	2.6	0.71827056	2	0.615212173	0.0%	$ 69,105	$23,706	0.613938029	26.5	0.388329589	3	0.629682454	24.7%	$ 277,137,798	$12,477,686	0.55091348	59,800,612	0.731194117	$ 0.07059	$ 4,221,148	0.347018909	111,253	0.515717823	$ 8.721	$ 970,290	$ 17,692,830	
58	0.12876625	3.8	0.614817475	2	0.921972257	0.0%	$ 10	$3	0.006809186	271.1	0.936128205	4	0.520906716	27.9%	$ 313,664,670	$4,640,611	0.391092574	58,452,057	0.78748127	$ 0.07192	$ 4,204,013	0.225956494	108,086	0.119610228	$ 7.039	$ 760,797	$ 9,605,424	
59	0.5319087	1.2	0.85437893	3	0.069823298	74.6%	$ 788,782,005	$402,989,588	0.604355963	27.4	0.122124008	3	0.913915705	34.9%	$ 392,093,151	$17,137,741	0.206428909	56,643,492	0.972907187	$ 0.08023	$ 4,544,445	0.755498433	120,832	0.254898682	$ 7.755	$ 937,069	$ 425,608,842	
60	0.056624282	5.4	0.857244137	3	0.523639168	0.1%	$ 621,443	$108,893	0.354147036	56.4	0.204550693	3	0.509502451	20.3%	$ 228,532,173	$5,919,283	0.00869168	51,443,148	0.211375727	$ 0.06014	$ 3,093,844	0.225400465	108,069	0.464154872	$ 8.542	$ 923,181	$ 10,045,202	

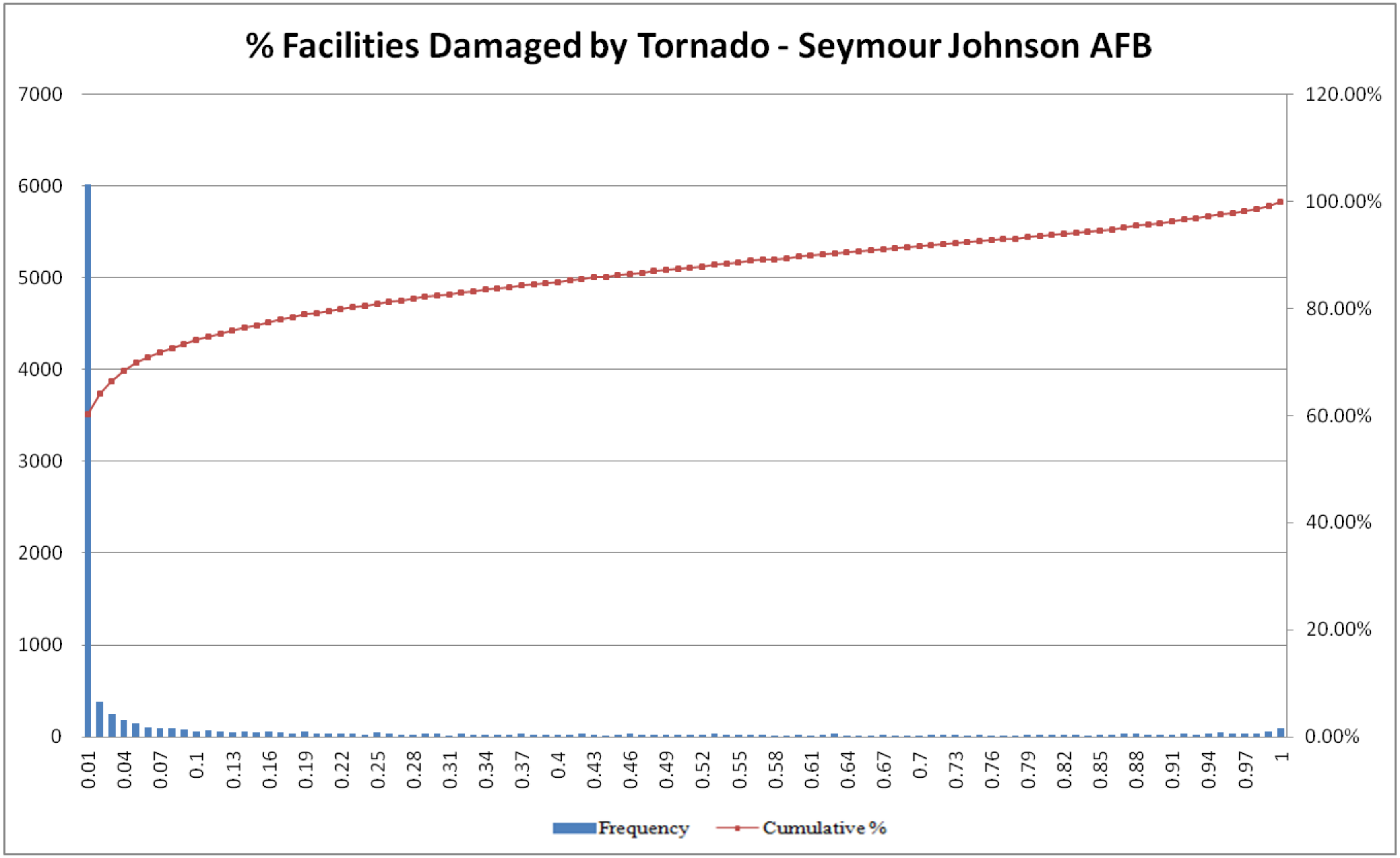

Random # Generator Histogram
140
120
100
80
60
40
20
0
0.01
0.04
0.07
0.1
0.13
0.16
0.19
0.22
0.25
0.28
0.31
0.34
0.37
0.4
0.43
0.46
0.49
0.52
0.55
0.58
0.61
0.64
0.67
0.7
0.73
0.76
0.79
0.82
0.85
0.88
0.91
0.94
0.97
1
Frequency

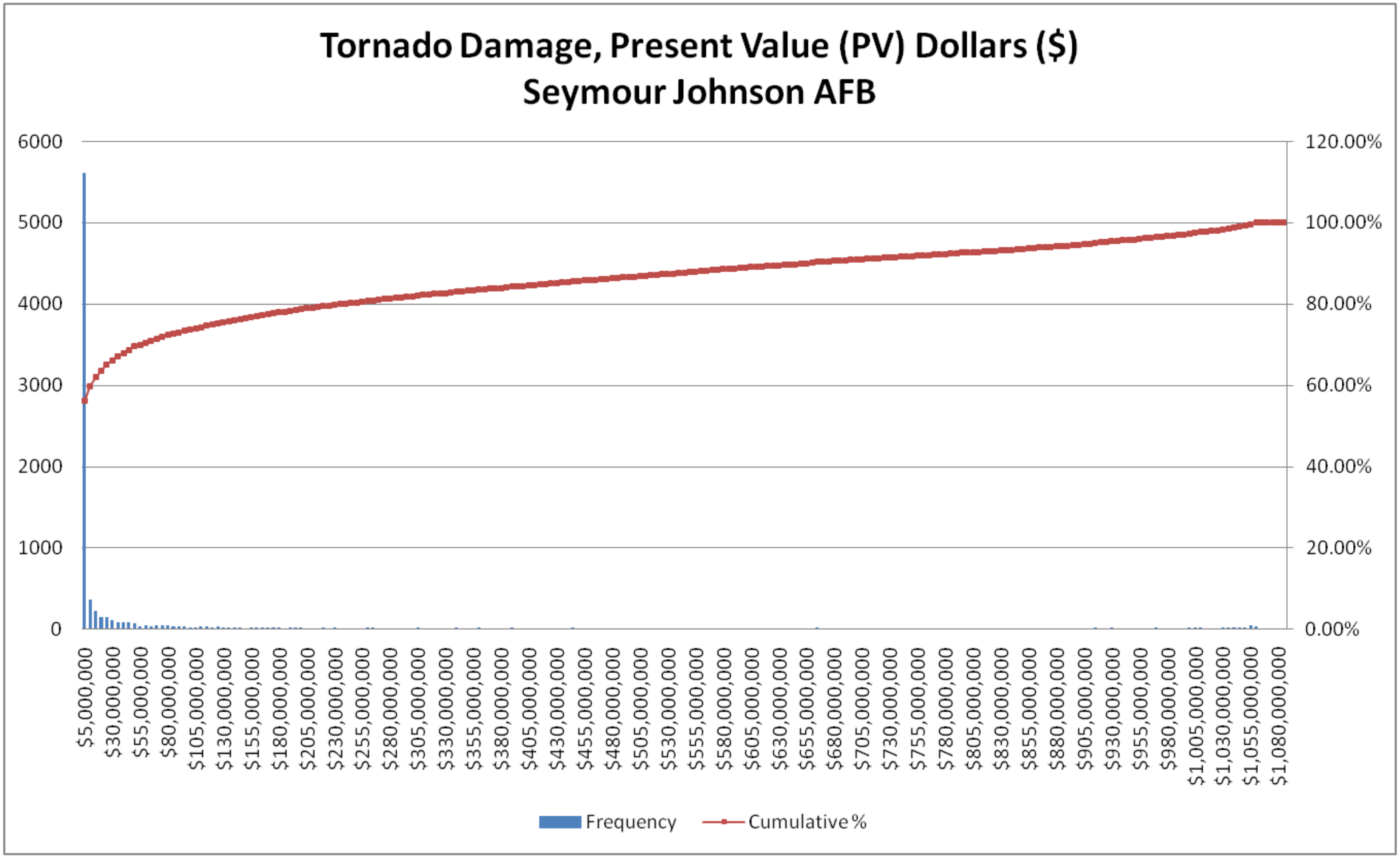


Tornado Return Period - Seymour Johnson AFB
4500
4000
3500
3000
2500
2000
1500
1000
500
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Series1
Series2



Tornado EF Distribution - Seymour Johnson AFB
8000
7000
6000
5000
4000
3000
2000
1000
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
2
3
4
5
Series1
Series2


% Facilities Damaged by Tornado - Seymour Johnson AFB
7000
6000
5000
4000
3000
2000
1000
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0.01 0.04 0.07 0.1 0.13 0.16 0.19 0.22 0.25 0.28 0.31 0.34 0.37 0.4 0.43 0.46 0.49 0.52 0.55 0.58 0.61 0.64 0.67 0.7 0.73 0.76 0.79 0.82 0.85 0.88 0.91 0.94 0.97 1
Frequency
Cumulative %


