THUNDERSTORM INITIATION AND EVOLUTION DURING IHOP: IMPLICATIONS FOR AVIATION THUNDERSTORM NOWCASTING

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1. Introduction

In this paper we summarize some findings from the International H_2O Project (IHOP) which was conducted over a 400,000 km^2 area in Kansas, Oklahoma and Texas during the spring of 2002. These findings on thunderstorm initiation and evolution are presented in a paper prepared by the above authors (Wilson and Roberts 2005). Here we examine those findings in relationship to implications for nowcasting thunderstorms for aviation purposes.

A primary goal of IHOP was to study thunderstorm initiation using a very impressive collection of radars, lidars, surface mesonet stations, soundings and rapid scan satellite. Wilson and Roberts (2005) examined all convective storm initiations (radar cells exceeding 40 dBZ) occurring during the 44 days of IHOP. These events were identified and grouped into 112 initiation episodes. As part of this study all surface convergence lines were identified and tracked during IHOP so that their impact could be examined on storm initiation and evolution. A variety of environmental variables were then used to characterize the conditions in the area of each initiation episode. Environmental variables included surface convergence, CAPE and CIN.

The 3 and 6 h forecasts from the operational numerical forecast model called the Rapid Update Cycle (RUC, Benjamin et al. 2004a, b) were examined for its ability to forecast thunderstorm initiation movement and evolution during IHOP. A special 10 km version of the operational RUC (RUC10) was specifically run by the NOAA Forecast System Laboratory for IHOP.

2. Data

Particularly important for the above studies were 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. Fig. 1 shows the study area, location of surface stations, radiosonde locations and radar locations. 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

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.

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. Boundaries were classified into 7 categories; frontal, gust fronts, trough lines, dry lines, colliding, bores and unknown. If no surface convergence feature was identified it was classified as an elevated initiation episode.

The evolution of each initiation episode was documented and was classified at its mature stage 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.

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.

The evolution of the initiation episodes covered a great range of situations including intense supercells, squall lines, mesoscale convective systems, short lived convective lines, and short lived unorganized groups of storms. The evolution and lifetime of the initiation episodes was closely tied to the development of gust fronts. Elevated systems were much less likely to develop gust fronts thus they were less likely to become well organized with long lifetimes.

4. IHOP findings and implications for aviation weather nowcasting

For a number of years NCAR and Lincoln Laboratory have been involved in developing, testing and implementing operational 0-2 hr thunderstorm forecasting systems for aviation enroute and terminal weather. These systems are called the Auto-nowcaster (Mueller et al 2003), National Convective Weather Forecast product (NCWF, Megenhardt et. al 2000) and the Growth and Decay Tracker (Wolfson et al. 1998). Most recently there has been a desire to extend this period to 6 h. While these systems make extensive use of radar extrapolation techniques they also forecast convective storm initiation, growth and dissipation. These techniques combine forecast parameters from numerical models, statistical methods and heuristic methods. Future significant forecast improvements will likely be closely tied to improved basic understanding and improved observations. Summarized in this section are findings from the IHOP research reported in Wilson and Roberts (2005) and their possible implications for nowcasting

1) The initiation episodes during IHOP were almost evenly divided between surface based and elevated. The surface based initiations occurred mostly during the afternoon and early evening and the elevated initiations during the night and early morning. The surface based episodes were triggered mostly by synoptic fronts and gust fronts.

   Implication: The importance of boundaries in initiating convection is again reinforced. Thus it is essential to continue to vigorously pursue human efforts to insert boundaries into the nowcast systems. The observation that new storm initiation tended to occur in close time and space proximity to each other reinforces the desirability to include in the nowcast systems a means to increase storm initiation likelihood near locations that have recently had storm initiation.

   Even though elevated nocturnal convection and its initiation is a common event over much of the central and eastern U.S., the Auto-nowcaster, Growth and Decay Tracker and NCWF nowcast systems have no procedures in place to nowcast these events. This is primarily because of a lack of basic understanding of how these events are triggered and factors influencing their evolution. New understanding from IHOP discussed below may provide some insight.

2) The cause of many of the elevated initiations during IHOP appeared to be associated with synoptic or mesoscale wind convergence or confluence at mid-levels (between 900 and 600 hPa). This convergence was often observed in the RUC analysis wind fields. However, there is no known method for anticipating the specific time of initiation with these features. It was uncertain if the RUC had the skill to forecast these convergence features or the initiation of elevated convection. In addition bores were frequently observed during the night which infrequently initiated convective storms.

   Implication: Consideration should be given toward producing an elevated storm initiation interest field that identifies intense prolonged convergence fields between 900 and 600 hPa. Improved basic understanding of elevated storm initiation is in need of research. However means for directly observing detailed wind and stability parameters are not yet possible.

