Numerical Modeling Study of Wind Flow over the Salt Lake City Region using integrated WRF-Noah-UCM Model at Meso-Gamma Scale

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Outline:

- **Objectives**
- **Numerical Experiments and Results**
  - WRF-Noah model with high resolution land-use
  - WRF-Noah-UCM with high resolution land-use
  - CFD-urban model with input from WRF/ WRF-UCM models
- **Summary**

Work supported by the US Air Force Weather Agency (AFWA) and Defense Threat Reduction Agency (DTRA)

Objectives

- **Ultimate goal: improve Transport and Dispersion (T&D) accuracy via merging capability of mesoscale (WRF) and microscale (CFD-urban) models**
- **To evaluate coupled WRF/Noah LSM /Urban Canopy Model (UCM) model's capability to represent fine scale (0.5-km) wind flow and temperature over the complex terrain and complex urban region of Salt Lake City (SLC)**
  - Do we model/parameterize turbulence right using 0.5-km grid spacing?
- **To couple the WRF/Noah/UCM with CFD (Computational Fluid Dynamics)-urban model**
- **Evaluate the utility of WRF/Noah/UCM-CFD-urban in T&D model**
- **Evaluate the above models performance with the IOP 10 data obtained from the Urban 2000 field experiment**
- **Explore strategies to couple WRF and CFD models**

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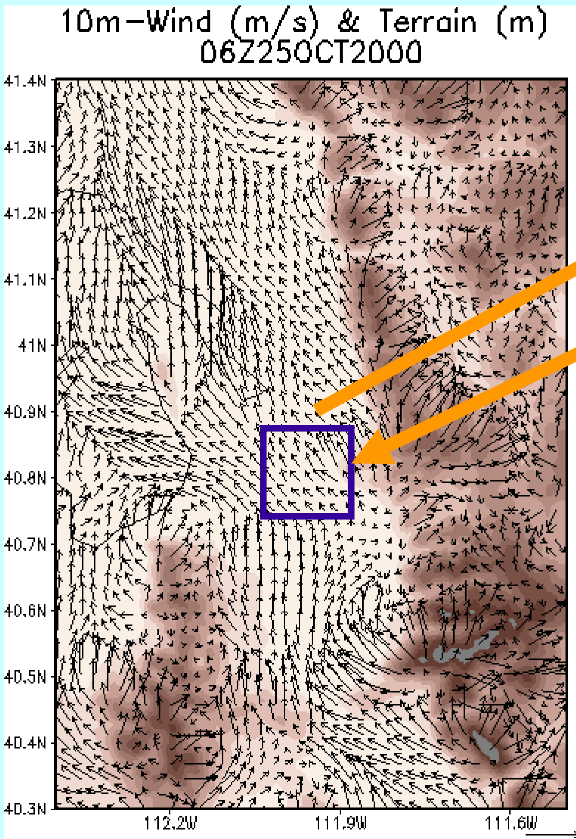
High-Resolution WRF/Noah/Urban Modeling Capability: Coupled to CFD-Urban

