Monitoring of greenhouse gases - methane (CH_4) and carbon dioxide (CO_2) - modelling of emissions and fluxes

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Susana Lopez-Aparicio, Hendrik Grythe, Leonor Tarrasón
Arve Kylling, Philipp Schneider, Martin Album Ytre-Eide, Kerstin Stebel
and colleagues

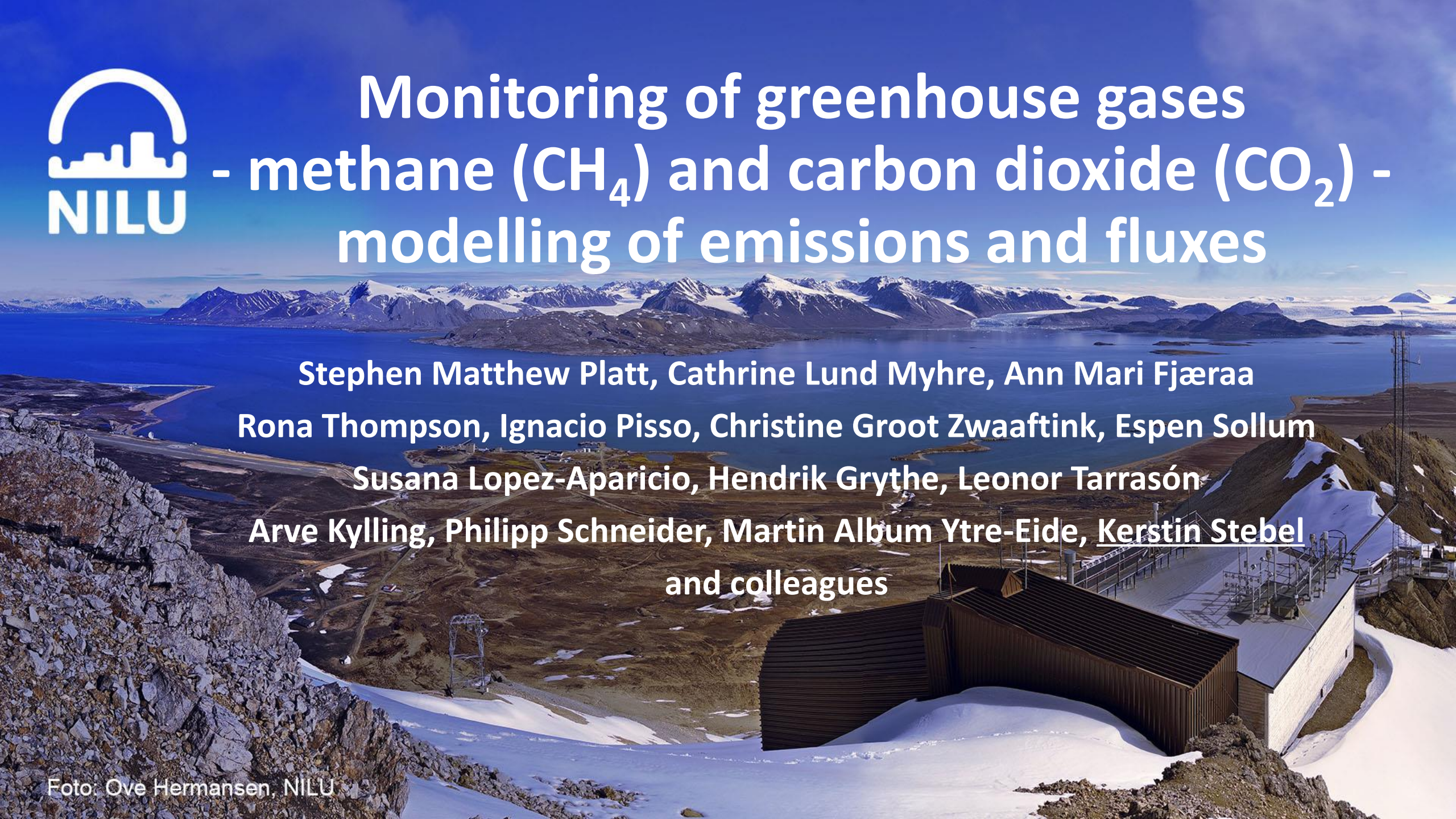

Foto: Ove Hermansen, NILU

GHG Monitoring

Foto: Ove Hermansen, NILU

Atmospheric ICOS stations in Norway

Zeppelin Observatory, Svalbard

- Unique location for atmospheric monitoring of the Northern Hemisphere and Arctic changes
- Established in 1989 (moved from Ny-Ålesund)
- Part of the national monitoring of greenhouse gases since 1999
- ICOS since 2012 (Class 1 since 2017)

Birkenes Observatory, Aust-Agder

- Established in 1971, downwind of the European continent, receiving air and pollution from Europe (regional change)
- Upgrade in 2020 to include 75 m mast to minimise influence of vegation next to the station
- ICOS Class 2 since 2021

ICOS | INTEGRATED CARBON OBSERVATION SYSTEM

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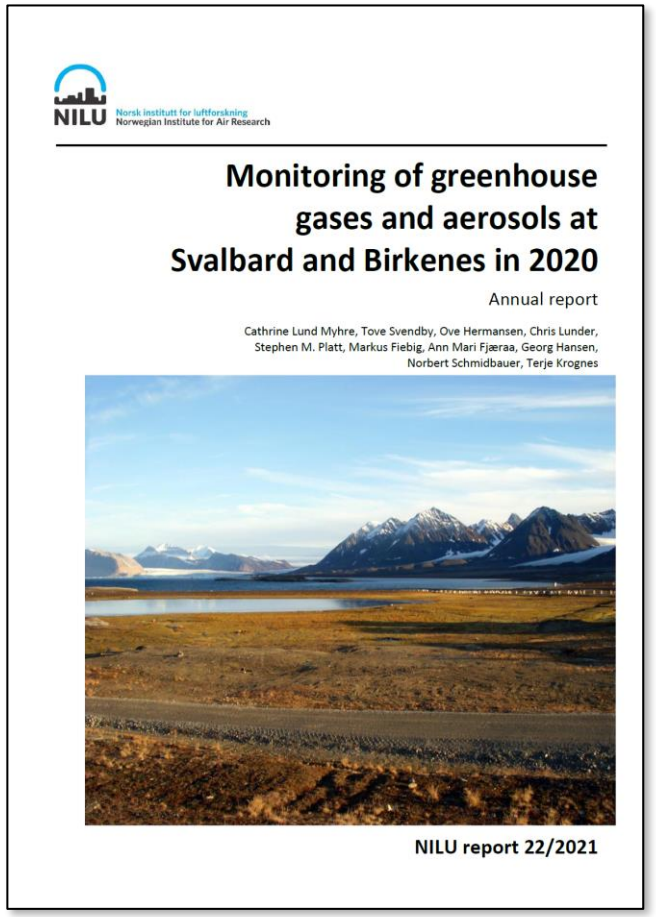
The greenhouse gas and aerosol monitoring program



- The Norwegian Environment Agency funds measurements of 40 greenhouse gases at Zeppelin, including ICOS operational costs for CO_2/CH_4
- ICOS implementation at both sites funded via ICOS Norway (NFR Infrastructure project)
- ICOS operational phase at Birkenes funded by NILU

- Optical, physical properties of particles, Birkenes and a few at Zeppelin
- Numerous measurement programmes:

emep ACTRiS ICOS INTEGRATED CARBON OBSERVATION SYSTEM AGAGE NOAA WMO GAW

ICOS INTEGRATED CARBON OBSERVATION SYSTEM

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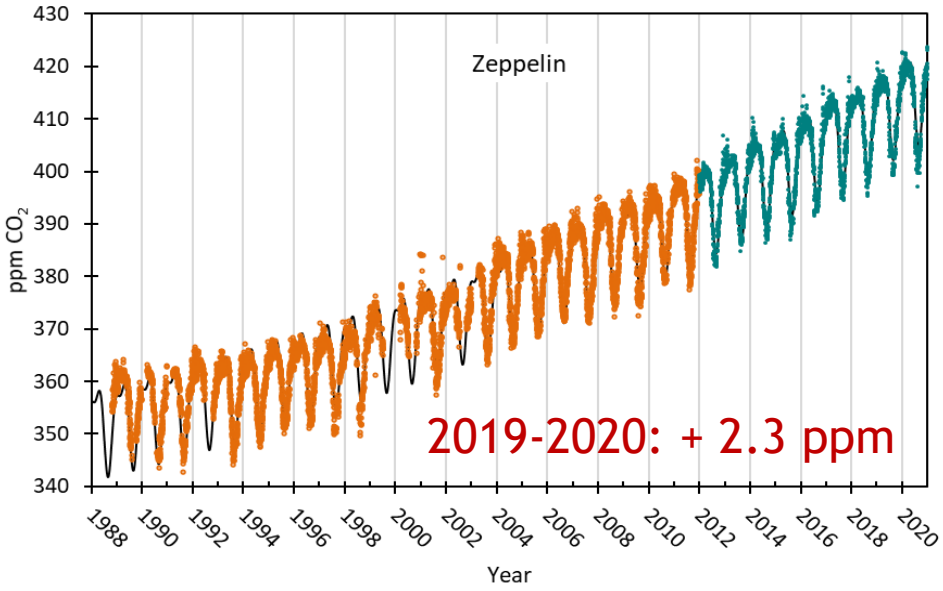
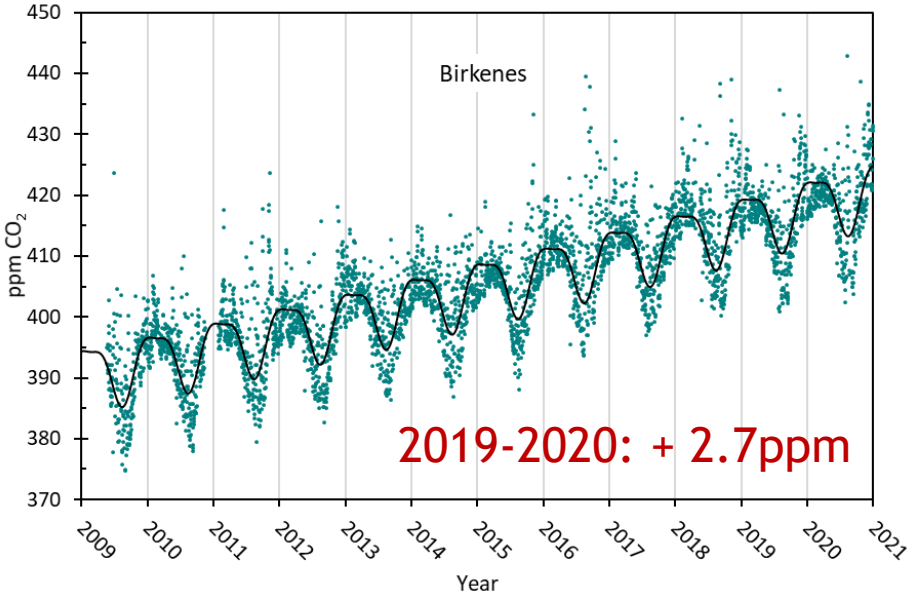
Carbon dioxide





Zeppelin
Long time series, small daily variations, reflecting the Arctic atmosphere and change

Birkenes
Large variety day to day, strongly influenced by Europe and regional vegetation

- Annual CO_2 means in 2020 reached new record levels: 414.2 ppm at Zeppelin and 418.8 ppm at Birkenes
- No apparent impact of COVID lockdowns (highlights the challenge ahead)
- No apparent slow down

