J5.3 ONSET OF THE 2002 NORTH AMERICAN MONSOON: RELATION TO GULF OF CALIFORNIA SEA SURFACE TEMPERATURES

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1. INTRODUCTION

This research is a continuation of research described in Mitchell et al. (2002; henceforth M02), where satellite observations of sea surface temperatures (SST) and precipitation amount indicated that the onset of the North American (NA) monsoon was a function of SST. That is, as a coastal current of warm tropical water proceeds poleward along the west coast of Mexico, and into the Gulf of California (GC), monsoon rainfall breaks out shortly after SSTs exceed 26°C. Heavy rainfall began in northwest Mexico after GC SSTs south of the island region (archipelago) exceeded about 27-28°C, and in Arizona/New Mexico after SSTs exceeded 29°C north of the archipelago (northern 1/4 of the GC; henceforth northern GC or N. GC).

This evolution of the monsoon system is reflected in Figure 1, which shows the long-term monthly mean (1974-1993) seasonal evolution of SSTs in the GC and eastern Pacific and also deep convection, where outgoing longwave radiation (OLR) is a proxy for convective activity. Color changes indicate a SST change of 1°C, with dark orange corresponding to 29°C. Numbers indicate OLR values (W m^{-2}). We estimate the 240 or 250 OLR line as the approximate boundary of the NAM. The spatial SST resolution is 1°C, too crude to capture the actual SSTs in the GC (by mid-July, the entire GC is generally 29-30°C). Nonetheless, the SST evolution here captures the temporal trend. The eastern Pacific warm pool expands in May due to intense solar insolation in April. A poleward propagating warm current along the Mexican coast (Collins et al. 1997; Castro et al. 1994; Ripa 1997; Beier 1997) is most active in May, introducing tropical water into the GC and raising SSTs there in May, June and July. As this warm water moves northward, so also does deep convection, evidenced by the movement of the 250 OLR line.

The M02 study was based on six monsoon seasons. More seasons should be analyzed to test and verify the conclusions in M02. Five of the six monsoon seasons studied in M02 were prior to

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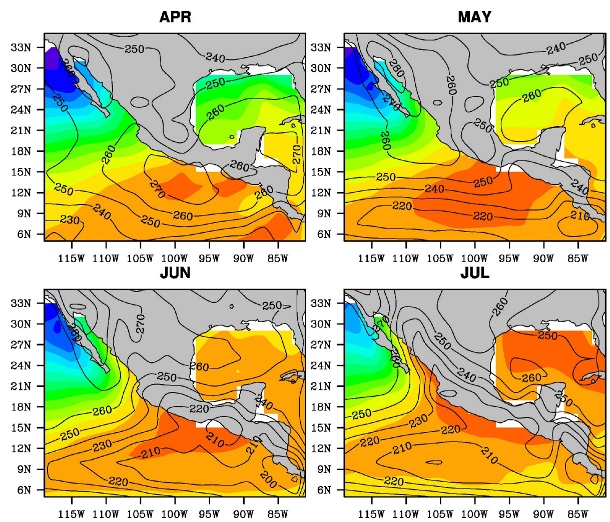

Figure 1. Long-term mean (1974-93) seasonal evolution of SST fields (°C) and OLR fields (W m^{-2}) in the eastern Pacific and monsoon region. Color changes indicate an SST change of 1°C, with dark orange corresponding to 29 °C. Numbers indicate OLR values.

1998. New satellite products since then have provided new ways of testing the proposed linkage between GC SSTs and monsoon rainfall. In this study, we use 14 km resolution SST fields taken every 2 days by NOAA-16; 24 hour blended geostationary passive microwave-based rain accumulation (mm) from the Naval Research Laboratory (Monterey, California, Marine Meteorology Division), initially at 0.1-degree/pixel resolution; total precipitable water (mm) from the NOAA GOES sounder, and wind data from Unisys Corporation. The websites containing this information are as follows:

http://www.osdpd.noaa.gov/PSB/EPS/SST/data/gulfcalf.c.gif

http://www.nrlmry.navy.mil/sat_products.html

http://www.nrlmry.navy.mil:80/sat-bin/display10?PHOT=yes&AREA=pacific/eastern/tropics&PROD=vapor&NAV=tropics&ARCHIVE=latest&CGI

