Short-term and long-term variations of the atmospheric CO_2 and O_2 observed at Ny-Ålesund, Svalbard

Daisuke GOTO*, National Institute of Polar Research (NIPR)

Hikaru SEKINE, **Shinji MORIMOTO**, Tohoku University (TU)

Shigeyuki ISHIDOYA, National Institute of Advanced Industrial Science and Technology (AIST)

Topics:

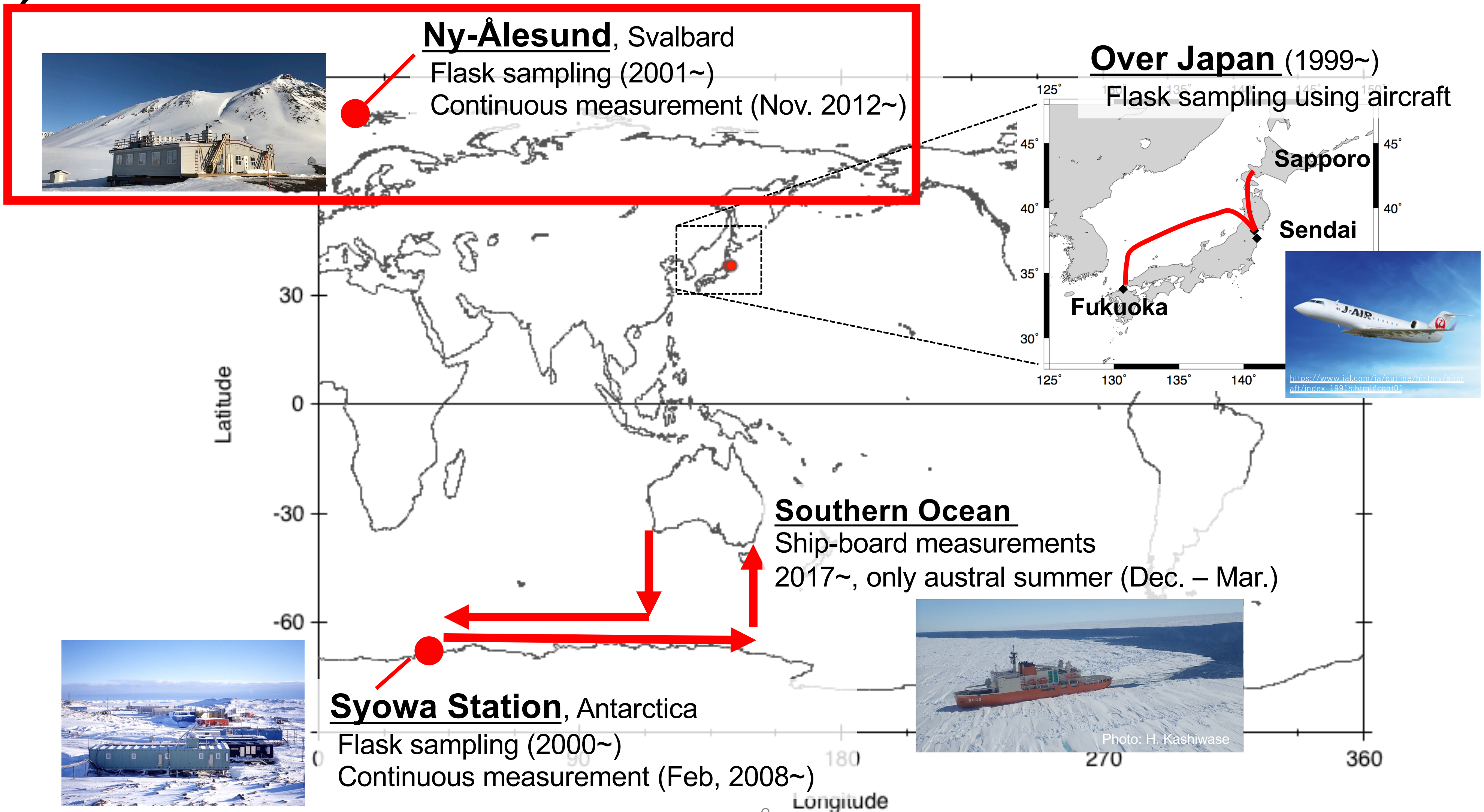
- Analysis of short-term variations:

The distribution of the oxidative ratio (OR) of fossil fuel combustion were examined from continuous CO_2 and O_2 data and footprints.

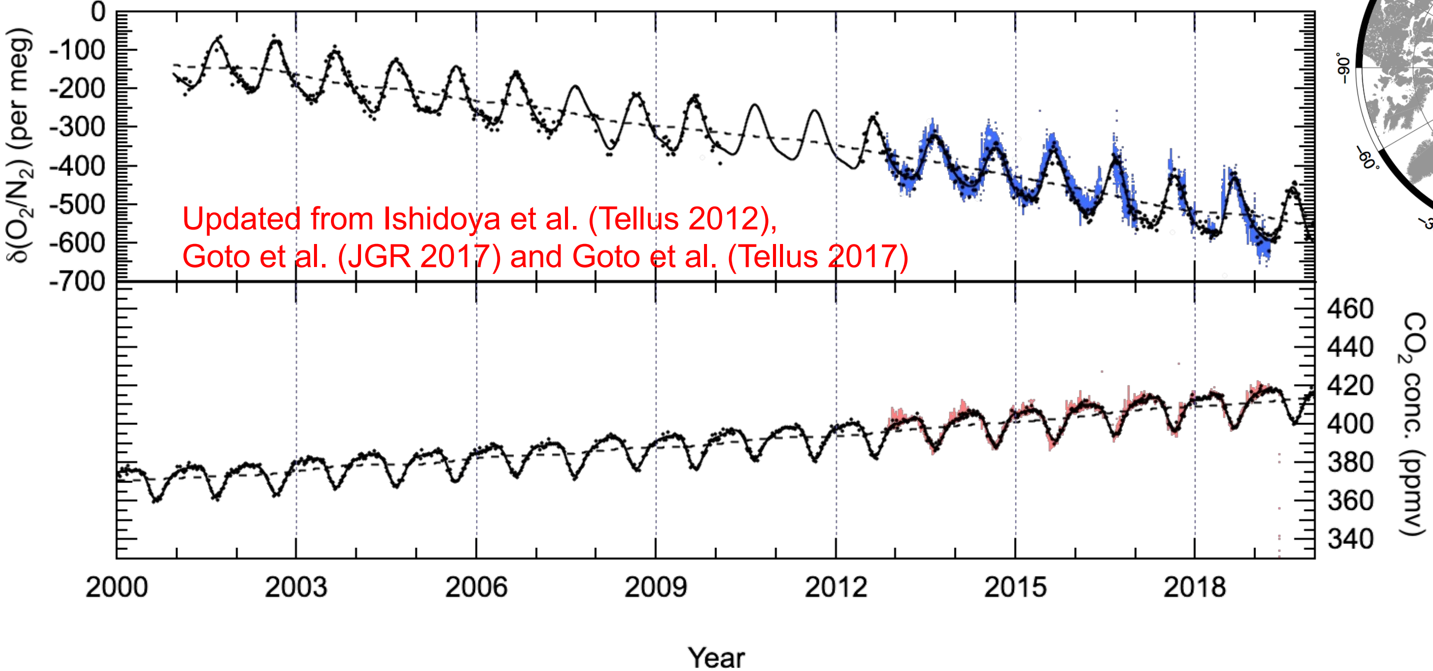
- Estimation of global carbon budget:

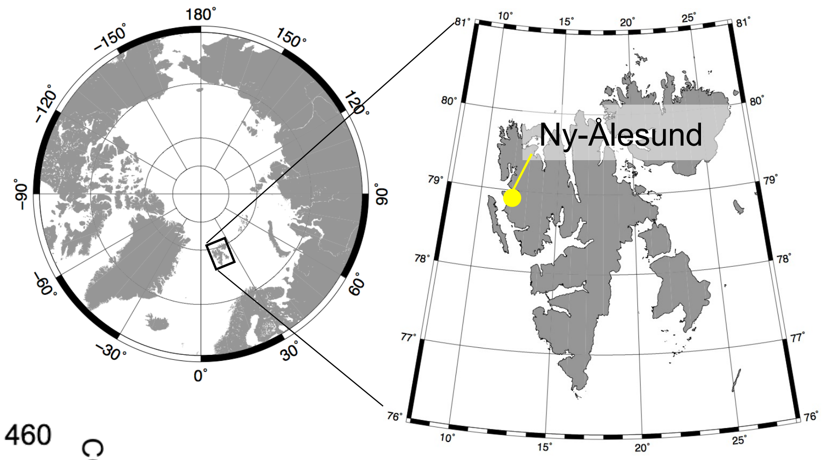
Oceanic and land biospheric CO_2 uptakes were estimated using long-term trends of CO_2&O_2 and CO_2&$\delta^{13}C$ of CO_2 observed at Ny-Ålesund.

