Intercomparison between different PBL schemes in the WRF model - application to GMAST

by Reneta Dimitrova

University of Notre Dame

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Motivation: to identify and study the limitation of PBL schemes implemented in WRF model for mountain-terrain weather prediction

- Parameterization is a method to represent the effects of physical processes which are too small or too complex or poorly understood

- The best way to improve parameterization is to understand the physical processes better by observations and high resolution simulations

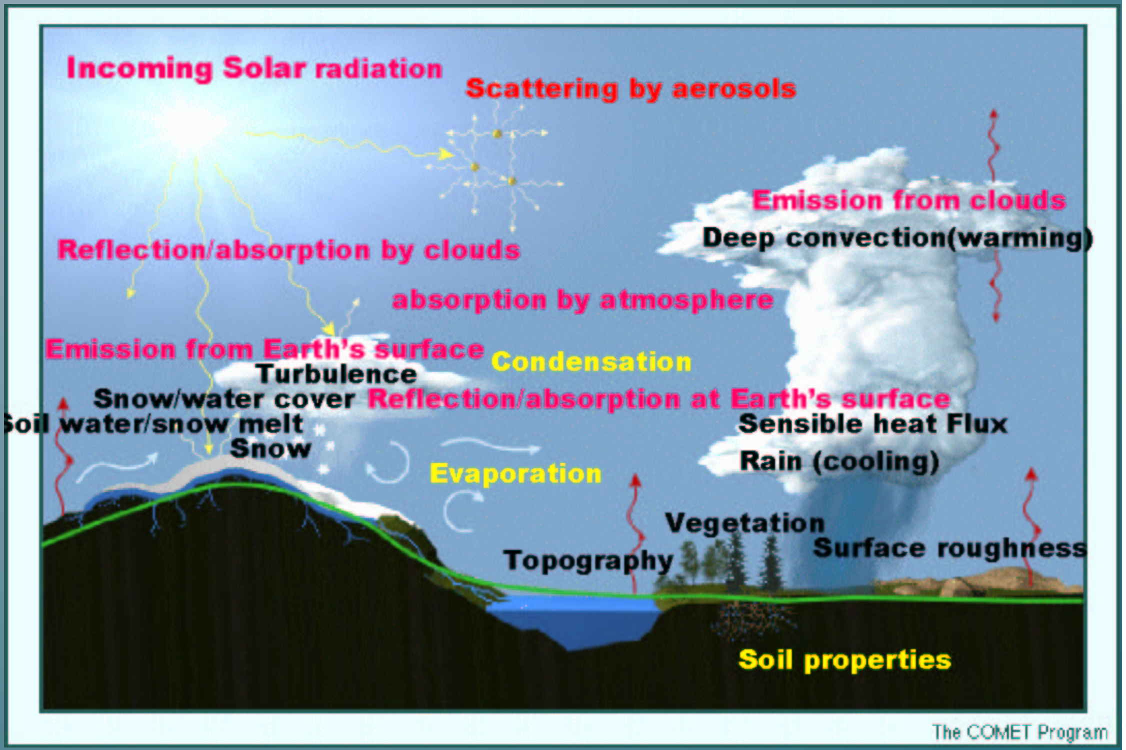
How do we do parameterization in numerical models?

- Ignore some processes (in simple models)
- Simplifications of complex processes based on some assumptions
- Statistical/empirical relationships and approximations based on observations
- Nested models and super-parameterization

What should be parameterized ?

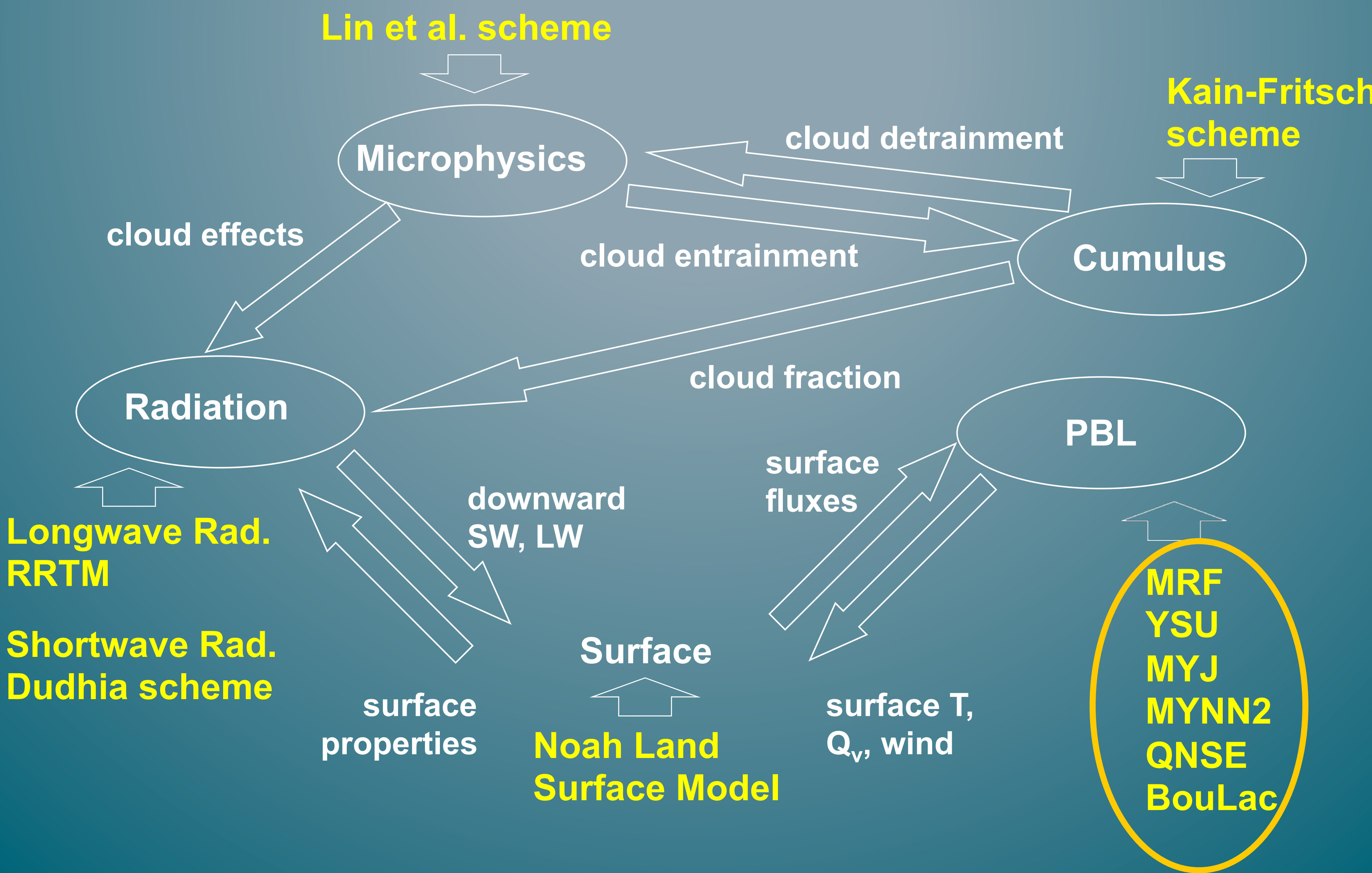
Model Physics include:

- ✓ Radiation transfer
- ✓ Surface processes
- ✓ Vertical turbulent processes
- ✓ Microphysics
- ✓ Cumulus convection
- ✓ Gravity wave drag



16 major physical processes in climate system. (from http://www.meted.ucar.edu/nwp/pcu1/ic4/frameset.htm)

