Creating Meteorology for CMAQ

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Meteorology Inputs for AQ Models

- Simple AQ models: diagnostic techniques for met
- RADM: Initialize with 4-D met model output where FDDA used for “dynamic analysis”
- CMAQ: Same as RADM, but enhanced (off-line) coupling between met and chemistry models
- Prognostic met models now standard input for state-of-science Eulerian chemistry models

Meteorology: Strong Influence on AQM

- Literature frequently cites influence of met model output on AQM simulation (cf., Seaman, *AE*, 2000; Pielke and Uliasz, *AE*, 1998)
- Errors in met simulation of winds, temperatures, clouds, PBL evolution, surface fluxes, precipitation reflected in AQM simulations
- Thus…important for AQ research to also pursue improvements in met models!

Meteorology Models and CMAQ

- CMAQ "generalized coordinate" (Byun, *JAS*, 1999) for maximum compatibility with input met model
- Handful of met models linked to CMAQ:
  MM5 (hydro), MM5 (non-hydro), RAMS, Eta
- Others independently by users (MC2, REMO)
- In practice, MM5 (non-hydro) generally used, and WRF planned

About MM5...

- Makes use of 3-D equations for:
  - Momentum
  - Thermodynamics
  - Moisture
- Non-hydrostatic model: pressure, temperature, and density defined by reference state and perturbations from reference state

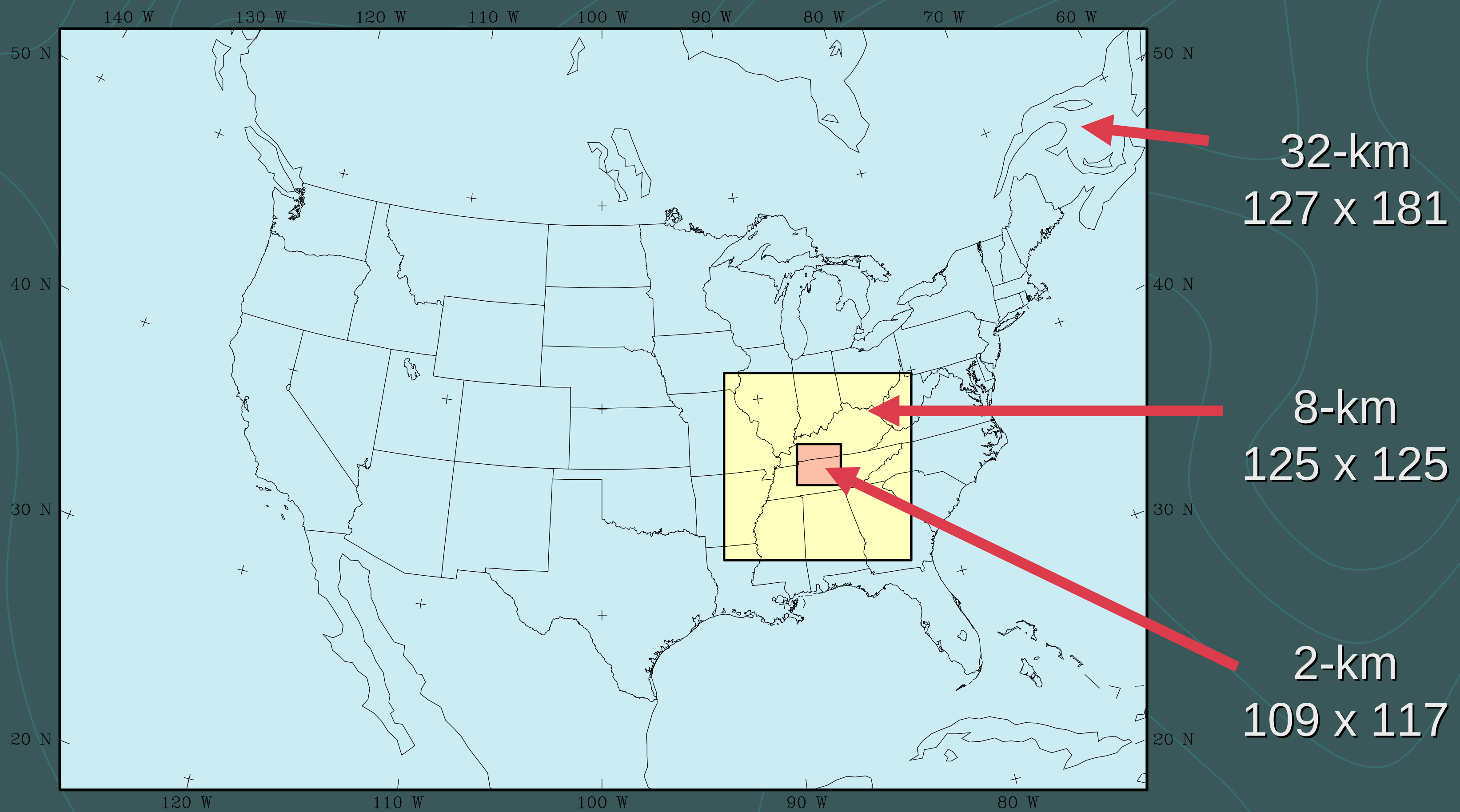
About MM5… (continued)

