Training event “Atmospheric standardized observations: Methods and maintenance in observatories – In-Situ.”

Dagmar Kubistin

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 “Education and Research” - Component 2: “From research to business” - Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

The research infrastructures for greenhouse gases ICOS atmosphere

Dagmar Kubistin,
on behalf of the ICOS RI Atmosphere and the Hohenpeissenberg team

Introduction

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

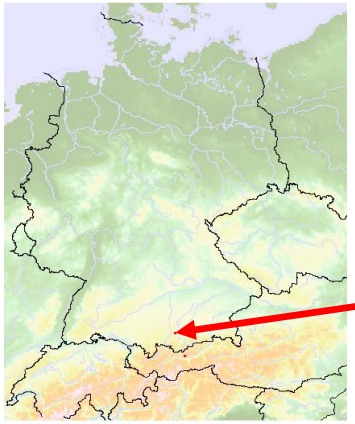
Hohenpeissenberg Meteorological Observatory (HPB)

Dagmar Kubistin
Head of the Trace Gas Department,
Deutscher Wetterdienst, Germany

GAW global station :

reactive and greenhouse gases
aerosols (physical, optical and chemical characteristics) & precipitation
O_3 (tropospheric and stratospheric profiles, total column) & solar radiation
meteorology

located in Southern Germany at 985 m asl, 40 km north of the alps & 65 km south-west from Munich

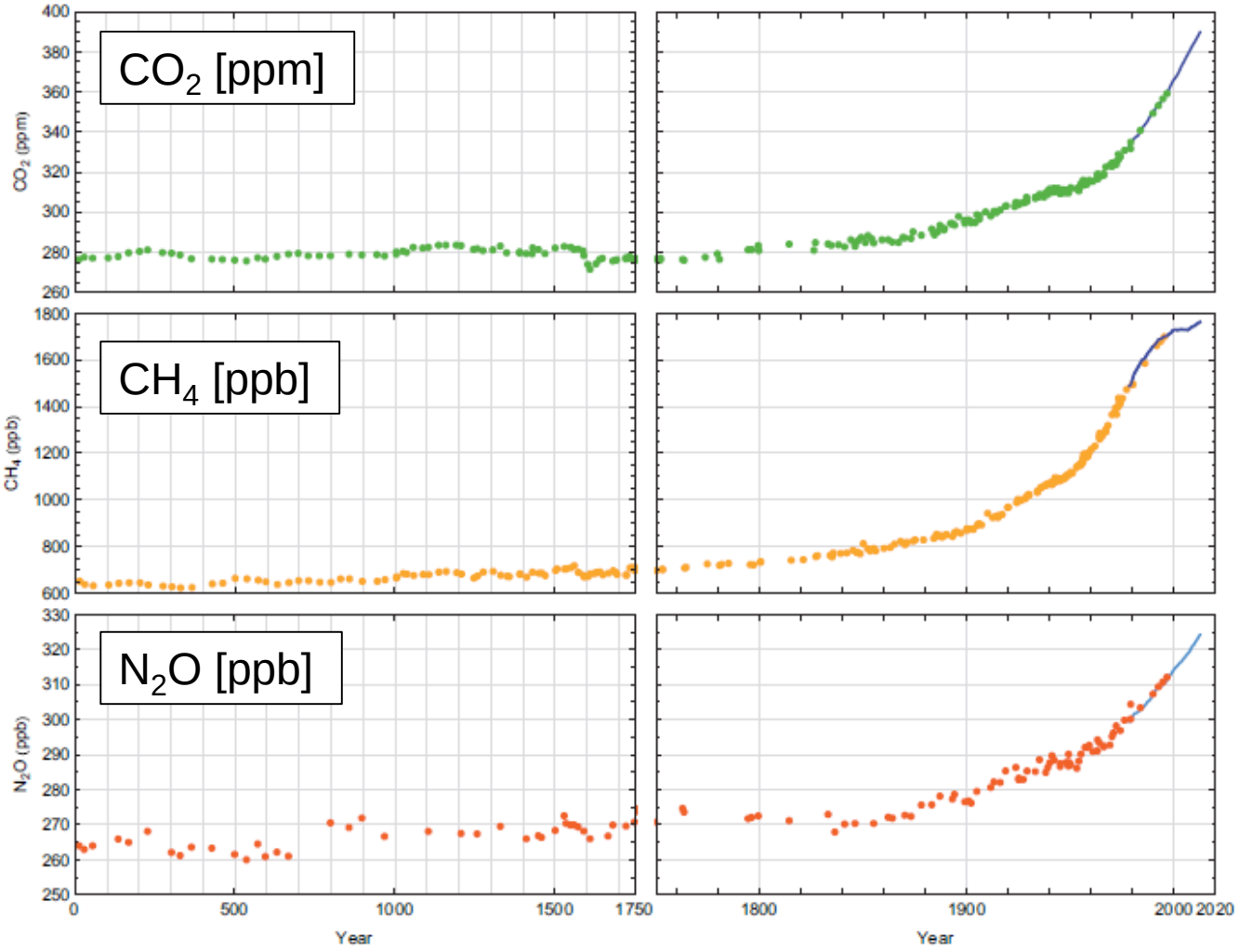


dagmar.kubistin@dwd.de

Atmospheric composition change

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Since onset of industralisation steep increase of predominant trace gases



Global mean (2023):

- CO_2 : 420.0 ppm
- CH_4 : 1934 ppb
- N_2O : 336.9 ppb

Increase compared to 1750:

- CO_2 : 151%
- CH_4 : 265%
- N_2O : 125%

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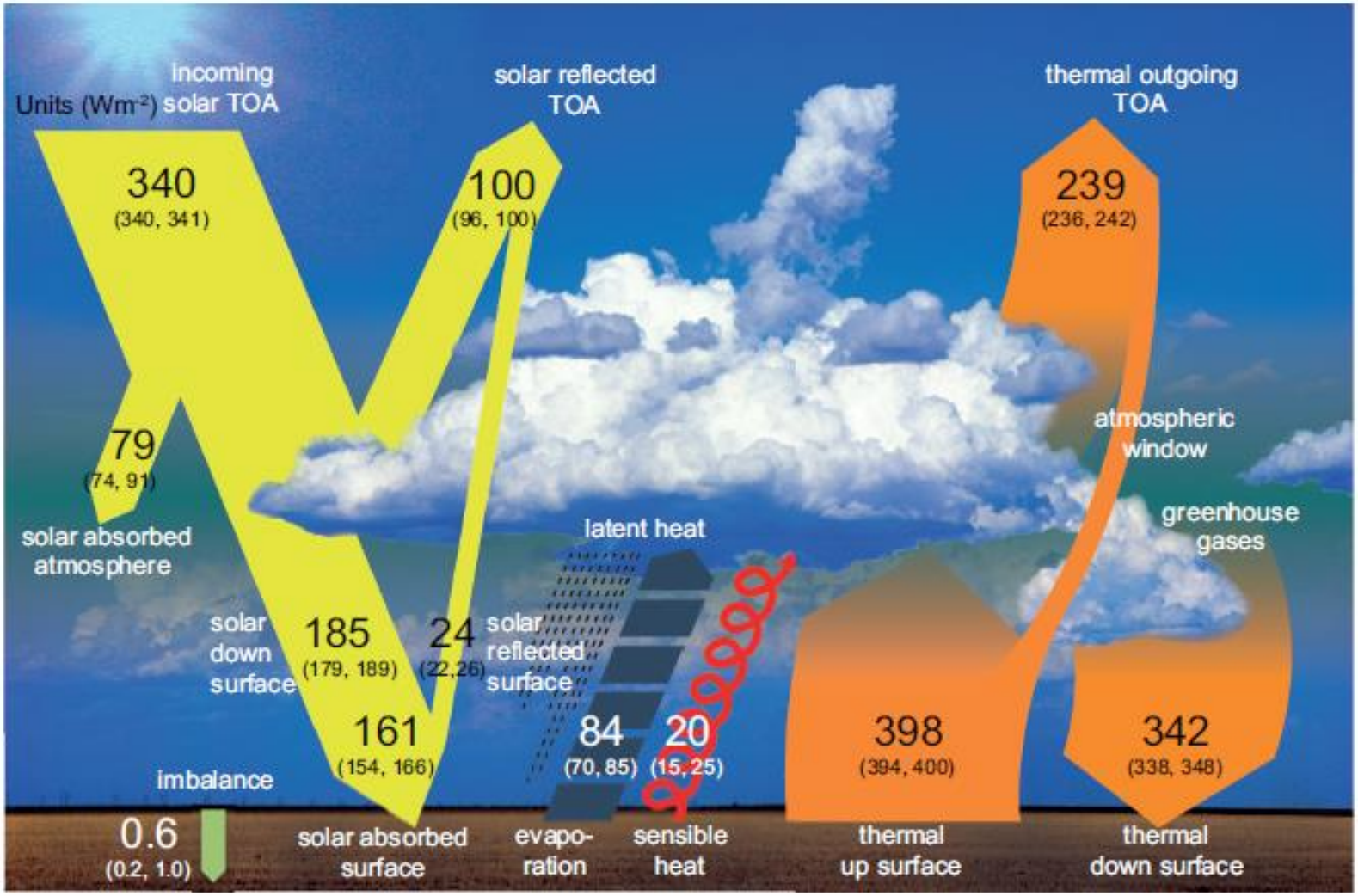
IPCC 2013: Climate Change 2013: The Physical Science Basis
https://gaw.kishou.go.jp/publications/global_mean_mole_fractions#content1

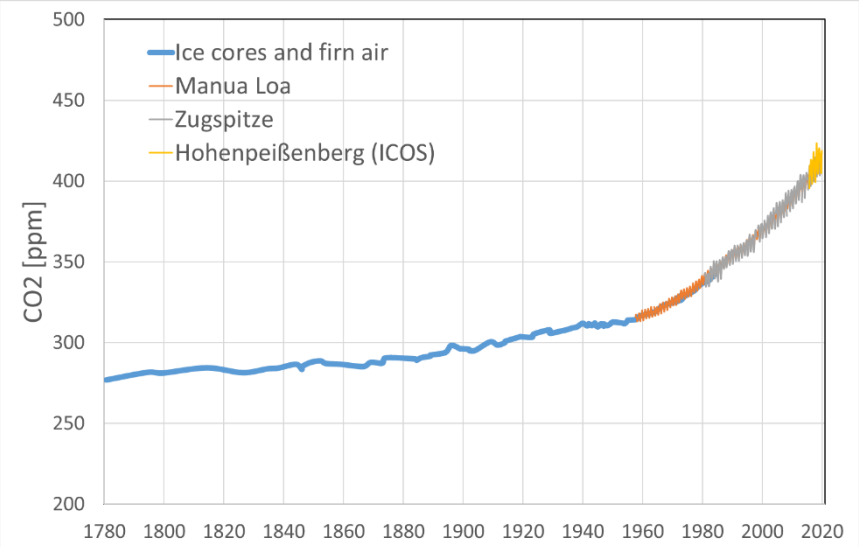
Greenhouse Effect

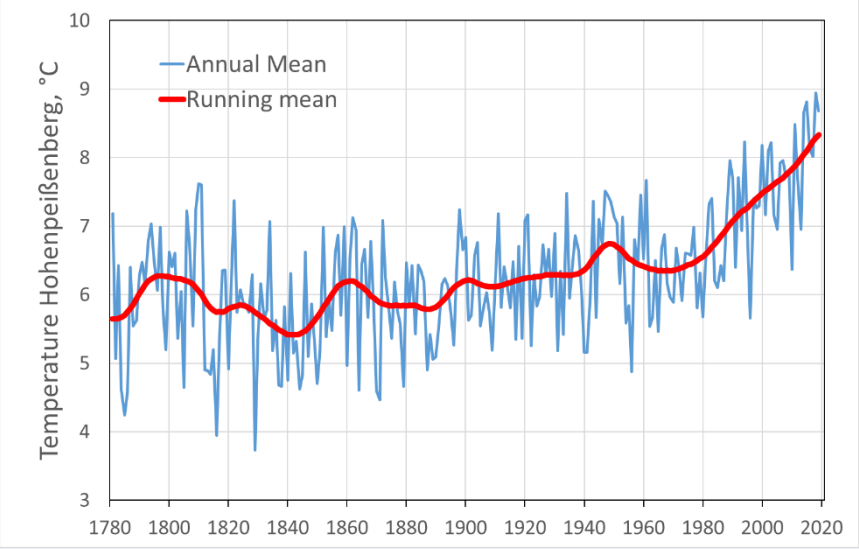


IPCC 2013: Climate Change 2013: The Physical Science Basis

Temperature at Hohenpeissenberg from 1781-2020

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



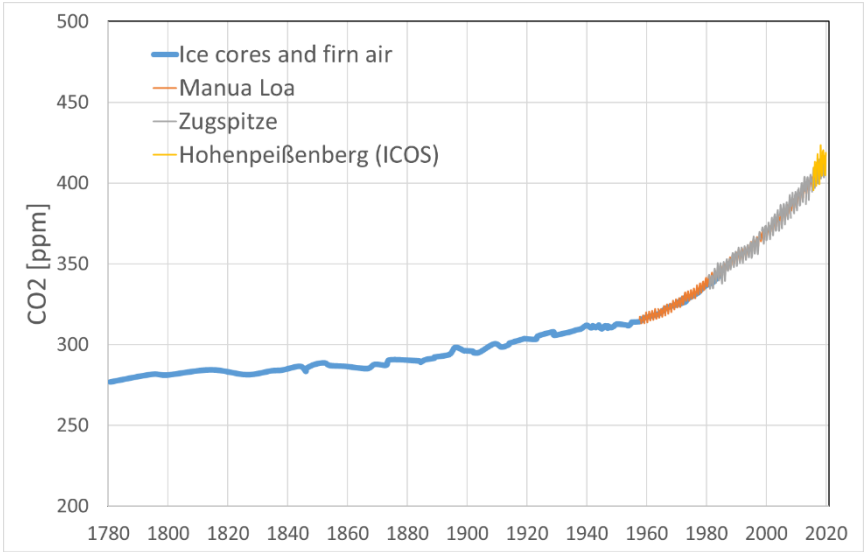


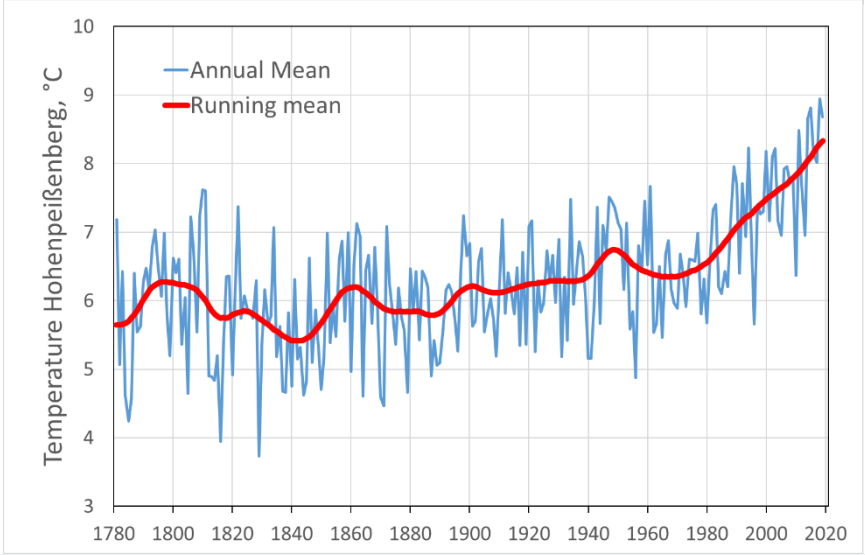
- Temperature observed at Hohenpeissenberg since 1781 tracks the global CO_2 concentration

Data taken from WDCGG: https://gaw.kishou.go.jp/ and references therein

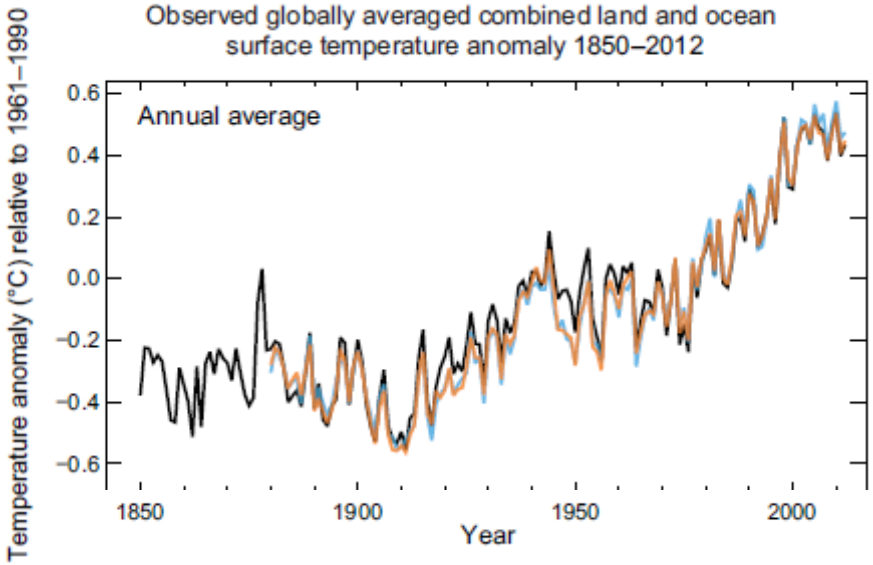
Temperature at Hohenpeissenberg from 1781-2020

Deutscher Wetterdienst
Wetter und Klima aus einer Hand





- Temperature observed at Hohenpeissenberg since 1781 tracks the global CO_2 concentration
- Increase of GHG and global warming requires political action (e.g. Paris agreement, WMO/I^{3}GIS)



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Data taken from WDCGG: https://gaw.kishou.go.jp/ and references therein
IPCC 2013: Climate Change 2013: The Physical Science Basis. .

GHG sources and sinks

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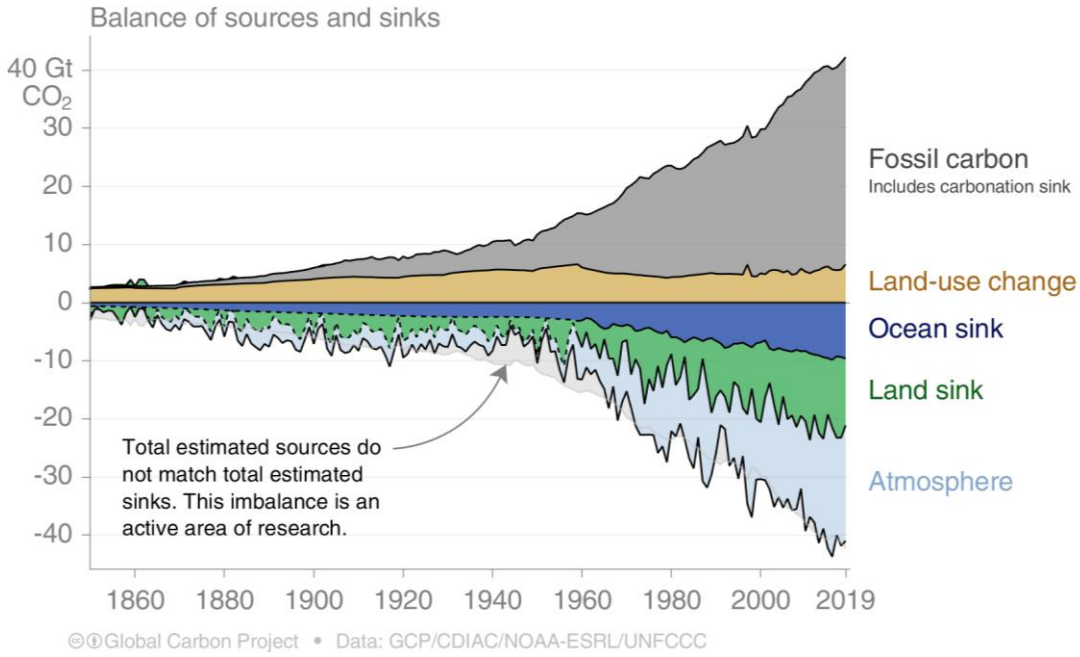
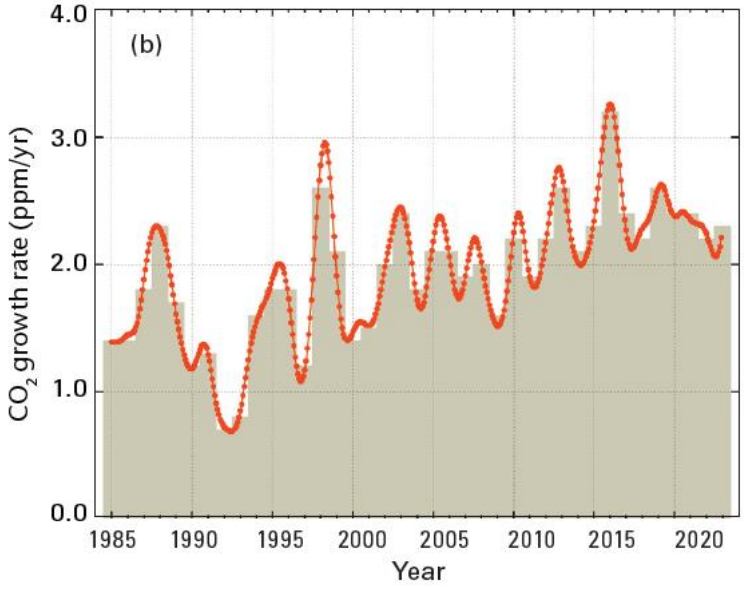
Trace gas concentrations are the results of emission and sinks (and transport):

$$\frac{d(concentration)}{dt} = emission\ rate\ - loss\ rate = growth\ rate$$

Major source and sinks for CO_2:



