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Adaptive Radar Data Quality Control and Ensemble-Based Assimilation for Analyzing and Forecasting High-Impact Weather

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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 advanced methodologies for radar velocity data QC and assimilation that will not only optimally utilize observations from operational Weather Surveillance Radar-1988 Doppler (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 the National Weather Radar Testbed (NWRT).

APPROACH

Use the automated radar-based wind analysis system (RWAS, Xu *et al*. 2009a) to monitor and record various data quality problems in operational WSR-88D and TDWR radar observations as well as NWRT PAR observations. Investigate and classify outstanding data quality problems, and develop advanced adaptive data QC techniques for various scan modes to satisfy data assimilation needs.

Extend the theoretical formulations derived for measuring information content from observations for data assimilation (Xu 2007, Xu *et al*. 2009d), so efficient data compression strategies and optimal PAR strategies can be designed based on the modern information theory to maximize the information content from observations and minimize data redundancy for ensemble-based radar data assimilation.

Explore and develop new hybrid sampling approaches based on Bayesian probability theory for ensemble-based radar data assimilation to improve real-time analysis and forecast of high-impact weather.

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 and Dr. Mark Yeary, PI of PAR multi-channel receiver project at the OU Atmospheric Radar Research Center (Yeary *et al.* 2010). Dr. Allen Q. Zhao at NRL Monterey and Drs. Shun Liu and David Parrish at NOAA/NCEP perform pre-operational tests as the radar data QC and assimilation packages are further upgraded and delivered.

WORK COMPLETED

Acquired and established a real-time access to high-resolution level-II data from the OKC airport TDWR radar through high speed internet, managed by an LDM (Local Data Manager) system. To process real-time TDWR radar data with adequate QC for data assimilation, the QC techniques (Xu *et al*. 2009b, 2010a) developed for operational WSR-88D (S-band) radars were modified and applied to real-time TDWR (C-band) radar data. The QC products were displayed and monitored together with TDWR raw data in real time by using the NSSL WDSS II (Warning Decision Support System-Integrated Information) system. Various TDWR data quality problems were identified and examined in details. Adaptive QC strategies were designed to deal with the TDWR data quality problems.

The singular-value formulations for measuring information content from observations for variational data assimilation (Xu 2007, Xu et al. 2009d) were further explored in spectral spaces. New spectral-space formulations were derived by using discrete Fourier transsformation and generalized Fourier transsformation. Numerical experiments were designed with PAR observations to explore and demonstrate the merits and utilities of the spectral-space formulations.

The previously developed 3.5Var radar data assimilation package (delivered to NRL for nowcasst applications) was refined and applied to a squall line case observed by the phased-array radar with rapid volume scans (Xu et al. 2010c). Based on this and previous applications, the 3.5Var package was further upgraded in combination with the hydrometeor thermodynamic analysis. In particular, the perturbation pressure and potential temperature increments derived from the hydrometeor thermodynamic analysis can be used as input “observations” together with the gridded radial velocities to produce incremental analyses for the vector velocity together with the perturbation pressure and potential temperature. In this way, the step-2 and step-3 in the original 3.5Var were combined into a single comprehensive step with all the incremental fields properly constrained by the model’s momentum and thermodynamic equations. This upgrading provides a good starting point for exploring various hybrid extensions of the 3.5Var with the recent time-expanded ensemble approach for further improvement.

