Imbalance of the Surface Energy Budget and role of the terrain heterogeneities

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WORKSHOP ON ADVANCES IN MESO- AND MICROMETEOROLOGY

Donja Stubica, Croatia, 3 and 4 november 2014

1. A quick look to the Surface Energy Budget equation

2. The Imbalance: terms and order of magnitude

3. Analisis of a 2-year series In Lleida (Ebro Valley): data and ECMWF

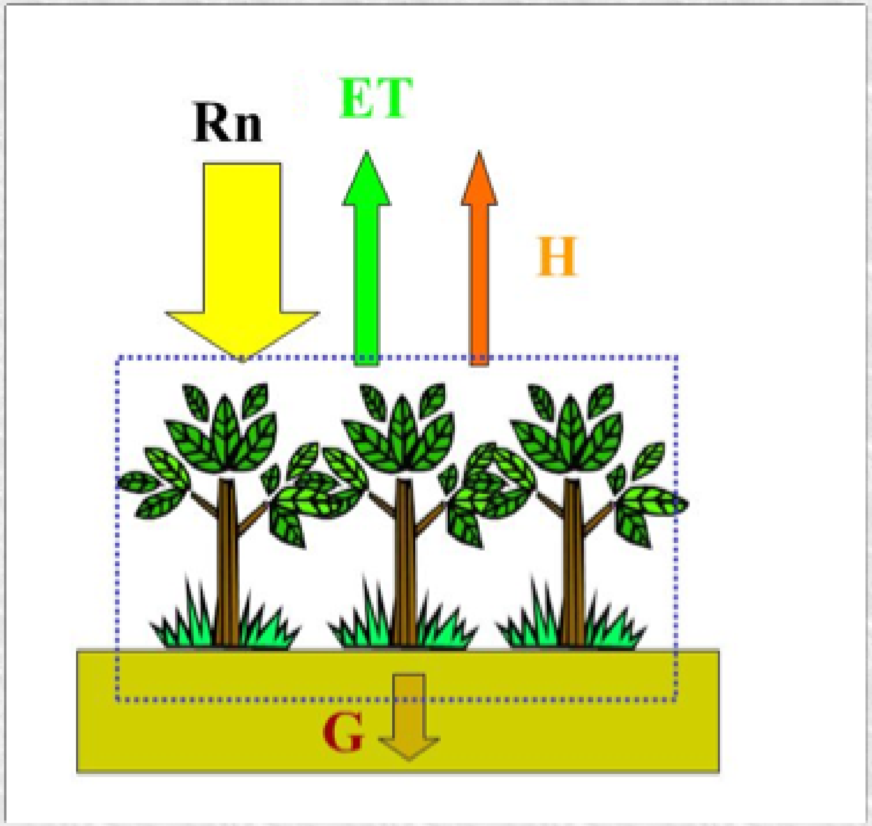
4. Effect of the surface heterogeneities in Lannemezan (Gascony)

5. Conclusions

Surface Energy Equation

Traditional:

Rn+ET+H+G =0

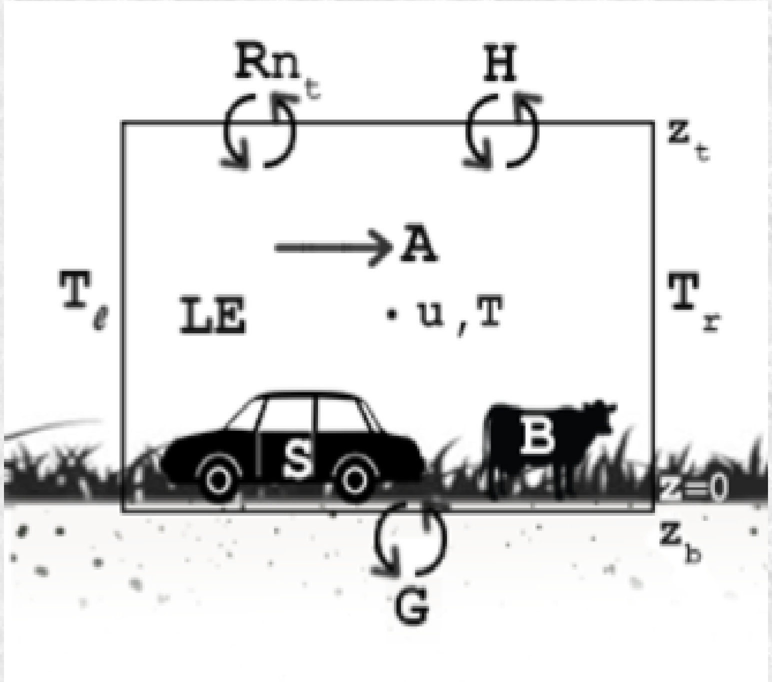


Complete:

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

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

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



Contributions to the Imbalance:

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)

