Observing the Interdependence of Precipitation and Precipitable Water Vapor during the North American Monsoon Experiment (NAME)

E. R. Kursinski - March 20, 2006

Abstract/Executive Summary

This project entitled “Observing the Interdependence of Precipitation and Precipitable Water Vapor during the North American Monsoon Experiment (NAME)” was funded by the Small Grants for Exploratory Research Program (SGER), under program scientist, Jay Fein. Our primary objective in this project was to acquire an important precipitable water vapor (PWV) and surface meteorology data set during the summer 2004 NAME field campaign complementing other NAME datasets, particularly the radar and rain gauge precipitation datasets. Unique aspects of our data include 30 minute resolution and high accuracy in all-weather conditions. Furthermore the locations we were able to select in and around the western side of the Sierra Madre Occidental (SMO) mountains provided significantly better sampling of the active convective areas than the primary NAME observations which were constrained primarily around the perimeter of the SMO where the necessary infrastructure was more readily available.

We ultimately obtained 7 new datasets of PWV and surface meteorological conditions at 5 locations during the wet portion of the North American monsoon in summer of 2004. With our instrumentation we measured the water vapor and its variability within the NAME region in the summer of 2004 in order to determine its relation to the warm season precipitation.

This project coordinated with and leveraged off of other existing GPS research efforts including those at the University of Sonora (UNISON) at Hermosillo, the Harvard-Smithsonian Center for Astrophysics, NOAA FSL, Suominet and JPL. With a tremendous amount of effort and coordination, we were successful for the most part. We acquired 7 PWV datasets of varying length over the 2004 NAM season. Plots of the PWV data sets are shown toward the end of this report. Ongoing research based on these data is discussed. Interesting results include identification of the time rate of change of PWV as an important variable diagnostic of moist convection. We are also in the process of quantifying the large sensitivity of summertime moist convection in the Southwest to initial moisture conditions and have reached the preliminary conclusion that the present moisture analyses produced by NOAA in the NAM region are not accurate enough to allow accurate precipitation forecasts to be generated in the area. We suggest that a GPS network in Mexico would be very useful for atmospheric and solid earth research.

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I. Key Participants

I.a Key Participants at the University of Arizona

Emil Robert Kursinski, associate professor in the Atmospheric and Planetary Sciences Departments at the University of Arizona, was Principal Investigator of this project, responsible for its overall coordination, implementation, operation and the interpretation of the results.

Graduate student Walter Kolczynski developed the software to interface with the anemometers acquire the anemometer data and developed the interface software in a very short period of time, took over and modified the UA GPS webpage to include additional FSL and our NAME-specific GPS receivers in the Southwest. He is presently completing his Master’s degree focused on characterizing the sensitivity of moist convection and precipitation forecasts to initial conditions in Southwestern North America.

Graduate student, Carlos Minjarez, was critically responsible for coordinating implementation with UNISON, doing much of the implementation, debugging the myriad of problems we encountered and performing data analysis.

Ron Mastaler, data analyst, helped with various aspect of the implementation and later assembled the datasets here at the University of Arizona.

Adjunct professor Robert Maddox co-developed our science objectives with the PI, coordinated our activities with the other NAME activities and is presently working with Walter and Carlos on interpreting the results.

I.b Key Collaborators at the University of Sonora at Hermosillo (UNISON)

Ismael Minjarez, head of the Geology Department at UNISON, during this experiment organized and oversaw the UNISON efforts supporting our joint project including identifying locations, negotiating agreements regarding facilities at the locations, developing mounts for the instrumentation, installing the instrumentation and maintaining the instrumentation.

Rosario Arellanes was responsible for installing the computers and instrumentation. He became an invaluable expert in setting up and running the satellite internet and debugging the computer-instrument interfaces at each site.

I.c Other key Collaborators

Seth Gutman (NOAA FSL) arranged that two extra sets of FSL GPS instrumentation were available on loan to our NAME experiment including training of UA personnel. Furthermore the data from those instrumentation would be processed at FSL.

Kirk Hollub (NOAA FSL) prepared and shipped the two FSL systems to Arizona and trained UA personnel and then did the GPS processing to generate PWV from the two FSL instrument sets.

Teresa van Hove, Suominet research scientist at UCAR, processed the data from all of the non-FSL instrumentation.

Rick Bennett, previously at Harvard-Smithsonian and now an assistant professor in Geosciences at the University of Arizona, arranged for the implementation of the USMX and YESX GPS receivers in Moctezuma and Yecora which captured the onset of the monsoon at those locations.
II. Funding

This SGER award was effective June 1, 2004 and expired May 31, 2005. The initial NSF SGER funding was $39,432. We minimized cost by borrowing as much equipment as possible. We spent these funds on interfacing and negotiating with collaborators in Mexico and the U.S., acquiring the equipment needed for our investigation, identifying and developing site locations in Mexico for our 7 sets of equipment, working with Mexican Customs and other agencies to get the equipment into and out of Mexico, installing the equipment in Mexico, getting the internet working in Mexico (which took far longer than expected), acquiring data from our equipment, monitoring the data acquisition, assembling the data, getting the data processed and performing initial evaluations and interpretation including the Master’s theses of Carlos Minjarez and Walter Kolczynski.

A supplemental request for $4,894 submitted Mar 14, 2005 was funded to cover the costs of removing equipment from Mexico before the end of 2004, the costs of continued satellite internet until the equipment removal and the salary of Carlos Minjarez through the end of the Fall semester 2004.

III. Background: The North American Monsoon Experiment (NAME)

The North American Monsoon Experiment (NAME) is part of the CLIVAR/VAMOS program, US CLIVAR Pan American research, and the GEWEX America Prediction Project (GAPP) (see http://www.joss.ucar.edu/name/). NAME was sponsored primarily by NOAA with support from NSF and NASA. NAME focuses on the North American Monsoon System (NAMS) which is an important large-scale feature of the warm season climatology of Mexico and the southwest U.S. The variability of summertime convective activity in this region results from a complex interaction between atmospheric circulation features at both the synoptic scale and mesoscale and the extremely varied topography.

The overarching goals of NAME are to improve understanding of the primary mechanisms responsible for establishing the warm season circulation and its associated variability and to improve the prediction of warm season precipitation over North America.