3) While individual storms typically have lifetimes of only 10 to 60 min the

complex of storms associated with an initiation episodes had lifetimes of hours. The lifetime of the storm complex was related to whether the convective system produced a gust front. Those systems that did not produce a gust front lived between 2 and 4 h whereas those that did produce a gust front typically lived >6 h.

Implication: This finding reinforces the notion that while the precise details of movement and intensity of individual storms within a complex have little predictability beyond about 30-60 min the storm complex and its statistical characteristics can be extrapolated for many hours particularly if a gust front develops.

4) Understanding processes that determine the precise location and timing of initiation was an objective of IHOP. While this particular study did not directly address this objective, our study of two cases on 12-13 June and 15-16 June using high resolution convergence and stability parameters points to the importance of small scale variations in convergence and CIN. Surface based storm initiation in high CIN areas is unlikely, however once a strong gust front develops storms can continue in regions of high CIN. Initiation of convection was not as sensitive to the magnitude of the corresponding CAPE values.

Implications: Observations of the necessary resolution of the convergence field 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 water vapor measurements as demonstrated in IHOP by radar refractivity measurements. Software should be installed on the WSR-88D and TDWR operational radars to provide refractivity measurements so that near surface water vapor measurements can be obtained as described by Fabry et al. (1997).

5) Given the observed importance of gust fronts and their associated convergence 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 the strength of the cold pools; 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 precipitation particle type and drop size distributions derived from polarimetric radar should prove a profitable avenue for research.

Implication: It is likely microphysical precipitation parameters strongly influence the emergence and strength of gust fronts thus the planned implementation of polarization on the WSR-88D’s will provide an excellent opportunity to identify precipitation particle types and size distributions for input into the nowcasting systems. Additional research focusing on the specifics for utilizing polarimetric observations in these nowcast systems should be pursued.

6) The evolution, movement and lifetime of the initiated storms appeared to be primarily influenced by the emerging gust fronts and their characteristics rather then stability parameters. Organized squall lines propagated with the motion of the gust front and not the steering level flow. In addition the RUC10 showed little skill in propagating large well developed storm complexes. This was likely because of difficulties with the model in producing realistic gust fronts.

Implication: Large storm complexes should be extrapolated with their observed motions or that of the gust front rather with steering level winds or numerical model motions.

7) The RUC10 convective precipitation forecasts were able to correctly forecast

precipitation for 62% of the initiation episodes given a tolerance of 250 km in space and 1-5 h in time; if no tolerance is allowed 15% were correct. The highest accuracy was with synoptic frontal systems. There was a tendency for the RUC to over forecast the amount of convection and the time length of convection.

Implication: Particularly for frontal situations the RUC can provide skill in defining broad scale regions for storm initiation. The NCWF system already produces a storm initiation interest field based on regions identified from RUC as likely frontal regions.

8) During IHOP NOAA Severe Storm Prediction Center forecasters provided special convective storm outlooks for project scientists that identified primary boundary (fronts, dry line and outflow boundaries) locations and assigned forecast probabilities for thunderstorm likelihood. These daily outlooks proved very beneficial for planning project operations.

Implications: Inclusion of this type of forecaster information into automated thunderstorm nowcasting systems will likely improve the nowcasts from these systems. This concept has already been demonstrated in Roberts et al. (2003) where the Auto-nowcaster system was modified to accept forecaster input. Improved automated convection initiation nowcasts using NWS forecaster input will ultimately benefit the aviation community. A rigorous test of this concept will be initiated in 2005 in Fort Worth Texas which will incorporate NWS and CWSU forecasters.

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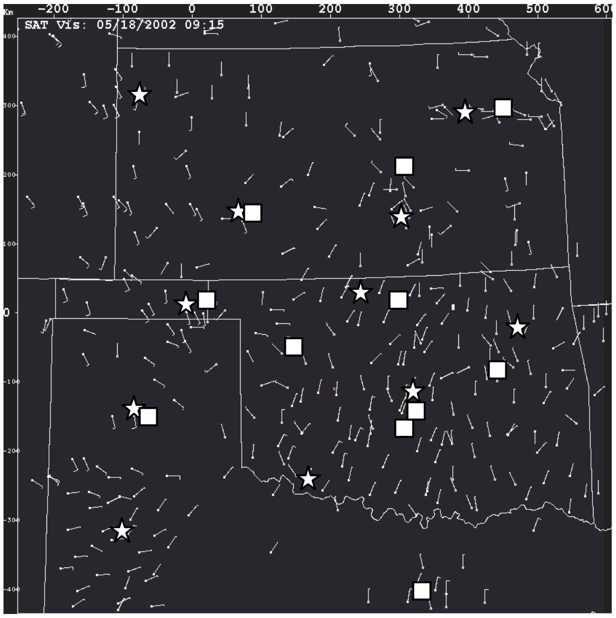

Fig 1. Location of surface stations (wind barbs), radars (stars) and radiosondes (squares) within the IHOP study area.