WRF-Noah/UCM
coupled model forecast

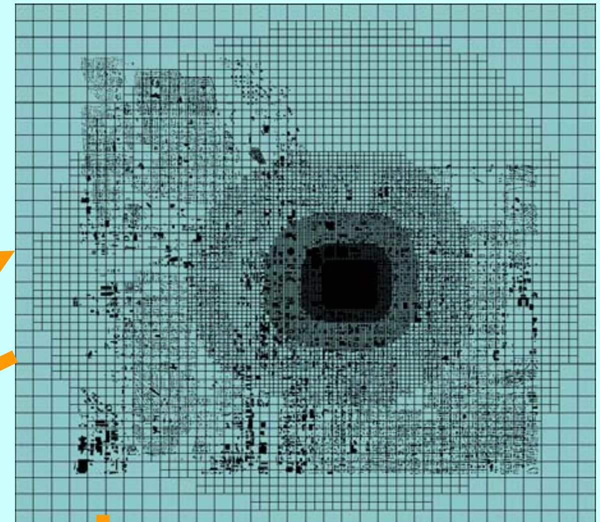


Coupling

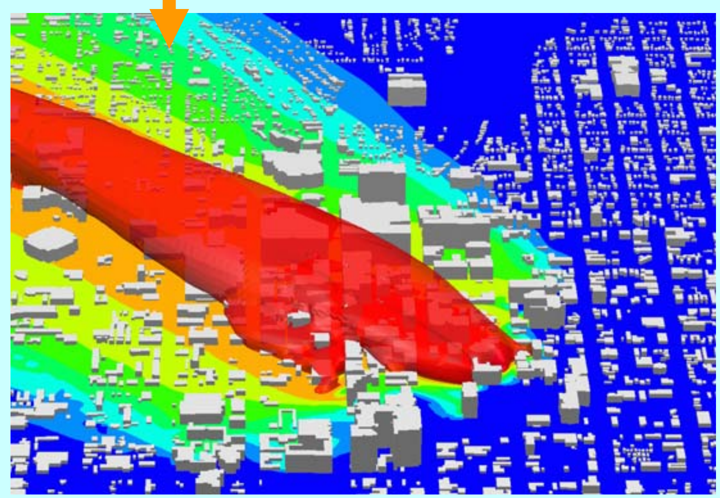
Down-
Scale

Up-
Scale

CFD-Urban:
Hi-Res Urban Model



T&D model



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WRF Model Experiments

- **WRF-Noah LSM**
  – Simple urban treatment (large roughness length, low surface albedo, and large thermal capacity and thermal conductivity for urban landuse)
- **WRF/Noah/UCM: couple a single layer urban-canopy model (UCM), based on Kusaka et al, 200, and Noah LSM**
  - User defined canyon orientations
  - Shadowing from buildings and reflection of short and long wave radiations in the canyon
  - Diurnal change of solar azimuth angle
  - Wind profile in the canopy layer
  - Multi-layer heat transfer equation for roof, wall, and road
  - Very thin bucket model for hydrological processes.
- **Numerical Experiments and Observations**
  – 24 hours starting at 26 Oct 2000, 00Z with each model
  – 5 domains nested runs (40.5km, 13.5km, 4.5km, 1.5km and 0.5km)
  – Observational data for IOP 10 of URBAN 2000 field experiment

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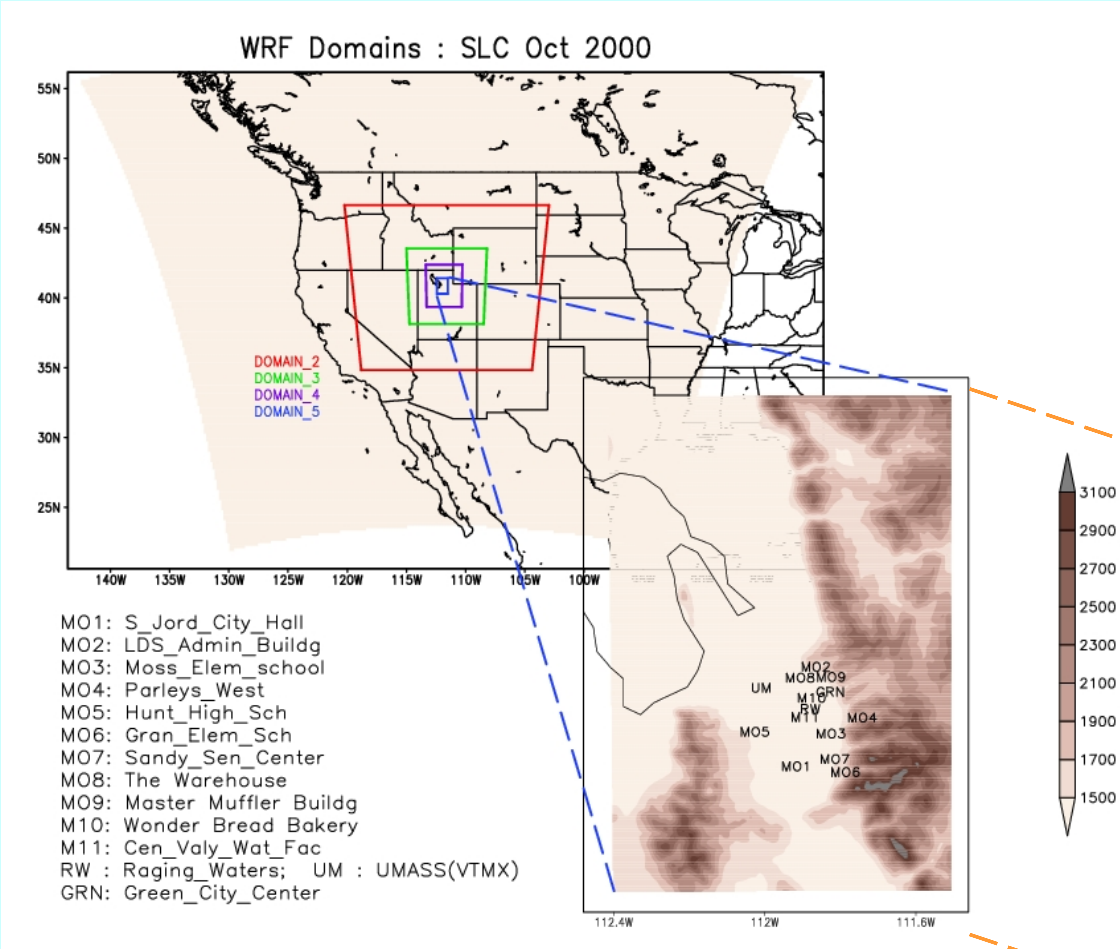
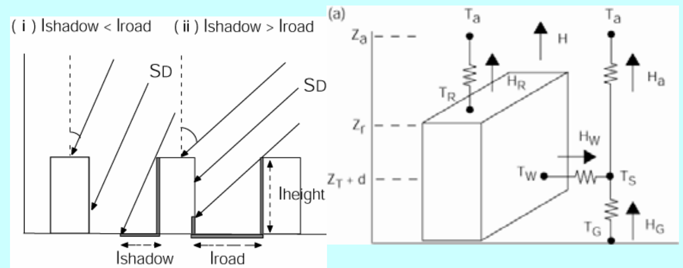
High-Resolution WRF/Noah/Urban Modeling

