Assessing the Impact of Meteorological Model Uncertainty on SCIPUFF AT&D Predictions

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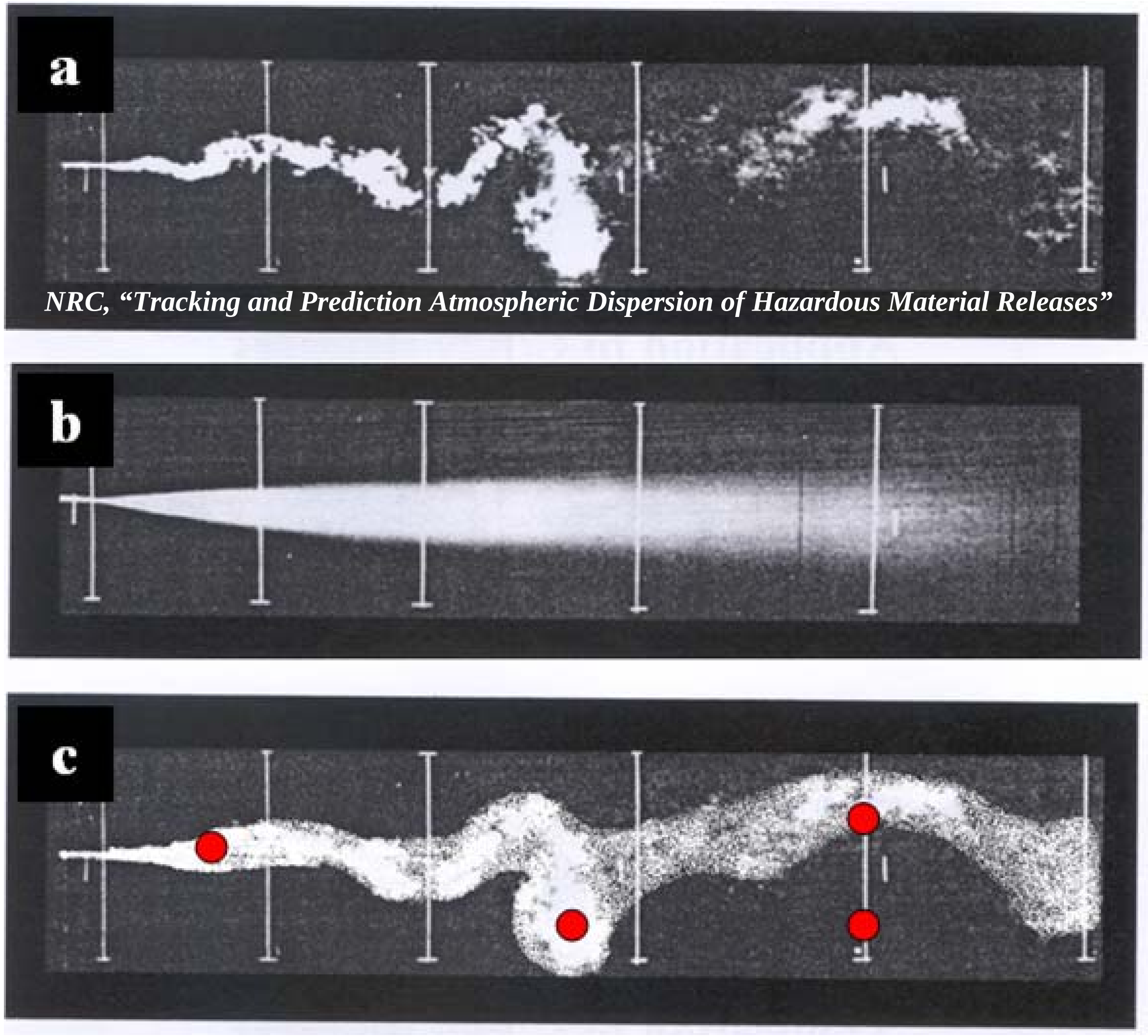
S. Hamilton (DTRA) and C. Kiley (Northrop Grumman)

Motivation

- Many physics-based atmospheric transport and dispersion (AT&D) models, e.g. SCIPUFF, derive their transporting wind field from meteorological (met) models – *met model winds*
- These AT&D and met models are sophisticated interplays of physics and parameterizations that have evolved over many years – *good T&D models*
- Given adequate initial and boundary conditions, these models can successfully reproduce dispersion episodes – *sensitive to ics & bcs*
- In a limited domain model, an ensemble of simulations can be used to include the statistical effects of large-scale (*outer*) variability – *dispersion uncertainty arises from met ensemble uncertainty*

Background

- *Realization*
  The actual wind field for a dispersion event
- *Statistic*
  Ensemble Mean Plume
- *Conditional Statistic*
  Reduced uncertainty through NWP skill



NRC, "Tracking and Prediction Atmospheric Dispersion of Hazardous Material Releases"

Background

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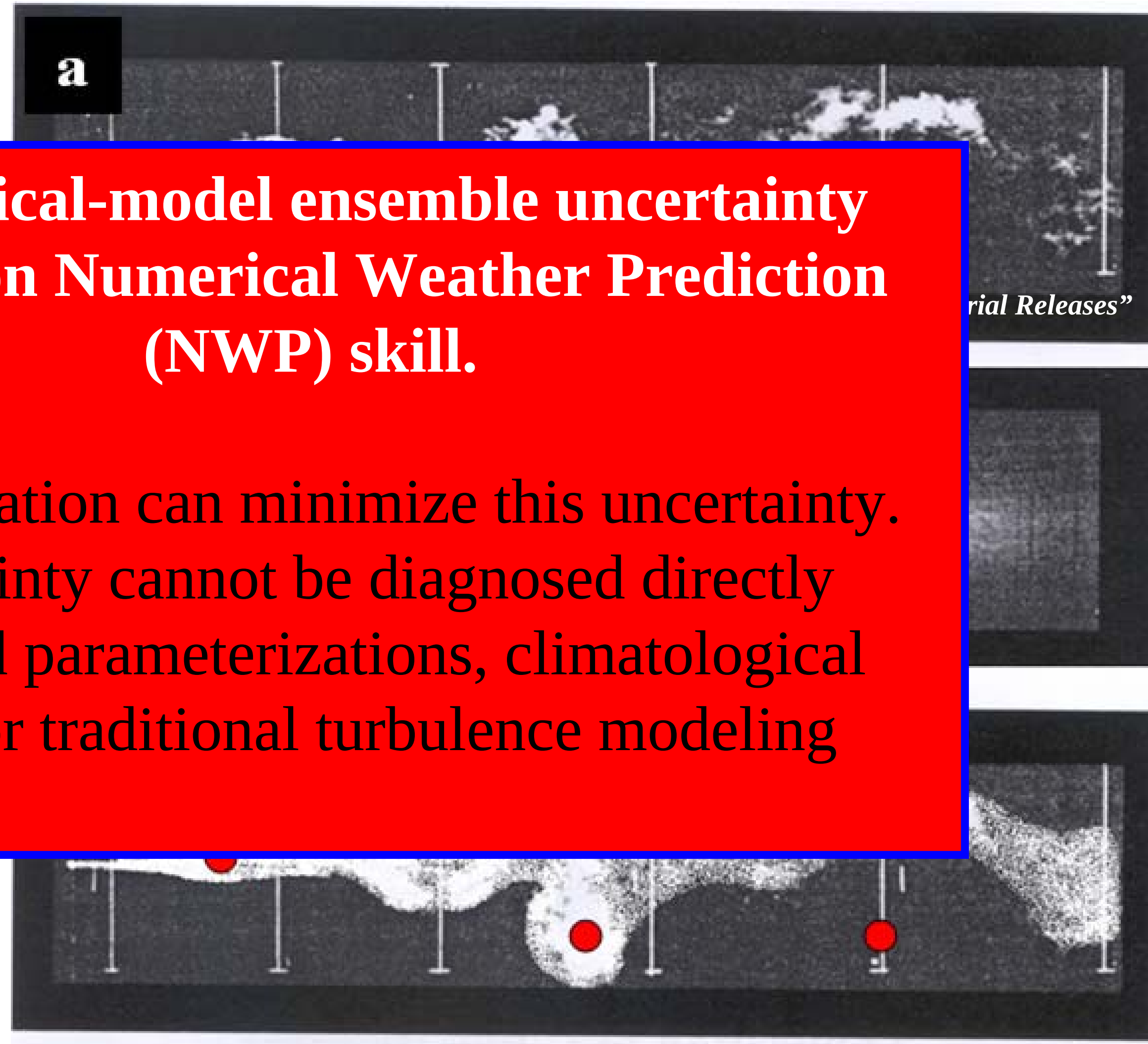


Meteorological-model ensemble uncertainty depends on Numerical Weather Prediction (NWP) skill.

- Data assimilation can minimize this uncertainty.
- This uncertainty cannot be diagnosed directly from subgrid parameterizations, climatological variability, or traditional turbulence modeling approaches.

