Atmosphere Monitoring

Integrated carbon cycle in reanalyses

Anna Agusti-Panareda

Thanks to Joe McNorton, Aura Lupascu, Souhail Boussetta, Gianpaolo Balsamo, Margartia Choulga, Michail Diamantakis, Sebastien Massart, Peter Weston, Patricia de Rosnay, Marco Matricardi, Nicolas Bousserez, Luca Cantarello, Ernest Koffi, Jerome Baree, Roberto Ribas, Antje Inness, Richard Engelen and CAMS colleagues

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ECMWF Annual Seminar
08/09/2023

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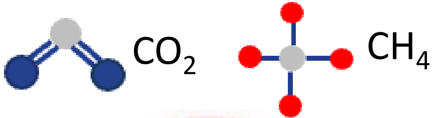
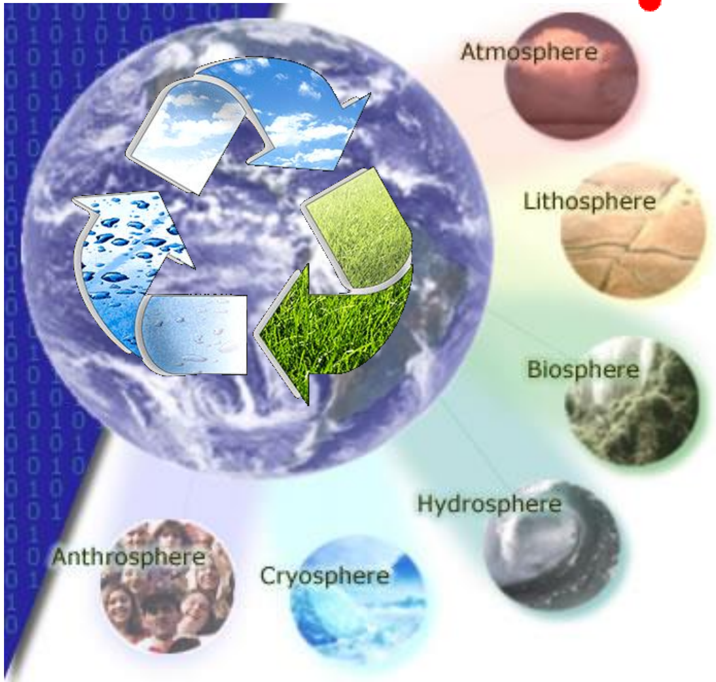
Integrated carbon cycle in reanalyses



- What is the carbon cycle and why is it important?
- Current representation of carbon cycle in the Integrated Forecasting System at ECMWF
    - ✓ Modelling
    - ✓ Observations
- Current CAMS IFS re-analysis of CO_2 and CH_4
- The development of a flux inversion system in the IFS to monitor emission of CO_2 and CH_4 (new Copernicus Service).
- Recent model developments and use of new observations
- Exploring synergies between composition and NWP
- Benefits of integrating the carbon cycle in Earth System re-analysis



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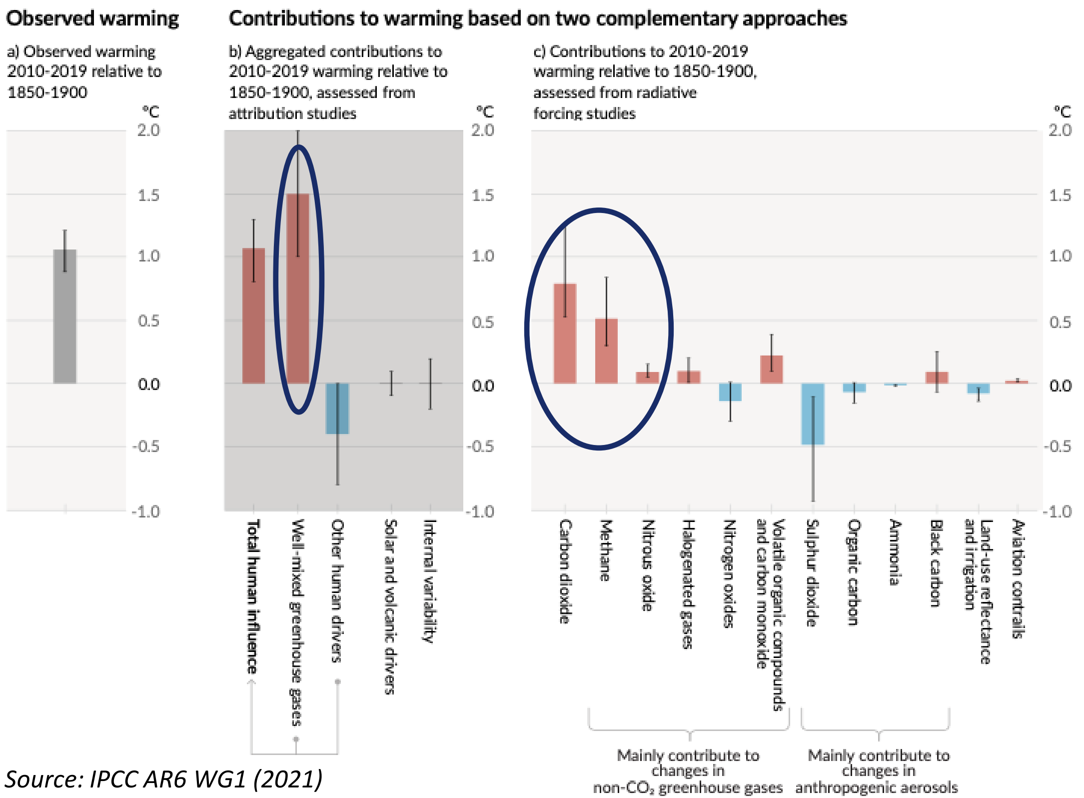
Motivation for integrated carbon cycle in reanalyses

- The two most abundant long-lived greenhouse gases Carbon dioxide (CO_2) and methane (CH_4) are controlled by the global carbon cycle
- They are released to the atmosphere by human activities and are responsible for human-induced greenhouse gas warming (IPCC AR6)
- Their concentrations have been increasing since pre-industrial levels (1750) by 49% CO_2, 150% for CH_4
- The integration of carbon cycle in re-analysis has the potential to improve the representation of the water and energy balance through their links with the biosphere, hydrosphere and radiative transfer processes.

Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling



Source: IPCC AR6 WG1 (2021)

Monitoring atmospheric CO_2 and CH_4 and associated emissions/natural fluxes

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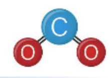
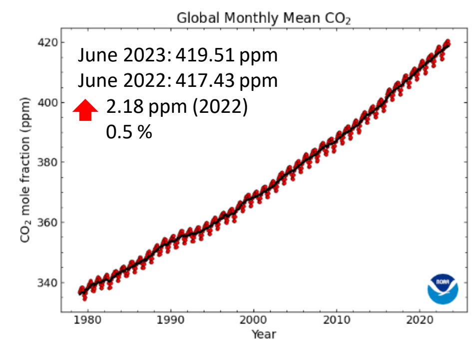
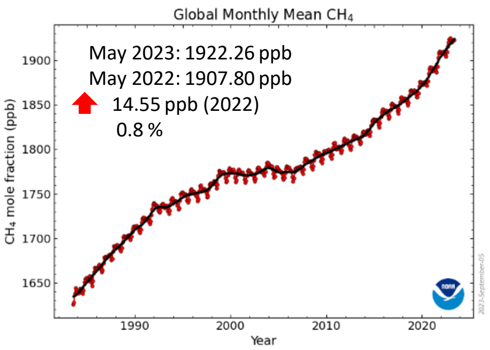
In situ observations





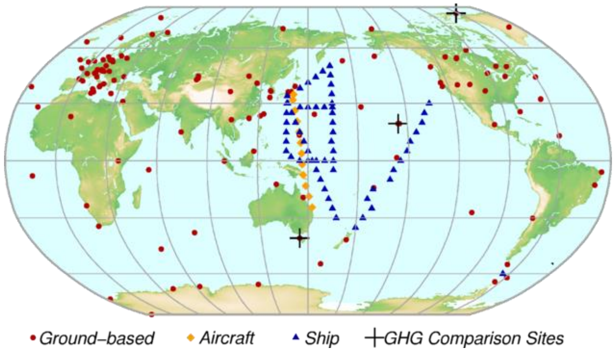
June 2023: 419.51 ppm
June 2022: 417.43 ppm
↑ 2.18 ppm (2022)
0.5 %

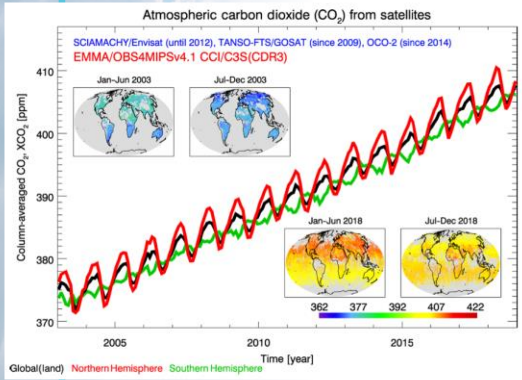


May 2023: 1922.26 ppb
May 2022: 1907.80 ppb
↑ 14.55 ppb (2022)
0.8 %

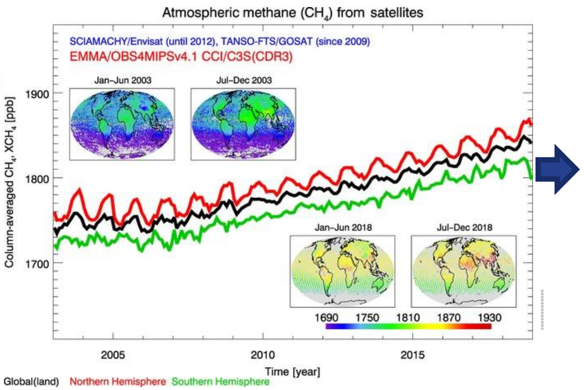
https://gml.noaa.gov/ccgg/trends/gl_gr.html

WMO GAW global in situ network



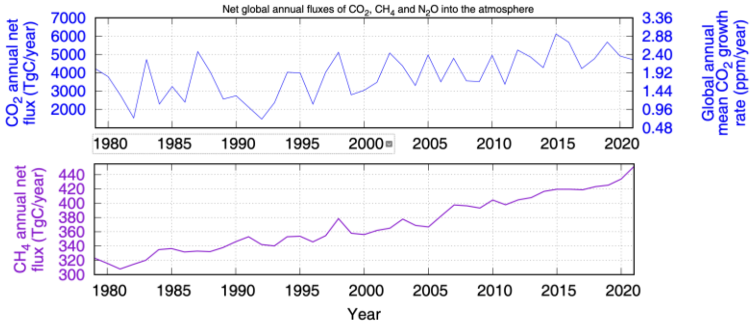


Reuter et al. (2020), AMT



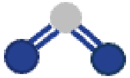
https://climate.copernicus.eu/greenhouse-gases