Growth rate:



https://www.globalcarbonproject.org/
https://gaw.kishou.go.jp/

CH_4 sources and sinks

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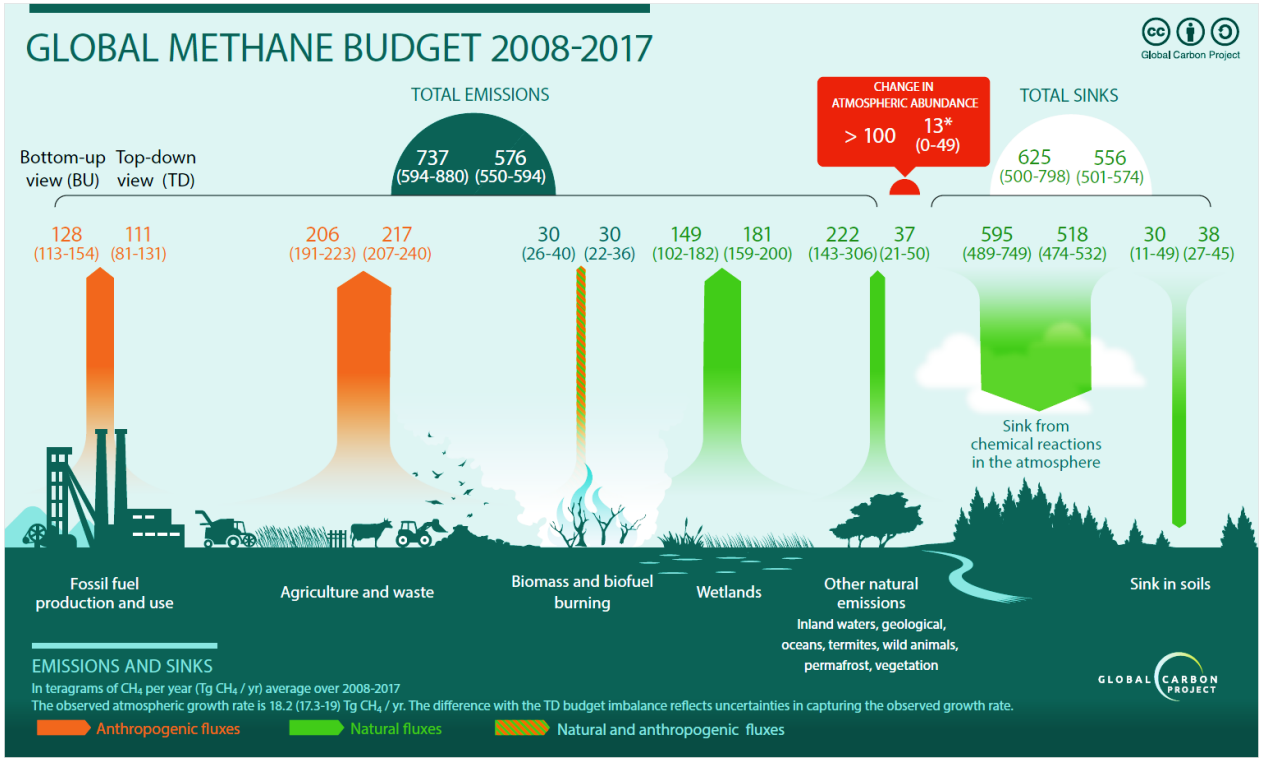

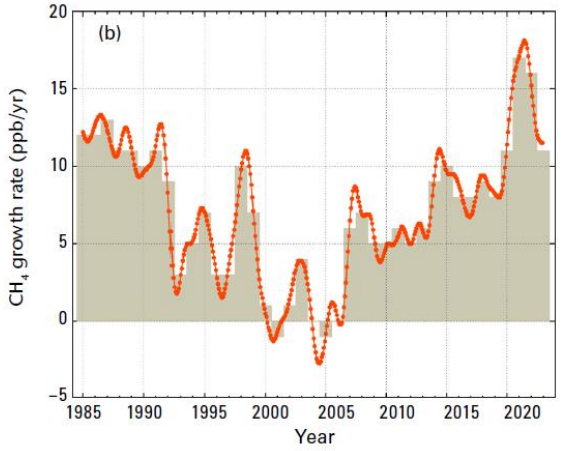

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https://www.globalcarbonproject.org/
https://gaw.kishou.go.jp/

N_2O sources and sinks

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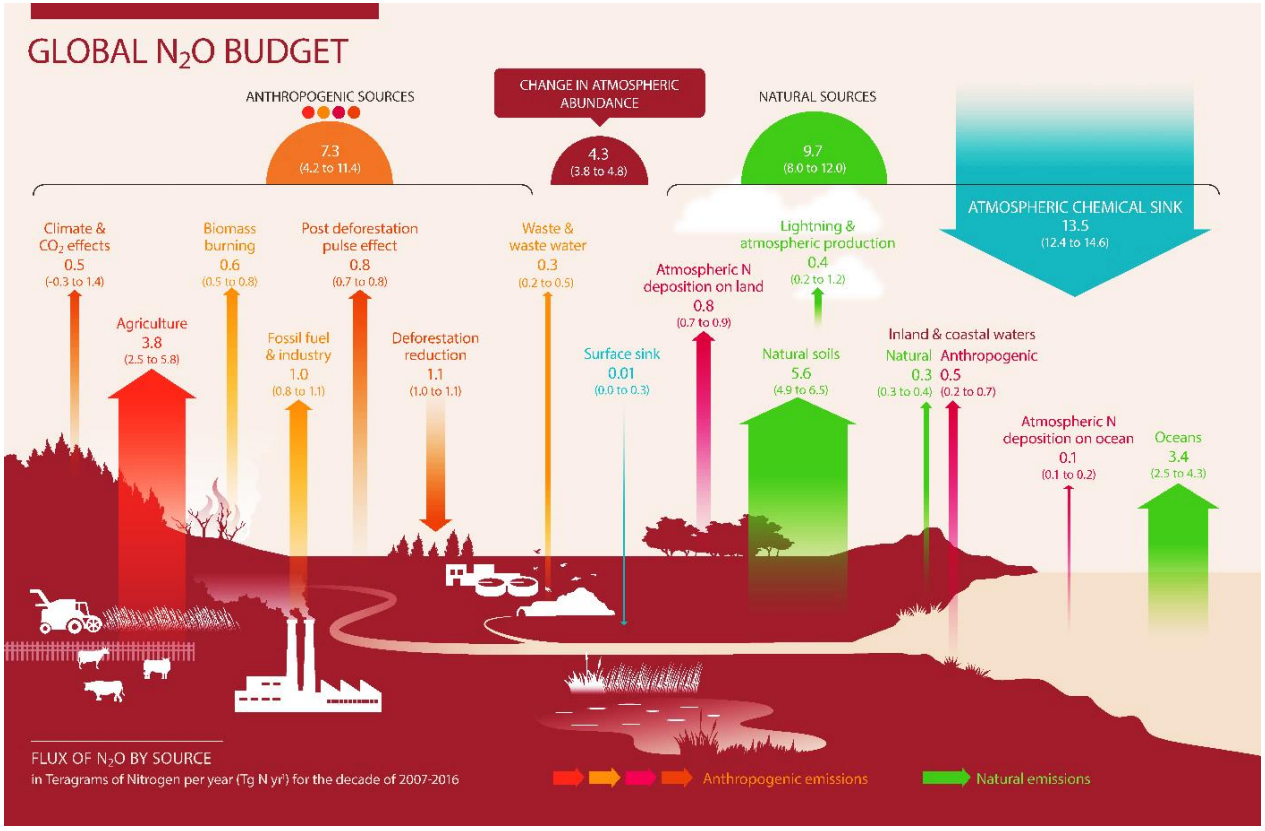

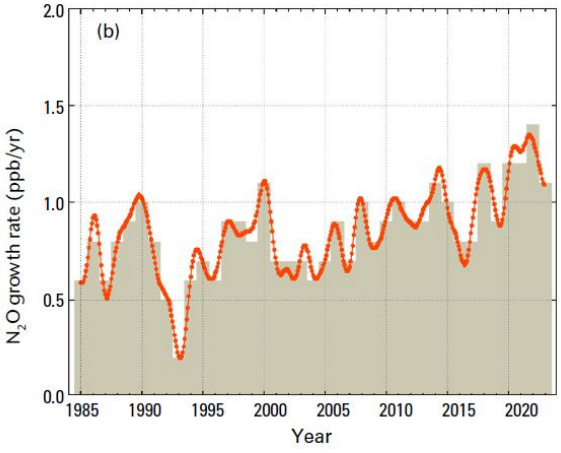

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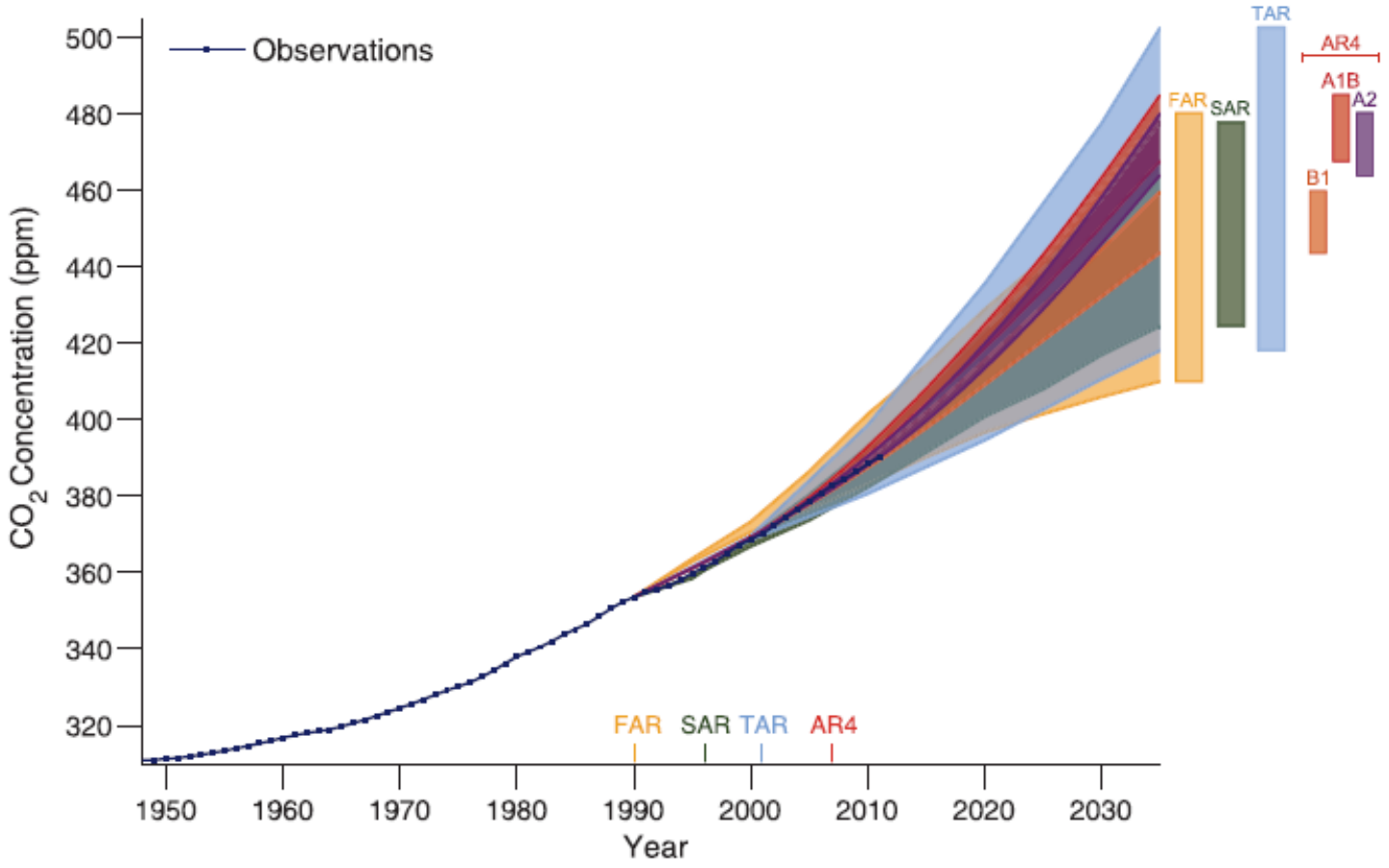
https://www.globalcarbonproject.org/
https://gaw.kishou.go.jp/

Future Predictions for GHGs



IPCC 2013: Climate Change 2013: The Physical Science Basis

Atmospheric composition networks

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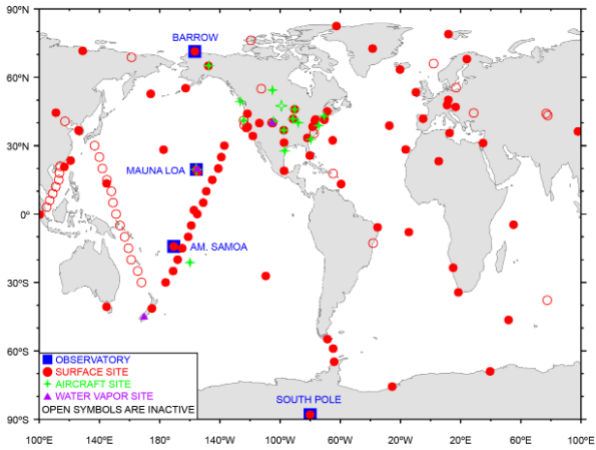
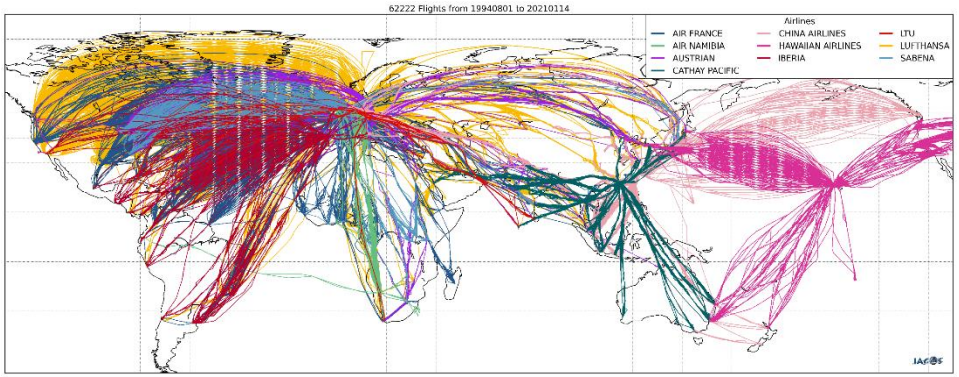
- WMO/GAW (and contributing networks)
- NOAA Global Greenhouse Gas Reference Network
- ICOS
- AGAGE
- Environmental Protection Agencies
- TCCON
- IAGOS
- …..

GAW global stations

NOAA network



IAGOS flight routes



Covering continuous in-situ, flasks, ground based/air borne / shipborne, remote sensing & satellite programmes (GOSAT, OCO-2, Copernicus CO2M, ….)

https://community.wmo.int/activity-areas/gaw/research-infrastructure/gaw-stations
https://www.esrl.noaa.gov/gmd/about/GMD_Research_Plan_2018-2022.pdf; http://www.iagos-data.fr/

Atmospheric composition networks

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- **Global Coverage**
- **Completeness**:
  high data coverage and uniformly distributed in time for continuous measurements
- **Compatibility**:
  Difference of two independent measurements at one side < measurement uncertainty
- **Comparability**:
  Tracability to same primary standard
- **Representativeness**:
  Location should be representative for the area
- **Long term perspective**

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https://gawsis.meteoswiss.ch/GAWSIS

European Research Infrastructures - ICOS

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Monitor European major greenhouse gases for:

- fundamental understanding of carbon cycle, greenhouse gas budgets and perturbations and underlying processes
- determinination of major source and sink regions at European and national scales
- verification of emission inventories
- reduction of uncertainties in Earth System models
- climate change prediction
- assessment of mitigation strategies

ICOS INTEGRATED CARBON OBSERVATION SYSTEM

ERIC[1] established Nov 2015

[1]ERIC (European Research Infrastructure Consortium)

ICOS – Greenhouse Gases in Europe

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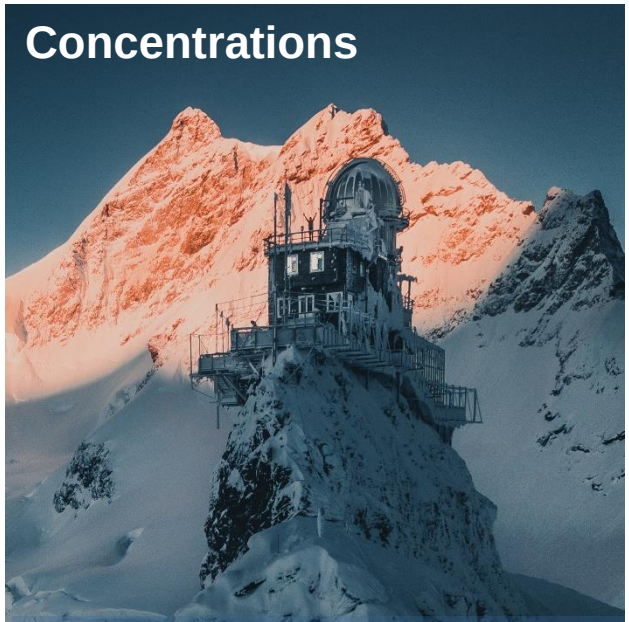
DWD

Atmosphere

Concentrations



of:

- CO_2, CH_4, N_2O, $^{14}CO_2$
- CO, 222Rn
- Meteorology
- …

Ecosystems

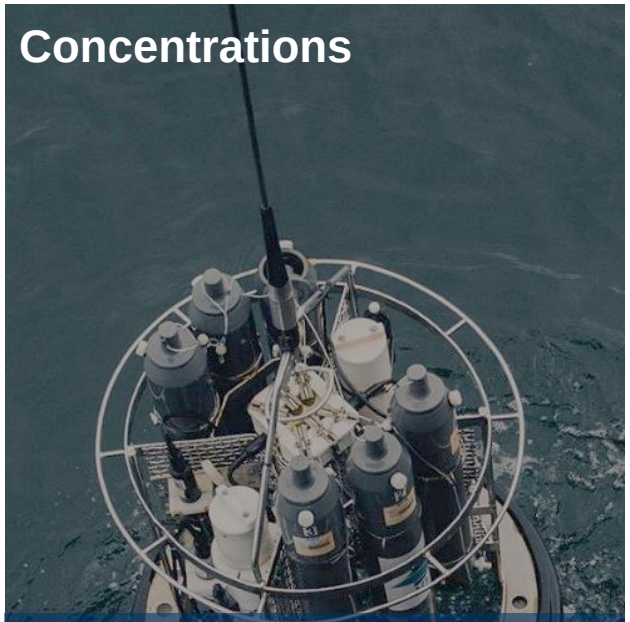
Fluxes

of:

- CO_2, CH_4, H_2O, N_2O, latent heat
- Soil parameters
- …

Oceans

Concentrations



of:

- pCO_2
- pH, T, salinity
- …

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https://www.icos-cp.eu/
Pictures taken by Konsta Punkka

ICOS – Greenhouse Gases in Europe

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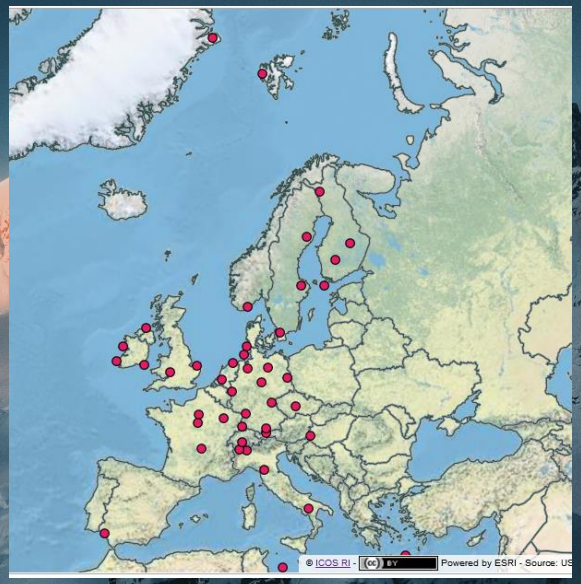
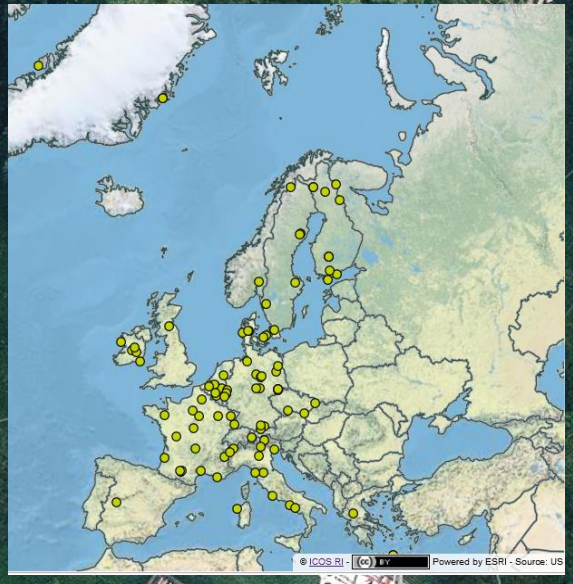
Atmosphere

