Relationships Between Gulf of California Moisture Surges and Tropical Cyclones in the Eastern Pacific Basin

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1.0 Introduction

Relationships between Gulf of California moisture surges and tropical cyclones (TC's) in the eastern Pacific basin are examined. Standard surface observations are used to identify gulf surge events at Yuma, Arizona for a multi-year (July-August 1977-2001) period. The surges are related to TC's using National Hurricane Center 6-hourly (HURDAT) track data for the eastern Pacific basin (Neumann et al. 1999). CPC observed daily precipitation analyses (Higgins et al. 2000) and the NCEP Regional Reanalysis (Mesenger et al. 2004) are used to examine the relative differences in the precipitation, atmospheric circulation and moisture fields for several categories of surge events, including those with direct, indirect, and no relationship to TC's.

It is shown that the response to the surge in the southwestern U.S. and northwestern Mexico is strongly discriminated by the presence or absence of TC's. Surges that are related to TC's tend to be associated with much stronger and deeper low-level southerly flow, deeper plumes of tropical moisture, and wetter conditions over the core monsoon region than surges that are unrelated to TC's. The response to the surge is also strongly influenced by the proximity of the TC to the GOC region.

This study is an extension of a recent study by Higgins et al. (2004) which examined relationships between moisture surges at Yuma AZ and precipitation in the southwestern United States for several categories of surge events, including those that were relatively strong (weak) and those that were accompanied by relatively wet (dry) conditions in Arizona and New Mexico (AZNM) after onset. Higgins et al. (2004) showed that the occurrence of wet versus dry surges in AZNM was not discriminated by tropical easterly waves or midlatitude westerly waves, but rather by the relative location of the upper-level monsoon anticyclone in midlatitudes at the time of the gulf surge.

2.0 Data Analysis

For all fields anomalies are defined as departures from base period (1979-2001) mean daily values. Time series for July-August 1977-2001 were constructed for each field prior to the analysis, except for Regional Reanalysis fields, which were only available during and after 1979. Surface observations for Yuma, AZ were missing during July-August 1992.

Statistical significance tests were performed on each anomaly pattern (shown in Figs. 2-11 below). Shaded anomalies on the figures were found to be significant at the 95% confidence level for the most part, except in a few cases when the anomalies were weak (usually several days before or after the onset date of the Yuma surges).

Surges were identified using the method of Fuller and Stensrud (2000), but with modifications as discussed in section 2.1 of Higgins et al. (2004). In this study the surges are further classified based on their relationships to eastern Pacific TC's. In particular, if a TC crossed 110°W within 3 days of a Yuma surge, then it was considered to be TC-related. All other surges were considered to be unrelated to TC's. Sixty-five of the 142 Yuma surge events were TC-related, with the remaining 77 cases not related to TC's.

For compositing purposes, the TC-related surge cases were further subdivided into those that appeared to have a direct (indirect) influence on the Yuma surges. To make this procedure objective, Eastern Pacific TC's are said to have a direct influence if the TC center of circulation moved Northwest or North to within 3° of Baja California, the Gulf of California or the Mexican Mainland (poleward of 22°N) within 3 days of onset. All other TC-related surge cases have an indirect influence.

3. Tropical Cyclone Tracks

The individual tracks for all the TC-related surges as captured by the Regional Reanalysis as well as the mean tracks for both direct and indirect cases in the Regional Reanalysis and in observations are shown on Fig. 1. TC center locations and intensities in the Regional Reanalysis are based on daily maximum surface wind speeds and daily minimum central pressures. Mean positions of the TC's in the Regional Reanalysis and in observations for both direct and indirect cases are shown from day -3 to day +3 relative to the onset of Yuma surges. Overall, the RR has realistic TC tracks that compare well to observations, with a slight southward shift of the mean position relative to observations.