Parameterization used with WRF simulations



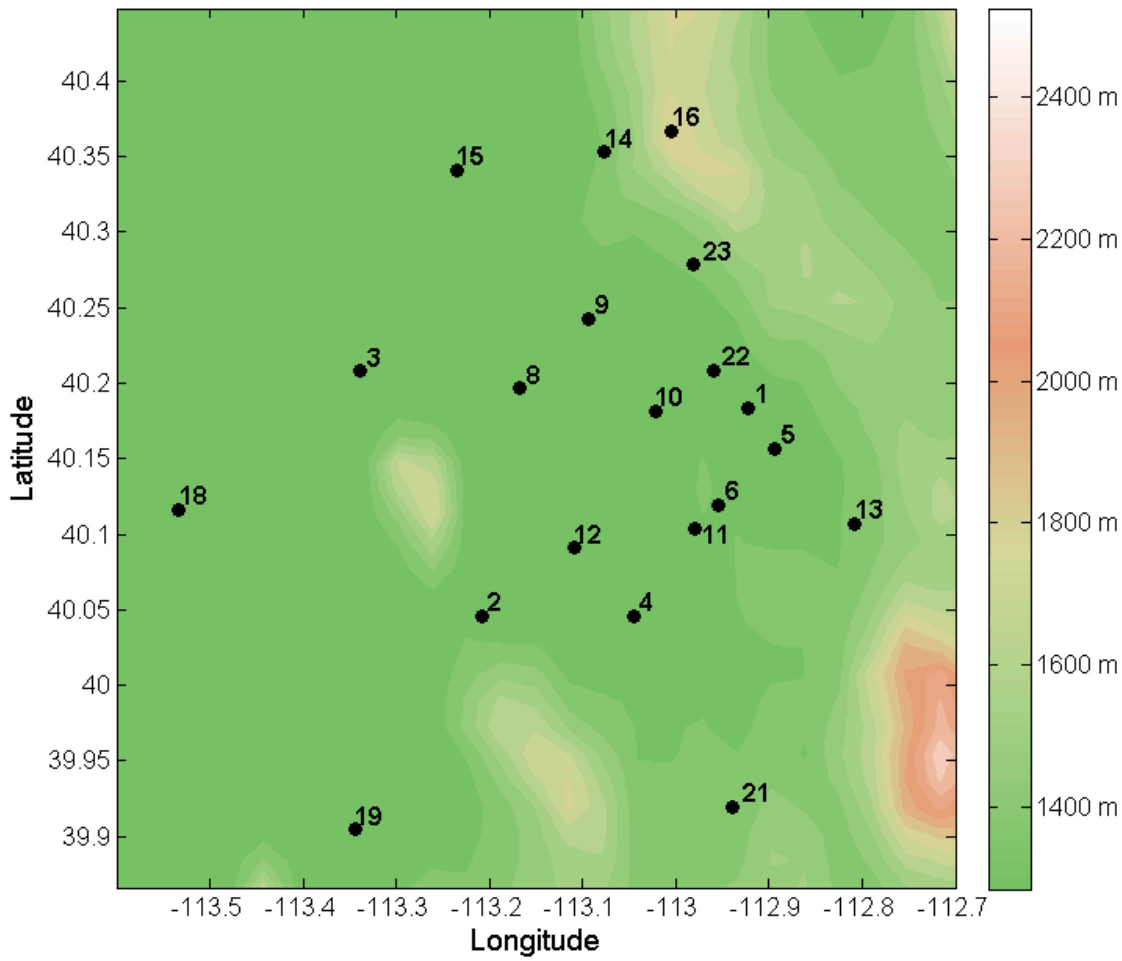
PBL numerical experiment

PBL Scheme	Reference	Surface Layer
MRF	Hong and Pan (1996, MWR)	MM5
YSU	Hong, Noh and Dudhia (2006, MWR)	MM5
MYJ	Janjic (1994, MWR)	Eta
MYNN2	Nakanishi and Niino (2006, BLM)	MYNN/MM5/Eta
QNSE	Sukoriansky, Galperin and Perov (2005, BLM)	QNSE
BouLac	Bougeault and Lacarrere (1989, MWR)	MM5/Eta

MRF: with implicit treatment of entrainment layer as part of non-local-K mixed layer
YSU: non-local-K scheme with explicit entrainment layer and parabolic K profile in unstable mixed layer
MYJ: one-dimensional prognostic turbulent kinetic energy scheme with local vertical mixing
MYNN2: level 2.5 PBL, predicts sub-grid TKE terms
QNSE: a TKE-prediction option that uses a new theory for stably stratified regions
BouLac: a TKE-prediction option

MM5 similarity: based on Monin-Obukhov with Carslon-Boland viscous sub-layer and standard similarity functions from look-up tables
Eta similarity: used in Eta model, based on Monin-Obukhov with Zilitinkevich thermal roughness length and standard similarity functions from look-up tables
MYNN: Nakanishi and Niino PBL's surface layer scheme
QNSE: Quasi-Normal Scale Elimination PBL scheme's surface layer

Weather Research and Forecast Model v.3.3



WRF domains:

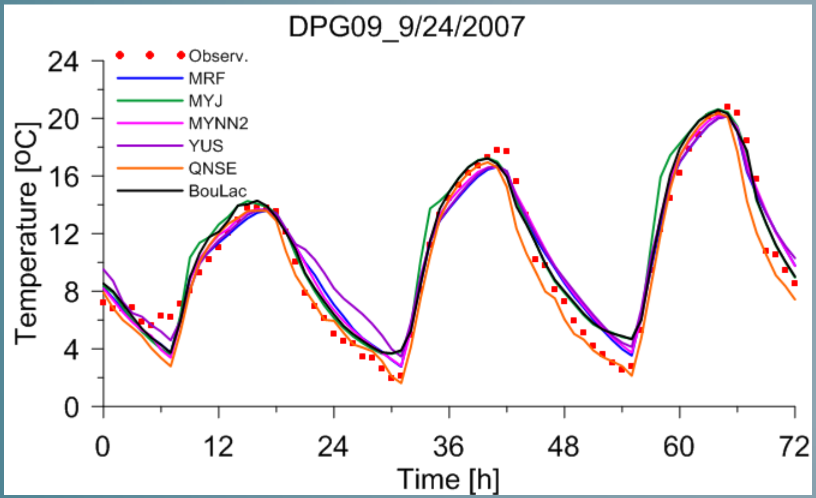
D1: 25x25 - 64km
D2: 57x57 - 16km
D3: 89x89 - 4km
D4: 121x105 - 1km

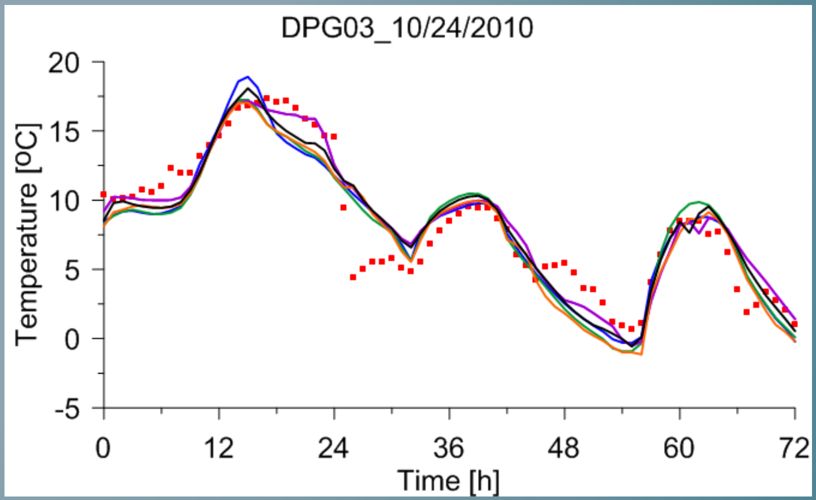
37 vertical levels

Simulated periods (3 days starting at):

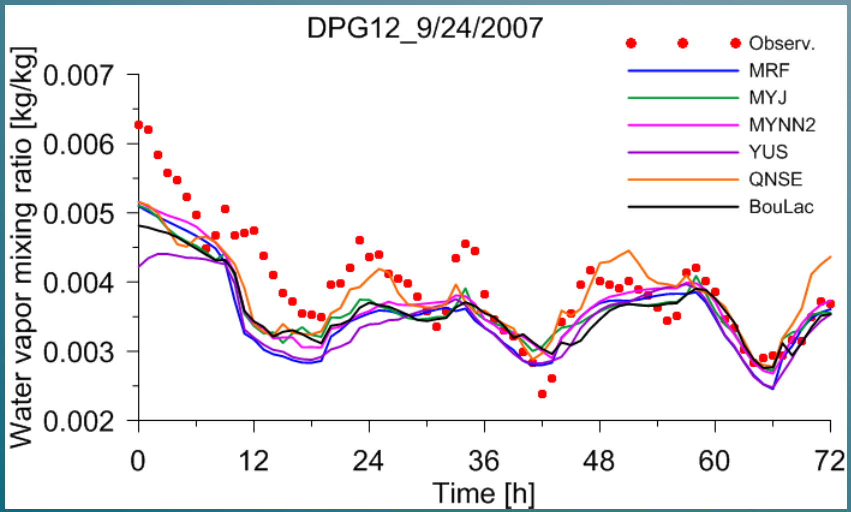
09/24/2007 - forced
10/22/2007 - local
10/08/2010 - local
10/24/2010 - forced

