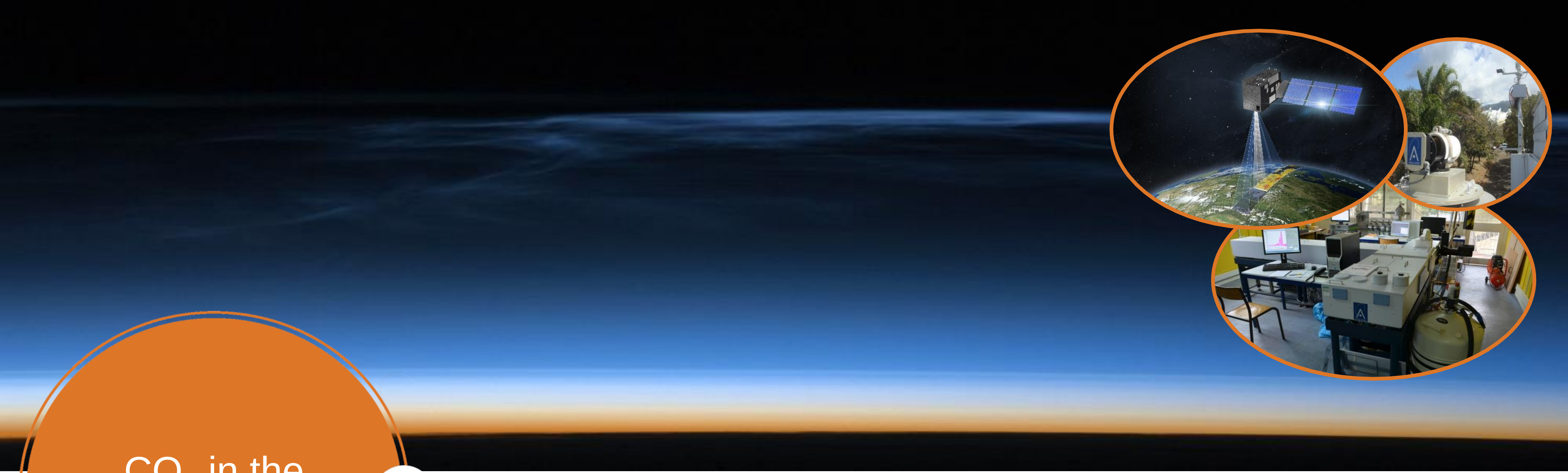

CO_2 in the atmosphere

Measurement techniques for quantifying CO_2 in the atmosphere and their role in understanding extreme events

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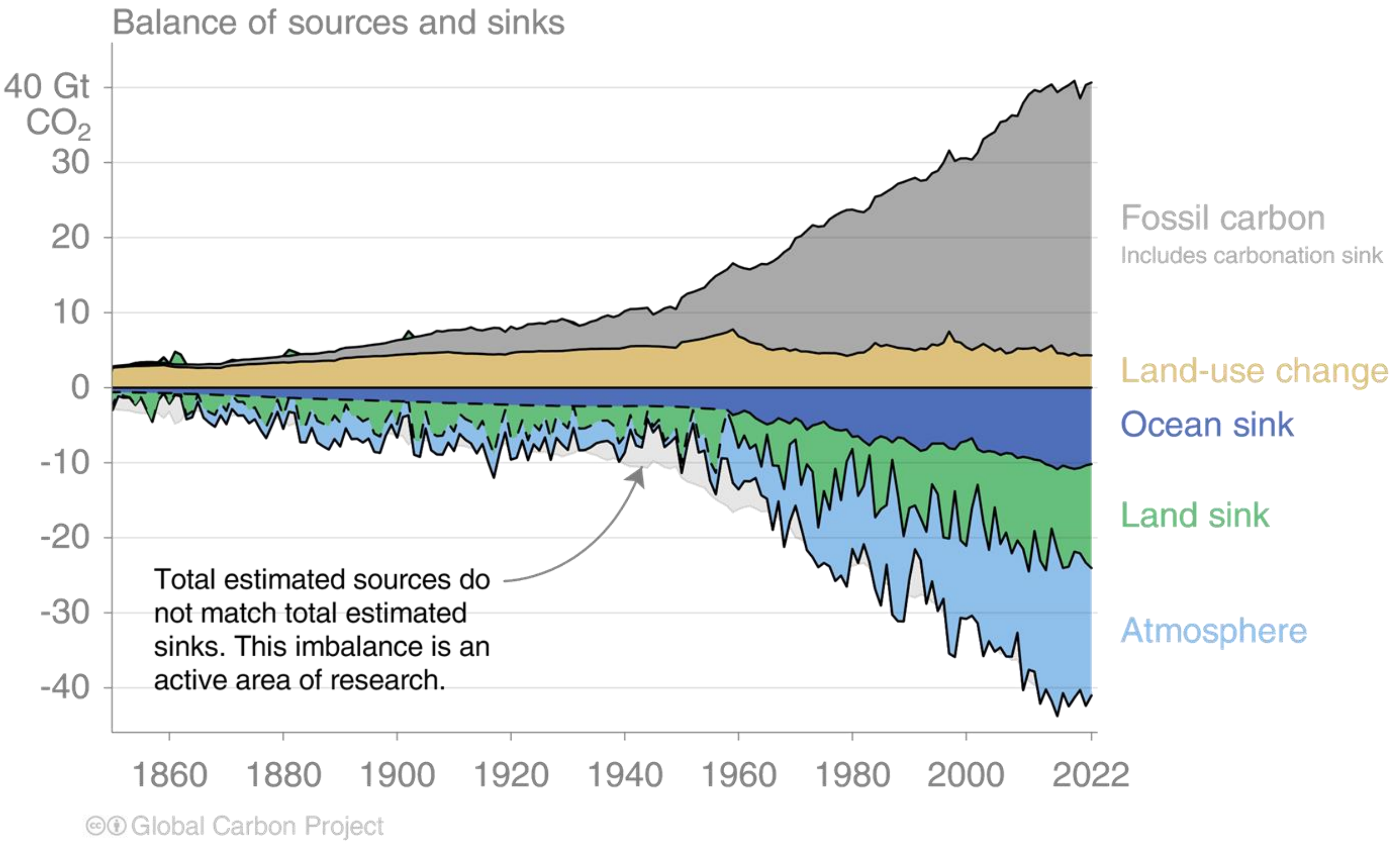
Scientific background – Sources and sinks of CO_2



