Forecast/Weather Summary for IOP#1

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An interesting storm that more than lived up to its potential, with nearly 4” of liquid equivalent at Blue Canyon (BLU) and over a foot of snow, all in ~24 h. This report presents an overview summary of the forecasts that went into the decision making process for calling the first IOP. As such, included will be a subjective assessment of the various models ranging from the long range global models to the GSD high-resolution runs up to 24-h before the event. It should be noted right off that the IOP decision was made easier by the fact that staffing was already present on site setting up for the program, so it was a matter of deciding to keep folks there for 2 or 3 more days as opposed to flying them out for the IOP.

Synoptic overview of the event: The main IOP period was from ~1800 UTC/Thursday/6 Dec to ~1800 UTC/Friday/7 Dec. The week began with a monster event in the Pacific Northwest from 2-4 Dec, as an atmospheric river set up from Hawaii to the Pacific Northwest with an associated strong jet. By 1200 UTC/4 Dec (Figure 1) the event was winding down in the Pacific Northwest with the plume and jet sinking slowly south but weakening with time. But as it drifted south it briefly passed across the HMT area (hereafter “ARB”), dumping a quick ~0.5” on the morning of 4 Dec with a rapid increase in integrated precipitable water (PW) exhibited on the soundings near the ARB (Figure 2).

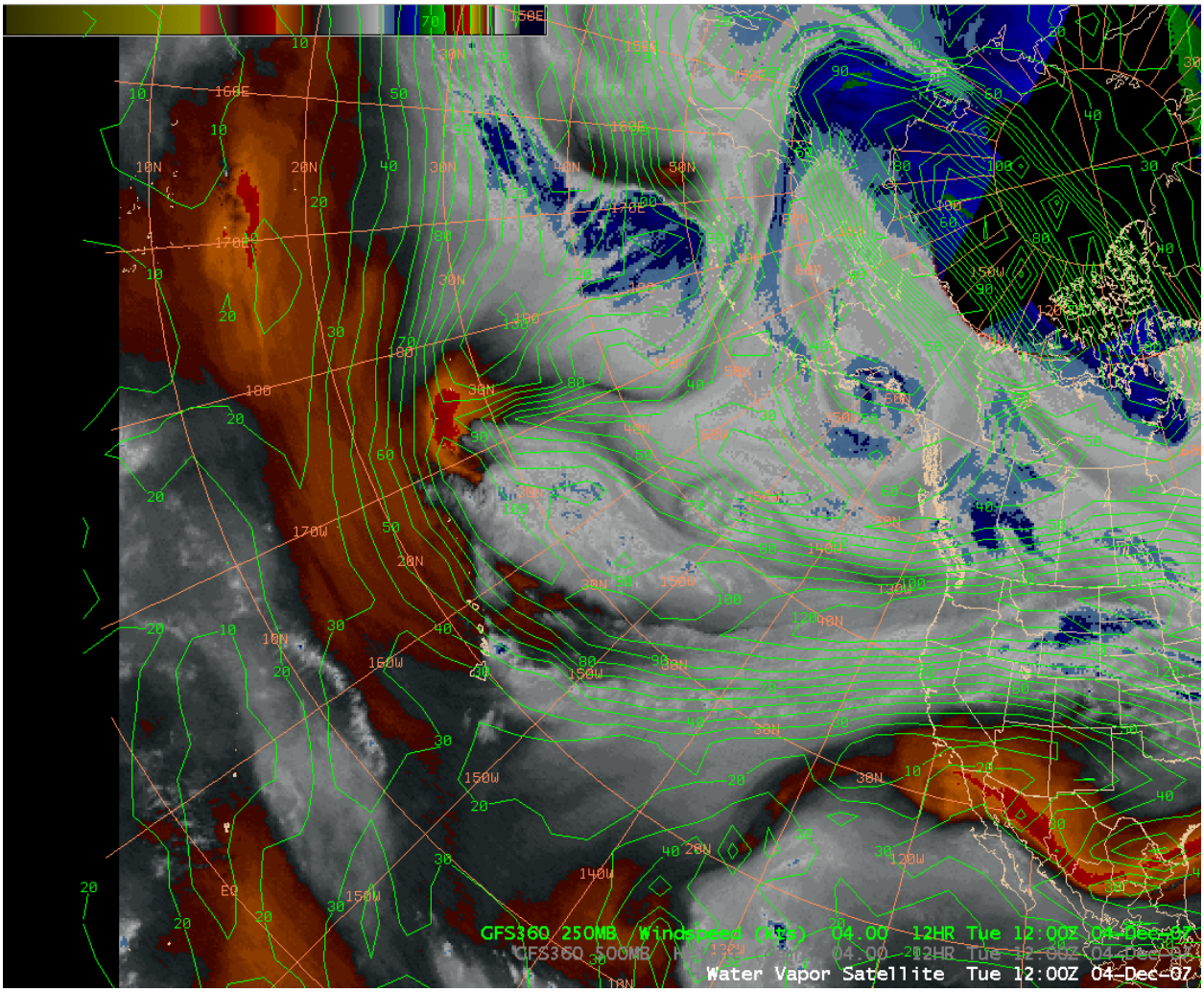
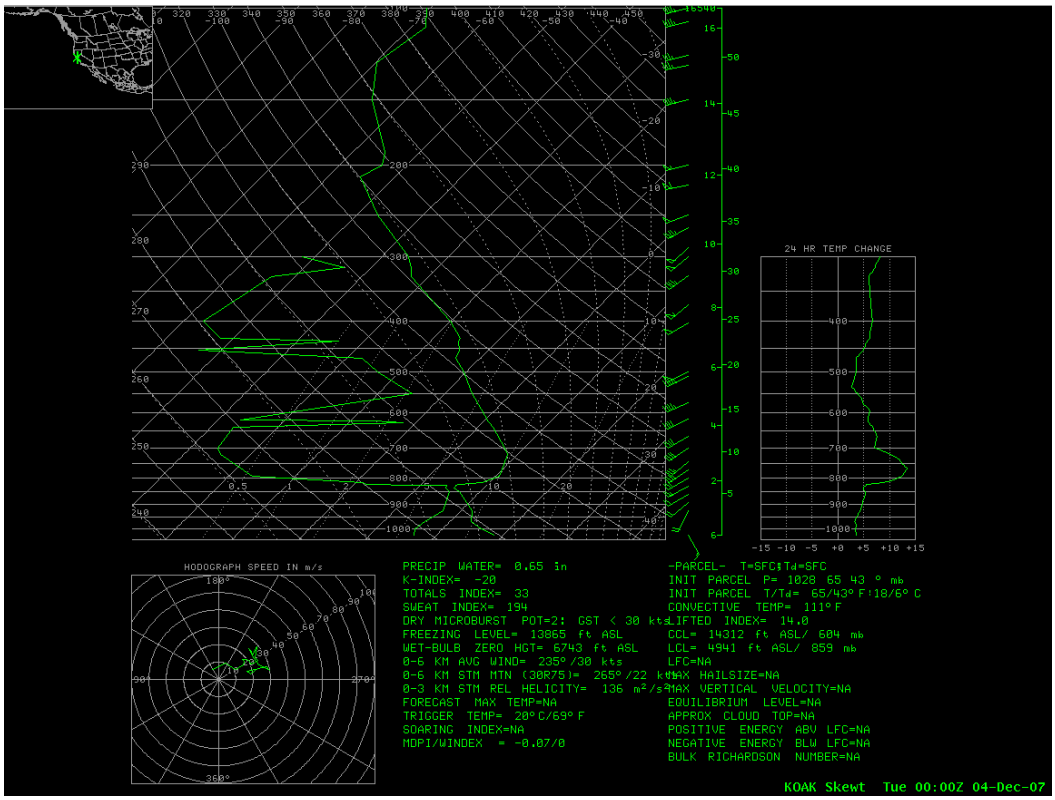


Figure 1. Water vapor imagery for 1200 UTC/4 Dec 07 with overlay of 250 mb wind speed (knots).



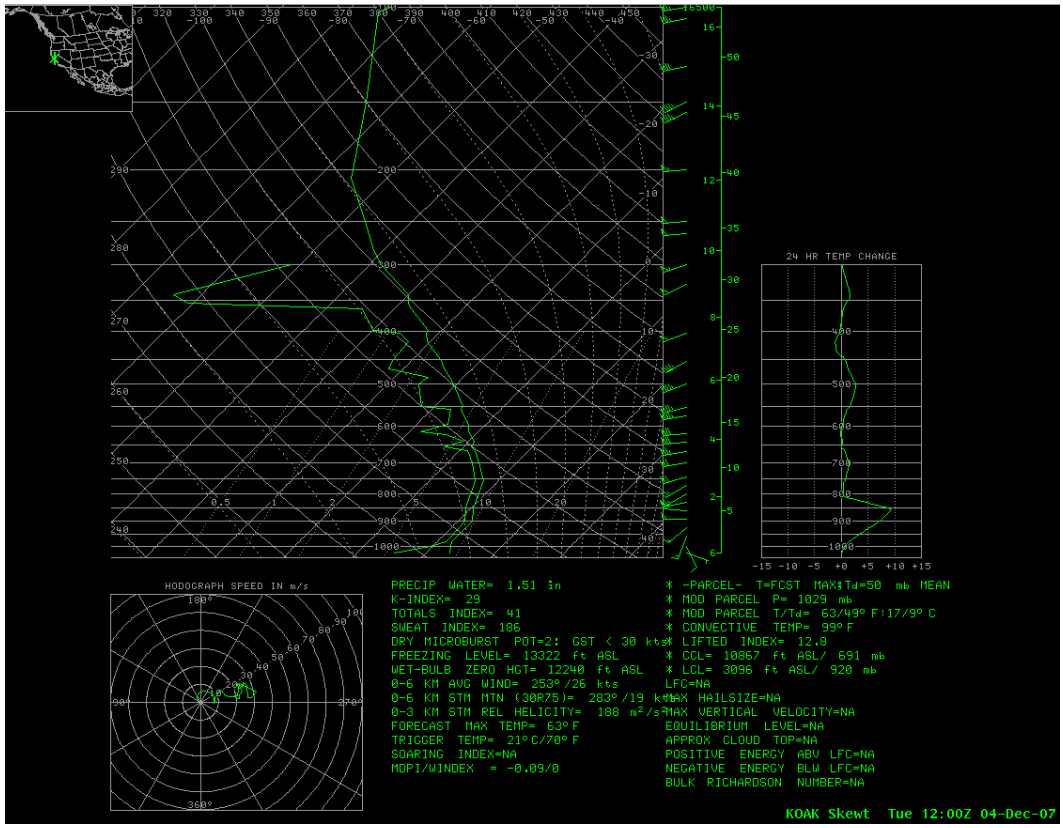


Figure 2. Oakland, California RAOBs for 0000 UTC/4 Dec (top) and 1200 UTC (bottom). Of note is the rapid increase in moisture as the remnants of the plume from the big Pacific Northwest event drifted south over the area, increasing the PW from 0.65 to 1.51 inches in only 12 h.

The main significance of noting this moisture plume and its passage across the ARB on 4 Dec is that while the plume continued to drift south and break up some, the plume and the jet remained in place in advance of the approaching system, with one of the forecast issues being how much of the moisture would be entrained into the storm. A good look at the approaching system is seen in the IR image in Figure 3. There are two distinct waves, the southern system near 25ºN/160ºW that broke off from the main flow and is diving to be north of Hawaii. This became a "Kona Low" which brought heavy precipitation to Hawaii with even a blizzard warning for the highest terrain on the big island. What it did for the storm system that hit the ARB was to pump moisture northward. This is seen on the IR image in Figure 3, with the cloud area approaching the eastern side of the northern wave which is located near 45ºN/150ºW. It is this northern wave that becomes the main system hitting the ARB on 6-7 Dec. A water vapor image overlaid with the upper level isotachs is shown in Figure 4. It is clear from this figure that both the moisture plume and the strong upper level jet that had been part of the atmospheric river into the Pacific Northwest earlier in the week were still in place, having drifted just south of the ARB, as the northern wave approached the California coast. Upper level ridging behind the approaching northern wave had not yet developed, so with the jet so strong still on the eastern side of the system it seemed unlikely that the storm would dive too far south and substantially miss the ARB.

Over the next 24 h the northern wave continued to intensify as it moved slightly south of east towards the ARB. The wave is nicely seen in the visible satellite imagery in Figure 5 from 1830 UTC on 6 Dec. The imagery makes it apparent that some of the moisture from the old atmospheric river that had fed

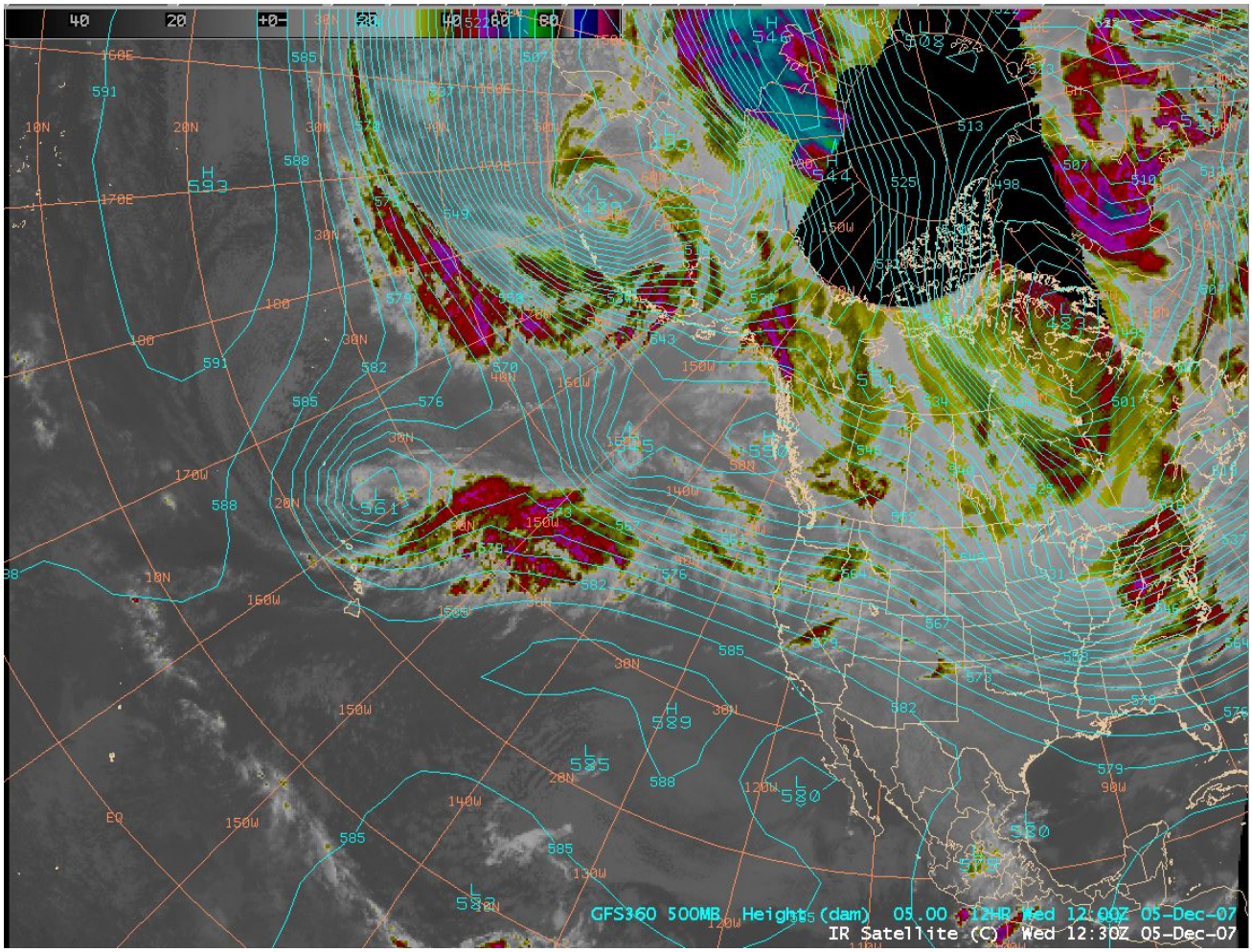


Figure 3. IR image at 1230 UTC 5 Dec 07 with 500 mb heights from the GFS 12 h forecast.

