Formations of Multiple Squall Lines and the Impact of WSR-88D Radial Winds in a WRF Simulation

Haldun Karan, Patrick J. Fitzpatrick, Christopher M. Hill, and Yongzuo Li · Northern Gulf Institute, Mississippi State University, Stennis Space Center, Mississippi, USA

Introduction

To improve the estimate of the initial atmospheric state, the assimilation of radial winds and reflectivity factors from multiple ground-based Doppler radars into high resolution mesoscale models have become a focus to deduce convective scale phenomenon (Xiao et al. 2005, 2008; Zhao et al. 2006; Hu et al. 2006).

The squall lines examined in this study formed in the south central U.S. The impact of the assimilation of radial wind data from multiple WSR-88D sites in a squall line simulation is examined. A detailed analysis indicated that two different convective initiation mechanisms were responsible for the formation of a primary and a secondary squall lines: Excitation of small gravity waves and lower tropospheric trough.

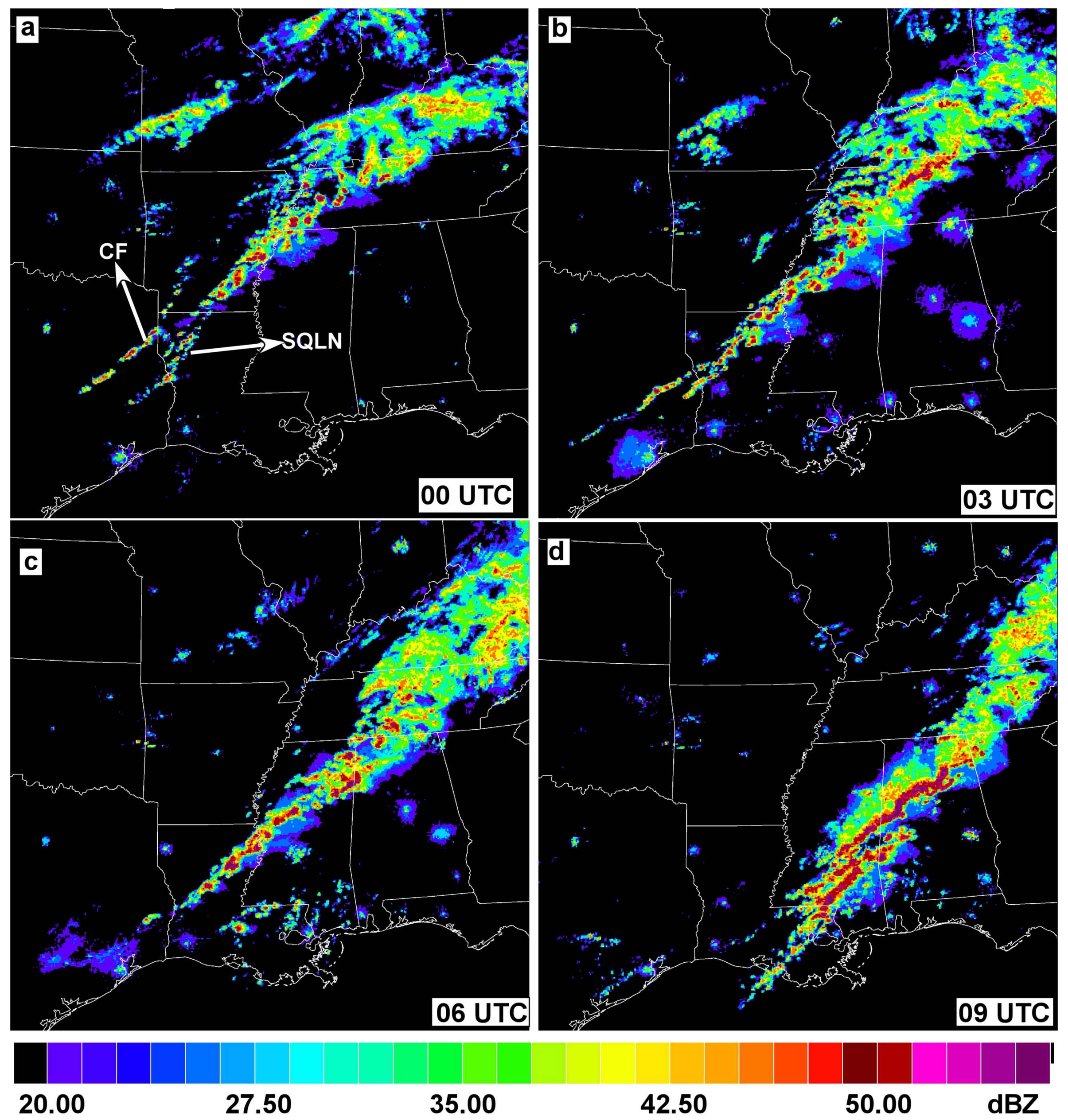


Fig 1. NEXRAD Composite Level-III reflectivity factor on 30 April 2005

Observations (Fig. 1) indicate two separate areas of convection initiation (CI): Along the cold front (CF) and 60-80 km east of the CF. A merging of these convective lines occurred as the CF propagated eastward. By 06 UTC, the line convection becomes one entity, and a new region of convection (secondary squall line) appears ahead of the primary squall line over southern Louisiana. The secondary squall line later merges with the primary squall line by 09 UTC.

Methodology

The Weather Research and Forecast (WRF) model and its three dimensional variational data assimilation system (3DVAR) are used to determine the differences in assimilating Global Telecommunication System (GTS) data, Soil Climate Analysis Network (SCAN) data, and radial wind data from nine WSR-88D Doppler radar sites. The North American Mesoscale (NAM) analysis with 40-km grid resolution is used to obtain the initial and boundary conditions for the WRF simulation. The background error covariances are determined using the "NMC method" (Parrish and Derber 1992) by performing the WRF simulations during 1-15 April in a 12-h cycling mode to generate a sample of model errors. A nested domain with a grid resolution of 4 km, 350 horizontal grid points, and 35 vertical points is used (Fig. 2). Standard observations from the GTS and USGS's SCAN are used in 3DVAR as a control experiment (CTRL). Radial velocities from nine WSR-88D radars, and GTS and SCAN observations are used in 3DVAR system as a second experiment (RADAR). The squall line case study is initialized at 1800 UTC 29 April 2005 for both the CTRL and RADAR experiments.