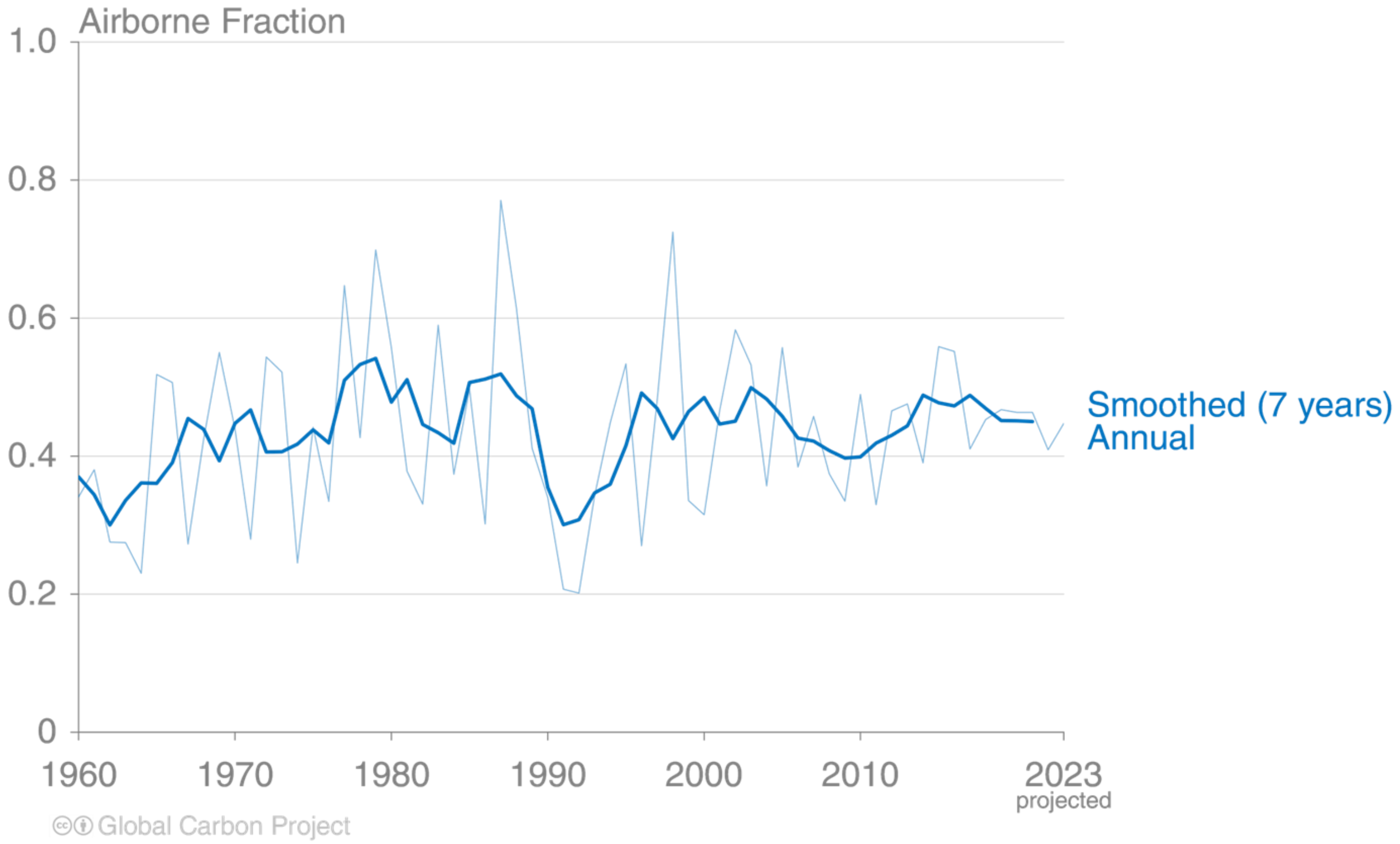
Sources of anthropogenic CO_2 emissions are fossil carbon and land-use change

Part of the emitted CO_2 is removed (sink) by the ocean and land and the rest is left in the atmosphere

The amount of CO_2 in the atmosphere is strongly dependent on the response of the natural sinks to climate change

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Scientific background – Airborne fraction of CO_2

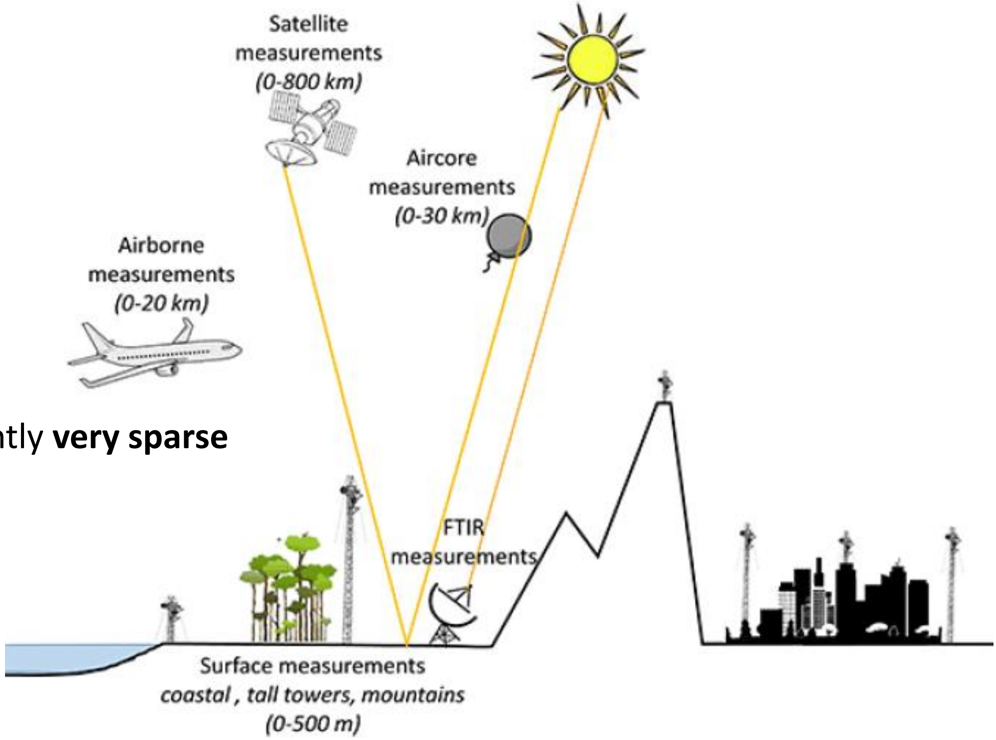


Airborne fraction representing the proportion of total annual CO_2 emissions remaining in the atmosphere

Around 45% of emitted CO_2 remains in the atmosphere despite sustained growth in CO_2 emissions

Source: Friedlingstein et al 2023; Global Carbon Project 2023

Atmospheric GHG measurement techniques and their complementarity



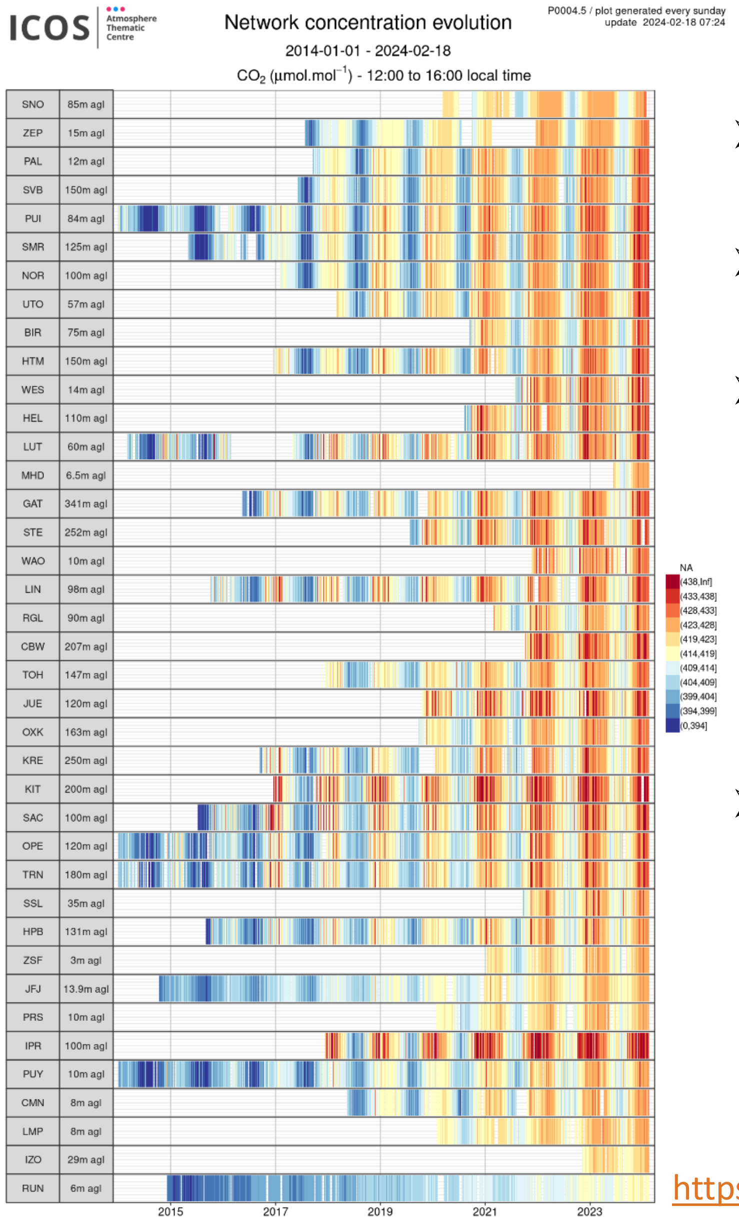
- Ground-based **in-situ** measurement network (surface air sampling, tower ~500 m)
  - Derived fluxes are **accurate** but are **affected by surface exchange and vertical transport** – highly variable but poorly simulated in global models
  - **High precision** and **inter-calibration accuracy**
  - **Limited / no column measurements** which limits its use for satellite validation

