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High Resolution Modeling for MATERHORN Field Campaign

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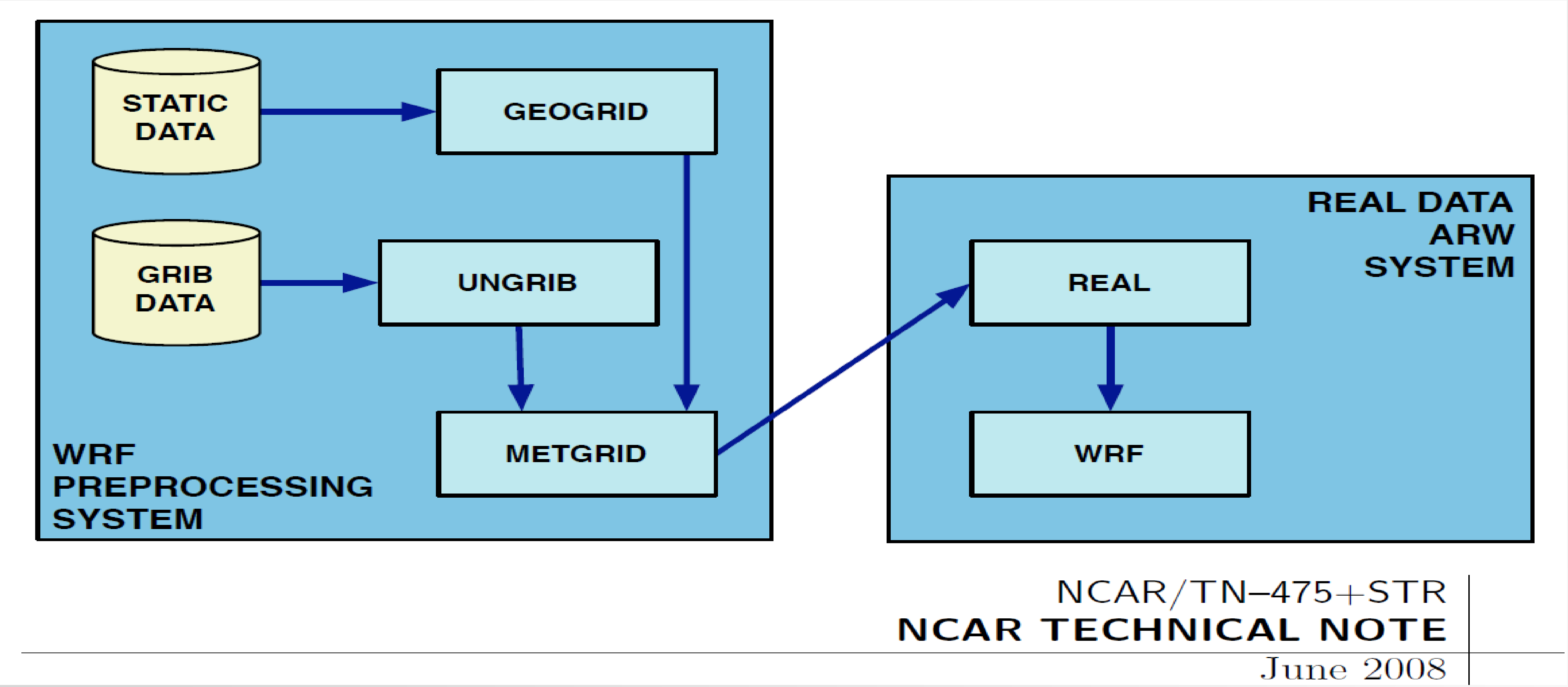
Aim of this work:

- Investigate the ability of the model to capture flow diversity in mountain terrain
- Compare with field campaign data and identify the best PBL scheme and vertical model resolution
- Work for further improvement of the existing PBL schemes or developed a new one

Overview

- **Model setup:**
  - **Modeling periods**
  - **Physics Options**
  - **Modeling domain**
- **Model performance against Mini-SAMS network**
- **East Slope Towers and Balloon comparison**
- **Summary**
- **Preliminary conclusions**

WRF Schematic



Modeling periods (6 PBL schemes used)

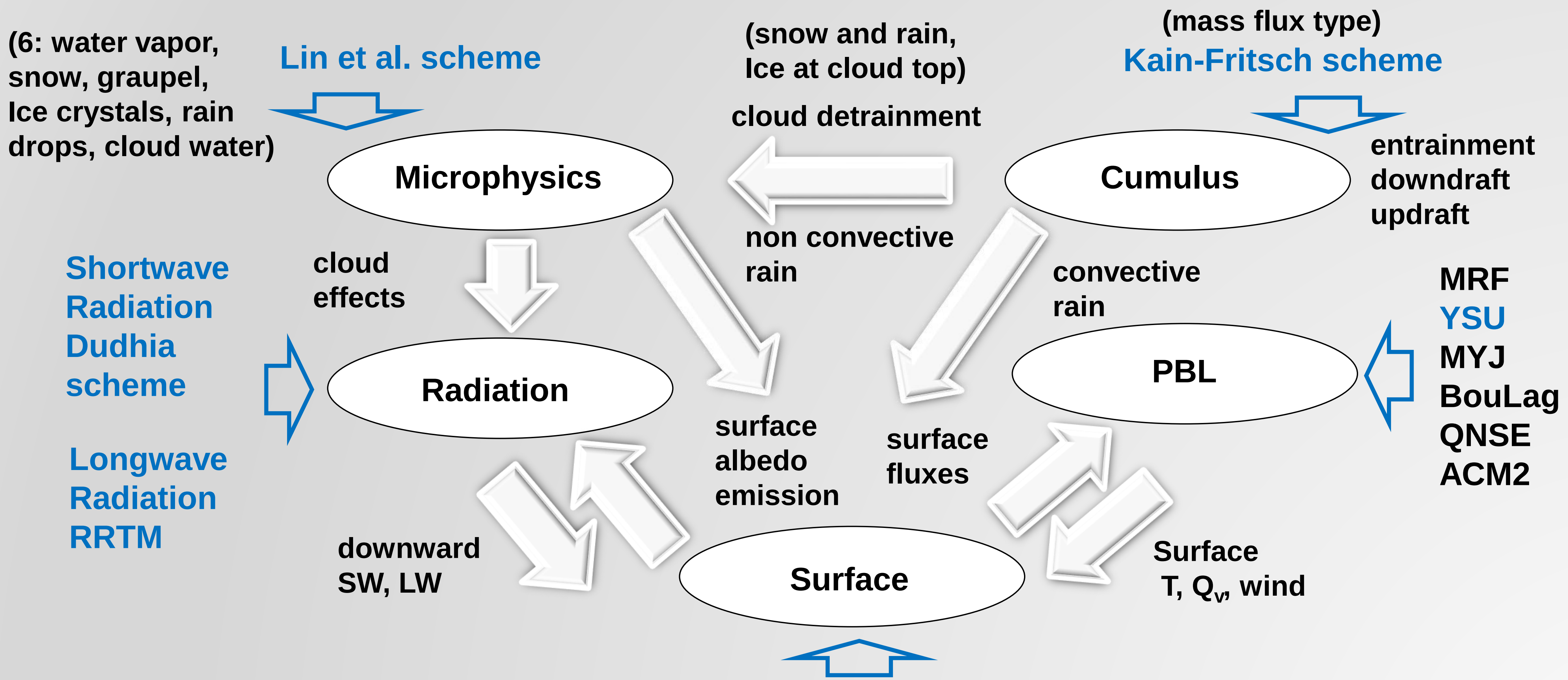
IOP - Fall	Start (MDT)	End (MDT)	Start (UTC)	End (UTC)	Clasification	Wind speed
IOP0	9/25/2012 14:00	9/26/2012 14:00	9/25/2012 20:00	9/26/2012 20:00	Quiescent	<5m/s
IOP1	9/28/2012 14:00	9/29/2012 14:00	9/28/2012 20:00	9/29/2012 20:00	Quiescent	<5m/s
IOP2	10/1/2012 14:00	10/2/2012 14:00	10/1/2012 20:00	10/1/2012 20:00	Quiescent	<5m/s
IOP3	10/3/2012 2:00	10/4/2012 2:00	10/3/2012 8:00	10/4/2012 8:00	Transitional	front
IOP4	10/6/2012 14:00	10/7/2012 14:00	10/6/2012 20:00	10/7/2012 20:00	Moderate	5 m/s – 10 m/s
IOP5	10/9/2012 14:00	10/10/2012 14:00	10/9/2012 20:00	10/10/2012 20:00	Moderate / Quiescent	front
IOP6	10/14/2012 2:00	10/15/2012 2:00	10/14/2012 8:00	10/15/2012 8:00	Quiescent	<5m/s
IOP7	10/17/2012 12:00	10/17/2012 20:00	10/17/2012 18:00	10/18/2012 2:00	Moderate / Quiescent	5 m/s – 10 m/s
IOP8	10/18/2012 5:00	10/19/2012 12:00	10/18/2012 11:00	10/19/2012 18:00	Quiescent	<5m/s
IOP9	10/20/2012 14:00	10/21/2012 14:00	10/20/2012 20:00	10/21/2012 20:00	Moderate	5 m/s – 10 m/s

IOP - Spring	Start (MDT)	End (MDT)	Start (UTC)	End (UTC)	Classification	Wind speed
IOP1	5/1/2013 14:00	5/2/2013 14:00	5/1/2013 20:00	5/2/2013 20:00	Moderate / Quiescent	<5 m/s – 10 m/s
IOP2	5/4/2013 14:00	5/5/2013 14:00	5/4/2013 20:00	5/5/2013 20:00	Moderate	5 m/s – 10 m/s
IOP3	5/7/2013 5:00	5/7/2013 17:00	5/7/2013 11:00	5/7/2013 23:00	Moderate	5 m/s – 10 m/s
IOP4	5/11/2013 14:00	5/12/2013 14:00	5/11/2013 20:00	5/12/2013 20:00	Quiescent	<5m/s
IOP5	5/13/2013 12:00	5/14/2013 12:00	5/13/2013 18:00	5/14/2013 18:00	Moderate / Transitional	5 m/s – 10 m/s
IOP6	5/16/2013 12:00	5/17/2013 12:00	5/16/2013 18:00	5/17/2013 18:00	Moderate / Transitional	5 m/s – 10 m/s
IOP7	5/20/2013 17:15	5/21/2013 14:00	5/20/2013 23:15	5/21/2013 20:00	Sandwich Quiescent	<5m/s
IOP8	5/22/2013 14:00	5/23/2013 14:00	5/22/2013 20:00	5/23/2013 20:00	Moderate	5 m/s – 10 m/s
IOP9	5/25/2013 10:00	5/26/2013 10:00	5/25/2013 16:00	5/26/2013 16:00	Moderate	5 m/s – 10 m/s
IOP10	5/30/2013 14:00	5/31/2013 10:00	5/30/2013 20:00	5/31/2013 16:00	Moderate	5 m/s – 10 m/s

PBL schemes used for model runs

WRF PBL option	Reference
Medium Range Forecast (MRF): modified K-theory with implicit treatment	Hong and Pan (1996, MWR)
Yonsei University (YSU): modified MRF scheme with explicit entrainment layer	Hong, Noh and Dudhia (2006, MWR)
Mellor-Yamada-Janjic (MYJ): one-dimensional prognostic TKE scheme with local vertical mixing	Janjic (1994, MWR)
Asymmetric Convective Model (ACM2): non-local upward mixing and local downward mixing	Pleim, J.E. (2007, J. Appl. Meteor.)
Quasi-Normal Scale Elimination (QNSE): A new spectral model for turbulent flows with stable stratification	Sukoriansky, Galperin and Perov (2005, BLM)
Bougeault and Lacarrere (BouLac): prognostic TKE-prediction option	Bougeault and Lacarrere (1989, MWR)