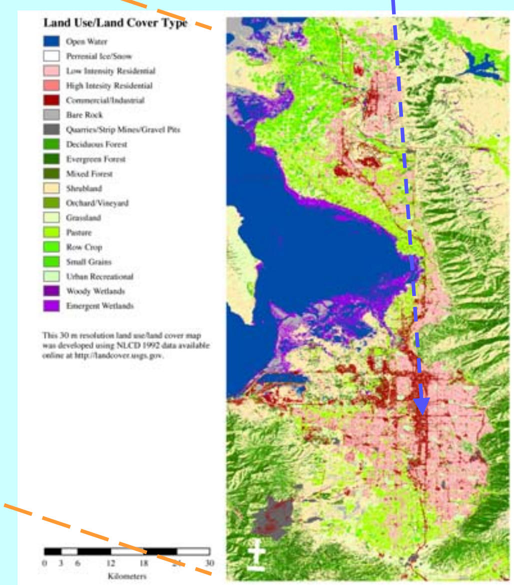
Domains: 40.5,13.5,4.5,1.5,0.5 Km



Single layer Urban Canopy Model



Complex terrain on WRF nested D-5 (0.5 km grid spacing) over the Salt Lake City area



Complex urban land use distribution over SLC

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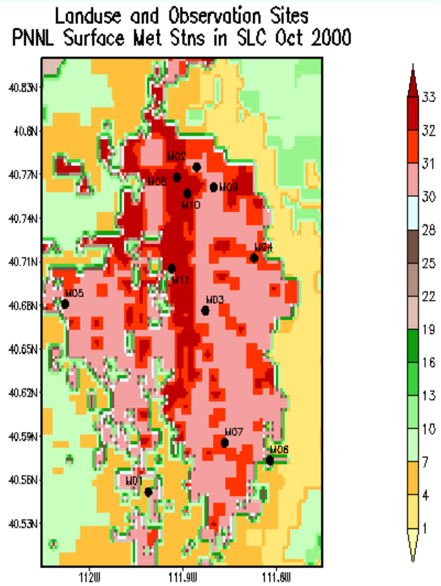
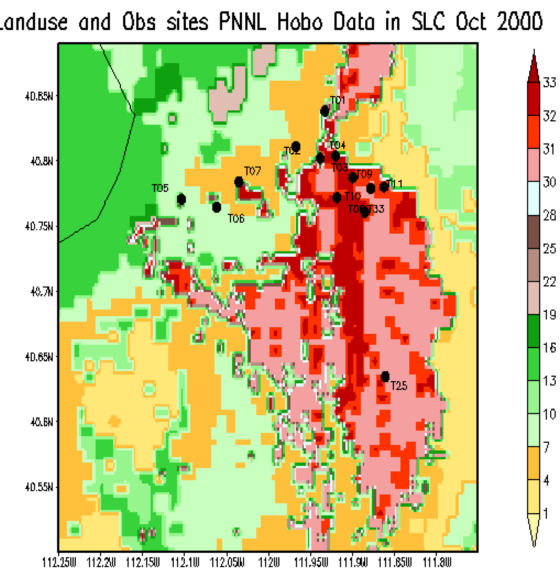
LAND-USE (500m) and Observation Sites at PNNL

PNNL Met Stns



M01: S Jordan City Hall
M02: LDS Admin Buildg
M03: Moss Elem. School
M04: Parleys West
M05: Hunter High School
M06: Granite Elem School
M07: Sandy Senior Center
M08: The Warehouse
M09: Master Muffler Buildg
M10: Wonder Bread Bakery
M11: Central Valley Water Fac.

PNNL Hobo Temp Loggers



T01: Redwood Road and I-215 Jordan City Hall
T02: 3200W and 2100N
T03: Redwood Road and 1580N
T04: 1795N Warm Springs
T05: W 7200W and I-80
T06: E 7200W and I-80
T07: End Amelia Earhart D
T08: 1000W and 200N
T09: 300W and 900N
T10: D St and 10th Av
T11: Trc Hills and 11th Ave
T25: Wheeler Farm Site
T33: 200E and 400S