NAME data sets are summarized at http://www.joss.ucar.edu/name/dm/archive/. They include data from surface observations, balloons, radar, satellite, aircraft and ship observations.

IV. Our contribution to NAME

This project was an enhancement to the primary NAME instrumentation centered around GPS receivers measuring precipitable water vapor within the SMO.

IV.a Location, location, location: Most of the NAME field campaign instrumentation was located around the perimeter of the Sierra Madre Occidental (SMO) mountains along relatively easily accessible primary roads and somewhat urban areas. While practical, these locations were far from optimal scientifically because most of the daily moist convection (the focus of NAME) develops and evolves within the SMO. Our plan was to place GPS water vapor instrumentation farther within the SMO than most of the other NAME instrumentation.

IV.b Precipitation forms from water vapor: A rain gauge network installed in the NAME region (Gochis et al., 2003) and several radars provided time-resolved coverage of the condensed and precipitating moisture over a portion of the NAM area. Understanding the
processes responsible for condensation and warm precipitation in the NAMS region requires measurements of water vapor because precipitation condenses from water vapor. The water vapor observations during NAME were limited primarily to a few radiosonde sites located around the SMO perimeter with limited diurnal coverage. Satellite observations of water vapor in the NAME area during the monsoon are limited because IR and visible wavelengths cannot penetrate the frequent cloudiness during the monsoon and surface emissivity variations limit interpretation of microwave water vapor observations to oceanic regions.

IV.c Time resolution: During the NAM, water vapor and precipitation evolve rapidly and must therefore be sampled at relatively high time resolution. Figure 1 shows precipitable water vapor in southeastern Arizona over 4 days in 2003 following the onset of monsoonal moisture into the region. During these days, convection formed in northeastern Arizona along the Mogolon Rim and propagated southward through southeastern Arizona in the late afternoon to early evening each day. The black curves show the GPS measurements in Tucson and Mt Hopkins further south. The red curves show the output from the daily forecasts of WRF model run at 1.8 km resolution. Clearly twice per day sampling by radiosondes will miss much of this rapidly evolving structure. The power of the GPS for quantitatively assessing and improving model performance is evident in the figure.

![Figure 1. Time series of PWV over four days in 2003 following the onset of the monsoon in southeastern Arizona. Upper curves are for Tucson. Lower curves are for Mt. Hopkins approximately 60 km south of Tucson. Black lines are GPS measurements. Red curves are daily forecasts from the WRF model run at 1.8 km resolution initialized with ETA analyses.](image)

IV.d Our observational plan: Our contribution to NAME was to use GPS receivers to measure the daily evolution of water vapor and surface conditions in the North American Southwest particularly within and around the Sierra Madre Occidental (SMO) mountains, complementing the larger NAME plan. This approach was feasible given the relatively low cost and maintenance of the GPS instrumentation. So, working with colleagues at UNISON our initial plan was to identify and implement 4 internet-capable instrumentation sites east of the
existing Suominet instrumentation at the UNISON campus at Hermosillo to form a transect of instruments across the Sierra Madre Occidental (SMO) along Highway 16, near to an existing precipitation gauge transect. As Figure 2 shows these locations would provide a nice transect across the region of high summertime precipitation. The goal is to combine our observations of the daily evolution of the column water vapor and the surface meteorological conditions with satellite cloud imagery to determine the flow of water vapor through the NAM region and its interaction with the topography in the daily convection and precipitation cycle.

![Figure 2: Originally conceived GPS locations on satellite-based precipitation contours](image)

**Pre-Existing GPS PW sites**

For reference and to show how the NAME-specific sites of this project fit in relative to the existing GPS sites in Southeastern North American we show most of the existing sites in Figure 3.

(S) Suominet, (F) NOAA FSL

**Tucson area:** SA21(S), COT1(F), COT2

**SE Arizona:** Douglas SA24 (S), Mt. Hopkins SA33 (S)

**Phoenix area:** SA31, SRP, Tolleson,

**Northern Arizona:** FST1, KING

**New Mexico:** SC01, WSNM

**Sonora, Mexico:** Hermosillo (SA27), Puerto Penasco (SA33)

![Figure 3 showing locations of pre-NAME GPS receiver network in the North American Southwest.](image)
We note that we made contact with the City of Tucson and obtained access to data from their second GPS site (COT2) in eastern Tucson. We have not yet processed the COT2 data into delays and PWV. We also note that the Mt. Hopkins site (SA 32) was moved to the Tohotom Nation west of Tucson in 2005 following our NAME project.

Collaboration with UNISON

In order to implement several GPS receiver/surface meteorological packages at locations in Northwestern Mexico with limited funding, we teamed with researchers at the University of Sonora (UNISON) in Hermosillo. We developed a plan with Ismael Minjarez, head of the Geology Department at UNISON, where UNISON would be responsible for setting up each of the NAME-specific sites complete with internet. The plan was to choose locations with existing internet where possible. UNISON would also buy one meteorological package to be used with a GPS receiver borrowed from JPL, courtesy of Yoaz Bar-Sever.

As we were able to borrow more equipment including a meteorological package from Joe Zehnder, a professor at ASU, the plan evolved such that UNISON paid for some of the internet costs, developed the instrumentation mounts and deployed most of the instrumentation in the field and provided support to maintain the equipment. UNISON provided the labor to install the satellite internet.

Table 1. Summary of GPS receiver and meteorological equipment sources

<table>
<thead>
<tr>
<th>Instrument Source</th>
<th>Receivers Plan/Actual</th>
<th>Met packages Plan/Actual</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA FSL</td>
<td>2/2</td>
<td>0/2</td>
<td>Courtesy of Seth Gutman</td>
</tr>
<tr>
<td>UA Suominet sites</td>
<td>1/2</td>
<td>1/2</td>
<td>Borrowed Tucson and Mt. Hopkins sites with Suominet permission</td>
</tr>
<tr>
<td>JPL</td>
<td>1/1</td>
<td>0/0</td>
<td>Courtesy of Yoaz Bar-Sever</td>
</tr>
<tr>
<td>Joe Zehnder (ASU)</td>
<td></td>
<td>0/1</td>
<td></td>
</tr>
<tr>
<td>Rick Bennett (UA)</td>
<td>0/2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UA Purchase</td>
<td></td>
<td>2/0</td>
<td></td>
</tr>
<tr>
<td>UNISON purchase</td>
<td></td>
<td>1/0</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>4/7</td>
<td>4/5</td>
<td></td>
</tr>
</tbody>
</table>

