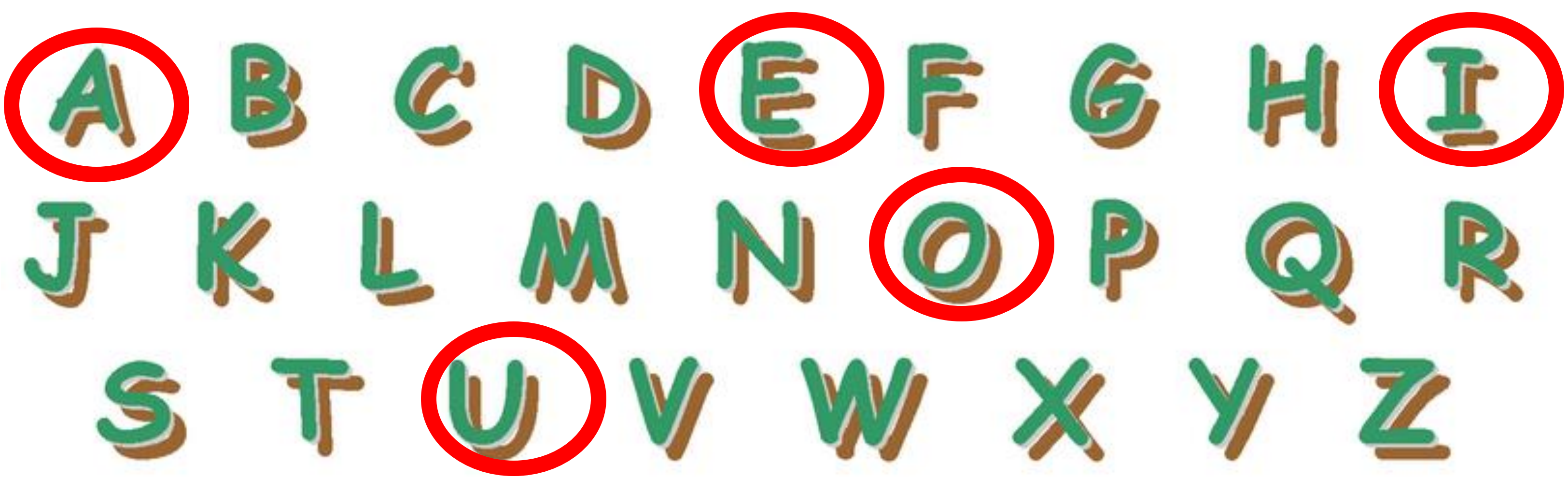
Characterization of the Spatio-Temoral Variability of the ABL Depths Observed During MATERHORN-X 1

S. Pal[1], S.F.J. De Wekker[1], G.D. Emmitt[2], K. Godwin[2], E. Pardyjak[4], L. Leo[3], S. Hoch[4], S. Sabatino[3], D. Zajic[5], M. Sghiatti[1] et al.

[1] University of Virginia. VA
[2] Simpson Weather Associates, VA
[3] University of Notre Dame, Notre Dame, IN
[4] University of Utah, Utah
[5] Dugway Proving Ground, Dugway, Utah



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Aerosol stratification

Entrainment processes near the top of the ABL

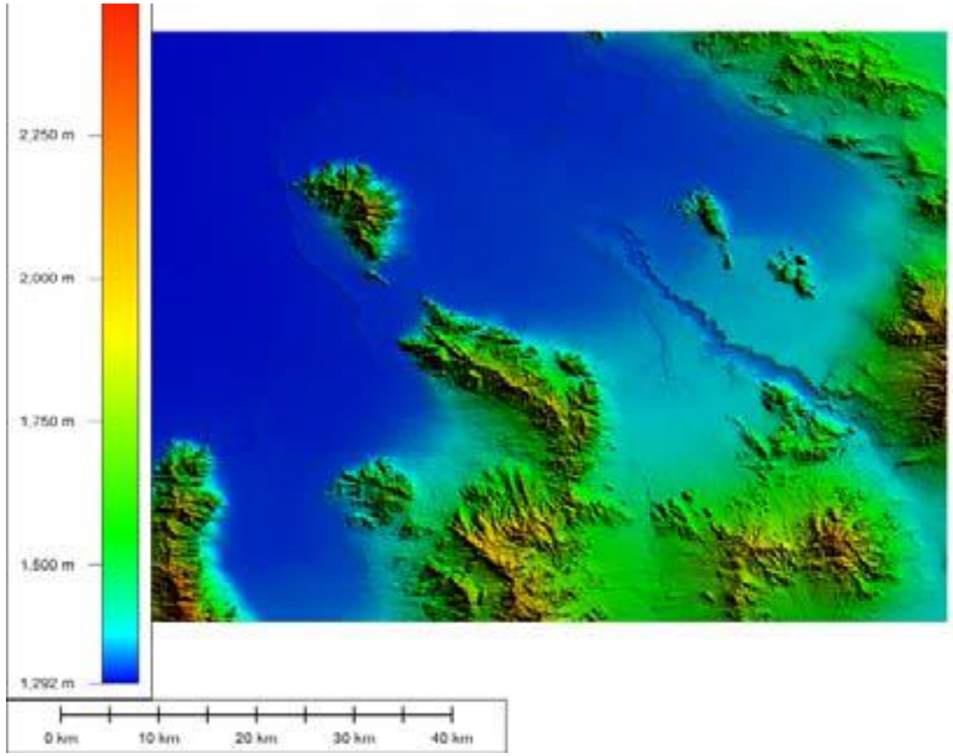
Inversion with different strengths

Orographical Effect

Under different atmospheric conditions

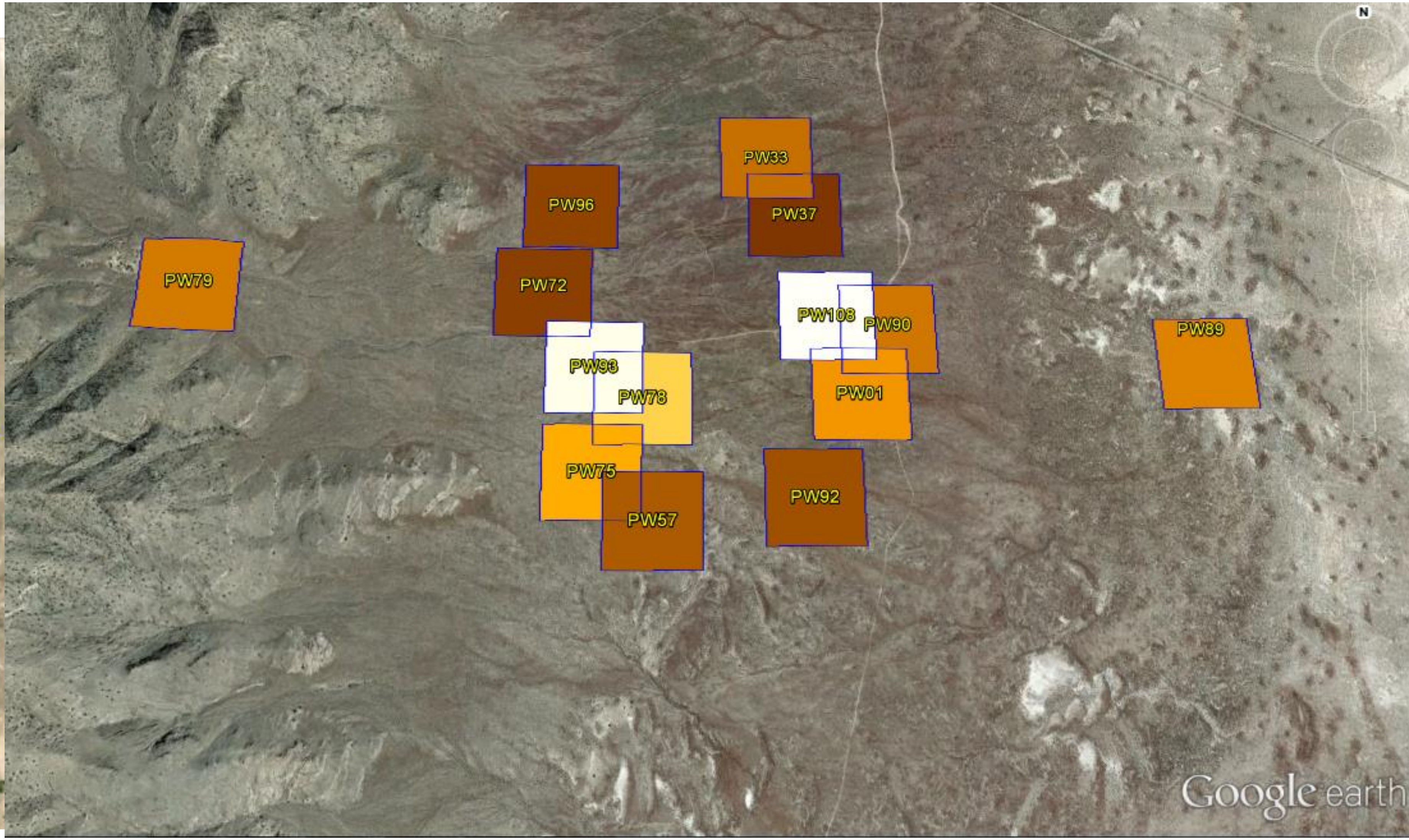
Zi = Top of the ABL

MOUNTAIN TERRAIN ATMOSPHERIC MODELING AND OBSERVATIONS (MATERHORN)



My research interests within MATERRHORN

- **<u>Boundary layer depth variability over low-mountain area like DPG</u>**
- Turbulence characterization combining ground-based and aircraft measurements
- Investigation of both morning and evening transitions in low mountain region



PW80 for SB, however used PW89
PW51 for Playa
PW62 for ceilometer CL31

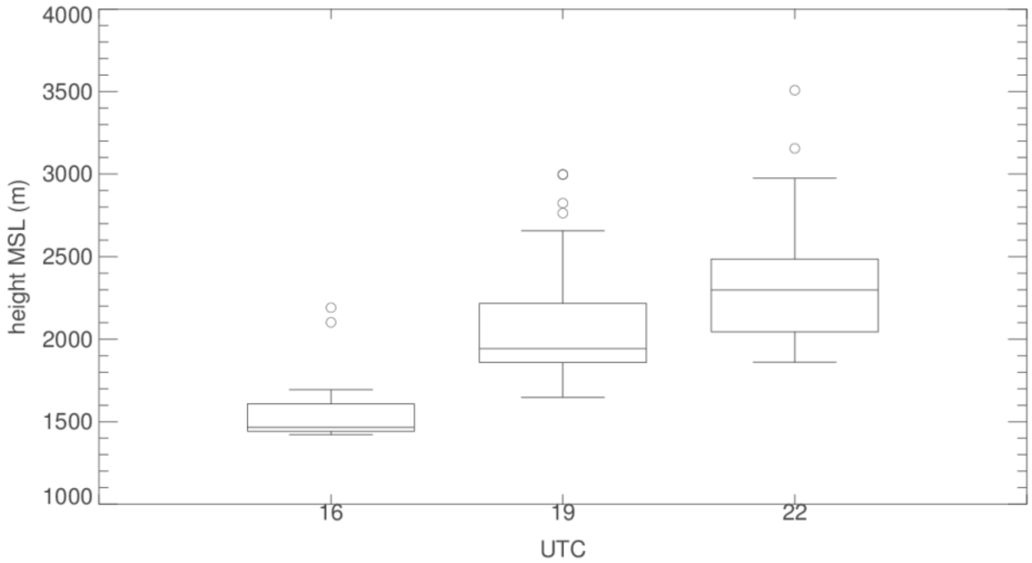
What's there in Today's Menu?

1. Pre-MATERRHORN **findings** and general overview **(ABL-perspective)**
2. **Near-surface** meteorological conditions (standard PTU)
3. **Micro-me**t characterization (high resolution EC data at around Playa and SB)
4. Features in the **lower most ABL** (Tethersondes)
5. **Thermodynamic** characteristics in the lower troposphere (RS-obs)
6. **Temporal evolution** of ABL depths (CL31, CT12K, different sites), **Intra-temporal variability** (thus general features in the **spatial-variability**)
7. **Spatial variability** in ABL depths and features observed in aerosol layers atop ABL (results obtained from TODWL measurements)
8. **1-7**: Detailed investigation of the **spatio-temporal variability** in the ABL depths

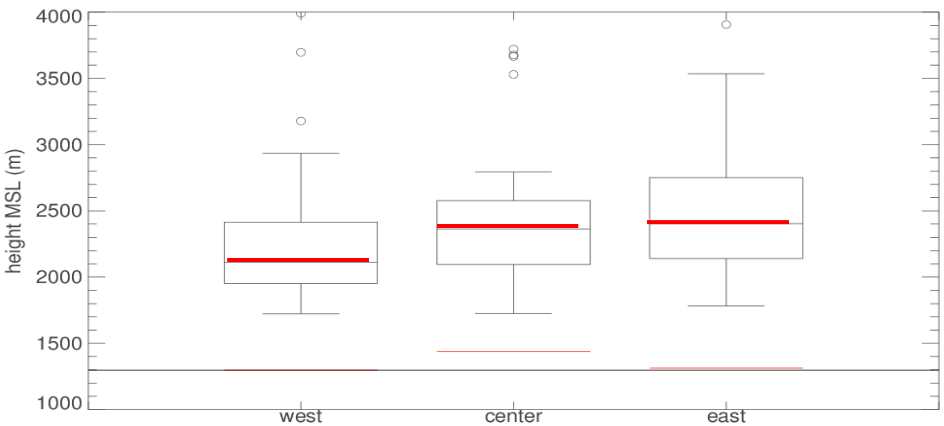
Temporal evolution of CBL in innermost domain (66x66km)

WRF –DPG model results

OCTOBER 2200 UTC



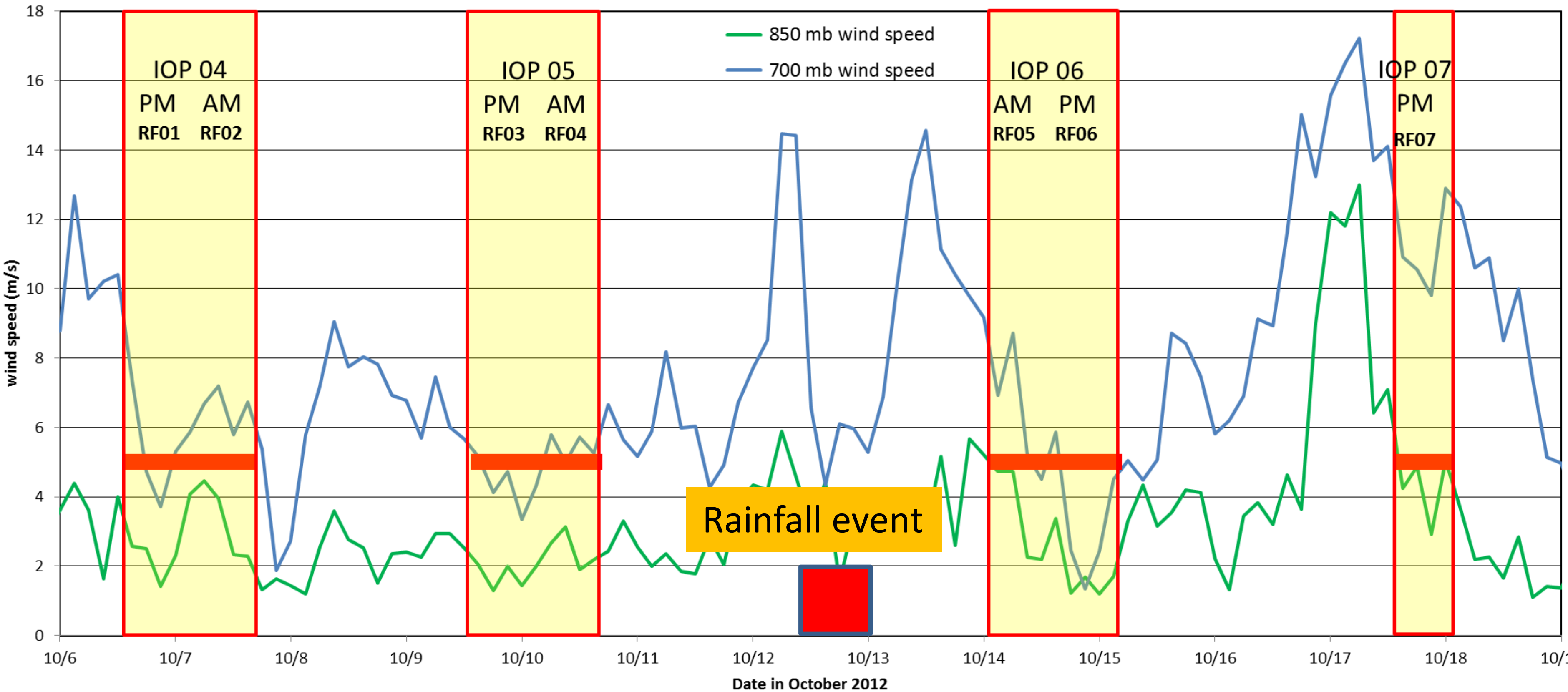
Spatial variability in CBL heights



WEST CENTRAL EAST

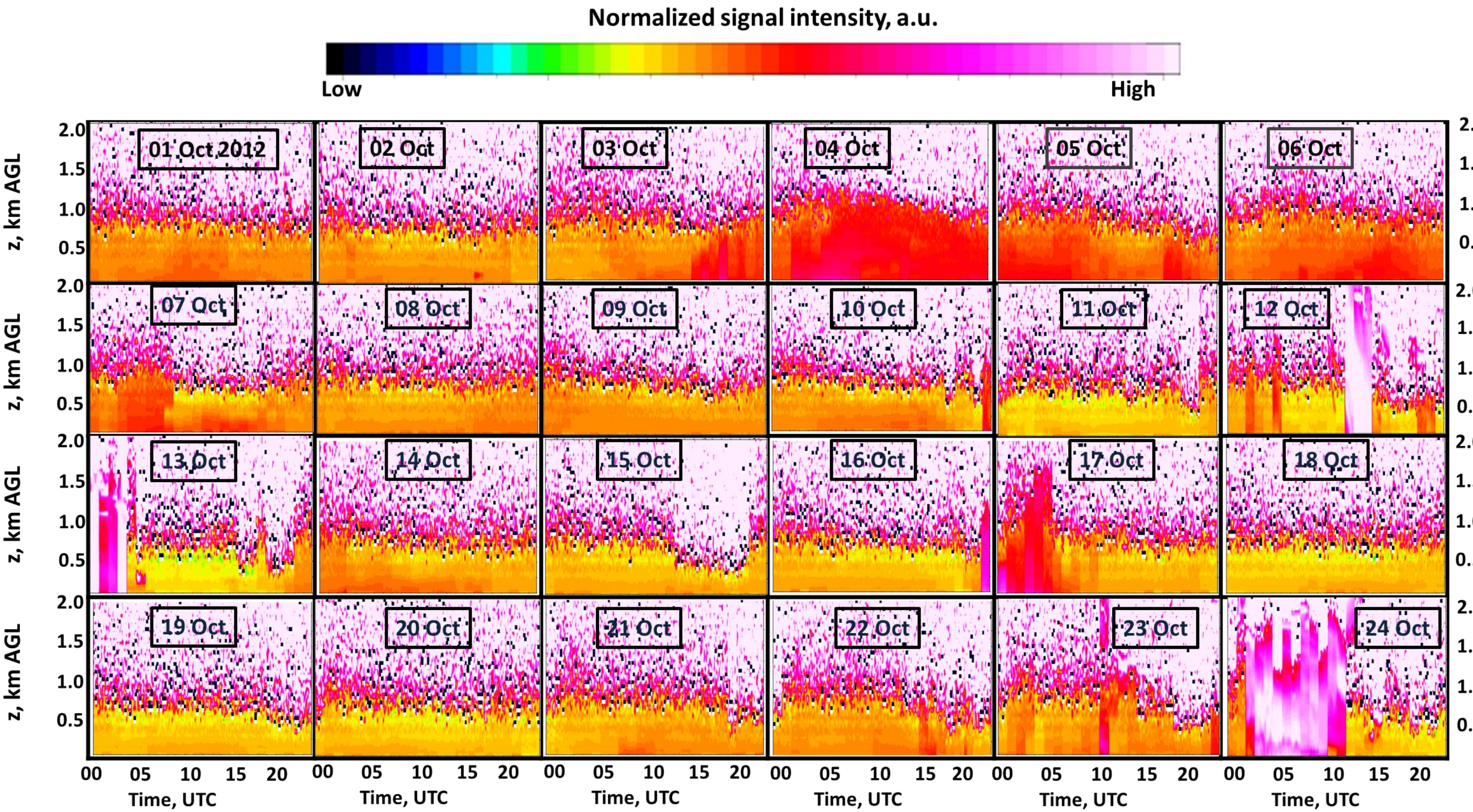
MATERHORN-X Fall - airborne

- Twin Otter in Utah between 5 October and 18 October, 2012, participated in 4 IOPs
- Missions lasted ~ 4 hours
- 7 research flights yielded ~3000 wind profiles between surface and 3400 m MSL

