Cloud Model Ensembles for Forecasting Severe Thunderstorms

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A fair bit of work has been done using single cloud model runs to predict thunderstorm characteristics. But, it is not clear that using single model runs produce accurate forecast guidance. When a forecast is made using a single cloud model run, to which particular storm does it apply? Because observed storm behavior is variable, how is a single realization verified? With more sophisticated models that contain numerous storms and time-varying environments, how lit-

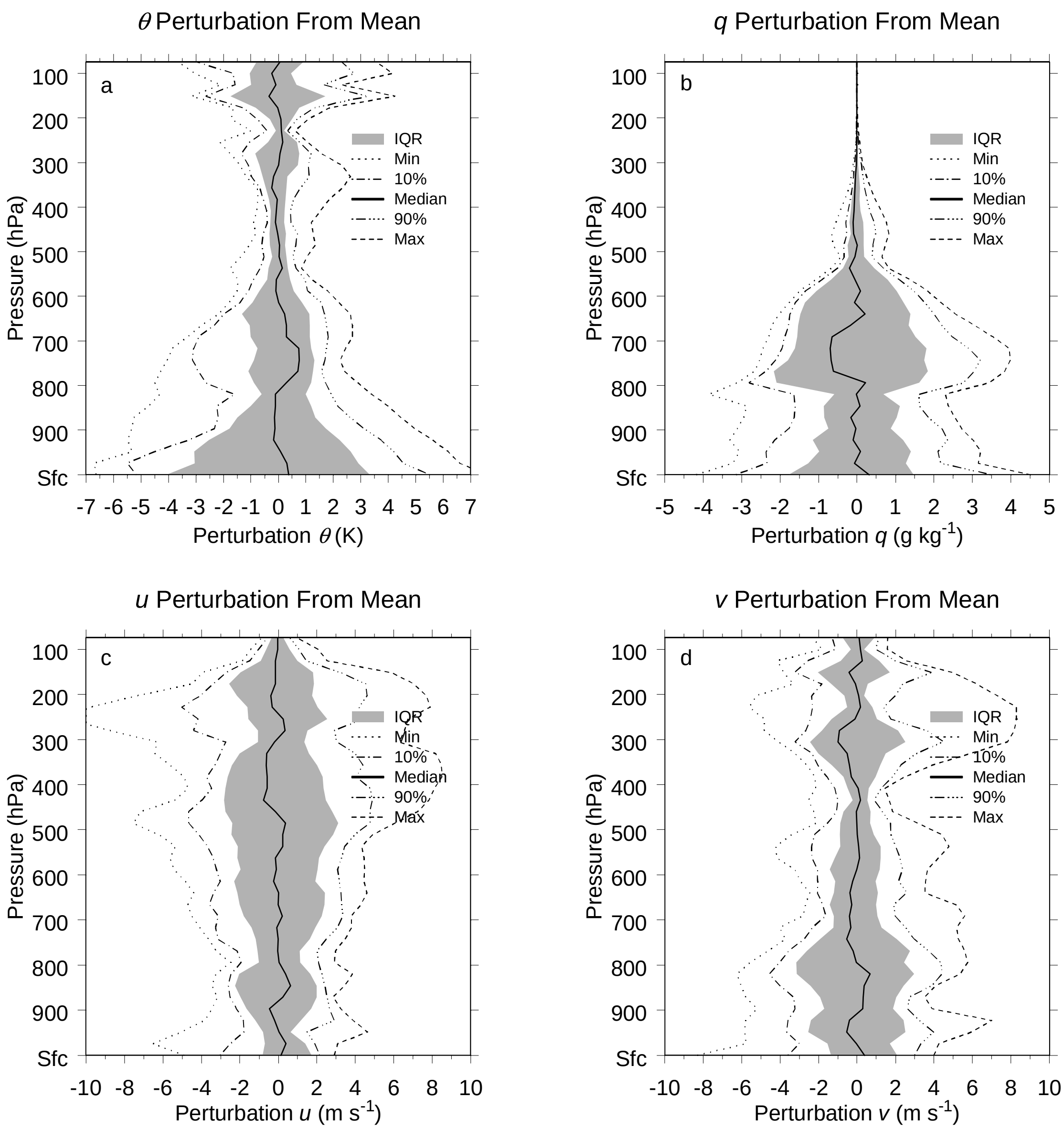

FIGURE 1. Distribution of forecast sounding parameters from daily means for 6/7 June 1996: a) potential temperature (θ), b) mixing ratio (*q*), c) *u*, and d) *v*. The solid line shows the median, and the grey region contains 50% of the data. The 10^{th} and 90^{th} percentiles are shown by dash-dot and dash-dot-dot-dot patterns (containing 80% of the data) as are maximum (dashed) and minimum (dotted) values.

erally should results be interpreted? If they are not interpreted literally, how are error bounds placed on the results? Keep in mind that a single model run cannot explicitly or objectively provide guidance about possible forecast errors. If a model run provides only one possible atmospheric state, how likely is the atmosphere to attain this state? What is the range of other, equally plausible states the atmosphere might also attain?

