The committee for the 12th International Regional Spectral Model (RSM) Workshop drew its members from the National Centers for Environmental Prediction (NCEP), the U.S. Forest Service, Yonsei University, the Cooperative Institute for Climate and Satellites, the University of Tokyo, the Food and Agriculture Organization of the United Nations (FAO), Hokkaido University, The Florida State University, and Woods Hole Oceanographic Institution. Details of the workshop history since its first meeting in 1999 can be found online (at http://rsm-workshop.wikispaces.com).

The purpose of this workshop, as in past years, was to discuss the development and applications of the RSM, originally developed at NCEP. RSM has been used extensively in regional downscaling of coarse-resolution forecasts, analyses, and simulations: one of the hottest topics in atmospheric modeling. Since the NCEP global atmospheric model in the Global Forecast System (GFS) was implemented operationally in a horizontal resolution of about 12 km, RSM has become an important tool for regional applications. The workshop aimed to address issues related to nonhydrostatic modeling and the transition of RSM to the mesoscale.
For many years, John Roads and Masao Kanamitsu were two of the primary promoters of the International RSM Workshop. Sadly, John passed away on 21 June 2008 and Kana passed away during our previous RSM workshop on 17 August 2011. John and Kana worked together very closely at Scripps for many years.

The session dedicated to John Roads—attended by several family members, including his daughter Emily Roads Boele—presented reminiscences, anecdotes, and overviews of his science contributions and academic life. Arthur Miller (University of California, San Diego) related early days with Roads at SIO and described fun memories of traveling with Roads to interesting parts of the world. Thomas Reichler (University of Utah), a former graduate student of Roads, chronicled Roads’s journal publication record. He pointed out that Roads’s research output actually peaked during the last few years of his career. Soroosh Sorooshian (University of California, Irvine) followed up by describing Roads’s contribution to many international programs, such as the Global Energy and Water Cycle Experiment (GEWEX). With many heartwarming stories and wonderful pictures, Sorooshian also commented on Roads’s generous nature, which he observed while traveling with him to many underdeveloped countries. Steve Brenner (Bar-Ilan University, Ramat Gan, Israel) affirmed Roads’s warmth and humanity with stories from their days as fellow graduate students at the Massachusetts Institute of Technology (MIT). Brenner also spoke of Roads’s enthusiastic support for his regional climate project over the Mediterranean area. Dian Putrasahan, Roads’s last graduate student, told how Roads guided her through her regional climate model (RCM) products from impact modelers and practitioners in seasonal forecasts and climate change issues. Therefore, end users of RCM simulation results—who represent wildfire, agriculture, water resources, energy, and other sectors—were invited to participate. In additional to the usual presentations, one day was dedicated to commemorate John Roads and Masao Kanamitsu.

**OVERVIEW OF RSM DYNAMICS AND PHYSICS.** Henry Juang gave a brief overview of the workshop’s history and reviewed the dynamics aspect of spectral modeling. The concept of spectral computation, model equation discretization, and some common numerics for model stable integration were presented. The numerics include spectral horizontal diffusion, semi-implicit time scheme, and time filter. The scale representation in regional model through its domain and resolution was illustrated. A brief on future modeling for RSM was presented.

Songyou Hong presented lectures on physical processes in atmospheric models. The lectures included a fundamental concept regarding the subgrid-scale representation of physics processes, and overviews on existing algorithms for radiation, land surface hydrology, turbulence, gravity wave drag, and precipitation processes.
**DYNAMIC DOWNSCALING.** Wednesday morning was focused on dynamic downscaling of coarse-resolution global climate model (GCM) output. Thomas Reichler (University of Utah) presented a new effort to simulate, understand, and predict changes in climate and water resources over mountains. The selected prototypical study region of this research is tropical South America with its high Andean Mountains and extreme gradients in topography. The study intends to downscale for the region the coarse-scale output from five different GCMs conducted in support of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change. The downscaling will utilize the Weather Research and Forecasting Model (WRF) coupled to a hydrological snow/glacier model. The coupled system will be used to perform decade-long high-resolution simulations at the 3–1-km scale. Reichler presented validation outcomes using Taylor diagrams and a large number of sensitivity experiments with different versions of WRF. Since the South and North American monsoon systems share many important features, the outcomes from this study are also expected to be relevant for the climate prediction problem over the mountainous western United States. The presentation by Hideki Kanamaru (FAO) cautioned against the improper use of downscaling climate model output. The users of such products are typically not part of the climate science community but rather belong to the impact assessment and adaptation community, and large amounts of funding are often provided to these communities. These users, however, are often not aware of the limitations, assumptions, and uncertainties that are inherent in downscaled products. Users therefore tend to overinterpret the outcomes from the regional models. Kanamaru concluded that stronger linkages between climate scientists and other communities are needed to better guide nonexperts in the use of downscaled data. Hideki further proposed to consider alternate methods to dynamical downscaling such as statistical approaches. Such methods could then be used to further test the robustness of the different outcomes.

**NUMERICAL MODELING.** Presentations on numerical methods were emphasized on Wednesday afternoon. Takeshi Enomoto (Kyoto University) compared two similar but distinct nonhydrostatic formulations based on the hydrostatic pressure by Laprise (1992) and Juang (1992). The differences exist in the definition of the geopotential used in the coordinate conversion. Laprise (1992) uses the full density to define the geopotential and Juang (1992) introduces the hydrostatic basic state. In the warm bubble experiment using MSM, results from both formulations are identical except for pressure perturbations. A hint of sound waves exists in Laprise’s formulation. In the cold bubble experiment, integration blows up quickly in Laprise’s formulation with the numerics of MSM. As an alternative to the prognostic hydrostatic temperature (Juang 2000), Enomoto proposed a spatial average of the full temperature as the hydrostatic temperature and applied it successfully in the warm and cold bubble experiments. Finally, he argued that the spectral transform method is still a viable approach in the nonhydrostatic regime and suggested options to convert GSM or MSM into a global nonhydrostatic model.

