# Some considerations on the effect of small scale surface heterogeneities in the surface energy budget

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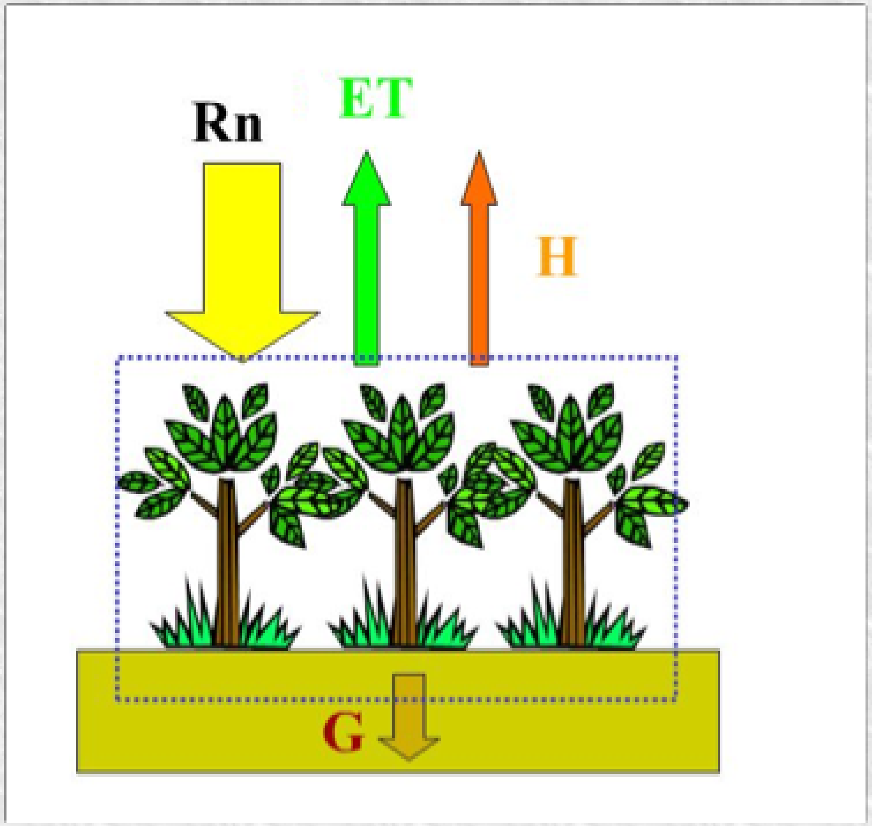
with contributions of many colleagues, a number of them in the room:
**D. Martínez, M.A. Jiménez, L. Conangla, M. Lothon, F. Lohou, J. Reuder, M. Jonassen, B. Wrenger, J. Dünnermann, O. Hartogensis, L. Mahrt, A. Garai** and many others around BLLAST

**BLLAST workshop, UPC, Barcelona, 2-3 February 2015**

# Surface Energy Equation

***Traditional:***

Rn+ET+H+G =0

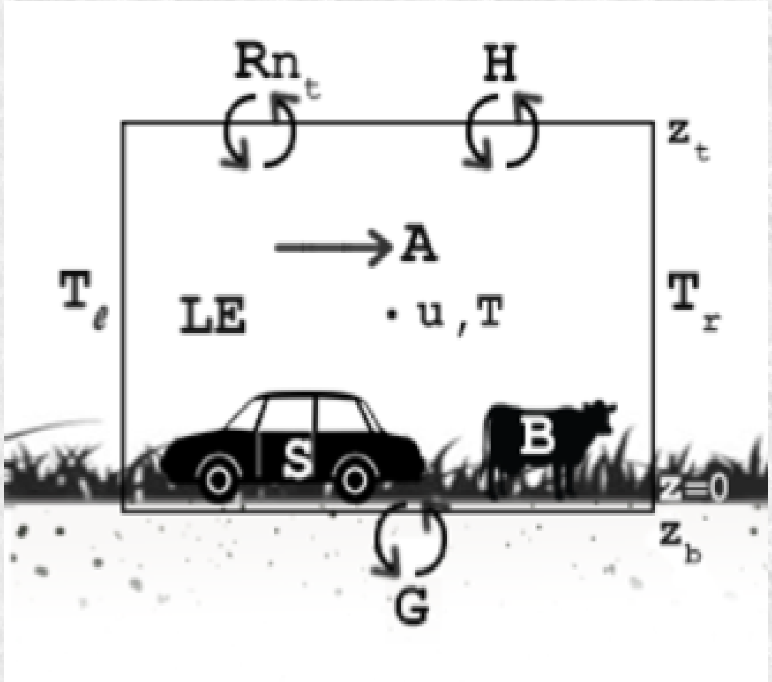



***Complete:***

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

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

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




*JGR-Atm (2015), Cuxart, Conangla, Jimenez*

## <u>Contributions to the Imbalance</u>:

***Imb = A + T + S + B + Other***

i. Advection in heterogeneous conditions: range of relevant scales?

ii. Non-stationary conditions: is tendency important, when?

iii. Storage: to warm and cold material objects (other than air and soil)

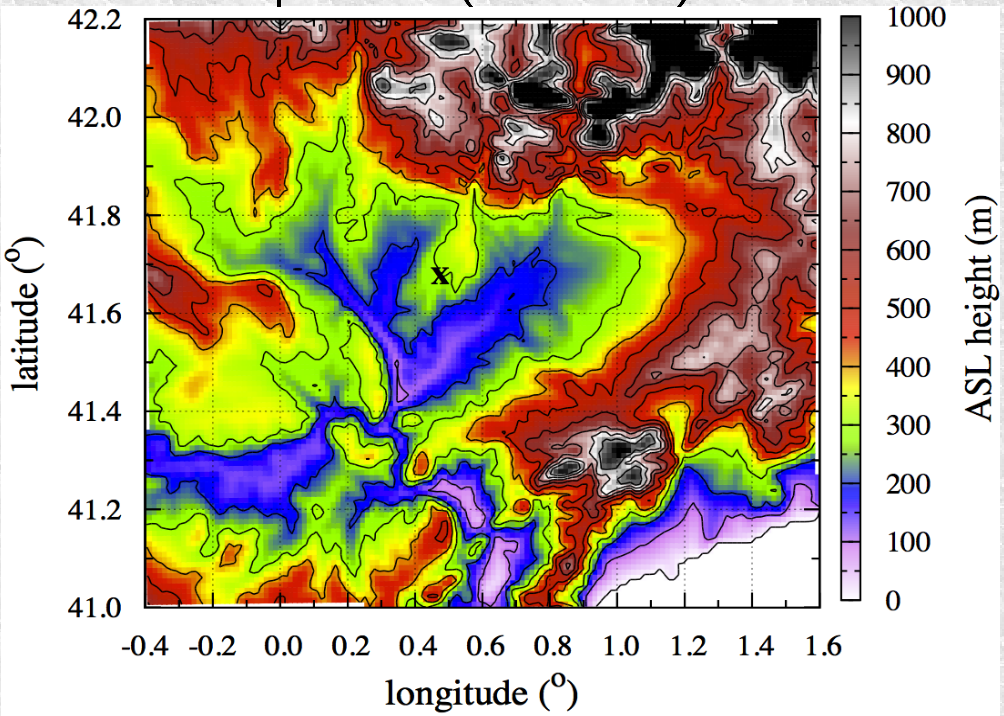
iv. Biological and soil processes:
- * Plants: respiration, transpiration and water transport
- * Soil: microbiological processes, phase changes in the porous spaces
- * Anthropogenic effects: houses, farms, industries, cities, traffic ...

v. Other:
- * Inconsistencies in the conceptual treatment of the budget
  (different sensors at different positions see different influences)
- * Processes with different timescales (but we use fixed averaging times)
- * Sensors have limitations: accuracy (radiation), missing eddies (H, LE),
  phase changes not reaching the sensor (LE), oversimplification (G)

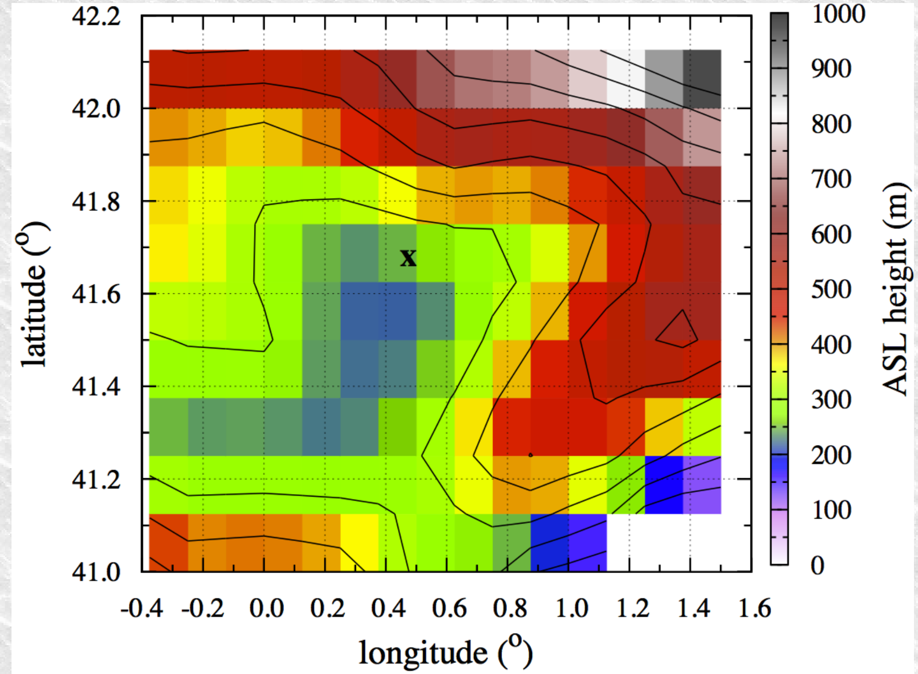
***<u>If the balance closed, it would be suspicious!</u>***