- **In-situ** aircraft (0 – 20 km) / AirCore (0 – 30 km) measurements
  - Derived fluxes are **accurate**, measurements are possible at **several altitudes**, but are currently **very sparse**
  - **High precision** and **inter-calibration accuracy**

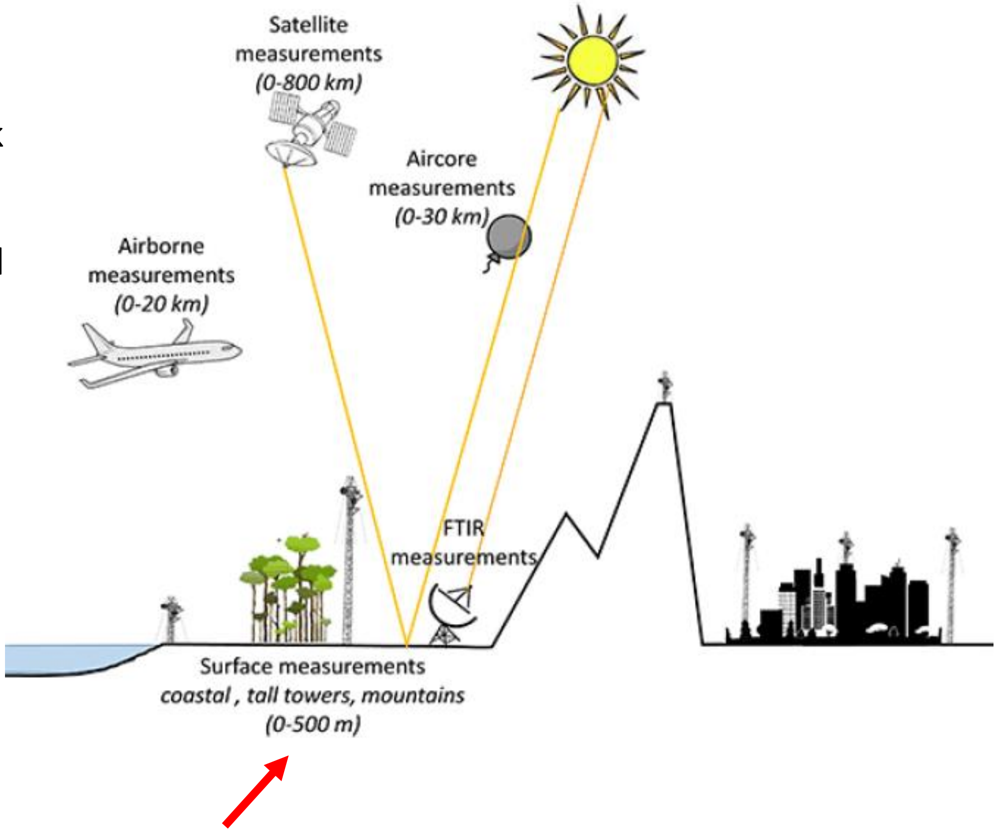
- Ground-based **remote sensing** measurement networks (0 – top of the atmosphere)
  - **Column** and / or **profile measurements** of GHGs
  - **High precision** and **inter-calibration accuracy**
  - Direct solar absorption measurements are advantageous over the satellite measurements recording the solar reflectance from the Earth's atmosphere. Limited number of sites do not provide a complete global picture
  - Ideal for calibration / validation of satellite instruments and model columns and carbon cycle science
  - Column measurements of GHGs in the near-IR using portable, low cost FTS (e.g., EM27/SUN, Vertex70/80, IRcube, …)

- Satellite **remote sensing** measurements (0 – top of the atmosphere)
  - Provides **global measurements** of total and / or partial columns of GHGs
  - Significant improvements in measurement and retrieval techniques over the last 19 years
  - Future improvements are expected to further improve the data quality and space-borne data to become more important for carbon cycle research
  - High quality reference data needed for detection and calibration of biases and / or temporal drifts in the sensors

In-situ measurements of surface concentrations of GHGs



- Ground-based in-situ measurement network (surface air sampling, tower ~500 m)
- Reference networks established by several counties, e.g., US, EU, …
- Integrated Carbon Observation System (**ICOS**) – the European research infrastructure dedicated to produce standardized, high-precision and long-term observations and facilitate research to understand the carbon cycle and to provide necessary information on GHGs.
  https://www.icos-cp.eu/; https://data.icos-cp.eu/
- BIRA-IASB operates an atmospheric ICOS station as part of the ICOS-Belgium network providing in-situ GHG concentrations of CO_2, CH_4, and CO.
  https://www.icos-atc.eu/panelboard/RUN/instrument/249



