Diagnosing the Climatology and Interannual Variability of North American Monsoon with the Regional Atmospheric Modeling System (RAMS): An Update

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Knowledge to Go Places

Introduction and Motivation

At last year's GAPP PIs meeting, preliminary results were shown using the Regional Atmospheric Modeling System (RAMS) for boreal summer simulations over North America. This included new developments to the RAMS model, presentation of large-scale teleconnection patterns related to Pacific sea surface temperature (ENSO and PDO), and a first look at how the model captures important features of the mean summer climate and interannual variability. Here we present an update of our ongoing analyses of these RAMS simulations.

Use of a regional climate model such as RAMS to study North American boreal summer weather has advantages over other approaches. General circulation models and atmospheric reanalyses have long records (on the order of 50 years) and contain large scale climate variability. However, because of their coarse resolution they poorly represent key details of summer climate such as the diurnal cycle of convection, the low-level jets that transport moisture into the continental interior, and the seasonal maximum in precipitation in western Mexico and the southwest U.S. due to the North American monsoon. Statistically based approaches can be used to determine spatial and temporal trends in surface data, like precipitation and temperature. Fine scale atmospheric data is necessary, however, to establish physical linkages to large-scale climate variability. In a regional modeling framework, we can pose two questions. First, does the regional model give a reasonable depiction of summer climate in North America and add value beyond that of a GCM? If so, then how does it represent interannual variability associated with variation in Pacific SSTs?

To investigate these questions two sets of RCM dynamical downscaling experiments were executed with the RAMS model for the summer season, with different lateral boundary forcing. The first set uses the NCEP-NCAR Reanalysis for the years 1950-2002 (53 years). The second set uses data from the NASA Seasonal to Interannual Prediction Project (NSIPP) GCM for a series of simulations executed with different Pacific SST conditions. For brevity, we focus our investigation to the downscaling results only using the observed years of the NCEP Reanalysis. Similar analysis on the NSIPP-RAMS simulations are in progress.

Figure 1: RAMS domain for North American Monsoon simulations.

RCM Experimental Design Recap

35 km grid spacing
Reynolds and Smith monthly SST
Simulation duration: 15 May to 31 August
Kain-Fritch cumulus parameterization interactive
with a dumpbucket scheme (no microphysics)
Heterogeneous initial soil moisture specified by
North American LDAS product and NCEP
global product.
Variable soil types according to FAO classification

RAMS Summer Precipitation Climatology

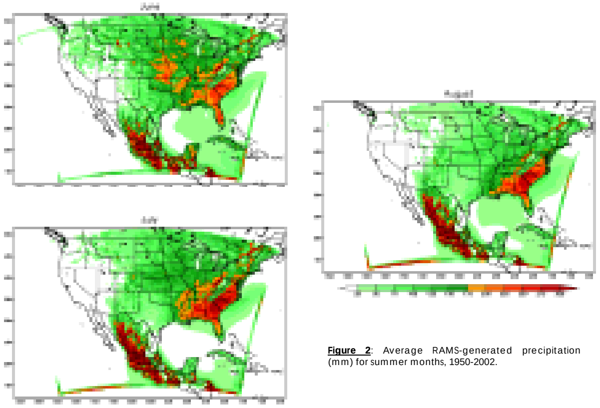

Figure 2: Average RAMS-generated precipitation (mm) for summer months, 1950-2002.

The evolution of the precipitation through the summer season is reasonable. There is a maximum in precipitation in the central U.S. in June and it is dry in the southwest U.S. and northwest Mexico (Sonora, Sinaloa, and Chihuahua) prior to NAMS onset. Development of the monsoon in July and August causes an increase in precipitation in the southwest U.S., northwest Mexico and southeast U.S., while the central U.S. becomes drier. The magnitude of precipitation is generally overestimated throughout the domain compared to NCEP observations (not shown), particularly in the southeast U.S.

RAMS Climatology of Moisture Flux and Moisture Flux Convergence

The RAMS-generated moisture flux (MF) and moisture flux convergence (MFC) are used as diagnostics to investigate the temporal variability. These variables were selected because they are directly related to rainfall via the water balance equation. Conventional Fourier analysis techniques are used to spectrally decompose both variables for the 30-day period about the date. Spectra are then averaged for the entire 53 years of simulation. Four distinct frequency bands were determined: a synoptic mode (4-10 days), a sub-synoptic mode (2-3 days), a semi-diurnal mode (1.5 days) and a diurnal mode (1 day). The spectral power was computed as the average of the power spectrum in the given frequency band. This quantity is then multiplied by the fraction of spectral power above the 95% confidence level in the band, with a value of zero meaning there is no statistically significant spectral power in the band and a value of one meaning all the spectral power in the band is significant. This weighting ensures that the most statistically significant features are emphasized.

