The California Extreme Precipitation Event of 8-10 January 2017

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1. Introduction

A strong Pacific jet and a surge of high precipitable water (PW: Fig. 1) brought extremely heavy precipitation to portions of California on 8-9 January 2017 (Fig. 2). Rainfall amounts in excess of 200 mm were observed and there were reports of extreme snowfall to include. NBC news reported "epic snowfall" in the Sierras. The Los Angeles Times reported flooding, record snow, extremely high winds at higher elevations, extreme snowfall, and blizzard conditions in the Sierras on 8-9 January 2017. Squaw Valley reported winds of 99 MPH with gusts as high as 159 MPH[1].

The strong Pacific system was associated with a near classic pattern for significant precipitation events in California which included a surge of high PW (Fig. 1) also known as an atmospheric river (AR: Neiman et al . 2008), a deep trough off the West Coast, a strong Ridge over the north Pacific and a ridge to the east (Fig. 3). This results in a strong 250 hPa jet (Fig. 4) moving into then over the affected region (Junker et al. 2008).

It will be shown that the general pattern was well forecast and thus the NCEP GEFS was able to forecast the general regions of heavy rain in California. This probably was an easy forecast as the mountains act as fixed forcing for the impinging moisture and energy from the Pacific.

This paper will provide an overview of the event and examine NCEP GEFS forecasts of the QPF. This was a multi-day event and the focus was on the heavy precipitation from 0000 UTC 8 to 0000 UTC 10 January. There was a significant event prior to this and another surge of precipitation after this time.

2. Methods and data

The climate forecast system re-analysis (CFSR) and Global Forecast System (GFS) data were used to reconstruct the pattern and the standardized anomalies associated with the event. Most of the data is focused to the time leading up to the event and during the height of the event. It should be noted that all times are GMT and the region is GMT-8. Thus all dates will be described based on GMT times which are nearly half a day off the local calendar date.

The Stage-IV rainfall data (Seo 1998) was used to estimate the rainfall over several 6, 12 and 24, monthly, and case related discrete times to show the impact of the pattern changing rainfall event. The rainfall pattern also revealed some interesting information about the southeastern drought and how both meteorologically and climatologically significant the precipitation event of 28-30 November 2016 was for the southeastern United States.

[1] NWS Reno, NV report circulated in the LA Times story maximum wind was observed at 0900 AM 8 January 2017.

Forecasts from the NCEP GEFS are the primary source here. The GEFS data was stored in GRIB2 format and processed using GrADS. Many of the images produced were produced in real-time in single panel images. They were reproduced here using a 6-panel format to facilitate the comparison of 6 GEFS forecast cycles spanning 6 days. This left the possibility of using 24 different GEFS forecast cycles. Nearly all the images shown here are either from the 0000 and 1200 UTC cycles. To get to longer ranges these data too were thinned from a potential of 12 to 6 times. Images of various other cycle times were made and showed a similar signal.

3. Results

a. *The Large scale patter*

The 500 hPa pattern over the northeastern Pacific (Fig. 3c) showed the basic pattern described by Junker et al. (2008). There was a large 500 hPa ridge over the Aleutians with 500 hPa height anomalies during the onset stage on the order of +2 to +4σ above normal. A strong 500 hPa trough (short-wave) moving down the eastern side of the ridge eventually produced a strong 500 hPa gradient along the California coast. This gradient was in part associated with the large 500 hPa ridge over the Mexico and the adjacent southeastern Pacific Ocean on the edge of the images.

In this strong gradient between the 500 hPa trough and the 500 hPa ridge a strong 250 hPa jet was present (Fig. 4). The plume of deep Pacific moisture is depicted in the PW field over the region (Fig. 1) which shows the deep subtropical Pacific connection of the AR and the commonly phrased “pineapple” express.

A regional perspective of the PW plume and 700 hPa jet impinging on the California is provide in 6-hour increments in Figures 5 & 6. Figure 5 shows the PW and PW anomalies focused over the period of heavy precipitation. Note the PW values in the +5 to +6σ range at 0000 UTC, 0600 UTC and 1200 UTC 8 January 2017. The PW values peaked again at +5σ at 0600 UTC 09 January 2017. These data show and enduring surge of Pacific moisture. The strong 700 hPa jet maximized slightly later in the period in the 1200 UTC 8 January to 0000 UTC 9 January time frame (Fig. 6c-e).

Figure 7 shows several of the key features which played a role in the event at 0000 UTC 9 January 2017.These data show a deep trough off the coast British Columbia, the strong ridge off the Mexican Coast (Fig. 7a), the strong low-level jet (Fig. 7b) over the Pacific impinging on California, the deep PW plume (Fig. 7c), and the deep surface cyclone (Fig. 7d) relatively well aligned with the deep 500 hPa cyclone.

b. Forecasts

The GEFS forecasts of 150 mm or more QPF for the 48 hours valid at 0000 UTC 10 January 2017 (Fig. 8) show that the GEFS was forecasting the potential for over 6 inches of QPF in the region close to the area where the highest QPF was analyzed by the Stage-IV data. The black dot is the approximate location of Mammoth Mountain where reports of 7 feet of snow were observed. This point is slightly east of the GEFS axis of maximum QPF.

The 150 mm of QPF (6 inches) was likely due to the continuous flow of deep moisture the GEFS members produced into the terrain of California. The ensemble means PW and PW anomalies (Fig. 9) show the high PW plume impinging on the Sierras. These data are valid at 1800 UTC 8 January. Other times from 0000 UTC 8 January through about 1200 UTC 9 January showed a similar pattern with high PW air impinging on the mountains.

The continuous flow of moisture and strong winds (not shown) produced high QPF amounts over several periods. The first 24 hour period from 0000 UTC 8-9 January (Fig. 10) showed a high probability of over 100 mm of QPF from most of the GEFS cycles. The 1200 UTC 3 January 2017 forecast had lower probabilities but they came up steadily as the forecast length decreased suggesting a convergence of solutions over time.

The probability of over 150 mm of QPF in 36 hours ending at 1200 UTC 9 January (Fig. 11) show higher confidence in the higher QPF amounts. These data indicated the issues with uncertainty related to spatial and temporal issues in the various GEFS cycles. Some of the earlier GEFS forecasts had a slightly later onset time of the higher QPF amounts. The final image (Fig.12) in the sequence shows the ensemble mean QPF for each GEFS cycle and the location of each member's 200 mm contour if present in the forecasts. In these cases every GEFS forecast had at least 1 member which produced at least 200 mm (8 inches) of QPF.

The final point is what did these QPF represent in the GEFS atmosphere relative to its internal QPF climate? The forecasts suggest the GEFS was producing record QPF over portions of California for many time periods. One example if provided using the GEFS initialized at 0000 UTC 5 January 2017 showing the 48 hour forecast valid at 1200 UTC 9 January 2017 (Fig. 13-right). These data show the GEFS mean QPF was over 6 inches and that for this time period and this time of year the GEFS was forecast a record QPF event. This was true of nearly every forecast cycle valid during the time period of 0000 UTC 8 to 0000 UTC 10 January 2017 (not shown). The forecasts from 0000 UTC 4 January are included as an additional 48 hour forecast example.

c. *Impacts*

This storm brought a wide range of impacts to northern California. There were widespread reports of small stream flooding across the entire region (ABC News). For example, Alta, in Placer County in the foothills east of Sacramento had a portion of Morton Road wash out. South of Sacramento, in Wilton the Cosumnes River flooded (Sacramento Bee), prompting a voluntary evacuation of around 2000 people. Water levels reached their highest levels since 1997. North of San Francisco, the Russian River crested well above flood stage with close to 3000 residence forced to evacuate in Sonoma County.

The Sacramento Weir, a flood control structure aimed to prevent flooding in and around Sacramento, on the Sacramento River, was opened for the first time in a decade spilling water onto farmland known as the Yolo bypass between Sacramento and Davis California.

Snowfall in the Sierra Nevada Mountains was copious. After years of drought this is welcome news, however it has created significant impacts for the time being. Over seven plus feet of snow fell over the higher elevations, and mountain highways including Interstate 80 and US Highway 50 were closed for long stretches. There were numerous reports of rescues of stranded motorists. A positive impact awaits the region as when the interstates and ski resorts reopen, there will be epic powder skiing for Sierra resorts for days and the snow pack will help restore low water levels produced by the enduring drought.

Finally, one F0 tornado was recorded north of Sacramento in South Natomas, producing tree and minor structural damage.

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4. Conclusions

The pattern as shown in Figure 7 was a classic West Coast heavy precipitation pattern as defined by Junker et al. (2008). Key features as shown at 0000 UTC 9 January 2017 included the deep trough off the coast British Columbia, the strong ridge off the Mexican Coast (Fig. 9a), the strong low-level jet (Fig. 9b) over the Pacific impinging on California, the deep PW plume (Fig. 9c), and the deep surface cyclone (Fig. 9d) relatively well aligned with the deep 500 hPa cyclone.

