Gulf of Mexico Moisture Input to
late Spring 2012 Upper Columbia Precipitation

Martin Lee (1)

Introduction

Near the Canadian border in fig. 1, there is a 1.5 to 2.5 inch center of rain concentrated in southeastern British Columbia (yellow and orange circular area north of Spokane, Washington). This bullseye of heavy rain was observed in the Upper Columbia during a late Spring 24 hour period from 12:00Z June 4, 2012 to 12:00Z June 5, 2012. Association of this Upper Columbia heavy precipitation pattern to limbs of some heavy central Cascades and Southwestern Oregon coast range rain seems somewhat obvious at this point. However, in fig. 1 the animated dashed black line - reaching from central Texas and curling northwestward into the Upper Columbia - also appears to have some precipitation pattern connectivity (where non-zero data is available) to this bullseye of heavy Upper Columbia precipitation. The significance of this eastward placed, weaker precipitation pattern to observed June 4-5, 2012 Upper Columbia heavy precipitation north of Spokane is explored in the following discussion.

Preliminary Analysis

Water vapor satellite imagery around 00:00Z on June 6, 2012 has a moist axis (highlighted in fig. 2 by an animated red dashed streamline) that closely parallels the black dashed line axis through non-zero available precipitation data in fig. 1. Lightning strikes scattered at this time along the Gulf Coast in fig 2. tend to trail off northward into Oklahoma, but there is also a decent concentration of lightning strikes that pick up across the Rocky Mountains in Western Montana. Notice the void of lightning strikes at this time across Idaho, Washington, and Oregon in fig. 2. About 11 hours earlier (around 13:00Z June 5, 2012) an axis of high Total Precipitable Water (TPW) has scattered local maxima of 1.18 to around 1.34 inches beaded along a northwestward arc through Kansas into Canada (animated white dashed streamline in fig. 3). Note the void of TPW greater than about 1.12 inches across northern Idaho and Washington in fig. 3.

A NAM80 850-700mb wind streamline and moisture transport magnitude analysis valid at 00:00Z June 6, 2012 places an axis of maximum moisture transport (animated yellow dashed streamline in fig. 4) that closely matches the animated red dashed water vapor moist axis in fig. 2. In fig. 4, also note the substantial diminishment of onshore Pacific 850-700mb moisture transport into the western North America (resulting from a large scale upstream, offshore split flow pattern).

The accumulating coincidental environmental circumstances discussed thus far are linked together a bit more by an NCEP 19:00Z June 5, 2012 surface weather depiction (fig. 5). In this product, a triple point type intersection is analyzed in southeastern Montana (near Hardin). A green dashed line in fig. 5 depicts a warm sector trough that continues northward past this triple point into an occluded trough (purple solid line in fig. 5). These two trough features - connected through the southeastern Montana triple point - are closely aligned with moisture axes maxima over nearly the same locations in fig. 1, fig. 2, and fig. 4. However, the trough analyzed over eastern Washington (blue solid line in fig. 5) has curvature concavity resembling that of a leading edge of a colder air mass boundary originating from over the Pacific. This is just a single example of circumstantial inconsistencies that arise while attempting to unify a solution into something like the red dashed line in fig. 5 - which, again, closely parallels axes maxima in figs. 1-2, and fig. 4. Other resistance to such a unified solution (i.e., the red dashed line in fig. 5) includes the common assumption that moisture from the Gulf of Mexico is typically too restricted mechanically to lower levels east of the pronounced Rocky Mountain barrier.

Conceptual Rationale versus Operational NWP

It's useful to start here by looking at the mechanical ascent that low level Gulf of Mexico moisture makes from sea level at the Gulf Coast to the northwestern corner of the Texas panhandle: respectively about a 3,900 foot rise over a horizontal distance of around 630 miles (that's a slope factor of nearly 1/853 and is roughly illustrated along the first animated yellow dashed streamline segment in fig. 4). Without sequential animations of this streamline pattern holding in place, it is not possible to effectively visualize actual particle trajectories involved here. The Air Resources Laboratory (ARL) HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model - using archived Global Data Assimilation System (GDAS) initialized runs - was used to convey this approximate matching of streamlines with trajectories; fig. 6 depicts an isentropic forward trajectory initiated June 4, 2012 12:00Z at 500 meters over the Gulf of Mexico about 80 miles east of Brownsville, Texas. The forward trajectory in fig. 6 illustrates how lower level Gulf of Mexico moisture was getting loaded into the northern panhandle of Texas - similar to first stage animated streamline segments in figs. 2 and 4.

The water vapor axis maxima in fig. 2 along this same commonly observed (and accepted) lower elevation, gradual trajectory (from the Gulf coast to northern Texas) actually appears more diffuse than along the following, approximately 1,200 mile track that just crests the Canadian Rockies near Banff National Park. Along this next roughly 1,200 mile intermediate path length, terrain rises from about 3,900 feet out of the Texas panhandle eventually to near an effective, assumed average height of around 8,000 feet across crests of the Canadian Rockies; this yields an average slope factor of only around 1/1,545 (about a -45% change [decrease] in slope compared to the mechanical terrain lift factor involved in moving low level Gulf of Mexico moisture from sea level just to the northern Texas panhandle)! Thus, if moist flow originating from the Gulf of Mexico tracked along this deeper interior 1,200 mile continental trajectory with only some cumulative atmospheric lofting, it would seem mathematically quite plausible to assume that this moist flow could acquire sufficient altitude to curl westward over the Rockies into the Upper Columbia (as per the black dashed trajectory animated in fig. 1).

Prior to reaching the Canadian Rockies, note the near absence of lightning in the moist trajectory axis (red dashed line) from southeastern Colorado to around Calgary, Alberta (fig. 2). It is evident from the weather depiction analysis in fig. 5 (and the water vapor imagery in fig. 2) that the portion of the trajectory between northern Texas and southeastern Montana (green dashed line) is in the warm sector of an occluding mid-latitude wave. Absence of pronounced convective instability, in combination with northward moving, warm-sector isentropic upglide into an occlusion along this mid-reach moisture axis maxima (figs. 2 and 4) is resulting in relatively stable, gradual lifting of moisture originating from the Gulf of Mexico. (2) (3) This more stable mid trajectory fetch partly explains the diminished precipitation effectiveness scattered in fig. 1 across Colorado, Wyoming, and most of Montana (compared to the more active dynamics in frontal driven precipitation pushing in from the Pacific across Western Oregon).