Henry Juang [National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction/Environmental...
Modeling Center (NOAA/NCEP/EMC) presented an improvement of NCEP GSM for horizontal resolution of O(1–10) km. Associated Legendre functions (ALF) have profound importance on the accuracy of the dynamical core of spectral transform models, since they are used in the spherical transform between the wave and physical spaces at each time step. ALF become less accurate as the truncation wavenumber becomes large because of underflow. Juang implemented extended-range arithmetic to compute associated Legendre functions in GSM to avoid the underflow. The more accurate ALF allow the use of large truncation wavenumbers above 2000. Experiments using the operational model show that the more accurate ALF improve the forecast skill. Although the earlier differences are very small, the differences grow over time to be nonnegligible. Enomoto commented on Juang’s presentation that the X number produces more accurate associate Legendre functions of very small values that are suited for parallelization, but the four-point recurrence is a few digits more accurate in the Legendre transform.

Dian Putrasahan (University of Miami) discussed mesoscale-coupled atmosphere–ocean dynamics in the Humboldt Current system and in the Kuroshio Extension region. A novel strategy was introduced to study the dependence of ocean–atmosphere coupling on various spatial scales through the implementation of a spatial smoother in a coupled framework. Putrasahan studied the spatial-scale dependence of surface wind response to mesoscale SST in the Kuroshio Extension region via two well-known mechanisms, the vertical mixing mechanism and the pressure adjustment mechanism. In the study, Putrasahan found significant coupling between SST, wind speed, and latent heat flux on the mesoscale and insignificant coupling on large-scale and full-scale modes, suggesting that the influence of mesoscale SST on latent heat flux is through both direct flux anomalies and indirectly through changes in the stability of the overlying atmosphere, which in turn affects the wind speeds and thus latent heat flux.

SEASONAL PREDICTION. Haiqin Li (The Florida State University) presented an analysis of the two-tiered Florida Climate Institute–Florida State University Seasonal Hindcast at 50 km (FISH50). Six ensemble members for each of the seasonal hindcasts were run for a 6-month period. FISH50 was initialized at two different times of the year: 1 June and 1 December of each year from 1982 to 2008. The unique aspect of FISH50 is its SST forcing. FISH50 used multimodel, monthly-mean forecasted SST from two coupled ocean–atmosphere models, which were bias corrected without using observations in the forecast period. The bias correction was done with a time-varying observed climatology that had the climate change signal and very low-frequency variations of SST prior to the forecast period. The time-varying CO2 concentration in the atmosphere was also applied to the seasonal hindcasts. The demonstrable improvement of predictability of zero lead and one season lead in FISH50 was shown in comparison with two other contemporary operational coupled ocean–atmosphere climate models from which the forecasted SST anomaly was borrowed. Li attributed the improvement in FISH50 to the relatively high resolution of the 50-km grid and the unique SST forcing used in the seasonal hindcasts. The probabilistic skill analysis shows that significant forecast skill can be harvested from these seasonal hindcasts relative to the deterministic skill analysis. Li concluded from this study that the coupled ocean–atmosphere seasonal hindcasts have reached a reasonable fidelity to exploit their SST anomaly forecasts to force such relatively higher-resolution two-tier prediction experiments to glean further seasonal prediction skill.

DOWNSCALING APPLICATION I. Bruce Anderson (Boston University) reviewed recent observational results indicating that over the course of the twentieth century there was a large-scale northward expansion of the summertime North American monsoon (NAM) precipitation deep into the interior of the western United States, suggesting that this region may serve as a “sentinel” region in which detectable trends in precipitation characteristics are already emerging from the envelope of interannual to decadal variability. Given the inability of global climate models to simulate many of the important rainfall-producing phenomena in this region, Anderson then highlighted that only through regional climate model experiments like those pioneered by John Roads would the community be able to diagnose and analyze the mesoscale, regional, and large-scale dynamic, thermodynamic, and hydrologic features of this northward expansion of the North American monsoon.

DOWNSCALING APPLICATION II. In this section, novel applications of G-RSM (e.g., isotopologues, data assimilation, downscaling at developing nations) were presented. Kei Yoshimura (Atmosphere
and Ocean Research Institute, University of Tokyo) presented a new trial of data assimilation with water vapor isotopologues (HDO and H$_2^{18}$O), which have recently begun to be measured by spectroscopic instruments on some satellites. The observing system simulation experiment (OSSE)-like experiment showed that the water vapor isotopologues have the potential to constrain not only themselves but also the meteorological variables. Nik Buenning (University of Southern California) presented that, with vapor tagging simulations, the modeled year-to-year changes in precipitation isotope ratios were also connected to variations in condensation height. The multiple influences complicate the interpretation of western U.S. climate proxies that are derived from the isotopic composition of precipitation. Mohan Das (Meteorological Research Centre, Bangladesh) presented the application of three-dimensional variational data assimilation (3DVAR) on their weather prediction. With the new radar network, the prediction skill was clearly improved. Finally, Abdoulaye Sarr (National Meteorological Agency of Senegal) presented the Coordinated Regional Climate Downscaling Experiment in Africa (CORDEX-Africa) activity and pointed out the global models’ performance over the area is still quite poor in some models. Finally, the entire group reached a conclusion to continue the RSM workshop once in two years, either by itself or along with other related conferences.

REFERENCES

