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 testing the radar data QC packages (delivered to NRL and NCEP) with raw level-II data collected in different regions (especially along the coasts of the United States) under various weather conditions (especially high-impact weather conditions, such Hurricane Ike landed in Houston TX on 9/13/2008). Collect difficult cases in which quality problems cannot be well detected or corrected by the existing automated QC techniques. Examine the detailed features in each type of data quality problems, and find proper solutions to improve the existing QC techniques.

Extend the recently derived entropy measure of information content from observations (Xu 2007), so it can be applied not only to 3D analyses (produced by the 3dVar and Kalman filter) but also to 4D ananlyses (produced by the 4dVar and Kalman smoother). By analysing the singular-value form of the entropy measure, some guiding principles can be derived to design optimal observation strategies (such as PAR scan strategies at NWRT) for a given data assimilation system.

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.

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14. ABSTRACT
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.

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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 Zhao at NRL Monterey and Dr. David Parrish at NOAA/NCEP (and their colleagues) perform pre-operational tests as the radar data QC algorithms and assimilation packages are further upgraded and delivered.

WORK COMPLETED

The theoretical formulations (Xu 2007) for using the relative entropy and Shannon entropy difference to measure information content from observations were extended for 4-dimensional data assimilation in connection with another known information measure – degrees of freedom for signal, which is defined as the statistical average of the signal part of the relative entropy. The extended formulations reveal that the information content increases (or decreases) as the model error increase (or decrease) and/or become more (or less) correlated in space and/or time. Illustrative examples were constructed to exemplify the properties revealed by the extended formulations, and the extended formulations were shown to be potentially useful for designing optimum phased-array radar scan configurations to maximize the extractable information contents from radar observations for data assimilation (Xu et al. 2008c). Numerical experiments were performed with an ensemble square root filter (EnSRF) and simulated radar observations to address practical issues in configuring phased-array radar scans to improve storm-scale radar wind analysis and assimilation (Lu and Xu 2008).

Research effort was made to optimize the performance of the recently developed time-expanded sampling approach for ensemble-based filters (Xu et al. 2008a,b) and avoid manual tuning. In particular, an adaptive scheme was designed and implemented to optimally select and adjust both the sampling time interval and covariance inflation. This scheme adjusts the covariance inflation adaptively based on the consistency ratio (between the ensemble spread and RMS error of the mean) computed for the standard (non-time-expanded) ensemble members, while the sampling time interval is selected based on the significance of the tailing singular values relative to the leading singular values of the time-expanded ensemble perturbation matrix. The effectiveness of the adaptive scheme was demonstrated with simulated observations. The scheme has been also tested with real radar observations.

An automated real-time system was developed to monitor radar data quality problems, accumulate innovation data for error covariance estimation and further test the previously delivered (to NRL and NCEP) radar data QC package (Xu et al. 2005, 2007; Zhang et al. 2005). The system was upgraded recently with new capabilities to integrate multi-sensor wind observations to produce real-time vector wind field at high (up to 2 km) spatial and (5-10 min) temporal resolution. This system has been applied to real-time wind observations from KTLX radar, Oklahoma Mesonet and four NOAA profilers (LMNO2, PRCO2, HKLO2 and VCIO2) in the central Oklahoma area. Through real-time monitoring and testing, improvements were made to the dealiasing and ground clutter removal algorithms in the QC package. The improved QC package was applied with the real-time system to velocity observations from KHGX radar and profiler LDBT2 in Houston area. The improved QC, especially the dealiasing algorithm, was successfully tested with severely aliased velocity scans from KHGX radar during the passage of Hurricane Ike over Houston on 13 September 2008.

RESULTS

Assimilation experiments were performed with simulated radar radial-velocity observations to examine the impacts of observation accuracy and resolutions on storm-scale wind assimilation with an ensemble square root filter (EnSRF) on a storm-resolving grid (Δx = 2 km). The observation error includes both measurement error and representativeness error. The results show that the analysis can be improved by properly coarsening the observation resolution (to 2 km in the radial direction) with an increase in measurement accuracy and further improved by properly enhancing the temporal resolution of radar volume scans (from every 5 to 2 or 1 min) with a decrease in measurement accuracy. There can be an optimal balance or trade-off between measurement accuracy and resolutions (in space and time) for configuring radar scans, especially phased-array radar scans, to improve storm-scale radar wind analysis and assimilation (Lu and Xu 2008). These numerical results are consistent with the theoretical analyses basen on the extended formulations for measuring information content from observations for four-dimensional data assimilation (Xu et al. 2008c).