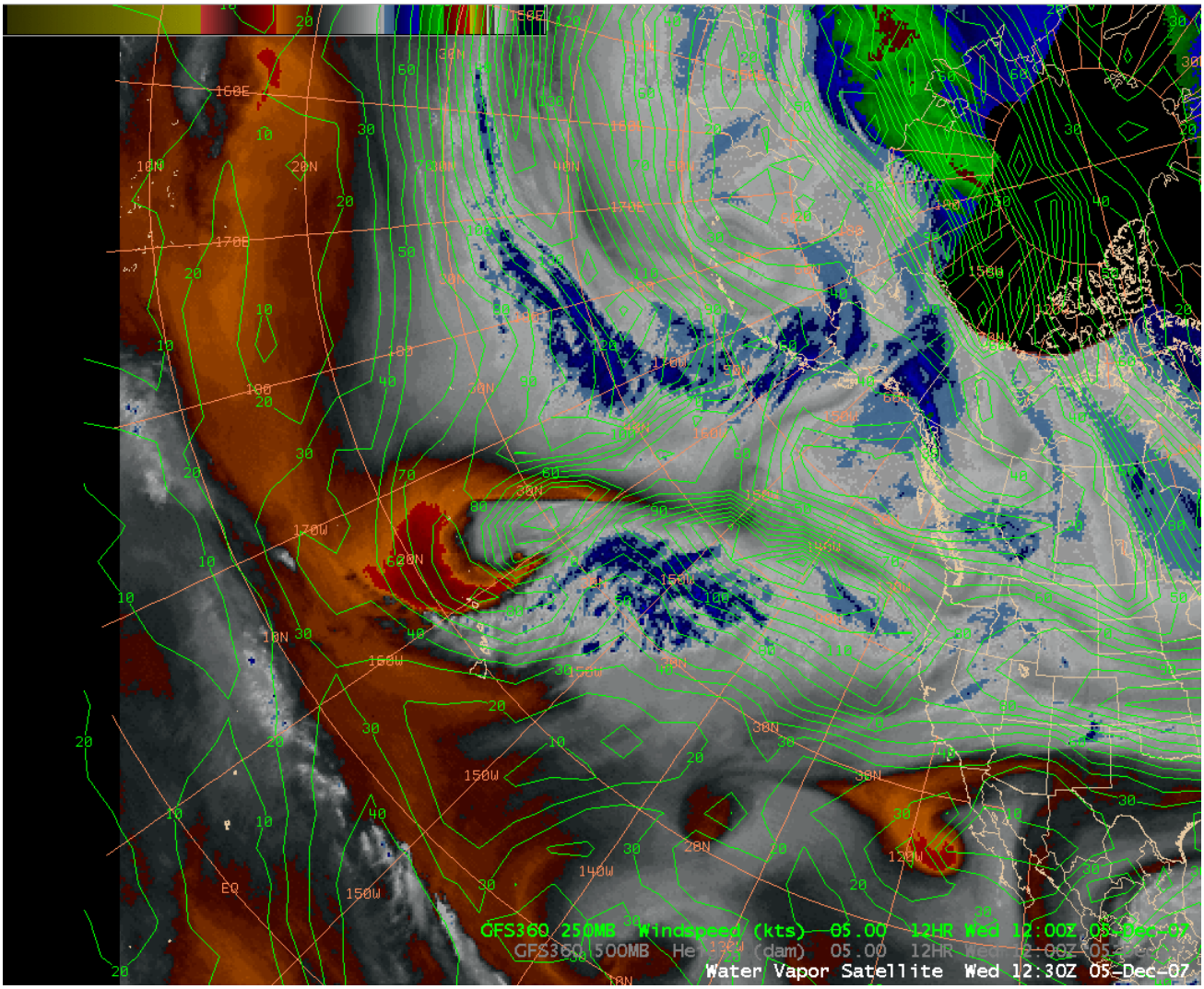


Figure 4. Water vapor image at 1230 UTC 5 Dec 07 with 250 mb isotachs from the GFS.

into
the Pacific Northwest earlier in the week is being entrained into the system ahead of the approaching northern wave (labeled the "main storm" in Figure 5). The imagery is even more dramatic just before sunset (Fig. 6, top). By 1800 UTC the next day visible imagery shows the system had quickly moved through (Fig. 6, bottom). Precipitation hit the coast in Northern California before 1200 UTC on 6 Dec (Figure 7), then spread inland into the ARB by 1800 UTC (bottom, Figure 7).

Precipitation increased in intensity during the afternoon and through the night into 7 December. A larger scale view of the progress of upper level system is given in Figures 8 and 9. The main upper level wave rapidly progressed across the ARB as an open shortwave, taking a perfect track that put the ARB in an area of intense forcing along with relatively strong sw flow ahead of the wave. So while this was certainly not the typical HMT IOP type system, heavy precipitation still occurred owing to the excellent location of the system and forcing that worked on a very moist environment already in place.

The series of soundings from Oakland shown in Figure 10 illustrates the rapid moistening of the environment feeding into the ARB. Although precipitation had reached the coast at 1200 UTC/6 December, it had not quite made its way down the coast as far as Oakland, and the sounding at 1200 UTC indeed still shows a very dry layer and then relatively dry conditions down low, but with moist conditions at mid-levels. By 0000 UTC/7 December, however, the sounding was saturated, winds had

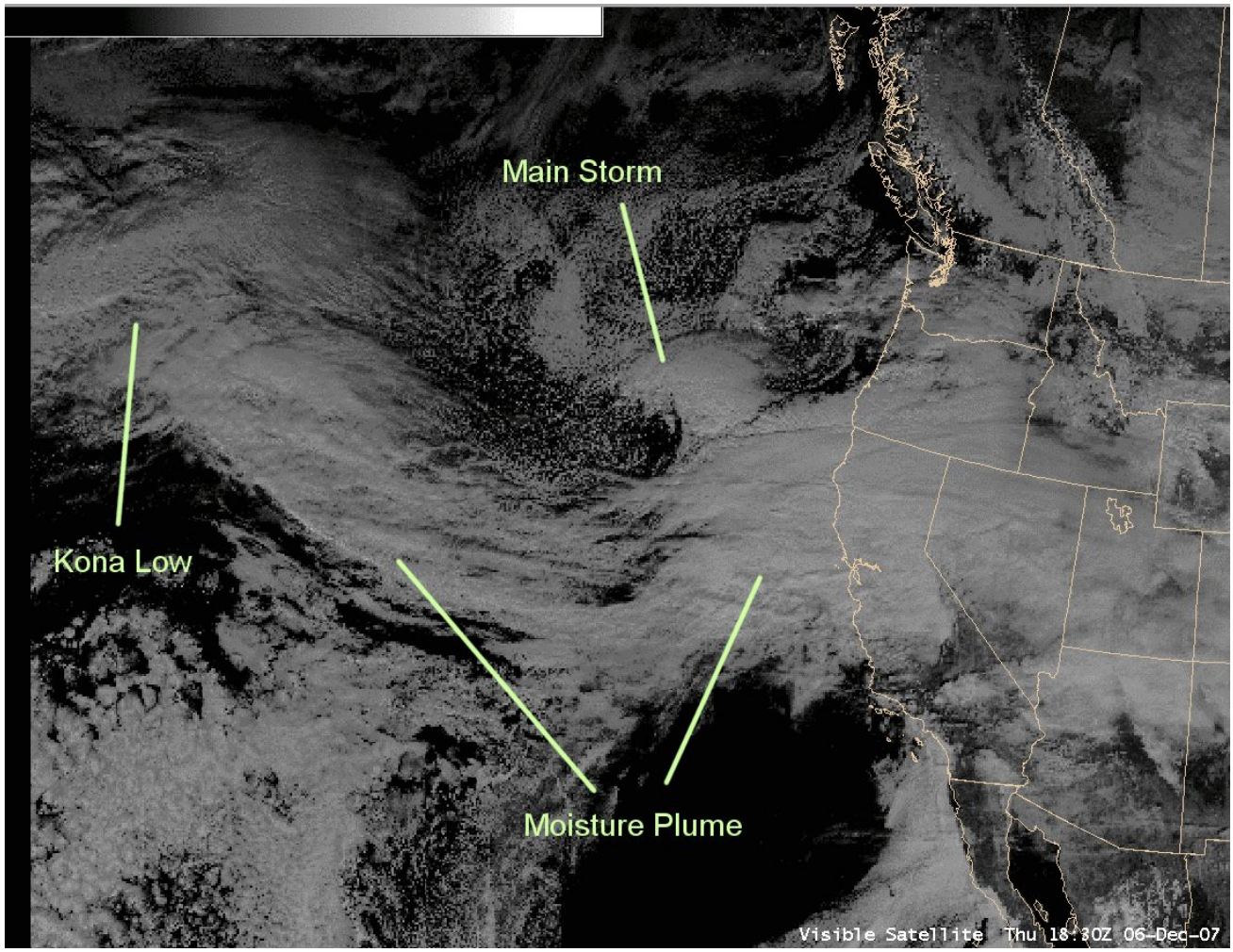


Figure 5. Visible satellite image at 1830 UTC on 6 Dec 2007 showing the approaching main storm as well as the old moisture plume being partly entrained into the system.

come around to w-wsw near mountain-top level at about 30 knots, with the freezing level lowering from over 9000 feet down to ~7800 feet. It is likely that the flow increased even more before the shortwave trough axis at 700 mb passed near 0600 UTC/7 December. By 1200 UTC the Oakland RAOB has nw flow through the tropopause with the snow level lowering still further.

The final figure shown for this portion of the report is the time series of various meteorological parameters from the Blue Canyon mesonet station (Figure 11), with the precipitation time series repeated in Figure 12. The elevation of Blue Canyon is 5282 feet, and clearly the freezing level is much lower than in the upstream Oakland sounding. The precipitation began as rain in the afternoon, with accumulations increasing after 2000 UTC and a changeover to snow. Overnight the snow accumulates to over 12”, but it was a very wet snow with the temperature remaining close to freezing through the event, and apparently heavy enough to knock out the wind sensor for much of the overnight hours. The precipitation time series is repeated in Figure 12, with accumulated amounts from the close-by METAR station's tipping bucket gage added for comparison. The METAR time series of observations at KBLU (shown in Appendix A) had precipitation beginning as rain at 1606 UTC, with 0.07” by 1800 UTC, when the precipitation changes over to snow. Clearly, from the time series comparison, the heated plate gage performs far better than the tipping bucket gages, and by 1500 UTC on 7 December 2.81” was recorded from the METAR gage, close to the ~3.0” from the mesonet's tipping bucket gage. Both are well behind the total of 3.83” measured by the gage with the heated plate, which clearly works much better in the heavy, wet snow conditions.

