Development of Multi-Scale Large-Scale Forcing for MC3E Cloud Modeling Studies

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Introduction

The large-scale forcing fields (e.g., vertical velocity and advective tendencies) are required to run single-column and cloud-resolving models (SCMs/CRMs), which are the two key modeling frameworks widely used to link field data to climate model developments.

The advanced objective analysis approach developed by Zhang and Lin (1997) is used to derive the required forcing data from the soundings collected by the Mid-latitude Continental Convective Cloud Experiment (MC^{3}E) in support of its cloud modeling studies. A unique feature of this approach is the use of domain-averaged surface and top-of-the atmosphere (TOA) observations (e.g., precipitation and radiative and turbulent fluxes) as constraints to adjust atmospheric state variables from soundings by the smallest possible amount to conserve column-integrated mass, moisture, and static energy so that the final analysis data is dynamically and thermodynamically consistent.

To support modeling studies on various-scale convective systems, the large-scale forcing data were created over three domains with the size of 300km x 300km, 150km x 150km, and 75km x 75km, respectively.

The Objective Variational Analysis

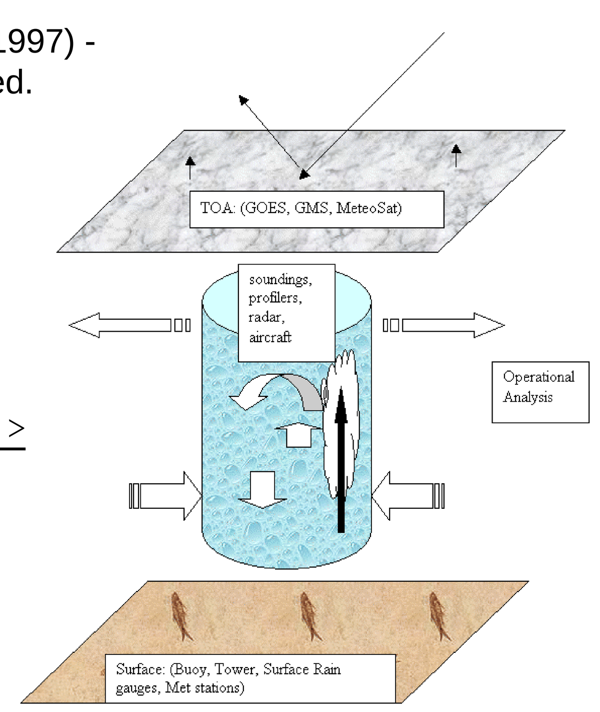
The constrained variational analysis (Zhang and Lin 1997) - Mass, moisture, energy and momentum are conserved.

$$\langle \nabla\cdot\vec{V}\rangle = -\frac{1}{g p_s}\frac{dp_s}{dt}$$

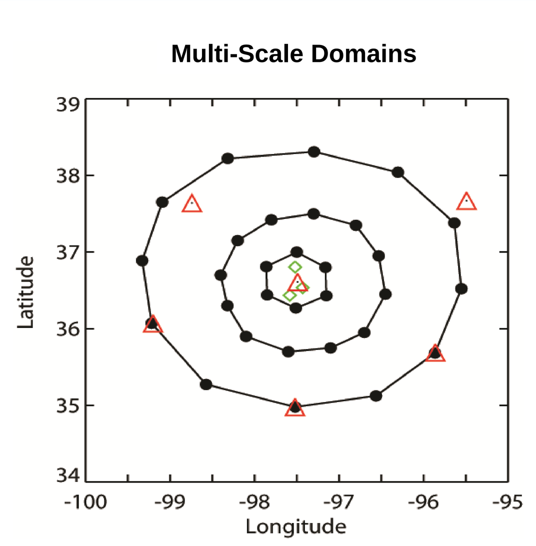
$$\frac{\partial\langle q\rangle}{\partial t} + \langle\nabla\cdot\vec{V}q\rangle = E_s - Prec - \frac{\partial\langle q_l\rangle}{\partial t}$$

