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Summary of convective storm initiation and evolution during IHOP

J. W. Wilson and R. D. Roberts

National Center for Atmospheric Research, Boulder, Colorado, USA

Abstract. The data rich IHOP_2002 experiment is used to study convective storm initiation and subsequent evolution for all days of the experiment. The initiation episodes and their triggering mechanisms are identified. Initiation episodes were almost evenly divided between those triggered along surface based convergence lines and so called elevated initiation episodes. The elevated episodes occurred mostly at night and the surface based during the afternoon and evening. Surface based initiations were mostly associated with synoptic fronts and gust fronts and less so with dry lines and bores.

Clearly gust fronts and their characteristics where the primary feature influencing the evolution of the initiated storms. The life time of storm systems was dependent on the generation of a gust front.

Successful forecasting of convective storm evolution will require the ability to first forecast the emergence and characteristics of the gust front. We suspect that precipitation microphysics plays a large role in determining the characteristics of the downdrafts and resulting gust fronts. Evolution to intense long lived convective systems appeared to be controlled primarily by the strength of the convergence with gust fronts rather than the magnitude of CIN or CAPE.

1 Introduction

The purpose of this paper is to provide a broad perspective of storm initiation and evolution in the IHOP region. Initiation and evolution for the entire 44 days of the project is examined. There have been many studies in the past concerning the nocturnal maximum in rainfall in the U.S. Great Plains (ex. Palmen and Newton 1969) and speculation for the reason (Wallace 1975 and Dia et al., 1999). There have also been numerous studies concerning the initiation of convective storms by the dry line (ex. Schaefer, 1986), by bores (ex. Carbone et al., 1990) and development of Mesoscale Convective Systems (Laing and Fritsch, 1997). This paper examines the frequency of these events during IHOP and initiation triggering mechanisms.

Correspondence to: J. W. Wilson
(jwilson@ucar.edu)

2 Data

Particularly important for the studies reported here are the mesonet, radiosonde, radar and satellite data. Within the IHOP study area there were about 275 surface stations generally reporting wind, temperature and dewpoint at time intervals between 1 and 60 min. Figure 1 shows the study area, location of surface stations, radiosonde locations and mosaic radar data. Visible and IR data were available from GOES-8 and 11. These data sets were used to identify storm initiation locations and times, as well as, to identify and characterize boundaries. Radar mosaics were prepared at 10 min intervals for the entire 44 day period of IHOP. Their primary use was to identify storm initiation locations, identify and track boundaries and to monitor storm evolution.

3 Analysis

The role of convergence lines on storm initiation and evolution is well documented (Byers and Braham, 1949; Purdom, 1976; Wilson and Schreiber, 1986; Koch and Ray, 1997) and is an important part of this study. The location of boundaries were entered into the data base every 20 min for the entire period of the project

Storm initiation was declared when a convective radar cell at the 0.5 deg elevation angle first reached 40 dBZ, and occupied an area of at least 4 km^2.

Storm initiations that clustered in time and space were identified and called storm initiation episodes. An episode consisted of two or more cell initiations whose close appearance in time and space suggested a common forcing mechanism. The number of cells in an initiation episode varied between 2 and 55 over time periods varying between 20 and 200 min. A total of 112 initiation episodes were identified during the 44 day study period. For each initiation episode the following were recorded: location, number of individual cells that initiated between the beginning and end of the episode, the orientation and size of the episode and the suspected initiation mechanism.

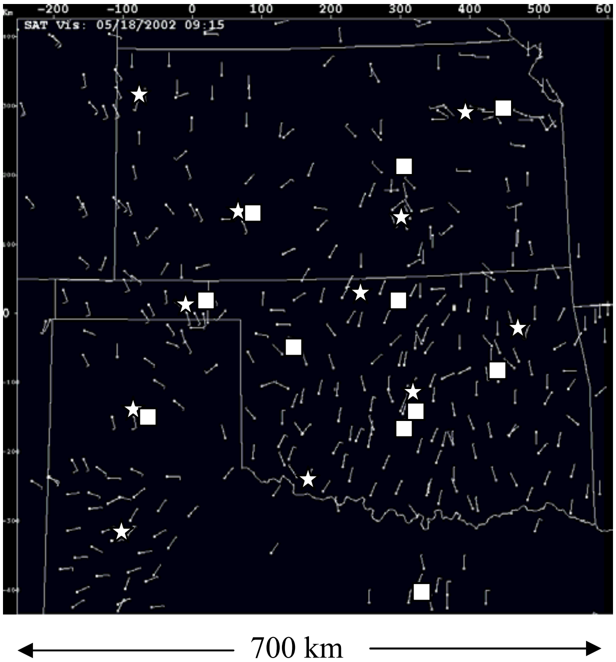

Fig. 1. Study area. The stars indicate the location of the 11 radars, the white boxes the location of radiosonde sights and the surface station locations are shown by the wind barbs.