O_2 observation sites of TU & NIPR



Ny-Ålesund Station





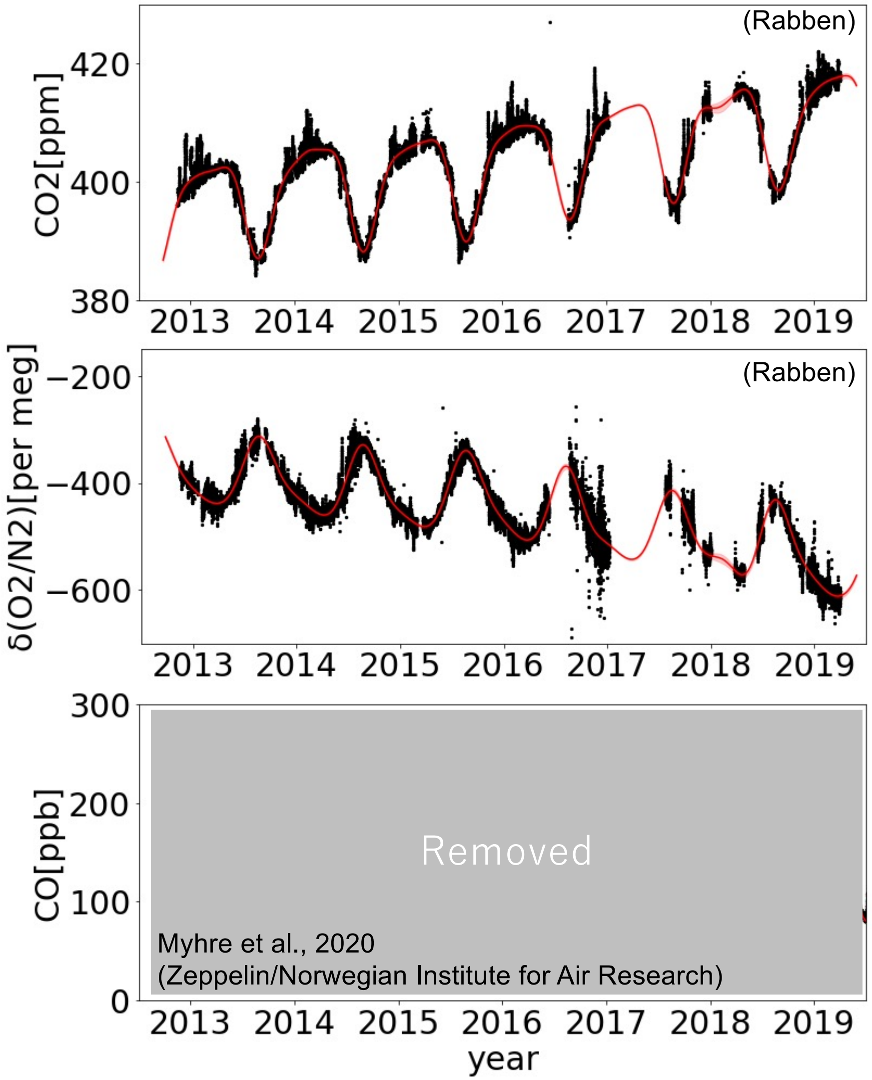
2021
Observatory relocation

- Weekly flask sampling for O_2 measurements have been conducted at Ny-Ålesund since 2001.
- Continuous observation was started in Nov. 2012 (Oxzilla & LiCor, Data missing from May 2020 to May 2021 due to COVID-19 situation)
- Short-term variations related to the marine biological activity were well captured from continuous APO data [Goto et al., Tellus, 2017]
- Estimation of the global carbon budget using flask data [Ishidoya et al., Tellus, 2012; Goto et al., JGR, 2017]

Analysis of short-term variations

The distribution of the oxidative ratio (OR) of fossil fuel combustion were examined from continuous CO_2 and O_2 data and footprints.

Identification of CO_2 events



In the continuous records of concentrations of CO_2, O_2 and CO at Ny-Ålesund, **short-term variations** have been observed.

We extracted the short-term CO_2 variations which were attributable to **fossil fuel combustion** between 2012 and 2019 as:

The definition of high CO_2 event

1. Deviation of the observed CO_2 concentration from the fitting curve (ΔCO_2) is **more than 1.5σ**, and the event lasts for **more than 4 hours.**
2. Correlation coefficients between ΔCO_2 & ΔO_2, and ΔCO_2 & ΔCO are **greater than 0.5**
3. In winter **(Dec. – Feb.)**

As a result, **868** short-term CO_2 increase events were identified.

Fig. Hourly means of the CO_2, $\delta(O_2/N_2)$ and CO observed at Ny Alesund (Rabben and Zeppelin). (Goto et al., 2013; Myhre et al., 2020)

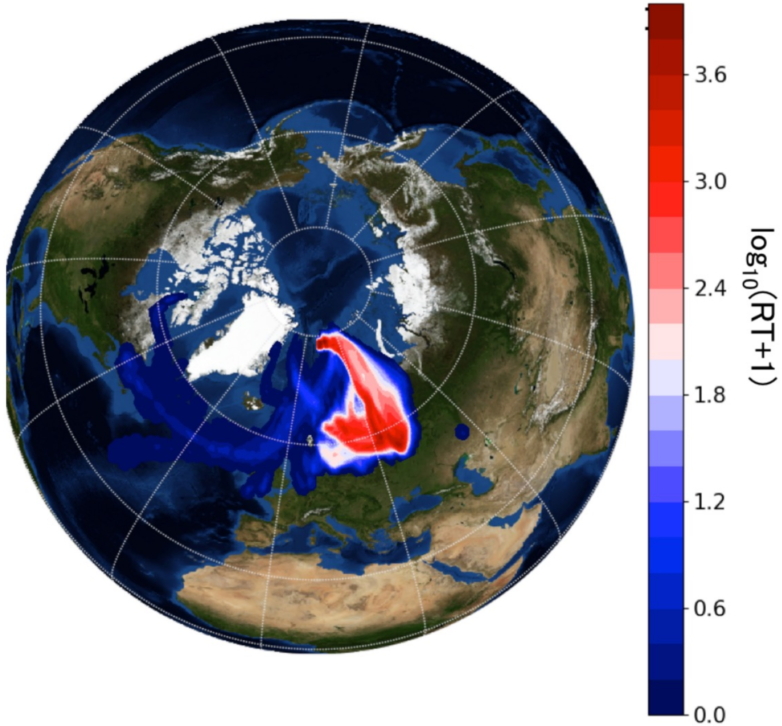
Lagragian Particle Dispersion Model & Calculation of OR

Origin of air masses reaching at Ny-Ålesund during each high CO_2 event was calculated by a Lagrangian Particle Dispersion Model, FLEXCPP* [Zeng et al., 2012, https://db.cger.nies.go.jp/ged/flexcpp/en/index.html]

*developed by NIES based on the open source FLEXPART (FLEXible PARTicle dispersion model https://www.flexpart.eu/)

Meteorological data	ERA5 (0.5°×0.5°, 37 vertical layers, 3 hourly)
Calculation duration (backward)	10 days
Output	Residence time[s] (1°×1°)

ERA5：Reanalysis data from ECMWF



Footprint (map of residence time) for 2016/2/24 1500UTC

OR distribution was examined by using OR values observed at Ny-Ålesund and the footprints.

