Bridging Operational Meteorology and Academia through Experiential Education

The Storm Prediction Center in the University of Oklahoma Classroom

Ariel E. Cohen, Richard L. Thompson, Steven M. Cavallo, Roger Edwards, Steven J. Weiss, John A. Hart, Israel L. Jirak, William F. Bunting, Jaret W. Rogers, Steven F. Piltz, Alan E. Gerard, Andrew D. Moore, Daniel J. Cornish, Alexander C. Boothe, and Joel B. Cohen

RESEARCH TO OPERATIONS AND THE NATIONAL WEATHER CENTER. The challenge of infusing research findings and theoretical principles into operational practice is no simple feat. The phrase "valley of death" (NRC 2001) has been linked to the repeated failure of meteorological research to become instilled within the practitioner's toolbox. It has been used to describe the gap between the academic and research communities in meteorology, and refers to cases where applied research fails to become implemented operationally (e.g., Hossain et al. 2014; Wolff et al. 2016). Alternatively, effective communication between research and operational communities is critical for creating scientifically relevant work, by which mutual missions are satisfied through collaboration. Strong relationships between research and operations entities can be considered a "bridge" to accomplish successful research-to-operations (R2O) initiatives, lessening the likelihood of research results falling into the valley of death.

As an integral member of the weather enterprise, academia not only lays the foundation for learning within the university classroom, but also plays a key role in fostering research development. As such, under the broader umbrella of academia, the university classroom can be considered as an incubator for R2O. Specifically, the classroom setting provides knowledge, guidance, and practice for students to successfully 1) conduct operationally relevant research as a part of their academic and eventual professional careers, and 2) learn ways of incorporating such research into the practice of meteorology. This incubator concept is more likely to succeed when academics and practitioners work together to offer tools and resources to the next generation of meteorologists that can be applied in their future professions. This article documents such efforts between the Storm Prediction Center (SPC) of the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS), and the University of Oklahoma (OU) School of Meteorology (SoM).

The National Weather Center (NWC; Fig. 1) is located on the south campus of OU in Norman, Oklahoma. In addition to housing the SoM, it is

AFFILIATIONS: A. Cohen*—NOAA/NWS/NCEP/Storm Prediction Center, and School of Meteorology, University of Oklahoma, Norman, Oklahoma; Thompson, Edwards, Weiss, Hart, Jirak, Bunting, and Rogers*—NOAA/NWS/NCEP/Storm Prediction Center, Norman, Oklahoma; Cavallo, Moore*, Cornish, and Boothe*—School of Meteorology, University of Oklahoma, Norman, Oklahoma; Piltz—NOAA/NWS/Weather Forecast Office, Tulsa, Oklahoma; Gerard—NOAA/National Severe Storms Laboratory, Norman, Oklahoma; J. Cohen—NiSource, Inc., Columbus, Ohio
*** CURRENT AFFILIATIONS**: A. Cohen—NOAA/NWS/Weather Forecast Office, Topeka, Kansas; Rogers—NOAA/NWS/Weather Forecast Office, Phoenix, Arizona; Moore—NOAA/NWS/Weather Forecast Office, Grand Forks, North Dakota; Boothe—NOAA/NWS/Weather Forecast Office, Las Vegas, Nevada
CORRESPONDING AUTHOR: Ariel Cohen, ariel.cohen@noaa.gov

DOI:10.1175/BAMS-D-16-0307.1

Fig. 1. Photo of the NWC, a facility on the south campus of OU that houses many agencies of the weather enterprise. (Image provided by R. Edwards.)

home to numerous partners of the weather enterprise, including the SPC, the Norman NWS Forecast Office, the National Severe Storms Laboratory (NSSL), and the NWS Warning Decision Training Division (WDTD), along with other OU meteorological entities, including the SoM and the Center for Analysis and Prediction of Storms. The collocation of these agencies inherently supports an R2O framework, and it helps to break down barriers otherwise present in collaborations over physical distance. Since its opening in 2006, the NWC has served as a fertile ground for intra- and interdisciplinary projects resulting from regular contact among a diversity of occupants.

Exemplifying within-NWC collaborative efforts, the SPC and the OU SoM have partnered to offer an OU course entitled, "Applications of Meteorological Theory to Severe-Thunderstorm Forecasting" (METR 5403/4403). This course has been conducted three consecutive years (2015–17) during each spring semester with a total enrollment of 56 students. The section "Course development and format" outlines some of the course objectives, and how it uniquely connects the research and operational communities. The section "Pedagogical practices and experiential education" provides an overview of some of the pedagogical practices that instructors have used to reinforce the linkages between academic knowledge and operational practice. Selected feedback from anonymous course evaluations is provided in the section "Final examination and student feedback." The last section reviews the course's framework and generalizes potential operational–academia partnerships. The appendix provides information regarding the "Severe Thunderstorm Forecasting Video Lecture Series," which presents many dozens of videos recorded from the spring semester 2017 METR 5403/4403 class available online (at www.spc.noaa.gov/exper/spcousom/), along with other related educational resources.

COURSE DEVELOPMENT AND FORMAT.

"Applications of Meteorological Theory to Severe-Thunderstorm Forecasting" is a three-semester-hour course offered to OU SoM graduate students and undergraduate juniors and seniors. This course interweaves theoretical concepts with real-world situations in operational severe weather forecasting. Students learn from highly experienced meteorologists at the SPC, NSSL, and other offices in the NWS who have also performed diverse research while strengthening relationships between the OU SoM and the SPC. Each year since its inception, the student population has been approximately half undergraduate and half graduate.

