Terrestrial Science Challenges for Dense Wireless Sensor Networks”

Timothy Hill

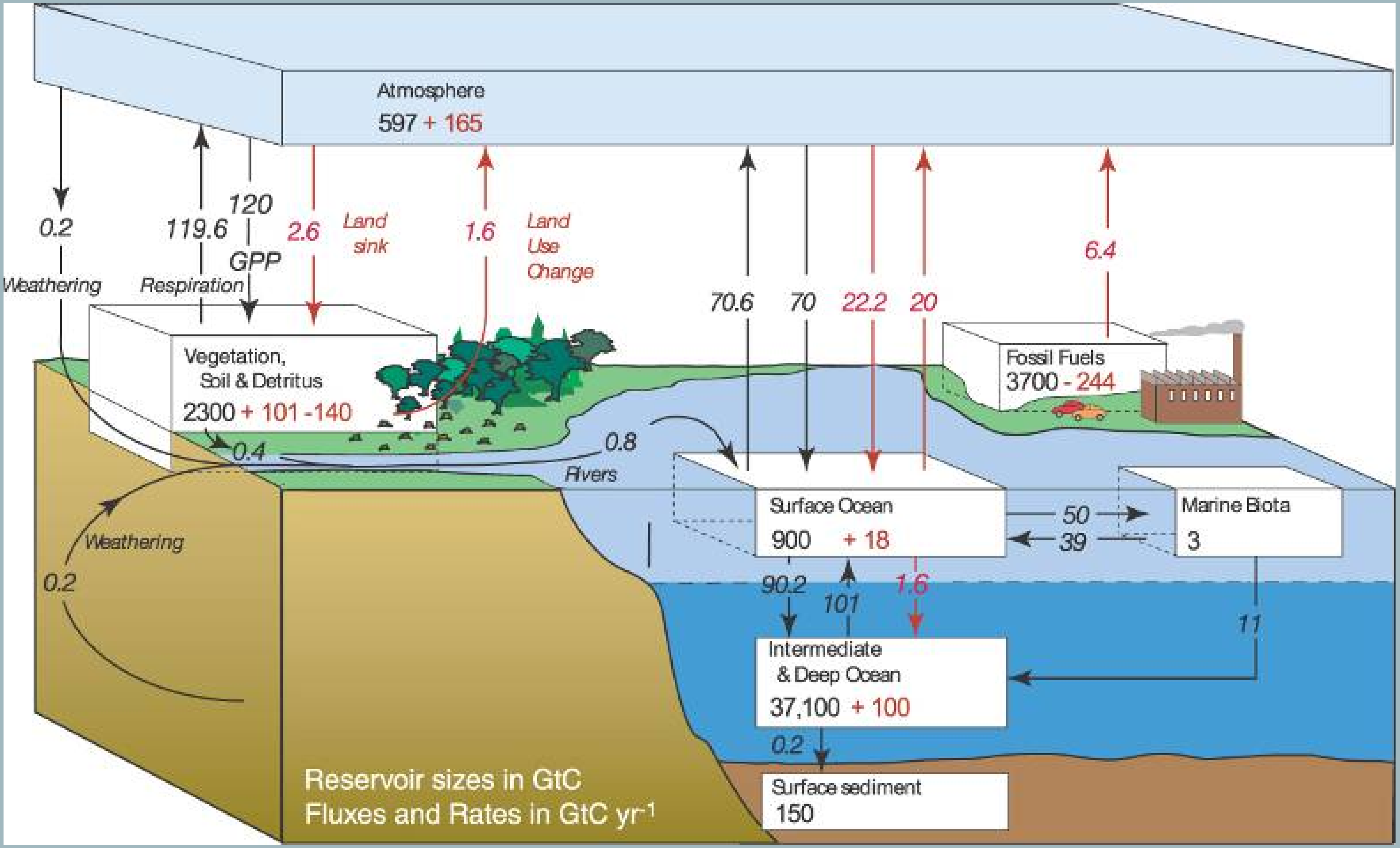
Contents

- My background
- General motivation
- Measurements approaches
- Limitations

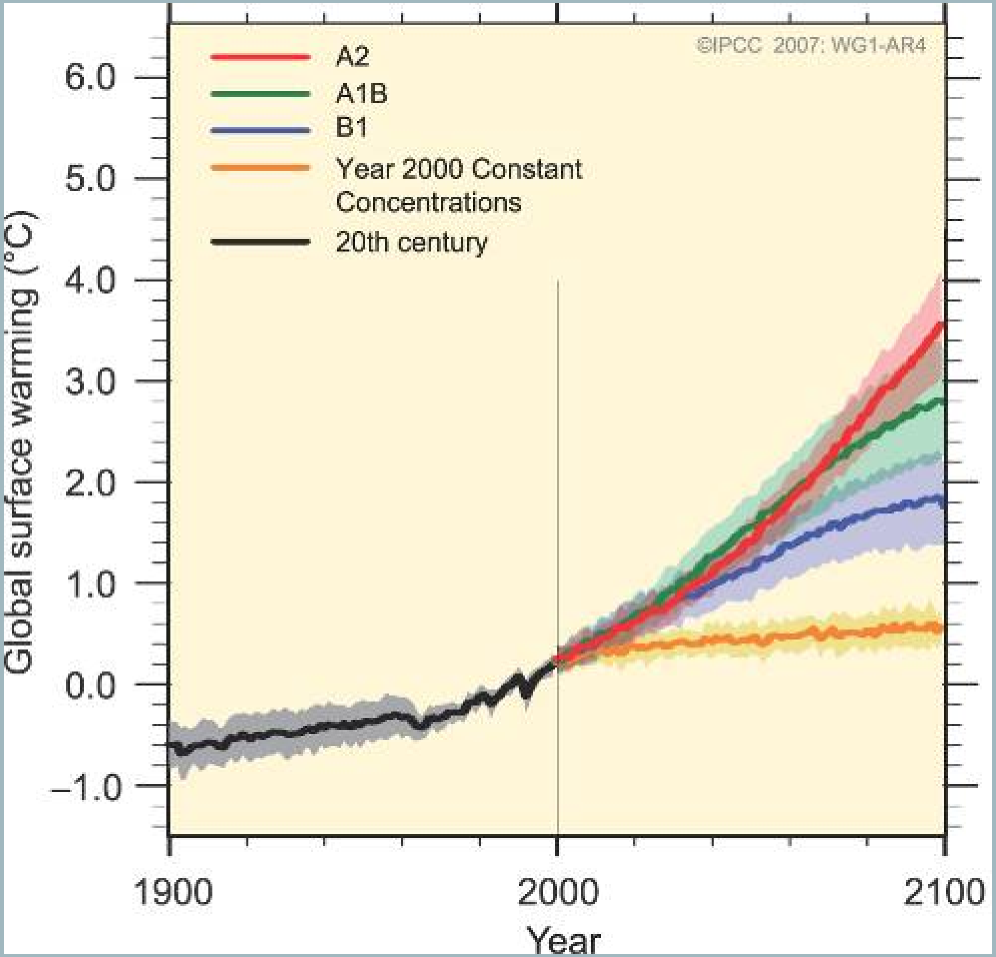
My background

- Modelling of land-surface exchanges of Water, Carbon and Energy.
- Measuring of land-surface exchanges from small aircraft.
- Utilising land-surface exchanges to assess and improve ecosystem models.