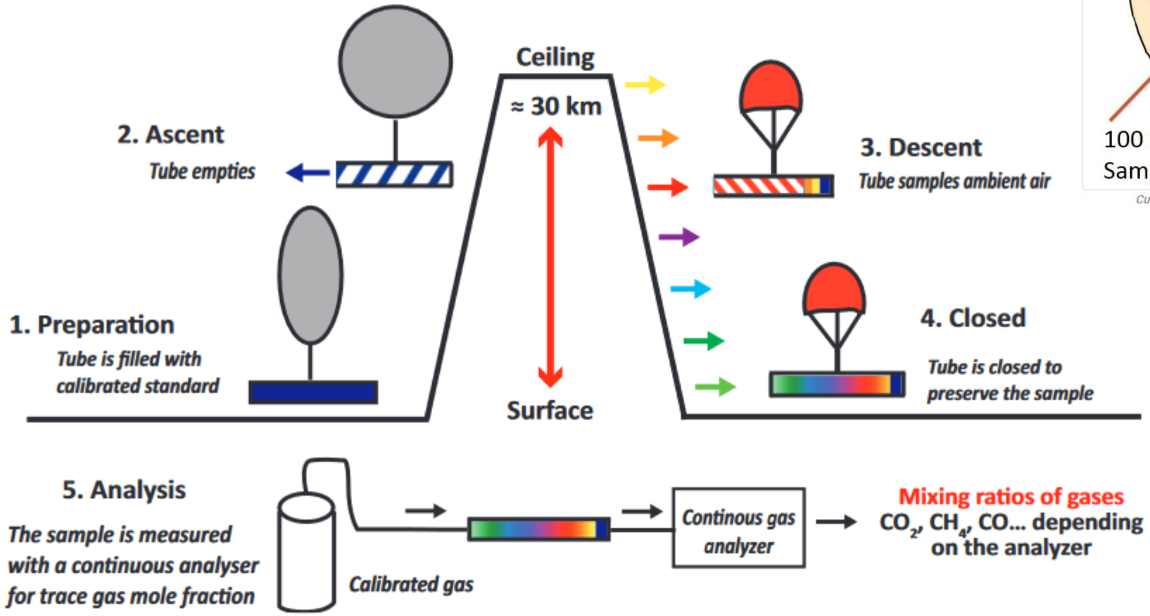
ICOS INTEGRATED CARBON OBSERVATION SYSTEM

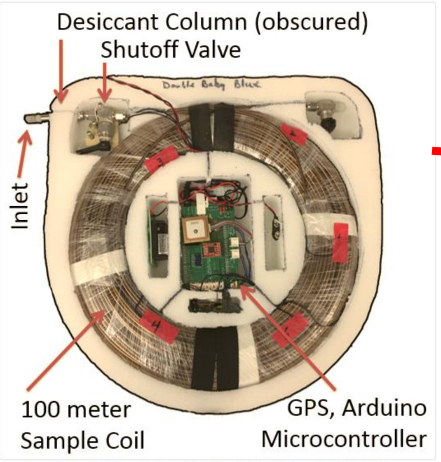
https://icos-atc.lsce.ipsl.fr/filebrowser/download/832

AirCore for in-situ measurements of atmospheric concentrations of GHGs

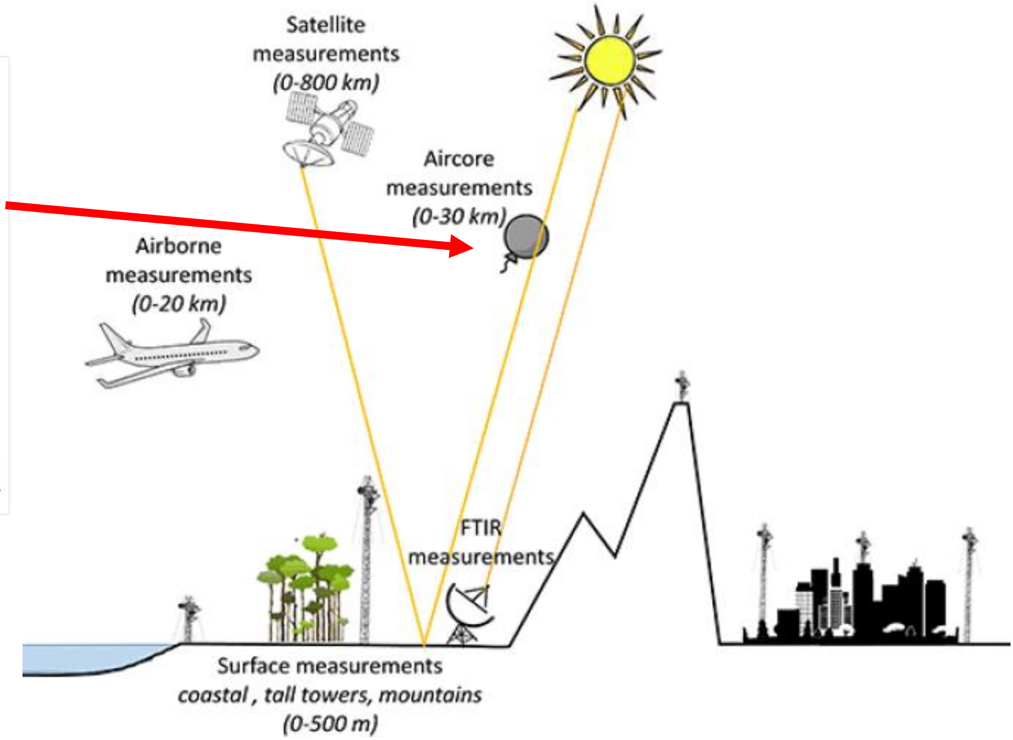
AirCore tube is a long (over 100 m) stainless steel tube treated with Suflinert coating to avoid interactions with gas

The measurements provide vertically resolved information on the concentration of gases sampled





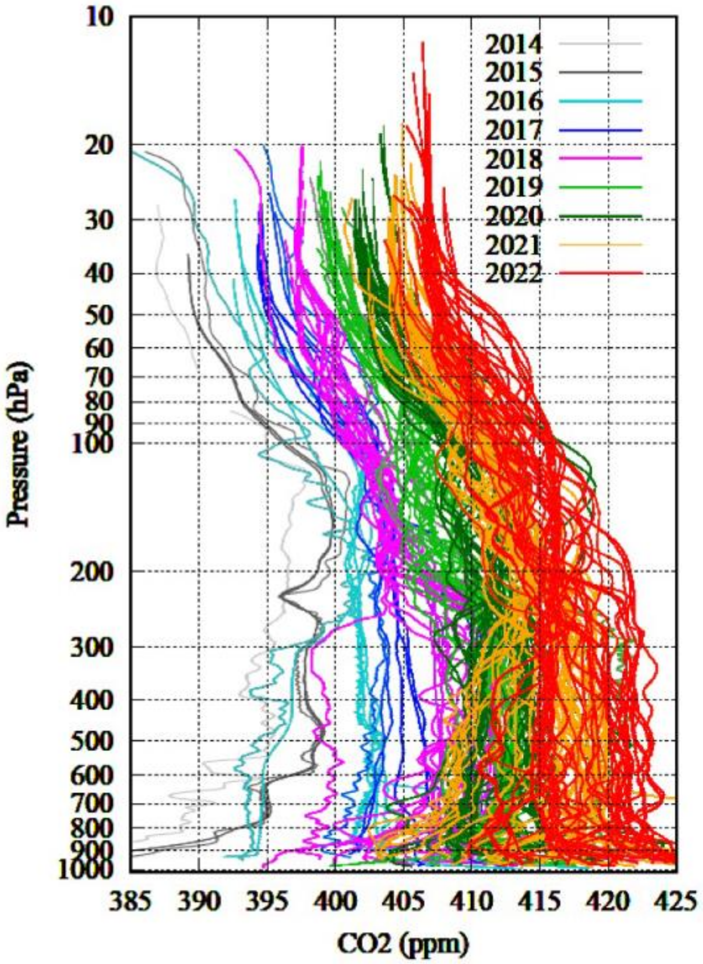
Current AirCore design with 100m 1/8" stainless steel tube coil



