The North American Monsoon Model Assessment Project (NAMAP):

Integrating numerical modeling into a field-based process study

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Improved warm season precipitation forecasts are of tremendous interest and value, especially in areas where water is relatively scarce such as southwestern North America. However climate prediction skill of warm season anomalies is currently very limited. The international North American Monsoon Experiment (NAME) was organized to improve understanding and prediction skill of warm season precipitation fluctuations in the monsoonal region of southwest North America. Investigators carried out enhanced observations in the heart of the North American Monsoon System (NAMS) during the NAME field campaign in summer 2004 .

To achieve its goals,[1] NAME will need to improve numerical simulations of the monsoon circulation and its large-scale effects. The project's activities over the next few years are aimed at delivering models capable of forecasting the evolution of warm season climate anomalies months to seasons in advance. NAME employs a tiered approach of monitoring, diagnostics, and modeling in the heart of the monsoon region, on the regional scale, and on the continental scale, defined as Tiers I, II and III respectively (Fig. 1). A driving hypothesis of NAME is that improved large-scale numerical simulations depend on the proper characterization of relatively small (spatial and temporal) scale climatic variability, especially the diurnal cycle, in the core of the continental monsoon precipitation maximum in northwestern Mexico.

Although the emphasis of NAME, like many climate process studies, is to improve dynamical models, it has typically been a challenge to engage the modeling community in advance of a major field campaign. We addressed this challenge with the NAME Model Assessment Project or NAMAP, which was designed to evaluate the state of the art of warm season climate modeling before the field campaign. For NAMAP, six groups independently carried out numerical simulations of a single summer across southwestern North America.

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[1] See the Science and Implementation Plan online at (http://www.cpc.ncep.noaa.gov/products/precip/ monsoon/NAME.html). Additional details of the NAME modeling strategy are summarized in a white paper entitled "NAME Modeling and Data Assimilation: A Strategic Overview", which is available on the NAME webpage (http://www.joss.ucar.edu/name).

NAMAP was designed to provide benchmark simulations of warm season precipitation, and the physical processes that control precipitation, in Tiers I and II. Examination of the cross-model variability, together with comparison to available observations, provided motivation for enhanced observations in data-sparse areas during the NAME 2004 Enhanced Observing Period. A NOAA/NCEP Atlas[2] documents the performance of the six NAMAP models in simulating several of the key variables--precipitation, surface air temperature and fluxes, and low-level winds and moisture transport--with emphasis on the diurnal cycle. These simulations can be also used by the research community to plan model sensitivity studies. In fact, the success of NAMAP will ultimately be revealed by the diversity and quality of follow-on modeling studies that can derive motivation from this organized effort.

MODELING METHODOLOGY. NAMAP was designed to assess a wide range of dynamical models with very different spatial and temporal resolutions, computational domains and physical parameterizations. Other than a common ocean surface temperature prescription, little effort was made to constrain the selection of parameterizations and other boundary conditions in the individual runs. Because of these differences, the six NAMAP simulations are not suitable for determining a "best" model and should not be interpreted for this purpose -- NAMAP is an "Assessment Project" and definitely not an "Intercomparison Project" with more tightly constrained protocols for boundary conditions.

The most fundamental distinction in model characteristics (Table 1) is between the four regional models and the two global models. The regional models are strongly forced by time varying analyzed fields around the lateral boundaries of their computational domain. No such lateral atmospheric forcing is imposed on the global models, which are forced only by prescribed lower

[2] Online at http://www.cpc.ncep.noaa.gov/research_papers/ ncep_cpc_atlas/11/index.html

boundary conditions. The regional models are therefore much more strongly constrained by the continual imposition of "correct" large-scale dynamical features at the lateral boundaries.

The NAMAP regional model simulations were run with significantly different configurations. Five simulations are continuous runs beginning with springtime initial conditions, while one is a succession of 24-36 hr forecasts reinitialized each day. The latter simulation was not notably closer to observations than the free-running simulations, suggesting that model drift is not the principal reason for apparent deficiencies in the simulations. Different land surface conditions, convection schemes and boundary layer parameterizations are employed. The lack of common specification of model physics and continental lower boundary conditions potentially allows considerable inter-model variability in precipitation and land surface fluxes, and indeed the comparative analysis of the model output shows such variability.[3]

The year 1990 was chosen for simulation because NAMS precipitation was unusually intense that year. In addition, the SWAMP 1990 field campaign occurred that year, providing some published analyses and model simulations for reference. Time-varying ocean surface temperatures were the only 1990-specific boundary condition for the global models.

