Assimilation of Observations with Gridded Meteorology for an Atmospheric Transport and Diffusion Model.

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MOTIVATION

- Operational Scenario / Emergency Response
  - Numerical Weather Prediction forecasts available
    - But analysis field is old and/or coarse resolution
  - Local wind observation(s) also available
- Current HPAC cannot utilize observations in conjunction with gridded meteorology
- Extend meteorological processing to assimilate observations with NWP forecasts

Data Assimilation

- "Iteration to optimal solution"
  - Daley, R. (1991), "*Atmospheric Data Analysis*"
  - Kovalets, et al. (2004), *Atmos. Env.* (RODOS emergency response system)
- Straightforward extension to the existing observation interpolation scheme
- Observed quantities assimilated
  - u, v, [pot. temp., pressure, humidity]
  - All treated as scalars

Limitations

- No true dynamics
  - No consideration of divergence or vorticity
  - [Adjustment to insure zero divergence applied after assimilation]
- Assumes homogeneous, isotropic correlation functions
- Does not utilize sophisticated statistical schemes such as multivariate “optimal interpolation”

Method

- Given observed and background (NWP) estimates, $\mathbf{f}_o$ and $\mathbf{f}_b$, of the "true" vector $\mathbf{f}$
- Optimal estimate ("analysis field")

$$\mathbf{f}_a = \mathbf{f}_b + \mathbf{B}\left[\mathbf{B}+\mathbf{O}\right]^{-1}\left[\mathbf{f}_o - \mathbf{f}_b\right]$$

- $\mathbf{B}$ and $\mathbf{O}$ background and observed error covariance matrices
- $\mathbf{f}$ is a column vector of velocity components at all locations on the assimilation grid
- May be augmented with temperature, pressure and humidity

Implementation

- Simplifying assumptions
  - $\mathbf{O} = E_o^2\ \mathbf{I}$ and $\mathbf{B} = E_b^2\ \mathbf{w}$
  - E_o^2 and E_b^2 are constant mean square errors
  - $\mathbf{w}$ matrix of interpolation weights
  - Constant ratio $E_b^2 \,/\, E_o^2$ is key parameter
- Use existing observation interpolation scheme

Iterative Solution

- Daley (1991) shows the following converges

$$f_a^{n+1}(\mathbf{x}_i) = f_a^n(\mathbf{x}_i) + (1+q_i)^{-1} \sum_{k=1}^{K} E_b^2 \, w_{ik} \, E_o^{-2} \left[f_o(\tilde{\mathbf{x}}_k) - f_a^n(\tilde{\mathbf{x}}_k) \right] +$$

$$(1+q_i)^{-1} \left[f_b(\mathbf{x}_i) - f_a^n(\mathbf{x}_i) \right]$$

$$q_i = \sum_{k=1}^{K} E_b^2 \, w_{ik} \, E_o^{-2}$$

- $\mathbf{x}_i$ assimilation grid point
- K number of observations, located at $\tilde{\mathbf{x}}_k$
- w_{ik} interpolation weights from $\tilde{\mathbf{x}}_k$ to $\mathbf{x}_i$

Simple Example

- Single observation located at grid point
  - Interpolation weight = 1
- Converged iteration

$$f_a = \frac{E_b^2 / E_o^2 \; f_o + f_b}{1 + E_b^2 / E_o^2}$$

- Weighted sum of background and observations

$$E_b^2 / E_o^2 \approx 9 \quad \Rightarrow \quad f_a = 0.9\, f_o + 0.1\, f_b$$

Procedure

- Assimilation grid defined by NWP or nested terrain
- Interpolate updated analysis field to observation locations using tri-linear interpolation
  - Vertical interpolation modified for surface layer
- Interpolate $\left[f_o(\tilde{\mathbf{x}}_k) - f_a^n(\tilde{\mathbf{x}}_k) \right]$ (observation *differences)* using current scheme
  - Account for surface layer by estimating u_* and L at observation locations

Procedure (cont'd)

- Iterate until convergence
  - Maximum wind speed change is less then 10%

$$MAX\left\{\frac{\left[U_a^{n+1}\left(\mathbf{x}_i\right)-U_a^n\left(\mathbf{x}_i\right)\right]^2}{\left[U_a^n\left(\mathbf{x}_i\right)\right]^2}\right\}<0.1$$

  - Limit to 8 iterations
- Increased CPU in meteorology processing
  - Current tests show 25% increase compared with NWP only
  - 100% increase over observation only

Observation Interpolation

- Product of horizontal and vertical weights

$$w_{ik} = w_h(r_{ik})\, w_v(\Delta z_{ik})$$

  - r_{ik} is distance from obs k to grid point i
  - Δz is the vertical distance from the obs to the vertical grid level

- Inverse square distance weighting

$$w_h = \left(1 + r^2 / a_h^2\right)^{-1}$$

$$w_v = \left(1 + \Delta z^2 / a_v^2\right)^{-1}$$

  - a_h and a_v are horizontal and vertical "influence" radii

Radius of Influence

- If using observations *only*, a_h set to insure smoothly varying flow while maintaining local observation influence
  - Function of area and number of observations
- With assimilation into NWP field, local influence of observation is primary concern
  - Function of NWP grid size (?) and local conditions
  - Currently set by user
    - 2 test cases: 4km, Δ_{NWP} = 5km; 1km, Δ_{NWP} = 1.333km

Mass-Consistent Adjustment

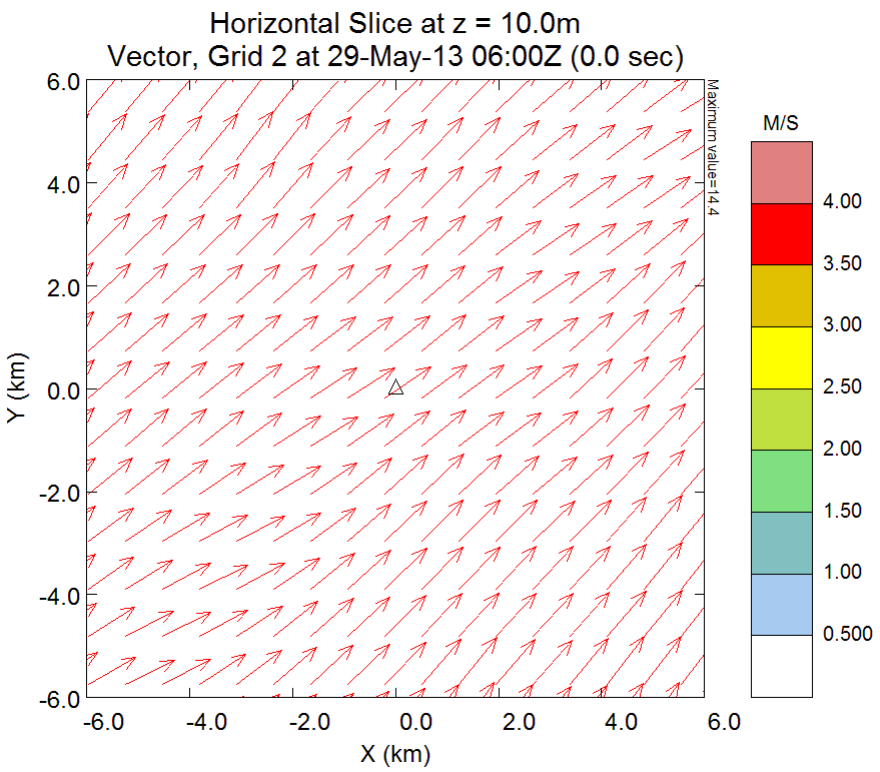
- Adjust assimilated velocity field to insure zero divergence
- Point relaxation iteration
- Weighted to reduce adjustment near observation locations
- Multi-grid scheme

Operational Scenario

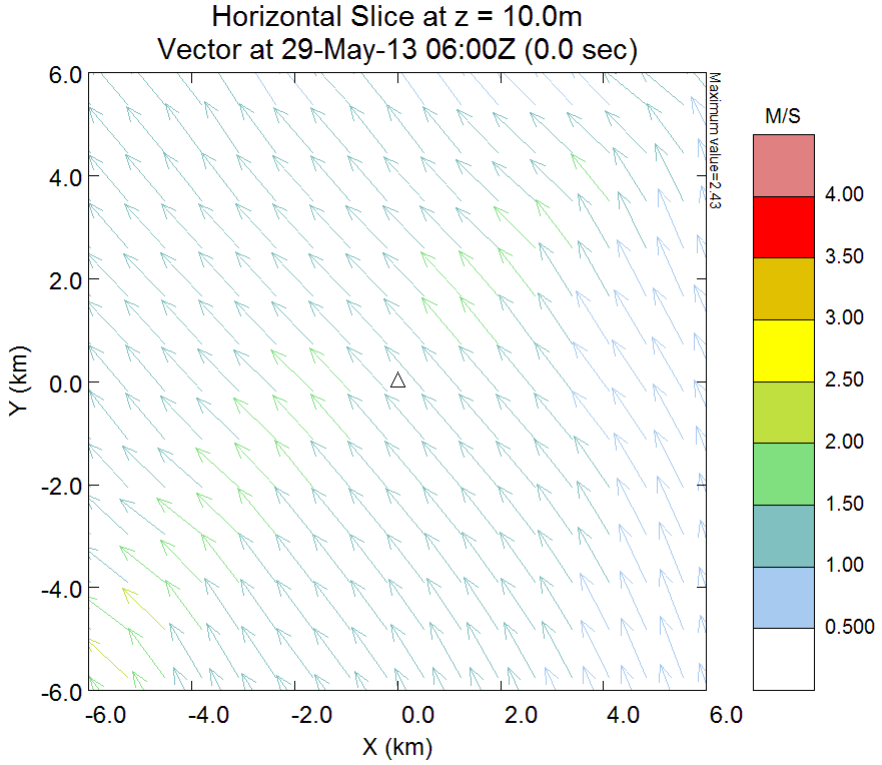
- Weather from DTRA Meteorology Data Server
  - WRF forecast from previous day
    - 5 km resolution, every 3 hours
  - Multiple surface observations
- Extract 2 closely located observations
  - Chosen since wind directions differ significantly from forecast
- Instantaneous release at one observation
  - 18 hours after analysis time