# Quantifying the Imbalance: Eastern Ebro Valley (Raimat, Catalonia, LBF'09)

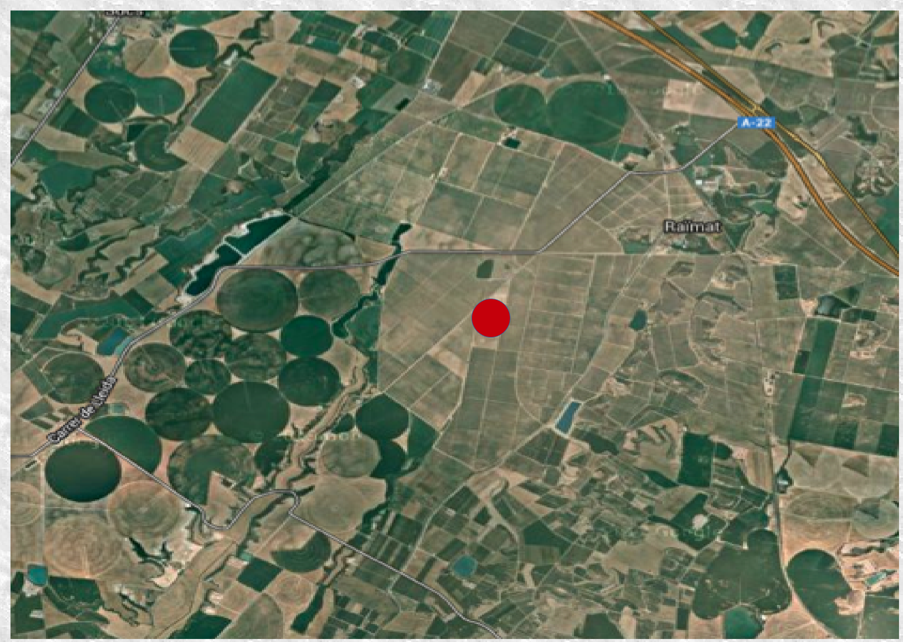
Topo: 1km (Meso-NH)




Topo: 16 km (ECMWF)







