Western Region Technical Attachment
No. 90-07
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EVALUATING VERTICAL MOTION or WHY IS IT SNOWING?

To a large extent, forecasting winter precipitation is closely related to the ability of the forecaster to evaluate the strength, timing, and location of the vertical motion field. The availability of moisture is important, but given the relatively long time-scales of winter systems compared to summer convection, moisture availability is not as key an issue as it is during the warm season. This is particularly true in the intermountain region where precipitable water values are typically low even during major winter events.

Vertical motions take place across a broad spectrum of spatial scales, ranging from narrow mesoscale convergence zones, to small synoptic scale frontal zones, on up to large synoptic scale areas ahead of upper-level troughs. The reasons for vertical motion are also quite broad in scope. Depending on the stability, air may rise due to orographic lift, terrain induced convergence, secondary circulations related to jet streaks, secondary circulations related to frontogenesis, secondary circulations due to large-scale dynamical forcing, e.g., PVA and warm advection, frontal lifting, and diabatic heating. The above is not an exhaustive list, and these lifting mechanisms overlap, e.g., frontogenesis and the associated secondary circulations are to some extent accounted for in large-scale dynamical circulations, and likewise the secondary circulations around jet streaks are also mostly accounted for in large-scale dynamical circulations. And of course, the response by the atmosphere to forcing depends on the stability and moisture content of the air.

This attachment will discuss only two methods of evaluating the large-scale dynamical motions associated with a synoptic scale trough that moved through the intermountain area February 7, 1990.

Forecasters look at numerical model output and apply concepts of quasi-geostrophic theory, as best they can, to arrive at estimates of the strength, timing, and location of vertical motion. This typically means trying to evaluate the two terms of the omega equation. One term is related to how the vorticity advection is changing with height, and the other is based on the Laplacian of the thermal advection. Within AFOS, this reduces to looking at 500 mb height/vorticity and then some combination of height or surface pressure with either thickness or isotherms.

Obviously there are many problems with this approach using the tools available in AFOS. Since vorticity is only available at 500 mb, only estimations based on assumptions of vertical wind shear can be made about how vorticity advection changes with height. And even then, it is only possible to "eyeball" the amount of vorticity advection at 500 mb by overlaying the height and vorticity and visually estimating how the lines cross. Estimating the Laplacian of thermal advection is even more difficult. Remember, the Laplacian is the rate of change of thermal advection. Forecasters are usually not good at "eyeballing" Laplacians and only a limited number of fields are available in AFOS, eg. 1000-500 mb thickness. And even if these two terms could be exactly determined, there is considerable cancellation between the two, eg. cold advection at low levels beneath strong 500 mb PVA.

Modelers may argue that forecasters should just use the vertical motion calculated by the model, since the models use the primitive equations (less restrictive than quasi-geostrophic approximation) with sophisticated physics and terrain. There is considerable merit to this argument, but on the other hand, the model terrain is very gross, and thus vertical velocity calculations may be contaminated by incorrect orographic lifting from the model boundary-level wind blowing along a fictitious terrain gradient. Also, although many physical processes are parameterized in the models, some are not, and others are done so only crudely. Thus model derived vertical velocities are due to more than just large-scale dynamical forcing. The bottom line for most forecasters is that it is still worth their time to try and subjectively evaluate vertical motions due to large-scale dynamic forcing, and then factor in local effects and frontal strength, etc., separately.

This takes us back to 500 mb PVA and rough thermal advection techniques. However, for quasi-geostrophic evaluation of vertical motion, there is an alternative. Most forecast offices may now use a PC to calculate some quasi-geostrophic diagnostics from observed data. One that is particularly useful is the Divergence of Q (DIV Q) field. Without going into the math, Q can be thought of as a complete solution of the omega equation, with areas of Q divergence corresponding with dynamical downward vertical motion, and vice versa. DIV Q has been around in the scientific literature at least a decade, and in forecast offices limited capability has been available at least 2-3 years via the UA and AUA PC programs authored by Mike Foster of the Southern Region. However, at this date QG diagnostic fields are not yet available from progged model output except in the few locations that have access to gridded numerical data, (NMC, NSSFC, NHC, WSFO Denver).

