PNAS

Strong isoprene emission response to temperature in tundra vegetation

Roger Seco, Thomas Holst, Cleo L. Davie-Martin, Tihomir Simin,
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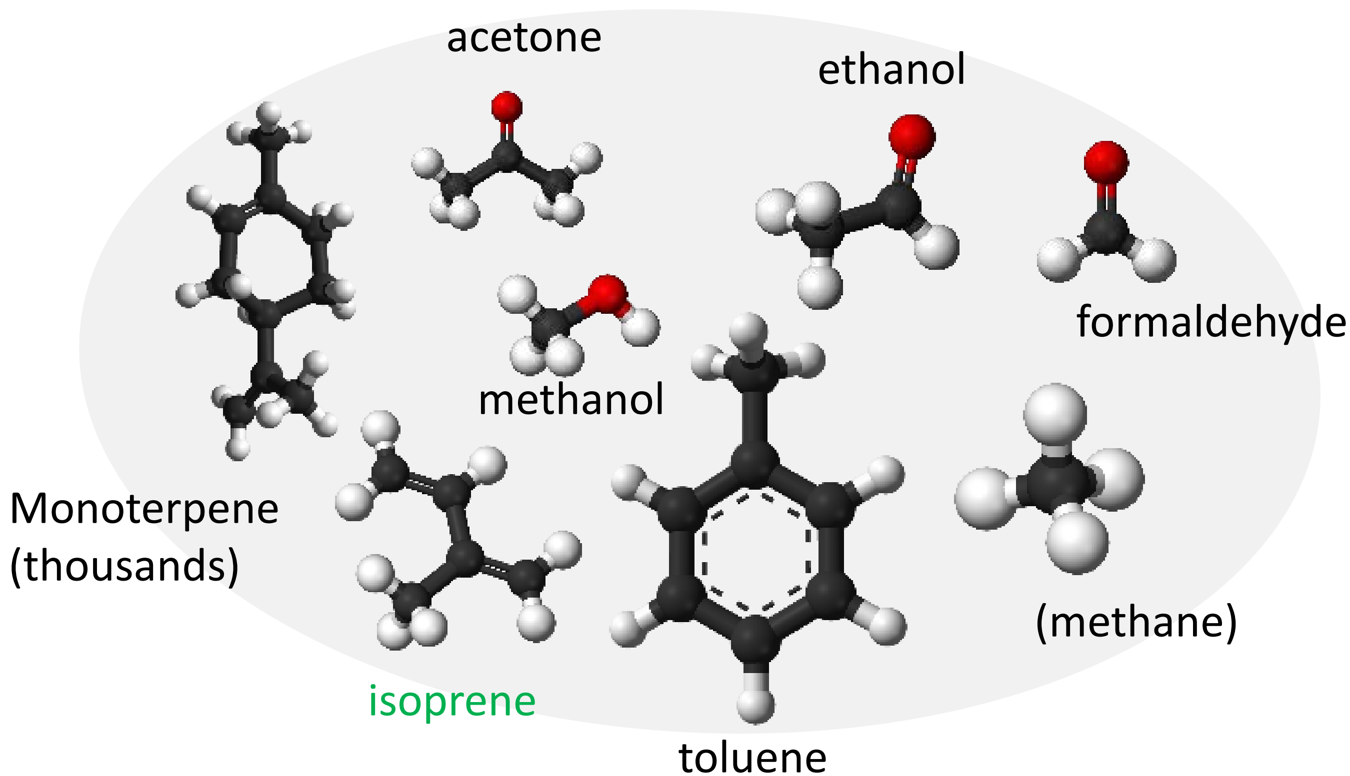
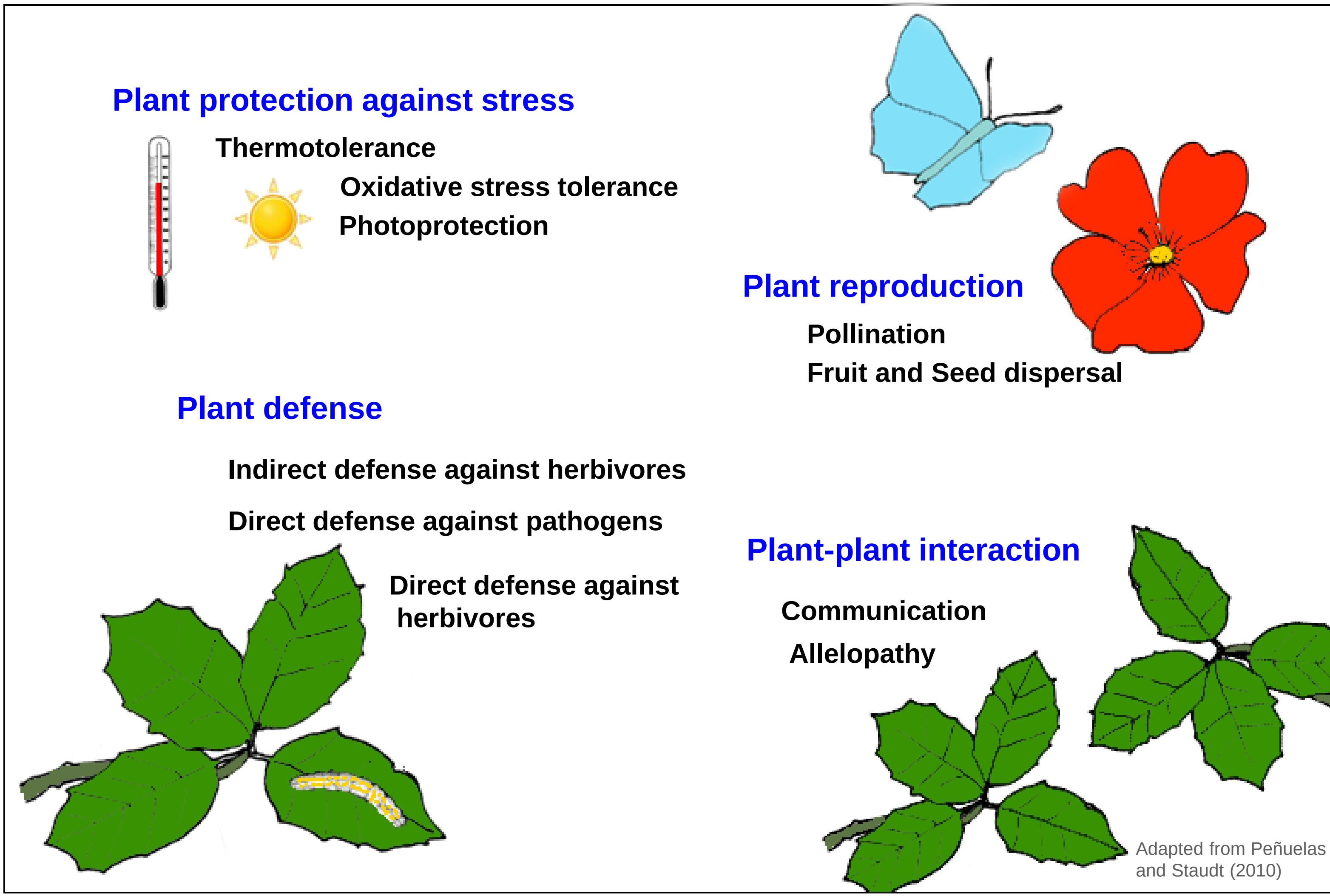
Biogenic volatile organic compounds (BVOCs)