The roots of METR 5403/4403 extend to the 2014/15 school year, when SPC forecaster Ariel Cohen and OU faculty member Steven Cavallo conceived and developed the course. That process was concurrent with SPC lead forecaster Richard Thompson's presentations of "Meteorology of Tornado Forecasting," also known by its Twitter alias "TorCast." TorCast is composed of nine video-recorded lectures on the analysis and forecast process and related physical underpinnings that SPC meteorologists consider in forecasting severe weather. Thompson joined Cohen and Cavallo as an official coinstructor for spring semesters 2016 and 2017.

A major motivation for the development of this course was the instructors' recognition of, and desire to mitigate, the apparent disconnect between the academic and research community of meteorology and the operational community. This course seemed to be an opportunity to encourage unification of a segment of the meteorological community, with the hopes of bridging the corresponding valley of death. Two primary course objectives characterize learning expectations for METR 5403/4403: 1) students are expected to integrate multiple observational datasets, numerical weather prediction output, conceptual models of convection, research results, and forecasting experience in formulating prognostic statements of the subsequent state of the severe thunderstorm threat both independently and collaboratively; and 2) students are expected to demonstrate an understanding of the irreducible uncertainty inherent to severe thunderstorm forecasting, both quantitatively through the expression of probabilistic severe

Fig. 2. Photograph of many of the students who have taken METR 5403/4403 from 2015 through 2017 and professional meteorologists who have instructed the course, along with other individuals involved in the recording, production, and dissemination of course-related videos. This image represents the large diversity in academic and professional experience within the NWC that has fostered a strong R2O linkage. Front row (left to right): Ariel Cohen (now NWS Topeka, KS Science and Operations Officer; previously adjunct assistant professor in the OU School of Meteorology and SPC Mesoscale assistant/Fire Weather forecaster), Elizabeth DiGangi (student), Makenzie Krocak (student), Dylan Reif (student), Zachary Wienhoff (student), Ryan Bunker (student), and Richard Thompson (SPC lead forecaster). Middle row (left to right): Benjamin Holcomb (information technology specialist in the OU School of Meteorology), Keli Pirtle (NOAA Communications Public Affairs specialist), Jared Guyer (SPC lead forecaster), Sarah Borg (student), Daniel Cornish (student), Austin Dixon (student), Elisa Murillo (student), Kelsey Britt (student), and Steven Weiss (chief of the SPC Science Support Branch). Back rows (left to right): Alan Gerard (deputy chief of the Warning Research and Development Division of NSSL), John Hart (SPC lead forecaster), William Bunting (chief of the SPC Operations Branch), Andrew Dean (SPC Techniques Development meteorologist), Steven Cavallo (associate professor in the OU School of Meteorology), Eric Jacobsen (now research associate with the OU Cooperative Institute for Mesoscale Meteorological Studies/WDTD; previously student), Andrew Moore (now NWS Grand Forks, ND meteorologist; previously student and METR 5403/4403 teaching assistant), Israel Jirak (SPC Science and Operations officer), Andrew Mahre (student), Matthew Flournoy (student), Hunter Luna (student), Benjamin Davis (student), Jarrett Quinn (student), Alexander Eddy (student), and Greg Blumberg (student).

weather forecasts and qualitatively through expressing limitations of our current understanding of severe thunderstorm forecasting theory and practice. Ultimately, these objectives center on the instructors' attempts to merge theoretical and practical realms of students' education, serving as a motivator for R2O in the academic setting, which is intended to encourage students to embrace education in a more experiential manner. Course activities, described in the next section, encourage mastery of these objectives and serve as the primary means for gauging student performance.

METR 5403/4403 is not the first class offered by the SoM that has placed a heavy emphasis on the operational practice of meteorology. On an irregular basis from 1989 to 2012, Charles A. Doswell III, a retired senior NOAA research scientist and adjunct professor at OU, instructed a rigorous graduate-level course entitled, "Advanced Forecasting Techniques" (AFT; with authors Edwards, Thompson, and Cohen having been AFT students). AFT emphasized the relationship between theoretical principles of meteorology and their application to near-real-time weather maps and forecasting problems while interweaving lectures and mandatory-participation discussions led by Doswell. AFT set a valuable precedent, and its ideals foundationally helped to inspire and outline METR 5403/4403.

A major distinguishing characteristic of METR 5403/4403 is its unique combination of lectures and exercises provided by a multitude of operational forecasters and scientists, emphasizing hands-on applications of meteorological theory and principles. This collaborative-instruction style (lectures

Table 1. Partial list of lecture topics addressed in OU METR 5403/4403, along with research authored (lead or coauthor) by the lecturer of the lecture topic (when applicable).

Lecture topics	Research authored by lecturer of the topic	Name of lecturer and affiliation
Severe thunderstorm ingredients		Ariel Cohen (SPC)
Skew T–log$p$ diagrams and their applications		Ariel Cohen (SPC) and Richard Thompson (SPC)
Lapse-rate tendency equation and applications		Ariel Cohen (SPC)
Quasigeostrophic theory—Derivations and applications		Ariel Cohen (SPC)
Applications of large-scale dynamics		Richard Thompson (SPC)
Manual analysis of surface and upper-air charts		Steven Weiss (SPC)
Forecast philosophy and decision-making		Steven Weiss (SPC)
Tropical cyclone tornadoes	Edwards (2012) and Edwards and Thompson (2014)	Roger Edwards (SPC)
Supercells and tornadogenesis		Richard Thompson (SPC)
Pressure perturbations in rotating storms and related relationships between vertical shear and buoyancy; related applications to hodographs		Ariel Cohen (SPC)
Supercell and tornado parameters	Thompson et al. (2003, 2004, 2007, 2012)	Richard Thompson (SPC)
Relationship between severe thunderstorm ingredients and storm mode; storm-scale interactions	Dial et al. (2010)	Andrew Moore (OU; now NWS Grand Forks, ND) and Richard Thompson (SPC)
Statistical Severe Convective Risk Assessment Model (SSCRAM)	Hart and Cohen (2016a,b)	John Hart (SPC)
Radar applications and severe weather warnings	Piltz and Burgess (2009)	Steven Piltz (NWS Tulsa, OK)
Tornado parameter climatology and tornado radar signatures	Thompson et al. (2013, 2017)	Richard Thompson (SPC)
Synoptic and mesoscale tornado patterns		Richard Thompson (SPC)
Numerical weather prediction applications in severe thunderstorm forecasting		Israel Jirak (SPC)
Southeast cold-season tornadoes and the planetary boundary layer	Cohen et al. (2015, 2017)	Ariel Cohen (SPC)
Northeastern U.S. severe thunderstorm forecasting	Hurlbut and Cohen (2014)	Ariel Cohen (SPC)
Monsoon convection	Carlaw et al. (2017); Rogers et al. (2017)	Jaret Rogers (SPC)
Impact-based decision support services		Matthew Moreland (NWS Key West, FL)
The human element of severe weather forecasting	Andra et al. (2002)	William Bunting (SPC)
Warn-on-Forecast and Forecasting a Continuum of Environmental Threats (FACETs) initiatives		Alan Gerard (NSSL)
Terrain-enhanced circulations, and circulations along the land–sea interface, that influence severe thunderstorm potential		Ariel Cohen (SPC)