As the warm sector moist conveyor from the Gulf of Mexico (green dashed line in fig. 5) reaches southeastern Montana, it is forced further aloft and entrained into an occlusion largely centered over western Montana (see figs. 2 and 5). Essentially, west of Billings, Montana the remainder of the conveyor trajectory in fig. 2 develops into a TROgh of Warm air Aloft (TOWAL). (4) This process results in further accelerated isentropic uplift prior to Gulf of Mexico moisture directly approaching the Canadian Rockies west of Calgary, Alberta (fig. 2).

Fig. 7 is a single frame from a University of Wisconsin Nonhydrostatic Modeling System (UW-NMS) simulation of a TROWAL. (5) The black dashed animated line in fig. 7 is analogous to the portion of the postulated red dashed streamline trajectory in fig. 5 that curls around western Montana. The 312K Theta-E surface simulation in fig. 7 has red contours of accumulated snowfall with 7.5 cm intervals. The maxima of this snowfall accumulation is wrapped far back into the west side of the simulated occlusion. From a pattern recognition perspective, this is quite similar to northern portions of the animated black dashed line in fig. 1 (with an Upper Columbia precipitation maxima of around 1.5 to 2.5 inches north of Spokane, Washington). Also, in fig.8, notice the blue dashed line marking arched, higher convective cloud top structure (visible satellite image valid at 14:31Z June 5, 2012). There is very TROWAL-like curvature (similar to that in fig. 7) to this higher topped convective cloud pattern in southwestern Canada. Note the extension of this enhanced convective cloud signature southward into the Upper Columbia, north of Idaho; this extended limb of convection has crossed or spanned west/southwestward of the Canadian Rocky Mountain Front Range. Furthermore, scale-wise, from the Pacific, there is not equivalent high topped convective structure reaching eastward from the coast across southern British Columbia, Washington, Oregon, or Idaho.

Fig. 9 is an ARL HYSPLIT GDAS isentropic forward trajectory (in effect, an extension of the trajectory in fig. 6 originating over the Gulf of Mexico) that was initialized June 5, 2012 00:00Z at 750 meters AGL out of the northern Texas panhandle (note the animated solid black and later solid green trajectory segments curling into an Upper Columbia occlusion). There is decent similarity in fig. 7 modeled TROWAL results with that of the animated black, and then green trajectory segments in fig. 9; and this similarity correlates fairly well with the animated alignment of higher convective cloud elements (along the blue dashed line) in fig. 8. The trajectory in fig. 9 shows flow moving north/northwestward out of the northern Texas panhandle (where fig. 2 shows Gulf of Mexico moisture was converging) along a track toward Calgary, Alberta, then west across the Canadian Front Range. Results of an ARL HYSPLIT GDAS June 6, 2012 12:00Z isentropic backward trajectory calculation initialized at 2000 meters AGL originating from around an Upper Columbia occlusion are depicted in fig. 10. The animated backward trajectory in fig. 10 spans east across the Rockies, from near Revelstoke, British Columbia back toward Calgary, Alberta, finally trailing off southeastward (dashed black line) to near the triple point in fig. 5 (close to Billings, Montana).

Around the 14:31Z June 5, 2012 valid time of visible satellite imagery in fig. 8, a range of then currently available NWP predicted 6 hours of varying concentrated rainfall across southern Alberta and parts of the NWRFC service area from 00:00Z 6 June, 2012 to 06:00Z 6 June, 2012 (a predominant 6 hour wet period on June 5, 2012 - relative to Pacific Daylight Time (PDT)). Except for the GFS40 solution in this case, NWP heavier precipitation guidance (e.g., from the NAM20, MM5eta, and ECMWF-HiRes) was generally between 100 to 200 miles too far east of the Upper Columbia - where local heavy 24 hour rain totals were observed on 5 June, 2012 PDT (fig. 11). The animated black dashed outline of local one to two plus inch rain observed through June 5, 2012 PDT in fig. 12 is just slightly to the east of an earlier Upper Columbia precipitation maxima documented on the previous day (fig. 1); notice that none of the key 6 hour period NWP solutions in fig. 11 do very well in characterizing (or focusing) precipitation that was actually observed around this Upper Columbia location in fig. 12.

Conclusion

In the preceding discussion, observational evidence in figs. 1, 2, 3, 4, 5, and fig. 8 was extended into what we know from studying isentropic analysis and processes like TROWALs (e.g., fig. 7). This conceptual rationale or conjecture was elaborated upon (partly by using modeled trajectories in figs. 6, 9, and 10) in a way to explain a late Spring Upper Columbia precipitation pattern (fig. 12) that operationally available NWP did not characterize very well (fig. 11). The conjectured rationale presented here was not exhaustively proven. Because highly variable intermountain terrain makes isentropic analyses at relevant low levels in locations like the Upper Columbia often intractable, [(2)] only conceptual extension of some ideas presented here (e.g., fig. 7) are practical (Moore, 1993). Some degree of uncertainty exists in extending this rationale into making forecasts (even with corroborating HYSPLIT trajectories); but making these inferences in a reasonable manner is a necessary meteorological function (Emanuel, 1986) - especially in data and resource (including time) sparse circumstances. So, the key circumstantial question to ask is whether available evidence is cumulatively valid enough to support making such inferences.

Compared to around two inch TPWs characteristic of atmospheric rivers (Ralph and Dettinger, 2012), using further hydrologic analogy, the track that lesser Gulf of Mexico moisture made in this case (fig. 3) might instead be more humbly likened to that of an intermittent tributary. Nonetheless, the surge in early June 2012 Upper Columbia precipitation discussed here contributed some of the runoff that gradually pushed nearby large reservoirs to risky full pool storage elevations later in June 2012 (most notably, upstream of Hungry Horse Dam and Libby Dam in northwestern Montana). Thus, from a cumulative water management perspective, the June 4-5, 2012 case discussed here was not a trivial or inconsequential QPF problem.