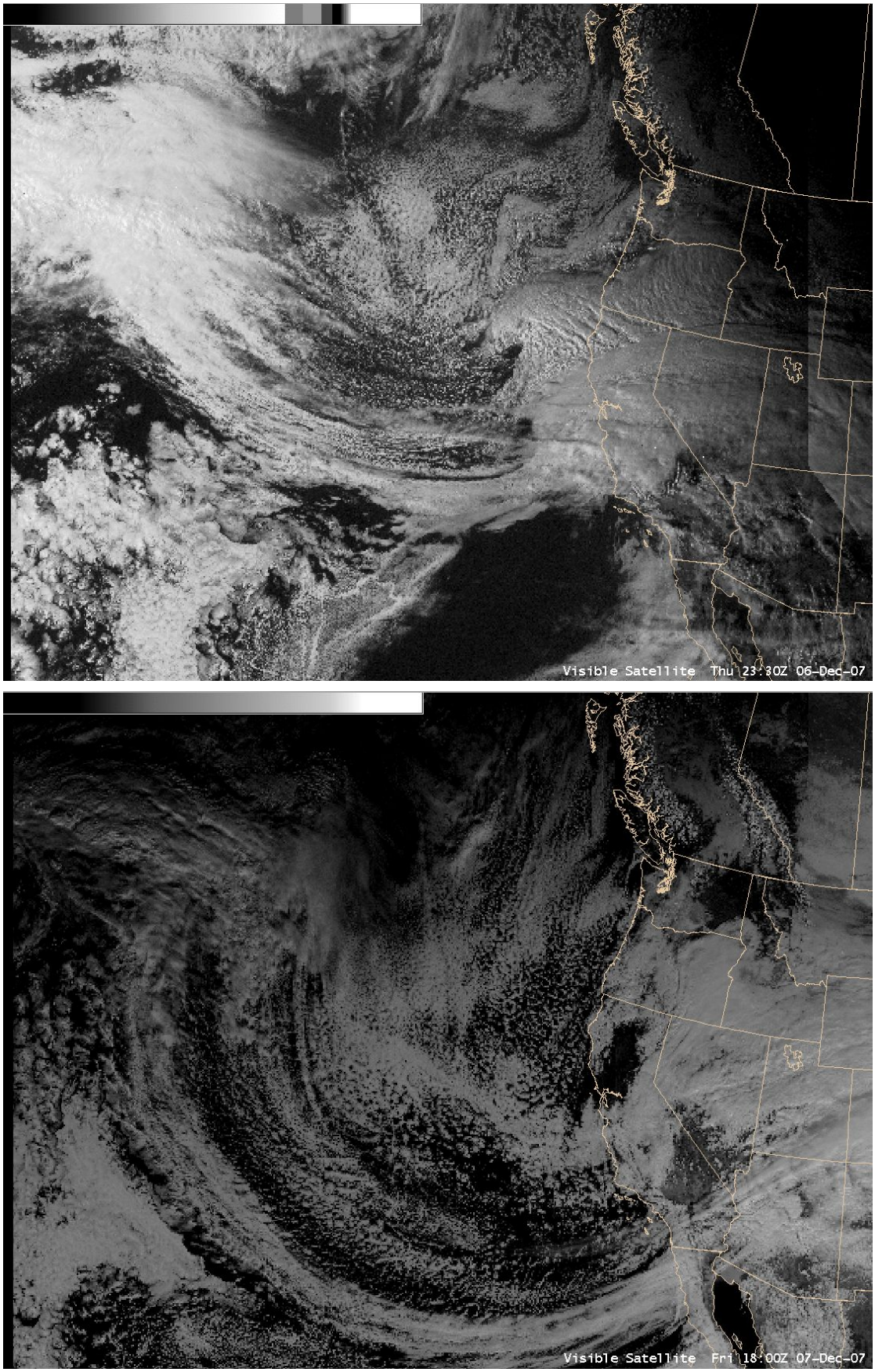


Fig. 6. Visible satellite image for 2330 UTC/6 Dec (top) and 1800 UTC/7 Dec (bottom).

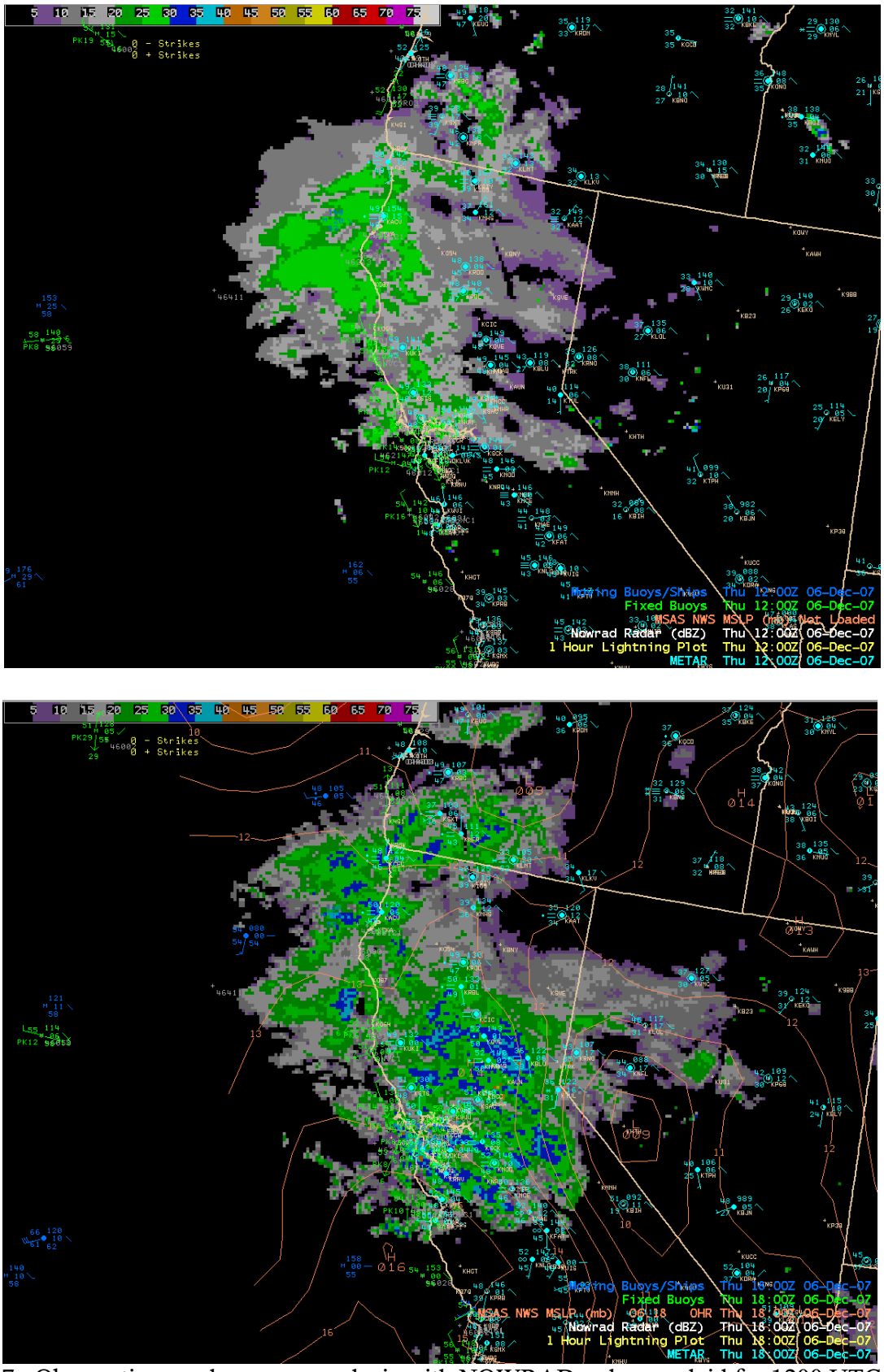


Figure 7. Observations and pressure analysis with NOWRAD radar overlaid for 1200 UTC on 5 December (top) and 1800 UTC 6 December (bottom).

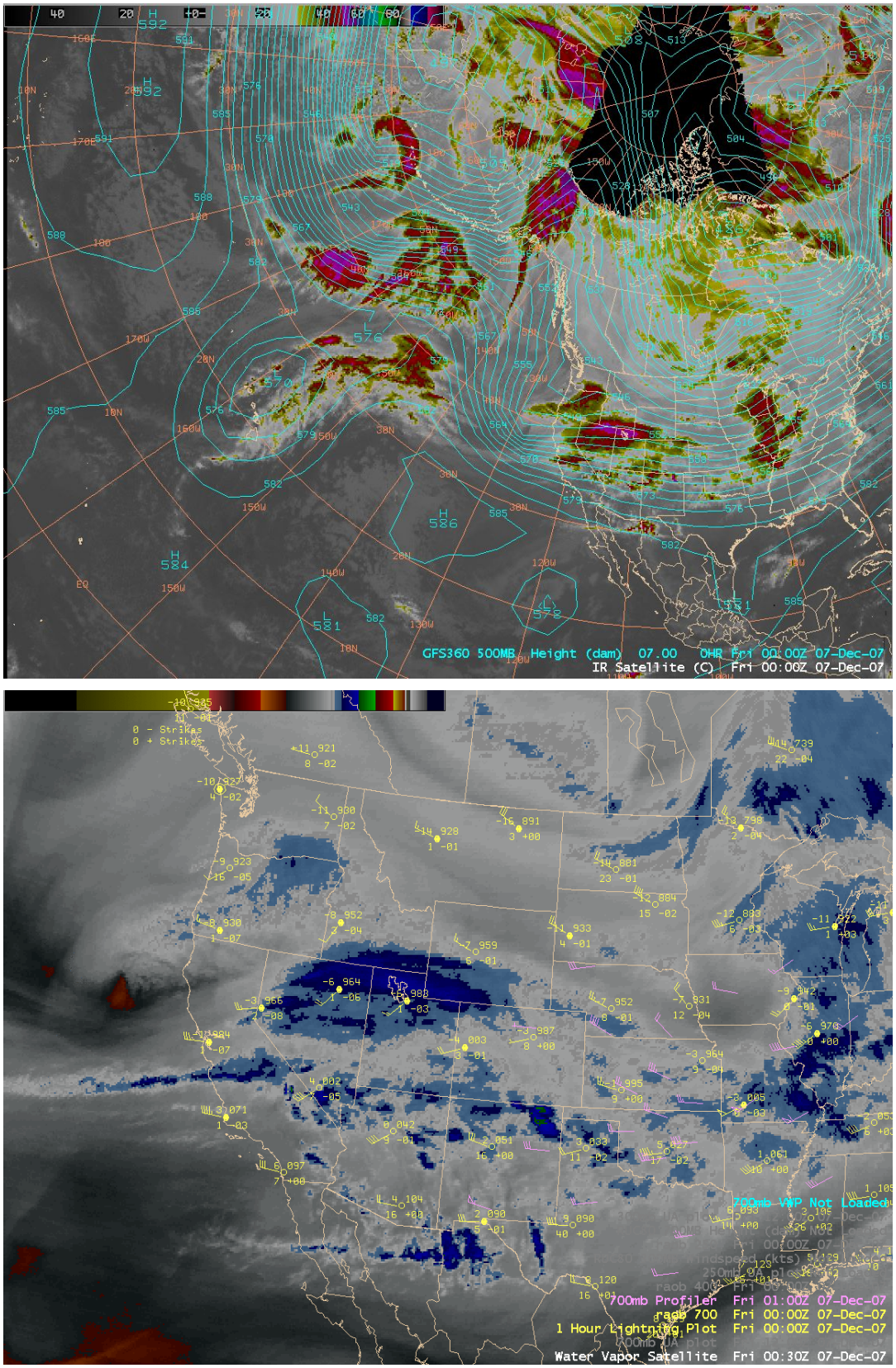


Figure 8. 0000 UTC 7 December 2007 data: top, IR image with GFS 500 mb analysis; bottom, water vapor satellite image with 700 mb RAOB plot and 700 mb profiler plot.

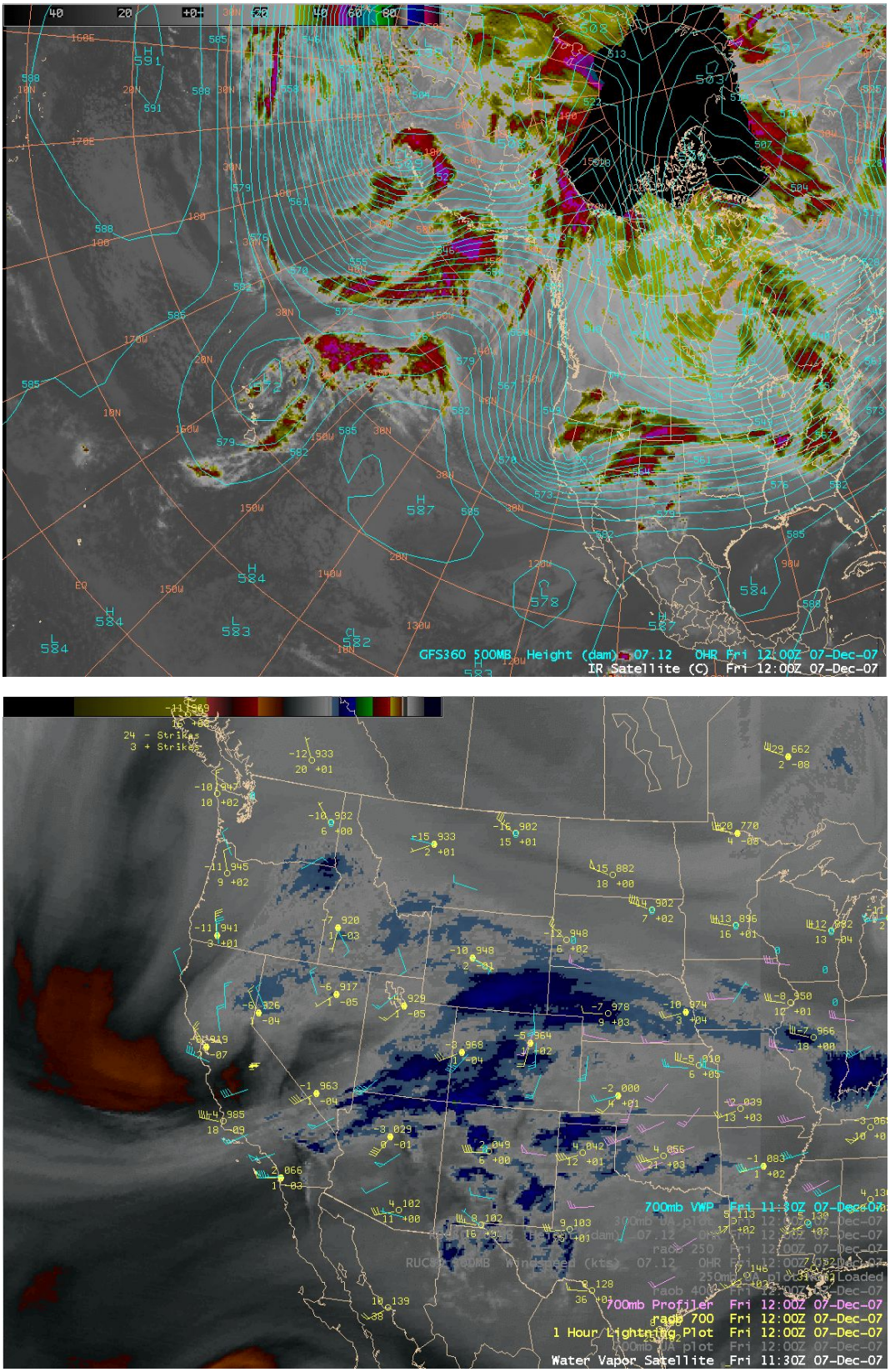


Figure 9. 1200 UTC 7 December 2007 data: top, IR image with GFS 500 mb analysis; bottom, water vapor satellite image with 700 mb RAOB plot and 700 mb profiler plot.

