

Probing into the Workings of Climate with the IPRC Regional Climate Model

Introduction

General circulation models (GCMs) of the global atmosphere are a key tool for climate research. They represent atmospheric dynamics, physics, and chemistry with mathematical equations, which are then solved on a three-dimensional grid that spans the globe. Computer capabilities currently limit the grid resolutions in the global GCMs that are used to simulate Earth's climate and make warming predictions and that are integrated over several decades (such as those reviewed in the latest report by the Intergovernmental Panel on Climate Change). As a consequence, they have a longitudinal grid spacing of only about 300 km, which is insufficient to resolve many important features of the atmospheric circulation. To deal with this limitation, scientists are turning to regional atmospheric models. Covering a smaller region, the available computing power in such models can be applied to represent climate-related processes and their interactions with Earth's geographic and vegetation features in finer detail.

The IPRC Regional Climate Model

At the IPRC, scientists have developed the IPRC Regional Climate Model (IPRC-RegCM; Y.Wang, O. Sen, and B. Wang, see *IPRC Climate*, Vol. 1, Fall 2001). The model was originally designed for application to East Asia, a region where climate variability is extremely difficult to simulate. Dominated by the monsoon, the large-scale atmospheric circulation is driven mainly by the heat contrast between the Eurasian continent and the tropical ocean to the south, and as such, East Asian climate is a result of complex interactions between the tropics and the higher latitudes. Furthermore, its highly varied topography—the highest mountain range on Earth, land surfaces ranging from tropical forests to deserts, and extensive coastlines—affects climate in many different ways. Developed from a mesoscale tropical cyclone model (Wang 1999, 2001, 2002), the IPRC-RegCM now includes a mass-flux cumulus parameterization scheme, a sophisticated and accurate radiation scheme, and a biosphere-atmosphere transfer scheme for land-surface processes that allows the representation of complex atmospheric interactions with high mountains, coastlines, and vegetation covers. The model is run with a horizontal grid spacing of 25–50 km.

The model has been tested in seasonal simulations for the East Asian region using ECMWF data for initial conditions and (continuously updated) horizontal boundary conditions, and Reynolds SST data for the lower boundary condition over the ocean. The model has successfully simulated the 1998 summer monsoon season, realistically reproducing the area-averaged daily rainfall, the daily minimum and maximum air temperatures and their monthly mean geographic patterns, and the extreme flooding observed in China that year—the worst since 1955. It also captured the distribution of the frequency of occurrence of heavy daily rainfall (Figure 8), something that other models have failed to do (Y.Wang, O. Sen, and B. Wang). This is a necessary capability for a model that is to be used for studying the climate system's response to changes and fluctuations in the atmosphere, land, and ocean, and for assessing the impact of global change on regional climate.

Long-Term Goals

The long-term goal of the IPRC scientists is to develop a grid-point GCM into which the IPRC-RegCM is nested, with explicit two-way interaction between the global atmospheric and the regional atmospheric circulations. This approach is new compared with the current common strategy in which conditions in the GCM affect conditions in the regional model but not *vice versa*. The two-way approach has the advantage that improved regional-scale simulation can feed back into the global model, improving global simulation, which then, in turn, may improve the regional climate simulation.

To reach this stage in development, however, the IPRC-RegCM must first be used for, and tested, on diverse climate regimes. Below are two examples of how the IPRC scientists are applying the model to probe into the workings of climate.

Cold Meanders in the Equatorial Eastern Pacific

One investigation with the IPRC-RegCM studies the effects of meanders called tropical instability waves (TIWs). The TIWs travel along cold-warm SST fronts to the north and south of the cold tongue in the eastern tropical Pacific, have periods of about one month and wavelengths of around 1,000 km, and are stronger to the north than to the south of

the cold tongue (Figure 9a). They affect the thickness of the atmospheric boundary layer (the first 2 km or so above Earth's surface), which can be as much as 500 meters lower over the cold water than over the warm water, resulting in large atmospheric pressure differences.

The surface winds are notably weaker on the cold tongue and the cold meanders. This is shown more clearly in the observed regression coefficients of SST and wind vector onto a TIW index (Figure 9b). Anomalous high southeasterly trade winds can be seen to occur over the warmer SSTs and weaker trade winds over the cold SSTs.