Anyone who studies thunderstorms, including the mythical, ever-present "casual observer" to whom everything is obvious, has noticed that on any given day, none of the storms are alike. Even on "outbreak" days, when tornados are considered commonplace, only a few thunderstorms, out of all that occur, actually produce tornados, and a few more reach severe limits without producing a tornado. The rest of the a storms do not produce severe weather. For example, a tornadic thunderstorm will often be in close proximity to a non-tornadic, and possibly non-severe, thunderstorm (as anyone who chases can attest). Therefore, there must be a range of thunderstorm characteristics. Rather than try to identify which particular thunderstorm will produce severe weather, an ensemble (or Monte Carlo) approach attempts to determine the likelihood of thunderstorms with the potential to produce severe weather.

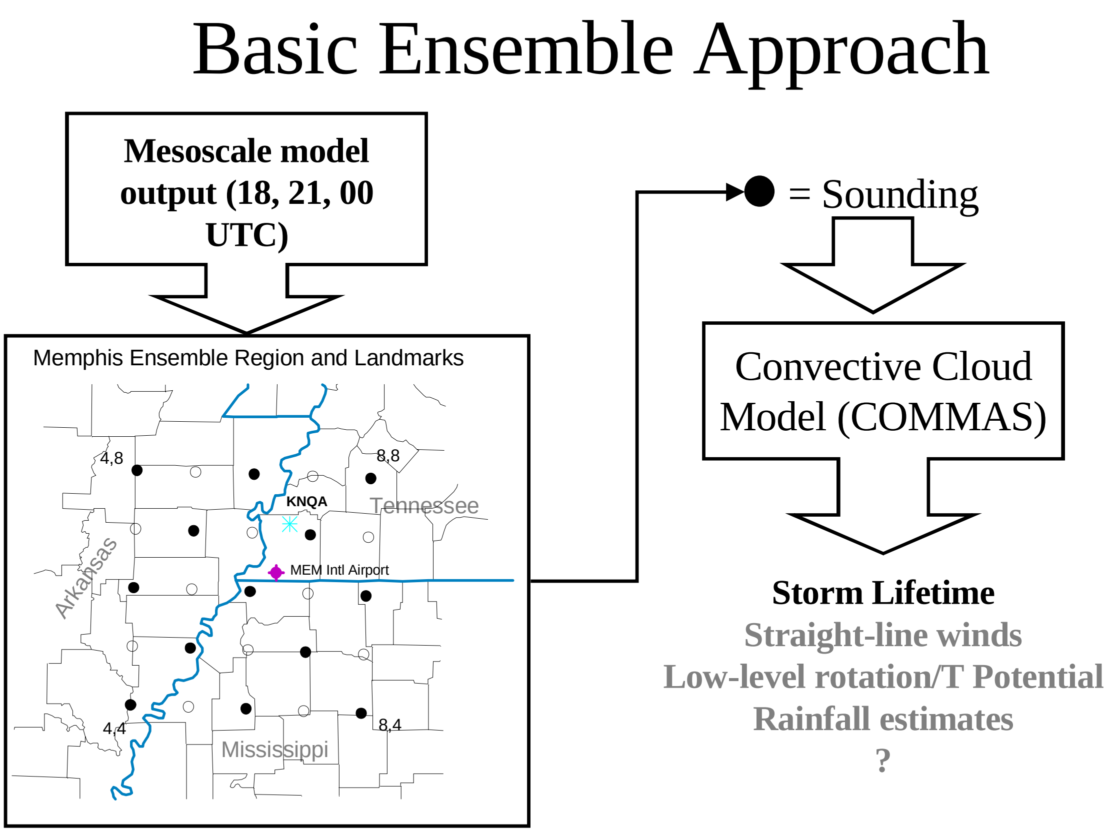

FIGURE 2. Ensemble generation method. Sounding data are derived from a mixture of the NCEP operational eta model, the RUC20 model, and the 22 km eat model run using the Kain-Fritch convective parameterization. This region is near Memphis, TN. The MEM International Airport is labeled, as is the Memphis WSR-88D location (KNQA). Filled dots indicate grid points from which soundings are extracted; open circles show available soundings that are not used.