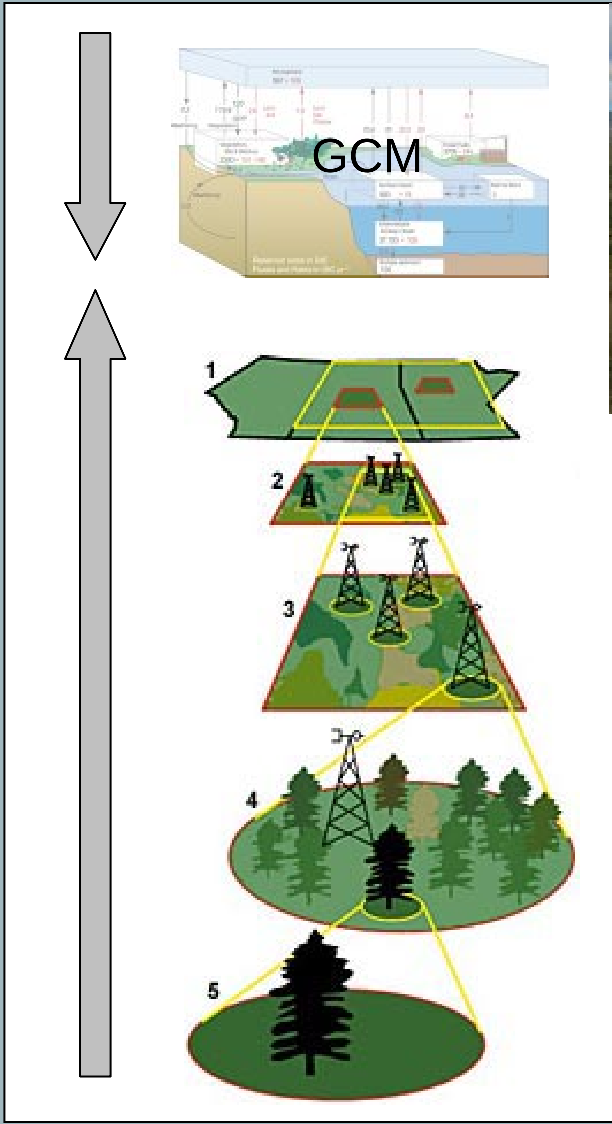
The Carbon Cycle

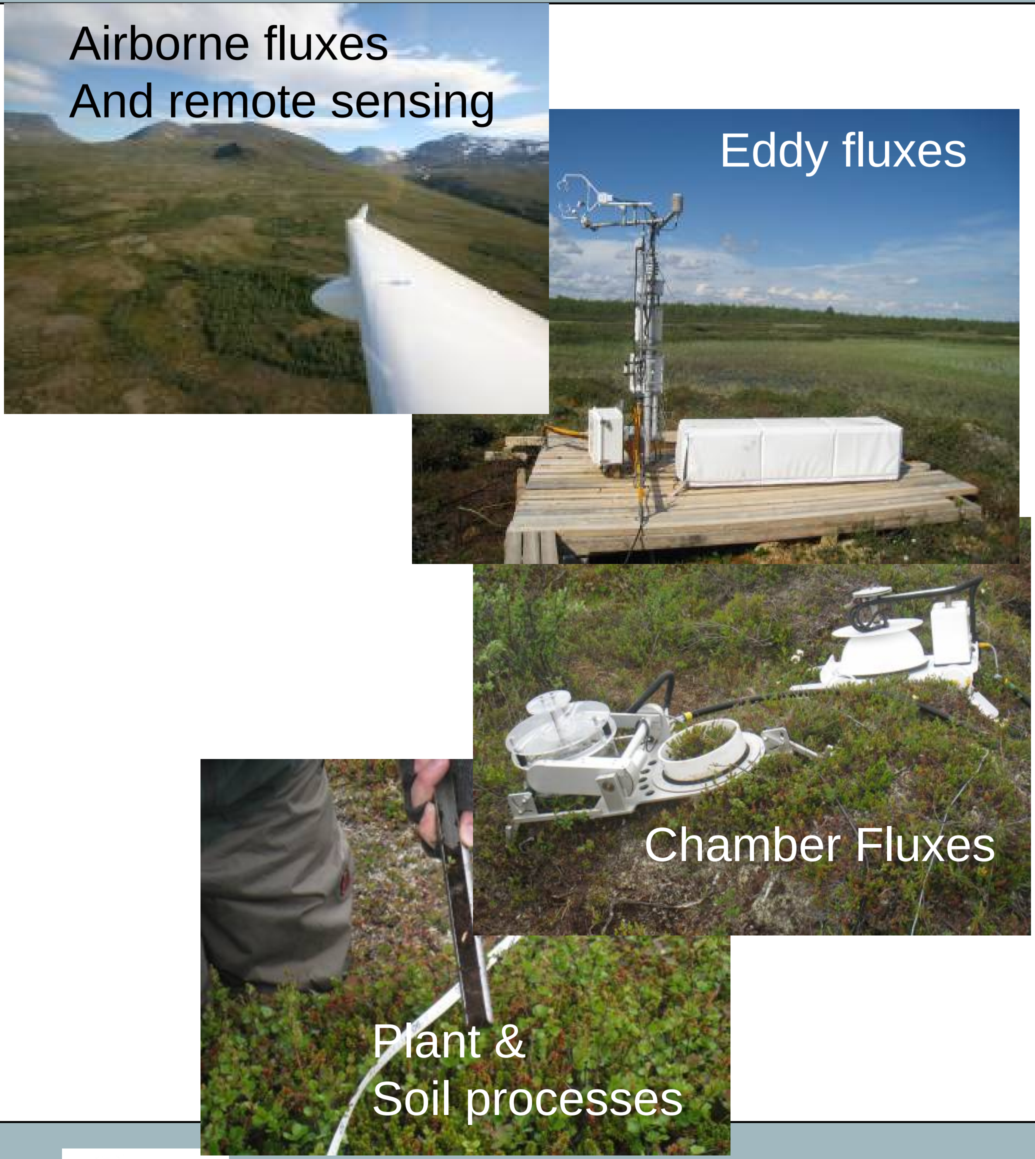


Global Circulation Models



Validating GCMs





Airborne fluxes
And remote sensing

Eddy fluxes

Chamber Fluxes

Plant &
Soil processes

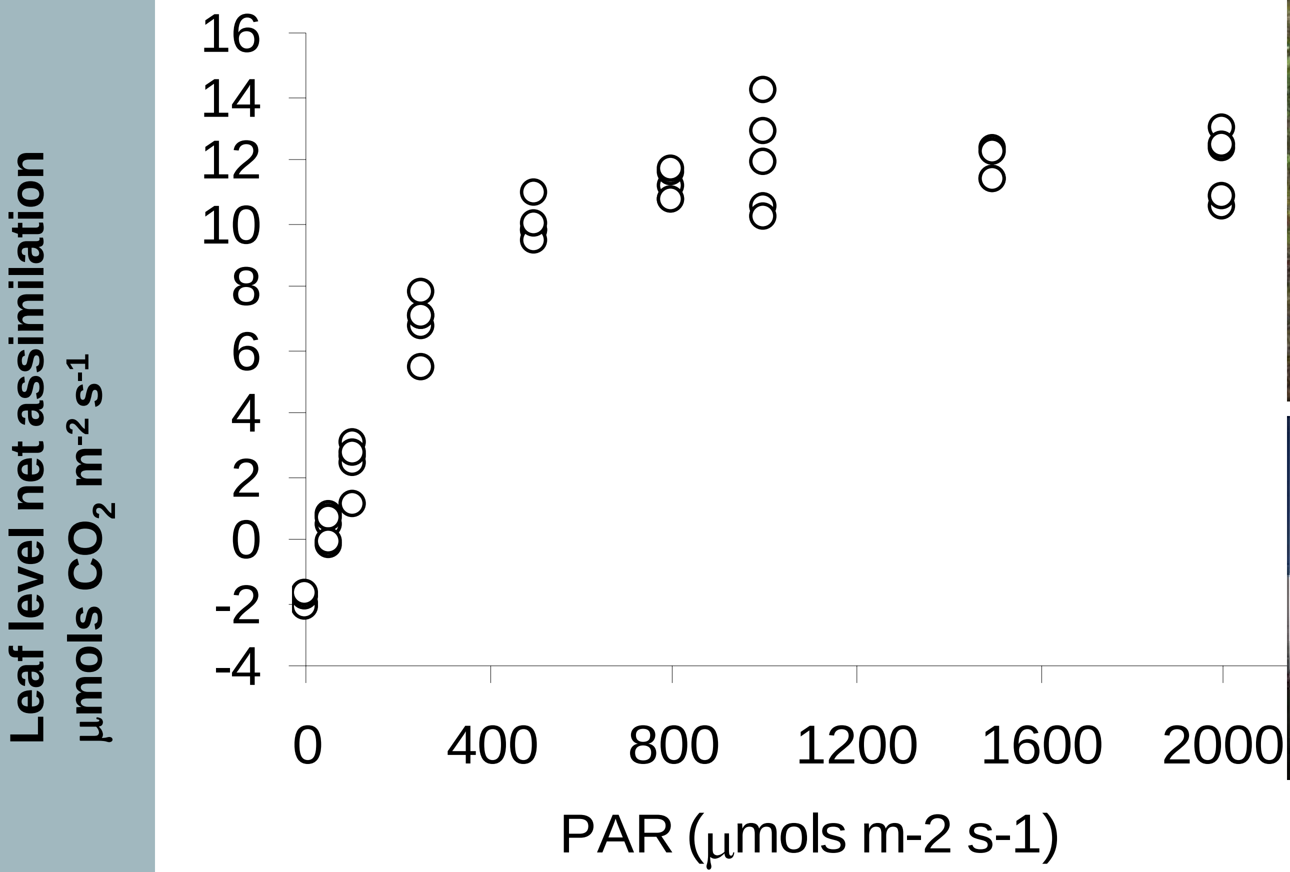
Components of Carbon Exchange

NEE = ER- GPP

- Net Ecosystem Exchange of Carbon (NEE)
- Gross Primary Production of Carbon (GPP)
- Ecosystem Respiration (ER)
  - Autotrophic (Ra), *linked to GPP*
  - Heterotrophic (Rh), *linked to Temperature*

Measurement Approaches: Chambers

Footprint: 0.1 m x 0.1 m ➔ 1 m x 1 m

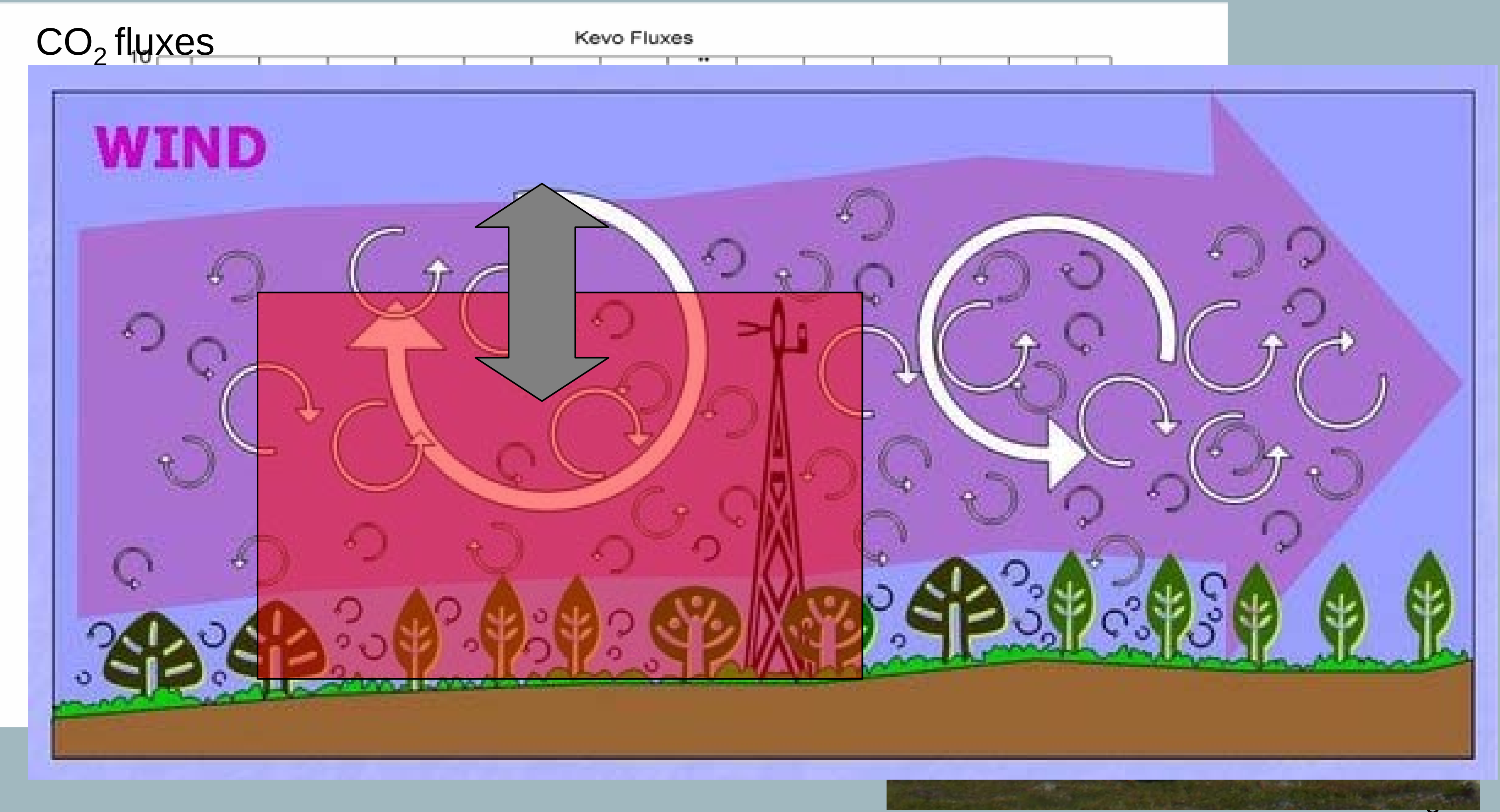


Rafael Poyatos, Jemma Gornall, Brian Huntley, Robert Baxter, Andreas Heinemeyer, Phil Ineson, Maurizio Mencuccini