The GEFS and other models (not shown) were able to correctly forecast the pattern in which this extreme if note epic QPF event developed in. The pattern was nearly a textbook example of the pattern identified by Junker et al (2008). As the GEFS was capable of producing the pattern and strong onshore flow it was also able to produce the extreme QPF amounts (Figs. 10-13). And as shown in Figure 13, the GEFS was producing record QPF within the forecast system. It was probably helpful to the GEFS that the mountains of California and Nevada represent fixed forcing. Thus the GEFS had an extremely long lead-time of an extreme QPF event.

The QPFs in the GEFS relative to the GEFS internal Climate (M-Climate) were extremely useful. Clearly, internal model climate data plays a critical forecast role in forecasting extreme QPF events. Experience using model QPF and M-Climate data clearly shows that when the models and ensemble forecasts systems forecast a record event in the model climate, record and at times historic events are often observed in the real atmosphere. Developing M-Climate data for global forecast systems is a critical tool in the forecaster's arsenal when forecasting record events.

The focus here was on one period of heavy QPE and QPF. As shown in Figure 14, this was an enduring event with several surges of high QPF. The areas of higher QPF shifted as the plume of deep moisture moved over time. The higher QPF amounts occurred in the 24 hour periods ending 1200 UTC 9 January and 1200 UTC 11 January. The enduring nature of this event implies some time averaging of the features may provide added insights. Clearly, a relatively persistent pattern played a role in this epic event. The mean pattern for the period of 0000 UTC 8 to 1800 UTC 10 January is shown in Figure 15. In a relative sense it contains all the key feature often associated with historic California QPE events just they persisted for several days. This image will be updated as 11 January CFSRV2 data comes in.

5. References

Junker, N. W., R. H. Grumm, R. Hart, L. F. Bosart, K. M. Bell, and F. J. Pereira, 2008: Use of standardized anomaly fields to anticipate extreme rainfall in the mountains of northern California. *Wea. Forecasting,* **23,** 336–356.

Neiman, P.J., F.M. Ralph, G.A. Wick, J. D. Lundquist, and M. D. Dettinger, 2008: Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the west coast of North America based on eight years of SSMI/satellite observations. *J. Hydrometeor*., 9, 22-47.

Seo, D.-J., C.R. Kondragunta, K. Howard, S.V. Vasiloff and J. Zhang, 2005: The National Mosaic and Multisensor QPE (NMQ) Project—Status and plans for a community testbed for high-resolution multisensor quantitative precipitation estimation (QPE) over the United States. Preprints, AMS 19th Conference on Hydrology, San Diego, CA. Paper 1.3.

A duck makes its way as Russian River floods, Jan. 10, 2017, in Monte Rio, California.

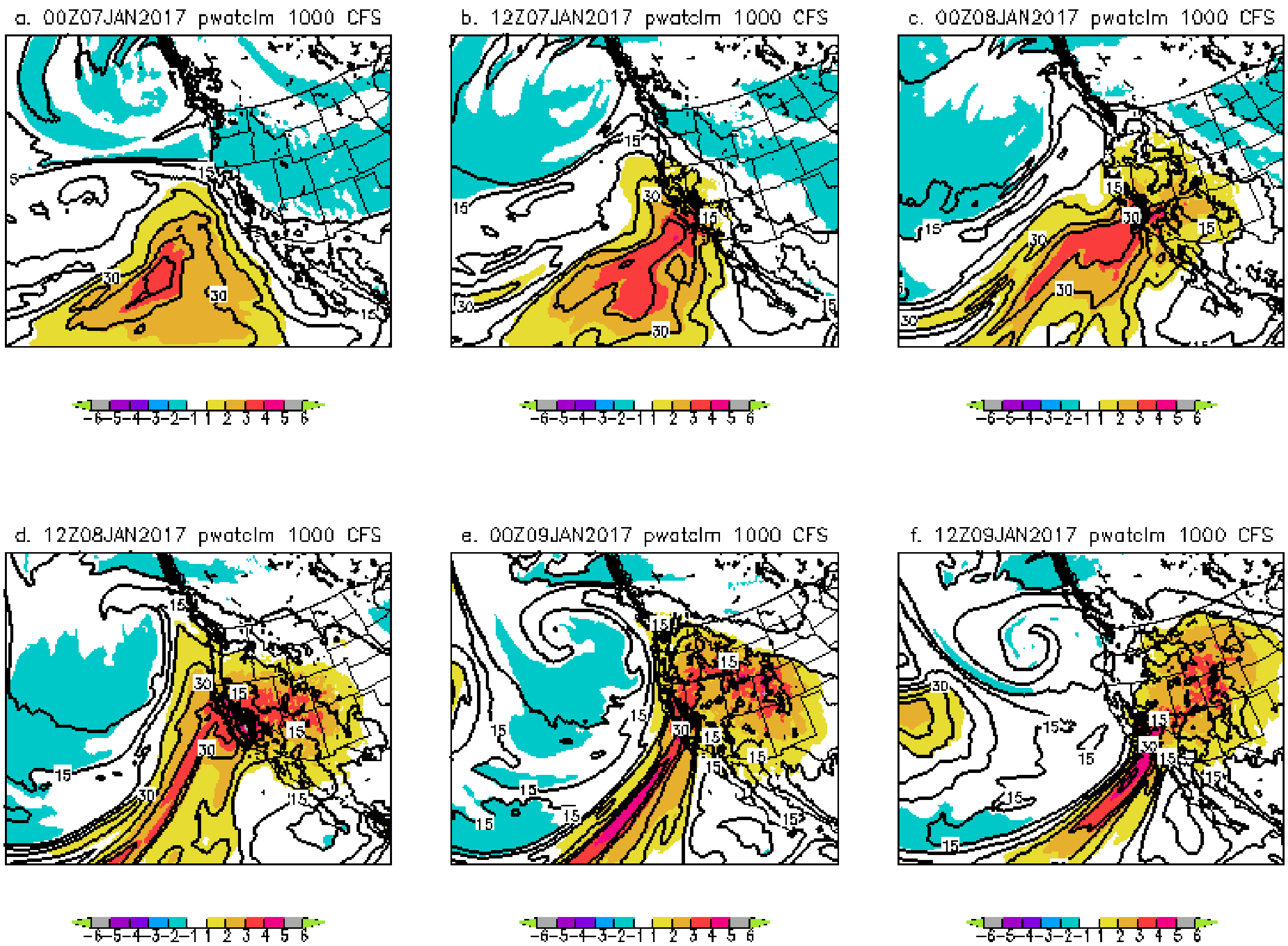

Figure 1. The CFSRV2 precipitable water (mm) over the eastern Pacific in 12 hour increments from a) 0000 UTC 7 to f) 1200 UTC 9 January 2017. Values in mm plot every 5mm and standardized anomalies relative to the 30 year mean. **Return to text.**

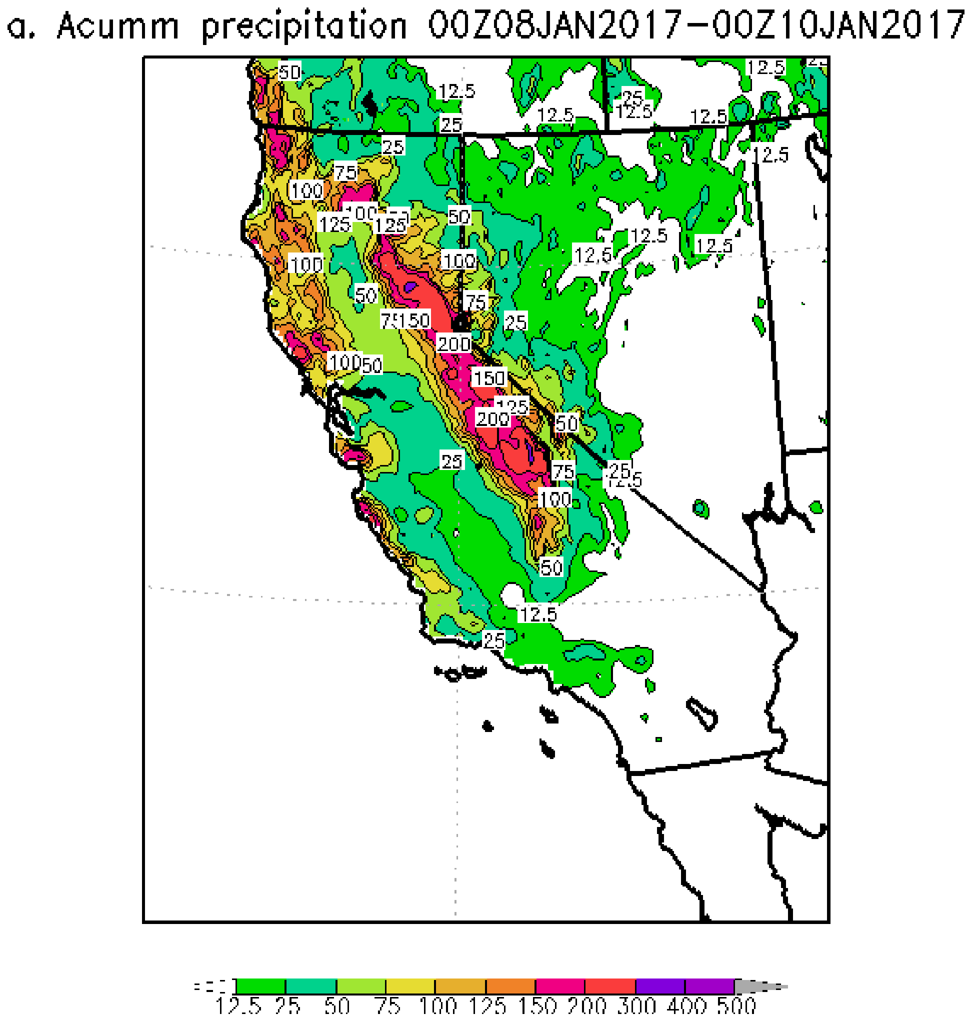

Figure 2. Total QPE from the Stage-IV data for the period of 0000 UTC 8 to 10 January 2017. Black do is the location of Mammoth Mountain. **Return to text.**

