9.4 Forecasting Extreme Wintertime Precipitation Events in Northern California

Norman W. Junker
Retired from NOAA/NWS/NCEP/ Hydrometeorological Prediction Center, Camp Springs, Maryland

Richard H. Grumm
National Weather Service, State College, Pennsylvania

Robert E. Hart
Department of Meteorology, Florida State University, Tallahassee, Florida

Lance F. Bosart
Department of Earth and Atmospheric Science, The University of Albany/SUNY, Albany, New York

Katherine M. Bell* and Frank J. Pereira
NOAA/NWS/NCEP/ Hydrometeorological Prediction Center, Camp Springs, Maryland

Introduction:

The official Hydrometeorological Prediction Center precipitation analyses (McDonald 2000) as described in Junker et al. (2002) were used to identify 100 mm (4-inch) and greater rainfall events that occurred in California. The purposes of developing this climatology were to identify cases that could be used to create composites of various fields, and to determine if these composites could then used to flag days when the synoptic pattern was favorable for producing a relatively large-scale 100-mm or greater precipitation area over the mountains of northern California. We also attempted to identify which parameters were most highly correlated with these events and, finally, tried to assess the uniqueness of the high anomaly fields that were identified for three multi-day extreme rainfall events during the period under investigation.

This paper is an extension of the research presented in Junker et al. (2004) that showed that anomaly patterns of 850 hPa winds and moisture flux and precipitable water appear to have utility in forecasting major precipitation events in the northern Sierra Nevada range in California. That research indicated that three multi-day extreme rainfall events that produced flooding and flash flooding occurred during periods when certain parameters had anomalies that departed from the norm by 2 to 5 standard deviations. In particular, the anomaly patterns of 850 hPa u- and v-component of the winds, 850 hPa moisture flux, and 700- and 500 hPa height fields from the three major flood events showed striking similarities. We attempted to identify which meteorological parameters provided the highest correlation with the observed maximum rainfall contour analyzed during each rainfall day.

When the original composites were developed and the similarities of the normalized anomalies for the three major multi-day flood cases were discussed at the conference in Seattle, the question was raised: How common are such high anomalies, and do they occur during non-events? The authors have tried to provide an answer to these questions as well.

Methodology:

For each day on which there was at least 100 mm of precipitation, the mean-sea level pressure and 500 hPa height analyses were examined at 12-hour intervals, beginning and ending at 1200 UTC. Gridded fields for these times were then compared to the daily climatological means from the 30-year period spanning 1961-1990 in a method similar to that described by Grumm et al. (2001) and Hart and Grumm (2000). The gridded data were retrieved from the National Centers for Environmental Prediction Center (NCEP) reanalysis project (Kalnay et al. 1996). The dataset has a 2.5^{o} x 2.5^{o} grid spacing at 17 pressure levels. Departures from normal for each grid point were obtained by comparing the selected meteorological field or parameter with the 21-day mean (from the 30-year NCEP reanalysis), centered on the day being investigated for each grid point. Standard deviations were also calculated using the 21-day running mean. GRADS(http://grads.iges.org/grads/) was used to compute and plot the means, anomaly fields and standard deviations of mean sea level

**Corresponding author address*: Katherine M. Bell, NOAA/NWS/NCEP/HPC, 5200 Auth Road, Room 410, Camp Springs, MD 20746

Hart and Grumm (2001) used normalized departures from climatology to objectively rank synoptic-scale events. We are attempting to build on their research by investigating whether normalized anomalies can be used to help identify when a significant rainfall event is likely to occur in the northern portions of the Sierra Nevada mountain range.

The normalized departure of any meteorological variable can be defined by

$N=(X-\mu)/\sigma$ (1)

where X is the value of the variable (e.g., 500 hPa height, u- and v-component of the 850 hPa wind, moisture flux, etc), μ is the daily mean value (based on the 21-day running mean) for that grid point, and σ is the standard deviation (based on the 21-day running mean) for each grid point.
Climatologies of derived fields such as precipitable water (PW) and (u- and v-components of, and total) moisture flux were also developed. Means, standard deviations and normalized anomalies of these fields were also calculated and plotted.

Composites of various parameters were constructed for twenty-two 100-mm (4 inch) or greater events that had almost identical locations over the Sierra Nevada of northern California (with a rainfall maximum located between 37N and 41N). This sample was thought to be large enough to identify which fields typically had the largest anomalies during extreme rainfall days in the northern portions of the Sierra Nevadamountains. In addition, this sample size was also small enough to allow us to plot the means and standard deviations for each field to make sure no obvious outliers would make the composite enough to make it unrepresentative of the overall population.

