A PCA Analysis of the Behavior and Evolution of Gulf Surges at Yuma, AZ based on a 50-year Record of Increased Temporal Resolution

Nick Novella
Creighton University, Omaha, NE
nicknovella@creighton.edu

Abstract:

In determining synoptic and mesoscale relationships associated with rainfall regimes of the Mexican Monsoon, the gulf surge remains one the most important agents for transporting moisture across climatologically drier domains for both U.S. and Mexico. In this study, the primary focus centers on the preferred patterns of gulf surge variability as well as the synoptic and mesoscale forcing within the monsoonal circulation. Gulf Surge "types" were categorized via PCA Analysis. Moreover, the implementation of hourly data also provides a "finer" temporal resolution of the mean behavior and evolution of gulf surge events. Key surface variables in this analysis include pressure, wind speed, and dew point temperature over the past 50 years at Yuma, AZ.

I. Gulf Surge Cases: Organizing datasets and methods.

- Based on research by Hales (1972), Brenner (1974), and Douglas and Leal (2003), Gulf surge events have been described using standard atmospheric variables as well as factors that include moisture sources, triggers and forcing.

- All pertaining works treat the Gulf Surge as being an integral component of the Mexican Monsoon.

- Gulf Surge onsets at a fixed spatial location became commonly classified as a significant rise in dew point temperature and mean sea level pressure, and departure in temperature accompanied with strong winds out of the south.

- Utilizing this subjective scenario, a 50+ year hourly dataset was assembled in order to determine gulf surge events.

- Data matching gulf surge descriptions of varying magnitude, were then statistically tested to determine intermonthly and interannual variability with respect to other pertinent meteorological variables (ENSO, PDO/AMO, Subtropical Ridge positioning, SST's, and regional rainfall, etc.)

- However, it was unknown how to quantitatively and objectively assess the frequency and magnitude of gulf surges with respect to the climatology and variability of the monsoonal circulation.

- To remove any uncertainty and maintain uniformity with gulf surge research, it was therefore appropriate to develop an index equation for measuring and/or verifying gulf surge onsets. This index is based on the previously mentioned atmospheric surface variables.

II. The Gulf Surge Index (GSI): A quantitative analysis of gulf surge onsets for the purpose of classifying gulf surge cases.

- The GSI is a mathematical representation of previously defined subjective gulf surge criteria at Yuma, AZ. (See Novella, 2005). It consists of linear terms that quantitatively assess the onset of a gulf surge by calculating the mean 24-hour values and tendencies of key atmospheric variables described above. The magnitude of these trends is also a function of the 50+ year climatology of Yuma, AZ.

- The aim was to measure the intensity of gulf surges on a scale, similar to those used for identifying the convective intensity of a thunderstorm, a tornado, or a hurricane. (Safir-Simpson, Fujita, etc.)

- Values ≥ 10.00 indicate gulf surge onset for present day, with greater values proportional to surge intensity. From 1950-2004, there were **1453** days with GSI values ≥ 10.00.

- Gulf surge events (onsets), were classified as days with GSI values ≥ 10.00, but were preceded with at least one day of dryness (GSI < 10.00). From 1950-2004, there were **655** separate gulf surge onset events.

- "Significant" gulf surge events (constituting the upper 25 % percentile), were classified as days with GSI values ≥ 60.00, and were also preceded with at least one day of dryness (GSI < 10.00). From 1950-2004, there were **106** significant onset events.

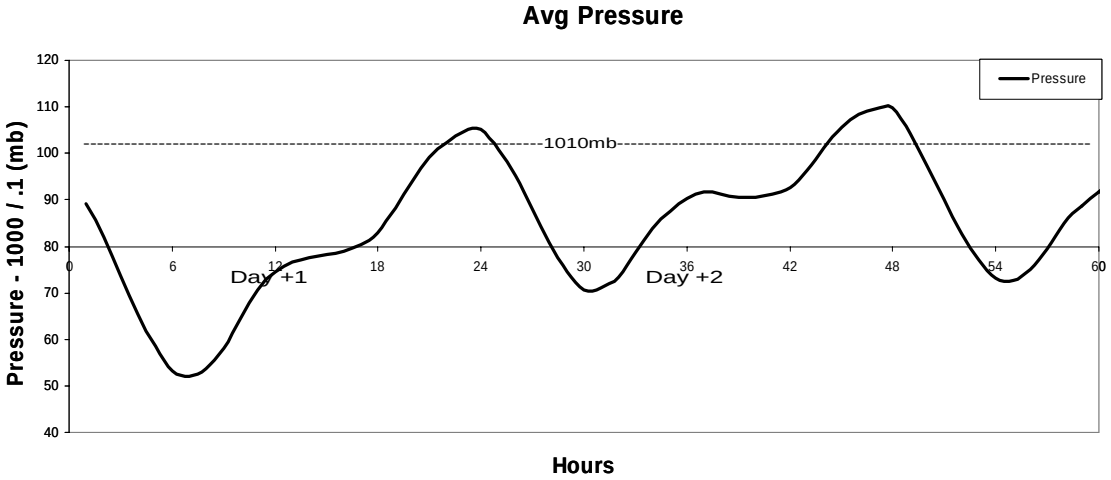
- The case studies presented in this paper, were based on **55** separate events with GSI values ≥ 60.00 (~ 1 event per year). Selection criterion was based on distinct events that were clearly separated from other minor surge events.

- Evolution of the gulf surge event was examined over a standard 60-hour period. The 60 Hour window was defined from 12 Noon LST (19Z) the day previous to observed surge onset to 12 Midnight LST (07Z) on the second day following the actual surge onset.

- By utilizing this "fine" temporal resolution, there was enough evidence to suggest that gulf surge evolution appeared to reflect more than one type of mesoscale or synoptic forcing.

III. Mean Behavior and Evolution: Exploring the mean lifecycle of the gulf surge with respect to pressure, wind speed, and dew point.

I. Evolution of Mean SLP with respect to time:



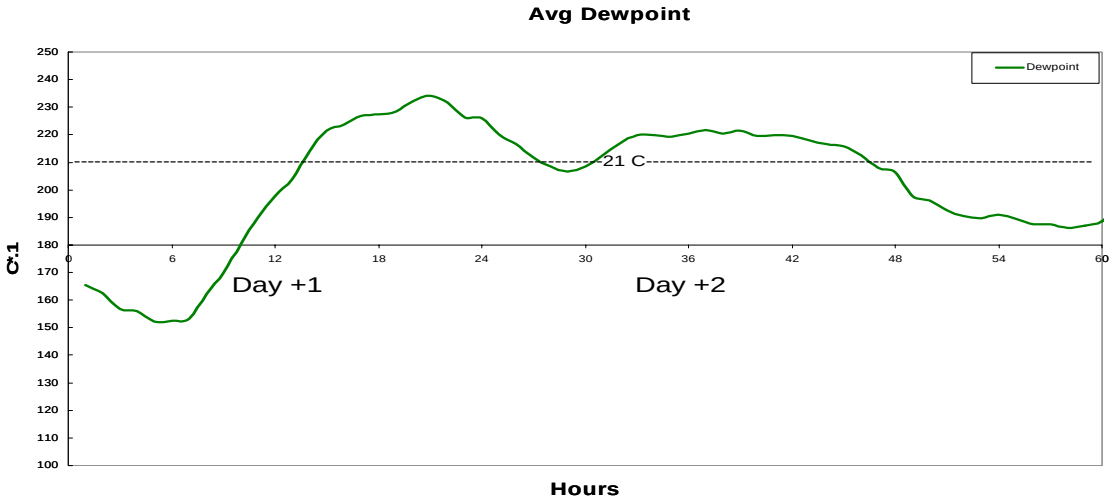
- Initial pressure rise with surge occurs at 6:00 P.M. LST (01Z) on Day -1. Pressure remains abnormally high throughout observed 60 hour period. SLP displays the greatest diurnal cycle compared to the other variables.

- Highest pressure peak (1010.9mb) during the surge occurs at 11:00 A.M. Day +2. This peak occurs after the peak in Dew point and Wind Speed. Pressure takes 17 hrs to achieve its first peak after surge onset (1010.5 mb) at 11:00 A.M. on Day +1.

- Though SLP most resembles the changes of diurnal heating, the lowest pressure occurs just prior to initial surge onset at 6:00 P.M. LST Day -1. This would indicate that Pressure patterns remain diurnal in behavior, but experience increased amplitude and phase shifts throughout surge event. Thus gulf surges are characterized by abnormally high pressure embedded within diurnal and nocturnal patterns.

- The lifecycle of SLP behaves differently than that of Dew point, and Wind Speed. This would also indicate that a general pressure rise would be the result of an invading air mass/boundary with embedded changes of dew point and wind speed

II. Evolution of Mean Dew point with respect to time:



- Mean Dew point rise occurs at 6:00 P.M. LST Day -1 and persists through Day +2 with notable diurnal pulses.

- The Dew point remains above climatological mean (18° C) after 60 hours, indicating an extended period of moisture. First Mean Peak at 23.4° C at 8:00 A.M. LST Day +1, Second at 22.1° C.

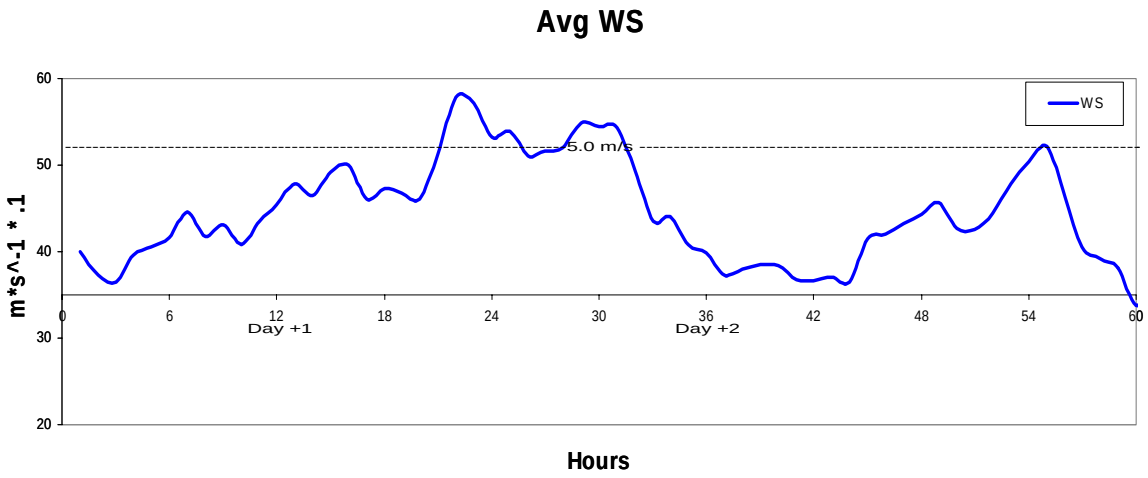
- Dew point oscillations appear to be directly affected by diurnal heating regimes, with amplitudes corresponding to nocturnal increases in humidity.

- Before the first peak, moisture decreases rapidly before onset of gulf surge. This occurs in late afternoon, and is coincident with the lowest mean pressure.

- The rapid onset of moisture takes an average of 14 hours to achieve its maximal mean dew point at 8:00 A.M. LST Day +1.

- Moreover, subsequent peaks appear to be better sustained after initial pulse (gulf surge onset), since lower-levels of the atmosphere are already moistened under a deepened boundary layer.

III. Evolution of Mean Wind Speed with respect to time:



- Mean Wind Speed increases gradually with highest winds occurring 2:00 P.M. LST Day +1. Wind Speeds remain above the climatological mean throughout the event with a 30 hour long building period.

- Unlike mean dew point tendency, wind speed displays a sharp drop-off by 6:00 P.M. LST on Day +1

- Compared to Pressure and Dew point fluctuations, the mean Wind Speed composite displays the greatest hourly "noise" along the time series.

