Battlefield Scale Modeling

Roger A. Pielke Sr.
Tim Nobis
Giovanni Leoncini
David Stokowski

- Urban-scale Dispersion [Tim Nobis]
- Linear/Nonlinear Analysis [Giovanni L.]
- Hydrostatic/Nonhydrostatic [Giovanni L.]
- EOF Parameterization Technique [Giovanni L.]
- Neural Network Parameterization [David Stokowski]
- Unified Parameterization [David Stokowski]

The Regional Atmospheric Modeling System [RAMS] has been enhanced in order to permit the representation of urban areas using the TEB Model

This added capability permits more accurate modeling of dispersion of chemical, biological and nuclear agents

RAMS Simulations of Urban Landscape

Objectives:

- Use RAMS coupled to an Urban Parameterization (the Town Energy Balance TEB, Model) to improve the modeling of the Urban Boundary Layer and resulting mesoscale flows
- Several days in 1984 were simulated in the Washington DC area to examine the effects of the urban parameterization to a model configured to mimic current AF operational settings (e.g., inner nest of 5km)

RAMS Simulations of Urban Landscape

DoD Relevance:

- DoD, Homeland Defense, and Civilian agencies rely on mesoscale model output in to drive their decision aids and finer scale modeling applications
- Many of these applications are very sensitive to boundary layer inputs or on the mesoscale scale wind regime
- Mesoscale modeling without urban effects will potentially feed poor initialization grids to these finer scale applications and decision aids in urban areas

RAMS Simulations of Urban Landscape

Principal Results and Deliverables:

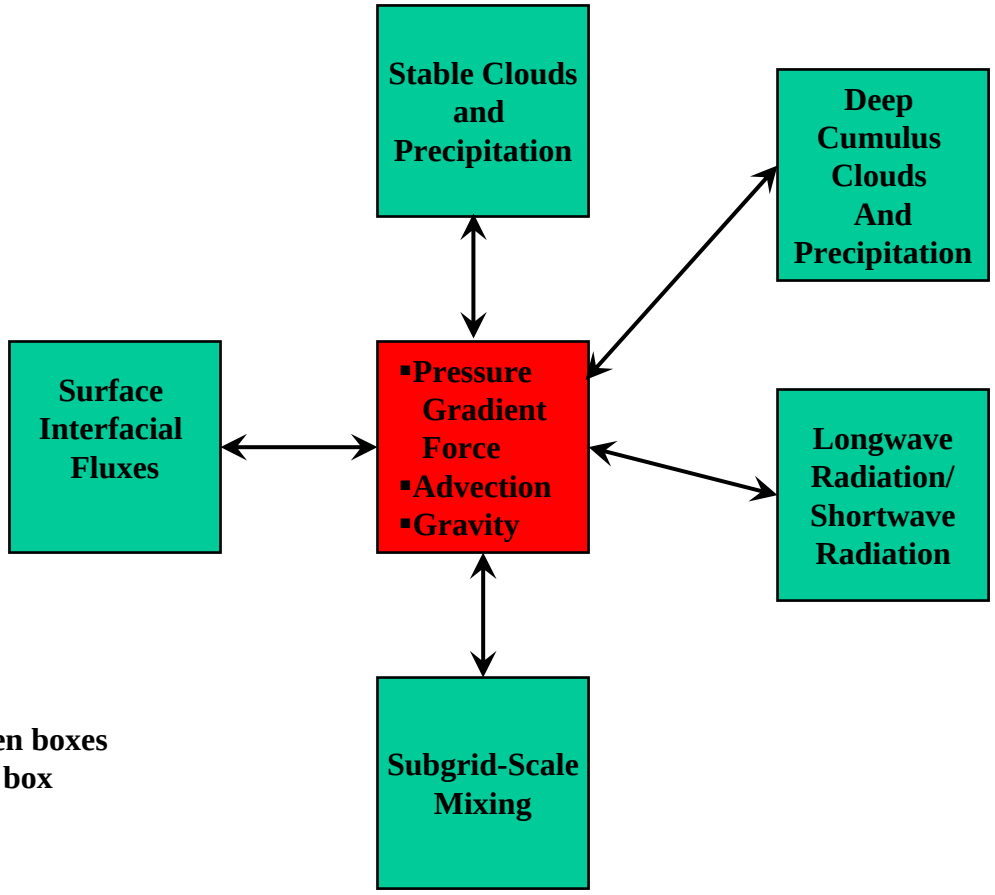
- Results from the simulations demonstrated the capability of RAMS when coupled to TEB to produce a reasonable urban heat island
- Comparison with point observations both at the surface and in the vertical demonstrated that RAMS with TEB produced a better urban boundary layer in most instances.
- The coupled system also had an influence on the mesoscale wind system around Washington DC which suggests influence well beyond the urban core of the city.
- Several sensitivity studies were also conducted to assess what aspects of the urban parameterization were most important at these scales (inner nest 5 km)