http://weather.unisys.com/upper_air/ua_850_inv.html

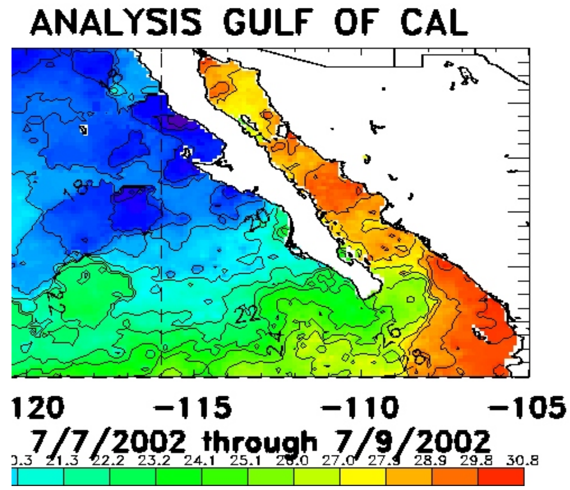

Figure 2. Gulf of California SSTs just prior to warming.

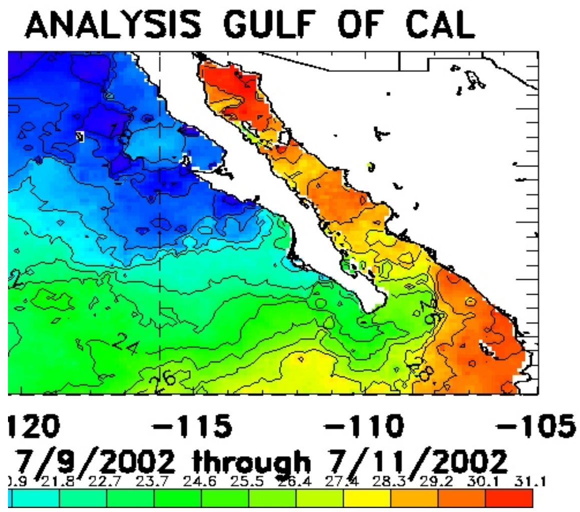

Figure 3. Gulf of California SSTs about two days later showing an SST increase of about 2.4°C in the northern GC.

The 2002 NA monsoon officially began in Phoenix Arizona (AZ) on July 9th. Monsoon onset is defined by the weather service as the daily average dewpoint temperature T_d exceeding 54°C for 3 consecutive days. The T_d on July 8th was 38°F, and was around that value for the previous July days. On July 9th, T_d jumped to 58°F, and remained relatively high for the rest of the month (mean T_d for period July 9-31 was 57± 5.3°F).

This dramatic rise in T_d corresponds exactly with a dramatic rise in the northern GC SST, as illustrated in Fig. 2 and 3. This NOAA SST data gives 3 day means and is taken every two days. So on average the N. GC SST on July 8th was about 27.4°C, while on July 10th it was 29.8°C. Over about a 2 day period, the N. GC SST increased about 2.4°C. Prior to the 8th, N. GC SSTs were not warmer than those in Fig. 2. In M02, a key finding was that heavy rainfall over AZ commenced only after N. GC SSTs exceeded about 29°C (depending on satellite source). If low level winds were favorable, the above SST increase may explain the increase in T_d at Phoenix on July 9th. Fig. 4 shows 850 mb winds at 00 UTC on July 10th, which correspond to 5:00 pm MST on July 9th. Winds do appear to be southerly, but there is also a flow of moist air from the Gulf of Mexico into New Mexico, and some of this air mass may be entering AZ. But other data may clarify this uncertainty in moisture source.

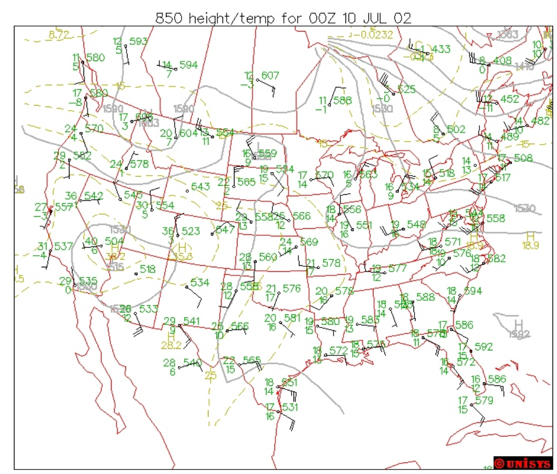

Figure 4. 850 mb winds at 5 pm MST on July 9th.