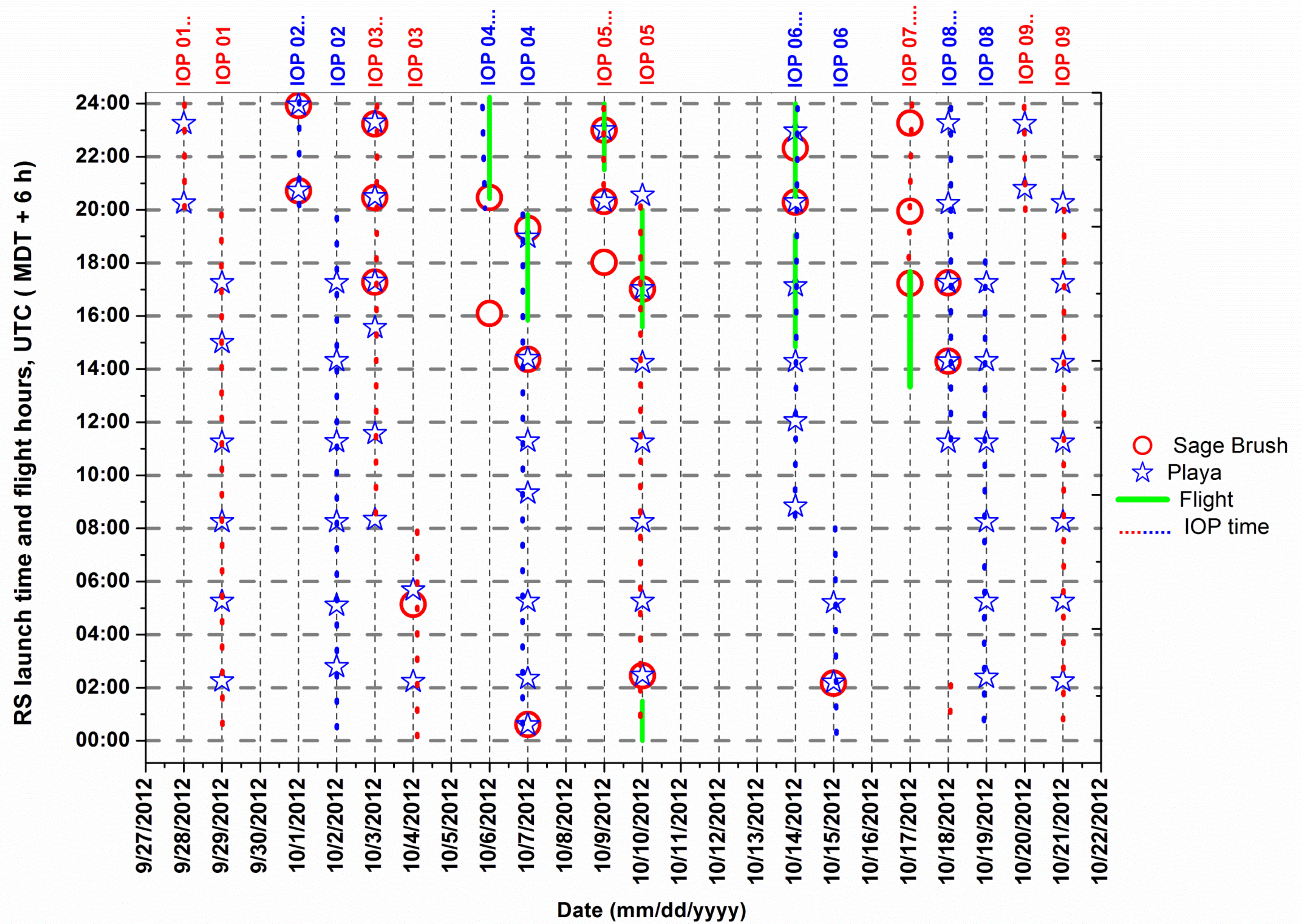


quiescent quiescent quiescent moderate

MATERHORN data analyses: UND Ceilometer west slope near playa



1. Instrument: UND Ceilometer, west slope near playa (40.101380, -113.337590, 1309.85 m ASL)
2. Plates of time-height cross-section of normalized signal intensity are shown to investigate aerosol stratification and boundary layer evolution during entire diurnal cycle during different days.
3. Temporal and spatial resolutions are 7.5 min and 50 m, respectively.
4. Time is in UTC, Height is in km above ground level (z, km AGL)
5. Moist elevated boundary layer (up to 1.2 km AGL) with high aerosol content within the ABL could be seen during the first one week of the experiment.
6. Precipitation signatures are well-observed during 12-13 Oct measurements. Also on 24 Oct!!
7. Last spell of the measurements show relatively drier ABL, however, needs to be confirmed.



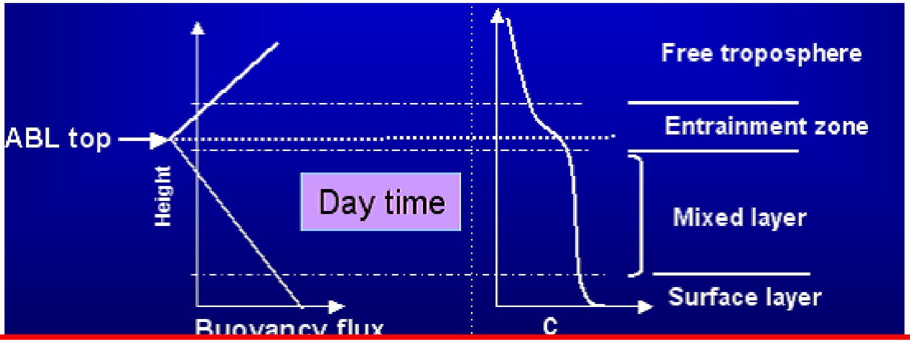
IOP 01..
IOP 01
IOP 02..
IOP 02
IOP 03..
IOP 03
IOP 04...
IOP 04
IOP 05...
IOP 05
IOP 06...
IOP 06
IOP 07....
IOP 08...
IOP 08
IOP 09..
IOP 09
RS launch time and flight hours, UTC (MDT + 6 h)
24:00
22:00
20:00
18:00
16:00
14:00
12:00
10:00
08:00
06:00
04:00
02:00
00:00
9/27/2012
9/28/2012
9/29/2012
9/30/2012
10/1/2012
10/2/2012
10/3/2012
10/4/2012
10/5/2012
10/6/2012
10/7/2012
10/8/2012
10/9/2012
10/10/2012
10/11/2012
10/12/2012
10/13/2012
10/14/2012
10/15/2012
10/16/2012
10/17/2012
10/18/2012
10/19/2012
10/20/2012
10/21/2012
10/22/2012
Date (mm/dd/yyyy)
Sage Brush
Playa
Flight
IOP time

A Classical Atmospheric Boundary Layer

JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES, VOL. 118, 1–19, doi:10.1002/jgrd.50710, 2013

Exploring a geophysical process-based attribution technique for the determination of the atmospheric boundary layer depth using aerosol lidar and near-surface meteorological measurements

Sandip Pal,[1,2] Martial Haeffelin,[3] and Ekaterina Batchvarova[4]



Monitoring of the ABL is an urgent issue
Largest variability contrary to any other part of the earth's atmosphere
Majority of the sources and sinks are located in the ABL.

Aerosol distribution and aerosol transport processes in the ABL in urban regions
Large pollution events for various anthropogenic activities

Wrong simulation of the ABL, entrainment zone, and residual layer including the diurnal/inter-diurnal development is crucial for the deficiencies in the numerical weather prediction models.

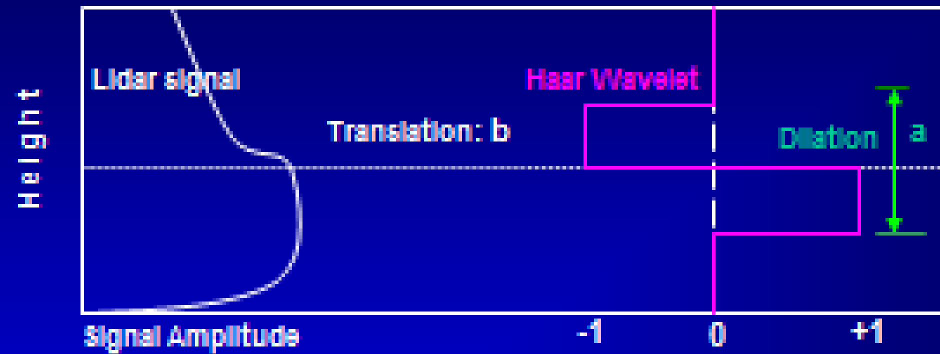
Wavelet transform method to determine ABL depths

Haar Wavelet Transform method

Equation: 1

Haar wavelet is defined as

$$h\left(\left(\frac{z-b}{a}\right)\right) \begin{cases} = 1 \text{ for } b - a/2 \le z \le b \\ = -1 \text{ for } b \le z \le b + a/2 \\ = 0 \text{ , otherwise} \end{cases}$$



Equation: 2

$$W_f(a,b) = \frac{1}{a}\int_{z_a}^{z_b}\left\{f(z)h\left(\frac{z-b}{a}\right)\right\}dz$$

Equation: 3

$$D^2(a) = \int_{Zb}^{Za}\left[W_f(a,b)^2\right]db$$

Calculation of convolution of R-square corrected backscatter profile and the haar function

↓

Equation 2

↓

Obtain covariance transforms $W_f(a,b)$

↓

Choose a dilation value and search for a maxima $W_f(a,b)$

↓

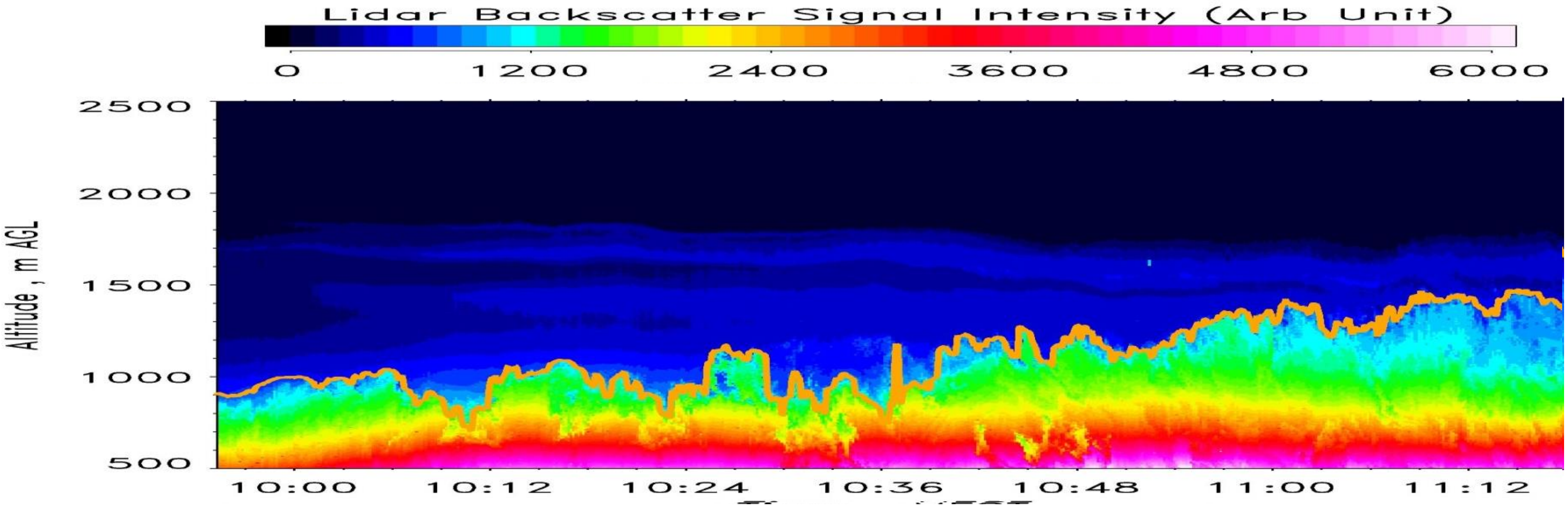
Find Location of the maxima

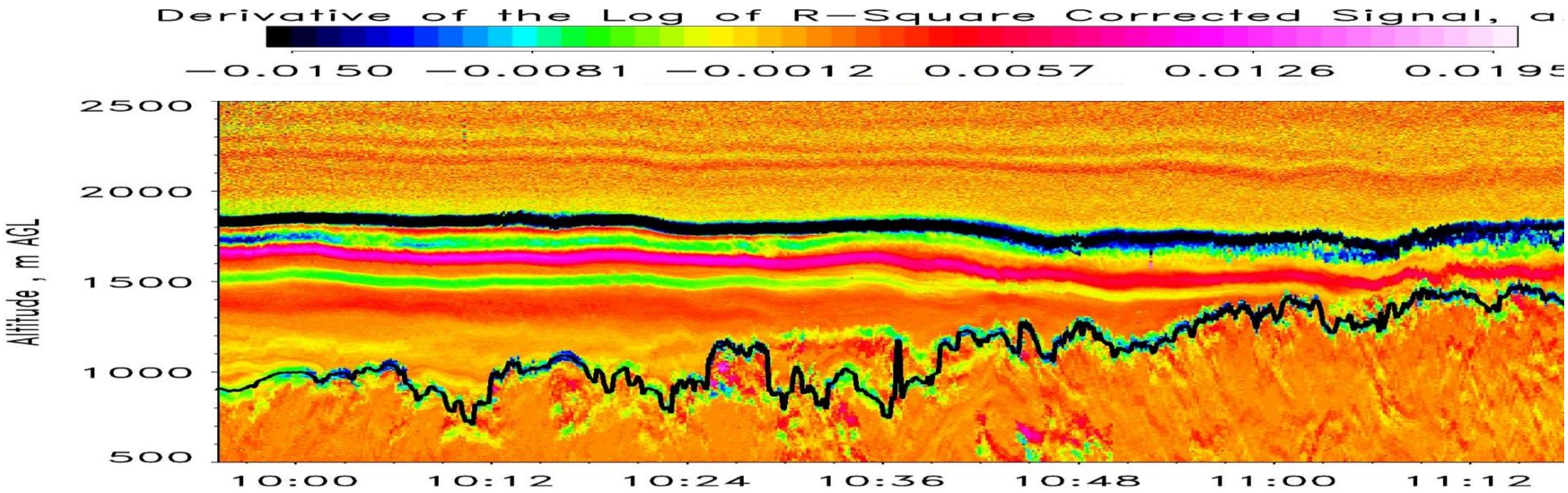
Assisting lidar-estimated ABL depth measurements by …………..

Possible ways !!!

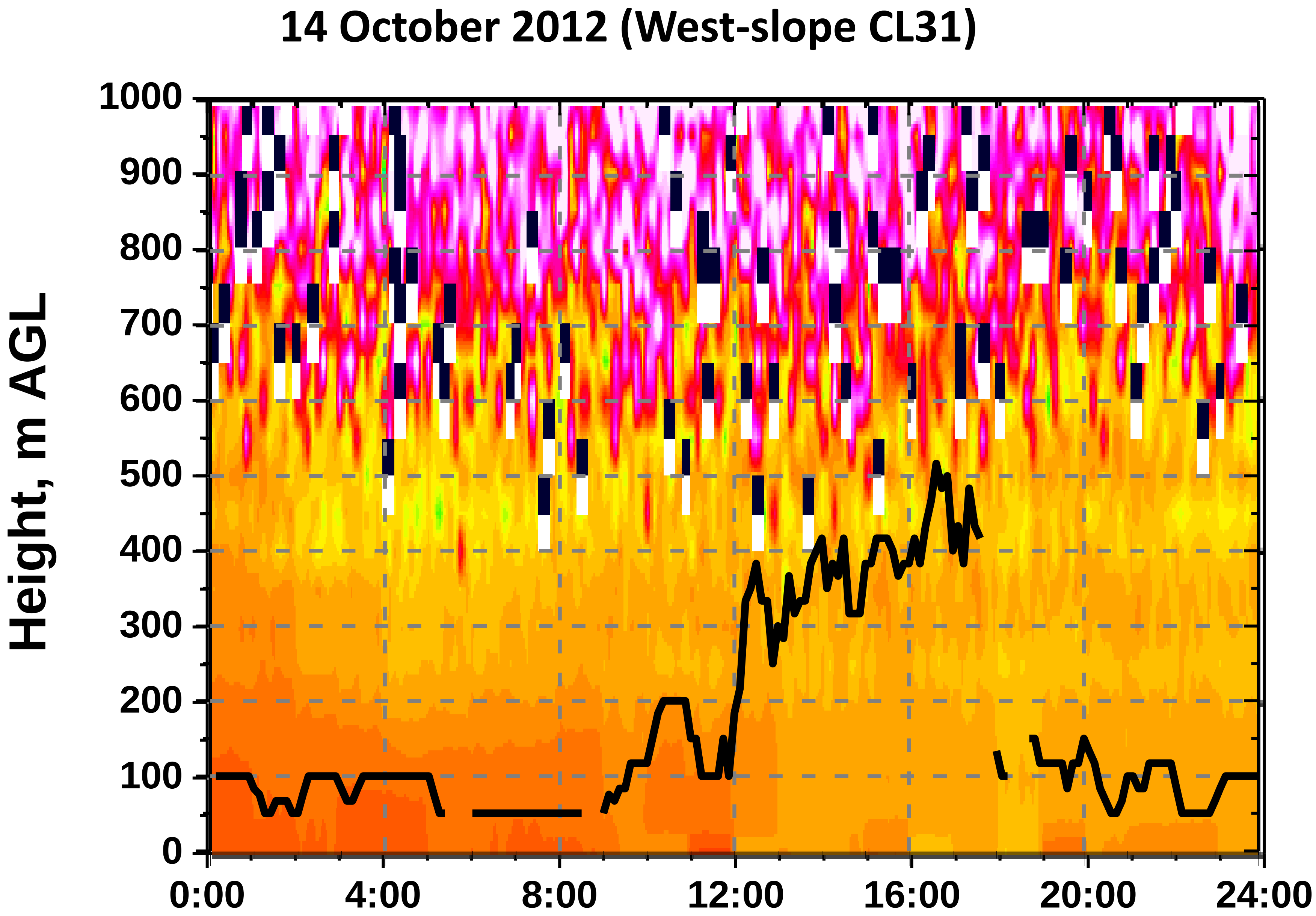
- Haar wavelet-based method (Subjective determination) (e.g., Pal et al., 2010 (ANGEO), Lac et al., 2013 (ACP))
- Combining ceilometer (for NBL) and lidar (CBL) time measurements (different limitations during different regimes, Behrendt et al., 2011 (QJRMS), Pal et al., 2012 (Atmos Env))
- Using surface-based turbulence measurements and combining gradient and variance profiles Pal et al., 2013 (JGR in review)
- **CO_2 profiles and lidar measurements (in this presentation)**
- **Radon-tracer method (in the outlook of this talk)**
- **Assisting with near surface meteorological measurements, heat fluxes, other in-situ (Not explored so far, looking very much forward in the next days!!)**