SIMULATIONS OF PRECIPITATION. The analysis described in the NAMAP Atlas includes discussion of monthly mean precipitation, temperature, low-level wind, and surface flux fields, archived to preserve the monthly mean diurnal cycle. We present a very small sample of these results, focusing on the monthly and diurnal fluctuations of precipitation in the heart of the NAMS domain.

Observations indicate that interannual variability of North American monsoon continental precipitation reaches its maximum in the CORE index region. When comparing model results (such

[3] Output files for the NAMAP runs are freely available online. See (http://www.joss.ucar.edu/name/namap/index.html) for modeling protocols, brief descriptions of each model, and an online order form for obtaining output via anonymous ftp.

as Figs. 3 and 4) with observations, it must be kept in mind that these observations are highly smoothed and contain large spatial gaps between raingauges. The set of observed precipitation maps in Fig. 2 describes a relatively typical monthly monsoonal evolution, although in 1990 the amplitudes of precipitation are unusually high.

The NAMAP analysis showed that current models are capable of simulating the basic evolution of a summer season precipitation maximum near the observed continental core of the North American monsoon (NAME Tier 1, as shown in Fig. 1). There are, however, important differences in the monthly evolution and diurnal cycle of precipitation generated by the models. All four regional models, including the model shown as an example in Fig. 3 (corresponding to the dark blue line in Fig. 5; this simulation produced monthly total precipitation closest to the CORE region raingauge observations), reproduce the July seasonal precipitation maximum across northwest Mexico shown in Fig. 2. The region of maximum precipitation is more heavily and tightly concentrated in the high topography of the CORE monsoon region in the regional models than the coarsely gridded observational estimates. In July all models exhibit a sharp increase in continental precipitation relative to June. Two of the regional models, including the model represented in Fig. 3, unrealistically produce no significant precipitation west of 112°W in any of the summer months.

The seasonal evolution of precipitation in the two global models (e.g. Fig. 4, corresponding to the light blue line in Fig. 5; this was the wetter of the two global simulations in the CORE region) is significantly different. Both global models show increases from July to August in precipitation across northern Mexico and the southwestern U.S., as precipitation spreads northward throughout the summer. Furthermore both global models generate no significant precipitation west of 112°W, effectively delaying the onset of the monsoon relative to observations.

The four regional models (which are provided observed lateral boundary conditions outside Tier II) all reproduce the observed July 1990 maximum in the CORE region quite distinctly (Fig. 5). However both global models produce peak precipitation in August in the CORE region. The monthly mean resolution of the NAMAP output makes this time lag impossible to quantify precisely, but the onset date is well-defined with the existing observational precipitation data set so there is little doubt that the delayed onset is a genuine deficiency in the global model simulations. Precipitation is markedly less in May and September (not shown) than in the three summer months in all models plus the observations, confirming that the models do reproduce the summer season monsoonal maximum.

The diurnal cycle of precipitation unmistakably indicates the convective nature of monsoonal precipitation. It is apparent from the comparison of model precipitation output that the interaction of convection with topography is handled very differently in the various models. Precipitation in most models exhibits similar diurnal phasing from month to month, but model-to-model differences are quite significant. The two wettest regional models (orange and red lines in Fig. 5) both simulate significant nocturnal precipitation (between 0300Z and 1200Z). Their diurnal cycles increase in amplitude with nearly unchanged phase from June through August. In contrast the global model corresponding to Fig. 4 (light blue line) produces the sharpest and earliest (2100Z) afternoon diurnal maximum, and almost no nocturnal precipitation. One of the driest regional models (green line) exhibits a striking change in the shape of the diurnal cycle from month to month: its observed decrease in total precipitation from July to August occurs entirely as the result of diminished nocturnal precipitation, considering that the late afternoon (0000Z-0003Z) diurnal peak has the same amplitude and phase in the two months.

