Atmospheric Boundary Layer features over complex heterogeneous terrain

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****Short Summer School on Atmospheric Physics****

Outline

1. A sustained ABL experimental effort

2. SEB closure

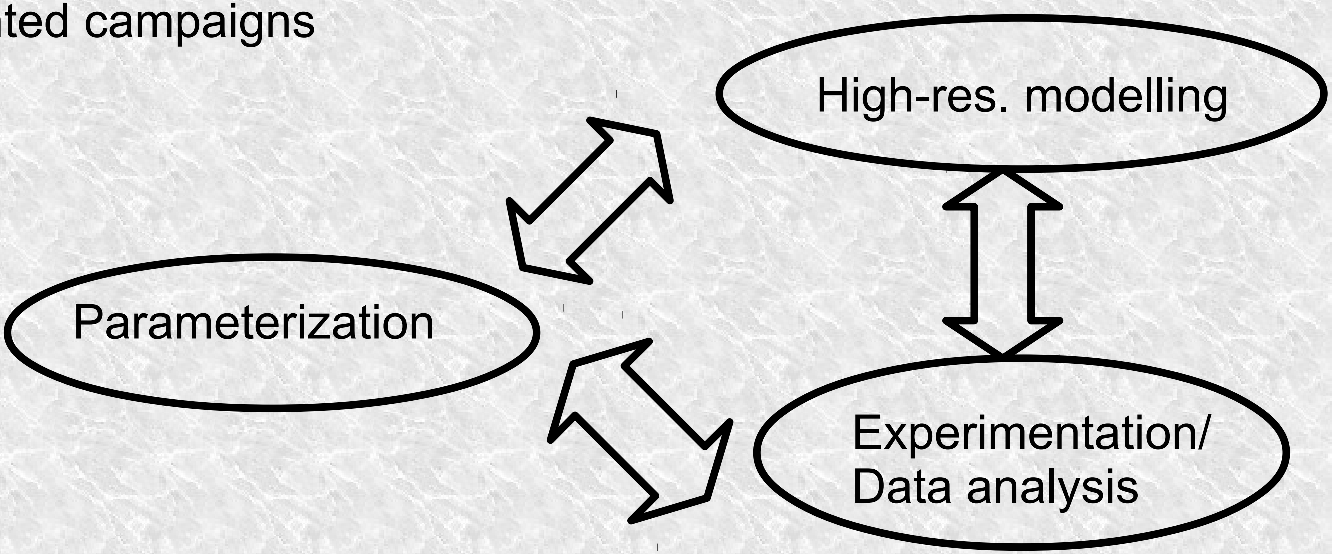
3. Flat reference sites?

4. Surface heterogeneities

5. Complex topography

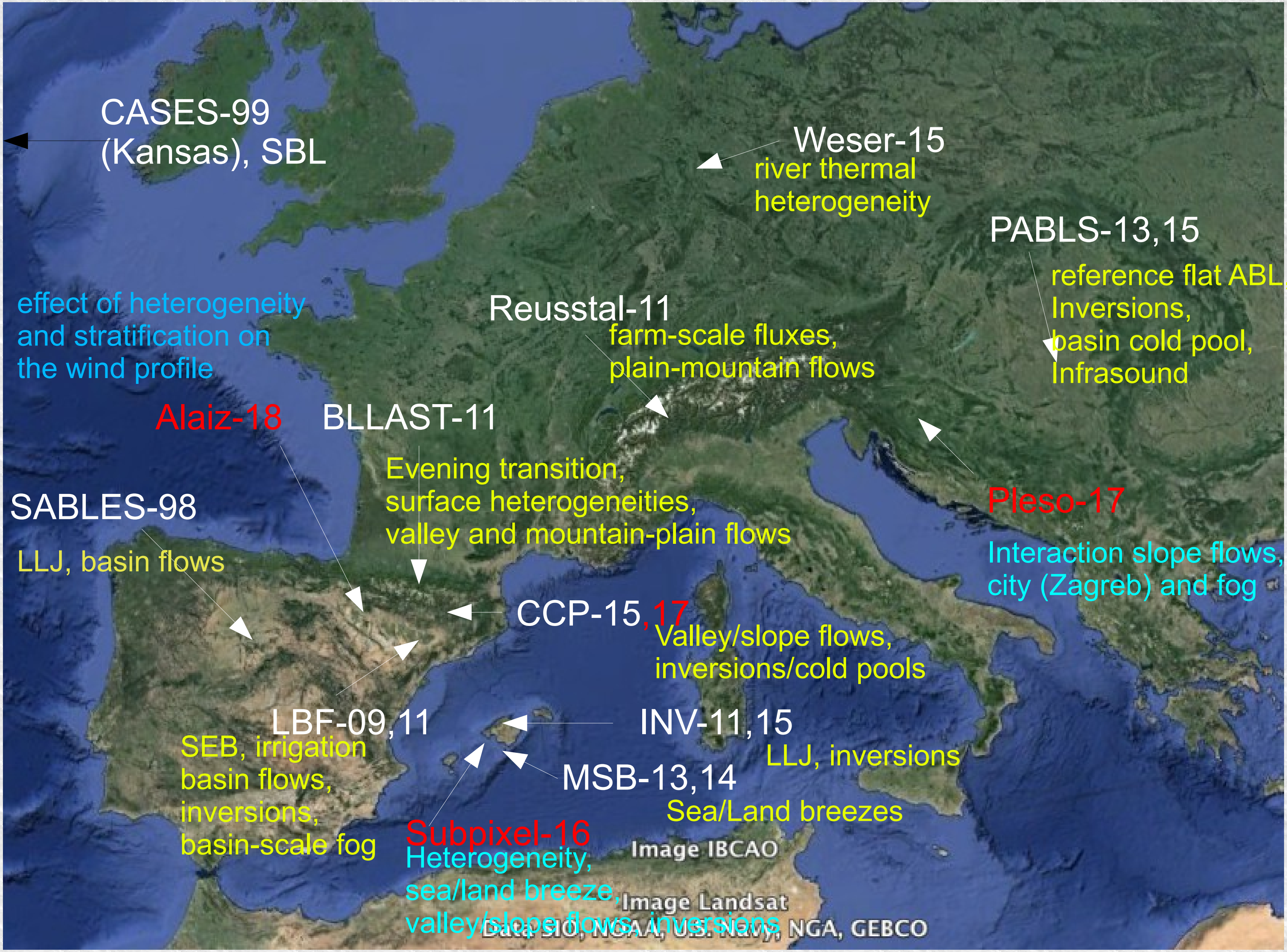
6. Surface thermal inversions and evening and morning transitions

7. Sites for question-oriented campaigns



General purpose: increase understanding of the ABL processes and translate it into applications (e.g. models)

1.1 Some past, recent and future campaigns where we have been involved in.



Some challenges

* Understanding processes: the surface energy budget as a guideline

* Heterogeneities at different scales: subgrid impact and change of profiles

* Complex terrain: coast and valley processes, non logarithmic profiles

* Is there something like flat terrain and reference cases?

* Difficult issues: surface thermal inversions and evening and morning transitions

Most campaigns have in common:

1) a priori ideal sites for well controlled regimes (flat homogeneous. sea/land breeze, valley flows, well defined heterogeneities, ...)

2) Unexpected measurements leading to re-interpretation of the ABL in those sites

3) Most unexpected results are due to local and mesoscale characteristics

4) Many of the unexpected results seem to have common issues

5) Models (even at high resolution) fail often to reproduce these unexpected results

Consequence: reference sites are more complicated than previously assumed to be

Low-cost experimental approach

Being a very small group with limited resources, we follow several strategies to be able to sample regimes of our interest:

Parasitic approach:

a) participating in campaigns organized by others bringing our own instrumentation, addressing sometimes other issues (BLLAST)
b) using data generated by others that fit well our interests (Reusstal)
c) convincing a colleague to make measurements (Weser, Pleso)
d) measuring where there are already measurements (PABLS)

Self-sustained approach:

e) Making campaigns locally to minimize costs and optimize operations
(Mallorca Sea-Breeze 13 and 14, and Mallorca Inversions 11 and 15)
f) Setting long-lasting displays locally to capture interesting phenomena as
they take place (ECUIB/Subpixel in Mallorca, LBF in Ebro, CCP in Pyrenees)
g) Using homemade instrumentation (after proper calibration) and data acquisition systems.

2.1. Some mutually related challenges: Closure of the surface energy budget

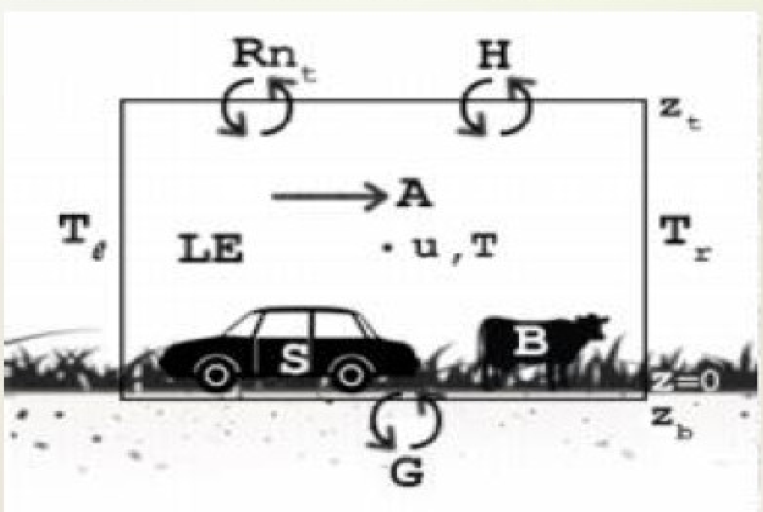
The surface energy budget seldom closes in reality, it does by construction in models.

Therefore the models put the energy missing somewhere, that may be perhaps a wrong place. In the long run, however, models do a correct job, since they manage to provide good cycles and energy conservation, but with some defaults in specific cases/moments.

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} = -\frac{1}{\rho C_p}\frac{\partial Rn}{\partial z} - \frac{\partial \overline{w'T'}}{\partial z} - \frac{\partial G^*}{\partial z} + S^* + B^* + LE^* + Ot^*$$

$$TT + A = -\mathbf{Rn} - \mathbf{H} - \mathbf{G} + S + B - \mathbf{LE} + Ot$$

$$\mathbf{Rn} + \mathbf{H} + \mathbf{LE} + \mathbf{G} = -TT - A + S + B + Ot = Imb$$

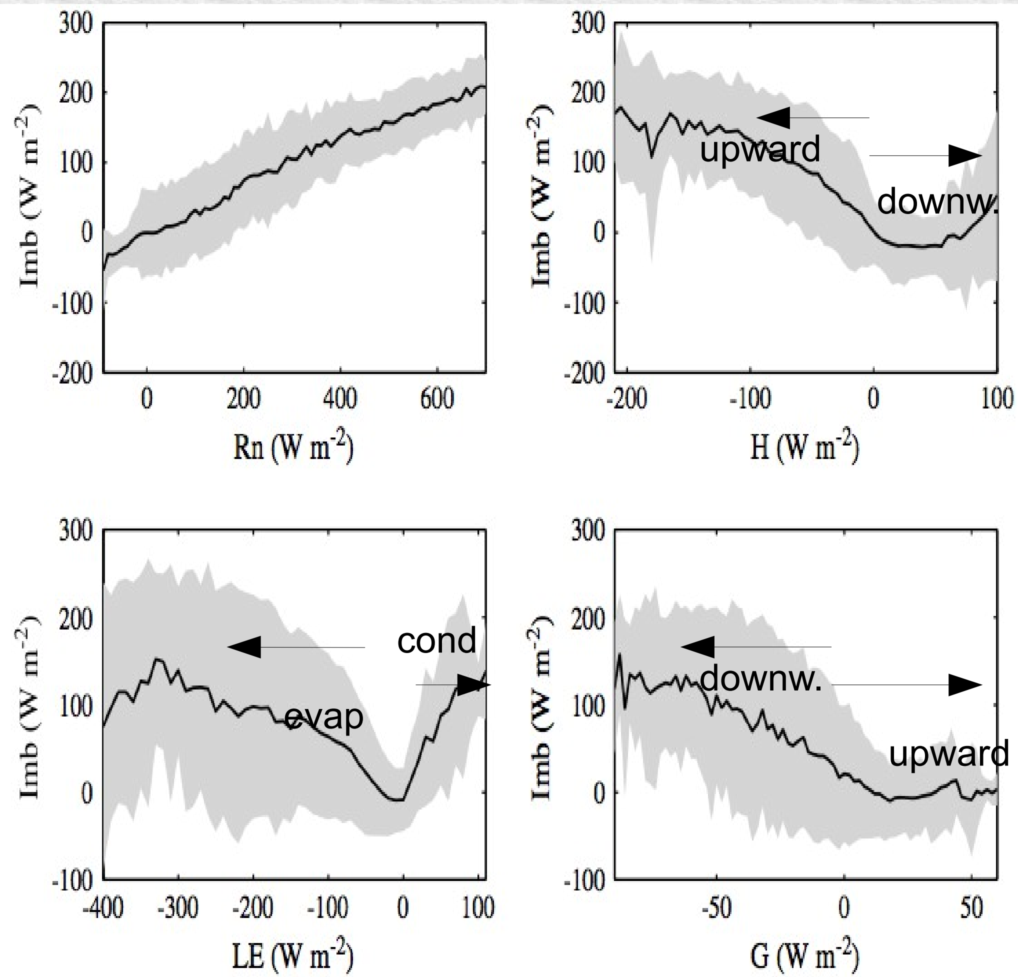


The lack of imbalance is, most of the time, energy missing (radiation is larger than the sum of the other terms).

Suspected reasons:
* Missing processes (A, S, B, ...)
* Understimated processes (H, LE, G...)
* Instrumental problems
* Conceptual design of the experiment
  (each sensor sampling a different volume)

(Cuxart, Conangla, Jimenez, JGR, 2015)

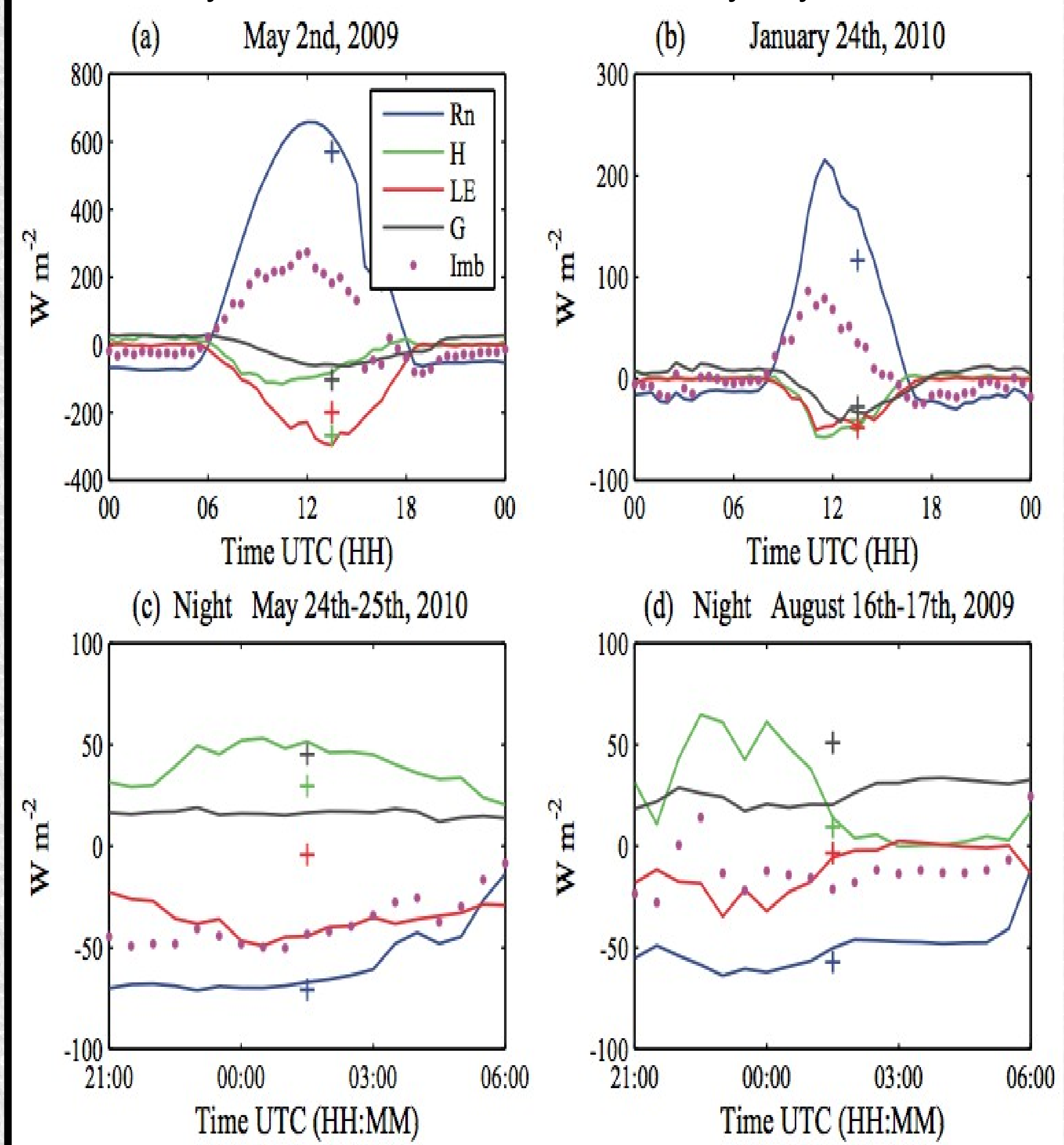
2.2 Imbalance over a wide irrigated area



2-year statistics (2009-2010)

Clear day, weak winds

Cloudy day, weak winds

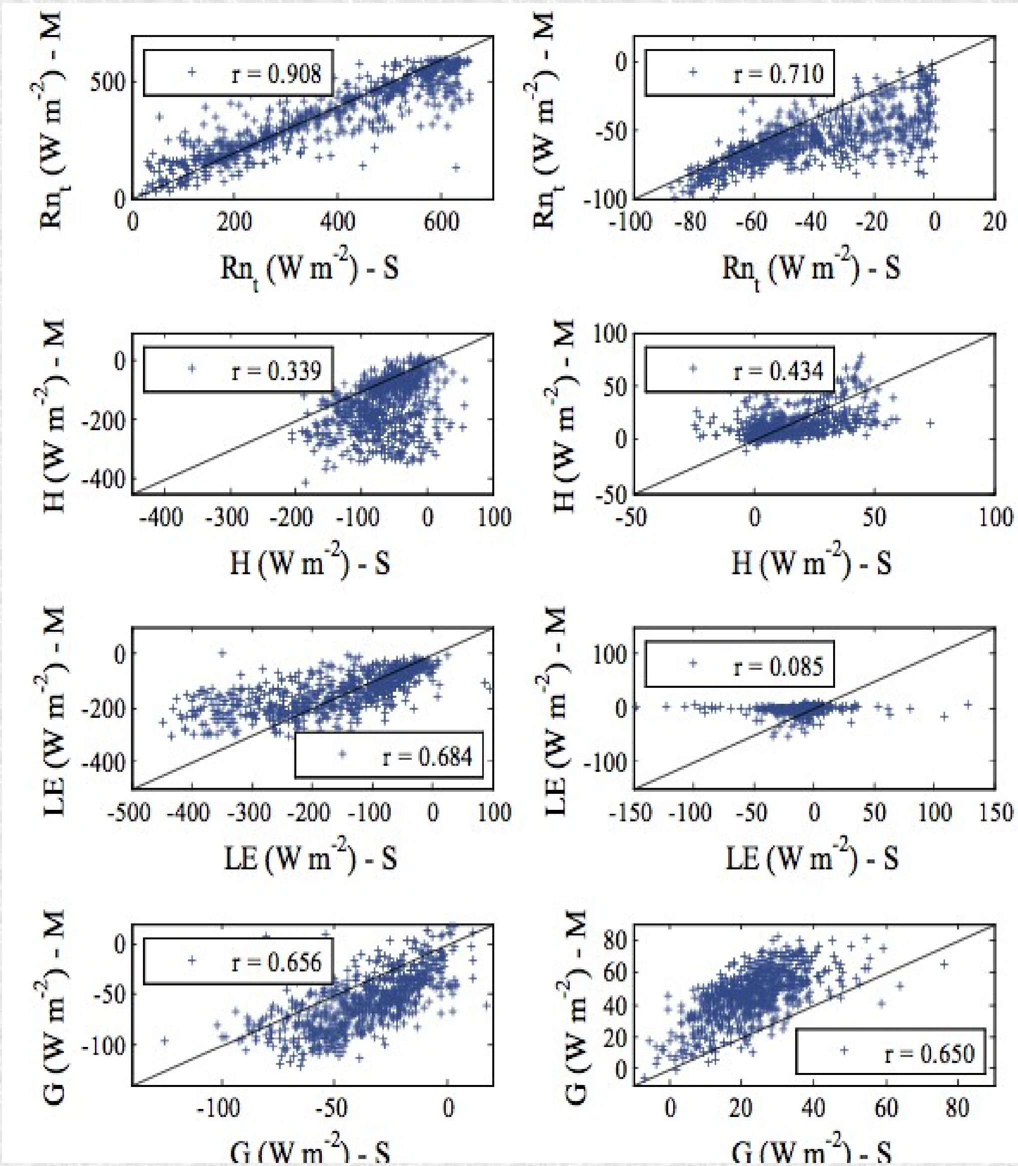


Cloudy and windy night

Clear night with weak winds

(Cuxart, Conangla, Jimenez, JGR, 2015)

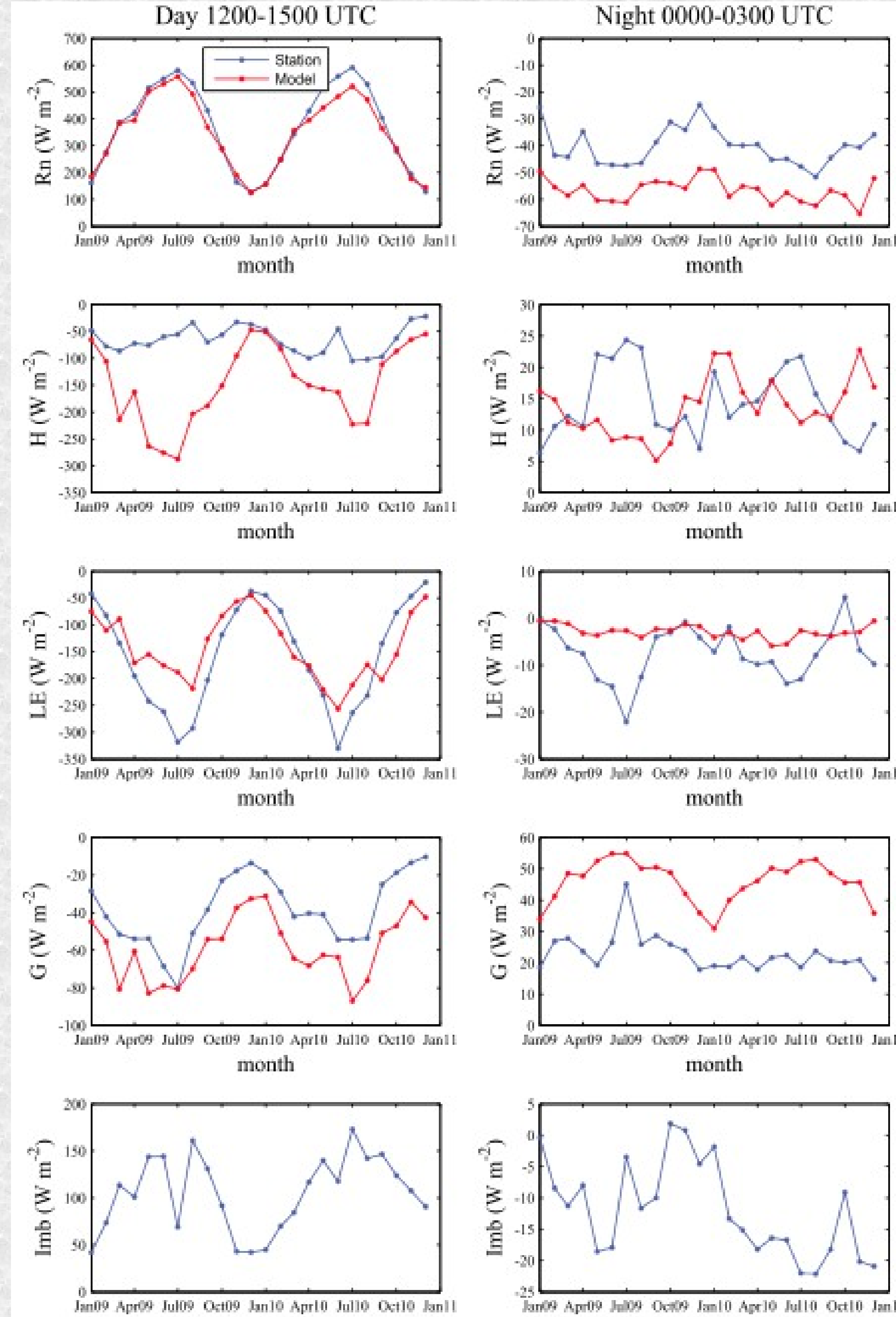
Observed vs Modelled (day -left- and night -right-).
Each point is a 3 hour average 12-15 or 00-03 UTC



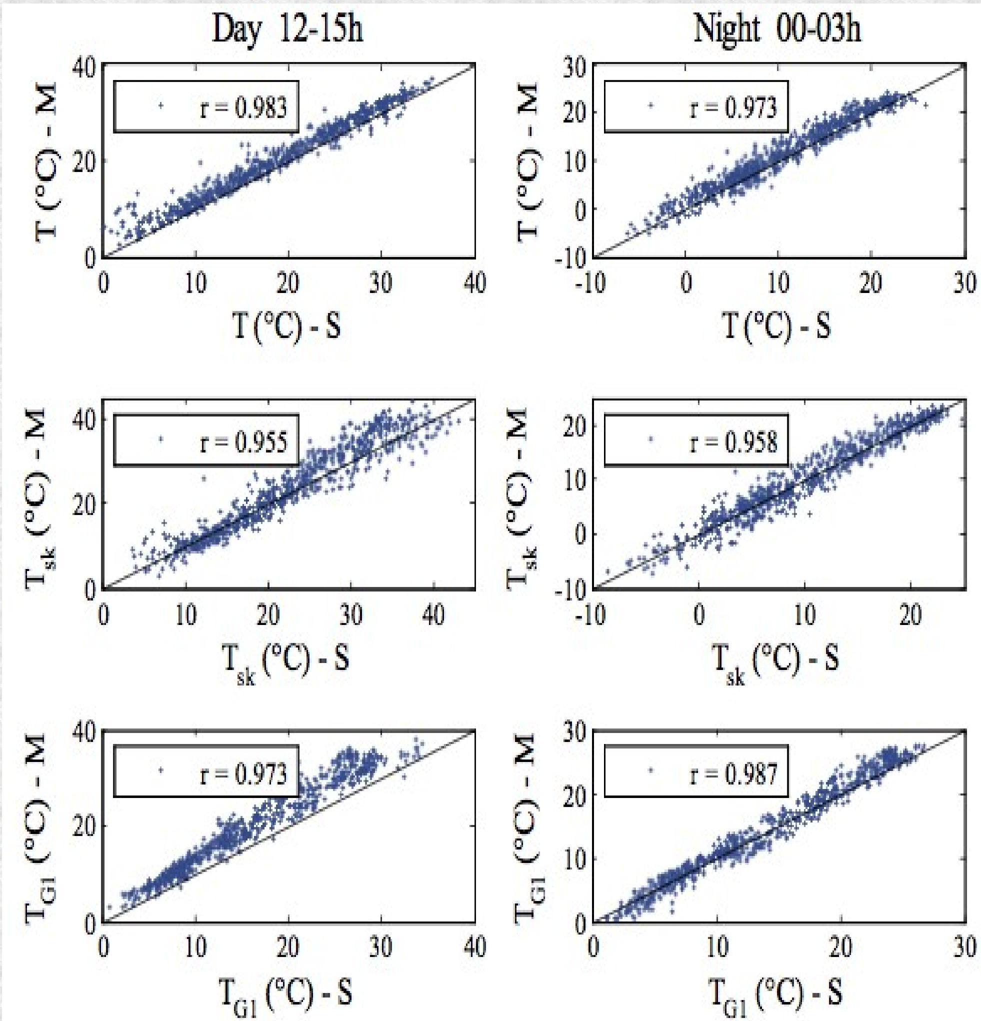
The advection term at the 10-km scale is negligible