Wind Vectors

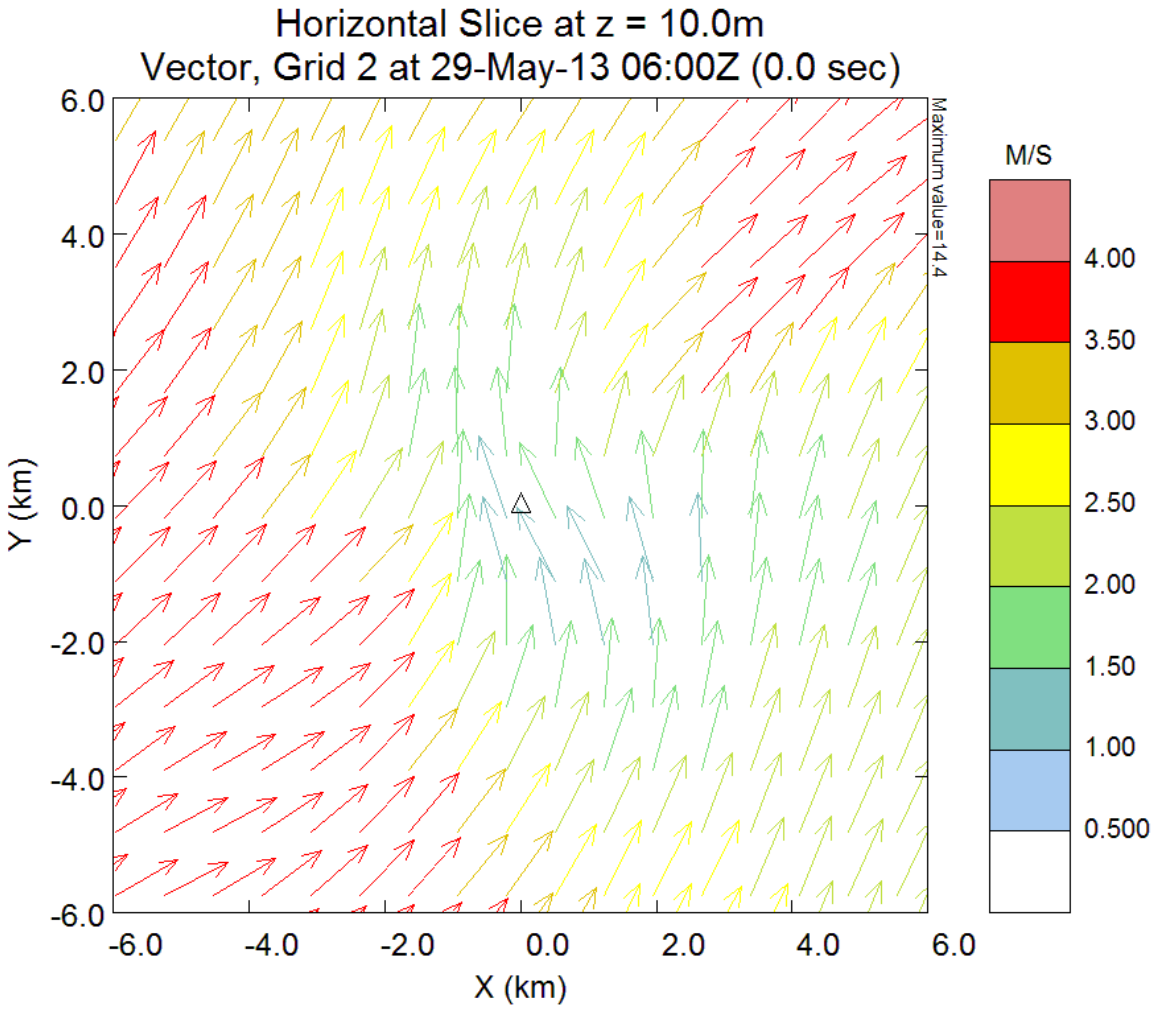
WRF Only



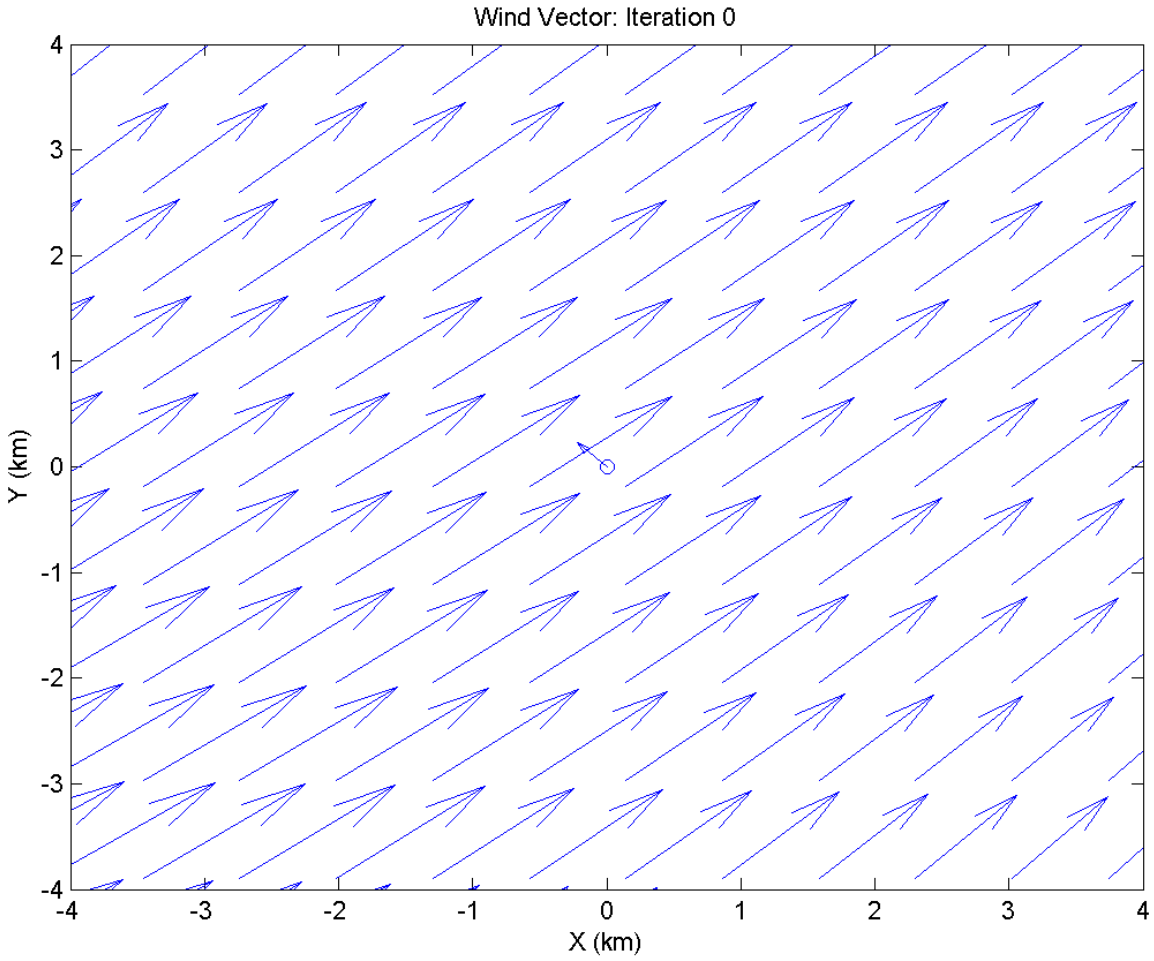
SFC Only



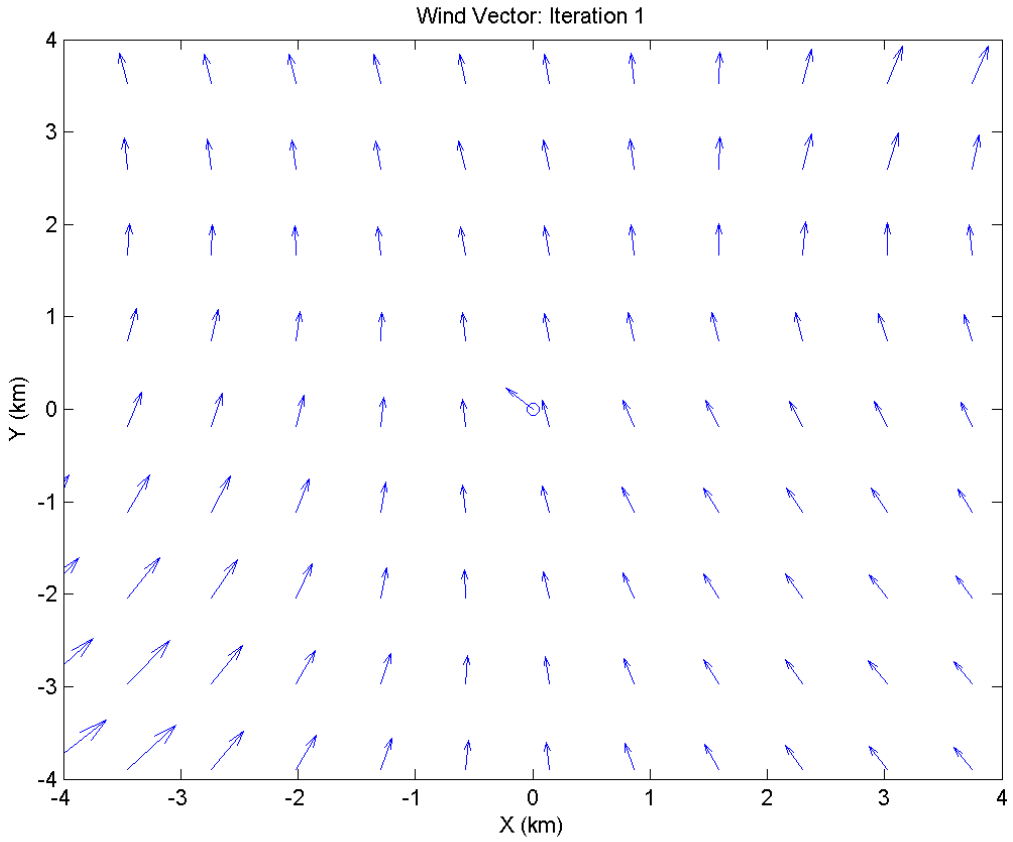
Wind Vectors – WRF + SFC



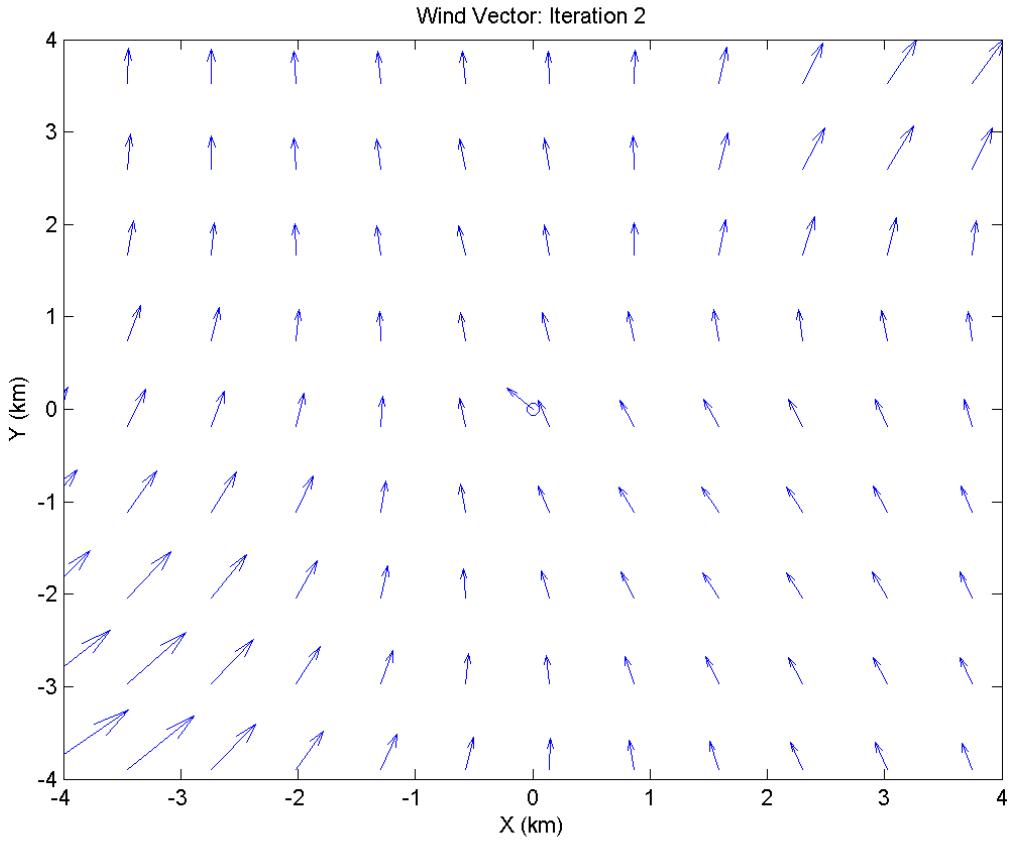
Assimilation: Initial



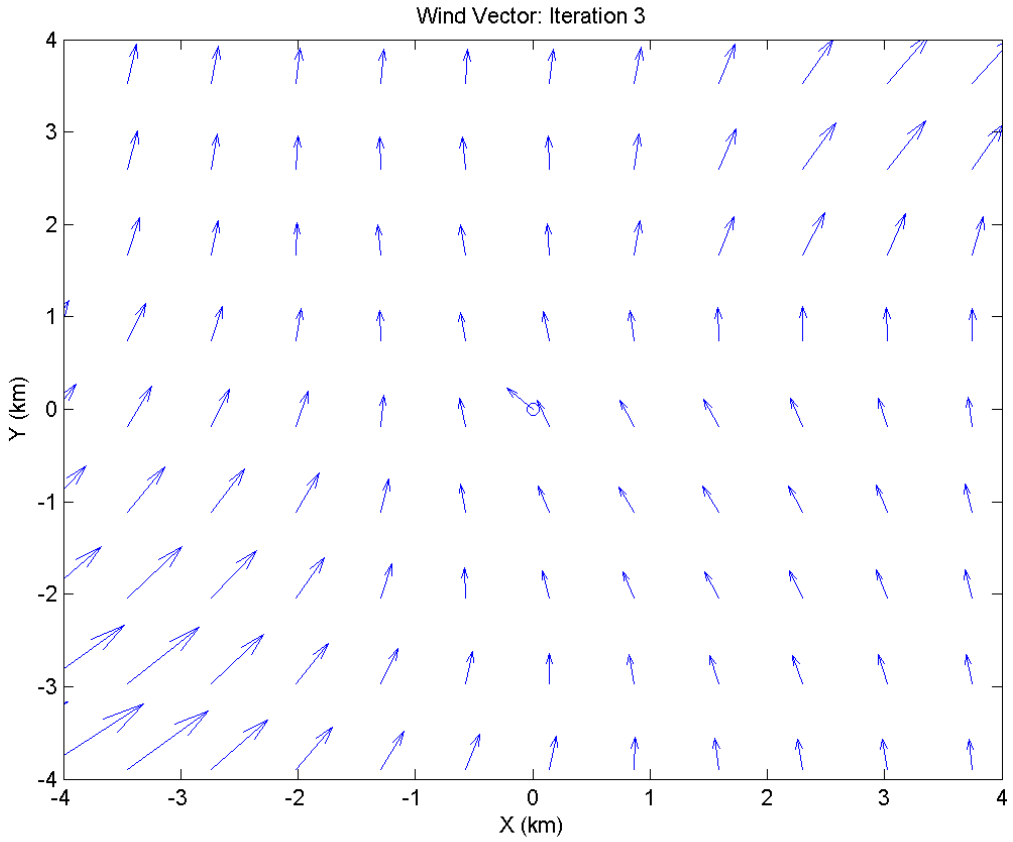
Assimilation: 1st Iteration



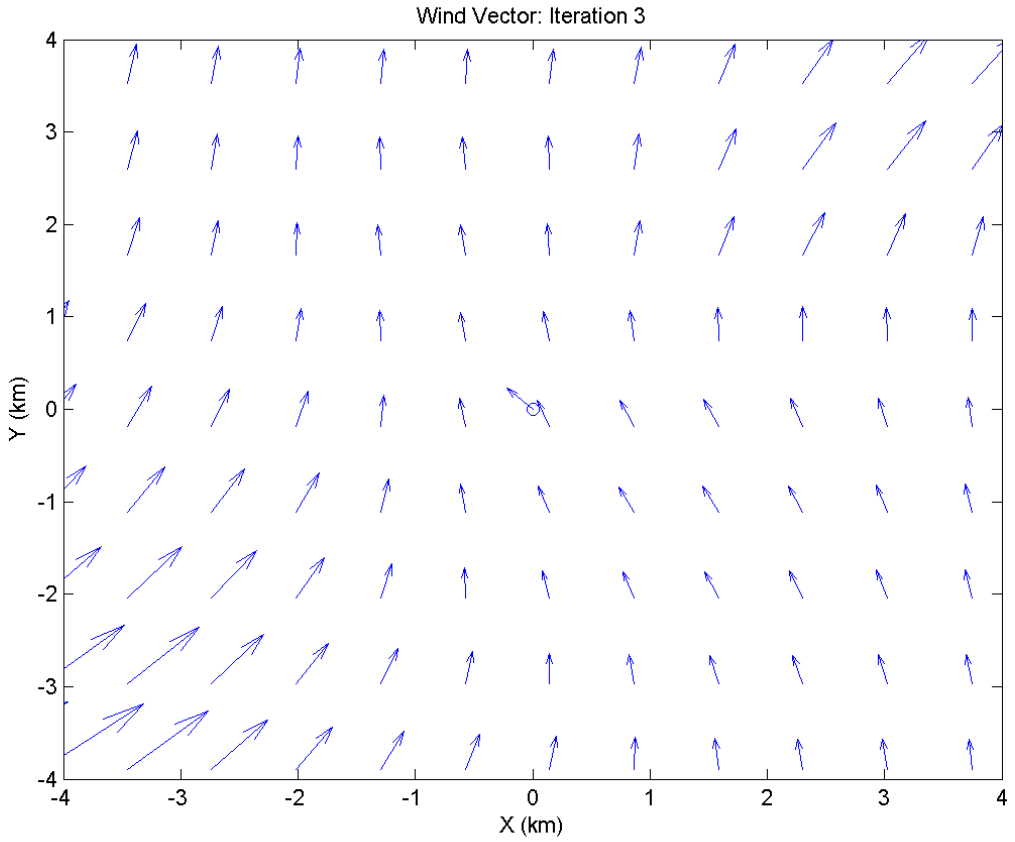
Assimilation: 2nd Iteration



