Capturing all relevant scales of biosphere-atmosphere exchange – the enigmatic energy balance closure problem

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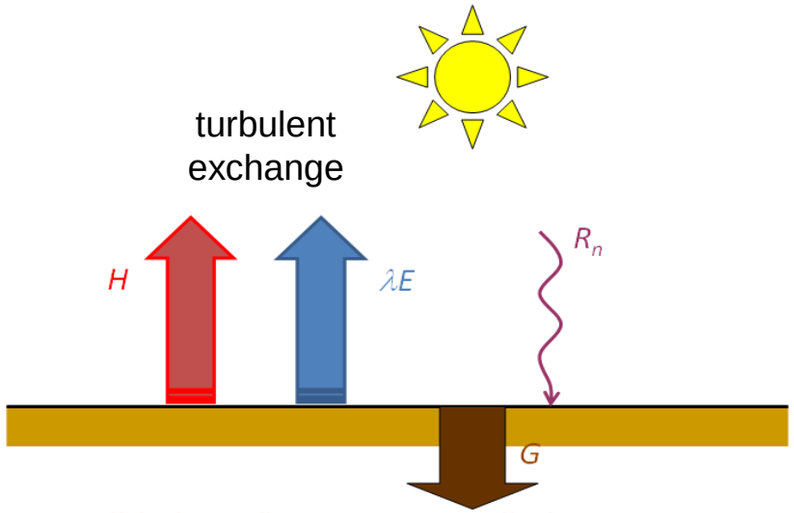
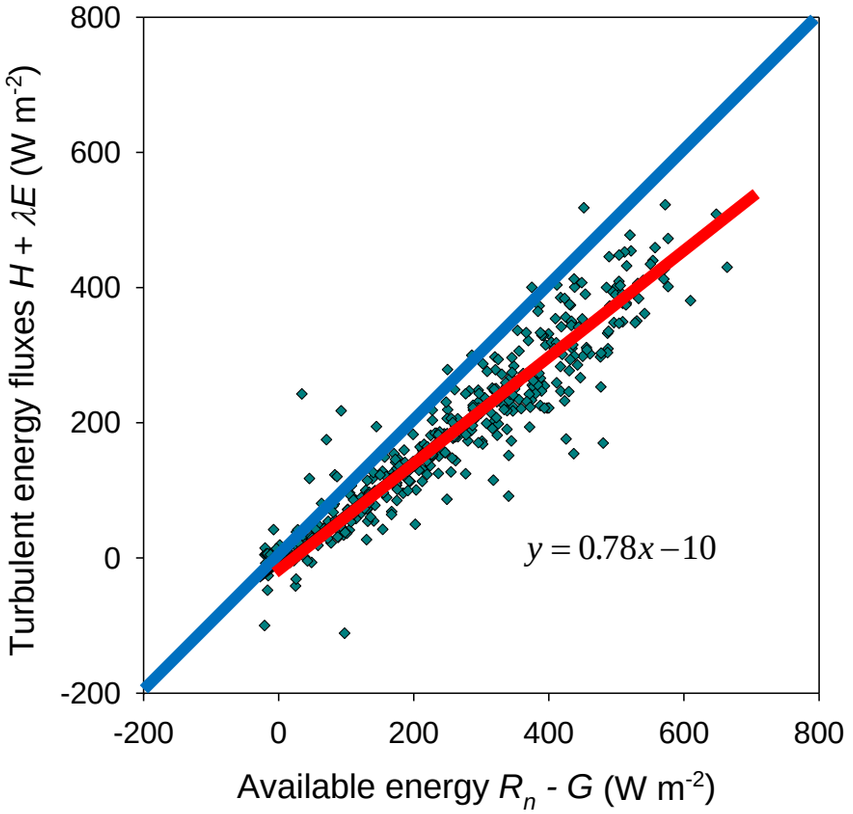
The Energy Balance Closure Problem

Energy Balance

$$R_n - G = \lambda E + H$$



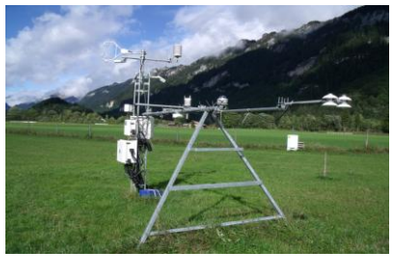
H: sensible heat flux, R_n *:* net radiation
λE: latent heat flux, *G:* soil heat flux



TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIA

HELMHOLTZ ASSOCIATION

Graswang site,
July/August
2010



- Worldwide in-situ measurements show:

  Underestimation of turbulent exchange (*λE + H)* **by 10-30%**

  (e.g. Stoy and Mauder, 2011, analysis of 180 FLUXNET sites)

Energy Balance Closure – Landmarks

1985

- **Desjardins** *AFM* 36, 29-41: First description of the EBC problem

1995

- **Foken and Oncley** *BAMS* 76, 1191-1193: Raise awareness of the EBC problem and test various hypotheses

1998

- **Mahrt** *JTECH* 15,416-429: Hypothesis: large-scale stationary circulations => spatial averaging

