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# A SATELLITE PERSPECTIVE OF THE PROPAGATION CHARACTERISTICS OF A MESOSCALE CONVECTIVE SYSTEM OVER NORTHWEST ALALBAMA AND NORTHEAST MISSISSIPPI

Jay W. Hanna
NOAA/NESDIS Satellite Services Division, Camp Springs, Maryland

## 1. INTRODUCTION

During the evening and nighttime hours of 14-15 July 2004, individual thunderstorms congealed into a mesoscale convective system (MCS) over central and southern Tennessee. A portion of the MCS moved rapidly southeastward into east central Alabama and northern Georgia before dissipating as it moved into an environment of higher static stability. In contrast, the upwind portion of the MCS experienced convective redevelopment that in turn resulted in a backward propagation vector that nearly opposed the advection vector for a time and resulted in a quasistationary convective complex over northeast Mississippi and northwest Alabama. The backward propagation vector eventually overwhelmed the advection vector and allowed the MCS to backbuild into north central Mississippi and southern Tennessee, before the system began to weaken by 0600 UTC 15 July 2004.

Figure 1 shows the precipitation analysis over the region ending at 1200 UTC 15 July 2004. The precipitation analysis is composed from Automated Surface Observing Systems (ASOS) locations, Cooperative Observers, while supplemented by WSR-88D rainfall estimates. Maximum rainfall reports generally ranged from between 2-4" with those amounts occurring from Tippah county in northeast Mississippi to Jackson county in northeast Alabama. Although the rainfall associated with the MCS was not historic, the case is an interesting one nonetheless, due to the upwind and downwind components of the MCS experiencing different directions of movement and rates of motion.

Previous studies (see e.g., Maddox, et. al. 1979, Jiang and Scofield 1987, Juying and Scofield 1989, Corfidi, et. al. 1996, Corfidi 1998, Corfidi 2003) have shown skill in predicting the preferential areas for MCS propagation based upon the collocation of low-level mass convergence with the surface based instability field in relation to the initial convection. This theory will be tested and augmented by using Geostationary Operational Environmental Satellite (GOES) Imager data, GOES Derived Product Imagery (DPI), upper air and surface observations to examine the MCS and it's environment during 14-15 July 2004 over the lower Tennessee Valley.

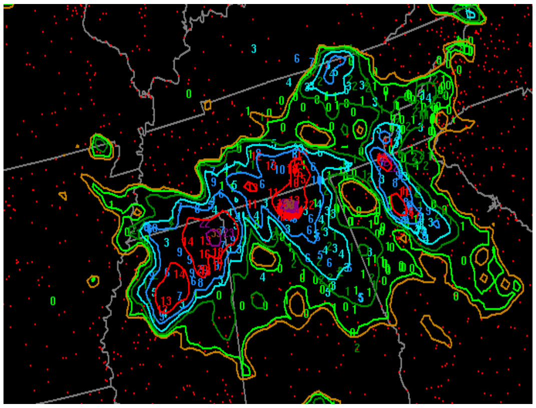

Fig. 1. Precipitation Analysis for the 24 hour period ending July 15, 2004

## 2. MCS MOVEMENT – PREVIOUS STUDIES

Overall movement of MCS's has long been known to be best represented as the sum of two vectors, the advection vector and the propagation vector (Newton and Katz 1958; Newton and Newton 1959; Chappel 1986; Jiang and Scofield 1987). The advection vector represents the advection of individual cells composing the MCS, which is largely controlled by the direction and magnitude of the cloud bearing winds. Meanwhile, the propagation vector represents the location and rate of new cell development on the periphery of the MCS, which is largely controlled by the direction and magnitude of boundary/cold pool relative flow and the distribution of static stability (Corfidi 2003). Propagation can thus speed up the overall MCS motion or it can slow down the overall MCS motion depending on whether the propagation occurs on the downwind edge or upwind edge of the system (Chappel 1986). Forward propagating MCS's are favored when boundary relative low-level mass convergence are collocated with a minimum in static stability on the downwind flank of the MCS. Backward propagating MCS's are favored when boundary relative low-level mass convergence

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*Corresponding author address*: Jay W. Hanna, Satellite Services Division, E/SP23, Camp Springs MD 20746; e-mail: Jay.Hanna@noaa.gov

are collocated with a minimum in static stability on the upwind flank of the MCS.

