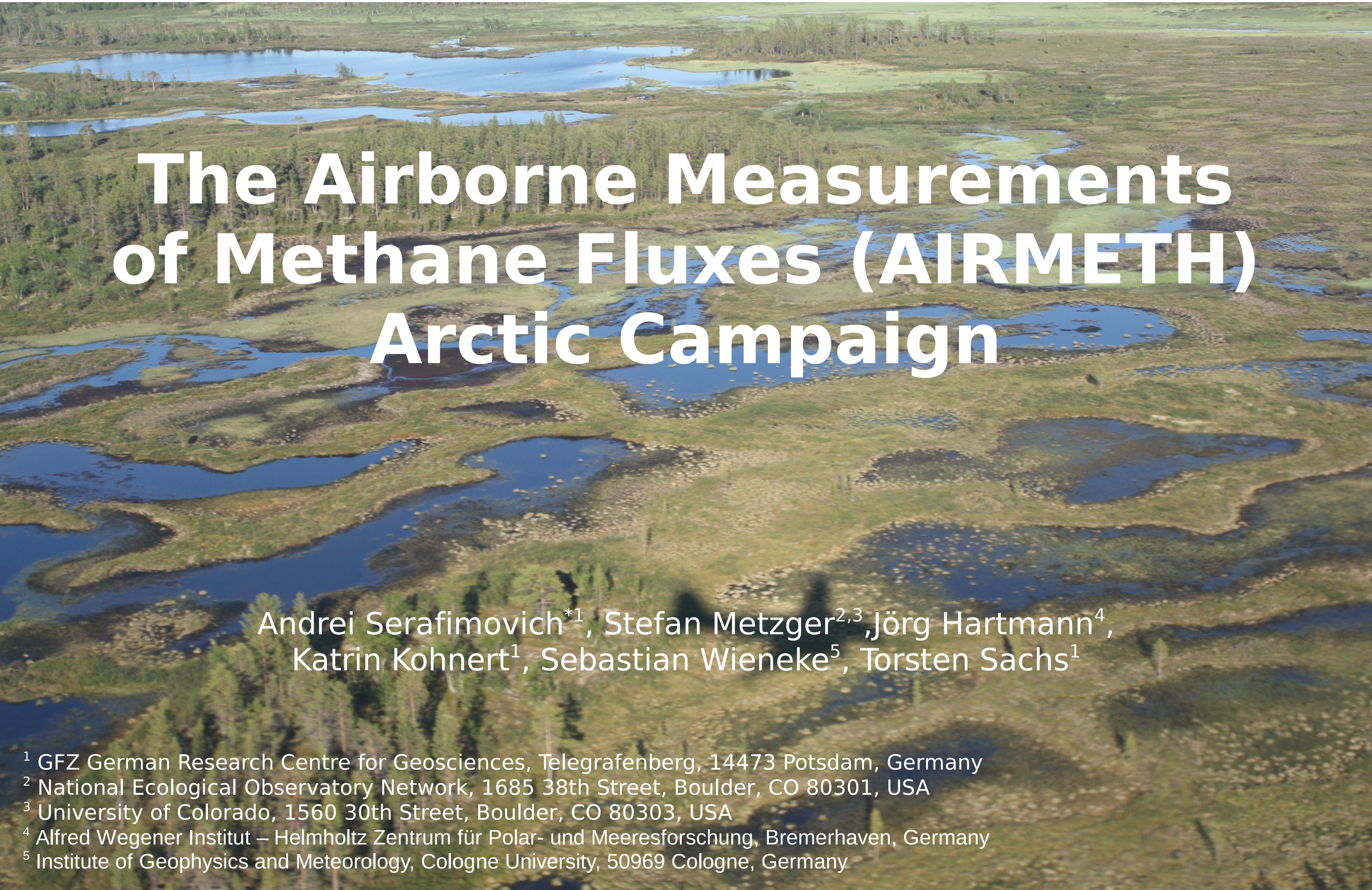

The Airborne Measurements of Methane Fluxes (AIRMETH) Arctic Campaign

Andrei Serafimovich[*1], Stefan Metzger[2,3], Jörg Hartmann[4],
Katrin Kohnert[1], Sebastian Wieneke[5], Torsten Sachs[1]

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[2] National Ecological Observatory Network, 1685 38th Street, Boulder, CO 80301, USA
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[4] Alfred Wegener Institut – Helmholtz Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany
[5] Institute of Geophysics and Meteorology, Cologne University, 50969 Cologne, Germany

Background

Global CH4 budget for the past three decades [Tg(CH_4) yr^{-1}]

Tg(CH_4)yr^{-1}	1980 - 1989		1990 - 1999		2000 - 2009	
	Top-Down	**Bottom-Up**	**Top-Down**	**Bottom-Up**	**Top-Down**	**Bottom-Up**
Natural Sources	203 [150 - 267]	355 [244 - 466]	182 [167 - 197]	336 [230 - 465]	218 [179 - 273]	347 [238 - 484]
Natural Wetlands	167 [115 - 231]	225 [183 - 266]	150 [144 - 160]	206 [169 - 265]	175 [142 - 208]	217 [177 - 284]
Other Sources	36 [35 - 36]	130 [61 - 200]	32 [23 - 37]	130 [61 - 200]	43 [37 - 65]	130 [61 - 200]

[IPCC, The Fifth Assessment Report AR5]

- **Wetlands are the dominant natural source of CH_4 over the globe**
- **Still large range of wetland emission estimates**
- **Permafrost wetlands not separately assessed**
- **Process-based models tend to be calibrated at individual wetland sites and then applied across the globe**
- **Spread in top -down approach is due to a lack of observations**

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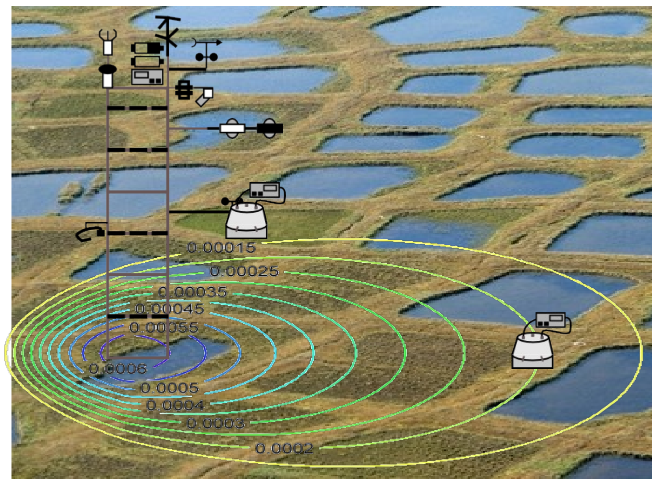

Photo: Konstanze Piel

Eddy Covariance & Chamber measurements

- **Continuous in-situ observations of the surface-atmosphere exchange**
- **Well suited for local process studies and for investigating the temporal variability of fluxes**