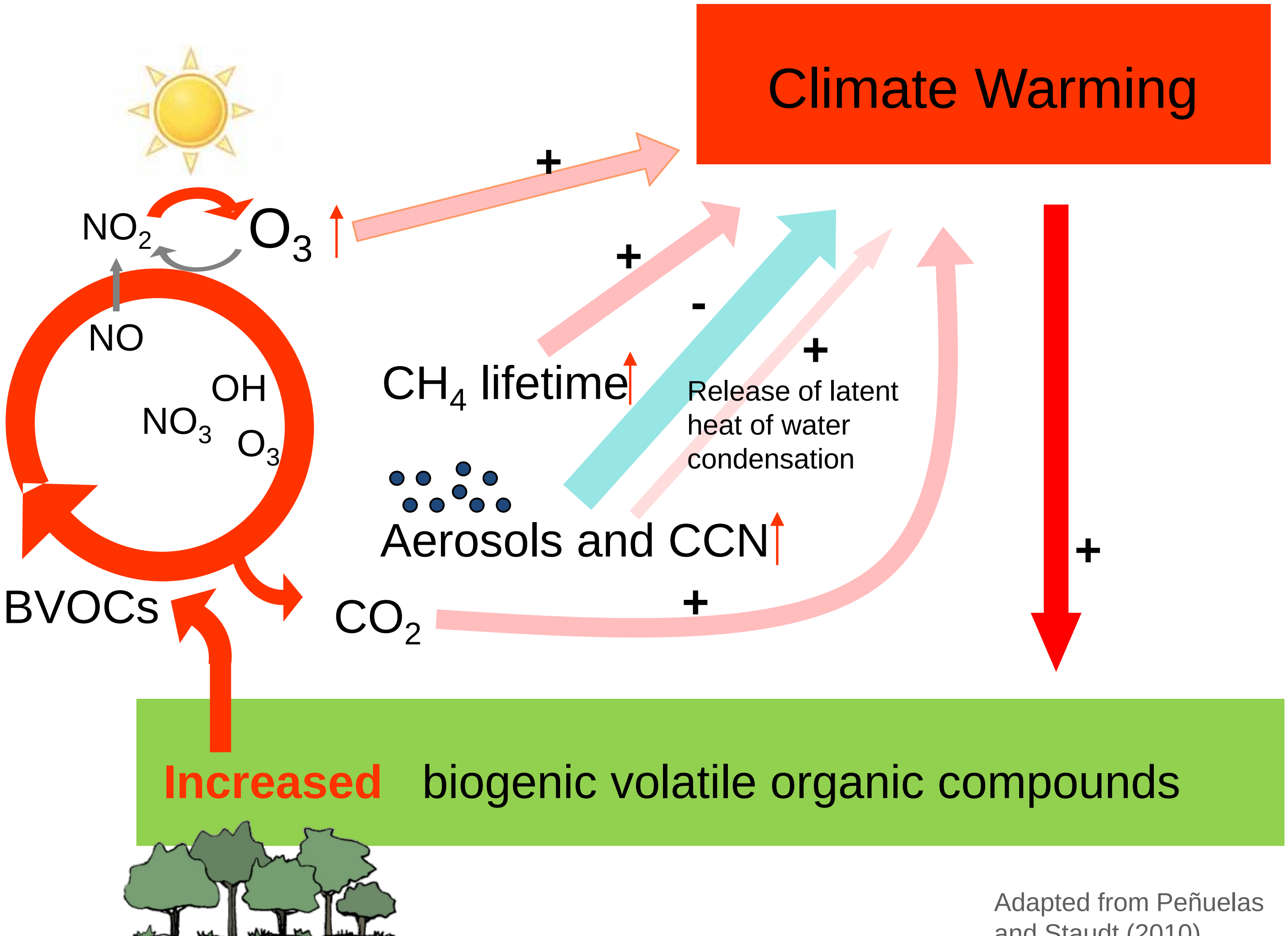
- BVOCs are found at concentrations **1.000-1.000.000 times lower** (~ppbv-pptv) than CO_2

Biological roles of BVOCs



Adapted from Peñuelas and Staudt (2010)

BVOC climatic implications



Adapted from Peñuelas and Staudt (2010)

NATURE CLIMATE CHANGE | VOL 11 | FEBRUARY 2021 | 95–105 |

Aerosols in current and future Arctic climate

Julia Schmale[1]✉, Paul Zieger[2] and Annica M. L. Ekman[3]

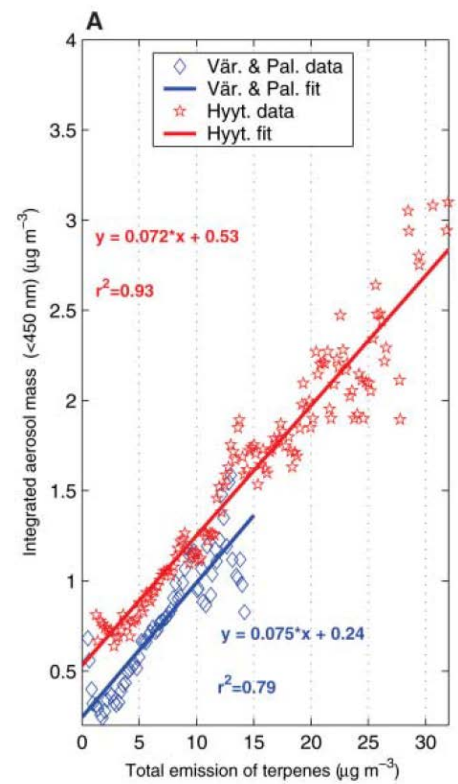
Table 1 | Measurement gaps and modelling issues for Arctic processes

Process	Measurement deficit	Modelling deficit
2b. Non-marine secondary aerosol formation	Contribution of boreal and tundra VOC emissions to the Arctic SOA budget	SOA formation in general and particularly from terrestrial VOC emissions

