Biosphere-Atmosphere Exchange: An Overview

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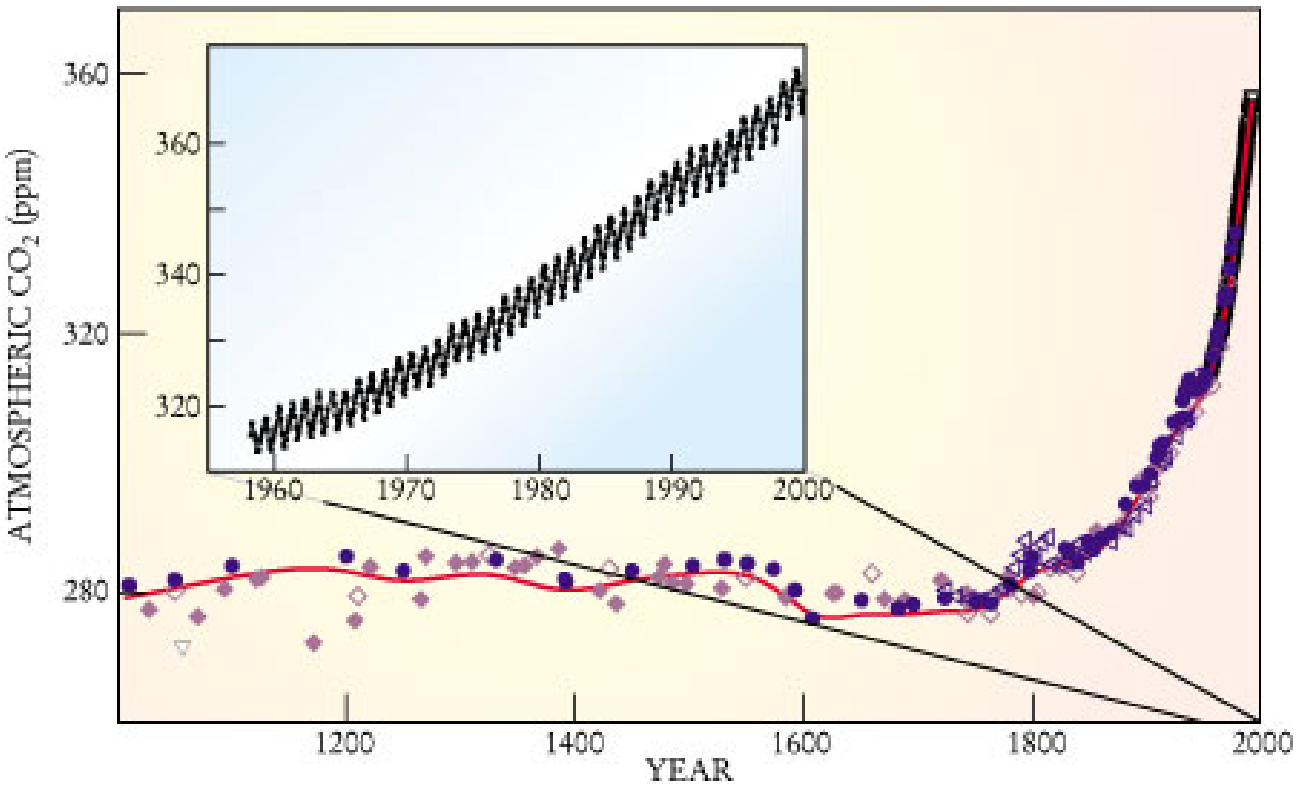
Atmosphere – Biosphere Exchange

Why is it relevant ?

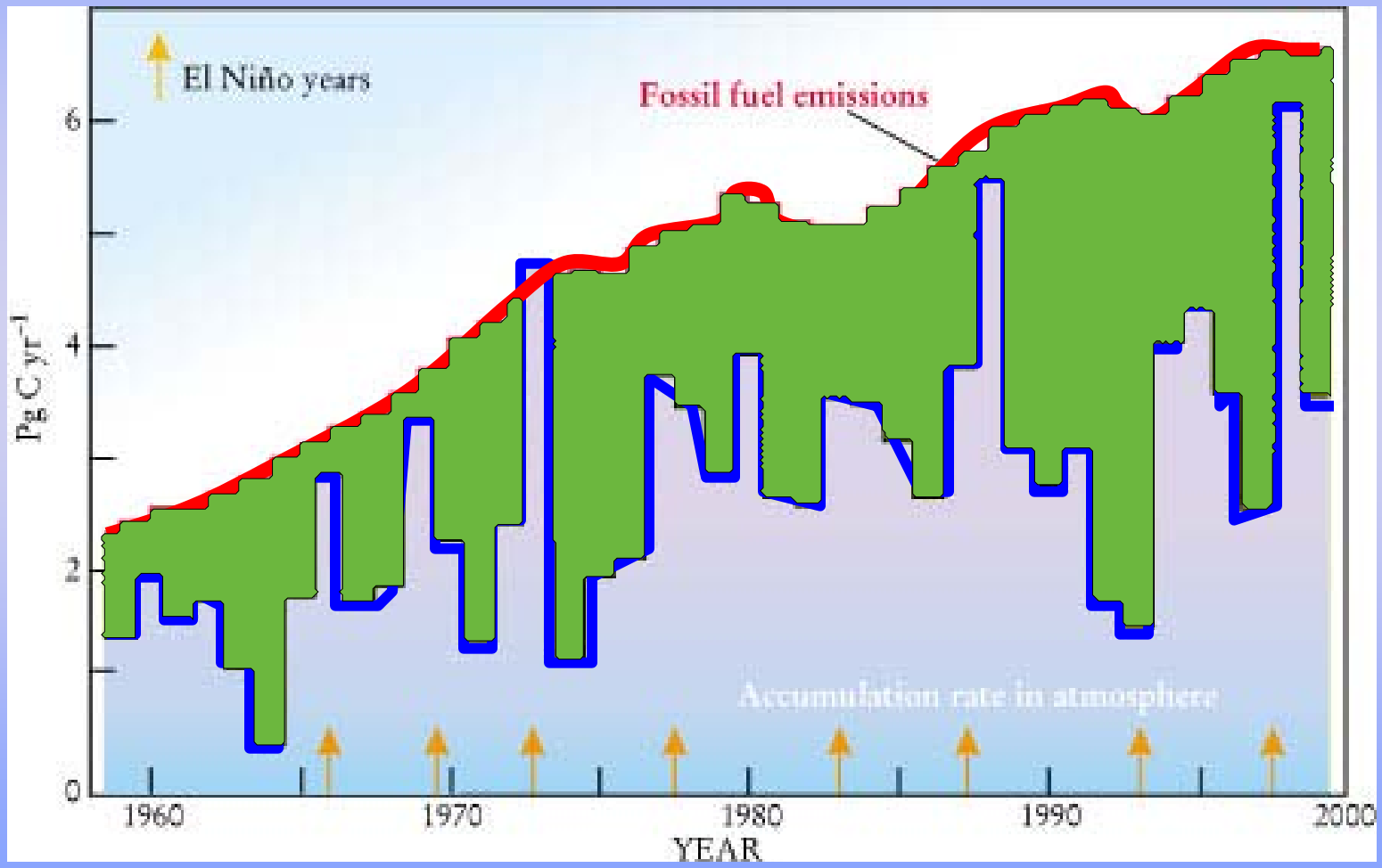
***For Example*: CO_2**



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

Background: Global Carbon Budget

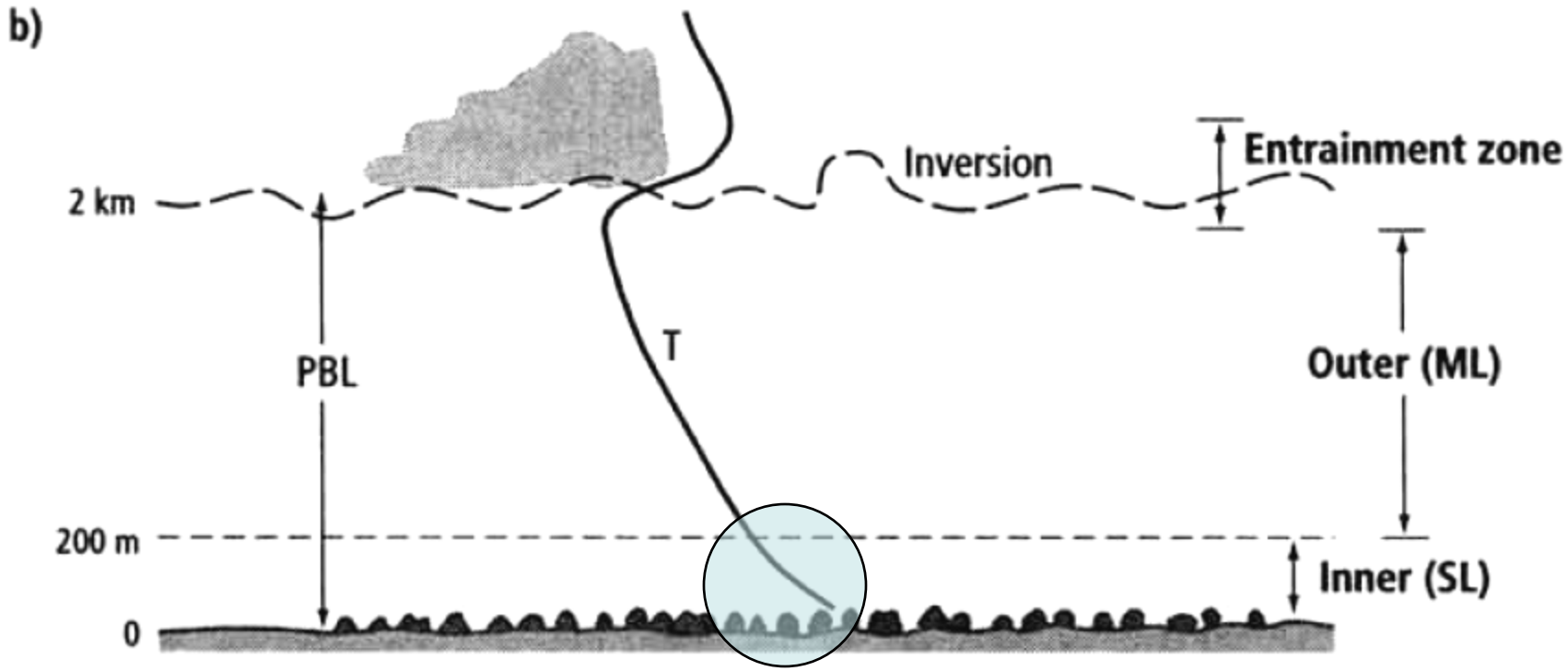
$CO_{2,Atm}$ Accumulation = CO_2 Source - Land & Ocean Sinks



(from Sarmiento and Gruber, 2002)

Discussion: Which part of the atmosphere is influenced by the biosphere?

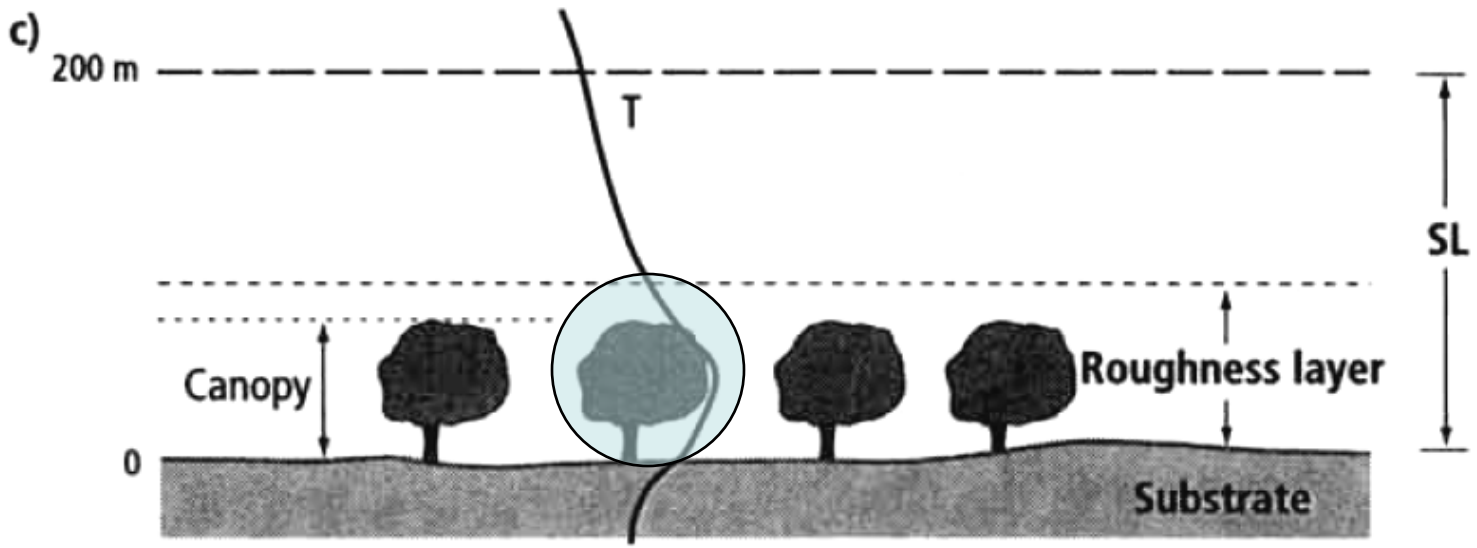
Layering of the Atmosphere: The Planetary Boundary Layer (PBL)



from Oke (1997)

Discussion: Which part of the atmosphere is influenced by the biosphere?