The snowstorm of February 7, 1990 is presented as an example of how these methods of evaluating large-scale vertical motion compared. Figure 1 shows 500 mb height/vorticity, 500 mb DIV Q, 700 MB DIV Q, and 300 mb plotted data at 12Z February 7. In each case, the shaded areas in northern Utah, southeast Idaho, and northeast Nevada were receiving significant snow at this time. Snowfall totals were generally 4 to 8 inches in the valleys with up to 34 inches at mountain locations. Most of the snow fell between 09Z and 18Z, although some snow did continue in northern Utah until after 00Z February 8. The NGM FOUS output for Salt Lake City from the 00Z run forecast .07 inches of water for the 18 hours ending at 18Z.

What does figure 1 show? The snow is out ahead of the strongest 500 mb PVA, which is back in central and western Nevada. Both of the DIV Q analyses show strong forcing for upward vertical motion (convergence of Q) in essentially the same place. Thus there is forcing through at least a moderate depth of the atmosphere. DIV Q is not available at 300 mb in the current UA program. The DIV Q field lines up very well with the snow. Although a few raobs are missing and others had limiting angles, it is clear the snow is under the 300 mb jet axis. By 12Z a cold front (not shown) had slowly moved through most of the area. The front was south of Salt Lake City, where winds were northwesterly, and the pressure was rising, but it did not pass through Ely, Nevada until 13Z. There was no precipitation falling over western Nevada at this time although strong 500 mb PVA was indicated.

Figure 2 shows the 12Z soundings for Salt Lake City, Ely, and Winnemucca, as well as a 12Z Infrared satellite photo. The winds in the Salt Lake City sounding show low-level cold advection associated with the frontal passage, then warm advection in the mid-levels, with strong vertical wind shear up to jet level. The veering winds in the Ely sounding show warm advection all the way up, again with strong shear until the balloon was lost. At Winnemucca, the backing winds with height indicate cold advection through the lower half of the sounding. The satellite photo shows a somewhat ill-defined cloud band over the baroclinic zone, with some enhancement (in a good reproduction) just south of the Great Salt Lake.

Why did the DIV Q fields correlate so much better with the area of snowfall than 500 mb PVA? It could be for a number of reasons. The 500 mb PVA "rule" assumes PVA increases with height. The UA diagnostic 850, 700, and 500 mb height/vorticity analyses (not shown) indicated the PVA rule was applicable over western Nevada. However, the thermal advection analyses (also not shown) suggested strong, warm advection forcing of upward vertical motion out ahead of the 500 mb PVA and strong, cold advection in the area where 500 mb PVA was strongest. The soundings support this notion to some extent. Even though Salt Lake City was post-frontal, with cold advection at the surface, there was warm advection at mid-levels, and the Ely sounding also indicated warm advection. By contrast, Winnemucca was under strong 500 mb PVA, but was experiencing considerable cold advection and no precipitation was falling. The DIV Q fields take all this into account. How the vorticity advection changes with height, and how the thermal advections are distributed, and how these two may cancel each other are all combined in the DIV Q analysis. Until gridded model forecast data are available in WSFOs, DIV Q will not replace 500 mb PVA as a primary means of predicting large-scale dynamic vertical motion, but it is well worth looking at analyses of these fields now to try and understand: "Why is it Snowing?"

Another possibility in this case could be the forcing related to jet dynamics that are in excess of those predicted by quasi-geostrophic considerations, but that is another Technical Attachment.

