An Evaluation of Mesoscale Model Predictions of Turbulence Kinetic Energy and Dissipation

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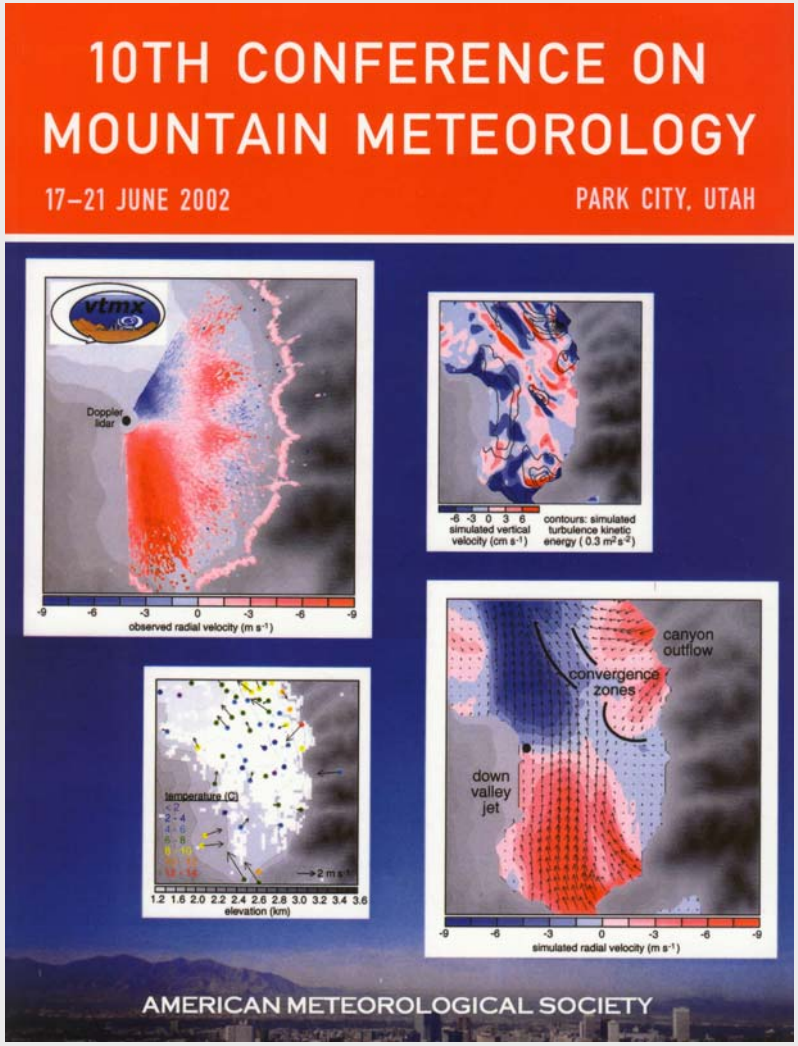
Accomplishments

Presentations at last year's VTMX Science Meeting have resulted in:

- **Zhong, S., and J.D. Fast, 2002: An evaluatin of MM5, RAMS, and Meso Eta at sub-kilometer resolution using VTMX field campaign data in the Salt Lake Valley, Accepted in *Mon. Wea. Rev.***
- **Fast, J.D., Forecasts of valley circulations using the terrain-following and step-mountain vertical coordinates in the Meso Eta model. To be submitted to *Mon. Wea. Rev.***

- **2 presentations at the *10th Conference on Mountain Meteorology***
- **2 presentations at the *15th Symposium on Boundary Layers and Turbulence***



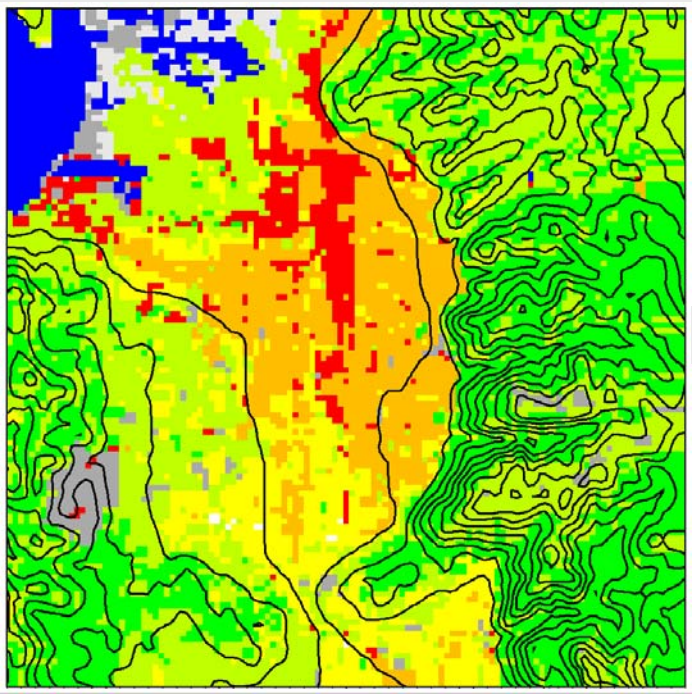
Mesoscale Model

Objective:

- **reconstruct local circulations with a high degree of confidence to evaluate the performance of the model in predicting TKE, dissipation rates, and surface momentum and heat fluxes**

Experimental Design for RAMS:

- **simulations of IOPs 6, 7, 8, and 10**
- **nested grids with Δx of 45, 15, 5, 1.7 km, and 555 m**
- **Δz = 15 m at the ground with 50 levels within 2 km of the surface (7, 22, 38, 54, 70, 87, 104, 122, …)**
- **updated land-use from USGS**
- **without data assimilation**



~ 54 km

Turbulence Parameterization

RAMS employs a Mellor-Yamada (1974, 1982) level 2.5 scheme based on a prognostic turbulent kinetic energy (e) equation, modified for growing turbulence (Helfand and Lagraga, 1988). Surface layer fluxes of heat, momentum, and moisture computed with the scheme of Louis (1979).

$$\frac{\partial e}{\partial t} = -\nabla \bullet (\vec{V} e) + \frac{\partial}{\partial z} K_e \frac{\partial e}{\partial z} + K_m \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right] - \frac{g}{\theta} K_h \frac{\partial \theta_v}{\partial z} + a_e \frac{e^{3/2}}{l}$$

transport	vertical mixing	shear production	buoyancy production	dissipation

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$$K_m = S_m l \sqrt{2e}$$

$$l = \left(\frac{1}{kz} + \frac{1}{l_o} \right)^{-1} \qquad l_o = \alpha \frac{\int_0^\infty e^{1/2} z dz}{\int_0^\infty e^{1/2} dz}$$

$$l \le 0.75 \left(\frac{2e}{\frac{g}{\theta} \frac{\partial \theta}{\partial z}} \right)^{1/2}$$