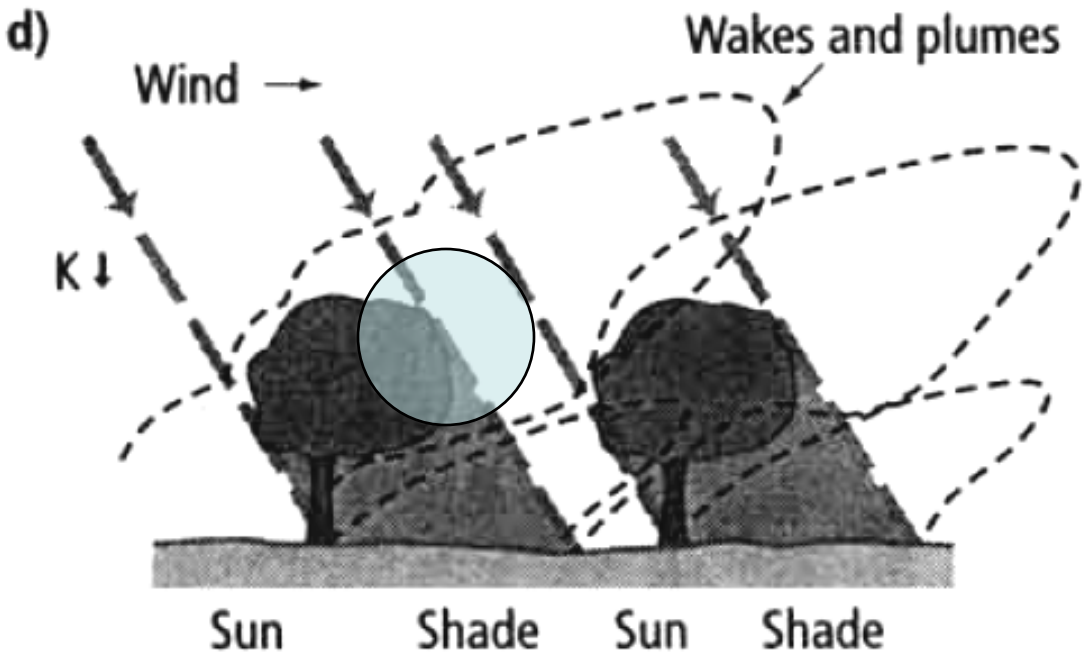
Layering of the Atmosphere: The Surface Layer (SL)



from Oke (1997)

Discussion: Which part of the atmosphere is influenced by the biosphere?

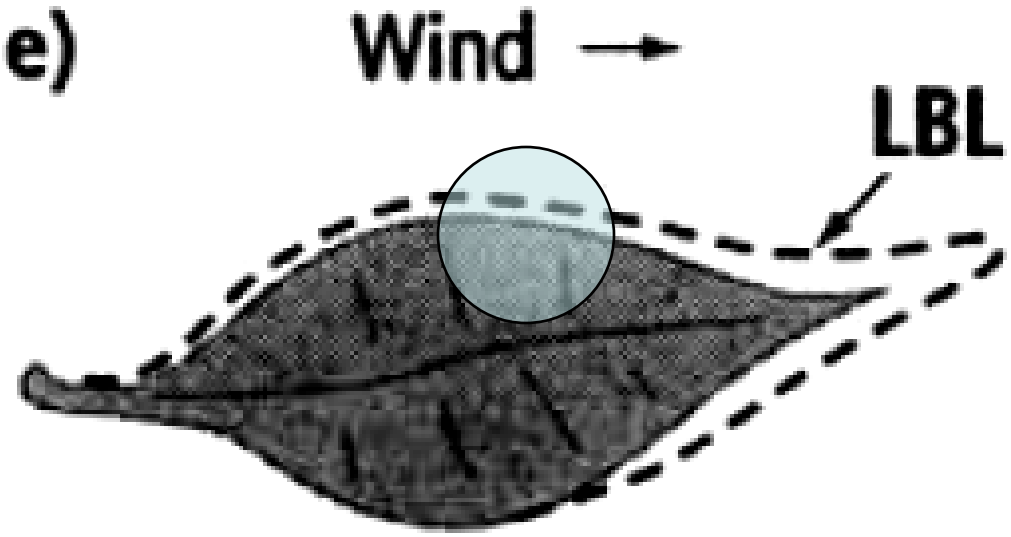
Layering of the Atmosphere: The Roughness Sublayer



from Oke (1997)

Discussion: Which part of the atmosphere is influenced by the biosphere?

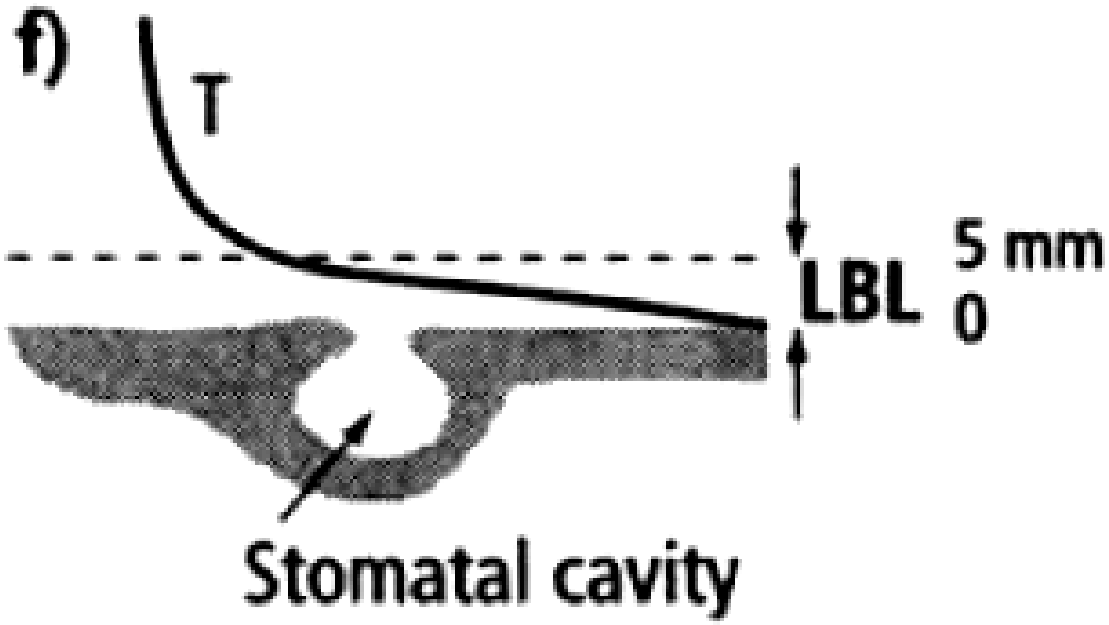
Layering of the Atmosphere: The Leaf Boundary Layer (LBL)



from Oke (1997)

Discussion: Which part of the atmosphere is influenced by the biosphere?

Layering of the Atmosphere: The Stomatal Cavity

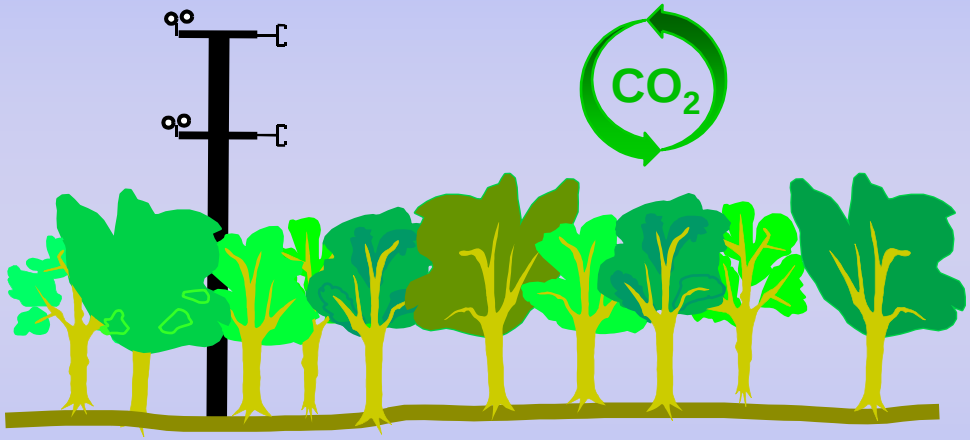


from Oke (1997)

Plant-Environment Interaction: CO_2

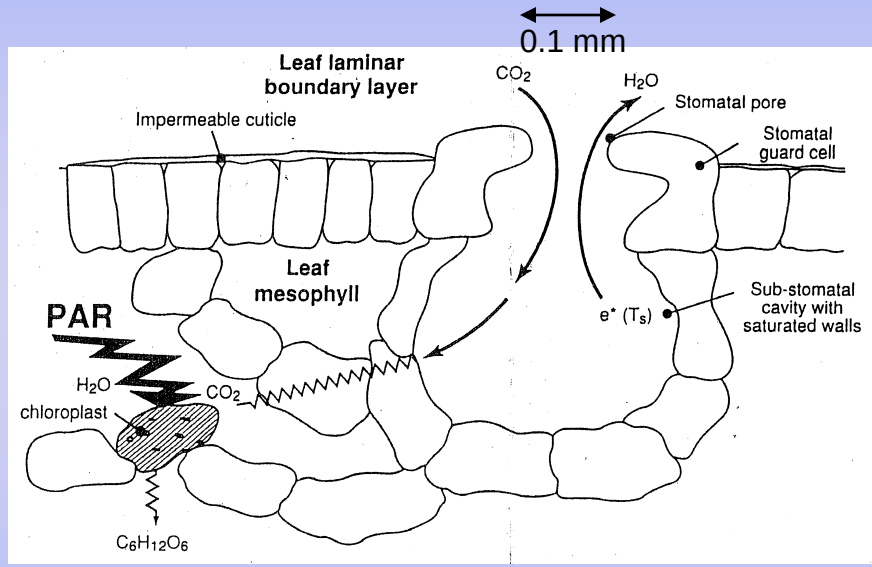
Scale of Approach

Macroscopic Approach



- ecosystem exchange
- transport
- 10^2 - 10^3 m
- hourly – multi-year

Microscopic Approach



- intercellular exchange
- transformation, chemical pathways
- 10^{-5} – 10^{-2} m
- seconds – hourly

everything in between

Biosphere-Atmosphere Exchange:

We can't cover everything all of the time …

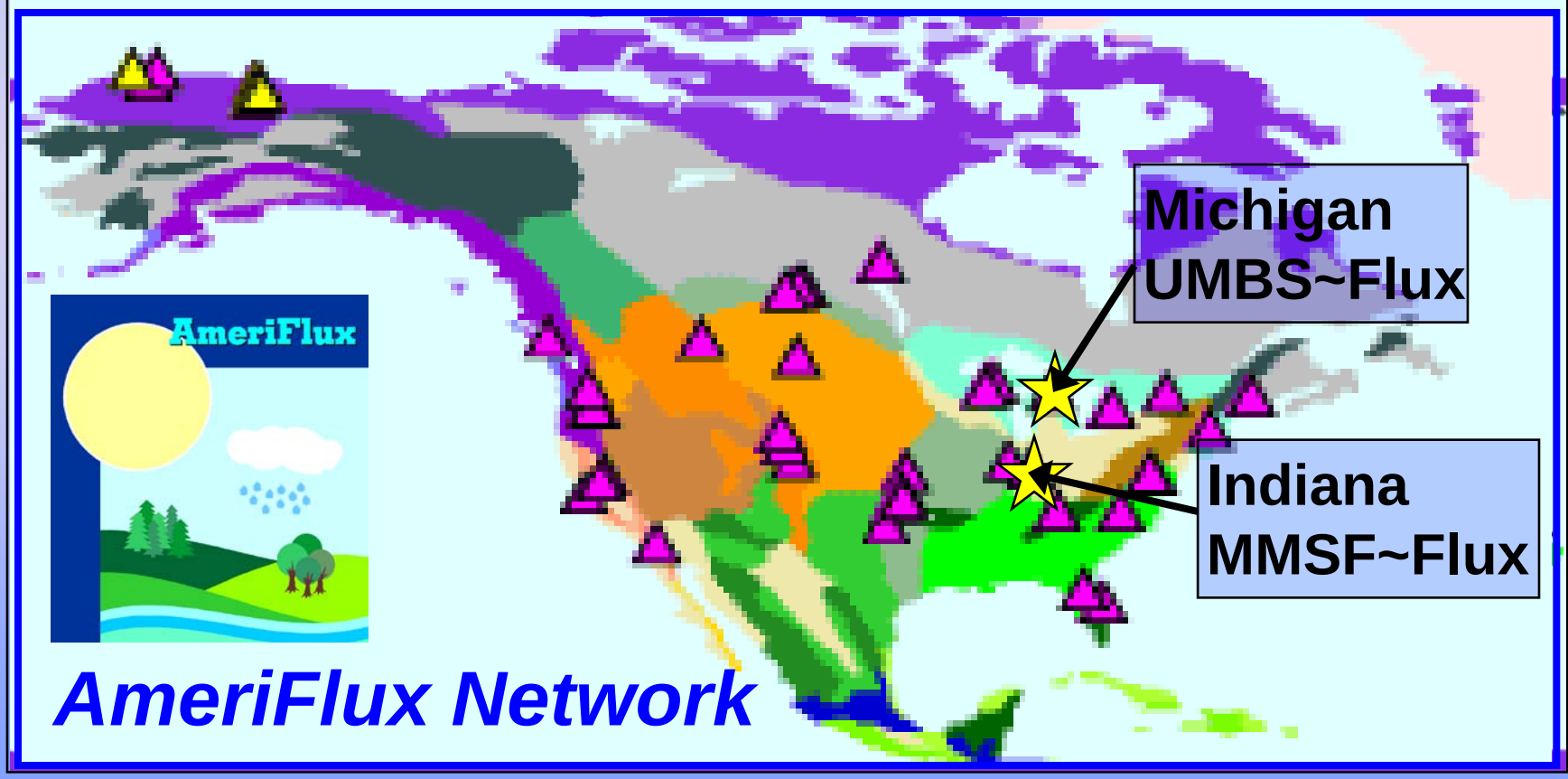
- **in-situ observations:** (chambers, flux towers)
  cover almost nothing but most of the time

