Simulation-driven analysis of airborne in-situ observations of natural methane emissions in northern Scandinavia

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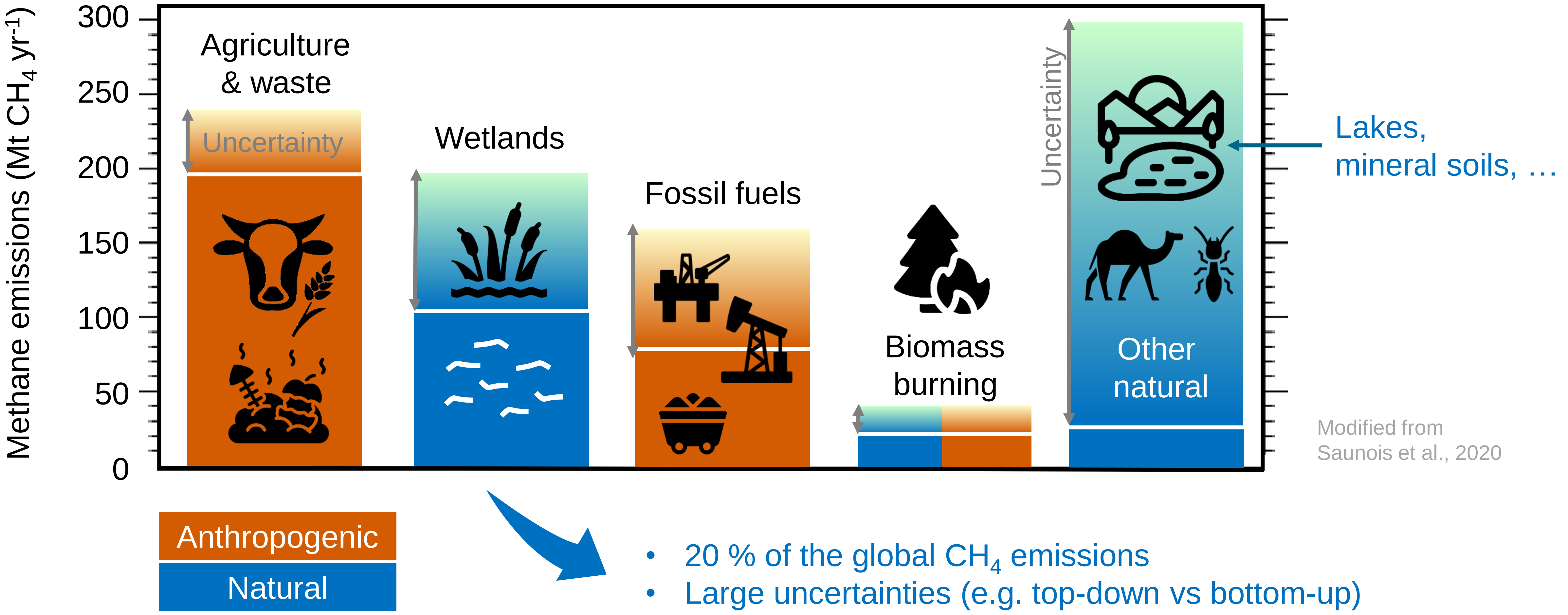
DLR

BACKGROUND

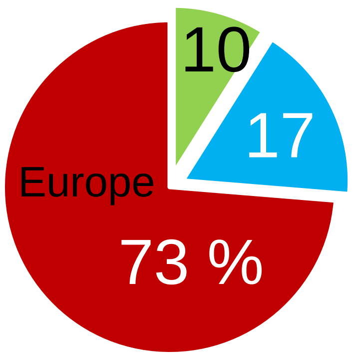
BACKGROUND
Global methane budget

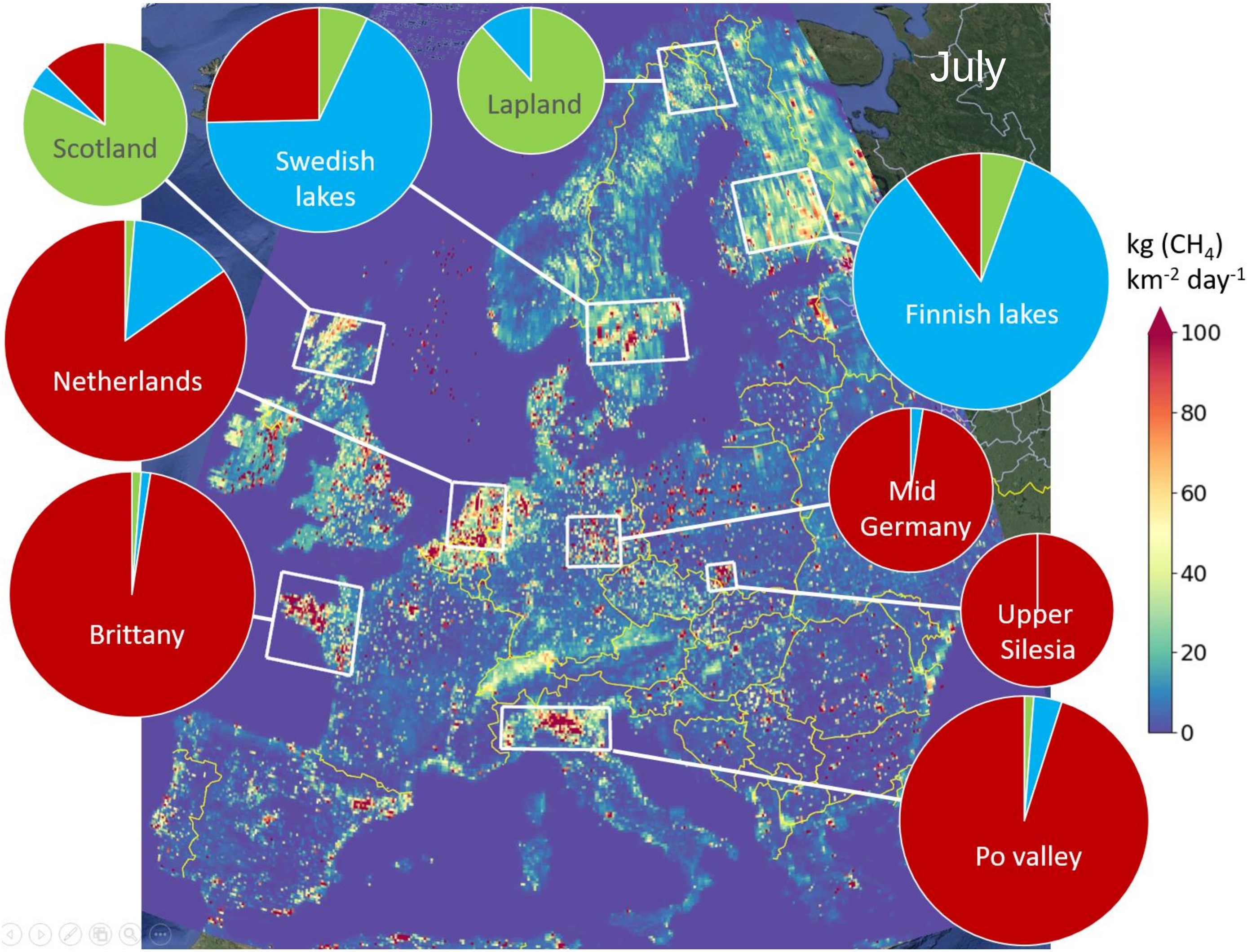


- 20 % of the global CH_4 emissions
- Large uncertainties (e.g. top-down vs bottom-up)
- Affected by climate change