Concentrations



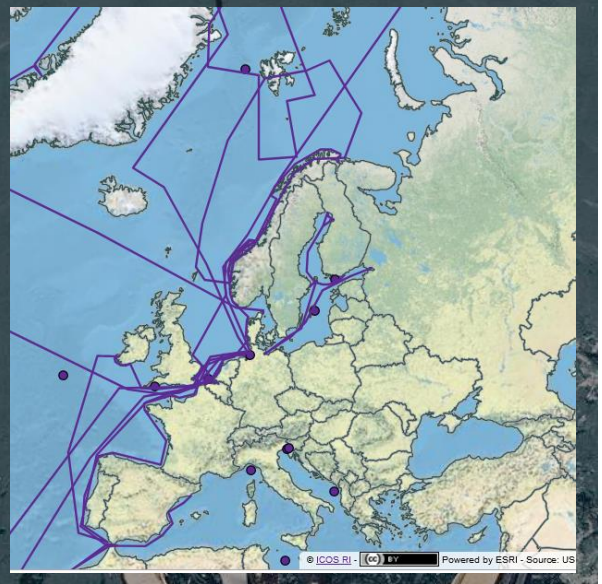
Ecosystems

Fluxes



Oceans

Concentrations pCO_2



14 Countries
150 Stations
500 Researchers

110 Institutions
100 Mio € Investment
20 Mio €/yr Running costs

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https://www.icos-cp.eu/
Pictures taken by Konsta Punkka

Design Atmospheric ICOS D Network

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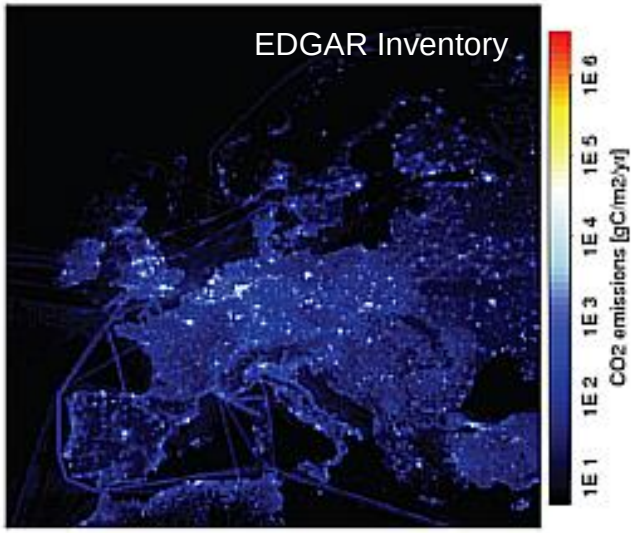
- Location:
  - compliant with ICOS Strategy
    – natural sources, sinks and their processes
  - Sufficient coverage of Germany
  - Infrastructure (stable power,
    accessibilty of stations,
    remote access and data transfer)
- Technical equipment:
  - High precision instrumentation
  - Calibration gases and system
  - Data aquisition system
- Trained personnel
- Sustainability



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Tall Towers

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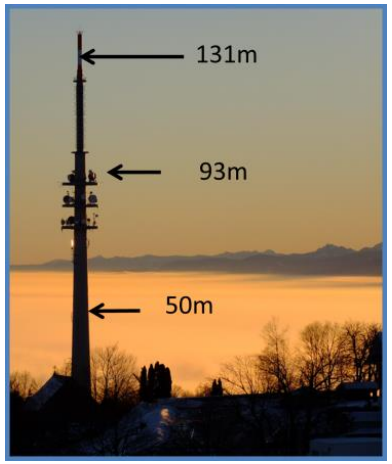
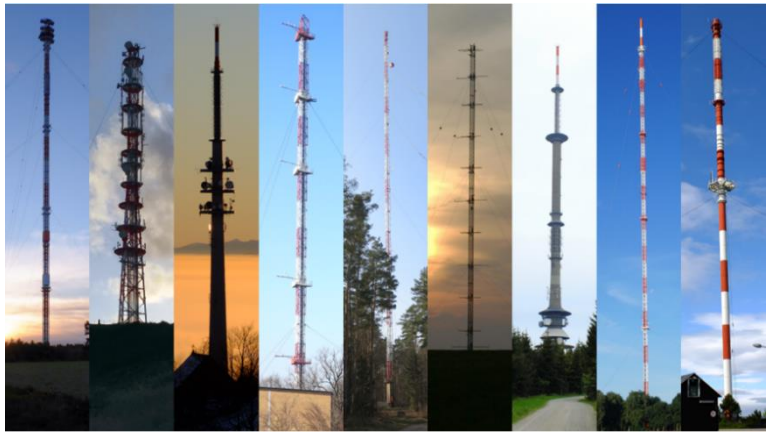
- larger footprint with increasing heights
- minimise effect of local pollution
- different levels for vertical profile measurements and gradients

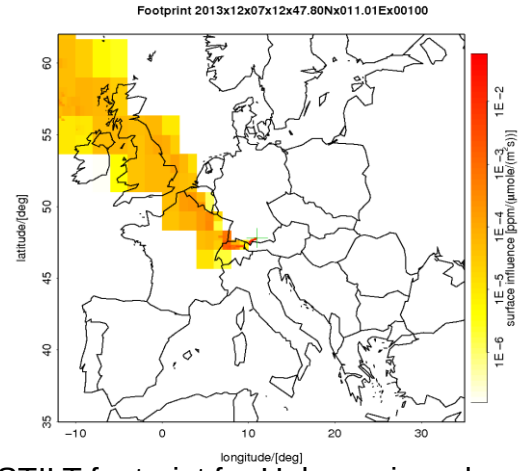


➔ Use of pre-existing telecommunication towers

Selection based on:

- location
- simulations
- tower structure
- rental fees
- accessibilty





STILT footprint for Hohenpeissenberg tall tower (07. Dec 2013, 12:00)

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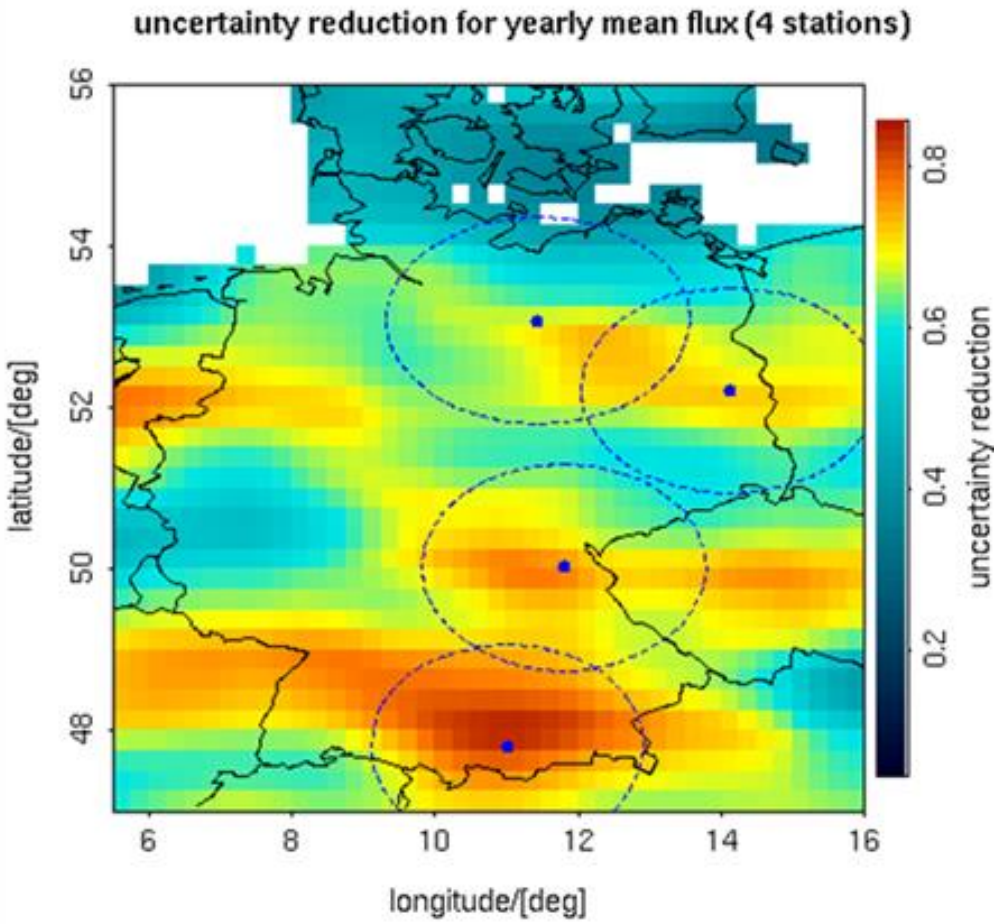
Model Study

Model study to determine location and number of tall tower stations:

- STILT-TM3 Inversion (0.25° x 0.25°)

- Prior fluxes:
  - VPRM model (biosphere)
  - IER (fossil fuel)
  - Ozean (M. Fletcher 2006)

- Calculated uncertainty of post flux vs uncertainty of prior flux



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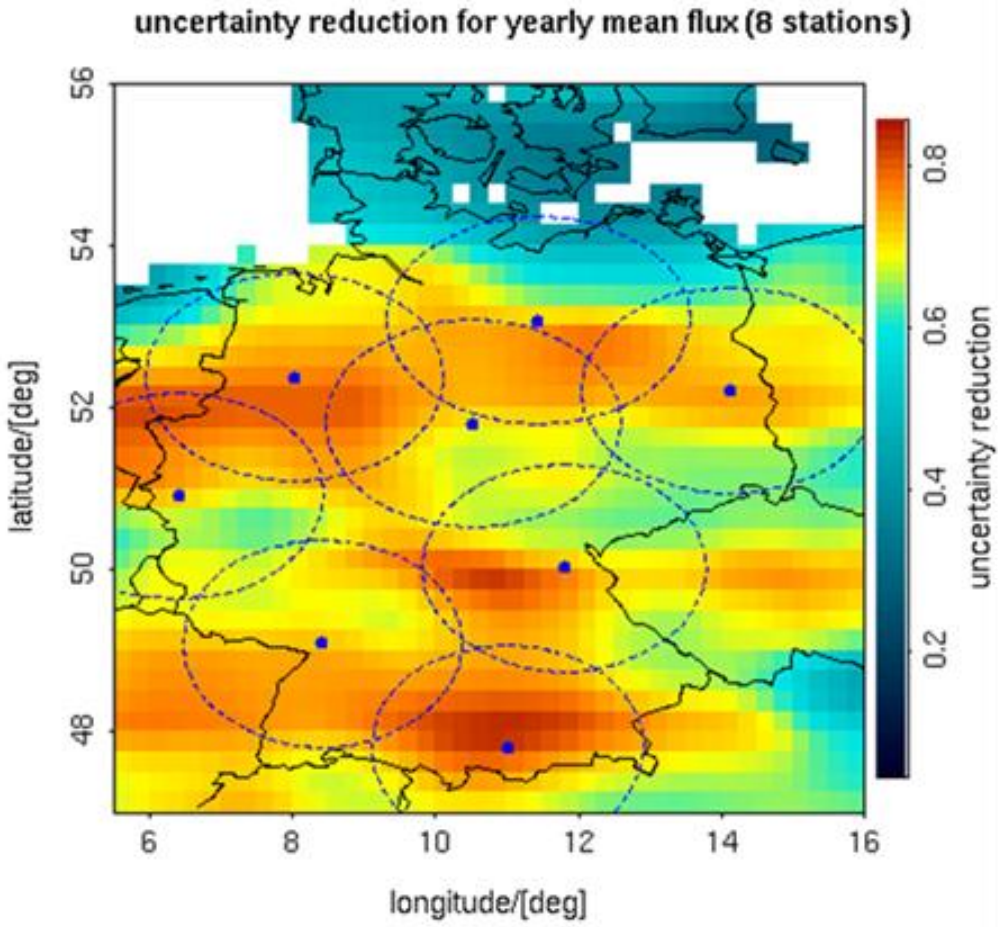

ICOS Germany Atmospheric Network

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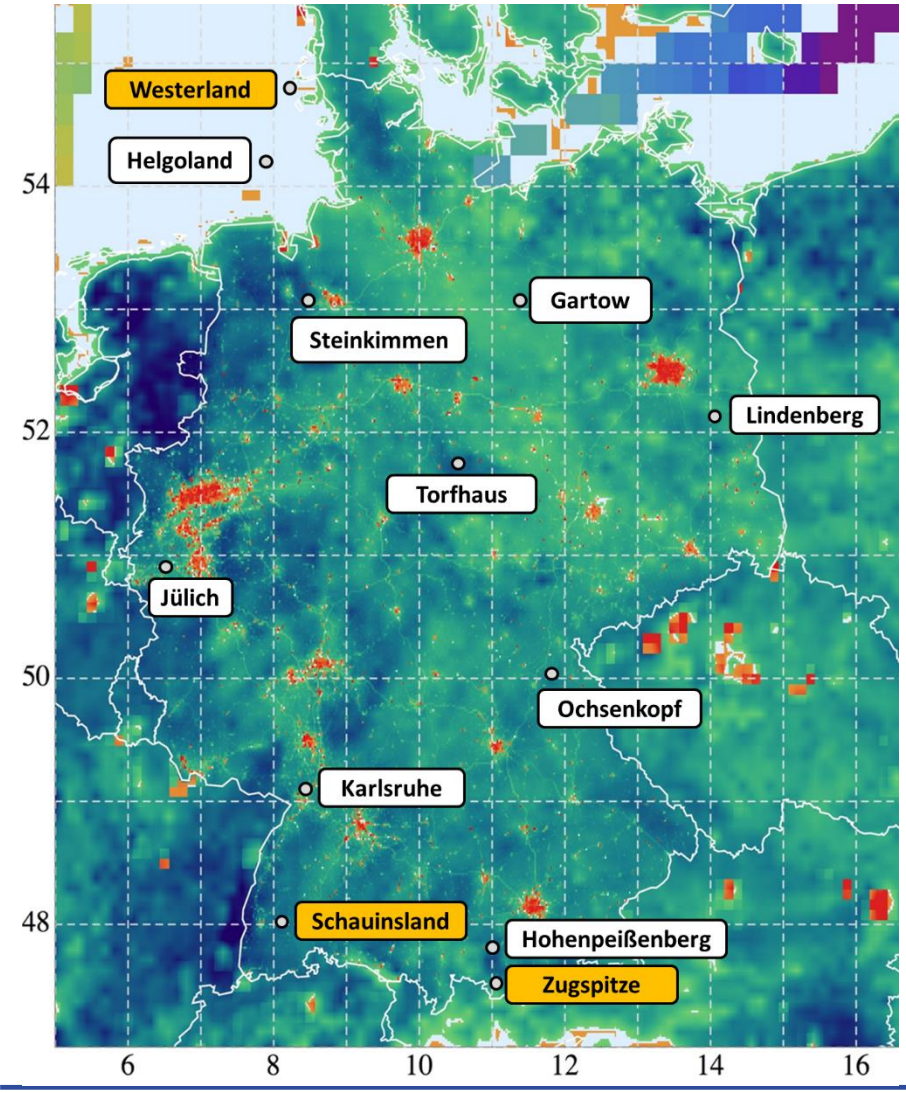
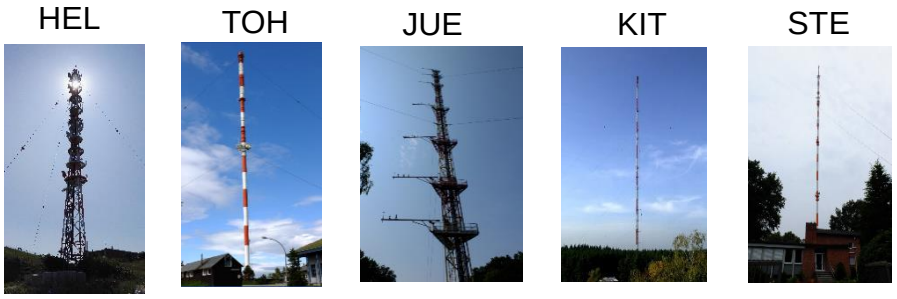
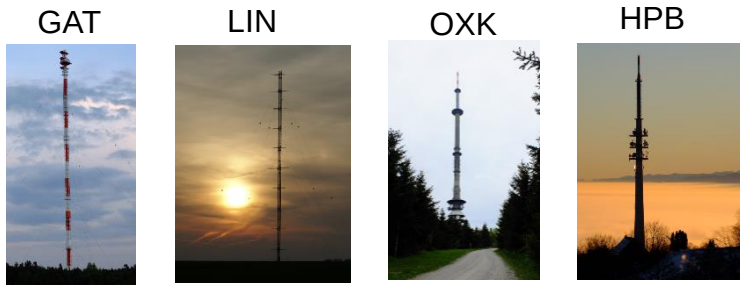
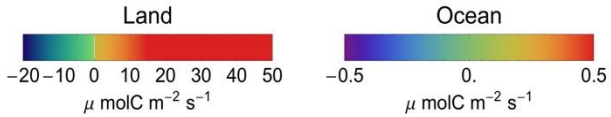


- 9 DWD Tall Tower Stations
- 3 Stations operated by the German Environment Agency (UBA)







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Stations network and modelled CO_2 fluxes for summer midday conditions represented by colour (in courtesy of M. Heimann, MPI-BGC).

ICOS Germany Atmospheric Network

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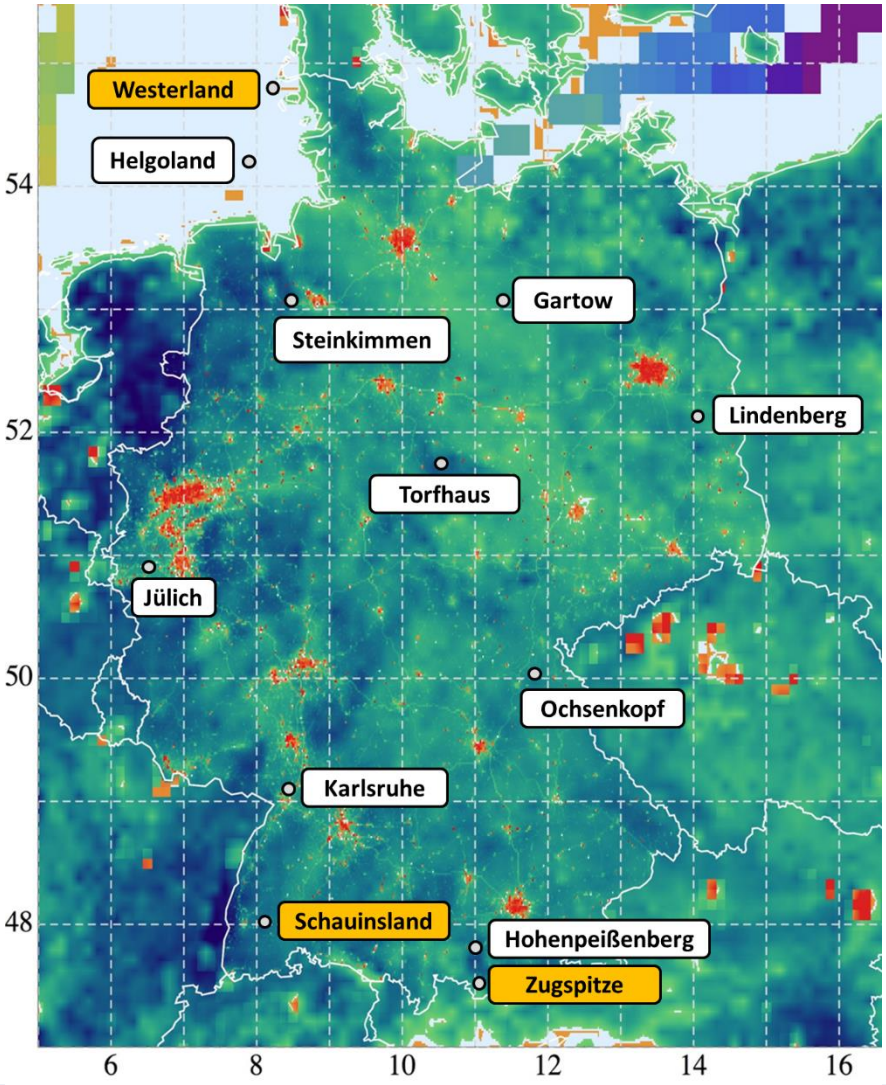

Class 1:

- Continuous in-situ CO_2, CH_4, CO meteorology (p, T, RH, wind direction/velocity) at every measurement level
- Weekly flask samples of CO_2, CH_4, N_2O, SF_6, CO, H_2, $^{13}C(CO_2)$, $^{18}O(CO_2)$, $^{14}C(CO_2)$ at highest level
- integrated $^{14}C(CO_2)$ over two weeks period

Class 2:

- Continuous in-situ CO_2, CH_4 meteorology (p, T, RH, wind direction/velocity) at every measurement level

Recommended:

- ^{222}Rn, N_2O, Planetary Boundary Layer Height

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Modelled CO_2 in courtesy of M. Heimann, MPI-BGC

ICOS RI (2020): ICOS Atmosphere Station Specifications V2.0 (editor: O. Laurent). ICOS ERIC

Data Quality Objectives (DQO)

WMO recommendation for compatibility of measurements of greenhouse gases

Component	*Network compatibility goal[1]*	*Extended network compatibility goal[2]*	*Range in unpolluted troposphere (approx. range for 2019)*	*Range covered by the WMO scale*
CO_2	0.1 ppm (NH) 0.05 ppm (SH)	0.2 ppm	380 - 450 ppm	250 – 520[3] ppm
CH_4	2 ppb	5 ppb	1750 – 2100 ppb	300 – 5900 ppb
CO	2 ppb	5 ppb	30 – 300 ppb	30 - 500 ppb
N_2O	0.1 ppb	0.3 ppb	325 – 335 ppb	260 – 370 ppb
$\Delta^{14}C\text{-}CO_2$	0.5‰	3‰	-80 to 20‰	

"Scientifically desirable level of network compatibility for measurements of well-mixed background air" for:

- Inferring regional fluxes from models
- Detection of small trends and gradients
- Minimise systematical uncertainty between stations and networks

Note: All mixing ratios are referred to dry mole fractions:

$$dry\ mol\ fraction\ of\ species\ X = \frac{number\ of\ molecules\ of\ X}{number\ of\ molecules\ of\ dry\ air}$$

This is important as atmospheric water content varies up to ~4 %, depending on region and season.