**SEB observed vs modeled by ECMWF**

*monthly averages Jan09-Dec10*

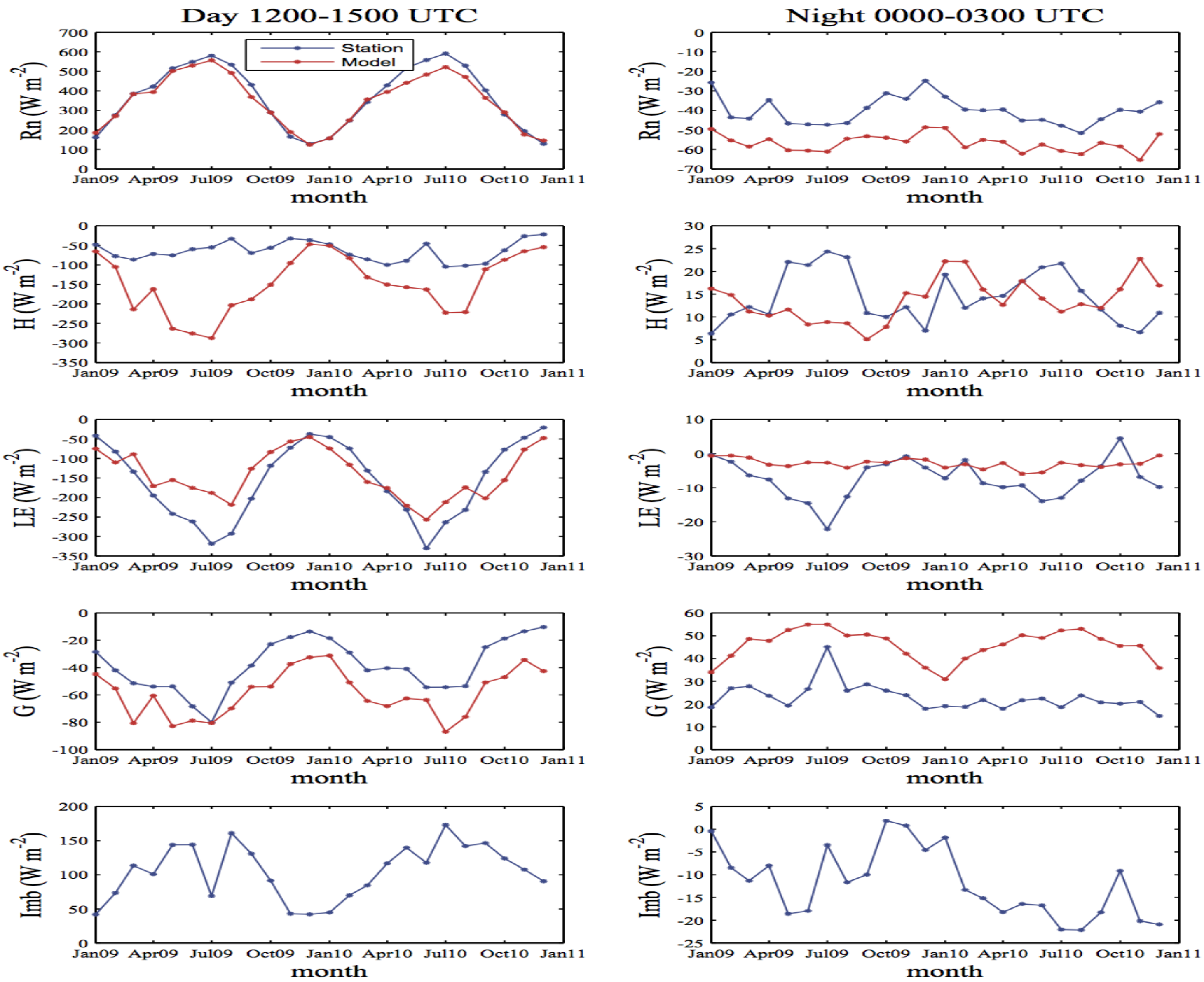
Net Radiation

Sensible heat flux

Latent heat flux

Ground flux

Imbalance




*Model in red, observations in blue*

## Terms of the budget

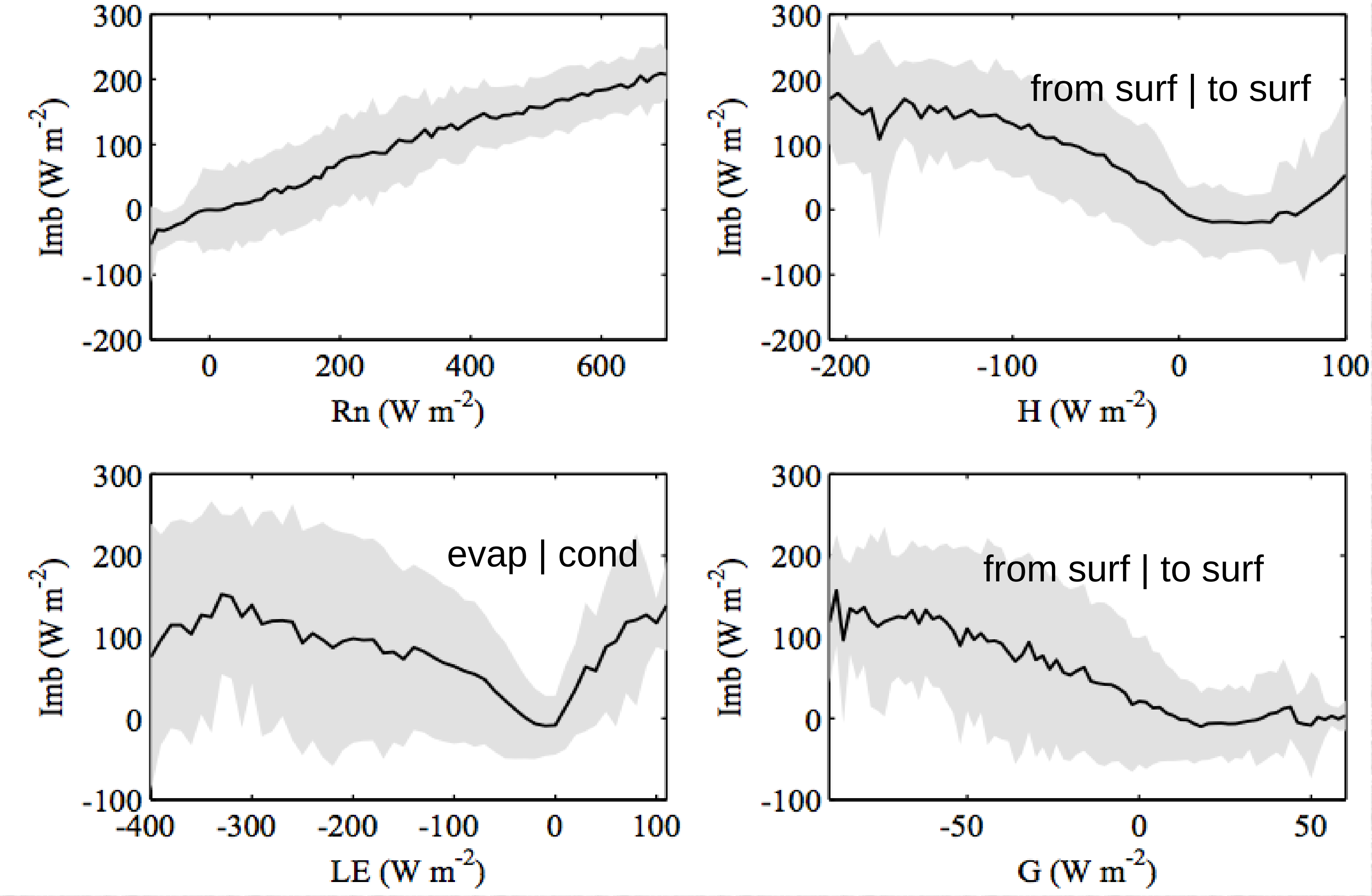
*16-km scale!* *~30% Rn*

| | | | TT | A | Rn | H | LE | G | Imb |
|---|---|---|---|---|---|---|---|---|---|
| 1200-1500 UTC | annual | station | 0.47 | 0.06 | 365.8 | - 64.7 | -155.9 | -36.6 | 104.0 |
| | | model | 0.23 | -0.03 | 347.8 | -148.6 | -140.4 | -58.9 | 0 |
| | winter | station | 0.37 | 0.07 | 180.1 | - 50.8 | -50.4 | -23.2 | 59.4 |
| | | model | 0.23 | -0.06 | 186.1 | -66.7 | -76.9 | -42.5 | 0 |
| | spring | station | 0.46 | 0.03 | 435.4 | - 84.8 | -185.8 | -47.1 | 116.3 |
| | | model | 0.23 | -0.02 | 412.1 | -180.2 | -162.0 | -70.0 | 0 |
| | summer | station | 0.62 | 0.11 | 555.9 | - 65.2 | -284.5 | -57.1 | 142.5 |
| | | model | 0.27 | -0.02 | 509.3 | -229.0 | -204.2 | -76.1 | 0 |
| | fall | station | 0.44 | 0.04 | 293.3 | - 56.4 | -104.8 | -22.7 | 105.2 |
| | | model | 0.17 | -0.02 | 279.5 | -116.3 | -116.8 | -46.3 | 0 |
| 0000-0300 UTC | annual | station | -0.29 | 0.21 | -40.2 | 14.3 | -7.5 | 23.0 | -11.7 |
| | | model | -0.28 | 0.00 | -56.7 | 13.7 | -2.9 | 45.9 | 0 |
| | winter | station | -0.16 | 0.25 | -33.5 | 11.0 | -4.3 | 19.2 | -8.0 |
| | | model | -0.16 | -0.05 | -52.1 | 17.8 | -1.8 | 36.1 | 0 |
| | spring | station | -0.33 | 0.23 | -41.8 | 15.3 | -9.2 | 22.0 | -14.6 |
| | | model | -0.33 | 0.01 | -57.9 | 13.3 | -3.6 | 42.8 | 0 |
| | summer | station | -0.38 | 0.16 | -47.6 | 21.2 | -14.0 | 27.3 | -15.4 |
| | | model | -0.37 | 0.04 | -59.5 | 10.6 | -3.5 | 52.4 | 0 |
| | fall | station | -0.30 | 0.22 | -38.1 | 9.9 | -2.5 | 23.3 | -8.9 |
| | | model | -0.24 | -0.02 | -57.3 | 13.2 | -2.7 | 46.9 | 0 |

*In the daytime. model has H ≥LE, data is usually the other way*

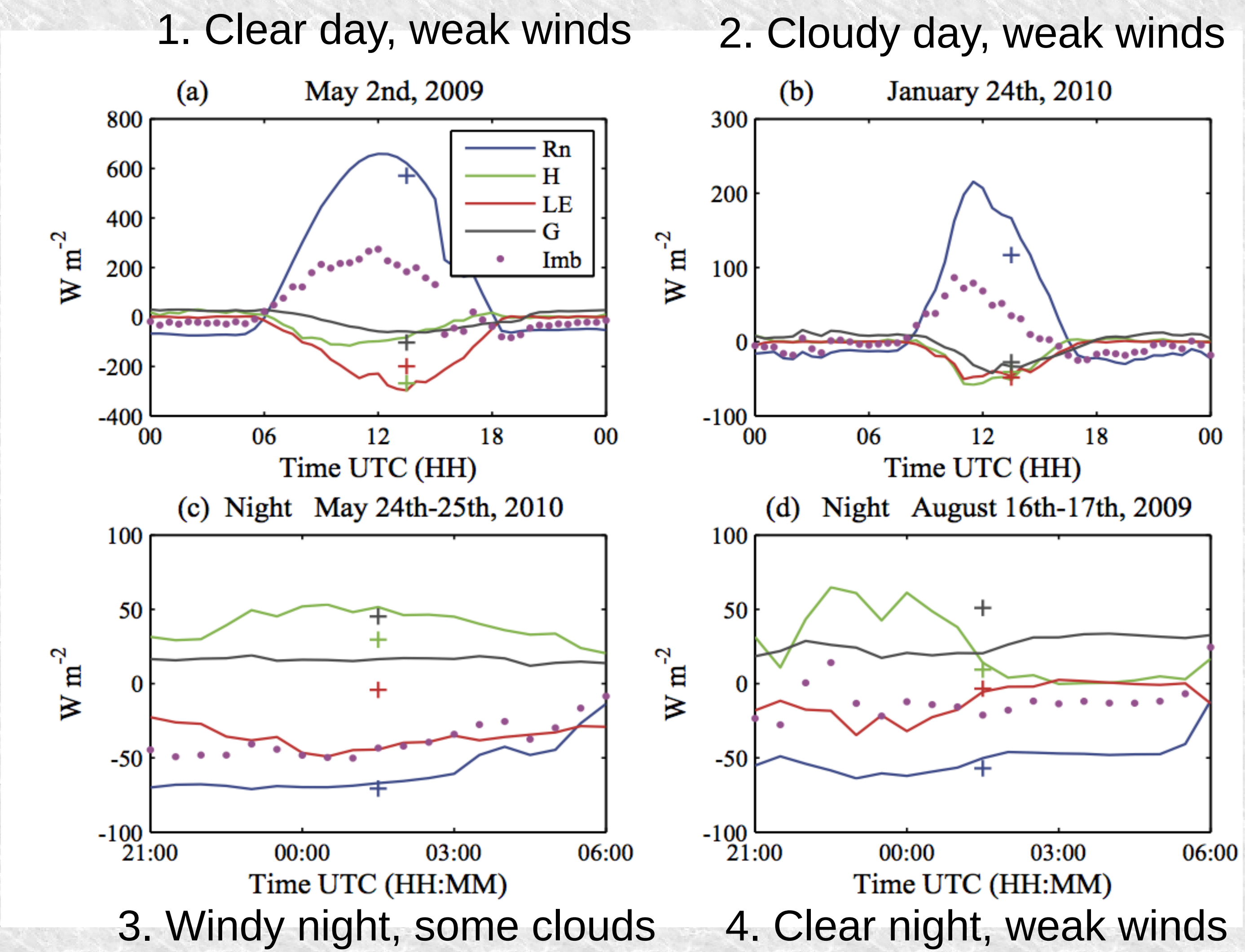
*model overestimates G*

# Imbalance in front of the other terms of the budget




* It increases linearly with the Net Radiation
* For large values of H, LE and G, the imbalance levels off (~150-200 W/m2)

## Some examples




| | day | $Rn$ | H | LE | $G$ | $Imb$ | $SM(\%)$ | $T_{sk}$ (°$C$ ) | $T_{G1}$ (°$C$ ) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 02/05/2009, 1200-1500 | 587/571 | -71/-268 | -271/-199 | -60/-103 | 185/0 | 26/23 | 25/28 | 17/22 |
| 2 | 24/01/2010, 1200-1500 | 143/117 | -41/-41 | -40/-48 | -32/-28 | 30/0 | 34/31 | 14/12 | 9/10 |
| 3 | 25/05/2010, 0000-0300 | -66/-71 | 48/30 | -42/-4 | 16/45 | -43/0 | 36/16 | 15/15 | 18/19 |
| 4 | 17/08/2009, 0000-0300 | -51/-57 | 18/9 | -8/-3 | 25/51 | -16/0 | 27/15 | 20/22 | 24/26 |

# Terms of the budget: data vs ECMWF

* At these times of the day, tendency is small and equally seen by S and M

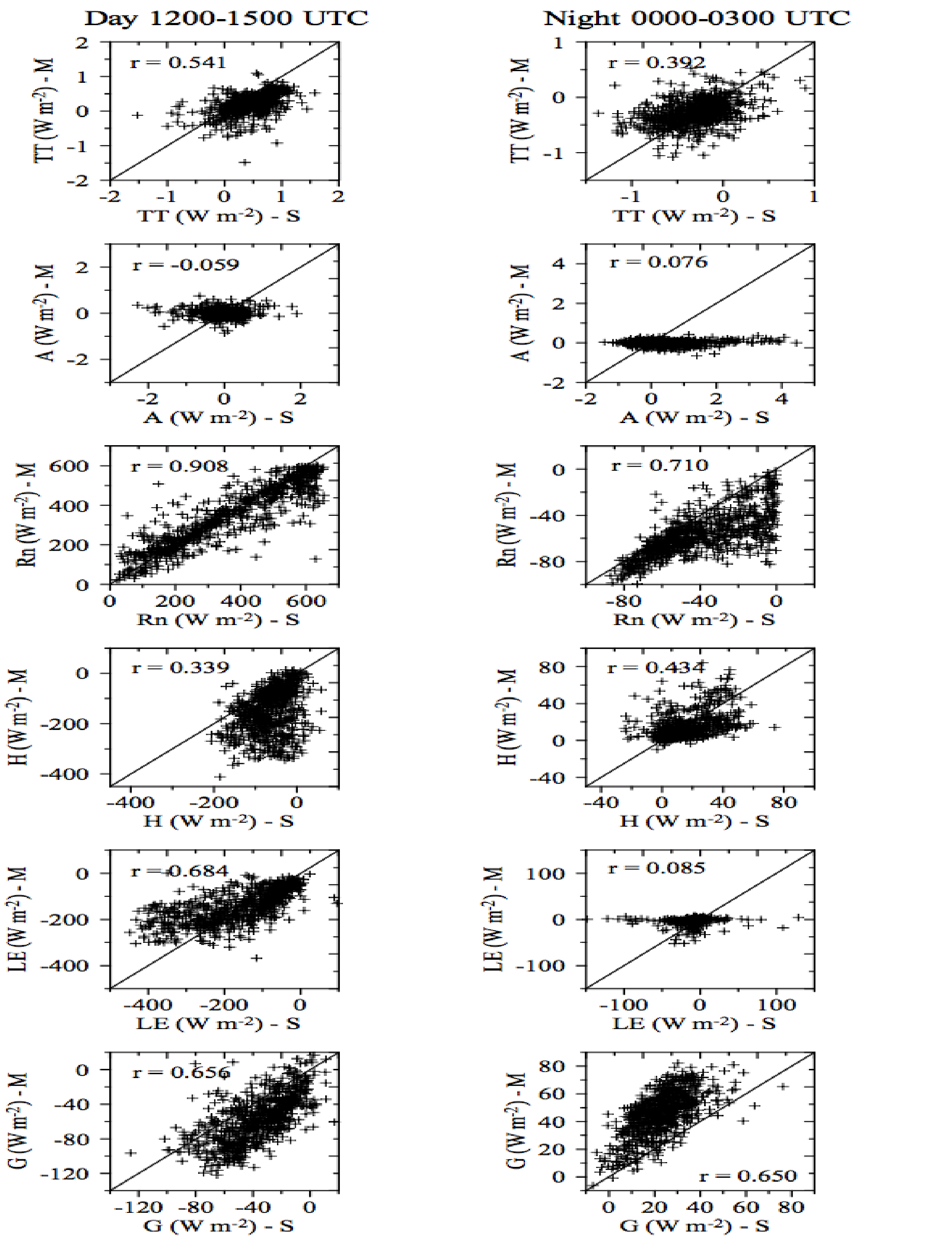
*Advection at the 10km-scale is not relevant, but in S is larger than in M

