The Importance of Frontogenesis in Cool Season Precipitation Events

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INTRODUCTION

Frontogenesis refers to the change in the magnitude and orientation of the temperature gradient at a level or within a layer due to directional and speed changes in the wind field (e.g. convergence and divergence). Identification of frontogenetical regions is important, especially in the cool season, because these areas typically will have significant upward vertical motions and the potential for banded precipitation. The precipitation event of 28 October 2004 is used here to illustrate the importance of identifying frontogenesis during cool season events, as it appeared that frontogenesis may have played an important role in increasing precipitation rates and lowering snow levels faster than model solutions indicated, thereby leading to significant impact to the area.

DESCRIPTIVE PHYSICS

Frontogenesis refers to an intensification of a temperature gradient at a level or within a layer due to patterns in the wind field. When the temperature gradient strengthens, the geostrophic winds must respond to maintain thermal wind balance. Ageostrophic winds form as a result which create regions of convergence and divergence. This leads to a pattern of upward vertical motion on the warm side of the frontogenetic forcing, with downward vertical motion on the cool side of the frontogenetic forcing. To put it another way, a direct thermal secondary circulation develops that slopes with height toward the cold air, with warm air rising and cool air sinking, acting together to reduce the increasing temperature gradient. It is this ageostrophic circulation that we are most interested in for precipitation forecasting.

The smaller-scale direct thermal circulation forced by frontogenesis usually enhances the larger-scale circulation found in the entrance regions of jet streaks. This synergistic relationship can lead to a focused area of ascent as these two circulations combine over a region. This area of ascent can be significantly stronger than indicated in a numerical model, and can lead to a distinct band of heavier precipitation within a broader area of lighter precipitation.

As gravitational or symmetric stability decreases, the horizontal scale of the precipitation band has been found to decrease while the intensity of the precipitation band increases. Multiple bands of precipitation can become established in an unstable regime. These multiple bands can contain much more intense precipitation rates leading to much higher snow or rainfall amounts than the synoptic situation might suggest. Additionally, the enhanced vertical motion field can cause enhanced adiabatic cooling, which can lead to lower snow levels than numerical models may predict.

Frontogenesis can be assessed by qualitatively examining isotherms and winds, however frontogenetical forcing can be assessed more quantitatively by looking at Q vectors or F vectors. Q and F vectors are used to describe how the geostrophic (Q vectors) or real wind (F vectors) affect the isotherm patterns. It has been found that examining Qn or Fn vectors, i.e. the frontogenetical component, can be useful in identifying those areas where forcing on the frontal scale may lead to banded precipitation. Convergence of the Qn or Fn vectors is associated with forcing for ascent.

SYNOPTIC OVERVIEW

On 28 October 2004, an area of low pressure moved into the southwestern United States and an associated band of moisture was progressing eastward into western Arizona. The image below was from 0600 UTC illustrating the 500 mb height pattern along with 850-700 mb specific humidity values (Figure 1).