- Highest peak wind occurs at 9:00 A.M. LST Day +1, which corresponds 1 hour after the highest mean dew point peak. A Second diurnal peak occurs at 6:00 P.M. LST Day +2 near the end of the mean composite.

- A number of significant wind speed peaks do not directly correspond with the general dew point pattern, however, the mean wind speed remains above climatological mean for entire event.

- With the initial onset, wind speed intensification contains a series of nearly sinusoidal waves in connection with moisture arrival (Noise or Real??)

- With respect to the diurnal cycle, wind speeds within the gulf surge event appear to be least affected by the diurnal cycle, and tend more towards forcing associated with MCS/MCC development or pressure gradient perturbations.

IV. Preferred Modes of Gulf Surges via PCA Analysis: Statistical Methods to produce Gulf Surge "Types" derived from Synoptic and Mesoscale Forcing

1. Statistical Methods:

- Fifty five cases of the strongest gulf surge events (GSI >75) were analyzed using both rotated and unrotated factor analyses of 3 key surge variables (SLP, Dew Point and Wind Speed). The analysis examined the evolution of these variables over a 60 hr period. The three variables were run together in a 55x180 matrix and individually as three separate 55x60 matrices.

- It was determined that both the combined variable and individual variable runs revealed similar behavior of evolution Dew point, mean sea level Pressure, and Wind speed. Thus, it was determined to confine all three variables within the matrix for analysis.

- In the analysis, 6 principal components were initially retained based on Preisendorfer's criteria for determining statistical significance. These top 6 modes yielded eigenvalues ranging from 37 to 8 with over 50% of the variance explained by the 6 principal components which are statistically significant at the 95% confidence level.

- The application of the North Test determined that modes 5 and 6 from the unrotated analysis were not separable though they appeared to be statistically significant based on Preisendorfer's criteria. Rotation of these 6 components still resulted in lower order modes that were characterized by low eigenvalues and small percent variance explained.

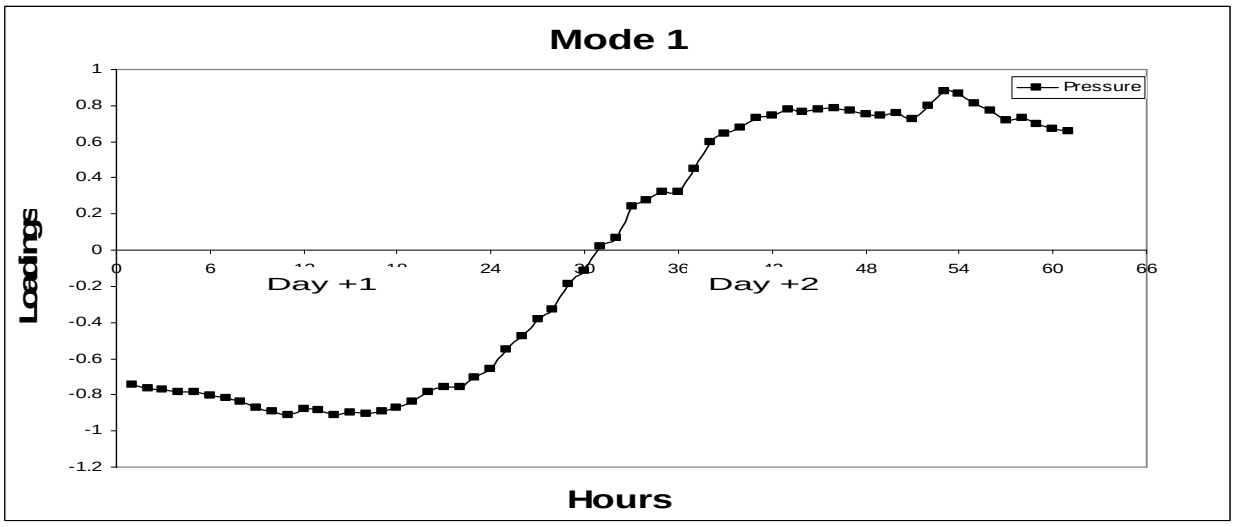
- Ultimately, only the top 4 unrotated principal components were retained for the study of Gulf Surge variability, and remain explicit towards the preferred modes of behavior. Factors 5 and 6 appeared to mimic the diurnal cycle and these lower order modes also contained considerable noise in the hourly component loadings.

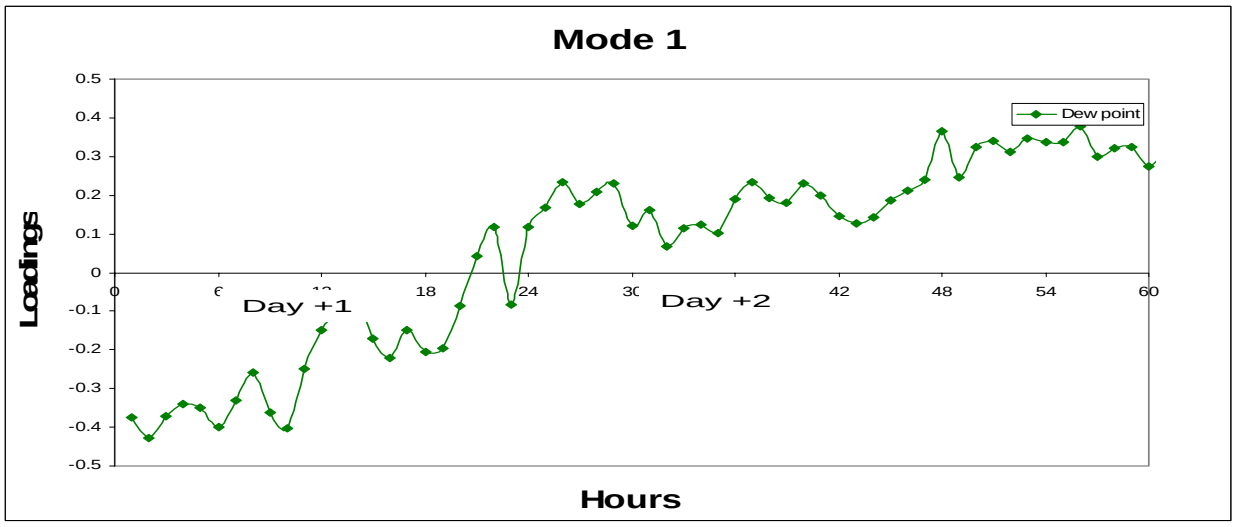
2. Gulf Surge "Types" and Synoptic/Mesoscale Forcing:

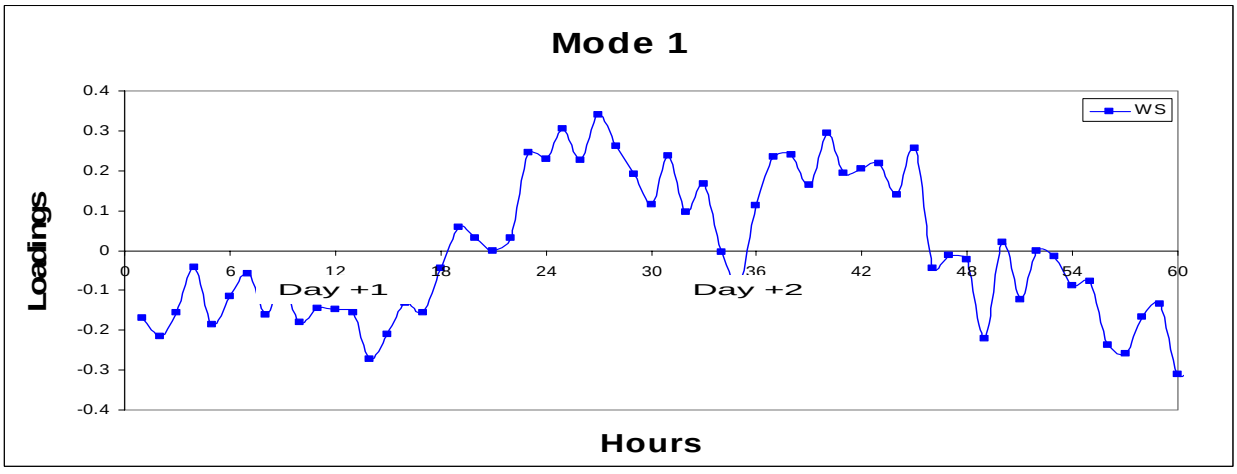
A. "Classic" Gulf Surge: *Most Common Surge based on behavior: MCS/MCC derived / locally forced*

- Typical onset time occurring between 4-8 a.m. LST. (16-20 hours from start of observed frame)
- Initial notable rises: Dew point rise followed Wind Speed and Pressure rises.
- Lifecycle exceeds 20 hours based on above normal wind speeds in connection with subsequent above normal Dew points and surface pressure.
- Given the nearly "sinusoidal" structure of the pressure pattern within observed temporal frame, above normal pressure does not occur until after 30 hours.
- Pressure pattern suggests that the weakening of the thermal low with sustained above normal Dew points after wind speeds decrease within the observed time frame. This is indicative of a well-mixed, moist, deep surge given the persistence of significant Dew points.
- Composite Analyses of 700mb Geopotential heights indicate synoptic features responsible are inverted trof passages advecting moisture from Mexico and/or northward moving tropical storm influences along the Gulf of California.
- In the MSLP composite (not shown) low pressure is noted off southwest Baja.
- *(Composites based on 5 Years)*