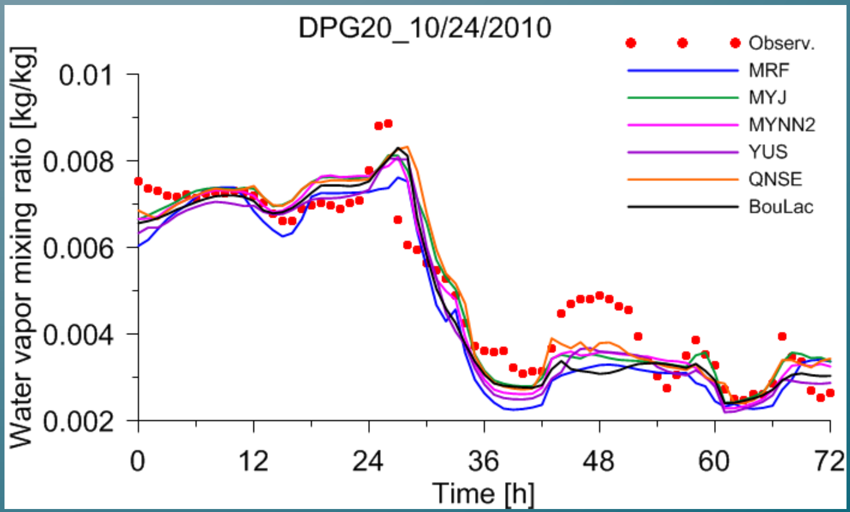
Temperature



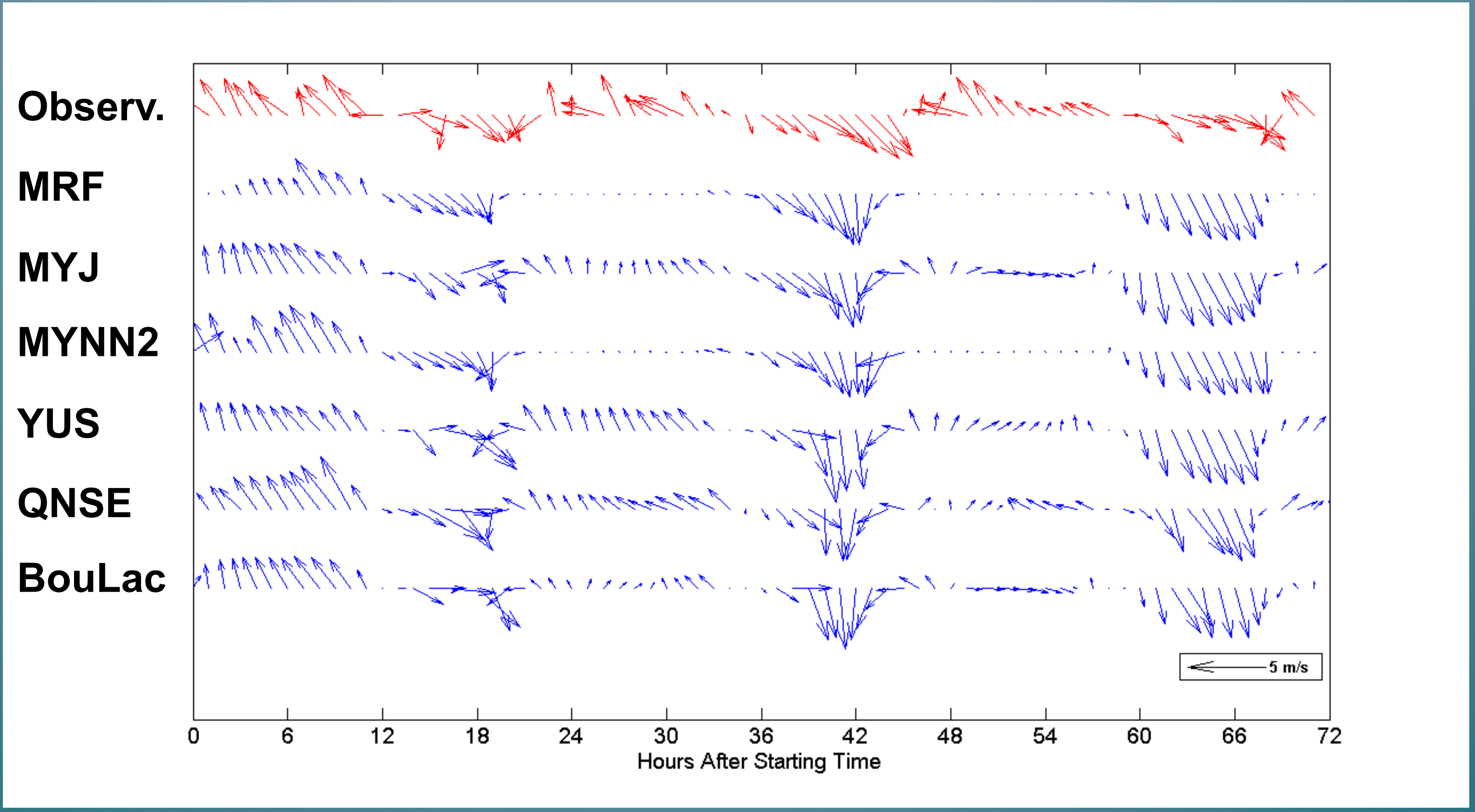


Water vapor mixing ratio

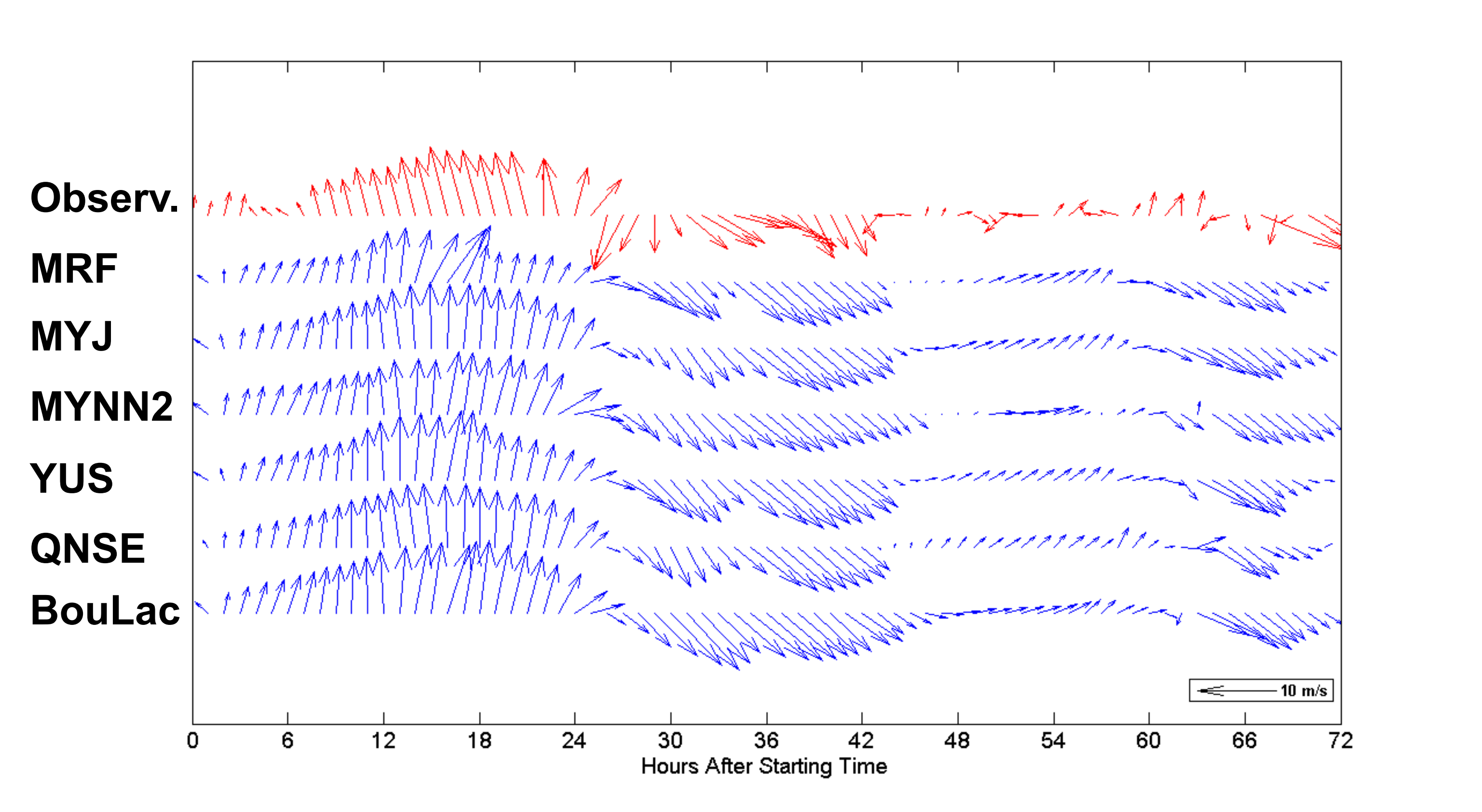




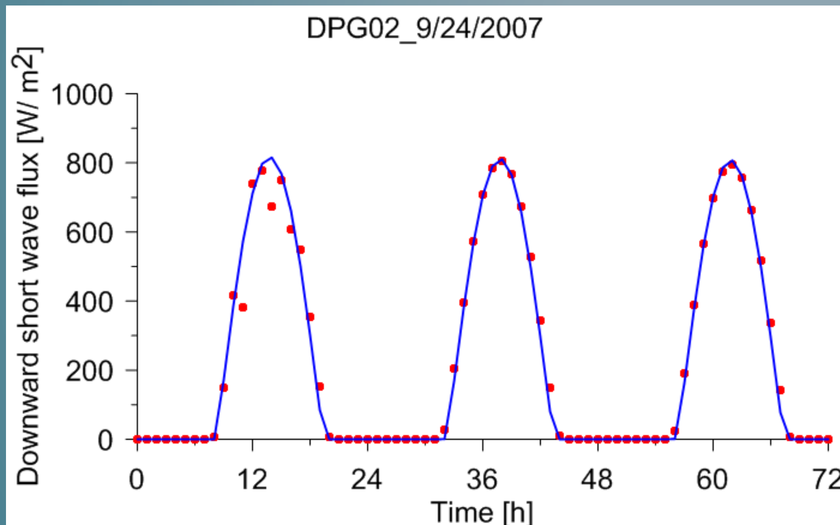
Wind vectors (DPG04_10/08/2010)

