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Sensitivity of Vertical Structure in the Stable Boundary Layer to Variations of the WRF Model's Mellor-Yamada-Janjic Turbulence Scheme

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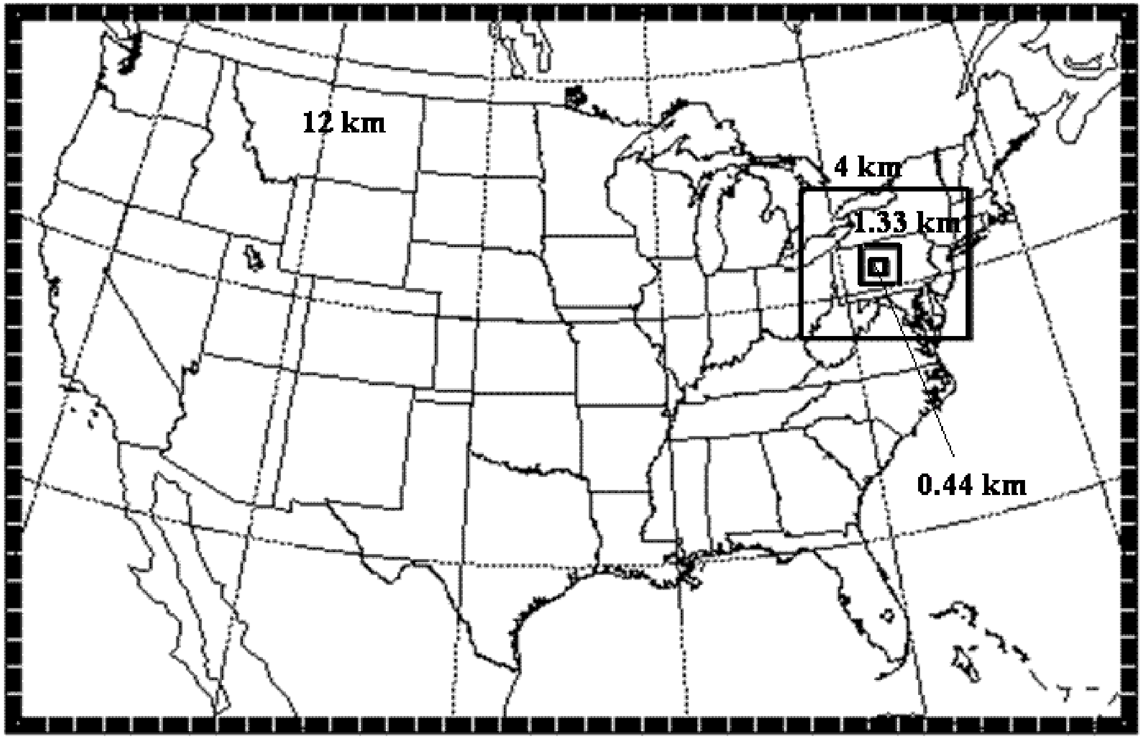
WRF Horizontal Configuration

- WFR-ARW configured with 4 nested domains:

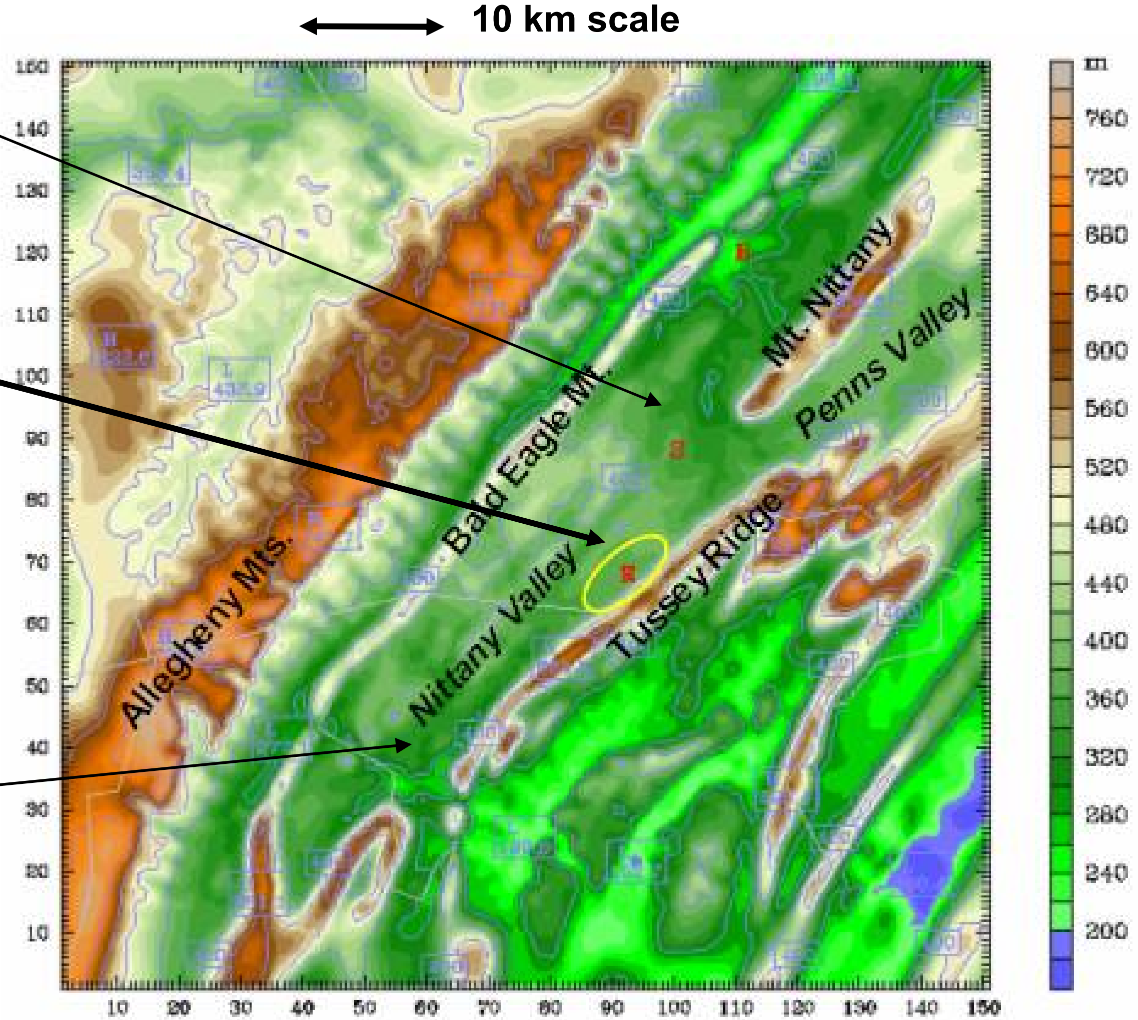
- 12 km: 421 X 271 pts
- 4 km: 193 X 169 pts
- 1.33 km: 121 X 121 pts
- **<u>0.444 km: 151 X 151 pts</u>**



- Sub-kilometer resolution is necessary to resolve fine-scale terrain important for shallow SBL flows.

- WRF wall clock **run time** on 4 nodes (dual 3 GHz cores): ~3 h per 12h fcst.