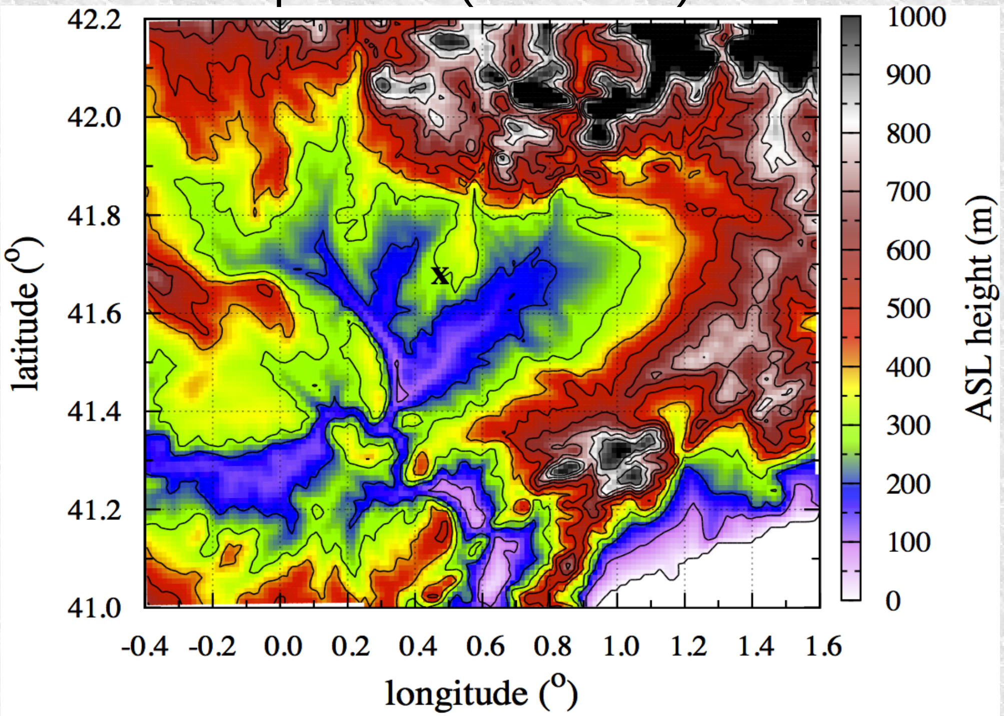
iv. Biological and soil processes:
- * Plants: respiration, transpiration and water transport
- * Soil: microbiological processes, phase changes in the porous spaces
- * Anthropogenic effects: houses, farms, industries, cities, traffic ...

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)

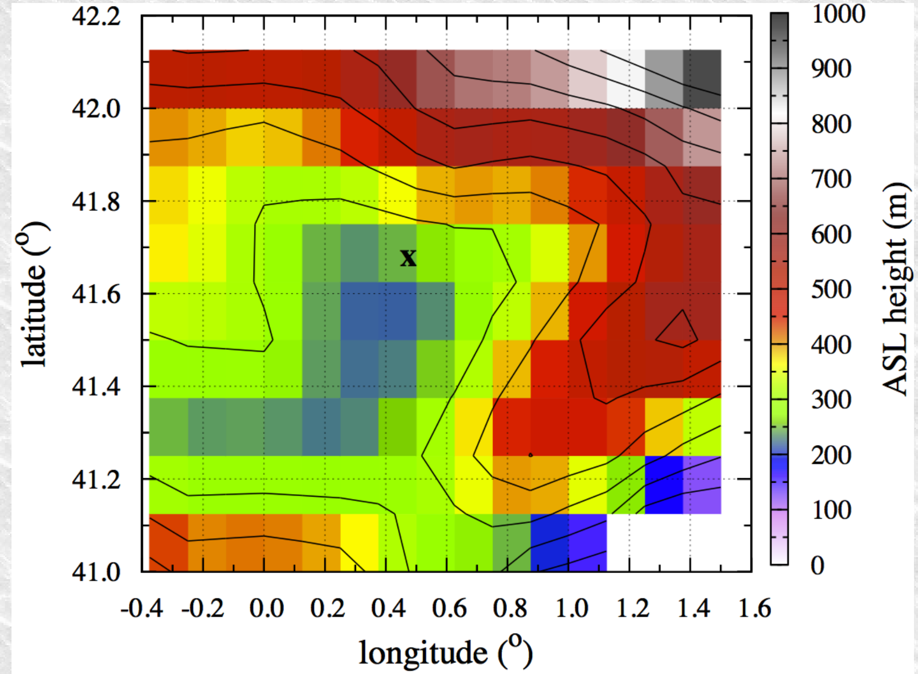
If the balance closed, it would be suspicious!

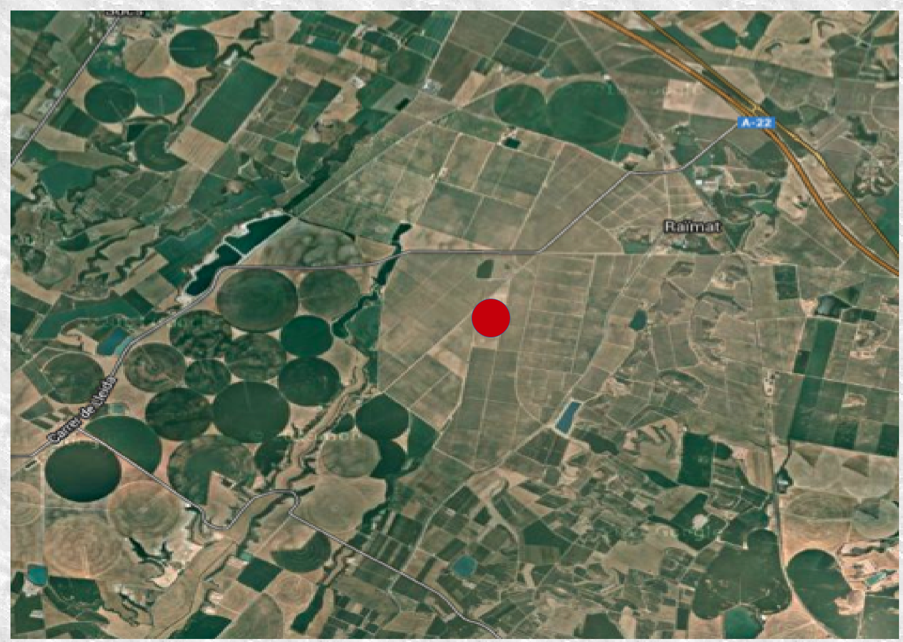
Quantifying the Imbalance: Eastern Ebro Valley (Raimat, Catalonia, LBF'09)

Topo: 1km (Meso-NH)



Topo: 16 km (ECMWF)