Thus, if this late Spring Upper Columbia QPF problem was of concern, and if NWP had not verified well in predicting what turned out to be a similar, recurring Upper Columbia precipitation pattern from one day to the next (for June 4-5, 2012), then identifying and extending the conceptual rationale discussed above to potentially improve upon Upper Columbia QPF would probably be considered a prudent approach (at least in the eyes of affected reservoir regulators trying to plan out relevant storage water release schedules).

The evidence presented in this discussion is not complete enough to make the inferences postulated here as being irrefutable. Nonetheless, the motivation for all this is that we should still reflect on what can be extended conceptually to get at something NWP is not keeping up with. For example, we know that if conveyor forcings in this type of fairly steady, training pattern sustain a relatively unchanging flow pattern long enough, instantaneous streamlines (e.g., in figs. 2, 3, and 4) begin to coincide with particle trajectories (e.g., figs. 6, 9, and 10). We might not have access to real-time idealised isentropic analyses in such instances (because of terrain roughness issues, model initialization data availability, etc.). However, we do understand that increased sloping of isentropic surfaces in otherwise unremarkable occlusions can produce strong vertical motions and heavy precipitation. [(4)] And if even just low grade additional moist conveyors (e.g., from the Gulf of Mexico) route more precipitable water into such an occlusion, then heavier precipitation is highly likely. The locations of this most relevant heavier precipitation will circumstantially vary, but research results such as in fig. 7 can serve as a guide or starting point with which to make a better informed, inductive (or probabilistic) type of forecast.

Acknowledgments

This early June 2012 case was as an active forecast problem while Ken Pomeroy, NWS Western Region Headquarters, made a short visit to the NWRFC. During Ken's visit, I briefly discussed with him some of the ideas presented here. Ken encouraged me to piece together technical documentation regarding this topic. I realized soon afterward that if I followed Ken's advice, it could potentially reduce confusion locally in the field here (resulting occasionally when I refer to this type of postulated macro scale mechanism in unclear discussions with other forecasters who are more attuned to focusing on their immediate CWA scale problems of the day). Charles Orwig, a Senior Hydrologist at the NWRFC, concurred that this effort could result in improved, wider understanding of a recurring process that he and I have seen over many years. I appreciated Chuck's preliminary review of this technical discussion, too. So, thanks to Ken and Chuck for encouraging me to put this attachment together. I hope the results here warrant that encouragement. And I also hope that, although not in PDF supported format, the use of animated figures I included here successfully illustrate (better and more concisely than I could write about) the more obscure subtleties of this somewhat elusive conjecture. The clarifying HYSPLIT trajectory calculations included here were suggested by Chris Smallcomb, NWS Western Region Headquarters; user defined HYSPLIT computations can be made using archived data via the Air Resources Laboratory web site (at http://ready.arl.noaa.gov/HYSPLIT.php). Finally, while making my last revisions to the above technical discussion, I realized that, most of all, I am grateful to Dr. James T. Moore (1952-2006) for his enthusiastic and well formulated advocacy of isentropic analysis.

Footnotes

1. National Weather Service, Northwest River Forecast Center (NWRFC), Portland, Oregon: ***Marty.Lee@noaa.gov*****.**

2. Isentropic Analysis, Jim Moore, COMET Program, University Corporation for Atmospheric Research, Copyright 2002 (http://www.meted.ucar.edu/isen_ana/index.htm).

3. Utilizing GOES Imagery to Forecast Winter Storms - Part 1, Dan Bikos, John Weaver and Jeff Braun. Virtual Institute for Satellite Integration Training (VISIT)Module (at http://www.ssec.wisc.edu/visitview/).

4. TROWAL Identification, Scott Lindstrom, Scott Bachmeier, Jon Martin. Virtual Institute for Satellite Integration Training (VISIT)Module (at http://www.ssec.wisc.edu/visitview/).

5. Structure of the TROWAL and the TROWAL Airstream (http://marrella.aos.wisc.edu/cyclwkshp.html), University of Wisconsin-Madison, Department of Atmospheric and Oceanic Sciences. Link summarizes research by Jonathan Martin (jon@marrella.meteor.wisc.edu) that was supported by the National Science Foundation, Division of Atmospheric Sciences, Grant Number ATM-9505849.

References

Emanuel, K., 1986: Overview and definintion of mesoscale meteorology. **Mesoscale Met. And Forecasting**, 1, pp. 1-17, AMS.

Moore, J.T., 1993: Isentropic Analysis and Interpretation - Operational Applications to Synoptic and Mesoscale Forecast Problems. National Weather Service Training Center, Kansas City, Missouri, 99 p.

Ralph, F.M., and M.D. Dettinger, 2012: Historical and National Perspectives on Extreme West Coast Precipitation Associated with Atmospheric Rivers during December 2010. ***Bull. Amer. Meteor. Soc.***, **93**, 783-789.

Figures

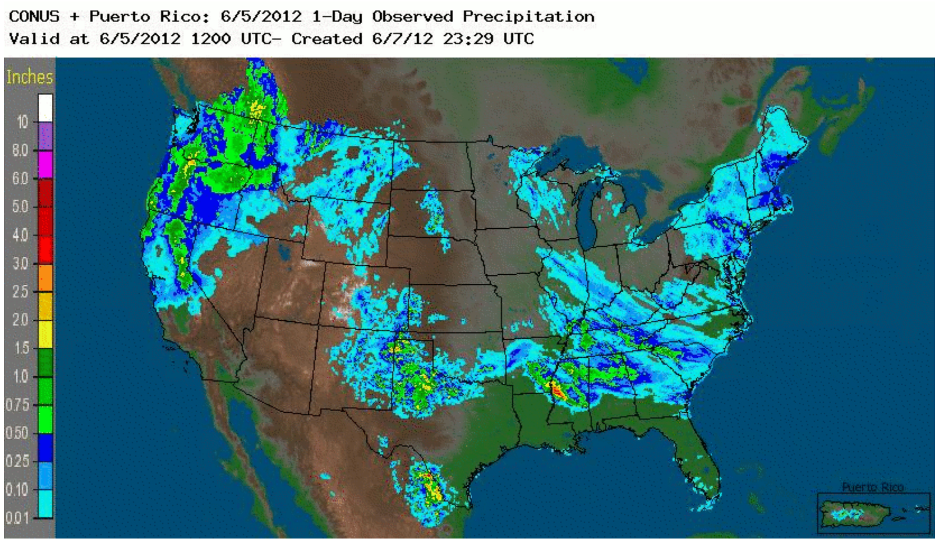

Fig 1. NWS Advanced Hydrologic Prediction Service 4x4 km 24 hour precipitation observed from 12Z 6/4/12 to 12Z 6/5/12. This product synthesizes CONUS RFC QPE. Note that Missouri Basin QPE (and hydrologic service area) extends only a short distance north into Canada.