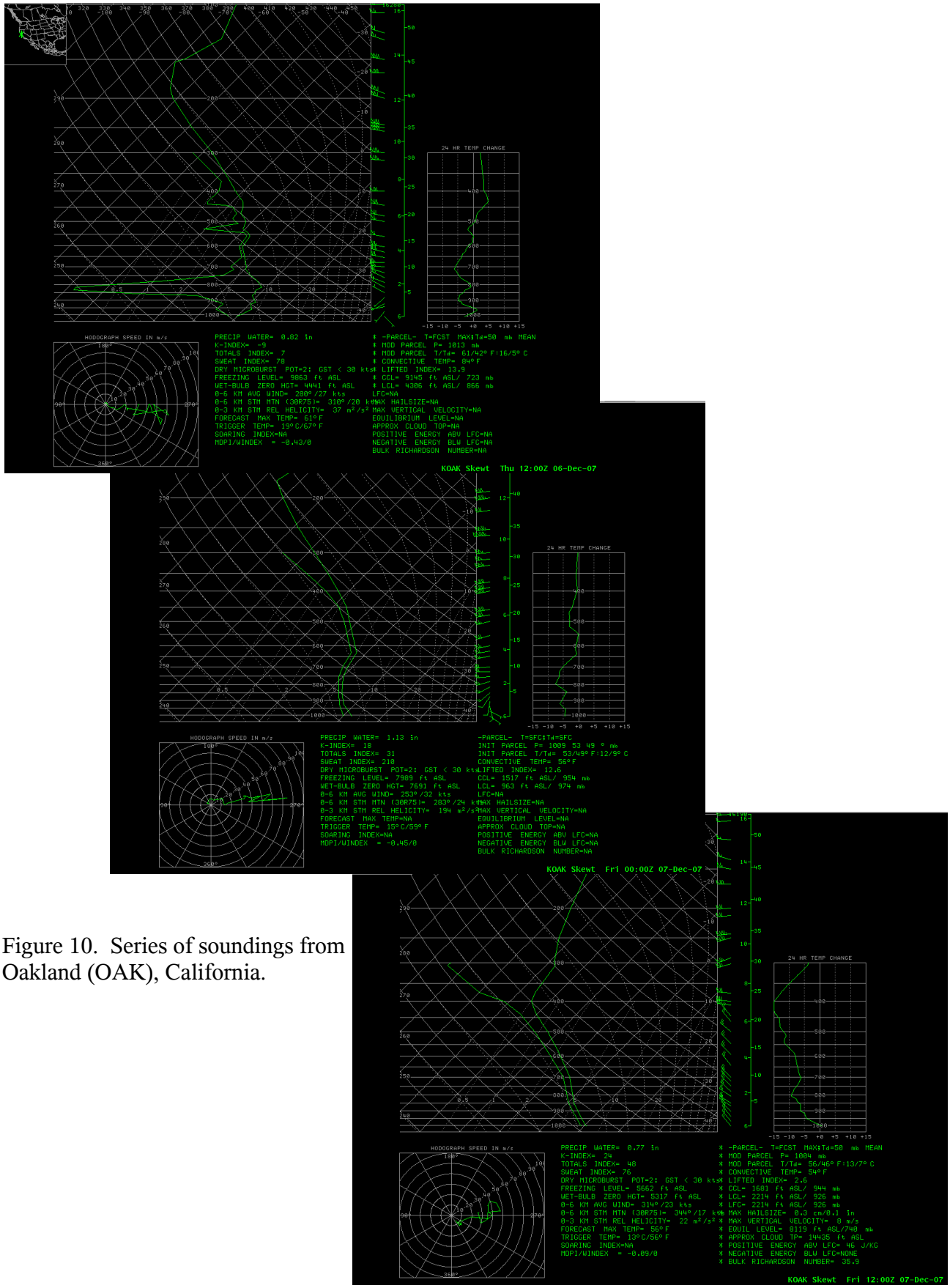


Figure 10. Series of soundings from Oakland (OAK), California.

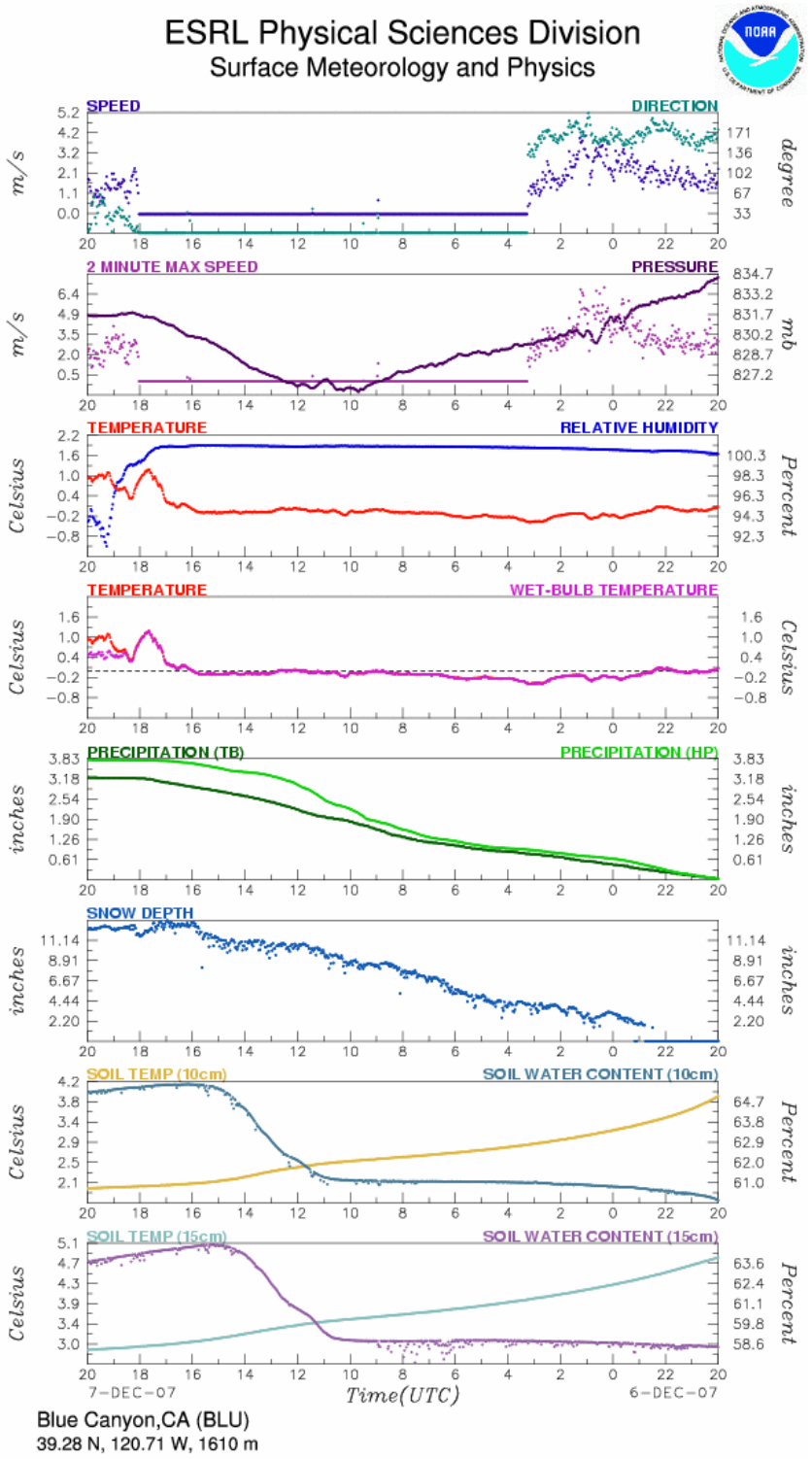


Figure 11. Time series of various parameters from Blue Canyon mesonet station.

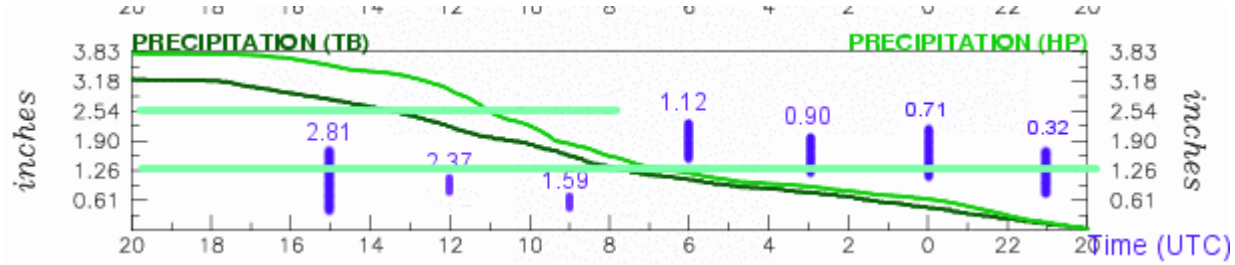


Figure 12. Repeat of the time series of precipitation from the Blue Canyon mesonet site from Figure 11. Added to the figure are the accumulated precipitation amounts from the Blue Canyon METAR station, with accumulated amounts in inches, for comparison with the automated precipitation gage. Two lines are shown for the automated gage; "TB" is the trace from the gage that uses a tipping bucket (similar to what the METAR uses), while "HP" is from the gage that uses a heated plate.

A steady precipitation rate is seen from 2000 UTC/6 December until about 0800 UTC/7 December, then the rate picks up for the next ~4 h, before steadying off again until it all ends around 1700 UTC. The 4 h of intense precip apparently occur just ahead of the when the trough passes through the ~500 mb layer, which is seen to occur rather sharply at 1100 UTC in the Sloughhouse (SHS) profiler time series (Figure 13). It is likely that the forcing just ahead of this sharp trough produced some embedded convection, and note that lightning was observed near 1200 UTC just south of the ARB (Figure 9). This 4 h burst added at least 1.50" to the total precipitation, and may have accounted for the final precipitation amounts higher than anticipated.

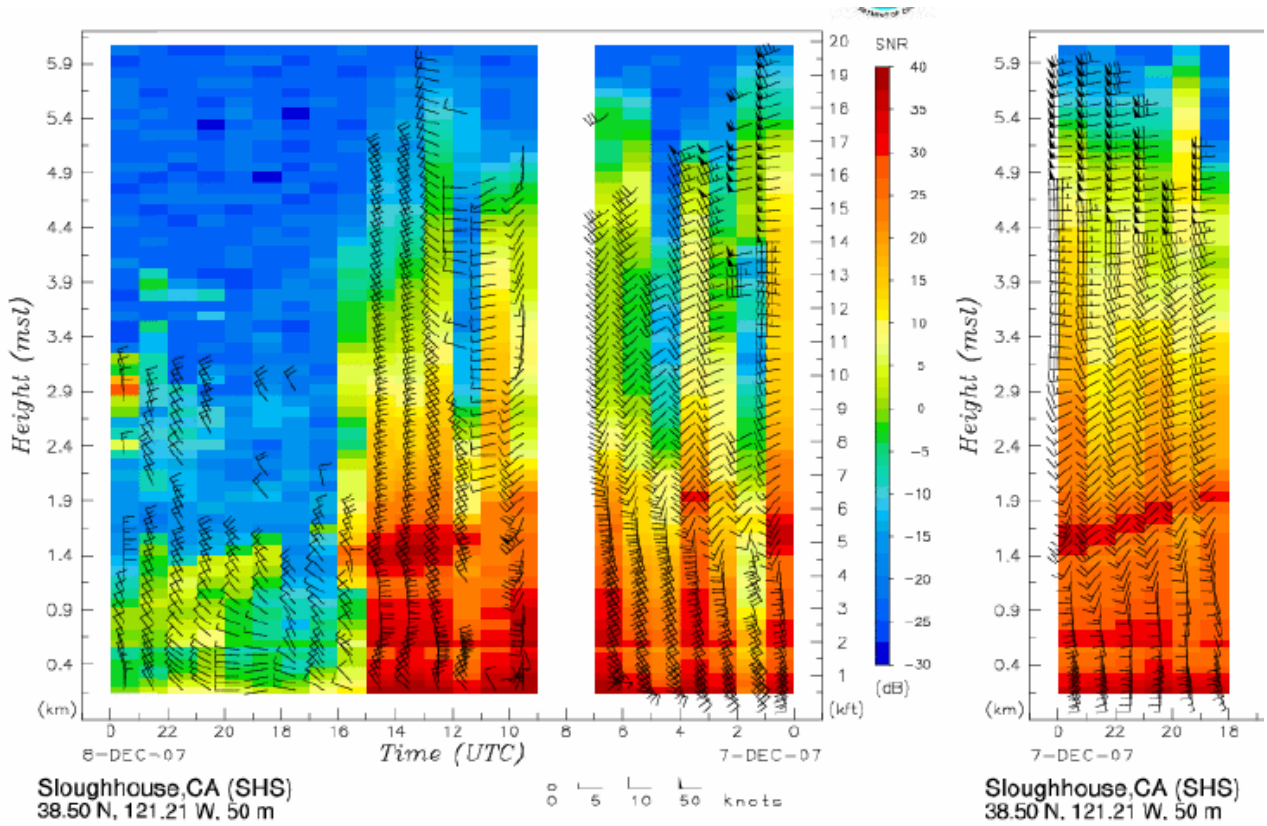


Figure 13. Profiler time series from the Sloughhouse site.