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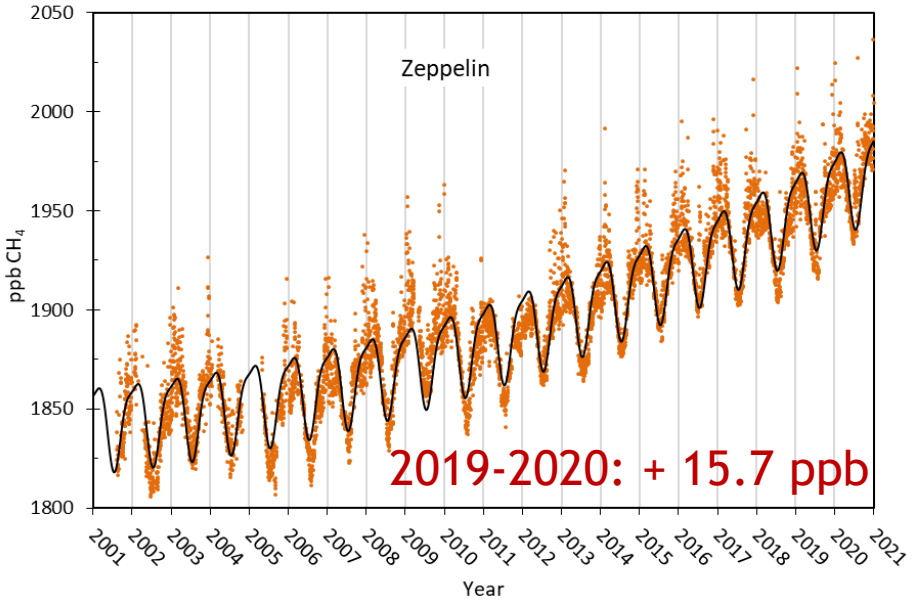
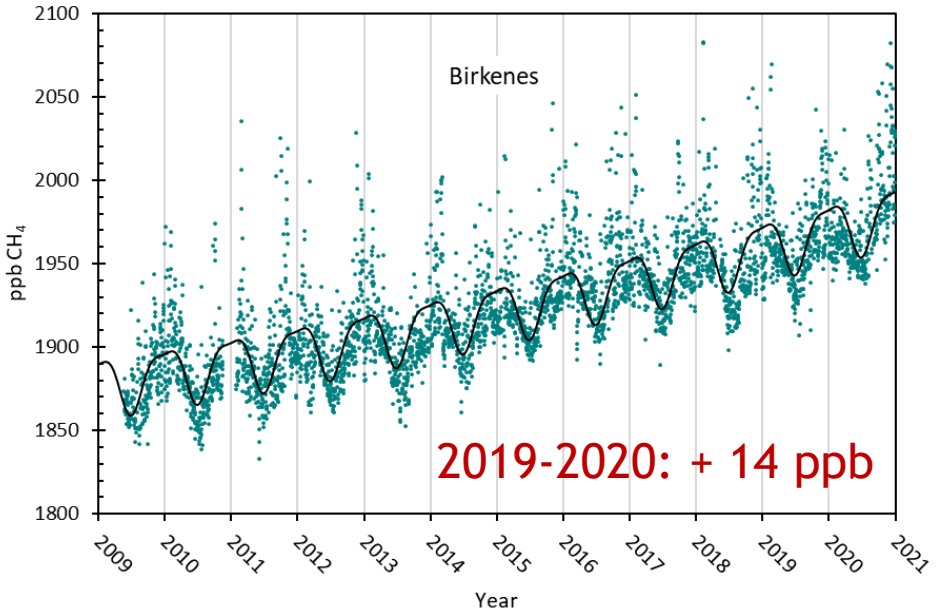
Methane





- Record increase to reach 1968.7 ppb at Zeppelin and 1975.2 ppb at Birkenes
- Still open questions regarding sources
- Potential of natural feedbacks to threated Paris Agreement.

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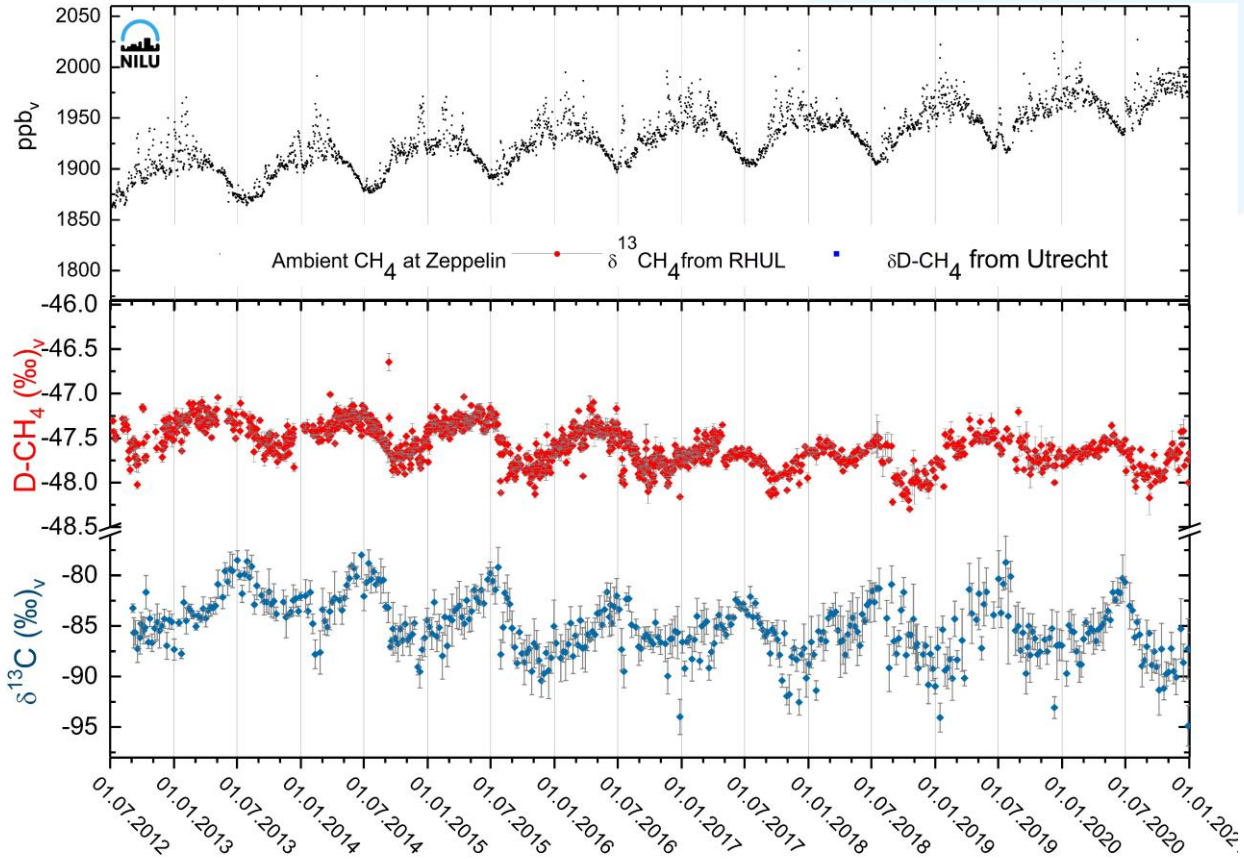
Methane - Isotopic time series



- Increase together with change in isotopic signature
- Suggesting changes in balance of sources and sinks
- Wetlands suggested (possible alongside reductions in fossil fuels, changes in biomass burning, OH radical sink)
- Might now have stabilized

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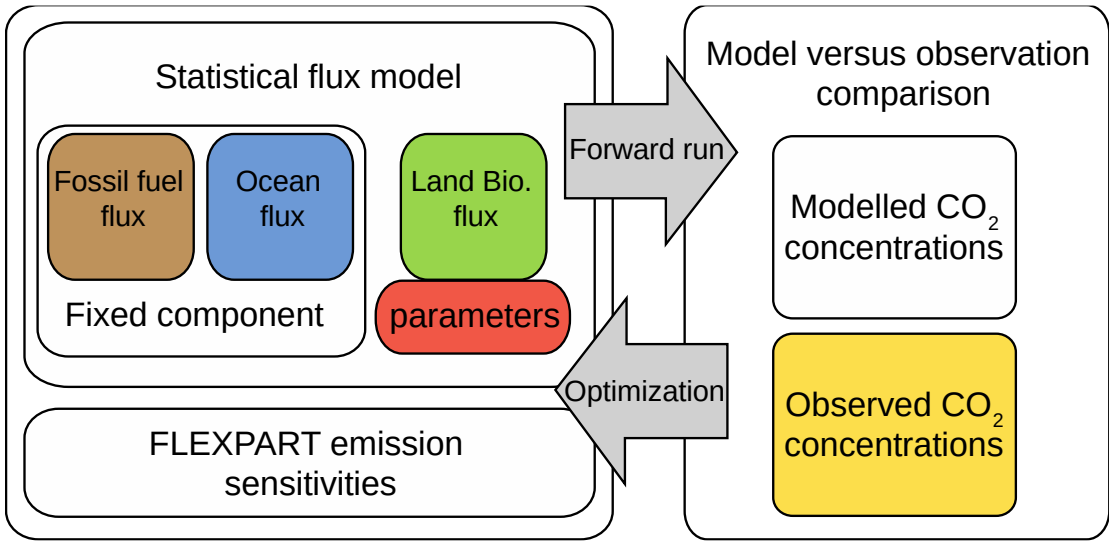
Global and regional GHG flux modelling

Foto: Ove Hermansen, NILU

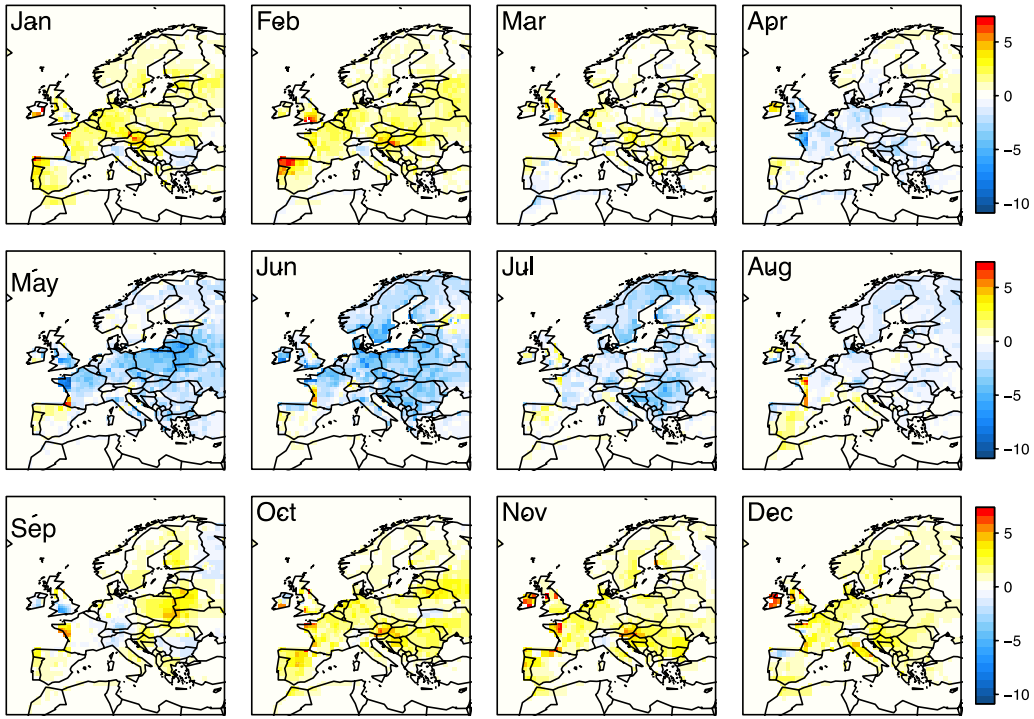
Land-biosphere CO_2 fluxes – contribution to ICOS Norway

- Atmospheric inversion method (**FLEXINVERT**) to estimate **Net Ecosystem Exchange (NEE) of CO_2** (fossil fuel emissions and ocean fluxes not optimized)
- Uses atmospheric CO_2 concentrations (currently ground-based sites) and model of atmospheric transport (FLEXPART)

FLEXINVERT Inversion framework for CO_2



Monthly mean optimized NEE for 2017 (gC/m^2/day)



