THE NAME 2004 FIELD CAMPAIGN AND MODELING STRATEGY

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An international team of scientists from the United States, Mexico, and Central America carried out a major field campaign during the summer of 2004 to develop improved North American monsoon precipitation forecasts.

THE NAME PROGRAM. The North American Monsoon Experiment is an internationally coordinated process study aimed at determining the sources and limits of predictability of warm-season precipitation over North America. NAME[1] seeks improved understanding of the key physical processes that must be parameterized for more realistic simulations and accurate predictions with coupled OAL

[1] All acronyms defined in Table 1.

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models. A fundamental first step toward improved prediction is the clear documentation of the major elements of the monsoon system and their variability within the context of the evolving OAL annual cycle.

NAME employs a multiscale (tiered) approach with focused monitoring, diagnostic, and modeling activities in the core monsoon region, on the regional- and continental-scale (Fig. 1). The NAME program is overseen and directed by an SWG that is charged with developing and leading the cooperative international research to achieve NAME objectives. Recently the SWG organized and implemented an international (United States, Mexico, Belize, Costa Rica), multiagency (NOAA, NASA, NSF, USDA, DOD) field campaign during the summer (June–September) of 2004. NAME 2004 was an unprecedented opportunity to gather an extensive set of atmospheric, oceanic, and land surface observations in the core region of the North American monsoon, which covers northwestern Mexico, southwestern United States, and adjacent oceanic areas. During the campaign, data were gathered from more than 20 different types of instrument platforms, including surface meteorological stations, radars, aircraft, research vessels, satellites, wind profilers, rawinsondes, and rain gauge networks. The campaign involved scientists from more than 30 universities, government laboratories, and federal agencies, including more than 30 weather forecasters. At least 15 U.S. National Weather Service/Weather Forecast Offices and 4 of the National Centers for Environmental Prediction (Hydrologic Prediction Center, the Tropical Prediction Center, the Storm Prediction Center, and Climate Prediction Center) participated in the campaign.

NAME 2004 produced immediate benefits, including enhanced (and sustained) observations for monitoring the monsoon, and a two-way exchange of information, technology, and training between NOAA/NWS and the Mexican National Weather Service (SMN). NAME empirical and modeling studies are leveraging the NAME 2004 data to accelerate improvements in warm-season precipitation forecasts, products, and applications over North America. A comprehensive NAME Web site (www.joss.ucar.edu/name) covers all aspects of the project, including a science and implementation plan (NAME Science Working Group 2004), data, and documentation.

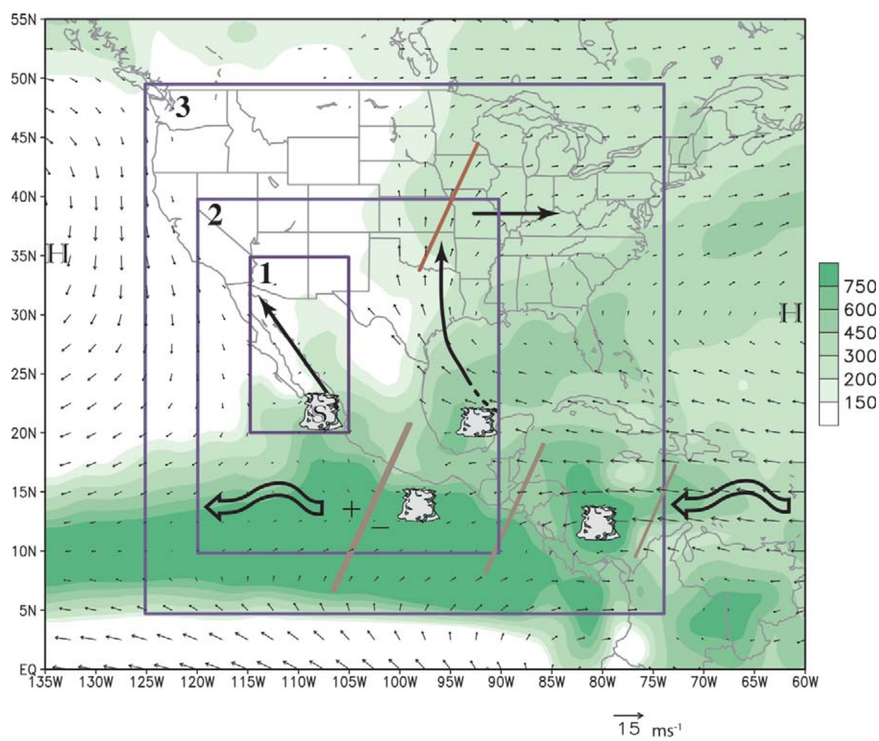

Fig. 1. Schematic illustrating the multitiered approach of NAME. The schematic also shows mean (July–September 1979–95) 925-hPa vector wind (m s^{-1}) and merged satellite estimates and rain gauge observations of precipitation (shading) in millimeters. Circulation data are taken from the NCEP–NCAR Reanalysis archive. The Gulf of California (Great Plains) low-level jet is indicated by the straight (curved) arrow in the GOC (southern plains). Schematic includes transient lines near 10°–15°N (40°N) to indicate westward (eastward) propagation of disturbances such as easterly waves (midlatitude fronts).

NAME 2004 FIELD CAMPAIGN. The NAME 2004 EOP occurred during June–September 2004, with IOPs during a six-week period (1 July–15 August 2004; Fig. 2). IOP missions included aircraft operations and enhanced frequency of observations at specified sites well beyond those required by the EOP; IOP mission summaries are available on the NAME Web site: www.joss.ucar.edu/name/catalog/missions.html. The IOP missions targeted the following scientific issues: the Gulf of California low-level jet and moisture surges, easterly wave and tropical cyclone influences, monsoon onset, and mesoscale convective systems. An important scientific consideration for these missions was how convective systems and regional circulations in the NAME tier-I domain vary over the diurnal cycle. As a consequence, NAME modeling activities (section 4) have a full suite of observations (subsurface to upper troposphere) with which to examine the modeled diurnal cycle.

The IOP days were selected in the field by the NAME Science Director during daily operations meetings held at the NAME Field Operations Center (located at the University of Arizona, Department of Atmospheric Science, Tucson, Arizona). The meetings included a review of the weather during the previous 24-h period, as well as forecasts for days 1, 2, 3–5, and 6–10, with specific emphasis on key synoptic and mesoscale features in NAME tiers I and II. The forecasts were made jointly by the NAME FOCs at the NWS Forecast Office in Tucson, Arizona, and at the SMN in Mexico City. Decisions were then communicated to the aircraft base of operations in Mazatlan, Mexico, and to the other observation sites. A timeline of the NAME 2004 daily operations and the implementation of NAME 2004 facilities is shown in Fig. 2.

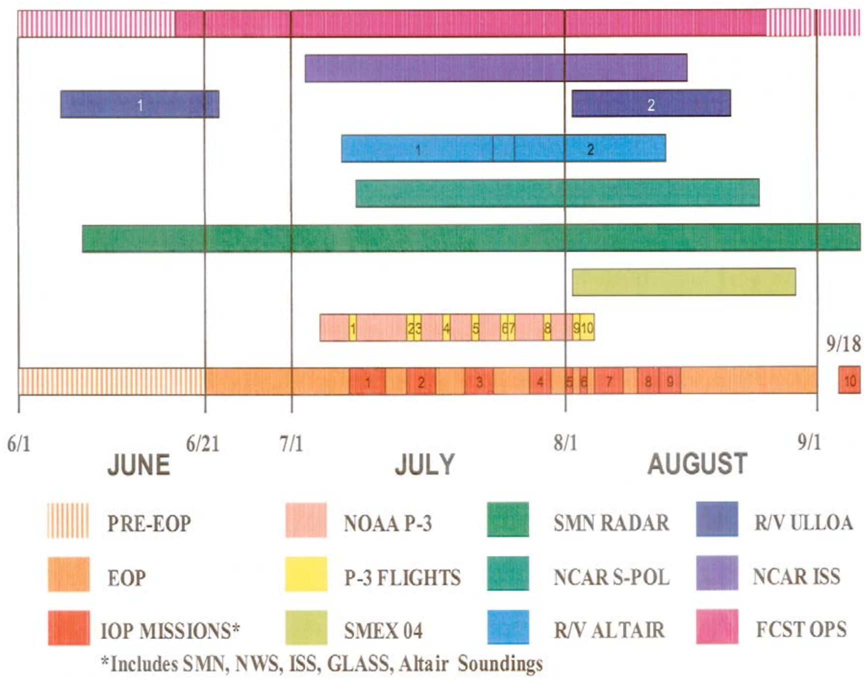

Fig. 2. Timelines for NAME 2004 facilities during June–September 2004. Hatching at the beginning and end of some bars indicates ramp-up and ramp-down periods. Numbers and red blocks on the EOP bar refer to IOP missions. Numbers and yellow blocks on the NOAA P-3 bar refer to P-3 missions. Numbers on the blue bars refer to Research Vessel cruises.

