RESEARCH THEME: DERIVATION OF BATTLESPACE PARAMETERS

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CG/AR Annual Review

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White Sands Missile Range, New Mexico

Research Foci

Chris Castro: Application of the downscaling assessment already applied to regional modeling to battlescale model domains; how much value added is provided from surface forcing as contrasted with lateral boundary condition forcing. (Ph.D. expected early 2005, where upon he transits into a Research Associate; part of this support is on this project, and part on a NOAA project)

Giovanni Leoncini: Assessment of the relative contributions of hydrostatic/nonhydrostatic and linear and nonlinear contributions to mesoscale flow (Ph.D. in progress)

Major Tim Nobis: Development of urban parameterization in RAMS and application to estimating dispersion over Washington DC. (Ph.D. expected early 2005)

Regional Modeling

Christopher L. Castro and Roger A. Pielke Sr.

R-276 Castro, C.L., and R.A. Pielke Sr., 2004: Dynamical downscaling: Assessment of value restored and added using the Regional Atmospheric Modeling System (RAMS). J. Geophys. Res. - Atmospheres, accepted with revision.

http://blue.atmos.colostate.edu/publications/pdf/R-276.pdf

Limited Area Modeling Types

Table 2: Examples of predictability.

NWP Mode

RCM Modes

		Constraints
Day-to-Day Weather Prediction	Type 1	Initial Conditions Lateral Boundary Conditions Topography Other Bottom Land Boundary Conditions Solar Irradiance Well-Mixed Greenhouse Gases
Seasonal Weather Simulation	Type 2	Lateral Boundary Conditions Topography Other Bottom Land Boundary Conditions Solar Irradiance Well-Mixed Greenhouse Gases
Season Weather Prediction	Type 3	Topography Other Bottom Land Boundary Conditions Sea Surface Temperatures Solar Irradiance Well-Mixed Greenhouse Gases
Multiyear Climate Prediction	Type 4	Topography Solar Irradiance Well-Mixed Greenhouse Gases

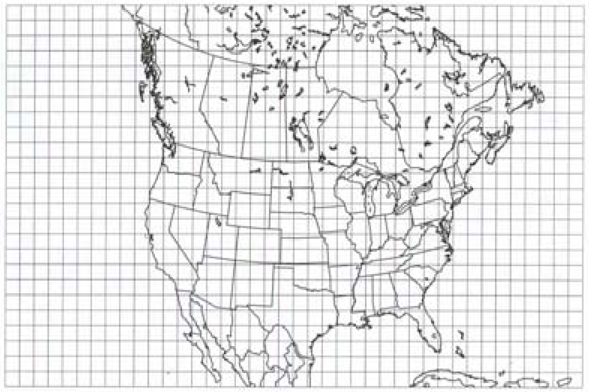
More Constraints | Greater Predictive Skill

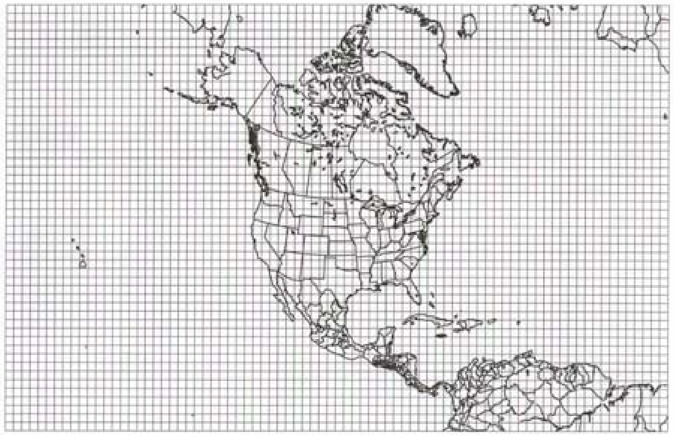
Fewer Constraints | Less Predictive Skill

Question asked here is in a Type 2 mode, how does a regional climate model:

1. **Retain the large-scale forcing data?**
2. **Add value at the small scales beyond the large-scale forcing data?**