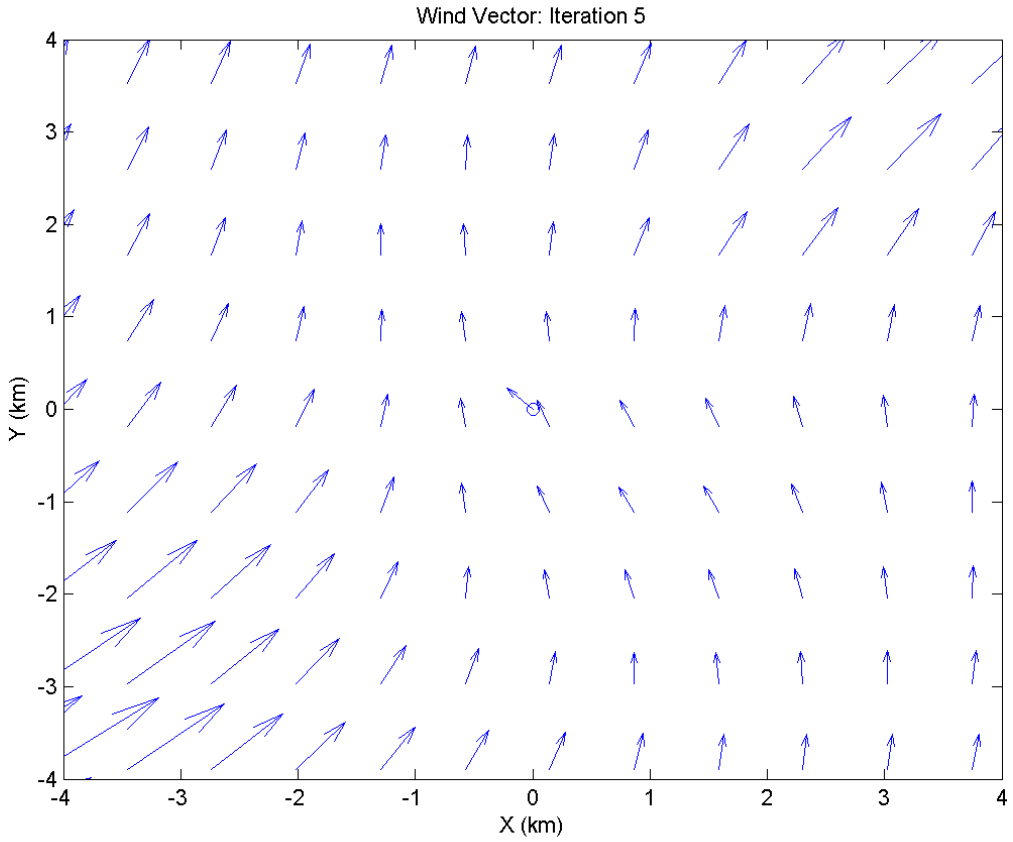
Assimilation: 3rd Iteration



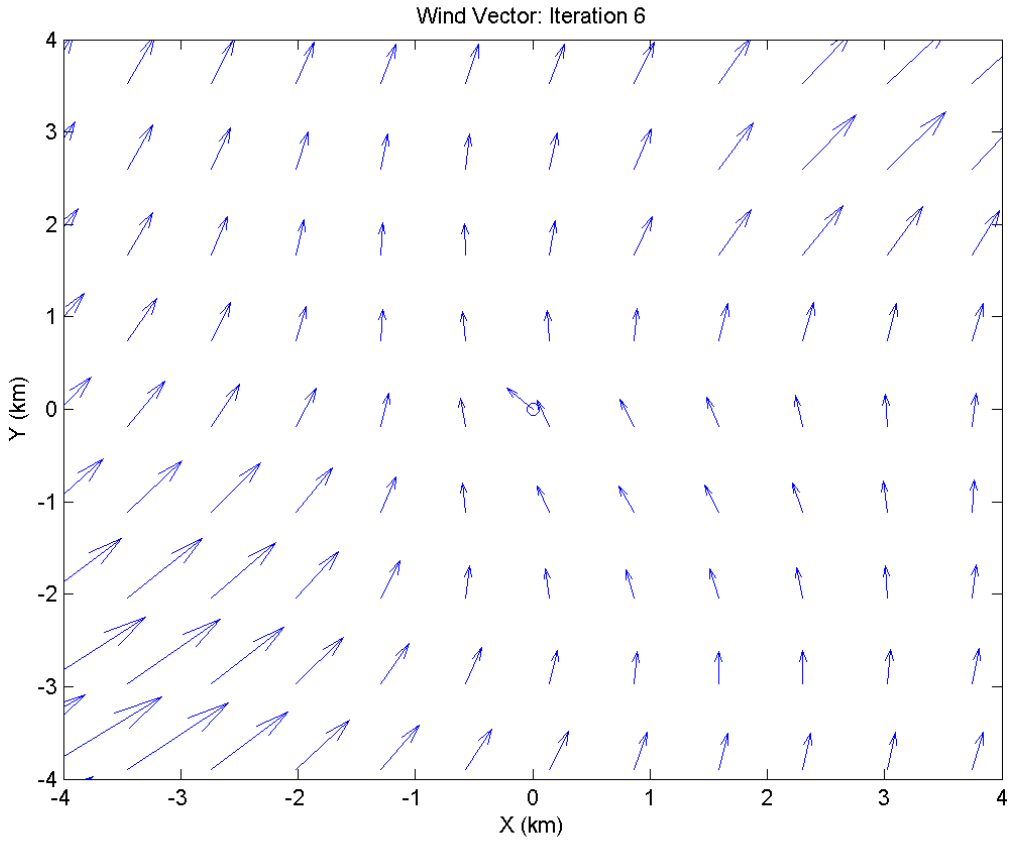
Assimilation: 4th Iteration



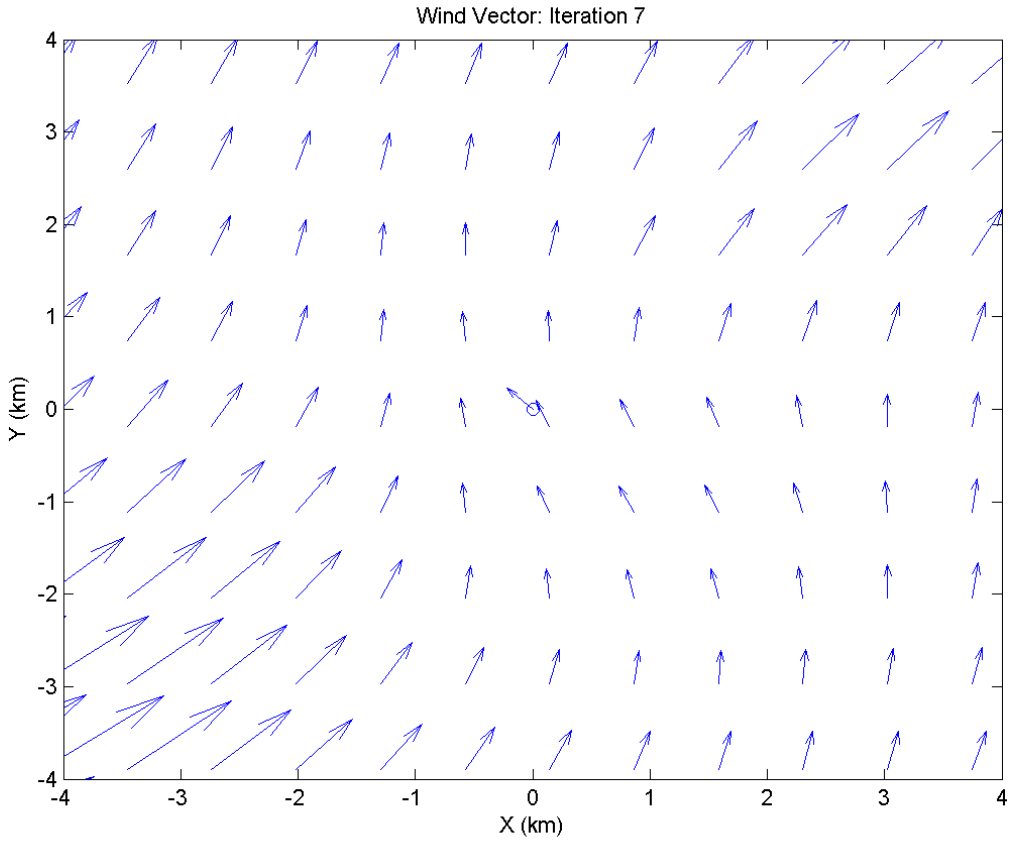
Assimilation: 5th Iteration



Assimilation: 6th Iteration

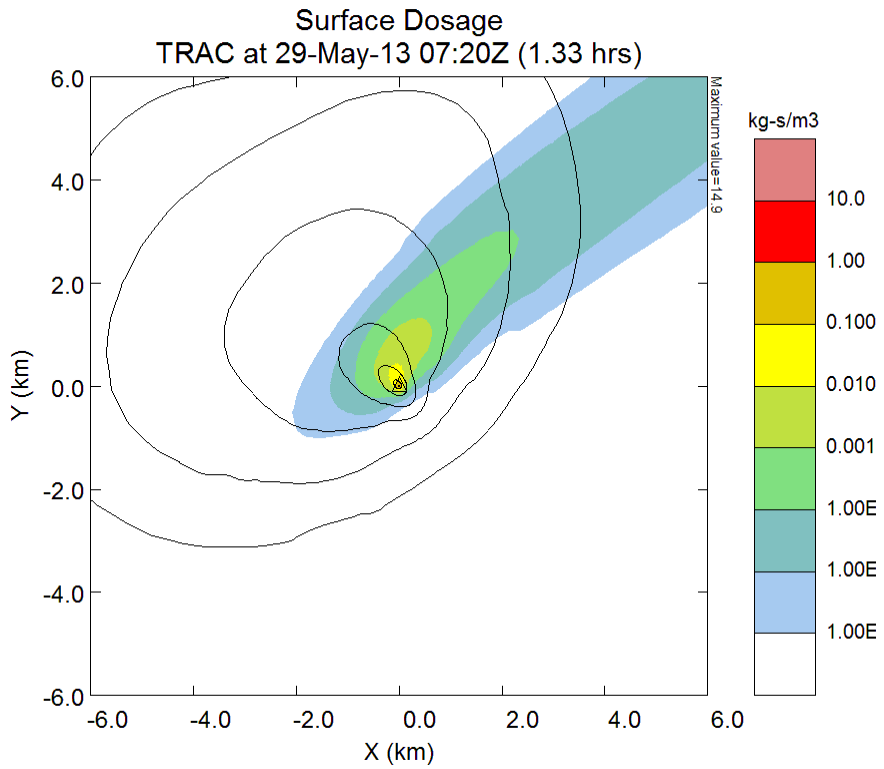


Assimilation: 7th Iteration

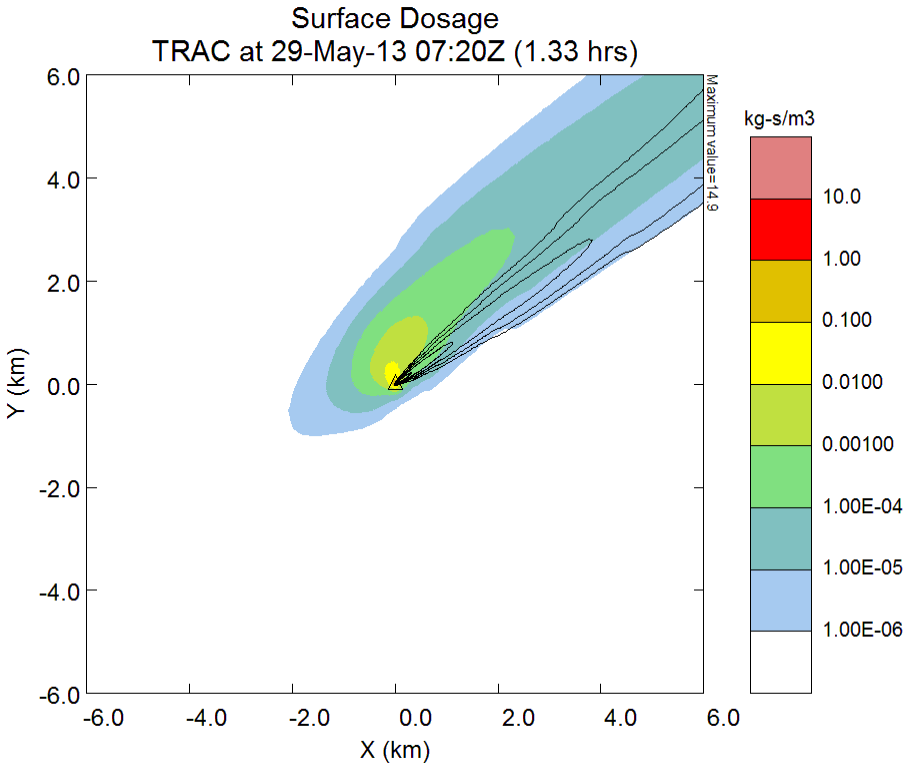


Dosage

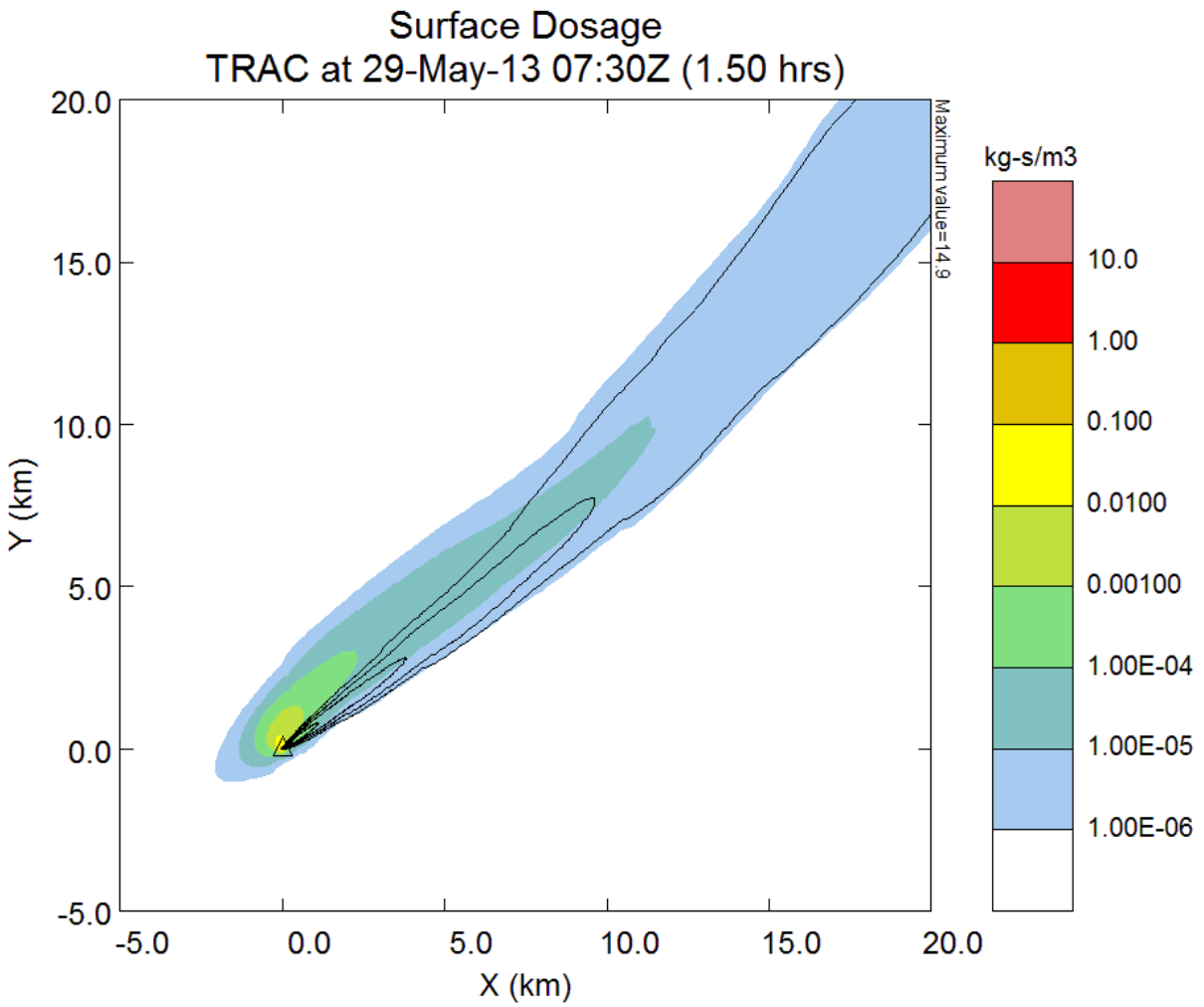