BACKGROUND
Methane emissions‘ hotspots in Europe

- Anthropogenic (EDGAR 8.0)
- Lakes (Johnson et al. 2022)
- (Wet)Land JSBACH-HIMMELI



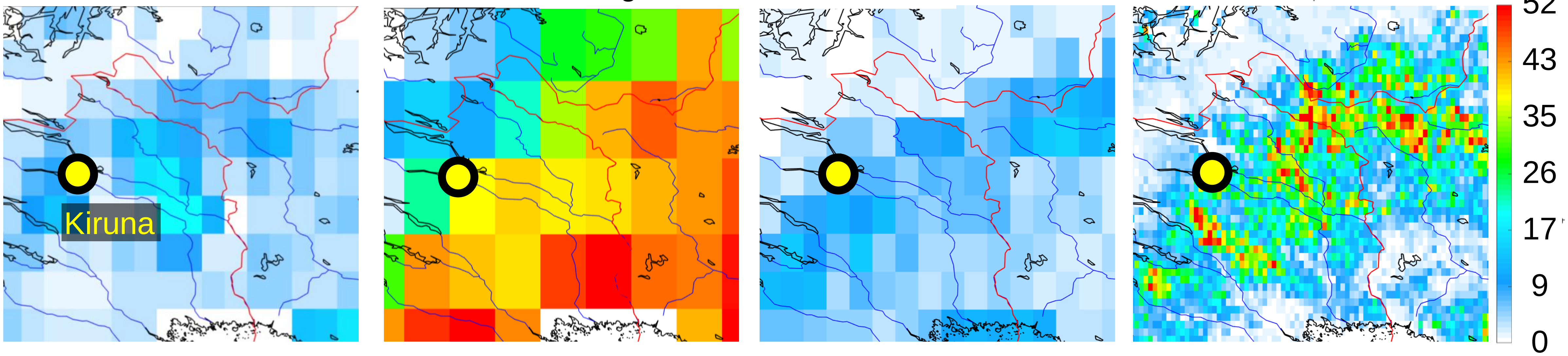


Lapland dominated by wetland emissions

BACKGROUND
Emission inventories

August mean emissions

Graphics: DLR / A. Fiehn



WetCHARTs	LPJ-WHyMe	LPX-Bern	JSBACH-HIMMELI
Process-based wetland emission model ens.	Dynamical vegetation model	Dynamical vegetation model	Biogeochemical model

CH_4 kg km^{-2} day^{-1}

Large discrepancies = Uncertainties

BACKGROUND
How can airborne in-situ CH_4 measurements help?

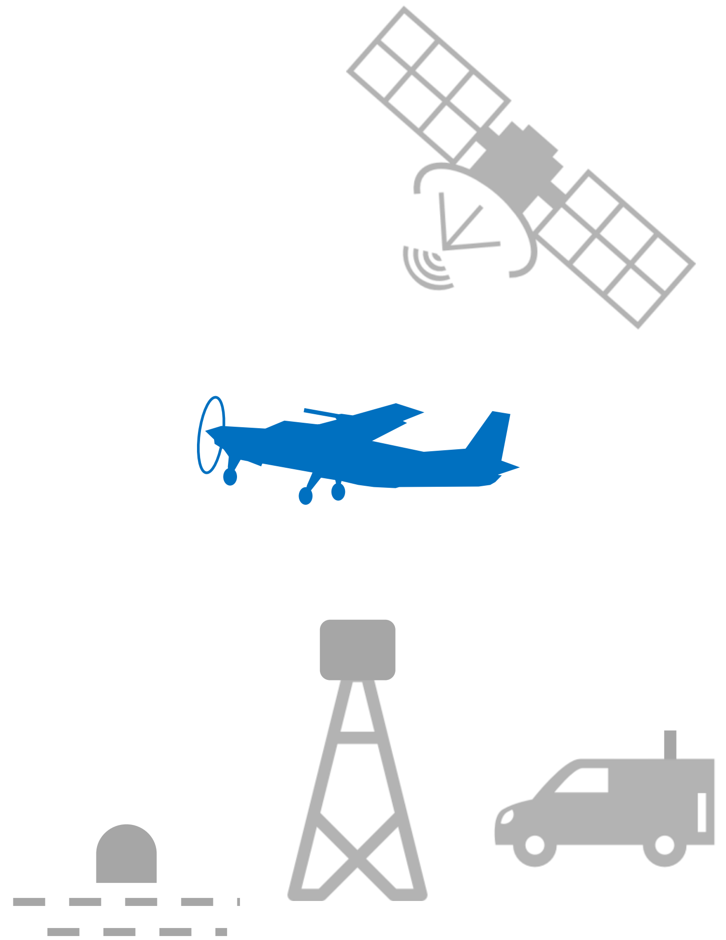
- Bridging spatial scales between ground-based and satellite data

- Supplement passive satellite sensors that struggle with
  - high solar zenith angle
  - difficult surface and thermodynamic conditions

- Provide high-quality data for validation of space missions
  → Currently few regional scale and profile data available
  for high northern latitudes

**Regional snapshots,
complementing other observations**

- **Allowing for regional flux estimates
  and process-related studies**



MAGIC 2021 CAMPAIGN

Monitoring of **A**tmospheric composition and **G**reenhouse gases through multi-**I**nstruments **C**ampaigns

→ 2021 in Kiruna

MAGIC 2021 CAMPAIGN
DLR Cessna

- Flexible measurement platform
- Operated mostly in the boundary layer during MAGIC
- Measured along flight track:
  Methane, 3d wind, T, p, $^{13}C(CH_4)$, CO_2, C_2H_6, H_2O
  @ 1 … 10 Hz
- In-situ instrumentation less affected by bad weather than remote sensing

Photo: DLR / K. Gottschaldt

Main scientific objective:
Evaluate inventories with observation-based flux estimates

