International Workshop on
Development and Application of Regional Climate Models

(Convenors: Kyung-Il Chang, Myron Peck, Michael Foreman)

Global oceans including the North Pacific and Atlantic Oceans together with their marginal seas have experienced pronounced climatic and environmental changes from the 20th century due to global warming and its associated thermodynamic consequences. Scientific understanding of these climate changes has advanced notably in recent years owing to the development of global climate models (GCMs). Current GCMs, however, have mainly been focused on simulating global climate features based on coarse horizontal and vertical grid resolutions. As a result, these models lack some key processes that occur at regional scales. Thus, it is important on the one hand to assess the performance of GCM products and to identify uncertainties for those regional key processes by comparing the model results with long-term observations. On the other hand, the development of regional climate models has become more and more important to fill the gap between the GCMs and the growing demand of climate predictions and scenarios on highly-resolved spatio-temporal scales, since the GCMs are usually not successful in doing such a job.

Regional ecosystem study based on numerical modeling is an emerging field. An international workshop on *Development and Application of Regional Climate Models* was held at the Mayfield Hotel, Seoul, Korea on October 11-12, 2011. This two-day workshop aimed to provide a platform to discuss various aspects of regional coupled or ocean climate modeling such as different approaches, downscaling, parameterizations, and coupling to the GCMs. It also encompassed the coupling of regional climate models (RCM) to ecosystem models. The workshop was co-sponsored by PICES, ICES, Research Institute of Oceanography/Seoul National University, and Ministry of Land, Transport and Maritime Affairs, Korea. Workshop conveners were Kyung-Il Chang (Korea, POC/PICES), Michael Foreman (Canada, POC/PICES), Chan Joo Jang (Korea, POC/PICES), Myron Peck (Germany, ICES), and Angelica Peña (Canada, BIO/PICES). About 65 marine scientists and postgraduate students from 8 countries (Canada, China, Germany, Japan, Korea, Norway, U.K., U.S.A.) participated in the workshop. Eighteen oral talks including those from 12 invited speakers, and 10 posters were presented. The workshop consisted of four scientific sessions: Global and Regional Coupled Models, Regional Ocean Projections, Analysis of Climate Models, and Ecosystem Modeling. The following provides the highlights of each of the oral presentations followed by a summary of the discussion section. A number of general recommendations emerged from this workshop and are listed in the final section.

SESSION 1
Global and Regional Coupled Models

Hiroyasu Hasumi – *Development of a coupled climate model with a two-way nested ocean component*

- Eddy resolution is needed to generate a realistic path and separation point of the Kuroshio Extension (KE)
- Nested ocean grids are effective to simulate critical current areas (only have 2 to 3 times increased cost as opposed to increasing total model resolution)
- Increased temperature suppressed meandering of KE
- Non-nested variance estimates were over-estimated (41% versus 21.5%)

Hyun-Suk Kang – *Global and regional climate projections based on the RCP emission scenarios for IPCC AR5*

- Only 3 figures in all of IPCC AR4 were based upon RCM or downscaled products
- Precipitation as well as evaporation need to be considered (soil moisture has decreased)
- Intense warming in the East Sea (critical to project changes in runoff and stratification)
- Lack of good boundary conditions is a problem

Tianjun Zhou – *Air-sea interaction and Northwestern summer monsoon variability: Comparison of AGCM & regional ocean-atmosphere coupled model simulations*

- 2 regional atmospheric and 2 ocean models (POM, LICOM)

- Warm and cold bias within the same model (POM)
- When threshold value (RH70) was used to suppress convection, agreement was much better
- Coupling atmospheric and oceanic models improved Pacific rainfall and wind field (anti-cyclonic circulation)
- This is likely a region-specific correction. Does one need far-field coupling?

Hyodae Seo – *Regional coupled downscaling: mesoscale air-sea interaction and regional climate change*
- In the equatorial Atlantic, large tropical instability waves (TIWs) influence SST (e.g., latitudinal troughs associated with 2.5°C SST differences)
- Eddy advection is important to the heat flux
- Enhanced current shears = stronger dynamic instability and TIWs (30% increase in eddy kinetic energy). Intensified eddy temperature advection
- GCMs might capture heat budget but lack critical processes (get the right result for the wrong reason)
- Upwelling requires a coupled ocean-atmosphere system to resolve dynamics
- There are pros and cons of downscaling GCMs that contain mean bias errors