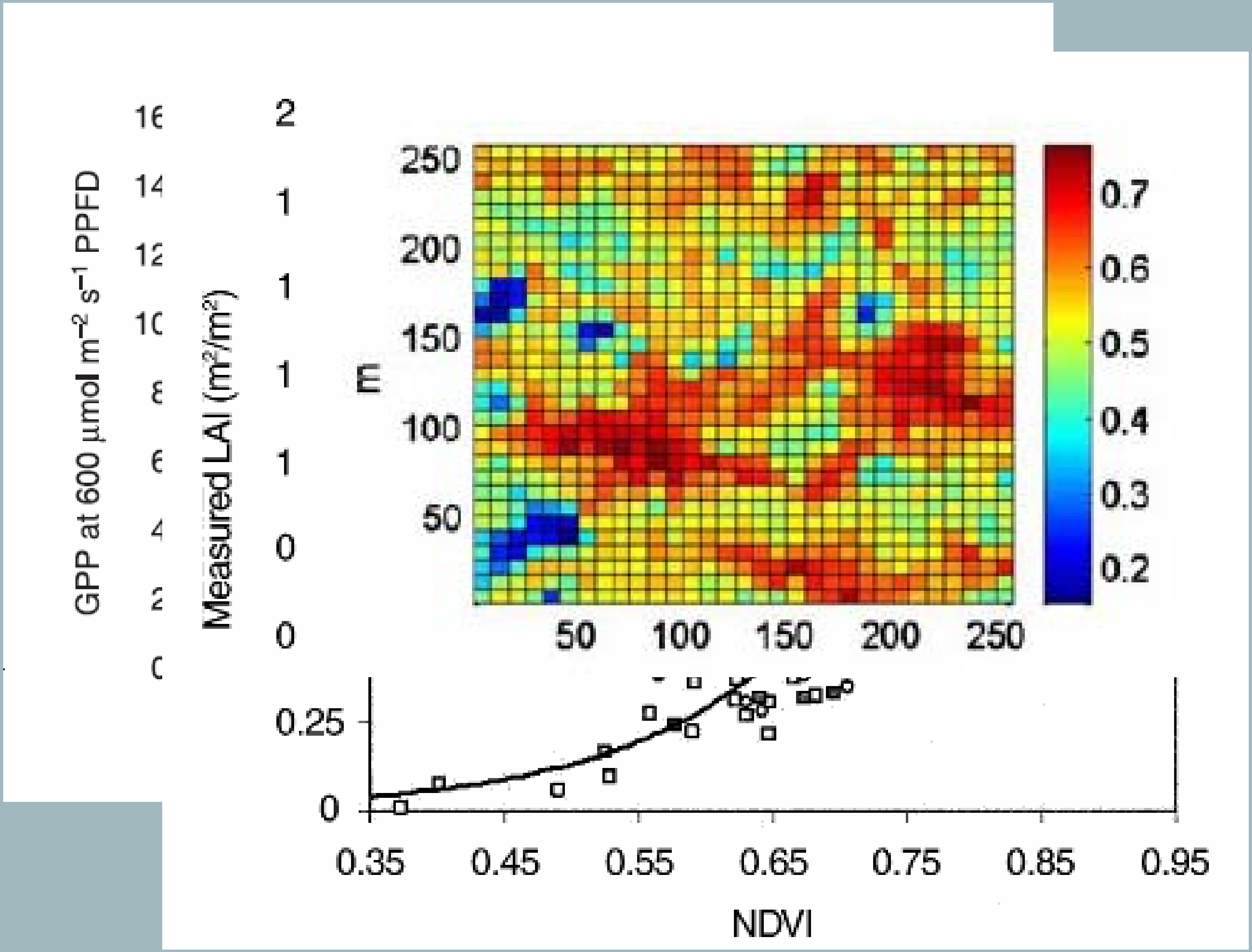
Measurement Approaches: Eddy Covariance

Tower Footprint: 100 m x 100 m ➔ 1 km x 1 km
Aircraft Footprint: 2 km x 2 km ➔ 100 km x 2 km

CO_2 fluxes



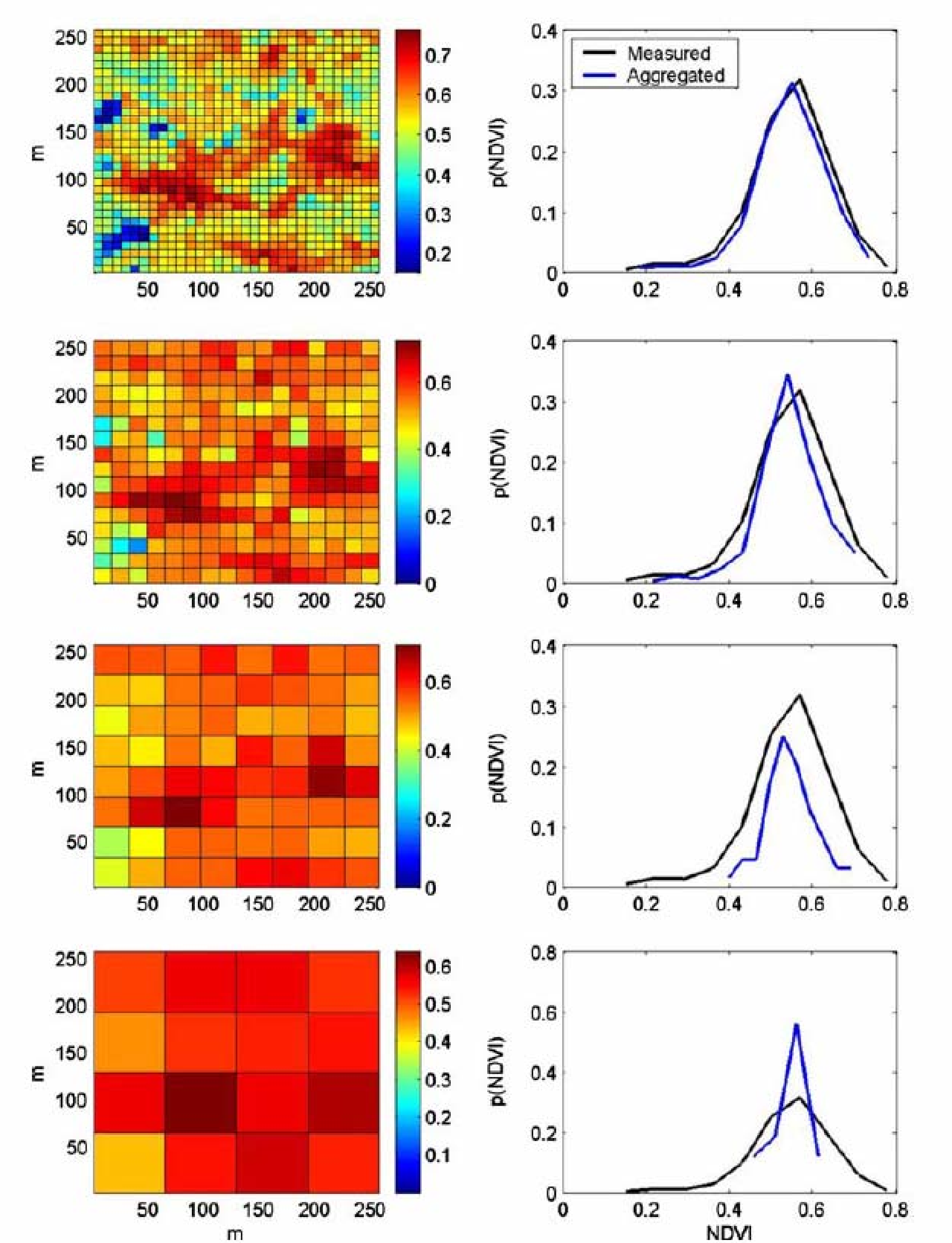
Extending the measurements



Van Wijk & Williams 2005

The problem of non-linearity

Stoy et al. 2009

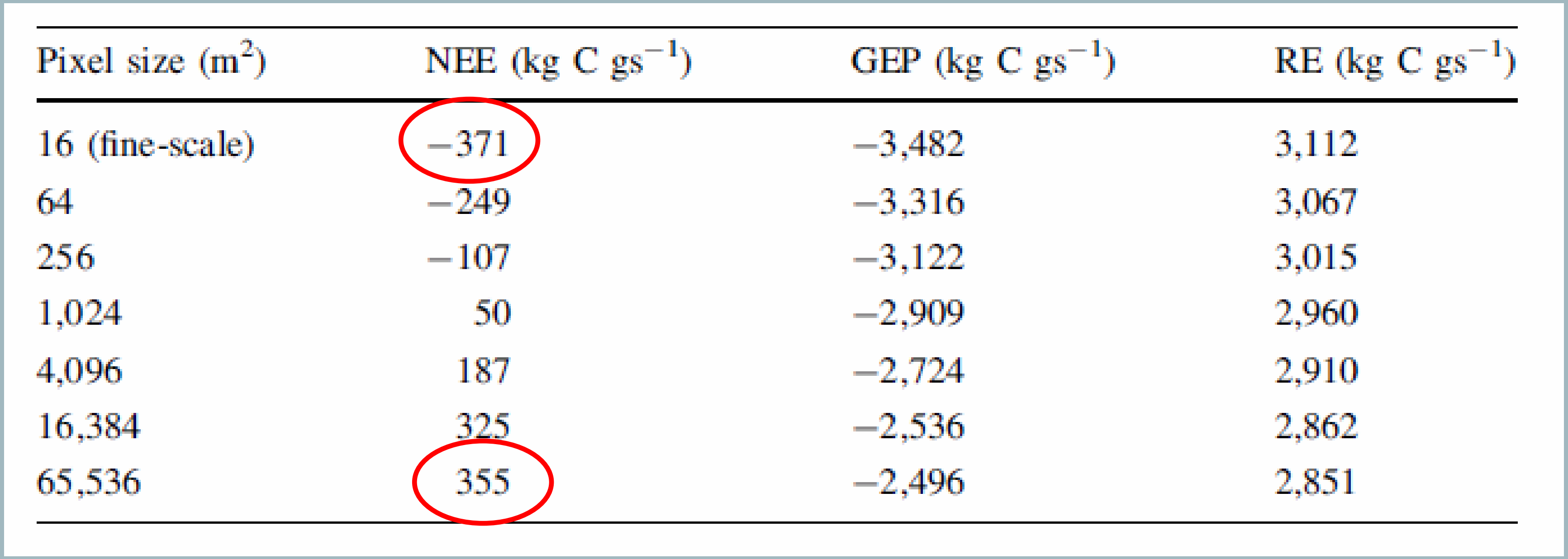


Spatial aggregation
of ATM-measured NDVI in
a tundra landscape near
Abisko, Sweden at
increasing pixel length scale