MAGIC 2021 CAMPAIGN
Methane measurements

Mixing ratios

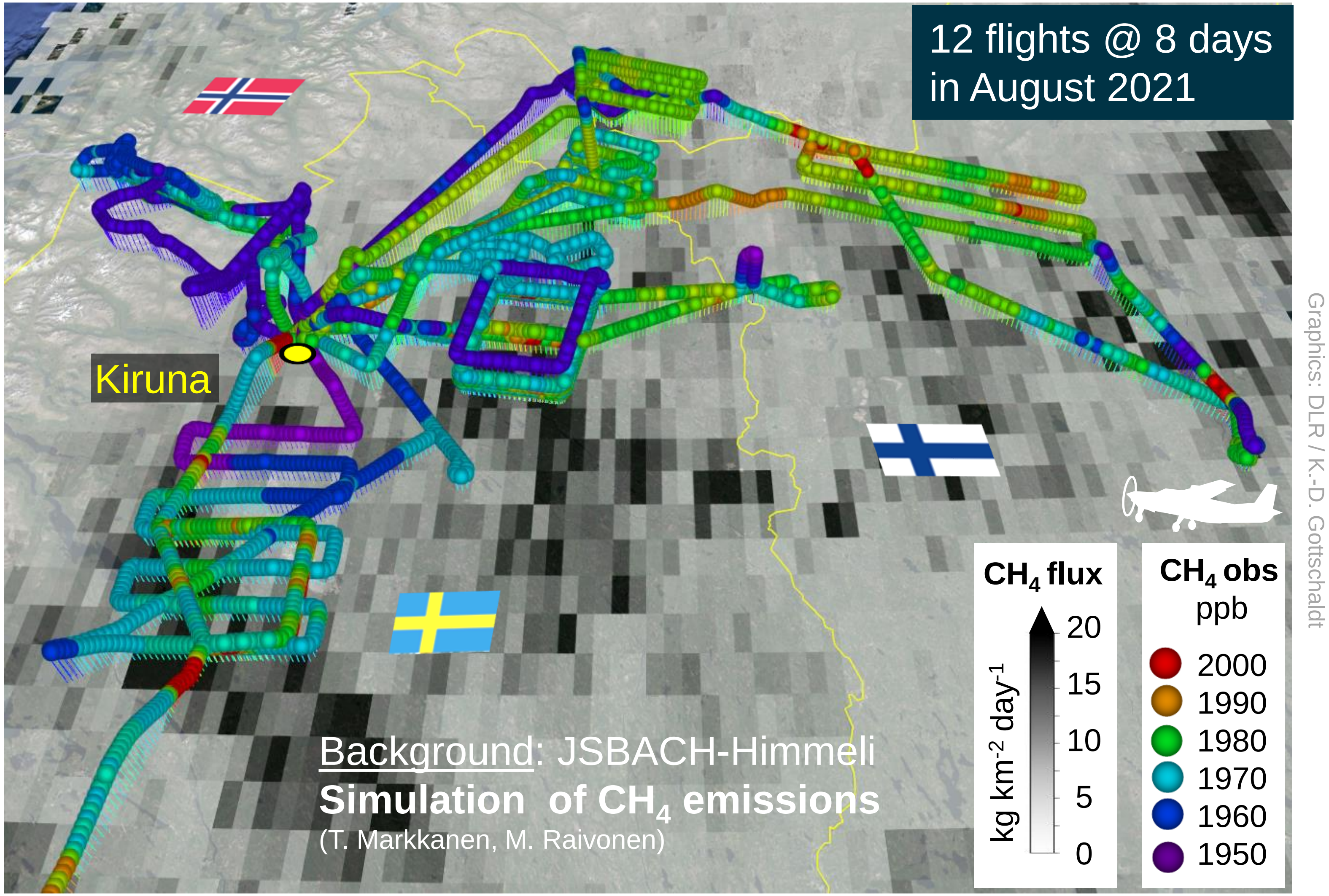
- Measured
- Observed variability ~50 ppb

Emission fluxes

- To be derived
- Area sources

Other methodologies needed than for point sources

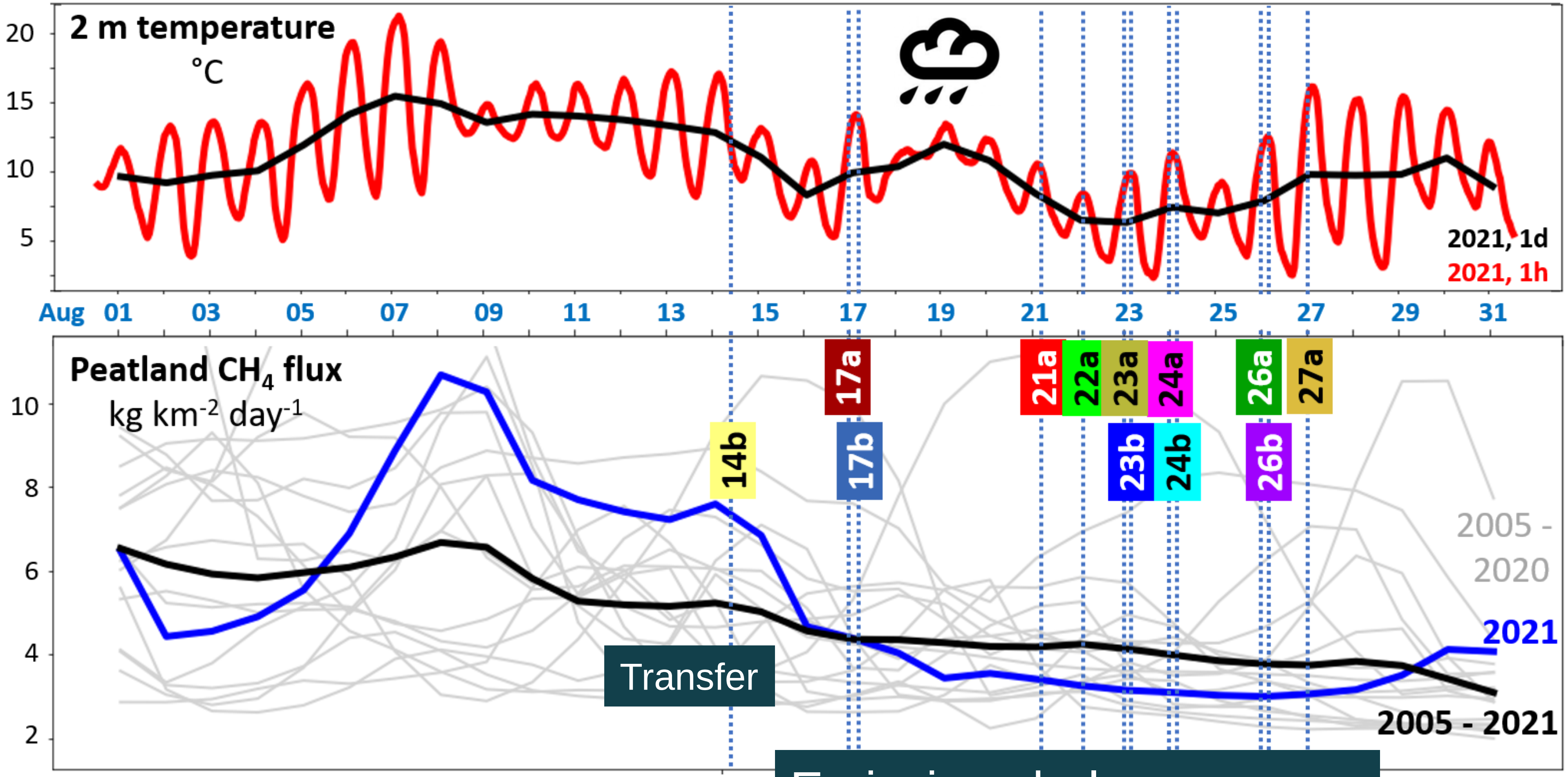
1. Eddy covariance
2. Inverse modelling
⋮