SESSION II
Regional Ocean Projections

Bjorn Adlandsvik – *Dynamical downscaling of future climate in the Barents and North Seas*
- GCMs lack resolution needed for shelf seas (coastline, bathymetry, exchange of deep-water, river run-off, eddies, frontal zones and mixing)
- Sea ice is an important problem for GCMs and reason for downscaling
- Objective is to get "sufficient realism"
- Downscaling = added value (e.g., sea ice cover, hydrographic structure of the water column, and current dynamics such as inflow into North Sea were all better represented)

Cheo-Ho Kim – *Comparison of the sea surface height distribution in the different grid resolution circulation models*
- Realistic sea surface height needed to examine the potential effect of global warming on sea level rise
- Compared GCM 1°x1°, 110 yrs; GCM_ 0.5°x0.5°, 30 years; NP_0.5 (0.5°x0.5°) 100 yrs
- Different temporal evolution of SSH among high and low resolutions
- Realistic air-sea boundary layer is critical to apply for the convergence / divergence of water mass through the lateral boundary for the realistic simulation of SSH in the RCM
- Question was posed: Is it always better to use higher-resolution models?

Dong-Hoon Kim – *Steric and non-steric effect on sea level rise projections of the Northwestern Pacific Ocean*
- Previous simulations showed that CO_2 doubling increased SST by 1.5°C leading to a 10 cm increase in SSH from the steric effect
- Compared MIROC3.2H vs HADCM3, and 2 scenarios
- A1B gets 3°C and 35 cm SSH increase vs. 2°C and 25 cm in series B1
- The two model systems predicted differences of about 1°C and 10 cm SSH
- Spatial estimates differ for CM2.1 versus ReMOM (due to differences in water circulation patterns)
- Steric effect projected to be driver in some areas while non-steric effect predicted to be more important in other areas

Mike Foreman – *A regional climate model for the British Columbia continental shelf*
- Coarse resolution of the GCM cannot represent the spatial structure of temperature in this (and other) coastal region(s)
- Seasonality in river discharge water is critical and model-dependent feature
- GCMs predict area to be fresher and warmer in the future, but magnitude displays spatiotemporal variability

- Forcing with anomalies because projections are not trusted
- Upwelling is coming later than before but it is stronger when it occurs. Also, downwelling is stronger. Both timing and magnitudes are critical for production cycles

Enrique Curchitser – *Up- and down-scaling effects of upwelling in the California Current System*
- Upwelling areas are poorly described in GCMs
- There are local and remote climate effects of eastern boundary upwelling system
- If models are not run long enough, results may reflect only internal variance in the model results which are falsely interpreted as climate signals
- Avoid making projections that ignore feedbacks between regional and larger-scale models because each one is evolving different mean climates
- Coupled system has local, regional, and global scale consequences

Yang-Ki Cho – *Development of a regional ocean climate model for Northwest Pacific marginal seas*
- Simulation with ROMS (10 km grid, 20-z layers, daily wind forcing, and discharge of major rivers)
- Mean SST and STD compared well with observations of SST from satellites and in situ measurements
- The 100 year trends of SST in the East Sea from the regional model are similar (greater warming in north than in south) to those from a GCM, but the regional models has a weaker trend, particularly in northern areas of model domain

SESSION III
Analysis of Climate Models

Inkweon Bang – *Climate change in the Northwestern Pacific seen in CSEOF analysis of SRES A1B simulations of AR4 models*
- Simulations compared (2011-2100), 12 atmospheric variables, and 5 oceanic variables examined using cyclostationary EOF (mode detection)
- Analysis allows you to decompose the variance components and understand the processes of warming / climate signal coming from the model both spatially and temporally
- Oceanic variables including dynamic height and cyclonic and anti-cyclonic circulation cells associated with KE – strong westward flow (strengthening of extension), no change in the position

Chan Joo Jang – *Evaluation of regional ocean simulation from CMIP3 models: a case for the North Pacific Ocean mixed layer depth*
- Mixed layer depth (MLD) is expected to change with climate warming
- Decrease MLD in the KE is mainly due to decreased wind stress during the wintertime. Increased MLD in the Oyashio is created by a northward shift of KE
- South of KE, MLD (ensemble average) is 120 m too deep while it is ~ 40 meters too shallow to the north
- Taylor diagram indicates that phenology is OK, but the amplitude of seasonal changes is too small
- Resolution (Kuroshio too wide and too weak) – surface wind stress bias – western winds are too strong (estimates of MLD may improve when using higher resolution models)