- State variables are:
  - Temperature
  - Mixing Ratio
  - Grid-relative wind components
  - Pressure
- State variables are mass-weighted with a modified surface pressure

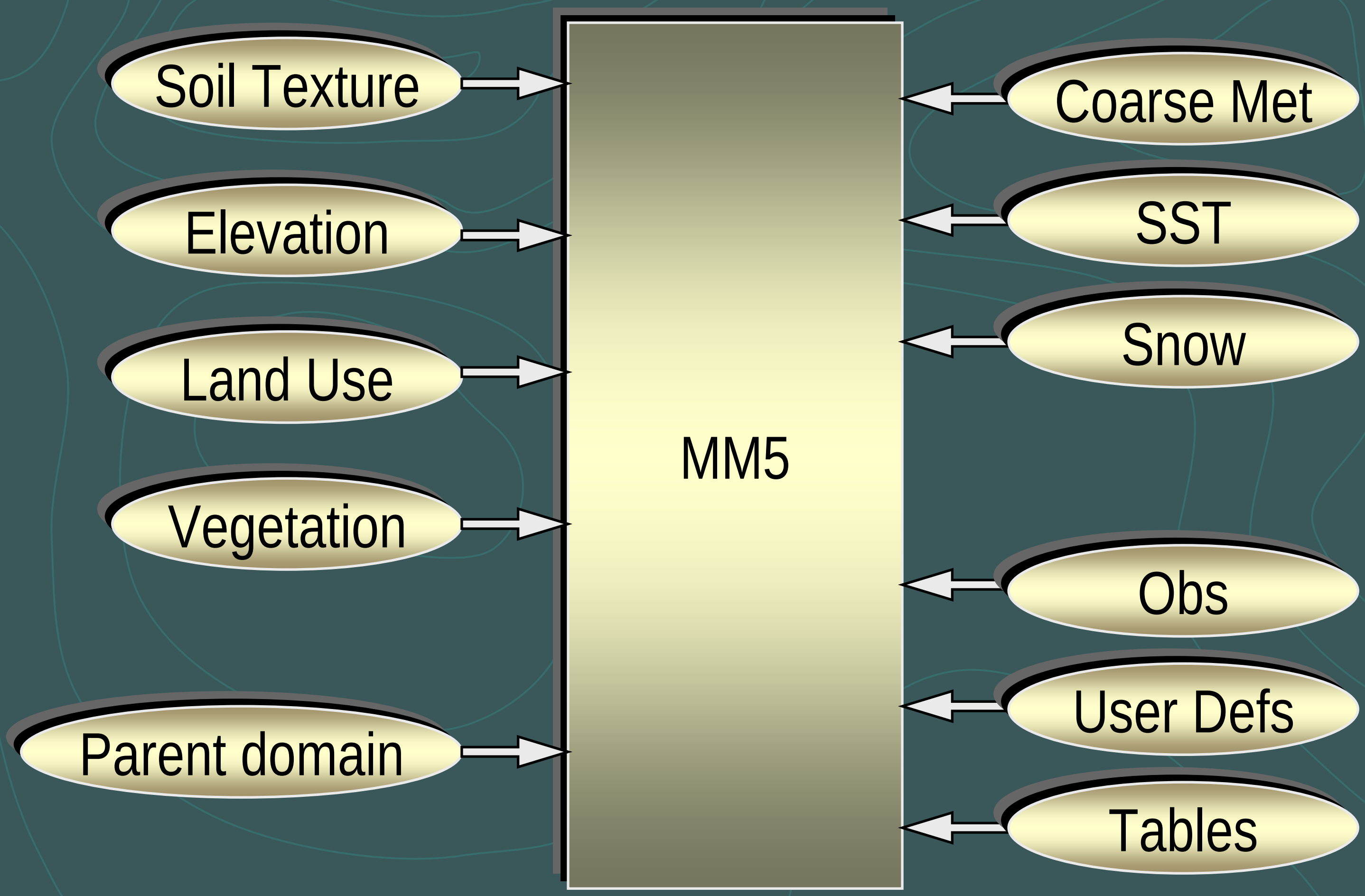
About MM5... (continued)

- Vertical coordinate is terrain-following σ, a function of reference pressure (a.k.a., σ-Z)
- FDDA via nudging used for AQM
- In AMD, usually use ~30 σ layers with ~5 layers in lowest 200 m
- Output in binary “MM5” format (not I/O API, like CMAQ programs)