Topography of Central PA
0.444-km domain



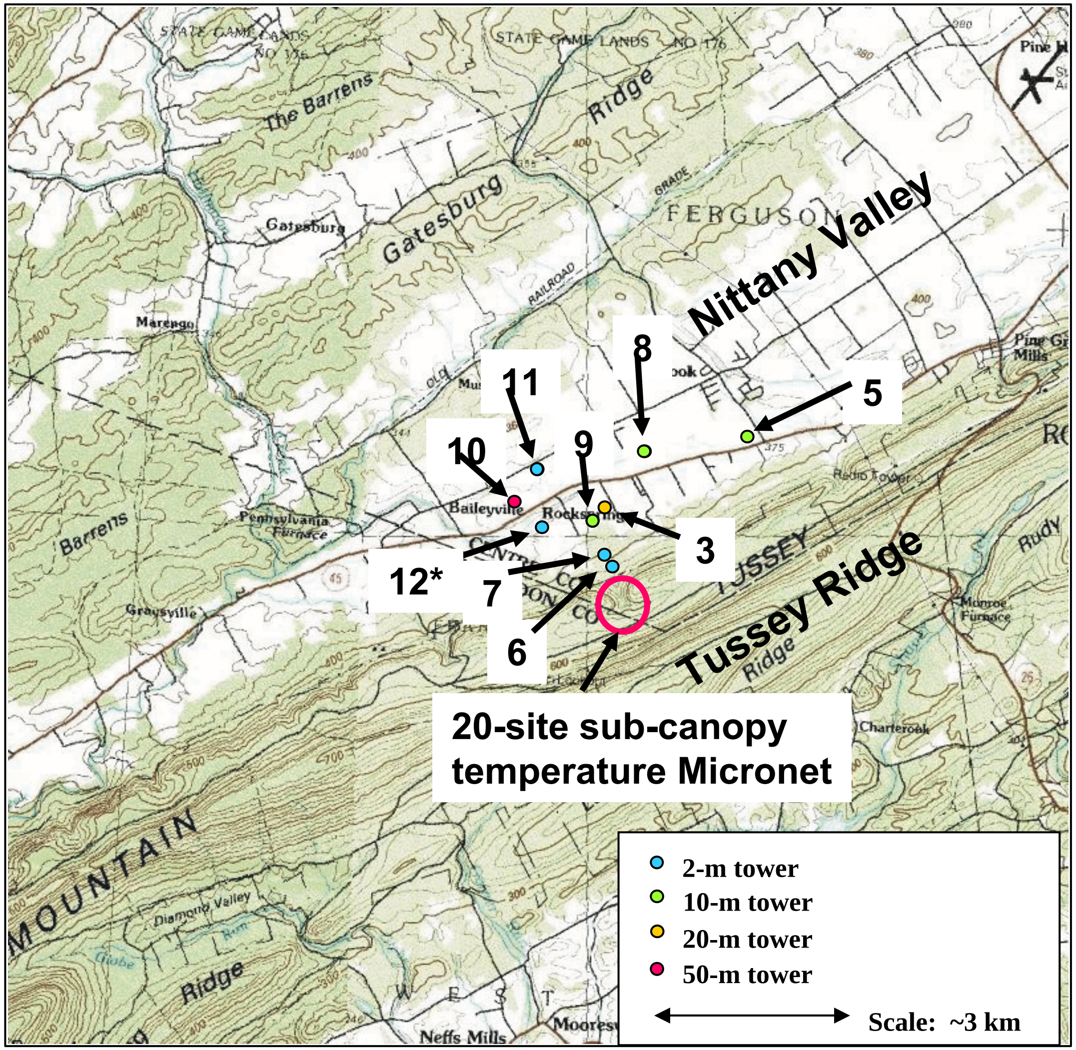
Spring Creek Watershed – drains to north

Field Site:

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

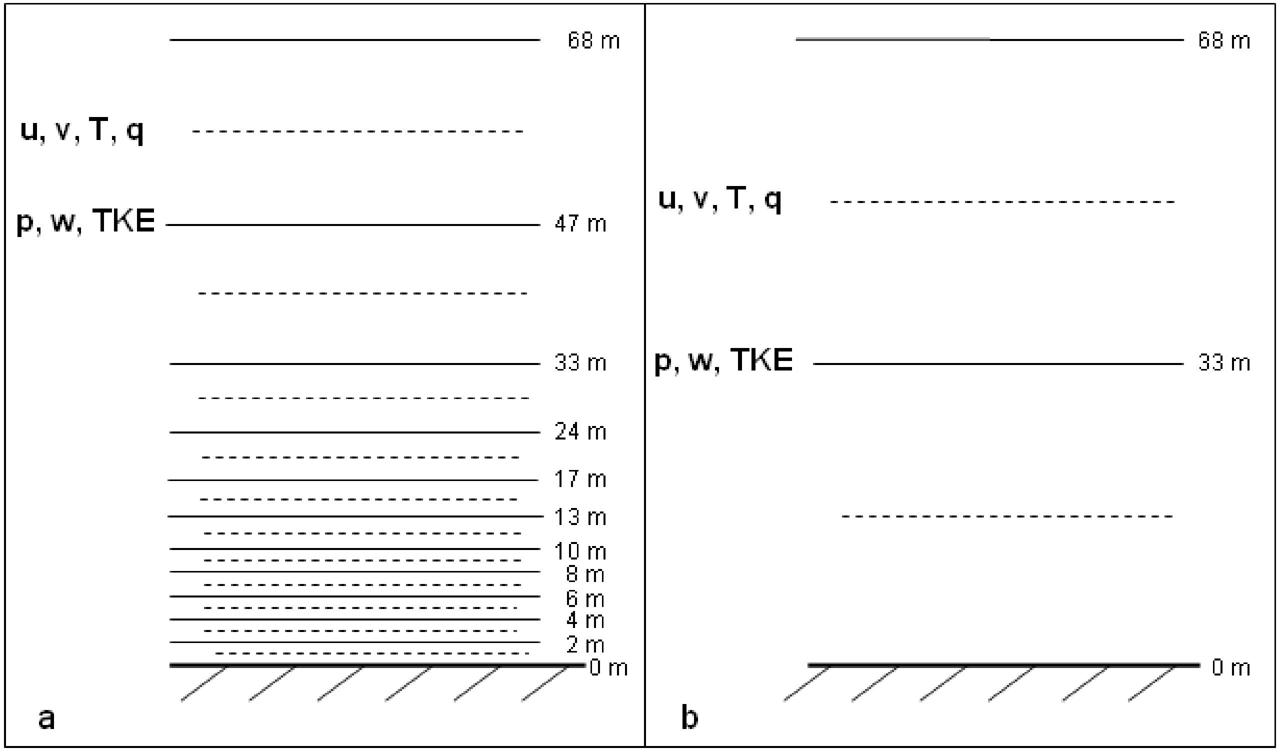
Spruce Creek Watershed – drains to south

Rock Springs Observing Network



WRF Vertical Grid Configurations

- WRF Exp. Baseline is configured with 43 layers; model top at 50 mb.
- Lowest five layers have ΔZ = 2 m, gradually increasing upwards
- 11 layers below 68 m AGL.



Baseline configuration
43 layers

Low vertical resolution
34 layers

WRF Grid Configurations and Experiment Design

1. Resolution experiments:

Baseline Physics:
- MYJ PBL
- Simple ice physics
- Dudhia shortwave
- RRTM longwave
- 5-layer soil model

Exper. Name	Horiz. Grid (km)	Sfc. Layer Depth (m)	Layers Below 68 m
Baseline	0.444	2	11
LrgDZ	0.444	30	2
LrgDX	1.333	2	11
LrgDXDZ	1.333	30	2

2. Turbulence physics experiments:

Exper. Name	Physics Scheme	TKE_{MIN} (m^2s^{-2})	l_B (m)
MYJ std	MYJ	0.10	0.32
QNSE std	QNSE	0.01	0.32
MYJ mod	MYJ	0.01	0.10

All experiments are run for 12 h during the nocturnal period, 0000 – 1200 UTC.