High Natural Aerosol Loading over Boreal Forests

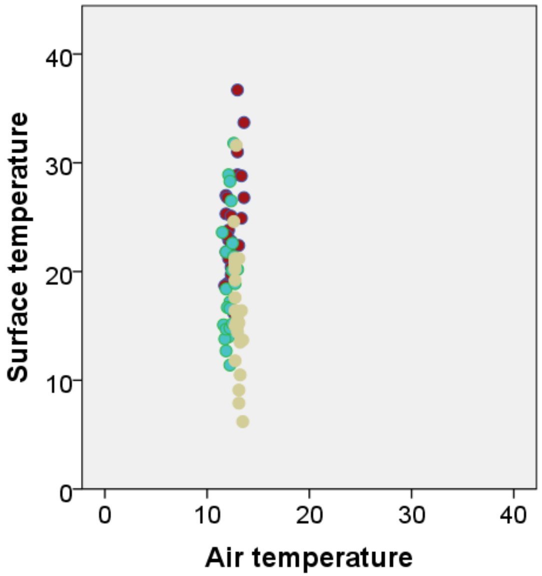
SCIENCE VOL 312 14 APRIL 2006

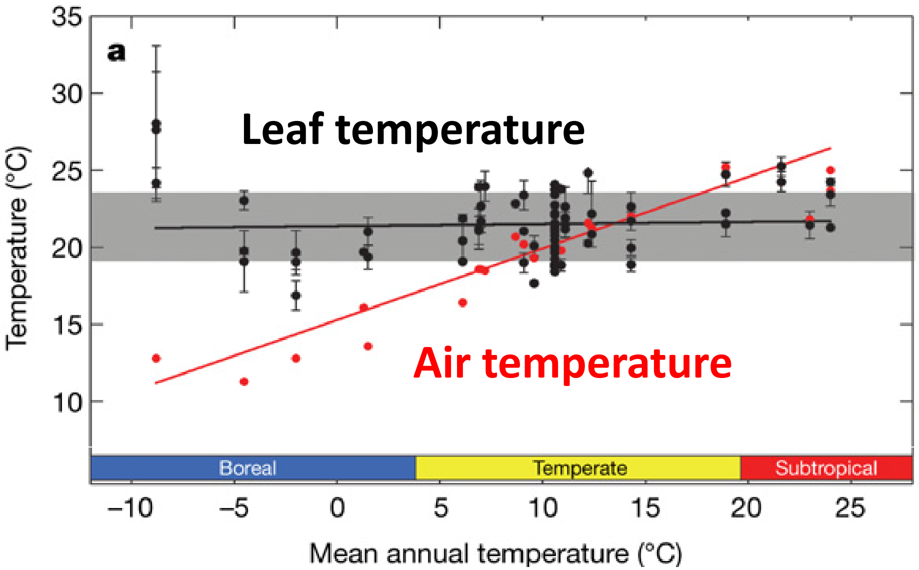
P. Tunved,[1*] H.-C. Hansson,[1] V.-M. Kerminen,[2] J. Ström,[1] M. Dal Maso,[3] H. Lihavainen,[2] Y. Viisanen,[2] P. P. Aalto,[3] M. Komppula,[2] M. Kulmala[3]



Arctic and boreal leaf temperature

Large difference between air and leaf temperature –
no leaf cooling like in other biomes





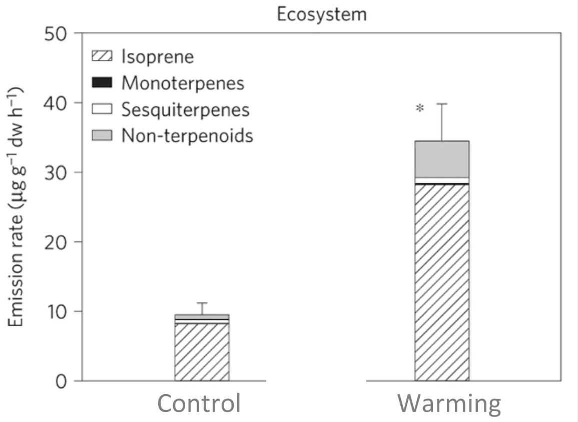
Lindwall et al. 2016

Helliker & Richter 2008, Nature

Arctic BVOC emissions

PREVIOUS RESEARCH northern high latitudes are warming at two to three times the global average rates

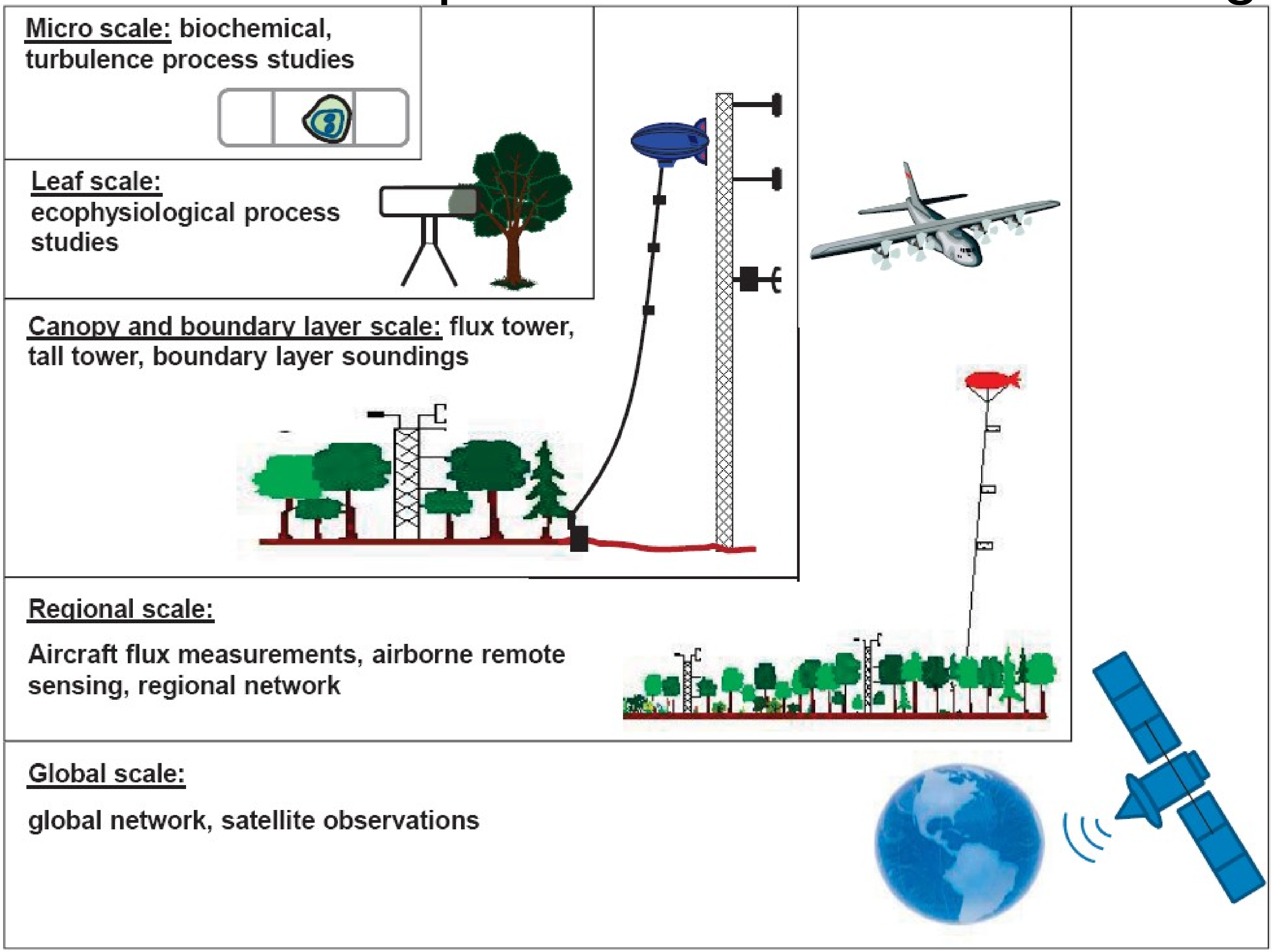
Enclosure-based measurements



Kramshøj et al., *Nature Geosci* (2016)

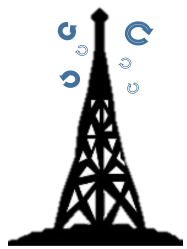
Undesired side effects
Only sporadic sampling