Calculation of OR distribution

The OR of each event was calculated as:

$$OR\_obs = -\frac{\Delta CO_2}{\Delta O_2}$$

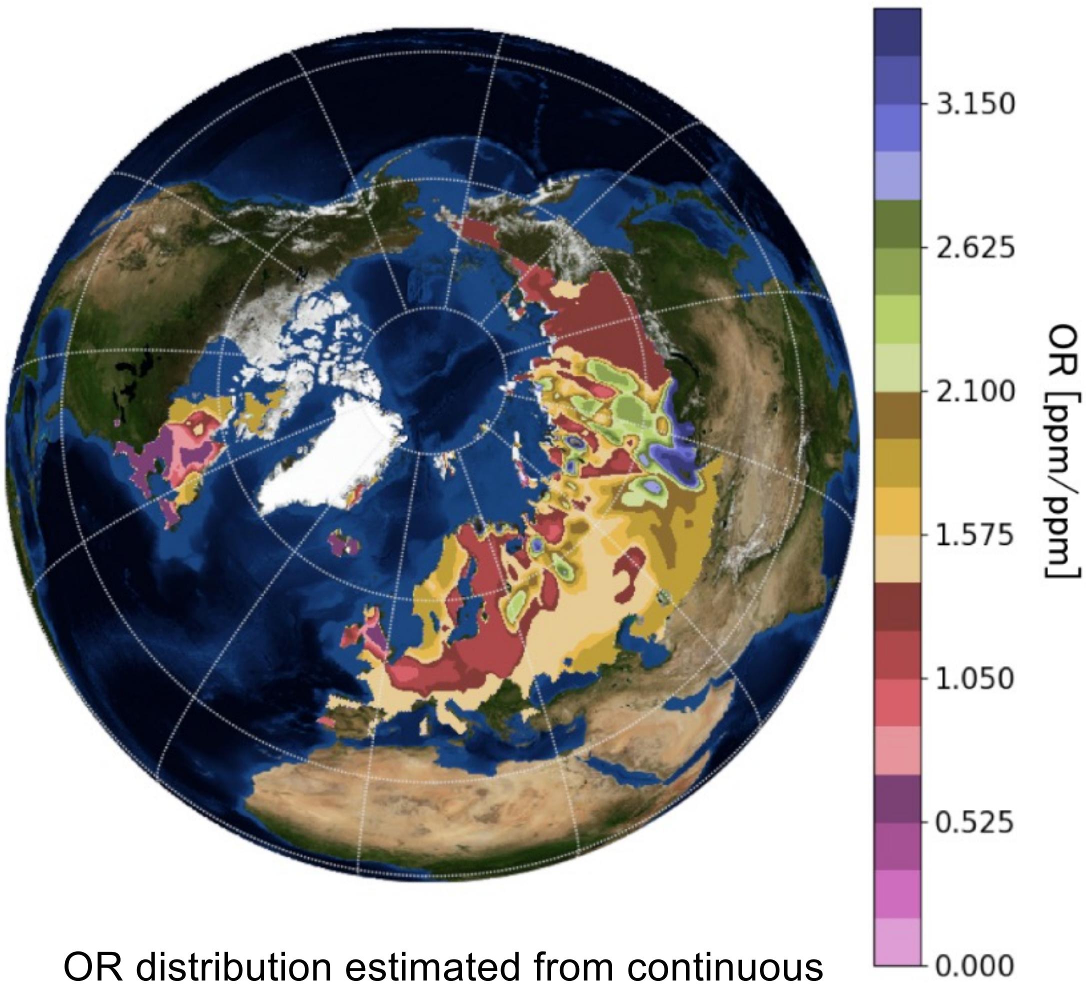
We multiplied the OR of each time by the footprint (residence time) and took a weighted average by the total residence time of each grid to examine the OR distribution.

Observed OR — Residence time

$$OR_{i.j} = \frac{\sum_k \boxed{OR\_obs_k} \times \boxed{RT_{i,j,k}}}{\boxed{\sum_k RT_{i,j,k}}}$$

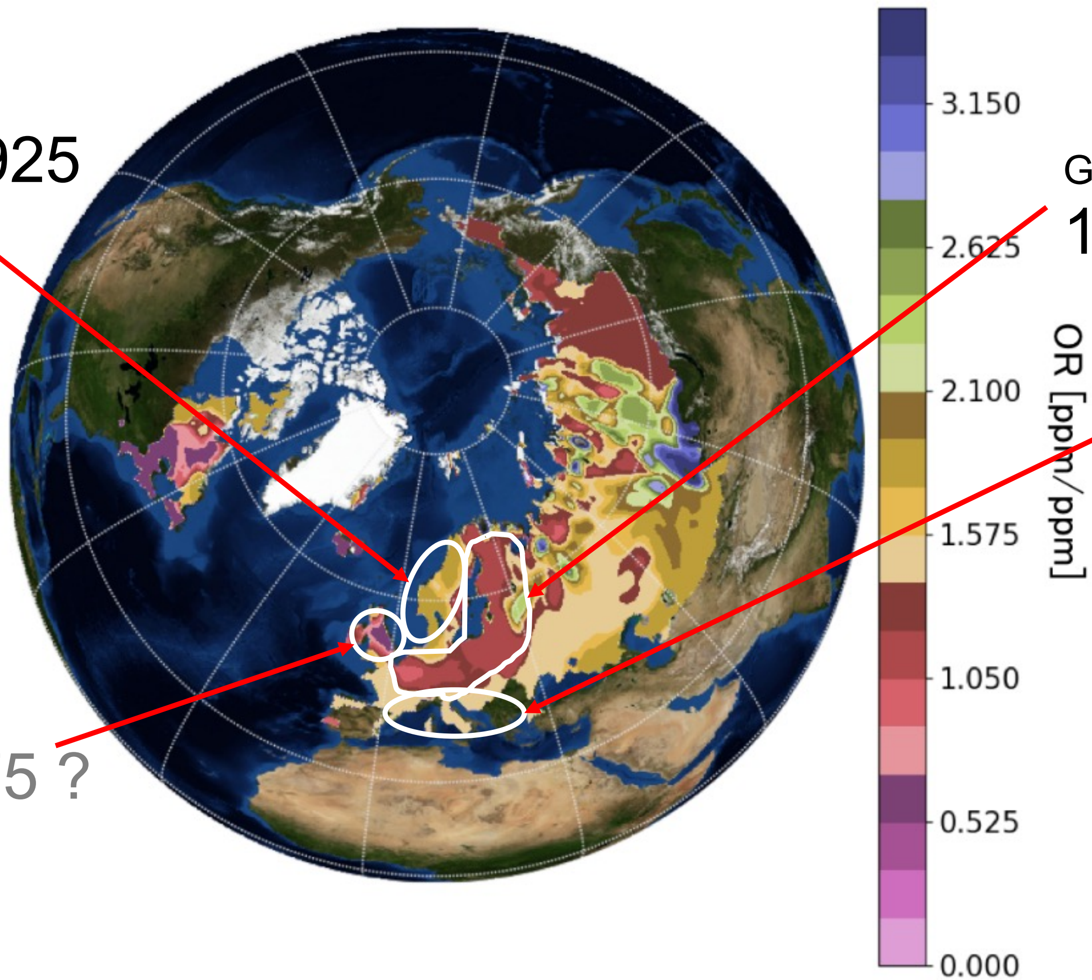
Total residence time

OR_obs : OR value calculated from observed ΔCO_2 and ΔO_2
RT : residence time [s]
i, j : latitude and longitude
k : time



OR distribution estimated from continuous O_2 and CO_2 data at Ny-Ålesund.

