Appendix 4

PICES Press Articles Related to WG 29

2012 Yeosu Workshop on "Climate Change Projections"

by Enrique Curchitser and Icarus Allen

A 2-day workshop on "*Climate change projections for marine ecosystems: Best practices, limitations and interpretations*" was held on May 13–14, 2012, preceding the 2nd International Symposium on "*Effects of Climate Change on the World's Ocean*" convened in Yeosu, Korea. The goal of the workshop was to explore different approaches to modeling the impacts of climate change and variability on marine ecosystems and to highlight their strengths and limitations. A significant motivation was to bring together both global and regional modelers whose communities often work separately. A particular interest of the convenors (co-authors of this article) was to insure that the definition of an ecosystem included higher trophic levels and both direct and indirect anthropogenic influences. The tone for the workshop was set by the opening remarks of Icarus Allen (Plymouth Marine Laboratory, UK) who discussed the scientific interest in understanding how ecosystems respond to climate change, the propagation of the climate signal through an ecosystem, difficulties in making future projections, issues with downscaling, whole ecosystem approaches, and anthropogenic effects questions of how to deal with uncertainty. The need to take risks in our approaches to these problems was indicated.

Over the two days, about 40 scientists participated in the workshop. Invited talks by Villy Christiansen and William Cheung (University of British Columbia, Canada), Jason Holt (National Oceanographic Centre, UK), Charles Stock (NOAA's Geophysical Fluid Dynamics Laboratory, USA dealt with research using both global and regional climate models coupled with marine ecosystem models. Together with submitted contributions, a range of models was presented which included global and regional coupled physics, fish and fishers.

Dr. Christiansen started the workshop with a talk about the NEREUS project led by the University of British Columbia. The work is motivated by the question of "Will there be fish for coming generations?" and the realization that many fisheries have collapsed across the globe. The project takes a global approach and models the ecosystem from biogeochemistry to the market. It includes on the order of 1000 fish species and nearly 250 fishing fleets (Fig. 1). NEREUS is also a leader in outreach activities, producing visualizations of model data for the public at large.

Dr. Holt tackled the topic of climate drivers on coastal marine ecosystems. His emphasis was on downscaling global climate models to the broad continental shelves of northern Europe and exploring the physical mechanisms (the

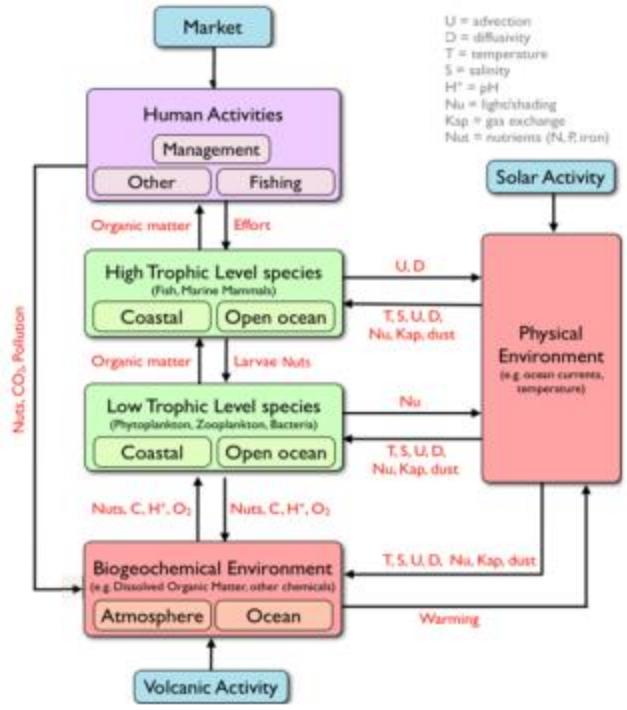

Fig. 1 Schematic diagram of the Nereus modeling framework. The model is being used to concurrently study the effects of climate change and human activity (such as fishing) on global fish stocks. Nereus takes a global approach to the problem simultaneously modeling 1000 species of fish and over 250 different fishing fleets (see http://www.nereusprogram.org/ for details).

interplay of turbulence, mixing and nutrient supply) that exert controls over phytoplankton growth. He presented several considerations for the treatment of uncertainty in complex coupled bio-physical models.

