Determining Biosphere-Atmosphere Exchange in Complex Terrain

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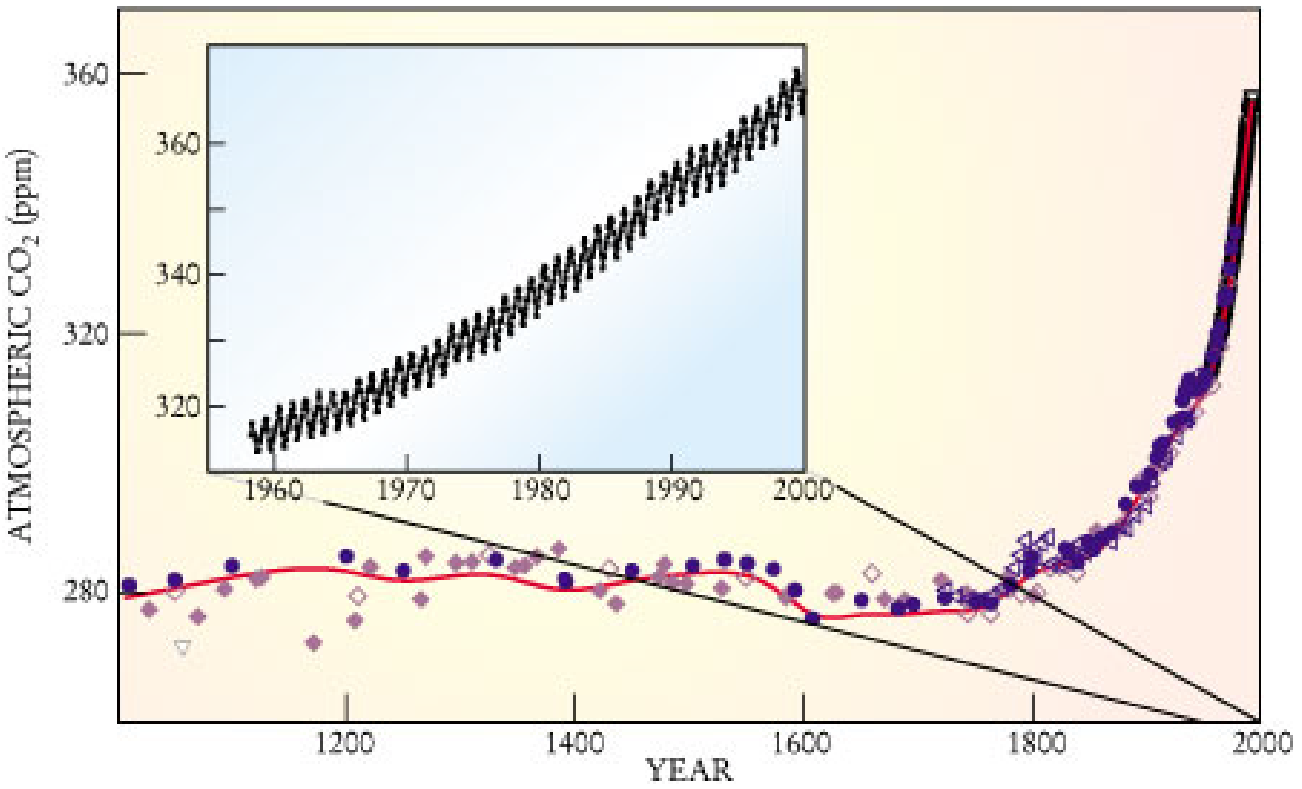
Atmosphere – Biosphere Exchange

Why is it relevant ?

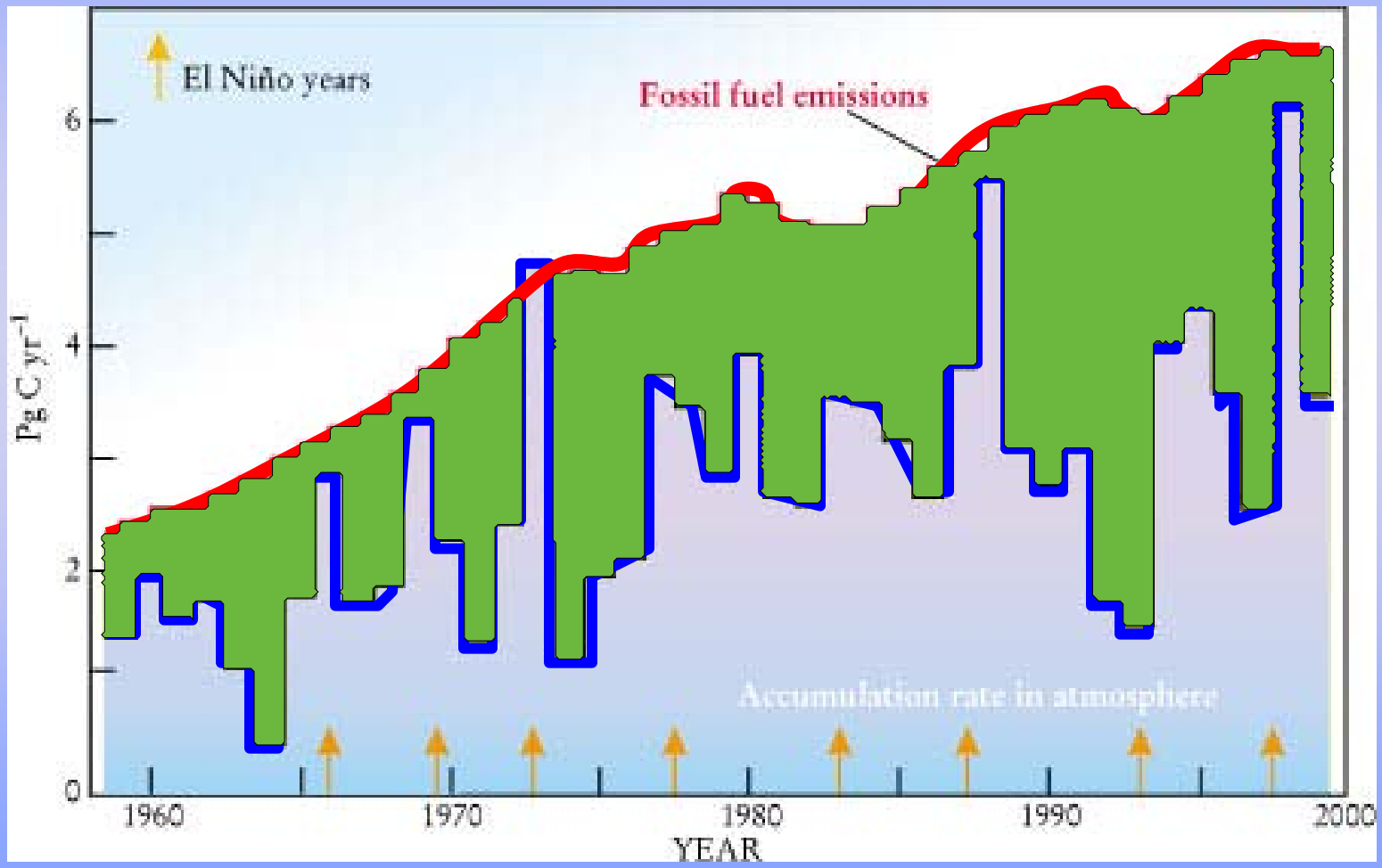
***For Example*: CO_2**



From: *Sarmiento and Gruber,* 2002 (*Phys. Today*)

Background: Global Carbon Budget

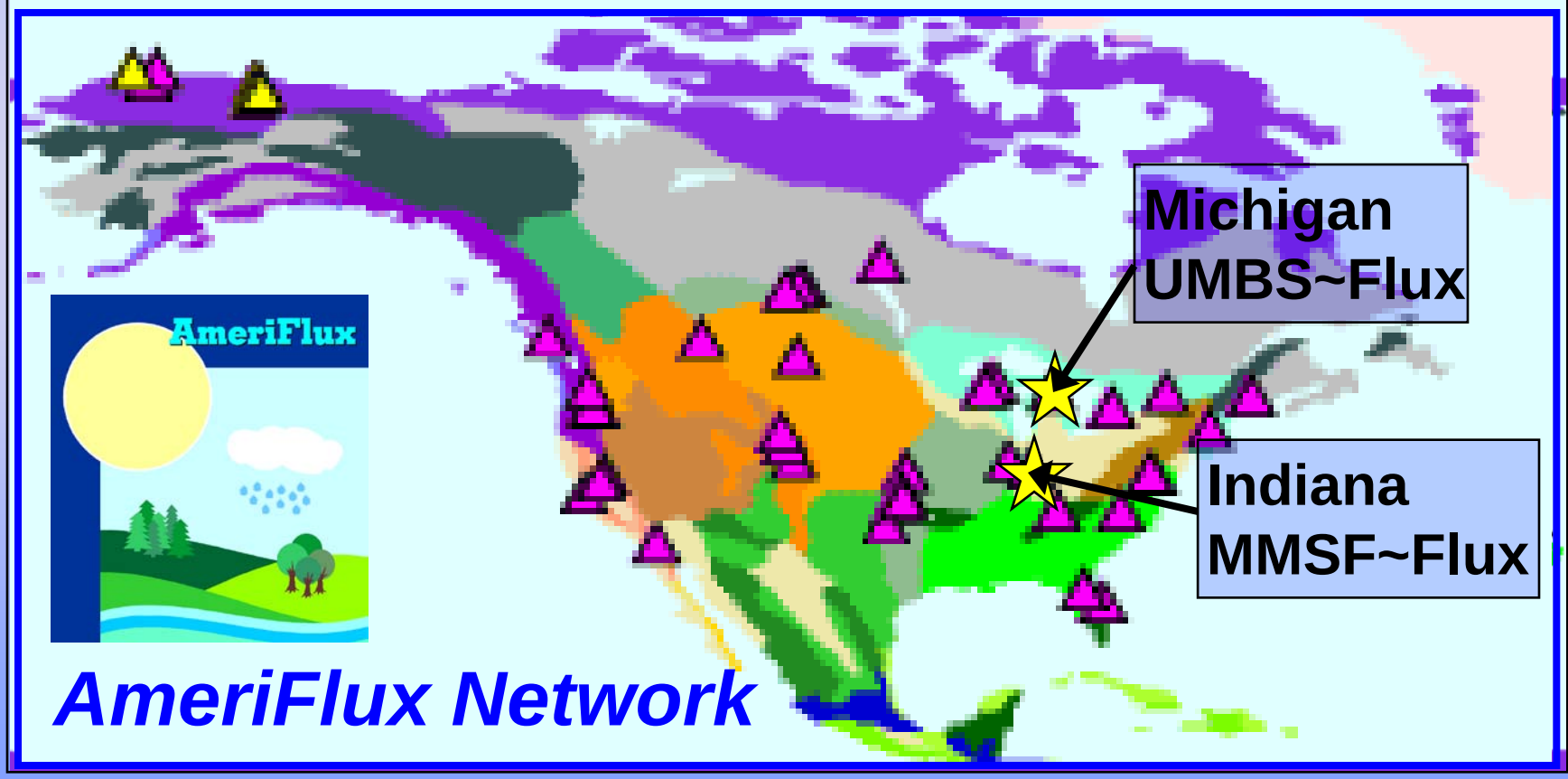
$CO_{2,Atm}$ Accumulation = CO_2 Source - Land & Ocean Sinks



