PENNSTATE 1855

Ensemble Prediction and Atmospheric Transport and Dispersion Modeling

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Penn State University

National Workshop on Mesoscale Probabilistic Prediction

Boulder, CO

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Outline

- Motivation: NWP, ensemble and AT&D modeling
- Background on model uncertainties for AT&D: complex-terrain / land-surface / PBL effects
- Case-study demonstration using ensemble methodologies - Linear Variance Calibration (LVC)
- Daily MET-SCIPUFF Ensemble Testbed
- Summary of challenges for ensemble prediction and AT&D

Air Force Technical Applications Center (AFTAC)

"The Air Force uses AT&D for nuclear treaty monitoring - like everyone else, we use ensembles to try and capture the full range of possibilities in the forecasts and we're interested in utilizing meteorological (MET) uncertainties so we can bound errors and produce confidence intervals." – Brian Strahl, AFTAC

Defense Threat Reduction Agency (DTRA)

DTRA Connection article…

DTRA team models wind, weather in support of Winter Olympics

by Irene Smith

Tracking snow and cold winds flowing from the Alps, the Defense Threat Reduction Agency's weather models and meteorology team supported the 2006 Winter Olympic Games in Turin, Italy.

Headed by Air Force Maj. Jimmie Trigg, the DTRA meteorology team operations were expanded to provide consequence assessment during the 2006 Winter Olympics at the request of the U.S. European Command.

Operating the Hazard Prediction and Assessment Capability (HPAC) software tool, the meteorology team took advantage of special weather observation datasets available in the domain of the Winter Olympic venues and undertook a project to improve weather modeling at high resolution.

The varied terrain provided a special challenge to the modelers on the meteorology team. Half of the Olympic venues were located in the mountains to the west of Torino, while the rest were located on the relatively flat plain in and around Pinerolo and the city of Torino to the east.

"Back at DTRA, we're making it easier for the Consequence Management Team (CMAT) to do their job," Trigg said. "If bad weather is predicted to happen during the curling competition, we can pull the weather file and do the calculations on it. The CMAT doesn't have to analyze 11 different weather models to get the best weather for the event. We do the analysis back here, post it on a webpage and then send them the data."

A DTRA CMAT, comprised of Air Force Maj. James Greene, Navy Chief Warrant Officer Peter Terrill and defense contractor Chris Schinnerer, was forward deployed to Stuttgart, Germany, to provide weather modeling to support hazard and consequence assessment operations

The HPAC and other tools use high-resolution weather data along with other environmental and source term information to produce estimates of the spread of accidentally or intentionally released hazardous material, such as chemical, biological, radiological, nuclear, and high explosive (CBRNE) agents.

The meteorology team performed three functions in support of the Olympics. They provided meteorological data for individuals using HPAC; they made a determination of the best performing medium-range model forecast for any given 12-to-48 hour timeframe; and they provided real-time help-desk support to users regarding acquisition and use of weather for HPAC consequence assessment applications.

"What we're doing is pulling high resolution data from the meteorological data server and overlaying it on the location of a specific sport venue, such as snowboarding," Trigg said. "Gathering 1.6 kilometer resolution data from the U.S. Air Force Weather Agency (AFWA), we then add high resolution weather data over the area and plot the flow and direction of the wind as it comes out of the mountains."

Prior to the Olympics, DTRA partners at Pennsylvania State University (PSU) and the U.S. National Center for Atmospheric Research (NCAR) established data collection and assimilation, and forecast modeling projects that used special weather station observations provided by Italy's ARPA Piemonte, the environmental agency for the region.

At Penn State, a version of the Mesoscale Model-5 (MM5) was prepared to use the special observation data to forecast weather in a four-nest configuration. At NCAR, versions of MM5 and the Weather Research and Forecast (WRF) models were integrated into a real-time four-dimensional data assimilation program which used the special Olympic weather data to initialize these models.

Dr. David Staufer, Penn State meteorology department, remarked, "It is very satisfying to apply our advanced technologies in numerical weather predication and data assimilation. So far our high-resolution meteorological modeling and data assimilation system has performed very well in capturing the localized mountain flows in and around the Olympic venues."

Two other DTRA partners provided independent weather forecast models against which the PSU and NCAR model data was compared against. The AFWA provided its MM5 forecast model data and the U.S. National Oceanic and Atmospheric Administration's National Centers for Environmental Prediction provided data from a special version of their WRF model.

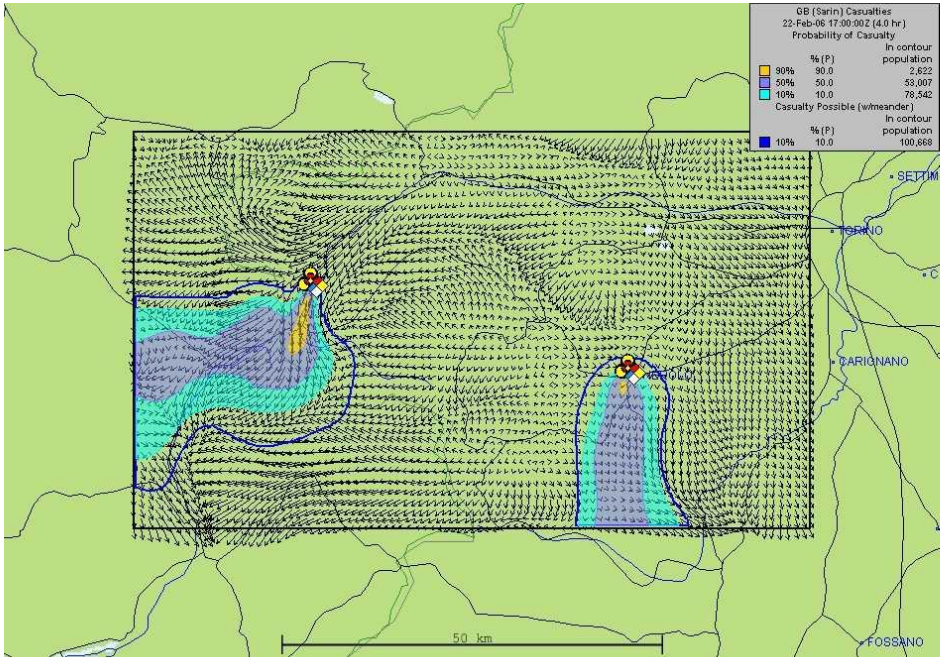
"We learned several important lessons during this project," Trigg said. "More research is needed for quantifying model uncertainties in the inputs and outputs of transport and dispersion models. The meteorology team and its partners used this experience to improve several areas of its weather support operations. We plan to expand upon this experience during upcoming field tests, and to further improve and expand the capability to provide accurate high-resolution weather forecast information to hazard and consequence assessment operations." ■

Irene Smith is a DTRA public affairs specialist

Navy Chief Warrant Officer Peter Terrill (right) and defense contractor Chris Schinnerer, members of a DTRA Consequence Management Assessment Team forward deployed to Stuttgart, Germany, provide weather modeling to support hazard and consequence assessment operations at the Winter Olympics.

8 DTRA Connection — Making the World Safer 9

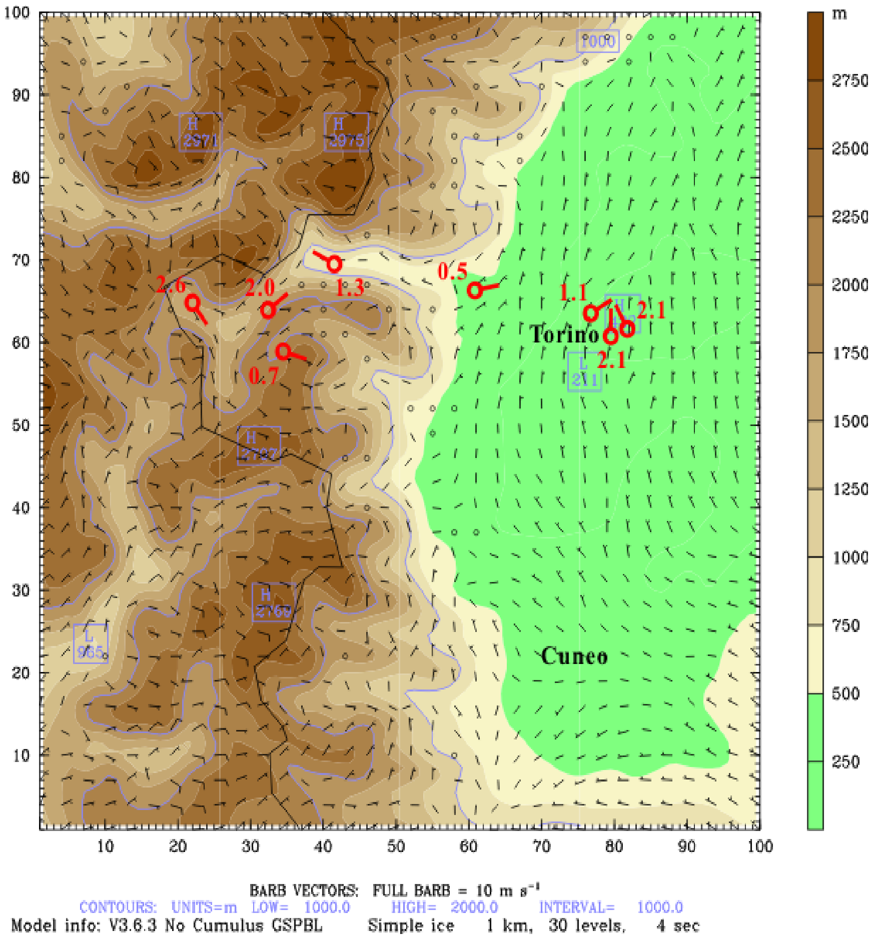
PSU-DTRA 1.3-km NWP model winds (Feb. 22/14 UTC) and HPAC/SCIPUFF predictions (Feb. 22/13-17 UTC)



