Tools for Storm Analysis Using Multiple Data Sets

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Abstract. This note describes a web-based tool for storm analysis using multiple data sets developed for use in research of thunderstorms and forecasting applications. The tool was developed for users to monitor atmospheric changes along the path of storm systems. It demonstrates the use of the Thematic Real time Environmental Data Distributed Services (THREDDS) being developed by University Corporation for Atmospheric Research's UNIDATA. However, the data sets currently available with THREDDS are still somewhat limited. For this reason, the data used are from a variety of sources including the NOAA/Storm Prediction Center. The functionality of integrating and overlaying data from multiple sources (radar, satellite, lightning, model) in Lagrangian (moving) reference systems is not fully available to the research or operational community and will be demonstrated here.

1 Introduction

The functionality of integrating and overlaying data from multiple sources has been useful in atmospheric and multidisciplinary research. Several tools have been developed over years to meet this need. These include the Man Computer Interactive Data Access System (McIDAS, Lazzara et al., 1999), VIS5D (Hibbard and Santek, 1990), VisAD (Hibbard, 1998), and more recently the Interactive Data Viewer (IDV).

The basic functionality of such systems includes the ability to animate imagery, usually as time sequences, overlay gridded or point data, provide statistical comparisons between images and other data, and to rotate the viewing angle in the case of three dimensional (3-D) gridded data. In the case of atmospheric data, the ability to visualize the distribution of data in space (3-D) and time is quiet useful. The wind is an example of an important atmospheric parameter to be viewed in 3-dimensions and time. In this case, the air flow can be visualized from plots of streamlines at an individual time, or as trajectories over a span of time.

In some cases, the ability to focus on an organized atmospheric system, such an individual thunderstorm is desirable. Since storms are rarely stationary, they must be identified and tracked in space and time in order to evaluate their evolution. Often the process of identification and tracking is done manually. Given a storm position and movement vector, wind or other data can be displayed in a storm relative frame of reference. Viewing imagery in a storm relative frame of reference provides insight into the interaction of the storm with its near environment, such storm relative inflow. In other applications, tools have been developed to automatically track storms and to plot attributes of the moving storm versus time (in the form of time-series plots). Examples of such applications include the Warning Decision Support System (WDSS, Lakshmanan, et al., 2005) which evaluates properties of storm rotation, hail signatures, etc from Doppler radar data. The output has wide applications, from severe storm research to warning guidance for the National Weather Service forecasters.

This paper reports on a conceptual tool which provides automated tracking of cloud systems from radar and satellite and interactive functionality to obtain time-series on-line. The time-series include attributes of: 1) the cloud systems, and 2) atmospheric conditions in a user selectable region relative to the moving cloud system. In concept, the tool uses on-line databases of satellite, radar, lightning, and model analysis data to provide both near-real time and archived information on storm attributes, and on the atmospheric environment surrounding them to users of the Internet. In principle, the tool can provide relatively quick access to a wealth of information relevant to the atmospheric research community on thunderstorm behavior. To date, this capability has yet to become widely available by other means.

2 Data access

Data are obtained in near-real time through the Internet from a variety of sources. Currently, forecast model data is available using the Thematic Real time Environmental Data Distributed Services (THREDDS) being developed by University Corporation for Atmospheric Research's Unidata and the NOAA Operational Model Archive and Distribution System (NOMADS) by the National Climatic Data Center (NCDC), National Centers for Environmental Prediction (NCEP) and the Geophysical Fluid Dynamics Laboratory (GFDL). Data retrieval is efficient in that only desired subsets of large data files are transfered from the remote servers for local archival and processing. Conceivably, all environmental data sets may become available from THREDDS in the future. Analysed meteorological fields which are derived from model and observed surface data are obtained directly from the NOAA Storm Prediction Center (SPC). Satellite and radar data are obtained from McIDAS Abstract Data Distribution Environment (ADDE) servers which also allow efficient transfer of compressed subsets of data.

3 Analysis of cloud clusters

The analysis of cloud systems is based on the automated identification and tracking of features in satellite or radar images which are deemed to be associated with deep convective thunderstorms. Often such storms form into clusters known as Mesoscale Convective Systems (MCS) during the summer months in the central U.S. These storms bring a variety of significant weather including heavy rain, high wind and hail. The initiation, movement, and decay of MCSs are relatively difficult to forecast. Although the individual storm elements may be short-lived, the clusters often last for several hours.