Goal and Approach/Outline

To parameterize meteorological model uncertainty for dispersion

- Representation
  - Evaluate meteorological model uncertainty from meteorological model ensemble variability
- Theory
  - Use Taylor dispersion arguments applied to ensemble dispersion to define the uncertainty modeling parameters
- Evaluation
  - Diagnose the uncertainty parameters from ensemble data (this study & related work by Walter Kolczynski, PhD, PSU)
- Modeling
  - Develop operational models for the uncertainty parameters

The Meteorological Ensemble

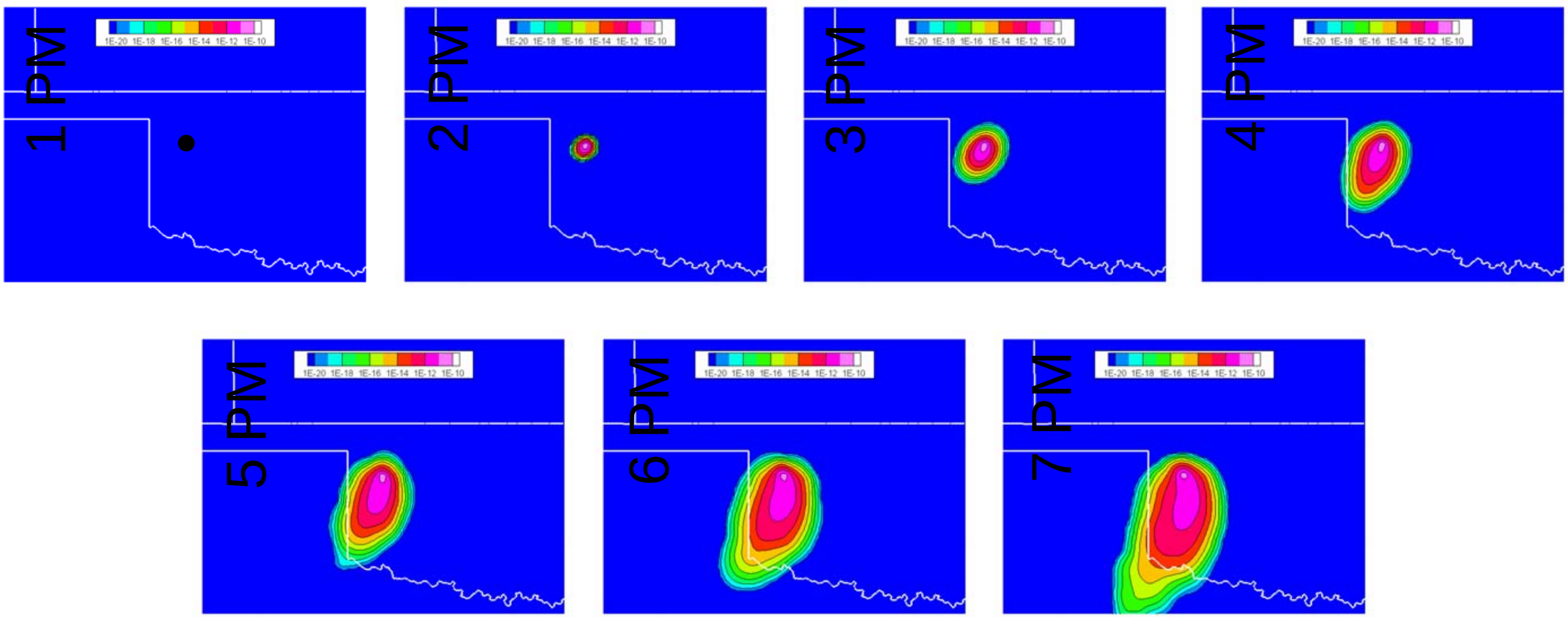
A fair weather day in Oklahoma

- Ensemble 1: *used to evaluate uncertainty modeling parameters*
  - A 29 member MM5 physics ensemble (PhD work of B. Reen, Penn State Meteorology) modeling the IHOP (International H2O Project) field experiment (light winds & precip.)
- Ensemble 2: *used to motivate ensemble uncertainty*
  - Research ensemble (11 members) intentionally constructed to emphasize wind-direction variability
- Other Ensembles: *"real-world" examples*
  - NCEP's SREF operational data
  - MM5 ensemble modeling the CAPTEX (Cross Appalachian Tracer Experiment) field study

Baseline Member of Ensemble 2

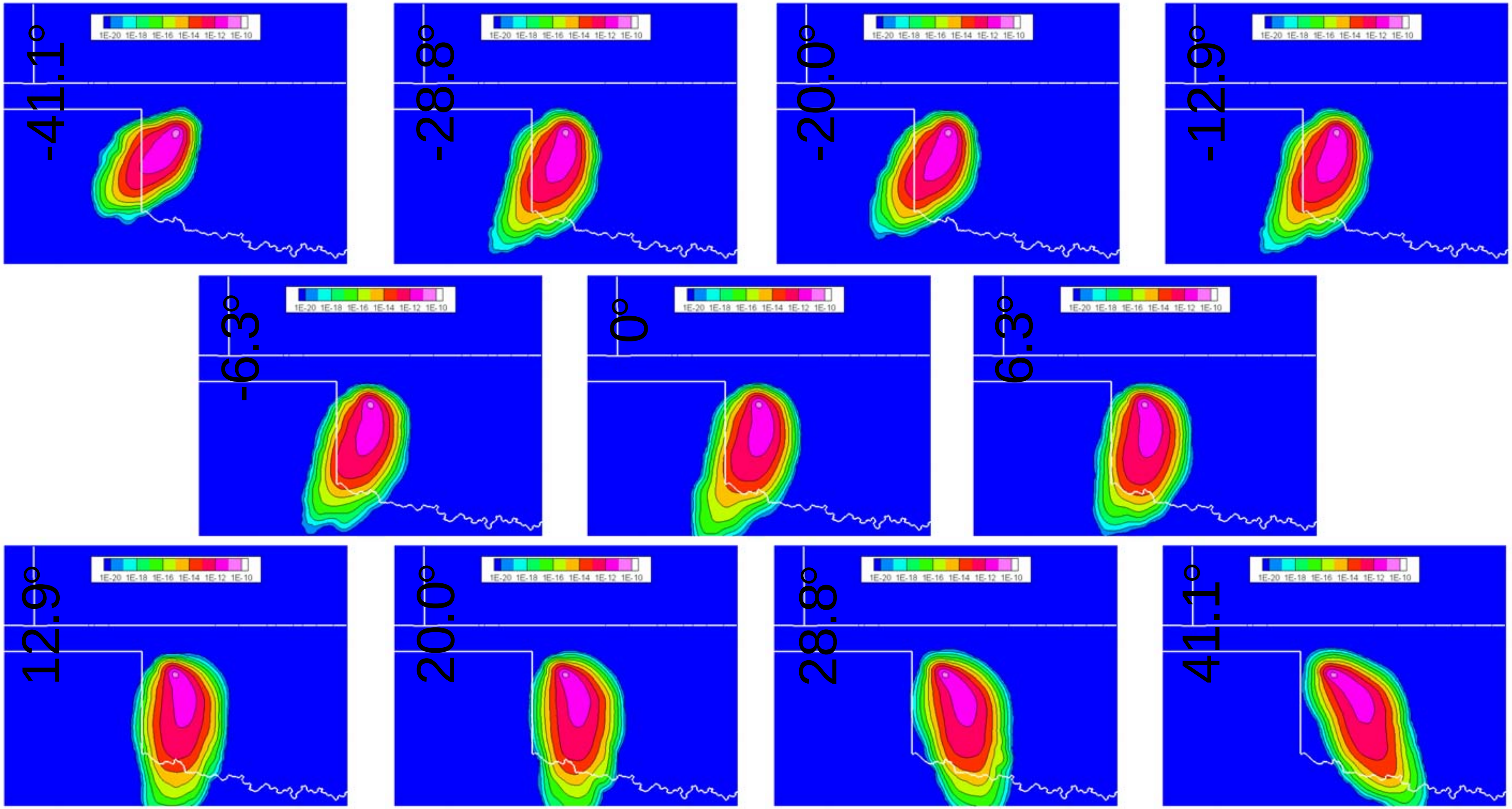
6 Hr Release of C7F14; 1 PM to 7 PM Local Time; 5/29/2002