Compare w/ SFC Only



Compare w/ WRF Only



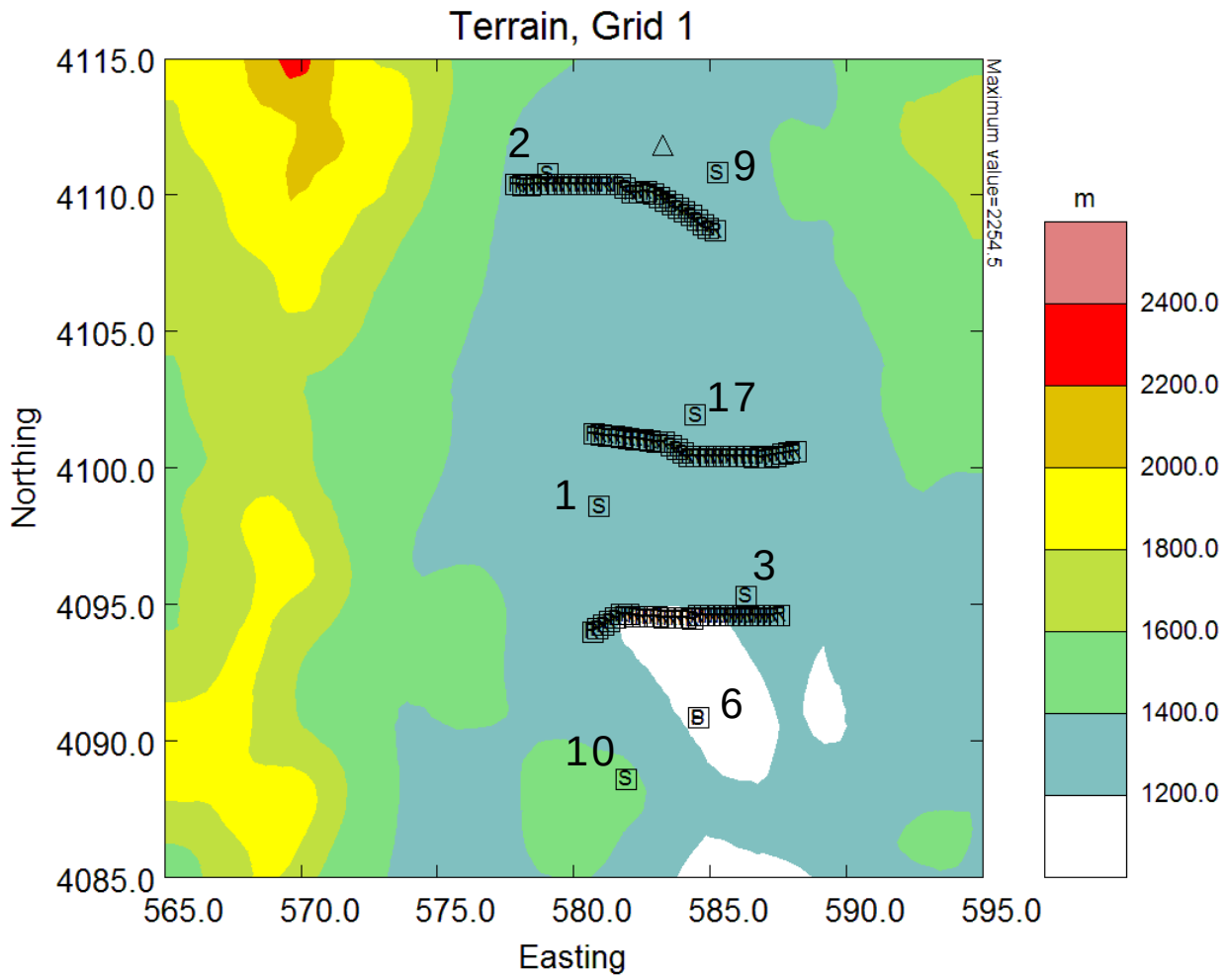
Dosage (Downwind)



Dipole Pride 26 Field Test

- SF6 releases at Nevada Test Site
- 3 Sampler lines
  - 1.5, 10, 17 km downwind (From North site)
  - 15 minute averages
- Meteorology observations
  - 8 surface and 1 upper air profile
  - 1 hour averages
- HPAC project files and observations provided by Joe Chang (DTRA-sponsored)

