FOUR-DIMENSIONAL VARIATIONAL DATA ASSIMILATION OF HIGH RESOLUTION X-BAND RADAR OBSERVATIONS OVER THE DALLAS-FORT WORTH METROPLEX

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ABSTRACT

The Variational Doppler Radar Assimilation System (VDRAS) is applied to observations collected by X-band radars over the Dallas-Fort Worth metropolitan area. VDRAS is specifically designed to assimilate radar observations of Doppler velocity and reflectivity. In order to cope with attenuation issues affecting short-wavelength radars, the rainwater mixing ratio is here estimated using a technique based on dual-polarization observations.

Preliminary results obtained from application to a severe storm case study are presented. The overall consistency of the resulting analyses demonstrates the feasibility of the proposed approach. The incorporation of observations from X-band systems sampling the lower atmosphere with high spatial and time resolution allows producing detailed analyses near the surface. In particular, the wind field reveals the capability to detect regions of low-level convergence associated with organized updrafts.

***Index Terms*—** Radar, data assimilation

1. INTRODUCTION

The Dallas Fort Worth (DFW) Urban Demonstration Network project is centered on the deployment of a network of several dual-polarization, X-band radars to demonstrate improved hazardous weather forecasts, warnings and response in a densely populated urban environment (pop. 6.3 million in 2010). Specifically, low level wind analysis and forecast ranging from 10 minutes to 3 hours are among the main research areas of the project. The scanning strategy of the radars is inherited from the CASA project distributed collaborative adaptive sensing concept [1] and is intended to sample with high time resolution the lower atmosphere (1-3 km above ground level). During standard operation, 4 or more full PPI or sector scans at elevations ranging between 1 and 7 deg and range resolution of 50-100 m are performed within 1 minute.

The Variational Doppler Radar Analysis System (VDRAS) is an advanced data assimilation system specifically designed for ingesting Doppler weather radar observations [2]. The system has been installed at many sites around the world and is typically running using long-range operational S-band or C-band radar networks. The core 4-dimensional data assimilation scheme is based on a cloud-scale model and considers a 12-15 minutes time window for the radar assimilation, with 1-3 km spatial resolution.

In this study we explore the feasibility of running VDRAS at high spatial resolution (≤ 1 km) with rapid update (5 minutes), exploiting the frequent low-level sampling of the atmosphere available within the DFW network of X-band radars.

2. VDRAS 4D-VAR ASSIMILATION

The central process of VDRAS is the 4D-Var radar data assimilation, which includes a cloud-scale numerical model, the adjoint of the numerical model, a cost function and a minimization algorithm [2], [3]. The assimilation scheme, through the iterative minimization of a cost function, fits the model to the observations on the three-dimensional spatial domain and over a specified time window. A cost function, measuring the distance between the model variables and the observations, is defined as:

$$J = \sum_{\sigma,\tau} \left[\eta_v \left(v_r - v_r^{obs} \right)^2 + \eta_q \left(q_r - q_r^{obs} \right)^2 \right] + J_b + J_p$$

where σ and τ represent the spatial and temporal domains, the variable v_r is the radial velocity computed from the model velocity components and v_r^{obs} is the observed radar Doppler velocity; q_r is the rainwater mixing ratio from the model and q_r^{obs} is the rainwater mixing ratio estimated from radar observations. The terms J_b and J_p represent respectively the background and the penalty term. The background term provides a measure of the distance between the analysis and a prior estimate, while the penalty term ensures a proper spatial and temporal smoothness.

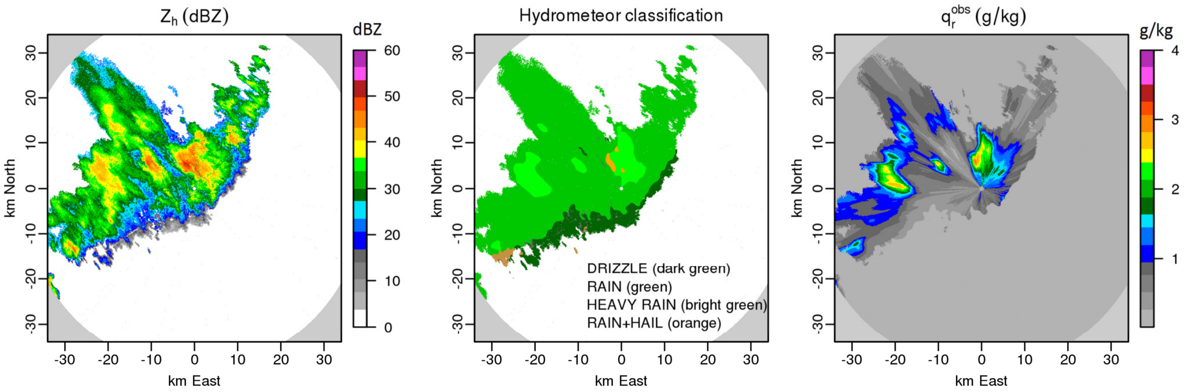

Figure 1. PPI from Midlothian radar at 20:39UTC. Left: reflectivity; center: hydrometeor classification; right: rainwater mixing ratio estimation

3. RADAR DATA PRE-PROCESSING

The rainwater mixing ratio is conventionally derived in VDRAS from reflectivity observations using a power-law relation obtained assuming a Marshal–Palmer raindrop size distribution. However, for X-band systems path attenuation greatly affects the reliability of reflectivity-based estimates in heavy precipitation. Dual-polarization measurements allow to correct for path attenuation and to estimate the rain rate and the rainwater content with higher accuracy [4].