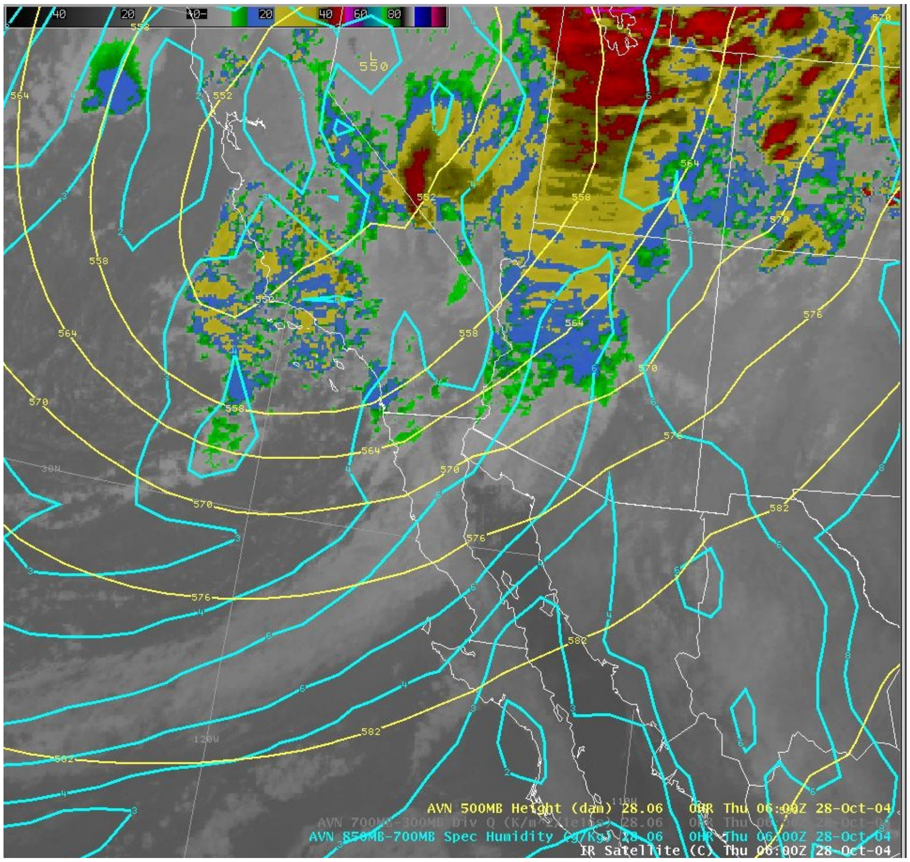

Figure 1: IR satellite imagery using cloud microphysics enhancements (shading), 500 mb heights (yellow), and 850-700 specific humidity values (cyan) for 0600 UTC 28 October 2004.

Examination of synoptic forcing for vertical motion indicated that the large scale ascent was not described completely by the Div-Q field. Although there was a large area of ascent indicated by the Div-Q field, only a weak area of Div-Q was co-located with the significant plume of clouds moving into the CWA. Figure 2 shows the 700-300 mb deep layer Div-Q field superimposed over the satellite imagery.