In the case of satellite imagery, storms are identified by unusually cold cloud top temperatures in the window infrared (IR) band (wavelength near 11 microns). A simple scheme for identification and tracking of these features has been employed following that of Mapes and Houze (1994). Other more sophisticated techniques could be substituted in the future. The technique is based on choosing a cloud top temperature threshold which contains most of the anvil cloud above the MCS. The selection of colder thresholds will identify and track sub-scale features, such as overshooting tops, possibly associated with individual storm updrafts. Tracking is obtained from movement of centroid positions of each identified cluster between successive IR images. The association of clusters in successive images is based on observed spatial overlap. This limits the analysis to features of a minimum horizontal scale which depends on the interval between images and propagation speed of the features. To allow for interactive user selection of cloud top temperature thresholds, the identification and tracking is automatically computed for temperature increments of 1^{o}C covering the range of possible conditions (-75 to -30 ^{o}C). Centroid location, cloud top size, and statistics such as mean and minimum temperature within each cloud cluster are stored in a file for display and relation to other variables, as described later.

An analysis similar to that of cloud top temperature is performed using patterns of radar reflectivity. In this case, thresholds of radar reflectivity correspond to echoes of different intensity.

4 Display

The display interface is based on a Java applet which allow client machines to interact with the server database of imagery and output analysis described in Section 3. Upon opening the tracker web page from any Java-enabled web browser:

http://tracker.nssl.noaa.gov/

the user can select movies of IR satellite images (3-hour duration) from the entire archive of data (staring in June 2003). The display can be magnified (zoomed) for closer examination of desired storms. Tracks of each cloud cluster during the 3-hour period are displayed corresponding to the default cloud top temperature threshold of -43 ^{o}C . The images can be enhanced to display only the cloud areas defined by the temperature threshold. This depicts the cloud features being tracked for this particular threshold. Smaller features within major clusters, such as overshooting tops, can then be examined by choosing progressively colder thresholds.

Images of radar reflectivity can be overlaid on the satellite IR movies. In this case, the selectable thresholds refer levels of reflectivity in dBZ. The same functionality described above for the satellite imagery can be applied the radar data. In this case, choosing progressively larger reflectivity values will identify the location and tracks of smaller features in the radar data.

Time series of variables following the motion of a selected cluster can be displayed. This includes variables associated with the satellite or radar data discussed in Section 3, such as cloud top size and mean temperature or reflectivity within each cloud cluster. The time series computed from additional data sets can also be selected for computation and display. Computation utilizes the VisAD library to facilitate sampling parameters from the model grids in space and time. These data sets include observations from other sensors such as lightning frequency, and analysis fields of atmospheric parameters which are factors to storm behavior, such thermodynamic stability and wind shear. By default, these variables are evaluated at the centroid position of the cluster for each time period. However, the user can interactively define any other location displaced from the default position. This is particularly useful in examining the environment of the inflow region to a storm which has not yet been modified by rain cooled air.

5 Examples

An example of a long-lived MCS in its mature and dissipating stage is shown in Figs. 1-2. The selected centroid tracks appear in red. Figures 3-4 show time series corresponding to the mature and dissipating stages. Gridded atmospheric variables were obtained at hourly intervals from the NOAA Storm Prediction Center (SPC). Three variables are selected for display. The cloud top temperature (CTT) warms and the deep layer shear (6 km shear) weakens (0715-1030 UTC) as the initial growth of the cloud cluster ceases (Fig. 3). The warming and decreasing shear signal future weakening of the storm system. During the dissipating stage (Fig. 4, 1045-1400 UTC), the cloud size rapidly decreases as the atmospheric conditions stabilize (Most Unstable Convective Available Potential Energy, MU CAPE decreases). The average cloud top temperature remains relatively steady during this period.

Another example of MCS tracks is given in Fig. 5. The storm cluster highlighted with the red track produced a series of tornadoes in central Illinois between 1930-2030 UTC. The trends of atmospheric parameters is given in Fig. 6. Gridded atmospheric variables were obtained from the NOMADS in this case. Plotted are convective inhibition (green), CAPE (purple), and helicity (red). The inhibition is a measure required energy to initiate storms. Helicity is a measure of wind shear conducive to development of rotating updrafts (with potential for tornado-genesis), Davies-Jones (1984), Kerr and Darkow (1996). There appears to be strong correlations between the time of the tornadoes and a maximum in helicity and a minimum in convective inhibition.