Numerous studies (Shi and Scofield 1987, Juying and Scofield 1989, Corfidi, et. al. 1996) have been conducted to aid in the short term prediction of the propagation characteristics and resultant movement of the meso-beta element (MBE) embedded in the MCS. Shi and Scofield (1987) and Juying and Scofield (1989) looked at the satellite characteristics of both forward and backward propagating MCS's and they found that forward propagating MCS's were favored when a synoptic or mesoscale boundary was evident on satellite imagery in the downwind portion of the MCS while the maximum 850hPa flow was maintaining unstable air to the leading edge of the MCS. In contrast, they found that backward propagating MCS's were favored when a synoptic or mesoscale boundary was evident on satellite imagery in the upwind portion of the MCS while the maximum 850hPa flow was maintaining unstable air to the back edge of the MCS. What is similar to the studies by Shi and Scofield and Juying and Scofield, is that both studies used the 850hPa wind and/or boundary evident on satellite imagery to approximate low-level mass convergence and a relative minima in static stability. Similar to Shi and Scofield and Juying and Scofield, Corfidi et al. (1996), using Bonner's (1968) criteria to define the low level jet (LLJ), uses the LLJ to approximate low-level mass convergence. In fact, Corfidi et al., have shown a reasonably good correlation using the negative (magnitude and direction) of the LLJ to approximate the propagation vector. This combined with the advection vector, represented by the 850-300hPa mean wind, has resulted in a simple vector technique which has been quite successful forecasting the resultant movement of MCS's.

Corfidi (1998) has also shown some success in distinguishing the predominant mode of propagation in MCS's by the thermodynamic potential to produce cold downdrafts. Specifically, dry air in the mid-troposphere and/or sub cloud is favored to produce a stronger and faster moving cold pool with the best boundary relative convergence and hence new cell development favored along the downwind edge of the MCS. Alternatively, when the mid troposphere and/or sub cloud layer is moist, a weaker and slower moving cold pool is expected, and thus a slower moving MCS. But recent work has determined the correlation between strong cold pools and forward propagating MCS's is not as robust as originally believed (Corfidi 2003). Corfidi (2003) notes that cases where strong cold pools can still lead to backward propagating MCS's are best illustrated in systems which exhibit both a forward and backward propagating component. These types of systems are kinematically supported by unidirectional flow and low cloud-layer shear (Chappel 1986). What appears to determine the preferential areas for cell propagation is the orientation of the gust front in relation to the mean cloud bearing winds (Corfidi 2003). By using vertical momentum transfer, Corfidi (2003) was able to illustrate that a cold pool evolving in a unidirectional wind profile should elongate in the direction where the profile is normal to the cold pool. It follows that the portion of the outflow boundary normal to the mean cloud bearing winds will be progressive while the portion of the outflow boundary parallel to the mean cloud bearing winds will be nearly stationary. Assuming the best boundary relative mass convergence is collocated with a suitable thermodynamic environment along the stationary outflow boundary, the environment is then conducive for cell redevelopment on the upwind edge of system and thus a propagation vector to oppose the advection vector of the overall MCS motion.

## 3. JULY 14 – SYNOPTIC OVERVIEW

The National Center for Environmental Prediction (NCEP) surface analysis from 18 UTC July 14, 2004 (Fig. 2) showed a low pressure centered over Lake Ontario, while a cold front extended from the surface low southwest through central Kentucky and then along the Missouri and Arkansas common border. In the mid and upper levels of the troposphere, water vapor imagery at 1815 UTC July 14, 2004, showed a seasonably amplified pattern over the United States, with a strong trough centered over the eastern United States while a strong mid level ridge was centered near the Red River of Oklahoma/Texas (Fig. 3). Between these, a broadly diffluent flow existed over the Tennessee and lower Mississippi Valleys while cirrus filaments from northeastern Missouri through central Kentucky and into northern Tennessee indicated the