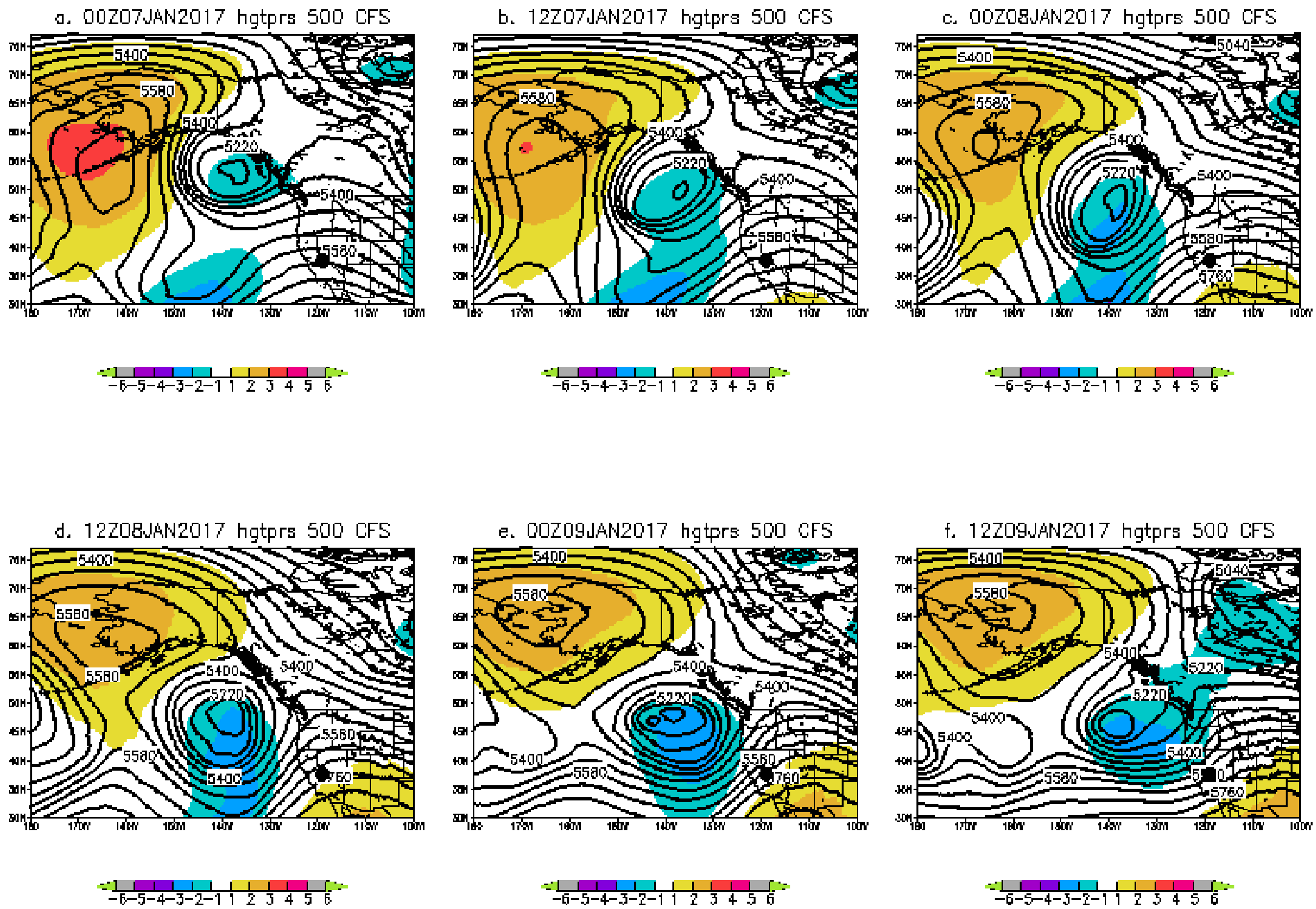

Figure 3. As in Figure 1 except for the 500 hPa heights and height anomalies from a) 0000 UTC 7 January through f) 1200 UTC 9 January 2017 in 12 hour increments. Contours are every 60 m. **Return to text.**

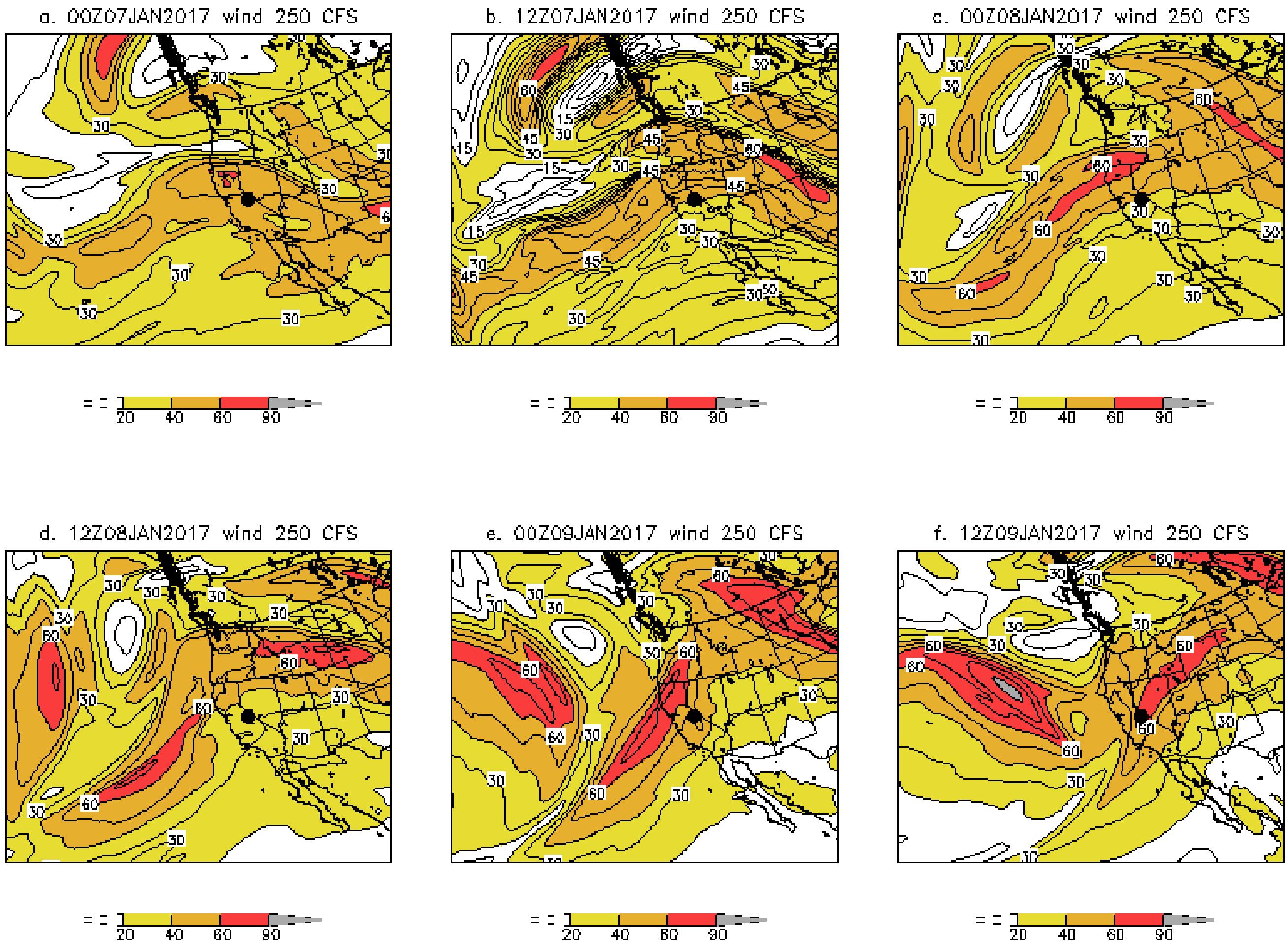

Figure 4. As in Figure 3 except for the 250 hPa winds over the eastern Pacific and western United States. Isotachs shading as in color bar and the isotachs values are every 10ms-1. **Return to text.**