6 Conclusions

This note describes a web-based tool for storm analysis using multiple data sets developed for use in research of thunderstorms and forecasting applications. The functionality includes: 1) access to a wide range of archived data, and 2) cross-referencing of trends in radar, satellite, and other atmospheric data in the moving frame of reference of storm clusters. The software allows users to look at loops of satellite and radar images and, using a mouse, to highlight a storm and view its track and time trends of cloud top temperature, radar reflectivity, environmental conditions etc. In addition to being a research tool, forecasters can use the tool to monitor changes in atmospheric stability, wind shear, and moisture fueling a mesoscale convective system as it moves along, as well as other conditions, which might alter the strength and longevity of a storm. The tool will be useful in future research on the effects of the atmospheric environment on storm evolution.

Acknowledgments

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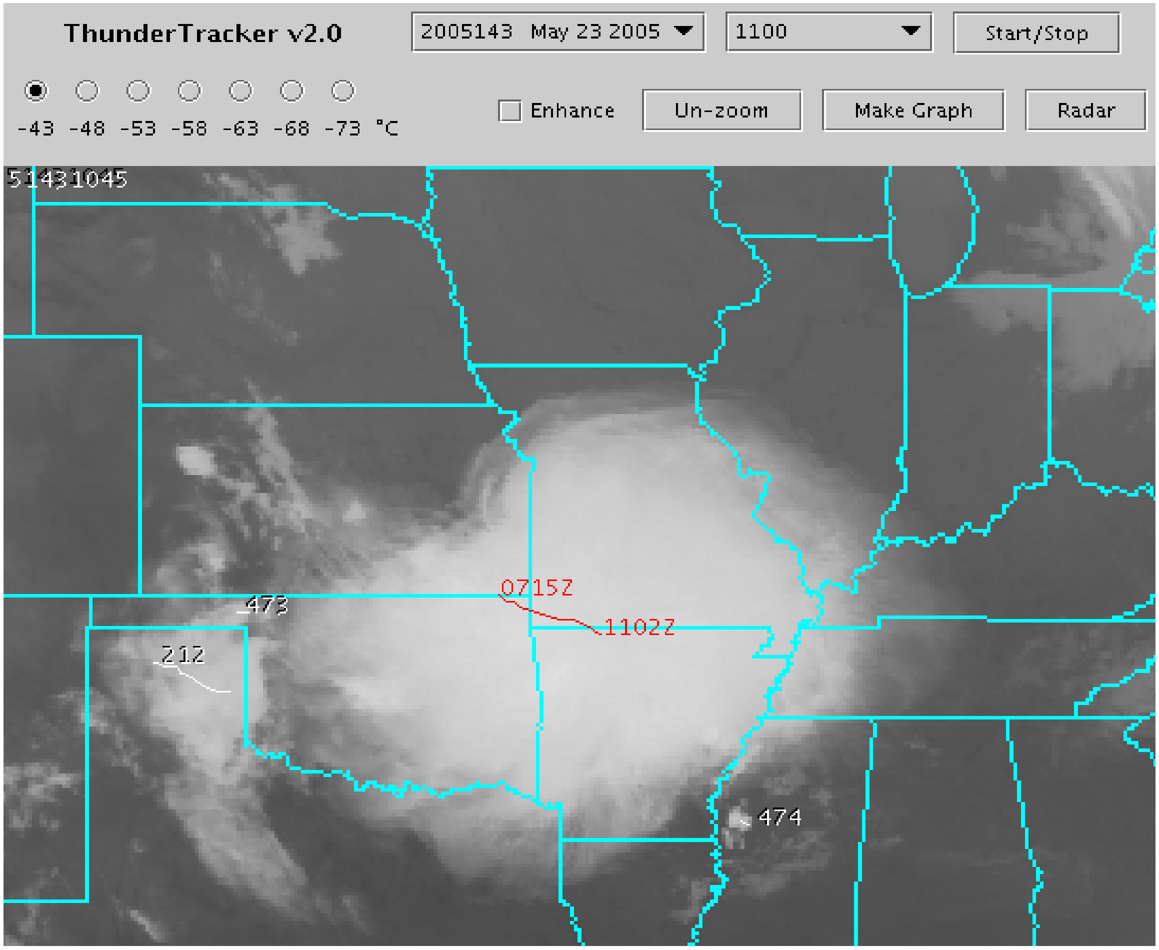

Fig. 1. Mesoscale Convective Complex, mature stage. Selected track (red) 0715-1102 UTC, 23 May 2005.