SEB observed vs modeled by ECMWF

monthly averages Jan09-Dec10

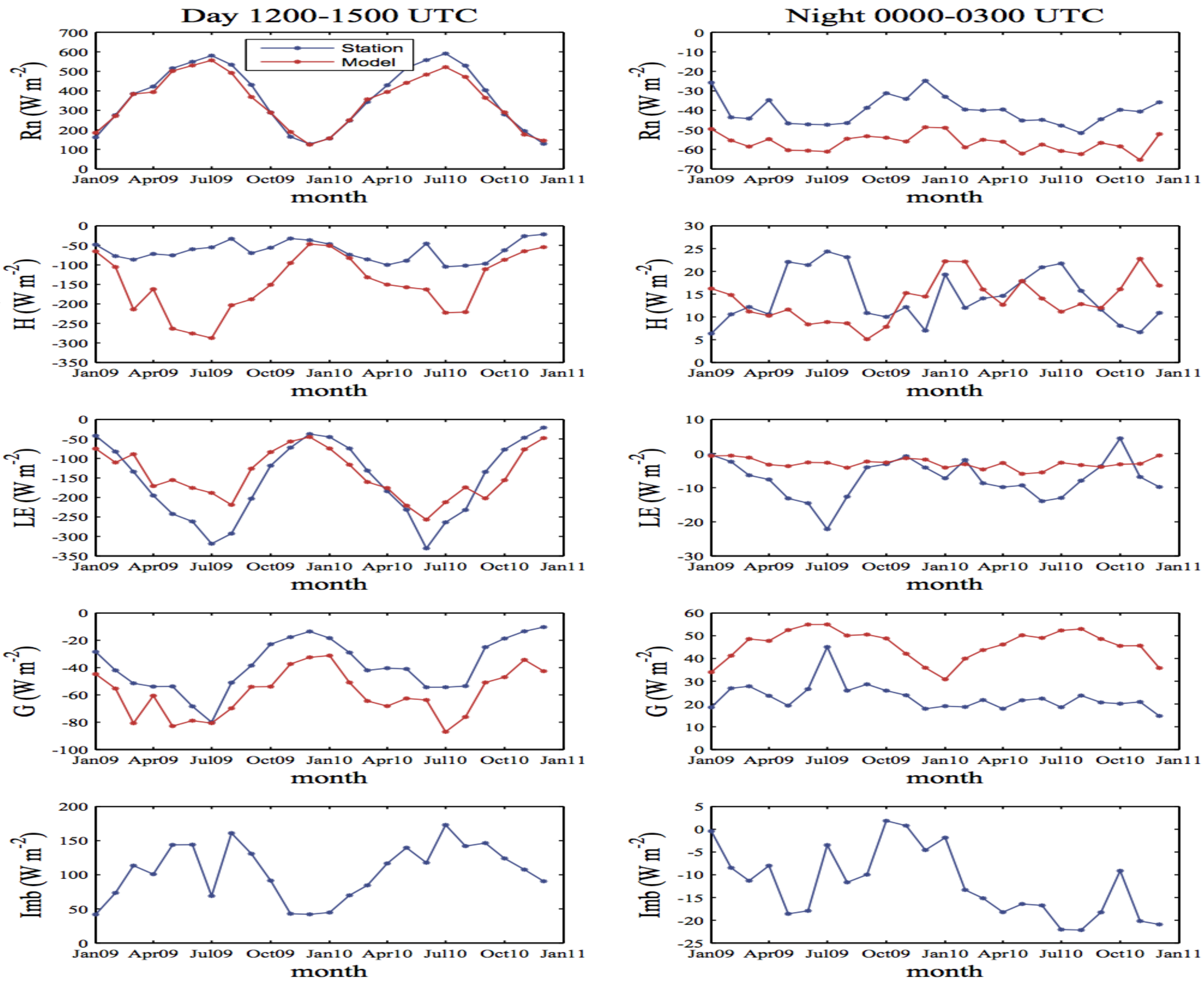
Net Radiation

Sensible heat flux

Latent heat flux

Ground flux

Imbalance



Model in red, observations in blue

Terms of the budget

16-km scale!