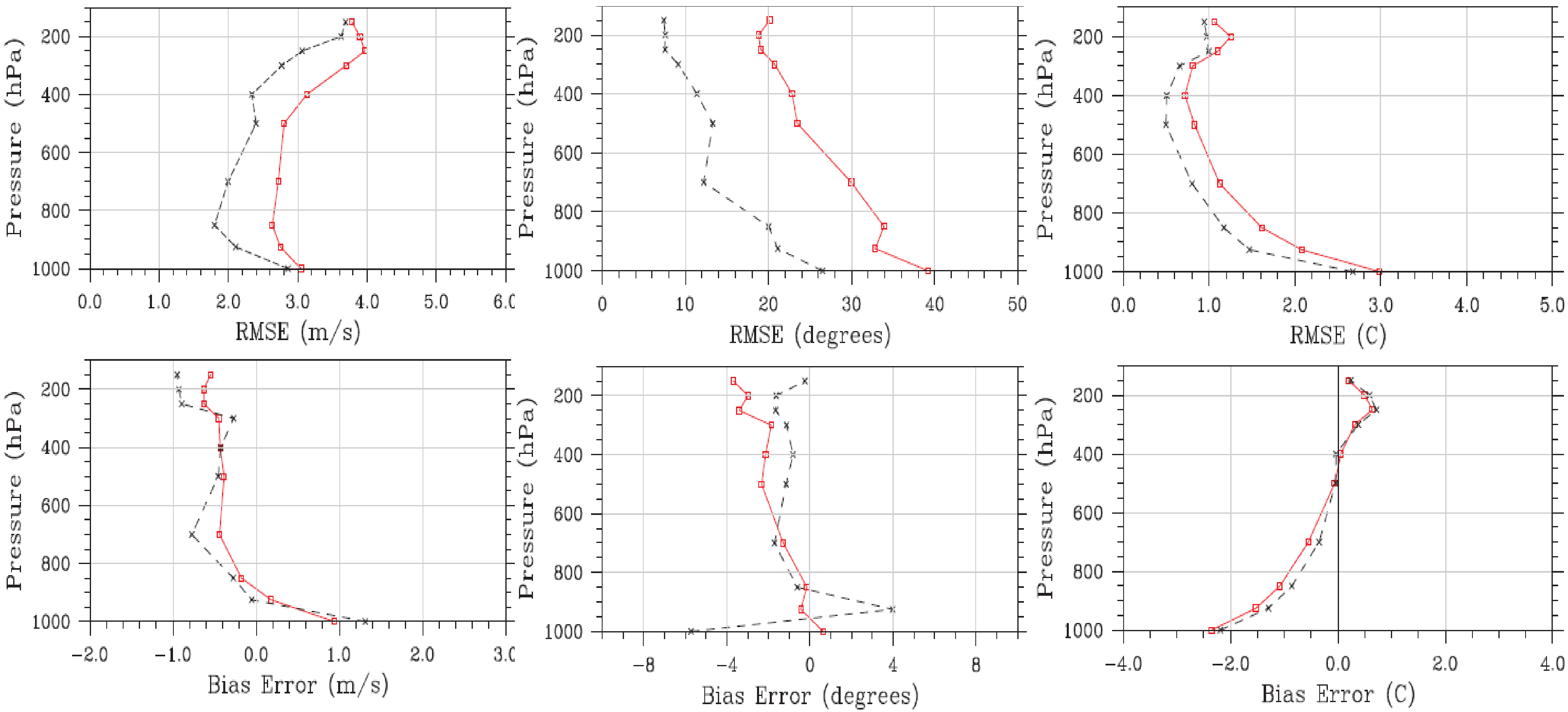
Coarse Domain Evaluations

19-case composite, Oct.-Nov. 2007

12-km CONUS domain: Red; 4-km regional domain: Black

All coarse-domain statistics based on Exp. Baseline, with standard MYJ scheme

Wind Speed Error **Wind Direction Error** **Temperature Error**



Fine Domain Evaluations

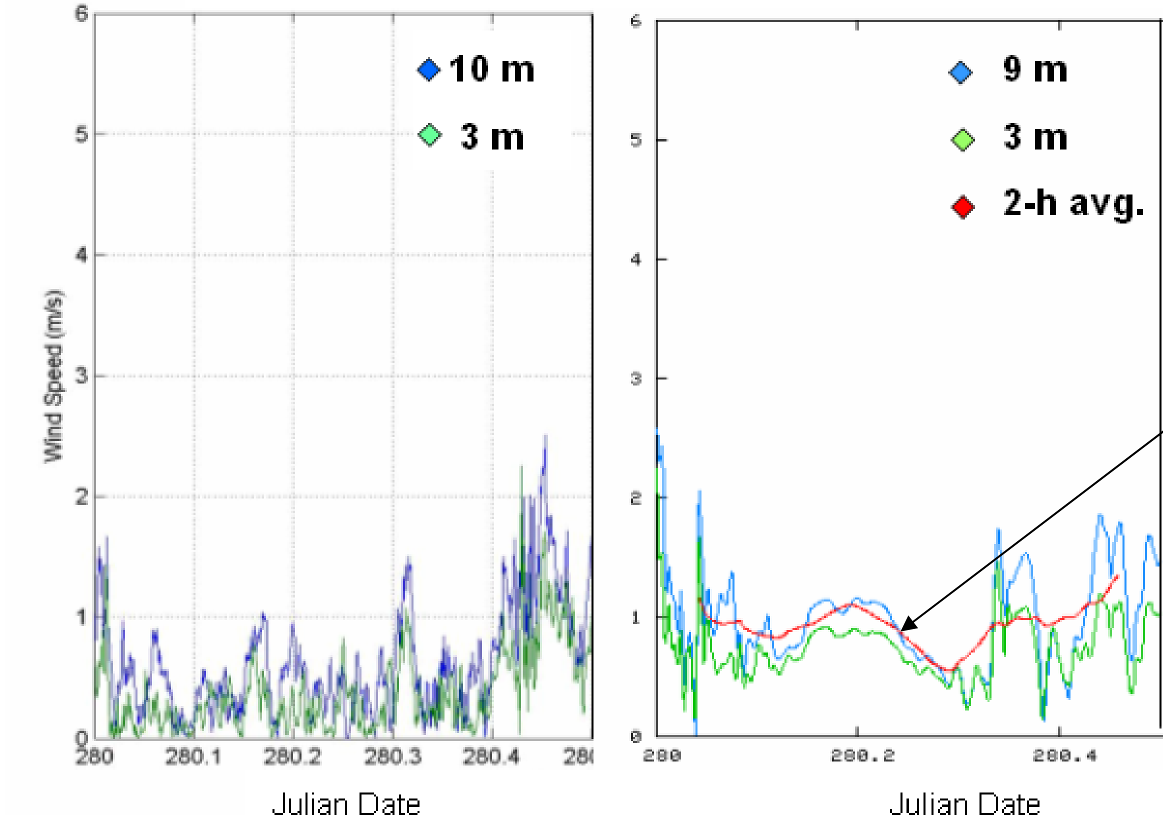
Oct.-Nov. 2007

Wind Speed at Rock Springs, PA

One-minute time series data

Case: 7 October 2007, 0000-1200 UTC

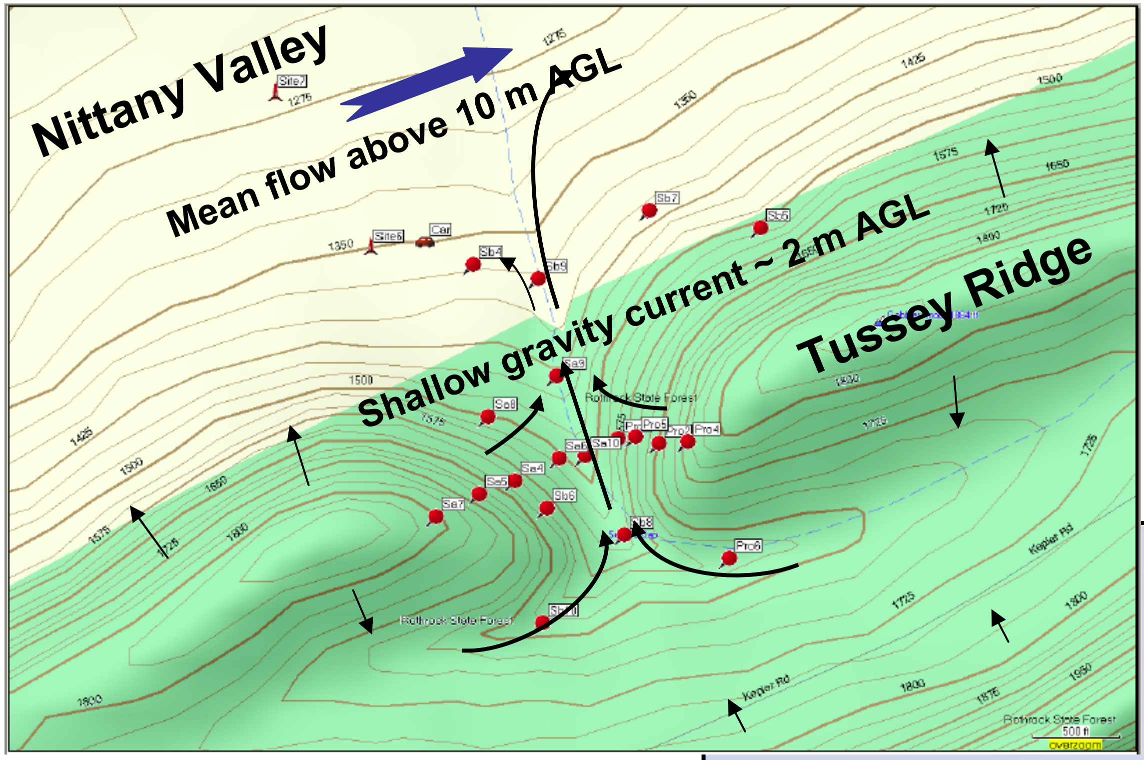
Observed WRF-Predicted