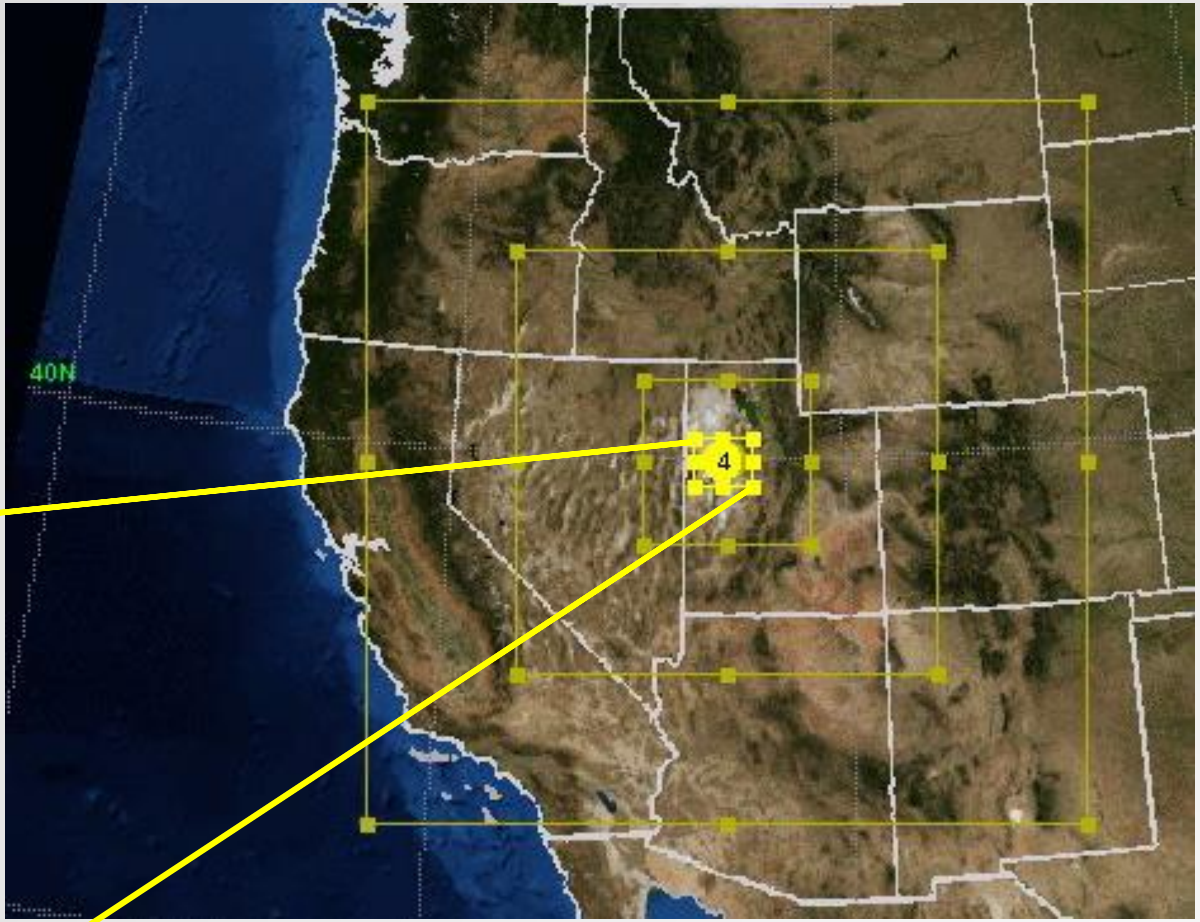
Physics options used for model runs

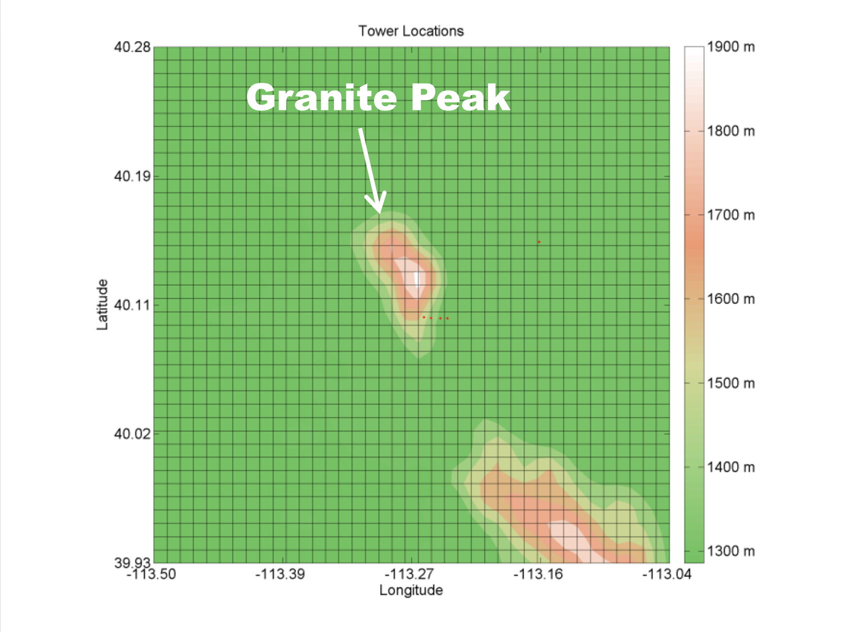


Noah Land Surface Model (with all PBL except ACM2)
Pleim-Xiu Surface Model (with ACM2 PBL)

Modeling domain

Lambert projection centered on Utah (113°W, 40°N)
Two-way nested domains (64, 16, 4, 1km)
Vertical levels: 39 (the lowest model level about 5 m; 15 levels below 1 km)
Initial and boundary conditions : 6-h NCEP FNL Operational Model Global Tropospheric Analyses (http://rda.ucar.edu/datasets/ds083.2/)





Measures of model performance

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)

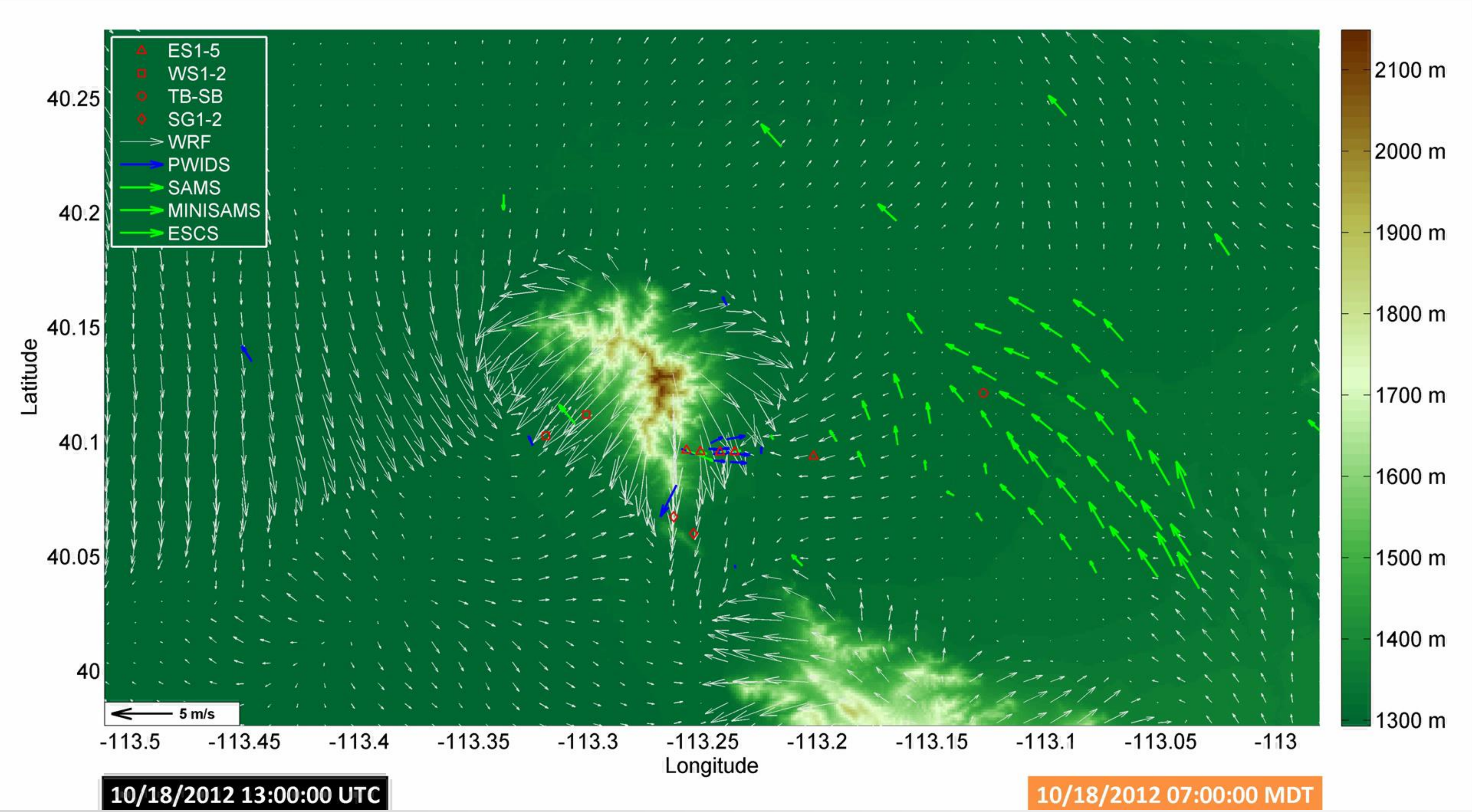
$$IA = 1 - \frac{\sum_{i=1}^{N}(M_i - O_i)^2}{\sum_{i=1}^{N}\left(\left|M_i - \overline{O}\right| + \left|O_i - \overline{O}\right|\right)^2}$$

Statistical correlations

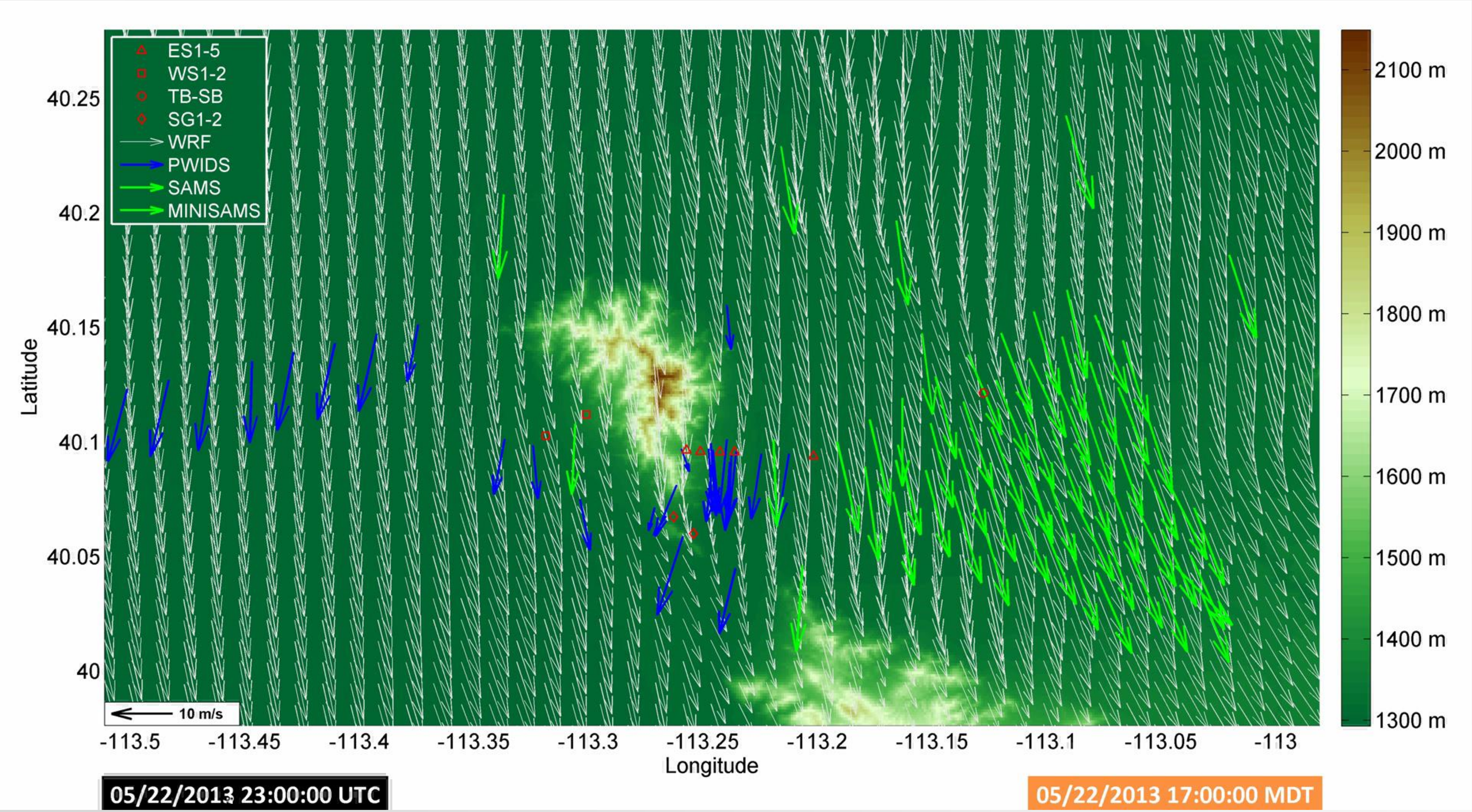
Fall experiment

		BouLag	MRF	MYJ	ACM2	QNSE	YSU
NMB	WD	-2.91	0.11	-8.08	2.61	-5.96	-3.02
	WS	7.29	0.86	7.16	-13.46	11.30	-3.60
	T	-8.88	-6.56	-14.61	14.45	-9.22	-9.65
NME	WD	50.92	48.37	52.01	50.09	49.31	49.25
	WS	55.73	55.77	55.44	51.55	55.11	54.81
	T	28.65	27.27	31.70	23.11	26.83	28.33
IA	WD	0.59	0.62	0.56	0.61	0.61	0.61
	WS	0.59	0.60	0.58	0.58	0.59	0.60
	T	0.80	0.81	0.75	0.87	0.82	0.80

Thermal circulation modeling (October 18-19, 2012)



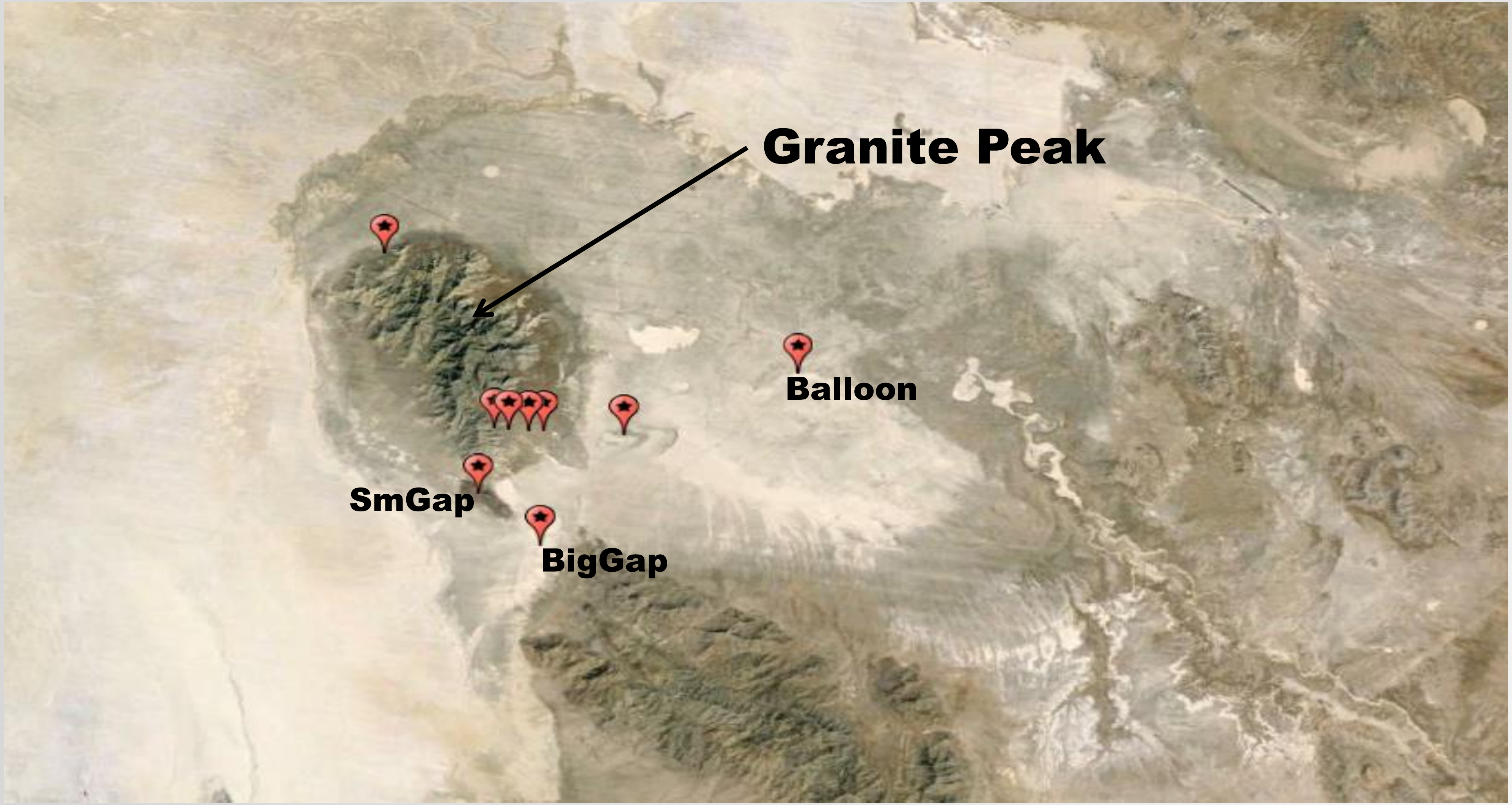
Synoptic NW flow modeling (May 22-23, 2013)



