National Weather Service

Gulf of California Moisture Surges

Gulf of California moisture surges, or simply Gulf Surges, are one of the most researched components of the North American Monsoon. As early as the 1970s, Gulf Surges were identified as a key contributor to thunderstorm development (Hales 1972; Brenner 1974). In 1990 and 1993, the Southwest Area Monsoon Project (SWAMP) was conducted to investigate these features (Reyes et al. 1994, Douglas and Li 1996). They came under even closer scrutiny during the North American Monsoon Experiment (NAME) in 2004 (Higgins, et al. 2006; Higgins and Gochis 2007). The reasons why Gulf Surges develop are varied and complex (Zehnder 2004), which makes forecasting them a challenge. However, knowing the strength, timing, duration, and amount of moisture these surges transport northward is critical to correctly forecasting thunderstorm outbreaks in the monsoon region, especially over Sonora, Arizona, and adjacent Great Basin states.

During the monsoon season, water temperatures in the Gulf of California warm to 90°F (32°C). Considerable moisture evaporates into the atmosphere, with surface dewpoints occasionally climbing above 80°F (25°C). During July and August, an area of low pressure tends to linger along the Colorado River as temperatures over 105°F (40°C) cause the air to become less dense and rise. Meanwhile, cooler water off the west coast of Baja California lowers air temperatures to 85-90°F (29-32°C) at the southern end of the Gulf, and creates an area of relatively high pressure. The resulting air pressure imbalance between the two ends of the Gulf causes winds to generally blow up the Gulf during the monsoon **(Figure 1)**.

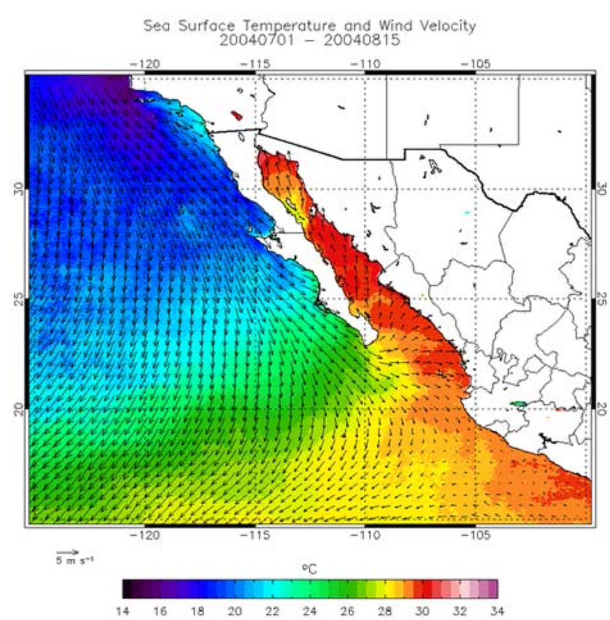

Figure 1: Mean sea surface temperatures (color) and mean surface wind, 1 July-15 August 2004. From Johnson, et al.

Douglas (1995) and Johnson et al. (2007) both indicated that this flow typically is about 4000 feet deep, tends to be strongest between midnight and 9am MST, and weakest during the afternoon. The core of the strongest winds is typically found about 500 feet above sea level with an average speed around 18mph (8.0 m/s). This nocturnal southerly flow occasionally extends north into extreme southwest Arizona. However by the time they arrive in Arizona, the flow is usually quite shallow, develops later in the night, and dissipates earlier in the day. These limited moisture incursions then tends to dissipate during the day as daytime heating takes place and mixes the lower atmosphere.

However, there are certain weather conditions that can greatly enhance this low level flow, and lead to significant increases both the amount and depth of the moisture that is pushed into Arizona. There are several ways to classify Gulf Surges, but in general, Fuller and Stensrud (2000) offers a useful summary of weather changes that occur as they push north from the northern Gulf of California:

- A significant increase in sea level pressure
- A significant increase in surface dewpoint temperatures
- A significant drop in surface temperature
- Greatest cooling and moistening found just above the surface
- Greatest cooling and moistening found along the northern Gulf shoreline, with decreased cooling and moistening as the surge fans out into the deserts of Arizona

The most common way to turn the normal low level flow into a Gulf Surge is to push thunderstorm outflows into the central or northern Gulf of California. Large thunderstorm clusters develop frequently over the Sierra Madre Occidental during the monsoon, usually as an upper tropospheric low moves west across northern Mexico, or as a tropical wave passes across central Mexico. The rain falling from these thunderstorms creates areas of cool high pressure which extend into the Gulf. As long as the atmospheric pressure remains relatively low over the Colorado River Valley, the high pressure cells moving out into the Gulf will enhance the preexisting air pressure differences, will enhance the flow up the gulf, and will feed more moisture into Arizona. The rain-cooled air moving north with the outflows will also bring considerable moisture with them. These surges can get quite deep, sometimes extending up to 10,000 feet MSL. However, the areas of high pressure tend to weaken rapidly as they move away from the thunderstorms that produced them. Since these surges typically last only a few hours, they transport only limited additional moisture into Arizona. However these outflow surges, or as Adams and Comrie (1997) named them: “minor surges”, can enhance thunderstorm development over Arizona, particularly if moisture is already rather plentiful, or if other triggering mechanisms are present.