Basic Experiments



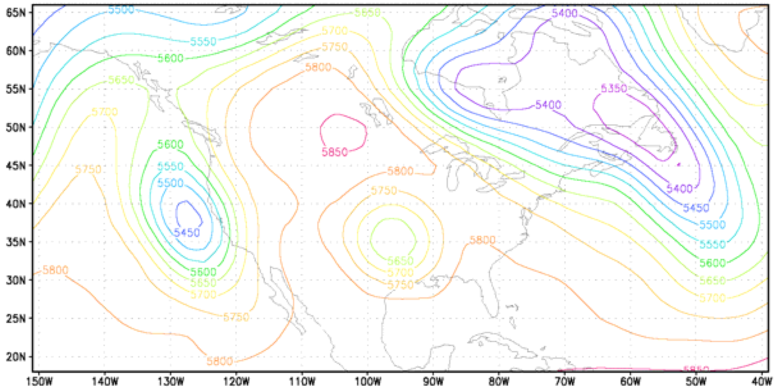


Run RAMS for two different domain sizes at 200 km, 100 km, and 50 km grid spacing for a sample month (May 1993).

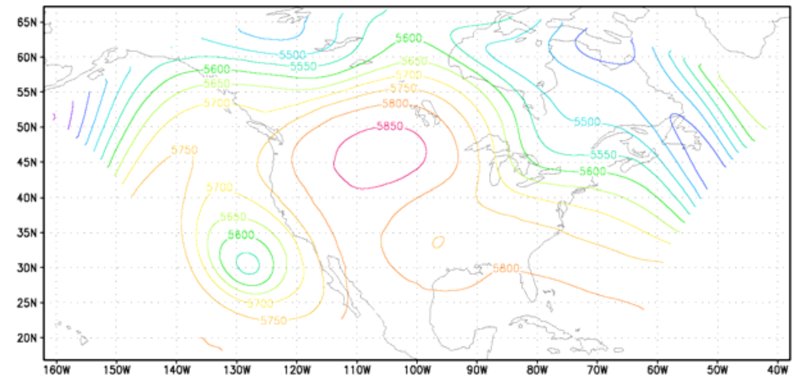
Only lateral boundary nudging and simplest model parameterizations were used for computational expediency.