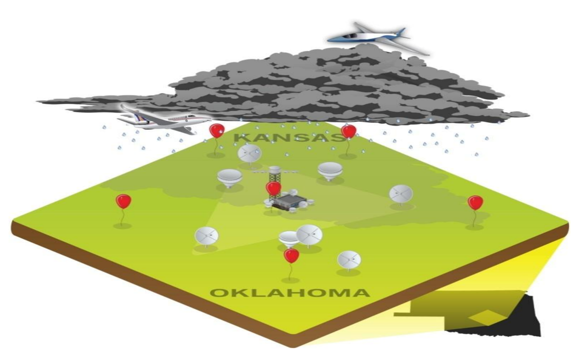
$$\frac{\partial\langle s\rangle}{\partial t} + \langle\nabla\cdot\vec{V}s\rangle = R_{TOA} - R_{SRF} + LPrec + SH + \frac{\partial\langle q_l\rangle}{\partial t}$$

$$\frac{\partial\langle\vec{V}\rangle}{\partial t} + \langle\nabla\cdot\vec{V}\vec{V}\rangle - f\hat{k}\times\langle\vec{V}\rangle - \nabla\langle\phi\rangle = \vec{\tau}_s$$



Analysis Details



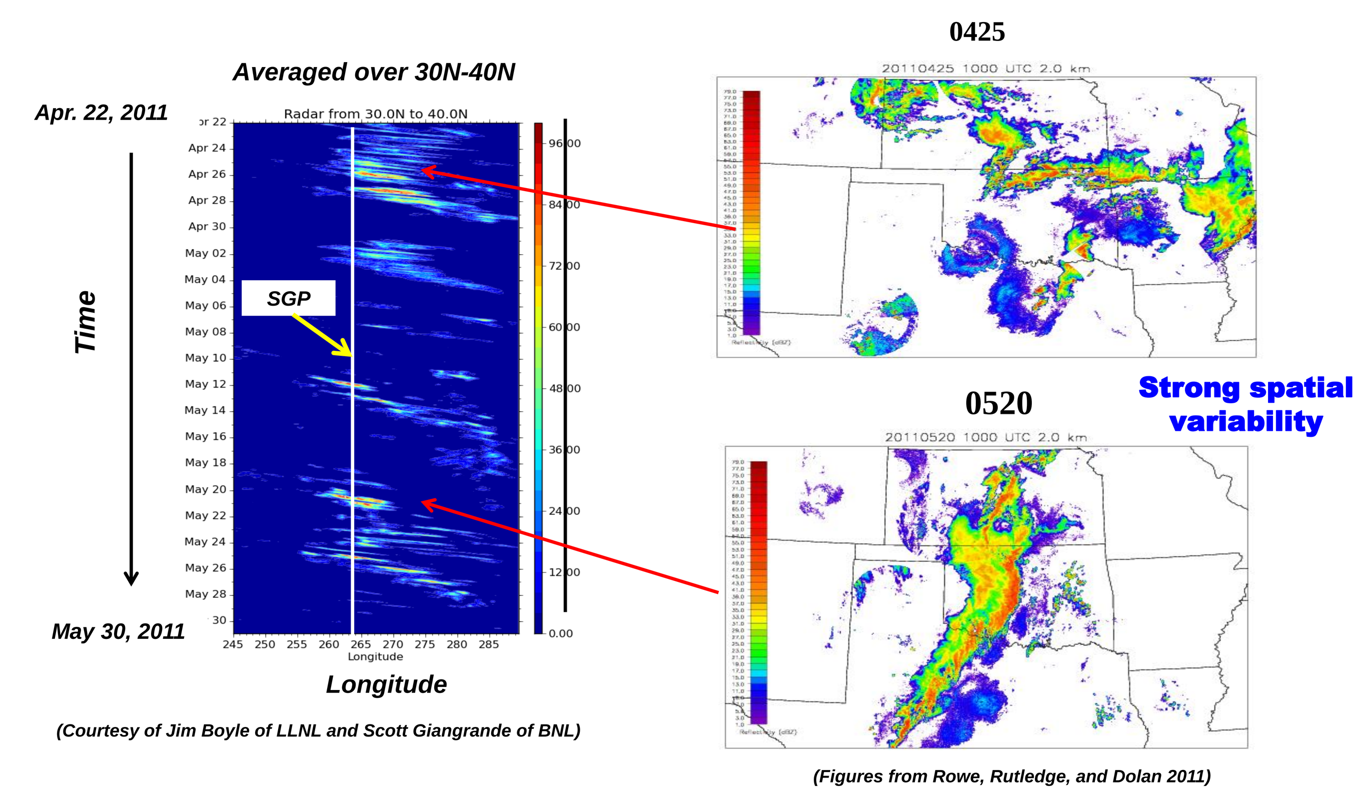


(Figure from Mike Jensen of BNL)

Some details

- Forcing over 300km x 300km, 150km x 150km, and 75km x 75km domains
- Resolutions: 3 hours, 25mb
- Coverage: 4/22/2011 - 5/26/2011
- Soundings are available at 6 stations every 3 hours
- RUC analysis is used as first guess
- ABRFC precip + ARM surface flux measurements
- ARM SMOS + OKM/KAS mesonets
- Satellite measured radiative fluxes at TOA
- RUC analysis plays more important role for smaller domains. The quality of RUC analyses is suitable for the analysis: RMSE < 0.2K in T, <2% in RH, < 0.5 m/s in u, and v.