Instrumentation

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- [1]CRDS (Picarro G2401) for CO_2/CO/CH_4/H_2O or
  CRDS (Picarro G2301) for CO_2/CH_4/H_2O
  CRDS (Picarro G5310) for N_2O / CO / H_2O
- Off-axis ICOS (LGR-913-0015(EP)) for N_2O / CO / H_2O
- Radon ^{222}Rn (University Heidelberg)
- $^{14}C(CO_2)$ (University Heidelberg – AMS, chemical absorption in NaOH)
- Meteorology: Wind, Temperature, Humidity
- Ceilometer (Lufft CHM15K)
- Flasksampler (MPI-BGC)

[1]CRDS = Cavity Ring Down Spectroscopy

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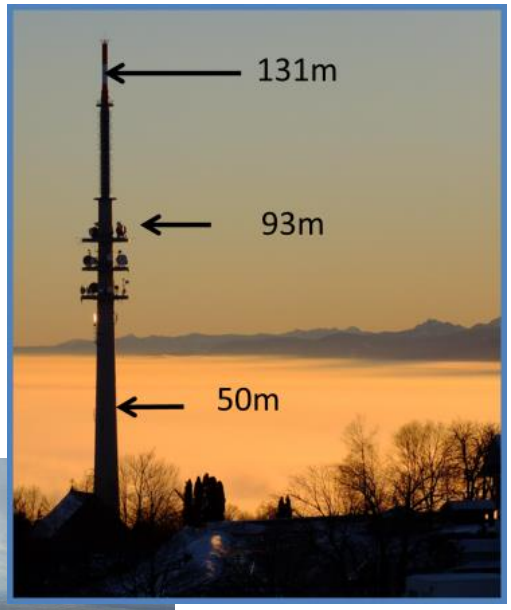
Inlet line design

- Material: Decabon/Synflex, stainless steel
- Seperate lines for each height
- Filter at entrance of inlets
- Reduced inlet line pressure to prevent condensation, in principle no drying required
- Nafion drying for N_2O/CO LGR Analyser



ICOS Moments

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ICOS Moments

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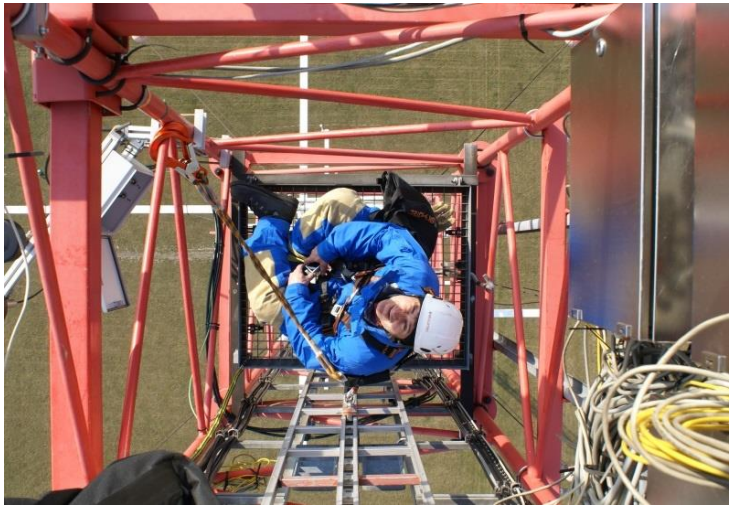

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QA/QC = Quality Assurance/Quality Control

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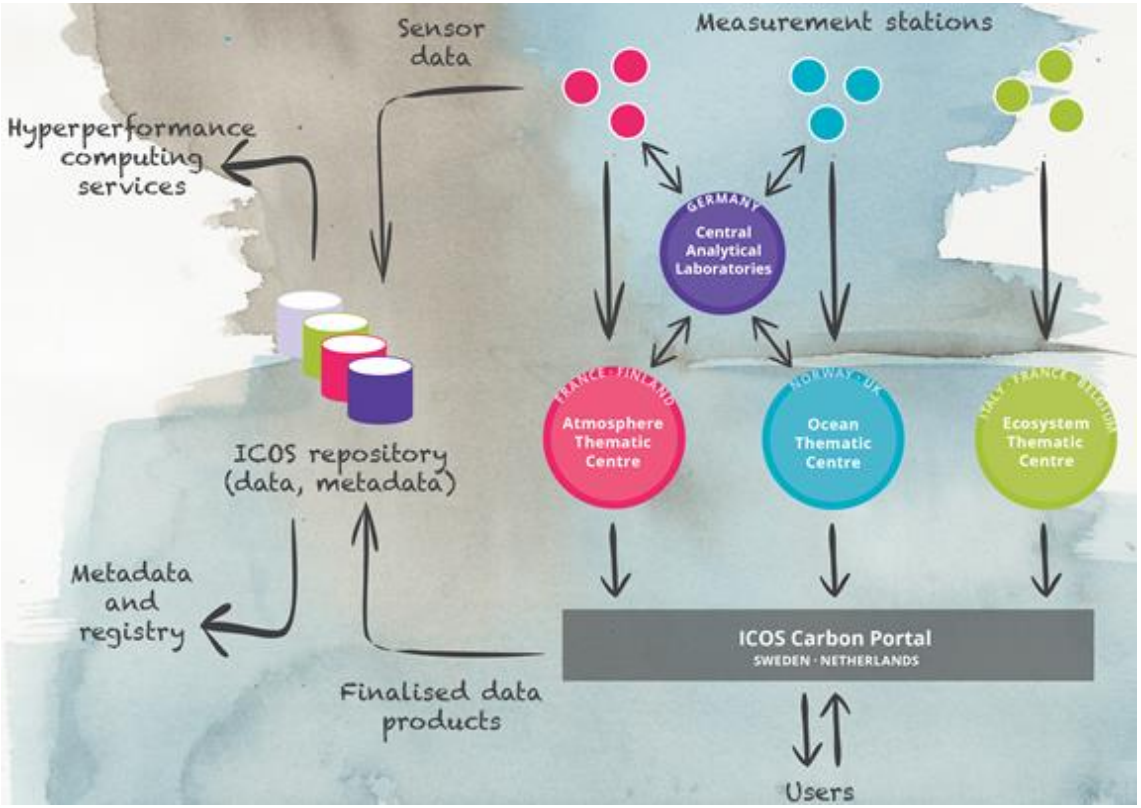
- **Central Facilities**: organisational set up supports QA/QC, i.e. structure of network ensures high quality measurements
- **Procedures**, i.e. specific tasks of Central Facilities and ICOS community
- At Station level: scientific and **station operation** and management



➔ **stringent** data QA/QC management! (stringent = strict, precise, and exacting)

ICOS Central Facilities CAL & ATC

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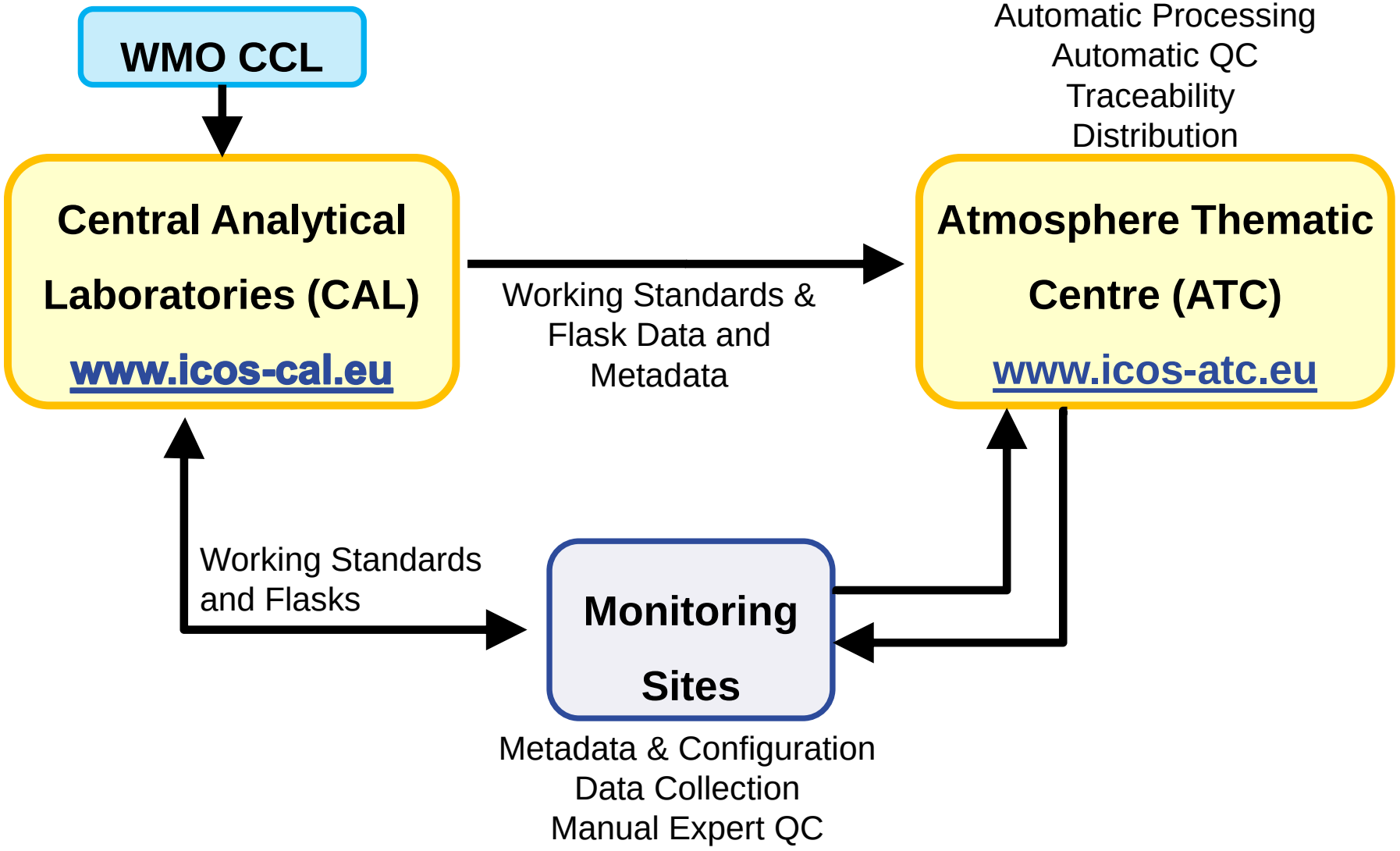
Wetter und Klima aus einer Hand



Procedures: becoming an ICOS Station

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- **Clear Specifications for Stations**:
  - ICOS RI (2020): ICOS Atmosphere Station Specifications V2.0 (editor: O. Laurent). ICOS ERIC. https://doi.org/10.18160/GK28-2188

- **Labelling Procedure:** All stations undergo rigorous assessment before receiving approval to join the network
  - Ywer-Kwok et al., 2021 https://doi.org/10.5194/amt-14-89-2021

- **Initial instrument tests by ATC Metrology Lab (MLab)** – instrument characterisation & check on ICOS compliance
  - Ywer-Kwok et al., 2015 https://doi.org/10.5194/amt-8-3867-2015

- **Station Audits by ICOS Mobile Lab,** traceable to WMO CCL and ICOS CAL

Procedures:
high quality data production

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- **Centralised data processing chain**
  - Hazan et al., 2016 https://doi.org/10.5194/amt-9-4719-2016
- **ATC QC data products** www.icos-atc.eu/dataproducts
- **Automated flask sampling for QC purpose**
  - Levin et al., 2020 https://doi.org/10.5194/acp-20-11161-2020
- **Regular Data Reviews (Meetings)**: Monitoring Station Assembly (MSA)
- **Coordination and science:** ICOS national meetings, ICOS Science Conference

QA/QC at Stations: Standardised Tests

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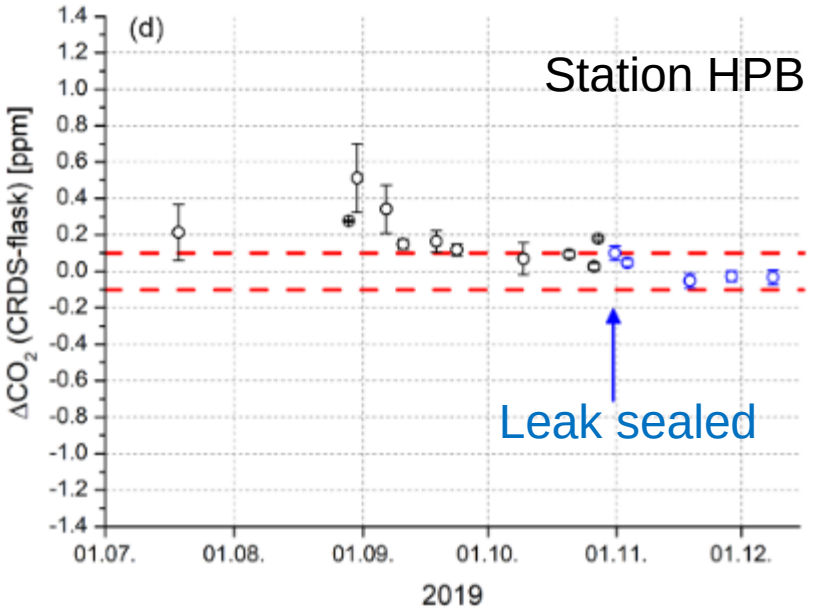
Determination of H_2O correction function (Droplet test)

System Leak tests

- Shelter test (measurement and standard gas delivery system)
- Line test (whole system, including inlet lines)
- Gradients in well mixed conditions

Flask sampling

In situ minus flask measurement for ambient CO2 variability <0.5 ppm. After sealing the leak: within the required ±0.1 ppm compatibility range.



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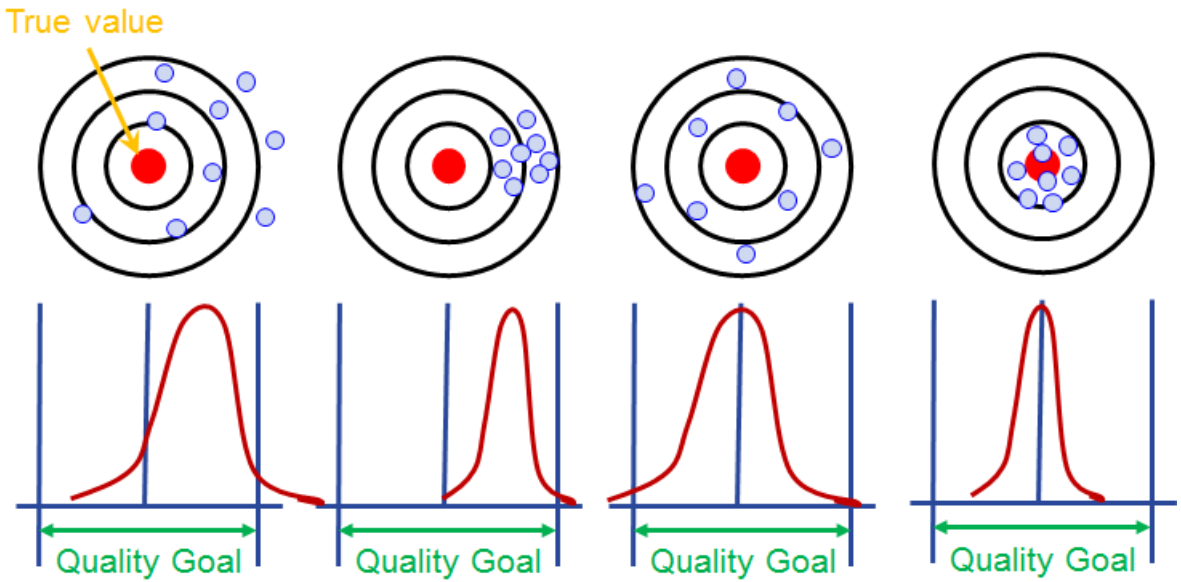
Levin et al., 2020 https://doi.org/10.5194/acp-20-11161-2020

QA/QC at Stations: Standardised Tests



Calibrations → correct for instrument drift & bias → achieve required **accuracy**

Target measurements

- Short/Long-term target → long-term **repeatability** (= reproducibility)
  → continuous monitoring **repeatability** (= precision)
  → **bias**
- Reference tank → to correct for short term variability / drift

[**Bias** = tank measurement minus its attributed value]

QA/QC at Stations: Calibrations

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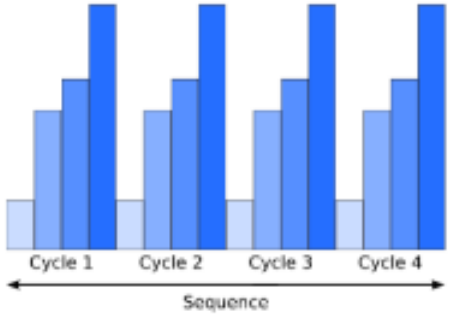


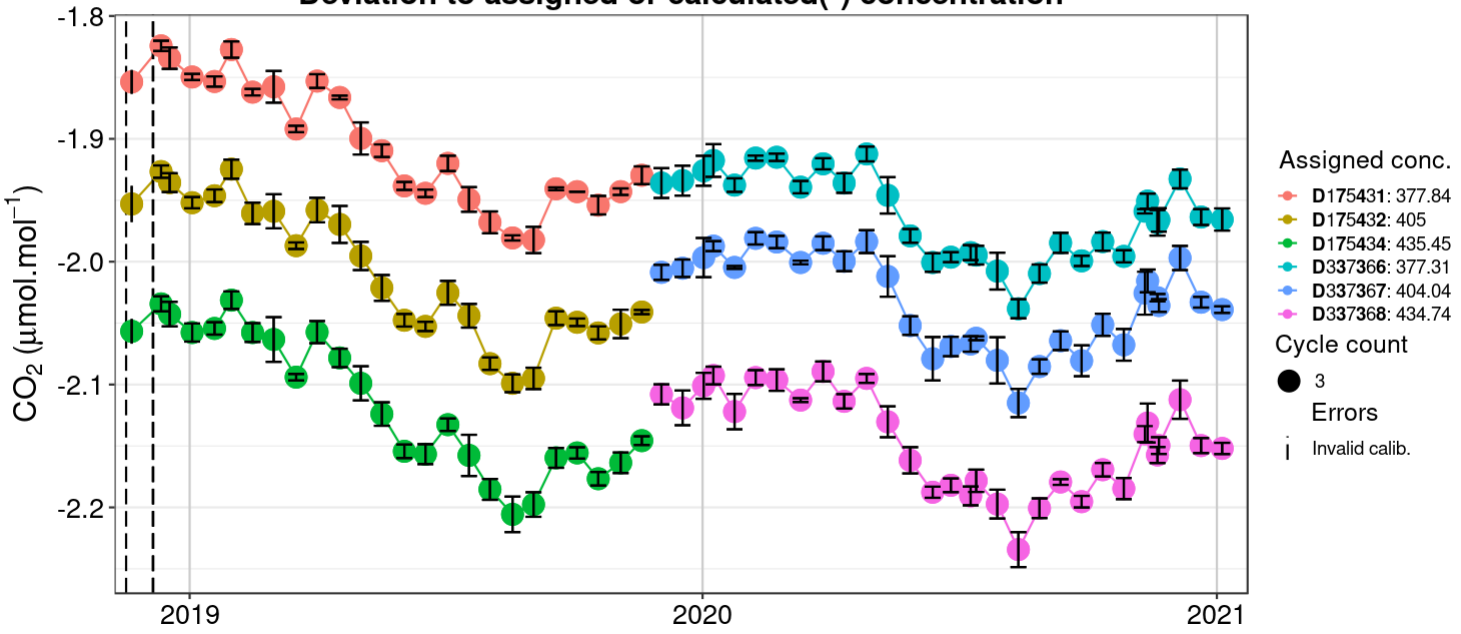
ICOS Atmosphere Thematic Centre

P0002.2 / plot generated everyda
update 2021-01-15 06:4

GAT 413 - Calibration tank drift

2018-11-16 - 2021-01-15

Deviation to assigned or calculated(*) concentration



QA/QC at Stations: Uncertainties (1)