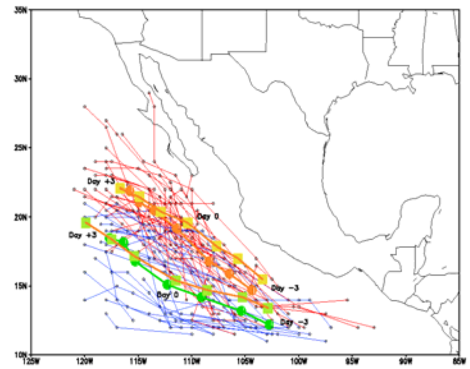

Figure 1. Tropical Cyclone (TC) tracks within 3 days of Yuma surges from the NCEP Regional Reanalysis. Yuma surges with direct (indirect) relationships to TC's are indicated by red (blue) lines. The mean tracks from the Regional Reanalysis (closed circles) and from observations (closed squares) for both the direct and the indirect cases are also shown. The day relative to onset is indicated along the mean tracks.

4. Precipitation Patterns

The composite evolution of daily precipitation anomalies over Mexico and the conterminous United States for all surges keyed to Yuma (Fig. 2a) show southeast to northwest progression of positive precipitation anomalies along the west coast of Mexico toward Arizona. Just prior to onset the conditions are drier than normal in northwestern Mexico and wetter than normal in southeastern Mexico. During onset, positive anomalies span the west coast of Mexico. After onset, positive anomalies are found in northwest Mexico and Arizona. The magnitude and areal extent of the anomalies increase considerably for TC-related surges (Fig.

2b) when compared to those that are not related to TCs (Fig. 2c).

The composites in Fig. 2b were divided into direct (Fig. 3a) and indirect cases (Fig. 3b). The composites for surges that are directly related to TC's show a southeast to northwest progression of large positive anomalies over Mexico just prior to onset, and Arizona after onset. The composites for cases that are indirectly related to TC's show positive anomalies along the west coast of Mexico and negative anomalies further to the east throughout the evolution, consistent with the location of these TC's further to the south and west. Other aspects of these precipitation composites (e.g. net increase or decrease in rainfall, fraction of total July-August precipitation associated with surges, changes in precipitation frequency) are examined in Higgins and Shi (2005).

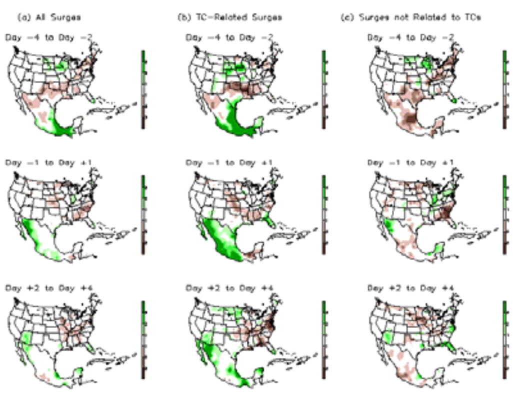

Figure 2. Composite evolution of accumulated precipitation anomalies (mm) for (a) all surges, (b) TC-related surges and (c) surges not related to TCs. Surges are keyed to Yuma, AZ.

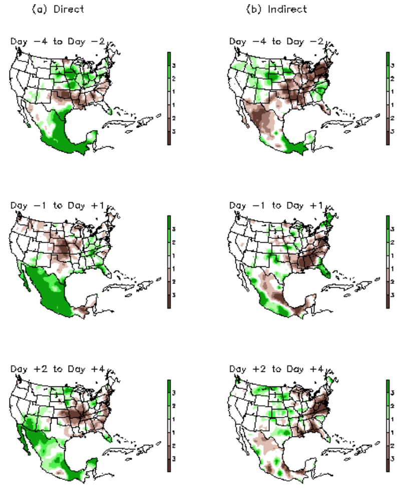

Figure 3. Composite evolution of accumulated precipitation anomalies (mm) for Yuma surges with (a) Direct and (b) Indirect relationships to TC's.