We now inspect the GOES Sounder total precipitable water vapor (PW) images for July 7, 9 and 11 taken at 00 UTC, or 5 pm MST the previous day. These are shown in Fig. 5, 6, and 7. Numbers in white show PW in mm for various stations, while red color corresponds to the highest PW levels, then yellow, then green, then blue, and then brown. Grey and white regions identify clouds, where PW retrievals cannot be made. Low level winds at 850 mb are shown by the yellow vectors.

The PW image for July 7th is prior to the SST increase, the image for July 9th is during the SST increase, and the image for July 11th is probably after the increase. While light and variable winds make it

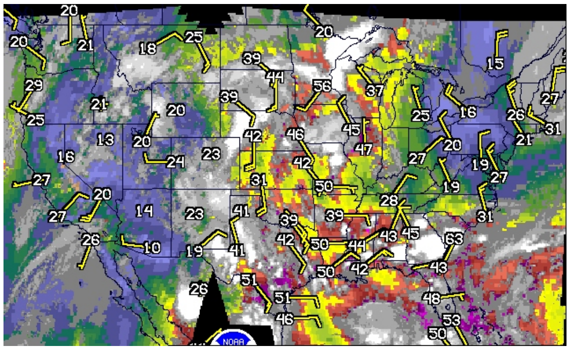

Figure 5. Total precipitable water vapor for 7 July at 00 UTC, or 5 pm MST July 6th. Also shown are 850 mb winds.

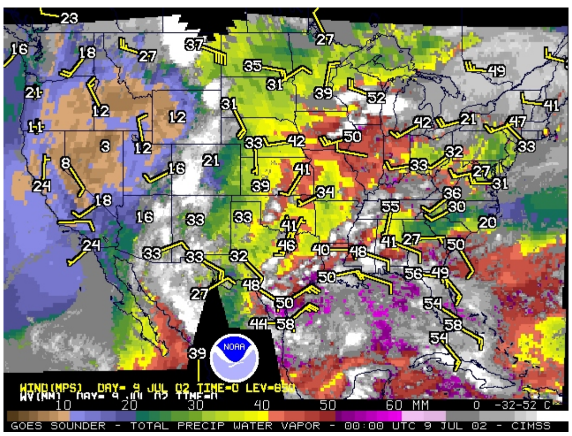

Figure 6. Same as Fig. 5 but for July 9th at 00 UTC.

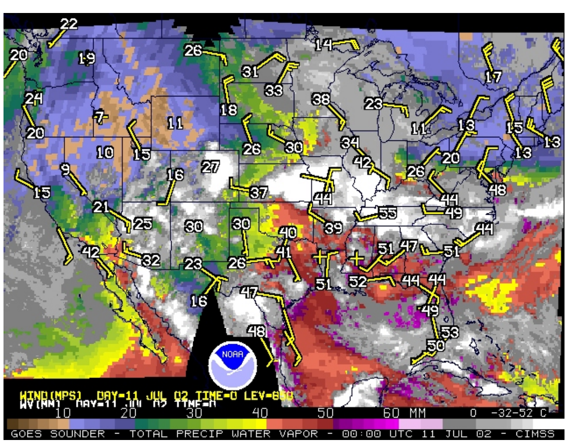

Figure 7. Same as Fig. 5 but for July 11th at 00 UTC.

difficult to decipher the mean wind flow, the evolution of PW and cloud fields suggest a very moist southerly flow out of the GC, with deep convection propagating northwards on the 9th, then being advected eastward on the 11th by westerly winds. This appears to be a very common pattern typical of the period during and after monsoon onset, where moist air from the GC and the Gulf of Mexico appears to interact with frontal boundaries near the Canadian border, producing supercells. The evolution of PW over the N. GC supports the findings in M02, that a critical SST of 29°C exists for the N. GC, above which deep convection and heavy rains commence over AZ. That is, the evolution of PW coincides with the increase in N. GC SST. On the 11th, a plume of moist air exits northward out of the GC into California and AZ. PW levels over the GC are about 45 mm.