What physical mechanism is causing such an atmospheric response at these ocean fronts? One idea is that, as air crosses from cold to warm SST, the air becomes unstable and mixes. This leads to a more homogeneous air column over the warm water, resulting in more uniform temperatures and stronger winds there. Conversely, as warm air crosses from warm to cold SST, the air becomes stable, mixing is reduced, and the air becomes more stratified,

resulting in stronger wind shear that weakens the surface winds. Another idea is that similar temperature anomalies develop in the atmosphere as on the ocean surface and, as a hydrostatic response, low pressure develops over the warm SST and high pressure over the cold SST. The near-surface winds are then directed from high to low pressure regions and are strongest over the SST gradients.

Which of these mechanisms actually occurs? The IPRC model with its very good representation of mixing processes makes it ideal for looking at these possibilities. Model simulations (R.J. Small, S.-P. Xie, and Y. Wang) result in a near-surface wind response that is similar to observations (Figure 9c). Detailed analysis of these simulations suggests that both vertical mixing and pressure-gradient are important, and that horizontal advection by the mean flow plays a role. In the simulation, the surface-pressure anomalies lie downstream of the SST anomalies, and the pressure-driven wind is strongest over the warmest SST, just as the observations indicate.

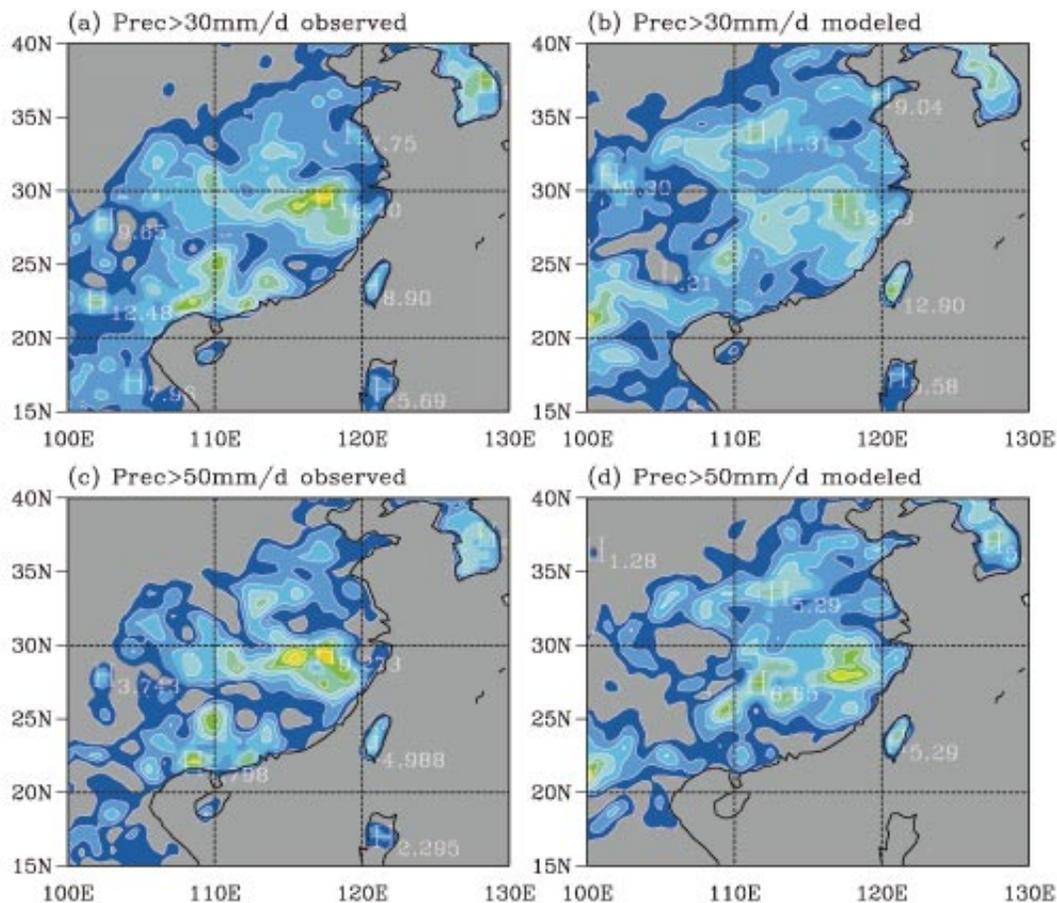


Figure 8: Observed (left) and modeled (right) distributions of frequency of occurrence (percentage of days in June 1998) of daily rainfall greater than 30 (top), and 50 (bottom) mm.