References

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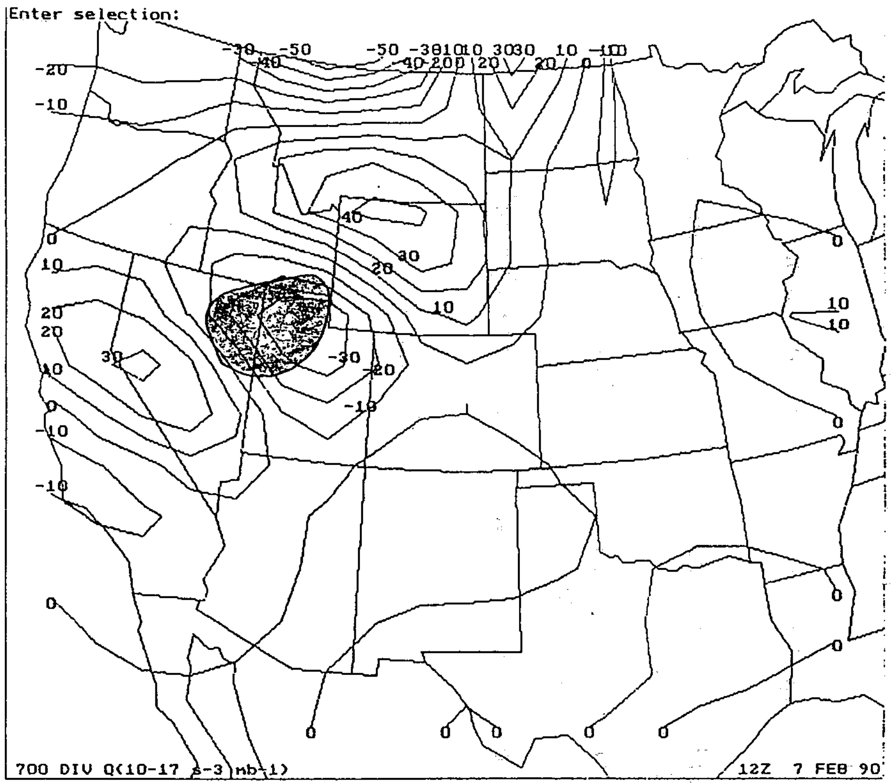
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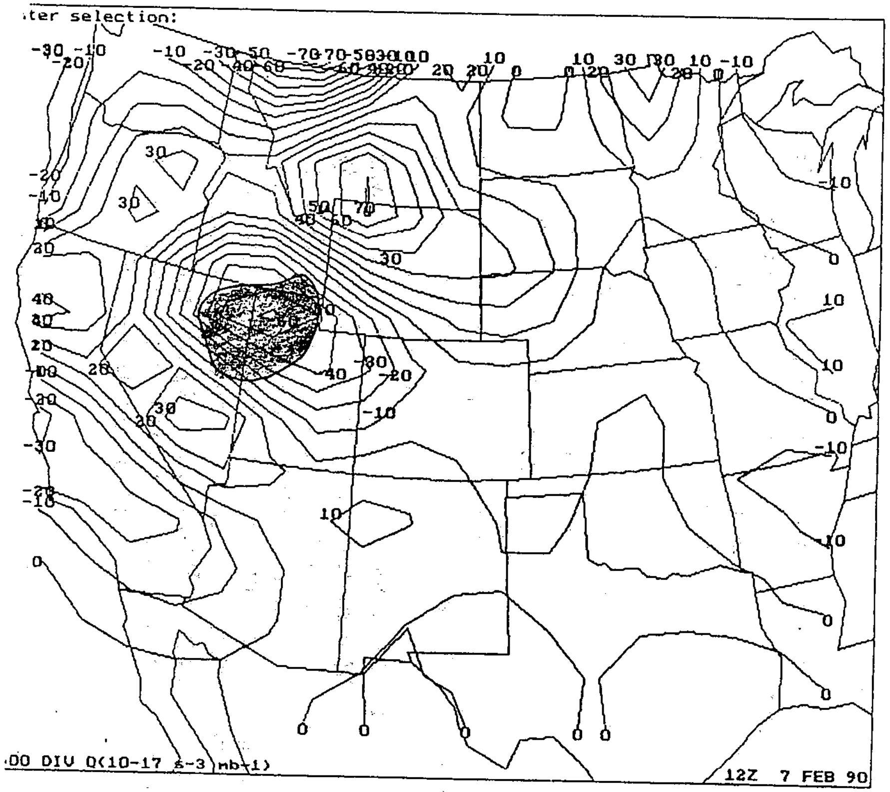