V. Actual Implementation:

V.a Site Selection:

Each of our NAME-specific sites on the Western side of the SMO required power, security and internet access. We ultimately chose the 5 locations shown in Figure 4 to the east of Hermosillo (29°N, 111°W). Note the topography in the figure, particularly the sharp western edge of the SMO. Below we describe each of the 5 sites in more detail

**Creel** is a town in the Mexican state of Chihuahua that provided our highest altitude site in the SMO well to the east of the other NAME GPS sites. We pushed to get a receiver in Creel for the opportunity to observe moisture, temperature and convective variations near the
continental divide where morning convection often initiates and the strong easterly flow pushes through toward deeper convection later in the day. Furthermore Creel is often an area of intense rainfall during the monsoon.

**Mazatan** is a small town approximately 80 km directly east of Hermosillo at the very western edge of the SMO. Ismael Minjarez established an agreement with Osvaldo Landavazo, mayor of Mazatan and professor emeritus at UNISON, to allow us to install a GPS meteorology site complete with internet at the town hall. Prof. Landavazo agreed to purchase a satellite internet station and pay for the basic monthly charges in exchange for internet access for the town hall.

**Moctezuma** is located in the SMO foothills northeast of Hermosillo and Mazatan and south of Douglas. It was selected because of its location in the western SMO foothills between Mazatan and Douglas and because of a college there with internet access (which unfortunately turned out to be problematical).

**Tezopaco** is the most southerly Sonoran site chosen for its latitude, near-coastal proximity to the SMO, use as a radiosonde launching site for NAME and its existing internet accessibility (which again turned out to be problematical).

**Yecora** is a resort town with internet access high in the western foothills of the SMO known for relatively cool and rainy summers. It is a key location in sharp topography near deep valleys as is evident in Figure 4. Despite existing internet in the town, we installed our own satellite internet there as we could not reach agreements with any of the local internet facilities.

### V.b Instrumentation

The equipment needed to obtain PWV measurements consists of a GPS receiver, a barometer and a thermometer. The temperature needed is actually the water vapor-weighted atmospheric column temperature which is usually estimated from the surface temperature. Normally a surface humidity sensor is also included to provide a little information about how the moisture is distributed vertically.

The signal propagation delay due to passage through the atmosphere has three terms: ionosphere, hydrostatic and wet delays. The ionosphere is removed via a dual frequency GPS calibration. The hydrostatic delay is significantly larger than the wet delay but is linearly related to the surface pressure which can be obtained easily with a barometer. Subtracting the
hydrostatic delay from the calibrated total delay yields the wet delay. Dividing the wet delay by
a scale factor that depends on the atmospheric temperature yields the precipitable water vapor.

We developed instrumentation plan summarized below.

Equipment borrowed for NAME
The final instrumentation consisted of 7 GPS receivers, 5 of which had associated surface
met instrumentation. All 7 of the NAME-specific GPS receivers were borrowed.

Temporary relocation of 2 Suominet equipment sets: We identified 2 of our 5 Suominet
instrumentation sets in Arizona that could be moved to Mexico to support the NAME field
campaign in summer 2004: our University of Arizona campus site and our site on Mt. Hopkins.
Since the City of Tucson has a GPS receiver (COT1) located a few miles from the UA campus in
downtown Tucson that is processed routinely by FSL, we decided the SA21 site on the UA
campus was movable to Sonora for the NAME campaign. Our Suominet site on Mt. Hopkins
was a potentially movable site as we were not using it much in our water vapor and precipitation
research. When contacted, the Suominet researchers in Boulder, CO, agreed that we could move
both sites temporarily to support NAME in the summer of 2004.

Two receivers and met packages courtesy of NOAA FSL: Based upon discussions
between Rob Kursinski and Seth Gutman at NOAA FSL, Seth was able to obtain 2 complete
GSOS GPS receivers and surface met packages on loan for our NAME experiment

Two geodesy receivers courtesy of Rick Bennett: Rob Kursinski contacted Rick Bennett in
early discussions about NAME. Rick offered to and was able eventually to obtain the equipment
needed to install a GPS receiver at Yecora and Moctezuma in Sonora, Mexico. These sites were
installed without computer, meteorological package and internet with the data being stored
directly on the receivers for approximately 40 days.

GPS Receiver courtesy of Yoaz Bar-Sever: Rob contacted Yoaz Bar-Sever at JPL about
receivers for NAME and Yoaz agreed to provide one receiver and computer on loan for NAME.

Meteorological instrumentation package courtesy of Joe Zehnder: Rob was able to
borrow a meteorological package from Professor Joe Zehnder at ASU who had purchased a
Suominet-compatible met package previously based upon a promised GPS receiver from
Suominet. However, because Suominet never delivered him a GPS receiver, his met package
available to us for NAME. We used this meteorological package to accompany the JPL GPS
receiver at the Moctezuma site.

Anemometers: Since we were able to borrow more equipment than we had planned
originally, we purchased anemometers for 5 sites. Our concept was to obtain surface winds to
combine with our surface pressure, temperature and moisture observations to constrain the fluxes
of near-surface moisture. With a great deal of effort spent in a short period of time, Walter
Kolczynski was able to make the data acquisition work for these systems in the lab shortly before
we sent the equipment to Mexico. However, we had a great deal of trouble in the field and only
the anemometer at Creel ultimately provided reliable anemometer results.

Web cams We planned to use inexpensive web cams to visually monitor convective activity
at each site. We purchased 5 very inexpensive cameras and built simple all-weather housings for
the cameras. Unfortunately we ran into several problems. First, the USB signal propagation
severely limits distance between the camera and the computer which was a problem for most
sites. Second, the Suominet computers have an old version of the linux operating system that
was incompatible with standard web cam software packages removing the NAM3 and NAM4 facilities from possibility. Ultimately only the Creel site webcam worked but it yielded very interesting movies of the daily convection there.