OR distribution in Europe

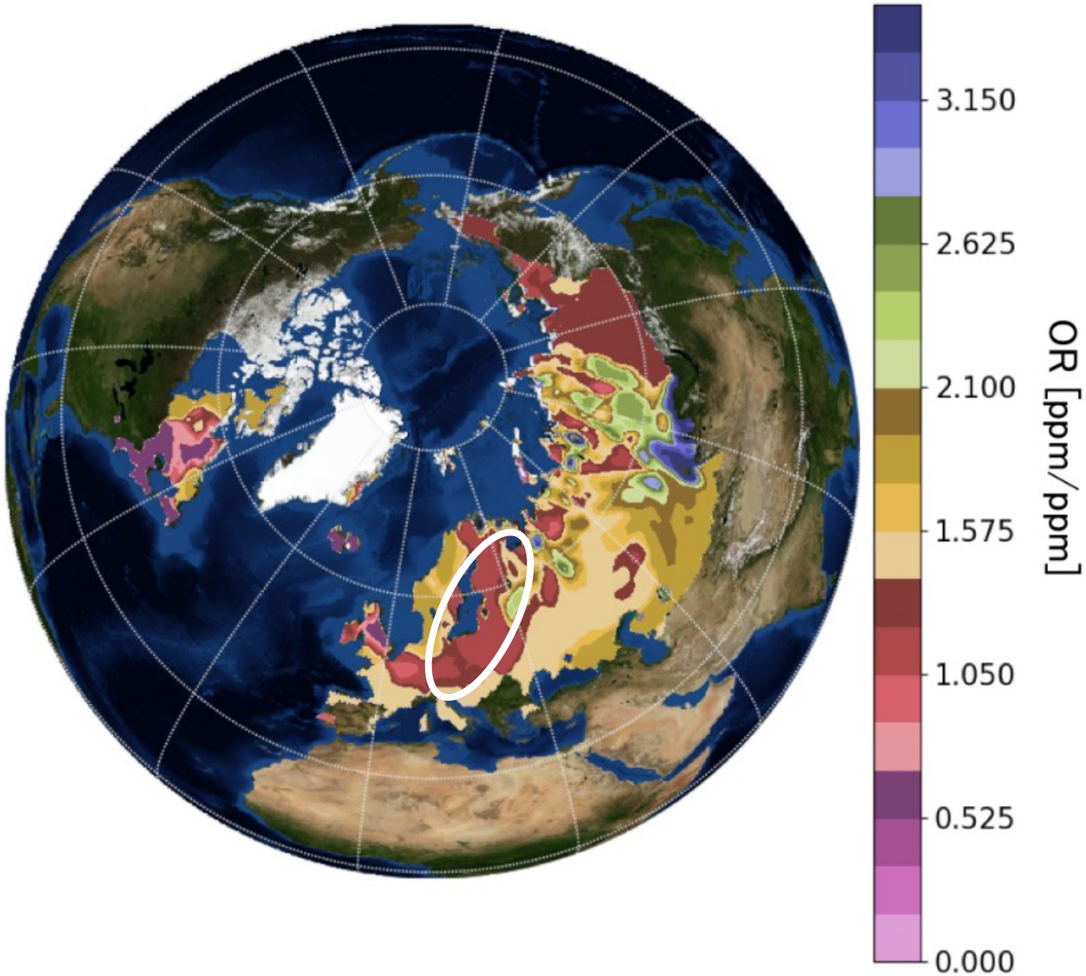


OR for the respective types of fossil fuel [Keeling, 1988]

Fuel type	OR value (ppm/ppm)
Natural gas	1.95 ± 0.04
Liquid	1.44 ± 0.03
Coal	1.17 ± 0.03

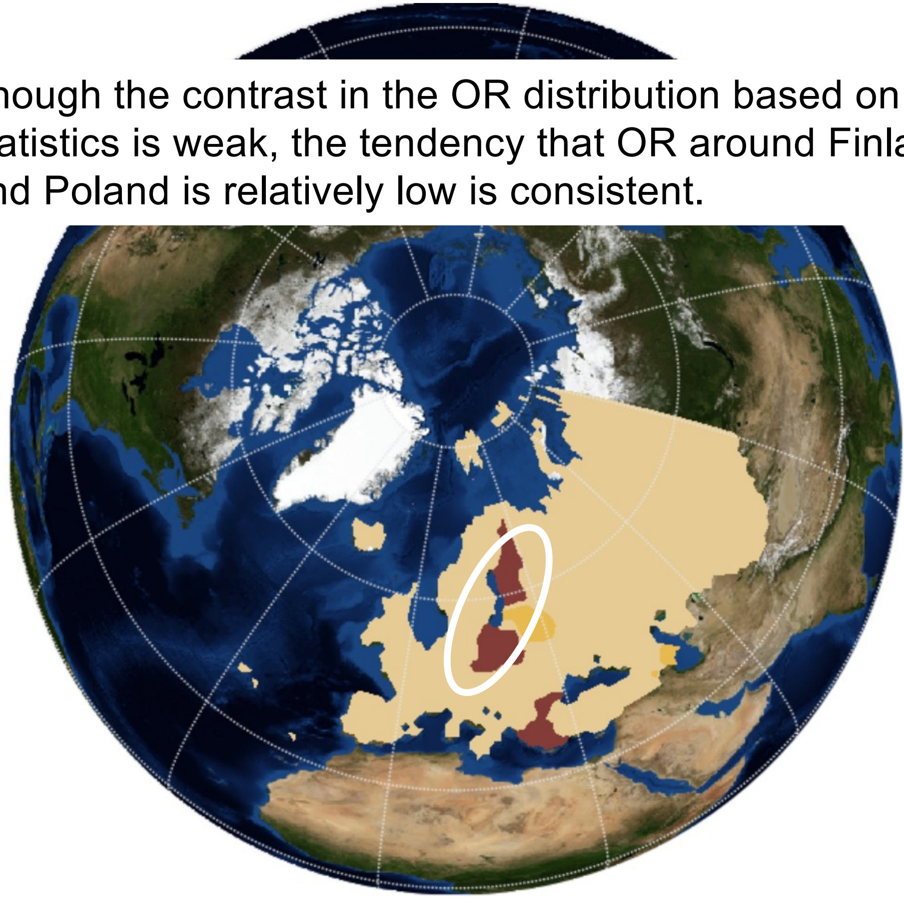
OR distribution estimated from observation.
OR values in Europe are distributed from 1.050 to 1.925.

OR distribution in Europe



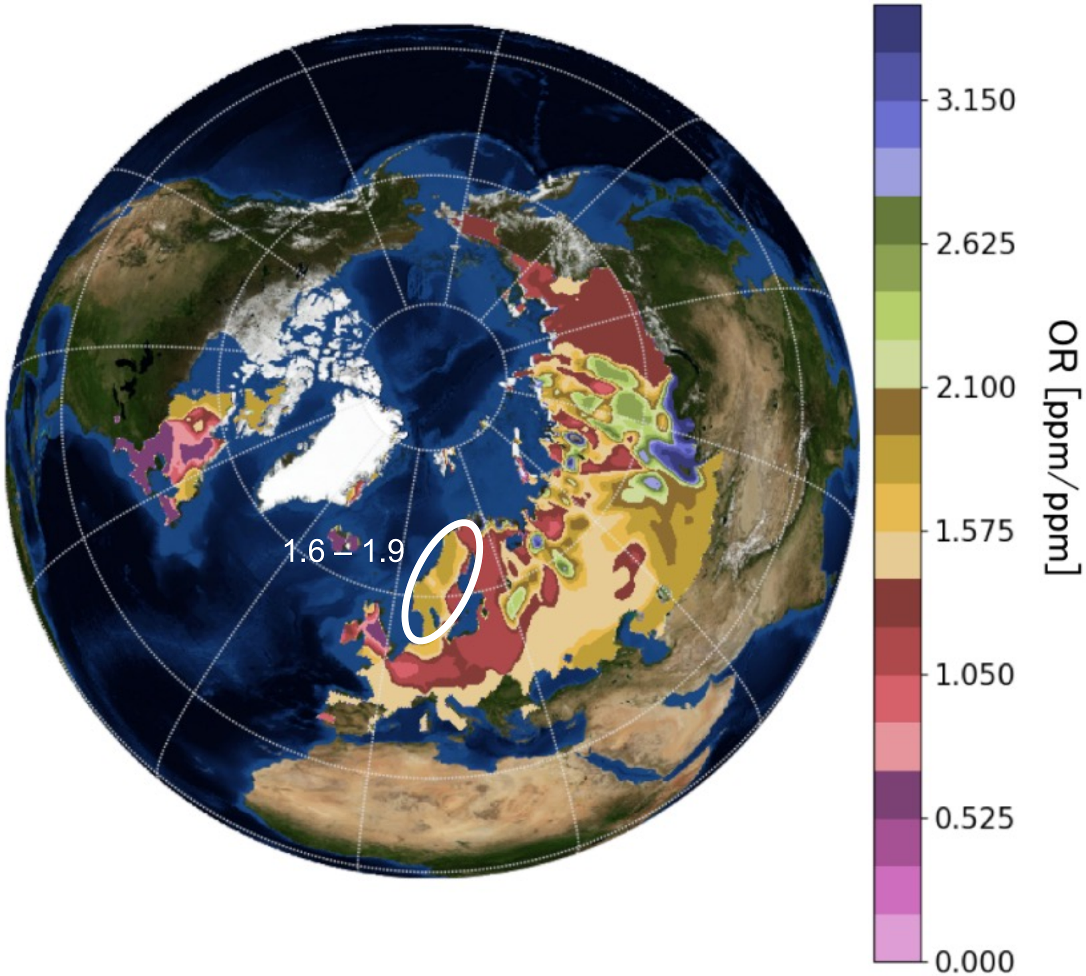
OR distribution estimated from **observation**.
OR values in Europe are distributed from 1.050 to 1.925.

Though the contrast in the OR distribution based on the statistics is weak, the tendency that OR around Finland and Poland is relatively low is consistent.