(from Sarmiento and Gruber, 2002)

FLUXNET

Integrating Worldwide
CO_2 Flux Measurements
(currently ~ 300 stations)



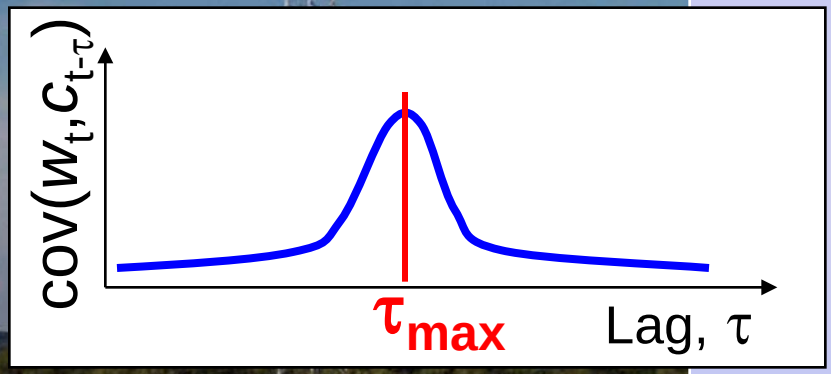
Eddy-Covariance: Closed Path System

UMBS~Flux Tower: ~~Instrumentation~~

Eddy-Covariance: $\overline{w'c'} = \mathrm{cov}(w_t, c_t)$

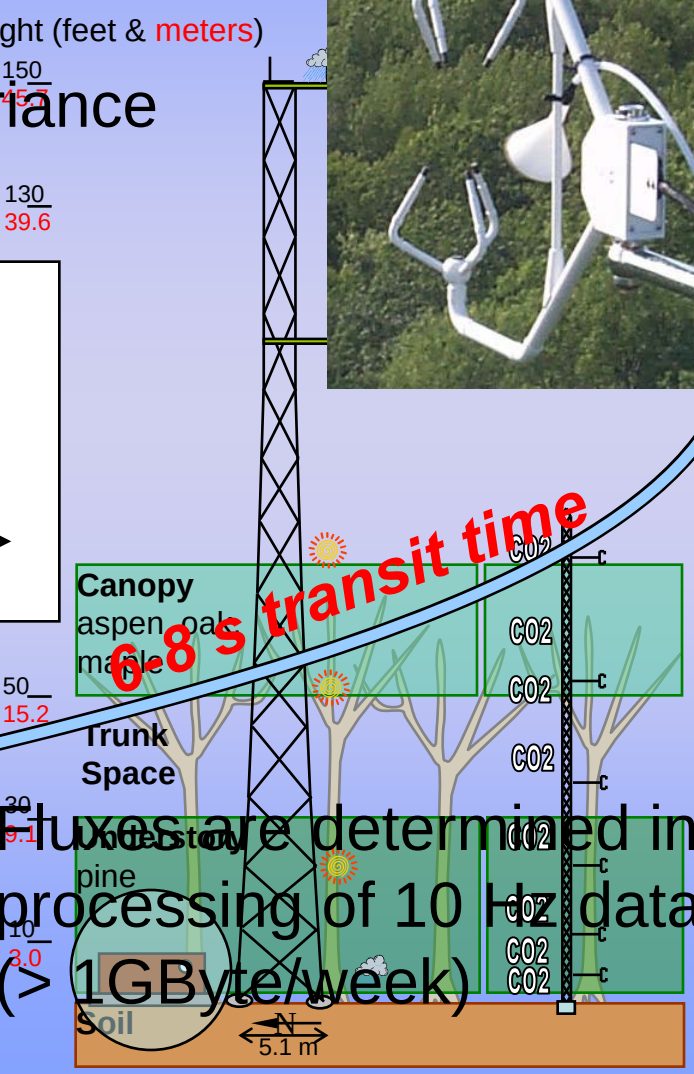
Lagged E-C: $\mathrm{cov}(w_t, c_{t-\tau})$

- τ: determined so that covariance is maximized



GAS

6-8 s transit time

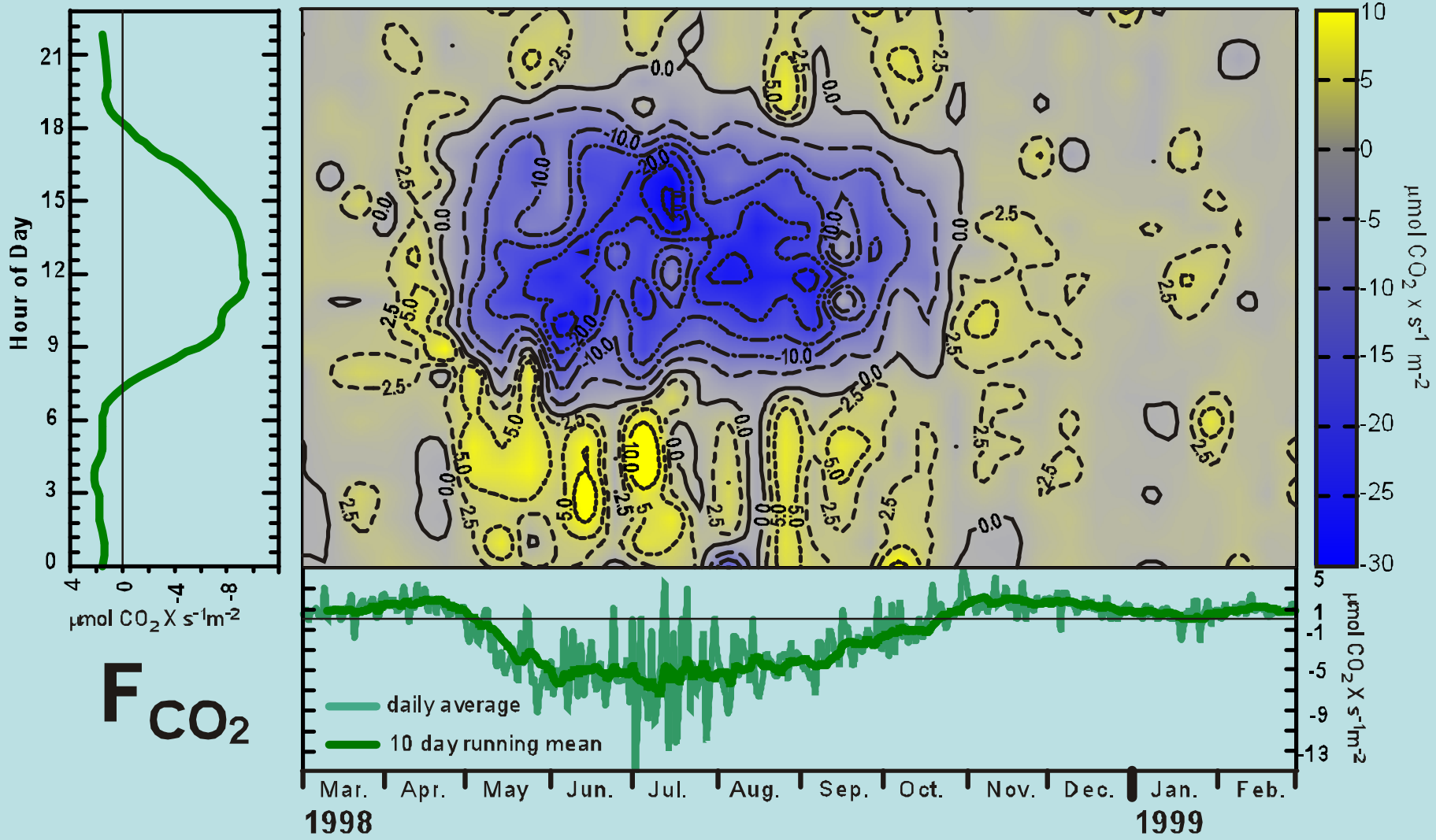


Fluxes are determined in post-processing of 10 Hz data-stream (> 1GByte/week)

MMSF~Flux (Indiana)

Energy and Carbon Fluxes:

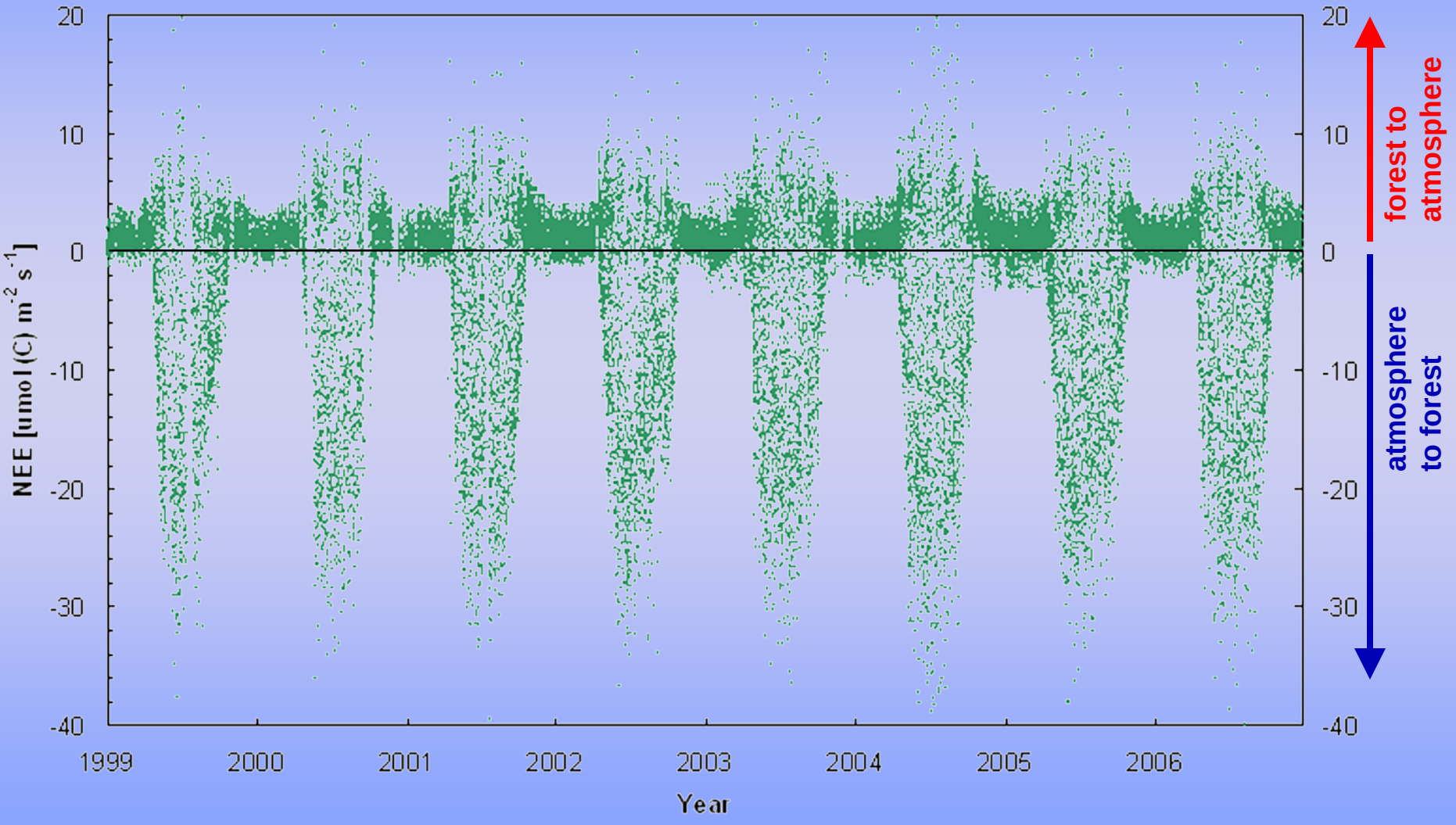
Annual "Fingerprints" of Variability



Schmid et al. 2000 (*Agric. For. Meteorol.* **103**, 355-373)