*Net radiation is well modeled at noon, but |Rn| is overestimated at midnight

* Sensible HF is largely overestimated at noon, better at night but not allowing negative values (top-down mixing)

*Latent HF well captured for small values but largely underestimated for larger ones at noon. At night in M, condensation ignored

*Ground flux overstimated in general in M, by a factor ~1.5



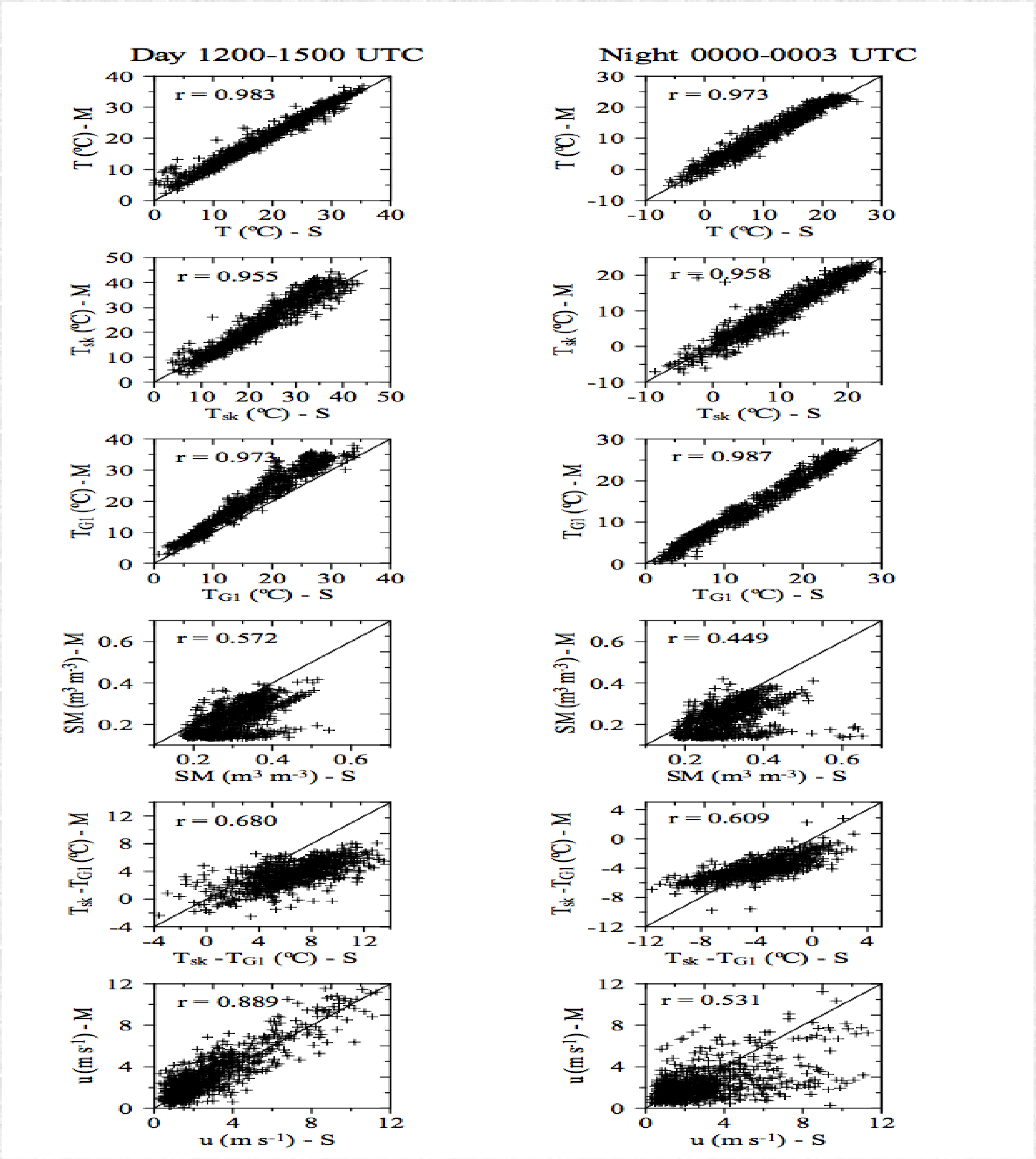
# Relevant variables: data vs ECMWF

*Air and surface temperatures:
very well captured

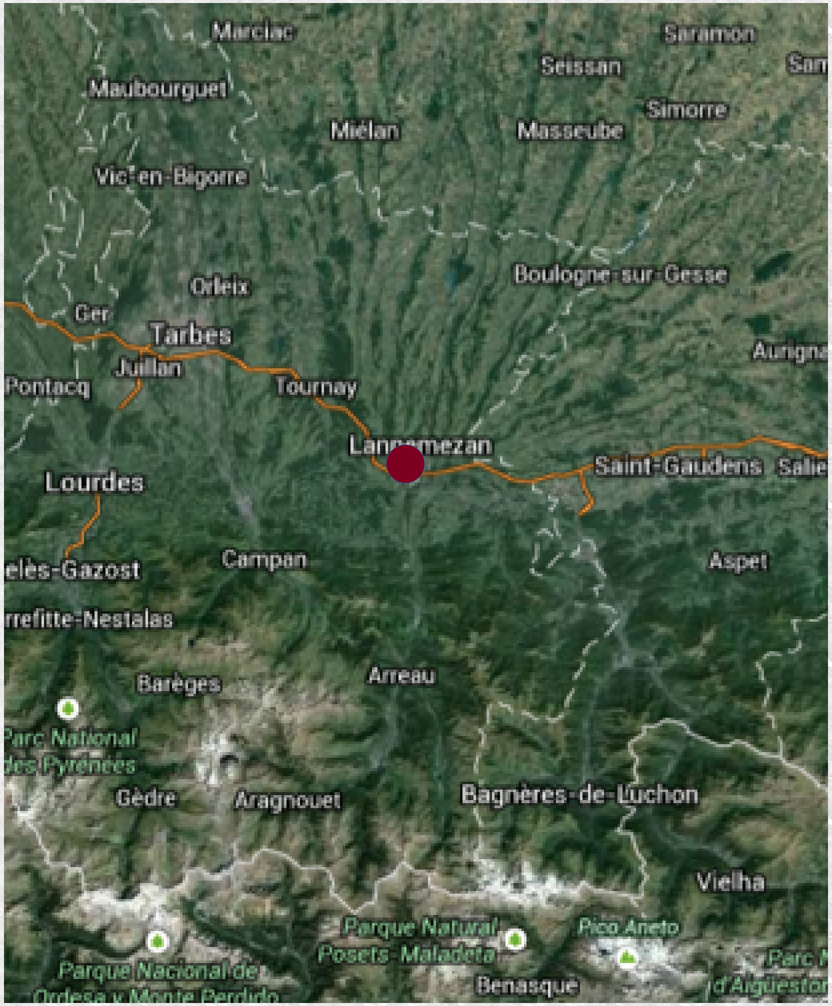
* Ground temperatures:
too warm in the model

* SM (K) & (Ts-Tg): underestimated
but G overestimated?
G=Λ (Ts-Tg)
(Λ adjustable parameter!)

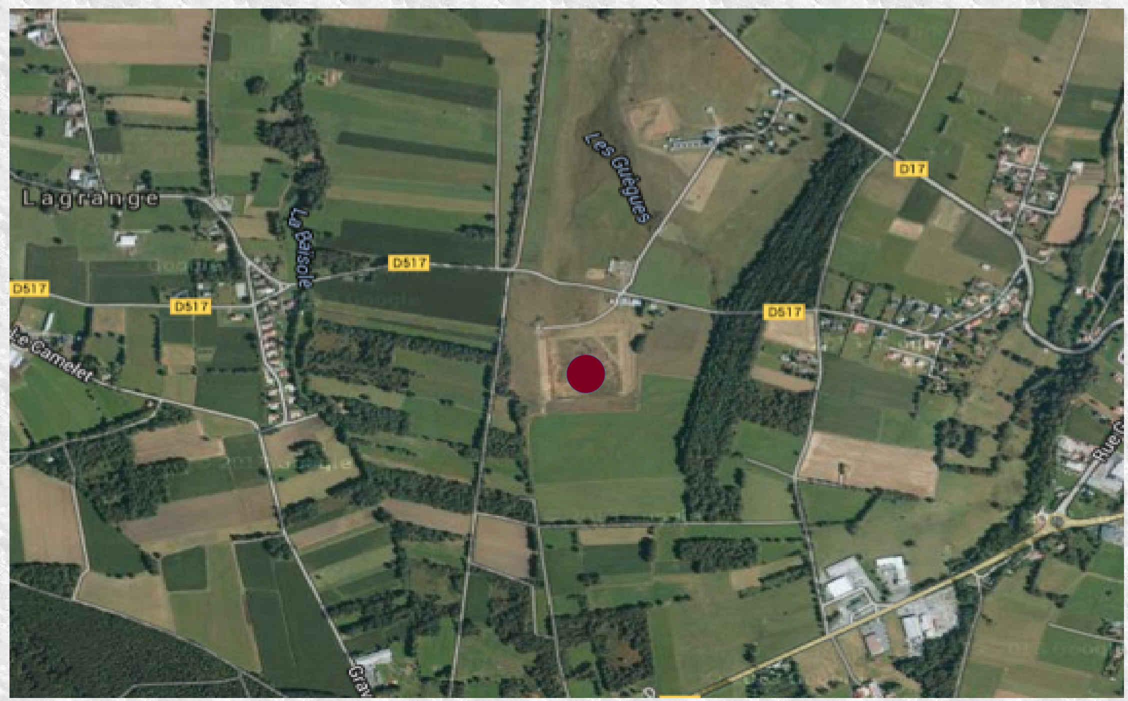
*Wind speed well captured:
not a problem of the turbulence scheme