Observed Clouds and Precipitation Systems



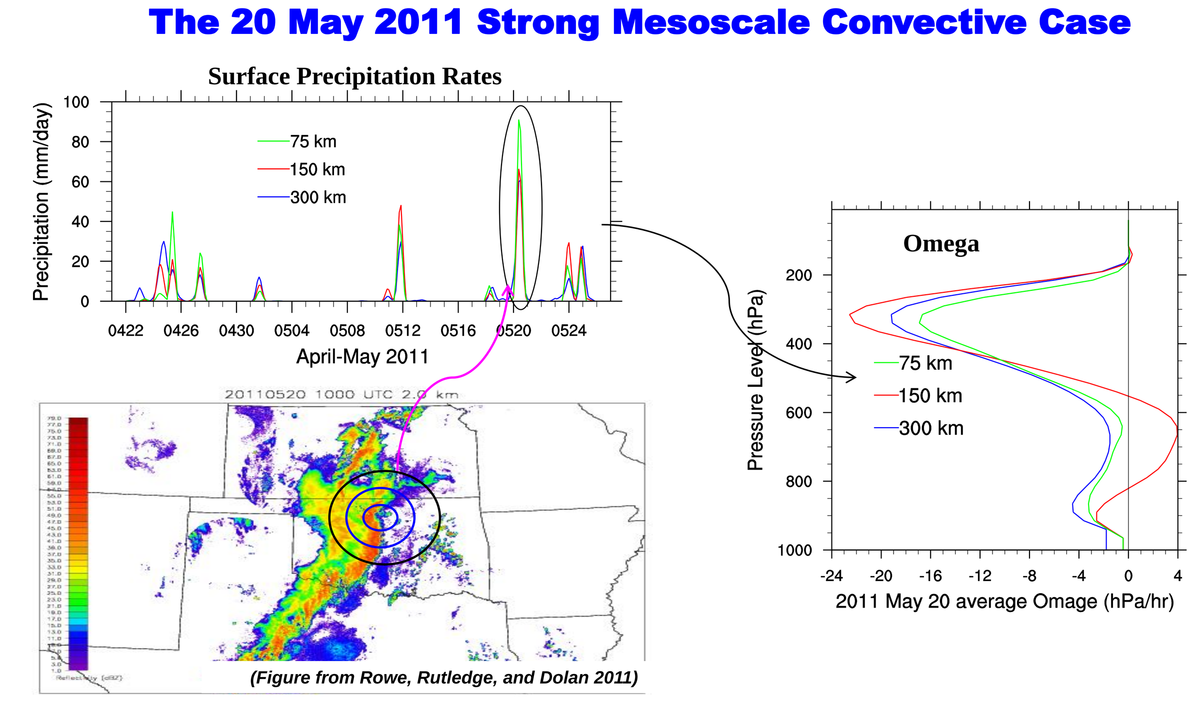
(Courtesy of Jim Boyle of LLNL and Scott Giangrande of BNL)

(Figures from Rowe, Rutledge, and Dolan 2011)

The Hovmöller plot shows the evolution of rainfall averaged over 30N-40N from the NEXRAD radar measurements. During MC3E period, several major convective systems propagated across the ARM SGP site, whose location is represented by the white line. The two radar snapshots corresponding to the two major precipitation events indicate strong spatial variability of these cloud systems.