provided by different people with varied expertise) is discussed in the subsequent section. Table 1 provides a partial listing of the lecture topics offered in METR 5403/4403, along with related research both authored and taught by class lecturers. While Cohen and Thompson have served as the primary team teachers for METR 5403/4403, numerous other instructors from the SPC, NWS Weather Forecast Offices, and NSSL lecture on specific areas of presenter expertise to students, representing a wide variety of educational experience from undergraduate to graduate level (Fig. 2). Augmenting the practical aspects of the course curriculum, students are expected to study and to retain an understanding of theoretical concepts, many of which are listed in Table 1. This includes derivations using partial differential equations, vector analysis, multivariable calculus, and atmospheric dynamics. The regular integration of this theoretical rigor with real-world applications throughout the course requires students to alternate referencing both elements at a fast pace.

PEDAGOGICAL PRACTICES AND EXPERIENTIAL EDUCATION. As indicated in the previous section, the instructors of METR 5403/4403 have structured and developed this course based on a collaborative-instruction style, which is discussed by Letterman and Dugan (2004). Letterman and Dugan (2004, and references therein) provide a thorough analysis of advantages and disadvantages associated with this method and advocate this instructional approach. This style of instruction, illustrated by the variety of topics outlined in Table 1, allows students to learn from a diverse range of lecturers' communication styles, experiences, and meteorological research and applications. Furthermore, this approach links students to professionals actively engaged in the R2O process while allowing students to learn directly from the meteorologists who developed research comprising their curriculum for a variety of topics. The METR 5403/4403 instructors have mitigated many of the hindrances associated with this teaching style. For example, many of the administrative tasks, such as grading most exams and homework assignments, are performed by only one instructor to ensure consistent evaluation.

Furthermore, the primary instructors of the course have received instructional training and experience at OU, which includes direct oversight and feedback from Cavallo (full faculty), to motivate positive teaching practices in METR 5403/4403. This has required the primary instructors to work with all other instructors in creating a classroom environment conducive for student learning, participation, and knowledge retention. In particular, primary instructors have met with each of the other instructors to encourage them to consider the background of their audience, the speed and tone of presentation delivery, the demonstration of applications and the ability for students to relate to the presented material, appropriate opportunities for students to ask questions, and other values that encourage a strong learning environment. Some of the instructors of the class have also familiarized themselves with the concepts stemming from the literature cited within this manuscript, further reinforcing positive teaching practices for this course. The collective experience in teaching the wide array of topics in METR 5403/4403 is frequently shared among instructors through numerous discussions, such that instructors have been able to share best teaching practices with one another.

The instructors of METR 5403/4403 have infused two other pedagogical methods into this course: experiential education and cooperative learning (group work). Carver (1996) expresses the concept of experiential education as guided learning that engages elements of the student's whole self. There are four important tenets of experiential education that Carver identifies: authenticity, active learning, drawing on student experience, and providing mechanisms for connecting experience to future opportunity. More recently, Croft and Ha (2014) document the successful use of experiential education in an undergraduate course on instrumentation in meteorology. Also, Johnson and Johnson (1982) strongly encourage instructors to employ cooperative learning methods in the science classroom. They indicate that this learning style supports the development of students' abilities to work with one another to cultivate investigative and problem-solving skills while simultaneously improving human-relational abilities.

The instructors of METR 5403/4403 frequently administer group work assignments and have found beneficial results. Since the spring semester of 2016, students are assigned semester-long study groups, composed of three to four students per group. Each group encompasses a diverse collection of student backgrounds, typically mixing undergraduate students with graduate students. The more experienced students are assigned the additional role of mentor to the less experienced students. The student groupings are maintained through the duration of the semester

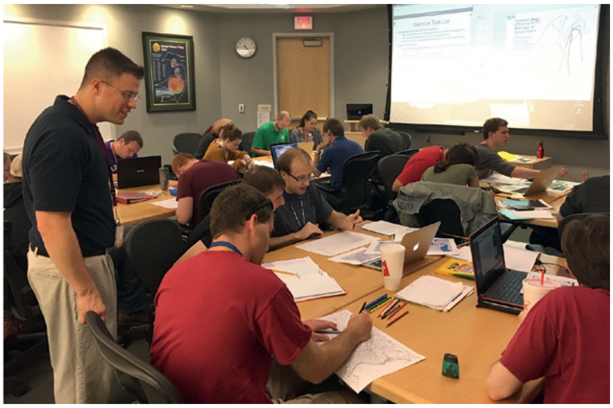


Fig. 3. Image illustrating the group work component of METR 5403/4403, where students of this class and an introductory meteorology course worked together to manually analyze and interpret weather charts.

to encourage students to establish regular communication and to practice teamwork skills. Within the groups, students are tasked to work together to complete various course assignments. Furthermore, in many instances, strong mentorship bonds form within individual groups, and many students experience academic and personal growth through collectively practicing, retaining, and synthesizing the course material.