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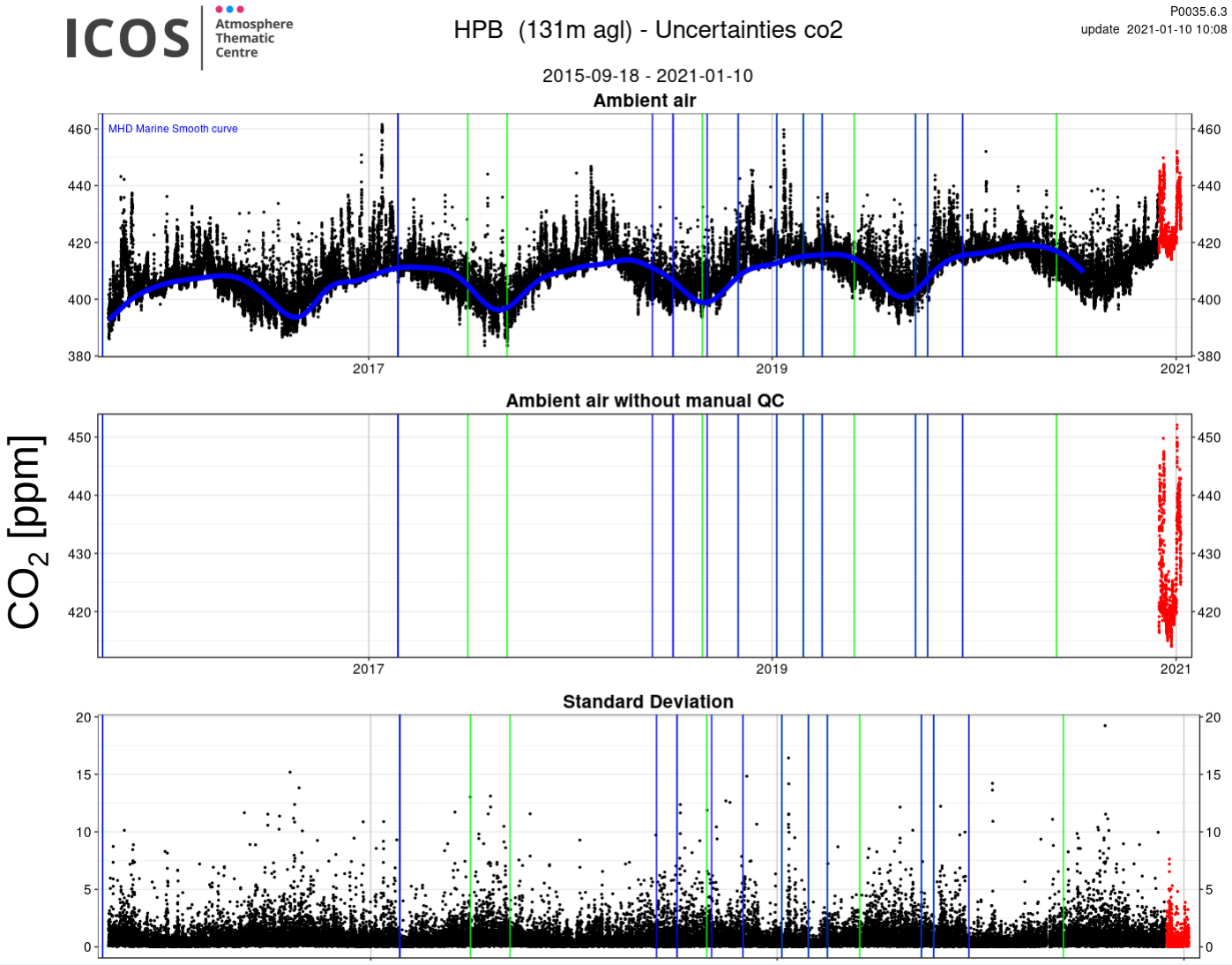
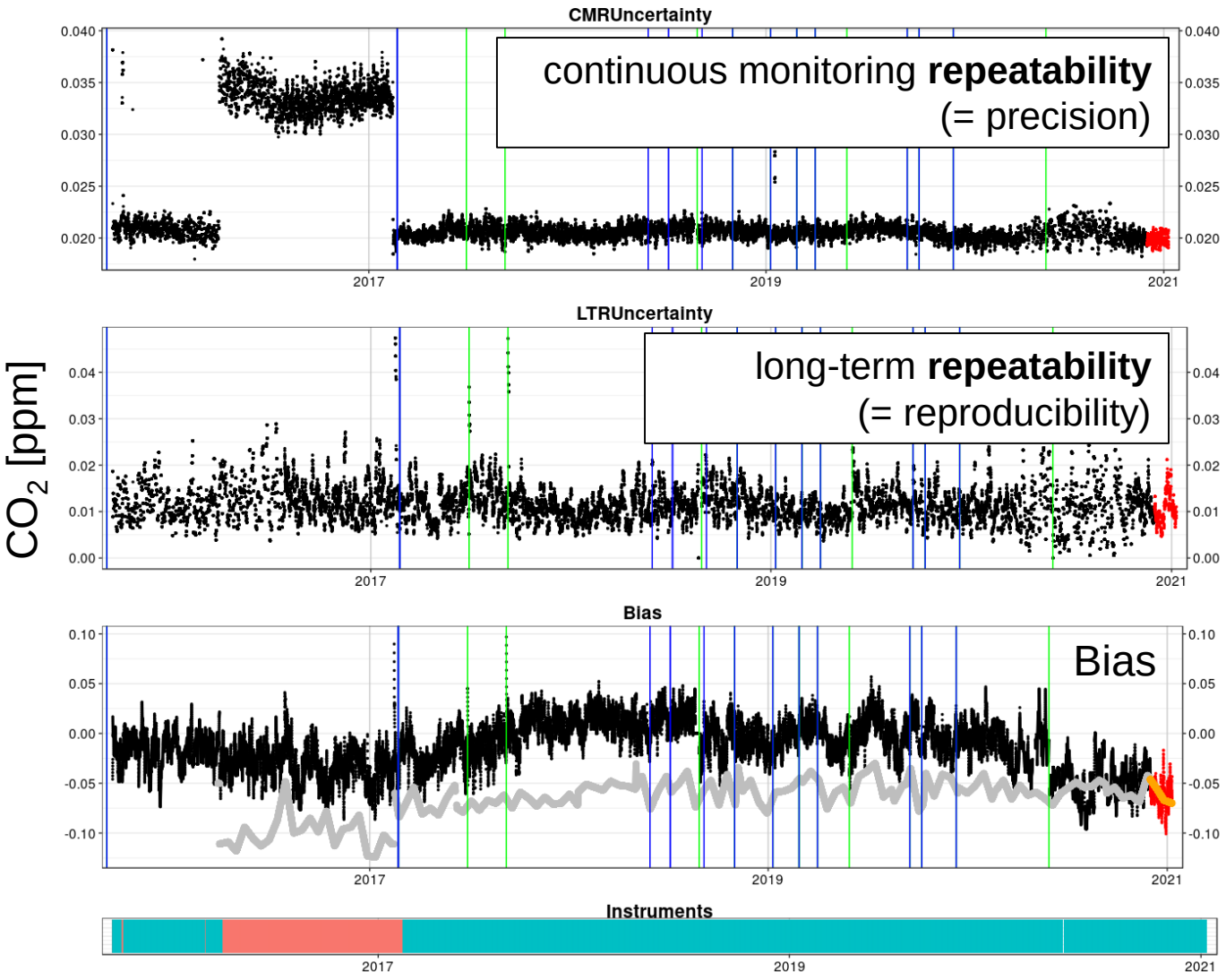


QA/QC at Stations: Uncertainties (2)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



CMR = Average SD over 24 hrs using 1min intervals of raw data

LTR = SD of averaged target measurements over 3 days

Target

Calibration/Configuration

271 | 382

Flag U

Flag O

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Theory vs Practice: achieving QC goals

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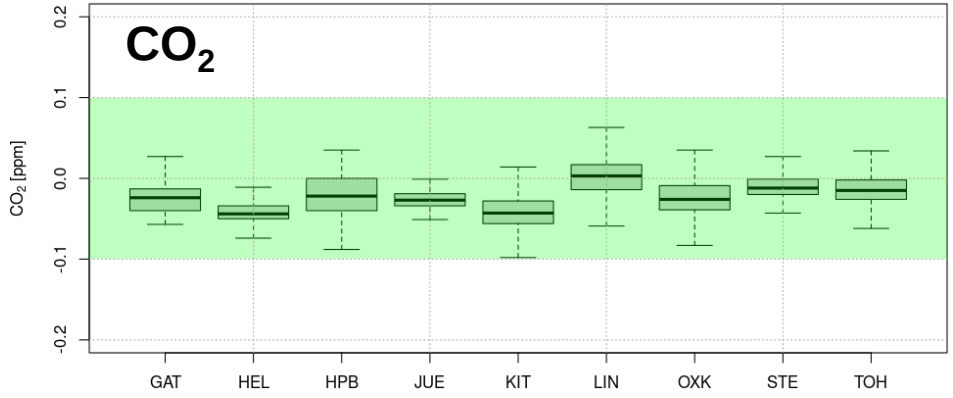

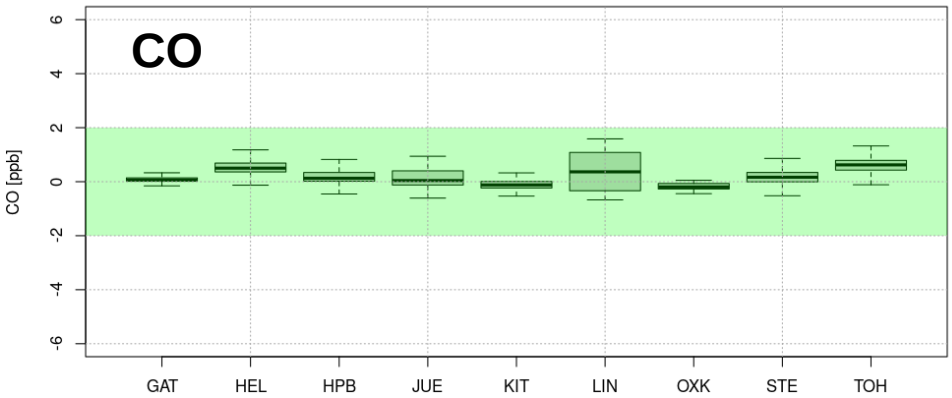

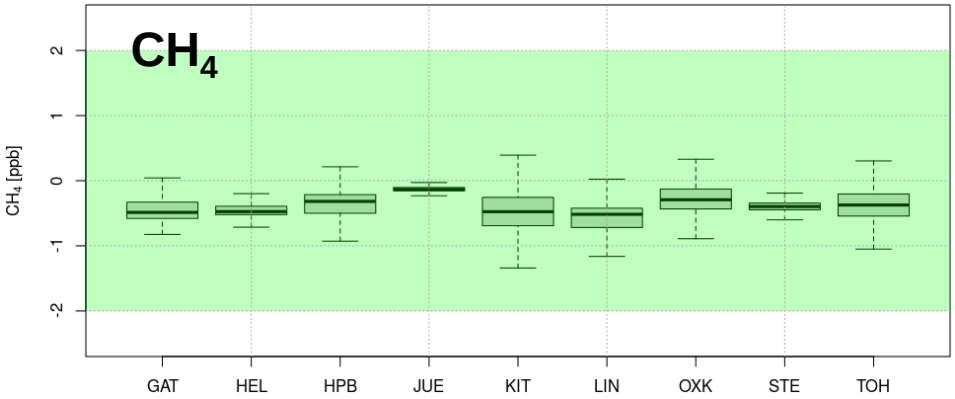

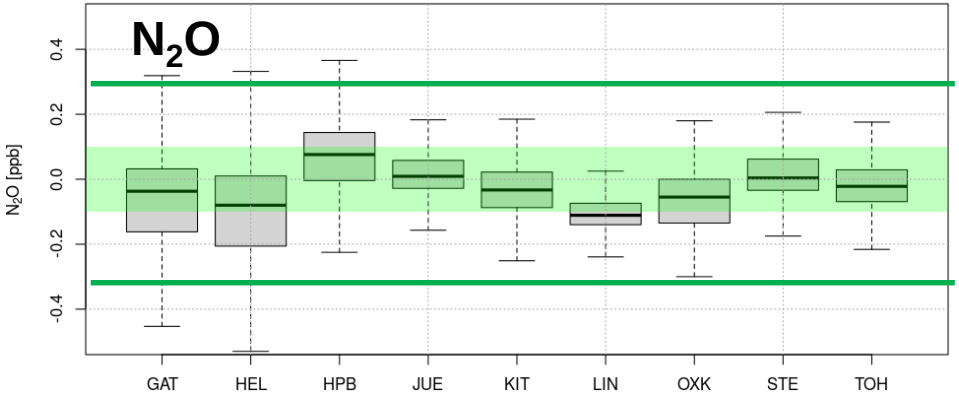

Boxplots based on short term target measurements for German DWD stations
The green area indicates the WMO compatibility goals (— extended compatibility goal for N_2O)

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Carbon Portal

www.icos-cp.eu/

@ICOS_CP

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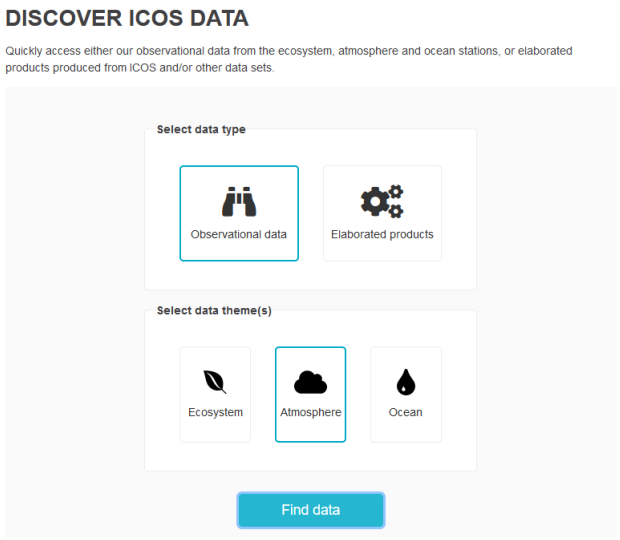
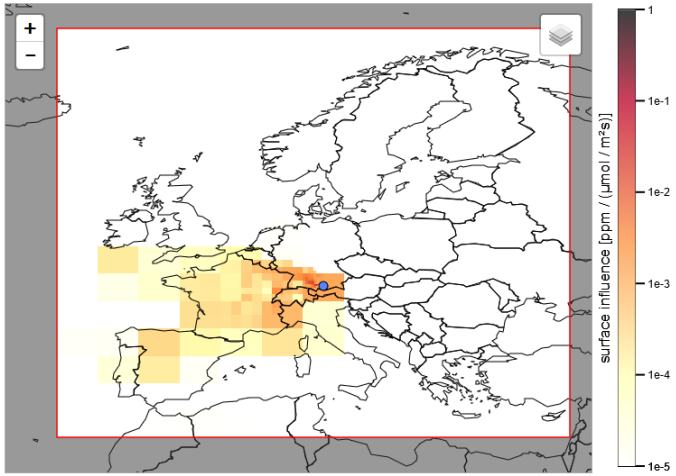
- **Information** for scientists, policy-makers, ICOS community and public, media & education
- **Observational ICOS data** and data products (free download)
  - ICOS Near Real Time Observational Data (Level 1)
  - ICOS Final Fully Quality Controlled Observational Data (Level 2)
- **Tools** for visualisation, analysis and management of data
  - **Footprint** Tool (simulations using model STILT Stochastic Time Inverted Lagrangian Transport; Lin et al., 2003)
  - Forecast of airmass **backtrajectories** at ICOS stations
  - ICOS **Jupyter Notebooks** for exploring and analysing ICOS data for scientific and educational purposes



STILT results viewer



Timeseries of CO_2, CH_4, N_2O

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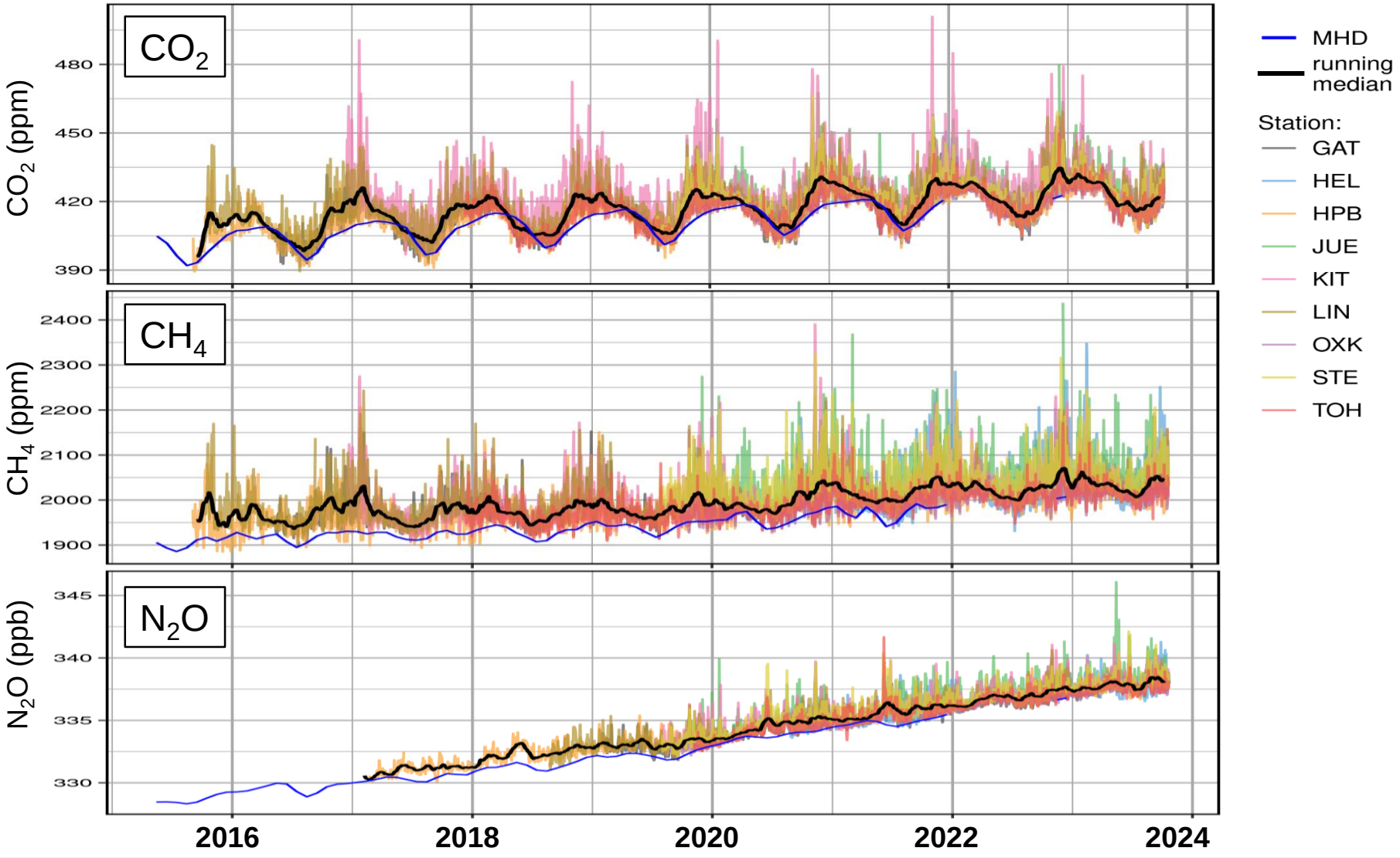

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ICOS Station Karlsruhe KIT

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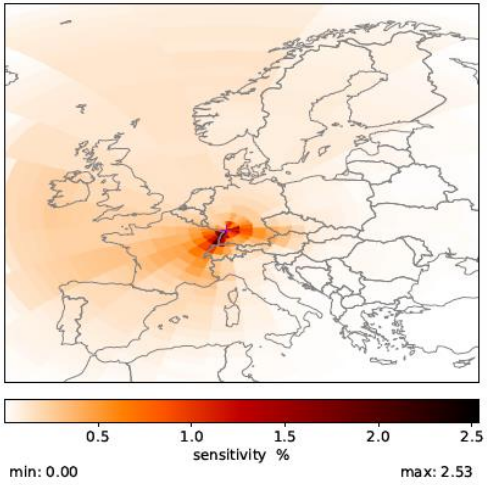