Coarser scale data produce
altered NDVI distributions

Stoy et al. 2009

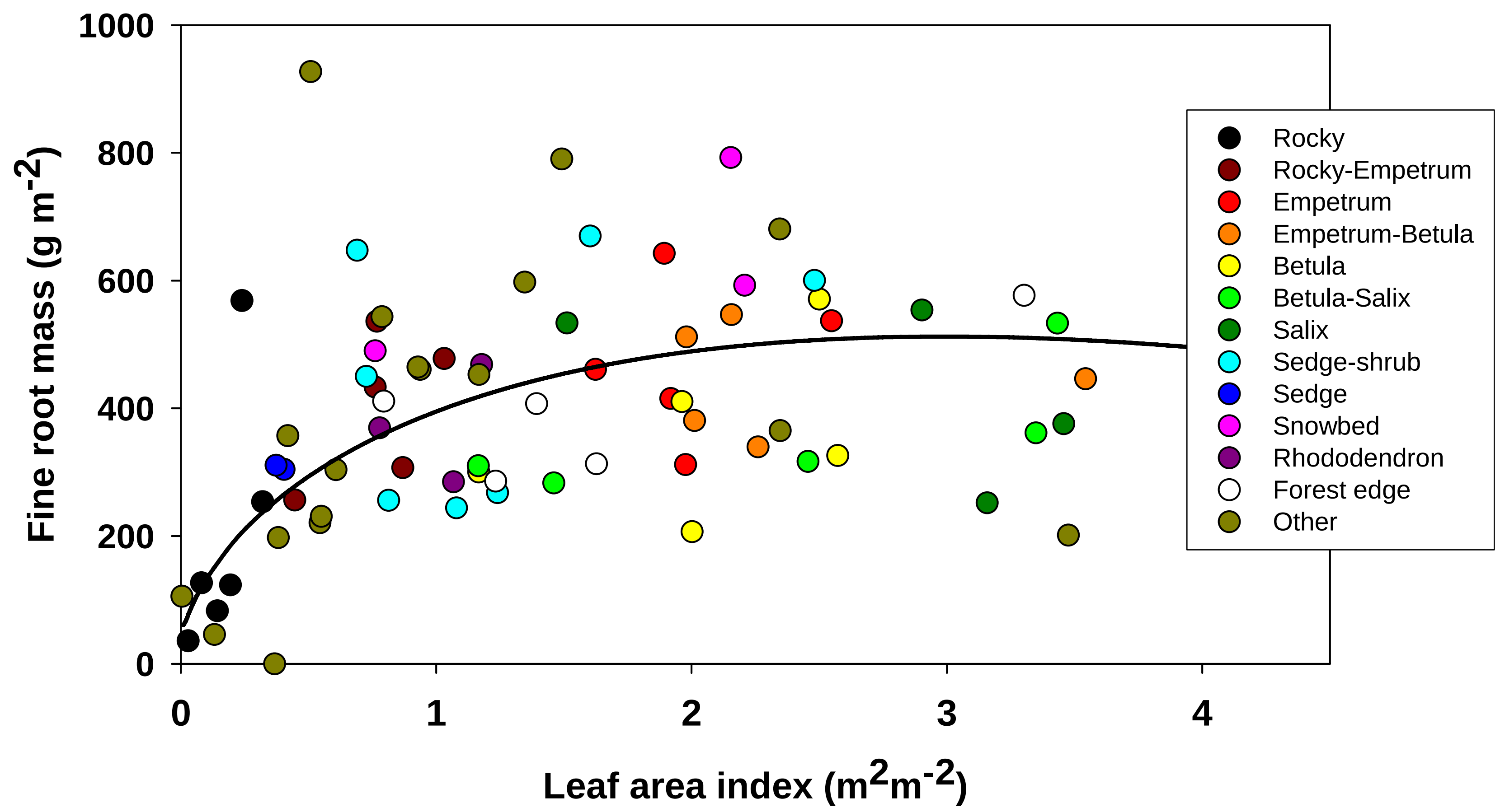
The problem of non-linearity



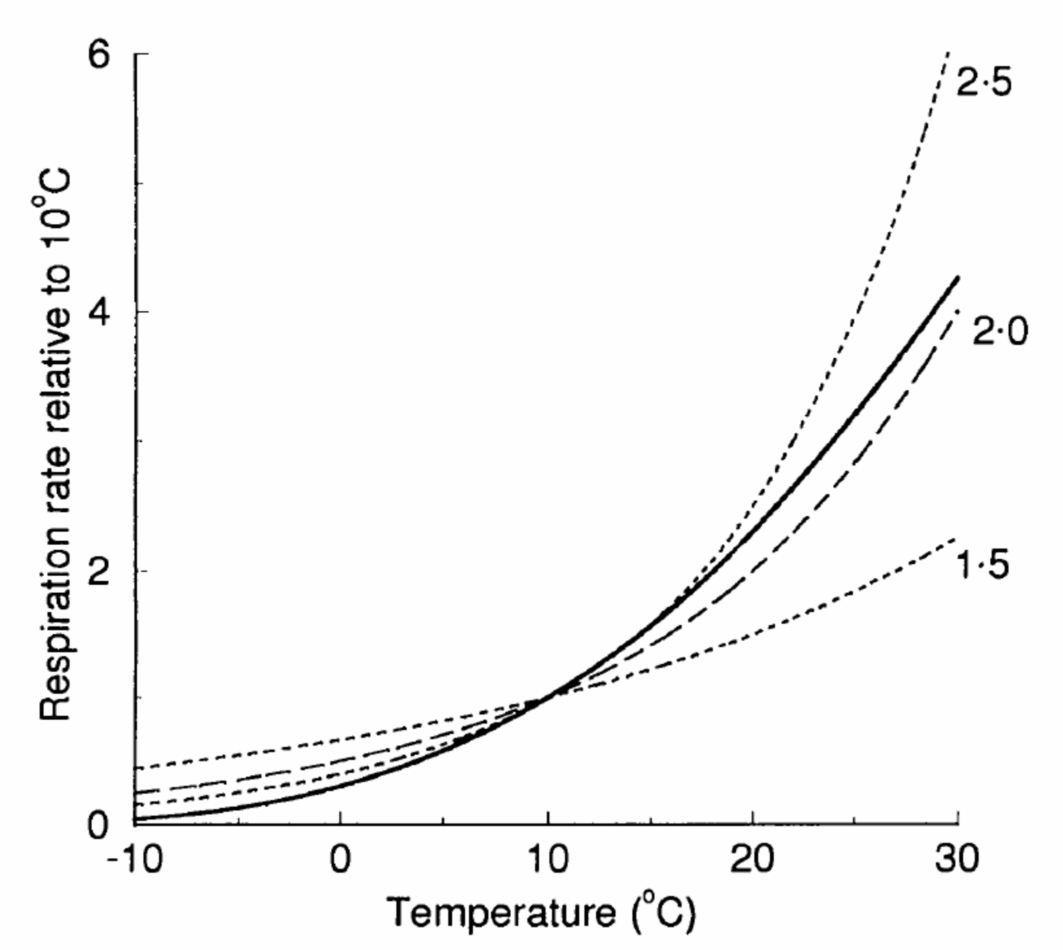
Pixel size (m^2)	NEE ($kg\ C\ gs^{-1}$)	GEP ($kg\ C\ gs^{-1}$)	RE ($kg\ C\ gs^{-1}$)
16 (fine-scale)	−371	−3,482	3,112
64	−249	−3,316	3,067
256	−107	−3,122	3,015
1,024	50	−2,909	2,960
4,096	187	−2,724	2,910
16,384	325	−2,536	2,862
65,536	355	−2,496	2,851