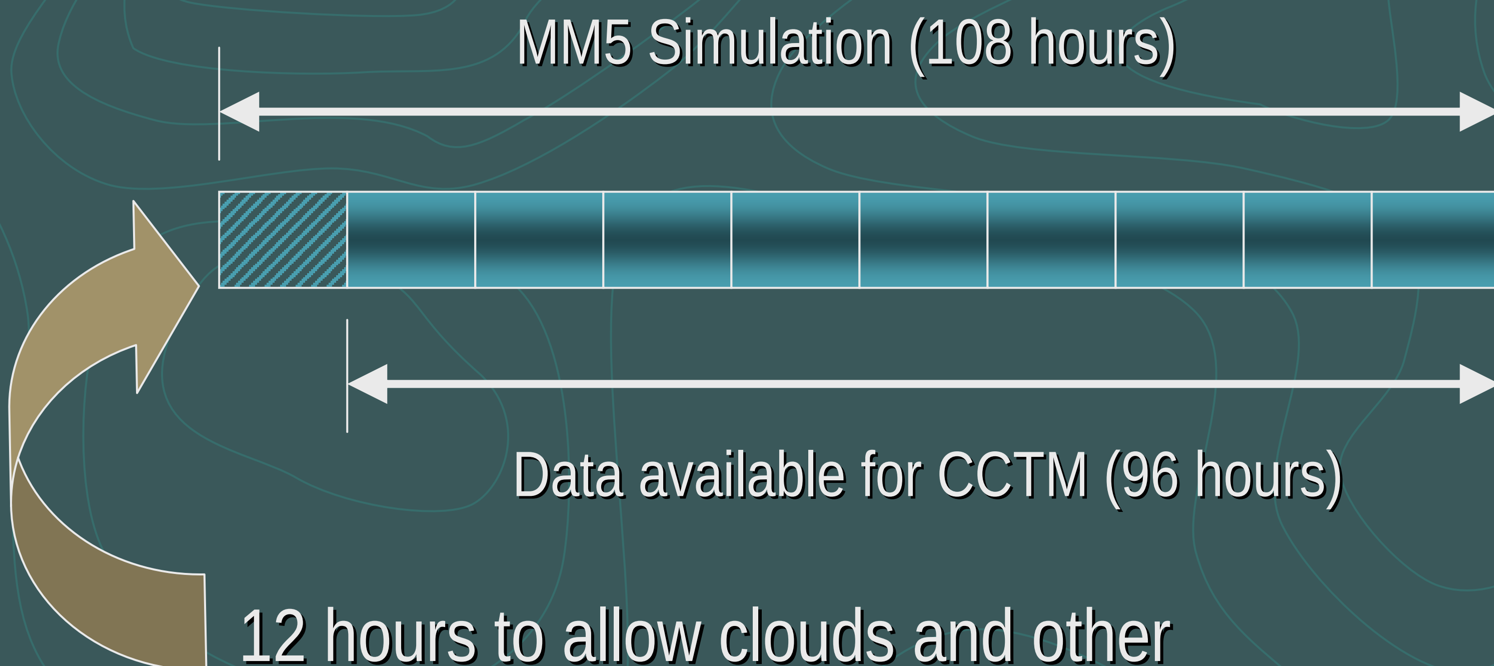
Sample MM5 Off-Line Nesting



Inputs to MM5



Simulation Length



12 hours to allow clouds and other processes to spin up in MM5

MM5 Output Variables Used in CMAQ

- Wind Components (*U*, *V*, *W*)
- Temperature (3-D, ground, soil)
- Moisture Mixing Ratios (Q_v, Q_r, Q_c, Q_s, Q_i, …)
- Pressure ("surface" and perturbation)
- PBL Parameters (PBL height, *u**, MOL, heat fluxes)
- Precipitation
- Static Variables (latitude, land use, ...)
- Others as needed...e.g., with Pleim-Xiu LSM

Linking Meteorology to Chemistry

- Currently done "off-line"
- Use CMAQ pre-processor, MCIP, which…
  - Retrieves prognostic meteorology variables
  - Diagnoses additional state variables for CMAQ
  - Transforms fields to generalized vertical coordinate
  - Interpolates fields to Arakawa-C grid
  - Calculates dry deposition velocities
  - Writes meteorology in I/O API format (std for CMAQ)

MCIP Version 2

- Major update to original MCIP software
  - Supports MM5v2 and MM5v3
  - "Pass-through" for PBL variables
  - Supports Pleim-Xiu LSM
  - Improved dry deposition routines
  - User-friendly
- Current release is MCIPv2.2 (June 2003)

Planned Upgrades to MCIP

- Improve linkage with MM5
  - NOAH LSM
  - Add’l prognostic fields (e.g., 2-m temperatures)
  - TKE PBL
  - Graupel-based microphysics
- Linkage with WRF

Meteorology Research Topics

- Pleim-Xiu LSM … in MM5v3.4 and beyond
- Linkage with Eta and WRF
- “Fine-Scale” (~1 km) Modeling
- FDDA Strategies
- Evaluation Methods
- On-Line Chemistry

Why use a UCP?

