1.3 NOWCASTING FOR URBAN AREAS BY VARIATIONAL ASSIMILATION OF DOPPLER RADAR AND LIDAR RADIAL WIND DATA

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1. INTRODUCTION

Accurate forecasts and analyses of low-level winds over urban areas are important in planning for and responding to weather systems and pollutant dispersion. Doppler radars are presently the main tool for sampling the detailed four-dimensional structure of atmospheric flows. However, with single Doppler coverage, only winds in radar radial directions are observed. To obtain a physically consistent estimate of the full atmospheric flow, data assimilation techniques are utilized.

Assimilation of high-frequency data is best accomplished with a 4-dimensional variational (4DVAR) system that constrains the analysis using a full-physics numerical model. However, such a full-physics 4DVAR assimilation system is so computationally intensive that it cannot be currently run operationally. To address this need, NCAR has developed a 4DVAR assimilation system that is based on a model with simple physics.

In Section 2, the Variational Doppler Radar Assimilation System (VDRAS) developed at NCAR, is introduced. Major components of the system, as well as the coupling of VDRAS with a dispersion model, are described. Specifics and examples from the operational runs of the system in support of the DoD Joint Urban 2003 field experiment are given in Section 3. Lastly, an example of adapting the system for higher resolution lidar data assimilation is briefly discussed.

2. THE VARIATIONAL DOPPLER RADAR ASSIMILATION SYSTEM

The VDRAS model assimilates a time history of radial winds from Doppler radars, as well as all other available meteorological data, to produce a three-dimensional analysis of the complete wind field and the other standard meteorological variables. A nowcast of 30 minutes can also be produced by the model. The system was recently implemented in a real-time setting for a number of field demonstration projects (Sun and Crook, 2001)

At the core of VDRAS is a 4DVAR system that is based on a set of Boussinesq governing equations and the corresponding adjoint equations. The approach of 4DVAR assimilation is to find the model variable fields by fitting the dynamical model to the observations. The best fit is found iteratively by minimizing a cost function which represents the distance between the model solution and the data over a time window. Also included in the cost function are smoothness constraints and background analysis constraints.

Surrounding the 4DVAR core are data ingest, pre-processing and display modules (Figure 1). For most metropolitan areas, WSR88D Level-II radar data are available at no cost via the high-speed CRAFT network (Droegemeier et al., 2002). Before input into the model, radar data are interpolated horizontally to a Cartesian grid. In the vertical, the data remain on planes of fixed elevation angles where the cost function is calculated. The final analysis fields are derived on a 3-dimensional Cartesian grid. Before the 4DVAR assimilation, a VAD analysis is performed. Other available observations, as well as RUC model analyses, are used to form a background analysis.

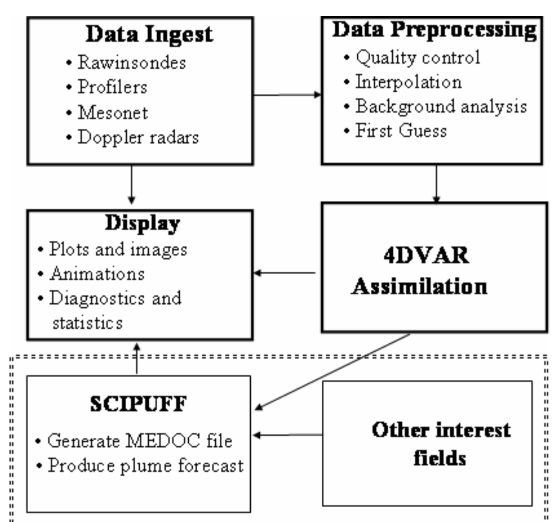

Fig. 1 Flow chart of VDRAS. Inside the dashed box are components for coupling the dispersion model.

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A continuous cycling procedure is employed in VDRAS. An optimal trajectory is obtained from each cycle using data within the assimilation window. The analysis fields at the final time of the assimilation window of one cycle are used in estimating the first guess fields in the next analysis cycle.

With radar data as input, the horizontal grid increment of the VDRAS analyses and forecasts is typically 1 km, and the dimension of the analysis areas is about 50-100 km. The length of the assimilation window in each analysis is typically set to 12 minutes, consisting of three WSR-88D radar volumes in storm mode or two volumes in clear-air mode. On a dual-processor PC, such a system requires about 10 minutes to produce an analysis and forecast. If lidar data are assimilated by the same model, the horizontal grid increment is approximately 75-100 m, and the analysis area has dimensions of 5-10 km.