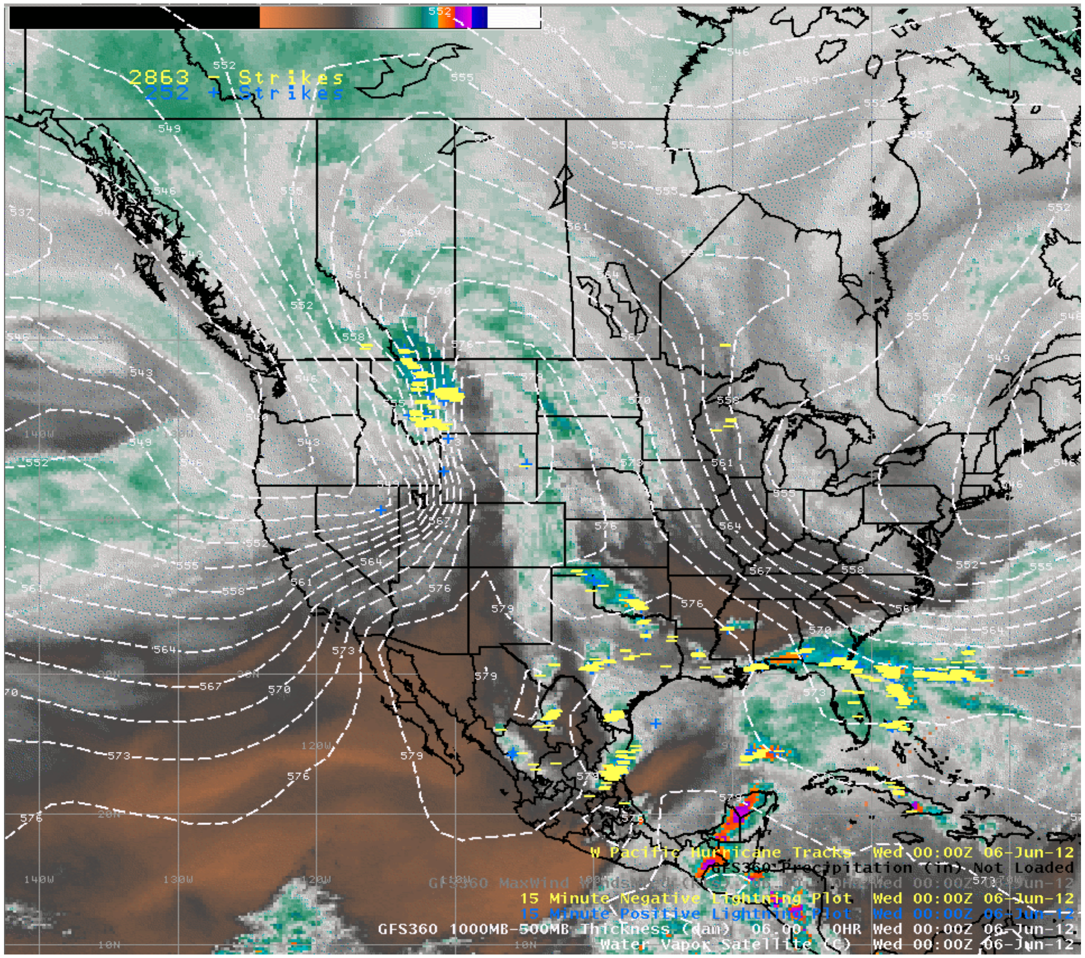

Fig 2. Water vapor satellite image combined with GFS360 1000-500mb thickness analysis (white dashed lines), and 15 minute lightning data (yellow for negative strike symbols and blue plus signs for positive strikes). This combined data is valid around 00Z 06/06/12.

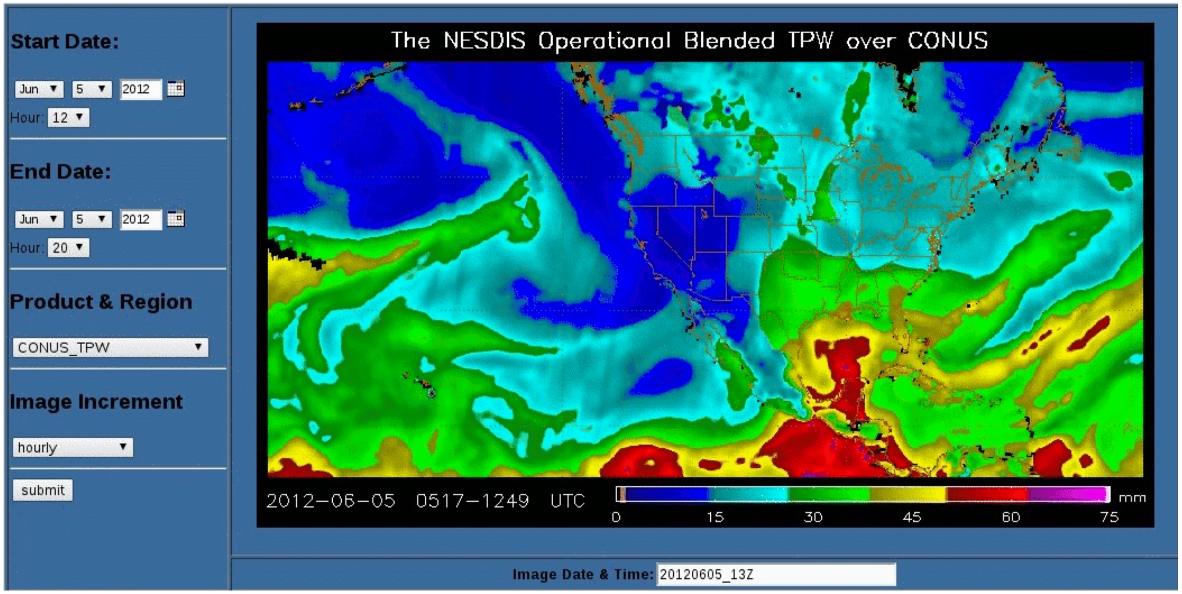

Fig 3. National Environmental Satellite, Data, and Information Service (NESDIS) Operational Blended Total Precipitable Water (TPW) valid at 13Z 06/05/12.