The long range forecasts: In this section the model forecasts will be reviewed with a subjective assessment of their performance for the first IOP. The first conference call of the HMT season was on Friday 30 Nov, with the applicable progs from 0000 UTC/30 Nov 168 h forecasts, so shorter than our typical HMT long range outlooks of 10-15 days. A number of sites have presentations of ensemble forecasts, including one from Penn State, NOAA/CDC, AWIPS, and Environment Canada. There is a relatively new presentation on the Environment Canada web page that displays the output from what is called the North American Forecast System (NAEFS), which is a combination of the ensemble forecasts from both the Canadian ensemble system and the GFS ensemble system. Figure 14 shows some of the forecasts from the NAEFS presentation for 168 h valid at 0000 UTC on 7 Dec. In addition to displaying different fields from all the individual ensemble forecasts (20 members from each

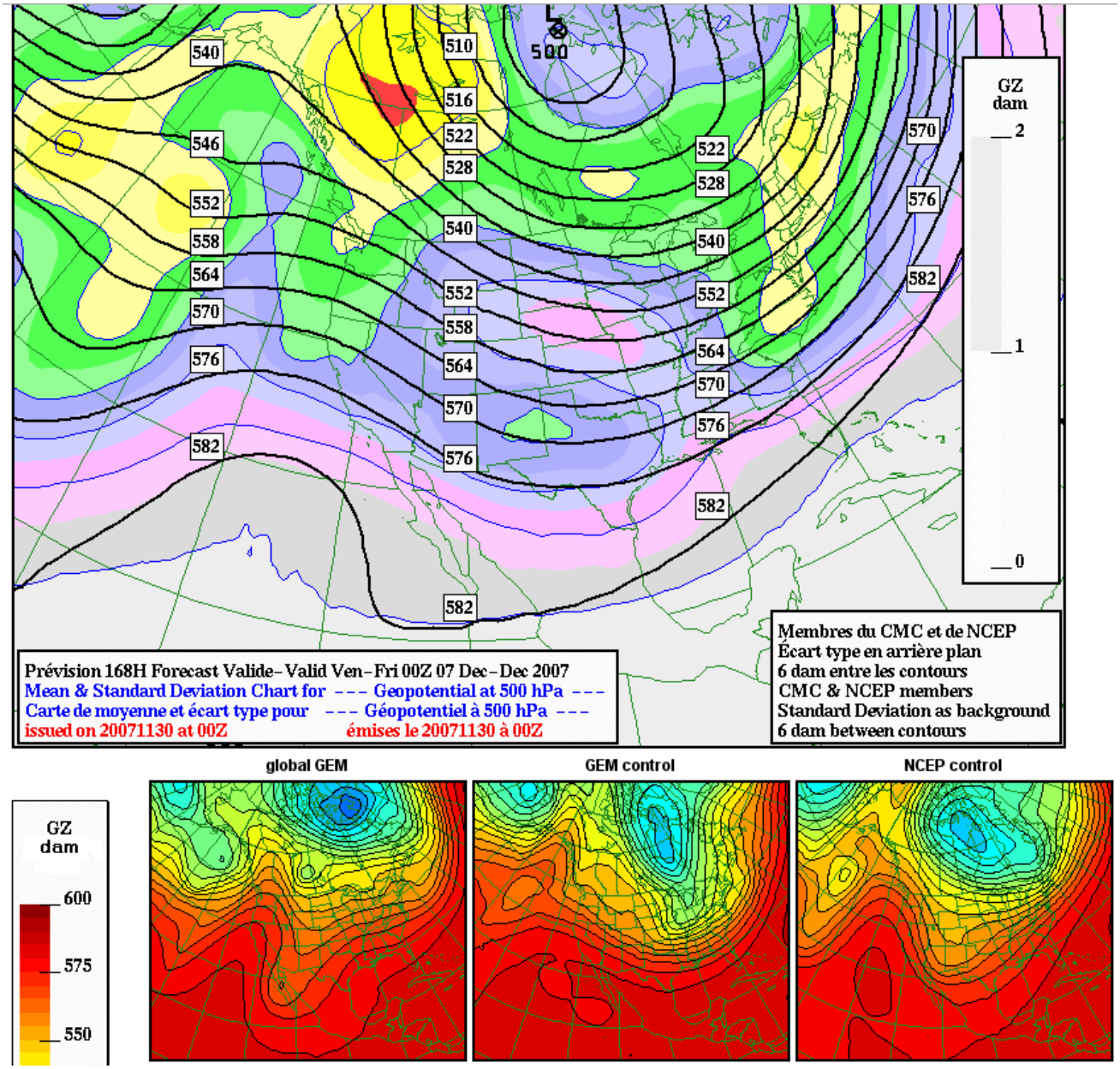


Figure 14 NAEFS mean 168 h 500 mb height forecast from 0000 UTC 30 Nov, valid 0000 UTC 7 Dec. The 3 images at the bottom are the individual 500 mb 168 h forecasts from: the Canadian Global GEM model (the deterministic run at higher resolution) the GEM control (unperturbed GEM run), and the NCEP control (unperturbed GFS run at T126 resolution).

system), a mean forecast from the members is shown, as well as an interesting meteogram presentation for a large number of cities. The general consensus of the ensembles was for ridging along the West Coast for later in the first week in December. It was noted in the discussion, however, that there were some members of the Canadian ensemble system and the ECMWF ensemble system that had different solutions, with the potential for a wave by the end of the week (the ECMWF ensemble system is only available to forecasters at NCEP, so this information was gleaned from the NCEP/HPC long range discussion and sometimes from the telcon). The 1200 UTC ensembles from the GFS began to show a little more diversity as well in the 7 December time frame.

The increase in diversity in the 1200 UTC/30 November GFS ensembles was a prelude to a significant change in the overall forecasts for 7 December. Some of the deterministic forecasts and the ensemble mean are shown next. In Figure 15 the GFS 156 h forecast from the 0000 UTC/1 December run valid on 1200 UTC/1 December, along with the analysis for the valid time. The forecast has a relatively high amplitude trough that verifies well in timing with the analysis that shows a broader trough just passing the HMT at 1200 UTC/7 December. This was quite a change from the previous forecast from 24-h earlier, but similar to some of the runs in the GFS ensemble from 12 h earlier. The ECMWF forecast from the 0000 UTC/1 December run valid on 0000 UTC/7 December is shown in Figure 16 and also forecasts a trough, in this case a bit farther north and still approaching the ARB (although note it verifies 12 h earlier than the GFS forecast). In Figure 17 is the ensemble mean and the control

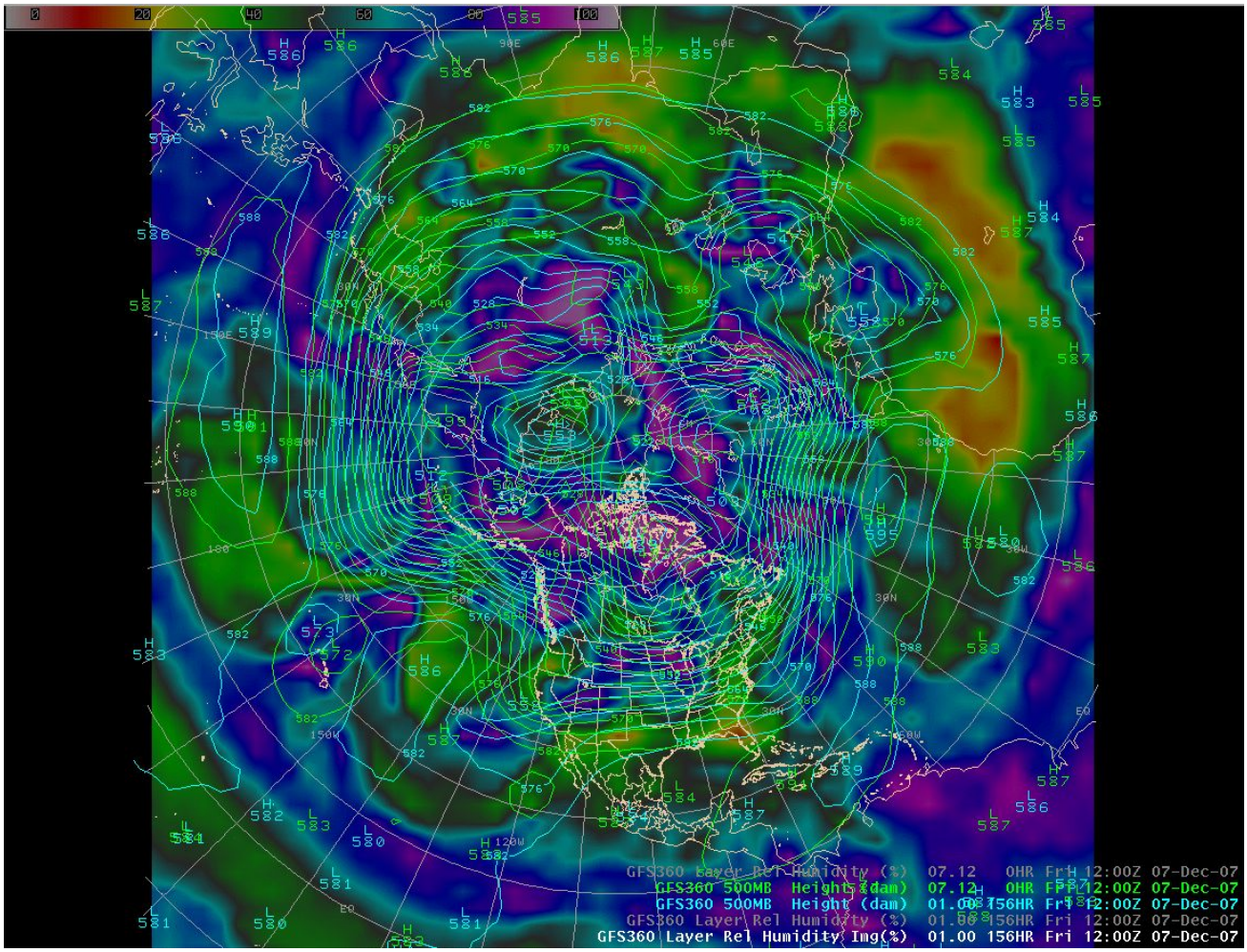


Figure 15. GFS 156-h 500 mb height and layer RH forecast from the 0000 UTC/1 December run, valid at 1200 UTC 7 December, with the 500 mb analysis for the valid time.

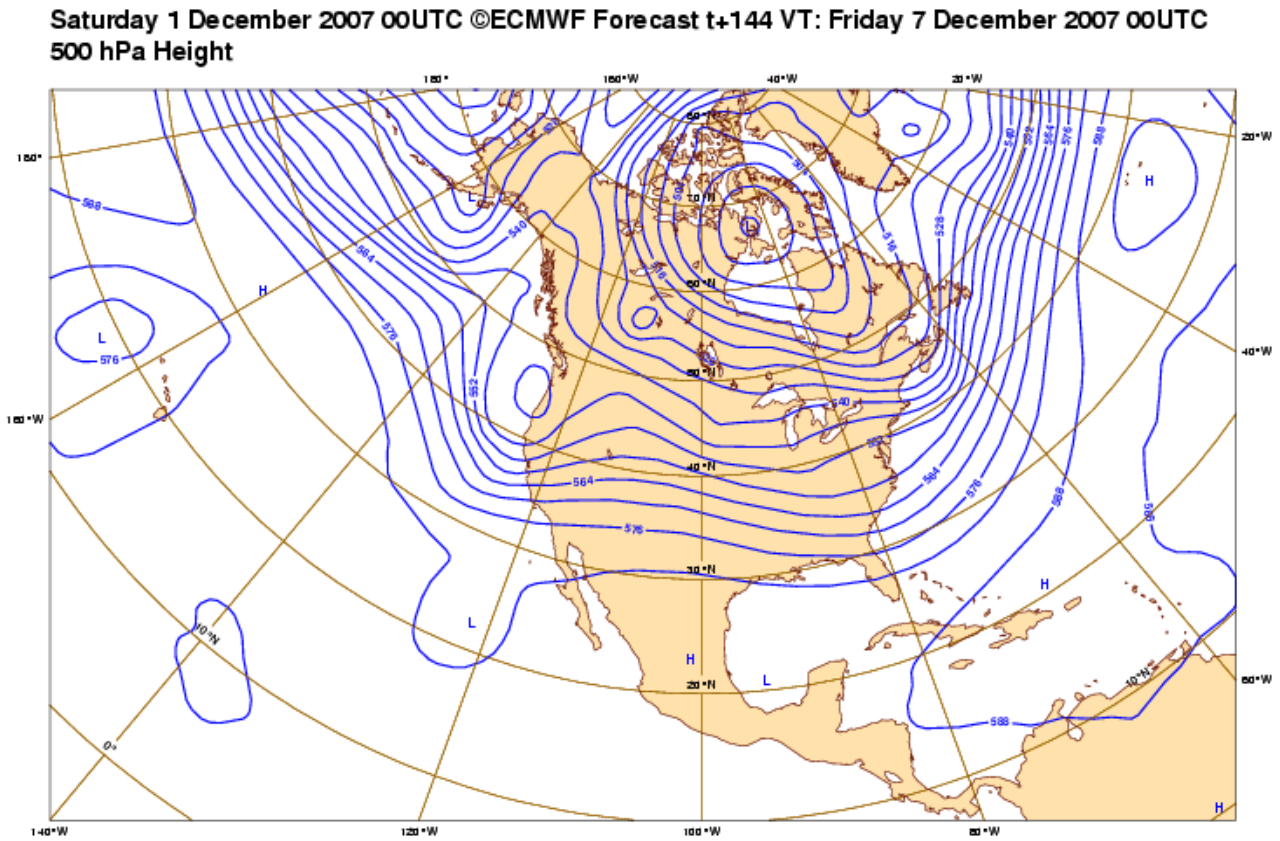
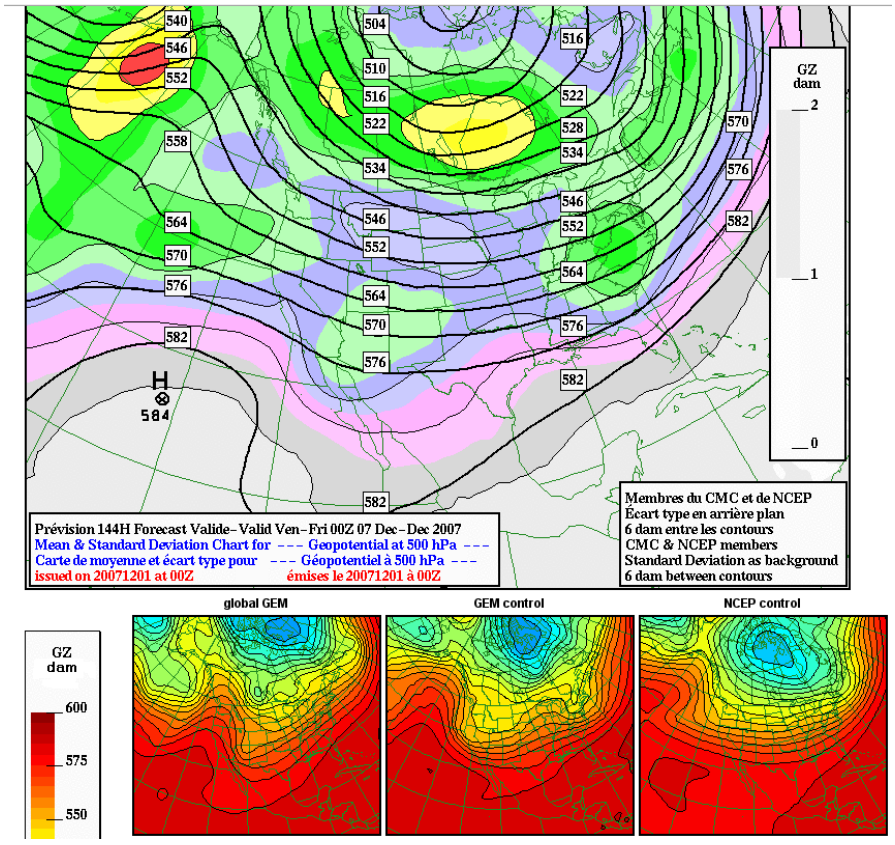


Figure 16. ECMWF 144-h 500 mb height forecast from the 0000 UTC/1 December run, valid at 0000 UTC 7 December

Figure 17. As in Figure 14, but for 144 h forecasts issued at 0000 UTC/1 December, valid on 0000 UTC/7 December.



forecasts, as shown earlier in Figure 14, but here for the 144 h forecast issued at 0000 UTC/1 December and valid on 0000 UTC/7 December. Even in the ensemble mean a trough has replaced the ridge near the ARB that was in the forecast from 24 h earlier.

