Retrieving Precipitation Microphysical State of Convective Storms Using Radar Data and the Ensemble Kalman Filter

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Introduction

An important piece of the puzzle for improving numerical weather prediction (NWP) is understanding the microphysical state of the system, specifically the size and shape of the hydrometeors. This includes knowledge of hydrometeors for model initialization. Basically, less currently used methods currently estimate cloud liquid water content and cloud ice water content using the Simple Cloud Model. However, many hydrometeor models are designed to handle ice hydrometeors, and this method is now known as hydrometeor type and needs at least the same number of independent measurements as the number of hydrometeor parameters sought. In reality, multiple species of hydrometeors exist in a convective system and there are additional parameters needed to estimate these species, specifically for multi-modal hydrometeor schemes in NWP models. In this case, model-based retrieval using the Ensemble Kalman Filter (EnKF) yields promising results. The EnKF uses ensemble covariances to update the microphysical state variables based on both observed reflectivity (Z) and radial velocity (Vr). These state variables can then be used to improve the OISD parameters.

For this study, the EnKF was applied to a mesoscale convective system (MCS) that passed over western Oklahoma early on May 9, 2007. Both a single-moment (SM) and three-moment microphysics scheme and a MesoNEX and You double-moment (DM) scheme were used in multiple experiments. Previous research has shown that use of a DM scheme over a SM scheme results in a significant improvement in the representation of the microphysical state of a MCS, specifically for the size sorting of hydrometeors. The event was observed by the Oklahoma Mesonet (OM), a network of 120 automated weather stations, and the National Weather Service, which gathered radar, satellite, and in situ data to support research on the event. The data were analyzed using the radar and satellite data and assimilated into the model using the EnKF to see if the system could improve the model's predictions.

Methodology

• CAPS Advanced Regional Prediction System (RAPPS) fully compressible, non-hydrostatic storm-scale model used.
• Model domain: 267 x 267 x 43 with 3km horizontal resolution and stretched vertical resolution with average spacing of 50m.
• Initial model variables, land boundary conditions, and surface conditions interpolated from 120km NCEP F90 0000 UTC 0000 UTC (NAM) model output.
• 48 NWP ensemble generated from 1 hour forecast by adding random, smoothed, Gaussian perturbations to each of the 48 hydrometeor state variables.
• Level 2 and 3 observations assimilated from 5 regional WSR-88D radars as well as the radar network.
• Analysis period consisted of 5 forecasts and assimilation cycles (2 and 3 UTC) on 1 hour centered between 0330 and 0900 UTC.
• 3 hour deterministic forecast made from the final ensemble mean analysis.

Microphysics schemes used included SM microphysics between members that consisted of 16 Lin et al. (1983) LWP members, 16 Weather research and Forecast (WRF) model SM and 4-knot microphysics scheme (Kumjian and Lin 2000) (WRF) members, and 8 simplified NWP explicit microphysics (NEM) members (Schulte 1999). To increase ensemble spread (Kumjian et al. 2011) for SM assimilation, and MesoNEX and You (2009) DM microphysics scheme for DM assimilation.
• Lin scheme used for SM forecast and MRF scheme for DM forecasts.
• Interpolant parameter used for rain adjusted by a factor of 10 from 8 x 10^5 m^-2 as is typically used in the LLF scheme to 8 x 10^-5 m^-2.
• The shape parameter was set to 0.5 in all cases.

Results

Fig. 1: Observations of total liquid water content (LWC, kg m^-2) at the surface and at 2500 m asl. LWC was defined as the sum of liquid water in rain, drizzle, and cloud and the water content of cloud. LWC at the surface was calculated as the sum of rainfall and drizzle, while LWC at 2500 m asl is the sum of cloud water and liquid water in the stratiform region. The LWC at the surface was calculated as the sum of rainfall, drizzle, and cloud.

Fig. 2: Observations of total liquid water content (LWC, kg m^-2) at the surface and at 2500 m asl. LWC was defined as the sum of liquid water in rain, drizzle, and cloud and the water content of cloud. LWC at the surface was calculated as the sum of rainfall and drizzle, while LWC at 2500 m asl is the sum of cloud water and liquid water in the stratiform region. The LWC at the surface was calculated as the sum of rainfall, drizzle, and cloud.

Fig. 3: Observations of total liquid water content (LWC, kg m^-2) at the surface and at 2500 m asl. LWC was defined as the sum of liquid water in rain, drizzle, and cloud and the water content of cloud. LWC at the surface was calculated as the sum of rainfall and drizzle, while LWC at 2500 m asl is the sum of cloud water and liquid water in the stratiform region. The LWC at the surface was calculated as the sum of rainfall, drizzle, and cloud.

Fig. 4: Observations of total liquid water content (LWC, kg m^-2) at the surface and at 2500 m asl. LWC was defined as the sum of liquid water in rain, drizzle, and cloud and the water content of cloud. LWC at the surface was calculated as the sum of rainfall and drizzle, while LWC at 2500 m asl is the sum of cloud water and liquid water in the stratiform region. The LWC at the surface was calculated as the sum of rainfall, drizzle, and cloud.

Fig. 5: Observations of total liquid water content (LWC, kg m^-2) at the surface and at 2500 m asl. LWC was defined as the sum of liquid water in rain, drizzle, and cloud and the water content of cloud. LWC at the surface was calculated as the sum of rainfall and drizzle, while LWC at 2500 m asl is the sum of cloud water and liquid water in the stratiform region. The LWC at the surface was calculated as the sum of rainfall, drizzle, and cloud.

Fig. 6: Observations of total liquid water content (LWC, kg m^-2) at the surface and at 2500 m asl. LWC was defined as the sum of liquid water in rain, drizzle, and cloud and the water content of cloud. LWC at the surface was calculated as the sum of rainfall and drizzle, while LWC at 2500 m asl is the sum of cloud water and liquid water in the stratiform region. The LWC at the surface was calculated as the sum of rainfall, drizzle, and cloud.

Conclusions

Both SS and SD M are used in terms of structure and microphysical state and combined spurious connection. However, SD M improved near the end of the forecast period as the system adjusted to the DM scheme.

Use of DM scheme during assimilation provided a better representation of the microphysical state of the system, specifically the size sorting of hydrometeors in the leading convective line and the size of droplets in the stratiform regions.

The DM forecast showed significant improvement in the structure of the system, including the breadth and vertical composition of the leading stratiform region and extent of the trailing stratiform region and leading convective line.

The DM forecast also showed improvement in the size sorting of droplets in the leading convective line and the size of droplets in the stratiform regions, as in the final analysis.

More significant improvement in DM was hampered by excessive hail production. An experiment with gridded instead of random resulted in excessive large hail and no structural improvement (not featured).

DD M analysis contained excessive hail and had a poorer 2 h to the observations in the stratiform region in the forecast.

DD R had a poorer handle on the leading convective line and the extent of the stratiform region was greater than observed.

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