Atmospheric inversions to monitor surface fluxes

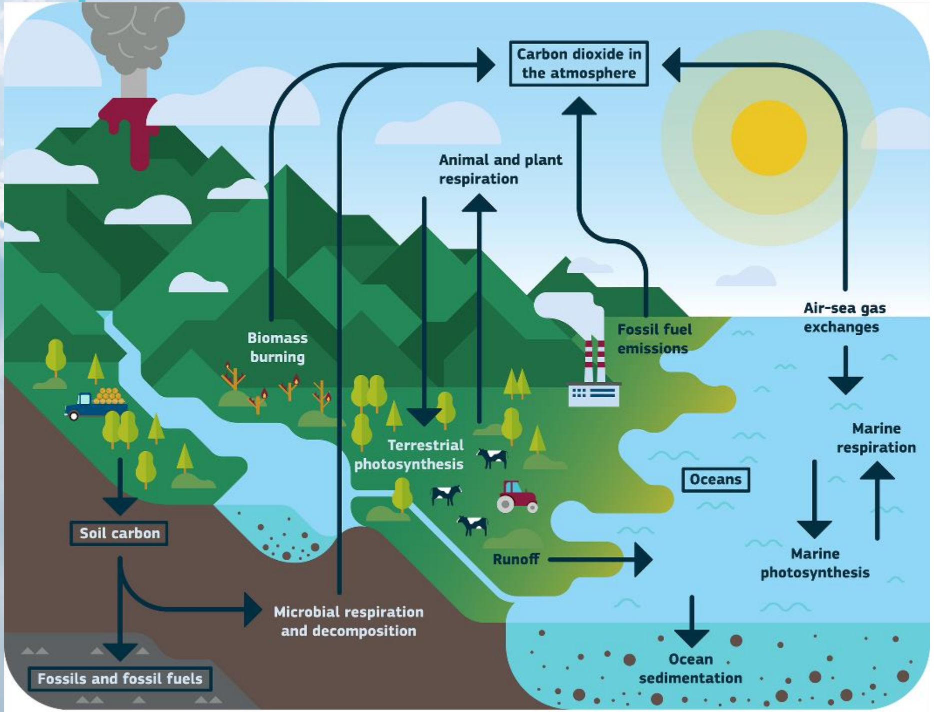


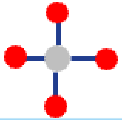
https://climate.copernicus.eu/climate-indicators/greenhouse-gas-fluxes

The carbon cycle: fluxes between different reservoirs

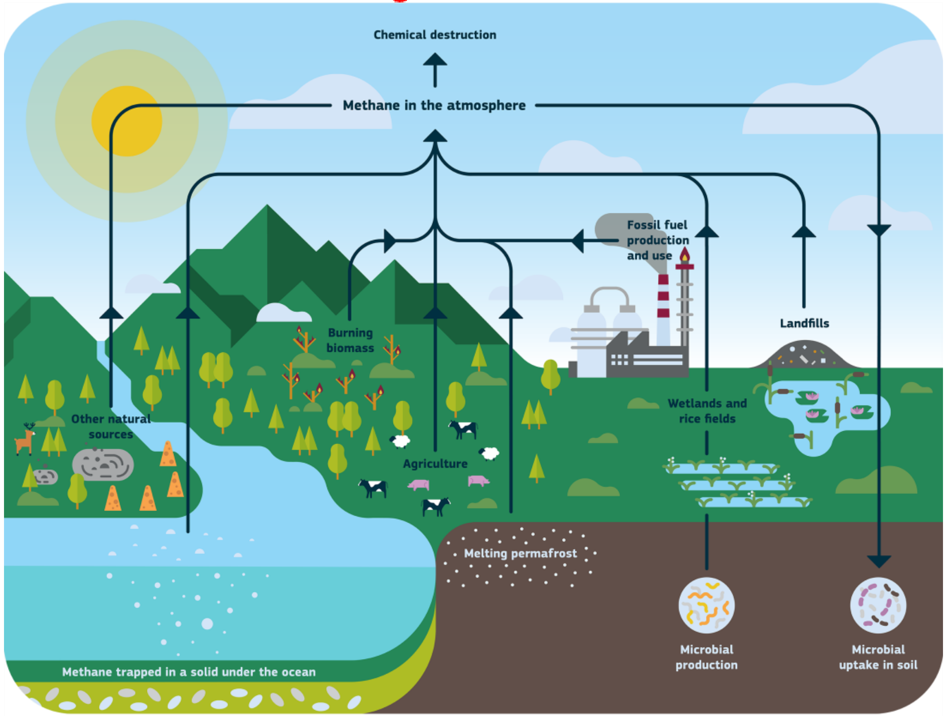


CO_2





CH_4



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Processes affecting atmospheric CH_4

Methane sources (2008-2017): 576 (550-594) TgCH_4/yr

60% anthropogenic emissions: 366 (349-393) Tg CH_4/yr
- ☐ Agriculture and waste: 217 (207-240)
- ☐ Fossil fuels production and use: 111 (81-131)

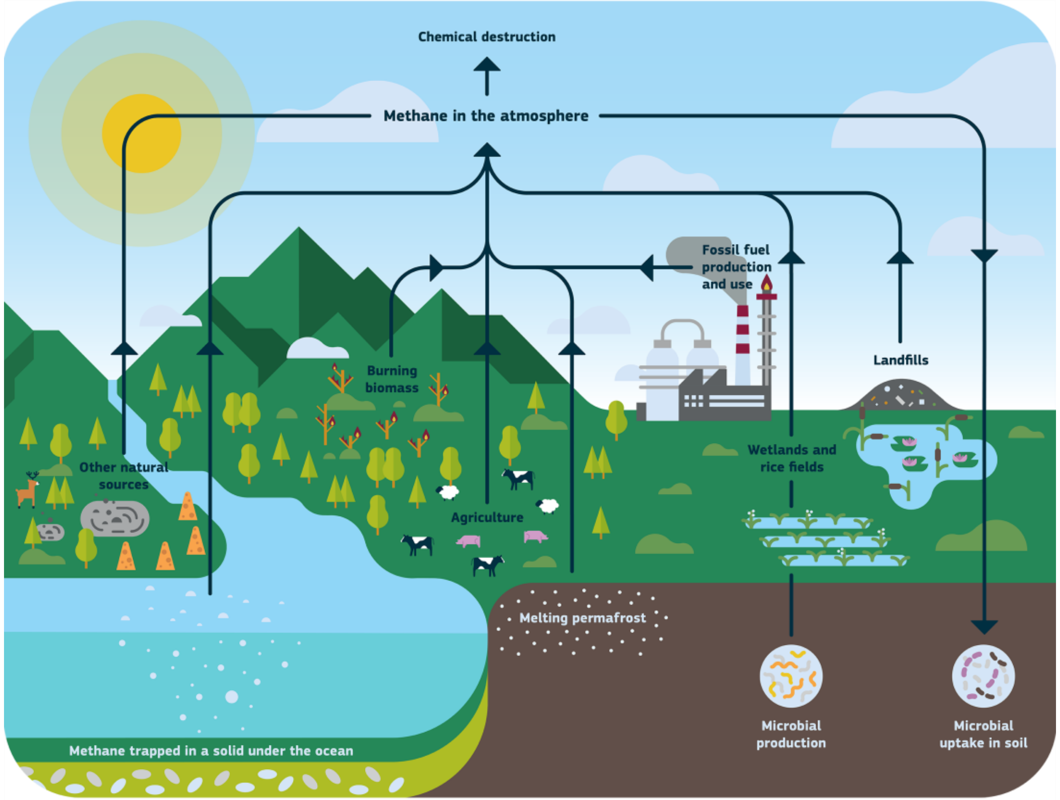
- ☐ Biomass and biofuel burning (26-40 TgCH_4/yr)