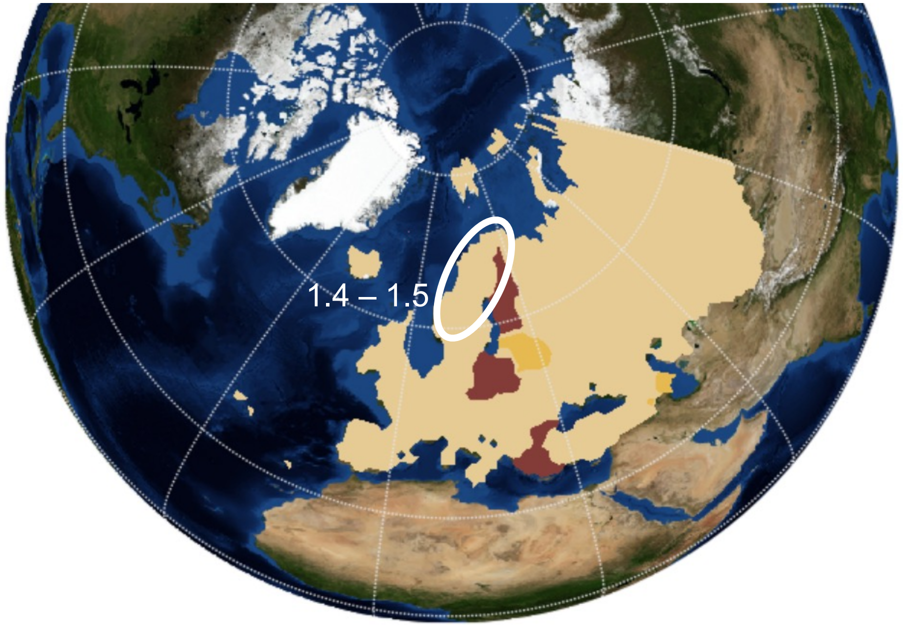
OR distribution based on **statistical data** from Statistical Review of World Energy
https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

OR distribution in Europe



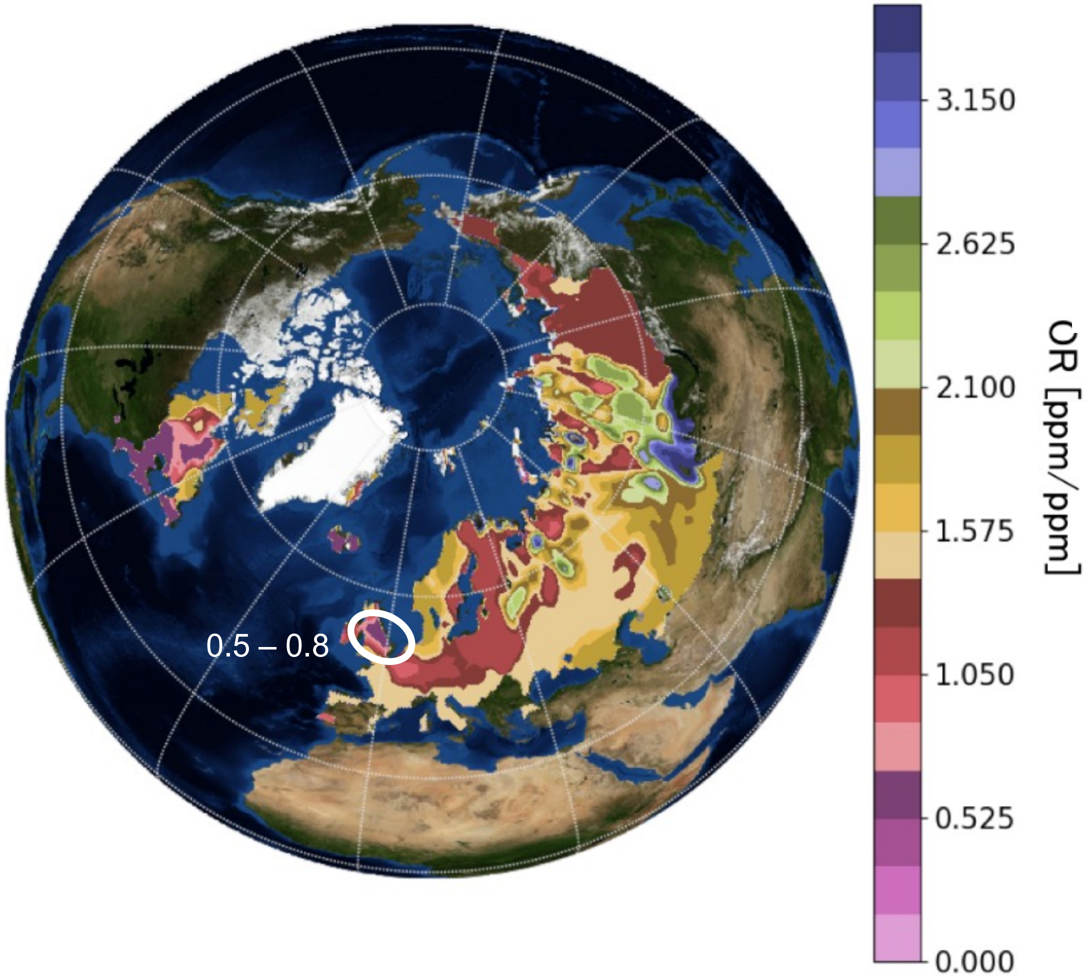
OR distribution estimated from **observation**.
OR values in Europe are distributed from 1.050 to 1.925.

The OR in Norway estimated from observation is higher than that from statistics. It may be implied that the reported natural gas consumption in Norway might be underestimated.

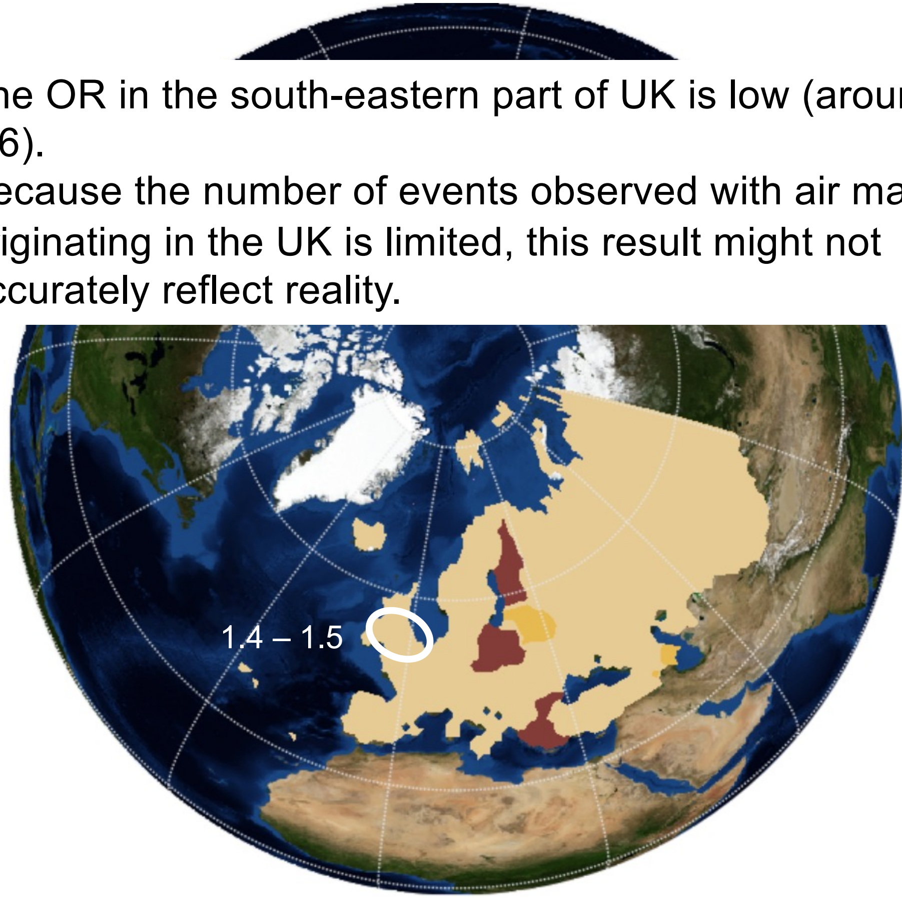


OR distribution based on **statistical data** from Statistical Review of World Energy
https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

