Radar Data Quality Control and Assimilation at the National Weather Radar Testbed (NWRT)

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LONG-TERM GOALS

Study and develop advanced approaches for radar data quality control (QC) and assimilation that will not only optimally utilize Doppler wind information from WSR-88D and Terminal Doppler Weather Radar (TDWR) but also take full advantage of rapid and flexible agile-beam scans from the phased array radar (PAR) at NWRT.

OBJECTIVES

Develop new variational methods to improve the existing radar wind analysis system so it can be applied to any radar scans to produce real-time vector wind displays and monitor data quality. Study radar data quality problems and develop statistically reliable quality control (QC) techniques. Explore new data assimilation techniques to optimally utilize the PAR scan capabilities.

APPROACH

Continue monitoring the real-time performances of the radar data QC packages (delivered to NRL and NCEP) with operational raw level-II data collected in different regions under various weather conditions (especially high-impact weather conditions). Develop reflectivity-velocity combined radar data QC and assimilation capabilities that expand and upgrade the existing radar data QC and assimilation packages.

Use the modern information theory to study how to measure information content from observations for data assimilation and design data compression strategies for the existing and currently developed assimilation capabilities based on the information theory.

Develop a new proto-type ensemble hybrid filter to combine the merits of the ensemble-based filters (such as the ensemble Kalman filter) and variational data assimilation (such as the 3.5dVar delivered to NRL) for flow-dependent covariance estimation and high-resolution radar data assimilation. Toward this goal, the first step is to explore new ideas and sampling techniques to improve the covariance estimation and computational efficiency of the existing ensemble-based filters.

The PI, Dr. Qin Xu, is responsible to derive basic formalisms and technical guidelines for the implementations. The data collections and QC algorithm developments are performed by project-supported research scientists at CIMMS, the University of Oklahoma. Collaborations between this project and the development of the NWRT PAR is coordinated by Douglas Forsyth, Chief of NSSL's Radar Research and Development Division. Dr. Allen Q. Zhao at NRL Monterey and Drs. Shun Liu and David Parrish at NOAA/NCEP (Liu *et al.* 2009) perform pre-operational tests as the radar data QC and assimilation packages are further upgraded and delivered.

WORK COMPLETED

Further tested the radar data QC packages (delivered to NRL and NCEP) with raw level-II data collected from the operational KTLX radar and many other operational WSR-88D radars under various high-impact weather conditions (Xu *et al*. 2009c, 2010b). An automated system was built to monitor and record the real-time performances of the QC for data assimilation applications.

The alias-robust VAD method (Xu *et al*. 2001a) was used to provide the background wind for the automated radar-based wind analysis system (RWAS, Xu *et al*. 2009a), while the latter was used to monitor low-level wind conditions over high-impact weather threatened areas in real time. The mesoscale environmental wind field produced by the RWAS was then used as the background and first guess for the simple adjoint (SA) method (Xu *et al*. 2001) to retrieve three-dimensional wind field at high spatial and temporal resolutions from PAR observations. The SA method was further developed into a two-step method to retrieve the horizontal wind field on the conical surface of radar scan at each elevation first and then the vertical velocity in selected vertical cross-sections. The two-step method was tested with PAR observations for selected cases of severe storms.

Integral formulae were derived for partitioning horizontal velocity into velocity potential and streamfunction in a limited domain of arbitrary shape (Xu *et al.* 2010d). In the absence of internal boundary (caused by data hole), the total solution is the sum of two integral solutions. One is the internally induced solution constructed uniquely from the divergence and vorticity inside the domain. The other is the externally induced solution produced purely but non-uniquely by the domain-external divergence and vorticity. By setting either the velocity potential (or streamfunction) component to zero, the other component of the externally induced solution can be expressed by the imaginary (or real) part of the Cauchy integral constructed from the boundary conditions that exclude the internally induced solution. In the presence of data holes, the total solution includes a data-hole induced solution in addition to the above internally and externally induced solutions. The data-hole induced solution can be constructed by placing point sources of divergence and vorticity at the centroid of each data hole to represent the net effects of the integrated flux and circulation around the data hole. Built on the above integral formulae, accurate numerical methods were developed for computing velocity potential and streamfunction (Xu and Cao 2010) to facilitate the studies of balanced versus unbalanced dynamics and their utilities in mesoscale data assimilation.