The VDRAS system can be used for homeland security applications, it can be employed in meteorological studies of boundary-layer processes, or it can be used for general operational nowcasting of convective or other weather in the urban area.

For the purpose of predicting toxin transport and dispersion, VDRAS has been coupled with the Second-order Closure Integrated Puff model (SCIPUFF, Sykes et al., 1993). VDRAS-retrieved wind and temperature provide the meteorological fields that drive SCIPUFF. For input to SCIPUFF, the VDRAS analyses are interpolated and converted to files in MEDOC format.

To run SCIPUFF, estimates of surface heat flux and PBL height are also needed. These fields may be obtained from mesoscale model runs in the same area or from climatological estimates. With lidar data, it is possible to derive PBL height from the backscatter field. The SCIPUFF model can be launched periodically, or at times when a new VDRAS becomes available. The output depicts the paths of the plumes that originate from selected release locations.

3. APPLICATION OF VDRAS-SCIPUFF AT OKC

The coupled VDRAS-SCIPUFF system was run operationally during June 28 - July 31, 2003 for Oklahoma City in support of the Joint Urban 2003 field experiment (JU2003). The objective of JU2003 was to collect meteorological and tracer datasets to evaluate and improve modeling of dispersion in urban areas.

The radar data for Oklahoma City were provided by KTLX, located to the SE of OKC, at 35°20'N & 97°17'W. The data were distributed from Unidata to an NCAR local machine via Local Data Manager (LDM). Usually the data were received within seconds of the observation time, although occasional transmission delays occurred.

A domain of 60 km x 60 km x 6 km was used in both VDRAS and SCIPUFF runs in OKC. The VDRAS grid resolution was 1 km in the horizontal and 375 m in the vertical. A timestep of 15 s was used. The VDRAS analysis was updated every 10-12 minutes. The system was relatively stable, with exceptions when the KTLX data reception experienced delays.

In each assimilation cycle, a total of 48 iterations was conducted. The cost function was typically reduced by more than an order of magnitude by the minimization. The analyses at the lowest model level (187.5 m) compared reasonably well with surface observations.

Typically in July, the wind approaching OKC is from a southerly direction (SSW or SE) at a speed of 5-7 m/s. The radar observations and VDRAS analyses showed a lot of spatial and temporal variability due to various types of forcing. An example of the VDRAS wind analysis at OKC is shown in Figure 2. The mesoscale model MM5 was also run for the region at the time. The VDRAS analyses provided additional small scale structures in space and time.

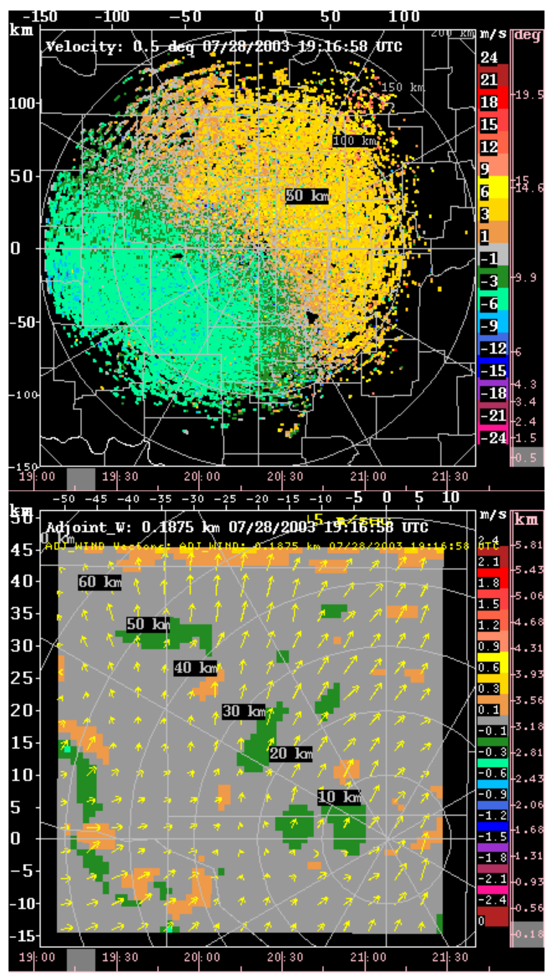

Fig. 2 Radial velocity field observed by KTLX and the corresponding VDRAS wind analysis.