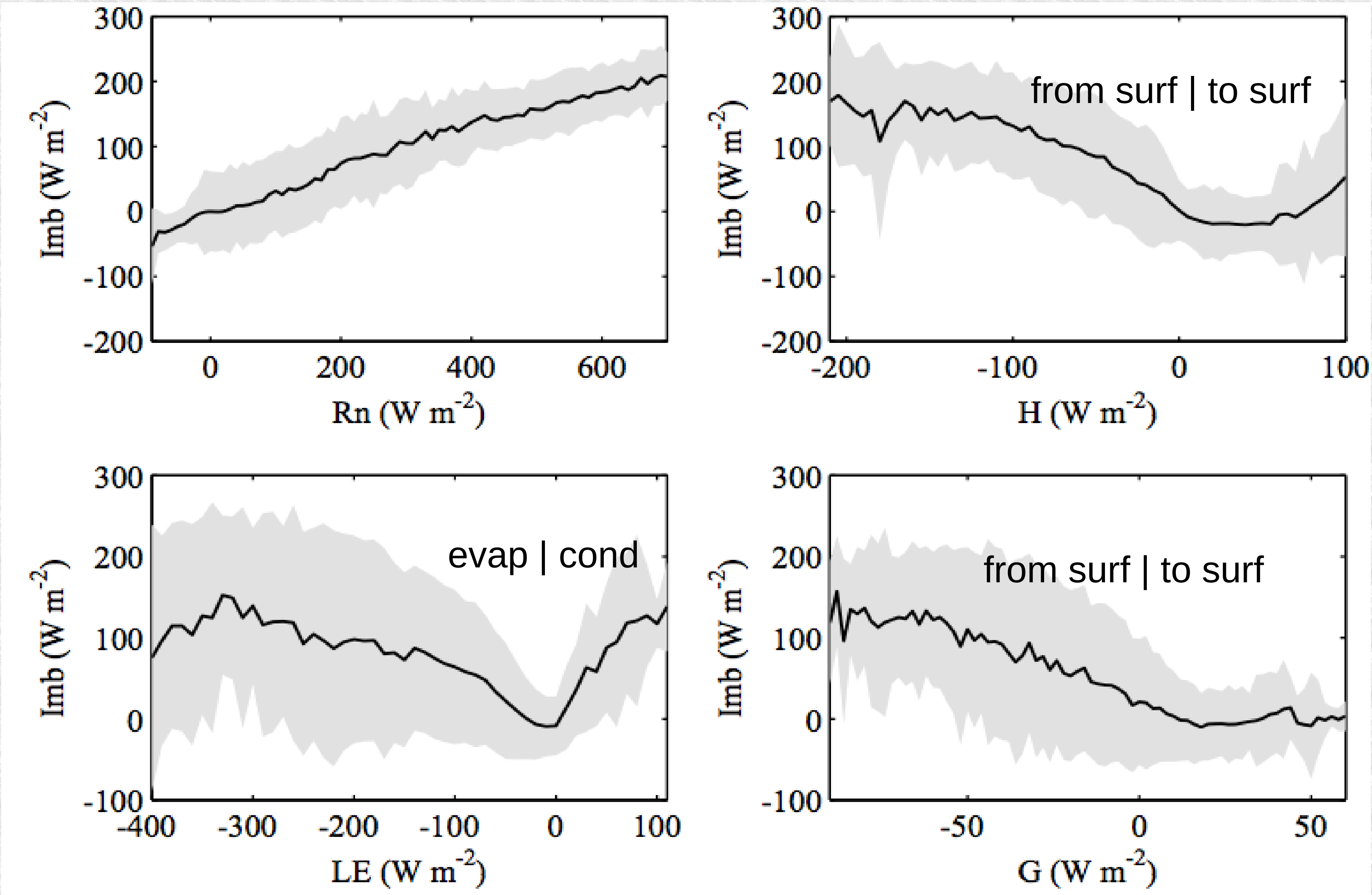
~30% Rn

			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

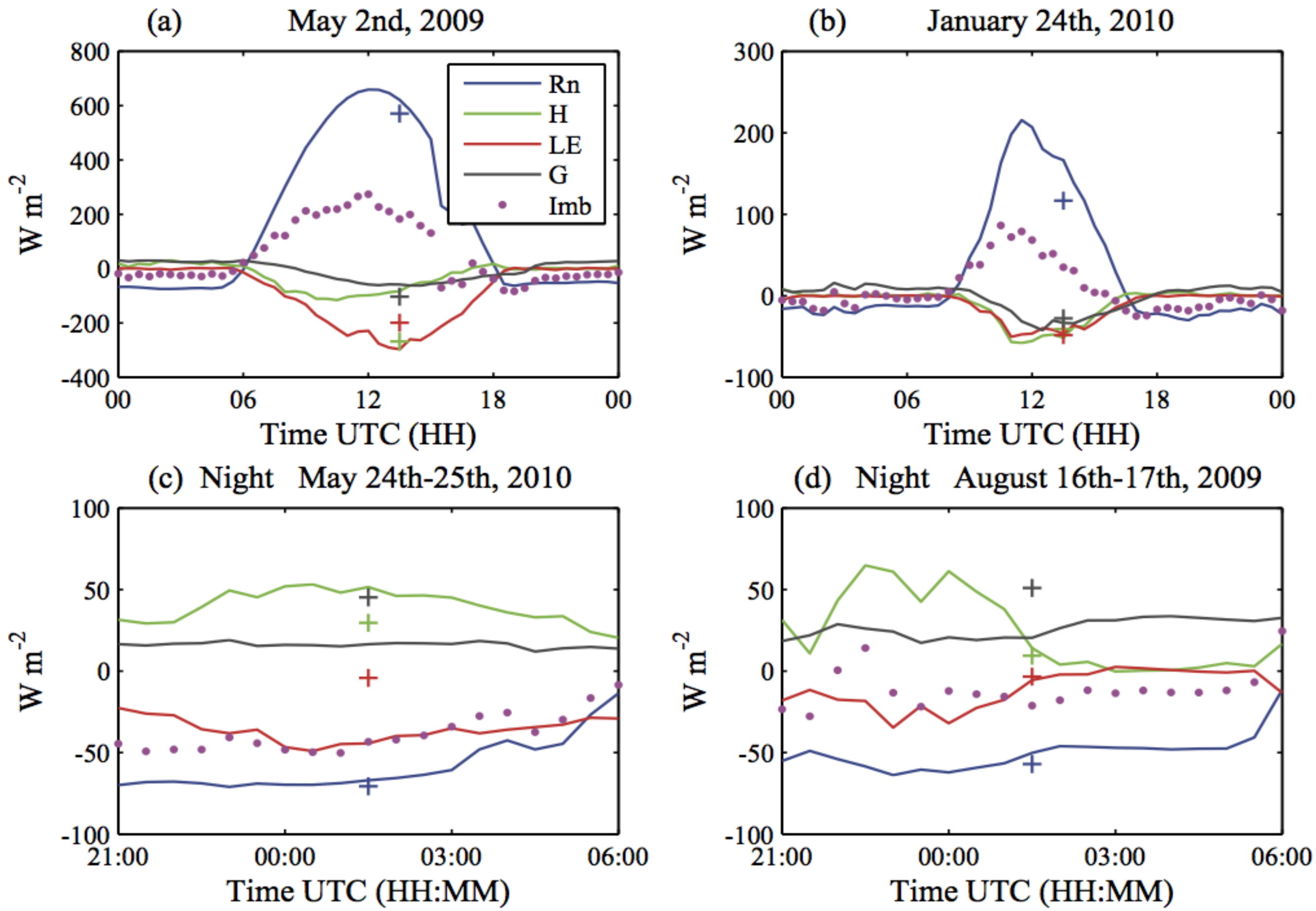


* It increases linearly with the Net Radiation
* For large values of H, LE and G, the imbalance levels off (~150-200 W/m2)