Often, mesoscale models generate forecast soundings that display surprising differences over small regions and brief time periods (Fig 1). In the familiar ensemble modeling approach, a

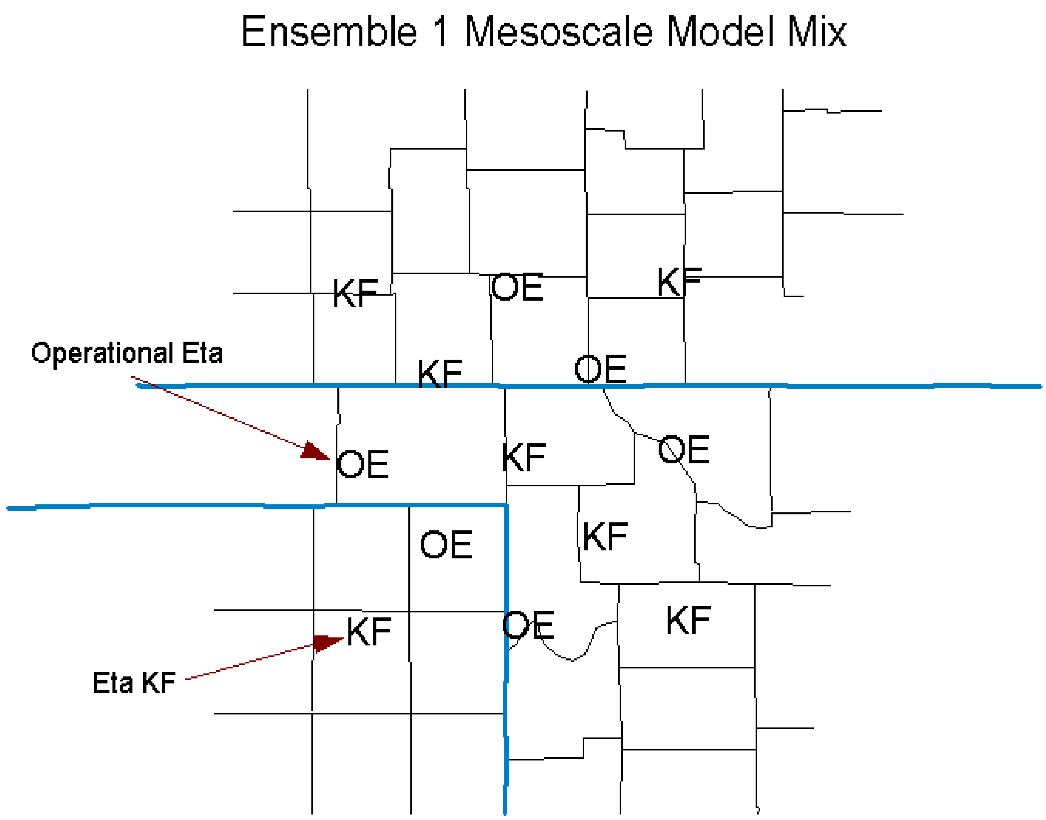

FIGURE 3. Map showing how the EtaKF and Operational Eta mesosocale models are combined. All soundings at locations marked KF are from the EtaKF, while all soundings from locations marked OE are from th eoperational Eta.

number of models are run. These may be completely different models, or the same models that start with different initial analyses. All of the resulting model output is then somehow combined, often by averaging, to yield a forecast that is statistically the "best," in that the expected error between the forecast and the verifying observation set is small. This makes sense for a single system: the atmosphere can possess only a single state at any one time. The same is true of a single thunderstorm. But thinking this way makes little sense when we consider a set of thunderstorms, such as will occur over some finite area. There will be many storms in such an area. Ensemble cloud modeling attempts to answer the question: What will be the range of characteristics that can be expected of storms over at given area during a given period?

