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# RELATING SNOWFALL PATTERNS OVER THE CENTRAL AND EASTERN US TO INFRARED IMAGERY OF EXTRATROPICAL CYCLONE COMMA HEADS

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## 1. Introduction

Despite recent advances in numerical weather prediction and in situ atmospheric observations, snowfall forecasting over the United States remains a difficult task. Weather forecast models often have flaws in the predicted track and intensity of cold-season extratopical cyclones, and important mesoscale features such as banded snowfall are poorly simulated. To compensate for these flaws, forecasters need to make use of other means of assessing the synoptic situation, such as conceptual models of extratropical cyclones, which can indicate possible areas of significant precipitation. It may be helpful for forecasters to first conceptualize broad synoptic-scale snowfall trends before moving on to individual forecasting techniques. This study uses geostationary infrared satellite imagery to find such broad trends in snowfall and classify cyclones based on a particular cloud-top temperature feature that was found in snowstorms over the central and eastern United States.

In an effort to relate snowfall patterns to observed infrared imagery from the GOES (Geostationary Operational Environmental Satellite) satellite, nearly 50 cases were found of well-defined snow swaths created by storms which featured an obvious comma head in infrared imagery. In classifying the systems, two broad categories emerged based on the continuity of the cyclone's cloud shield. While most cases featured the "textbook" example of a continuous cloud shield wrapping cyclonically around to the north of the surface low pressure center, several cases exemplified a discontinuity in the cloud shield. In these cases, the coldest cloud-tops of the comma head were visibly separated from the frontal zone by an area of warmer cloud tops (the frontal zone mentioned here refers to the area extending roughly along the cold front southward from the northern tip of the cyclone). These cases did not completely fit the cyclone categorization schemes provided in earlier publications (Evans et al., 1994). Additionally, it was discovered that the cases with "separated" comma heads featured a noticeably different snow swath than the "classic" comma-head cases. The separated comma-head cases had a more organized swath of heavier snow focused on the southern side of the comma head, whereas the snow swath of the classic cases tended to be more diffuse, spreading throughout the entire comma head with localized maxima.

The attempt to separate the cases into classic comma heads and separated comma heads based on cloud-top temperatures yielded yet another category: warm-separated comma heads. Some of the cases with discontinuous comma-head cloud shields featured comma heads with cloud-top temperatures which were notably warmer than their respective frontal zones. The snow swaths from these storms were similar to the standard separated comma-head cases in terms of shape and areal extent, although the measured snow totals were generally less. However, the differences in cloud-top structure and the probable thermodynamic differences were sufficient to merit the creation of a third cyclone category.

## 2. Methodology

### 2.1 Case Collection

The case search yielded about 50 cases of extratropical cyclones with snowfall observations of at least five inches for the period 1996 to the present. The cases were placed into three categories based on the cloud fields and snowfall swaths: classic comma heads, separated comma heads, and warm separated comma heads. Roughly ten of each type were discovered, narrowing the total number of cases to around 30. Further work in defining the cloud-top temperatures and spatial dimensions of each category resulted in eight cases for each of the three categories.

Classic cases were defined as having a frontal-zone length of at least 1000 km as seen in infrared satellite imagery, and a comma head extending upstream of the frontal zone at least 500 km. Cloud-top temperatures from the frontal zone through the comma head varied by no more than 15 K, meaning that the comma head appeared continuous in the satellite imagery. Separated cases were defined as having an area of cloud tops within the comma shield on the order of 30 K warmer than the surrounding frontal zone and comma head, thus making a visible separation between the two. This area of separation was at least 200 km wide, while the remaining comma head was at least 450 km long by 250 km wide with cloud-top temperatures within 15 K of the average temperatures of the frontal zone. The last category, warm-separated comma head, had no spatial requirements because the comma head tended to be smaller and more diffuse than the separated comma-head cases. The primary definition for the warm-separated cases was comma-head temperatures averaging at least 15 K warmer than frontal-zone temperatures. In contrast with the separated comma-head cases, the warm-separated cases did not exhibit the same distance of separation in the infrared imagery. Rather, the distance of separation (while still evident) was as little as 50 kilometers, and the cloud tops within the area of separation were about 20 K warmer than the

Table 2.1 – Summary of the characteristics of the three cyclone categorizations.

| | Classic | Separated | Warm Separated |
|---|---|---|---|
| Comma-Head Clouds | Continuous throughout the cloud shield extending from the frontal zone to the tip of the comma head | Distinct separation between the comma head and the frontal zone, clouds in comma head are nearly as cold as those of the frontal zone | Separation between the comma head and the frontal zone, clouds in comma head are warmer than those of the frontal zone |
| Snow Swath | Broad with local maxima | Narrow structure extending ~100 km south of the coldest cloud tops | Narrow structure extending just south of the coldest cloud tops |

colder regions of the comma head. Table 2.1 provides a summary of the distinctions for each category in terms of the clouds of the comma head, as well as the resulting snow swaths.