Some examples

1. Clear day, weak winds

2. Cloudy day, weak winds



3. Windy night, some clouds

4. Clear night, weak winds

	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

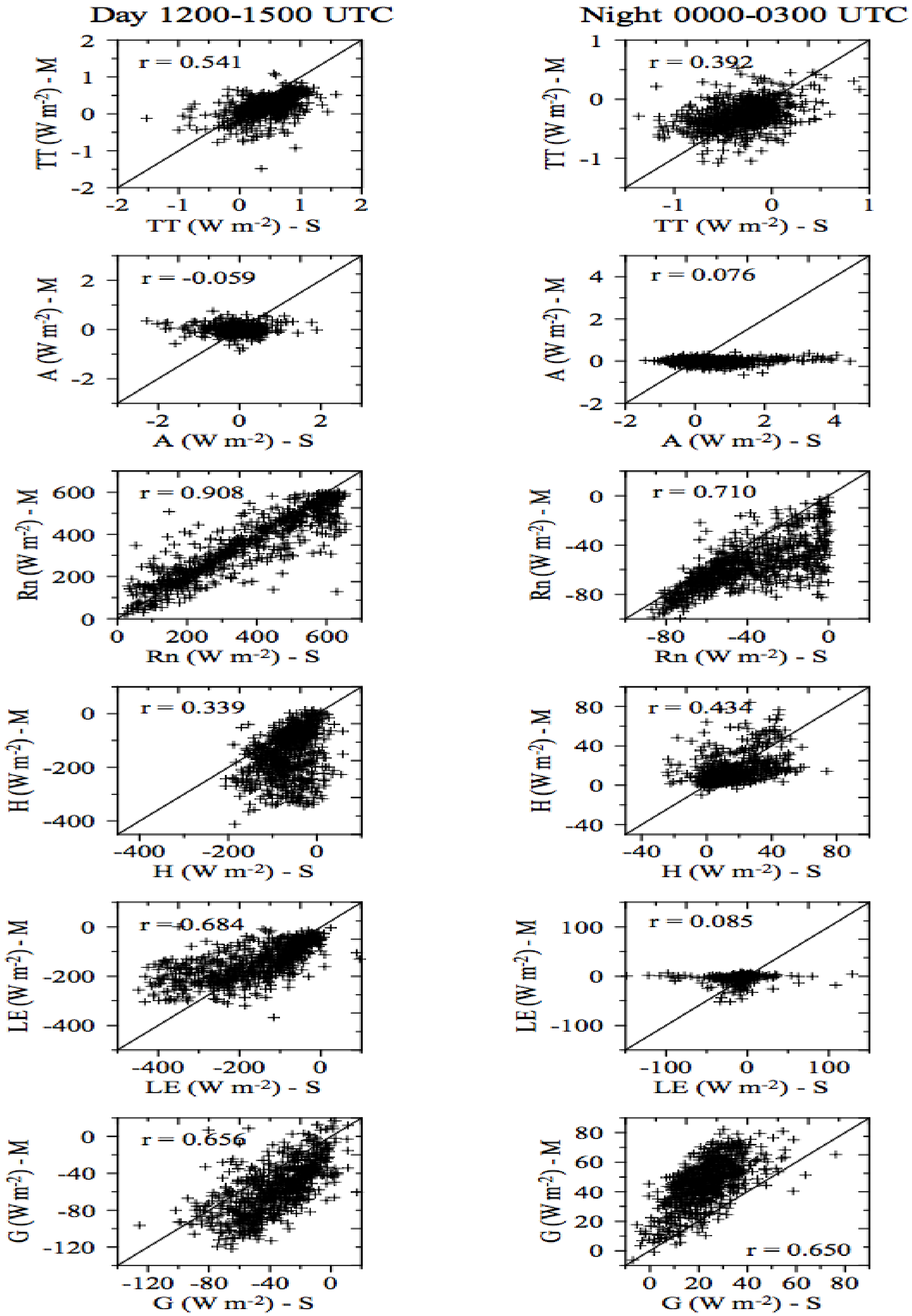
*Advection at the 10km-scale is not relevant, but in S is larger than in M