The cloud model ensemble consist of 39 separate cloud model runs, each initialized with a different sounding. The cloud model used here is the **CO**llaboartive **M**odel for **M**esoscale **A**tmospheric **S**imulation (COMMAS) developed by Dr. Lou Wicker. It is initialized as a horizontally homogenous environment using a single sounding, derived from a mesoscale model. The soundings come from a 160 ×160 km region over a period of 9 h (Fig. 2). Two, separate ensembles are run. the first uses a mixture of the operational eta and the eta run at 22 km grid spacing using the

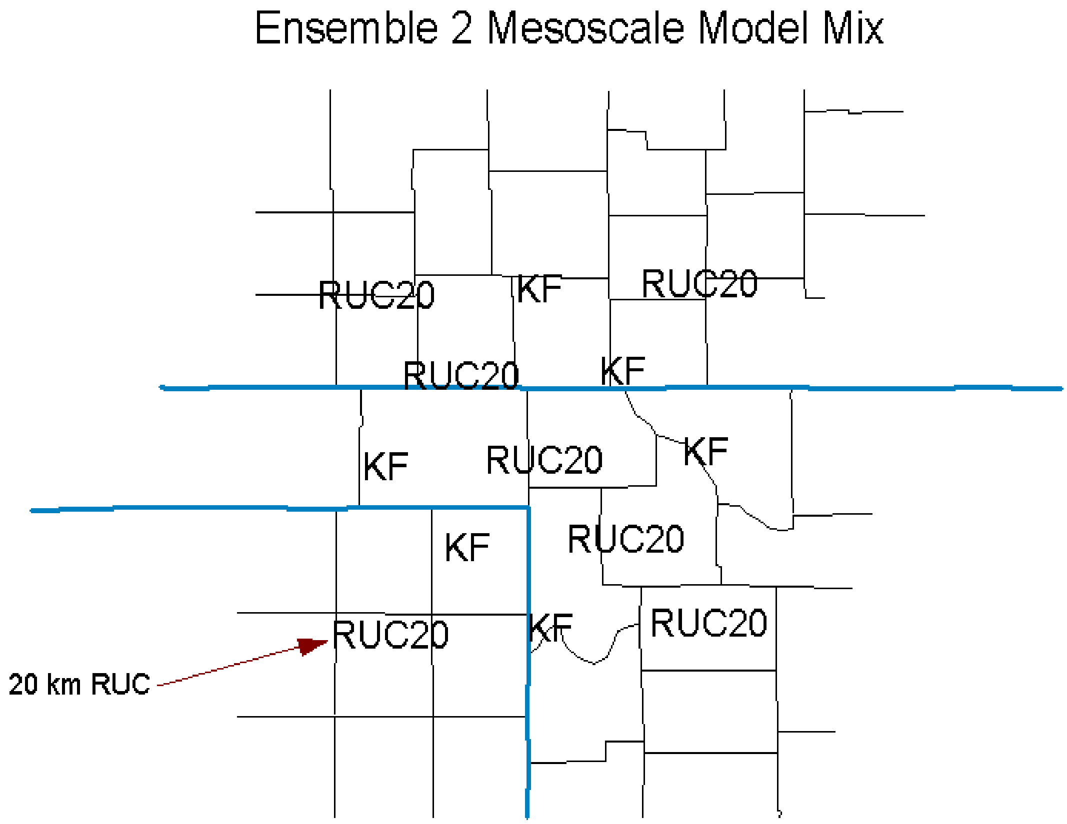

FIGURE 4. Same as Fig. 3, but for a mix of the RUC20 and EtaKF.

Kain-Fritch convective parameterization (called the EtaKF, Fig. 3). The second ensemble uses a mixture of the RUC20 and the EtaKF (Fig. 4). The cloud model uses 1.25 km horizontal grid spacing and a stretched vertical grid with an equivalent computation spacing of 450 m. the model is run for a 2 h simulation and convection is initialized with a 3.5 K warm bubble. Because a warm bubble constitutes and unbalanced initial state, there is a "spin-up" period for the model. Hence, the first 30 min of simulation time is discarded. Note that this kind of initialization does not help determine *if* convection will occur. Insight into convection initiation is generally not available from the ensemble. The ensemble provides conditional guidance; should storms occur, the ensemble is intended to provide insight into the nature of the convection.

The maximum vertical velocity anywhere in the grid domain is retained from each run. A storm is defined to exist when the maximum vertical velocity exceeds 8 m s^{-1} (Fig. 5). A time series of the maximum vertical velocity is analyzed to yield likely modes for the convection. For example, there may be a strong, long-lived mode, a medium length and medium strength mode, and finally and short, weak "pulse-type" mode (Figs. 6a and b). Thus, the range of storm behavior can be estimated at a glance.