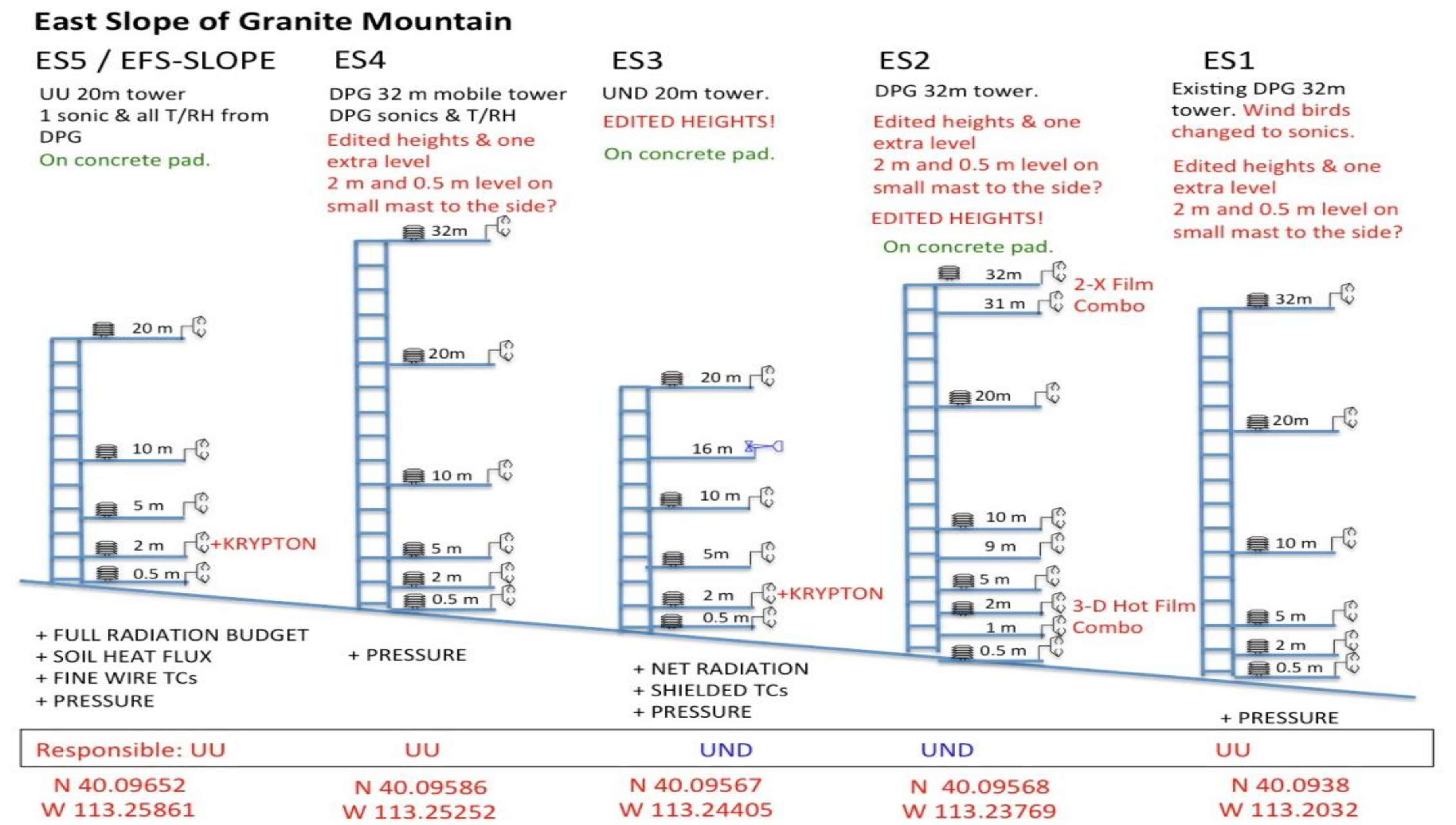
Statistical correlations

	Fall experiment						Spring experiment		
	IOP 1	IOP 2	IOP 5	IOP 6	IOP 7	IOP 8	IOP 1	IOP 4	IOP 7
Temperature									
Averaged	17.18	16.44	13.95	11.46	13.13	7.54	5.71	19.43	16.22
Standard deviation	9.85	10.18	7.15	6.32	1.88	6.85	6.01	7.55	12.16
Mean Bias	-1.27	-0.37	-0.67	-1.48	-3.15	-0.56	-2.34	-2.33	-0.98
Mean Error	5.93	5.13	4.56	4.07	3.32	4.45	3.79	4.76	3.00
Index of agreement	0.51	0.63	0.73	0.74	0.48	0.74	0.74	0.74	0.51
Wind speed									
Averaged	2.32	2.34	2.01	2.08	2.50	2.01	3.13	2.60	4.55
Standard deviation	1.16	1.15	1.14	1.26	1.10	1.01	2.35	1.29	2.41
Mean Bias	-0.27	-0.33	-0.45	-0.01	0.31	-0.02	0.05	0.40	0.86
Mean Error	1.43	1.22	1.34	1.24	1.23	1.28	1.27	1.66	2.00
Index of agreement	0.34	0.46	0.42	0.66	0.57	0.46	0.90	0.37	0.64

Location of different points of interest

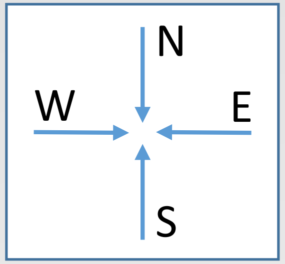


East Slope Towers

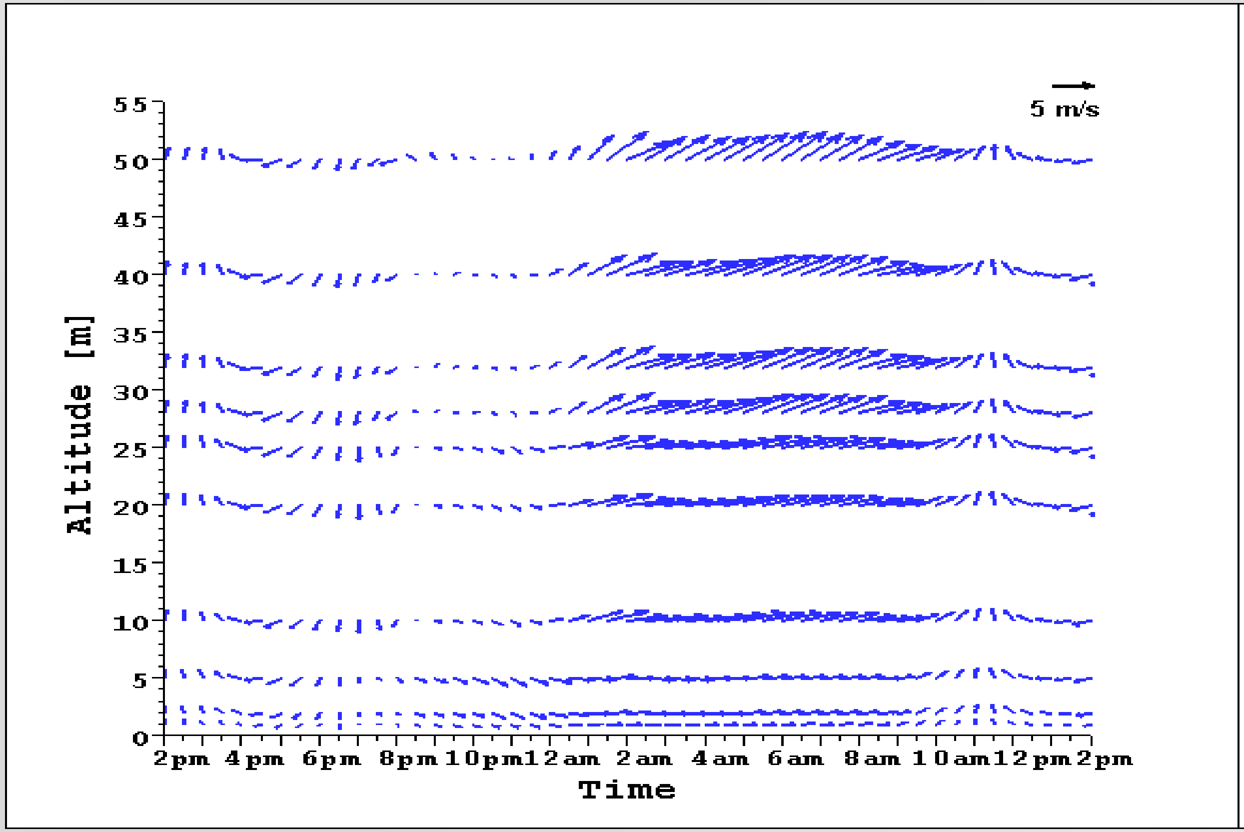


Di Sabatino and Leo, 2012

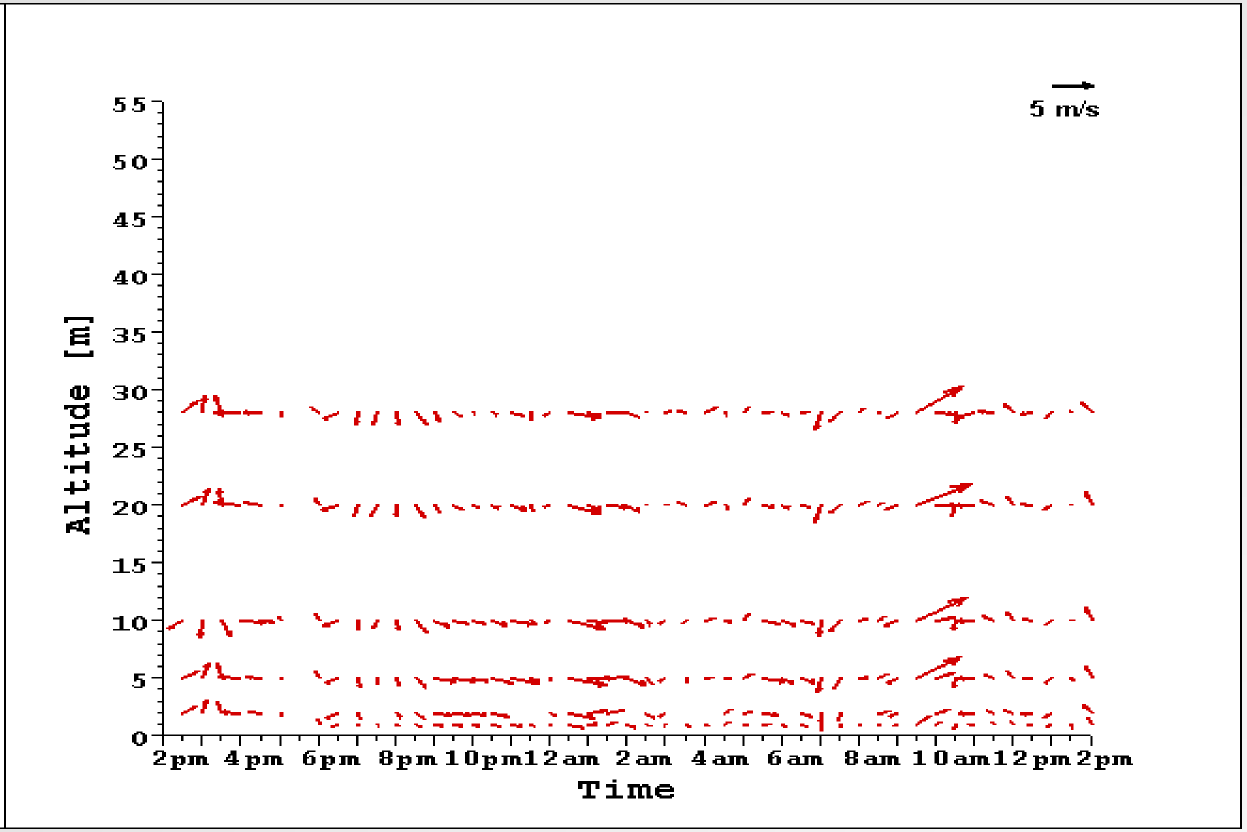
IOP1 (Sep. 28, 2012, 2:00pm – Sep. 29, 2012, 2:00pm)