Finally, the climatology developed from the NCEP reanalysis data was scanned to check for days when the parameters listed in Table 1 had anomalously high or low values at the grid points shown in Figure 1. The highest normalized anomaly values and associated raw magnitudes of 850 hPa and 700 hPa moisture flux and u- and v- component of the wind were recorded for all grid points on Figure 1. In addition, the highest normalized anomaly and its associated magnitude for the fields listed above plus the 1000-300 hPa mean relative humidity were recorded for the point nearest Blue Canyon in the Sierra Nevada (the red dot on Fig. 1) and for the point nearest San Francisco. The locations where the normalized anomalies were initially examined and recorded is shown on Table 2.

This dataset was then entered into a relational database to evaluate whether these fields could be used to discriminate between days when 100-mm or greater rainfall fell over northern California from days when less rainfall occurred. 194 rainfall events were chosen and the maximum observed rainfall contour in the Sierra Nevada mountains between 37N and 40N was recorded for each day and entered into the database. The rainfall events were almost equally divided between 1) hthose aving 100 mm (4 inches) or more of rain, 2) those having at least 50 mm (2 inches), but less than less than 100 mm, and 3) those having 12.5 mm (.50 in.), but less than 100 mm. The correlations between the observed rainfall maximum and various parameters were then calculated for the specified points.

Discussion:

One of the first things we noted was that high anomalies sometimes occurred during the warm season, but observed rainfall amounts were usually modest at best during this time of year. Pandey et al. (1999) have noted that moisture flux is stronger in winter than summer. Moisture flux anomalies of various magnitudes were plotted at 37.5N and 125W by time of year (Fig.2) to see whether there was a significant difference between the moisture flux during warm versus cold season moisture surges into northern California.

Note that in August a moisture flux anomaly of five standard deviation is associated with a significantly lower 850 hPa moisture flux than an anomaly with a similar standard deviation during January. In addition, the magnitude of the moisture flux associated with a normalized anomaly of 5 standard deviations (Std) in August is considerably less than the magnitude of the moisture flux for a 2.5 Std anomaly during the cold season. The relatively low moisture flux associated with summer moisture surges explains the lack of observed large-scale 4-inch or greater rainfall amounts in the northern Sierra Nevada mountains in summer and why the bulk of extreme precipitation events in California occur in the cold season.

Not surprisingly, the highest correlations between any of the meteorological parameters investigated in detail were found to correspond to the point closest to the Sierra Nevada mountains. The farther the axis of high moisture flux, precipitable water (PW) or the u- and v-component of the winds were from the mountains and from the location where the rainfall was measured for the correlations, the less likely the axis of higher values of the parameter were to intersect with mountains.

We chose the point at 37.5N and 120W as our point closest to the Sierra Nevada mountains since we wanted to use a point upstream rather than downstream from the mountains (for example the point at 40N 120W). We felt that moisture parameters might be negatively impacted by using a point east of the mountains where downsloping and its associated subsidence were likely.

The correlations (in this case, r squared) for the various normalized anomalies present at 37.5N 120W are shown in Table 2. The highest correlations between the observed rainfall amounts and the normalized anomalies for the various parameters were for the magnitude of the moisture flux at 850 hPa and 700 hPa with the latter having an r squared only slightly lower than the former. The big surprise was the relatively low PW values compared to the moisture flux or wind components. The composite of PW developed from the Sierra Nevada heavy rain cases shows a greater than the 2 standard deviation anomaly near the coast.

There were relatively high r squared values for both 850 hPa and 700 hPa moisture flux anomalies despite the low temporal resolution of the data. Only the 12 UTC starting time, 00 UTC mid-time and 12 UTC ending time were used to test the correlations. The anomalies for the three times were simply averaged and the resulting single value was used to test strength of the correlation between the magnitude of the anomaly and the variable. Higher temporal and spatial resolution data would probably lead to significantly higher correlations.

Correlations were higher when the highest of either the u- and v- component of the wind was recorded and then plugged in to test the correlations rather than when using only the u- or v- component of the wind. It is interesting to note that r squared was significantly higher for the v-wind component than the u-component at 850 hPa, while at 700 hPa the opposite was true.

A very similar 700 hPa height and normalized anomaly pattern was present for the three multi-day heavy rain events that led to federal disaster declarations (9-10 January 1995, 9-10 March 1995, and 31 December 1996- 2 January 1997); the moisture flux and normalized flux anomaly patterns during these events were also similar.

Figs. 3 and 4 show the pattern for both parameters at 0000 UTC 10 March 1995. While the authors have chosen to show only these two maps, the patterns for the other times during these events were very similar. In particular, note the greater than three standard deviation height anomaly in the Pacific on Fig. 3, and the greater than three standard deviation anomaly in moisture flux values over the Sierra Nevada range (the shading differences are subtle).

