Analysis of the 13-14 July Gulf Surge Event During The 2004 North American Monsoon Experiment

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INTRODUCTION

Gulf surges are northward propagating disturbances along the **G**ulf **o**f **C**alifornia (GoC) that advect cool, moisture-laden air from the GoC or eastern tropical Pacific Ocean into the low deserts of the southwest United States and northwest Mexico during the **N**orth **A**merican **M**onsoon (NAM). High resolution observational data collected during the 2004 **N**orth **A**merican **M**onsoon **E**xperiment (NAME) (1 July to 15 August) are used to describe the structure and probable dynamical mechanisms of a significant surge event on 13-14 July.

DATA AND METHODS

Three **N**ational **C**enter for **A**tmospheric **R**esearch (NCAR) **I**ntegrated **S**ounding **S**ystem (ISS) sites were deployed at:

- Puerto Peñasco, Sonora
- Bahia Kino, Sonora
- Los Mochis, Sinaloa

Each site consisted of four major platforms:

- Vaisala GPS sounding system
- Enhanced surface observing station
- 915 MHz Doppler clear-air wind profiling radar
- **R**adio **A**coustic **S**ounding **S**ystem (RASS)

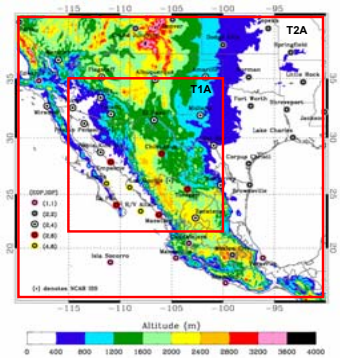


Figure 1: 2004 NAME rawinsonde sites. Site color code refers to number of launches per day during the **e**xtended **o**bserving **p**eriod (EOP) and nine **i**ntensive **o**bserving **p**eriods (IOP).

Rawinsonde data from the ISS sites and the NAME enhanced sounding network (Fig. 1) were objectively analyzed onto the:

- T2A domain at 00 and 12 UTC
- T1A domain at 00, 06, 12, and 18 UTC

Each domain has 1°x1° horizontal grid spacing every 25 hPa from 1000 to 50 hPa.

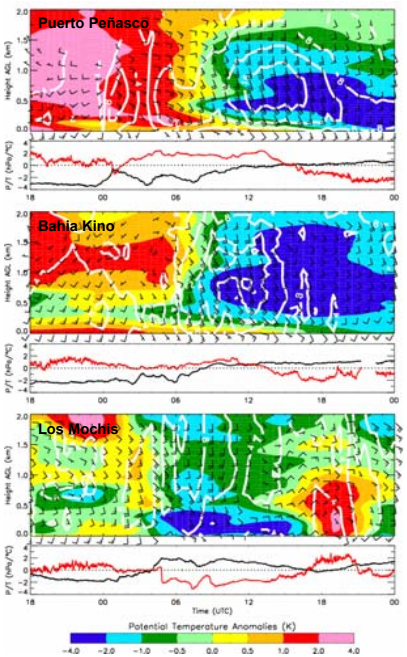
OBSERVATIONAL RESULTS AND DISCUSSION

Two transient synoptic features were evident on 13-14 July:

- **700 hPa: T**ropical **S**torm (TS) Blas moved northwest from the eastern Pacific Ocean to the west of Baja California.
- **200 hPa:** An inverted trough propagated westward across north central Mexico south of the subtropical high.

Gulf surge evolution from 00 UTC to 18 UTC 13 July (Fig. 2):

- 00 UTC: Strong convection developed along the Sierra Madre Occidental and south of the GoC in association with TS Blas. Surge initiation was observed over the southern GoC as a cold-air dome below 800 hPa.
- 06 UTC: A large mesoscale convective system built up near the central GoC as TS Blas' rain bands reached the gulf's mouth. The cold-air dome was ~2° latitude farther north and a low-level stable layer developed along the northern gulf.
- 12 UTC: Convection over the central GoC dissipated. Surge-related southeasterly wind (> 10 m s^{-1}) and moisture (> 15 g kg^{-1}) below 800 hPa propagated north of 28° N.
- 18 UTC: TS Blas' circulation dominated the southern GoC as the surge weakened slightly to the north.