In this work we adopted a blended algorithm that combines the available dual-polarization observations (namely reflectivity, differential reflectivity and the specific differential phase shift) using different relations, providing a rainwater estimate less sensitive to DSD (Drop Size Distribution) variations and mostly un-affected by attenuation. The same algorithm is applied to X-band and to S-band NEXRAD radars. The basis to apply different relations is provided by a preliminary hydrometeor classification [5], which drives the choice of the most proper relation. For assimilation in VDRAS, the radar observations of v_r^{obs} and the estimates of q_r^{obs} in the polar domain are first interpolated to Cartesian PPIs with 500 m-resolution. Figure 1 shows an example of a reflectivity PPI at 2.0deg elevation from Midlothian X-band radar, with hydrometeor classification and the resulting q_r^{obs} estimation.

4. MODEL SETUP AND WIND ANALYSIS

Data assimilation experiments have been initially conducted for a hailstorm event occurred on 12 May 2014. For this case the data from the S-band NEXRAD KFWS radar have been considered, in addition to the X-band radars located in Arlington and Midlothian. The experiment started at 19:25UTC, using a WRF model simulation as background, and then cycled every ~5 minutes using the previous forecast as background. In addition to the radar observations, the surface METAR reports have been used for the analysis. The cycling procedure is actually matched with the NEXRAD volume update frequency, which was slightly less than 5 minutes, ensuring the availability of a large scale 3-dimensional coverage for the analysis. Within the 5-min window, in addition to the NEXRAD volume scan, about 10 PPIs at the same low elevation angle (~2deg) are available from each of the X-band radars. Adaptive sector scans at higher elevations were not considered in these first experiments.

The model domain is 133x100x37 (nx,ny,nz) grid points, with horizontal resolution of 2 km and vertical resolution of 400 m, and the integration time step is 4 s. The runtime for the analysis is about 20 minutes on 8 processors. In fig. 2 the VDRAS analysis from the first (cold start) 4D-Var cycle is shown on the full model domain.

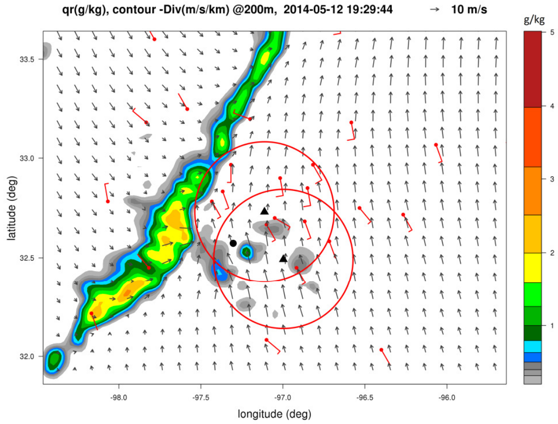

Figure 2. VDRAS analysis of q_r (colors) and winds at 19:29:44UTC from the first cycle on the full model domain. The red wind barbs represent the METAR surface observations, the red circles indicate the 40 km-range domain of the two X-band radar (black triangles). The small

filled black circle indicates the position of the NEXRAD KFWS radar.

The Doppler radial velocity observations from the three radars allowed a detailed retrieval of the 3-dimensional wind field, when the storm entered the central area of the model domain. Fig. 3 shows the observed Doppler wind from Midlothian radar and the analysis on the 200 m height model vertical level, evidencing a band of intense convergence near the surface. In this region the outflow generated by the evaporative cooling of the precipitation within the approaching squall line from the West meets the warmer southerly flow on the eastern portion of the domain. This convergence leads to relevant upward motions, which continued for about 30 minutes until a hailstorm eventually formed (fig. 4).

This analysis and the following ones are consistent with the subsequent development of the storm, as illustrated in fig. 4 (right panel). In particular figure 4 (left panel) shows the wind analysis at 20:33UTC, when the intensity of the main convective core within the squall line was actually decreasing. At this time the VDRAS wind analysis shows a well-defined updraft with vertical velocities in excess of 16 m/s.