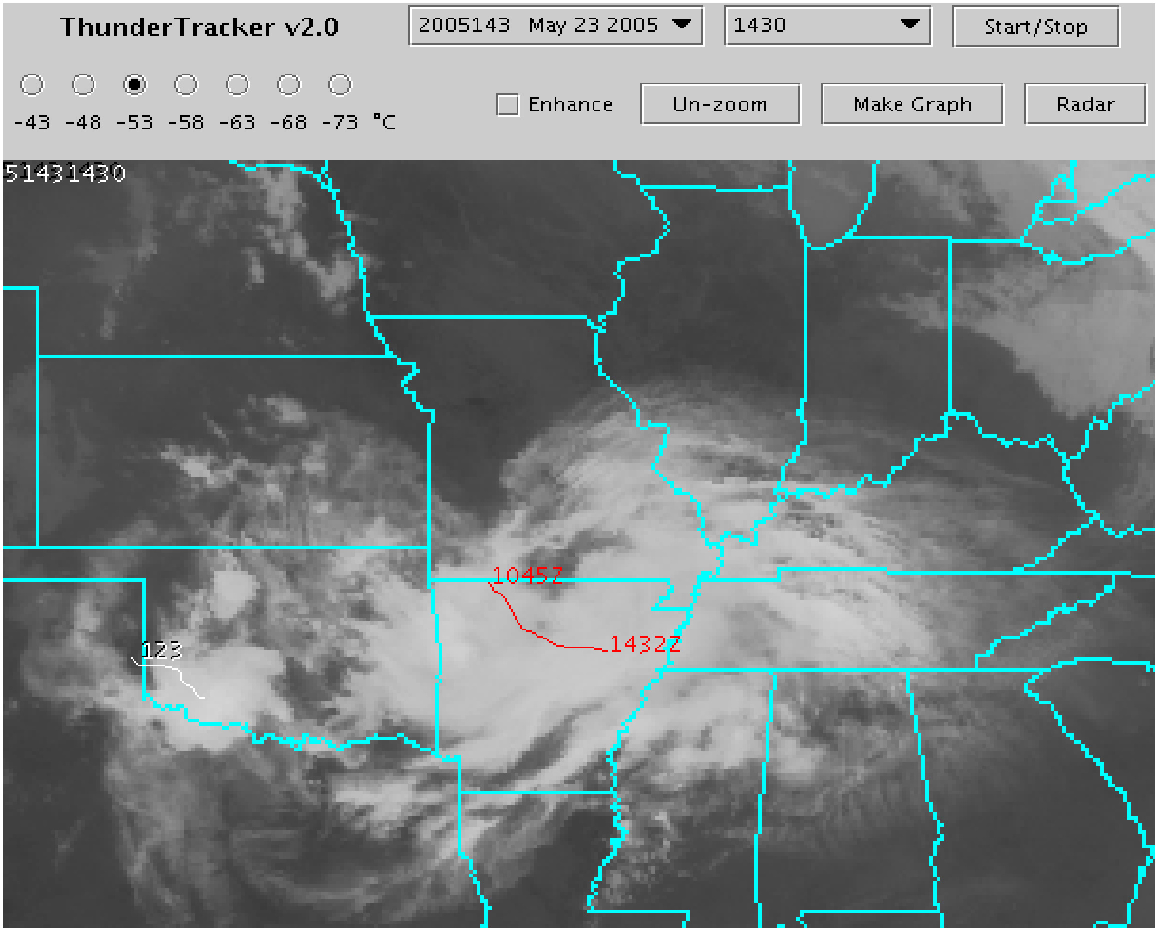

Fig. 2. Mesoscale Convective Complex, decaying stage. Selected track 1045-1432 UTC, 23 May 2005.