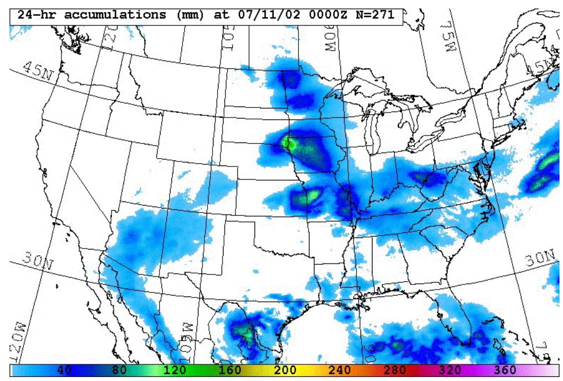

Figure 8. 24 hour rainfall accumulations (mm) for July 11 at 00 UTC, or 5 pm MST on July 10th.

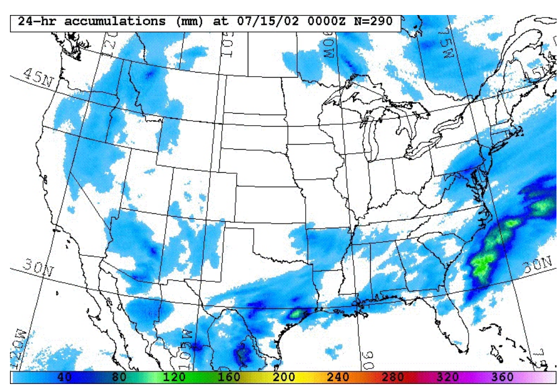

Figure 9. Same as Fig. 8, but for July 15th at 00 UTC, or 5 PM MST on July 14th.

Finally, we evaluate the satellite rainfall estimates over the monsoon region. Prior to July 10th 5 pm MST, satellite rainfall estimates showed light rainfall in eastern AZ on July 9th and possibly the 8th UTC (Tucson measured 0.05 inches on the 9th, the 1st rainfall for the monsoon season). But on the 10th rainfall amounts over AZ appeared much greater and covered most of AZ, as shown in Fig. 8. This is the time that N. GC SSTs reached about 30°C, and is consistent with the 29°C threshold finding in M02 for heavy rainfall. As discussed in M02, moisture is typcally transported out of the GC on the order of 500 km per day, which can easily account for rainfall over AZ within 24 hours. Figures 7 and 8 both suggest moisture is moving up the GC axis and into AZ, where it is advected eastward by westerly winds.

During July 13th (not shown) and 14th UTC, moisture was circulated further north as shown in Fig. 9 and 10. Moisture over AZ and the GC was apparently rotated around a high centered over S. Idaho as shown by the 700 mb heights in Fig. 10. This resulted in the rainfall pattern over the western U.S. shown in Fig. 9. Figure 9 gives 24 hour rainfall accumulation just prior to 5 pm MST on the 14th. On July 14th, Tucson received 0.96 inches of rain, its largest daily allocation for the monsoon season. Also on the 14th, strong thunderstorm winds forced the closure of the Phoenix International airport for many hours, causing extensive damage and many flight cancellations. Phoenix received 0.77 inches of rain that day (mostly after 5 pm).

The onset of the 1999 monsoon reported in M02 was very similar to the onset of this 2002 season, and resulted in a major flash flood in Las Vegas Nevada, causing over $20,000,000 in property damage. Rainfall over AZ commenced in July of 1999 within 24 hours after the N. GC SST threshold of 29°C was exceeded, and the Vegas flood followed a few days later. It is possible that the first heavy summer rains are associated with the most violent thunderstorms, and more research should be focused on this possibility and the attendant mechanisms.

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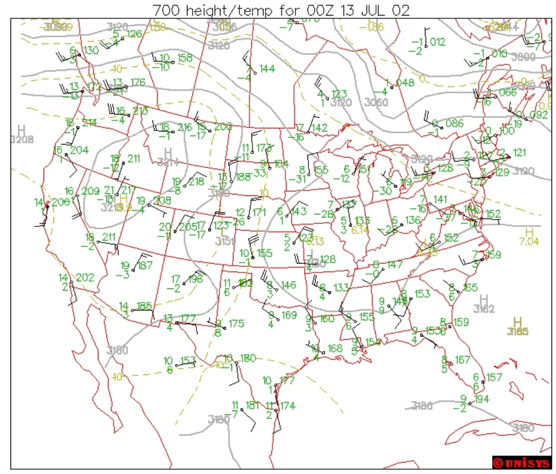

Figure 10. 700 mb winds at 5 pm MST on July 12th.

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