Nine IOPs were selected during the originally scheduled window of opportunity (1 July–15 August 2004). A tenth IOP was chosen during 17–20 September to capture the influence of Hurricane Javier on the core monsoon region. Ten research aircraft missions were flown between 7 July and 3 August, half of which occurred during five of the nine IOPs during this period (for a total of 80 flight hours).

Some enhanced monitoring activities (e.g., event-logging rain gauge network) began prior to the campaign, while others (e.g., simple rain gauge network) remained active after the campaign. An important aspect of the NAME program is to determine those observing systems that should be sustained for improved weather and climate prediction.

NAME 2004 FIELD OBSERVATIONS. NAME 2004 field instruments (Fig. 3) included wind profilers, radars, rawinsondes, research vessels, buoys, rain gauges, soil moisture sensors, and research aircraft.

Rain gauges and weather stations. While the general behavior of monsoon precipitation has been under investigation for many years, confident analysis of detailed spatial and temporal characteristics has been lacking due to deficiencies in the operational precipitation monitoring network. This deficiency was addressed, in part, during NAME 2004 using strategic augmentations of the operational gauge-based observing network. Complementing national networks operated by the NWS, the SMN, and the Mexican CNA, hundreds of new rain gauges were installed by NAME investigators in the tier-1 region to fill in data-sparse regions and to help ameliorate a low-elevation bias in the existing observing network (cf. Gochis et al. 2003, 2004). The variety of new gauge types included simple wedge gauges that record daily accumulations, event-logging tipping-bucket gauges, and sophisticated siphoning tipping-bucket gauges. Building on preliminary analyses from the NERN (blue stars in Fig. 3), which showed that summer rainfall tends to initiate over the high terrain early

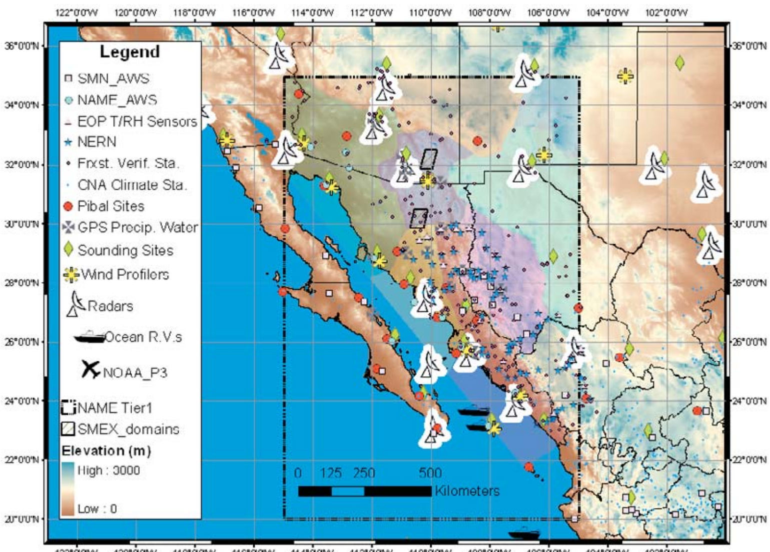

Fig. 3. Observing system enhancements for the NAME 2004 EOP.

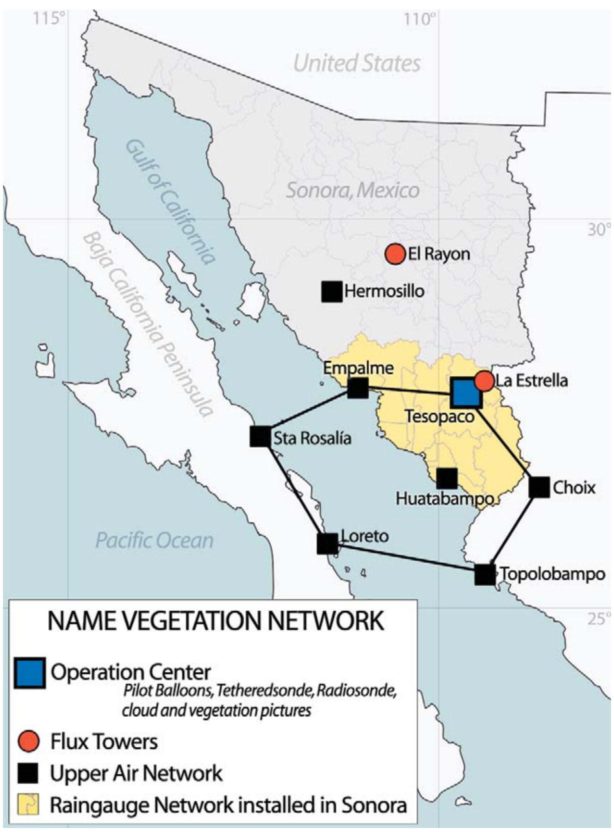

Fig. 4 NAME Vegetation Network showing the dry forest flux tower installation, the regional Pibal network, and the region where a special network of 250 simple rain gauges were installed. (Figure provided by Jose Galvez.)

in the afternoon and then propagate or reform toward the Gulf of California later in the evening, emphasis was placed on improving the sampling of precipitation within a transition region along the western slope of the Sierra Madre Occidental Mountains. A second special observing network was implemented during the 2004 EOP to measure this shift. A dense (~250 sites; see yellow-shaded region in Fig. 4) network of simple, daily accumulation rain gauges was installed over southern Sonora. As of this writing, more than 900 simple gauges have been installed along the GOC and across the desert regions in northern Sonora and Chihuahua (not shown) as a cooperative network to improve the regional sampling of precipitation; if the network continues to be successful, the SMN has agreed to take primary responsibility for data collection starting in 2006. Following quality control, data from all of the participating networks are to be merged and provided to the research community.

Atmospheric profiling. The NAME 2004 EOP atmospheric profiling program was aimed at gathering upper-air data to study the dynamic and thermodynamic structure and temporal variability of the troposphere in the core monsoon region, its relationship with large-scale systems, and the development of deep convection and rainfall in the region. The operational sounding systems of the southwestern United States and Mexico were enhanced to allow for an increased frequency of balloon launches (4 or 6 times per day depending on the site and IOP status) to better characterize the diurnal evolution of the troposphere. The enhanced operational soundings were augmented by additional soundings within the tier-I region conducted by NAME PIs, students and sponsoring agencies such as the Department of Defense at Yuma, Arizona, and the Salt River Project in Phoenix, Arizona (see Fig. 5 for the atmospheric profiling site). Enhanced operational soundings during IOPs were also made in the neighboring countries of Belize and Costa Rica and from the Research Vessel *Altair* (detailed below), which was moored at the southern entrance to the GOC.

During the EOP three NCAR ISSs and one GLASS were deployed along the GOC. An ISS consists of a Global Positioning System sounding system, a 915-MHz wind profiler, an RASS, and a surface meteorological station. The GLASS consists only of the GPS sounding system. The ISSs were located at Puerto Peñasco, Sonora; Bahia Kino, Sonora; and Los Mochis, Sinaloa, on the eastern side of the Gulf; and the GLASS at Loreto, Baja California Sur, to the west (Fig. 5). A 915-MHz wind profiler and sounding system were also placed on the RV *Altair* (Mexican Navy) in the mouth of the GOC (Fig. 3). The NOAA Environmental Technology Laboratory and Aeronomy Laboratory operated a meteorological supersite in Sinaloa, Mexico. The site included two wind profilers, a RASS, a laser ceilometer, a GPS integrated precipitable water vapor system, and a 10-m meteorological tower that sampled eight standard meteorological and radiation parameters. The NCAR systems operated from early July until mid-August and the NOAA ETL/AL system operated from early July through midSeptember. Combined, these systems successfully sampled monsoon onset, GOC low-level jets and moisture surges, the diurnal cycle of convection, land–sea breezes, influences of easterly waves and tropical cyclones, and upper-level inverted troughs.