Multiple scale measurements for atmosphere-surface exchange

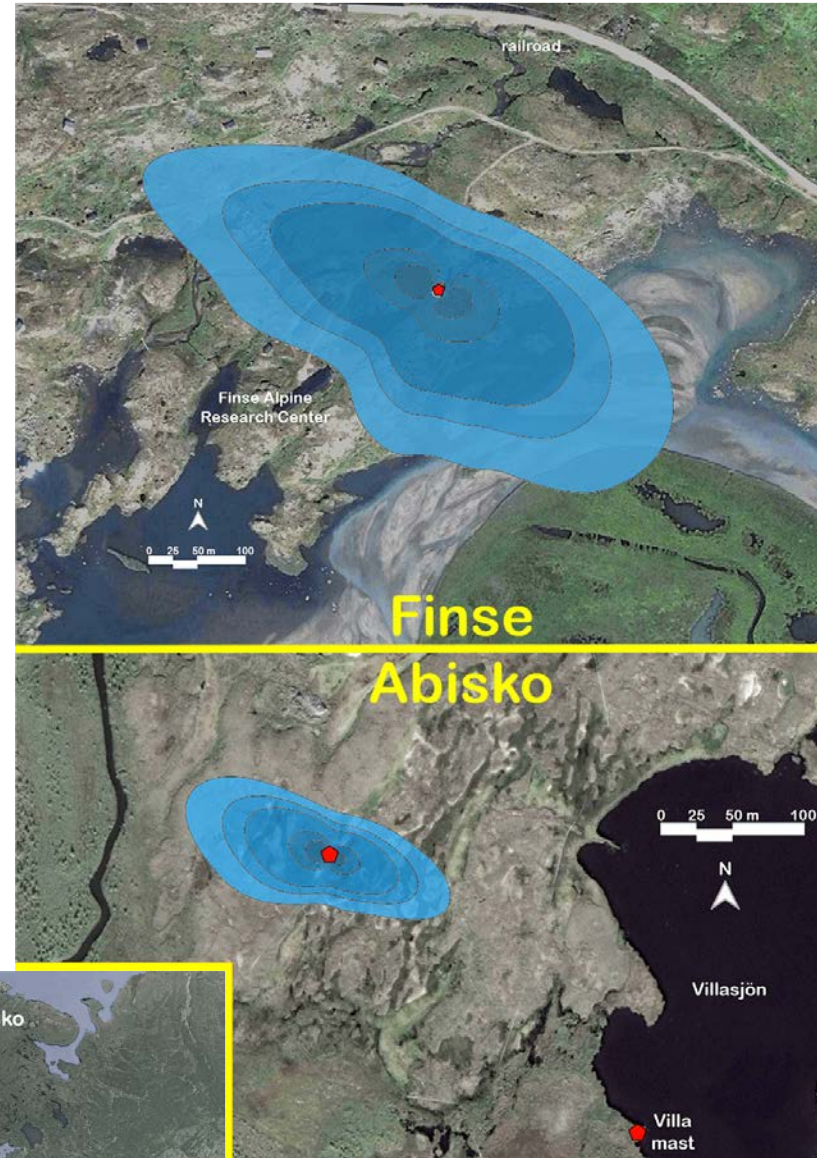


2 tundra sites in Scandinavia

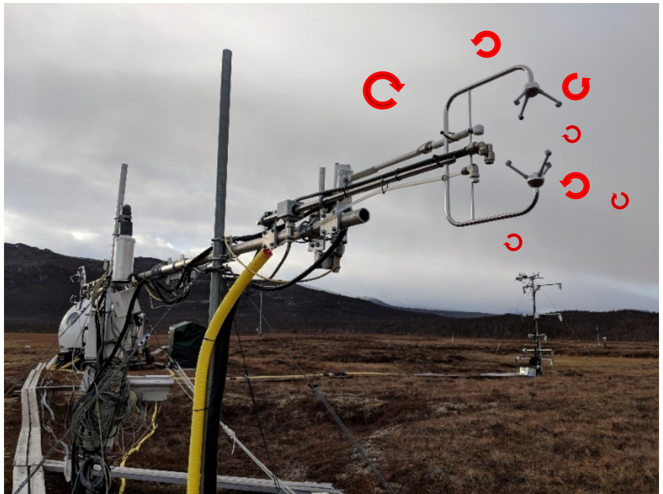
Season-long Eddy Covariance with PTR-TOF-MS



- Ecosystem-scale flux measurements taking advantage of air turbulence
- High time resolution
- Continuous measurements
- No manipulation of the vegetation or environment



2018 Abisko campaign



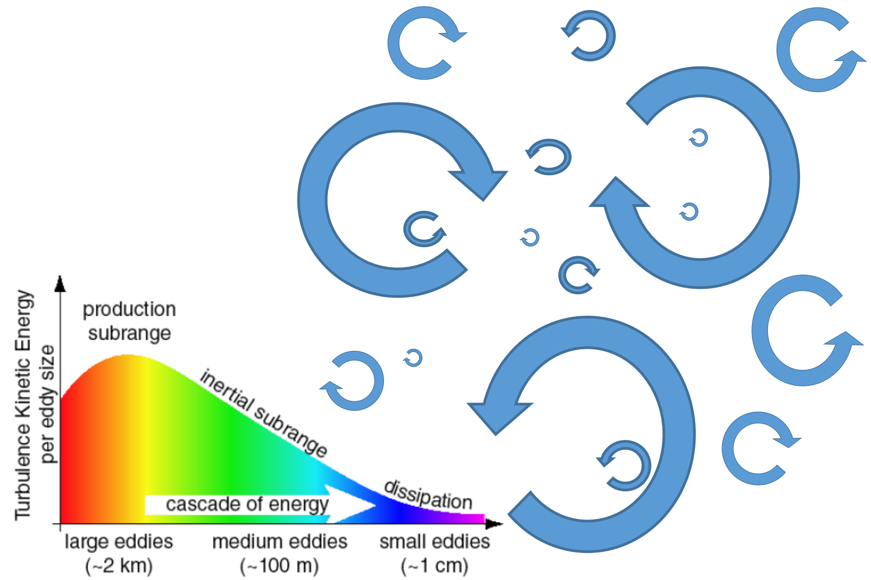
Turbulence

- Atmospheric flow is a complex superposition of many different horizontal scales of motion, where the scale

Table 9.1 Scales of horizontal motion in the atmosphere

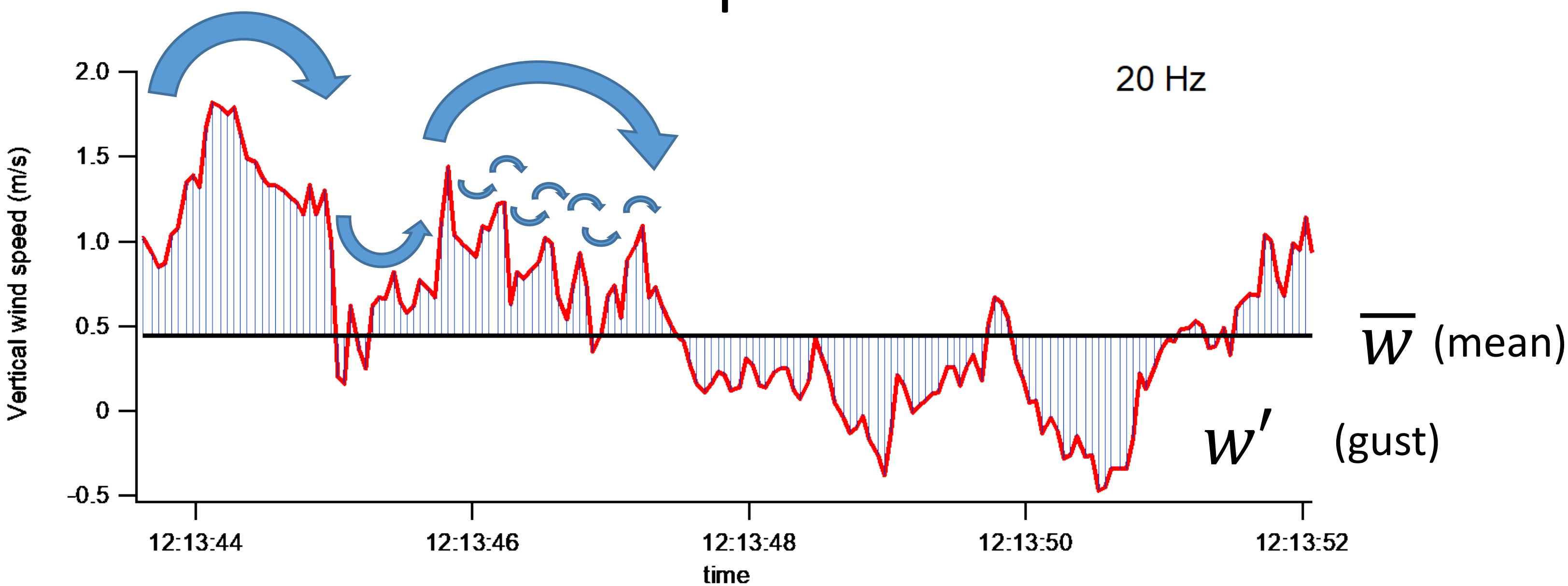
Stull 2005

Larger than	Scale	Name
20,000 km		Planetary scale
2,000 km		Synoptic scale
200 km	Meso-α	Mesoscale
20 km	Meso-β	Mesoscale
2 km	Meso-γ	Mesoscale
200 m	Micro-α	Boundary-layer turbulence
20 m	Micro-β	Surface-layer turbulence
2 m	Micro-γ	Inertial subrange turbulence
2 mm	Micro-δ	Fine-scale turbulence
Air molecules	Molecular	Viscous dissipation subrange