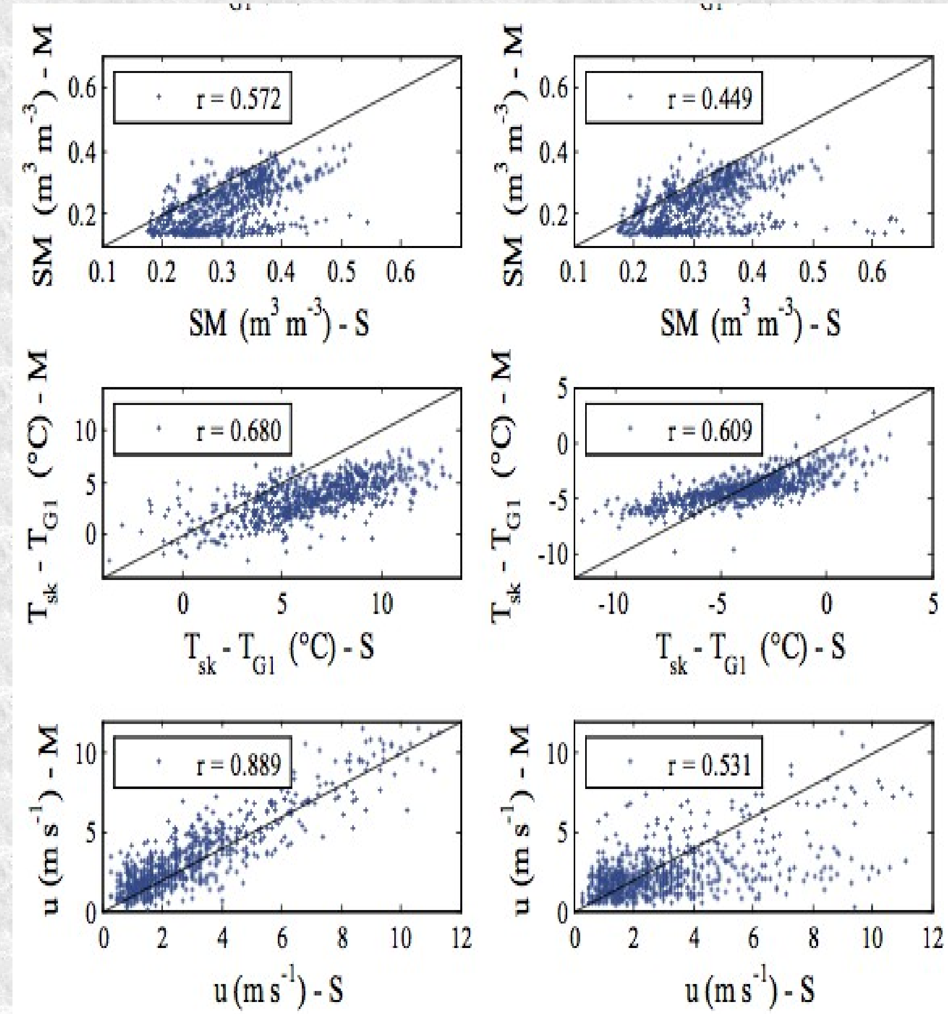
(Cuxart, Conangla, Jimenez, JGR, 2015)

Monthly averages 2009/2010



SEB imbalance: consequences in models

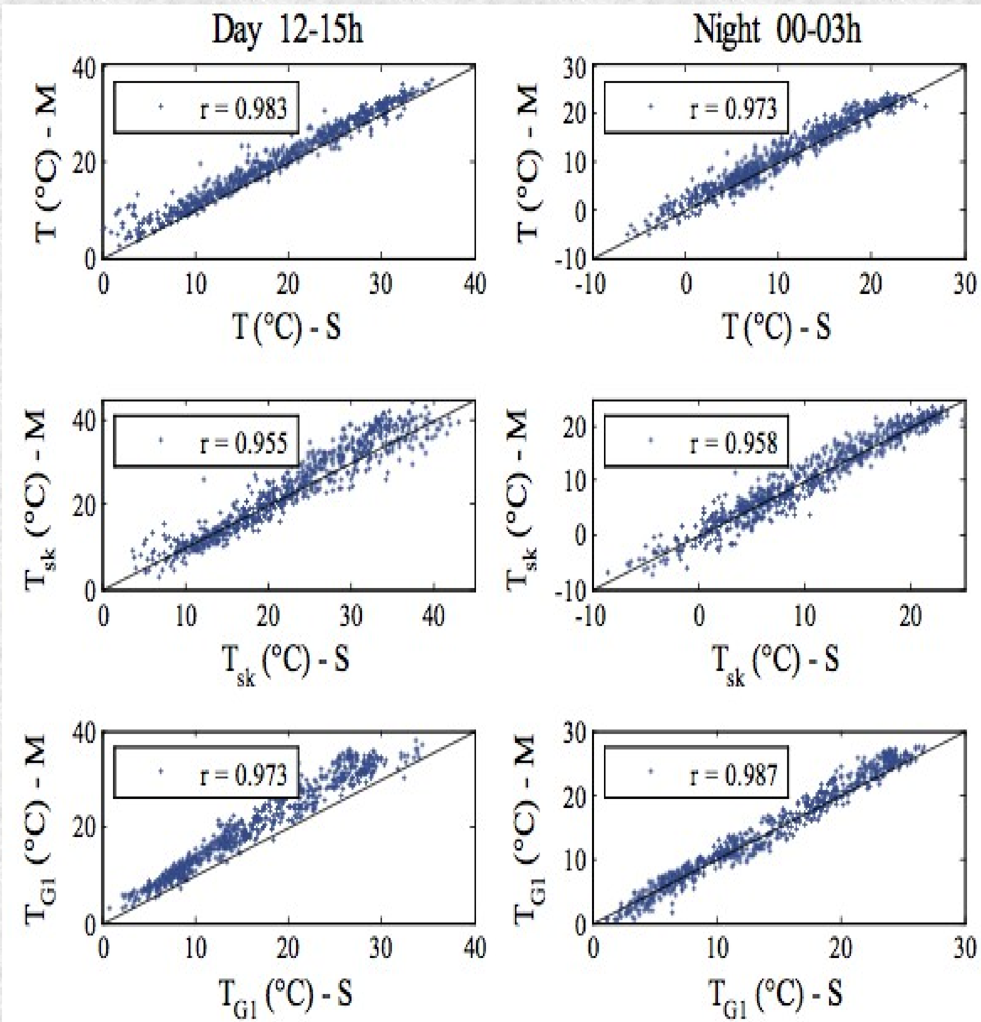


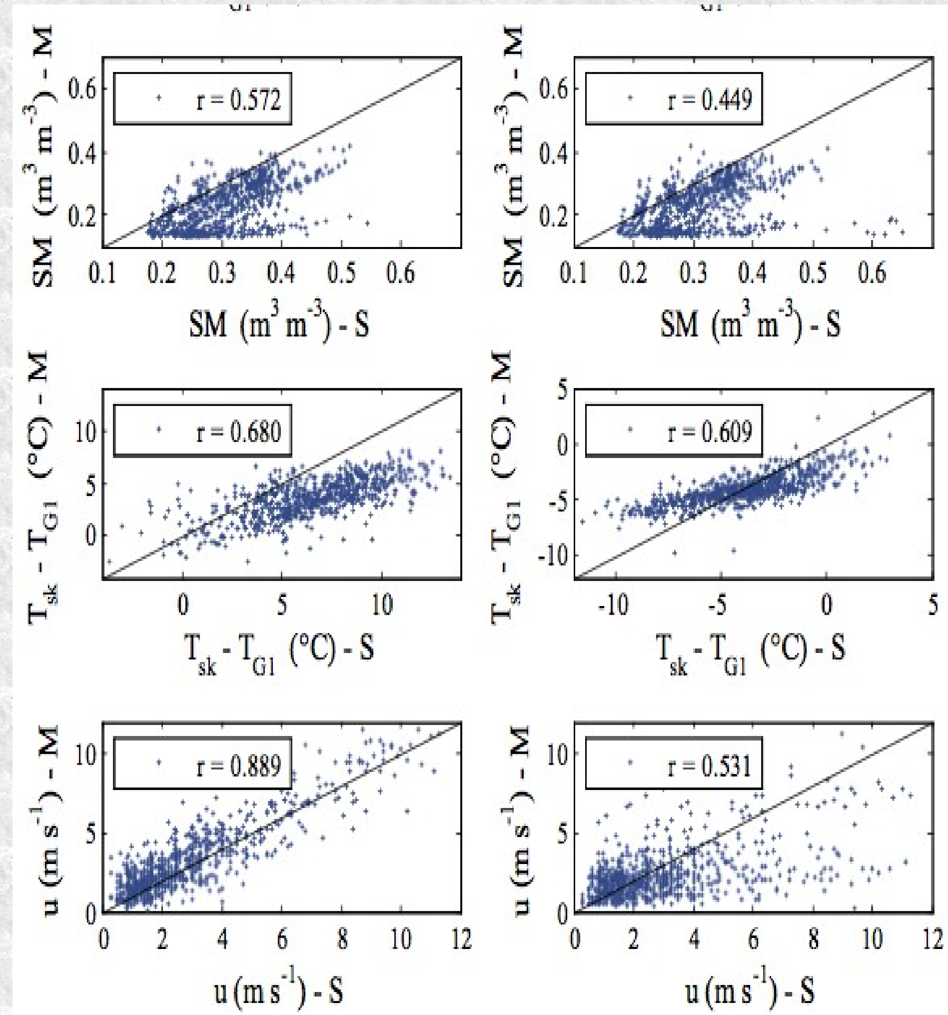


(Cuxart, Conangla, Jimenez, JGR, 2015)

Tair, T skin and wind speed compare well, soil variables compare worse.
The soil seems to be the system absorbing the imbalance, probably because the turbulence fluxes are well adjusted to observations after previous studies.

SEB imbalance: consequences in models





(Cuxart, Conangla, Jimenez, JGR, 2015)

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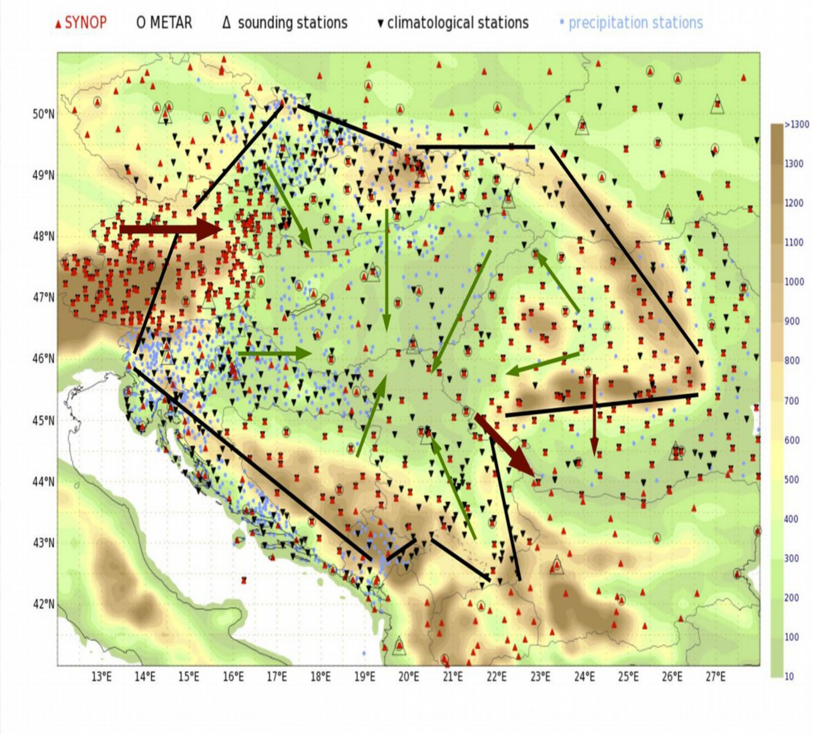
The soil seems to be the system absorbing the imbalance, probably because the turbulence fluxes are well adjusted to observations after previous studies.

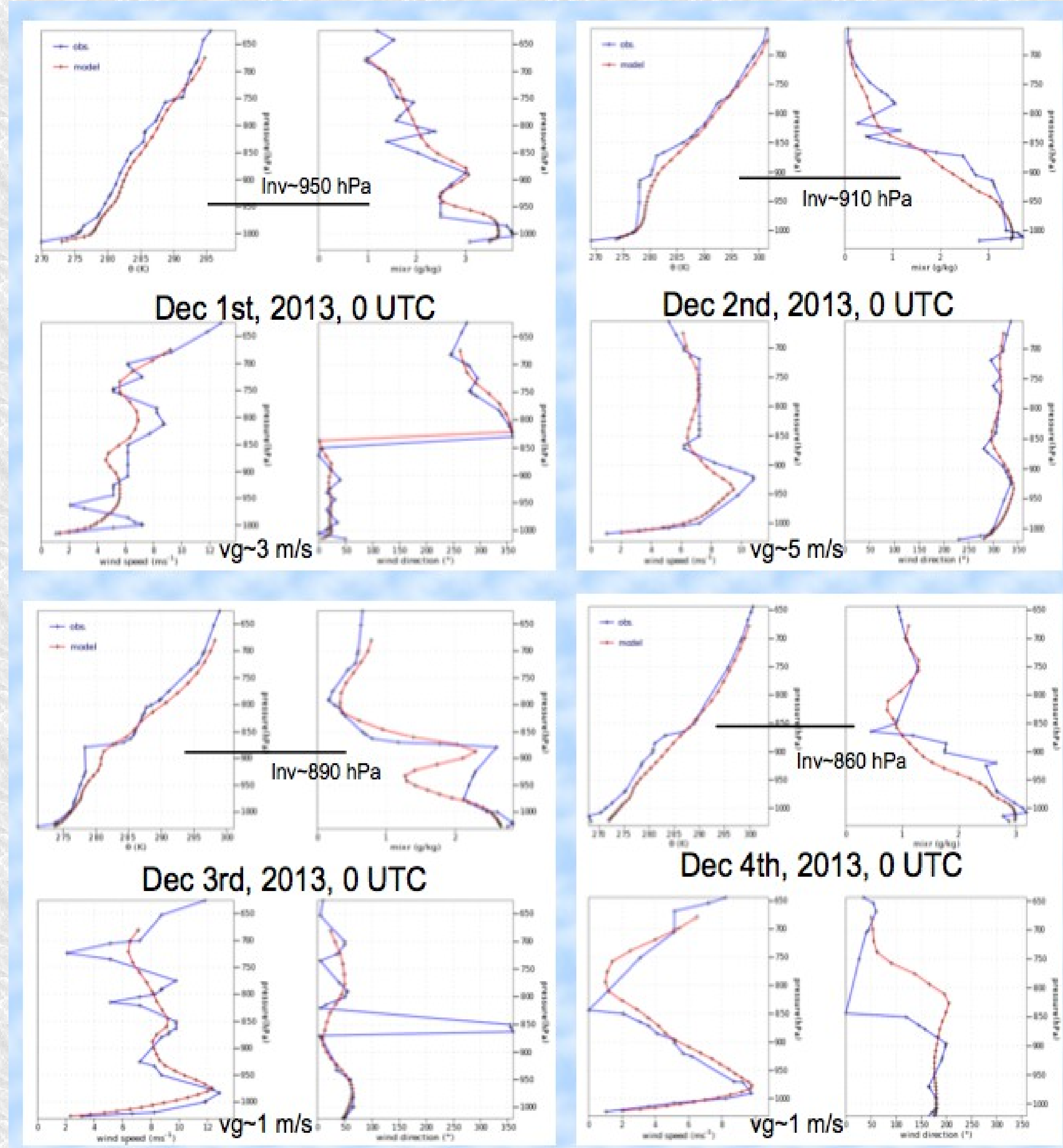
3.1. Do reference “textbook” sites exist?

Pannonian Basin



Szeged OMSZ profiling station (RS, VHS, T-prof)

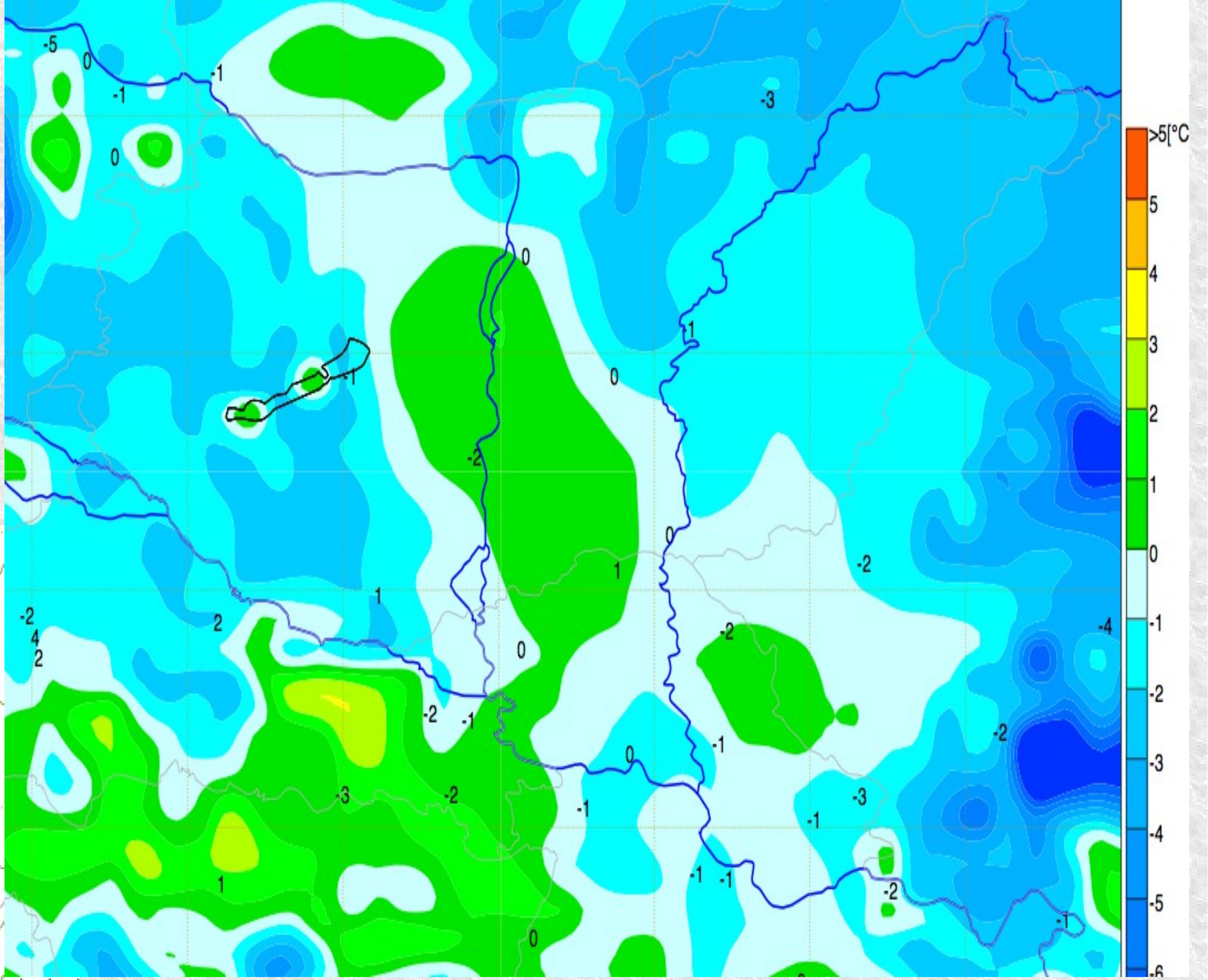
Basin-wind cold pool with strong LLJ (analysis vs RS)

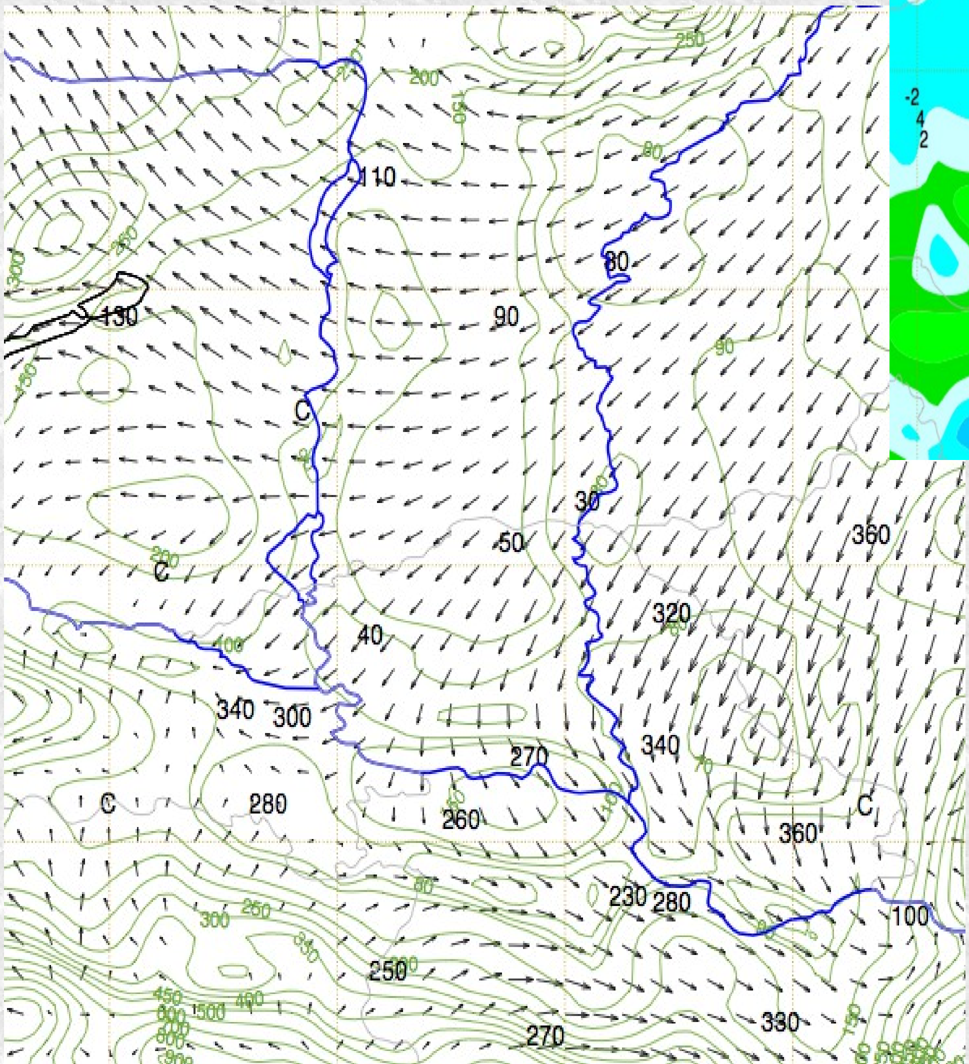


(Matjacic and Cuxart, 1[st] Pannex workshop, 2015)

3.2 Difficulties even for the analysis

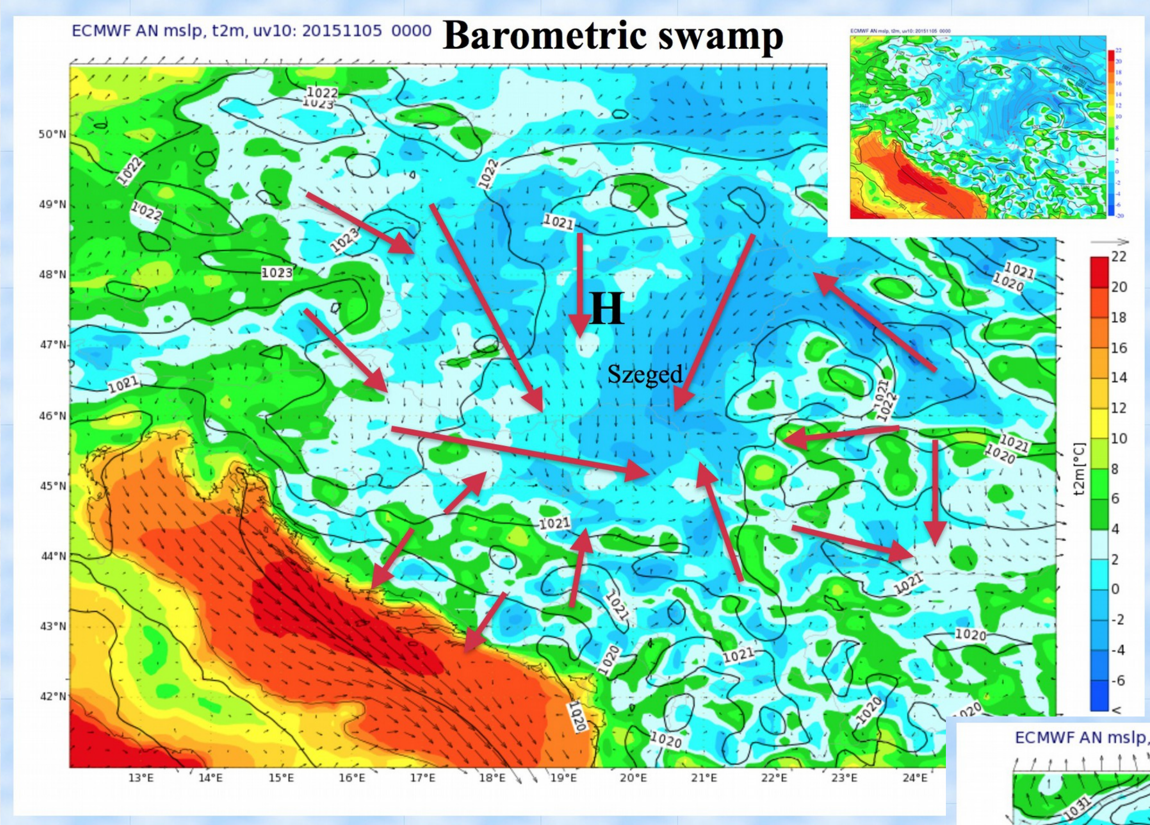
(December 3rd, 2013, 00 UTC)

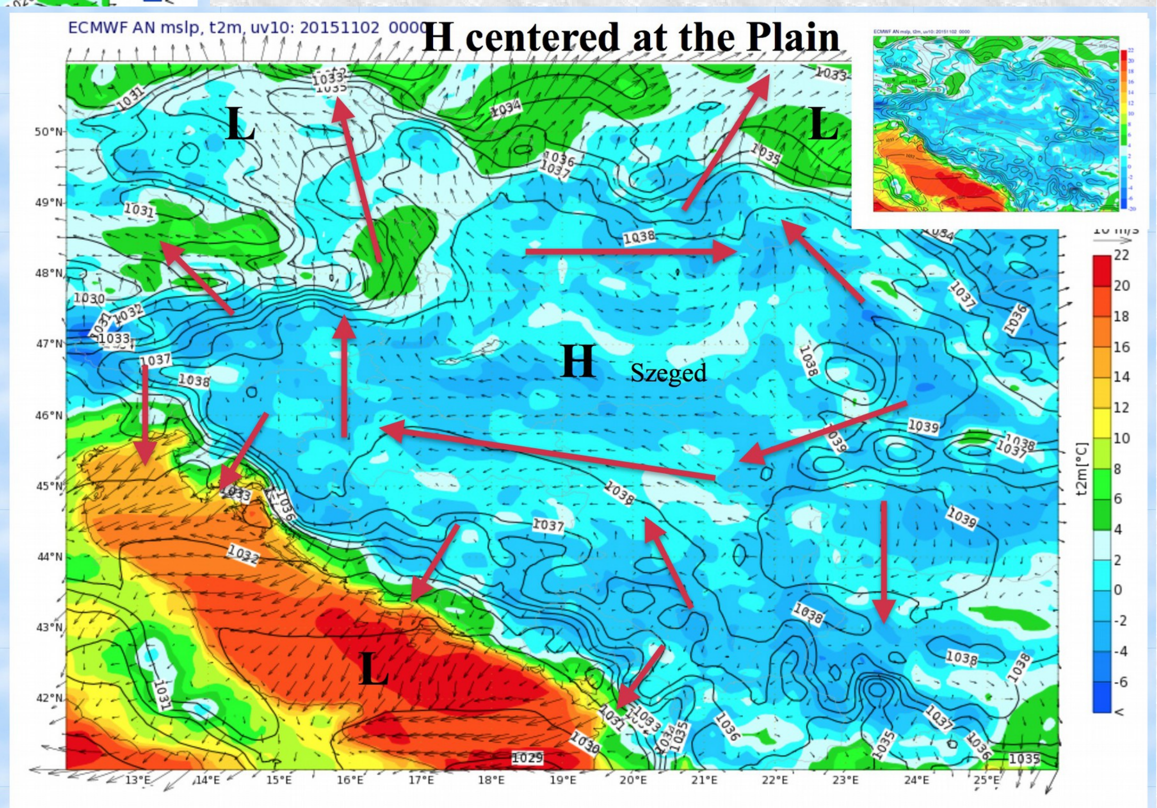




2.6

(Matjacic and Cuxart, 1st Pannex workshop, 2015)

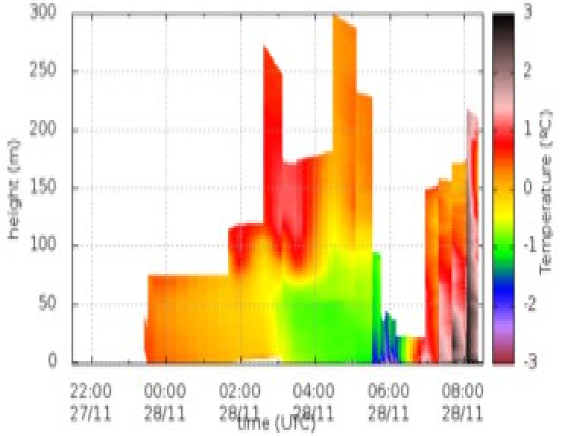


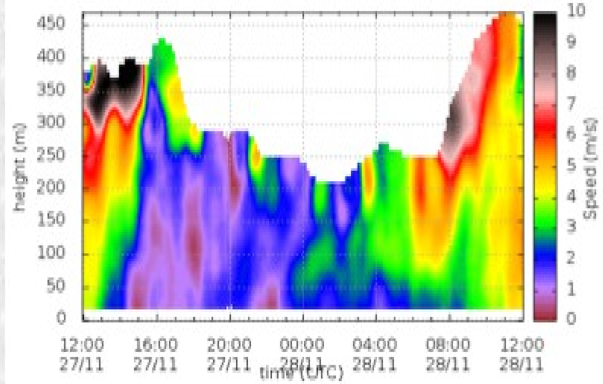


(Matjacic and Cuxart, 2nd Pannex workshop, 2016)