Dipole Pride 26 Layout



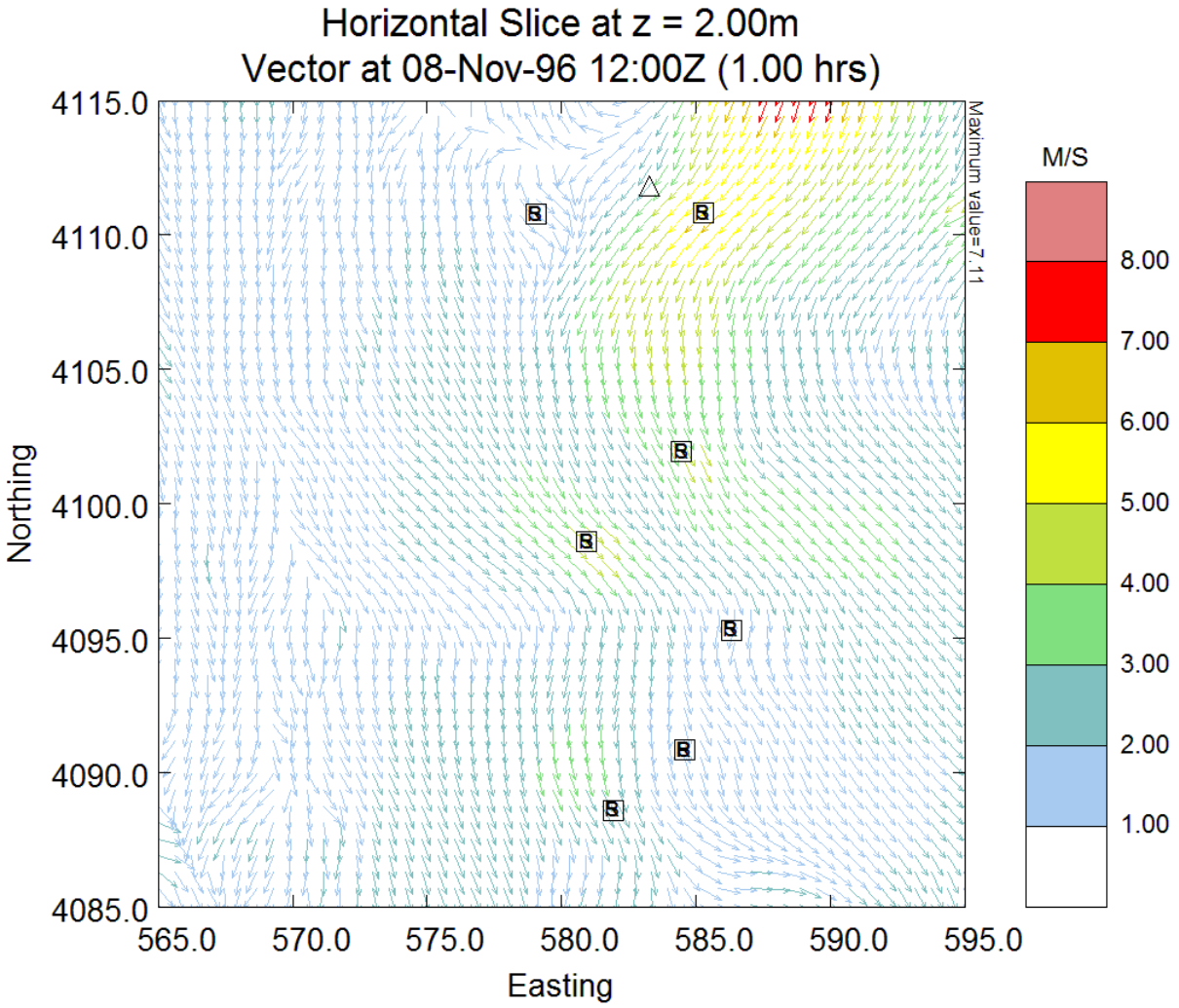
DP 26 Case 3

- November 11, 1996
- Nighttime release (12Z, 5L)
- Drainage flow over complex terrain
- 3 SCIPUFF calculations:
  - Met observations (only)
  - MM5 (only)
  - Assimilation (MM5 + Obs)
  - All with terrain at 600 m resolution
- Emphasis on wind fields
- Comparison of predicted and observed dosages

