Pacific Northwest
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PNNL-32002

Assimilating Scanning Radar Data into Cloud-Scale Models

September 2021

James Marquis
Sheng-Lun Tai
Jerome Fast

U.S. DEPARTMENT OF ENERGY
Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Abstract

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Summary

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1.1 Heading 2

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Figure 1. Caption-Fig

Table 1. Caption-Tab (same basic rules as Caption-Fig). If a caption stretches to multiple lines, it needs to wrap below with a hanging indent (as in this example). Tables may have alternating gray bands if it makes scanning information easier. While in a table, see various PNNL design options in the Table Design ribbon.

Experiment(b)	F (cm^3/hr)	ρ_b (g/cm^3)	θ	V_w (mL)	v (cm/hr)	t_o (V_w)	R	K_d (mL/g)
Sodium orthophosphate	30.37	1.478	0.386	20.89	16.01	11.22	5.54	1.19
Sodium pyrophosphate	41.93	1.444	0.385	20.33	22.18	15.90	7.61	1.76
Sodium tripolyphosphate	40.80	1.460	0.392	21.27	21.22	14.70	5.17	1.12
Calcium	31.41	1.478	0.386	20.89	16.57	11.95	14.14	3.44

(a) F = flow rate; ρ_b = bulk density; θ = average volumetric water content (standard deviation); V_w = average pore volume; v = average pore water velocity; t_o = step input; R = retardation factor; K_d = sediment water distribution coefficient based on R.
(b) Columns appeared saturated and had reached a stable water content.

2.0 Section

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3.0 References

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Appendix A – Title

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1. Background:

The aim of this project is to improve the initial conditions of large eddy simulations (LES) of deep convective storms by assimilating scanning radar reflectivity and radial velocity data as well as local environmental observations. Accomplishing this goal often results in more accurate numerical forecasts of clouds and precipitation than if the background initial meteorological conditions are solely relied upon for convection initiation and intensification, as is typical of most operational and research models. Conducted in a storm-scale LES framework, these more accurate numerical analyses can serve as tool to better understand and parameterize land-atmosphere coupling, boundary layer turbulence, and cloud processes, each used for model parameterization development of convection. Our work examined the sensitivity of the numerical representation of cloud-scale wind and microphysical structures to: i) the assimilation of radiosonde observations characterizing the near-storm inflow, ii) the assimilation of radar data of varying resolution for model simulations with grid spacings of 1-km and 0.25-km, and iii) to the assimilation of three-dimensional plan-projection-indicator (PPI) and range-height indicator (RHI) radar volumes. Few studies have explored deep convective storm analyses and forecasts produced by assimilation of radar observations to cloud-scale LES. Furthermore, to our knowledge, no storm-scale DA study has explored the value of assimilating high-resolution sector RHI volumes to determine if they can improve the retrieval of the vertical kinematic and microphysical storm structure aloft over the use of traditionally utilized PPI scans.

2. Method:

We assimilated 3-D volumes of reflectivity and velocity data collected by the ARM CSAPR2 scanning radar deployed during the CACTI field campaign because of the vertically deep scanning strategy utilized, and the excellent spatial resolution achieved within nearby convective storms. This high quality radar data permits testing the upper limit of spatial resolution and coverage on reproducing numerical storm structure. We focused on 2 hours of data collected on 10 November 2018 and on 4 November 2018, during which a deep convective precipitating cloud developed within 20 km of the radar and travels eastward. During the 10 November case, CSAPR2 collected twelve 3-D PPI radar volumes, hemispheric RHI scans, and three high-azimuthal-resolution sector RHI volumes. The 10 November case also contains significant additional value because many radiosonde measurements are available in the near storm inflow, permitting an examination of the sensitivity of analyzed storm structure to the refinement of the initialized background meteorological condition. Thus, though we experimented with data from both cases, we primarily focused on the 10 November case.