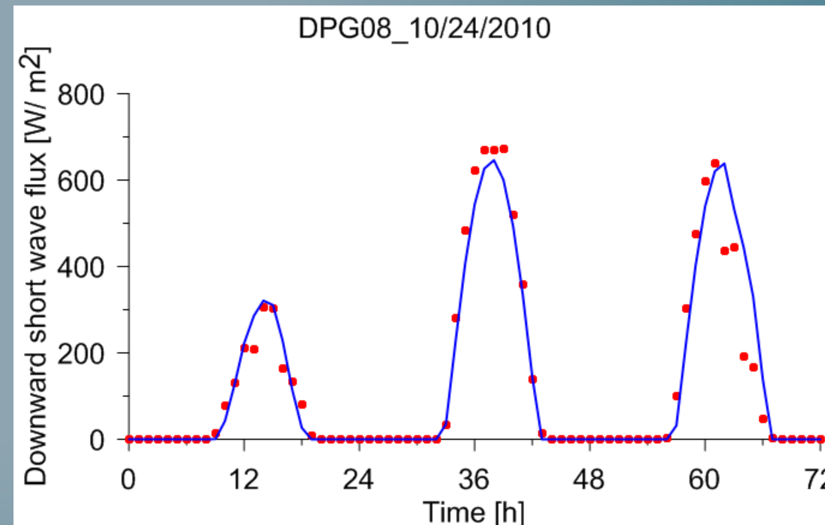


Wind vectors (DPG03_10/24/2010)