*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



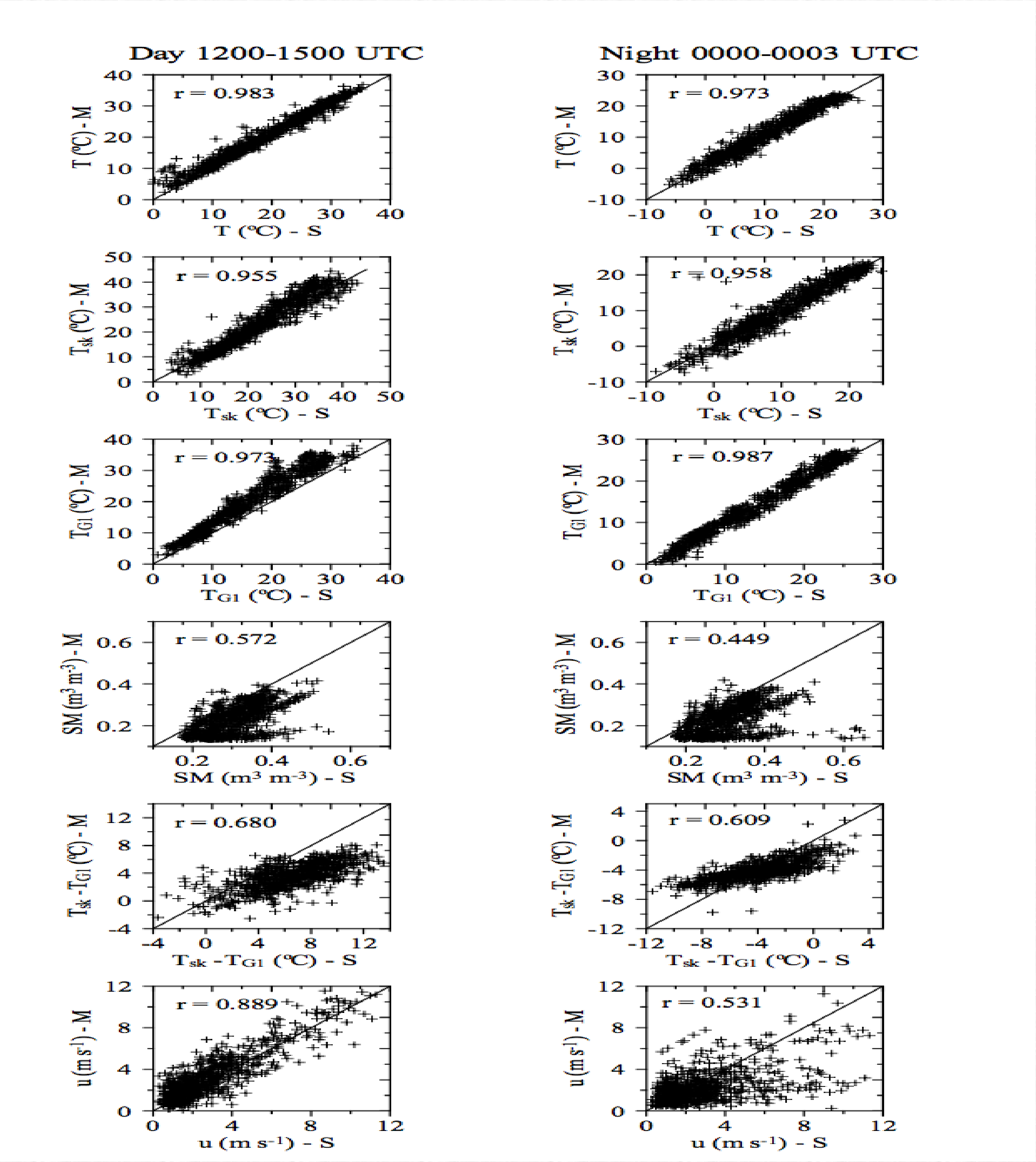
Relevant variables: data vs ECMWF

*Air and surface temperatures:
very well captured

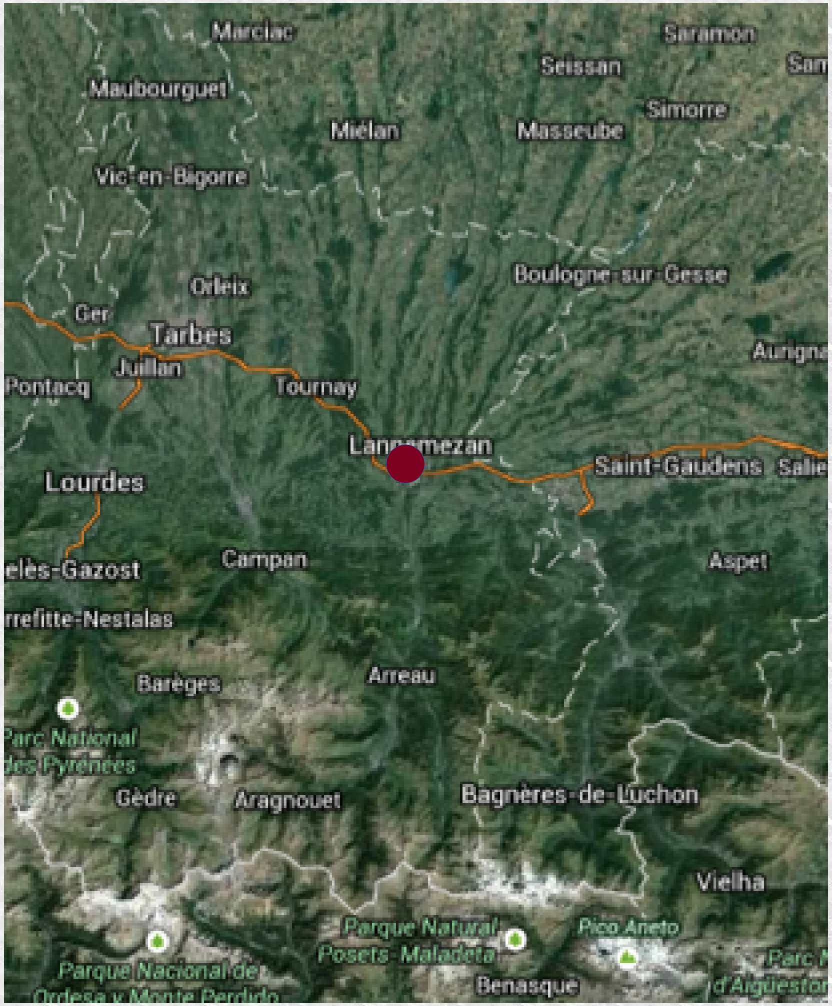
* Ground temperatures:
too warm in the model