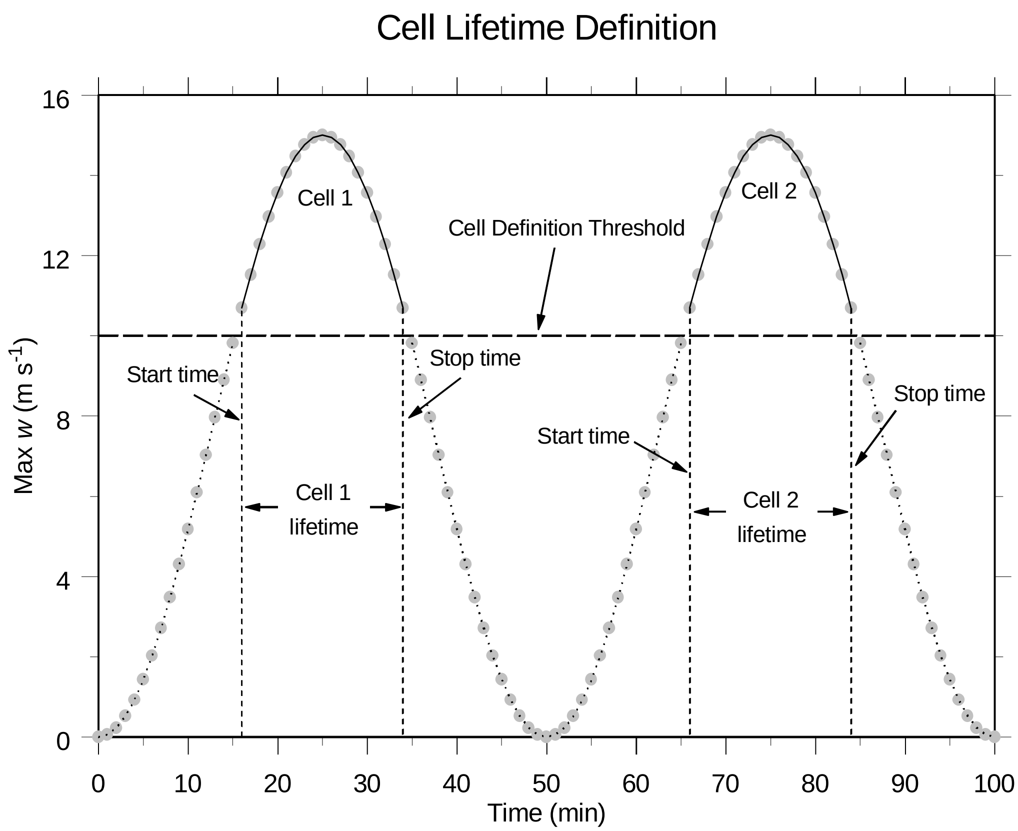

FIGURE 5. Schematic representation of how cell lifetime is determined. The data interval is 1 min and is shown by grey dots. Solid traces show the period for which cell lifetime is counted, and dotted traces show the period for which cell lifetime is not computed. The threshold that defines the existence of a cell shown by the horizontal dashed line at $w \geq 10$ m s^{-1}. Vertical short-dashed lines show the time intervals for which cell lifetime is counted. Two, separate, distinct cells are shown.

The probability that storms have a lifetime between, say, 45 and 60 min, is provided with the help of a kernel density estimate (Fig. 7). The kernel density estimate generates a probability density function (pdf). Viewing the pdf also yields insight into how storms might behave. Later in the season, the likelihood of supercells will be estimated using the correlation between vertical velocity and vertical vorticity.

Previous work has shown that when the ensemble generates cells that last longer than 60 min, it is likely that severe weather reports will be generated, though the nature of those reports (whether they are tornadoes, hail or straight-line winds) is not known. Also, previous work has shown that, under certain conditions, the ensemble provides information about where convection is most likely (Fig. 8).

On a daily basis, SPC forecasters will be asked to choose a target area for the cloud model ensemble run. Initial conditions will be extracted from that region, and the ensemble will be created. Output should be available by 10 AM each morning. Output will consist of maps of the grid points that generate deep convection and the associated storm lifetime (encoded by color) for each ensemble and for both ensembles combined (the Super Ensemble), plots of the convective mode analysis for each ensemble and the Super Ensemble, a plot of the pdf for each ensemble, a plot of all the individual maximum vertical velocity time series for each ensemble member for both