Red curve:

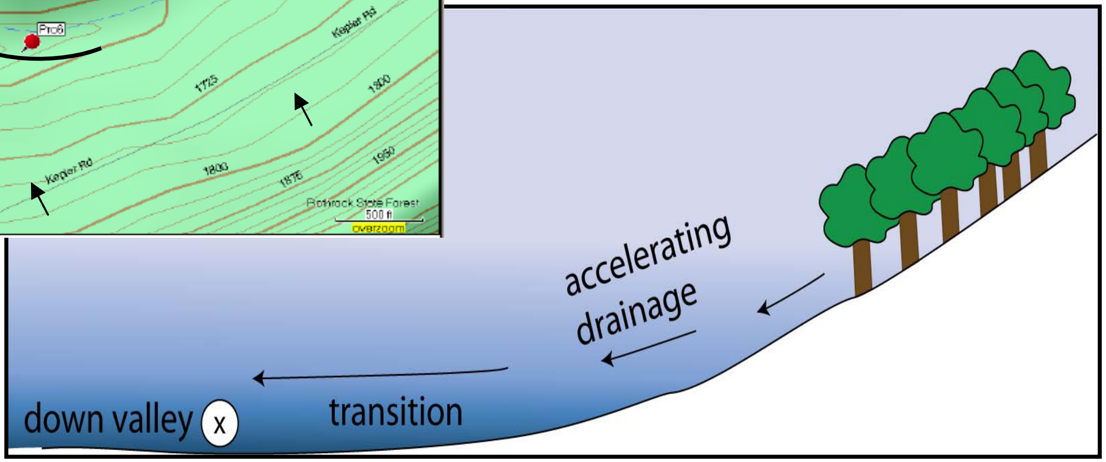
2-h running mean filter is applied to local time series data to remove sub-meso fluctuations prior to statistical evaluations.

Nocturnal gravity-driven drainage flow modulated by transient submeso motions



Conceptual model:

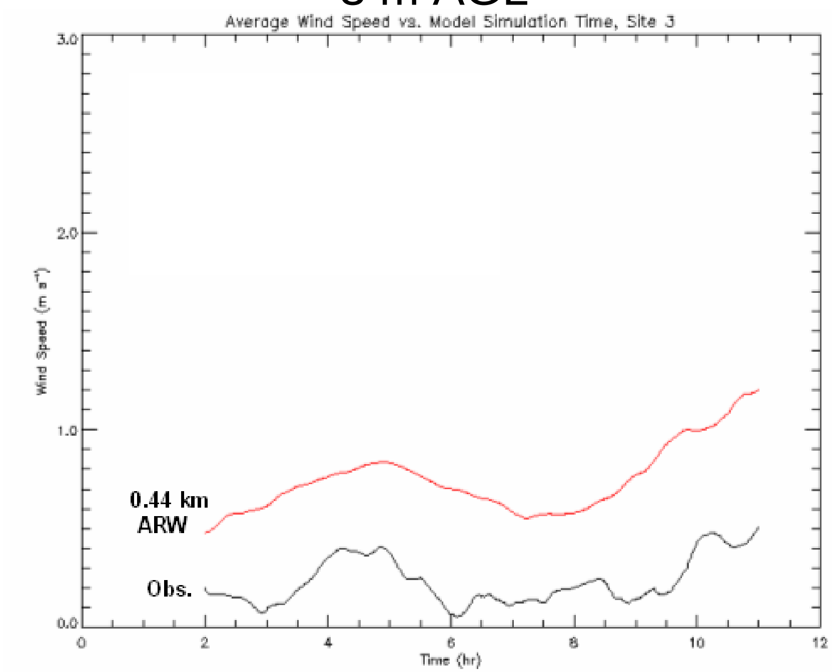
Shallow gravity-driven drainage flow overrides coldest air on valley floor, gradually filling Nittany Valley.



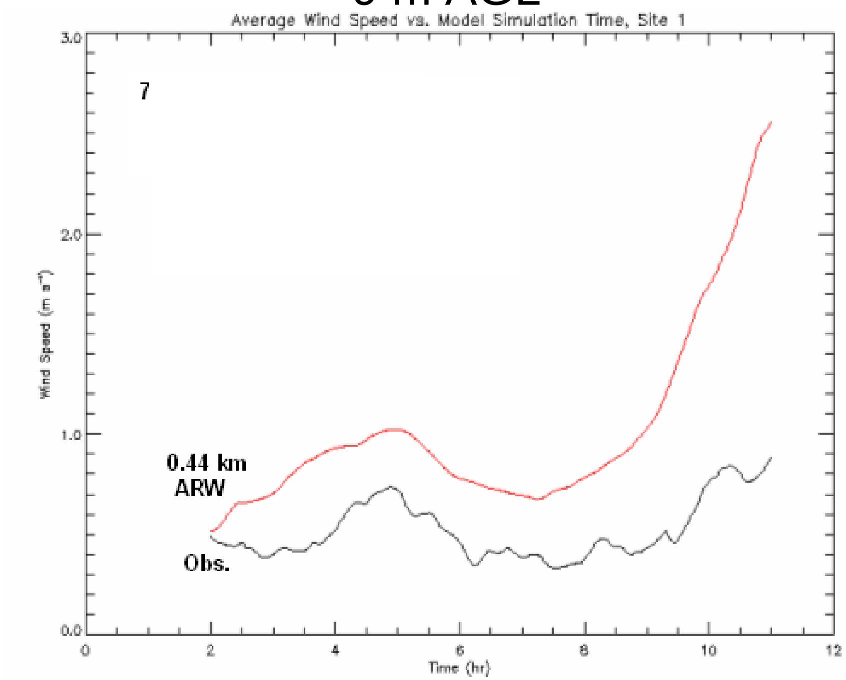
Wind Shear at Rock Springs In Stable Boundary Layer