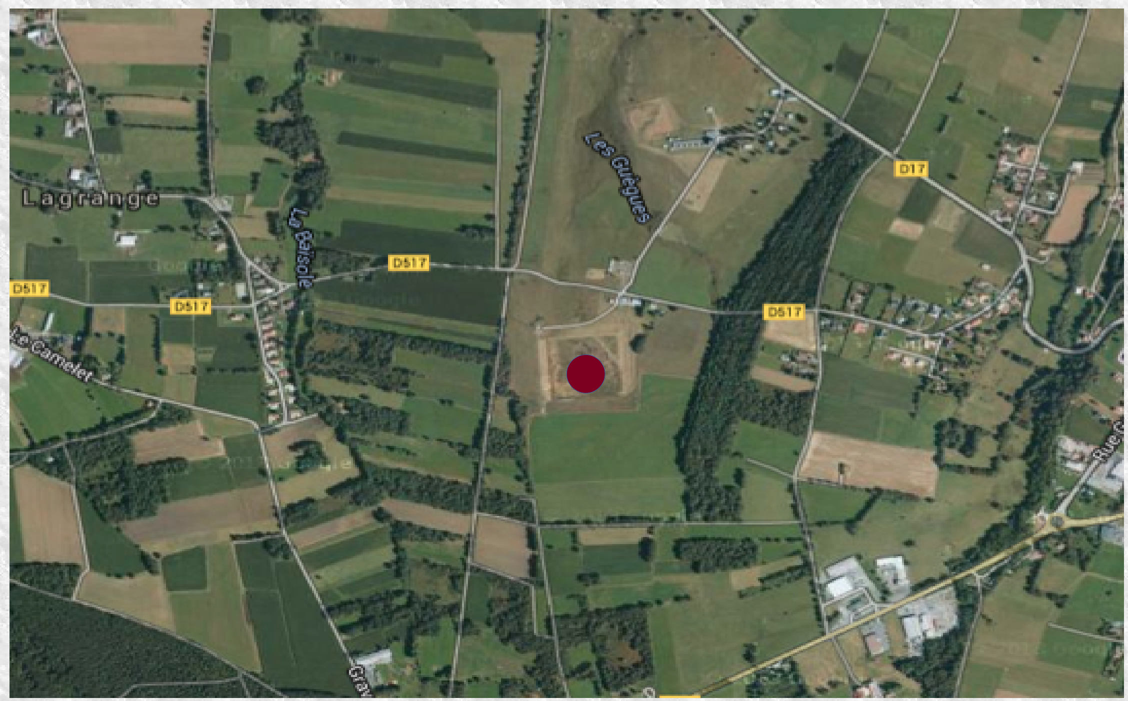
* SM (K) & (Ts-Tg): underestimated
but G overestimated?
G=Λ (Ts-Tg)
(Λ adjustable parameter!)

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

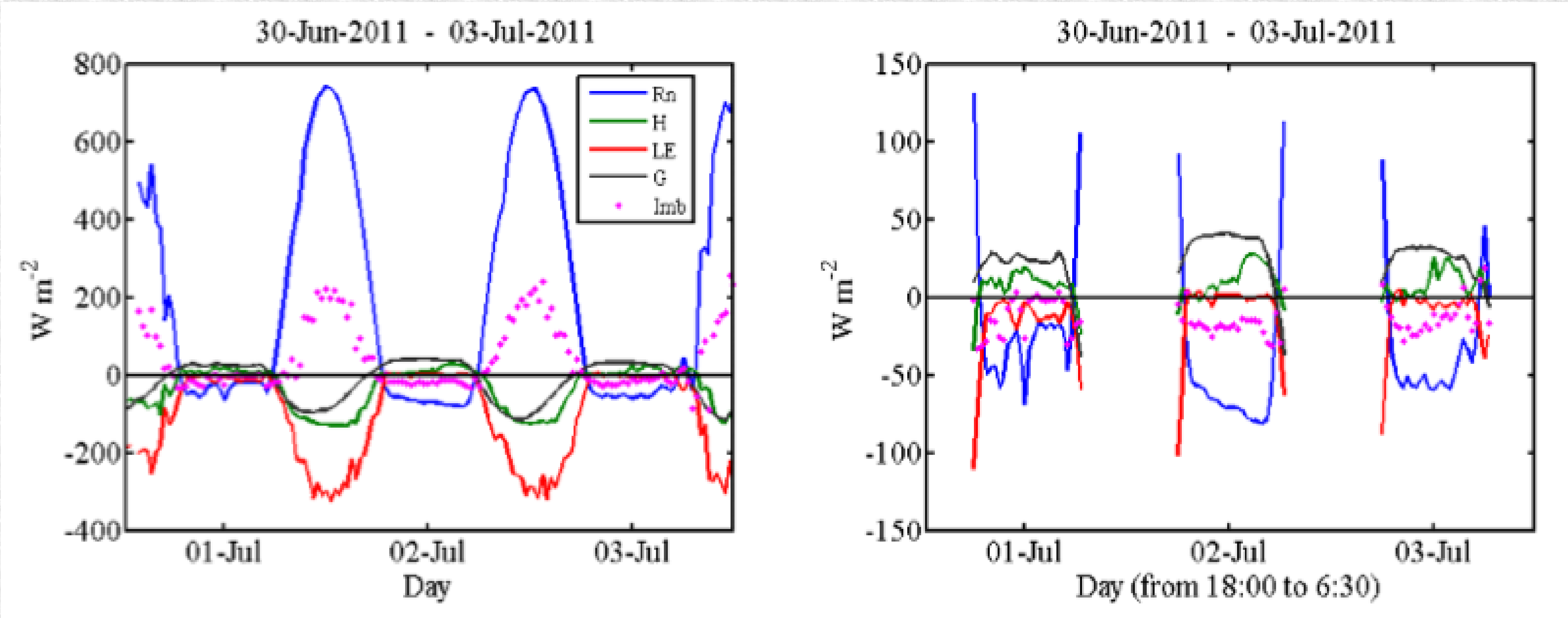


Exploring the advection at smaller scales: Pyrenees Foothills, (Lannemezan, Gascony, BLLAST'11)