40% natural fluxes: 230 Tg CH_4/yr
- ☐ Wetlands: 181 (159-200)
- ☐ Other natural emissions (inland waters, geological, wild animals, termites, permafrost, vegetation): 37 (21-50)

Methane sinks (2008-2017): 556 (501-574) TgCH_4/yr
- Chemical destruction in atmosphere
- Soil sink
- ➢ **CH4 lifetime of ~ 10 years.**

Atmospheric Ch4 growth rate: +18.2 (17.2-19.0) TgCH_4/yr

https://www.globalcarbonproject.org/methanebudget
Sanois et al. (2020)



EUROPEAN UNION

https://atmosphere.copernicus.eu/ghg-services/methane-budget

Processes affecting atmospheric CO$_2$

Atmosphere
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Global CO$_2$ budget of fluxes into/from atmosphere (2012-2021)

Sources = Sinks

35.2 GtCO$_2$/yr
89%

11%
4.5 GtCO$_2$/yr

19.1 GtCO$_2$/yr
48%

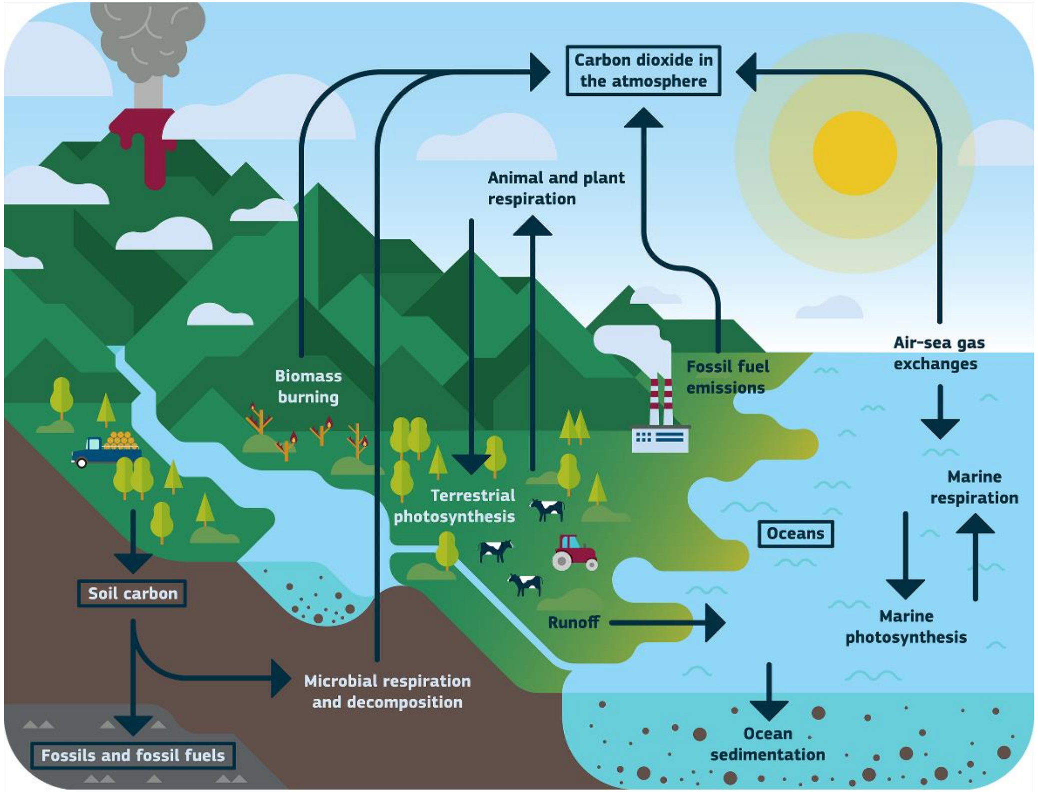
29%
11.4 GtCO$_2$/yr

26%
10.5 GtCO$_2$/yr

Budget Imbalance:
3%
-1.0 GtCO$_2$/yr

(the difference between estimated sources & sinks)

Source: [Friedlingstein et al 2022](); [Global Carbon Project 2022]()