Tornado Damage, Present Value (PV) Dollars ($)
Seymour Johnson AFB
6000
5000
4000
3000
2000
1000
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
$5,000,000
$30,000,000
$55,000,000
$80,000,000
$105,000,000
$130,000,000
$155,000,000
$180,000,000
$205,000,000
$230,000,000
$255,000,000
$280,000,000
$305,000,000
$330,000,000
$355,000,000
$380,000,000
$405,000,000
$430,000,000
$455,000,000
$480,000,000
$505,000,000
$530,000,000
$555,000,000
$580,000,000
$605,000,000
$630,000,000
$655,000,000
$680,000,000
$705,000,000
$730,000,000
$755,000,000
$780,000,000
$805,000,000
$830,000,000
$855,000,000
$880,000,000
$905,000,000
$930,000,000
$955,000,000
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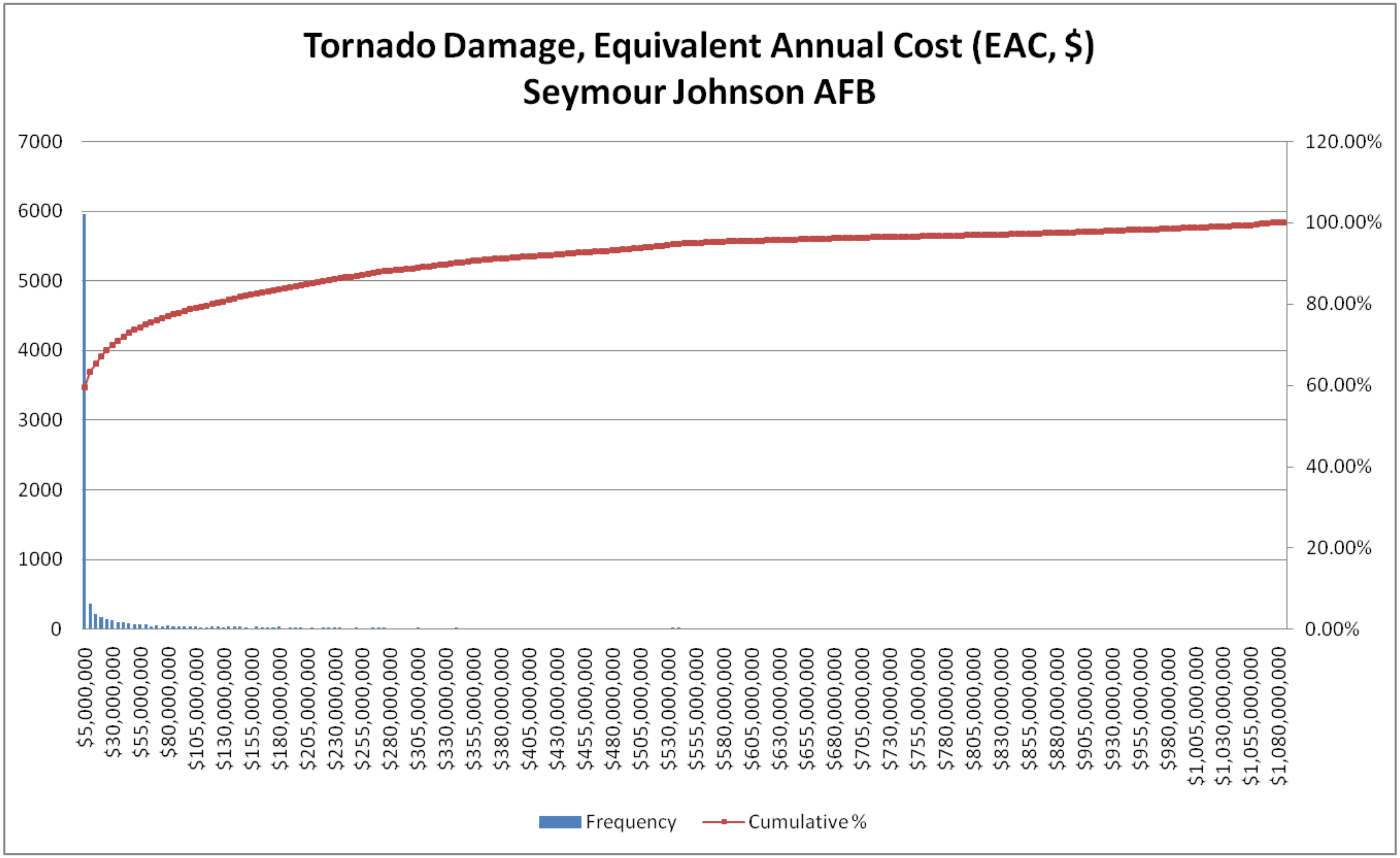
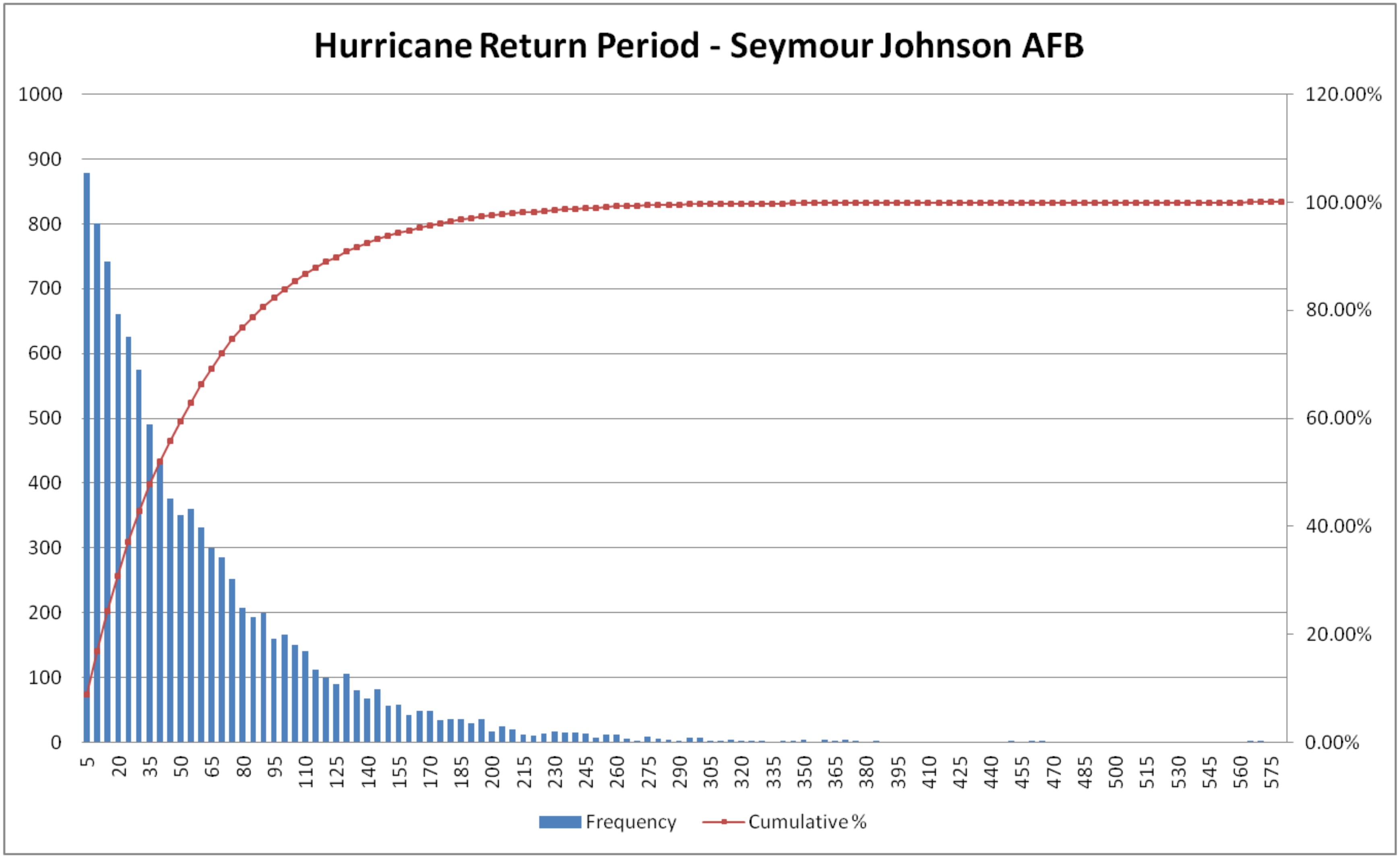
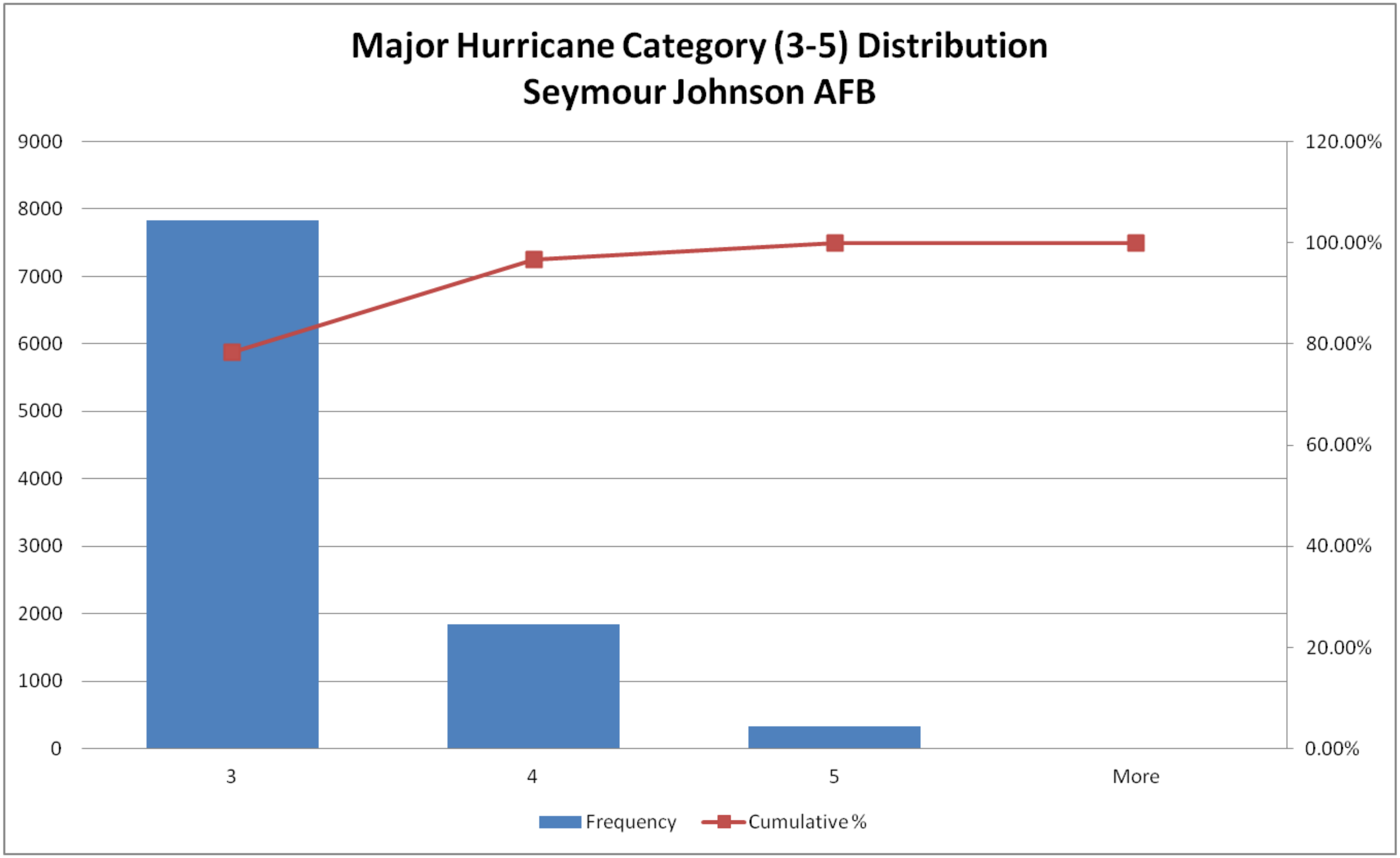
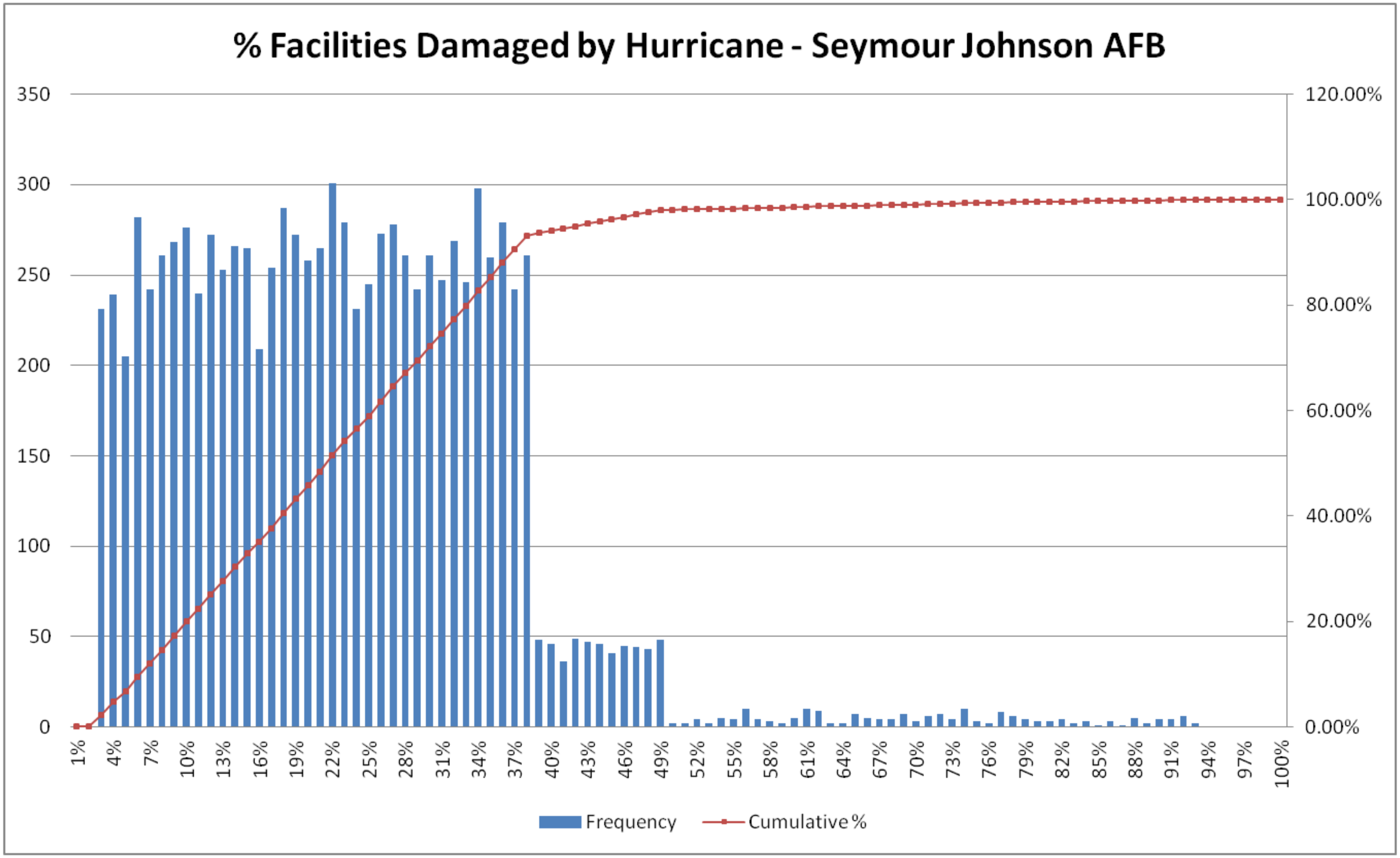
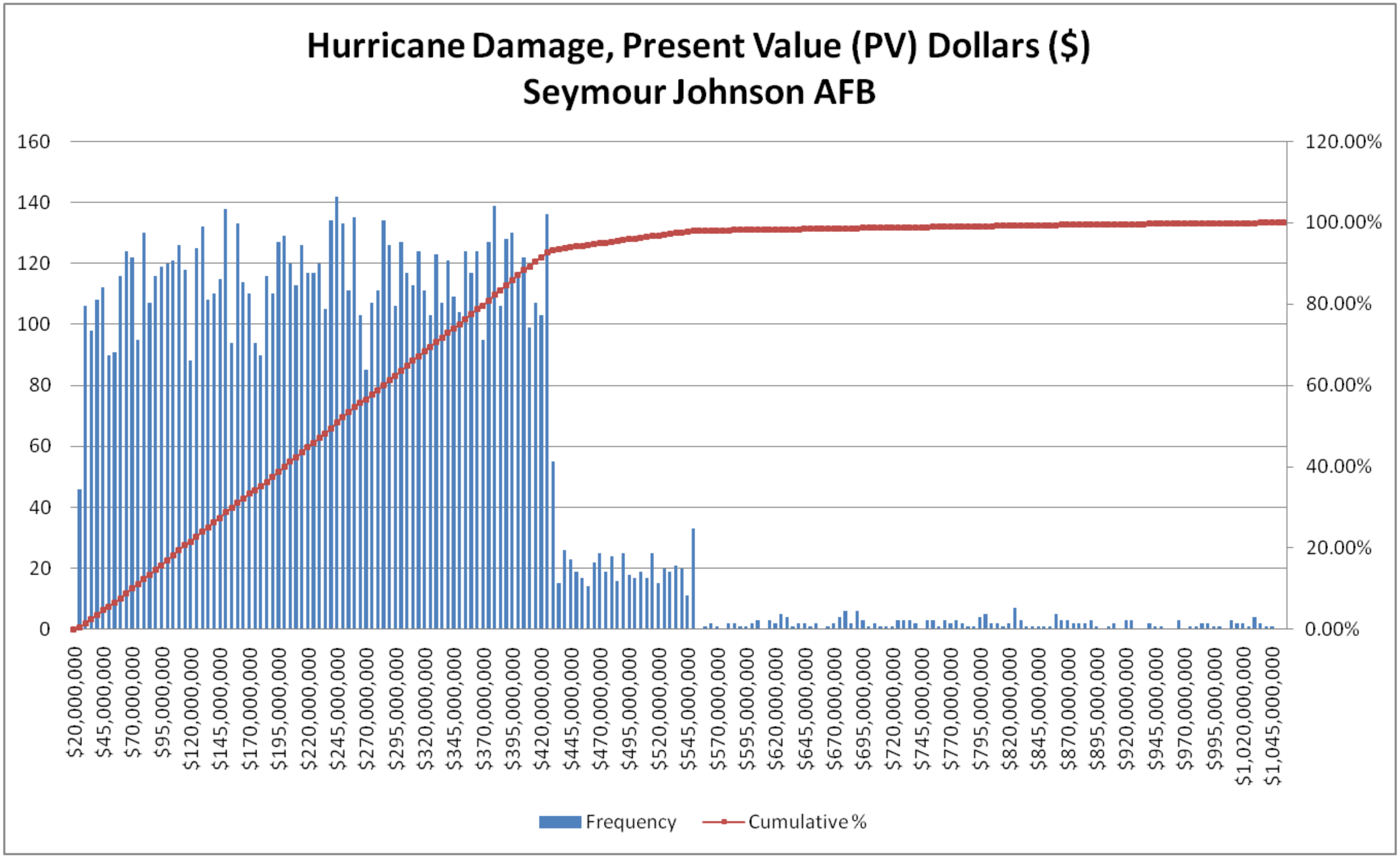
Frequency
Cumulative %