In contrast, major surges usually involve the entire Gulf of California. It is still not entirely clear how these surges initiate, but extensive research has shown that a strong disturbance near the mouth of the Gulf of California, usually a tropical cyclone or tropical wave, can force more air into the southern Gulf of California than usual. The push of slightly cooler air apparently starts a complex process where an intense atmospheric wave, or series of waves, is forced up the Gulf between the two mountain ranges on either side. These waves can move at over 30 mph, and greatly enhance the typical low level flow. Winds as high as 50 mph have been detected just a few hundred feet above the surface with the strongest surges, and despite being rather shallow, this enhanced, moisture-laden, low level flow can push deep into Arizona. Instead of mixing out like thunderstorm outflows, these surges can continue well into the day, and can even continue over a couple of days. An example of a strong Gulf Surge, which is described in detail by Rogers and Johnson (2007) is shown in **Figures 2 and 3**.

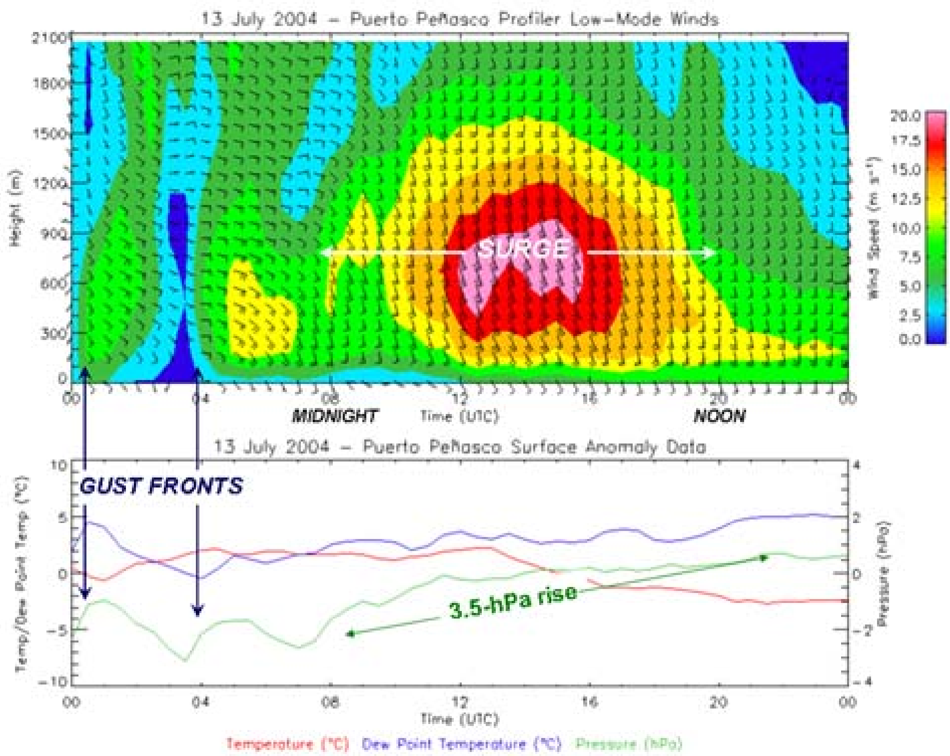

Figure 2: Weak outflow Gulf Surges are followed by a strong (gravity wave) Gulf Surge at Puerto Peñasco, Sonora, 13 July 2004. Note the 20 m/s (45mph winds) just above the surface between 12 UTC (5am MST) and 19 UTC (Noon MST). [NAME data repository on line at http://www.eol.ucar.edu/projects/name