Dr. Stock described his work on using IPCC-class models to assess the impact of climate change on living marine resources. He described some of the challenges of using global models: resolution, separating variability and trends and the fact that these models were not designed to address marine ecosystems, in particular on regional scales (Fig. 2). However, an understanding of the functioning of coupled global climate models and the careful design of ecosystem models can yield insight into ecosystem functioning under projected climate change scenarios.

Dr. Cheung focused on the modeling of large-scale effects of global change on marine ecosystems and fisheries. The motivating issues were ocean warming, de-oxygenation, acidification and overfishing. His presentation dealt with the question of the combined effect of these issues on fisheries

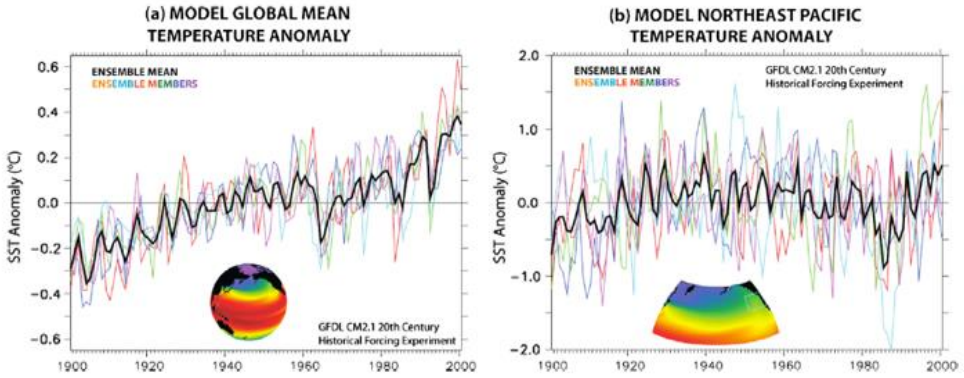

Fig. 2 Temperature anomalies from an ensemble of future projections using the GFDL CM2.1 model. Left: Global mean, Right: Northeast Pacific. This figure illustrates the difference in global and regional variability in the climate model suggesting needed caveats when evaluating global models on a regional basis and interpreting regional ecosystem responses to a global climate signal. Stock et al., 2011. Prog. Oceanog. 88, 1–27.

and explored the sensitivity of model results to projected climate scenarios. His model results suggest that by 2050 warming may cause regions in the tropics to lose catch potential, while high-latitude regions may gain. However, global catch potential is predicted to decrease.

Further presentations at the workshop discussed various approaches to linking climate and ecosystem models, and several threads emerged from these presentations:

- How useful these models are for management, planning and policy purposes,
- The need, advantage and issues of downscaled climate solutions, and
- The validity of regional interpretations of global climate model results.

The topic of model resolution and the multi-scale nature of the problem (both in physics and biology) permeated throughout the presentations and the ensuing discussions. In particular, the participants articulated the needs of coastal ecosystem research that are not necessarily well served by global climate models. A significant amount of time was devoted to a discussion on the communication of model results and model uncertainty to a variety of constituents. The challenge of taking research models and developing them to be useful tools for operational oceanography or management strategy evaluation was also discussed (Fig. 3).

It was recognized at the workshop that as we move forward in trying to make projections of future ecosystem health under likely climate change, it is important for the regional ecosystem and global climate communities to continue working together. Current modeling capacities are inadequate for some of the questions that are being posed. In particular, the challenge of making policy-relevant predictions over the next 2 or 3 decades in the face of a modeled climate signal, which is indistinguishable from the natural variability of the system, was noted. The participants agreed that at present, the community is not ready to describe "best practices", but enough different approaches exist that we can contrast "current" practices. A review manuscript on state-of-the-art approaches highlighting their strengths and weaknesses for making projections of particular ecosystems is expected as the outcome from the workshop.

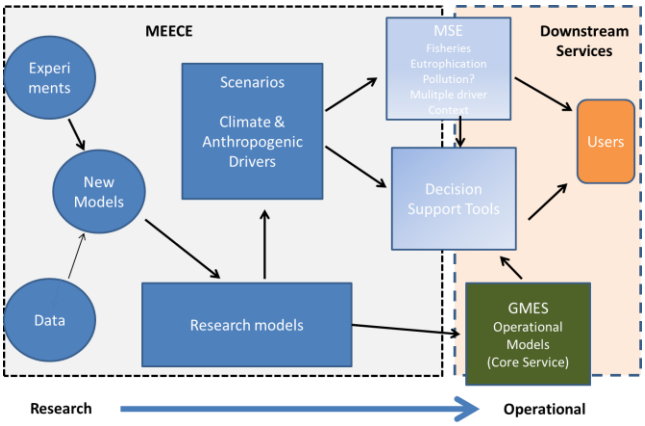

Fig. 3 Schematic of the model development process illustrating the challenge of building research models and pulling them through to operational and decision support tools.