Tornado Damage, Equivalent Annual Cost (EAC, $)
Seymour Johnson AFB
7000
6000
5000
4000
3000
2000
1000
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
$5,000,000
$30,000,000
$55,000,000
$80,000,000
$105,000,000
$130,000,000
$155,000,000
$180,000,000
$205,000,000
$230,000,000
$255,000,000
$280,000,000
$305,000,000
$330,000,000
$355,000,000
$380,000,000
$405,000,000
$430,000,000
$455,000,000
$480,000,000
$505,000,000
$530,000,000
$555,000,000
$580,000,000
$605,000,000
$630,000,000
$655,000,000
$680,000,000
$705,000,000
$730,000,000
$755,000,000
$780,000,000
$805,000,000
$830,000,000
$855,000,000
$880,000,000
$905,000,000
$930,000,000
$955,000,000
$980,000,000
$1,005,000,000
$1,030,000,000
$1,055,000,000
$1,080,000,000
Frequency
Cumulative %

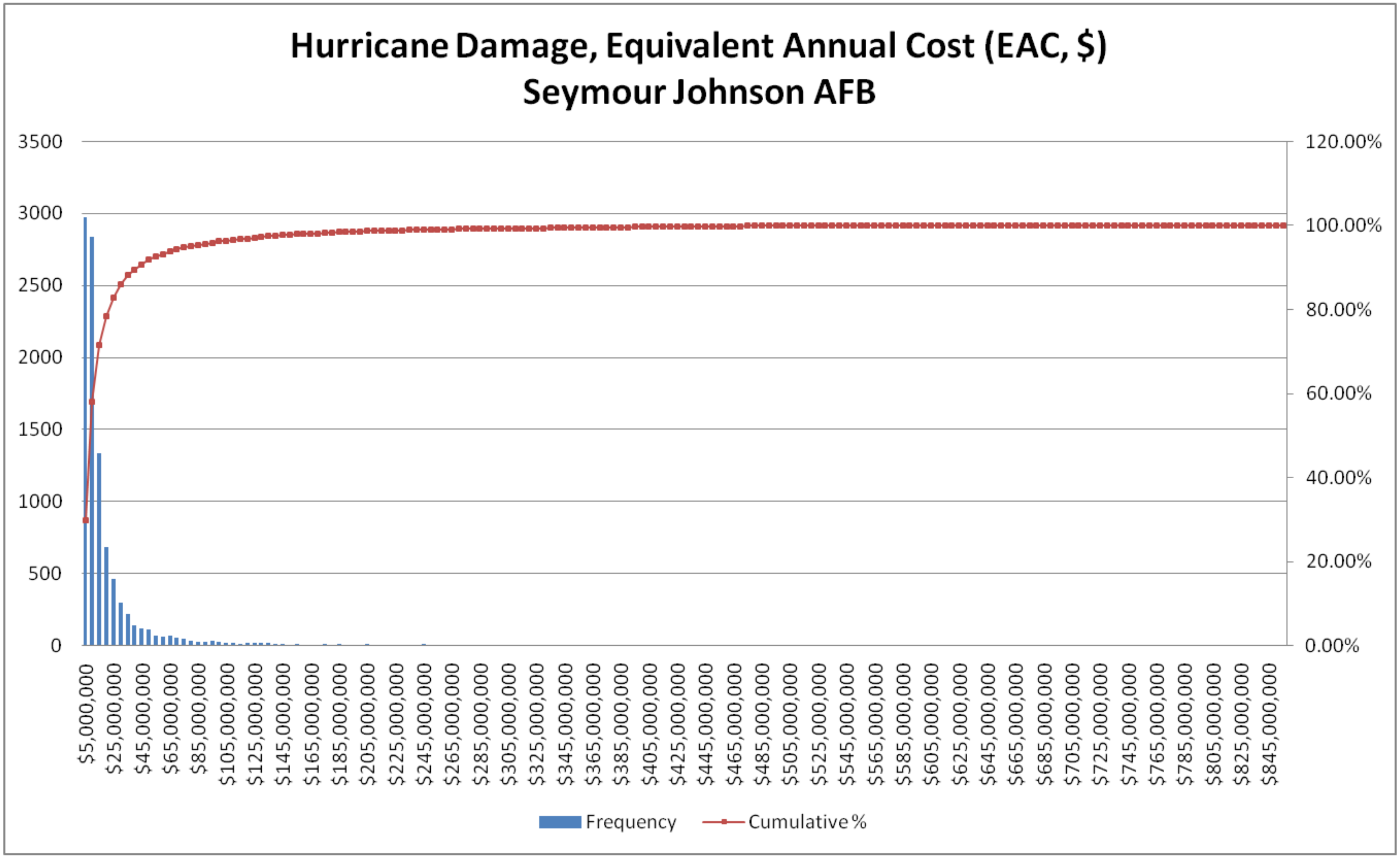

Hurricane Return Period - Seymour Johnson AFB
1000
900
800
700
600
500
400
300
200
100
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
5 20 35 50 65 80 95 110 125 140 155 170 185 200 215 230 245 260 275 290 305 320 335 350 365 380 395 410 425 440 455 470 485 500 515 530 545 560 575
Frequency
Cumulative %


Major Hurricane Category (3-5) Distribution
Seymour Johnson AFB
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
3
4
5
More
Frequency
Cumulative %

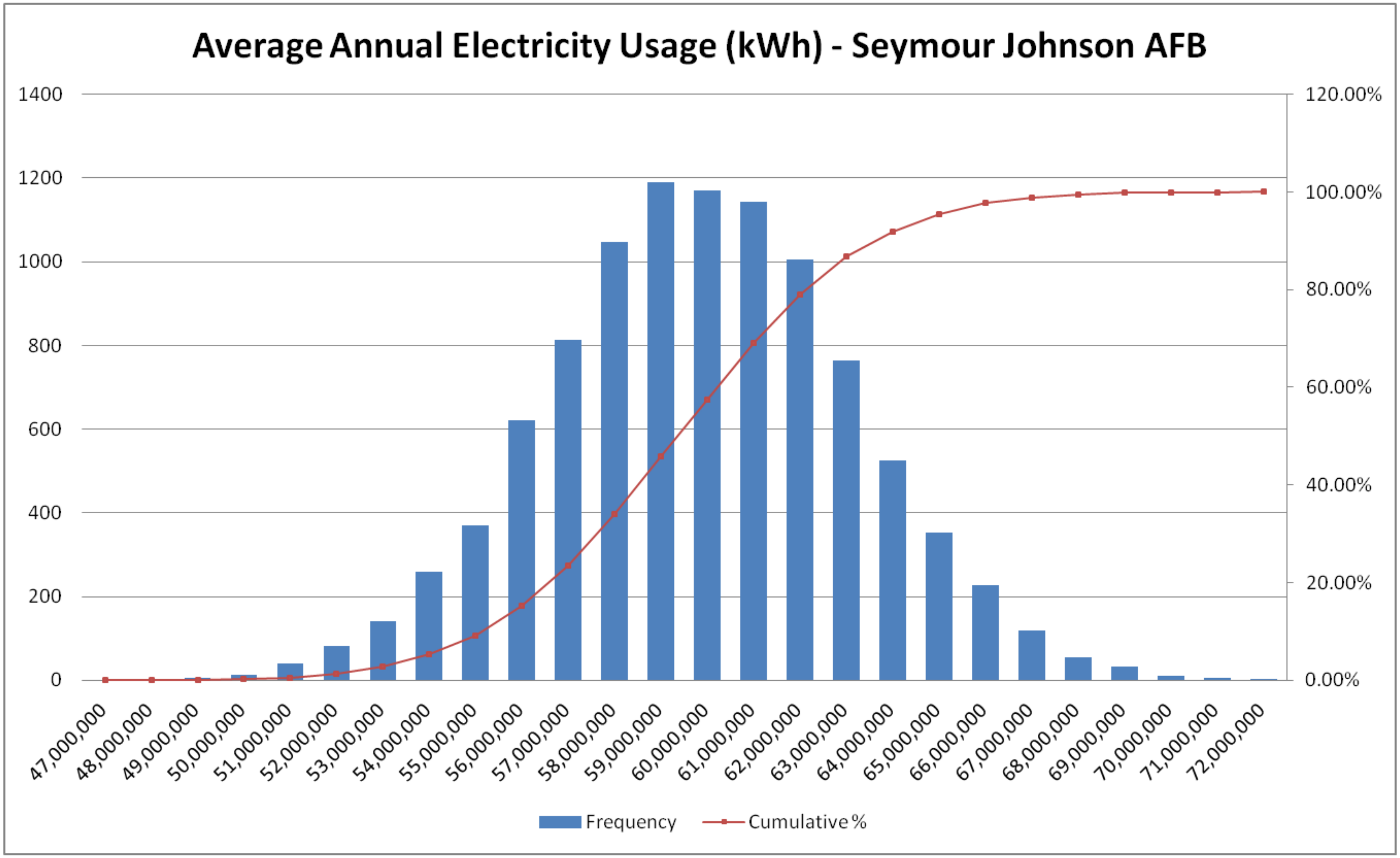

% Facilities Damaged by Hurricane - Seymour Johnson AFB
350
300
250
200
150
100
50
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
1% 4% 7% 10% 13% 16% 19% 22% 25% 28% 31% 34% 37% 40% 43% 46% 49% 52% 55% 58% 61% 64% 67% 70% 73% 76% 79% 82% 85% 88% 91% 94% 97% 100%
Frequency
Cumulative %