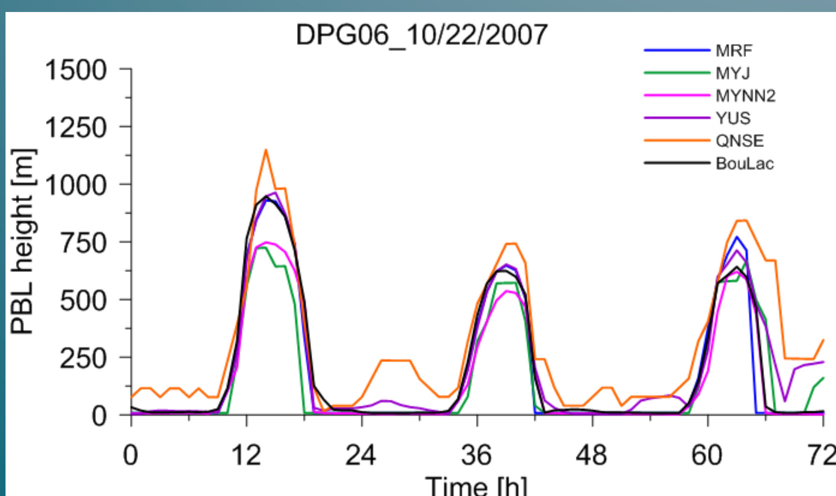


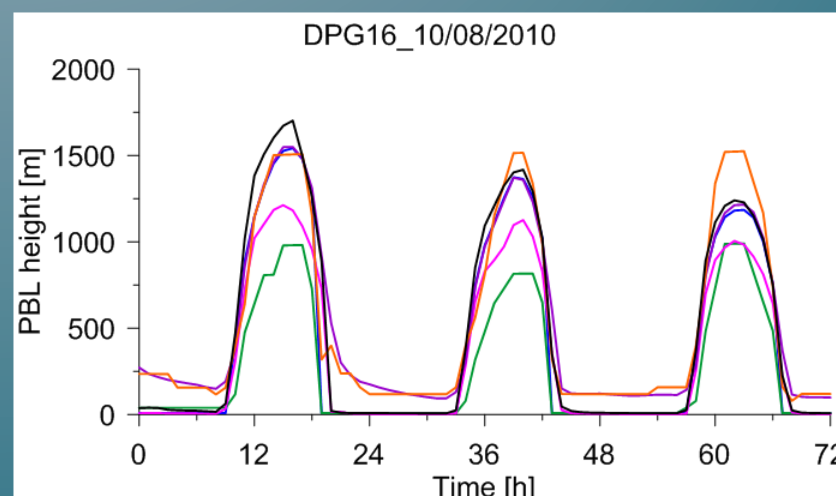
Downward short wave flux



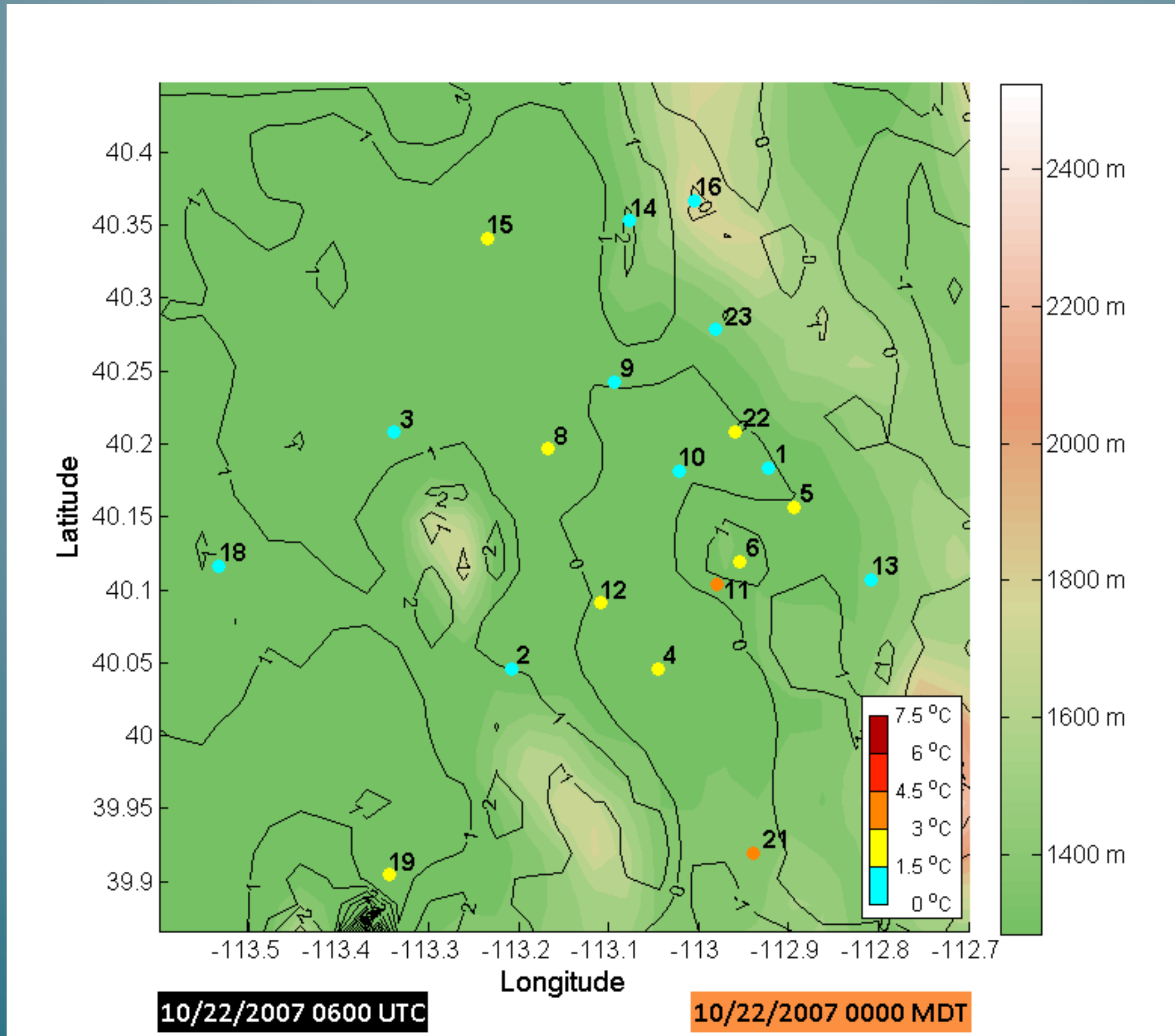


PBL height

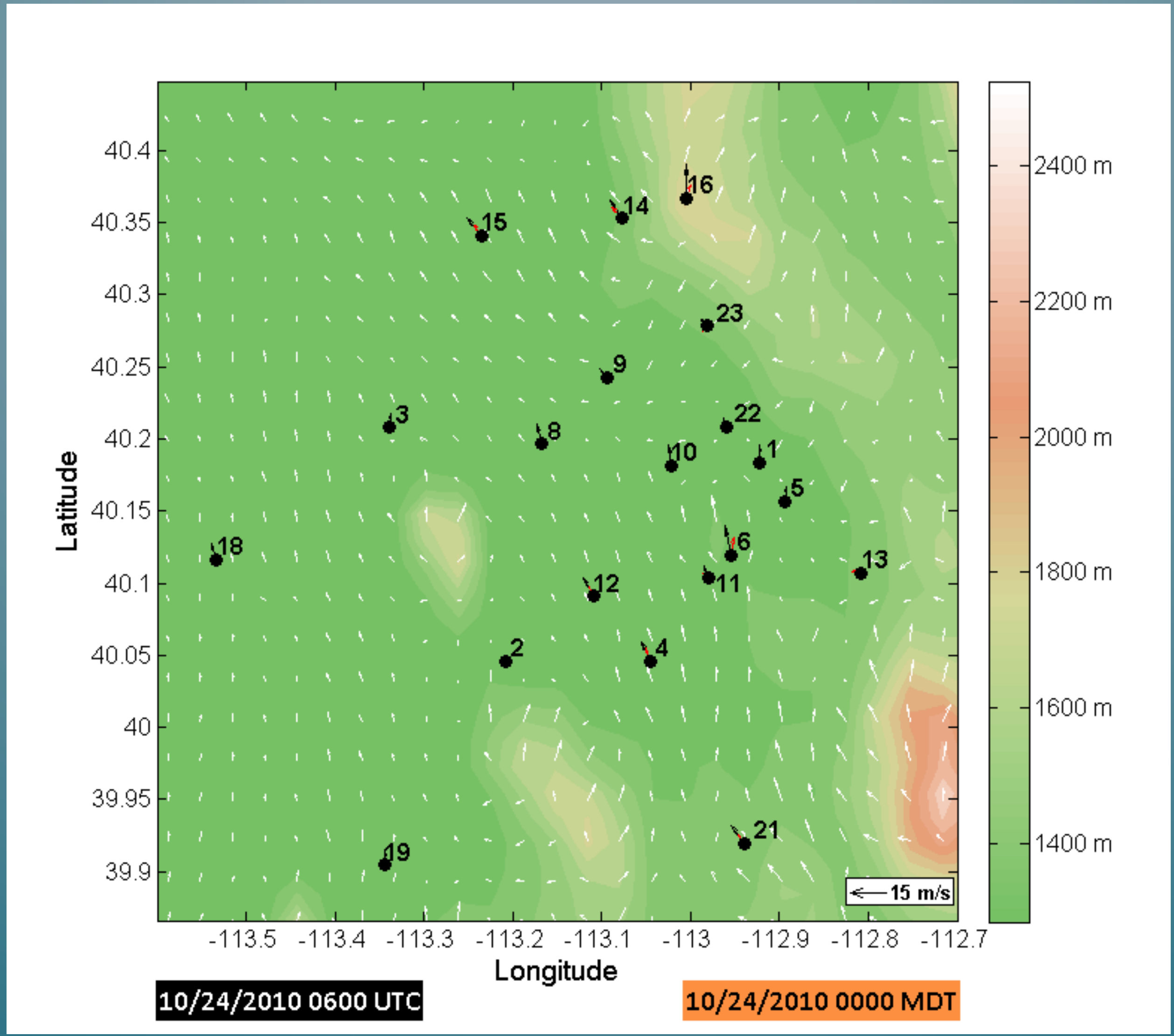




Temperature



Wind vectors



Mean Bias (var. units)

$$MB = \frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)$$

Mean Error (var. units)

$$ME = \frac{1}{N}\left|\sum_{i=1}^{N}(M_i - O_i)\right|$$

Normalized Mean Bias (%)

$$NMB = \frac{\sum_{i=1}^{N}(M_i - O_i)}{\sum_{i=1}^{N} O_i} 100\%$$

Normalized Mean Error (%)

$$NME = \frac{\sum_{i=1}^{N}\left|M_i - O_i\right|}{\sum_{i=1}^{N} O_i} 100\%$$

Mean Fractional Bias (%)

$$MFB = \sum_{i=1}^{N}\left(\frac{(M_i - O_i)}{\frac{1}{2}(M_i + O_i)}\right) 100\%$$

Mean Fractional Error (%)

$$MFE = \sum_{i=1}^{N}\left(\frac{\left|M_i - O_i\right|}{\frac{1}{2}(M_i + O_i)}\right) 100\%$$

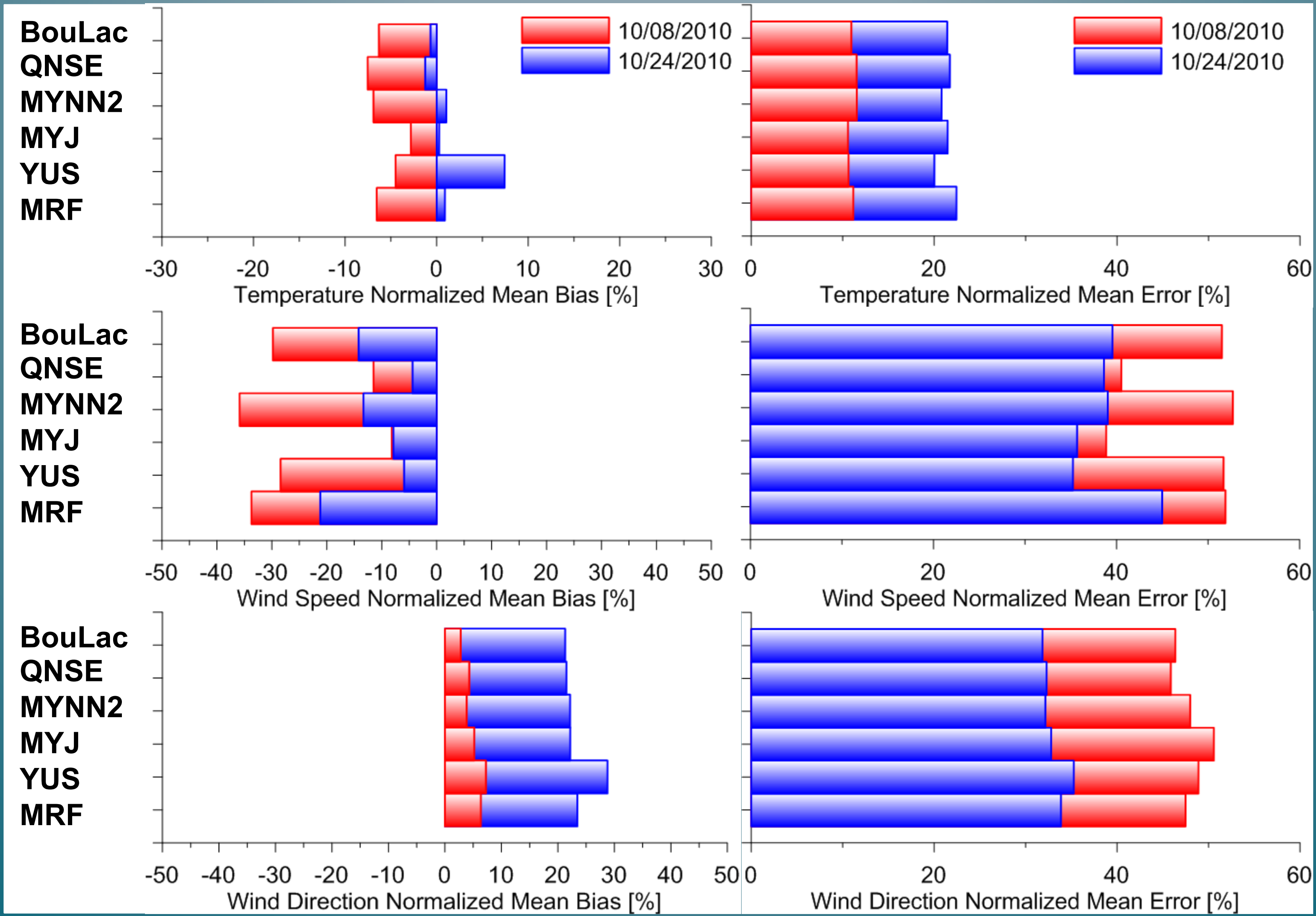
Root Mean Square Error (var. units)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(M_i - O_i)^2}{N}}$$

Index of Agreement Willmott (1981)

$$IA = 1 - \frac{\sum_{i=1}^{N}(M_i - O_i)^2}{\sum_{i=1}^{N}\left(\left|M_i - \overline{O}\right| + \left|O_i - \overline{O}\right|\right)^2}$$

