An evaluation of the Energy budget computed with observed Enthalpy surface fluxes.

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1 Motivations - Introduction.

The energy budget of the atmosphere simulated by GCM or NWP models is currently monitored with the aim of having closed values for the "surface energy budget". However, it is explained in Marquet (2015a,b) that the way the surface fluxes of sensible (temperature) and latent (water) energies are computed is still a subject of debate, and in particular for the latent heat flux.

In the present study, the new moist-air enthalpy fluxes derived in Marquet (2015b) are evaluated and compared to the usual (standard) ones based on the latent heats of vaporization or sublimation. This evaluation is made by using the observation datasets of the Météopole-Flux observatory located at the CNRM, Toulouse, France.

2 The moist surface energy flux.

The simple case of no condensed water will be considered in this study, and the moist air is thus composed only of dry air and water vapor.

According to Marquet (2015a,b), the energy flux at the bottom of the atmosphere is computed by $F_h \approx \overline{\rho}\;\overline{w'\,h'}$, where the overbar means Reynolds averaging, primed values refer to fluctuations, and h is the thermal enthalpy given by

$$h \;=\; h_{\text{ref}} \;+\; c_{pd}\,T \;+\; L_h\,q_v \;, \qquad (1)$$

$$\text{where} \quad L_h\,(T) \;=\; h_v(T) \;-\; h_d(T)\;, \qquad (2)$$

h_{ref} is a constant reference value, and q_v is the specific content of water vapor. The difference in enthalpies $L_h(T) = (c_{pv} - c_{pd})\,(T - T_r\,) + L_h(T_r)$ is computed with $L_h(T_r) = (h_v)_r - (h_d)_r = 2603$ kJ/kg at $T_r = 273.15$ K. The difference of specific heats at constant pressure for water vapor and dry air is $c_{pv} - c_{pd} = 1846.1 - 1004.7 = 841.4$ J/K/kg.

The turbulent flux of h is equal to

$$F_h \;=\; \overline{\rho}\;c_p\;\overline{w'\,T'} \;+\; \overline{\rho}\;L_h(T)\;\overline{w'\,q'_v}\;, \qquad (3)$$

where c_p is the moist-air value $(1-q_v)\;c_{pd} + q_v\;c_{pv}$. This flux of enthalpy F_h is thus different from the usual sensible (SH) plus latent (LH) heat fluxes given by

$$SH + LH \;=\; \overline{\rho}\;c_p\;\overline{w'\,T'} \;+\; \overline{\rho}\;L_v(T)\;\overline{w'\,q'_v}\;, \qquad (4)$$

where the latent heat of vaporization is $L_v(T) = L_v(T_r) + (c_{pv} - c_l)\,(T - T_r\,)$, with $L_v(T_r) = (h_v)_r - (h_l)_r = 2501$ kJ/kg and $c_{pv} - c_l = 1846 - 4218 = -2372$ J/K/kg, where c_l is the specific heat at constant pressure of liquid water.

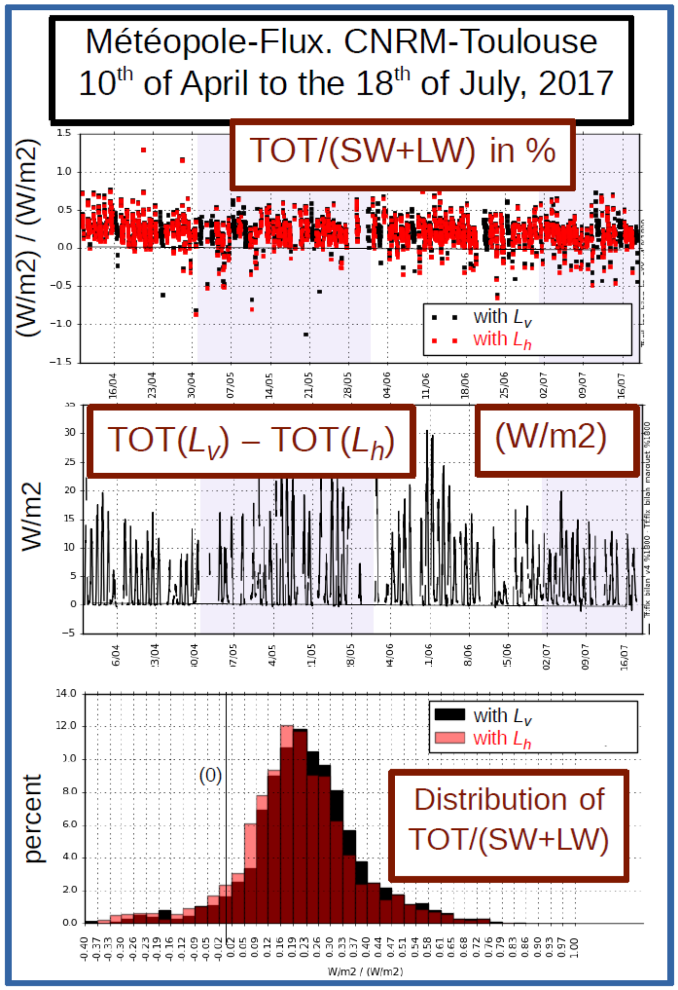

Figure 1: *The formulations with $L_v(T)$ and $L_h(T)$ are compared for a period of 100 days: the relative impact with respect to SW + LW (top); the difference of total budgets (center); the distribution of the relative impact (bottom).*

It is shown in Marquet (2015b) that $L_h(T)$ is about 4 % to 8 % larger than $L_v(T)$, depending on T. Therefore, the latent heat flux computed with $L_h(T)$ in Eq.(3) is expected to be about 6 % larger than the usual one computed with $L_v(T)$ in Eq.(4).