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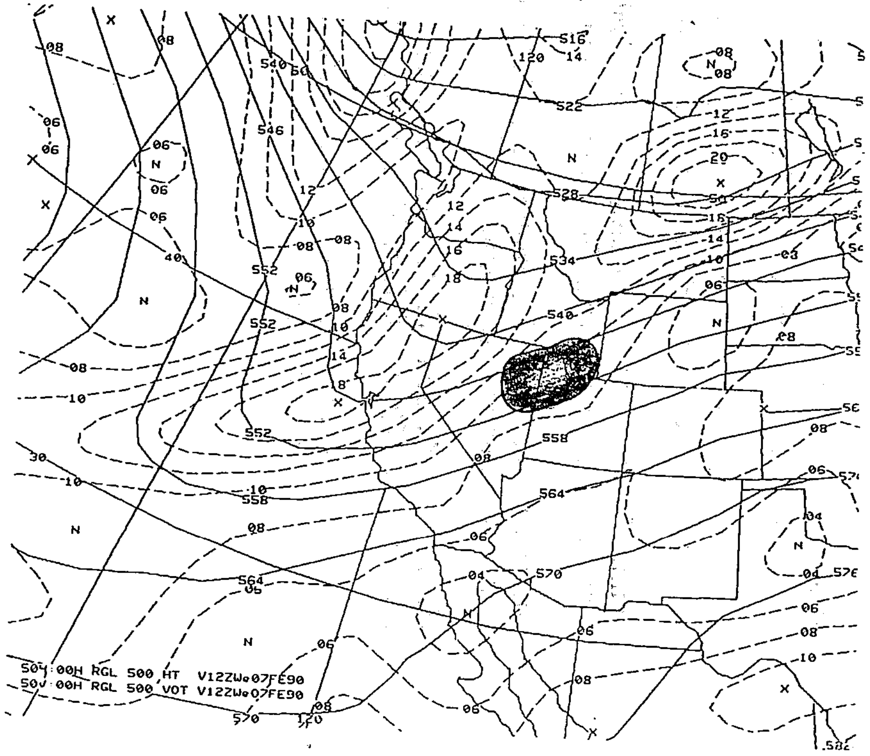
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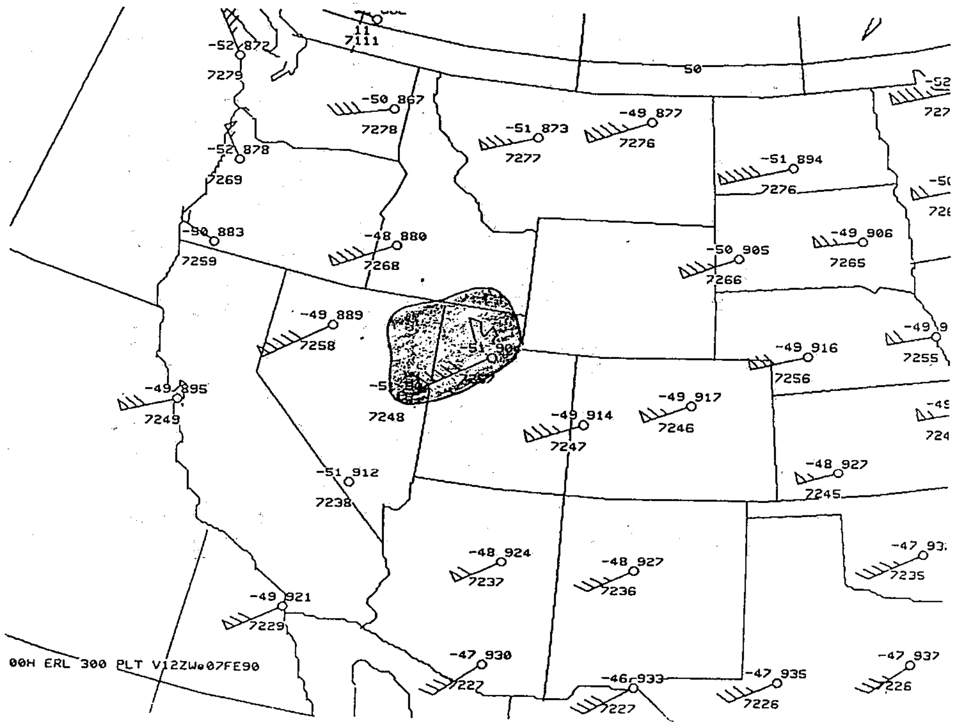