Measures of model performance



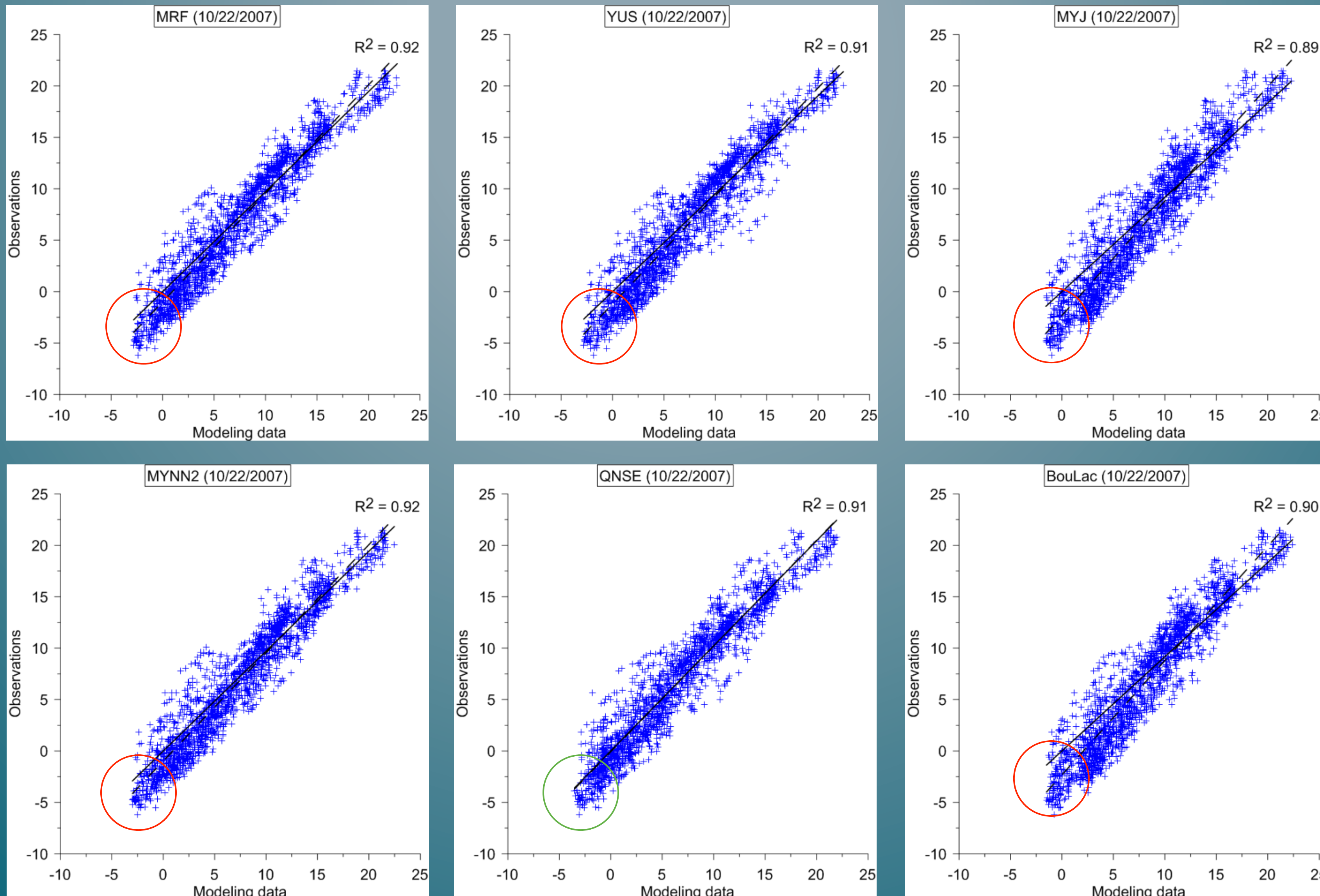
Measures of model performance

PBL	MRF	YUS	MYJ	MYNN2	QNSE	BouLac
Temperature						
9/24/2007	0.97	0.96	0.96	0.97	0.97	0.97
10/22/2007	0.97	0.97	0.95	0.97	0.97	0.97
10/8/2010	0.96	0.96	0.96	0.96	0.96	0.96
10/24/2010	0.95	0.95	0.95	0.95	0.95	0.95
Wind speed						
9/24/2007	0.62	0.59	0.67	0.61	0.67	0.62
10/22/2007	0.47	0.48	0.56	0.47	0.54	0.47
10/8/2010	0.67	0.67	0.72	0.67	0.72	0.69
10/24/2010	0.72	0.82	0.82	0.80	0.80	0.79
Wind direction						
9/24/2007	0.67	0.67	0.63	0.66	0.66	0.66
10/22/2007	0.60	0.61	0.59	0.60	0.61	0.62
10/8/2010	0.64	0.63	0.61	0.62	0.64	0.64
10/24/2010	0.67	0.63	0.66	0.67	0.67	0.67

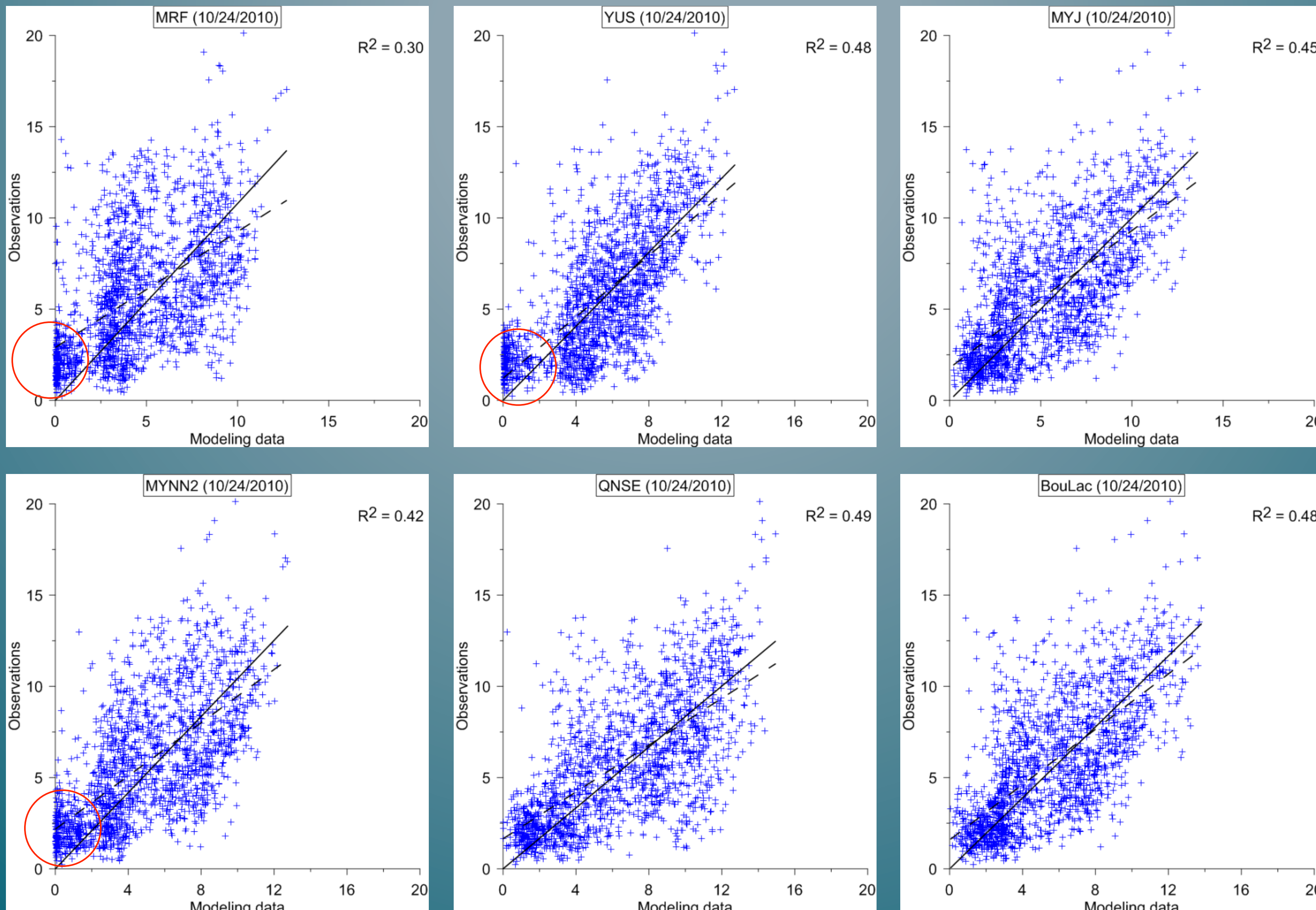
Index of Agreement Willmott (1981)

$$IA = 1 - \frac{\sum_{i=1}^{N}(M_i - O_i)^2}{\sum_{i=1}^{N}\left(\left|M_i - \bar{O}\right| + \left|O_i - \bar{O}\right|\right)^2}$$

Temperature at 2m (October 22, 2007)



Velocity speed at 10m (October 24, 2010)



Summary

- Unequivocal conclusion cannot be done based on the statistics (26 sites, 4 three days periods)
- All PBL schemes predict well the daytime and under-predict nocturnal temperature (QNSE is the best for nocturnal conditions)
- All PBL schemes under-predict the water vapor mixing ratio
- MYJ, BouLac and QNSE perform better for low speed events
- QNSE and YUS calculate higher PBL depth during the stable conditions in agreement with CASES-97 data (NCAR)

Work in progress

➢ **Implementation of parameterization for eddy diffusivities of momentum and heat in the WRF model for stable PBL (VTMX experiment, 2000)**

$$\frac{K_m}{\sigma_w^2 \left| d\vec{V} / dz \right|} = 0.34 Ri_g^{-0.02}$$

$$\frac{K_h}{\sigma_w^2 \left| d\vec{V} / dz \right|} = 0.08 Ri_g^{-0.49}$$

$$Ri_g = \frac{N^2}{\left(\frac{\partial \overline{U}}{\partial z}\right)^2 + \left(\frac{\partial \overline{V}}{\partial z}\right)^2}$$