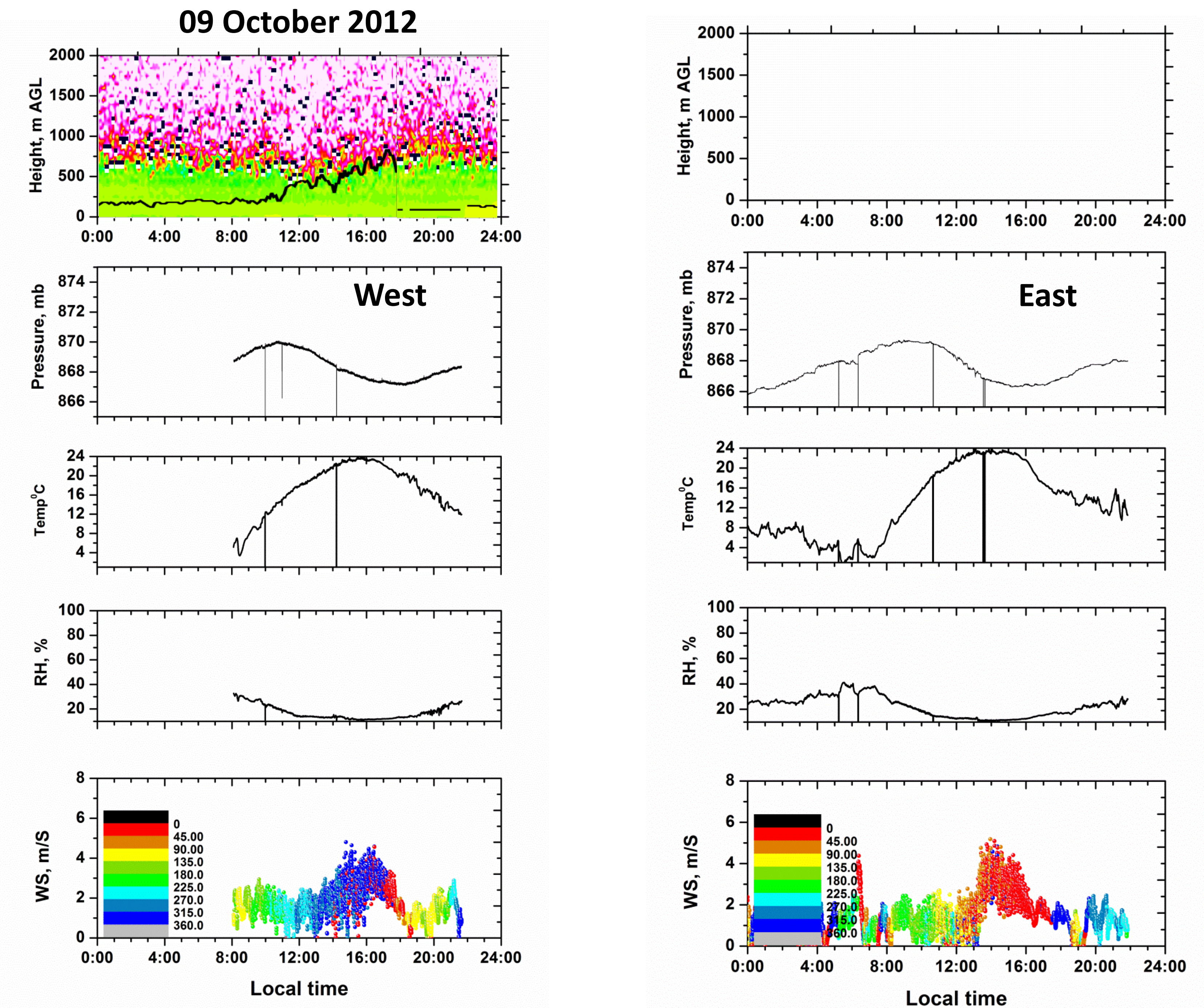
Haar wavelet transform results



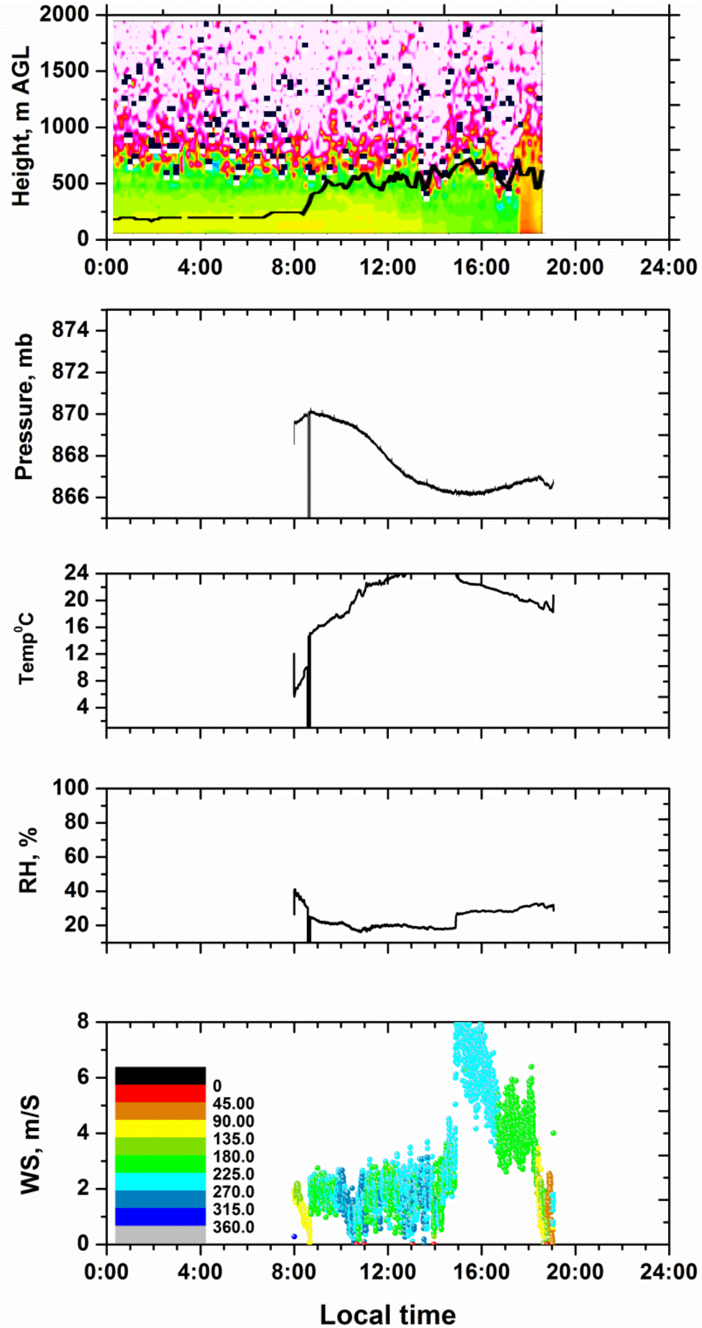


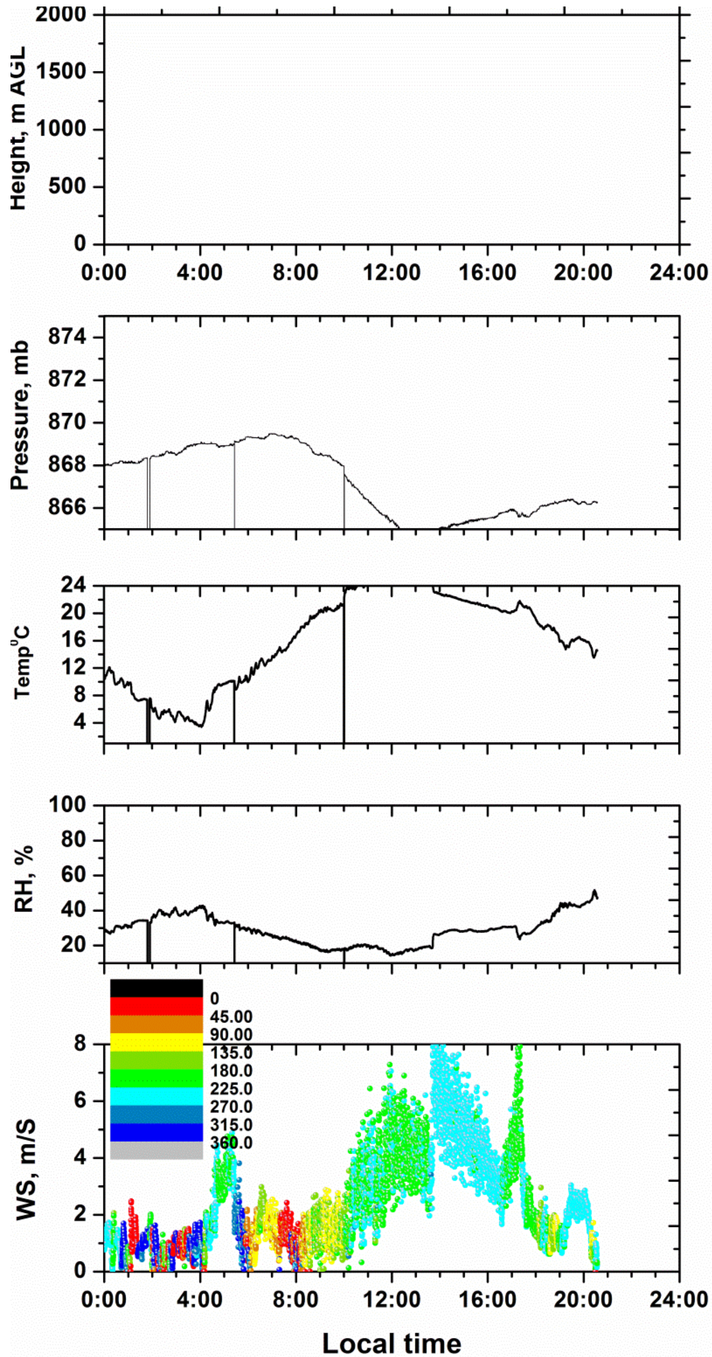
Wavelength: 1064 nm, Time resolution:0.33 s

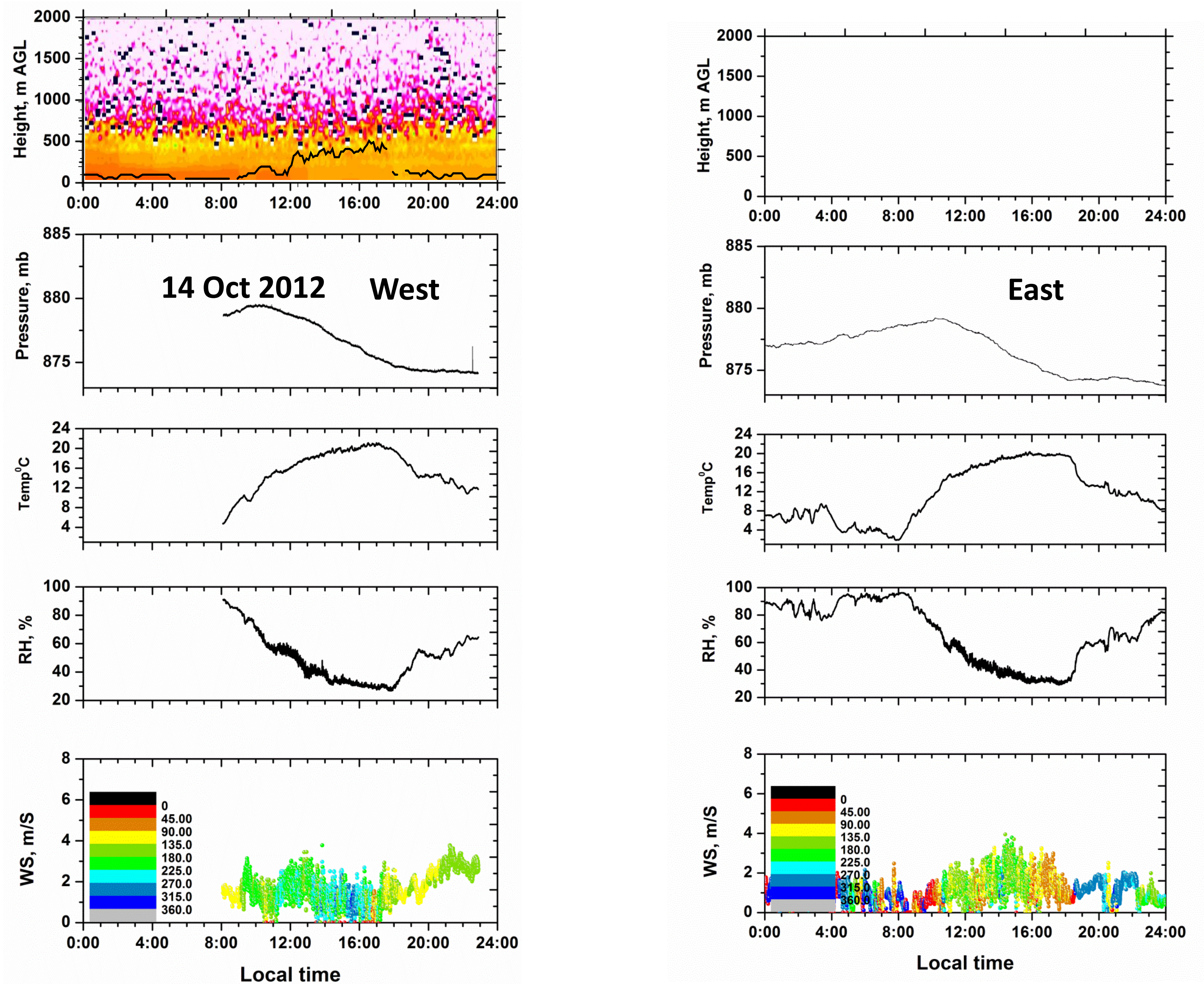

14 October 2012 (West-slope CL31)
Height, m AGL
1000
900
800
700
600
500
400
300
200
100
0
0:00
4:00
8:00
12:00
16:00
20:00
24:00


09 October 2012
West
East
Height, m AGL
Pressure, mb
Temp⁰C
RH, %
WS, m/S
Local time
0
45.00
90.00
135.0
180.0
225.0
270.0
315.0
360.0

