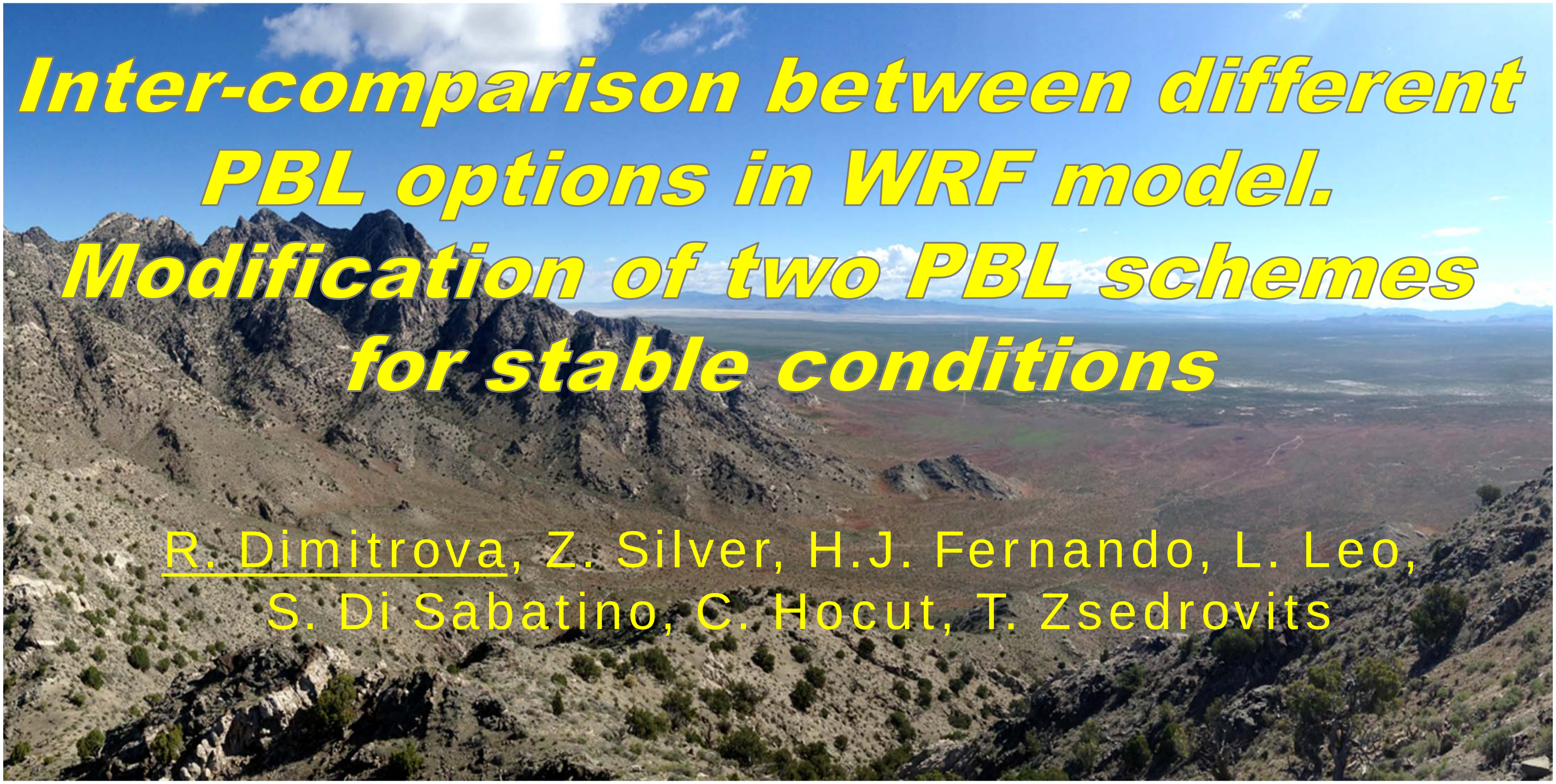


Inter-comparison between different PBL options in WRF model. Modification of two PBL schemes for stable conditions

R. Dimitrova, Z. Silver, H.J. Fernando, L. Leo, S. Di Sabatino, C. Hocut, T. Zsedrovits

94th AMS Annual Meeting, 2-6 February, 2014, Atlanta, Georgia

Current meso-scale models

Poorly represent SPBL in terms of:

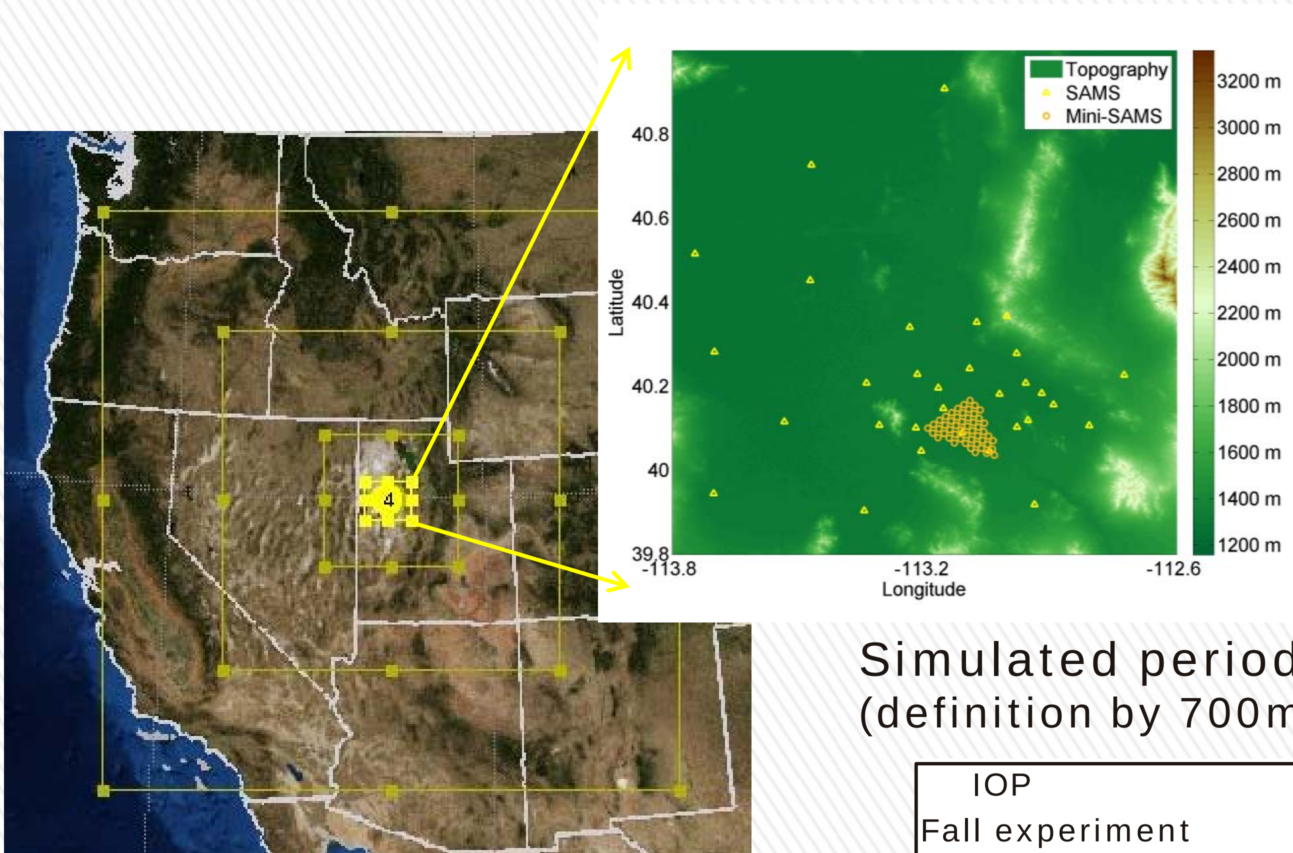
- The SPBL depth
- Near-surface inversion characteristics
- Low-level wind profiles
- Overall mixing properties