The system predicted for 7 December was still on track in the next day's forecasts, with more confidence in the event as the models continued to converge. The main difference in the GFS forecast (Figure 18) was a deeper system that was trending a bit more to the south, with some threat that the heaviest precipitation would end up too far south. Verification at 500 mb, also shown in Figure 18, indicates this forecast was a bit too deep for the wave, but generally a decent prediction for a 120 h forecast. Note that with the deeper forecast in the GFS, the predicted moisture plume was suppressed south of where it actually ended up, which was in a more favorable position for heavier precipitation into the ARB. The ECMWF forecast (Figure 19) remained consistent in its 0000 UTC/2 December forecast, but note that the forecast from the next run at 1200 UTC was deeper and farther south, similar to the 0000 UTC/2 December GFS run. In terms of the ensemble forecasts from 0000 UTC/2 December, a majority of the GFS members were now predicting a trough, as well as a good number of the Canadian Global model members (though, as usual, there was more spread in the Canadian system). This better agreement among the members is reflected in the mean 500 mb forecast from the NAEFS (Figure 20), which has a little deeper trough than 24-h earlier that is approaching the ARB at 0000 UTC/7 December.

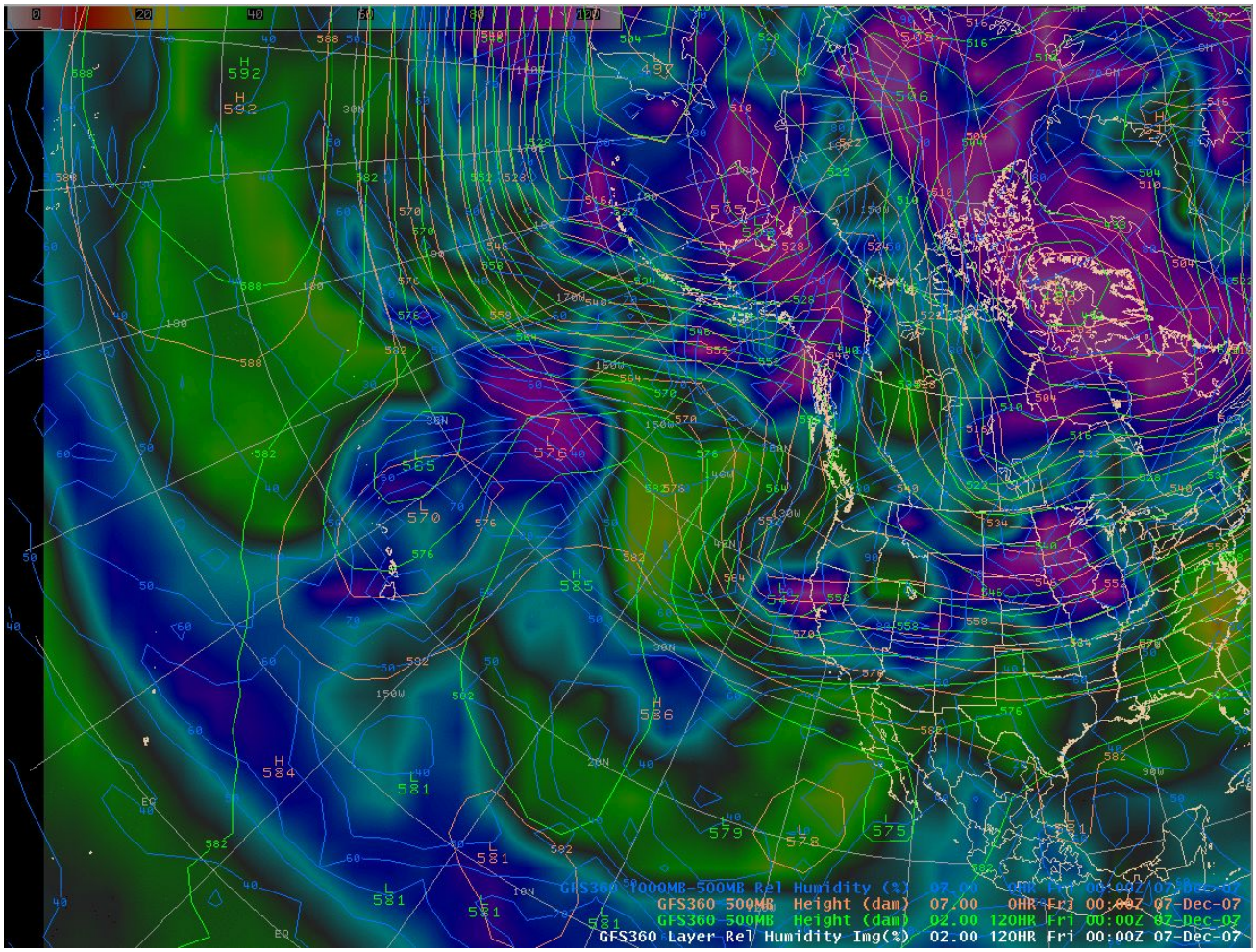


Figure 18. Comparison of the 2 December 0000 UTC GFS 120-h forecasts with verifying analyses at 7 December 0000 UTC, for 500 mb heights and layer relative humidity (1000-500 mb layer).

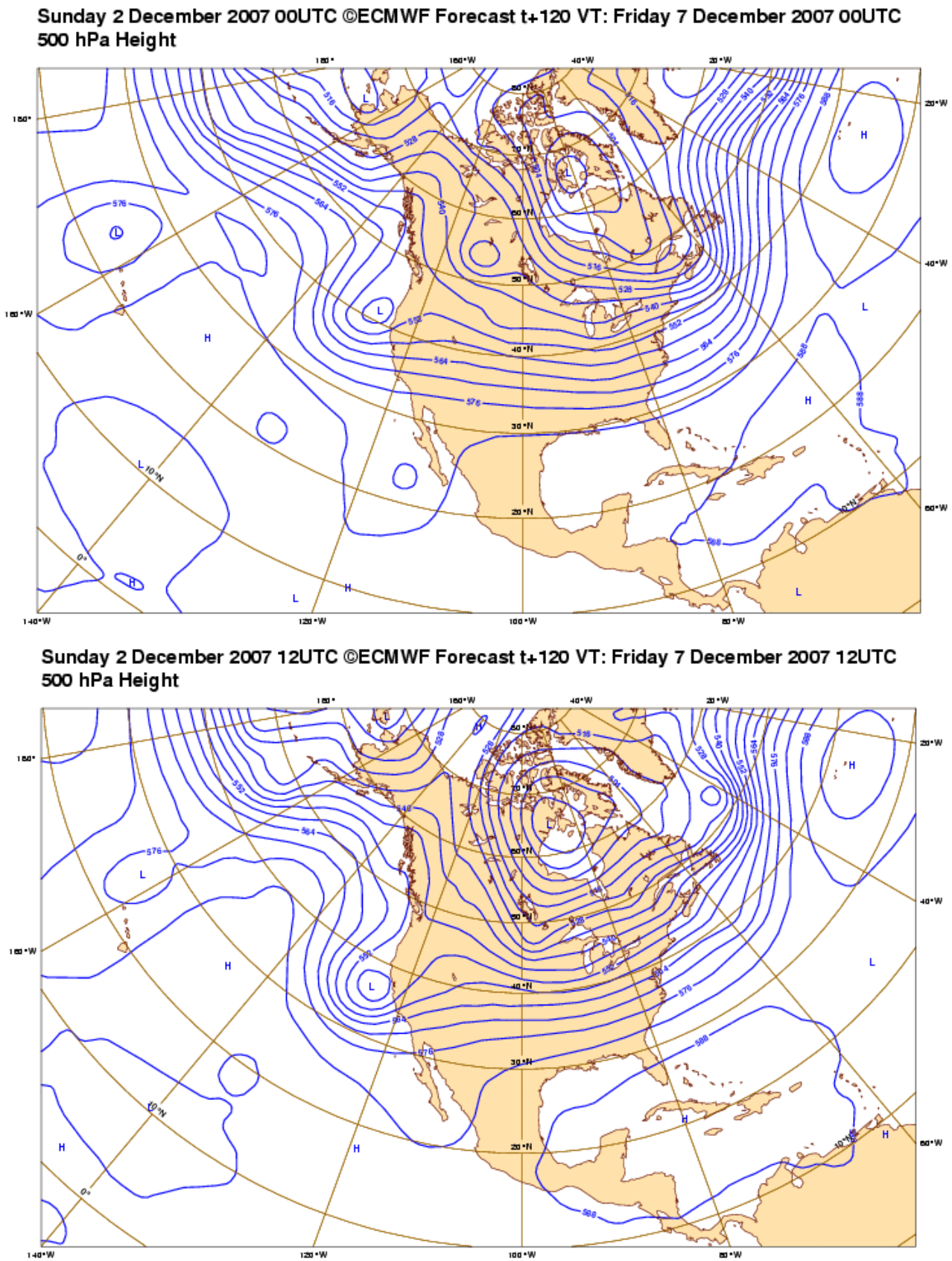


Figure 19. ECMWF 500 mb forecasts, as labelled.

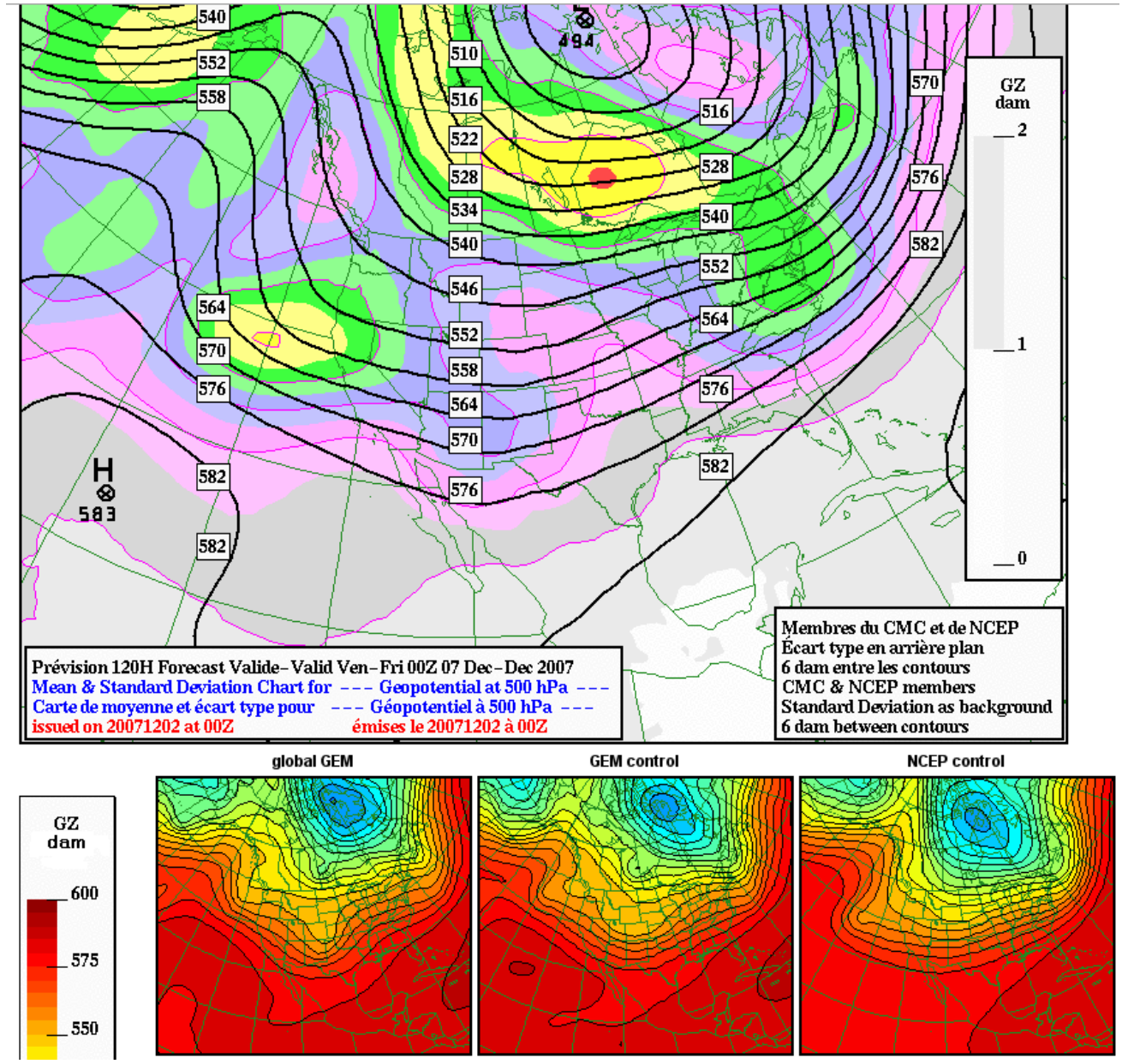


Figure 20. As in Figure 14, but for 120 h forecasts issued at 0000 UTC/2 December, valid on 0000 UTC/7 December.