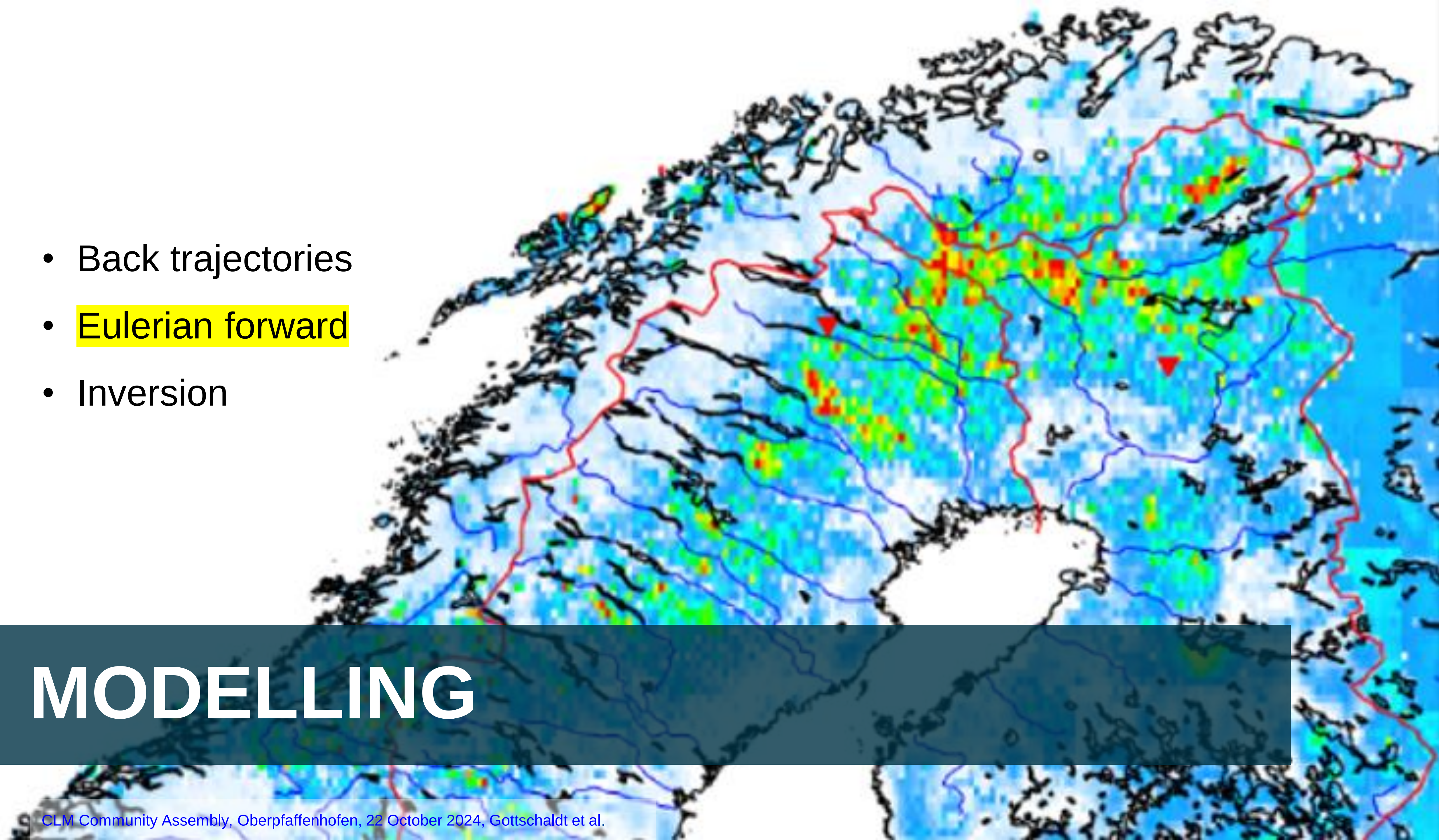
MAGIC 2021 CAMPAIGN
Putting the flights into perspective

ERA5

JSBACH-HIMMELI



Emissions below average



- Back trajectories
- Eulerian forward
- Inversion

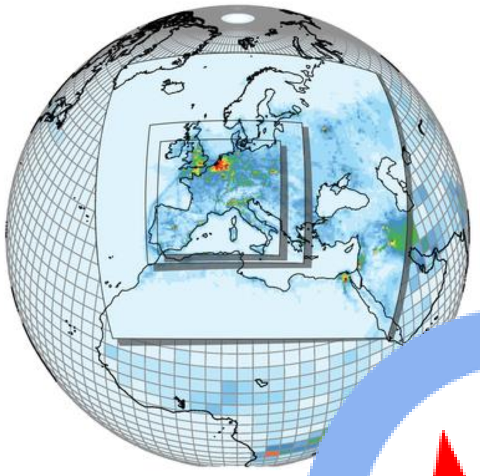
MODELLING

MODELLING
Regional Eulerian forward simulation

- MECO(n) = global ECHAM + regional COSMO

  MESSy-fied ECHAM and

  COSMO/MESSy models nested n times

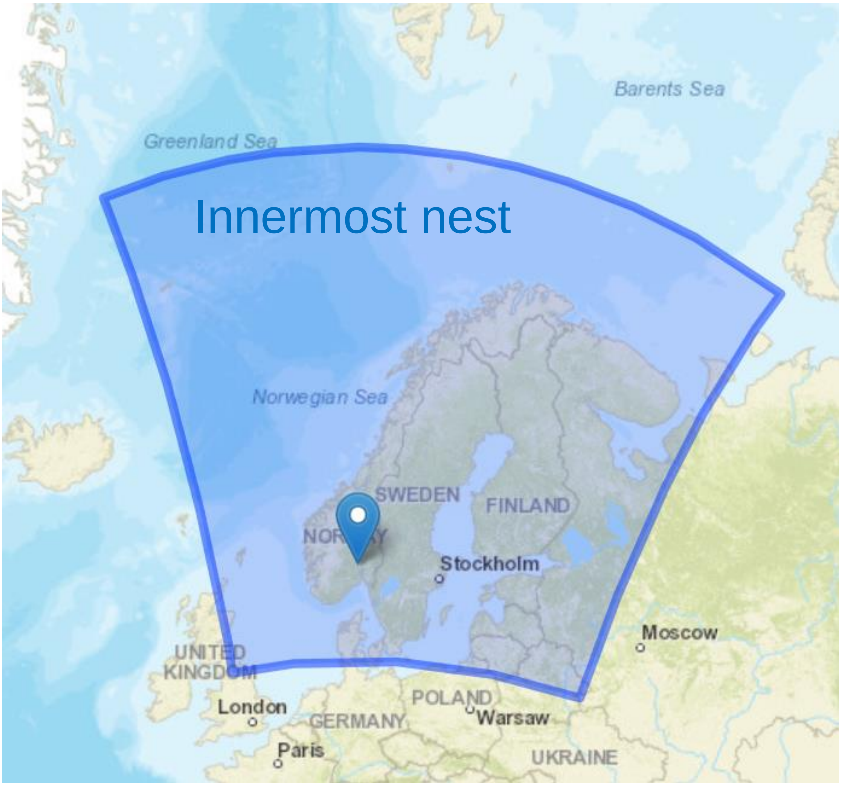


Jöckel et al. (2010)
Kerkweg & Jöckel (2012ab)
https://messy-interface.org

- **Characterization of sources contributing to the observations,** where the simulation sufficiently reproduces the measurements → Identify deficiencies in inventories or model
- **Estimate background CH_4 for inverse modelling**

MODELLING
MECO(2) setup

Global ECHAM (EMAC) instance	Regional COSMO nests
T106	50 km and 7 km nests with dynamical and chemical bc from global instance
Synoptic scale dynamics nudged to ERA5	Without nudging, but coupled via boundaries
Full chemistry	CH_4 sink due to OH and dry deposition
Branched off a decadal global simulation, July 2021 spinup	August 2021 for analyses
Dedicated output along the given flight tracks (curtains) each time step (S4D) → **Best possible co-location**	



Acknowledgement HPC:
DKRZ project bd0617
„Multiscale Earth System Chemistry Modelling“