**Internet:** In order to take advantage of the routine near-realtime processing of GPS PWV data by the Suominet and FSL processing centers as well as to monitor the data acquisition during NAME, we wanted sites in Mexico with internet service, either satellite or telephone. UNISON identified and assessed potential sites either with telephone service or that could have telephone service added relatively easily. However, because the telephone requires some lead time and since our funding source appeared relatively late after trying two other funding sources in NOAA and NSF, we decided to use satellite internet as it was relatively inexpensive and could be purchased and installed quickly. After assessing a number of satellite internet services, we chose DirectWay as the best suited to our needs being relatively inexpensive and readily available in Tucson. DirectWay allowed us to purchase the hardware and perform the installation ourselves at remote locations in Mexico. We purchased 3 Directway satellite internet stations that we later installed at our NAME sites in Mexico.

V.c Installation Timeline Summary

We began in May after receiving the go-ahead on funding from NSF ATM. We purchased the 3 sets of satellite internet equipment to be installed at Mazatan, Yecora and Creel. Kirk Hollub sent two sets of GPS, surface meteorological station equipment and computers from NOAA FSL to the University of Arizona. He then visited UA to give a presentation and train UA personnel in setting up and running the FSL equipment. During this visit we discovered an intermittent problem with one of the NOAA computers which may have been related to the later problems experienced at the NAM1 site in Yecora. On June 10, Mr. Minjarez and Mastaler delivered 5 sets of equipment to Mexican Customs at the US/Mexico border in Nogales and the equipment is taken to UNISON in Hermosillo a week later. The two stand-alone geodetic GPS receivers courtesy of Rick Bennett were installed in Yecora and Moctezuma, Sonora on June 11 and 12 by CICESE and UNAVCO personnel. UNISON personnel then developed the mounts for the other 5 sets of equipment and were trained in setting up the satellite internet equipment at remote locations by early July. UNISON personnel began installation of the NAM5 equipment at the Universidad de la Sierra in Moctezuma on July 8 but cabling problems delayed completion for another week. They installed the NAM4 equipment at Mazatan July 14-16 but without working satellite internet. Installation of the NAM5 equipment at Moctezuma was completed July 16 but the Universidad internet went down during the installation because of storm and rain on the day the Universidad closed for a month for summer vacation. On July 20-21, NAM2 equipment was installed at Creel, again without working satellite internet in a very large convective storm. July 22, NAM1 equipment was installed at Yecora but it was determined that the NOAA NAM1 computer was not working properly and the satellite internet was not working. On July 23 UNISON installed our NAM3 equipment at Tezopaco. However, it was discovered that the existing internet at the local internet café where we installed the equipment was not working.

On July 27 several people from UA and UNISON converged on Mazatan and worked intensely to solve the satellite internet problem. They realigned the satellite dish and Rosario
was able to get the satellite internet working and establish a local router and LAN in the Mazatan City Hall such that computers there were able to see the outside internet world. However, we then discovered via phone discussions with Teresa van Hove that the Suominet processing computer in Boulder, CO was not able to access the NAM4 GPS computer as needed for routine Suominet GPS processing and monitoring. The problem that we discovered over a number of phone discussions with several different DirectWay technicians was that we needed to upgrade the DirectWay internet service to their “Professional” version to allow access from the outside. DirectWay made the change two days later and Teresa was able to access the Mazatan from the Suominet control and routine data processing began for the NAM4 site and continued into December.

At this same time, since they had filled their 40 days worth of memory on the receiver, the two geodetic receivers (USMX and YESX) were removed from Moctezuma and Yecora respectively and taken to the US where the data was offloaded. On August 17, the Universidad de la Sierra in Moctezuma reopened and their local internet problem was fixed which allowed JPL to access their receiver and discover that the receiver and the met package had not been acquiring data. JPL restarted the equipment and began routine operations. A week later Rosario got Creel up and running. Since the NAM1 computer was still not working, Rosario dismantled the Yecora equipment and moved it to Hermosillo. A day later he moved and installed the Yecora satellite internet equipment at Tezopaco which allowed Tezopaco to run routinely until it was dismantled in December.

In October we brought the NOAA and JPL equipment back to the US and returned it to FSL and JPL. In December we dismantled the two Suominet sites, Tezopaco and Mazatan and returned them to the UA.

### Table 2. Final equipment location and processing summary

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Location</th>
<th>Lat. (deg.)</th>
<th>Long. (deg.)</th>
<th>Alt (m)</th>
<th>GPS Source</th>
<th>GPS Rcvr (Type)</th>
<th>Met Type</th>
<th>Start</th>
<th>End</th>
<th>Processing</th>
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</thead>
<tbody>
<tr>
<td>NAM1</td>
<td>Yecora, Son</td>
<td>28.37</td>
<td>108.9</td>
<td>1544</td>
<td>NOAA FSL</td>
<td>Trimble 4000</td>
<td>SMN site</td>
<td>22 Jul 05</td>
<td>29-Aug 05</td>
<td>NOAA</td>
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<tr>
<td>NAM2</td>
<td>Creel, Chi</td>
<td>27.74</td>
<td>107.6</td>
<td>2337</td>
<td>NOAA FSL</td>
<td>Trimble 4000</td>
<td>GSOS</td>
<td>18 Aug 04</td>
<td>08 Oct 04</td>
<td>NOAA</td>
</tr>
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<td>NAM3</td>
<td>Tezopaco, Son</td>
<td>27.84</td>
<td>109.4</td>
<td>434</td>
<td>SuomiNet SA21</td>
<td>Trimble 4700</td>
<td>ParoScientific 3A</td>
<td>06 Aug 04</td>
<td>late Dec</td>
<td>SuomiNet</td>
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<tr>
<td>NAM4</td>
<td>Mazatan, Son</td>
<td>29.00</td>
<td>108.1</td>
<td>549</td>
<td>SuomiNet SA32</td>
<td>Trimble 4700</td>
<td>Vaisala</td>
<td>14 Jul 04</td>
<td>late Dec</td>
<td>SuomiNet</td>
</tr>
<tr>
<td>NAM5</td>
<td>Moctezuma, Son</td>
<td>29.82</td>
<td>109.7</td>
<td>654</td>
<td>Yoaz Bar-Sever, JPL</td>
<td>Trimble 4000</td>
<td>ParoScientific</td>
<td>15 Aug 04</td>
<td>late Dec</td>
<td>JPL/SuomiNet</td>
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<tr>
<td>YESX</td>
<td>Yecora, Son</td>
<td>see NAM1 for approximate location</td>
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<td></td>
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<tr>
<td>USMX</td>
<td>Moctezuma, Son</td>
<td>see NAM5 for approximate location</td>
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<td></td>
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<td></td>
<td>SuomiNet</td>
</tr>
</tbody>
</table>

### VI. Data Monitoring

Walter made major changes to the UA Atmospheric Sciences GPS web page to include the FSL receivers in the southwestern US and the new NAME-specific receivers. We used this to monitor the data acquisition and quality and interesting events such as hurricane Javier’s path
through the NAM region in September 2004. The updated site can be viewed at
http://www.atmo.arizona.edu/faculty/research/gps/gps_pwv.html.