10 October 2012

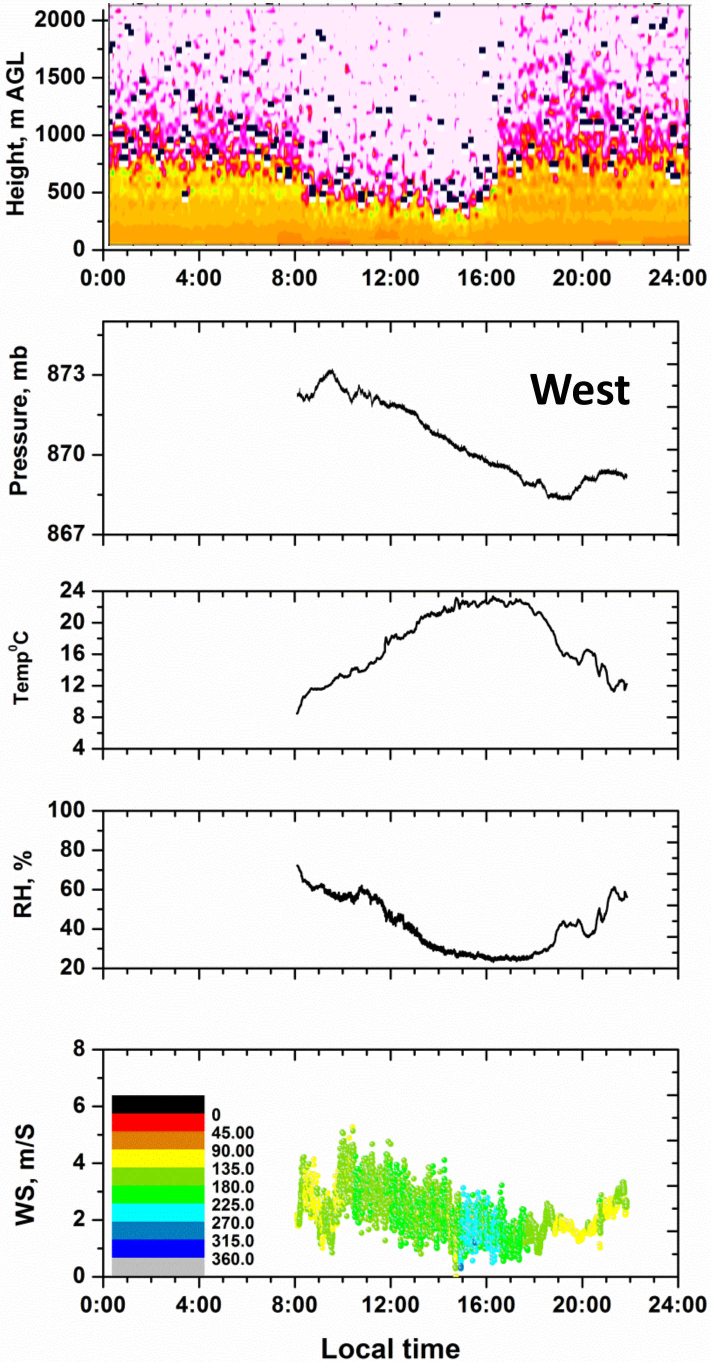


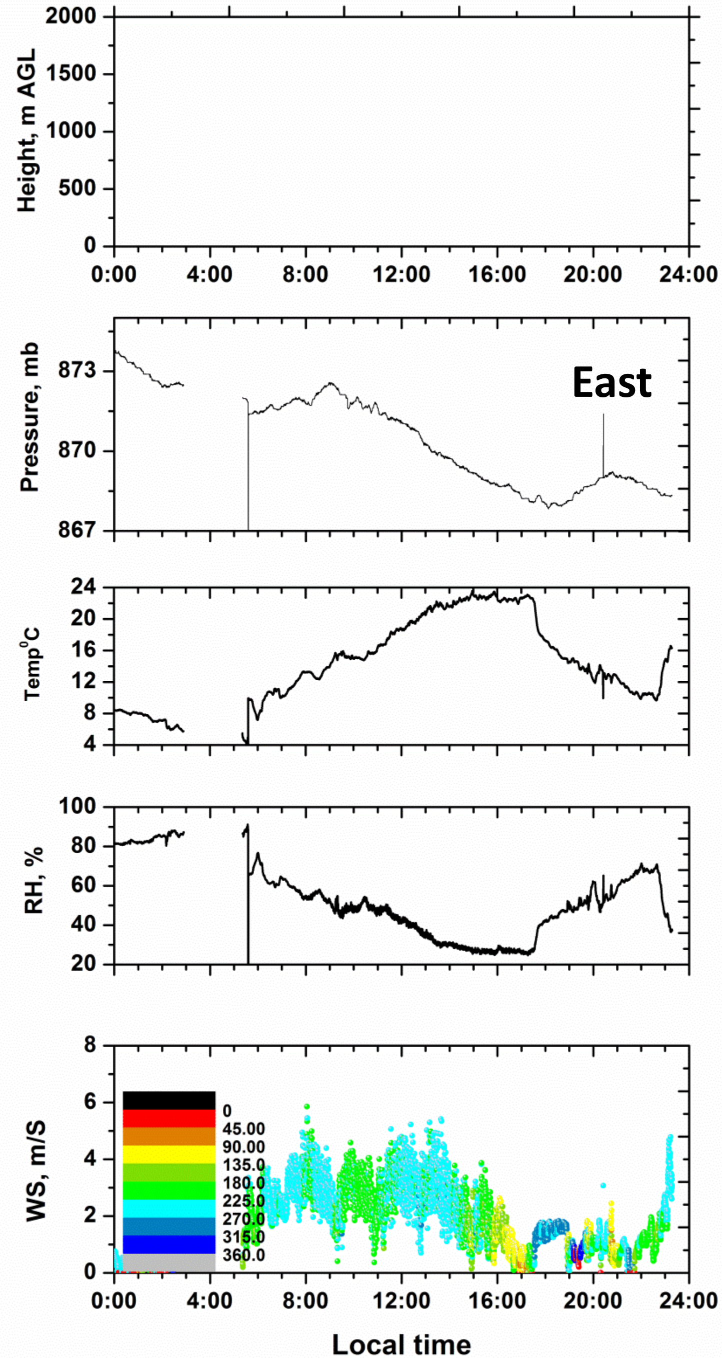




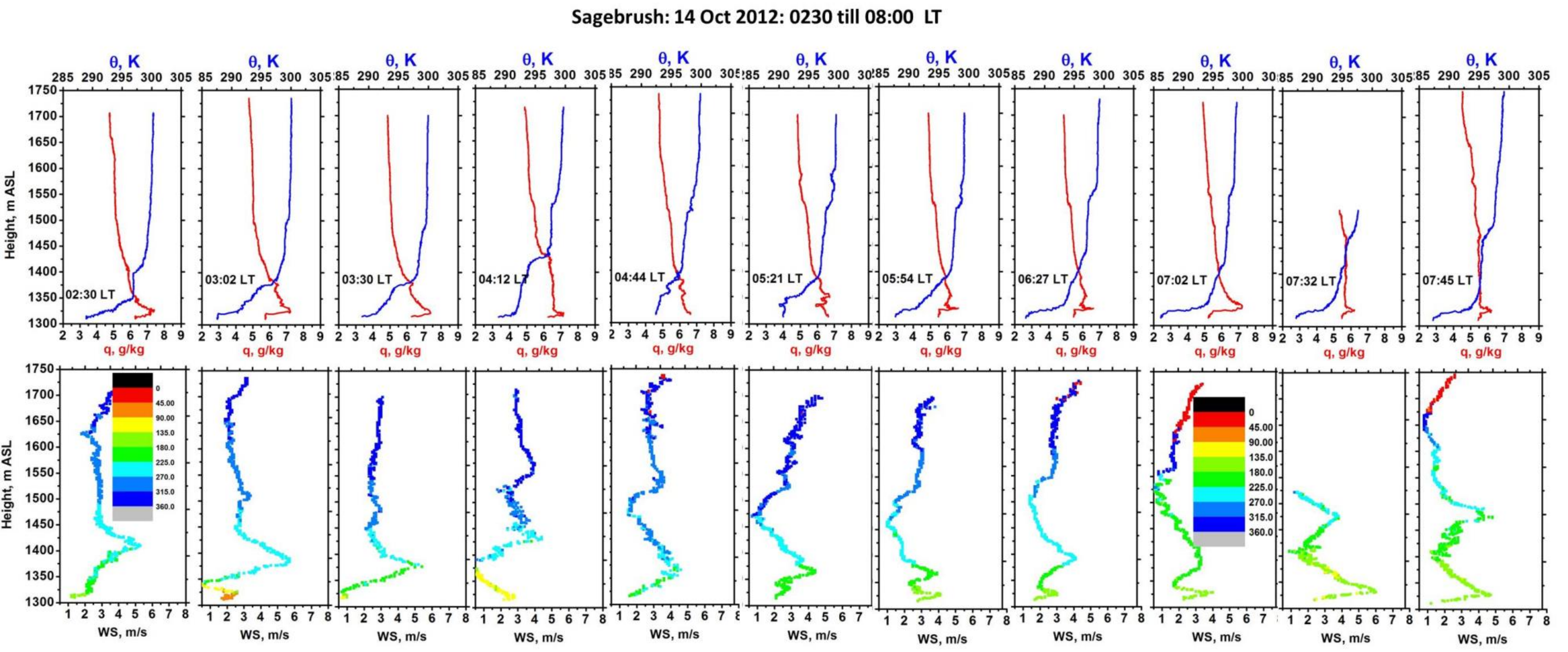
14 Oct 2012
West
East
Height, m AGL
Pressure, mb
Temp 0C
RH, %
WS, m/S
0
45.00
90.00
135.0
180.0
225.0
270.0
315.0
360.0
Local time

15 Oct 2012


West
Height, m AGL
Pressure, mb
Temp^{0}C
RH, %
WS, m/S
0
45.00
90.00
135.0
180.0
225.0
270.0
315.0
360.0
Local time

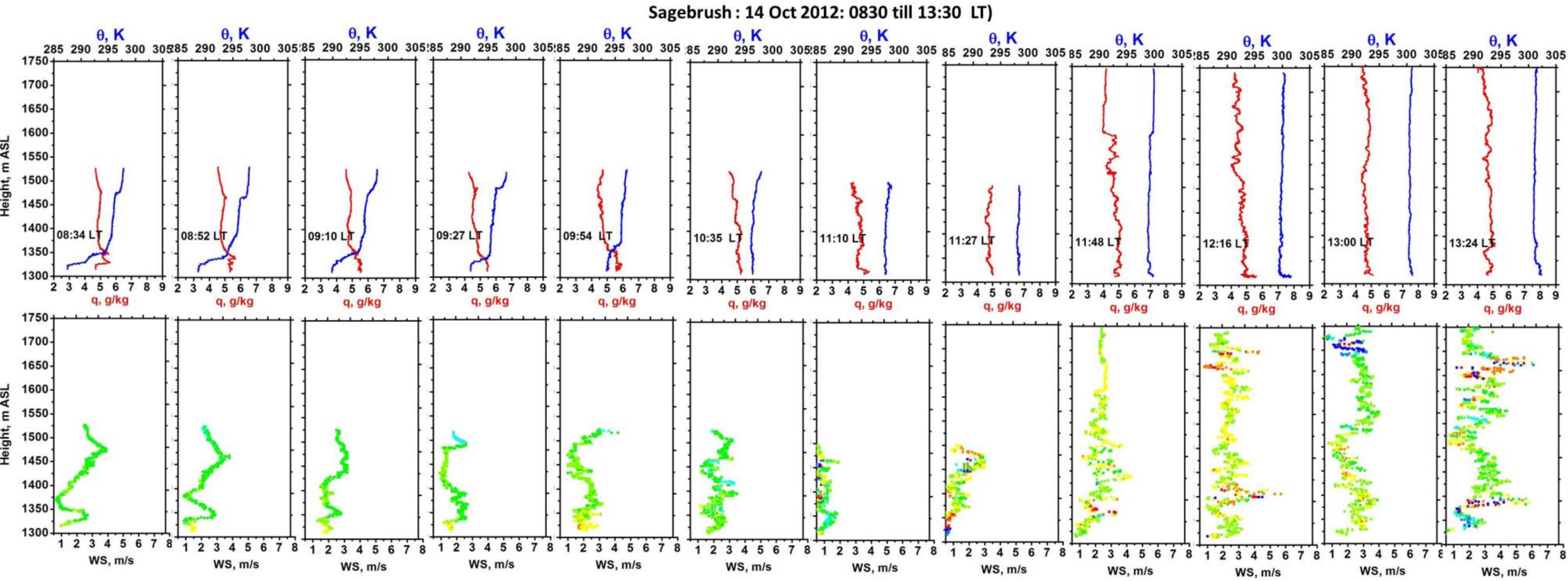

East
Height, m AGL
Pressure, mb
Temp^{0}C
RH, %
WS, m/S
0
45.00
90.00
135.0
180.0
225.0
270.0
315.0
360.0
Local time

Sagebrush: 14 October 2012 (0230 till 0800 LT)

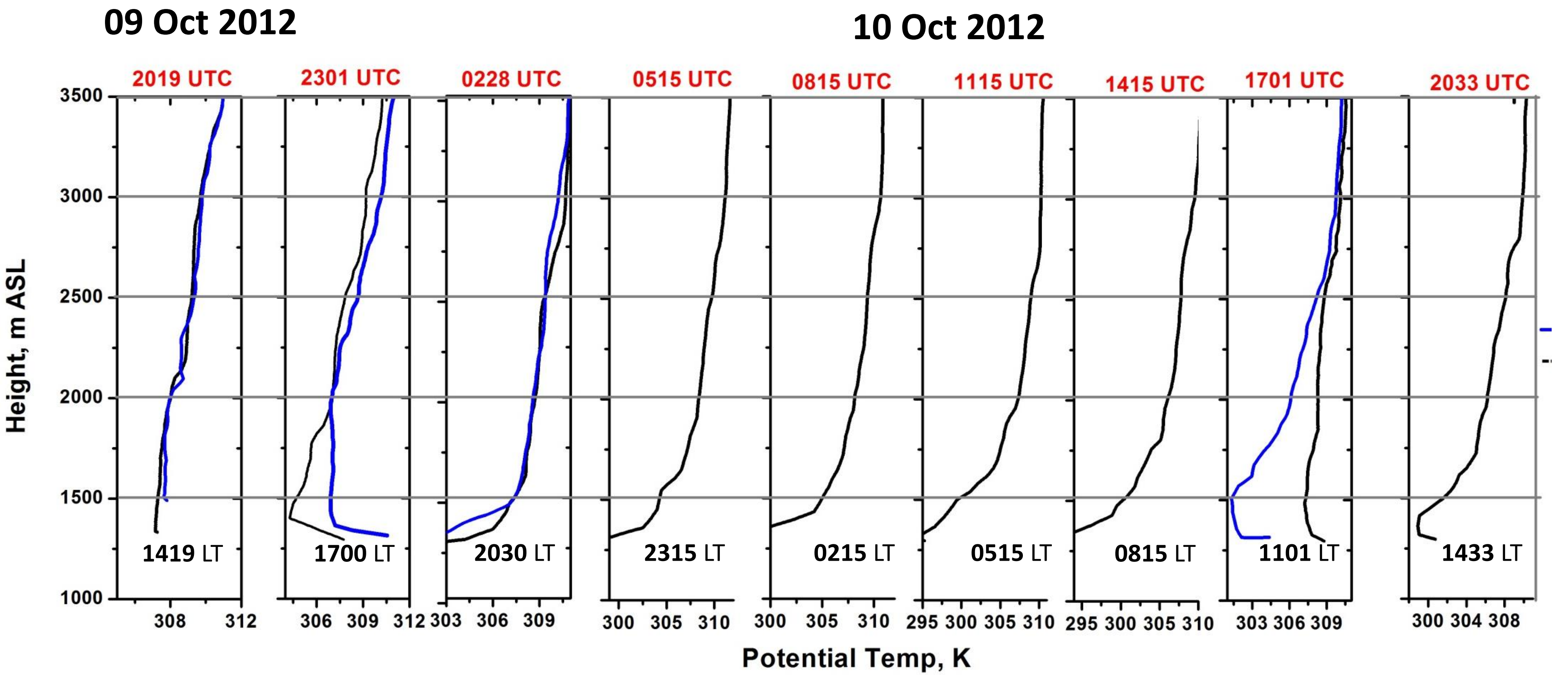


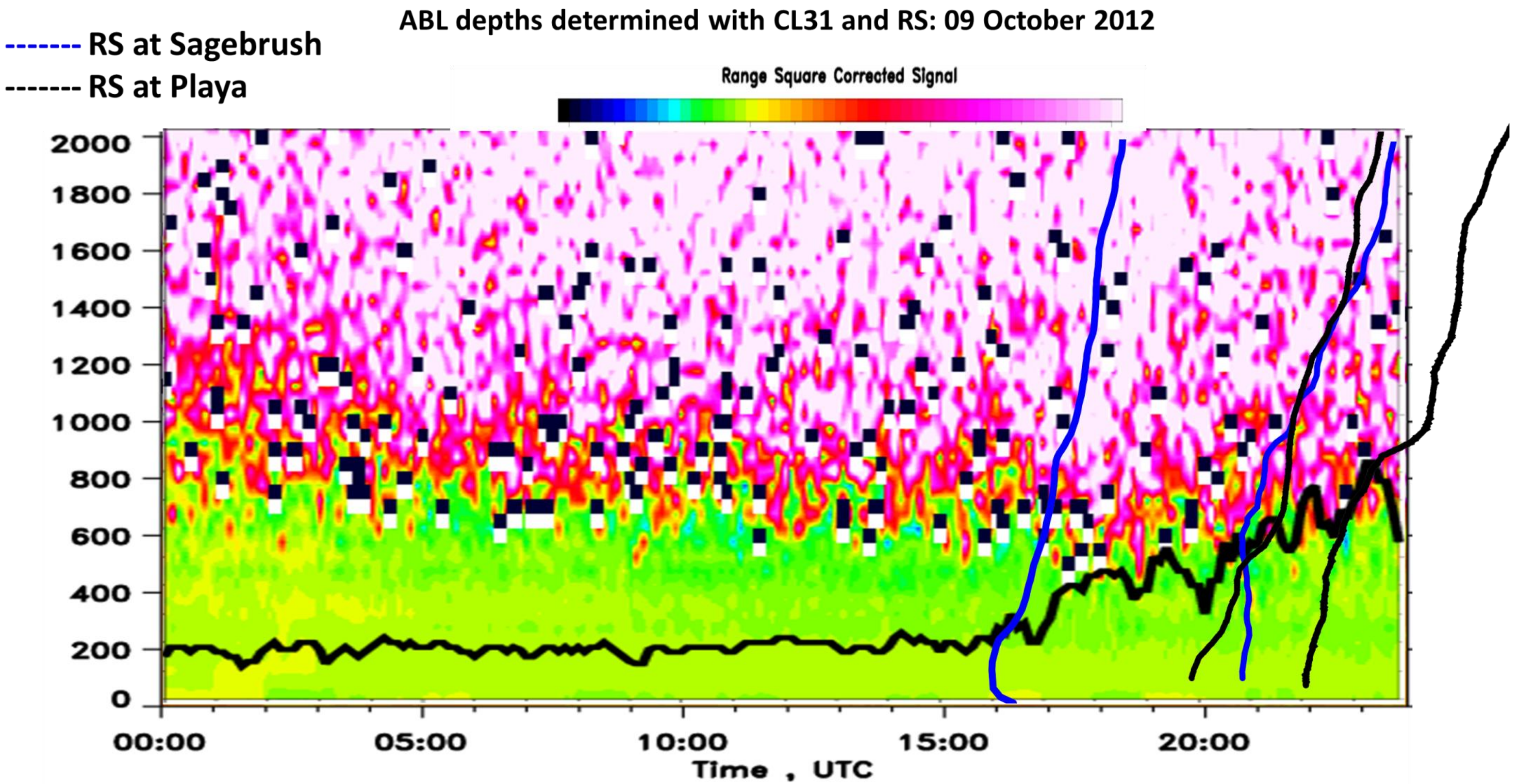
Application 01: NBL (often SBL) depths (Physical processes)
Application 02: Detection of the erosion of the NBL inversion (Physical processes)
Application 02a: Using 02 for ABL depth retrieval (Practical purpose: another candidate for attribution though for case studies)

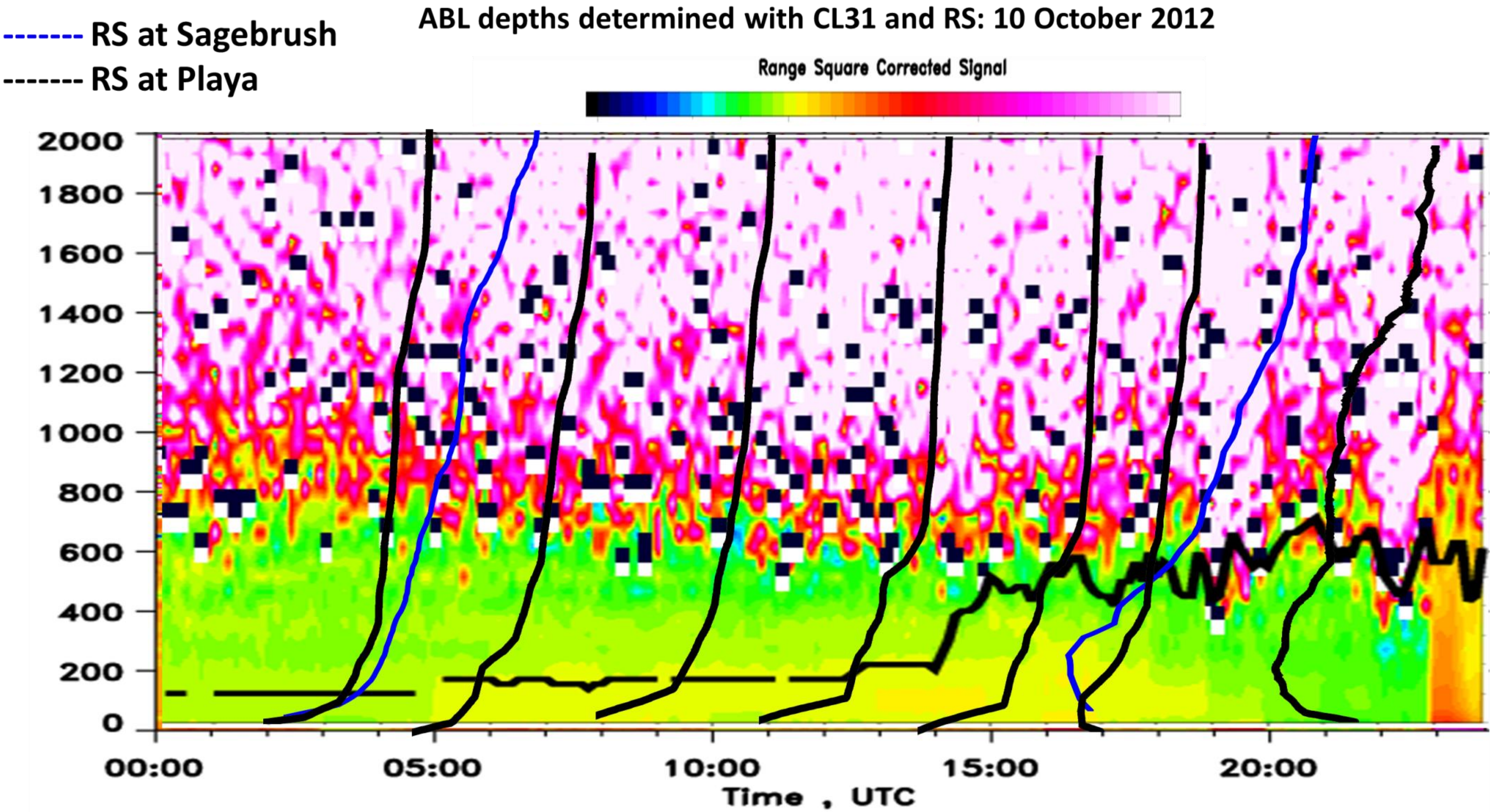
Sagebrush: 14 October 2012 (0830 till 1330 LT)



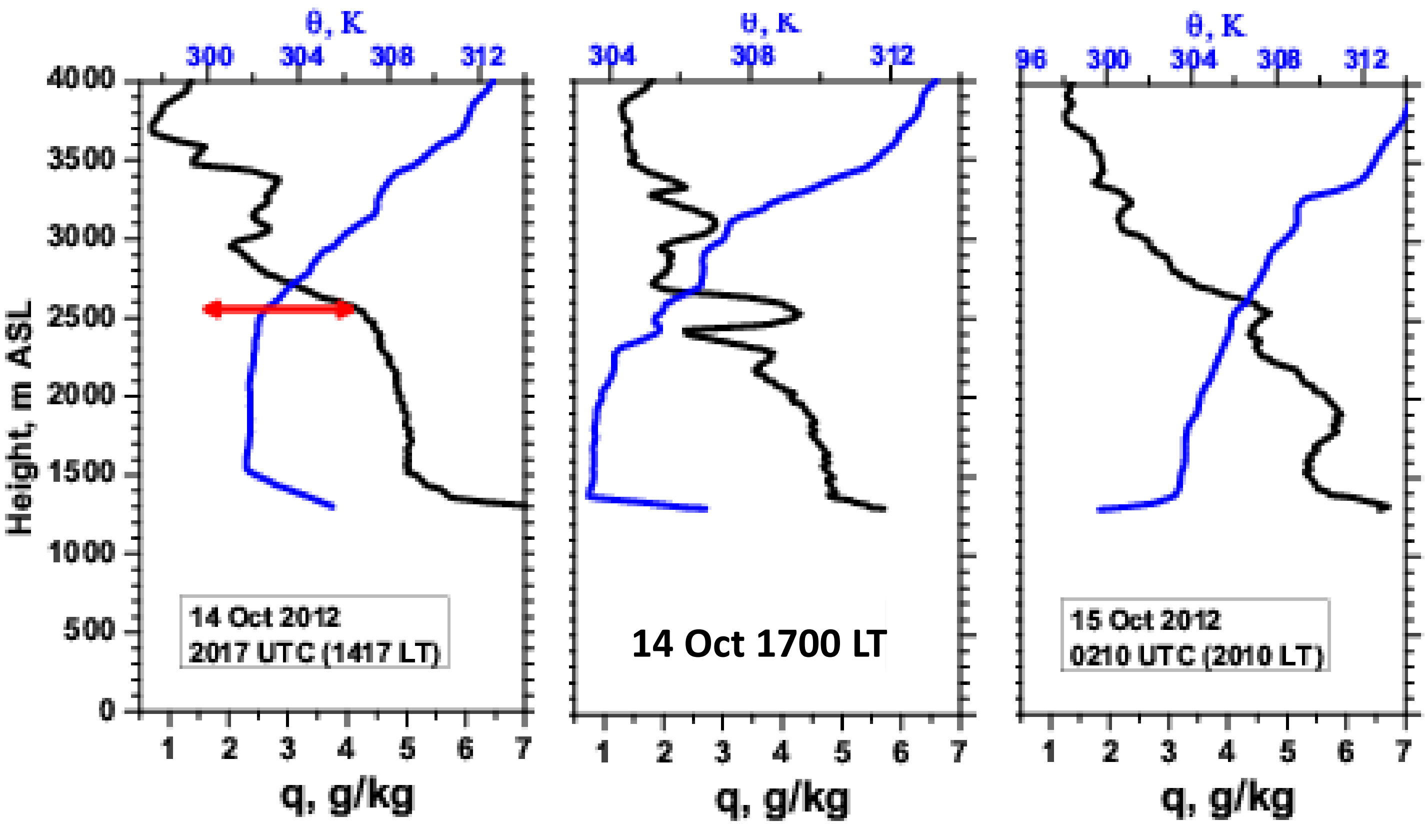
09-10 October IOP (Intercomparison)