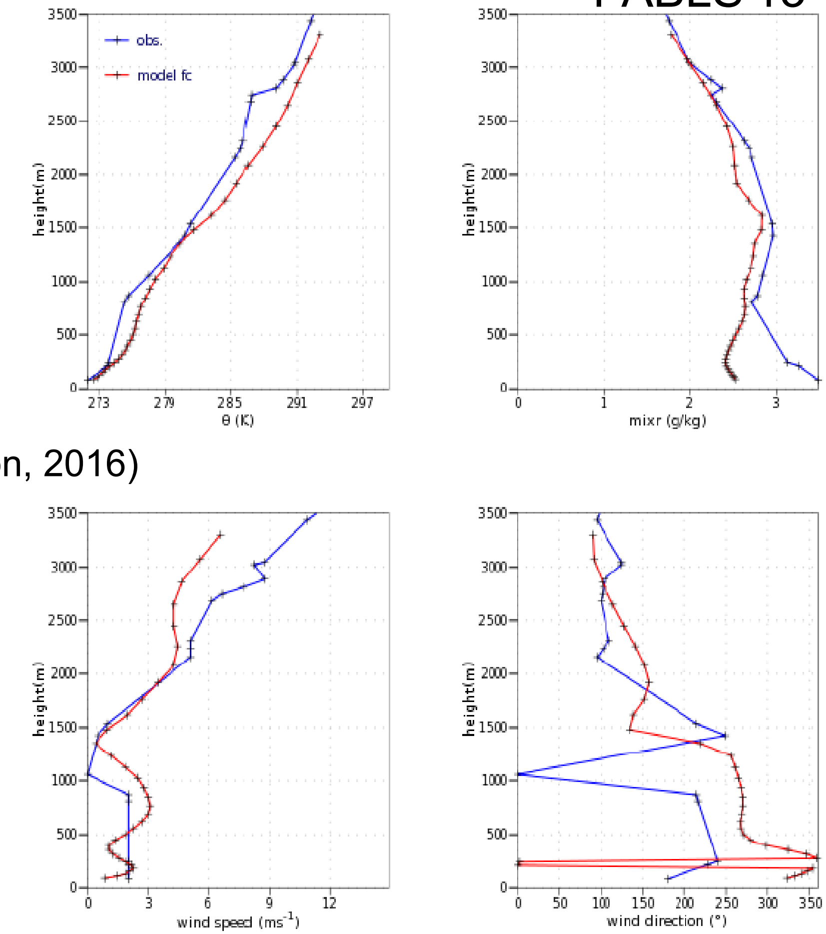
3.3 IOP1 (27-28 Nov 2013): an unstable night

PABLS'13

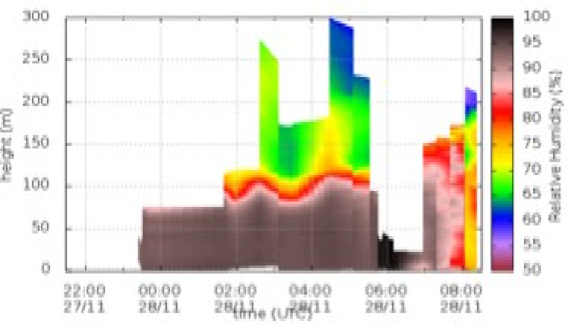


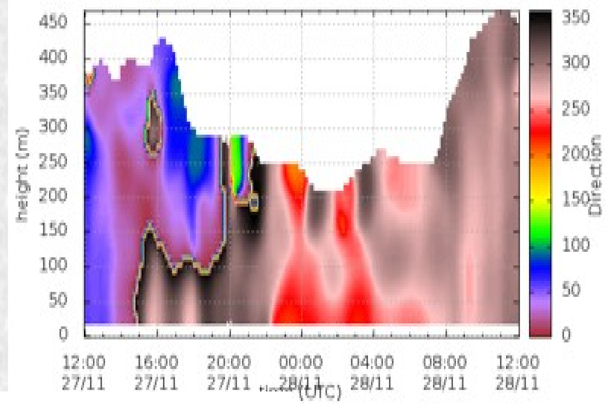


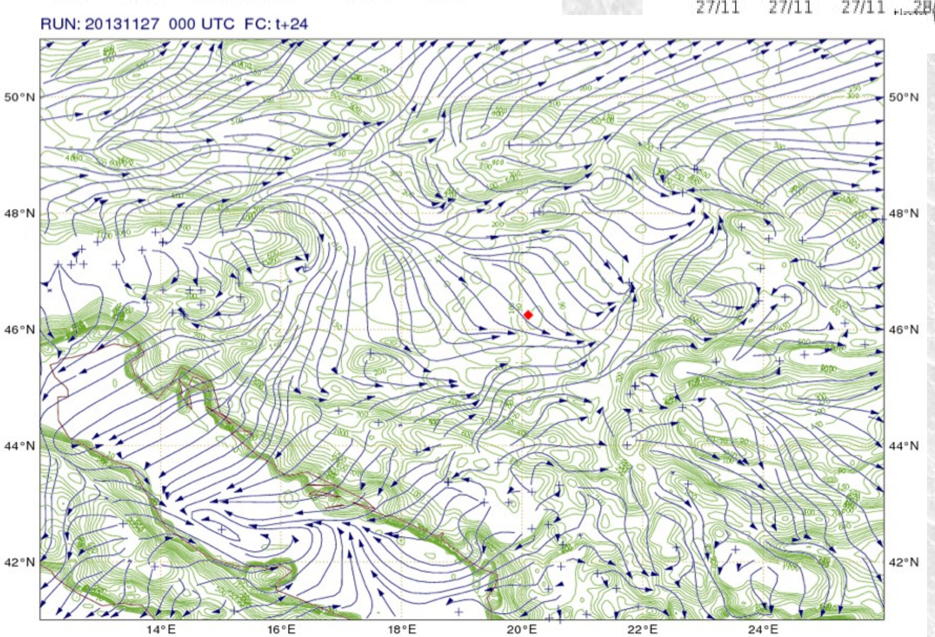
FC: 20131127 00Z t+24

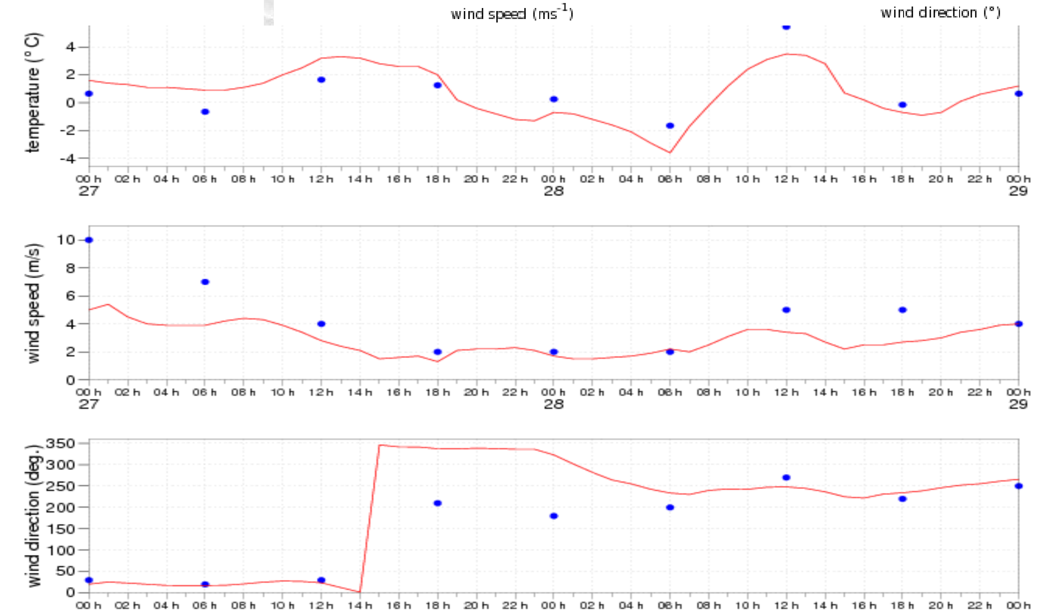


Simó et al (BLM, in preparation, 2016)

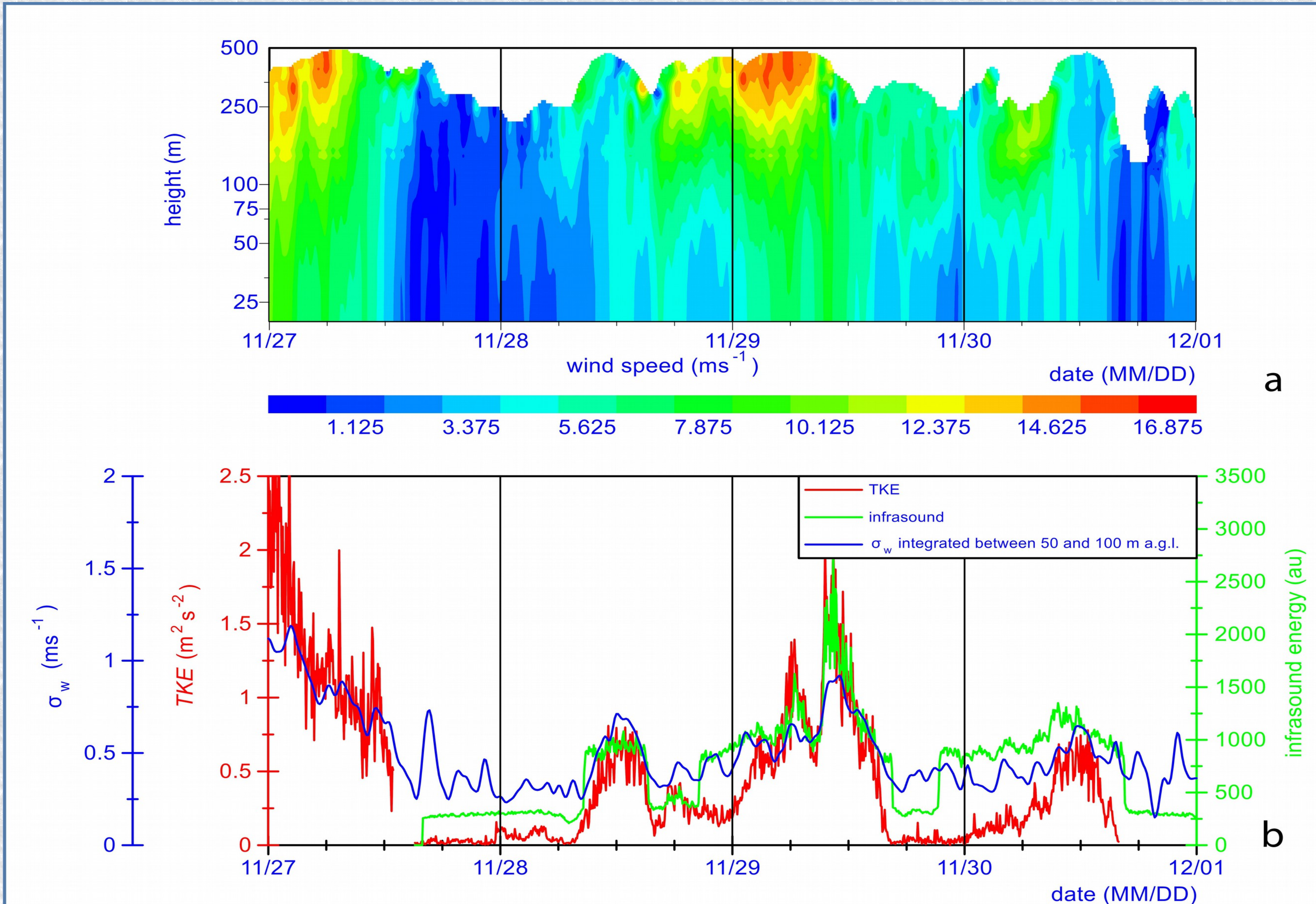






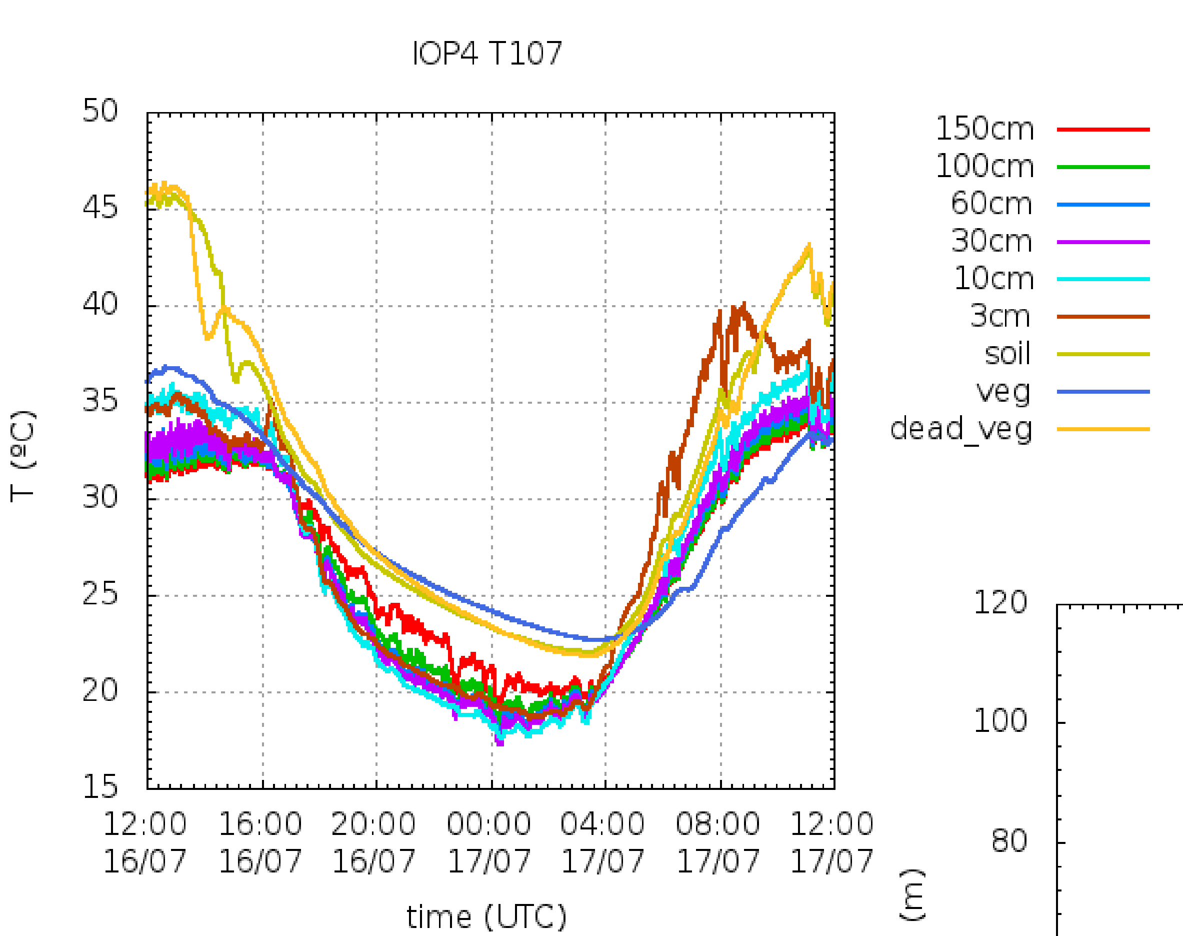


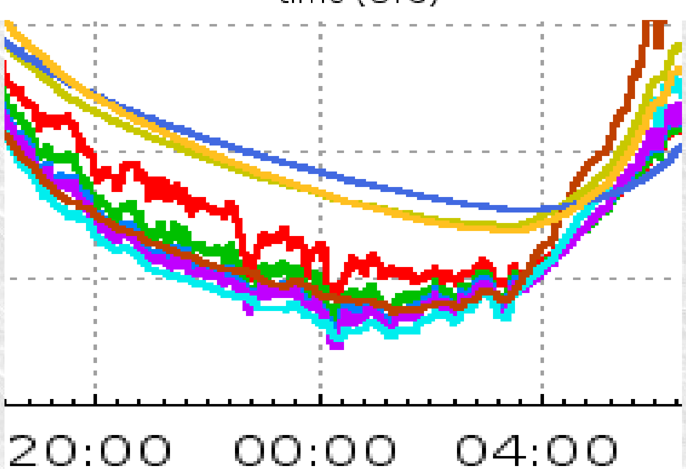
3.4 Using Infrasound as "cheap" turbulence detector



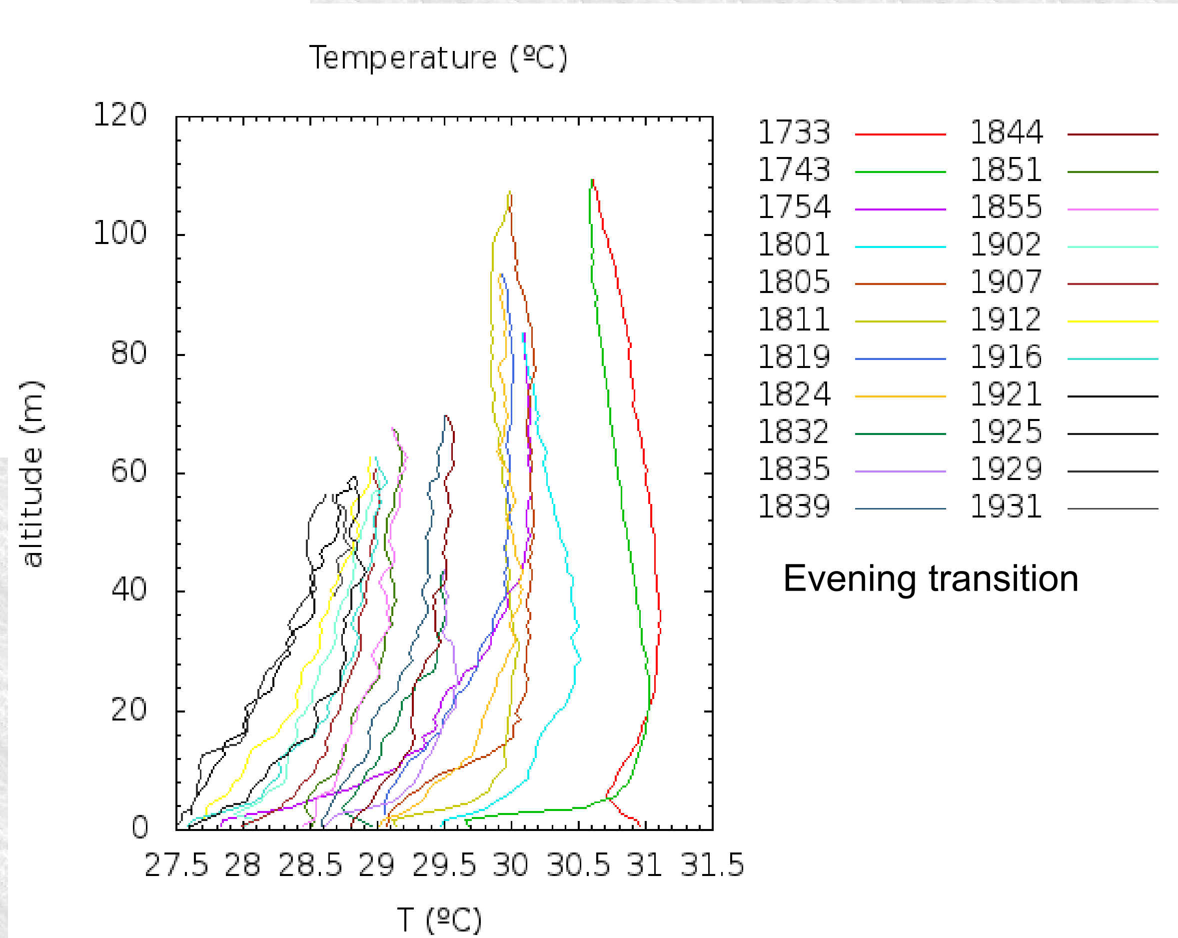
(Cuxart et al, BLM, 2016)

3.5 The summer side of PABLS (July'15)

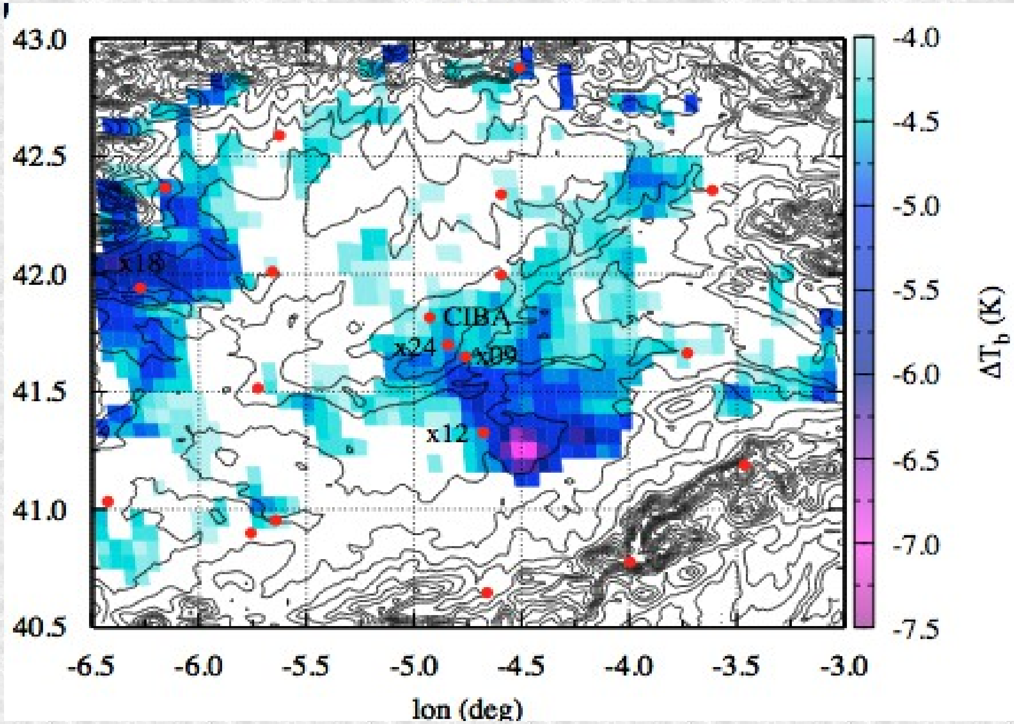




(Cuxart et al, 1st Pannex workshop, 2015)



4.1 Heterogeneities at the basin scale: Duero

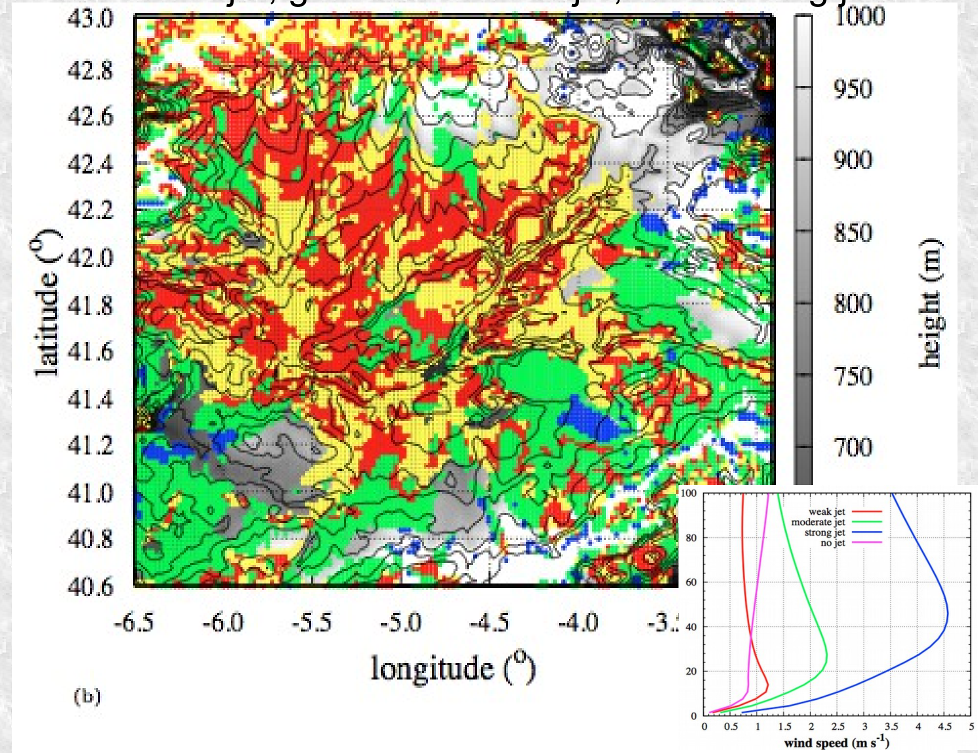


Cooling since sunset

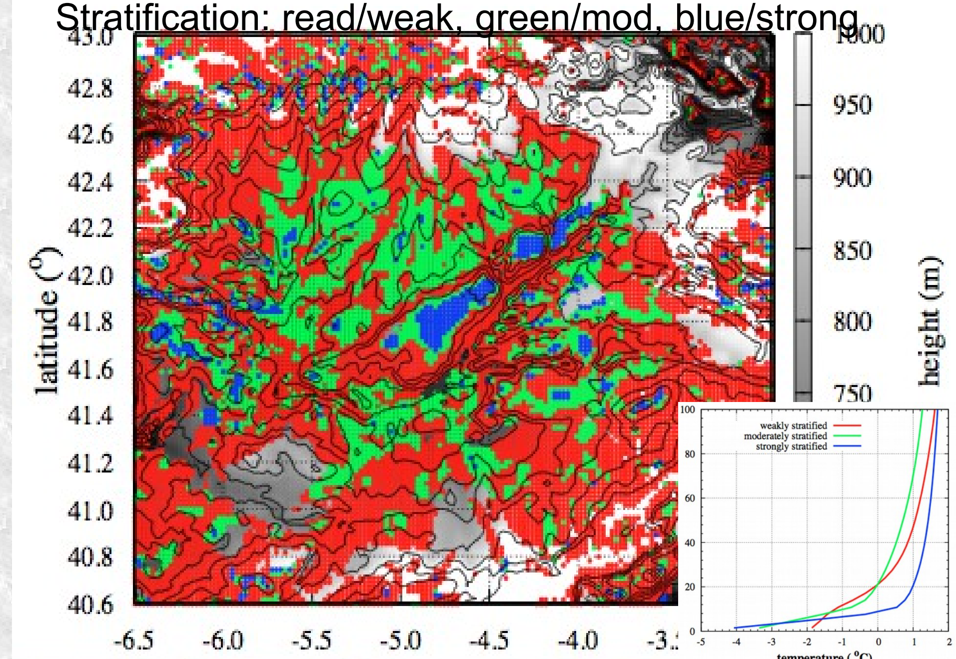
Table 1 Percentage of the cases (19430 in total) for the classification of the points at 0000 UTC according to the wind maxima (up to 100 m) and the temperature gradient (up to 10 m where $\Delta\theta = \theta_{10.5m} - \theta_{1.5m}$). The jet category is counted when the wind above the jet is, at least, 0.5 m s^{-1} smaller than in the jet height.