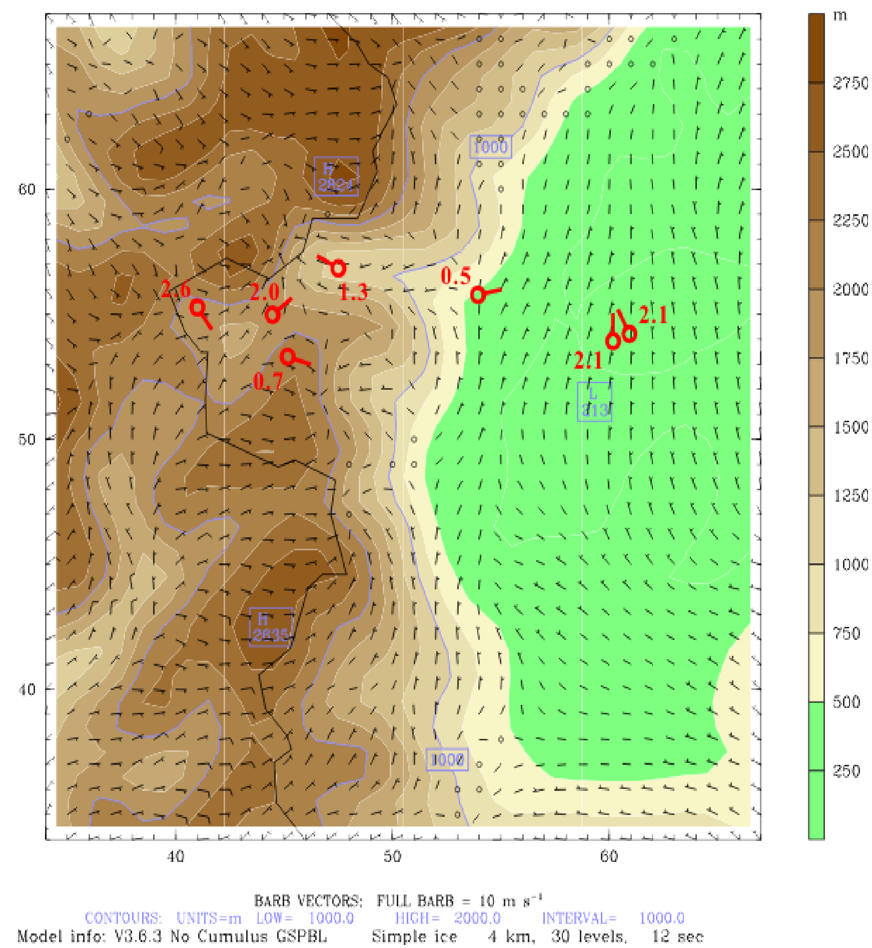
Hazard Prediction and Consequence Assessment ...

18-h NWP Model Forecast of Surface Layer Winds with Mesonet Observations (red) Valid at 18 UTC, 21 February 2006

1.3-km domain



4-km domain



18-h NWP Model Forecast of Surface Layer Winds with Mesonet Observations (red) Valid at 18 UTC, 21 February 2006

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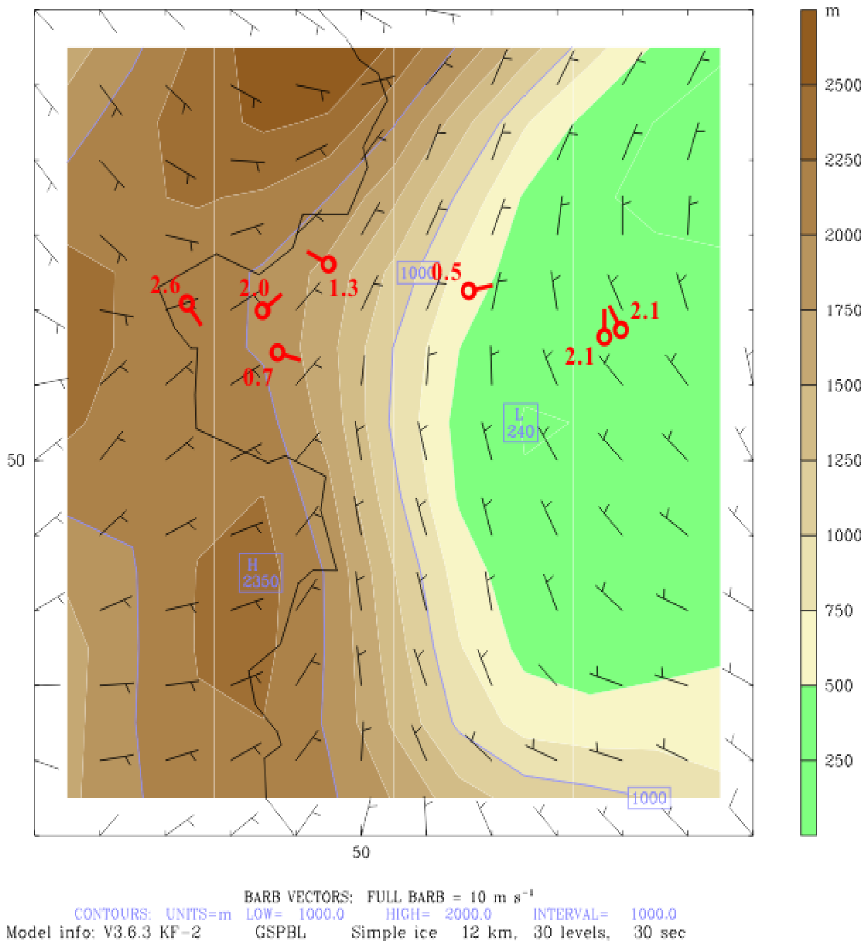
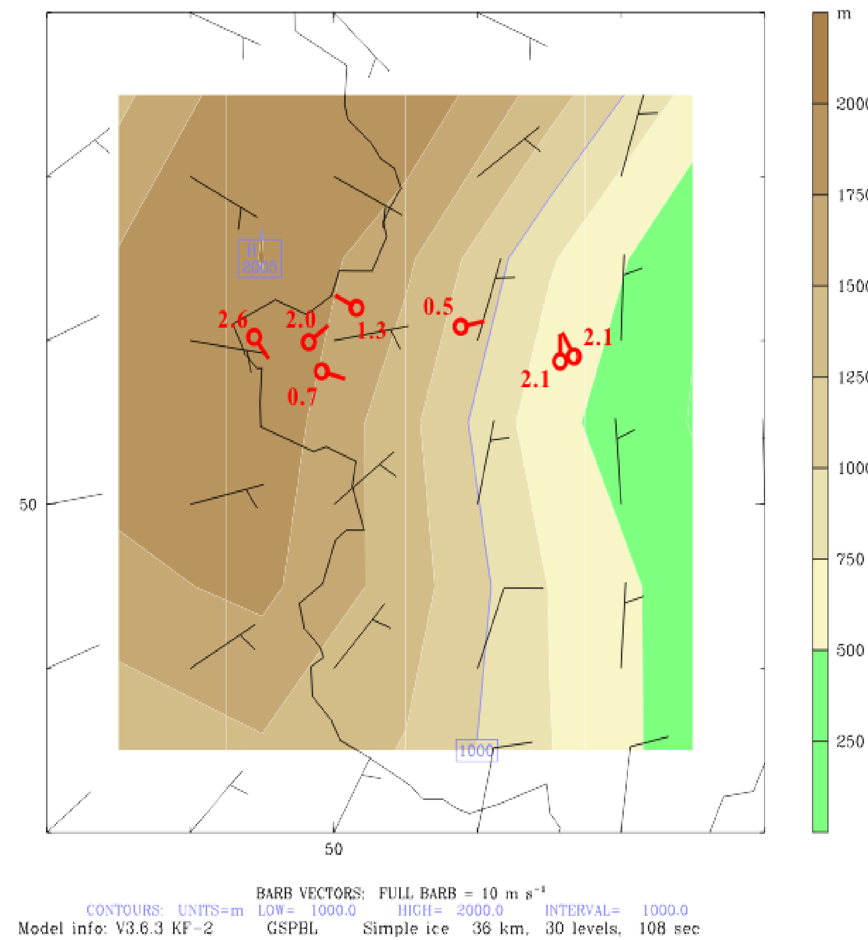
12-km domain



36-km domain



Rockies Front Range Application

The use of a 1.3
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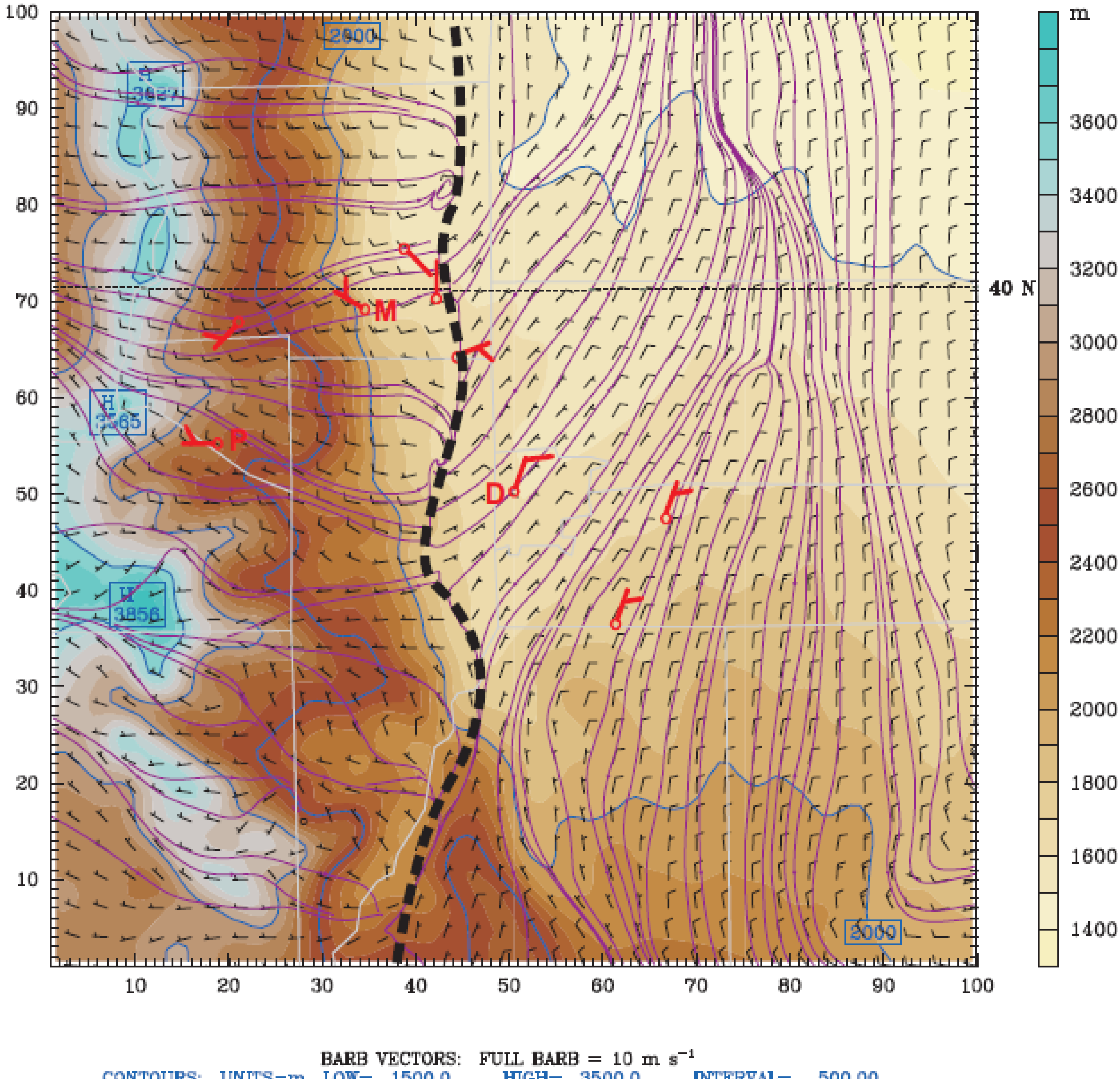