More detailed diagnosis that could lead to model improvements will require improved observational data, in order to determine more confidently how close each model simulation is to the actual spatial average of precipitation. Simulation of intense convective precipitation in regions of extremely complicated terrain poses an exceptional challenge to these dynamical models, and improvements in convective parameterizations are a fundamental prerequisite to enhancing climate prediction skill in the NAMS domain.

It is also clear from the results in Fig. 5 that the late afternoon convective peak is not the only issue that models need to address. The substantial differences in nocturnal precipitation suggests that systematic propagation of convective systems is occurring to varying degrees in the model simulations, and that different model physics and dynamical schemes are generating a transition to resolved precipitation in various ways. This issue could be addressed in more detail with other NAMAP data sets, especially with better observational data from the 2004 field campaign to establish ground truth.

GOALS FOR AN IMPROVED OBSERVATIONAL DATA BASE. Some of the pronounced inter-model differences seen in the NAMAP analysis cannot be properly assessed with the existing observational data base. At present, observational uncertainties in many surface variables, including precipitation and turbulent fluxes, are very large across the continental North American monsoon region. The NAME 2004 field campaign will yield improved observations that can help to constrain the model results. A broad set of observational recommendations are presented in the NAMAP Atlas; among these are the following recommendations to help reduce model precipitation uncertainties:

- In situ and radar estimates of precipitation should include high-quality large-scale spatial averages over at least a few selected areas. The CORE and AZNM regions highlighted in this modeling study would be among the good candidate areas for such estimates, considering the focus on these regions in several previous observational papers. The NAMAP archive allows retrospective analysis of any region within NAME Tier I.

- The diurnal cycle of precipitation varies widely among the different NAMAP models. Radar-based and in situ precipitation measurements should quantify both the magnitude of the convective peak in precipitation rate and any nocturnal precipitation following the convection (if indeed the lower rates of precipitation following the convective peak in the NAMAP models are related to antecedent deep convection).

METRICS FOR MODEL IMPROVEMENT. The NAMAP analysis motivated metrics to quantify model simulation quality and improvement. The following precipitation metrics were proposed as targets for model simulation.

- *Monsoon onset:* Global models exhibit delayed monsoon onset in the NAMAP simulations. A plausible goal for all models would be to simulate the initiation of regular deep convection (i.e. monsoon onset) within a week of its observed initiation. It is possible that improved specification of SST, especially in the Gulf of California, could significantly affect monsoon onset simulations.
- *Afternoon precipitation maximum:* The models should seek to reproduce the full diurnal cycle of observed precipitation over the special averaging areas called for above. A goal of matching well-constrained monthly mean observations to within 20% throughout the diurnal cycle presents a stiff challenge.
- *Nocturnal precipitation:* Simulate the observed extent and propagation of convective systems throughout the night, including lower precipitation rates that may be associated with nonconvective precipitation. Observations taken along transects defined by the NAME event-logging precipitation network, enhanced by radar observations, could provide the validation data required to address this issue.

The NAMAP Atlas outlines other primary metrics for model improvement pertaining to moisture transport and large-scale circulation across the NAMS domain.

A MODELING ROADMAP FOR NAME. The NAMAP simulations have clarified many of the principal modeling challenges that need to be addressed in NAME. All of the groups that participated are already following NAMAP with model sensitivity experiments. An intensive research effort focusing on the diurnal cycle of precipitation simulated in global models is underway. The enhanced observations gathered during the NAME 2004 field campaign will be used to test the large-scale impacts of assimilating much-improved estimates of atmospheric circulation and precipitation across NAME Tier I. Experimental predictions will test the relative importance of oceanic and continental boundary conditions on simulations of the monsoon. The influence of model resolution and sensitivity on various configurations of the model physics, especially convective parameterizations, will be examined in global and regional models, including those at the operational centers.

The analysis of the NAMAP output fields necessarily addressed a very limited number of issues with a small subset of the NAMAP archive. Many other fields are available for analysis and could be used for other benchmark studies. The scope of the NAMAP analysis was deliberately limited to motivate further studies and to prepare the NAME community for the 2004 field campaign. Despite these limitations, NAMAP accomplished its primary goal of engaging the modeling community and integrating it into a major field campaign.