	$\Delta\theta < 0$ K	$0 \le \Delta\theta < 2$ K	$2 \le \Delta\theta < 4$ K	$\Delta\theta \ge 4$ K	Total
weak jet ($0.5 \le wind_{max} < 2$ m s^{-1})	0.04	18.08	6.85	1.02	**25.99**
moderate jet ($2 \le wind_{max} < 4$ m s^{-1})	0.02	21.98	2.17	0.25	**24.42**
strong jet ($wind_{max} > 4$ m s^{-1})	0.00	2.30	0.07	0.00	**2.37**
no jet-weak ($wind_{below100m} < 2$ m s^{-1})	0.08	12.10	8.32	2.05	**22.55**
no jet-moderate ($wind_{below100m} \ge 2$ m s^{-1})	0.12	20.45	3.29	0.81	**24.67**
total	**0.26**	**74.91**	**20.70**	**4.13**	**100.00**

red: weak jet, green: moderate jet, blue: strong jet

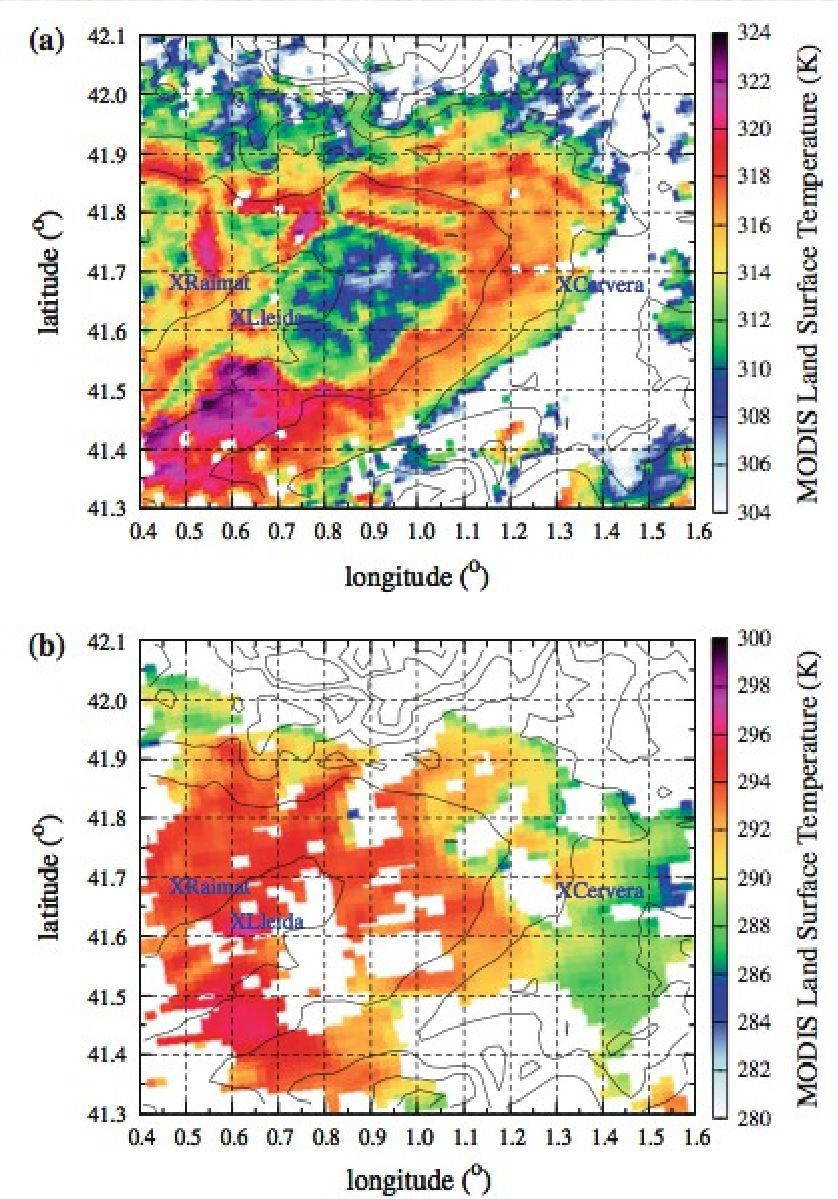


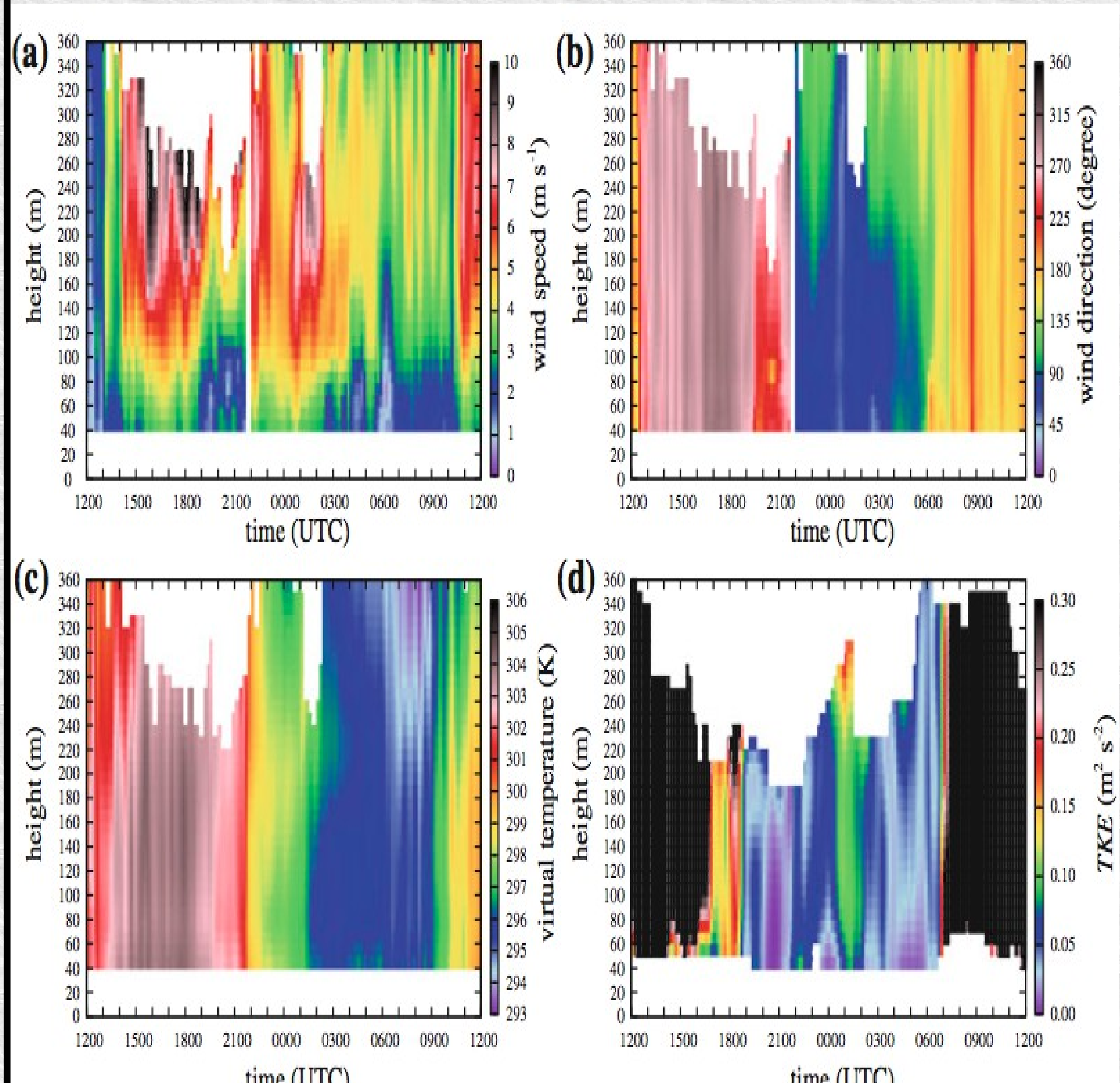
Stratification: read/weak, green/mod, blue/strong



(Martinez et al, BLM, 2010)

4.2 Ebro Sub-basin flows (dry-irrigated, June 2009)





(Cuxart et al, BLM, 2012)

4.3 LST heterogeneities for Mallorca

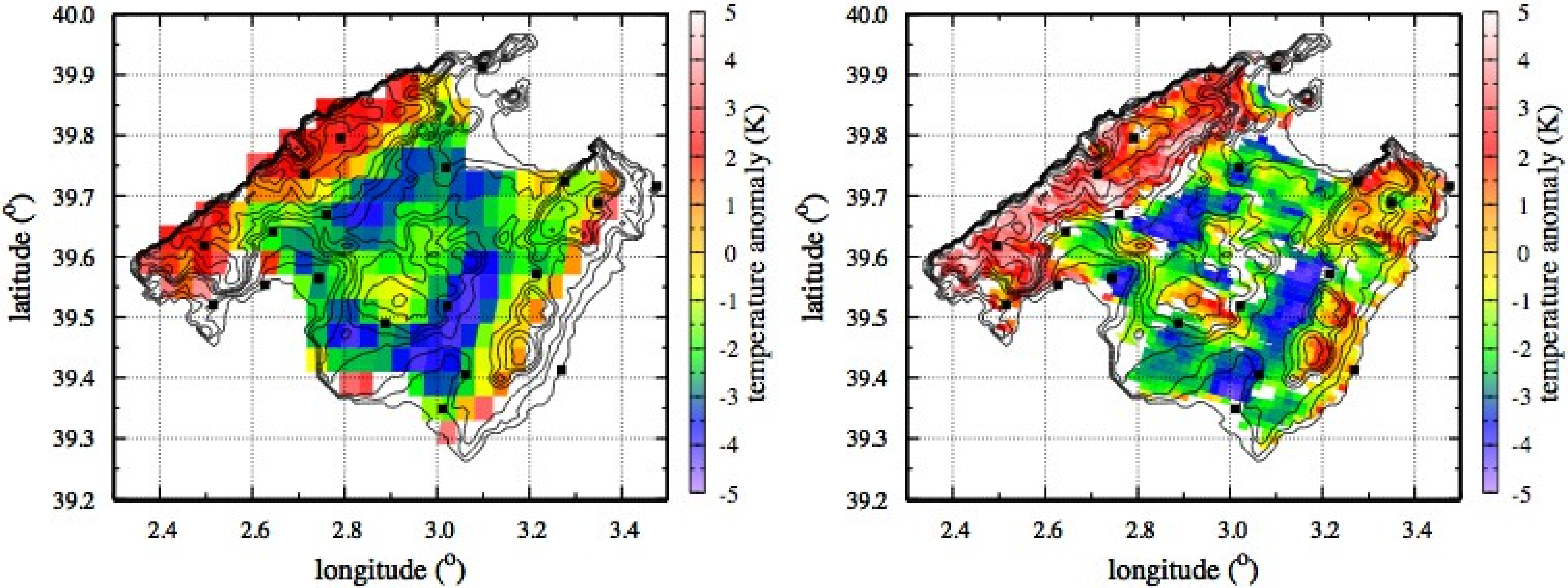
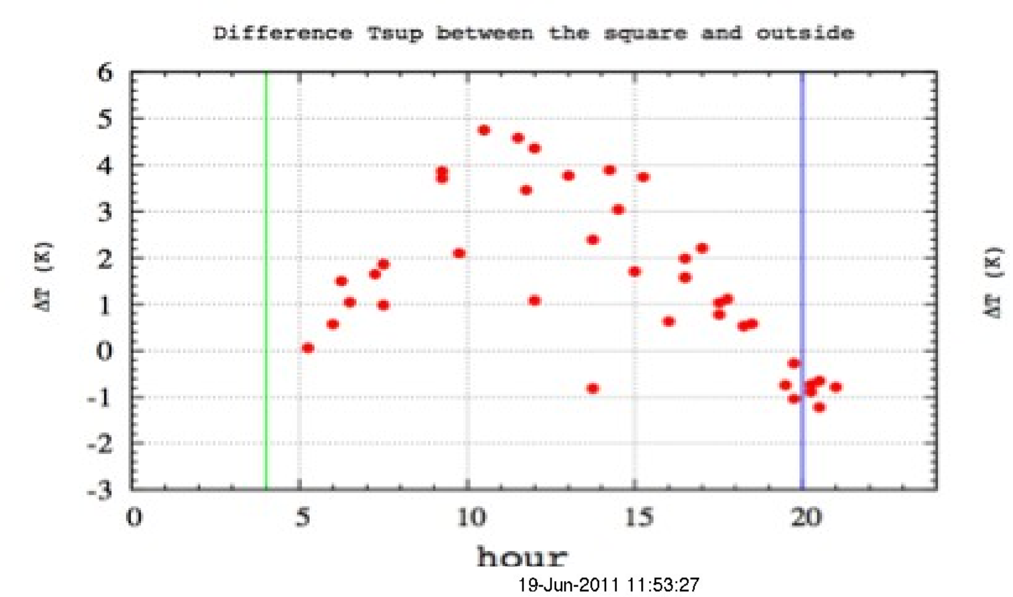


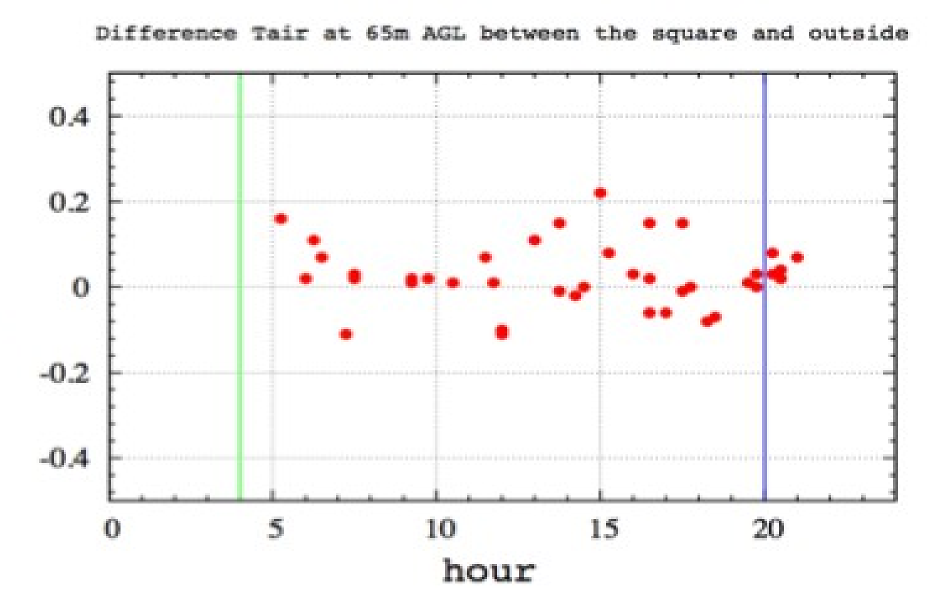
Figure 4: Land Surface Temperature anomalies on January, 29th 2008 at 0200 UTC for **(a)** MSG and **(b)** MODIS, where the mean temperature over the island is $< LST_{MSG} > = 278.7$ K and $< LST_{MODIS} >= 277.3$ K, respectively. The topography lines are included as well as the AEMET surface weather stations in dots.

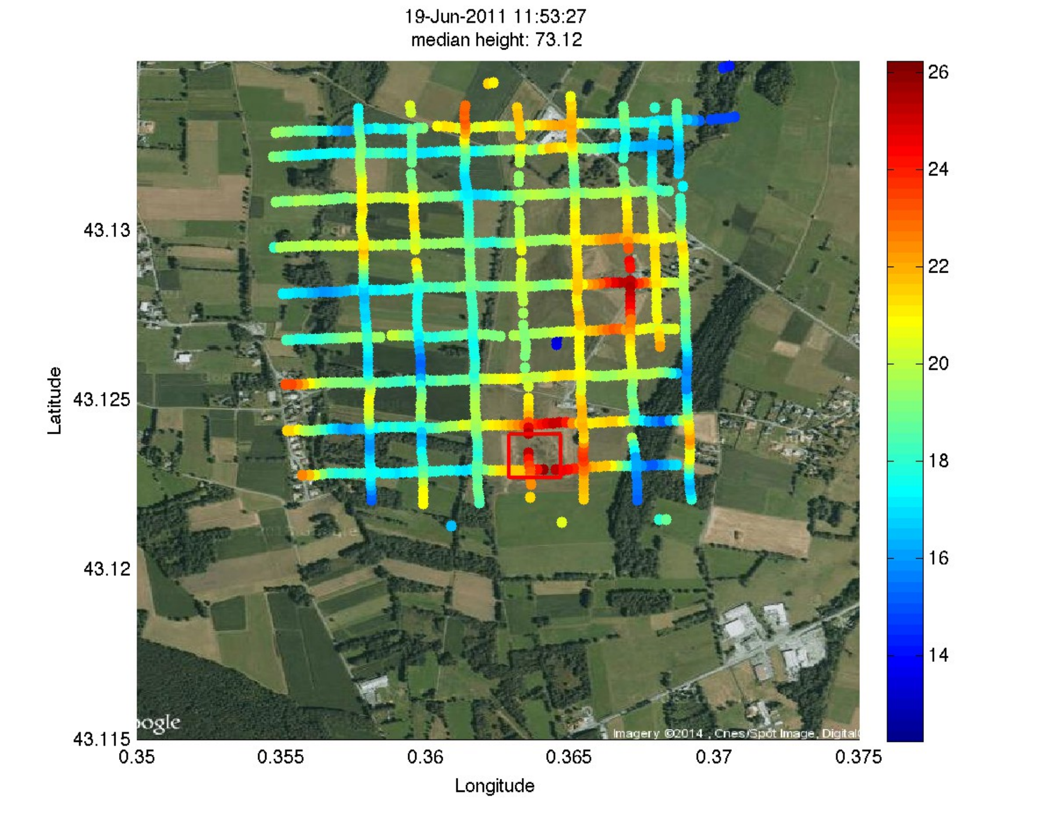
(Jimenez et al, AFM, 2015)

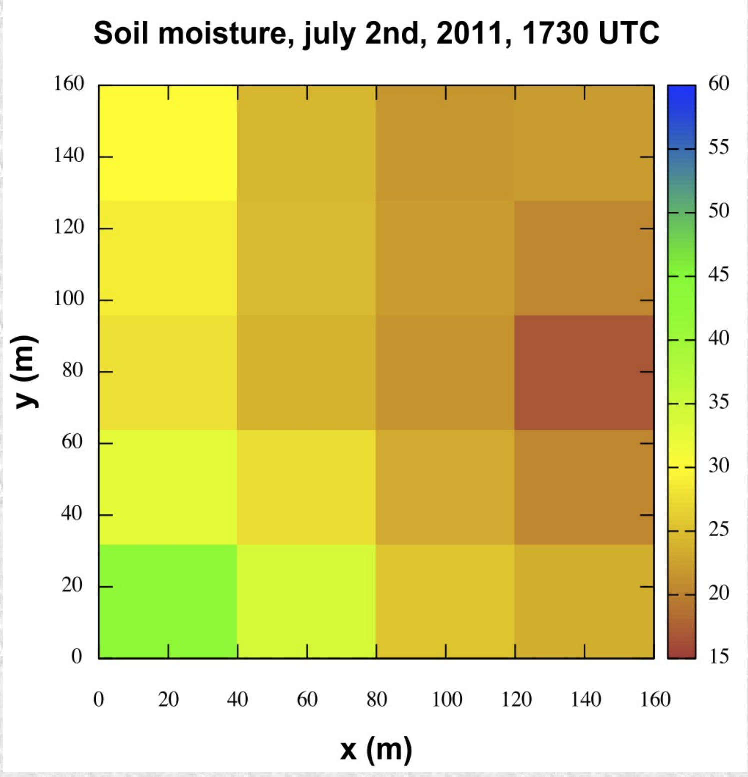
4.4 Heterogeneities at the km, hm & dm scales (BLLAST'11)

(Cuxart et al, ACP, 2016)









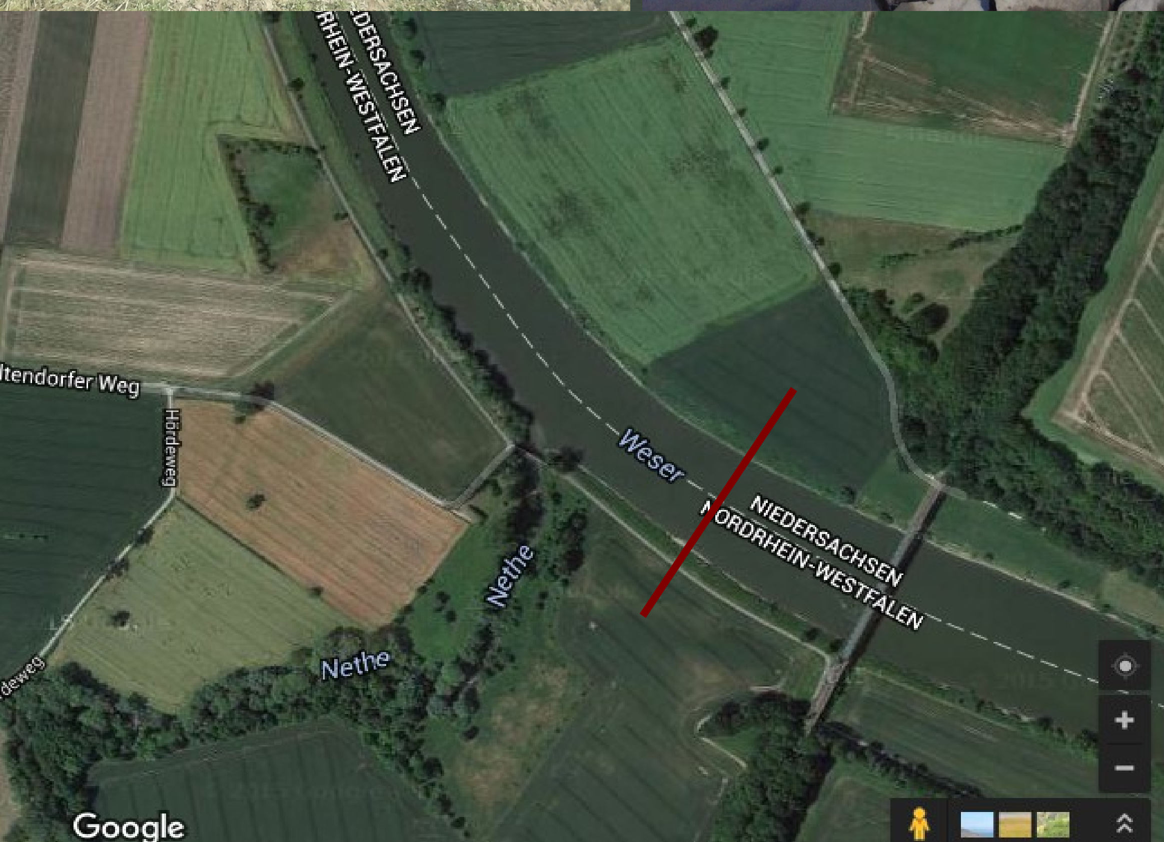
4.5 Orders of magnitude of the advection term depending on the scale for BLLAST'11

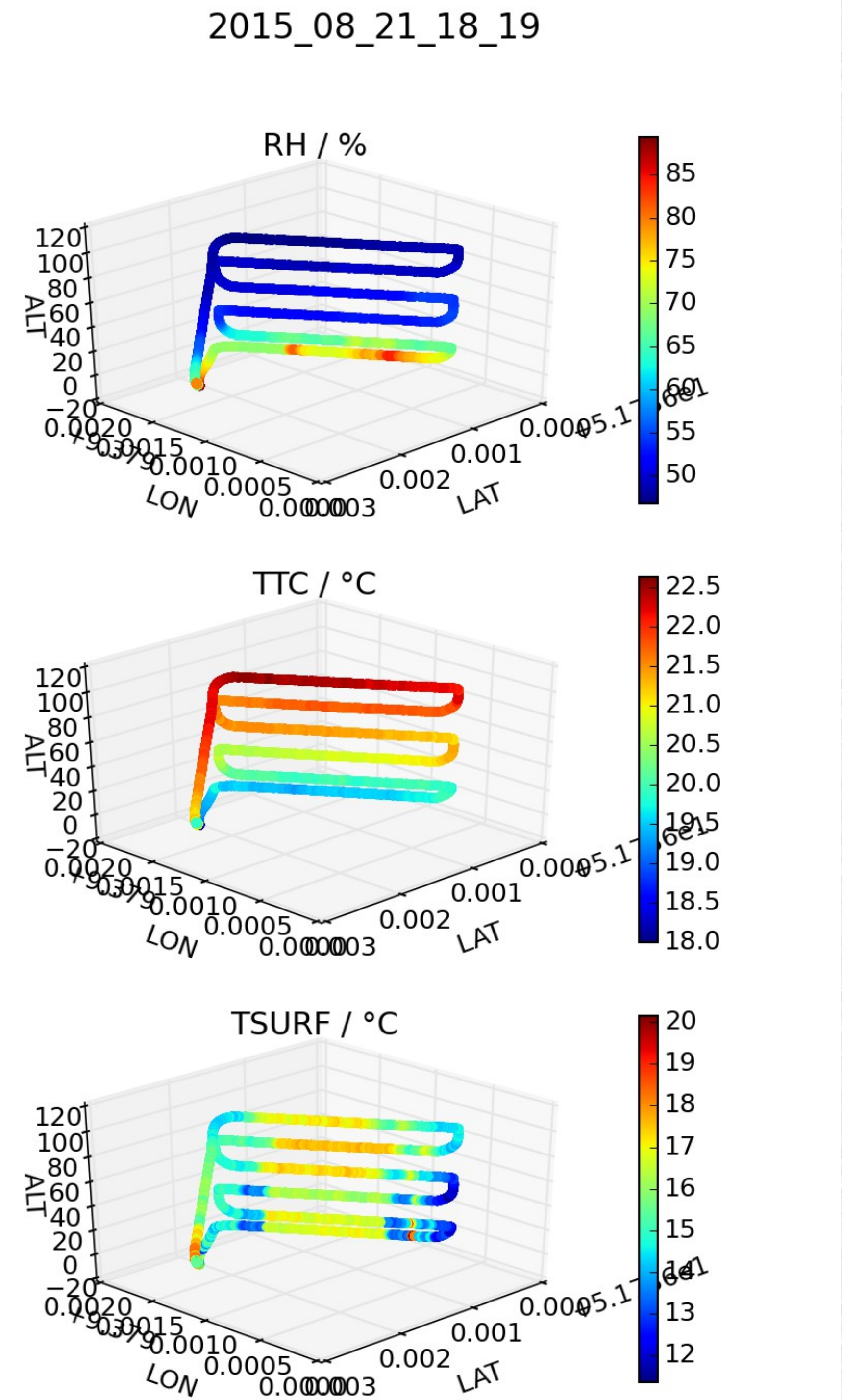
Table 1. Estimation of the advection scale for different sources and scales, taking 200 W m^{-2} as imbalance at the center of the day (D) and 30 W m^{-2} at night (N). The orders of magnitude are rounded, as are the percents of the imbalance.

Source	Scale r (m)	D/N	$\sigma(T)(K)$	$O(\sigma(T)/r)(K/m)$	$O(Adv(T))(W\,m^{-2})$	% Imb
Model and satellite	2000	D	2	0.0010	1	0.5
		N	1	0.0005	0.5	2
Model	400	D	1.5	0.0038	10	5
		N	1	0.0025	5	15
SUMO	100	D	2	0.0200	50	25
		N	1	0.0100	25	30
Model	80	D	0.5	0.0063	15	7.5
		N	0.5	0.0063	15	50
Multicopter	10	D	0.5	0.0500	125	60
		N	0.2	0.0200	50	160
Thermal camera	1	D	0.5	0.5000	1250	600
	1	N	0.1	0.1000	250	800

(Cuxart et al, ACP, 2016)

4.6 The thermal signature of a river (Weser, Aug'15)





Wrenger and Cuxart, BLM (in preparation)

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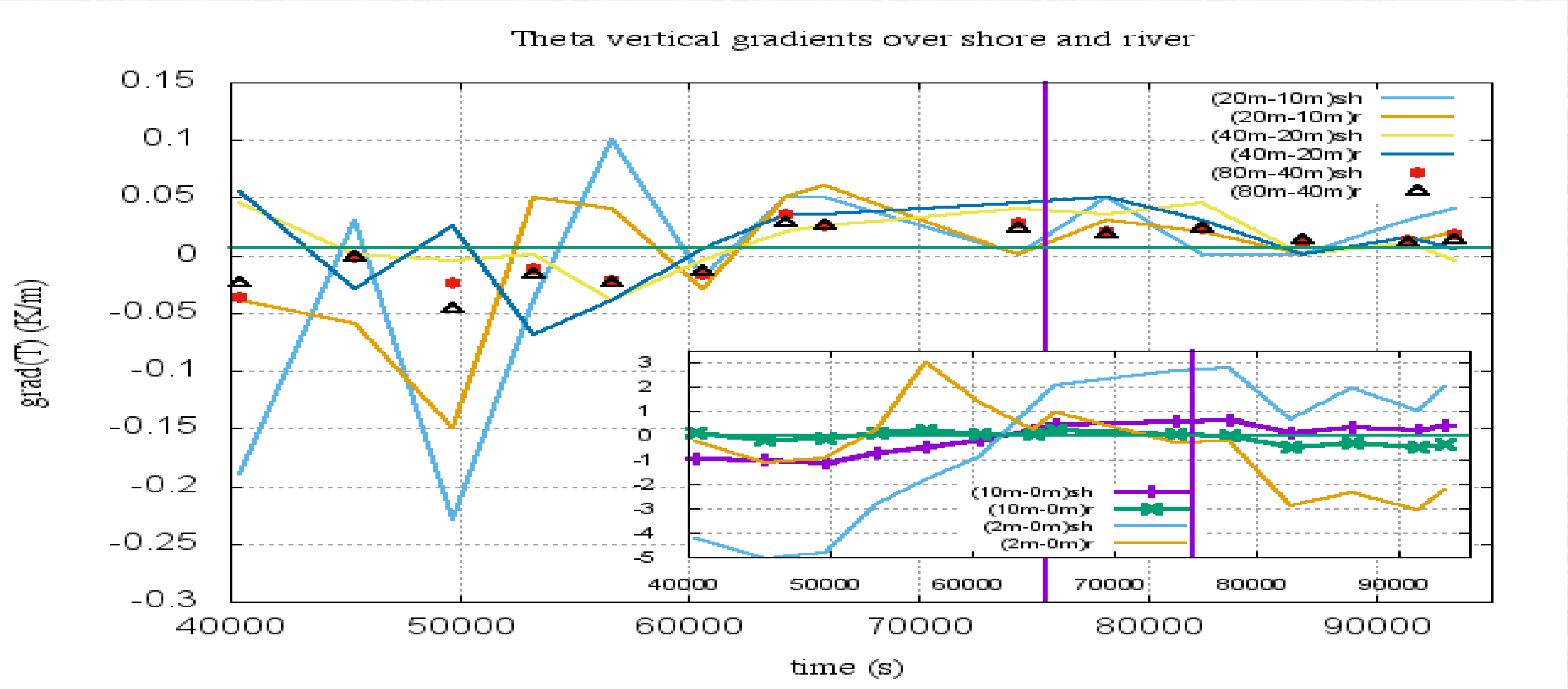
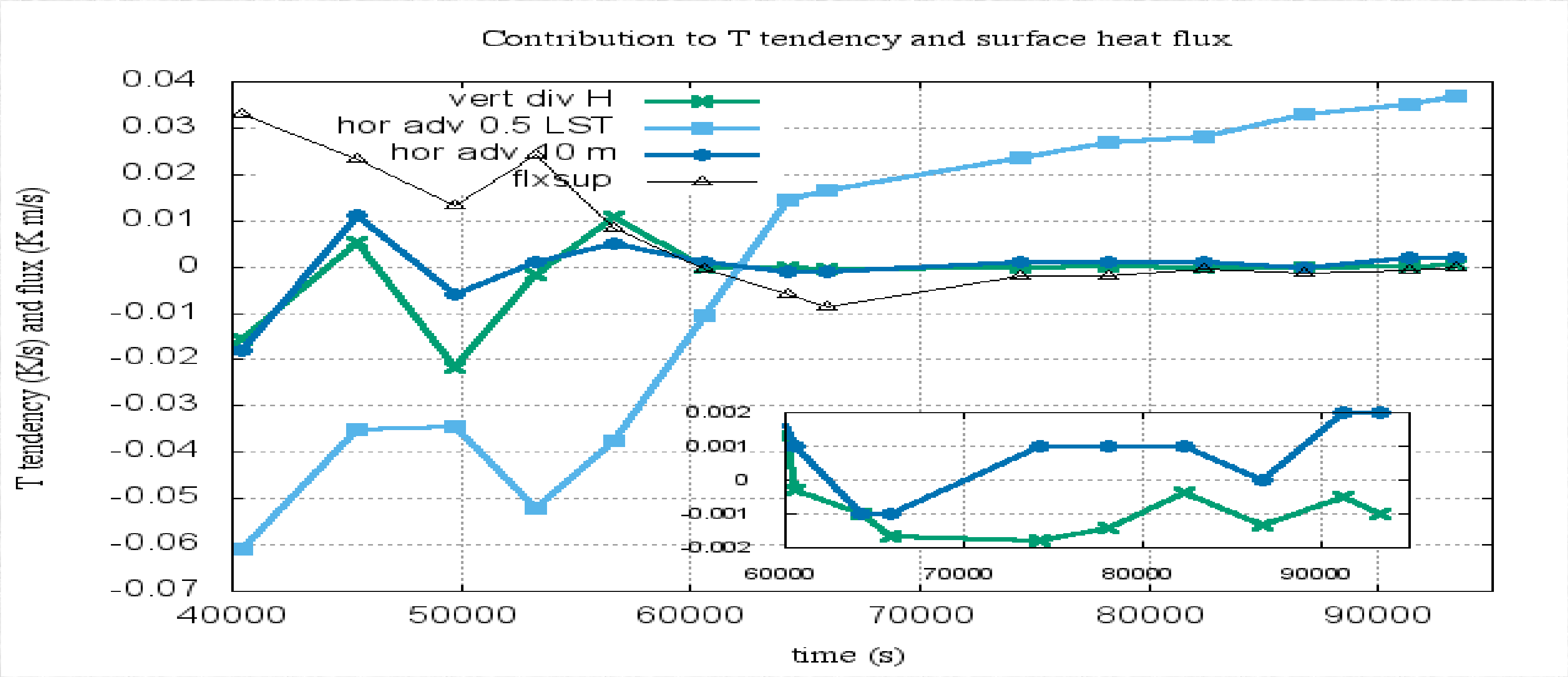