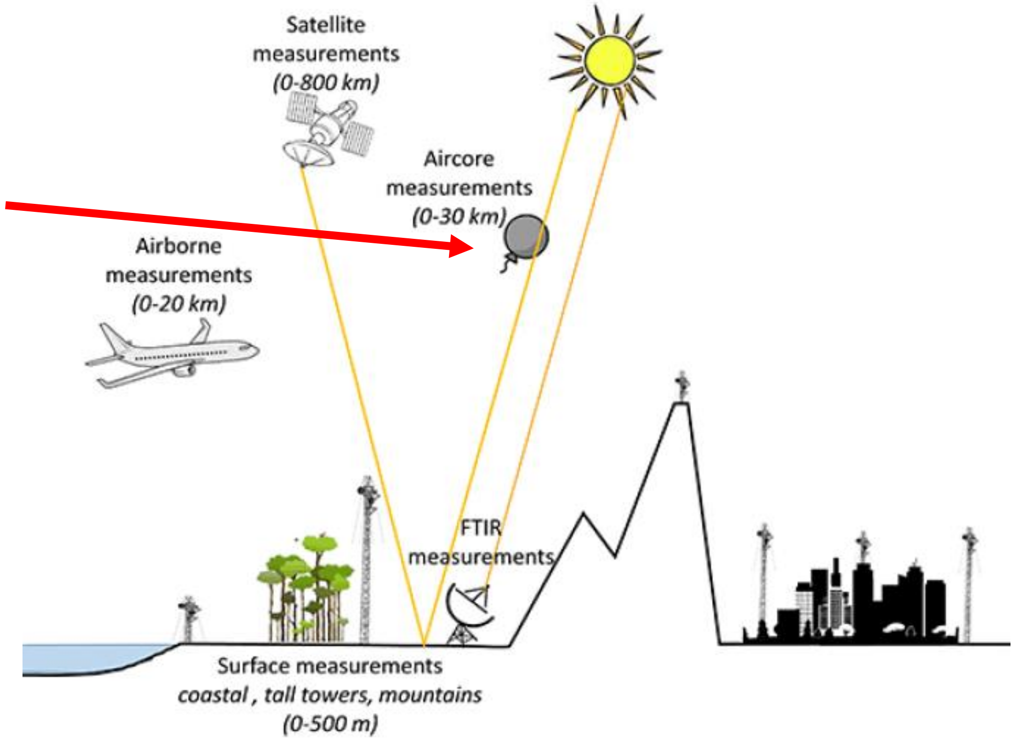
Membrive et al., 2017; Kairon et al., 2010

AirCore for in-situ measurements of atmospheric concentrations of GHGs

Here is an example of AirCore profiles per year performed mostly over France but also Canada, Finland, Australia, Sweden and Cyprus

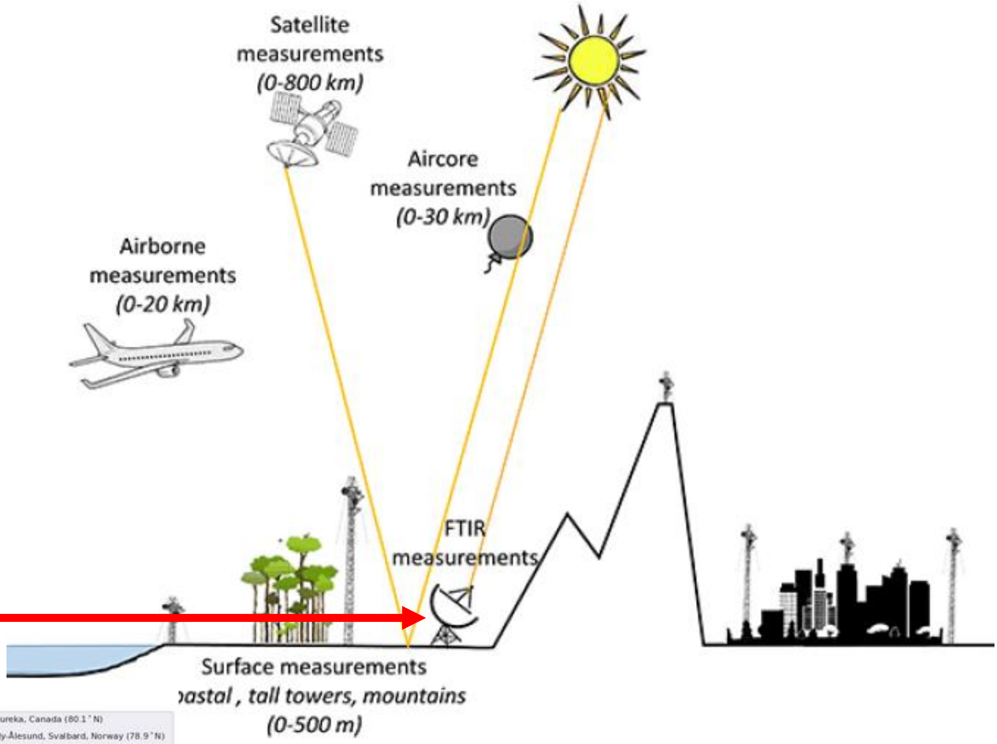


Crevoisier et al., 2023, IWGGMS-19

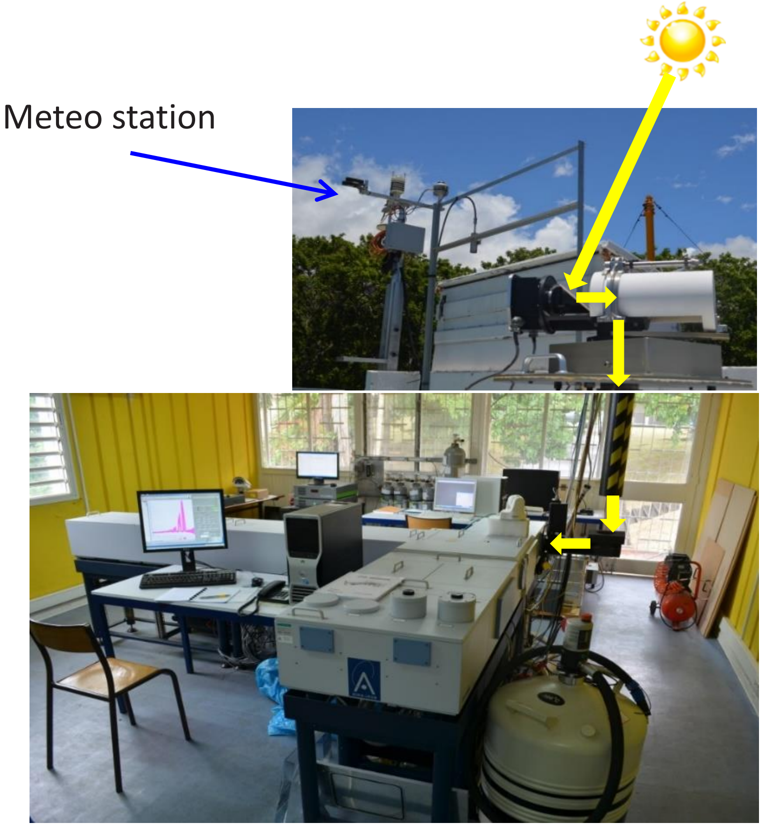


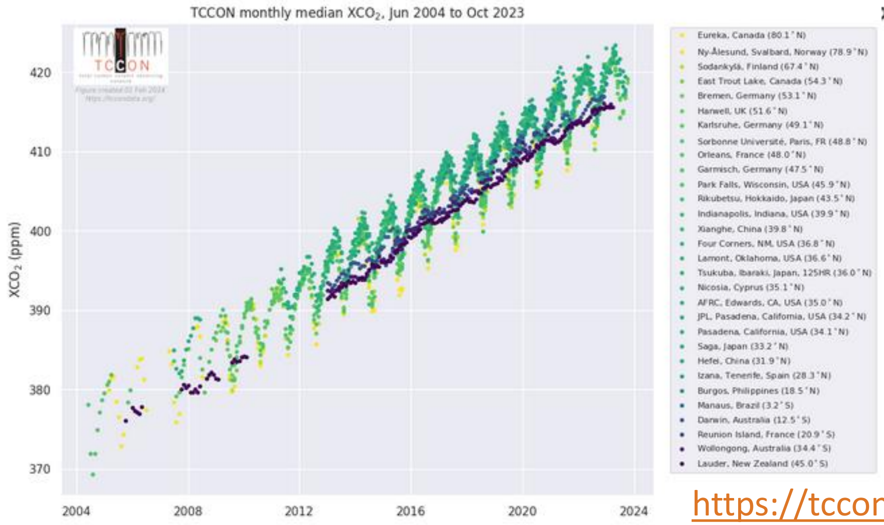
Remote sensing measurements of atmospheric concentration of GHGs

