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Application of the Variational LAPS (STMAS) data assimilation system in a tornadogenesis numerical simulation

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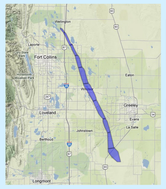
Introduction

The May 2008 Windsor tornado case has been simulated using the Weather Research and Forecasting (WRF) model. The Variational Local Analysis Prediction System (LAPS), *i.e.* Space and Time Multiscale Analysis System (STMAS), are used to produce initial conditions. The Variational LAPS (STMAS) improves humidity analysis and assimilates various observations, including liquid profiles from a microwave radiometer. The impact of data assimilation (DA) on tornadogensis and tornadic development has been investigated.



http://www.crh.noaa.gov/bou/?n=news_116

Tornado touched down at Windsor, Colorado around 17:40 UTC, 22 May 2008.

Most expensive tornado in Colorado's history

1 fatality, 15-20 injuries, 850 home damages, ~$200 million loss

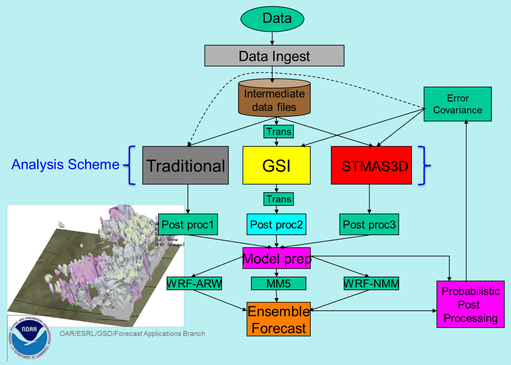
EF3 (wind as high as 130 to 150 mph)

Objective

To study the impact of the Variational LAPS (STMAS) on the numerical simulation of the Windsor tornado case:

- Diagnosis of synoptic and mesoscale conditions (focus on 3-km simulation)
- Analysis of thermodynamic quantities and moisture conditions (3-km)
- The diabatic initialization (hot start) and the tornadic development (1-km)

The LAPS DA-Ensemble System



The Variational LAPS (STMAS) developed at NOAA/ESRL/GSD is a multigrid variational DA system, which provides a multiscale and inhomogeneous analysis.

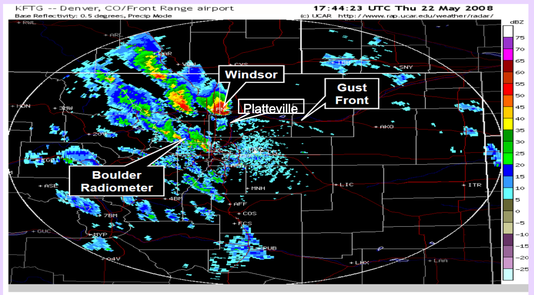
- Multigrid scheme resolves multiscale (long wave to short wave)
- Optimize background information from NWP models and observations
- Assimilate all data types
- Constrains (weak geostrophic and hydrostatic balance, strong continuity)
- Diabatic (hot start) initialization
- Sequence of 3-4DVARs with proper balances
- Similar to traditional LAPS analysis with less requirement of covariance
- Computationally efficient

Model and data

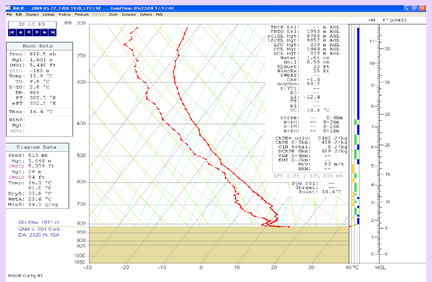
- The WRF-ARW (Advanced Research WRF)
- Background (BC): 13-km Rapid Update Cycle (RUC) , 3-h, 40 levels.
- Thompson microphysics, PBL: YSU, RUC LSM, no convective
- 3-km and 1-km single domains, 81 levels, Ptop=100 mb
- The Variational LAPS (STMAS) DA hot-start initialization; DA update BC

Observations and environmental conditions

Strong radar reflectivity was observed when the tornado was formed, accompanied by the gust front. The measurement of the radiometer in Boulder shows favorable environmental conditions for tornadogeneisis, such as relatively high humidity (mixing ratio: 14.3 g/kg), very high convective available potential energy (CAPE) and low lifting condensation level (LCL, 339 m).



Strong reflectivity near Windsor at 11:44 am (local time).



The radiometer observed maximum CAPE (3,462 J/kg) at 11:17 am (local time) when the tornado touched down near Platteville.