Scientific Objectives

- To compare six available PBL schemes in WRF model and identify the best scheme
- To improve MRF and YSU schemes in WRF model by implementation of new formula for the eddy diffusivities under stable conditions
- To investigate thermally forced small-scale processes in complex terrain (near-surface jets, collisions between katabatic and valley flows)

Weather Research and Forecasting Model (WRF–ARW v.3.4.1)

http://www.mmm.ucar.edu/wrf/users/



WRF domains

Lambert projection
Utah (113°W, 40°N)
Two-way nested (64, 16, 4, 1km)
vertical levels: 48
without data assimilation

Updated land-cover and terrain elevation dataset based on the newer 33-category National Land Cover Database (NLCD) (J. of Appl. Met. and Climatology, Jeffrey Massey et al., 2013)

Simulated periods: *Quiescent IOPs*
(definition by 700mb wind speed < 5m/s)

IOP	Run Date and Times (MDT)
Fall experiment	
1	9/28/2012 14:00 - 9/29/2012 14:00
2	10/1/2012 14:00 - 10/2/2012 14:00
6	10/14/2012 2:00 - 10/15/2012 2:00
8	10/18/2012 5:00 - 10/19/2012 12:00
Spring experiment	
4	5/11/2013 14:00- 5/12/2013 14:00
7	5/20/2013 17:15 - 5/21/2013 14:00

Evaluation of six PBL schemes for SPBL

WRF PBL option	Reference
Medium Range Forecast (MRF): non-local closure; modified K-theory with implicit treatment of an additional counter-gradient term	Hong and Pan (MWR, 1996)
Yonsei University (YSU): modified MRF with explicit treatment of entrainment rate at the PBL top; Prandtl number depending on height	Hong, Noh and Dudhia (MWR, 2006)
Asymetric Convective Model (ACM2): explicit non-local upward mixing and local downward mixing; shuts off nonlocal transport and use local closure for stable and neutral conditions	Pleim J. E. (J. Appl. Met., 2007)
Mellor-Yamada-Janjic (MYJ): Eta operational scheme, one-dimensional 1.5 order level 2.5 prognostic turbulent kinetic energy scheme with local vertical mixing, use master turbulent length scale	Janjic (MWR, 1994)
Bougeault and Lacarrere (BouLac): prognostic TKE prediction, local vertical mixing, eddy viscosities depend on TKE and length scale	Bougeault and Lacarrere (MWR, 1989)
Quasi-Normal Scale Elimination (QNES): a TKE-prediction option that uses a new spectral Quasi-Gaussian spectral closure model for stably stratified regions	Sukoriansky, Galperin and Perov (BLM, 2005)

SL sch.	Description	PBL sch.
MM5	stability functions; four stability regimes (stable, unstable free driven turbulence and forced convection, mechanically; no thermal roughness length parameterization	MRF/YSU
Eta	similarity theory; parameterizations of a viscous sub-layer; variable roughness height for temperature and humidity as proposed by Zilitinkevich (1995)	MYJ/ BouLag
QNSE	similarity theory; the integrals at the first level for velocity and potential temperature are computed analytically as function of z/L; derived SL parameterization based on LES calculations	QNSE
Pleim-Xiu	similarity theory; parameterizations of a viscous sub-layer in the form of a quasi - laminar boundary layer resistance	ACM2

Statistics measures – night time

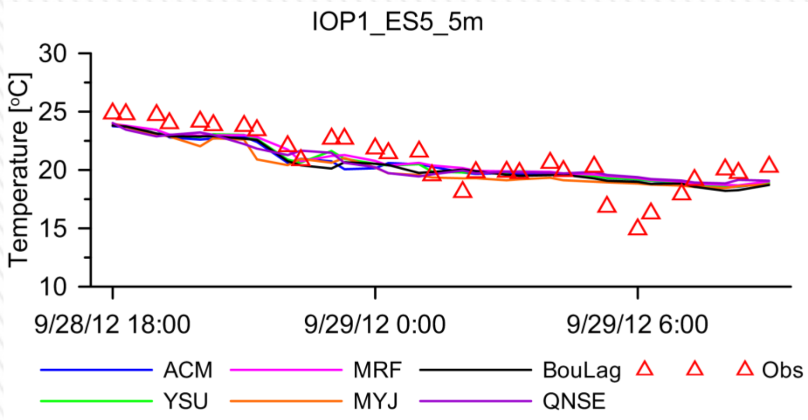
	BouLag	MYJ	QNSE	ACM	YSU	MRF	Observ.
Temperature							
Averaged [C]	14.50	13.93	12.73	13.89	14.36	14.63	11.09
Standard deviation	4.06	4.28	4.45	4.34	4.38	4.20	7.21
Wind speed							
Averaged [m/s]	2.94	2.99	2.78	3.19	2.96	3.12	2.65
Standard deviation	1.45	1.48	1.14	1.41	1.61	1.82	1.27
Wind direction							
Averaged [degrees]	159.02	156.87	149.74	157.53	154.68	155.37	141.78
Standard deviation	79.11	75.92	67.70	75.46	78.26	78.91	70.01