3 Numerical evaluations.

The Météopole-Flux dataset is described in the web site `https://www.umr-cnrm.fr/spip.php?article874&lang=en`. Daily reports are available at `http://www.umr-cnrm.fr/data/FL_1jour.png` and

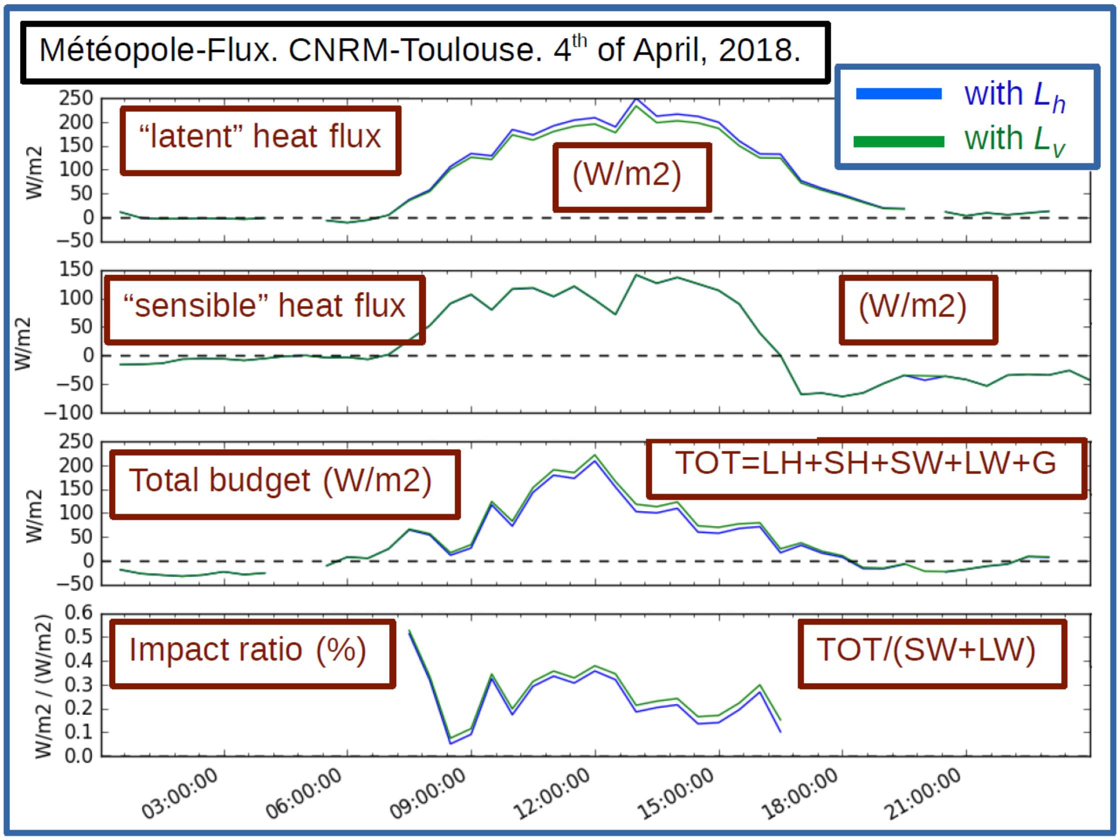

Figure 2: *The energy budgets at the Météopole-Flux site and for one particular day (the 4th of April 2018). The formulations with $L_v(T)$ (in green) or $L_h(T)$ (in blue) are compared (from the top to the bottom) for: the latent heat fluxes; the sensible heat fluxes; the total budgets; the relative impact in comparison with the net radiative fluxes.*

`http://www.umr-cnrm.fr/data/ST_ARP_ARO_7J.pdf`

The turbulent fluxes of temperature and water are observed at the Météopole-Flux by using an eddy-correlation method with 2D-rotation and high-band running-mean filter. The instruments are installed on a mast at 3.70 m above the ground level. Three wind components (u, v, w) and the sonic temperature (T) are measured at 20 Hz with a Gill Windmaster Pro sonic anemometer. A Licor-7500 hygrometer measures water vapor concentration at 20 Hz. Mean absolute temperature and humidity are measured with PT100 and Vaisala HMP110 instruments located in a shield.

Three HFP01 plates (Hukseflux Thermal Sensors) are used to compute the ground flux G as a mean value over three areas of 1 m^2, in order to reduce the variability in space. The heat flux plates are placed at 5 cm soil depth. These sensors are used extensively by the community to measure G in surface energy budgets.

Fig.1 shows, for a period of 100 days, an evaluation of the impact on the energy balance of using F_h in place of the classical sum $SH + LH$. The residual energy is globally decreased by about 3 to 4 % when $L_h(T)$ is taken into account, with a resulting improved total energy budget $TOT = SH + LH + SW + LW + G$, where $SW + LW$ is the net radiative flux, and G is the ground flux.

For one day measurements, Fig.2 shows that the latent heat flux calculated with $L_h(T)$ is slightly greater (about +6 %) than the one calculated with $L_v(T)$ during the day (between 09 UTC and 18 UTC). The change for the sensible heat flux is very small.

4 Conclusions.

The expected impact of about +6 % of LH is observed for the new latent heat flux computed with $L_h(T)$, in comparison with the usual one computed with $L_v(T)$. The difference in energy budget can reach 15 to 30 W/m^2 on some days. However, the average decrease of the imbalance in surface energy budget observed at the Météopole-Flux site is small, and a significant imbalance still exists which cannot be explained by the errors in computing the latent heat flux.

References

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