Radar data were first processed using Taranis (a tool developed by the CMDV-MCS and ICLASS projects) and further manually revised to remove ground clutter, and other noise signals. Subsequent processing smoothed the data using a 2-pass running filter to 1-km and 500-m horizontal grids using a Matlab script written by PI Marquis. We coupled the Weather Research and Forecasting (WRF) model with a 3DVAR data assimilation scheme for our experiments. PPI volumes were assimilated at 15-min intervals, starting at 1845 UTC, with intermediate 15-min forecasts conducted between available radar volumes. Experiments utilizing sector RHI volumes begin assimilation at 2000 UTC. Our model employed a dual nested domain, with a 1-km and 250-m grid. We used these grids for two purposes: a) assimilating radar data to both the 1-km and 250-m grids to compare sensitivity of retrieved storm structure to the use of a cloud-resolving model resolution versus a coarser resolution that is akin to common weather prediction models; and b) assimilating radiosonde meteorological observations to the 1-km grid during experiments where we refine the initial background meteorological condition. Simulations performed during this project leverage initial storm-scale data assimilation efforts afforded to us by a small LDRD seed opportunity in FY2020.

3. Outcomes:

Initial simulations employing an operational model initial condition and no data assimilation produce significant geographical position and morphological precipitation errors of the targeted storm on 10

November (c.f., Fig 1a-b). Assimilation of environmental radiosonde measurements prior to storm formation improved position errors and reduced some spurious neighboring convection but did not necessarily improve the forecasts and of storm morphology into one coherent precipitation signal (Fig. 1c).

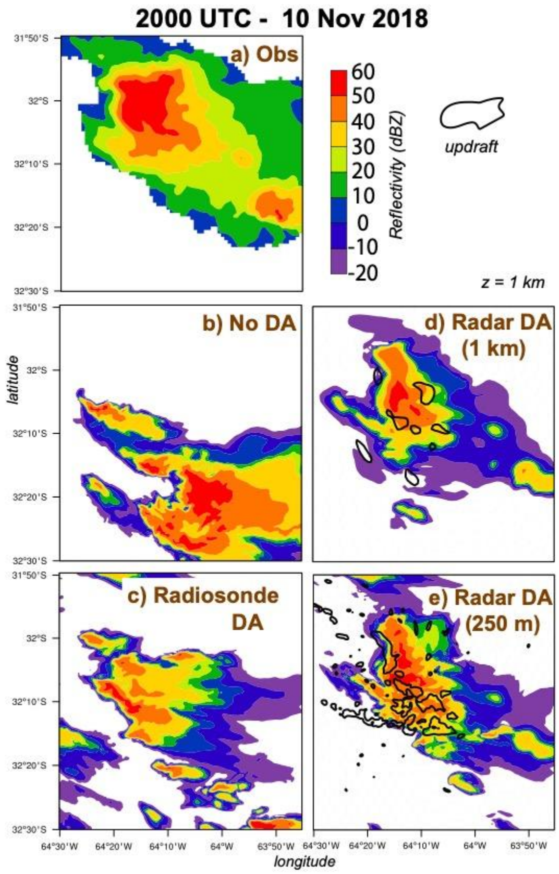

Figure 1. a) Radar reflectivity within a storm at 2000 UTC on 10 Nov 2018. Forecasts of reflectivity at 2000 UTC from simulations assimilating no observations (b), radiosonde observations (c), and radar PPI volumes (d-e). Simulations in panels b, c, and e utilize a 250-m model grid, while that in panel d utilizes a 1-km grid.

Our next set of experiments explored analyses and forecasts resulting from the assimilation of PPI radar volumes to 1-km and 250-m model grids (Fig. 1d-e). Overall, forecasted storm structure is qualitatively similar across the two grid resolutions during our tested 45-min periods. Perhaps not surprisingly, precipitation and updraft structures forecasted on the 250-m grid are finer than 1-km forecasts; 250-m forecasts include greater updraft area than in 1-km forecasts, which has been discussed in past studies as being important for deep convection to thrive. This indicates the potential for this method to produce valuable cloud-scale analyses and forecasts for the evaluation of deep convective processes. These analyses and forecasts were produced by assimilating radar data analyzed on a 1-km grid. Further improvement in forecasted cloud structure may result from assimilating finer-resolution observations to the model with 250-m grid spacing. Spurious neighboring convection that contaminated the structure of the primary storm was suppressed by assimilating 'clear-air' radar reflectivity observations. This was helpful for isolating the modifications of the primary storm by data assimilation rather than by contamination from and interaction with unrealistic neighboring cells.