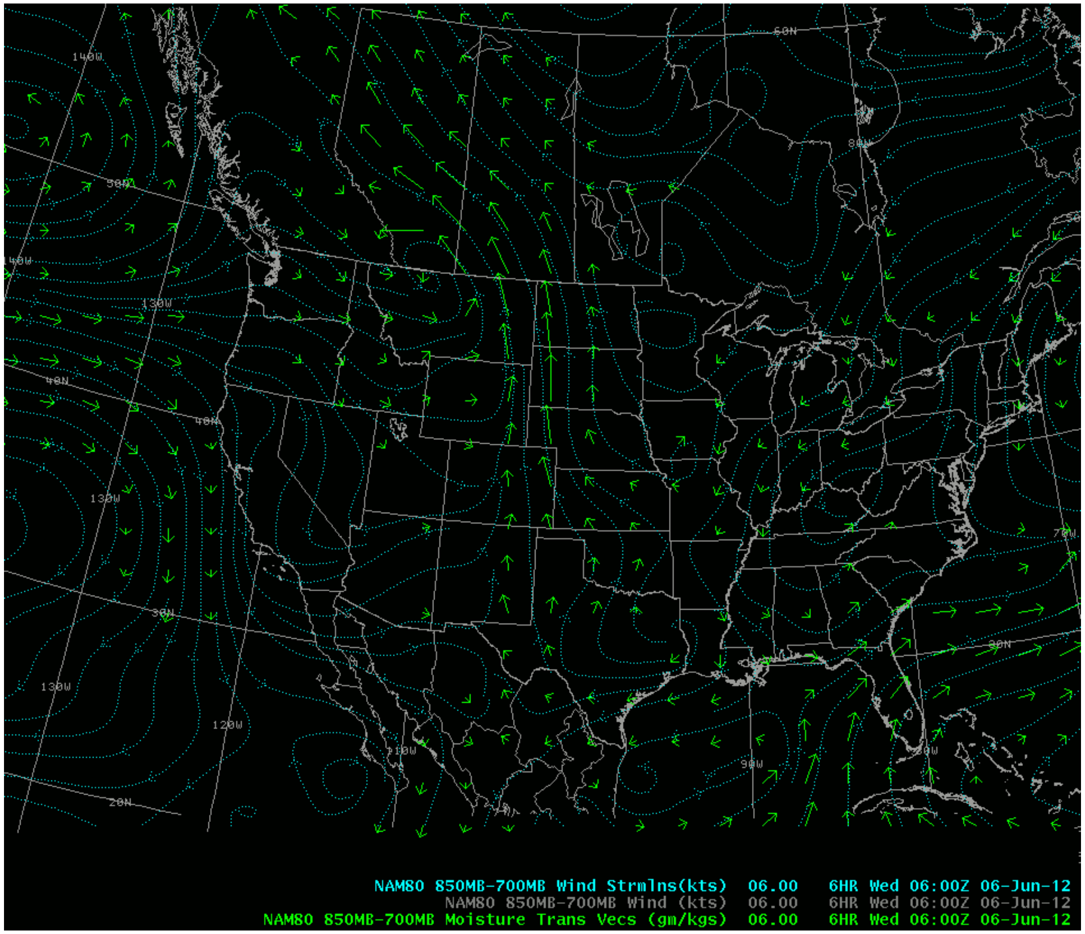

Fig 4. National Centers for Environmental Prediction (NCEP) 80 km resolution North American Mesoscale (NAM) model analysis valid at 00Z 06/06/12.