In order to help characterize tropical variability on diurnal and subseasonal time scales over portions of the NAME tier-III region, NAME 2004 included an observing program in Costa Rica from 16 June to 5 September 2004. The main observing site was the Juan Santamaria International Airport (WMO 78762) and included, for the first time ever, 4-times-daily soundings to analyze the tropospheric diurnal cycle. Preliminary analyses have shown that the maximum zonal wind, characterized as the Caribbean low-level jet (Amador et al. 2003), occurs just below 700 hPa (near the top of the planetary boundary layer) and its intensity appears to be almost independent of the diurnal cycle.

Although the NAME rawinsonde network was much improved over the preexisting network, it was not spatially dense, so a network of pilot balloon stations was also established (Fig. 5) to provide twice-daily wind observations. In all, some 4000 pilot balloon observations were made over the period from 15 May to 30 September. The measurements sought to describe the seasonal change in the intensity of the land–sea-breeze circulations at sites both inland and along the coast of the GOC. The network also improved the specification of tropical waves propagating across central Mexico, described wind flow across Baja California, described heat low variability over the low deserts of Arizona, and captured intraseasonal wind field fluctuations. The sidebar (see next page) provides a preliminary look at the 2004 NAME EOP sounding data.

Aircraft operations. A NOAA WP-3D research aircraft was employed during the EOP in part to provide additional sounding coverage over open water bodies, such as the GOC. The WP-3D was deployed to Mazatlan, Mexico, from 6 July to 4 August (Fig. 2) and carried out 10 flights. The aircraft was flown almost entirely in porpoising mode (i.e., slowly varying vertical oscillations) between 300 and 3000 m AGL, with approximately 60 soundings per flight over 7 hours (e.g., Fig. 6). The altitudinal ranges of the porpoises were adjusted to sample desired features of interest. Most flights were intended to measure moisture flux into NAME tier I across southern Baja California, over the southern end of the GOC, and over the northern end of the GOC. However, there were additional objectives, such as flying nearly identical legs over the GOC on different days to provide better estimates of synoptic variability of the along-gulf moisture fluxes. Several flights were also dedicated to measuring the horizontal and vertical structure of the GOC low-level jet, measuring outflow associated with mesoscale convective systems, and describing the afternoon sea-breeze flow over the coasts of Sonora and Sinaloa.

Radar observations. A radar network, consisting of the NCAR S-Pol polarimetric Doppler radar near Mazatlan, Sinaloa, and two upgraded SMN Doppler radars in Guasave, Sinaloa, and Los Cabos, Baja

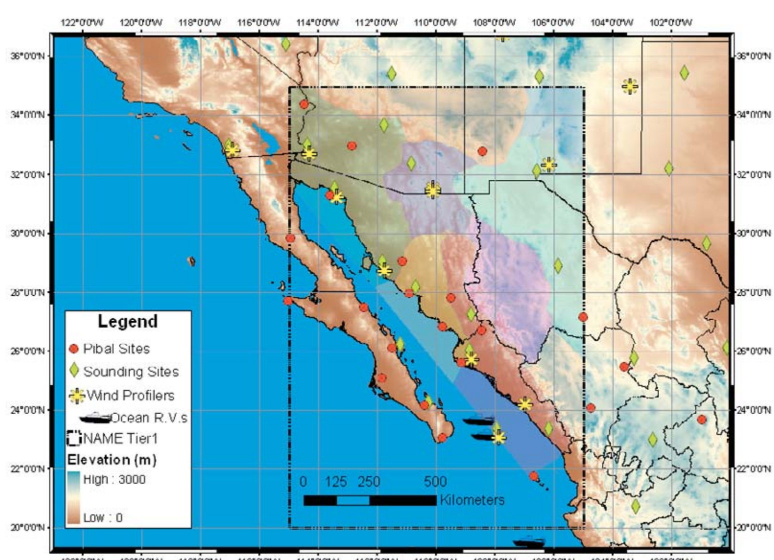

Fig. 5. Upper-air network during the 2004 NAME EOP. Shading indicates the nine zones used in NAME practice forecast exercises during 2003 and 2004.

PRELIMINARY LOOK AT NAME IOP-2 SOUNDING DATA

A major influx of moisture into the southwestern United States occurred during NAME IOP-2 (12–15 July 2004) in association with the passage of Tropical Storm Blas to the south of tier I (Fig. SB1). This storm produced several significant changes over tier I. First, it altered the midlevel flow over the GOC from southeasterly to easterly, thus allowing afternoon/evening convection over the SMO to propagate west of the mountain barrier over a greater distance than on preceding nights. Second, its departure from the area led to an increase in surface pressure over the southern Gulf, thereby enhancing the north–south pressure gradient along the GOC. Normally, the pressure in the southern Gulf is higher than that over the north because of a strong heat low centered near the Imperial Valley of California. In this case, a strong north–south pressure gradient associated with significant pressure rises in the southern GOC region occurred on 13 July as TS Blas moved away from the region. The Puerto Peñasco ISS documented the Gulf surge on 13 July in real time. It was preceded by the passage of two gust fronts exhibiting wind shifts in the lowest 500 m of the atmosphere. Following that, a prominent moisture surge occurred with a peak wind near 20 m s^{-1} at 600–800 m AGL (Fig. SB2). Increases in surface pressure of ~5 hPa were associated with this surge. The other ISS sites at Bahia Kino and Los Mochis also recorded surges and significant surface pressure rises, although the winds were strongest at Puerto Peñasco. Pilot balloon measurements around the GOC region (e.g., Loreto) also observed changes in lower atmospheric winds due to the passage of the surge. These strong winds were confirmed by a NOAA WP-3D aircraft mission (IOP-2) over the northern GOC at the same time. Accompanying this moisture surge was a northward transport of water vapor and increase in precipitation over northwest Mexico and Arizona. Additional work is underway to understand the influence of the surge events on the precipitation and tropospheric circulation patterns using the NAME EOP dataset (e.g., Higgins et al. 2004; Higgins and Shi 2005).

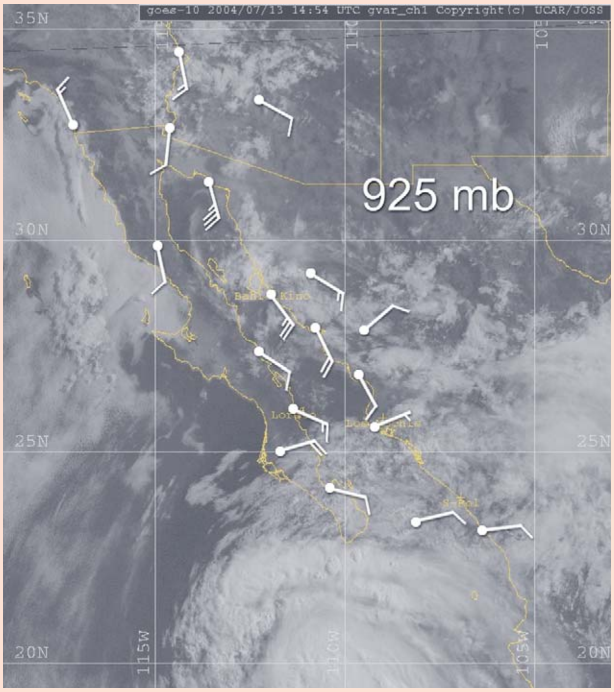

Fig. SB1. ***GOES-10*** **visible satellite image of Tropical Storm Blas along the southern edge of tier I and 925-hPa winds in the Gulf of California region at 1454 UTC 13 Jul 2004. Winds are obtained from a combination of NAME 2004 special soundings (including RV** ***Altair*** **sounding, Bahia Kino and Los Mochis profiler data, Loreto GLASS, SMN and NWS soundings, and pilot balloon soundings). (Figure provided by Jose Galvez.)**