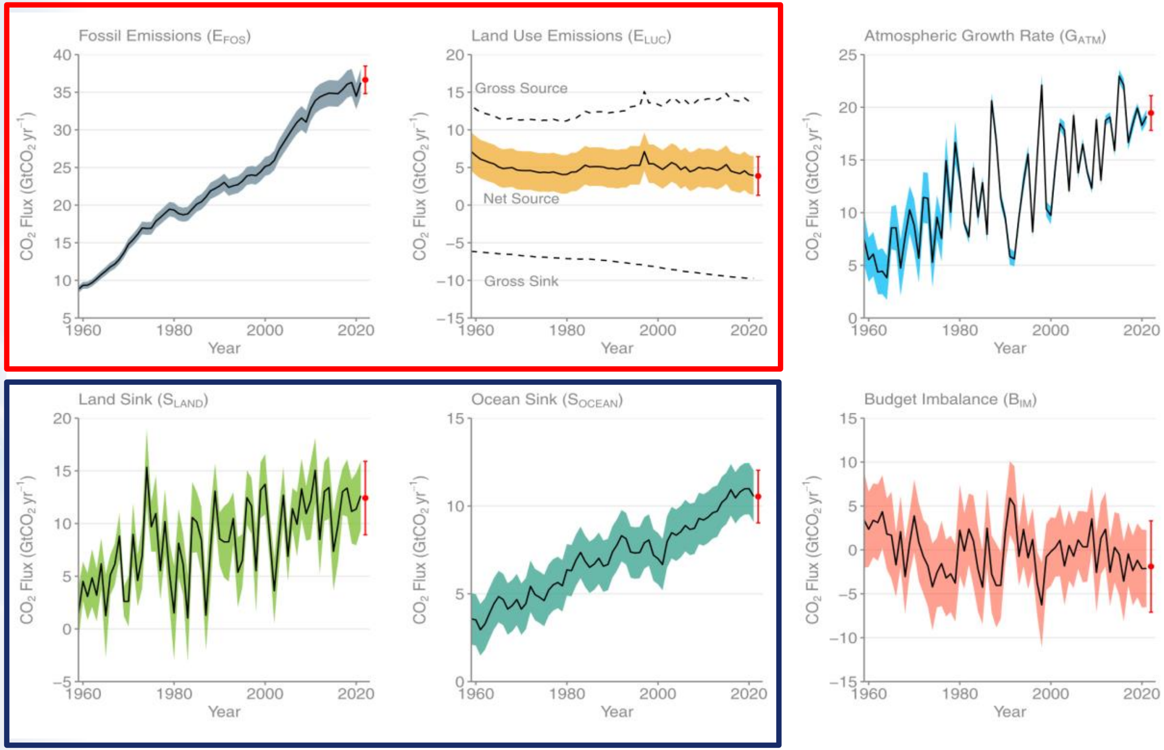


EUROPEAN UNION
Copernicus
IMPLEMENTED BY ECMWF

https://atmosphere.copernicus.eu/ghg-services/carbon-cycle

Changes in the global CO_2 budget over time

The sinks have continued to grow with increasing emissions, but climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere



The budget imbalance is the total emissions minus the estimated growth in the atmosphere, land and ocean. It reflects the limits of our understanding of the carbon cycle.

Source: Friedlingstein et al 2022; Global Carbon Project 2022

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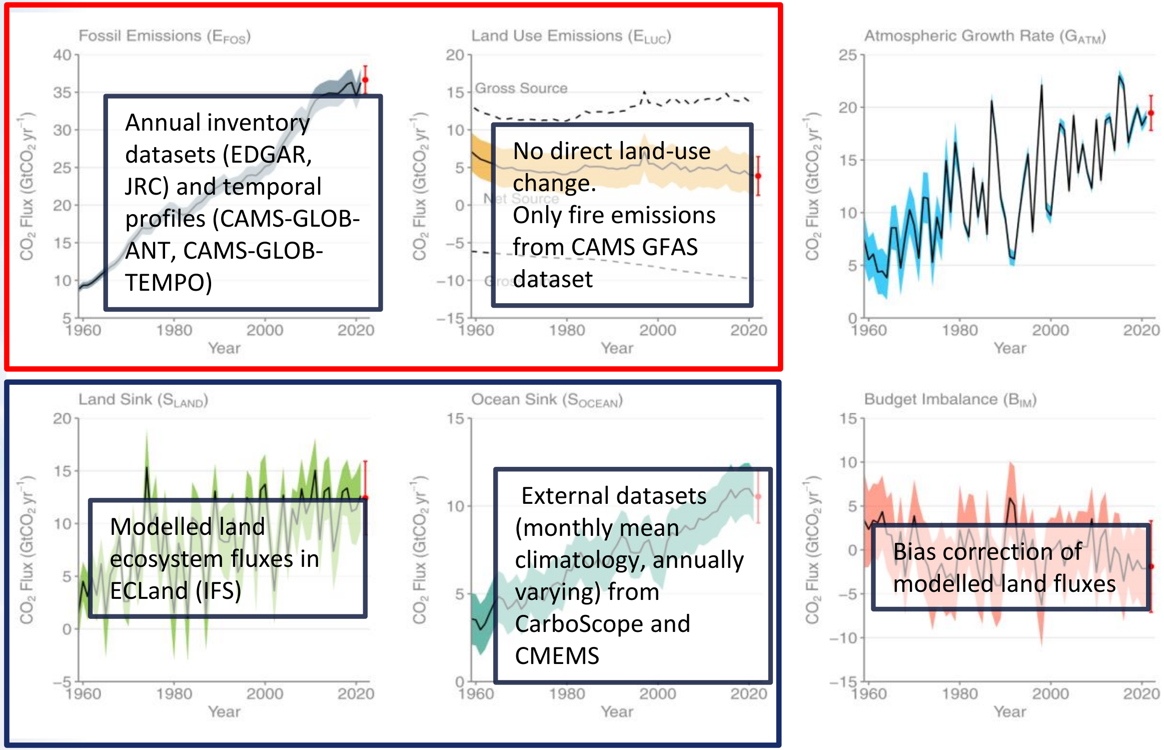
Model representation of CO$_2$ fluxes (boundary forcing)

A mix of prescribed and modelled fluxes are used as boundary conditions in IFS CAMS model



Annual inventory datasets (EDGAR, JRC) and temporal profiles (CAMS-GLOB-ANT, CAMS-GLOB-TEMPO)

No direct land-use change.
Only fire emissions from CAMS GFAS dataset

Modelled land ecosystem fluxes in ECLand (IFS)

External datasets (monthly mean climatology, annually varying) from CarboScope and CMEMS