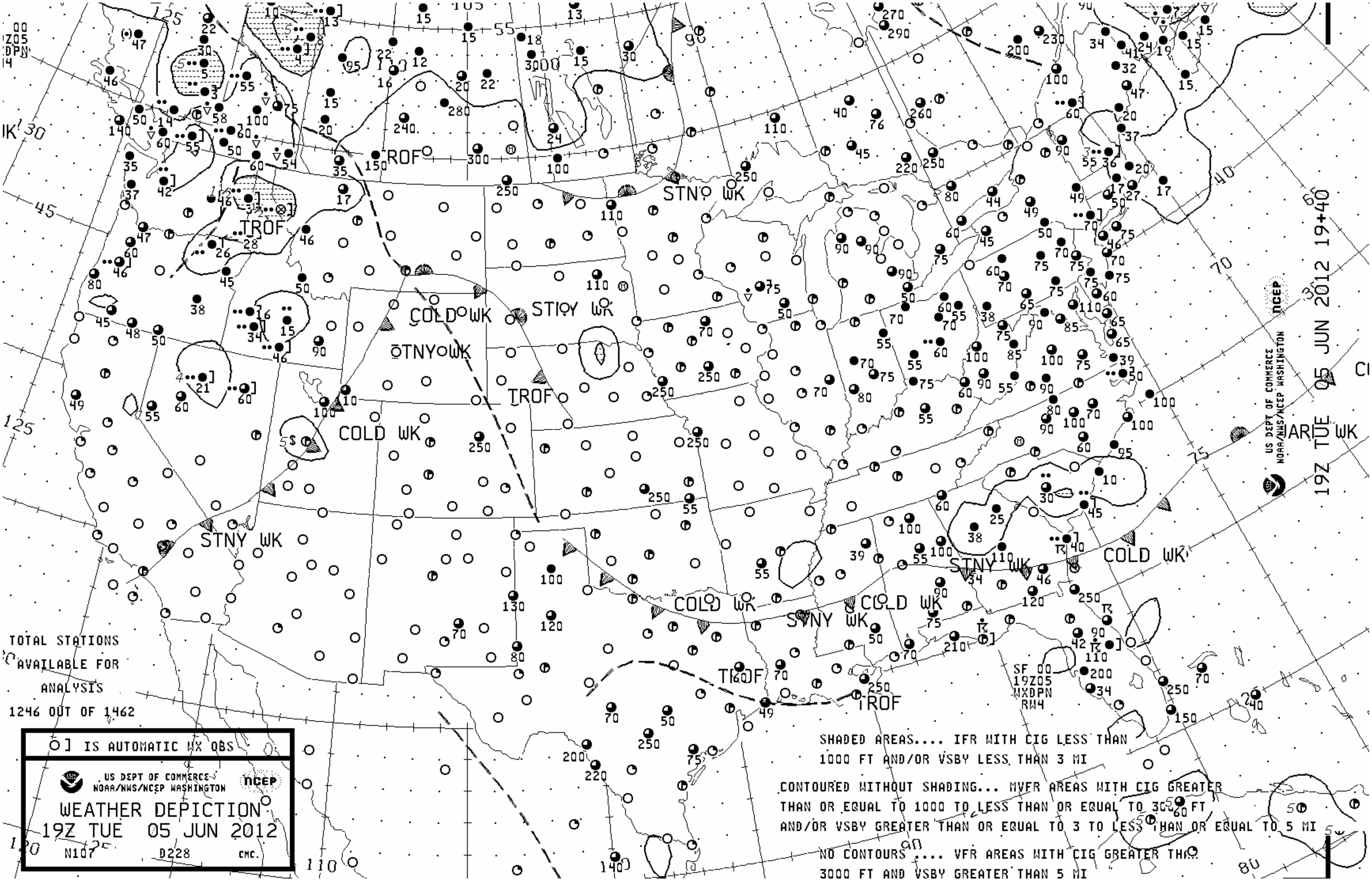

Fig 5. National Centers for Environmental Prediction (NCEP) Weather Depiction analysis valid at 19Z 06/05/12.

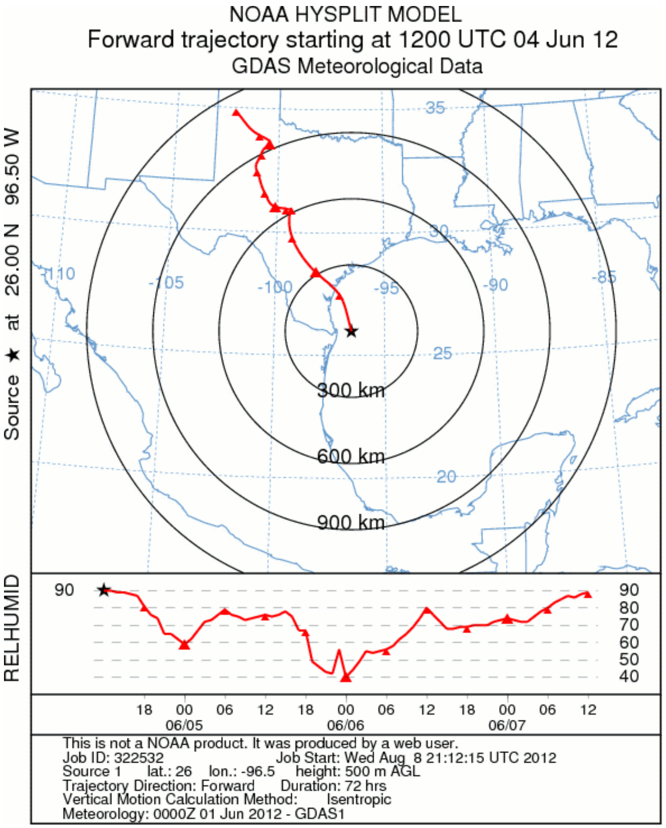

Fig 6. ARL HYSPLIT isentropic GDAS forward trajectory calculation initiated at June 4, 2012 12:00Z near 500 meters AGL over the Gulf of Mexico about 80 miles east of Brownsville, Texas.

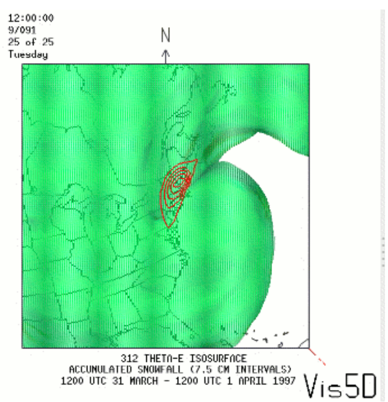

Fig 7. A 12Z 03/31/97 University of Wisconsin Nonhydrostatic Modeling System (UW-NMS) simulation of a TROWAL (from research supported by the National Science Foundation and made available by Jon Martin).