SESSION IV
Ecosystem Modeling

Myron Peck – *New ICES PICES working group on integrative physical-biological and ecosystem modelling*
- Described movement towards establishing a working group to develop end-to-end models and apply biophysical models to practical management applications
- Topics to be addressed might include dynamic model coupling - feedbacks, effects of biology on physics, micro-, meso- to basin-scale issues

- Opportunity also exists to establish an ICES-PICES working group on Regional Climate Modelling and dynamic downscaling (likely via strategic initiative on climate change)
- Gave examples of current issues / challenges facing individual-based models for marine fish early life stages (illustrative of challenges facing many different models)

Icarus Allen – *Regionally downscaled climate modeling: physics to fisheries*
- ERSEM coupled model is a good example
- Variety of issues facing models of productivity of key ecosystem players
- Important feedback exists between physical and biological aspects and climate which are not well represented in many models
- Sources of model uncertainty change with time, particularly when scenarios are being used
- Devise skill assessment by removing physics from the system (e.g., using empirical relationships between chlorophyll and size-class)

Angelica Peña – *Development of a regional plankton ecosystem model for the Pacific coast of Canada*
- Complex dynamics between physical, chemical and biological processes
- Accurate hydrography is essential to capture features of primary and secondary production
- Response of ecosystem depends upon the physical forcing utilized. (e.g., very sensitive to differences in freshwater input, winds, tides and mixing scheme)
- Major (biological) issue is the ability to understand adaptive capacity of ecosystems that will require reliable estimates of physical processes that, over time, may gradually change

Corinna Schrum – *Climate change downscaling to marine ecosystems, lessons learned from exercises with AR4 and AR5 GCM scenarios*
- North Sea and Baltic Sea have very different physical processes (e.g., exchange times of 0.3 versus 30 yrs)
- Wind field and shortwave radiation had largest effects on primary production estimates
- Re-analysis data and climate models have large differences in the wind speeds (nearly a factor of 2). All climate models tested predicted region to be significantly wetter
- The ability to change the variability in forcing is also a topic that needs to be addressed (weakness, you lack the dynamic consistency)
- Nutrient dynamics very important to consider (only included in the earth system models)

SESSION V

Wrap-up and Recommendations

Current Challenges Facing Regional Climate Modelling

Spatio-temporal differences in the sensitivity of different areas to climate warming exist and current GCM estimates are too coarse in coastal / shelf sea regions and too poor at high latitudes to provide robust estimates of future climate. For these, and other, reasons, downscaling of GCMs using RCMs will be necessary. There was a general consensus that, although developing regional coupled (atmosphere-ocean) model systems is very time-consuming, in many cases this will be required for proper treatment of climate system dynamics. This is particularly clear in near-coastal areas such as upwelling zones where most of ocean / fish productivity occurs.

Despite the ongoing development of GCMs with higher resolution, regional downscaling will be required. Benefits include:

i) a reduction of GCM biases
ii) the usefulness of downscaled products for ecosystem applications, and
iii) an ability to provide more highly resolved estimates needed for regional impact studies.

One opinion was expressed that regional downscaling cannot be avoided because, regardless of GCM spatial resolution, increasing computer power will be taken as an opportunity for increasing the resolution of existing regional models.

Assessing impacts on marine systems will require an amalgamation of both climate and anthropogenic drivers. Thus, scenario definition is critical. Some differences exist between AR4 and AR5 GHG emission scenarios. The choice of scenarios will depend upon the targets of the research – and targets may be unique to the audience with which one is working (e.g., the worst case scenario needed for risk assessments). Moreover, one may not need to use a range of scenarios but to merely prescribe different boundary conditions (e.g., different greenhouse gas concentrations).

Resolving the issues with physical (climate) models and choosing the correct scenarios to run is only part of the challenge facing environmental scientists charged with projecting climate effects on living marine resources and ecosystems. Bottom-up factors do not always control the system. In some cases, anthropogenic pressures such as fishing can be more important than bottom-up factors and must be incorporated alongside regionally downscaled climate estimates into biological models. There is a general need to separate "physics" and "biology" within coupled biophysical models to gain a better representation of key biological processes. When biological models are viewed in isolation, much can be learned by perturbing the systems – whether motivated by climate or not. This will lead to the development of more robust biological models that can link to physical / biogeochemical models and make use of regionally downscaled products.