- Sun as the source
- Sun tracker + FTIR spectrometer
- Meteorological sensors
- BIRA-IASB operates several FTIR sites and contributes to international networks like Total Carbon Column Observing Network (TCCON), COllaborative Carbon Column Observing Network (COCCON) and Infrared Working Group of the Network for the Detection of Atmospheric Composition Change (NDACC-IRWG)



Meteo station



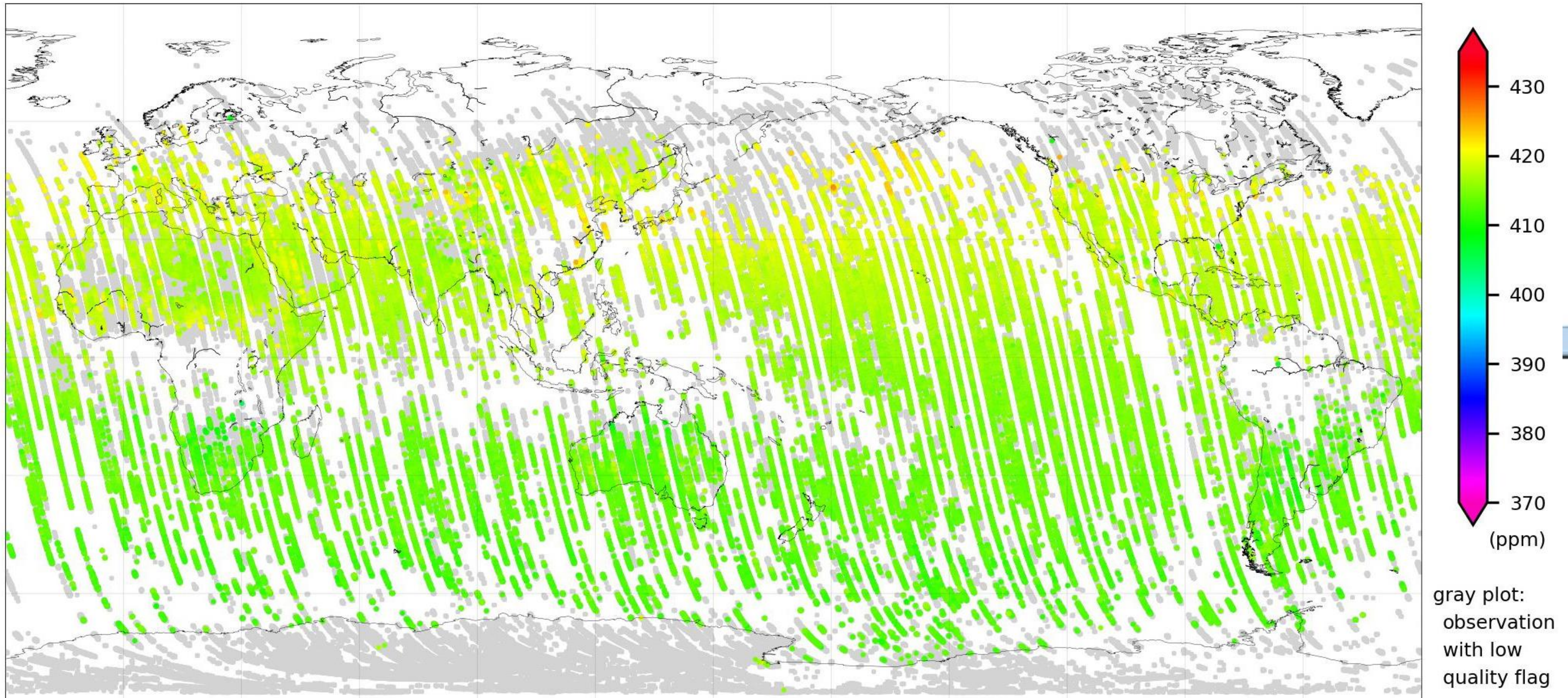


https://tccon-wiki.caltech.edu/

Remote sensing measurements of atmospheric concentration of GHGs

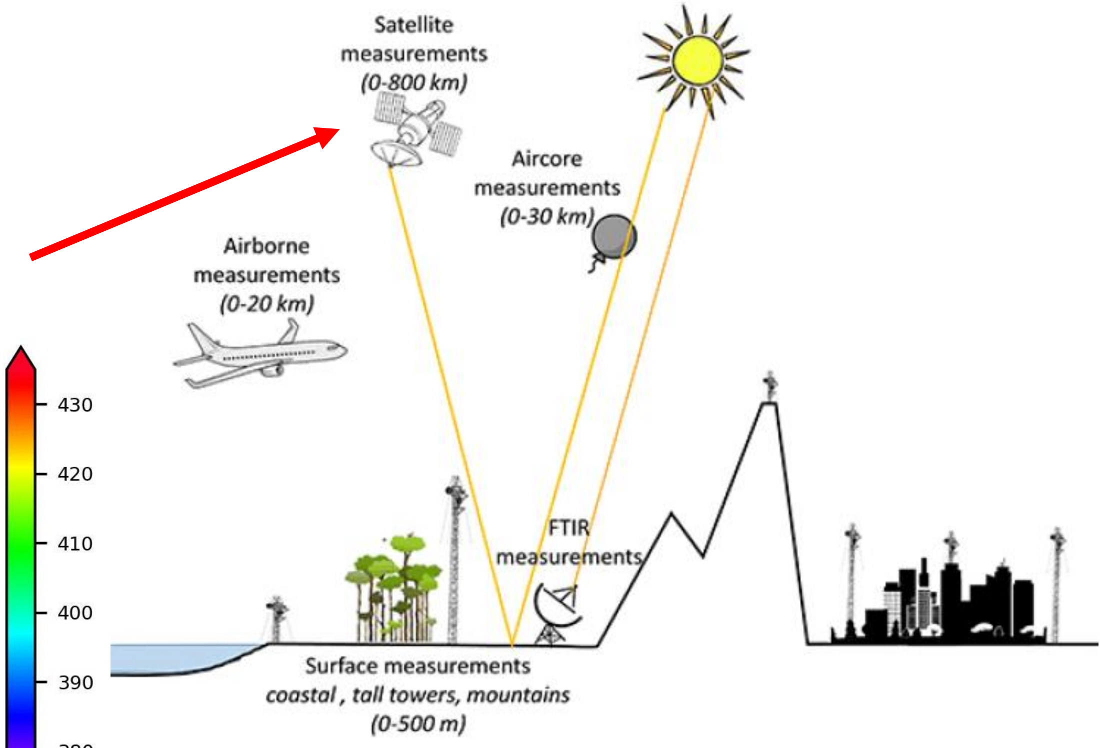
- Satellites provide total and / or partial columns of GHGs
- An example of monthly map of XCO_2 estimates derived from NASA's OCO-2 measurements for February 2022

OCO-2 L2 (Bias Corrected ; V10) XCO2 : 2022/02



(c) WMO WDCGG Original data provided by the OCO-2 project at the Jet Propulsion Laboratory, California Institute of Technology.