MM5 wind field; SCIPUFF dispersion model



11 Member of Ensemble 2

6 Hr Release of C7F14; 7 PM Local Time; 5/29/2002



Members constructed to emphasize wind-angle uncertainty

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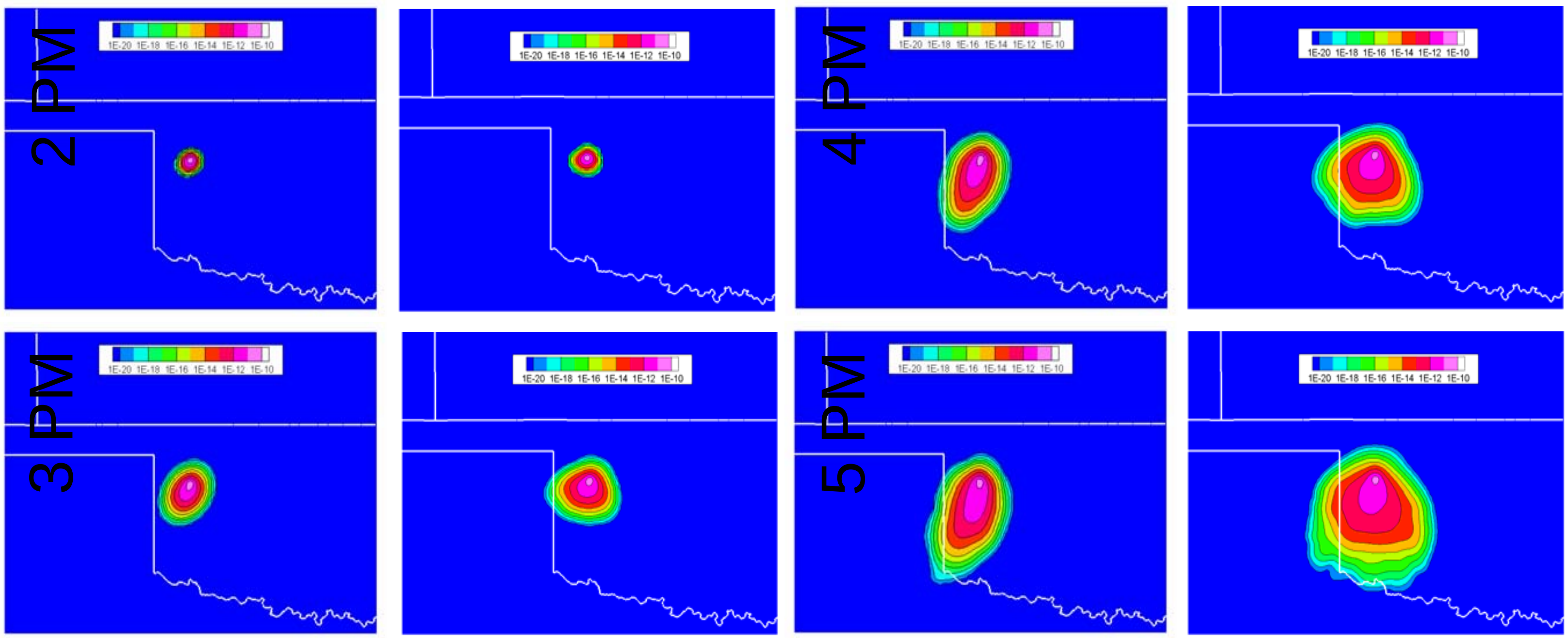
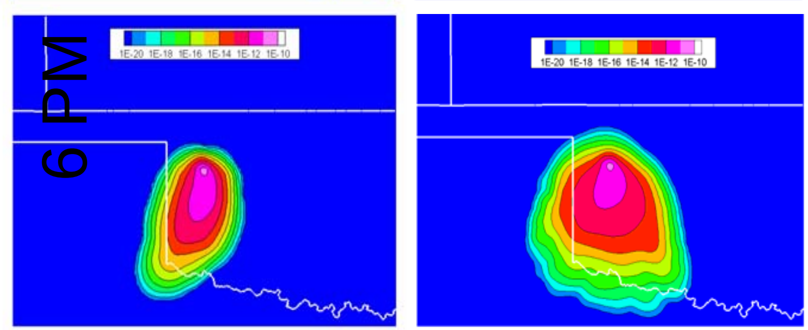
Baseline/Ensemble-Mean Plumes

6 Hr C7F14 Release; 2 PM to 6 PM Local Time; 5/29/2002

Baseline *Ensemble-Mean* *Baseline* *Ensemble-Mean*



- Member- and mean-plume footprint differences depict effects of ensemble uncertainty.



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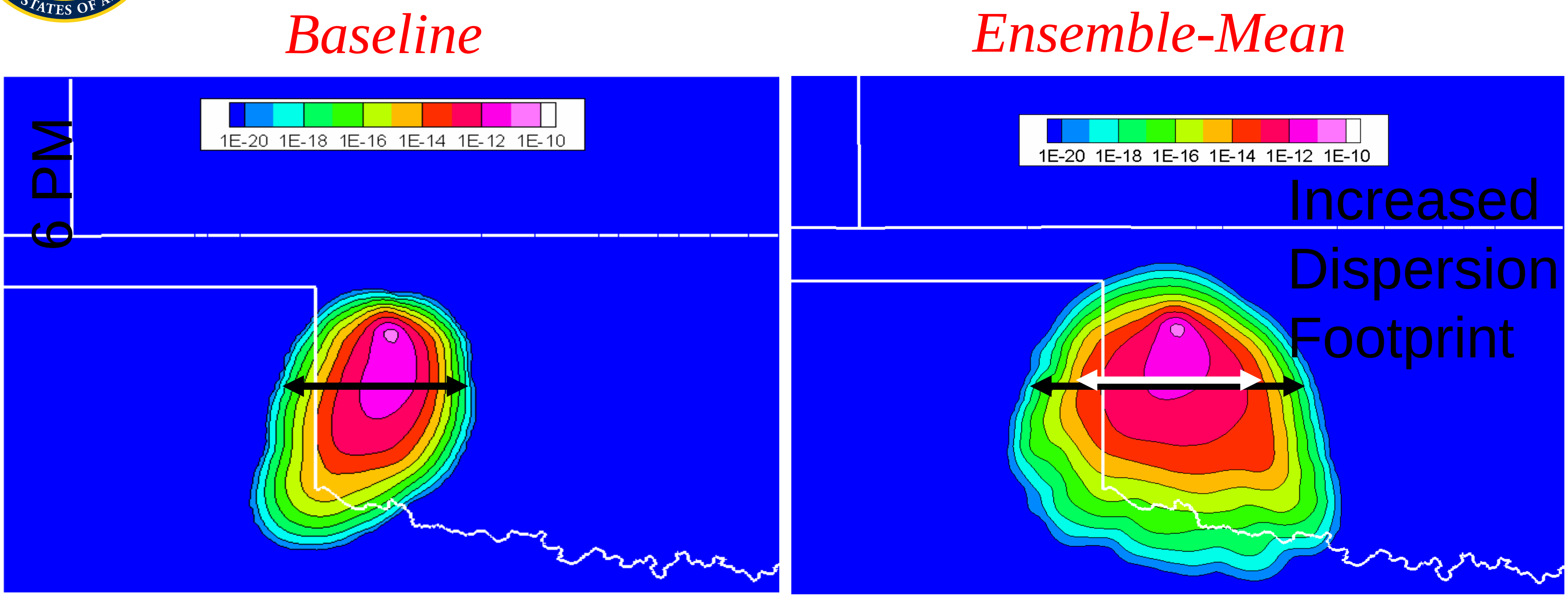
Effects of Wind Direction Variability

6 Hr Release of C7F14; 6 PM Local Time; 5/29/2002



- The mean-plume footprint is larger than the member plume footprint due to meteorological variability.
- The characteristic dispersion length, therefore, is larger.
- Planform differences between these plumes demonstrate the effects of meteorological uncertainty on dispersion.

Relation to Dispersion Uncertainty

Taylor-dispersion arguments can be used to relate dispersion uncertainty to meteorological model ensemble variability

- The theory describes dispersion in homogeneous environments.
- It isolates Lagrangian velocity and integral-time statistics as the relevant modeling parameters.
- They yield the ensemble-uncertainty model parameters.

Taylor Dispersion

This is a variant of the "Taylor dispersion" problem (Taylor, 1921). Its key parameter is the Lagrangian integral time scale τ_L,

$$\tau_L = \frac{1}{\overline{v^2}} \int_0^\infty \overline{v(t)v(t+\tau)} d\tau.$$

The overbar represents the average over a large ensemble of dispersion realizations and v is the lateral velocity of a diffusing particle in coordinates aligned with the ensemble-mean flow.

Taylor Dispersion

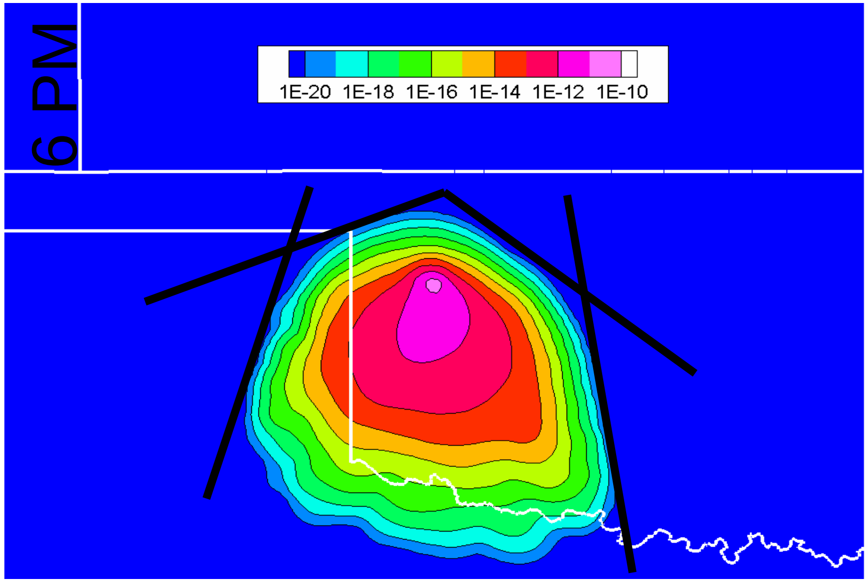
6 Hr C7F14 Release; 2 PM to 6 PM Local Time; 5/29/2002

- The plume width parameter σ has linear and parabolic growth asymptotes

$$\sigma(t) = (\overline{v^2})^{1/2}\, t, \quad t \ll \tau_L$$

$$\sigma(t) = (\overline{v^2}\tau_L)^{1/2}\, t^{1/2}, \quad t \gg \tau_L$$

Ensemble-Mean



- A characteristic width parameter is

$$\Lambda \simeq \underline{\tau_L} \times \underline{(\overline{v^2})}^{1/2}$$

Uncertainy modeling parameters

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Uncertainty Parameters

- SCIPUFF parameters UUE, VVE, and UVE can be diagnosed from ensemble deviation-velocity fields
- The Lagrangian integral time can be diagnosed from Lagrangian particle trajectories through the meteorological model data
- SCIPUFF parameter SLE can be diagnosed from the ensemble deviation velocities and the Lagrangian integral time
  - $SLE \sim \tau_L (UUE+VVE)^{1/2}$
- Direct evaluation of these parameters from meteorological data provides the "truth" for modeling efforts.