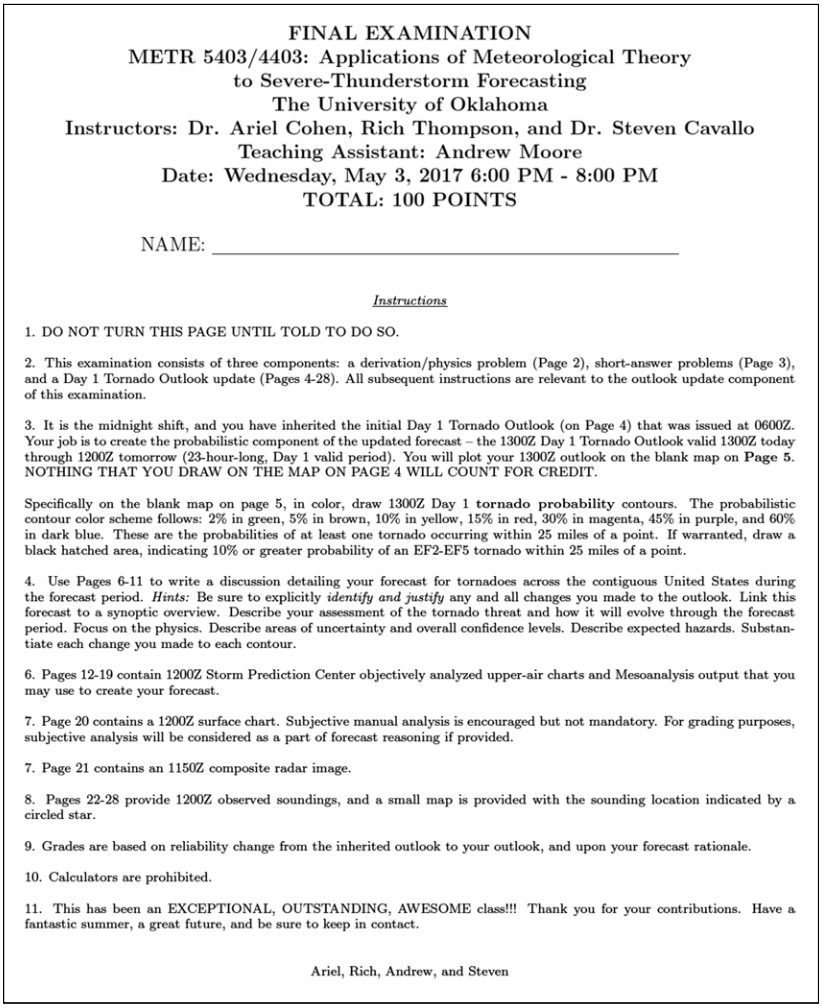
Concerning variations of student experience level (e.g., undergraduate vs. graduate), all students are held to the same knowledge expectations. While undergraduate students have typically less academic experience prior to this class, the community-based approach to class instruction and exercises has been found to encourage the success of all students. The leadership role that the graduate students undertake in mentoring and tutoring the undergraduate students has facilitated achievement among students of METR 5403/4403, despite the large variability in incoming knowledge. Instructors have worked with students to encourage their communication, relational, and teaching skills to account for the variability inherent in the class, permitting coherence among students and knowledge reception and retention. This includes semiregular student–teacher meetings where instructors and students discuss the progress of the course and personal behaviors, and is an opportunity for instructors to guide students through their own leadership experiences to support a community-learning atmosphere.

Merging both group work and experiential education concepts, there are several examples of students completing exercises to replicate the real-time SPC and NWS Forecast Office operational environment. For instance, SPC Science Support Branch Chief Steven Weiss trains METR 5403/4403 students on performing manual surface and upper-air analysis to assess severe weather risk. This experience provides students with insight from a well-seasoned meteorologist with decades of experience in training SPC forecasters. Weiss also facilitates workshop-style retrospective forecasting sessions for students, requiring study groups to work together to apply theoretical principles to analyzed maps in crafting forecast expectations for an area of severe weather potential. Figure 3 illustrates this collaborative endeavor during spring semester 2016 when METR 5403/4403 students were joined by introductory meteorology students, under Weiss's tutelage, to manually analyze and interpret weather charts. The purpose of incorporating the introductory meteorology students into this particular class session was to encourage team and relationship building among students in the SoM in the context of an applications exercise. As a part of this process, METR 5403/4403 students were mentoring students earlier in their academic careers. This particular incorporation was a single-time event during the semester.

METR 5403/4403 incorporates other examples of experiential education. For example, students are tasked with simulating convective outlook and watch preparation, similar to SPC operations. This is accomplished through multiple workshop-type activities requiring students to consider meteorological data corresponding to past severe weather events in retroactively preparing forecasts. These activities prepare students for their final examination, of which a major component requires them to identify and to justify changes to a convective outlook based on a limited subset of observational diagnostics and model guidance for a past event (Fig. 4).

Furthermore, students simulate convective-warning decision-making processes and activities involving the provision of impact-based decision support services (NOAA 2013) associated with severe weather. In particular, students assess short-term severe weather potential using a variety of observational data, including radar, and simulate critical decision-making skills, including warning issuance. This is also performed in workshop-type settings under the guidance of meteorologists who have considerable short-fused forecasting experience.

The aforementioned methods for conducting METR 5403/4403 appear to have encouraged students to think critically about the ways in which their own educational and life experiences foster achievement in operational meteorology, based on graded student work and student feedback (addressed in more detail in the next section). Individual instructors not only present relevant curricular material while leading open discussions and workshop forums but also share their own experiences, successes, and missteps. This offers students numerous tools and resources for consideration as they proceed with their academic and professional careers.