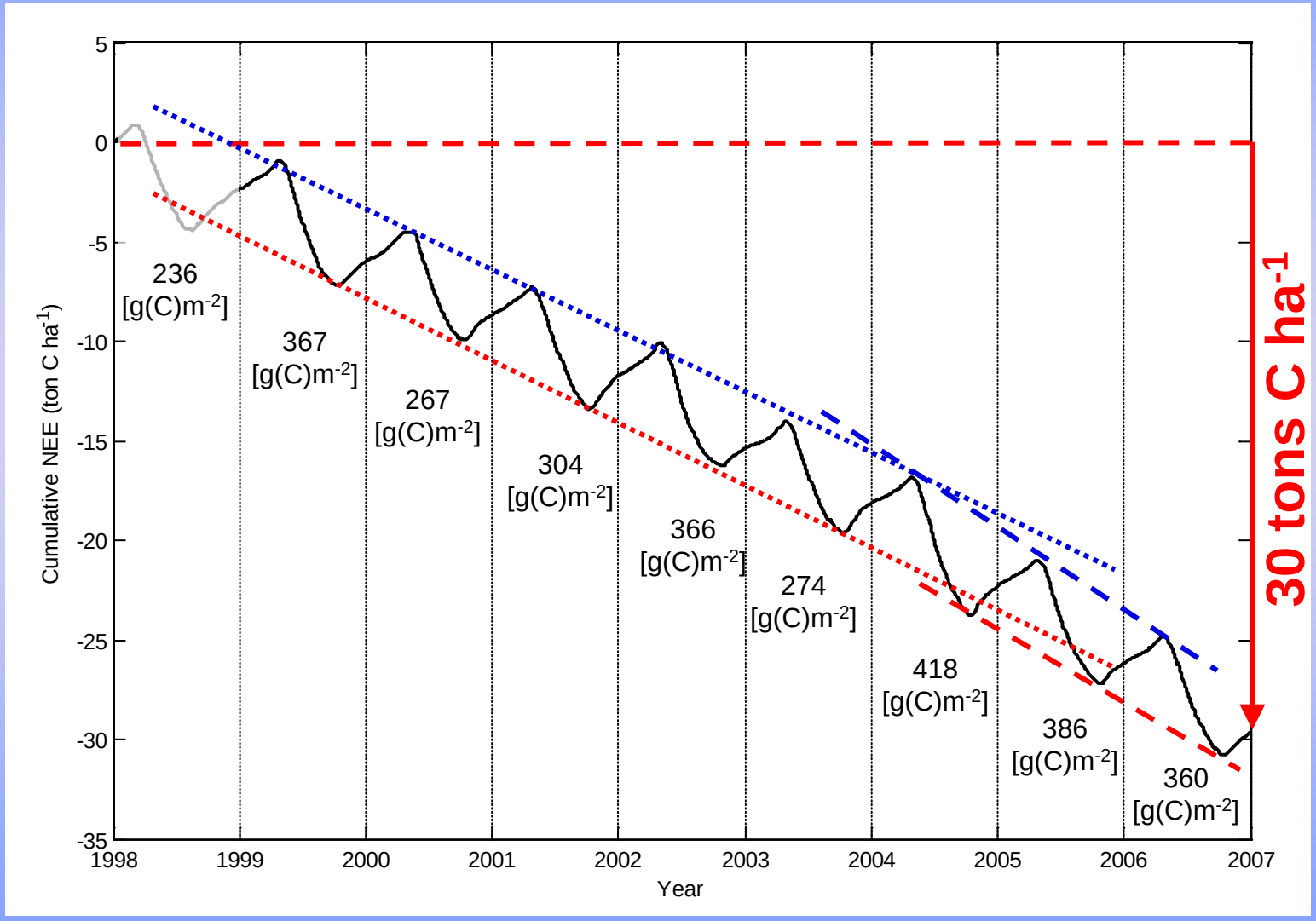
Hourly Fluxes of CO_2 over 8 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation



Cumulative Exchange of CO_2 over 9 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation

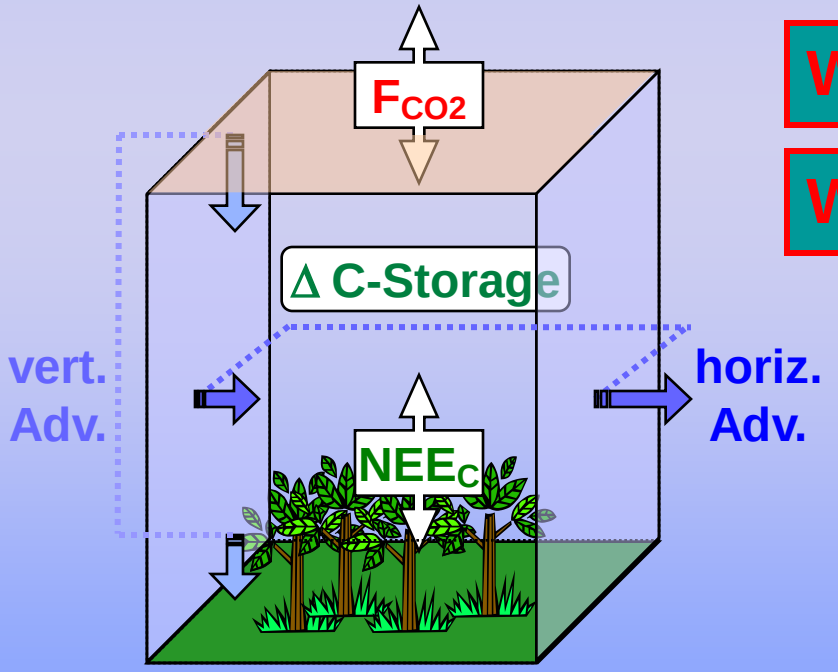


30 tons C ha^{-1} = 3 kg C m^{-2}

Are fluxes capturing the right processes ?

Examine CO_2 Conservation Equation!

$$NEE_C = \frac{z_m}{V} \int_{-\delta x}^{+\delta x} \left(\int_0^{z_m} \left[\frac{\partial \bar{C}}{\partial t} + \bar{u} \frac{\partial \bar{C}}{\partial x} + \bar{w} \frac{\partial \bar{C}}{\partial z} \right] dz + F_C(z_m) \right) \cdot dx$$



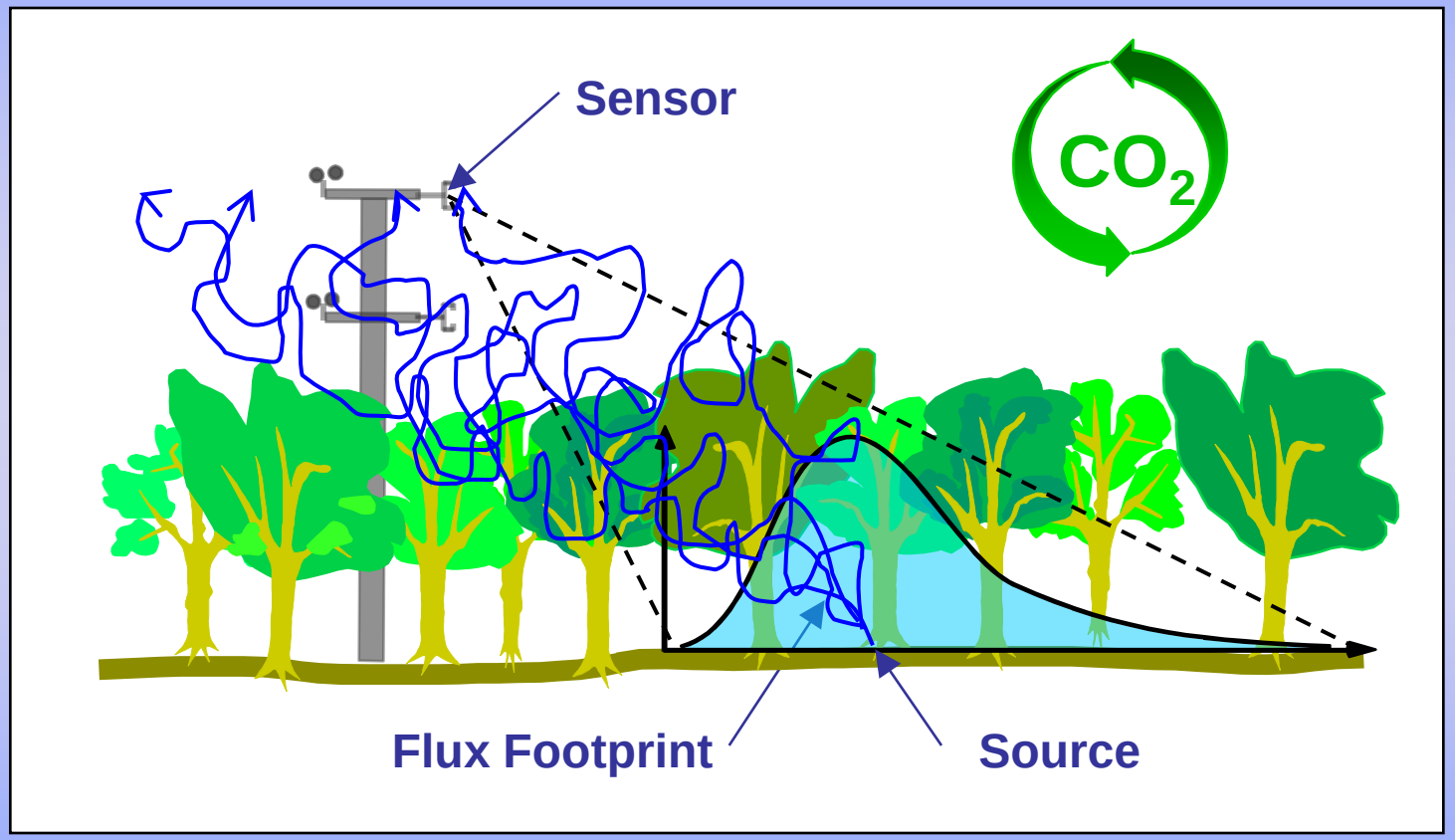
What do we want? **NEE !**

What do we have? **F_C (+ storage)!**

Potential problems:

- location, shape of the box
- “leaking” out of the box

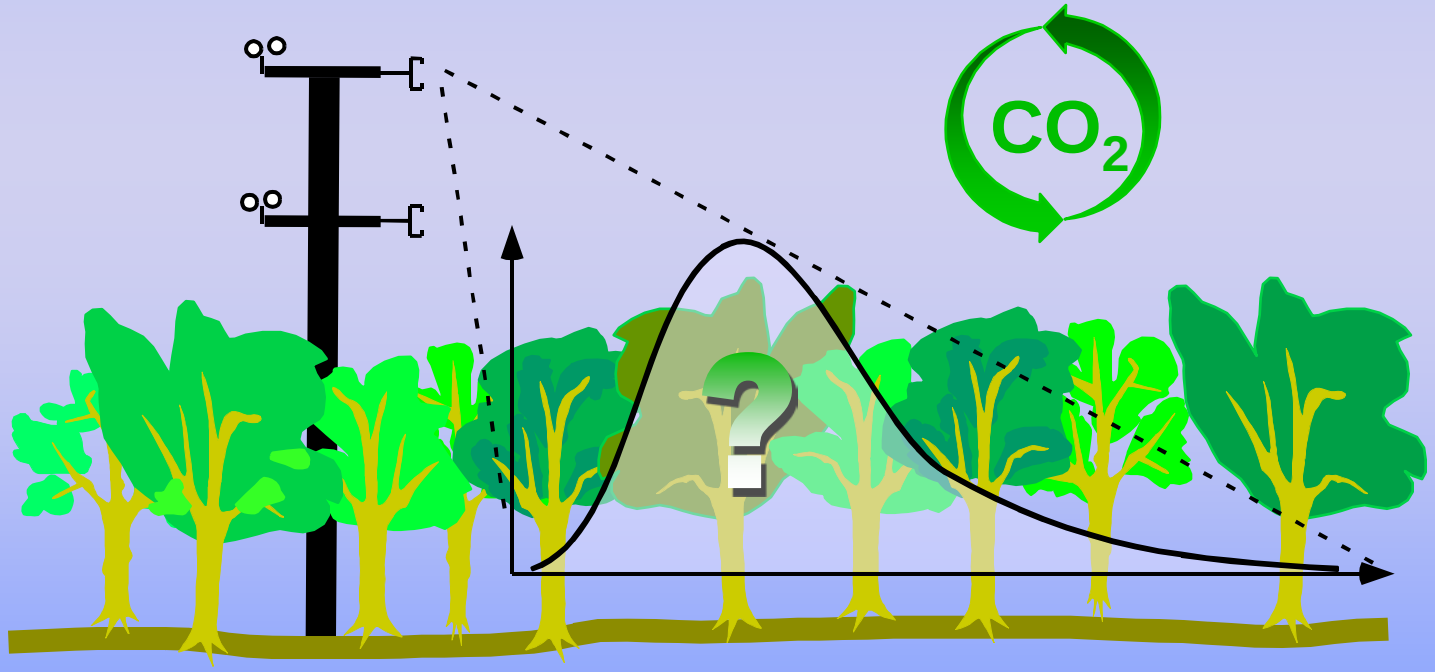
Micrometeorological Flux Measurements:
at what scale?



Schmid 2002 (*Agric. For. Meteorol.* **113**, 159-184)

The Flux Footprint:

- **What Part of the Ecosystem does the Flux Sensor ‘see’ ?**
- **Is that Part Representative of the Ecosystem? (answer varies over time)**
- **<u>If yes</u>: use data; <u>if not</u>: reject data**

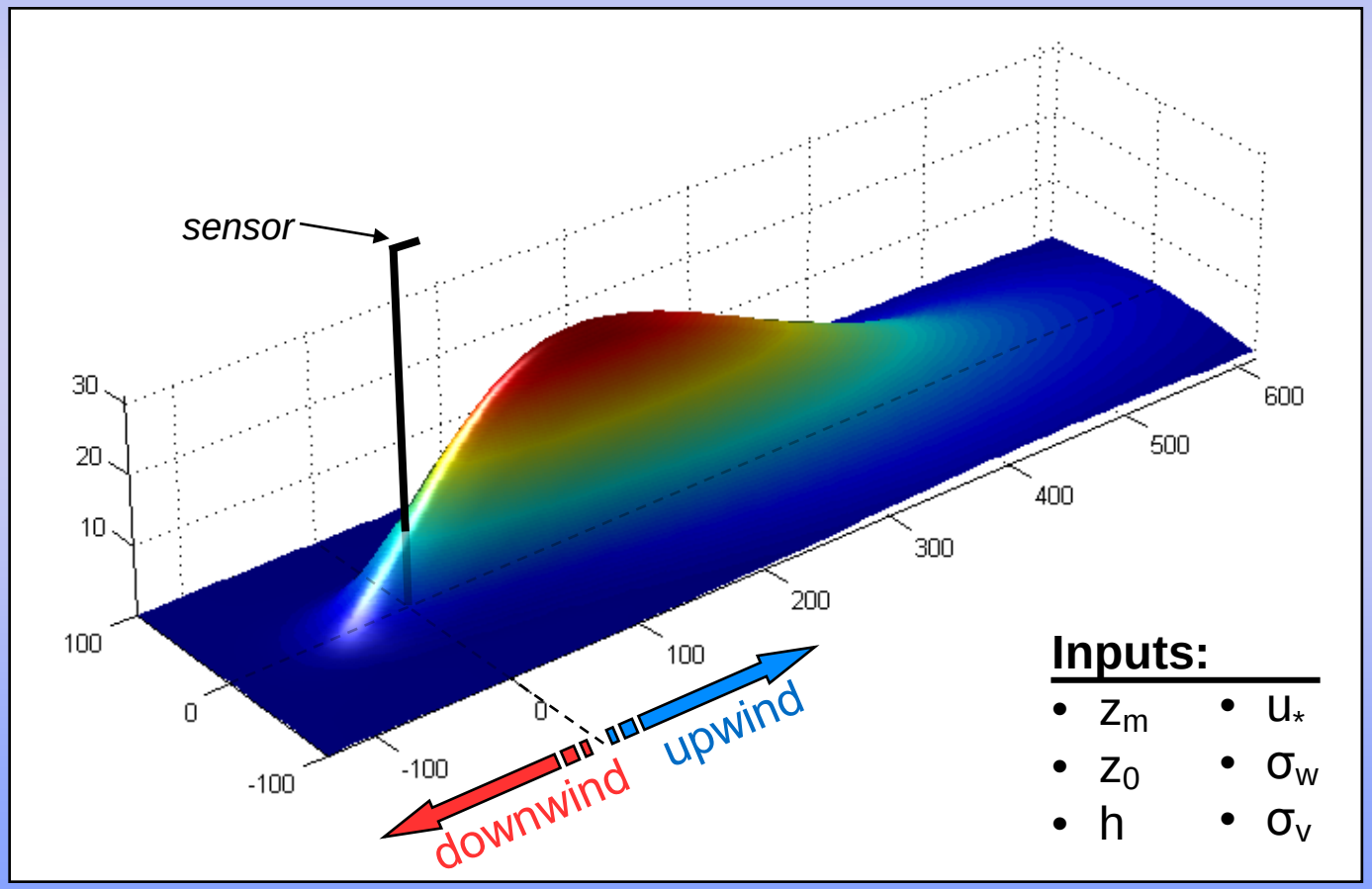


e.g.: Schmid (2002, *Ag. For. Met.*, **113**, 159-184)

Flux Footprint = *spatial* ***filter****, "field of view"*

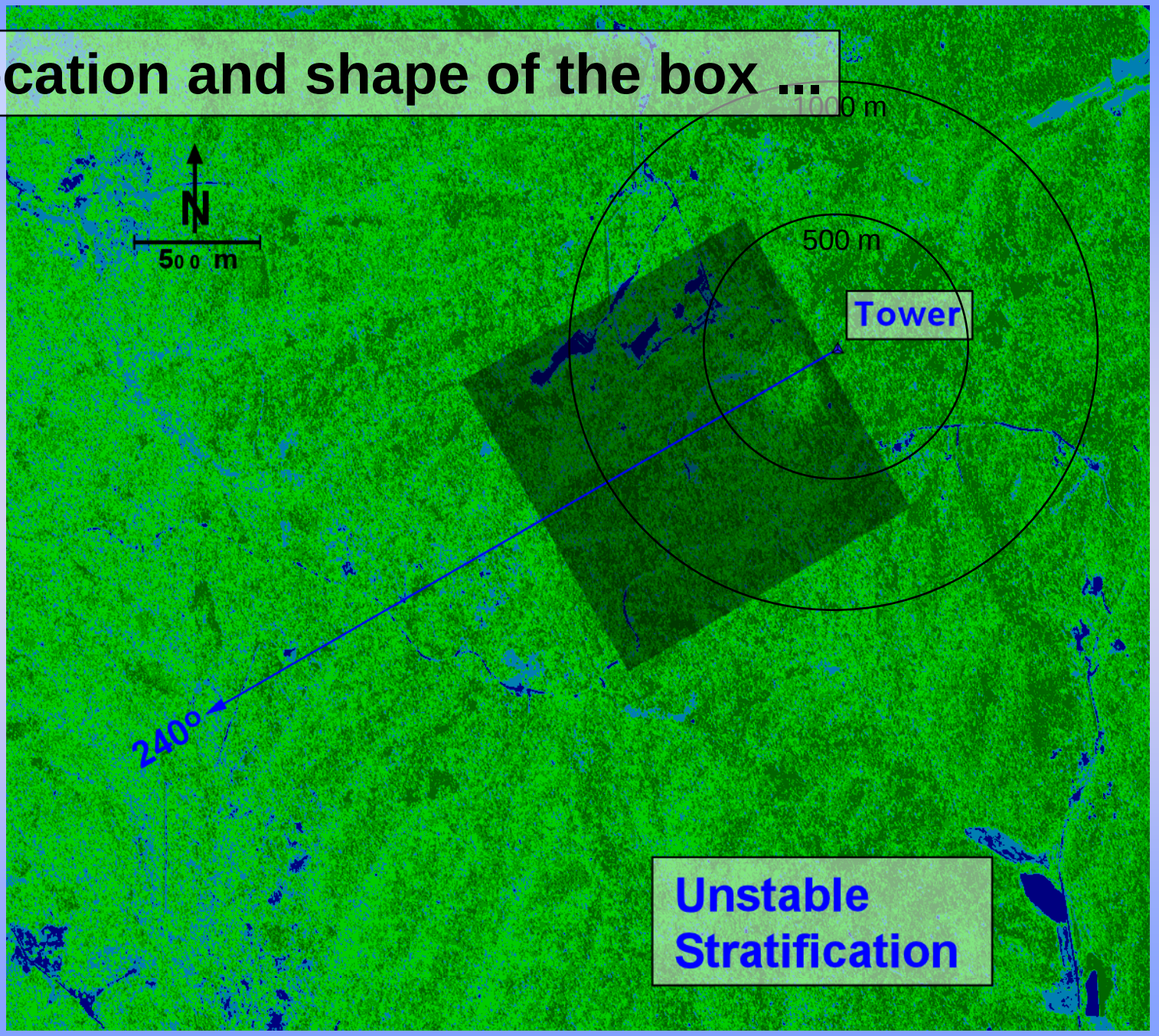
$$F(\mathbf{x}) = \iint_{\Re} Q_s(\mathbf{x}') \cdot f(\mathbf{x} - \mathbf{x}') \cdot d\mathbf{x}' = Q_s * f$$