500 mb Height in "RCM" mode: 12 May 1993

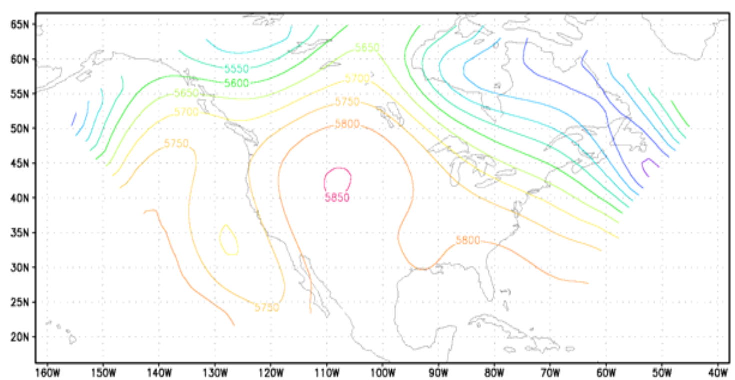
NCEP Reanalysis



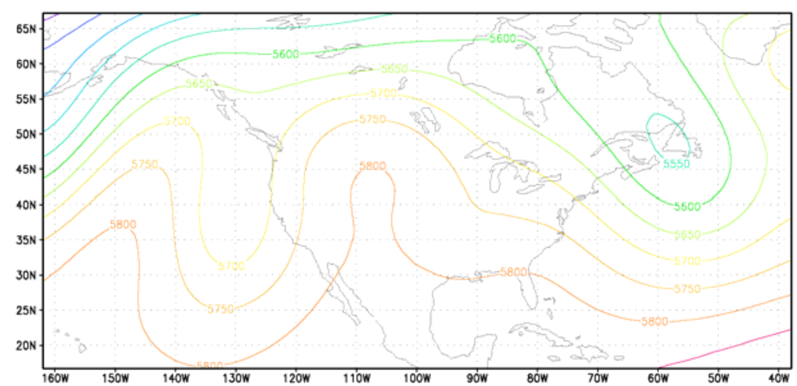
50 km Small Domain



200 km Small Domain



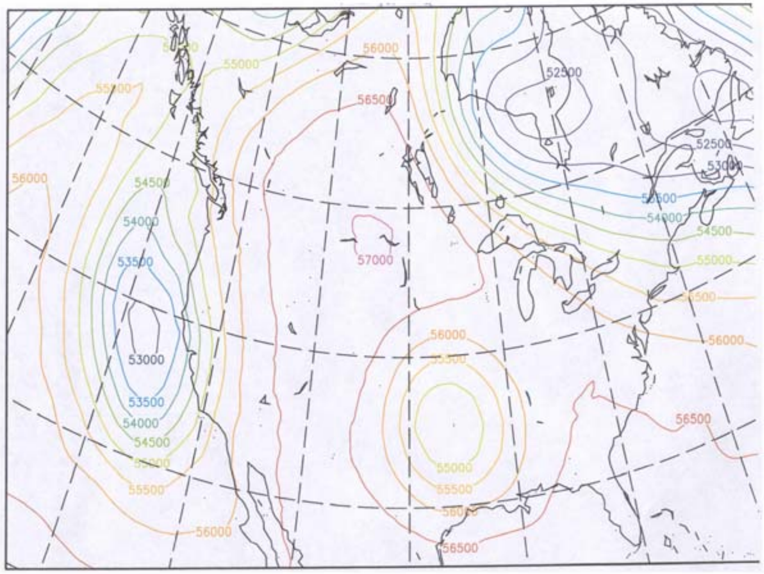
200 km Large Domain



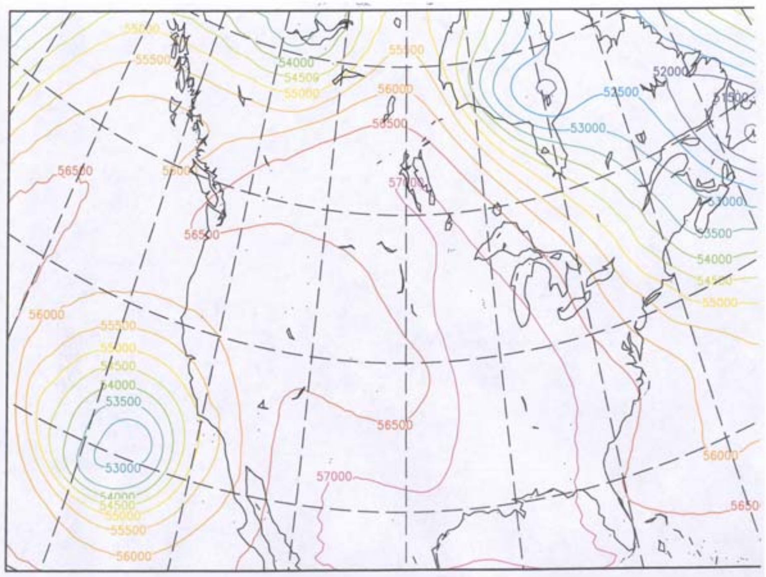
RAMS is unable to maintain the amplitude of circulation features. This problem worsens with large grid spacing and increased domain size.

Similar Results with REMO RCM (Courtesy of H. von Storch, personal communication)