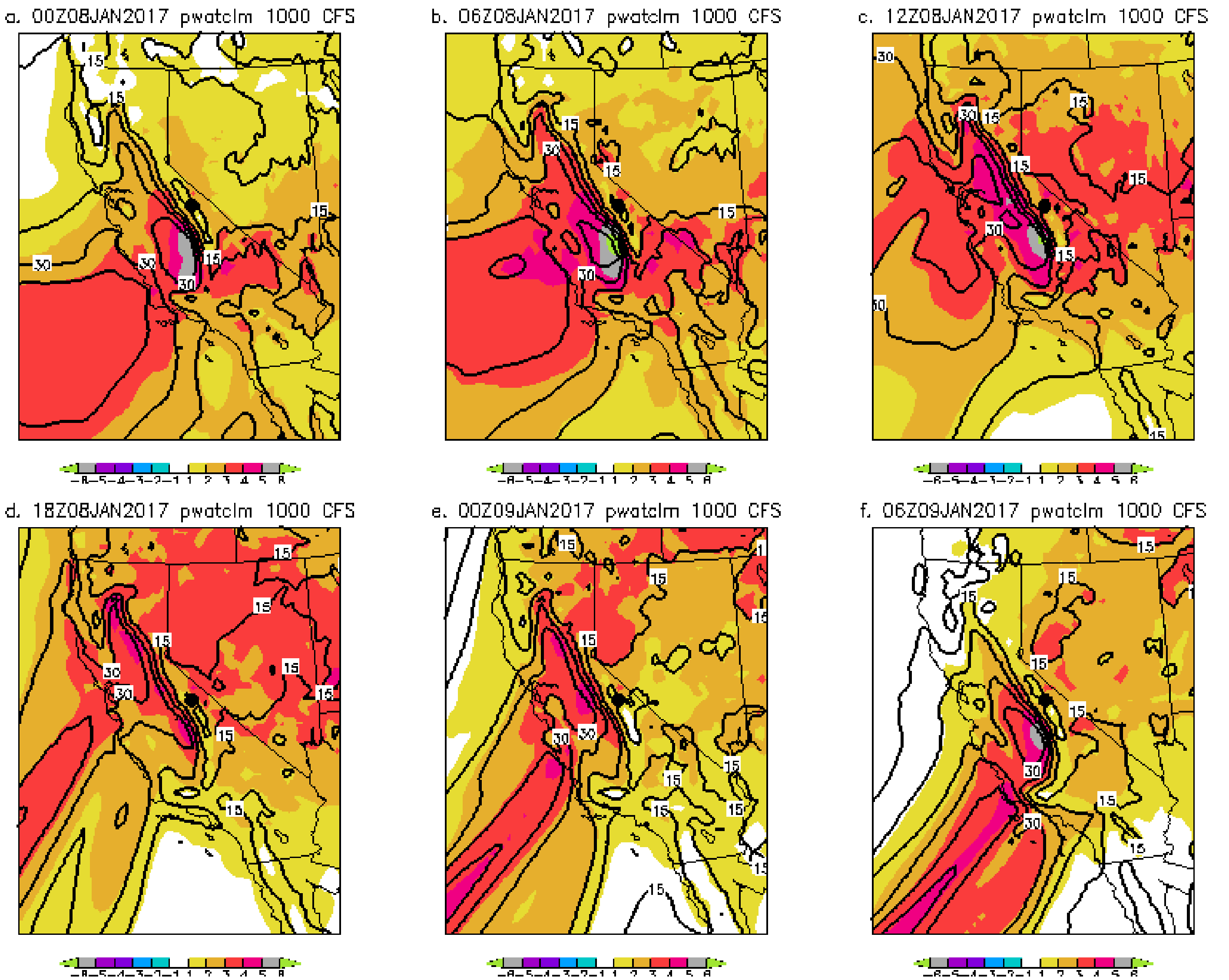

Figure 5. As in Figure 3 except regional view of the CFS Precipitable water in 6 hour increments from a) 0000 UTC 8 January to 0600 9 January 2017 in 6-hour increments. **Return to text.**

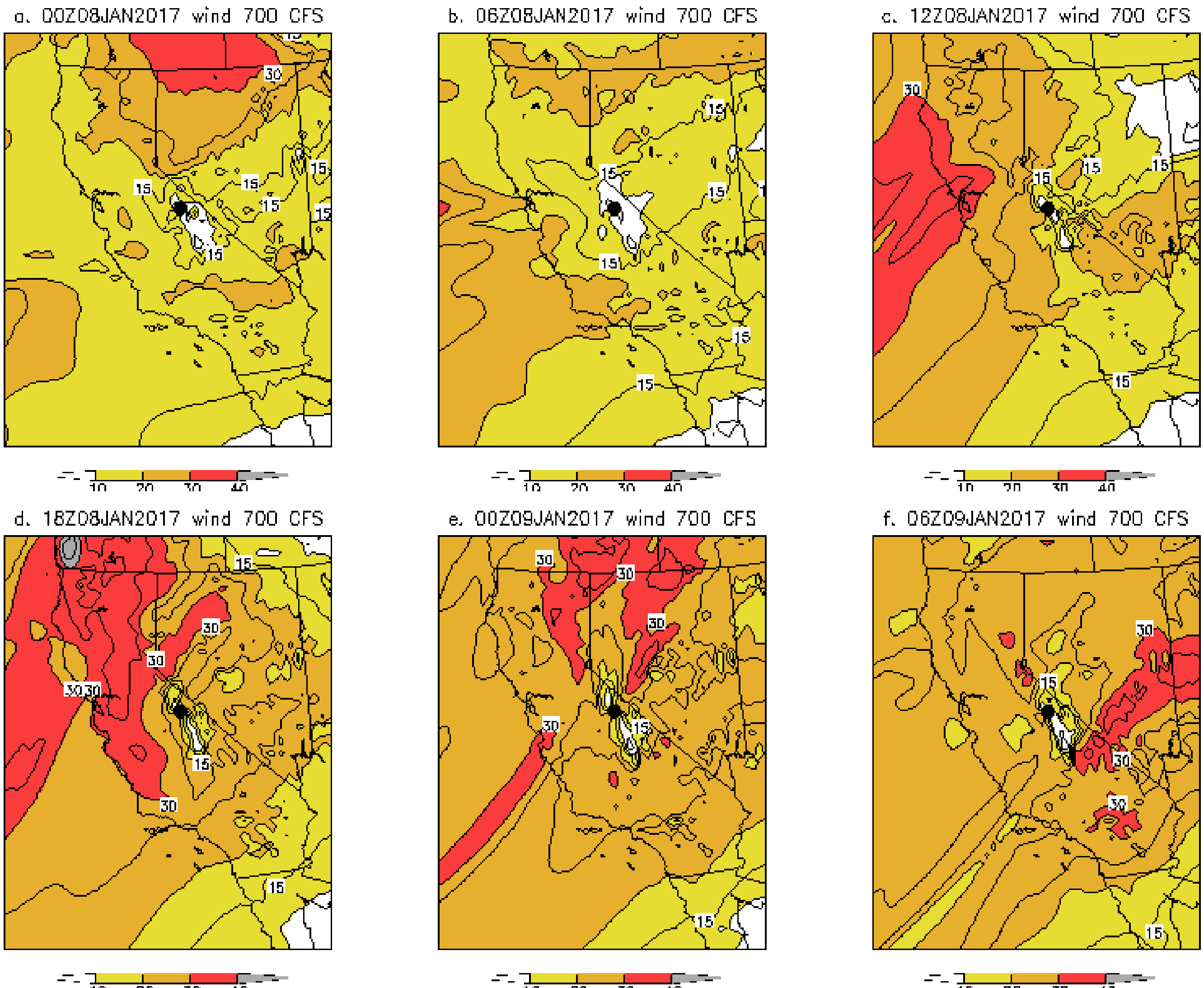

Figure 6. As in Figure 5 except for 700 hPa winds (ms-1) shading shows the values indicated in the color bar. Return to text.