For each VDRAS analysis of wind and temperature, a 1-h SCIPUFF run was conducted, assuming an instantaneous release from a point source. The modeled release point is at Sheridan & Robinson in downtown OKC, one of the actual sulfur hexafluoride release locations during the field experiment.

Results from the real-time runs were published though a website. Radar radial velocity and reflectivity fields, the VDRAS retrieved wind field, as well as one-hour animations of the SCIPUFF plumes were displayed. The MEDOC files were also available for downloading.

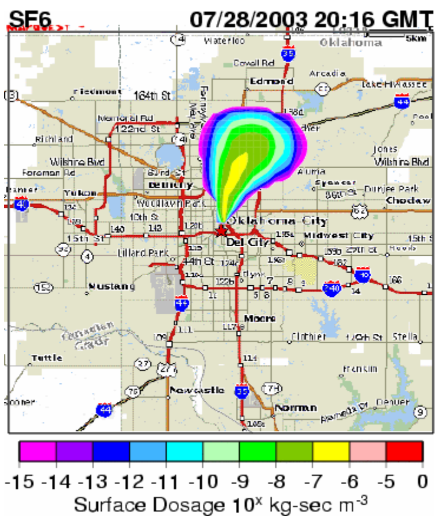

Fig. 3 Plume of time-integrated exposure of SF6 one hour after release. The background map is used with permission from MapQuest.

4. ASSIMILATING DOPPLER LIDAR DATA

A Variational Lidar Assimilation System (VLAS), which assimilates high-resolution Doppler lidar data and other meteological data, is currently under development and testing at NCAR. VLAS is based on the same numerical model as VDRAS, but it has modified features to accommodate the resolution and scan characteristics of Doppler lidars.

The best available eye-safe Doppler lidar is the WindTracer manufactured by Coherent Technologies Incorporated (CTI). The horizontal resolution for winds is typically 50-100 m, radial ranges are 5-7 km, and the layer measured extends from the surface to about 2 km. Very few lidar data assimilation studies have been done previously. Using CTI lidar data from CASES-99 and a 4DVAR model, Chai et al. (2003) showed that the model is capable of retrieving microscale turbulent structures.

The VLAS system was tested using CTI lidar data in Kansas and in Colorado. For the test in Colorado, each lidar volume consisted of several 90^o sector sweeps and lasted for 4 minutes. A domain of 6 km x 6 km x 2 km was used. The horizontal grid increment was 100 m, and the vertical grid increment was 50 m. An example of the analysed wind field is shown in Figure 4.

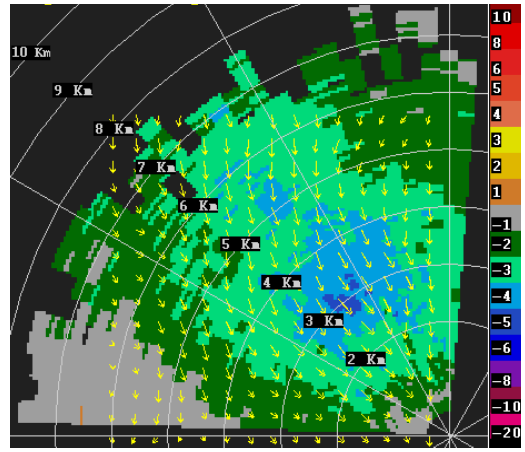

Fig. 4 Radial velocity field observed by WindTracer at 20:31 UTC 7/28/2003. The vectors are the VLAS retrieved wind analysis at 25 m ASL.

5. SUMMARY

A 4DVAR assimilation system was tested in real-time operations. The VDRAS system can be used to retrieve boundary-layer flows and temperature perturbations in urban areas from Doppler radar observations. The retrieved meteorological fields can then be used to drive a dispersion model. A coupled VDRAS-SCIPUFF system was run for Oklahoma City during JU2003. It is currently running for the Washington DC area in support of Defense Threat Reduction Agency operations. A 4DVAR system can also be used to resolve finer-scale atmospheric flows by assimilating Doppler lidar data.

One of the limitations of the current VDRAS system is the lack of surface and PBL physics. Methods are also needed to increase the speed of the minimization algorithm, in order to make it more efficient to run the system with more grid points.

ACKNOWLEDGEMENT

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