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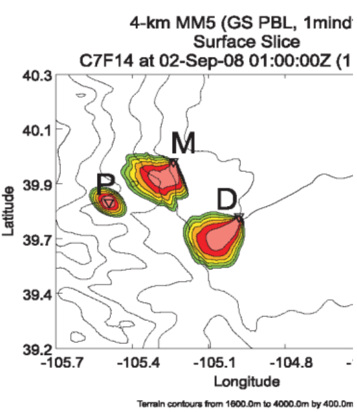
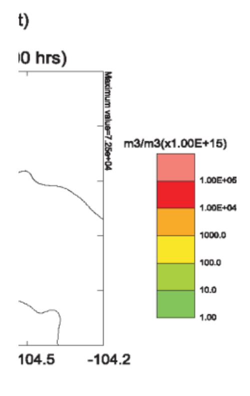
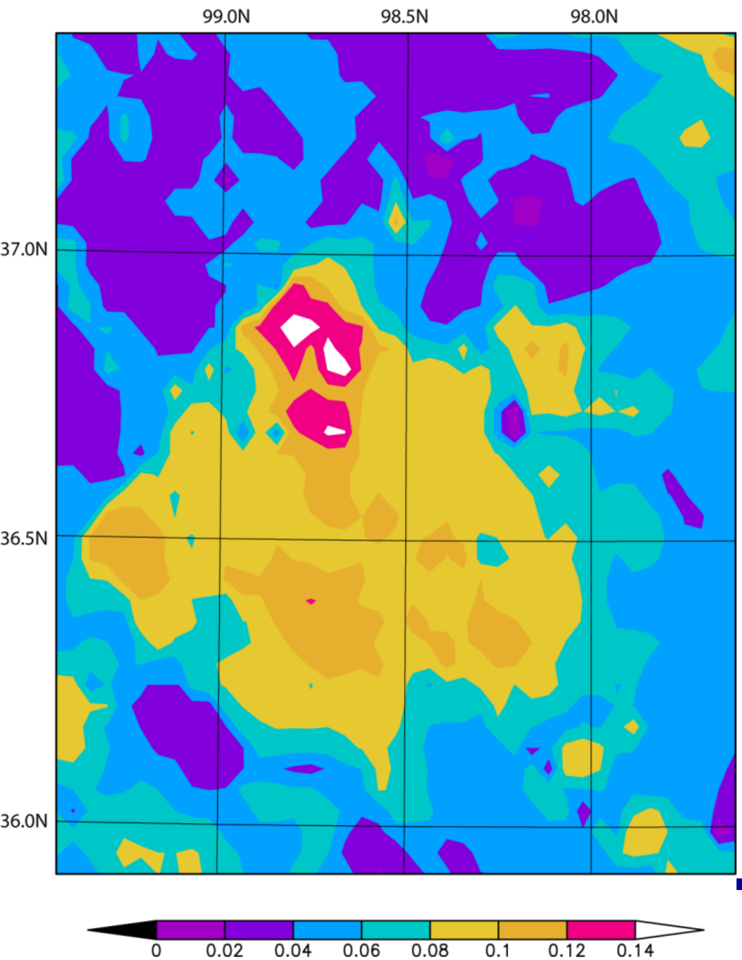




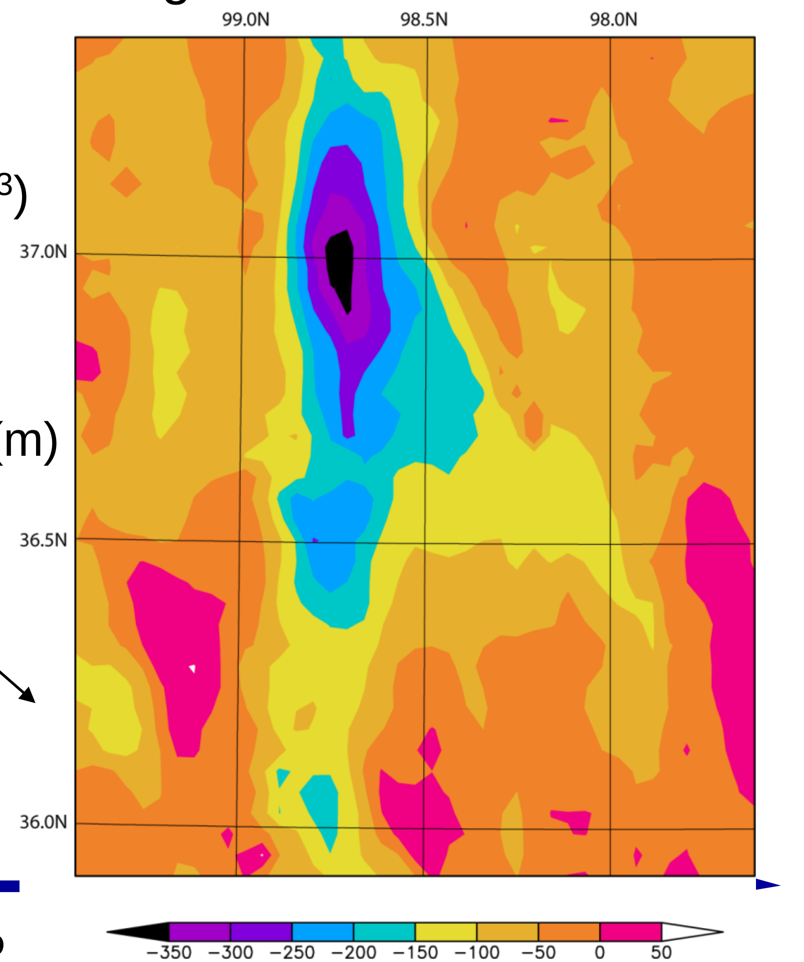
Spatial Structure of PBL Sensitivity to Realistic Soil Moisture Variation

Sensitivity of 4-km NWP Model PBL Depth (right) to HRLDAS Soil Moisture Difference Between Wettest and Driest Soil Days (left) over Southern Great Plains During IHOP



Δ Soil Moisture Content (cm^3/cm^3)

Δ PBL Height (m) at 21 UTC 07 June 2002



Beijing Olympics Application

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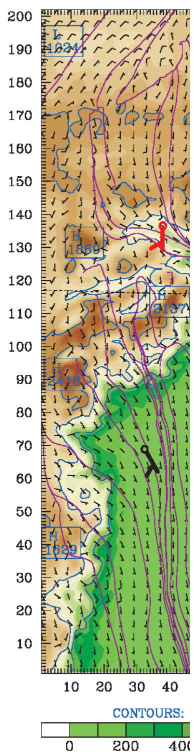
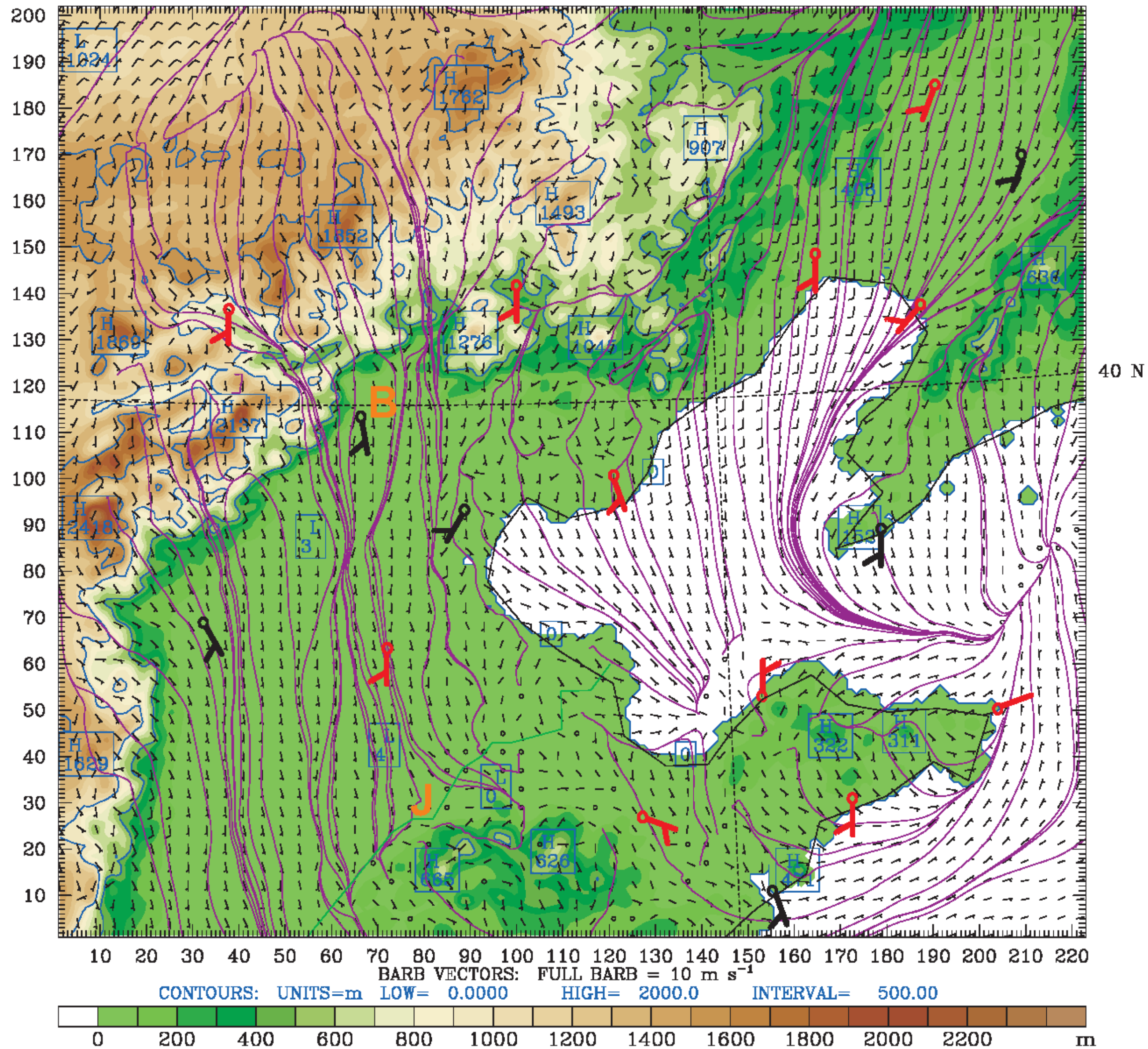
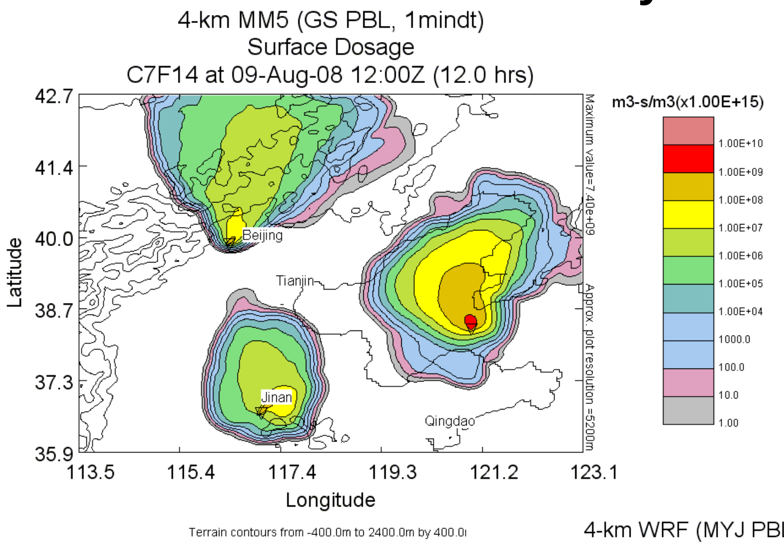