Assimilation Case

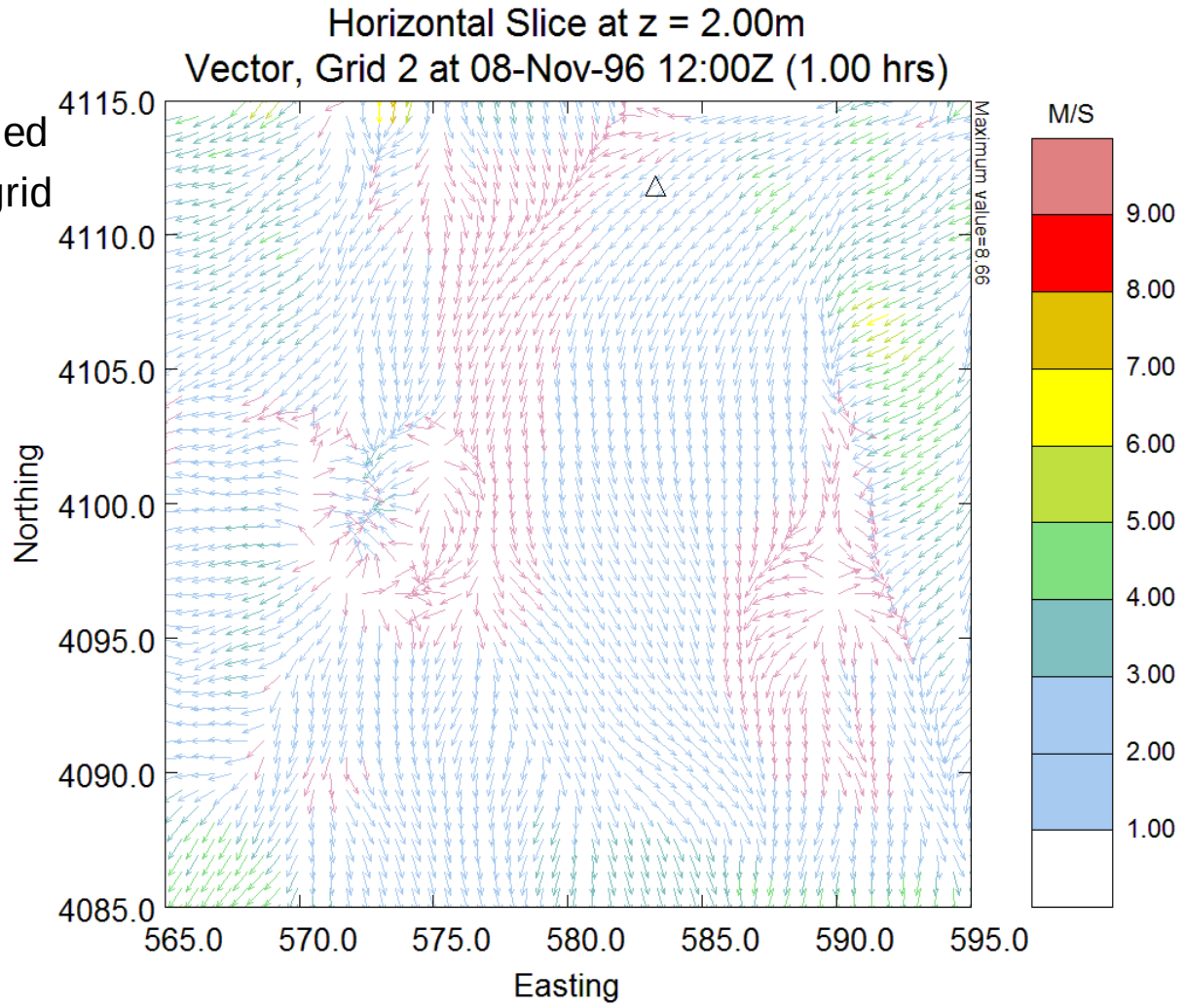
- MM5 calculation by PSU
  - DTRA-sponsored
  - 1.333 km nest (from 36/12/4 km outer domains)
  - No observation assimilation
  - Initialized from 0.5° GFS
- Background field
  - Interpolated from MM5
  - Nested terrain 600m resolution
  - Mass-consistent adjustment

Velocity Vectors – Obs Only

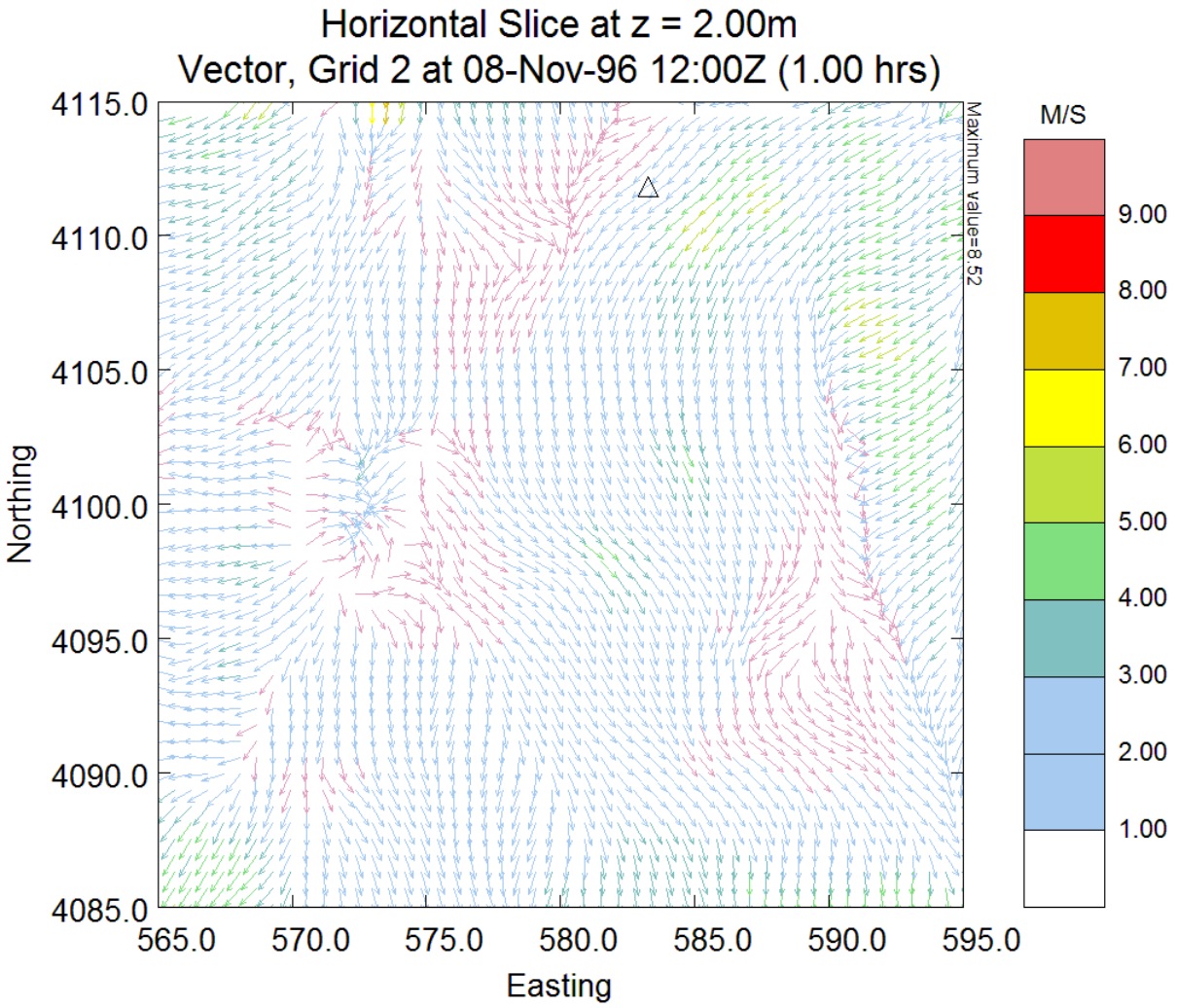


Velocity Vectors – MM5 Only

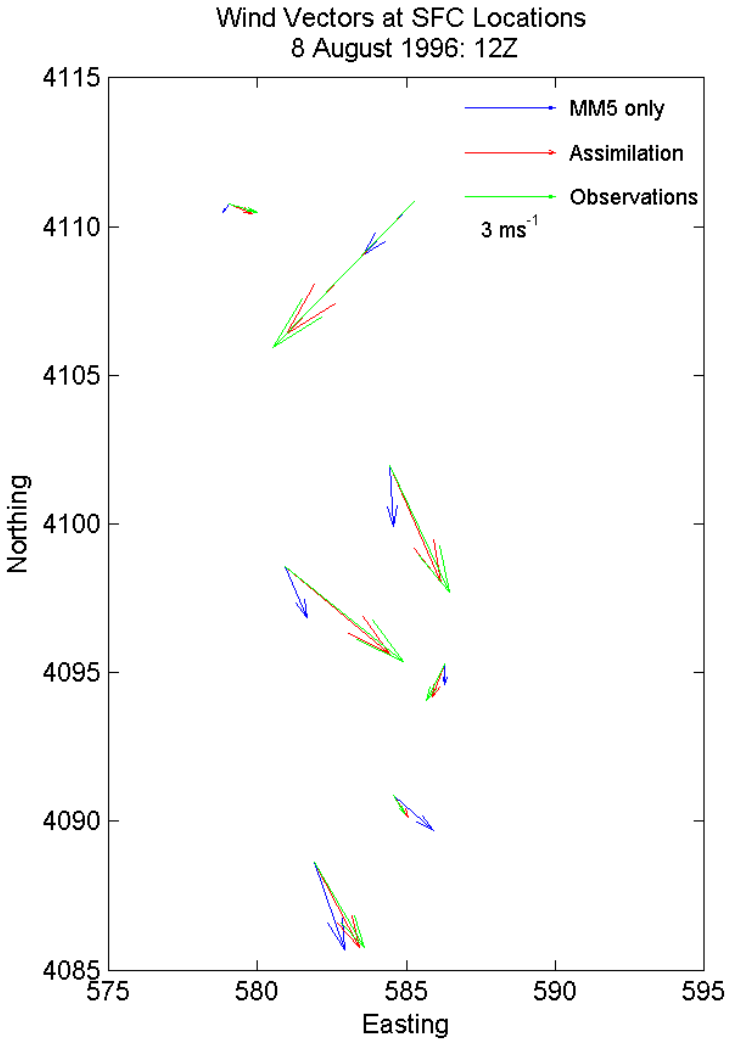
MM5 fields interpolated onto nested terrain grid



