On the relevance of mesoscale transport for in-situ energy balance measurements and its partitioning between sensible and latent heat

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Scales of atmospheric motion

Reynolds decomposition (1895)

\[ x = \bar{x} + x', \quad x' = 0, \]

\[ F = wq = wq + w'q' \]
The energy balance closure problem

Eddy covariance energy balance station

\[ R_n - G = \lambda E + H \]

\( R_n \): net radiation, \( G \): soil heat flux, \( \lambda E \): latent heat flux, \( H \): sensible heat flux

Worldwide in-situ measurements show energy balance closure of 84% ± 20% (Stoy, Mauder et al., AFM, 2013, analysis of 180 FLUXNET sites)

One possible cause: Mesoscale transport

TERENO Graswang site, July/August 2010

\( y = 0.78x - 10 \)
Questions

- How can mesoscale transport cause a systematic underestimation?
- Can mesoscale transport be significant in the surface layer?
- Can mesoscale structures be found at typical eddy tower heights?
- What are potential predictors for mesoscale flux contributions?
- Do mesoscale structures even affect the roughness sub-layer?
- How to adjust tower fluxes for mesoscale transport?
1. How can mesoscale transport cause a systematic underestimation?

- Mahrt (1998): 'Flux sampling errors for aircraft and towers', JTECH

![Diagram showing flow and partitioning between sensible and latent heat](image)

is usually neglected, as would occur with homogeneous flow where $\bar{w} = 0$, in which case the heat flux is $\bar{w}'\theta'$. However, with stationary eddies, $\bar{w}'\theta'$ is an inadequate estimate of the total heat flux so that spatial averaging over the scale of the eddies is required. This can be expressed by decomposing the local time average flow $\bar{w}(x)$ into a spatial average of the time average $[\bar{w}]$, and the deviation of the time average from this spatial average.
2. Can mesoscale transport be significant in the surface layer?

- Candle Lake Runs (BOREAS/BERMS) @ 30 m measurement height

20 flights analyzed
=> 5 – 20% mesoscale flux contribution (2 km)

(Mauder et al., JGR, 2007)
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3. How far down towards the surface can mesoscale structures be found?

DUAL Doppler Lidar (KIT Cube)

17-04-2013 1030 – 1100 UTC
U = 3.0 m/s, Dir = 225°

(Eder et al., JAMC, submitted)

(Etling and Brown, 1993)
3. How far down towards the surface can mesoscale structures be found?

DUAL Doppler Lidar (KIT Cube)

DUAL Doppler Lidar (KIT Cube)

RHI Scan (Halo Photonics)

17-04-2013 1030 – 1100 UTC

$U = 3.0 \text{ m/s, } \text{Dir} = 225^\circ$

(Eder et al., JAMC, submitted)
What are potential predictors for the mesoscale flux contribution?

TERENO Energy balance station Selhausen + KIT HATPRO

\[ \text{Residual} = a_0 + a_1 \cdot \frac{1}{u^*} + a_2 \cdot \lambda \frac{\Delta a}{\Delta z} : \text{multiple } R^2 = 0.60 \ (0.40) \]

(\text{Eder et al., JAMC, submitted})
Do mesoscale structures even affect the roughness sub-layer?

Yatir Forest, Israel

Aug/ Sept 2013

- desert:  
  - ceilometer (boundary layer height)  
  - mobile flux tower

- forest:  
  - Doppler lidar (boundary layer height + wind)  
  - flux tower
Do mesoscale structures even affect the roughness sub-layer?

Desert: EBR = 0.76

Forest: EBR = 1.03

Data from two meteorological towers and one Doppler Lidar: 2013-08-23
How to adjust for tower fluxes for mesoscale transport?

Polar 5 (AWI)

Twin Otter (NRC)

All flight tracks > 100 km

mesoscale Bowen ratio

small-scale turbulent Bowen ratio


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Conclusions

- Mesoscale structures cause a systematic underestimation in the presence of vertical gradients of temperature and humidity in the CBL.

- Mesoscale transport can be as large as the energy balance residual in the surface layer, even at typical eddy tower heights.

- Potential predictors for mesoscale energy flux contributions are $u_*$, vertical gradients in $q$ and $\Theta$.

- In the roughness sub-layer, mesoscale structures get broken up by shear; the energy balance is closed.

- The mesoscale Bowen ratio is not generally conserved; we often found a larger portion of mesoscale energy exchange in $\lambda E$. 