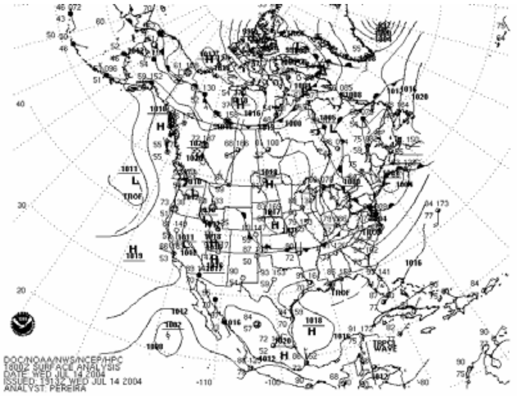

Fig. 2. NCEP/HPC Surface analysis valid 1800 UTC, 14 July 2004.

existence of an approaching mid and upper level jet streak. GOES-12 High Density satellite derived winds at 18 UTC July 14, 2004, confirmed the existence of this jet streak as 90-110 knot 100-399hPa winds were noted from western Illinois into the Tennessee Valley (not shown). The 18 UTC July 14, 2004, NCEP ETA numerical model initialization (not shown) indicated an area of upper level divergence on the nose and in the left exit region of the 90-100 knot jet streak at 300hPa which was overspreading the surface frontal boundary. Another interesting aspect of (Fig. 3) is the amount of mid level dry air evident over the Tennessee Valley. The most representative sounding on a temporal and spatial scale for the event was at Shelby County airport in Alabama at 00 UTC July 15 (Fig. 4), where the sounding verified the dry mid levels seen in water vapor imagery while also exhibiting a nearly unidirectional wind profile with little cloud layer shear.

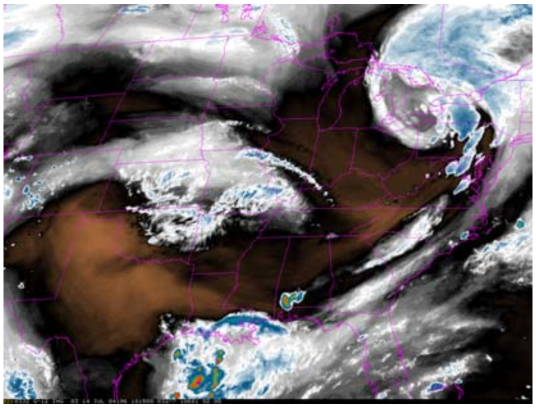

Fig. 3. GOES-12 Water Vapor imagery at 1815 UTC, 14 July 2004.

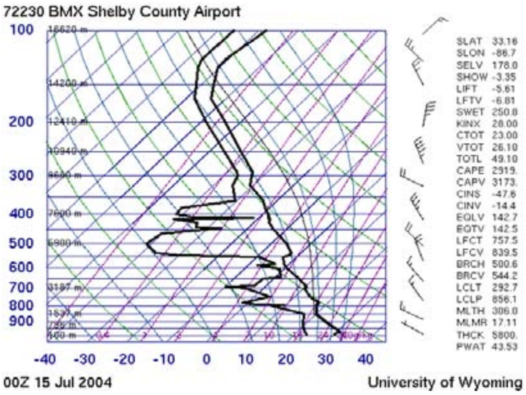

Fig. 4. Skew T-log P plot of radiosonde observations for Shelby County airport (near Birmingham) at 0000 UTC 15 July 2004.

## 4. JULY 14 – MESOSCALE OVERVIEW AND MCS EVOLUTION

Objectively analyzed surface moisture flux convergence, a parameter commonly associated as a precursor to convection (Doswell 1982), showed a 6 x $10^{-4}$ g kg $^{-1}$ s $^{-1}$ maximum (not shown) centered just south of Nashville at 18 UTC July 14. By approximately 1845 UTC visible and infrared imagery (Fig. 5a and 5b) began to show numerous individual convective cells developing in response to the low level moisture convergence along the synoptic frontal boundary and also aided by the vertical motion and resultant destabilization caused by the ageostrophic circulation in the exit region of the upper level jet streak approaching the area.