Stoy et al. 2009

Additional issues with non-linearity

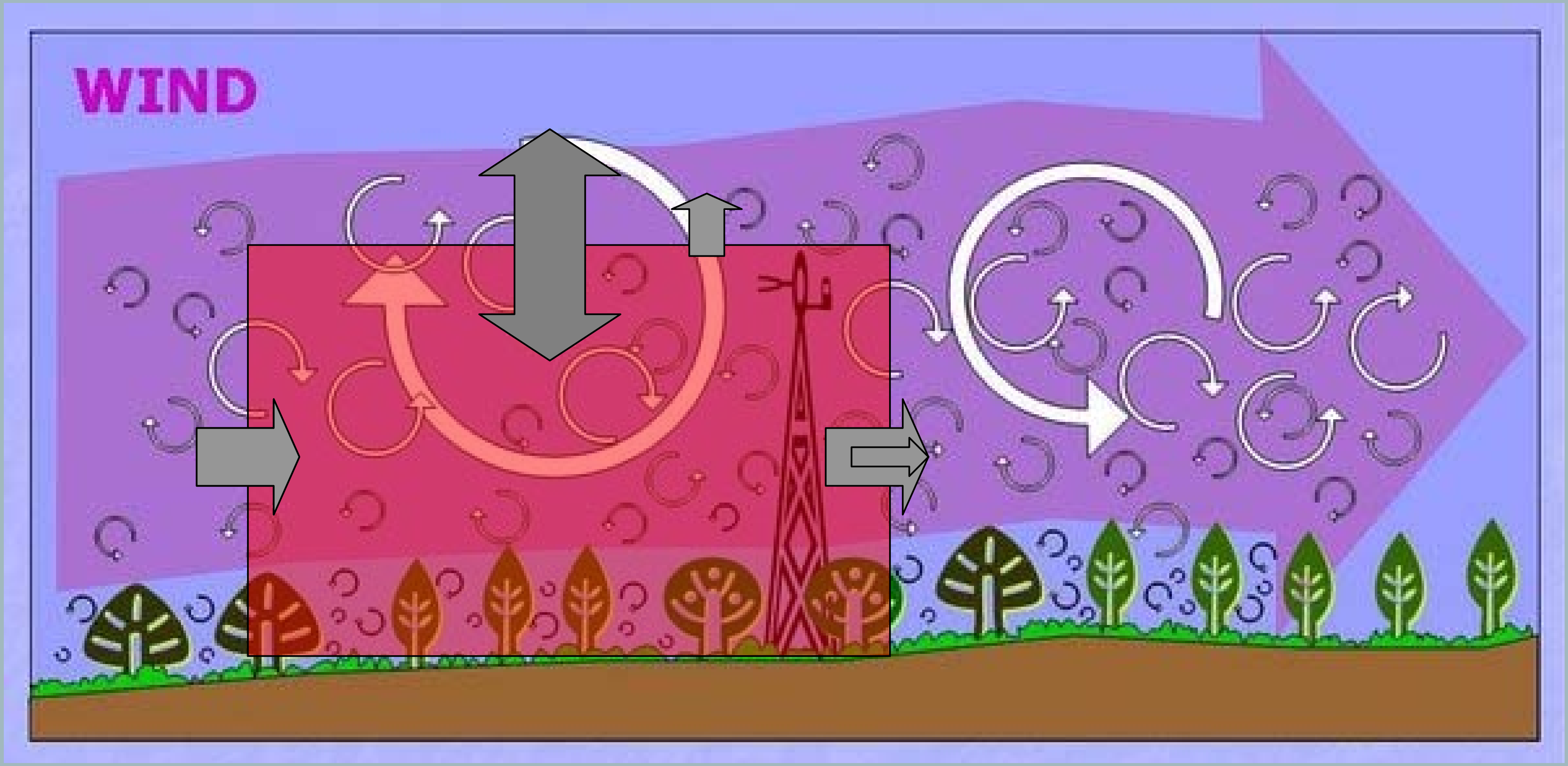


Additional issues with non-linearity

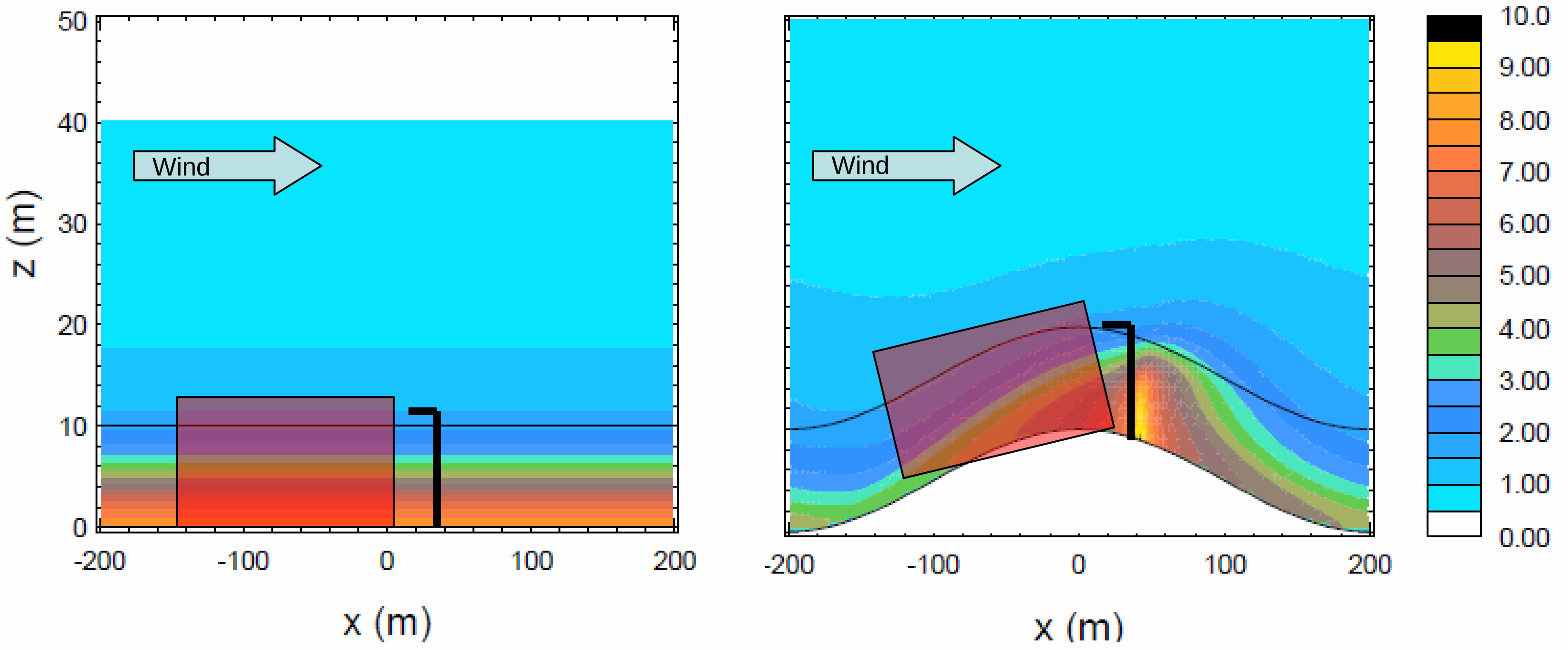


J. Lloyd and J. A. Taylor Source: 1994

Measurement deficiencies



Measurement deficiencies



How Can Dense Networks Help?

Spatially explicit time-series of:

1) Meteorological `drivers’

- Air temp.
- Radiation
- Wind speed
- Precipitation
- Humidity

2) Vegetation `states’

- Soil moisture
- Canopy composition
- Sap flow
- Tree diameter
- Leaf temperatures

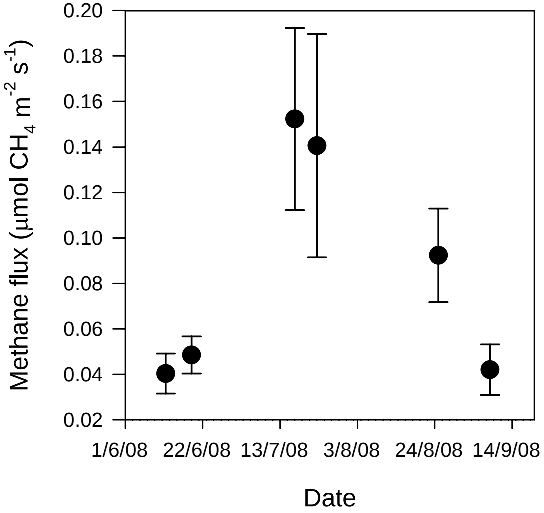
3) (For Eddy Covariance) Trace gas concentrations

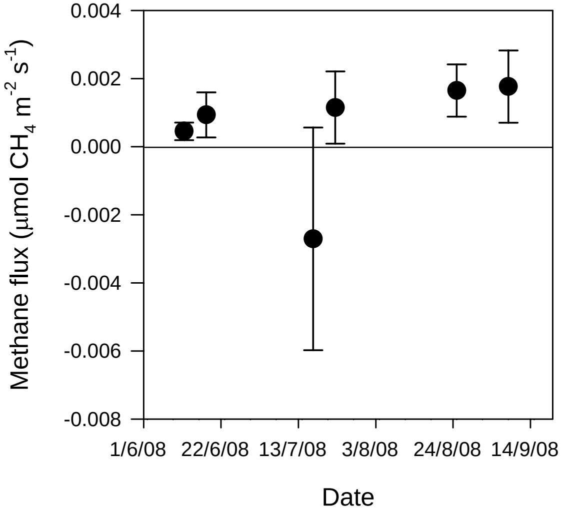
- Carbon dioxide, methane, water vapour, nitrous oxide