Wrenger and Cuxart, BLM (in preparation)

4.7 The Subpixel campaign (June 16-March 17) at the UIB Campus, Palma Basin, Mallorca

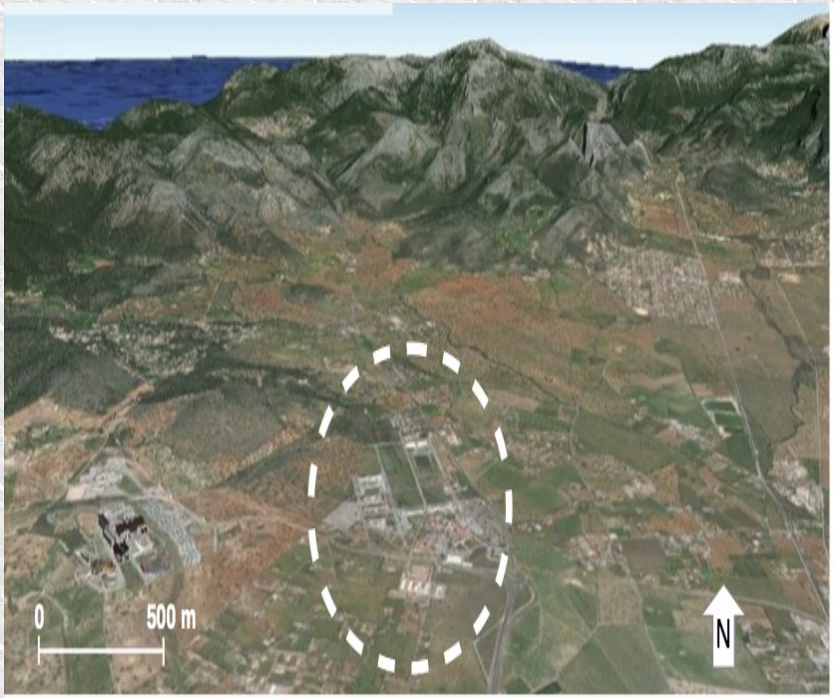
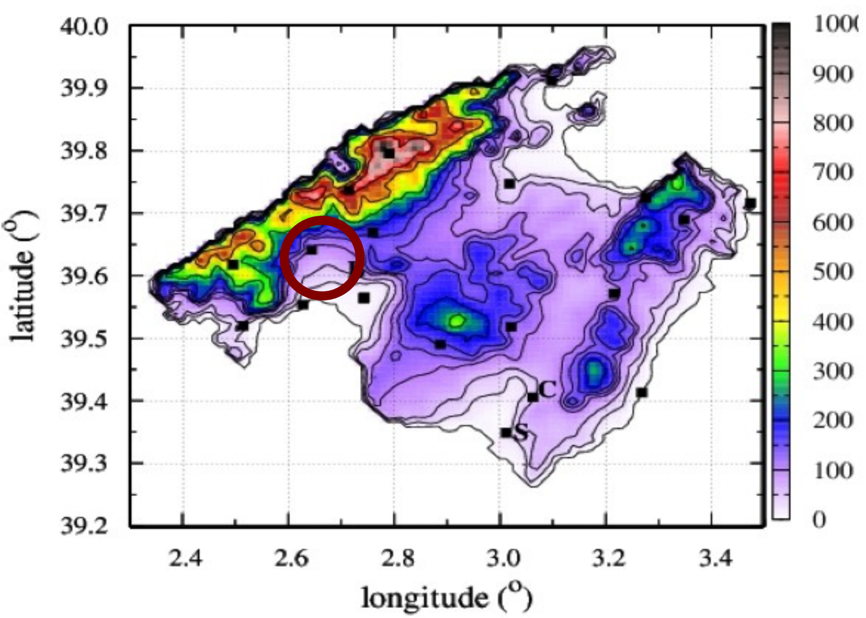


Fig. 2: Location of Campus UIB, at the foothill of Tramuntana mountain range (font: Google Earth)



(Simó et al, Remote Sensing, submitted 2016)

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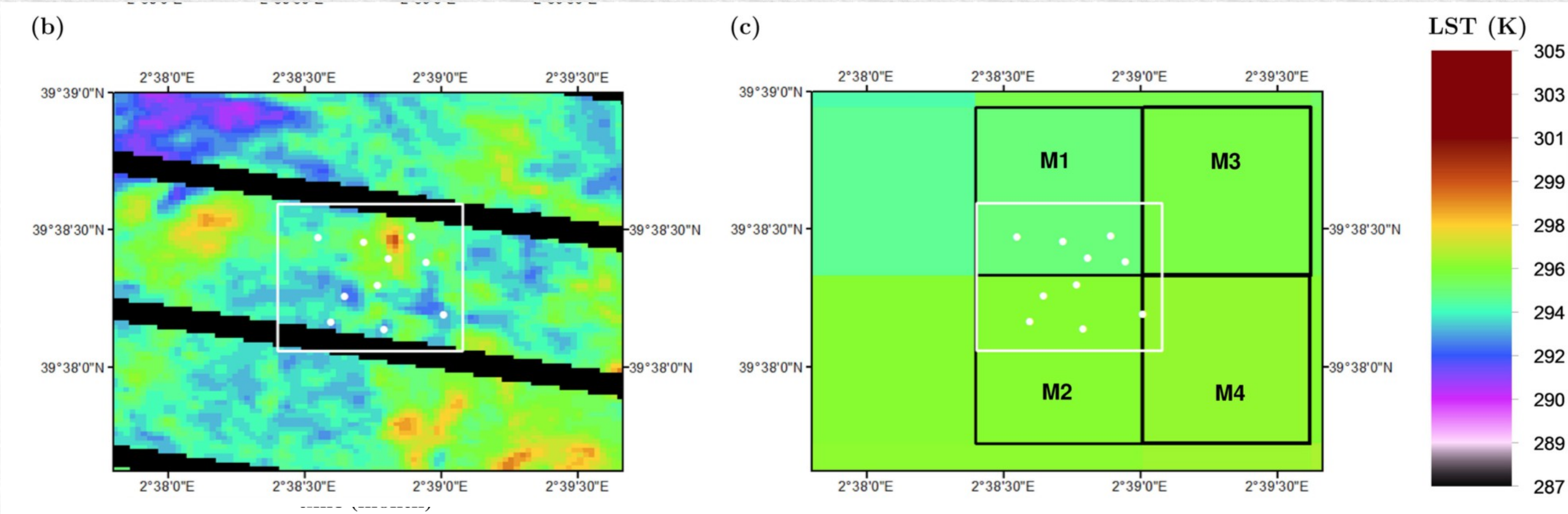
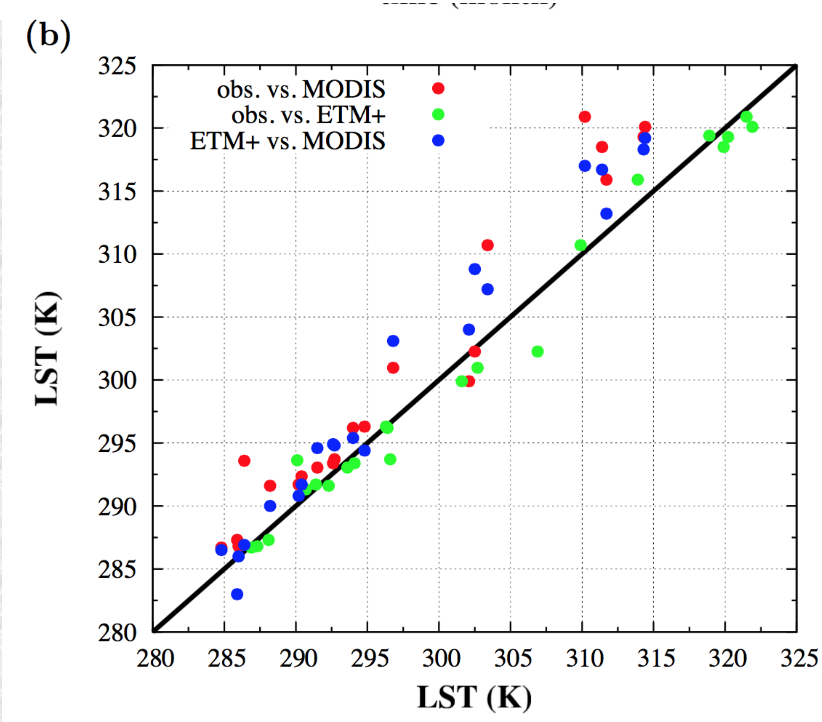
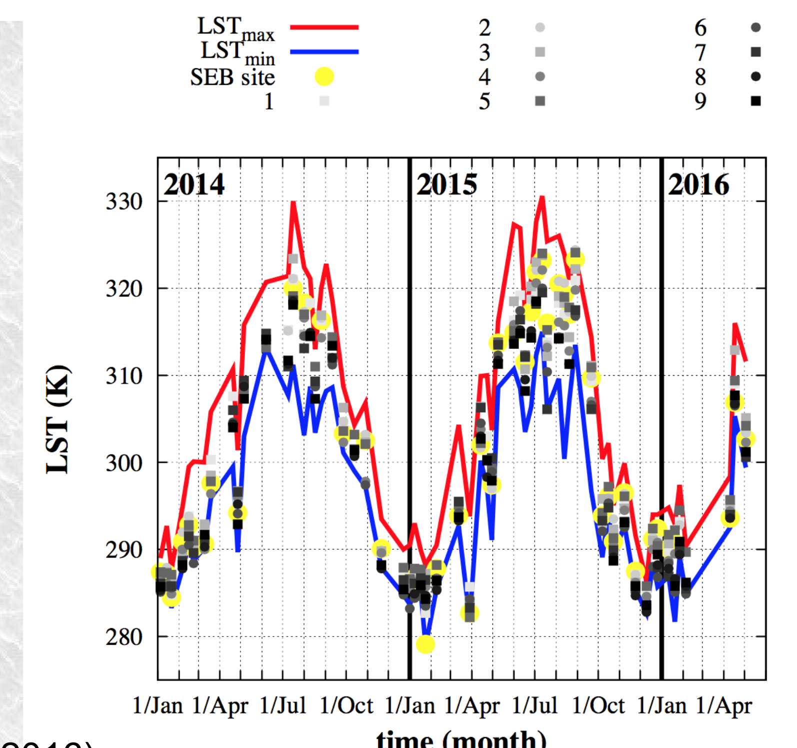


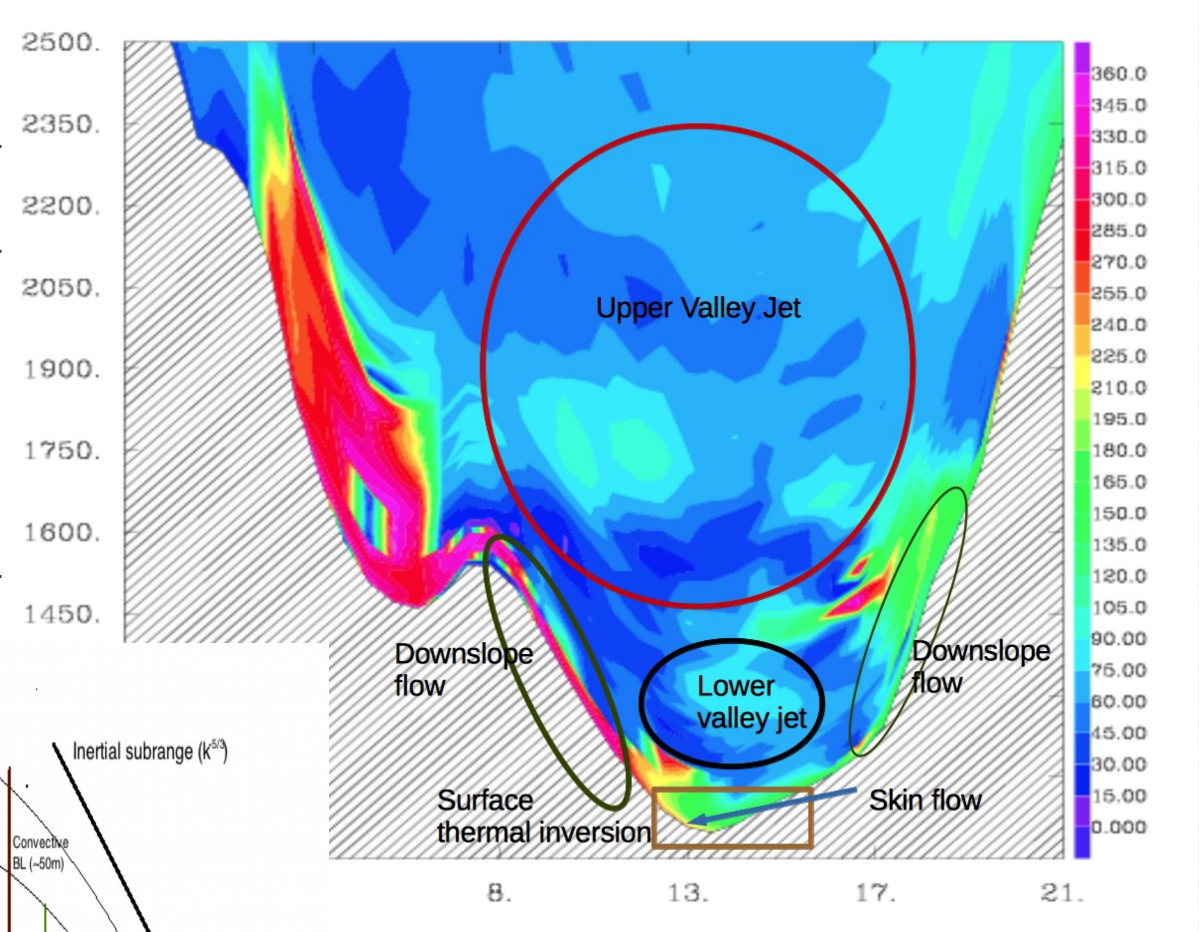


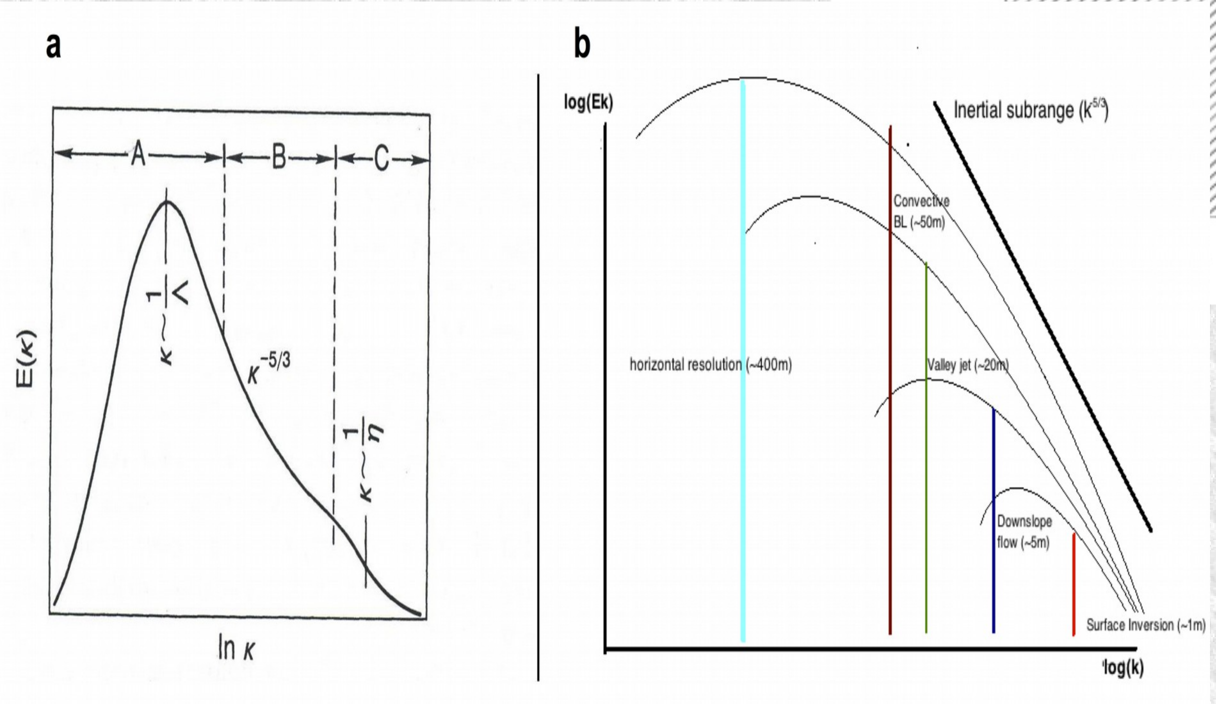


(Simó et al, Remote Sensing, submitted 2016)

5.1 Complex topography: No clear distinction between mesoscale-gamma and ABL processes

Structure	horizontal scale	vertical scale	Inertial Subrange
Upper valley jet	O(10 km)	O(1km)	O(100m)
Lower valley jet	O(1 km)	O(100m)	O(10m)
Downslope flow	O(100m)	O(10m)	O(1m)
Skin flow	O(100m)	O(1m)	O(0.1m)
Surface inversion	O(1km)	O(100m)	O(1m)
Shallow surface inversion	O(1km)	O(10m)	O(0.1m)

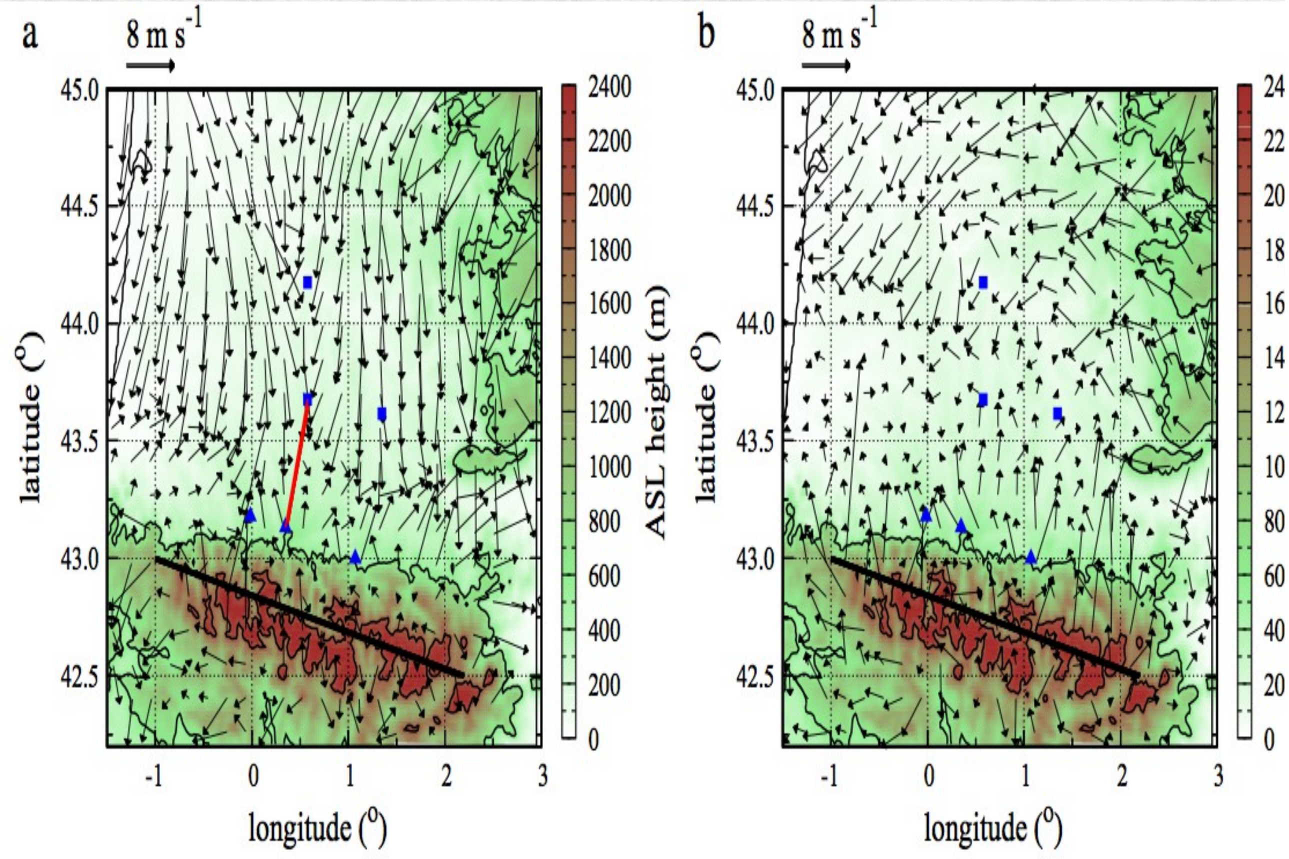


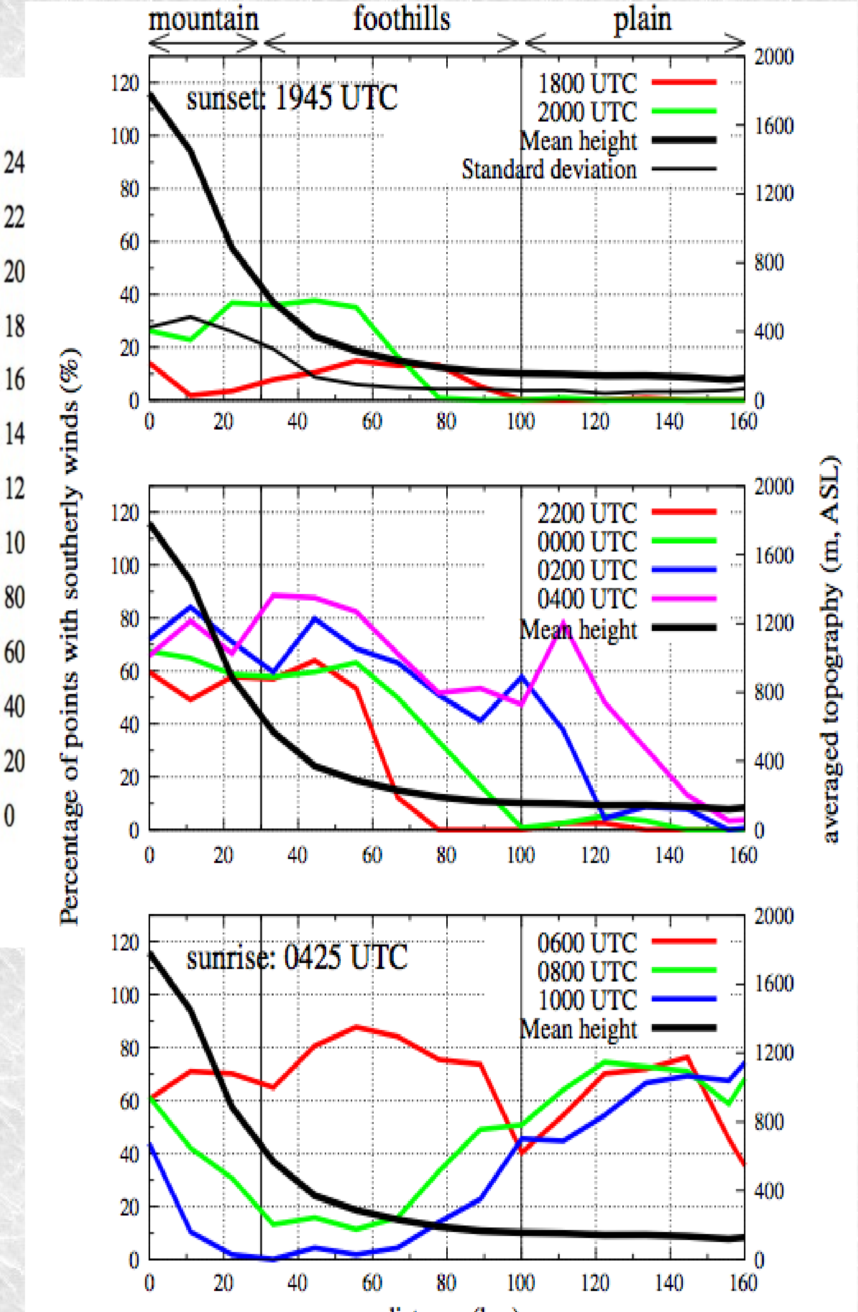


(Cuxart, Frontiers in Earth Science, 2015)

