CHARACTERIZATION OF THE MORNING TRANSITION FROM DOWNSLOPE TO UPSLOPE WINDS OVER A GENTLE SLOPE

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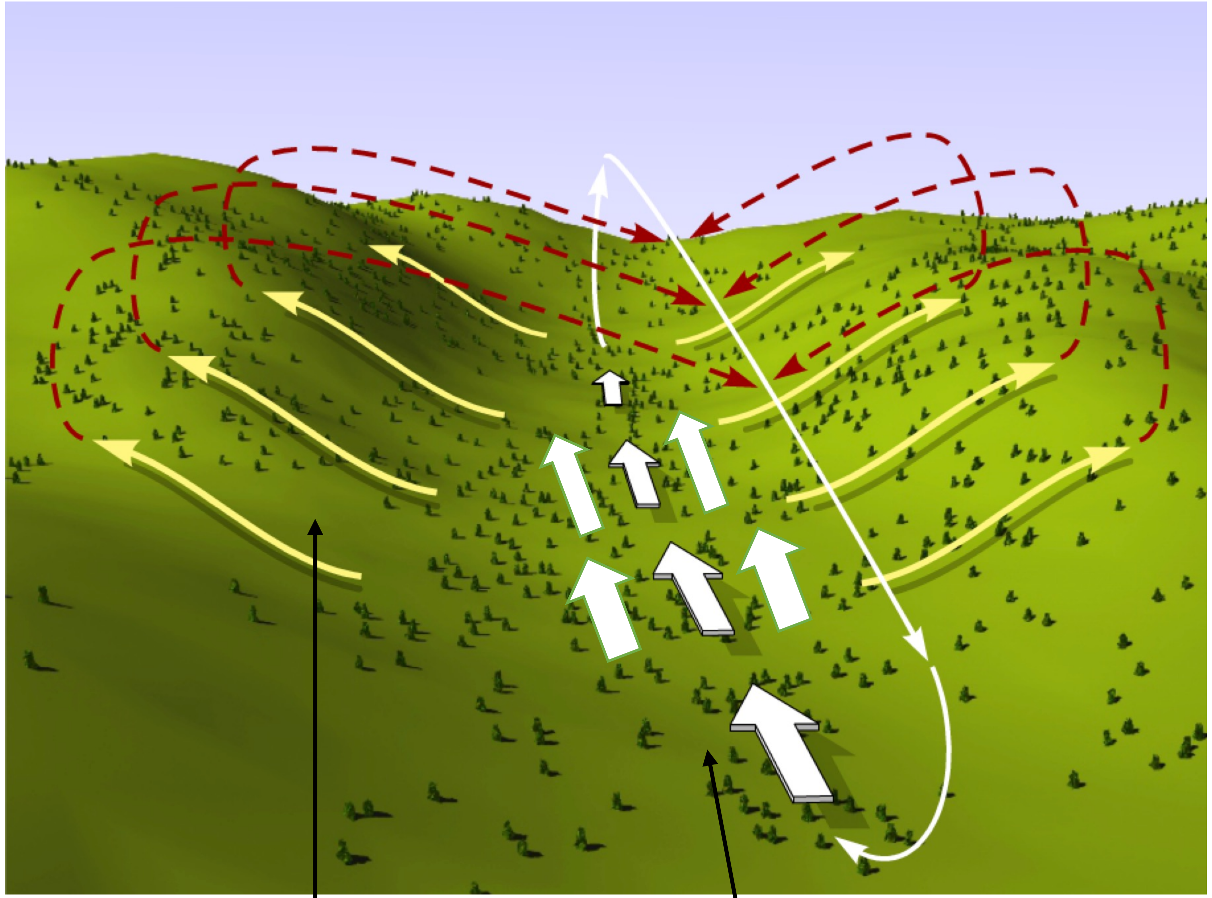
OUTLINE

- Analysis of the dataset and investigation of the **Surface Energy Budget** over a gentle slope.
- Identification of a **criterion** for the identification **of slope wind days.**
- **Characterization of the morning transition** using selected case studies.
- Identification of the main patterns of **erosion of the nocturnal inversion** in the valley at the foot of the slope.
- Connection between the erosion of the nocturnal inversion in the valley and the **mechanisms driving the morning transition.**
- Test of **an analytical model** (Zardi and Serafin, 2015) for the reproduction of the transition.