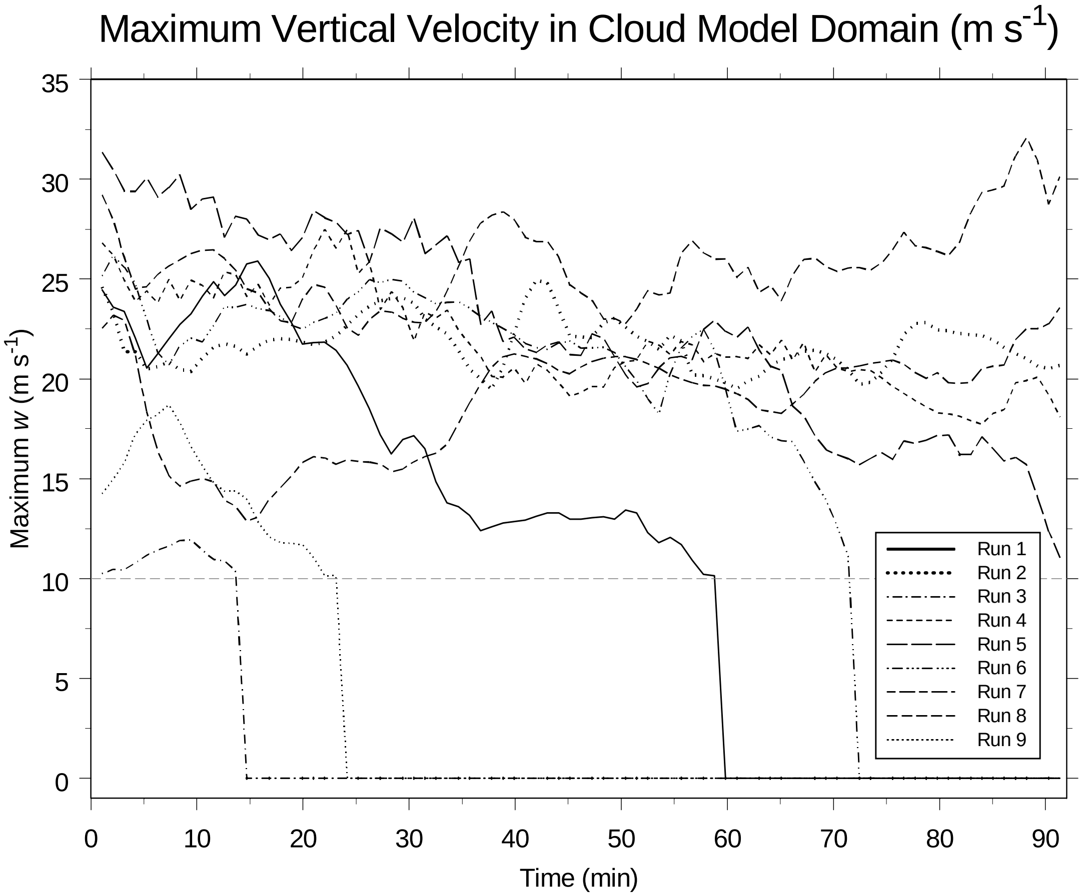

FIGURE 6A. Raw vertical velocity time series from nine ensemble members.

ensembles and the Super Ensemble, and a plot any cells that meet supercell criteria, defined as any cell that lasts longer than 40 min and displays a correlation of 0.5 or greater between mid-level vertical velocity > 1 m s^{-1} and mid-level vertical vorticity for at least 20 min.