Urban Categories

31: Low Intensity
32: High Intensity
33: Industrial

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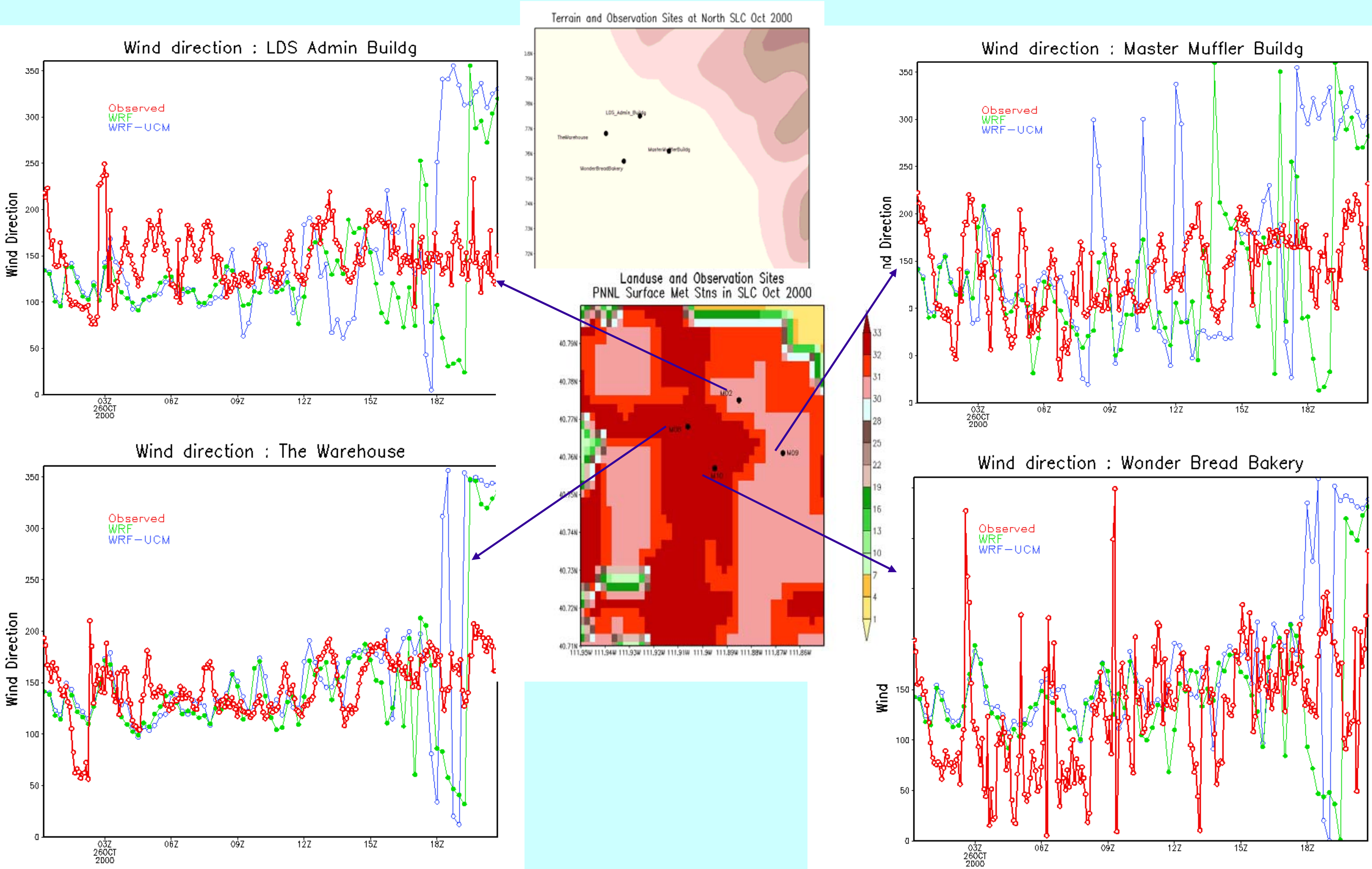
Diurnal Wind Direction at North Downtown