### 2.2 NARR Composite

Before compositing, the NARR (North American Regional Reanalysis) data of 32x32 km was first remapped within MATLAB onto a $0.25^{o}$ x $0.25^{o}$ equirectangular projection grid using triangle-based linear interpolation. This projection allowed for a more straight forward compositing algorithm. After interpolation, noise was reduced by applying a rotationally symmetric Gaussian lowpass filter.

Three model times for each case were utilized in making the composites. The first hour was selected as the hour in which the storm first met the criteria for the desired cyclone category. For the classic cases, this was the hour in which the comma head first began to extend cyclonically around the low, or the hour in which the trailing frontal zone first formed a continuous cloud shield extending the requisite 1000 km to the south of the low. For the separated and warm separated cases, the first hour was the time at which the comma head separated from the main frontal zone or cooled to temperatures within the requisite threshold. The last hour for the classic cases was defined as either the hour the storm evolved to a structure which no longer met the spatial requirements of the classic cyclone definition, or more commonly, the hour wherein the storm moved outside of the area of data coverage. The last hour for the separated and warm separated cases was the time at which the comma head began to warm and dissipate, or the time at which the distance of separation between the comma head and frontal zone began to decrease. For all cyclone categories, the middle hour was then defined as the hour between the first and last hours. Since the NARR data is only available every three hours, this methodology required the first and last hours to be selected in such a way as to allow a center hour at a midpoint between the two.

After the compositing timeframe was determined for all cyclone categories, the composites were calculated at the desired compositing hour by constructing grid boxes of a predefined size around the point of minimum mean sea-level pressure (MSLP) for all cases within a category and averaging the desired NARR field within those boxes. The composite could then move with the storm since the composites were always centered on the surface low (the minimum MSLP grid-point) as the storm progressed. The grid box utilized was 109x109 grid points, which translates to 27.25 degrees length and width, an area that encompasses the entire eastern United States as well as a portion of Canada and the Gulf of Mexico. A representative map was added to the background of plots to give a sense of scale.

## 3. Results and Conclusions

### 3.1 Causes of the Separated Comma Head

The most definitive thermodynamic signature associated with the three cyclone categorizations is the position of the upper-level jet, as shown in Fig. 3.1. For the classic cases, a dual-jet configuration is present, wherein one jet resides on the northern fringes of the cyclone upstream of the low and another weaker jet wraps cyclonically around the low on the cold-air side of the frontal zone. For the separated cases, the southern jet is much further upstream and does not wrap cyclonically, while the warm separated jets are between the two extremes. The ageostrophic circulation which is associated with these jet positions matches up very well with the location of the observed clouds in infrared satellite imagery. For the classic cases, the left exit of the southern jet and the right entrance of the northern jet are aligned such that enhanced rising motion will be present between the two, as documented by Uccellini and Kocin (1987). For the separated cases and warm separated cases, the left exit and thus the rising branch of the ageostrophic circulation of the southern jet is co-located with the colder cloud tops of the separated comma head, while the right entrance of the northern jet is positioned along the northern extent of the clouds of the frontal zone. For the warm-separated cases, the ageostrophic circulations of the two jets are still too far apart to enhance each other, although their closer proximity places the cloud head closer to the frontal zone than the separated cases. Therefore, the lack of enhanced rising motion from the reinforcing circulations of the double-jet structure is at least partially responsible for the warmer clouds separating the comma head and frontal zone within the separated and warm separated cases.