2004

- **Kanda** et al. *BLM* 110, 381-404.: First LES study of the EBC problem => spatial averaging

Agricultural and Forest Meteorology, 36 (1985) 29—41
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

CARBON DIOXIDE BUDGET OF MAIZE

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(Received December 21, 1984; revision accepted April 17, 1985)

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underestimation of flux densities, which can be estimated using the energy balance approach, where net radiation minus soil heat flux density ($Q_n - Q_g$) should equal $Q_h + Q_e$. A sample of these flux densities recorded on a 10 minute basis, on calendar day 207 (1984), is presented in Fig. 3A. It can be seen that $Q_h + Q_e$ versus time are highly correlated with $Q_n - Q_g$. The extent of the underestimation of $Q_h + Q_e$ is taken into account in arriving at the corrected above-canopy CO_2 flux densities in Fig. 3B. It resulted in a mean increase in the CO_2 flux density of 15%. This approach

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Energy Balance Closure – Landmarks

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Scale analysis of airborne measurements

Mauder, M., **Desjardins, R.L.**, MacPherson, J.I.: 2007, 'Scale analysis of airborne flux measurements over heterogeneous terrain in a boreal ecosystem' *JGR* 112, D13112, doi:10.1029/2006JD008133.

115 km flight track
30 m above surface
"Candle Lake Run"

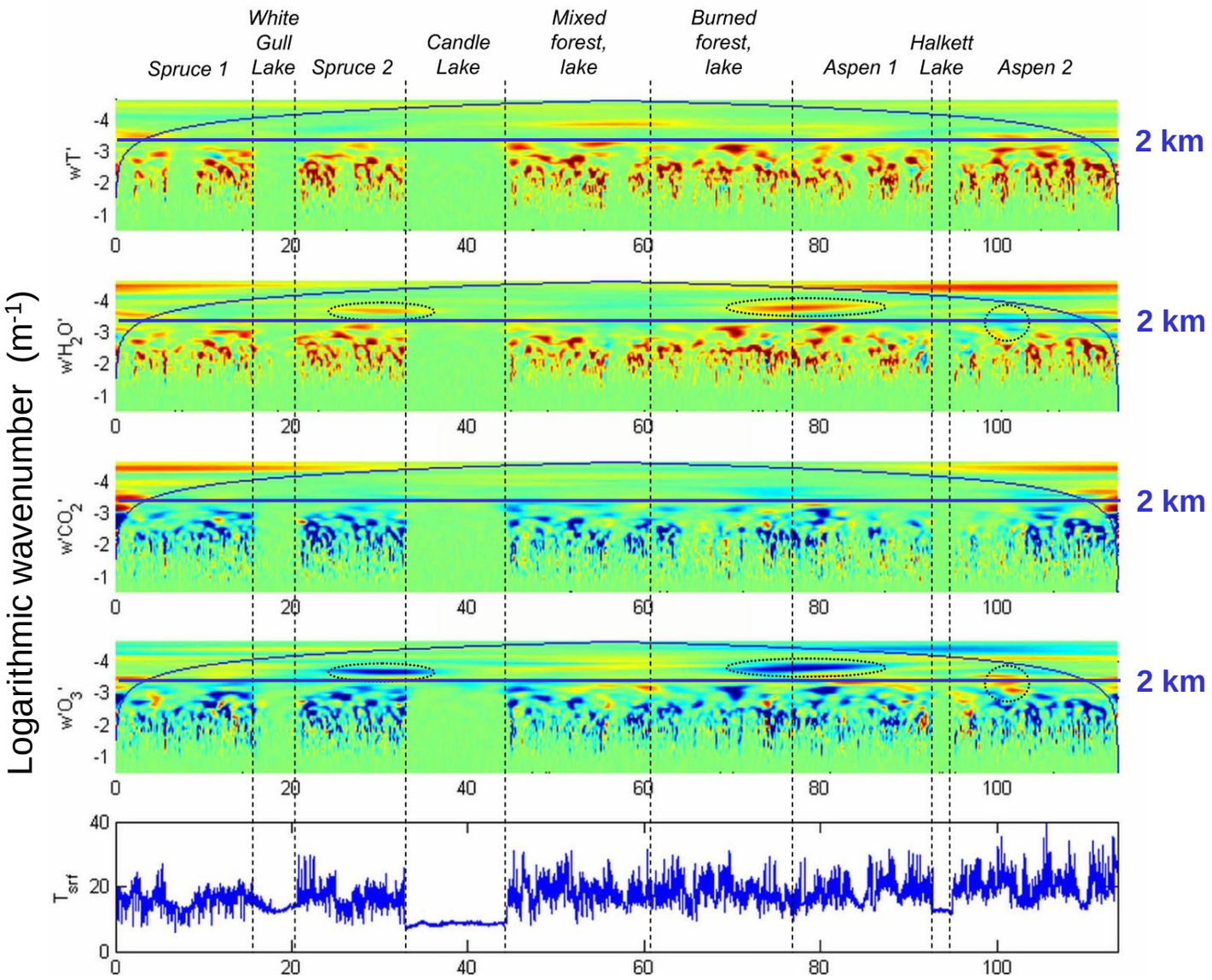
Figure 1. Land cover classification of a Landsat thematic mapper (TM) image of the area around Candle Lake from 2 September 1994 [after *Hall et al.*, 1997]. The flight track of the National Research Council (NRC) Twin Otter Candle Lake Run is indicated by a triple line.