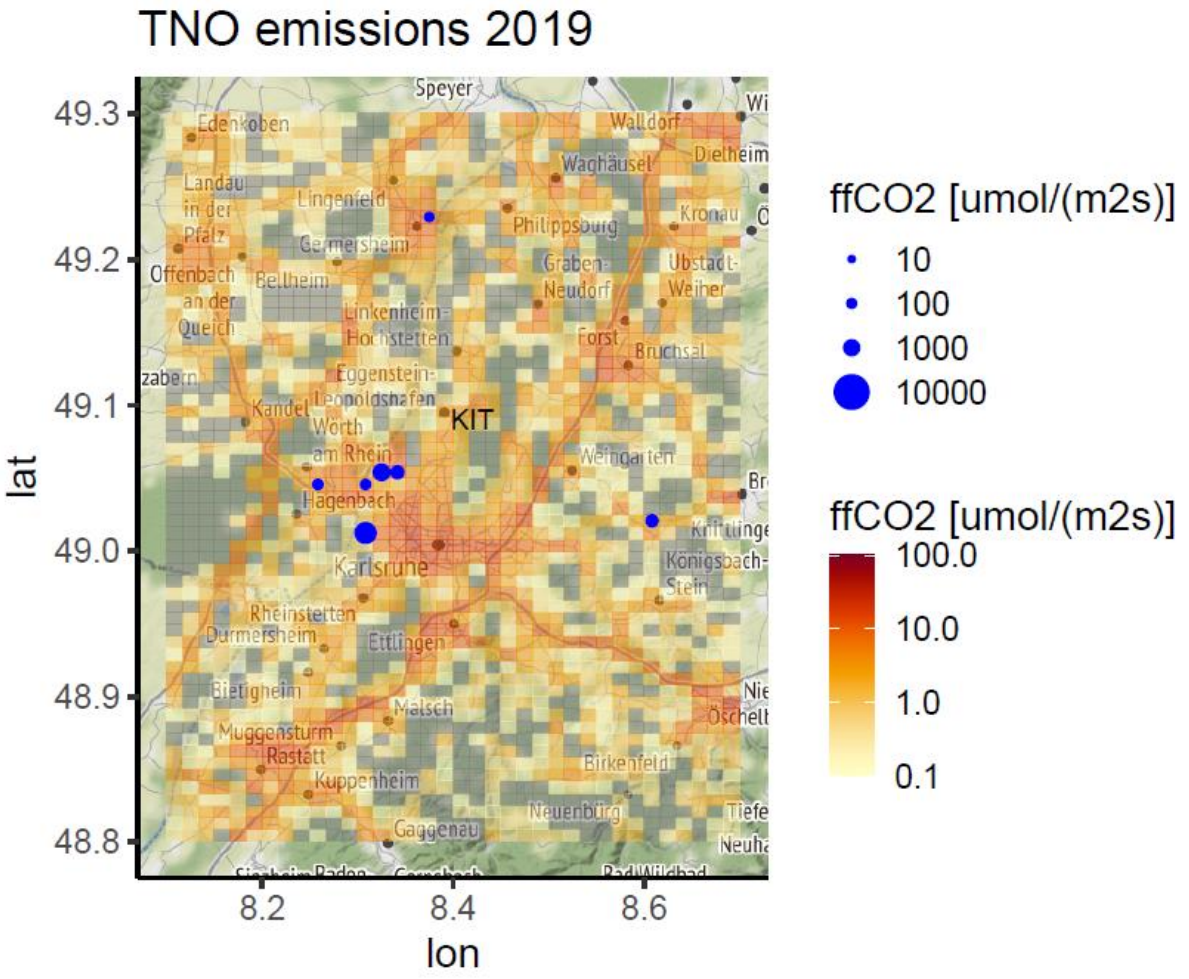

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Courtesy to Fabian Meier, UHEI

Concentrations and anomalies

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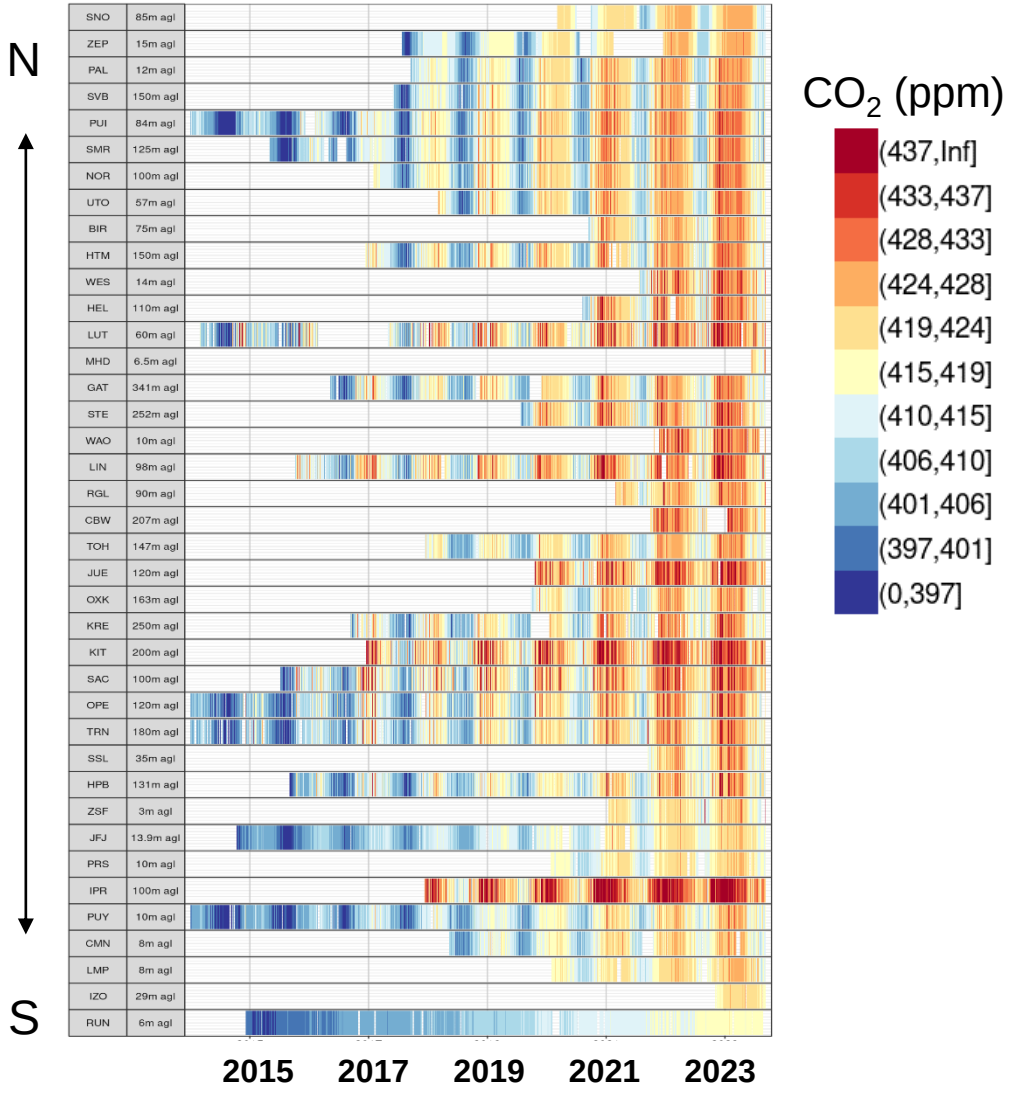
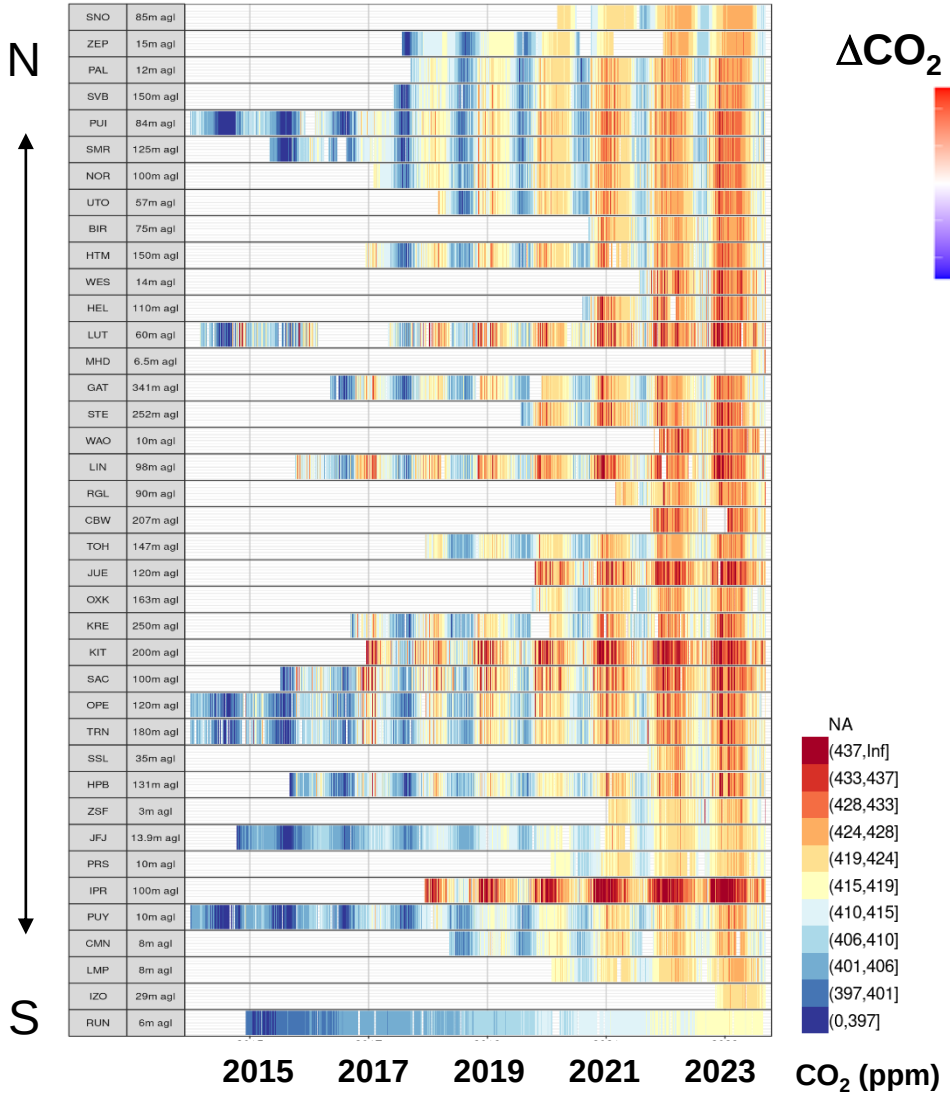
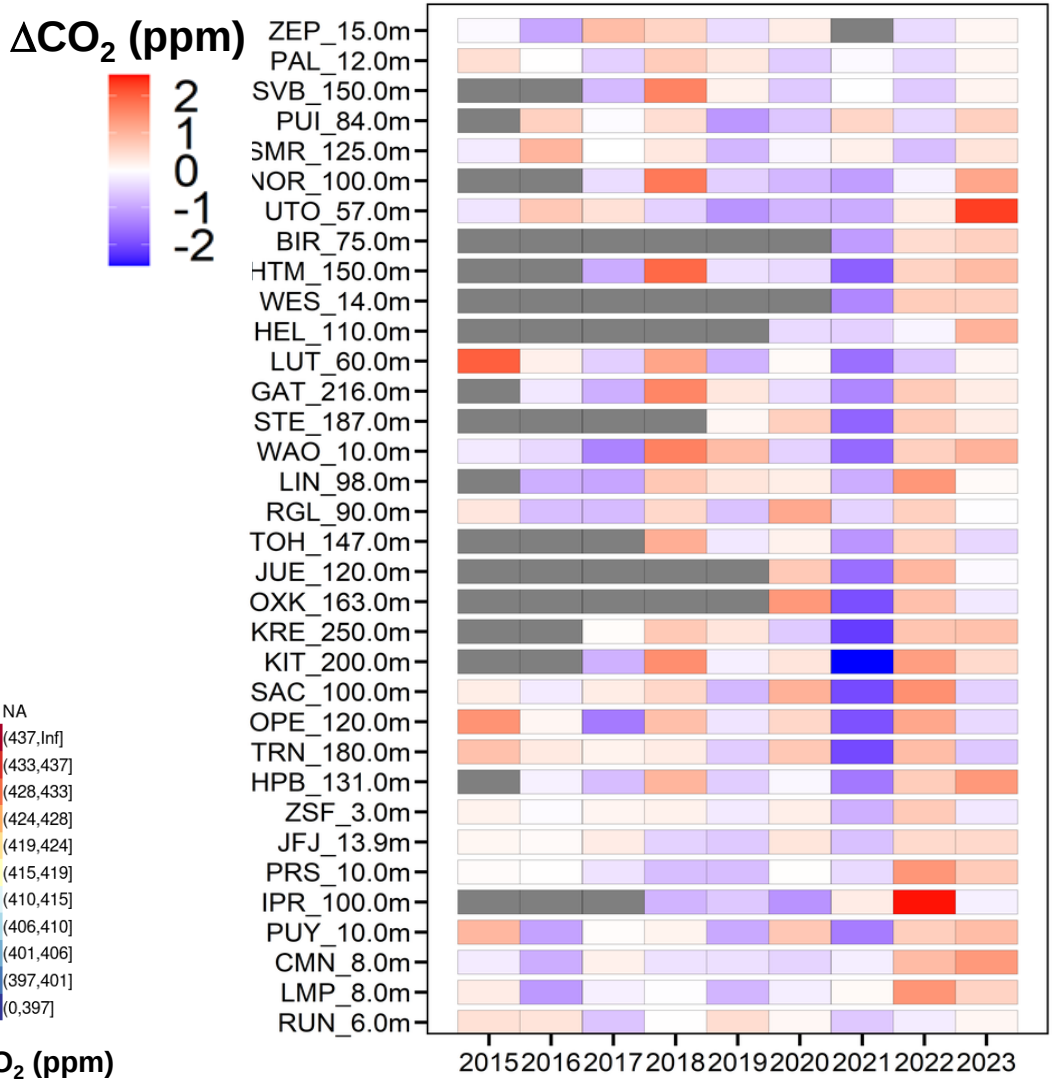


Concentrations and anomalies

Deutscher Wetterdienst
Wetter und Klima aus einer Hand





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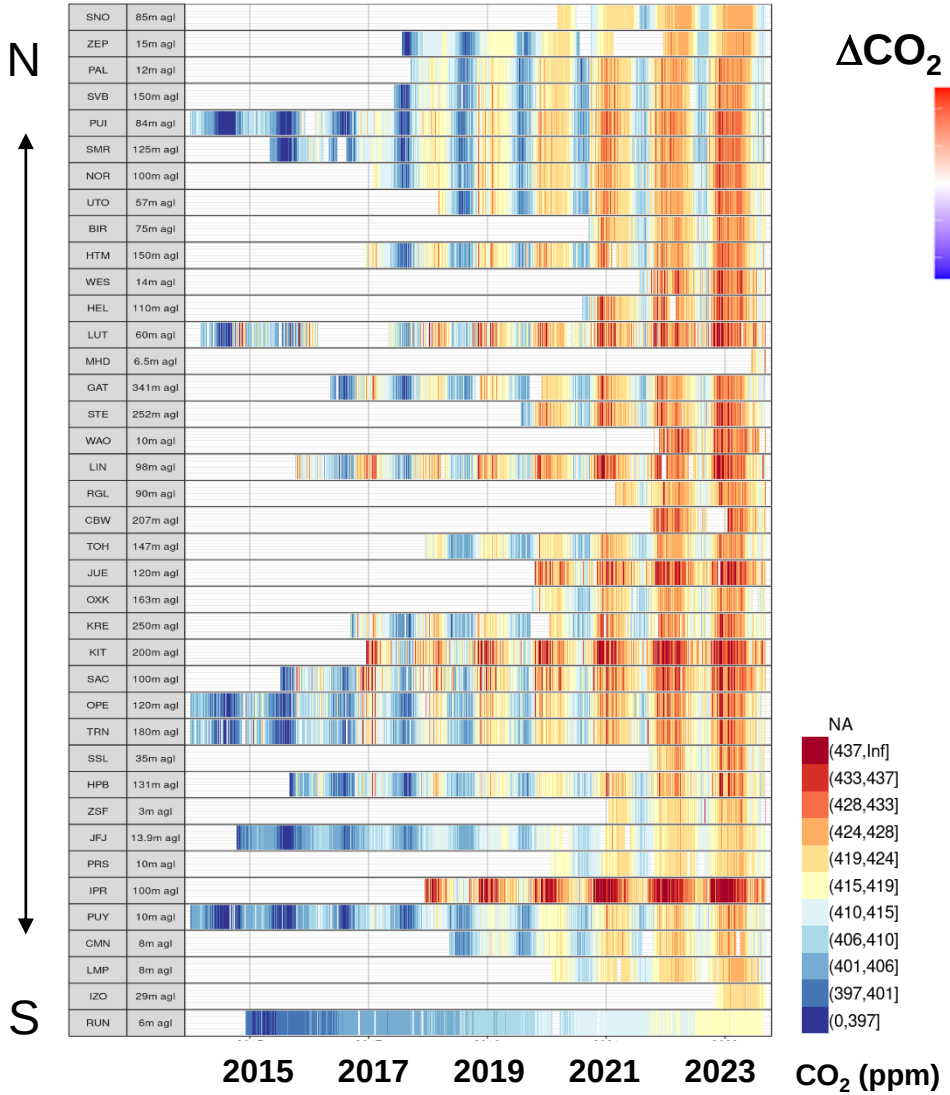
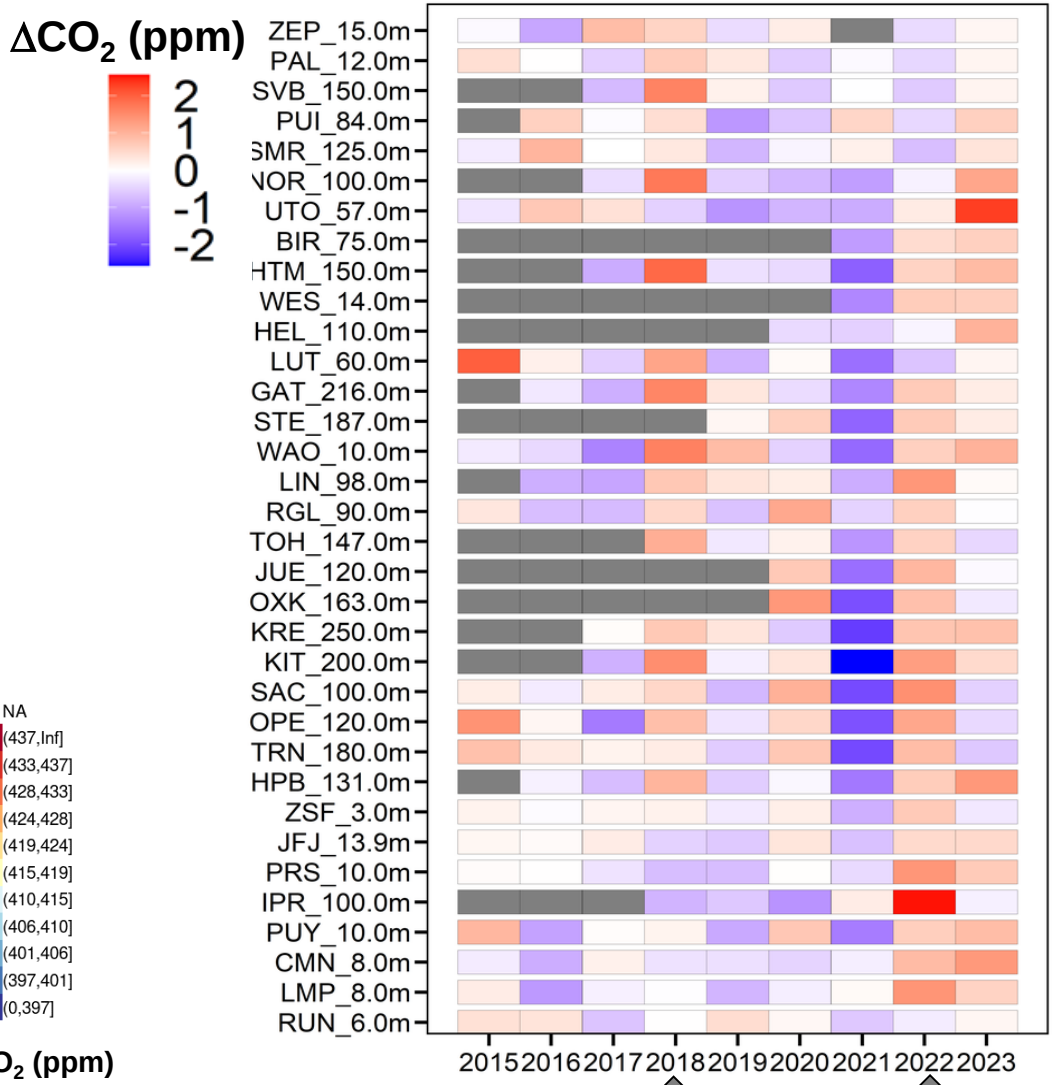
https://icos-atc.lsce.ipsl.fr
Credit to Michel Ramonet, LSCE

Concentrations and anomalies

Deutscher Wetterdienst
Wetter und Klima aus einer Hand





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Credit to Michel Ramonet, LSCE