The authors attempted to answer to discover how common such large anomalies were during the 10-year period under examination. There were 7304 separate 12 or 00 UTC times. Only 26 times did anomalies of the 700 hPa heights (negative departures) and 850 hPa moisture flux anomalies exceed equal or exceed 3 standard deviations. Of those 26 times, only 4 times did the 24 hour precipitation analysis show amounts below 3 inches in the Sierra range. All but 6 were associated with days when more than 4 inches was observed.

Cases having 3 standard deviation anomalies in both 700 hPa heights and moisture flux were even rarer. Only 16 cases were found. However, the 31 Dec 1996-01 Jan 1997 event did not have both present at the same time.

Conclusions

Normalized anomalies appear to have potential to help identify at least some extreme rainfall events with a fairly low false alarm rate. Cases having a standardized anomaly of greater than 3 for 700 hPa height and 850 hPa moisture flux anomaly are rare but were present during the three federal disaster events.

There were positive correlations between the magnitude of the normalized anomaly of various parameters and the observed rainfall. Moisture flux at 850 hPa and 700 hPa have the highest correlations. However, the strong differences between the magnitude of the normalized moisture flux depending on the time of year suggests that using the raw values of moisture flux might lead to higher correlations especially with higher temporal and spatial resolution.

References:

Grumm 2001, R.H. and R. Hart, 2001: Standardized anomalies applied to significant cold season weather events: preliminary findings. *Wea. Forecasting*, **16**, 736-754.

Hart, R., and R. H Grumm, 2000: Using normalized climatological anomalies to rank synoptic scale events objectively. *Mon. Wea. Rev*., **129**, 2426-2442.

Junker, N.W., R. H. Grumm, R. Hart, and L. F Bosart, 2002: Establishing a 10 year climatology of 101.6 mm (4-inch) rainfall days, Part 1. 19th Weather Analysis and Forecasting Conference, San Anonio, TX, August 12-16, American Meteorological Society, **6.1**.

Junker, N.W., R. H. Grumm, R. Hart, and L. F Bosart 2002: A climatological study of 100mm or greater days in northern California. 20th Conference of Weather Analysis and Forecasting, Seattle, WA, American Meteorological Society, **16.2.**

McDonald, B. E., T. M. Graziano, and C. K. Kluepfel, 2000: The NWS national QPF verification program. Preprints, 15th Conference on Hydrology, Long Beach, CA, January 9-14, American Meteorological Society, 247-250.

Pandey, G. R., D. R. Cayan and K. P. Georgakakos, 1999: Precipitation structure in the Sierra Nevada of California during winter. *J. Geophys. Res*., **104**, No. 10, 12019-12030.

Table 1

PARAMETER	LOCATION	MAGNITUDE	NORM. ANOMALY VALUE
Max 850 moisture flux	Any point on Fig 1	Yes	Yes
Max 700 moisture flux	Any point on Fig 1	Yes	Yes
Max 850 u-wind component	Any point on Fig 1	Yes	Yes
Max 850 v-wind component	Any point on Fig 1	Yes	Yes
Max PW Anomaly	Any Point on Fig 1	No	Yes
850 moisture flux	Point at 37.5N 120W	Yes	Yes
Magnitude 700 moisture flux	Point at 37.5N 120W	Yes	Yes
850 u-wind component	Point at 37.5N 120W	Yes	Yes
850 v-wind component	Point at 37.5N 120W	Yes	Yes
700 u-wind component	Point at 37.5N 120W	Yes	Yes
700 v-wind component	Point at 37.5N 120W	Yes	Yes
PW anomaly	Point at 37.5N 120W	No	Yes
850 u-wind component	Point nearest SFO	Yes	Yes
850 v-wind component	Point nearest SFO	Yes	Yes
700 u-wind component	Point nearest SFO	Yes	Yes
700 v-wind component	Point nearest SFO	Yes	Yes
1000-300 mean RH	Point nearest SFO	Yes	No
1000-300 mean RH	Point at 37.5 N 120W	Yes	No

Table 2

Parameter	R squared
850 moisture flux	.57
700 moisture flux	.54
700 highest of u- or v- wind component	.44
850 highest of u- or v- wind component	.40
850 v-component	.32
700 u-component	.28
700 v-component	.11
850 u-component	.10
Precipitable water	.07

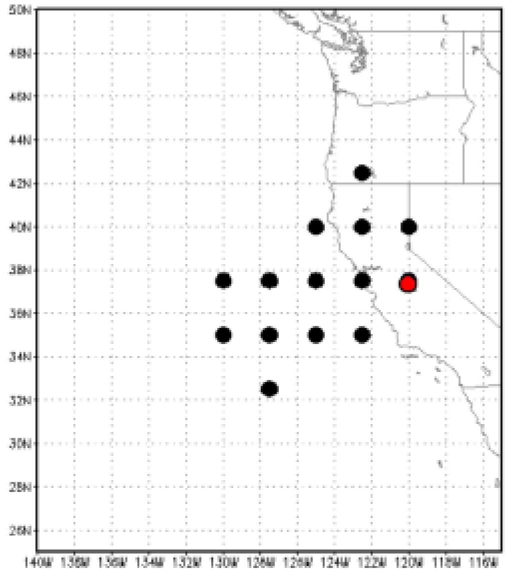

Figure 1. Points from which the highest and lower normalized anomalies were recorded for 00 UTC and 12 UTC each day. The red dot indicated the point for which normalized anomalies of various parameters were correlated with the observed precipitation.