A. "Classic" Gulf Surge: *Most Common Surge based on behavior: MCS/MCC derived / locally forced*

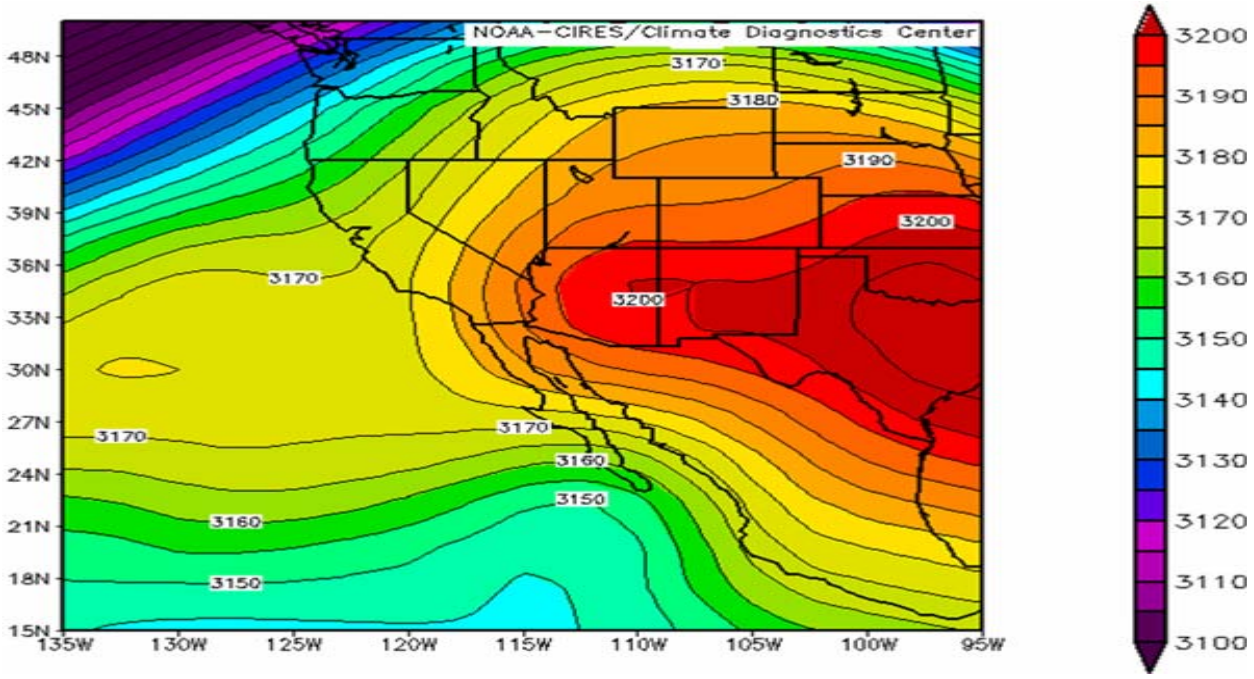




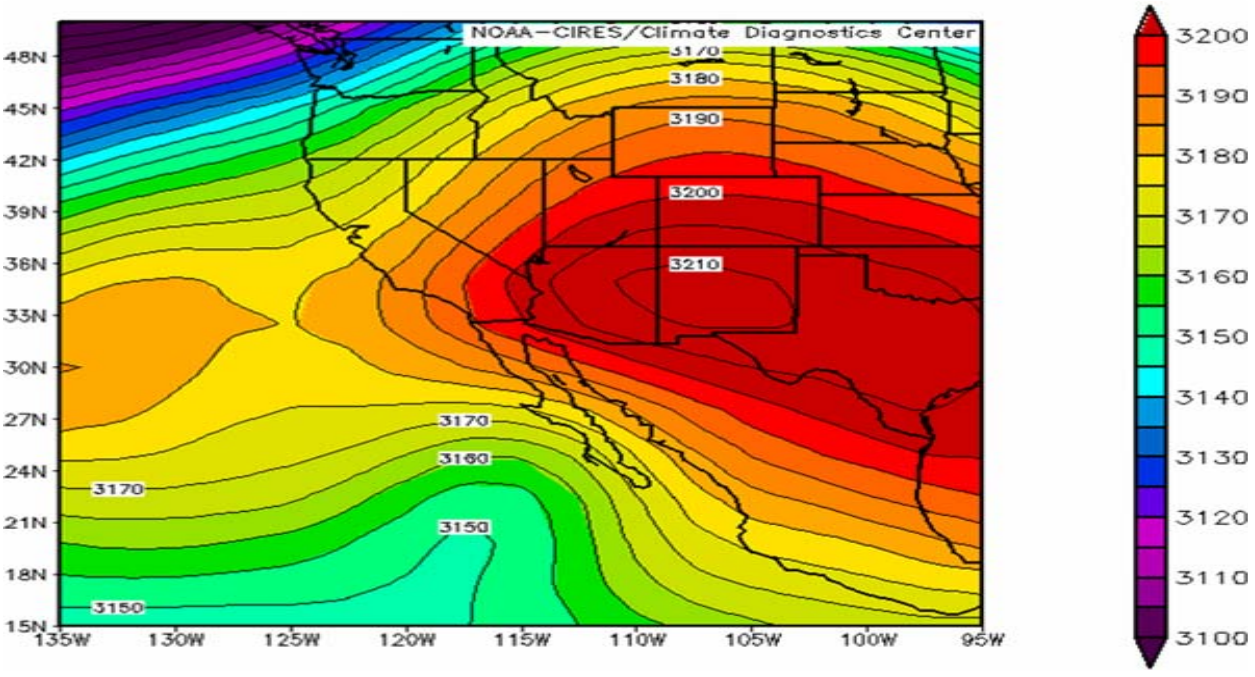


A. "Classic" Gulf Surge: *Most Common Surge based on behavior: MCS/MCC derived / locally forced*

700mb Height Composite Day +1



700mb Height Composite Day +2



B. "Push/Pull" Gulf Surge: *Gulf surges responding to Upper-Level forcing and dynamics: Induced by Westerly Waves*

- Typical onset time occurring at approx 10 p.m. – 12 Midnight LST Day-1. (10 hours earlier than classic type)

- Initial notable rises: Simultaneous rise in Dew point and Wind Speed, followed by Pressure.

- The late evening initiation yields "classic" gulf surge type behavior for 30 hours, until pressure rapidly falls below normal.

- This pressure pattern is indicative of the deepening of the thermal low associated with an approaching westerly trof that peaks at 12 p.m. on the day after surge onset.

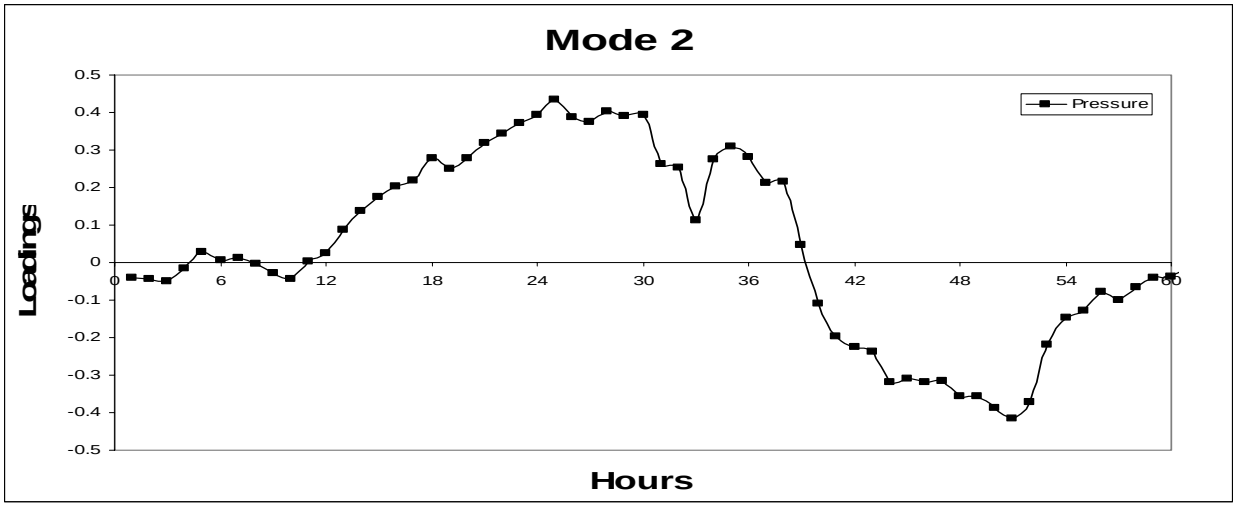
- Since Wind Speed and Dew point remain above normal and static after 30 hours, it appears that the ensuing dynamics of the upper-levels sustain the thermal low and maintain high surface dew points.

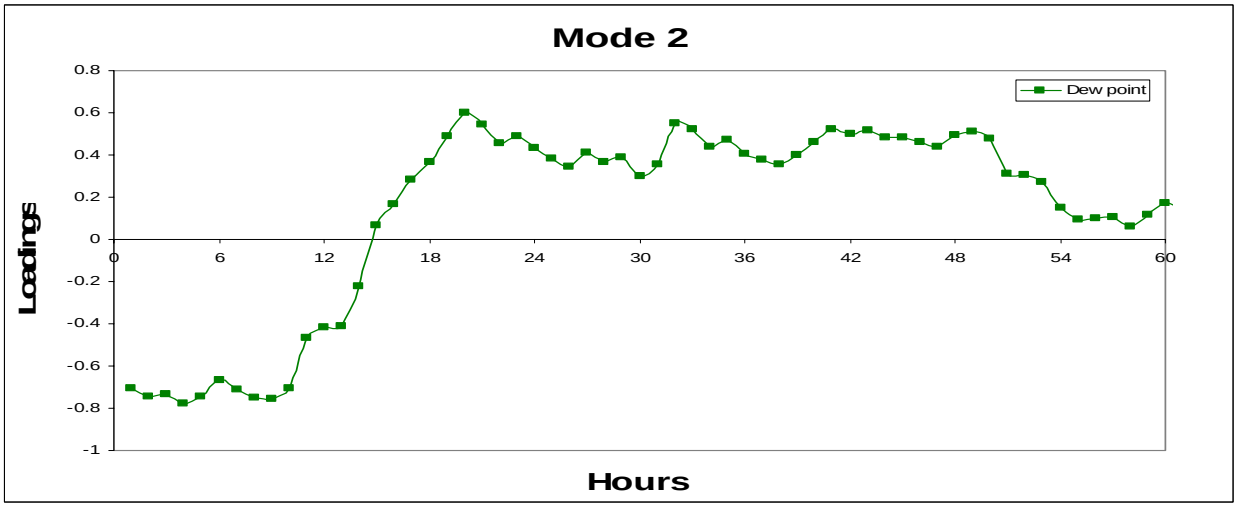
- Composite Analyses of 700mb Geopotential Heights indicate similar features of a "classic" surge in the Upper-levels on Day 0, including tropical storm influences (as indicated by SLP composite charts not shown), with the exception of a mid-latitude trof in the North Pacific.

- However on Day 1, the progression of this trof, and the weakening of the Subtropical ridge allows the thermal low to deepen after 30 hours.

- *(Composites based on 7 years)*

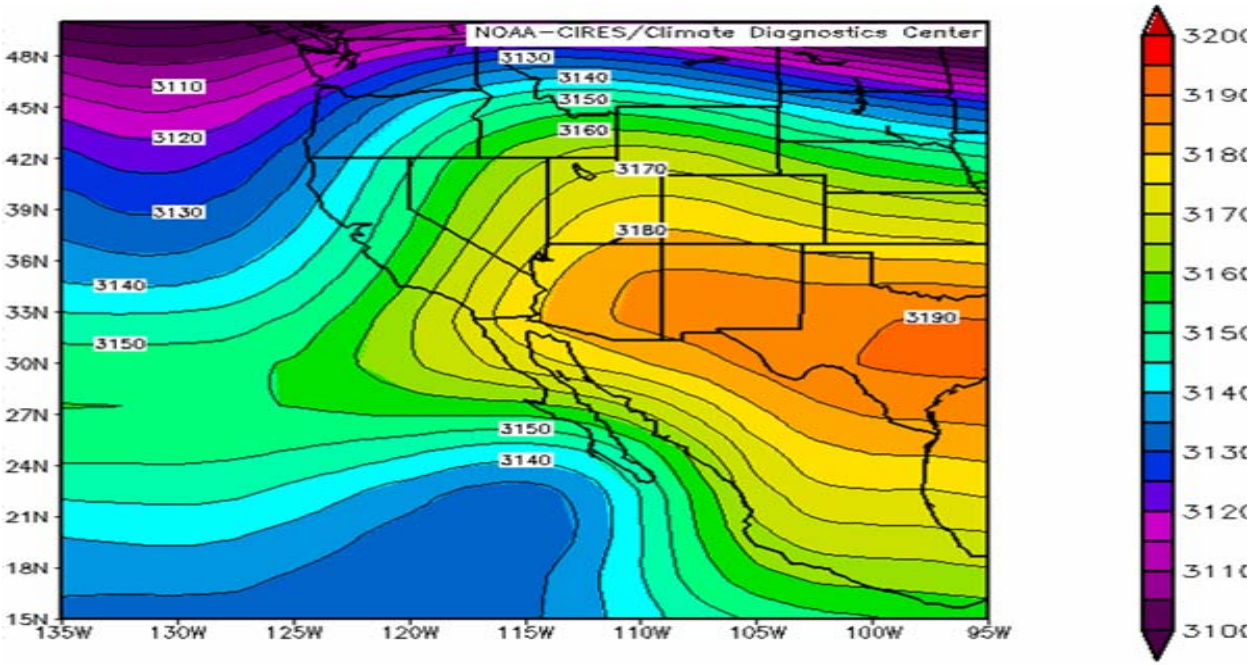
B. "Push/Pull" Gulf Surge: *Gulf surges responding to Upper-Level forcing and dynamics: Induced by Westerly Waves*