ABL depths determined with CL31 and RS: 09 October 2012
------- RS at Sagebrush
------- RS at Playa
Range Square Corrected Signal
2000
1800
1600
1400
1200
1000
800
600
400
200
0
00:00
05:00
10:00
15:00
20:00
Time , UTC


ABL depths determined with CL31 and RS: 10 October 2012
------- RS at Sagebrush
------- RS at Playa
Range Square Corrected Signal
2000
1800
1600
1400
1200
1000
800
600
400
200
0
00:00
05:00
10:00
15:00
20:00
Time , UTC

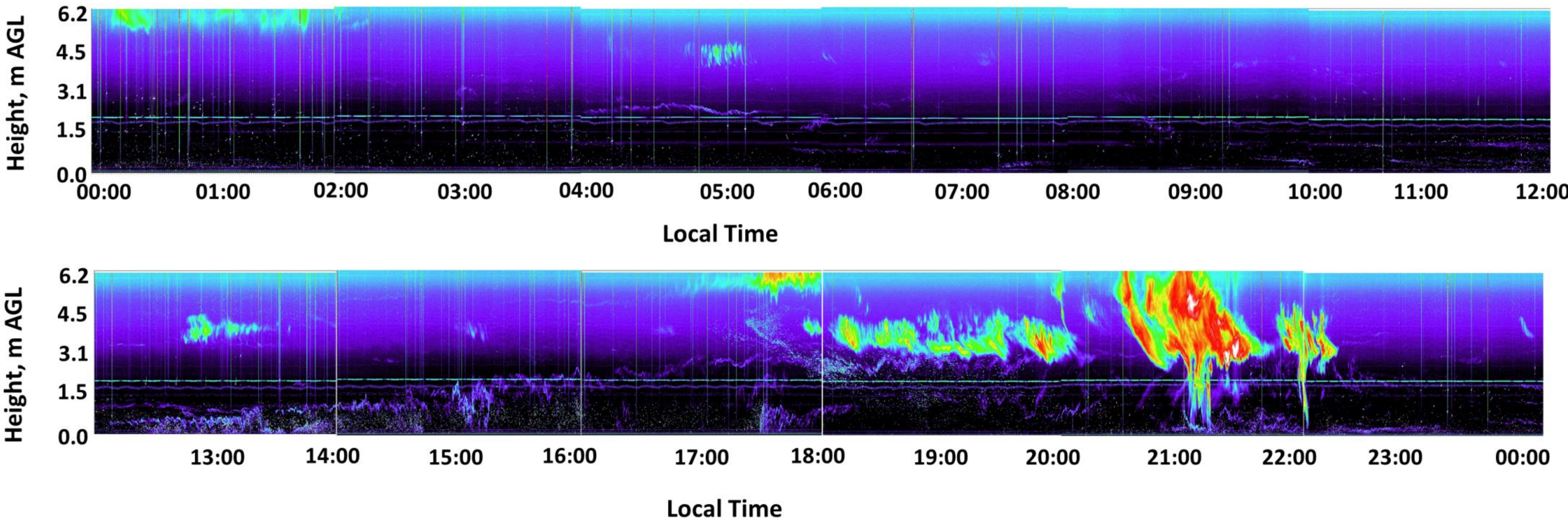
Radiosonde observation of thermodynamic variables: SB Site: 14 Oct



ABL depths
SB: 2600,2350, 200
Playa: 2300, 2200, 130

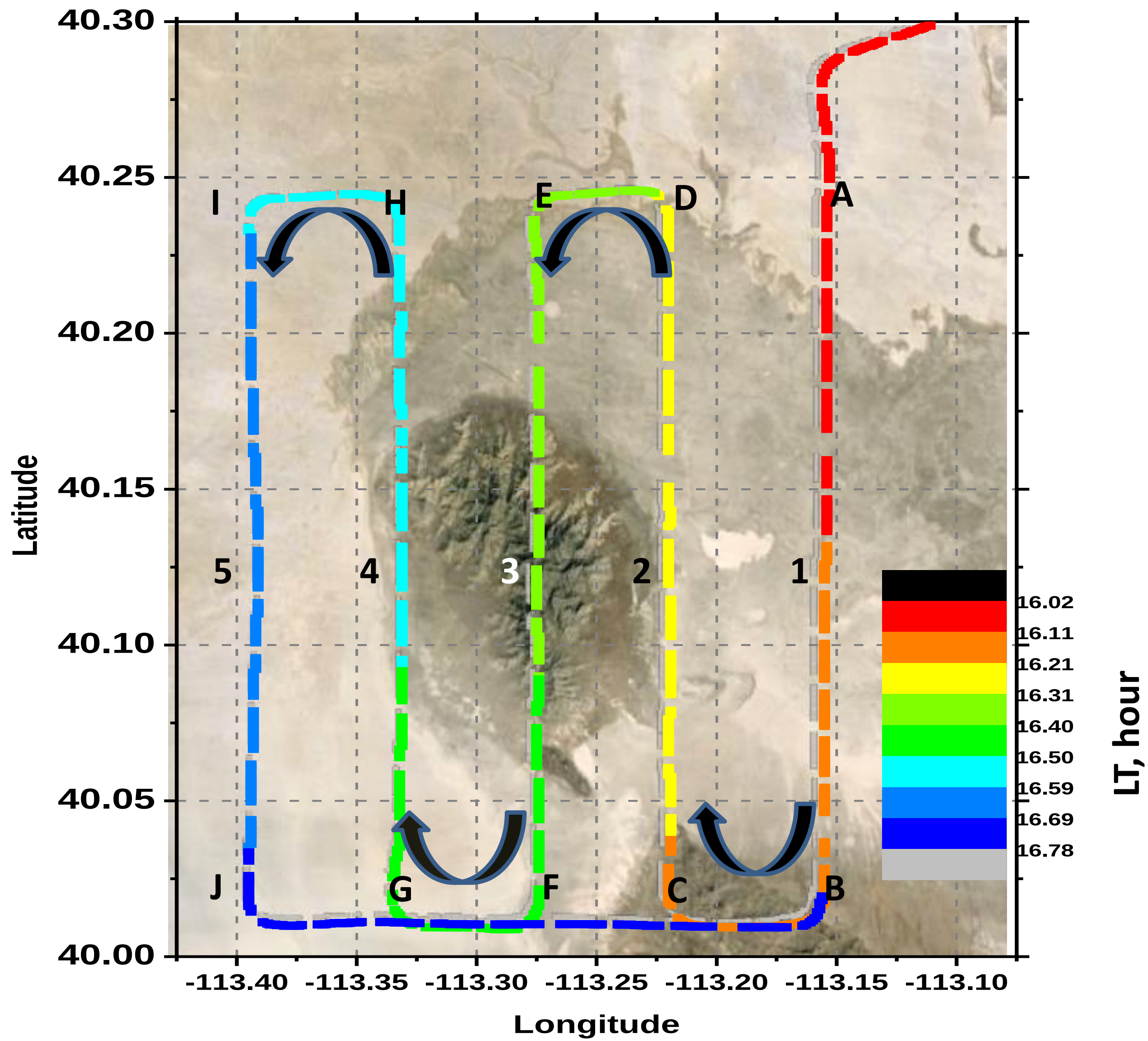
Frequency modulated continuous wave Radar
On 10 October

40.196902, -113.167763



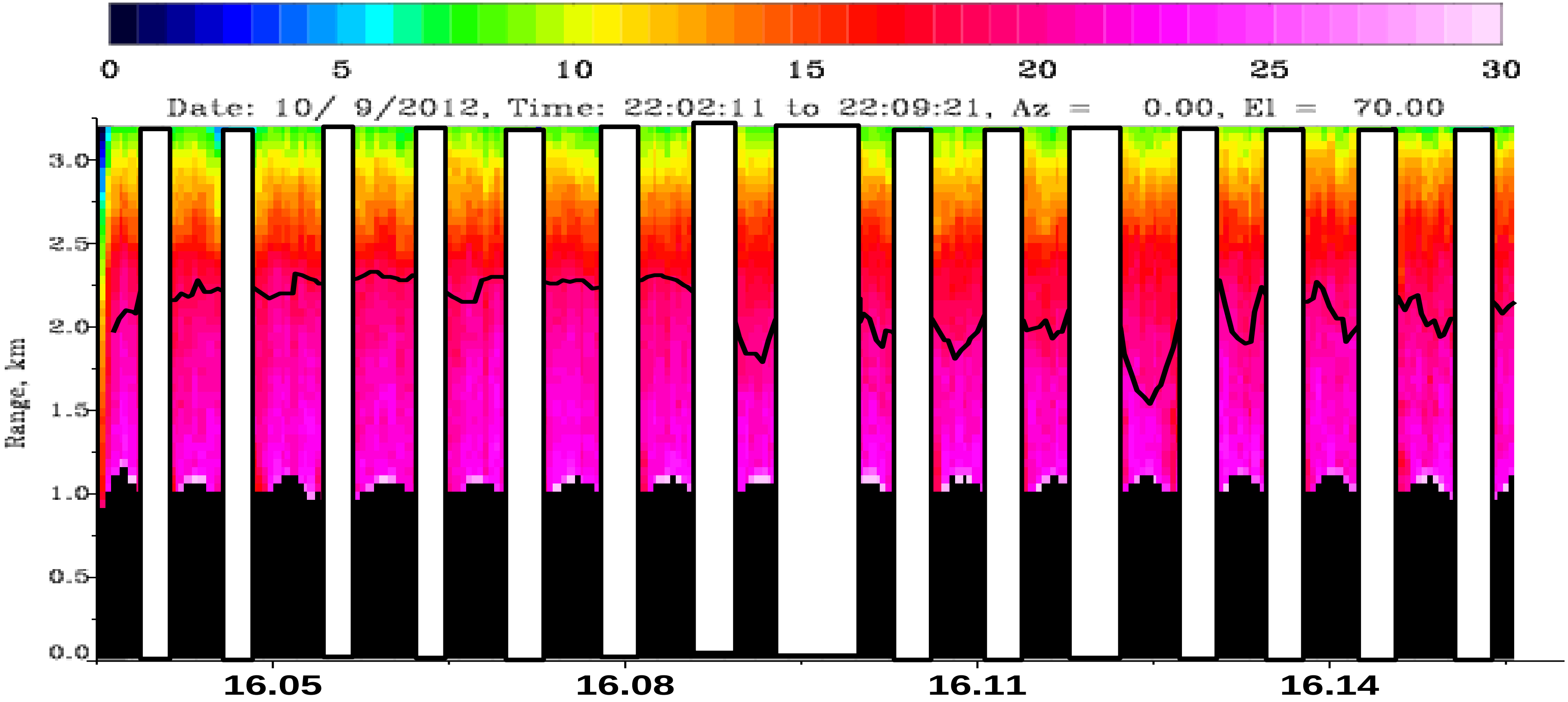
09 October 2012 (North-South-North flight legs)