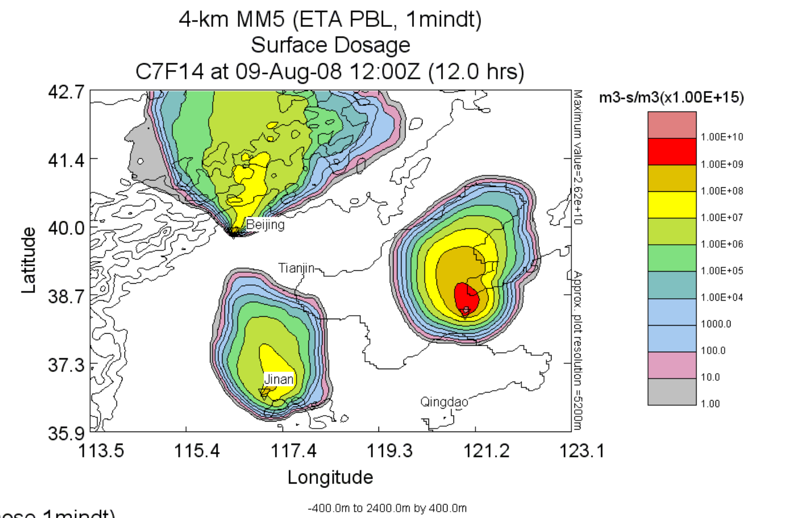


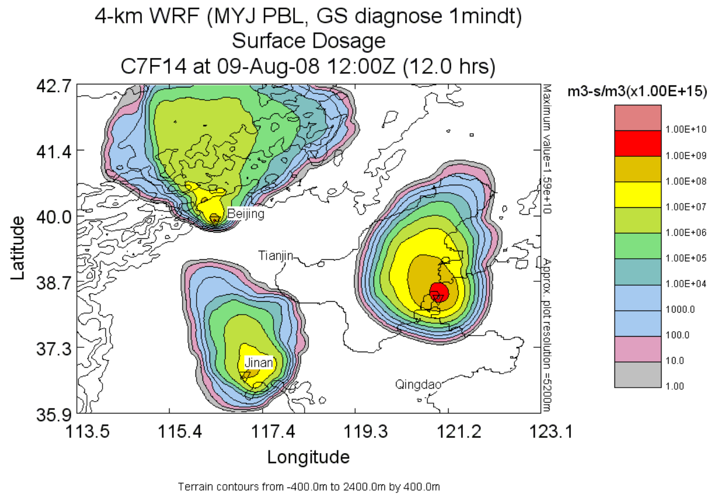
Black=WM

12-h Surface Dosage Forecasts

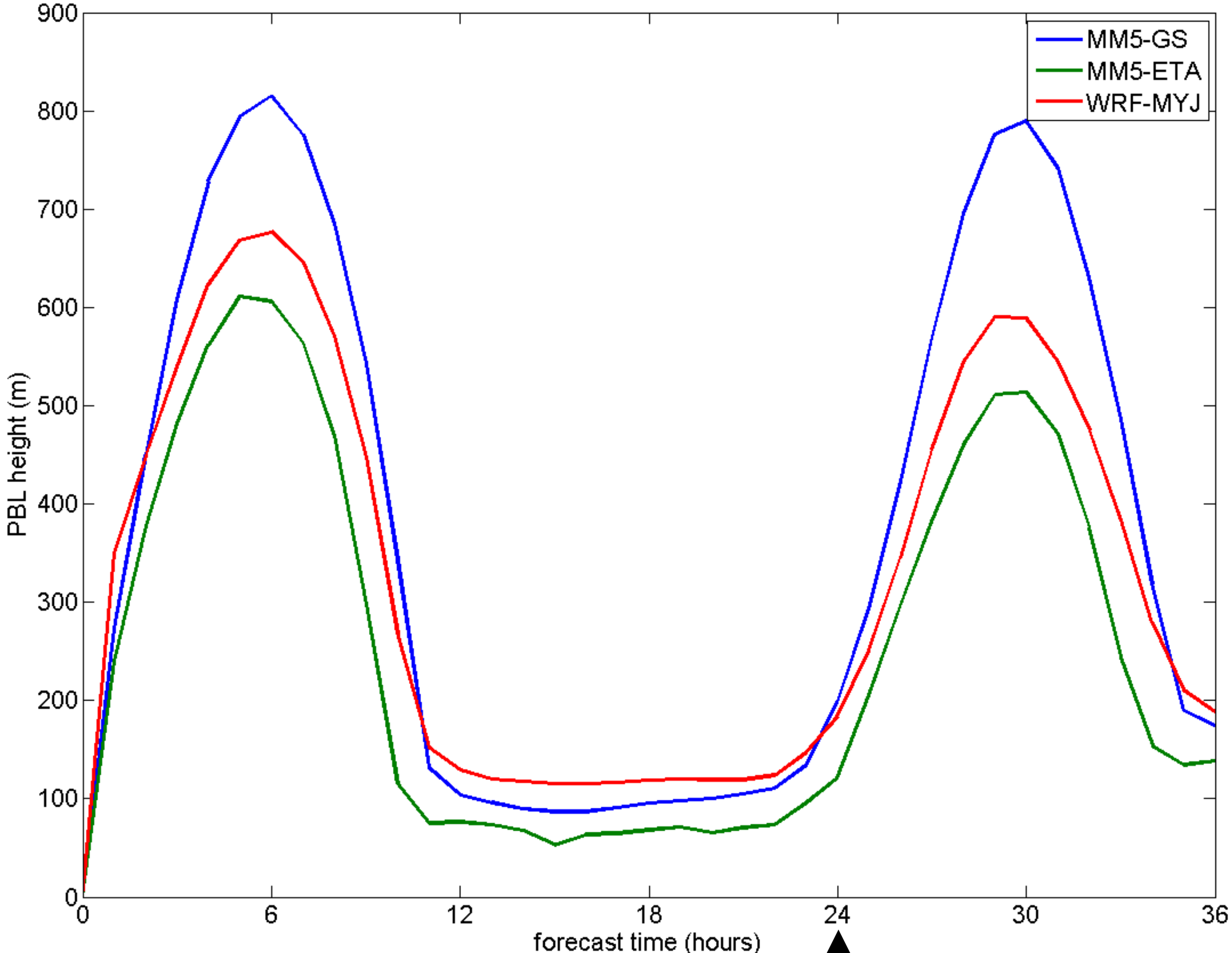
Variability Due to PBL Physics ...