- Want to improve urban simulations for ~1 km
- Parameterized roughness may not adequately account for heterogeneities in urban areas
- UCP allows for more specific treatment of urban contributions to dynamics and thermodynamics

- Ultimately want to run CMAQ to simulate photochemical pollutant species at that scale

Practical Difficulties for UCP in MM5

- Land Use – need more urban "stratification"
- Morphology – need realistic database
- Surface Properties – tabular OK?
- Drag Coefficient – appropriate setting here?
- Vertical Resolution Increase
- Verification Data – field study data?

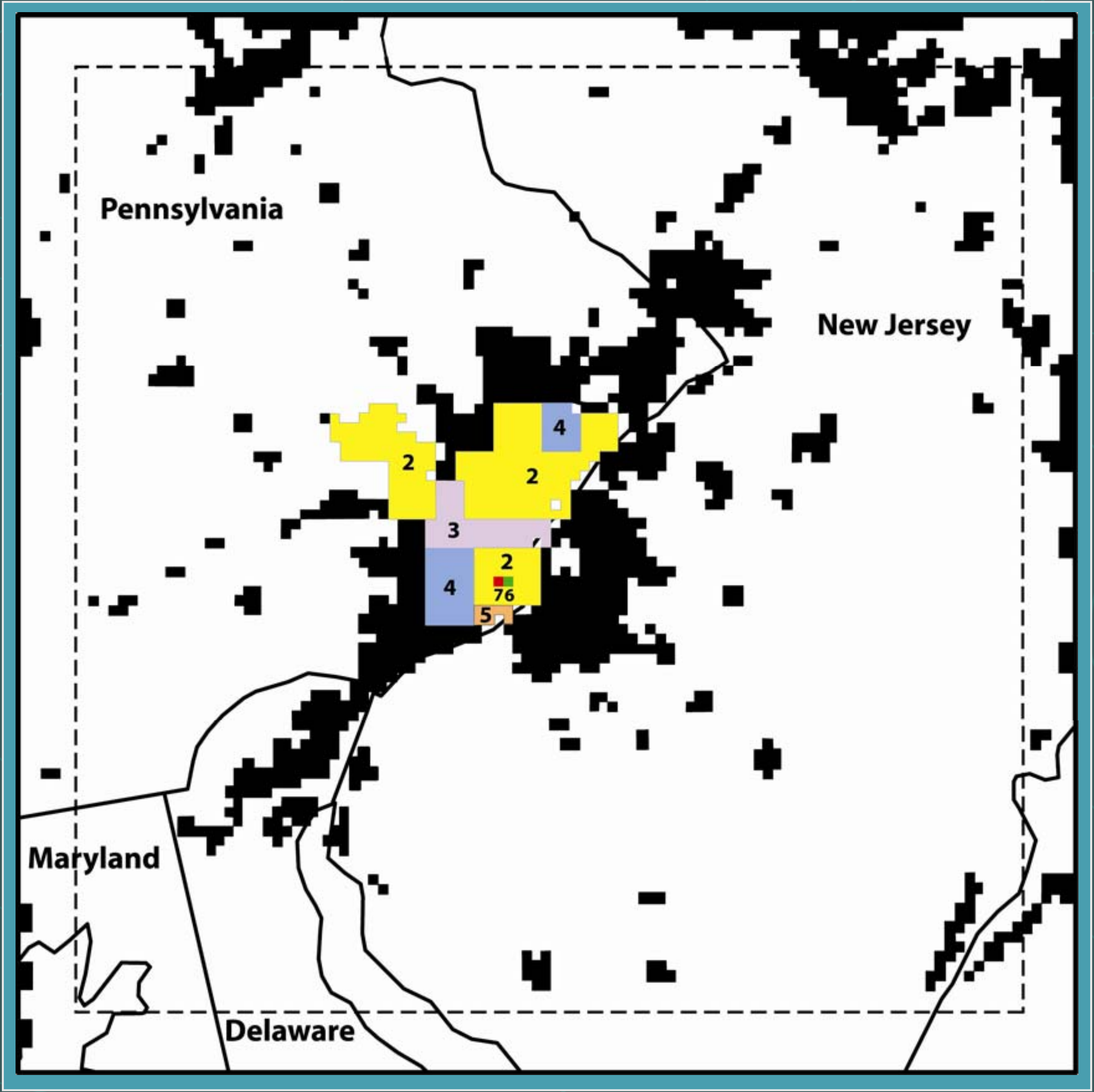
About the UCP

- Based on Brown and Williams “drag approach”
- Applied in 1.3-km and 1-km MM5 simulations
- Directly impacts grid cells with non-zero urban
- Drag and TKE effects due to urban structures
- Anthropogenic heat as time-varying function
- Extinction of radiation in city canyons
- Roof top contribution by temperature proxy