5.2 Mountain-Plain circulation (a BLLAST type case)

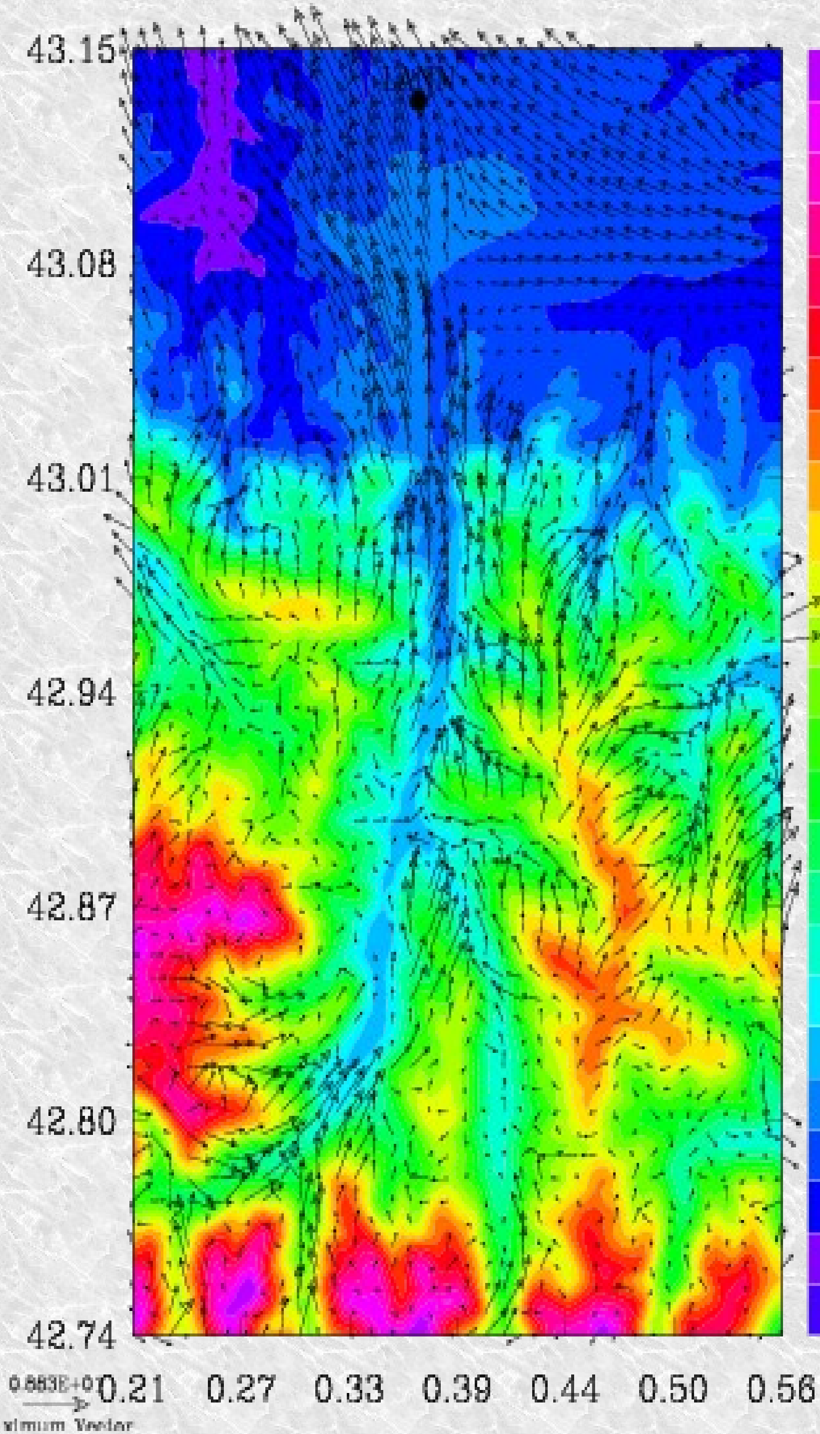
Bllast

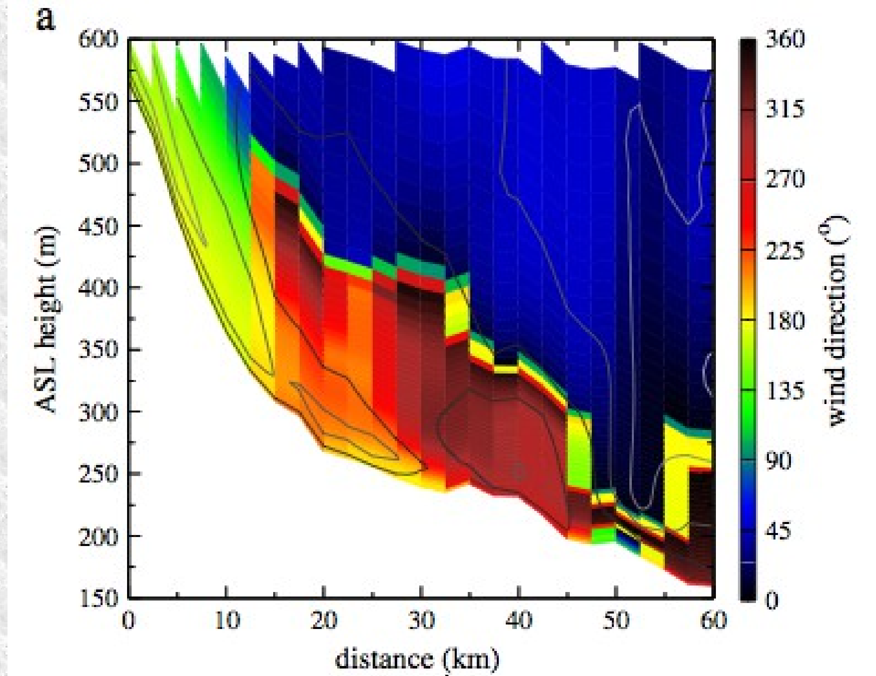




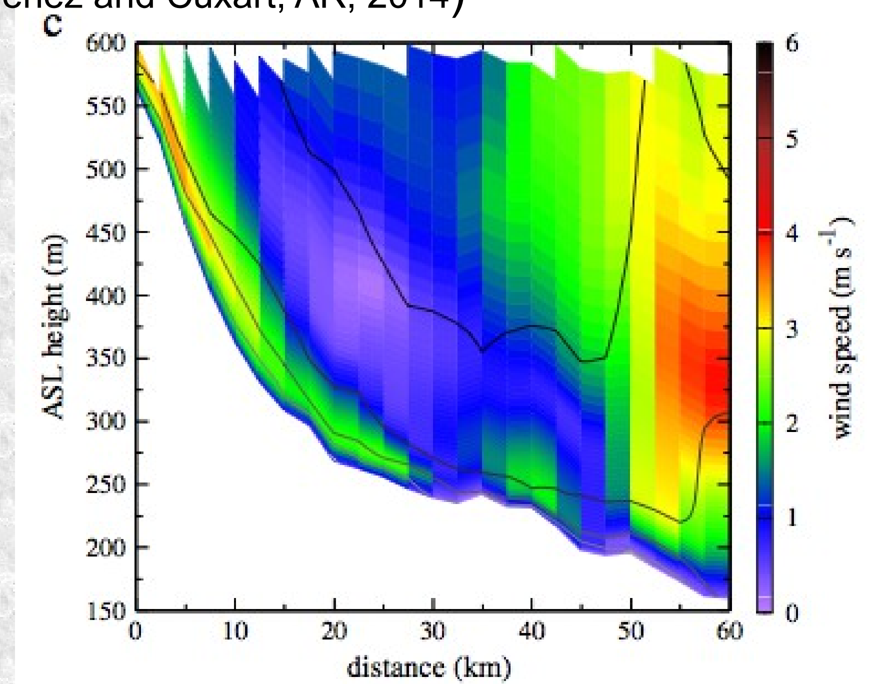
(Jimenez and Cuxart, AR, 2014)

5.3 Out-valley jet over the Lannemezan Plateau (BLLAST type case)

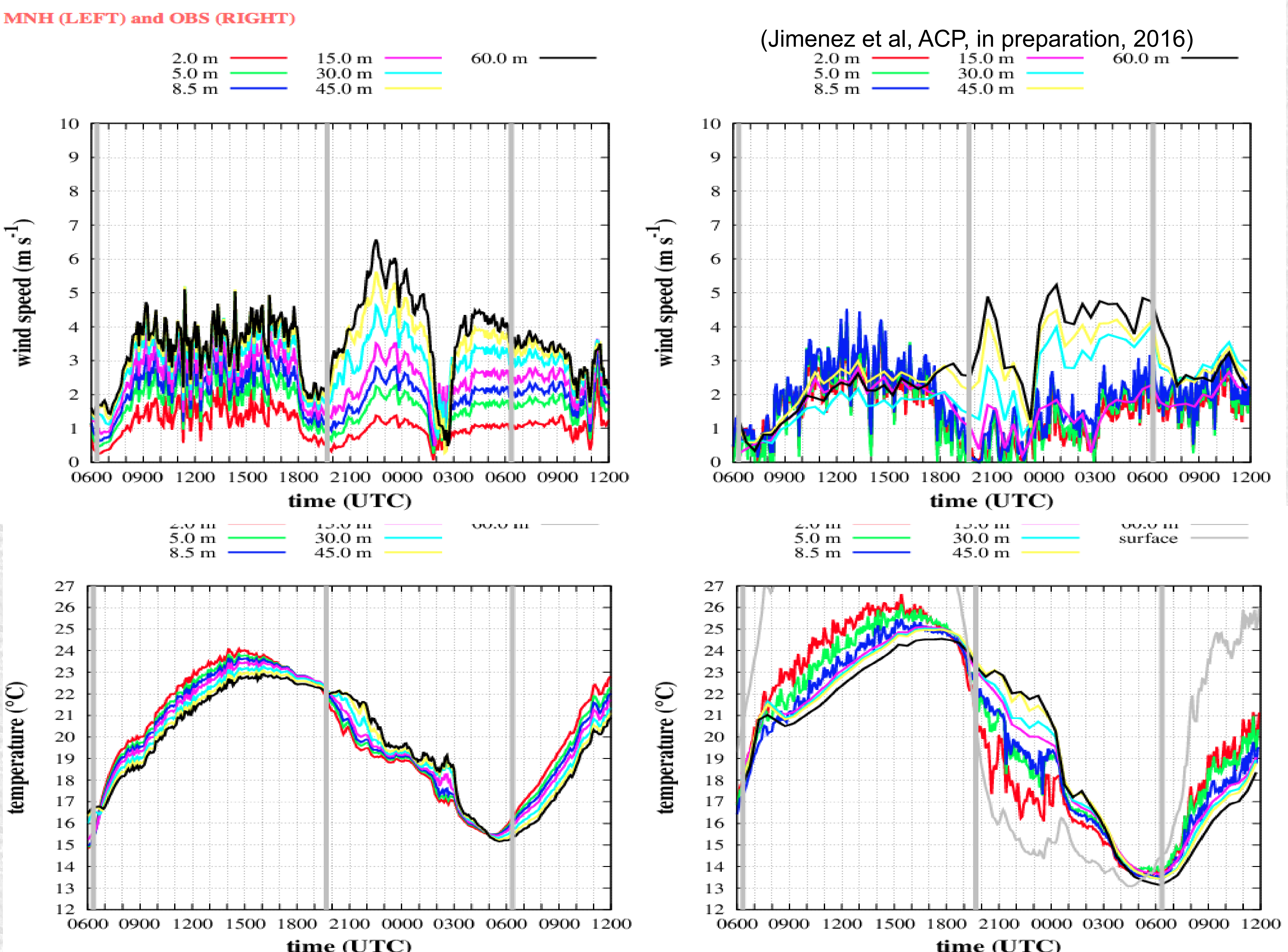




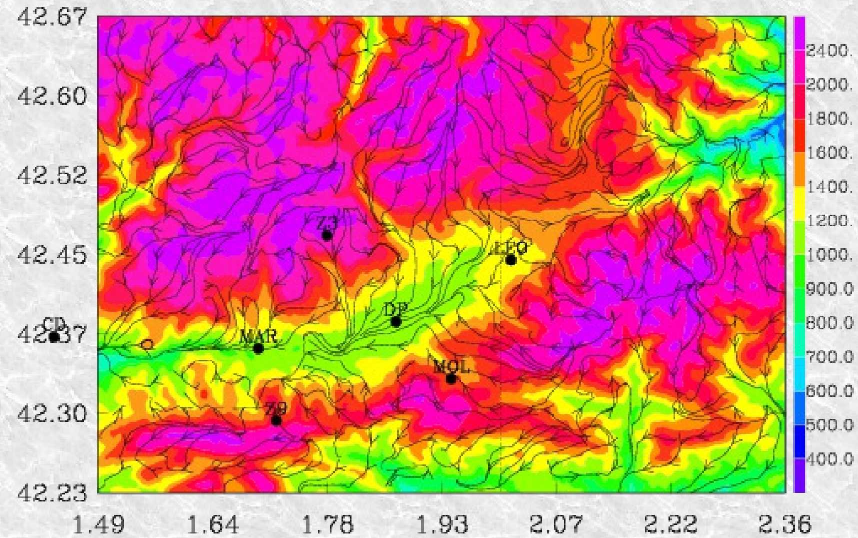
(Jimenez and Cuxart, AR, 2014)

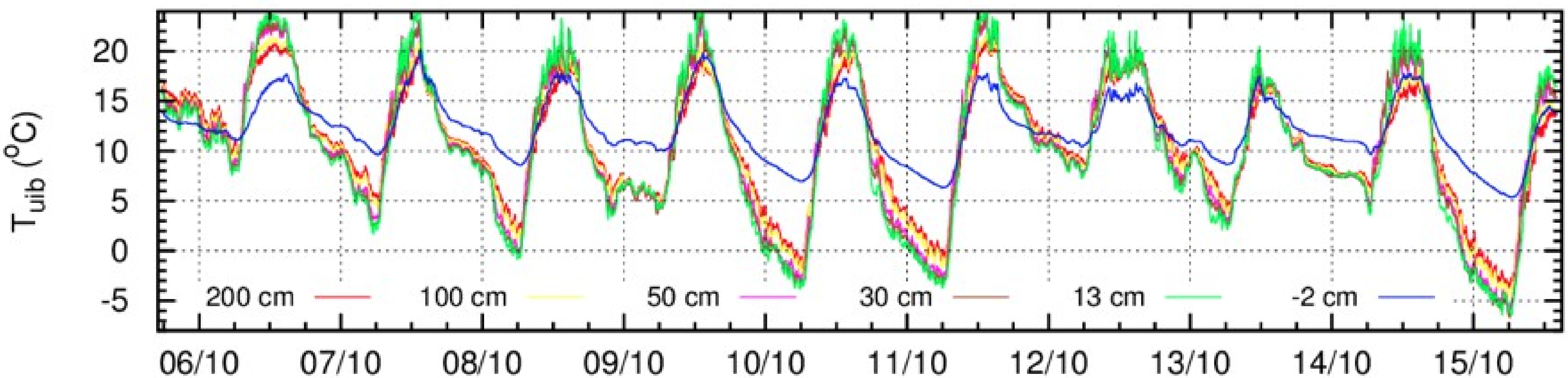


5.4 Modelled and observed wind and T profiles over the Lannemezan Plateau (BLLAST)

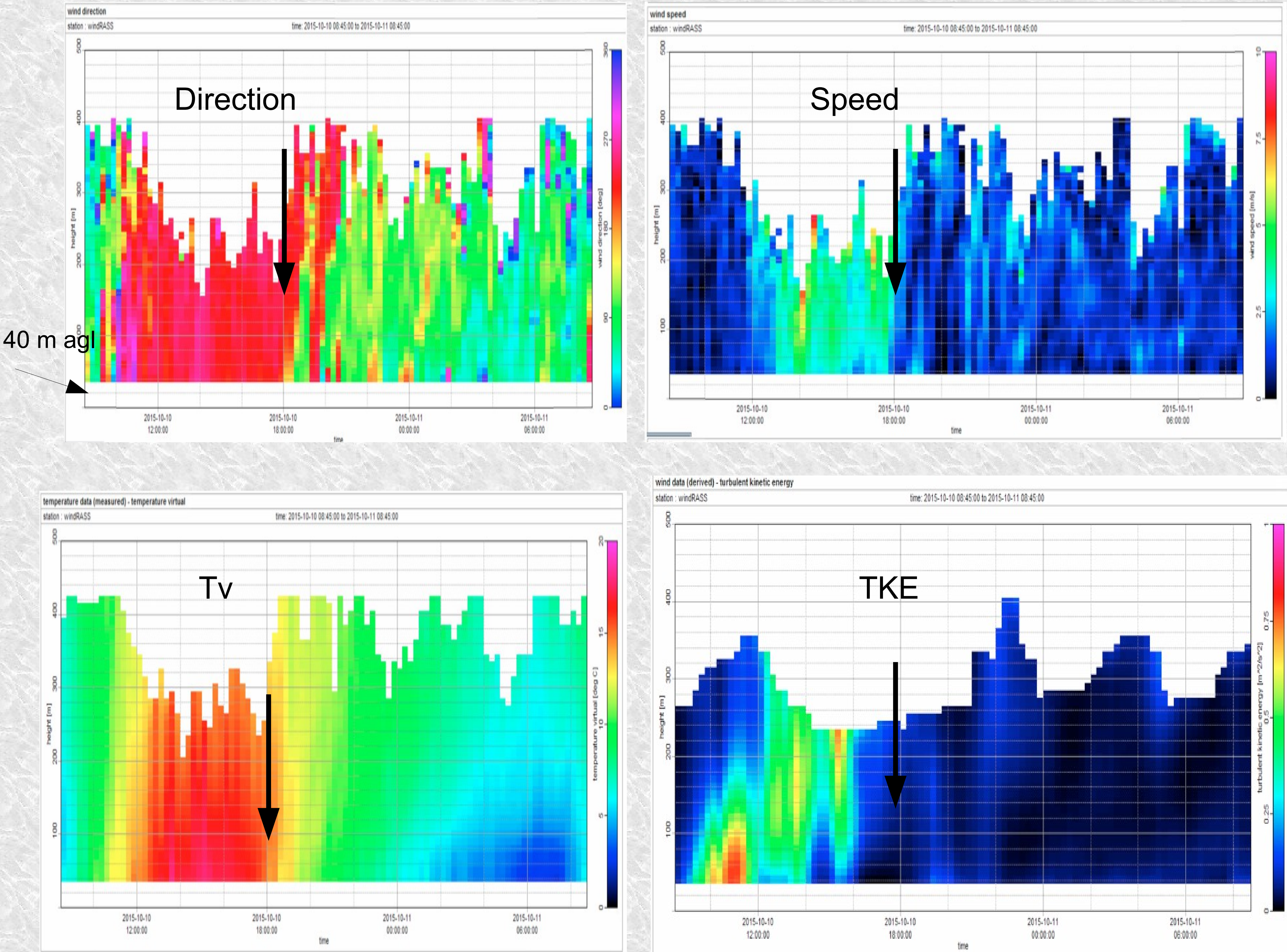


5.5 The Cerdanya Cold Pool experiment (CCP'15, Pyrenees, October 2015)

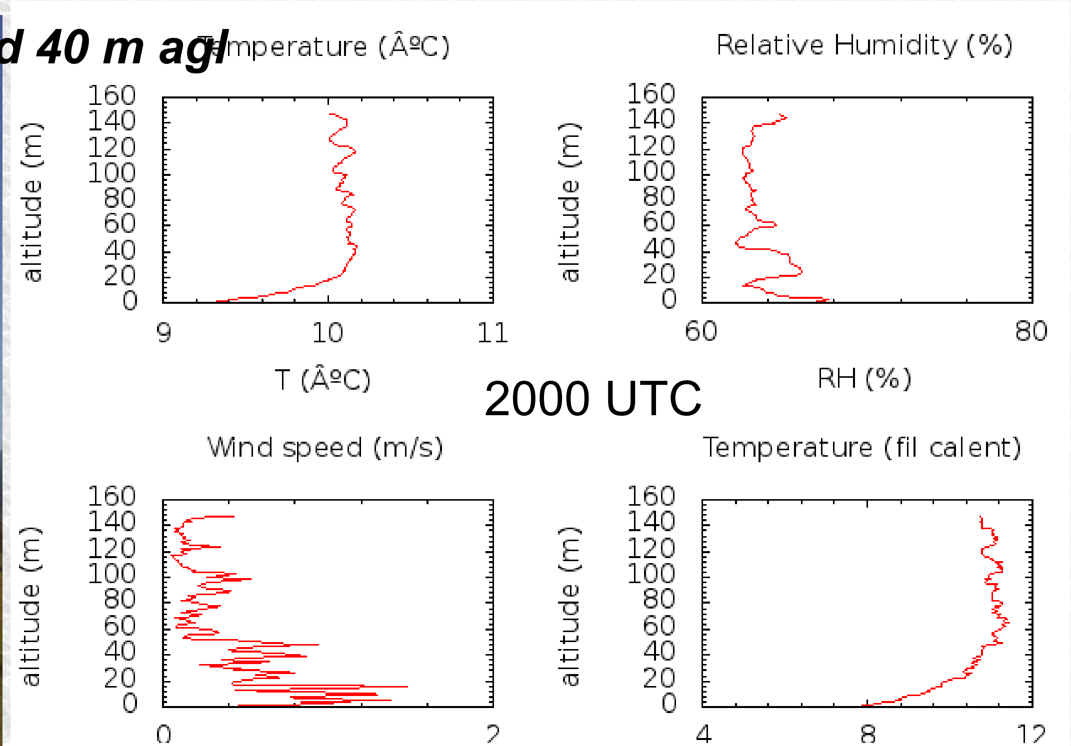


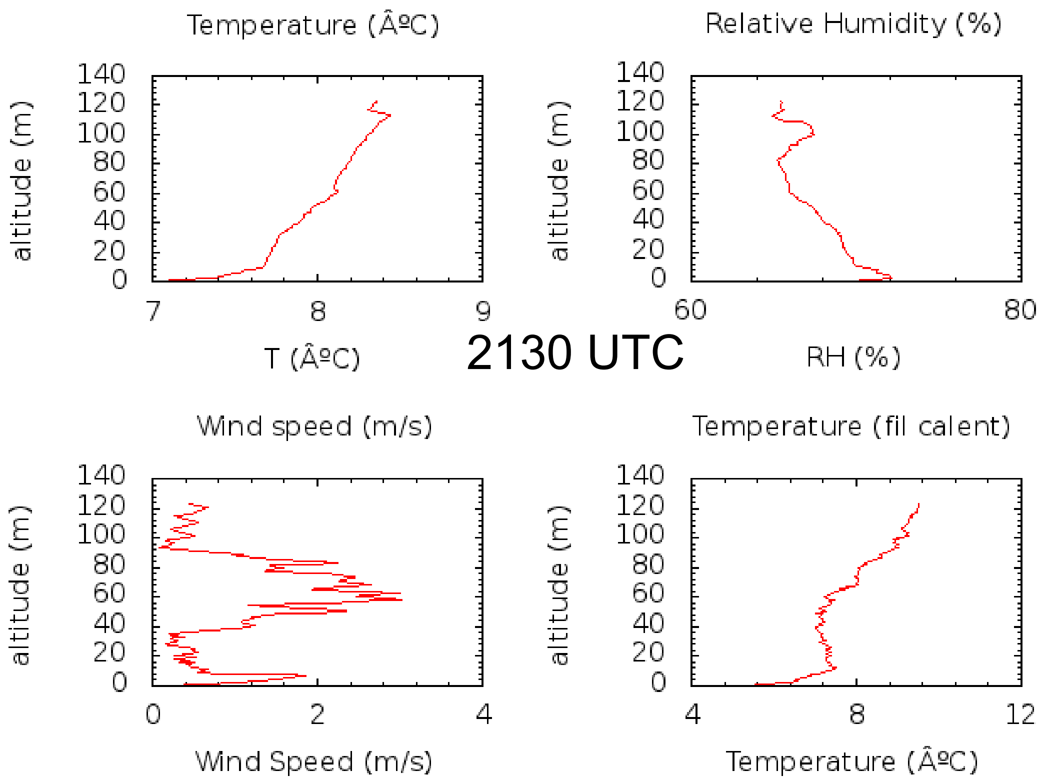


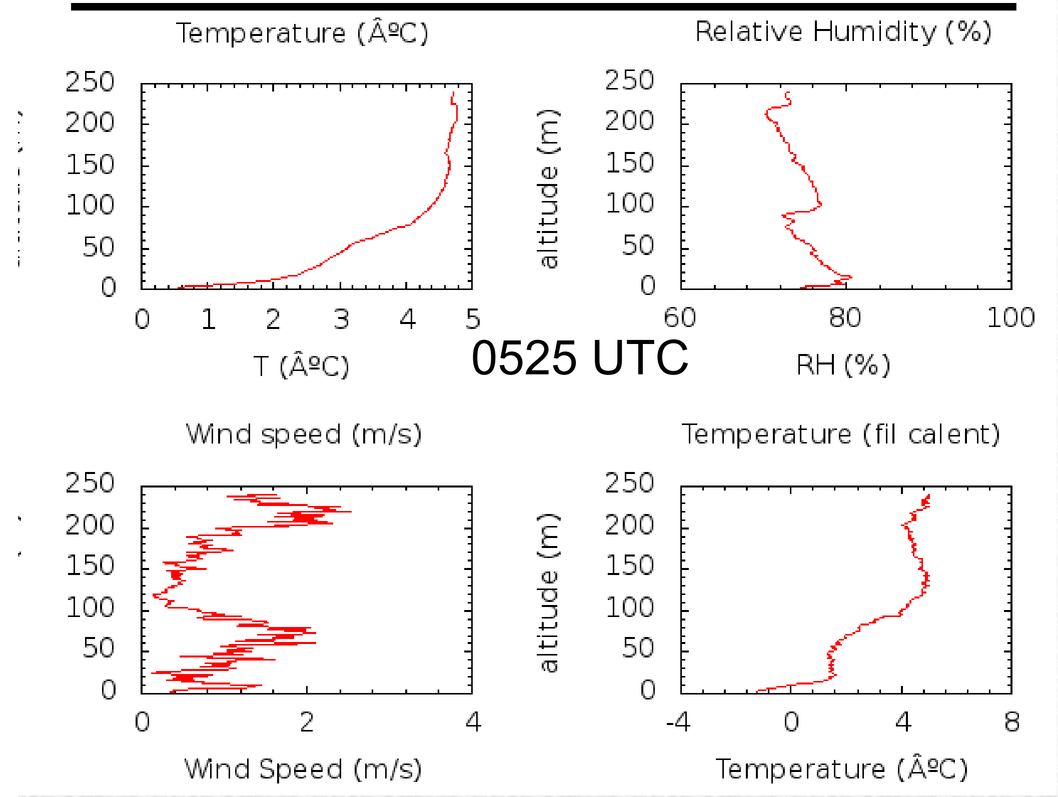
5.6 The reversal of the wind as seen by the WindRASS (CCP'15, IOP3, 10-11 Oct 2015)



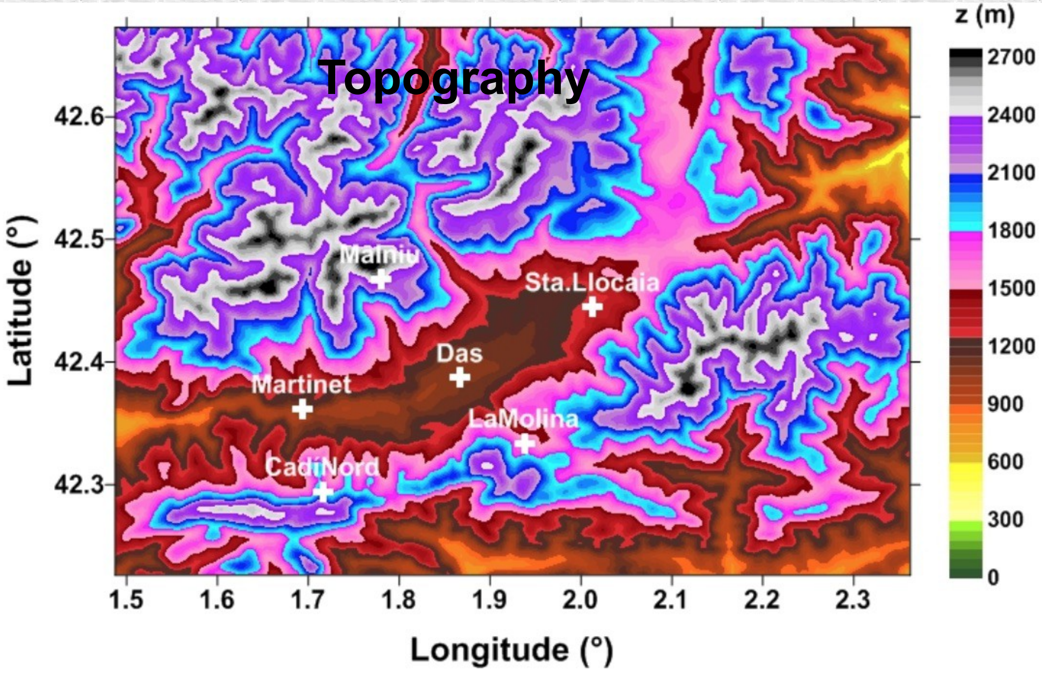
5.7 CCP'15 detailed structures between 2 and 40 m agl

