Geophysical Research Abstracts
Vol. 14, EGU2012-1336, 2012
EGU General Assembly 2012

The surface energy imbalance problem

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The 'energy imbalance problem' in micrometeorology arises because at most flux measurement sites the sum of eddy fluxes of sensible latent heat ($H + \lambda E$) is 50 – 200 W m^{-2} less than the available energy (A) at half-hourly time scales. Thus either eddy fluxes of H and $\lambda E$are underestimated or A is overestimated. Lack of energy closure is caused by: 1) a failure to satisfy the fundamental assumption of one-dimensional transport needed for measurements on a single tower to represent spatially-averaged fluxes to/from the underlying surface; 2) measurement errors in: i) eddy fluxes, ii) net radiation, iii) changes in energy storage in soils, air, and biomass below the measurement height.

Review of the literature shows that radiometric errors are unlikely to cause significant overestimates of A at *all* flux measurement sites, but phase lags between $H + \lambda E$ and A caused by incorrect estimates of the energy storage terms that contribute to A can explain why $H + \lambda E$ *systematically* underestimates A at half-hourly time scales. Energy closure is observed at only 8% of flux sites in the La Thuile dataset (http://www.fluxdata.org/DataInfo/default.aspx), with a median slope of 0.75 for $H + \lambda E$ versus A for half-hourly averages. Using 24h averages leads to energy closure at 45% of the La Thuile sites, and the median slope of $H+\lambda E$ versus A increases to 0.90. Increasing the averaging time reduces the bias in A because energy entering the soil, air and biomass in the morning is returned in the afternoon and evening.

Unrealistically large positive horizontal temperature gradients of 4 – 10 ºK km^{-1} are needed for horizontal advective flux divergences to explain the 50 – 200 W m^{-2} underestimate of $H + \lambda E$ compared to A often observed at half-hourly time scales. Similarly, unrealistically large mean vertical velocities and temperature gradients are needed for vertical advective flux divergences to account for the 'missing' energy. Imbalances between $H + \lambda E$ and A still occur in daily averages but the small residual energy imbalances are explicable by positive and negative horizontal and vertical advective flux divergences. Systematic underestimates of the vertical heat flux also occur if horizontal $u'T'$covariances contaminate the vertical $w'T'$ signal due to incorrect coordinate rotations. An incorrect tilt angle of 2º will cause a 5% underestimate of H.

Closure of the energy balance is possible at half-hourly time scales by careful selection of horizontally homogeneous sites to satisfy the assumptions of one-dimensional transport underpinning eddy covariance measurements on single towers , attention to all sources of measurement and data processing errors in the eddy covariance system, and by accurate measurement of net radiation and every energy storage term needed to calculate available energy.