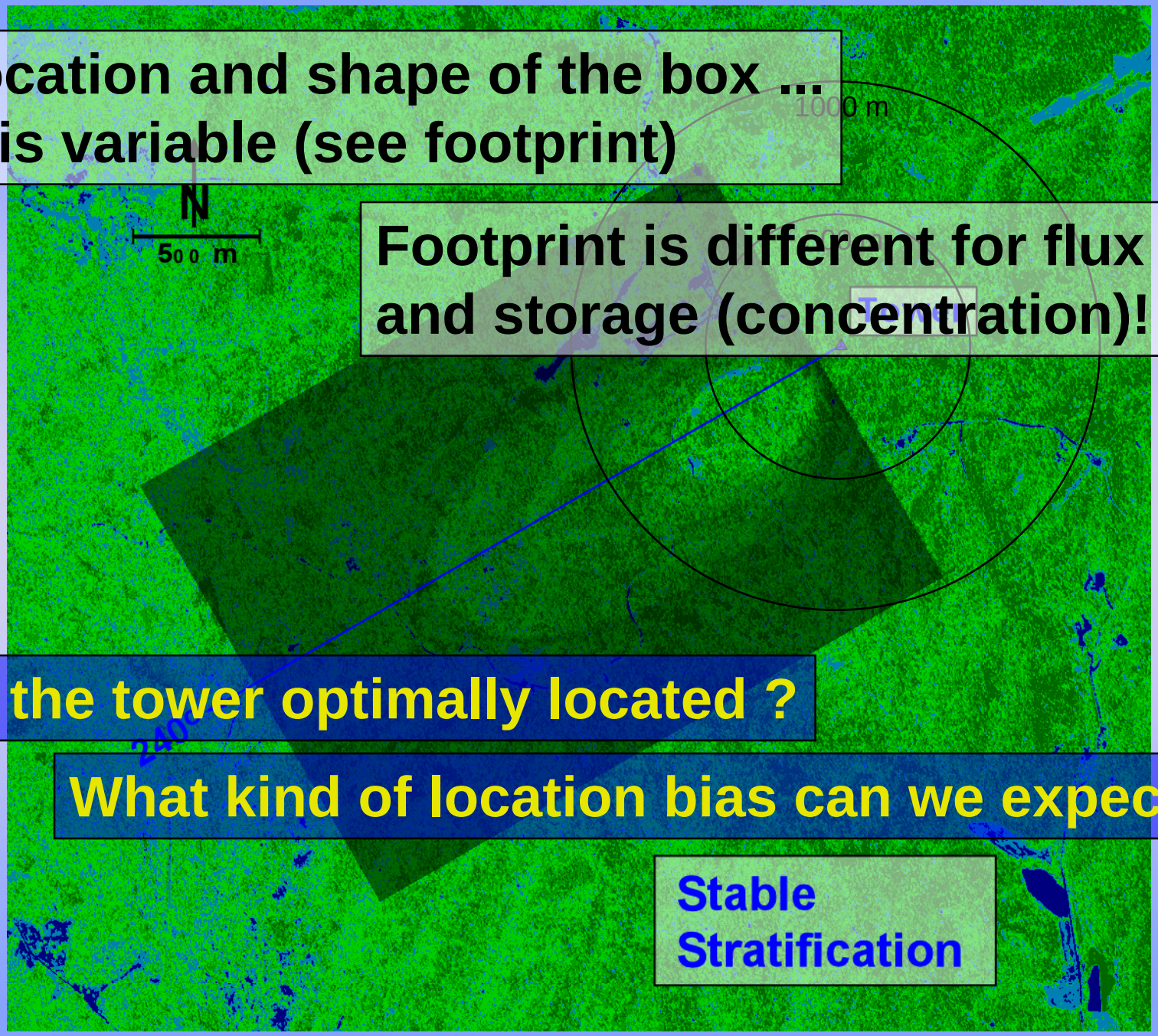
(**convolution** of the **source distribution**, Q_s, with the **footprint**, f)

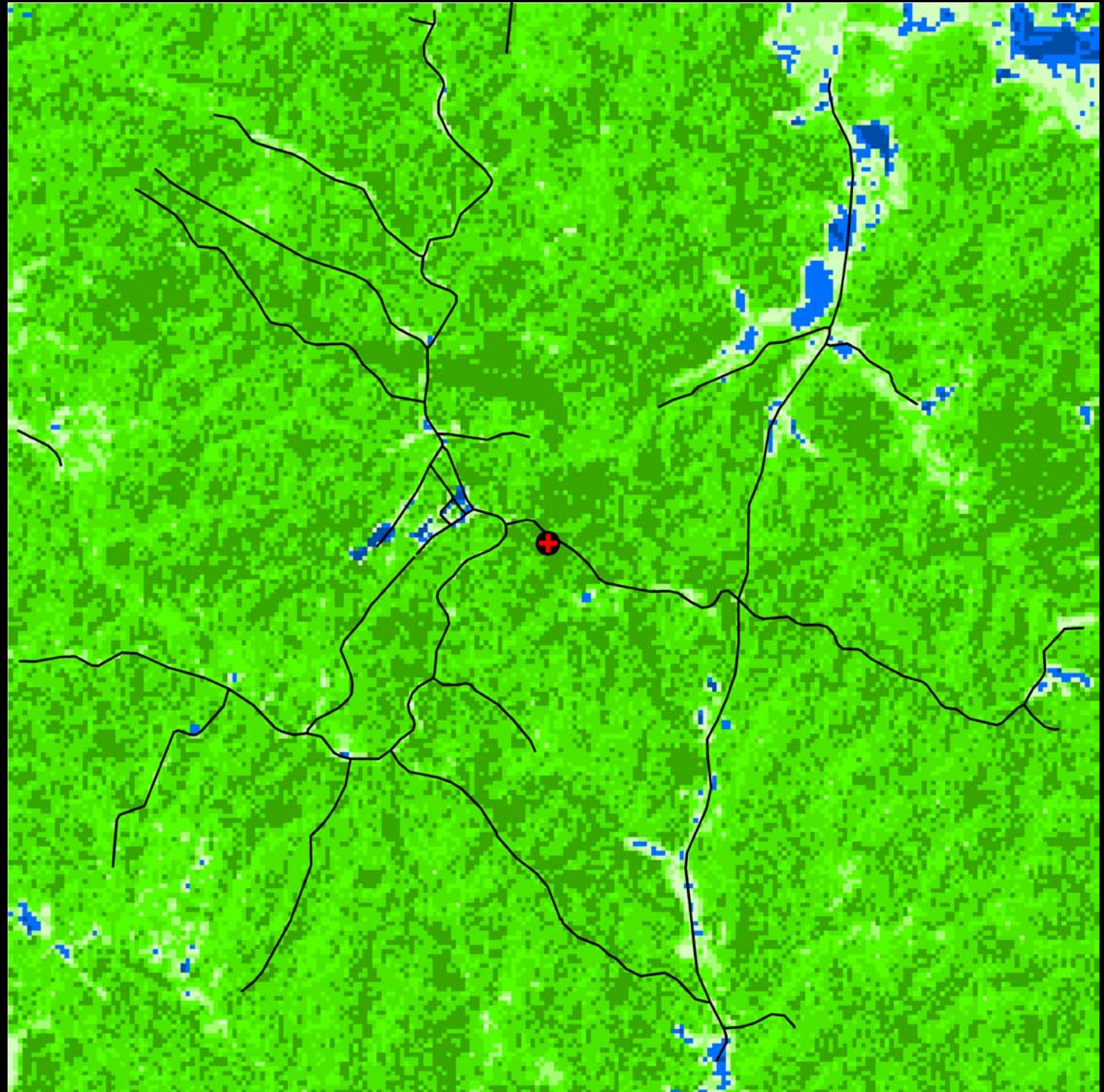


Schmid 1994 (*Boundary-Layer Meteorol.*, **67**, 293-318)

Location and shape of the box ...



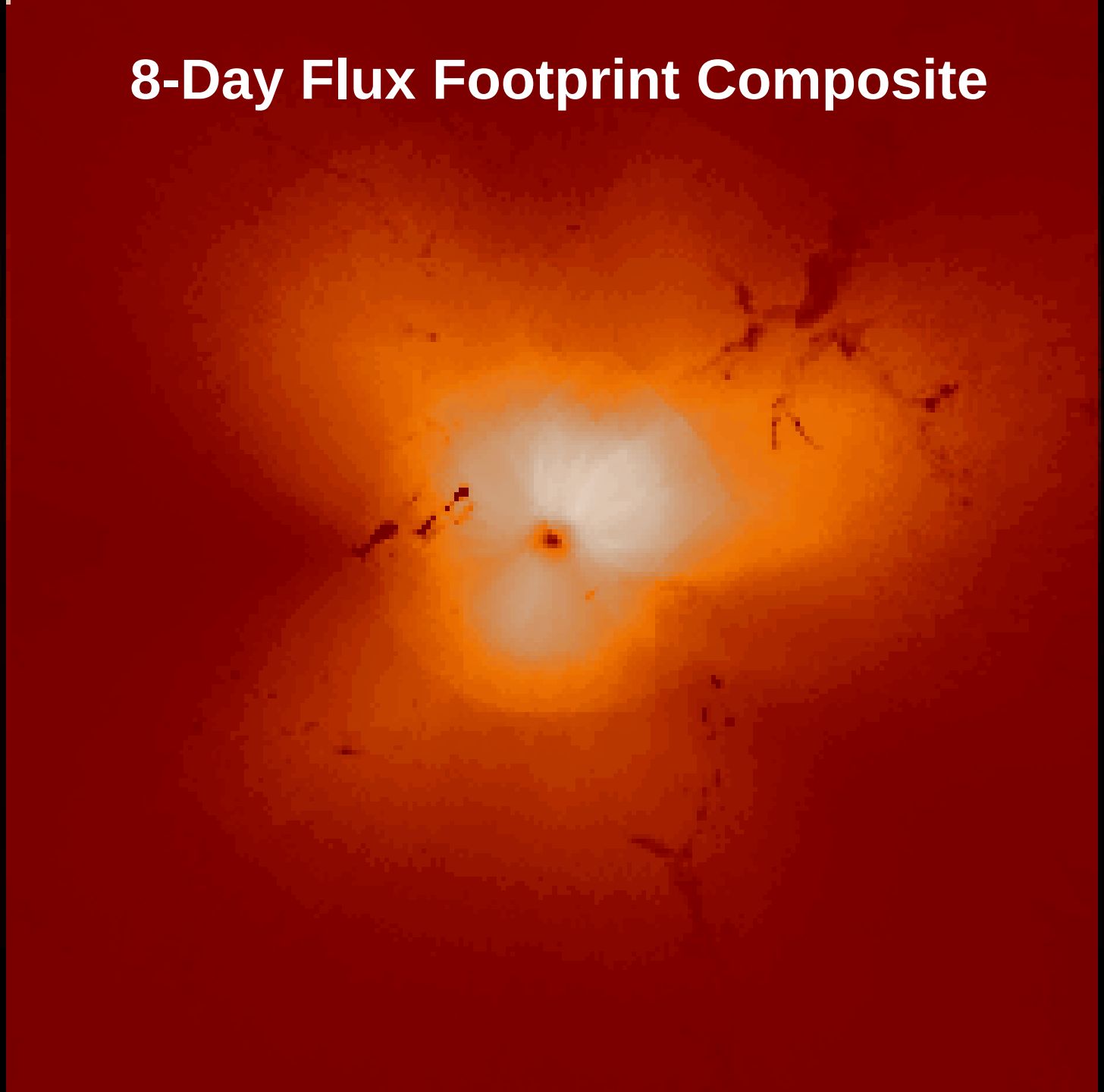

Location and shape of the box ...
... is variable (see footprint)
N
500 m
1000 m
Footprint is different for flux and storage (concentration)!
Is the tower optimally located ?
What kind of location bias can we expect ?
Stable Stratification



Hourly Footprints 2001: YD 217- YD 225

Aug 5 – Aug 13

8-Day Flux Footprint Composite



Hourly Footprints 2001: YD 217- YD 225

Aug 5 – Aug 13

Mead rain-fed: land use

Problem: Complex Terrain
Biosphere-Atmosphere Exchange Measurements in "Difficult Conditions"

"Difficult Conditions" ???