THERMALLY DRIVEN CIRCULATION

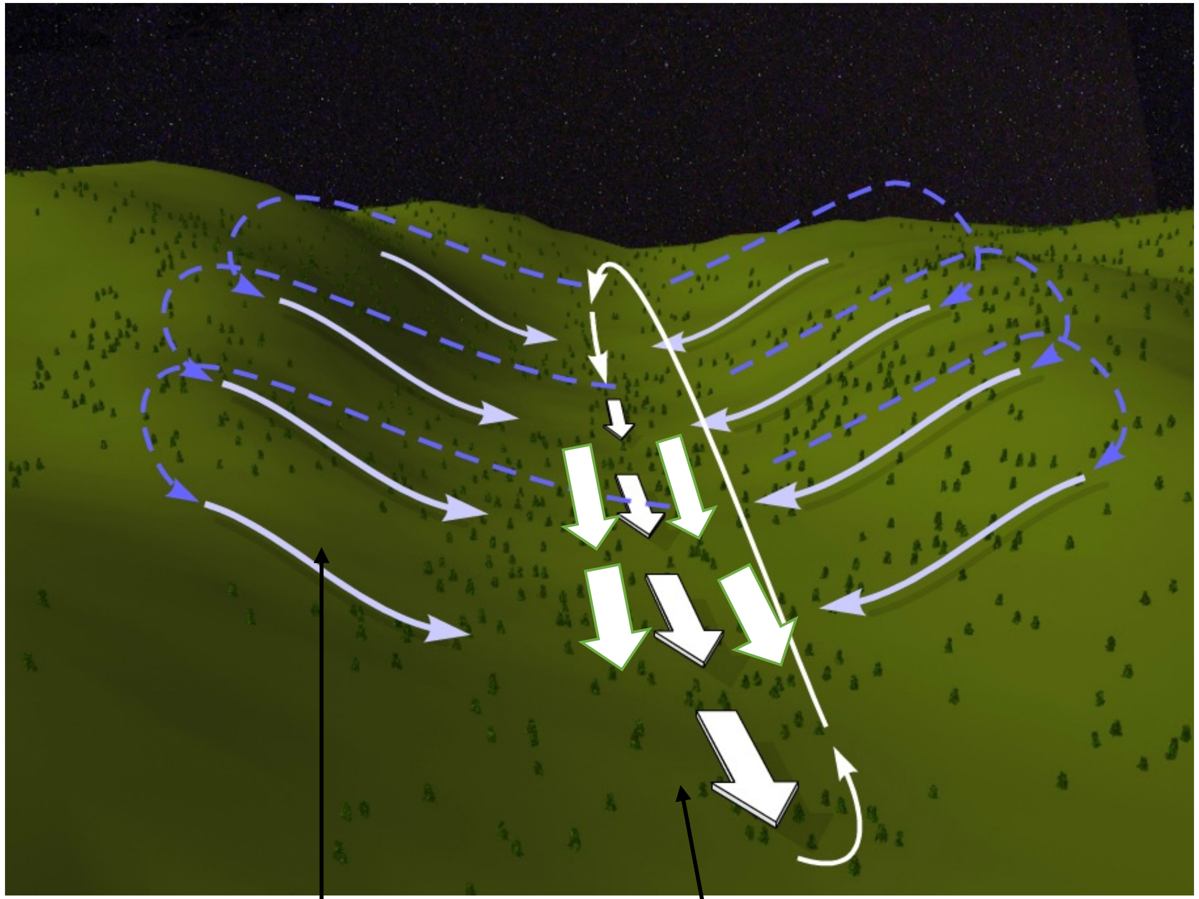
DAYTIME


Penn State University

slope winds

valley winds

NIGHTTIME



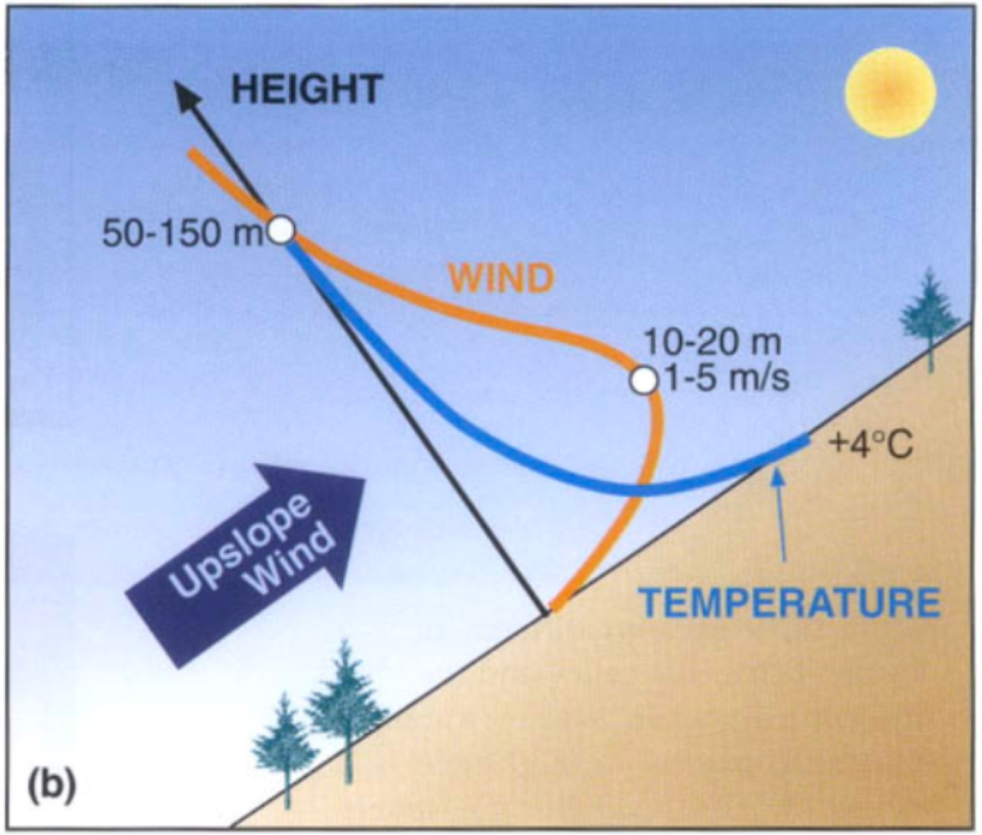
slope winds

valley winds

SLOPE WINDS

DAYTIME

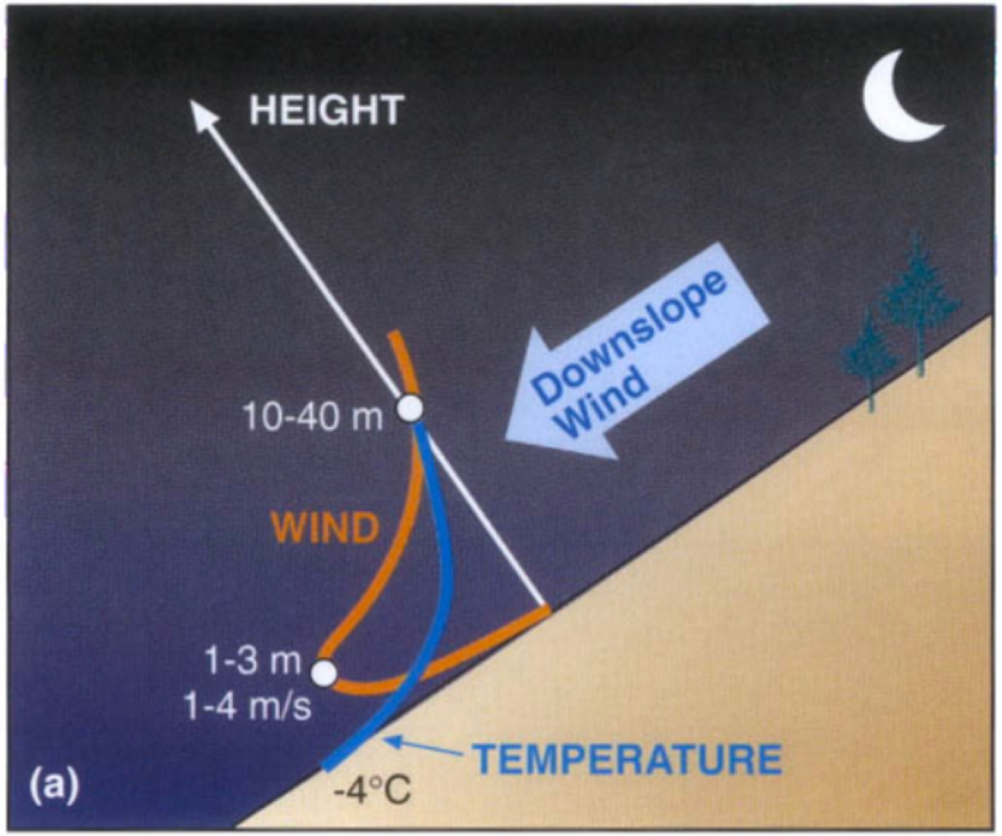
NIGHTTIME



Whiteman 2000

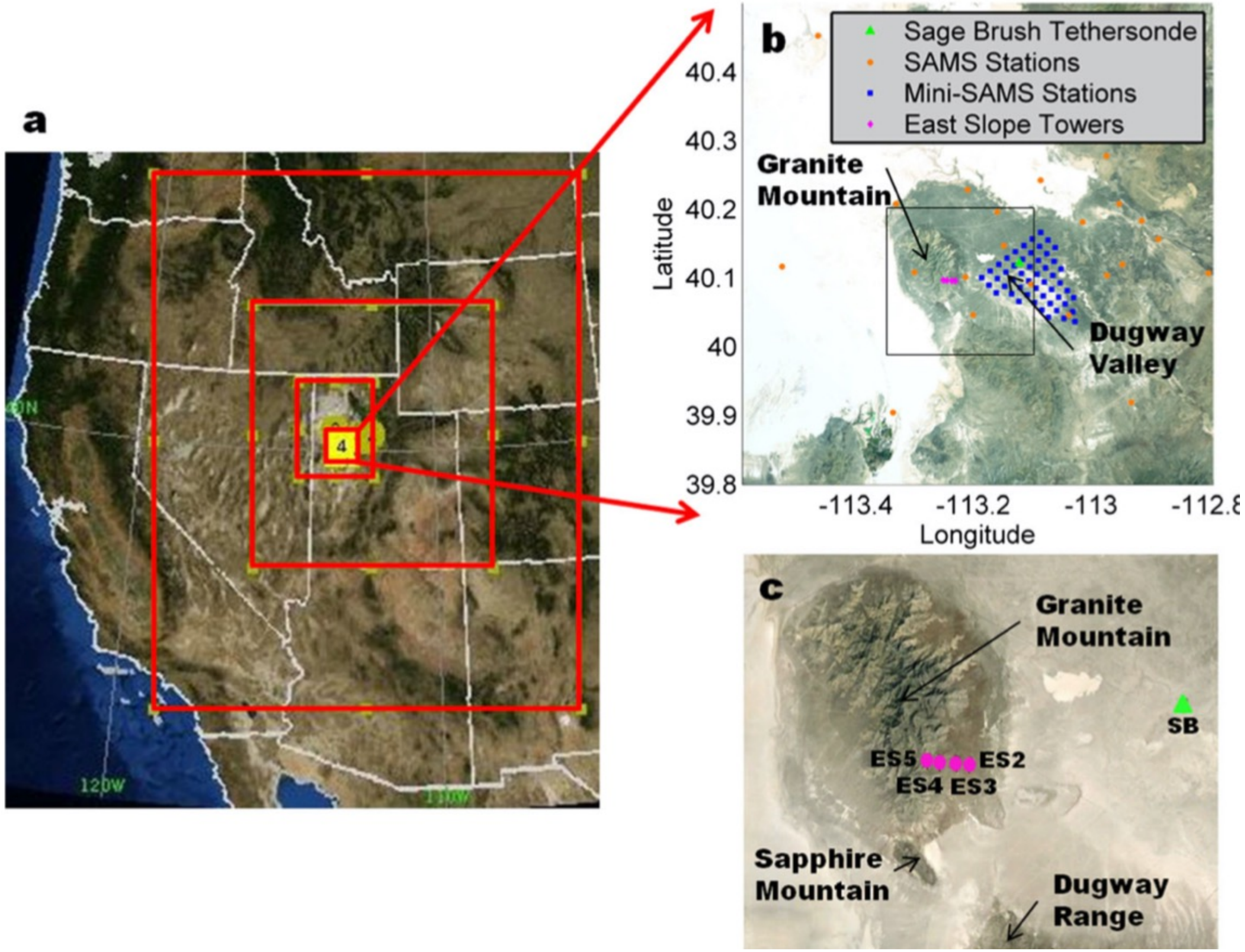
Morning transition @ sunrise

Evening transition @ sunset



THE MATERHORN EXPERIMENT

Data analyzed are collected in the Mountain Terrain Atmospheric Modeling and Observations (**MATERHORN**) experiment which took place in Salt Lake Desert, in Utah (USA) between fall 2012 and spring 2013.
The experimental field and its localization is represented in figure.

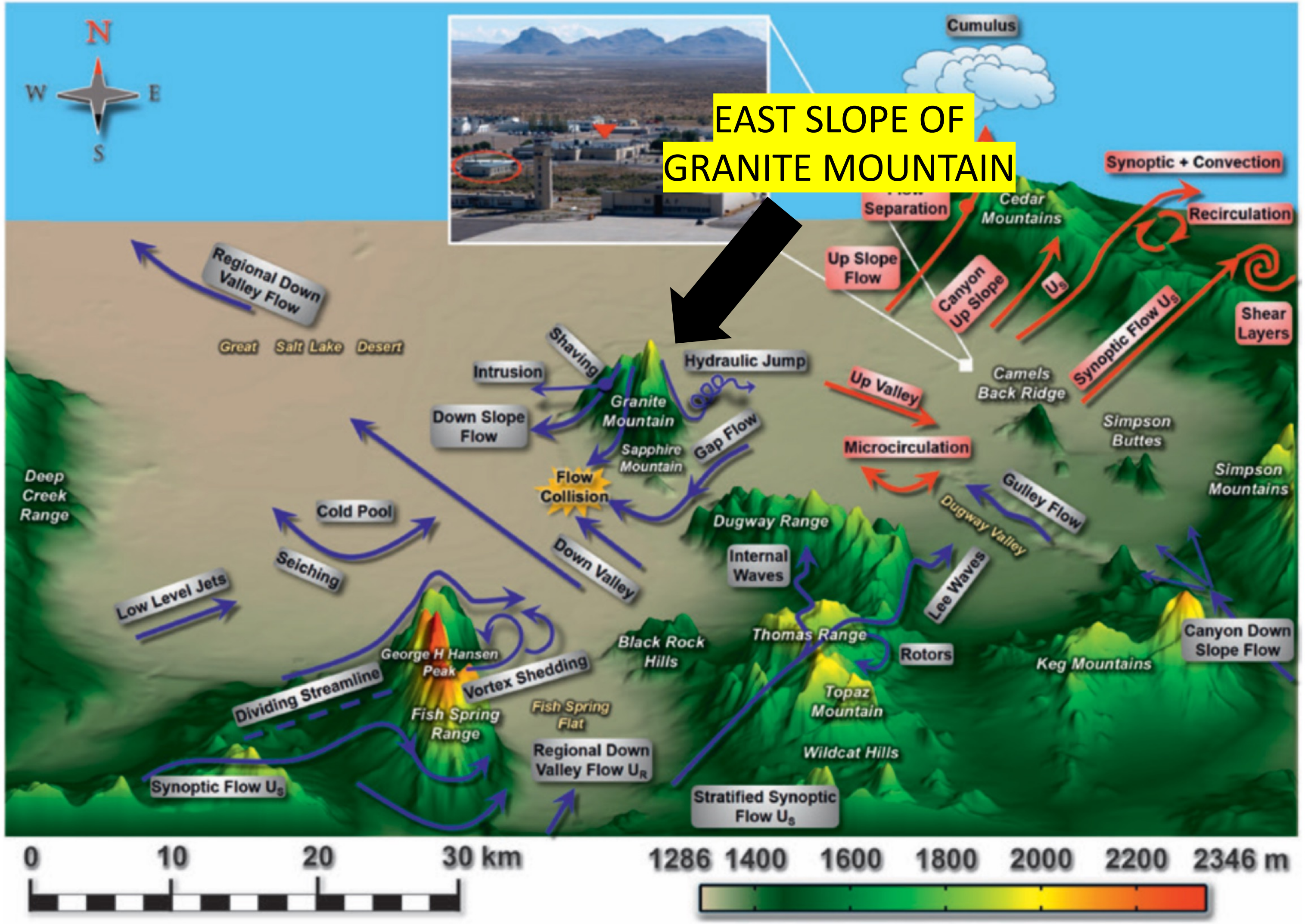


Fernando et al, 2015

THE MATERHORN EXPERIMENT

The experimental field and the relative atmospheric phenomenon observed are reported in figure.

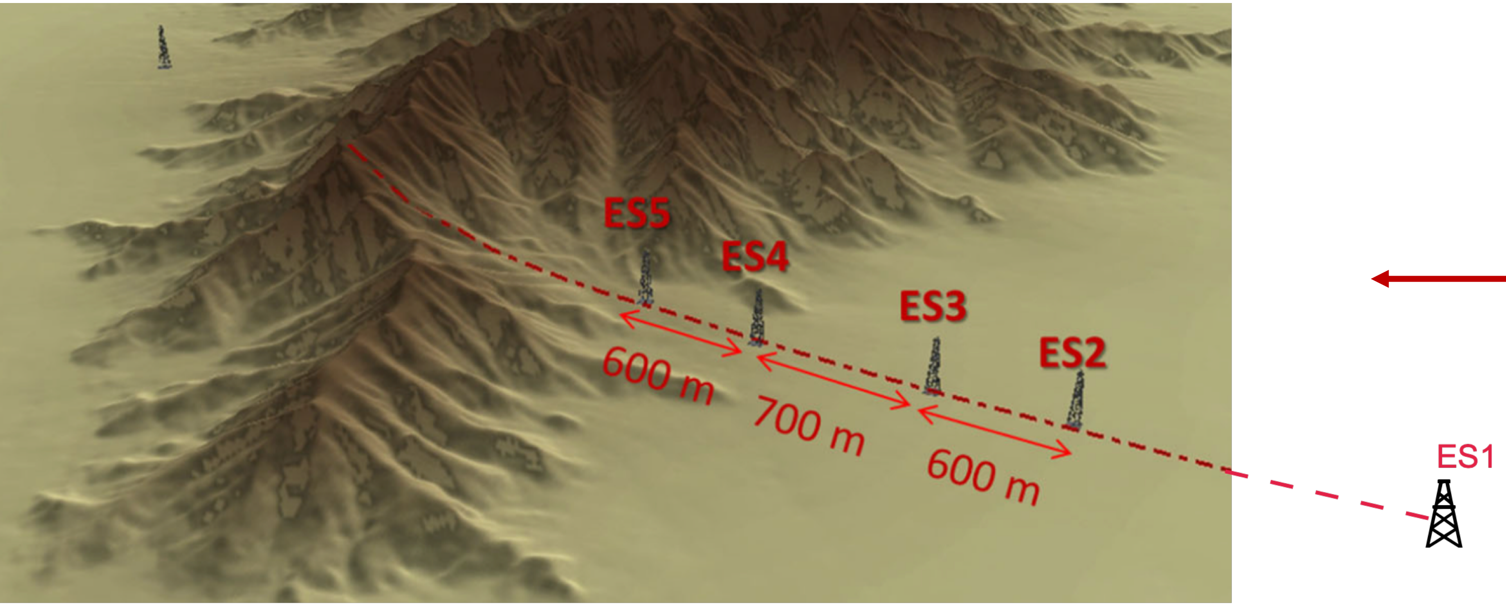
The analysis performed focused on the **East Slope of Granite Mountain** and in the valley (**Dugway Playground**) at its foot.