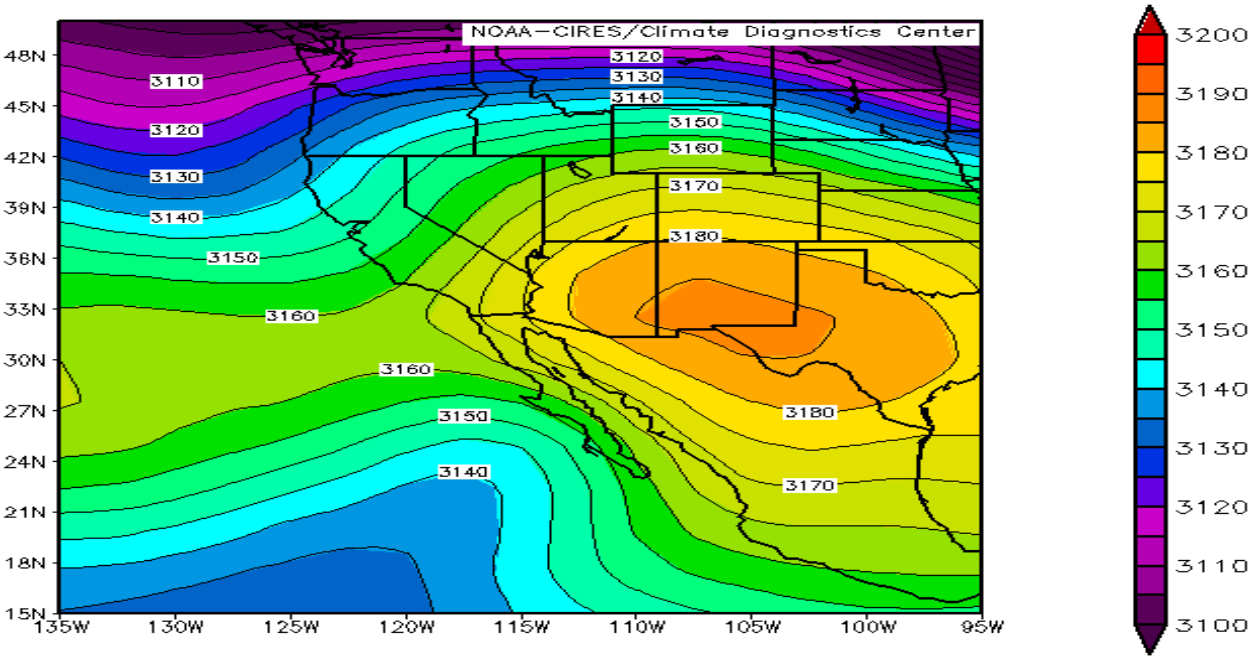


B. "Push/Pull" Gulf Surge: *Gulf surges responding to Upper-Level forcing and dynamics: Induced by Westerly Waves*

700mb Height Composite Day +1



700mb Height Composite Day +2



C. "Pull" Gulf Surge: *Gulf Surges responding to more synoptic forcing and Upper-Level dynamics with a more-southerly-displaced and deeper trof.*

- Typical onset time identical to previous type at approx 10 p.m. – 12 Midnight LST.

- Initial notable rises: Nearly Simultaneous rise in Dew point and Wind Speed associated with a long period of falling SLP.

- Since gulf surges are generally characterized by increasing pressure upon onset, this gulf surge type suggests the initial deepening of the thermal low directly corresponding to a deepening, and southerly displaced westerly wave.

- Dew point tendencies within the observed mode indicate surge onset that is short lived.

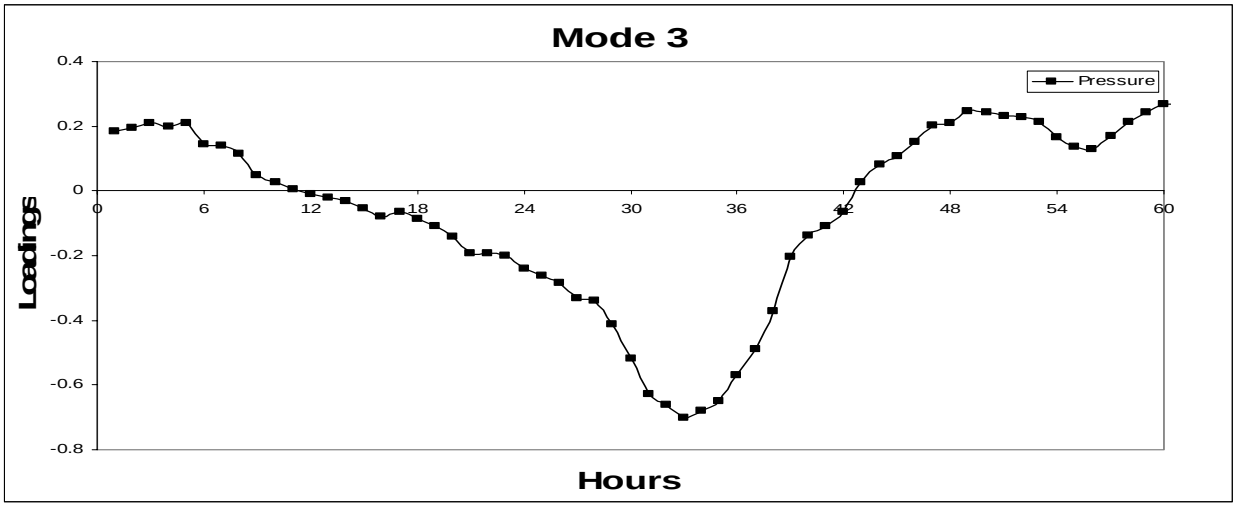
- Wind Speed also achieves its highest peak shortly after the pressure minimum, with wind speed remaining steady and above normal levels throughout the remaining period.

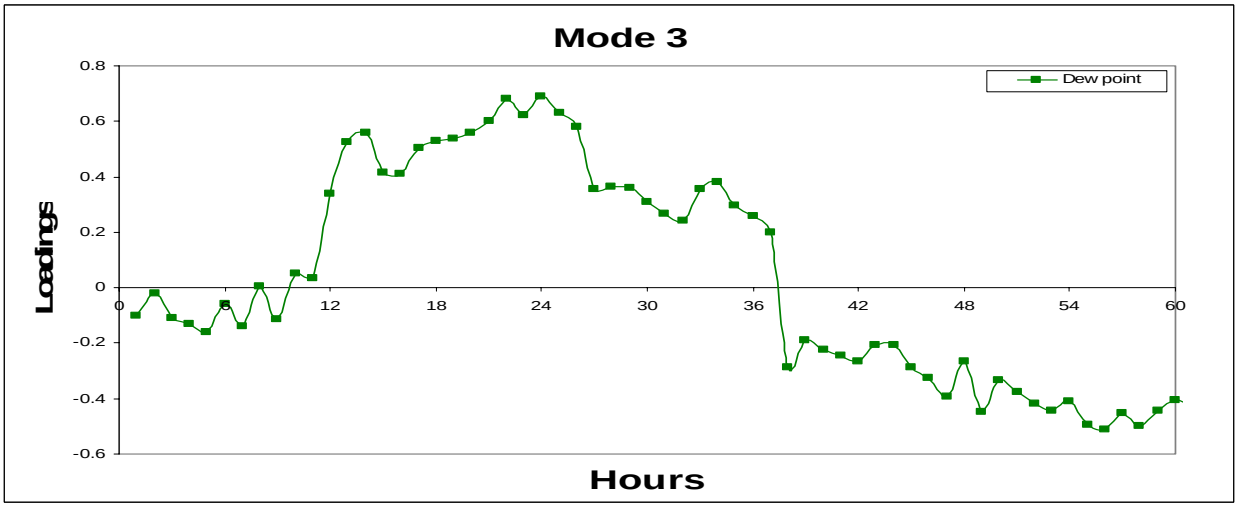
- These characteristics suggest a strong influence from a passing westerly wave and its associated dynamics aiding the intensification of the thermal low with sustained moisture advection ahead of the trof, and strong drying behind the trof 30 hours later.

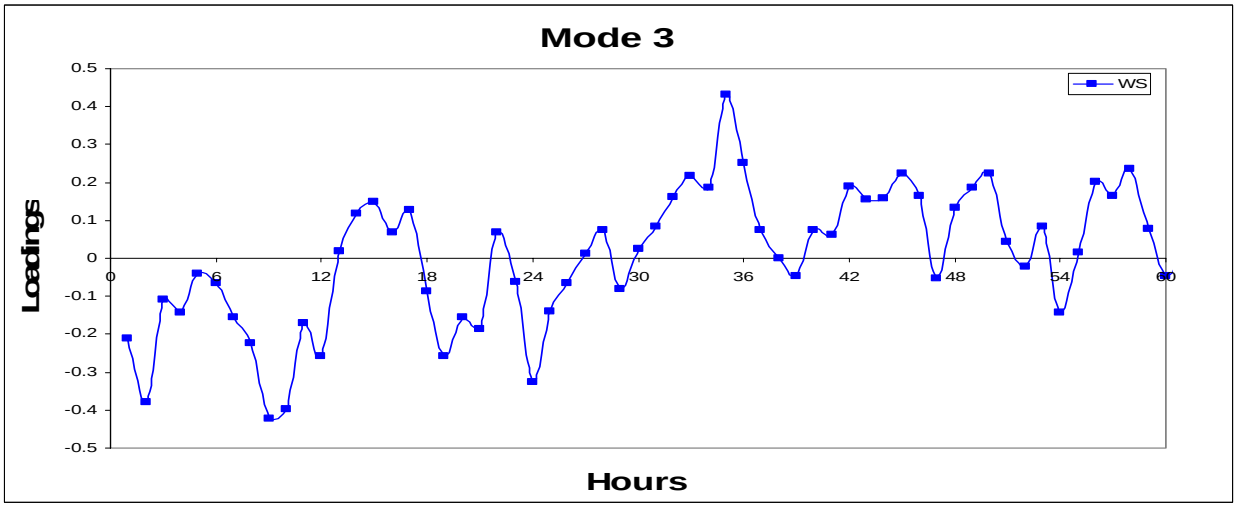
- Composite analyses of 700mb heights indicate a deepening trof that passes east of Yuma through the 60 hour period. The upper-level charts suggest an eastward shift of the subtropical ridge towards the plains, with dry air being advected into CA and AZ after 30 hours.