Case study: 7 October 2007, Exp. Baseline

3 m AGL



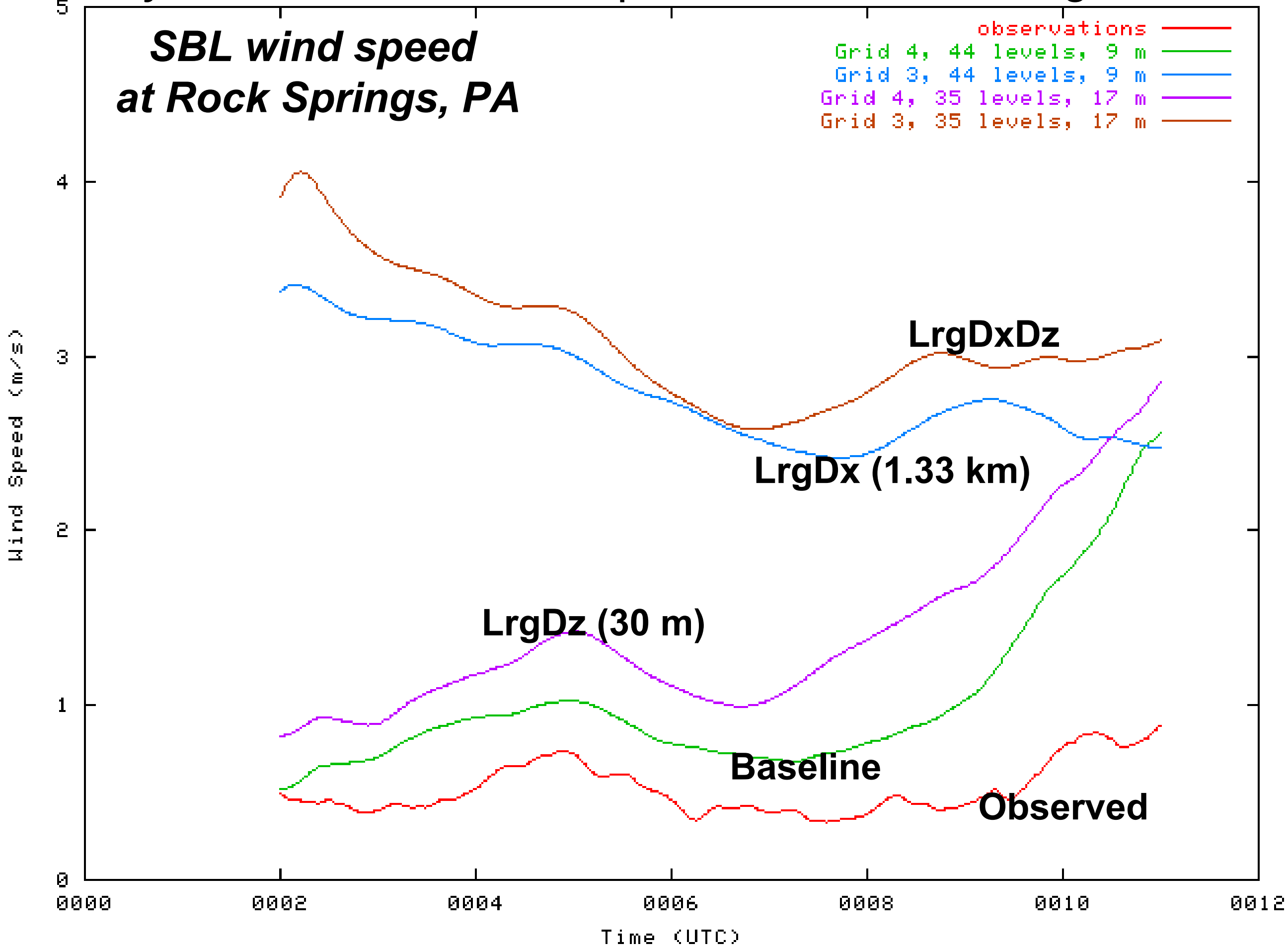
9 m AGL



- Wind increases with height, as observed.
- Good correlation with observed trends.
- Positive speed bias: Bias Error ~0.5 ms-1 at 3m
  Bias Error ~0.7 ms^{-1} at 9 m

Sensitivity of Wind Speed to Horizontal and Vertical Resolution

Case study: 7 October 2007, Exp. Baseline height: 9-m AGL

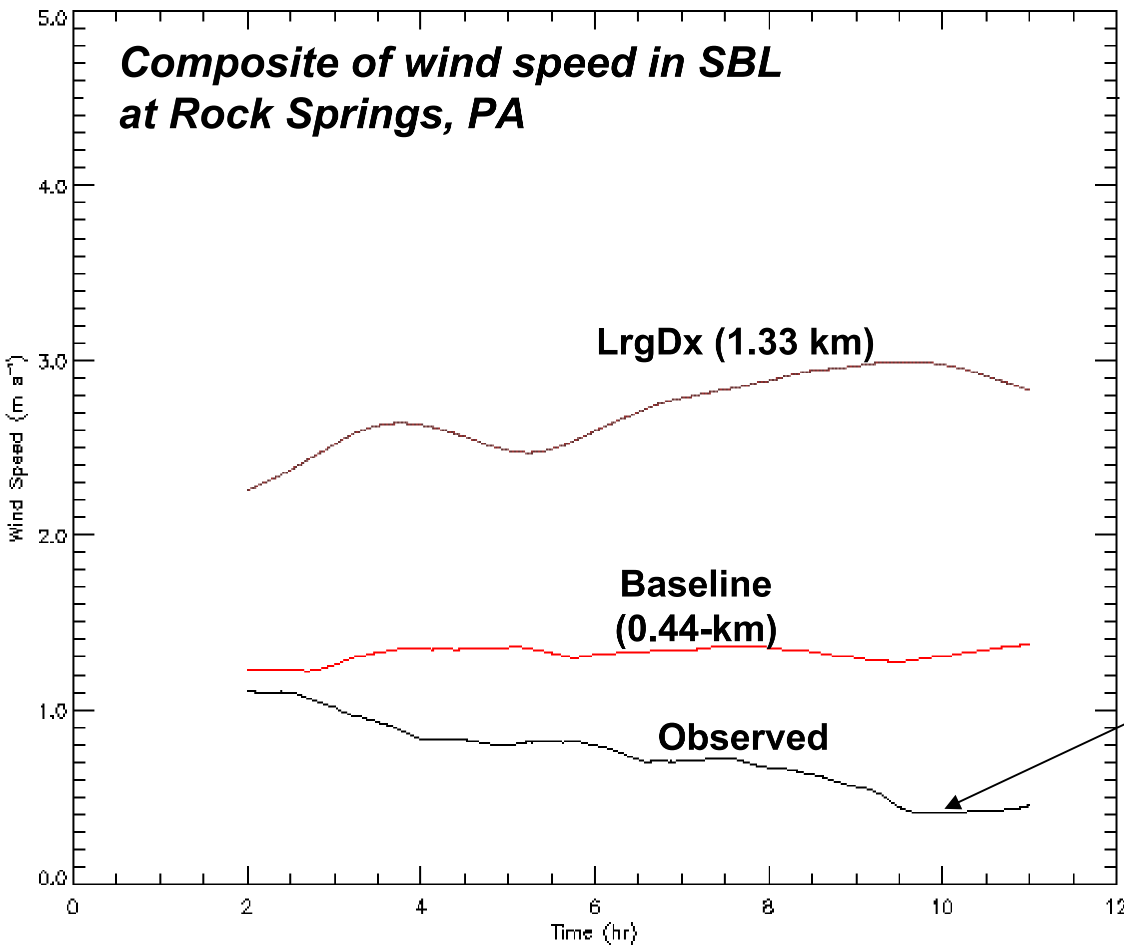


(2-h running-mean filter has been applied)

16-Case Composite Wind Speed vs. Time

Oct-Nov 2007

9 m AGL
0000 – 1200 UTC



Composite obs'd speed gradually weakens thru nocturnal period as Nittany Valley fills with cold air.