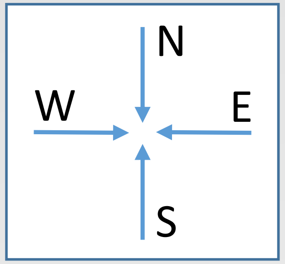
ES4 model



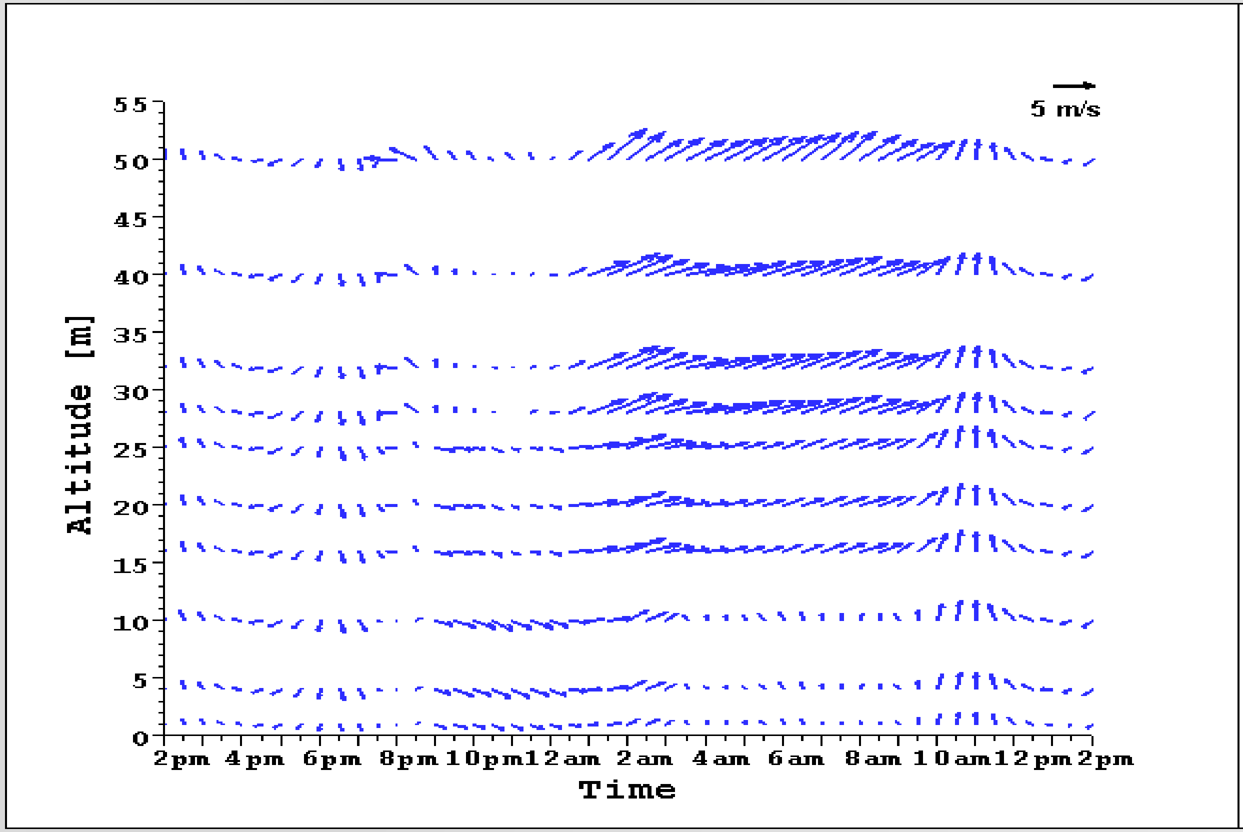
ES4 observation



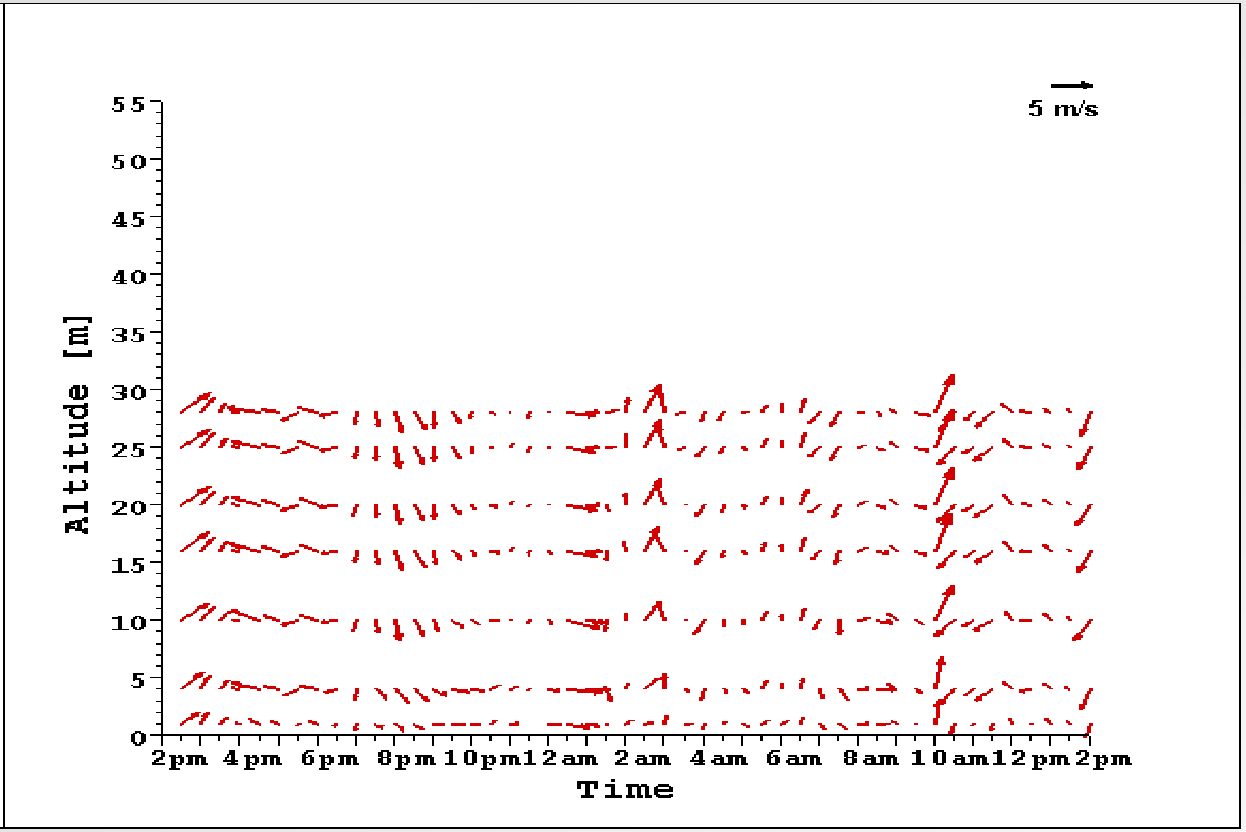
IOP1 (Sep. 28, 2012, 2:00pm – Sep. 29, 2012, 2:00pm)



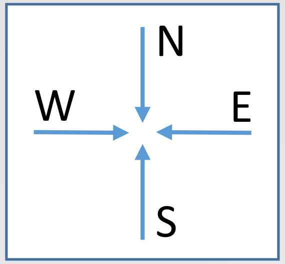
ES2 model



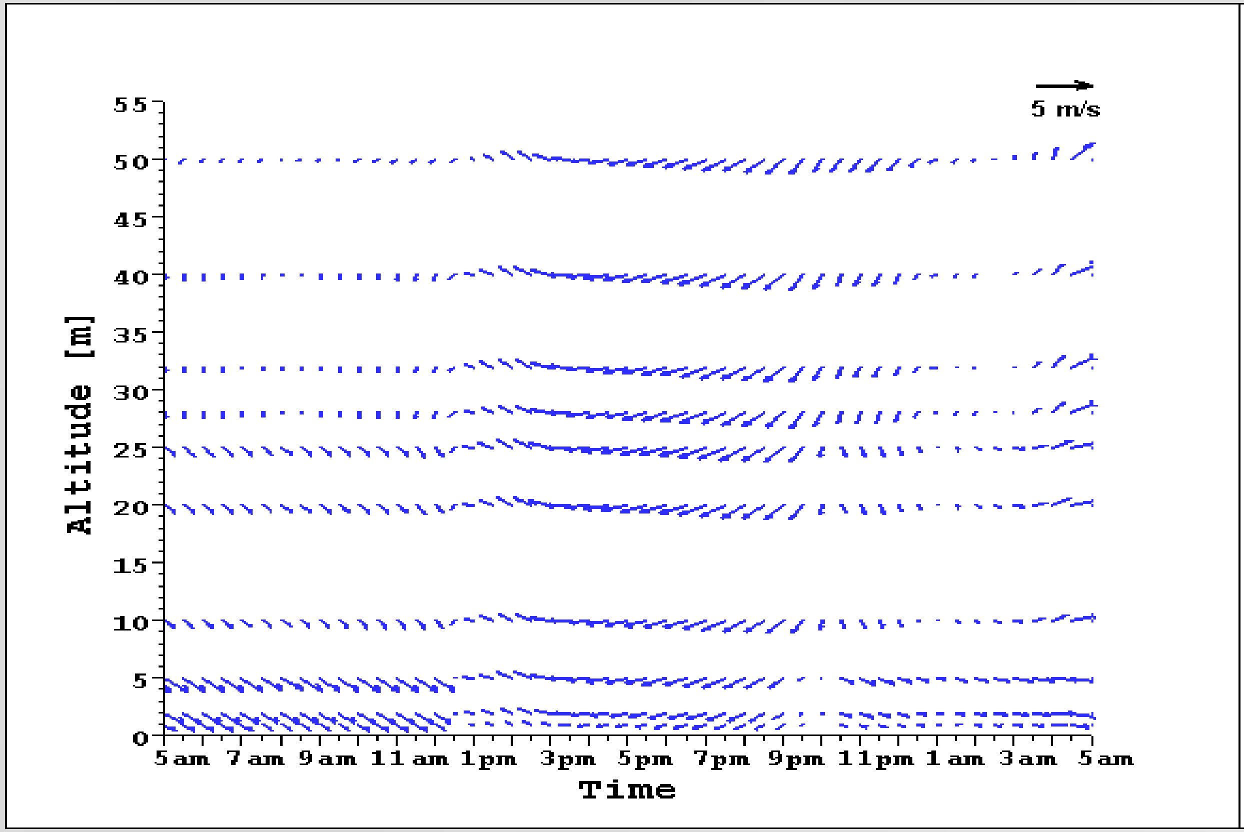
ES2 observation



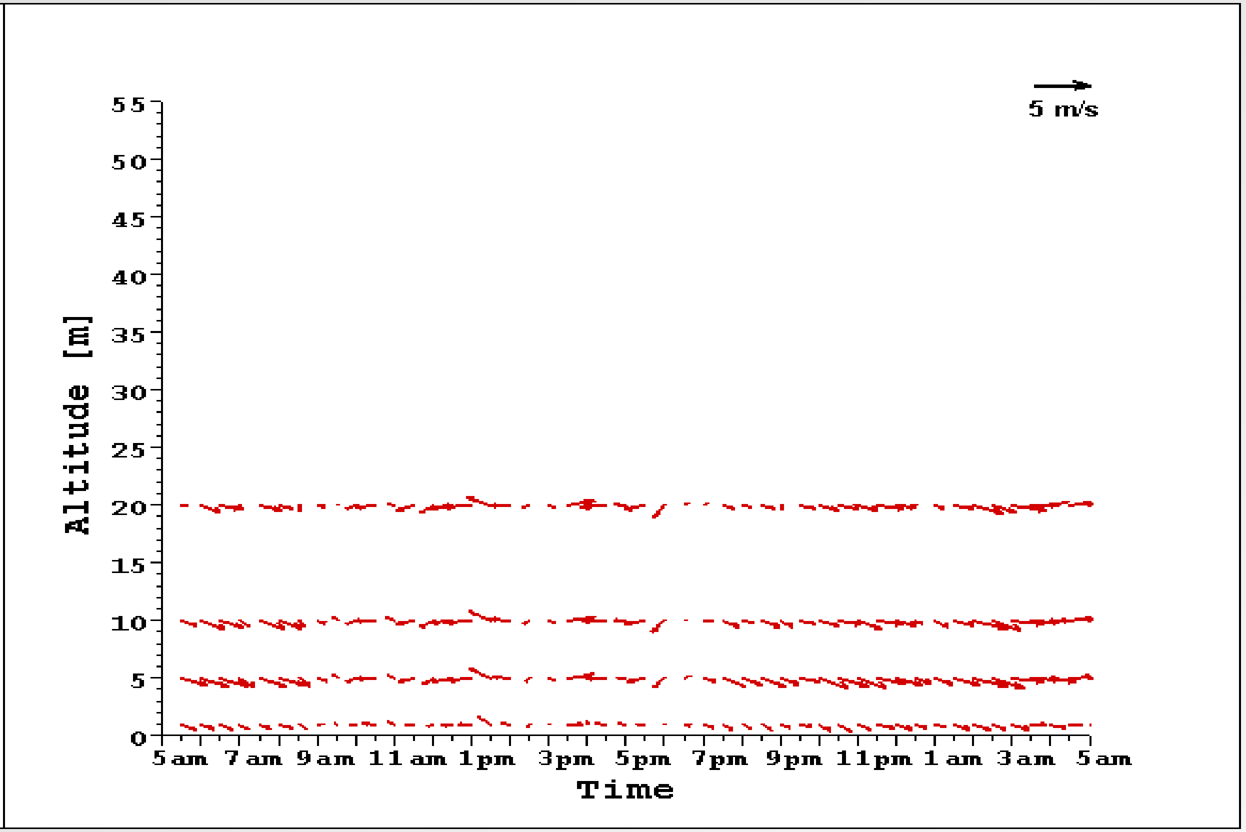
IOP8 (Oct. 18, 2012, 5:00am – Oct. 19, 2012, 5:00am)