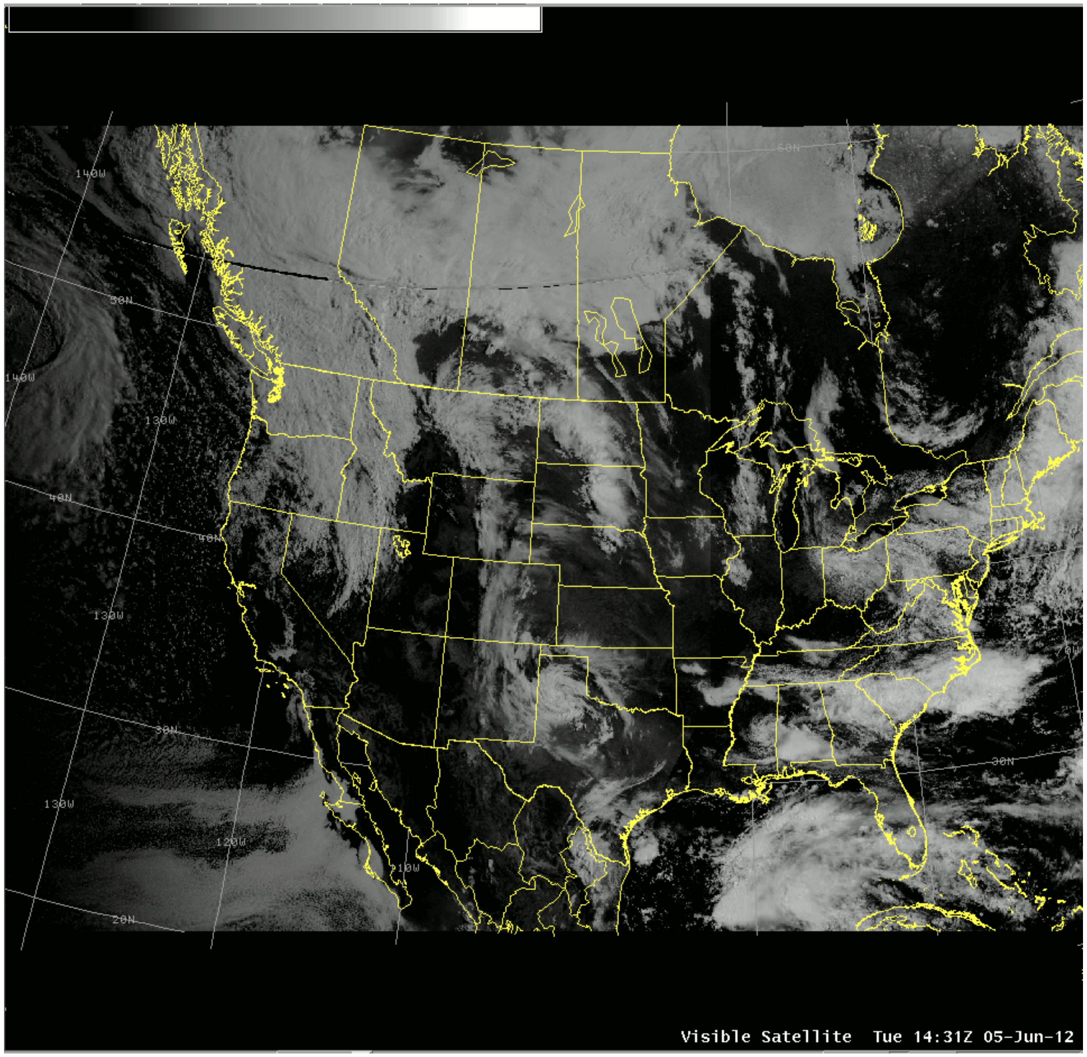

Fig 8. Visible satellite image (valid 14:31Z 06/05/12).

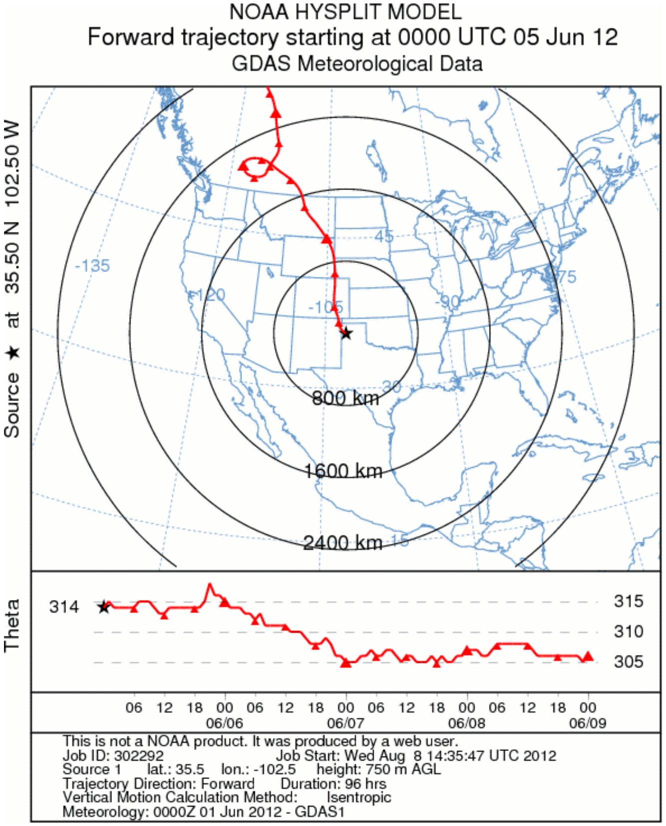

Fig 9. ARL HYSPLIT isentropic GDAS forward trajectory calculation initiated at June 5, 2012 00:00Z near 750 meters AGL over the northwestern Texas panhandle.

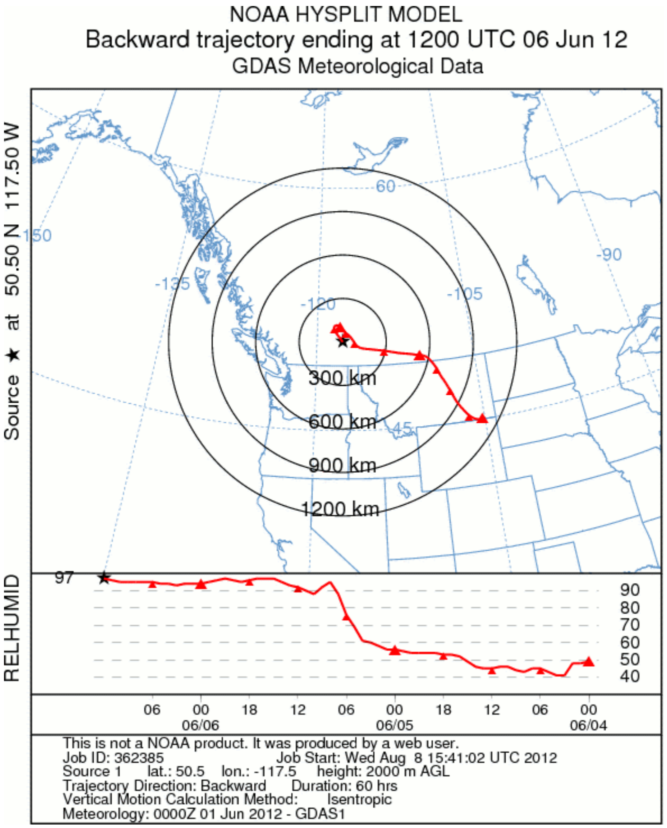

Fig 10. ARL HYSPLIT isentropic GDAS backward trajectory calculation initiated at June 6, 2012 12:00Z near 2000 meters AGL over the Upper Columbia, north of Idaho.