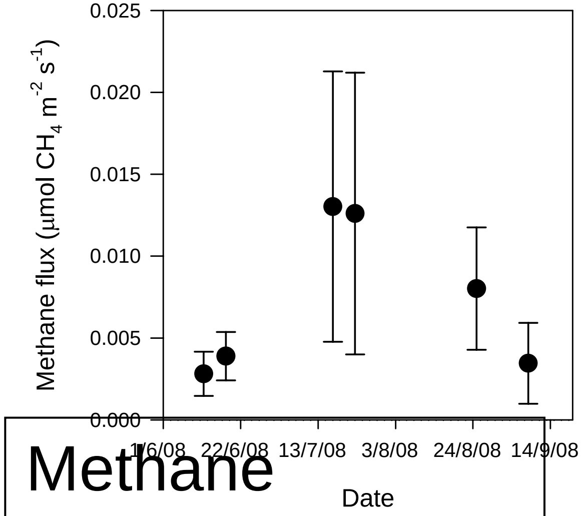
4) Others

- Flame temp.
- Snow depth

Case 2: Methane

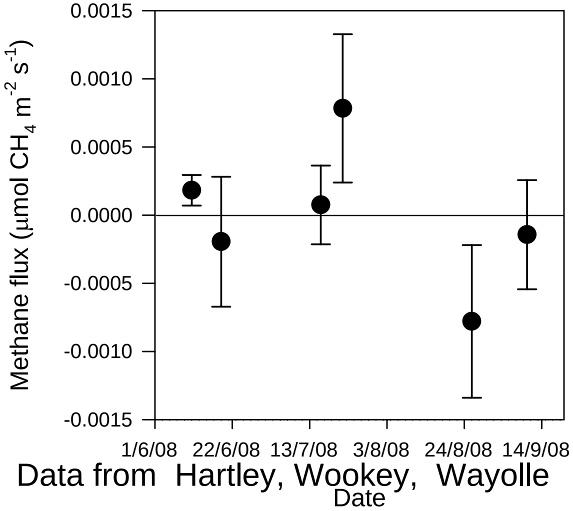

LAWNS

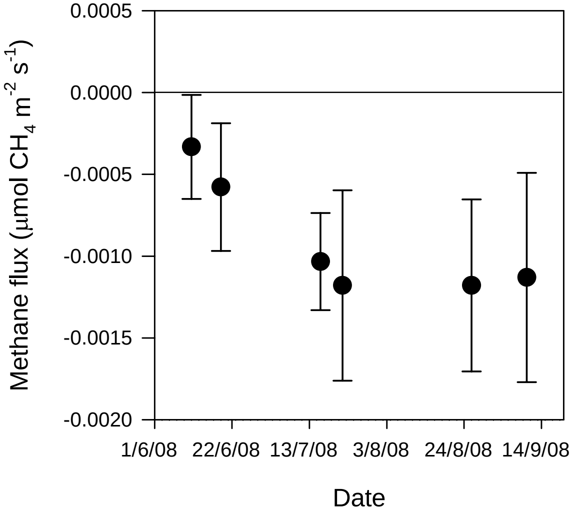

HUMMOCKS


INTERHUMMOCKS

Methane exchange measurements from chambers

Kevo 2008

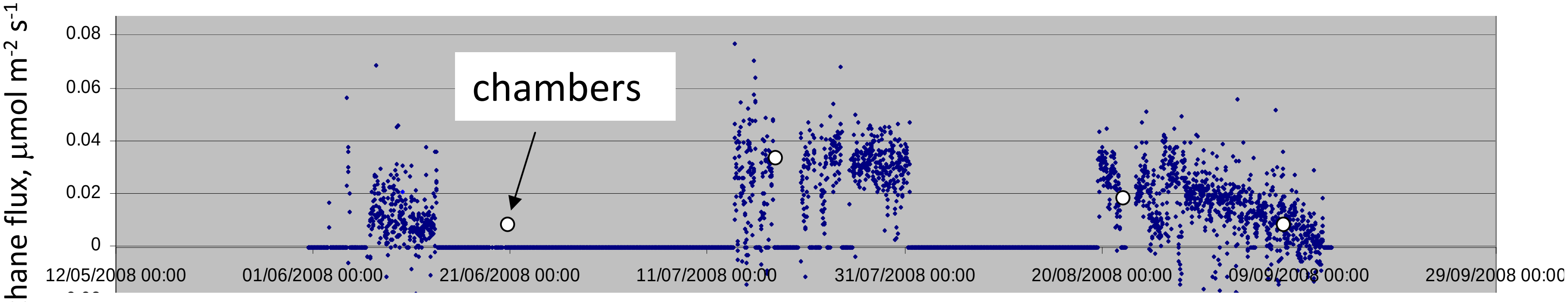

MIRE EDGE


BIRCH FOREST

Data from Hartley, Wookey, Wayolle

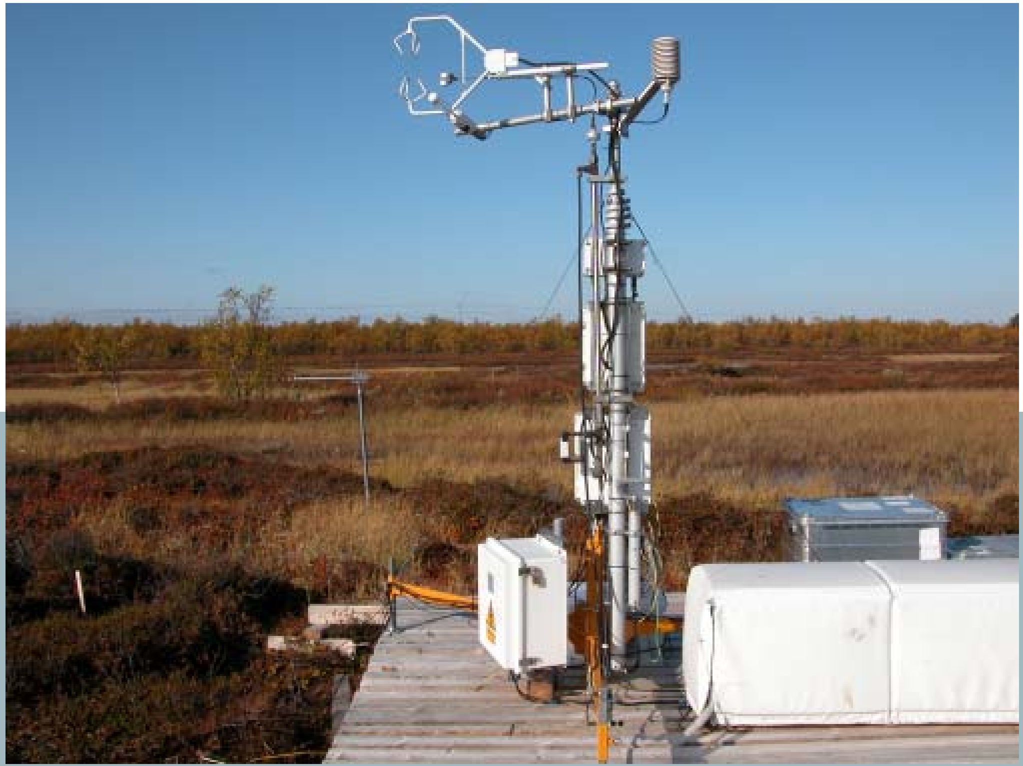
Case 2: Methane

Comparing tower and chamber CH_4 fluxes



Methane exchange measurements from micrometeorology

Kevo 2008
3 campaigns

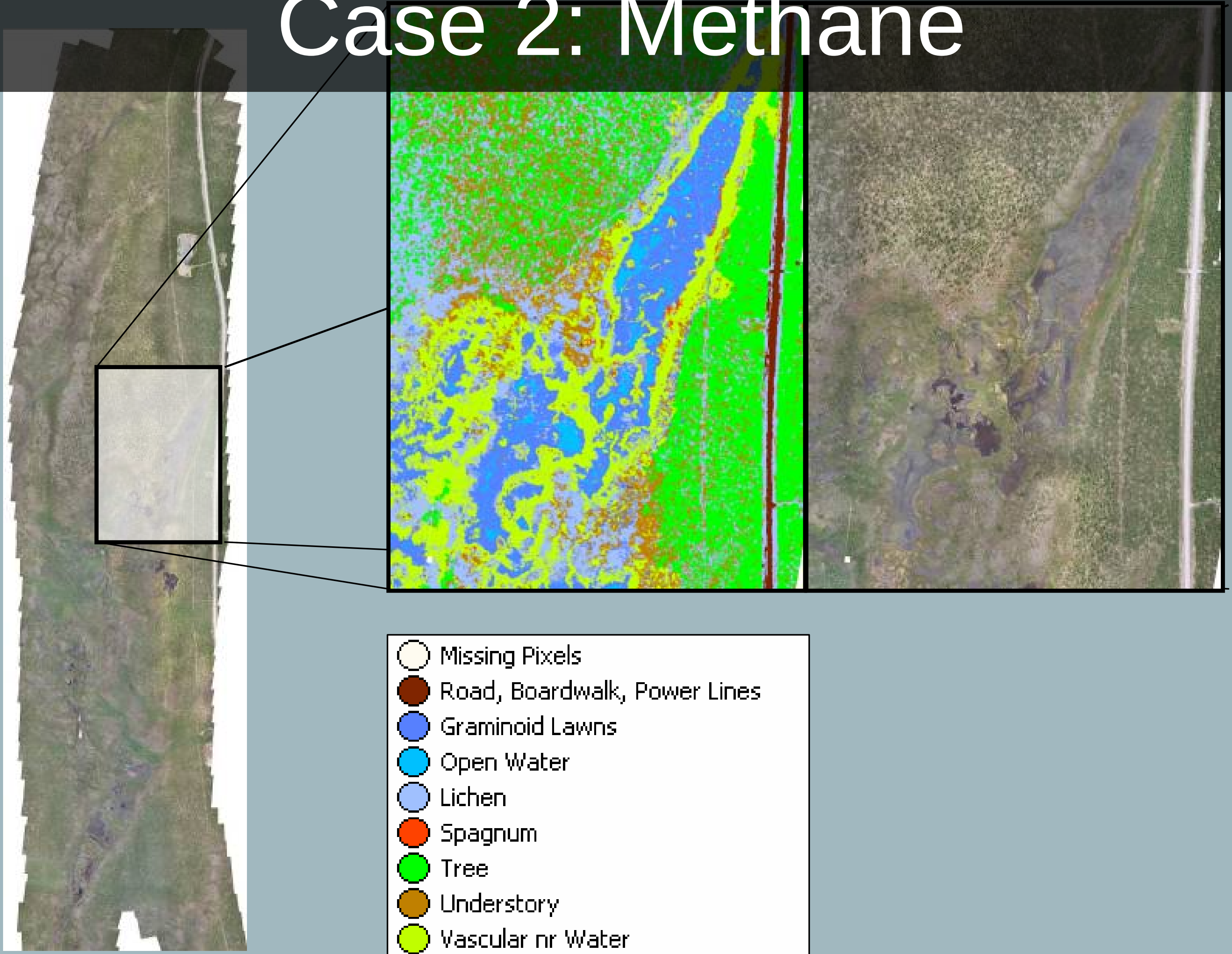


Kevo, Finland

Data from Baxter, Huntley, Hartley

ABACUS

Case 2: Methane



⚪ Missing Pixels
🟤 Road, Boardwalk, Power Lines
🔵 Graminoid Lawns
🔵 Open Water
🔵 Lichen
🔴 Spagnum
🟢 Tree
🟠 Understory
🟡 Vascular nr Water

Case 2: Methane

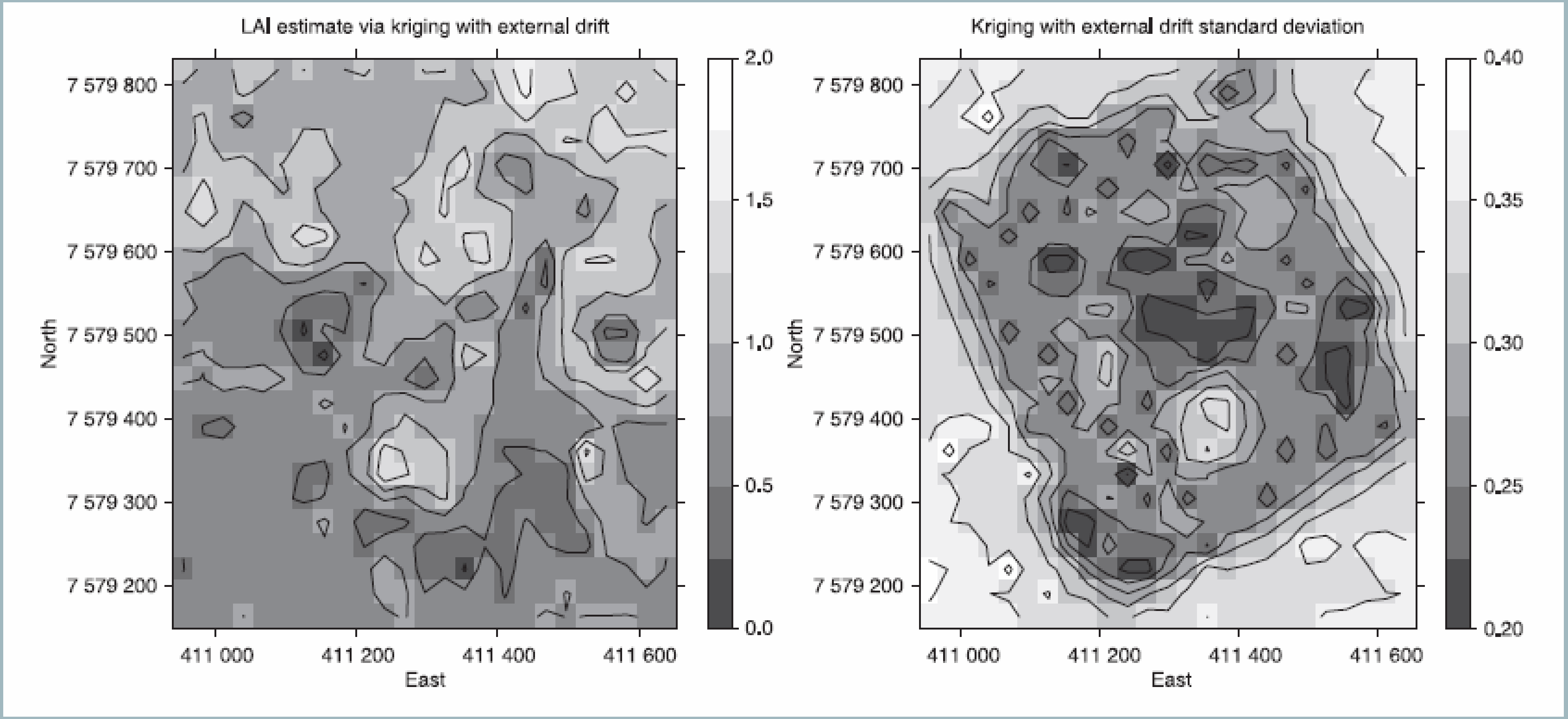
Additional Issues:

- Water Table
- Soil Temperature

Dense Sensor Network Requirements:

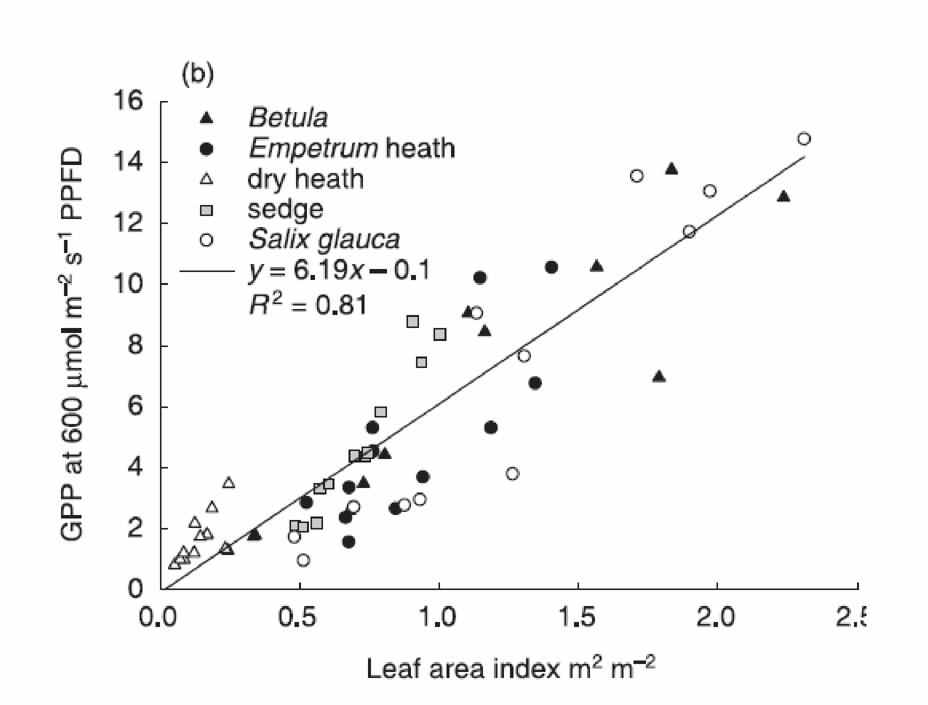
- Soil Temperature
- Water Table
- Pressure