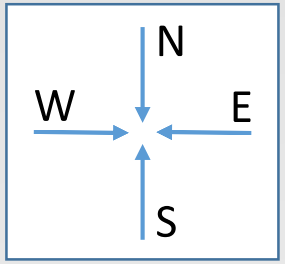
ES5 model



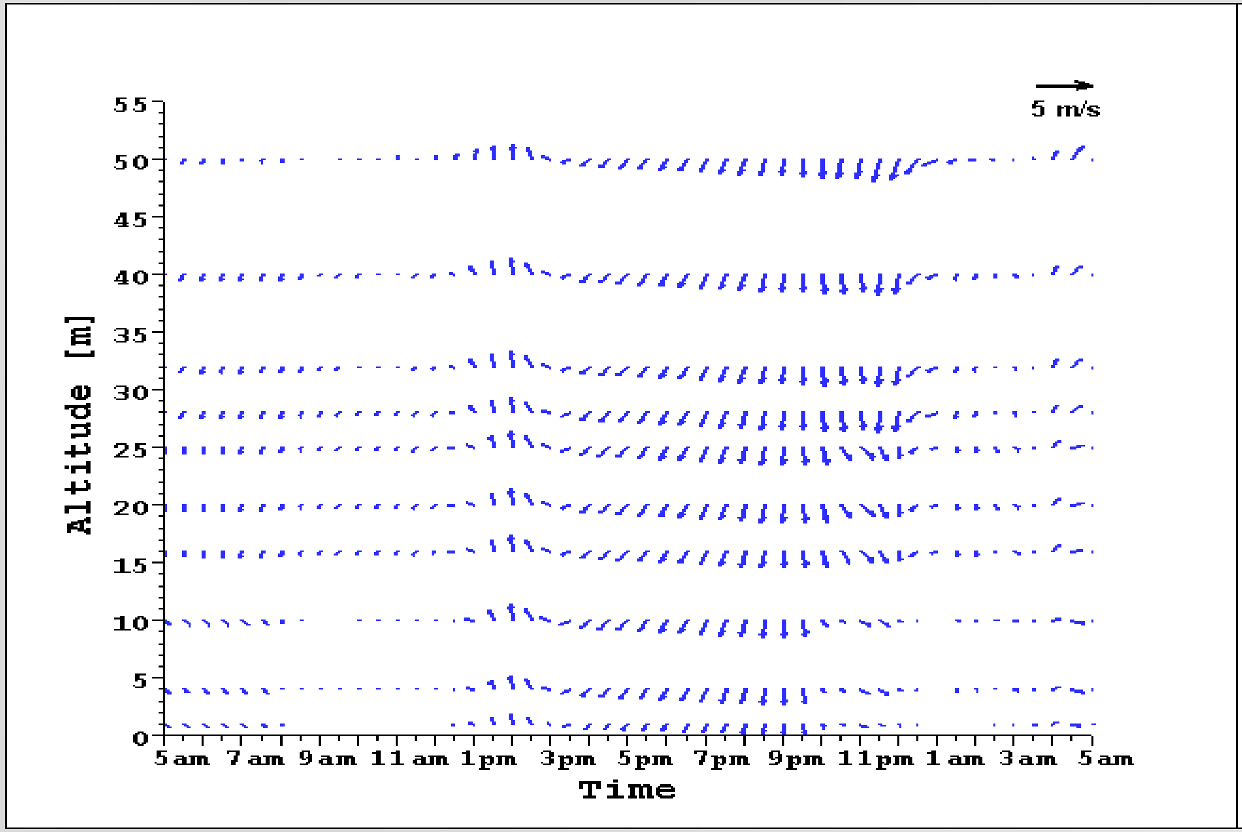
ES5 observation



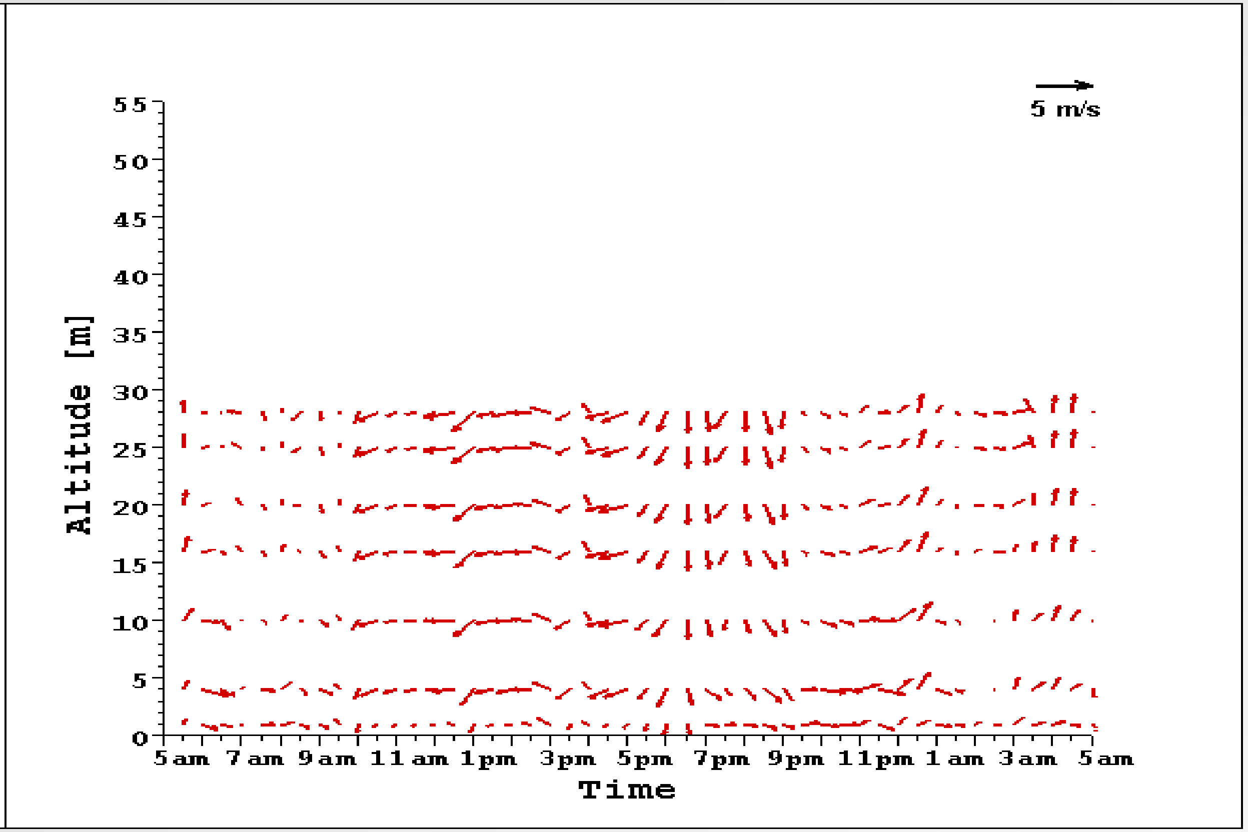
IOP8 (Oct. 18, 2012, 5:00am – Oct. 19, 2012, 5:00am)

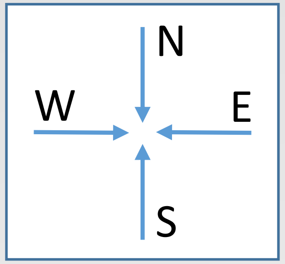


ES2 model



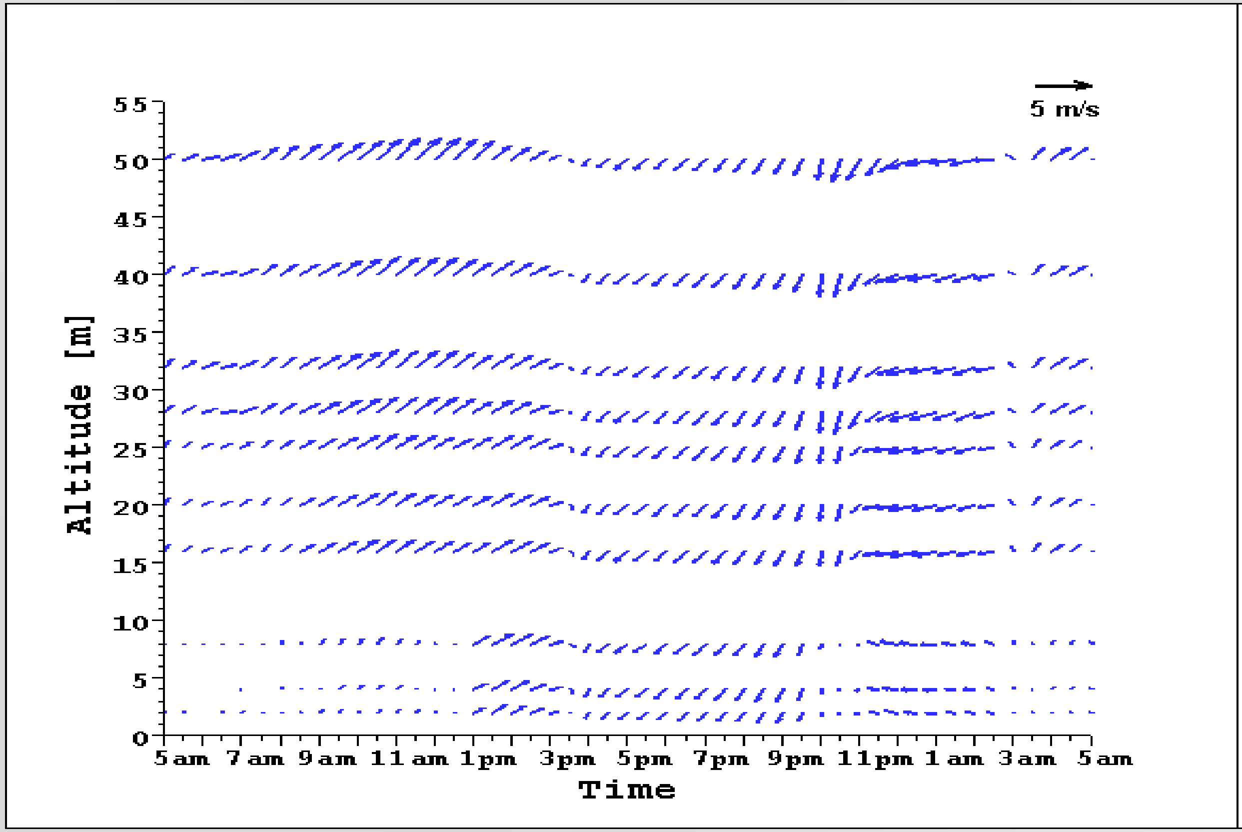
ES2 observation



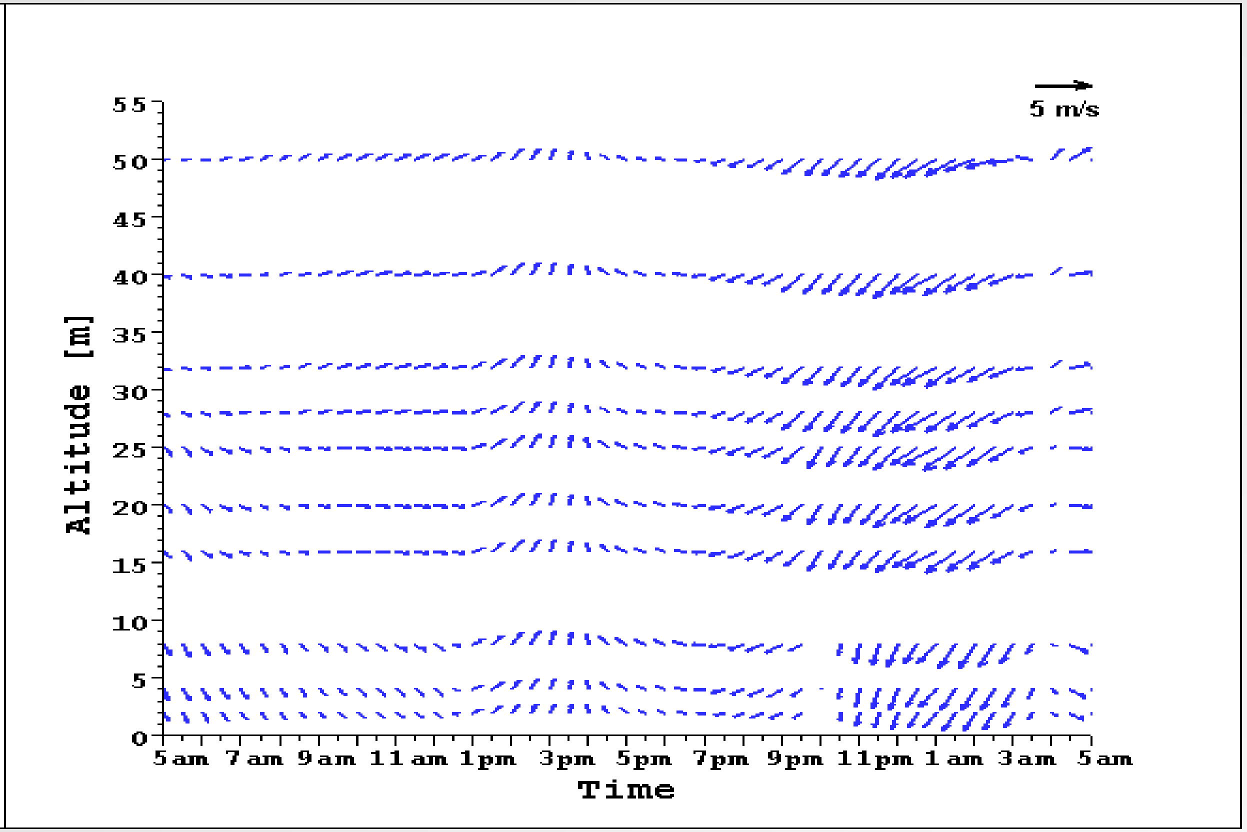


IOP8 (Oct. 18, 2012, 5:00am – Oct. 19, 2012, 5:00am)