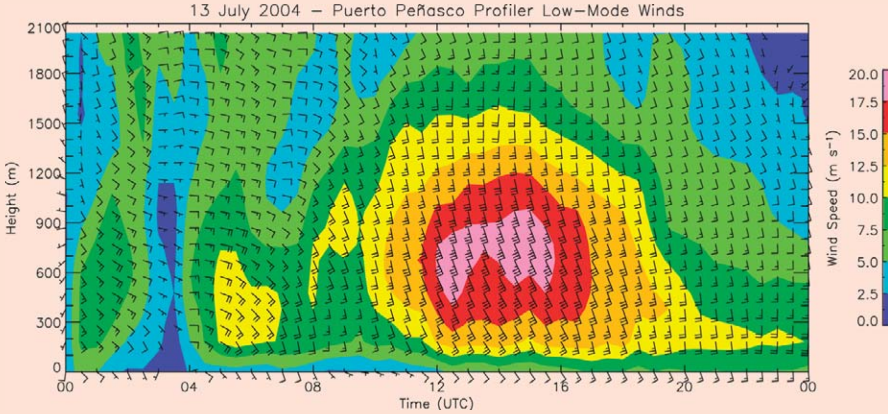

Fig. SB2. Wind profiler time series of wind speed (m s^{-1}) at Puerto Peñasco for a 24-h period starting at 0000 UTC 13 Jul 2004. (Here 1 full barb = 5 m s^{-1}.) Surface winds are from the surface meteorological station.

California Sur, was operated from 8 July–21 August during NAME 2004 to characterize mesoscale and convective-scale processes in tier I. The network provided improved observations of the diurnal cycle of rainfall and storm morphology in the region. S-Pol was operated in two scanning modes: long-range, multitilt 360° volume scans to emphasize mesoscale organization of storms, and short-range, rapid-update sector volume scans to emphasize individual storm structure. Both modes featured low-level 360° scanning every

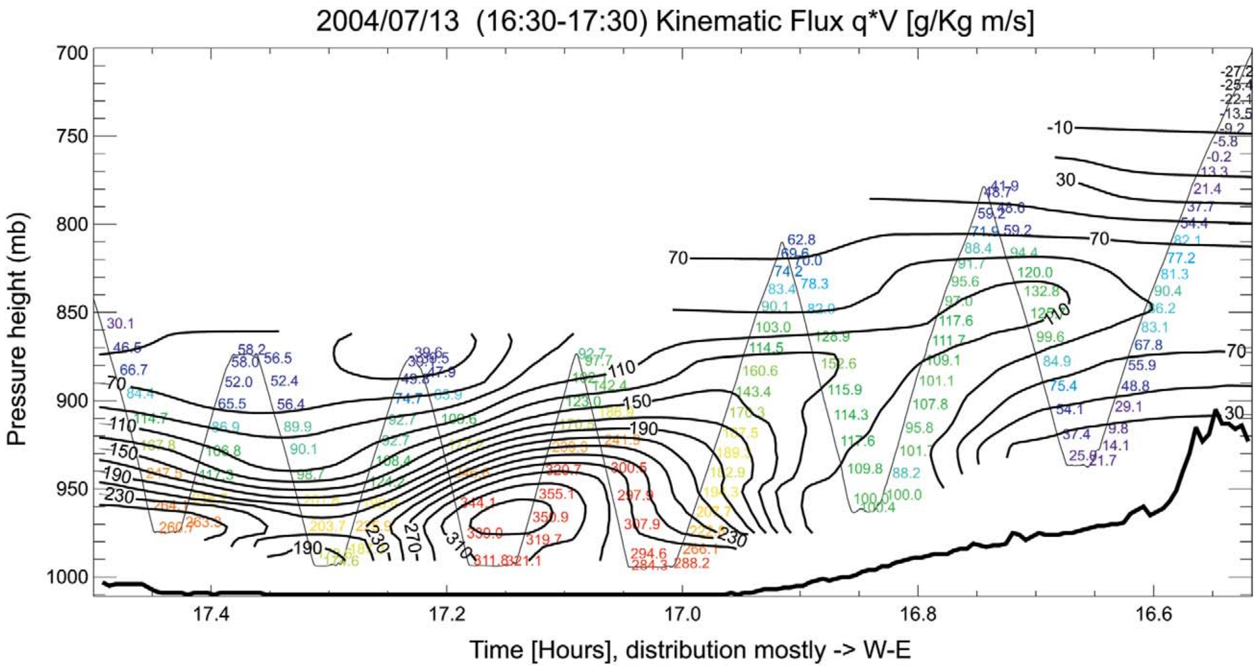

Fig. 6. NOAA WP-3D cross sections of meridional moisture flux (m s^{-1} g kg^{-1}) across the northern GOC (near 31.5°N) during IOP-2 on 13 Jul 2004. The results are obtained by averaging 1-s data over 20-s intervals and applying an objective analysis. For reference, time in UTC is indicated along the abscissa. (Figure provided by John Mejia.)

15 min to produce accurate rainfall maps based on polarimetrically retrieved variables. Additionally, polarimetric data from S-Pol provides information on microphysical structure and evolution of storms.

The SMN radars scanned 360° sweeps at a single low-level tilt. Guasave operated from 10 June to 30 September (except no coverage from 22 to 29 July) while Cabo San Lucas operated from 15 July to 30 September (Fig. 2). The SMN data will be merged with S-Pol, NERN, and other automated rain gauge data to create a gridded composite regional product that provides near-surface rainfall, reflectivity, and Doppler velocity every 15 min during the EOP. Combined, these products will be used to initialize and validate modeling work at multiple spatial scales, as well as to validate satellite rainfall estimates.

A representative example of the microphysical information provided by S-Pol is seen in a vertical cross section through an intense mesoscale convective system that occurred over the Sierra Madre Occidental (Fig. 7). Within the black-bounded area aloft, the collocation of high reflectivity, negative differential reflectivity (Z_{DR}), and high linear depolarization ratio indicates the presence of large hail (diameter > 2 cm). Just below this area is a region of strong differential phase shift, indicating that the hail there was melting as it fell through the 0°C level near 5 km MSL. At the surface, higher Z_{DR} and lower LDR values indicate that the hail completely melted into rain before reaching the ground. That SMO convection often is intense enough to produce large hail aloft is one of the many interesting findings from the NAME 2004 radar network.

Land surface and vegetation. An 18-m micrometeorological tower was established near Tezopaco, Sonora (Fig. 4), in a tropical deciduous forest to measure the changes in fluxes from the forest canopy during rapid leaf-out after onset of the monsoon rains. Meteorological measurements were made at three levels on the tower (fluxes measured only at the top of tower), and soil temperature and moisture measurements were made in the ground below.

At the aforementioned NOAA ETL/AL supersite, components of the surface energy budget were also estimated using in situ observations of the net radiative, latent, sensible, and ground heat fluxes. Upwelling and downwelling solar irradiance were measured at 2.0 and 5.0 m above ground while upward and downward IR fluxes were observed at 2.0 m above ground. The sensible heat flux was computed using 20-Hz samples of the vertical wind component and temperature. Latent heat and CO_2 fluxes were also estimated using sonic vertical wind components and 20-Hz samples of humidity and CO_2. Ground heat flux measurements were made at a depth of 3.0 cm below the soil surface. Soil temperatures were obtained at depths of 5.0, 10.0, 15.0, and 50 cm. Volumetric soil wetness fraction observations at 15.0 cm below the soil surface were also