A new round of comparative model runs, NAMAP2, is now in the planning stage. The metrics outlined above will be revisited in NAMAP2 using improved versions of the same, and possibly additional, models to simulate the 2004 summer.

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For further reading:

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Table 1

NAMAP Participating Models

The NAMAP Atlas (available online at http://www.joss.ucar.edu/name) contains more complete technical information and references for these models.

Model name	Institution	Resolution	Computational Domain	Simulation Type
Regional Spectral Model (RSM)	NCEP	20km / L28	Regional	Free running
Regional Spectral Model (RSM)	Scripps Inst. of Oceanography	20km / L28	Regional	Reinitialized each day
MM5	University of New Mexico	15km / L23	Regional	Free running
Eta	NCEP	32km / L45	Regional	Free running
Spectral Forecast Model (SFM)	NCEP	2.5º / L28	Global	Free running
NASA Seasonal-Interannual Prediction Project Model (NSIPP)	NASA Goddard Space Flight Center	0.5º / L34	Global	Free running

Figure Captions

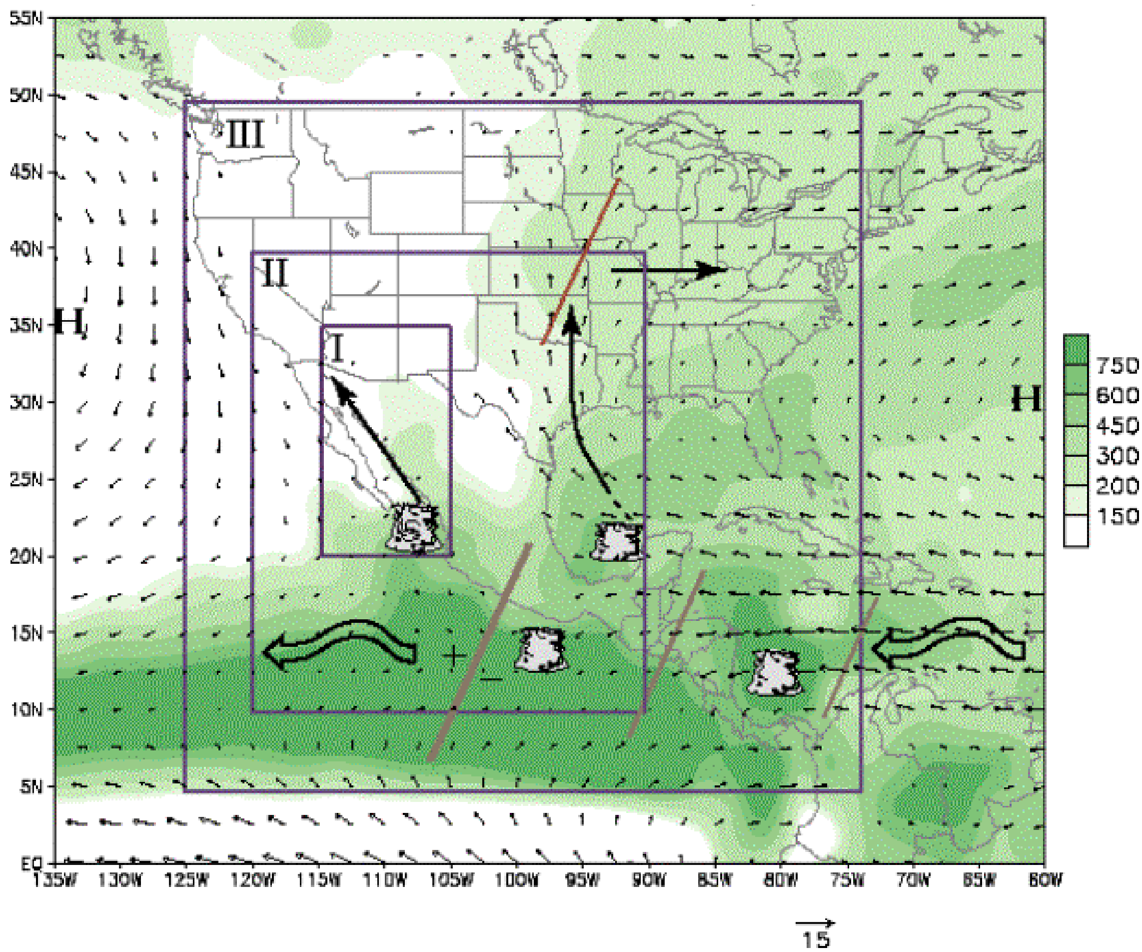
1. Schematic diagram of operational domains for the North American Monsoon Experiment. Green shading and gridded vectors represent Jul-Sep climatological precipitation [mm] and 925 hPa wind. Larger lines and vectors are schematic depictions of principal circulation features affecting the North American Monsoon domain (see the NAME Science Plan for details).