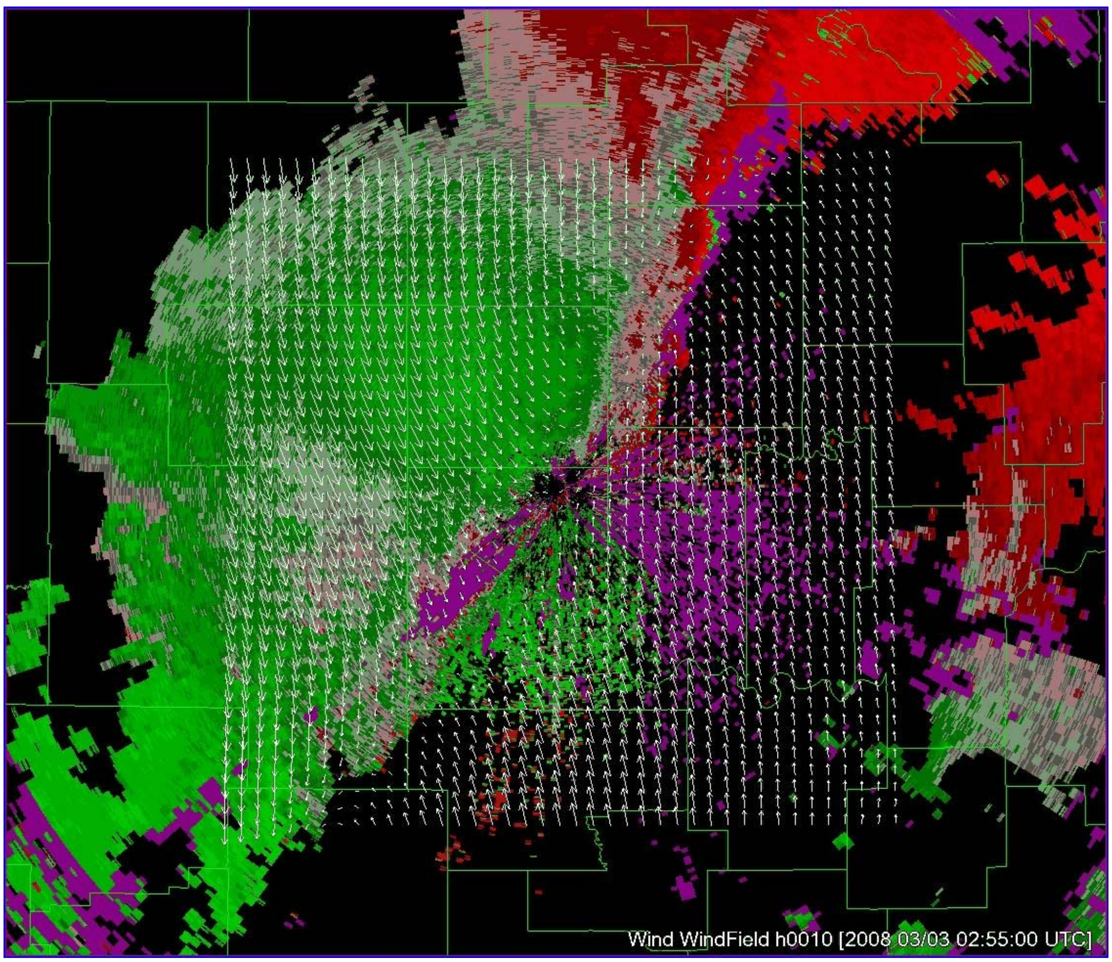

Fig. 1. Retrieved vector winds at z = 10 m overlayed with the radar radial-velocity imagery at 0.5^o elevation from KTLX radar for a storm at 02:55 UTC 3 March 2008. The color scale on the top of the penel is for radar radial-velocity.

As stated in the previous section, an automated real-time system has been developed to not only monitor radar data quality problems but also produce real-time vector wind field at high (up to 2 km) spatial and (5-10 min) temporal resolution. This system has been running with multi-sensors wind observations in the central Oklahoma area to retrieve the horizontal vector wind field on each conical surface of radar scans and to display the vector winds and related divergence and vorticity fields at each selected vertical level. This system can also animate the retrieved winds in time/height series. All these products can be synchronized and overlapped with real-time reflectivity and/or Doppler radial-velocity fields from the radar. The system can also run archived data to perform case studies for further improvements. An example is shown in Fig. 1.