Gradient Richardson number

$$N^2 = \frac{g}{\overline{\theta}} \frac{d\overline{\theta}}{dz}$$

Brünt – Väisälä frequency

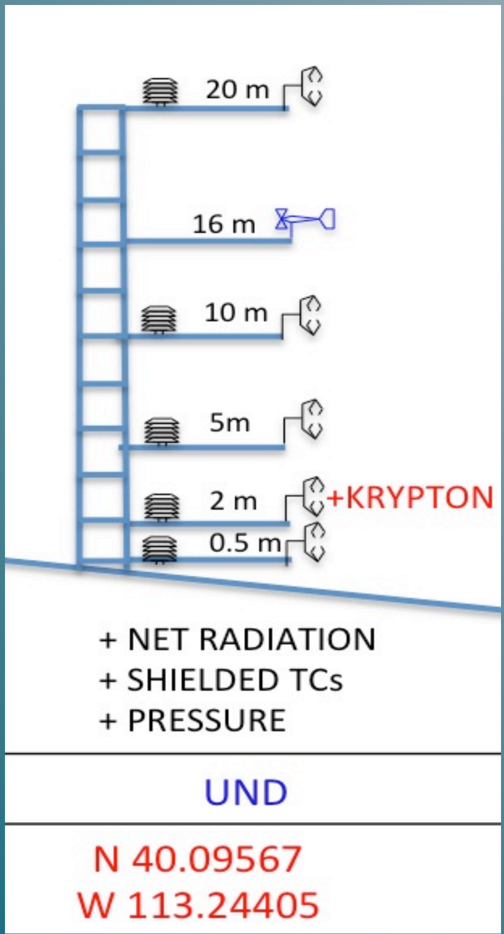
Vertical wind variance $\sigma_w^2 = \overline{\omega'^2}$

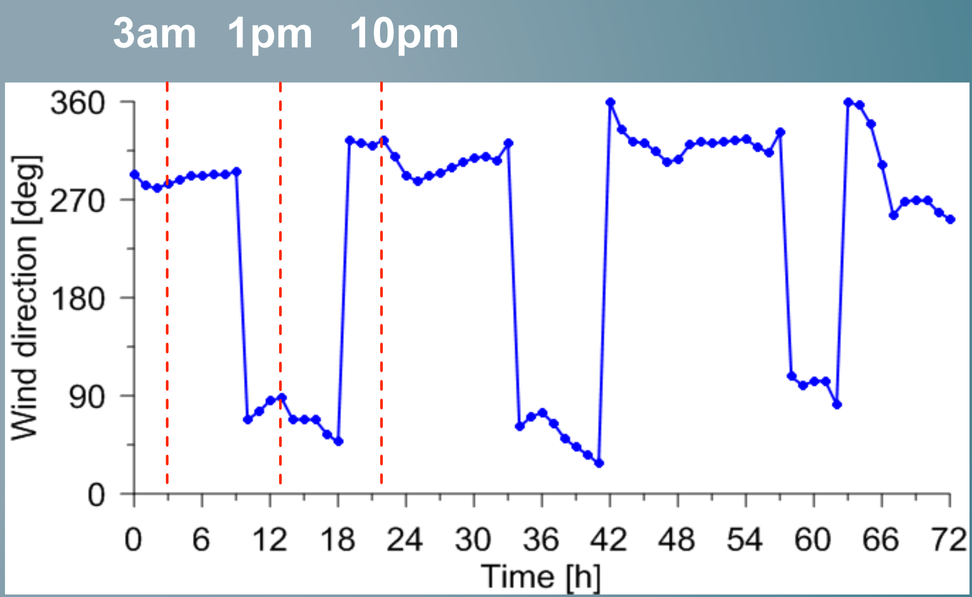
$$\frac{\overline{\omega'^2}}{u_*^2} = 2.5\left[1 - \left(\frac{z}{h}\right)^{0.6}\right]$$

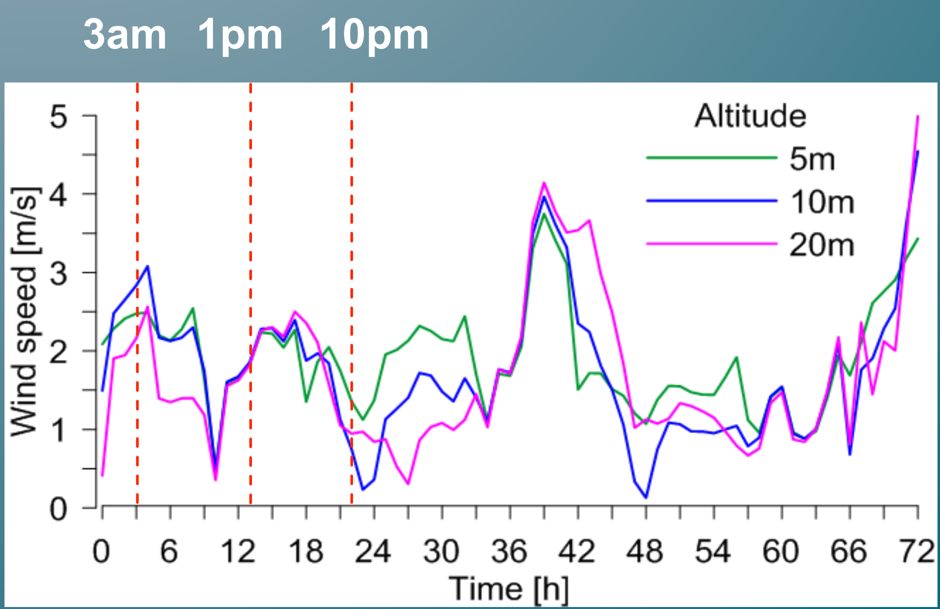
Stull (1988)

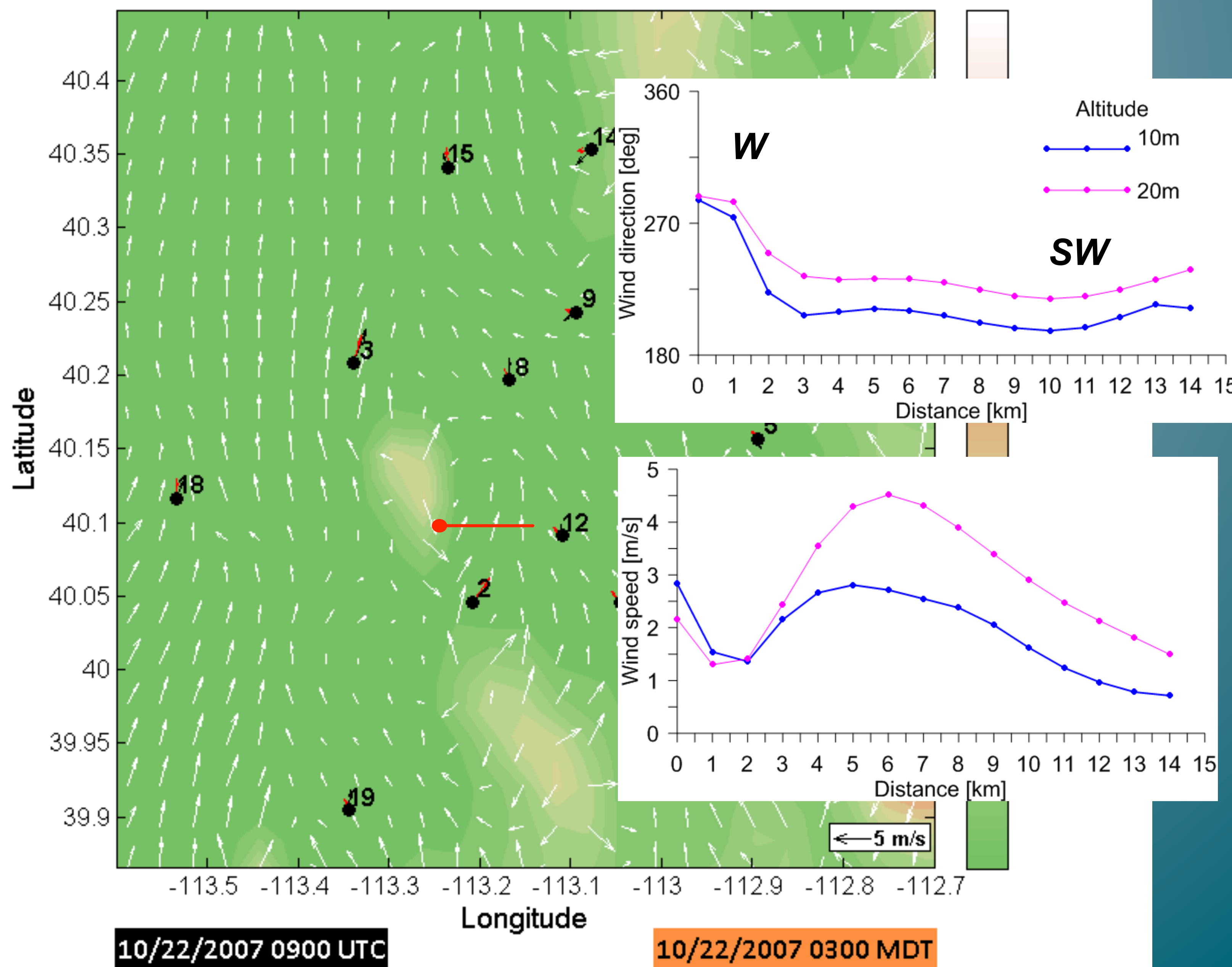
(Monti et al., 2002, "Observations of flow and turbulence In the nocturnal boundary layear", J. Atmos. Sci., 31)