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Second Regional Climate Modeling Workshop

by Kyung-Il Chang, Enrique Curchitser, Chan Joo Jang and Kelvin Richards

Participants of the second Regional Climate Modeling Workshop (September 10–12, 2013, Busan, Korea).

A second Regional Climate Modeling Workshop (RCM-II) took place from September 10–12, 2013, in Busan, Korea. The workshop was co-organized by PICES, Seoul National University and the Korean Ministry of Oceans and Fisheries. Drs. Kyung-Il Chang (Seoul National University, Korea), Enrique Curchitser (Rutgers University, USA), Chan Joo Jang (Korea Institute of Ocean Science and Technology, Korea) and Kelvin Richards (International Pacific Research Center, USA) served as co-convenors. The first workshop (RCM-I) was held in 2011, in Seoul, Korea.

Workshop participants were given a warm welcome to the beautiful seaside city of Busan by Mr. Song-Hack Lim, Director for Marine Environment Policy Division of the Ministry of Oceans and Fisheries. In his remarks, Mr. Lim drew attention to the work of the Intergovernmental Panel on Climate Change (IPCC) and the concern for global society that IPCC reports have generated during the last 25 years. The Korean peninsula has experienced significant increases in temperature and changes in marine biology in its adjacent seas. Fishes from the subtropical oceans, for example, are replacing many of the native species of fish in the southern sea of Korea near Jeju Island. Mr. Lim pointed out that rapid physical and ecological changes in regional seas are a great concern and an ability to develop accurate projections of future climate change is of utmost importance for the Korean government, and encouraged participants to engage in vigorous discussions that will lead to more accurate regional climate models. Following Mr. Lim, Dr. Skip McKinnell (PICES Deputy Executive Secretary), introduced the activities of PICES Working Group 29 on *Regional Climate Modeling* (2011–2014) and described how international workshops like RCM-II are contributing to the goals of this expert group.

Workshop presentations were grouped on a thematic basis beginning with *Mesoscale and Sub-mesoscale Motions* on the first day, then *Regional Climate Projections* on the second day, and finishing with *Climate Variability in the North Pacific* on the final day. The full program of the workshop and extended abstracts can be downloaded from WG 29's webpage.

Invited speakers at the workshop supported by PICES included Drs. Shoshiro Minobe (Hokkaido University, Japan) and Michael Foreman (Institute of Ocean Sciences, Canada). Dr. Minobe presented on "*Regional influence of basin-scale wind stress variability via jet-trapped Rossby waves in the western North Pacific*". His main point was that jet-trapped Rossby waves are newly discovered features that are not yet captured by regional climate models whose zonal domain and spatial and temporal resolutions are insufficient to realize the jet. Model spatial resolution must be increased, perhaps by an order of magnitude. One consequence of missing this feature (in the Kuroshio Extension) is that jet-trapped waves create a different sea level anomaly pattern around Japan compared to linear long Rossby waves. Dr. Foreman spoke on "*Regional ocean climate projections for the British Columbia continental shelf*" and showed how regionally downscaled climate models were being used to support regional climate projections for the coast of British Columbia, Canada.

On the last day, a discussion session was moderated by Drs. Kelvin Richards and Enrique Curchitser. Questions stimulated by the workshop included: How useful are idealized process models? At what spatial resolution do results converge? How important are sub-mesoscale processes in a global sense? Is it possible to simply

parameterize the impact of the sub-mesoscale? How much can be learned from one-way nesting? How to quantify the impact of global warming? What is the way forward – Limited area *versus* basin scale models?