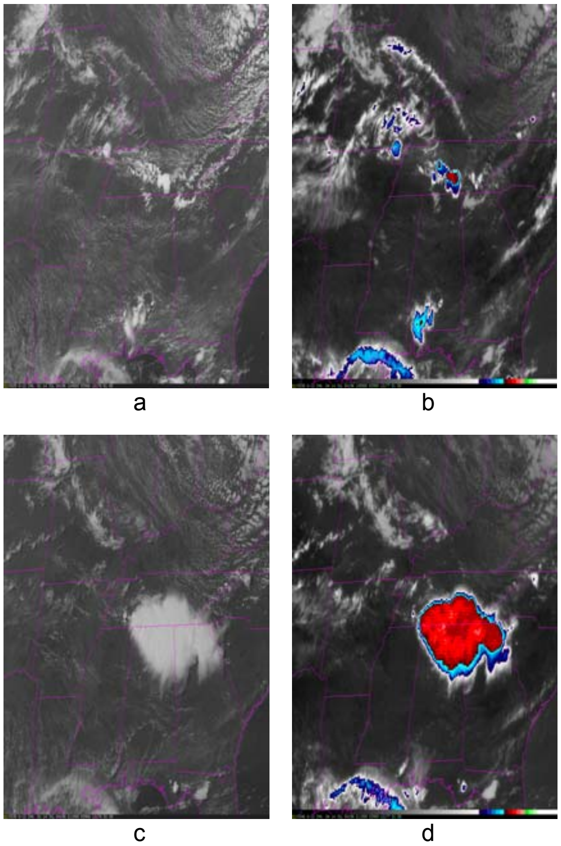

Fig. 5. GOES-12 Visible and Enhanced infrared imagery at (a) and (b) 1845 UTC 14 July 2004 and (c) and (d) 2115 UTC 14 July 2004

Infrared and visible satellite imagery at 2115 UTC (Fig. 5c and 5d) showed that the individual convective cells anvil shield had consolidated into a large MCS. Surface mesoanalysis at the same time (Fig. 6a) was beginning to show the development of a surface cold pool centered over the northern third of Alabama which is consistent with the amount of dry air in the mid troposphere observed on water vapor imagery and the Shelby County airport RAOB (Figs. 3-4). Fig. 4 also shows that the tendency for the cold pool over time should be for it to elongate towards the southeast due to vertical momentum transfer from the nearly unidirectional cloud bearing wind profile (Corfidi 2003). Boundary relative convergence focusing along the progressive portion of the outflow boundary would be expected to maintain a southeastward moving (forward propagating) component to this portion of the MCS. Increasing static stability further to the southeast, as evidenced by GOES DPI Most Unstable Convective Available Potential Energy (MUCAPE) over the lowest 100mb of less than 1000 J/kg over east central Alabama and central Georgia (Fig. 7a), suggests that an eventual weakening trend should be expected as the system continued southeast. Development of towering cumulus and cumulonimbus clouds on the western edge of the convective wedge type feature of the MCS (Fig. 5c and 5d) was evidence to the mesoscale boundary and associated low-level mass convergence located upwind of the developing MCS. The GOES DPI products (Figs. 7a-d) showed that ideal thermodynamic conditions were in place along the upwind mesoscale boundary as MUCAPE's were over 4000 J/kg, best lifted indices (LI) of nearly -10ºC, total precipitable water of 2.0" and little remaining cap with convective inhibition (CINH) below 30 J/kg. Given the low level mass convergence and thermodynamic conditions in place upstream of the initial MCS, it would be expected for convection to redevelop along this boundary and in turn induce a propagation vector that would oppose the advection vector.