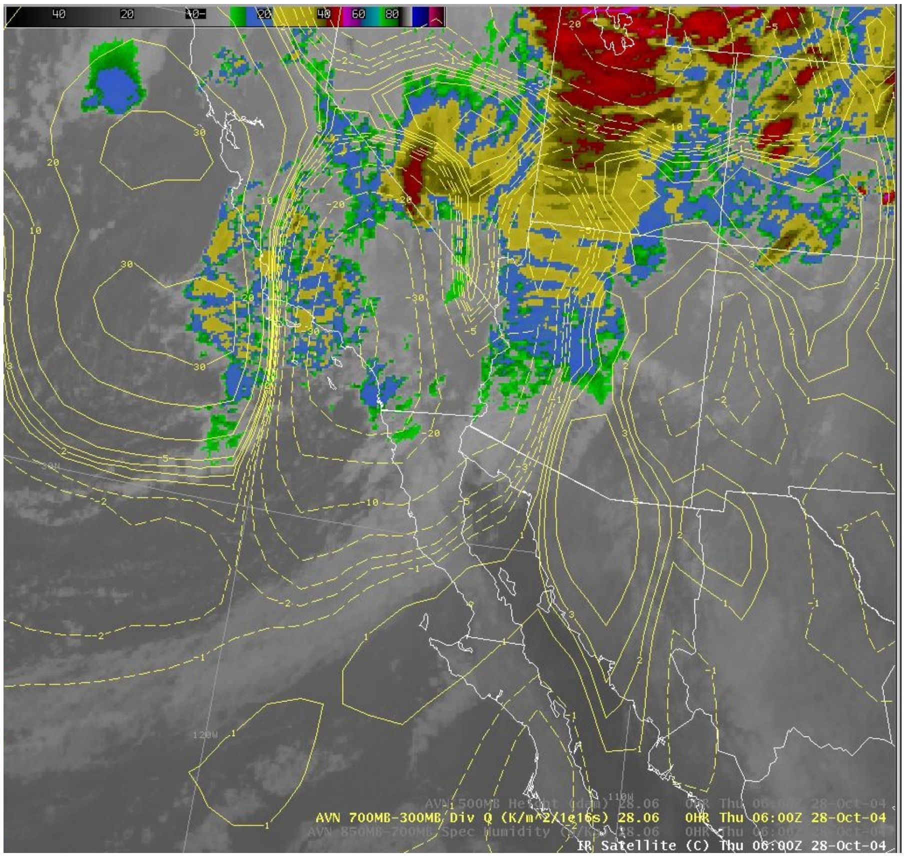

Figure 2: IR satellite imagery using cloud microphysics enhancement (shading), Div-Q (yellow) for 0600 UTC 28 October 2004.

Further examination identified a linear field of frontogenesis collocated with much of the primary moisture band. Figure 3 shows the 850 mb 2-D frontogenesis field (Pettersen Frontogenesis) at the same time.

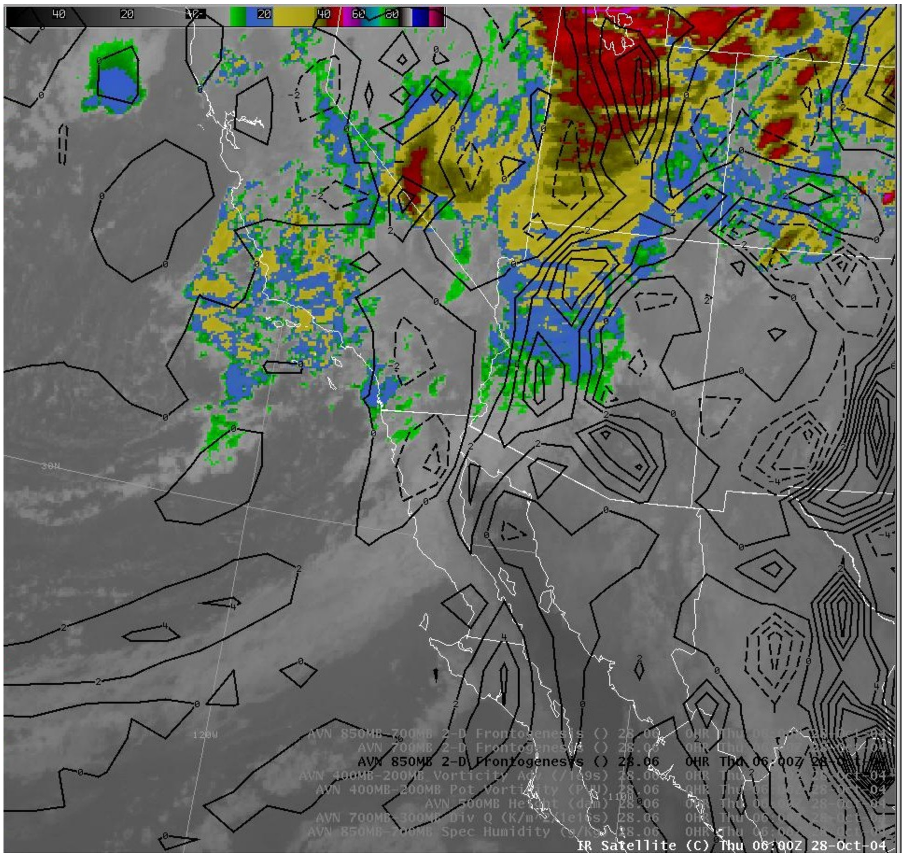

Figure 3: IR satellite imagery using cloud microphysics enhancement (shaded), 850 mb 2-D frontogenesis (black).

Based on the examination of the main features associated with the primary moisture band, it appeared that low-level frontogenesis was playing a role in the orientation and possibly the strength of the cloud band.

Examination of the radar data at this time showed that much of the band of precipitation was occurring under a weak area of forcing as shown by the Div-Q overlay. However, an area of possible banded precipitation could be seen ahead of this area over the higher terrain of northern Arizona along the Mogollon Rim (Figure 4).