The relative importance of sub-mesoscale processes sparked considerable interest and discussion. Dr. Jason Holt (National Oceanography Centre, UK) believed that they must be parameterized in global models and that super-parameterization might be a route to go. Dr. Richards suggested embedding downscaled models within global models. Dr. Paulo Calil (Universidade Federal do Rio Grande, Instituto de Oceanografia, Brazil) noted that when trying to understand the carbon cycle, for example, the parameterization must be based on physical understanding, and he emphasized a need to understand the influence of small-scale structures. Drs. Christopher Edwards (University California Santa Cruz, USA) and Kelvin Richards indicated that our ability to parameterize processes in large-scale models is limited because the processes are too complicated. That led to a question whether we can be clever enough to parameterize all of the important sub-mesoscale processes. "Probably not" was the response. Process studies though are useful to understand the sub-mesoscale approach. A question was also raised if sub-mesoscale processes need to be resolved in regional models and, if yes, then what resolution is needed? It was noted that: the response must consider distinguishing shelf seas from the open ocean (Dr. Holt), the decision probably depends on the context (Dr. Minobe), and we are not at a point yet to quantify the overall impact of sub-mesoscale processes and need to assess their importance (Dr. Richards).

Dr. Annalisa Brocco (Georgia Institute of Technology USA) expected that the next IPCC assessment will use higher resolution without adding greater complexity. Dr. Richards reminded participants of Dr. Clara Deser's paper suggesting that 40 ensemble members are needed so that, at the present time, it might not be possible to afford higher resolution although it could be useful to have higher resolution for southern ocean winds, for example.

On discussing the need for RCM-III, there was a suggestion that it could be important to attract atmospheric and land surface modelers to the workshop. Recognizing that Korea was the host of RCM-I and RCM-II and may also be a host of RCM-III, Dr. Foreman asked about modeling issues of greater interest to Korea? Dr. Chang re-iterated what Mr. Lim had said in his welcome address – that sea level rise and ecosystem change are the two issues of greatest interest to the Korean government. He suggested that RCM-III might focus on physical/biological coupling, although noted that no one in Korea is doing ocean/atmosphere coupling. Dr. Minobe proposed the idea of a workshop or session on regional climate modeling that might include the scientists working in the Atlantic, possibly in conjunction with the 3rd International Symposium on "*Effects of climate change on the world's oceans*" (March 23–27, 2015, Santos, Brazil).

Dr. McKinnell closed the workshop with some encouraging words on the need for, and value of, regional climate models. It is not uncommon to find that GCMs are not capturing variability at the scales that are of interest to scientists working at regional scales.

Dr. Kyung-Il Chang (kichang@snu.ac.kr) is an Associate Professor at the Seoul National University (SNU, Korea), working on various aspects of physical oceanography of the East Sea: deep circulation and currents, hydrography and currents in Korea Strait, and interaction of near-inertial waves with mesoscale eddies. In PICES, he has been a member of the Physical Oceanography Committee (POC) since 2006 and a member of the CREAMS/PICES Advisory Panel since 2009, and he is currently serving his second term as Chairman of POC.

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Dr. Chan Joo Jang (cjjang@kordi.re.kr) is a Research Scientist at the Korea Institute of Ocean Science and Technology (KIOST). His research interests include climate change analysis and modeling, observation and modeling for ocean turbulence mixing, and physical-biogeochemical couple models. In PICES, he co-chairs WG 29 on Regional Climate Modeling, and is a member of POC and WG 27.

Dr. Kelvin Richards (rkelvin@hawaii.edu) is a Professor at the Department of Oceanography and International Pacific Research Center, University of Hawai'i at Manoa. His research interests include ocean processes and dynamics, ocean/atmosphere interactions, and ecosystem dynamics. In the early 2000s he chaired the CLIVAR Pacific Panel and helped organize two PICES/CLIVAR workshops.

FUTURE OSM Session on "*Regional climate modeling in the North Pacific*"

by Enrique Curchitser and Chan Joo Jang

A one-day session exploring regional climate modeling in the North Pacific was convened on April 15, 2014, at the FUTURE Open Science Meeting (on the Big Island of Hawaii) to report progress made towards the goals of FUTURE science program. The session was an opportunity for members of the PICES Working Group on *Regional Climate Modeling* (WG 29) to summarize their activities and develop links to other FUTURE efforts.

The topic of regional climate models has generated interest in the PICES community since it recognizes the need to both explore the implications of the global IPCC-class models for PICES member countries and assess state-of-the-science techniques for downscaling global models. Regional downscaling—effectively running models with higher spatial resolution in target areas—of global models is a means of representing climate on time and space scales more appropriate for socio-economic and coastal ocean studies. WG 29 has been focusing on ocean processes and the implications to marine ecosystems.