- Swirls (*eddies*) of many sizes that are superimposed and interact nonlinearly to create quasi-random, chaotic motions. Each individual eddy is evanescent and quickly disappears to be replaced by a succession of different eddies.
- But when averaged over many eddies, we can observe persistent patterns and similarities that can be measured and described.

Statistical description of turbulence



$$w = \overline{w} + w'$$

instantaneous wind speed

mean wind speed (e.g. 30 minute average)

deviation from mean wind speed (fluctuating term)

Reynolds decomposition

Eddy Covariance

Burba 2013

In turbulent flow, vertical flux can be presented as:
(s is the dry mole fraction of the gas of interest in the air)

$$F = \overline{\rho_d w s}$$

Reynolds decomposition is then used to break terms into means and deviations:

$$F = \overline{(\overline{\rho}_d + \rho_d')(\overline{w} + w')(\overline{s} + s')}$$

Opening the parentheses:

$$F = \overline{(\overline{\rho}_d \overline{w}\overline{s} + \cancel{\overline{\rho}_d \overline{w} s'} + \cancel{\overline{\rho}_d w' \overline{s}} + \overline{\rho}_d w' s' + \cancel{\rho_d' \overline{w}\overline{s}} + \rho_d' \overline{w} s' + \rho_d' w' \overline{s} + \rho_d' w' s')}$$

averaged deviation from the average is zero

Equation is simplified:

$$F = (\overline{\rho}_d \overline{w}\overline{s} + \overline{\rho}_d \overline{w's'} + \overline{w}\,\overline{\rho_d' s'} + \overline{s}\,\overline{\rho_d' w'} + \overline{\rho_d' w' s'})$$

Now an important assumption is made (for conventional eddy covariance) – air density fluctuations are assumed to be negligible:

$$F = (\overline{\rho}_d \overline{w}\overline{s} + \overline{\rho}_d \overline{w's'} + \cancel{\overline{w}\,\overline{\rho_d' s'}} + \cancel{\overline{s}\,\overline{\rho_d' w'}} + \cancel{\overline{\rho_d' w' s'}}) = \cancel{\overline{\rho}_d \overline{w}\overline{s}} + \overline{\rho}_d \overline{w's'}$$

Then another important assumption is made – mean vertical flow is assumed to be negligible for horizontal homogeneous terrain (no divergence/convergence):

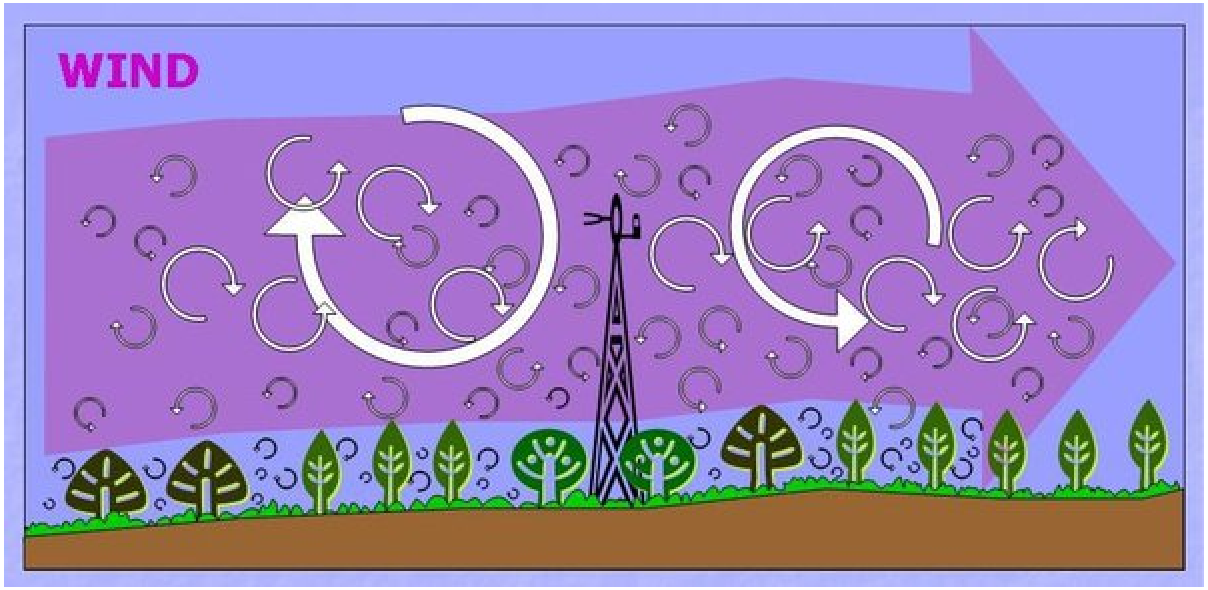
Eddy Covariance mathematical principle

$$F \approx \overline{\rho}_d \overline{w's'}$$

'Eddy Flux'

Vertical flux can be represented as a covariance of the vertical velocity and concentration of the entity of interest