Field experiment - east slope of Granite Mountain

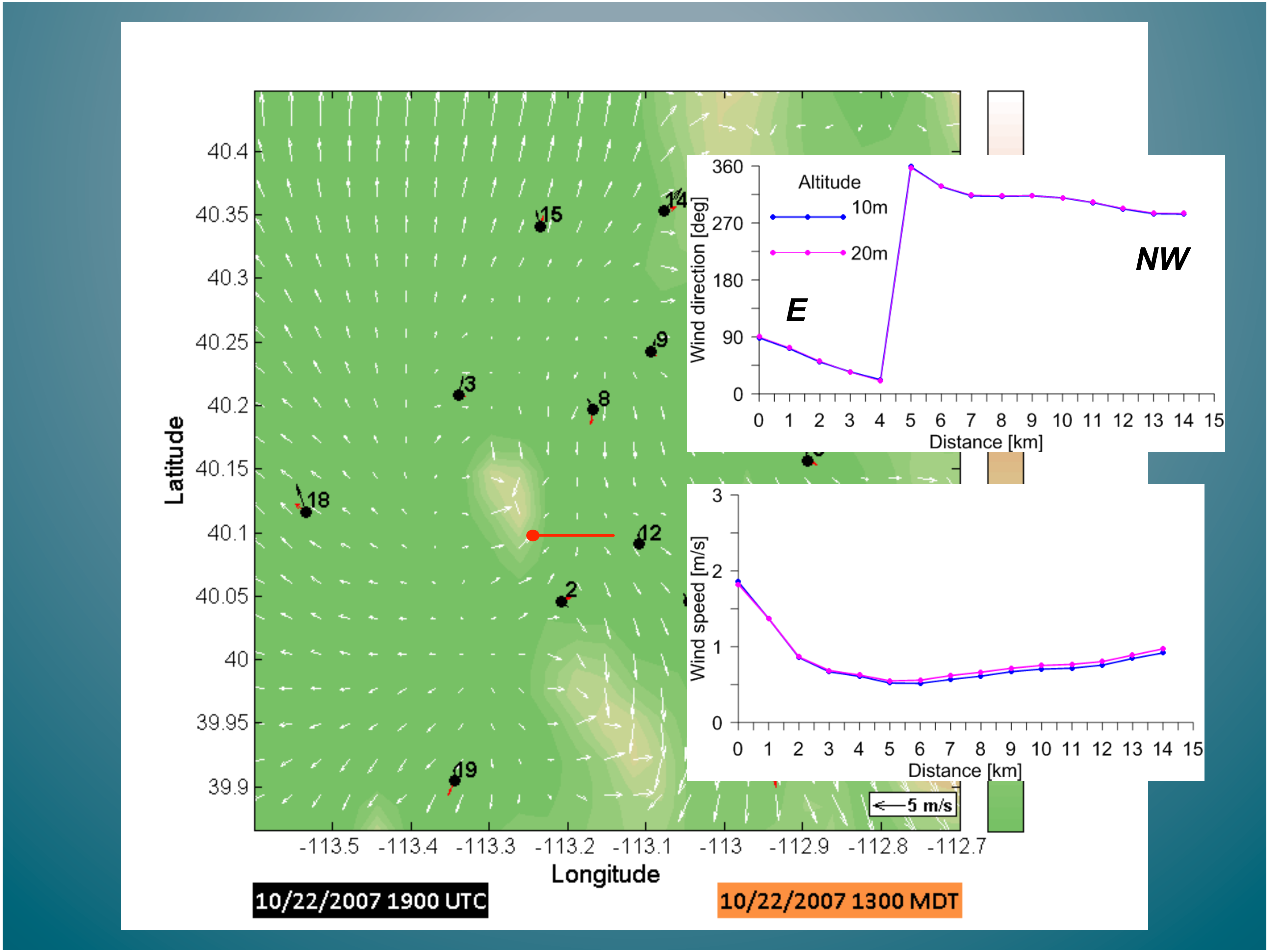




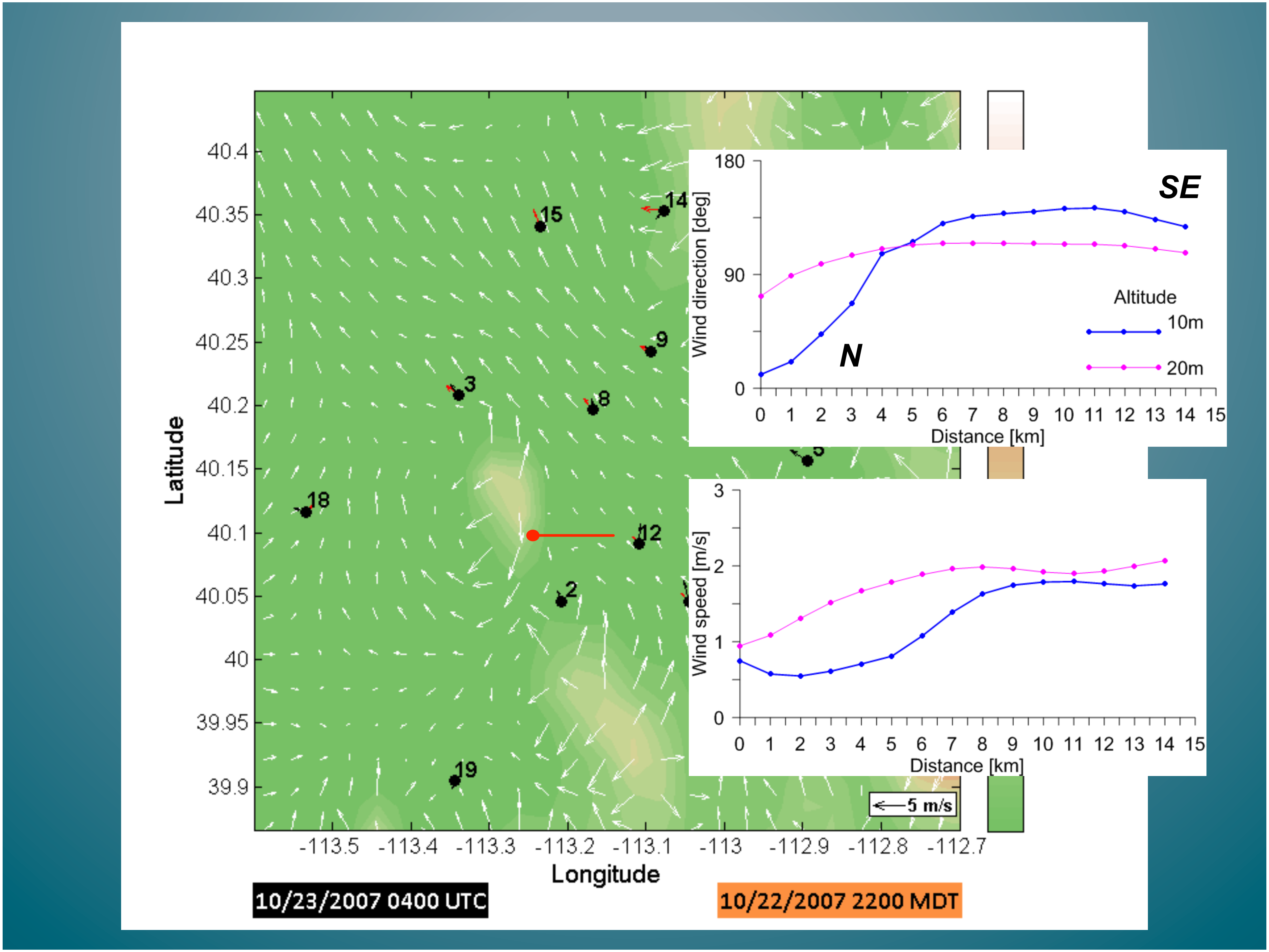




Latitude
Longitude
40.4
40.35
40.3
40.25
40.2
40.15
40.1
40.05
40
39.95
39.9
-113.5
-113.4
-113.3
-113.2
-113.1
-113
-112.9
-112.8
-112.7
15
14
9
3
18
18
12
2
19
5
←5 m/s
Altitude
10m
20m
W
SW
Wind direction [deg]
360
270
180
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Distance [km]
Wind speed [m/s]
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Distance [km]
10/22/2007 0900 UTC
10/22/2007 0300 MDT



Latitude
Longitude
Altitude
10m
20m
E
NW
Wind direction [deg]
Distance [km]
Wind speed [m/s]
Distance [km]
5 m/s
10/22/2007 1900 UTC
10/22/2007 1300 MDT


Latitude
Longitude
40.4
40.35
40.3
40.25
40.2
40.15
40.1
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40
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-113.5
-113.4
-113.3
-113.2
-113.1
-113
-112.9
-112.8
-112.7
15
14
9
3
8
18
12
2
19
5 m/s
SE
N
Wind direction [deg]
180
90
0
Altitude
10m
20m
Distance [km]
Wind speed [m/s]
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
10/23/2007 0400 UTC
10/22/2007 2200 MDT

Thank you!