NCEP Reanalysis

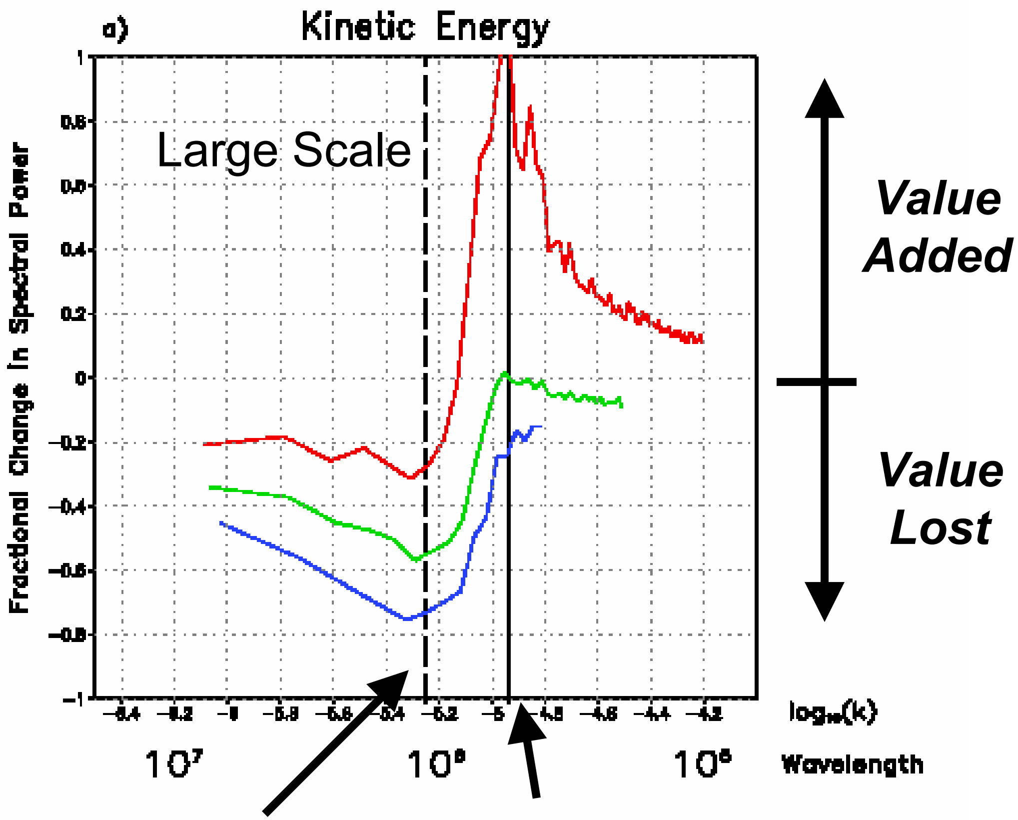


REMO for 50 km Small Domain



In a completely different RCM, we see similar misrepresentation of the large-scale with only lateral boundary nudging. Implies such behavior may be universal to all RCMs, and not just RAMS.

Change in RAMS Spectral Power as Function of Wavelength Compared to Reanalysis



Max resolved wavelength in reanalysis (4Δx)

Nyquist wavenumber of reanalysis (2Δx)

At large scales the regional model cannot retain kinetic energy. Loss of kinetic energy worsens with increased grid spacing and domain size (not shown)

The greatest loss appears to be near minimum resolved wavelength of the reanalysis

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RAMS Loss of Kinetic Energy and Kinetic Energy Variance with Time

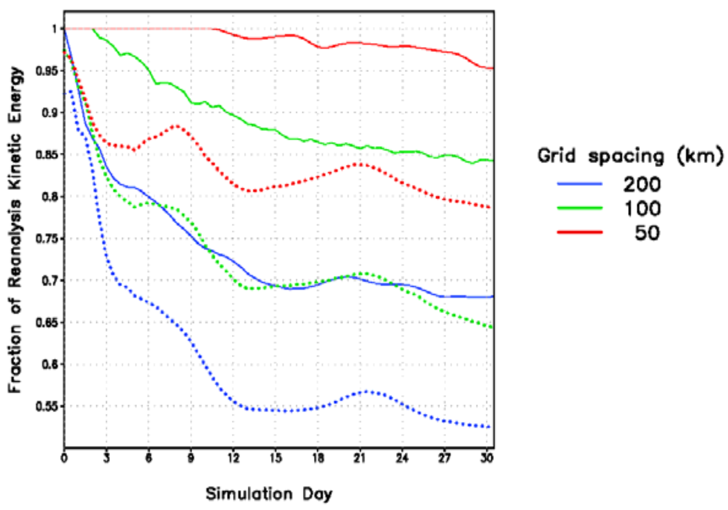


Figure 6: Time evolution of the fraction of model simulated to reanalysis regridded domain averaged total kinetic energy for the six basic experiments on equivalent grids. The small domain is indicated by a solid curve and the large domain is indicated by a dashed curve.