Bias correction of modelled land fluxes

Source: Friedlingstein et al 2022; Global Carbon Project 2022

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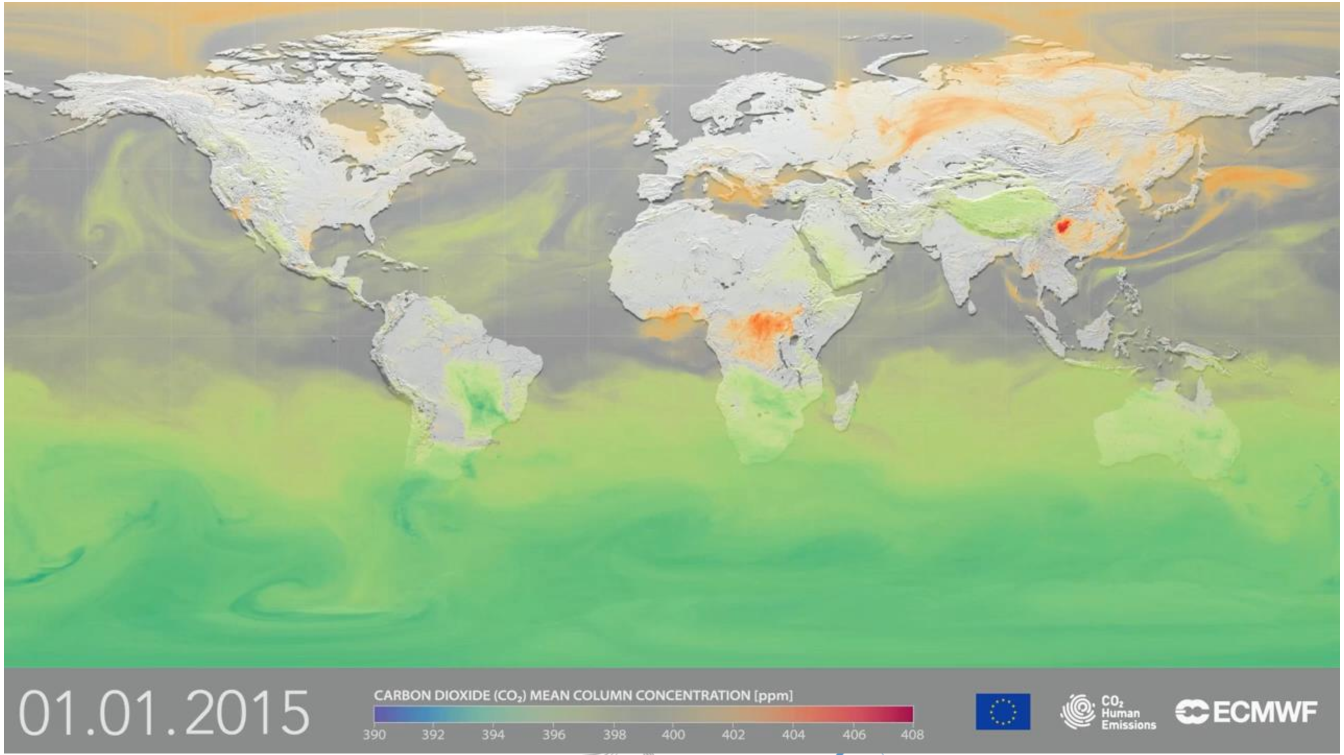
Processes represented in the Integrated Forecasting System (IFS) at ECMWF

Carbon cycle components in IFS

- Fossil fuel emissions
- Natural fluxes from land ecosystems and ocean
- Fires
- Atmospheric tracer transport with Integrated Forecasting System (IFS) at ECMWF.
- *Chemical sink of CH4 from a climatology*
- *Chemical production of CO_2 by CO oxidation not yet included*

One year simulation of atmospheric column-mean CO_2 molar fraction (XCO_2) [ppm]



Carbon dioxide nature run for 2015, created as part of the Carbon Dioxide Human Emissions (CHE) project. Credit: ECMWF.
CHE nature run, Agusti-Panareda et al. (2022, Sci. Data)

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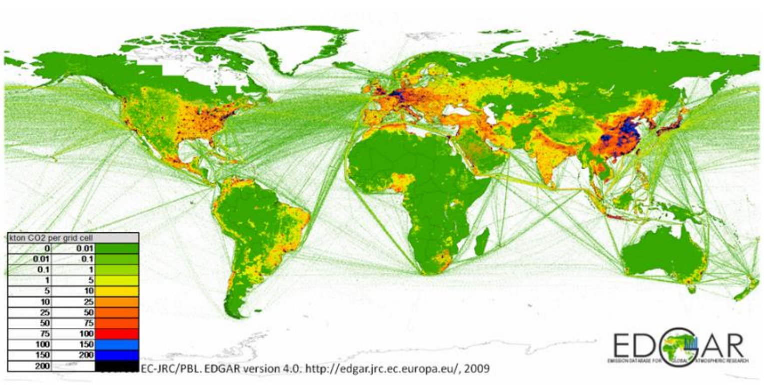
Monitoring

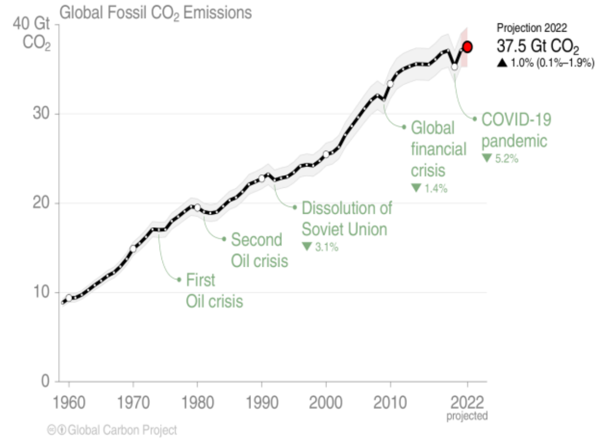
Fossil fuel emissions

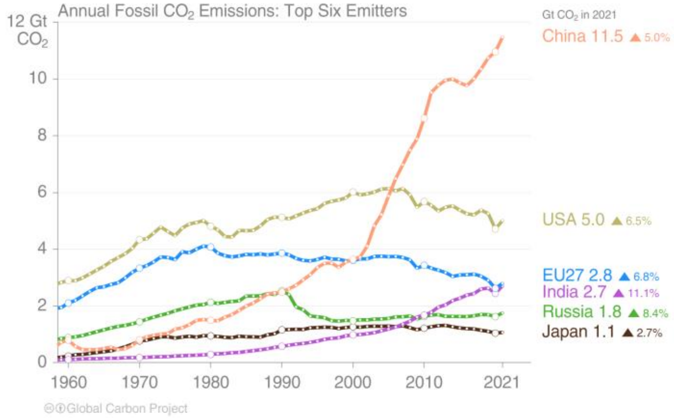
Global fossil CO_2 emissions from inventories