VII. Installation, Data Collection and Processing
An overall summary of GPS data acquired in the North American southwest is summarized in
the excel file
C:\Documents and Settings\ward\Desktop\Kursinski\proposals\name\Data\NAME GPS Data
ERK 02282005.xls. This file is available to anyone upon request. It includes additional GPS
receivers we discovered in Arizona and New Mexico that may be of use for the NAME
experiment.

The following is a site by site data acquisition and processing summary in order of the successful
date of data acquisition.

**Yecora (YESX):** The YESX GPS receiver was installed on June 11-13 and run on batteries
without internet access and therefore without any monitoring. Because of the limited data
storage on the receiver, the raw GPS data was sampled every 2 minutes and stored on the
receiver. Approximately 40 day’s worth of data was acquired by the YESX receiver including
the onset of the monsoon approximately on July 4. The data span complemented quite nicely the
data acquired by our other Yecora receiver, NAM1, installed near the completion of the 40 day
acquisition by YESX. While YESX had no meteorology package installed with it, we were able
to obtain surface meteorology data from the SMN (Mexican equivalent of the U.S. National
Weather Service) site in Yecora which allowed us to convert the GPS delays to a very nice set of
PWV. Miguel Cortez Vázquez (mcortez@mailsmn.cna.gob.mx) provided the data to us because
the normal web access to the SMN meteorological data did not work because of a defective
transmitter at the Yecora SMN site. The processing of the YESX GPS data to derive delays and
PWV was done by Teresa van Hove at Suominet.

**Moctezuma (USMX):** The USMX GPS receiver acquired GPS data from June 15 (DOY
167) to July 25 (DOY 207) standalone with no internet capability or accompanying surface
meteorological instrumentation. The USMX site installation and operation was very similar to
YESX being run on batteries without internet access with no monitoring visibility and 2 minute
sampling stored on the receivers. The USMX data span complemented data acquired later by our
NAM5 receiver and met station at Moctezuma. The USMX GPS data was processed by Teresa
van Hove at Suominet. The conversion to PW was done at the UA.

**Deriving PWV data from the USMX GPS observations:** As described previously in
the Instrumentation Section, deriving PWV from GPS data requires precise knowledge of
surface pressure. Surface pressure was not measured in Moctezuma during the period of
USMX GPS measurements. In order to derive PWV from the USMX we have to estimate
the surface pressure there. There are different possible approaches. One could use forecast
model output of pressure at Moctezuma but we have found that such pressure estimates do
not reproduce the relatively large surface pressure variations in the summertime Southwest
very well in terms of magnitude or timing of the diurnal cycle. Therefore we chose to
interpolate surface pressure measured simultaneously at other locations relatively nearby. To
date, we have scaled surface pressures measured by the Yecora SMN site to estimate the
surface pressure at the USMX site in Moctezuma. We calibrated this Yecora-to-Moctezuma
pressure scaling using a period of overlap in late August 2004 between the NAM5 surface

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pressure observations and the SMN observations in Yecora. In the future, we will refine the USMX Moctezuma pressure estimates using a weighted average of surface pressure measurements from Hermosillo, Yecora, Douglas and Mazatan all scaled appropriately for the height of the USMX GPS antenna. This will be calibrated by deriving the optimum scale factors and weighting during the overlap between these sites and the NAM5 surface pressure measurements beginning in late August. While the PWV derived using the scaled surface pressure will not be as good as that derived using direct barometric measurements at the site, we have found the pressure errors produce about $+1$ mm of PWV error during the August overlap period. The biggest errors tend to be on timescales shorter than a day because this interpolative scaling will not fully capture the diurnal surface pressure variations associated with local topography.

**Mazatan (NAM4):** After some initial problems with the satellite internet, the Mazatan site worked quite well and yielded the longest GPS and surface meteorology data set (150 days) of our NAME-specific sites. We initially had some concerns about the relatively close proximity of Mazatan and Hermosillo and therefore potential redundancy between the two sites. However, we have found in examining the data that their diurnal behavior in particular differs significantly, associated apparently with the closer proximity of Mazatan to the SMO orography. This data was processed by Teresa van Hove at Suominet.

**Yecora (NAM1):** We installed one of the two NOAA FSL GPS receiver, surface meteorological instrumentation and computer packages at Yecora in late July. We immediately had a problem with the computer and could not configure the entire package to work properly. The receiver was left running and Kirk Hollub was later able to extract data from July 23 to August 29 that was stored directly on the receiver. Kirk used surface meteorological data from the automated SMN surface station in Yecora that we obtained from Miguel Cortez Vázquez (mcortez@mailsmn.cna.gob.mx) to convert the GPS delay measurements into PWV. When Rosario dismantled the NAM1 equipment, he moved the satellite internet equipment there to Tezopaco.

**Tezopaco (NAM3):** The Tezopaco site is our farthest south in Sonora and was the last site where equipment was installed. UNISON developed an agreement with the county treasurer at Tezopaco to install the equipment in an internet café in the town. UA and UNISON personnel installed our GPS equipment there but also discovered the existing satellite internet capability did not work. The instrumentation began successfully acquiring data August 4 without working internet. When the NAM1 equipment was removed from Yecora, Rosario took the satellite internet equipment and installed it at Tezopaco. Once the internet was working there, we were able to offload the data and Suominet was able to process it routinely until the site was dismantled in December, 2004. Our NAM3 GPS PWV and surface meteorological data should complement the NAME radiosonde data acquired at Tezopaco prior to our data acquisition.