Deviation-Velocity Statistics

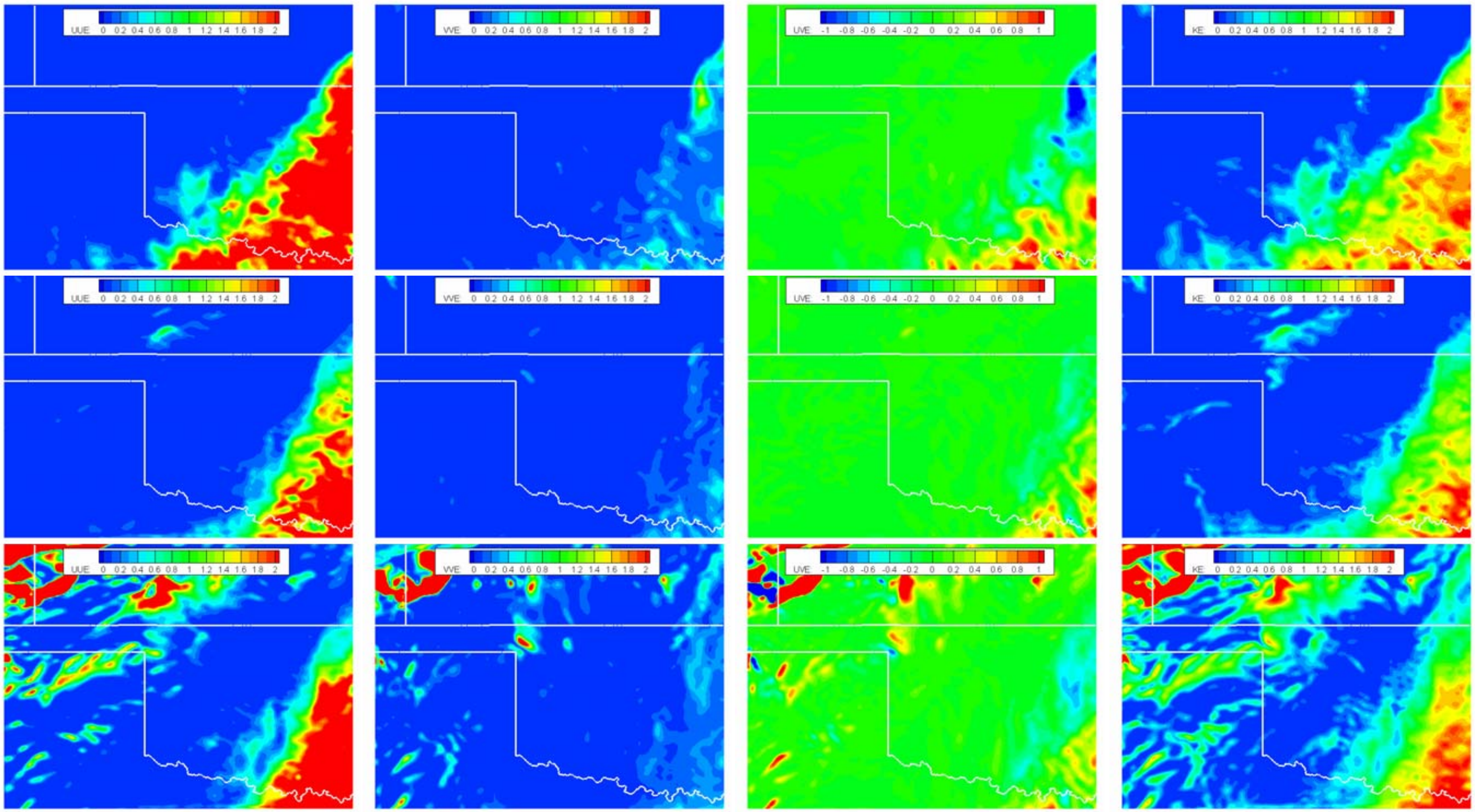
Deviation-Velocity Statistics

UUE | VVE | UVE | KE

1 PM

4 PM

7 PM



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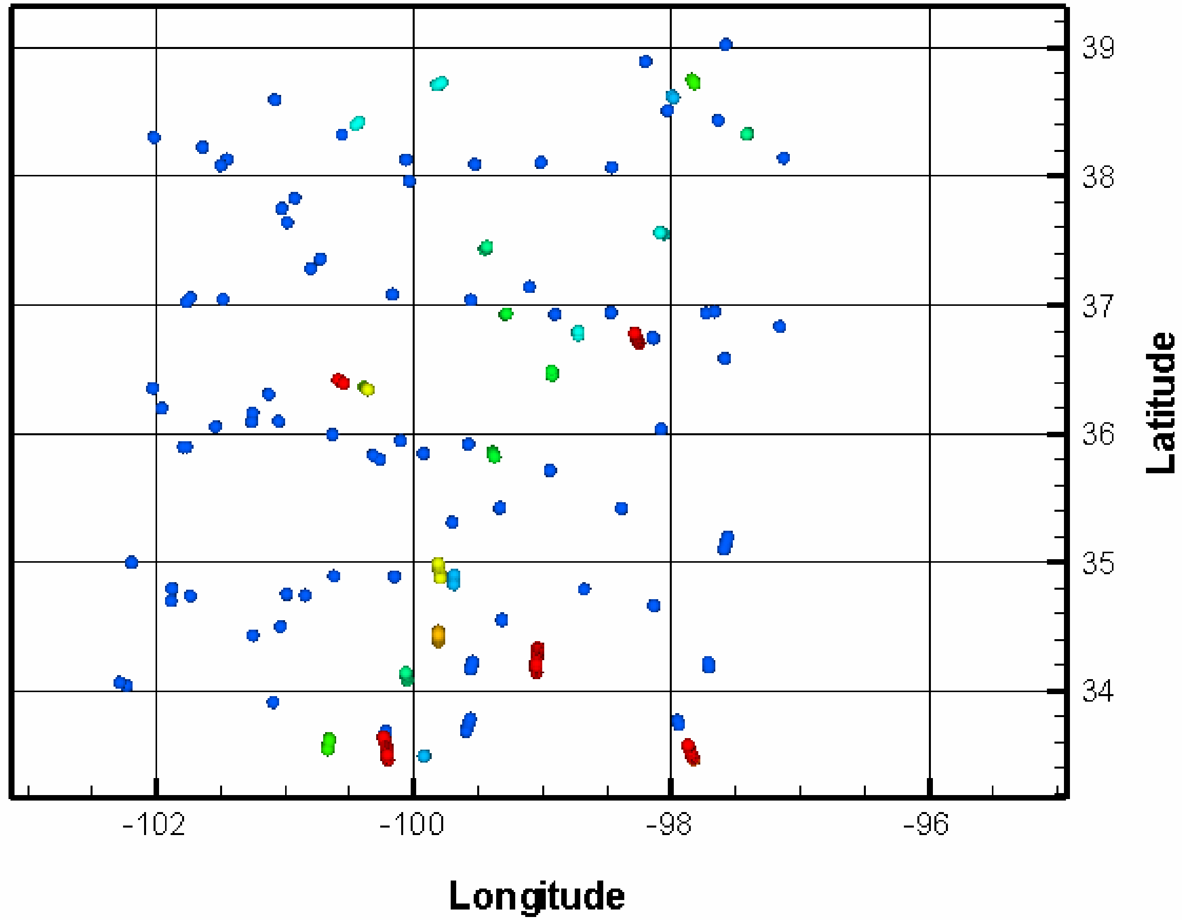
Lagrangian Particle Trajectories