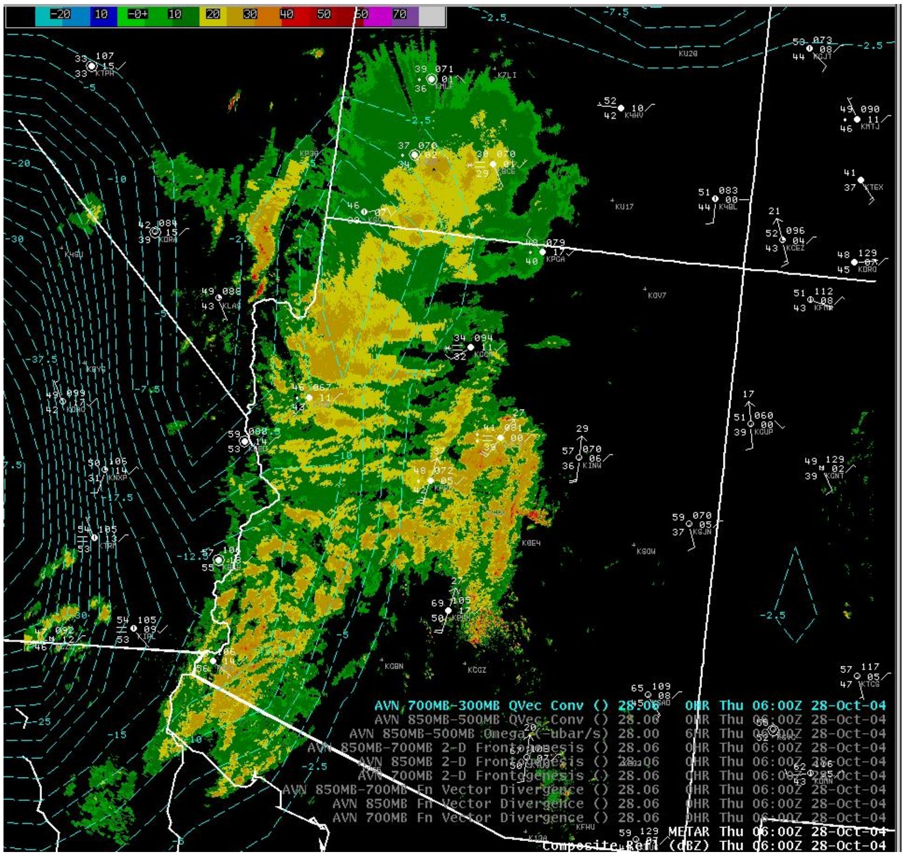

Figure 4: Radar imagery at 0600 UTC 28 October 2004, with METAR observations (white plots) and 700-300 mb Div-Q (cyan). Note the area of precipitation ahead of the weak area of Div-Q which appears to have a banded structure.

When frontogenesis was examined, this area of apparently banded precipitation lies within an area of Fn vector convergence (which highlights the location of the ascent portion of the frontogenetical forcing). In this case, the 850-700 mb Fn vector divergence field suggested that this precipitation may have been modulated by frontogenetical forcing (Figure 5).