⇒ deviations from micrometeorological ideal:

• flat terrain	• topography
• homogeneous fetch	• patchy land-cover
• low, homogeneous vegetation (if any)	• deep, multy-layer vegetation canopy
• stationarity	• instationarity
• well-developed turbulence (MOST)	• weak turbulence; free convection

Difficult Conditions: Patchy Land Cover

Heterogeneous Scalar Field

(ΔLAI, ΔBowen-Ratio)

Heterogeneous Flow/Turbulence

(disturbance, forest edges)

Difficult Conditions: Deep Canopies

Tall Trees

Multi-Layer Understorey

Difficult Conditions: Topography

Large Scale Topography

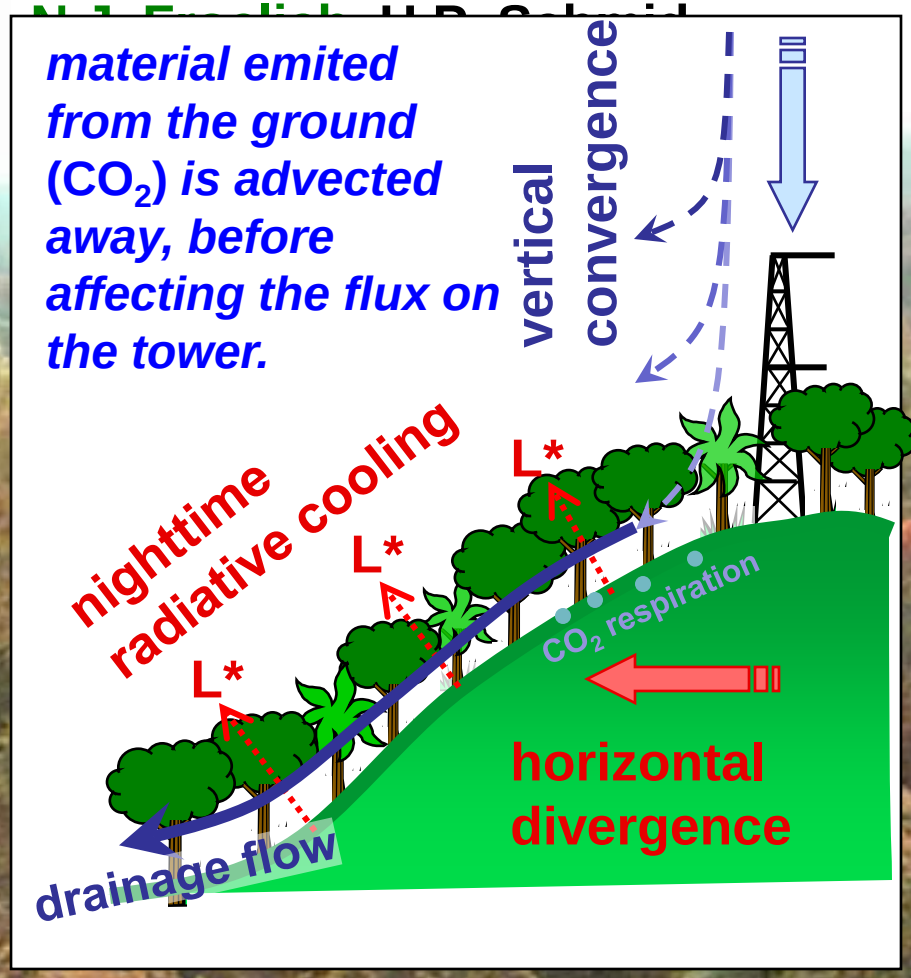
Small Scale, Gentle Topography

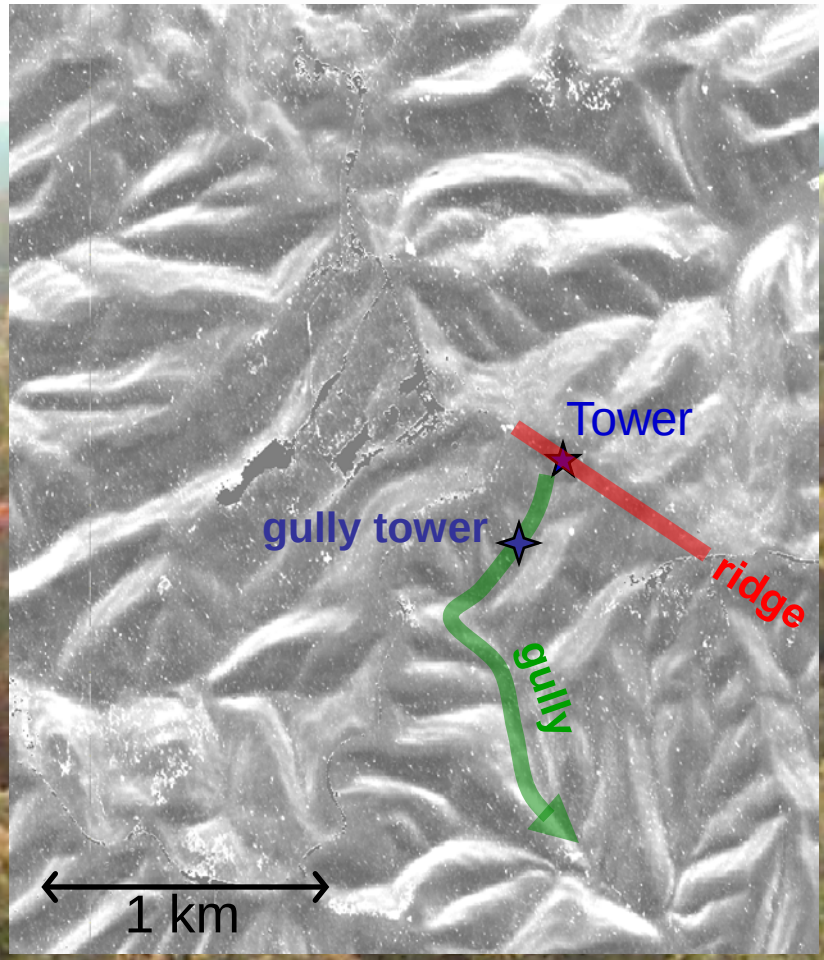
Problem with Nighttime Fluxes in Topography?

Is respired CO_2 at night "leaking" out of the box, without a trace detectable by the flux sensor?

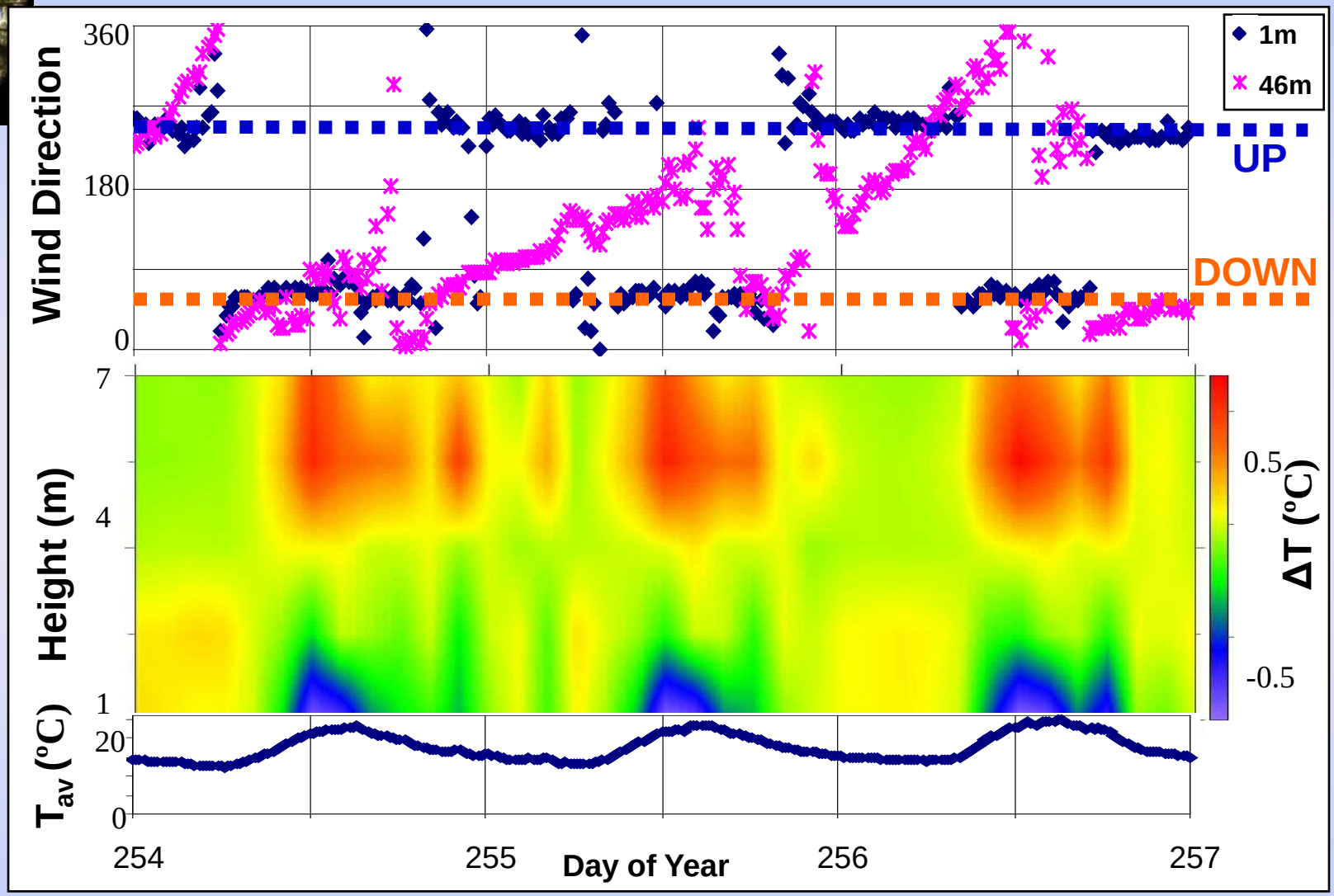
Advection and Gully Flows in Complex Forested Terrain