Assimilation experiments were designed and performed with real radar data to test the time-expanded sampling approach (Xu *et al*. 2008a,b) in comparison with the conventional ensemble sampling used by ensemble-based filters, such as the ensemble square root filter (EnSRF). In these experiments, 15, 30, 45 and 60 ensemble members were generated by the time-expanded sampling from only 5, 10, 15 and 20 prediction runs (1/3 of the prediction runs required by the conventional sampling in EnSRF), respectively, the sampling time interval was allowed to vary over a wide range (from 150 to 240 s), and quality-controlled radar data were compressed into super observations with properly coarsened spatial resolutions to improve the EnSRF performances. Through these assimilation experiments, the merits and unitility of the time-expanded sampling approach were further explored and demostrated for real cases.

RESULTS

The SA method (Xu *et al*. 2001) was further developed into a two-step method to retrieve the horizontal and vertical winds from PAR rapid scans of severe storms. In this two-step SA method, the horizontal wind fields on the conical surfaces of radar scans at different elevation angles are retrieved in parallel simultaneously in the first step, and then the vertical velocity is retrieved in selected vertical cross-sections in the second step. Since the horizontal winds are retrieved in parallel at different elevation angles in the first step and the vertical velocity is retrieved with much reduced control variable dimension in the second step, the method is computationally very efficient for real-time applications to PAR rapid scans. The method was tested with the PAR rapid scans of a severe storm and its produced microburst (Qiu *et al*. 2010). An example of the retrieved wind field is shown together with the PAR observed reflectivity on the conical surface at 0.51º elevation in Fig. 1a and in the vertical cross-section in Fig. 1b. The retrieved horizontal flow and downdraft are consistent with the observed reflectivity pattern movements. Similar flow structures and consistencies are seen in all other 27 retrieved wind fields (not shown).

The radial-velocity and reflectivity data collected by the operational KTLX radar for the Oklahoma City tornadic storm on 8 May 2003 were processed through data quality control and then compressed into super observations on each tilt of radar scans to reduce the spatial-resolution redundancy. These super observations were used to test the time-expanded sampling approach (Xu *et al*. 2008a,b) in comparison the conventional ensemble sampling used in EnSRF. The results further demonstrated and verified the effectiveness of the time-expanded sampling in reducing the computational cost and improving the analysis accuracy, especially when the ensemble size is severely limited due to computational constraints for real radar data assimilation (Lu *et al.* 2010). An example is shown in Fig. 2. As shown, the observed storm grew quickly and propagated slowly during this assimilation period (from 12^{th} cycle at t = 2131 UTC 2131 to 16^{th} cycle at t = 2151 UTC). The main pattern of the observed reflectivity, especially the magnitude and locations of observed reflectivity cores, are well captured by TS-3x15 with the time-expanded sampling approach but not by CS-45 with the conventional ensemble sampling. The assimilated storm with the conventional ensemble sampling grows too slow and moves too fast in comparison with the observed storm.

