Research and Development of Advanced Radar Data Quality Control and Assimilation for Nowcasting and Forecasting Severe Storms

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Award Number: N000141410281

LONG-TERM GOALS

Advance the state of the art in radar data quality control (QC) and assimilation for nowcasting and forecasting severe storms and other high-impact hazardous weather by attacking outstanding problems and addressing basic science and applied research issues in radar data QC and assimilation that are important and yet very challenging for nowcasting and forecasting high-impact hazardous weather not only over US homeland but also in US Navy’s battle spaces worldwide, especially over oceans and in remote areas where conventional observations are very limited.

OBJECTIVES

Develop automated high-standard radar data QC techniques for nowcasting severe storms and operational data assimilation. Explore and develop new concepts and formulism for ensemble-based radar data assimilation with enhanced dynamic balances on multiple scales to improve nowcast and forecast of high-impact weather.

APPROACH

Upgrade the radar-based wind analysis system (RWAS, Xu et al. 2009, 2013a,b) for nowcasting severe storms and use it to monitor radar data quality problems and test new QC techniques. Use model predictions and analyses to improve and extend the adaptive radar velocity dealiasing techniques (Xu and Nai, 2012; Xu et al. 2013b, 2014a) for various weather conditions scanned by operational WSR-88D radars, Terminal Doppler Weather Radar (TDWR) and the phased array radar (PAR) at the National Weather Radar Testbed.

Extend and use the theoretical formulations for measuring information content from observations for data assimilation (Xu 2007, 2011; Xu et al. 2009b, Xu and Wei 2011) to develop efficient data compression and multistep incremental analysis strategies adaptively for different radars and data assimilation systems to minimize data redundancy and information loss.

Explore and develop new concepts and formulism for probabilistic-deterministic hybrid approaches in data assimilation with enhanced dynamic balances to improve nowcast and forecast of high-impact...
weather. Optimize the sampling time interval and covariance inflation and localization in the time-expanded sampling (Xu et al. 2008a,b; Lu et al. 2011) for time critical applications of ensemble-based data assimilation with the Navy’s Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®, Hodur 1997).

The PI, Dr. Qin Xu, is responsible for designing the overall approaches for the proposed objectives and providing 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. Dr. Allen Q. Zhao and his colleagues at NRL Monterey will perform pre-operational tests as the radar data QC and assimilation packages are upgraded and delivered.

WORK COMPLETED

The RWAS (Xu et al. 2009, 2013a,b) was upgraded to produce vector wind fields for nowcasting severe storms using radial-velocity observations from five operational WSR-88D radars (KTLX, KFDR, KINX, KVNX, KSRX) and one TDWR radar (TOKC) in combination with GOES water-vapor winds and surface mesonet wind data. A two-step incremental analysis strategy was designed to improve the mesoscale vector wind analysis. In each consecutive step, the radar radial velocities were compressed into superobservations at consecutively refined resolution (from 30 km to 10 km) and the background covariance horizontal de-correlation length was adjusted adaptively to consecutively refined scale (from 100 km to 50 km). The upgraded RWAS was used to examine the pre-storm environment conditions of the 20 May 2013 Moore Oklahoma tornadic storm (Rabin et al. 2014).

The Doppler velocity dealiasing techniques for radar wind data quality control and assimilation were further improved beyond those reported in Xu et al. (2013b) by using different techniques for different scales and structures in the following three steps: (a) A model-based variational dealiasing method using a numerical model predicted wind field as the first guess was developed to cover broad areas while the local areas of misfit are flagged on each tilt. (b) The previous block-to-point continuity check was modified for the local areas of misfit while the small areas of discontinuities are flagged. (c) A beam-to-beam discontinuity check was developed for small areas of discontinuities. This formed a multi-step hybrid dealiasing package. In addition, an effort was also made to extend the alias-robust least-squares method with a two-parameter vortex model for correcting aliased radial-velocity data around a hurricane (Xu et al. 2013b) into an alias-robust variational method with a 6-parameter vortex model for correcting aliased radial-velocity data around tornadic mesocyclones.