PBL scheme	BouLag	MYJ	QNSE	ACM	YSU	MRF
Temperature						
Mean Bias [C]	3.42	2.85	1.65	2.81	3.28	3.55
Normalized Mean Bias [%]	30.84	25.70	14.87	25.36	29.57	32.02
Mean Error [C]	4.34	3.87	3.16	3.84	4.13	4.35
Normalized Mean Error [%]	39.17	34.88	28.52	34.67	37.25	39.20
Root Mean Square Error [C]	6.63	6.29	5.77	6.28	6.51	6.64
Index of agreement	0.66	0.69	0.73	0.70	0.69	0.67
Wind speed						
Mean Bias [m/s]	0.29	0.35	0.13	0.54	0.31	0.47
Normalized Mean Bias [%]	10.77	13.06	5.03	20.41	11.66	17.76
Mean Error [m/s]	1.39	1.41	1.22	1.43	1.55	1.69
Normalized Mean Error [%]	52.57	53.29	45.87	54.11	58.35	63.66
Root Mean Square Error [m/s]	1.80	1.84	1.57	1.85	1.96	2.10
Index of agreement	0.48	0.47	0.48	0.46	0.45	0.46
Wind direction						
Mean Bias [degrees]	17.27	15.08	7.90	15.68	12.91	13.55
Normalized Mean Bias [%]	12.18	10.64	5.57	11.06	9.10	9.56
Mean Error [degrees]	61.10	61.61	56.31	61.21	63.15	64.19
Normalized Mean Error [%]	43.10	43.45	39.72	43.18	44.55	45.27
Root Mean Square Error [degrees]	93.92	94.08	89.65	94.70	97.46	98.99
Index of agreement	0.56	0.53	0.52	0.53	0.51	0.50

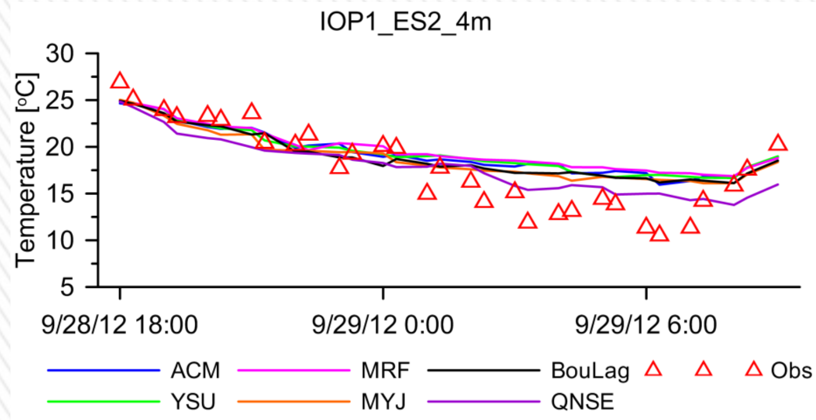
Index of Agreement Willmott (1981)

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

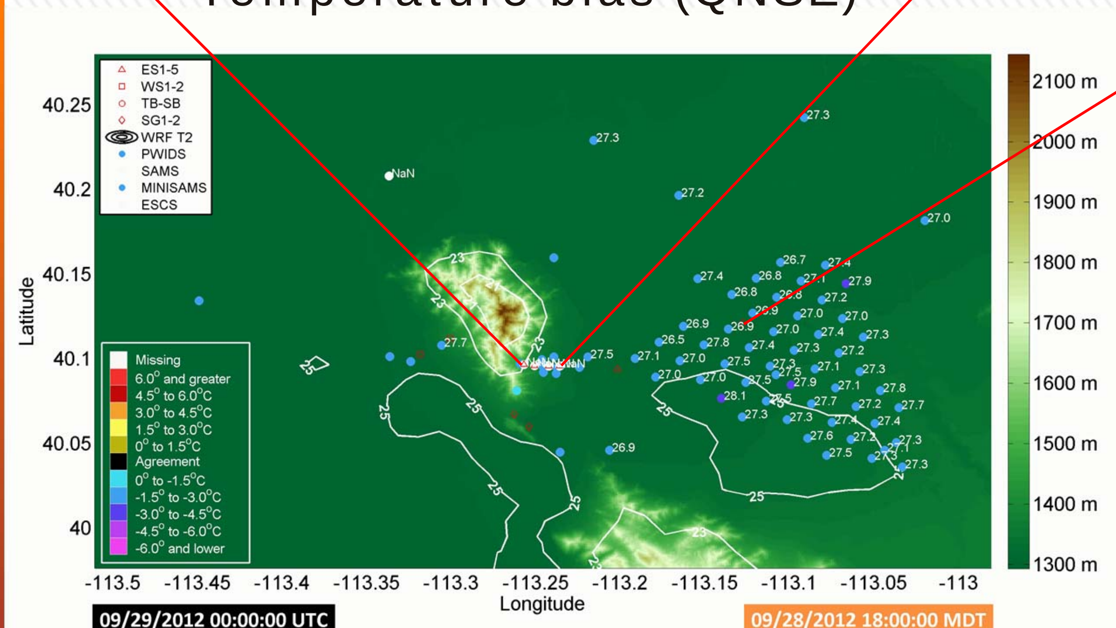
East slope tower ES5



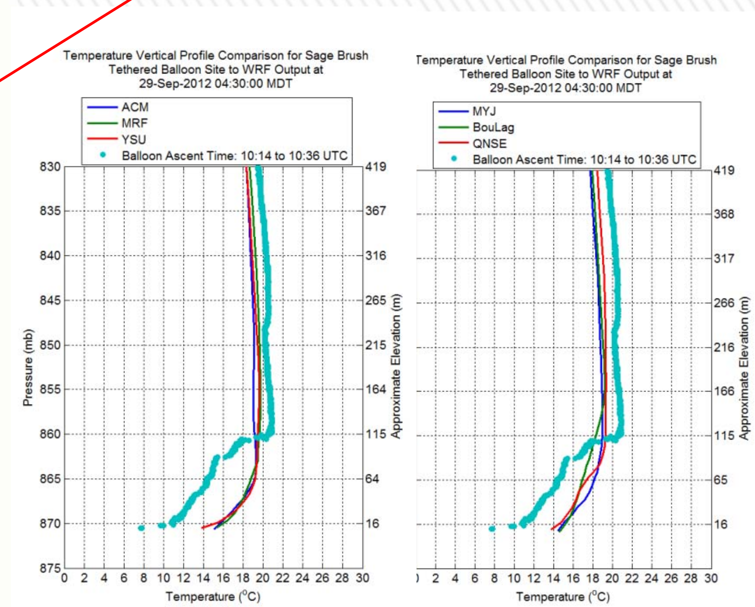
East slope tower ES2



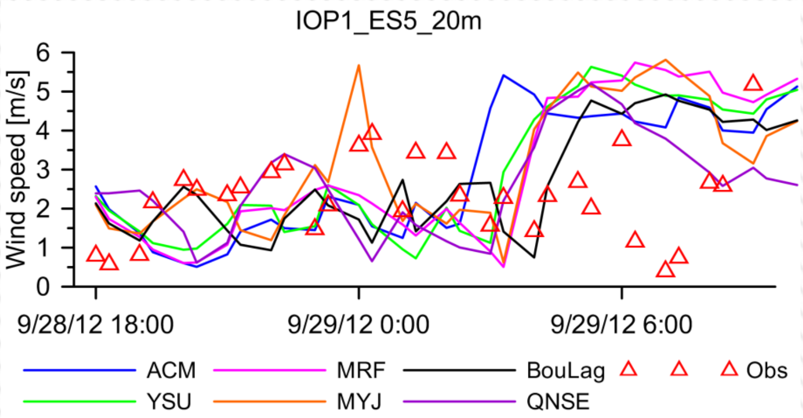
Temperature bias (QNSE)