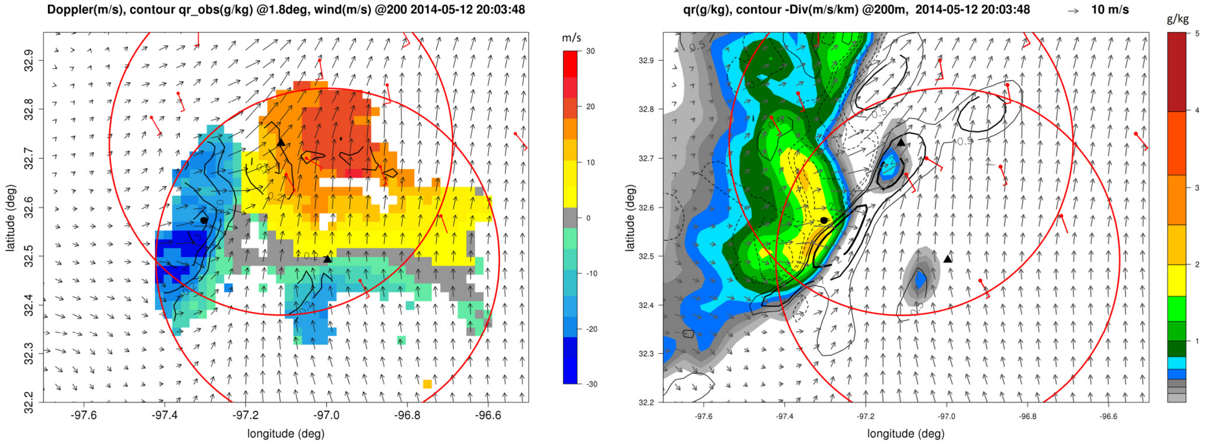

Figure 3. Analysis at 20:03:48UTC on a smaller portion of the model domain, for vertical level at 200 m height. Left: Doppler velocity from Midlothian radar (color) interpolated on the model grid, with analyzed wind vectors and observed q_r^{obs} contours. Right: analysis of rainwater mixing ratio q_r displayed in color and convergence as black contours.

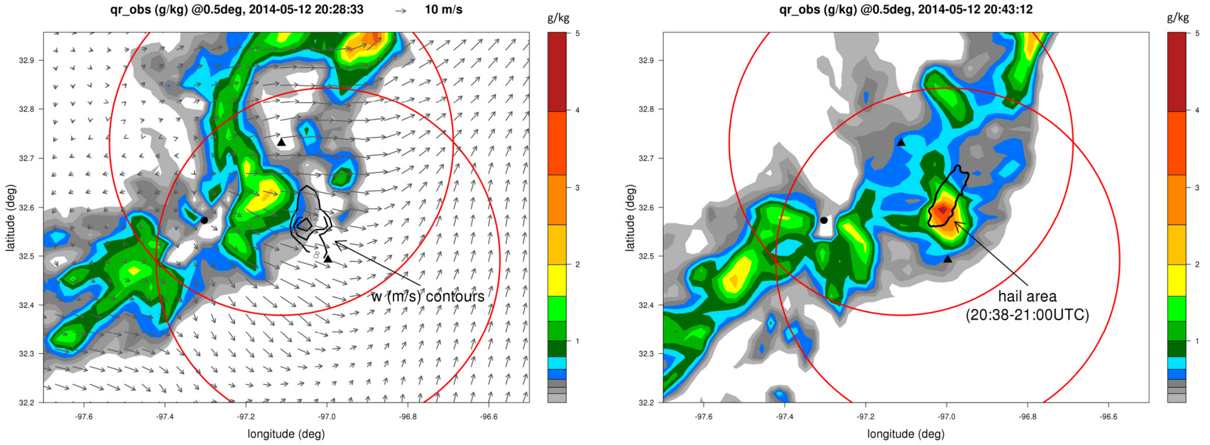

Figure 4. Left: estimated rainwater mixing ratio (color) from NEXRAD at 20:28:33UTC (0.5deg elevation) with overplotted wind vectors and contour of the maximum vertical velocity from the VDRAS analysis at 20:33:00. Right: estimated rainwater mixing ratio at 20:43:12UTC with overplotted the hail area, as inferred from a dual-polarization based hydrometeor classification algorithm [5].

At 20:43UTC (fig. 4, right panel) the estimated rainwater mixing ratio shows a well-defined convective core downwind of the region previously characterized by the intense updraft. The hydrometeor classification algorithm based on dual-polarization radar observations initially identified hail within a heavy rain region around 20:38UTC and during the subsequent 20 minutes (hail area delineated in fig. 4, right panel).

4. CONCLUSIONS

VDRAS simulations using X-band radar data in addition to a single NEXRAD radar were performed in this preliminary study. In order to cope with path attenuation affecting short-wavelength radar a new estimation of the rainwater mixing ratio from radar has been implemented, exploiting dual-polarization observations.

The availability of multiple short-range radars is fundamental to provide radial velocity observations and rainwater estimates near the surface. In addition, the scan strategy implying very frequent low-level scans appears especially suitable for running an analysis system based on four dimensional data assimilation. First results are encouraging and indicate the potential for low-level wind analysis over the DFW metropolitan area. The quality of the analysis will be further evaluated, also running short-term forecasts using the same cloud model employed for the assimilation.

11. REFERENCES

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