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). 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

After the radar data QC package (Gong et al. 2003; Liu et al. 2005; Zhang, et al. 2005) was delivered to NRL and NCEP, the package was further tested with raw level-II data collected from six radars (KINX, KLZK, KSGF, KSRX, KTLX and KVNX) under both clear and rainy weather conditions. The QC package was able to detect contaminations caused by migrating-bird were well detected by the automated bird-detection algorithm, but the three-step dealiasing algorithm (Cong et al. 2003) was not always successful in correcting aliased radar velocities. The dealiasing algorithm was also tested with raw level-II data collected from three radars (KAKQ, KMHX and KRAX) under very strong-wind conditions caused by the long-lived Hurricane Isabel that made landfall near Drum Inlet, North Carolina on 18 September 2003. Correction failures were detected in the three-step dealiasing algorithm although the algorithm still largely outperforms the operational dealiasing algorithm. Detailed examinations were performed to identify the cause of each type of failures. Various modifications were designed, tested and redesigned to improve the stand-alone dealiasing algorithm. The improved algorithm was successfully tested with the above difficult cases. The collected radar data were also used to further test and refine the innovation method (Xu et al. 2003, 2005) to estimate radar radial-velocity error and background wind error covariances (Xu et al. 2007a,d).

Theoretical and numerical studies are conducted to address two basic issues: (i) how to measure information content extracted from radar observations by an optimal 4D analysis; and (ii) how to balance radar observation accuracy with observation spatial and temporal resolutions to optimally design PAR scans for a 4D assimilation system. The recently derived singular-value formulation of relative entropy measure of information content from observations (Xu 2007) was extended, so it can be applied to 4dVar analyses (section 2 of Xu et al. 2007f). Assimilation experiments were performed with simulated radar radial-velocity observations of a supercell storm to examine the impacts of observation accuracy and resolutions on the assimilated storm winds by using an ensemble-based filter (section 3 of Xu et al. 2007f). To examine the impacts of PAR rapid volume scans versus operational KTLX volume scans, numerical experiments were also performed by applying the simple adjoint technique (Xu et al. 2001a,b) to radial-velocity observations from the NWRT PAR and the operational KTLX radar for the Oklahoma Union City tornadic storm on 5 September 2007.

Research effort was made in exploring new ideas to improve the covariance estimation and computational efficiency of the ensemble-based filters in data assimilation. In particular, one idea was motivated by the consideration of timing errors in model predictions since this type of error can be significant or even pervasive with considerable uncertainties as suggested by model verification studies (Manobianco and Nutter 1999; Colle et al. 2001; Mass et al. 2002; Colle and Charles 2007; Gregory and Grumm 2007). Timing errors and timing-related spatial displacement errors were also were often distinct in operational model predictions including those produced by the experimental convection-allowing WRF models at the NOAA/NWS Storm Prediction Center, especially when considering the movement/location of precipitation systems (Weiss et al. 2007). In the presence of timing error, the predicted field at a time before (or after) the analysis time may represent the true field better than the predicted field at the analysis time, at least, over the area covered by the weather system. In this case, the localized forecast error covariance may be better estimated by sampling ensemble members not only at the analysis time but also at properly selected times before and after the analysis time. Based on this consideration, a time-expanded sampling approach was developed for ensemble-based filters and tested with simulated observations (Xu et al. 2007b,c).

RESULTS

Through extensive tests and redesigns (as described in the previous section), the three-step dealiasing algorithm in the previously developed radar data QC package (delivered to NRL and NCEP) was substantially modified and improved. In particular, the step-1 reference check in the original algorithm was replaced by a robust sign-check procedure between two zero radial-velocity azimuthal directions along each qualified circle on each tilt of radar scans within each vertical layer within 80 km radial distance from the radar, and this improved the accuracy of the reference VAD velocity computed from the qualified circle. As the computed VAD velocity is used for the refined reference check within 80 km radial range from the radar (rather than over the entire radial range as in the original algorithm) in step-2, the quality of the refined reference check is greatly improved. In step-3, by using super-observation inferences computed based on the error correlation derived in Xu and Gong (2001), a new check procedure has been designed (to replace the “buddy check” in the original algorithm). As this new check procedure is implemented circle-by-circle, the corrected data coverage can be extended from 80 km radial range to the entire range. The above improved dealiasing algorithm has been successfully tested with the difficult cases mentioned in the previous section, while the previous algorithm and the operational dealiasing algorithm showed serious failures in these difficult cases. One of the difficult cases is shown as an example in Fig. 1.