Forcing with Different Domain Sizes

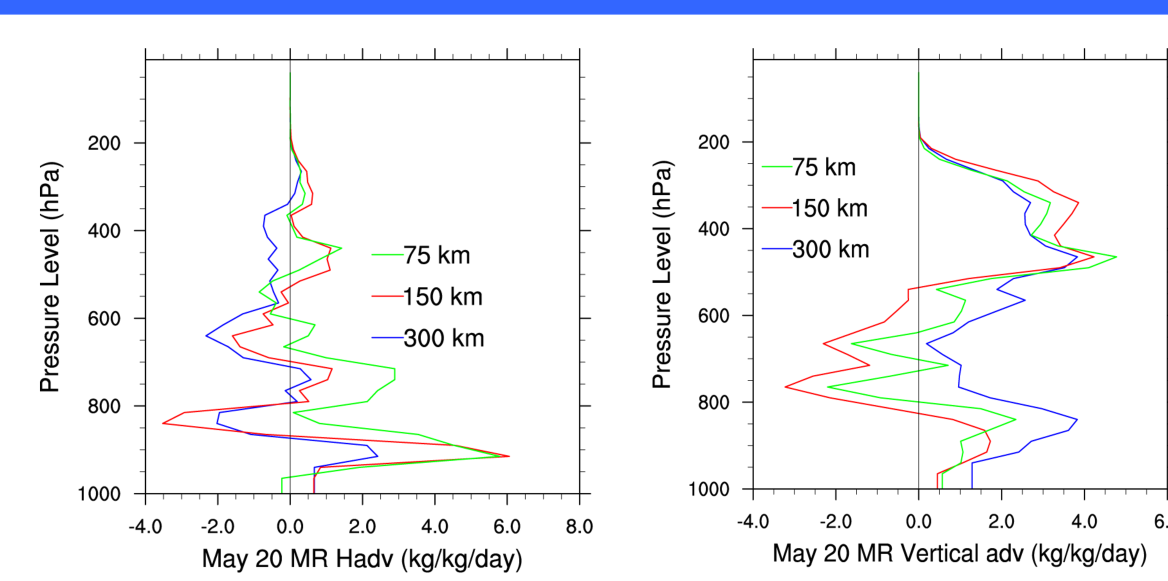
The 20 May 2011 Strong Mesoscale Convective Case



(Figure from Rowe, Rutledge, and Dolan 2011)

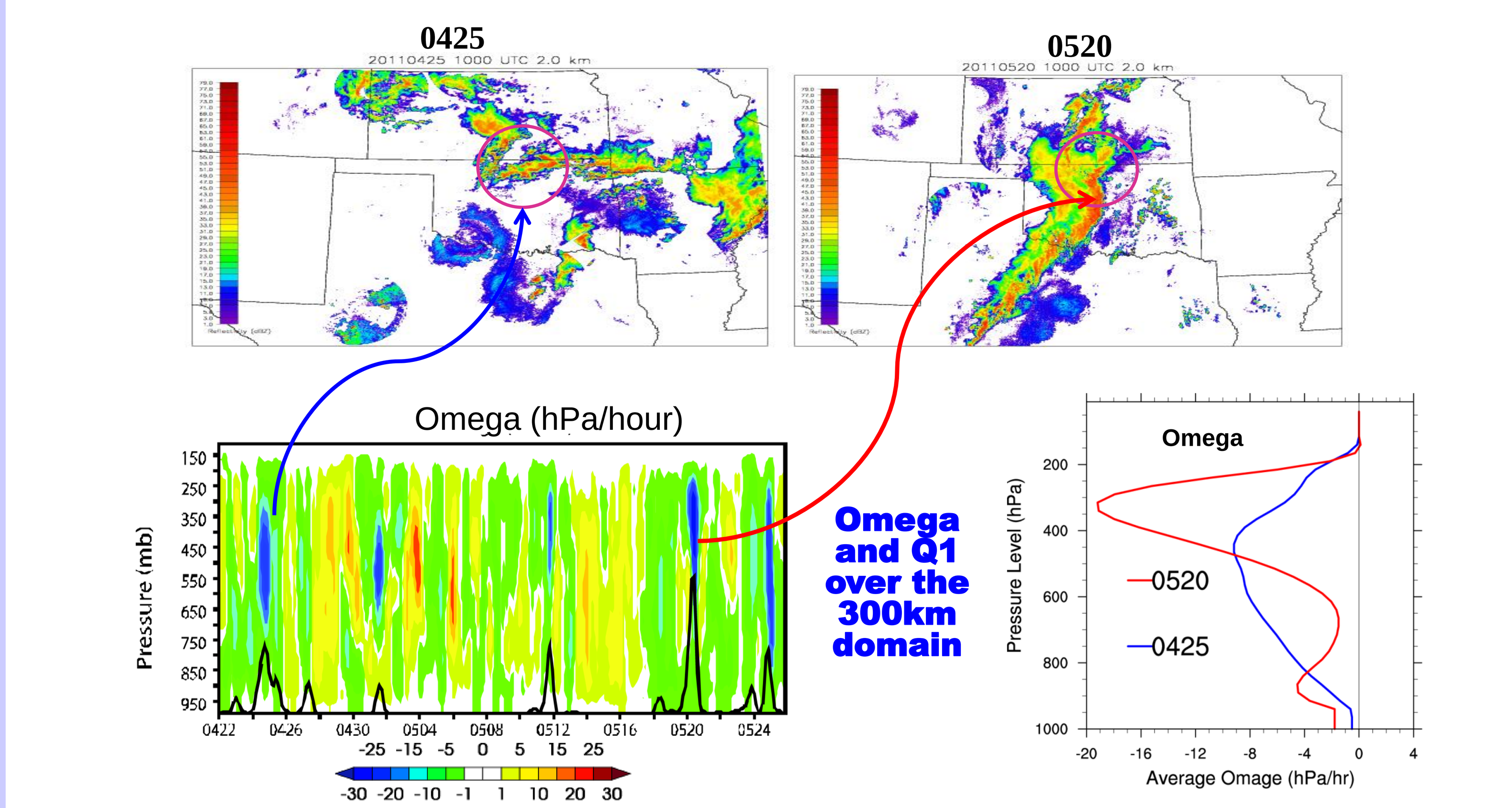
The precipitation rates increase when reducing the size of domain however this is not always corresponding to stronger forcing. In the upper troposphere, strongest domain-average upward motion is found over 150 km domain while the weakest one is seen for 75 km domain. Between 500 to 850 mb, the weak updraft is shown over the 300km and 75 km while it is downdraft over the 150km domain.