Particle Position at 1 PM

Colored by Height



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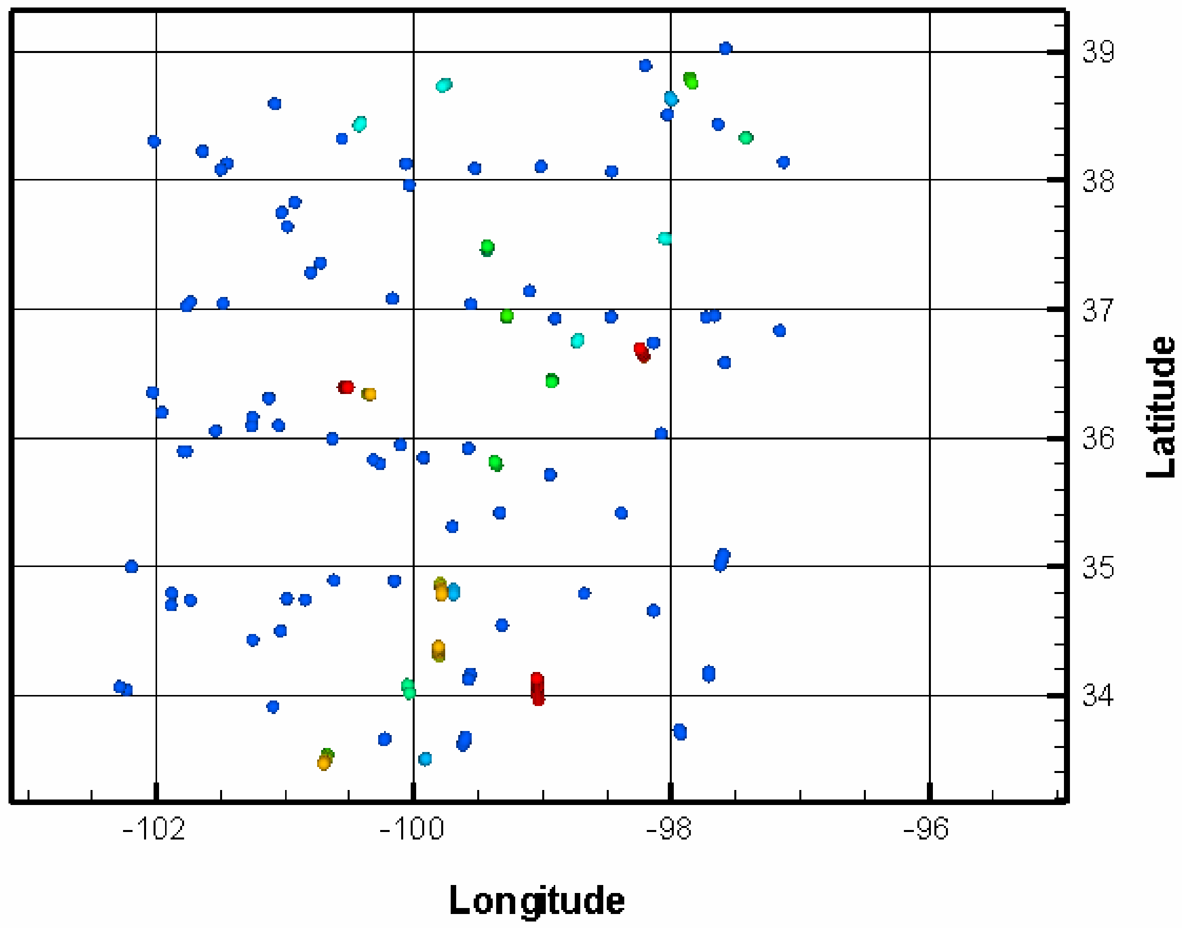
Lagrangian Particle Trajectories

Particle Position at 2 PM

Colored by Height



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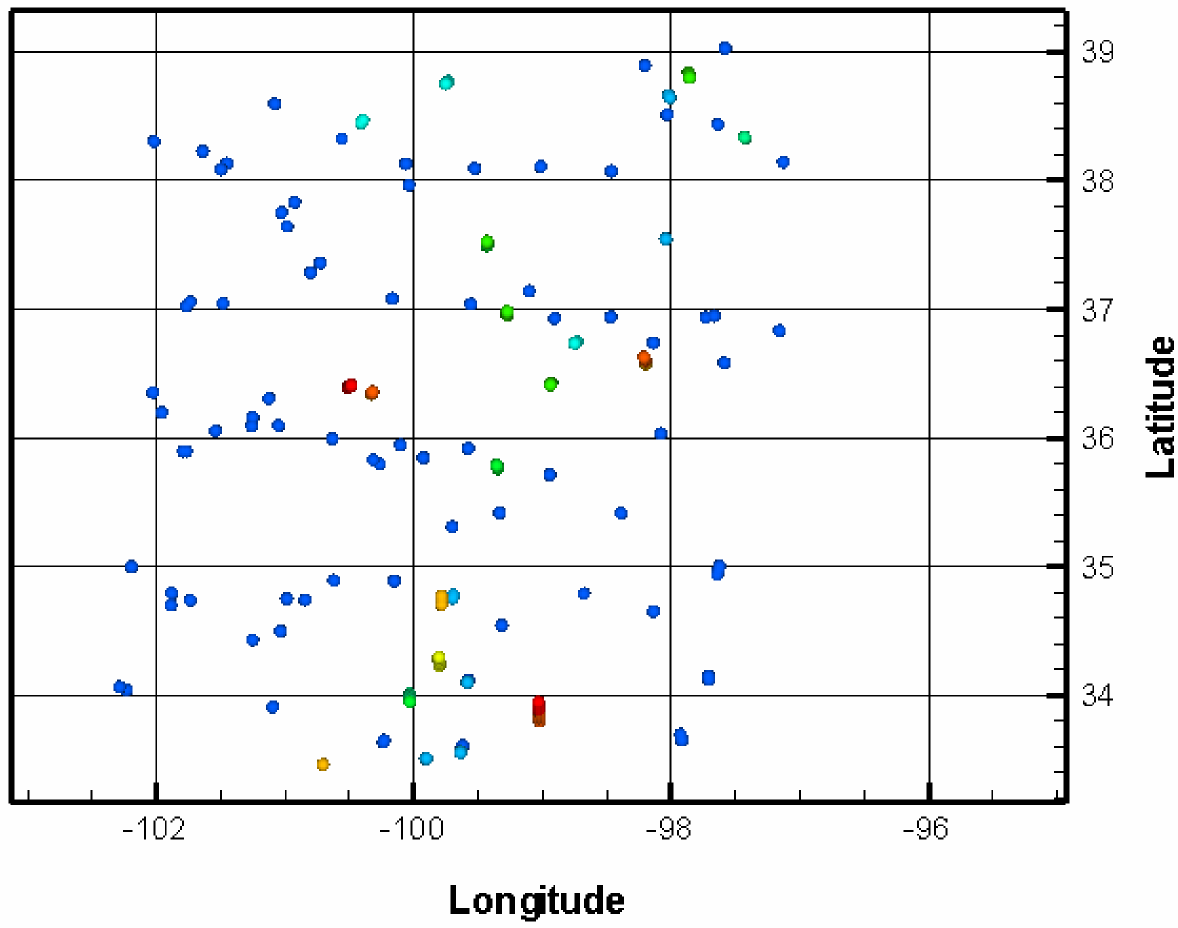
Lagrangian Particle Trajectories

Particle Position at 3 PM

Colored by Height



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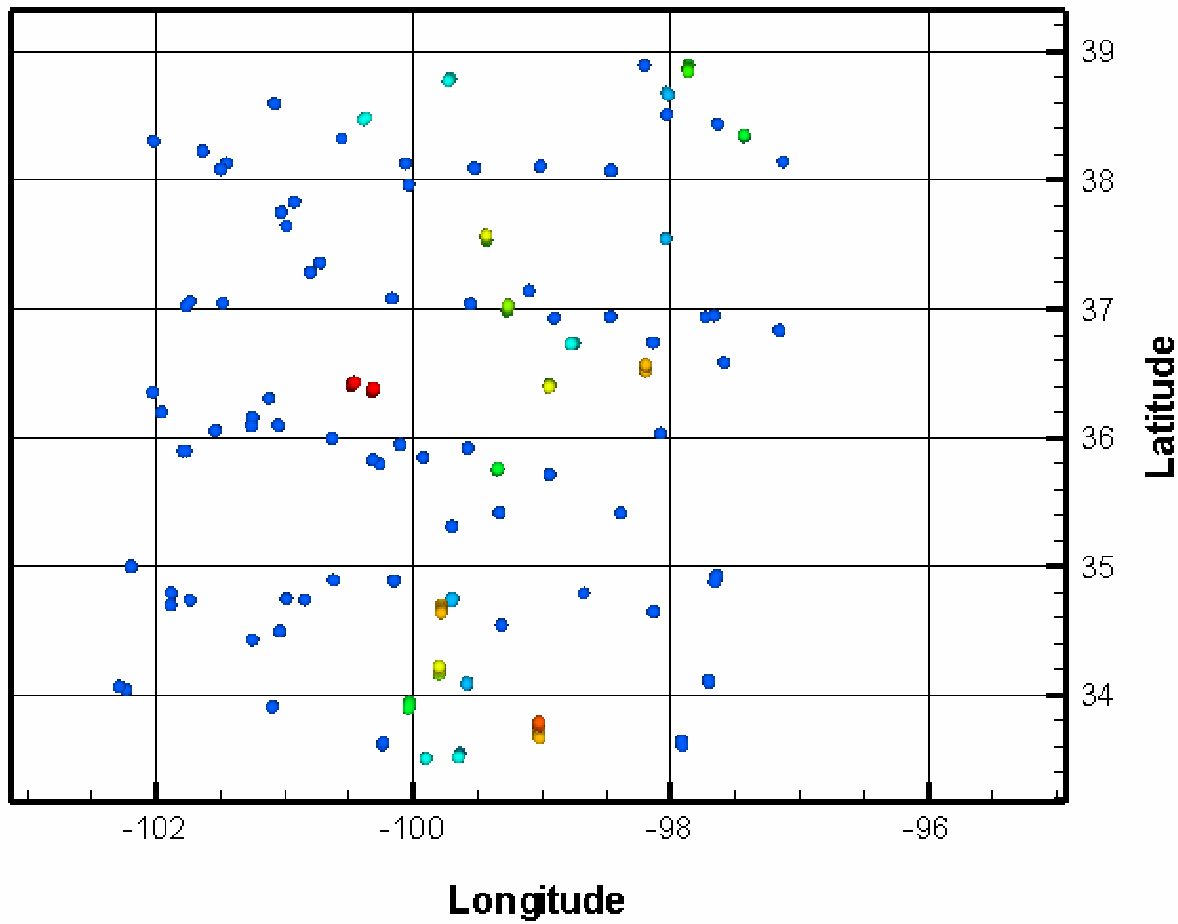
Lagrangian Particle Trajectories