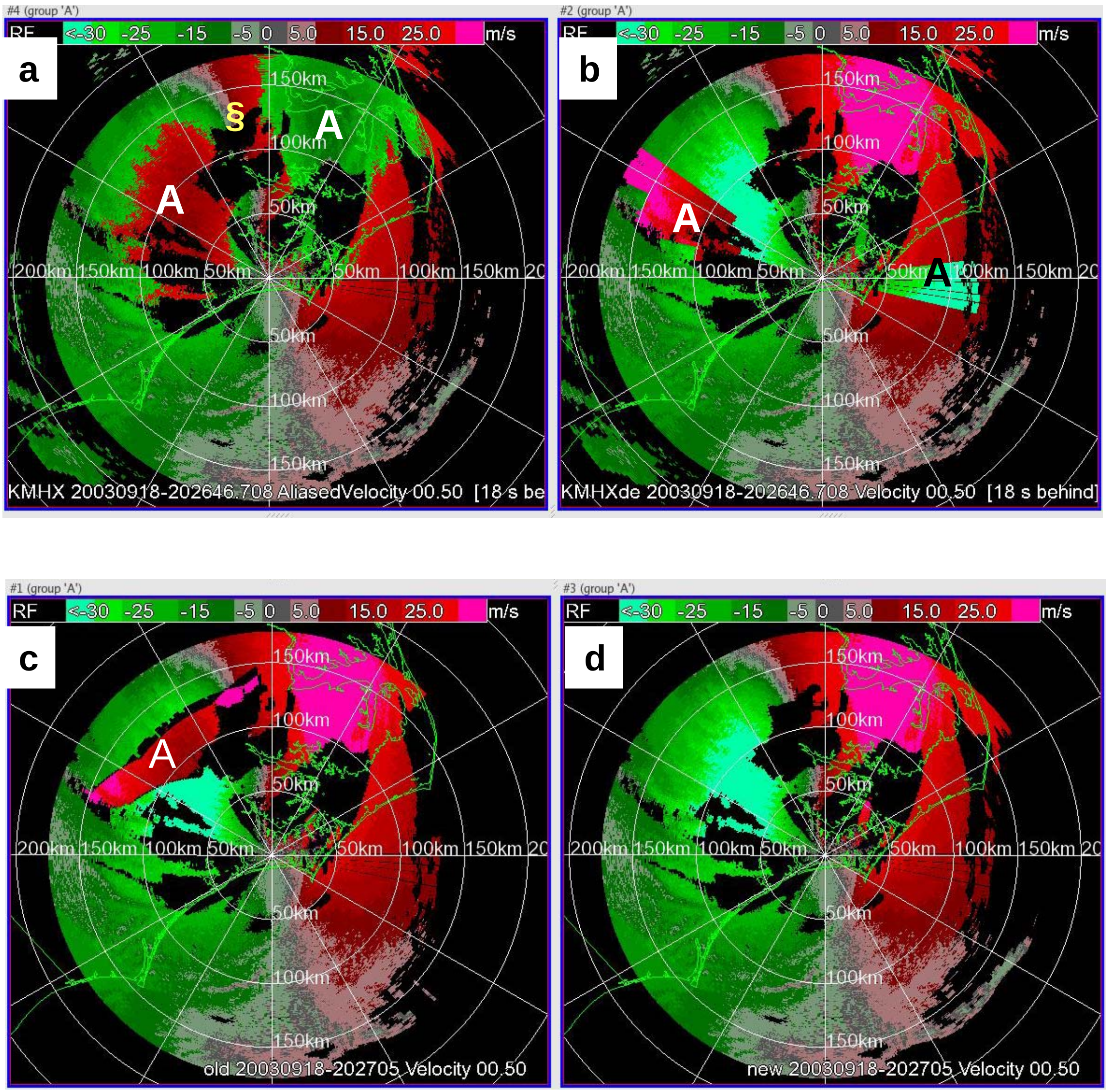

Fig. 1. a) Raw level-II Doppler radial velocities on 0.5^o elevation from KMHX radar at 2015 UTC 18 Sept. 2003; b) radial velocities dealiased by the NSSL/WDSSII operational algorithm; c) radial velocities dealiased by the previously developed three-step algorithm; d) radial velocities dealiased by the improved algorithm. The center of Hurricane Isabel is marked by the yellow symbol "§" in panel (a). Aliased-velocity areas are marked by white and black letters "A" in (a), (b) and (c).