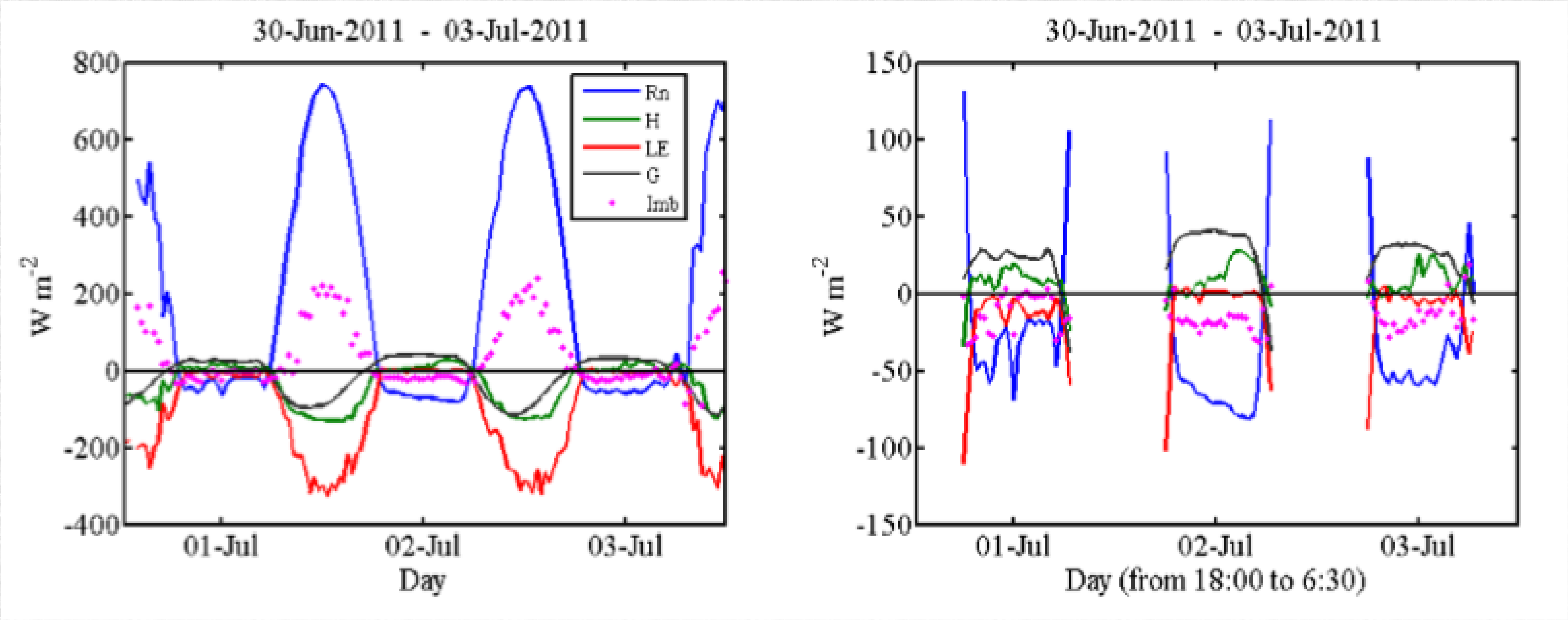
## ***Exploring the advection at smaller scales: Pyrenees Foothills, (Lannemezan, Gascony, BLLAST'11)***







## SEB for a period with clear skies and local wind between two rain events



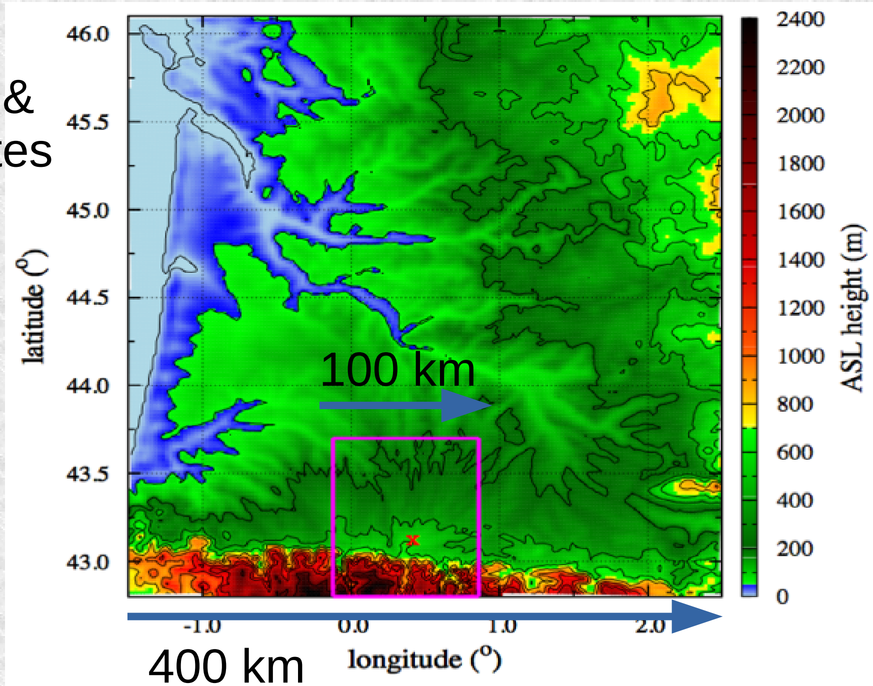

*In the daytime:* LE and Imb explain each 30% of Rn, H and G and 15% each

*In the nighttime*: G explains more than 50% of Rn, Imb as large as H and LE

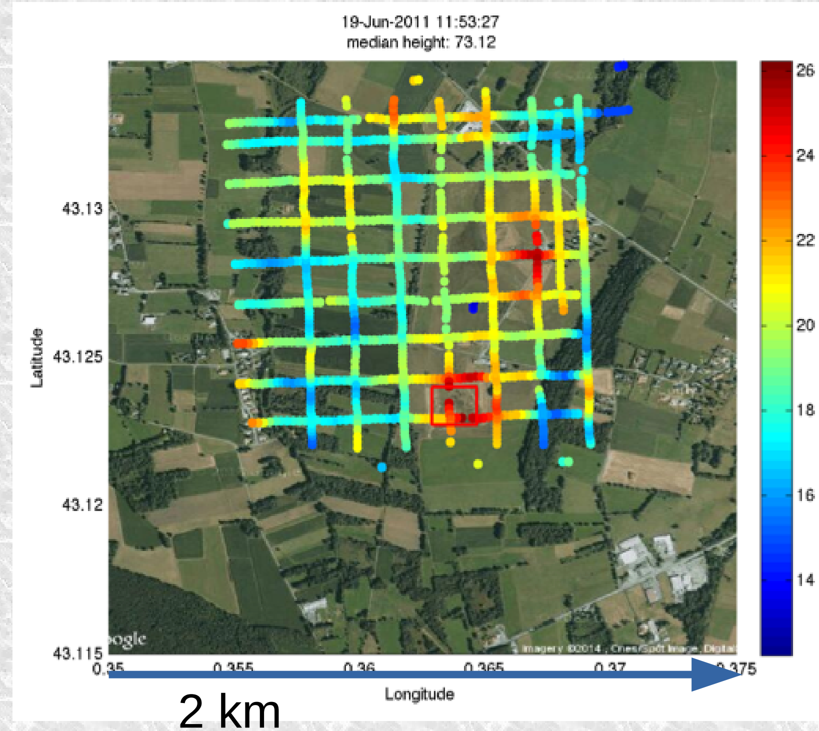
*Morning and evening transitions:* not explored in detail yet