2. Observed total monthly precipitation over land [cm], calculated from the 1°×1° NCEP "Unified" Raingauge Dataset. Box denoted "CORE" shows the spatial subregion used for time series analysis in Fig. 5. (a) Jun 1990 (b) Jul 1990 (c) Aug 1990.

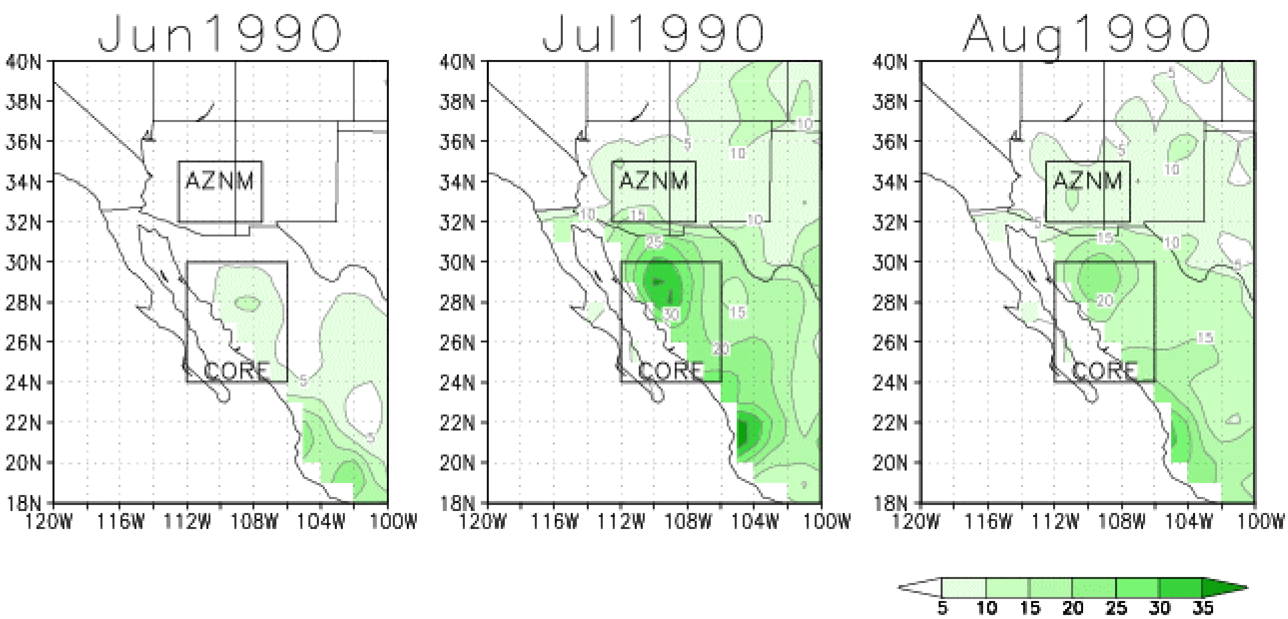
3. Like Fig. 2, but simulated by one of the regional models. Time series of monthly total precipitation for this model are shown as the dark blue line/squares in Fig. 5. (a) Jun 1990 (b) Jul 1990 (c) Aug 1990.

4. Like Fig. 2, but simulated by one of the global models. Time series of monthly total precipitation for this model are shown as the light blue line/circles in Fig. 5. (a) Jun 1990 (b) Jul 1990 (c) Aug 1990.