The next set of 0000 UTC forecasts from 3 December continued to show an event for 7 December, with the GFS deterministic run now the most robust with 2.5 inches maximum precipitation in the ARB, though the Canadian Global model was also close to this amount. This is reflected in a more closed off 500 mb wave in the GFS forecast (Figure 21), leading to a more extended and intense event. Most of the 0000 UTC models generally had this trend for a bit slower event. This is seen in the 0000 UTC run of the ECMWF (Figure 22), compared to the earlier ECMWF runs. The ensemble mean (Figure 23) has a sharper trough as well approaching the ARB, although the individual members were split between a more progressive system and one slowing down (as in the GFS deterministic run). The 1200 UTC runs from 3 December, however, trended towards a consensus to a considerably faster moving system with less overall maximum precipitation. For example, both the Canadian Global model and GFS deterministic runs were down to about an inch maximum for the event, while the ECMWF 1200 UTC forecast produced only ~0.6 inches. The 1200 UTC GFS ensembles had a very wide range of predicted total precipitation, ranging from very little to around 2 inches. Overall then, there was confidence in an event, but ~96 h out still quite a range of possibilities as to its significance.

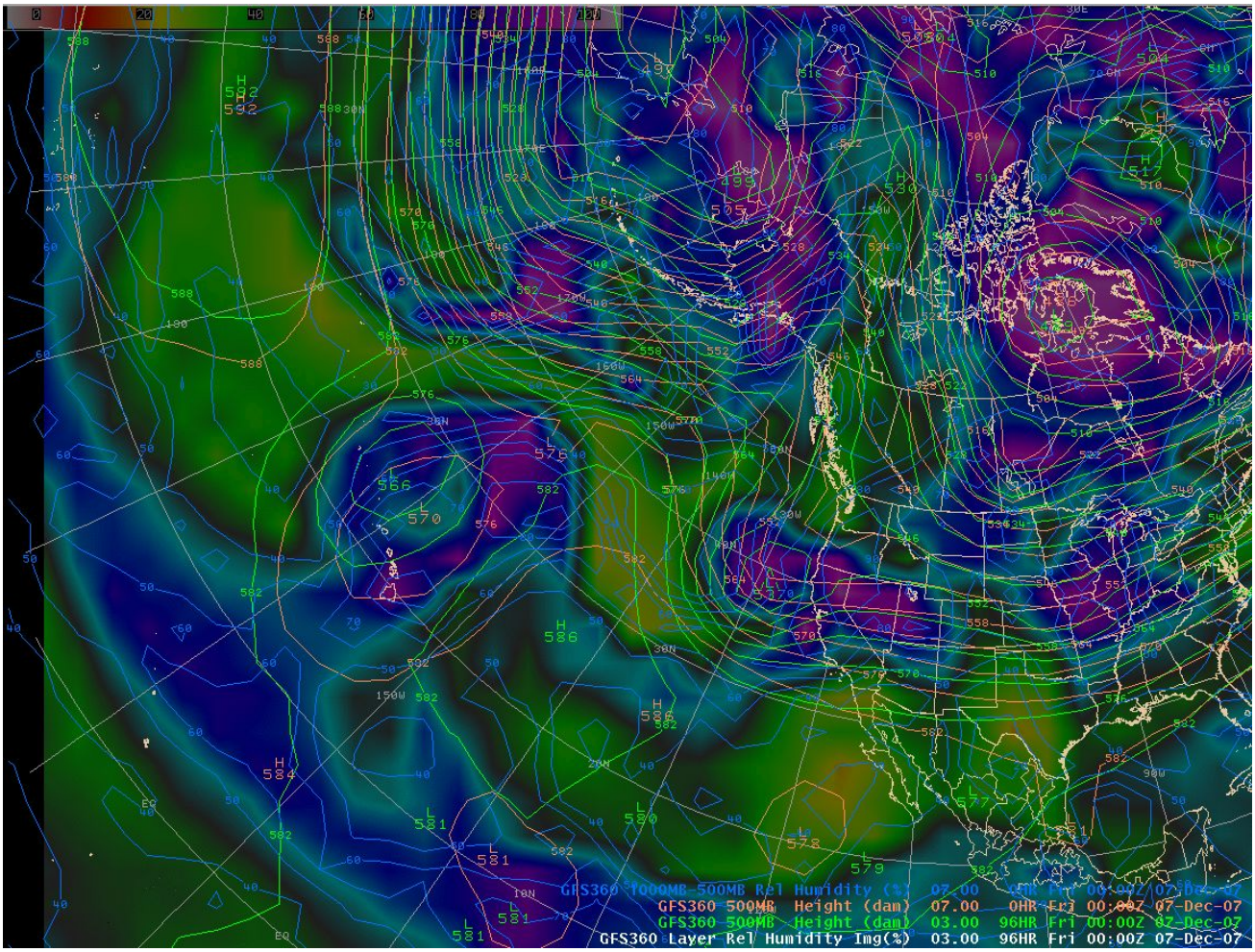
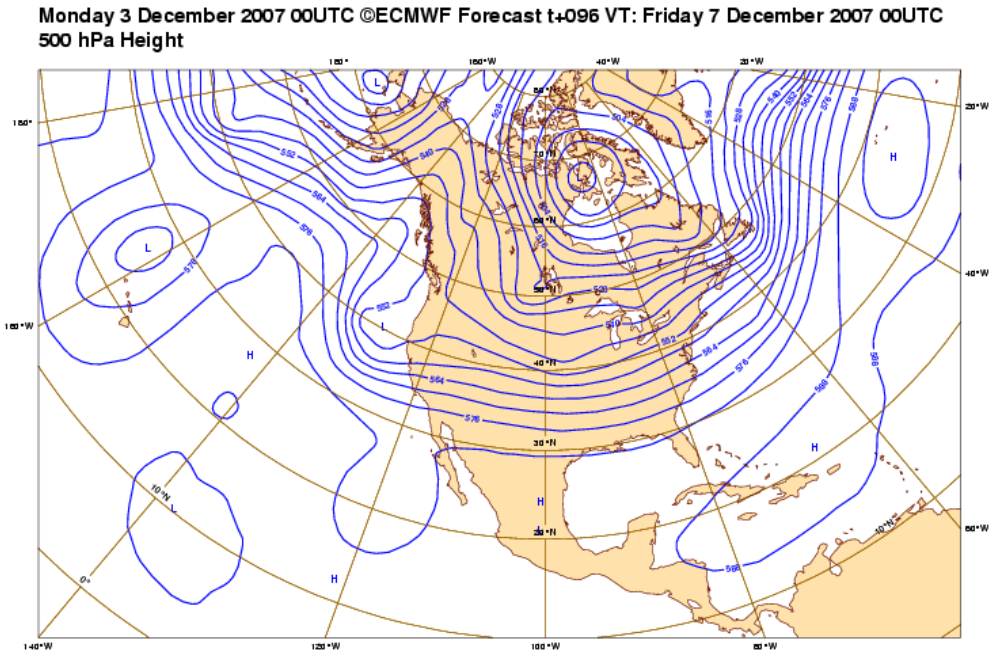


Figure 21. Comparison of the 3 December 0000 UTC GFS 96-h forecasts with verifying analyses at 7 December 0000 UTC, for 500 mb heights and layer relative humidity (1000-500 mb layer).

Figure 22. ECMWF 500 mb 96-h forecast from the 0000 UTC 3 December run, valid at 0000 UTC 7 December.



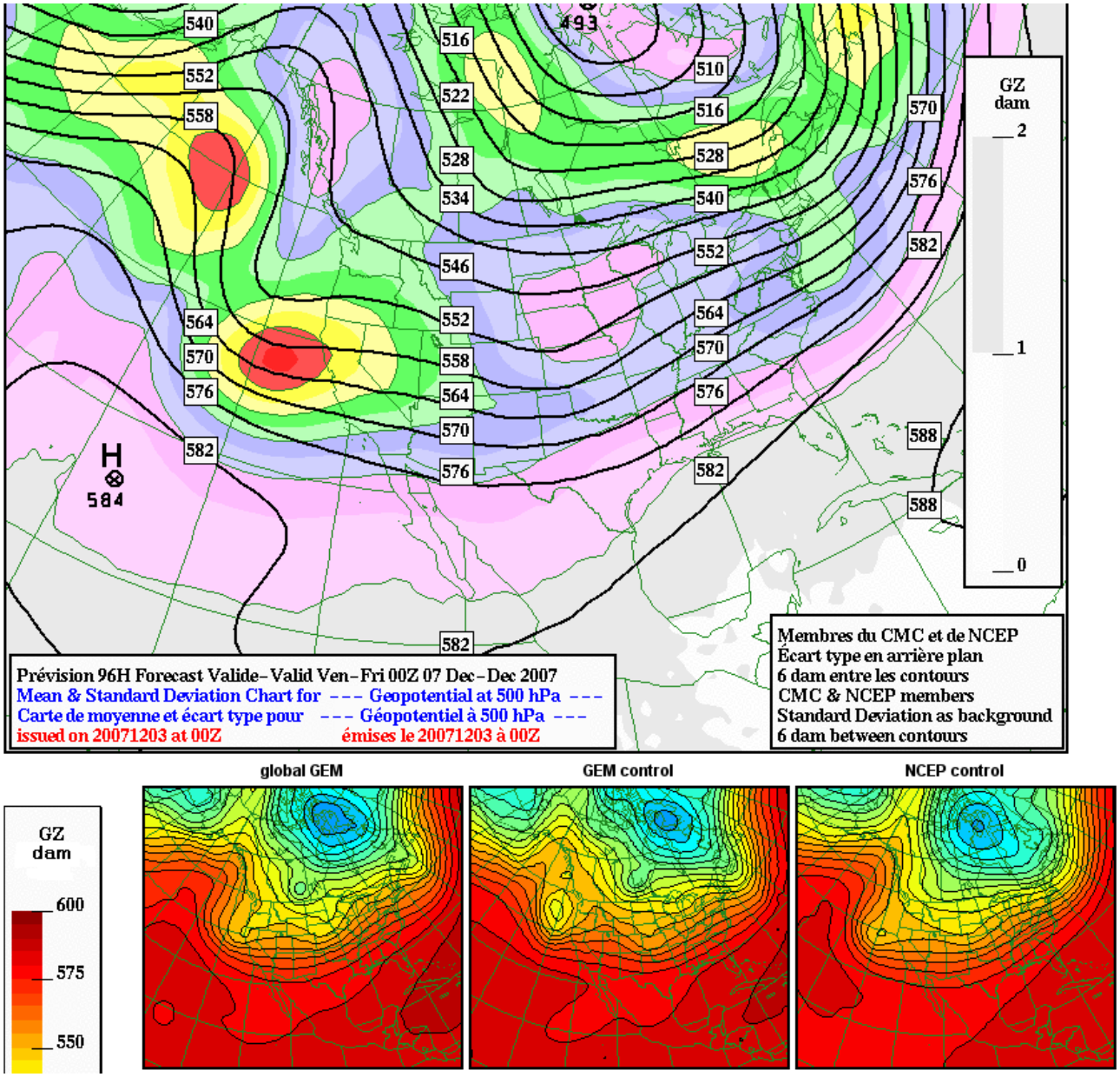


Figure 23. As in Figure 14, but for 96-h forecasts issued at 0000 UTC/3 December, valid on 0000 UTC/7 December.

Although only 3 days from the event, the 0000 UTC/4 December model runs threw in some differing opinions as to the significance of the approaching event. The deterministic runs for the most part remained quite favorable for an IOP, with the exception of the GFS. Figure 24 shows the 84-h GFS 500 mb and layer RH forecast from the 0000 UTC/4 December run, verifying at 1200 UTC/7 December, with the verifying analysis. The position of the forecast trough is quite good, but it is deeper, and therefore farther south, than what verifies. As a result, most of the moisture in the GFS run was predicted to pass to the south of the ARB, with ~1 inch maximum precipitation predicted for the event, compared to 1.5-2.5 inches in general from the other models, which were farther north with the wave, similar to the forecast from the ECMWF (Figure 25).

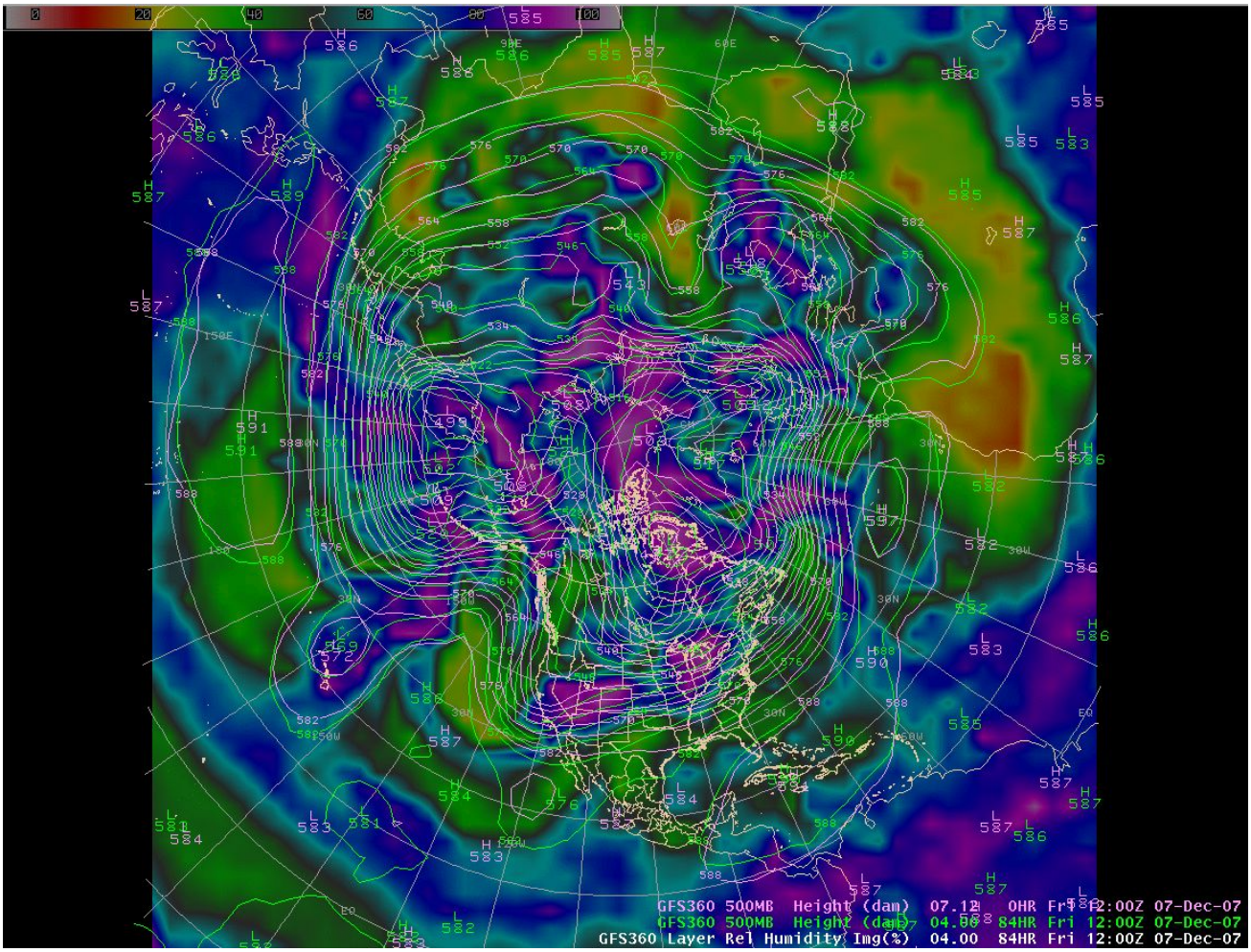


Figure 24. Comparison of the 4 December 0000 UTC GFS 84-h forecasts with verifying analyses at 7 December 1200 UTC, for 500 mb heights and layer relative humidity (1000-500 mb layer).