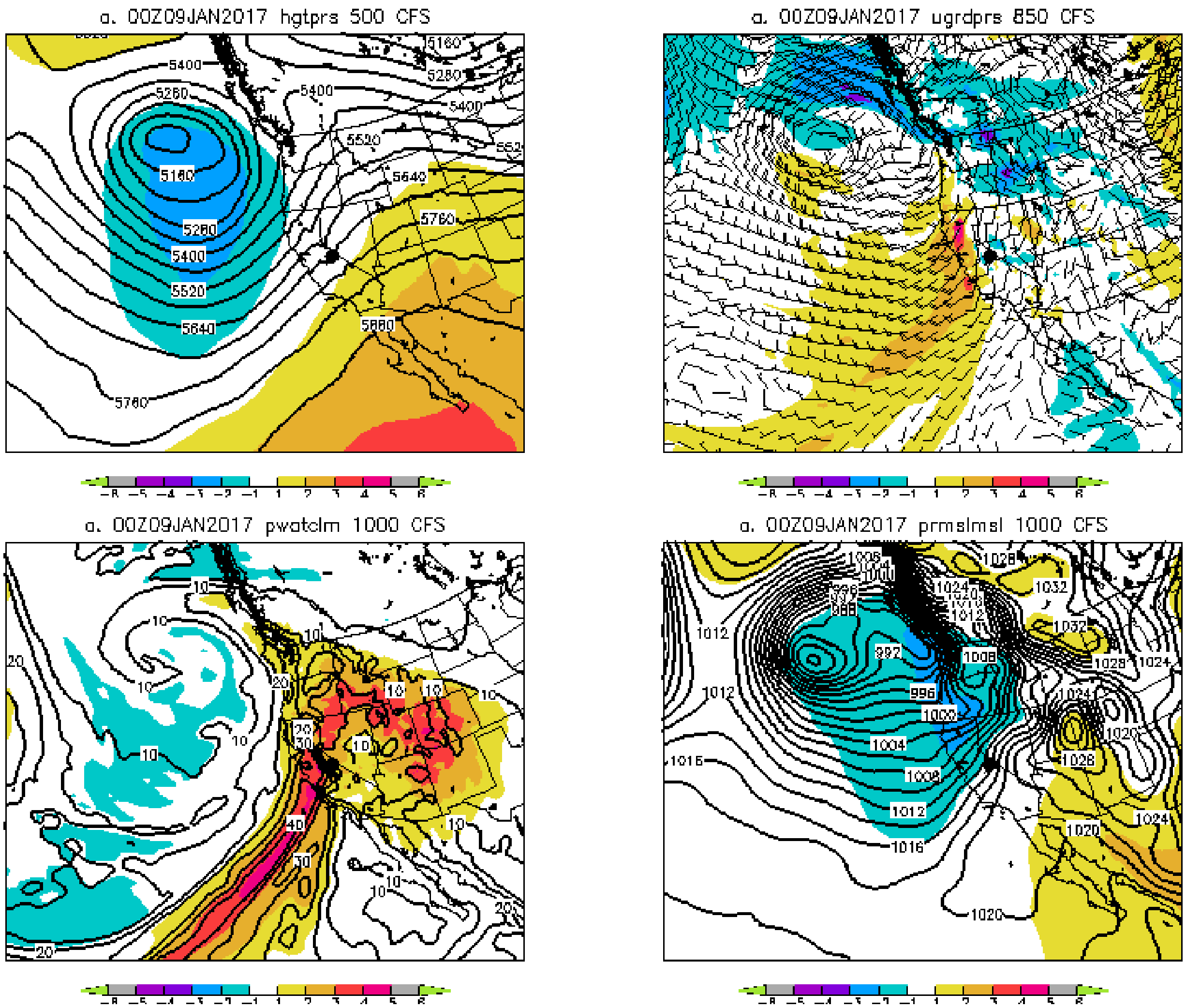

Figure 7. As in Figure 6 except for CFSR at 0000 UTC 9 January 2017 showing a) 500 hPa heights and anomalies, b) 850 hPa winds and u-wind anomalies, c) precipitable water and anomalies, and d) mean sea-level pressure an pressure anomalies. **Return to text.**

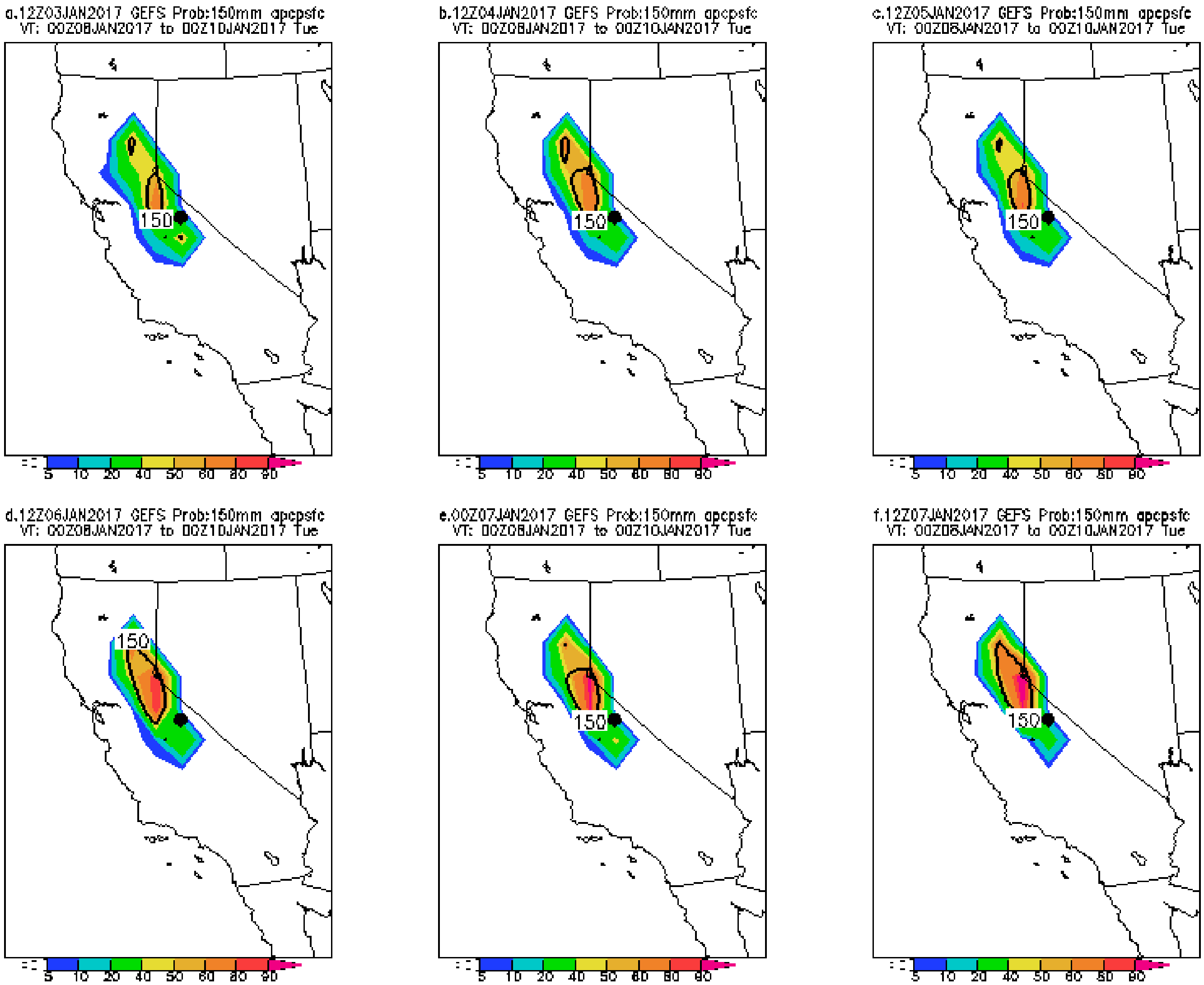

Figure 8. GEFS forecast of QPF greater than or equal to 150 mm (shaded) for the 48 hour period ending at 10 January 2017. Solid line shows the mean 150 mm contour if present. GEFS forecasts initialized at a) 1200 UTC 3 January, b) 1200 UTC 4 January, c) 1200 UTC 5 January, d) 1200 UTC 6 January, e) 0000 UTC 7 January, and f) 1200 UTC 7 January 2071. Return to text.