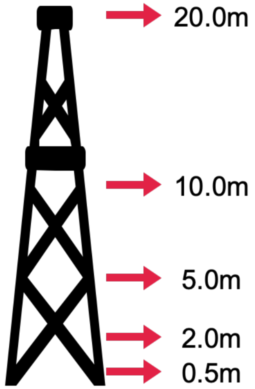


Fernando et al, 2015

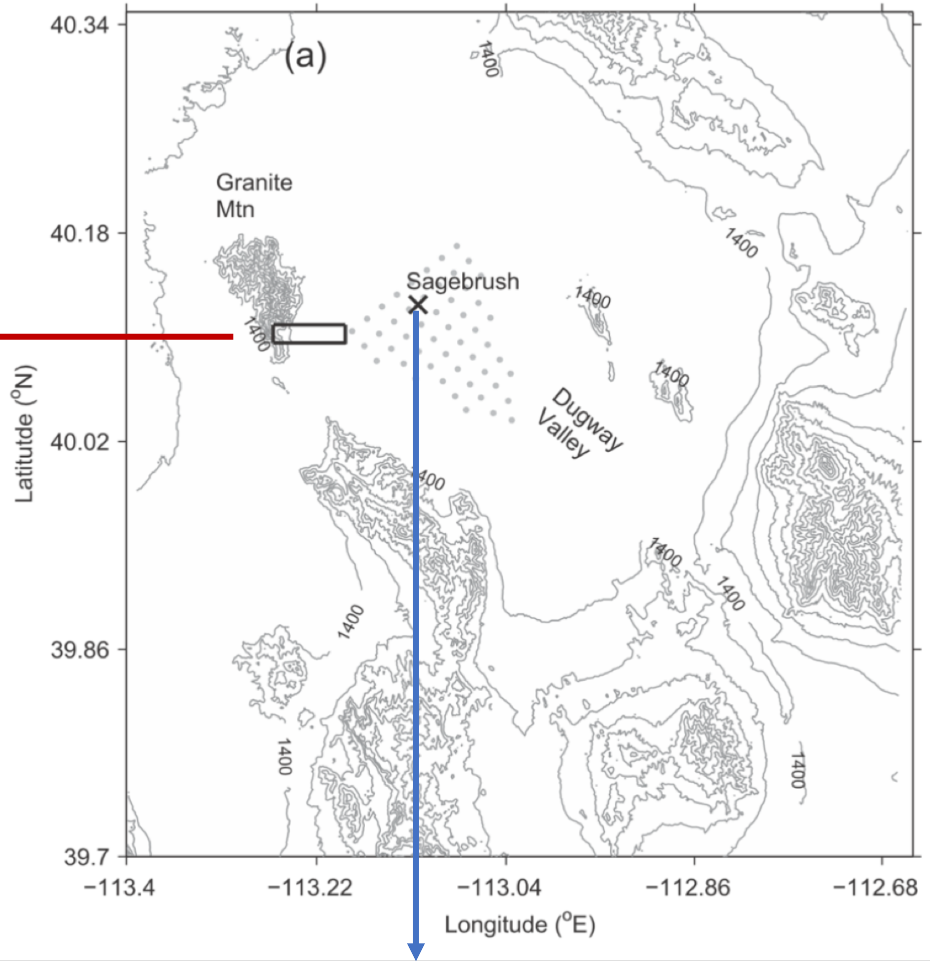
INSTRUMENTATION

East Slope Meteorological Towers





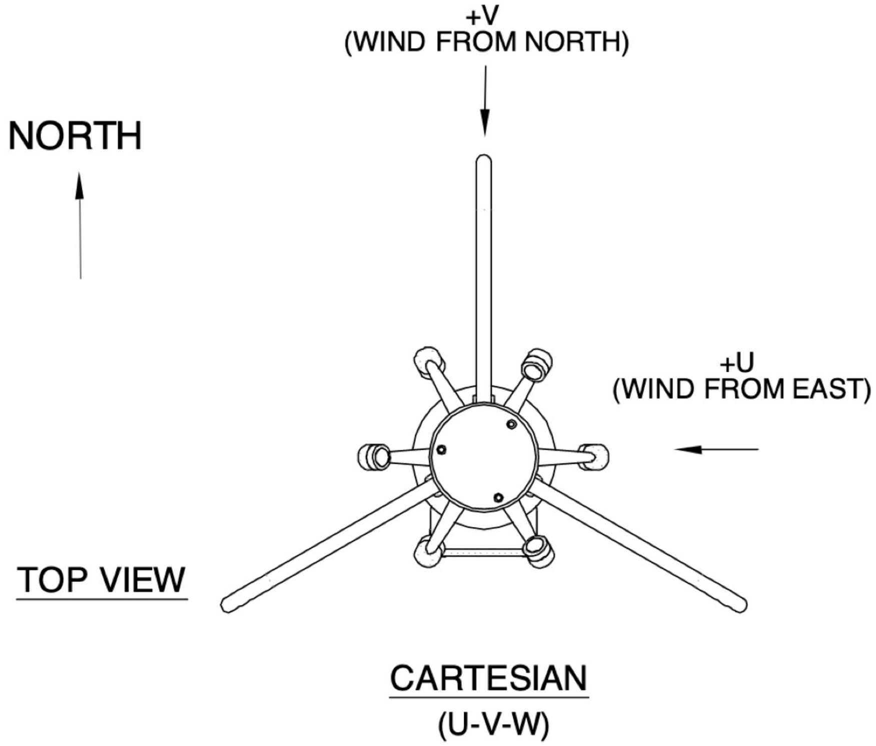
Sonic anemometers, hygrometers, thermometers + Radiometers, soil heat flux plates



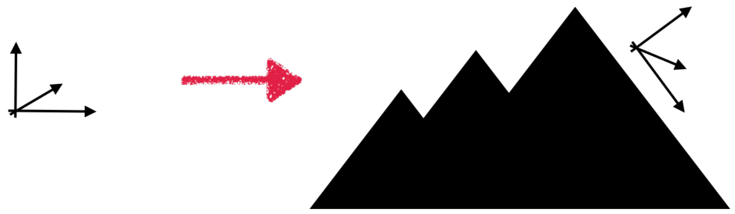
Launching Site for Tethersonde
Valley meteorological towers
Radars

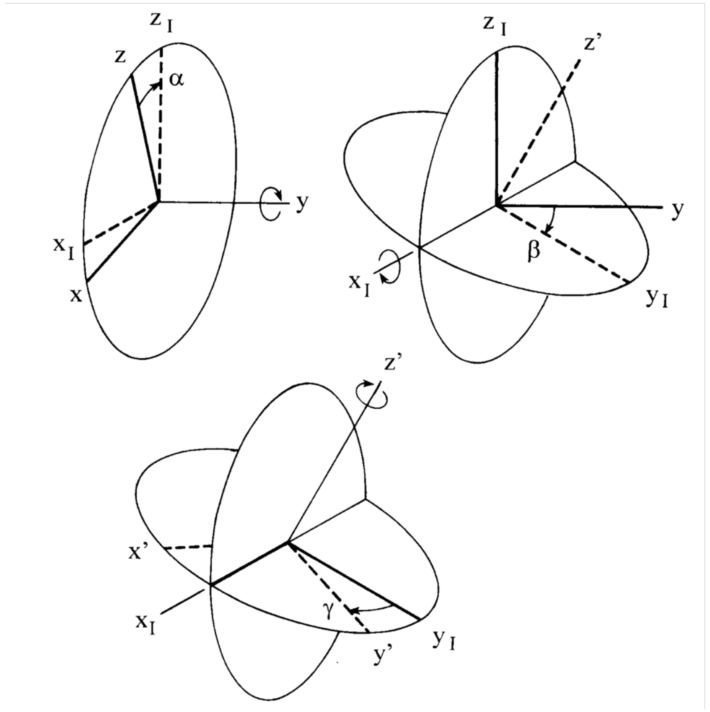
DATA PROCESSING FOR SONIC ANEMOMETERS

Sonic anemometers orientation



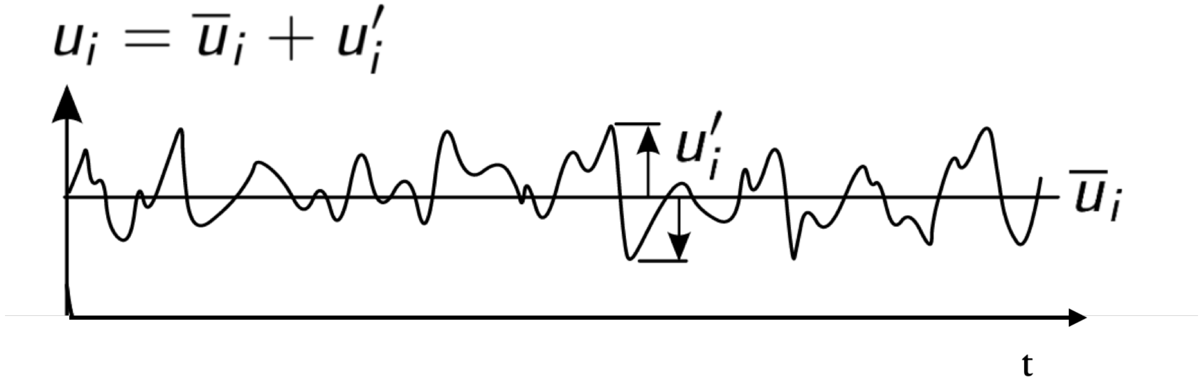
Double rotation for slope flows



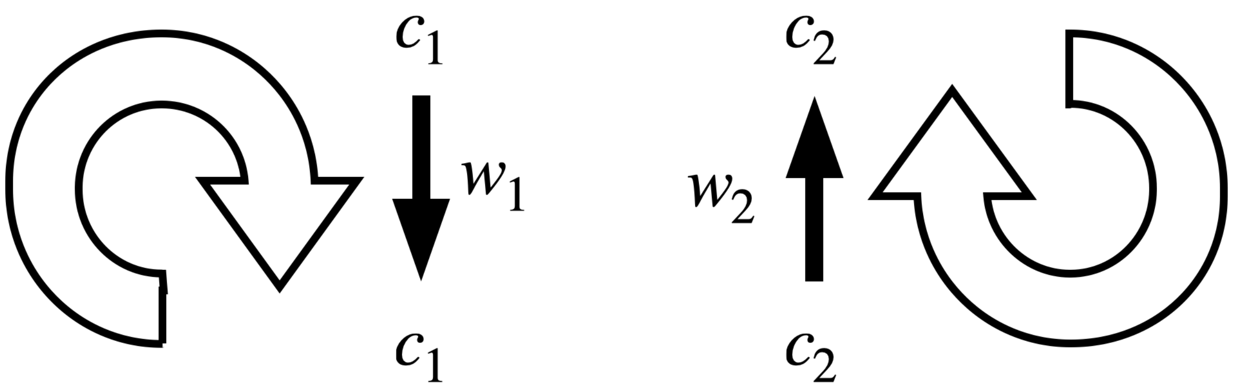


TURBULENT COMPONENT ANALYSIS

Reynolds decomposition



Eddy covariance method



CRITERION FOR THE IDENTIFICATION OF SLOPE WIND DAYS

Tested criterion – originally meant for valley wind days (Giovannini et al, 2017)

- the global daily solar radiation has to be > 50% of the maximum daily radiation measured in the month, to identify days of significant heating of the valley atmosphere,
- wind blowing up-valley with wind speed > 2m/s for at least two hours between local 09 and 19
- wind blowing down-valley or quiescent for most of the period between local 00 and 08
- diurnal pressure range between 2 and 8 hPa, thresholds selected on the base of a preliminary screening.

<u>Not working for slope wind days selection!</u>

Proposed criterion – specifically meant for the detection of slope wind days

- Wind measured @700 hPa U < 5 m/s
- Average net radiation of the day > Average net radiation of the month
- Average SW radiation of the day > average SW radiation of the month
- Average pressure of the day > average pressure of the month

<u>Stronger constraint on synoptic conditions!</u>

CRITERION FOR THE IDENTIFICATION OF SLOPE WIND DAYS

Proposed criterion – specifically meant for the detection of slope wind days

- Wind measured @700 hPa U < 5 m/s
- Average net radiation of the day > Average net radiation of the month
- Average SW radiation of the day > average SW radiation of the month
- Average pressure of the day > average pressure of the month

Comparison between the two criteria

Spring dataset

Day	Giovannini	Obs	New
30/04			
1/05	X		
2/05	X	X	X
3/05	X	X	X
4/05			
5/05			
6/05			
7/05			
8/05			
9/05	X	X	X
10/05	X	X	X
11/05	X		
12/05	X	X	X
13/05			
14/05			
15/05			
16/05			
17/05	X		
18/05	X		
19/05	X		
20/05	X		
21/05	X	X	X
22/05	X		
23/05	X		X
24/05	X		
25/05	X		
26/05	X		
27/05	X		
28/05			

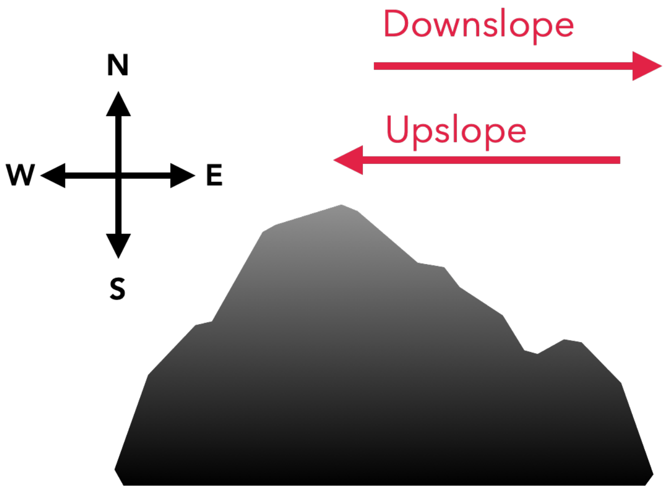
Fall dataset

Day	Giovannini	Obs	New
29/09		X	X
30/09	X		
1/10	X		
2/10	X		
3/10			
4/10			
5/10	X	X	X
6/10	X	X	X
7/10	X		
8/10	X		
9/10	X		
10/10	X		
11/10	X		
12/10			
13/10			
14/10	X	X	X
15/10	X		
16/10	X		
17/10			
18/10		X	X
19/10			X
20/10	X		
21/10	X		
22/10	X		
23/10			
24/10			
25/10			
26/10			
27/10			