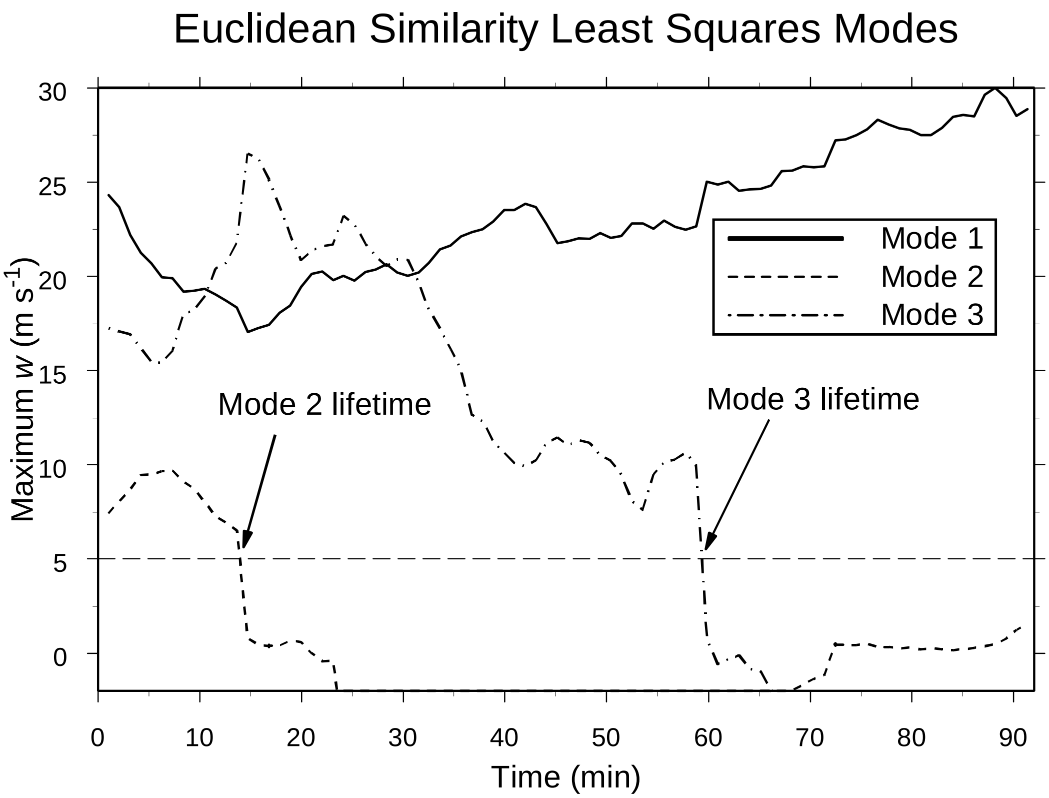

FIGURE 6B. Modes extracted from the time series in Fig. 2a.

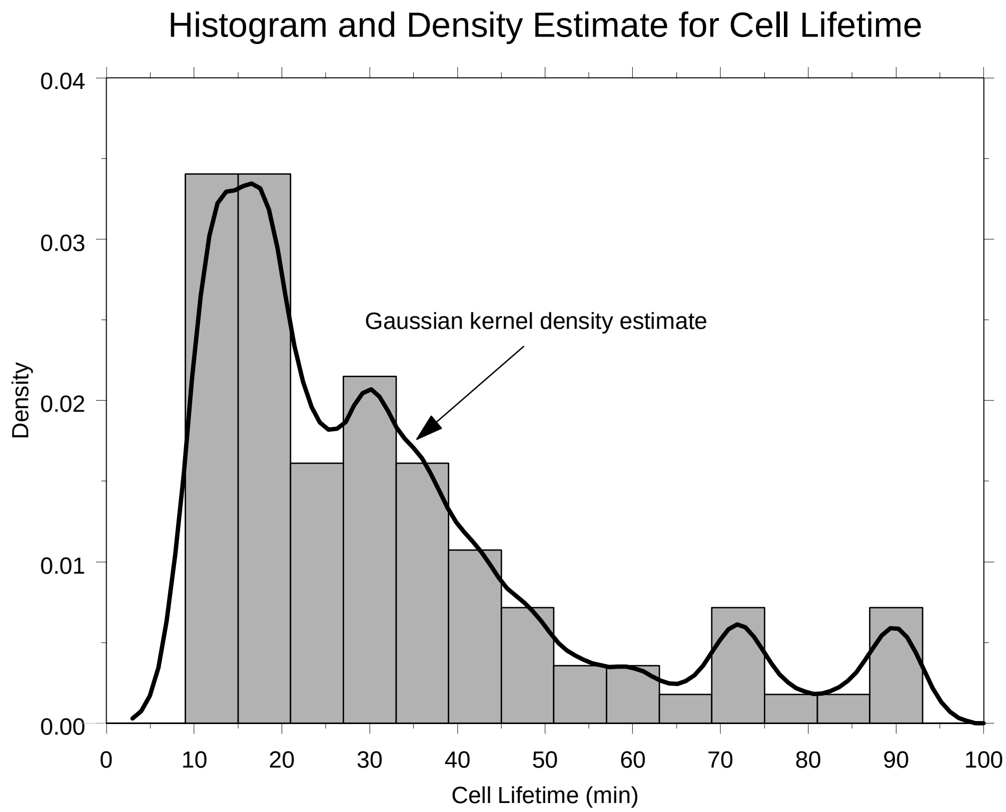

FIGURE 7. Schematic of a kernel density estimate. The kernel density estimate is similar in appearance to a smoothed histogram. The probability that a storm lasts between 45 and 60 min is the area beneath the solid curve. Unlike a histogram, the probability density function is continuous.