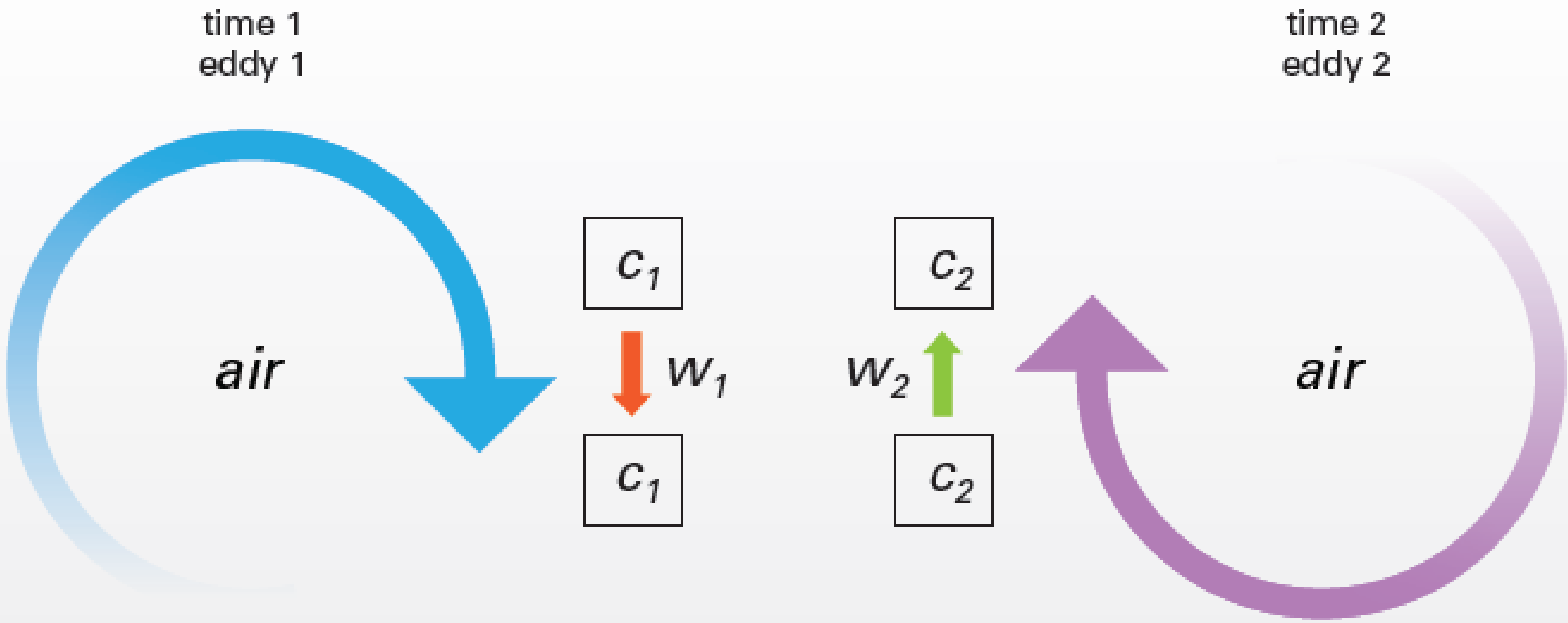
Air flow in Ecosystem



Burba & Anderson 2010

- Air flow can be imagined as a horizontal flow of numerous rotating eddies
- Each eddy has 3-D components, including a vertical wind component
- The diagram looks chaotic but components can be measured from tower

How does the Eddy Covariance method work?



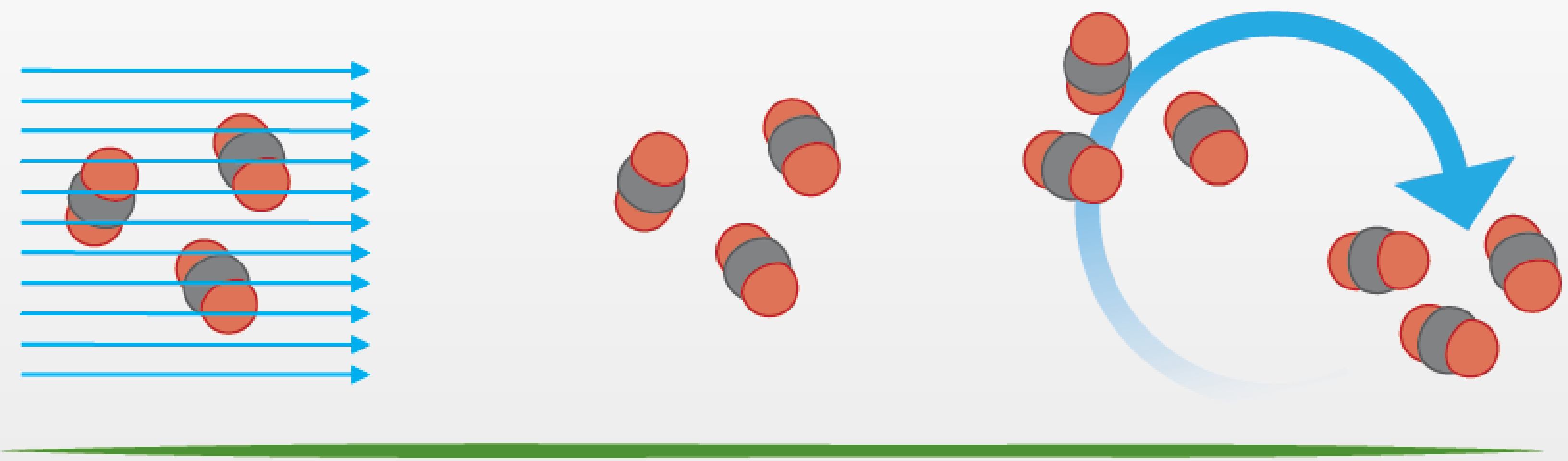
At a single point on the tower:

Eddy 1 moves parcel of air c_1 down with the speed w_1, then eddy 2 moves parcel c_2 up with the speed w_2

Each parcel has concentration, temperature, humidity; if we know these and the speed – we know the flux

Burba 2013

- The eddy covariance method works by measuring vertical turbulent transport of gas to and from the surface
- With no flux added into the mean flow by the measured area, the eddies move the same number of gas molecules up and down



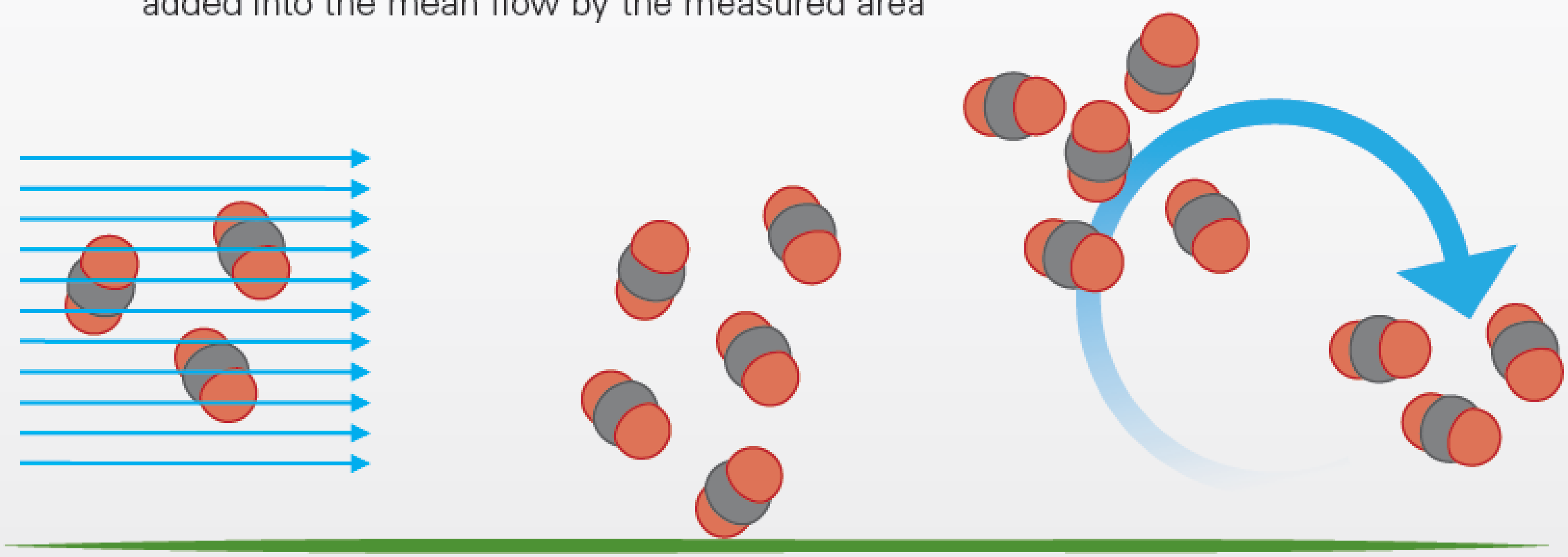
Mean flow carries gas molecules over the measured area

Measured area adds no molecules into the mean flow (= no flux)

Eddy motions carry the same number of molecules up and down

Burba 2013

- With flux added into the mean flow by the measured area, the eddies move more gas up than down, transporting it from the surface into the atmosphere
- If we know the bias between up and down motions, we know how much was added into the mean flow by the measured area