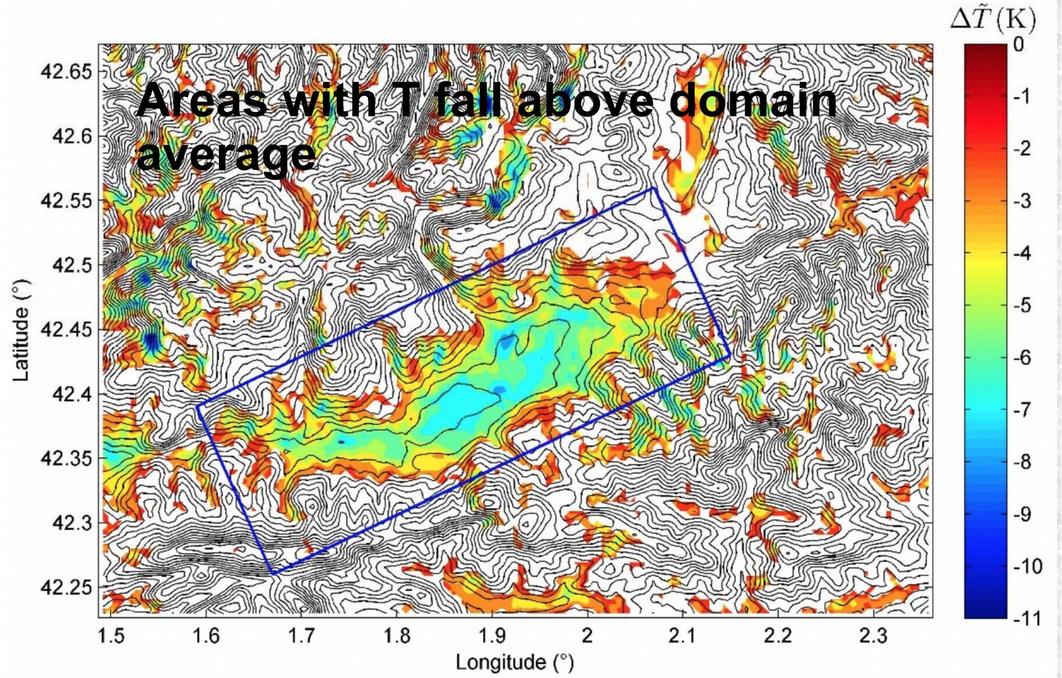


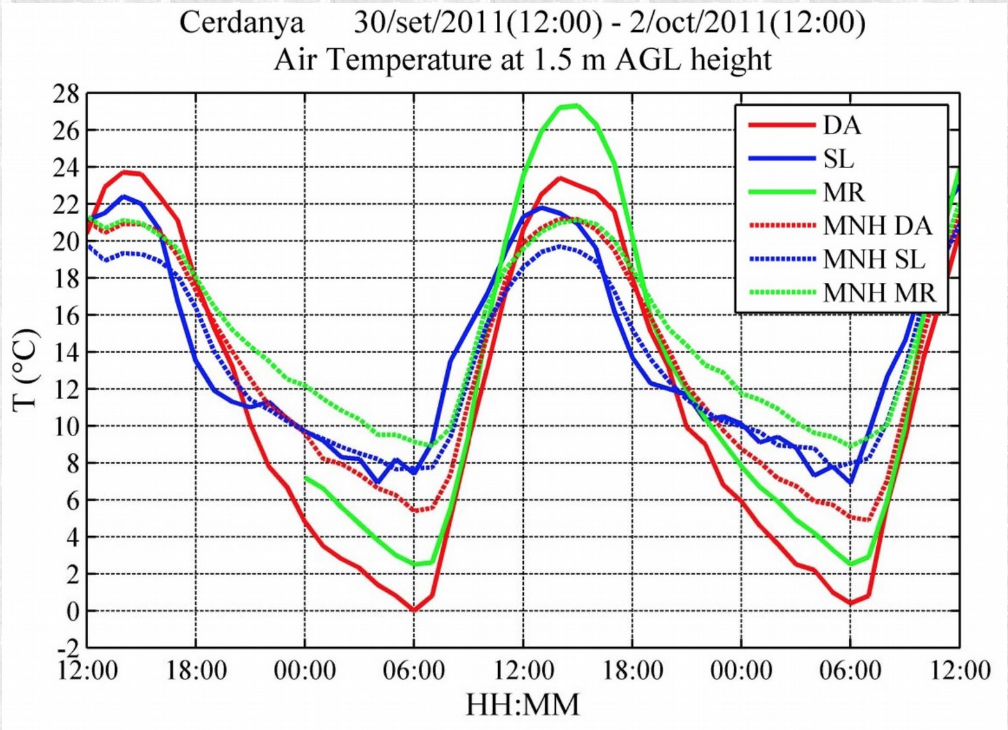


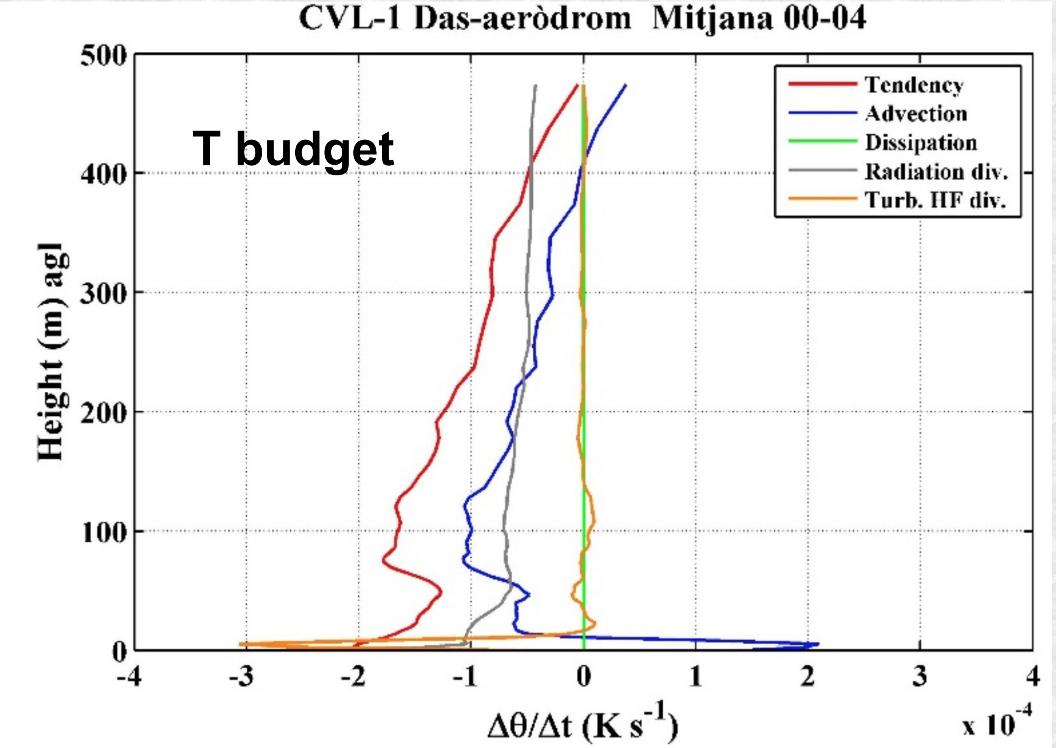


5.8 The Cerdanya Cold Pool as seen by a high-resolution simulation





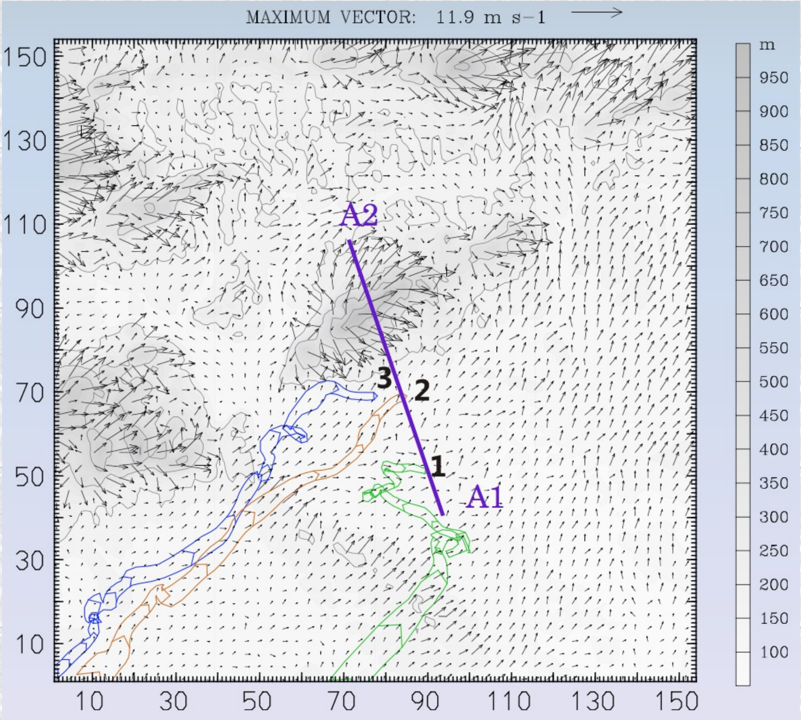




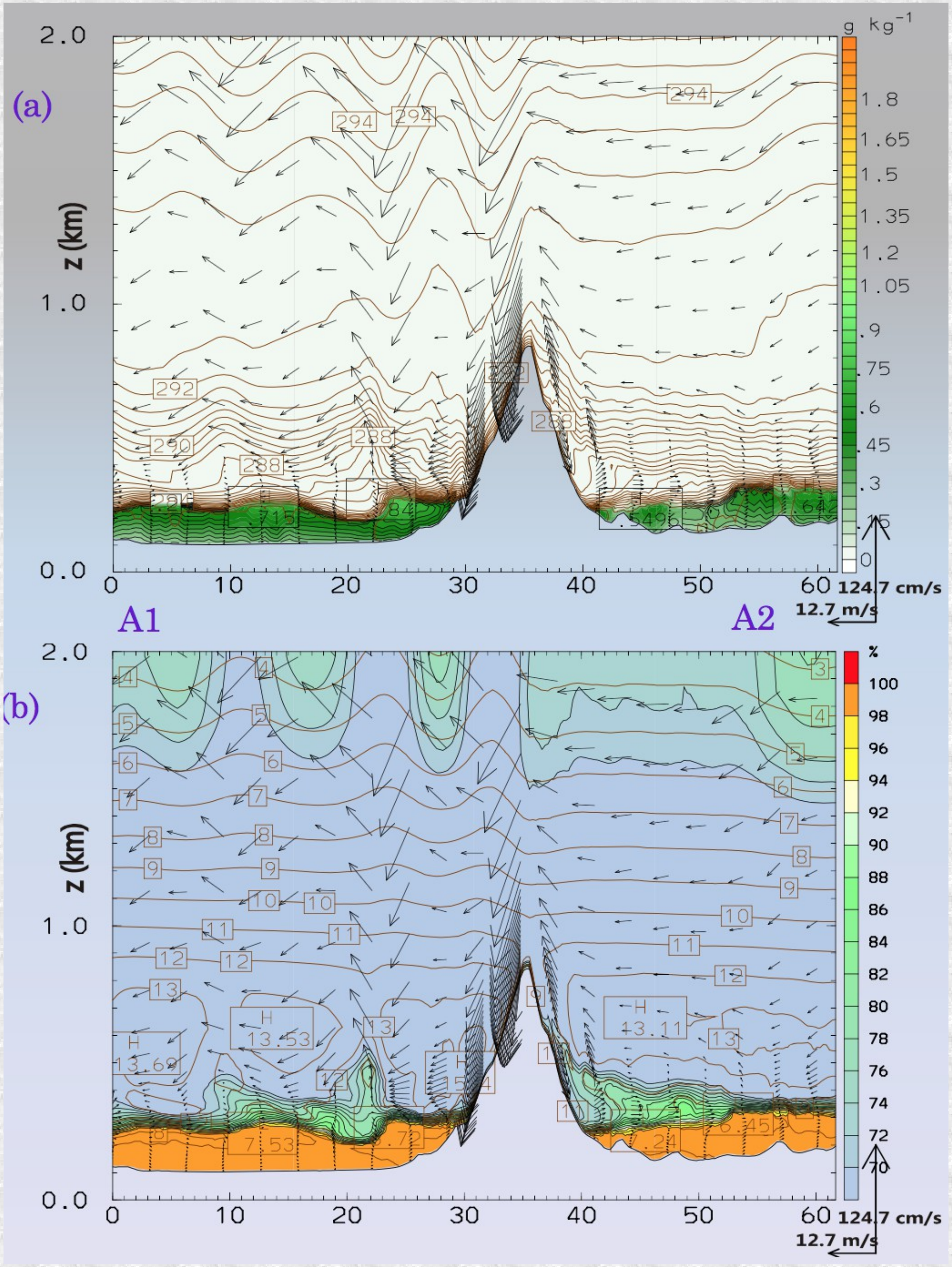
(Conangla et al, JAMC, in preparation)

Medvenica-Zagreb-Pleso airport

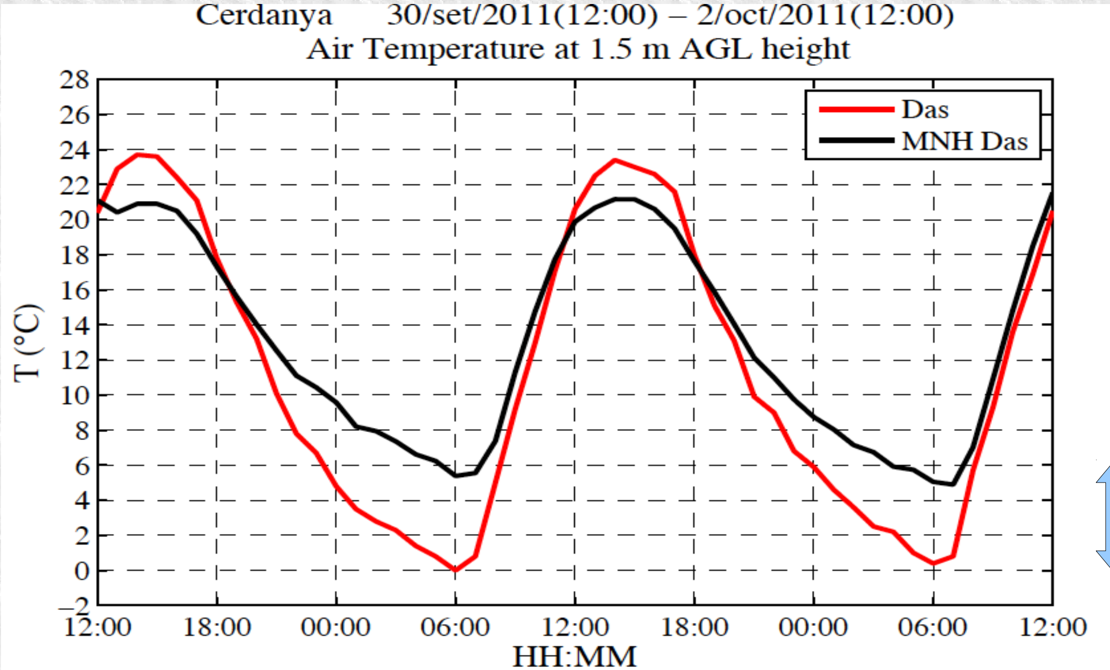
Downslope flows over city blowing over the surface thermal inversion



(Telisman-Petenjak et al, 1st Pannex workshop, 2015)



6.1 Inversions and transitions



Diurnal cycle in the bottom of the Cerdanya valley in autumn anticyclonic conditions

(Conangla et al, JAMC, in preparation)

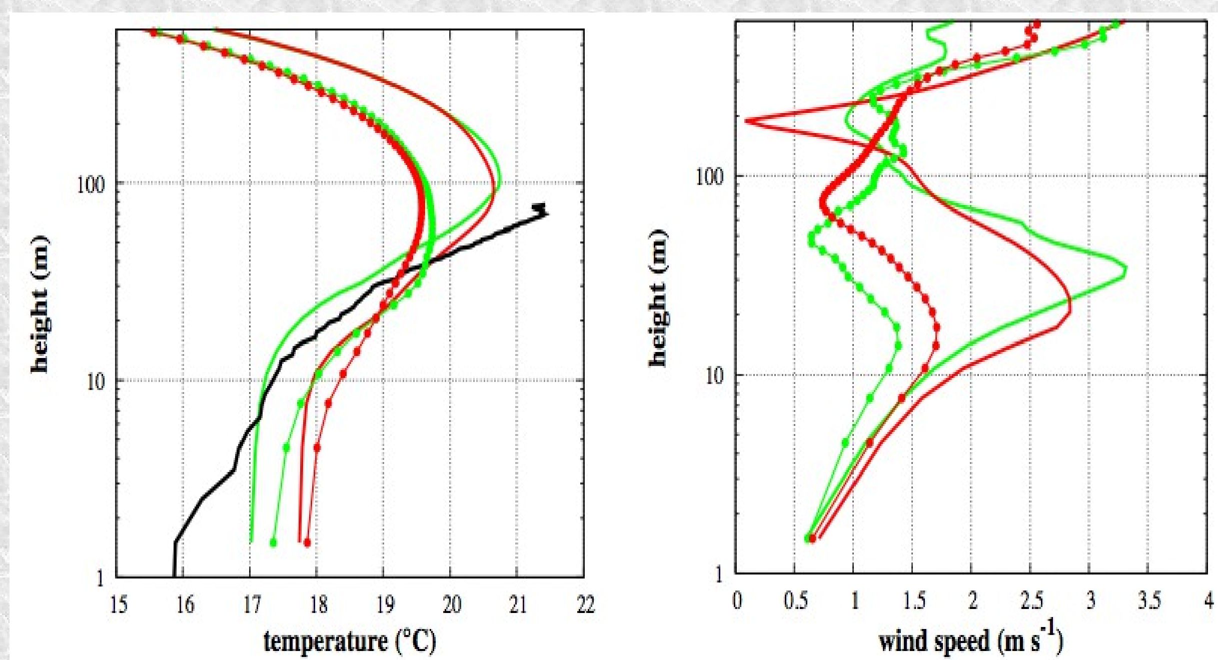
~6 K ! Slope and valley flows seem to weaken too much the cold pool

Inversion at Mallorca (20S2013)

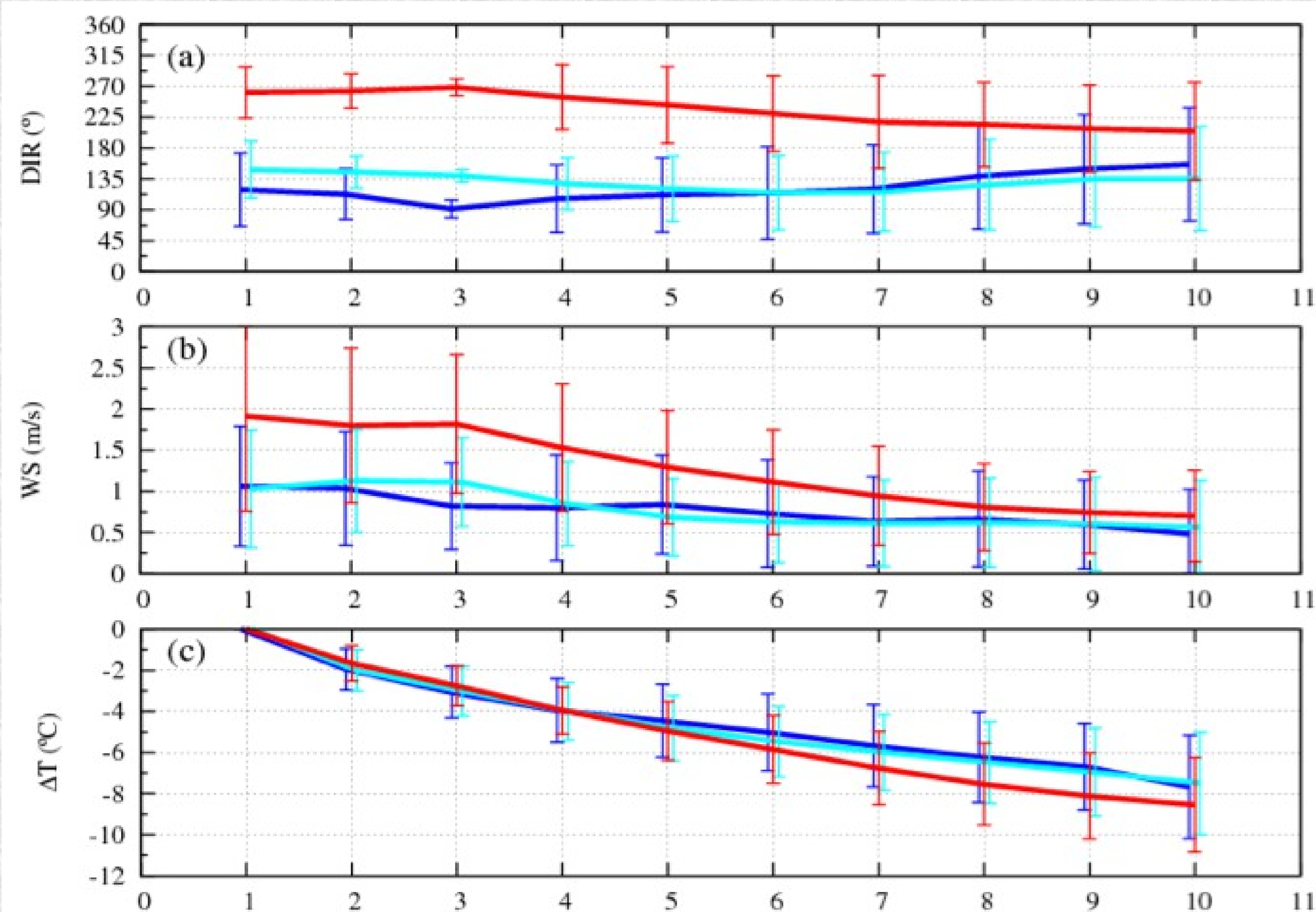
T profile (logscale)
- obs (black)
- mod high TKEMIN (red)
- mod low TKEMIN (green)

Right (modelled wind speed)

(Jimenez et al, AR, 2016)



6.2 Two stable regimes: westerlies and local flows (Ebro, climatological study)



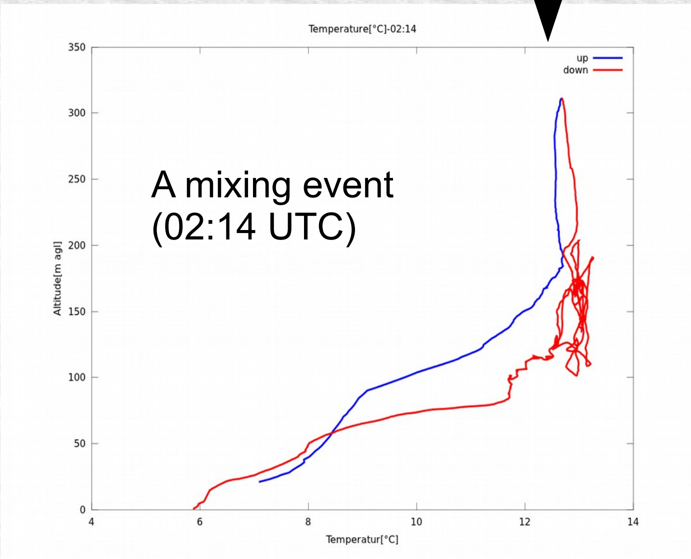
Westerlies blow stronger but cool more than local winds. All the column cools
Local winds display a two layer structure with intermittent mixing warming the SL:

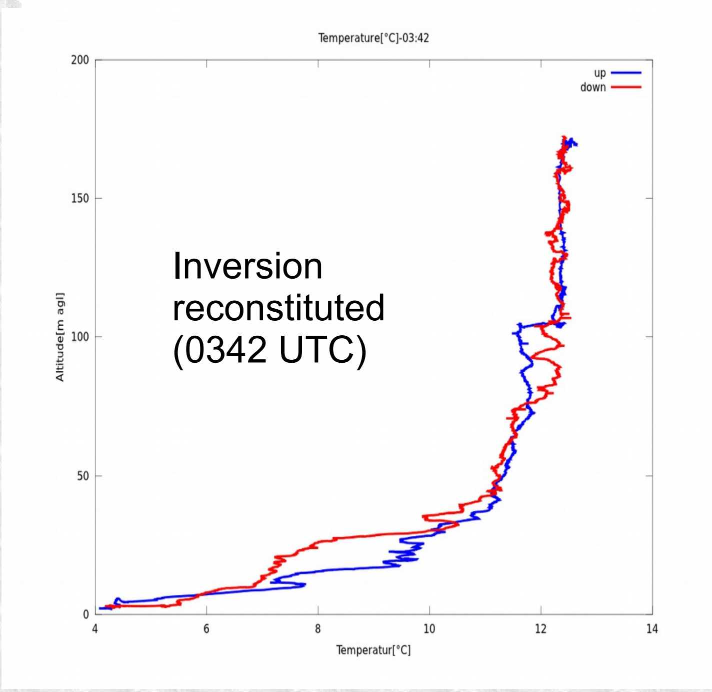
(Martinez et al, Tethys, 2008)

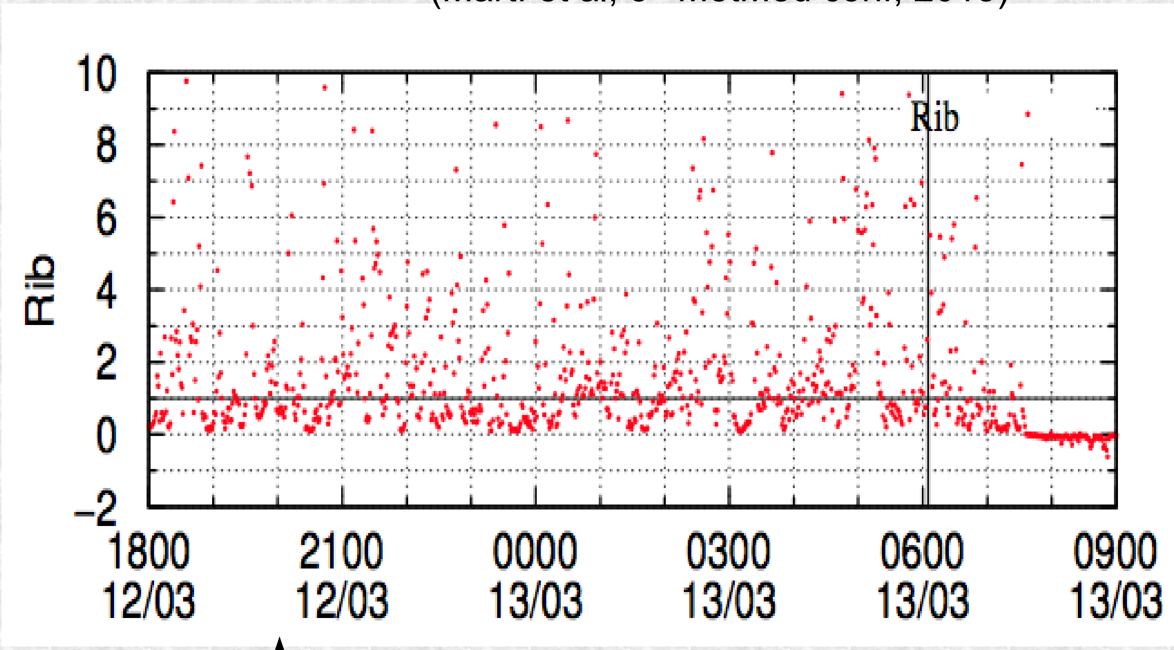
6.3 Inversions at Mallorca

(Martí et al, 5th MetMed conf, 2015)

Two soundings in a night with a downslope flow

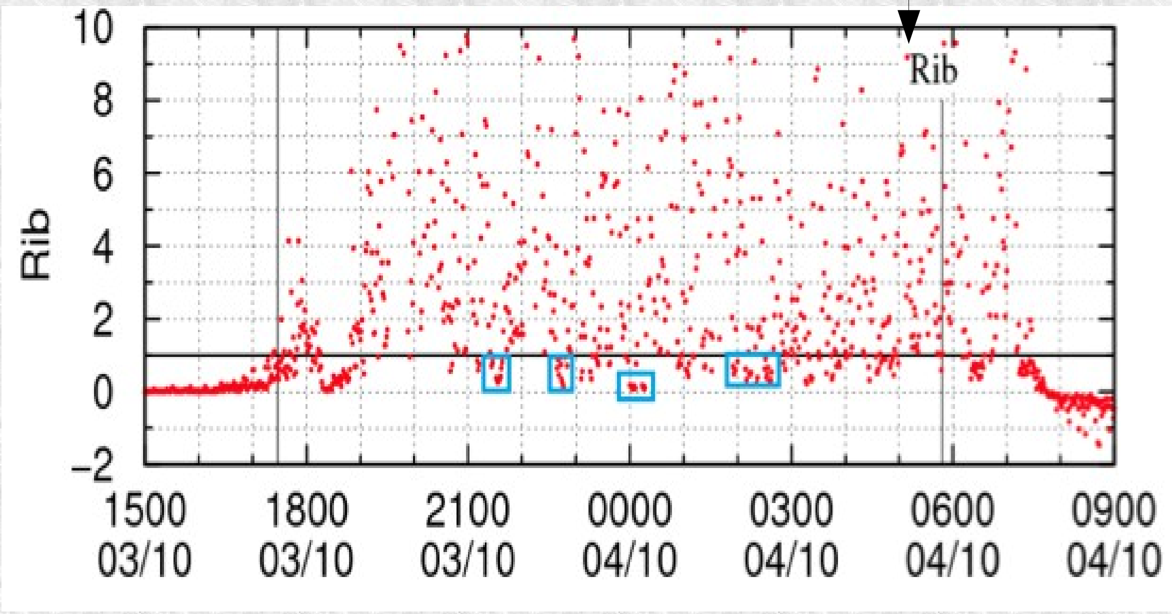




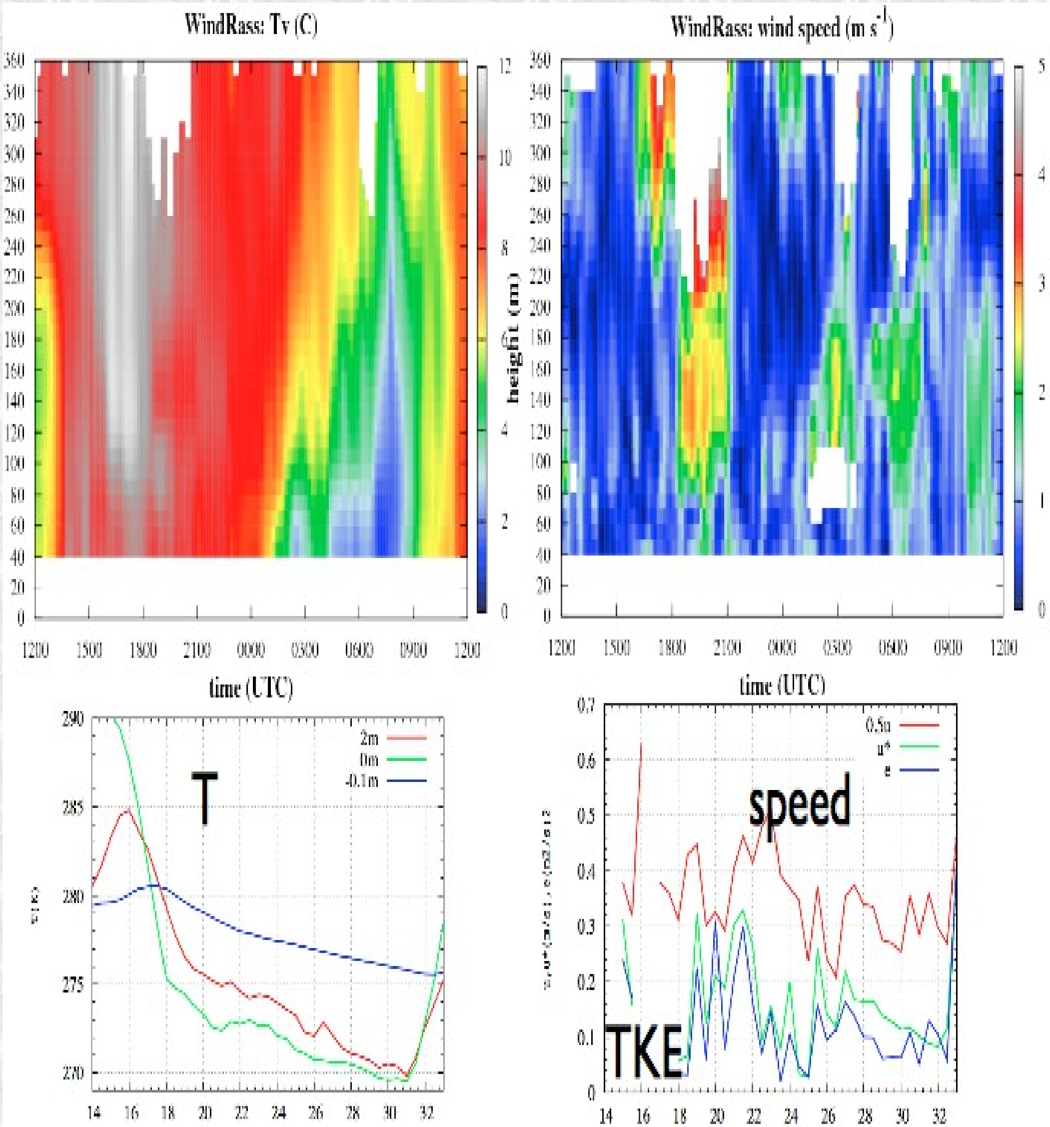


West

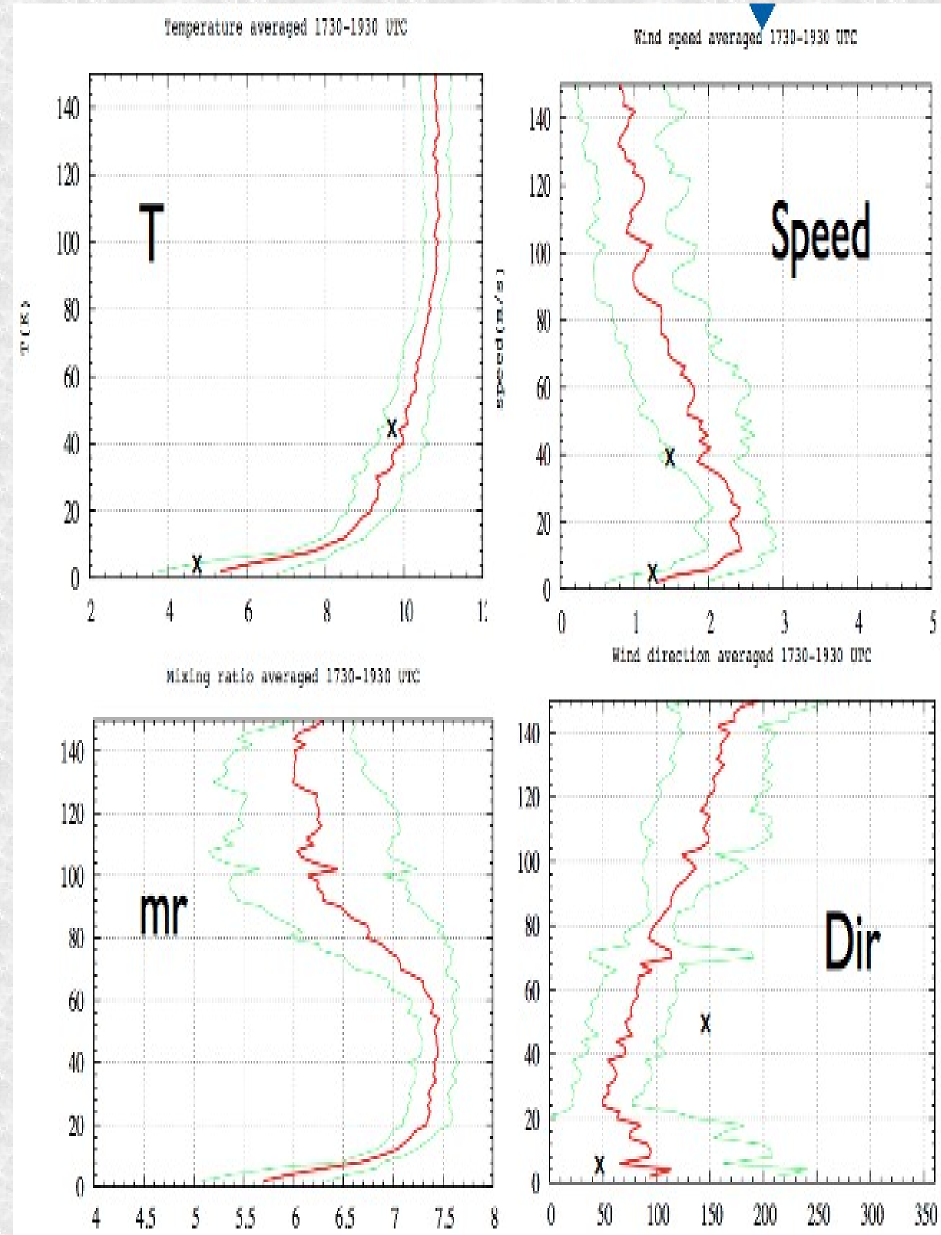
Local



6.4 Inversion in the Eastern Ebro basin: beware of missing the point!



(Cuxart et al, ES0802 COST workshop, 2011)