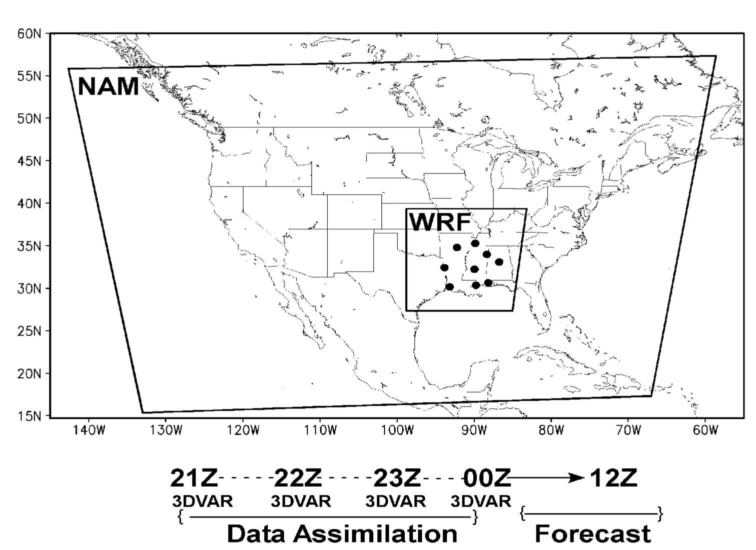
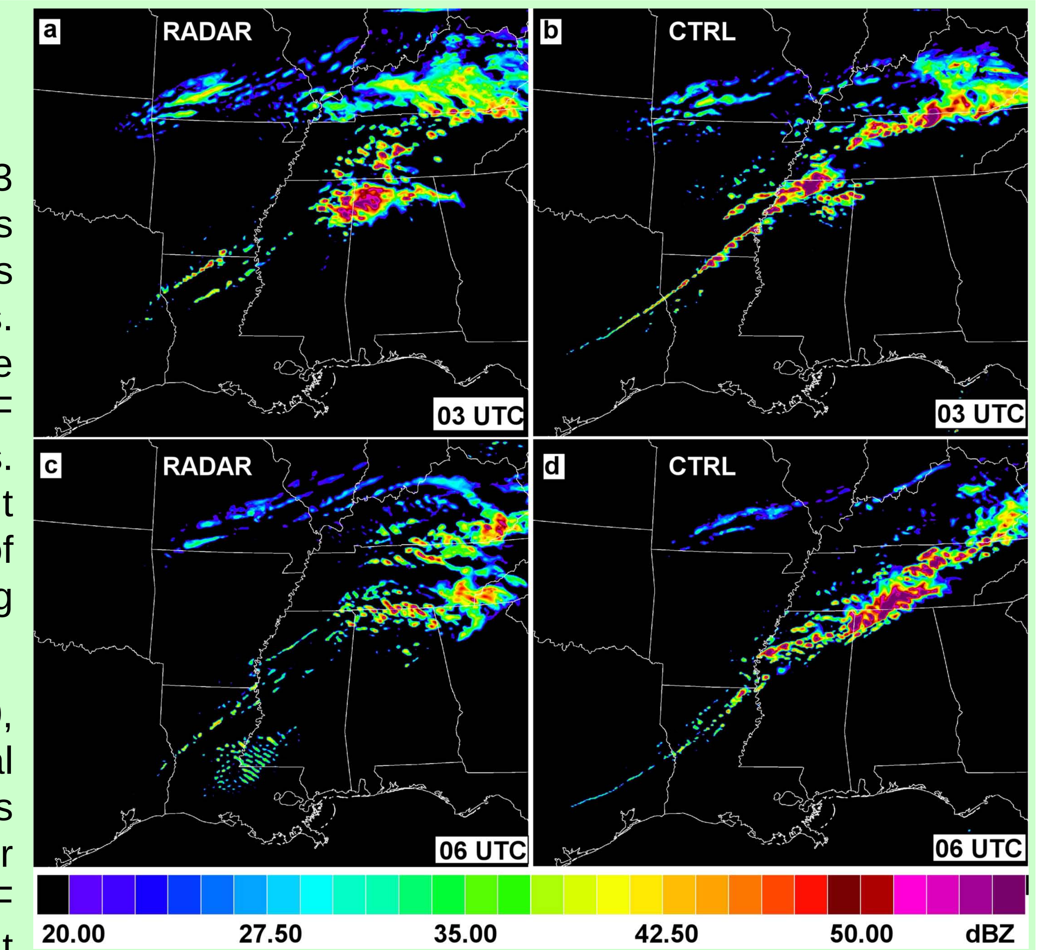