CASE STUDIES SELECTION

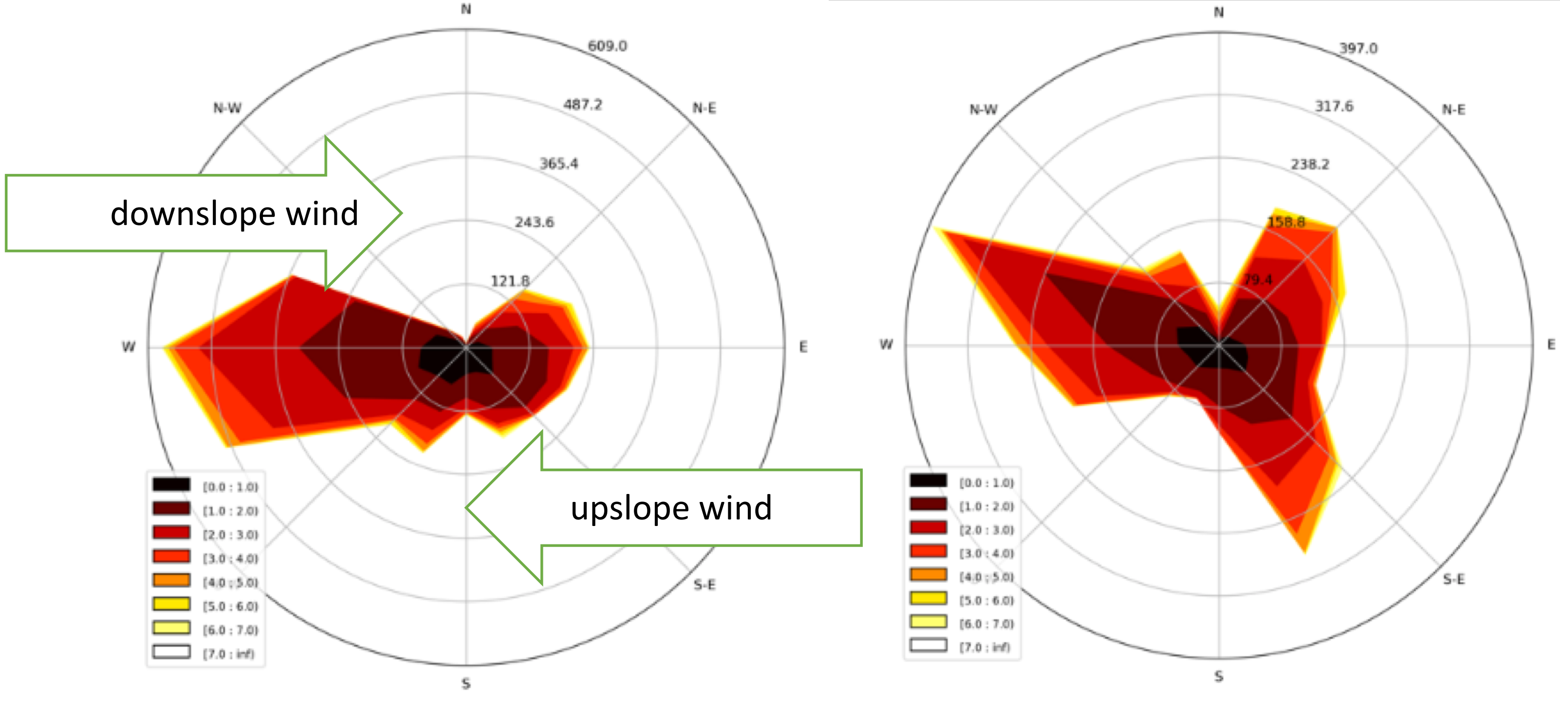
Selected case studies

- October, 14, 2012
- October, 18, 2012
- September, 29, 2012
- May, 2, 2013
- May, 16, 2013



East Slope Granite Mountain

Seasonal averages

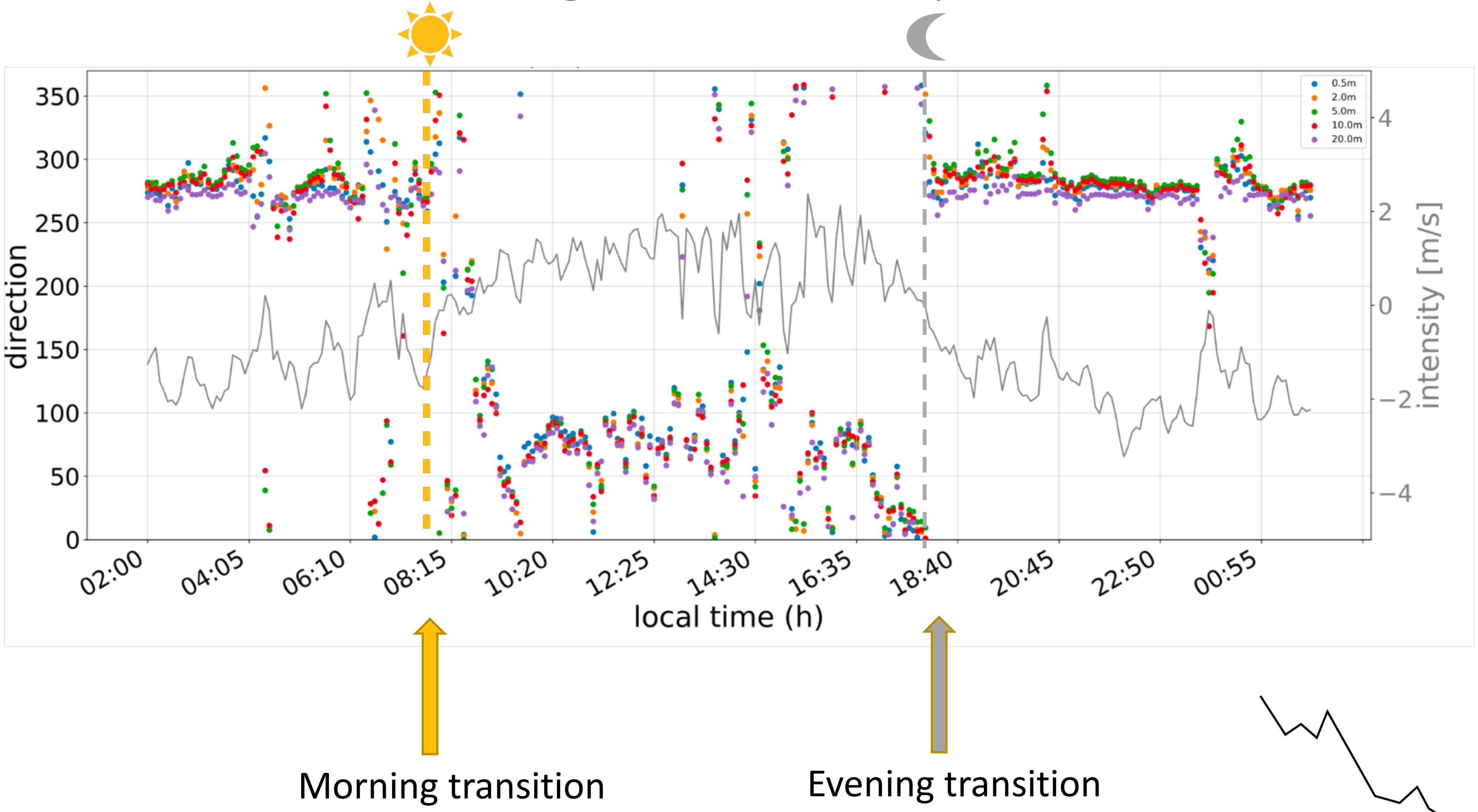


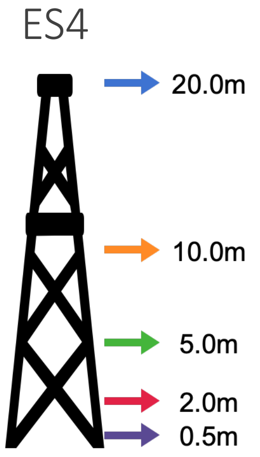
(a) Fall (b) Spring

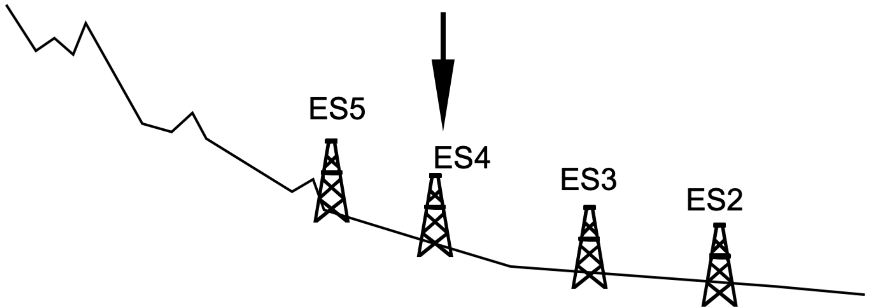
Both in the spring and fall datasets, the downwind component is statistically stronger and more consistent. The diurnal upslope motion is particularly disturbed in the spring dataset.