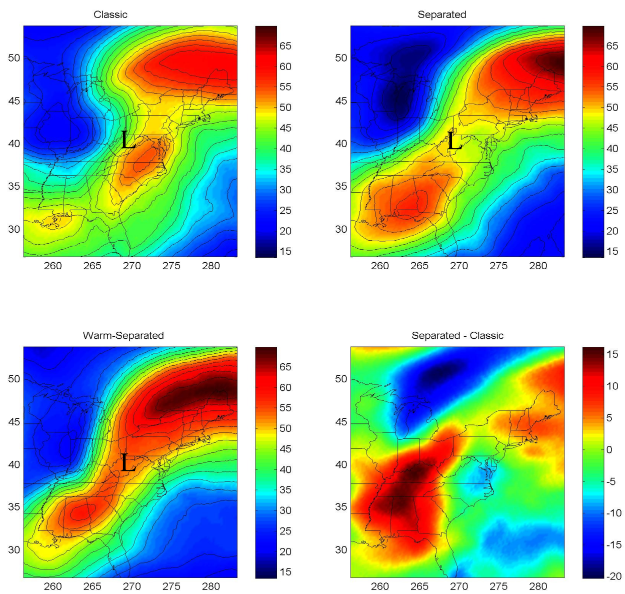


Fig. 3.1 – Composites of the upper-level jets (250 hPa wind speeds in $ms^{-1}$). The position of the surface low is indicated as an "L" in the composites.

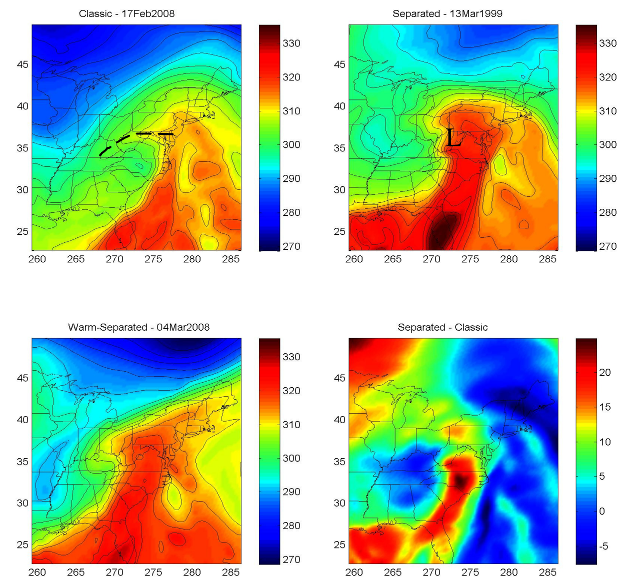


Fig. 3.2 – Equivalent potential temperature (K) at 750 hPa for select cases representing the three cyclone categories. The dashed line for the classic case represents the trowal location.

Another persistent thermodynamic signature was the appearance or absence of a trowal (**tro**ugh of **w**arm air **al**oft), as shown in Fig. 3.2. As noted by Martin (1998), the trowal airstream rises quickly as it turns cyclonically around the surface low and is associated with clouds and precipitation northwest of the low. It is therefore reasonable that the absence of this airstream could lead to a discontinuity in the cloud and precipitation fields as is seen in the separated and warm separated cases. Indeed, the separated cases which exhibit the greatest spatial discontinuity also completely lack the trowal feature, while the warm separated cases which have a lesser discontinuity feature a weak but developing trowal. Thus, the absence of the rising motion of the trowal airstream is probably also related to the observed lack of continuous cold clouds within the separated and warm-separated cases.

### 3.2 Snow Swaths

As shown in Fig. 3.3, the snow swath of the representative classic case is fairly broad to the north and west of the dry slot. Most of the snow is confined to the southern side of the comma head, although no snow is observed south of the coldest cloud tops. In contrast, the representative separated case shows snow contours extending southeast of the coldest cloud tops, which is in agreement with the findings of Johnston (1995). Fig. 3.3 also shows the snow swath positioned slightly south of the coldest cloud tops for the separated case. In agreement with the snow-swath composite (not shown), the snow swath in the classic cases extended over a longer area than the separated case, with the warm separated being in-between the two. In addition, the snow swath of the classic case has several maxima unevenly distributed throughout. In contrast, the swath of the separated case is smoother and narrower, while the warm separated is between the two extremes.

### 3.3 Forecasting Implications

From an operational weather forecasting perspective, this research is useful in two ways: knowledge of cyclone classifications can give insights into future storm evolution, and links between cyclone categories and resulting snow swaths can assist forecasters in snowfall nowcasting.