World Data Center for Greenhouse Gases https://gaw.kishou.go.jp/satellite/

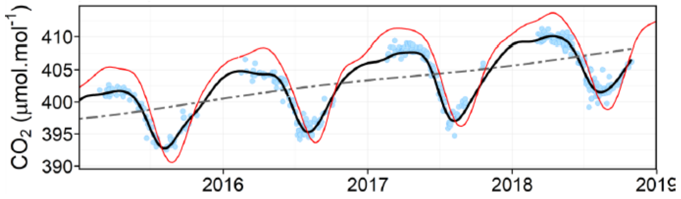


Understanding extreme events – in-situ and remote sensing

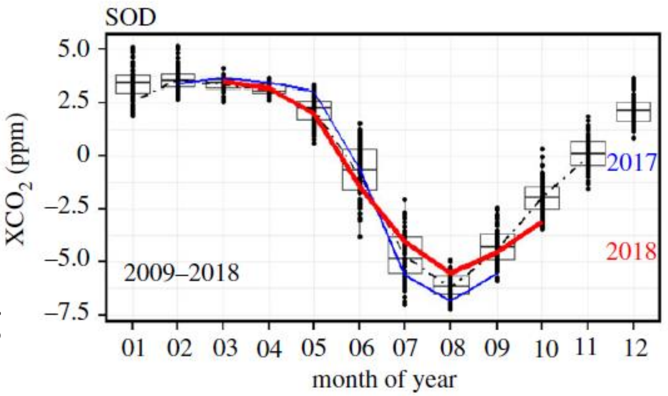
The fingerprint of the **summer 2018 drought in Europe** on ground-based atmospheric CO_2 measurements

Minimum monthly CO_2 occurs in summer due to the uptake of carbon into the biosphere

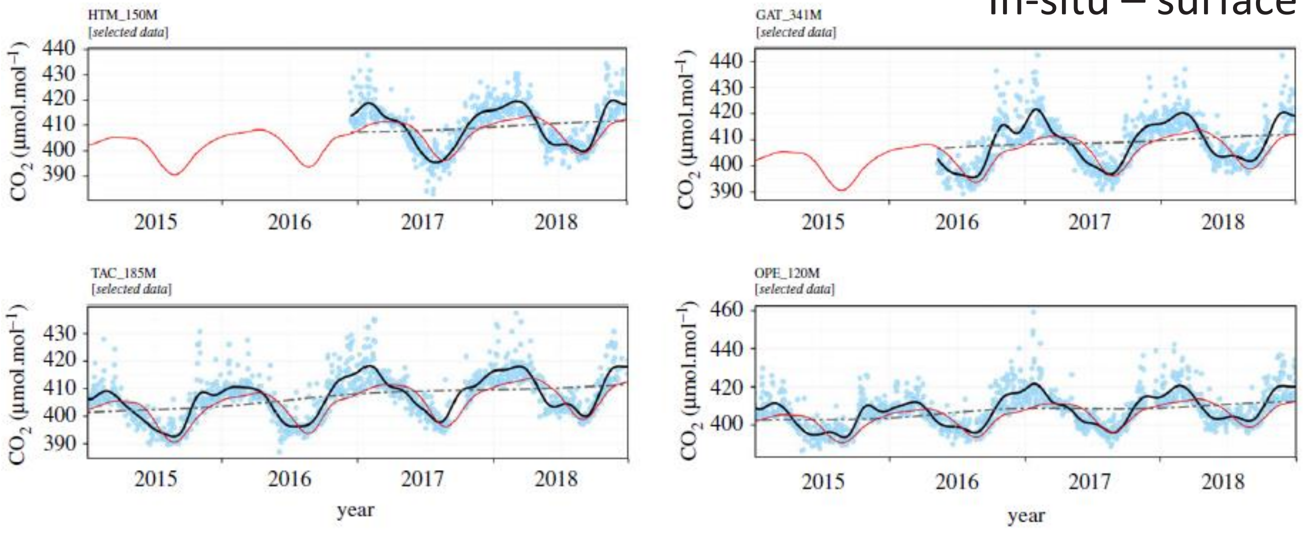
HTM – Hyltemossa (Sweden); GAT – Gartow (Germany);
TAC – Tacolneston (UK); OPE – Obs. pérenne de l’environnement (France);
SOD – Sodankylä (Finland)

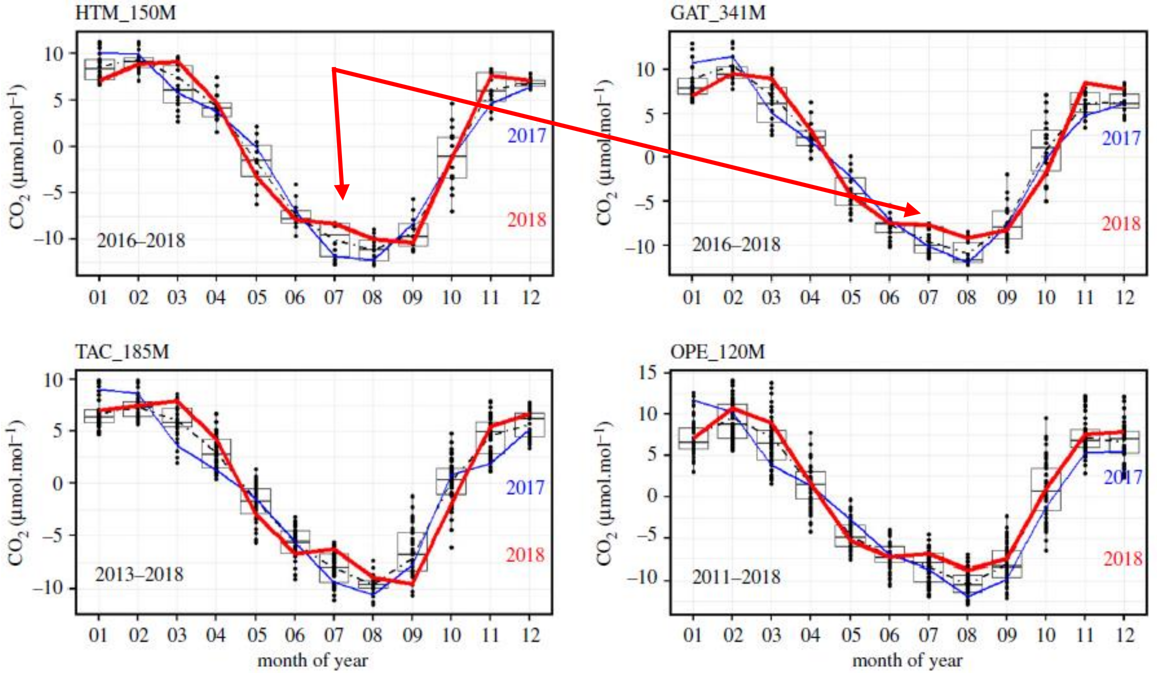


Total column – remote sensing



In-situ – surface concentrations





Ramonet et al., Phil. Trans. R. Soc. B 2020;
http://dx.doi.org/10.1098/rstb.2019.0513