Scale analysis of airborne measurements

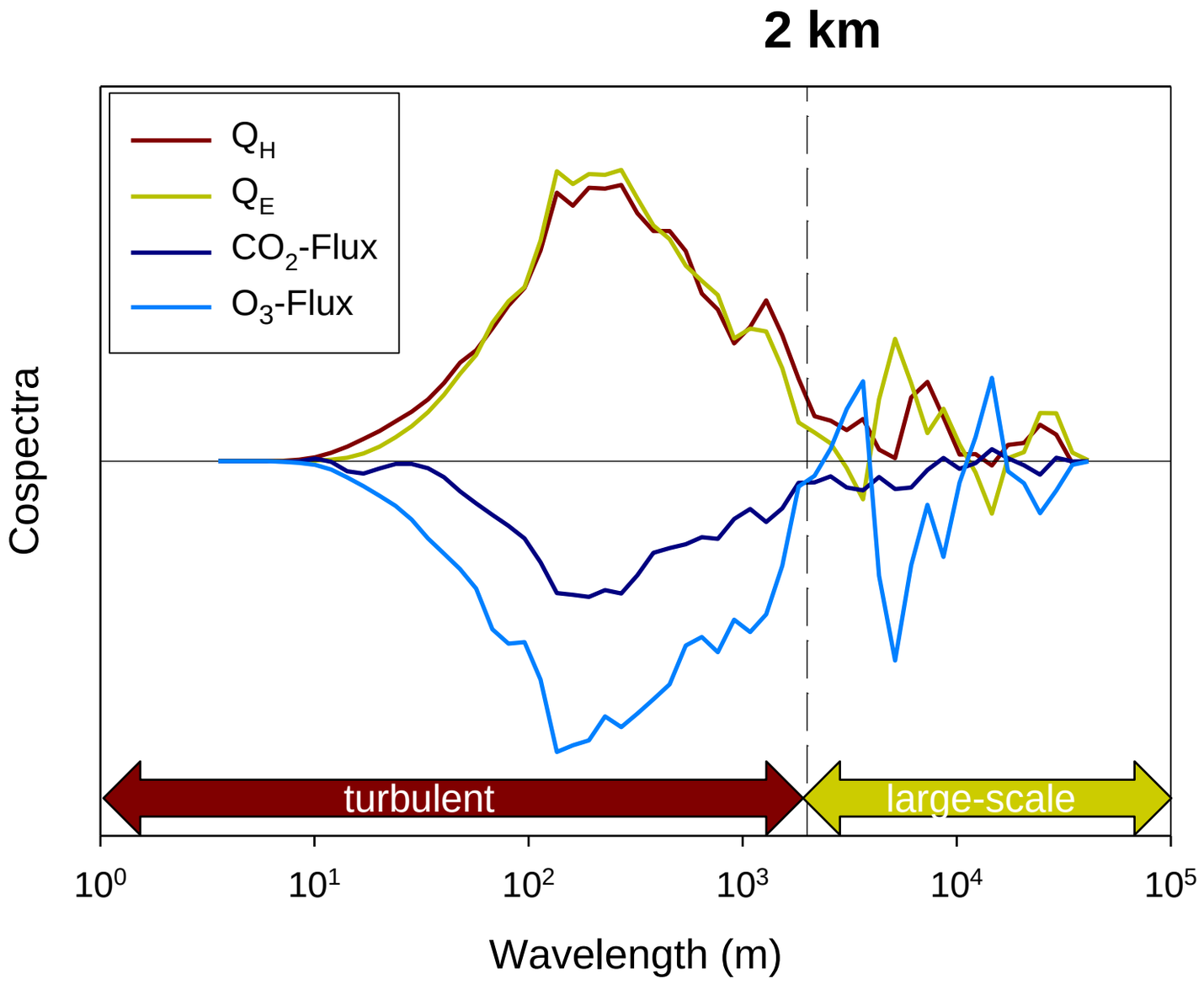
Wavelet cross-scalograms

Flight BOREAS 1