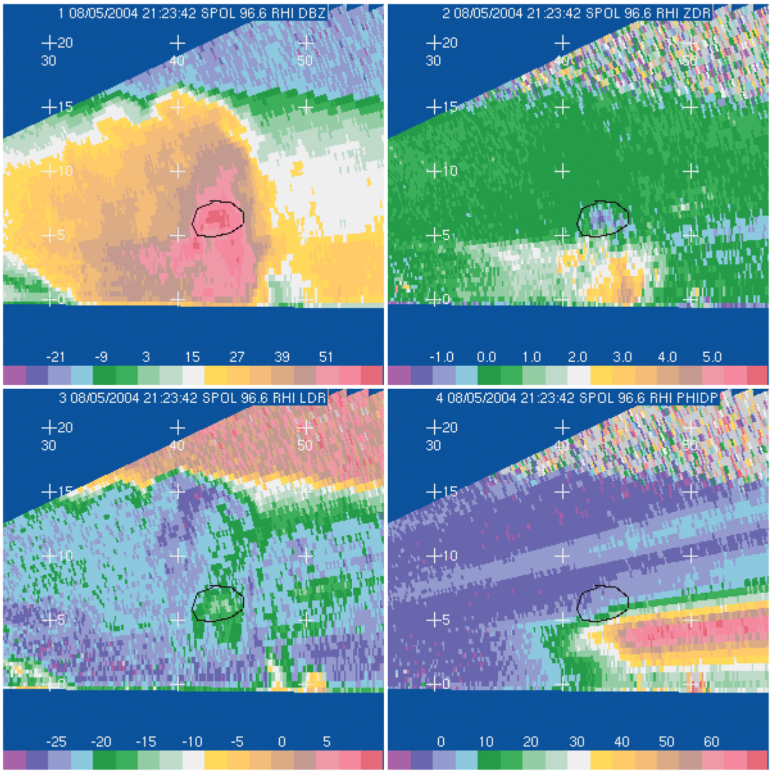

FIG. 7. Vertical cross section at (upper left) 97° azimuth of S-Pol reflectivity, (upper right) differential reflectivity, (lower left) linear depolarization ratio, and (lower right) differential phase at 2123 UTC 5 Aug 2004. Vertical scale is km MSL, and horizontal scale is range from the radar (km). The closed black curve highlights the region of large hail aloft.

made. The supersite included a 2875-MHz vertically pointing radar and a surface raindrop disdrometer to measure the microphysical properties of the rainfall (e.g., the raindrop size distribution) from the surface to the melting layer. The supersite was 45 km from the NCAR S-Pol radar, which will enable coordinated profiler and scanning radar analyses.

Soil moisture. Soil moisture data were collected via a combination of aircraft passive microwave and in situ sensors over two sites in Arizona and the Sonora River basin in northern Mexico (small boxes on Fig. 3). Aircraft operations with supporting intensive ground based sampling were conducted 2–27 August 2004 (Fig. 2) as part of the Soil Moisture Experiment 2004. In situ measurements began prior to June 2004 and have continued since then. SMEX04 had the primary objective of obtaining concurrent ground- and aircraft-based soil moisture measurements in support of the development and refinement of microwave radiometers and soil moisture retrieval algorithms. The objective of the SMEX04 activities in connection with NAME was to estimate the space–time variability of soil moisture over a large enough area to calibrate and verify subsequent estimates of satellite-based soil moisture (from instruments such as AMSR-E and TMI) over the entire period of the NAME 2004 field campaign, and over much of NAME tiers I and II. In addition to the aircraft and in situ soil moisture observations, the SMEX04 team gathered systematic observations of precipitation, surface energy, water budget, and boundary layer parameters in Sonora during a 3-week period starting in mid-July 2004. Data collection activities centered on the deployment of the NCAR/ATD tethersonde system, a small rain gauge network and a micrometeorological tower, near the town of Rayon, Sonora.

Oceanographic observations. Upper-air, surface, and PBL meteorological and ocean atmosphere flux measurements were made from the RV BI-03 *Altair* (Mexican Navy). The *Altair* remained at the mouth of the Gulf of California (23.5°N, 108°W) from 7 July to 22 August (Fig. 2), with a few days missing in the middle for a port visit. Instrumentation included 915-MHz wind profiler and sounding system, cloud ceilometer, CTD ocean profiles, and surface flux measurements. Upper-air soundings aboard the *Altair* were important in helping to document the structure of observed low-level jets, easterly waves, and moisture surges near the mouth of the GOC. The profiler and rawinsonde data taken aboard the *Altair* were the only sounding measurements at the center of the GOC, and hence represent critical contributions for studies of Gulf surges and the atmospheric moisture budget of the region.

Previous studies had suggested that sea surface temperatures over the GOC are a factor in determining the date of onset of the summer rains over northwestern Mexico and the southwestern United States (e.g., Mitchell et al. 2002). The RV *Ulloa* was deployed during 6–23 June and 2–19 August to determine what factors control SST variability in the GOC. Argos-tracked drifters were deployed during both cruises to obtain near-surface currents and density and conductivity–temperature–depth sensor casts were carried out over the mouth of the GOC. The June cruise identified a narrow current along the east coast of the GOC, which suggested that horizontal advective processes may be important in controlling the surface temperature field. Surface and upper-air observations made from the ship provide bulk estimates of the latent and sensible heat fluxes during the cruises.

The tropical meteorology group from the Universidad Nacional Autónoma de México conducted a field campaign on board the Oceanographic Vessel El Puma from 3 to 17 August to examine the relationship between the warm pool off the Pacific coast of Mexico and the structure of the boundary layer south of the entrance of the GOC. Vertical profiles of various parameters were obtained to determine the structure of the oceanographic mixed layer and the planetary boundary layer using a CTD and a tethersonde. The cruise identified boundary layer winds south of the GOC (near 18°N) that were primarily northerly, with winds closer to the "mouth" of the GOC (near 19°N) primarily southerly.

Field catalog and data archive. UCAR/JOSS implemented a Web-based NAME online field data catalog to support NAME 2004 field operations (section 2). In addition, UCAR/JOSS maintains a comprehensive NAME 2004 data archive available to climate researchers (see appendix A).

NAME MODELING STRATEGY. One of the unique features of the NAME program is the collaboration between the observational and modeling communities. NAME modeling activities, which have been underway for several years, helped to motivate the enhanced observations gathered during NAME 2004. Conversely, the NAME 2004 dataset will be used to improve our ability to simulate and ultimately predict monsoon precipitation months to seasons in advance. A driving hypothesis of NAME is that we must develop proper simulations 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. The NAME SWG developed a comprehensive modeling strategy that included the NAME 2004 EOP as a critical component from the outset to help guide progress. Details of the modeling strategy are found in a white paper entitled "NAME modeling and data assimilation: A strategic overview," available online at www.joss.ucar.edu/name/. Progress on various components of that strategy is summarized below.

Climate data assimilation. NAME 2004 DATA IMPACT. Global and regional data assimilation and forecast experiments are underway at NCEP to test the impact of NAME 2004–enhanced observations on operational analysis quality. The goals are to determine possible influences of the regional monsoon circulation on the large-scale circulation, and to identify requirements for sustained observations that are necessary to improve operational analysis quality for real-time climate monitoring and assessments. The NCEP Regional Reanalysis assimilation system (Mesinger et al. 2005) has been implemented in real time for the regional experiments, so that the RR climatology can be used to put current anomalies in the proper historical context. The NCEP operational Climate Data Assimilation System II (Kanamitsu et al. 2002a) and the Global Data Assimilation System are used for the global experiments. Analyses both with and without NAME 2004 data provide initial and boundary conditions for the regional model experiments, verification data for the global model experiments, and serve as a benchmark for other data impact studies. The North American Land Data Assimilation System (Mitchell et al. 2004), which was run in near-real-time during the NAME 2004 EOP, is a useful addition to the overall NAME monitoring program and provides an excellent linkage to new-and-improved application products (e.g., water resource, agriculture, fire risk, drought).

Climate model assessments. NAMAP. The NAME Model Assessment Project was designed to stimulate organized modeling activity in advance of the NAME 2004 field campaign. The objectives were to establish a general baseline of the quality of simulations produced by global and regional models using a common warm season (1990), and to identify time-averaged variables of special interest for model improvement that are now poorly constrained by observations. The NAMAP analysis (Gutzler et al. 2004, 2005) showed that current models are capable of simulating the basic evolution of a summer season precipitation maximum near the core monsoon region (NAME tier 1 on Fig. 1), but there are important differences in the monthly evolution and diurnal cycle of precipitation generated by the models. For example, the global models showed significant delays—on the order of a full month—in monsoon onset (defined in terms of precipitation) compared to observations (Fig. 8). The NAMAP analysis motivated several metrics to quantify model simulation quality and improvement (Gutzler et al. 2004, 2005) that are focused on monsoon onset and the diurnal cycle of precipitation (including important aspects of the afternoon precipitation maximum and nocturnal precipitation). The

NAMAP Atlas (Gutzler et al. 2004) outlines other primary metrics for model improvement pertaining to moisture transport and large-scale circulation across the NAMS domain. The complete set of NAMAP model output fields is freely available online at the NAME Web site. NAME 2004 field observations (and associated integrated and synthesis products) are being used in a new round of comparative model runs (NAMAP2) focused on simulations of the 2004 North American monsoon season. NAMAP2 will focus on variables and metrics identified as leading targets for model simulation improvement in NAMAP.