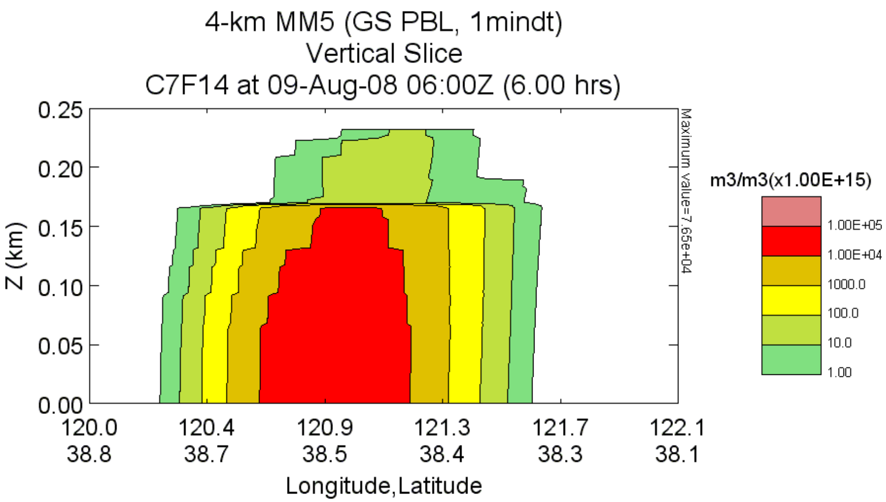


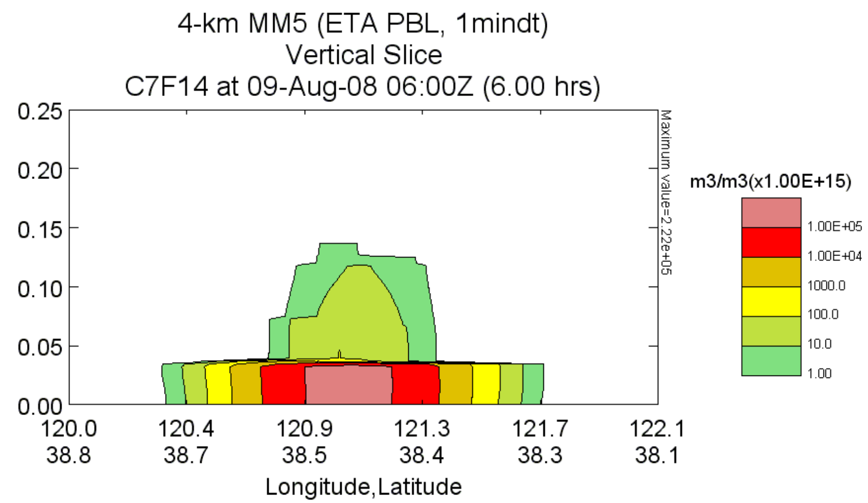
Domain-Average PBL depths

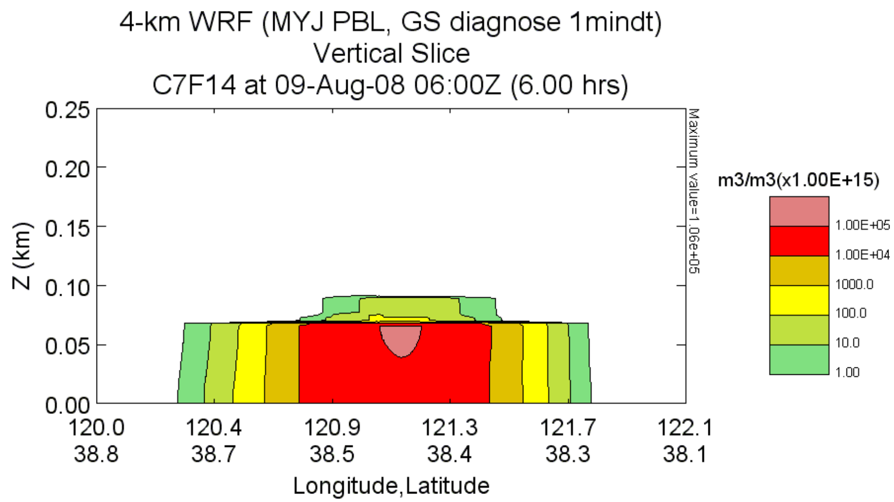


Release Time

6-h Concentration Forecasts: Yellow Sea West-East Cross Section







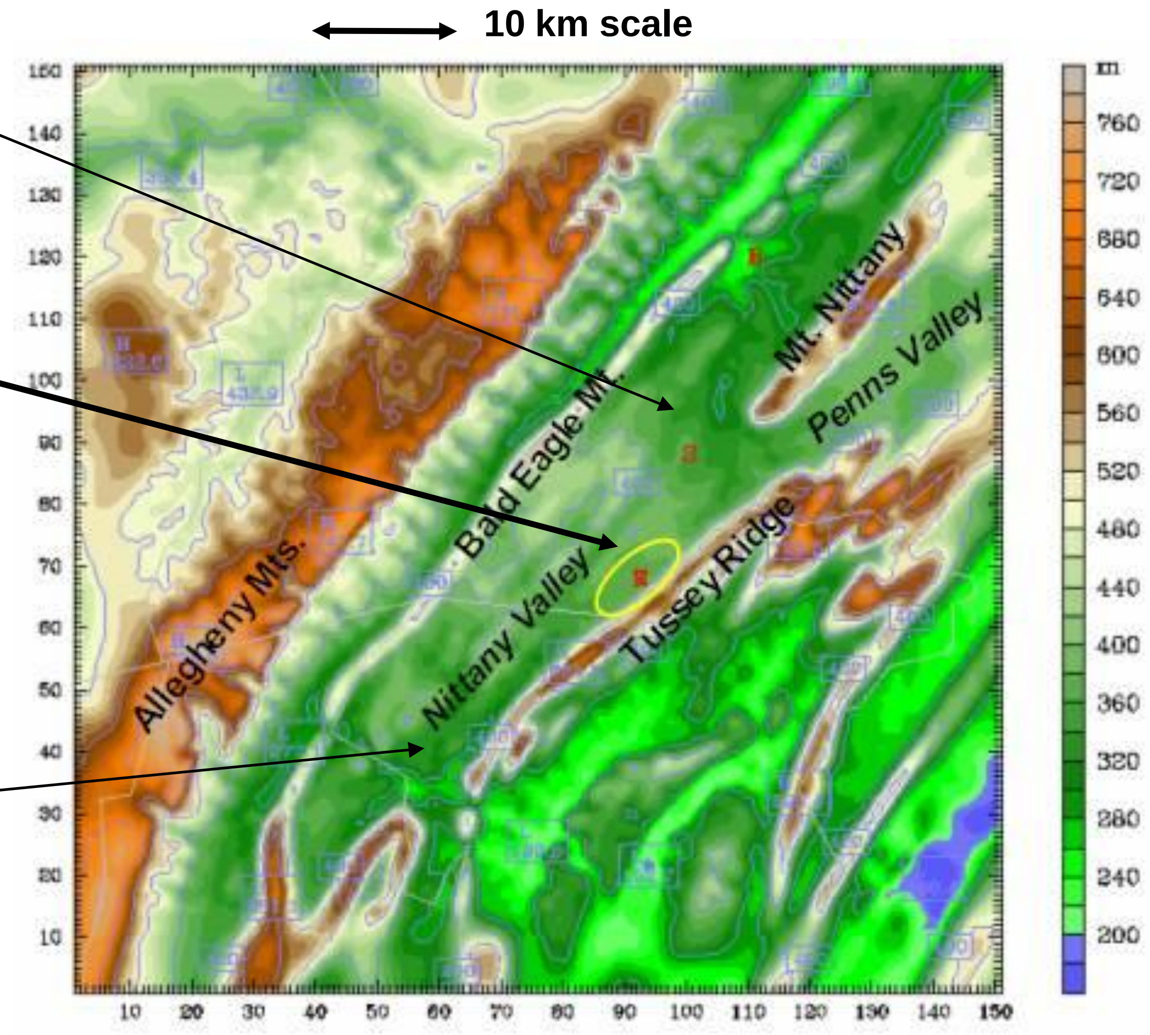
Central PA Stable Boundary Layer (SBL) AT&D Study (0.444-km domain terrain)

Spring Creek Watershed – drains to north

Instrumented Field Site:

Extensive PSU-owned agric. land at Rock Springs, PA

Spruce Creek Watershed – drains to south

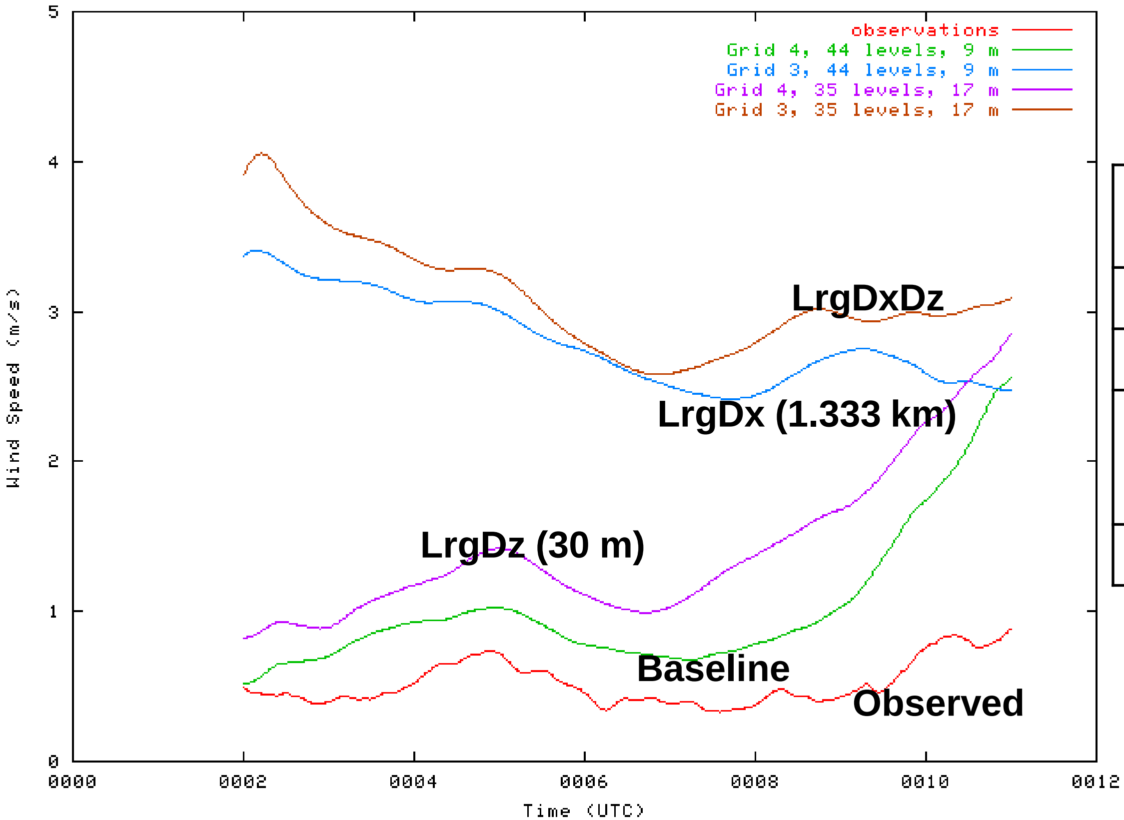


Sensitivity of Wind Speed to Horizontal and Vertical Resolution

Case study: 7 October 2007

height: 9-m AGL

SBL Wind Speed
at Rock Springs, PA

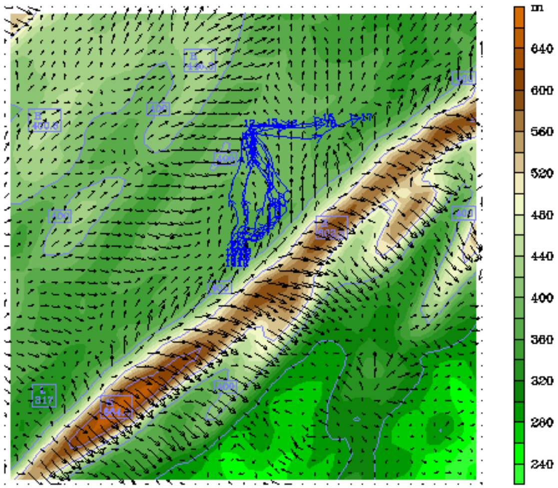


Exper. Name	Horiz. Grid (km)	Layers Below 68 m
LrgDXDZ	1.333	2
LrgDX	1.333	11
LrgDZ	0.444	2
Baseline	0.444	11

(2-h running-mean filter has been applied)

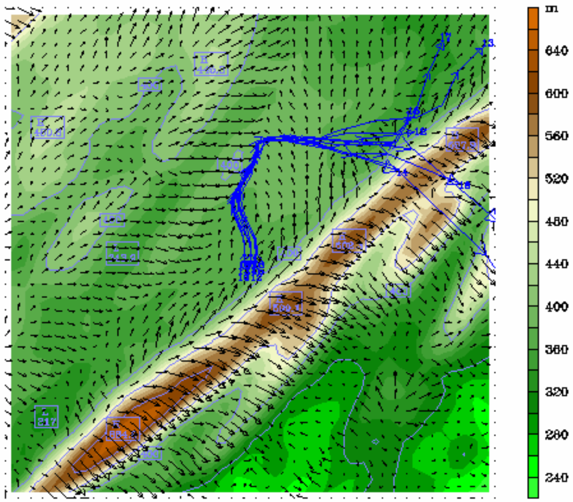
Sensitivity of Parcel Trajectories and SCIPUFF Dosage to Output Frequency