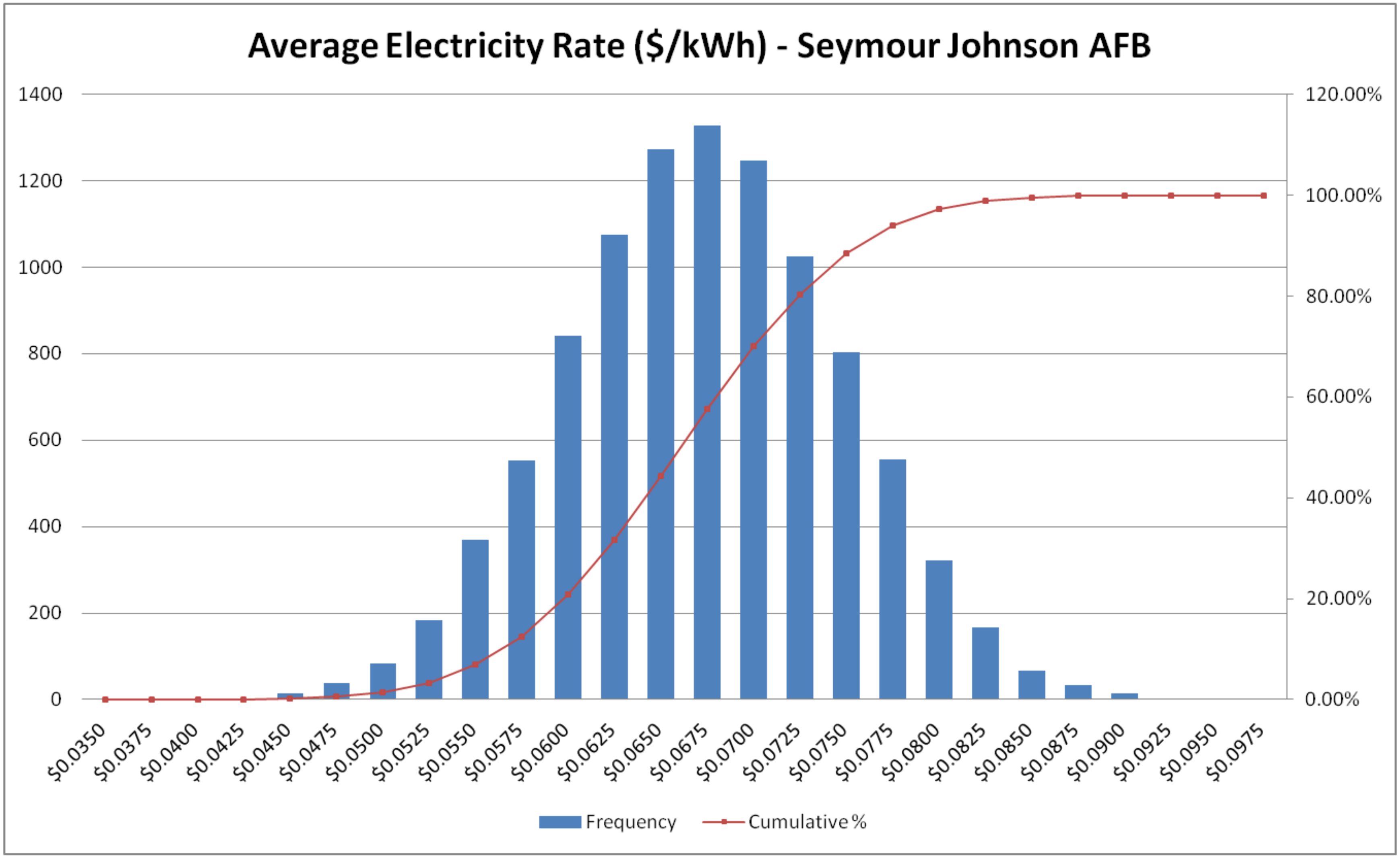
Hurricane Damage, Present Value (PV) Dollars ($)
Seymour Johnson AFB
160
140
120
100
80
60
40
20
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
$20,000,000
$45,000,000
$70,000,000
$95,000,000
$120,000,000
$145,000,000
$170,000,000
$195,000,000
$220,000,000
$245,000,000
$270,000,000
$295,000,000
$320,000,000
$345,000,000
$370,000,000
$395,000,000
$420,000,000
$445,000,000
$470,000,000
$495,000,000
$520,000,000
$545,000,000
$570,000,000
$595,000,000
$620,000,000
$645,000,000
$670,000,000
$695,000,000
$720,000,000
$745,000,000
$770,000,000
$795,000,000
$820,000,000
$845,000,000
$870,000,000
$895,000,000
$920,000,000
$945,000,000
$970,000,000
$995,000,000
$1,020,000,000
$1,045,000,000
Frequency
Cumulative %

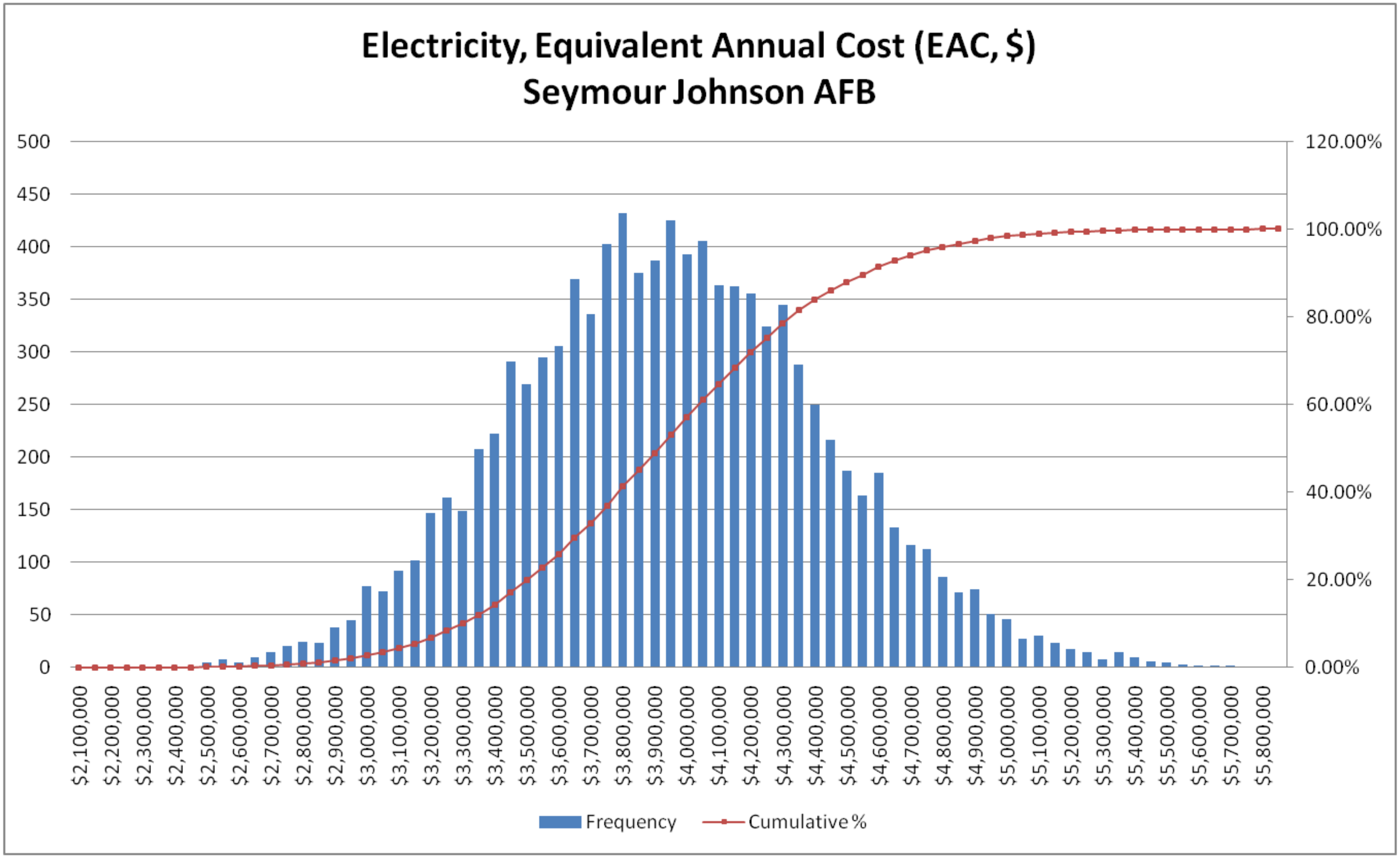


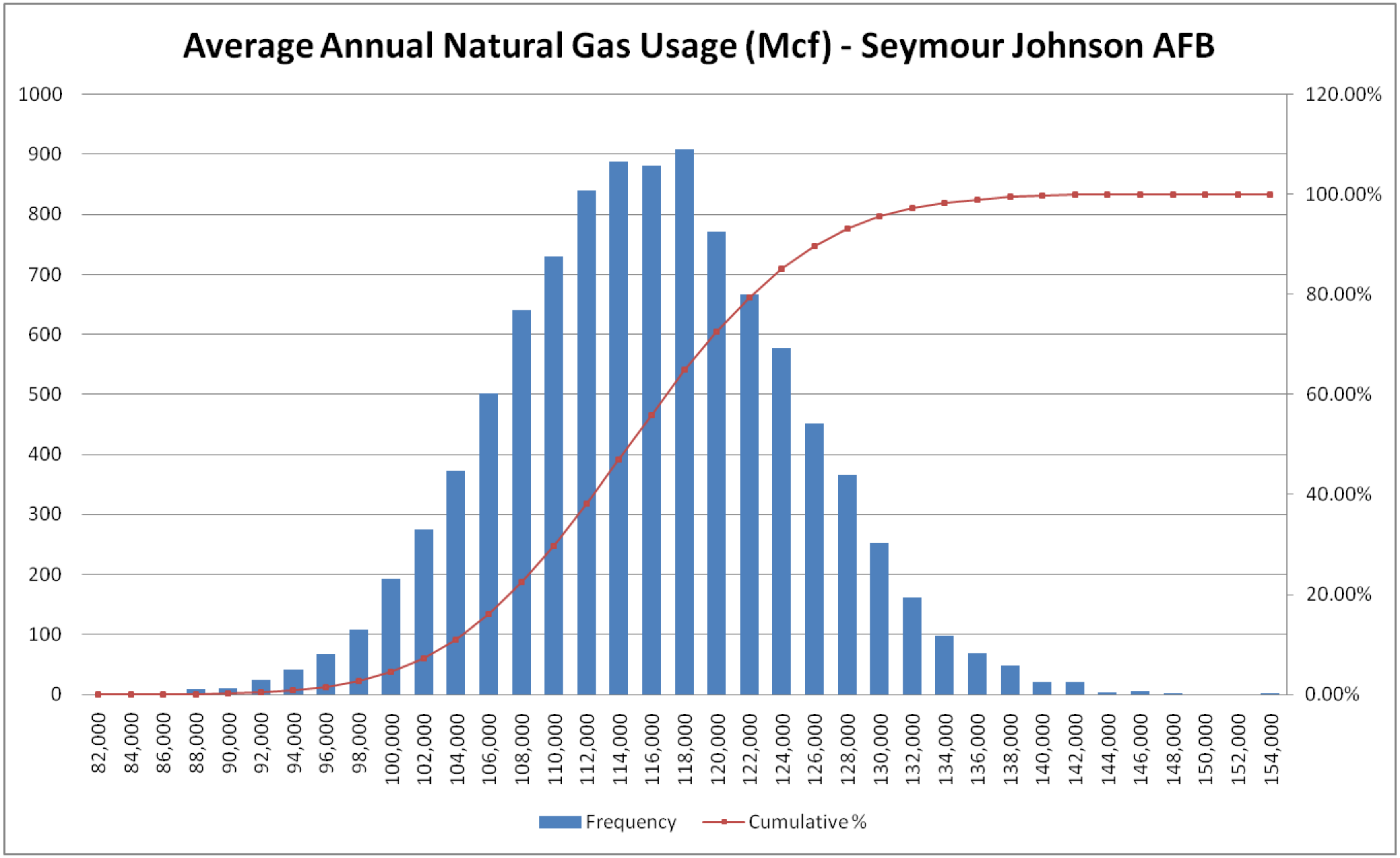
Hurricane Damage, Equivalent Annual Cost (EAC, $)
Seymour Johnson AFB
3500
3000
2500
2000
1500
1000
500
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
$5,000,000
$25,000,000
$45,000,000
$65,000,000
$85,000,000
$105,000,000
$125,000,000
$145,000,000
$165,000,000
$185,000,000
$205,000,000
$225,000,000
$245,000,000
$265,000,000
$285,000,000
$305,000,000
$325,000,000
$345,000,000
$365,000,000
$385,000,000
$405,000,000
$425,000,000
$445,000,000
$465,000,000
$485,000,000
$505,000,000
$525,000,000
$545,000,000
$565,000,000
$585,000,000
$605,000,000
$625,000,000
$645,000,000
$665,000,000
$685,000,000
$705,000,000
$725,000,000
$745,000,000
$765,000,000
$785,000,000
$805,000,000
$825,000,000
$845,000,000
Frequency
Cumulative %