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



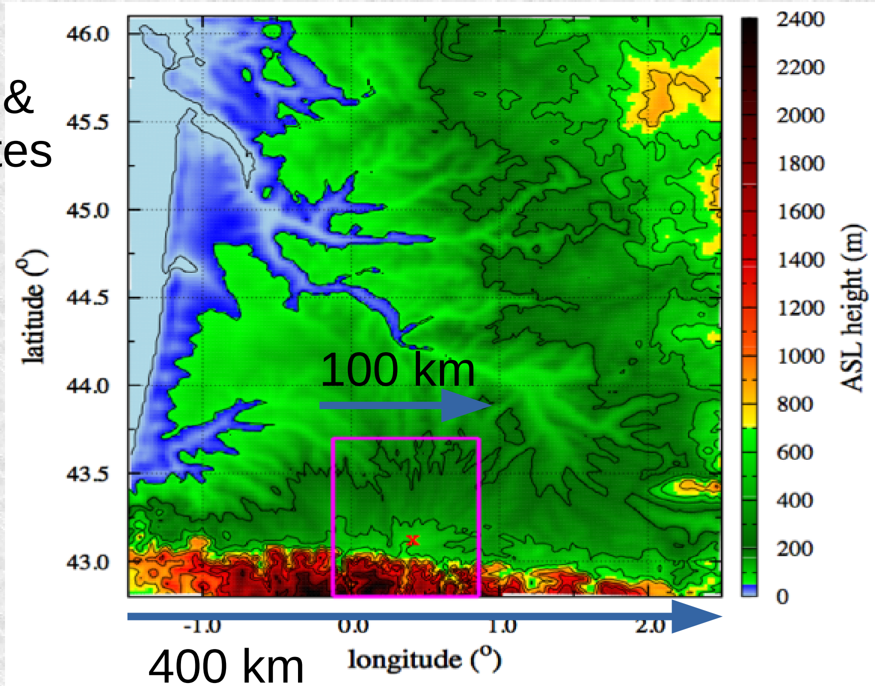
In the daytime: LE and Imb explain each 30% of Rn, H and G and 15% each

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

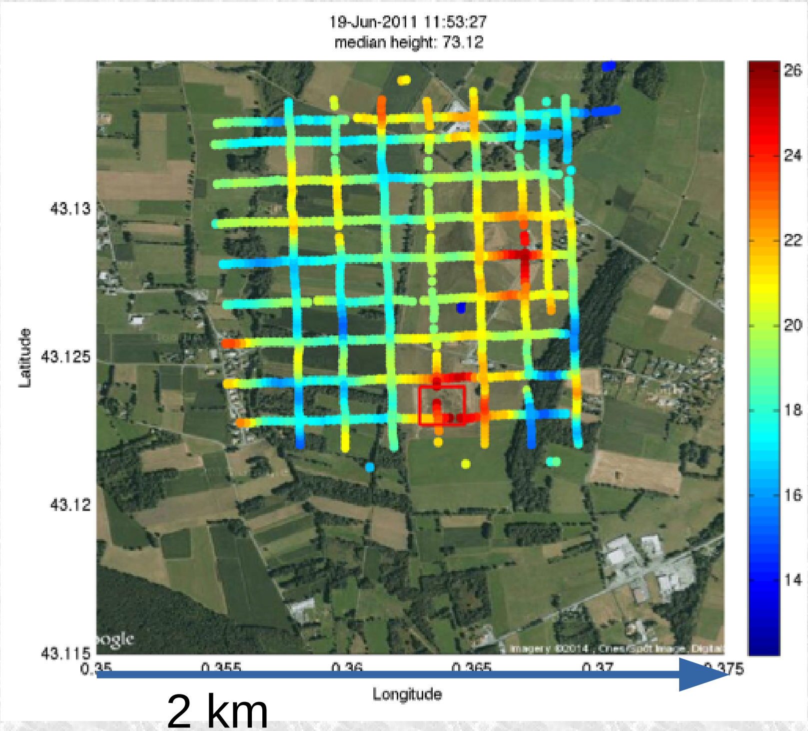
Morning and evening transitions: not explored in detail yet

Sources to estimate ΔT/Δx

Model & Satellites

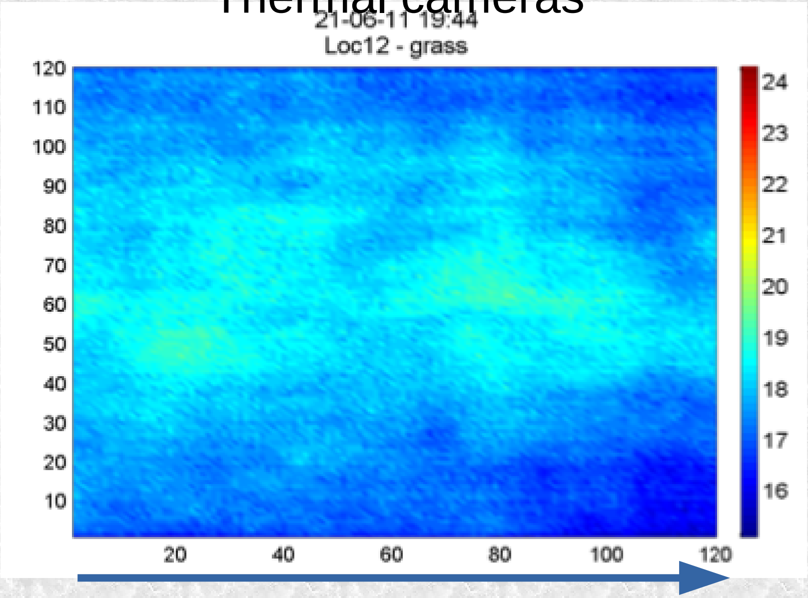


Drones (planes) and HR satellites



Drones (multicopters)

Thermal cameras



5 m

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

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

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.

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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 (accepted)
Cuxart, J., Wrenger, B. et al: Sub-kilometric heterogeneity effects on the surface energy budget in BLLAST, ACP (to be submitted)