Our final set of experiments explored the sensitivity of storm analyses to assimilation of PPI or RHI radar data volumes. Coherent 3-D flow and precipitation structure is produced after the assimilation of only one RHI volume; albeit, with unrealistically intense simulated radar reflectivity below the freezing level (Fig. 2a-b). This may be due in part to incongruity errors resulting from assimilation of C-band radar reflectivity observations and model microphysical schemes utilizing S-band reflectivity assumptions in their calculations, as well as sensitivities to various data assimilation and model microphysical scheme parameters. The RHI-assimilating simulation offered slightly improved depiction of the vertical precipitation profile aloft over the PPI-assimilating simulation. However, evolution and motion of the storm over a 5-min period between when the collection times of the PPI and RHI volumes adds some uncertainty to this comparison. Storm structure in subsequent forecasts are qualitatively similar across RHI-only and PPI-only DA experiments; however, RHI-assimilating forecasts more realistically simulate the storm with a stronger eastward motion than do the PPI forecasts. However, it is unclear if this a result of an accurate depiction of the storm interacting with the environment or because of excessive cold pool winds resulting from overly intense near-surface precipitation, which drive a rapid motion of the low-level updraft (Fig. 2b)

4. Considerations for future application:

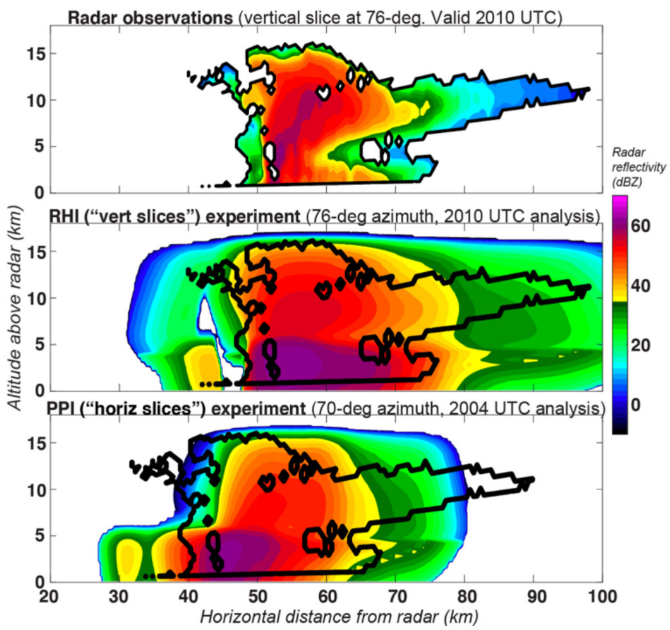

Figure 2. top) Radar reflectivity RHI observation at 76-deg azimuth and 2010 UTC on 10 Nov 2018. Middle) Same as the top panel, but an analysis of simulated radar reflectivity in an experiment that assimilates one RHI volume at 2010 UTC. Bottom) Same as middle panel, but from an experiment that assimilates one PPI volume at 2005 UTC. The position of the black contour that outlines the observations at 2010 UTC is adjusted to 2005 UTC using a mean storm motion.

Although our analyses did not always faithfully reproduce the observed storm structure, forecasts from radar- and radiosonde-assimilating experiments were far more successful than in simulations lacking data assimilation. These results suggest promise in the assimilation of both in-cloud radar data in an LES framework for the evaluation of storm-scale processes. Analyses and forecasts of the 10 November 2018 case were more realistic than analogous simulations of the 4 November 2018 case (not shown). This suggests highly variable forecast performance per radar data set, model initial condition, and available background meteorological measurements. Analysis and forecasts for additional cases will likely be required to further understand the range of optimal data assimilation parameters required to generalize broad applicability across many events. This refinement may be aided by improvement of microphysical forward operators, more sophisticated assimilation schemes (e.g., ensemble Kalman filtering, 4DVAR), and the use of an OSSE framework; the latter of which provides "truth" simulations to serve as a precedent for optimized observing, numerical analysis, and forecast strategy.

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