EC-JRC/PBL. EDGAR version 4.0. http://edgar.jrc.ec.europa.eu/, 2009

Global fossil CO_2 emissions have risen steadily over the last decades





Some challenges in representing FF fuel emissions in NWP model

- Fossil fuel emissions in near-real time
- Point sources with different injection heights
- Very high-resolution requirements
- High temporal variability (e.g. energy production, traffic, CH_4 leaks)

Source: Friedlingstein et al 2022; Global Carbon Project 2022

CO_2 exchange between the land biosphere and atmosphere

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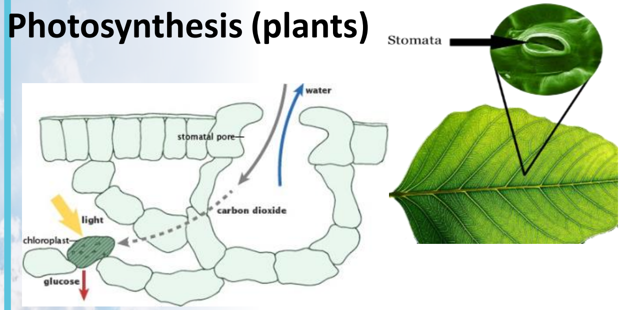
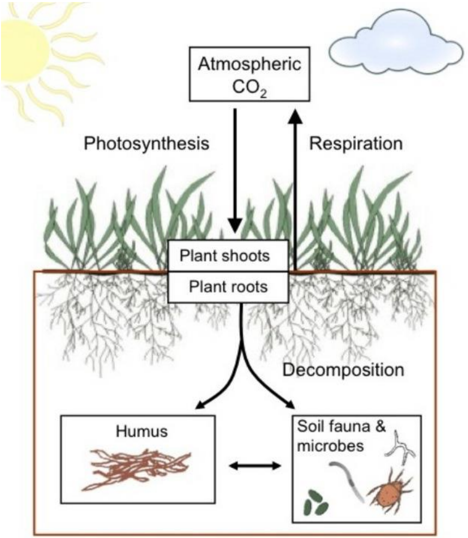
Net Ecosystem Exchange (NEE)

Atmospheric CO_2 sink

Photosynthesis (plants)



$CO_2 + H_2O + \text{energy} \rightarrow CH_2O + O_2$



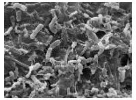
Ontl, T. A. & Schulte, L. A. (2012)

Atmospheric CO_2 source

Respiration (plants, animals) + decomposition of organic carbon in soil by microbes

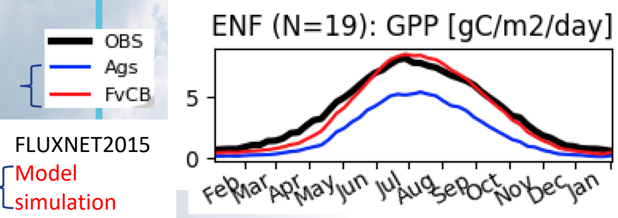
$CH_2O + O_2 \longrightarrow CO_2 + H_2O + \text{energy}$

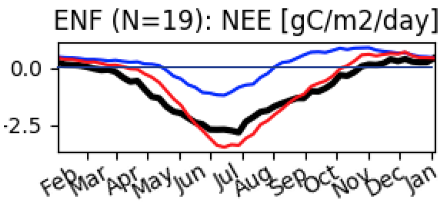
$CH_2O \longrightarrow CH_4 + \text{energy}$



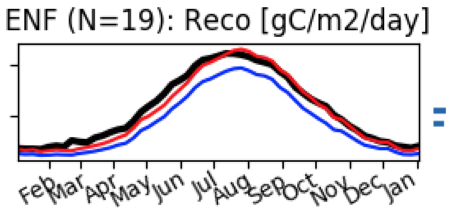
in anoxic conditions

Gross Primary Production (GPP)





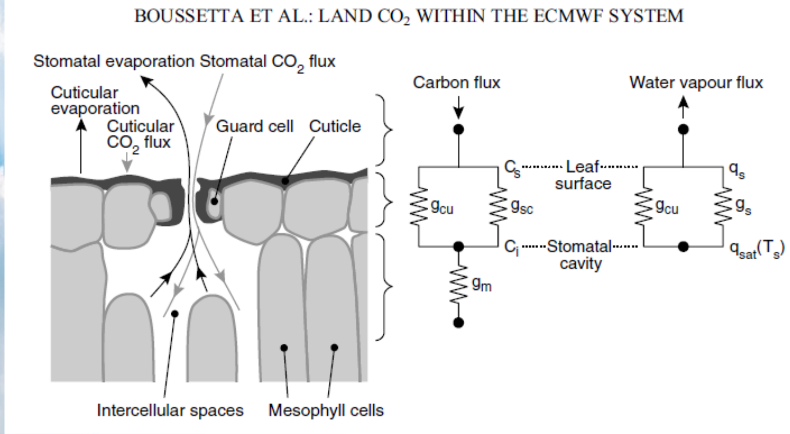
Ecosystem Respiration (Reco)



Modelling Net Ecosystem Exchange (NEE) CO_2 flux in the IFS

Photosynthesis

A-gs (Jacobs et al. 1996) & Farquhar, von Cammaer and Berry (1991)



$$r_s = \frac{1}{g_s}$$

$$g_s = \frac{A_n}{(C_s - C_i)}$$

$$A_n = min(A_c, A_j)$$

Ecosystem Respiration

Boussetta et al. (2013)

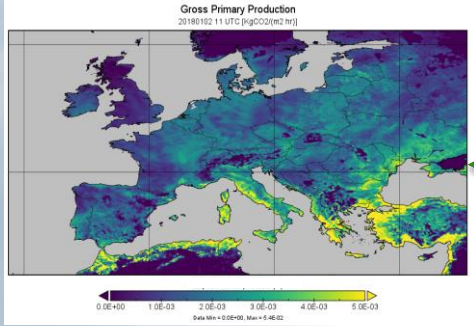
$$R_{\text{soilstr}} = R_0(25)\,Q_{10\text{Ro}}^{\left(\frac{T_{\text{soil}}-25}{10}\right)}\,f_{\text{sm}}\,f_{\text{sn}}$$