DAILY EVOLUTION OF METEOROLOGICAL VARIABLES

18/10/2012: average wind intensity and direction

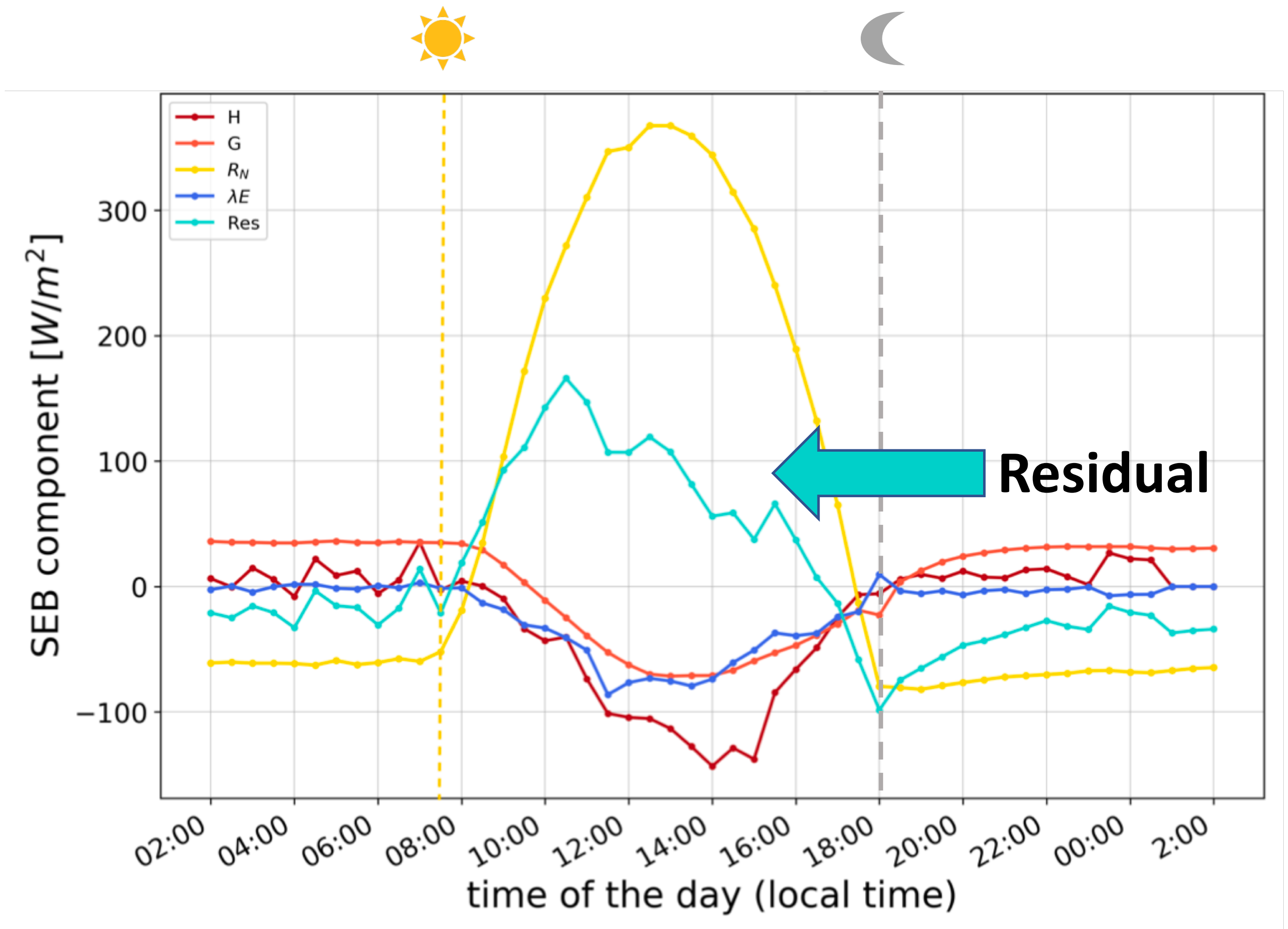


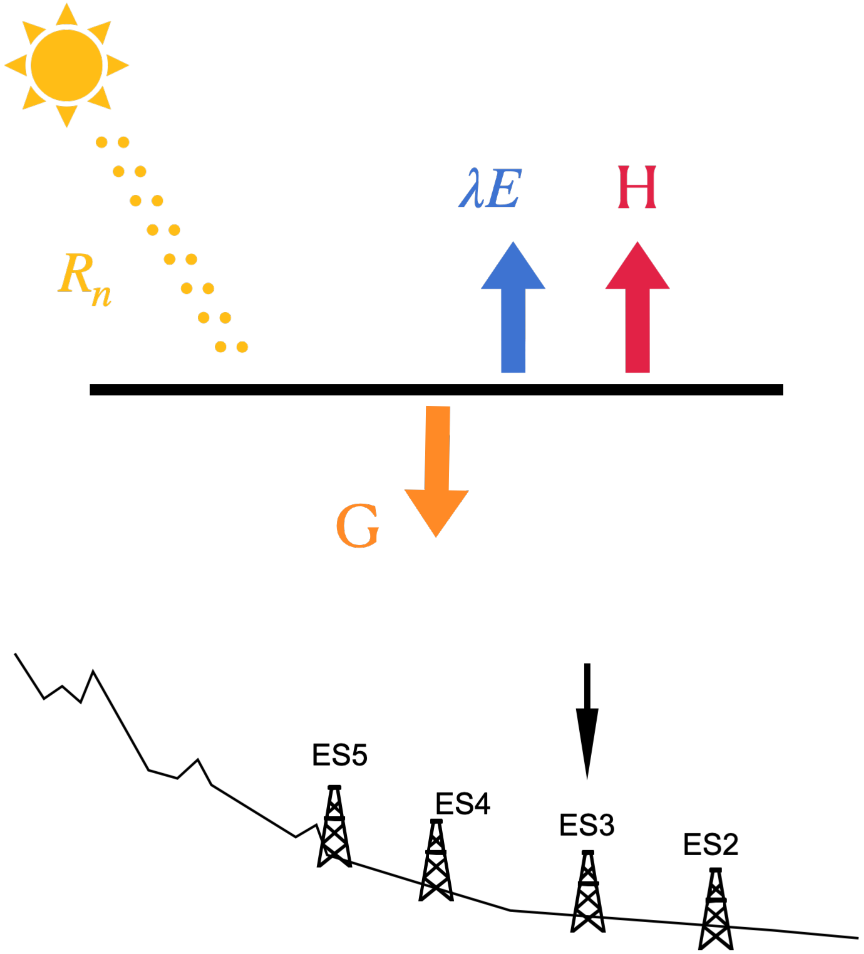




DAILY EVOLUTION OF METEOROLOGICAL VARIABLES

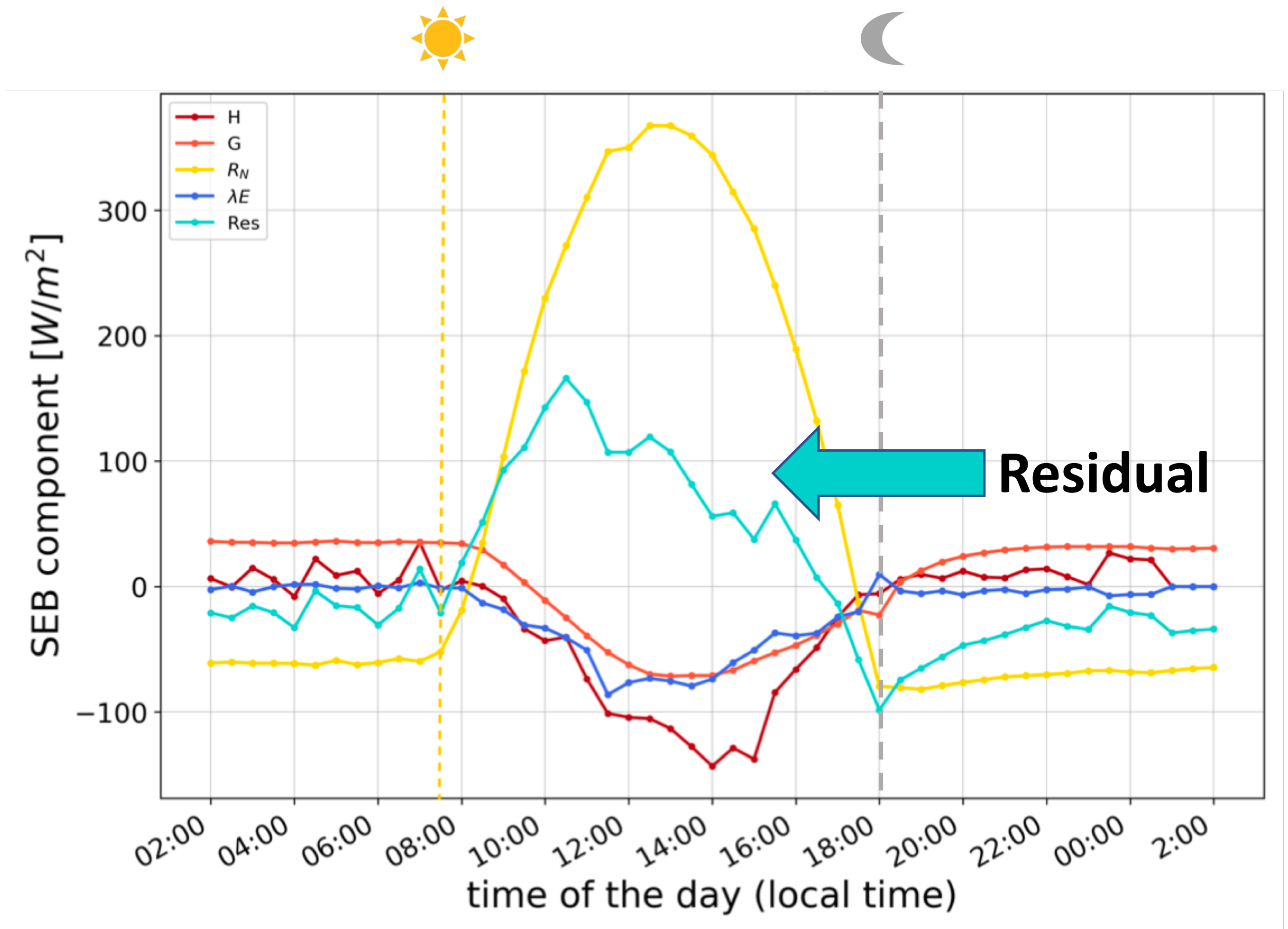
18/10/2012: components of the surface energy balance





DAILY EVOLUTION OF METEOROLOGICAL VARIABLES

18/10/2012: components of the surface energy balance

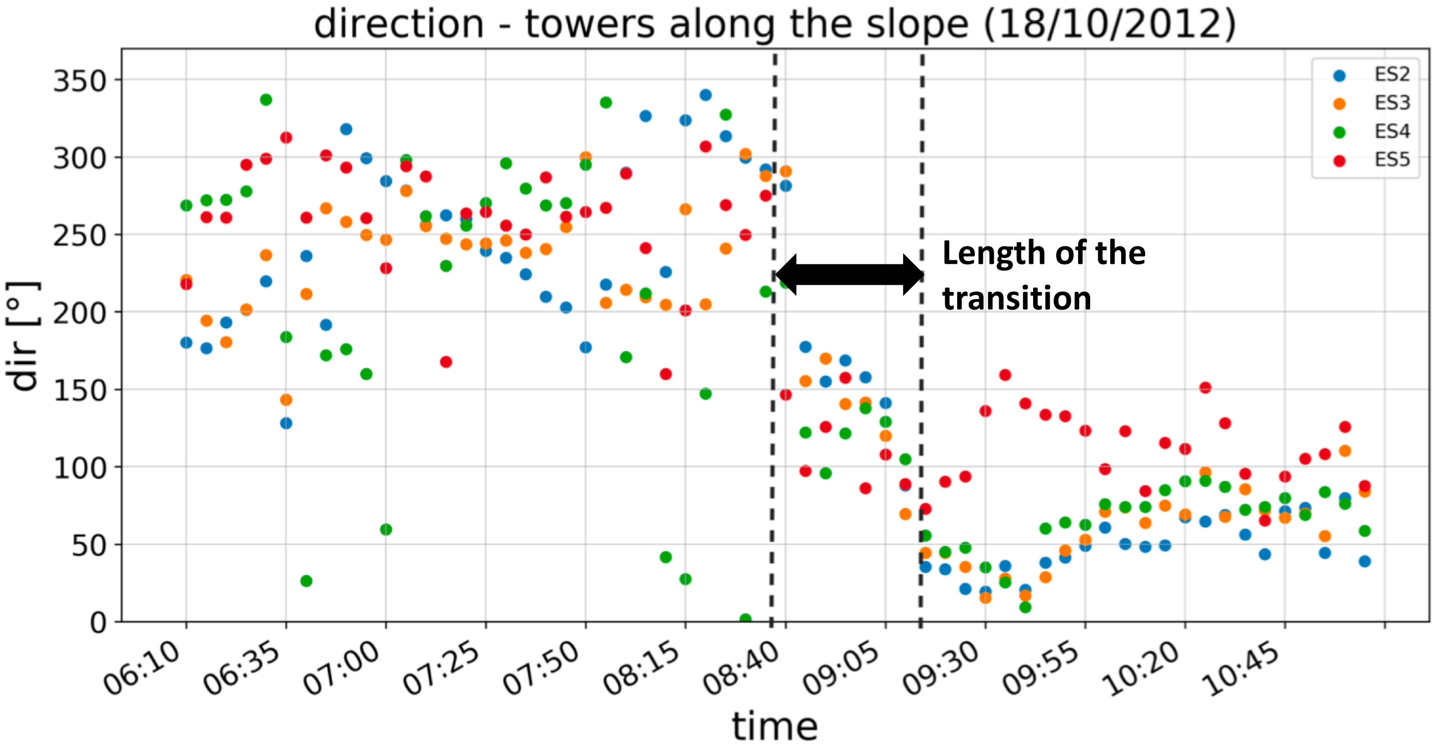


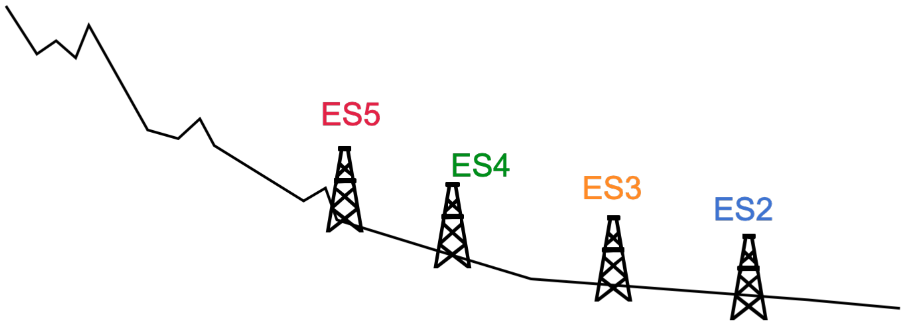
The surface energy budget does not close.

Additional terms have been tested to close the budget but still no missing component has been identified.

CHARACTERIZATION OF THE MORNING TRANSITION

- Test of **different definitions**
- **Length**: extreme variability (from 5 to 75 minutes) and seasonality (longer in fall case studies)
- **Radiation**: the initiation coincides with the net radiation becoming positive.
- **Propagation**: propagation of the transition is observed both along the slope and along the vertical direction.

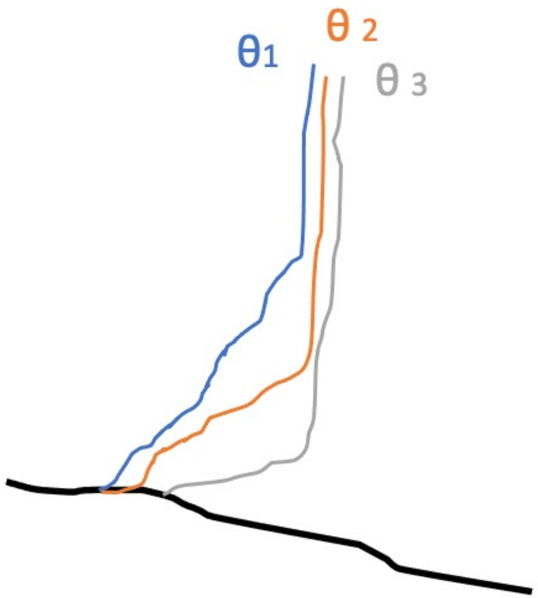


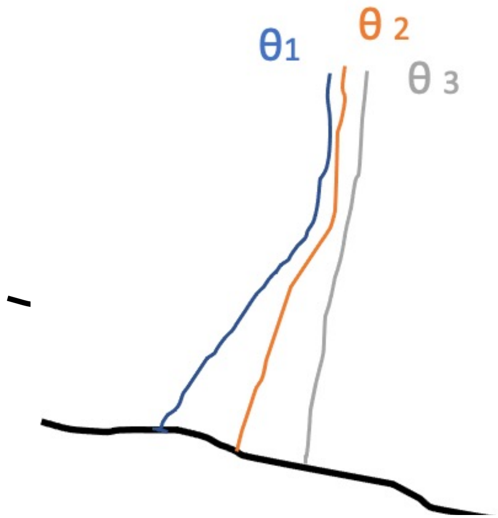


DILUTION OF THE KATABATIC LAYER

Two main mechanisms:

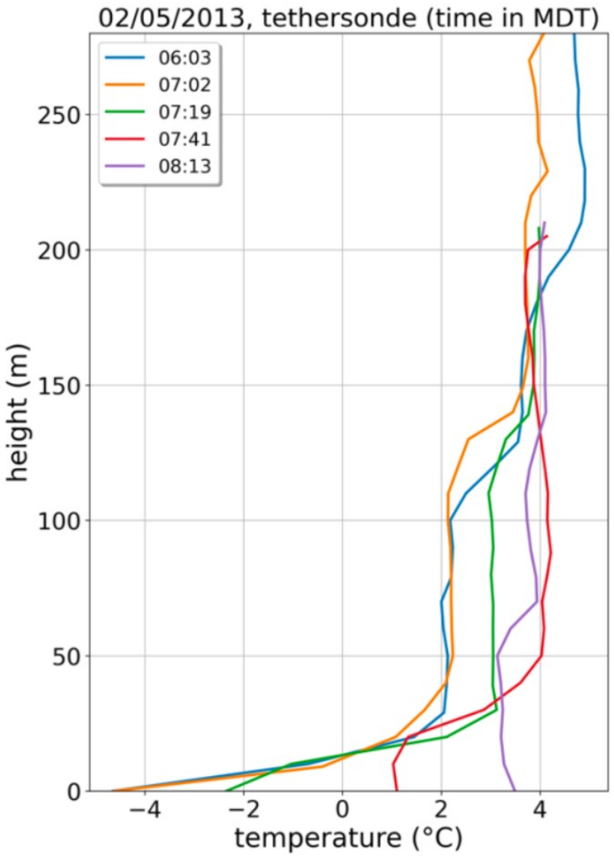
- Warming of the air from above through *mixing* → top-down destruction
- Warming of surface air from below due to *surface heating* → destruction from below



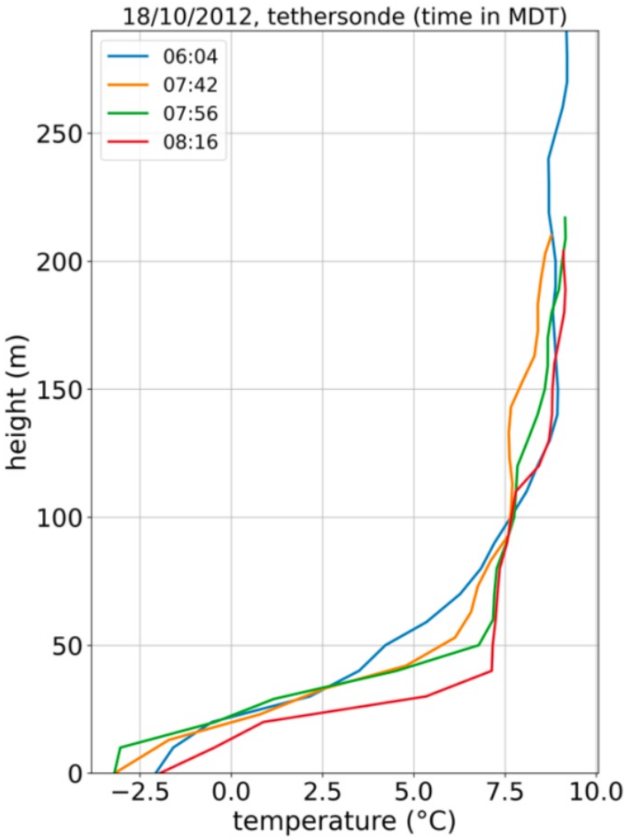


EROSION OF THE NOCTURNAL INVERSION

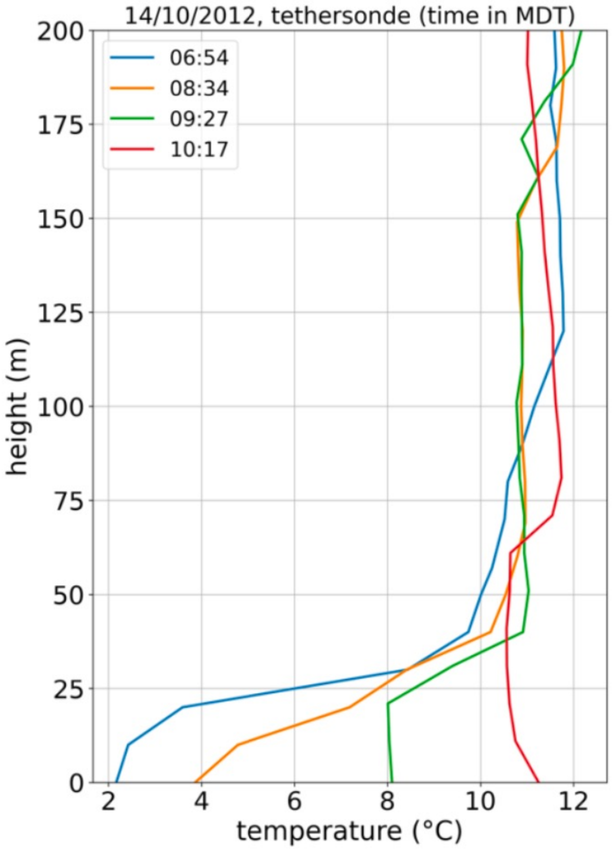
Pattern 1: upward growth of a convective boundary layer



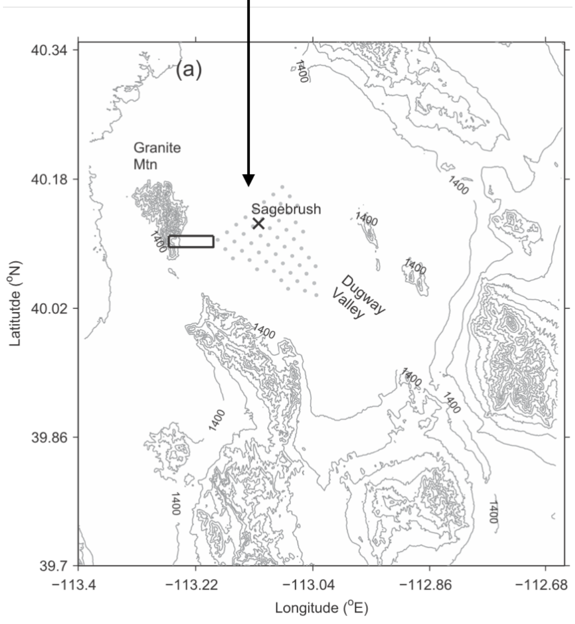
Pattern 2: descent of the inversion top



Pattern 3: mix of the two processes

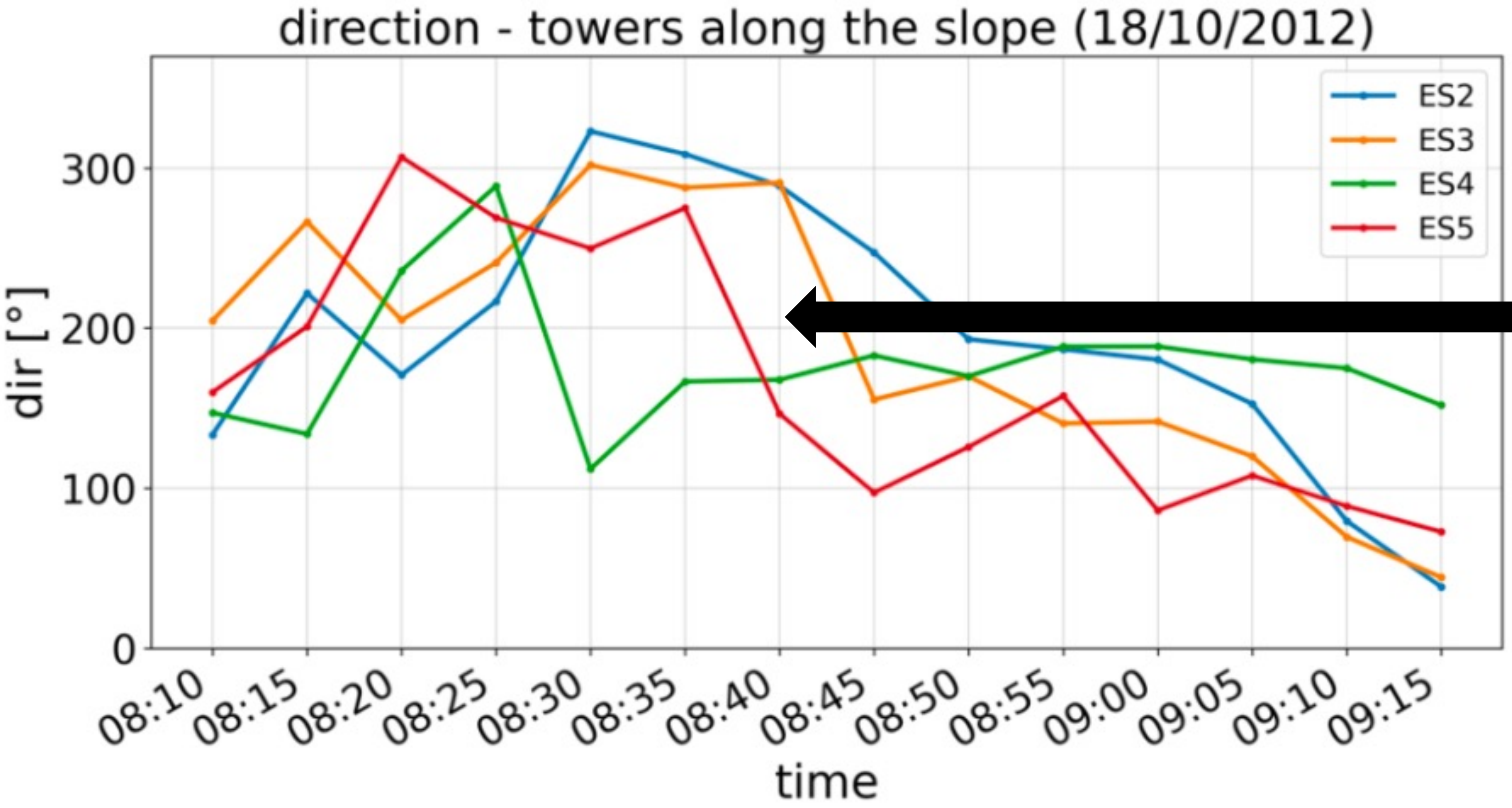


Data measured from Sagebrush with tethered balloons

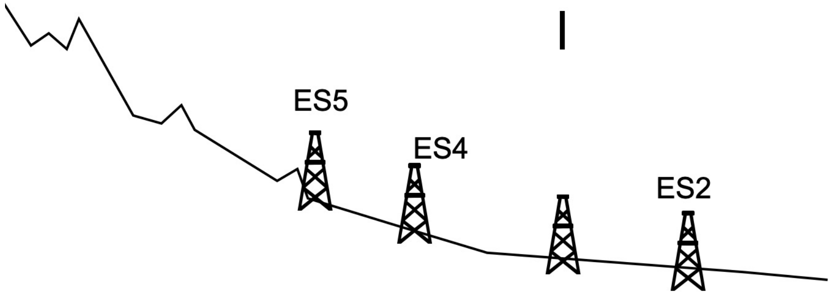


TOP-DOWN DESTRUCTION

Erosion of the nocturnal inversion due to descent of the inversion top → Morning transition due to top down destruction



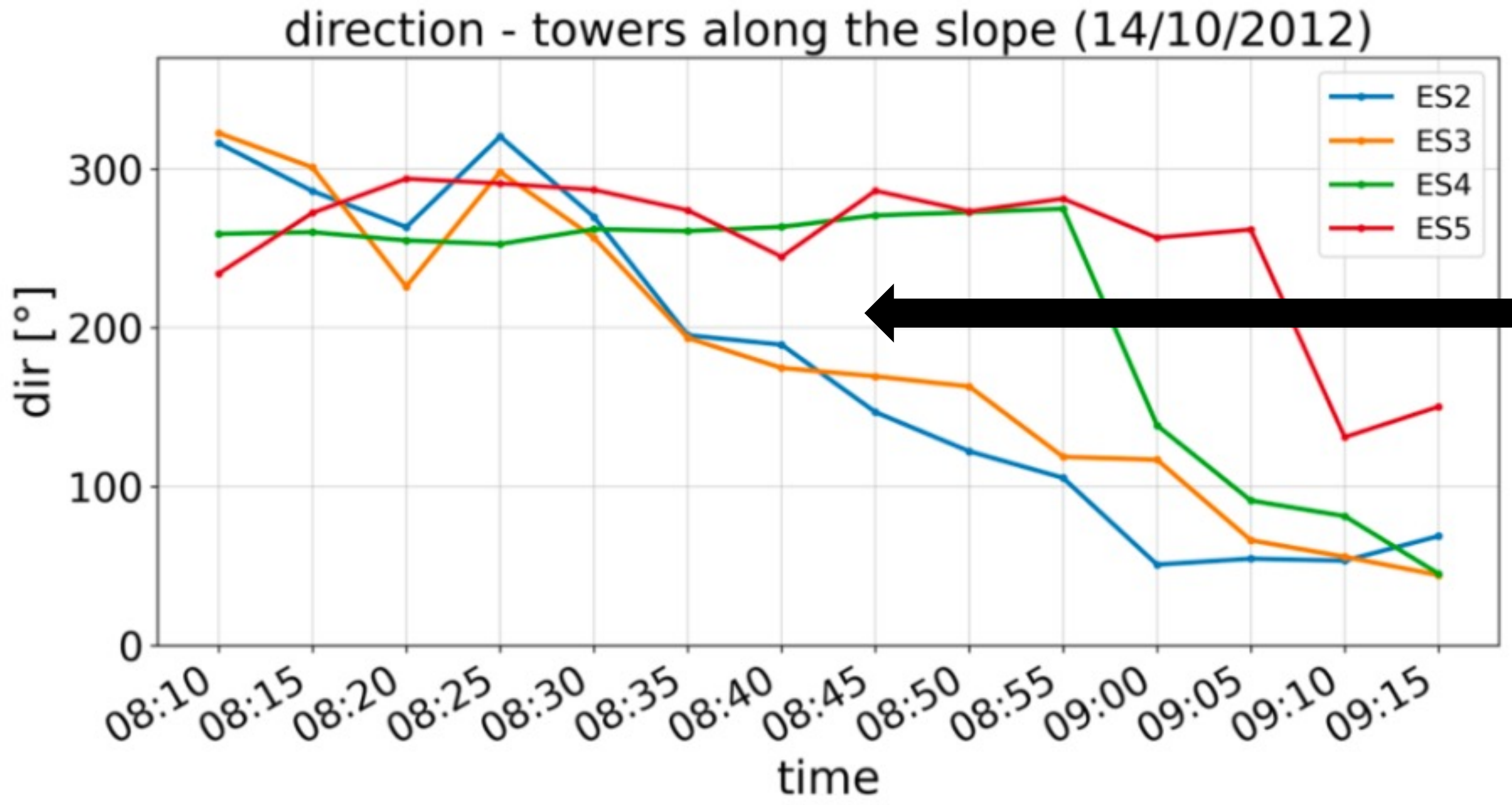
Towers on the **upper** part of the slope are the first ones to experience transition