K = eddy diffusivity
S = nondimenional eddy diffusivity
l = length scale

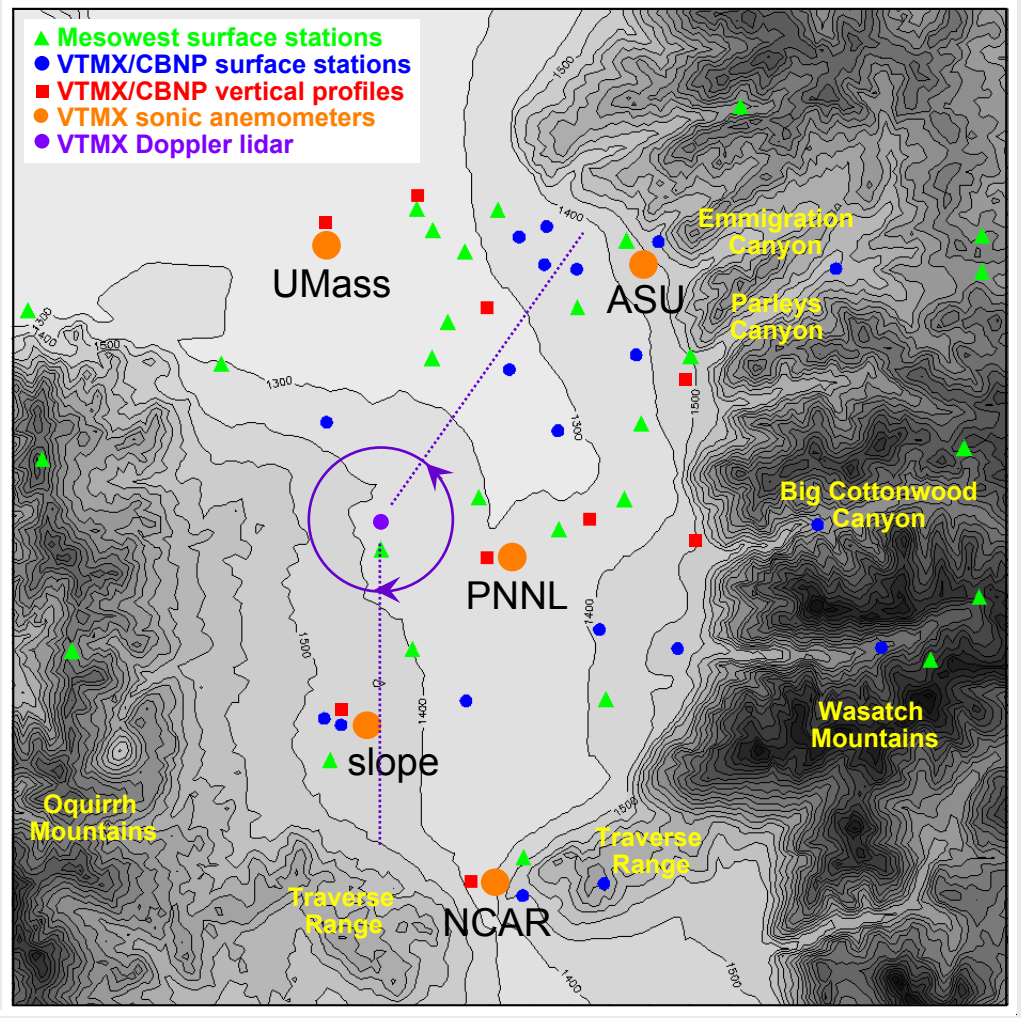
unstable and neutral conditions

stable conditions

VTMX Measurements

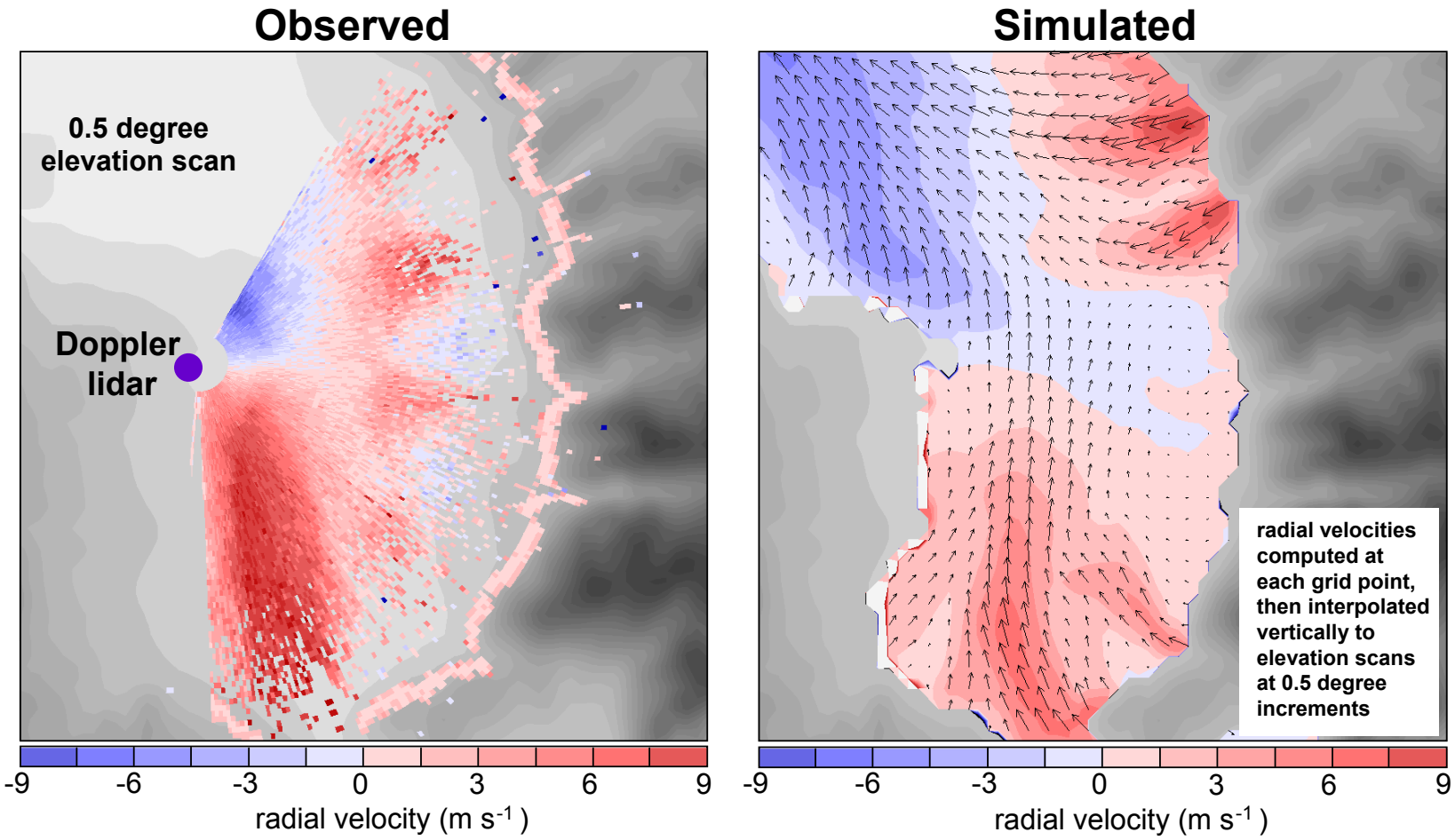
October 2000 measurements:

- Mesowest sfc stations
- VTMX / CBNP sfc stations
- VTMX / CBNP vertical profiles (radiosondes, radar wind profilers, sodars, tethersondes)
- VTMX sonic anemometers
  - UMass - 3.3 m AGL
  - ASU - 4.5, 13.9 m AGL
  - PNNL - 8.5 m AGL
  - NCAR - 8.2 m AGL
  - Slope - 9.1 m AGL
- VTMX Doppler lidar

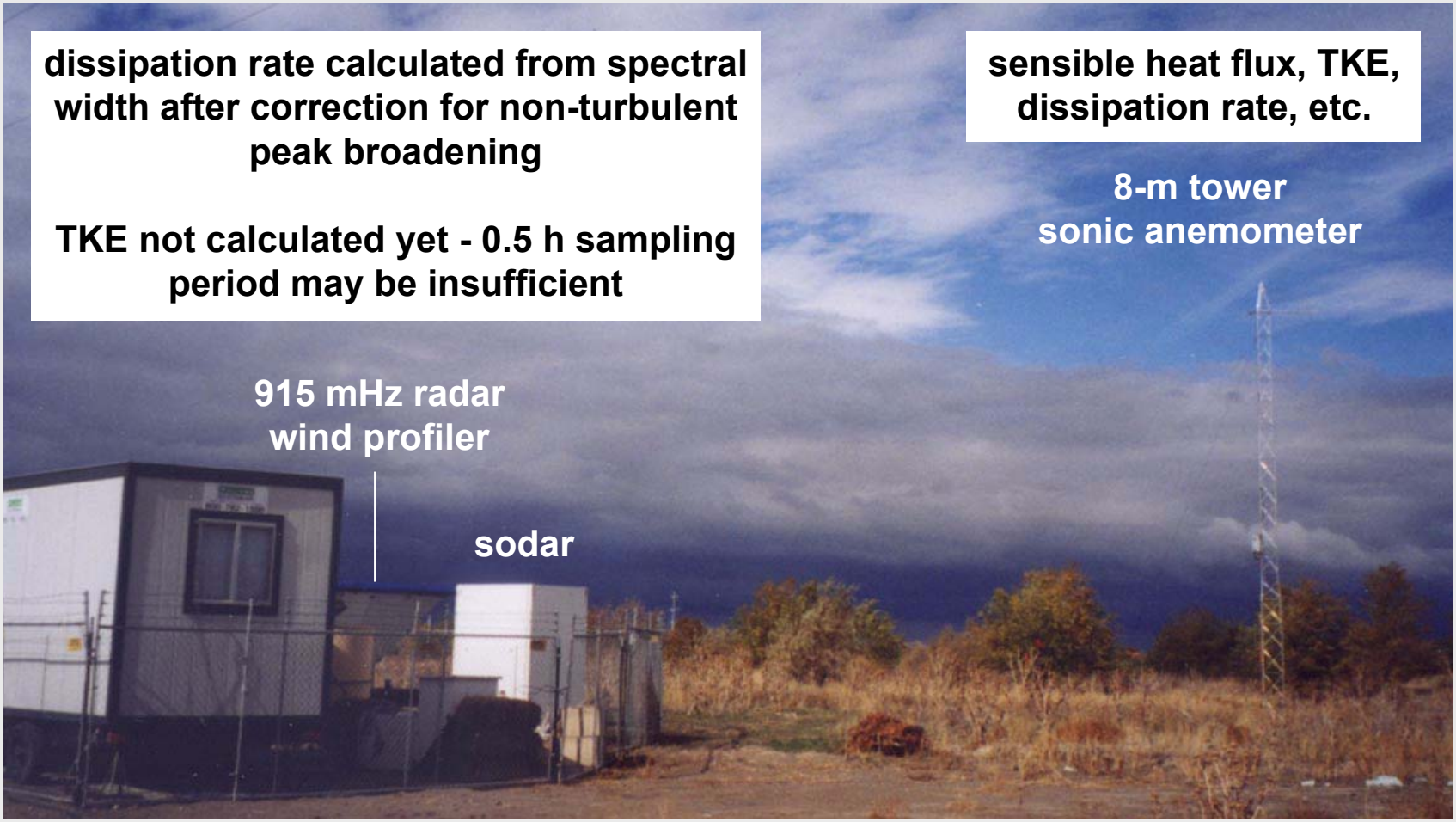


Valley Wind Field

1330 UTC (0630 MST) 20 October, IOP 8



PNNL Site


dissipation rate calculated from spectral width after correction for non-turbulent peak broadening
TKE not calculated yet - 0.5 h sampling period may be insufficient
sensible heat flux, TKE, dissipation rate, etc.
8-m tower
sonic anemometer
915 mHz radar
wind profiler
sodar

Observed vs Simulated TKE

Observed TKE:

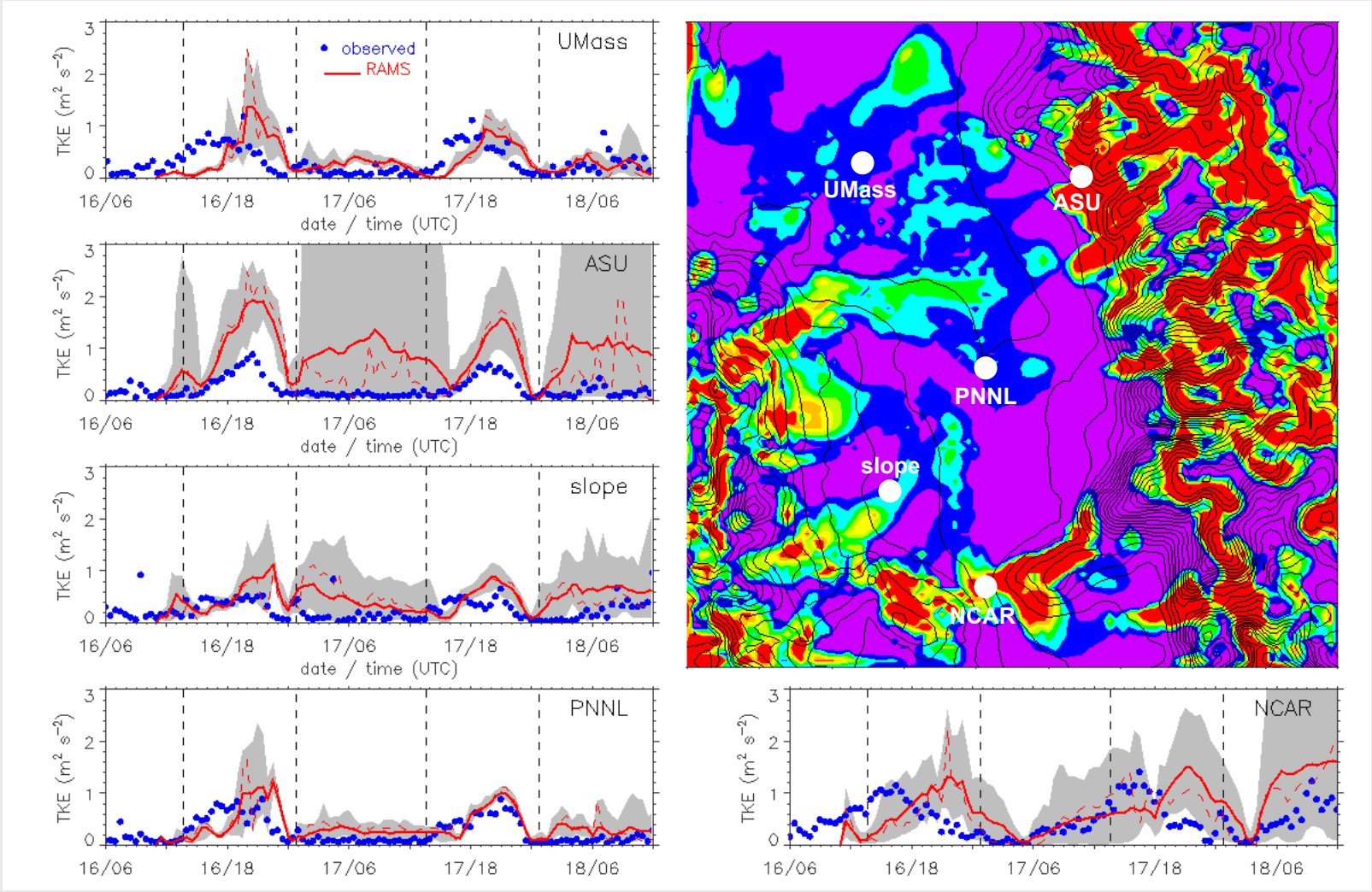
- point measurement
- 30-min averages, no de-trending
- TKE derived from 0.1 s u'^2, v'^2, w'^2 data