FINAL EXAMINATION
METR 5403/4403: Applications of Meteorological Theory
to Severe-Thunderstorm Forecasting
The University of Oklahoma
Instructors: Dr. Ariel Cohen, Rich Thompson, and Dr. Steven Cavallo
Teaching Assistant: Andrew Moore
Date: Wednesday, May 3, 2017 6:00 PM - 8:00 PM
TOTAL: 100 POINTS

NAME: ______________________________

Instructions

1. DO NOT TURN THIS PAGE UNTIL TOLD TO DO SO.

2. This examination consists of three components: a derivation/physics problem (Page 2), short-answer problems (Page 3), and a Day 1 Tornado Outlook update (Pages 4-28). All subsequent instructions are relevant to the outlook update component of this examination.

3. It is the midnight shift, and you have inherited the initial Day 1 Tornado Outlook (on Page 4) that was issued at 0600Z. Your job is to create the probabilistic component of the updated forecast – the 1300Z Day 1 Tornado Outlook valid 1300Z today through 1200Z tomorrow (23-hour-long, Day 1 valid period). You will plot your 1300Z outlook on the blank map on **Page 5**. NOTHING THAT YOU DRAW ON THE MAP ON PAGE 4 WILL COUNT FOR CREDIT.

Specifically on the blank map on page 5, in color, draw 1300Z Day 1 **tornado probability** contours. The probabilistic contour color scheme follows: 2% in green, 5% in brown, 10% in yellow, 15% in red, 30% in magenta, 45% in purple, and 60% in dark blue. These are the probabilities of at least one tornado occurring within 25 miles of a point. If warranted, draw a black hatched area, indicating 10% or greater probability of an EF2-EF5 tornado within 25 miles of a point.

4. Use Pages 6-11 to write a discussion detailing your forecast for tornadoes across the contiguous United States during the forecast period. *Hints:* Be sure to explicitly *identify and justify* any and all changes you made to the outlook. Link this forecast to a synoptic overview. Describe your assessment of the tornado threat and how it will evolve through the forecast period. Focus on the physics. Describe areas of uncertainty and overall confidence levels. Describe expected hazards. Substantiate each change you made to each contour.

6. Pages 12-19 contain 1200Z Storm Prediction Center objectively analyzed upper-air charts and Mesoanalysis output that you may use to create your forecast.

7. Page 20 contains a 1200Z surface chart. Subjective manual analysis is encouraged but not mandatory. For grading purposes, subjective analysis will be considered as a part of forecast reasoning if provided.

7. Page 21 contains an 1150Z composite radar image.

8. Pages 22-28 provide 1200Z observed soundings, and a small map is provided with the sounding location indicated by a circled star.

9. Grades are based on reliability change from the inherited outlook to your outlook, and upon your forecast rationale.

10. Calculators are prohibited.

11. This has been an EXCEPTIONAL, OUTSTANDING, AWESOME class!!! Thank you for your contributions. Have a fantastic summer, a great future, and be sure to keep in contact.

Ariel, Rich, Andrew, and Steven

Fig. 4. Title page of the final examination for spring semester 2017, which illustrates the substantial emphasis on students applying METR 5403/4403 coursework by simulating the preparation of a convective outlook update for course credit.

FINAL EXAMINATION AND STUDENT FEEDBACK. Metrics for gauging the accomplishment of the two aforementioned course objectives (in general terms, formulating prognostic statements about the severe weather risk and demonstrating understanding of forecast uncertainty) culminate in student preparation of an updated convective outlook in the final examination, as illustrated in Fig. 4. This outlook update section represents a large portion of the final exam score (65% of 100 total points). Student grades for this activity are based upon the instructors' evaluation of students' work in convective outlook preparation, specifically that portion pertaining to tornadoes. To specifically evaluate whether students are successful in accomplishing course objectives, the 65 points of outlook preparation are decomposed into eight subcomponents: 1) identifying the area of greatest concern for tornadoes (some significant) (worth 10 points); 2) identifying reduced tornado potential in an area where previous convection had stabilized the environment, thus limiting subsequent tornado potential (worth 10 points); 3) providing a written description of the motion and depth of a mid- and upper-level trough associated with the severe weather risk using quasigeostrophic theory (worth 5 points); 4) providing a written description of the motion and depth of a surface cyclone associated with the severe weather risk using quasigeostrophic theory (worth 5 points); 5) providing a written discussion of ingredients favoring supercells (worth 10 points); 6) providing a written explanation detailing foci for convective initiation (e.g., relevant surface boundaries, such as cold fronts, prefrontal troughs, and outflow boundaries) (worth 5 points); 7) providing a description and justification for anticipated convective mode and its influence on the updated outlook (worth 10 points); and 8) justifying changes reflected in the updated outlook in relation to the aforementioned elements (worth 10 points). Ultimately, these subcomponents directly gauge students' ability to quickly integrate numerous datasets together and to apply conceptual models while developing a severe thunderstorm forecast and simultaneously accounting for limitations in the science manifest in expressed uncertainty, consistent with course objectives.

Considering student performance on the final exam requiring the update to the convective outlook, nearly all 13 students of spring semester 2017 correctly identified the area of greatest concern for tornadoes (some significant), while around half of the students correctly lowered the tornado level in an area where previous convection had stabilized the environment and limited subsequent tornado potential. This level of performance was encouraging to instructors that course objectives were being fulfilled, and most instructors agreed that the experiential education component of this course was fulfilled.