Issues Emphasized by Workshop Participants

1) Climate drift can occur after some time within models due to numerical artefacts. There are ways to control it with spectral nudging, etc. The magnitude of the problem may vary for different models.
2) There should be a unified treatment of the dynamics between RCM and GCMs and the metrics needed for evaluating uncertainties in both modelling approaches. Uncertainty can be decomposed into different classes (internal variability, parameter uncertainty, scenario variability), all of which should be quantified (see Hawkins and Sutton, 2009 BAMS, 90 (8). pp. 1095-1107).
3) RCMs and GCMs should be analyzed for inherent differences in their parameterizations to test for potential mismatches prior to downscaling.
4) Two-way interactions allowing feedback between an RCM and GCM are needed (a uni-directional coupling from GCM to RCM is normal but not sufficient). Examples are up-welling and the potential impacts of clouds on GCM radiative forcing.
5) Land-ocean coupling is needed (freshwater discharge, nutrient and carbon fluxes). This is a large topic that was not sufficiently addressed in the talks.
6) For downscaling from GCMs with known biases in their projections, utilizing anomalies to present day simulations was thought to be a better approach. One pitfall discussed is that you are not capturing the variability by utilizing anomalies.
7) The ensemble approach is powerful – this can also include the choice of scenarios. How can this be addressed properly (particularly with regard to wind)?
8) Testing whether projected changes in the ocean are due to "real" climate effects or are these merely due to internal dynamics of the model may require that models are run for a very long periods of time (150 + years).

Future Prospects for Collaboration

A Strategic Initiative on Climate Change Effects on Marine Ecosystems is proposed for PICES and ICES. A group that focuses on regional downscaling could be formed under this umbrella. Care should be taken not to overlap with activities of other groups. A report was just submitted from PICES's Working Group on Evaluations of Climate Change Projections (WG-20) focusing on historical simulations and skill assessment of RCMs. A second ToR of WG-20 was the development of RCMs. There was support to create a new "parent group" for this type of activity. Both ICES and PICES are focusing on climate projections in marine ecosystems and RCMs will be needed for this. Prof. Chang can bring this forward to the PICES Science Board and Myron Peck will talk with the ICES SCICOM. Regional climate modelers are also encouraged to attend the new ICES Working Group on Integrative Physical-biological and Ecosystem Modelling (WGIPEM), particularly for discussions with End-to-End models dealing with future climate.

A question was posed as to whether this group would like to collaborate with CORDEX (Coordinated Regional Downscaling Experiment) – a world-wide effort to produce regionally downscaled atmospheric models. There is no ocean component in that effort (only the atmospheric component). Although there is a strong case for the need for an active ocean underneath the atmosphere, the CORDEX community may not be the easiest route towards creating such coupled models. There is a large community of meteorologists that would be willing to collaborate that may not be part of this established community. A second group that could be interested in these activities is CLIVAR. Its work is focused on global ocean models however they may be leveraged to fund some of the regional workshops.

After the Workshop

The PICES 2011 Annual Meeting followed the RCM Workshop beginning on October 14 in Khabarovsk, Russia. During the Annual Meeting, Drs. Enrique Curchitser and Michael Foreman, participants of the Workshop, prepared a proposal for a new working group on regional downscaling and Dr. Curchitser presented the proposal at the POC Meeting. A possible linkage with the new ICES working group (WGIPEM) was considered but since the theme of the WGIPEM is end-to-end modeling not regional downscaling of physical environments and low-trophic level ecosystems, it was decided not to pursue formal linkage. The POC Committee proposed the group to Science Board and Governing Council as the Working Group on Regional Climate Modeling (WG-29) (visit http://www.pices.int/members/working_groups/wg29.aspx for more details including membership).

Important issues included in the ToRs of WG-29 are: i) Assembling a comprehensive review of existing regional climate modeling efforts; ii) Assessing the requirements for regional ecosystem modeling studies (*e.g.*, how to downscale the biogeochemistry); iii) Continuing the development of RCM implementations in the North Pacific and its marginal seas; iv) Collaborating with other PICES expert groups such as the Working Group on North Pacific Climate Variability and Change (WG-27), the Section on Climate Change Effects on Marine Ecosystems (S-CCME), and the FUTURE Advisory Panels possibly by producing "Outlooks", and also establishing connections between PICES and climate organizations (*e.g.*, CLIVAR) and global climate modeling centers (*e.g.*, NCAR, JAMSTEC, CCCMA). Within ICES, S-CCME is known as SICCME, the Strategic Initiative on Climate Change Effects on Marine Ecosystems.