OR distribution in Europe



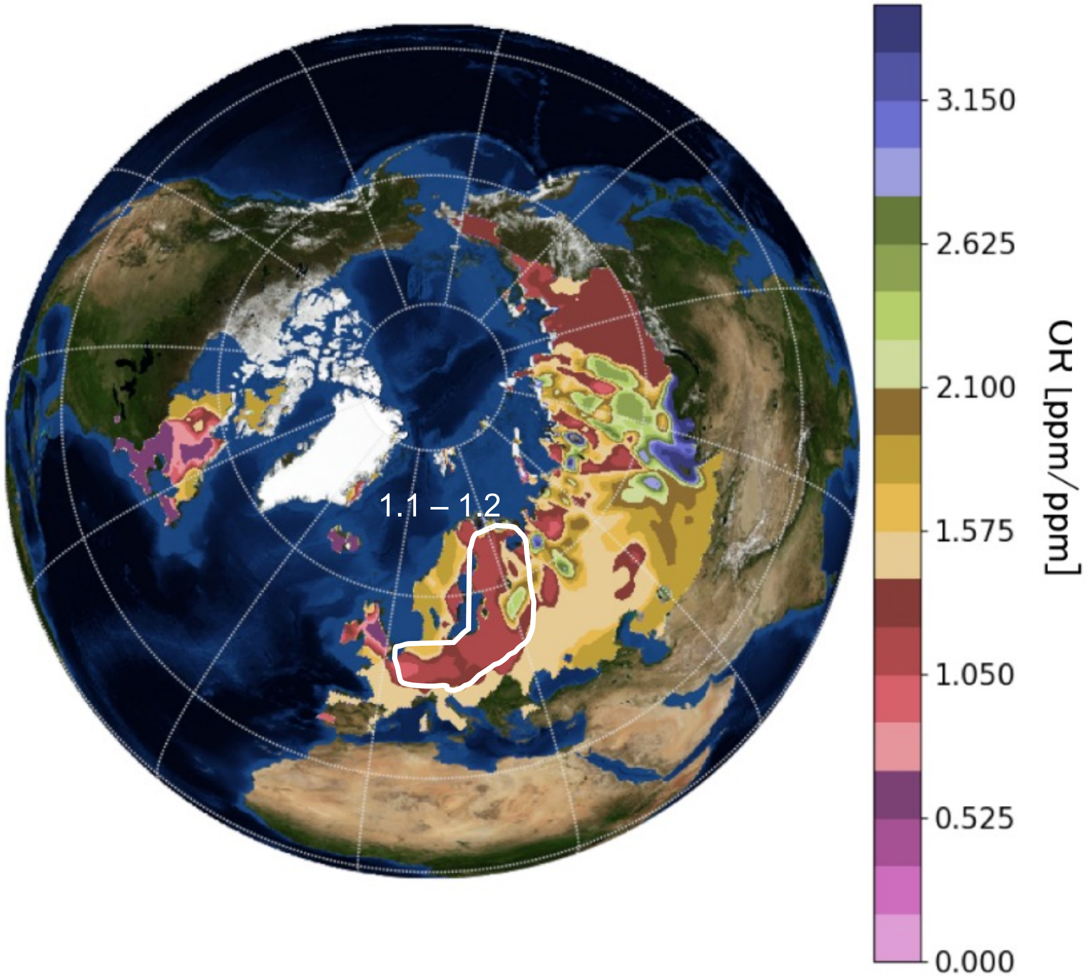
The OR in the south-eastern part of UK is low (around 0.6).
Because the number of events observed with air masses originating in the UK is limited, this result might not accurately reflect reality.



OR distribution estimated from **observation**.
OR values in Europe are distributed from 1.050 to 1.925.

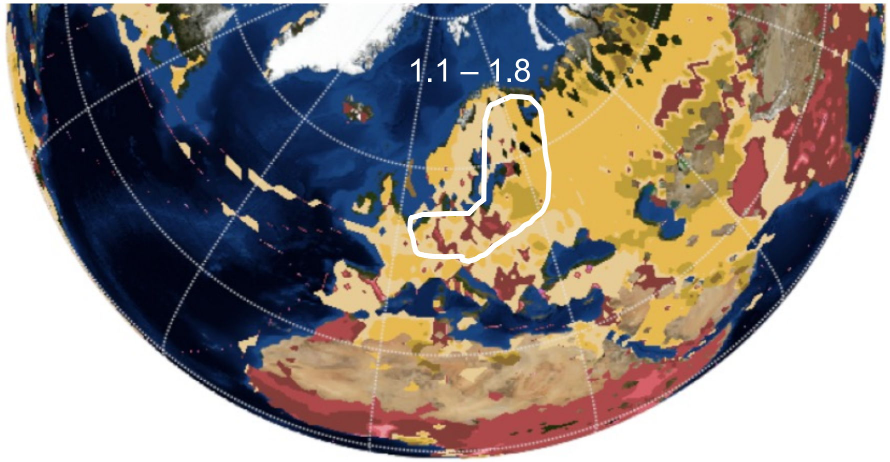
OR distribution based on **statistical data** from Statistical Review of World Energy
https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

OR distribution in Europe



OR distribution estimated from **observation**.
OR values in Europe are distributed from 1.050 to 1.925.

The OR around Germany, Poland, Finland estimated from observation is low compared to that based on COF-FEE dataset.
COF-FEE considers only coal, oil and natural gas, and doesn’t consider the biofuel. Our observation possibly detected the effect of increasing biofuel consumptions in Europe.



OR distribution based on **COF-FEE** (CO_2 release and Oxygen uptake from Fossil Fuel Emission Estimate; Steinbach et al., 2011)

Summary --- analyses of short-term variations

- The distribution of the oxidative ratio (OR) of fossil fuel combustion were examined from continuous CO_2 and O_2 observed at Ny-Ålesund and footprints.
- The OR values calculated from observations were generally consistent with those estimated from statistical data, but partly lower than those estimated in the previous study (Steinbach et al., 2011).
- It would be implied that OR distribution estimated from the continuous data of CO_2 and O_2 at Ny-Ålesund could validate the statistical data of fossil fuel consumption in Europe.

Estimation of global carbon budget

Oceanic and land biospheric CO_2 sinks were estimated using long-term trends of CO_2&O_2 and CO_2&$\delta^{13}C$ observed at Ny-Ålesund

(Update of Goto et al. (2017, JGR))