Summer Drought 2018 and ICOS Observations

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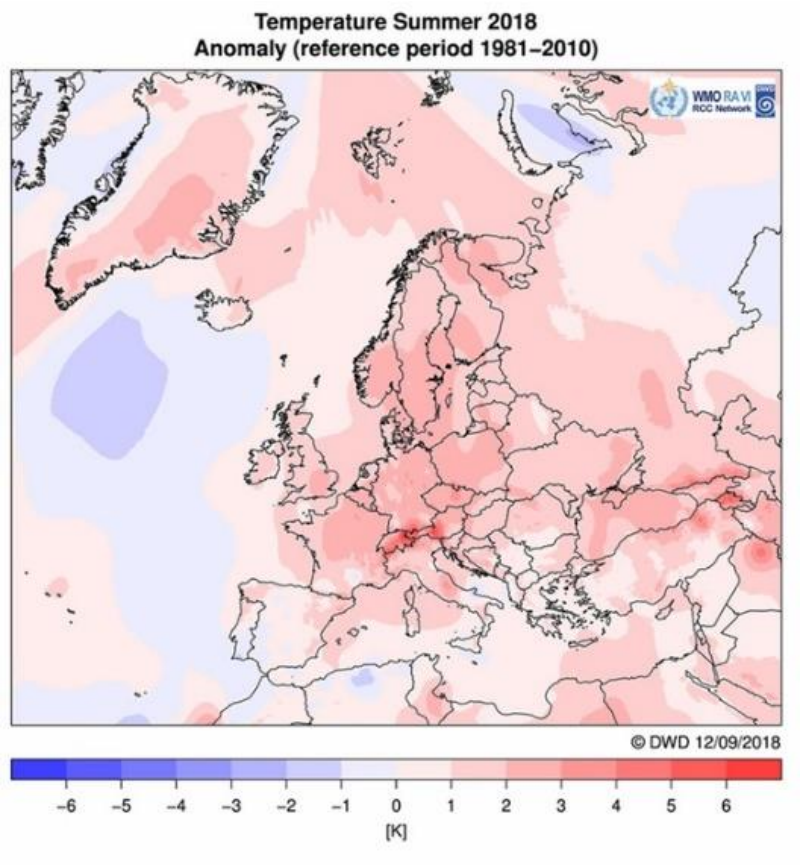

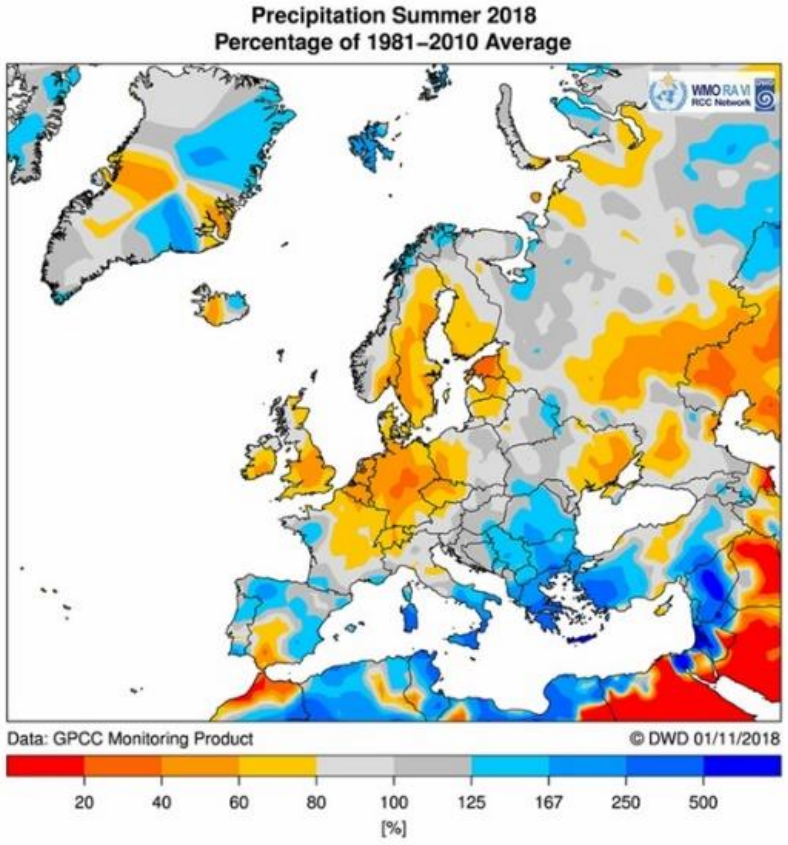

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Ramonet et al., 2020, https://doi.org/10.1098/rstb.2019.0513

Annual CO_2 Amplitude & Anomaly

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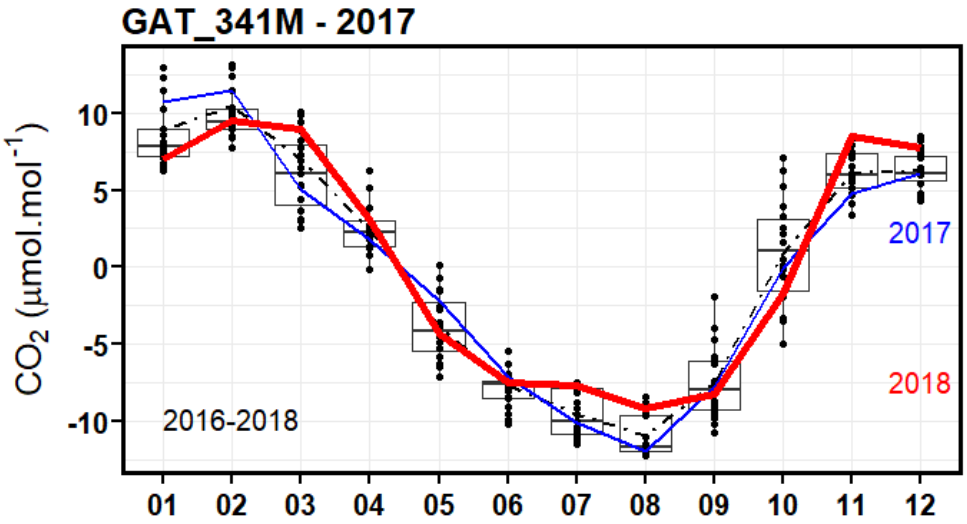

ICOS Station Gartow:
→ Station in Central Europe

Ramonet et al., 2020, https://doi.org/10.1098/rstb.2019.0513

Annual CO_2 Amplitude & Anomaly

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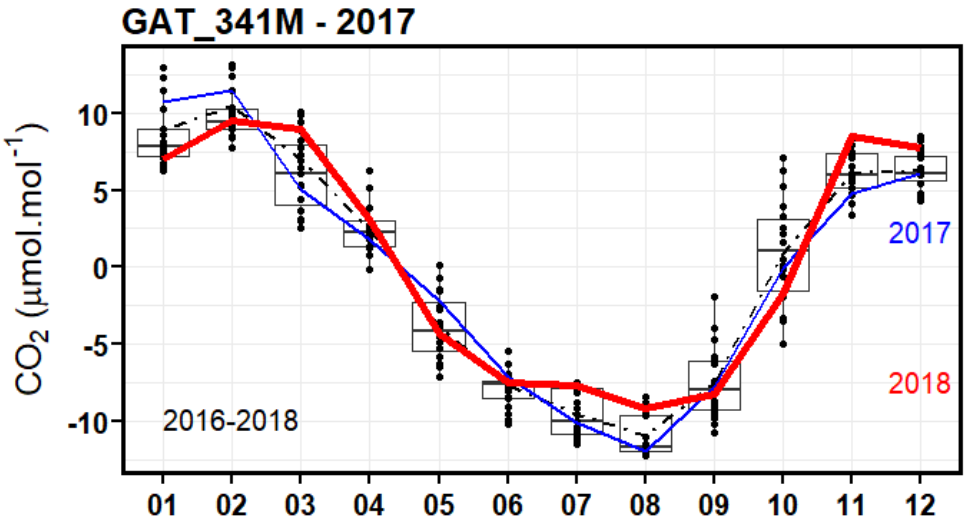
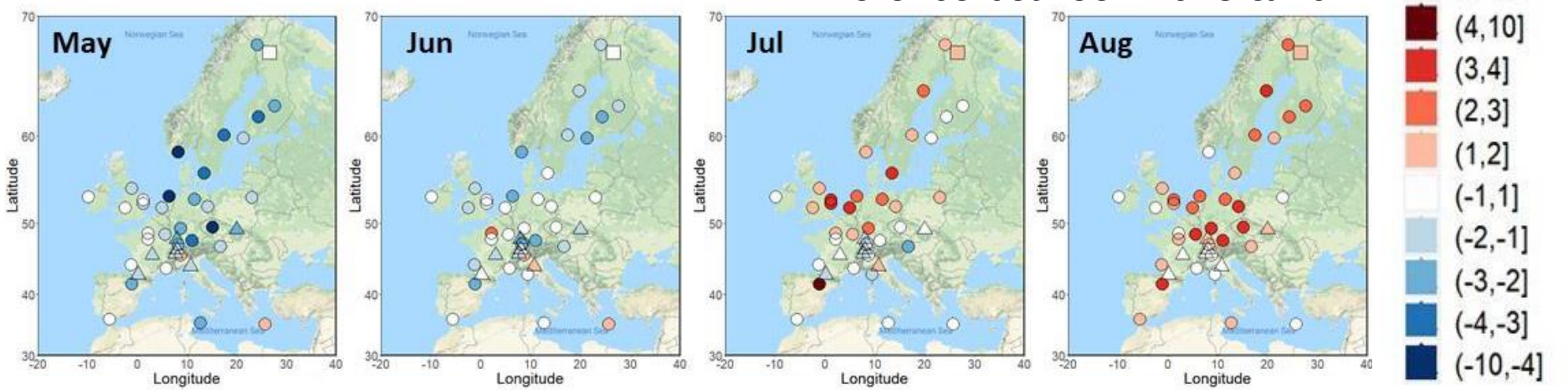


ICOS Station Gartow:
→ Station in Central Europe

Difference between 2018 & 2017



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Ramonet et al., 2020, https://doi.org/10.1098/rstb.2019.0513

Annual CO_2 Amplitude & Anomaly

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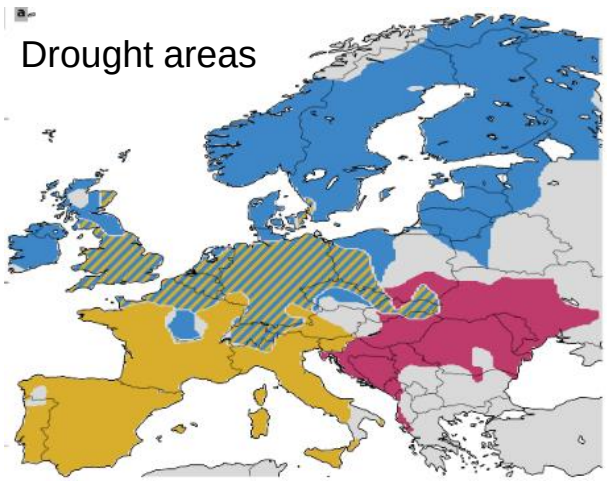
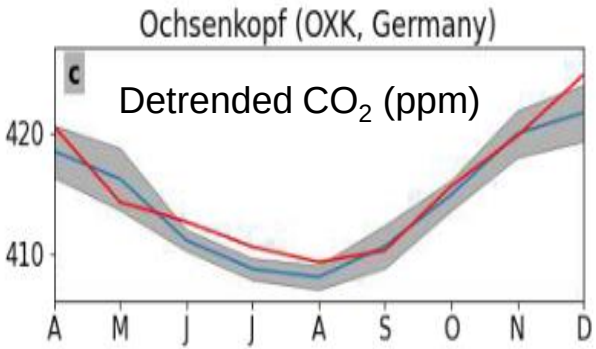
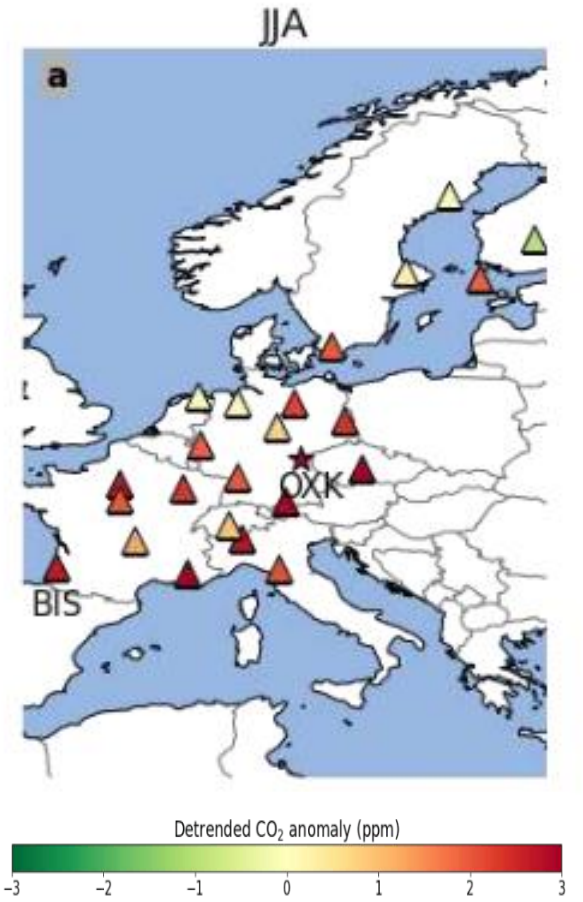
ΔCO_2 uptake is reduced during the growing season in summer 2018 by 1.4 ppm or **12 %**

Comparison with other drought periods (1.5 σ T anomaly):

2003	3.0 ± 1.1 ppm
2015	1.0 ± 0.6 ppm
2018	1.4 ± 0.5 ppm
2022	Similar to 2018, Van der Woude et al.







2018: blue – “North“
2022: yellow – “South“, red – “East“
2018+2022: blue/yellow hatched – “Central“

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Ramonet et al., 2020, https://doi.org/10.1098/rstb.2019.0513
Van der Woude et al., Nat. Comm., 2023

Model Simulations – Validation CAMS & Inverse Modelling

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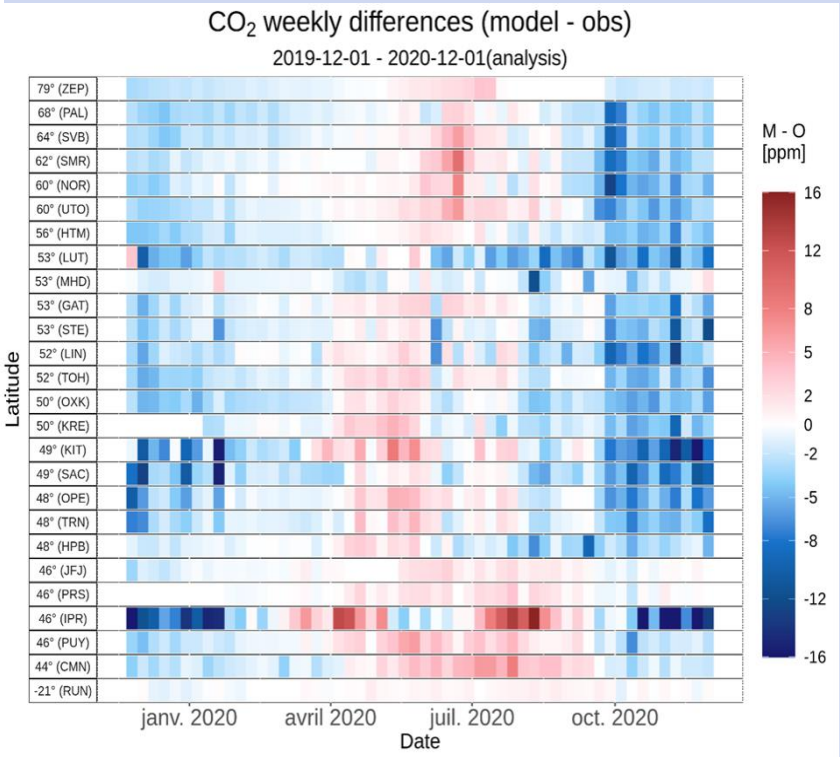
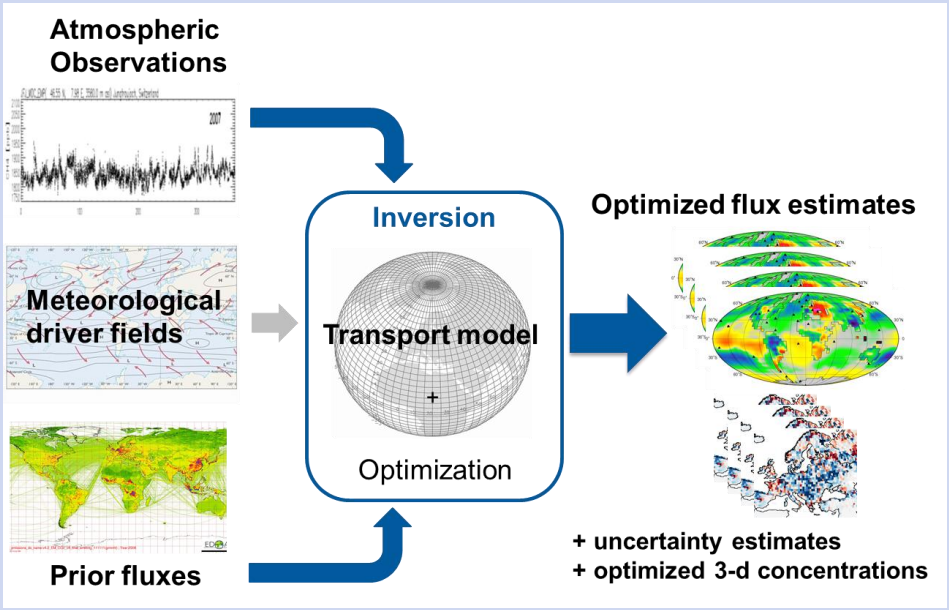
Atmosphere Monitoring Service





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https://global-evaluation.atmosphere.copernicus.eu/co2/ghg/insitu-icos
https://www.icos-cp.eu/

Integrated GHG Monitoring System for Germany

Integrated Global Greenhouse Gas Information System

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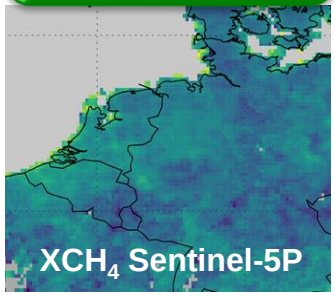
ITMS - National contribution to WMO/IG³IS

ICOS INTEGRATED CARBON OBSERVATION SYSTEM

GHG Observations



Atmospheric Models & Inverse Methods

Operational System

Information for politics, society

Sources and Sinks

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GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel
GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN
Max-Planck-Institut für Biogeochemie
TECHNISCHE UNIVERSITÄT DRESDEN
Umwelt Bundes Amt Für Mensch und Umwelt
IOW Leibniz-Institut für Ostseeforschung Warnemünde
JÜLICH
Universität Bremen
DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386
KIT Karlsruher Institut für Technologie
THÜNEN

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ITMS

IGS Integrated Global Greenhouse Gas Information System

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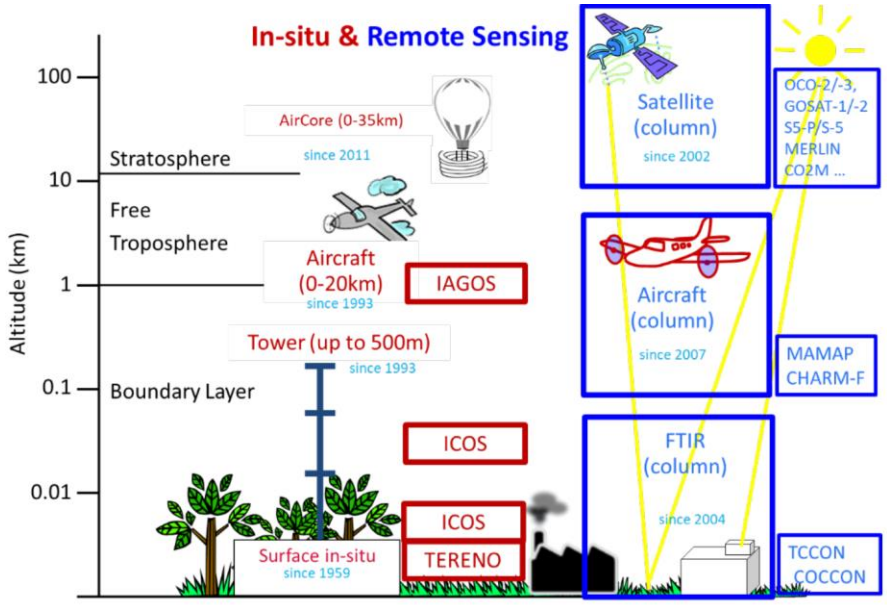
Wetter und Klima aus einer Hand