+ source

- sink

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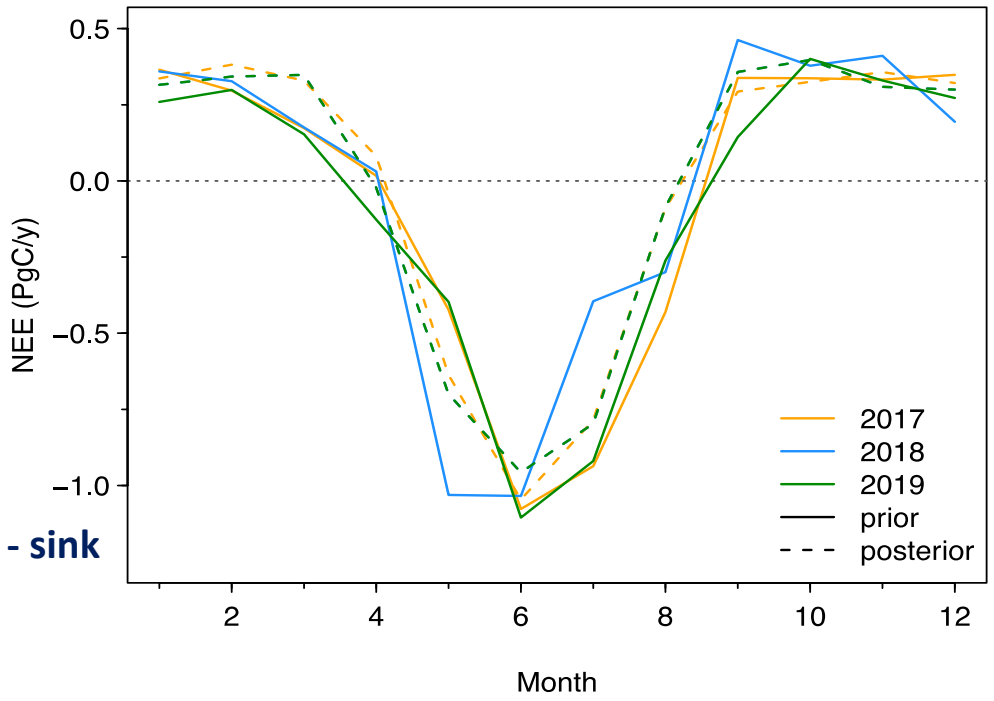
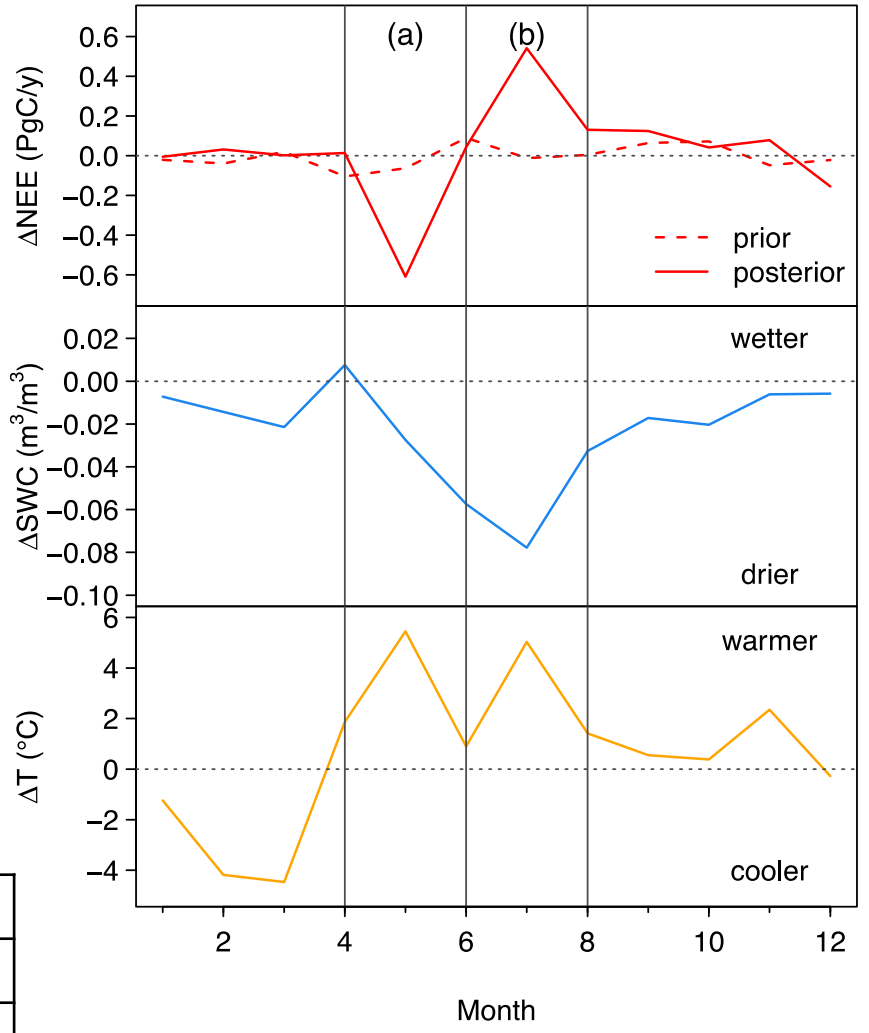
CO_2 Seasonal Net Ecosystem Exchange

Monthly NEE (PgC/y) for Fennoscandia for 2017 - 2019



(a) spring/early summer: warmer, minimal soil water deficit → increased C uptake

(b) late summer: warm, large soil water deficit → decreased C uptake



Year	Prior	Post
2017	-0.011	**-0.055**
2018	-0.016	**-0.035**
2019	-0.016	**-0.079**

Annual NEE in 2018 more positive (less C uptake) compared to 2017 and 2019

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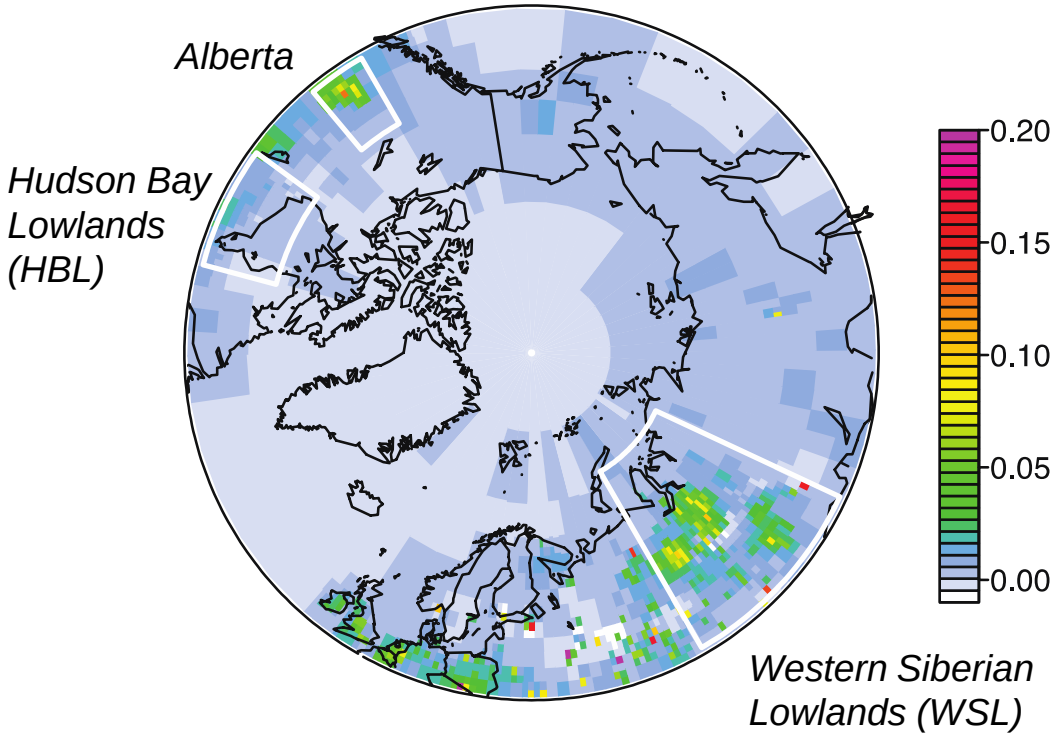
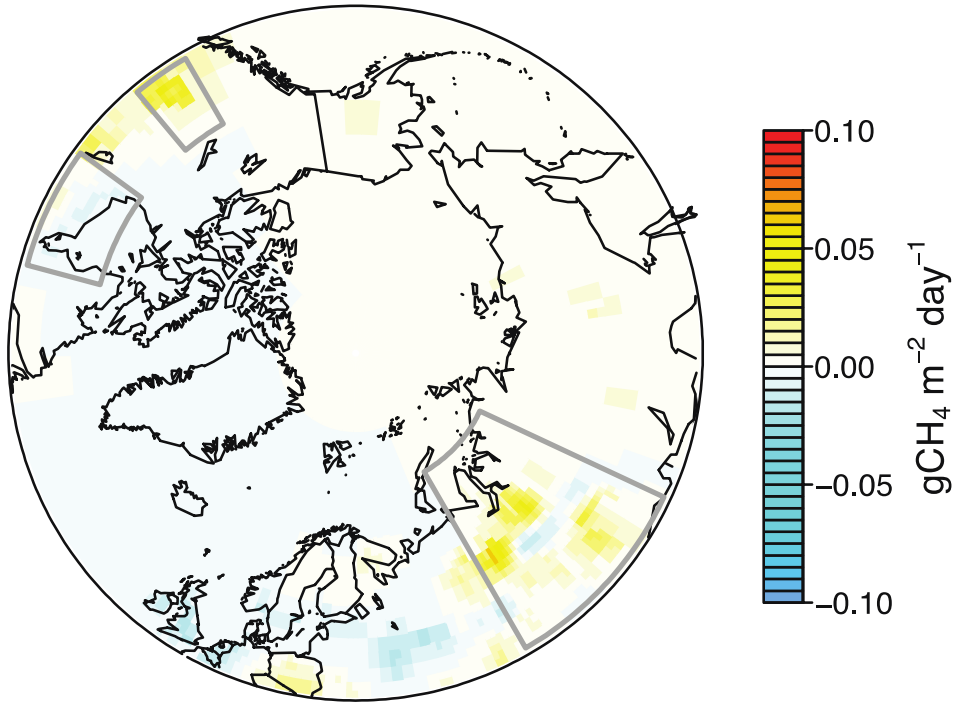
Emissions of CH_4

Study of Arctic CH_4 emissions using FLEXINVERT with atmospheric observations of CH_4 from large number of ground-based sites

Mean posterior flux (gCH_4 m^{-2} day^{-1})



Mean flux difference (gCH_4 m^{-2} day^{-1})



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Emissions of CH_4

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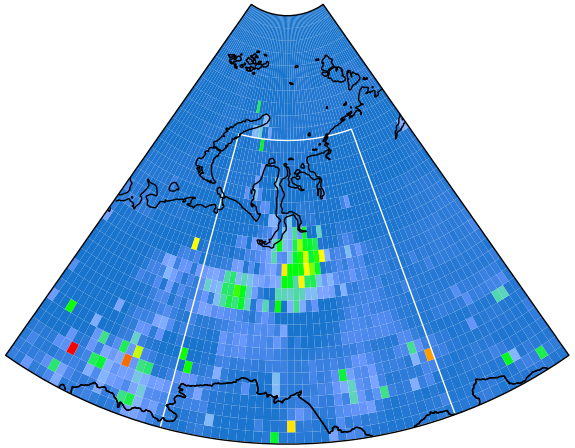
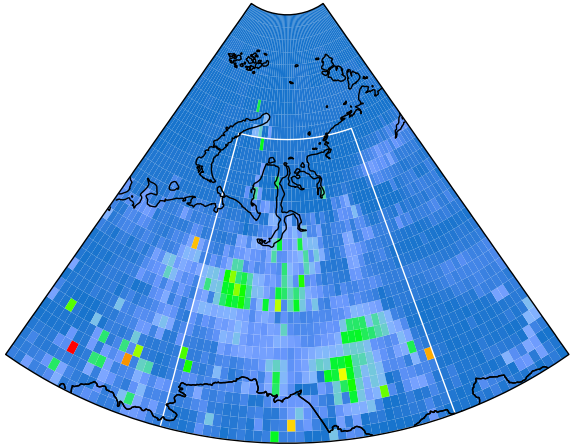
Winter