- **aircraft observations:** (fluxes, concentrations)
  cover almost everything but hardly ever

- **modeling:** (leaf …. region)
  only pretend to **cover everything all of the time**

FLUXNET

Integrating Worldwide
CO_2 Flux Measurements
(currently ~ 300 stations)



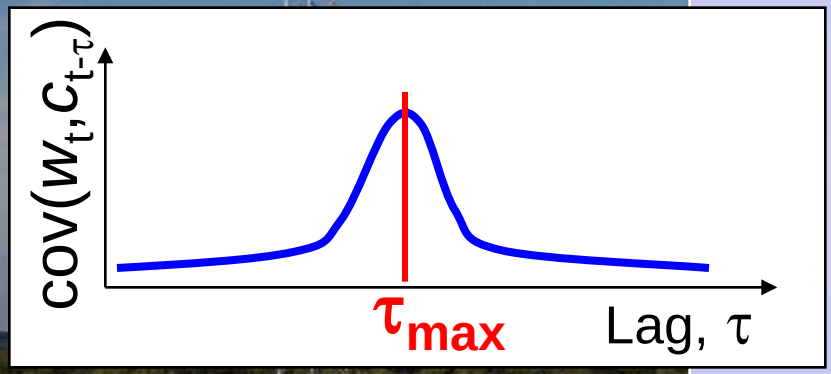
Eddy-Covariance: Closed Path System

UMBS~Flux Tower: ~~Instrumentation~~

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

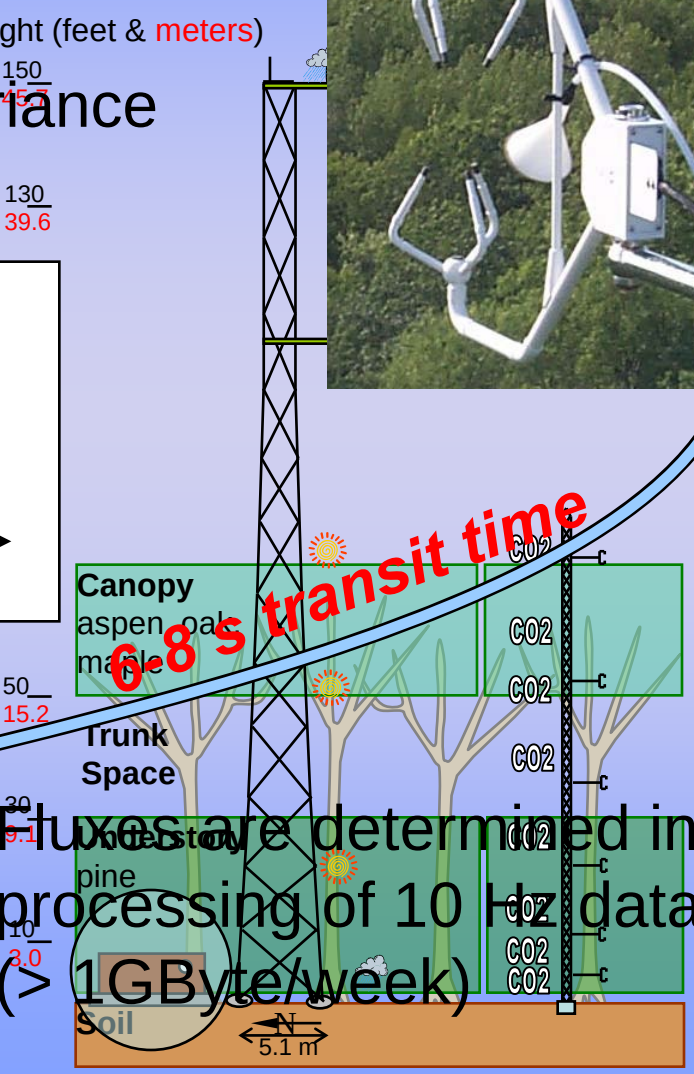
Lagged E-C: $\mathrm{cov}(w_t, c_{t-\tau})$

- 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)

Turbulent Flux: the correlation of eddies

$$\overline{wC} = \bar{w}\bar{C} + \overline{w'C'}$$

eddy covariance

Sonic Anemometer

- measures transit time of ultrasonic pulse → depends on air velocity
- fast sampling rate (~10-60 Hz)
- three velocity components
- sonic temperature
- at ≥ 10 Hz: resolves most fluctuations in turbulence
- $w = \bar{w} + w'$

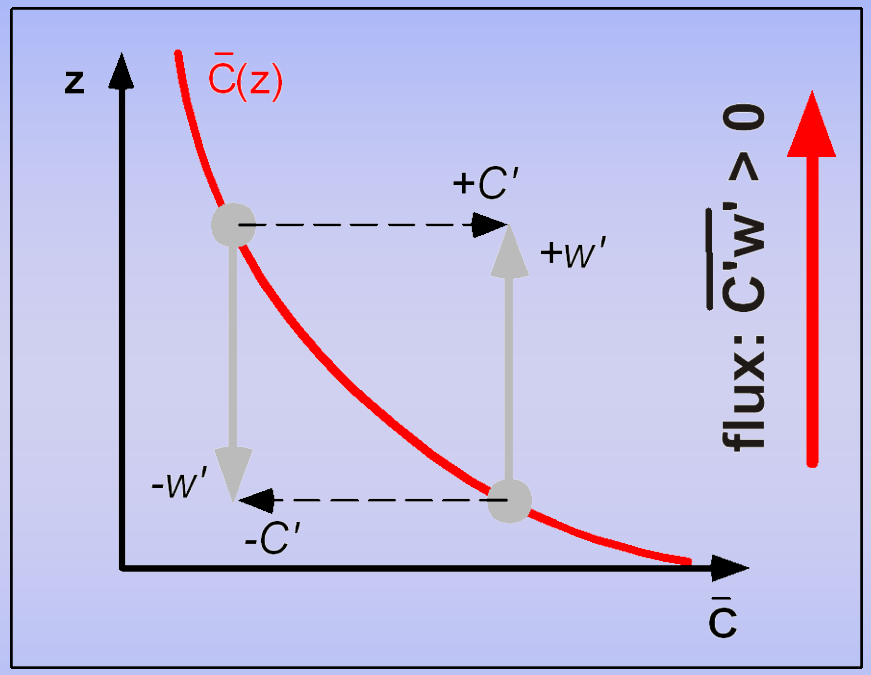
Scalar Concentration

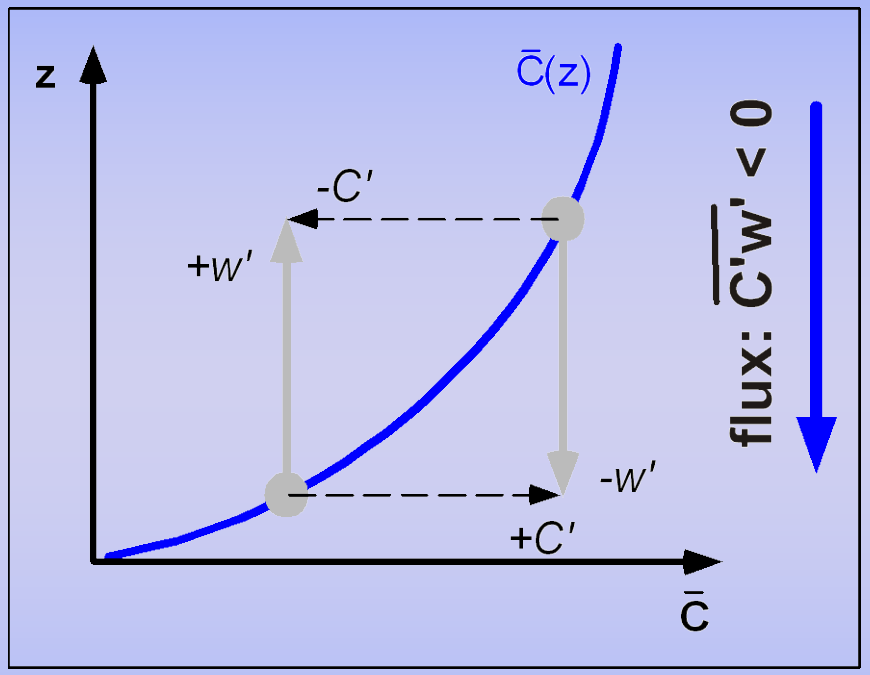
- sample-air intake
- synchronized analysis with sonic signals
- $C = \bar{C} + C'$

$\overline{w'C'}$ Eddy Covariance -- Turbulent Flux

Common situation: vertical gradient in 3-D turbulent motion

Two possibilities:

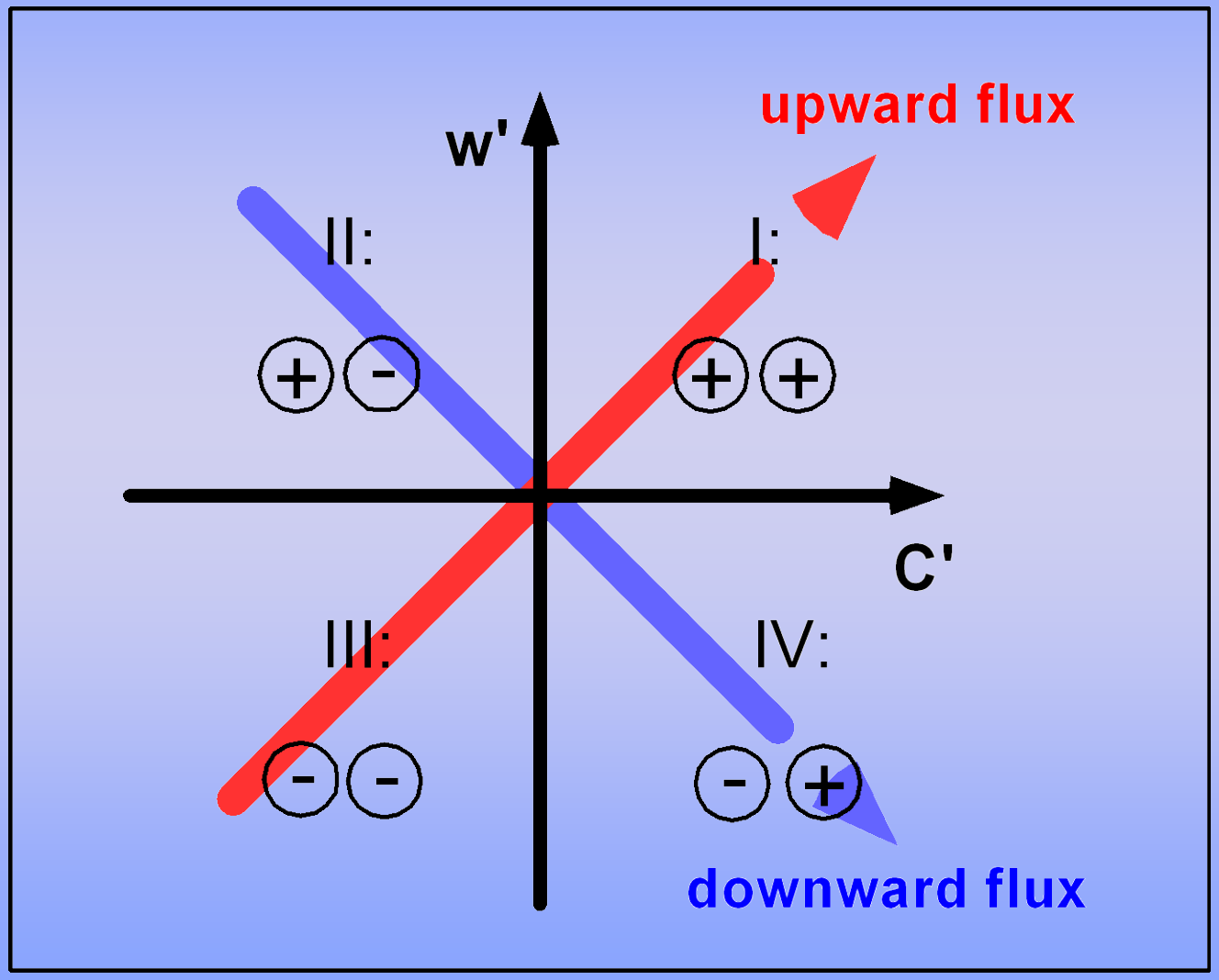




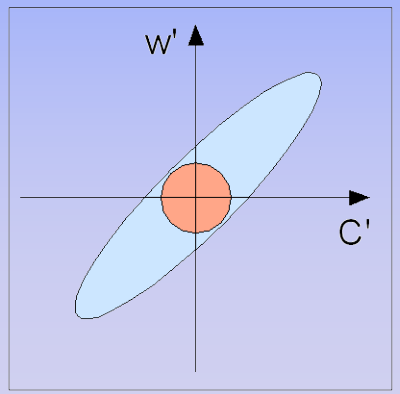
$$\mathrm{cov}(C,w) = E\left(\left[C - E(C)\right]\left[w - E(w)\right]\right) = \boxed{\overline{w'C'}}$$

$$\left[\overline{w'C'}\right]\frac{P}{R_* T_v} = \frac{m}{s}\frac{\mu mol_C}{mol_d}\frac{P}{R_* T_v} = \frac{\mu mol_C}{s \cdot m^2}$$