The ensemble mean forecast from the NAEFS (Figure 26) remained consistent with a shortwave trough passing much farther to the north than in the 0000 UTC GFS deterministic forecast. It was interesting that the more southern trajectory in the GFS forecast only occurred as the forecast system got close to the California coast, with the ECMWF and GFS forecasts quite similar through the forecasts valid at 1200 UTC/6 December. The 0000 UTC GFS run apparently was an anomaly, however, as the 1200 UTC run went back to a system that was farther north, in agreement with the majority opinion expressed by the 0000 UTC runs. As a result of this more northern position, the forecast maximum precipitation by the GFS went back up into the 1.5-2 inch range again. This left only one unfavorable forecast from the 1200 UTC/4 December runs, that being the NAM, which dropped the system way to the south and as a result predicted almost no precipitation for the event. This of course turned out to be a terribly poor forecast, and at the time was discarded from consideration. Since it was now getting closer to the event, the short-range ensemble forecast system (SREF) became applicable. The 0900 UTC/4 December SREF had quite a bit of spread, but the mean precipitation forecast had ~0.50 inches, with the Eta members generally the most moist, at over 2 inches for the event.

The 0000 UTC/5 December runs were in quite good agreement for an event, with generally 1-2 inches maximum predicted by the global models, with some of the runs predicting 2 to more than 3 inches maximum nearby to the south of the ARB. In general, the forecast was for an open wave at 700/500 mb passing near or just to the north of the ARB, putting the region in a good track for an intense but

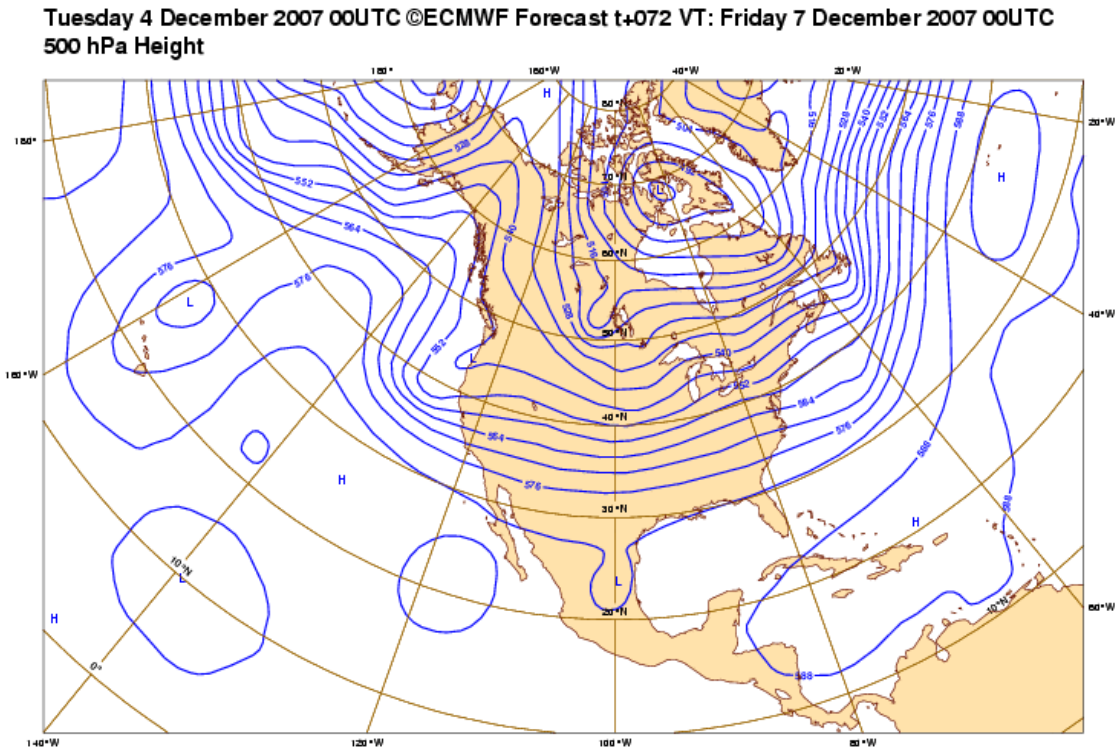


Figure 25. ECMWF 500 mb forecast valid at 0000 UTC 7 December.

relatively quick period of heavy precipitation. The NAM remained the outlier of the 0000 UTC runs, again sending the system too far south, but it finally came around to a good forecast by the 1200 UTC/5 December run. At only 48 h out there was good agreement among the ensembles, with only one member of the GFS ensemble system having much variation. More spread amongst the SREF in terms of total precipitation, ranging is from a minimum of 0.75 inches to 2-3 inches from the more moist Eta members, and a mean now of 1-1.25 inches (similar numbers from both the 0900 UTC and 1500 UTC SREF).

The only note to be made about the forecasts from the following day, as the event was just beginning, concerns the local GSD models. The runs from 5 December provided good guidance as to the timing of the precipitation, with the forecast reflectivity fields quite useful. The forecast total precipitation from the runs from 1200 UTC/6 December was generally below what actually occurred. For example, the 24-h maximum precipitation in the ensemble mean forecast for the period ending 1200 UTC/7 Dec was in the 1-1.5 inch range over the higher terrain of the ARB. Similar amounts were forecast from the 1800 UTC high-resolution model runs. The probability of an inch of precipitation was given at 50% from the ensemble forecasts. This under prediction is in contrast to some tendency for the high-resolution models to forecast somewhat higher amounts than what occurred for other IOPs. In this case it may reflect an underestimate of the amount of moisture offshore in the remnants of the plume.

Closing comments: The longer range forecasts about a week ahead of the event showed some hints of a potential system in some of the ensemble members, with a quick trend towards a majority of the members forecasting a potential storm by the 0000 UTC/1 Dec runs. The deterministic model runs from this time also had a trough moving towards the California coast, but over the next few days there was variation in precisely where the open wave would hit more than the timing of a possible system. Given that the storm was forecast to be a relatively fast-moving open trough, such position shifts led to considerable forecast differences in precipitation at times between models and model run times. For example, there was a southward shift to the forecast trough on the 0000 UTC/4 December GFS run that

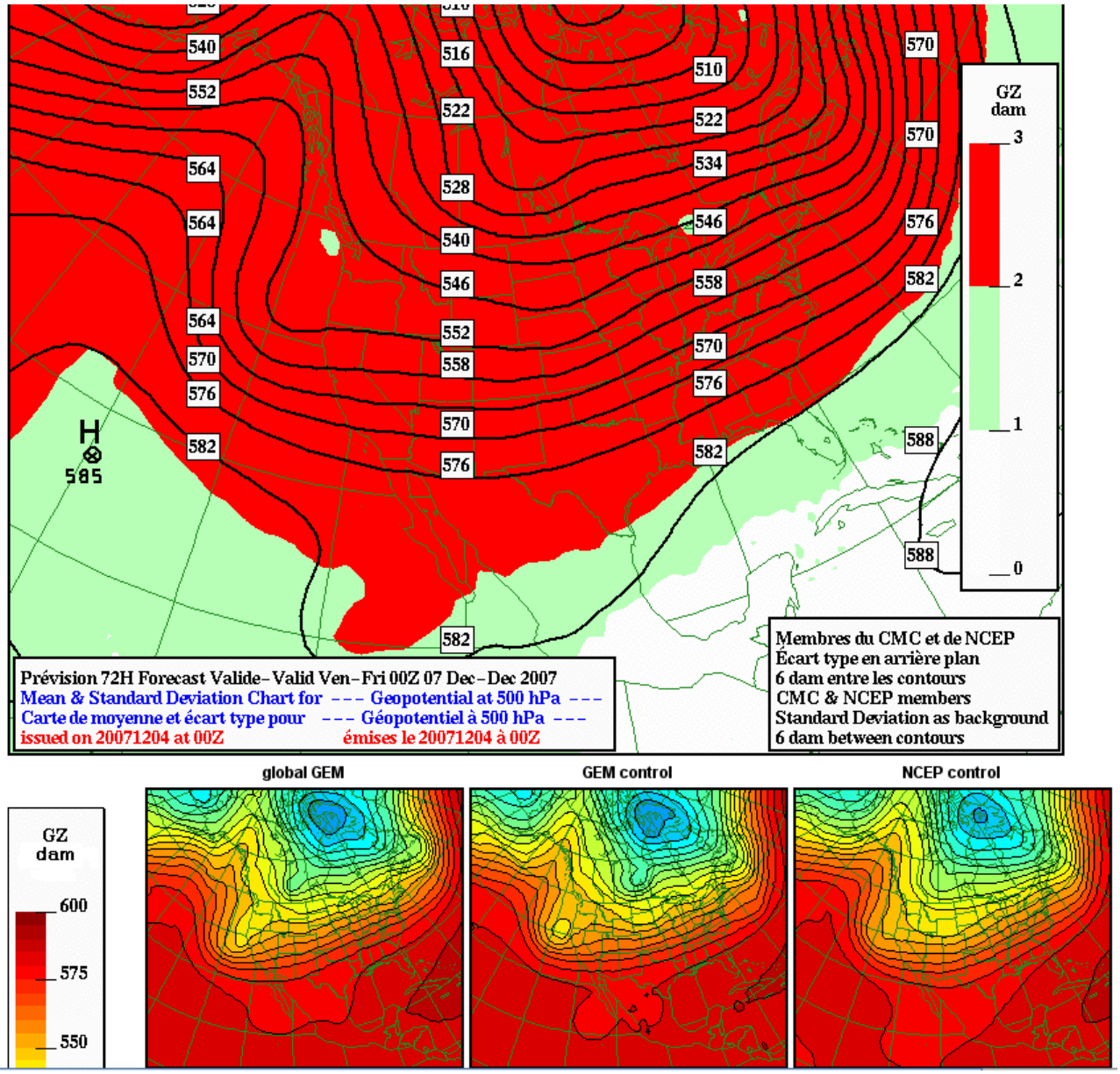


Figure 26. As in Figure 14, but for 72-h forecasts issued at 0000 UTC/4 December, valid on 0000 UTC/7 December.

resulted in a subsequent southward shift in the precipitation and far less forecast for the ARB, but this proved to be a temporary forecast error. The GFS was prone to more of this shifting then the ECMWF and other models. The behavior of the GFS mimicked that seen in other storms, that is, a good longer range forecast, variation in the mid-range (96 to 72 h out), and then settling back to a good forecasst. Generally, the ensembles trended more smoothly towards a stronger wave with time, as evidenced by the gradually stronger wave shown in the NAEFS ensemble mean 500 mb forecasts. The first applicable prediction from the NAM was way too far south, but within a day it came in line with the other forecast models. Within the applicable 87-h period the SREF gave useful guidance, with gradually shrinking spread. For the most part the Eta members of the SREF system were the most moist, which overall was a better forecast. High-resolution guidance (3 km GSD runs) were useful for timing of the precipitation, particularly with the displays of equivalent radar reflectivity. Precipitation amounts were actually somewhat under forecast for this event by the high-resolution models.

Appendix A. Listing of observations from the KBLU METAR from 0152 UTC/6 Dec through 1521 UTC/7 Dec.

KBLU 071521Z AUTO 00000KT 1/2SM SN FG CLR 01/M01 A2972 RMK AO2 P0007 TSNO
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KBLU 071440Z AUTO 00000KT 3/4SM -SN BR VV003 01/M01 A2970 RMK AO2 P0006 TSNO
KBLU 071433Z AUTO 11004KT 1SM -SN BR VV002 01/M01 A2969 RMK AO2 P0004 TSNO
KBLU 071426Z AUTO 11004KT 1 1/4SM -SN BR SCT003 01/M01 A2969 RMK AO2 P0003 TSNO
KBLU 071408Z AUTO 09004KT 3/4SM -SN BR OVC003 01/M01 A2967 RMK AO2 P0002 TSNO
KBLU 071352Z AUTO 12003KT 1 1/4SM -SN BR BKN003 01/M01 A2966 RMK AO2 SLP048 P0012 T00061006 TSNO
KBLU 071340Z AUTO 00000KT 1SM -SN BR VV003 01/M01 A2965 RMK AO2 P0011 TSNO
KBLU 071252Z AUTO 00000KT 3/4SM -SN BR BKN004 OVC011 01/M01 A2963 RMK AO2 SLP034 P0024 T00111006 TSNO
KBLU 071214Z AUTO VRB04KT 1 1/4SM -SN BR BKN004 OVC011 01/M01 A2962 RMK AO2 P0011 TSNO
KBLU 071152Z AUTO 04005KT 1 1/2SM -SN BR BKN004 OVC011 01/M01 A2961 RMK AO2 SLP027 P0033 60125 70237 T00111006 10011 20006 56002 TSNO
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KBLU 071030Z AUTO 03007KT 1 1/2SM -SN BR BKN002 OVC008 01/M01 A2960 RMK AO2 P0012 TSNO
KBLU 071006Z AUTO 35007KT 1/2SM SN FG OVC002 01/M01 A2961 RMK AO2 P0006 TSNO
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