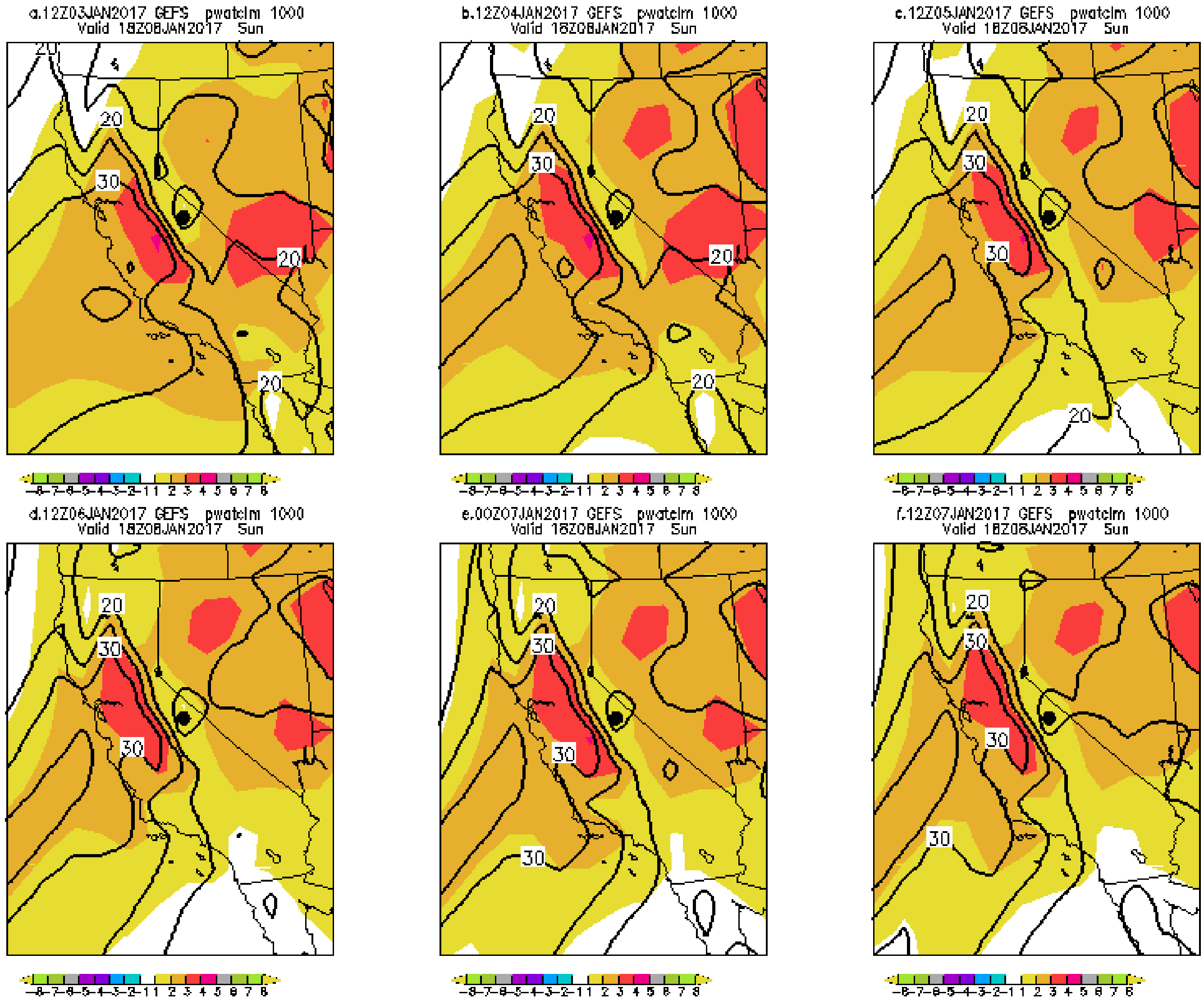

Figure 9. As in Figure 8 except GEFS forecasts of ensemble mean precipitable water and precipitable water anomalies valid at 1800 UTC 8 January 2017. Values of PW in mm. **Return to text**.

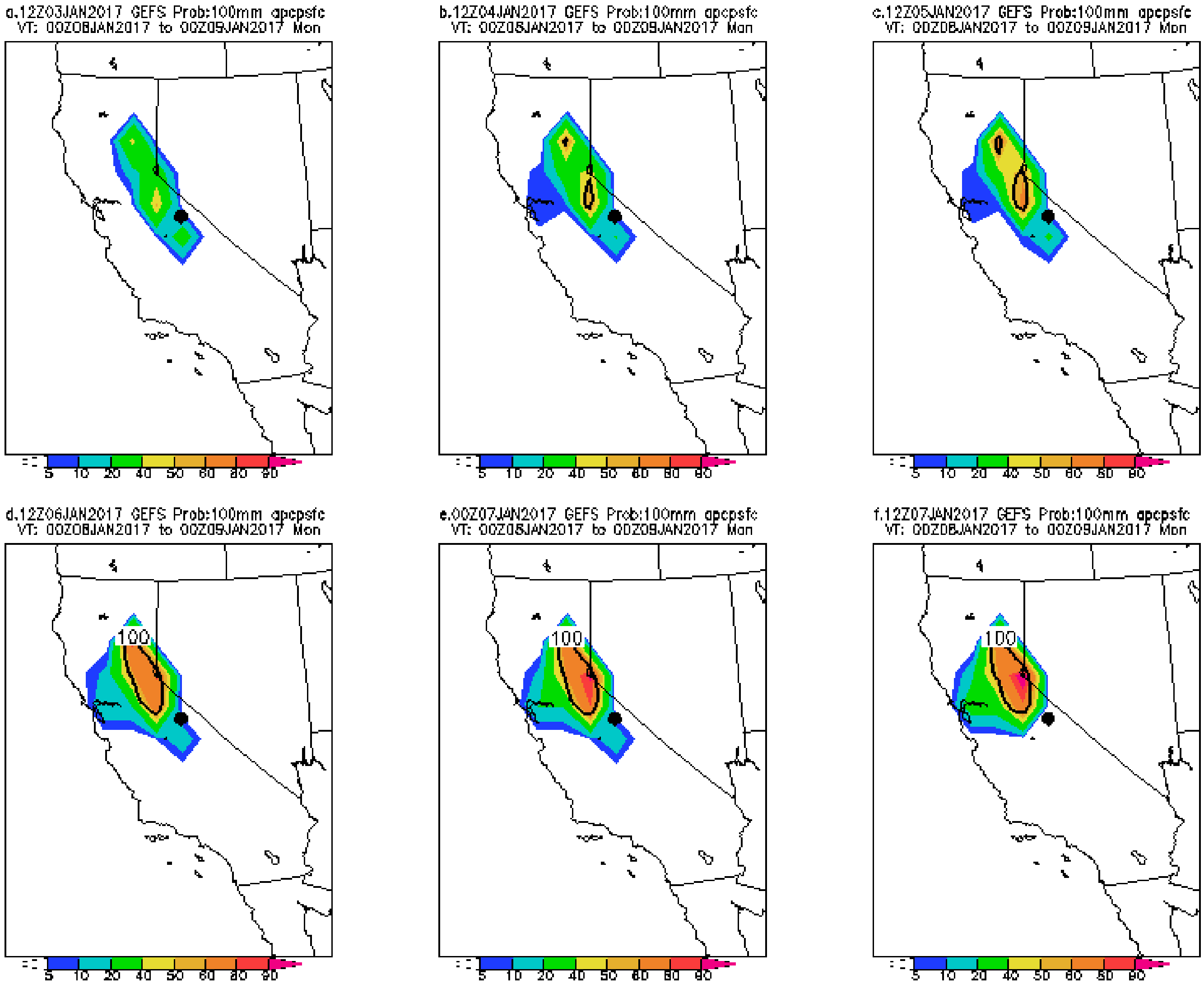

Figure 10. As in Figure 8 except GEFS forecasts of the probability of 100 mm of QPF valid for the 24 hour period ending at 0000 UTC 09 January 2017. Return to text.