Simulated TKE:

- grid volume, 555 x 555 x 7 m cell
- instantaneous quantities every 30 min
- u'^2, v'^2, w'^2 not solved directly - TKE derived from prognostic equation (which is what we want to evaluate)

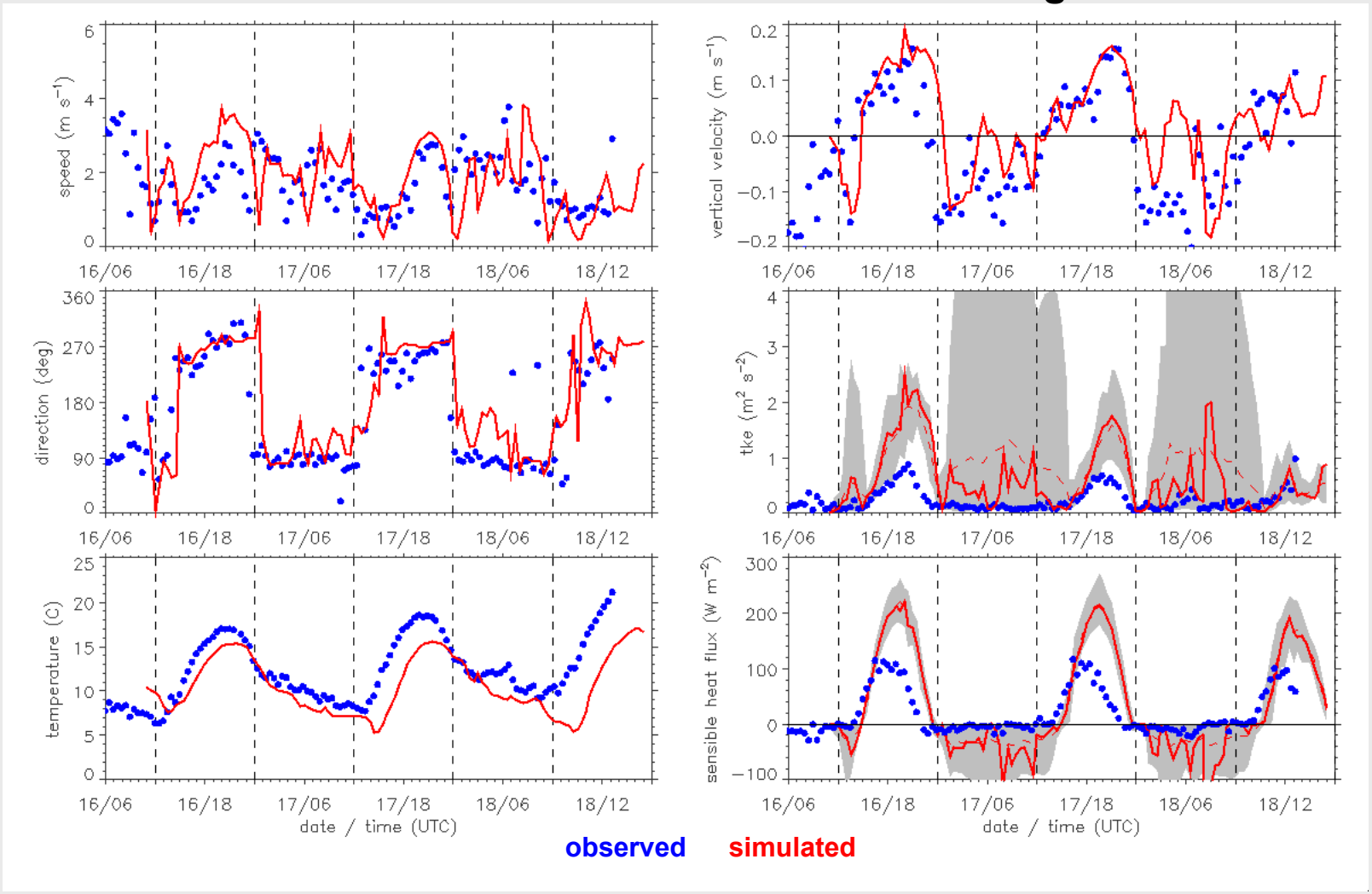
Are observed and simulated quantities comparable?

TKE during IOPs 6 and 7



Slope Flow at ASU Site

Observed and Simulated Values at ASU Site during IOPs 6 and 7



Eddy Diffusivity

Since temperature also available at two levels (4.5 and 13.9 m AGL) at the ASU site, observed K_h can be calculated from:

$$w'\theta = K_h \frac{\partial \theta}{\partial z}$$

Observed K_h:

- **daytime: 0.05 - 0.25 $m^2 s^{-1}$**
- **nighttime: < 0.05 $m^2 s^{-1}$**

Simulated K_h:

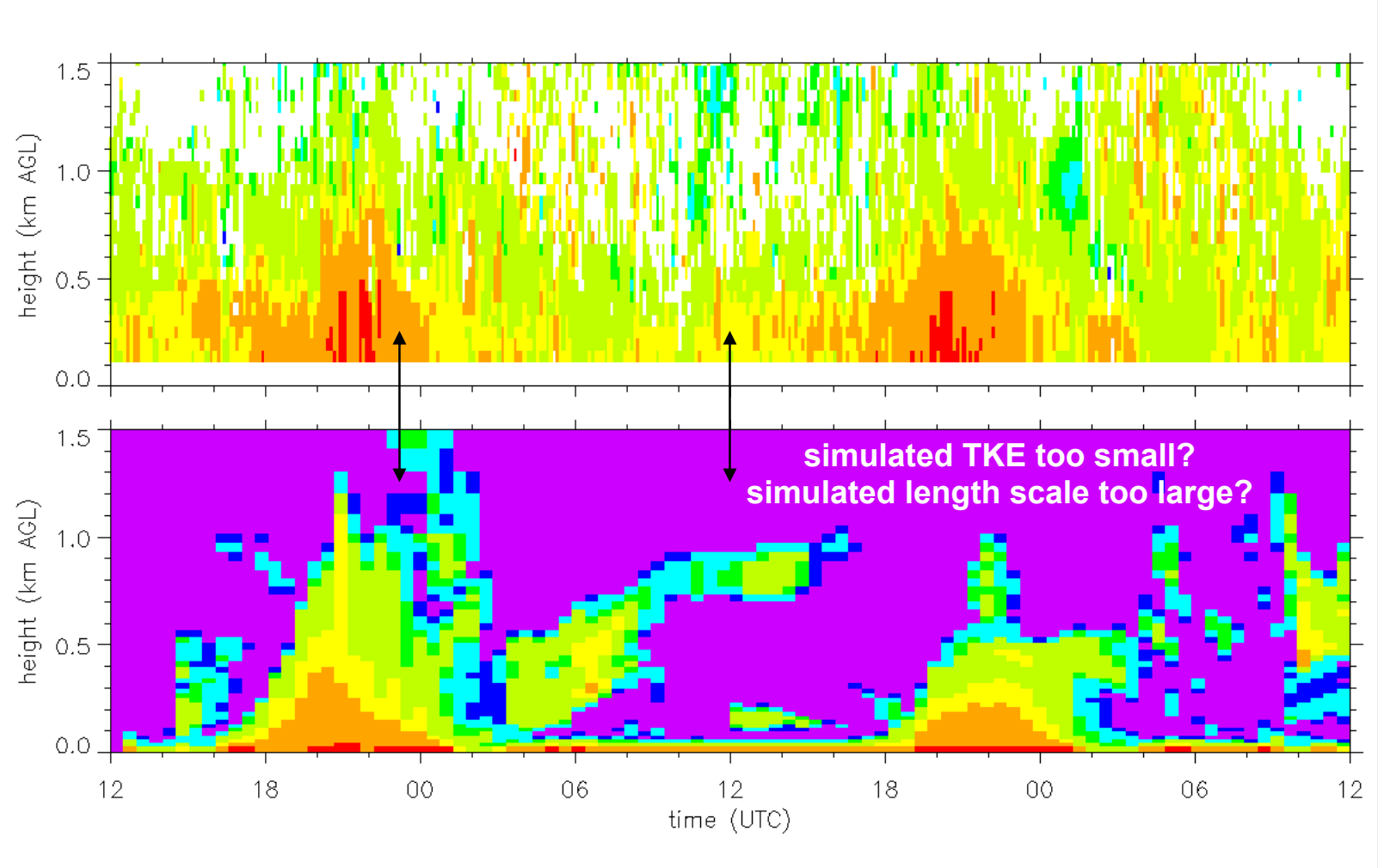
- **daytime 1 - 4 $m^2 s^{-1}$**
- **nighttime: 0.5 - 2 $m^2 s^{-1}$**

➔ **simulated K_h are too high, similar to simulated TKE and dissipation rates, indicating that the model produces too much vertical mixing near the ground**

How does the model perform aloft?