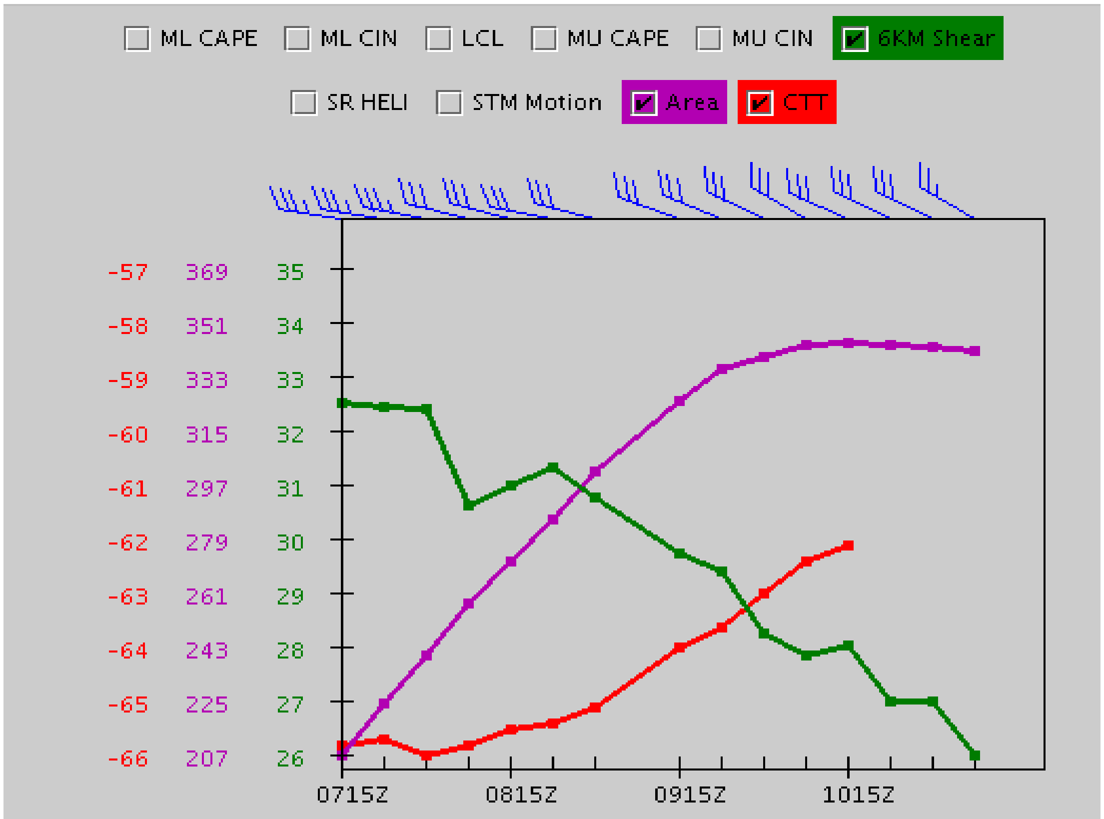

Fig. 3. Time series plots from Mesoscale Convective Complex (mature stage). The following three parameters are selected for plotting: 1) Size of cloud cluster (Area, 10^4 km^2) is expanding, then steady, 2) Cloud top temperature (CTT, $^\circ C$) is warming, 3) Deep layer shear (6 KM Shear, knots) is weakening (from the north-northwest).