- *(Composites based on 3 years)*

C. "Pull" Gulf Surge: *Gulf Surges responding to more synoptic forcing and Upper-Level dynamics with a more-southerly-displaced and deeper trof.*

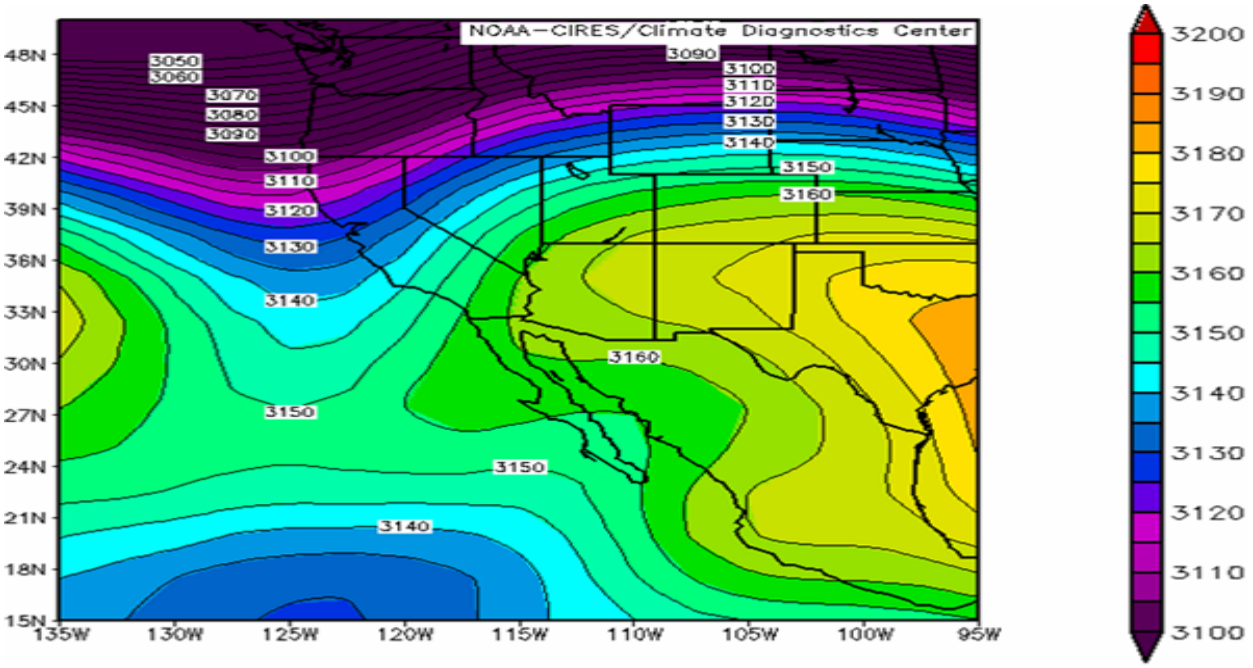




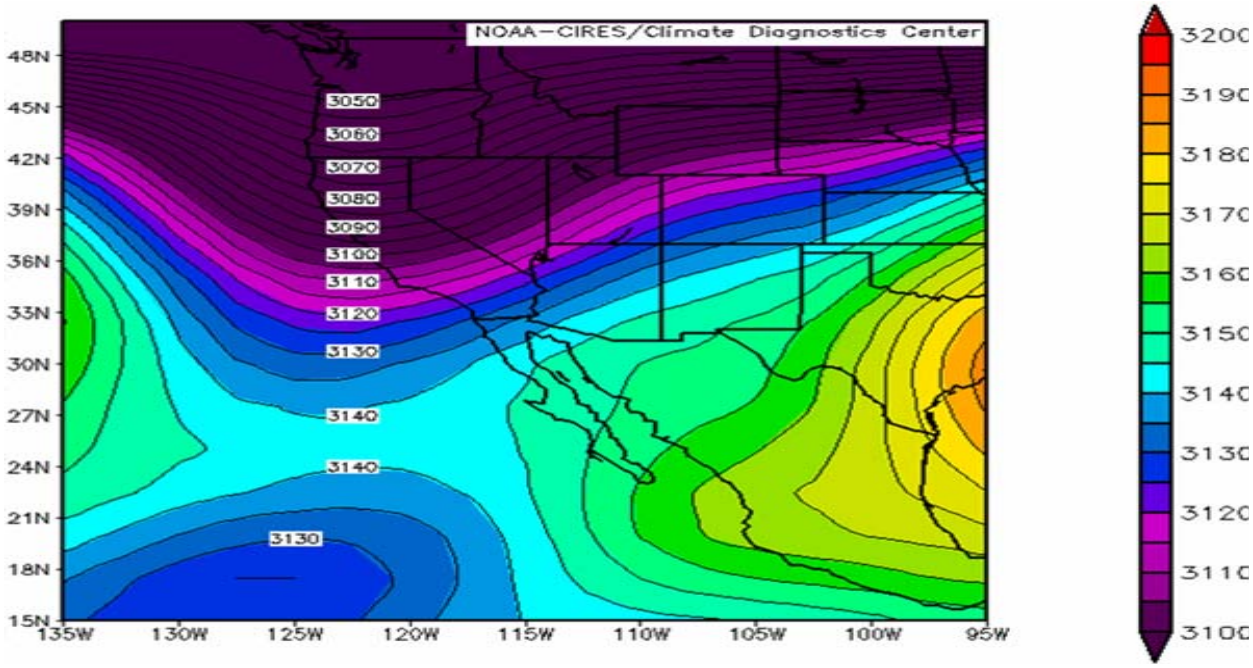


C. "Pull" Gulf Surge: *Gulf Surges responding to more synoptic forcing and Upper-Level dynamics with a more-southerly-displaced and deeper trof.*

700mb Height Composite Day +1



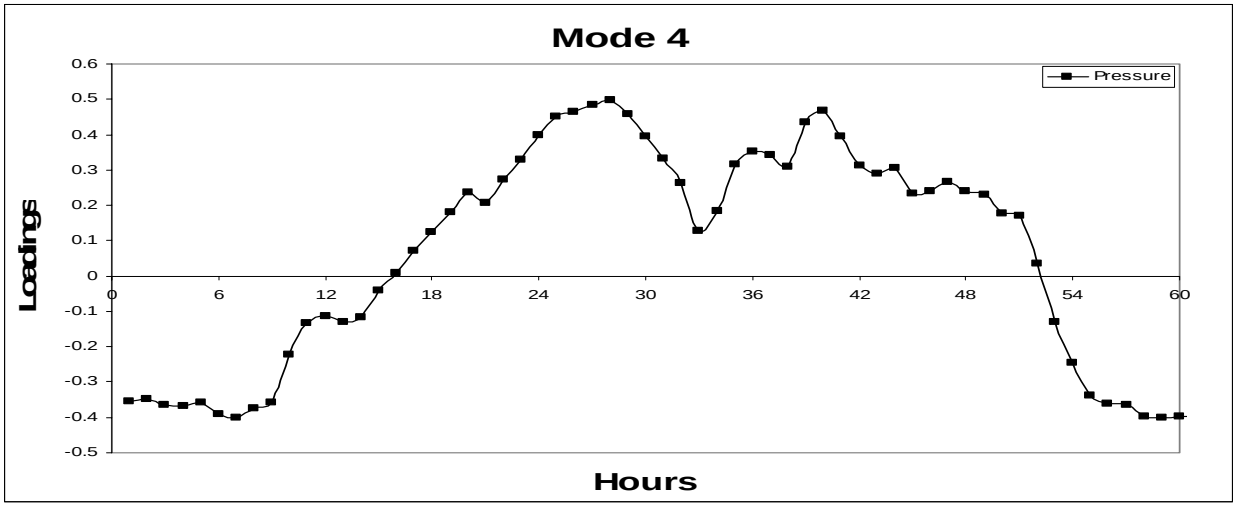
700mb Height Composite Day +2

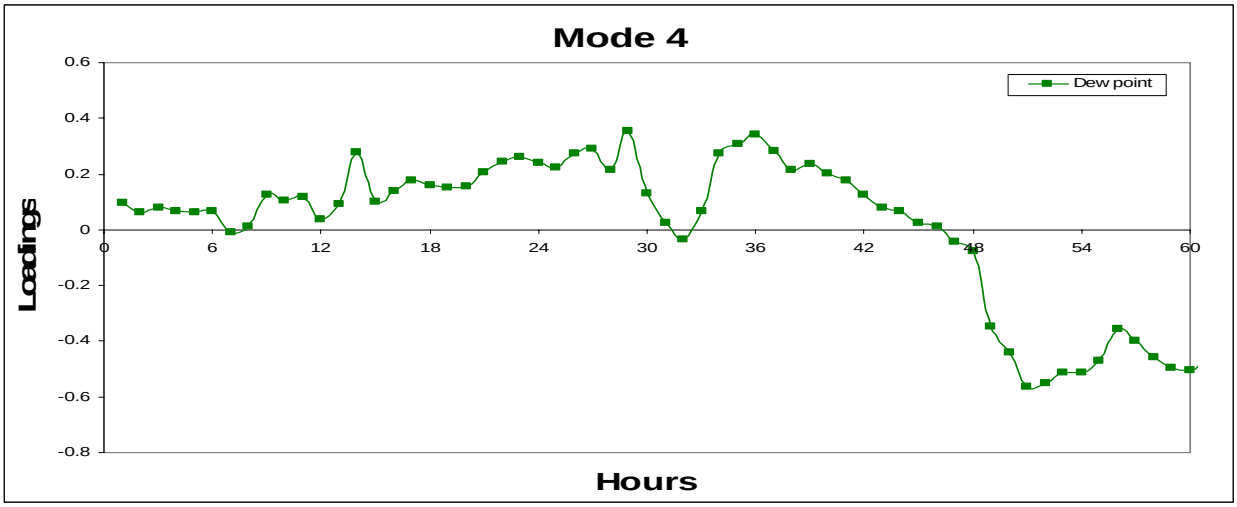


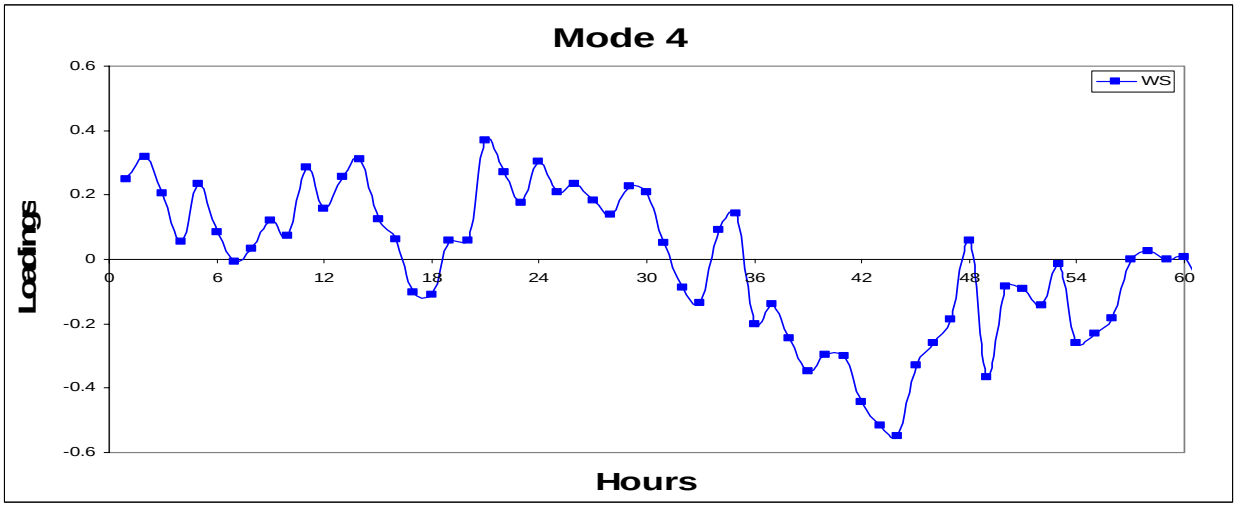
D. "Shallow" Gulf Surge: *Gulf Surges initially behaving similar to those of the "classic" regime, but subsequently become dried out by a weakened subtropical ridge but unaffected by westerly dynamics.*

- Typical onset time occurring at approx 2 a.m. – 4 a.m. LST.
- Initial notable rises: Low amplitude rises in both Dew point and Wind Speed followed by pressure rises.
- The initialization of above normal Dew point and Wind Speeds indicate that moisture advection is occurring, or has been occurring prior to observed frame as a result from local forcing.
- After 30 hours, there is a suggestion of a deepening/recovery of the thermal low, and the weakening of synoptic and mesoscale forcing that had favored continuous pumping of moisture into Yuma.
- With respect to pressure tendencies during this time, an immediate pressure rise associated with nocturnal cooling and upper-level subsidence may account for this observed pattern. Dew points rapidly diminish during subsequent daytime heating.
- Composite Analyses of 700mb heights show a prevailing flow out of the SSE at the beginning of the period, with the moisture source shifting south and weakening after 30 hours.
- The transition between Day +1 and Day +2 indicates possible subsidence and a cutting-off of moisture sources.
- *(Composites* based on 8 years)

D. "Shallow" Gulf Surge: *Gulf Surges initially behaving similar to those of the "classic" regime, but subsequently become dried out by a weakened subtropical ridge but unaffected by westerly dynamics.*