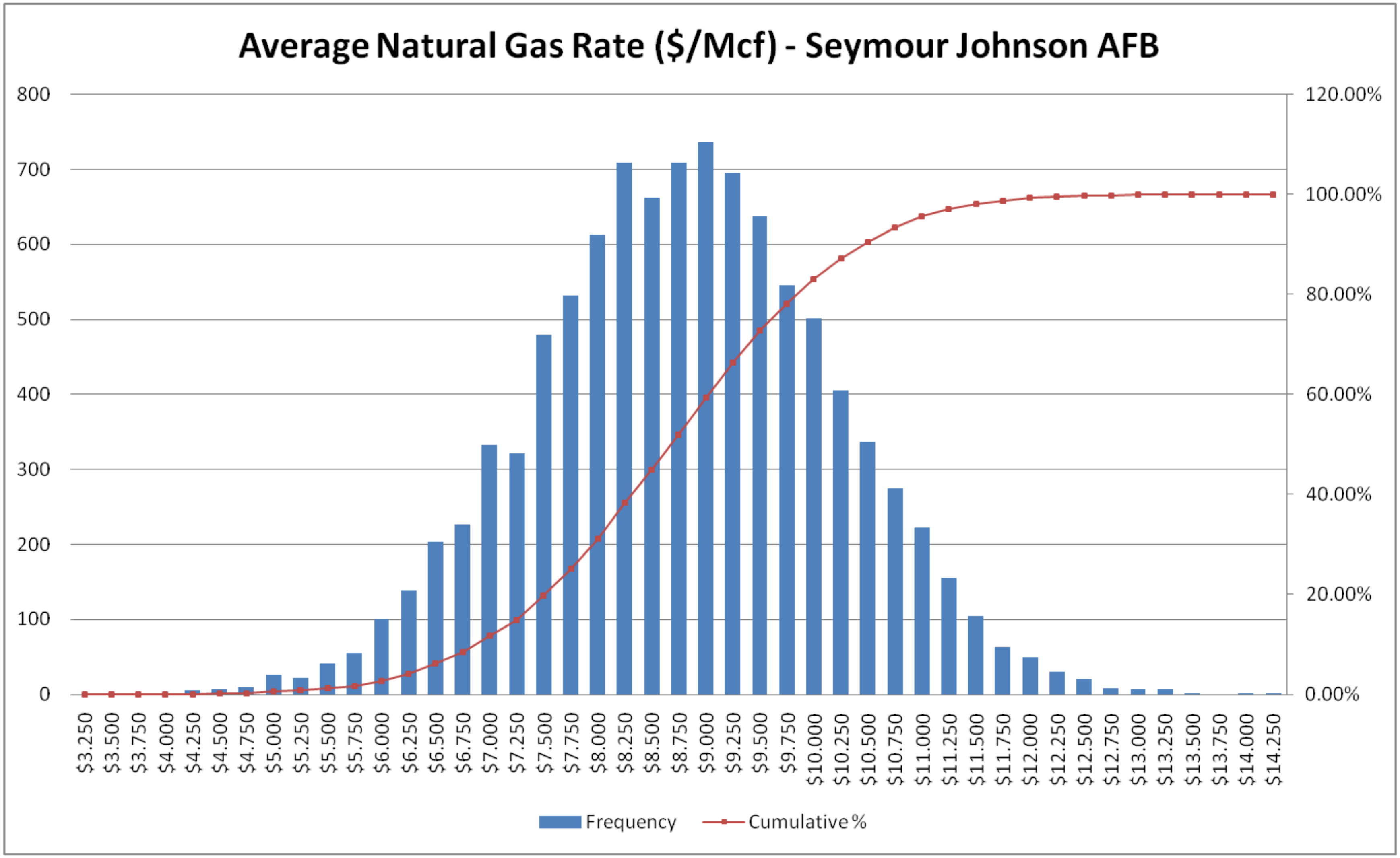
Average Annual Electricity Usage (kWh) - Seymour Johnson AFB
1400
1200
1000
800
600
400
200
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
47,000,000
48,000,000
49,000,000
50,000,000
51,000,000
52,000,000
53,000,000
54,000,000
55,000,000
56,000,000
57,000,000
58,000,000
59,000,000
60,000,000
61,000,000
62,000,000
63,000,000
64,000,000
65,000,000
66,000,000
67,000,000
68,000,000
69,000,000
70,000,000
71,000,000
72,000,000
Frequency
Cumulative %

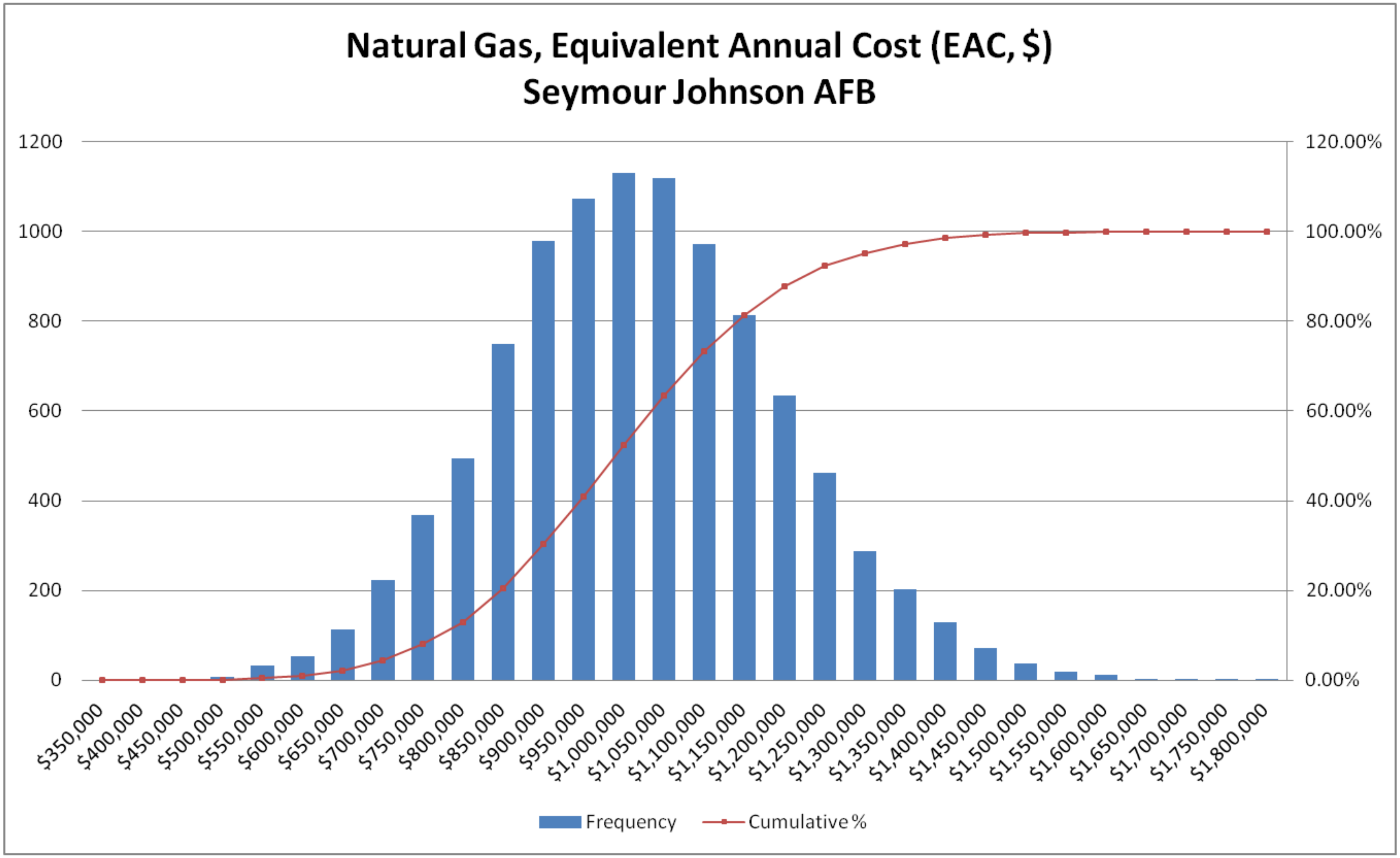

Average Electricity Rate ($/kWh) - Seymour Johnson AFB
1400
1200
1000
800
600
400
200
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
$0.0350
$0.0375
$0.0400
$0.0425
$0.0450
$0.0475
$0.0500
$0.0525
$0.0550
$0.0575
$0.0600
$0.0625
$0.0650
$0.0675
$0.0700
$0.0725
$0.0750
$0.0775
$0.0800
$0.0825
$0.0850
$0.0875
$0.0900
$0.0925
$0.0950
$0.0975
Frequency
Cumulative %


Electricity, Equivalent Annual Cost (EAC, $)
Seymour Johnson AFB
500
450
400
350
300
250
200
150
100
50
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
$2,100,000
$2,200,000
$2,300,000
$2,400,000
$2,500,000
$2,600,000
$2,700,000
$2,800,000
$2,900,000
$3,000,000
$3,100,000
$3,200,000
$3,300,000
$3,400,000
$3,500,000
$3,600,000
$3,700,000
$3,800,000
$3,900,000
$4,000,000
$4,100,000
$4,200,000
$4,300,000
$4,400,000
$4,500,000
$4,600,000
$4,700,000
$4,800,000
$4,900,000
$5,000,000
$5,100,000
$5,200,000
$5,300,000
$5,400,000
$5,500,000
$5,600,000
$5,700,000
$5,800,000
Frequency
Cumulative %



Average Annual Natural Gas Usage (Mcf) - Seymour Johnson AFB
1000
900
800
700
600
500
400
300
200
100
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
82,000
84,000
86,000
88,000
90,000
92,000
94,000
96,000
98,000
100,000
102,000
104,000
106,000
108,000
110,000
112,000
114,000
116,000
118,000
120,000
122,000
124,000
126,000
128,000
130,000
132,000
134,000
136,000
138,000
140,000
142,000
144,000
146,000
148,000
150,000
152,000
154,000
Frequency
Cumulative %


Average Natural Gas Rate ($/Mcf) - Seymour Johnson AFB
800
700
600
500
400
300
200
100
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
$3.250 $3.500 $3.750 $4.000 $4.250 $4.500 $4.750 $5.000 $5.250 $5.500 $5.750 $6.000 $6.250 $6.500 $6.750 $7.000 $7.250 $7.500 $7.750 $8.000 $8.250 $8.500 $8.750 $9.000 $9.250 $9.500 $9.750 $10.000 $10.250 $10.500 $10.750 $11.000 $11.250 $11.500 $11.750 $12.000 $12.250 $12.500 $12.750 $13.000 $13.250 $13.500 $13.750 $14.000 $14.250
Frequency
Cumulative %


Natural Gas, Equivalent Annual Cost (EAC, $)
Seymour Johnson AFB
1200
1000
800
600
400
200
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
$350,000
$400,000
$450,000
$500,000
$550,000
$600,000
$650,000
$700,000
$750,000
$800,000
$850,000
$900,000
$950,000
$1,000,000
$1,050,000
$1,100,000
$1,150,000
$1,200,000
$1,250,000
$1,300,000
$1,350,000
$1,400,000
$1,450,000
$1,500,000
$1,550,000
$1,600,000
$1,650,000
$1,700,000
$1,750,000
$1,800,000
Frequency
Cumulative %

Seymour Johnson
AFB - Monte Carlo Sir

Sample Monte Carlo Simulation Spreadsheet – Seymour-Johnson AFB, NC

(See Attachments Tab in .pdf File for Actual Spreadsheet)