Moreover, instructors' judgment of students' participation in class exercises and group discussions throughout the semester serves as a metric for evaluating course objectives, more subjectively determined. This participation element supports a classroom setting where students are expected to interact with one another and the instructors, encouraging students to be receptive to unique experiences shared by instructors and for students to practice career-related activities under the direct guidance of those established in the field. As stated in the course syllabus, "participation scores will be assigned based on the quality of contributions to class discussions/asking and answering questions, general courtesy towards instructors and speakers, involvement in class activities including occasional, irregularly scheduled weather briefings" (http://weather.ou.edu/~acohen/ACOHEN_Syllabus.pdf). The instructors' collective assessment of the participation component of the course also serves as a metric for evaluating whether students meet the objectives.

At the end of each semester, students have the opportunity to provide anonymous feedback regarding the course. In this section, we provide excerpts of the expository portion of the evaluation to highlight students' perceptions of the course (collected during spring semesters 2015 and 2016).

Selected responses corresponding to the evaluation question "How would you summarize this course for a fellow student?" follow:

> I would summarize this course as a challenging but extremely beneficial course in not only understanding the theory of forecasting severe storms, but the application of these topics, in addition to a great insight into how the operational world works in a professional sense. It is also an excellent networking opportunity to meet some people that are well renowned for their work in their field, and is an excellent learning opportunity because of this.

> This is an excellent course that will give exposure to both concepts key to severe weather forecasting as well as practical application of those concepts. Getting to hear from people who work with these problems on a daily basis is an invaluable experience, and I would recommend this course to any meteorology student who is interested in severe weather. I feel like this is something that could only happen at OU, and I would encourage fellow students to seize the opportunity that this course provides to further their learning and application of their degree.

> This course is extremely helpful if you are interested in forecasting or even if you are interested in the theory. It offers something for everyone in every part of meteorology.

This anecdotal evidence reflects positive experiences, based on early student feedback. In particular, it highlights that the holistic curriculum of METR 5403/4403 is derived from the wide variety of professional experience within the NWC, such that collaboration therein has provided a positive educational experience to students. The second anecdote further supports the idea that this class offers an opportunity for students to network with professional meteorologists through many of the previously presented activities.

Selected responses corresponding to the evaluation question "What, if anything, made your learning in this course more difficult?" follow:

> The initial half of the course was taught at a rapid pace for those who had not been familiarized with the material beforehand, but the groups were well equipped to help each other with the material. I must also note that the fast pace of the class was necessary in order to get to the class exercises that were so helpful in the second half of the semester.

> The pace of the course was fast, but not unmanageable. The knowledge gap between the grad students and underclassmen [sic] was large as well, which sort of made it intimidating.

Table 2. Bulk statistics corresponding to the anonymous survey statement, "This course helped me develop competence consistent with the course objectives."

Semester	Mean (out of 5.0; rounded to tenths place)	Median (out of 5)	Standard deviation (rounded to tenths place)	Sample size
Spring 2015	4.7	5	0.6	20
Spring 2016	4.6	5	0.6	24
Spring 2017	4.9	5	0.3	11

> With having all the different lecturers from SPC, it was sometimes difficult to take notes because some lecturers would go through their notes too quickly to allow notes to be taken and most lecturers [sic] powerpoints [sic] were not available to look at afterward.

Student feedback is critical in terms of adapting the class to better meet students' learning needs in the future. Table 2 provides bulk statistics corresponding to the statement "This course helped me develop competence consistent with the course objectives." These are examples that have reinforced the value and fulfillment of the instructors' objectives. As an example of the fulfillment of these objectives, a former student describes how the material from this course has been beneficial for related research:

> Since it tied in meteorological theory into its implications on severe thunderstorm forecasting, the depth of useful material to real world applications in forecasting and research that was presented during the course was unlike any other class offered at the university. Knowledge gained from this class, specifically extensive map analysis and meteorological theory, helped me tremendously on my senior capstone research project, which investigated distinguishing characteristics of tornadic environments in southeastern United States open warm sector convection.

This is an example of feedback that specifically demonstrates this class as serving as an incubator for R2O.

Other constructively critical feedback has been necessary for restructuring elements of the class format. For example, the initial pace of the more theoretical work presented at the beginning of the semester was slowed by removing the instruction of selected theoretical topics that rarely recurred for the remainder of the class. Furthermore, the course format has been adjusted to modestly decrease the number of instructors from the initial iteration to encourage more topical depth as opposed to breadth while still retaining substantial curriculum breadth (Table 1).

CONCLUSIONS. This manuscript documents the collaborative course offered within the School of Meteorology at the University of Oklahoma, instructed primarily by forecasters from the Storm Prediction Center: "Applications of Meteorological Theory to Severe-Thunderstorm Forecasting." This discussion demonstrates the crucial components of experiential education, and collaborative work and instruction, serving as the foundation for course activities. A topical overview illustrating the breadth and applicability of the course curriculum has been provided, and emphasizes students' experience in practicing tasks that operational meteorologists regularly perform. The collocation of the complementary academic, research, and operational entities within the National Weather Center support numerous research-to-operations initiatives, including experiential education. Ultimately, METR 5403/4403 students are instructed by representatives of these entities, and the instructors hope that such experience and perspective will foster lifelong learners and contributors to the field of meteorology.

While the specific focus of METR 5403/4403 is severe thunderstorm forecasting, the general approach to instructing an experiential-education-based course within the broader field of meteorology is plausible in many settings. Locations where collegiate meteorology programs are near operational or research facilities would be ideal for the development of classes like METR 5403/4403. However, even programs that are separated from these facilities may also benefit from remote collaborations, especially given recent advances in communication technology. The authors hope that such experiences will set the groundwork for incoming professional meteorologists by teaching them how operational meteorologists function, thus encouraging their appreciation for real-world problems and their ability to communicate their theoretical work in the context of forecast applications while ascertaining tools and resources to mitigate the "valley of death" concept.