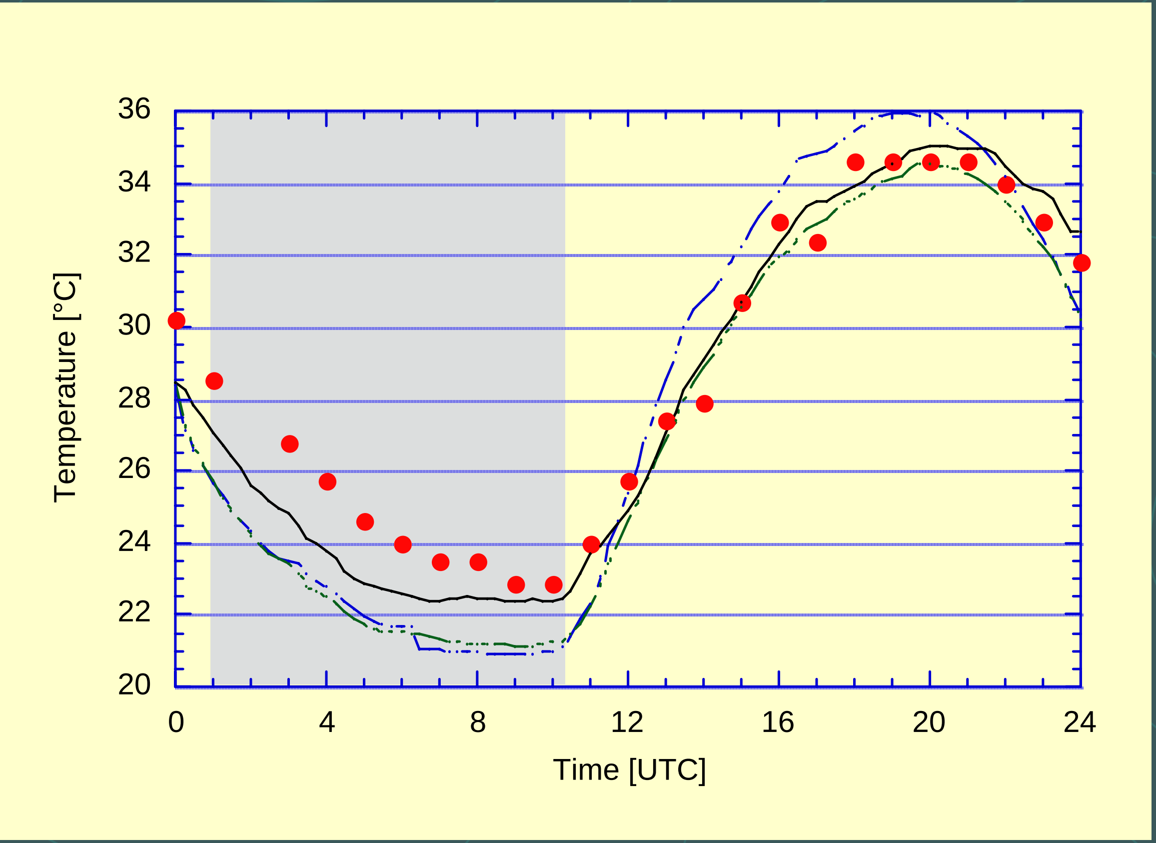
Implementing the UCP in MM5

- 40 layers: 12 in lowest 100 m
  - Typical setup has 30 layers, 3 in lowest 100 m
- Updates U, V, TKE in Gayno-Seaman PBL
- Energy modifications in RRTM, solve, slab
- Uses fractional land use categories
- Added new “urban zones” definitions