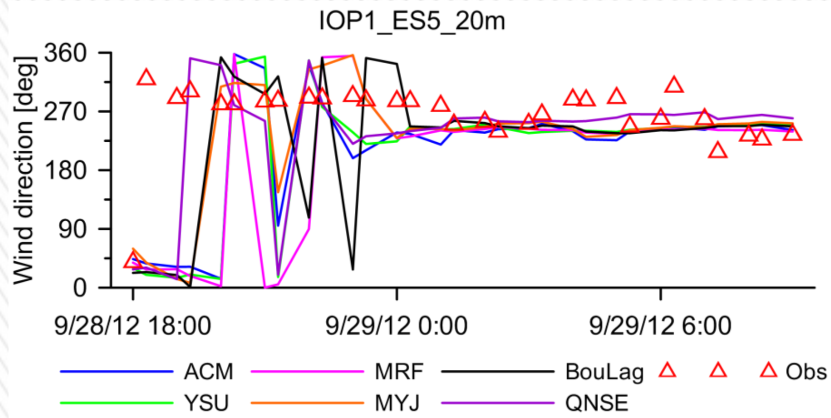
Sagebrush site



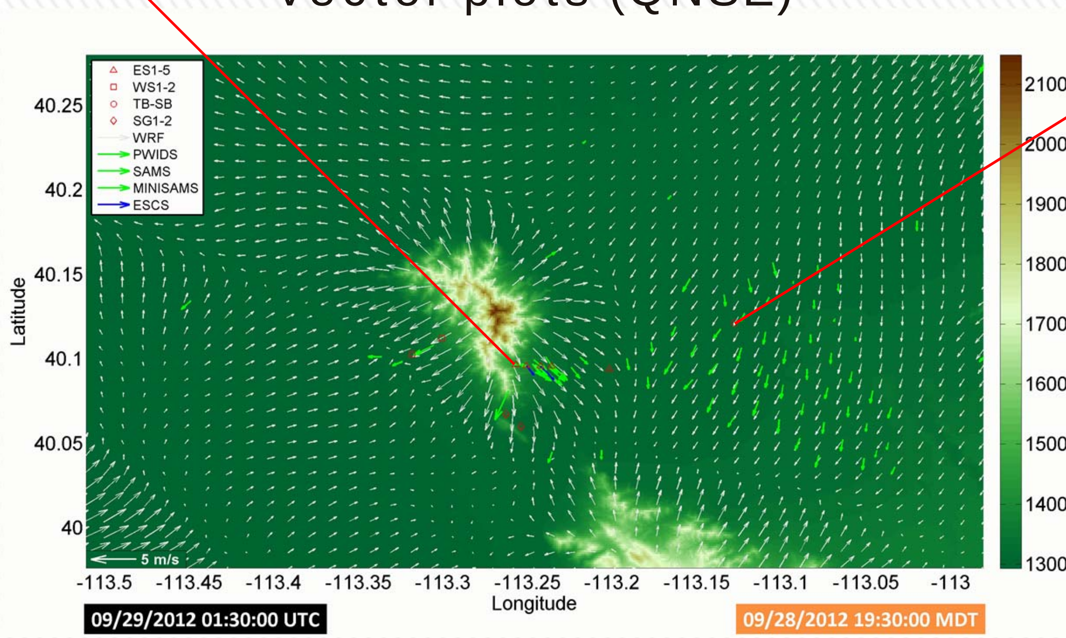
East slope tower ES5



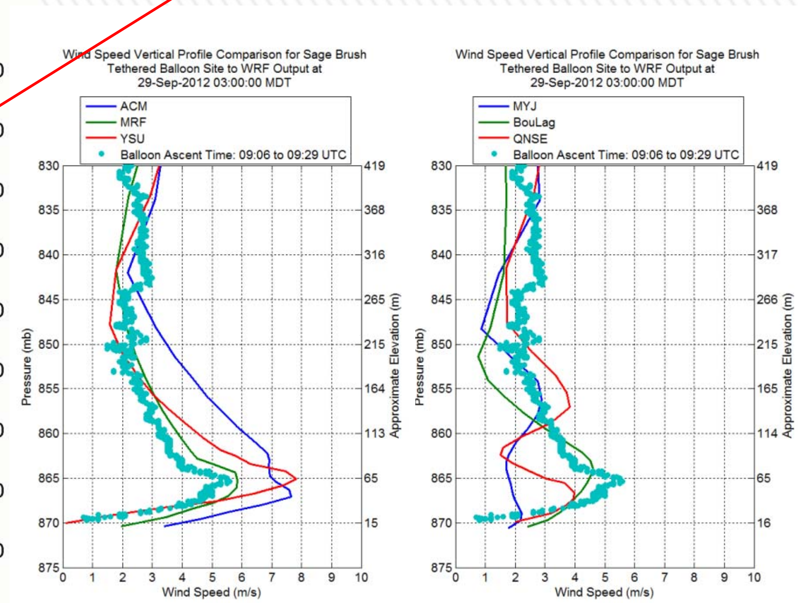
East slope tower ES5



Vector plots (QNSE)



Sagebrush site



Turbulence parameterization – MRF and YSU PBL (first-order non-local closure based on similarity theory)

Advantages

- Simple and most popular for numerical weather prediction
- Well evaluated for different conditions
- Computationally inexpensive
- Better in predicting convective boundary layer than local closure schemes

Disadvantages

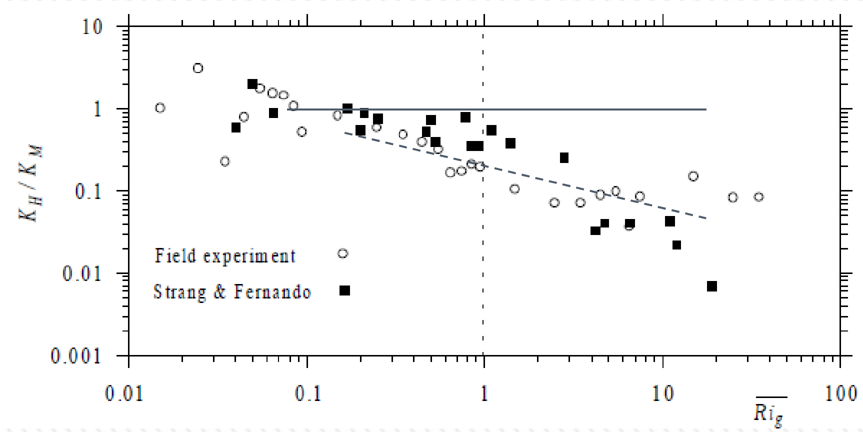
- Over-predict the minimum temperature inside the "Valley cold pool"
- Cannot well capture the maximum velocity of the low-level jet