# Sources to estimate ΔT/Δx

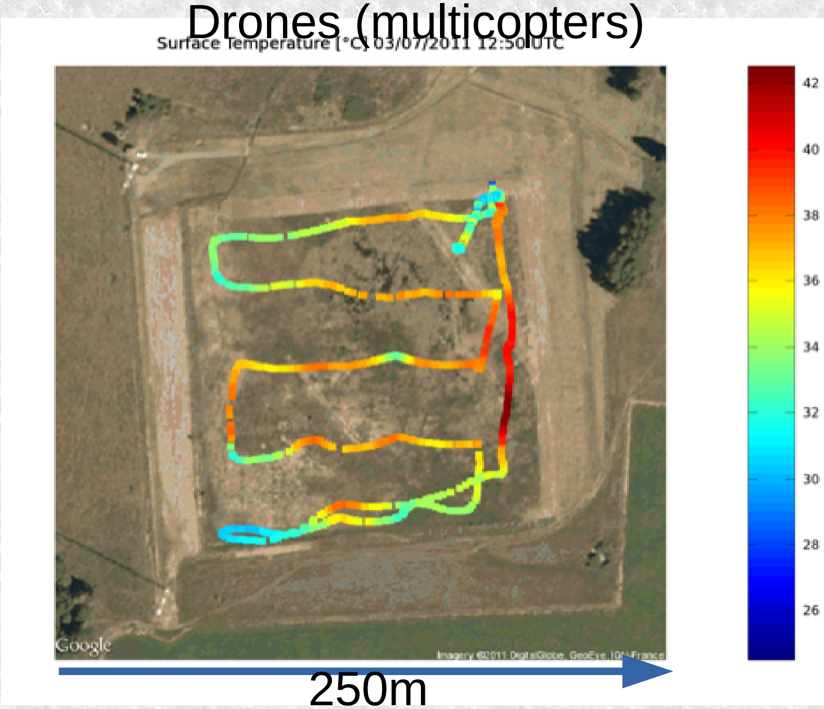
Model & Satellites



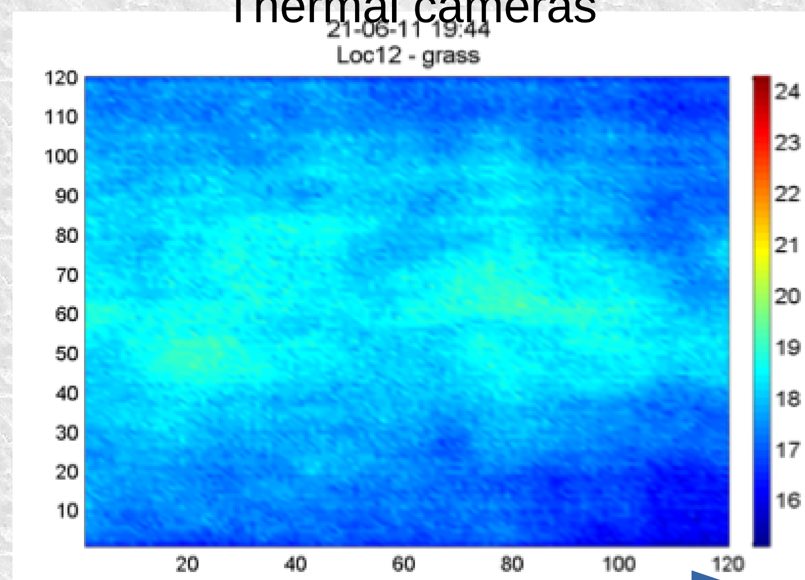

Drones (planes) and HR satellites



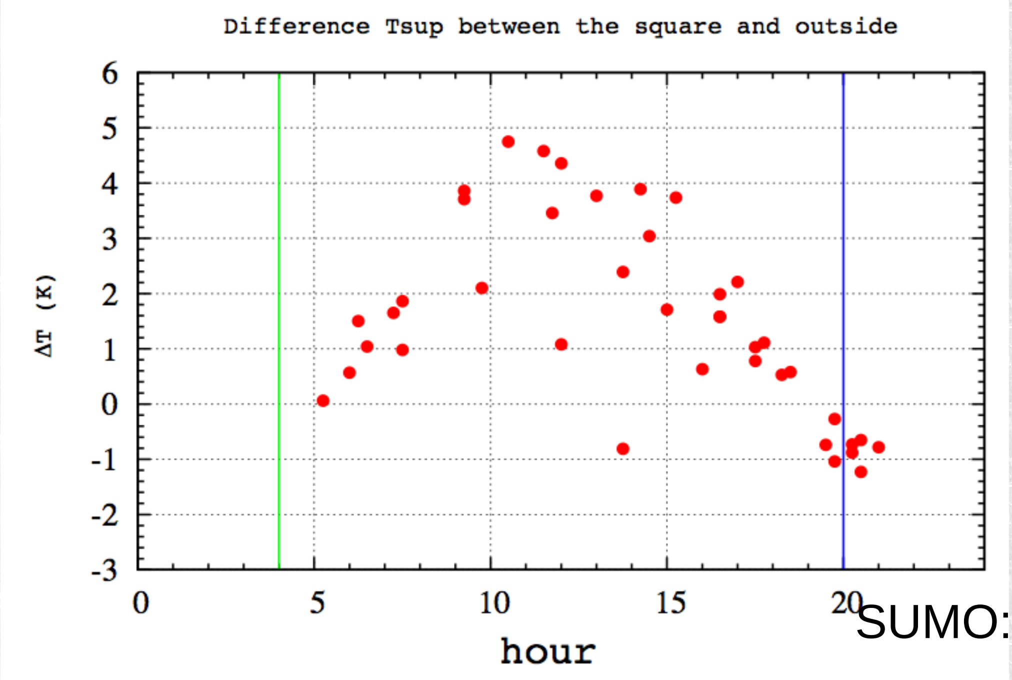

Drones (multicopters)

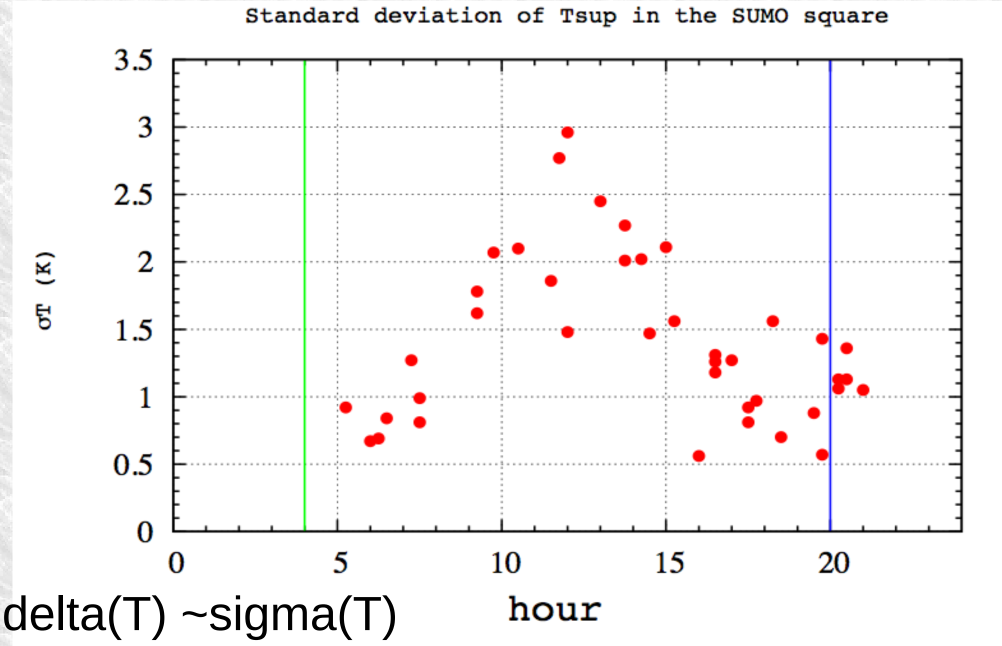



Thermal cameras

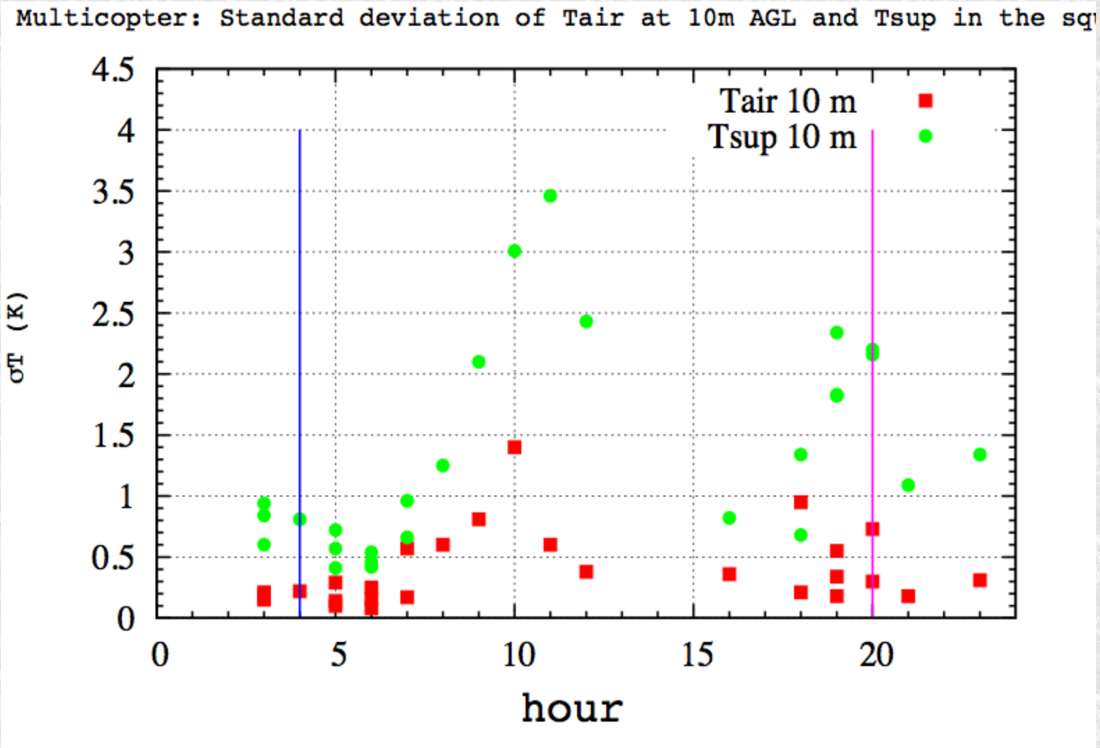



5 m




SUMO: delta(T) ~sigma(T)




Multicopter: sigma(Tair) proportional to sigma (Tsup)