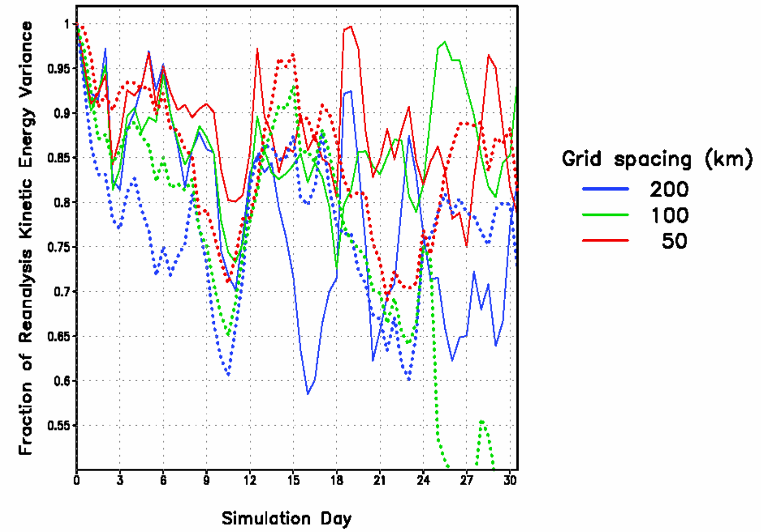
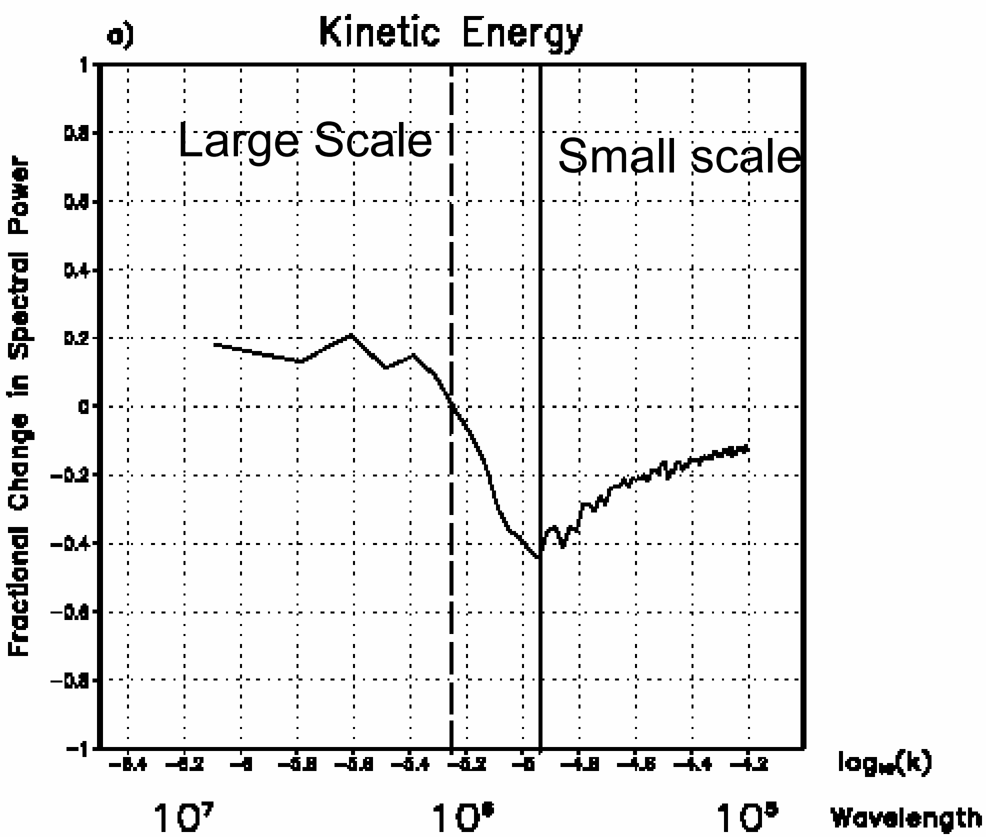


Figure 7: Same as Fig. 6 for model domain-averaged kinetic energy variance.

Loss of kinetic energy at large scales leads to an overall loss of kinetic energy and kinetic energy variance with time. Loss worsens with increased domain size and grid spacing.