A research effort was made to address how properly define and accurately determine the vortex center for a model-predicted tropical cyclone (TC) from a dynamic perspective. This issue is very important for the vortex relocation with size and intensity adjustments in operational TC data assimilation. Ideally, a dynamically determined TC vortex center should maximize the gradient wind balance or, equivalently, minimize the gradient wind imbalance measured by an energy norm over the TC vortex. Practically, however, such an energy norm cannot be used to easily and unambiguously determine the TC vortex center. An alternative yet practical approach was then developed to dynamically and unambiguously define the TC vortex center. In this approach, the TC vortex core of near solid-body rotation is modeled by a simple parametric vortex constrained by the gradient wind balance so the modeled vortex can fit simultaneously the streamfunction and perturbation pressure over the TC vortex core area (within the radius of maximum tangential wind) in the model-predicted field, while the misfit is measured by a properly defined cost-function. Minimizing this cost-function yields the desired dynamic optimality condition that can uniquely define the TC vortex center. Using this dynamic
optimality condition, a new method was developed in the form of iterative least-squares fit to accurately determine the TC vortex center. The new method was shown to be efficient and effective for finding the TC vortex center that satisfies the dynamic optimality condition accurately. The detailed method and results are presented in Xu et al. (2014b).

RESULTS

The RWAS (Xu et al. 2009, 2013a,b) was upgraded to produce mesoscale vector wind fields for the supercell storm that generated a devastated tornado over the Moore area in central Oklahoma around 20:00 UTC on 20 May 2013. As shown in Fig. 1a, the mesoscale vector wind field produced by the upgraded RWAS captured the lower-middle level jet in the pre-storm environment at 19:00 UTC for the 20 May 2013 Moore Oklahoma supercell storm, and this lower-middle level jet is more distinctive than those produced by the previous RWAS (Fig. 1b) and the operational model (Fig. 1c). As an important feature in the pre-storm environment, this jet was conducive for the subsequent intensification of the supercell (marked by the yellow “S” in Fig. 1a) that moved to the jet-caused strong shear and convergence area (marked by the red “S” in Fig. 1a) during the next two hours.

![Fig. 1. Mesoscale vector wind fields at z = 4 km produced by (a) the upgraded RWAS, (b) the previous RWAS, and (c) the operational RUC model. The vector winds are plotted every 20 km in x and y directions by the white (< 25 m/s), yellow (between 25 and 30 m/s) and red (> 30 m/s) arrows superimposed on the reflectivity from 5 radar and county maps (bright green lines).](image)

The alias-robust least-squares method developed with a two-parameter vortex model for correcting aliased radial-velocity data around a hurricane (Xu et al. 2014a) was extended into an alias-robust variational method with a 6-parameter vortex model for correcting aliased radial-velocity data around tornadic mesocyclones. This provides an additional step of dealiasing beyond those reported in Xu et al. (2013b). This step is more effective than previous techniques in detecting and correcting the aliased radial-velocity data within each mesocyclone, as shown by the example in Fig. 2.
Fig. 2. (a) Image of raw radial velocity (superimposed on the Moore city street map plotted by bright green lines) scanned from KTLX radar on 0.5° tilt at 20:13:01 UTC on 20 May 2013 for the Moore, Oklahoma tornadic storm. (b) Image of dealiased radial velocity produced by the previous method (Xu et al. 2013b). (c) Image of dealiased radial velocity produced by the newly improved method in which the alias-robust variational method with a 6-parameter vortex model is used to detect and correct severely aliased radial-velocity data around each tornadic mesocyclone. The white letters “A” in (a) mark the aliased-velocity areas. The yellow circle in (b) and (c) encircles the mesocyclone and its produced EF5 tornado. The black pixels within the yellow circle in (b) show the flagged (missed) data in the vortex center area.

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 various types and platforms of radar observations to improve timely and accurate analysis and prediction of severe storms and other hazardous weather. New methods and computational algorithms developed in this project will be delivered to NRL Monterey for further tests and potential operational applications.

TRANSITIONS

The radar data QC package developed in this project will be delivered to NRL Monterey for operational tests and applications. The techniques will also be available to the science community and the National Weather Services (NWS). Based on the feedbacks from NRL and NWS, the code will be upgraded and delivered subsequently. The previously developed radar data assimilation package (delivered to NRL for nowcast applications) will be further improved with the new probabilistic-deterministic hybrid approaches explored and developed from this project, in collaboration with Dr. Allen Q. Zhao at NRL Monterey, to enhance the Doppler radar/satellite data assimilation capabilities at NRL Monterey.

RELATED PROJECTS

“Ensemble assimilation of Doppler radar observations” (funded by ONR to NRL Monterey).
REFERENCES


PUBLICATIONS