Summer

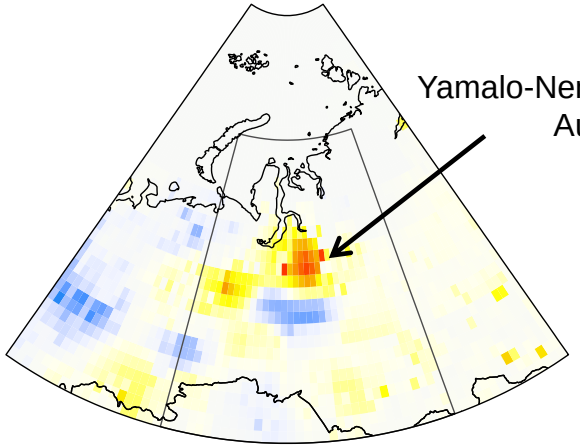
Posterior flux (g m^{-2} d^{-1})

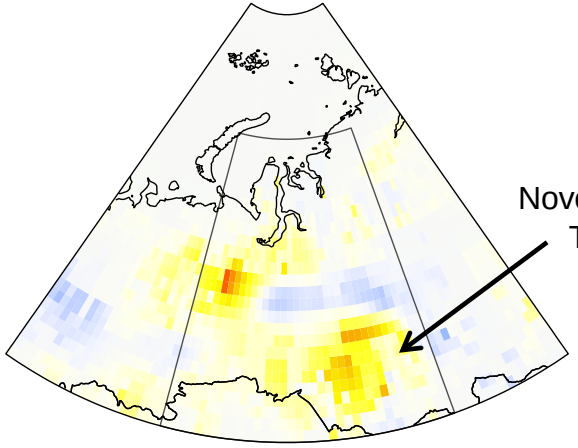




0.00 0.05 0.10 0.15 0.20

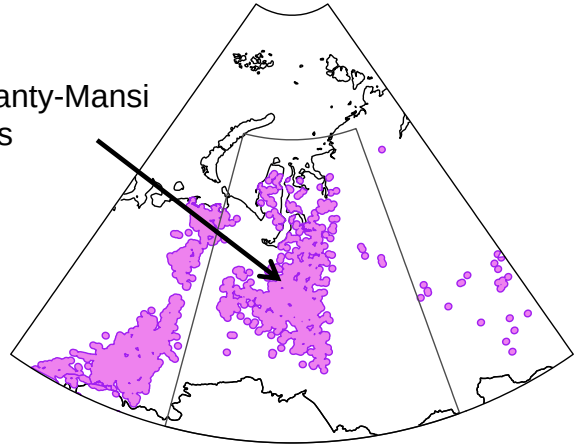
Posterior-prior (g m^{-2} d^{-1})



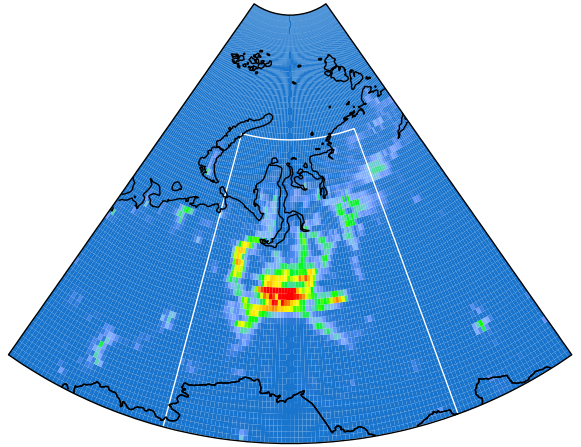


−0.08 −0.04 0.00 0.04 0.08

Oil and gas field locations



Wetland area fraction (summer)



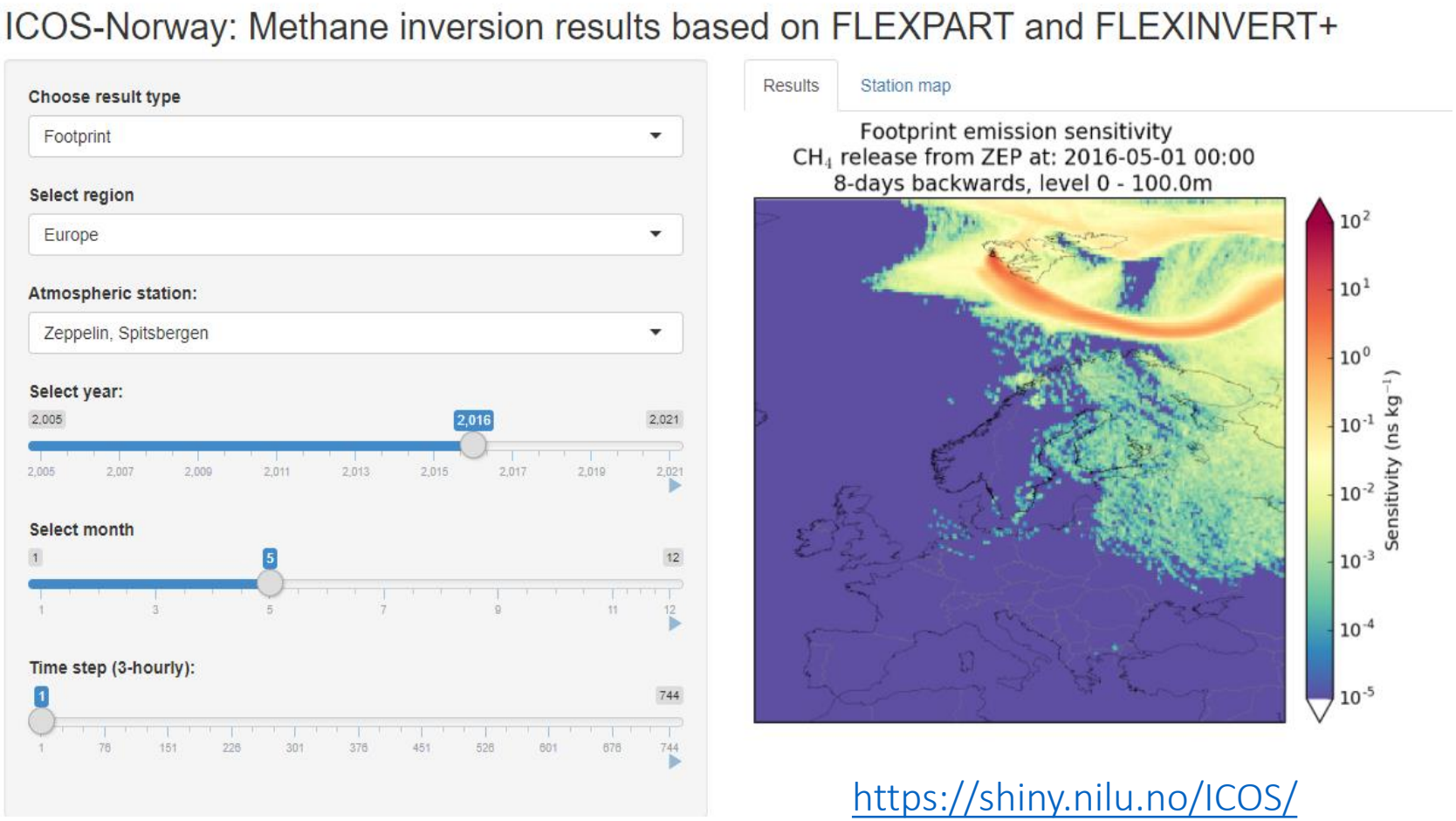
0.0 0.1 0.2 0.3 0.4 0.5

ICOS Integration

The integration component aims to assemble all measurements into an inversion model to constrain the net CO_2 and CH_4 balance of Norway.

Products

- Footprints
- Flux maps
- Uncertainties
- Monthly time series stations
- Monthly emissions Northern Europe



https://shiny.nilu.no/ICOS/

Further European GHG activities

VERIFY

- **N_2O** inversions over Europe 2005-2019
- Exploring usefulness of **CH_4 isotopes** (d13C) and ethane to constrain CH_4 sources in inversions
- Development of Community Inversion Framework (CIF)

CAMS_73 Greenhouse gas fluxes

- Inverse modelling of N_2O fluxes

NILU

High resolution GHG emission modelling

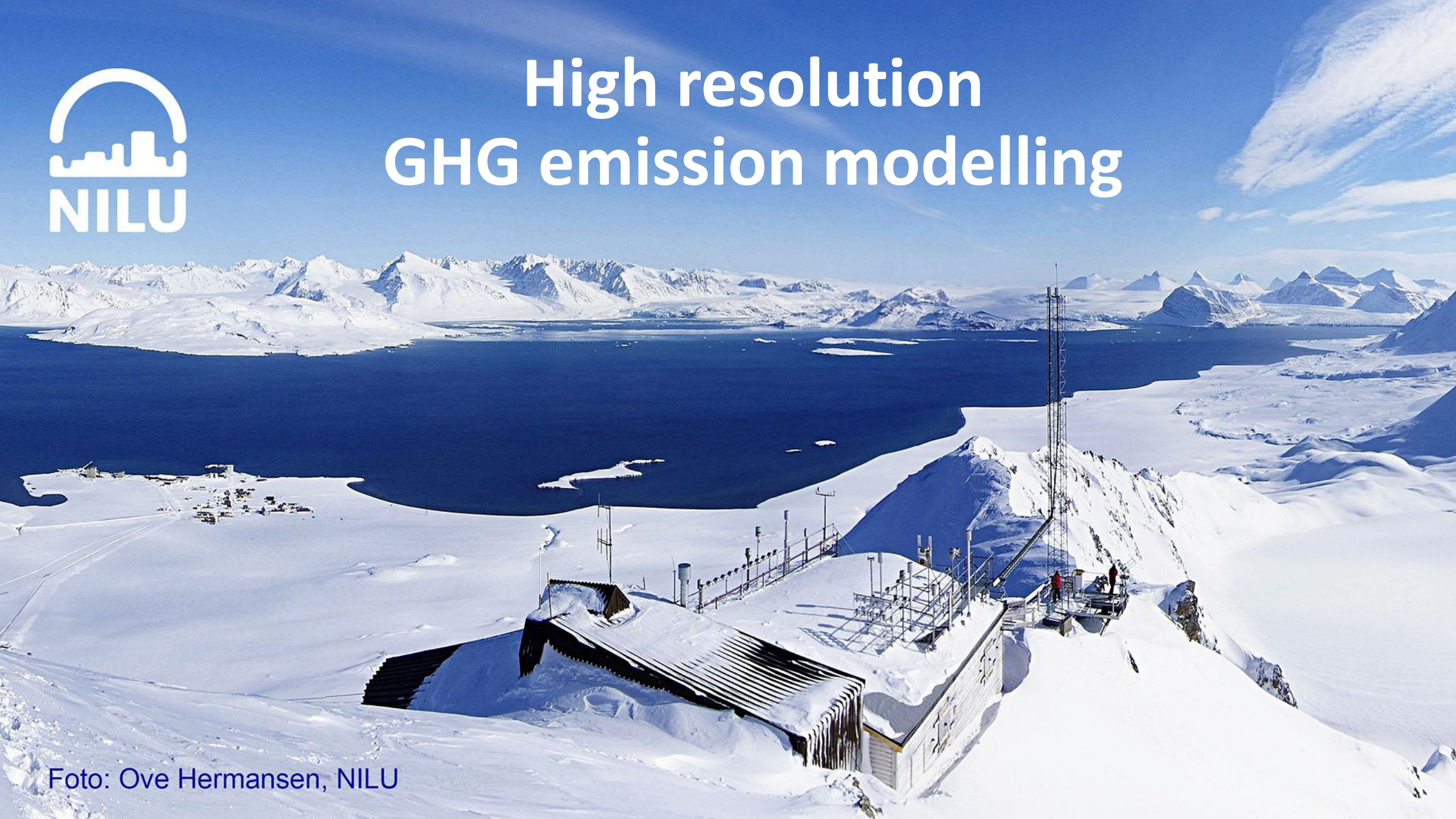


Foto: Ove Hermansen, NILU

High Resolution GHGs Emission Modelling

Group dedicated to the development of models based on the understanding of emission processes, considering all variables that affect emissions.