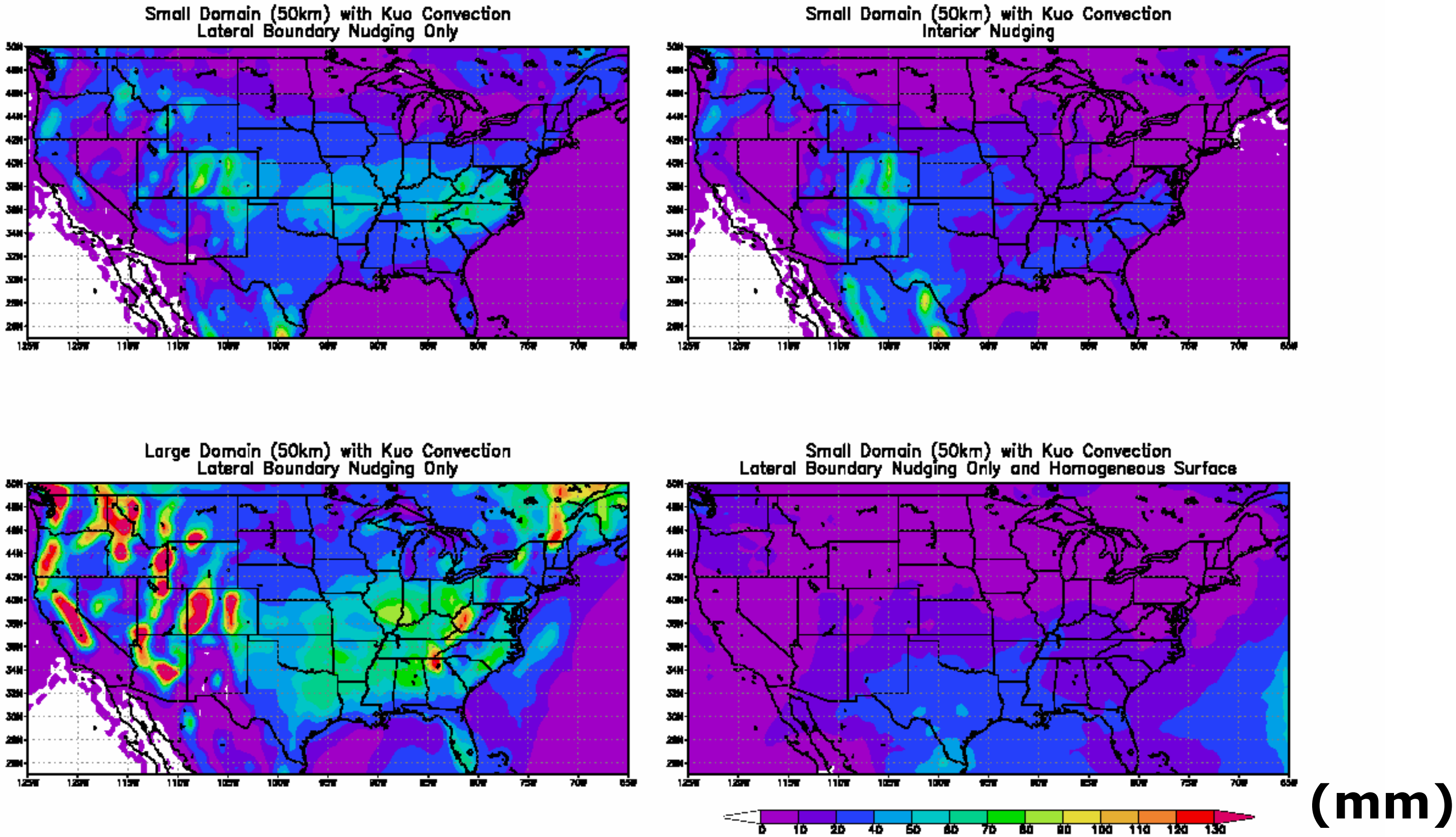
Model-to-Model Comparison of Internal Nudging at One Day Timescale Versus no Internal Nudging



Variability is increased at the larger scales with internal nudging, but decreased at the smaller scales

The best solution is probably spectral nudging which selectively nudges wavelengths only at the large scale

Precipitation Solutions Using Various Model Constraints



There can be large differences, for example, in model-generated precipitation solely due to the prescription of lateral boundaries, the surface boundary, and domain size. These are choices the model user must necessarily make.

Summary

- **Value retained and added by dynamical downscaling has been quantitatively evaluated by considering the spectral behavior of a RCM in relation to its domain size and grid spacing.**

- **At large scales, the RCM cannot restore variability present in the global model forcing data, and this loss is particularly acute at the limit of global model physically resolved waves. Worsens with increased grid spacing and domain size. This is probably true for all RCMs.**

- **Underestimation of kinetic energy is due to the one-dimensional column parameterizations in the model.**

- **The only solution is to constrain the RCM with large-scale model (or reanalysis) values using some sort of internal nudging technique. Spectral nudging, which selectively nudges on the large scale only, is probably the way to go.**

- **These conclusions are based on a Type 2 framework, assuming a perfect model, so the same conclusions will apply to RCM applications with greater degrees of freedom.**

- **The utility of the RAMS-RCM, then is not to add increased skill to the large scale, rather the value added is to resolve smaller-scale features which depend on the surface boundary.**

Dynamics

Giovanni Leoncini

and

Roger A. Pielke Sr.