Mean flow carries gas molecules over the measured area

Measured area adds molecules into the mean flow (= flux)

Upward eddy motions carry more molecules than downward motions

Burba 2013

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RESEARCH ARTICLE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES
ENVIRONMENTAL SCIENCES

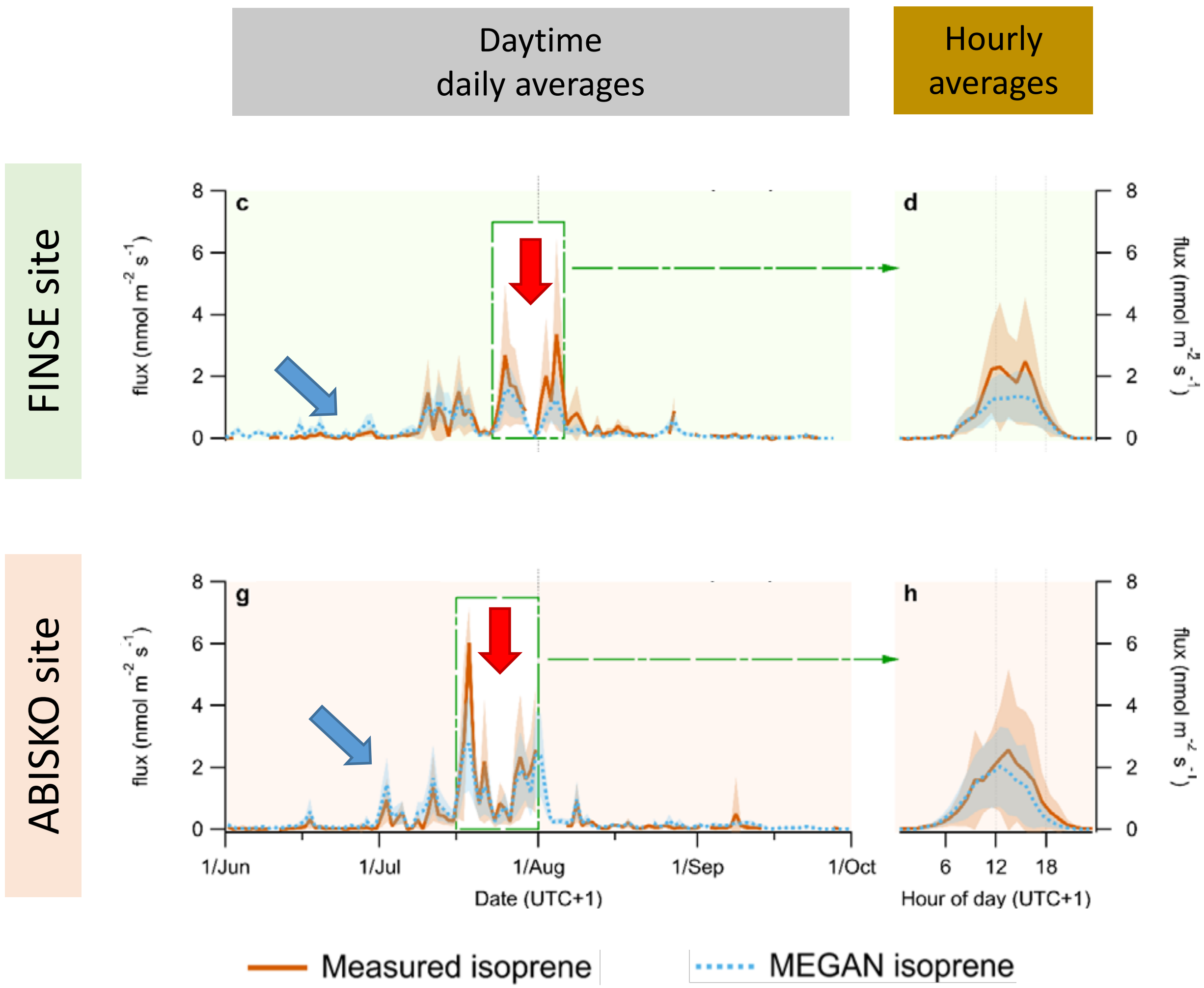
Strong isoprene emission response to temperature in tundra vegetation

Roger Seco[a,b,c,1], Thomas Holst[d], Cleo L. Davie-Martin[a,b], Tihomir Simin[a,b], Alex Guenther[e], Norbert Pirk[f], Janne Rinne[d], and Riikka Rinnan[a,b,1]

Longest *eddy covariance* isoprene flux dataset ever reported for tundra ecosystems

2 full growing seasons

Comparison to single-point MEGAN v2.1 emission model



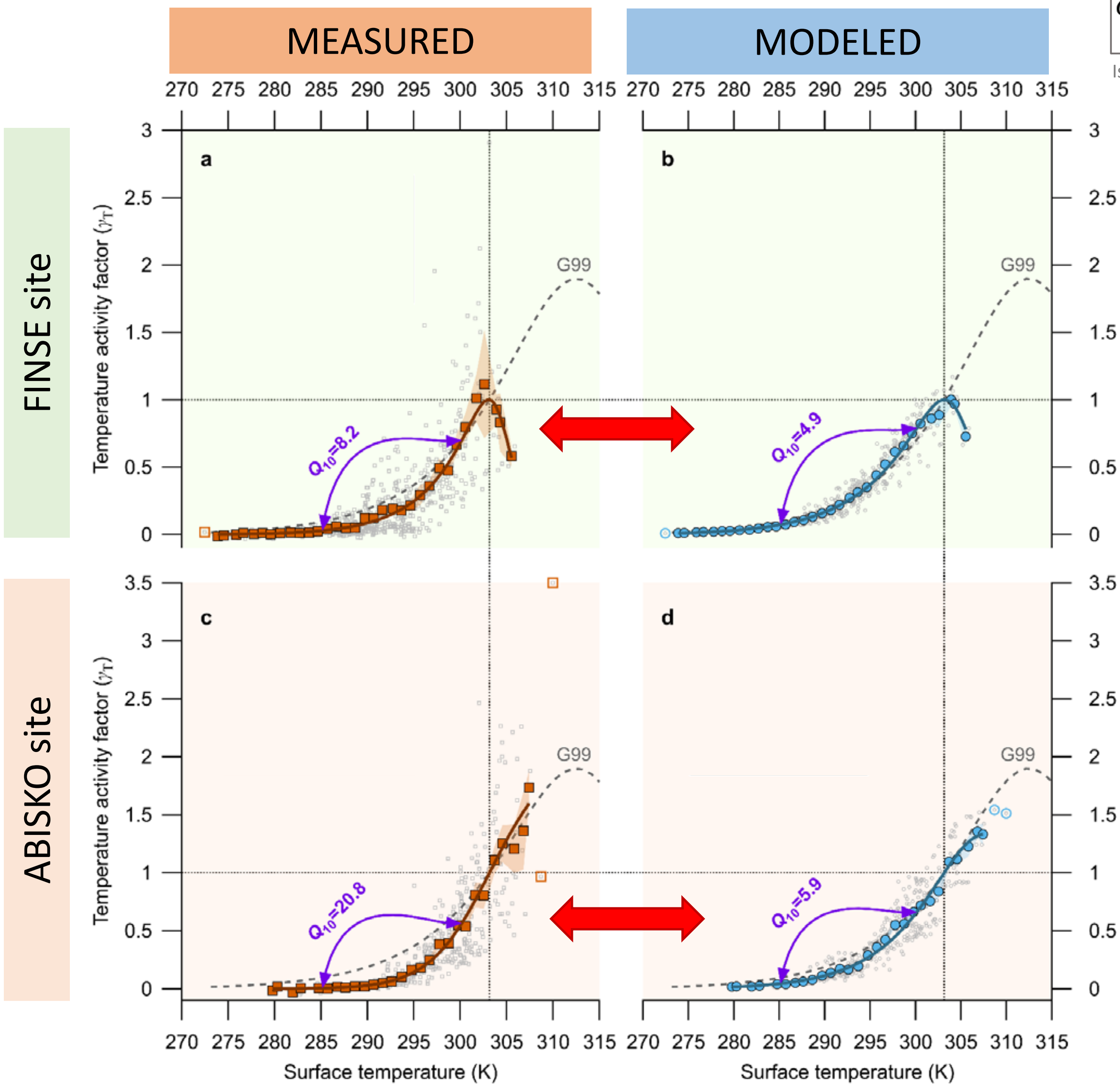
MEGAN v2.1

- Default isoprene emission factor ($1600\ \mu g\ m^{-2}\ h^{-1}$)
- Leaf temperature prescribed to equal the measured vegetation surface (IR radiometer)
- Overall, MEGAN performed reasonably well but with some discrepancies