- **Wetlands are the dominant natural source of CH_4 over the globe**
- **Still large range of wetland emission estimates**
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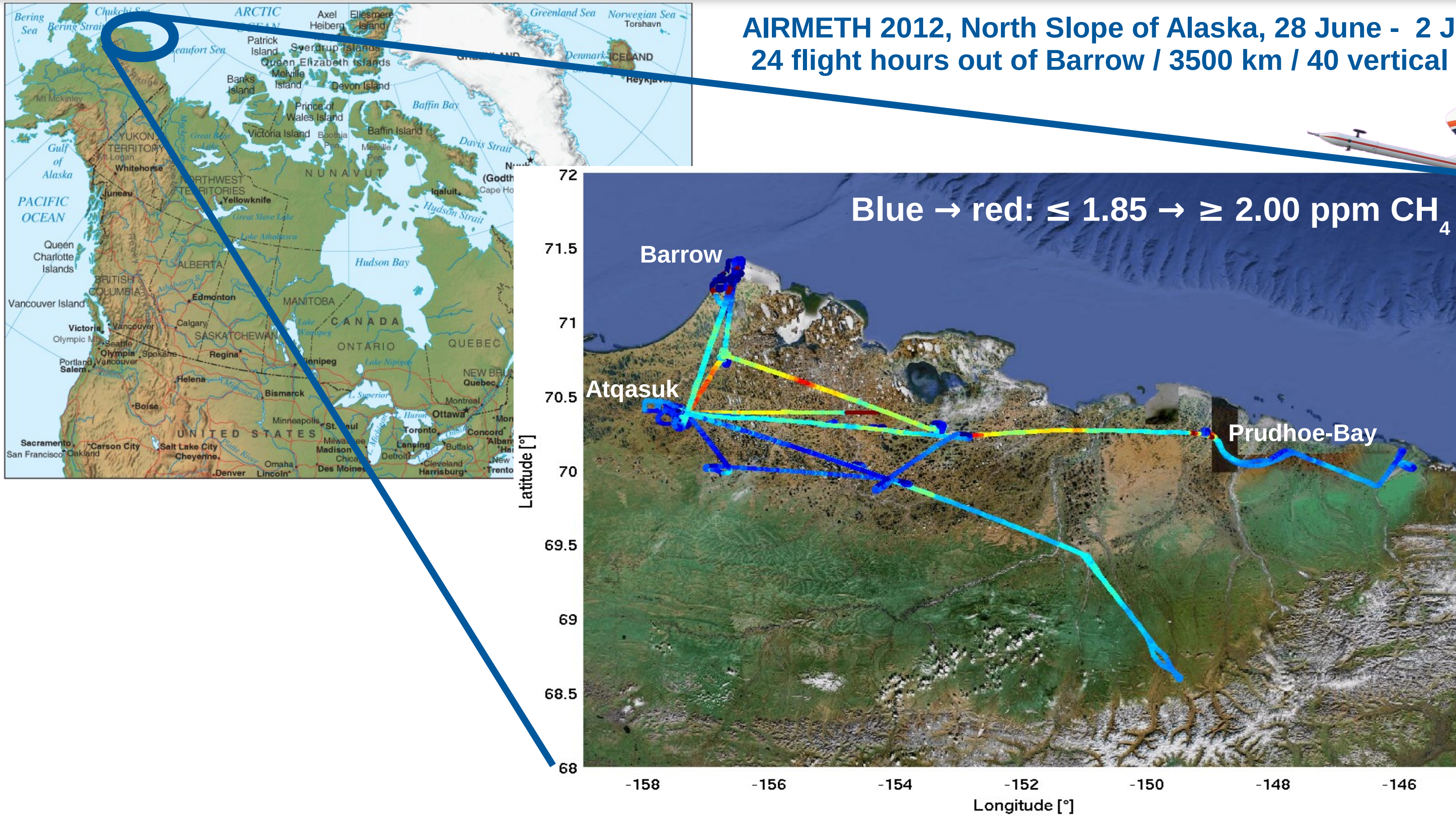
- **Spread in top -down approach is due to a lack of observations**

But:

- **Rare in the Arctic permafrost zone**
- **Site selection is bound by logistical constraints among others**
- **These observations cover only small areas that are not necessarily representative of the region of interest**

Airborne Flux Measurements

AIRMETH 2012, North Slope of Alaska, 28 June - 2 July 2012
24 flight hours out of Barrow / 3500 km / 40 vertical profiles

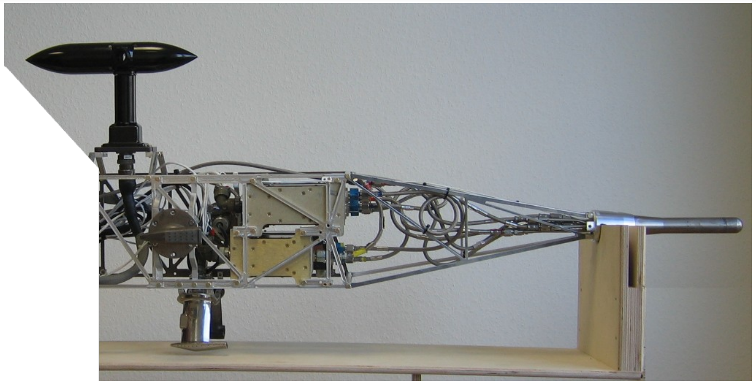


- **Closing the gap between tower and sattelite measurements**
- **Assessing heterogeneity of sources and sinks**

But:
- **Expensive and provide a snapshot at a particular time**

Research Aircraft POLAR5

Los Gatos RMT-200
CH_4, precision: 3 ppb @ 10 Hz



messWERK GmbH
3D wind, precision: 0.1 m/s @ 100Hz
Temperature, precision: 0.01 K @ 100 Hz

- **Inertial Navigation System**
- **GPS**
- **Radar altimeter**
- **Laser altimeter**
- **Radiation thermometer**
- **Pyranometer**
- **Pyrgeometer**
- **Total Temperature Sensor**
- **Humidity / Temperature sensors**
- **Photo / Video cameras**

Workflow

Aims

- Link the measurement to surface properties
- Land cover specific CH_4 flux
- Maps of the predicted CH_4 fluxes
- CH_4 budget and budget uncertainty

Workflow

Low-level flights
- 3D location
- 3D wind vector
- CH_4 concentration
- Humidity
- Air pressure & temperature

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- Spatially resolved contributions of land cover, LST, EVI, NDVI, albedo to each observation of CH_4 flux

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Machine learning
- Environmental response functions

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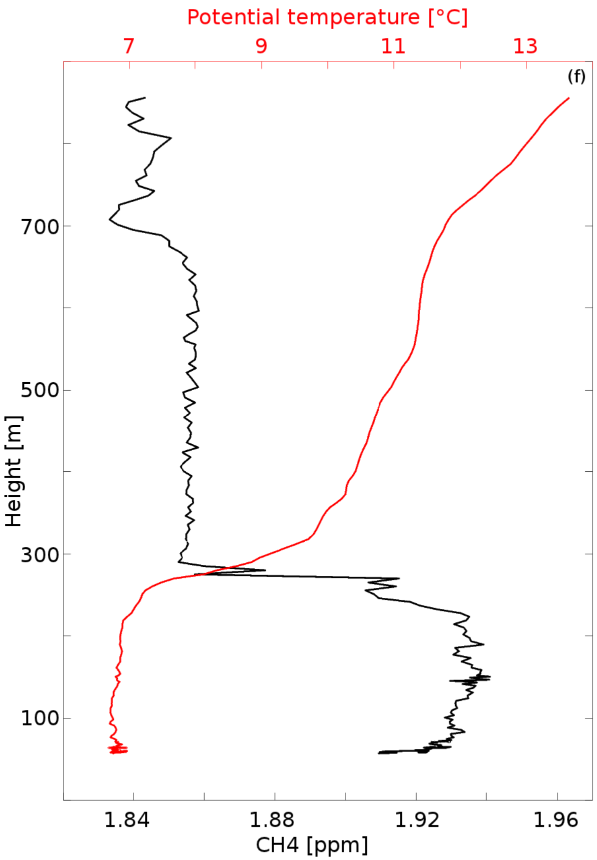
Atmospheric Scales

Excluded 20 runs (~1600 km) of 44 (~3500 km)

- **above surface layer (> 10% boundary layer height) measured flux not representative of surface flux**
- **below mechanical blending height z_{blend} turbulence not representative of mechanical setting in entire source area**



$$z_{blend} = \frac{u_*}{U} \frac{L_{hetero}}{C_{blend}}$$ *[Mahrt 2000, Bange 2007]*