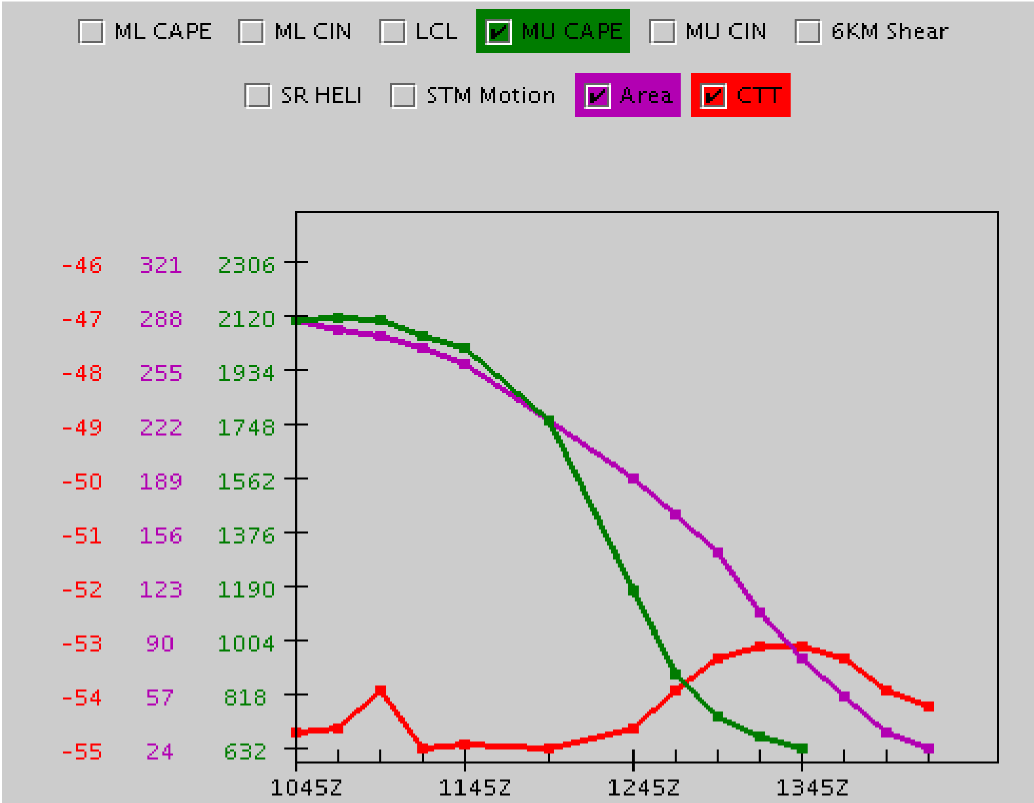

Fig.4. Time series plots from Mesoscale Convective Complex (decaying stage). The following three parameters are selected for plotting: 1) Size of cloud cluster (Area, 10^4 km^2) is decreasing, 2) Cloud top temperature (CTT, ^oC) is steady, 3) Most Unstable Convective Available Potential Energy (MU CAPE, J kg^{-1}) is decreasing.