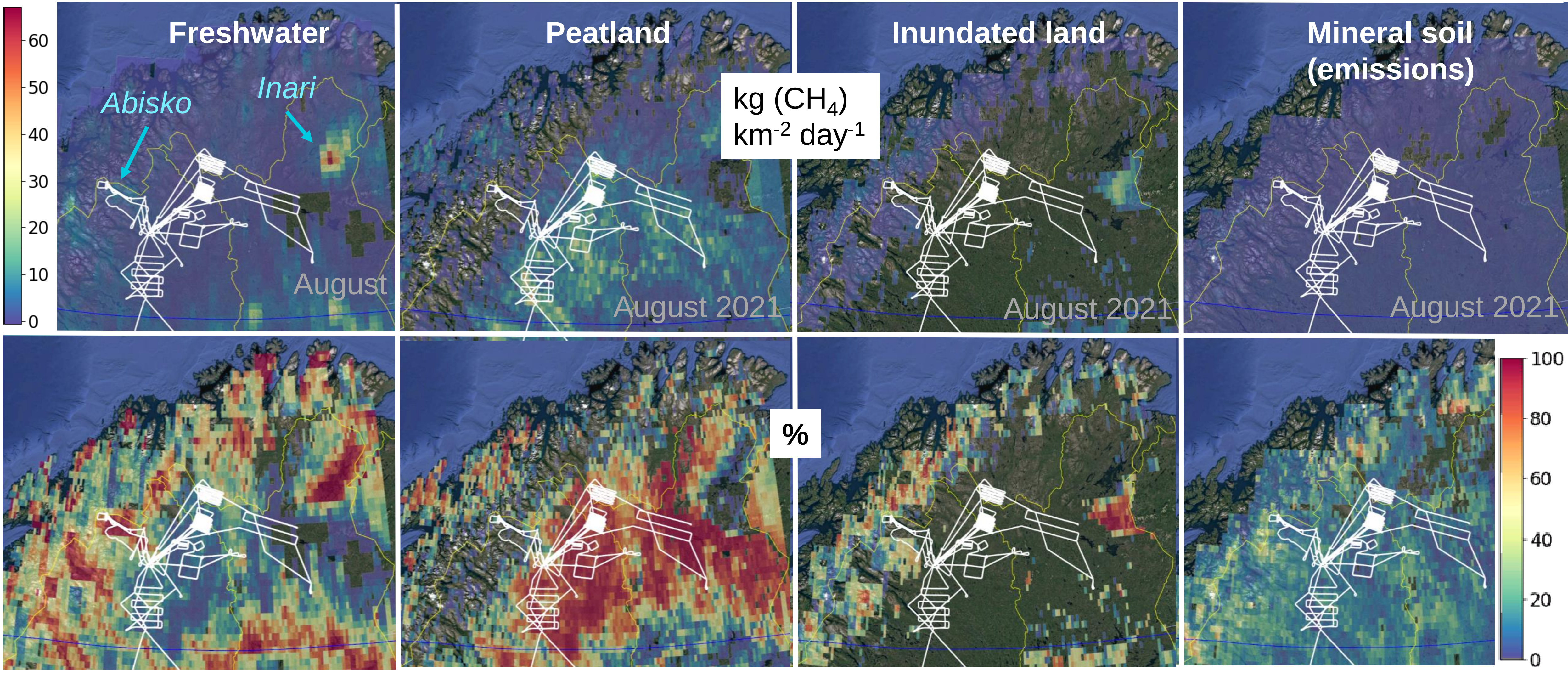
MODELLING
Methane inventories for campaign analyses

	EMAC	COSMO		
EDGAR + EMPA total CH_4	✓	✓ +bc	Inversion-optimized anthropogenic + natural	Other years
WetCHARTs mean	✓	✓ + bc	Wetlands	Other years
WetCHARTs #2913	✓	✓ + bc	Wetlands	Other years
JSBACH-HIMMELI	✓	✓ + bc	Peatland + inundated land + mineral soil	Other years
JSBACH-HIMMELI		✓ + bc	Peatland + inundated land + mineral soil	Daily for campaign period
JSBACH-HIMMELI		✓ + bc	Peatland	Daily for campaign period
JSBACH-HIMMELI		✓ + bc	Inundated land	Daily for campaign period
JSBACH-HIMMELI		✓ + bc	Mineral soil emissions	Daily for campaign period
Johnson et al. (2022)	✓	✓ + bc	Freshwater diffusion + ebullition	Other years
GFAS → MESSy BIOBURN	✓	✓ + bc	Biomass burning	Other years

bc = Transport across boundaries into finer domain
(One-way coupling)

Selection of separate methane tracers

MODELING
Individual emission classes: JSBACH-HIMMELI

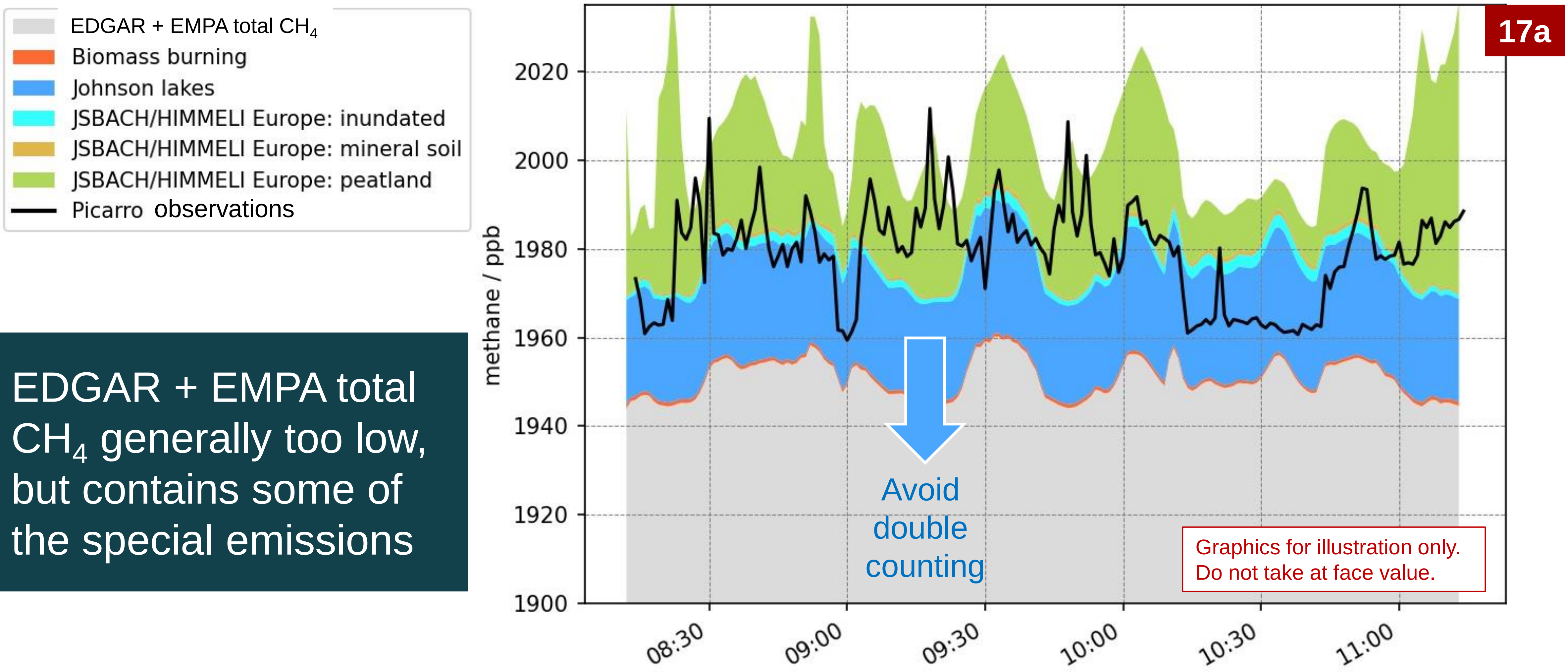


Inventories: FMI / Markkanen & Raivonen | Background: Google Earth | Graphics: DLR / Gottschaldt