Red: Obs, Green: WRF/Noah, Blue: WRF/Noah/UCM

NIGHT DAY

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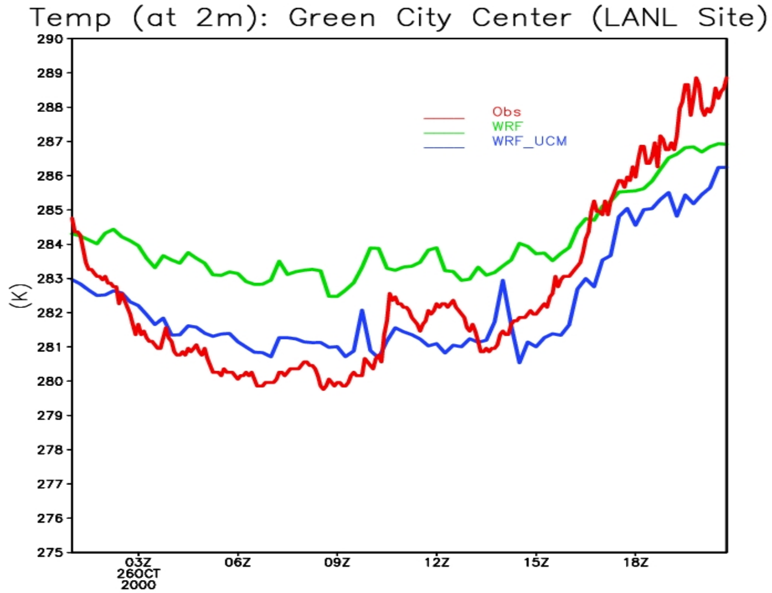
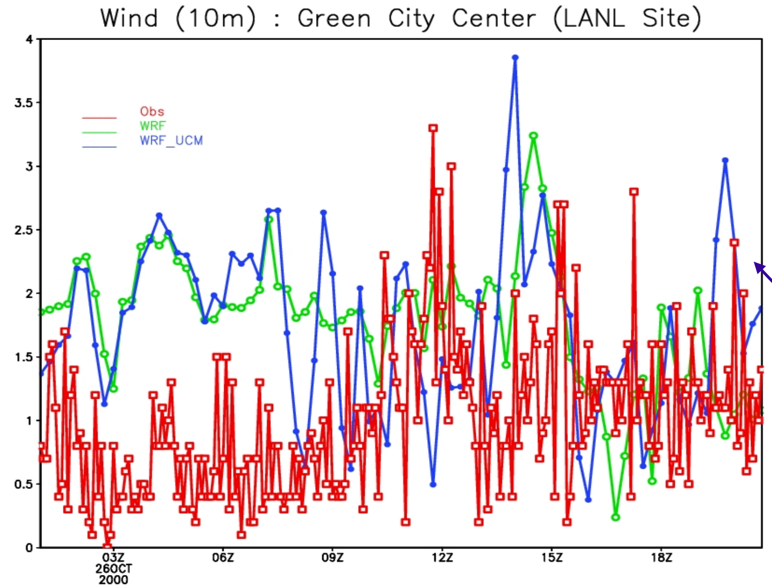
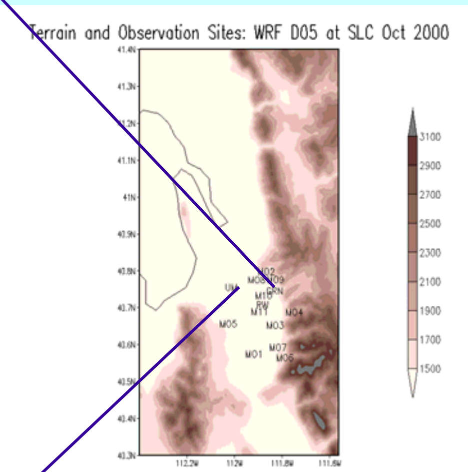
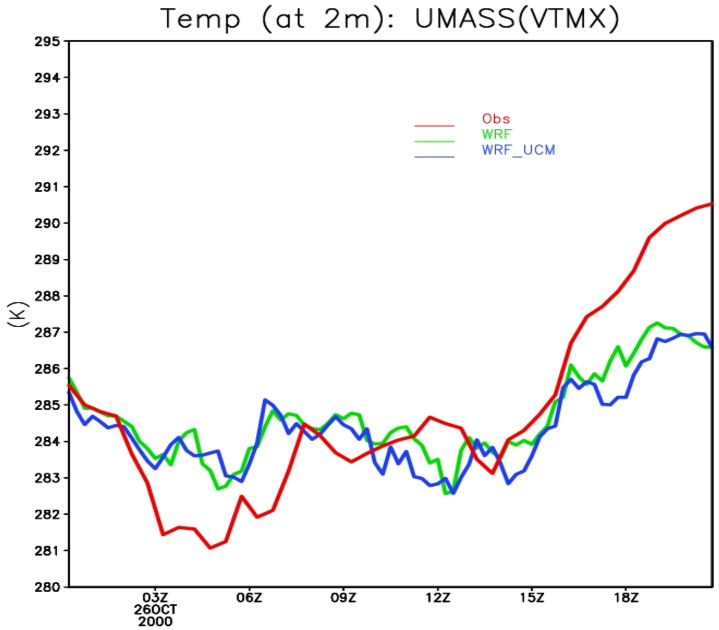
Temperature and Wind Speed

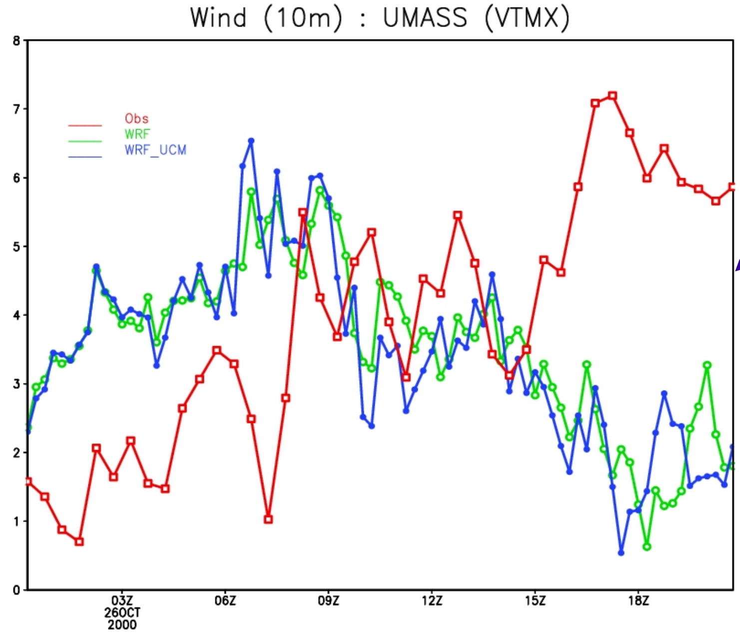




Green City, LANL Obs Site







UMASS, VTMX Obs Site

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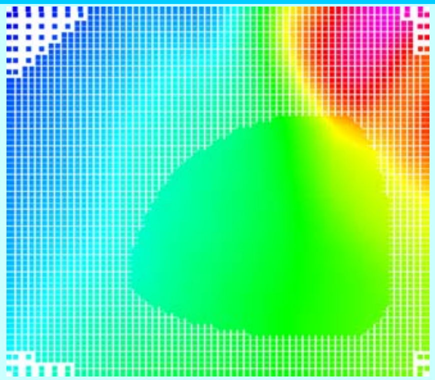
Red: Obs, Green: WRF/Noah, Blue: WRF/Noah/UCM