1041 – 1116 CST
25 May 1994

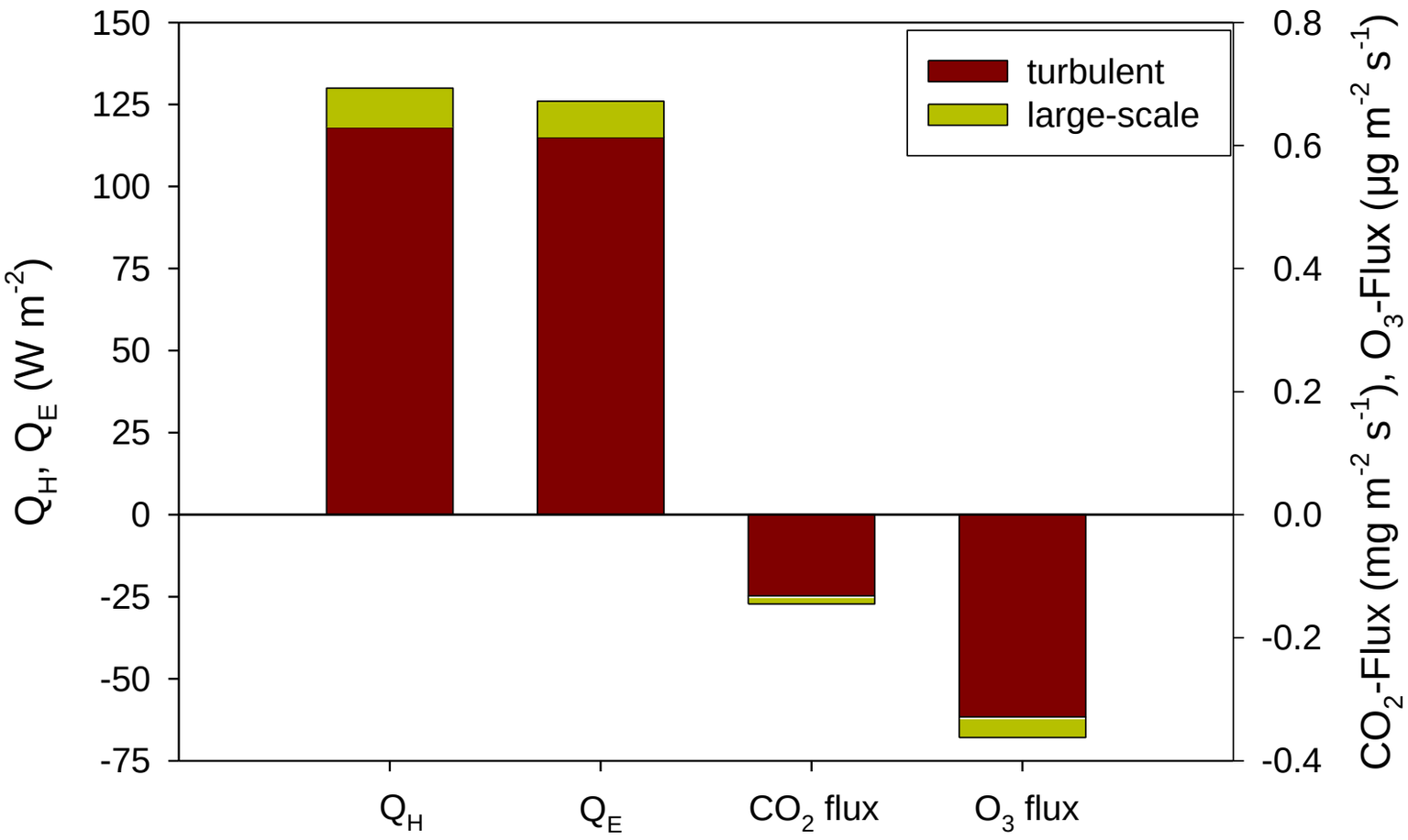
Taylor-hypothesis:
2 km =
30 min x 1.1 m s^{-1}