RESULTS

The radar data QC techniques (delivered to NRL and NCEP) have been tested extensively with raw level-II data collected from many operational WSR-88D (S-band) radars under various high-impact weather conditions (Xu *et al*. 2009c, 2010b). However, applying these QC techniques to TDWR (C-band) radar data requires modifications and additional tests. This is especially true when the VCP80 scan mode is used by TDWR with reduced Nyquist velocities (< 18 ms^{-1}) for windy or stormy weather. Besides, the raw level-II TDWR data are often very noisy at high elevations and thus must

be adequately filtered, and this is done by using TDWR spectrum width data. When the VCP80 scan mode is used with a reduced Nyquist velocity (< 18 ms^{-1}) for windy or stormy weather, the alias-robust VAD analysis (Xu *et al*. 2010a) becomes less effctive or even ineffective for the reference check in the VAD-based dealiasing technique (Xu *et al*. 2010b). To solve this problem, the alias-robust variational radar wind analysis (Xu et al., 2009b) is used in place of the VAD analysis for the reference check in the radar vicinity area, and then the block-to-point continuity check procedure (Xu *et al*. 2010b) is used adaptively to extend the dealiased data areas away from the radar at the lowest few tilts ($\leq 1^o$). This modification is found to be effective and has been implemented to process real-time raw level-II data from the OKC airport TDWR radar for data assimilation applications. The supurior performace of this adaptively modified technique is shown by the example in Fig. 1. As shown, the new scheme can correct the alias errors in the raw TDWR radial velocities without false dealiasing. The operational algorithm, however, produces false dealiasing in many areas (marked by white-A letters in panel c).

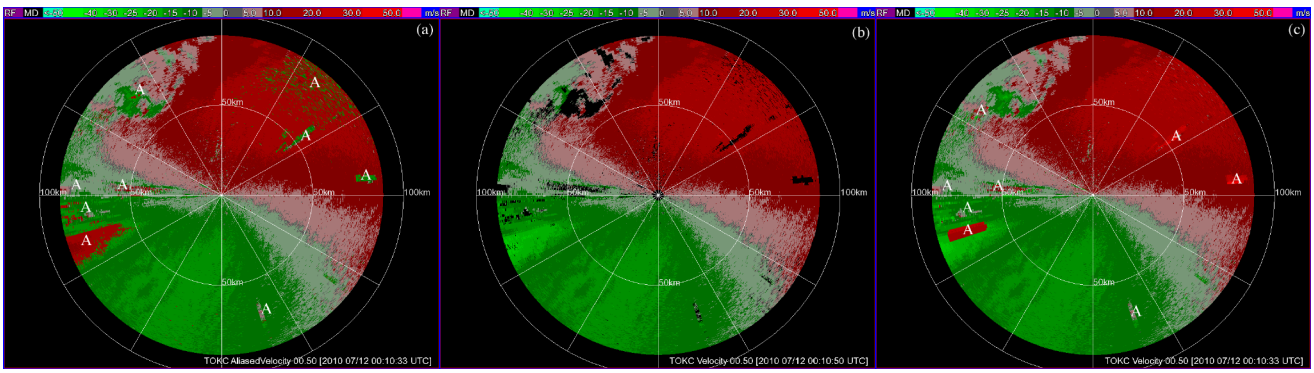

Fig. 1. (a) Raw radial-velocity image scanned by the OKC TDWR radar with VCP80 mode and Nyquist velocity = 15.39 ms^{-1} at 0.5^o tilt for the pre-frontal flow and intruding cold front (into the northwest sector of the radar covered area) at 043637 UTC on 12 July 2010. (b) Dealiased radial-velocity image by the new scheme. (c) Dealiased radial-velocity image by the operational algorithm. The white-A letters mark aliased data areas in panel (a) and false-dealiasing areas in penal (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 observations to improve numerical analyses and predictions of severe storms and other hazardous weather. New methods and computational algorithms developed in this project will be delivered to NRL Monterey for operational tests and applications, 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 will be delivered to NRL Monterey for operational tests and applications. The QC package will be also made available to NCEP for their operational applications. Based on the feedbacks from NRL and NCEP, the code will be upgraded and delivered subsequently. The previously developed 3.5Var radar data assimilation package

(delivered to NRL for nowcasst applications) 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 improved Doppler radar/satellite data assimilation capabilities at NRL Monterey.

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). Radar data quality control and assimilation at the National Weather Radar Testbed (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). Improved Doppler radar/satellite data assimilation (funded by ONR to NRL Monterey).

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