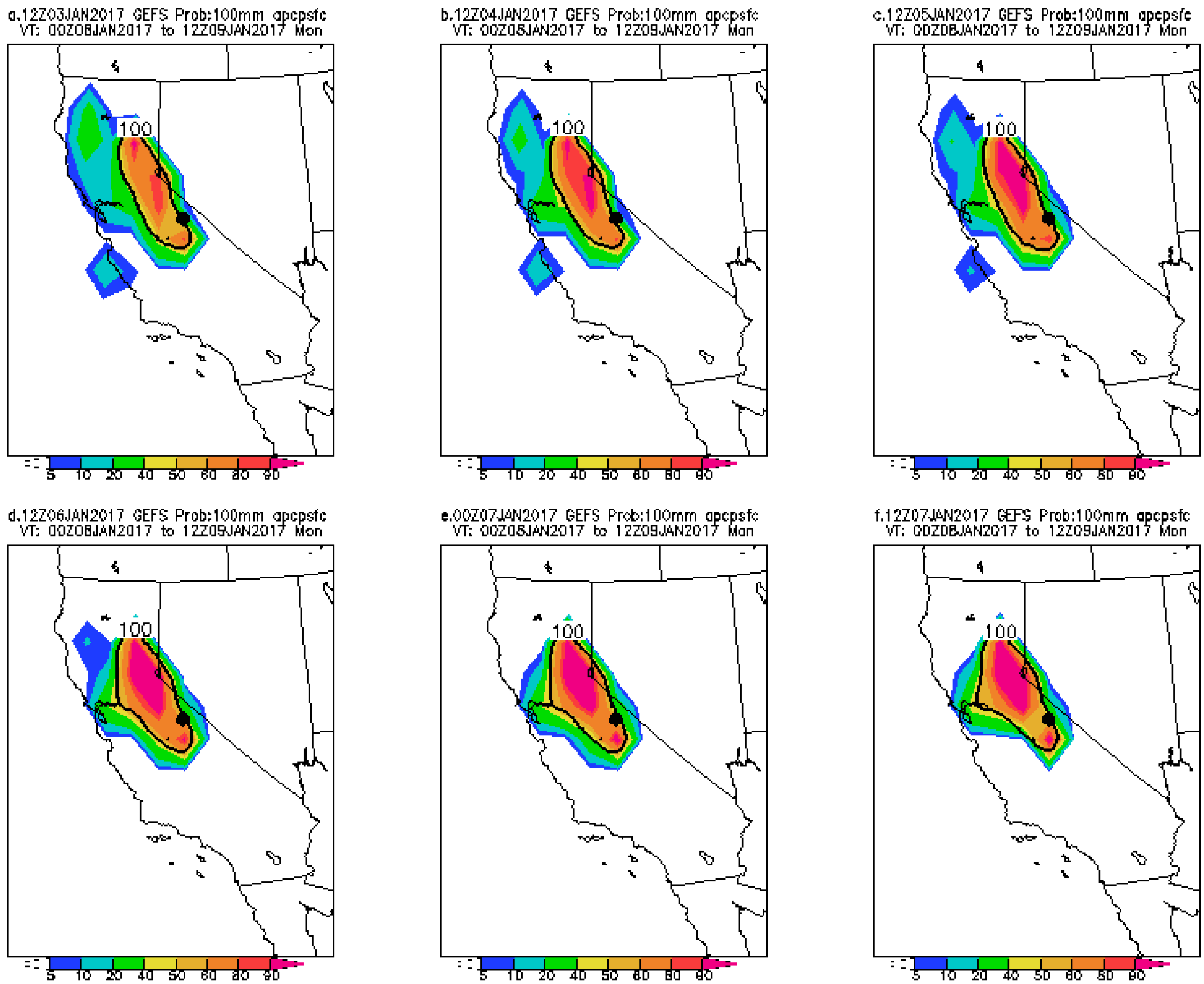

Figure 11. As in Figure 8 except GEFS forecasts of the probability of 100 mm of QPF valid for the 36 hour period ending at 1200 UTC 09 January 2017. **Return to text.**

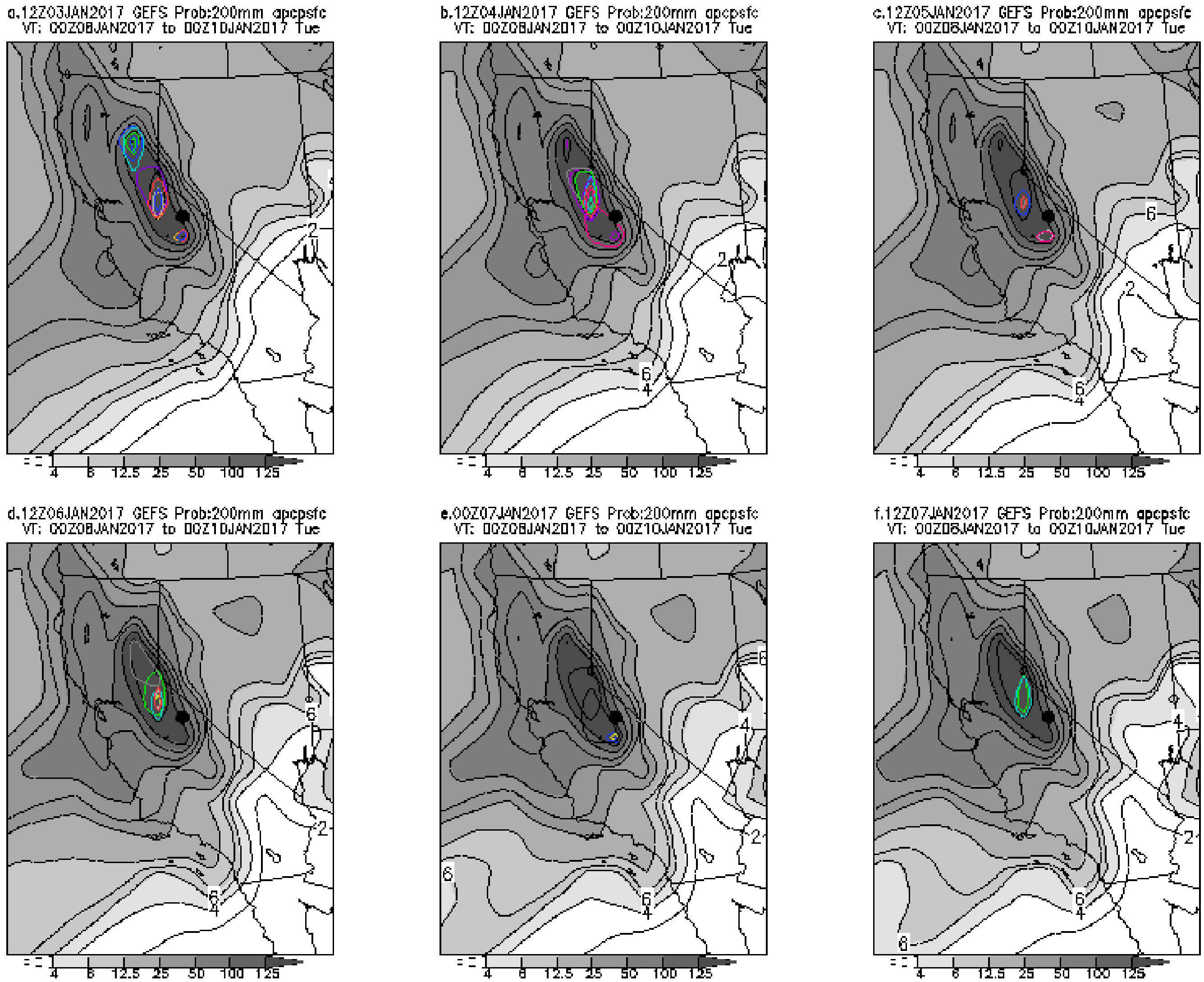

Figure 12. As in Figure 8 except GEFS ensemble mean QPF for the 48 hour period ending at 0000 UTC 10 January 2017 and the position of any members 200 mm contour if forecast. Return to text.

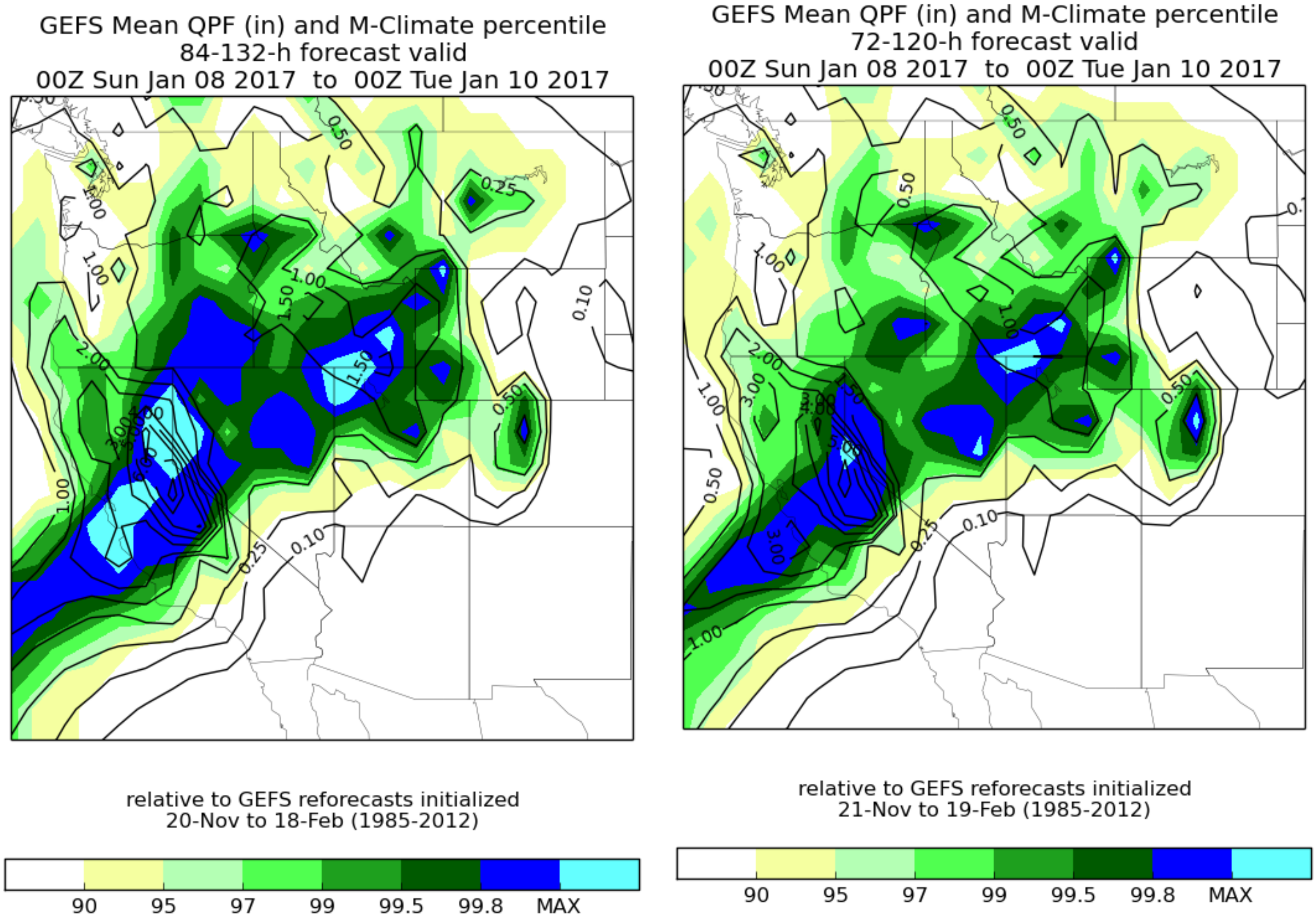

Figure 13. The GEFS ensemble mean QPF and the location in the PDF of this QPF verse the M-Climate from the GEFS QPF climatology for 48 hour forecasts valid in early January. Data shown include the 48-h QPF valid from 0000 UTC 8 to 0000 UTC 10 January 2017. **Return to text.**