- GHGs emissions for single sectors at **high spatio-temporal resolution** based on **big data** processing and analysis.
- Methodologies based on **bottom-up** principles
- OUTCOMES: whole **Norway at resolution from road link to 250 meters**, depending on the sector
- GHGs data for time series and being updated on a **yearly** basis
- Contribution to societal/industrial problems where knowledge on emissions is essential

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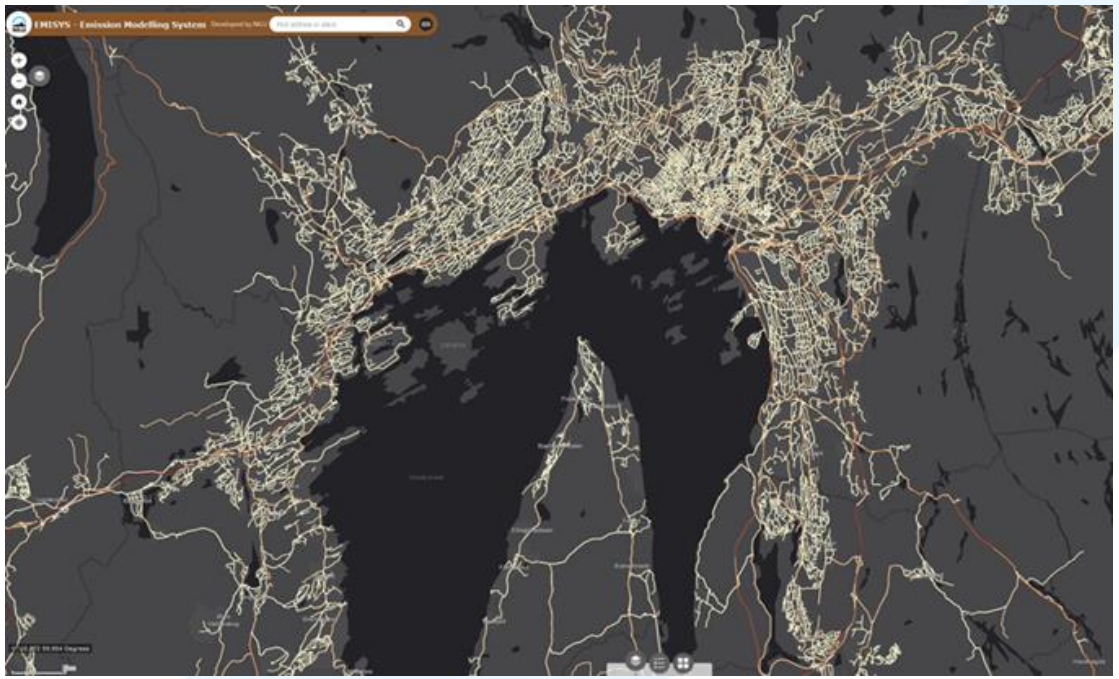
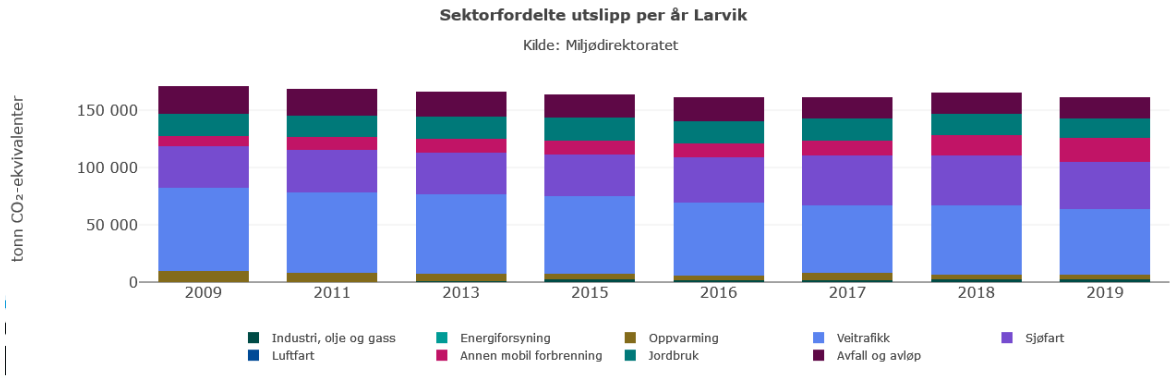
Examples - High Resolution GHGs Emission Modelling





NERVE – On-road Traffic emissions

INPUT:

- Traffic models
- Traffic across municipalities
- Vehicle fleet composition at municipality level
- Driving conditions, type of road, slope….
- Emissions factors

OUTPUT:

- GHGs (CO_2, CH_4 and N_2O) emission at road link and municipality level

APPLICATIONS:

Currently used in the Klimaregnskap at municipality level, as input for concentration modelling and as research tool

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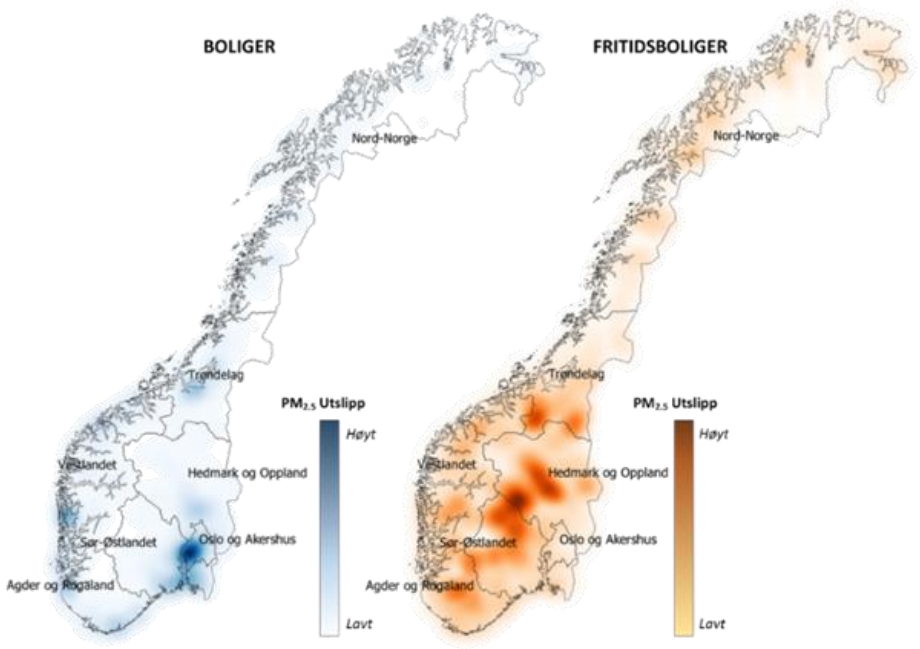
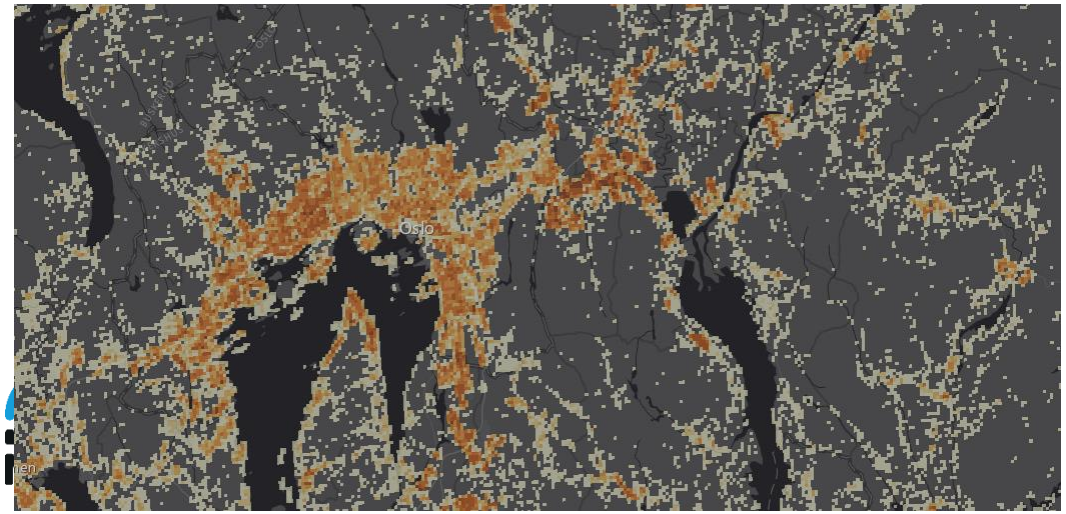
Examples - High Resolution GHGs Emission Modelling





METVED – wood burning heating

INPUT:

- Wood consumption / Emission Factor
- Type/size of dwelling
- Wood burning appliances / Webcrawling data
- Alternative energy heating sources
- Energy consumption
- Meteorology

OUTPUT:

- GHGs (CO_2, CH_4 and N_2O) emission at 250 m resolution

Applications:

Currently used in the Klimaregnskap at municipality level, as part of air quality modelling systems and as research tool to evaluate energy transitions

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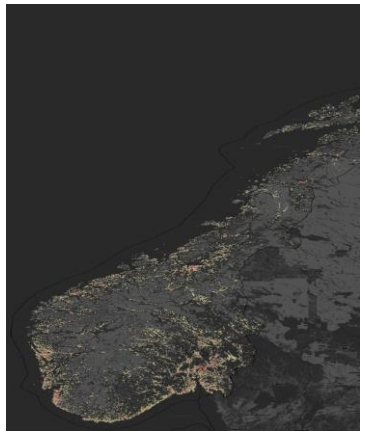
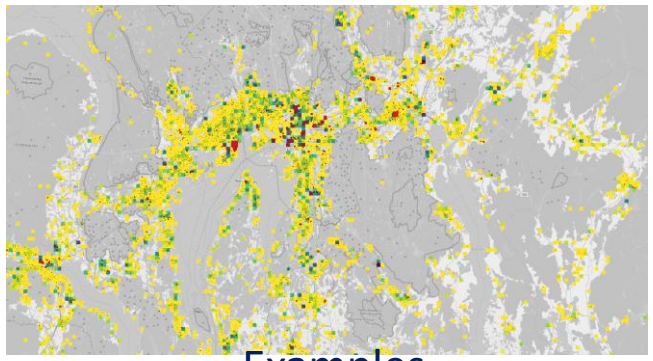
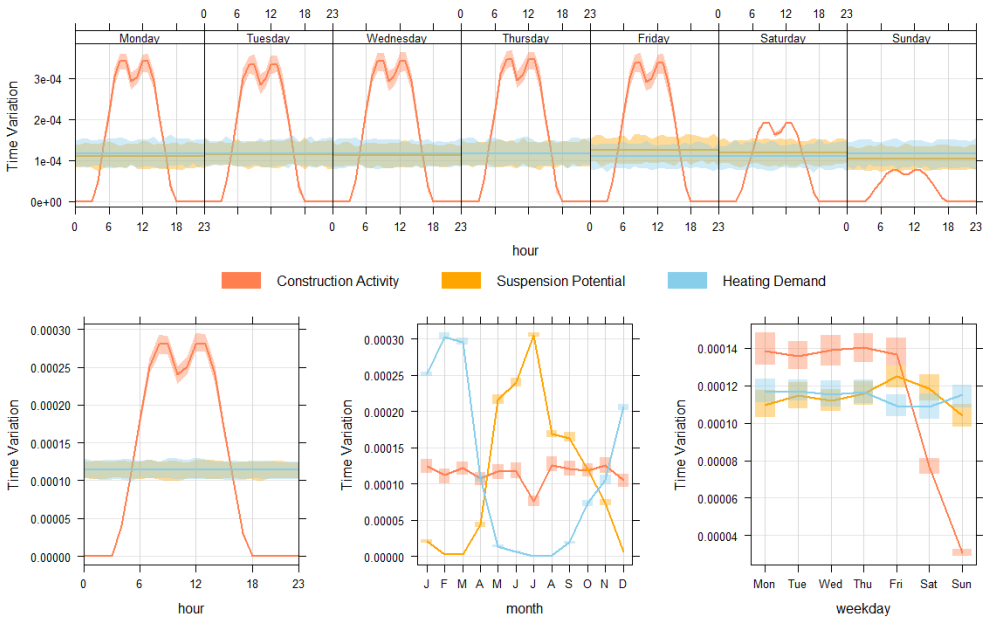
Examples - High Resolution GHGs Emission Modelling