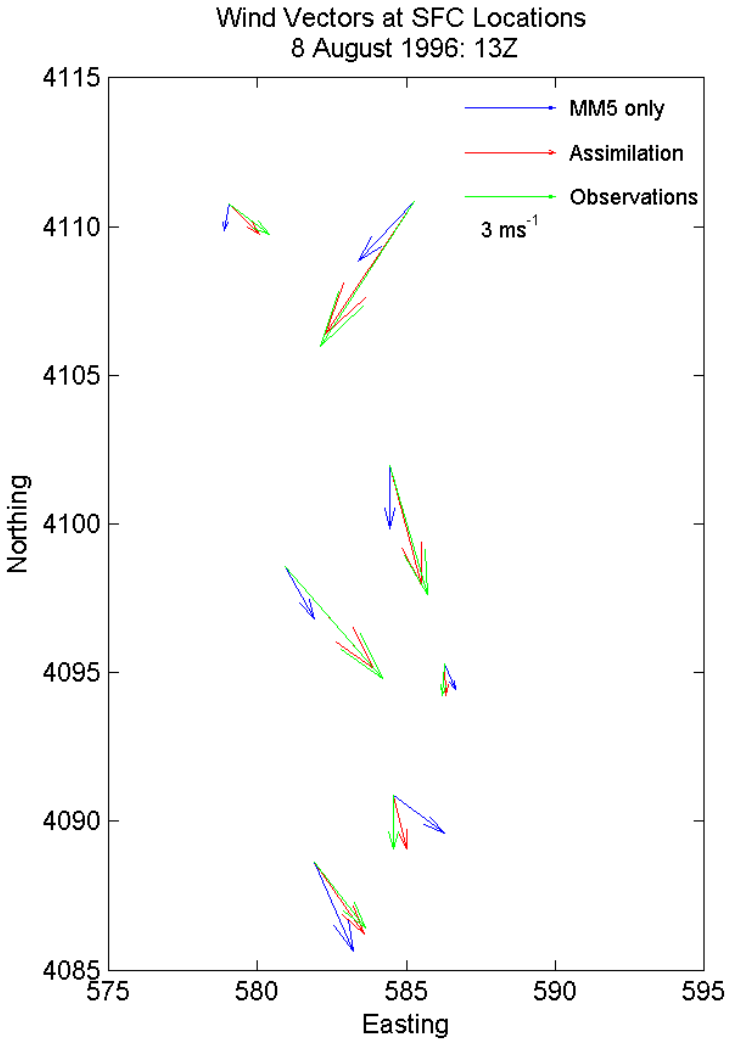
Velocity Vectors – MM5 + Obs



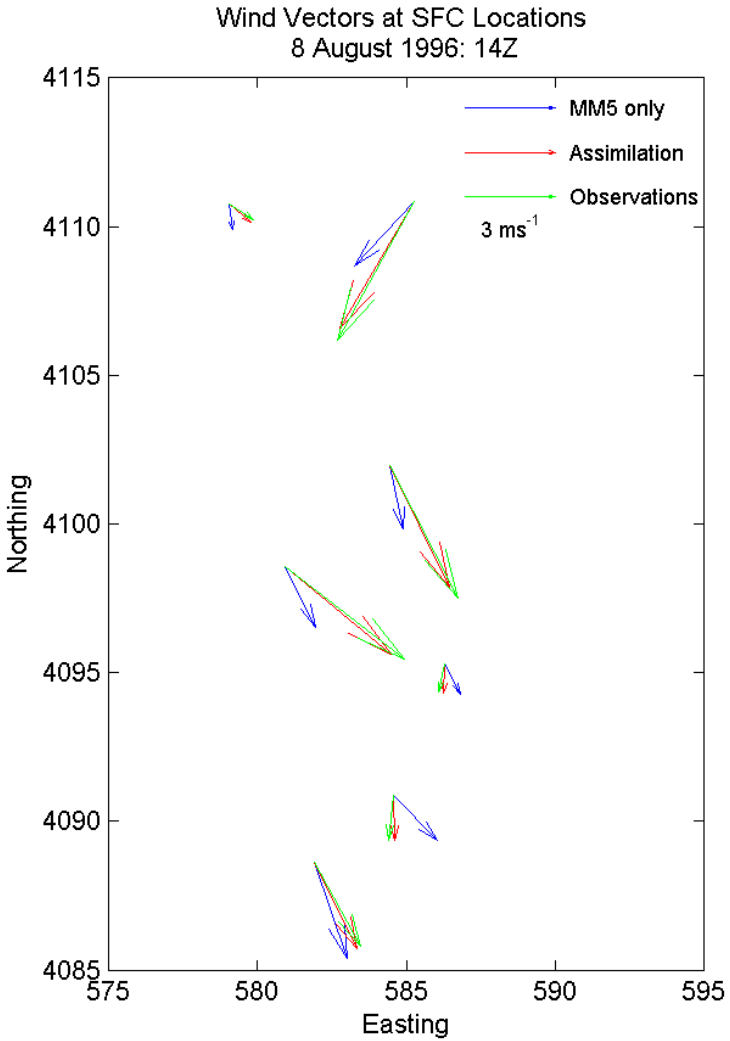
Velocity Comparison



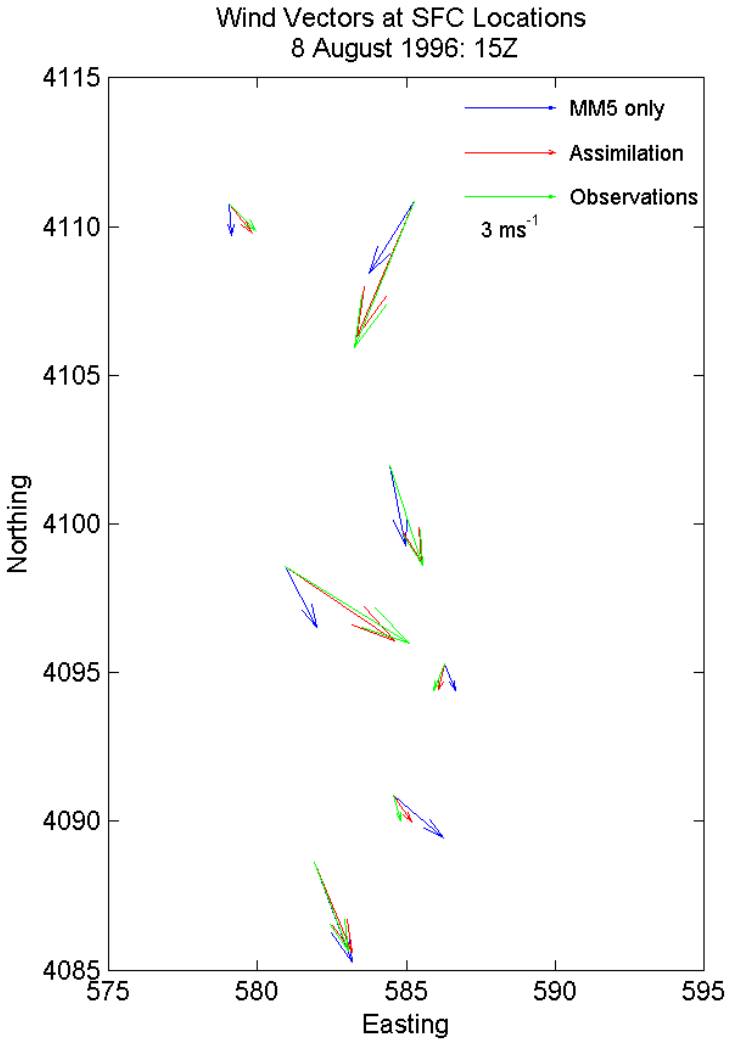
Velocity Comparison



Velocity Comparison

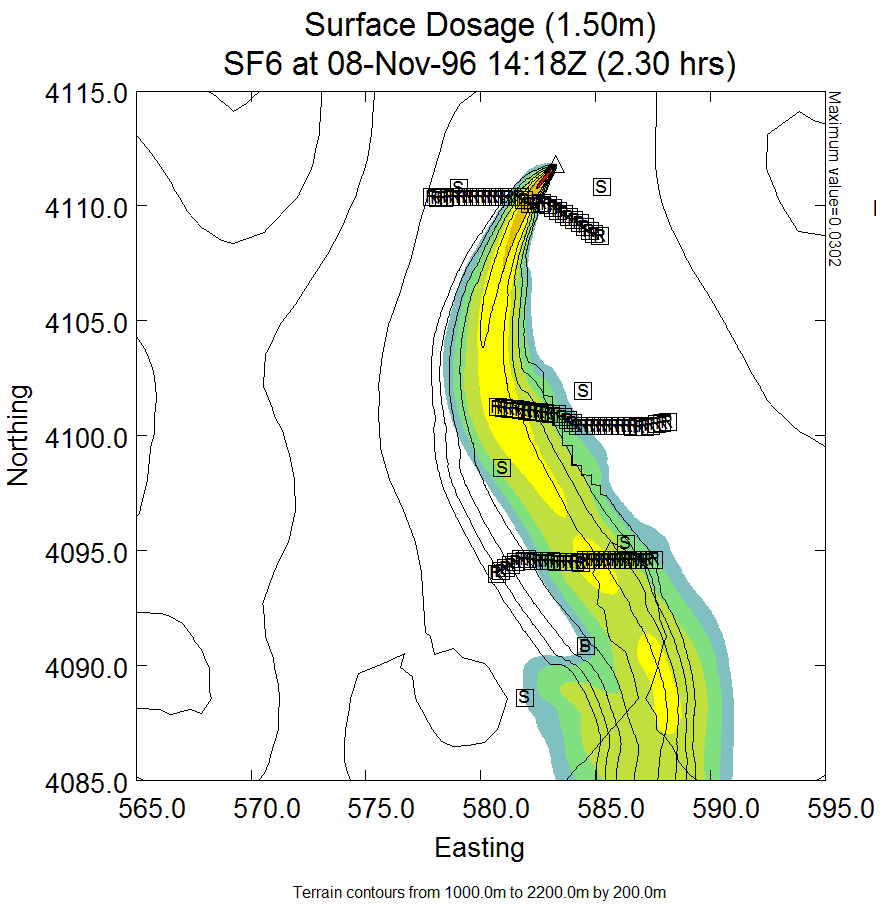


Velocity Comparison

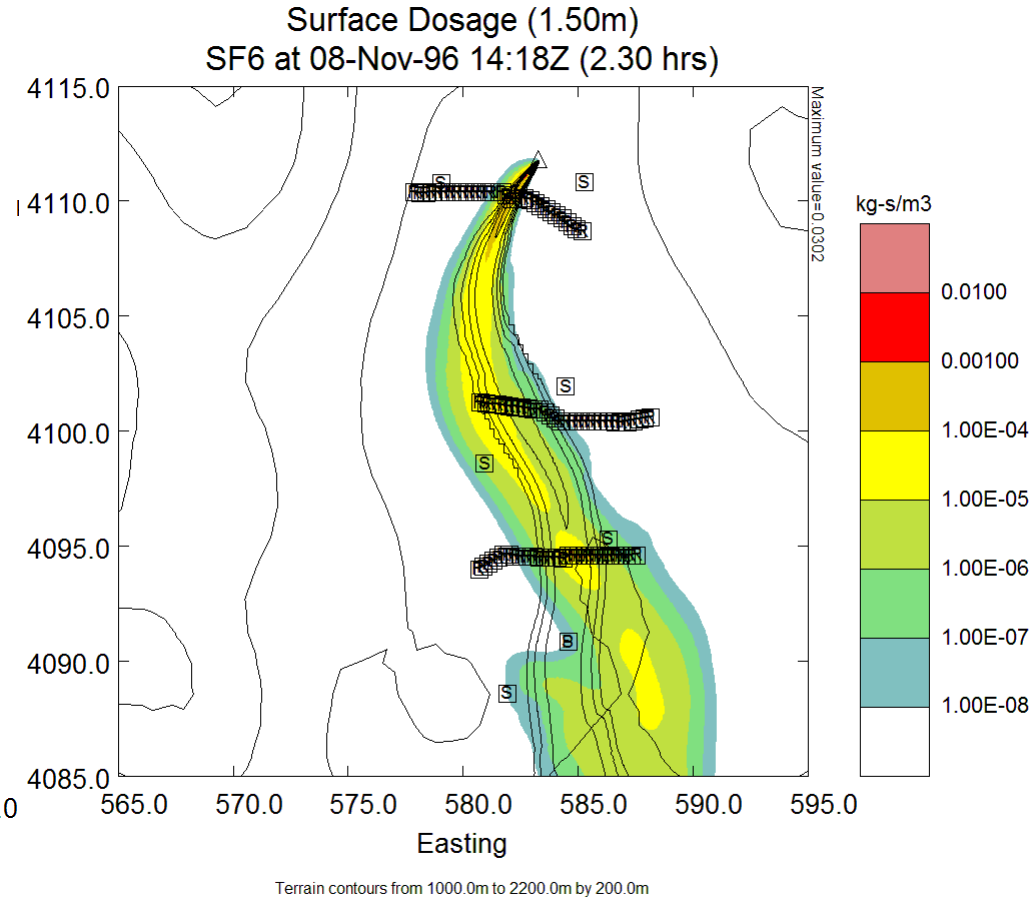


Dosage Comparisons

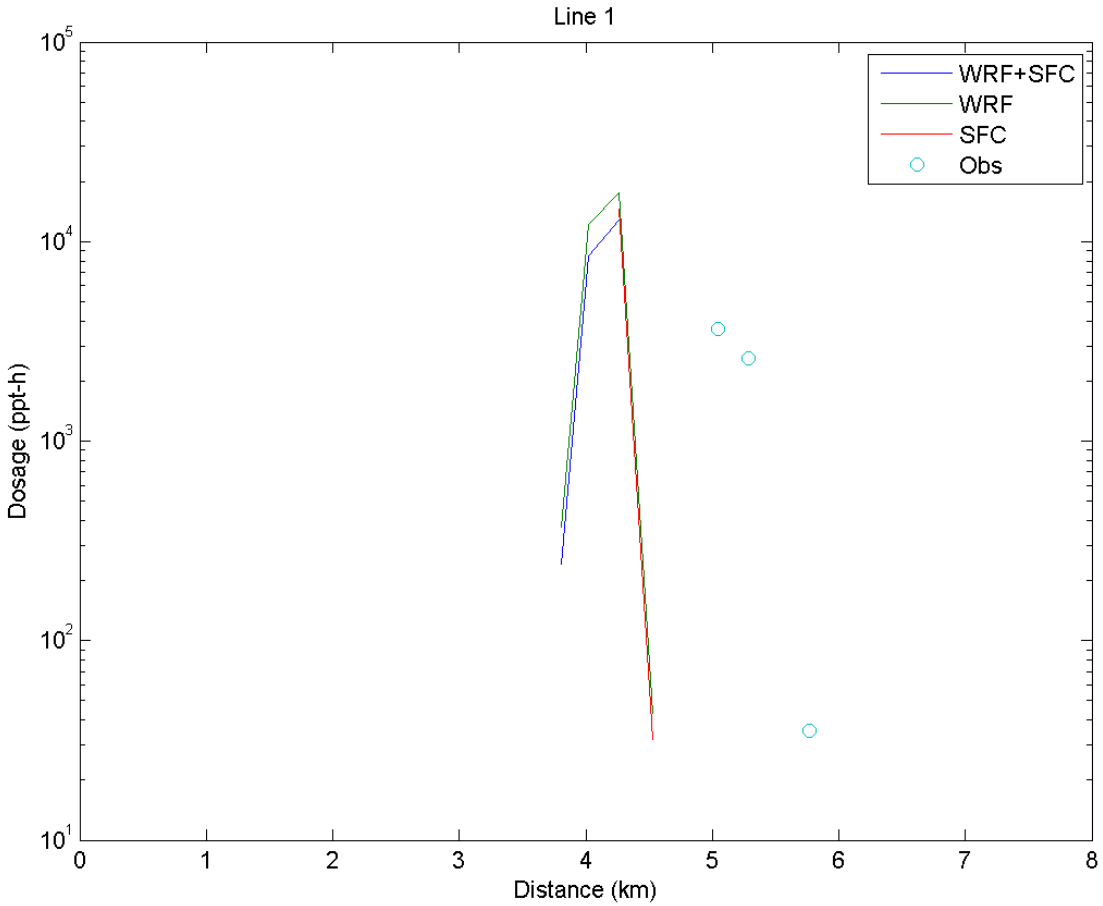
Assimilation compared with MM5 only



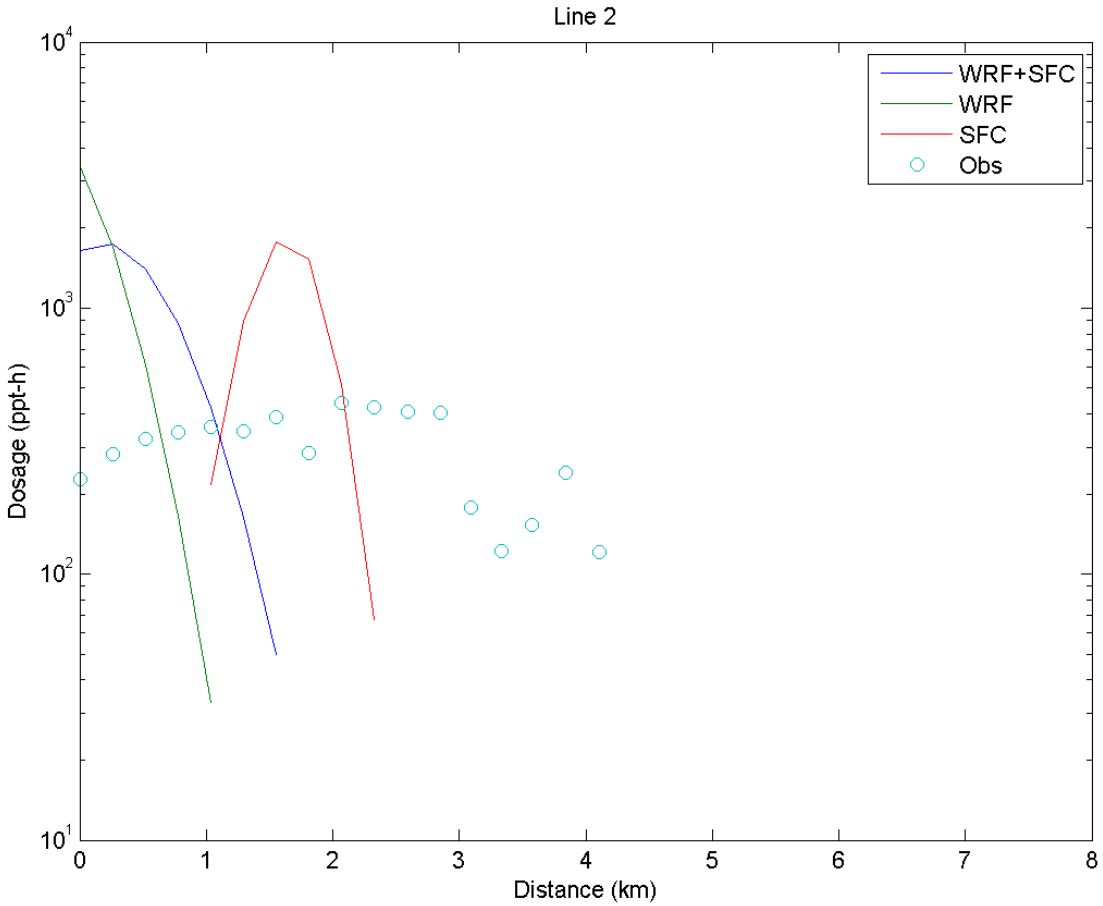
Assimilation compared with Obs only



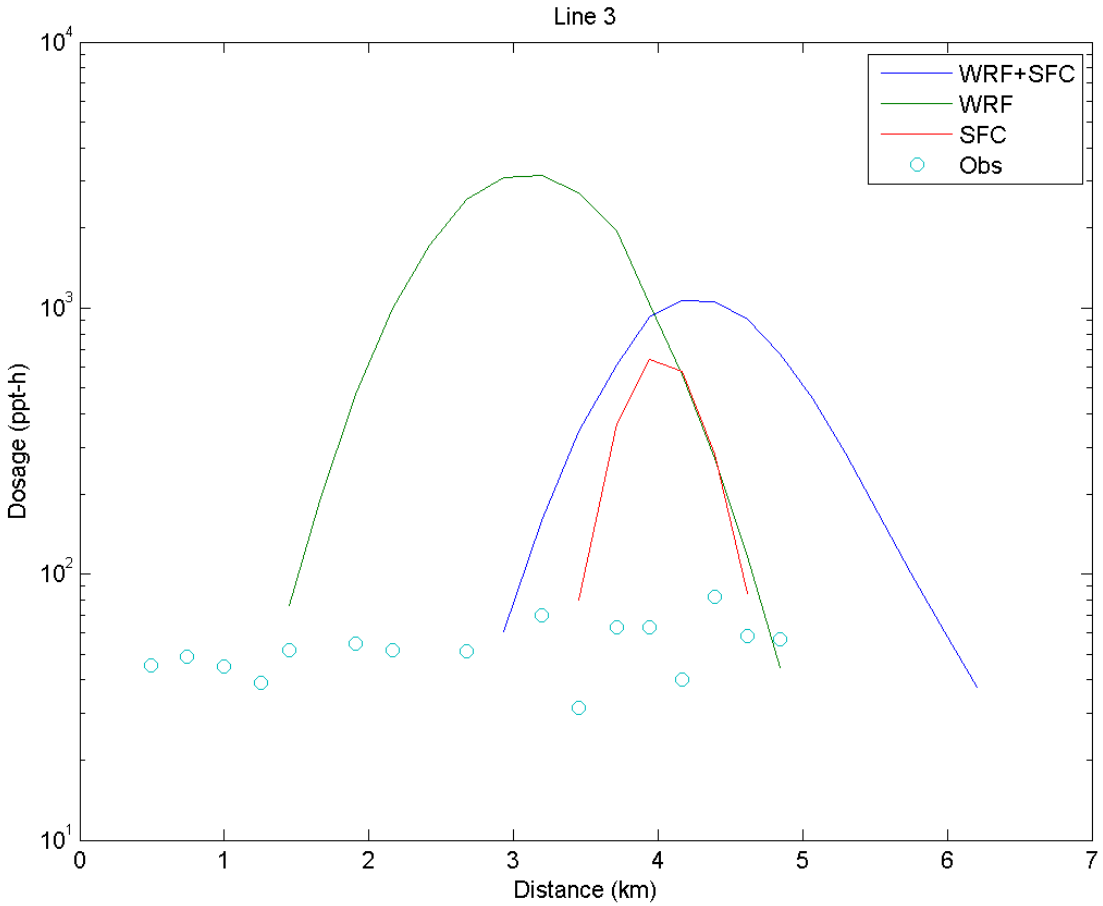
Comparison: Line 1



Comparison: Line 2



Comparison: Line 3



Summary

- Extension to current HPAC/SCIPUFF
  - Input gridded *and* observational meteorology files
  - Assimilate observations into gridded fields
- Demonstrated with operational scenario
  - 18 hour WRF forecast w/ local SFC observation
- Dipole Pride 26 field test
  - Assimilated observations w/ MM5 analysis field
  - Improved match with observed winds
  - Negligible improvement in concentration predictions

Further Work

- Estimating ratio E_b^2 / E_o^2 especially near-surface
- Function of:
  - Forecast time (since analysis)
  - Time since observation
  - NWP spatial resolution
  - Local terrain
- Observation radius of influence
- Investigate use of multivariate “optimal interpolation”