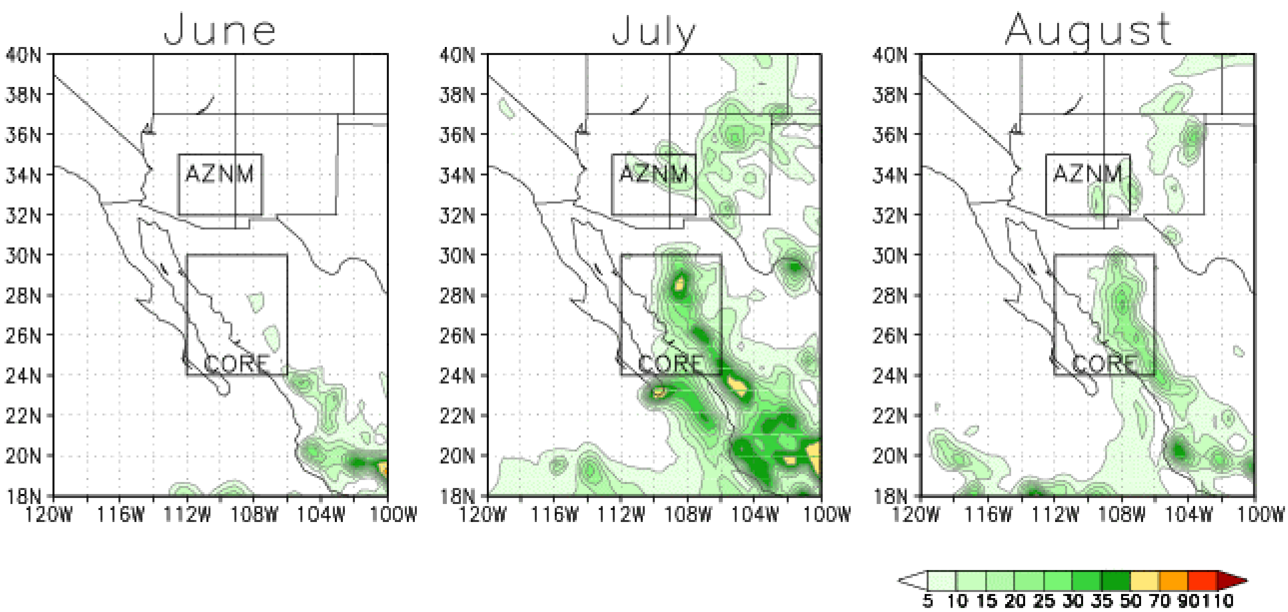
5. Monthly average diurnal cycle of total precipitation rate [mm/hr], CORE subregion, for (a) Jun 1990 (b) Jul 1990 (c) Aug 1990. Time is labelled on the abscissa in UTC. There are no comparable observed estimates of precipitation across this region. The two global models are represented by the light blue line/circles and black solid line/ squares. Yellow shading surrounding the black solid line shows $\pm 1\sigma$ envelope of variability of a ten-simulation ensemble.