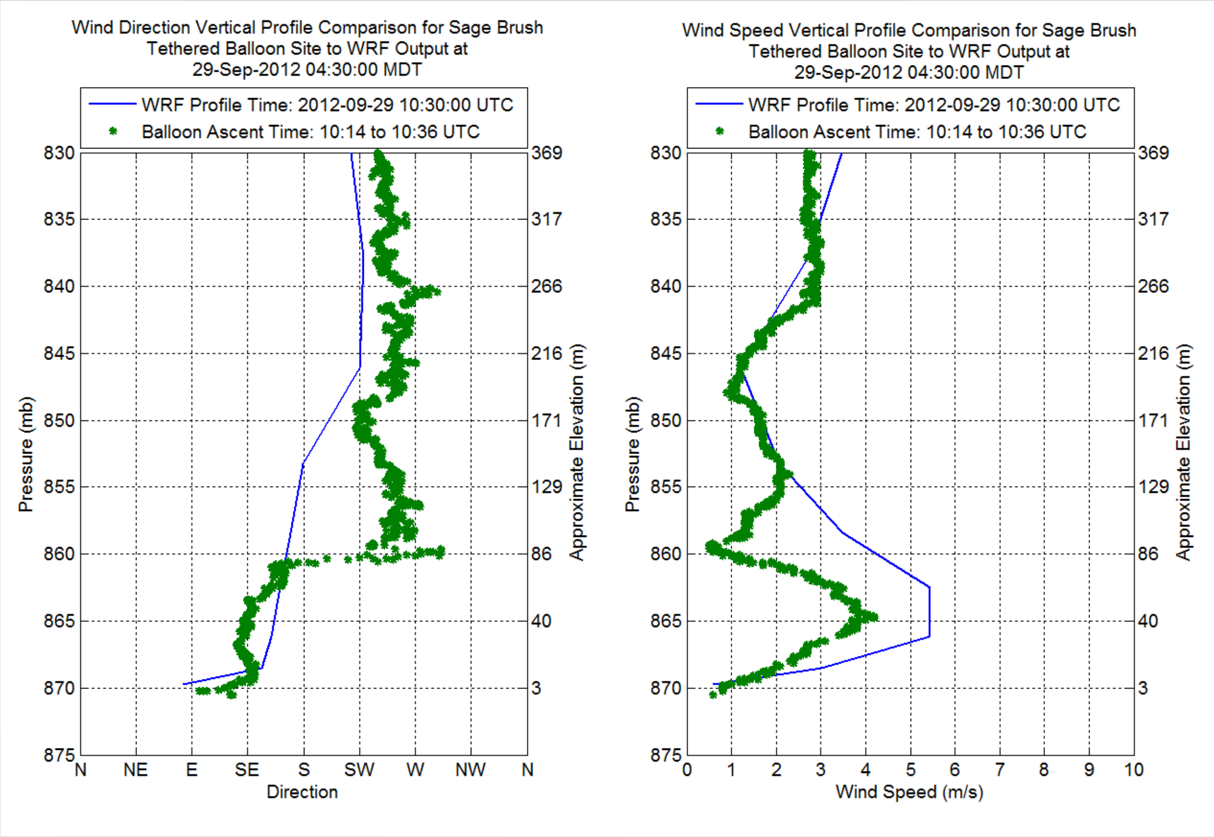
BigGap model

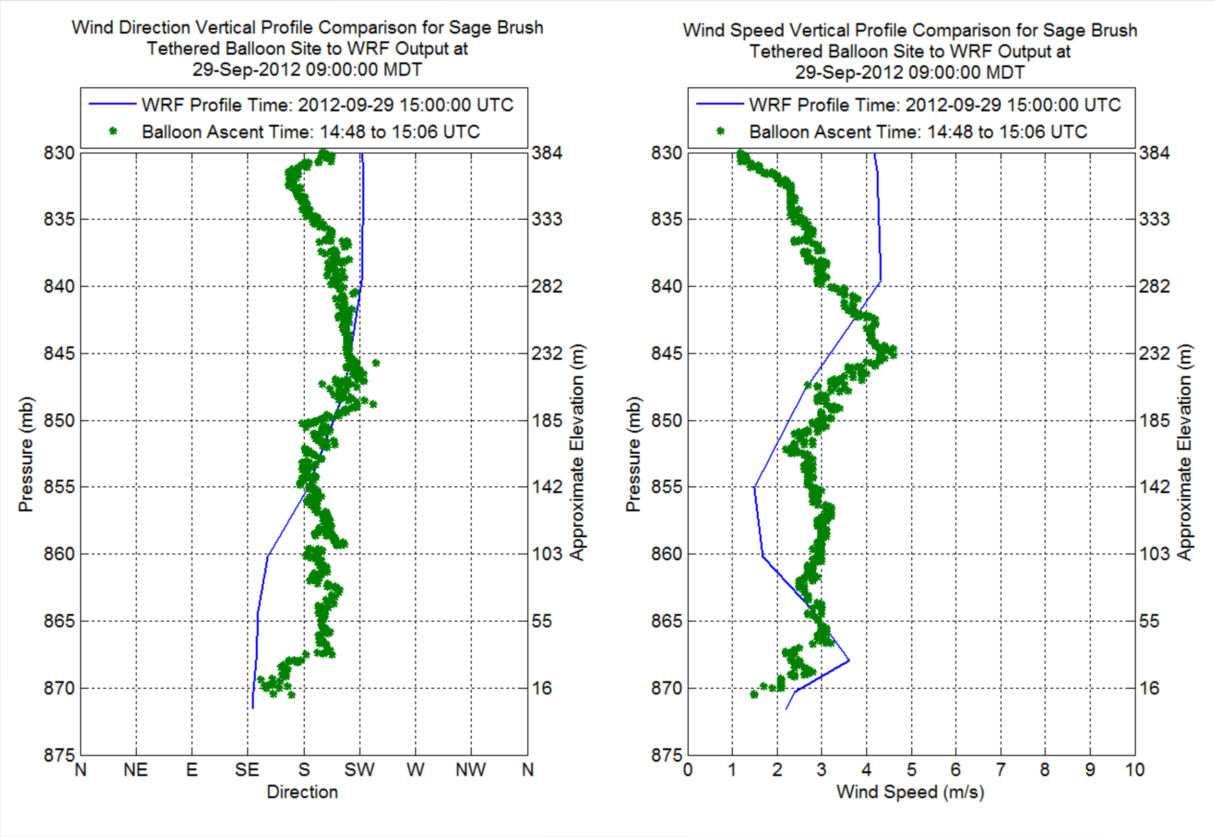


SmallGap model

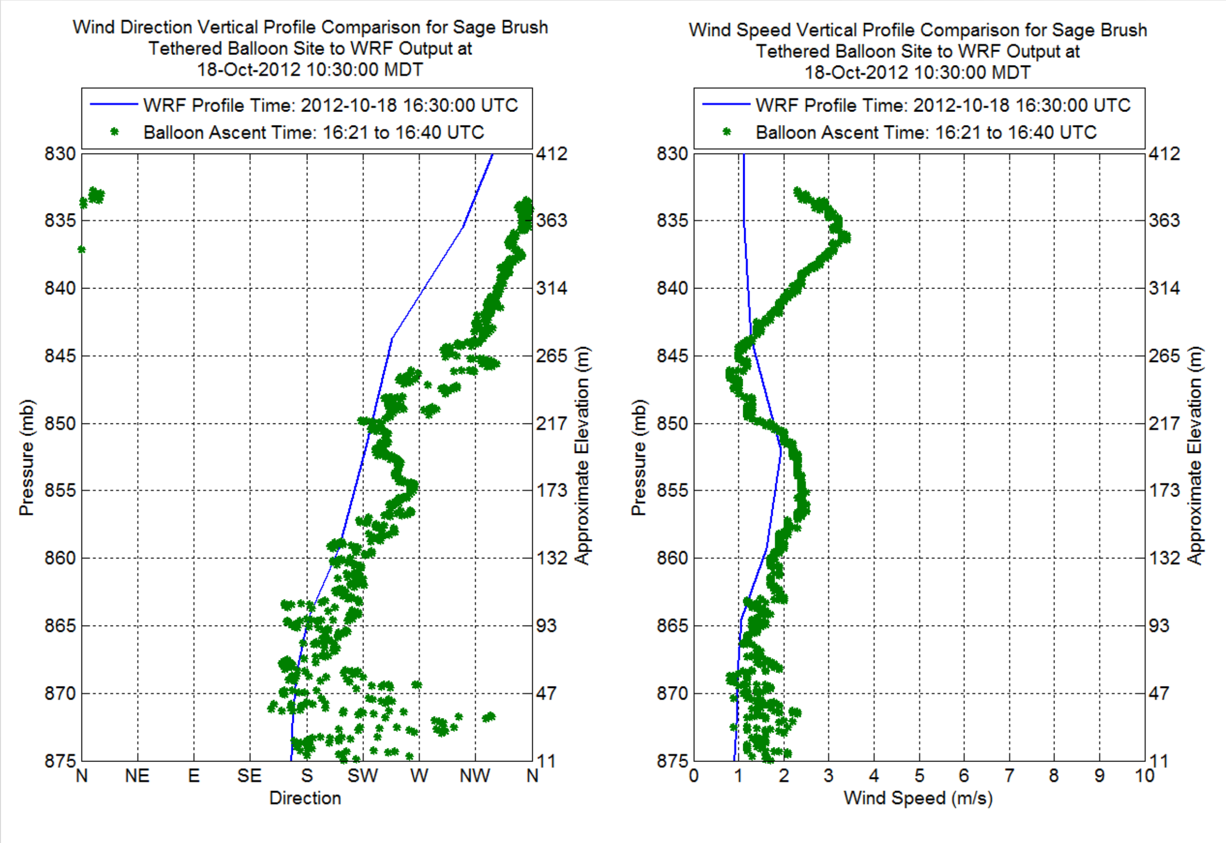


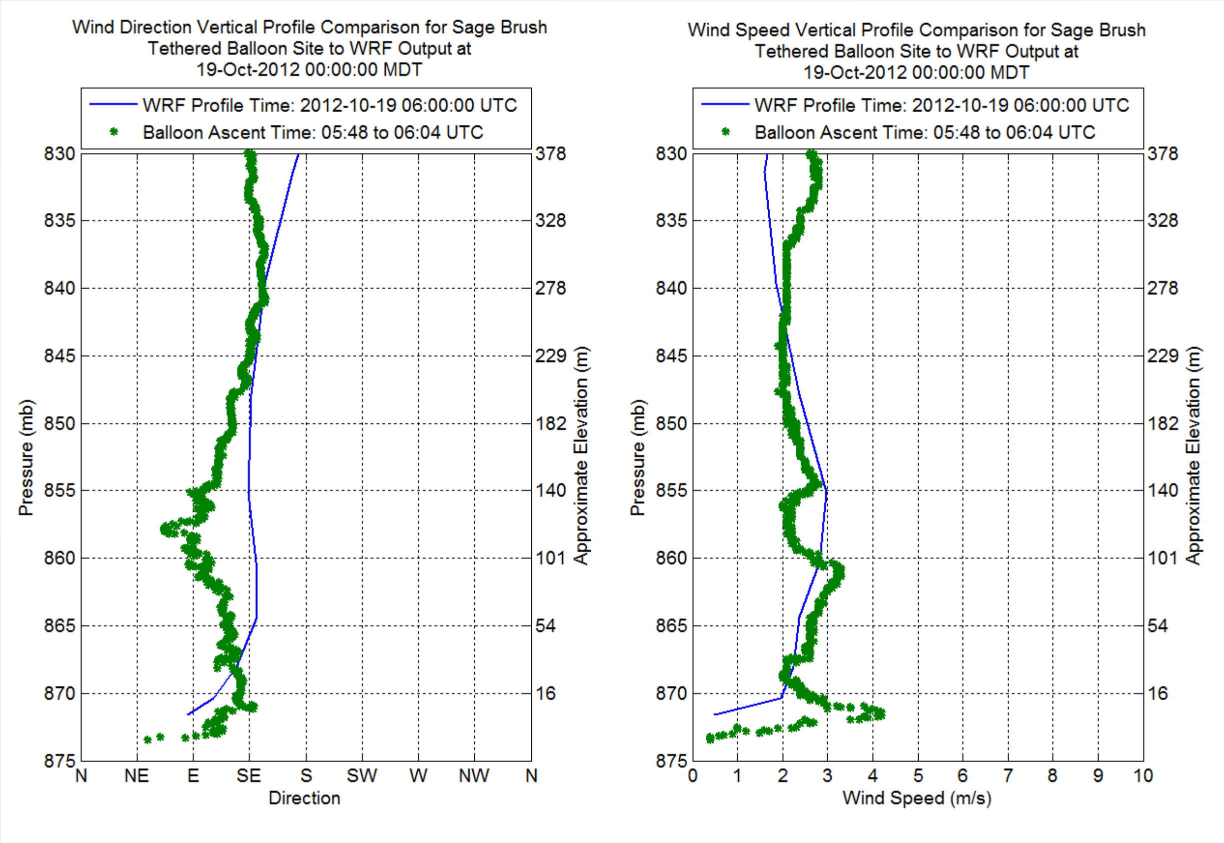
IOP1 (Sep. 28, 2012, 2:00pm – Sep. 29, 2012, 2:00pm)



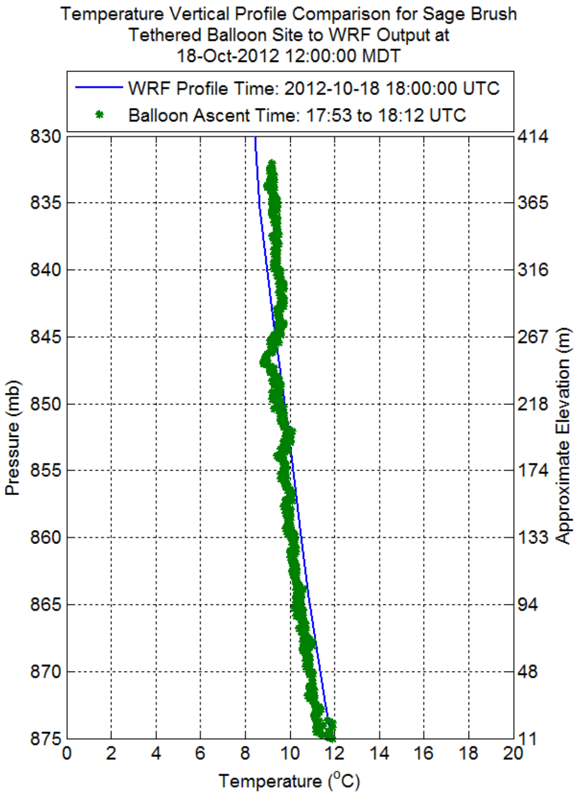


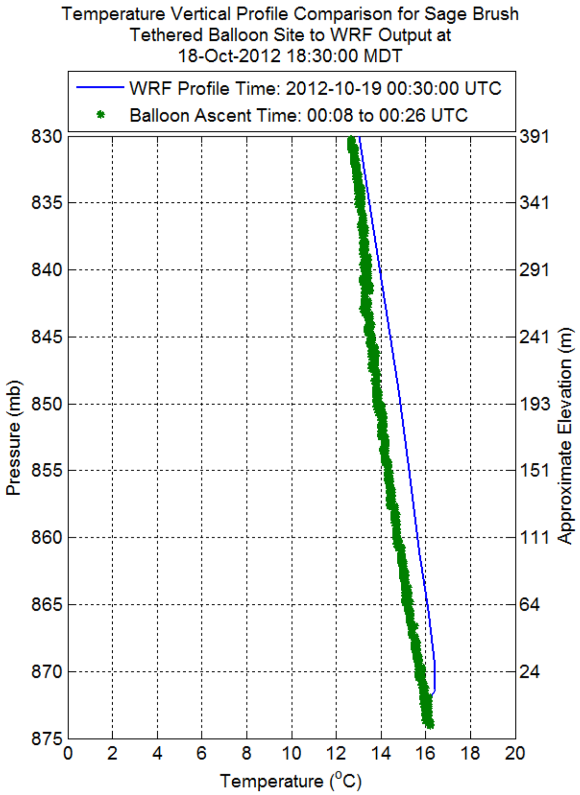
IOP8 (Oct. 18, 2012, 5:00am – Oct. 19, 2012, 5:00am)