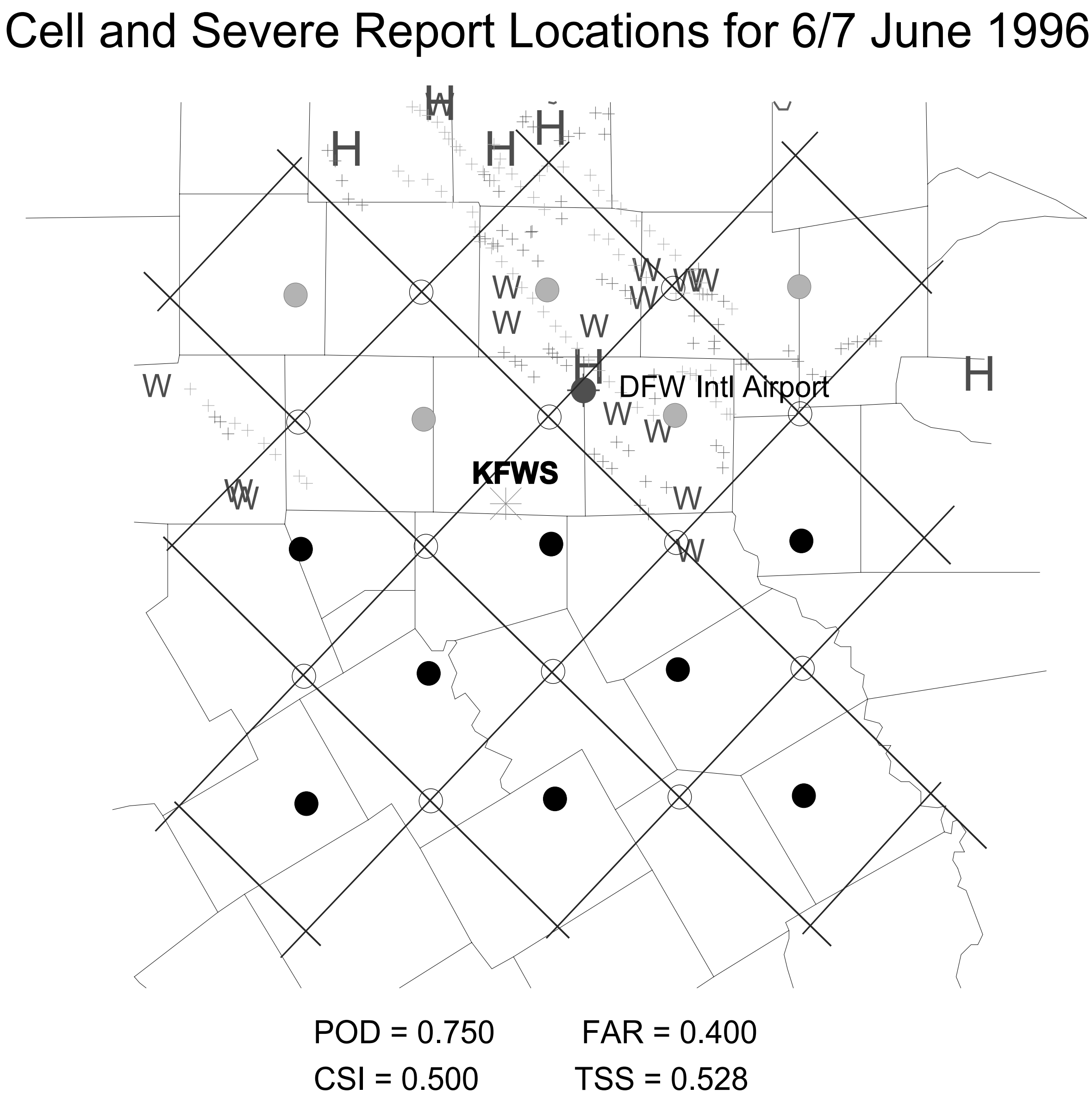

FIGURE 8. Observed storm locations for 6/7 June 1996. Grey crosses show locations for all storms that last 30 min or less, and lighter crosses show the same for cells that last longer than 30 min. Grey dots represent locations that generate soundings which result in deep convection (defined as a cell that lasts longer than 6 min with *w* at least 8 m s^{-1}) within the ensemble model. Skill scores, based on whether cells were observed within the diamond boxes around each grid point, are shown at the bottom of the figure. The w symbol shows the location of a severe wind report and the H symbol shows the location of a severe hail report, between the hours of 2230 UTC 6 June 1996 and 0730 UTC 7 June 1996.