Particle Position at 4 PM

Colored by Height



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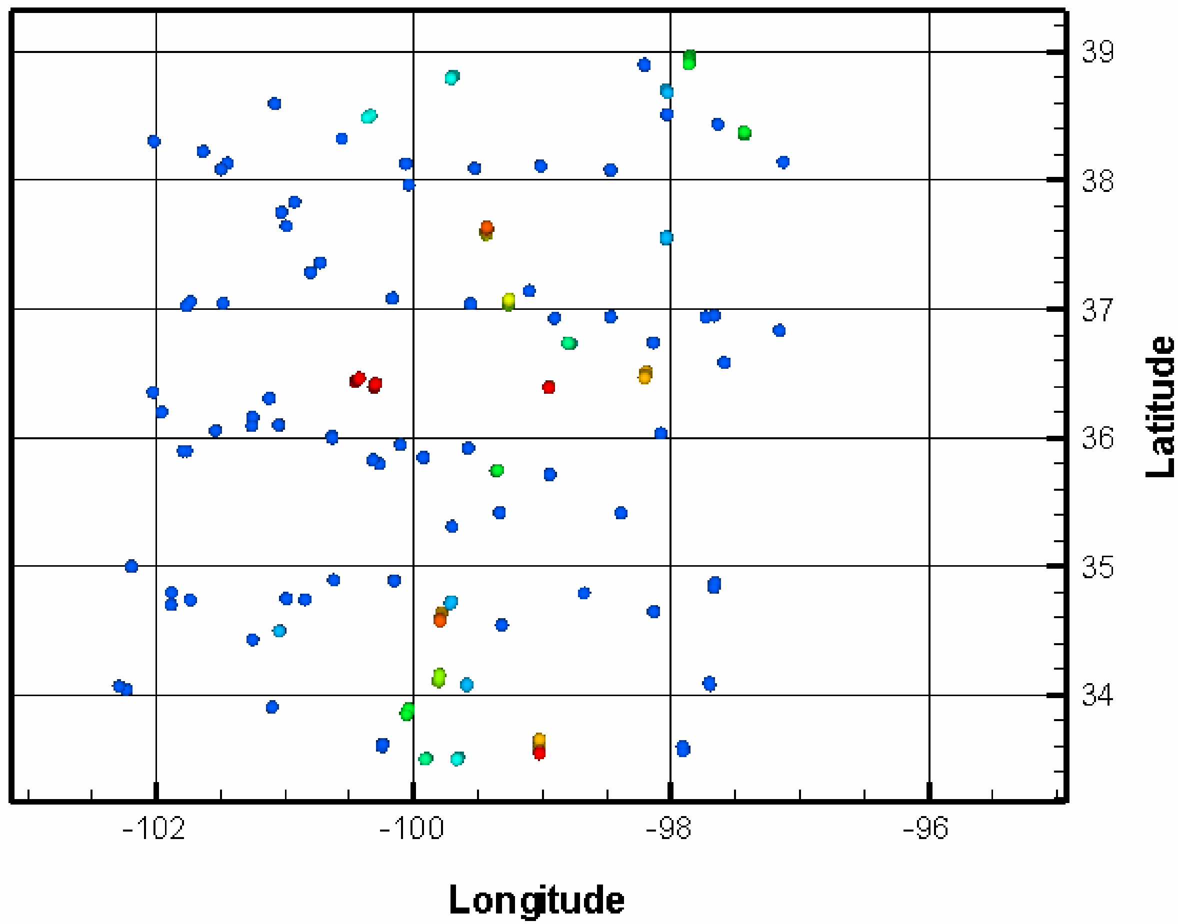
Lagrangian Particle Trajectories

Particle Position at 5 PM

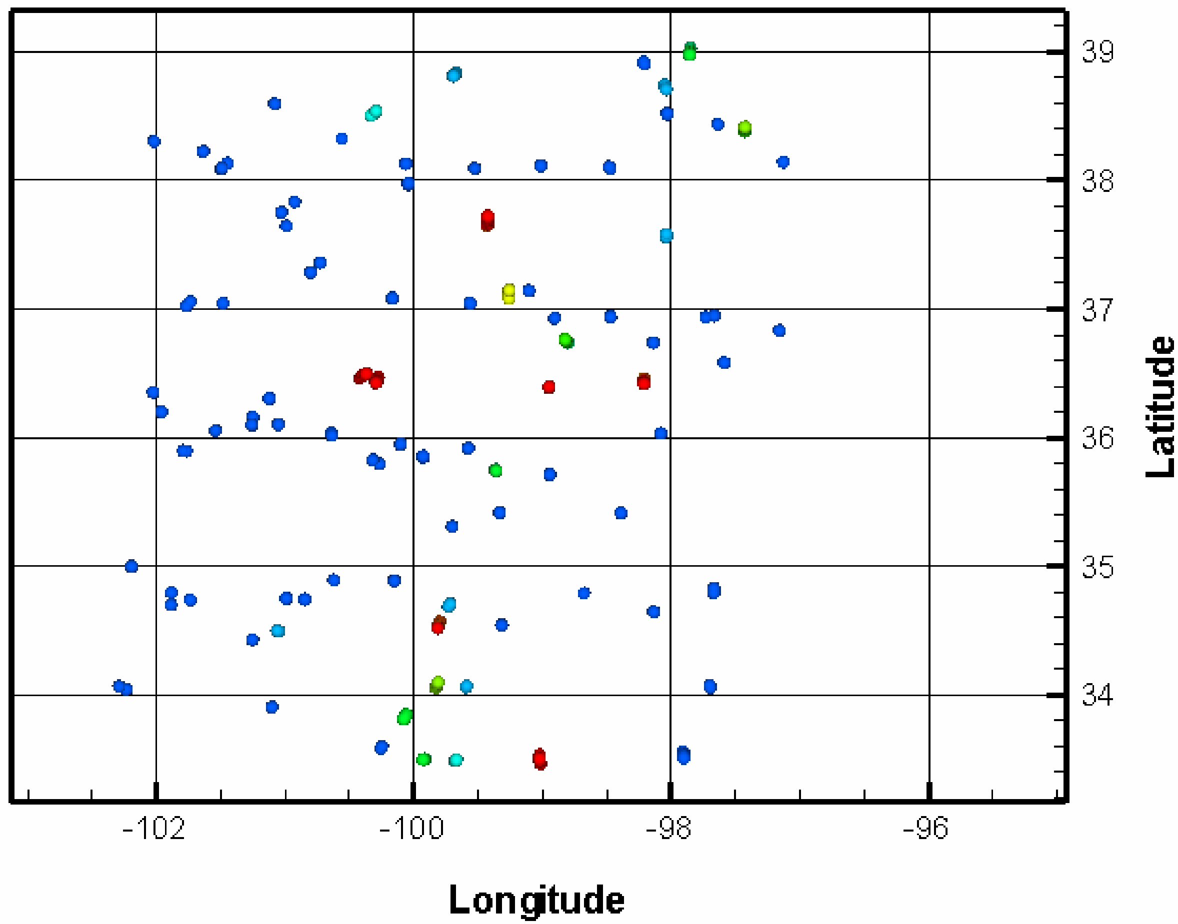
Colored by Height



Lagrangian Particle Trajectories

Particle Position at 6 PM

Colored by Height



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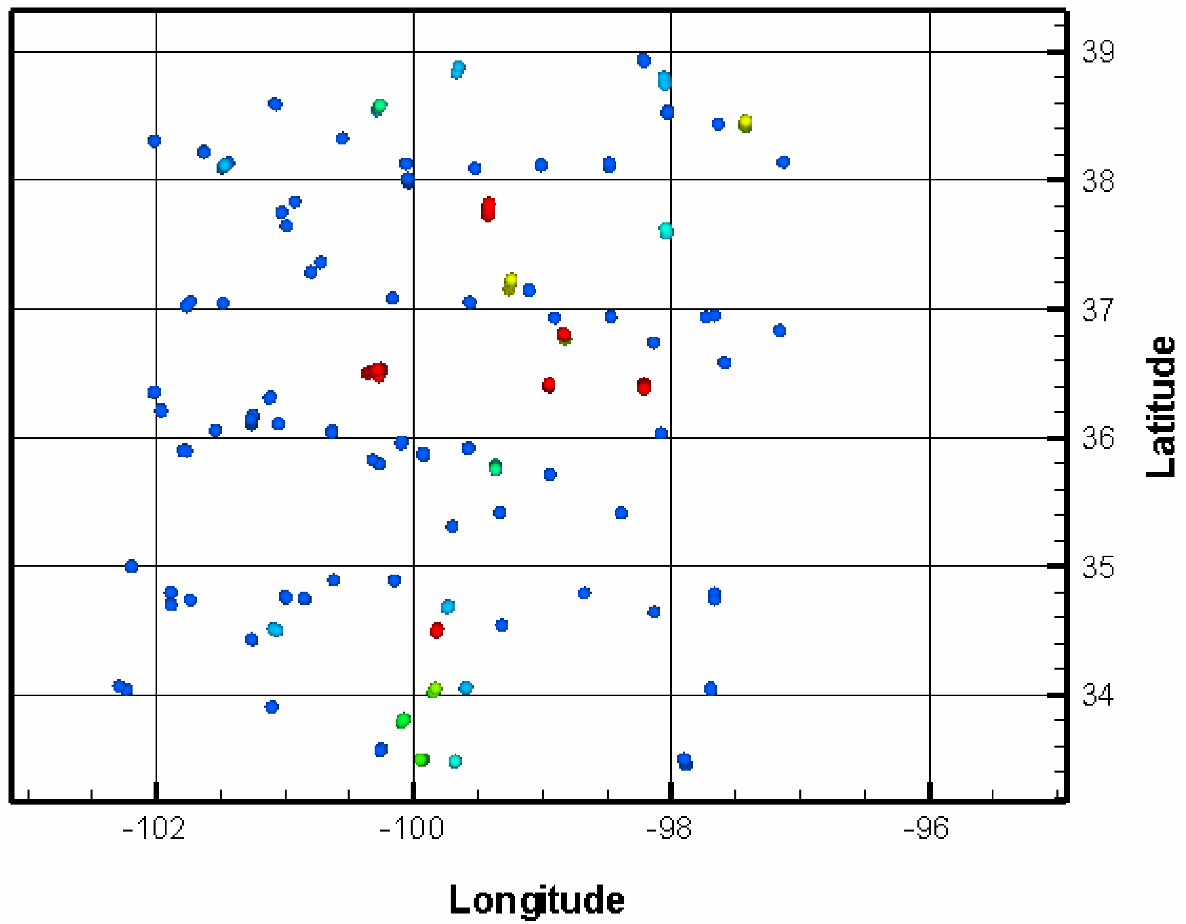
1 8 5 5