The extended formulation of relative entropy (in section 2 of Xu et al. 2007f) showed that the information content extracted from 4D observations by an optimal 4D data assimilation system depends on the scaled 4D observation operator (left-multiplied by the inverse square-root of the observation error covariance matrix and right-multiplied by a lower-triangle block matrix composed of the square root of the background error covariance matrix and the tangent-linear model forward operators applied to the square roots of the model error covariance matrix). The scaled 4D observation operator can be a much larger matrix than its 3D counterpart and more information can be extracted from 4D observations especially if model errors are not correlated in time. The theoretical results also suggest that observations will (or will not) be partially redundant if they have (or have no) excessive spatial and/or temporal resolutions for a given assimilation system. Theoretically, an increase in observation accuracy should increase the information content for a truly optimal assimilation system, but this is not always true for a practically used sub-optimal assimilation system (in which the background covariance is not accurately estimated). Thus, practically, there should be a proper balance or trade-off between observation accuracy and resolutions when radar scans are configured to improve storm-scale data assimilation and predictions. The above theoretical results were further verified by assimilation experiments (in section 3 of Xu et al. 2007f).

The potential benefits from PAR rapid scans were further examined by applying the newly upgraded version of the simple adjoint technique to radial-velocity observations from the NWRT PAR and the operational KTLX radar for the Oklahoma Union City tornadic storm on 5 September 2007. Detailed comparisons between the analyzed vector wind fields from the two radars are shown in Figs. 2-3.

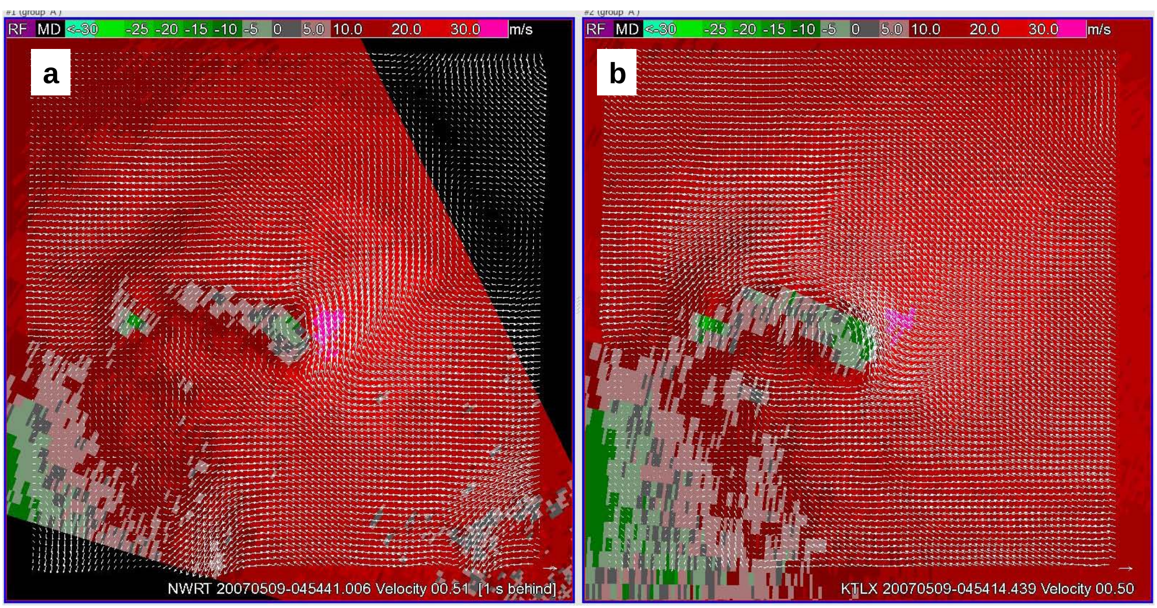

Fig. 2. Analyzed vector velocity fields on 0.5° elevation from (a) NWRT PAR sector volume scans (every 1 min) and (b) operational KTLX volume scans (every 4 min) at 0454 UTC 5 May 2007. The color background shows the radar observed radial-velocity field in each panel. The analysis time window covers three volume scans, so the window is 2 min for the analysis in (a) but is 8 min for the analysis in (b). The analysis domain is 40x40 km with 500m spatial resolution in a moving frame with moving speeds of (U, V) = (2, 11) m/s.