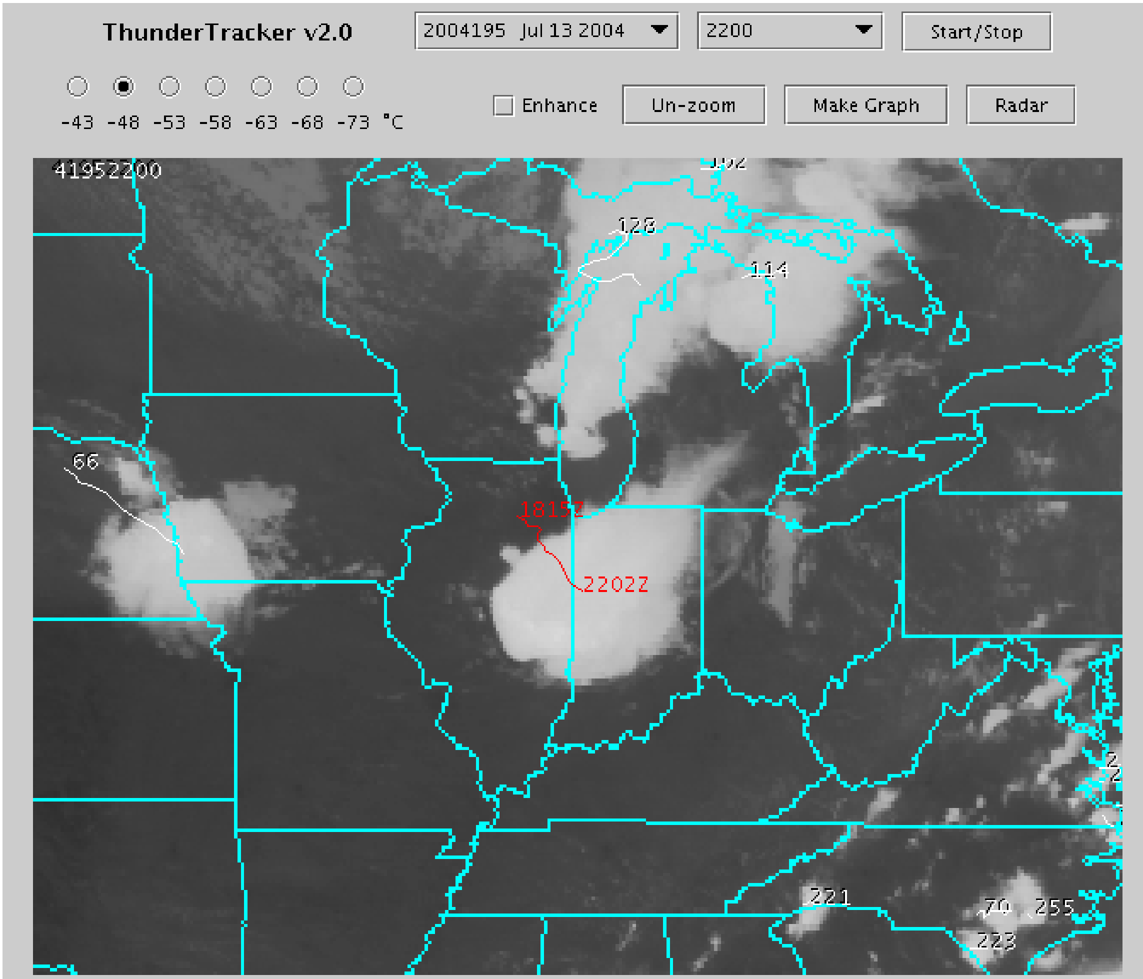

Fig. 5. Storm track, MCS associated with central Illinois tornadoes, 13 July 2004.

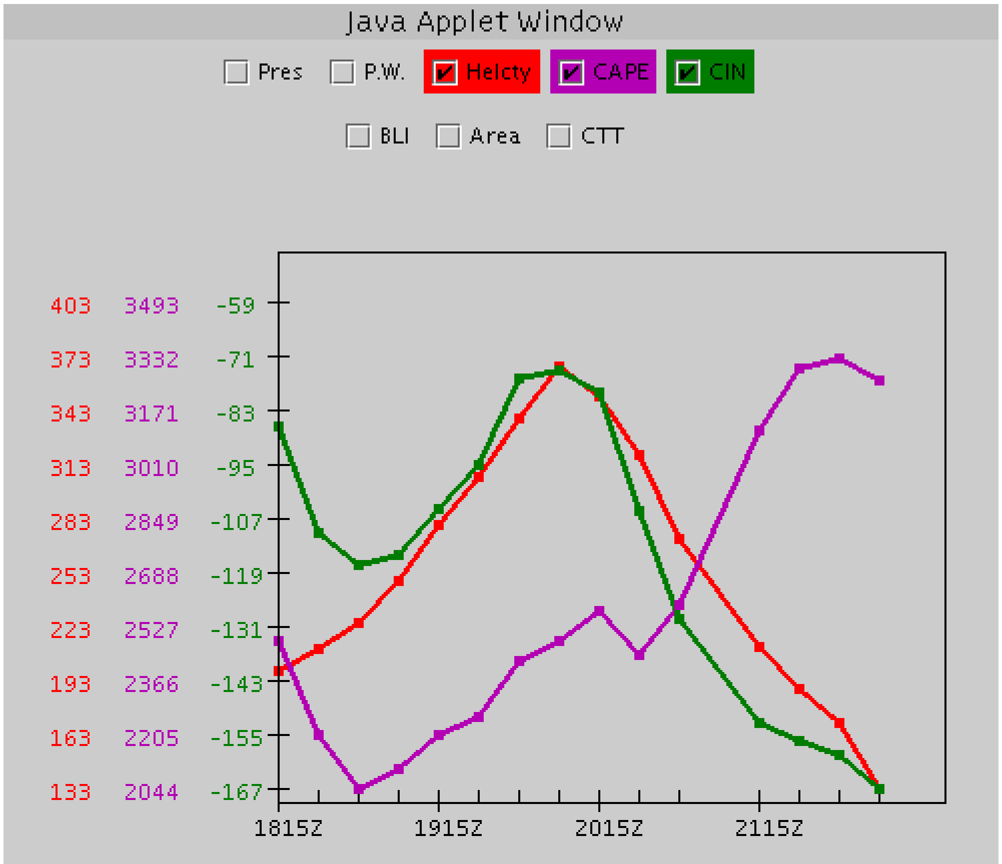

Fig. 6. Time trends of atmospheric variables associated with MCS in Fig. 5. Variables plotted are: helicity (Helcty), Convective Available Potential Energy (CAPE, J kg^{-1}), and Convective Inhibition (CIN, J kg^{-1}).