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Application of Ensemble Kalman filter (EnKF) using real radar data is a promising while challenging issue Up to now, storm forecast from EnKF analysis using real radar data is often unsatisfactory. In the real world, when mesoscale forcing is involved with convective storm initiation, relevant atmospheric processes span multiple spatial-temporal scales. The multi-scale complexity is believed to be an important factor in the EnKF assimilation and forecasting for storms using real radar data. To address this multi-scale issue, an analysis procedure involving multiple domains of different resolutions is designed. EnKF using radar data is run on the finest (inner-most) domain. The analysis of non-radar observations on the outer domains provide improved initial conditions for EnKF using radar data. EnKF using high-resolution Mesonet wind observations are run on the intermediate domain and its initial ensemble perturbations are designed to sample mesoscale uncertainties. With additional convective scale perturbations introduced to the convective analysis, multi-scale forecast errors are much more adequately sampled. For a supercell storm case chosen in this study, in the 65 min forecast from the mean analysis using radar, the supercell storm movement is captured well and the forecast of hook echo and low level vorticity is reasonable. Besides this encouraging progress, outstanding problems are also documented.

Multiscale analysis procdure

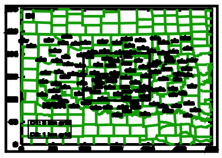


Fig.1. Two nested domains.D1 is the domain of horizontal resolution 3 km and D2 the domain of 1 km resolution. Mesonet stations and KTLX and KFDR radars are also labeled. The coordinates are in kilometer.

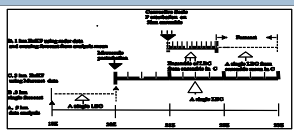


Fig. 2.Diagram for the multiscale analysis procedure

The most outer domain (D0) of 9 km horizontal resolution covers the whole North America and the inner two domains (D0 and D1) are of horizontal resolutions of 3 km and 1 km as shown in Fig. 2. For D1 (Panel A), hourly analyses between 1800 UTC, 8 May and 0000 UTC 9 May, 2003 are obtained using the ARPS 3DVAR using available sounding and surface observations, as described in Hu and Xue (2007). They provide unperturbed lateral boundary conditions (LBCs) to the 3 km model runs. As shown in Panel B of Fig. 2, a single pre-forecast at the 3 km horizontal resolution is first performed from 1800 UTC, starting from ARPS valid at 2000 UTC, is used as the background to initialize 3 km EnKF in Panel C.

To initialize the 3 km ensemble at 2000 UTC, perturbations aimed at sampling mesoscale uncertainties are introduced (Lei, et al.,2009). Starting from this set of perturbed initial conditions at the 3 km grid at 2000 UTC, fifteen-minute-long EnKF analysis cycles are performed through 2300 UTC, analyzing Oklahoma Mesonet wind observations.

To initialize the 1 km EnKF analysis cycles, the 3 km ensemble analyses are interpolated to the 1 km grid at 2100 UTC. Additional convective perturbations are added to these 1 km analyses, and the perturbations are generated by applying a smoothing procedure on random perturbations, as described in Tong and Xue (2008). The 1 km EnKF analysis cycles using radar data are then started from 2105 UTC every 5 minutes.

Performance of the mulsticale anlaysis procedure

Forecasts without EnKF radar analysis

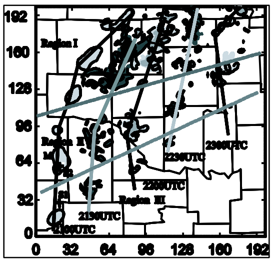
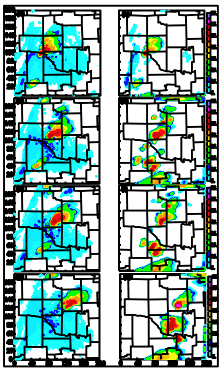


Fig. 3. The grayscale map of vertical velocity in the 1 km baseline forecast (see text) at 7 km MSL from 2100-2300 UTC at 30 min intervals in the 1 km domain D2 with coordinates in kilometer. Only values larger than 5 m s-1 are shown. The grayscales of the shade at two consecutive times are different. The dotted lines separate the whole domain into three regions: I,II and III. The solid lines join major forecast cells validate at the same time (tagged with those lines) for those cells on the former. The cross signs tagged with S1 and S2 indicate position of soundings generated at 2100 UTC allowing for growing "thermal bubble initialized" storms .

Forecasts from EnKF radar analysis



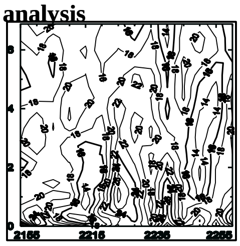


Fig. 5. Time and Height figure of the maximum vertical vorticity (s^{-1}) associated with the main storm (see text) multiplied by 1000 at each height in the forecast initialized from the ensemble analysis mean at 2155 UTC in Ectr_1km to 2300 UTC. The vertical coordinates are height above the ground in kilometer. The horizontal coordinates are universal time in May 8th 2003.

Fig. 4 (left). Reflectivity at 0.45° elevation angle in 1 km domain D2 with coordinate in kilometer at 2155,2220 2230 and 2300 UTC respectively from first row to the fourth row. The left column is for observations by KTLX, and the right for projections from the ensemble analysis mean (b) and subsequent forecast (d,f and h) in the control run.