5.0 Circulation and Moisture Fields

In the previous section we found that TC-related surges are the most prolific rain producers in the GOC region, especially for surges with a direct relationship to TC's. To understand why this is the case, it is important to distinguish the circulation and moisture fields for each category of surge event.

5.1 Large-scale characteristics

The composite evolution of 925-hPa specific humidity and vector wind anomalies show enhanced southeasterly flow and moist conditions both in the vicinity of the GOC and to the southwest during and after onset of the surges at Yuma (Fig. 4). There is considerably more low level moisture present in the GOC region for the TC-related surges (Fig. 4b) than for surges that are not related to TC's (Fig. 4c). Differences between direct and indirect cases (Fig. 5) are pronounced with moisture transport from the southeast along the entire GOC in the direct cases (Fig. 5a), especially during and after onset, and mainly to the west of the GOC in the indirect cases (Fig. 5b).

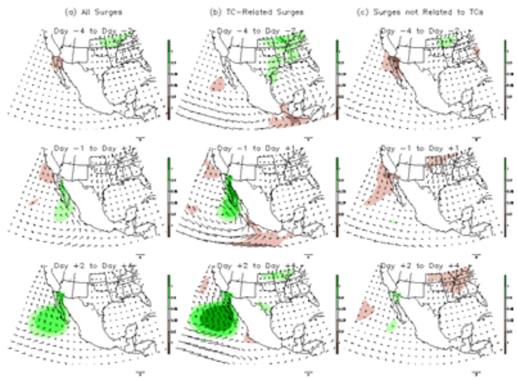

Figure 4. Composite evolution of 925-hPa specific humidity anomalies (g kg^{-1}) and vector wind anomalies (m s^{-1}) for (a) all surges, (b) TC-related surges and (c) surges not related to TCs.

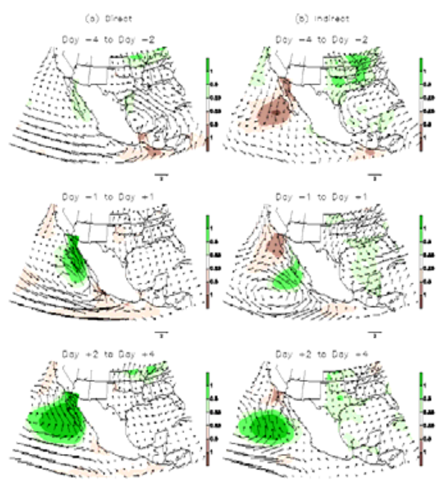

Figure 5. Composite evolution of 925-hPa specific humidity anomalies (g kg^{-1}) and vector wind anomalies (m s^{-1}) for Yuma surges with (a) direct and (b) indirect relationships to TC's.

The composite evolution of 200-hPa vector wind anomalies shows an anticyclonic anomaly over the western U.S. during and after onset for all surges (not shown). The composite shows strong northeasterly (and diffluent) flow over the southwestern U.S. and northwestern Mexico. The anticyclonic circulation feature is stronger and shifted to the southwest for the TC-related surges, reflecting the strong upper level divergence and anticyclonic circulation typically located directly over the TC's. The anticyclonic anomaly is somewhat stronger and closer to the west coast of North America for the direct cases and further from the coast for the indirect cases. The anticyclonic anomaly is replaced by a weak cyclonic one during the evolution of the surges that are not related to TC's.

Thus, it appears that two critical factors that help determine when TC-related gulf surges may produce wetter-than-normal conditions in AZNM are (i) the presence of a deep fetch of moist low-level southerly or southeasterly flow along the GOC associated with the passage of the TC to the west and (ii) the presence of a strong anticyclonic circulation at upper levels directly over the TC.

