An Examination of the 4 December 2001 Snow Event Using the Weather Event Simulator (WES)

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January 21, 2003

Introduction

A significant winter storm affected portions of northern Arizona on 4 December 2001. Most locations above 6000 feet received 3 to 6 inches of snowfall, however enhanced snowfall of 7 to 16 inches fell in a 60 mile wide corridor from Flagstaff southeast to Blue Ridge Reservoir. Through examination using the Weather Event Simulator (WES), it was found that a strong potential vorticity maxima (PV), mid-level frontogenesis, and a quasi-stationary jet-induced cirrus band were important features of this event. Deep vertical motion induced by the PV anomaly combined with the secondary circulations of the frontogenetical forcing to produce an environment capable of a general 3-6 inch snowfall across much of the forecast area. Due to the quasi-stationary location of a strong jet maximum over the forecast area, a persistent band of cirrus was located over the heavy snow corridor before the snow event began. It is theorized that this persistent cloud shield created a localized environment with enhanced snow microphysics, deeper moisture, and abundant ice crystals which led to enhancement of the synoptically and mesoscale driven circulation as it passed across the forecast area. This enhanced environment, from the synoptic scale down to the cloud scale, created a prime environment for enhanced snowfall in a localized area.

Synoptic and Mesoscale Features

Satellite imagery at 0600 UTC 4 December 2001 (. Fig1) indicated the general synoptic situation. A deep 500 mb trough was located off the California coast with two strong jet streaks of greater than 130 kt. Two distinct cloud bands can be identified, one running from southern California northward into Nevada and the other across central Arizona into Colorado. A cross section was taken along the line shown in Figure 1 to identify some of the main forcing features. As illustrated in Figure 2, the first cloud band was associated with a strong PV anomaly and associated mid-level frontogenesis. Strong vertical motion can be seen in the cross section associated with a large area of warm air advection aloft and vorticity advection increasing with height, both directly tied to the strong PV anomaly (not shown). The second cloud band, which was located on the anticyclonic side of the strong jet core, was associated with a slowly ascending stream of air that originated over the subtropical Pacific Ocean. This air stream then merged with an air stream having a history of descent and drying as it passed through the western portion of the trough, leading to the sharp western edge to the clouds.

Model diagnosis using an ingredients-based snowfall methodology indicated that the environment over northern Arizona would be improving for heavy snowfall during the day as the strong forcing moved through. Significant vertical motion forcing in an unstable environment, combined with a temperature structure conducive for snow above 6000 feet, adequate moisture, and an excellent snow microphysics environment were all expected to develop over the forecast area through the morning, peak at around 1800 UTC near the Flagstaff area, and decrease during the afternoon and evening hours. Satellite imagery at 1730 UTC along with 700-300 mb Fn Vector Divergence and the 850-700 mb specific humidity indicate this favorable environment (Fig. 3). Heavy snow was being reported in many locations under this snow band at this time, with 7 inches of snow reported at Happy Jack (located in the above mentioned corridor of heavy snow). Snow advisories were upgraded to heavy snow warnings at this time for the area from Flagstaff eastward along the anticipated heavy snow path.

Radar and satellite imagery of this event indicate that as the strong forcing approached northern Arizona, low-level clouds rapidly developed over eastern and central portions of the forecast area. These clouds developed rapidly in the vertical and those over central Arizona, from Flagstaff southeastward, developed most vigorously. Precipitation developed rapidly after 1400 UTC over much of western Arizona and into portions of central Arizona, especially under the cirrus cloud band. As the event continued, radar echoes moving northward off the lower deserts enhanced significantly as they moved over the location where the cirrus band had been located and then weakened as they moved past this area. By the time the snowfall ended around 0600 UTC 5 December, up to 16 inches of snow had fallen in this enhanced snowfall area.

Discussion

A large area of rising motion, focused by the PV anomaly, led to general snowfall over the region. It appears that snowfall began first under the quasi-permanent cirrus cloud band and became heaviest there first, most likely due to enhanced snow microphysics and an atmosphere that was already primed for heavy snow production with abundant ice crystal formation. The added focusing of the secondary circulation caused by mid-level frontogenesis enhanced this upward vertical motion creating a band of heavier snowfall as the trough moved through the forecast area. Numerical models handled the situation adequately, although underplayed the strength of the vertical circulation and the likely importance of the cirrus cloud band. This case underscores the importance of looking beyond just normal parameters such as omega and Q-vectors and looking at other parameters such as Potential Vorticity, 2-D frontogenesis, Fn Vectors, and the precursor satellite imagery to get a better indication of the potential of heavier embedded snow bands in what appeared to be just a normal snow advisory event. The WES enabled the forecasters and SOO to examine this interesting winter case and to deliver applicable training which was well received by the staff.