Forcing mechanisms for initiation episodes were divided into two groups: surface based and elevated. The classification of surface based required the observation of a nearby boundary. If no surface convergence feature was identified it was classified as an elevated initiation episode. Boundaries were classified into 7 categories; frontal, gust fronts, trough lines, dry lines, colliding, bores and unknown.

The evolution of each initiation episode was followed and was classified at its most mature stage of convection as a multi-cell complex, linear feature or squall line. A squall line was differentiated from a linear feature by the presence of a gust front. Other features recorded are size of the most mature stage, lifetime of the storm complex, development of a gust front and if the initiation episode merged with other initiation episodes.

Computer programs were developed for obtaining a) high resolution near surface divergence fields from the surface stations, and b) high resolution fields of Convective Available Potential Energy (CAPE) and Convective Inhabitation (CIN) derived from the IHOP sounding data set and a lifted surface parcel based on the mesonet data.

4 Initiation Episode Results

4.1 Surface based and elevated

The beginning times of the 112 initiation episodes are shown in Fig. 2. The distribution is bimodal with a distinct peak in the afternoon between 13:00 and 16:00 LST and a broader nocturnal maximum between 22:00 and 04:00 LST. Figure 2

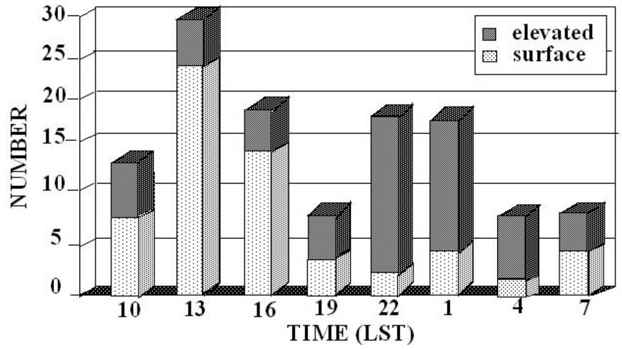

Fig. 2. Beginning time of convective storm initiation episodes during IHOP separated into elevated and surface based storm initiation. For example between 10 and 13 LST there were 7 surface initiation episodes and 5 elevated episodes for a total of 12.

also divides the initiation episodes into elevated (dark) and surface forced (light). The number of initiations is almost evenly divided between surface and elevated. As might be expected the afternoon initiation episodes are primarily surface based and the nocturnal are elevated. Thus we see that elevated nocturnal storm initiation is a contributing factor to the nocturnal maximum in rainfall that has been observed over the southern plains.

Thirty-seven percent of the surface based initiations were triggered by fronts and 21 % by gust fronts. The remaining were divided among trough lines, colliding boundaries, bores and unknown boundaries. Two-thirds of the elevated events were associated with convergence wind features between 900 and 600 hPa.

There were 8 days were triple points occurred; all involved a front. The triple point is where two boundaries intersect separating three different air masses. The second boundary was a dry line, trough line or unknown boundary. Storm initiation occurred on 6 of 8 days at the triple point. These storms often had the tendency to be among the more intense storms.

The frequency of undular bores observed during IHOP was surprising large (Weckwerth et al., 2004). Given the strong vertical motions occurring with these mostly nocturnal events bores are a possible cause for some of the nocturnal storm initiation that was observed. There have been a number of case studies showing storm initiation by bores (Karyampudi et al., 1995; Carbone et al., 1990; Locatelli et al., 2002).

Twenty bore trains were observed in the radar data on 15 different days. They were observed between 02:30 and 11:00 UTC (20:30–05:00 LST). Six of the bores did initiate storms, however in only three of these cases were the storms sufficiently large or intense to qualify as an initiation episode. While bores were frequent occurring phenomena during the night they played only a small role in initiating nocturnal thunderstorms.