5.2 Regional characteristics

The NAME 2004 field campaign (Higgins et al. 2004) presented a unique opportunity to study tropical cyclone – moisture surge relationships in the Gulf of California region. The campaign featured observing system enhancements for monitoring and measuring moisture surge events including atmospheric profiling (radiosondes, pilot balloons and wind profilers) along the GOC as well as raingauge and radar data over western and northern Mexico. Ten

Intensive Observing Periods (IOP's) were carried out during the campaign, and the second of these (00Z 12 July – 00Z 15 July 2004) presented an opportunity to study the influence of Tropical Storm Blas on Gulf of California surge events. From that case, the following regional circulation characteristics were noted (Johnson, and Ciesielski, 2004):

- A strong North-South pressure gradient (heat low over SW US; pressure rises behind TS Blas);
- Increased easterly flow leading to storms moving off the SMO, with convective downdraft outflows, followed by surges at sites in the central and northern GOC;
- Pressure rises ~6 hPa over 8-10 h period; 2-3°C temperature drop; P-rise signal moved rapidly up Gulf (~25 ms-1)
- Peak surge winds near 1 km AGL; maximum wind ~20 m s-1 at Puerto Penasco; shallow convective outflows (wind peak near 300 m);
- Surge led to increase in precipitable water and rainfall over NW Mexico and SE Arizona.

Next we examine the extent to which these regional characteristics are captured in the surge composites using Regional Reanalysis data.

5.2.1 Pressure Jumps

The composite evolution of SLP and 700-hPa wind anomalies for all, TC-related and TC-unrelated surge composites was examined. Composites for Yuma surges with a direct relationship to TCs (Fig. 6a) exhibit a North-South pressure gradient (heat low over the SW US and pressure rises behind TC's moving away from the GOC) during the evolution, suggesting that this pressure distribution is common for surges in this category. An increase in easterly flow is clearly evident over northwestern Mexico and the northern half of the GOC during the onset period, consistent with the observation during NAME IOP 2 that increased easterly flow led to an increase in storms moving off the SMO (with associated convective downdraft outflows), hence to an increase in precipitation in the core monsoon region. High pressure shifts to the north during the evolution, covering most of Mexico during and after onset. Pressure differences between the northern and southern Gulf of California (~1 hPa) are much smaller than in the NAME 2004 case study, but generally in the same sense during the evolution. These features are also present for Yuma surges with indirect relationships to TC's (Fig. 6b), though the features are weaker still.

At central and northern GOC locations and over west central Mexico the pressure rises persist for roughly 4 days after surge onset, consistent with the observation in the NAME 2004 case study that pressure "rises to a new level" and then stays there following the passage of the surge.

Recall that the mean TC-tracks for direct and indirect cases are considerably different (Fig. 1). We speculate that differences in the TC-tracks associated with the direct and indirect cases are related to the intensity and westward extent of the subtropical anticyclone in the western Atlantic basin. This is clearly evident in Fig. 6c, which shows that the anticyclone is stronger and extended further to the west in the direct cases. In these cases the anticyclone exerts more of a steering influence on the TC's, guiding them along its western flank towards the GOC. In contrast, TC's in the indirect composite are not as strongly influenced by the anticyclone, and hence tend to move off to the west rather than northwest in the tropical eastern Pacific basin.

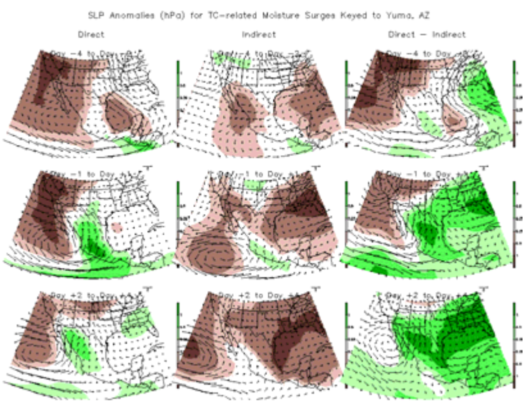

Figure 6. Composite evolution of sea level pressure anomalies (hPa) and 700-hPa vector winds (m s-1) for Yuma surges with (a) direct and (b) indirect relationships to TCs.