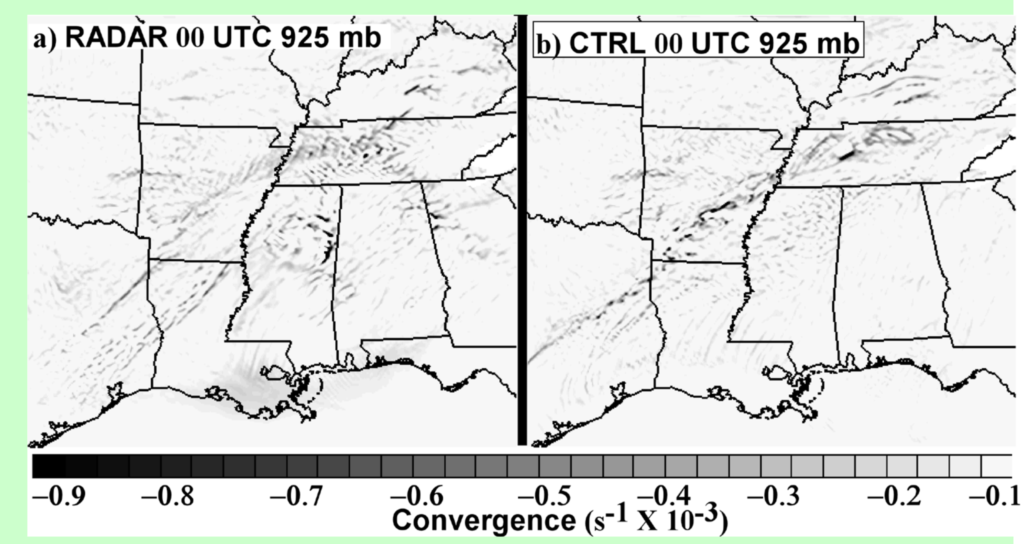
Fig 2. Domains for ETA/NAM and WRF models and Doppler radar sites.

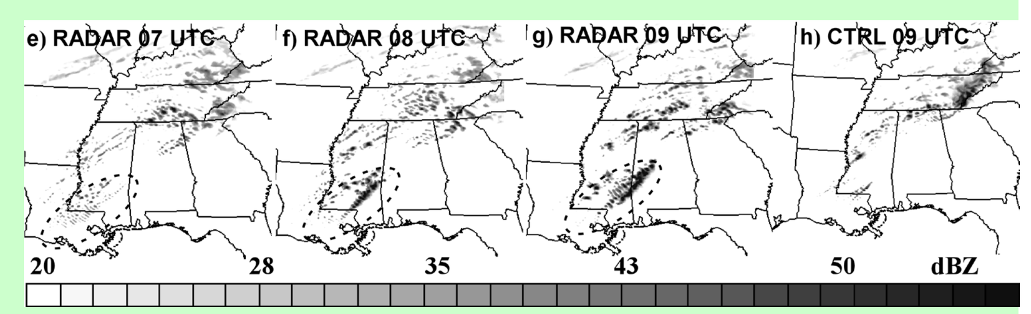
Results



WRF composite reflectivity factor at 03 UTC forecast hour (a, b) reveals important characteristic differences between the two WRF experiments. The CTRL experiment yielded more pronounced convection along the CF resembling the 03 UTC observations. However, the RADAR experiment clearly depicts two regions of convection: along the CF, and along the primary squall line.

Divergence fields at 925, 850, 700, and 500 mb levels at the model initial time between the two experiments indicate that the CTRL exhibits greater convergence along the surface CF than the RADAR. Convergence at 925, 850, and 700 mb along the CF is two times greater than the RADAR. The RADAR captured better the location and structure of the primary squall line though. The resemblance in the structure of the squall line depicted by the observations (Fig 1a) and the RADAR experiment is quite remarkable.



