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COOL SEASON MESOSCALE CONVECTIVE TRAINS

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[Editor's Note: In order to reduce printing costs, the figures are not included in the hard copy version. The entire Technical Attachment (with 20 figures) can be viewed on the home page at http://www.wrh.noaa.gov.]

Introduction

During the Sierra Cooperative Pilot Project (Reynolds and Dennis, 1988), a recurring radar precipitation echo type was observed as part of a sequence of radar echo types during passage of major winter cold fronts (Vardiman and Heggli, 1981). This echo type was called CT's (convective trains). It followed passage of strong cold fronts (ana fronts - Browning, 1985). The typical convective train echo was usually 10 to 25 km wide and 100 to 250 km long. They were observed to last from 2 to 4 hours and remained nearly stationary during this time. Individual reflectivity maxima moved along the long axis of these echo types, thus, the name "train echos". Their origins were usually in the Coast Range or Sacramento Valley and extended up into the Sierra Nevada foothills. These trains were usually observed at locations where major river drainages empty into the Sacramento Valley. Thus, it was hypothesized that local mesoscale convergence helped initiate these CT's. Research flights using the fully instrumented University of Wyoming King Air observed that in many instances cloud-top temperatures in the train echoes were warmer then -10C. A mixed phase (coalescence growth and ice phase) precipitation process dominated in these echo types. A very active Halley-Mistype (Halley and Mistype, 1974) ice multiplication process was often observed. Thus, these clouds were very efficient precipitation producers.

An important point to note is that these train echos usually follow major frontal passage and, thus, heavy widespread precipitation events. Soil moisture conditions are often near saturation and streams are usually running high prior to train development. The potential for flash flooding, or at least urban and small stream flooding, is very high where CT's are located.

It appears CT's develop under a well-defined set of atmospheric conditions. These conditions are very similar to those described by Emanuel (1983) for CAI (Conditional Symmetric Instability) induced banding of precipitation. These bands, if in fact induced by

CAI, are not classic in that the classic CAI bands occur pre-frontally many times near or ahead of the warm front within a cyclonic storm. Further investigation is needed to determine the exact forcing mechanism for these mesoscale phenomena. This Technical Attachment (TA) will provide examples of several of these events and describe the atmospheric conditions that are conducive to their development.

Satellite and Radar Observations of Convective Trains

Over the past three winter seasons, which were all above normal in precipitation and runoff, several incidences of CT's have been observed using both NOAA Polar Orbiting satellite imagery (AVHRR) as well as WSR-88D reflectivity data. It will be shown that there appears to be some preferred locations for development of these. One is in the upper Sacramento Valley near Lake Shasta and the second near Folsom Reservoir just east of Sacramento. However, as will be shown, CT's can develop anywhere.

10 January 1995

Figure 1 shows an AVHRR 1 km visible resolution image for 10 January 1995. The most significant of these CT's are annotated. The cloud line noted as near Roseville produced devastating flooding in the town of Roseville and was considered to be a 100-year flood event (Curtis and Humphrey, 1995). Upwards of 4 in of rain fell in 6 hours. Two to three hour rainfall amounts exceeded the 500-year rainfall event for the Dry Creek drainage basin. Figure 2 shows rainfall data from the Orangevale Alert gauge near Dry Creek. Note that over 1 in/hr rainrates was caused by this CT. This heavy rain followed 1-3 in of rain which fell about 2 hours earlier during the passage of a major cold front which produced major flooding over much of northern and central California (frontal clouds noted in Figure 1 to the southeast of the CT's). Figure 3 is the corresponding KMUX low-level reflectivity product corresponding to Figure 1. Moderate to heavy rain can be seen within the band extending back to the KMUX radar.

Figure 4 is rainfall data from the tipping bucket gauge at Lakeshore on the west side of Lake Shasta . This gauge is under the CT located near the top of Figure 1. Again, rain rates were moderate to heavy for a short period between 8 and 9 LST under this train. Note that another train echo developed in the afternoon over this same location. It is important to emphasize that it is the intensity of the rain and not the total rain amounts that are critical to the onset and magnitude of flooding.

01 May 1995

Figure 5 is an AVHRR 1 km resolution visible image from 1532 UTC 01 May 1995. The CT of interest was at the top of the image located just to the east of Lake Shasta. A plot of precipitation from a tipping bucket rain gauge located at Hillcrest, just to the northeast of Lake Shasta, is shown in Figure 6. Note there was over 1.5 in of rain in less than one hour. This is an excessive rain rate and certainly capable of producing flash flooding. No report of such phenomena was reported however.

12 December 1995

Following the major wind and rain storm of December 12 1995, a convective train developed in the south San Francisco Bay Area. Figure 7 is the low-level reflectivity product from the KMUX radar showing the well-developed train echo just south of San Francisco. The frontal boundary is south of Monterey. Spotter reports from the east bay hills reported rainfall rates in excess of .6 in/hr. It is useful to view the 80 km Eta model forecasted sounding for Oakland valid at this time, Figure 8. It is typical of the environment that is conducive to the development of CT's. Note the strong vertical speed shear indicative of a baroclinic environment, the near neutral stability, and near saturated conditions. These conditions match those discussed by Emanuel (1983), for development of CAI induced rain bands. A quick summary of the necessary conditions for CAI are

1) a cool season event,
2) near saturated conditions,
3) near neutral stability (but not conditionally unstable),
4) strong vertical speed shear, and
5) in an area of large-scale forcing.