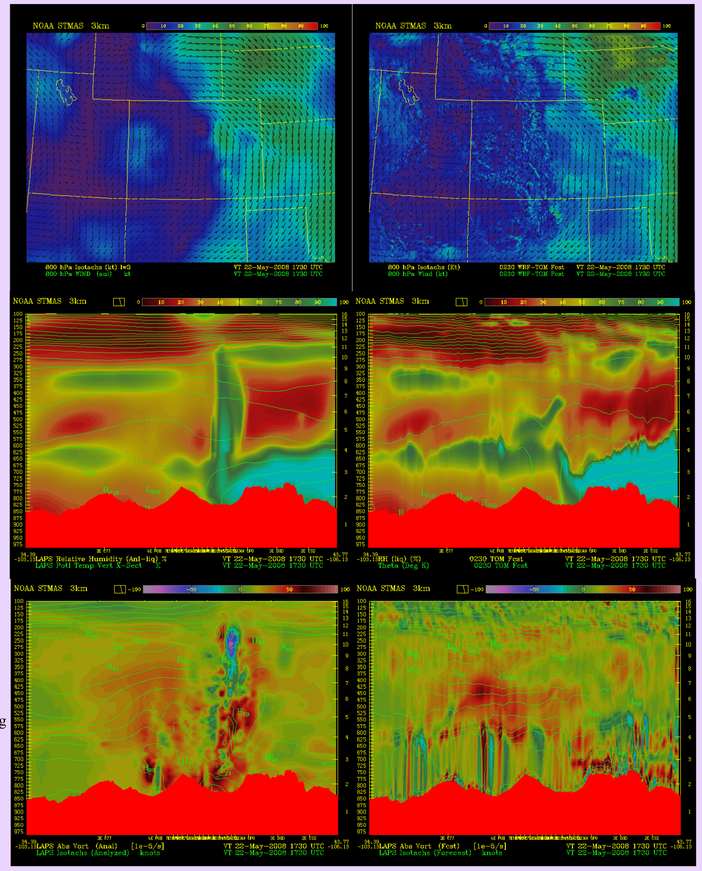
Thermodynamic and moisture conditions

Left: Analysis (Varational LAPS) at 17:30 UTC **Right:** 3-km LAPS-WRF 3-h Forecasts (initial time: 1500 UTC)

800hPa wind bars and wind speed (shading)

cross section of RH (shading) and Θ (contour) along the tornado path

cross section of vorticity wind (shading) and wind speed (contour) along the tornado path

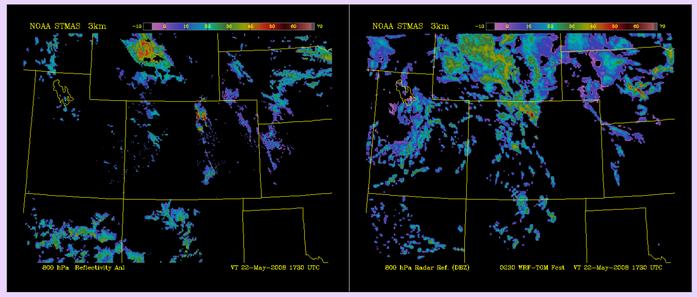


Top: The 800hPa wind forecast enhanced southeasterly flow and weakened the cyclonic vortex.

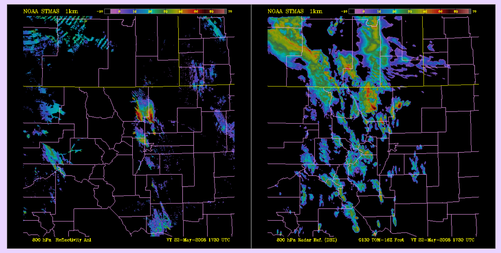
Middle: The cross sections of relative humidity (RH) and potential temperature (Θ) along the tornado path show that the forecasted moisture did not reach high enough to higher levels near the touchdown location.

Bottom: The forecasts of vorticity wind and wind speed misrepresented the feature of strong cyclonic motion at low levels and anticyclonic motion at high levels near the touchdown location.

Analyzed and forecasted reflectivity

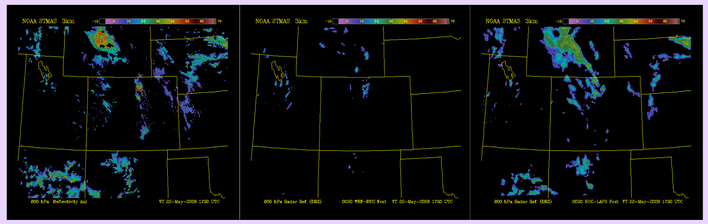


The 800hPa composite radar reflectivity (left) measured at 17:30 UTC (Note the radar blockage over the Rocky Mountains), and the forecasted radar reflectivity (right) from the 3-km LAPS-WRF model output (initial time: 15:00 UTC). The supercell was forecasted westward, which corresponds to the wind forecast with southeasterly flow.



The 800hPa composite radar reflectivity (left) measured at 17:30 UTC and the forecasted radar reflectivity (right) from the 1-km LAPS-WRF model output (initial time: 16:00 UTC). Multiple cells were forecasted and the supercell was not sustained, although the LAPS initialization had the quite similar distribution as the observation (not shown).

Diabatic initialization (hot start)



The 800hPa composite radar reflectivity (left) measured at 17:30 UTC, and the forecasts from the RUC analysis initialized WRF output (middle) and the 3-km LAPS-WRF output (initial time: 17:00 UTC). The hot start initialization in LAPS improved the simulation of the hydrometeors and reduced the spin-up problem, but the intensity was weaker compared to the earlier initialization.

Summary

The Variational LAPS (STMAS) is an effective data assimilation system, and improves the Windsor tornado forecasting at fine resolution with improved humidity analysis. And hot start initialization is very important for tornado forecasting and helps the tornadogenesis. The life cycle of the supercell and tornadic development is worthy of investigation.

Future work

Integrate cloud, humidity, derived fields and dynamic balances by the unified Variational LAPS (STMAS)

Add satellite data assimilation capability using Community Radiative Transfer Model (CRTM)

New terrain following coordinate, improve interpolation schemes, better terrain boundary conditions

NIM (Non-hydrostatic Icosahedral Model, a global model of ESRL) data assimilation, a sequential 4DVAR of the Variational LAPS (STMAS)

References

Xie, Y., S. E. Koch, J. A. McGinley, S. Albers, and N. Wang, 2005: A sequential variational analysis approach for mesoscale data assimilation. 21st Conf. on Weather Analysis and Forecasting, Washington, D.C., *Amer. Meteor. Soc.*, CD-ROM, 15B.7.

Xie, Y., S. Koch, J. McGinley, S. Albers, P. E. Bieringer, M. Wolfson, M. Chan, 2011: A Space–Time Multiscale Analysis System: A sequential variational analysis approach. *Mon. Wea. Rev.*, **139**, 1224–1240.