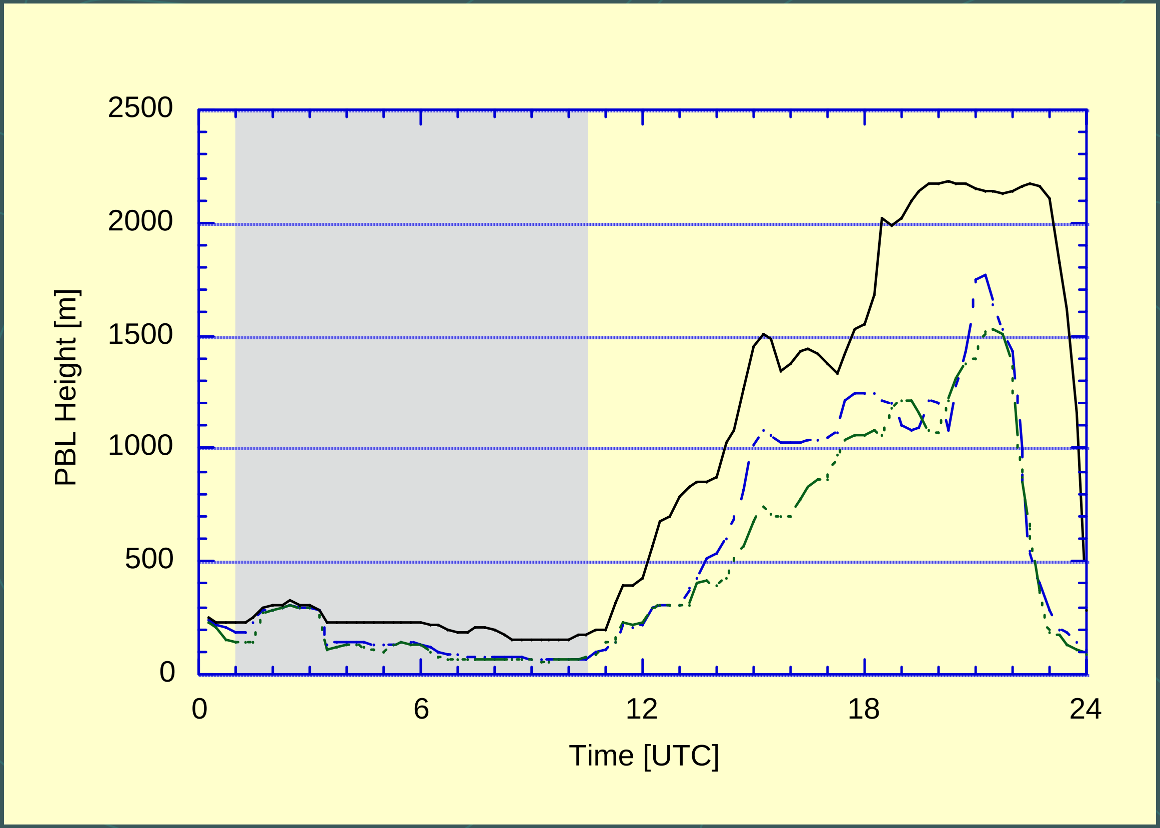
Pseudo-Morphology for Philadelphia



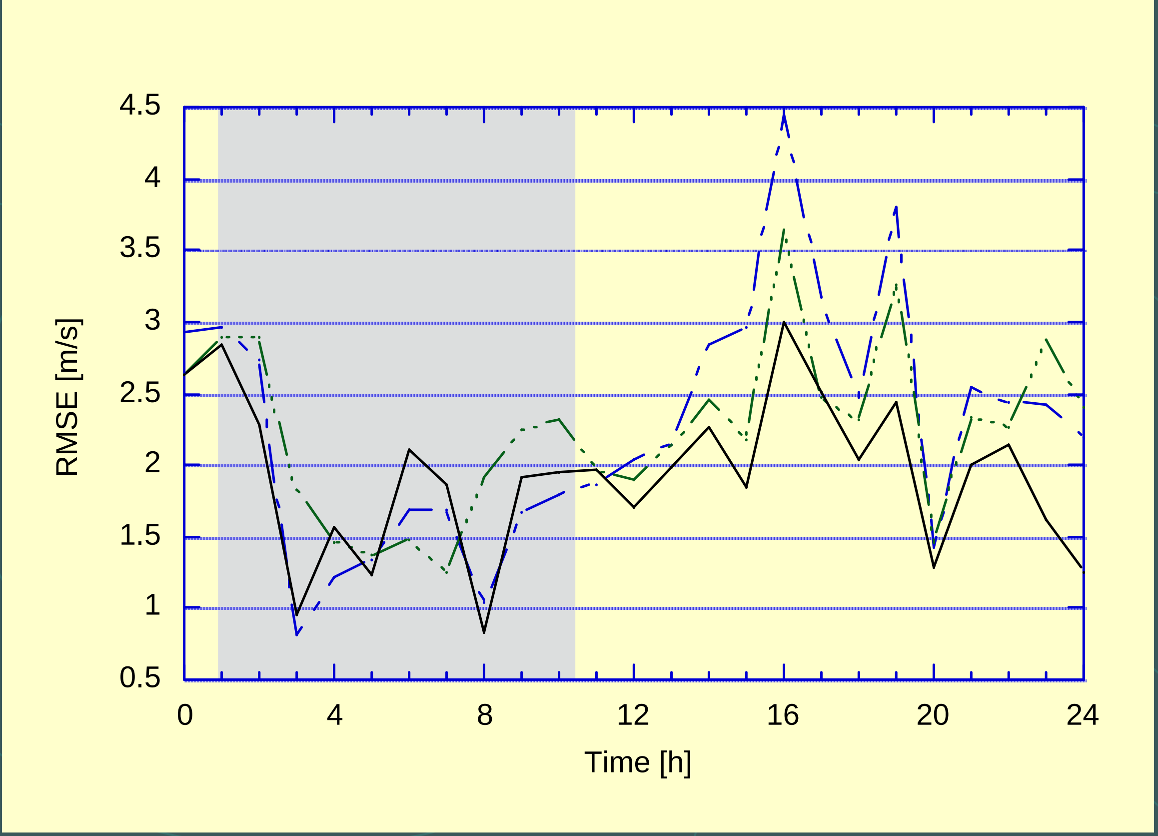
Temperature at Urban Site (ILG)



PBL Height at Urban Site (Cat. 6)



VWD RMSE at Five Urban Sites



Summary of UCP

- UCP at 1.3-km tends to produce desired effects
  - Changes to wind, TKE, temperature
- UCP tends to be superior to 40-layer run without UCP and 30-layer run without UCP
- Comparisons with surface obs, PBL heights, and wind tunnel profiles all favorable for UCP
- Encouraging results…continue to pursue research