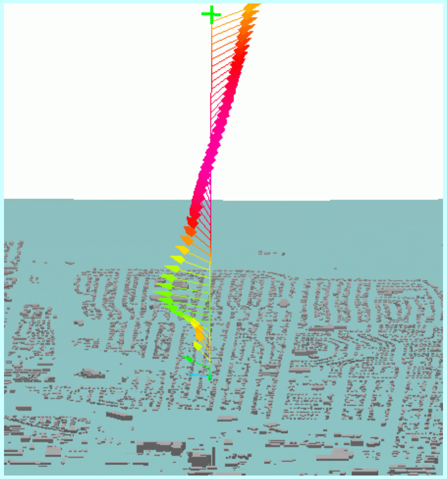
WRF + CFD-Urban: Boundary Condition Procedures

- **DTRA project at CFDRC: SBIR Phase I: "Improved High-Fidelity Forecasting Capability using Combined Mesoscale and Microscale Models"**
  - **Tech Monitor: Cmdr. Stephanie Hamilton**
- **Process WRF datasets (NetCDF format):**
  - **Interpolate data to CFD-Urban grid boundary faces**
  - **Continuous, linear interpolant**
- **Pressure: Remove hydrostatic variation by subtracting ideal atmosphere and imposing it on this "column"**
  - **Allows imposition of lateral pressure gradient from WRF**
- **Turbulence Field:**
  - **Directly use TKE from the MYJ model ("TKE_MYJ")**
  - **Compute TKE dissipation rate using TKE and momentum diffusion coefficient ("AKM_M")**

Lateral, WRF Imposed Pressure Gradient



Flow Turning



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Preliminary Results: IOP 10 Urban 2000

- Urban 2000: Field Test conducted in Salt Lake City
    - SF6 released in Central Business District
    - Samplers located in CBD and on “arcs” located downstream
- Statistical Comparison of Predicted to Measured Concentration Data

$$FB = \frac{\left(\overline{C_o} - \overline{C_p}\right)}{0.5\ \left(\overline{C_o} + \overline{C_p}\right)}$$

$$NMSE = \frac{\overline{\left(C_o - C_p\right)^2}}{\overline{C_o}\ \overline{C_p}}$$

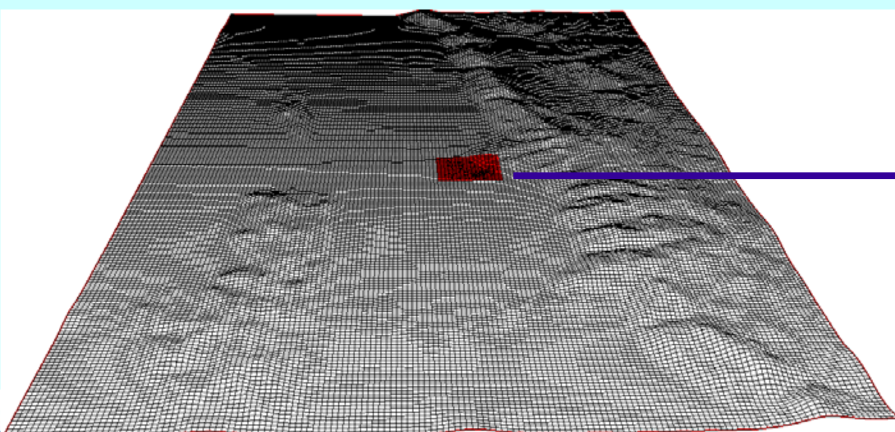
$$MG = \exp\ \left(\overline{\ln C_o} - \overline{\ln C_p}\right)$$

$$FAC2 = \text{fraction of data that satisfy}\ \ 0.5 \le \frac{C_p}{C_o} \le 2.0$$

$$VG = \exp\left[\overline{\left(\ln C_o - \ln C_p\right)^2}\right]$$

Acceptable values:

- FAC2 > 0.5
- -0.3 < FB <0.3 (0.7 <MG < 1.3)
- NMSE < 4 (VG <1.6)



Preliminary Results: IOP 10 Urban 2000

- Three sets of calculations:
  - Raging Waters Input: Use sounding data (single sounding) at all boundary faces
  - WRF Boundary Conditions: Unsteady Flow, Turbulence and Contaminant
  - WRF Boundary Conditions: Steady Flow ("Wind Library"), Frozen Hydro Contaminant Transport

	Near Source	R2	R3	R4	All
FAC2: RW	0.12	0.17	0.36	0.38	0.18
FAC2: Unsteady	0.08	0.17	0.36	0.38	0.16
FAC2: Quasi-Unsteady	0.57	0.42	0.36	0.5	0.51
MG: RW	25.42	14.11	4.58	5.06	15.83
MG: Unsteady	15.89	11.64	4.77	5.679	11.69
MG: Quasi-Unsteady	0.74	1.59	1.96	2.05	1.04

- Quasi-Steady approach appears to be best mode of operation:
  - Steady-state wind/turbulence fields at set intervals in time using WRF data as boundary conditions
  - Significantly improve FAC2 (FAC>0.5 acceptable) and MG (0.7<MG<1.3 acceptable)
- Unsteady flow/turbulence/transport: Time step restrictions
  - Too costly for accuracy or inaccurate because timestep too big