29.06.12 17:45 – 18:00 UTC

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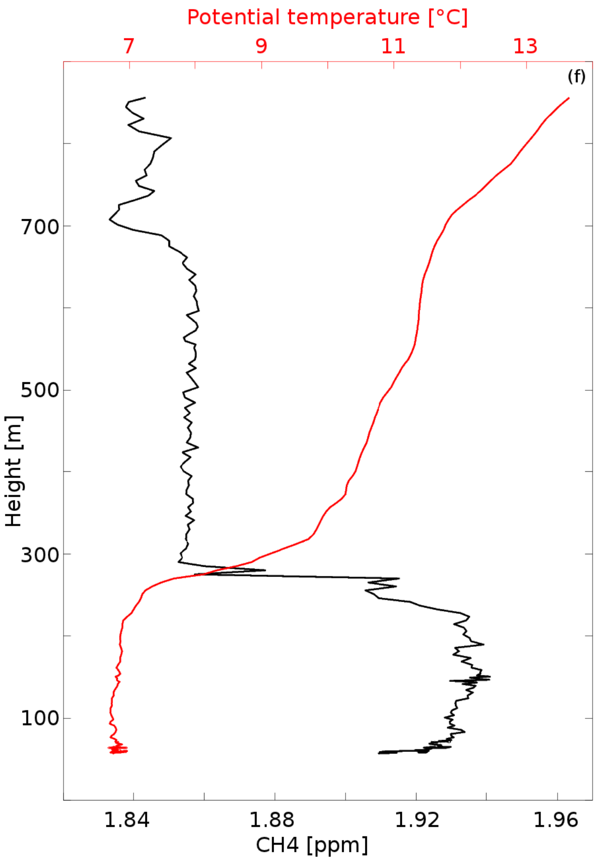

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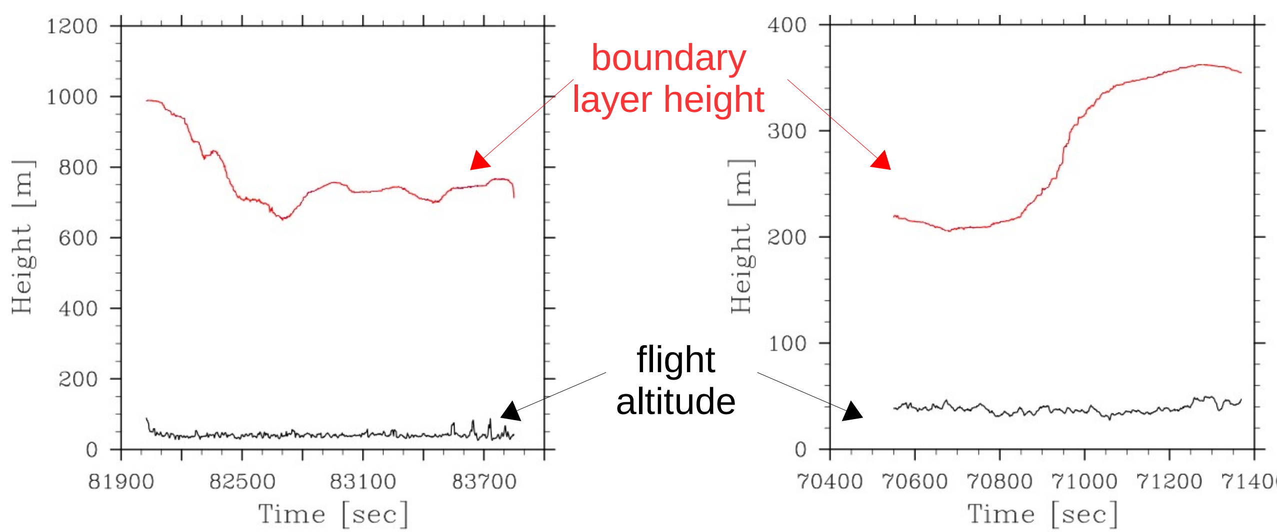
WRF THE WEATHER RESEARCH & FORECASTING MODEL



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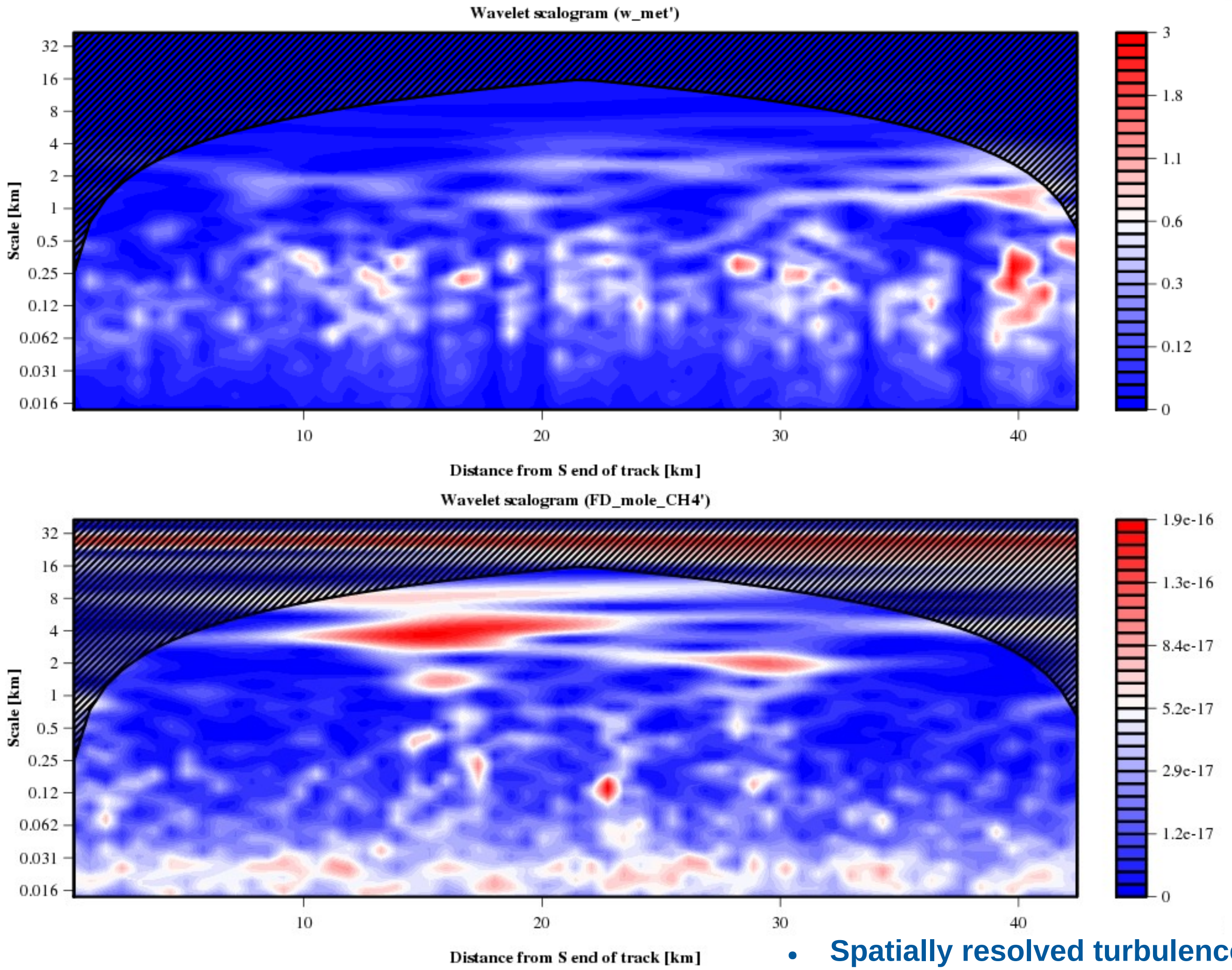
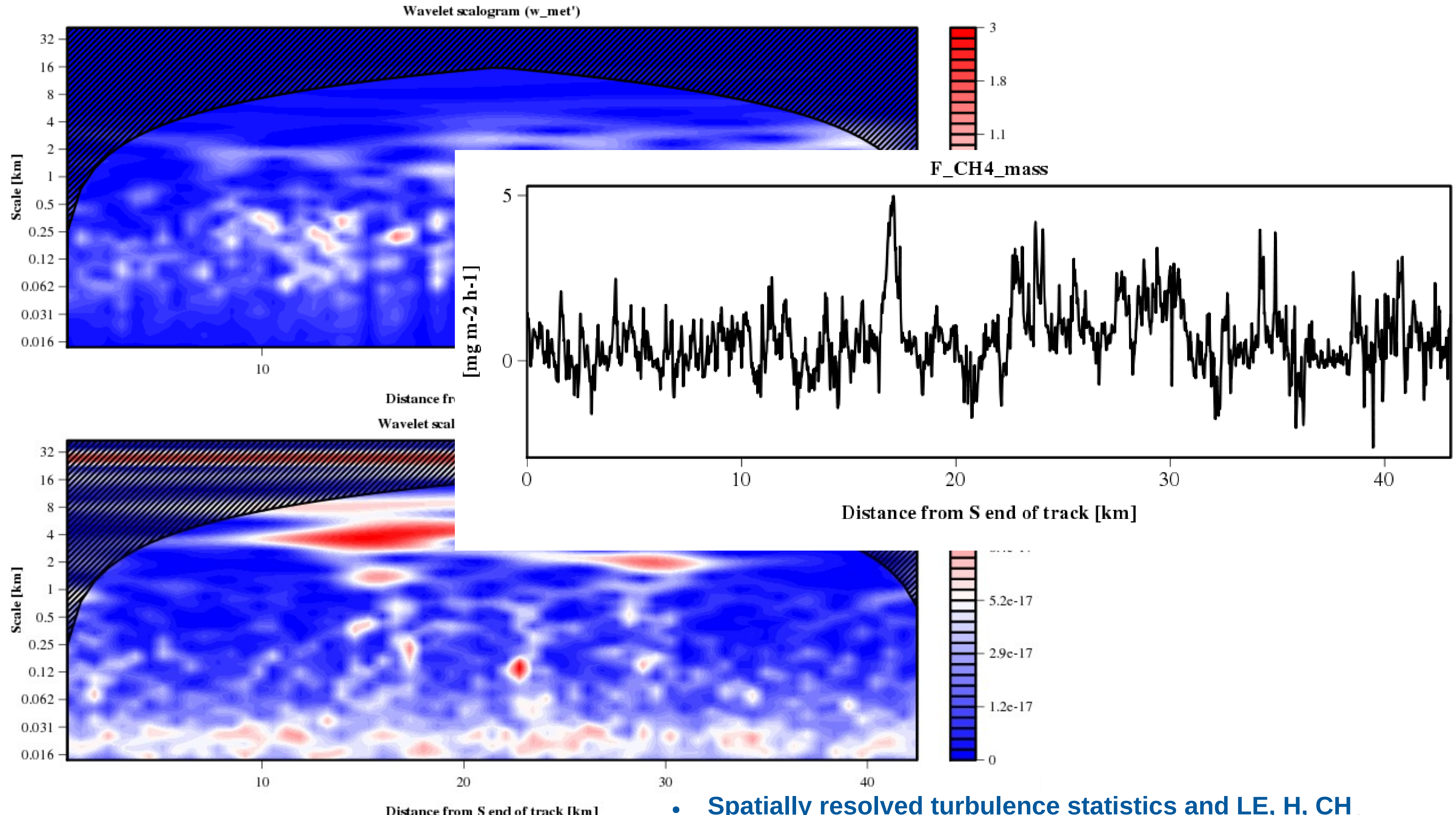
Wavelet Analysis