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Biogeosciences

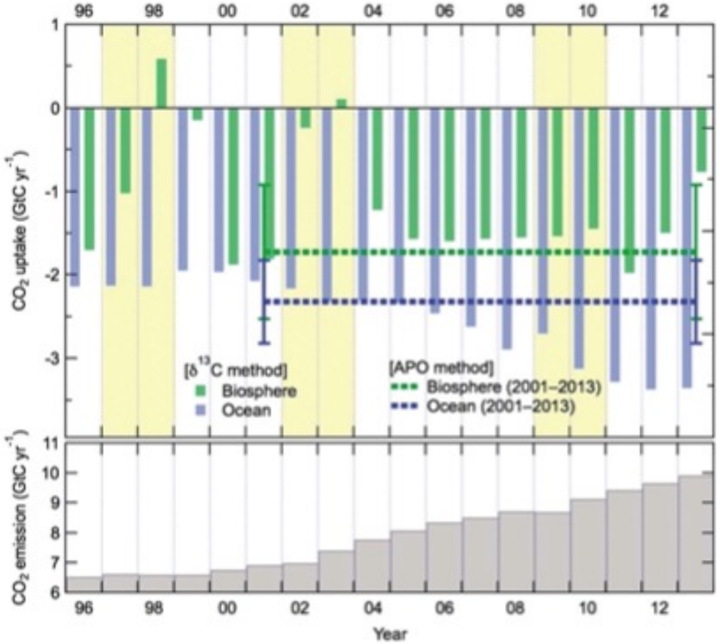
RESEARCH ARTICLE

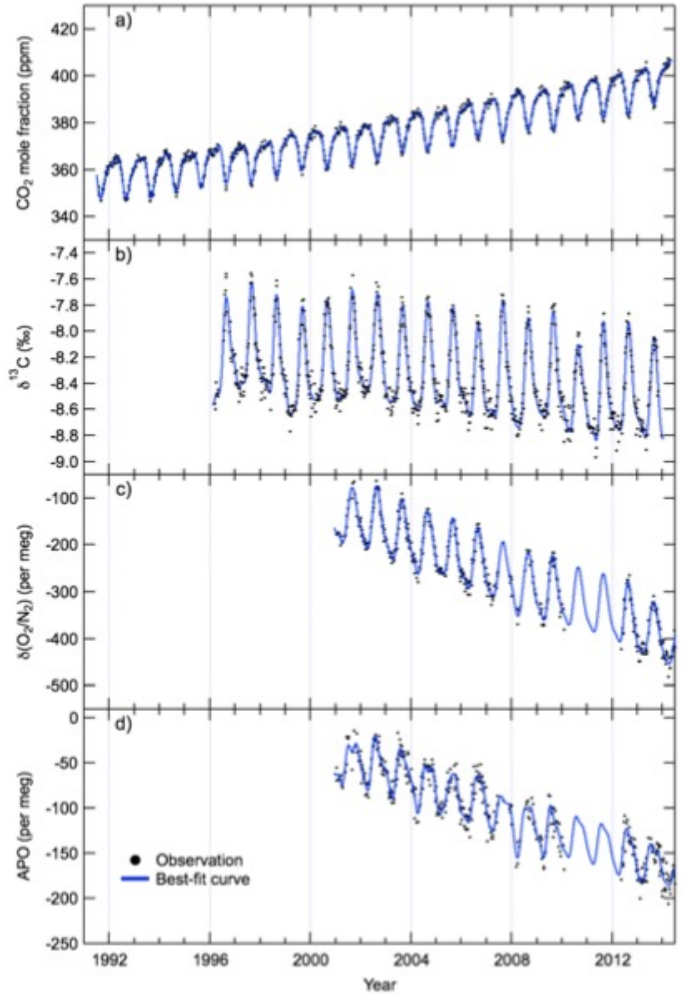
10.1002/2017JG003845

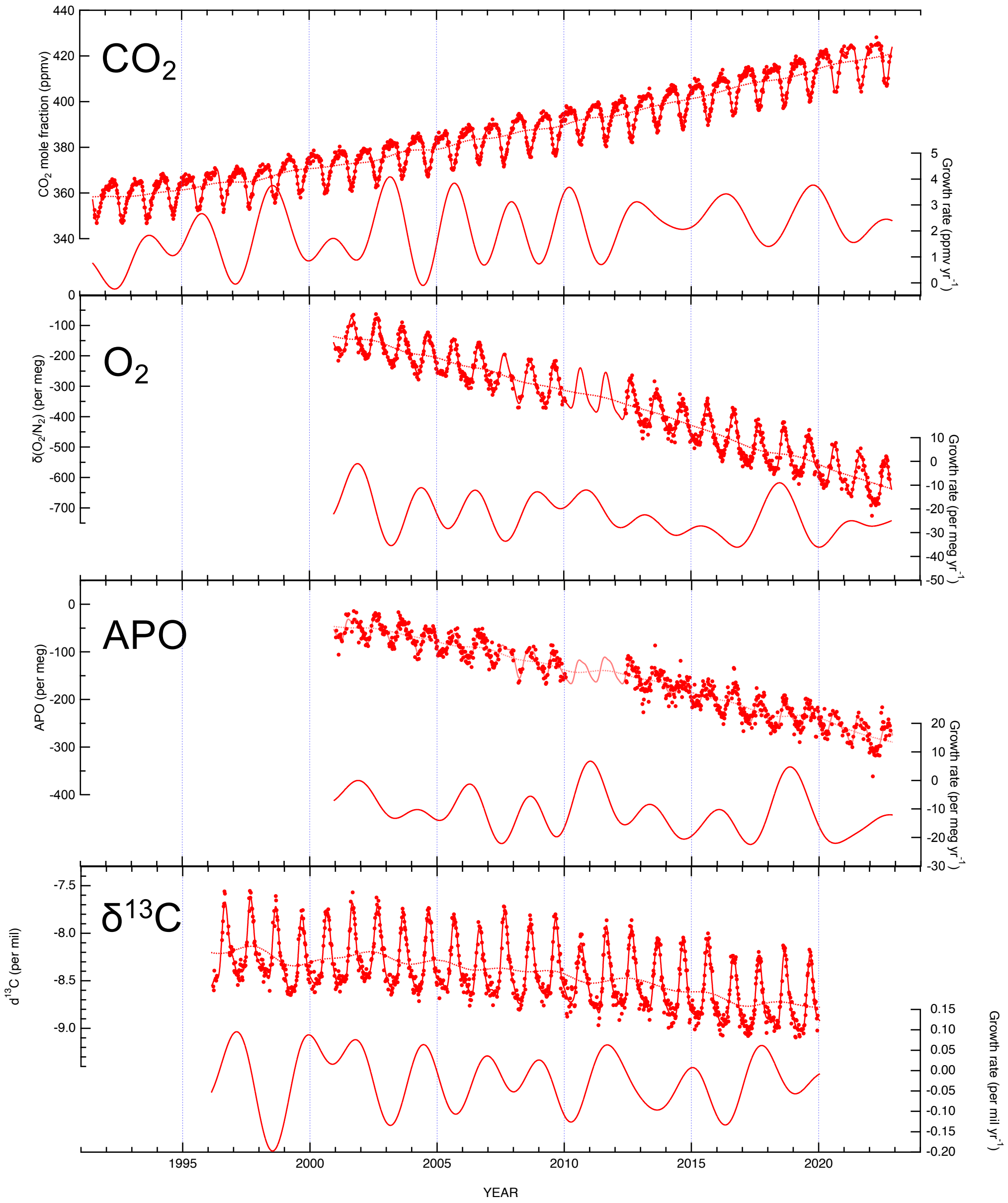
Terrestrial biospheric and oceanic CO_2 uptakes estimated from long-term measurements of atmospheric CO_2 mole fraction, δ13C, and δ(O_2/N_2) at Ny-Ålesund, Svalbard

Daisuke Goto[1,2], Shinji Morimoto[3], Shigeyuki Ishidoya[4], Shuji Aoki[3], and Takakiyo Nakazawa[3]

[1]National Institute of Polar Research, Tachikawa, Japan, [2]Department of Polar Science, The Graduate University for Advanced Studies (SOKENDAI), Tachikawa, Japan, [3]Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University, Sendai, Japan, [4]National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan







$\delta^{13}C$ method

$$\frac{dCO_2}{dt} = F + O + B$$

$$\frac{dCO_2\delta_a}{dt} = F\delta_f - O(\delta_a - \varepsilon_{as}) - B(\delta_a - \varepsilon_{ab}) + G$$

O_2(APO) method

$$\Delta CO_2 = F - O - B$$

$$\Delta O_2 = -1.4F + 1.1B + Z$$

Fossil fuel CO_2 emission (F)

Global Carbo Project (Friedlingstein et al., 2022)

Isoflux (G)

~2013：Use the values of Goto et al., (2017)

(Estimated by box diffusion model (Oeschger et al., 1975))

2014~： Assumed to be constant at 2013 values

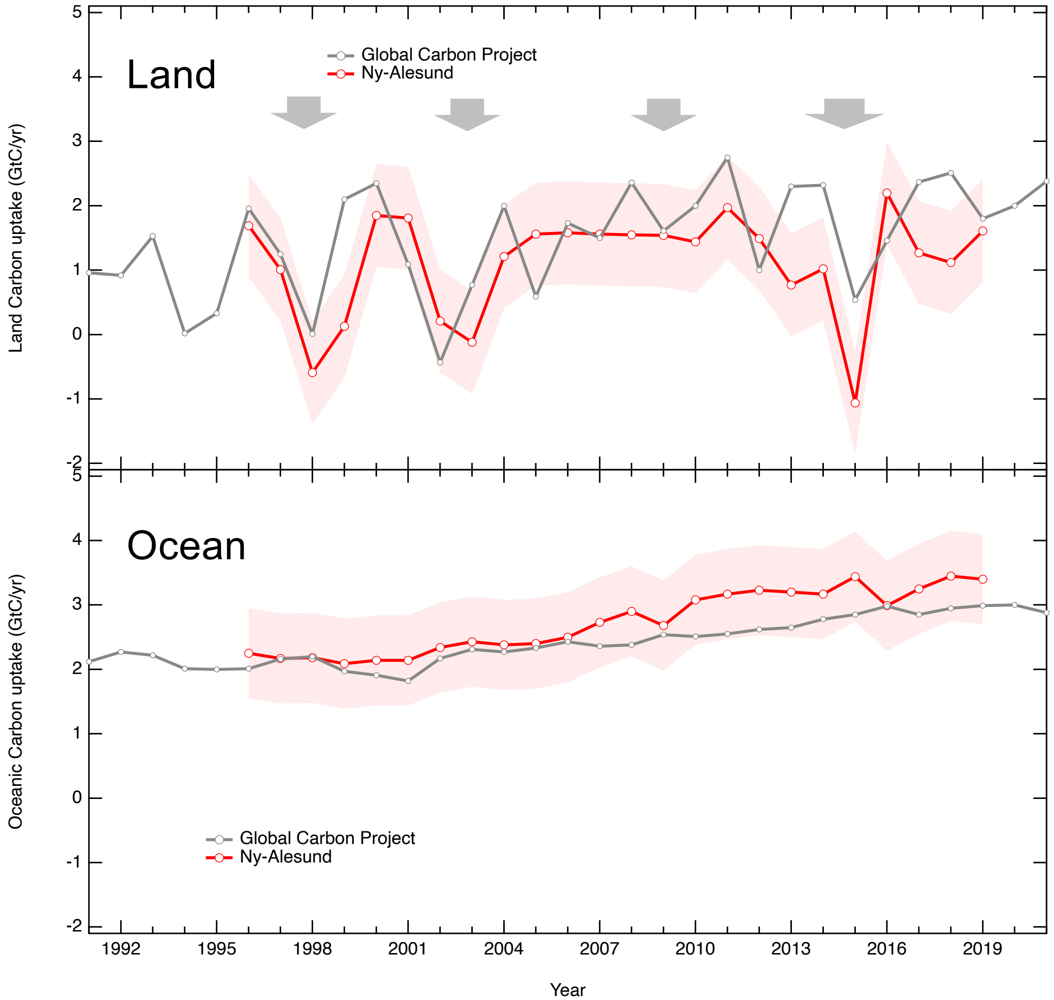
O_2 outgassing (Z)