**Moctezuma (NAM5):** We chose to place our Moctezuma instrumentation at the Universidad de la Sierra because of its existing internet access. The JPL GPS receiver and computer and the surface meteorological instrumentation package borrowed from Joe Zehnder at ASU were installed there by UNISON personnel in the second week of July. Due to a series of problems with internet, computer software and physical access to the site when the Universidad was closed for the summer, successful data acquisition did not begin until August 26. Once running, it ran pretty much flawlessly through October 21 when we dismantled the site and returned the equipment to the US. The NAM5 data set complemented the USMX data set taken roughly 100 meter away. Furthermore, the NAM5 surface pressure data allowed us to precisely
calibrate the pressure offset between Moctezuma and our other relatively close sites which enabled us to scale their surface pressure to that of Moctezuma and derive PW from the earlier USMx data set. The NAM5 GPS data was processed both at JPL and Suominet. 

**Creel (NAM2):** As mentioned, Creel was a very interesting site located high in the SMO near the continental divide. Unfortunately its remoteness posed difficulties in monitoring and solving problems. Once debugged, the site ultimately produced excellent data for approximately 1.5 months from late August until removal in October. We established an agreement with the Principal of the Creel High School and we installed the second NOAA FSL equipment set there on July 21 and began the GPS and meteorological data acquisition without the satellite internet working. Unfortunately a day after leaving, a lightning strike knocked out power and the equipment stopped acquiring data, a fact that we did not discover until later. We attempted to monitor the equipment via one of the teachers at the (closed) school but were unsuccessful. Rosario returned in late August and found the receiver had not been acquiring data and restarted the equipment and got the satellite internet working as of August 27. We did obtain a good anemometer data set and webcam movie at Creel. The Creel GPS data was processed by FSL.

**Data Processing Summary**

The processing of the data from our 7 GPS receivers was as follows:

- Teresa van Hove at Suominet processed the data from the two Suominet sites, NAM3 and NAM4.
- Kirk Hollub at NOAA FSL processed the data from the two FSL sites, NAM1 and NAM2
- Dave Stowers at JPL processed the data from its receiver and the ASU met package in Moctezuma once we got the internet there working.
- Teresa van Hove at Suominet processed the data from the USMx and YESX sites installed courtesy of Rick Bennett.

**Data Set Summary**

We now show figures of the PWV data acquired from our 7 NAME-specific stations. Note the scales differ from site to site depending on both the range of PWV and the duration of the data acquisition period. We begin with USMx and YESX which were installed first.

![Figure 5. Preliminary PWV from Moctezuma (USMx). Time scale from June 13 (165) to July 28 (210). Since no surface pressure measurements were available in Moctezuma during this period, the surface pressure at Yecora measured by SMN has been scaled to the altitude of Moctezuma to estimate and remove the hydrostatic delay.](image-url)
Figure 6. PWV from Yecora (YESX). Time scale from June 13 (165) to July 28 (210). The sharp rise between DOY 183 and 187 (July 5) is the onset of the monsoon at Yecora.

Figure 7. PWV from Yecora (NAM1) from July 23 (205) to August 28 (242).

Figure 8. PWV from Mazatan (NAM4) from July 18 (200) to December 16 (351).

Figure 9. PWV from Tezopaco (NAM3) from August 4 (217) to December 16 (351).
Figure 10. PWV from Moctezuma (NAM5) from August 26 (239) to October 21 (295).

Figure 11. PWV from Creel (NAM2) from August 27 (240) to October 5 (279).

**Hurricane Javier:** We also note that a very interesting moisture event was captured by our instrumentation when the remnant of hurricane Javier moved northeastward through our GPS instrumentation domain from September 15 to 20, 2004 (DOY 259-264). The signature is evident in Figures 8-11. Graphs of the Javier PWV data time sequence for 12 of our GPS receivers are available at http://www.atmo.arizona.edu/faculty/research/gps/Javier/javier_pwv.html.

**VIII. Data Archive Access**

Researchers interested in gaining access to this data can contact the PI, E. Robert Kursinski at kursinski@atmo.arizona.edu. We will move the data to the UCAR JOSS NAME database (http://www.joss.ucar.edu/name/dm/archive/). Data includes

- Raw GPS
- Raw met package data
- Processed GPS
- Anemometer (Creel only)
- Web cam movie (Creel only)
IX. Ongoing Research

The funding for our project was focused primarily on making PWV observations during the NAME field campaign in the summer of 2004 and did not support much of the interpretation. Nonetheless we have begun research in several areas described briefly below.

Sensitivity of NAM precipitation to initial conditions

Figure 12. The 5 panels each show the time derivative of PW in mm/hour over the identical time interval, 22:15 to 22:30 UTC (15:15 to 15:30 MST) on July 29, 2004 (DOY 211) as produced by the WRF model at 1.8 km resolution. The difference between the panels is the initial PWV field. The percentage of the ETA analyzed PWV field used to initialize the WRF model run for the five panel is 90%, 92.5%, 95%, 100% and 105%. A uniform scaling is applied to all WRF grid cells.

By creating and examining many summertime forecast cycles, we have found that the Weather Research and Forecasting (WRF) model when run in very high resolution (≤ 1.8 km) is able to capture important features of summertime convection in the North American Southwest. In particular the convective storms are able to form over the topographical high points and migrate away from the topography as they evolve, a noticeable improvement over MM5. Thus WRF is apparently able to better capture the interactions between the topography, dynamics and energetics including diurnal heating and latent heat release. One of our key objectives embodied
in Walter’s master’s thesis (Kolczynski, 2006) has been to use our NAME observations to assess and quantify the WRF model performance in capturing the circulation, water vapor and precipitation in the SMO during the NAM. As Walter began his thesis research it became quickly apparent that the precipitable water vapor evolution produced by WRF was being dominated by errors in the upstream initial moisture conditions which were quite poor, particularly south of the US-Mexico border. Much of the moisture that passes through the southwestern US originates there where observations are quite limited. As such, Walter has adapted his research plan to assess (1) the sensitivity of the WRF forecasts to changes in the initial water vapor field, (2) the quality of the ETA analyzed water vapor field used to initialize WRF and (3) the accuracy of WRF forecasts when the initial field is apparently correct.