PRELIMINARY RESULTS

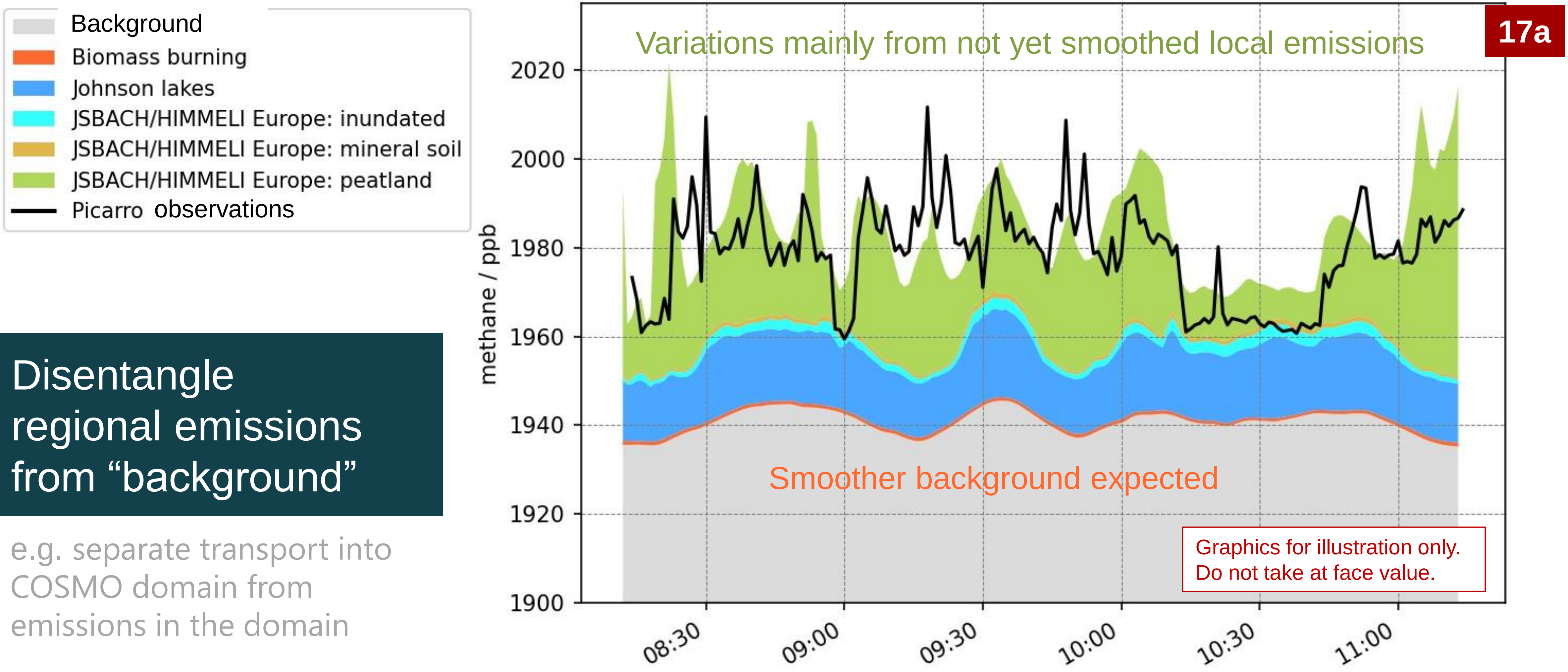
Photo: DLR / K.-D. Gottschaldt

PRELIMINARY RESULTS
Contributions of individual sources to measurements



EDGAR + EMPA total CH_4 generally too low, but contains some of the special emissions

PRELIMINARY RESULTS
Contributions of individual sources to measurements



Disentangle regional emissions from "background"

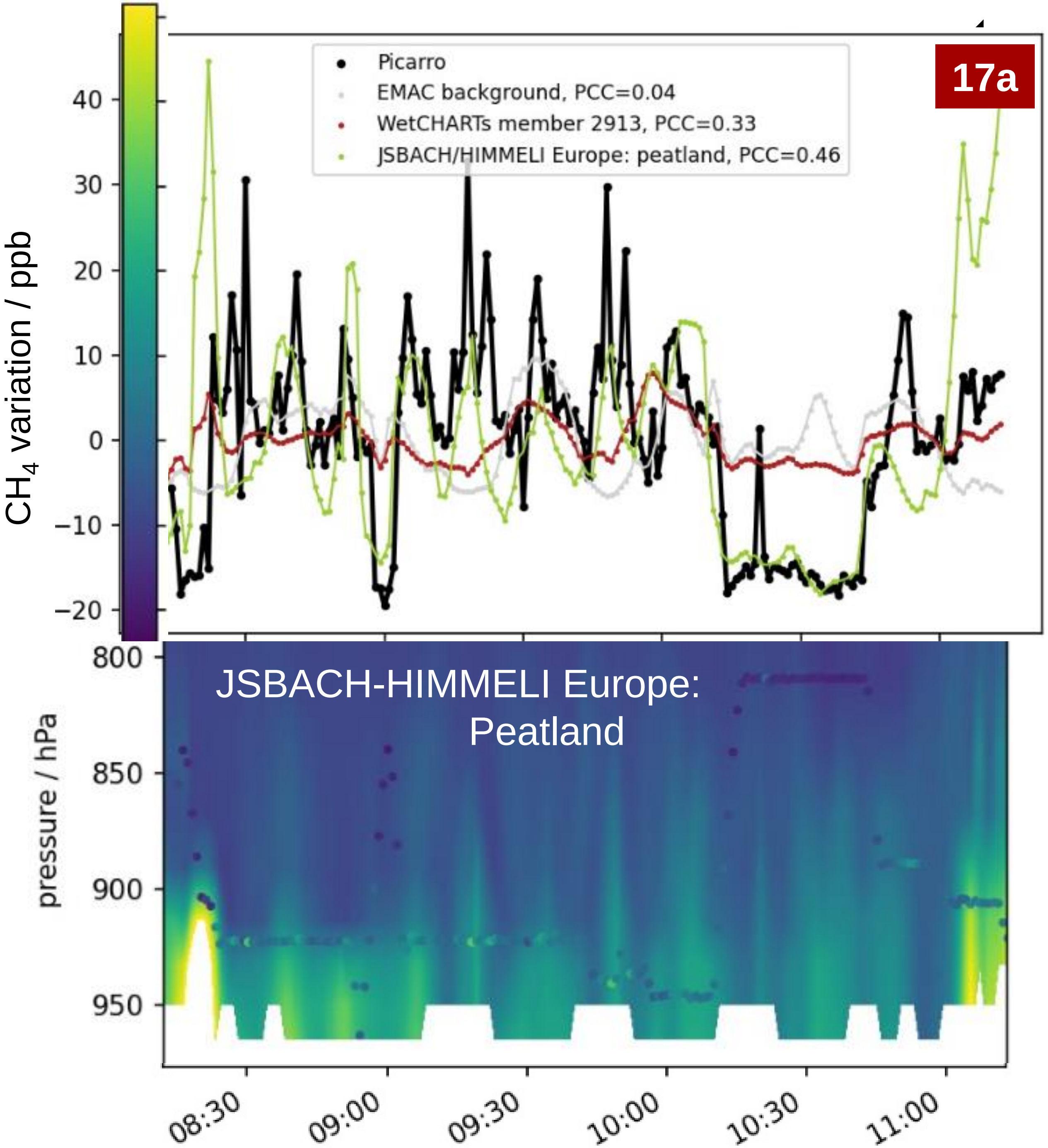
e.g. separate transport into COSMO domain from emissions in the domain