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UBA

Summary table on emission trends for Germany since 1990, all GHGs in kt CO_2 equi			
Emissions Trends	2014	2015 (kt)	20
Net CO_2 emissions/removals (with LULUCF)	777.033	780.981	
CO_2 emissions (without LULUCF)	793.636	797.078	
CH_4 with LULUCF	56.671	56.469	
CH_4 without LULUCF	55.806	55.602	54.403
N_2O with LULUCF	39.120	39.663	38.808
N_2O without LULUCF	38.273	38.809	37.948
HFCs (CO2 equivalent, 1995 base year)	11.219	11.354	11.148
PFCs (CO2 equivalent, 1995 base year)	235	244	261
SF6 (CO2 equivalent, 1995 base year)	3.487	3.652	3.881
NF3 (CO2 equivalent, 1995 base year)	20	12	11
Total Emissions/Removals with LULUCF (CO_2 equi.)	887.785	892.376	894.925
Total Emissions without LULUCF (CO_2 equi.)	902.676	906.752	909.404
Emission source and sink categories	2014	2015 (kt)	2016
1. Energy	762.351	768.072	771.901
2. Industry	62.361	60.925	61.797
3. Agriculture	66.289	66.690	65.228
4. Land-Use Change and Forestry	-14.891	-14.376	-14.479
CO_2 (net emissions)	-16.603	-16.097	-16.204
N_2O + CH_4	1.712	1.721	1.725
5. Waste	11.674	11.065	10.478

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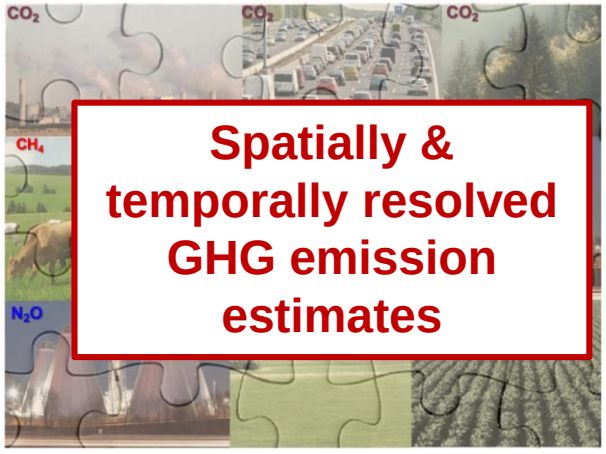
Wetter und Klima aus einer Hand

→



Spatially & temporally resolved GHG emission estimates

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Global Greenhouse Gas Watch

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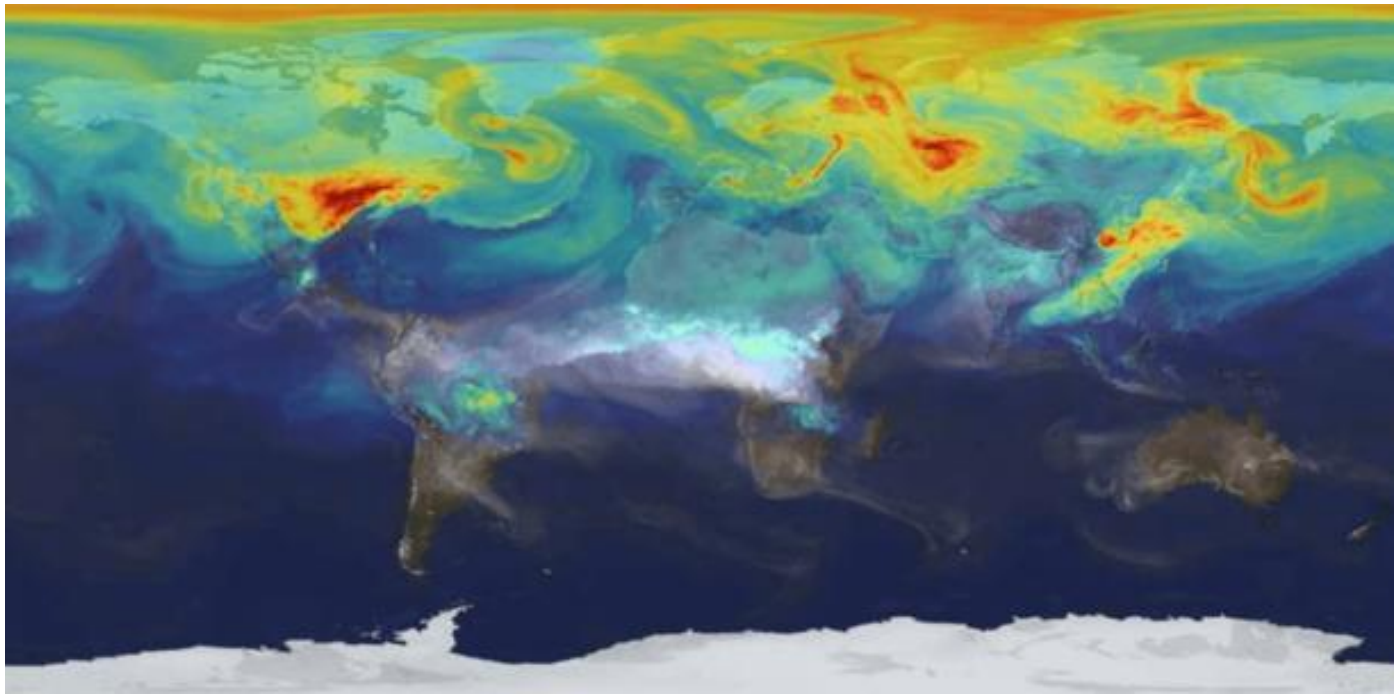
WORLD METEOROLOGICAL ORGANIZATION

GAW

IG3IS Integrated Global Greenhouse Gas Information System



World Meteorological Congress approved Global Greenhouse Gas Watch on 24th May 2023

GAW ICOS INTEGRATED CARBON OBSERVATION SYSTEM ITINERIS

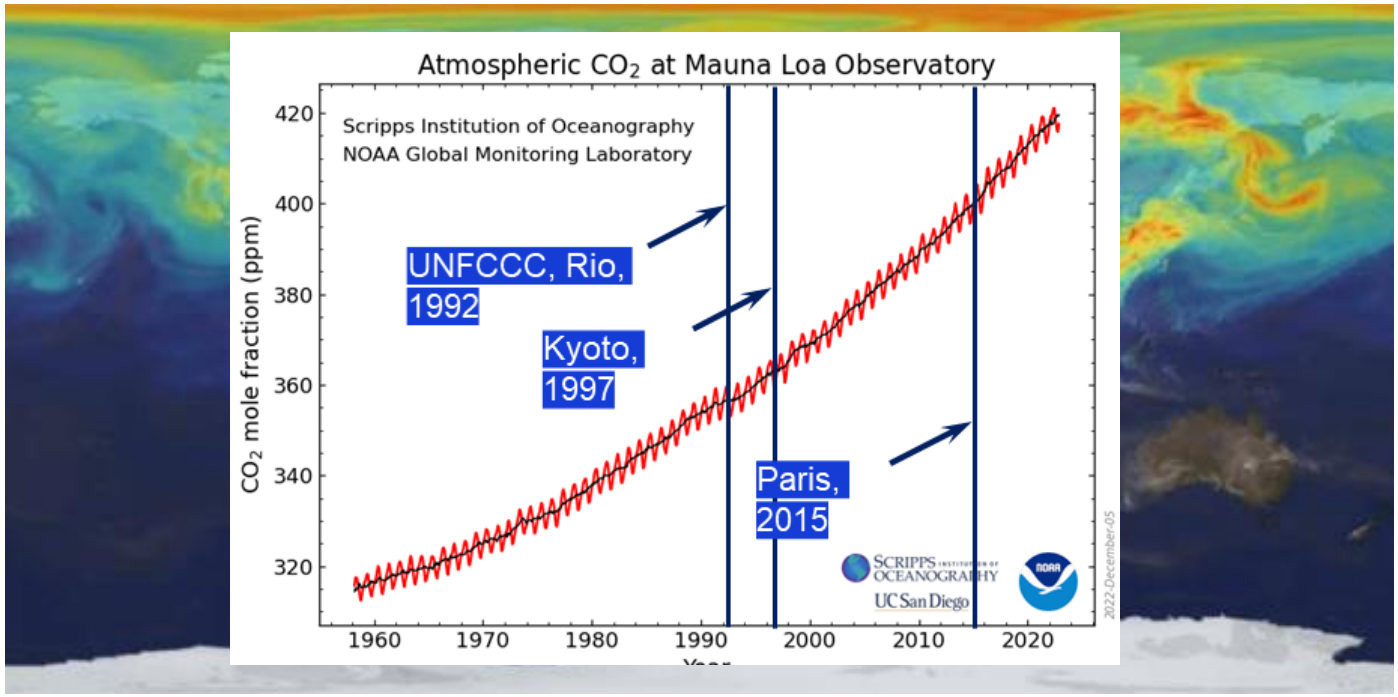
Global Greenhouse Gas Watch

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

WORLD METEOROLOGICAL ORGANIZATION

GAW

IG3IS Integrated Global Greenhouse Gas Information System



Monthly GHG net fluxes with 1x1 degree horizontal resolution within one month
Based on surface and satellite observations and global modeling/data assimilation

Nordstream Pipeline Leakage

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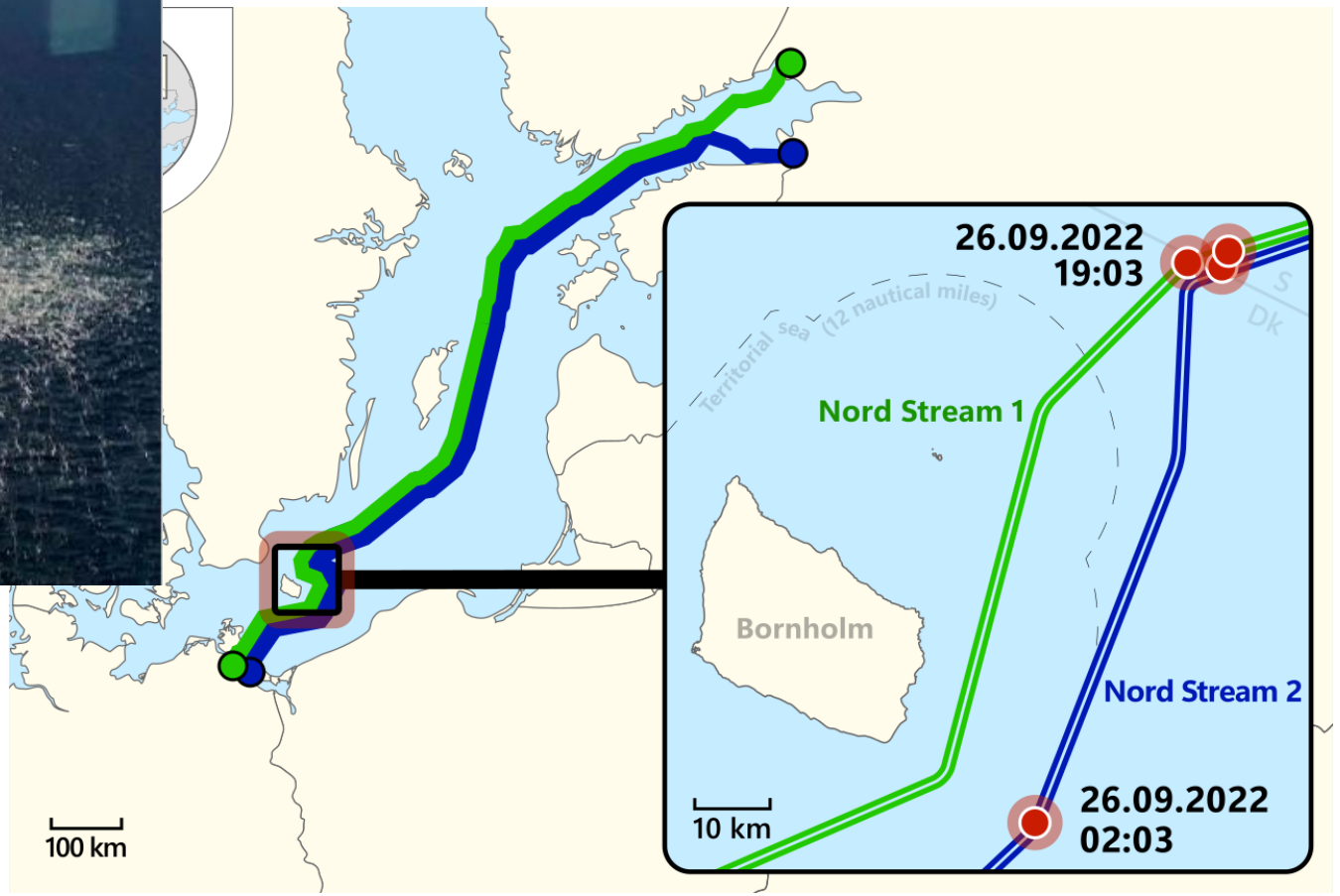
Wetter und Klima aus einer Hand



https://en.wikipedia.org/wiki/2022_Nord_Stream_gas_leaks

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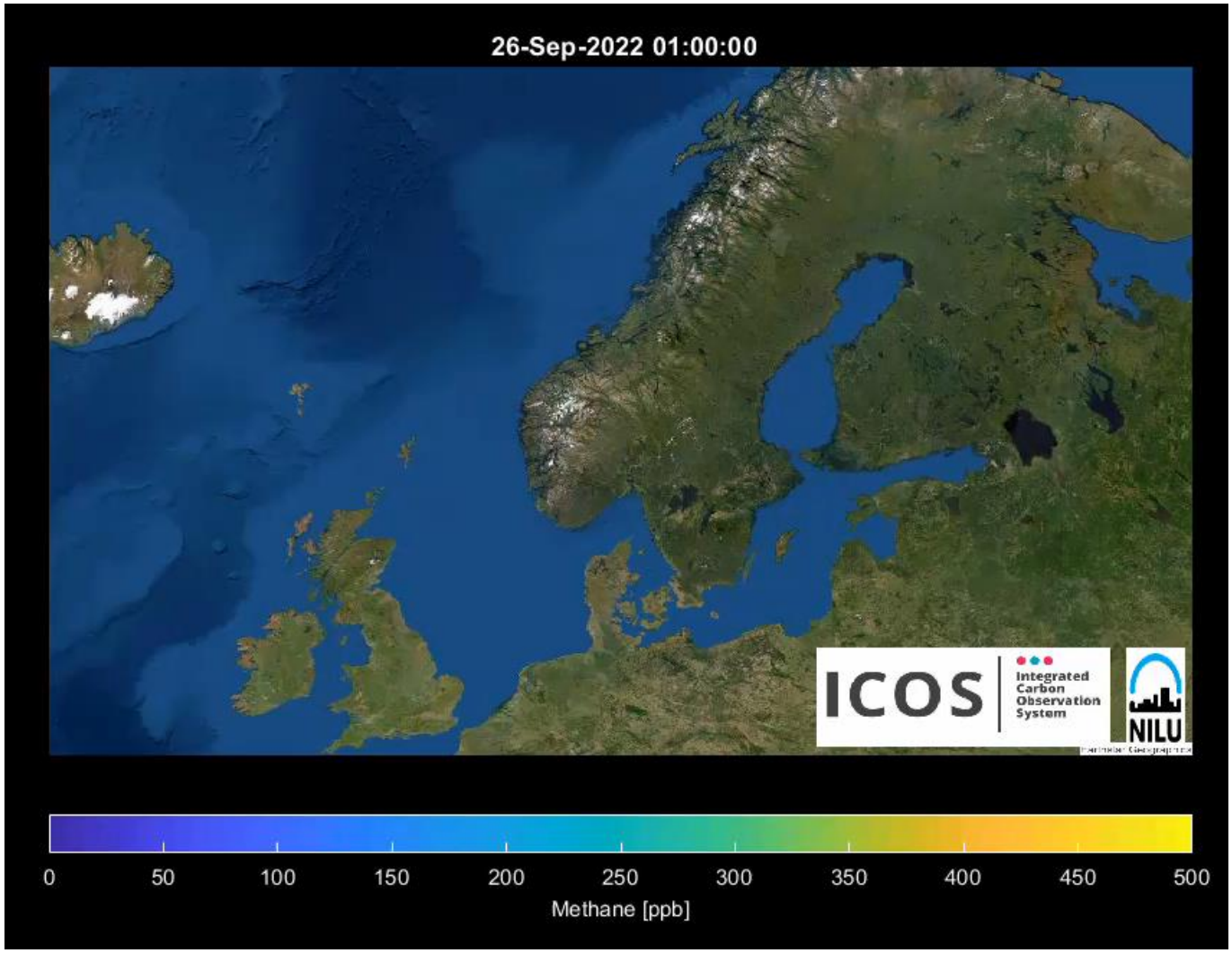

https://www.icos-cp.eu/event/1221

Nordstream Pipeline Leakage

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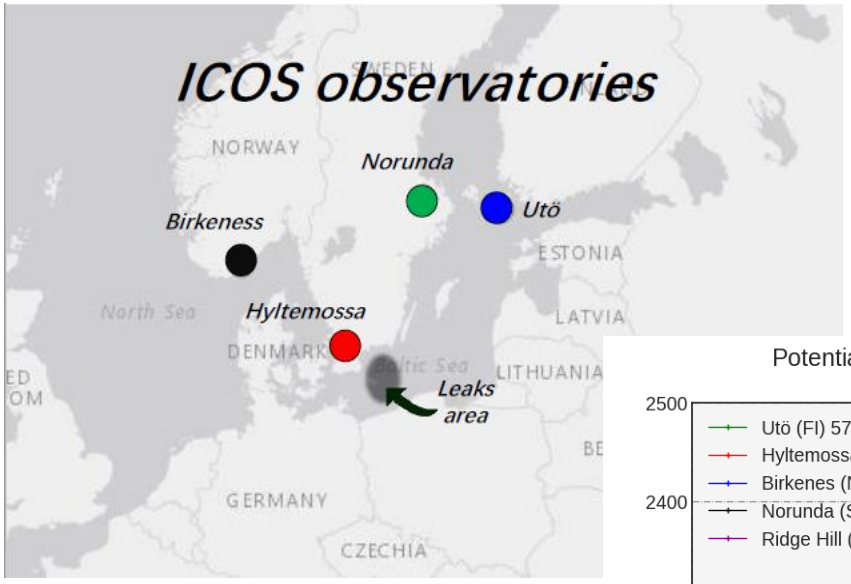
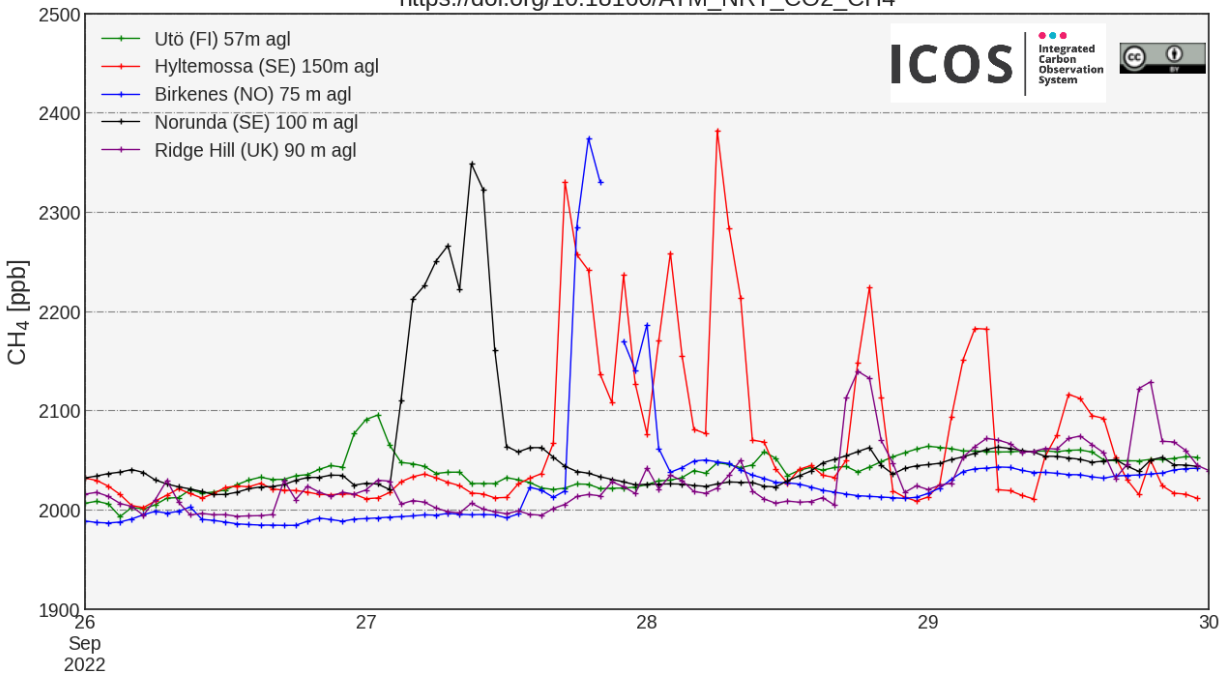


Potential CH_4 signals of Nord Stream leaks detected at ICOS atmospheric station network
https://doi.org/10.18160/ATM_NRT_CO2_CH4



https://www.icos-cp.eu/event/1221

Summary

- **Integrated Carbon Observation System (ICOS)** provides high-quality, standardised, transparent greenhouse gas measurements throughout Europe
- ICOS **measurement data** (NRT & QCed) freely available via the **Carbon Portal**
- **QA/QC data products** available through **ATC** Atmospheric Thematic Centre
- **Expanding** measurement network (e.g. Cities) and modelling capabilities (e.g. Integrated Greenhouse Gas Monitoring System ITMS)

ICOS Carbon Portal
www.icos-cp.eu/

ICOS Germany
www.icos-infrastruktur.de/

ICOS @ DWD
www.dwd.de/icos

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