09 October 2012



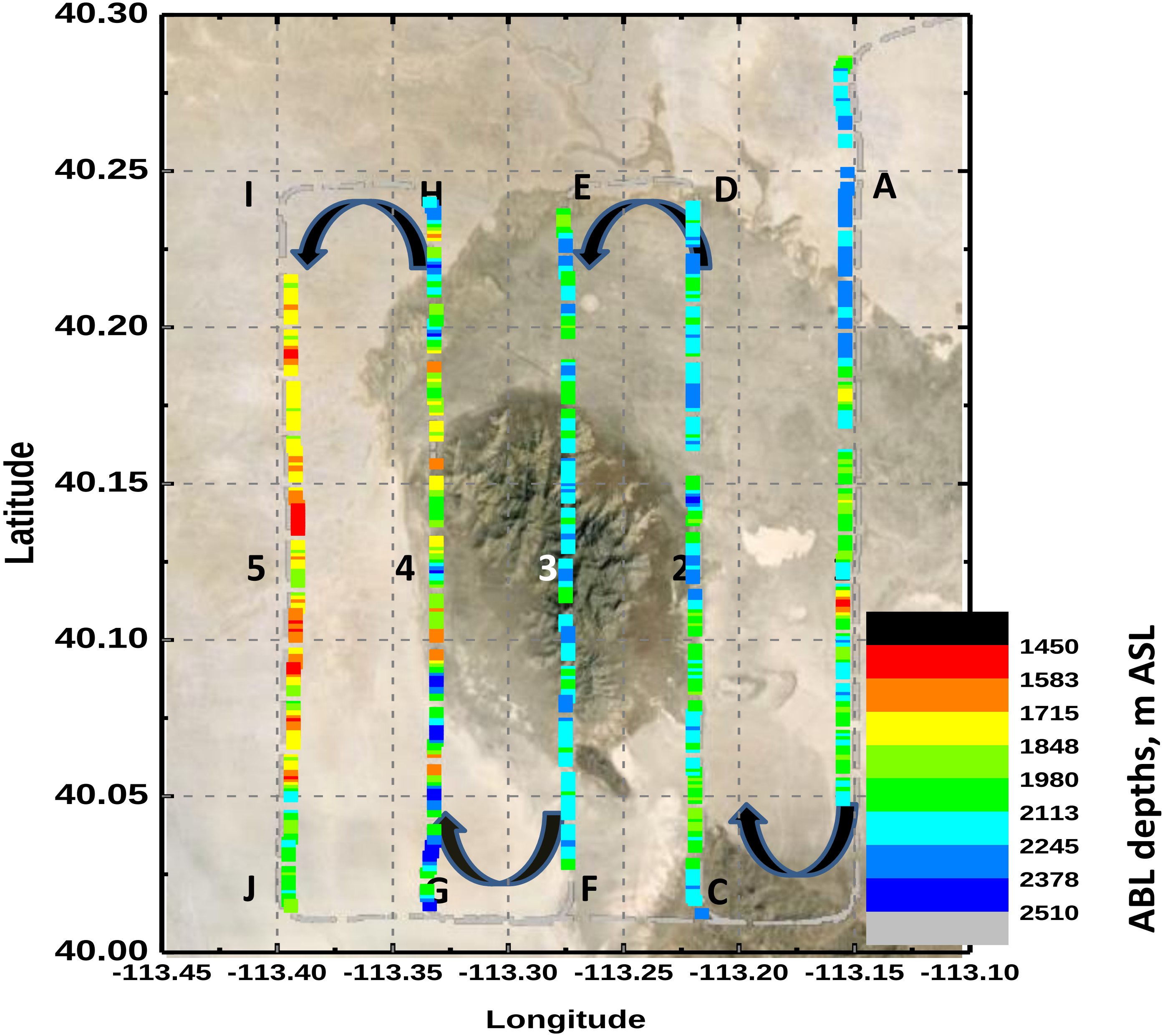
09 October 2012

NS Leg 01 A to B

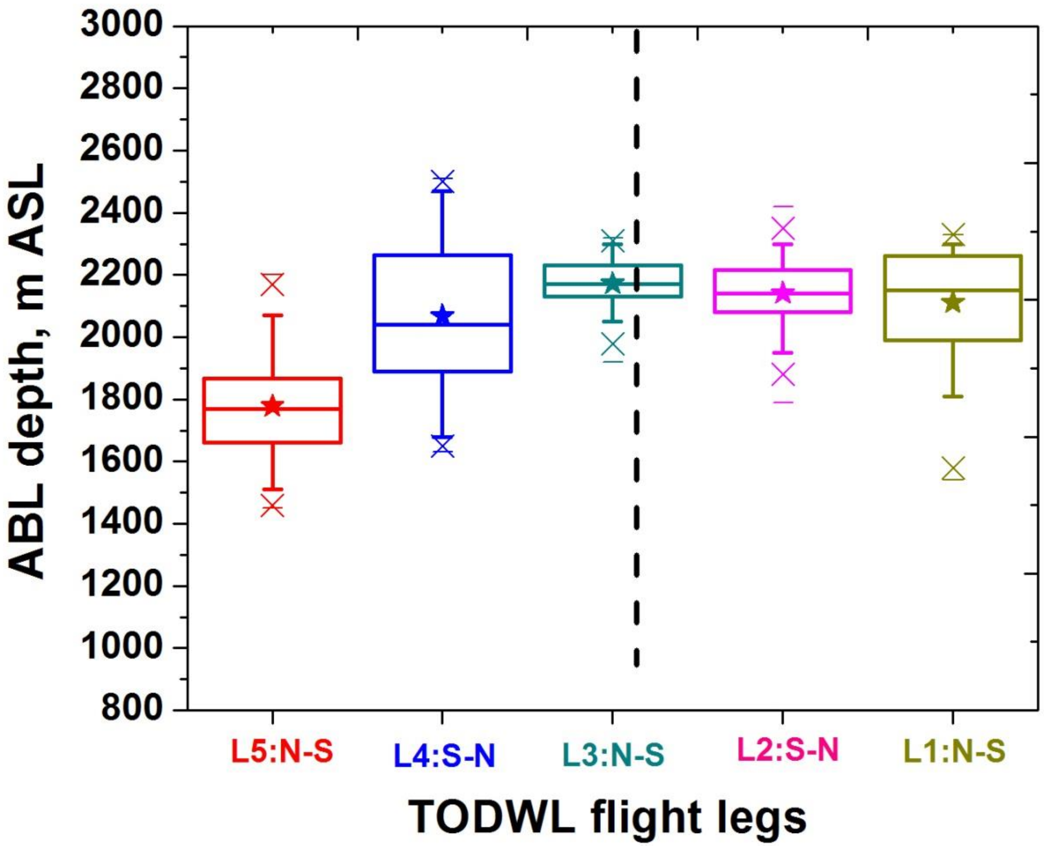


Overview Spatial variability: NS flight legs

09 October 2012

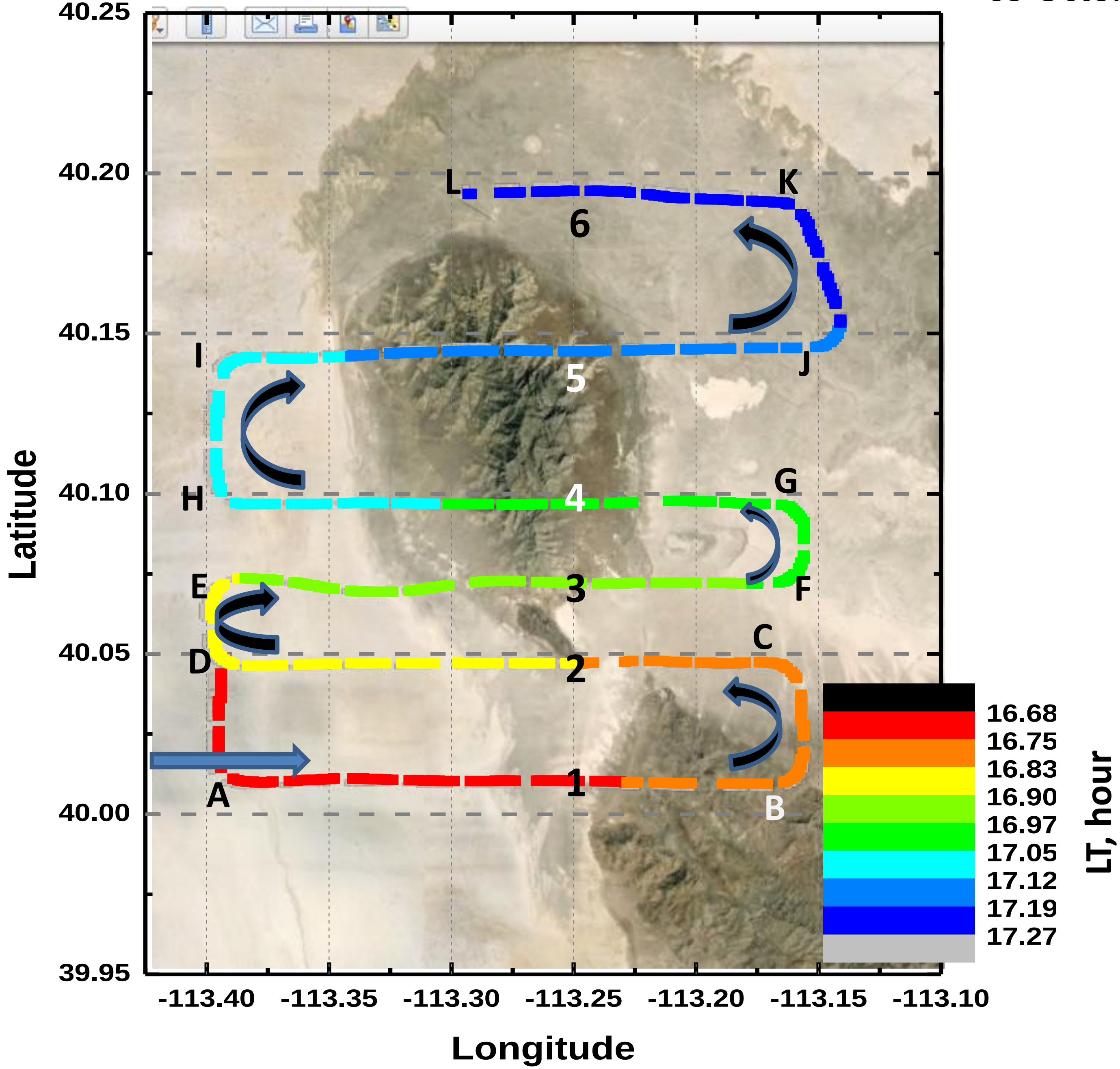


Summary of the NS and SN legs on 09 Oct 2012



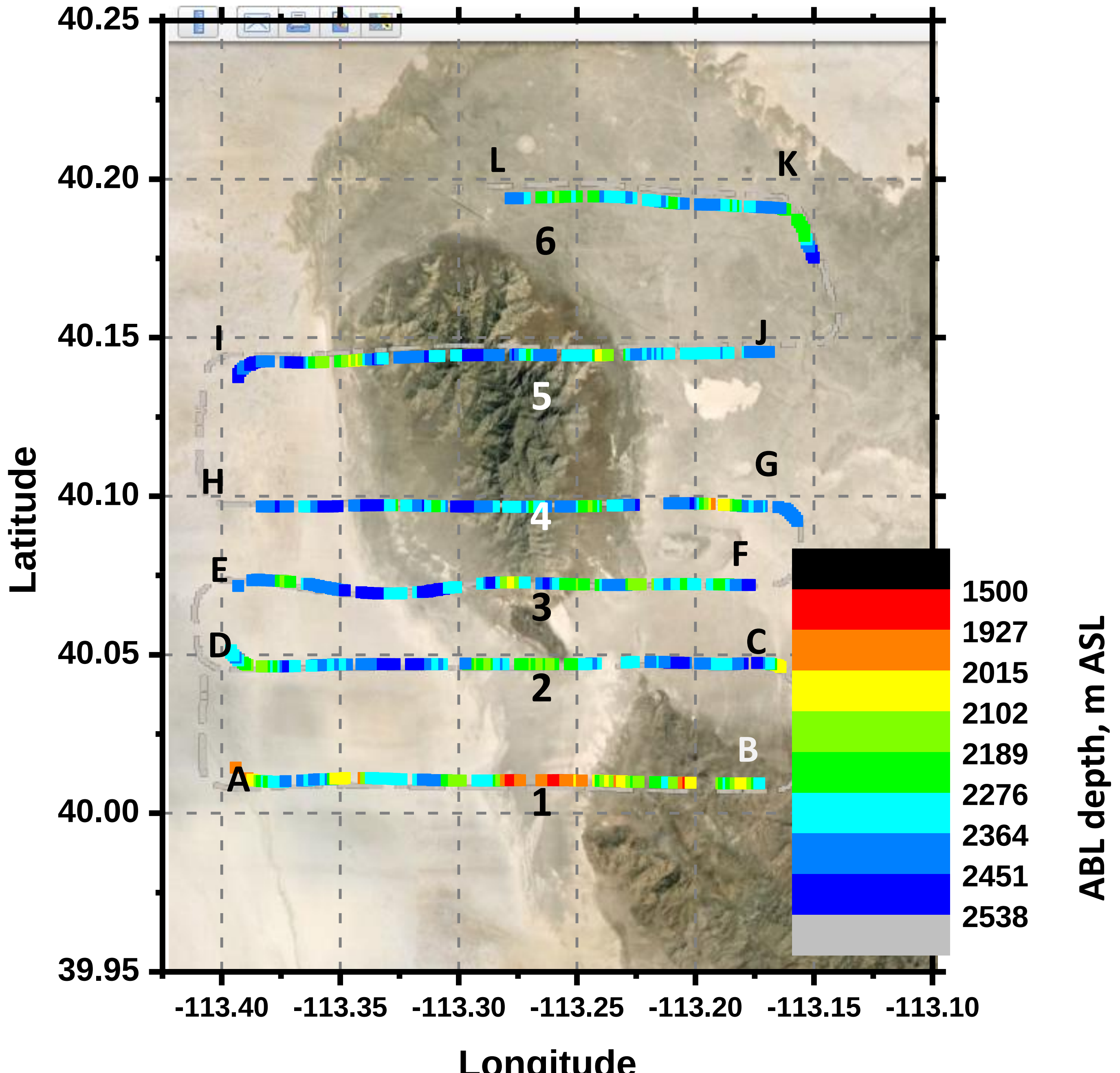
09 October 2012 (East-West-East flight legs)