PBL turbulence parameterization for nocturnal flow in complex terrain

Data from Vertical Transport and Mixing eXperiment (VTMX), 2002

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

Non-dimensional form for eddy diffusivities



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

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

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

Gr. Richardson number

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

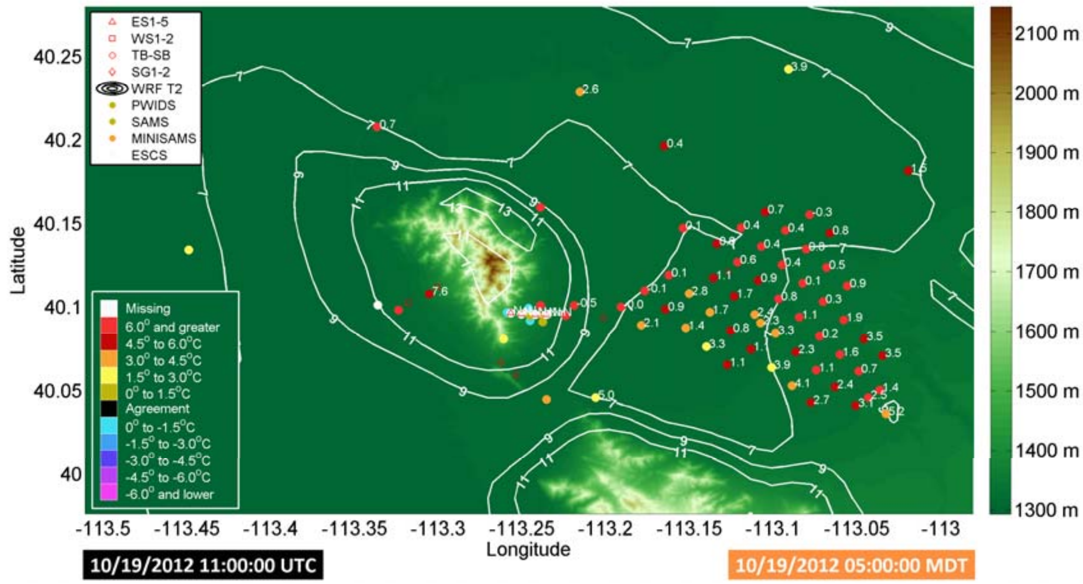
Buoyancy frequency

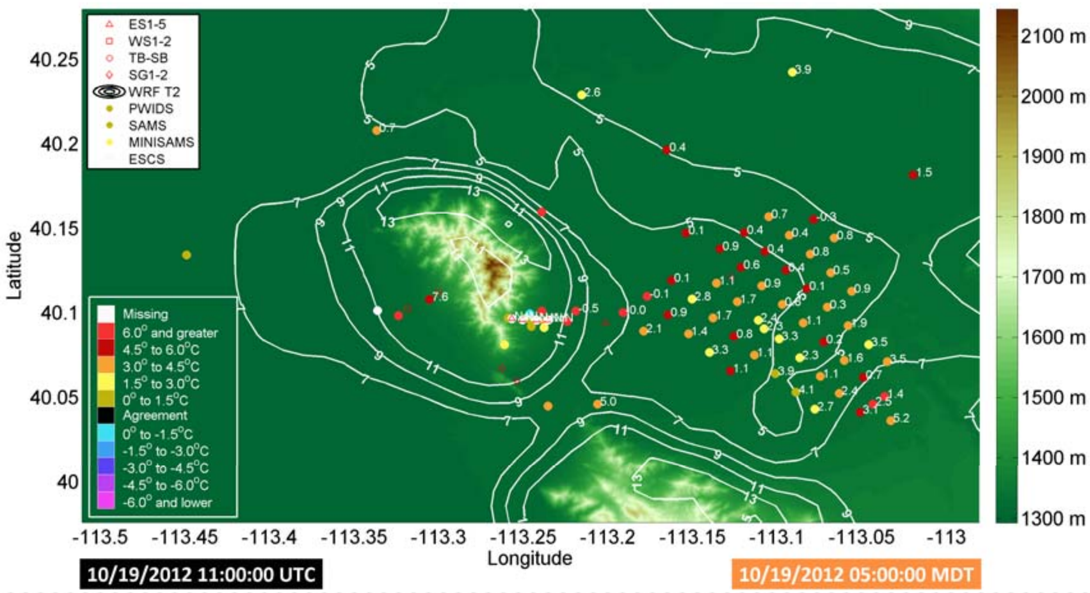
Vertical wind variance $\sigma_w^2 = \overline{w'^2}$

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

Stull (1988)

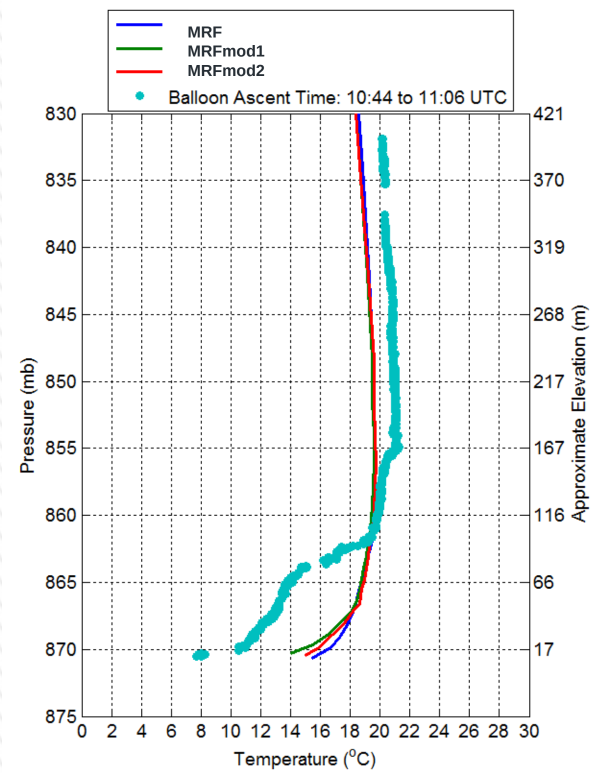
Temperature bias – comparison MRF and MRFmod1