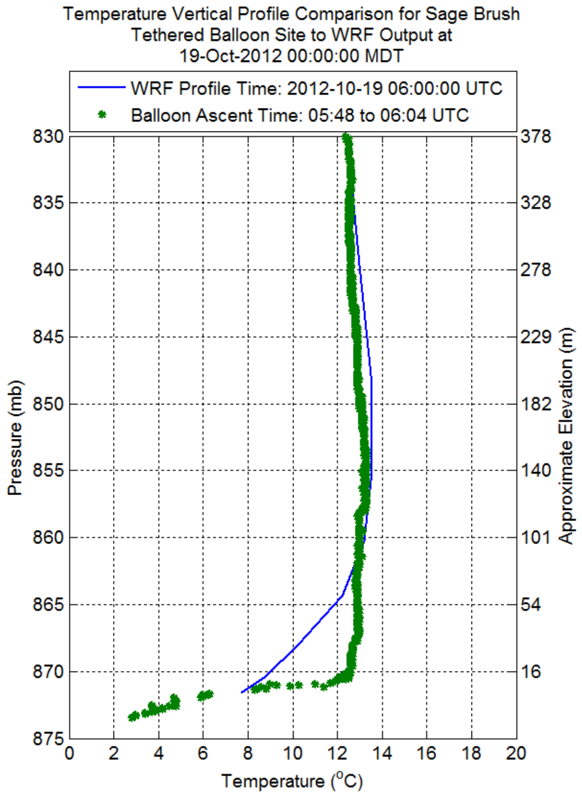


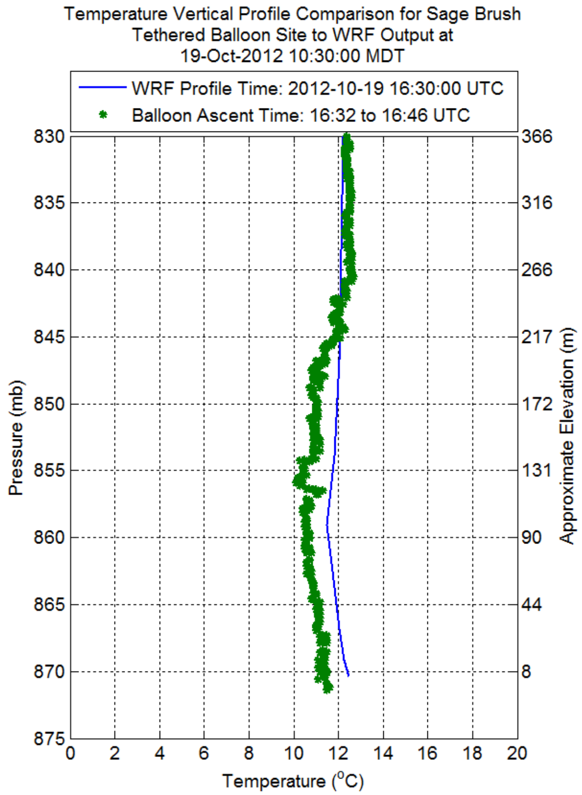


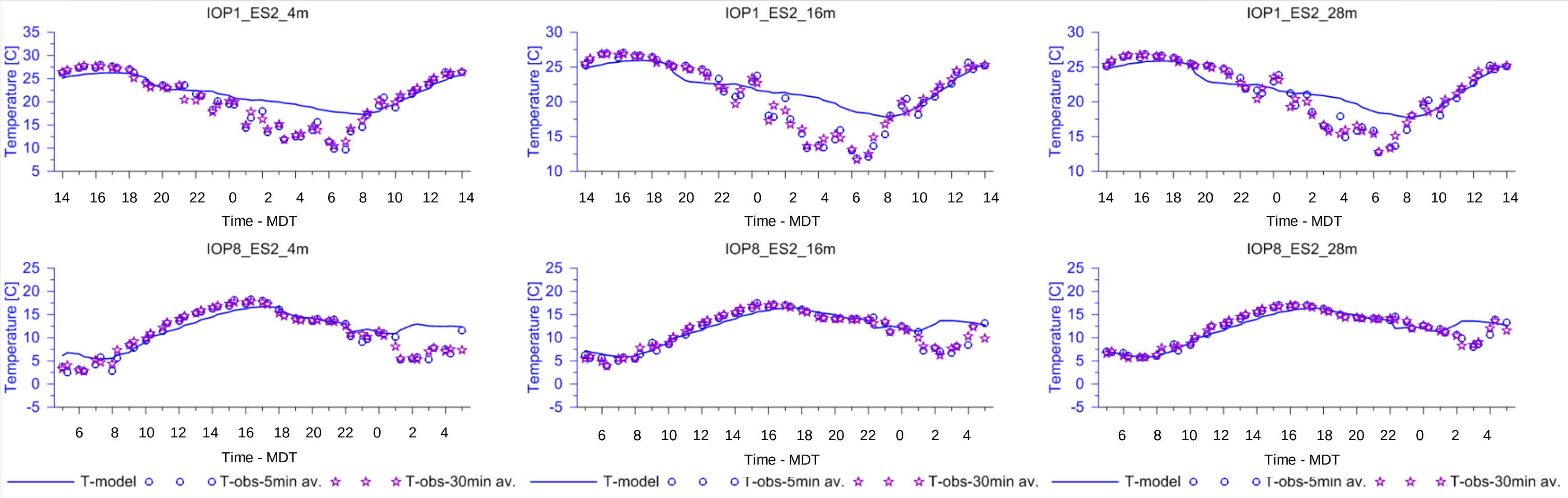
IOP8 (Oct. 18, 2012, 5:00am – Oct. 19, 2012, 5:00am)