09 October 2012

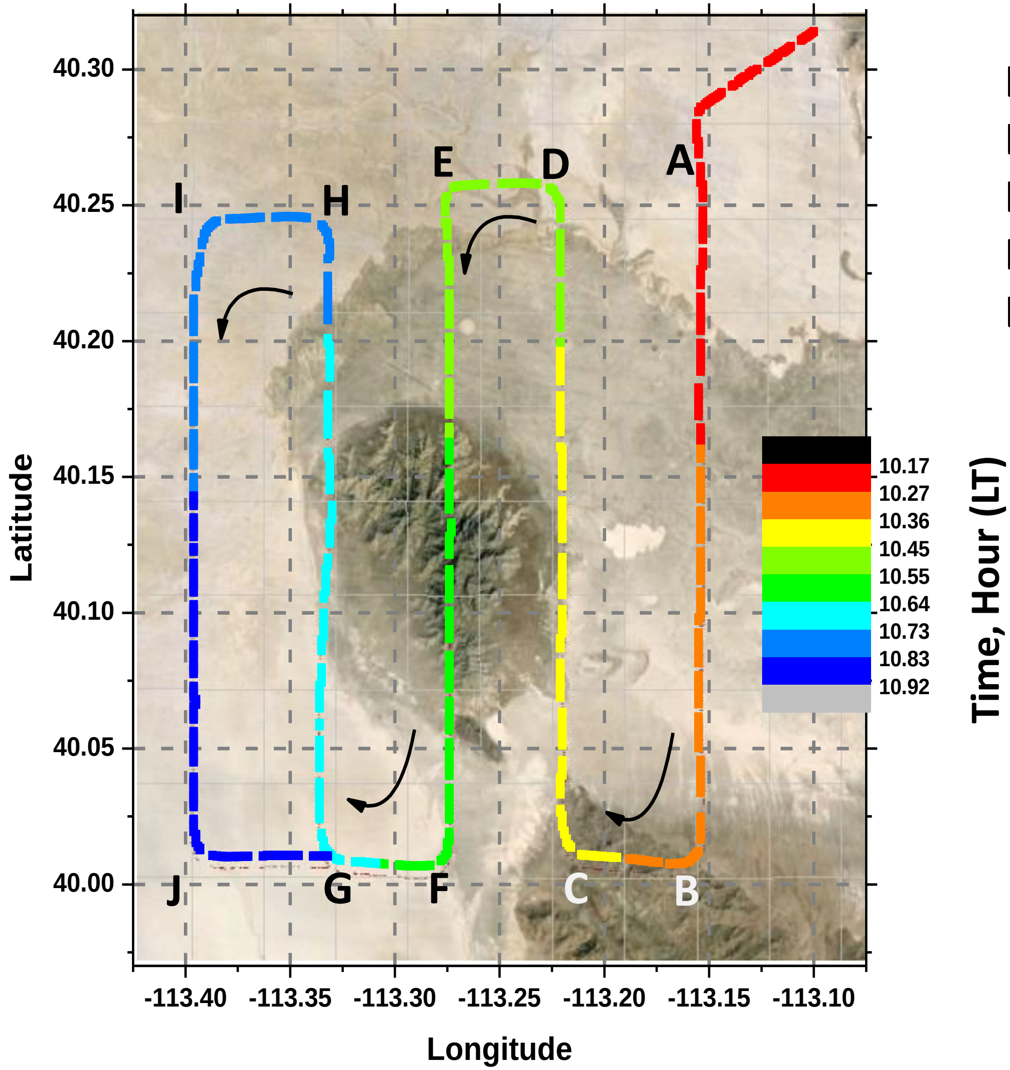


09 October 2012 (East-West-East flight ABL depths)

09 October 2012



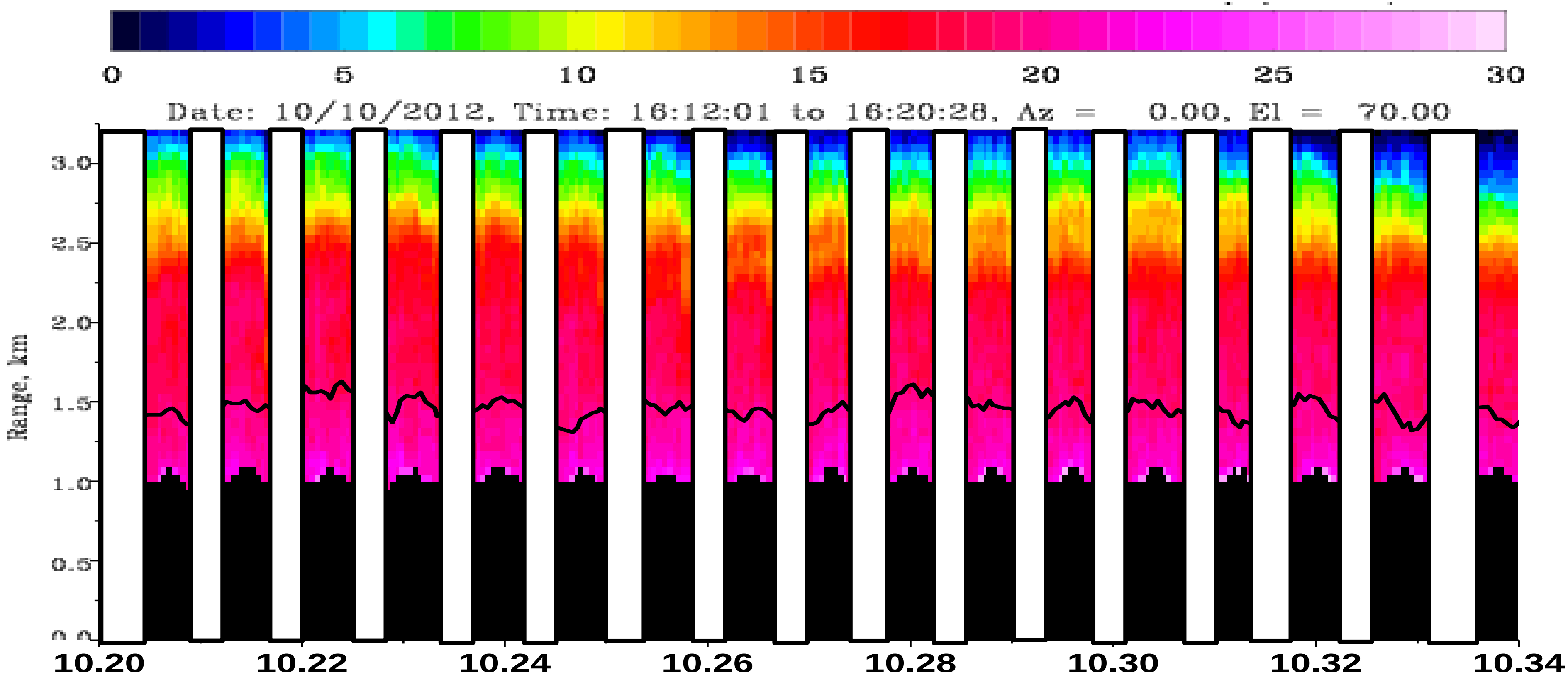
10 October 2012



Leg 1: A to B
Leg 2: C to D
Leg 3 : E to F
Leg 4: G to H
Leg 5: I to J

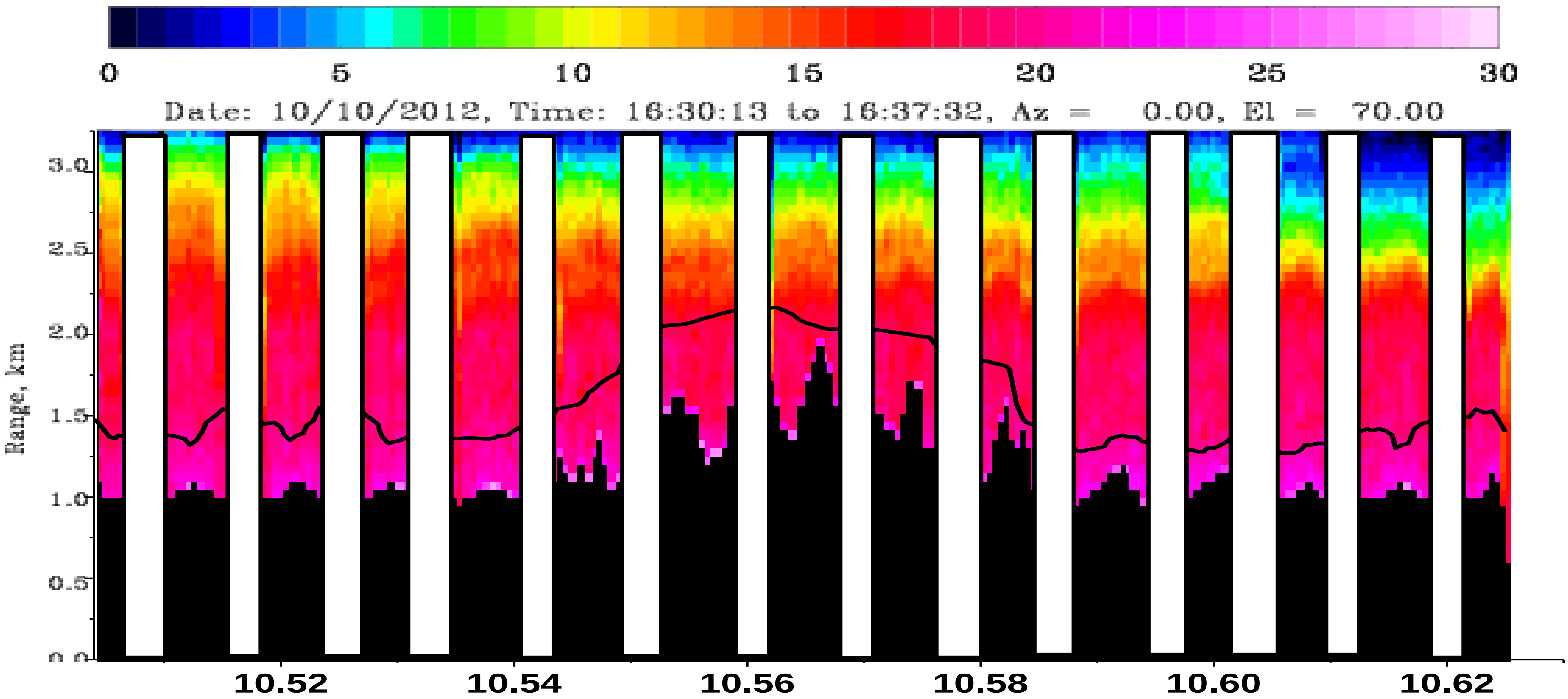
NS Leg 1: A to B

10 October 2012

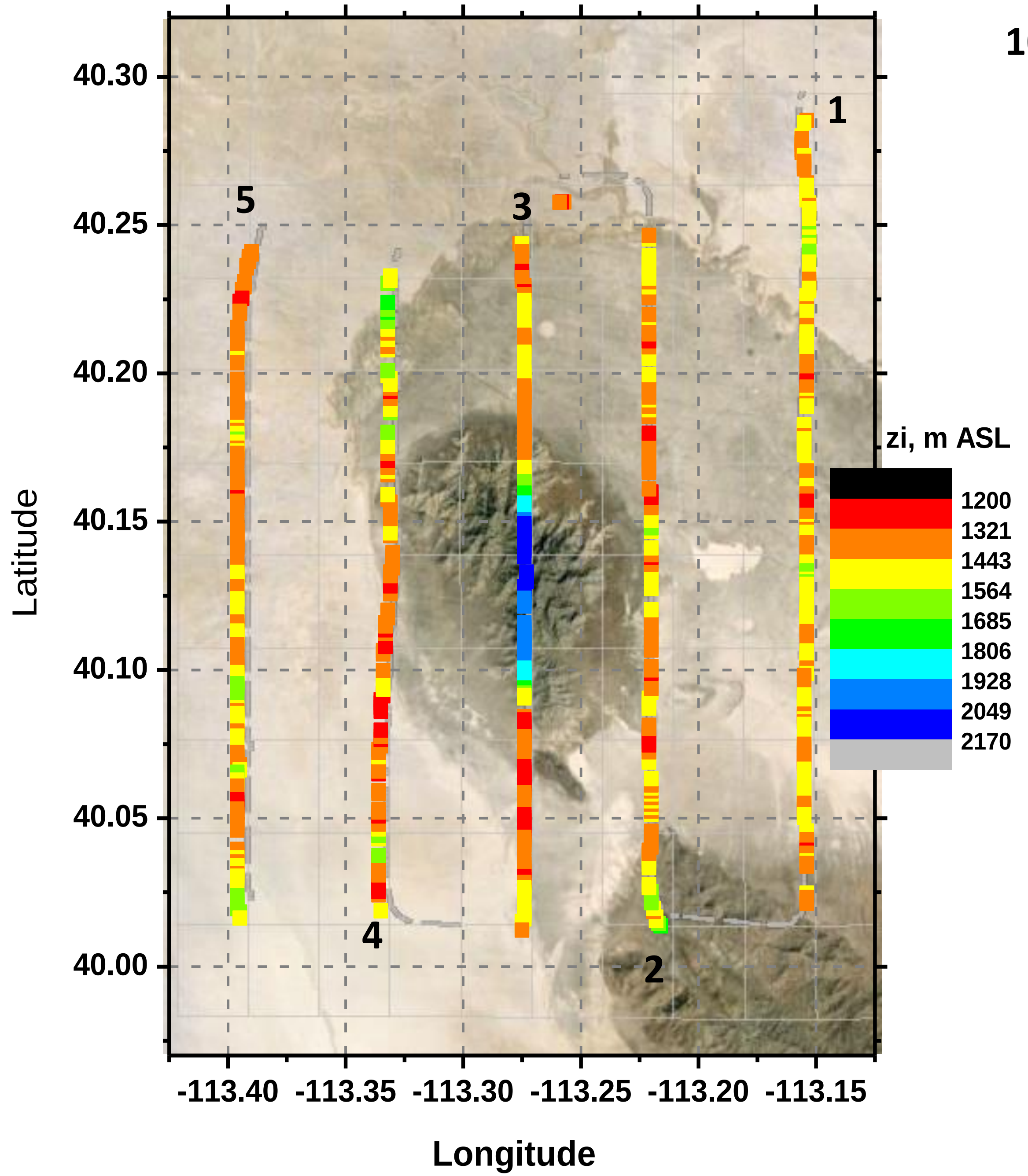


NS Leg 3: E to F

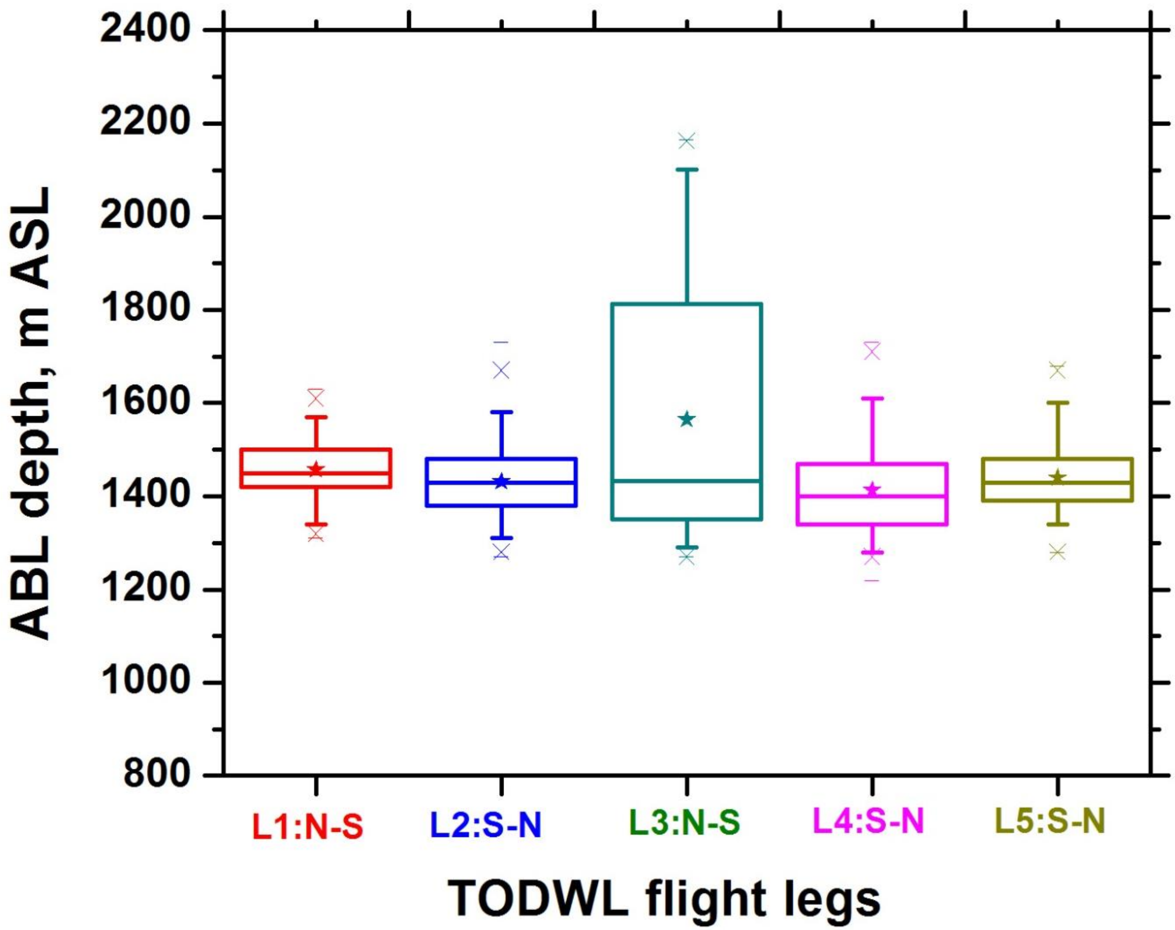
10 October 2012



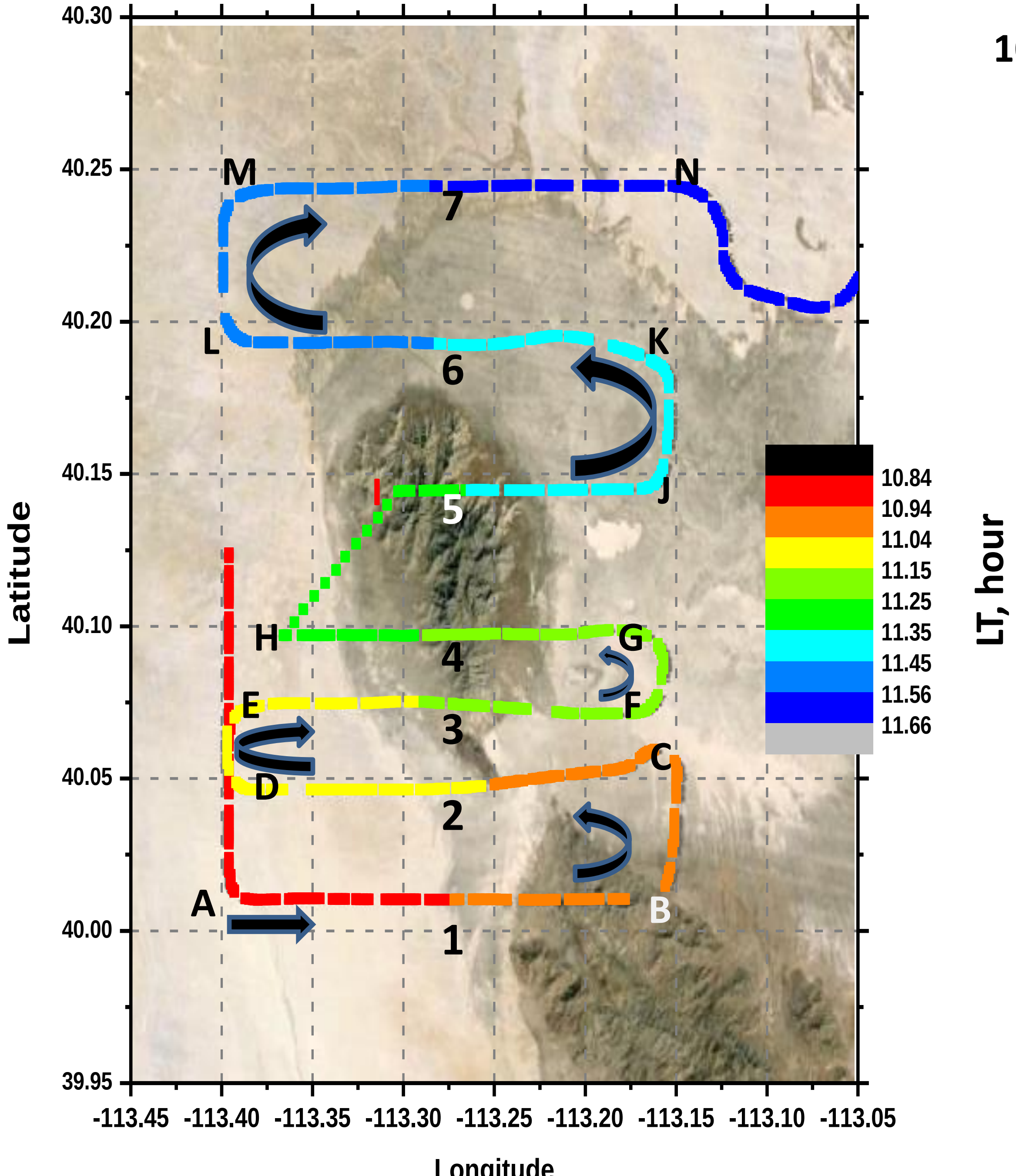
10 October 2012



Summary of the NS and SN legs on 10 Oct 2012

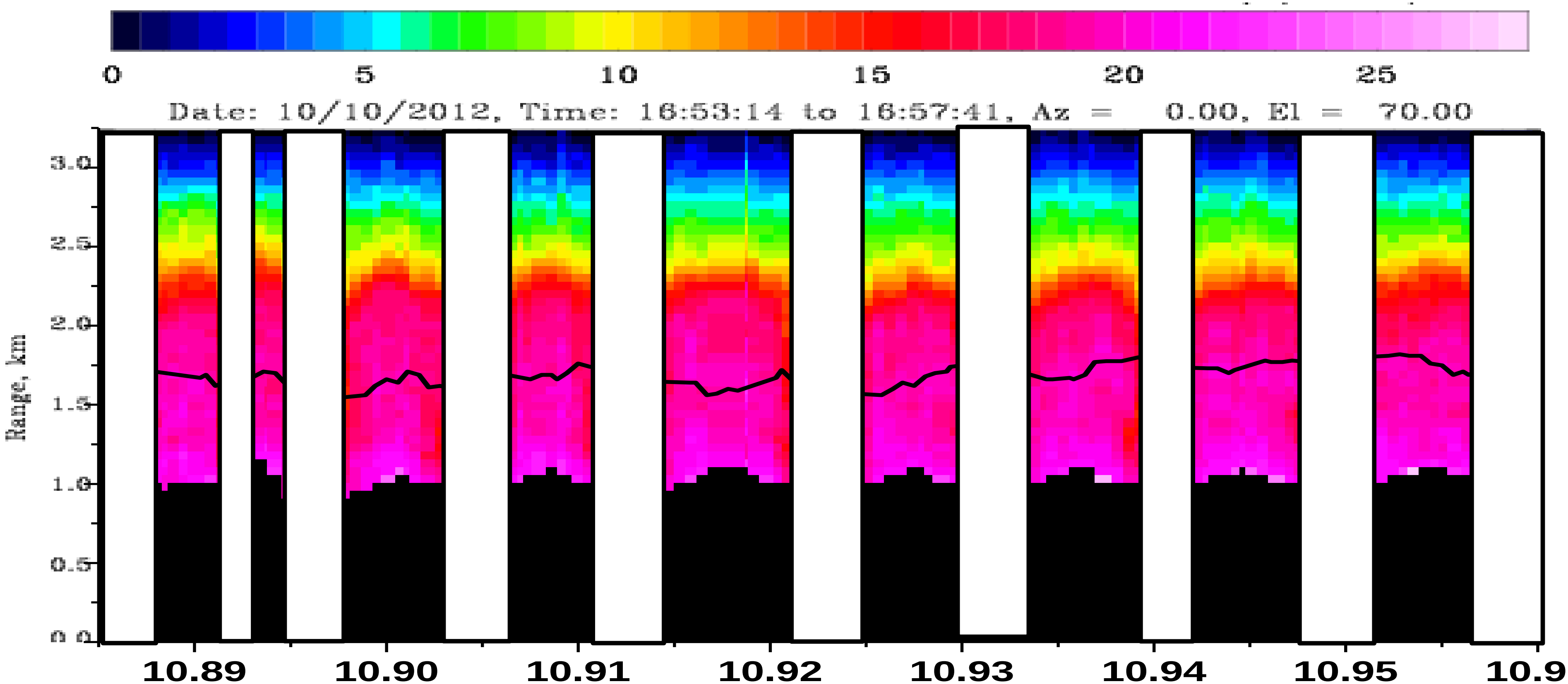


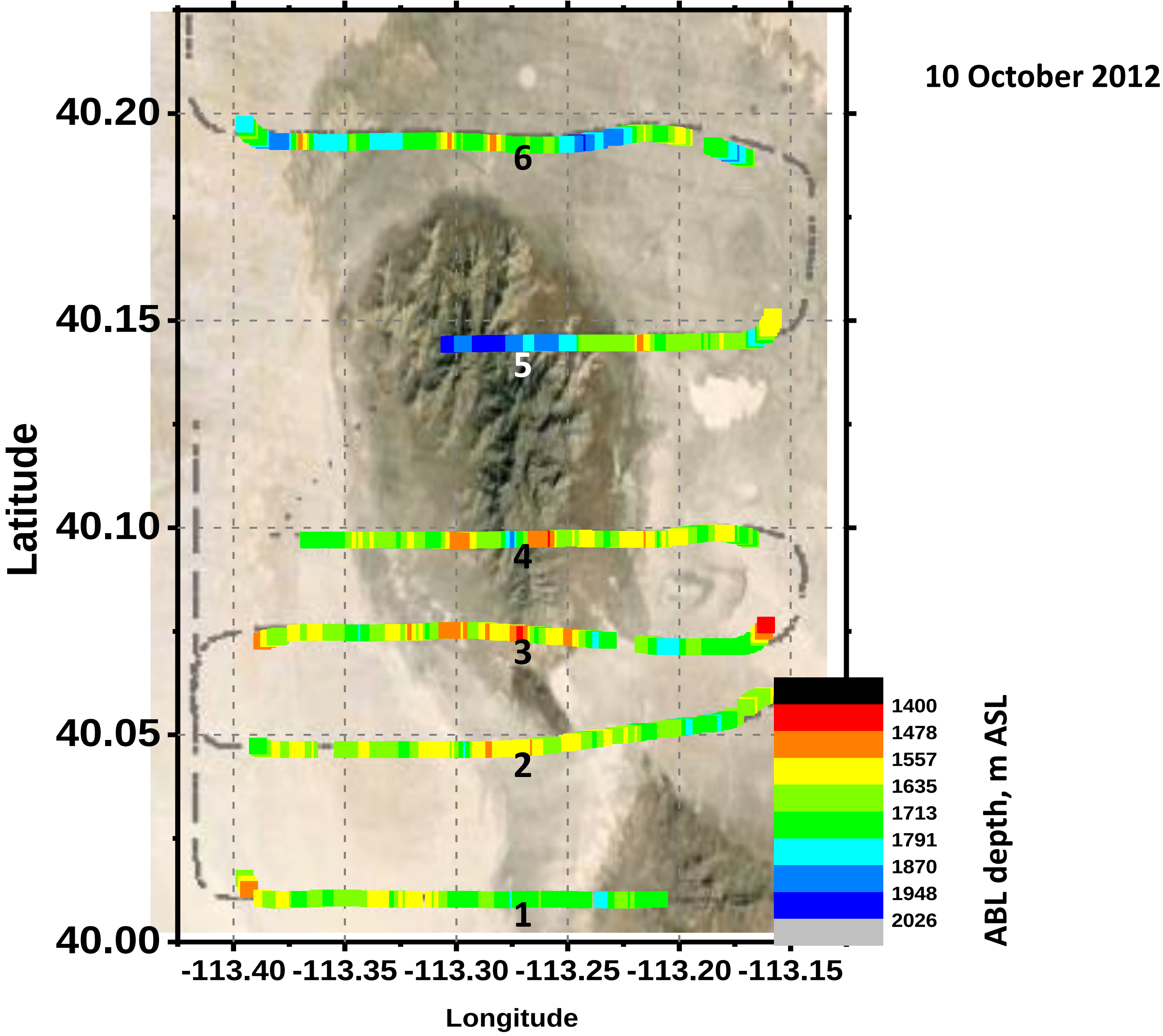
10 October 2012

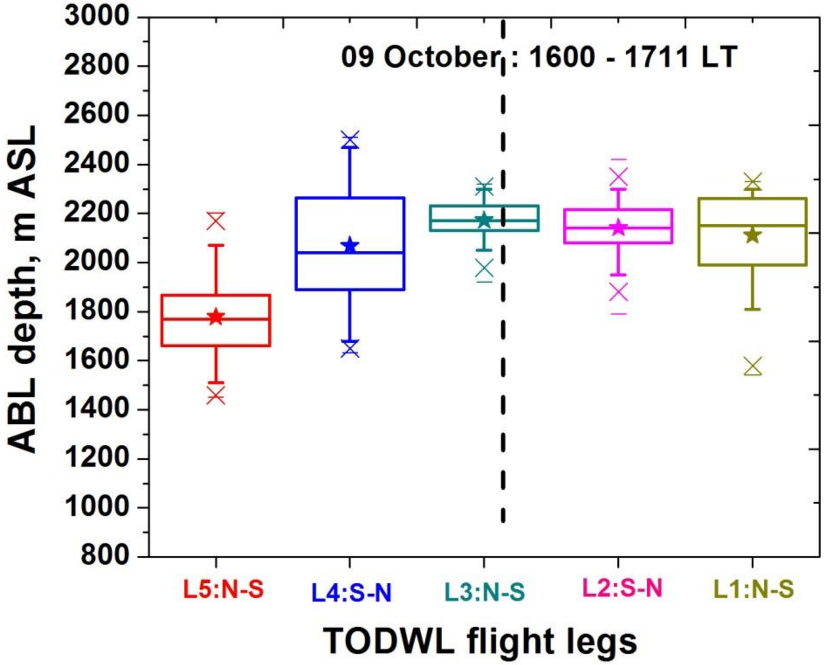


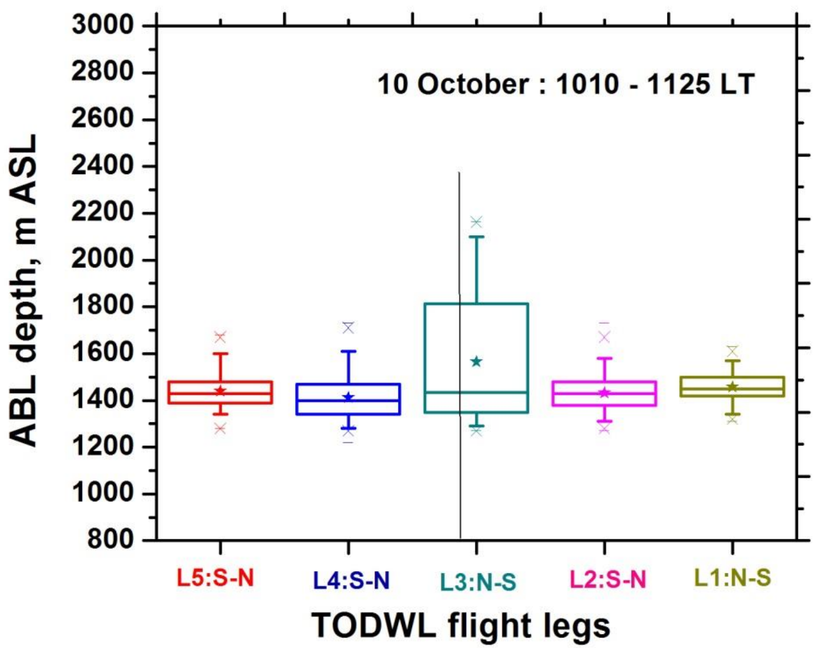
WE Leg 1: A to B

10 October 2012



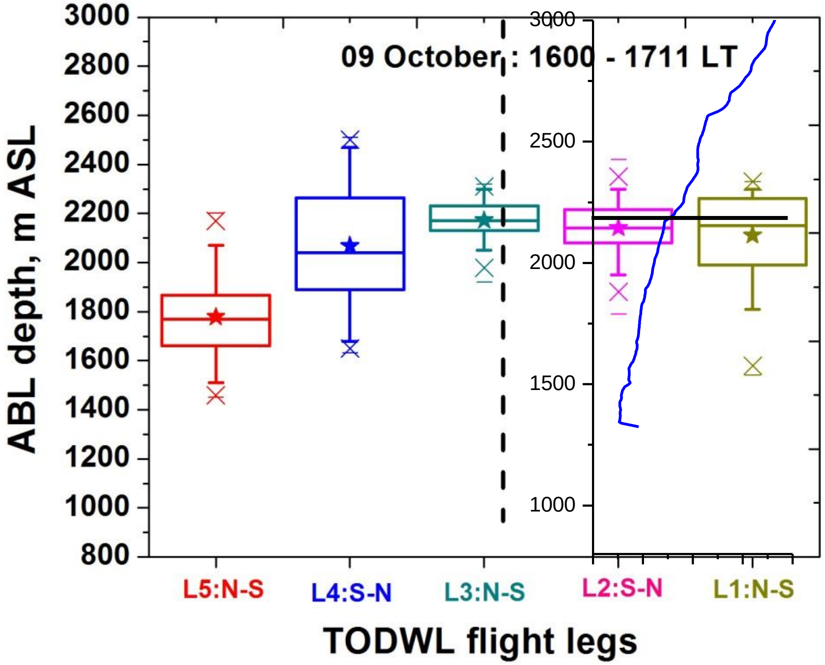

10 October 2012
Latitude
40.20
40.15
40.10
40.05
40.00
-113.40
-113.35
-113.30
-113.25
-113.20
-113.15
Longitude
1
2
3
4
5
6
ABL depth, m ASL
1400
1478
1557
1635
1713
1791
1870
1948
2026