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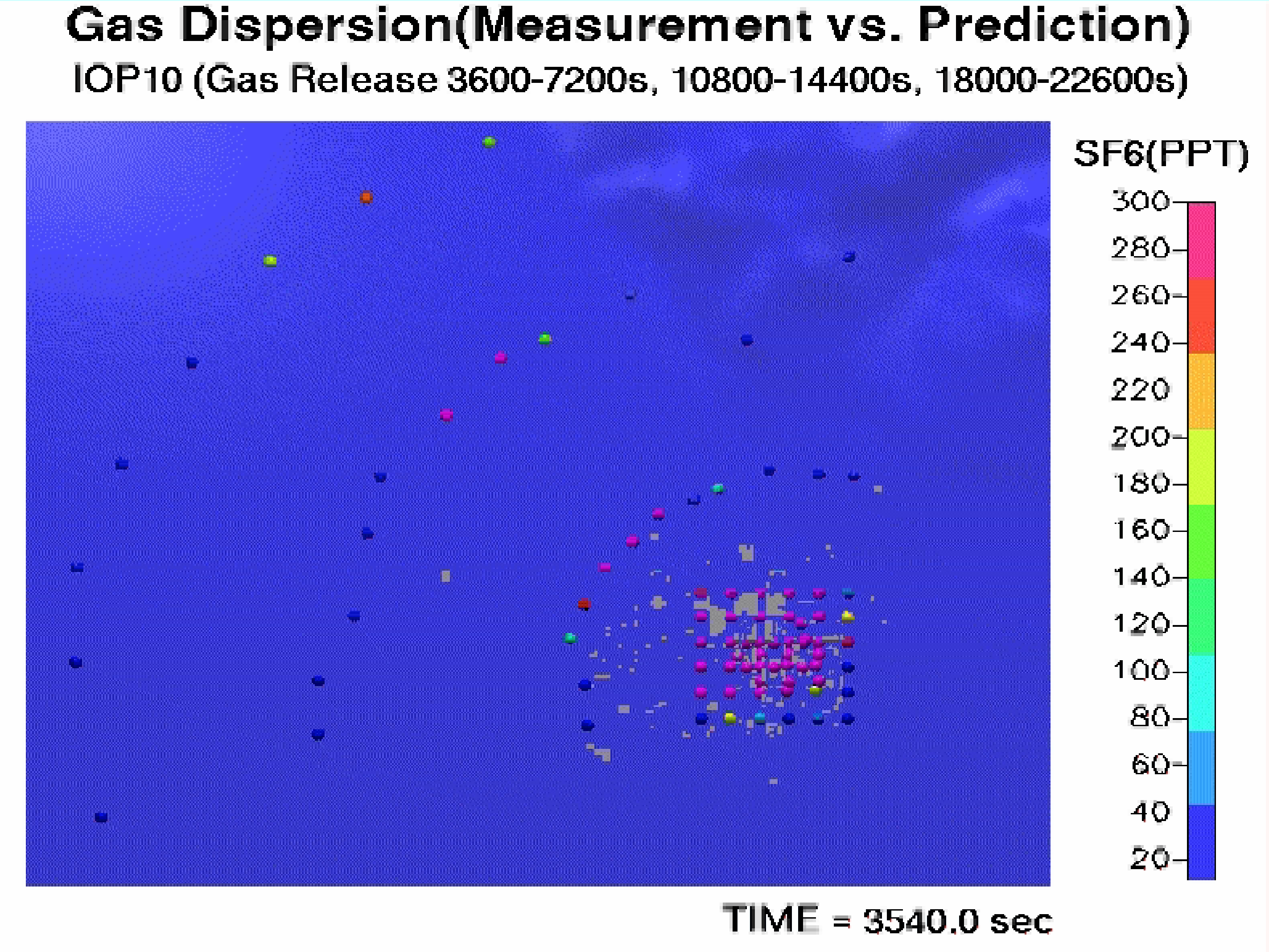
Preliminary Results: IOP 10 Urban 2000

- Entire IOP 10
    - 3 Releases/Pauses
- WRF/Noah Data for BC
- Quasi-steady approach:
    - Wind/Turbulence fields at 15 minute intervals
    - Unsteady T&D using Unified Frozen Hydro Solver
- Flow turning is replicated, which causes plume to travel NNW