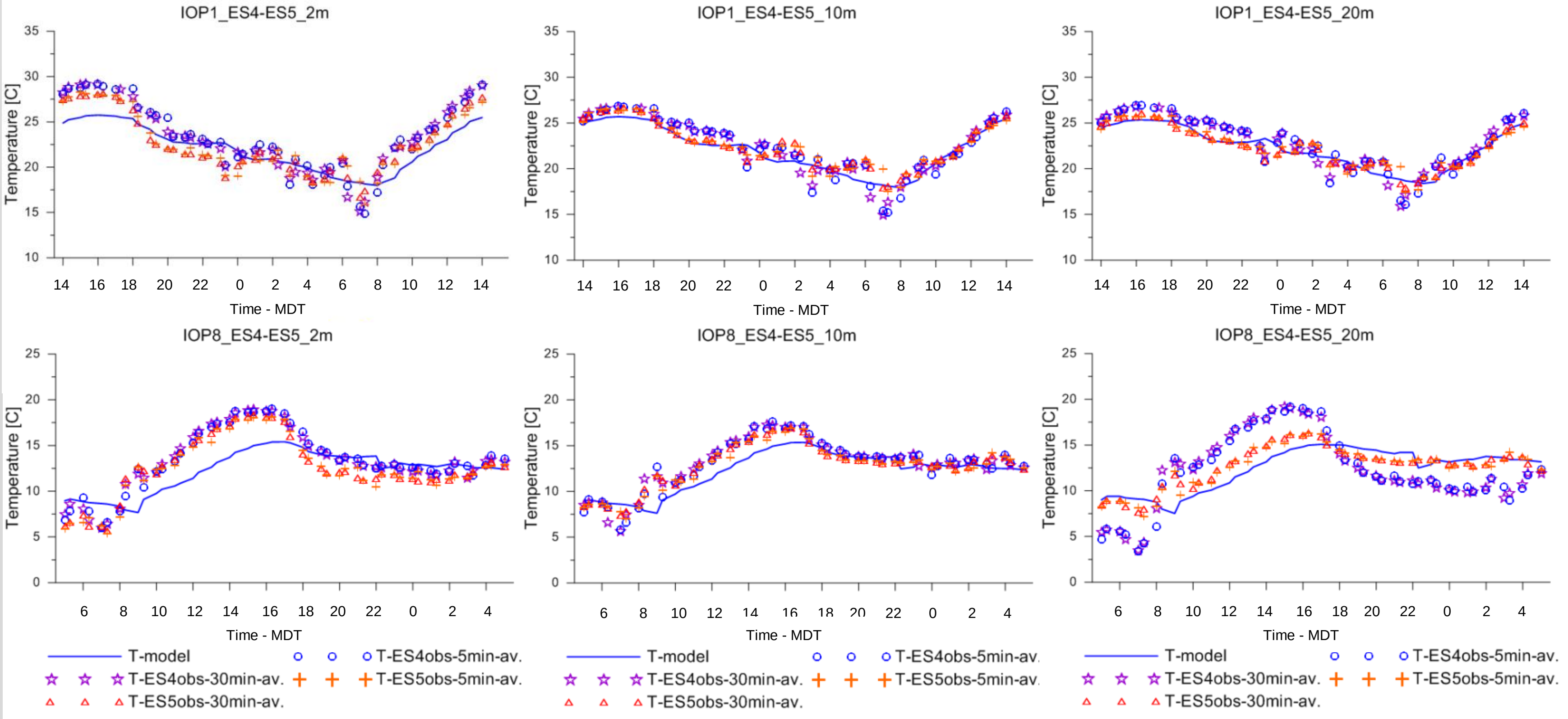




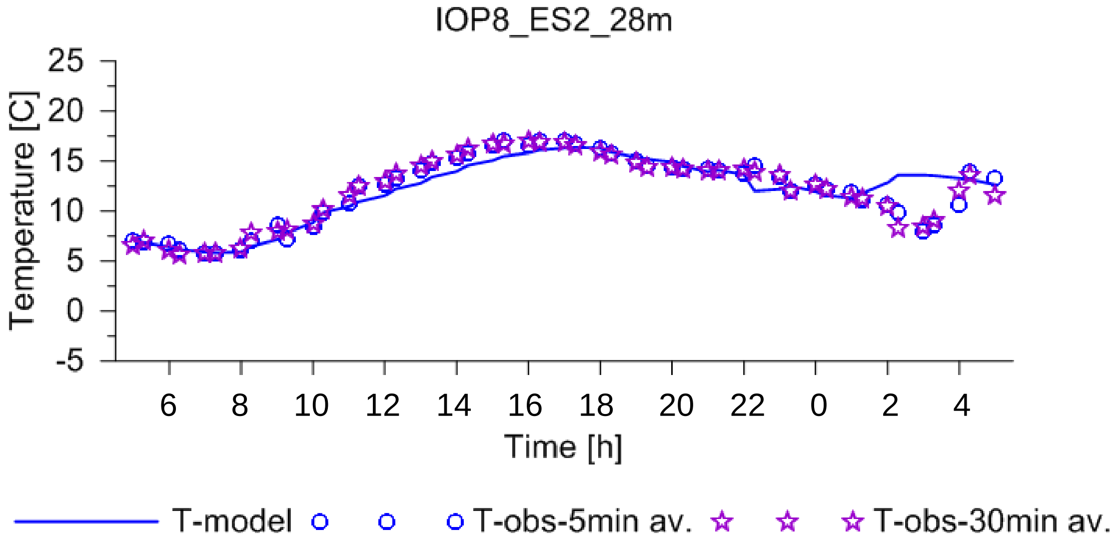


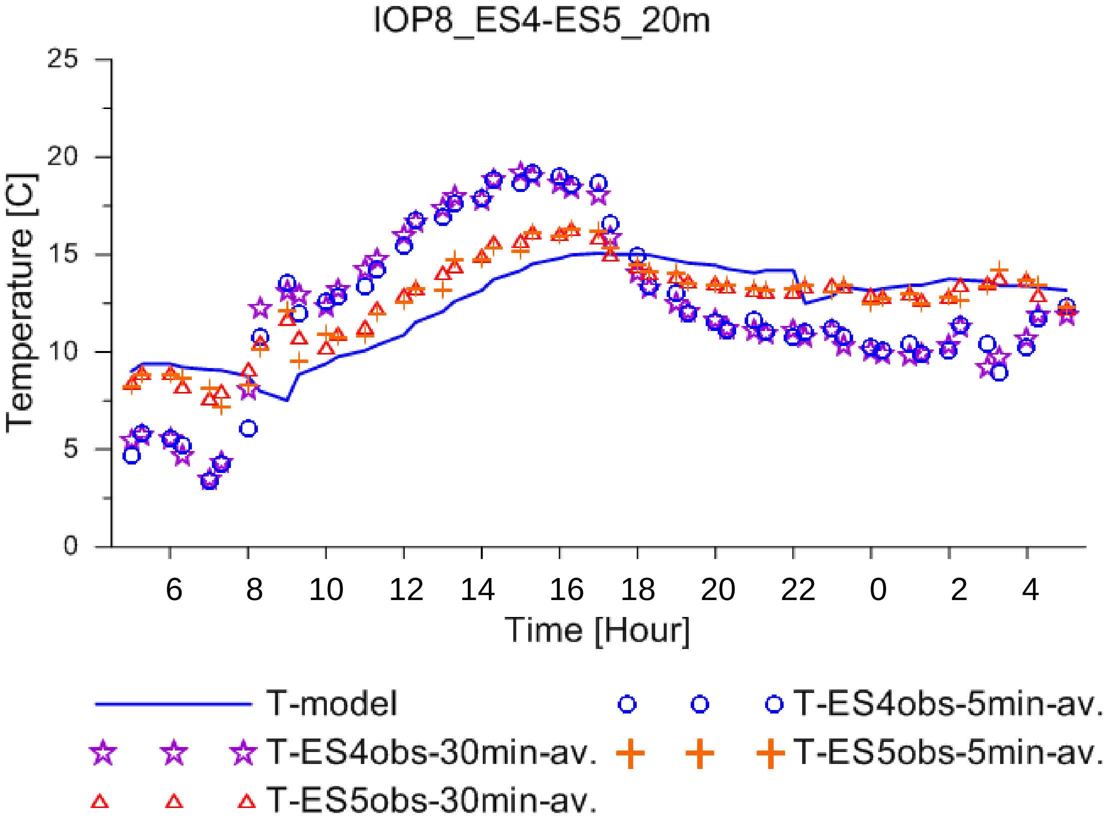


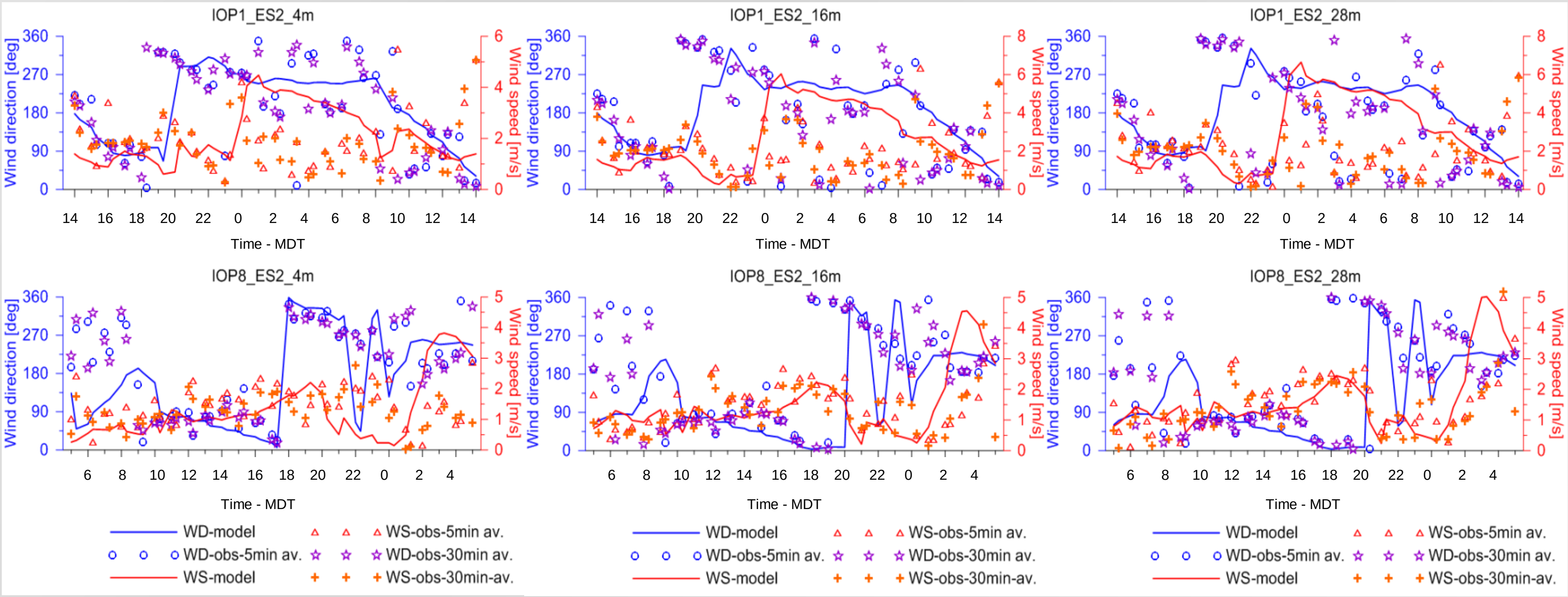
Temperature evaluation at different levels for site ES2



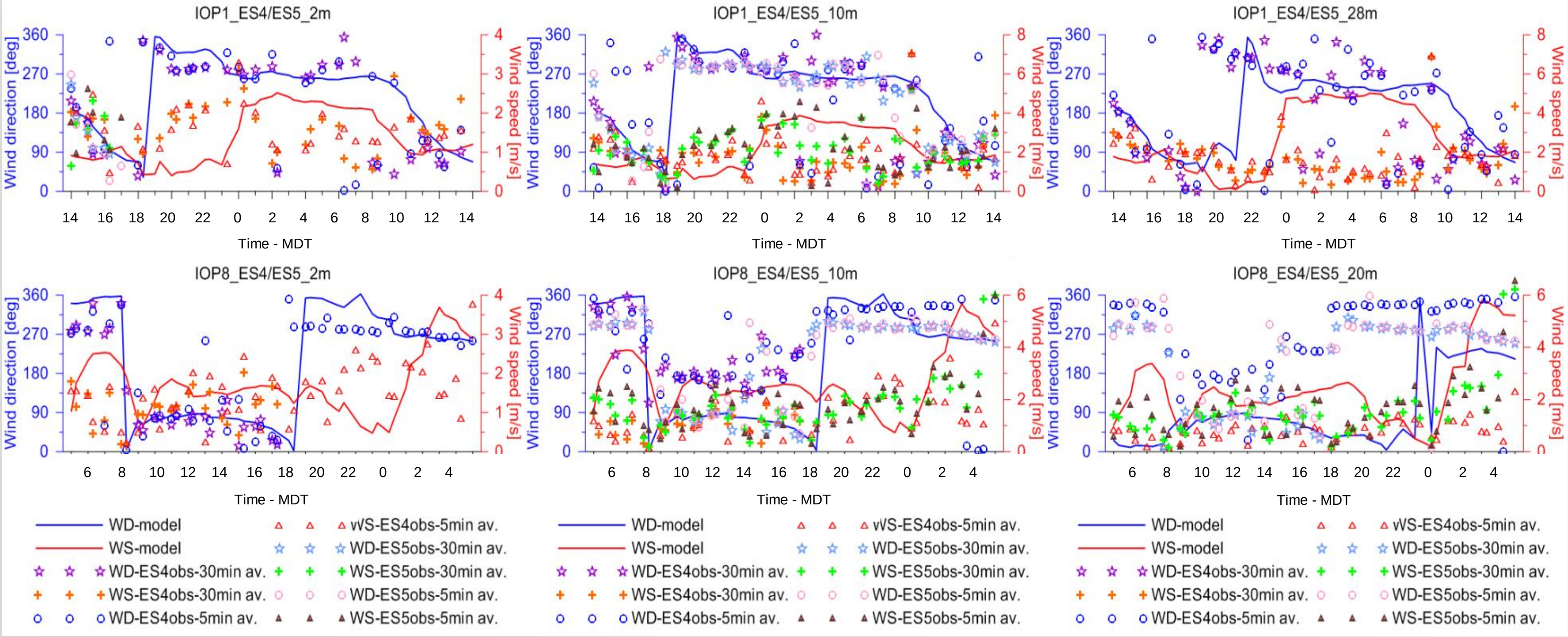
Temperature evaluation at different levels for site ES4/ES5


IOP8_ES2_28m
Temperature [C]
25
20
15
10
5
0
-5
6
8
10
12
14
16
18
20
22
0
2
4
Time [h]
T-model
T-obs-5min av.
T-obs-30min av.

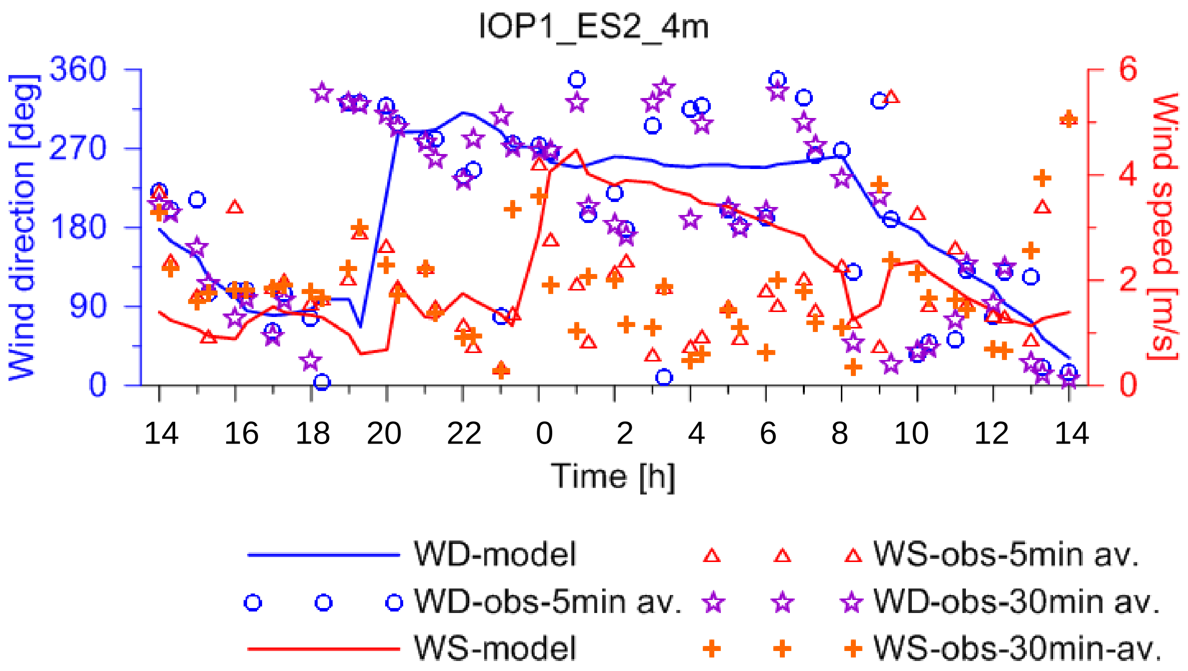

IOP8_ES4-ES5_20m
Temperature [C]
25
20
15
10
5
0
6
8
10
12
14
16
18
20
22
0
2
4
Time [Hour]
T-model
T-ES4obs-5min-av.
T-ES4obs-30min-av.
T-ES5obs-5min-av.
T-ES5obs-30min-av.

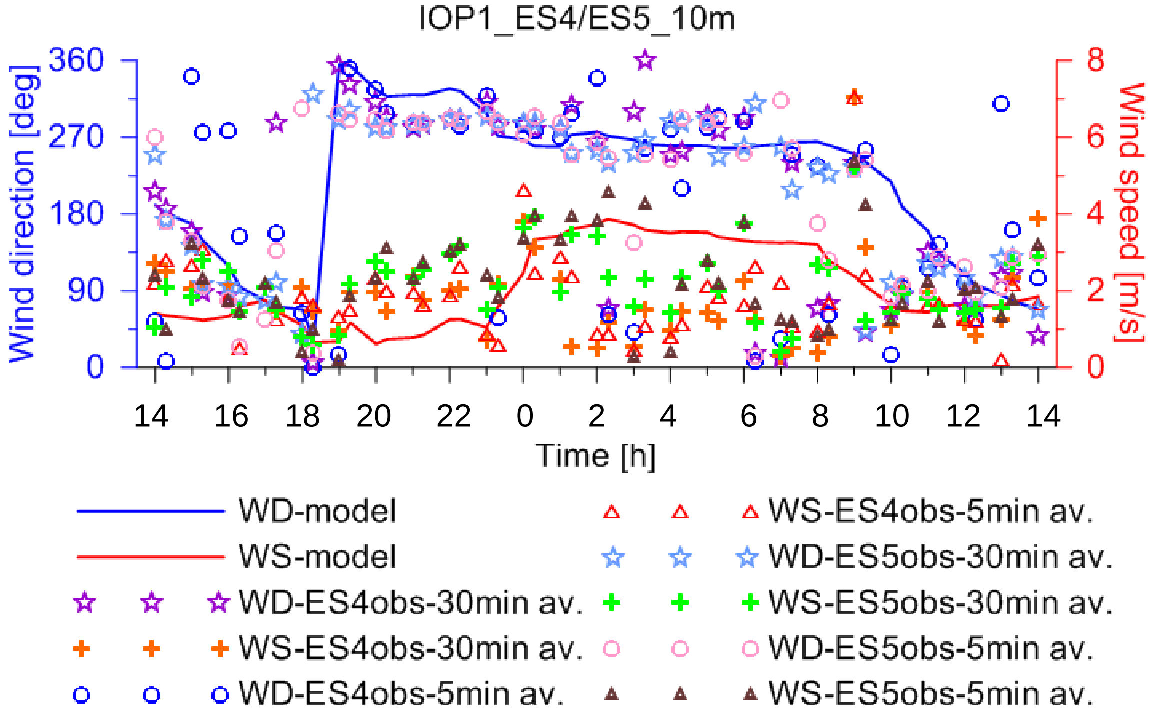


Wind evaluation at different levels for site ES2



Wind evaluation at different levels for site ES4/ES5


IOP1_ES2_4m
Wind direction [deg]
360
270
180
90
0
Wind speed [m/s]
6
4
2
0
14 16 18 20 22 0 2 4 6 8 10 12 14
Time [h]
WD-model
WD-obs-5min av.
WS-model
WS-obs-5min av.
WD-obs-30min av.
WS-obs-30min-av.


IOP1_ES4/ES5_10m
Wind direction [deg]
360
270
180
90
0
Wind speed [m/s]
8
6
4
2
0
14 16 18 20 22 0 2 4 6 8 10 12 14
Time [h]
WD-model
WS-model
WD-ES4obs-30min av.
WS-ES4obs-30min av.
WD-ES4obs-5min av.
WS-ES4obs-5min av.
WD-ES5obs-30min av.
WS-ES5obs-30min av.
WD-ES5obs-5min av.
WS-ES5obs-5min av.

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Summary

- Modeling for all IOP cases was completed using six PBL schemes and two land surface models
- The model was tested with a different number of vertical levels
- Statistical measures were calculated using the Mini-SAMS network
- Wind vector comparisons were made for all IOP cases against the Mini-SAMS network (YSU scheme only)
- Wind and temperature comparisons were made for the east slope towers at different levels and for vertical profiles from the sage brush tethered balloon data (IOP1 and IOP8 from the fall experiment with YSU scheme only)

Preliminary conclusions

WRF model performance in general:

- Is able to capture local thermal circulation in agreement with observations (captures the slope flow better than the area of interaction)
- Performs better for synoptic flow than quiescent conditions

Slope flow:

- Calculated down-slope flow is stronger than up-slope flow
- The depth of the flow on the east slope is smaller than it is registered by observations
- The slope temperature is underestimated during the day (at ES5, ES4, ES3 towers) and overestimated at the lower slope elevation (ES2 tower) close to the ground

Preliminary conclusions – cont.

Flow interactions:

- There is an overestimate of down-slope flow and collision between currents from the surrounding mountains forming a convergence zone inside the valley during the first hours after sunset
- The transition period for reversal of the flow into the interaction area is longer; the reverse flow is developed a few hours later than registered by the observations
- The layer structure inside the interaction area is not well captured (more levels are need up to 500m)
- Cannot capture nocturnal cool pool inside the valley

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