Temperature sensitivity of isoprene fluxes

$$C_T = \frac{E_{\mathrm{opt}} \cdot C_{T_2} \cdot e^{C_{T_1} \cdot x}}{C_{T_2} - C_{T_1} \cdot (1 - e^{C_{T_2} x})}, x = \frac{\frac{1}{T_{\mathrm{opt}}} - \frac{1}{T}}{R}$$

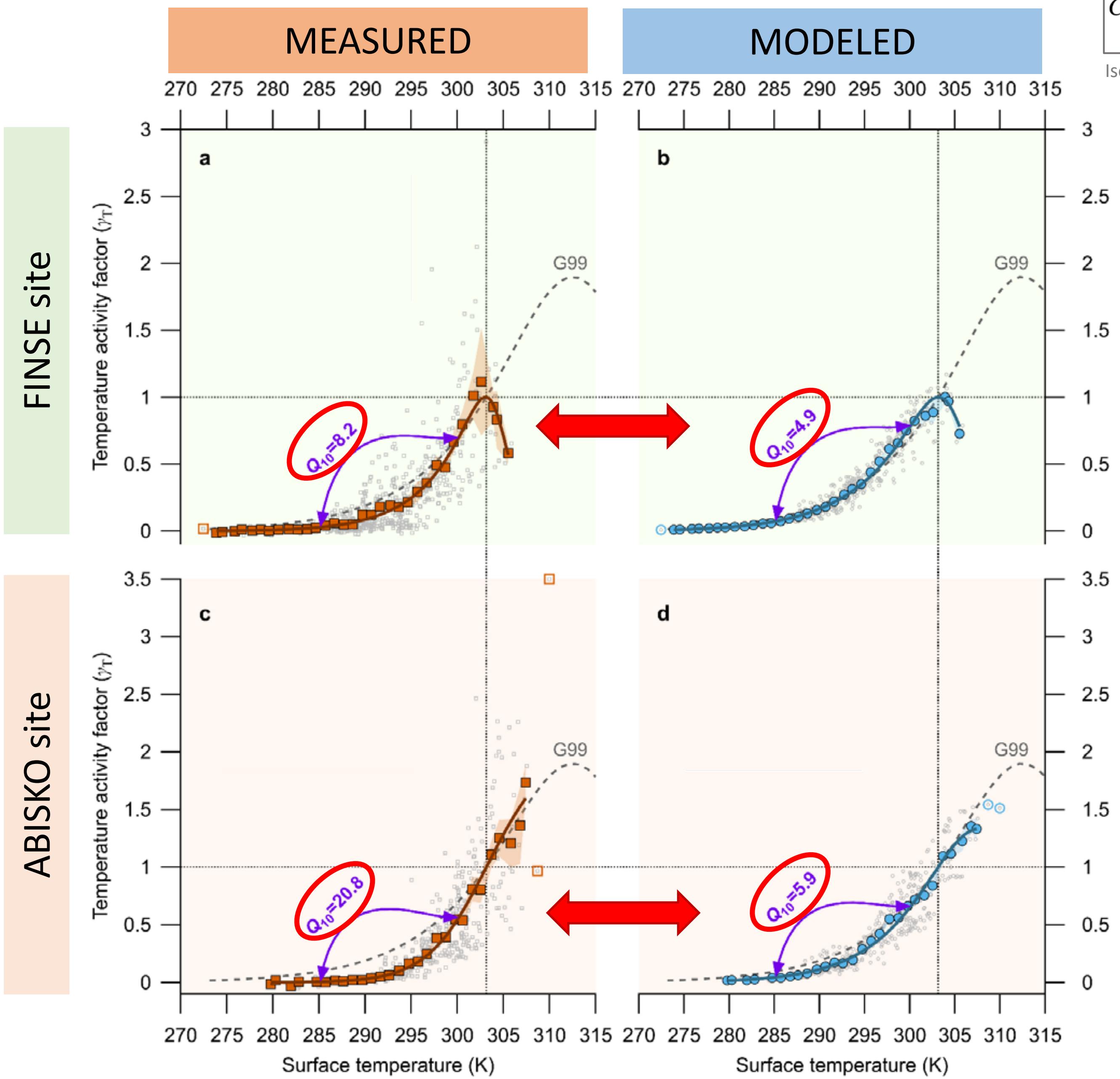
Isoprene temperature response algorithm from MEGAN



Temperature sensitivity of isoprene fluxes

$$C_T = \frac{E_{opt} \cdot C_{T_2} \cdot e^{C_{T_1} \cdot x}}{C_{T_2} - C_{T_1} \cdot (1 - e^{C_{T_2} x})}, x = \frac{\frac{1}{T_{opt}} - \frac{1}{T}}{R}$$

Isoprene temperature response algorithm from MEGAN



- Tundra vegetation could enhance their isoprene emissions by up to 41% (87%) –that is 46% (55%) more than estimated by models– with a 2 °C (4 °C) warming

Conclusions

- We showed that the **strong temperature response** –*as earlier shown by experimental work with chamber-based methods*– **holds in the "real" world**

- Tundra has the potential to **substantially boost** its isoprene emissions in response to rising temperatures, **at rates that exceed the current** Earth System Model **predictions**.
  - Potential repercussions for the regional atmospheric chemistry and climate in the unpolluted high-latitude environments
  - Models need to account for this temperature response
  - Interaction with warming-induced vegetation composition changes

Thanks for your attention

- Funding and support
  - ICOS Sweden, the Abisko Research Station (ANS), SITES
    - Swedish Research Council grant 2019-00205
  - Finse Alpine Research Centre
    - LATICE "Land–ATmosphere Interactions in Cold Environments" (Faculty of Mathematics and Natural Sciences, University of Oslo, project UiO/GEO103920)
    - EMERALD "Terrestrial ecosystem–climate interactions of our EMERALD planet" project funded by the Research Council of Norway (project 294948).
  - Rinnan group at University of Copenhagen
    - TUVOLU "Tundra Biogenic Volatile Emissions in the 21st Century" (ERC Consolidator grant 771012)
    - Independent Research Fund Denmark/Natural Sciences (grant DFF–4181-00141)
    - Danish National Research Foundation (CENPERM grant DNRF100)
  - Spanish grants
    - Ramón y Cajal grant (RYC2020-029216-I), funded by the Spanish Ministry of Science and Innovation and the State Research Agency (MCIN/AEI/10.13039/501100011033) and by the European Social Fund "ESF Investing in Your Future".
    - IDAEA-CSIC is a Severo Ochoa Centre of Research Excellence (MCIN/AEI, project CEX2018-000794-S)

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