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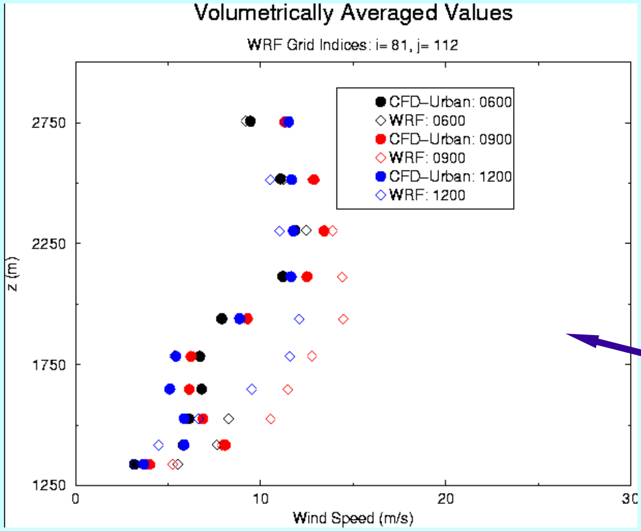
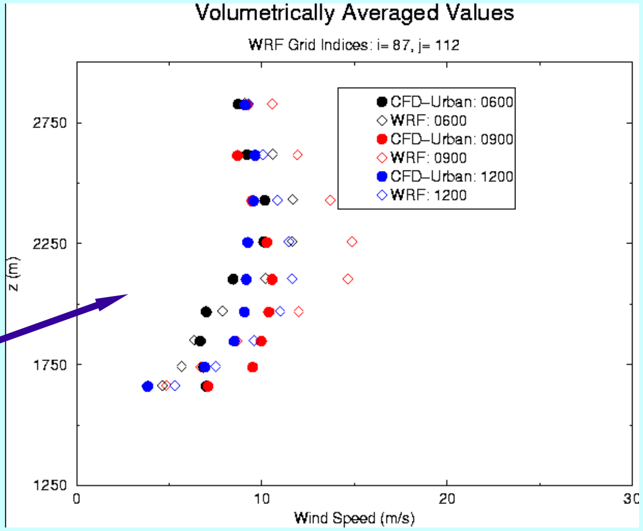
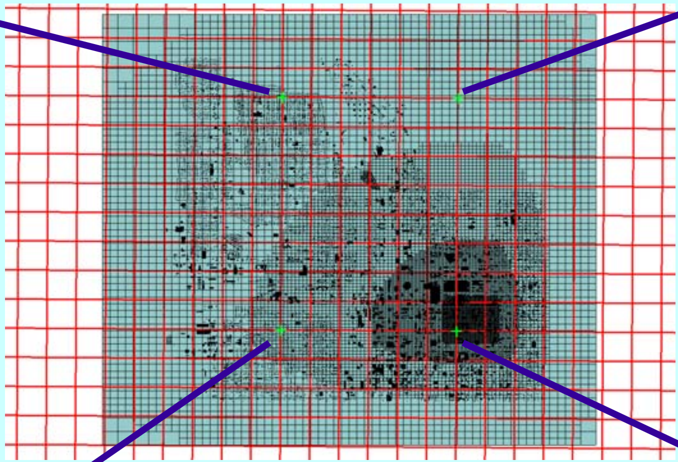
Preliminary Results: IOP 10 Urban 2000

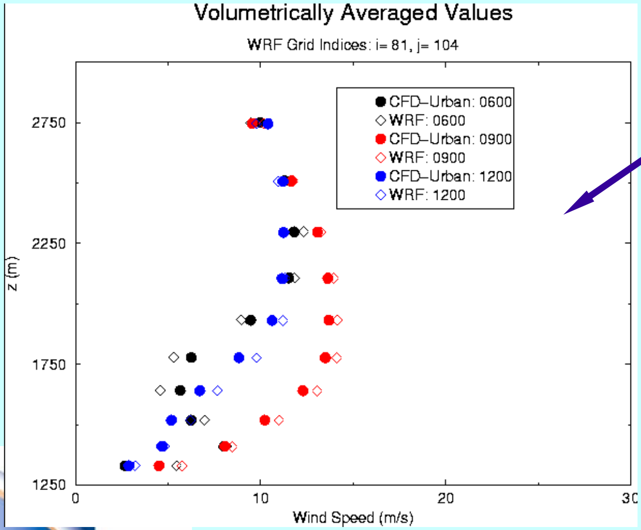


Compare Volumetrically Averaged CFD-Urban Field Quantities

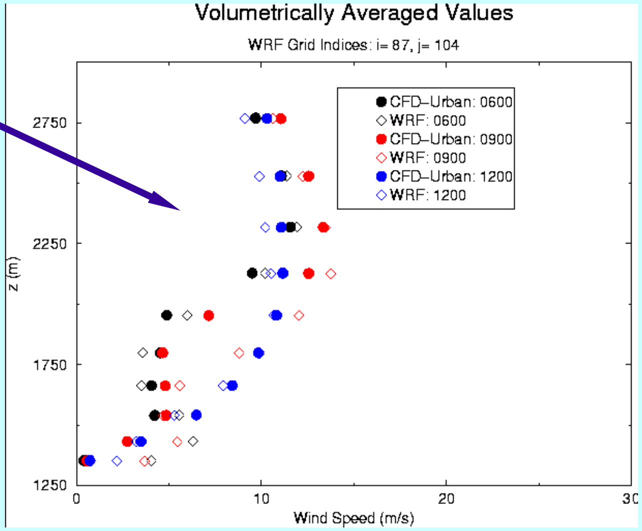
“Quasi-Steady” at 3 times







Wind Speed



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Conclusions and Future Work

- **High-res nested (0.5-km grid spacing) WRF simulations of wind field are reasonable (compared to obs and CFD results)**
- **Coupled WRF/Noah/UCM model generally produced better wind field and temperature than WRF-Noah model**
  - Performance of UCM is sensitive to the urban parameters
- **Using WRF forecast to drive CFD-urban model (quasi-steady) approach significantly improve CFD-urban and T&D results**
  - **4 to 5 times improvement in FAC2 and MG over single sounding as input (Raging Waters)**
- **Recommend WRF-to-CFD-Urban "coupling" using wind library and Unified Frozen Hydrodynamics Approach**
- **Phase-II: two-way coupling between WRF and CFD-urban**
  - utilize separate WRF and CFD executable, and ESMF coupler

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