Examples -



EmSite – Emissions from machinery in building and construction

INPUT:

- Building permit in Norway (2010 – 2020)
- Type / Size of building construction project
- Energy demand per phase of construction / heating
- Ground conditions / soil type / meteorology
- Dynamic Emission Factors

OUTPUT:

- GHGs (CO_2, CH_4 and N_2O) emission at 250 m resolution in Norway

Will be used in the Klimaregnskap at municipality level, as part of air quality modelling systems and as research tool

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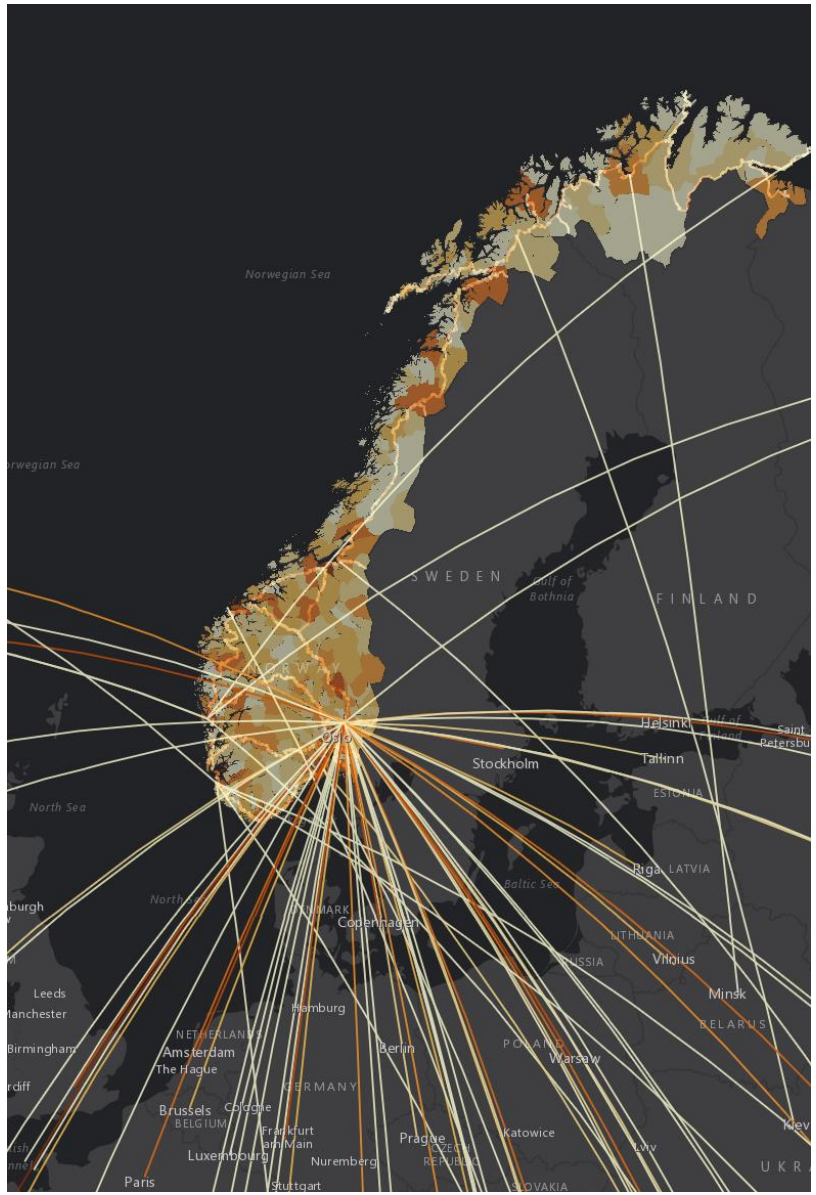

High Resolution GHGs Emissions

- The results are essential to **design mitigation measures and evaluate the progress towards the emission targets set at local and national level.**
- High resolution GHGs emissions are **consistent / complementary to the emissions officially reported to the UNFCCC.**
- Bottom-up emissions can be used in combination with other data such as in-situ observation, inverse modelling and satellite information for **validation purposes and a better understanding on real world emissions.**

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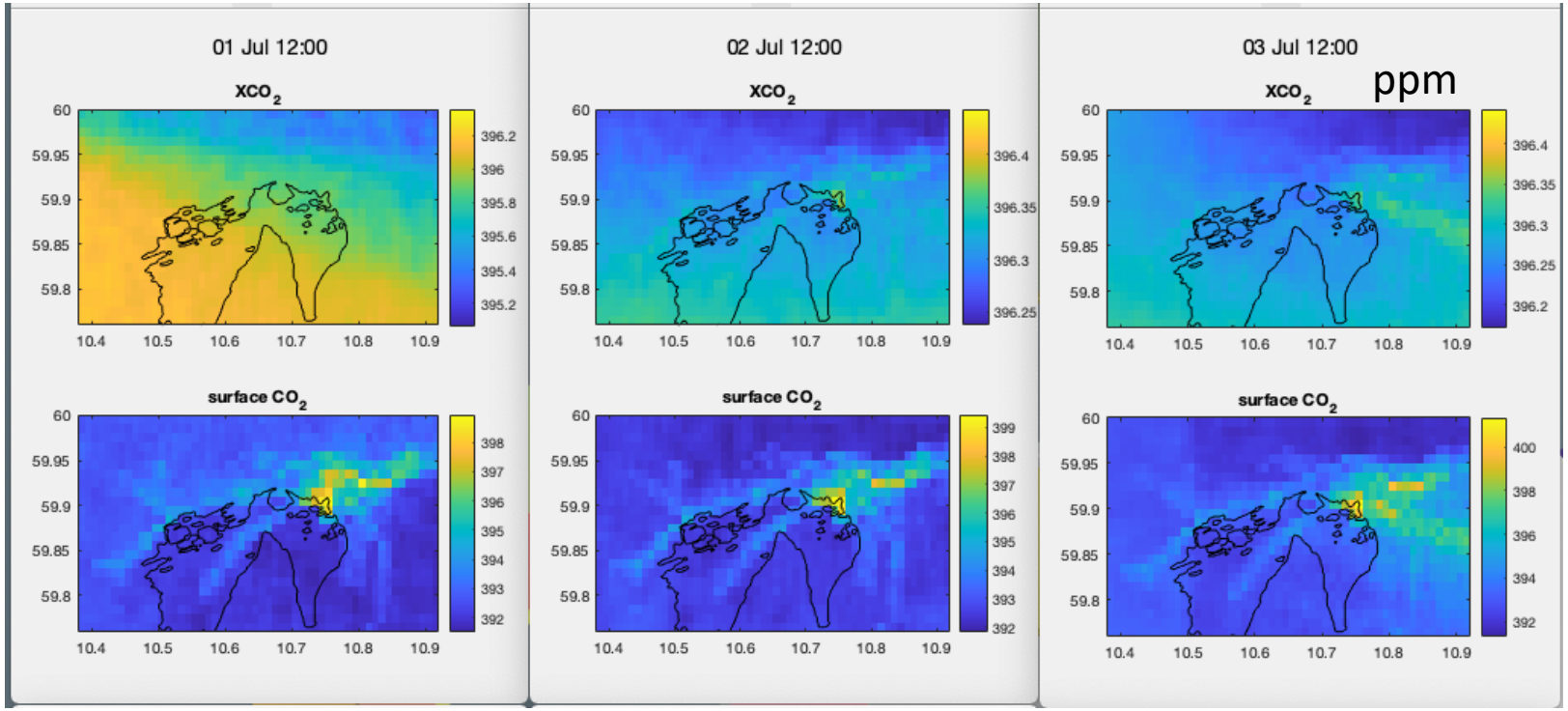
FLEXPART simulations of CO_2 ground mixing ratio and XCO_2 total column over Oslo

Forward city plume + global atmosphere background at ~1km resolution vertical column (not slanted path)



Carbon Human Emissions (CHE) project

- Ground sources from NILU emission inventory (S. Lopez Aparicio)
- High atmosphere concentration from FLEXPART-CTM (C. Groot Zwaaftnik)

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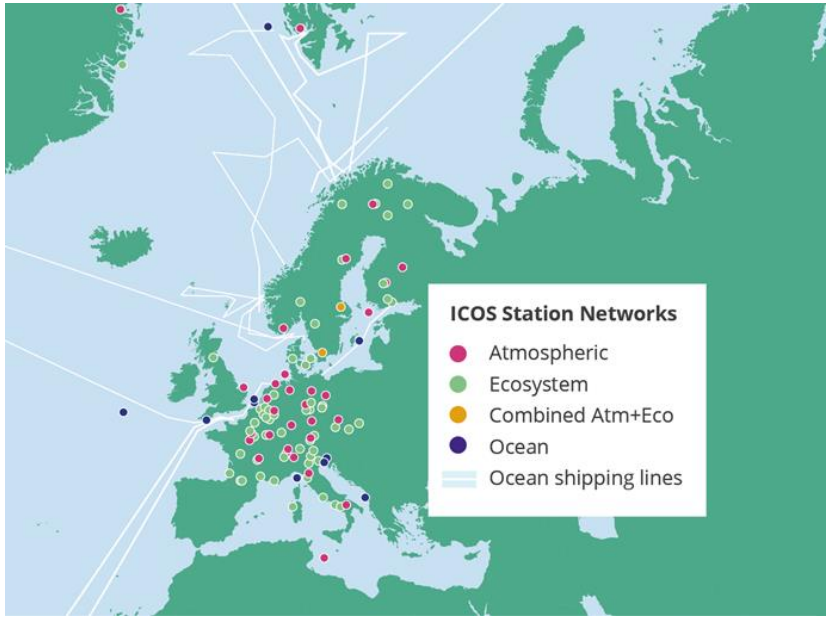
Support to European Commission (DG-ENV)

The on-going process on the revision of the Ambient Air Quality Directives (AAQD) involves enhacing alignment with climate change

- NILU has supported DG_ENV with in-situ monitoring issues during this process
- Two different contracts for strengthening regulatory monitoring network activities
- New application to analyse the feasibility of introducing **CO_2 and CH_4 monitoring in city areas** in the revised AAQDs

Links to ICOS related activities in cities with H2020 projects ICOS Cities (PAUL) and RI_URBAN



An important step in the roadmap to CO_2 Monitoring and Validation Services nationally and within Copernicus