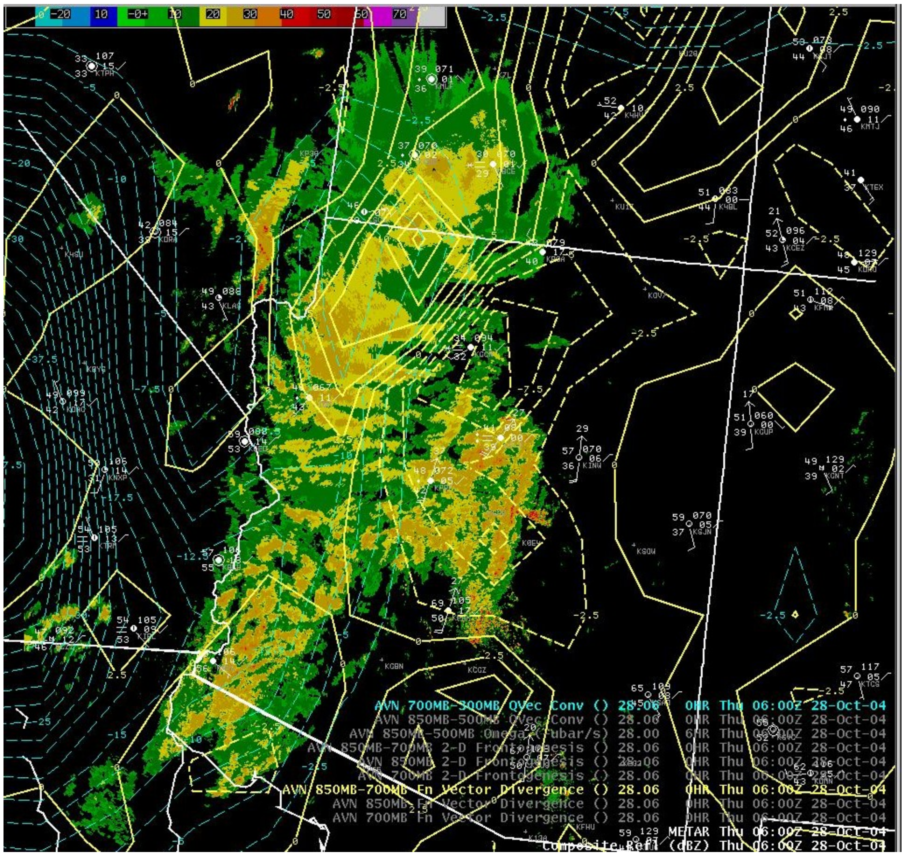

Figure 5: Radar imagery at 0600 UTC 28 October 2004, with METAR observations (white plots) and 850-700 mb Fn-divergence (yellow).

Further examination of parameters indicated that this frontogenetical forcing was occurring in an environment with 850-700 lapse rates greater than 7.5C/km, moderate orographic forcing with southwest winds of 30 kt at 700 mb, and a moist airmass that only required minimal lift to realize the instability. Thus, the potential for multiple bands of precipitation was likely in this situation.

Time height cross sections can be very useful for identifying the depth and strength of the frontogenesis regions along with assessing the stability of the airmass. Assessment of upper level charts indicated that there was a small jet streak co-located with the area of frontogenesis at this time, allowing for possible enhancement of both secondary circulation patterns (not shown). The time height cross section for Flagstaff for this event indicated that the area of low-level frontogenesis was co-located with a jet streak aloft in an environment with potential instability as shown in theta-e (Figure 6). Maximum model omega was forecast for 1200 UTC, however with the frontogenetical forcing ahead of this area of omega, it could be expected that stronger omega might occur earlier and be associated with banded precipitation. The strongest Div-Q forcing for ascent was not expected until after 1800 UTC.