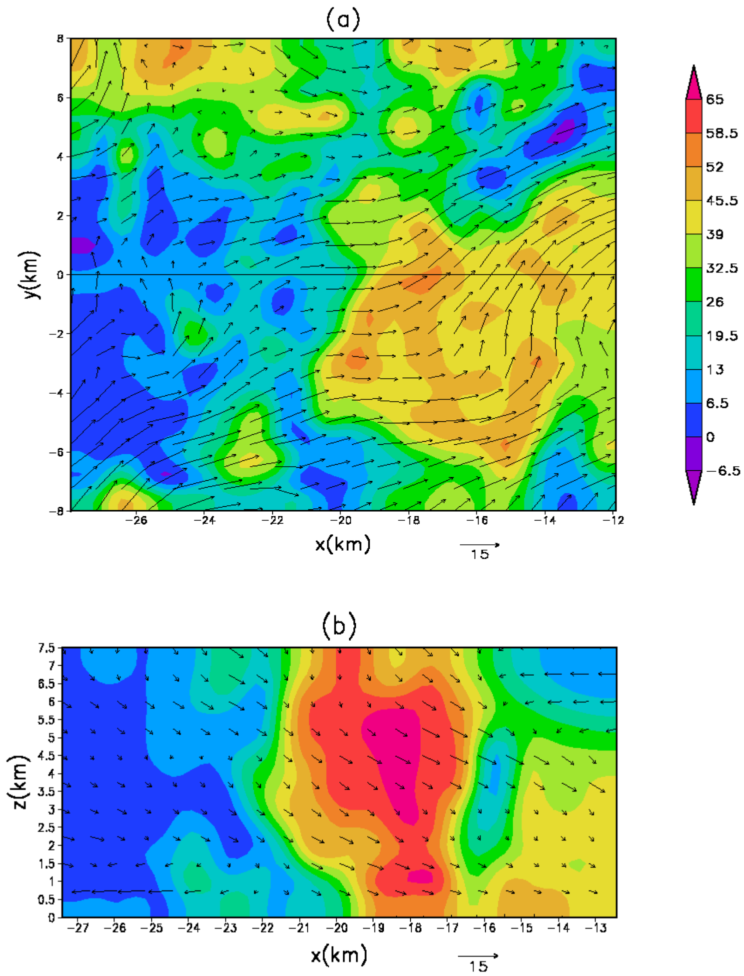

Fig. 1. Retrieved wind vectors (arrows in ms^{-1}) on the conical surface at 0.51º elevation (a) and in the vertical cross-section along the x-axis (b) plotted with PAR observed reflectivity (color in dBZ) over the time window from 1948:33 to 1949:41 UTC for the microburst on 10 July 2006. The x-axis is along the selected radar beam (210.7º azimuth from PAR).