Analysis of the infrared satellite imagery loops for the eight cases of the three categories shows consistent trends that are intrinsic to each group. The evolution of the classic cases in this study aligns very well with the classifications of previous work (Evans et al., 1994). For the separated cases, the separated comma head reconnected with the frontal zone as seen in infrared imagery for six of the eight cases. For the cases in which the separated comma head reconnected, the average duration of separation was eight hours. Four of the cases featured cyclogenesis as the features merged, and the remaining four either showed steady MSLP or cyclolysis. More significantly, the separated comma heads for seven of the eight of the warm-separated cases eventually merged with the frontal zone, and six of the eight exhibited a pressure fall within the surface low after the merger. Two of those cases exhibited a substantial surface pressure decrease of 15 mb in 24 hours or less. Averaging the pressure falls for all the cases showed an average decrease of 7 mb in 12 hours, a notable deepening of the low. Therefore, if a forecaster discovers a storm exhibiting the likeness of a warm separated cyclone, it can be assumed that the cyclone will likely deepen with the next 12 hours, which can then be supported by forecast model data.

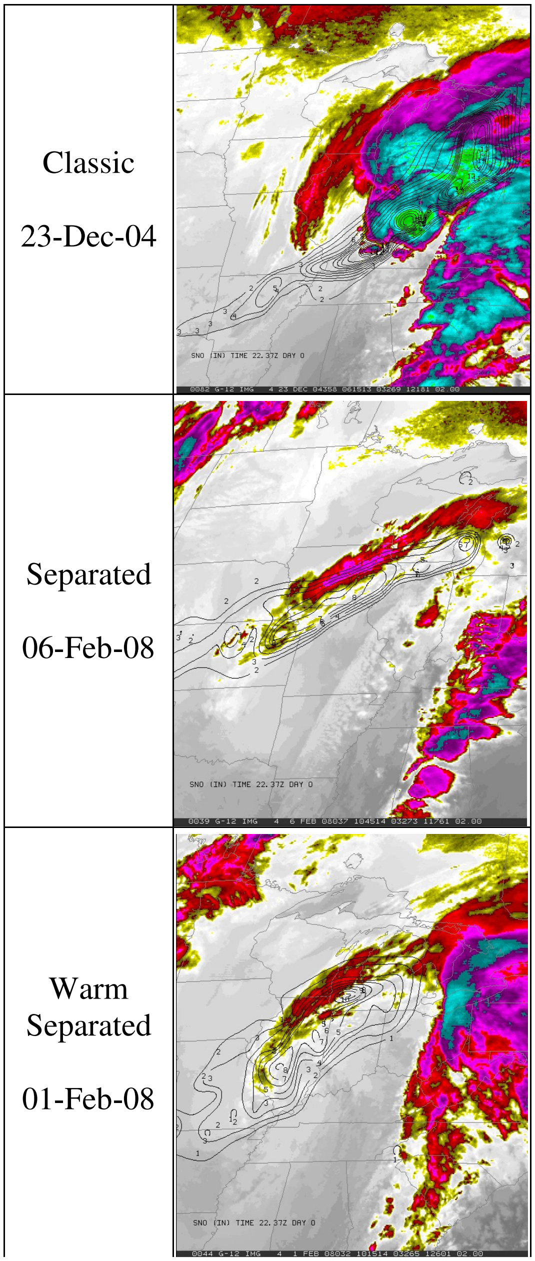


Fig. 3.3 – Contours of snowfall (inches) plotted on infrared satellite imagery for cases representing the three categories

The other forecasting implication of this study is snowfall forecasting. The appearance of a classic cyclone implies that there will be broad swath of snow with several maxima within the cloud shield of the comma head, while the observation of a warm separated or separated cyclone implies a more even distribution throughout an organized snow band. Secondly, if the cyclone is a warm separated case or particularly if it is a separated case, the heaviest snow would be expected just to the south of the coldest cloud tops of the comma head; conversely, if it is a classic case, the snowfall would be concentrated towards the southern side of the comma head, but extended more throughout and not extending southward of the coldest clouds.

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**References**

Evans, M. S., D. Keyser, L. F. Bosart, and G. Lackmann, 1994: A satellite-derived classification scheme for rapid maritime cyclogenesis. *Mon. Wea. Rev.,* **122,** 1382–1416.

Johnston, E.C., 1995: Updated satellite technique to forecast heavy snow. *Wea. Forecasting*, **10**, 1995, 219-228.

Martin, J. E., 1998: The structure and evolution of a continental winter cyclone. Part I: Frontal structure and the occlusion process. *Mon. Wea. Rev.,* **126,** 303–328.

Uccellini, L.W., and Kocin, P.J., 1987: The interaction of jet streak circulations during heavy snow events along the east coast of the United States. *Wea. Forecasting*, **2**, 289-308.

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