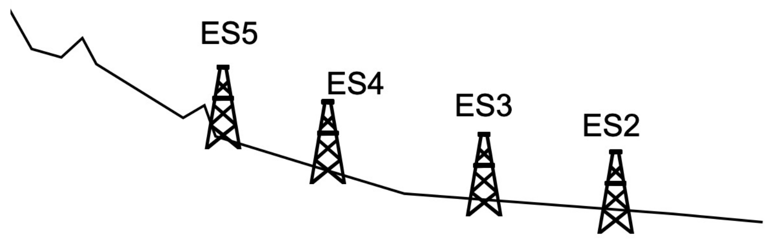
DESTRUCTION FROM BELOW

Erosion of the nocturnal inversion due to upward growth of the CBL

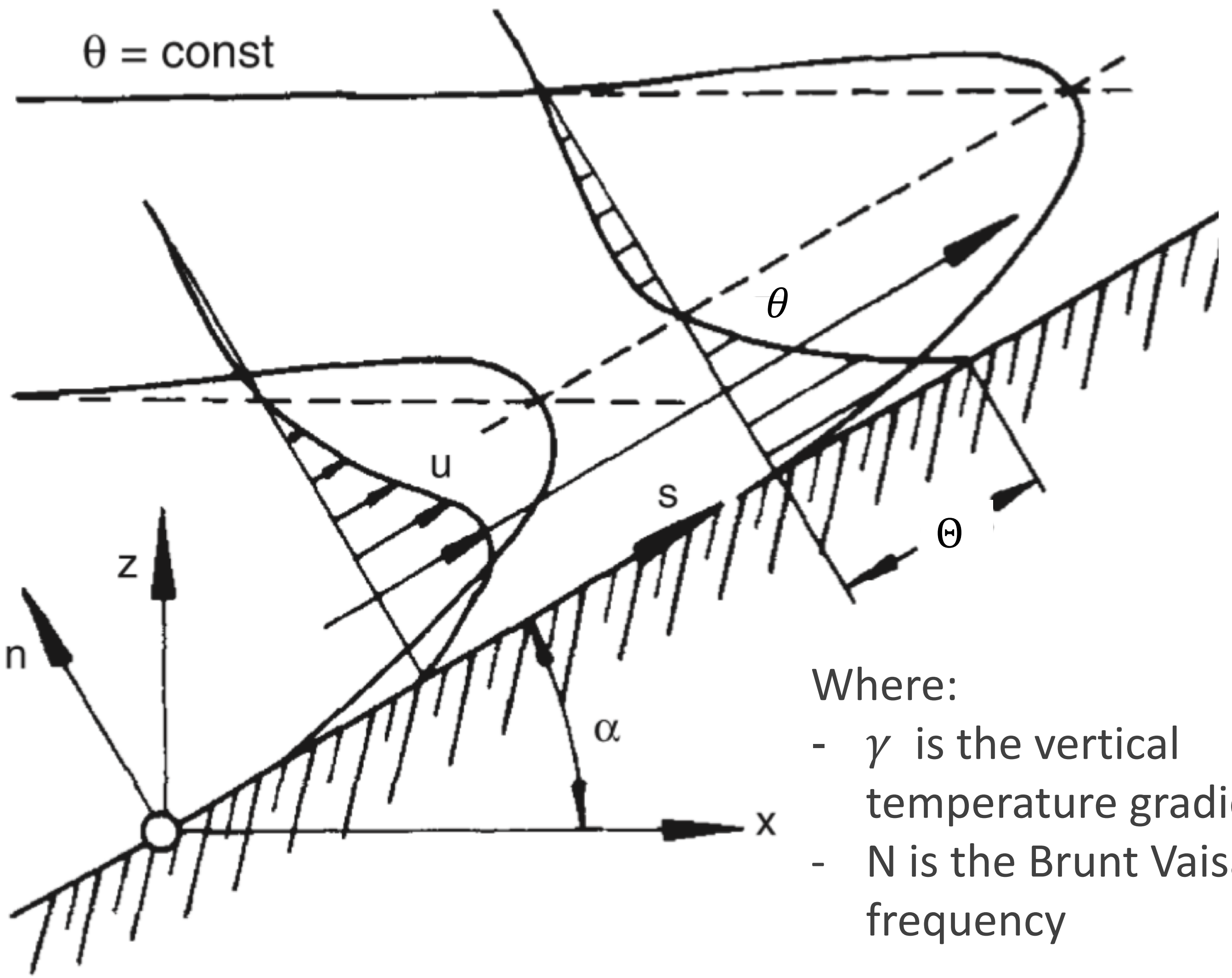
Morning transition due to destruction from below



Towers on the **lower** part of the slope are the first ones to experience transition



ANALYTICAL MODEL (ZARDI AND SERAFIN, 2015)



Zardi and Serafin, 2015

Where:

- γ is the vertical temperature gradient
- N is the Brunt Vaisala frequency

Governing equations

$$\frac{\partial \overline{u}}{\partial t} = \overline{\theta}\frac{N^2}{\gamma}\sin\alpha + K_m\frac{\partial^2 \overline{u}}{\partial n^2}$$

$$\frac{\partial \overline{\theta}}{\partial t} = \overline{u}\gamma\sin\alpha + K_h\frac{\partial^2 \overline{\theta}}{\partial n^2}$$

with

$$K_m = K_h = K$$

$$\overline{\theta}(0,t) = \Theta\sin(\omega t + \phi)$$

The solution can follow two regimes:

> ***critical***, when $N_\alpha \leq \omega$

> ***subcritical***, when $N_\alpha > \omega$

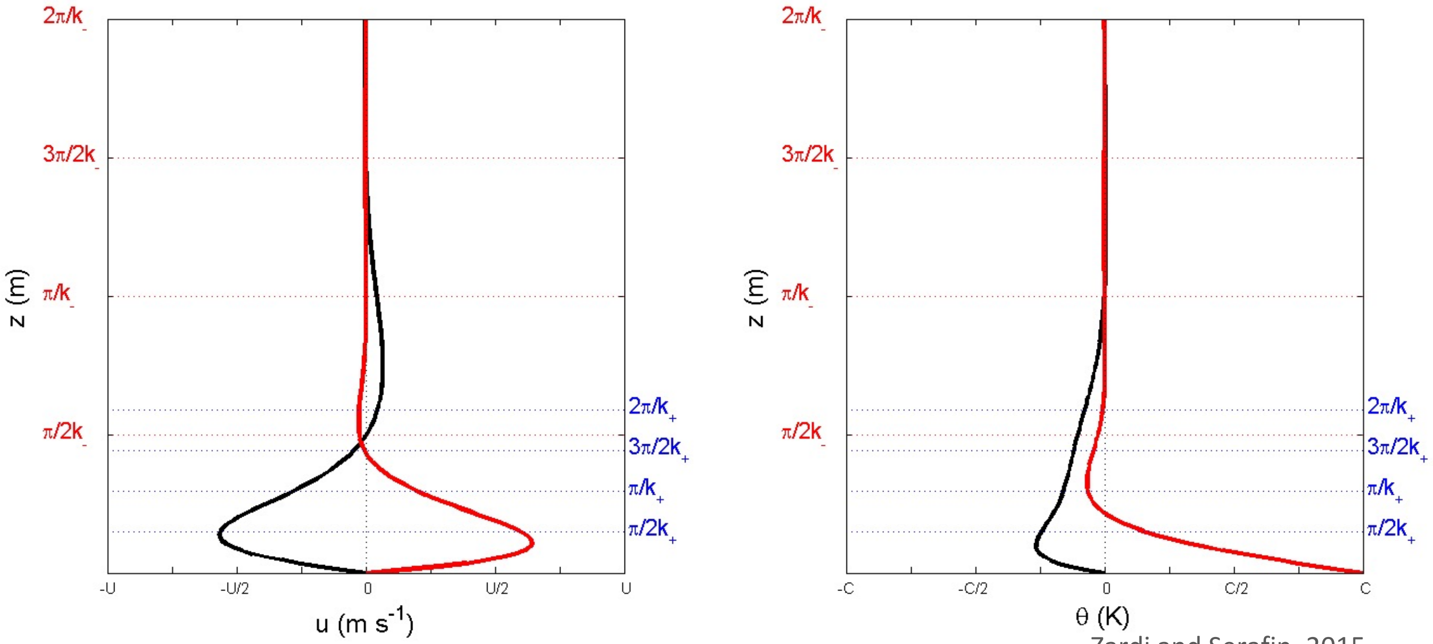
SUB-CRITICAL SOLUTION

$$\bar{u} = \frac{\Theta}{2}\frac{N}{\gamma}[\exp(-\frac{n}{l_+})\cos(\omega t - \frac{n}{l_+}) - \exp(-\frac{n}{|l_-|})\cos(\omega t - \frac{n}{|l_-|})]$$

$$\bar{\theta} = \frac{\Theta}{2}[\exp(-\frac{n}{l_+})\sin(\omega t - \frac{n}{l_+}) + \exp(-\frac{n}{|l_-|})\sin(\omega t - \frac{n}{|l_-|})]$$

Where: $\omega_\pm = N_\alpha \pm \omega, l_\pm = \sqrt{\frac{2K}{\omega_\pm}}$ and $\eta = \frac{n}{2\sqrt{Kt}}$

ϕ_p, $\gamma = 0.0014$ K m^{-1}, $\alpha = 0.5°$, $\theta_{00} = 288$ K, $\omega = 1/86400$ s^{-1}, K = 3 m^2 s^{-1}, C = 5 K, U = 12.16 ms^{-1}, $\omega t/2\pi = 0.0000$