$\overline{w'C'}$ Eddy Covariance -- Turbulent Flux

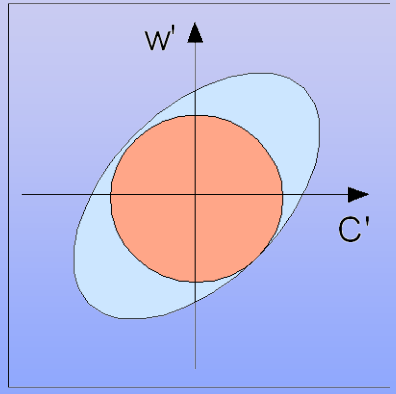


good correlation



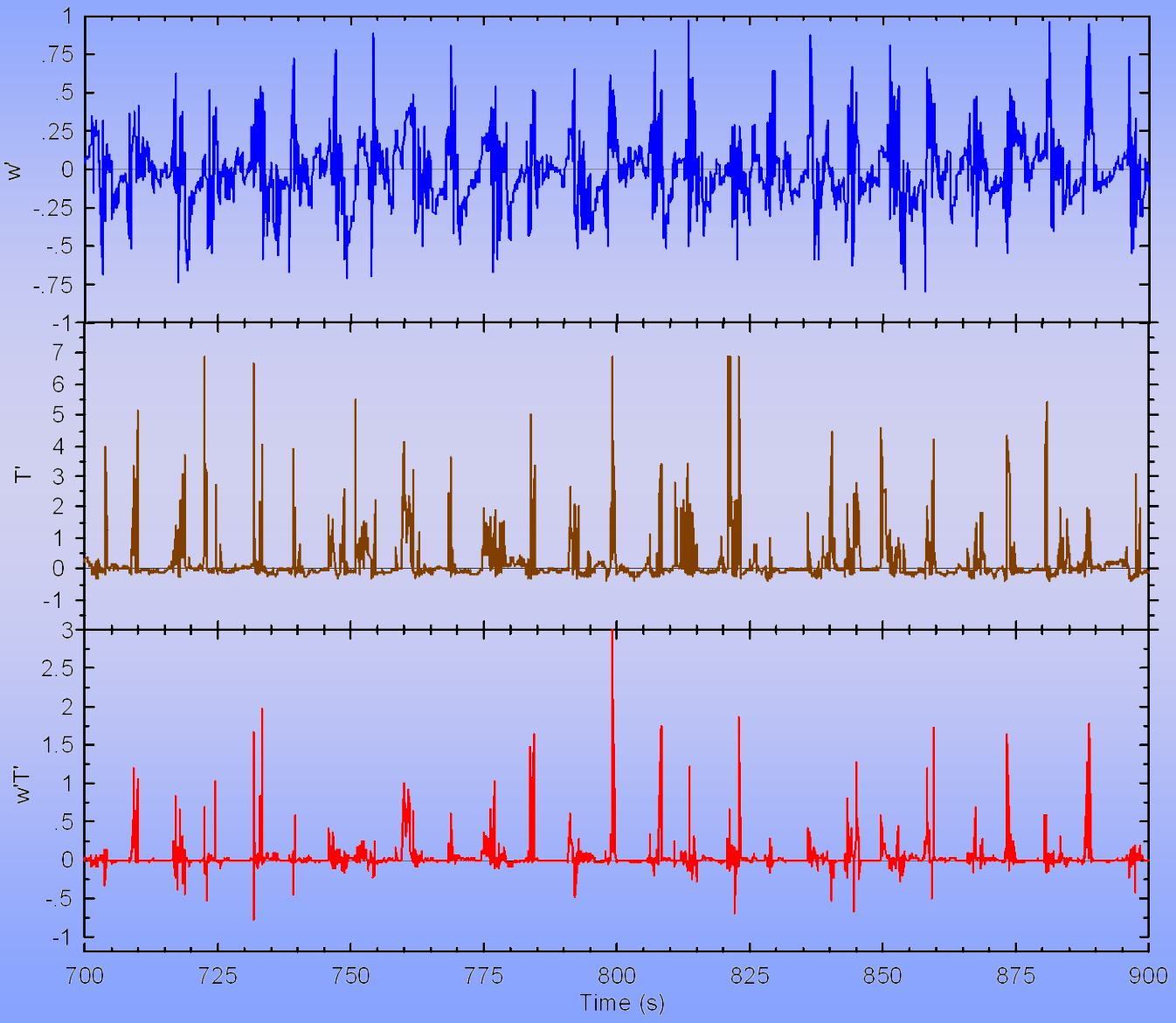
high organisation

poor correlation



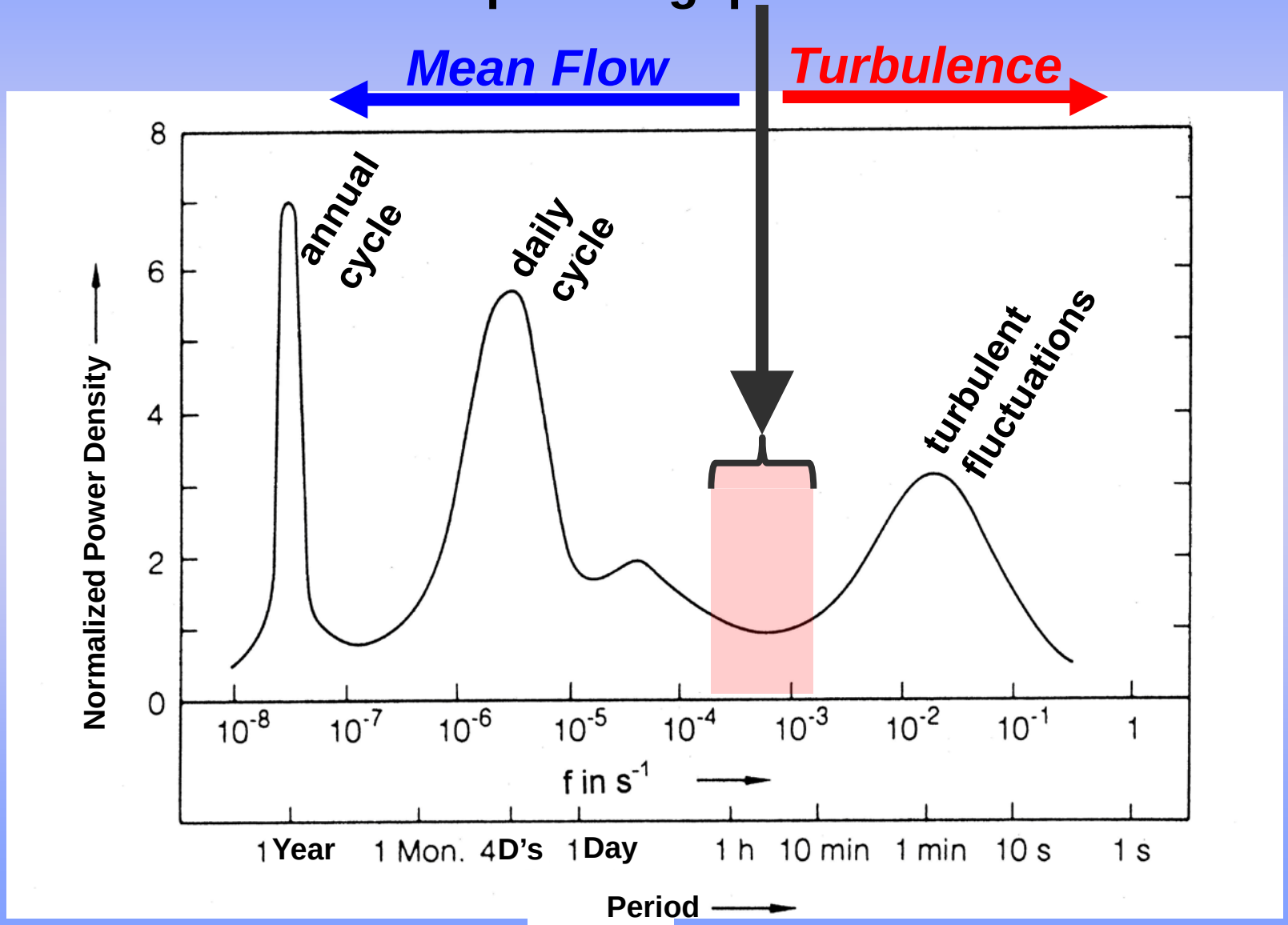
low organisation

$\overline{w'C'}$ Eddy Covariance -- Turbulent Flux



Turbulent Time Series: Averaging Period?

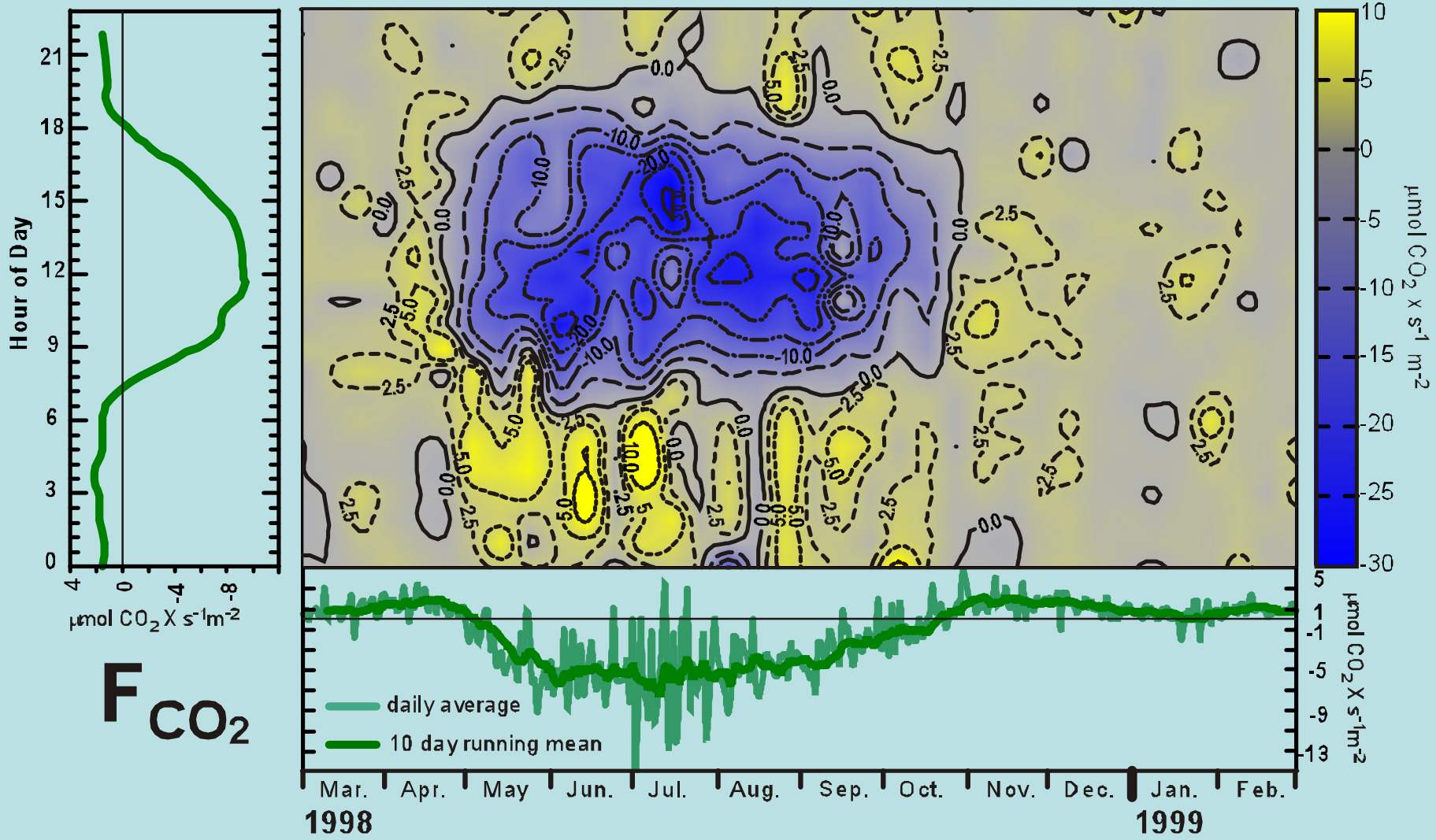
“spectral gap” ~ 10 min – 1 h



MMSF~Flux (Indiana)

Energy and Carbon Fluxes:

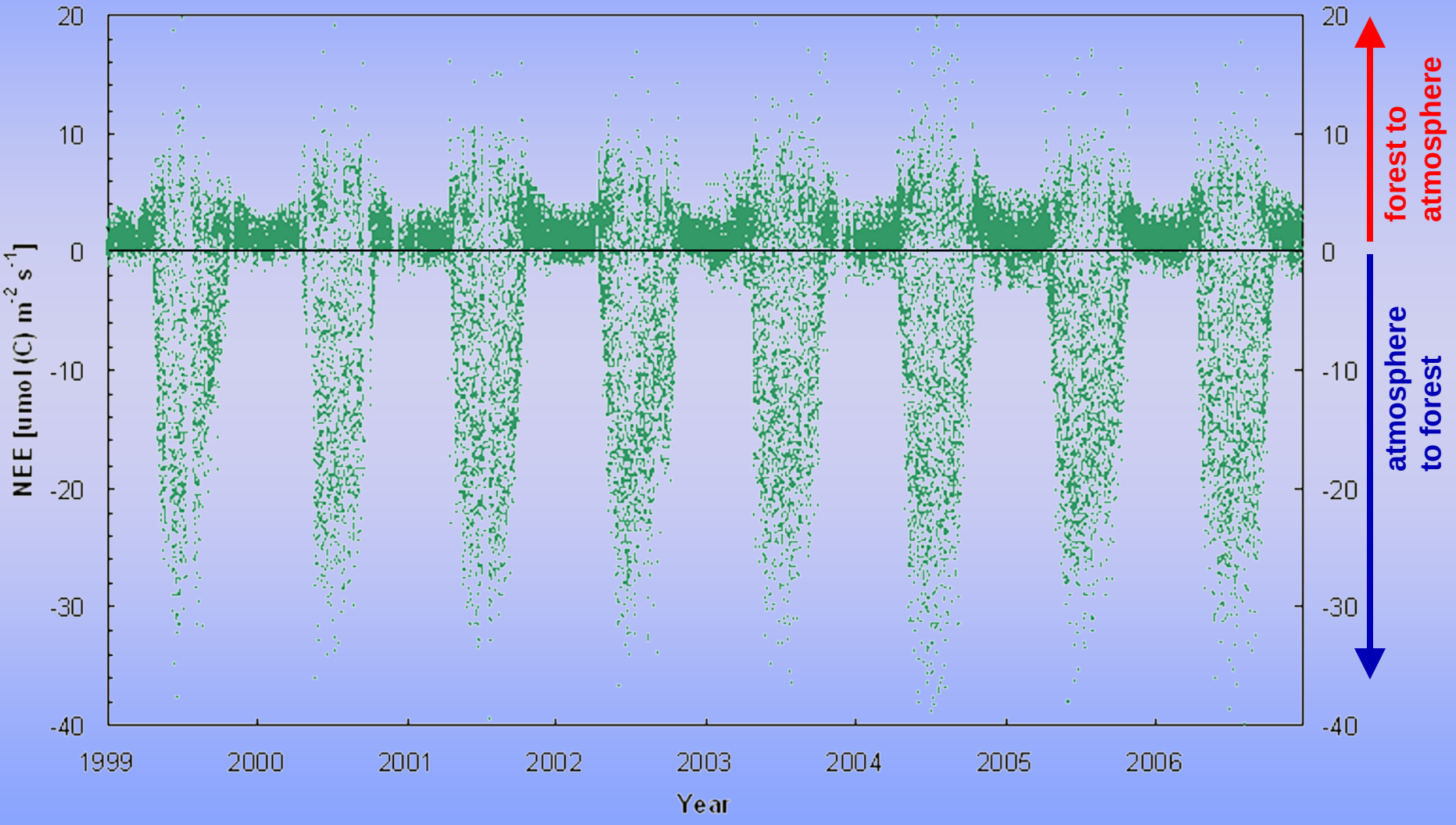
Annual "Fingerprints" of Variability



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

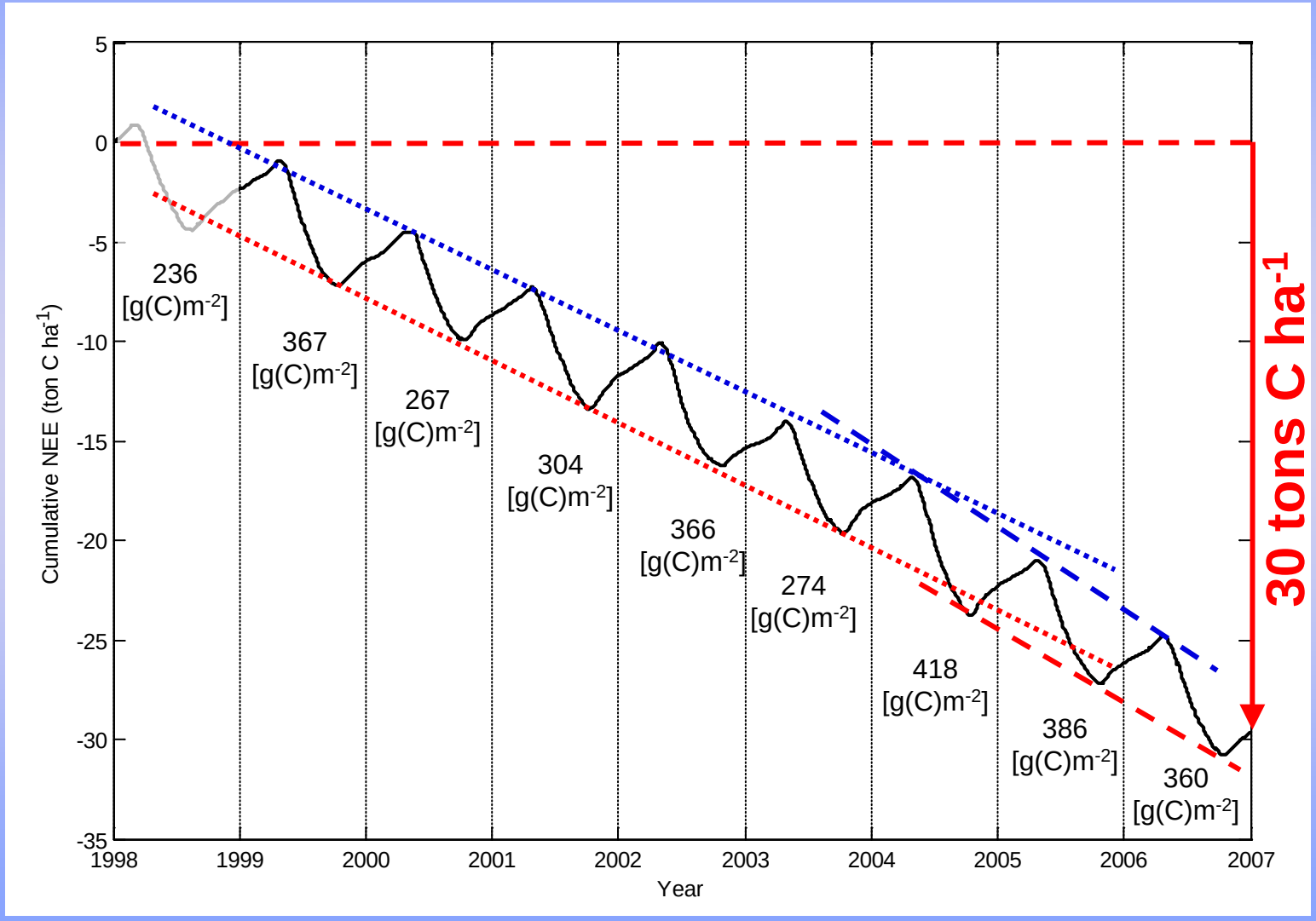
Hourly Fluxes of CO_2 over 8 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation



Cumulative Exchange of CO_2 over 9 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation

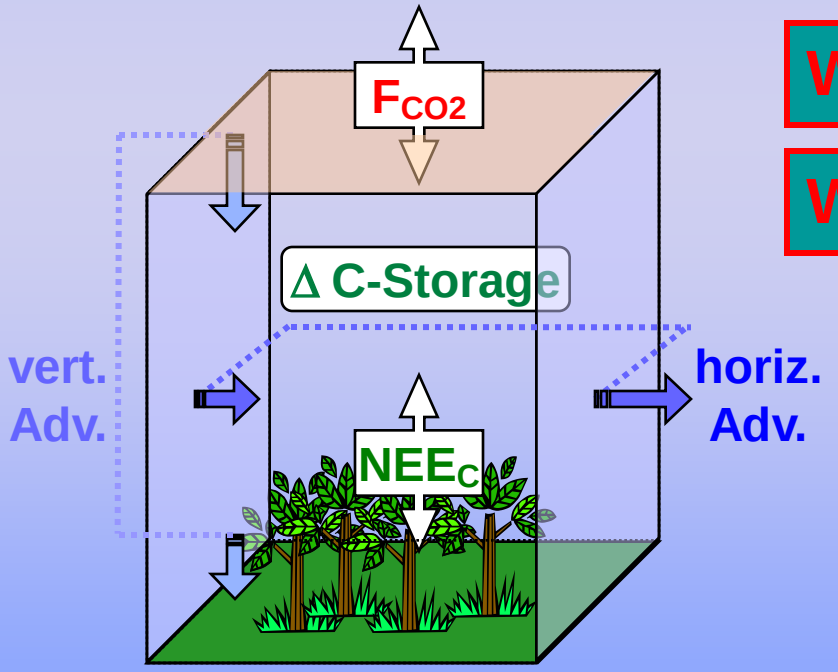


30 tons C ha^{-1} = 3 kg C m^{-2}

Are fluxes capturing the right processes ?

Examine CO_2 Conservation Equation!

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



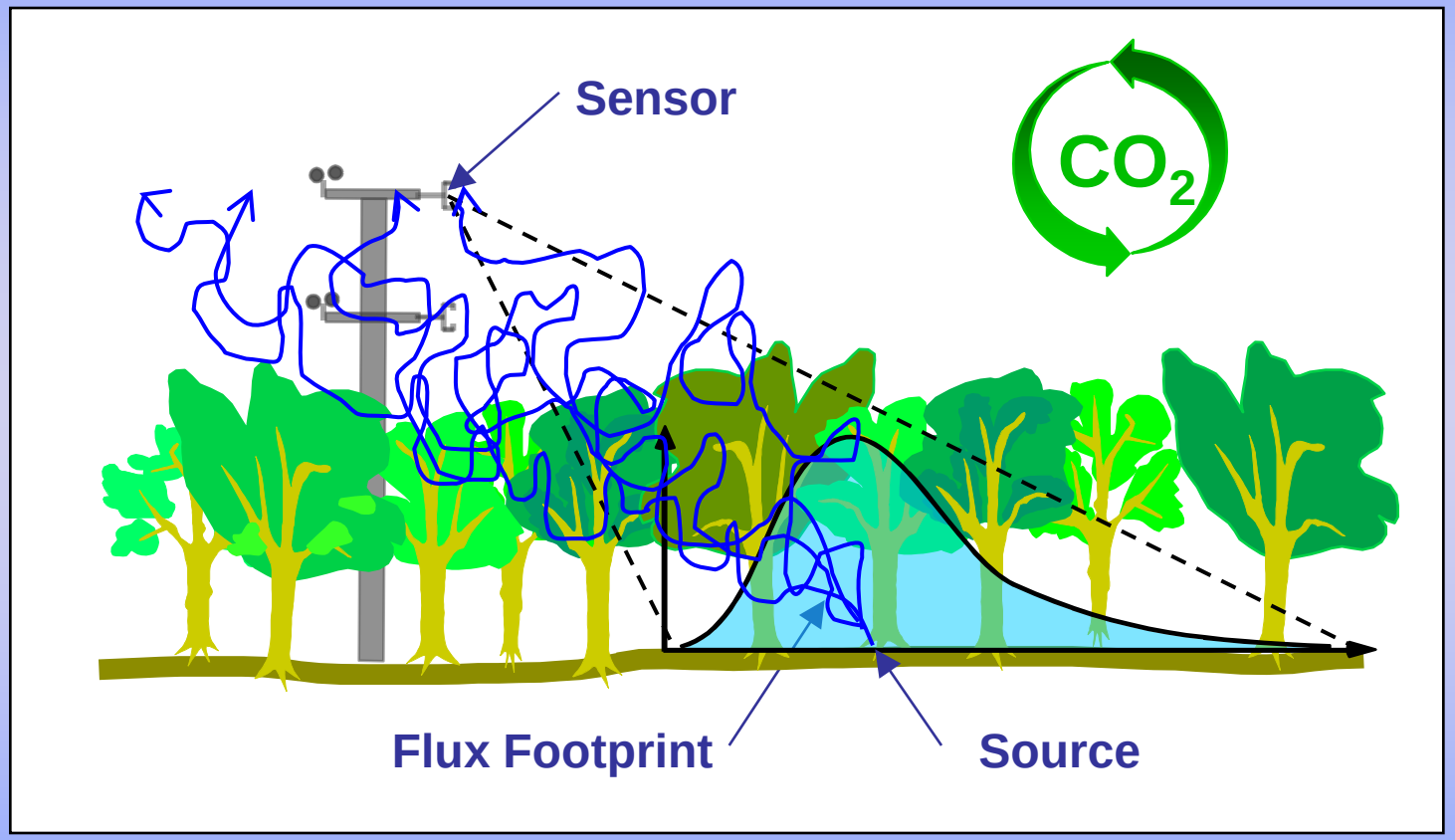
What do we want? **NEE !**

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

Potential problems:

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

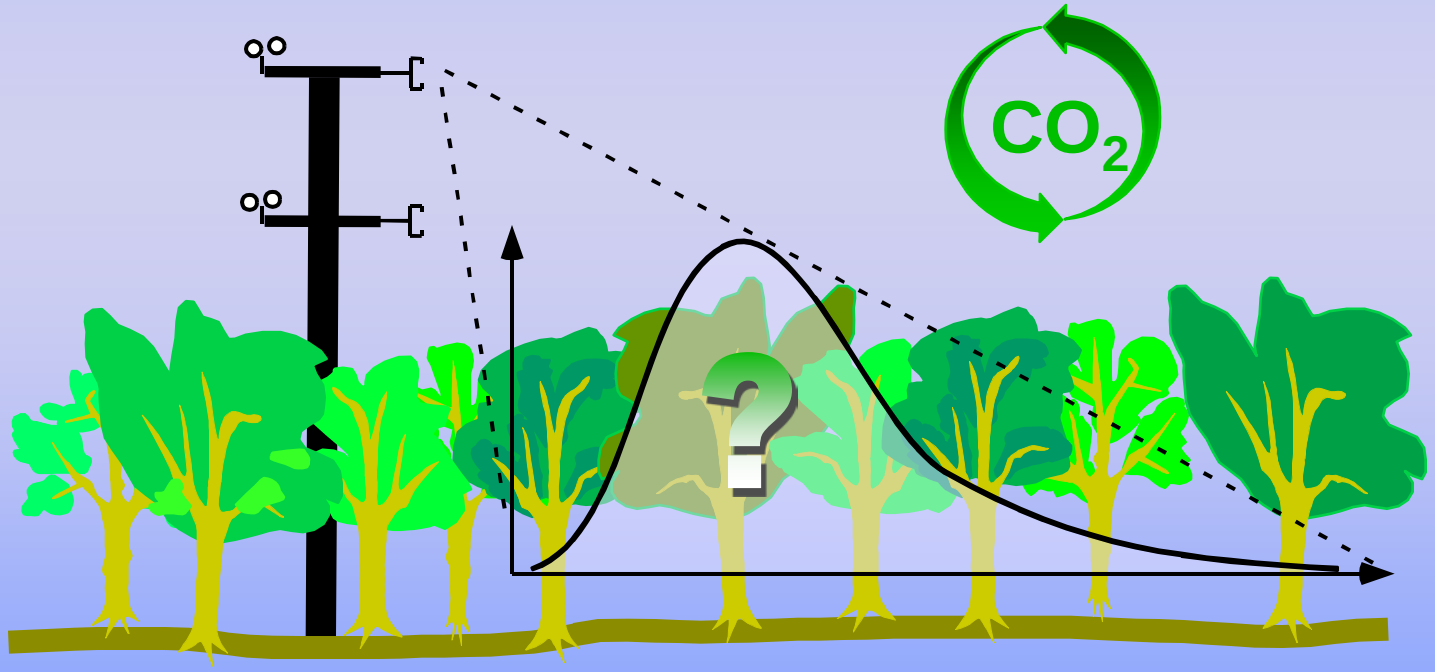
Micrometeorological Flux Measurements:
at what scale?



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**

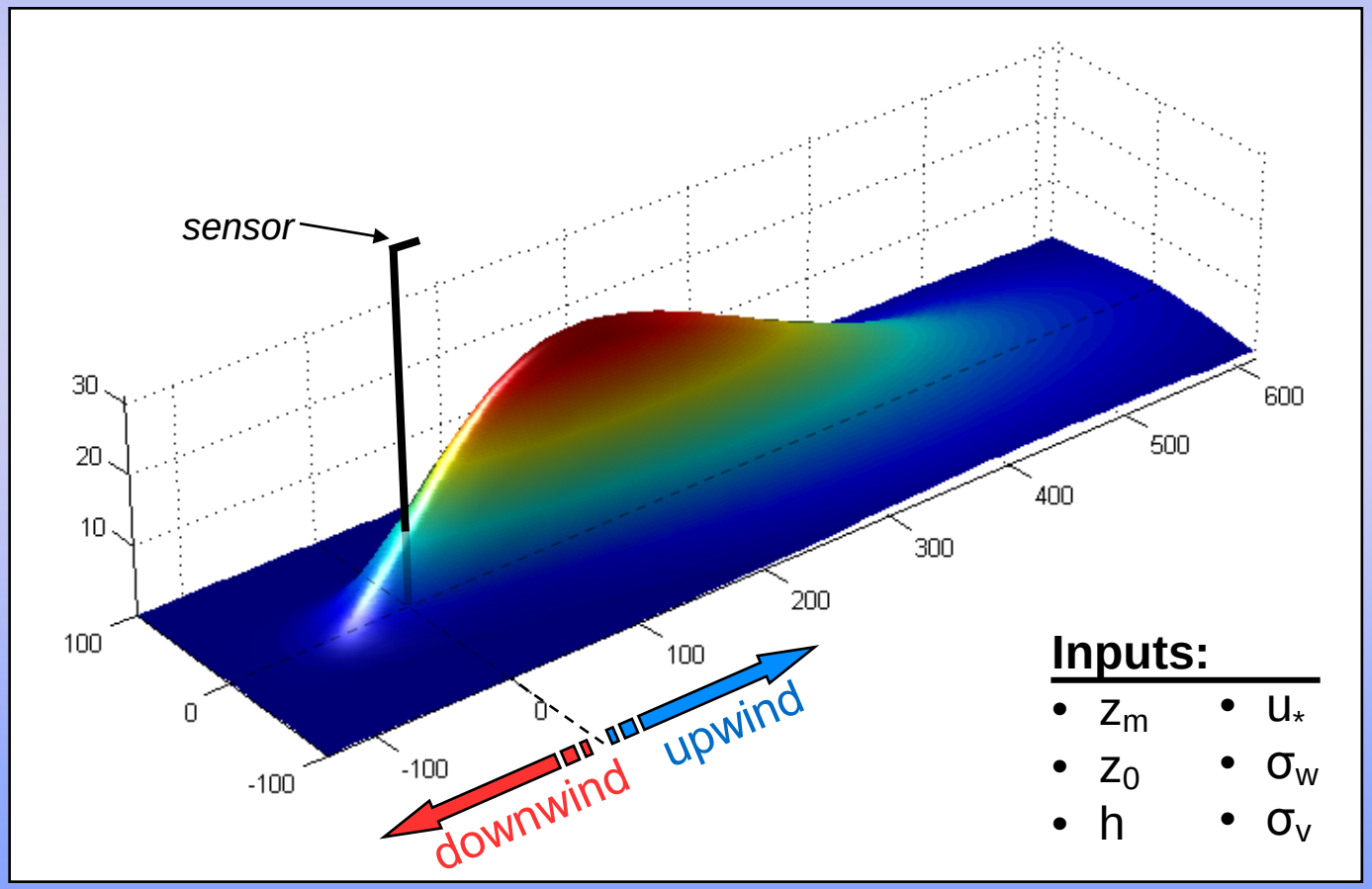


e.g.: Schmid (2002, *Ag. For. Met.*, **113**, 159-184)

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

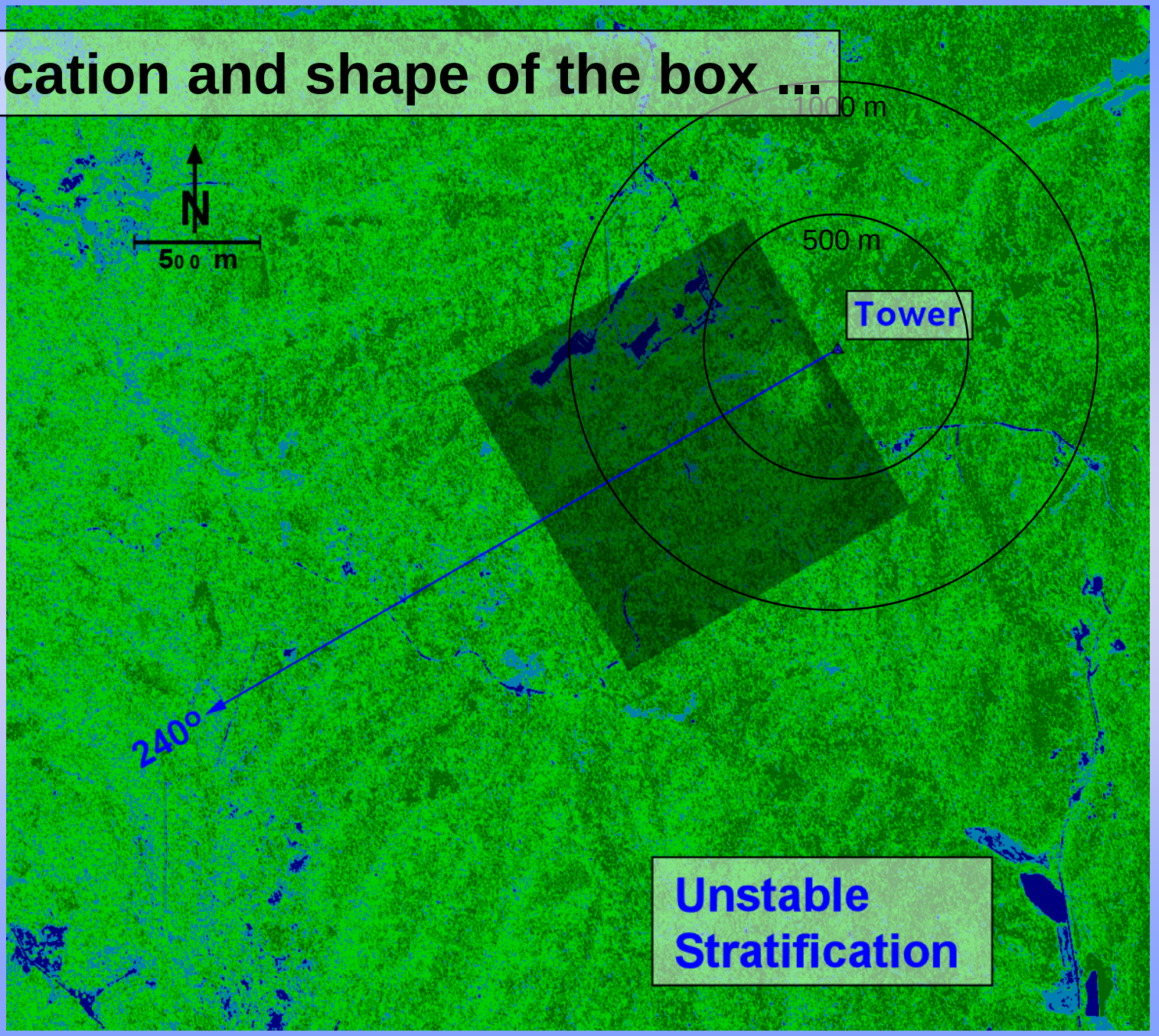
$$F(\mathbf{x}) = \iint_{\Re} Q_s(\mathbf{x}') \cdot f(\mathbf{x} - \mathbf{x}') \cdot d\mathbf{x}' = Q_s * f$$

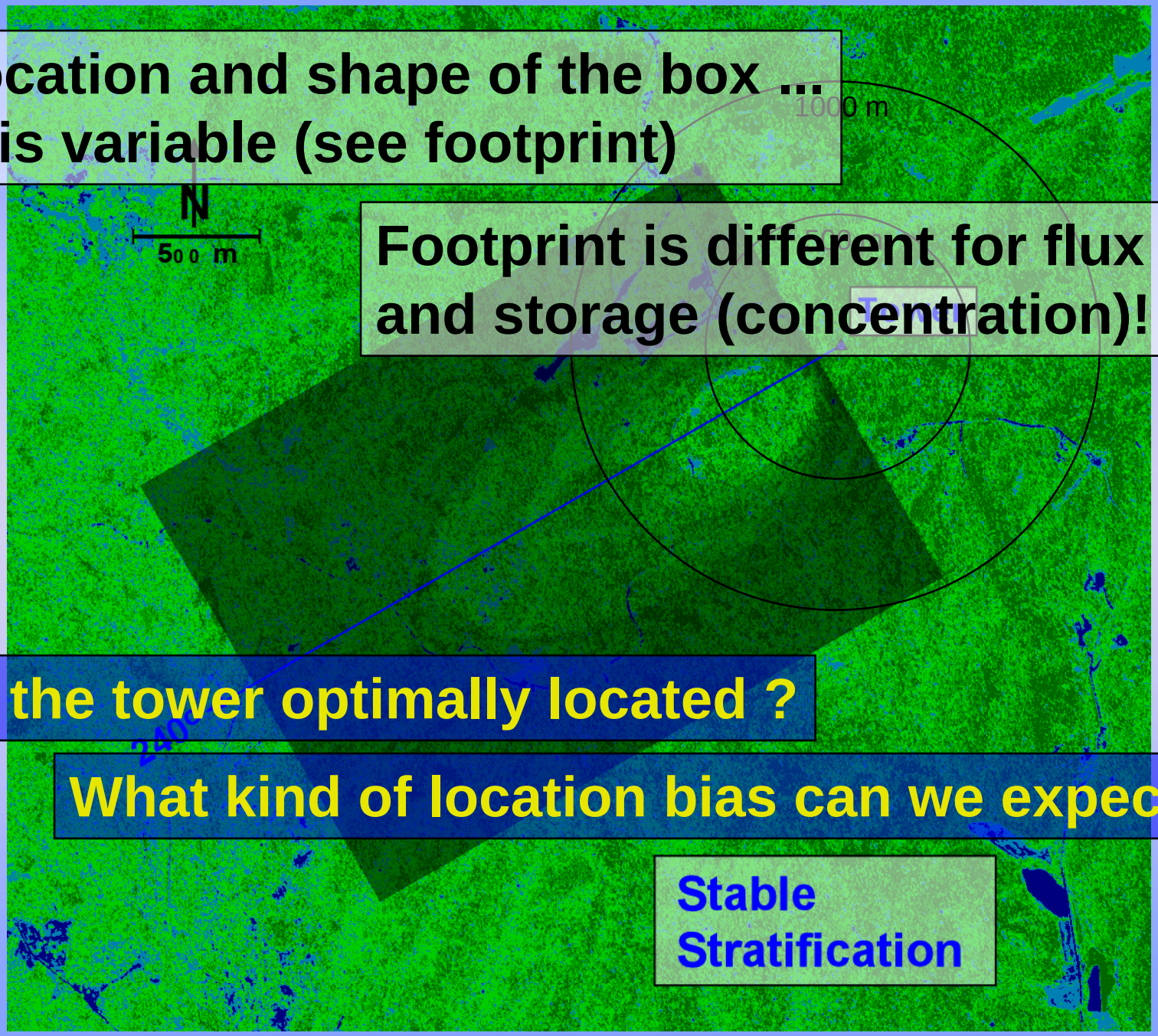
(**convolution** of the **source distribution**, Q_s, with the **footprint**, f)