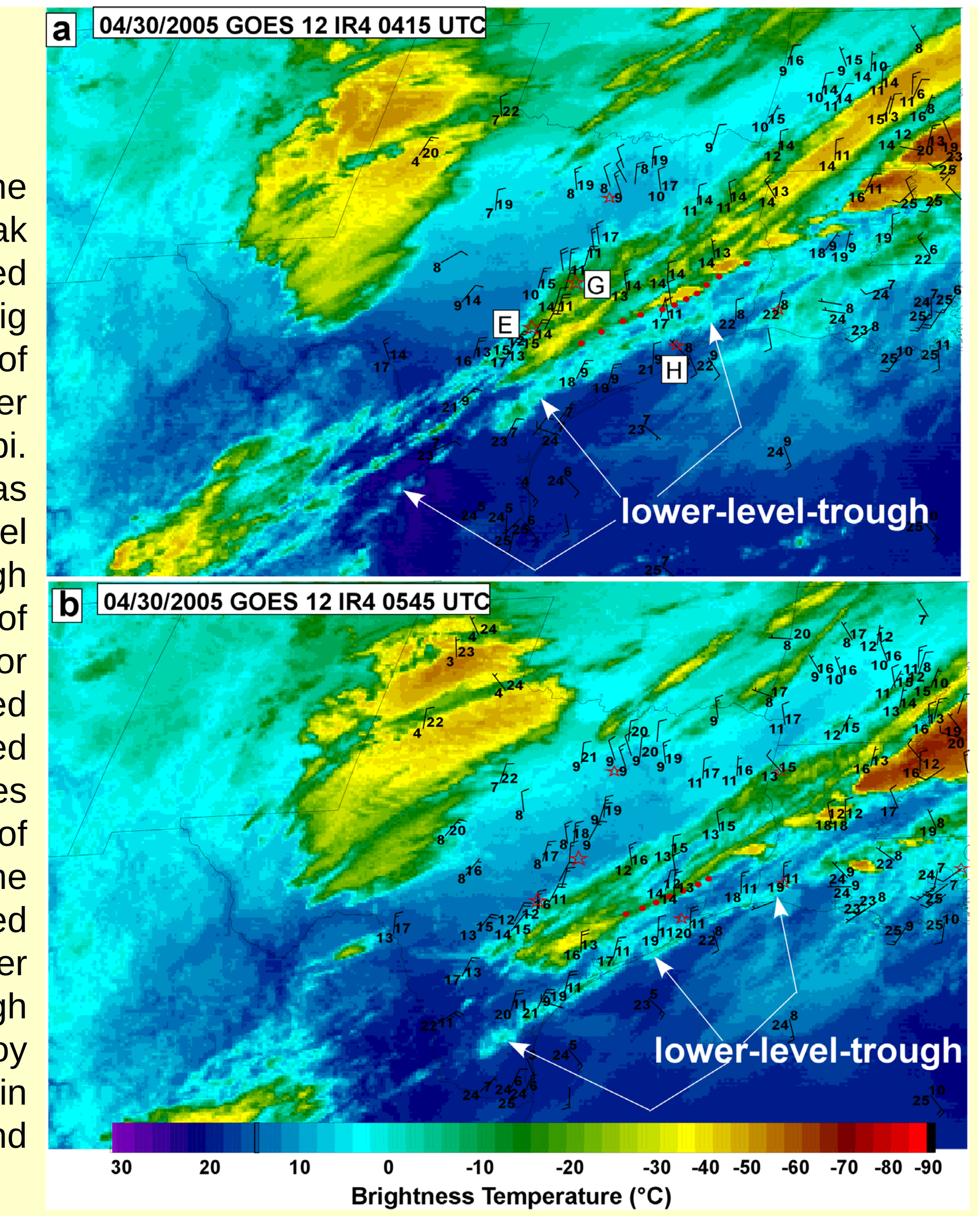


At the model initial time, the RADAR starts with warmer temperatures (~2-4 K) and higher water vapor (~1-6 g/kg) over the southern regions. Wind vector differences between the two experiments revealed 5-10 m/s more southerly flow in RADAR simulations. Vertical structures of temperature and water vapor at the model initial time indicated that these differences (warmer and more moist atmosphere to the south for the RADAR) only existed mainly at and below 850 mb for the temperature and 700 mb for the water vapor. Greater advection of temperature and water vapor in the RADAR simulation yielded temperature and water vapor increases of more than 1 K and 1-2 g/kg per hour over the southern regions.