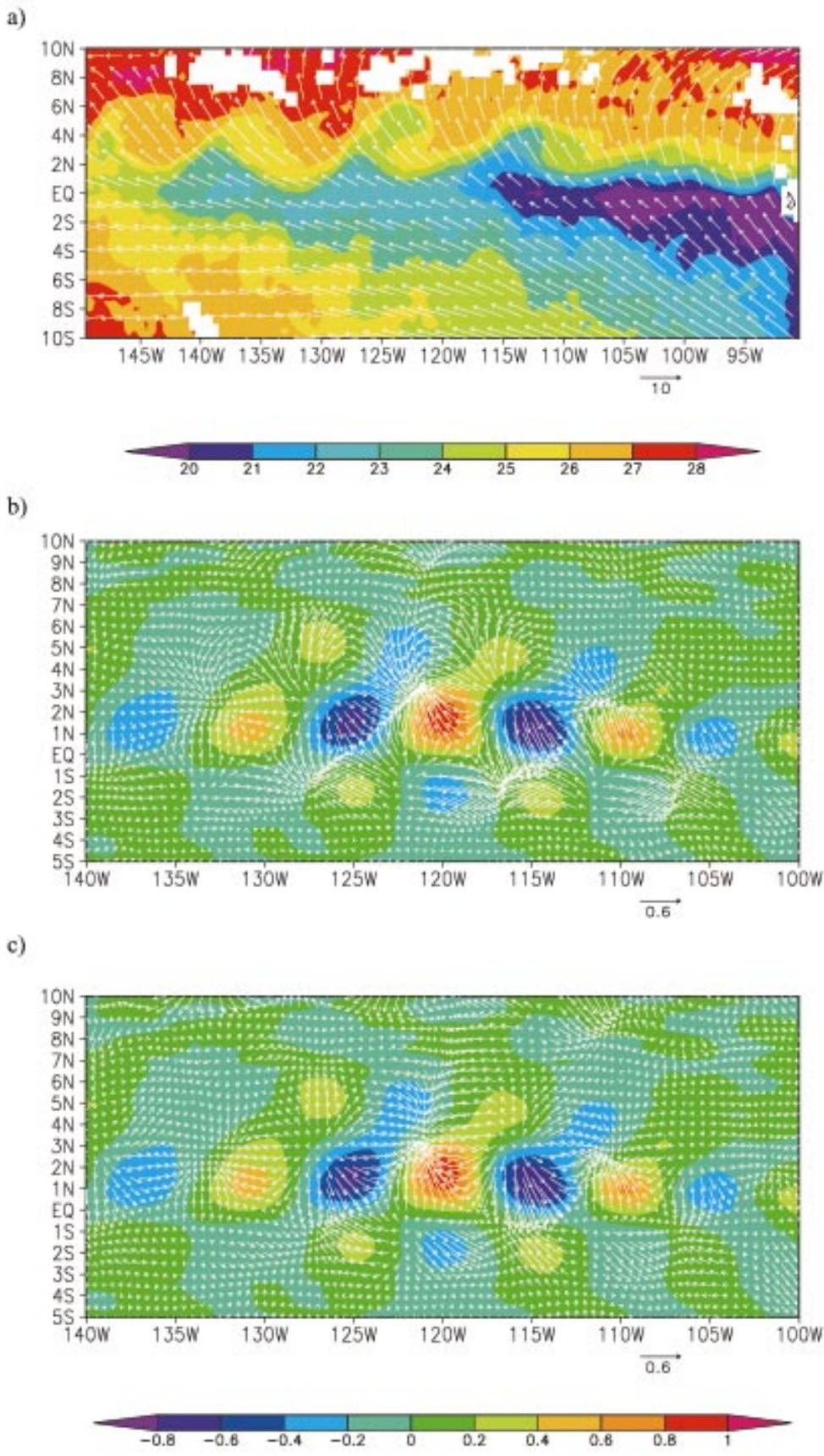


Figure 9: (a) SST variations (color; Tropical Rainfall Measuring Mission Microwave Imager measurements) associated with tropical instability waves (TIWs) and their effect on surface winds (vectors; QuikSCAT scatterometer measurements). White areas denote data gaps, which occur primarily in the ITCZ region due to precipitation. (b) Regression coefficients of observed SST and surface wind onto a TIW index. (c) Corresponding regression coefficients obtained from a run of the IPRC-RegCM. A comparison of (b) and (c) shows similar features, suggesting the model is capturing the appropriate boundary-layer response.