Diurnal cycle experiments. NAME is evaluating the diurnal cycle of precipitation over the United States and Mexico in the GFDL, NASA/GMAO, and NOAA/NCEP atmospheric general circulation models (Lee et al. 2005, manuscript submitted to *J. Climate*). For each model, an ensemble of five warm-season simulations was made using the same climatological SST and sea ice distributions (Reynolds et al. 2002; taking an average of the 1983–2002 period). The three models are characterized by very different diurnal cycles of rainfall over the monsoon region in terms of both amplitude and peak phase (Fig. 9). Compared with the observed diurnal cycle, the models generally tend to reach their maximum phase 2–3 hours earlier over the convective region (e.g., AZNM is shown in Fig. 9). All three models employ deep convection schemes that assume fundamentally the same mass flux closure based on simplified versions of the Arakawa–Schubert scheme. The different responses between the models highlight the importance of differences in the implementation of the convection schemes. Local diurnal variations of CAPE show an afternoon peak in the models and the observations (not shown). While the diurnal cycle of convection tends to be in phase with CAPE in the simulations, that is not the case for the observations, suggesting that regional- and large-scale dynamical forcing (e.g., orography, land–sea breeze, and moisture transport) play an important role in triggering or inhibiting the diurnal cycle of rainfall, and that this is not well represented in the models.

Sensitivity to resolution. Experiments have been carried out to determine the horizontal resolution required for the NCEP operational Global Forecast System to forecast realistic North American monsoon precipitation. Summer season simulations for selected years were produced at both high (T126) and low (T62) horizontal resolution with the same vertical resolution (28 levels) in each case. Experiments were performed with prescribed observed sea surface temperatures to ensure that simulation errors come from model deficiencies (Mo et al. 2005). Results showed that the T126 model had a significant advantage over the T62 model in simulating monsoon precipitation throughout the annual cycle, including during the monsoon season (Fig. 10). The T126 model also did a better job capturing transient features of the monsoon system, including the GOC low-level jet and GOC moisture surges (not shown). The extent to which these resolution-dependent improvements are confined to western North America has not been investigated.

Sensitivity to boundary conditions. Land surface conditions, and soil moisture in particular, have been shown to have a large impact on warm-season climate prediction

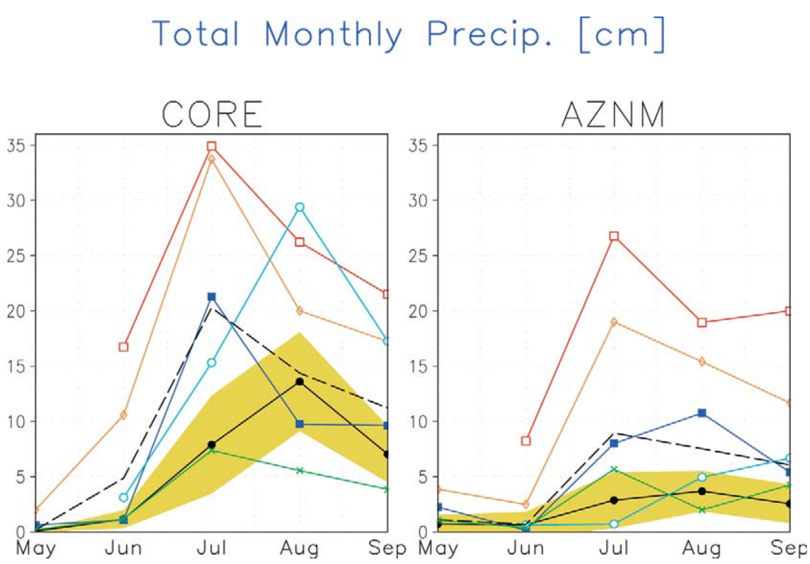

Fig. 8. Time series of total monthly precipitation (cm) May–September 1990, averaged over the (left) CORE (24°–30°N, 112°–106°W) and (right) AZNM (32°–35°N, 112.5°–107.5°W) subregions. The observations are represented by the black dashed line. The two global models are represented by the light blue line/open circles and black line/closed circles. Yellow shading surrounding the black line shows ± 1σ envelope of variability of a 10-simulation ensemble produced by this model. The three regional models are represented by the red line/open squares, the orange line/open diamonds, and the dark blue line/closed squares.

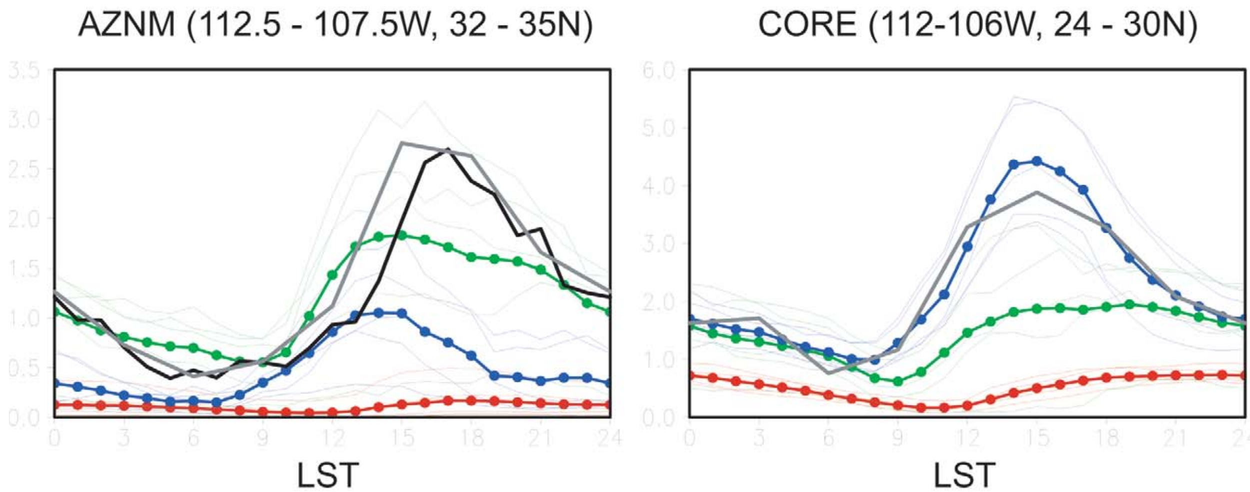

Fig. 9. Hourly precipitation rate (mm day^{-1}) averaged over the AZNM (32°–35°N, 112.5°–107.5°W) and the CORE (24°–30°N, 112°–106°W) subregions as indicated. Results are local standard time. The thick solid lines indicate the observed NCEP hourly precipitation data (black, AZNM only) and the North American Regional Reanalysis (gray, 3 hourly). Thick lines with filled circles are ensemble means of each model (NCEP in green, GFDL in red, and NASA in blue, respectively). Thin colored lines indicate the ensemble spread of the models.

in observational and modeling studies (e.g., Kanamitsu et al. 2002b). Soil moisture conditions affect the surface heat balance by directly influencing latent and sensible heat fluxes, and hence modifying temperature and humidity near the surface, and ultimately precipitation and large-scale circulation. In the NCEP operational seasonal forecast system (Kanamitsu et al. 2002a), hindcast runs are currently initialized with climatological soil moisture. However, a set of experimental runs was made with initialized soil moisture from the NCEP–DOE Reanalysis 2 to study the impact of initial soil moisture anomalies on warm-season prediction. The experimental runs were initialized with the R2 analysis at 12-h intervals for the first 5 days of May 1979–99, as in the current operational suite. The influence of initial soil moisture was found to last at least 3 months in both the soil moisture and near-surface temperature fields. The prediction skill of surface temperature increases considerably in midlatitudes, and especially over the United States. Importantly, the impact is also found in the upper-tropospheric circulation (Fig. 11). In particular, the location of the monsoon anticyclone is significantly improved with initialized soil moisture when compared to observations. Overall, these experiments show that a proper description of the land surface is required to improve warm-season climate prediction. In addition to these experiments, additional experiments that focus on sensitivity to SST (both local and remote) as well as the relative influences of SST, soil moisture, and vegetation are in progress.