The new dealiasing algorithm in the improved QC package (Y2008 version) has been successfully tested with real-time radial-velocity observations from KTLX radar under various weather conditions and also tested recently with real-time radial-velocity observations from KHGX radar during the passage of Hurricane Ike over Houston TX. Due to the very high winds produced by Hurricane IKE, Doppler radial-velocity observations from KHGX radar were severely aliased in every 0.5^{o} elevation scan during the period from 00:04 UTC to 15:54 UTC on 13 September 2008. For these (total 196) severely aliased radial-velocity scans, the dealiased radial-velocity fields produced by the new dealiasing algorithm were examined in details by human expertise in comparison with those produced by the operationally used dealiasing algorithm in the NSSL WDSS II system. The detailed examination showed that the new dealiasing algorithm was able to correctly unfold severely aliased radial-velocities with no false dealiasing although it rejected some ambiguous velocities that did not pass the quality check in fractional areas and thus increased data holes. On the other hand, the operational algorithm made a fewer rejections of ambiguous velocities but produced false dealiasing over some severely aliased sector areas in almost every of the total 196 severely aliased scans. A typical example of the comparison is shown in Fig. 2.

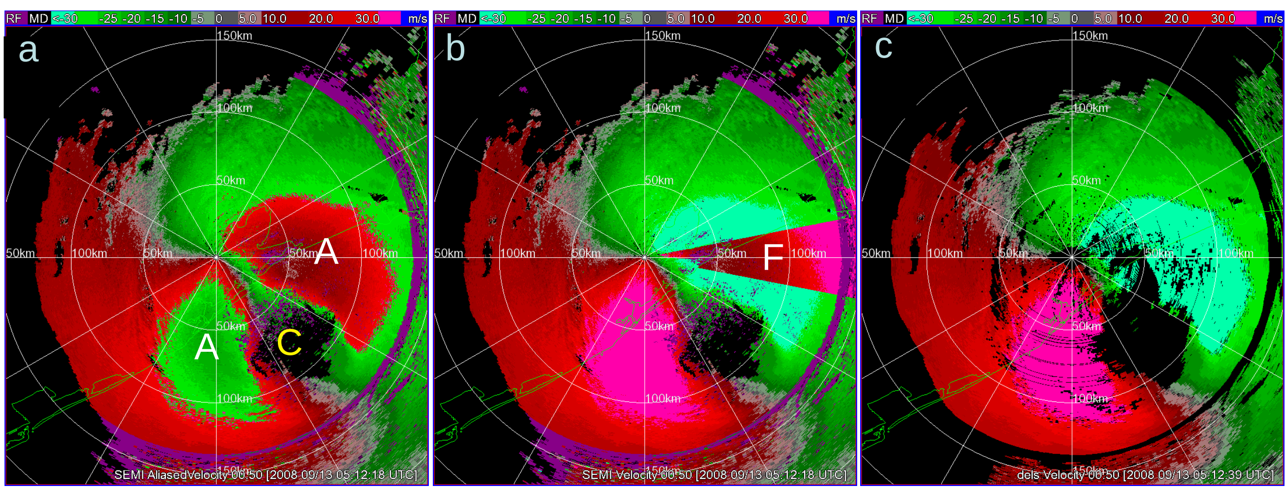

Fig. 2. (a) Doppler radial-velocity field scanned at 0.5^{o} elevation angle by KHGX radar at 05:12 UTC on 13 September 2008. (b) Dealiased radial-velocity produced by the operational dealiasing algorithm. (c) Dealiased radial-velocity produced by the new dealiasing algorithm. Rang rings are every 50 km and azimuths every 30^{o}. The center of Hurricane IKE is marked by the yellow symbol "C" and the severely aliased radial-velocity areas are marked by white letter "A" in panel (a). The false dealiasing area is marked by white letter "F" in panel (b).

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 "Improved Doppler Radar/Satellite Data Assimilation" 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 several times and delivered to NRL Monterey. The QC and vector wind retrieval packages in the real-time system were requested by and delivered to Pacific Northwest National Laboratory for real-time implementations over major urban areas (currently Phoenix AZ) to support and initialize their emergency response dispersion models for homeland security applications (Fast et al. 2008). The new code for compressing radar radial-velocity observations into super-observations was delivered to NRL Monterey for radar data assimilation applications. The recentlly developed time-expanded sampling algorithm for ensemble-based filters will be adapted and installed, in collaboration with Dr. Alan Zhao at NRL Monterey, into the hybrid (combined variational and ensemble approaches) data assimilation system developed at NRL Monterey and applied to COAMPS (Hodur 1997). 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). Automated retrieval and display of phased-array radar echo movement vector field in vertical cross-section (funded by NOAA HPCC to NSSL and OU). Improved Doppler Radar/Satellite Data Assimilation (funded by ONR to NRL Monterey).

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