ACKNOWLEDGMENTS. The authors extend substantial appreciation for all of those individuals who have contributed their time and resources to instructing students in METR 5403/4403, along with meteorologists at the NOAA/NWS Warning Decision Training Division for their assistance with integrating selected course material into official NWS training. SPC forecaster Joseph Picca, who was also a student of this course during spring semester 2016, has provided additional and beneficial instructional material to students of this course outside of normal class periods. The authors also express deep gratitude to the management of the SPC and the leadership of the OU School of Meteorology for offering the flexibility and time to form the necessary partnership to make this course happen. Benjamin Holcomb and Shawn Riley (information technology specialists of the OU School of Meteorology) have offered substantial time and effort to document the course through recordings, and Keli Pirtle (NOAA Communications Public Affairs specialist) and James Murnan (NOAA Weather Partners Audio/Visual Production specialist) have provided substantial assistance in organizing course promotional material. Patrick Hyland (coordinator of External Relations at the National Weather Center) prepared the graphic displayed on the Science On a Sphere® (SOS) exhibit, serving as background for Fig. 2. The authors greatly appreciate the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) for their gracious support of this publication. Furthermore, the lead author extends deep appreciation to Ryan Bunker (OU School of Meteorology student) and Brett Borchardt (NOAA/NWS/Weather Forecast Office, Marquette, Michigan) for their loyalty and dedicated friendship while supporting this work. In addition to many of the authors, numerous other NOAA meteorologists contributed lecture material to students during formal class sessions: Gregory Carbin, Michael Coniglio, Stephen Corfidi, Andrew Dean, Gregory Dial, Jeremy Grams, Jared Guyer, Ryan Jewell, Patrick Marsh, Corey Mead, Matthew Moreland, and Louis Wicker. Four reviewers provided substantial guidance for improving this manuscript. Finally, having been reflected in the instructional style of this class, the lead author is grateful for the numerous opportunities for experiential education he received at especially the Linworth Alternative Program and Thomas Worthington High School, as well as at Worthingway Middle School and Worthington Estates Elementary School in Worthington, Ohio, and expresses tremendous gratitude to his father, Joel Cohen, for his constant encouragement of academic and professional excellence; to his mother, Hallie Cohen, for encouraging strong emotional intelligence; and to his sister, Ariana Cohen, for her loyalty and sense of humor.

APPENDIX: THE "SEVERE THUNDERSTORM FORECASTING VIDEO LECTURE SERIES" AND OTHER RELATED EDUCATIONAL RESOURCES. During spring semester of 2017, most of the METR 5403/4403 classes were recorded, and edited, closed-captioned videos have been made available on the SPC website as the "Severe Thunderstorm Forecasting Video Lecture Series" (at www.spc.noaa.gov/exper/spcousom/). These videos include numerous presentations covering the majority of the course curriculum, and the release of this video series is intended to make the educational resources developed for this class readily available to the community. Multiple videos provide specific instructional material that could be adapted in a laboratory setting, especially those concerning manual analysis of surface and upper-air charts, along with elements of the philosophy of forecasting and integrating conceptual models with data. Many resources are available in the "Forecast Tools" section of the SPC website, including real-time mesoanalysis information, upper-air observations, and sounding climatologies, along with related educational materials. These can serve as the basis for laboratory exercises in severe thunderstorm forecasting, applying the material now presented in the publicly available "Severe Thunderstorm Forecasting Video Lecture Series."

FOR FURTHER READING

Andra, D. L., Jr., E. M. Quoetone, and W. F. Bunting, 2002: Warning decision making: The relative roles of conceptual models, technology, strategy, and forecaster expertise on 3 May 1999. *Wea. Forecasting,* **17,** 559–566, https://doi.org/10.1175/1520-0434(2002)017<0559:WDMTRR>2.0.CO;2.

Carlaw, L. B., A. E. Cohen, and J. W. Rogers, 2017: Synoptic and mesoscale environment of convection during the North American monsoon across central and southern Arizona. *Wea. Forecasting,* **32,** 361–375, https://doi.org/10.1175/WAF-D-15-0098.1.

Carver, R., 1996: Theory for practice: A framework for thinking about experiential education. *J. Experiential Educ.,* **19,** 8–13, https://doi.org/10.1177/105382599601900102.

Cohen, A. E., S. M. Cavallo, M. C. Coniglio, and H. E. Brooks, 2015: A review of planetary boundary layer parameterization schemes and their sensitivity in simulating southeastern U.S. cold season severe weather environments. *Wea. Forecasting,* **30,** 591–612, https://doi.org/10.1175/WAF-D-14-00105.1.

——, ——, ——, ——, and I. L. Jirak, 2017: Evaluation of multiple planetary boundary layer parameterization schemes in southeast U.S. cold season severe thunderstorm environments. *Wea. Forecasting*, **32**, 1857–1884, https://doi.org/10.1175/WAF-D-16-0193.1.

Croft, P. J., and J. Ha, 2014: The undergraduate “Consulting Classroom”: Field, research, and practicum experiences. *Bull. Amer. Meteor. Soc.,* **95,** 1603–1612, https://doi.org/10.1175/BAMS-D-13-00045.1.

Dial, G. L., J. P. Racy, and R. L. Thompson, 2010: Short-term convective mode evolution along synoptic boundaries. *Wea. Forecasting*, **25**, 1430–1446, https://doi.org/10.1175/2010WAF2222315.1.

Edwards, R., 2012: Tropical cyclone tornadoes: A review of knowledge in research and prediction. *Electron. J. Severe Storms Meteor.,* **7,** http://ejssm.org/ojs/index.php/ejssm/article/view/97.

——, and R. L. Thompson, 2014: Reversible CAPE in tropical cyclone tornado regimes. *27th Conf. on Severe Local Storms,* Madison WI, Amer. Meteor. Soc., P88, https://ams.confex.com/ams/27SLS/webprogram/Paper254328.html.