Case 1a: Carbon Uptake

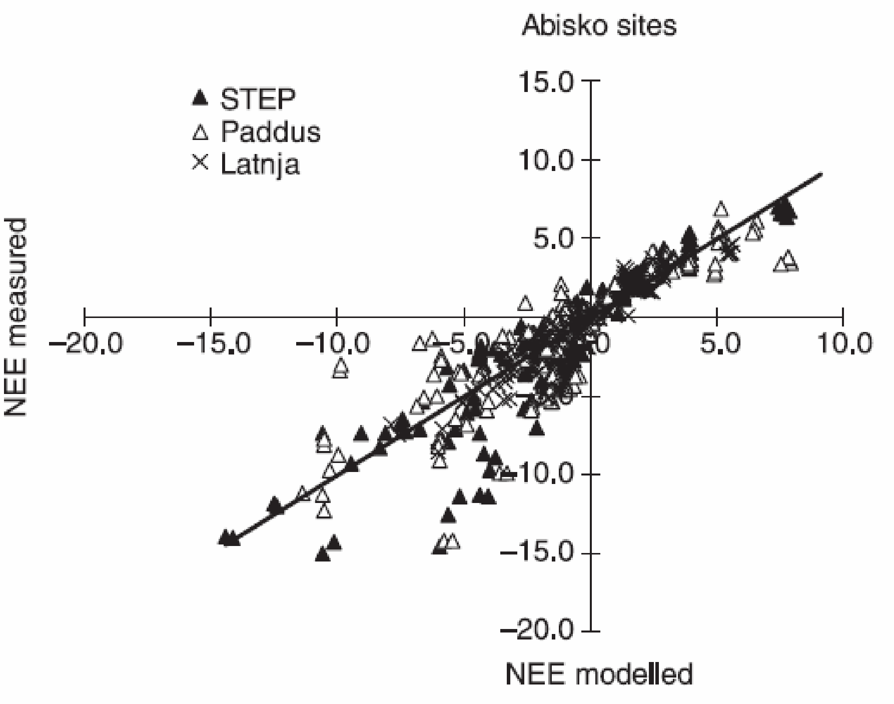


Williams et al (2008)

LAI and C Fluxes



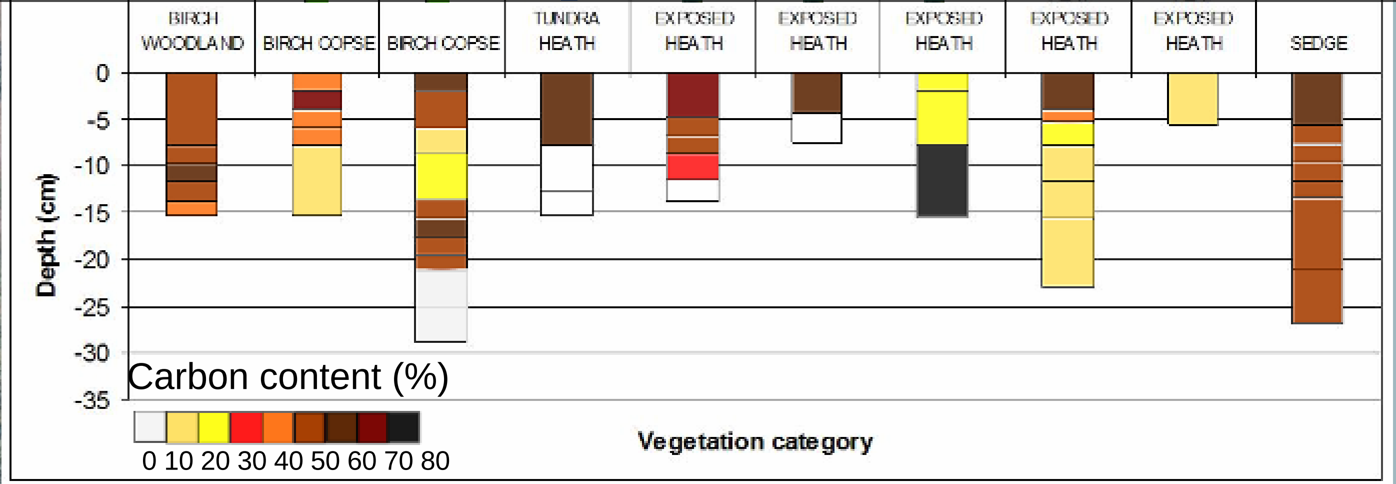
Street et al, 2007

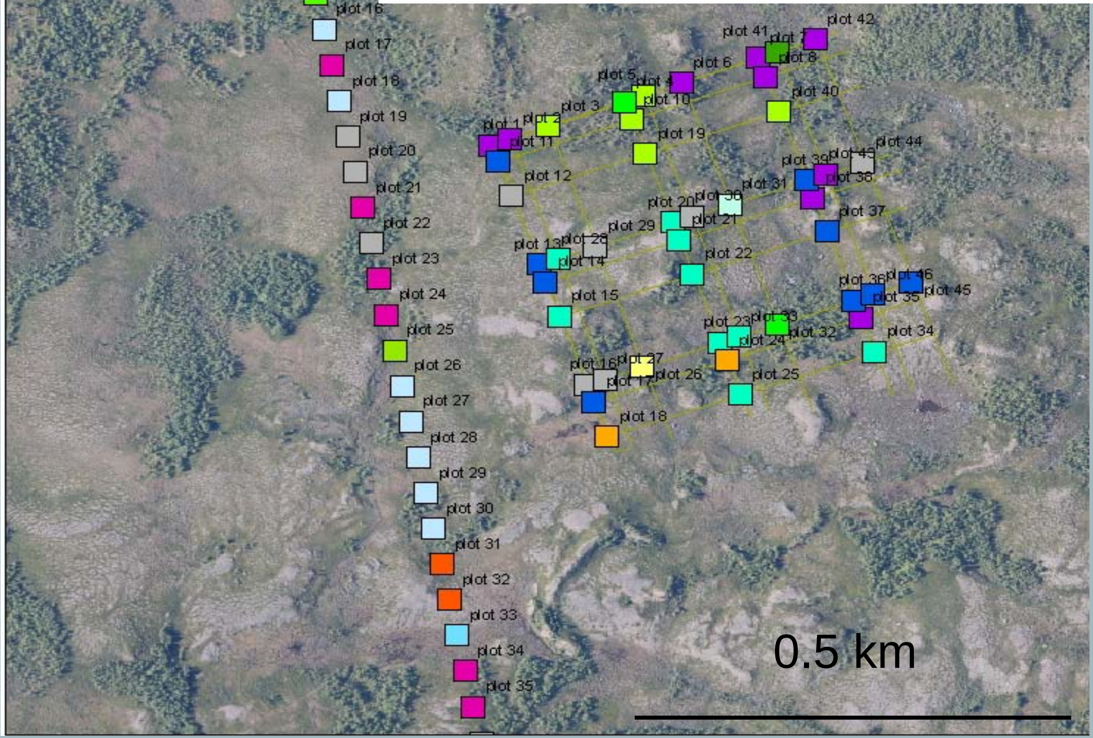


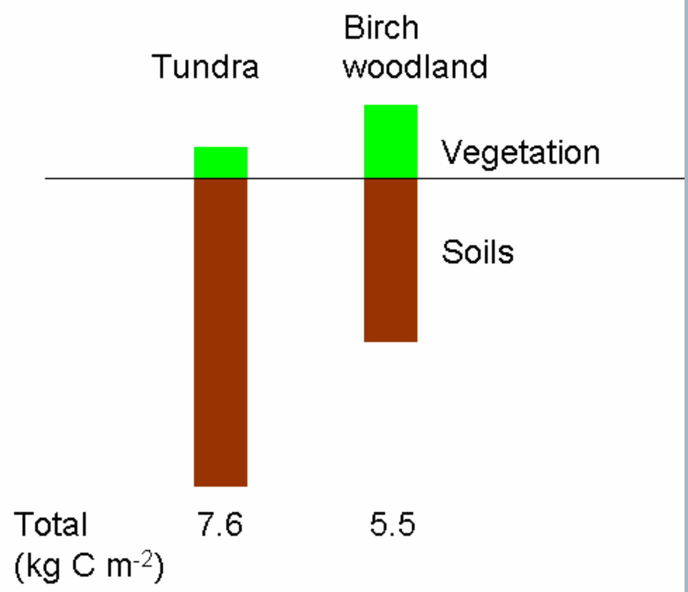
Shaver et al, 2008

NEE = *f*(LAI, temp, PPFD)