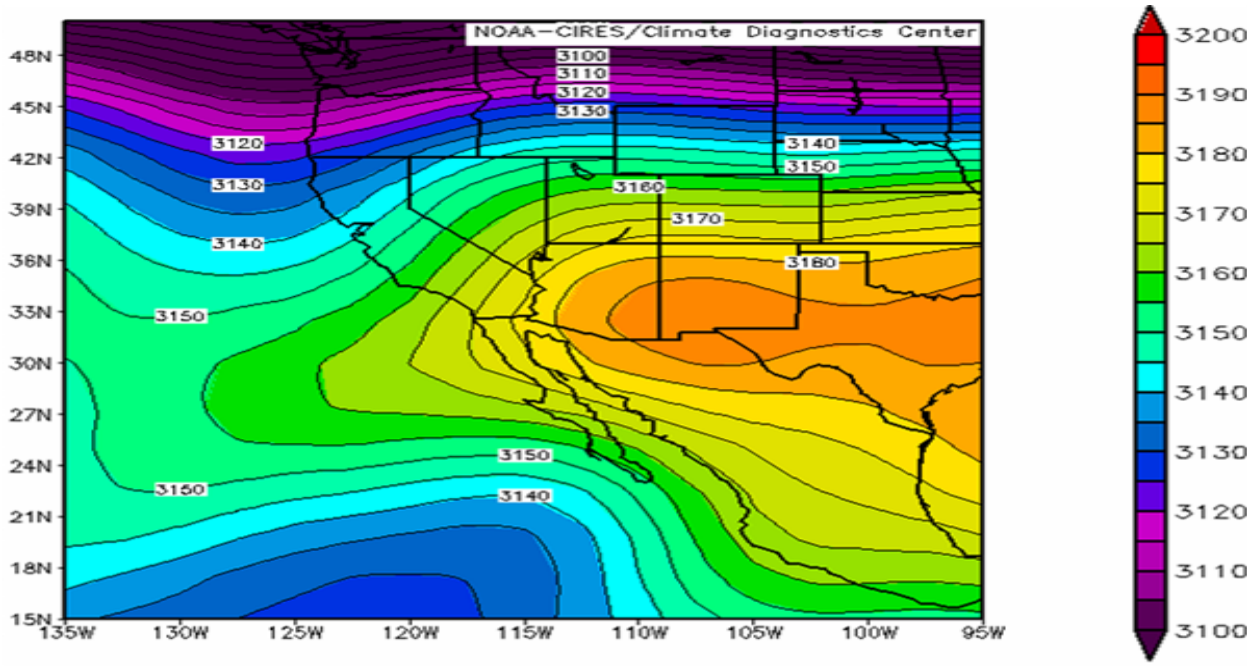




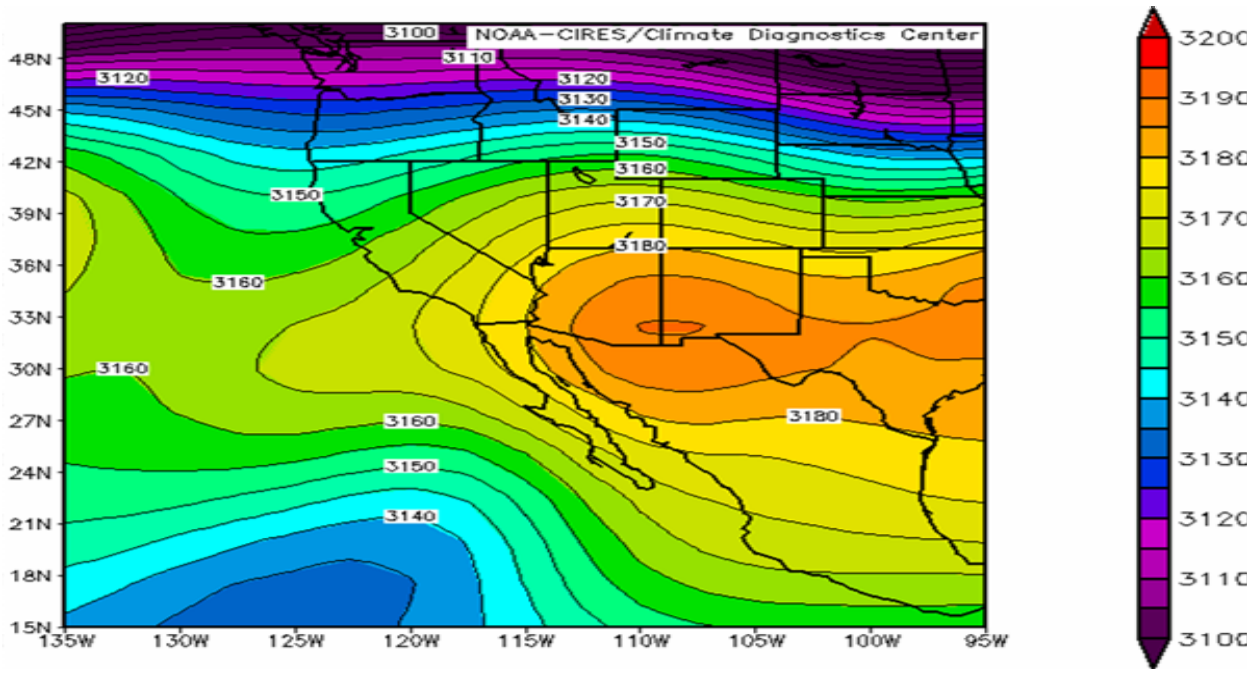


D. "Shallow" Gulf Surge: *Gulf Surges initially behaving similar to those of the "classic" regime, but subsequently become dried out by a weakened subtropical ridge but unaffected by westerly dynamics.*

700mb Height Composite Day +1



700mb Height Composite Day +2



V. Climatology of the GSI and Application to Surges during the NAME Field Campaign 2004:

- In 2004, there were a total 13 gulf surge events in Yuma, AZ which is one event above the climatological norm for 54 years (mean 11.89).
- Monthly totals in 2004 indicate 5 surges in September, which also is above the 54-year mean.
- Significant surge events (GSI values ≥ 60.00) were above normal in 2004. 2 of the 3 significant surge events (onsets) occurred in July, with no significant events occurring in August.
- The second significant surge event in July will be examined in the following case study utilizing the observational network provided by the NAME field campaign.

Climatology of Gulf Surge Events

Based on Days with GSI values >= "10.00", with at least one preceding day of dryness (GSI value < 10.00).

By Month 1950-2003

	June	July	August	September	Total
Total	22	223	257	140	**642**
Mean	0.41	4.13	4.76	2.59	**11.89**
Percent	3.4%	34.7%	40.0%	21.8%	

By Month (2004)

	June	July	August	September	Total
Total	0	4	4	5	**13**

Based on Days with GSI values >= "60.00", with at least one preceding day of dryness (GSI value < 10.00)

By Month 1950-2003

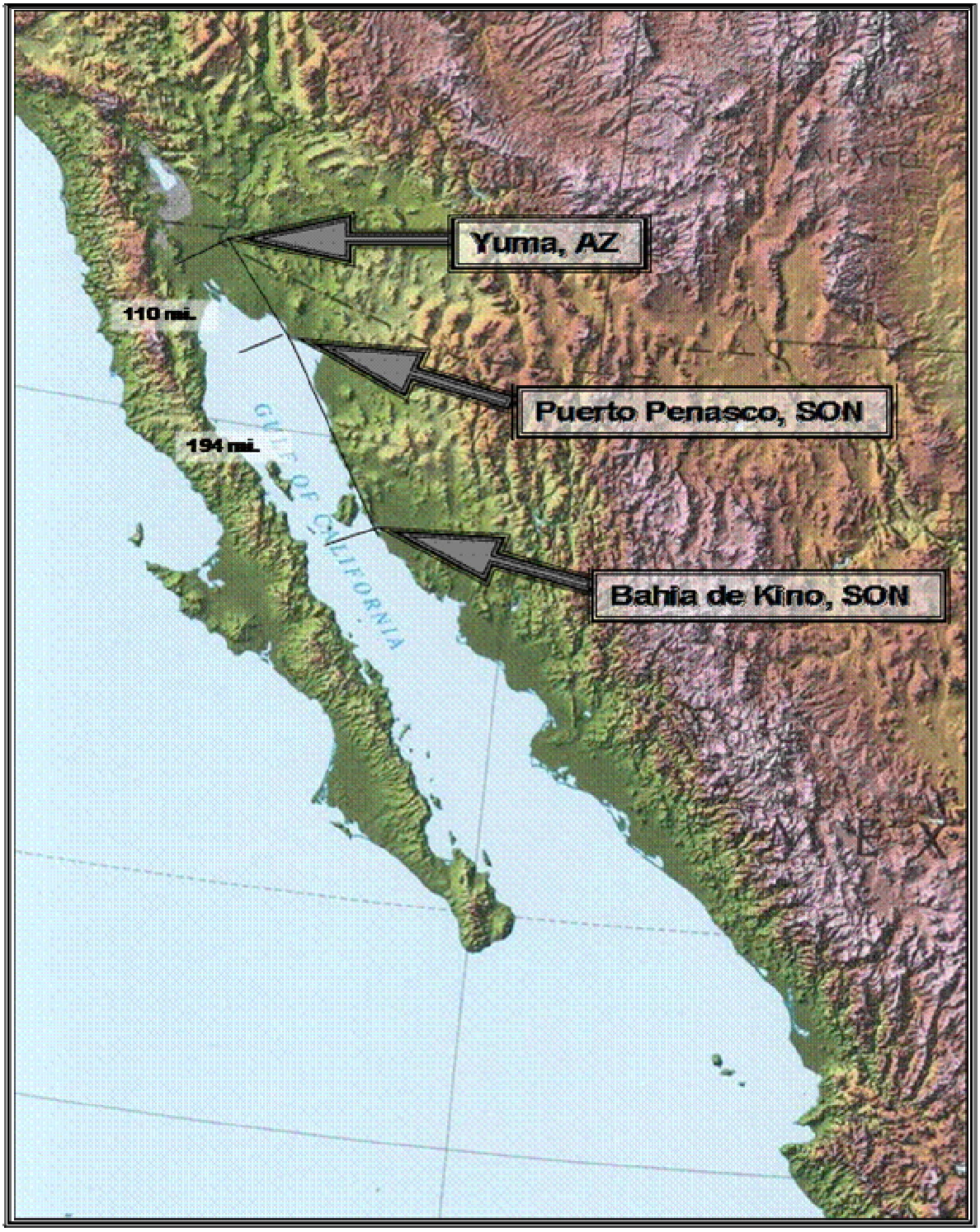
	June	July	August	September	Total
Total	0	28	57	18	**103**
Mean	0.00	0.52	1.06	0.33	**1.91**
Percent	0.0%	27.2%	55.3%	17.5%	

By Month (2004)

	June	July	August	September	Total
Total	0	2	0	1	**3**

Evolution of the July 23, 2004 Gulf Surge:

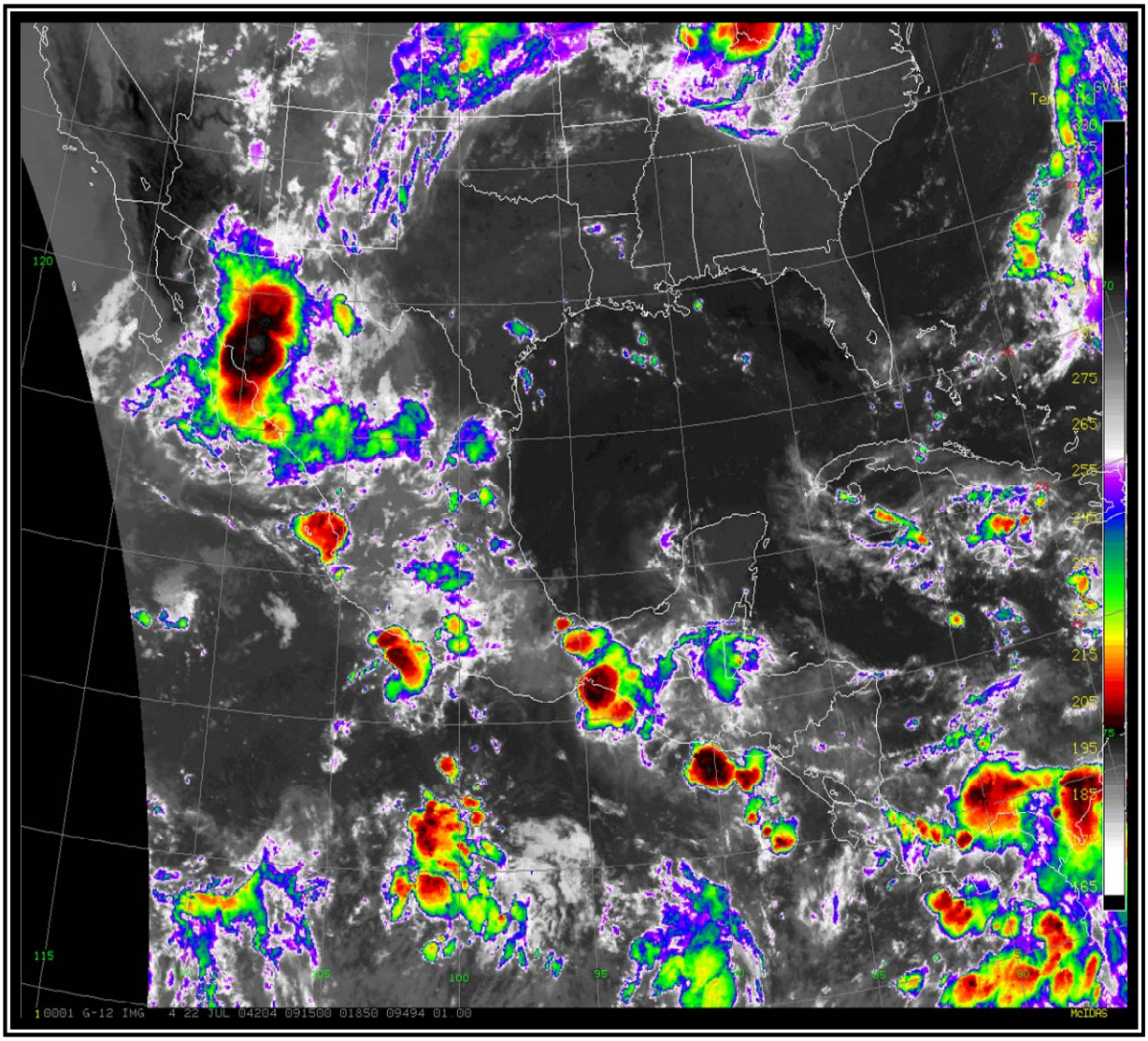
Incorporating NAME 2004 Observations



- This Gulf Surge was triggered from an MCC that developed over the Sierra Madre Occidental.

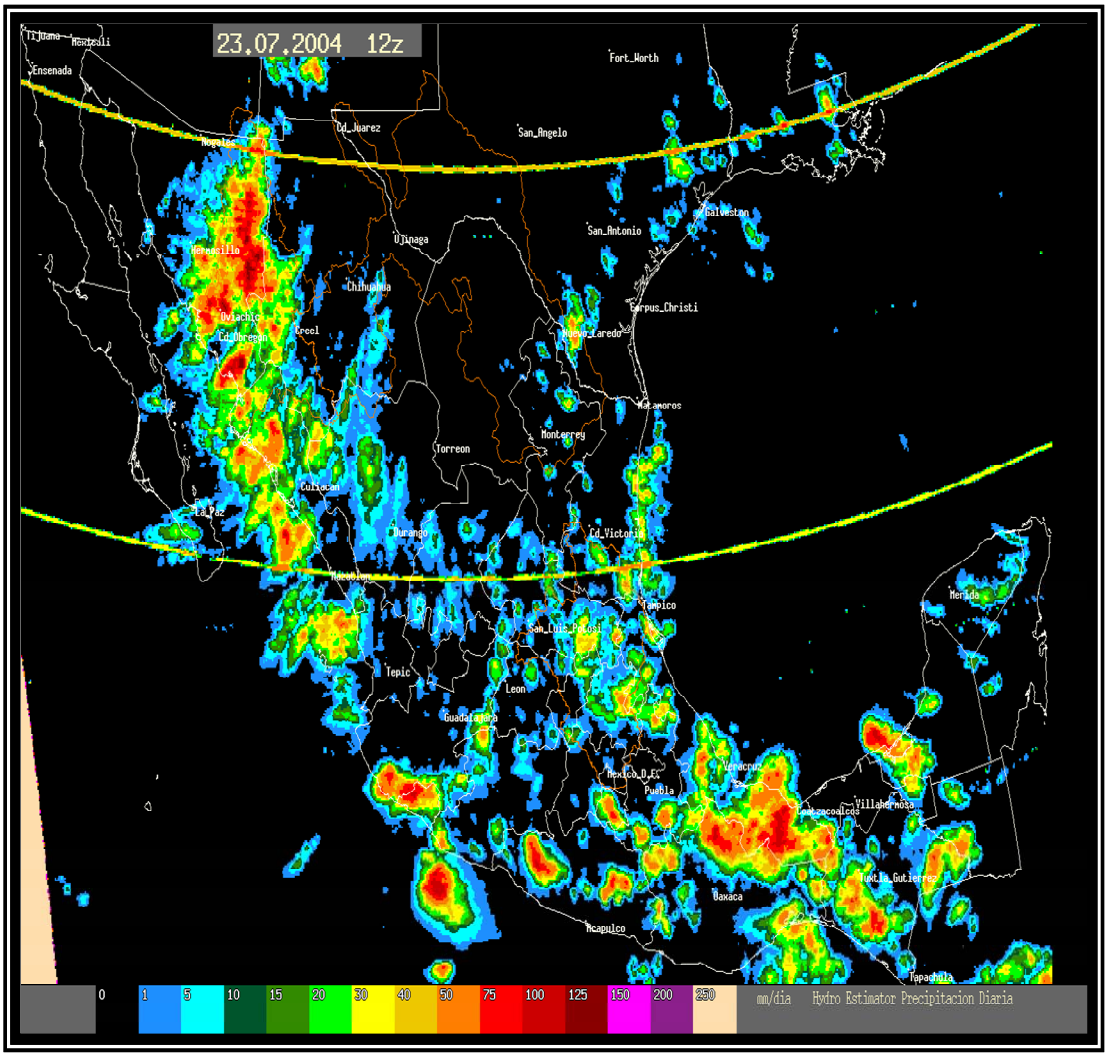
- Based on IR temperatures, this mesoscale system reached its peak at approx 01-02 Z 22 July, 2004.

Gulf Surge Trigger on GOES IR: 22 July 01Z



- Total 24hr rainfall with this system is indicated by the Hydro Estimator product provided by the SMN (Servicio Meteorologico Nacional).

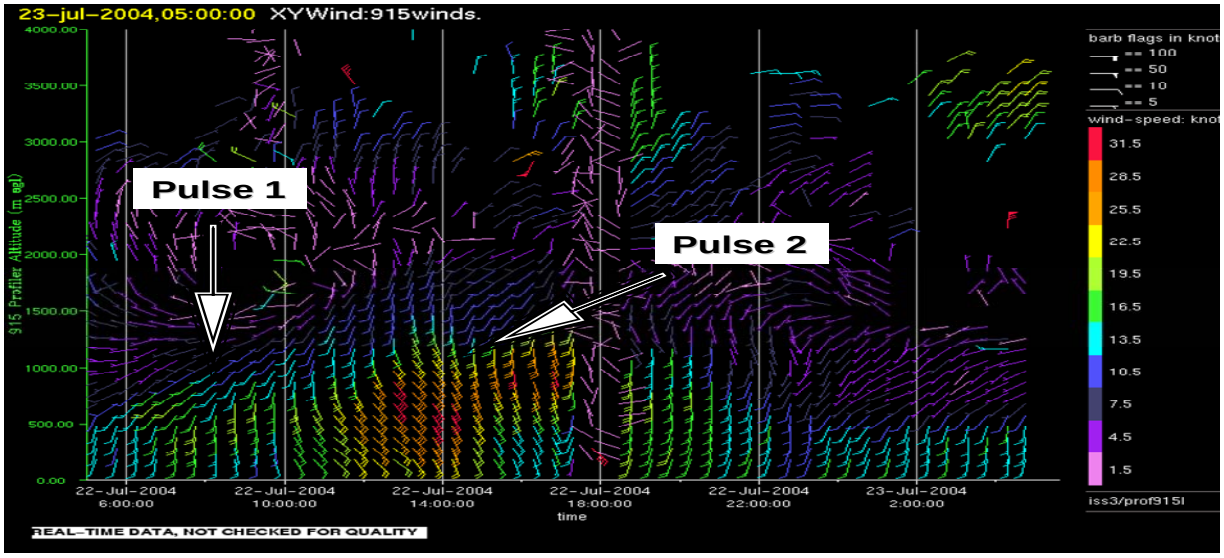
SMN Hydro Estimator with respect to local MCS/MCC: 23 July 12Z



- According to the NAME 2004 Wind Profiler site products, the gulf surge initiated by this system arrived in the form of multiple pulses.

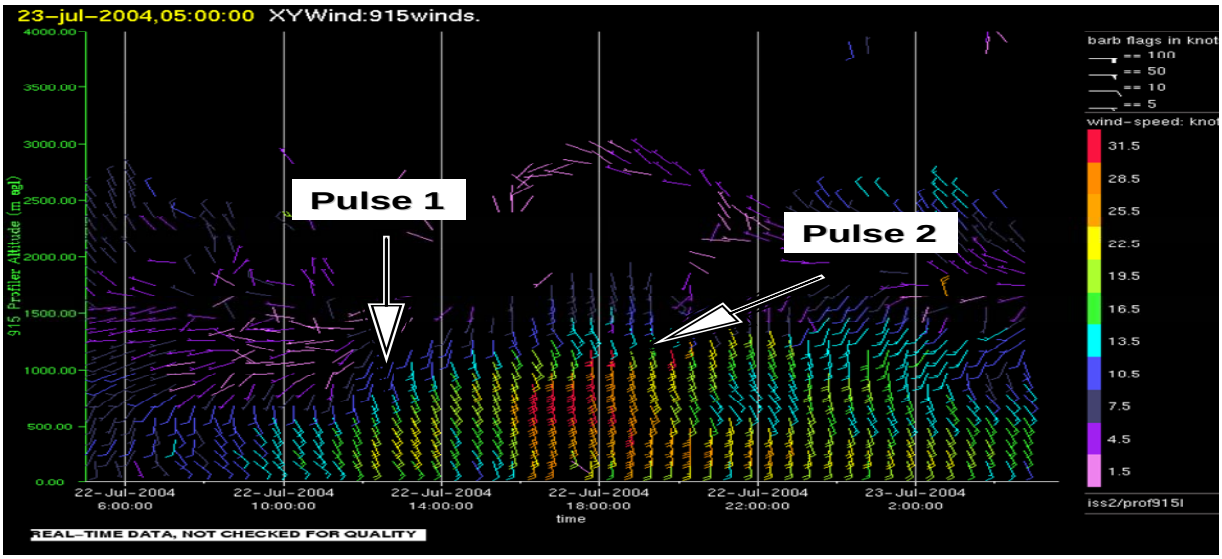
NAME Wind Profiler: Bahia De Kino, Sonora

22 July 06Z – 23 July 02Z



NAME Wind Profiler: Puerto Penasco, Sonora

22 July 06Z – 23 July 02Z



- This surge occurred from a mesoscale event and is indicative of the "classic" type. However, this surge arrived at Yuma in the afternoon, while a majority of surges typically occur during late evening hours.