- Spatially resolved turbulence statistics and LE, H, CH_4
- Large contribution from structures >1 km
- Mesoscale transport is not "visible" in flux tower measurements

Wavelet Analysis



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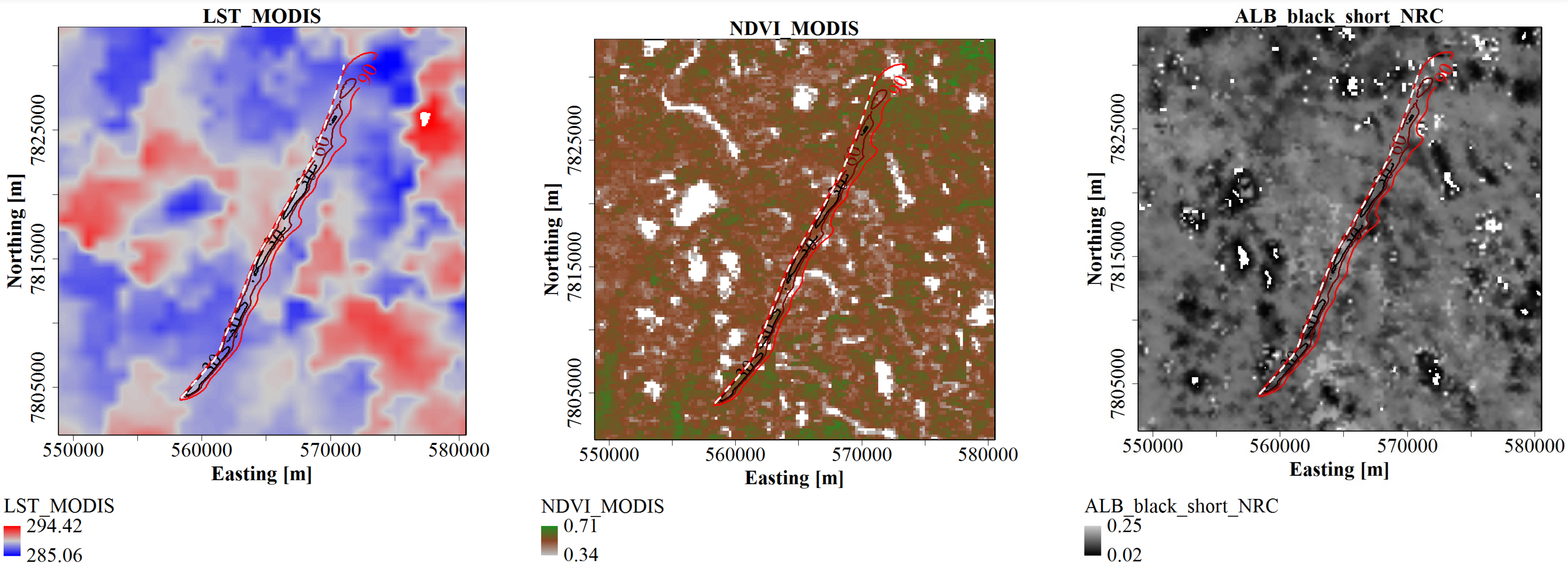
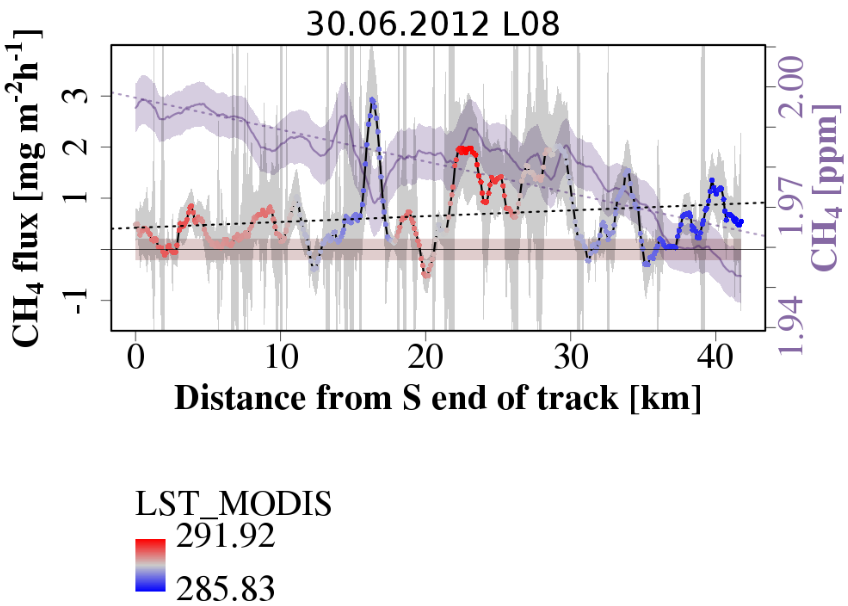