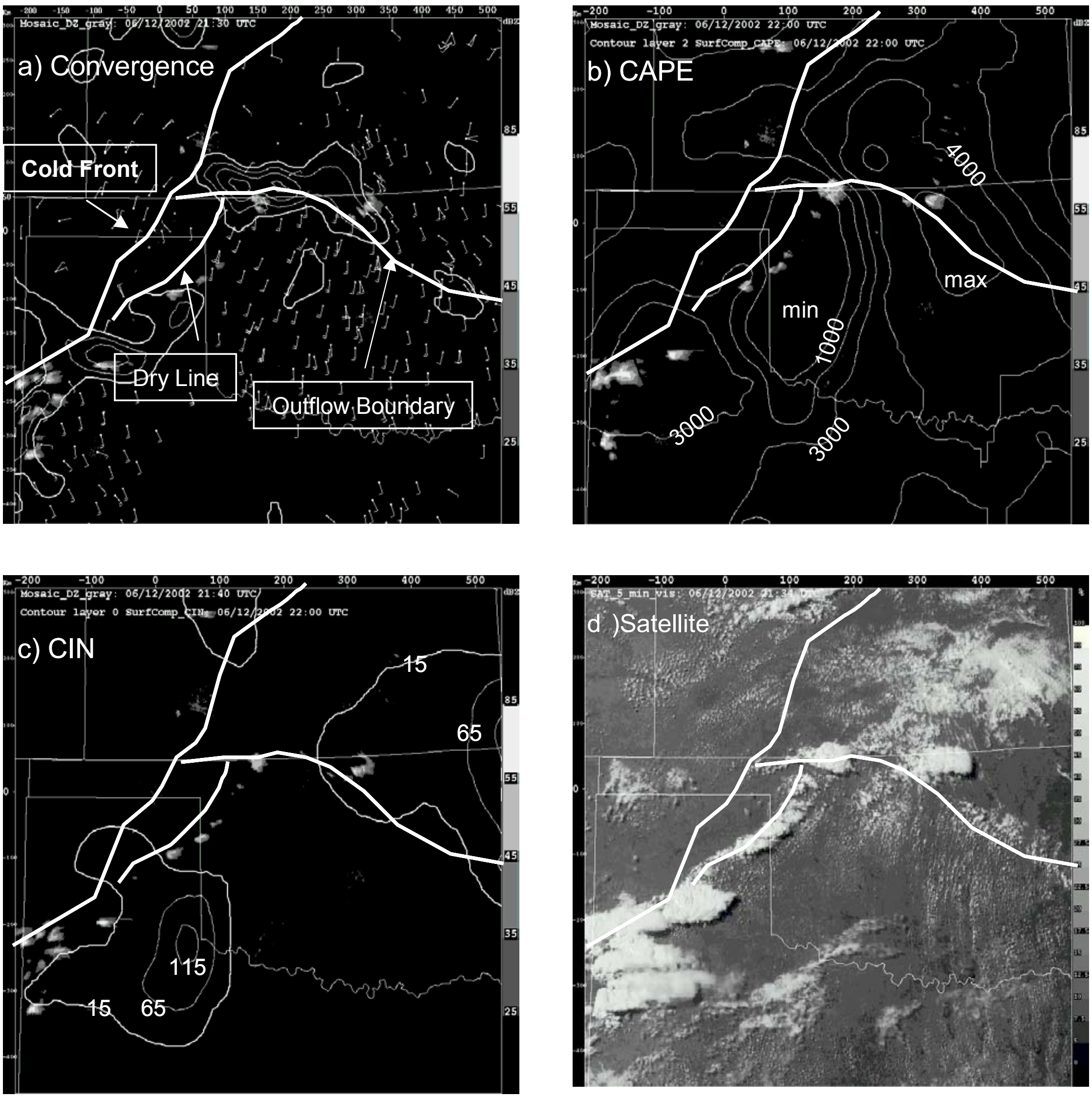

Fig. 3. June 12 at 21:40 UTC boundaries (solid white lines) overlaid on a) radar reflectivity (gray scale shades on right in dBZ) and convergence (first contour $5\times10^{-4}\,s^{-1}$ with contour interval of $5\times10^{-4}\,s^{-1}$), b) radar reflectivity and CAPE (contour interval of $1000\,j\,kg^{-1}$), c) radar reflectivity and CIN (first heavy contour $15\,j\,kg^{-1}$ with contour interval of $50\,j\,kg^{-1}$) and d) visible satellite.