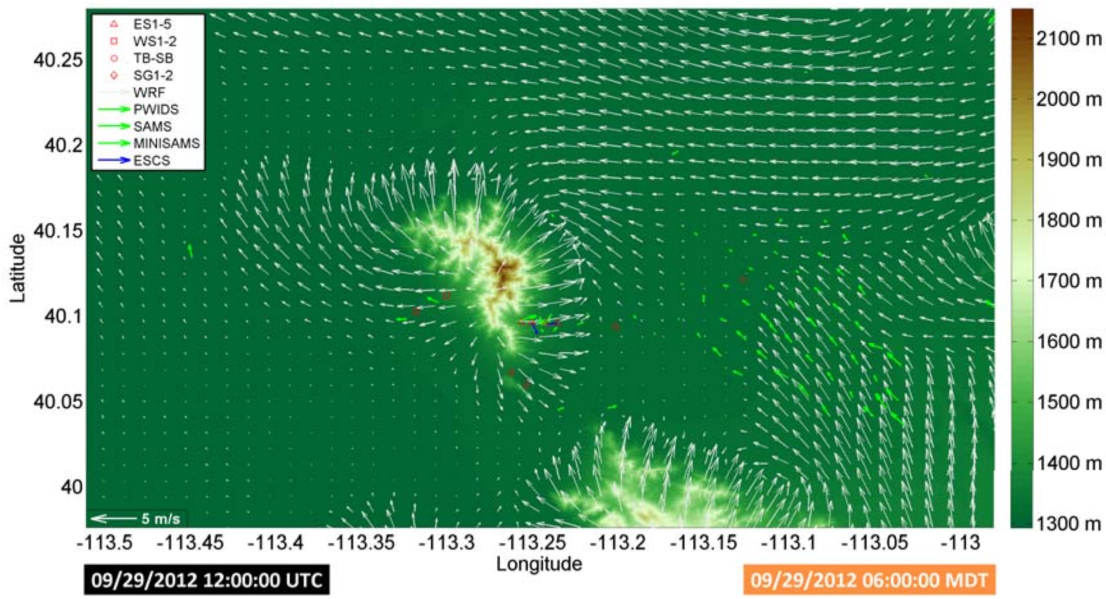


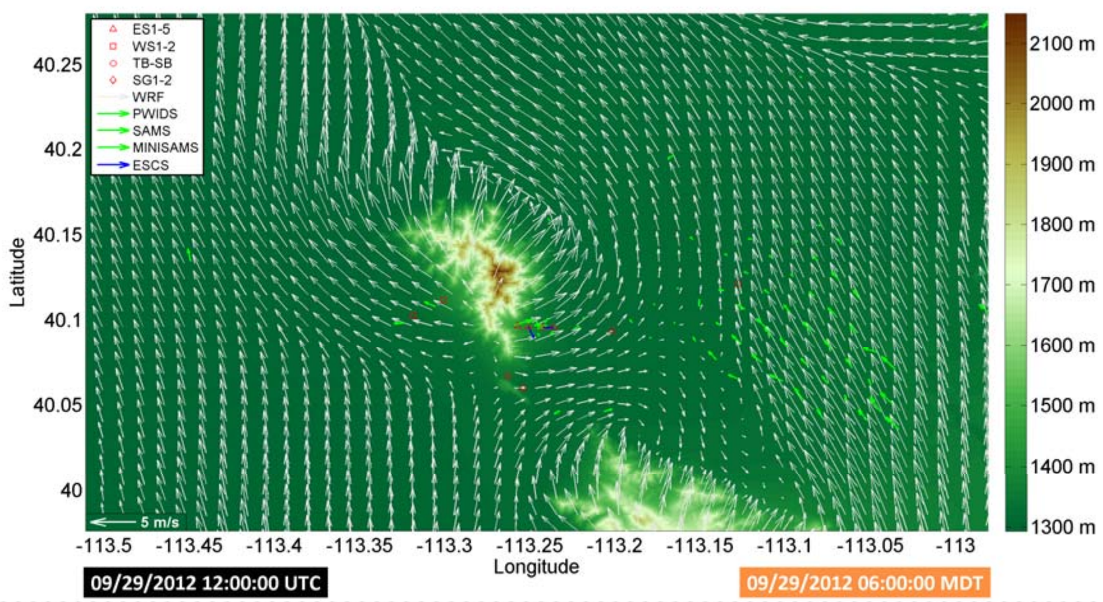
PBL scheme	MRF	MRF-mod1
Mean Error [C]	4.35	3.85
Normalized Mean Error [%]	39.20	34.76
Root Mean Square Error [C]	6.64	6.28
Index of agreement	0.67	0.70

Sagebrush site
29 Sep. 2012 - 05:00 MDT



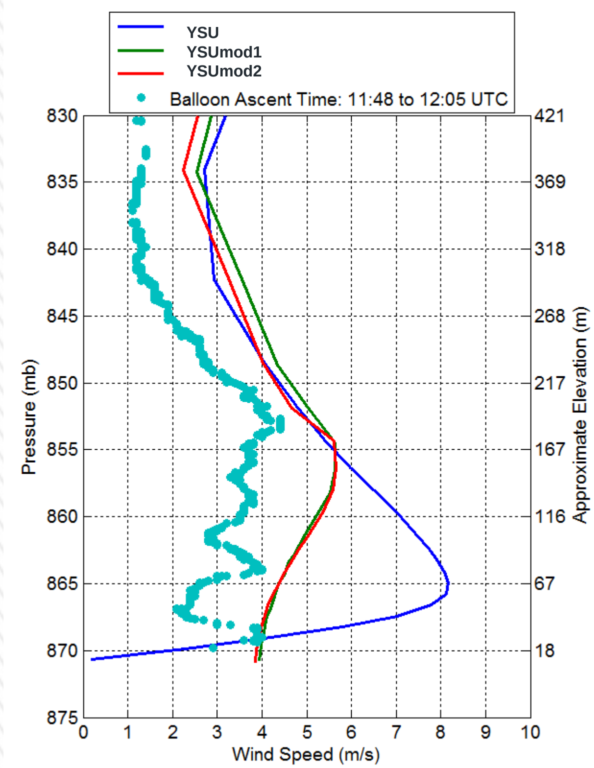
Wind vectors – comparison YSU and YSUmod2





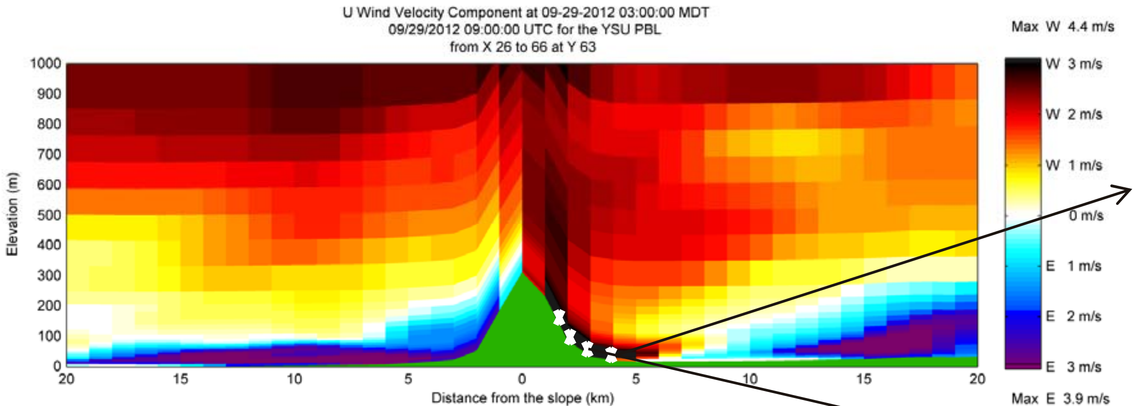
PBL scheme	YSU	YSU-mod2
Mean Error [m/s]	1.55	1.47
Normalized Mean Error [%]	58.35	55.59
Root Mean Square Error [m/s]	1.96	1.86
Index of agreement	0.45	0.46