PRELIMINARY RESULTS
Example: Variations

- Double counting issues affect absolute values

→ Analyse variations instead

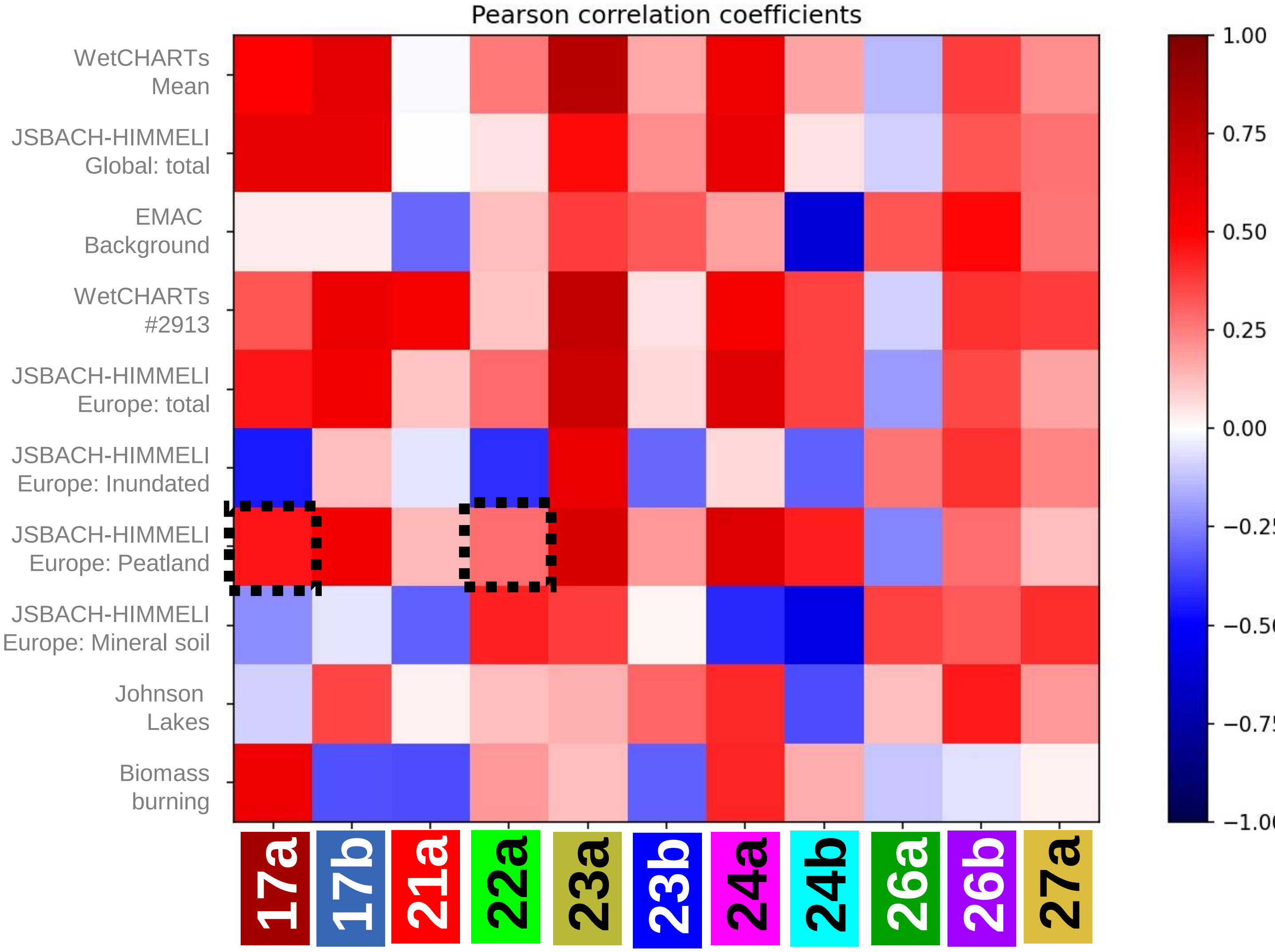
- Variations along track correspond to spatial gradients
- Gradients likely reflect local emissions
- Emission flux estimates use gradients
- Curtains may provide hints on deviations due to representation of vertical gradients in the PBL



PRELIMINARY RESULTS
Correlations of variations

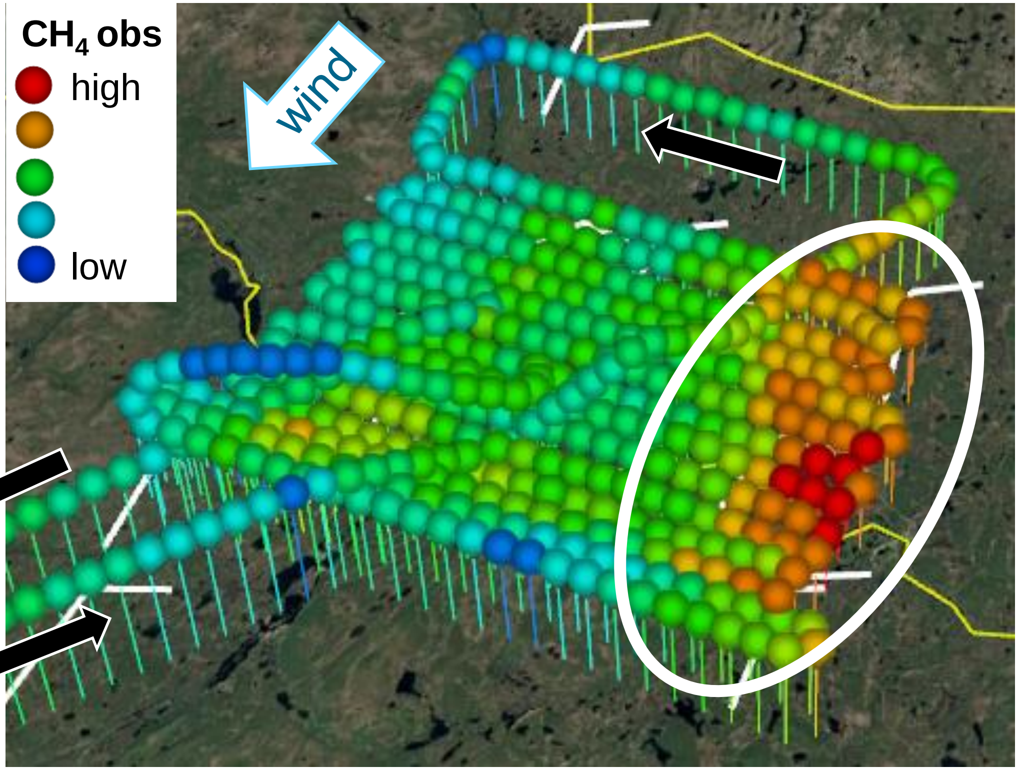
- Indication of which emissions dominate the observed variation per flight
- Compare inventories

- Refine by e.g. separating profiles from level measurements
- Consider additional statistical parameters