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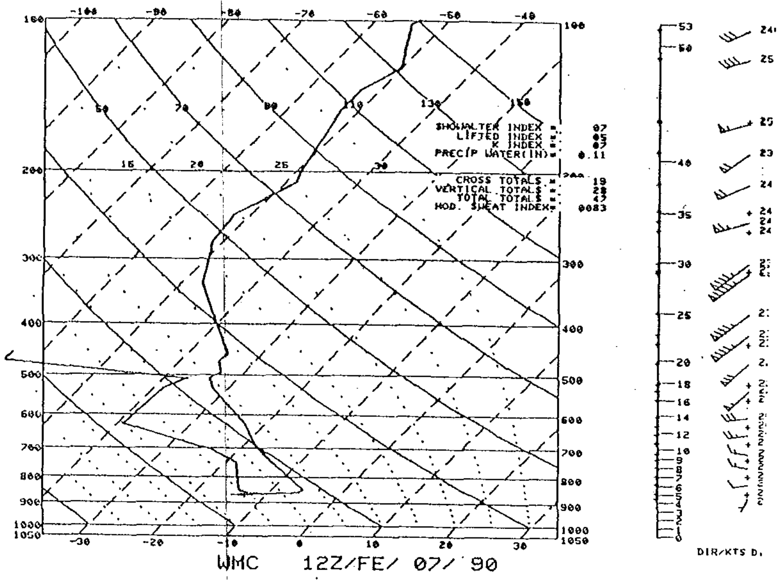
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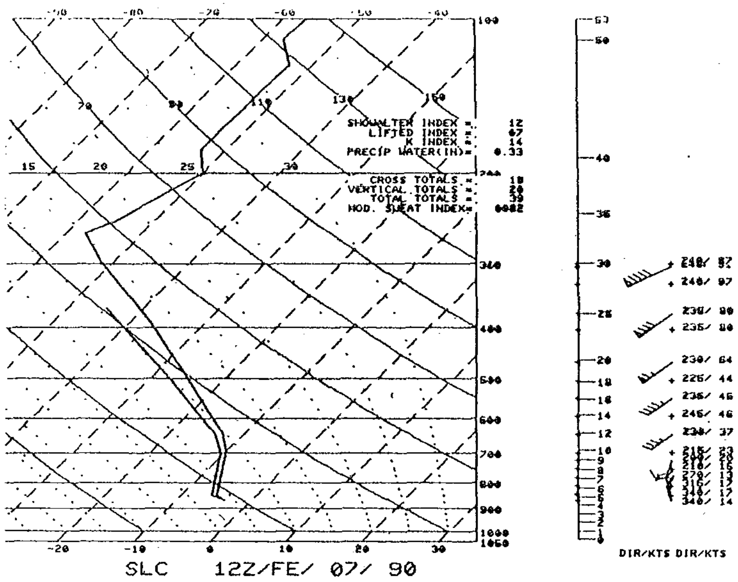
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