Higher moisture and warm air advection at lower atmospheric layers with stronger southerly flow for the RADAR experiment are observed from the start of the model initialization to the 06 UTC forecast hour. The RADAR experiment was able to forecast the timing and the location of the secondary squall line (depicted as dashed ellipse areas in e, f, and g). CTRL simulation, on the other hand, did not capture such a secondary squall line formation (h). The RADAR experiment yielded larger CAPE (Convective Available Potential Energy) values over most of the Gulf cost region due to greater water vapor and warm air advection at lower atmospheric levels. By 09h forecast time, the RADAR experiment showed a merger of the two squall lines over southern and central Mississippi and Alabama, US.

Conclusions

During the secondary squall line formation at around 06 UTC, weak synoptic scale updrafts associated with the lower tropospheric trough (Fig a, b) brought about additional lifting of air parcels to the LFC level over southern Louisiana and Mississippi. The low-level trough feature was accompanied with a line of low-level cloud formation observed through GOES IR imagery. As the band of clouds which was used as a proxy for the mid-tropospheric trough moved eastward, surface pressure increased about 2 mb, and temperatures dropped for 2ºC during the period of 0415-0545 UTC. There were some stations that observed wind speed increase from 5 m/s to 8-10 m/s. Over the Gulf of Mexico, as the trough propagated to the east, the buoy stations experienced only a shift in wind direction, while temperature and pressure remained unchanged.



Velocity-Azimuth Display (VAD) acquired from Doppler radar sites indicated a disturbance in the wind field at 1.5-2 km above ground level. Upper level (500 mb) observations indicated the existence of a mid-tropospheric trough which was co-located with the cloud shield that was oriented northeast-southwest as seen in Fig. a and b.

- The model results and observations indicated slow destabilization over the region through advection of colder air aloft, and warm air advection at 850 and 700 mb levels.
- Although the RADAR experiment predicted convection along the CF that is weaker than observed, the RADAR experiment performed better with respect to the timing and location of the secondary squall line.
- The upper air and surface observations, together with GOES infrared imagery, suggested the existence of low-level trough passage. Geopotential height analysis of the model experiments showed that the RADAR experiment was able to capture short wave passage at 850 mb-700 mb layer.
- While meso-α, and synoptic scale characteristics of the primary squall line system were captured well by the CTRL experiment, localized effects and small scale features were better depicted by the RADAR experiment.
- Significant thermodynamic and kinematic differences between the two experiments seem to be confined to the low troposphere. A vast quantity of the radial wind information introduced to the 3DVAR was measured at low elevation angles, which contributed to the differences.

References

Hu, M., M. Xue, J. Gao and K. Brewster, 2006: 3DVAR and cloud analysis with WSR-88D level-II data for the prediction of the Fort Worth, Texas, tornadic thunderstorms. Part II: Impact of radial velocity analysis via 3DVAR. *Mon. Wea. Rev.*, **134**, 699-721.

Parrish, D. F., and J. C. Derber, 1992: The National Meteorological Center's spectral statistical-interpolation analysis system. *Mon. Wea. Rev.*, **120**, 1747-1763.

Xiao, Q, Y. H. Kuo, J. Sun, W. C. Lee, E. Lim, Y. R. Guo, and D. M. Barker, 2005: Assimilation of Doppler radar observations with a regional 3DVAR system: Impact of Doppler velocities on forecasting of a heavy rainfall case. *J. Appl. Meteor.*, **44**, 768-788.

—, E. Lim, D. J. Won, J. Sun, W. C. Lee, M. S. Lee, W. J. Lee, J. Y. Cho, Y. H. Kuo, D. M. Barker, D. K. Lee, and H. S. Lee, 2008: Doppler radar data assimilation in KMA's operational forecasting. *Bull. Amer. Meteor. Soc.*, **89**, 39-43.

Zhao, Q, J. Cook, Q. Xu, and P. R. Harasti, 2006: Using radar wind observations to improve mesoscale numerical weather prediction. *Wea. and Forecasting*, **21**, 502-522.