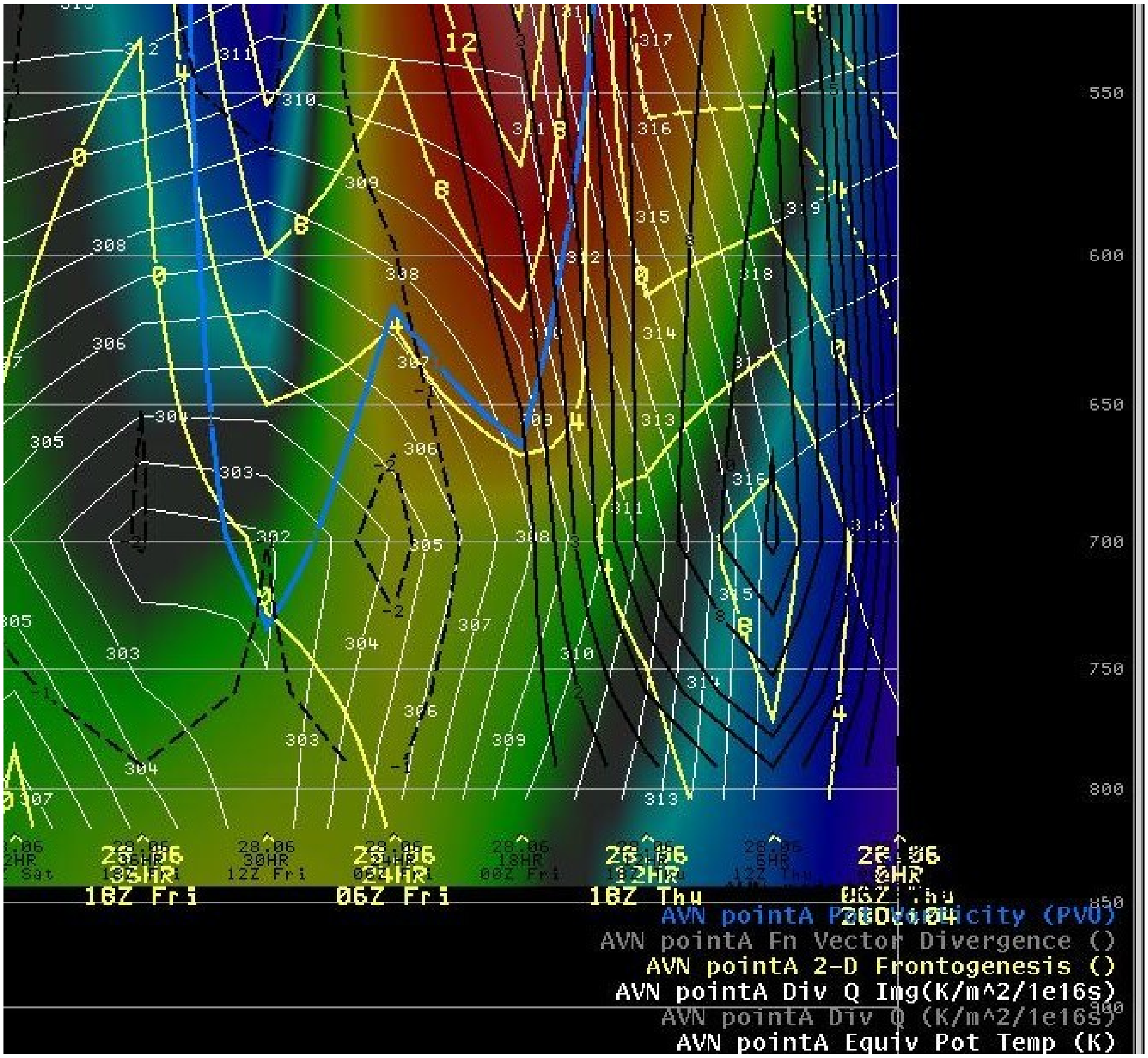

Figure 6: Time height cross section for Flagstaff Arizona from the 0600 UTC GFS model run. Shown in the image are Div-Q (shaded with red areas associated with convergence), theta-e (white lines), frontogenesis (yellow contours), omega (black contours), and potential vorticity (blue contours).

As the system approached Flagstaff, surface observations of rain at 34 degrees F transitioned to observations of light snow, increasing to moderate and at times heavy snow as the main axis of frontogenesis moved though the area around 1200 UTC. Model-predicted thickness and 700 mb temperatures indicated a snow level above Flagstaff for this time period; however it was likely that the enhanced vertical motion field acted to cool the airmass more than the large scale model predictions, leading to a lower snow level and accumulating snow ahead of the main area of large-scale synoptic forcing.

This area of moderate to heavy snowfall ahead of the main large-scale dynamics led to numerous traffic accidents around the area during morning commuting hours. Interstate 40 was closed for some time due to one of these accidents.

CONCLUSION

Frontogenesis refers to an intensification of a temperature gradient at a level or within a layer due to patterns in the wind field. Areas of frontogenesis typically lead to more intense precipitation rates due to enhanced secondary circulations that are not handled well by numerical models. This means that forecasters need to identify areas of frontogenesis to anticipate the potential for banded precipitation, along with the associated intense precipitation rates and accumulations, which will not be shown by numerical model solutions. The case of 28 October 2004 was used as an illustration of the importance of frontogenesis in the precipitation process.