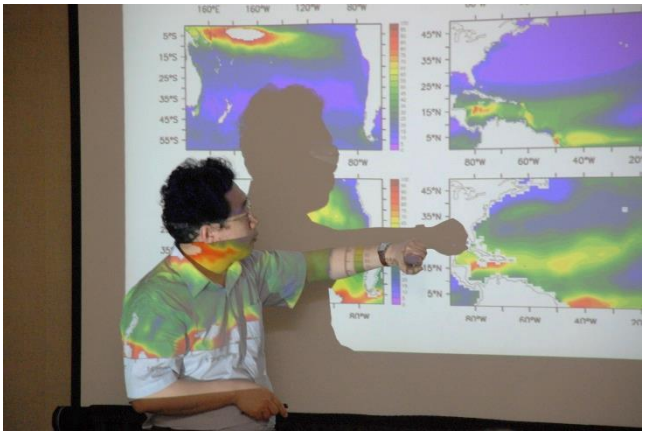
The session was co-convened by Drs. Enrique Curchitser (Rutgers University, USA) and Chan Joo Chang (KIOST, Korea) and had three invited speakers, Drs. Michael Foreman (Institute of Ocean Sciences, Canada), Arthur Miller (Scripps Institution of Oceanography, USA) and Takashi Mochizuki (JAMSTEC, Japan) and a total of 11 contributed papers. In the first invited presentation, given at the plenary session, Dr. Foreman described new techniques for downscaling climate projections for coastal, coupled physical–biological studies. The technique relies on bias correction of winds from global-scale future projections based on seasonal historical patterns. He demonstrated an application of this technique to the coast of British Columbia where both wind magnitude and direction are crucial to determining the patterns of coastal circulation.

Co-Convenor, Dr. Chan Joo Jang (KIOST, Korea), introducing the list of presentations for the theme session.

Dr. Miller presented results from a coupled ocean–atmosphere regional model of the Kuroshio Extension region, which is characterized by energetic oceanic eddies and fronts. He explored mechanisms for air–sea coupling of high-resolution components and highlighted the important role of the ocean in forcing the atmosphere on regional scales.

Dr. Mochizuki discussed the role of internal model variability to future projections using global models, in particular for the coming decades. He concluded that accurate initial and boundary conditions are essential for developing reliable decadal-scale climate projections.

Other abstracts in the session considered diverse topics and approaches: Downscaled projections of future climate in the California Current (Dr. Francisco Werner); the role of model resolution on the air–sea CO_2 exchange (Dr. Jerome Fiechter *et al.*); regional biogeochemical downscaling in coastal British Columbia (Dr. Angelica Peña *et al.*); ensemble regional predictions in the Bering Sea (Dr. Albert Hermann *et al.*); Dynamical downscaling of global models in the western Pacific (Dr. Chan Joo Jang); the role of a wave mixing parameterization in improving projections (Dr. Fangli Qiao) and a look at a global 1/10° model.



Dr. Fangli Qiao (First Institute of Oceanography, State Oceanic Administration, China) comparing mixed layer depths of two different oceans with and without wave effects.

Overall, the presentations can be categorized into three main topics: 1) additional value (*e.g.*, addressing known biases, coastal currents, *etc*.) derived from regional climate models, 2) regional projections of future climate and 3) applications of regional downscaling to ecosystem studies.

The main topic during the open discussion period focused on the question of what resolution is desirable in regional studies. The participants noted that the answer may depend

on the region and dynamics of interest. Furthermore, it may be necessary to adjust model resolution after an initial exploratory investigation. Another topic during the discussion was on the need and future of ensemble modeling in regional settings and the unique challenges that could emerge. Of note was the conversation on the expected number of ensemble members and the need for multi-model ensembles. Finally the participants discussed the topic of bias propagation from global to regional models and from physics to biogeochemistry. The discussion focused on ways to identify and quantify model biases in the different model components.

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Dr. Jang Joo Chan (cjjang@kiost.ac) has been a Principal Research Scientist in the Ocean Circulation and Climate Research Division of the Korea Institute of Ocean Science and Technology since 2011. His research interests include analysis and modeling of climate change in the North Pacific Ocean, focusing on Korean waters, circulation–ecosystem couple modeling, and turbulence modeling. He is a member of the PICES Physical Oceanography and Climate Committee, Working Group 27 on Climate Variability and Change in the North Pacific and co-chairs Working Group 29 on Regional Climate Modeling.

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