Advanced UCP

- Extend drag approach to all roughness elements inside canopy (buildings and vegetation)
- Couple drag approach to urban soil model (SM2-U from French SUB-MESO)
- Applied to both urban and rural areas
- Use actual urban morphology database

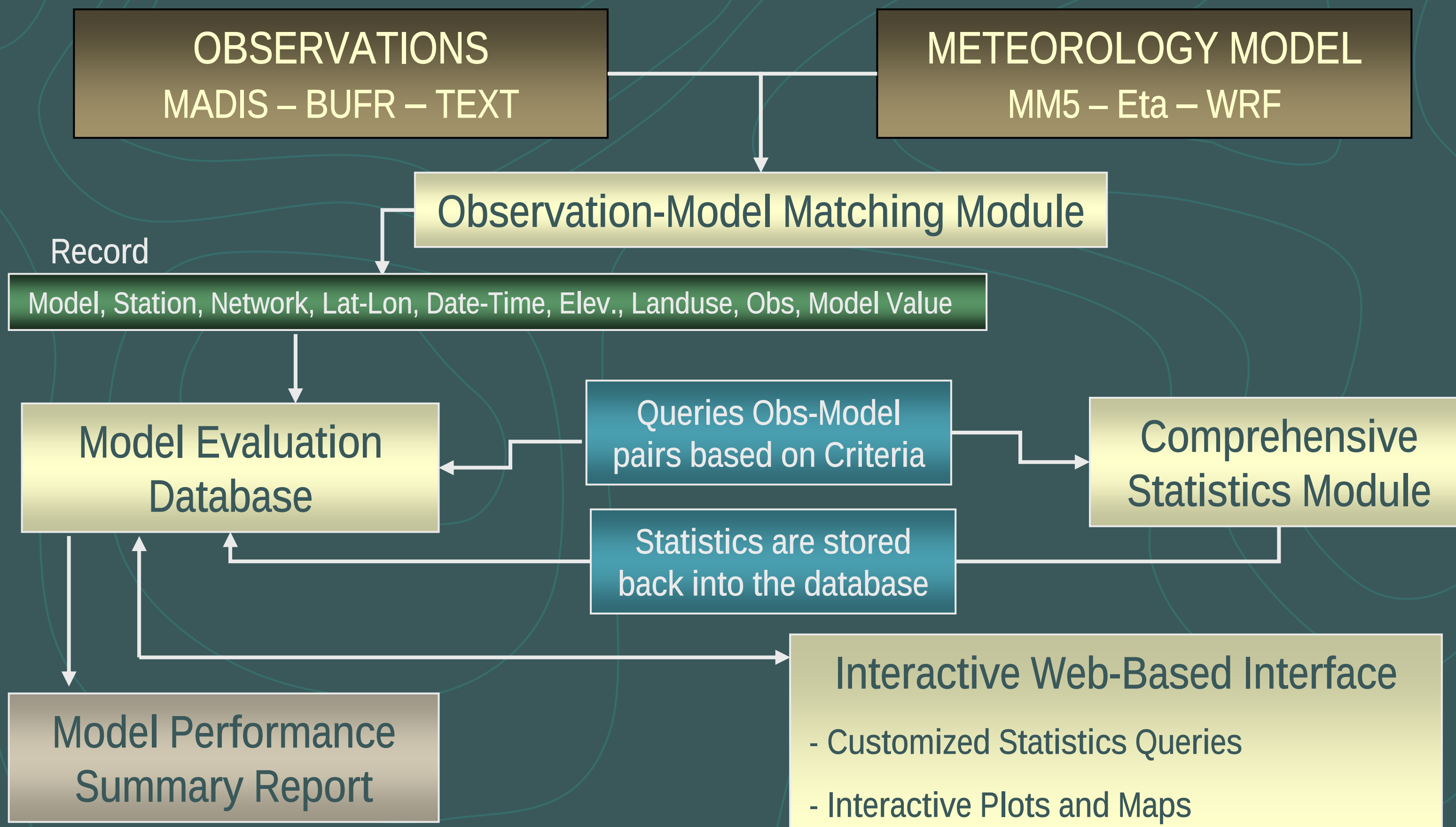
Meteorology Model Evaluation

- Many objective and subjective methods
- No “absolutely right” answer
  (issues with representativeness of obs on grid)
- Different methods for different scales
- Influence of spatio-temporal data density
- Statistics not only criteria for success…
  must still reproduce mesoscale circulations and other physical structures

Model Evaluation Methods

- Subjectively use visualization programs for meteorological “soundness”
- Statistical comparison to observations
  - Want to use all observations in model
  - May lose independent data set
- Satellite, Radar, Rain Gage
- Inferences from other “signatures” (e.g., sea breeze from ozone drop-off)