Yuma, AZ Hourly Observations:

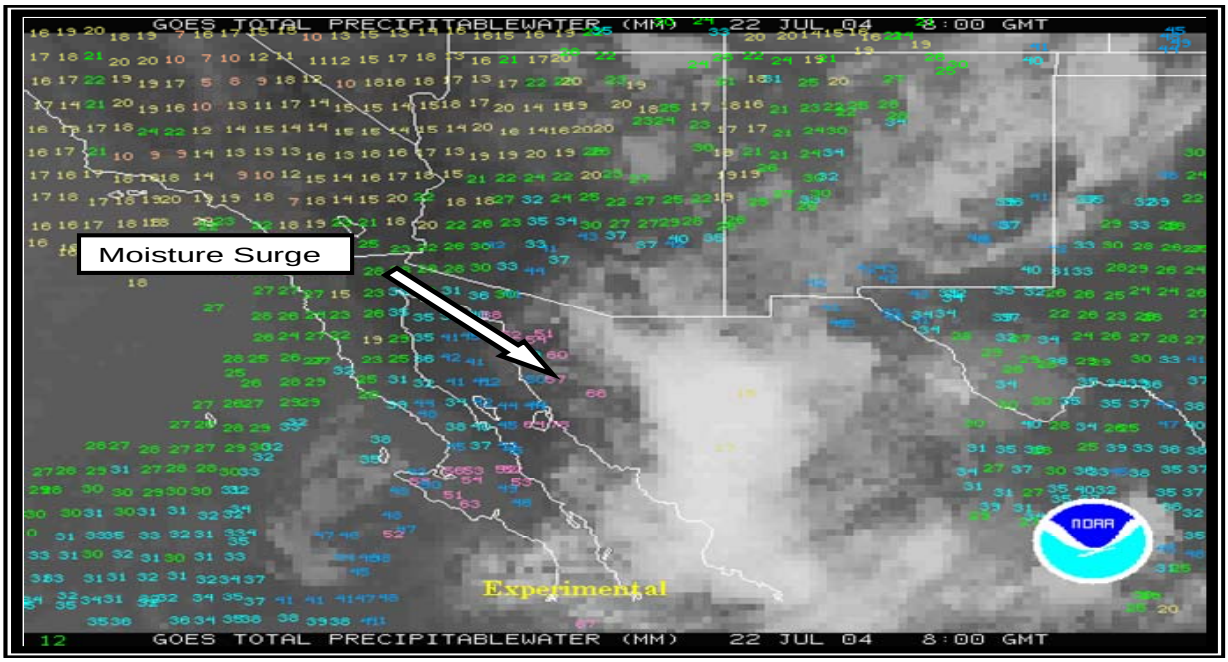
22 July 07Z – 24 July 06Z 2004

Pulse 1 Pulse 2

Date	HR (UTC)	HR (LST)	Pressure	T(F)	DP (F)	WindSpeed	WD
7/22/2004	7	(Day -1) 0	1005.7	93	69.1	4	241
7/22/2004	8	1	1005.4	93	66.9	4	191
7/22/2004	9	2	1005.5	89.1	65.1	7	161
7/22/2004	10	3	1005.5	86	64.9	5	159
7/22/2004	11	4	1005.3	84.9	64.9	8.1	150
7/22/2004	12	5	1005.4	84	66	7	150
7/22/2004	13	6	1005.9	82.9	63	9	139
7/22/2004	14	7	1006.5	84.9	57	7	150
7/22/2004	15	8	1007.1	90	55.9	5.1	140
7/22/2004	16	9	1007.8	93.9	66	15.1	150
7/22/2004	17	10	1007.7	98.1	63	14.1	160
7/22/2004	18	11	1007.6	100.9	64.9	16	170
7/22/2004	19	12	1007.6	104	63	14.1	160
7/22/2004	20	13	1006.6	105.1	66	18	160
7/22/2004	21	14	1006	106	66	17.9	150
7/22/2004	22	15	1005.5	105.8	66.2	16	170
7/23/2004	0	17	1004.5	105.8	68	-999	159
7/23/2004	1	18	1004.1	105.8	64.4	16	170
7/23/2004	2	19	1003.9	100.4	66.2	15	180
7/23/2004	3	20	1004.1	96.8	68	10.1	170
7/23/2004	4	21	1004.3	93.2	69.8	15.1	160
7/23/2004	5	22	1004.8	89.6	69.8	14.1	160
7/23/2004	6	23	1005.2	87.8	69.8	10.9	160
7/23/2004	7	(Day +1) 0	1005.3	87.8	71.6	10.1	170
7/23/2004	8	1	1005.4	84.2	73.4	6.9	170
7/23/2004	9	2	1005	84.2	75.2	10.1	150
7/23/2004	10	3	1005.2	84.9	75	11.9	150
7/23/2004	11	4	1005.4	84.2	75.2	11	150
7/23/2004	12	5	1005.9	84.2	75.2	11.9	150
7/23/2004	13	6	1006.4	82.4	75.2	11.9	150
7/23/2004	14	7	1007.1	84.2	75.2	13	150
7/23/2004	15	8	1007.5	87.8	75.2	15.9	150
7/23/2004	16	9	1007.9	91	75	15.1	150
7/23/2004	17	10	1008	91.9	73.9	15.1	160
7/23/2004	18	11	1007.8	96.1	72	12	160
7/23/2004	19	12	1007.5	97.3	71.8	12	160
7/23/2004	20	13	1007.2	98.6	71.6	12	160
7/23/2004	21	14	1006.6	100.4	68	12.1	180
7/23/2004	22	15	1005.8	100.4	69.8	13.9	150
7/23/2004	23	16	1004.8	102.2	60.8	12	170
7/24/2004	0	17	1004.4	102.2	60.8	10.9	160
7/24/2004	1	18	1004.2	102.2	64.4	10.9	160
7/24/2004	2	19	1004.8	100.4	62.6	15	180
7/24/2004	3	20	1005.5	96.8	62.6	13	170
7/24/2004	4	21	1006.5	91.4	68	13.9	140
7/24/2004	5	22	1006.9	89.6	68	11.9	150
7/24/2004	6	23	1007.2	87.8	71.6	13	150

Above Normal Dew points

Before Onset at Yuma:
22 July 08Z



- These pulses occurred with varying intensity and speed at the sites. The table below demonstrates approximate arrival times of the pulses as indicated by the NAME profiler sites and Yuma surface data.

Approximate Arrival Times
(UTC) on July 22, 2004

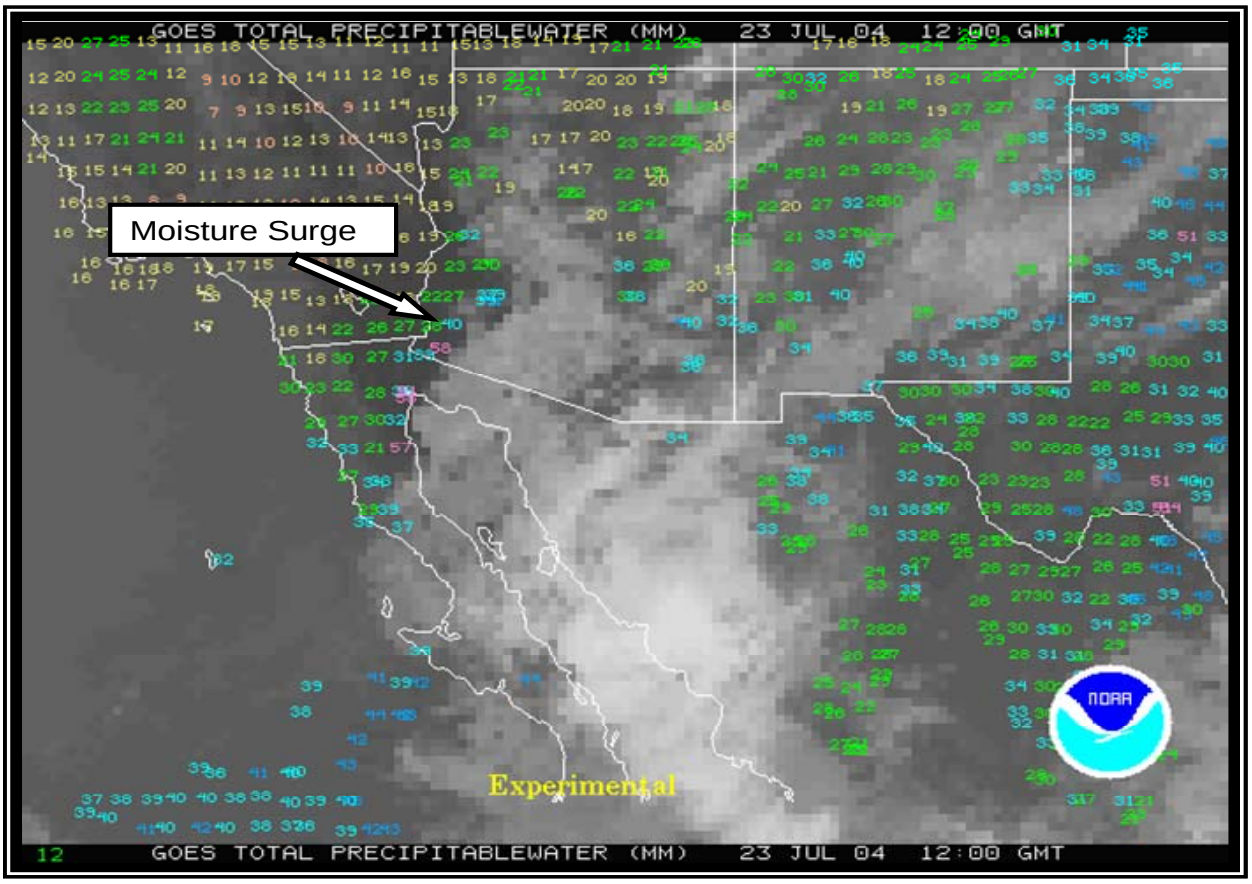
	Pulse 1	Pulse 2
Bahia de Kino, SON	**07Z**	**12Z**
Puerto Penasco, SON	**12Z**	**16Z**
Yuma, AZ	**16Z**	**20Z**

From the above schematics and products, pulse 1 was weaker in intensity and speed than pulse 2.

- Based on Precipitable water products and surface observations at Yuma, after the onset of this surge, Yuma experienced strong moisture advection.

- The GSI of this surge was "**98.51**", yielding the highest GSI valued event for 2004. This event helped to push July 2004 into the "above normal" category for GSI values >=60.00

After Onset at Yuma: 23 July 12Z



Acknowledgements

The author would like to thank the following people for their tremendous contributions and assistance during the course and completion of this project: Phillip Englehart, Brian Rockwood, and other support from the students and staff of the Department of Atmospheric Science at Creighton University. The author also thanks the folks at NCEP, CPC, NCDC, CDC, UCAR, JOSS, and Bob Maddox from the University of Arizona for their professional support and data products. Last, and certainly not least, the author especially thanks Arthur Douglas for his knowledge, cooperation, and patience.

References

Brenner, I.S., 1974: A surge of maritime tropical air - Gulf of California to the southwestern United States. ***Monthly Weather Review.,*** **102, 375-389.**

Douglas, M.W., Leal, J.C., 2002: Summer surges over the Gulf of California: Aspects of their climatology, mean structure, and evolution from radiosonde, NCEP Reanalysis, and rainfall data.

Hales, J.E., Jr. 1972: Surges of maritime tropical air northward over the Gulf of California. ***Monthly Weather Review.,*** **100, 298-306.**

Novella, N, S., 2005: M.S. Thesis. Department of Atmospheric Science, Creighton University.