Understanding extreme events – ICOS example in Europe

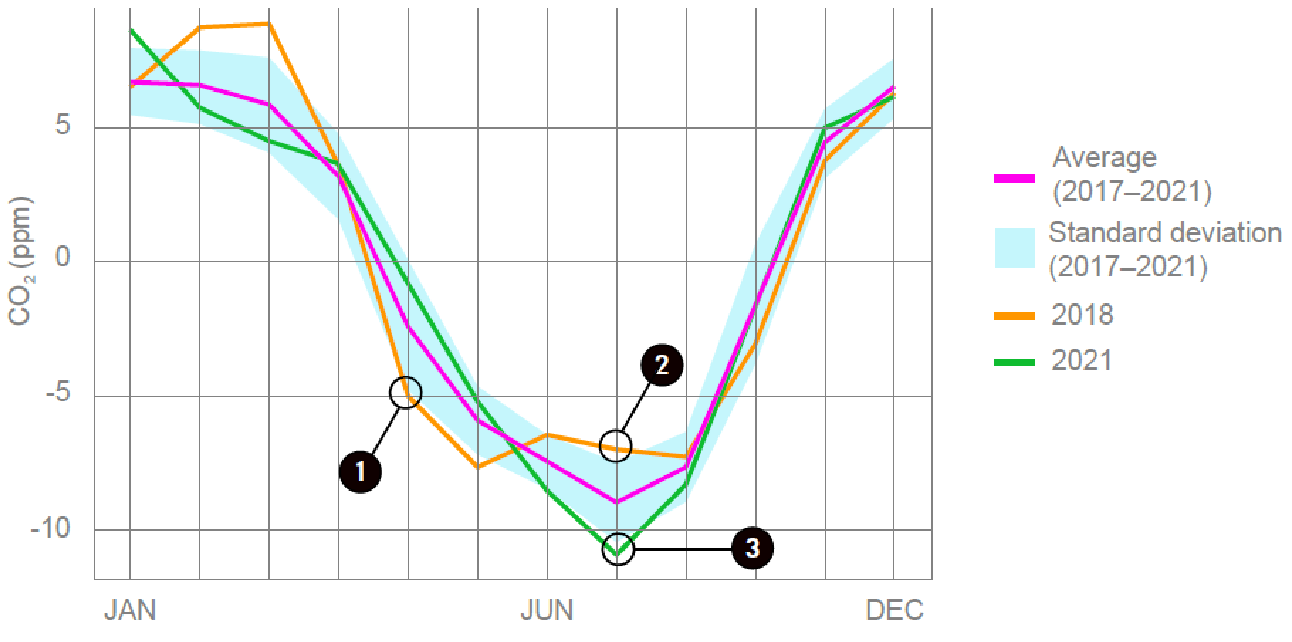


Figure 3 CO_2 seasonal cycles calculated from daytime measurements at the Torfhaus tower station (147 meters above ground level), Germany.

The mean seasonal cycle is represented as a pink line, with the light blue area showing the standard deviation (2017—2021). The cycle is characterized by a drop in concentration during spring and summer and an increase in autumn. Seasonal cycles observed in 2018 and 2021 are represented in orange and green respectively.

1. 2018 had a warm and sunny spring. Due to the resulting high CO_2 uptake by the vegetation the concentration dropped early.
2. During summer, a drought period dimmed the uptake resulting in a summer minimum smaller than usual.
3. In 2021, the high precipitation supported the CO_2 uptake by the vegetation, resulting in a minimum larger than usual.

FLUXES - The European Greenhouse Gas Bulletin, Volume 1, September 2022 "Are sinks at risk?"
https://doi.org/10.18160/8NKQ-65S1

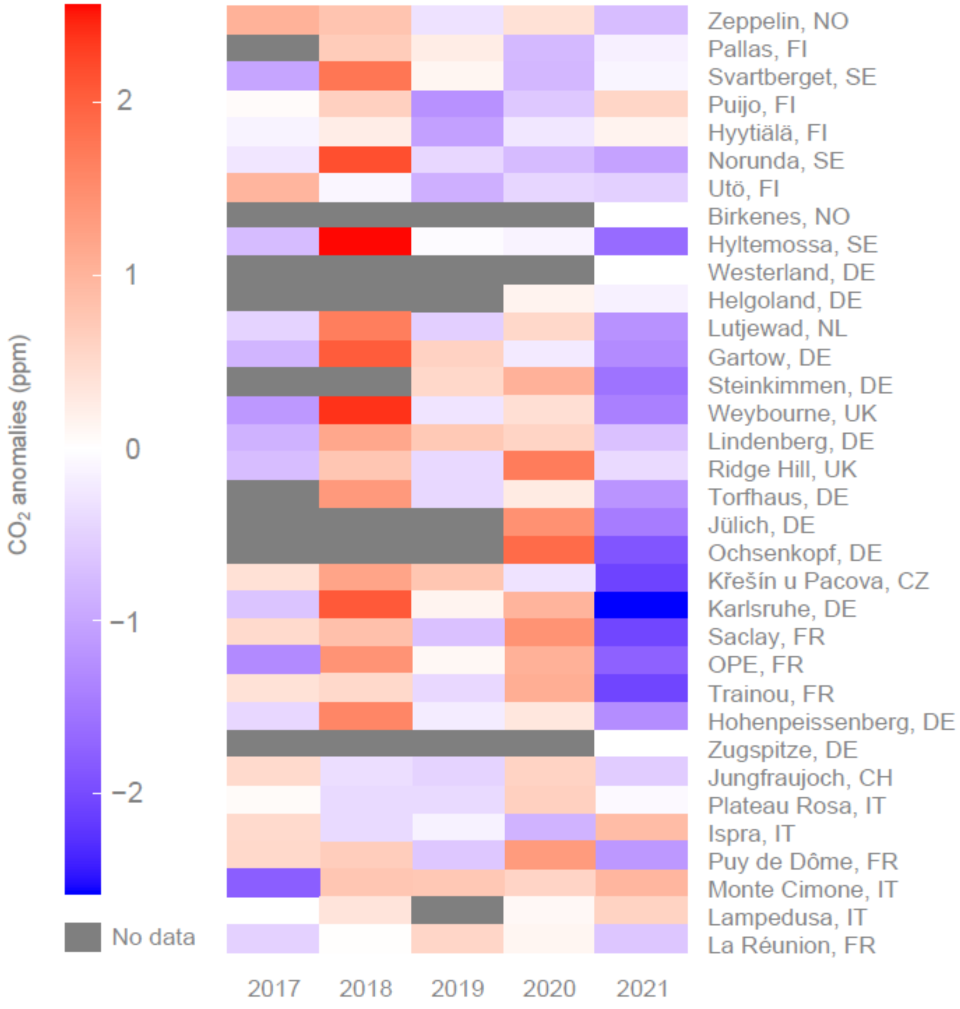


Figure 4 CO_2 summertime (July—August) anomalies, 2017—2021.

The stronger the red colour is, the less there has been CO_2 uptake during the period. The stronger the blue, the more the vegetation has taken up CO_2. The picture also shows that most ICOS stations observed small CO_2 uptakes in year 2018; this is most probably due to the drought experienced in Europe in that summer. The stations are listed in order of latitude from north to south.

Take home messages

- The global CO_2 emission continues to raise
- The amount of CO_2 in the atmosphere is strongly dependent on the response of the natural sinks to climate change
- In-situ and remote sensing measurement techniques provide complementary information on the distribution of CO_2 in the atmosphere
- The precise continuous monitoring helps to characterize the inter-annual differences in amplitude and phase of the seasonal cycles at the site
- Future high-spatial resolution satellite missions, such as the Copernicus Carbon Dioxide Monitoring Mission or CO2M will help to quantify how much CO_2 is released into the atmosphere specifically through human activity
- Further reading – **CO_2 in the Atmosphere: Growth and Trends Since 1850**, https://doi.org/10.1093/acrefore/9780190228620.013.863

Thank you for your attention!