6.5 Magnifying glass close to the surface (Mallorca)

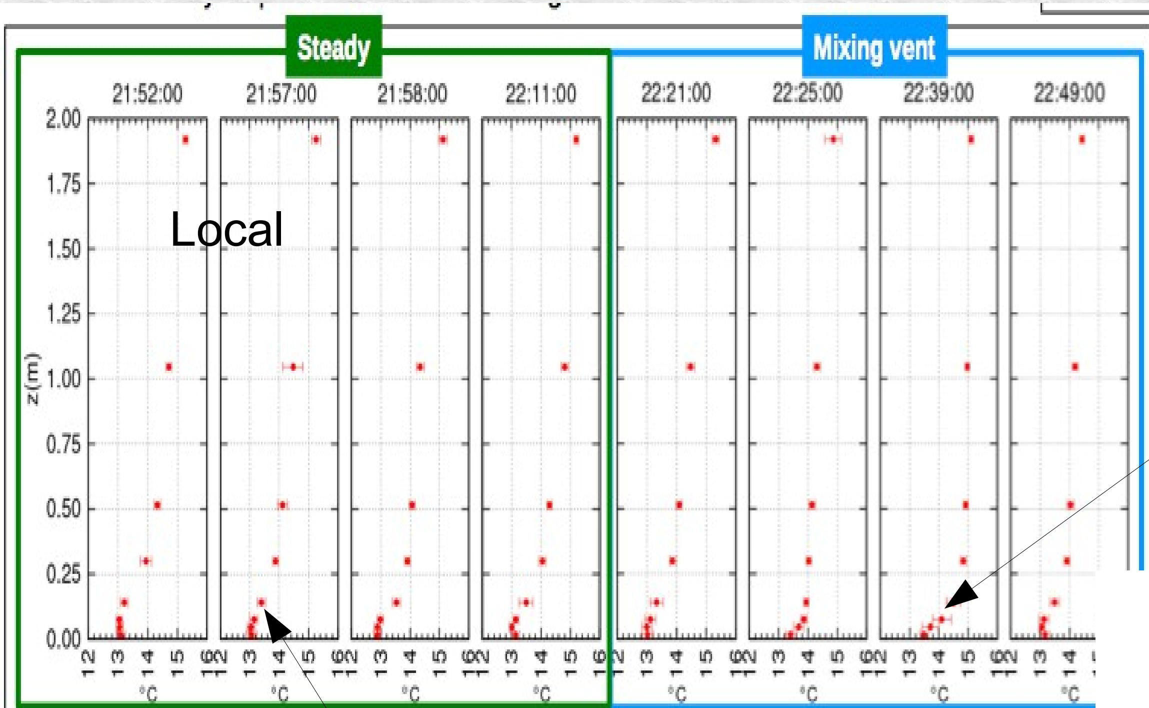
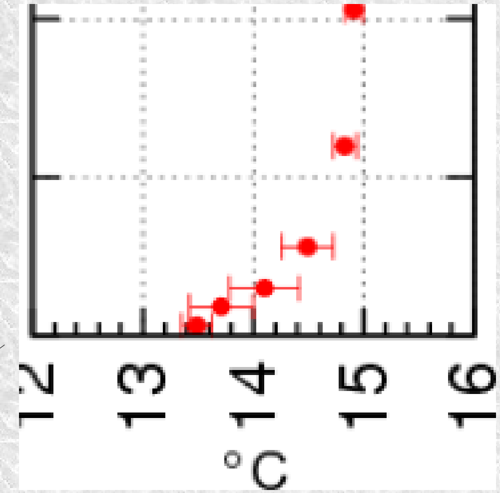
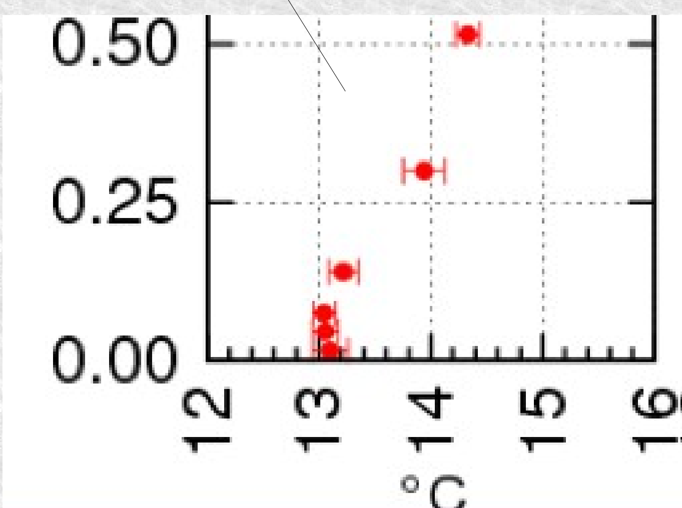
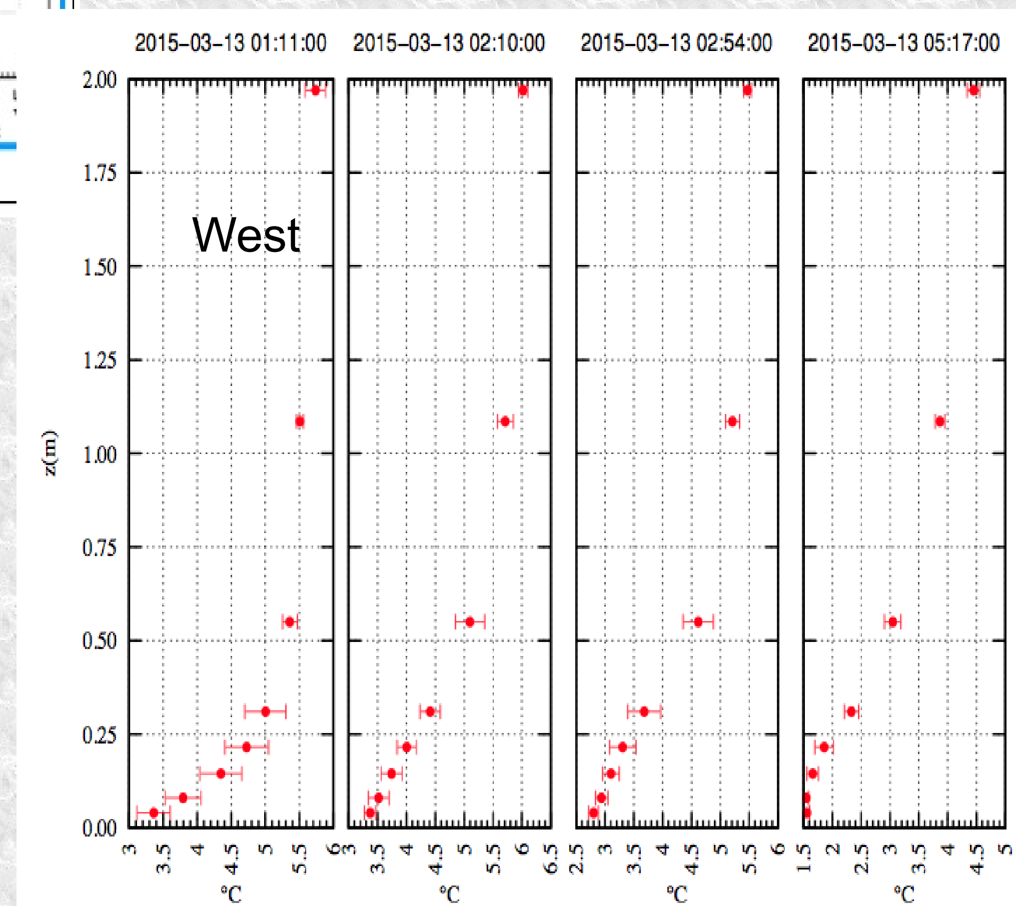


Fig. 5: Vertical profiles of 1-min averaged temperature for 8 representative instants. Error bars indicate standard deviation.

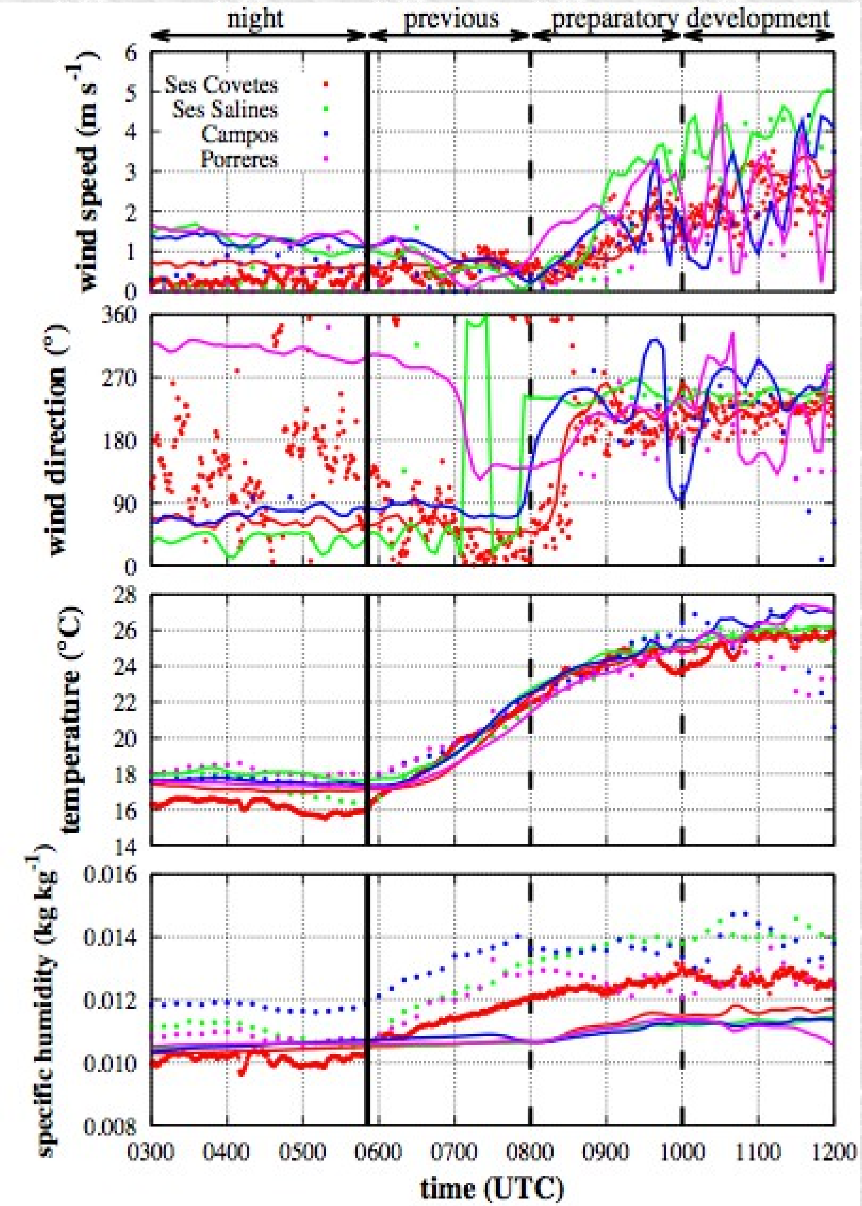


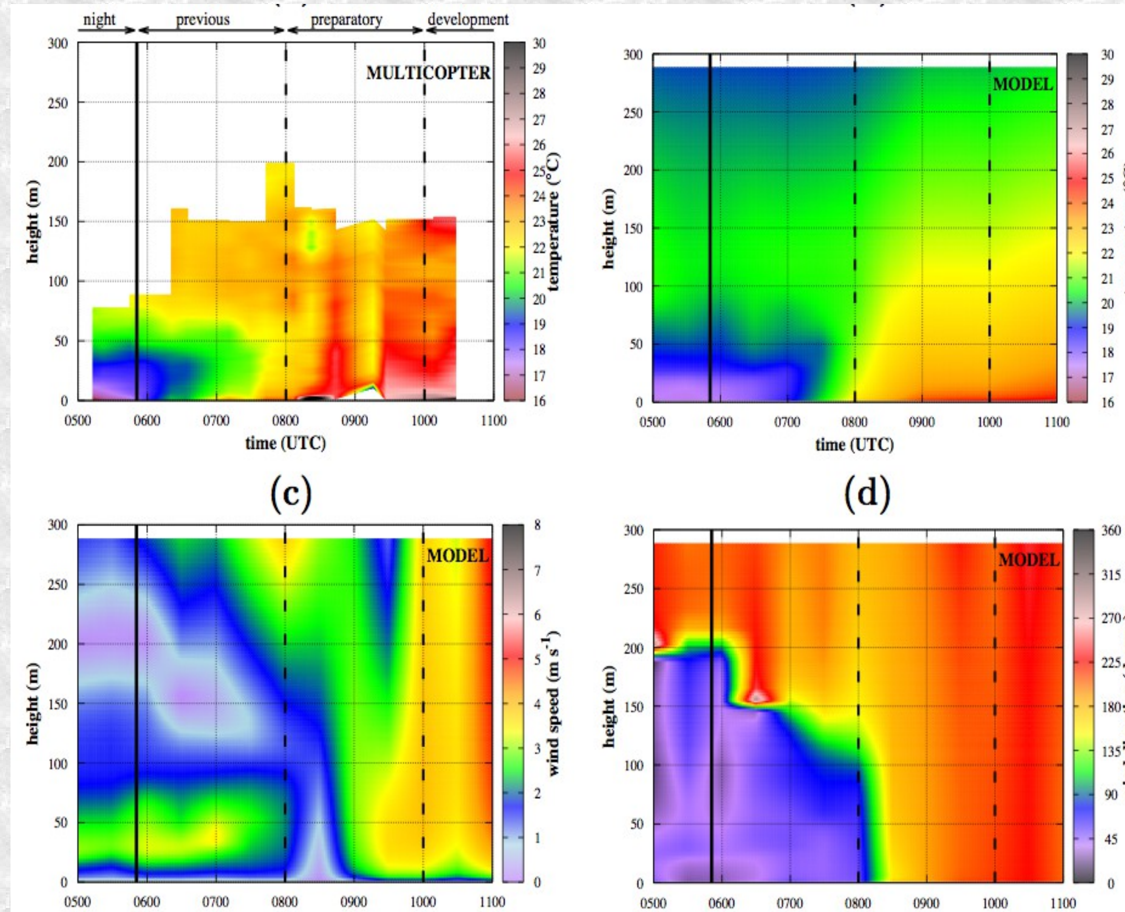


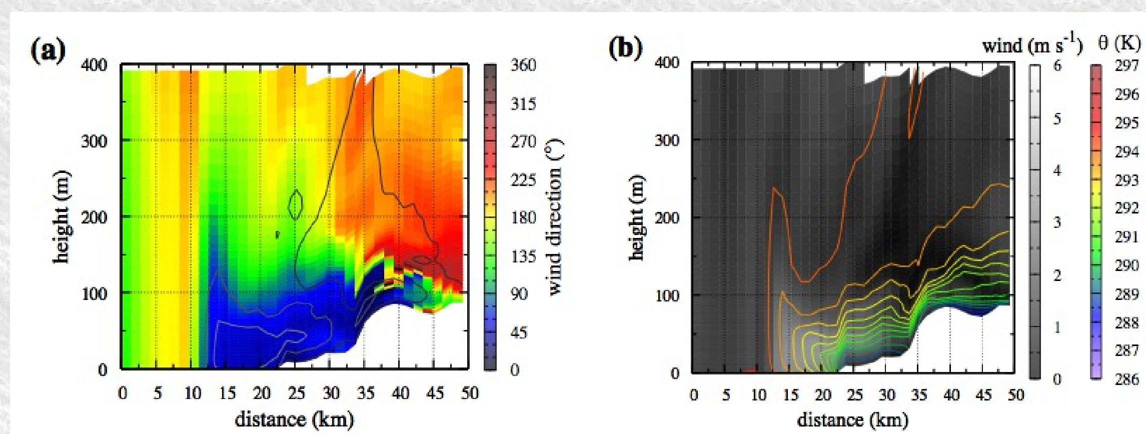
(Martí et al, 5th MetMed conf, 2015)



6.6 A morning transition between land and sea breezes (Mallorca, Sept 2013)

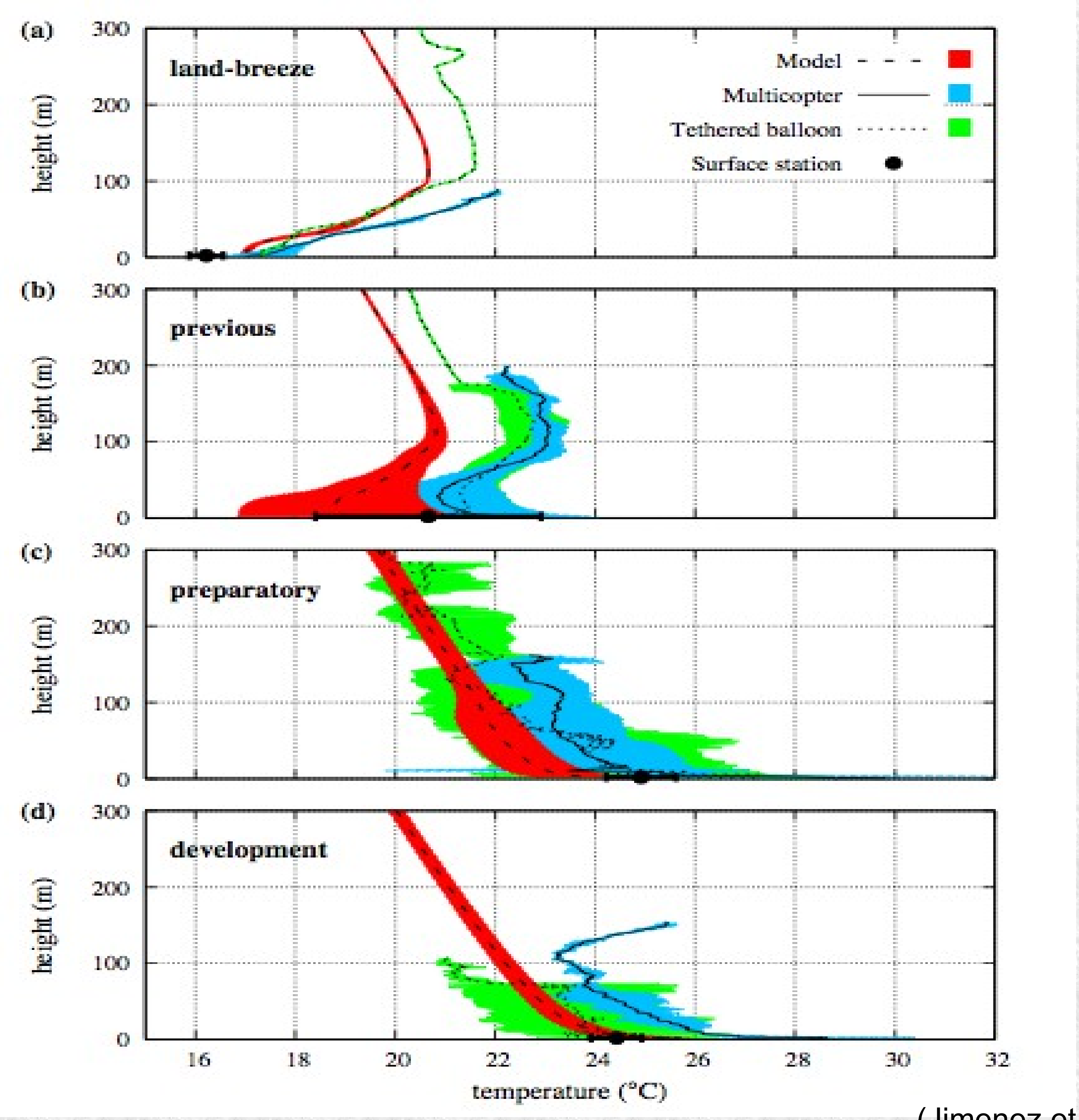






(Jimenez et al, AR, 2016)

6.7 Morning transition delayed, but the model catches up later



(Jimenez et al, AR, 2016)

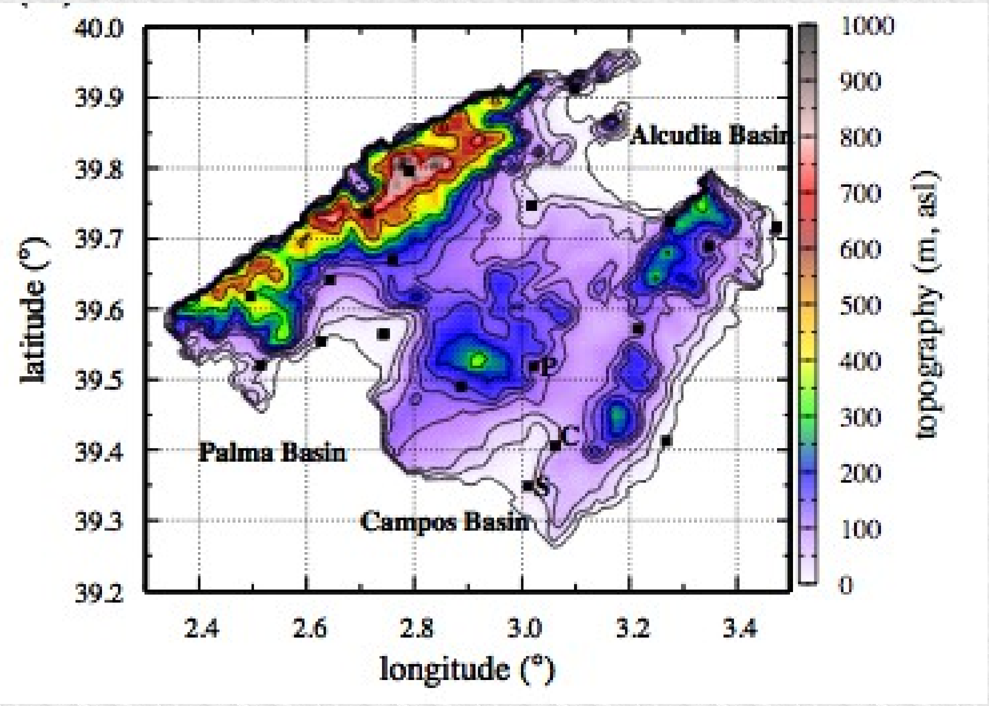
7. 1 Typical Experimental setup (at disposal at the Pyrenees, Hungary and Mallorca)

* Standard meteorological measurements (T2m, RH2m, wind10m)
* Supplementary measurements
    (LST, soil T, Soil moisture, T/RH/Wind_other_levels, wet surface...)
* Radiative (Rn or the 4 components), turbulence (H, LE) and conductive (G) heat fluxes
* Gas fluxes (water, CO2)

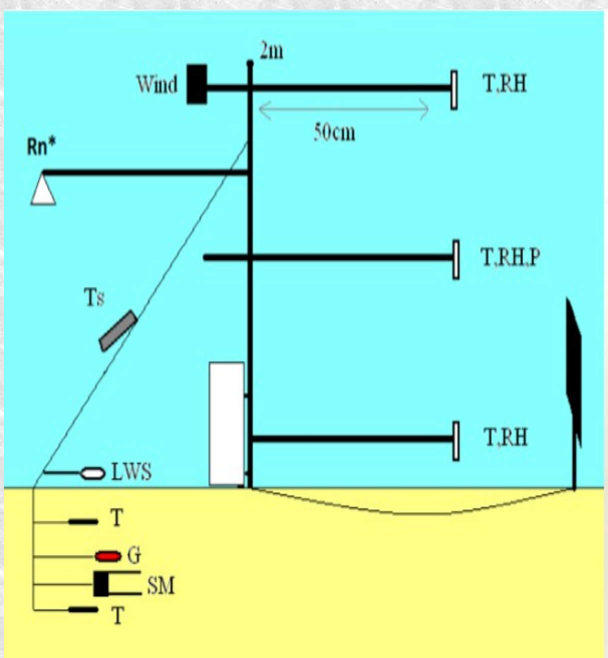
* Local operational surface network
* Supplemental surface network

* Operational RS
* Tethered balloon operation
* Multicopter remotely controlled (profiles and
    transsects of T, RH and LST)

* Remote Sensing: Sodar, Radar, WindRASS,
    T profiler, Scintillometer, ...



7.2 The UIB Campus site at Mallorca



List of instruments

Sounding:

our own: tethered balloon up to 400 m agl homemade
colleague B. Wrenger (HS-OWL): multicopter for soundings and transsects
institutions: Windrass (Meteocat at Lleida and Pyrenees),
sodar (U. Debrecen at Szeged; DHMZ at Pleso),
RS (Aemet at Mallorca, OMSZ at Szeged, DHMZ at Pleso),
VHS wind profiler and radiometric T profile (OMSZ at Szeged)
At the Pyrenees: scanning lidar, UHF and radiometer profilers (MF)

Surface layer:

our own: SEB at Campus (including extensive soil measurements);
portable network of extended Bowen ratio stations with soil meas.

colleague Tamás Weidinger (ELTE): SEB at Szeged
colleague Joachim Reuder (U. Bergen): lends scintillometer at Mallorca
colleague David Tatrai (U. Szeged): infrasound microphones
institutions: SEB, MF at Cerdanya (Meteocat)

Satellite images: cooperation with the University of Valencia

8. Summary

1. We have the capability of doing question-oriented campaigning “quick and cheap”

2. SEB is not closing and we still have not figured out why, although some guesses exist.

3. Surface heterogeneities may explain some of the imbalance. In any case, their effect is significant at the hectometer scales, while for finer scales it may be wiped out by local mixing.

4. Reference sites are difficult to find, instead reference cases seem at hand

5. Complex topography generates flows that are dominant in anticyclonic conditions, with very-low-level jets and high shear, that induces mixed profiles at night close to the ground.

6. Measuring inversions needs detailed sampling in the first decameters above ground level. Our high vertical/horizontal resolution runs so far are not able to generate multiple jets in the vertical that last as observed, neither the good T/wind profiles close to the ground.

7. The site in Mallorca is apt for many detailed process studies. Hungary and Cerdanya provide complementary inputs in more extreme conditions (flat or mountaineous).