9 trajectories released within a 444-m x 444-m area at 5 m AGL



Baseline:

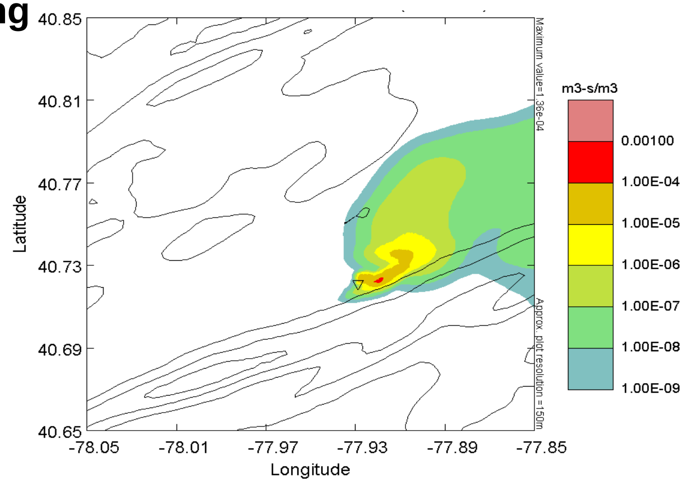
0.444-km 12-min sampling

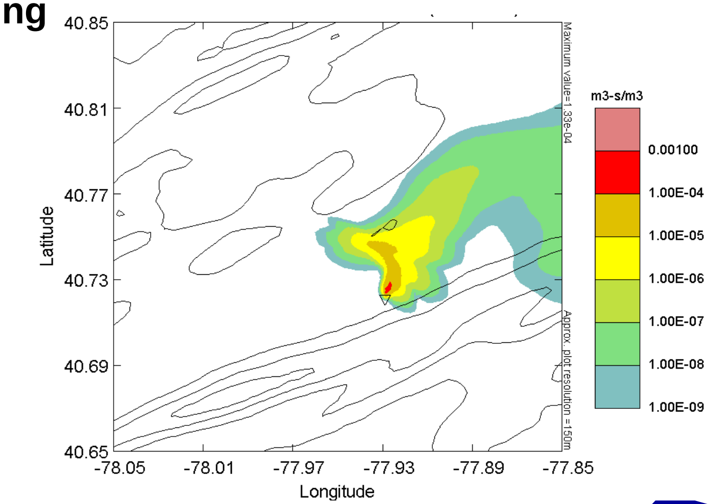


Baseline:

0.444-km 1-h sampling

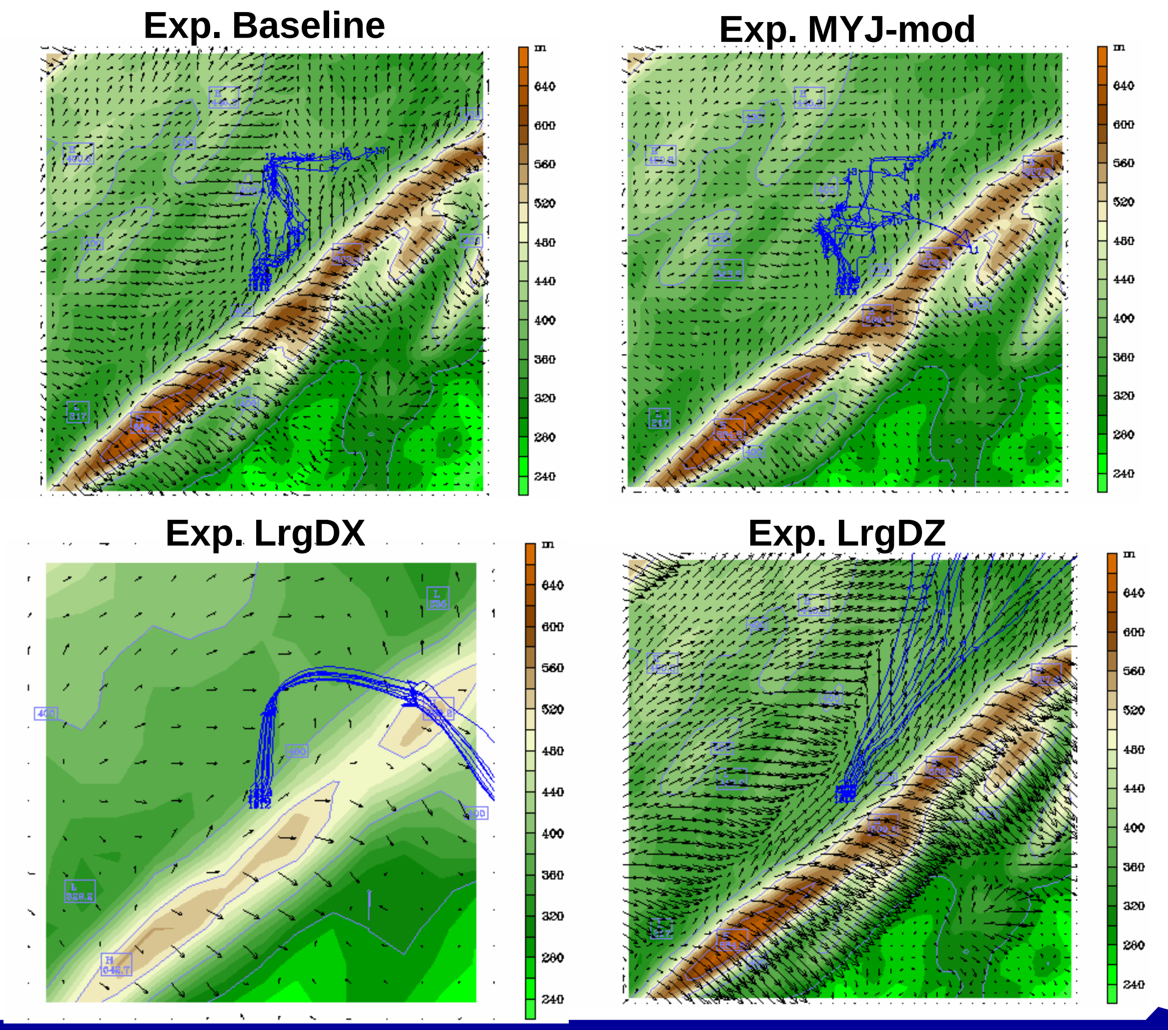
12-min cont. release at 5 m AGL





Sensitivity of Parcel Trajectories to Model Resolution & PBL Physics

Time: 0800 – 1112 UTC Case: 7 Oct. 2007



Trajectory Sensitivity:

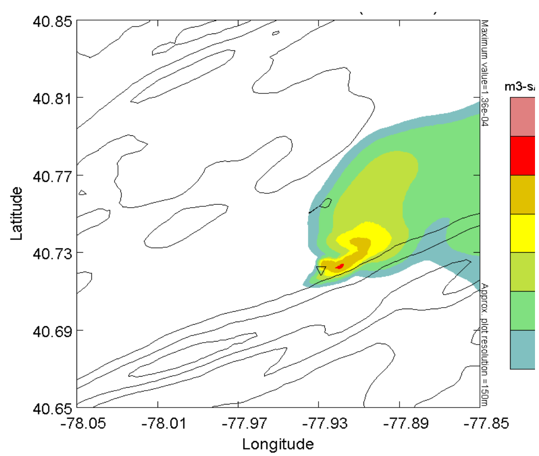
- Reduced mixing in MYJ-mod allows more sub-meso motions and inter-parcel variability.
- Lower horizontal resolution produces larger speed bias.
- Lower vertical resolution suppresses gravity-driven slope flows.

Surface Dosage at 3 h Following Release and Valid at 11 UTC

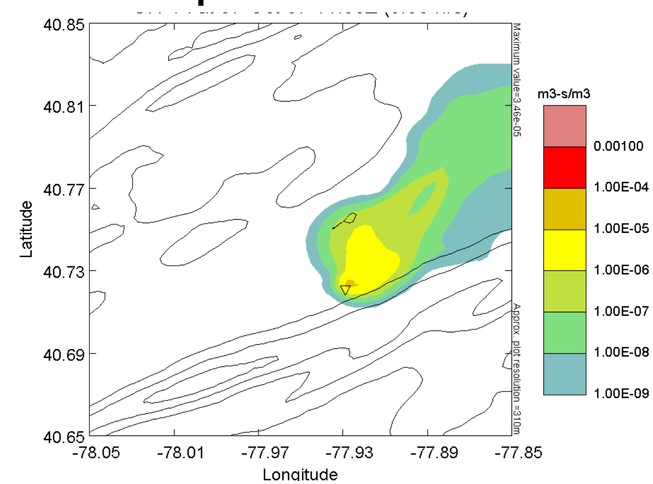
SCIPUFF Sensitivity:

- Reduced mixing in MYJ-mod allows more sub-meso motions and greater dispersion.
- Lower horizontal resolution produces larger speed bias, less-resolved drainage flow and less lateral (cross-plume) dispersion.
- Lower vertical resolution suppresses gravity-driven slope flows and produces a plume more parallel to the mountain.