Research Project Title

Future Work:

- Major Nobis is continuing work to complete the write up of the Dissertation and defend
- The Dissertation is being written to provide two publishable manuscripts with the following tentative titles:
  - Coupling RAMS to an Urban Parameterization I: Methodology, Results and Sensitivity Studies over Washington DC
  - Coupling RAMS to an Urban Parameterization II: Influence on follow-on applications using the Air Force's Tactical Acquisition Weapons Software (TAWS)
- Material for a possible third paper on the development of the morphology database used in this study is presented as a poster at this session

All Parameterizations are 1-D Column Models



Parameterizations: green boxes
Dynamic Core: red box

Importance of determining the relative roles of linear and nonlinear terms in the dynamic core of models

- The linear portion of the dynamic core can be evaluated analytically and exactly
- Only the nonlinear portion needs to be evaluated numerically thus reducing computational errors

Importance of determining the hydrostatic pressure relative to total pressure in an atmospheric model simulation

- If the hydrostatic pressure component dominates, then instantaneous diagnosis of the temperature field yields the pressure field.
- The hydrostatically determined pressure field (based on the temperature measurements) can permit the diagnosis of synoptic scale information such as the large scale wind shear (through the thermal wind relation) for mid- and high-latitudes.

Leoncini et al.

- Paper: Mesoscale Dynamics of Idealized Heat Flux Divergence, Part I: Linearized Advection vs. Nonlinear Advection

  Paper: Mesoscale Dynamics of Idealized Heat Flux Divergence, Part II: Hydrostatics vs. Nonhydrostatics

The Plan

- Modify RAMS to simulate Dalu et al atmosphere:
  - ✓ Isothermal background
  - ✓ Linear advection
  - ✓ Constant K diffusivity
  - ✓ Rayleigh friction
  - ✓ Hydrostatic
  - ➢ Incompressibility
- Verify Dalu et al results:
  - ✓ Analytical solution in RAMS
  - ➢ Simulations w/ forcing scales: 1 to 200 km, 20 min to 1 day
    - ➢ *Spacing designed to capture the main features*
    - ➢ Linear vs. Nonlinear
    - ➢ Hydrostatic vs. Nonhydrostatic
    - ➢ Verify Song et al correction
- Extend theory to more realistic atmosphere
  - ✓ More realistic temperature profile
  - ✓ Better representation of turbulence

Parameterization Reality

All Parameterizations Have Tunable Coefficients and Functions

All Boundary-Layer Parameterizations Are Tuned From Golden Day Data

Boundary-Layer Data For The Parameterizations Are Developed For Horizontally Homogeneous (Including Flat) Landscape, And For Near-Steady Or Slowly Changing Atmospheric Conditions