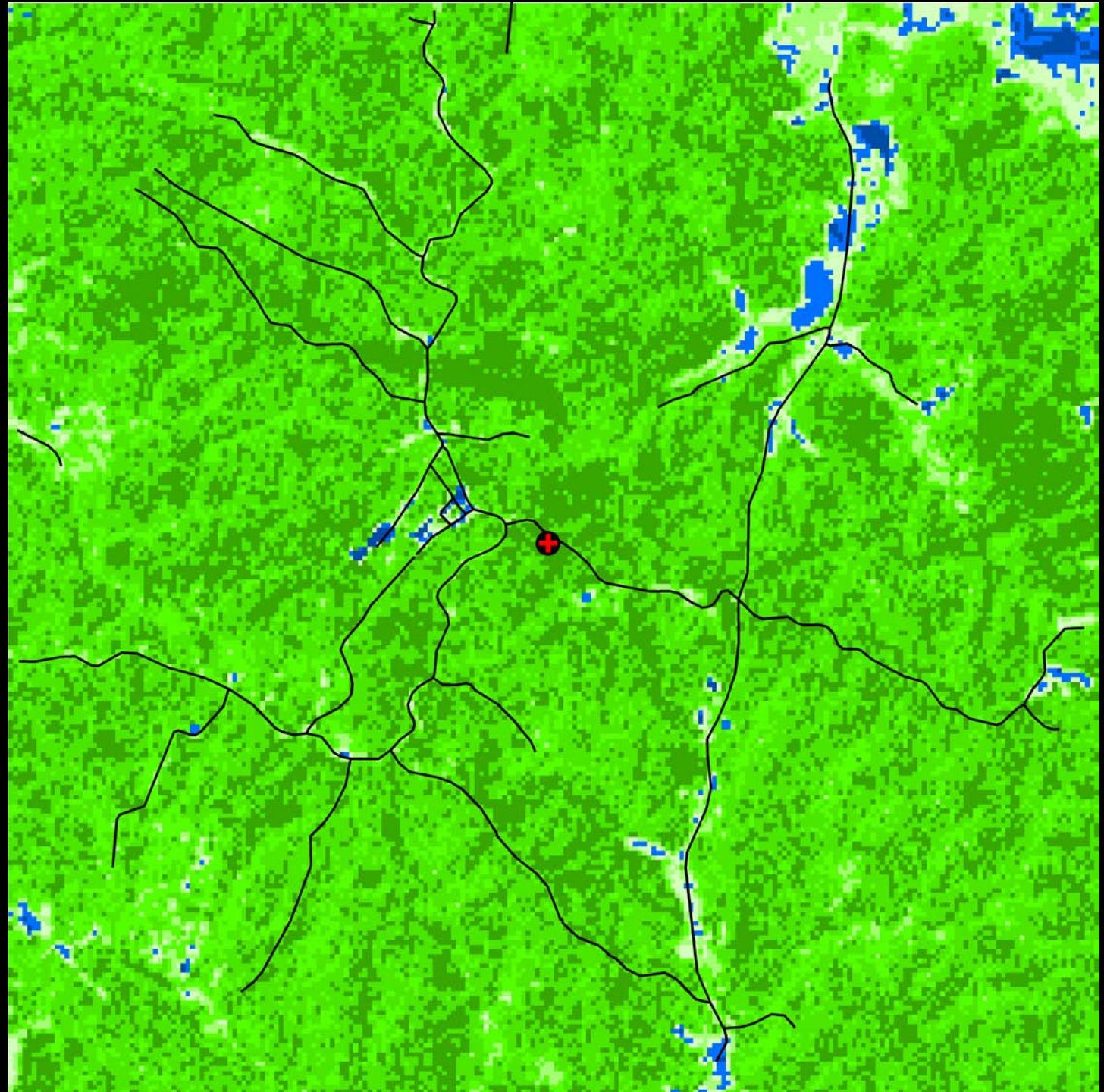


Schmid 1994 (*Boundary-Layer Meteorol.*, **67**, 293-318)

Location and shape of the box ...



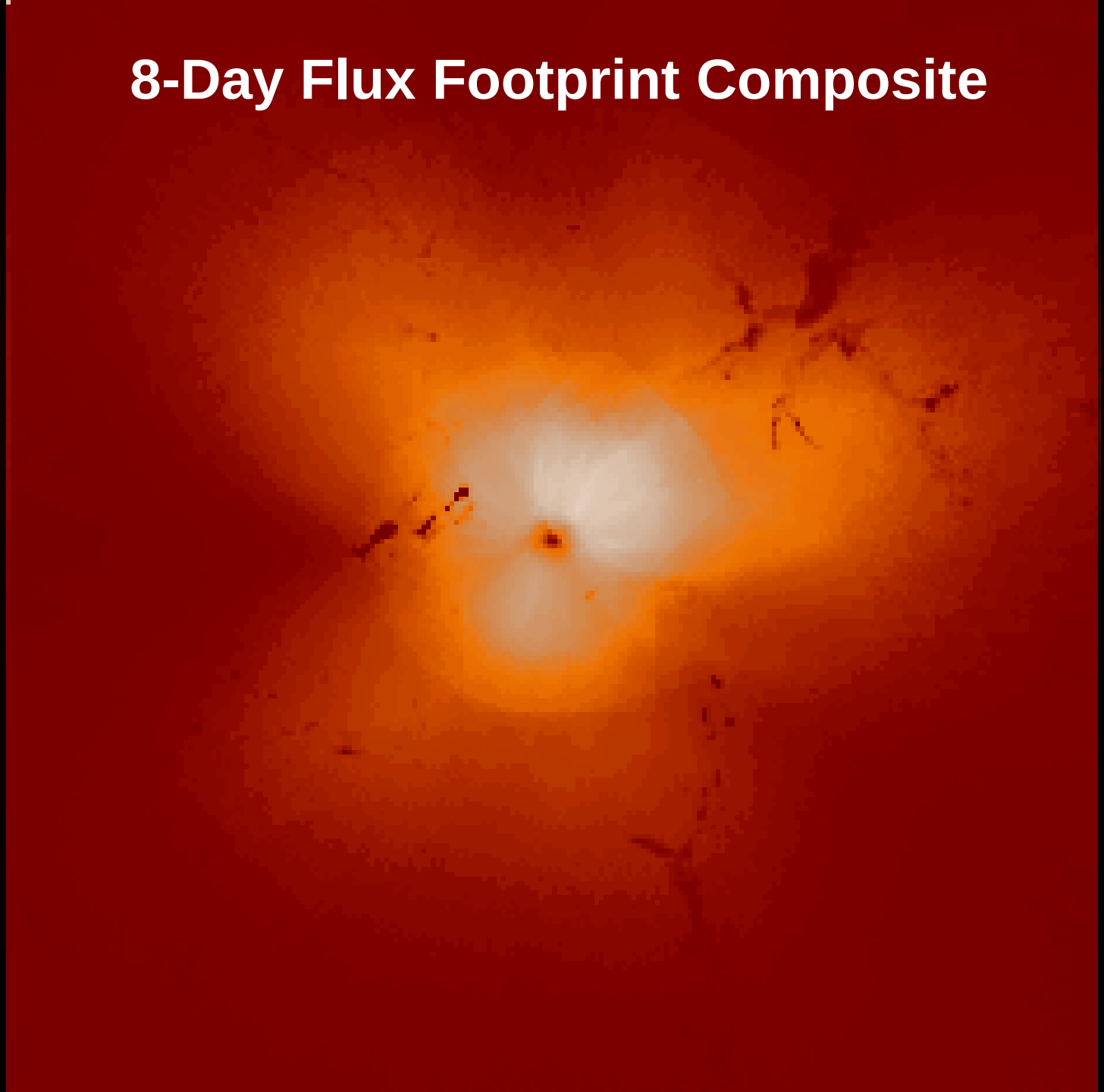

Location and shape of the box ...
... is variable (see footprint)
N
500 m
1000 m
Footprint is different for flux and storage (concentration)!
Is the tower optimally located ?
What kind of location bias can we expect ?
Stable Stratification



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:
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

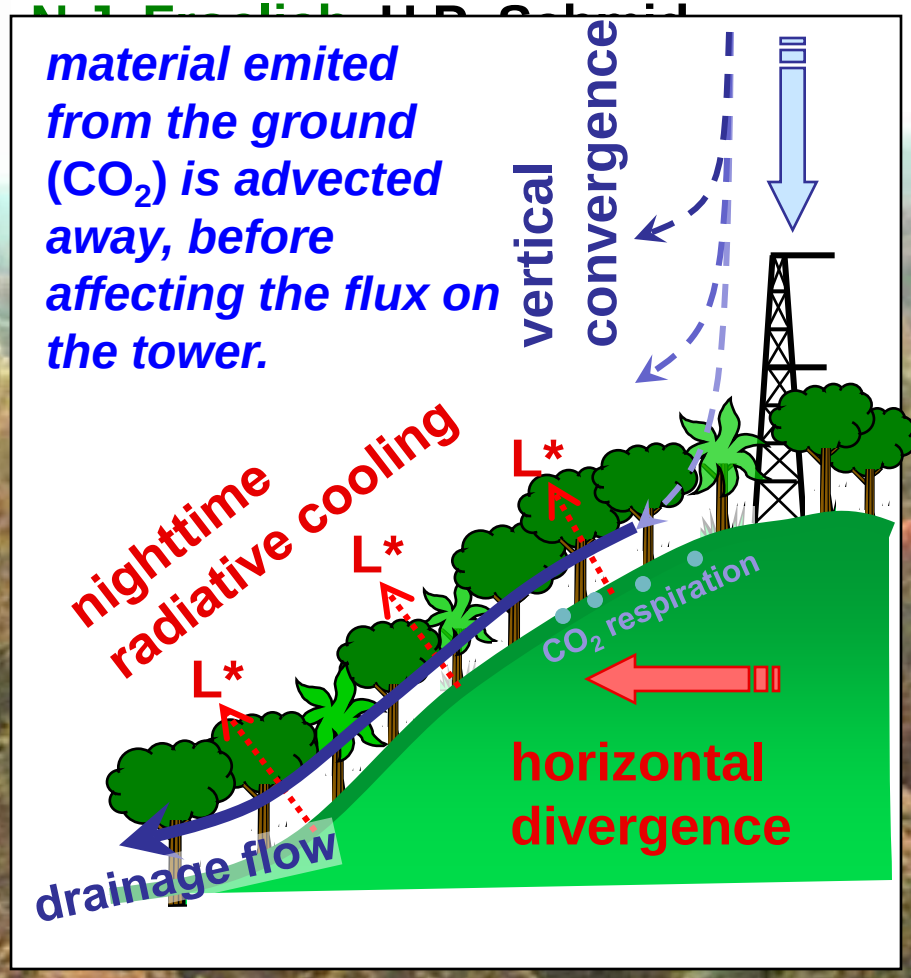
Small Scale, Gentle Topography

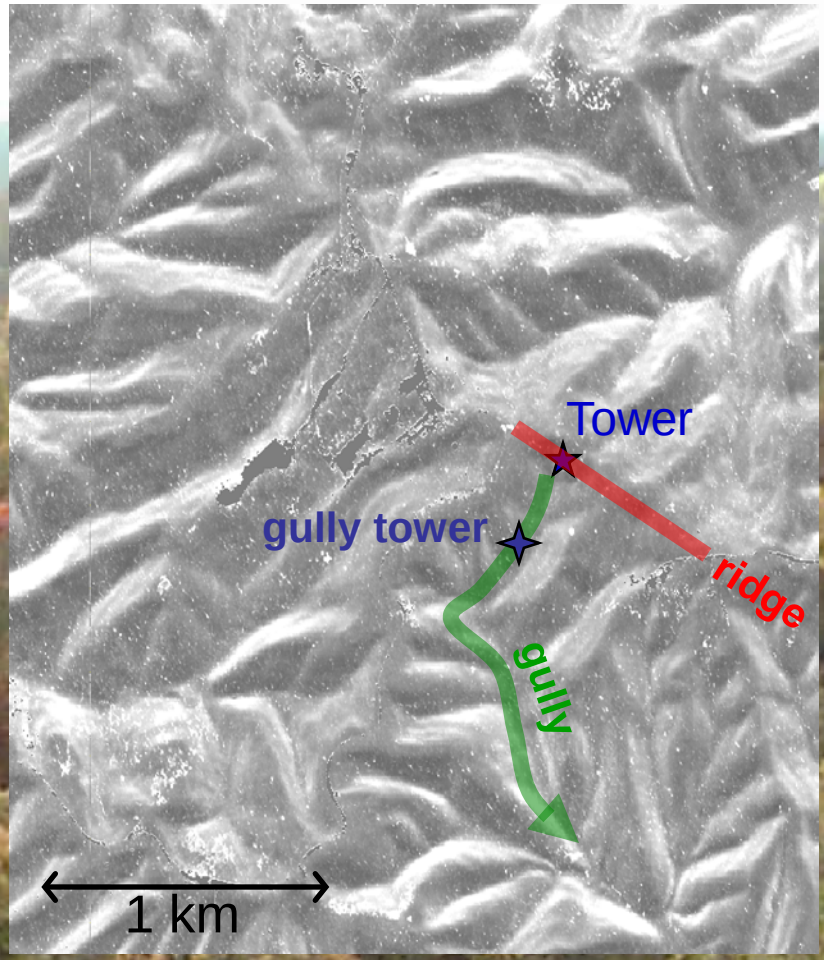
Problem with Nighttime Fluxes in Topography?