Lagrangian Particle Trajectories

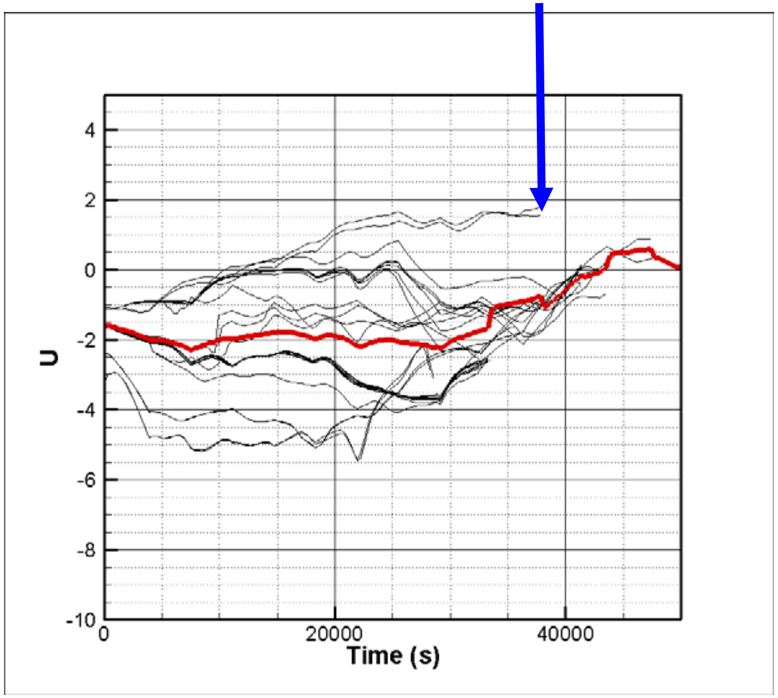
Particle Position at 7 PM

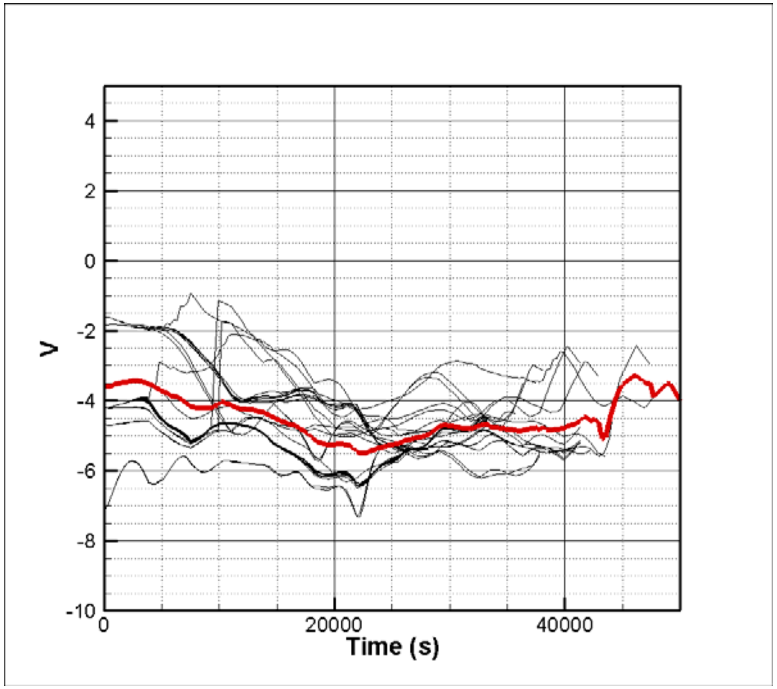
Colored by Height



Lagrangian Particle Histories

Fewer members with increasing time





- Lagrangian Particle Data (Ensemble Members – black, Ensemble Mean – Red)

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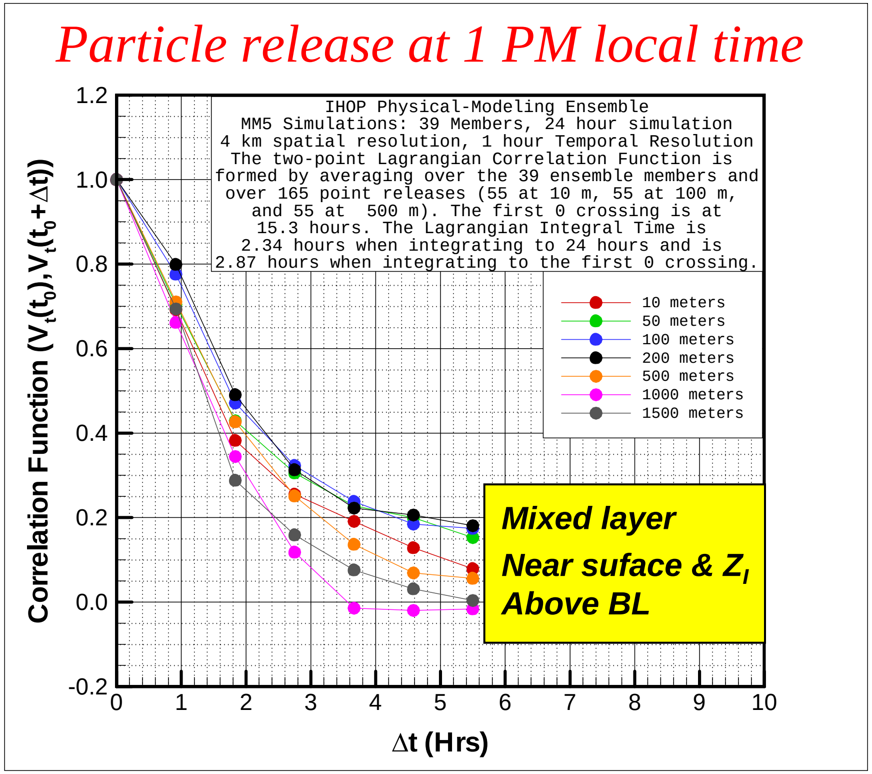
Lagrangian Particle Correlations

- The Lagrangian correlation functions were computed
  - Ensemble averaging for each release location and
  - Spatial averaging over release locations at the same height (to increase the sample contributing to the statistic)

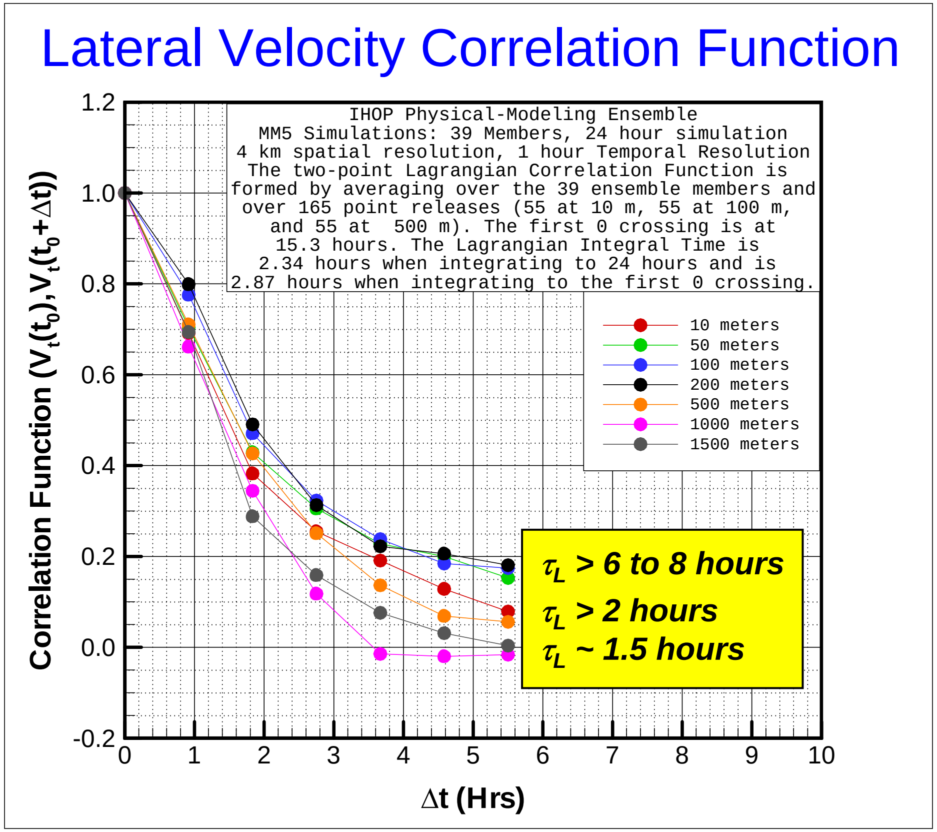
Lateral Velocity Correlation Function



Lagrangian Integral Times

- By extrapolating the correlation curve to 0 followed by integration, estimates for the Lagrangian Integral Time, τ_L, as a function of height can be computed:

These data indicate that τ_L is larger than 6-8 hours



IHOP Great Plains Model

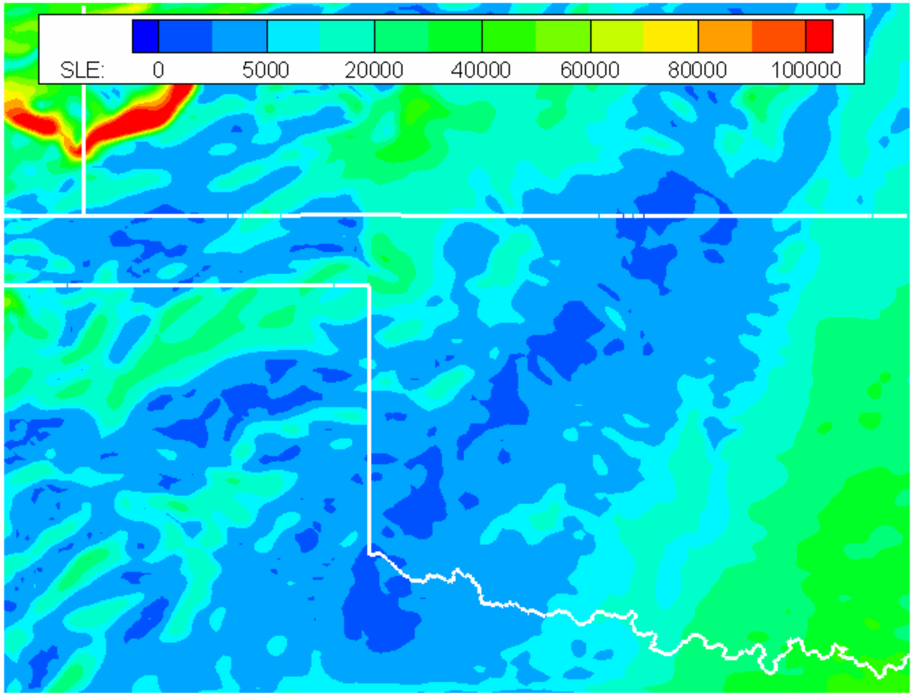
6 Hr C7F14 Release; 7 PM Local Time; 5/29/2002

SLE

- Using τ_L ~ *6-8 hours*, a field of SLE can be computed.
- The definition for SLE is a function of time and space.
- For this case,

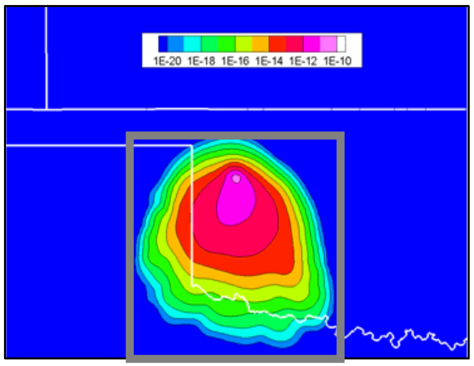
  0.0 km < SLE < 200 km

  large/small values depend on the local deviation velocities (on the uncertainty)

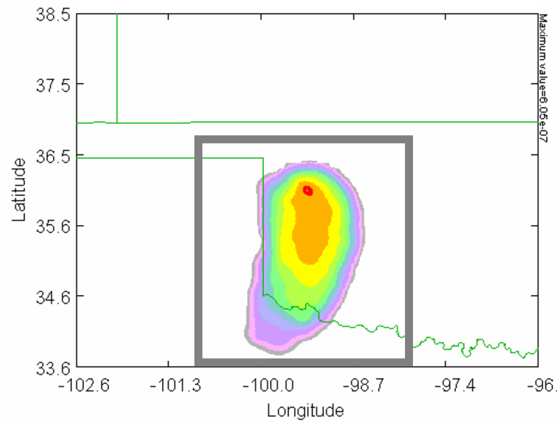


SCIPUFF (Hazard Mode)

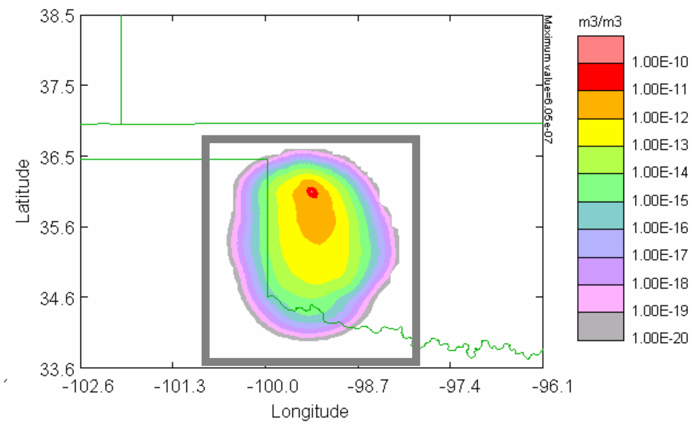
Ensemble Mean



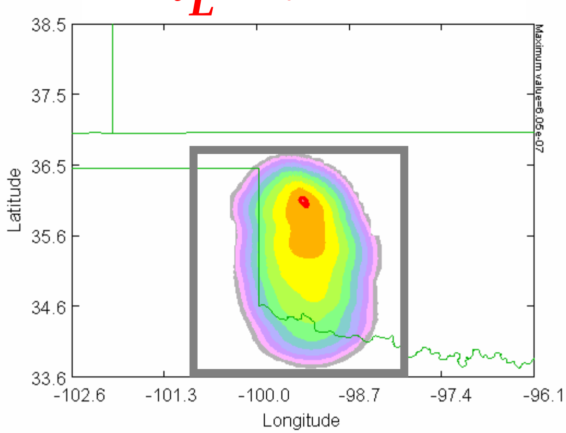
Baseline



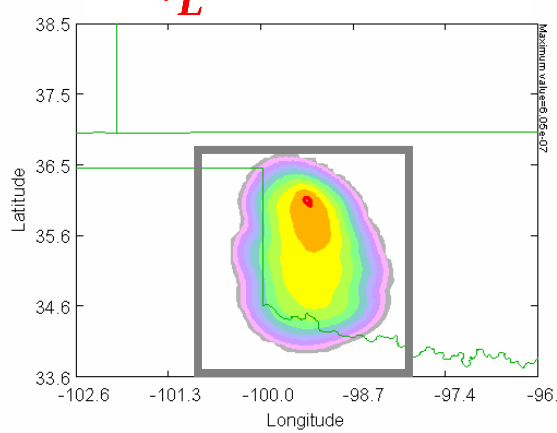
SLE=200 Km



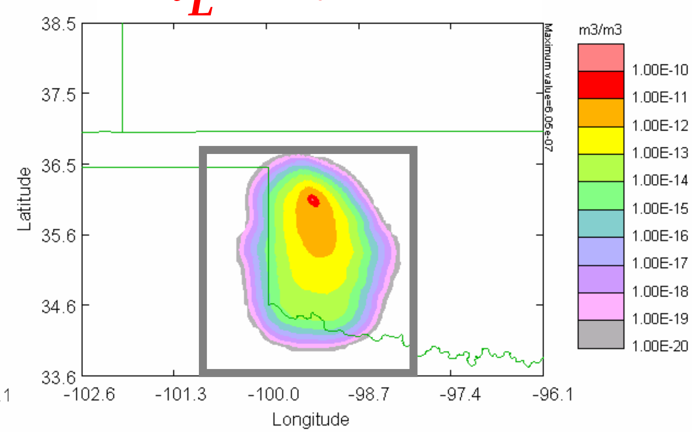
τ_L=7.0 Hrs



τ_L=14.0 Hrs



τ_L=24.0 Hrs



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Summary

- Taylor-dispersion arguments relate meteorological model variability to dispersion uncertainty
  - Modeling parameters depend on Eulerian ensemble deviation-velocity statistics and on the Lagrangian Integral Time
- Evaluation of the modeling parameters using a meteorological physics ensemble suggests
  - A Lagrangian Integral Time > 6 to 8 hours yielding SLE ranging from < 1 km to ~200 km under low wind & light rain
- Evaluation using SCIPUFF is ongoing.

Continued Work

- Further evaluation of the ensemble variability modeling parameters for geometrically and meteorologically complicated cases
  - CAPTEX (Cross Appalachian Tracer Experiment) field experiment
  - NCEP's SREF ensemble with weather and topography
- Model the uncertainty parameters using these meteorological-ensemble-computed fields as "truth"
  - This project
  - 2-point spatial correlations (W. Kolczynski/D. Stauffer, PSU)