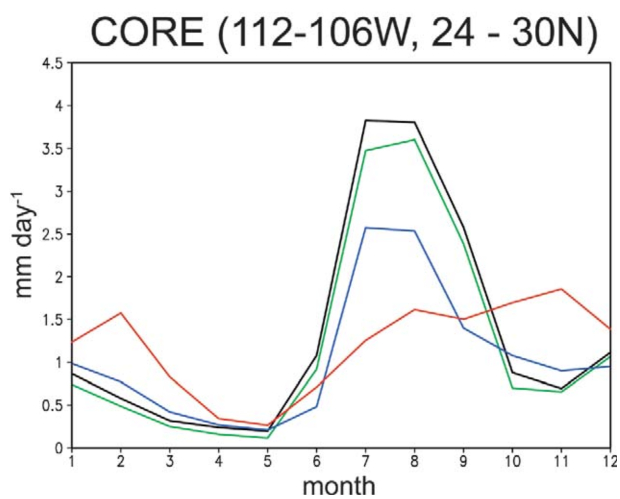

Fig. 10. Mean precipitation rate (mm day^{-1}) averaged over the CORE (24°–30°N, 112°–106°W) subregion from the NCEP-observed precipitation analysis (black line), the NCEP Regional Reanalysis (green line), the T126L28 AMIP climatology (blue line), the T62L28 AMIP climatology (red line). The base period for the climatology is 1981–2000.

Climate forecast system development. NAME CLIMATE PROCESS AND MODELING TEAM. The U.S. CLIVAR Program has implemented several climate process and modeling teams to link process-oriented research to modeling for the purpose of addressing key uncertainties in coupled climate models (U.S. CLIVAR Scientific Steering Committee 2002). With support from the NOAA Office of Global Programs Climate Prediction Program for the Americas, NAME has established a CPT-like activity

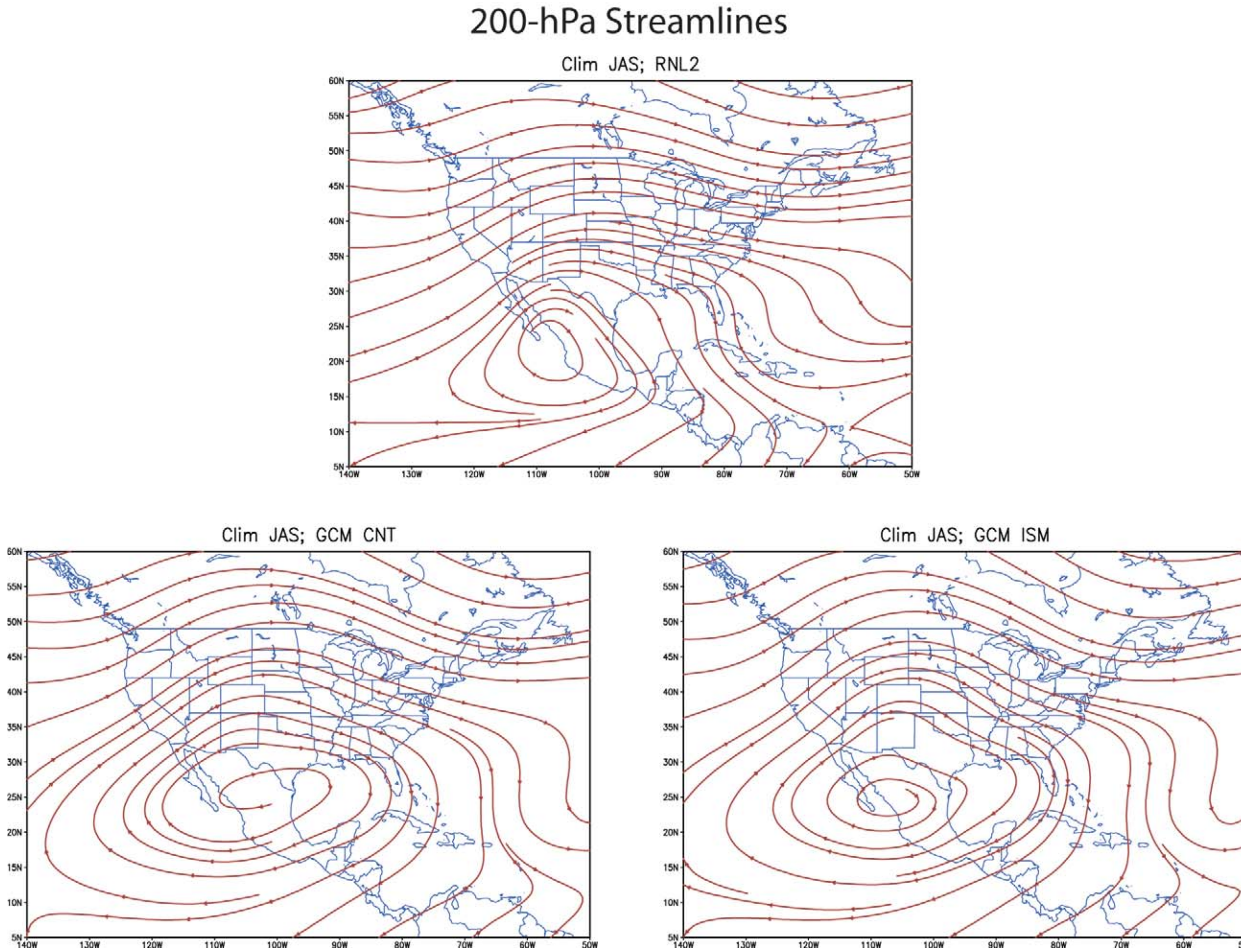

Fig. 11. Climatological 200-hPa streamlines over the North American sector from (upper) the NCEP/DOE Reanalysis 2, (lower left) from the SFM hindcast runs with climatological soil moisture, and (lower right) from the SFM hindcast runs with R2 initial soil moisture. The base period for the climatology is 1979–99.

focused on improved treatment of the diurnal cycle of convection over the complex terrain of southwestern North America. In particular, the CPT is focused on the ability of the NCEP operational CFS to simulate the diurnal and seasonal evolution of warm-season precipitation during the NAME 2004 EOP, and on changes to the treatment of deep convection that are necessary to improve the simulations, and ultimately predictions of warm-season precipitation. This activity is strongly tied to NAMAP2 to ensure technology transfer from research to operations. The team is also working with the NAME modeling community to identify additional process studies that are necessary to improve climate model fidelity, and to develop sustained observational requirements for climate model systems.

NOAA climate test bed. Building on recent improvements in S/I prediction, NOAA has organized a Climate Test Bed facility to facilitate faster improvement of NOAA operational climate forecasts, products, and applications. The CTB provides infrastructure (computing resources and system and science support teams) to support both internal (NOAA) and external projects that result in a direct influence on NOAA climate forecast operations. Several of the NAME modeling activities, including the NAME CPT-like effort discussed above, are important seed efforts for the CTB. The motivation, framework, resources, and organization of the CTB are discussed in several documents available online at www.cpc.ncep.noaa/gov/products/ctb.

Milestones. The NAME program has a series of annual milestones to track progress toward the development and implementation of improved monitoring, analysis, and prediction systems that support the delivery of a new operational product line for the summer season over North America. During 2004, a milestone was established for reporting on the implementation of NAME 2004. During 2005, NAME focused on post-field phase dataset development and quality control, and evaluation of the impact of the NAME 2004–enhanced observations on NCEP operational analysis products. During the next several years, NAME will assess global and regional model simulations of the 2004 monsoon (2006), evaluate the impact of changes in model parameterization schemes (2007), measure improvements in model simulations of monsoon onset and variability (2008), and implement recommended changes to operational climate prediction systems to improve monsoon precipitation forecasts.

NAME LEGACY. NAME 2004 was a major field campaign during the summer of 2004. The campaign generated an unprecedented dataset for the climate community (www.joss.ucar.edu/name/dm/archive/). Some of the NAME networks (e.g. simple rain gauge) will continue beyond the end of the NAME program. NAME modeling and prediction studies will continue for the next several years. By the end of the program in 2008, NAME will deliver an improved observing system design for monitoring and predicting the North American monsoon, a more comprehensive understanding of North American summer climate variability and predictability, strengthened scientific collaboration across Central and North America, and measurably improved climate models that simulate and predict monsoon variability months to seasons in advance.