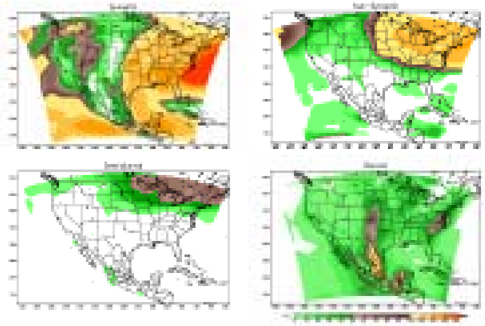

Figure 3: Average spectral power of RAMS MF of the defined frequency bands for the month of July. Shown is the spectral power multiplied by the percentage of the spectrum exceeding the 95% confidence interval in the band. Units of $kg^2\ m^2\ s^{-2}$.

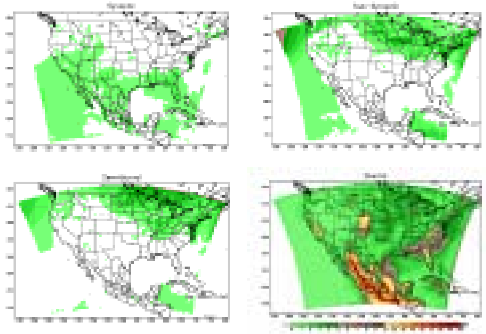

Figure 4: Same as Figure 3 for MFC. Units of $mm^2\ day^{-2}$.

Synoptic Mode: The Great Plains and Baja low-level jets (LLJ) have maximum power, though they are very different in magnitude These jets have connections to sources of tropical moisture, the Gulf of Mexico and Gulf of California, respectively. The variability of the Baja LLJ in this mode is due to gulf surge events, which is a principal mechanism for monsoon rainfall in the southwest US and northwest Mexico.

Sub-synoptic and Semidiurnal Modes: Variability at these timescales is due to fast-moving disturbances in the summer jet stream or from eastward-propagating convection which originates over the Rocky Mountains and organizes into mesoscale convective systems. This mode is important for rainfall in the Midwest and Northeast U.S.

Diurnal Mode: Not surprisingly, this mode is statistically significant almost everywhere and has greatest magnitude where terrain induced and/or sea-breeze circulations present. The largest amplitude in the diurnal cycle of MFC occurs where extreme terrain gradients are present near a warm body of water, such as in the Sierra Madre Occidental in western Mexico. In MF, note the diurnal component of the Great Plains LLJ in the central U.S. and a similar, but weaker, LLJ in the lee of the Appalachians.

Interannual Variability and Relationship to Pacific SST Modes

It has been established that time-evolving teleconnection patterns related to the first (ENSO) and second (PDO) modes of Pacific SST variability exist in early boreal summer and affect the continental distribution of rainfall (e.g. Castro et al. 2001). The 53 RAMS-simulated summers were classified according to their signature in Pacific SST in a manner similar to this earlier work. As an example, the subset of 14 positive PDO phase years is compared to the remaining 39 years. These positive PDO years exhibited the most statistically significant signal in observed and RAMS-generated precipitation. For the negative PDO years, the relationships for precipitation, MF, and MFC are approximately the reverse of what is shown here.

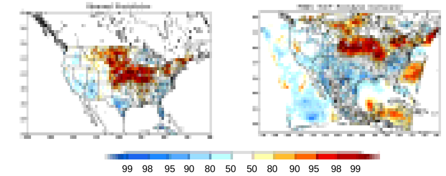

Figure 5: Observed and RAMS-simulated Precipitation differences (mm) for July between high PDO summers and the remainder of summers in the 1950-2002 record. Shading indicates statistical significance by a two-tailed t-test (percentage labeled in color bar).

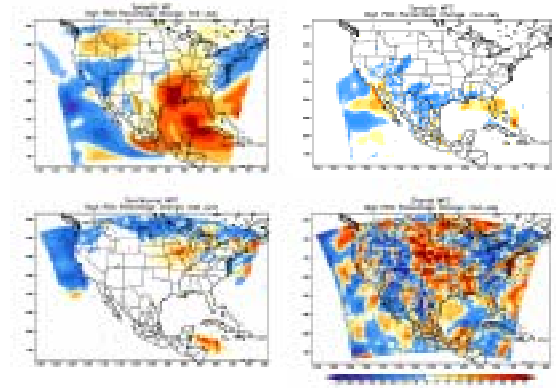

Figure 6: Percentage change in variance of MF and MFC in years with a positive PDO signal versus remaining years in the period 1950-2002. As in previous figures, the percentage change in variance is multiplied by the percentage of the climatological spectrum above the 95% confidence level. Note only selected modes and times shown that show the strongest and most spatially coherent signal.

The RAMS simulations reveal that the statistically significant differences in precipitation in early summer are directly related to interannual differences in MF and MFC. The timescale at which the difference is realized depends on geographic location. In the positive PDO years, for example:

Core NAMS Region (SW U.S. and NW Mexico)

A more stable environment inhibits the initiation of diurnal convection west of the continental divide. There is a reduction in the strength of the Baja LLJ due to less intense and less frequent gulf surge events. The decreased moisture transport at synoptic timescales inhibits the development of westward propagating MCSs that originate on the Mogollon Rim or SMO.

Great Plains and Midwest

Enhanced transport of moisture by the Great Plains LLJ and a more convectively unstable environment intensifies strength of diurnal convection east of the continental divide. This stronger convection is more likely to organize into longer-lived MCSs that affect the Midwest.

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