5 Storm Evolution Results: Observational and Model

The organization of each episode at maturity was classified as a squall line, linear or multi-cell complex. Also recorded were the lifetime of the event and whether a gust front was produced.

While the lifetime of individual cells is generally only about 20–30 min (Battan, 1953 and Foote and Mohr, 1979) the lifetime of the complex of storms associated with an initiation episode is measured in hours. Squall lines tended to have the longest length and also the longest life time. The lifetime of the storm systems was related to whether the convective system produced a gust front. Those systems that produced a gust front were likely to live at least 8 h where those that did not were most likely to live between 2 and 6 h.

The evolution of the 11 most significant storm complexes (based on size, intensity and organization) that evolved from the initiation episodes were examined. These storm complexes had almost continuous lines of storms >40 dBZ with lengths from 350 to >800 km.

In all but one of these storm complexes significant gust fronts developed and the system propagated with the motion of the gust front rather than the steering level winds.

6 Case Studies

The initiation and evolution of squall lines were studied for 12–13 June and 15–16 June. These squall lines were 350 and >800 km long and formed from the merger of several initiation episodes.

Figure 3 is an example of a single time period for 12 June as initiation of storms is just beginning along a dry line, front and outflow boundary. Convergence lines are overlaid on radar reflectivity, convergence, CAPE, CIN and visual satellite. As discussed in Sect. 3 the surface convergence is derived from the surface mesonet stations and the CIN and CAPE are derived from the surface mesonet stations and IHOP soundings. Figure 3 shows: a) that along the boundaries there is a maximum in convergence with a peak where they intersect, b) surface CIN is generally very small (less than 15 $\mathrm{j\,kg^{-1}}$), c) surface CAPE is moderate (between 1000 and 5000 $\mathrm{j\,kg^{-1}}$), with the higher values along the outflow boundary and d) in the visible satellite image there is incipient convection along much of the boundaries. The low CIN values, moderate to high CAPE, substantial convergence and observed cumulus along the boundaries indicate a promising situation for continued storm initiation.

Space does not allow presentation of these case studies. However the studies showed the initiation was primarily influenced by details of the surface convergence and CIN and the evolution was controlled primarily by the gust fronts and their characteristics.

7 Study implications

The large number of elevated initiation episodes was somewhat of a surprise and the cause not well understood. Our experience suggests that elevated convective initiation episodes are infrequent during the summer in Colorado and Florida, relatively common in the upper mid-west and common in the IHOP area. The cause of many of the elevated initiations during IHOP appeared to be associated with synoptic or mesoscale wind convergence at mid-levels (between 900 and 600 hPa). Convergence associated with the low-level jet did not appear to be a significant factor. We speculate that the high frequency of elevated initiation episodes in the Midwest is a result of relative frequent mid-level synoptic and mesoscale convergence features coupled with an abundance of mid-level instability. Synoptic scale feature in Florida and Colorado are less frequent and moisture in Colorado is much less.

Given the observed importance of gust fronts and their characteristics on the evolution and motion of the initiated storm complexes it is essential for very short period forecasting techniques to anticipate which storms will produce gust fronts and their characteristics; this is a major research challenge for observational and numerical model scientists. Precipitation microphysics probably plays a key role in determining the timing and characteristics of the downdraft and associated gust front. This suggests that particle type and drop size distributions derived from polarimetric radar should prove a profitable avenue for research.

Understanding processes that determine the precise location and timing of initiation was an objective of IHOP. Specific timing and location of initiation along boundaries appears to be very dependent on small scale variations in convergence and CIN. Observations of the required convergence resolution would seem to require station spacing at least as dense as in Oklahoma combined with the WSR-88D reflectivity and Doppler velocity observations. Observation of stability variations may require high resolution near surface water vapor measurements as demonstrated in IHOP by radar refractivity measurements from S-pol as well as detailed observation of the capping inversion.

While many of the elevated initiations were associated with synoptic or mesoscale convergence features observed in the RUC analysis there is no known method for anticipating the specific time of initiation. Improved basic understanding of elevated storm initiation is in need of research. However means for directly observing in detail wind and elevated stability parameters are not yet possible.

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