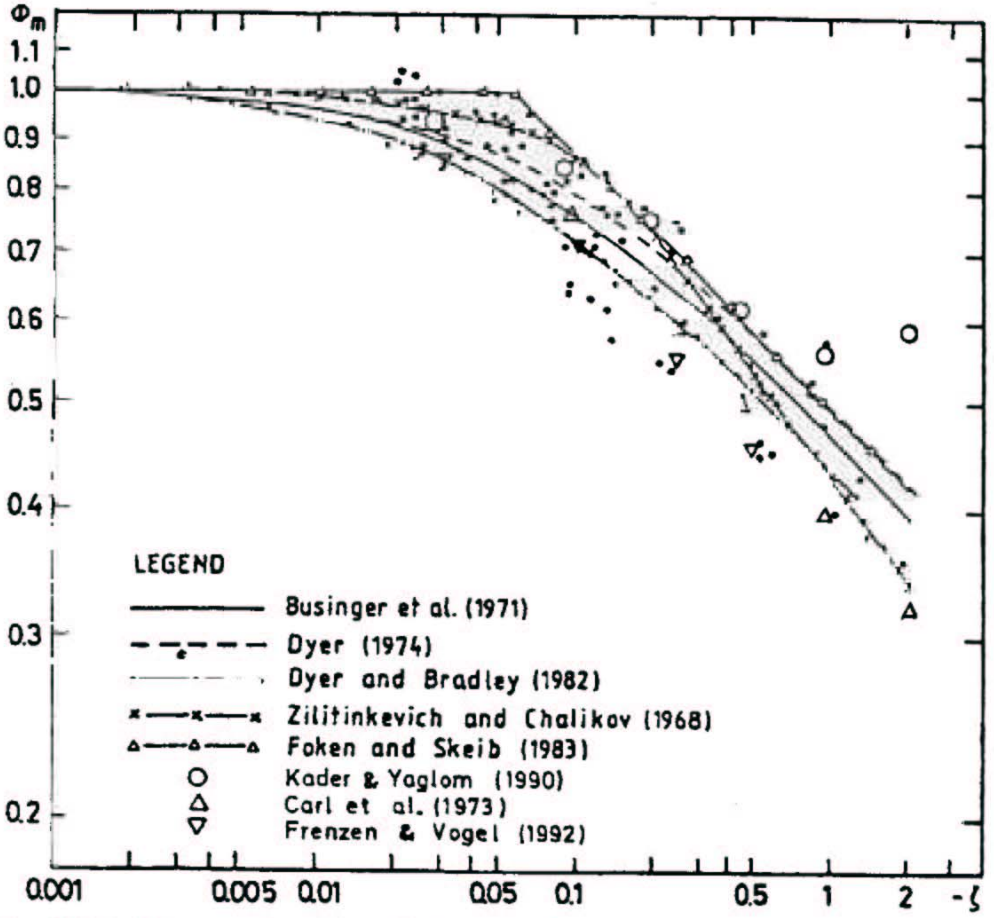


Fig. 7-3. Plot of ϕ_M against $(z - d)/L$ in log-log representation for unstable stratification. The small dots are data from Högström (1988). The other symbols have been derived from modified expressions from the sources listed in the key. (From Högström 1996 with kind permission from Kluwer Academic Publishers.)

New Parameterization Approach

- Replace existing individual parameterizations with look up tables or its equivalents
- Replace the physics of the set of parameterizations for specific physical processes with look up tables or its equivalent (unified parameterizations)

Documentation of Methodologies

- For individual parameterizations:

  (i) Matsui, T., G. Leoncini, R.A. Pielke Sr., and U.S. Nair, 2004: A new paradigm for parameterization in atmospheric models: Application to the new Fu-Liou radiation code. Atmospheric Science Paper No. 747, Colorado State University, Fort Collins, CO 80523, 32 pp.

  (ii) Pielke Sr., R.A., T. Matsui, G. Leoncini, T. Nobis, U. Nair, E. Lu, J. Eastman, S. Kumar, C. Peters-Lidard, Y. Tian, and R. Walko, 2006: A new paradigm for parameterizations in numerical weather prediction and other atmospheric models. National Wea. Digest, 30, 93-99.

Leoncini et al.

- Dissertation: "Improving Numerical Weather Prediction Speed: Specialized Models and Look-Up Table Approach"

  Paper: "From Model Based Parameterizations to Look Up Tables: an EOF approach"