Summary: The forecast supercell storm maintains its strength and propagates in good agreement with observations. The forecast hook echo appears at about 2200 UTC and disappears at 2255 UTC. This time span matches well with observed hook echo. The existence of low level vortex couplet straddling the hook echo in the forecast is consistent with conceptual models (Straka et al. 2007)). The forecast maximum vertical vorticity at each height reasonably captures some basic evolution characteristics of observation in Burgess, et al. (2004), though there are also recognizable forecast errors. An obvious shortcoming is the continued development of the south storm in the forecast, which decayed at about 2250UTC in reality.

The only difference is that the fields at 2045UTC are used at 2100UTCT to initialize the 1 km EnKF with a 15 min -backward error. In the so generated initial condition at 2100UTC, the convection line now is displaced to the west and outside of the observed radar echo. \
The following are a few comparisons between the control run and Em15m. Except for Fig. 6, the left is for analysis mean of the control run and the right for Em15min at the final cycle at 2155UTC..

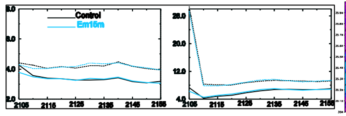


Fig.6, Innovation on radial velocity (left) and reflectivity (right) observed by KTLX. Solid lines are for analysis mean,dashed for forecast mean and black for the control run and the blue for Em15m.

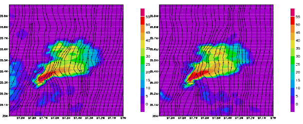


Fig.7. Analyzed reflectivity and stream lines at 1 km AGL

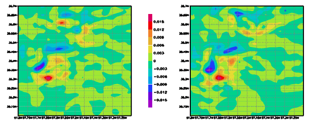


Fig.8. the vertical voriticity at about 7.5 km AGL

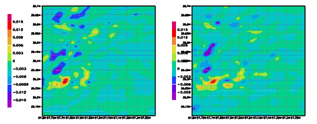


Fig.9. the vertical voriticity at about 3 km AGL

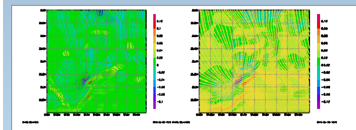


Fig.10.Vertical velocity and stream lines at 10 m AGL.

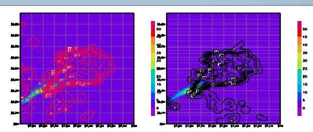


Fig.11. The accumulated precipitation during the radar data analysis cycles (2105-2155). The analyzed reflectivity mean at 10 m at 2155UTC are also overlapped.

Analysis: 1. the above comparison (Fig.6-10)show analysis of Em15min at 2155UTC is apparently similar to the control run, while many supercell characteristics are retrieved. 2. Potentially significant difference exist, including weaker downdraft,weaker cold pool and less organized vertical vorticity at the region near 2-3 km ABL.

Forecast: The forecast storm initialized from 2155UTC decays in 30 min in Em15m. Through forecast experiments with mutual replacement of either kinematic or thermodynamic fields in analyses of the control run and Em15, it's evident that errors in the analyzed storm kinematic structures cause the forecast storm to decay quickly.

Questions: Is it the kinematic storm structure that can't generate required vertical pressure gradients to maintain the supercell storm? Does and how the unrealistic precipitation process in the analysis cycles(almost only half of that in the control run, as evident in Fig.11) contribute to errors in the analyzed storm kinematic structure?

The forecast storm initialized from 2230UTC decays after 30 min in Em15m. It apparently indicates that EnKF using radar is reducing the relevant errors existing at 2155UTC, though not enough.

Discussion

Many factors, like model errors, can contribute to less satisfactory analysis of radar data retrieving dynamical processes responsible for supercell storm maintenance. Multiscale complexity is highlighted and addressed by the proposed multiscale analysis procedure in this work. The different performance between the control run and Em15min reveal: (1). A mechanism through which the multiscale analysis procedure are supposed to address and, hence, significantly improve the EnKF using radar data. (2) An indication of less than satisfactory ability of EnKF using radar in this Multiscale analysis procedure to deal with gross errors in its initial condition.

. There are two important components in this multiscale analysis procedure. The first is the multiscale construction of ensembles. The second key component is the multiscale analyses (in 9 km and 3 km grids in this work) to improve representation of convection /storm initiation and, hence, better initial conditions for EnKF using radar data. Em15m also reveals how gross errors in initial deep convection positions can cause failure in the storm-scale EnKF analysis and subsequent forecast.

Convection initiation (including storm initiation) is itself a challenging issue. Methods of its representation are not the focus of this work. The multiscale analysis procedure is designed to make use of the state of the art methods of convection initiation representation, and its' performance depends on the later.

Much work is to be done, including, for example, test and development of the surface observation operators used in high resolution models and schemes to use them in this multiscale analysis procedure. Also, in present configuration, the observations analyzed after the next level analysis (at finer grids) has begun are not considered to have any significant impact on the latter. Those analyses of those observations can be skipped to save a significant computation burden. Of course, study of use of those observations in the finest grid is also worthy.

Studies on the reasons of unrealistically quickly decaying storm in the forecast from mean analysis of EnKFuing using radar data, like the forecast from 2155UTC in Em15m, will benefit much to this fields. A existing good forecast as the comparison, like the control run in this work, will be helpful.

In current EnKF using radar data, the horizontal (vertical)covariance localization radius is 6 (4) km. That horizontal radius is less than expected when the covariance contains multiscale information about the forecast errors. But significantly larger radius (say, 12 km) will cause the member forecast unstable during the analysis cycles. Hence, multiscale methods dealing with the multiscale covariance, like Zhou,et al.,2006, are desirable.

Reference

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