In the course of this work we identified a new variable, the time rate of change of the precipitable water vapor, $dPW/dt$, that has proven very insightful for visualizing and characterizing the time evolution of moist convection. As shown in Figure 1, PW changes rapidly and significantly around moist convection as the moisture concentrates into the atmospheric column during convection and then falls off rapidly as the convective perturbation passes. Mazany et al. (2002) used the rising portion of the PW signature to improve their prediction of lightning. As Figure 12 shows, the systematic rising and falling PW signature can identify convection in model output. In the Figure, transverse waves of moist convection are apparent as color dipoles with the direction of propagation indicated by the colors, green and blue, being the leading (rising PW) edge of the wave.

The 5 panels in Figure 12 show how the character and timing of the moist convection as represented by the WRF model vary with the amount of moisture available initially. All 5 panels show $dPW/dt$ at 3:30 PM MST on July 29, 2004. The differences between the 5 panels are relatively small changes in the initial ETA analyzed PW field ranging from 10% below to 5% above the analyzed moisture field. The substantial differences in the 5 panels clearly indicate that the magnitude and timing of the convection and precipitation is quite sensitive to the initial moisture available. One can see for instance that under wetter initial conditions, convection must have initiated and evolved significantly earlier which resulted in the convective storms that have intensified and propagated much further to the west by 3:30 PM local time. The propagation speeds are approximately 10 meters per second are likely tied to the mid-level wind velocity but this relation still needs to be examined further.

**Quality of initial conditions**

The results in Figure 12 raise an immediate question regarding how the accuracy of the (ETA) analyses used to initialize the forecast models compares with the sensitivity of the precipitation to the initial conditions. We are presently addressing this issue using the GPS data we acquired during this project. Based on comparisons of near-coincident GPS and radiosonde PW measurements in Tucson, the standard deviation of the GPS-radiosonde PW differences are approximately 1.9 mm (Minjarez, 2005), consistent with the findings of other research groups such as Gutman et al. (2004). This suggests the GPS PW accuracy is likely about 1.4 mm and certainly no worse than 1.9 mm, facts that we can use to estimate the ETA PW analysis accuracy at each of our GPS sites.

Table 3 summarizes our GPS-ETA comparisons to date from Carlos Minjarez Master’s thesis (Minjarez, 2005) and Walter Kolczynski’s ongoing analysis. In Tucson, where the ETA analyses include the assimilation of the twice per day radiosonde profiles, we estimate the 1-sigma ETA PW error to be 2.6 to 2.9 mm. At the sites far from radiosondes, the 1-sigma ETA
error increases to 3 to 4 mm. At Hermosillo and Puerto Penasco in Sonora, the 1-sigma ETA errors are 3.7 to 4 mm. To put this into perspective, a 5% change in the initial water vapor field that so dramatically altered the moist convective behavior in Figure 12 is equivalent to 2.25 to 2.5 mm at Hermosillo.

Based on these results we can reach a significant conclusion: the initial conditions currently being provided by ETA moisture analyses are simply inadequate for making accurate forecasts of summertime precipitation in the NAME region when convectively active conditions are present (which are typical during the monsoon). Furthermore, to the extent that precipitation analyses in the NAM region rely on accurate water vapor to estimate precipitation, the precipitation analyses must be degraded in the region. This conclusion also does not bode well for climatological hydrological studies in the region. The other obvious conclusion is that routinely available GPS PW observations in the region would substantially improve forecasts and analyses and would likely improve our general understanding of the hydrological cycle in the region significantly.

Table 3. Statistics of the ETA PW analysis evaluation for JJAS 2002 and 2003 and JJA 2004

<table>
<thead>
<tr>
<th>Location/Station</th>
<th>Year</th>
<th>GPS PWV – ETA PWV Bias(mm)</th>
<th>Standard deviation of ETA PW (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tucson/SA21</td>
<td>2002</td>
<td>2.36</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>2003</td>
<td>2.57</td>
<td>2.6</td>
</tr>
<tr>
<td>Douglas/SA24</td>
<td>2002</td>
<td>2.10</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>2003</td>
<td>1.35</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>1.88</td>
<td>3.3</td>
</tr>
<tr>
<td>Hermosillo/SA27</td>
<td>2003</td>
<td>1.61</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>2.31</td>
<td>3.8</td>
</tr>
<tr>
<td>Phoenix/SA31</td>
<td>2003</td>
<td>-0.61</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>1.20</td>
<td>3.1</td>
</tr>
<tr>
<td>P.Penasco/SA33</td>
<td>2003</td>
<td>-0.03</td>
<td>3.7</td>
</tr>
</tbody>
</table>

NAM Onset and Flow regimes

Bob Maddox and Carlos Minjarez are working on a short note discussing the variability of the monsoon onset and flow regimes in the North American Southwest as captured in the GPS PW and radiosonde mid-level wind data. The year to year variability that we have observed makes it very clear that one summer’s field campaign as was planned for NAME is insufficient to capture the variability of the region at least in terms of the onset of summertime into the region. Figure 13 compares the monsoon onset as captured by GPS PW data in 2004 and 2005 at Hermosillo and Douglas showing that the onset of the monsoon was earlier and more sharply defined in 2004 relative to 2005. A closer examination is underway examining the direction of the moisture flow revealing that it differs significantly from the southerly and southeasterly flow typically taken to be monsoonal.
Our research interests are tied in one way or another to determining how PW, dynamics, convection and precipitation are coupled in the NAM area. We plan to further examine interannual variability of moisture in the region and its relation to precipitation. Our Suominet GPS PWV record started in Tucson and Douglas in 2002 and Hermosillo, Puerto Penasco and Phoenix in 2003. Since the Yecora (YESX) and Moctezuma (USMX) sites were reinstalled in 2005 complete with internet access we hope to provide a long term record that began in 2004 with our NAME project. We have seen interesting hints of the impact of orography on the surface and column moisture in comparing our Mazatan and Hermosillo data records that we want to pursue in determining the influence of orography on circulation and precipitation. We also want to reprocess the GPS data to shorter 5 to 15 minute intervals instead of the current 30 minute intervals, in order to derive dPW/dt to better capture the PW variations and in particular waves of propagating convection.