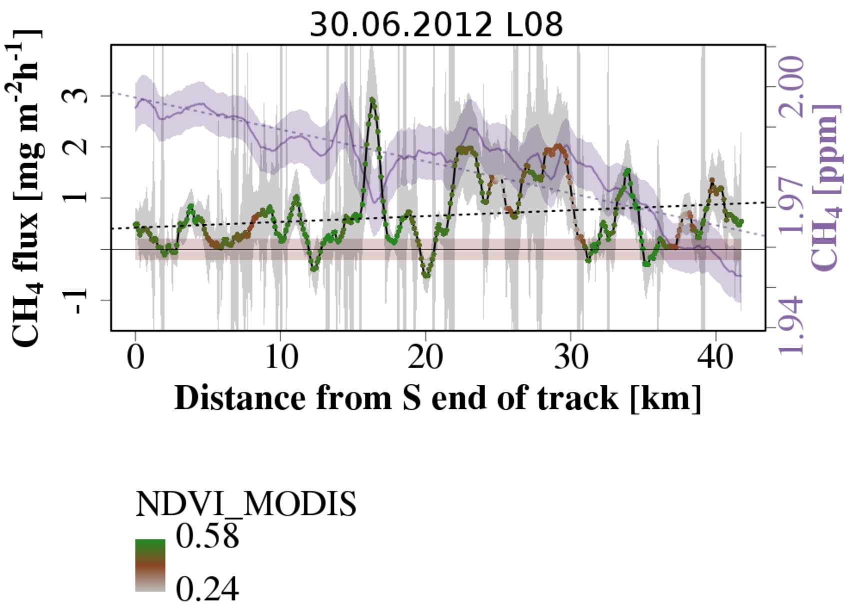
Footprint model of Kljun et al. (2004)

80% cum. footprint distance:

- **250–8400 m, median 800 m**
- **Spatially resolved contribution of land cover, LST, NDVI, EVI etc to each flux observation**

Turbulent CH_4 Fluxes





- **Purple: 95% confidence interval, grey: 1 σ random sampling error**
- **Color scale: dominant LST and NDVI in each 100 m slice**

QA / QC tests:

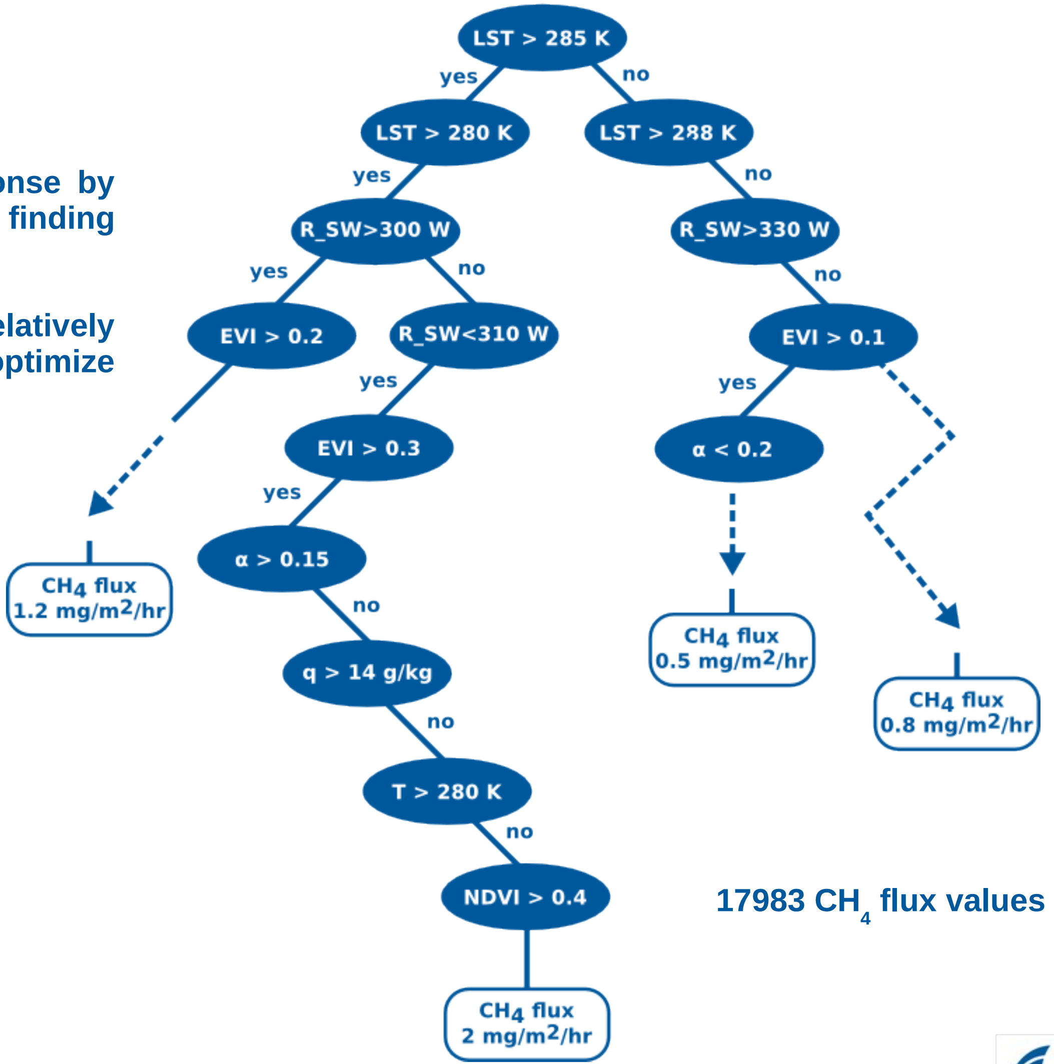
- **Steady state tests [Foken and Wichura, 1996; Vickers and Mahrt, 1997]**
- **ITC test [Foken, 2008]**
- **Rejection of fluxes below 95% detection limit**