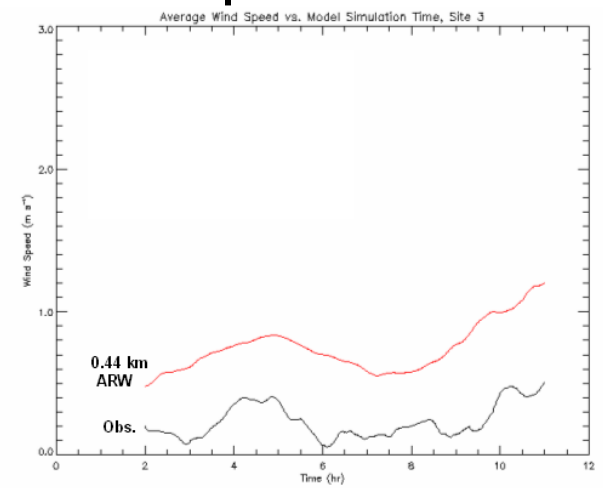
(2-h running-mean filter has been applied to each case in the composite)

Sensitivity of 3-m Wind Speed to PBL Physics

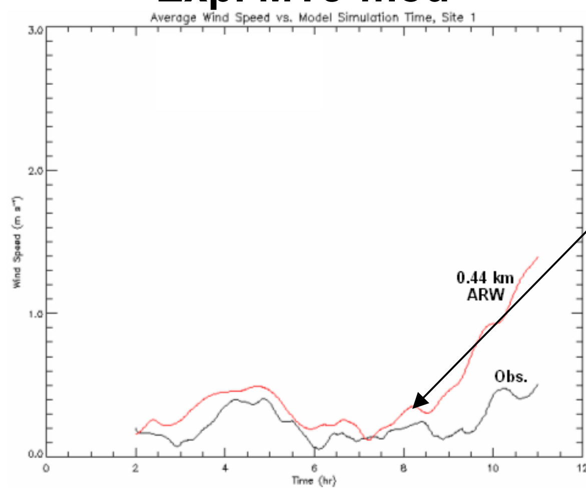
Case study: 7 October 2007

Exp. Name	Bias Error	RMS Error	Corr. Coeff.
MYJ-std	0.48	0.51	0.77
MYJ-mod	0.22	0.33	0.80
QNSE-std	0.23	0.30	0.59

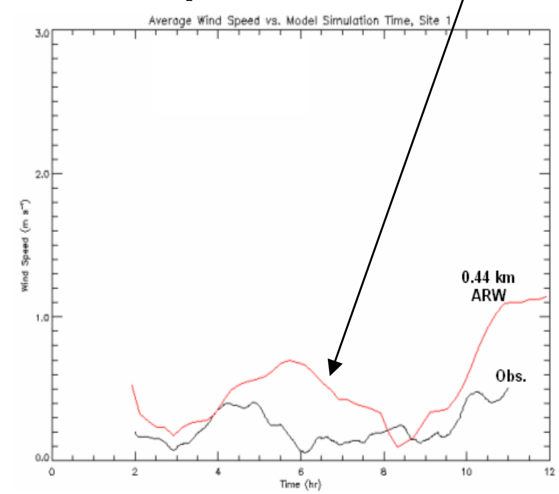
Exp. MYJ-std



Exp. MYJ-mod



Exp. QNSE-std



Smaller TKE_{MIN} in Exps. MYJ-mod and QNSE-std is important for reducing excessive mixing in the very stable nocturnal boundary layer, thereby reducing high speed bias in weak-wind conditions.

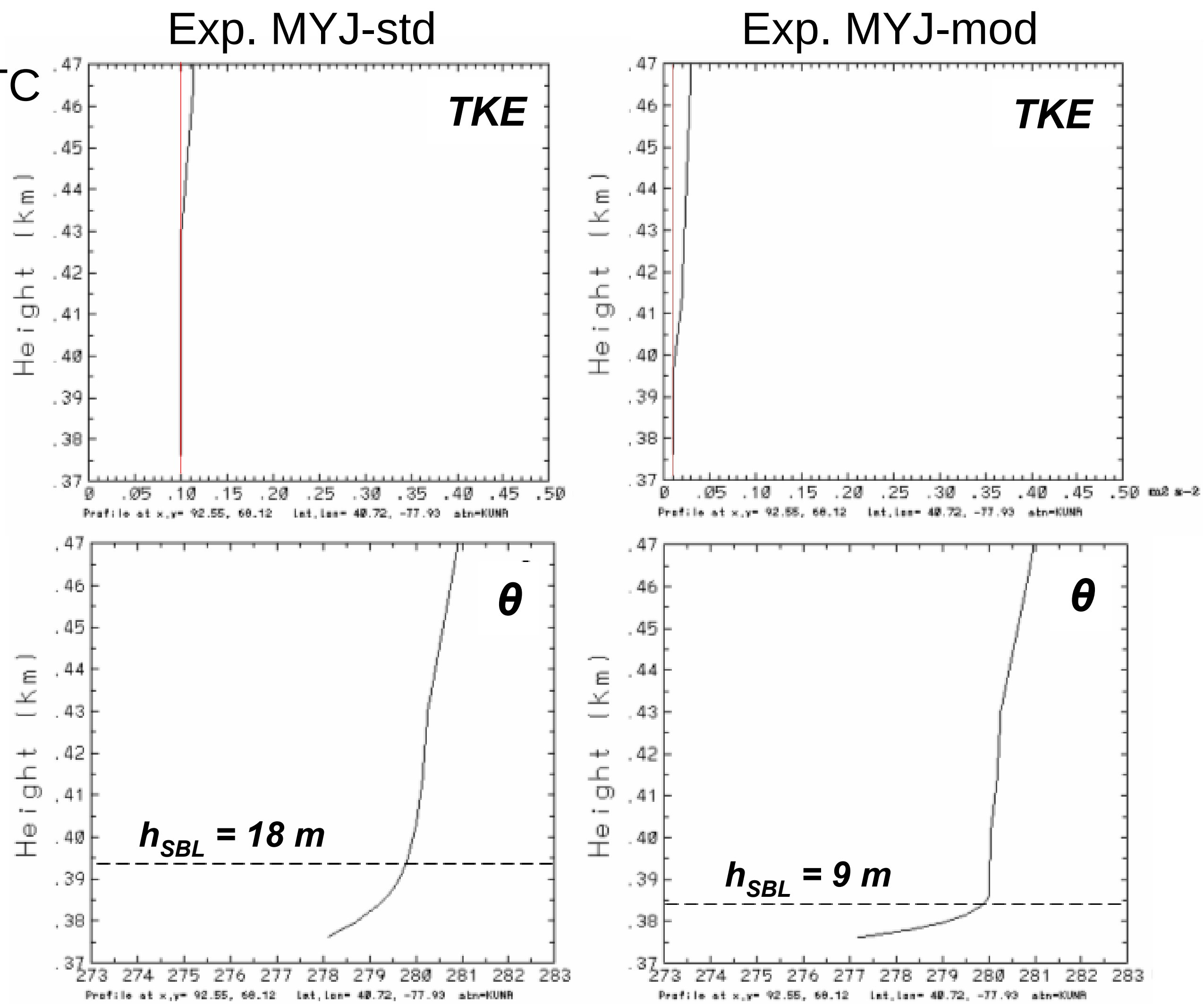
Predicted Vertical Structure of TKE & θ in Stable Boundary Layer

Case: 3 Nov. 2007, 0400 UTC

(TKEMIN shown in red)

Smaller TKE_{MIN} = 0.01 m^2s^{-2} in Exp. MYJ-mod reduces mixing in the very stable nocturnal boundary layer, producing:

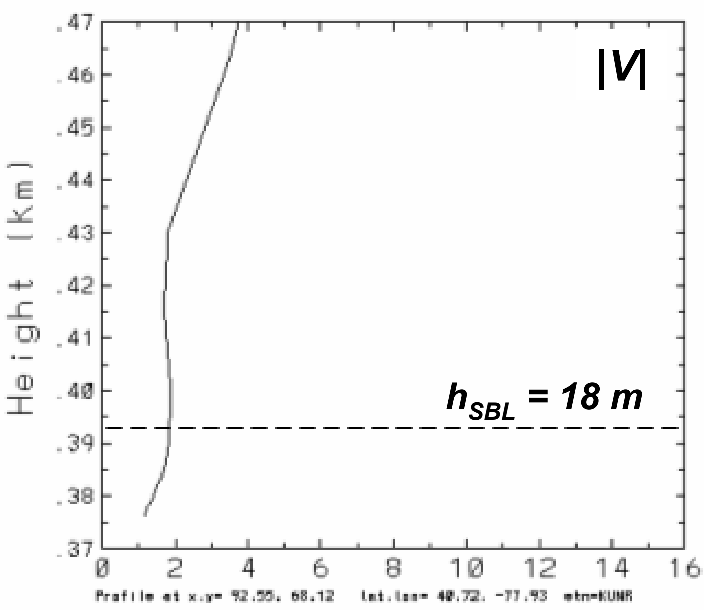
- ***shallower SBL***
- ***colder sfc. temp.***
- ***stronger inversion***



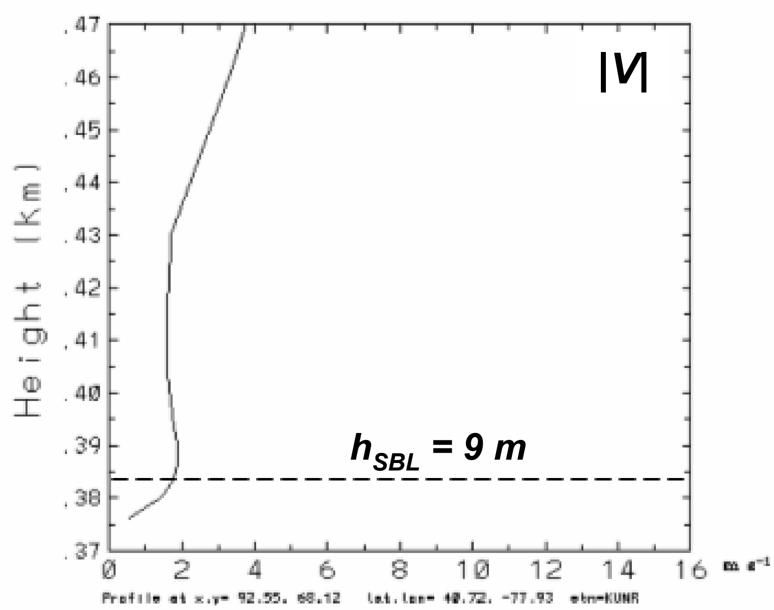
Predicted Vertical Structure of |V| in Stable Boundary Layer

Case: 3 Nov. 2007, 0400 UTC

Exp. MYJ-std



Exp. MYJ-mod

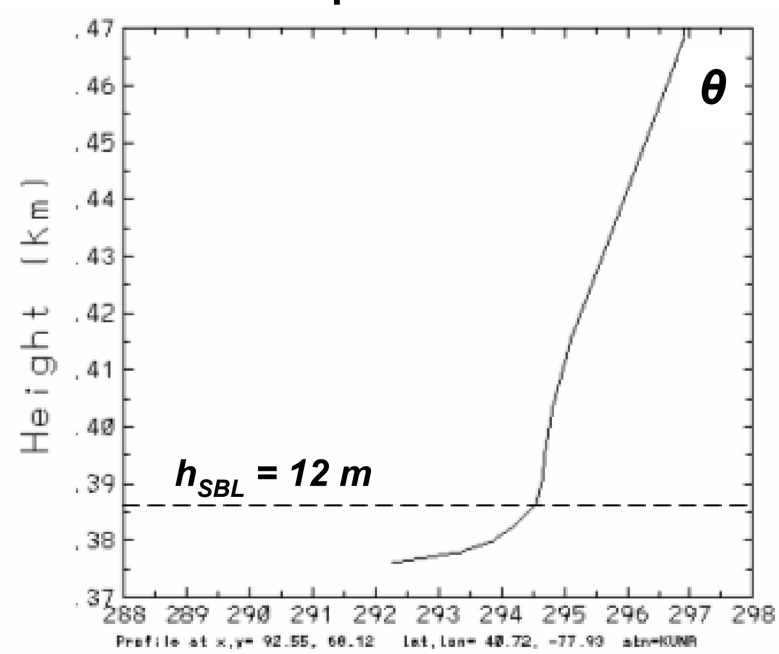


Smaller TKE_{MIN} = 0.01 m^2s^{-2} in Exp. MYJ-mod reduces mixing in the very stable nocturnal boundary layer, producing:

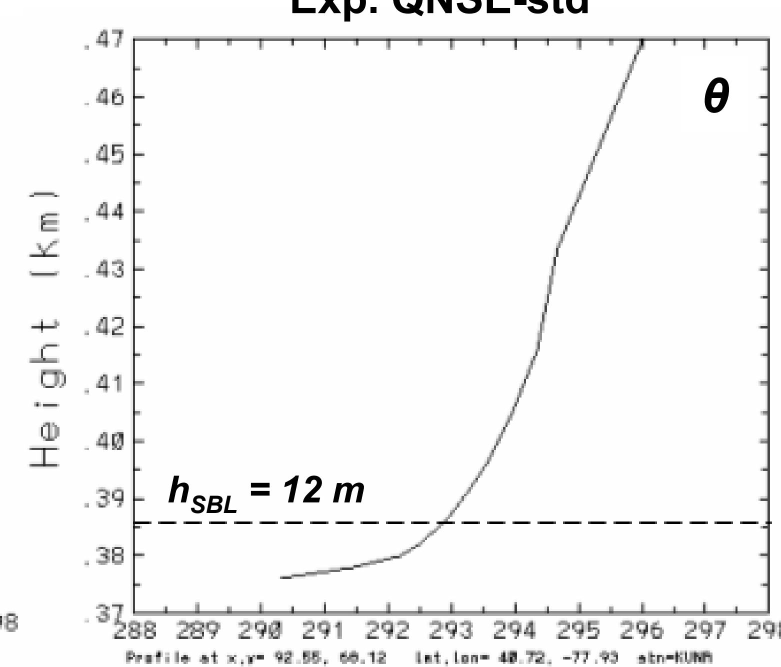
- ***shallower SBL***
- ***weaker surface wind speed***
- ***distinctive LLJ at top of SBL***
- ***stronger shear in SBL***

Predicted Vertical Structure of Stable Boundary Layer

Exp. MYJ-mod



Exp. QNSE-std



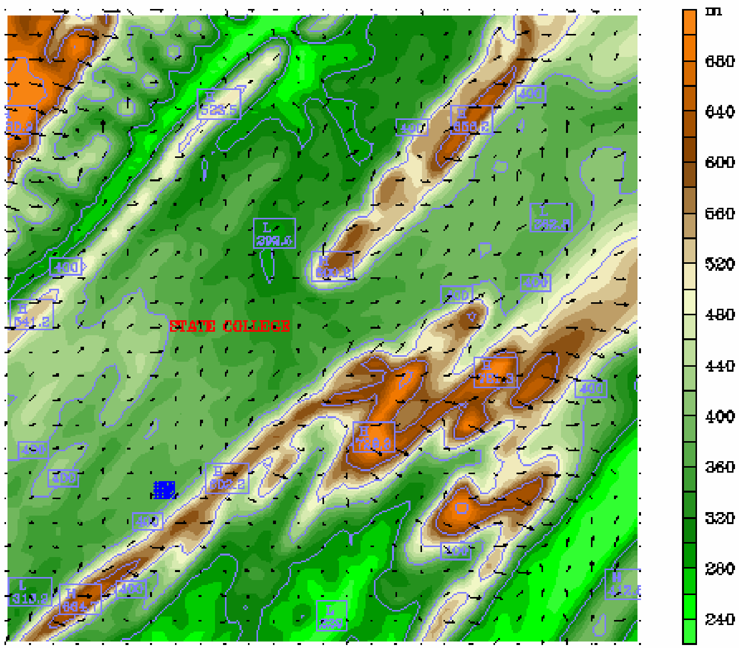
QNSE scheme produces:

- ***2 C cooler surface temperature***
- ***less distinct transition to free troposphere***
- ***weaker LLJ at top of SBL (not shown)***

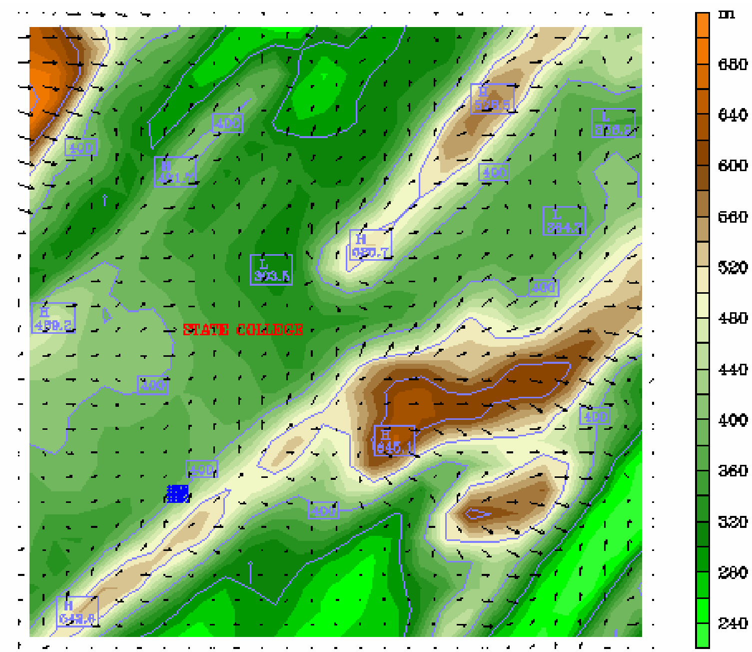
Sensitivity of Parcel Trajectories to Horizontal Resolution

Case: 7 October 2007, 0800 – 1112 UTC

- Coarser horizontal resolution increases mean wind speed in SBL.



Exp. Baseline, 0.444 km



Exp. LrgDX, 1.333 km

(Both experiments use 43 layers, with 11 layers below 68 m AGL.)

Sensitivity of Parcel Trajectories to Vertical Resolution & PBL Physics

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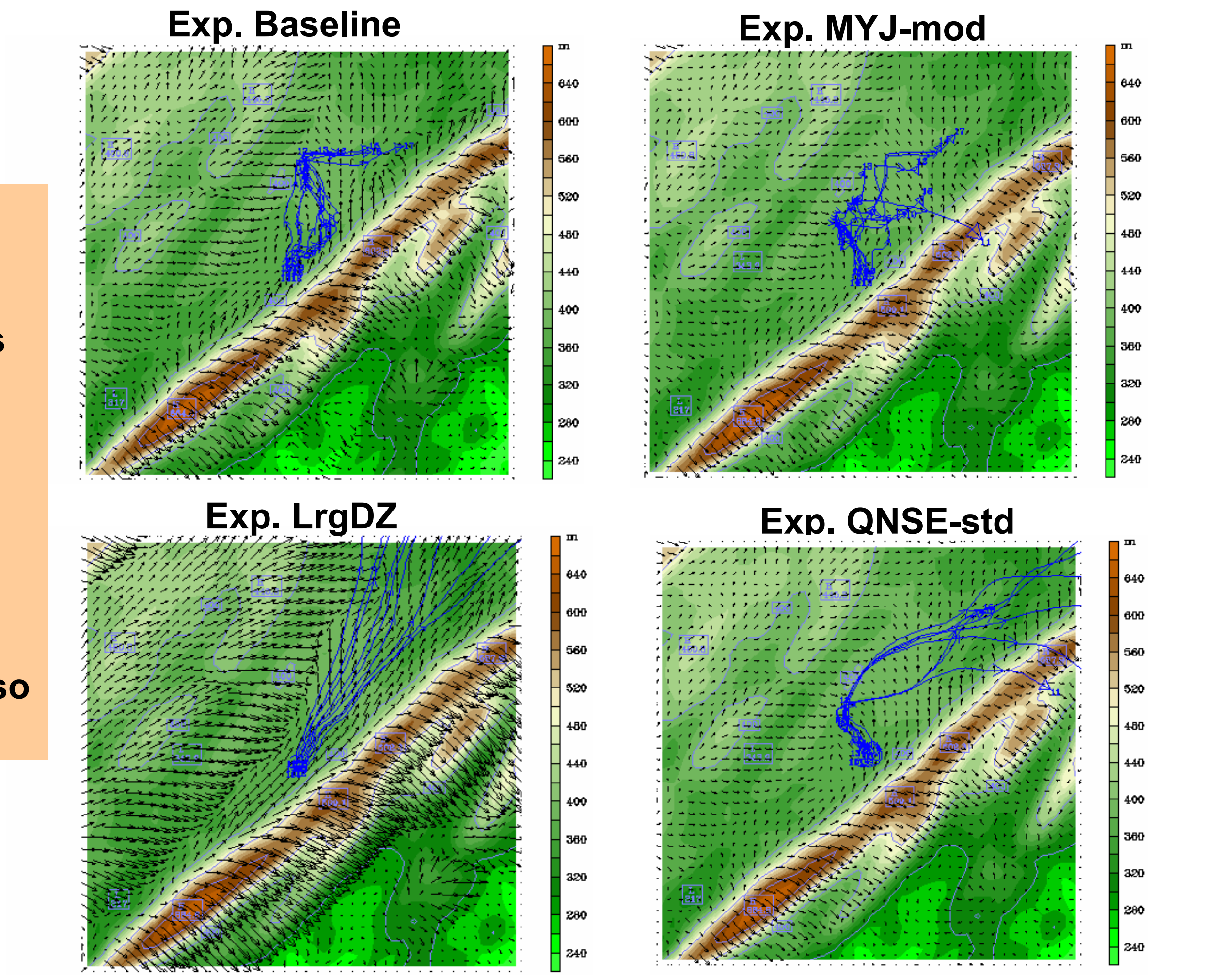
Time: 0800 – 1112 UTC   Case: 7 Oct. 2007



Trajectory Sensitivity:

- Reduced mixing in MYJ-mod allows more sub-meso motions and greater dispersion.
- Low vertical resolution suppresses gravity-driven slope flows.
- QNSE scheme exhibits faster mean flow and weaker sub-meso perturbations in SBL.

Summary

- WRF is tested at high resolution:
  - horizontal: 0.444-km vs. 1.333-km grid
  - vertical: 11 layers vs. 2 layers below 68 m AGL.
- Large impact on trajectories due to resolution and turbulence physics.
- Speed bias is reduced significantly by sub-kilometer (0.444-km) resolution.
- Smaller TKE_{MIN} and l_B (Exp. MYJ-mod) significantly reduces speed bias and promotes more dispersive sub-meso motions.
- Coarser vertical resolution in SBL severely damps gravity-driven slope flow and suppresses shallow sub-meso fluctuations.
- QNSE scheme affects vertical structure of SBL and parcel trajectories.
  - More extensive evaluations and more cases are recommended.