Automated Model Evaluation Tool



Meteorology Evaluation Variables

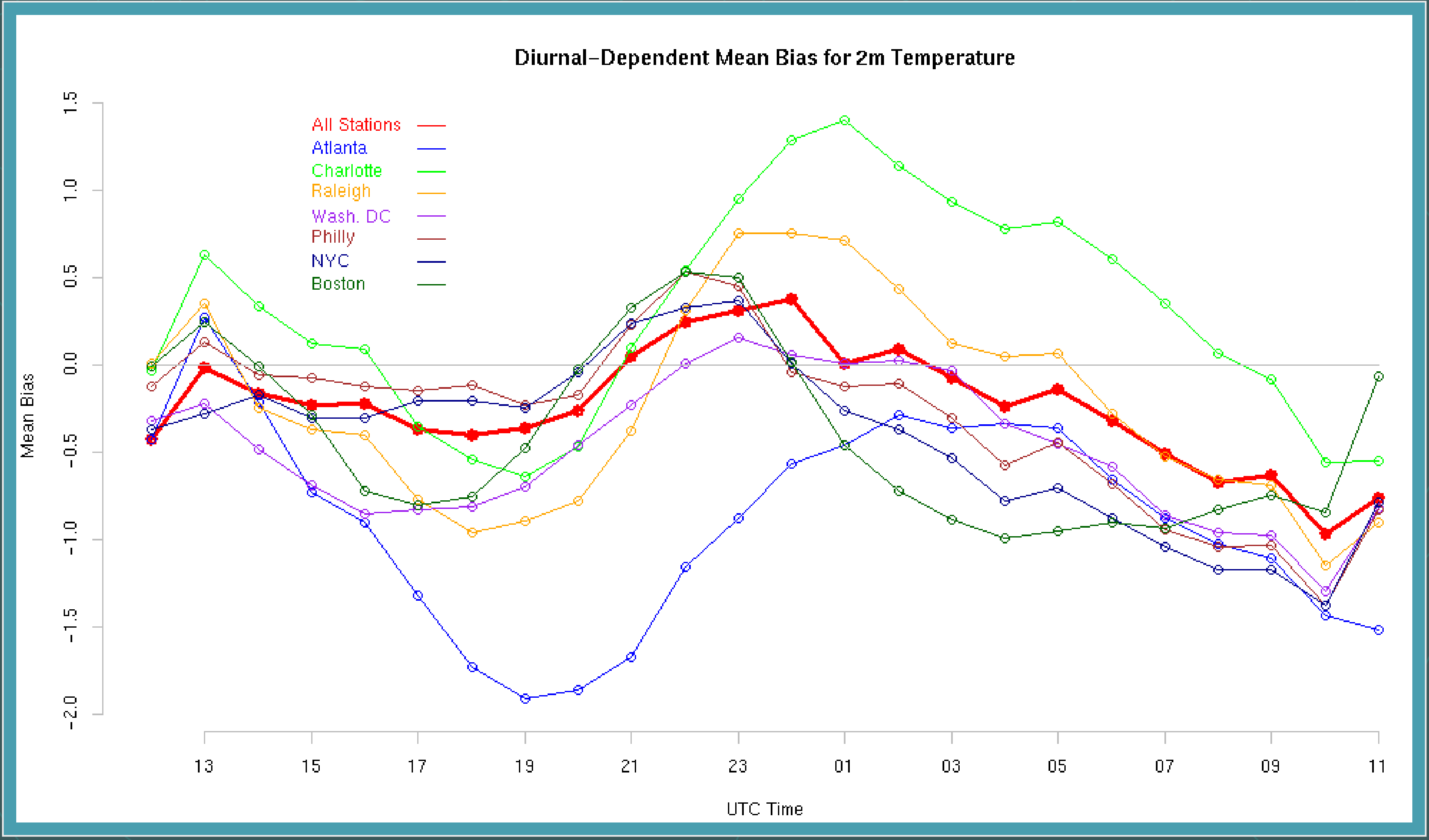
- Surface: Temperature, Moisture, Wind Speed/Direction, Precipitation, Solar Radiation
- Boundary Layer: PBL height; near-surface Wind, Temperature, and Moisture profiles
- Upper-air: Wind, Temperature, and Moisture

Objective Evaluation Techniques

- Summary statistics (e.g., absolute error, bias, RMSE)
- Pattern matching statistics (e.g., index of agreement)

- Statistical summary available for:
  - Full-domain (all stations at all times for each variable)
  - Geographical subsets including individual stations
  - Observation networks
  - Temporal analysis: diurnal, monthly, seasonal periods
  - Weather conditions (e.g., hot or rainy weather)

Example: Eta (July-August 2003)



Met. Modeling Challenges for AQM

- Land-Surface and PBL modeling
- Fine-resolution modeling
  - Convection: parameterize vs. resolve
  - PBL: parameterize vs. LES
  - UCP
  - Point of diminishing returns???
- Radiation schemes and cloud simulations
- Nudging (special data, “boundaries”, WRF)
- Hardware to run “big” problem