Machine Learning

Airborne measurements & Remote sensing data

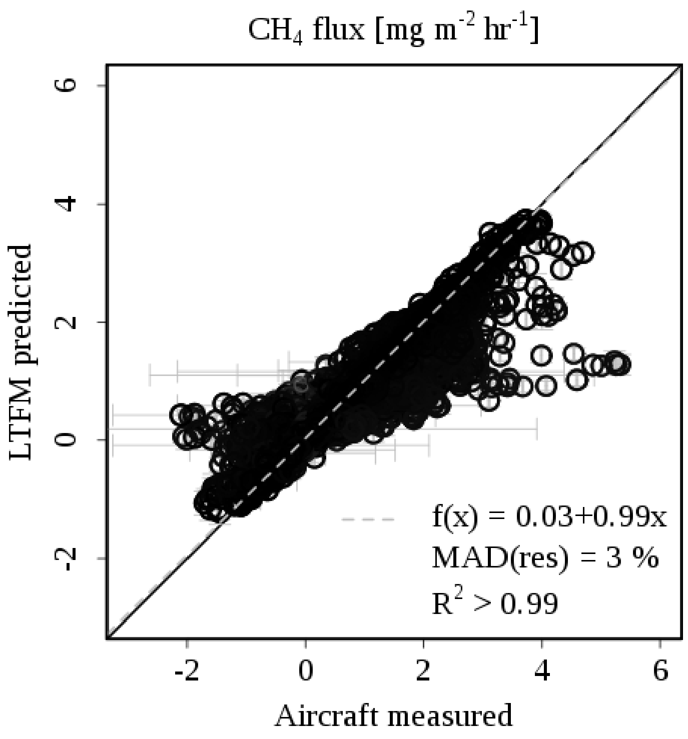
Boosted Regression Trees

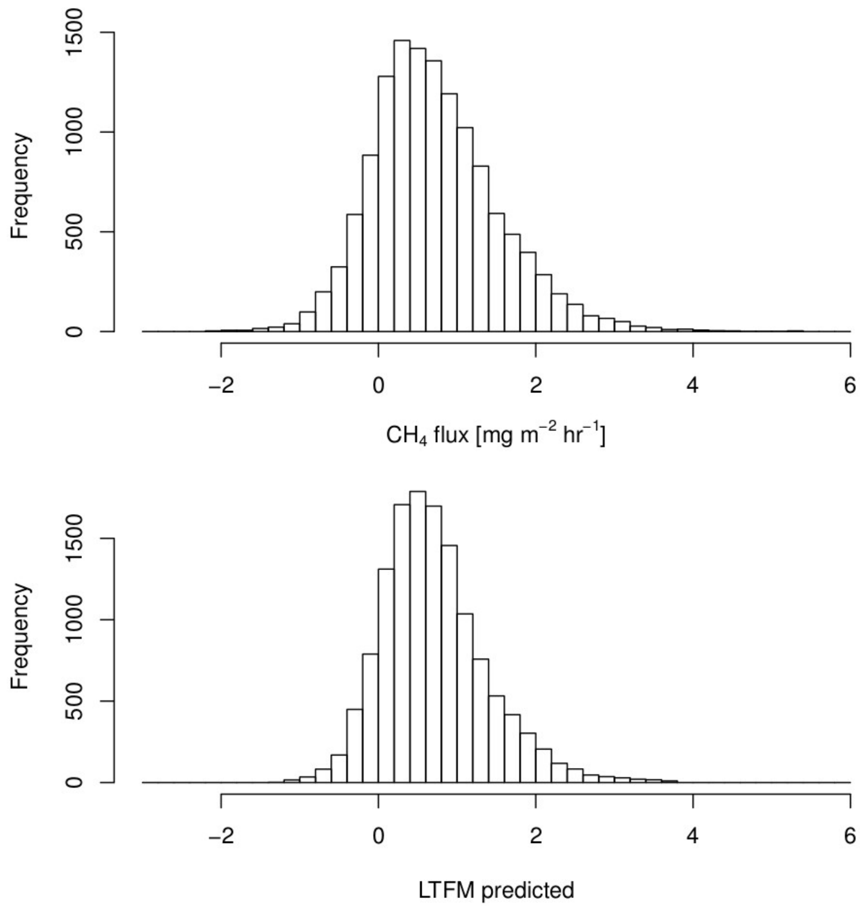
- **ML approach tries to learn the response by observing inputs and responses and finding dominant patterns (regression tree)**
- **Boosting combine large numbers of relatively simple tree models adaptively, to optimize predictive performance**