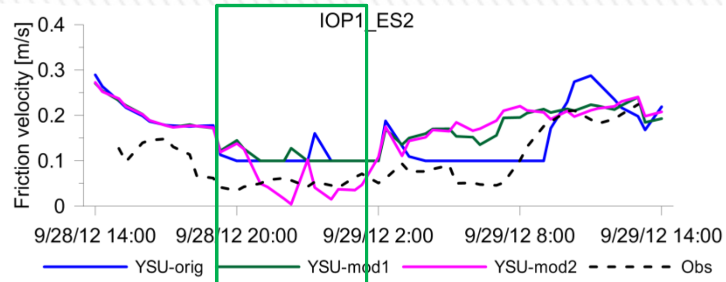
Sagebrush site
29 Sep. 2012 - 06:00 MDT

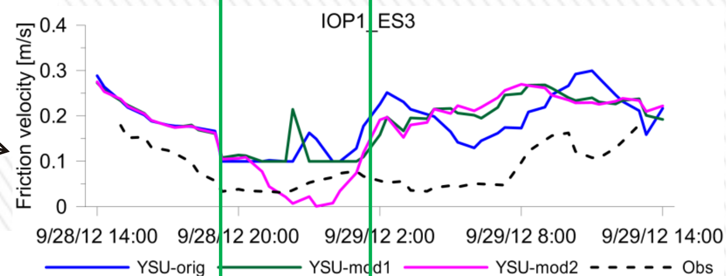


U velocity component vertical cross-section

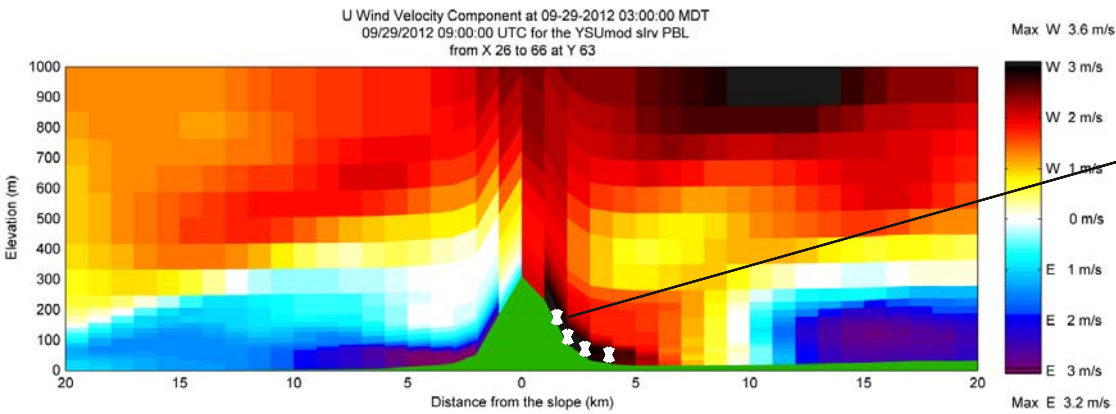
YSU original scheme

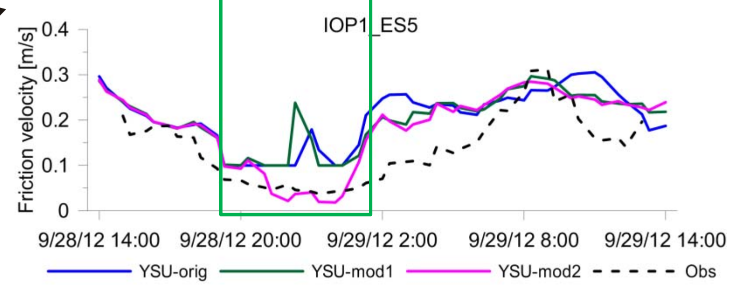






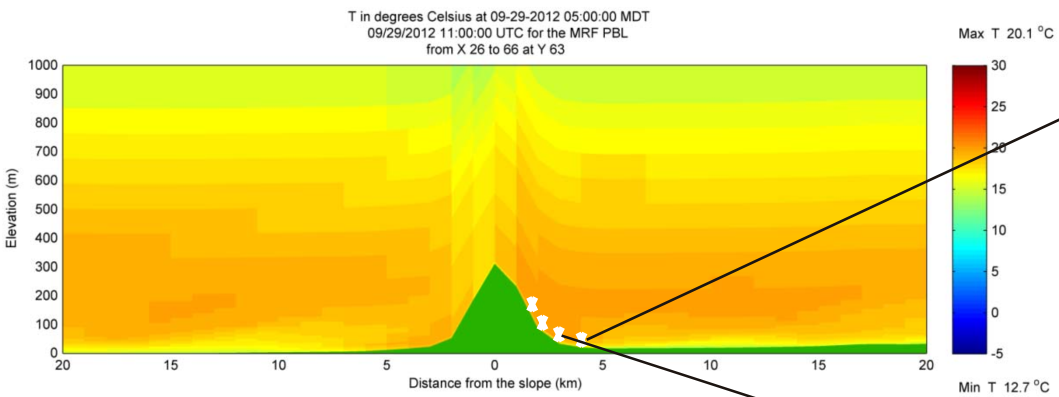
YSU modified scheme

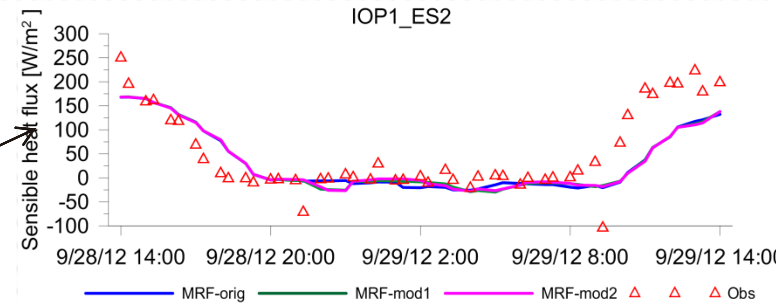


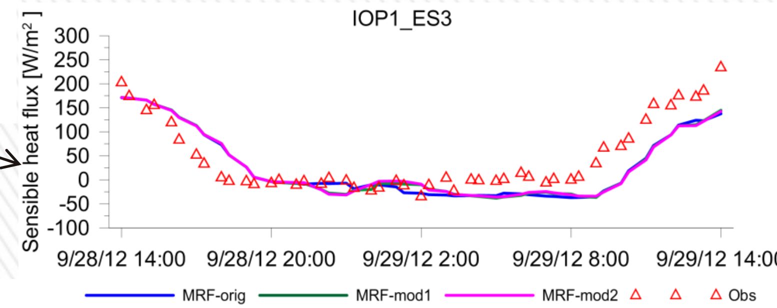


Temperature vertical cross-section

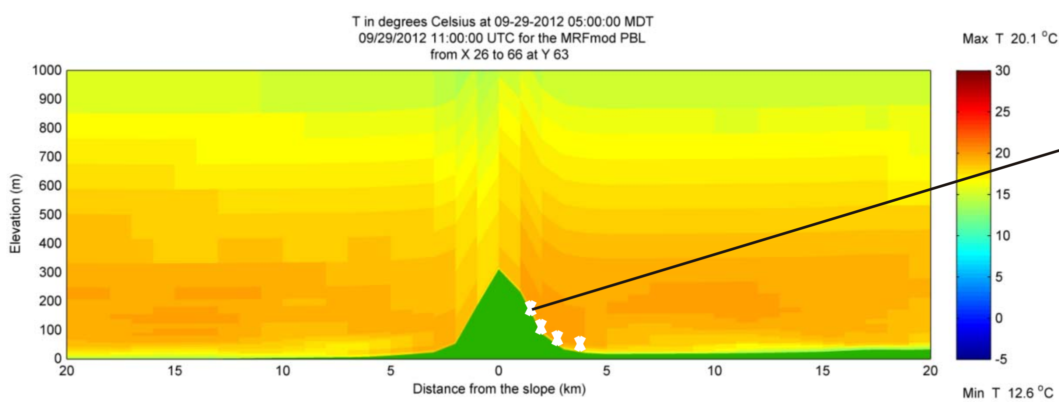
MRF original scheme

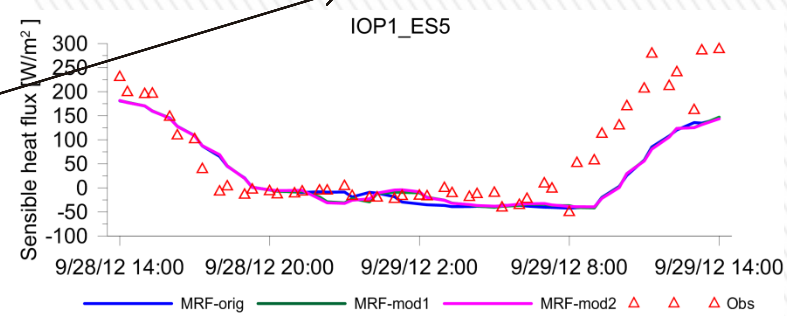






MRF modified scheme



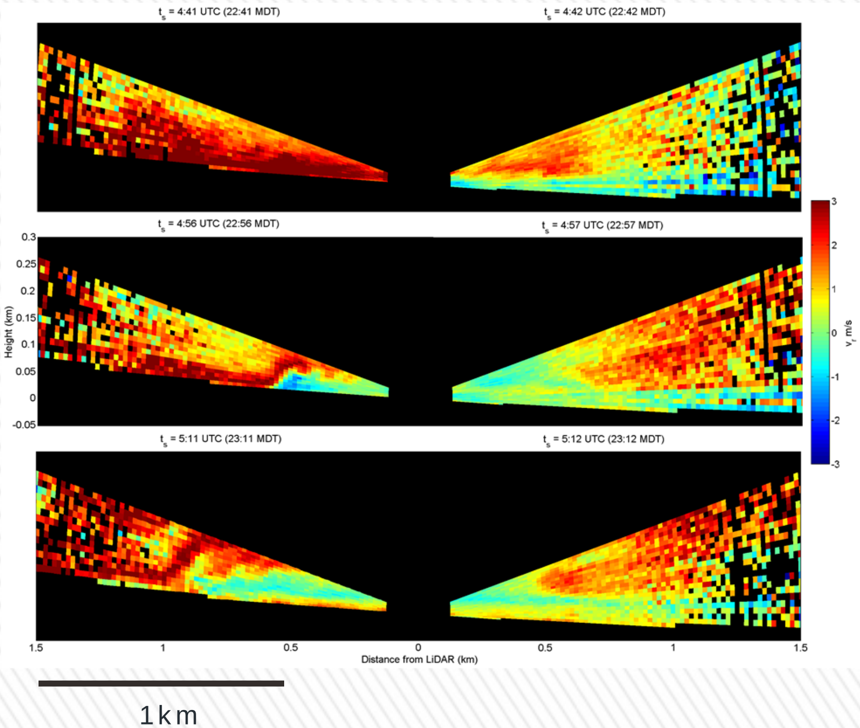


Summary

- All evaluated PBL schemes over-predict the minimum temperature inside the “Valley cold pool” and cannot well capture the low-level jet and the vertical layering due to flow interactions
- The best performance for near surface temperature (2m) and wind (10m) is the QNSE scheme during SPBL