Figure 1

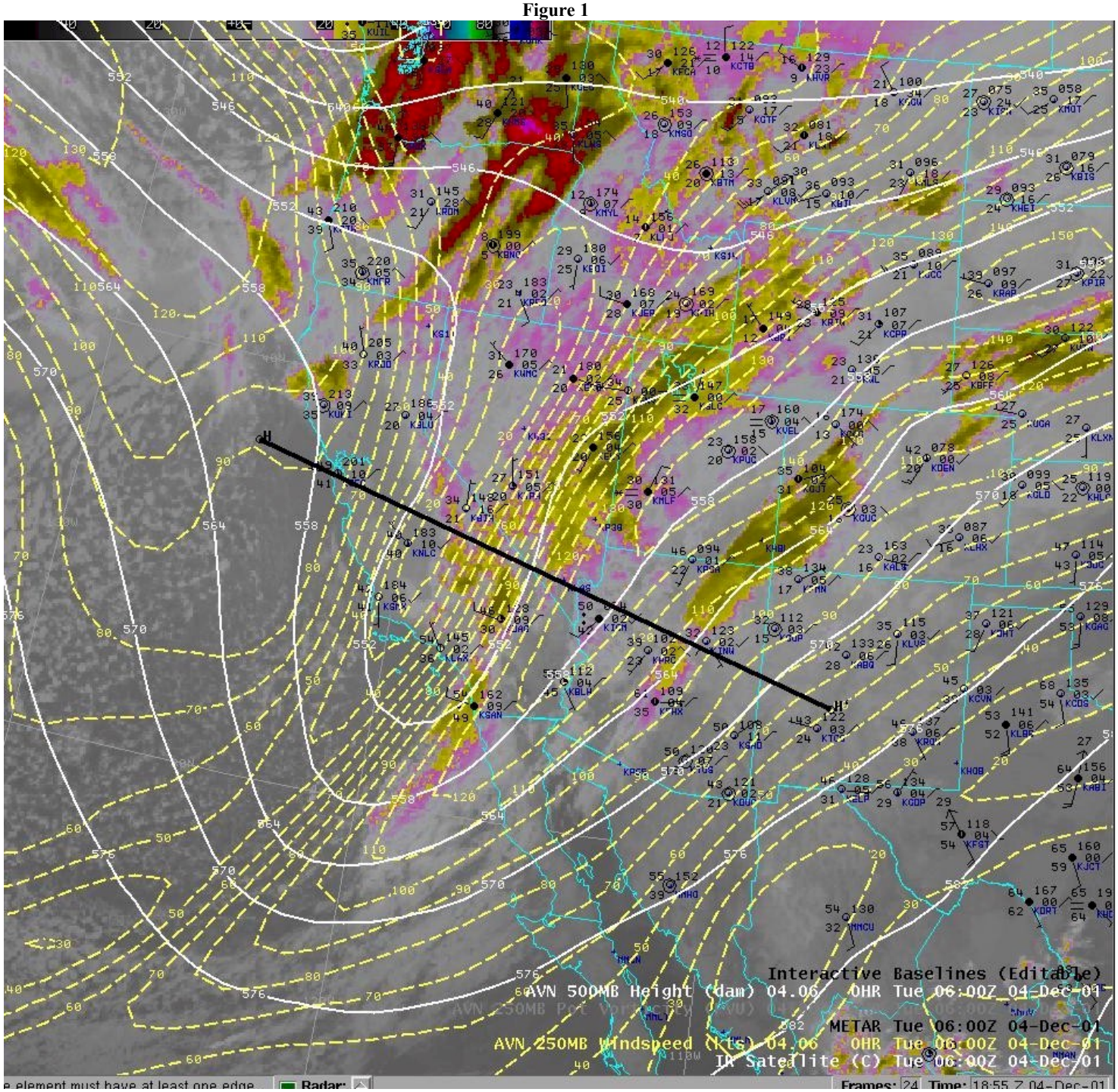