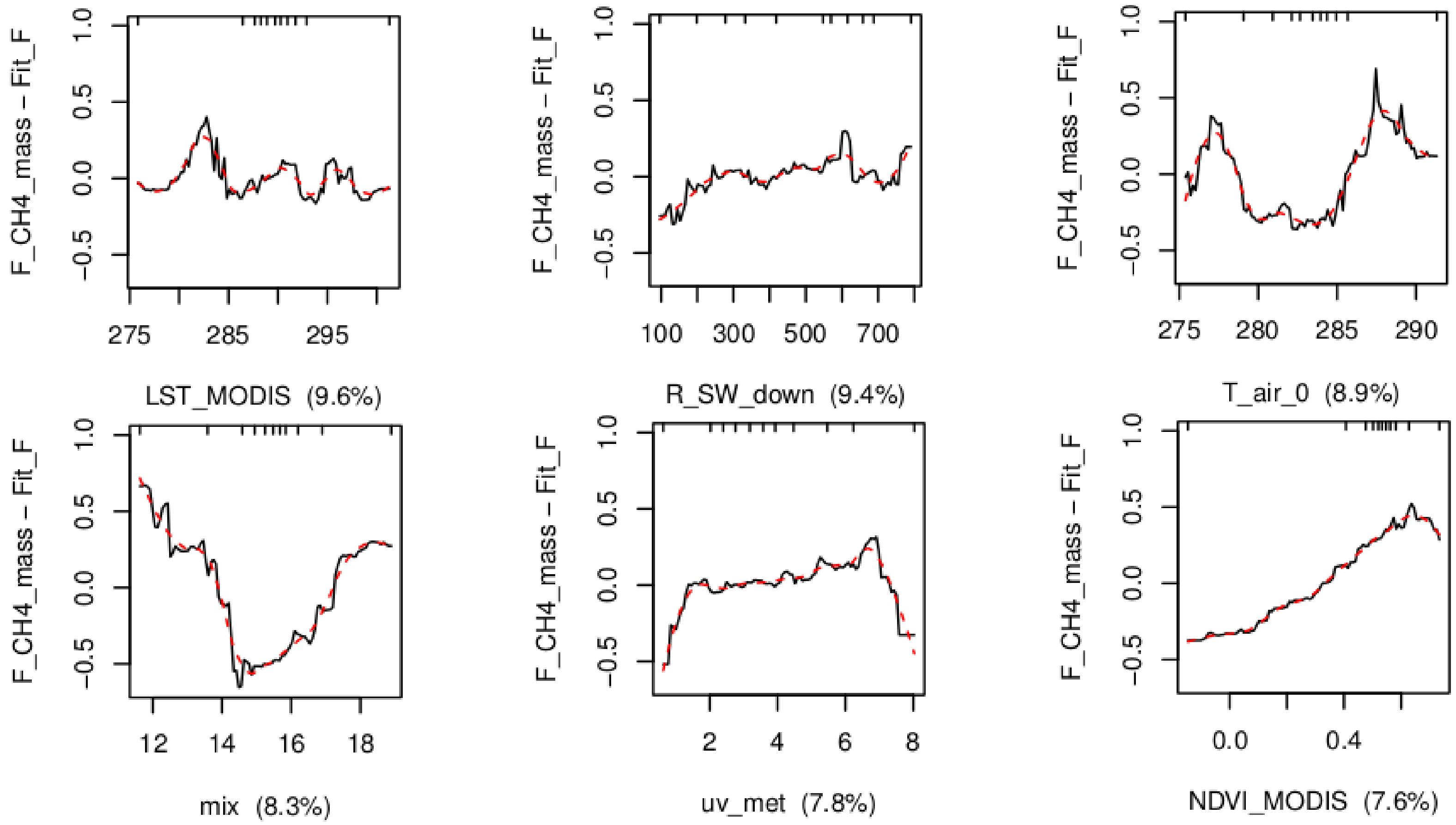
17983 CH_4 flux values

Boosted Regression Trees

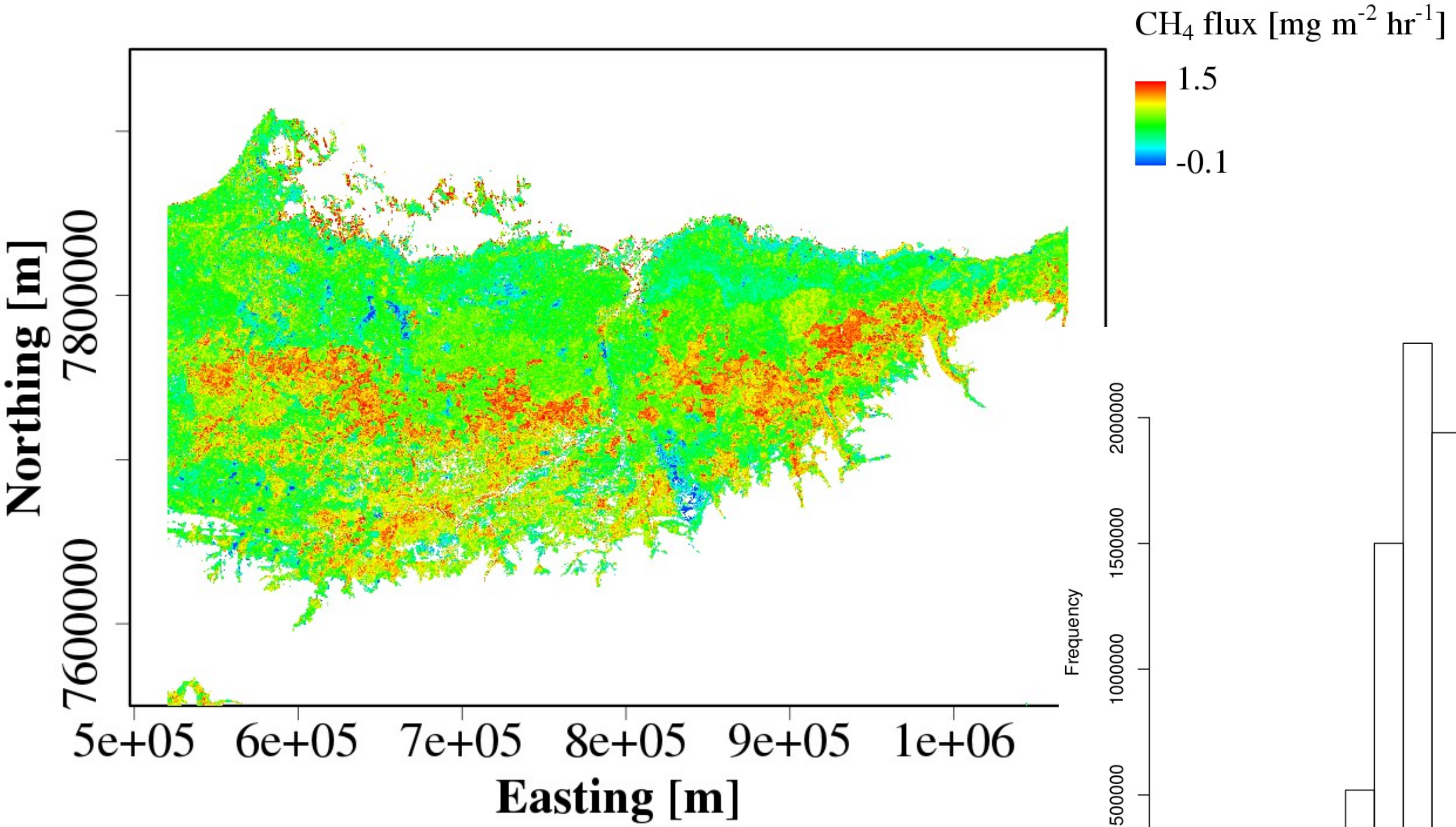


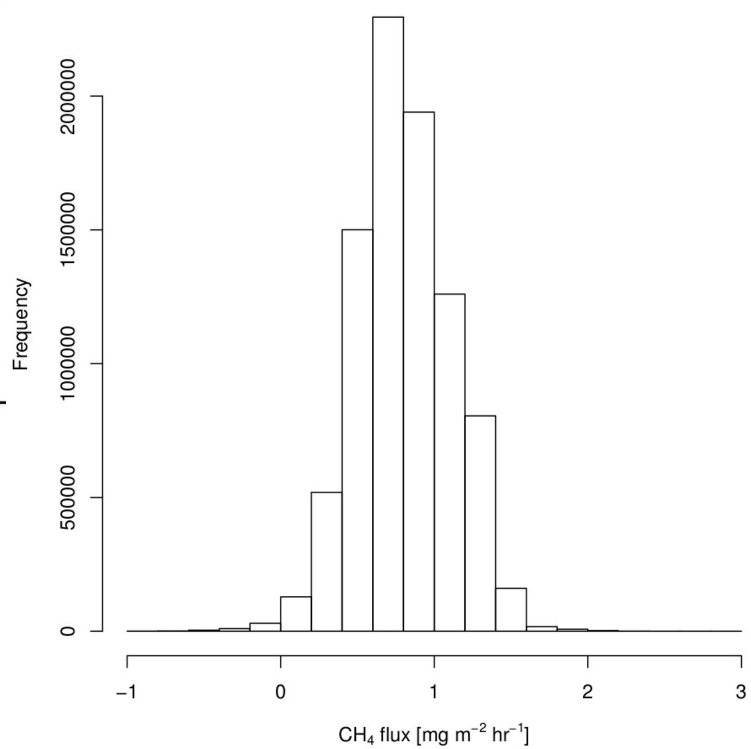


Environmental Mean Response Functions



Map of predicted CH_4 Flux

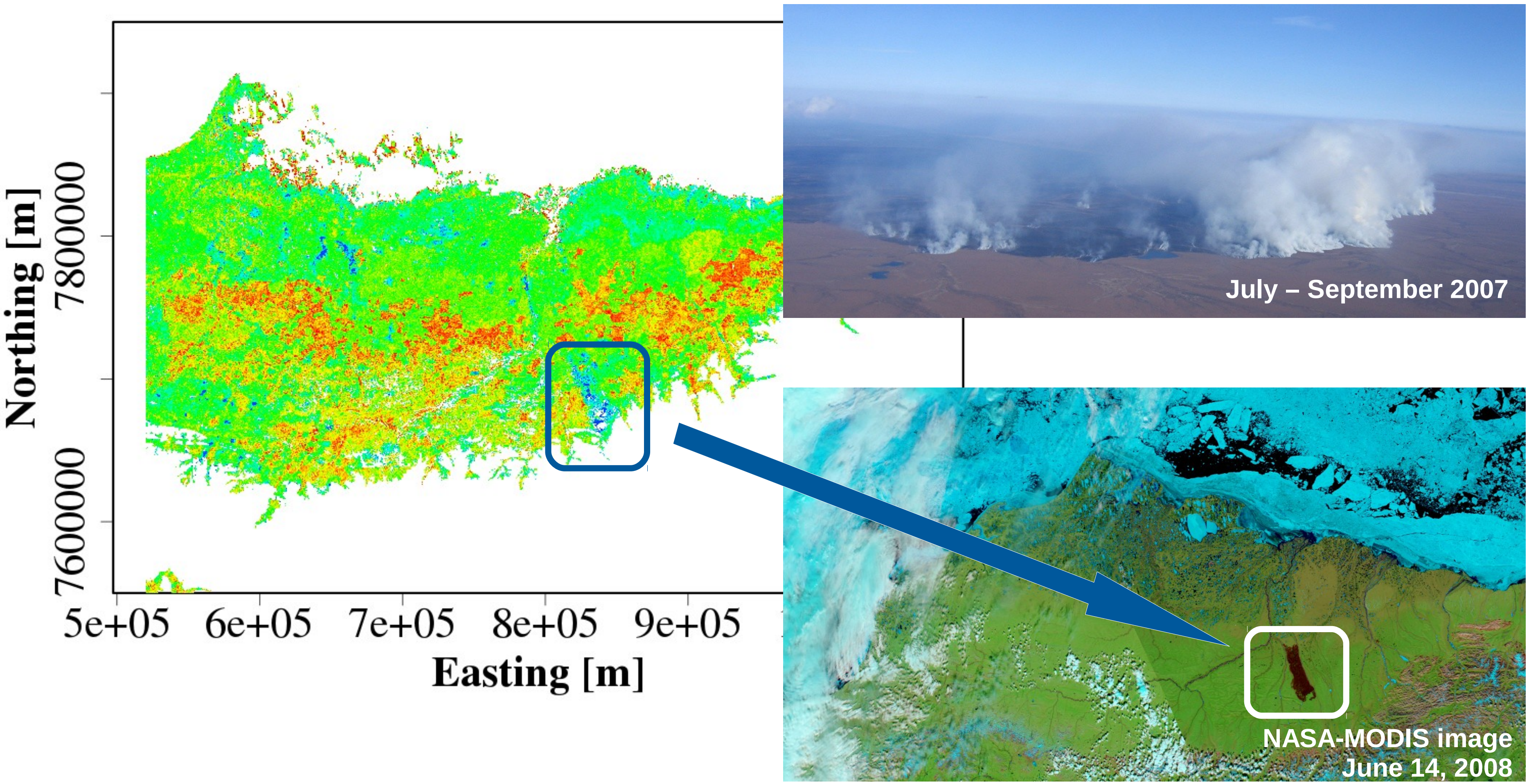




Median measured CH_4 flux along transects: 13.1 mg/m^2/day
Median predicted CH_4 flux across the area: 18.9 mg/m^2/day