Analysis of Nonlinear/Linear, Hydrostatic/Non-Hydrostatic

Objective:

At what scales are Coriolis, advection, diabatic heat flux, and buoyancy important in the equation of motion?

If advection can be approximated linearly, then we have analytical solutions which are much faster and more exact.

If advection cannot be approximated linearly, then we can numerically integrate only the nonlinear part of the equation which is faster and more accurate.

Analysis of Nonlinear/Linear, Hydrostatic/Non-Hydrostatic

Principal Results:

- A hydrostatic option in RAMS 4.3 is being implemented using several different techniques of integration.
- Model top wave reflection has been fixed.
- Hydrostatics algorithms that have been developed create an artificial divergence tendency.
- Despite extensive tests, this option has not yet been successfully implemented to date.

Analysis of Nonlinear/Linear, Hydrostatic/Non-Hydrostatic

If the atmosphere is hydrostatic, pressure is uniquely diagnosed from the vertical temperature distribution overhead. When this assumption is valid, remote sensing of the instantaneous spatial pattern of the temperature distribution provides a procedure to monitor the spatial pressure pattern. Monitoring the evolution of this pressure pattern in time, permits us to use a model to diagnose the vertical and horizontal wind field.

The nonhydrostatic component is recoverable for the most part (e.g., Song, Pielke et al. 1985).

All of this is particularly useful to develop very specific models where assumptions, more restrictive than regular NWP, can be made.

Analysis of Nonlinear/Linear, Hydrostatic/Non-Hydrostatic

Objective:

Verify, in a nonlinear environment (e.g., RAMS) the conclusions reported in Dalu, Pielke et al. (2003) for mesoscale flow:

- **Poisson equation for ϕ composed by 5 terms**
  - **Vertical divergence of heat flux**
  - **Linear convergence of mass**
  - **Linear advection of buoyancy**
  - **Nonlinear convergence of buoyancy**
  - **Dynamic pressure**

Analysis of Nonlinear/Linear, Hydrostatic/Non-Hydrostatic

Progress:

- Implemented Padé compact scheme in RAMS (3 points, 4th order accuracy) to compute divergence

$$\nabla^2 \pi$$

- Designed experiments to verify approximation and contributions to π from

- Simulations will begin once testing of the above scheme is completed

Additional Work in Progress

Look-Up Table Approach:

Climatological analysis of soundings for one site is being performed to define bins and ranges of input space. We plan to use this approach with the Harrington radiation parameterization.

Additional Work in Progress

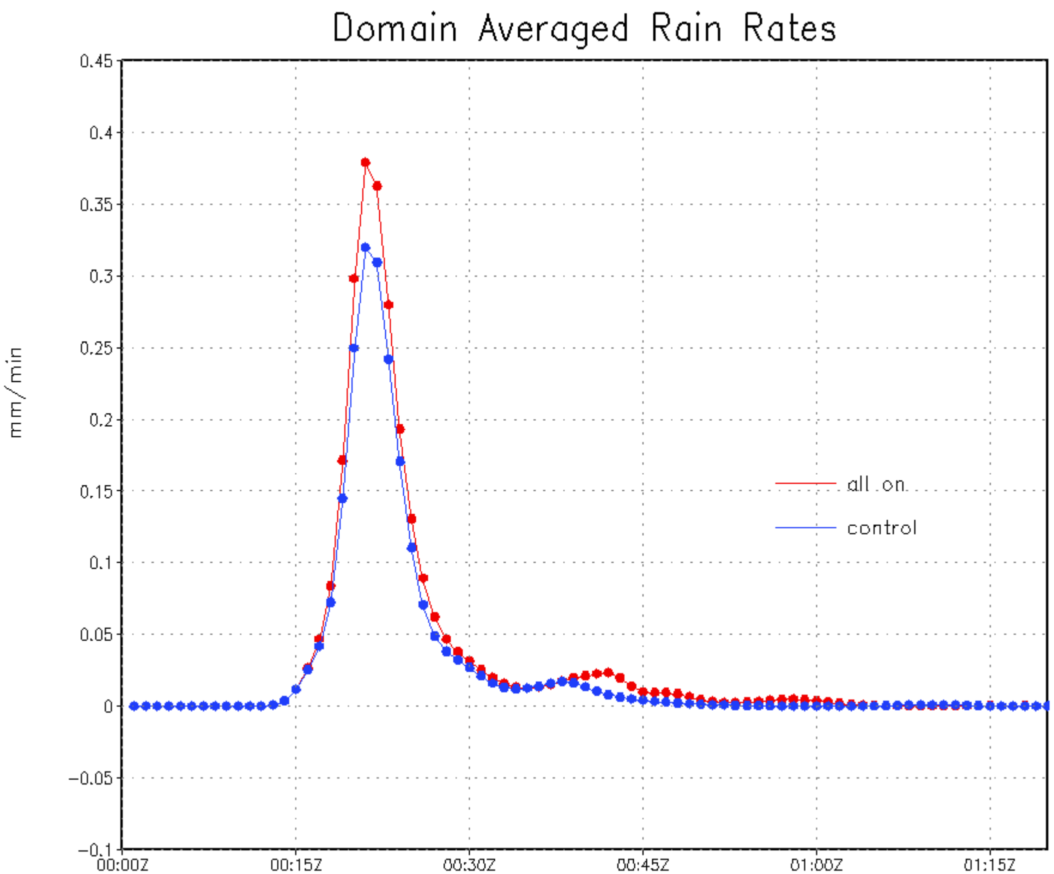
Mass Conservation and Exact Pressure Gradient Effects on 2D Thunderstorm:

$$\frac{\partial}{\partial t}u = \ldots\ldots + \left(\theta_0 + \theta'\right)\frac{\partial \pi'}{\partial x} + \ldots.$$

New additions to the RAMS standard version

$$\frac{\partial \pi'}{\partial t} = -\frac{R\pi_0}{C_v\rho_0\theta_0}\left(\frac{\partial \rho_0\theta_0 u}{\partial x} + \frac{\partial \rho_0\theta_0 v}{\partial y} + \frac{\partial \rho_0\theta_0 w}{\partial z}\right) - \left(u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z}\right)\pi' - \frac{R\pi'}{C_v}\nabla\cdot\vec{u} + \frac{R\pi}{C_v\theta}\frac{d\theta}{dt}$$

Additional Work in Progress



The added terms do not change dramatically the development of the 2D idealized storm (only the secondary rain event is delayed), but they do increase the rain rates by ~ 10%.

The graph shows 1 minute mean values averaged over the 50 km domain with 250 m grid spacing.

A similar effect occurs for hail rates (not shown).

We plan on moving to a more realistic 3D storm.

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Urban Modeling

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and

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Urban Modeling

Principal Results:

- Fully coupled the Town Energy Balance (TEB) urban parameterization to RAMS
- Created a 1 km resolution urban morphology database (c. 1982) for a 32 X 36 km area around Washington DC to drive TEB
- Completed simulations on three different synoptic days during the 1984 METREX campaign with and without TEB
    - 26 Jun 84: The Golden Day – Ideal urban heat island day
    - 7 Jan 84: Double dry frontal passage (warm and cold front)
    - 7 Nov 84: Building fall high pressure with moderate NW winds

Urban Modeling

Objective:

- Couple RAMS to an Urban Parameterization (the Town Energy Balance Model-TEB) to improve the modeling of the urban boundary layer
    - Civilian, Military, and Homeland Defense are routinely using boundary-layer data from mesoscale models to drive Tactical Decision Aids (TDA's) in and around urban areas
    - Current mesoscale models don't account for urban impacts to the boundary layer (UHI's and resultant flow patterns)
- Create a LUT version of TEB to reduce the simulation cost of adding the parameterization

Urban Modeling

Principal Results:

- Analyzed the results in three different ways
  - Macro view: Plot differences between TEB and no TEB versions to confirm that the TEB version produces typically observed UHI behavior
  - Rural vs Urban: Select a data point in the urban and in the rural area and track the observed vs. modeled temperature and wind deviations
  - Point verification: Examine the actual modeled vs. observed trends for an urban data point

Urban Modeling

Principal Results:

Preliminary conclusions:

- **The TEB version does create many typically observed UHI signatures suggesting an improvement in boundary layer behavior in the urban area**
- **The TEB version showed better results with the urban/rural difference verification, however 5 km resolution was not ideal for this**
- **Point verification of RMSE can be worse with TEB than without due to model bias' being pushed further astray by the presence of TEB**

Urban Modeling

Future Deliverables:

- Complete analysis of sensitivity studies
- Analyze impact of TEB in a 'Tactical Decision Aid' (The HYPACT dispersion model)
- Complete creation of LUT version of TEB to improve time penalty
- Finish the Dissertation and defend!