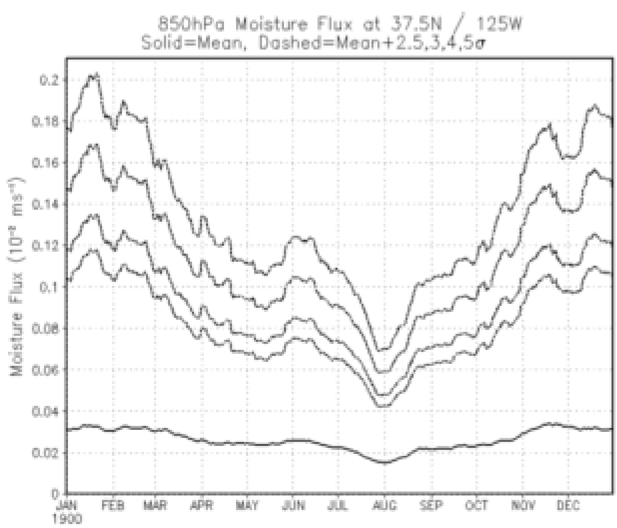

Figure 2. Mean values of 850 moisture flux for the 2.5, 3, 4 and 5 standard deviation normalized 850 moisture flux anomalies found at 37.5N 125W were plotted by time of year. The bottom line represents the mean moisture flux at the point.

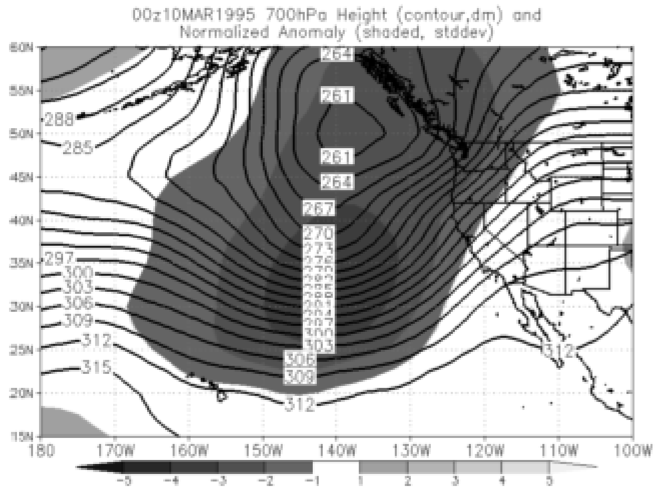

Figure 3. 00 UTC 10 Mar 1995, 700 hPa heights (contour,dm) and normalized anomalies (shaded, standard deviation)

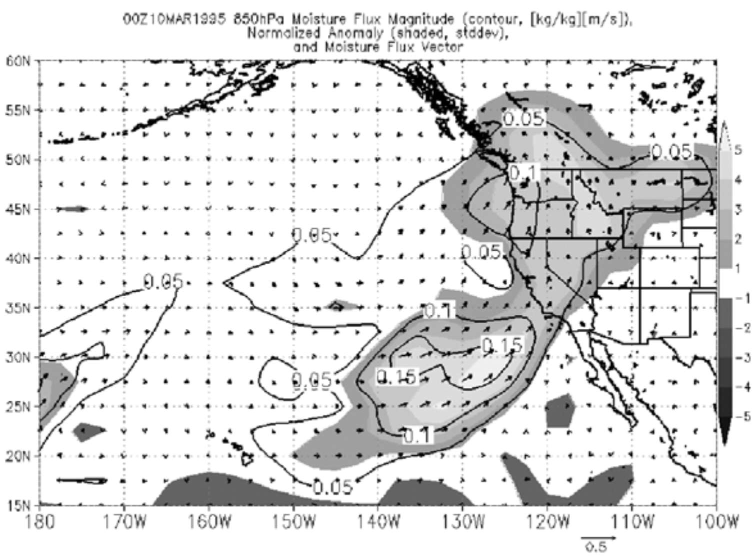

Figure 4. 00 UTC 10 Mar 1995, 850 hPa magnitude of moisture flux (contour, [kg/kg][m/s]), normalized anomaly of the magnitude of moisture flux (shaded, standard deviation) and moisture flux vector.