Anaktuvuk River Fire

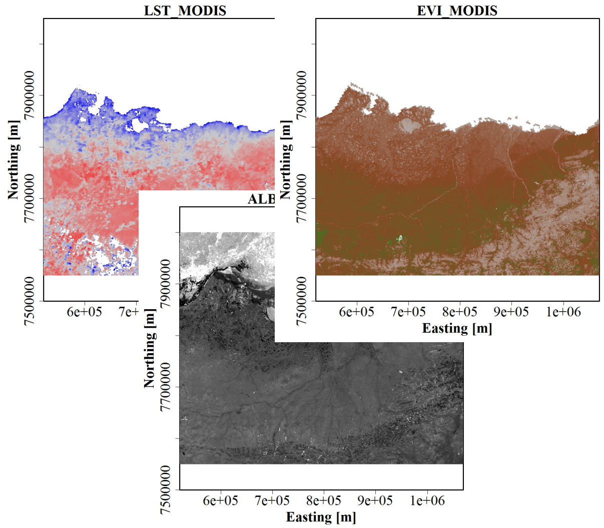
Credit: Bureau of Land Management, Alaska Fire Service



Credit: Courtesy of Jim Laundre, Marine Biological Laboratory

Future Plans

Seasonality of drivers



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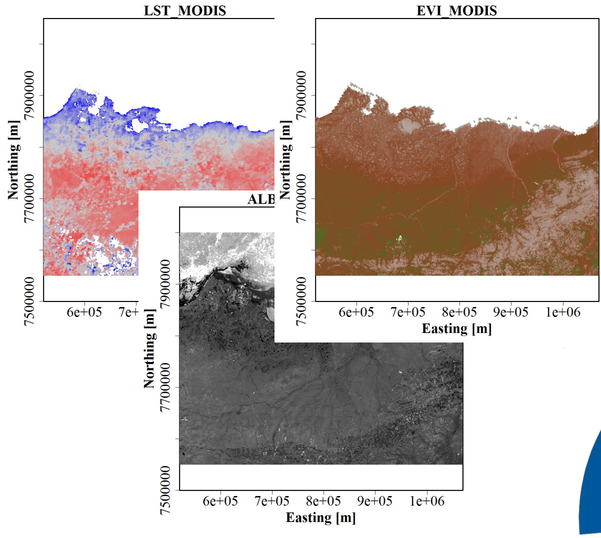
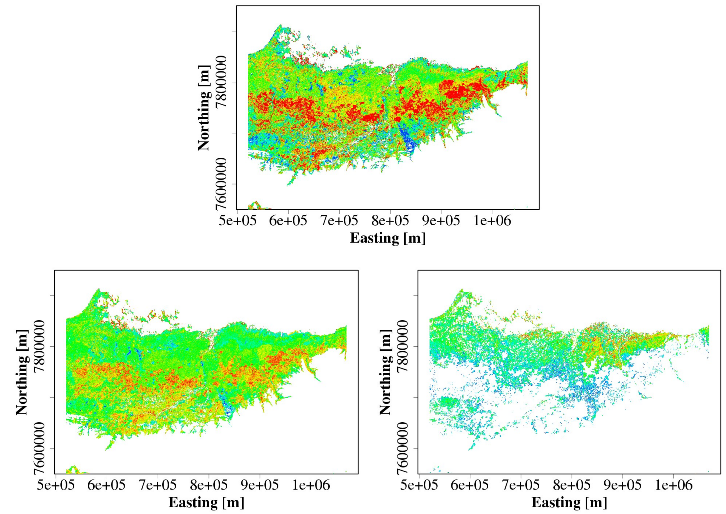


Temporal maps of predicted CH_4 flux



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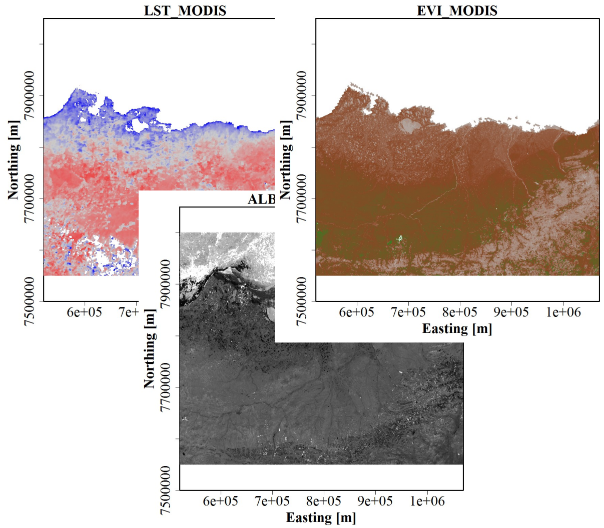

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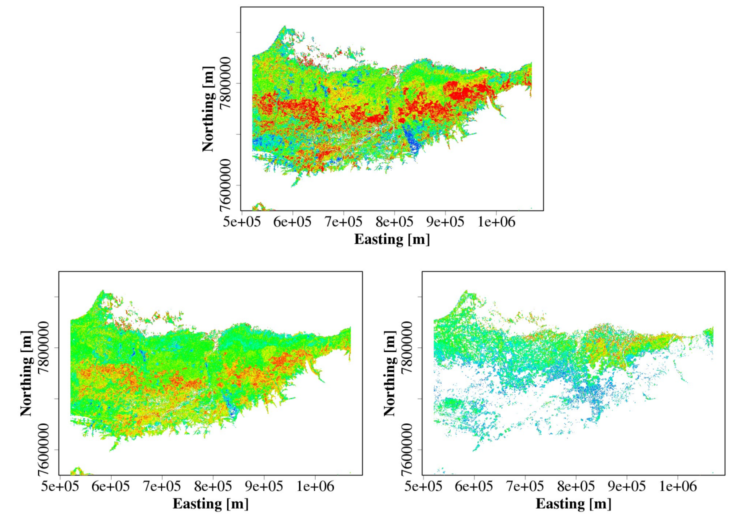
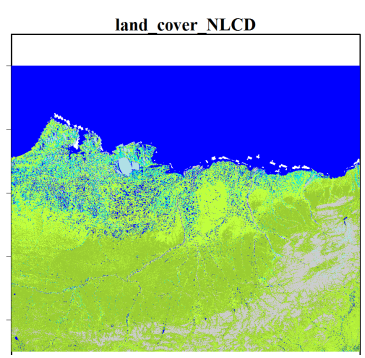


Land cover & soil type specific CH_4 budget and budget uncertainty



Land cover	CH_4 [mg/m²/hr]
Wetlands	0.8
Shurb	0.3
Sedge	0.6
...	0.4

Summary

- **Airborne flux data covering extensive areas of terrestrial permafrost**
- **Wavelet decomposition yields high spatial resolution of the flux observations**
- **Footprint modelling to map spatially resolved contribution of environmental drivers**
- **Boosted regression trees to link the methane exchange to meteorological and biophysical drivers in a high latitude permafrost areas**
- **Environmental response functions assist bridging observational scales:**
  - **isolate and quantify relevant land-atmosphere exchange processes**
  - **extend airborne flux measurements to regional scale**
  - **estimate land cover specific emission factors**
  - **assess the spatial representativeness of flux tower measurements**

Acknowledgments

Helmholtz Young Investigators Group
TEAM
Trace Gas Exchange in the Earth-Atmosphere System on Multiple Scales

- **Engineers and flight crew: Christian Müller, Christian Konrad, PIC Jon Sipko, FO Dereck Peterson, AME Luke Cirtwill**
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- **Scott Dallimore et al., Jens Greinert, Matthias Mauder, and many more**