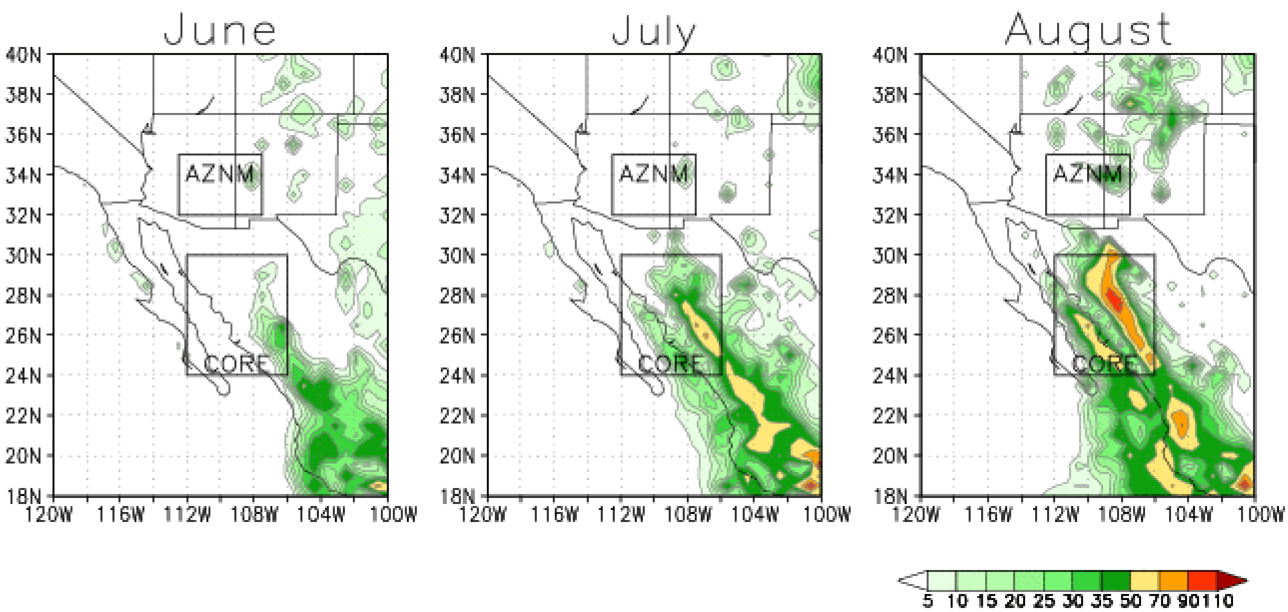
BAMS 1869/Gutzler
Figure 1



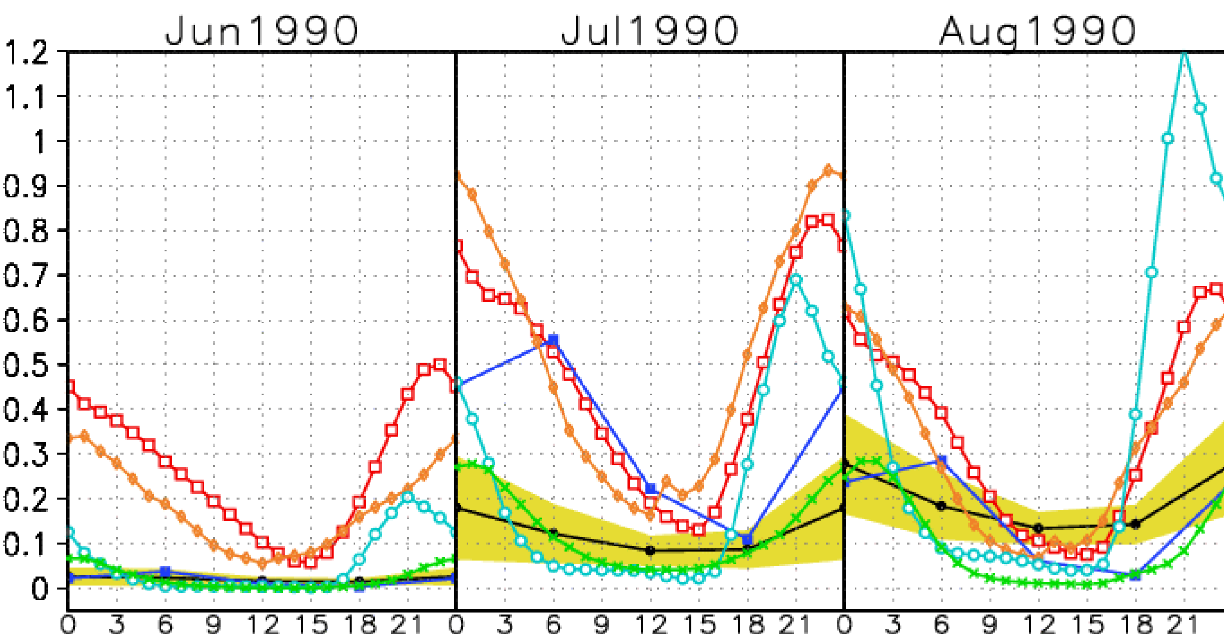
BAMS 1869/Gutzler
Figure 2



BAMS 1869/Gutzler
Figure 3



BAMS 1869/Gutzler
Figure 4



BAMS 1869/Gutzler
Figure 5