NILU

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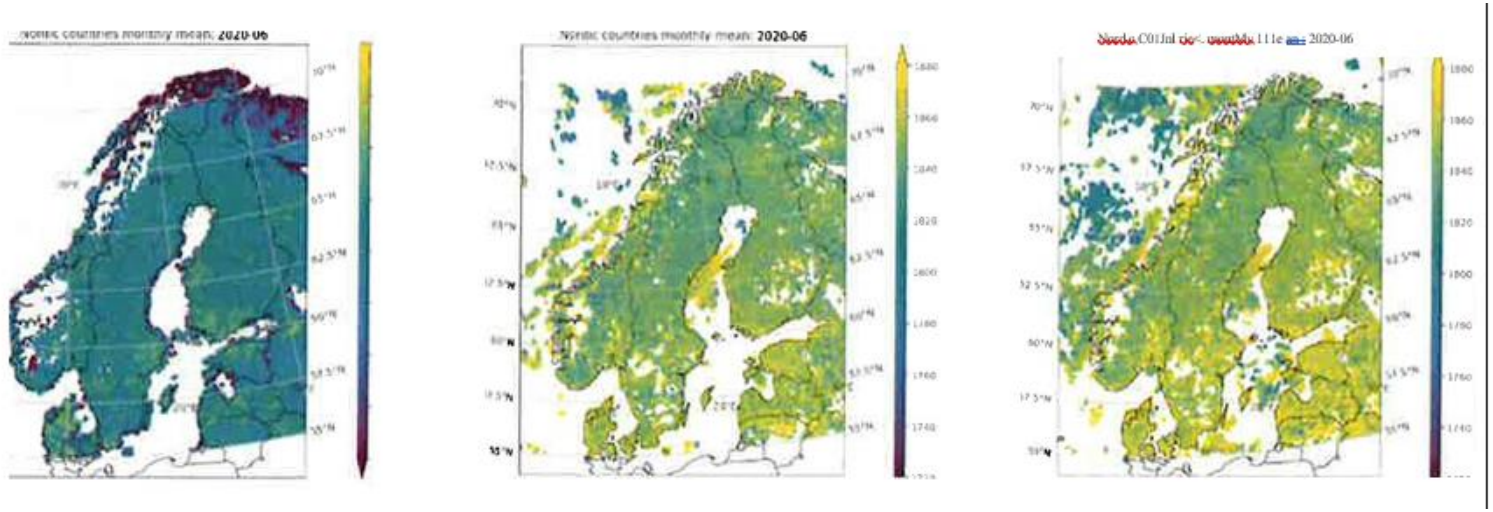
Remote sensing

Foto: Ove Hermansen, NILU

Remote sensing of CH_4 using Sentinel-5P



Monthly averaged operational (left plot) and ESA-CC/ xCH4 (center plot, version 1.2 and right plot, version 1.5) data June 2020

Near infrared remote sensing of CH_4 challenging for Norwegian interest areas:

- Difficult topograpy (mountains and fjords)
- Low sun
- Clouds
- Ocean (low signal due to low albedo)

Projects:

- Feasibility study financed by Norwegian Environment Agency
- STEPS - SynergisTic Exploitation of the methane Product from Sentinel-SP for applications in the Arctic – Copernicus/Post-74 financed by NoSA/NILU
- EO-SIS (WP3 GHG) - financed by NILU

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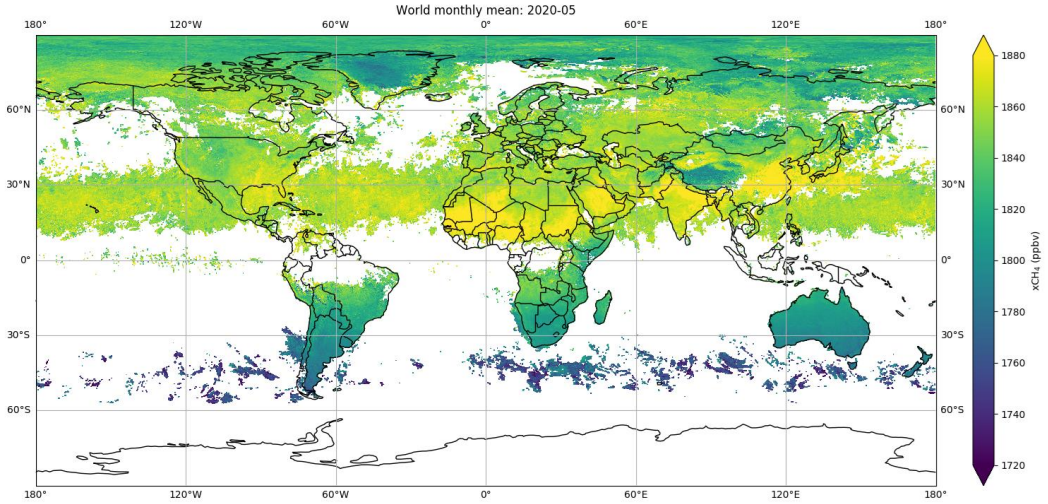
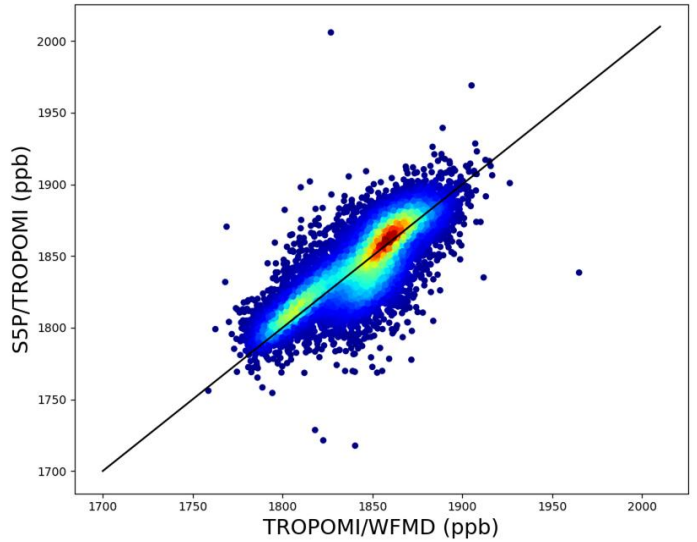
xCH_4 - Monthly averages

University of Bremen TROPOMI/WFMD





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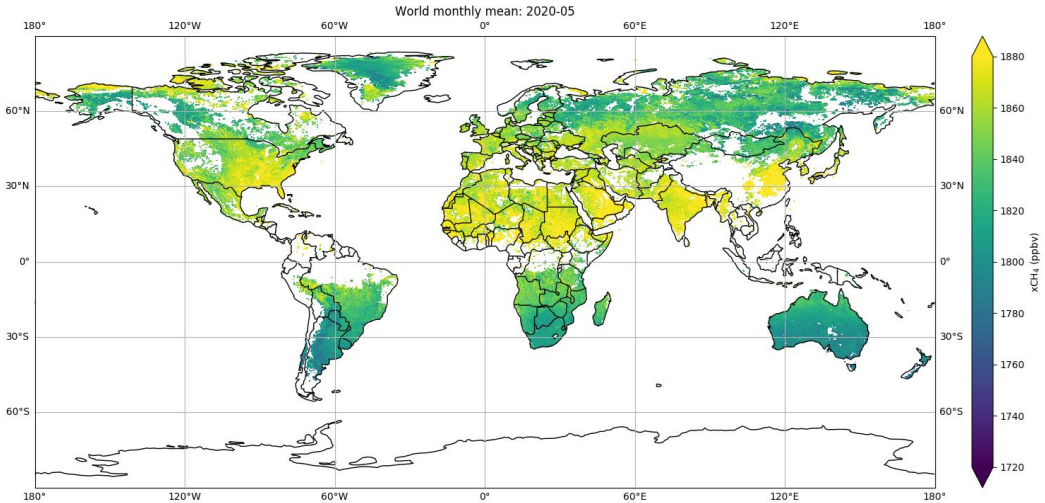
Operational S5P/TROPOMI Methane



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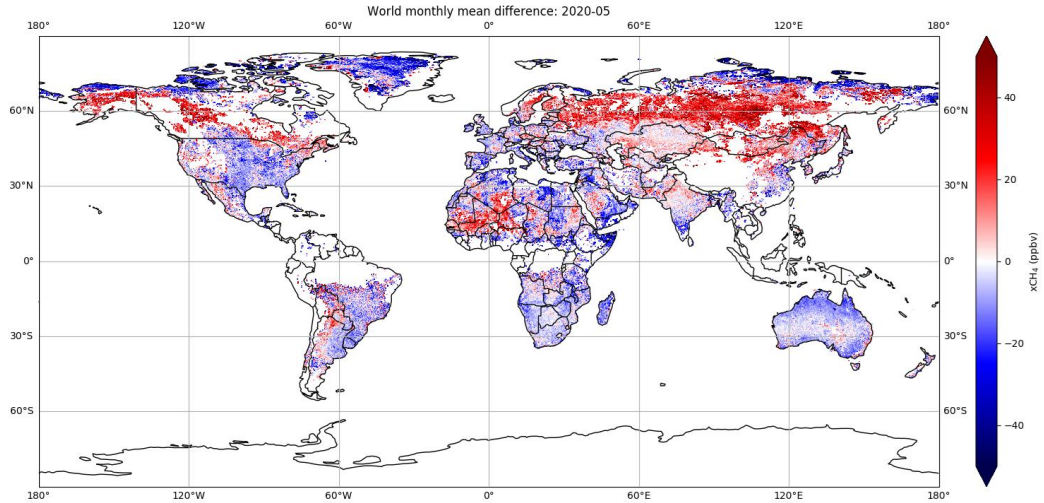

No coverage over oceans
No coverage over mountain areas

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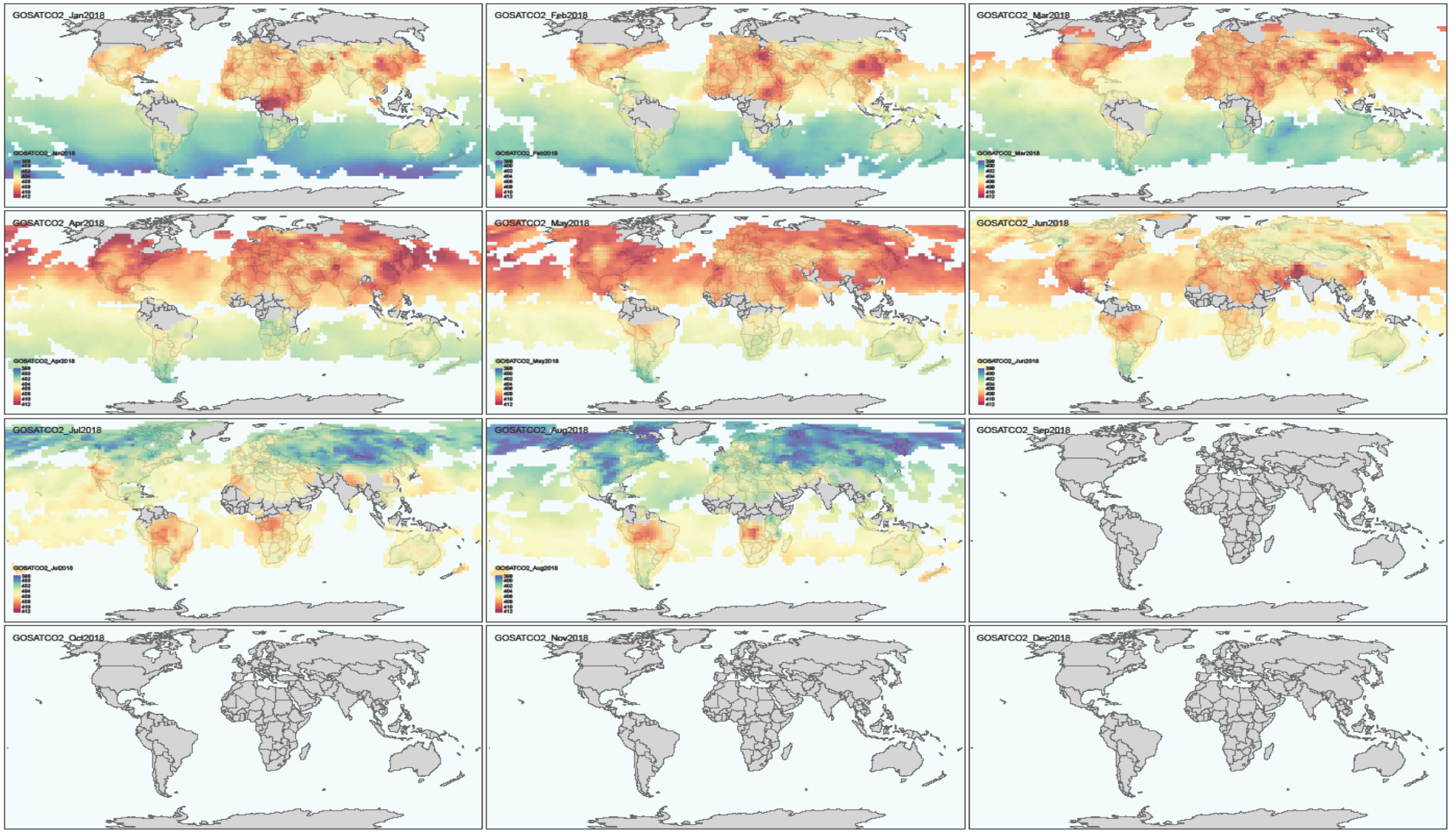
xCO_2 – Global monthly averages from GOSAT 2018