Moisture Advection



The 75km and 150km domains show much larger horizontal moist advection in the lower levels. The increase of precipitation with the 75km domain is mainly due to the stronger horizontal advection of moisture. The significant drying between 800-500mb seen for the 150km domain is consistent with the downward motion in these levels. These differences suggest strong scale variability in the forcing corresponding to various-scale cloud systems.

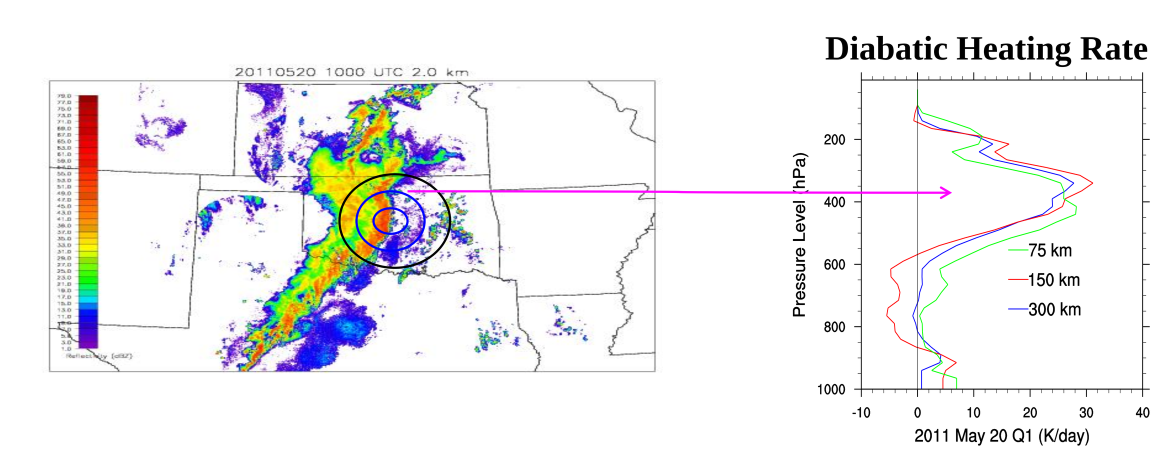
Omega and Q1 for Different Cloud Systems



In general, strong deep upward motions are associated with precipitation events and downward motions are found during the quiet periods. However, the detailed vertical structure of Omega varies with cloud systems. These differences may be caused by how well these systems are resolved by the analysis domain. The vertical structure of omega profiles indicate that the 0425 case might be mainly dominated by convective cloud systems while the 0520 case is results from both shallow and deep convection as well as stratiform precipitation, consistent with the cloud systems observed.

Diabatic Heating with Different Domain Sizes

The 20 May 2011 Strong Mesoscale Convective Case



The cooling in the mid-troposphere seen over the 150 km domain is likely associated with convective and mesoscale downdrafts.

Summary and Future Work

- Multi-scale forcing datasets have been developed
- Forcing and diabatic heating/moistening vary with different convective systems
- Forcing and diabatic heating/moistening show strong spatial variablity
- Future work:
  - Ensemble forcing to address uncertainties in the constraints
  - Forcing at 10 mb resolution to better resolve the boundary layer structure
  - Improve the forcing with improved sounding data
    - Corrected sounding (Mike Jensen and Tami Toto, BNL)
    - High resolution merged sounding and wind profiler data (Paul Ciesielski, CSU)
  - Collaborative study with the CSU group
    - Compare the variational analysis forcing with the forcing data derived from the CSU group

Acknowledgments

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