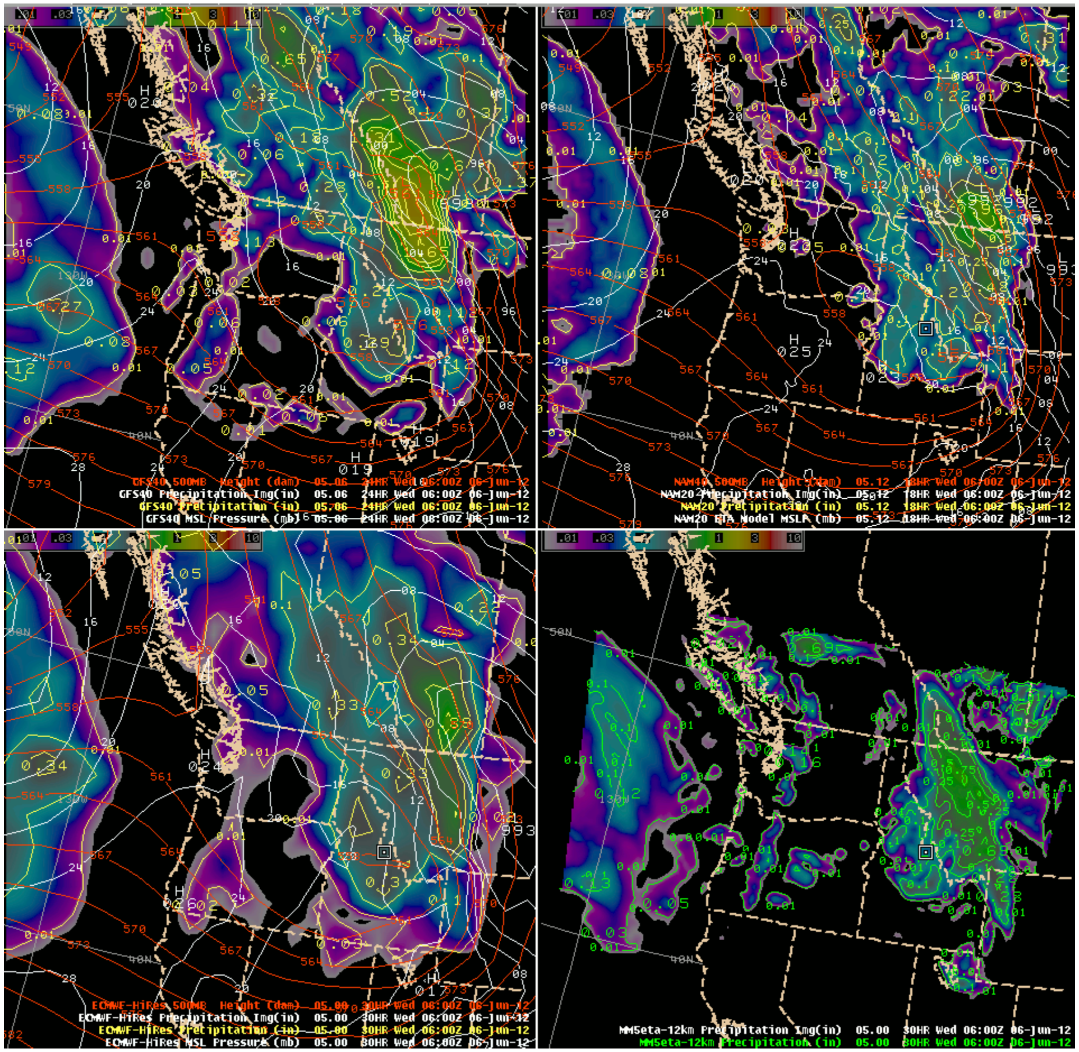

Fig 11. NCEP 6 hour Precipitation in inches (image field and yellow contours), 500 mb heights in decameters (red contours), and mean sea level pressure in millibars (white contours) from the GFS40 (upper left), NAM20 (upper right), MM5eta-12km (lower right), and ECMWF (lower left) valid at 00Z 06/06/12.

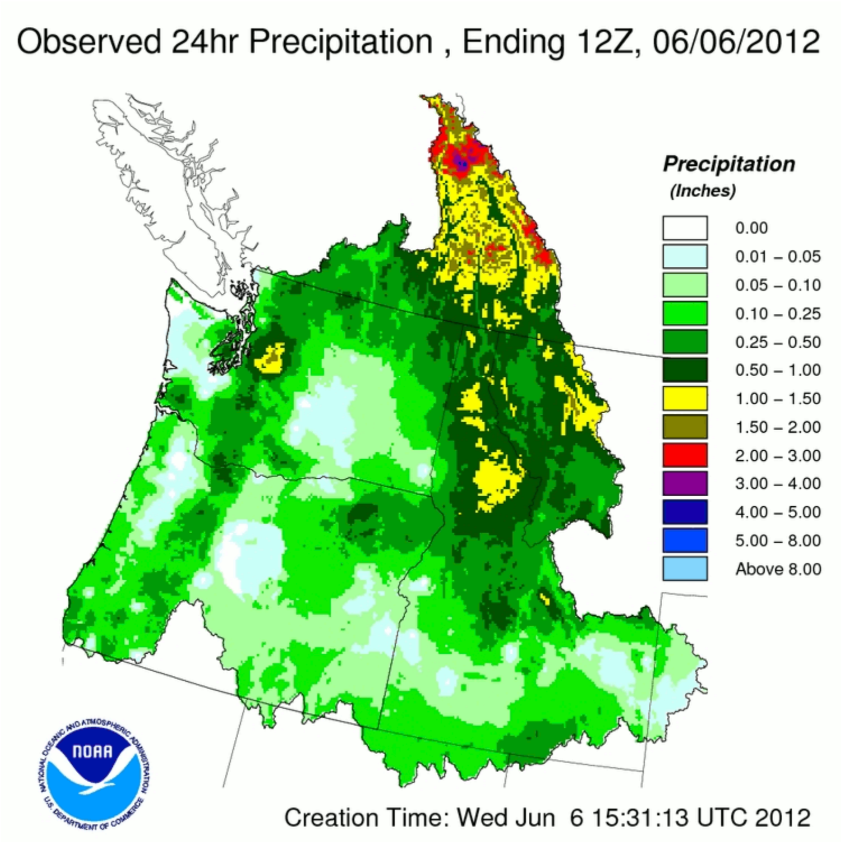

Fig 12. NWRFC 24 hour QPE analysis valid from 12Z 06/05/12 to 12Z 06/06/12.