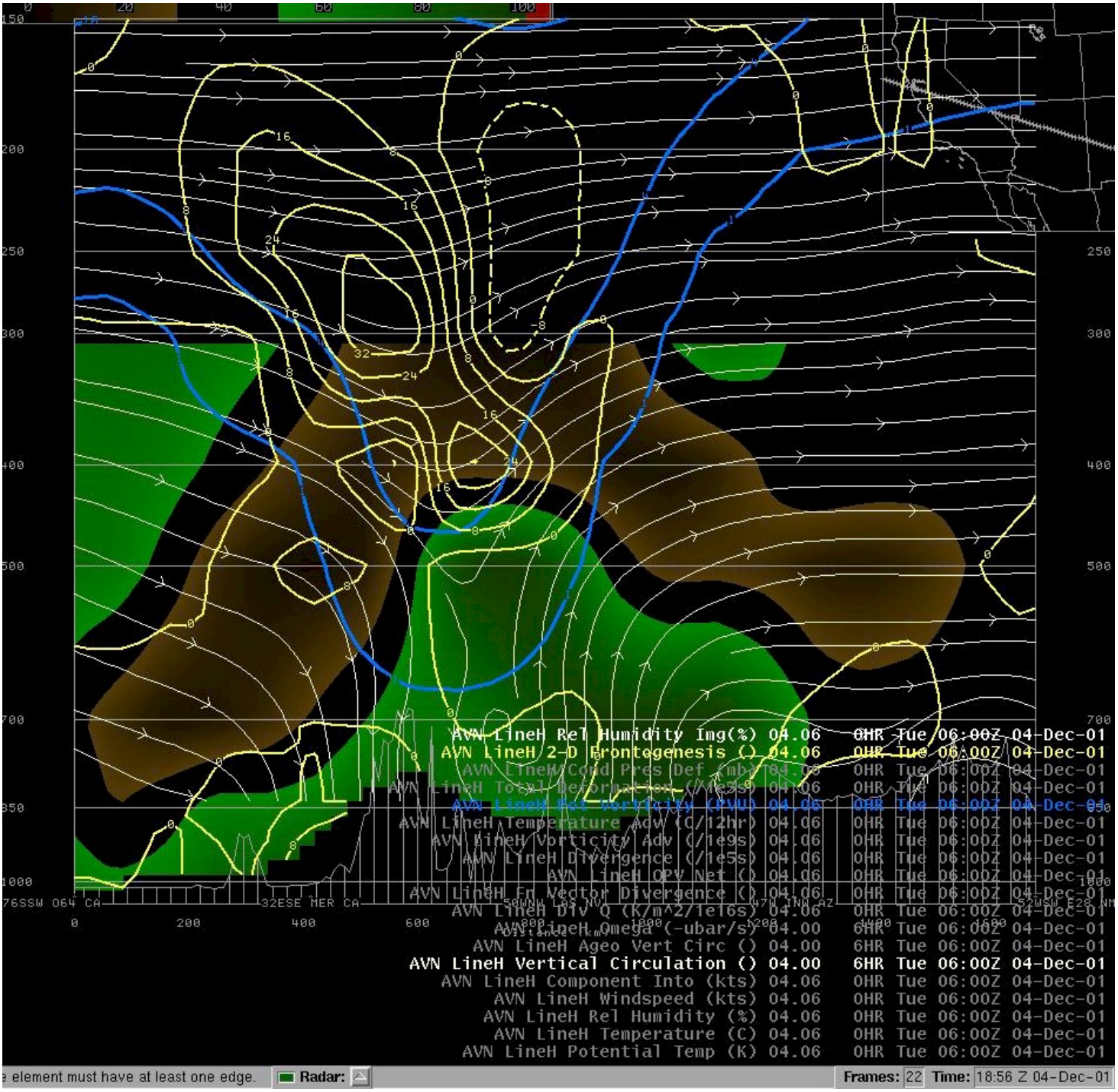