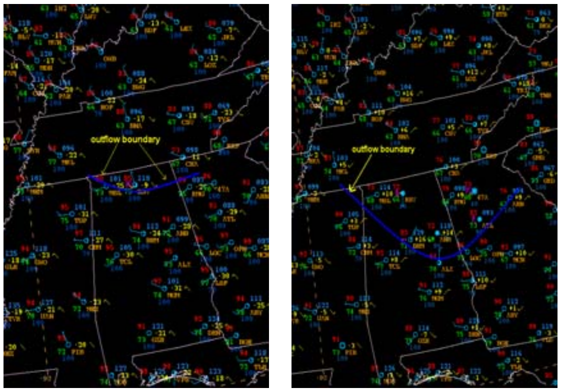

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Fig. 6. Surface analysis of outflow boundary at (a) 2100 UTC 14 July 2004 and (b) and (d) 0000 UTC 15 July 2004

By 00 UTC 15 July 2004, surface mesoscale analysis (Fig. 6b) showed that the surface cold pool had strengthened significantly and was centered north of Birmingham, AL. The leading edge of the cold pool had elongated to the southeast very similarly to what was predicted by the vertical momentum transfer theory. The associated outflow boundary extended from near Athens, GA to Alexander City, AL and then northwest through northeast Mississippi to where it intersected the synoptic boundary just northeast of Memphis, TN. Comparing Figs. 6a and 6b, it is evident that the western portion of the outflow boundary experienced very little movement, especially near Muscle Shoals, AL, as Fig. 4 shows this portion of the boundary was aligned nearly parallel to the nearly unidirectional northwesterly profile. The stationary portion of the outflow boundary provided the focus for the most active convective cores to train along from Hardeman county in Tennessee southeast to Colbert county in northwest Alabama. Compare Fig. 5d to Fig. 8b and note how the upwind portion of the MCS has moved very little during the three hour time period between 2100 UTC 14 July and 0000 UTC 15 July 2004. During this time period convective redevelopment (propagation vector opposing advection vector) on the upwind side of the system was rapid enough that very little movement was noted on the upwind edge of the system. On the contrary, the forward propagating feature weakened dramatically, as the system moved into the area of greater static stability over east central Alabama and central Georgia, as evidenced by the cloud top warming since 2100 UTC 14 July 2004 (Fig. 8b).

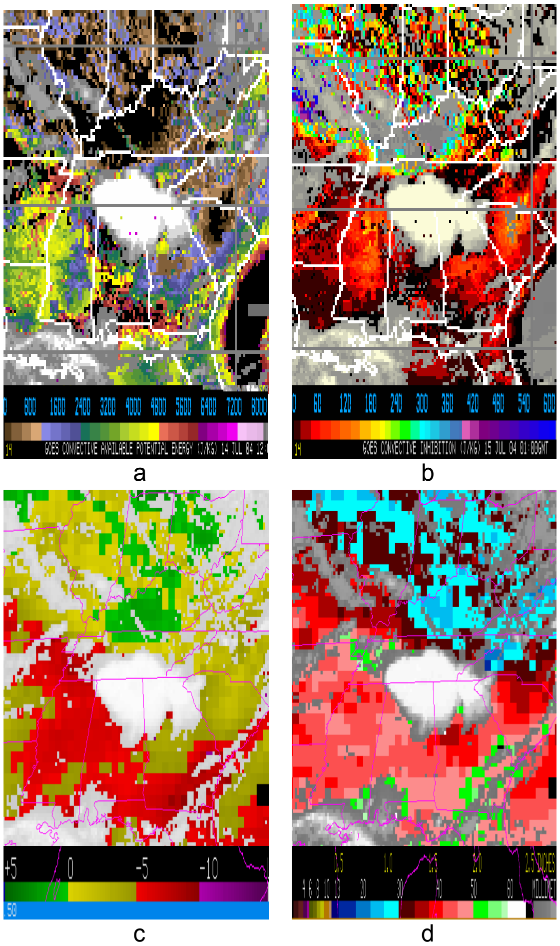

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Fig. 7. GOES DPI products at approximately 2100 UTC 14 July 2004 (a) Most Unstable Convective Available Potential Energy over the lowest 100mb (MUCAPE) product; (b) Convective Inhibition (CINH) product; (c) Best Lifted Indices (LI) over the lowest 100mb; (d) Total Precipitable Water