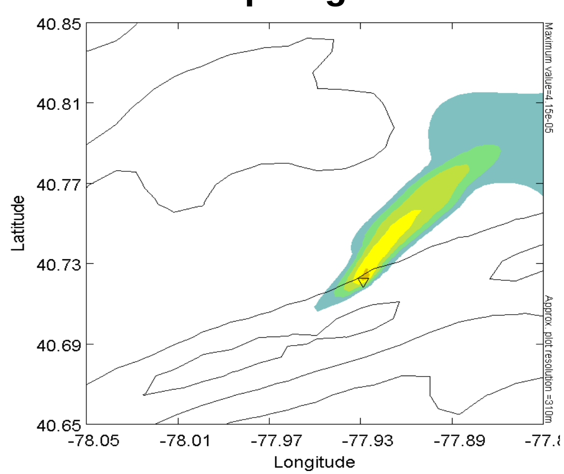
Exp. Baseline



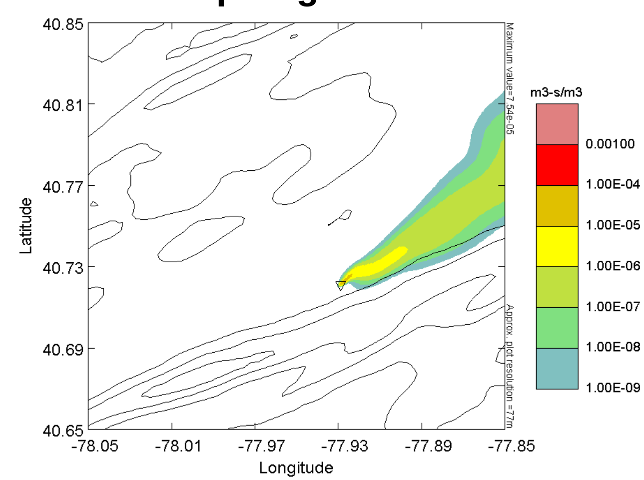
Exp. MYJ-mod



Exp. LrgDX



Exp. LrgDZ

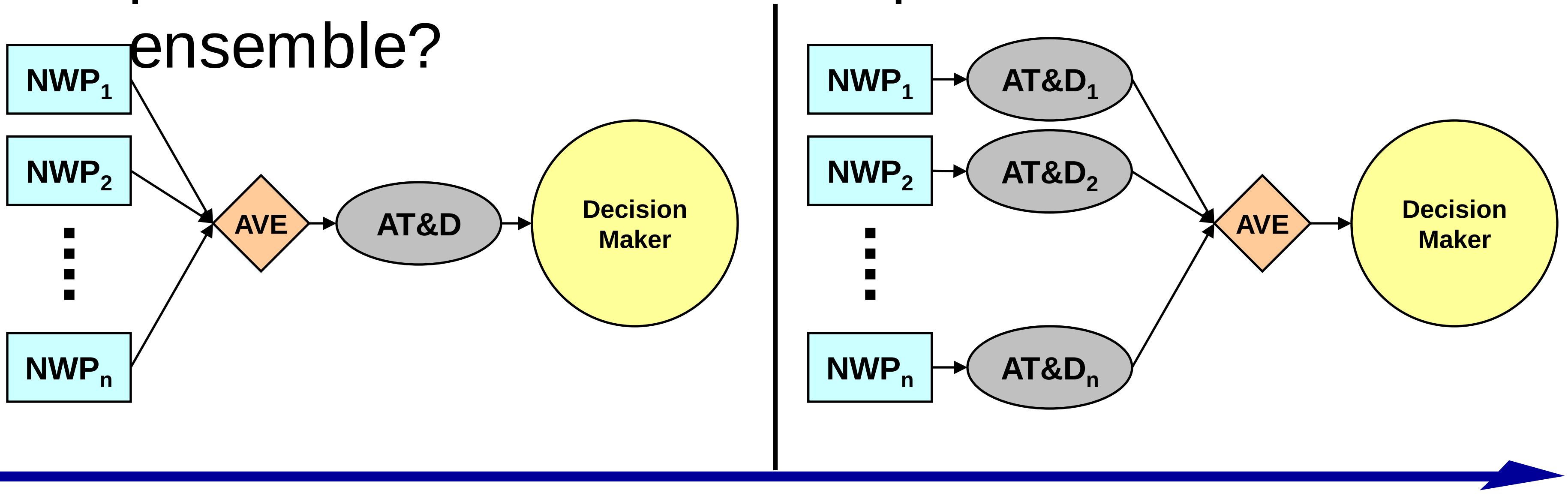


MET Uncertainty and Ensembles

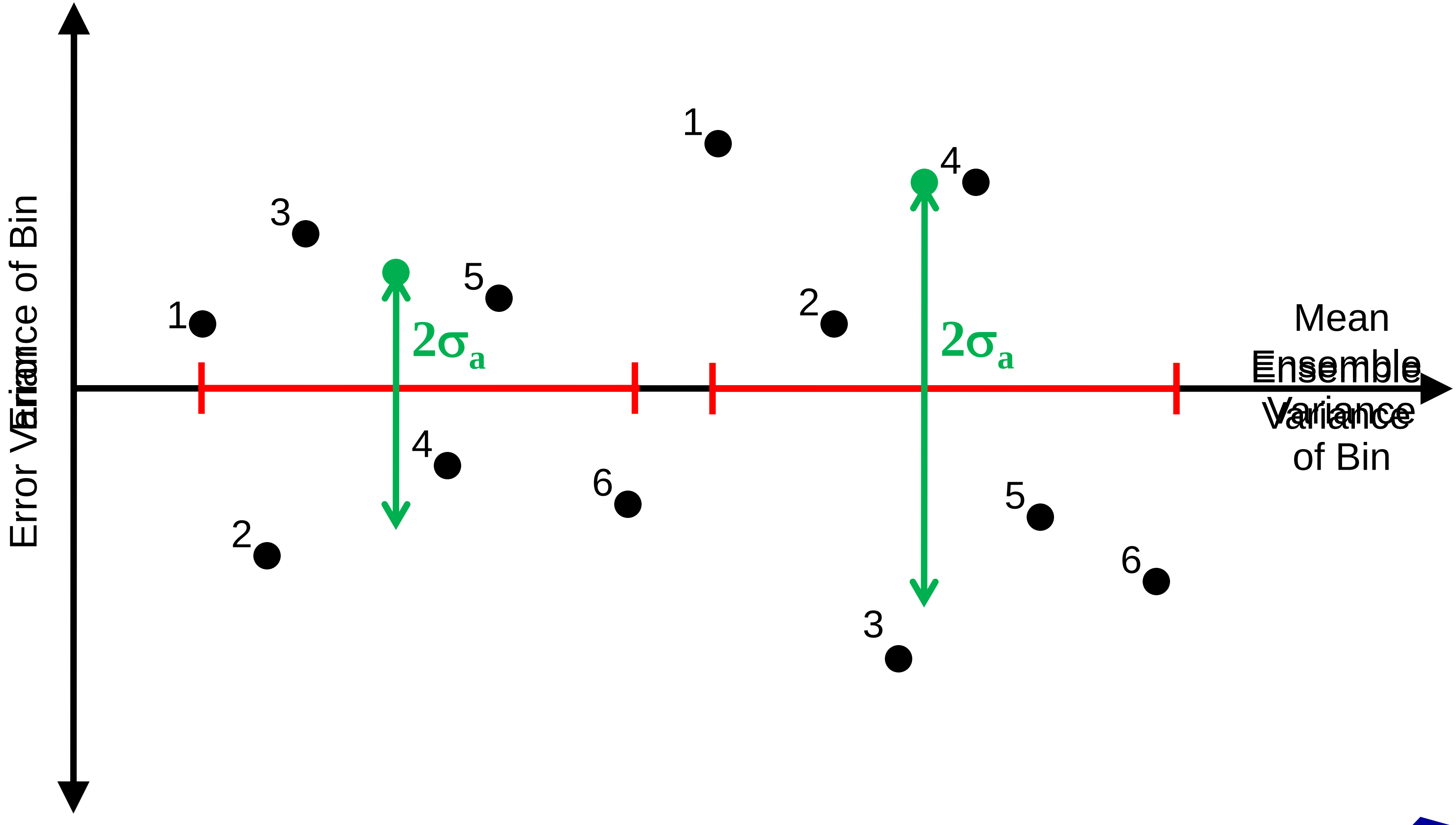
- MET errors have important implications to AT&D predictions
- Ensemble of AT&D models attractive but not practical for operations
- Efficient way to compute MET uncertainty from an NWP ensemble for input into a single AT&D model solution (HPAC/SCIPUFF wind variance matrices, UUE, VVE, UVE)
- NWP-ensemble variance (spread) is at best an approximate measure of actual uncertainty/error variance…

Question

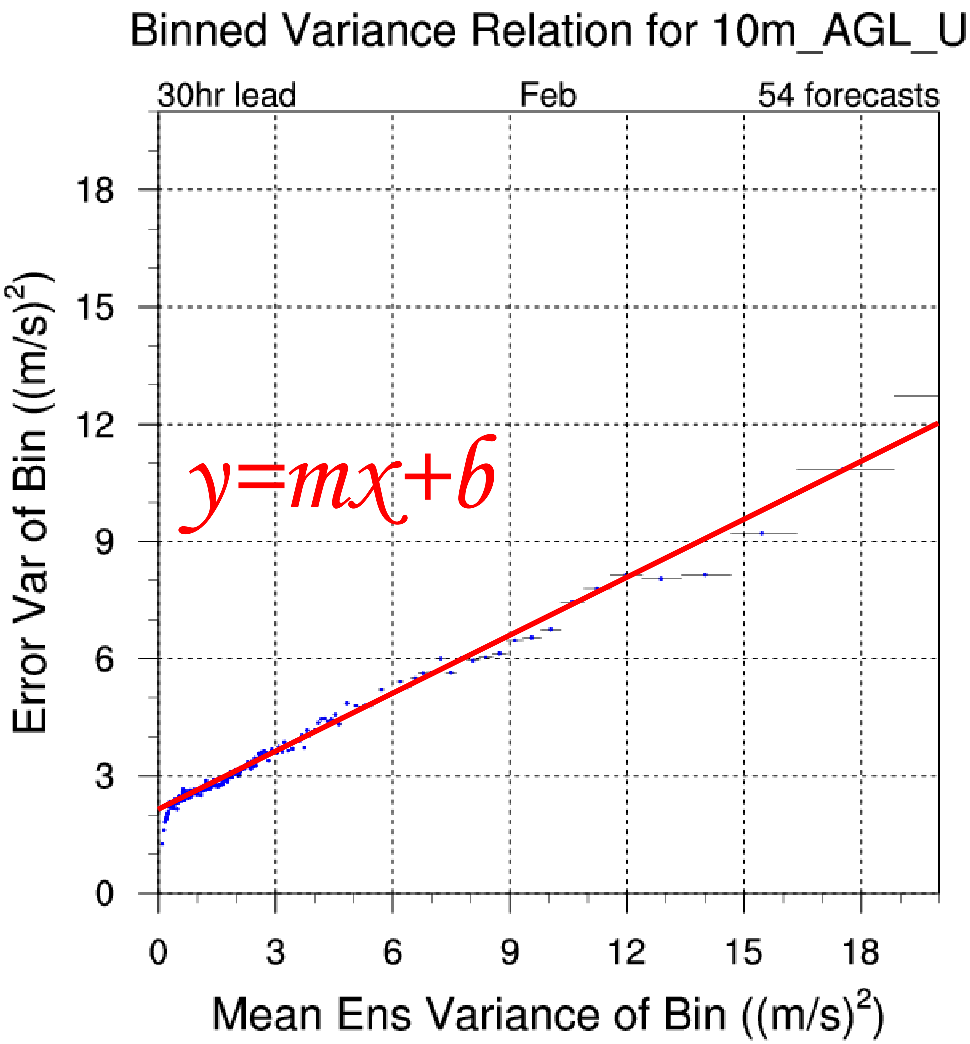
- Can a single AT&D prediction using NWP-ensemble derived MET fields and wind variances (uncalibrated or calibrated) approximate and improve upon an AT&D prediction based on an explicit AT&D ensemble?