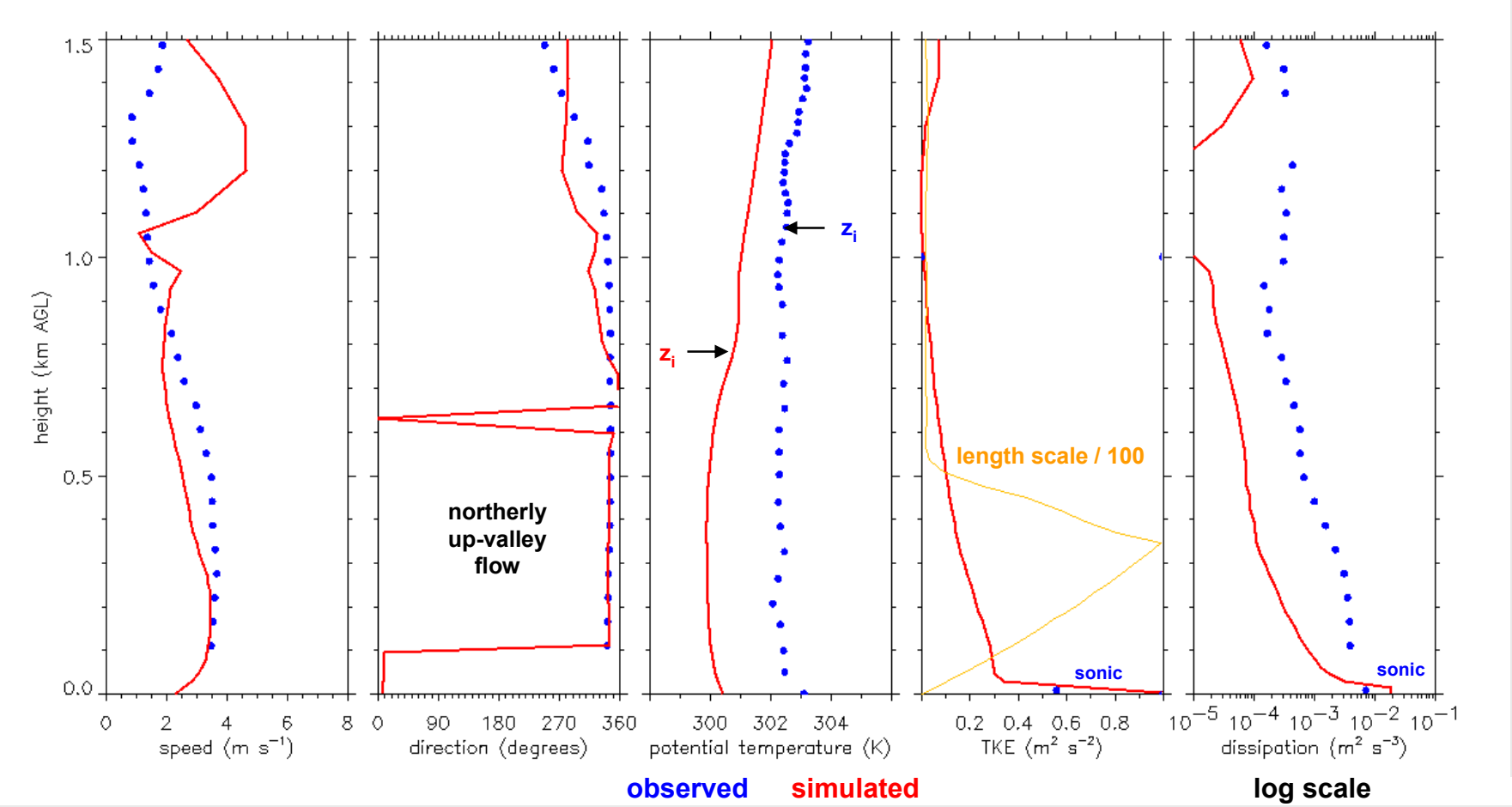
Dissipation Profiles

Observed and Simulated Dissipation at the PNNL Site during IOPs 6 and 7



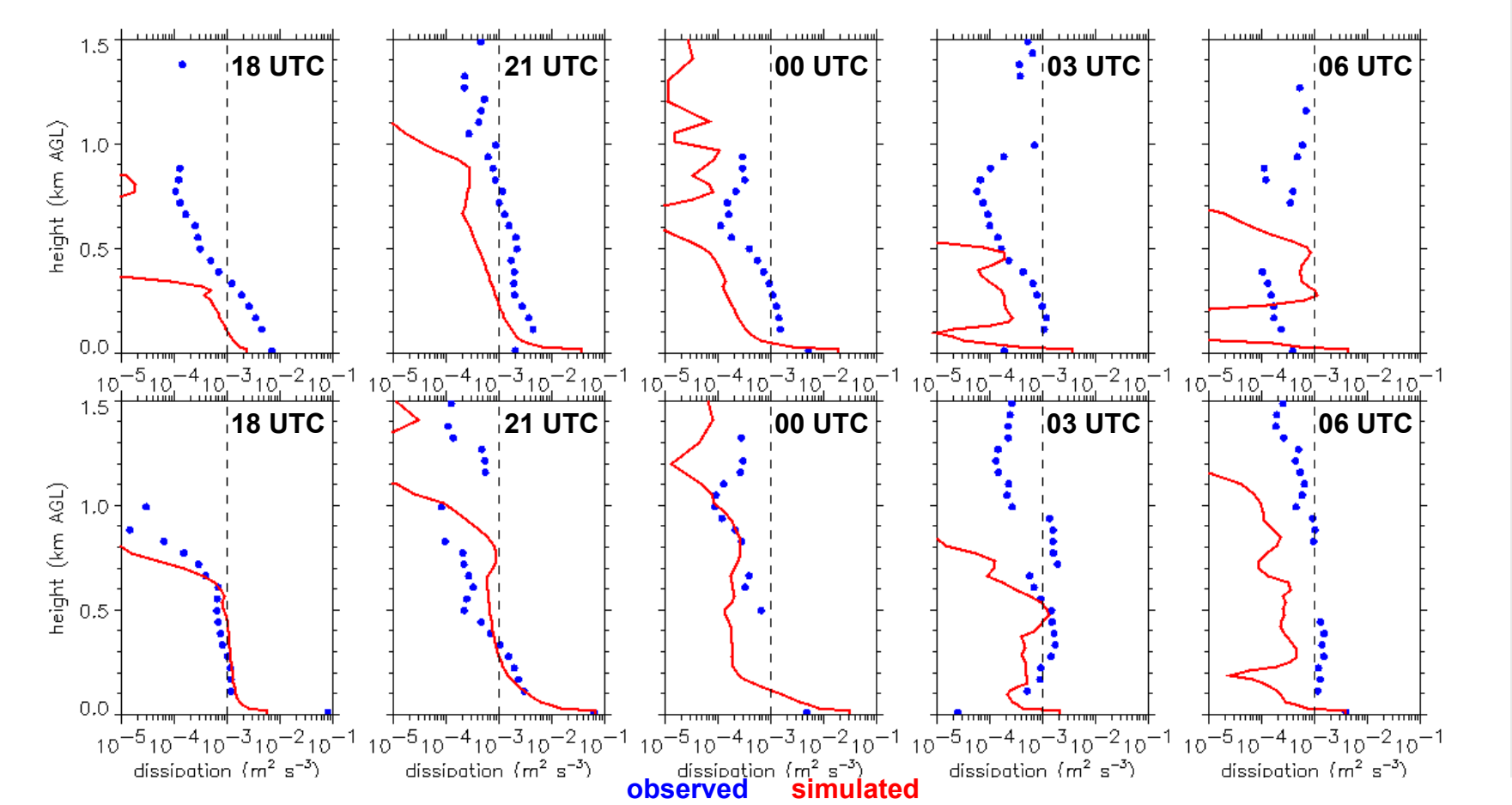
Afternoon Profiles

Profiles at PNNL Site at 23 UTC (16 MST) 16 October
(temperature profiles at Wheeler Farm site)



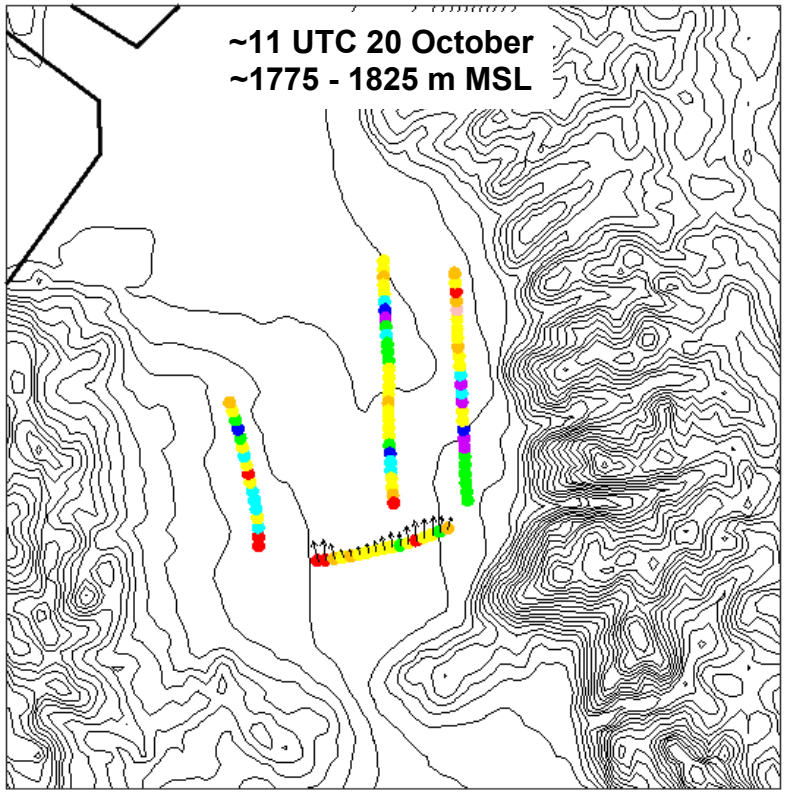
Effect of Synoptic Forcing

Dissipation Profiles at PNNL Site for Weak Ambient Winds IOP 6 (top) and Strong Ambient Winds IOP 10 (bottom)