$$Adv(T) = \rho C p \Delta z \sum_{i=1}^{3} u_i \frac{\Delta T}{\Delta x_i}$$

main wind ~1 m/s

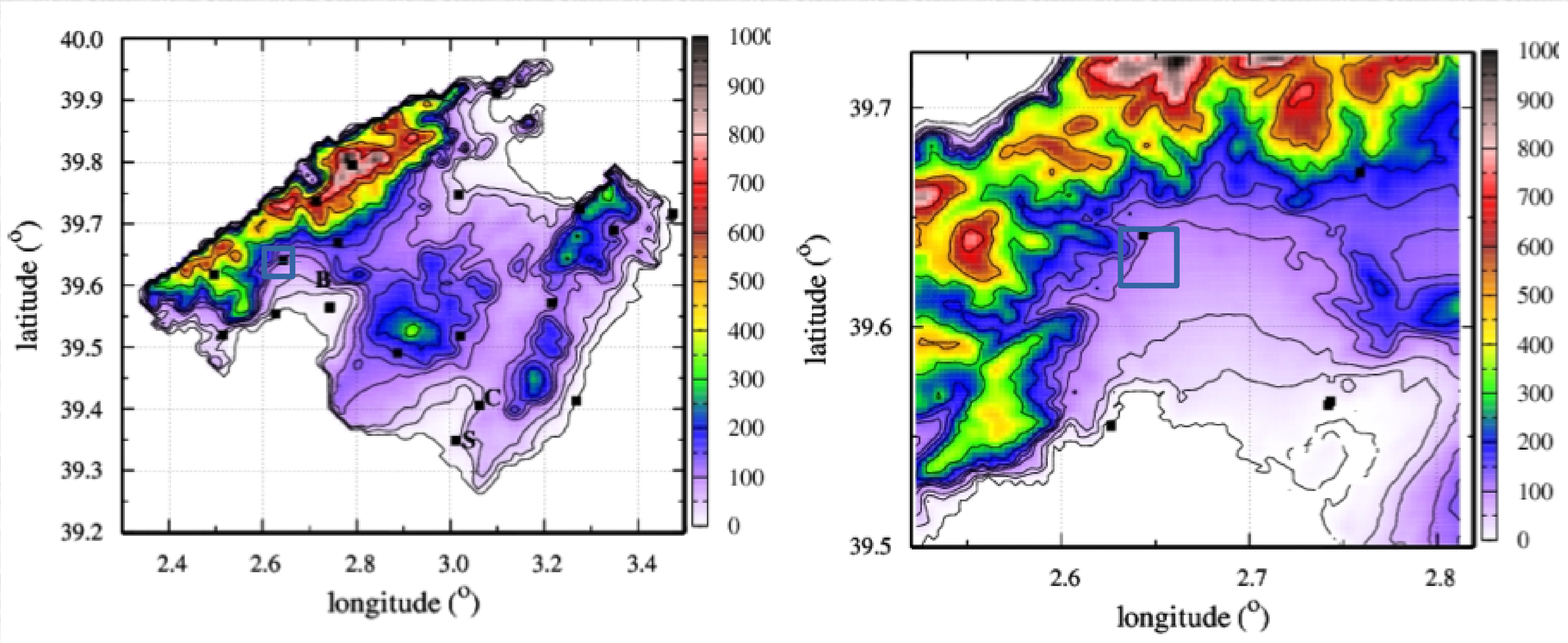
Δz = 2 m

$$O[Adv(T)] \approx 2500 \frac{\Delta T}{\Delta x}$$

**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
30 W m$^{-2}$ at night (N). The orders of magnitude are rounded, as are the percents of the imbalance.

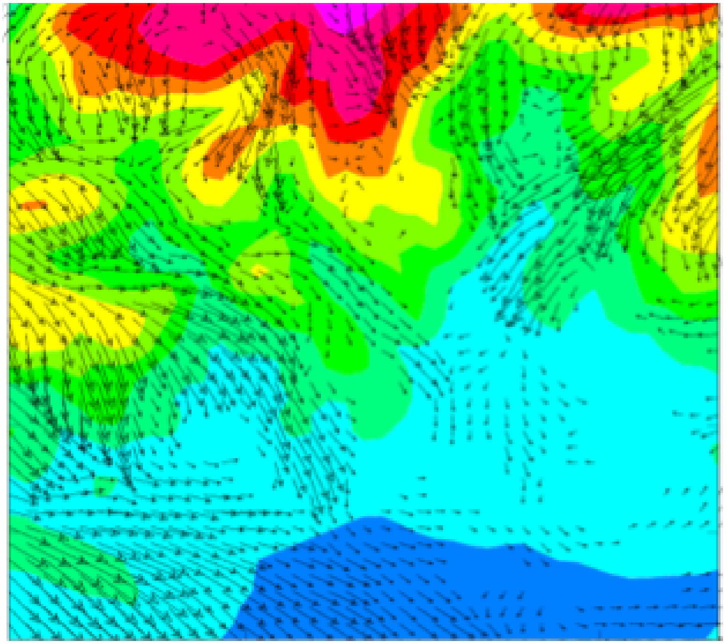
| Source | Scale r (m) | D/N | $\sigma(T)(K)$ | $O(\sigma(T)/r)(K/m)$ | $O(Adv(T))(W\,m^{-2})$ | % Imb |
|---|---|---|---|---|---|---|
| Model and satellite | 2000 | D | 2 | 0.0010 | 1 | 0.5 |
| | | N | 1 | 0.0005 | 0.5 | 2 |
| Model | 400 | D | 1.5 | 0.0038 | 10 | 5 |
| | | N | 1 | 0.0025 | 5 | 15 |
| 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 |