- The preliminary results show better performance for modified MRF scheme in improving slightly the minimum temperature, and for modified YSU for reducing the maximum of the low-level jet winds
- Further evaluation and testing of the modified PBL and existing surface layer schemes is necessary

Future work

East Slope LiDAR (22:41 – 23:11 MDT) for IOP2



Characteristics of collision

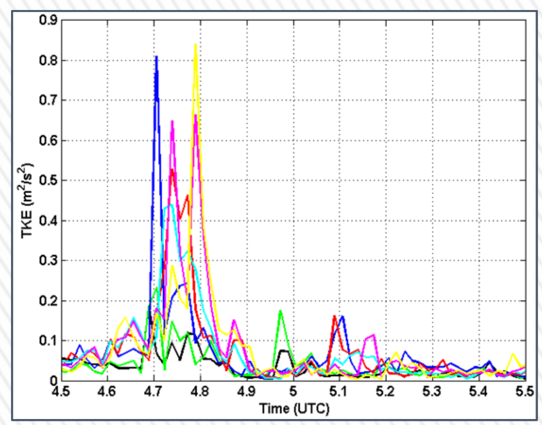
- Rapid drop in temperature
- Intense turbulence
- Strong vertical velocity
- Destruction of downslope flow

Interaction contributes vigorously to sub-grid heat and momentum transfer

Collision is a sub-grid process for the meso-scale models

Can we parameterize the process and implement into the models?

East Slope tower ES2 for IOP2




Thank you!
Questions???
Acknowledgements
Funding thanks to the ONR MURI MATERHORN project
Jeffrey Massey from the University of Utah for the updated land and soil data provided