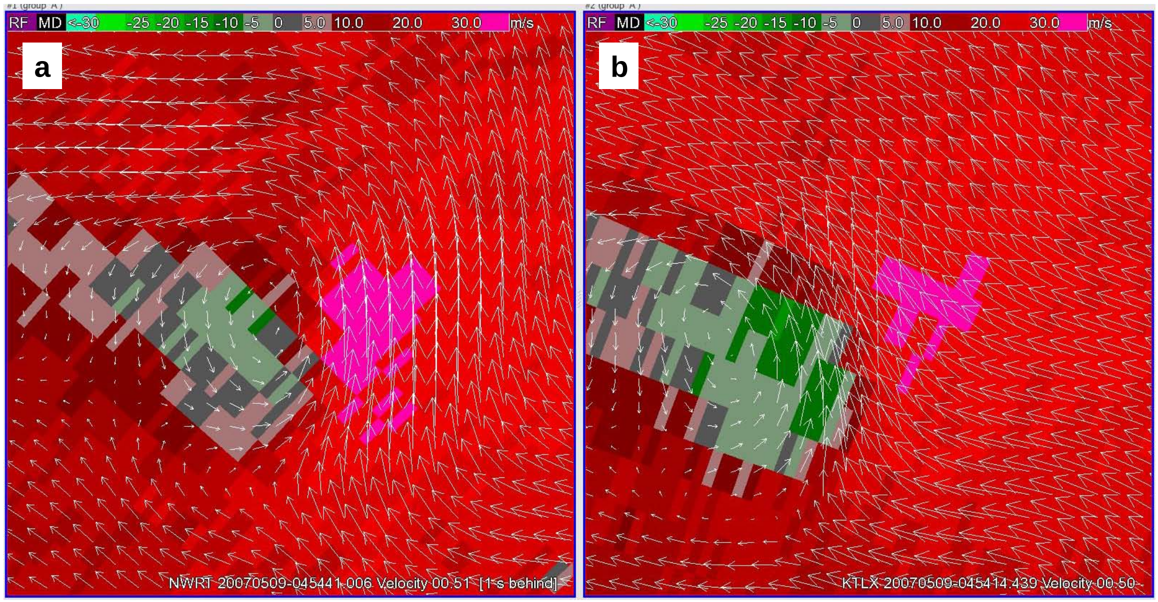

Fig. 3. As in Fig. 2 but enlarged in the vicinity of the observed tornadic mesocyclone. The analyzed vortex from NWRT PAR scans is well cocentered with the observed mesocyclone in (a), but the analyzed vortex from KTLX scans is not well cocentered with the observed mesocyclone in (b).

As stated in the previous section, the proposed time-expanded sampling was motivated by the consideration of timing errors. The applicability of time-expanded sampling, however, is not limited by this consideration, and this is demonstrated by the assimilation experiments performed in Xu et al. (2007b,c). Since time-expanded members are used in addition to the standard members to construct the ensemble and compute the localized covariance, the number of required prediction runs can be greatly reduced and so is the computational cost. By properly selecting the sampling time interval, the proposed approach can improve the ensemble spread and enrich the spread structures so that the filter can perform well even though the number of prediction runs is greatly reduced (as shown in Xu et al. 2007b,c).

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 data 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, 2007), 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. It 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. A phased array radar data decoder was also adapted to the QC package and delivered to NRL Monterey for the Navy radar data ingestion system. The newly developed code for compressing radar radial-velocity observations into super-observations was delivered to NRL Monterey for radar data assimilation applications. The newly developed time-expanded sampling algorithm for ensemble-based filters will be applied to COAMPS (Hodur 1997) 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 system and interface for monitoring low-level wind conditions prior and during severe storms (funded by NOAA HPCC to NSSL and OU). Improved Doppler Radar/Satellite Data Assimilation (funded by ONR to NRL Monterey). Advanced Assimilation of Non-conventional Data for Improved High-Impact Weather Prediction (funded by ONR through NRL base program).

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