Appendix L – Sample Energy Data from AFCEC

MAJ	Installation	Reporting Month	Commodity (Electricity or Natural Gas)	FY14 Energy (MBTU)	FY13 Energy (MBTU)	FY12 Energy (MBTU)	FY14 Electricity Usage (kWh)	FY13 Electricity Usage (kWh)	FY12 Electricity Usage (kWh)	FY14 Natural Gas Usage (Mcf)	FY13 Natural Gas Usage (Mcf)	FY12 Natural Gas Usage (Mcf)	FY14 Energy Cost ($)	FY13 Energy Cost ($)	FY12 Energy Cost ($)	FY14 Energy Rate ($/MBTU)	FY13 Energy Rate ($/MBTU)	FY12 Energy Rate ($/MBTU)	FY14 Elec Rate ($/kWh)	FY13 Elec Rate ($/kWh)	FY12 Elec Rate ($/kWh)	FY14 Natural Gas Rate ($/Mcf)	FY13 Natural Gas Rate ($/Mcf)	FY12 Natural Gas Rate ($/Mcf)
AETC	ALTUS AFB	1 - Oct	Electricity	11,102	11,712	11,693	3,253,800	3,432,470	3,427,000				$206,825	$210,325	$222,873	$18.63	$17.96	$19.06	$ 0.0636	$ 0.0613	$ 0.0650			
AETC	ALTUS AFB	2 - Nov	Electricity	9,988	10,411	10,721	2,927,400	3,051,300	3,142,000				$192,728	$193,602	$209,353	$19.30	$18.60	$19.53	$ 0.0658	$ 0.0634	$ 0.0666			
AETC	ALTUS AFB	3 - Dec	Electricity	9,999	10,387	11,133	2,930,400	3,044,400	3,263,000				$188,164	$188,852	$204,470	$18.82	$18.18	$18.37	$ 0.0642	$ 0.0620	$ 0.0627			
AETC	ALTUS AFB	4 - Jan	Electricity	10,889	10,707	11,304	3,191,400	3,138,100	3,313,000				$198,758	$181,458	$195,723	$18.25	$16.95	$17.31	$ 0.0623	$ 0.0578	$ 0.0591			
AETC	ALTUS AFB	5 - Feb	Electricity	9,971	9,482	10,577	2,922,200	2,779,000	3,100,000				$199,889	$168,140	$185,868	$20.05	$17.73	$17.57	$ 0.0684	$ 0.0605	$ 0.0600			
AETC	ALTUS AFB	6 - Mar	Electricity	10,999	10,729	10,550	3,223,700	3,144,500	3,092,000				$239,823	$195,636	$196,396	$21.80	$18.23	$18.62	$ 0.0744	$ 0.0622	$ 0.0635			
AETC	ALTUS AFB	7 - Apr	Electricity	10,754	10,305	12,041	3,151,900	3,020,100	3,529,000				$227,916	$189,535	$201,977	$21.19	$18.39	$16.77	$ 0.0723	$ 0.0628	$ 0.0572			
AETC	ALTUS AFB	8 - May	Electricity	12,059	11,604	13,668	3,534,300	3,400,900	4,006,000				$241,563	$204,591	$217,874	$20.03	$17.63	$15.94	$ 0.0683	$ 0.0602	$ 0.0544			
AETC	ALTUS AFB	9 - Jun	Electricity	13,437	13,436	14,361	3,938,300	3,937,800	4,209,000				$270,334	$237,153	$235,348	$20.12	$17.65	$16.39	$ 0.0686	$ 0.0602	$ 0.0559			
AETC	ALTUS AFB	10 - Jul	Electricity	13,822	13,594	15,624	4,051,000	3,984,300	4,579,000				$275,444	$251,501	$254,420	$19.93	$18.50	$16.28	$ 0.0680	$ 0.0631	$ 0.0556			
AETC	ALTUS AFB	11 - Aug	Electricity	14,626	14,626	15,378	4,286,600	4,286,600	4,507,000				$291,500	$255,111	$252,656	$19.93	$17.44	$16.43	$ 0.0680	$ 0.0595	$ 0.0561			
AETC	ALTUS AFB	12 - Sep	Electricity	12,648	12,648	13,266	3,707,000	3,706,800	3,888,000				$252,036	$221,209	$223,331	$19.93	$17.49	$16.84	$ 0.0680	$ 0.0597	$ 0.0574			
AETC	ALTUS AFB	1 - Oct	Natural Gas	3,358	4,020	6,271				3,257	3,900	6,083	$40,167	$45,229	$63,995	$11.96	$11.25	$10.20				$12.33	$11.60	$10.52
AETC	ALTUS AFB	2 - Nov	Natural Gas	18,980	11,868	8,621				18,409	11,511	8,362	$87,367	$60,265	$69,497	$4.60	$5.08	$8.06				$4.75	$5.24	$8.31
AETC	ALTUS AFB	3 - Dec	Natural Gas	27,594	25,522	16,907				26,765	24,754	16,399	$121,455	$100,563	$103,463	$4.40	$3.94	$6.12				$4.54	$4.06	$6.31
AETC	ALTUS AFB	4 - Jan	Natural Gas	27,779	25,515	14,663				26,944	24,748	14,222	$121,566	$103,829	$94,576	$4.38	$4.07	$6.45				$4.51	$4.20	$6.65
AETC	ALTUS AFB	5 - Feb	Natural Gas	25,910	22,306	14,495				25,131	21,635	14,060	$110,533	$94,974	$94,217	$4.27	$4.26	$6.50				$4.40	$4.39	$6.70
AETC	ALTUS AFB	6 - Mar	Natural Gas	19,694	19,314	9,624				19,102	18,733	9,334	$92,404	$86,371	$73,958	$4.69	$4.47	$7.69				$4.84	$4.61	$7.92
AETC	ALTUS AFB	7 - Apr	Natural Gas	5,378	13,113	2,930				5,216	12,718	2,842	$49,665	$78,286	$41,664	$9.23	$5.97	$14.22				$9.52	$6.16	$14.66
AETC	ALTUS AFB	8 - May	Natural Gas	1,531	3,622	1,770				1,485	3,513	1,717	$31,276	$40,273	$36,012	$20.42	$11.12	$20.34				$21.06	$11.47	$20.97
AETC	ALTUS AFB	9 - Jun	Natural Gas	1,531	1,235	1,526				1,485	1,198	1,480	$31,276	$28,231	$36,590	$20.42	$22.86	$23.98				$21.06	$23.57	$24.73
AETC	ALTUS AFB	10 - Jul	Natural Gas	1,207	876	687				1,171	849	666	$27,250	$24,302	$32,483	$22.57	$27.76	$47.28				$23.27	$28.62	$48.75
AETC	ALTUS AFB	11 - Aug	Natural Gas	759	759	1,191				736	736	1,155	$26,345	$26,345	$37,097	$34.72	$34.73	$31.15				$35.79	$35.81	$32.11
AETC	ALTUS AFB	12 - Sep	Natural Gas	833	833	1,449				808	808	1,406	$25,000	$25,125	$36,310	$30.01	$30.16	$25.06				$30.94	$31.09	$25.83
	ALTUS AFB	**Annual Summary**		**274,849**	**268,622**	**230,451**	**41,118,000**	**40,926,270**	**44,055,000**	**130,509**	**125,103**	**77,725**	**3,549,288**	**3,210,903**	**3,320,151**									
AFMC	ARNOLD AS	1 - Oct	Electricity	109,948	63,258	44,155	32,224,000	18,540,000	12,941,000				$1,730,682	$1,116,781	$820,788	$15.74	$17.65	$18.59	$ 0.0537	$ 0.0602	$ 0.0634			
AFMC	ARNOLD AS	2 - Nov	Electricity	124,159	52,439	130,987	36,389,000	15,369,000	38,390,000				$1,871,717	$979,751	$2,294,554	$15.08	$18.68	$17.52	$ 0.0514	$ 0.0637	$ 0.0598			
AFMC	ARNOLD AS	3 - Dec	Electricity	63,531	56,588	82,147	18,620,000	16,585,000	24,076,000				$1,239,143	$1,125,594	$1,583,862	$19.50	$19.89	$19.28	$ 0.0665	$ 0.0679	$ 0.0658			
AFMC	ARNOLD AS	4 - Jan	Electricity	94,898	41,596	34,502	27,813,000	12,191,000	10,112,000				$2,031,762	$851,678	$737,022	$21.41	$20.48	$21.36	$ 0.0731	$ 0.0699	$ 0.0729			
AFMC	ARNOLD AS	5 - Feb	Electricity	129,011	45,687	59,580	37,811,000	13,390,000	17,462,000				$2,508,163	$855,038	$1,061,452	$19.44	$18.72	$17.82	$ 0.0663	$ 0.0639	$ 0.0608			
AFMC	ARNOLD AS	6 - Mar	Electricity	66,473	60,529	53,138	19,482,000	17,740,000	15,574,000				$1,321,081	$1,135,193	$1,017,782	$19.87	$18.75	$19.15	$ 0.0678	$ 0.0640	$ 0.0654			
AFMC	ARNOLD AS	7 - Apr	Electricity	89,459	67,237	27,856	26,219,000	19,706,000	8,164,000				$1,545,530	$1,172,023	$567,722	$17.28	$17.43	$20.38	$ 0.0589	$ 0.0595	$ 0.0695			
AFMC	ARNOLD AS	8 - May	Electricity	43,551	115,104	44,121	12,764,000	33,735,000	12,931,000				$852,510	$2,019,108	$807,450	$19.58	$17.54	$18.30	$ 0.0668	$ 0.0599	$ 0.0624			
AFMC	ARNOLD AS	9 - Jun	Electricity	56,148	65,343	51,781	16,456,000	19,151,000	15,176,000				$1,332,938	$1,385,007	$1,132,698	$23.74	$21.20	$21.87	$ 0.0810	$ 0.0723	$ 0.0746			
AFMC	ARNOLD AS	10 - Jul	Electricity	84,242	128,687	56,243	24,690,000	37,716,000	16,484,000				$1,767,303	$2,739,533	$1,211,328	$20.98	$21.29	$21.54	$ 0.0716	$ 0.0726	$ 0.0735			
AFMC	ARNOLD AS	11 - Aug	Electricity	119,625	101,633	92,093	35,060,000	29,787,000	26,991,000				$2,406,121	$1,889,011	$1,714,640	$20.11	$18.59	$18.62	$ 0.0686	$ 0.0634	$ 0.0635			
AFMC	ARNOLD AS	12 - Sep	Electricity	159,767	81,465	40,794	46,825,000	23,876,000	11,956,000				$2,851,380	$1,565,026	$1,057,721	$17.85	$19.21	$25.93	$ 0.0609	$ 0.0655	$ 0.0885			
AFMC	ARNOLD AS	1 - Oct	Natural Gas	41,763	31,914	29,538				40,507	30,954	28,650	$237,233	$185,006	$163,293	$5.68	$5.80	$5.53				$5.86	$5.98	$5.70
AFMC	ARNOLD AS	2 - Nov	Natural Gas	65,966	42,932	45,685				63,983	41,641	44,311	$587,199	$231,895	$285,341	$8.90	$5.40	$6.25				$9.18	$5.57	$6.44
AFMC	ARNOLD AS	3 - Dec	Natural Gas	62,076	51,814	57,184				60,210	50,256	55,465	$342,403	$272,719	$315,117	$5.52	$5.26	$5.51				$5.69	$5.43	$5.68
AFMC	ARNOLD AS	4 - Jan	Natural Gas	77,566	62,796	67,958				75,234	60,907	65,915	$466,461	$324,806	$347,898	$6.01	$5.17	$5.12				$6.20	$5.33	$5.28
AFMC	ARNOLD AS	5 - Feb	Natural Gas	72,044	63,687	59,412				69,878	61,772	57,626	$518,352	$326,662	$346,909	$7.19	$5.13	$5.84				$7.42	$5.29	$6.02
AFMC	ARNOLD AS	6 - Mar	Natural Gas	62,578	59,249	46,354				60,696	57,467	44,960	$367,095	$307,269	$251,846	$5.87	$5.19	$5.43				$6.05	$5.35	$5.60
AFMC	ARNOLD AS	7 - Apr	Natural Gas	40,431	41,928	37,507				39,215	40,667	36,379	$200,954	$235,162	$215,130	$4.97	$5.61	$5.74				$5.12	$5.78	$5.91
AFMC	ARNOLD AS	8 - May	Natural Gas	33,971	37,014	30,700				32,949	35,902	29,777	$193,120	$208,855	$150,036	$5.68	$5.64	$4.89				$5.86	$5.82	$5.04
AFMC	ARNOLD AS	9 - Jun	Natural Gas	34,903	30,416	25,127				33,854	29,502	24,372	$224,777	$179,479	$133,030	$6.44	$5.90	$5.29				$6.64	$6.08	$5.46
AFMC	ARNOLD AS	10 - Jul	Natural Gas	37,732	32,229	24,787				36,597	31,260	24,042	$242,560	$192,834	$153,561	$6.43	$5.98	$6.20				$6.63	$6.17	$6.39
AFMC	ARNOLD AS	11 - Aug	Natural Gas	28,026	28,947	23,515				27,183	28,077	22,808	$193,057	$172,902	$144,498	$6.89	$5.97	$6.14				$7.10	$6.16	$6.34
AFMC	ARNOLD AS	12 - Sep	Natural Gas	27,075	31,444	19,472				26,261	30,499	18,886	$187,296	$187,149	$122,915	$6.92	$5.95	$6.31				$7.13	$6.14	$6.51
	ARNOLD AS	**Annual Summary**		**1,724,944**	**1,393,935**	**1,184,637**	**334,353,000**	**257,786,000**	**210,257,000**	**566,568**	**498,903**	**453,191**	**25,218,837**	**19,658,481**	**16,636,593**									

Sample Energy Data – Altus and Arnold AFBs (Only 2 of 62 Bases Shown)

References

Air Force Materiel Command (AFMC). (2014). Air Force Materiel Command Units and Fact Sheets. Retrieved from http://www.afmc.af.mil/units/index.asp

Air Force Space Command (AFSPC). (2014). Air Force Space Command Units and Fact Sheets. Retrieved from http://www.schriever.af.mil/library/factsheets/factsheet.asp?id=3909

Air Force Weather Agency (AFWA). (2014a). 14th Weather Squadron (14th WS), Climatological Products and Services (14 WS/WXC). Retrieved from https://www.climate.af.mil/

Air Force Weather Agency (AFWA). (2014b). 14th Weather Squadron (14th WS), Engineering Weather Data (EWD). Retrieved from https://www.climate.af.mil/products/ewd/

Anderson, D. (2009). Squeezing Value Out of Idle Assets: Enhanced Use Leasing in the U.S. Army. *Journal of Contract Management*. Summer 2009.