Scale analysis of airborne measurements



Scale analysis of airborne measurements

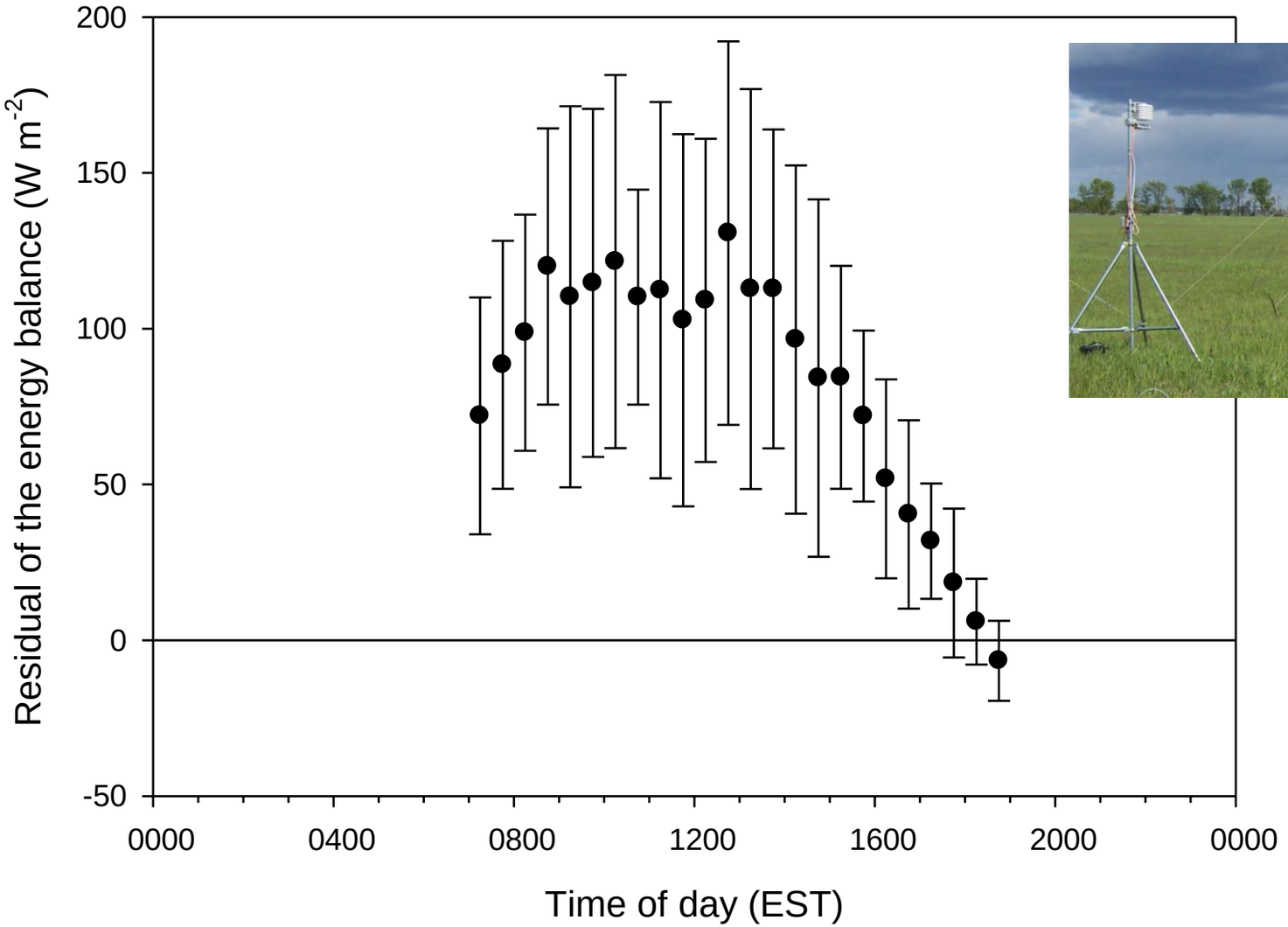


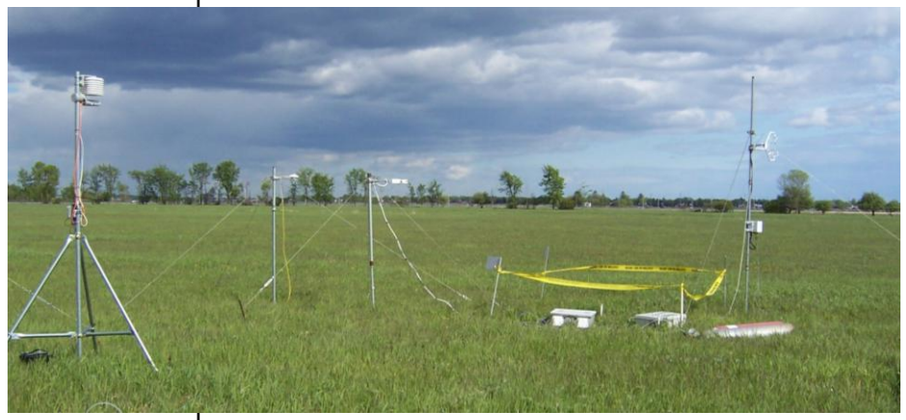
20 flights analysed
⇒10 – 30% large-scale flux contribution
⇒ Same magnitude as the imbalance of tower measurements below the flight track