To conclude this Section we note that we will present our data and research results at the NAME Science Working Group meeting this summer in Tucson.
X. Recommendation for permanent GPS receiver network in Northwestern Mexico

We recommend that a permanent GPS receiver network be implemented in Northwestern Mexico to provide a multi-functional network for atmospheric and solid earth research as well as surveying and to provide a backbone for an internet network in Northwestern Mexico. Such a network could be assembled relatively inexpensively either from existing older GPS receivers or new internet ready receivers and low cost surface meteorological packages. The internet could likely be paid for by the community where the internet would be placed as was accomplished in Mazatan. A quick summary of applications include

1) Atmospheric research and operational forecasting
   a) Weather forecasting which will use the network to determine the upstream moisture before it flows into the semiarid southwestern North America.
   b) Hydrology which will use observations of water in the gas phase to complement the rain gauge and radar network in the NAM area.
   c) Climatic monitoring which will use a long term, precise and all-weather hydro-meteorological record of the important and relatively remote and certainly poorly sampled NAM area.

2) Solid earth applications for a high-rate GPS network in Mexico
   a) High-precision tectonics characterized by measuring plate boundary deformation in and around the Gulf of California (a focus site for the NSF MARGINs program) and possible diffuse deformation within the Mexican Basin and Range province.
   b) Seismology using surface waves (e.g., Larson et al., SCIENCE, 2003) and records of near-field displacements captured by high-rate GPS receivers.
   c) a network complementing the US-based PBO facility by extending CGPS coverage into northern Mexico, and other relatively smaller-scale CGPS networks in southern Mexico.

3) Surveying and mapping applications such as exist in the Southwestern US in places like Tucson and Phoenix.

4) an Internet accessible phone/satellite network as required for data access which would provide a series of internet hubs at relatively remote locations across Northwestern Mexico, fulfilling the internet accessibility goal defined by the Mexican government.

XI. Evaluation of Project Success and Lessons learned

Overall we consider this project quite successful. With little funding we acquired 7 unique data sets characterizing the summertime water vapor distribution and its variations over a relatively remote area in the southwestern North America. These datasets complement our other GPS data sets in Sonora and the southwestern US by extending coverage into more remote and convectively active areas. Together these sets provide an important and complementary component of NAME by characterizing moisture behavior in the areas where much of the convective action takes place but was not well sampled by most of the other NAME instrumentation. Overall we believe these observations will provide unique insight into the behavior of the North American Monsoon and will contribute significantly to the NAME objectives of better models and predictions of warm season precipitation.
Lessons learned

We have learned a number of implementation lessons that we summarize briefly in the following list about the installation and operation of a GPS network in Mexico.

- More time is needed to set up such a network particularly when it includes internet and remote access. We started very late (mid-May) for capturing the monsoon onset (early July) at most of the sites.
- While we accomplished the project with support from many people, a more effective approach would be to include a few personnel fully dedicated to this project and only this project.
- All of the equipment should be fully tested together as a unit before sending it to Mexico. While we tested the GPS and the surface pressure, temperature and humidity instrumentation, we did not test the satellite internet which turned out to be difficult to debug remotely once it was in Mexico. This includes time to deal with problems experienced in obtaining accurate and relevant equipment information such as that from the Directway technical support.
- We made a mistake in locating some of our equipment at Mexican educational facilities during the monsoon period. The location selection was made for reasons of power and safety and anticipated local educational interest in the observations. However, the problem was that such facilities are closed and locked and virtually empty for the summer making it virtually impossible to fix problems if and when they occur during the monsoon. Problems related to educational facilities significantly affected the length of data acquired at the Moctezuma and Creel sites.
- A standardized equipment configuration would have made things simpler. However, since we were borrowing equipment, we had to adapt to the equipment we could readily obtain.

XII. Special Thanks

As we have indicated, this project was a collaborative effort involving many researchers who each made critical contributions to this project. Here we list many of them and their contributions.

Andrea Hahmann (UA and now NCAR) for participating in the early stages of developing the GPS receiver observational plan for NAME.

Yoaz Bar-Sever (JPL) for providing a GPS receiver and linux computer for the summer.

Rick Bennett for finding the funds and receivers and organizing the installation of the USMX and YESX receivers.

Miguel Cortez Vázquez (SMN) (mcortez@mailsmn.cna.gob.mx) for providing us the SMN surface meteorology data at Yecora for the summer of 2004.

Dave Gochis (NCAR) for general interest and supportive discussions regarding this project and the suggestion to contact Miguel Cortez Vázquez to obtain the Yecora SMN data which allowed us to convert the YESX and NAM1 GPS data sets to PWV.

Javier Gonzalez Garcia javier@cicese.mx at CICESE in Ensenada and others for installing the USMX and YESX receivers. Also for the subsequent removal and offloading of the data from these two receivers.
Seth Gutman (NOAA FSL) for helping us develop our plan and convincing FSL to provide us 2 complete sets of GPS receiver, meteorological package and computer.

Kirk Hollub (NOAA FSL) for assembling preparing the NAM1 and NAM2 equipment, training UA personnel, debugging and finding the NAM1 data on the GPS receiver and processing the NAM1 and NAM2 data sets.

Teresa van Hove (UCAR) for processing all of the disparate data sets we could throw at her.

Cyrus Jones (UA) for help in debugging the equipment prior to shipping it to Mexico.

Razmik Khachikyan (JPL) for offloading and processing data from the JPL receiver (NAM5) and met package.

Osvaldo Landavazo, Mayor of Mazatan, for allowing and partially funding our installation at Mazatan.

Mike Leuthold (UA) for providing many WRF computer runs to help in assessing expected behavior and help in configuring and debugging equipment prior to shipment to Mexico.

Dave Stowers (JPL) for working with us on the NAM5 setup, downloading the met package acquisition software and processing the data.

Stig Syndergaard for work on the original version of this project proposed to NOAA.

Chuck Weidman (UA) for building the protective casings for the web cameras.

Joe Zehnder (ASU) for providing the met package to accompany the JPL receiver in Mazatan.

and finally,

Jay Fein (NSF) for the insight and support to fund this effort on very short notice, without which none of this would have come to fruition.

XIII. References


Kolcynski, W., Sensitivity of summertime moist convection to initial moisture conditions, Master’s thesis in preparation, Department of Atmospheric Sciences, University of Arizona, 2006.


NAME web site: http://www.joss.ucar.edu/name/

Suominet home page: http://www.suominet.ucar.edu/support/index.html