5.2.2 Propagation Speed

Time-latitude sections of the composite mean 925-hPa meridional wind anomalies at along-gulf locations (i.e. gridpoints with latitude and longitude coordinates along the GOC between 20 N and 32 N) were used to obtain estimates of the average propagation rates of surge events. Results for Yuma surges with direct, indirect and no relationship to TC's were examined (see Higgins and Shi 2005). The average propagation speeds of the surge events up the GOC are roughly 15 m s^{-1} between the southern GOC and northern GOC in all 3 composites. Note that the southerly meridional wind anomalies are largest for the direct cases and smallest for the cases with no relationship to TC's, consistent with the stronger meridional moisture transport along the GOC for the direct cases. The propagation rates found here are roughly a factor of 2 slower than those inferred during NAME IOP 2.

5.2.3 Wind and Moisture Profiles

The temporal evolution of vertical profiles of the wind and moisture anomalies were examined for each category of surge event. Results were examined at northern, central and southern GOC locations near Puerto Penasco (114°W, 32°N), Bahia Kino (112°W, 29°N), and Los Mochis (109°W, 26°N), respectively, to coincide with locations of windprofilers during the NAME 2004 field campaign (Higgins et al. 2004).

TC-related surges have stronger low-level southerly flow and more significant increases in moisture along the GOC than surges not related to TC's. Peak wind anomalies typically occur near 900-950 hPa (approximately 1 km AGL) at all 3 locations within a day of onset for TC-related surges. Surges at Bahia Kino and Puerto Penasco are characterized by easterly anomalies at mid-tropospheric levels during and after onset. Moisture anomalies are present for the longest period after onset at Puerto Penasco.

Surges that are directly related to TC's have dramatically stronger low-level southerly flow and the most significant increases in moisture along the GOC (Fig. 7). These events flood the AZ/NM region with abundant low-level moisture, leading to significant rains during and after onset (Fig. 3a). For surges that are directly related to TC's, the specific humidity anomalies are as large as 25% of the mean value at Puerto Penasco (Fig. 7). Deep easterly flow is present at midlevels both during and after onset at Bahia Kino and Puerto Penasco.. The low-level southeasterly flow weakens at Puerto Penasco after day +1 and is replaced by weaker southeasterly flow.

The results in the previous 3 subsections confirm many of the regional characteristics of the circulation and moisture fields noted in the NAME 2004 IOP 2 case study. Clearly there is a need to examine the individual cases in the composites, and especially the range of variability for specific types of synoptic disturbances associated with the surge events in an effort to sort out the potential mechanisms involved (e.g. Zehnder 2004).

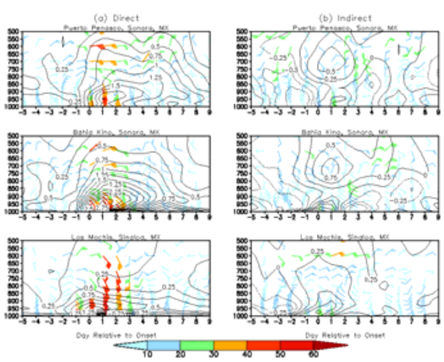

Figure 7. Composite evolution of vertical profiles of wind direction and wind speed anomalies (tenths of knots) and specific humidity anomalies (g kg^{-1}) at Puerto Penasco, Bahio Kino and Los Mochis for Yuma surges with (a) direct and (b) indirect relationships to TC's. . Wind barbs are used and wind barb flags are shown in tenths of knots where half a barb flag is 0.5 knots and a full barb flag is 1.0 knot. The wind barbs point in the direction the wind anomalies are blowing from (e.g. the barbs point upwards for southerly winds, etc.).

6.0 References

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