Multi-tower set-up, 2008

27 June to 6 August 2008, Energy balance residual at central site

Research farm near Ottawa, Canada

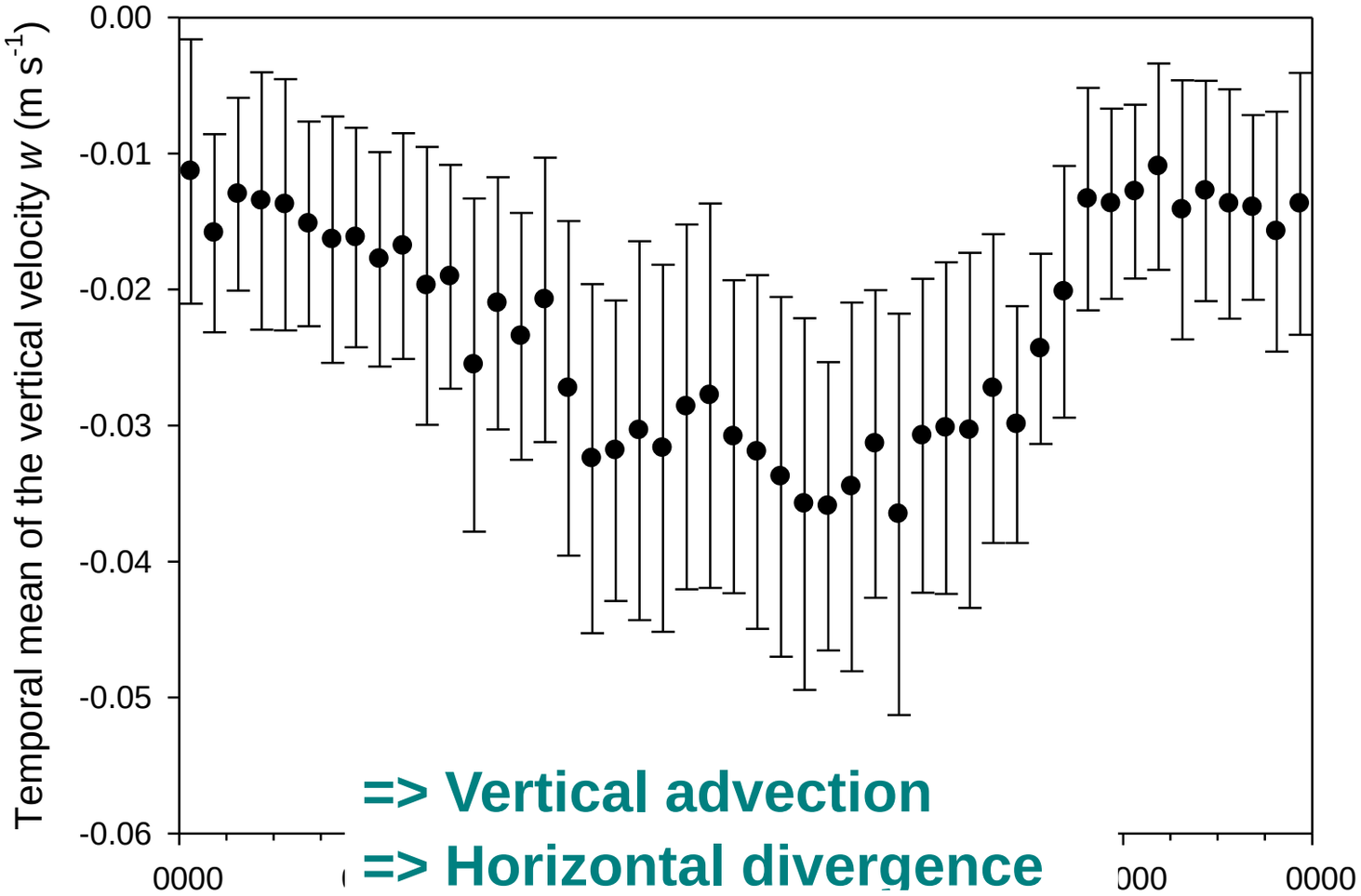




Mauder, M., **R. L. Desjardins**, E. Pattey, D. Worth, 2010: An attempt to close the surface energy balance using spatially-averaged flux measurements. *BLM* **136**, 175-191.