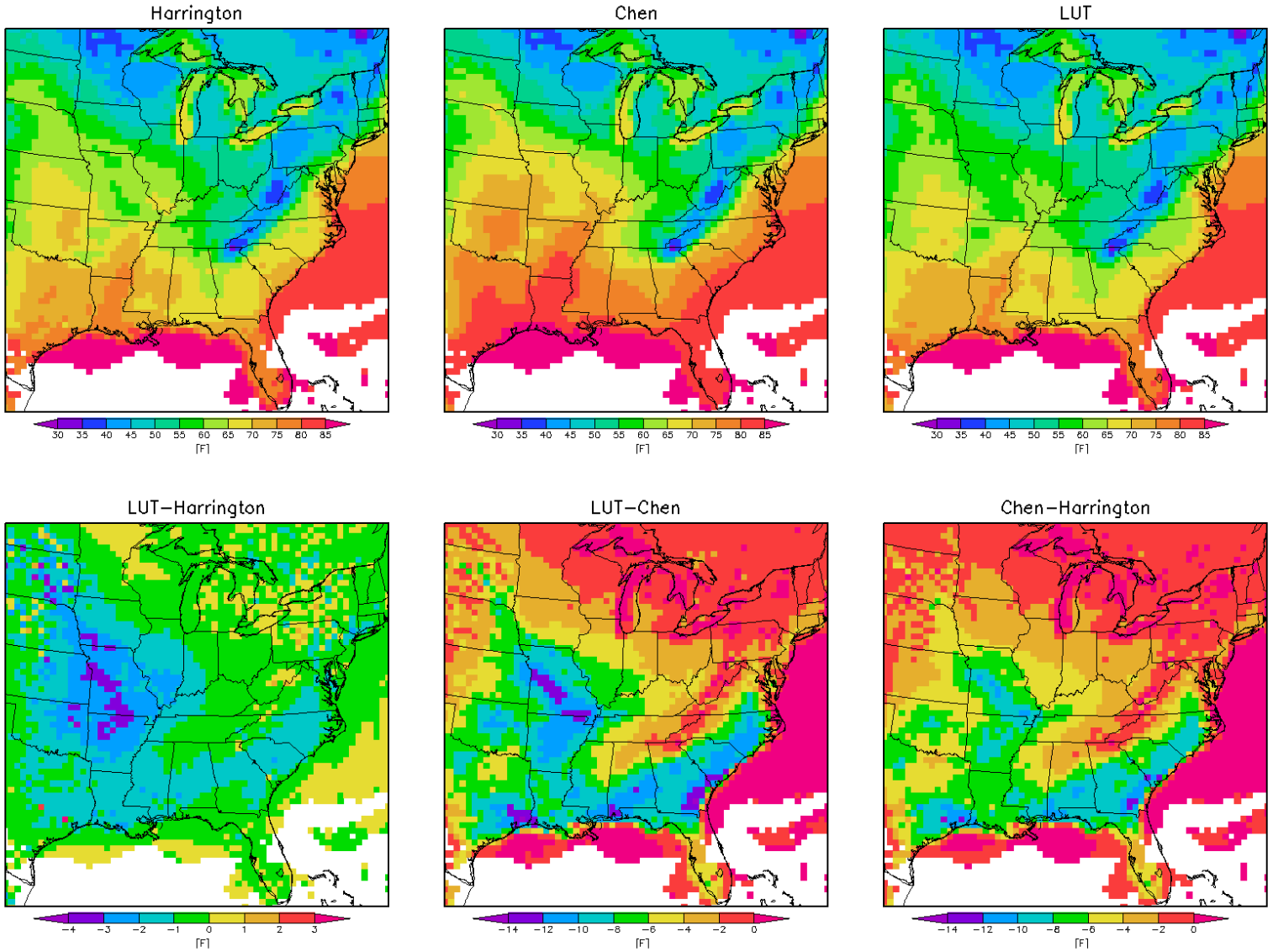
Neural Network Method

- Initial testing showed feasibility of artificial neural network approach:
  - The Mahrer-Pielke LW radiative flux divergence scheme was used a candidate for replacement
  - Small neural networks performed the best, both in accuracy and time testing (reduction in time of 50%).

EOF Method

EOF method is faster then either of the two main options for radiative flux divergence parameterization within RAM

EOFs are showing time increases between 10- and 20-fold over original


Harrington
30 35 40 45 50 55 60 65 70 75 80 85
[F]
Chen
30 35 40 45 50 55 60 65 70 75 80 85
[F]
LUT
30 35 40 45 50 55 60 65 70 75 80 85
[F]
LUT−Harrington
−4 −3 −2 −1 0 1 2 3
[F]
LUT−Chen
−14 −12 −10 −8 −6 −4 −2 0
[F]
Chen−Harrington
−14 −12 −10 −8 −6 −4 −2 0
[F]

The best EOF parameterization provides a speed up, for example, of 11 times the original Harrington parameterization when used in a 48 hour model simulation.

- Since many of the inputs within the different parameterizations are the same, it would be redundant to have many individual neural networks, so why not create a “universal” neural network?
  - This idea was postulated in a recent article (Pielke et al. 2007) where satellite data would be used to drive NWP models.
    - This data would replace the need for parameterizations, since 3-D real-world interactions would be implicit within the construct of the process.
  - This satellite data could then be used to create and drive a neural network (or other LUT) based NWP model.

Documentation of Methodologies

- Replacement of All Parameterizations Based On Physical Processes

Pielke Sr., R.A., D. Stokowski, J.-W. Wang, T. Vukicevic, G. Leoncini, T. Matsui, C. Castro, D. Niyogi, C.M. Kishtawal, A. Biazar, K. Doty, R.T. McNider, U. Nair, and W.K. Tao, 2007: Satellite-based model parameterization of diabatic heating. EOS, Vol. 88, No. 8, 20 February.

Proof of Concept

- Use existing model parameterizations within existing mesoscale/regional models to construct unified look up tables or its equivalent
- Replace existing parameterizations with the new unified parameterization and run the existing mesoscale/regional models with the unified parameterization
- Compare the mesoscale/regional model predictions using the two approaches in terms of accuracy and computational speed

Improvement of Parameterization Accuracy

- Use satellite and other observations to construct a unified parameterization
- Real world (3-D) physics would be represented by this parameterization
- Run this real world based unified parameterization with mesoscale/ regional models and determine if predictive skill is improved

- All parameterizations can be replaced.
  - Other candidates for replacement, include:
    - Cumulus convection
    - Cloud and precipitation driven microphysics
    - Land-surface interactions
    - Turbulence
  - This could eventually save up to 90% of the model time from current NWP simulations and with improve forecast skill.