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

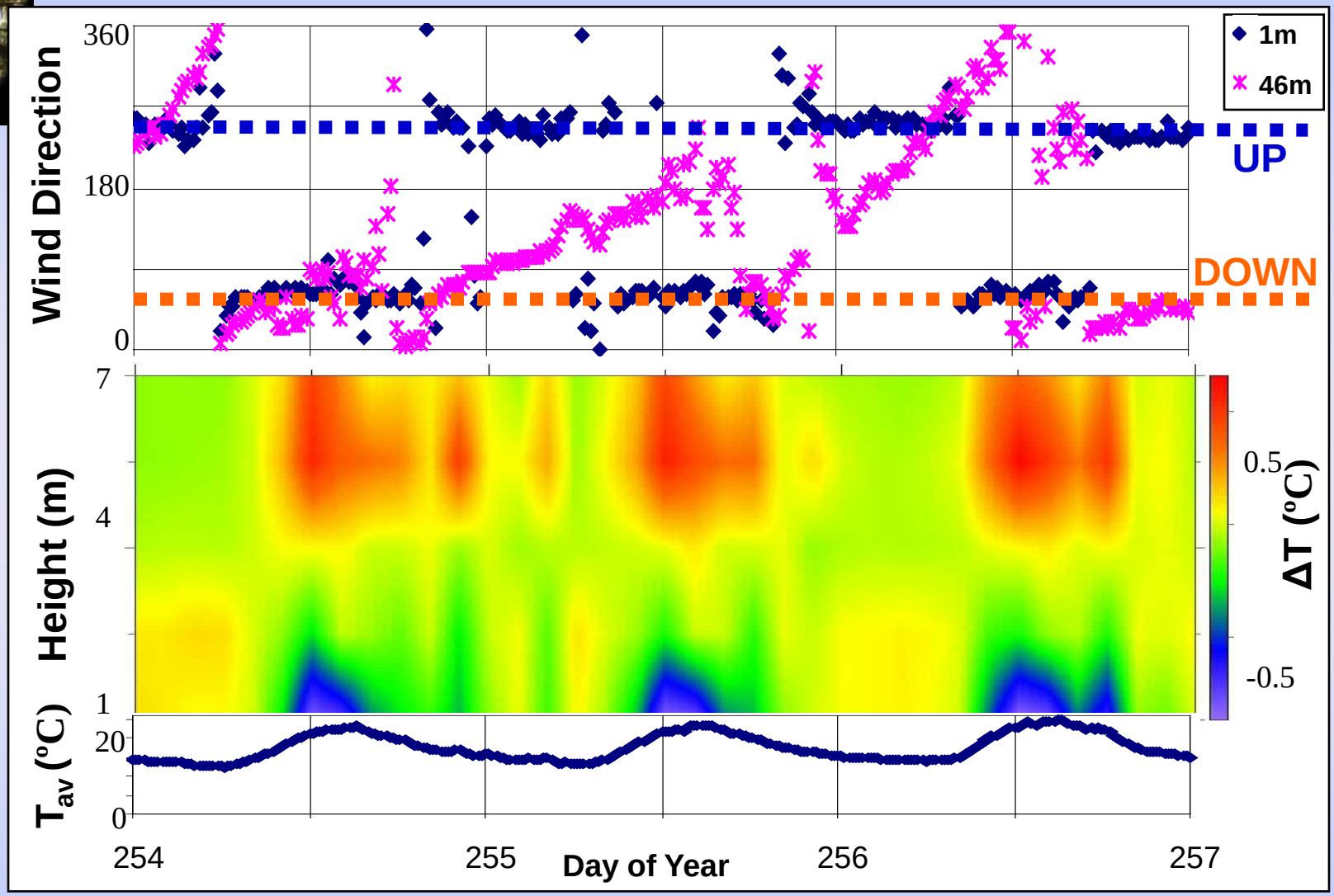
Advection and Gully Flows in Complex Forested Terrain

N.J. English, H.P. Schmid

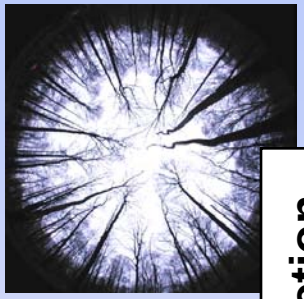




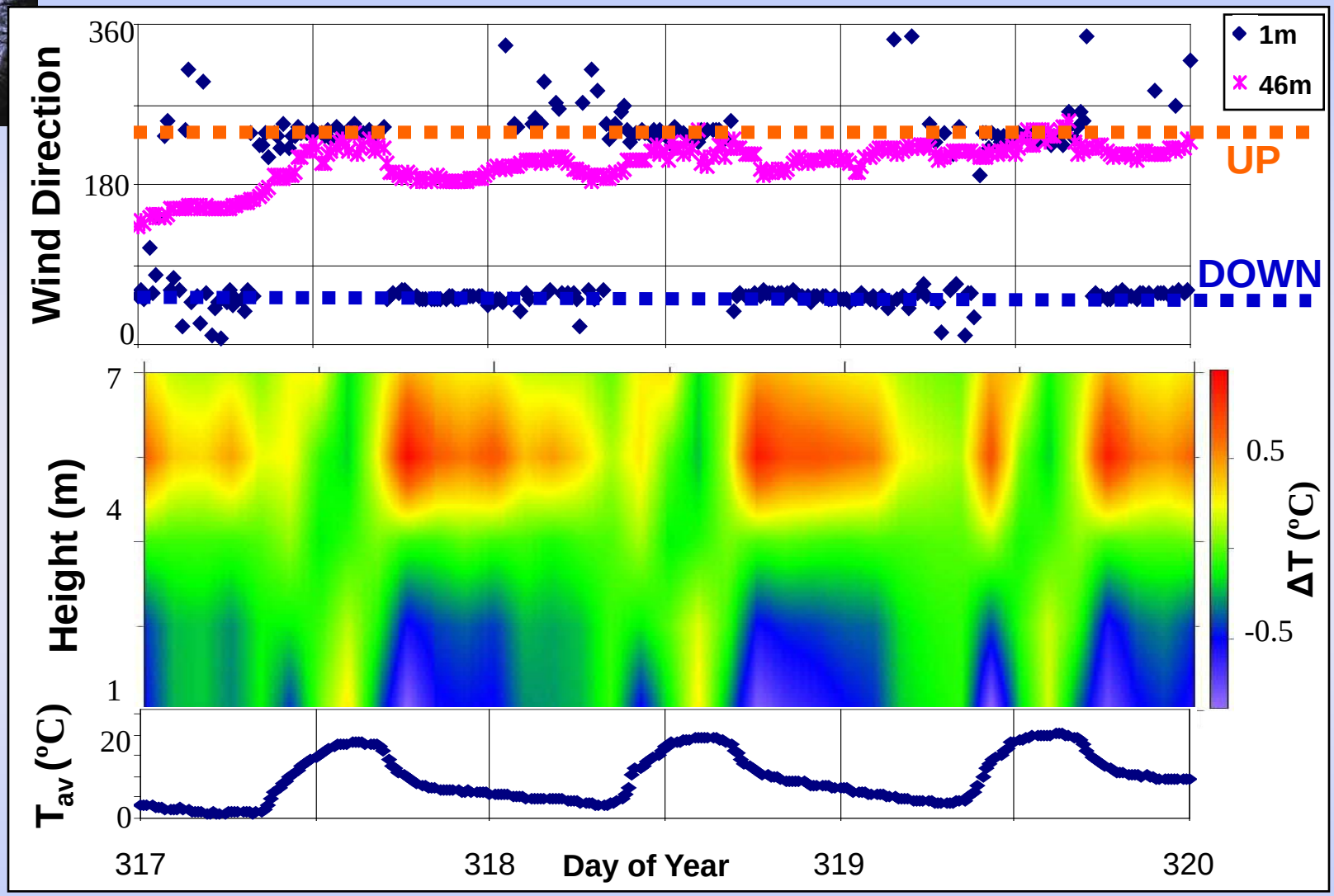
Thermotopographic Flow – Leaf-On



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

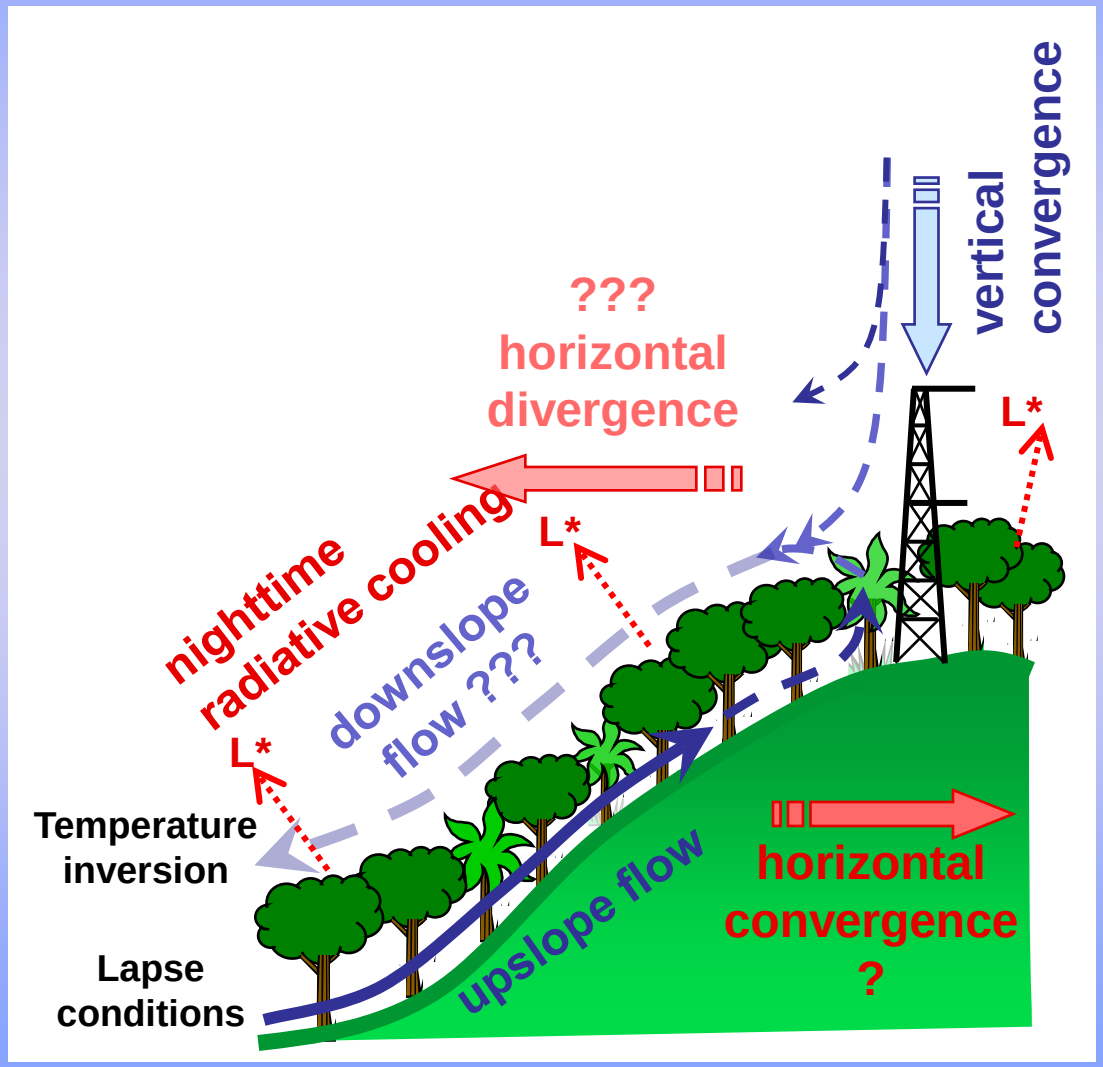


Thermotopographic Flow – Leaf-Off



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

Flow Patterns: Leaf-On Nighttime



Wishes

(for Bio-Atmo Measurements in „Difficult Conditions“):

- **3-D distribution of trace-gas „clouds“**
  - CO_2, H_2O, CH_4, VOC, stable isotopes
  - Over box 10 m – 100 m a side
  - Tomography?
- **Simultaneous „fast“ multi-species trace-gas measurements (~10 Hz)**
  - CO_2, H_2O, CH_4, VOC, stable isotopes
  - VOC‘s: low PPT precision
  - Continuous operation (days, months, years)
- **High-resolution (~10^0 m), short rang (~10^3 m) scanning Doppler-LIDAR**
  - thermal structure, velocity, trace-gas (CO_2, H_2O, ?)

Requirements

(for Bio-Atmo Measurements in „Difficult Conditions“):

- Fast measurements (~10 Hz, 0.1 s „grab samples“)
- **Sensor** path, or gas intake **small**
- **Analyzer separated** from intake or open-path
- **Weather proof** (wind, precipitation, Δ-temperature, radiation)
- **„Portable“**
- **Low power** consumption (battery/solar power)

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MMSF

UMBS

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