Multi-tower set-up, 2008

27 June to 6 August 2008, mean vertical wind velocity

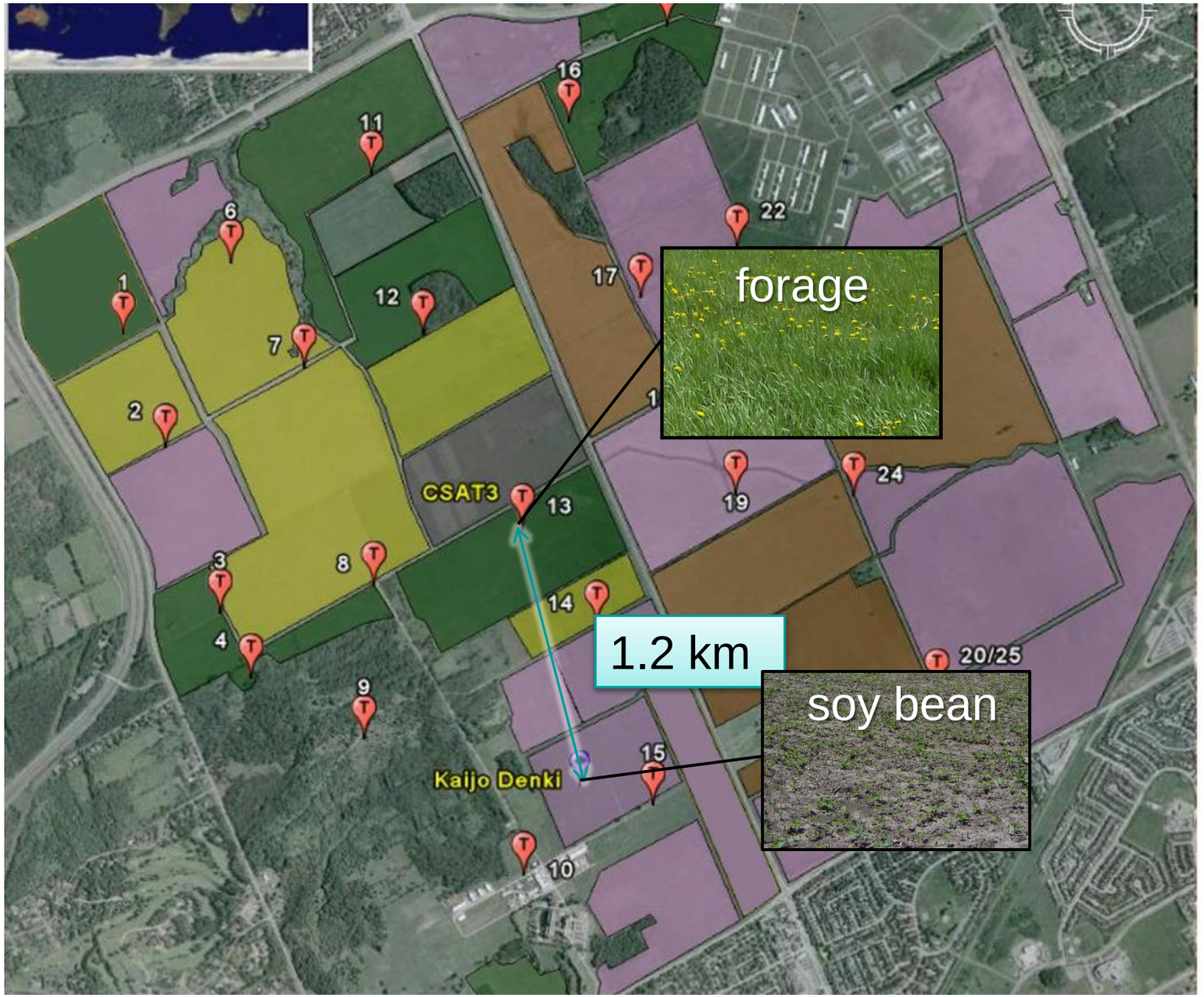


=> Vertical advection

=> Horizontal divergence

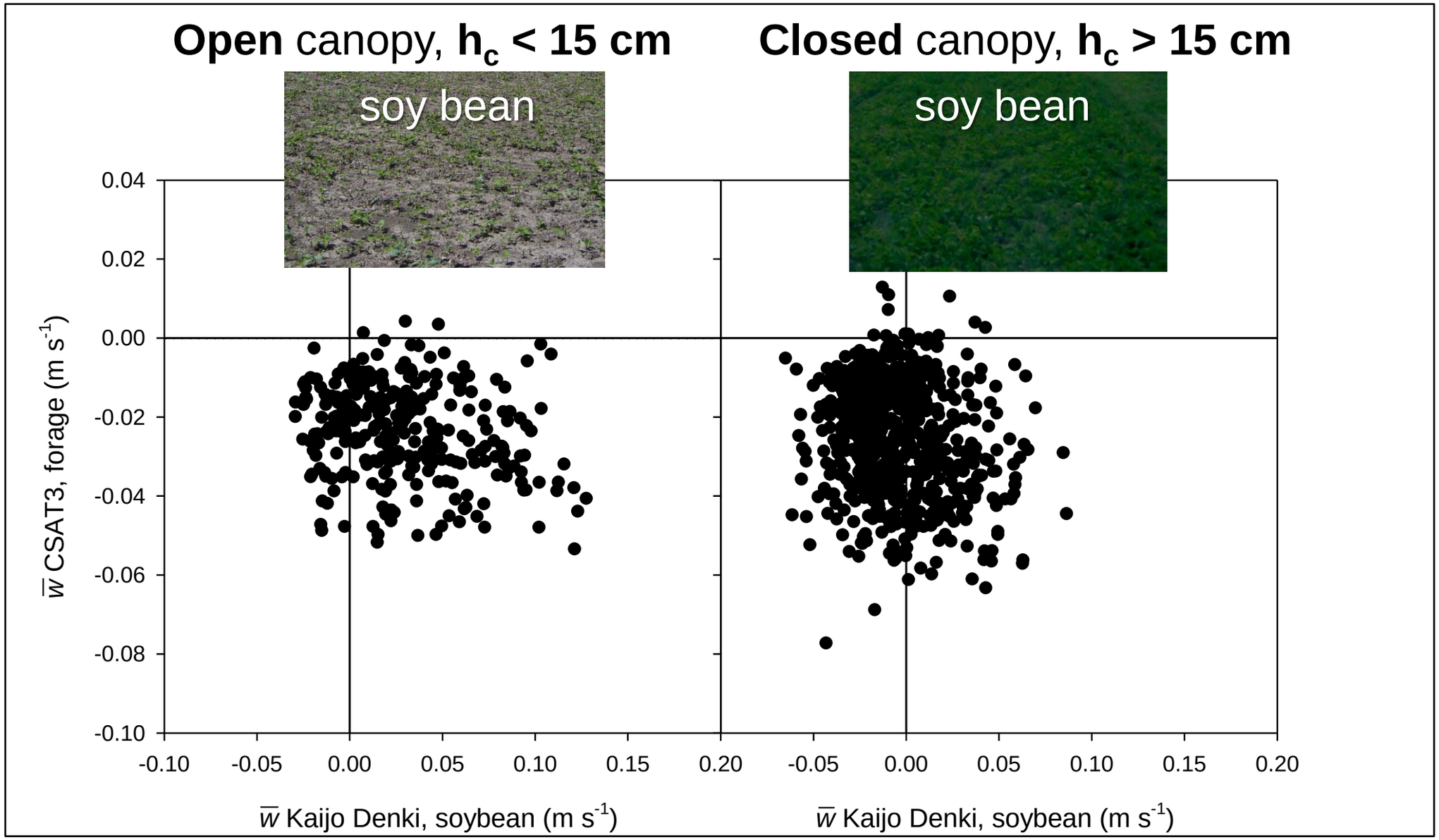
=> Updraft at some distance

Multi-tower set-up, 2008, land use map

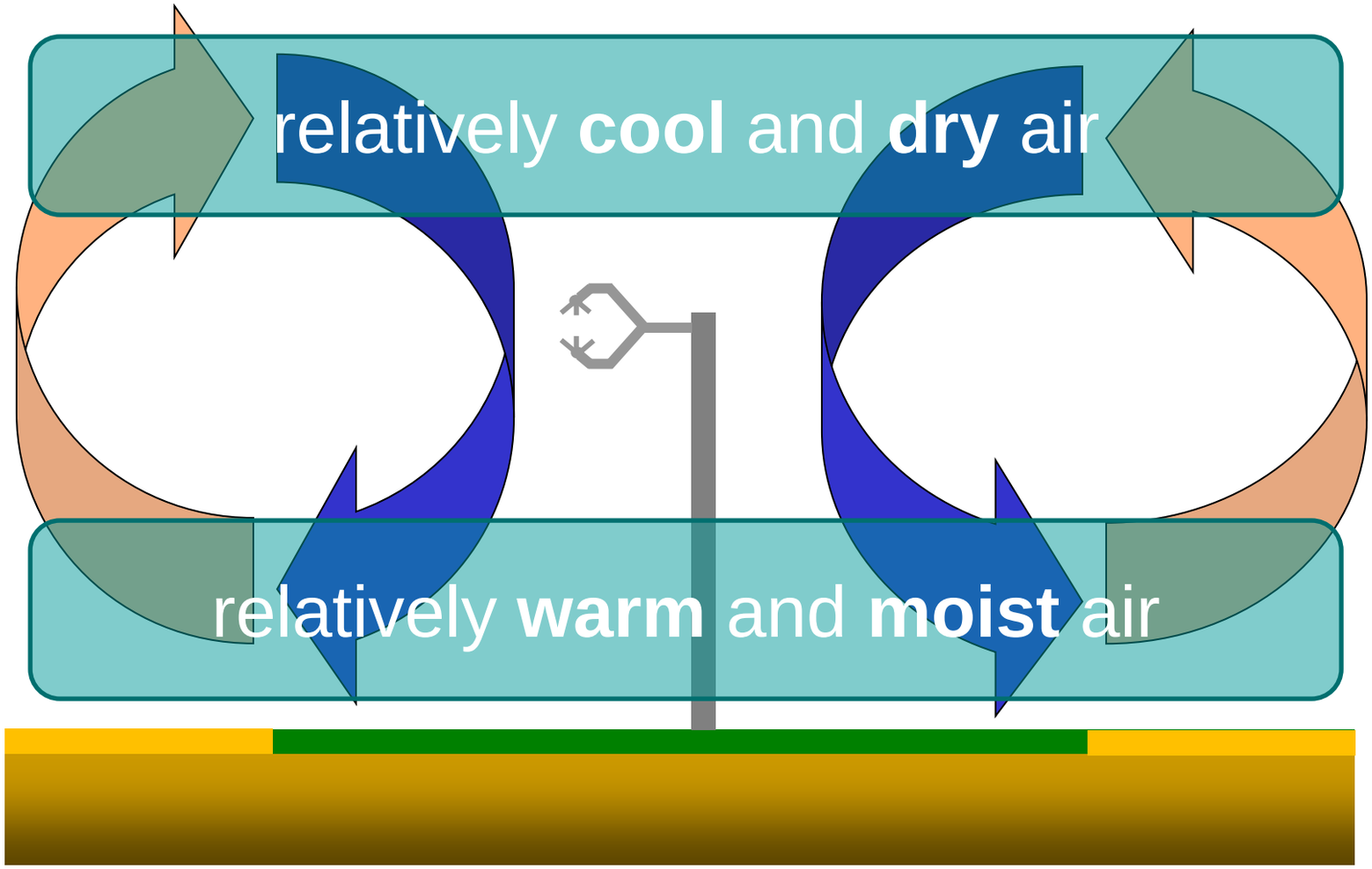


Mean vertical wind velocity

27 June to 6 August 2008



How can large-scale circulations cause a **systematic** lack of energy balance closure?



Conclusions

- Large-scale circulations superimposed on the general wind field are a dominant cause for the energy balance closure problem

- Aircraft measurements show that the magnitude of large-scale transport is the same as the missing flux of tower measurements

- From a multi-tower set-up, the updraft regions and downdraft regions of large-scale circulations could be identified

- The development of innovative approaches for quantifying the complete biosphere-atmospheric exchange of a scalar is warranted

Thank you for your attention!

And special thanks to Ray Desjardins and my former coworkers in Ottawa,

Dave Dow, Zhiling Gao, Ian MacPherson, Marc Lefebvre, Elizabeth Pattey, Ramesh Srinivasan, Ronald van Haarlem, and Devon Worth.