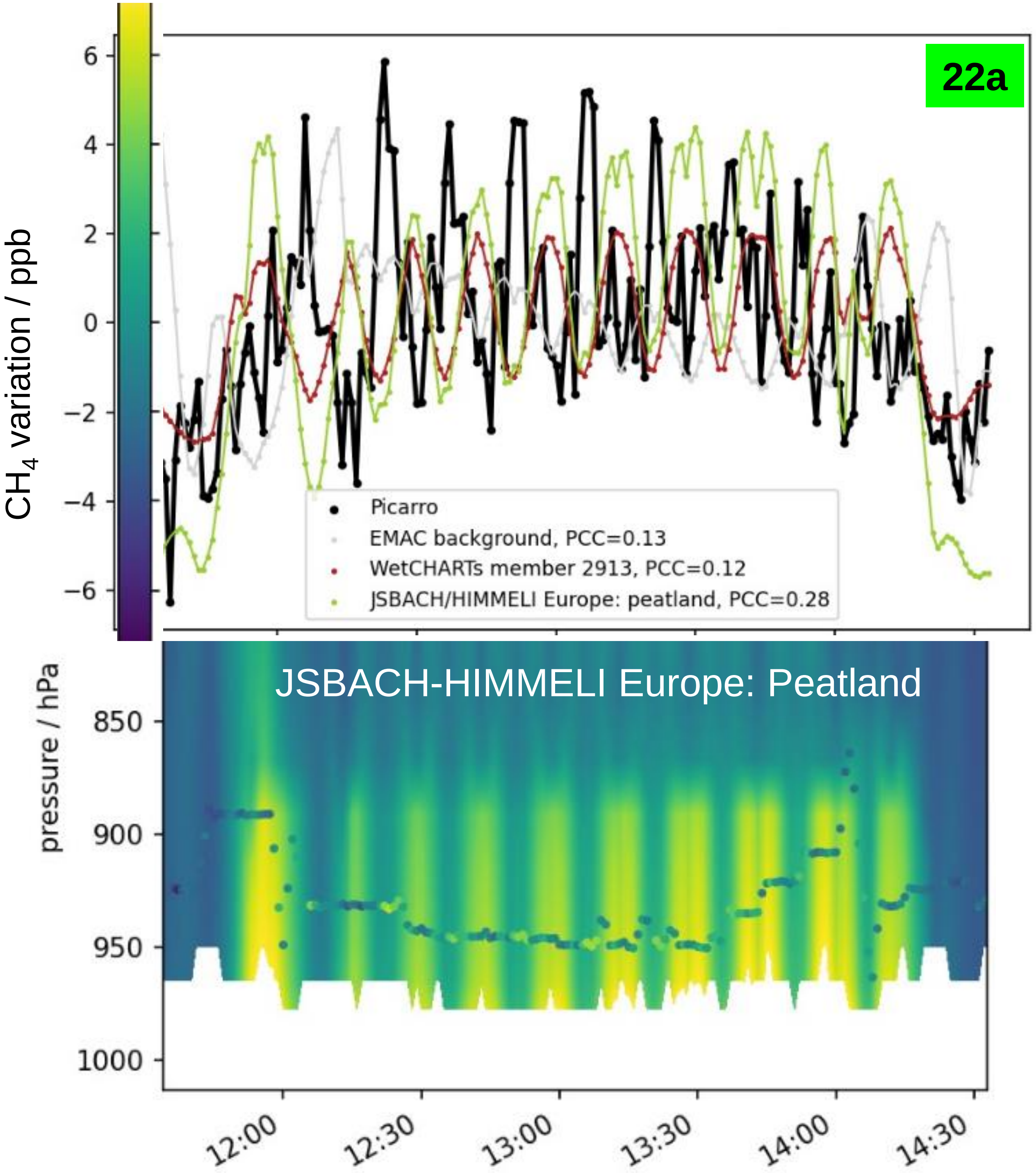


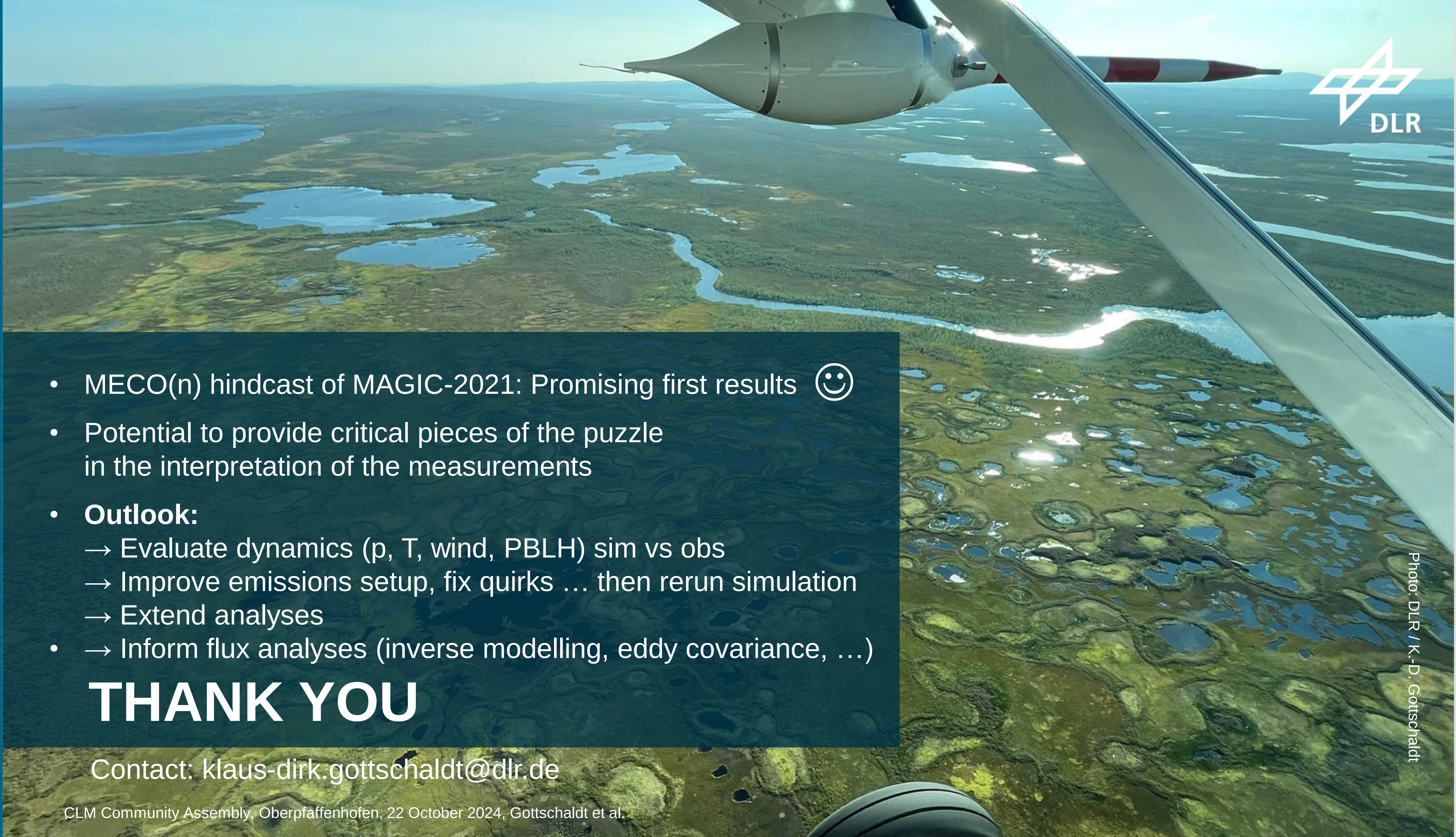
Interpret case by case

PRELIMINARY RESULTS
Example: Narrow miss?



Distinct airmass at eastern edge of the flight pattern might just be at a slightly different position in the simulation → Check 4d output fields





- MECO(n) hindcast of MAGIC-2021: Promising first results ☺
- Potential to provide critical pieces of the puzzle
  in the interpretation of the measurements
- **Outlook:**
  → Evaluate dynamics (p, T, wind, PBLH) sim vs obs
  → Improve emissions setup, fix quirks … then rerun simulation
  → Extend analyses
- → Inform flux analyses (inverse modelling, eddy covariance, …)

THANK YOU

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Photo: DLR / K.-D. Gottschaldt

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