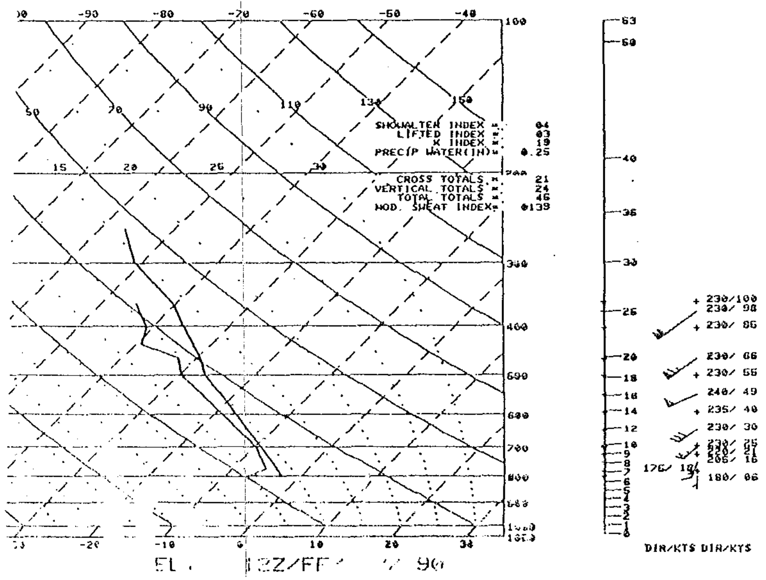
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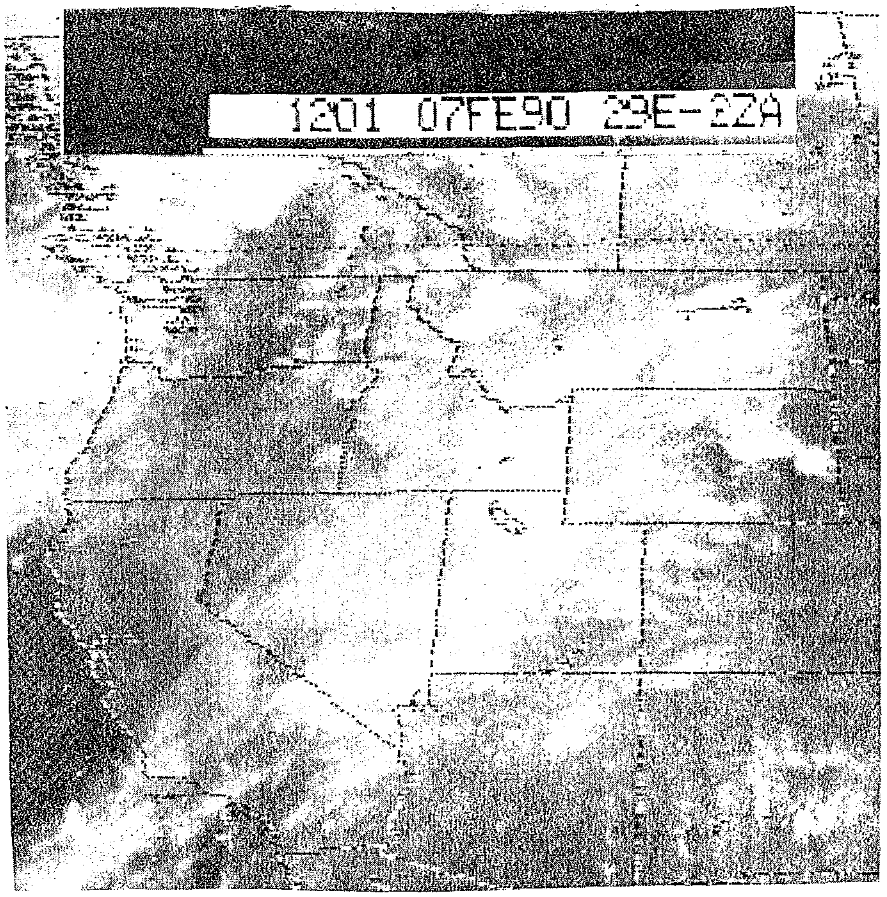
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