Ang, A. H. S., & Tang, W. H. (2007). Probability Concepts in Engineering: Emphasis on Applications to Civil and Environmental Engineering. 2nd Edition. John Wiley & Sons.

Berg, R. (2009). Tropical Cyclone Report – Hurricane Ike. 1-14 September 2008. National Hurricane Center. Retrieved from http://www.nhc.noaa.gov/pdf/TCR-AL092008_Ike_3May10.pdf

Blake, E.S., Rappaport E.N., & Landsea, C.W. (2007). The Deadliest, Costliest and Most Intense United States Tropical Cyclones from 1851-2006 (and Other Frequently Requested Hurricane Facts). NOAA, Technical Memorandum NWS-TPC-5, 43 pp.

Blake, E.S., Landsea, C.W., & Gibney, E.J. (2011). The Deadliest, Costliest and Most Intense United States Tropical Cyclones from 1851-2010 (and Other Frequently Requested Hurricane Facts). NOAA, Technical Memorandum NWS NHC-6, 49 pp.

Brooks, H. E., & Doswell III, C. A., III. (2001). Normalized Damage from Major Tornadoes in the United States: 1890-1999. *Weather and Forecasting*, *16*(1), 168-176. Retrieved from http://journals.ametsoc.org/doi/pdf/10.1175/1520-0434%282001%29016%3C0168%3ANDFMTI%3E2.0.CO%3B2

Chu, P. S., & Wang, J. (1998). Modeling Return Periods of Tropical Cyclone Intensities in the Vicinity of Hawaii*. *Journal of Applied Meteorology*, *37*(9), 951-960. Retrieved from http://journals.ametsoc.org/doi/pdf/10.1175/1520-0450%281998%29037%3C0951%3AMRPOTC%3E2.0.CO%3B2

Cidell, J. (2003). The conversion of military bases to commercial airports: Existing conversions and future possibilities. *Journal of Transport Geography*, *11*(2), 93-102.

Code, U. S. (2011). Title 10 U.S. Code, Subtitle A, Part IV, Chapter 159, § 2687 – Base closures and realignments. Retrieved from http://www.gpo.gov/fdsys/pkg/USCODE-2011-title10/pdf/USCODE-2011-title10-subtitleA-partIV-chap159-sec2687.pdf

Cowan, T. (2012). Military Base Closure: Socioeconomic Impacts. Congressional Research Service, Natural Resources and Rural Development. www.crs.gov. Published 7 February 2012. Retrieved from http://fas.org/sgp/crs/natsec/RS22147.pdf

Defense Base Closure and Realignment Commission. (2005). 2005 Defense Base Closure and Realignment Commission Report. Final Report to the President. Retrieved from http://www.brac.gov/finalreport.html

Department of Defense (DOD). (1993). Department of Defense 5126.46-M-2, *Defense Utility Energy Reporting System.* DUSD, Washington, DC: Government Printing Office.

Department of Defense (DOD), (2005a). Department of the Air Force Analysis and Recommendations BRAC 2005, Volume V, Part 1 of 2. Retrieved from http://www.defense.gov/brac/pdf/VAirForce-o.pdf

Department of Defense (DOD). (2005b). Energy Manager's Handbook. U. S. Department of Defense. Retrieved from http://www.acq.osd.mil/ie/irm/irm_library/DoD%20Energy%20Manager%20Handbook%20Aug%202005.doc.

Department of Defense (DOD). (2005c). Base Realignment and Closure 2005. Frequently Asked Questions. Retrieved from http://www.defense.gov/brac

Department of Defense (DOD). (2005d). Cost of Base Realignment Actions (COBRA) Users Manual. U.S. Department of Defense. Retrieved from http://www.defense.gov/brac/minutes/cobra/COBRAUsersManual.pdf

Department of Defense (DOD). (2005e). Base Realignment and Closure 2005. 2005 BRAC Definitions. U.S. Department of Defense. Retrieved from http://www.defense.gov/brac/definitions_brac2005.html

Department of Defense (DOD). (2013). Base Structure Report, Fiscal Year 2014 Baseline. A Summary of the Department of Defense's Real Property Inventory. Deputy Under Secretary of Defense, Installations and Environment. Retrieved from http://www.acq.osd.mil/ie/download/bsr/Base%20Structure%20Report%20FY14.pdf

Department of Defense (DOD). (2014a). 2015 Budget Reduces Infrastructure Spending, Official Says. Published 12 March 2014. Retrieved from http://www.defense.gov/news/newsarticle.aspx?id=121823

Department of Defense (DOD). (2014b). Base Closure Account - Air Force. Fiscal Year (FY) 2015 Budget Estimates. Retrieved from http://www.saffm.hq.af.mil/shared/media/document/AFD-140310-017.pdf

Department of Defense (DOD). (2014c). Department of Defense Annual Energy Management Report – Fiscal Year 2013. Office of the Deputy Under Secretary of Defense (Installations and Environment). Published June 2014. Retrieved from http://www.acq.osd.mil/ie/energy/energymgmt_report/FY%202013%20AEMR.pdf

Department of Energy (DOE). (2014). 2009 International Energy Conservation Code (IECC), Interactive Map Viewer. Retrieved from https://energycode.pnl.gov/EnergyCodeReqs/index.jsp

Doswell, C. A., III., Weiss, S. J., & Johns, R.H. (1993) Tornado Forecasting: A review. *The Tornado: Its Structure, Dynamics, Prediction, and Hazards.* Geophysical Monograph Series. No. 79, American Geophysical Union, 557–571.

Energy Information Administration (EIA), (2014). Energy Consumption Data, Electric and Natural Gas Rates for United States and State by State. Retrieved from http://www.eia.gov/

Eto, J. H. (1988). On Using Degree-days to Account for the Effects of Weather on Annual Energy Use in Office Buildings, *Energy and Buildings*, 12: 113-127.

Everstine, B. (2014). Too many bases: The plan to sidestep Congress' opposition to closures. Air Force Times. Retrieved from http://archive.airforcetimes.com/article/20140414/NEWS/304140032/

Ferguson, K. (2014). Military Construction, Environmental, Energy, and BRAC. United States Air Force. Presentation Before the Senate Committee on Armed Services, Subcommittee on Readiness and Management Support. Published 2 April 2014. Retrieved from http://www.armed-services.senate.gov/imo/media/doc/Ferguson_04-02-14.pdf

Garamone, J. (2013). Pentagon Official Says DOD Needs More BRAC. U.S. Department of Defense. American Forces Press Service. Published 22 November 2013. Retrieved from http://www.defense.gov/news/newsarticle.aspx?id=121221

Government Accountability Office (GAO). (2010). Military Base Realignments and Closures: DOD Is Taking Steps to Mitigate Challenges but Is Not Fully Reporting Some Additional Costs. GAO-10-725R. Washington, D.C., Jul 21, 2010.

Government Accountability Office (GAO). (2012). Military Base Realignments and Closures: Updated Costs and Savings Estimates from BRAC 2005. GAO-12-709R. Washington, D.C., June 29, 2012.

Government Accountability Office (GAO). (2013a). DEFENSE INFRASTRUCTURE: Improved Guidance Needed for Estimating Alternatively Financed Project Liabilities. GAO-13-337. Washington, D.C., April 2013.

Government Accountability Office (GAO). (2013b). Military Bases: Opportunities Exist to Improve Future Base Realignment and Closure Rounds. GAO-13-149. Washington, D.C., March 7, 2013.

Government Accountability Office (GAO). (2014). Climate Change Adaption. DOD Can Improve Infrastructure Planning and Processes to Better Account for Potential Impacts. GAO-14-446. Washington, D.C., May, 2014.

Griffin, J. S. (2008). *Impacts of weather variations on energy consumption efforts at US Air Force installations.* MS thesis, AFIT/GEM/ENV/08-M08. Air Force Institute of Technology, School of Engineering and Management, Wright-Patterson AFB, OH, March 2008.

Hamid, S. (2013). Florida Public Hurricane Loss Model 5.0 (FPHLM V5.0 2013). International Hurricane Research Center, Florida International University. Revision Submitted on July 12, 2013. Retrieved from http://www.sbafla.com/method/portals/methodology/ModelSubmissions/2013/20130725_FIU_2011Standards_Submission.pdf

Headquarters Air Force Civil Engineer Support Agency (HQ AFCESA). (2011). Engineering Technical Letter (ETL) 11-6: Utilities Reporting for Air Force Facilities. Published 21 June 2011. Retrieved from http://www.wbdg.org/ccb/AF/AFETL/etl_11_6.pdf

Headquarters Air Force Personnel Center (HQ AFPC), (2014). FY14 Officer Reduction in Force (RIF) Board. *Personnel Services Delivery Memorandum (PSDM), 13-130.*

Heniff, B., Rybicki, E., & Mahan, S. M. (2011). The Budget Control Act of 2011. Congressional Research Service, Library of Congress.

Homestead Air Reserve Base (ARB) website. (2012). History of Homestead Air Reserve Base. Retrieved from http://www.homestead.afrc.af.mil/library/factsheets/factsheet.asp?id=3401

Hong, T., Chang, W., & Lin, H. (2013). A fresh look at weather impact on peak electricity demand and energy use of buildings using 30-year actual weather data. *Applied Energy, 111*(0), 333-350.

House Armed Services Committee (HASC). (2013). National Defense Authorization Act for Fiscal Year 2014. *113th Congress, 1st Session.* Legislative Text and Joint Explanatory Statement to Accompany H.R. 3304, Public Law 113-66. Retrieved from http://www.gpo.gov/fdsys/pkg/CPRT-113HPRT86280/pdf/CPRT-113HPRT86280.pdf

House Armed Services Committee (HASC). (2014). Joint Explanatory Statement to Accompany the National Defense Authorization Act for Fiscal Year 2015. Joint House and Senate Explanatory Statement. Retrieved from http://armedservices.house.gov/index.cfm/files/serve?File_id=78ED7A79-9066-43FD-AA75-1D8F14B4B4A2

Huang, Z., Rosowsky, D. V., & Sparks, P. R. (2001). Long-term Hurricane Risk Assessment and Expected Damage to Residential Structures. *ReliabilityEengineering & System Safety*, *74*(3), 239-249. Retrieved from http://www.sciencedirect.com/science/article/pii/S0951832001000862

Insurance Information Institute (III). (2015). NAT CATS 2014: What's Going on with the Weather? Report produced by Munich RE for III. Retrieved from http://www.iii.org/sites/default/files/docs/pdf/munichre-010715.pdf

International Code Council (ICC). (2012). *International Energy Conservation Code (IECC).*

Jenks, G. F. (1967) The Data Model Concept in Statistical Mapping. International Yearbook of Cartography, Vol.7, pp.186-190.

Keesler Air Force Base (AFB) website. (n.d.). Hurricane Preparedness Info. Retrieved from http://www.keesler.af.mil/hurricaneinfo.asp

Langley AFB History Office. (2003). Costs of Hurricane Isabel Flood Damage. Retrieved from http://www.jble.af.mil/news/index.asp

Li, D. H. W., Yang, L., & Lam, J. C. (2012). Impact of climate change on energy use in the built environment in different climate zones – A review. *Energy, 42*(1), 103-112.

Losey, S. (2013). New personnel chief: Know your options under force cuts. *Air Force Times*. http://www.airforcetimes.com/article/20131231/NEWS/312310016/New-personnel-chief-Know-your-options-under-force-cuts

Lott, N., & T. Ross, (2006). Tracking and evaluating U. S. billion dollar weather disasters, 1980-2005. *AMS Forum: Environmental Risk and Impacts on Society: Successes and Challenges*, Atlanta, GA, American Meteorological Society, 1.2.

Lott, N., & T. Ross, (2003). A Climatology of 1980-2003 Extreme Weather and Climate Events, Technical Report.

Maddox, R. A., & Crisp, C. A. (1999). The Tinker AFB Tornadoes of March 1948. *Weather and Forecasting*, *Vol. 14*(4), 492-499.