Figure 2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AVN LineH 2-D Frontogenesis () 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Cond Pres Def (mb) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Total Deformation (/1e5s) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Pot Vorticity (PVU) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Temperature Adv (C/12hr) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Vorticity Adv (/1e9s) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Divergence (/1e5s) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH OPV Net () 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Fn Vector Divergence () 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Div Q (K/m^2/1e16s) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Omega (-ubar/s) 04.00 6HR Tue 06:00Z 04-Dec-01
AVN LineH Ageo Vert Circ () 04.00 6HR Tue 06:00Z 04-Dec-01
AVN LineH Vertical Circulation () 04.00 6HR Tue 06:00Z 04-Dec-01
AVN LineH Component Into (kts) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Windspeed (kts) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Rel Humidity (%) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Temperature (C) 04.06 0HR Tue 06:00Z 04-Dec-01
AVN LineH Potential Temp (K) 04.06 0HR Tue 06:00Z 04-Dec-01
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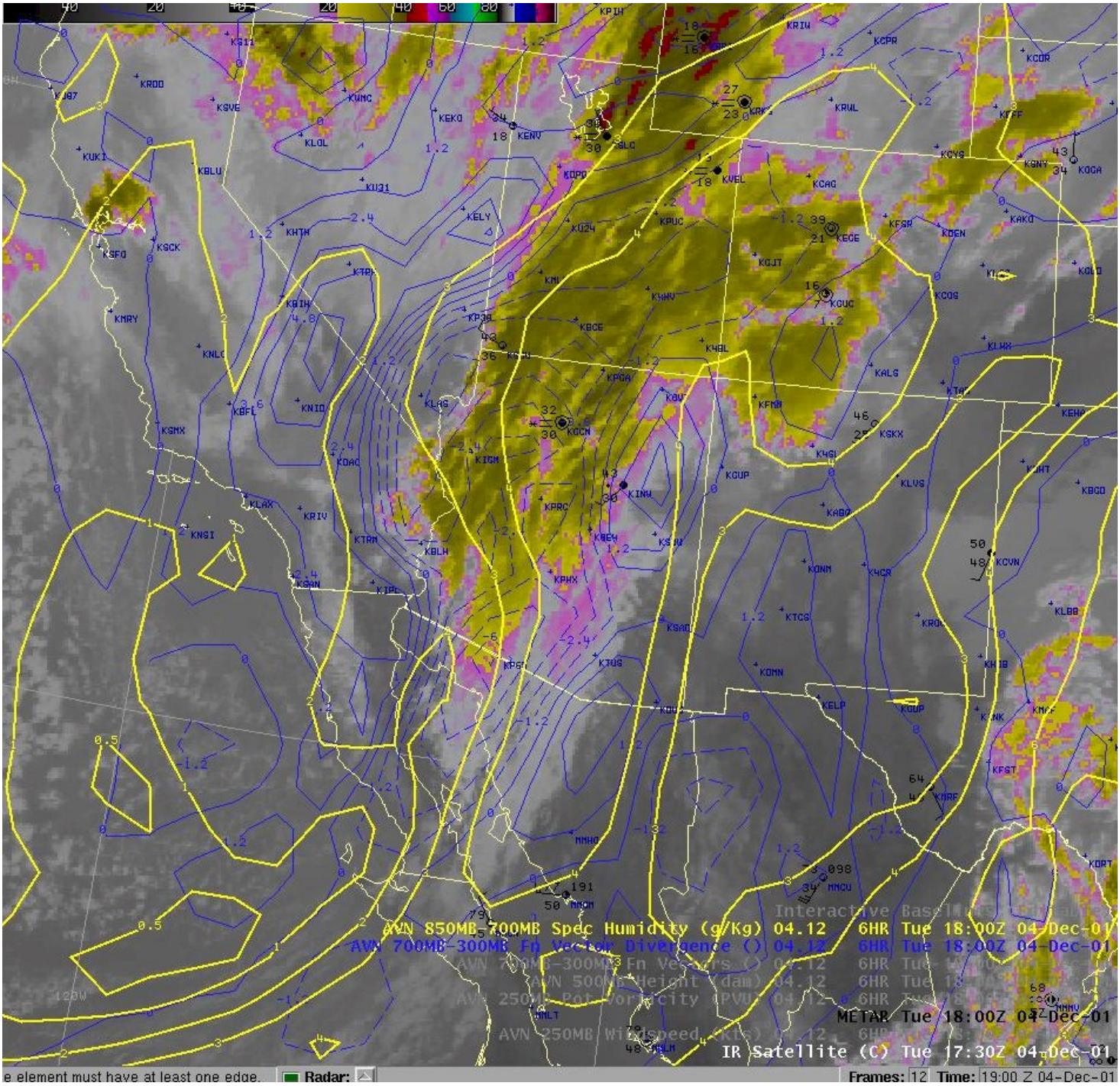
Frames: 22 Time: 18:56 Z 04-Dec-01

Figure 3


AVN 850MB-700MB Spec Humidity (g/Kg) 04.12 6HR Tue 18:00Z 04-Dec-01
AVN 700MB-300MB Fn Vector Divergence () 04.12 6HR Tue 18:00Z 04-Dec-01
METAR Tue 18:00Z 04-Dec-01
IR Satellite (C) Tue 17:30Z 04-Dec-01
Radar:
Frames: 12 Time: 19:00 Z 04-Dec-01