Hart, J. A., and A. E. Cohen, 2016a: The Statistical Severe Convective Risk Assessment Model. *Wea. Forecasting,* **31,** 1697–1714, https://doi.org/10.1175/WAF-D-16-0004.1.

——, and ——, 2016b: The challenge of forecasting significant tornadoes from June to October using convective parameters. *Wea. Forecasting,* **31,** 2075–2084, https://doi.org/10.1175/WAF-D-16-0005.1.

Hossain, F., and Coauthors, 2014: Crossing the “valley of death”: Lessons learned from implementing an operational satellite-based flood forecasting system. *Bull. Amer. Meteor. Soc.,* **95,** 1201–1207, https://doi.org/10.1175/BAMS-D-13-00176.1.

Hurlbut, M. M., and A. E. Cohen, 2014: Environments of northeast U.S. severe thunderstorm events from 1999 to 2009. *Wea. Forecasting,* **29,** 3–22, https://doi.org/10.1175/WAF-D-12-00042.1.

Johnson, R. T., and D. W. Johnson, 1982: What research says about student–student interaction in science classrooms. *Education in the 80’s: Science,* M. B. Rowe, Ed., National Education Association, 25–37.

Letterman, M. R., and K. B. Dugan, 2004: Team teaching a cross-disciplinary honors course: Preparation and development. *Coll. Teach.,* 52, 76–79.

NOAA, 2013: National Weather Service weather-ready nation roadmap, version 2.0. National Oceanic and Atmospheric Administration, 75 pp., www.weather.gov/media/wrn/nws_wrn_roadmap_final_april17.pdf.

NRC, 2001: *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death.* National Academies Press, 96 pp.

Piltz, S. F., and D. W. Burgess, 2009: The impacts of thunderstorm geometry and WSR-88D beam characteristics on diagnosing supercell tornadoes. *34th Conf. on Radar Meteorology,* Williamsburg, VA, Amer. Meteor. Soc., P6.18, https://ams.confex.com/ams/34Radar/techprogram/paper_155944.htm.

Rogers, J. W., A. E. Cohen, and L. B. Carlaw, 2017: Convection during the North American monsoon across central and southern Arizona: Applications to operational meteorology. *Wea. Forecasting,* **32,** 377–390, https://doi.org/10.1175/WAF-D-15-0097.1.

Thompson, R. L., R. Edwards, J. A. Hart, K. L. Elmore, and P. Markowski, 2003: Close proximity soundings within supercell environments obtained from the Rapid Update Cycle. *Wea. Forecasting,* **18,** 1243–1261, https://doi.org/10.1175/1520-0434(2003)018<1243:CPSWSE>2.0.CO;2.

——, ——, and C. M. Mead, 2004: An update to the supercell composite and significant tornado parameters. *22nd Conf. on Severe Local Storms,* Hyannis, MA, Amer. Meteor. Soc., P8.1, https://ams.confex.com/ams/11aram22sls/techprogram/paper_82100.htm.

——, C. M. Mead, and R. Edwards, 2007: Effective storm-relative helicity and bulk shear in supercell thunderstorm environments. *Wea. Forecasting,* **22,** 102–115, https://doi.org/10.1175/WAF969.1.

——, B. T. Smith, J. S. Grams, A. R. Dean, and C. Broyles, 2012: Convective modes for significant severe thunderstorms in the contiguous United States. Part II: Supercell and QLCS tornado environments. *Wea. Forecasting,* **27,** 1136–1154, https://doi.org/10.1175/WAF-D-11-00116.1.

——, ——, A. R. Dean, and P. T. Marsh, 2014: Spatial distributions of tornadic near-storm environments by convective mode. *Electronic J. Severe Storms Meteor.,* **8**, 1–22.

——, and Coauthors, 2017: Tornado damage rating probabilities derived from WSR-88D data. *Wea. Forecasting*, **32**, 1509–1528, https://doi.org/10.1175/WAF-D-17-0004.1.

Wolff, J. K., and Coauthors, 2016: Mesoscale Model Evaluation Testbed (MMET): A resource for transitioning NWP innovations from research to operations (R2O). *Bull. Amer. Meteor. Soc.,* **97,** 2135–2147, https://doi.org/10.1175/BAMS-D-15-00001.1.

AMS titles now available as eBooks at springer.com

AMS BOOKS

RESEARCH | APPLICATIONS | HISTORY

www.ametsoc.org/amsbookstore

Springer

Scan to see
AMS eBook titles
at springer.com

» *American Meteorological Society*

American Meteorological Society

Promoting the development and dissemination of information and education on the atmospheric and related sciences.

American Meteorological Society eBooks

AMS Books grew out of a monograph publishing program related to the peer-reviewed journals published by the AMS and now encompasses a series of meteorological and historical monographs that reaches back five decades (formerly out-of-print volumes of which have been brought back on SpringerLink as eBooks) as well as a growing list of academic, policy, and general-interest books related to the atmospheric sciences.

Sort listing by: ○ Relevance ● Publication date ○ Title ○ Author ○ Copyright Year

Export to CSV

AMERICAN METEORLOGICAL SOCIETY EBOOKS

» Show all 11 results

Eloquent Science

A Practical Guide to Becoming a Better Writer, Speaker, and Atmospheric Scientist

Schultz, David

2009

Price from **$45.00**

Available Formats:

AMERICAN METEOROLOGICAL SOCIETY

» About the American Meteorological Societ...
» Order print copies of AMS Books
» Booksellers seeking print copies of AMS ...
» For AMS Journals Online

RESOURCES

Stay Informed

Receive notification of new releases from AMS Books

Submit a Book Proposal to the AMS

Download our book proposal guidelines

Become an AMS Member

Learn about the benefits of membership

CONNECT WITH THE AMERICAN METEOROLOGICAL SOCIETY

Like AMS on Facebook

Follow AMS on Twitter

AMERICAN METEOROLOGICAL SOCIETY