GOES infrared imagery at 0245UTC 15, July 2005 (Fig. 9a) shows that several convective cores continue to develop upstream of the MCS towards the maximum instability axis which is largely unchanged from earlier GOES DPI imagery (Fig. 7a-d). It is interesting to note that the upwind edge of the system has started to make a noticeable west-northwest movement since 2345 UTC 14 July, which is indicative that the opposing propagation vector was starting to overwhelm the advection vector of overall system movement. In addition to the west-northwest movement of the upwind edge of the system, there are also some hints that there has been a southwest shift to the coldest cloud tops over northeast Mississippi. Corresponding surface mesoanalysis at 0245UTC 15 July (not shown) was showing a subsequent southwest shift to the outflow boundary as well, possibly due to an altered orientation of the outflow boundary and deep layer wind field. The southwest shift to the coldest cloud tops continued through 0632 UTC July 15 but by this time the overall cirrus canopy of the MCS is starting to warm. Significant rainfall continued over portions of north central Mississippi but weakening of the complex continued fairly rapidly after this time period.

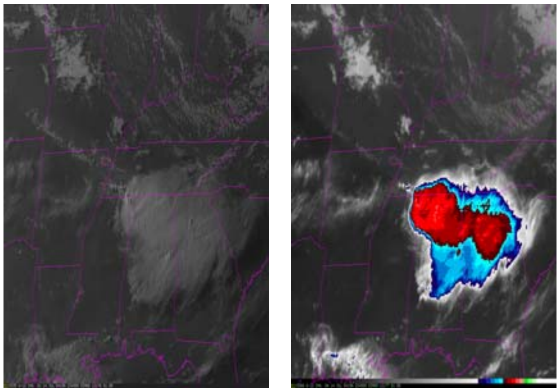
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Fig. 8. GOES-12 Visible (a) and Enhanced infrared (b) imagery at 2345 UTC 14 July 2004

## 5. SUMMARY

A case study of an MCS that exhibited two modes of movement was conducted using GOES Imager, GOES DPI, surface and upper air observations. In this case individual convective cells consolidated into a much larger MCS over the Tennessee Valley on 14 July 2004. Dry mid tropospheric air provided favorable conditions for surface cold pool development and with a nearly unidirectional wind profile a portion of the outflow boundary was normal to the mean wind. This portion moved steadily southeast with a sustained period of boundary relative convergence on to fuel convective development which helped to progress a portion of the MCS fairly rapidly into Georgia. The western portion of the outflow boundary remained nearly stationary due to the alignment of the boundary with the cloud bearing winds. This allowed for a sustained period of training, as convection continuously regenerated and then eventually backbuilt towards an instability axis that was collocated with a maximum area of low level convergence upwind of the initial convection. Results of this study agree with previous studies in that the propagation vector is preferentially favored to be directed towards the location where the greatest boundary relative low-level mass convergence, minima in static stability and convective inhibition coincide in relation to the initial MCS.

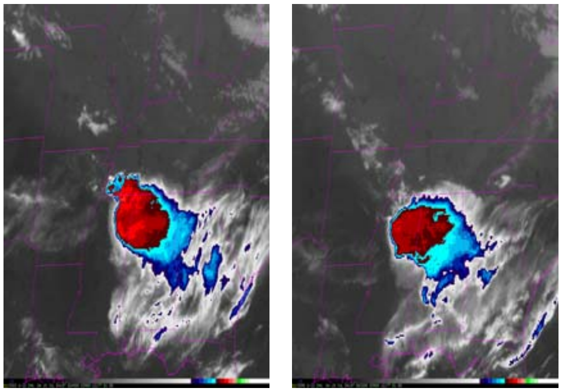
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Fig. 9 GOES-12 Enhanced infrared imagery at (a) 0245 UTC 15 July 2004 and (b) 0632 UTC 15 July 2004

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