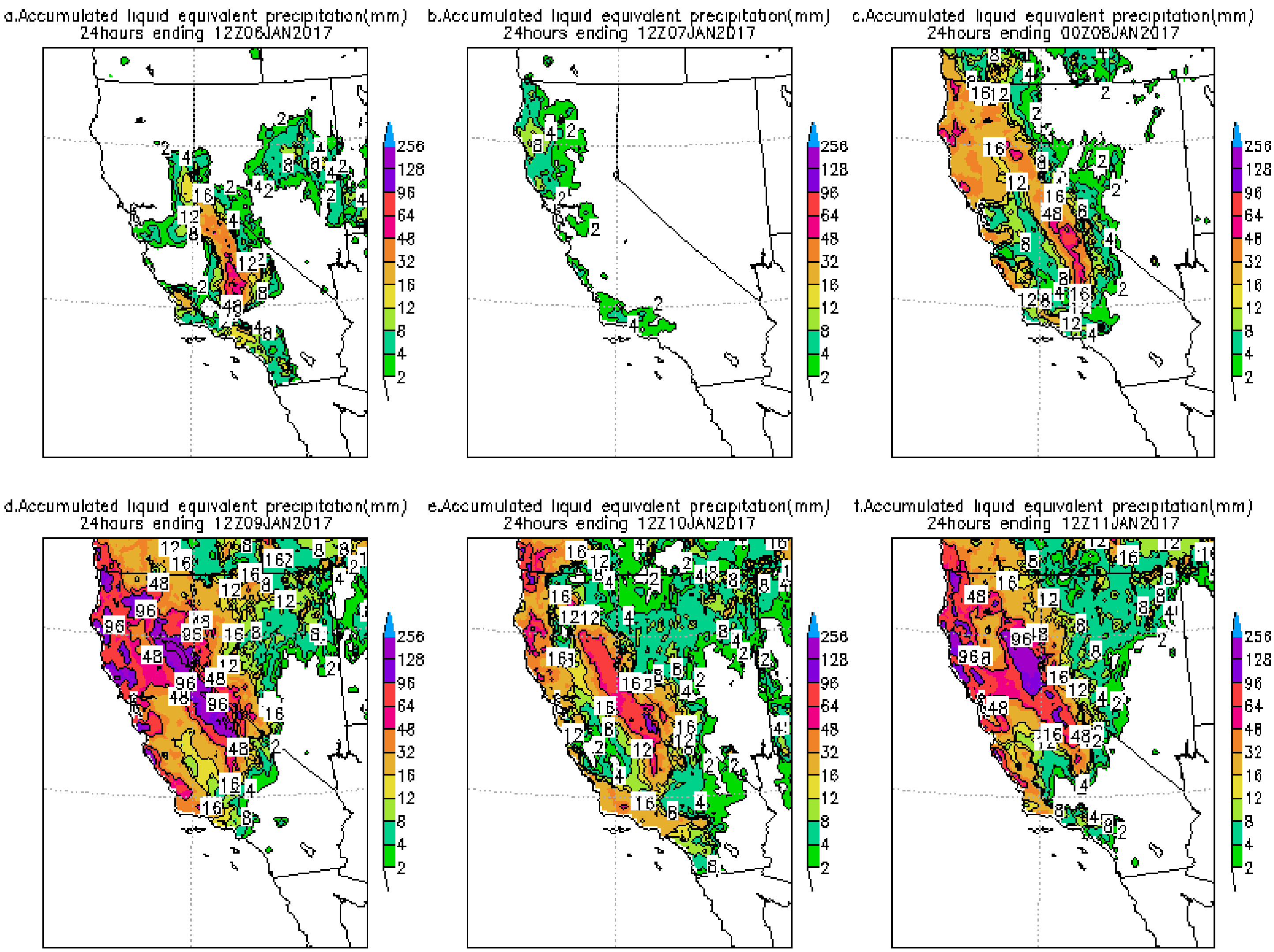

Figure 14. As in Figure 2 except for the 24 hour total QPE for the 6 times ending at 1200 UTC a) 6 January, b) 7 January, c) 8 January, d) 9 January, e) 10 January, and f) 11 January 2017, **Return to text.**

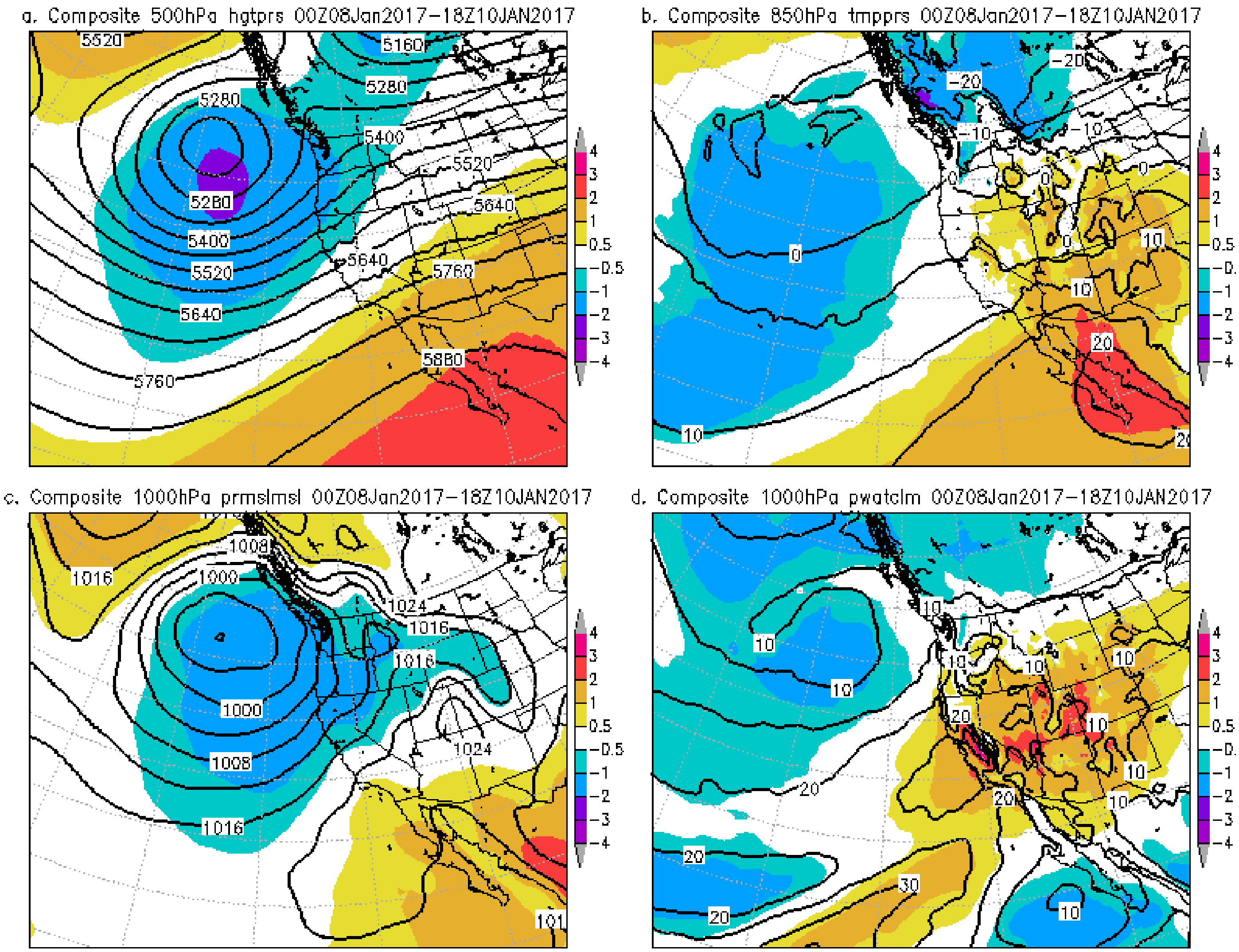

Figure 15. As in Figure 7 except for the pattern over the period from 0000 UTC 8 to 1800 UTC 10 January 2017. [Return to text.]

A portion of Morton Road near the Alta exit of Interstate 80 was swept away, the Placer County Sheriff's Office reports.

Placer Sheriff
@PlacerSheriff

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CHP #Colfax shared this from Morten Road washout, near Alta exit of #Interstate80. Stay out of area. I-80 remains closed.

12:43 PM - 11 Jan 2017 · North Auburn, CA

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