The cases presented in this TA developed in an environment that met all of these conditions.

16 April 1996

This case is very similar to the 1 May 1995 case with the CT located in almost the exact location but less well developed. Figure 9 is the 1.1 km AVHRR visible image for 1515 UTC 1 May. The precipitation data from the Hillcrest gauge (Figure 10) shows maybe one-half inch of rain over an hour (between 7 and 8 am LST). This, however, is greater than the precipitation that fell during frontal passage. It should be mentioned that given the narrow horizontal extent of this band that the gauge may not represent the heaviest rainfall occurring under the band. Figure 11 is the hodograph from the 12 UTC Medford sounding, showing again strong vertical speed shear within the cloud layer. The temperature/moisture structure is, however, nearly conditionally unstable for this case (not shown).

12 December 1996

Figure 12 shows an AVHRR 1.1 km IR image for 1413 UTC 12 December, 1996. The CT is located from about Sacramento over Folsom Reservoir into the American River Basin. It is interesting to note that the cloud-top temperatures are slightly colder than -5 C. This is similar to the CT's studied over the American River Basin during the Sierra Project. Note that in the IR image, the lower warmer clouds extend off the California coast. This length provides sufficient growth time for coalescence to be very efficient leading to an efficient warm rain process. The corresponding composite radar reflectivity product is shown in Figure 13. Note that radar echoes are seen extending back to the coast indicating large drops have already grown to radar detectable size. The precipitation record from a tipping bucket ALERT gauge located just south of Folsom Dam (Figure 14) indicates very intense rain of about .4 inches in 15 minutes near 7 a.m. PDT.

03 June 1997

As shown in the previous examples, CT's are mesoscale in nature. Thus, it would take a high resolution mesoscale model to be able to resolve CT's and predict when and where they develop. The Naval Post-Graduate School is currently running the NCAR/Penn State MM5 mesoscale model at 36 and 12 km resolution with the inner nest centered over California. Theoretically, 12 km is not sufficient resolution to resolve CT's. However, the MM5 model run initiated from 1200 UTC on 3 June 1997, implies that a mesoscale band of precipitation will develop between 0000 and 0300 UTC over Lake Shasta as shown by the precipitation maxima in Figure 15 at the top of the image. Note in this image the position of the frontal rainband (Ana front or narrow cold front at the leading edge of cloud shield) to the south is forecasted quite well by the model. The precipitation data for Shasta Dam (Figure 16) shows the high rain rates between 1800 and 1900 LDT or 0100 to 0200 UTC 4 June. The 0000 UTC Medford sounding, (Figure 17) again is typical of the environment in which these CT's develop, that is, the strong speed shear, near neutral stability and a saturated low-level air mass. Although this particular CT is masked somewhat by higher clouds, it is still resolvable, especially in the AVHRR 1 km visible image as a north-south oriented cloud band parallel to the mean wind as shown in the Medford sounding (Figure 18). Low-level reflectivity data from the Beal radar was able to detect this CT. Figure 19 is the 0055 UTC .54 nmi resolution reflectivity scan showing the narrow CT located several miles southwest of Redding and extending up over Shasta Dam and Lake Shasta. Figure 20 shows the one hour rainfall estimates from the Beal radar indicating .75 to 1.25 in/hr rain rates occurred along this CT before the train began to drift slowly east. The cell table for these reflectivity scans indicated individual cells averaged about 10 km in height. The center of the .54 degree tilt over Redding at 75 nm range is 2500 m. Thus, even though the radar is sampling above cloud base, the rainfall estimates are in good agreement with the Shasta Dam rainfall.

Summary and Conclusions

Convective trains can be described as semi-stationary rainbands oriented along the cloud layer mean shear vector that can produce moderate to heavy rainfall over a one to three hour period. They tend to be about 10 to 25 km wide and can be from 100 to 250 km long.

They appear to be produced by 1) a combination of low-level convergence as they tend to be located near major river canyons aligned parallel to the in-cloud shear vector and 2) conditional symmetric instability. An apparent necessary factor, but not necessarily sufficient condition for their formation, is strong speed shear and near saturated conditions below 700 mb. This environment is most often produced following major winter cold fronts and, thus, CT's are normally confined to the cool season unless a strong frontal system like June 3 occurs. These characteristics are similar to what Emanuel has described for CAI rainband formation. It should be stated, however, that these CT's do not occur as embedded bands in the warm sector of a cyclone as is usually the case. Thus, further observations and research would be needed to confirm the actual forcing mechanisms.

As these mesoscale phenomena tend to form behind intense cold fronts (strong baroclinicity), the moderate to heavy rainfall produced (.5 to 1.5 in/hr) may fall on already saturated ground. In fact the rainfall rates from narrow cold frontal rainbands may meet or exceed the rain rates from CT's. Thus, the potential for flash flooding or at least urban and small stream flooding is quite high. Although the author has only observed CT's in California, it is likely they may form in the Pacific Northwest where similar terrain and atmospheric conditions exist during the cool season.

References

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