Linear Variance Calibration (LVC) Methodology



LVC Methodology



SREF Case Study - Experimental Design

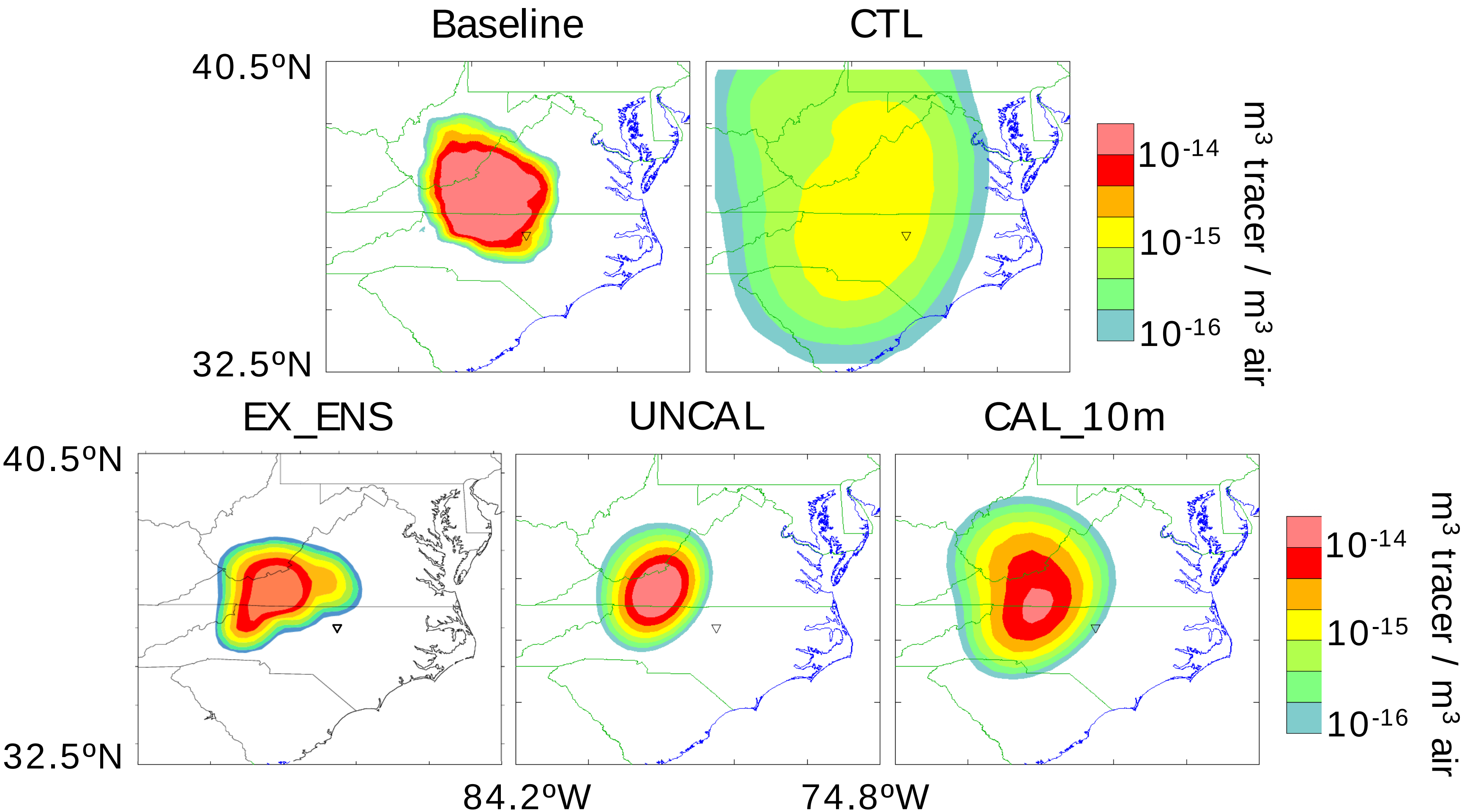
- Single-SCIPUFF experiments
  - Control (CTL) experiment using mean SREF NWP MET and default hazard mode uncertainty model (no UUE, VVE, UVE)
  - Uncalibrated (UNCAL) experiment using SREF ensemble UUE, VVE and UVE.
  - Calibrated (CAL_10m) experiment using calibrated SREF UUE and VVE based on 10-m U and V calibration at midpoint of AT&D forecast period.
- Ensemble-SCIPUFF experiment
  - Explicit 10-member SCIPUFF ensemble (EX_ENS) experiment driven by 10-member SREF NWP ensemble
- All of above as presented in Kolczynski et al. 2009 (JAMC)

Case Study - Objectives

- Compare single-SCIPUFF experiments (40-km) against Baseline SCIPUFF using output from dynamic analysis created using high-resolution (4-km) MM5 with FDDA
- Compare the above results to the mean concentrations and patterns from the explicit 10-member SCIPUFF ensemble that uses the output from each SREF member (EX_ENS)

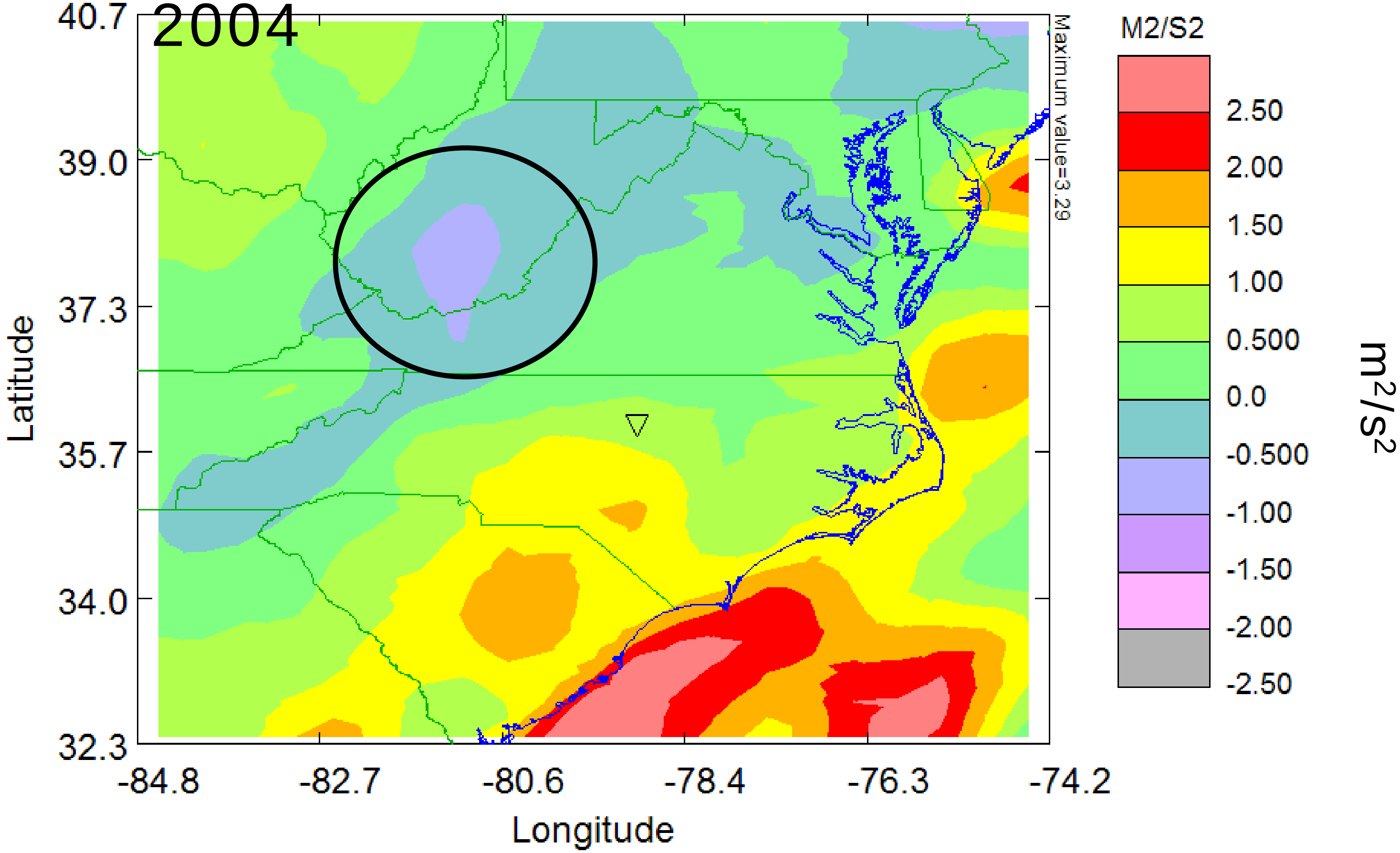
Proof-of-Concept: Case Study

Mean Surface Concentration 18 h – 03 UTC 25 Aug 2004



Proof-of-Concept: Case Study

UVE at 12 h 21 UTC 24 Aug 2004



Case Study Summary

- The inclusion of wind variance information from an NWP ensemble improves the resulting 24-h single-SCIPUFF forecast and yields results similar to that of an explicit ensemble of SCIPUFF predictions at reduced computational cost.
- Calibration of the variance information provides a further improvement in the resulting single-SCIPUFF prediction.

Daily MET-SCIPUFF Ensemble Testbed Overview

- Use 21 NCEP 32-km SREF members (ARW, NMM, ETA, RSM)
- Run 21 SCIPUFF dispersion calculations
  - Combine dosage statistics (explicit ensemble)
- Run SCIPUFF using 4-km MM5 FDDA to generate "ground truth" dispersion
- Process SREF outputs for mean ensemble MET and MET uncertainty (wind variances)
- Run single 24-h 32-km SCIPUFF with ensemble MET uncertainty wind variances (SREF hazard prediction)
- Compare single-SCIPUFF SREF hazard prediction with 32-km explicit SCIPUFF ensemble using probabilistic verification and "ground truth" dispersion calculations
- Continue testing of LVC, ensemble best member and single SCIPUFF vs. explicit SCIPUFF ensemble

Summary of Challenges for Ensemble Prediction and AT&D

- Optimal ensemble design to support AT&D modeling
  - Surface/PBL winds and stability
  - Land-surface and cloud properties
  - Sufficient ensemble spread for short-term vs. long-term forecasts
  - Sufficient model spatial/temporal resolutions (number of ensemble members vs. model resolution)
- Efficient and accurate way to quantify MET/AT&D uncertainty
  - Single AT&D model using MET ensemble information (uncalibrated or calibrated?) vs. explicit AT&D model ensemble
  - In-line vs. off-line AT&D modeling
- Verification of ensemble AT&D methods
  - Very few actual field trials
  - Daily testbeds with simulated “ground truth”

Acknowledgements

- Defense Threat Reduction Agency under the supervision of Dr. John Hannan and Lt. Col. Charles Harris
- AFTAC under the supervision of Dr. Anil Rao and Dr. Brian Strahl
- Contributions from the Penn State team, Sage Mgmt., NCEP, L-3