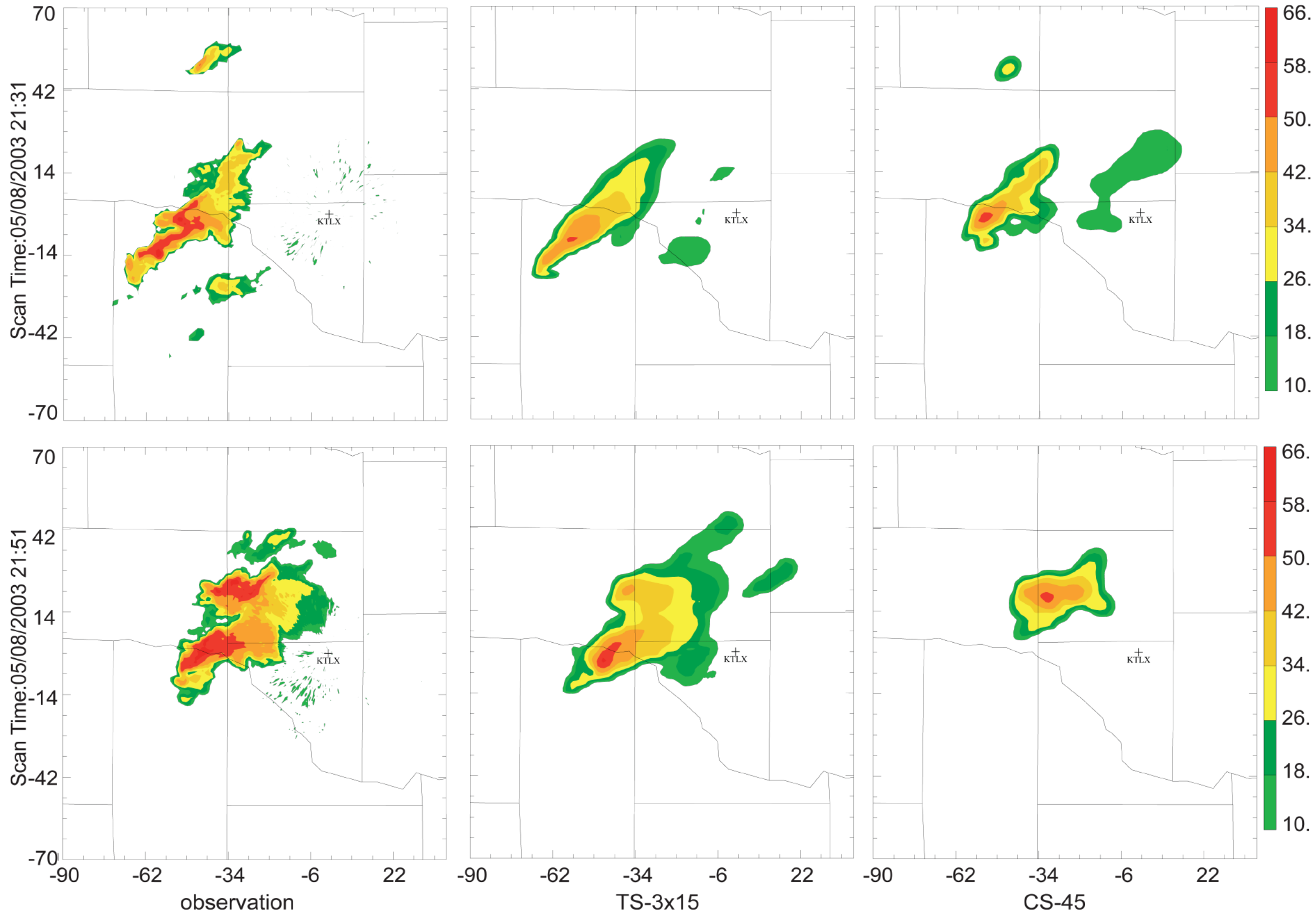

Fig. 2. Observed reflectivity fields (the first column) on the 1.45° elevation at 2131 and 2151 UTC, 8 May 2003, and corresponding analyzed reflectivity fields from two experiments: TS-3x15 (the second column) in which 45 ensemble members are generated by the time-expanded sampling from 15 forecast runs, and CS-45 (the third column) in which 45 ensemble members are sampled by the conventional ensemble sampling from 45 forecast runs. The reflectivity contours begin from 10 dBZ with interval of 8 dBZ. The **x** ***and*** **y** ***coordinates are in kilometers and originate at the radar site.***

IMPACT/APPLICATIONS

Fulfilling the proposed research objectives will improve our basic knowledge and skills in radar data QC and assimilation, especially concerning how to optimally utilize rapid-scan radar observations to improve numerical analyses and predictions of severe storms and other hazardous weather (including chemical-biological warfare environmental conditions). New methods and computational algorithms developed in this project have been and will continue to be delivered to NRL Monterey for operational tests and applications (Zhao *et al*. 2006, 2008), in connection with another ONR funded project entitled “Ensemble assimilation of Doppler radar observations” at NRL Monterey.

TRANSITIONS

The radar data QC package developed in this project was delivered to NRL Monterey for operational tests and applications. The QC package was also made available to NCEP for their operational applications. Based on the feedbacks from NRL and NCEP, the code was upgraded and delivered subsequently. The QC and vector wind retrieval packages in the real-time system were also previously requested by and delivered to Pacific Northwest National Laboratory for real-time implementations over major urban areas to support and initialize their emergency response dispersion models for homeland security applications. The recentlly developed En4DVar will be combined with the time-expanded sampling algorithm for ensemble-based filters and used, in collaboration with Dr. Alan Q. Zhao at NRL Monterey, to develop the hybrid (combined variational and ensemble approaches) data assimilation system at NRL Monterey. The algorithm package will be adapted and tested by the PI's group at CIMMS and then delivered to NRL Monterey for further tests and applications.

RELATED PROJECTS

Radar velocity data quality controls (funded by NOAA/NCEP to NSSL and OU). Multimedia displays of adaptive high-resolution radar wind retrievals over high-impact weather threatened areas (funded by NOAA HPCC to NSSL and OU). Adaptive radar data quality control and ensemble-based assimilation for analyzing and forecasting high-impact weather (funded by ONR to OU). Development of a multi-channel receiver for the realization of multi-mission capabilities at the NWRT (funded by NSF to OU). Ensemble assimilation of Doppler radar observations (funded by ONR to NRL Monterey).

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