Deforestation and Rainfall Patterns

Although it is accepted that deforestation affects climate, its influence on the atmosphere is unclear: Are the effects local or global? Are they suppressed or enhanced by large-scale atmospheric circulation? Is rainfall increased or reduced? Indochina is of particular interest because the strong summer-time monsoon winds that flow over the peninsula may interact in unusual ways with different land-surface covers. Using the IPRC–RegCM, IPRC scientists are investigating how the recent deforestation in the region may have affected the monsoon flow, and what impact it may have downstream on rainfall over China, which can be plagued by both droughts and floods during the monsoon season (O. Sen, Y. Wang, and B. Wang).

Simulations with the model were run under two land-surface conditions: the current agricultural land cover and a forested cover. The experiment was conducted for the period of April through September of 1998—the summer of the severe flooding in China mentioned above. Results (based on the average of 5 ensemble runs for each condition) show that deforestation can have remote effects as well as local effects on climate, even appearing to modify the monsoon flow. The area downstream of the deforestation gets more rainfall in the model, whereas part of the area over and upstream of the deforestation gets less (Figure 10). The extent of the change in modeled rainfall, particularly in the area of deforestation, however, depends upon the strength of the monsoon. Next steps in understanding the workings of the region’s climate will be to investigate how the wind and rainfall changes that are seen in the present simulations are influenced by summers less wet than 1998, and then to determine the physical mechanisms responsible for the changes.

Conclusion

These are only two examples of how the IPRC–RegCM is being used to probe into the climate system, and some of the above findings are already useful in regional climate predictions. A wide range of similar experiments with the model is now either being conducted or planned at the IPRC. The experiments focus on understanding the mechanisms responsible for such widely different climate phenomena as intraseasonal oscillations in the tropical Indian and western Pacific Oceans and their role in gener-

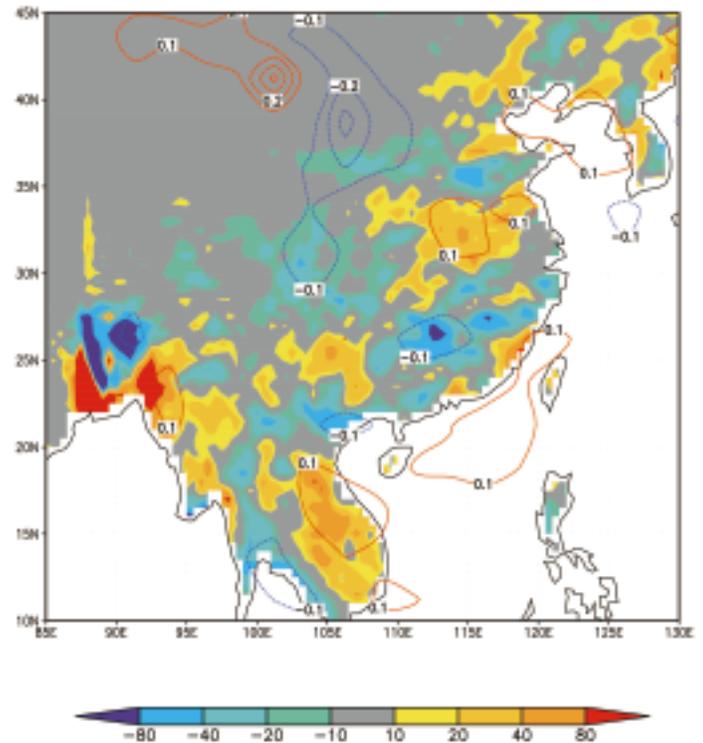


Figure 10: Differences in June-July-August 1998 Indochina rainfall between the current vegetation and a forested vegetation cover, as simulated with the IPRC–RegCM. Absolute differences in mm/month are shown in color, relative differences are represented by contours. Results are based on a 5-member ensemble simulation for each condition.

ating tropical cyclones, and events in the eastern Pacific that affect convective activity in the intertropical convergence zone. The climate picture that will emerge from these studies should significantly advance the quality of simulations in general circulation models and their global warming predictions.

The next issue of the *IPRC Climate* will report research with the IPRC–RegCM on the eastern Pacific atmosphere and ocean climate and how it is affected by the Andes.