# L'entorn: Mallorca i la conca de Palma

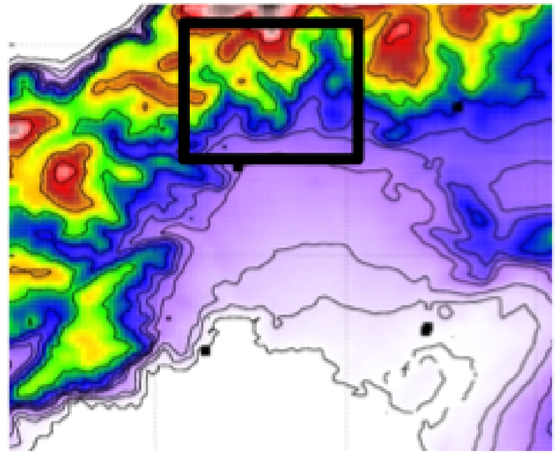


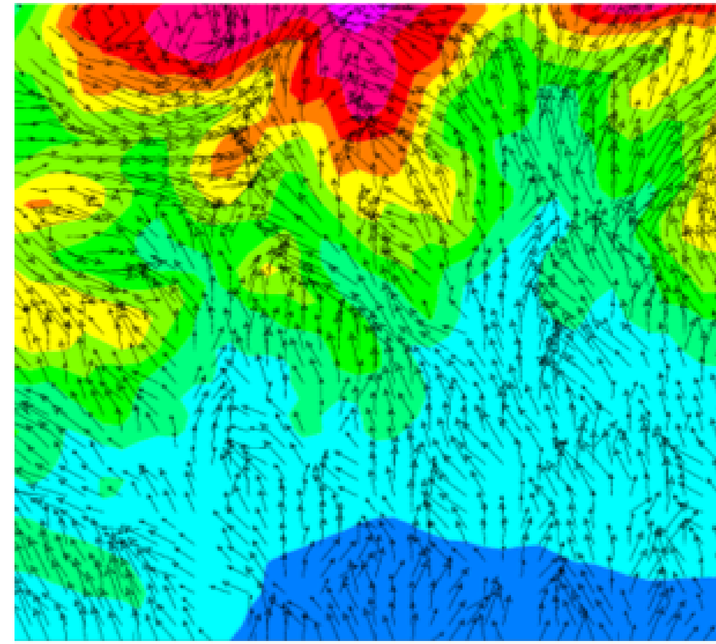
**Terral + catabàtics**
**0200 UTC**

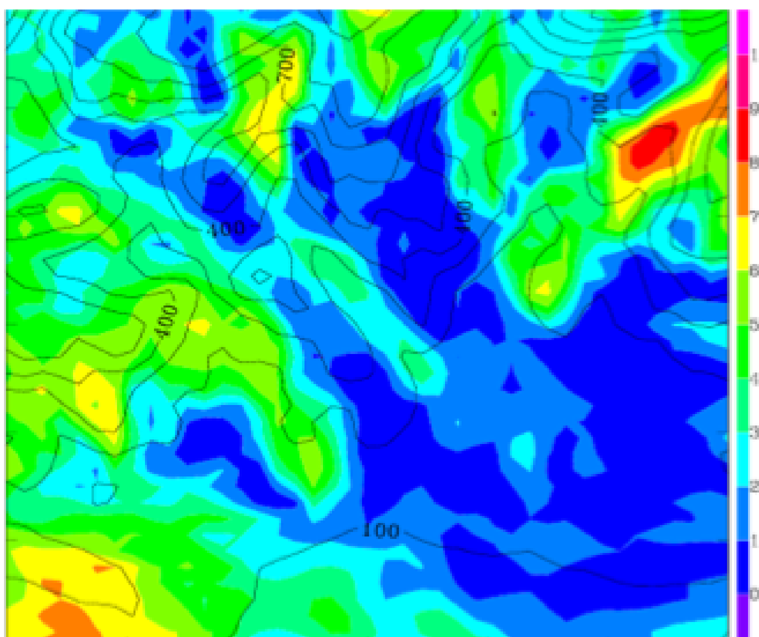
**Brisa + anabàtics**
**1200 UTC**

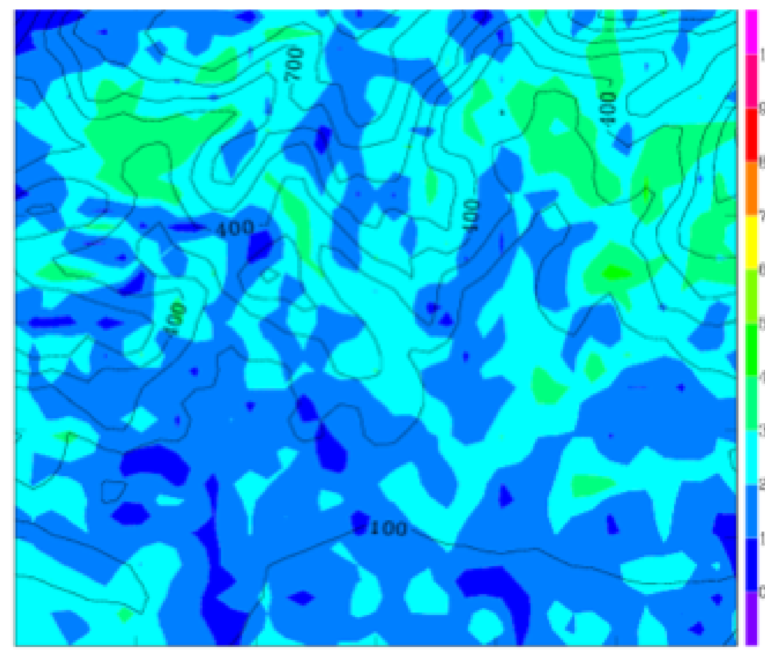


**zoom**
**250m x 250m**
**resolució**



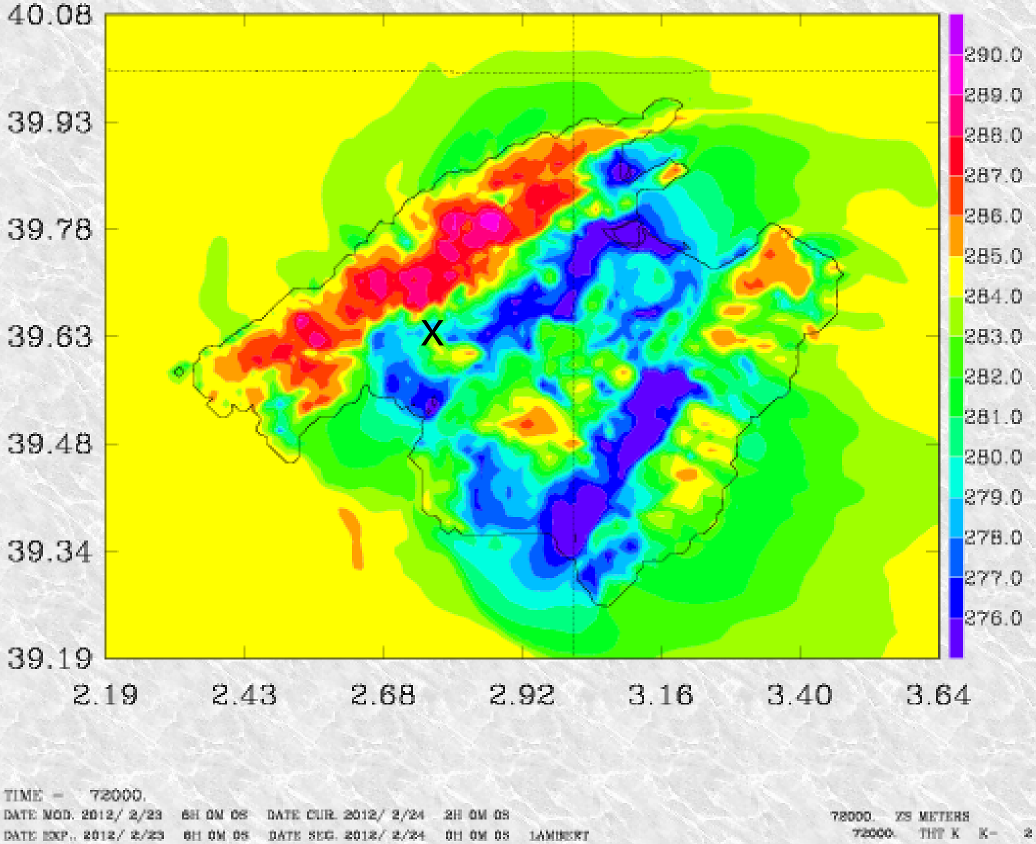





*intensitat i direcció del vent (en m/s) a 50m sobre el terreny (23 febrer 2012)*

## *Example for a february night*




Km scale: (model run at 1 km hor.res.)

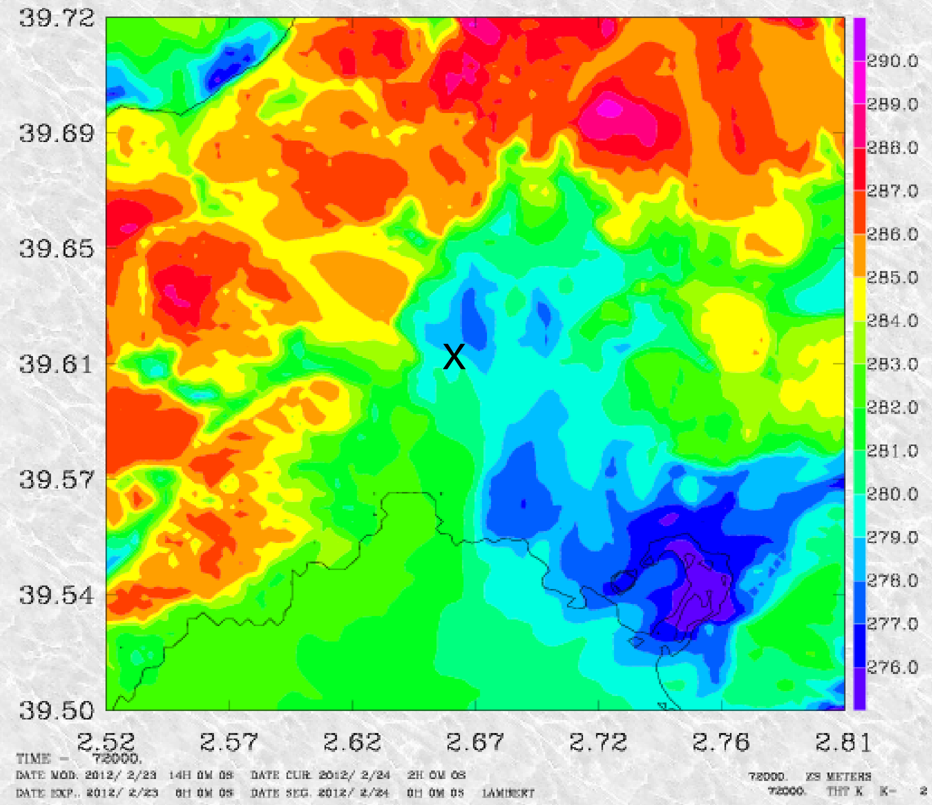
***ΔT/Δx=***7/15000 K/m

=> ***Adv(T)~ 1 W/m2***

Hm scale: (model run at 250 m hor.res.)

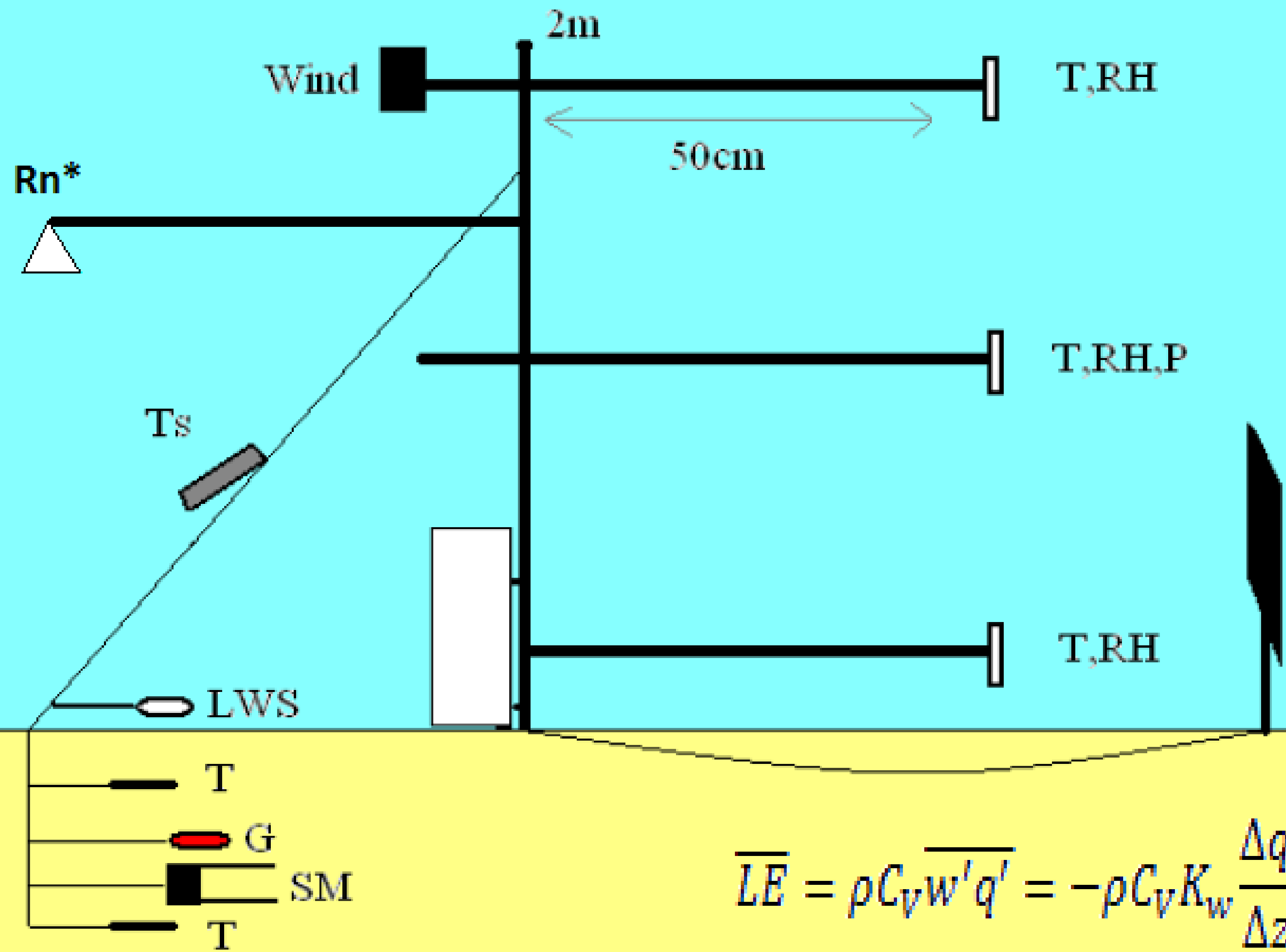
***ΔT/Δx=***8/3000 K/m

=> ***Adv(T)~ 10 W/m2***




Circles: stations

Line: Scintillometer path (J.Reuder)




$$\overline{LE} = \rho C_V \overline{w'q'} = -\rho C_V K_w \frac{\Delta q}{\Delta z}$$

$$\overline{H} = \rho C_D \overline{w'T'} = -\rho C_P K_H \frac{\Delta T}{\Delta z}$$

*Rn sols a un dels autònoms

## Some key points to retain

1. Imbalance amounts in average 30% of the Net Radiation.
It consists on tendency, advection, storage, biological processes and other issues (mainly conceptual and instrumental)

2. For ECMWF good representation of mean variables does not necessarily imply good representation of processes (case of the soil)

3. Evaluation of the advection term in moderately inhomogeneous conditions shows that the hectometer scale may explain a significant part of the Imbalance.

4. A 1-year long experiment is ready to start at UIB Campus to evaluate more soundly these preliminary conclusions.

***Acknowledgements:***
*To the meeting organisers:* *David Pino, Marie Lothon, Fabienne Lohou*
*For the funding:* *MINECO and FEDER (projects CGL2012-37416-C04-01)*

*Cuxart, J., Conangla, L. Jiménez, M.A.: Evaluation of the Surface Energy Budget equation with experimental data and the ECMWF model in the Ebro valley, JGR-Atm 2015 (online)*
*Cuxart, J., Wrenger, B. et al: Sub-kilometric heterogeneity effects on the surface energy budget in BLLAST, ACP (to be submitted)*