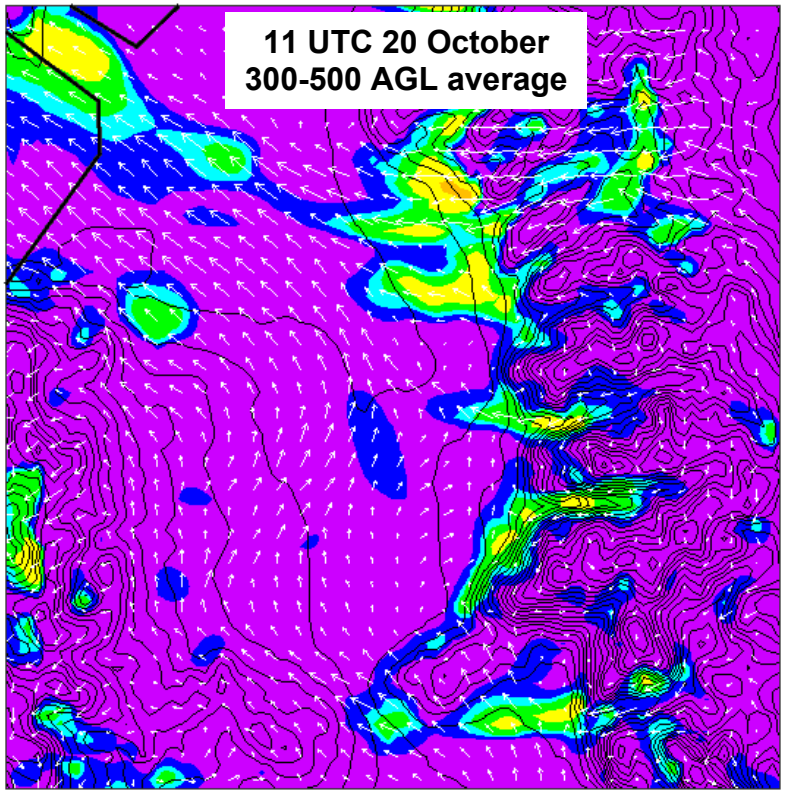


LongEZ: IOP 8

Observed TKE and winds



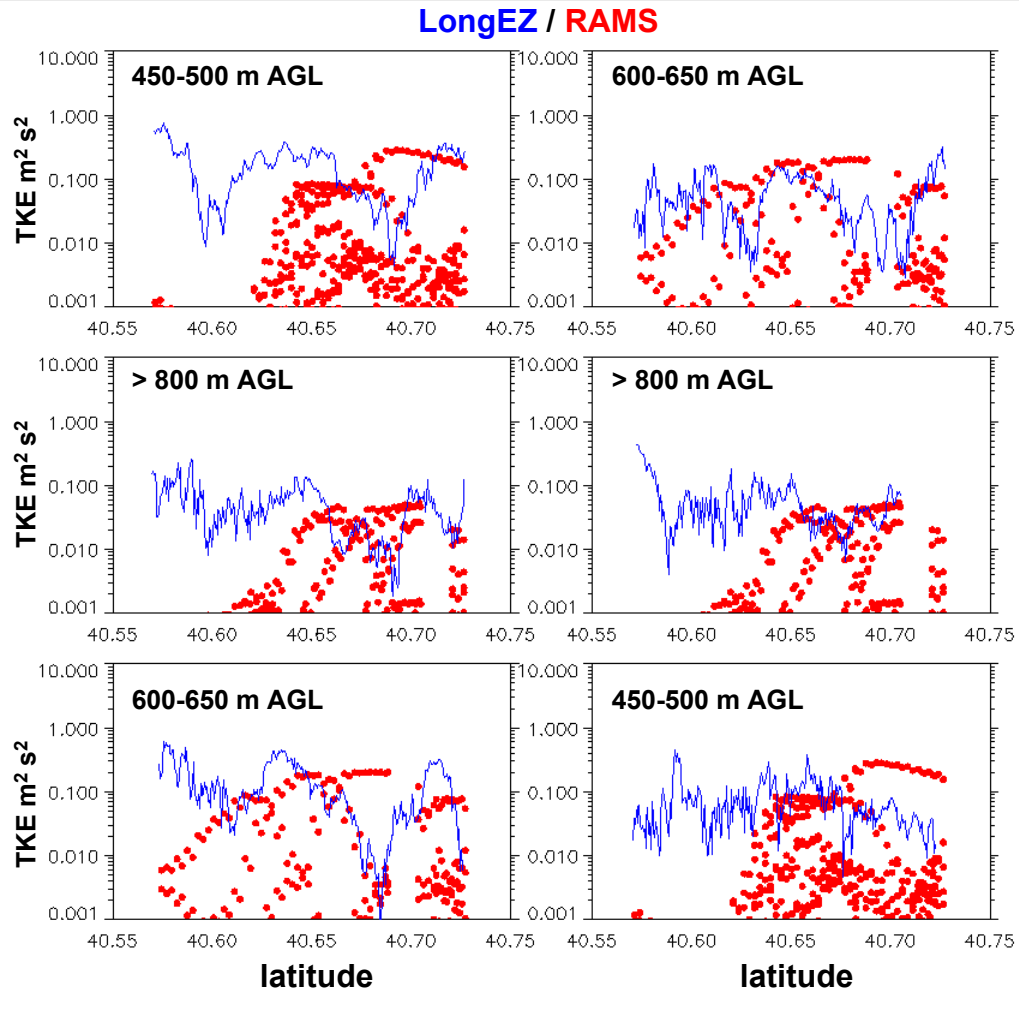
Simulated TKE and winds



< 0.1 0.1-0.3 0.3-0.5 0.5-1.0 1.0-3.0 3.0-5.0 > 5 $m^2 s^2$

- **peak simulated values similar to observations, but TKE significantly under-predicted over the valley center**