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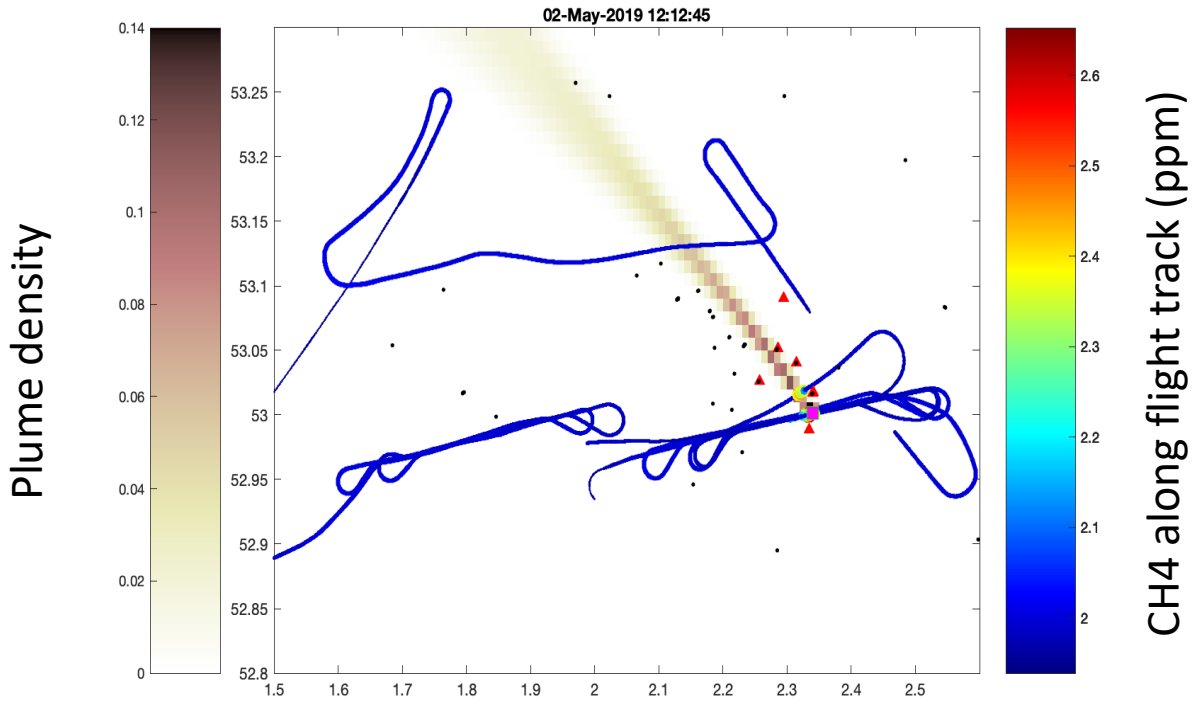
Point source emissions – relevant preparation for CO2M

FLEXPART CH_4 modelled plume from an oil platform in the North Sea (ORME)



The dots (and triangles) indicate (selected) oil rigs

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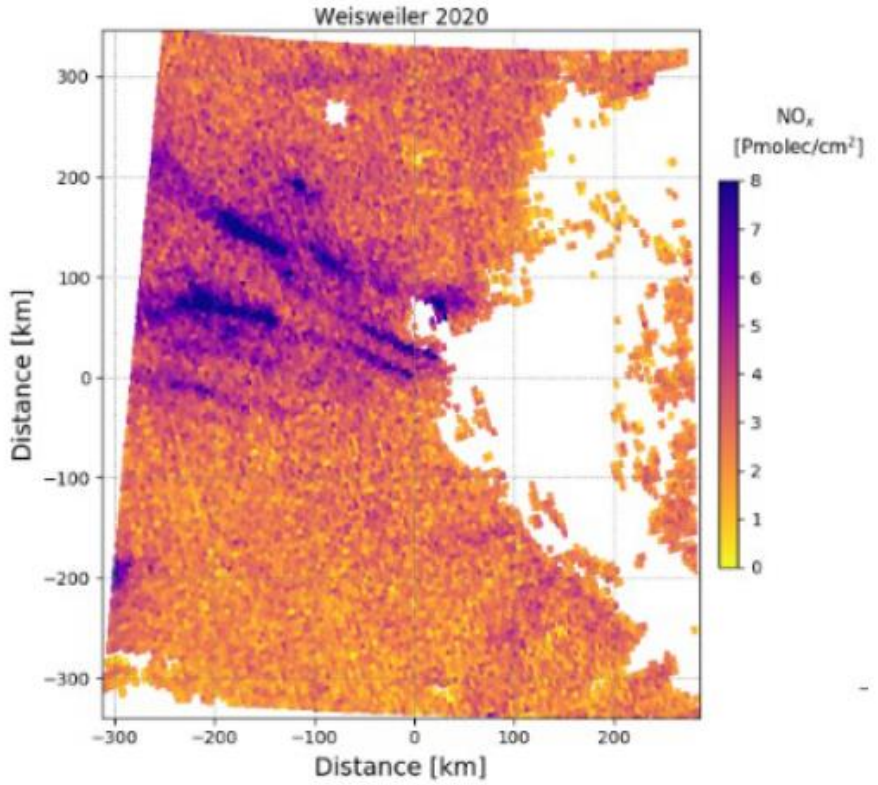
Satellite power plant NOx emissions (funded by EEA)



NOx observed on 25st June 2020

Kerstin Stebel | kst@nilu.no

REGAME

Foto: Ove Hermansen, NILU

Forskningsrådet

Reliable methane emissions estimates in a changing world - REGAME

NILU–Norwegian Institute for Air Research, CAGE–Centre for Arctic Gas Hydrate, Environment and Climate, UiT The Arctic University of Norway
CICERO–Centre for International Climate and Environmental Research
University of Vienna, Vienna, Austria + additional collaborator

NILU

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Goals

Constrain the global methane budget including vulnerable Arctic reservoirs + changes in atmospheric chemistry

Improve / update inversion and transport models to use of state-of-the-art data (isotopes / satellite)

Determine implications of improved methane budget and state of methane reservoirs for the Paris Agreement and produce a report for policy makers

Norwegian Research Council (4 years project, 24 MNOK), **KO 14/12/2021**

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Methods

Improved observations of CH_4

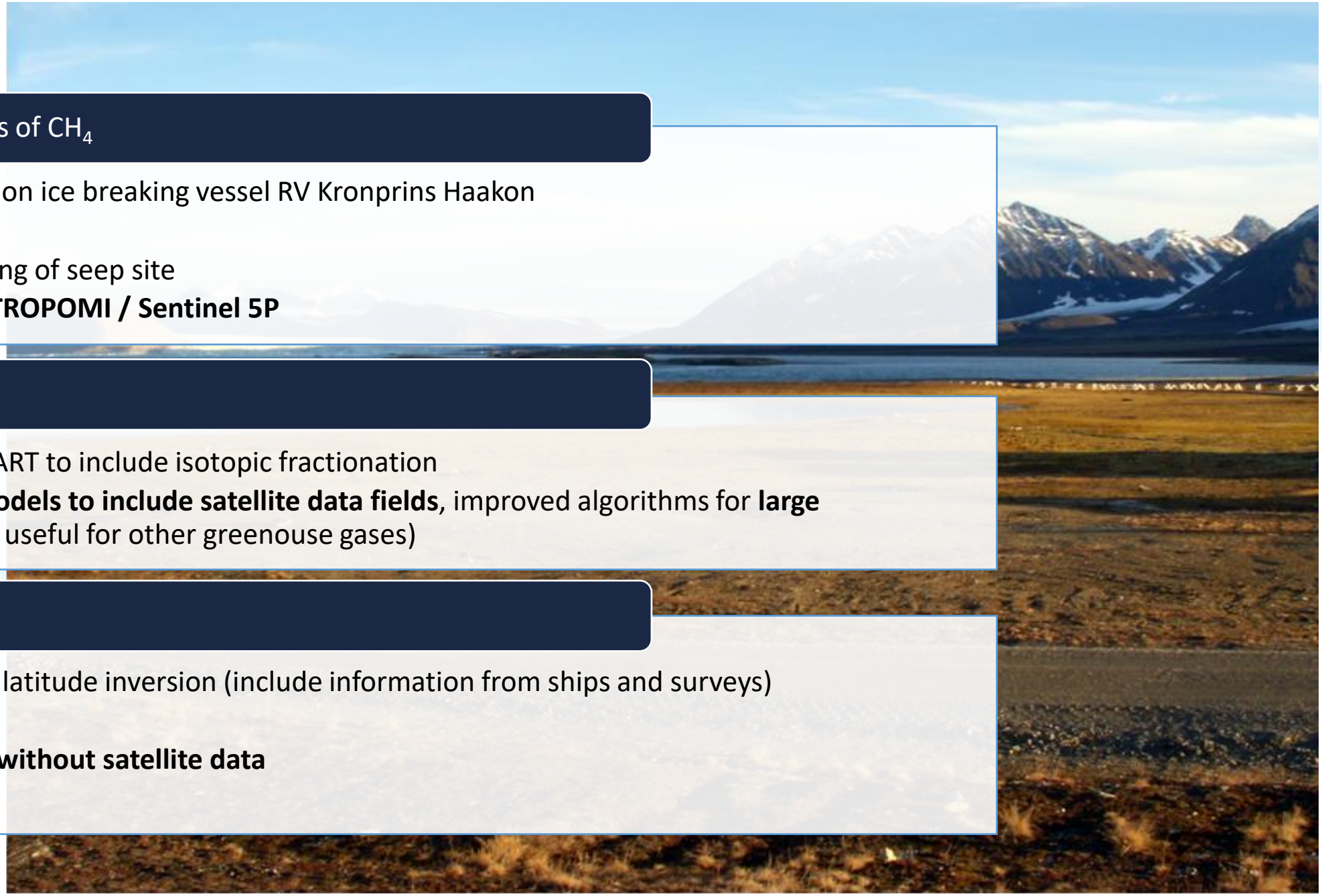
- New measurements on ice breaking vessel RV Kronprins Haakon
- Seep surveys
- Year-round monitoring of seep site
- **Satellite data from TROPOMI / Sentinel 5P**

Updated models

- OsloCTM and FLEXPART to include isotopic fractionation
- **Update inversion models to include satellite data fields**, improved algorithms for **large datasets** (eventually useful for other greenouse gases)

Methane budget

- High resolution high latitude inversion (include information from ships and surveys)
- Global inversion
- **Evaluated with and without satellite data**
- CTM study on OH



NILU

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Main contributions

ICOS
REGAME

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FLEXINVERT
CO_2 NEE
CH_4 emissions
ICOS, VERIFY

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Remote sensing
S-5P CH_4

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Bottom up
GHGs emission
modelling

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FLEXPART
CO_2 Oslo
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Policy support

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Remote sensing
STEPS, EO-SIS

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