Makela, E. (2011). Comparison of Standard 90.1-2010 and the 2012 IECC with Respect to Commercial Buildings. US Department of Energy.

Mantovani, K. R. (2006). AFIT/ENV/GEM/06M-10. *Effect of Base Realignment and Closure (BRAC) on Real Estate Values.* Air Force Institute of Technology, Wright-Patterson AFB, OH, School of Engineering and Management.

McClave, J. T., Benson, P. G., & Sincich, T. (2011). *Statistics for business and economics* (11th ed.). Pearson Education.

Meurer, F., Morris, S., Bonner, S., Zgabay, C., & Rowe, W. (n.d.). Installation-Community Partnerships: A New Paradigm for Collaborating in the 21st Century. *Journal of Defense Communities. Vol 1*. Retrieved from http://www.sonricorp.com/uploads/P4_ADC_Journal2.pdf

Meyer, C. L., Brooks, H. E., & Kay, M. P. (2002). A hazard model for tornado occurrence in the United States. In *Preprints, 16th Conf. on Probability and Statistics, Orlando, FL, Amer. Meteor. Soc., J88–J95*.

National Oceanic and Atmospheric Administration (NOAA). (1999). NOAA: Hurricane Basics. Retrieved from https://www.hsdl.org/?view&did=34038

National Oceanic and Atmospheric Administration (NOAA). (2013a). Most Intense (3, 4, 5) Continental United States Hurricanes: 1851 - 1950, 1969 (Camille), and 1983-2013. Hurricane Research Division. Atlantic Oceanographic & Meteorological Laboratory. Retrieved from http://www.aoml.noaa.gov/hrd/hurdat/most_intense.html

National Oceanic and Atmospheric Administration (NOAA). (2013b). *Service Assessment*. Hurricane/Post-Tropical Cyclone Sandy, October 22-29, 2012. U.S. Department of Commerce. Published May 2013. Retrieved from http://www.nws.noaa.gov/os/assessments/pdfs/Sandy13.pdf

National Oceanic and Atmospheric Administration (NOAA). (2014a). National Climatic Data Center. *Extreme Events*. Retrieved from http://www.ncdc.noaa.gov/climate-information/extreme-events

National Oceanic and Atmospheric Administration (NOAA). (2014b). National Severe Storms Laboratory. *Severe Weather 101*. Retrieved from http://www.nssl.noaa.gov/education/svrwx101/tornadoes/

National Oceanic and Atmospheric Administration (NOAA). (2014c). Storm Surge Overview. National Hurricane Center. Retrieved from http://www.nhc.noaa.gov/surge/

National Oceanic and Atmospheric Administration (NOAA). (2015a). Historical Hurricane Tracks. United States Department of Commerce. Retrieved from http://coast.noaa.gov/hurricanes/

National Oceanic and Atmospheric Administration (NOAA). (2015b). Tornado Probabilities. Storm Prediction Center, National Severe Storms Laboratory. Retrieved from http://www.spc.noaa.gov/new/SVRclimo/climo.php?parm=allTorn

National Weather Service (NWS). (2007). Enhanced F Scale for Tornado Damage. Storm Prediction Center. Retrieved from http://www.spc.noaa.gov/faq/tornado/ef-scale.html

National Weather Service (NWS). (2012). Saffir-Simpson Hurricane Wind Scale. National Hurricane Center. Retrieved from http://www.nhc.noaa.gov/aboutsshws.php

National Weather Service (NWS). (2014a). National Weather Service Data in Shapefile Format. Retrieved from http://www.nws.noaa.gov/gis/shapepage.htm

National Weather Service (NWS). (2014b). Strike Circle. National Hurricane Center. Glossary of NHC Terms. Retrieved from http://www.nhc.noaa.gov/aboutgloss.shtml#STRIKE and http://www.nhc.noaa.gov/gifs/strikezone.gif

Office of Management and Budget (OMB). (2014a). Fiscal Year 2015 Budget of the U.S. Government. Retrieved from http://www.whitehouse.gov/sites/default/files/omb/budget/fy2015/assets/budget.pdf

Office of Management and Budget (OMB). (2014b). OMB Circular No. A-94. Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. Discount Rates in Effect for the Calendar Year 2014. Published 7 February 2014. Retrieved from http://www.whitehouse.gov/sites/default/files/omb/memoranda/2014/m-14-05.pdf

Pellerin, C. (2011) DOD Gives High Priority to Saving Energy. Department of Defense (DOD). American Forces Press Service. Retrieved from http://www.defense.gov/news/newsarticle.aspx?id=65480

Pincus, Walter. (2014). For Pentagon, it's always a tough battle to get Congress to close military bases, facilities. The Washington Post. Retrieved from http://www.washingtonpost.com/world/national-security/for-pentagon-its-always-a-tough-battle-to-get-congress-to-close-military-bases-facilities/2014/03/17/a7eda064-a887-11e3-8599-ce7295b6851c_story.html

Pinelli, J. P., & O'Neill, S. (2000). Effect of Tornadoes on Residential Masonry Structures. *Wind and Structures, 3(1)*, 23-40.

Pinelli, J. P., Subramanian, C., Zhang, L., Gurley, K., Cope, A., Simiu, E., Diniz, S., & Hamid, S. (2003). A Model to Predict Hurricanes Induced Losses for Residential Structures. In *Proceedings of the European Safety and Reliability Conference. Maastricht, Netherlands*. Retrieved from https://www.pwri.go.jp/eng/ujnr/joint/35/paper/63pinell.pdf

Quayle, R. G., and Diaz, H. F. (1980). Heating Degree Day Data Applied to Residential Heating Energy Consumption. *Journal of Applied Meteorology*: 241-246.

Roberts, B. (2012). Electricity Price Map. U.S. Department of Energy. National Renewable Energy Laboratory. Created on 14 December 2012. Retrieved from http://en.openei.org/wiki/File:2012_12_14_Electricity_Price-01.jpg

Sailor, D. J. & Munoz, J. R. (1997). Sensitivity of Electricity and Natural Gas Consumption to Climate in the U.S.A. – Methodology and Results for Eight States, *Energy* 22: 987-998.

Smith, A., & R. Katz, (2013). U.S. Billion-dollar Weather and Climate Disasters: Data Sources, Trends, Accuracy and Biases. *Natural Hazards*.

Sorenson, D. S. (1998). Shutting down the Cold War: The politics of military base closure. Palgrave Macmillan.

Sorenson, D. S. (2007). Military base closure: a reference handbook. Greenwood Publishing Group.

Teke, C. L. (2014). Optimization of the Most Cost Effective and Energy Efficient Wall Section to Use When Renovating an Air Force Facility in a Given Climate Type. Asset Management II Final Report. Air Force Institute of Technology.

United States Air Force (USAF). (2010). Air Force Instruction (AFI) 10-503. Operations. Strategic Basing. HQ AF/A8PB. Published 27 September 2010. Retrieved from http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afi10-503/afi10-503.pdf

United States Air Force (USAF). (2012). Air Force FY2012 Implementation Plan for the DoD Strategic Sustainability Performance Plan. 2012 Report. Secretary of the Air Force, Installations, Environment and Energy. SAF/IEE. Retrieved from http://www.safie.hq.af.mil/shared/media/document/AFD-121211-038.pdf

United States Air Force (USAF). (2013). Air Force Policy Directive 10-5. Operations. Basing. AF/A8P. Published on 14 November 2013. Retrieved from http://static.e-publishing.af.mil/production/1/af_a8/publication/afpd10-5/afpd10-5.pdf

United States Air Force (USAF). (2014). AF Announces Basing Criteria for Installation, Mission Support Center HQ. Air Force News Service (AFNS). Published on 15 September 2014. Retrieved from http://www.af.mil/News/ArticleDisplay/tabid/223/Article/497372/af-announces-basing-criteria-for-installation-mission-support-center-hq.aspx

United States Automobile Association (USAA) Magazine. (2014). Preparing for Natural Disasters. Know the risks most common in your area and how to best protect your home. Pg. 7. Fall Edition.

United States Census. (2010). State & County Quick Facts. United States Census Bureau. Retrieved from http://quickfacts.census.gov/qfd/states/06000.html

Wynne, M.W. (2005). MEMORANDUM FOR INFRASTRUCTURE EXECUTIVE COUNCIL MEMBERS. 2005 Base Closure and Realignment Selection Criteria. (Dated Jan 4 2005). Retrieved from http://www.brac.gov/docs/criteria_final_jan4_05.pdf

Yazdani, N., Green, P. S., & Haroon, S. A. (2006). Large wind missile impact capacity of residential and light commercial buildings. *Practice Periodical on Structural Design and Construction*, *11*(4), 206-217.

Online GIS Data Sources

http://www.nws.noaa.gov/gis/shapepage.htm
(Tornado Shape File extracted from this website)

http://www.spc.noaa.gov/gis/svrgis/ (extracted zip files for: tornado, hail, wind, NWS_County_Warning_Areas, Counties, Cities, and States)

http://www.acq.osd.mil/is/bei/opengov/installations_ranges.zip (Point and polygon data for all major US military installations and ranges)

http://www.nws.noaa.gov/gis/

http://nationalatlas.gov/atlasftp.html?openChapters=chppeopl%2Cchptrans#chptrans

http://www.nationalatlas.gov/atlasftp.html?openChapters=#chptrans

http://water.usgs.gov/maps.html

http://earthexplorer.usgs.gov/

http://www.lib.ncsu.edu/gis/energy.html

http://www.nrel.gov/gis/

http://www.nrel.gov/gis/tools.html

http://www.nrel.gov/analysis/data_resources.html

http://www.nrel.gov/gis/femp.html

http://www.csc.noaa.gov/digitalcoast/dataregistry/#/

http://www.nws.noaa.gov/gis/

http://www.census.gov/geo/maps-data/index.html

http://www.census.gov/geo/maps-data/data/tiger-line.html

http://www.census.gov/geo/maps-data/data/tiger-geodatabases.html

http://data.octo.dc.gov/

http://www.esri.com/industries/climate/resources

http://energycode.pnl.gov/EnergyCodeReqs/

http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm
(oil & gas field info and energy related data)

Vita

Major Christopher L. Teke graduated from Summit High School, near Silverthorne, Colorado, in 1998 and entered undergraduate studies at the University of Colorado (CU). He graduated in December 2002 with a Bachelor of Science degree in Civil Engineering and was commissioned through CU's AFROTC Detachment 105 on 30 April 2003.

Major Teke was first assigned to Nellis AFB, Nevada, in August 2003, where he spent three years as a project engineer and a SABER section leader for the 99th Civil Engineer Squadron. In June of 2006, his next duty assignment took him to Travis AFB, California, where he was assigned to the 571st Contingency Response Group (CRG). While at the CRG, Maj Teke was responsible for bare-base beddown planning to support the Air Force's "Open the Airbase" Concept of Operations. He also completed numerous airfield surveys and pavement evaluations in support of mobility air operations throughout the continental United States, Central America, Africa, Southwest-Asia, and Afghanistan. In July of 2008, he was assigned to the 386th Expeditionary Civil Engineer Squadron at Ali Al Salem AB, Kuwait, supporting of Operations Iraqi and Enduring Freedom. In July 2009, following his overseas assignment, he worked as the Readiness and Emergency Management officer for the 21st Civil Engineer Squadron and as a staff officer at Headquarters Air Force Space Command; both located at Peterson AFB, Colorado. In August 2013, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

Upon graduation in March 2015, Major Teke will be assigned to the 18th Civil Engineer Squadron in Kadena AB, Japan, working as the Civil Engineering Operations Flight Commander.

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14. ABSTRACT

The Air Force is in a period of downsizing, both aircraft and personnel. In recent years, the service has cut hundreds of aircraft from its fleet and decreased military end-strength, but has not substantially reduced its infrastructure. Consequently, the cost to operate and maintain Air Force Bases is not decreasing. Mitigation methods are needed to manage the costly burden of excess infrastructure. A new Base Realignment and Closure (BRAC) round will help the Air Force reduce unnecessary infrastructure and alleviate precious resources necessary for weapon modernization and improved readiness. Cost savings through BRAC can help the Air Force achieve reduced spending and realign itself to post-war budget reductions and a constrained fiscal environment. This research analyzed new severe weather and energy factors at 62 major Air Force Bases in the United States. Adding these new factors should better account for other potential costs and savings associated with BRAC. To estimate these costs, a Monte Carlo simulation is used to forecast annual costs and account for uncertainty with tornado and hurricane risks, along with annual electricity and natural gas costs. Annual cost estimates of these four factors range from approximately $1-million to $100-million dollars. Each base is ranked in a 1-to-n list, according to the total annual cost of the four factors, from highest to lowest. The base with highest annual cost is the best candidate, according to the new proposed criteria, to be eligible for a future BRAC round. If a base is selected for closure, forecasted costs are avoided and ultimately become savings that help offset other expenses in a BRAC scenario.

15. SUBJECT TERMS

Base Realignment and Closure; BRAC; Severe Weather; Climate Zone; Energy; Monte Carlo

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