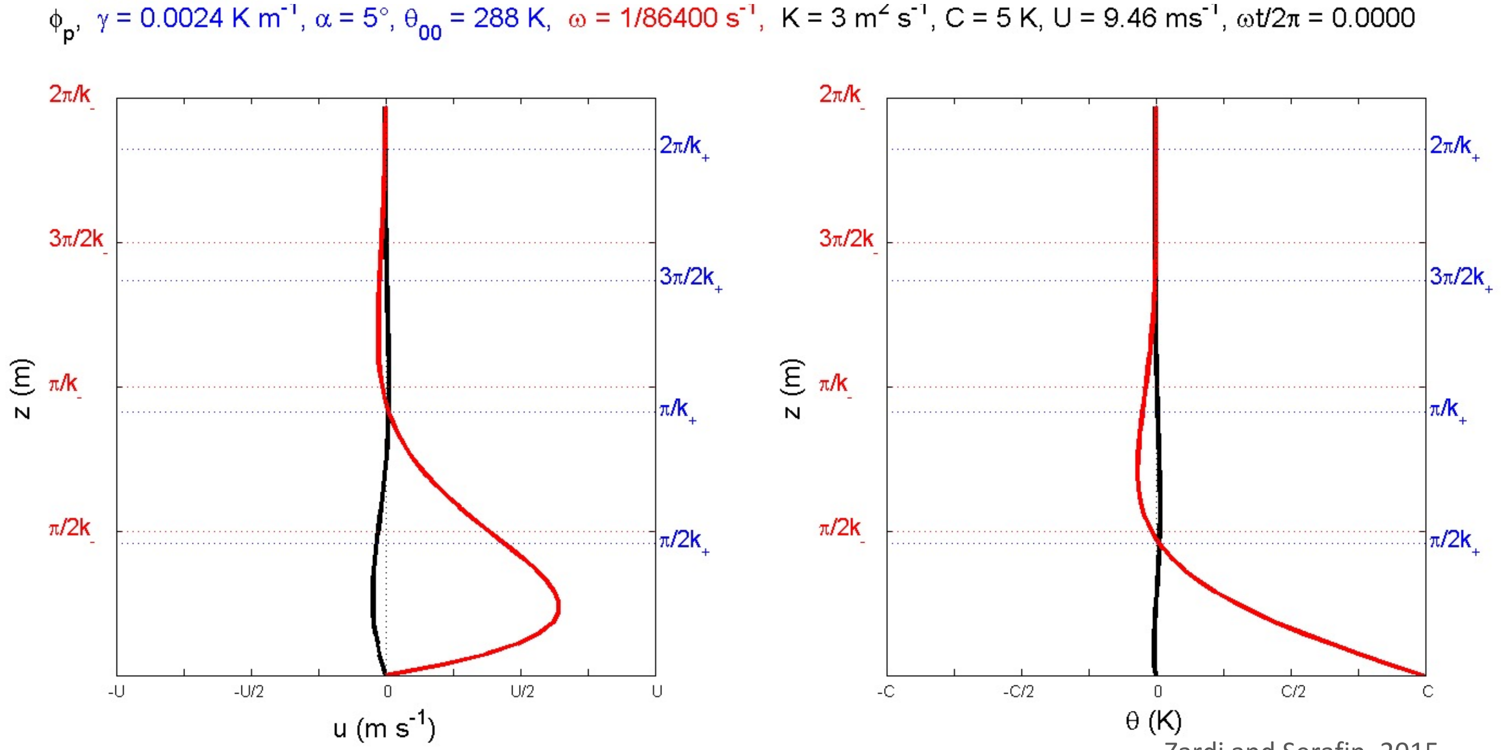
Zardi and Serafin, 2015

SUPER-CRITICAL SOLUTION

$$\bar{u} = \frac{\Theta}{2}\frac{N}{\gamma}[\exp(-\frac{n}{l_+})\sin(\omega t - \frac{n}{l_+}) + \exp(-\frac{n}{|l_-|})\sin(\omega t - \frac{n}{|l_-|})]$$

$$\bar{\theta} = \frac{\Theta}{2}[\exp(-\frac{n}{l_+})\cos(\omega t - \frac{n}{l_+}) - \exp(-\frac{n}{|l_-|})\cos(\omega t - \frac{n}{|l_-|})]$$

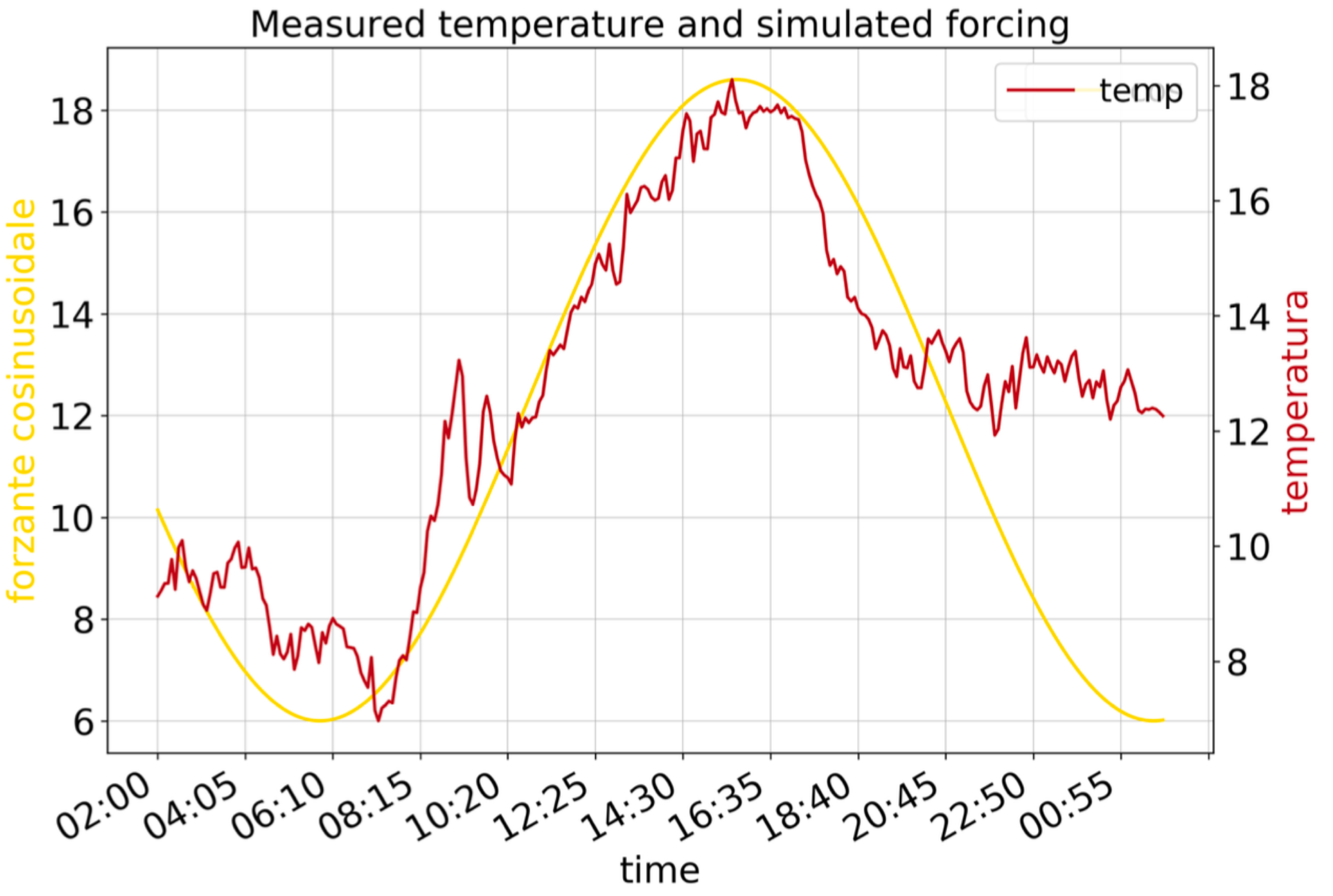
Where: $\omega_\pm = N_\alpha \pm \omega, l_\pm = \sqrt{\frac{2K}{\omega_\pm}}$ and $\eta = \frac{n}{2\sqrt{Kt}}$



Zardi and Serafin, 2015

ANALYTICAL MODEL: FIT OF THE FORCING

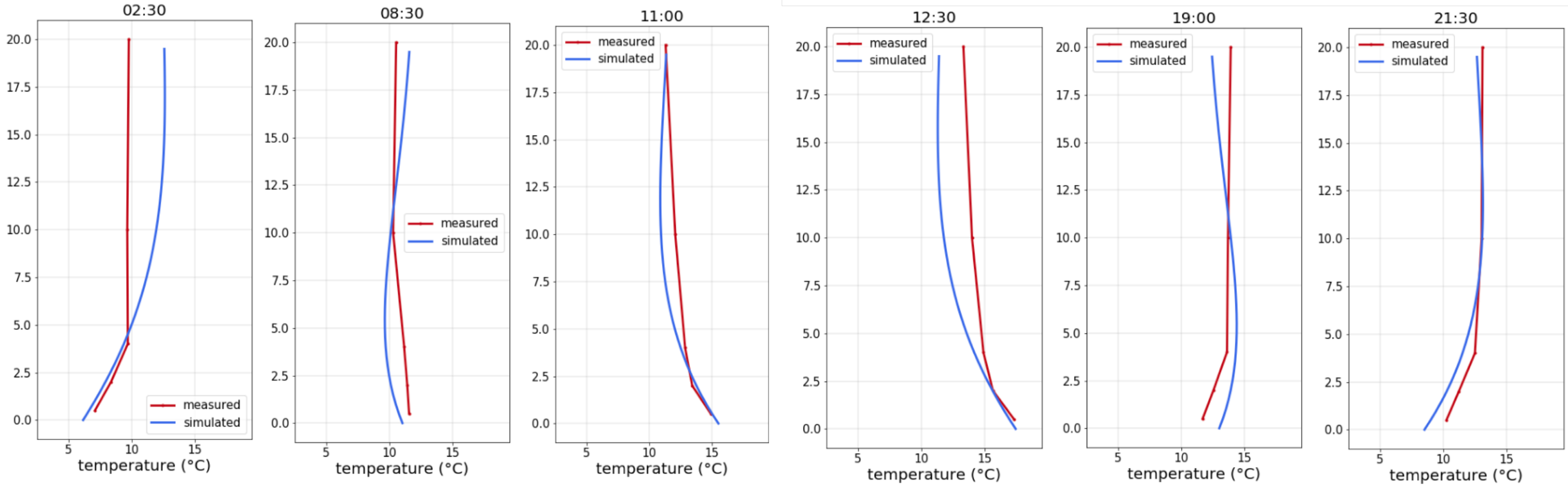
This case falls in the under-critical situation.



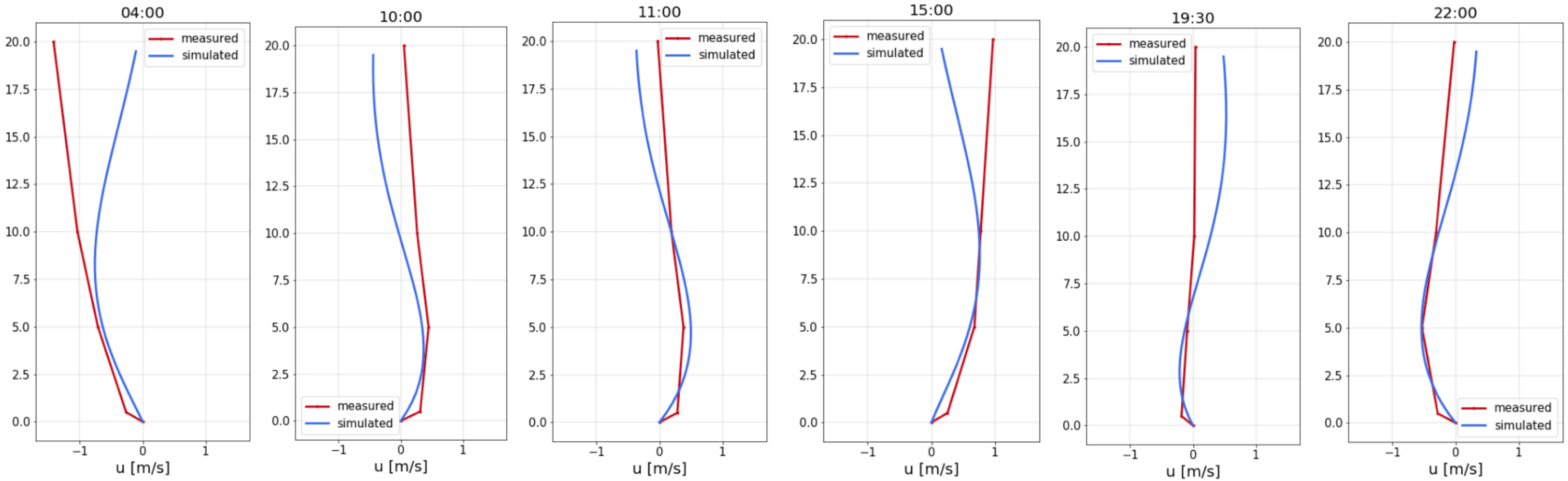
Parameters values

- $K = 0.07 m^2 s^{-1}$
- $\gamma = 0.0003 K m^{-1}$
- $\alpha = 3.6^\circ$
- $\Theta = 6.3 K$
- $\omega = 8.798 \cdot 10^{-5} Hz$

ANALYTICAL MODEL: TEMPERATURE



ANALYTICAL MODEL: VELOCITY



CONCLUSIONS

- The morning transition from katabatic to anabatic flows over a gentle slope is characterized.
- Three main patterns of erosion of the nocturnal inversion at the foot of a gente slope in wide valley are identified.
- The patterns of erosion of the nocturnal inversion are linked to two different processes driving the morning transition.
- The considered analytical model (Zardi and Serafin, 2015) is able to reproduce the transition.

Thank you for your interest!

For more information do not hesitate to contact me at s.farina@unitn.it

BIBLIOGRAPHY

- Zardi, D. and Serafin, S. (2015), An analytic solution for time-periodic thermally driven slope flows. Q.J.R. Meteorol. Soc., 141: 1968-1974. doi:10.1002/qj.2485
- Fernando, H. J. S., Pardyjak, E. R., Di Sabatino, S., Chow, F. K., De Wekker, S. F. J., Hoch, S. W, Zsedrovits, T. (2015). The MATERHORN: Unraveling the intricacies of mountain weather. Bulletin Of The American Meteorological Society, 96, 1945-1967. doi: 10.1175/BAMS-D-13-00131.1
- Whiteman, C. D., 2000: Mountain Meteorology: Fundamentals and Applications. Oxford University Press.