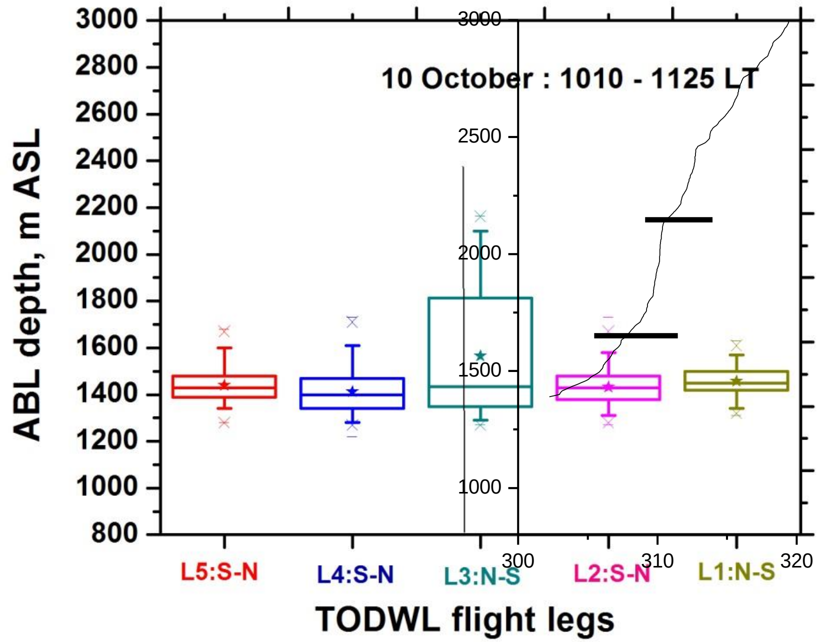




- Significant East-West ABL depth gradient exists
- Well-mixed regimes exist
- NS legs over Granaite did not evince terrain following characteristics

- Along the NS leg over Granite: Terrain following feature observed
- Little East-West ABL depth gradient exists: Note BL did not grew fully during this time
- Cross-leg feature shows: Also local ABL and hence high ABL depths over Granite peak





- Significant East-West ABL depth gradient exists
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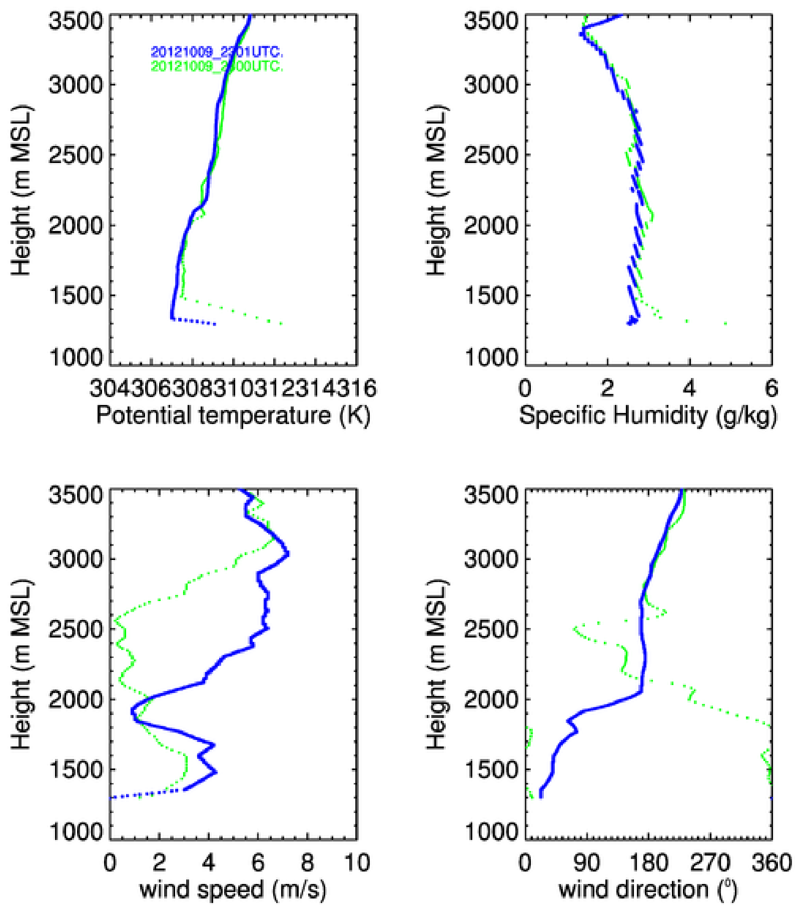
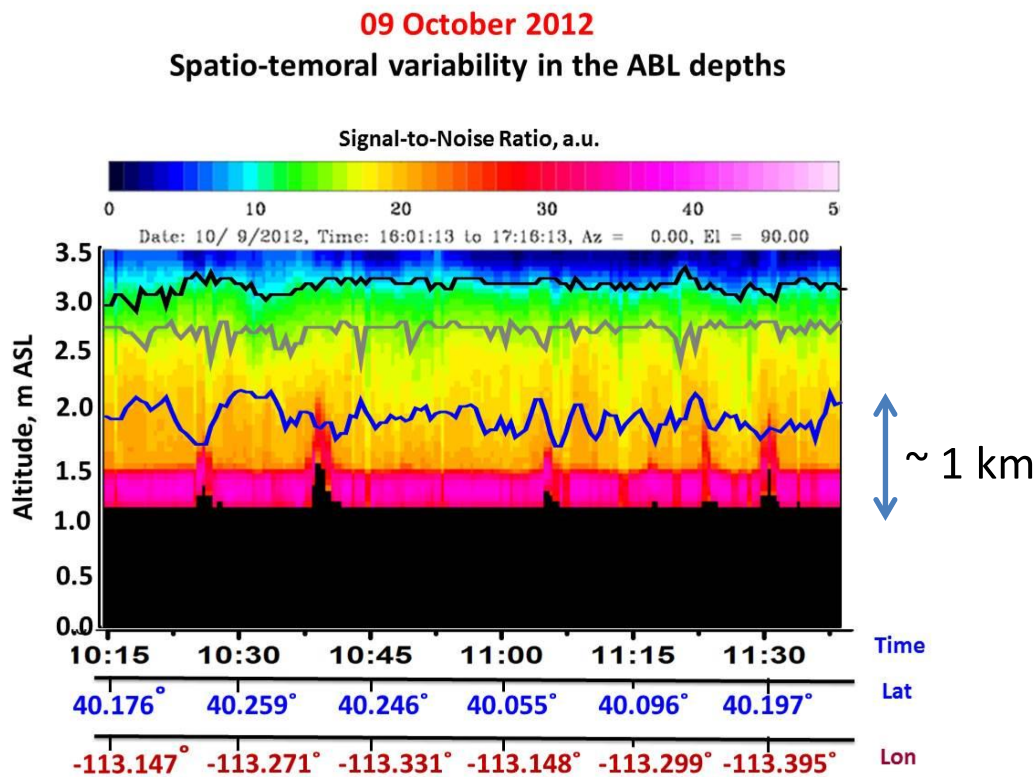
- Little East-West ABL depth gradient exists: Note BL did not grew fully during this time
- Cross-leg feature shows: Also local ABL and hence high ABL depths over Granite peak

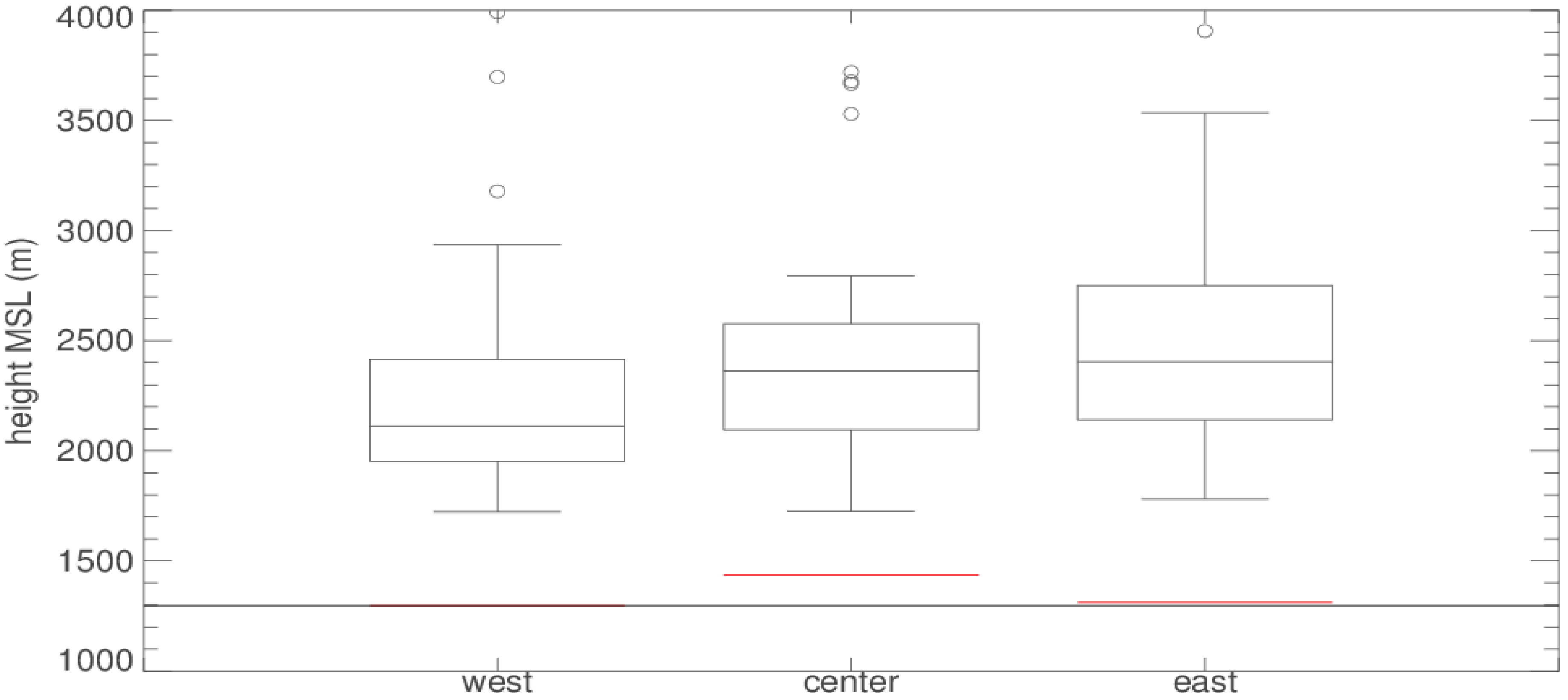
Aerosol Stratification as well as ABL depths …

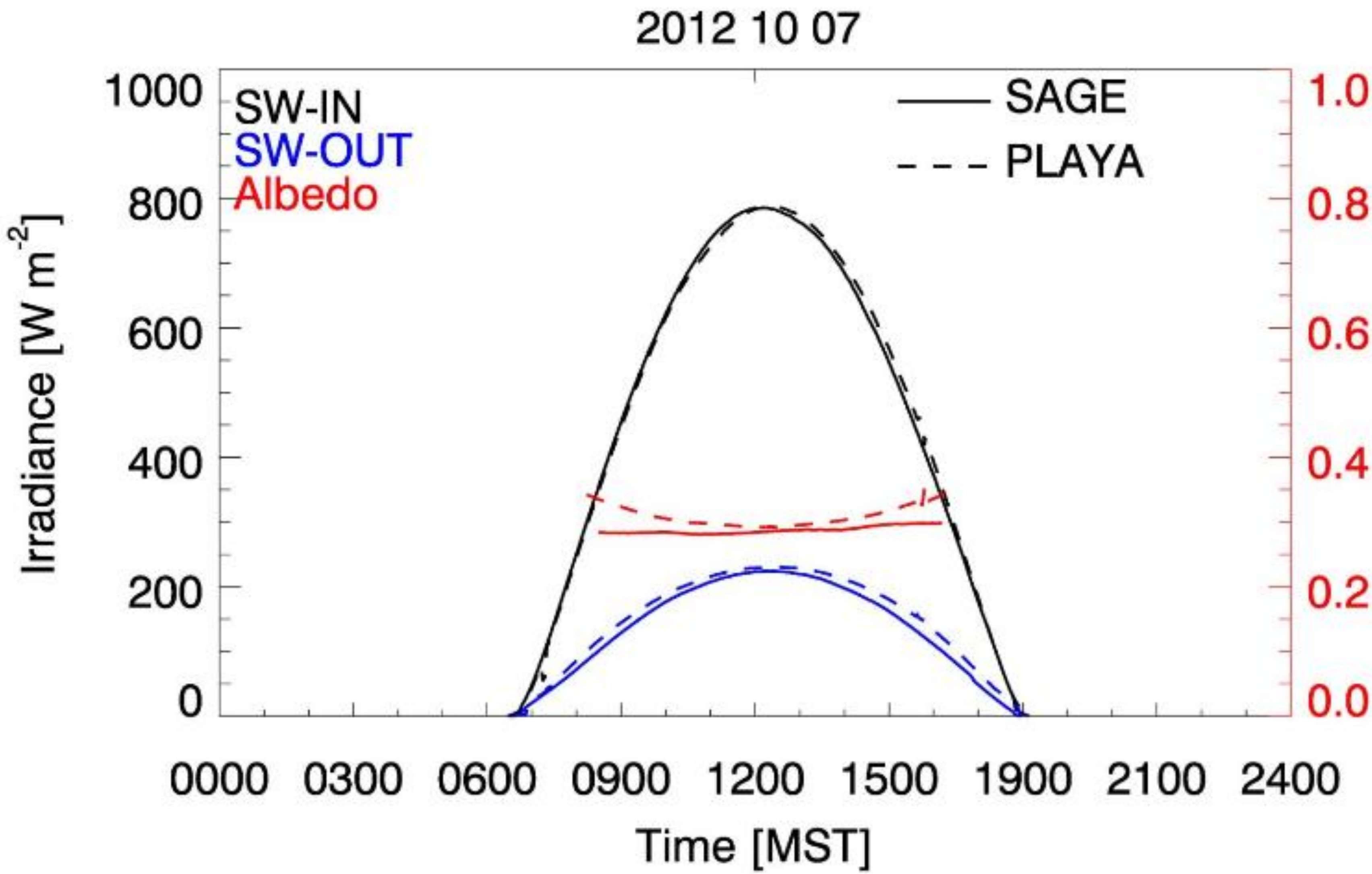




Both observations-based and model results are promising

OCTOBER 2200 UTC




2012 10 07
SW-IN
SW-OUT
Albedo
SAGE
PLAYA
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800
600
400
200
0
Irradiance [W m-2]
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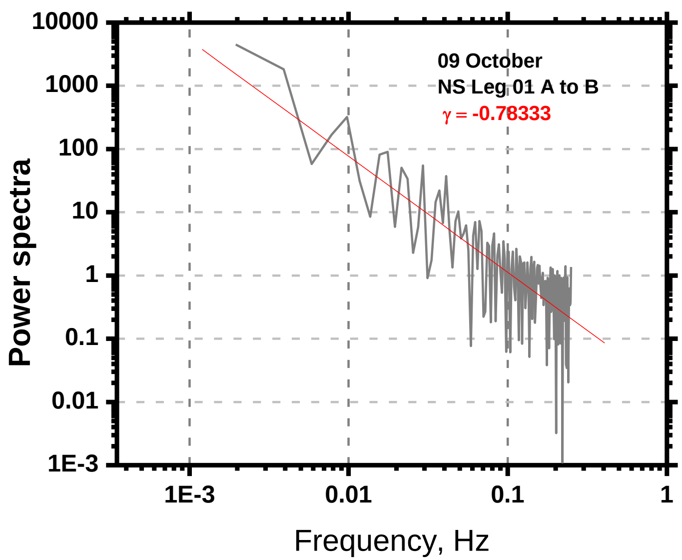
0.8
0.6
0.4
0.2
0.0
Albedo [-]
0000
0300
0600
0900
1200
1500
1900
2100
2400
Time [MST]

Further analyses on the spatial-variability of ABL depths

Davis, A., Marshak, A., Wiscombe, W., and Cahalan, R.: 1994, 'Multifractal characterizations of nonstationarity and intermittency in geophysical fields: Observed, retrieved, or simulated', J. Geophys. Res., 99, 8055-8072.



Multifractal characterizations of nonstationarity and intermittency ...
onlinelibrary.wiley.com › ... › Vol 99 Issue D4
by A Davis - 1994 - Cited by 294 - Related articles
Sep 21, 2012 - **Multifractal characterizations** of **nonstationarity** and **intermittency** in **geophysical fields**: **Observed**, **retrieved**, or **simulated**. Anthony **Davis**; Alexander **Marshak**; Warren **Wiscombe**; Robert **Cahalan**. Article first published online: **...** Volume **99**, Issue D4, pages **8055–8072**, 20 April **1994**. Additional Information **...**

The power-law dependence can be found from $S_F(f) \sim f^{-\gamma}$ where S_F is the power and f is the frequency and γ is the corresponding spectral exponent. The slope of $\ln[S_F(f)]$ versus $\ln[f]$ yields the value of γ. The value of γ determines whether the process is self-affined or not. If $1 < \gamma < 3$ then, the signal is a non-stationary process with stationary increments.

Three independent sets of data : One physical problem

Vertical velocity turbulence features around an isolated mountain

Topic 01: Using aircraft in-situ measurements, TODWL and ground-based Doppler lidar

Title: Combination of ground-based and airborne Doppler lidar measurements to investigate vertical velocity turbulence structures in the convective boundary layers

Practical Motivation: Illustrate the challenges of comparing a point sensor making measurements over time to a moving platform making similar measurements horizontally. **Three independent measures** of vertical velocity turbulence are available. How close they are using the technique developed by Lenschow et al. 2000 which has been used by numerous researchers.

Scientific issues/questions

1. Higher-order moments (e.g., variance, skewness) profiles from both platform
2. How does the turbulence feature change: spectra above the CBL, in the interfacial layer at the CBL top, and within the CBL?
3. Discussion on the non-stationarity that influences the turbulence features.
4. What is the impact of the different regimes of CBL: Deep and shallow CBL
5. Processes governing the differences in skewness profiles for two different scenarios (role of thermals or coherent structures). Note most of the literature found the convectively generated thermals play a big role in the variance compared to the background turbulence. What do we learn from our data?
6. Discussion on the turbulence statistics relevant to the length scale from two instruments (results obtained from integral time scale and integral length scale)

Multi-site multiple instruments: Two physical mechanisms

Impact of terrain heteoroginity on both morning and evening BL transitions

Topic 02: Impact of the terrain heterogeneity on both early morning and evening transitions

Practical Motivation: Demonstrate existing methodologies to define the EMT and the EET periods at selected sites that are perturbed by nearby complex terrains. Concurrent lidar/ceilometer measurements help attribute the erosion of the SBL inversion as well as the development of the SCBL (shallow convective boundary layer)

Scientific issues/questions

1. Defining both early morning and evening transition periods: searching and selecting a method among the methods available in the literature (inflection point in the near-surface temperature, boundary layer dilution effect in the water vapor mixing ratio, crossover by the SHF, and onset by stability parameters z/L etc.)
2. How do the collocated lidar/ceilometer measurements assist the attribution of the transition periods?
3. Applying a unified definition on the measurements obtained at three/four sites, can we illustrate the impact of flow features (on EET and EMT) that are generated due to the mountains in the area?

Preliminary findings and outlook

- Observations in the low isolated mountain showed that while the CBL structure in the morning is highly inhomogeneous, the afternoon CBL structure tends to be horizontally homogeneous

- Two different behaviors of the ABL: evolution of a CBL that follows the underlying terrain towards a CBL which seems to be unaffected by the terrain in homogeneity.

- Intra-temporal variability : CL31 would provide another mean of spatial variability

- RS-based observations also confirm the spatial variability in the ABL depths (WE gradient)