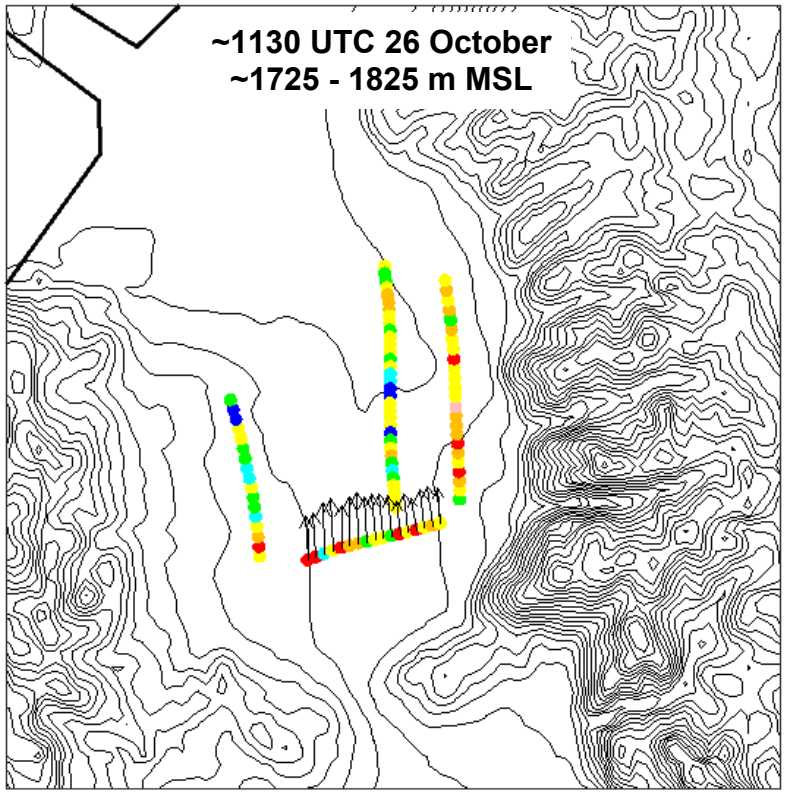
TKE Aloft: IOP #8



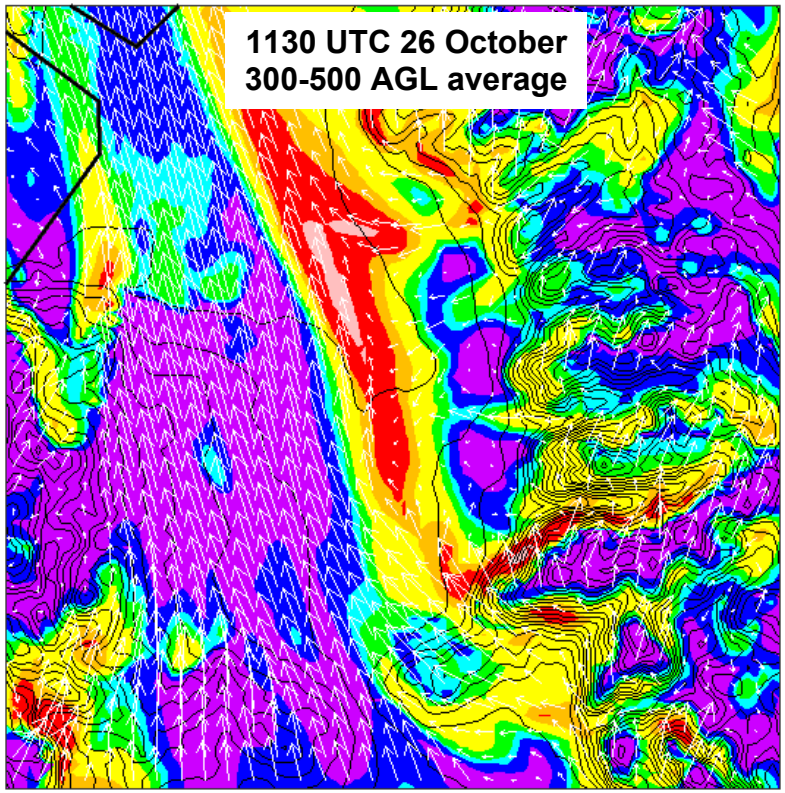
- observed transects between 11 and 1230 UTC 20 August
- simulated results between 10 and 14 UTC

LongEZ: IOP #10

Observed TKE and winds



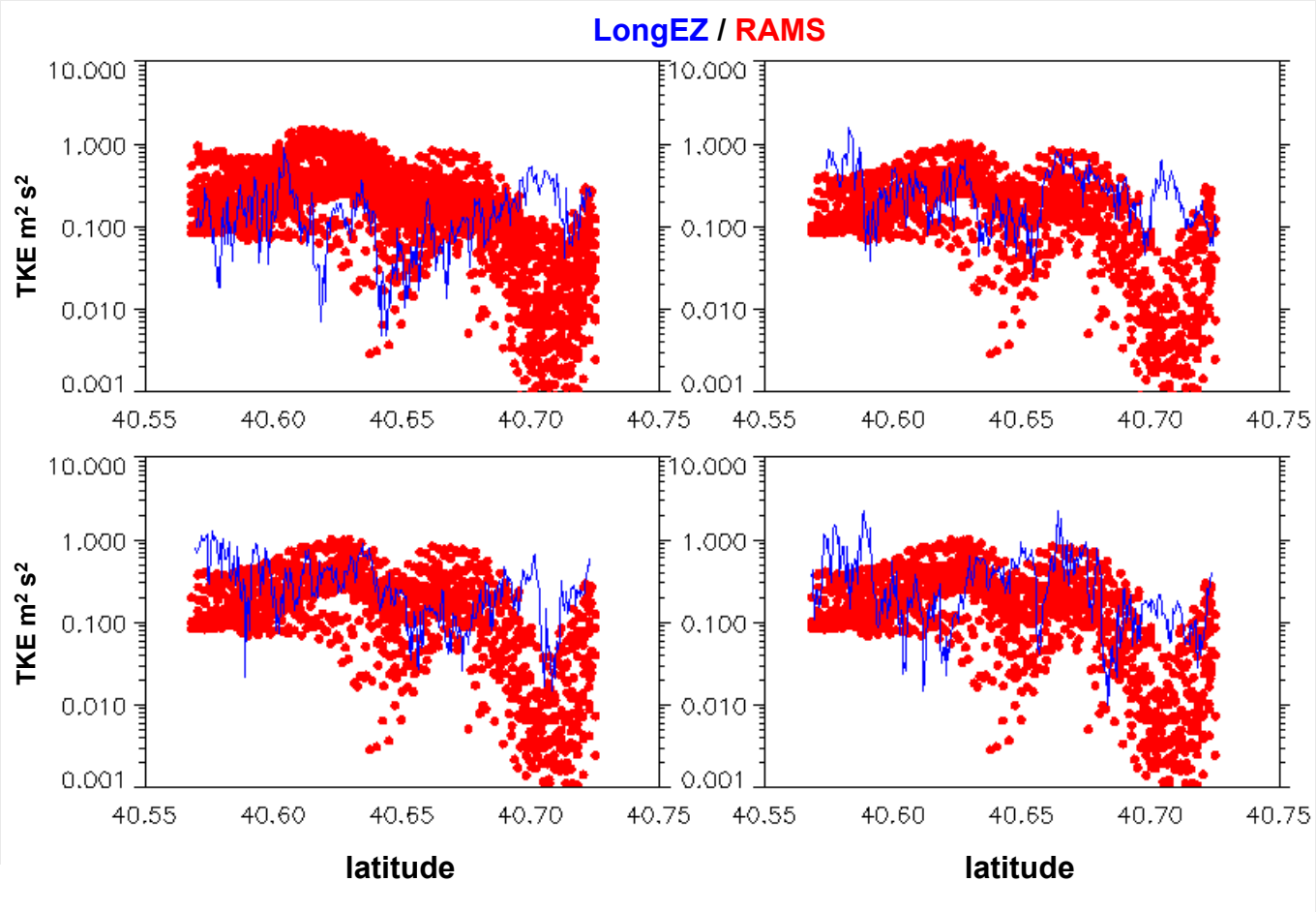
Simulated TKE and winds



< 0.1 0.1-0.3 0.3-0.5 0.5-1.0 1.0-3.0 3.0-5.0 > 5 $m^2 s^2$

- simulated TKE closer to observations than in IOP #8

TKE Aloft: IOP #10



- observed transects between 1130 and 1230 UTC 26 August
- simulated results between 10 and 14 UTC

Summary

- mesoscale model reproduced many of the observed local circulations including valley, slope, and canyon flows
- at times, trends in the simulated TKE and dissipation rates were very similar to trends of the sonic anemometer measurements, but ...
  - at the surface, magnitudes of the simulated TKE and dissipation rates were usually a factor of two higher than observed at night
  - aloft, simulated dissipation rates and TKE were usually an order of magnitude too small
  - performance depends on synoptic forcing - simulated TKE and dissipation rates at the surface and aloft closer to observations during strong ambient wind case (IOP 10)
- model often reproduced observed mean quantities even though there were relatively large errors in turbulent quantities
- higher vertical resolution not necessarily the solution
- next step: evaluate other turbulence parameterizations