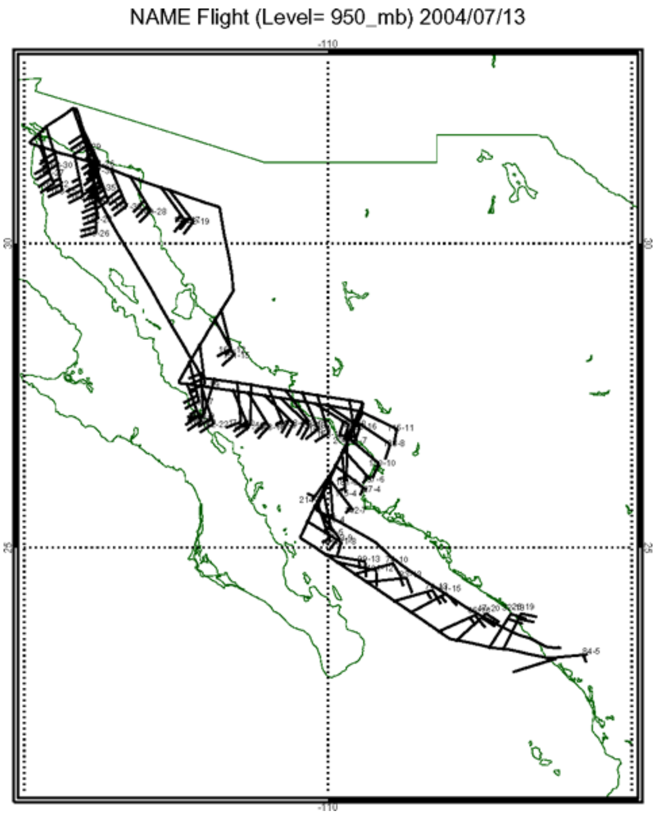

Figure 3: NOAA-P3 aircraft data from a Gulf Surge on 13 July 2004. Winds are at 950mb/about 1000ft above sea level. East winds at the southern end were from outflows pushing off the Sierra Madres and a tropical storm well to the south. Farther north, the winds were accelerating from 20-30mph at mid-Gulf to 35-45mph at the northern tip. (NAME data repository)

Strong surges, especially if they last for at least 12 hours, can cause surface dewpoints in the Arizona deserts to soar above 65°F, and sometimes as high as 75°F. However, the more humid airmass also does not heat up as much as a drier airmass. Surges also bring the slightly cooler air temperatures from the Gulf into the state. Thus on the same day a surge pushes into the deserts, afternoon temperatures may be held down by a few degrees. That can actually suppress thunderstorm development despite the significant humidity increase. Eventually though, usually by the next day, as the moist and relatively cool air mixes deeper into the atmosphere, the deserts once again heat up, while the additional moisture brought into Arizona by the surge, provides the fuel for widespread thunderstorms and heavy rain.

References

Adams, D.K., and A.C. Comrie, 1997: The North American Monsoon. *Bull. Amer. Meteor. Soc.,* **78,** 2197-2213.

Brenner, I.S., 1974: A surge of maritime tropical air – Gulf of California to the Southwestern U.S. *Mon Wea Rev,* **102,** 375-389.

Douglas, M.W., 1995: The summertime low level jet over the Gulf of California. *Mon. Wea. Rev.,* **123,** 2334-2347.

Douglas, M.W., and S. Li, 1996: Diurnal variation of the lower tropospheric flow over the Arizona low desert from SWAMP-1993 observations. *Mon. Wea. Rev.,* **124,** 1211-1224.

Fuller, R.D. and D.J. Stensrud, 2000: The relationship between tropical easterly waves and surges over the Gulf of California during the North American Monsoon. *Mon Wea. Rev.,* **128,** 2983-2989.

Hales, J.E.: Surges of maritime tropical air northward over the Gulf of California. *Mon Wea Rev,* **100,** 298-306.

Higgins, R.W., and Coauthors, 2006: The North American Monsoon Experiment (NAME) 2004 field campaign and modeling strategy. *Bull. Amer. Meteor. Soc.,* **87,** 70-94.

Higgins, R.W., and D Gochis, 2007: Synthesis of results from the North American Monsoon Experiment (NAME) process study, *J. Climate,* **20,** 1601-1607.

Johnson, R.H., P.E. Ciesielski, B.D. McNulty, P.J. Rogers, and R.K. Taft, 2007: Multiscale variability of the flow during the North American Monsoon Experiment. *J. Climate,* **20,** 1628-1648.

Reyes, S., M.W. Douglas, and R.A. Maddox, 1994: El Monźon del suroeste de Norteamérica (TRAVASON/SWAMP). Atmósfera, **7,** 117-137.

Rogers, P. J. and R.H. Johnson, 2007: Analysis of the 13-14 July gulf surge event during the 2004 North American Monsoon Experiment. *Mon. Wea. Rev.,* **135,** 3098-3117.

Zehnder, J.A., 2004: Dynamic mechanisms of the gulf surge. *J. Geophys. Rea.,* **109,** D10107, 14pp.

National Weather Service