Estimated from Ocean heat content(Levitus et al., 2012)

Estimation of global carbon sinks

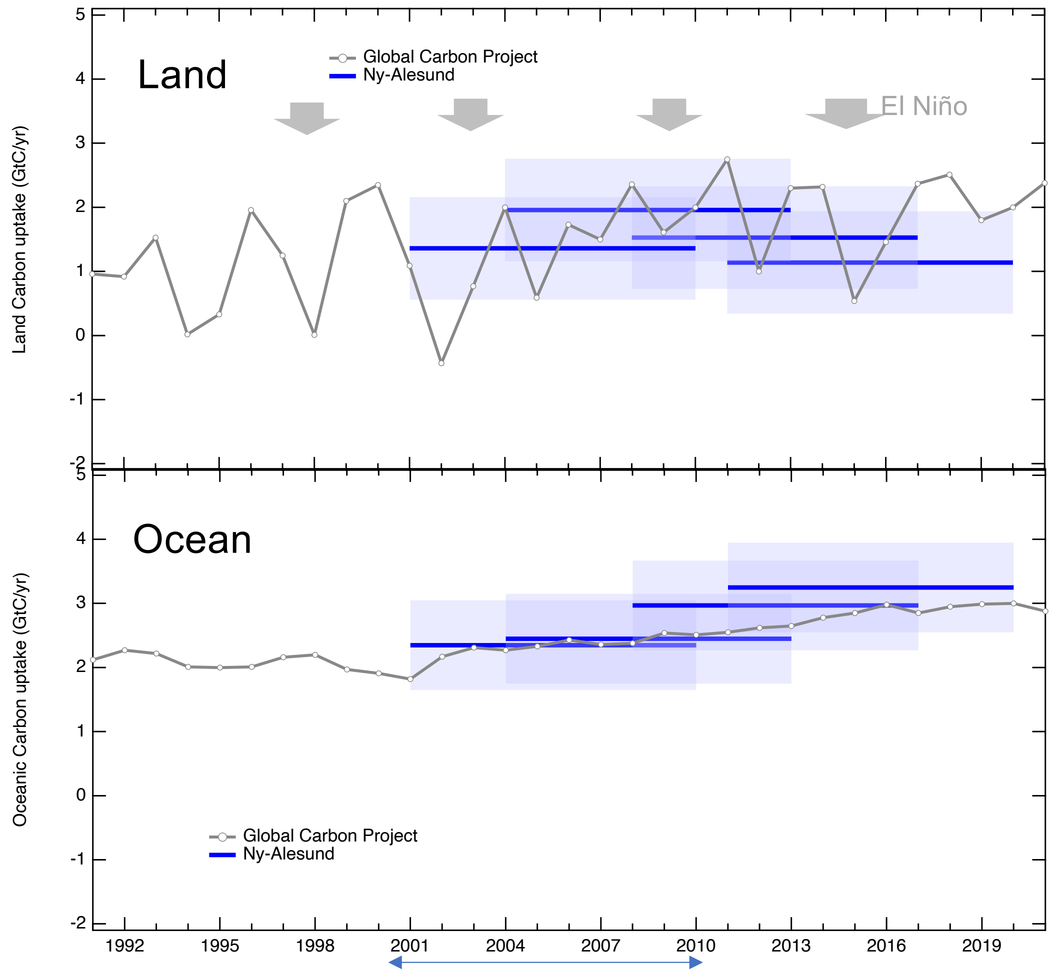
Preliminary

$\delta^{13}C$ method



Goto et al., 2017

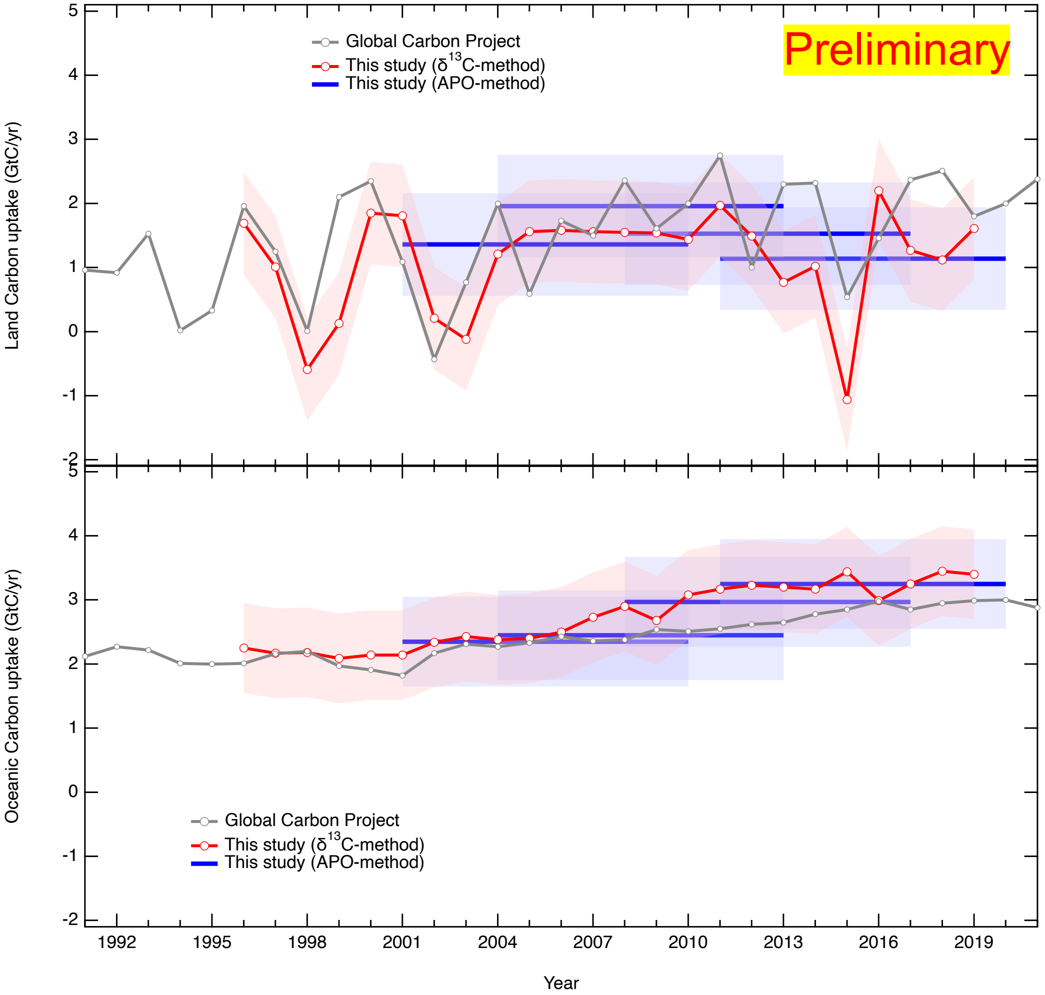
O_2 (APO) method



Ishidoya et al., 2012

Goto et al., 2017

Summary



- Based on the observed secular trends of the CO_2 and O_2 (O_2-method), the average terrestrial biospheric and oceanic CO_2 uptakes during 2001–2020 were estimated to be 1.5±0.8 and 2.5±0.6 GtC yr^{-1}, respectively.

- By using the observed CO_2 and $\delta^{13}C$ ($\delta^{13}C$-method), the corresponding CO_2 uptake of 1.2±0.8 and 2.8±0.6 GtC yr^{-1} were obtained for the same period.

$\delta^{13}C$ method

- The terrestrial biospheric CO_2 uptake showed large inter-annual variability in association with El Niño events. On the other hand, the oceanic uptake increased secularly with less inter-annual variability during 1996–2020.

O_2 method

- The oceanic CO_2 uptake of the decadal periods (2001–2010, 2004–2013, 2008–2017, and 2011–2020) showed an increasing trend.

- These oceanic uptake rates and the increasing trends estimated in this study agree with those reported by the GCP within the estimation uncertainty.

Thank you