N.J. English, H.P. Schmid

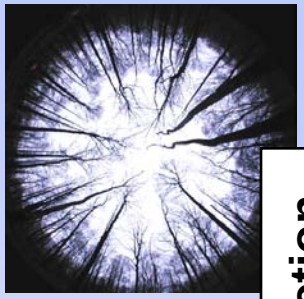




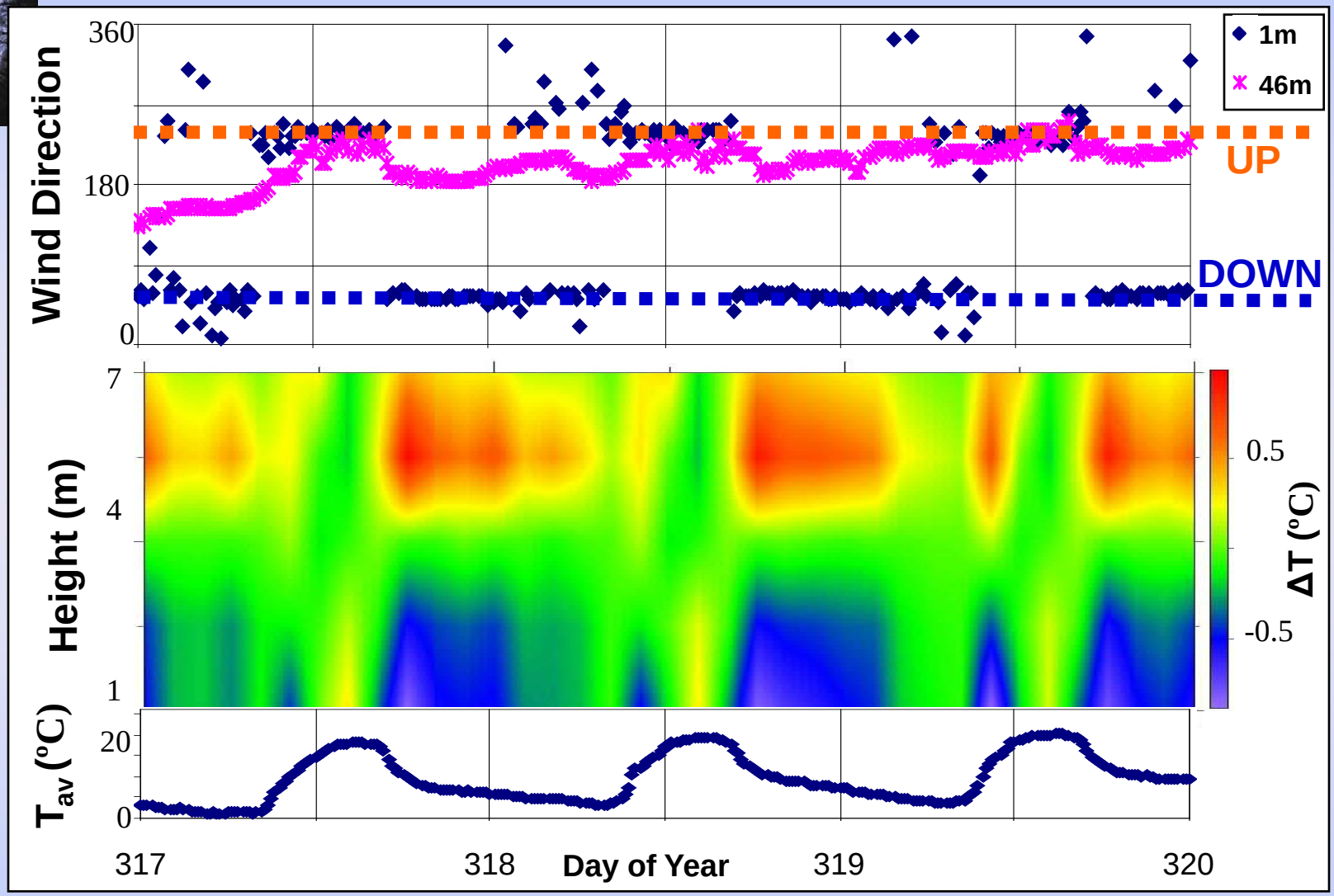
Thermotopographic Flow – Leaf-On



- Night «—» Up-gully flow with lapse conditions
- Day «—» Down-gully flow with inversion conditions

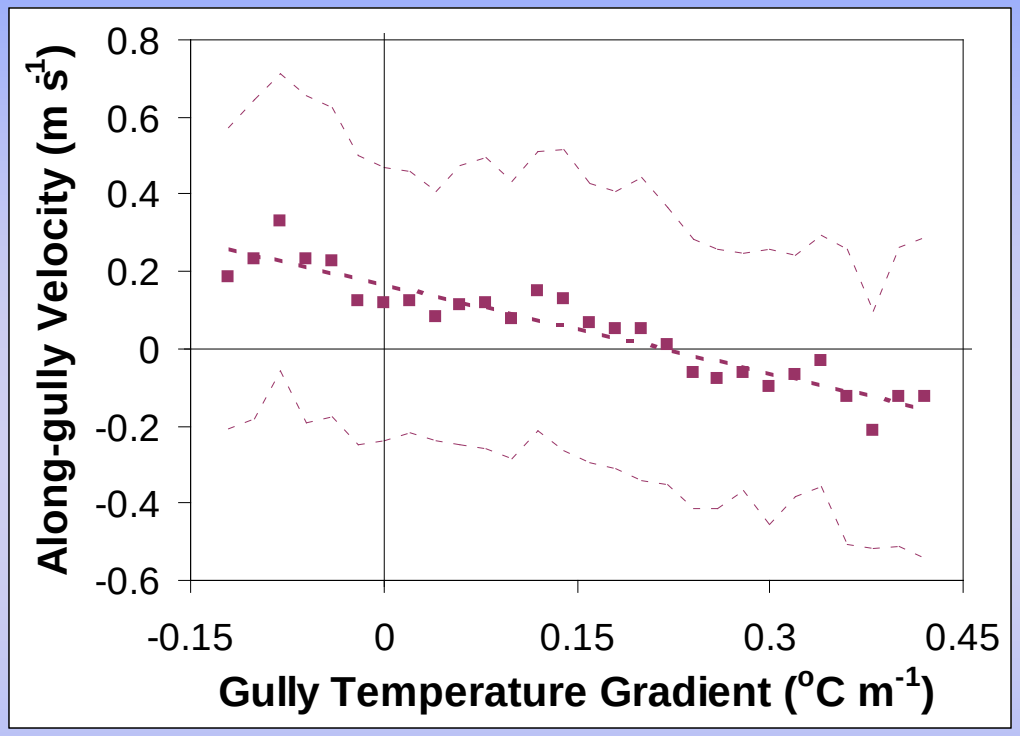


Thermotopographic Flow – Leaf-Off



- Night «—» Down-gully flow with inversion conditions
- Day «—» Up-gully flow with lapse conditions