Case 1b: Respiration

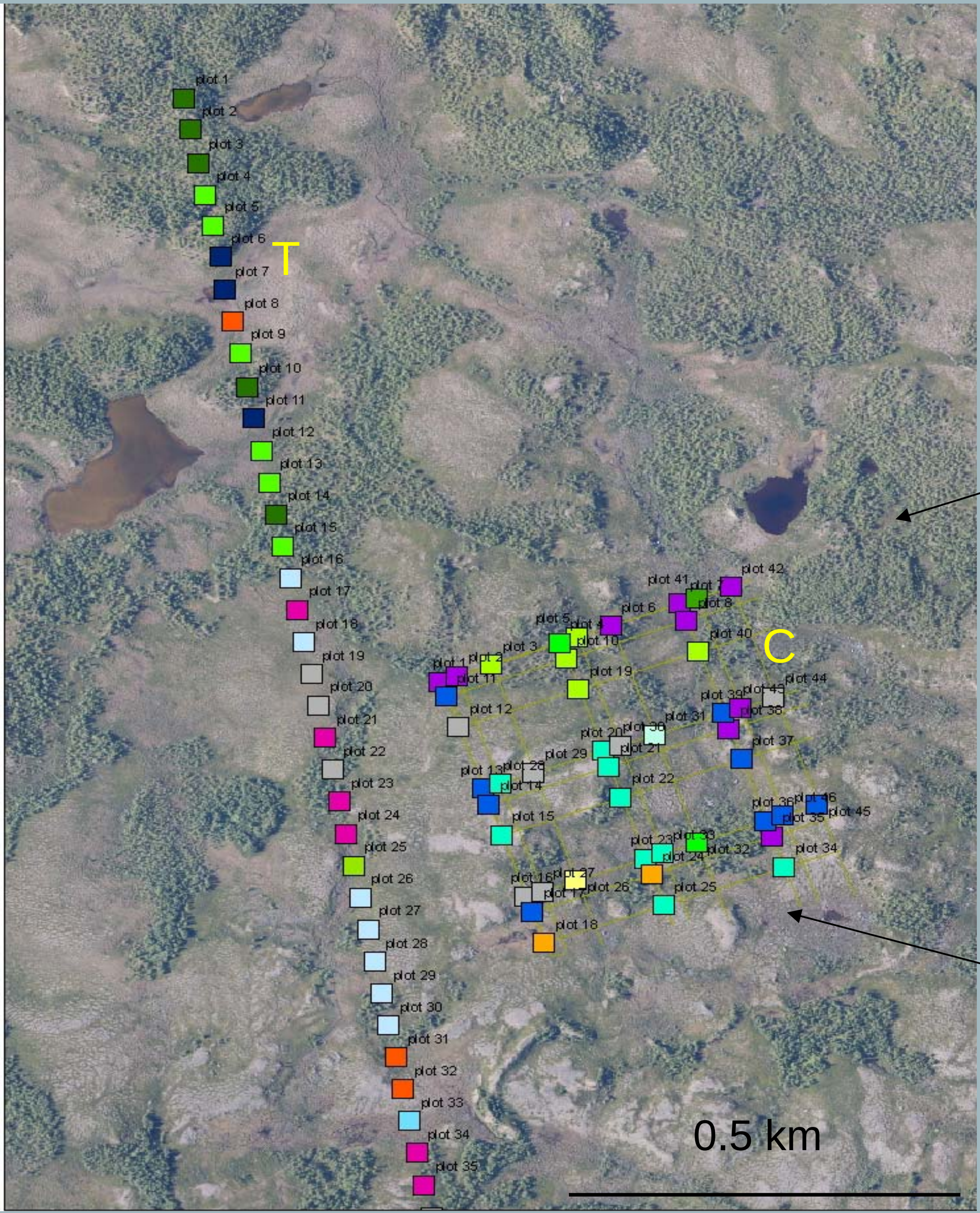






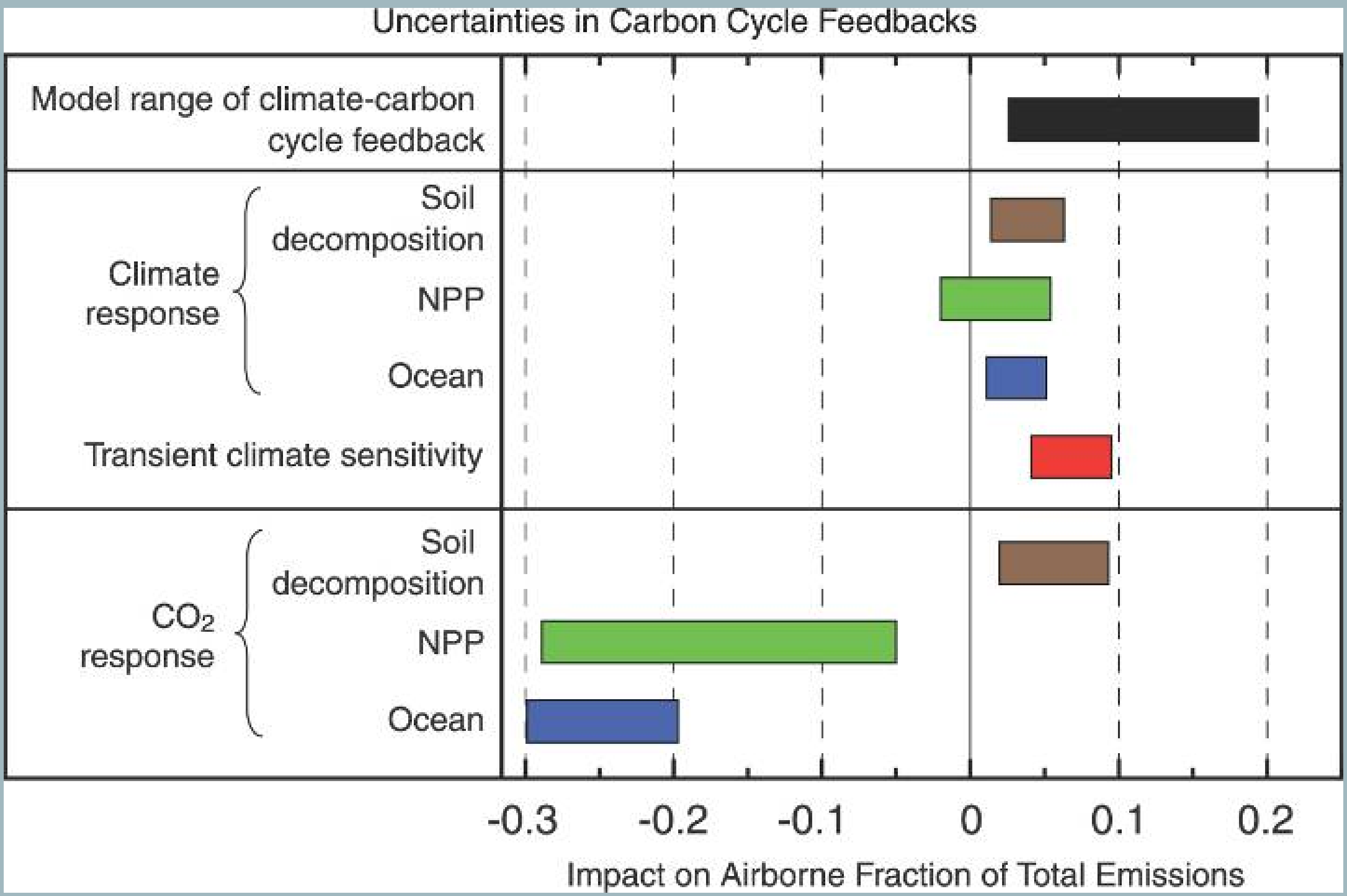
Data from Wayolle, Wookey, Williams

Quantifying the heterogeneity of a sub-Arctic landscape using altitudinal transects (T) and cyclic sampling (C)

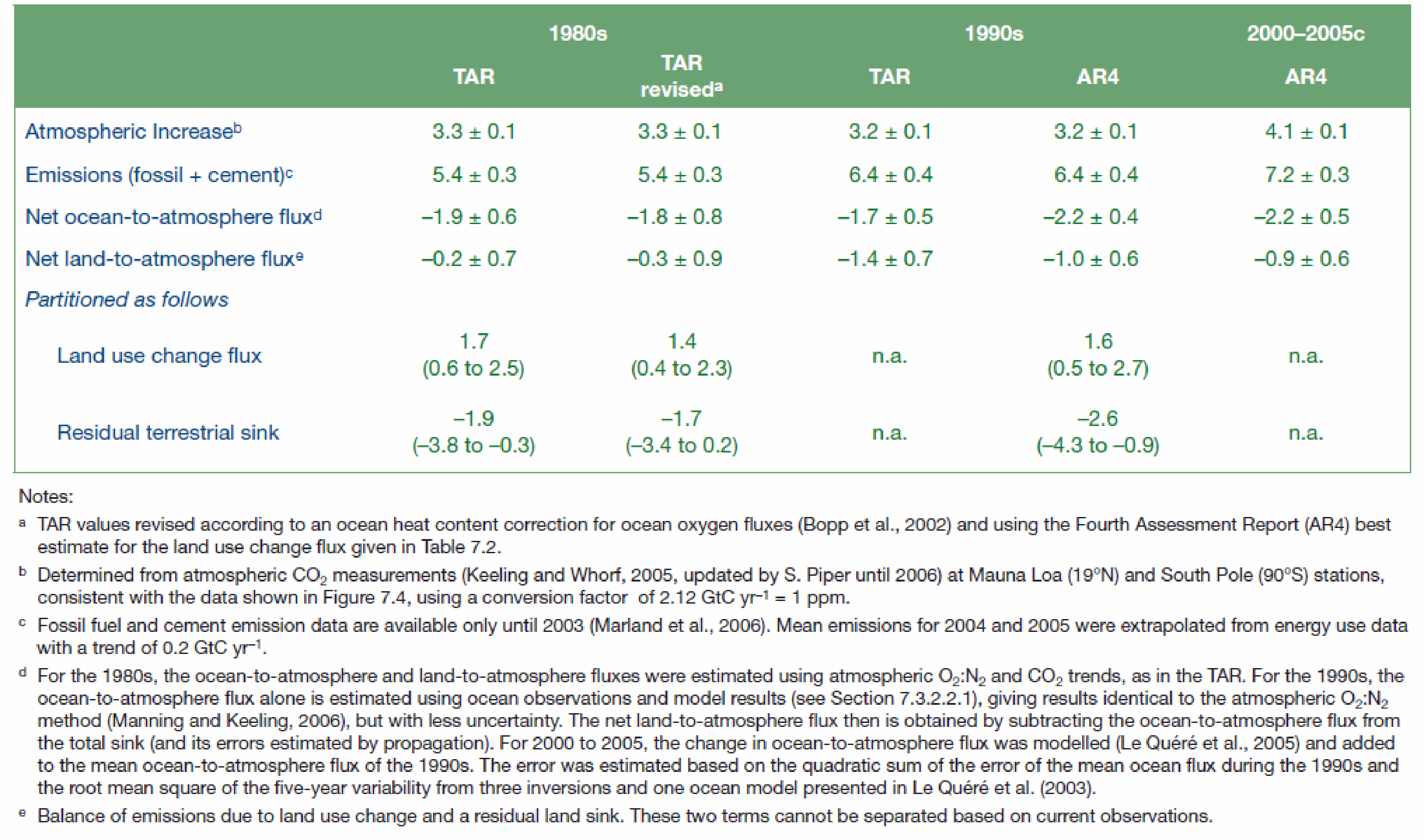


Birch woodland

Tundra heath


Uncertainties in Carbon Cycle Feedbacks
Model range of climate-carbon cycle feedback
Climate response
Soil decomposition
NPP
Ocean
Transient climate sensitivity
CO_2 response
Soil decomposition
NPP
Ocean
-0.3
-0.2
-0.1
0
0.1
0.2
Impact on Airborne Fraction of Total Emissions

Uncertainty Slide



	1980s		1990s		2000–2005c
	TAR	TAR revised[a]	TAR	AR4	AR4
Atmospheric Increase[b]	3.3 ± 0.1	3.3 ± 0.1	3.2 ± 0.1	3.2 ± 0.1	4.1 ± 0.1
Emissions (fossil + cement)[c]	5.4 ± 0.3	5.4 ± 0.3	6.4 ± 0.4	6.4 ± 0.4	7.2 ± 0.3
Net ocean-to-atmosphere flux[d]	–1.9 ± 0.6	–1.8 ± 0.8	–1.7 ± 0.5	–2.2 ± 0.4	–2.2 ± 0.5
Net land-to-atmosphere flux[e]	–0.2 ± 0.7	–0.3 ± 0.9	–1.4 ± 0.7	–1.0 ± 0.6	–0.9 ± 0.6
Partitioned as follows					
Land use change flux	1.7 (0.6 to 2.5)	1.4 (0.4 to 2.3)	n.a.	1.6 (0.5 to 2.7)	n.a.
Residual terrestrial sink	–1.9 (–3.8 to –0.3)	–1.7 (–3.4 to 0.2)	n.a.	–2.6 (–4.3 to –0.9)	n.a.

Notes:

[a] TAR values revised according to an ocean heat content correction for ocean oxygen fluxes (Bopp et al., 2002) and using the Fourth Assessment Report (AR4) best estimate for the land use change flux given in Table 7.2.

[b] Determined from atmospheric CO_2 measurements (Keeling and Whorf, 2005, updated by S. Piper until 2006) at Mauna Loa (19°N) and South Pole (90°S) stations, consistent with the data shown in Figure 7.4, using a conversion factor of 2.12 GtC yr^{-1} = 1 ppm.

[c] Fossil fuel and cement emission data are available only until 2003 (Marland et al., 2006). Mean emissions for 2004 and 2005 were extrapolated from energy use data with a trend of 0.2 GtC yr^{-1}.

[d] For the 1980s, the ocean-to-atmosphere and land-to-atmosphere fluxes were estimated using atmospheric O_2:N_2 and CO_2 trends, as in the TAR. For the 1990s, the ocean-to-atmosphere flux alone is estimated using ocean observations and model results (see Section 7.3.2.2.1), giving results identical to the atmospheric O_2:N_2 method (Manning and Keeling, 2006), but with less uncertainty. The net land-to-atmosphere flux then is obtained by subtracting the ocean-to-atmosphere flux from the total sink (and its errors estimated by propagation). For 2000 to 2005, the change in ocean-to-atmosphere flux was modelled (Le Quéré et al., 2005) and added to the mean ocean-to-atmosphere flux of the 1990s. The error was estimated based on the quadratic sum of the error of the mean ocean flux during the 1990s and the root mean square of the five-year variability from three inversions and one ocean model presented in Le Quéré et al. (2003).

[e] Balance of emissions due to land use change and a residual land sink. These two terms cannot be separated based on current observations.