Education module. NAME is also developing an education module for grades K–12 that aims to help students recognize that there is a summer monsoon in the Southwest and (especially for those that live there) that it is relevant to their daily lives. Details of the module are described in appendix B.

ACKNOWLEDGMENTS. Literally hundreds of individuals and dozens of institutions contributed to the success of the NAME 2004 Field Campaign and associated modeling activities. Thanks are extended to each participant and institution for making the campaign an outstanding success and the resulting datasets truly unparalleled in quality and scope. The NAME SWG would like to extend a special thanks to supporting agencies and organizations (NOAA/OGP, NOAA/NWS, NSF, DOD/Army, NASA/THP, NASA/*Aqua*, USDA/ARS, U.S. and International CLIVAR and GEWEX), and to several institutions in Mexico (SMN, IMTA, UNAM, CICESE, IMADES, Universidad de Sonora, Universidad Veracruzana and Universidad Autónoma de Guadalajara), Belize, and Costa Rica (University of Costa Rica, National Meteorological Institute, and National Center for High Technology). The SWG would also like to thank several organizations (JOSS/NAME Project Office, the Forecast Operations Centers in Tucson, Mazatlan and Mexico City, Vaisala, Salt River Project), government laboratories and centers (NCEP, NWS/Weather Forecasting Offices, NCAR/ATD, NOAA ETL/AL), universities (Department of Atmospheric Science, University of Arizona, Department of Atmospheric Science, Colorado State University), and groups (science directors, forecasters, forecaster assistants, monitoring directors, and field observers) that were instrumental to the success of the field campaign. An extra special thanks is extended to Dr. Robert Maddox of the University of Arizona in Tucson, who did a terrific job organizing and integrating the NAME Forecast Operations Center into the Field Program. This article is dedicated to the memory of Dr. Gandikota V. Rao (1934–2004), professor of meteorology and chair of the Department of Earth and Atmospheric Sciences at Saint Louis University, who passed away on 31 July 2004 in the Pacific waters of Mazatlan, Mexico, during the NAME 2004 field campaign.

APPENDIX A: NAME FIELD CATALOG AND DATA ARCHIVE

UCAR/JOSS implemented a Web-based NAME online field data catalog (www.joss.ucar.edu/name/catalog) to support NAME 2004 field operations (e.g., weather forecasts, facility status, daily operations summaries, and mission reports). Both operational and research products have been entered into the catalog. The catalog allows both data entry (e.g., data collection details, field summary notes) and data browsing (e.g., listings, plots). Daily operations summaries contain information on field operations (e.g., aircraft flight times, major instrument systems, sampling times, etc.). Users can also obtain information on the current status of the data collection.

UCAR/JOSS also maintains a comprehensive data archive for NAME. Most NAME-related datasets are available to the scientific community for the period from 1 June 2002 to 30 September 2004. A NAME 2004 data management plan (www.joss.ucar.edu/name/dm/name_dm_index.html) describes the data management policies, the strategy and functional description of the data management systems, and the implementation details of the NAME 2004 datasets. Access to specific datasets (sorted by category) is provided via a one-stop linkable master list of all datasets (available online at www.joss.ucar.edu/name/dm/archive/).

APPENDIX B: NAME EDUCATION MODULE

The NAME education module has three major components: a monograph; Teachers in the Field program; and a curriculum, unit, and lesson plans. The monograph, entitled *The North American Monsoon,* is included in the NOAA "Reports to the Nation" series. It discusses basic aspects of the monsoon in a friendly, easily comprehensible format. Topics addressed by the monograph include basic monsoon definitions, monsoon weather, variations within the monsoon season, the monsoon and society, monsoon prediction, and monsoon safety. The monograph is available online on the NAME Web site (www.cpc.ncep.noaa.gov/products/precip/monsoon/report.html).

The NOAA Office of Global Programs, in conjunction with the National Science Foundation, sponsored two NAME Teachers in the Field during NAME 2004. The teachers were Rhonda Feher, an elementary school science teacher from Kayenta Intermediate School in Kayenta, Arizona, and Josefina Hinojos, a high school biology and chemistry teacher at Centro de Estudios Tecnológicos in Sonora, Mexico. The NAME TIFs traveled to Tucson in mid-July to join with NAME 2004 researchers. They also traveled to the operations center at Mazatlan, Mexico, where they flew aboard the NOAA WP-3D aircraft, and visited the NCAR S-POL radar. The NAME TIFs kept daily logs (science, technology, culture) and prepared lesson plans that coordinate with the science and that described their expeditions. Additional information, including their daily logs, videos, and other information on the NOAA Teachers in the Field Program are available (www.ogp.noaa.gov/tas/).

A North American monsoon curriculum, unit, and lesson plans are under development by Steve Uyeda, a ninth-grade earth science teacher at Sunnyside High School in Tucson. The initial set of lesson plans (targeting sixth–ninth grade) addresses questions on the NAME across four science strands: weather and climate, the monsoon season and society, the monsoon season and the natural landscape, and monsoon storm prediction. In the future these lessons will be expanded to other grade levels and organized into a unit and curriculum that meets National Education Association standards. Key issues that are being addressed include what teaching materials are useful at different grade levels, how the teaching materials address standards, how to package and disseminate the module, and how to evaluate the materials.

Table 1. List of acronyms used in the text.

AGL	Above ground level	ETL	Environmental Technology Laboratory
AL	Aeronomy Laboratory	EOP	Enhanced Observing Period
AMIP	Atmospheric Model Intercomparison Project	EOS	Earth Observing System
AMSR-E	Advanced Microwave Scanning Radiometer for EOS	FOC	Forecast Operations Center
ARS	Agriculture Research Service	GEWEX	Global Energy and Water Cycle Experiment
ATD	Atmospheric Technology Division	GDAS	Global Data Assimilation System
AWS	Automatic Weather Stations	GFDL	Geophysical Fluid Dynamics Laboratory
AZNM	Arizona–New Mexico	GFS	Global Forecast System
CAPE	Convective available potential energy	GLASS	GPS-Loran Atmospheric Sounding System
CDA	Climate Data Assimilation System	GMAO	Global Modeling and Assimilation Office
CFS	Climate Forecast System	GOC	Gulf of California
CLIVAR	An International Research Programme on Climate Variability and Predictability	GOES	Geostationary Operational Environmental Satellite
CNA	Comisión Nacional del Agua	IOP	Intensive Observing Period
CPPA	Climate Prediction Program for the Americas	ISS	Integrated Sounding System
CPT	Climate Process and modeling Team	JAS	July–August–September
CTB	Climate Test Bed	JJA	June–July–August
CTD	Conductivity–Temperature–Depth	JOSS	Joint Office for Science Support
DOD	Department of Defense	LDR	Linear Depolarization Ratio
DOE	Department of Energy	MSL	Mean Sea Level

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NAMAP	NAME Model Assessment Project	RV	Research Vessel
NAME	North American Monsoon Experiment	SFM	Seasonal Forecast System
NAMS	North American Monsoon System	SMEX04	Soil Moisture Experiment 2004
NASA	National Aeronautics and Space Administration	SMN	Servicio Meteorólógico Nacional
NCAR	National Center for Atmospheric Research	SMO	Sierra Madre Occidental
NCEP	National Centers for Environmental Prediction	S-Pol	S-band Polarimetric Doppler Radar
NERN	NAME Event Rain Gauge Network	SST	Sea Surface Temperature
NLDAS	North American Land Data Assimilation System	SWG	Science Working Group
NOAA	National Oceanic and Atmospheric Administration	THP	Terrestrial Hydrology Project
NSF	National Science Foundation	TIF	Teachers in the Field
NWS	National Weather Service	TMI	Tropical Rainfall Measuring Mission Microwave Imager
OAL	Ocean–Atmosphere–Land	T/RH	Special Temperature/Relative Humidity
OGP	Office of Global Programs	TS	Tropical Storm
PBL	Planetary boundary layer	WMO	World Meteorological Organization
PI	Principal investigator	UCAR	University Corporation for Atmospheric Research
Pibal	Pilot balloon	UNAM	Universidad Nacional Autónoma de México
R2	NCEP–DOE Reanalysis 2	USDA	United States Department of Agriculture
RASS	Radio Acoustic Sounding System	Z_{DR}	Differential Reflectivity
RR	Regional Reanalysis		

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