Below-Canopy Temperature Gradient and Along-Gully Velocity



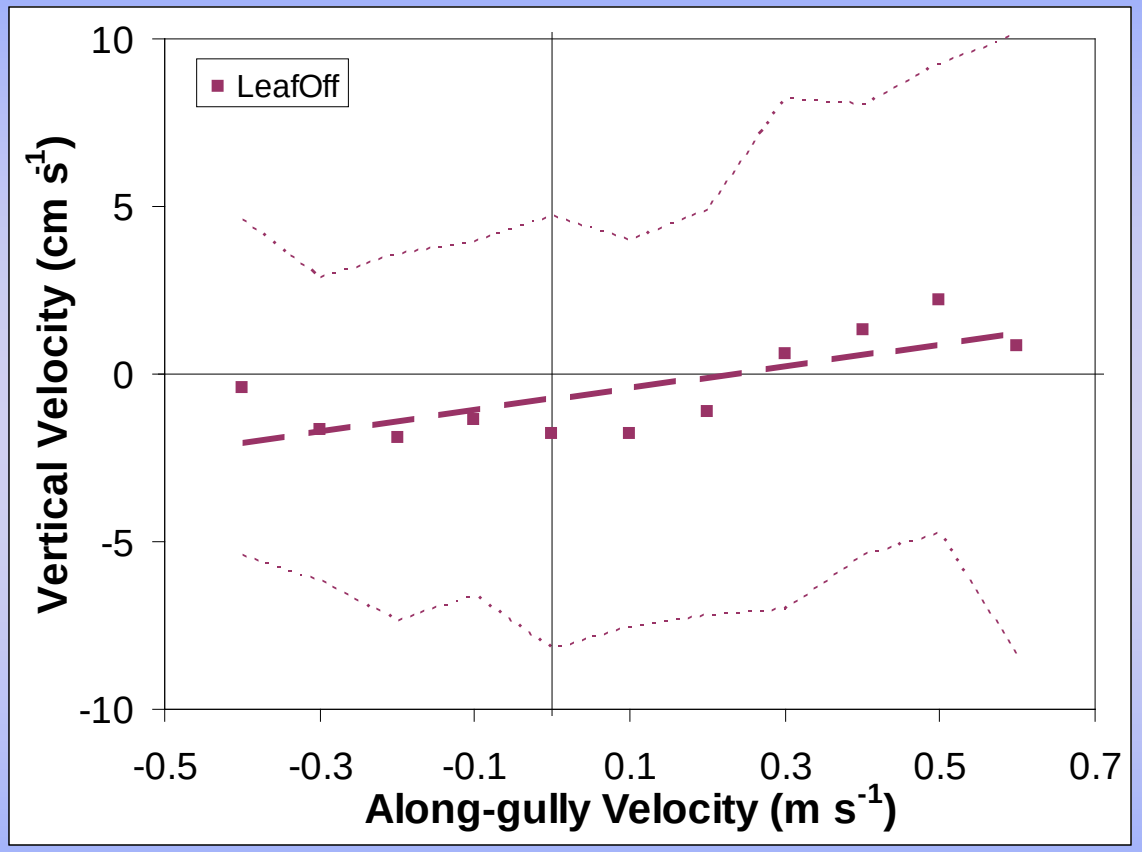
Includes all data bin-averaged data

temperature inversion «—» down-gully velocities

lapse conditions «—» up-gully velocities

Thermotopographic forcing of gully flows

Along-Gully Velocity and Vertical Velocity Above-canopy

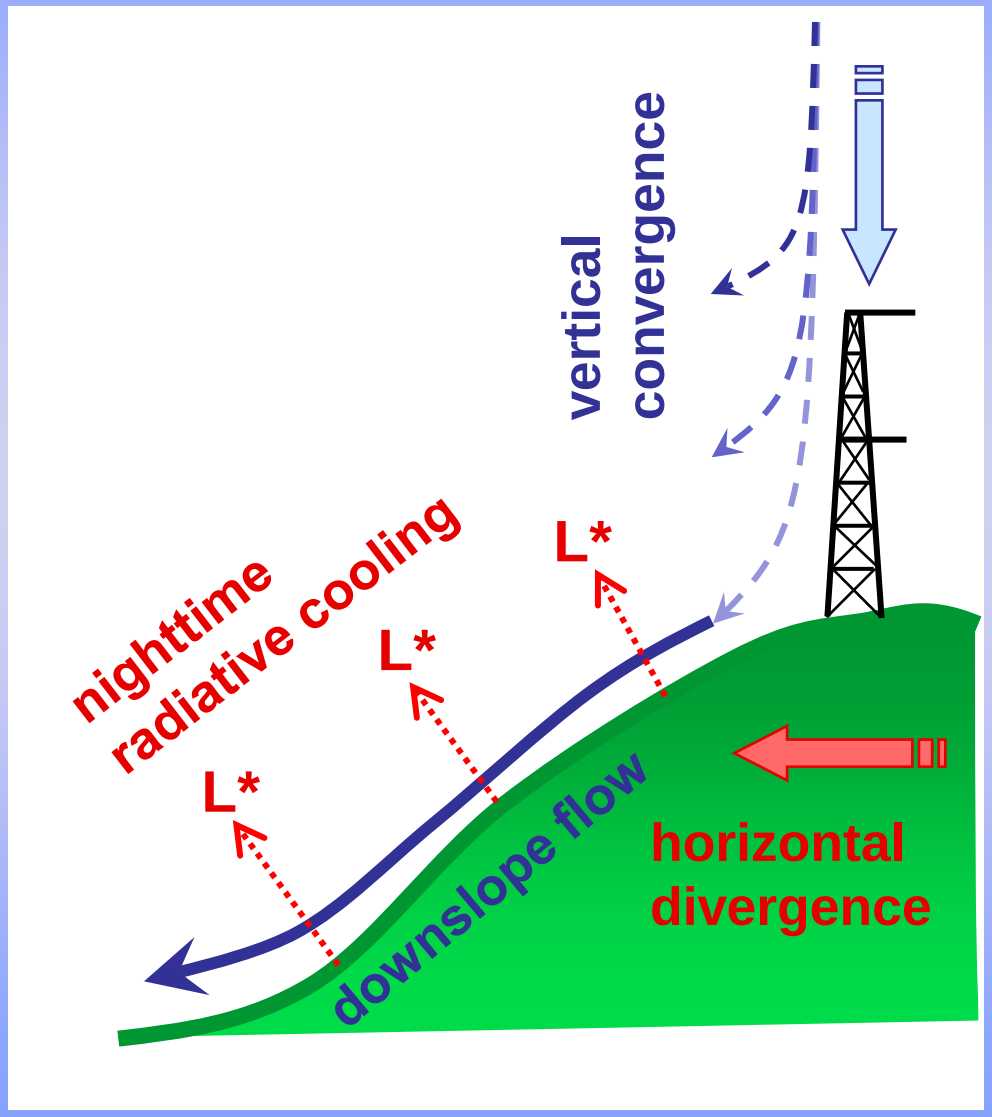


Includes all Leaf-Off data

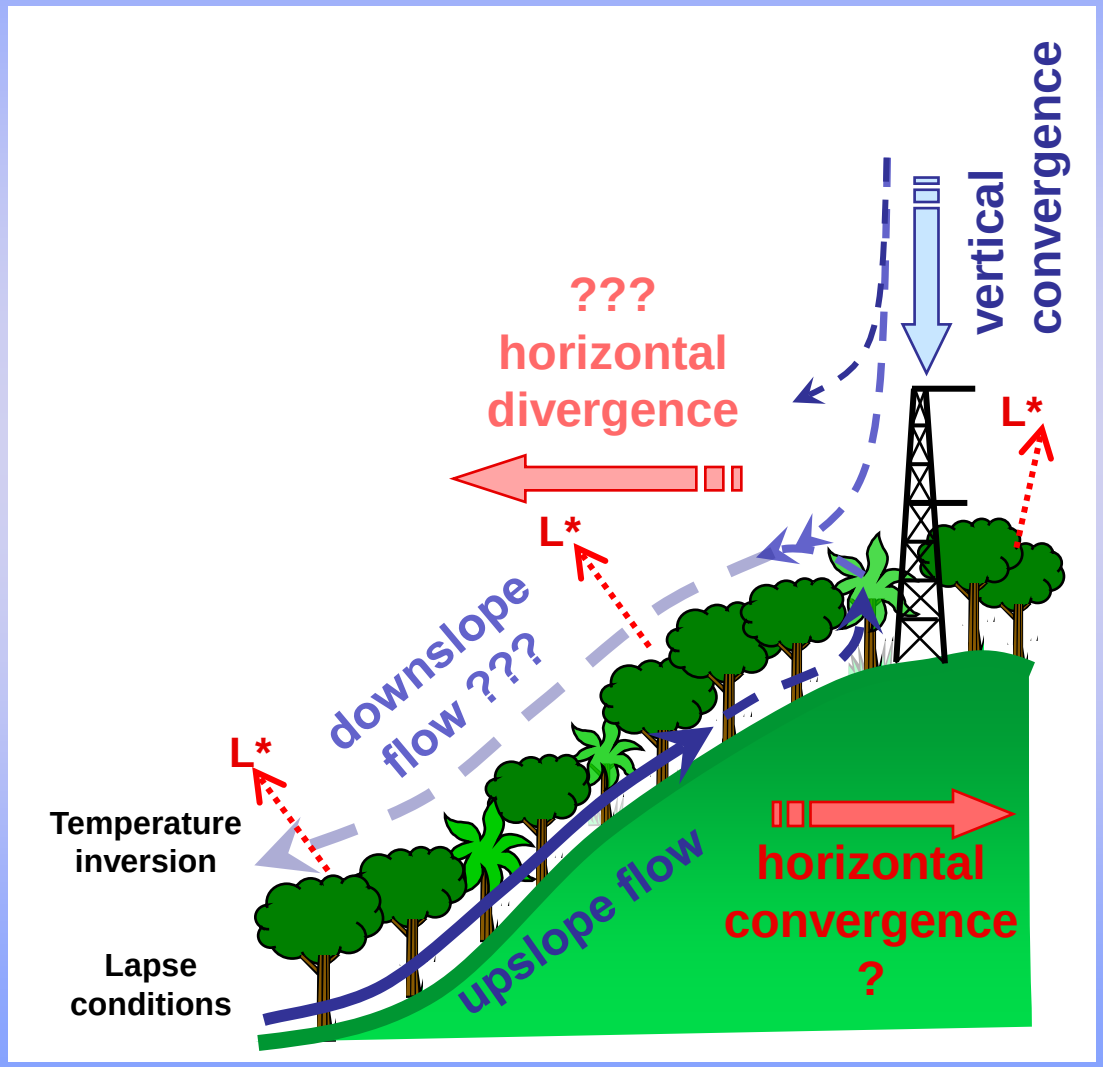
bin-averaged data

down-gully velocities «—» stronger convergence / weaker divergence aloft

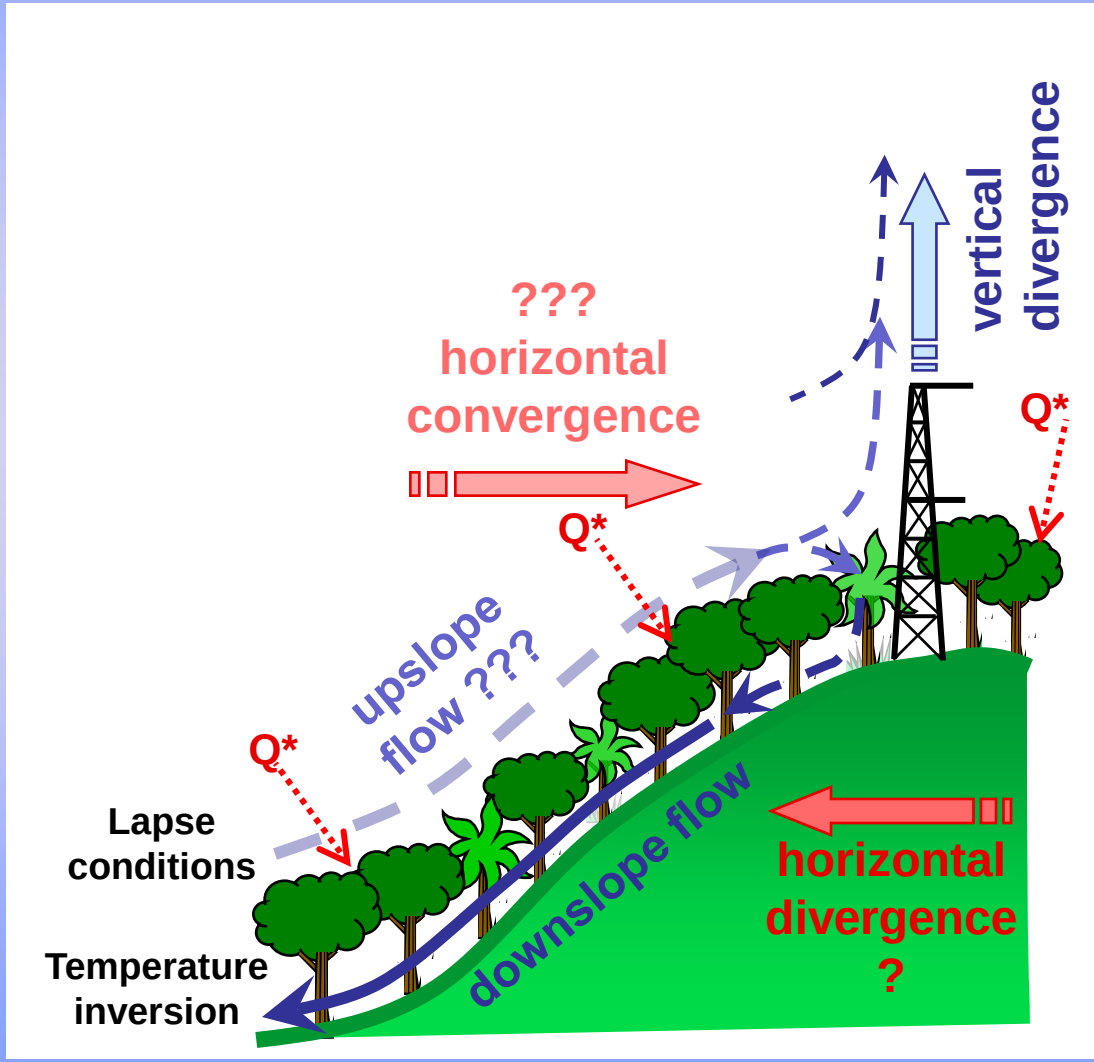
Flow Patterns: Leaf-Off Nighttime



Flow Patterns: Leaf-On Nighttime



Flow Patterns: Leaf-On Daytime



Summary of Results

Nocturnal vertical convergence above canopy

- tendency to downward vertical velocities

Nocturnal below-canopy thermotopographic flows

- down-gully (divergence) in Leaf-Off season
- up-gully (convergence) in Leaf-On season

Implications

Above-canopy conditions may misrepresent below-canopy conditions

Need to consider complex 3-D flow patterns at each site, via both measurement campaigns and modeling

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MMSF

UMBS

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