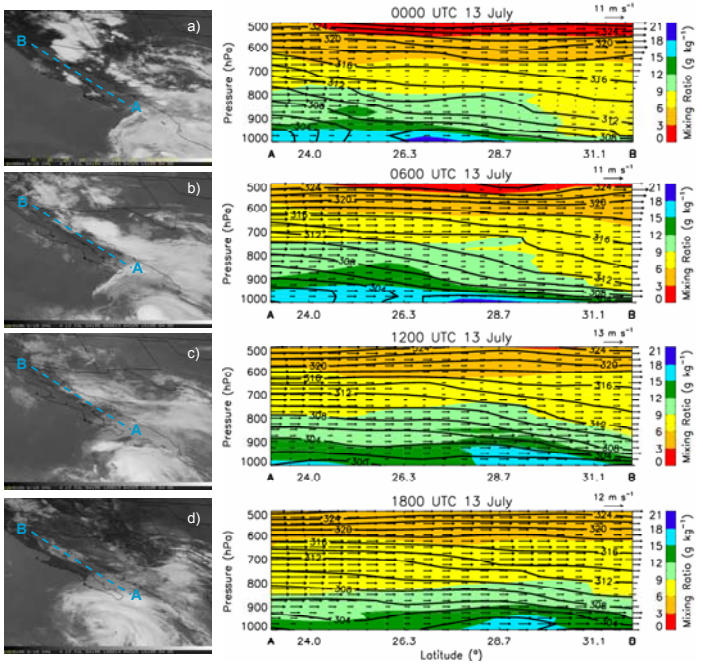


Figure 2: Left panels depict infrared GOES-10 satellite imagery over the core NAM domain at a) 2346 UTC 12 July, b) 0600 UTC 13 July, c) 1200 UTC 13 July, and d) 1800 UTC 13 July 2004. Right panels depict corresponding T1A potential temperature (K), mixing ratio (g kg^{-1}), and along-gulf wind component (m s^{-1}) along a cross section through the GoC from 23°N,108°W to 32°N,115°W (dashed line from **A** to **B**).

Gulf surge structure as observed at the ISS sites (Fig. 3):

- Puerto Peñasco and Bahia Kino, Sonora:

1) Gulf surge passage occurred between 06 and 12 UTC 13 July.
2) This was evident in strong (up to 20 m s^{-1}) south-southeasterly flow up to 2 km combined with anomalous cooling aloft (-2 to -4 K). Tongues of low-level cooling between ~250-500 m AGL preceded the deep-layer cooling.
3) Anomalous surface cooling occurred four to five hours later and pressures increased markedly, remaining at a new level thereafter.
4) Surge passage was preceded by strong anomalous lower-tropospheric warming (+1 to +4 K) at both sites and two convective outflows at Puerto Peñasco at ~00 and 04 UTC 13 July.

- Los Mochis, Sinaloa:

1) The gulf surge structure was different than at the northern ISS sites, possibly due to Los Mochis' more inland location and/or its remoteness from the northern GoC low-level jet.
2) Strong cooling beginning at ~04 UTC 13 July near the surface was due to a strong convective outflow, perhaps masking the low-level surge signal.
3) Moderate cooling (-0.5 to -2 K) and wind speeds (5 to 10 m s^{-1}) above the convective outflow signature were related to surge passage.

Figure 3: Top panels depict half-hour linearly interpolated sounding potential temperature anomalies (K) at the ISS sites from 1800 UTC 12 July to 0000 UTC 14 July. Also shown are profiler and surface wind data every hour. White contours highlight wind speed (m s^{-1}). Bottom panels depict surface pressure (hPa) (black) and temperature (°C) (red) anomalies. Anomalies (with tidal effects removed) calculated from 7 July - 14(15) August 2004 means.

DYNAMICAL MECHANISMS

Theories for gulf surges suggest they are either advective (gravity current, isallobaric flow) or propagating (Kelvin or Rossby wave) phenomena.

Tracking the centroids of wind-speed maxima at the three ISS sites (Fig. 3) yield surge propagation speeds of (assuming the surge is channeled along the axis of the GoC):

- ~17 m s^{-1} between Los Mochis and Bahia Kino
- ~22 m s^{-1} between Bahia Kino and Puerto Peñasco

Observations suggest that the initial surge impulse resembled a bore-like disturbance:

- The surge arrived along the northern GoC at night following the development of a nocturnal inversion.
- Downdraft outflows from surrounding convection impinging on this low-level layer could potentially trigger an atmospheric bore.
- The shelf-like layer of cooling just below 500 m at Bahia Kino and Puerto Peñasco may be evidence of bore-related cooling.
- The surface pressure rapidly rose and remained at a new level.

Following this initial impulse there was a deeper layer of cooling and strong wind, which may be related to a Kelvin wave-like disturbance that traversed the entire length of the GoC.

CONCLUSIONS

- Using high-resolution 2004 NAME data, the 13-14 July gulf surge structure and its properties have been defined in a detail heretofore not possible.
- The overall surge propagated rapidly north along the GoC (~ 17-22 m s^{-1}).
- The surge was characterized by sharp cooling and strong south-southeasterly wind in the lowest 2 km.
- Inferences regarding surge dynamics are inconclusive, but the weight of evidence suggests the initial surge impulse was a bore-like feature, followed by a Kelvin wave-like disturbance.
- Future work should further integrate other platforms from the 2004 NAME field campaign into the gridded analyses as a means to more accurately compare against mesoscale model simulations.

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