Reference respiration

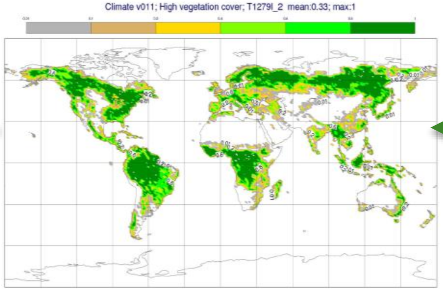
soil moisture

snow cover

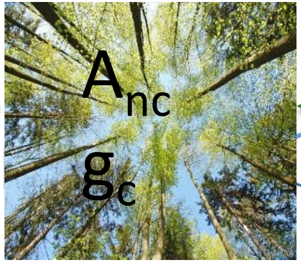
Environmental factors:
light, CO_2, temperature, humidity, soil moisture



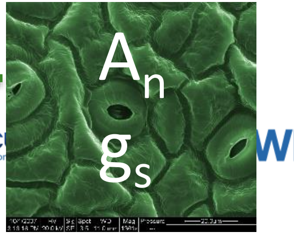
Upscaling to model gridpoint with vegetation dominant type/cover



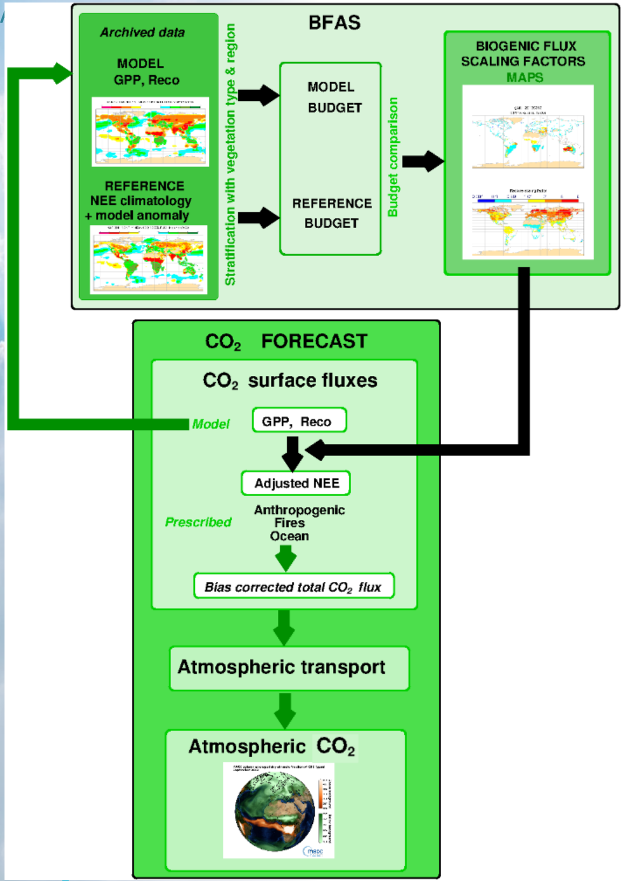
Upscaling to canopy with LAI



Photosynthesis at leaf scale



Biogenic Flux Adjustment Scheme (BFAS)



BFAS

Archived data

MODEL
GPP, Reco

REFERENCE
NEE climatology
+ model anomaly

Stratification with vegetation type & region

MODEL BUDGET

REFERENCE BUDGET

Budget comparison

BIOGENIC FLUX SCALING FACTORS
MAPS

CO_2 FORECAST

CO_2 surface fluxes

Model GPP, Reco

Adjusted NEE

Prescribed Anthropogenic
Fires
Ocean

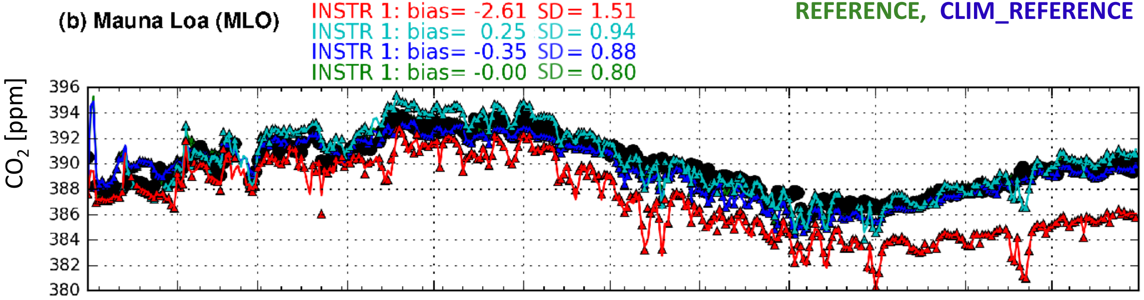
Bias corrected total CO_2 flux

Atmospheric transport

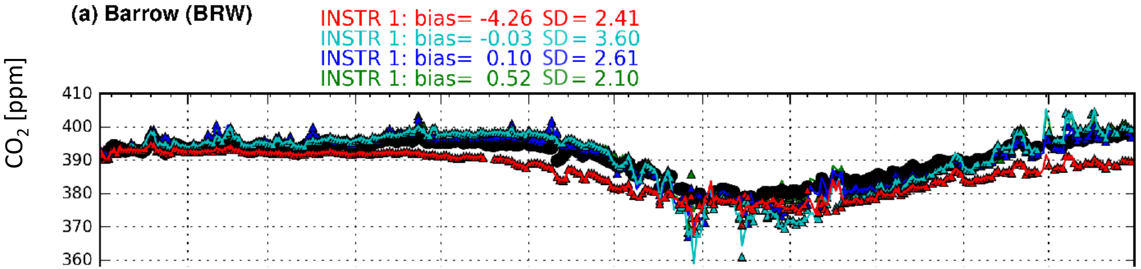
Atmospheric CO_2

Bias correction of Net Ecosystem Exchange

OBS
CHTESSEL (ECLand)
With BFAS correction
REFERENCE, CLIM_REFERENCE



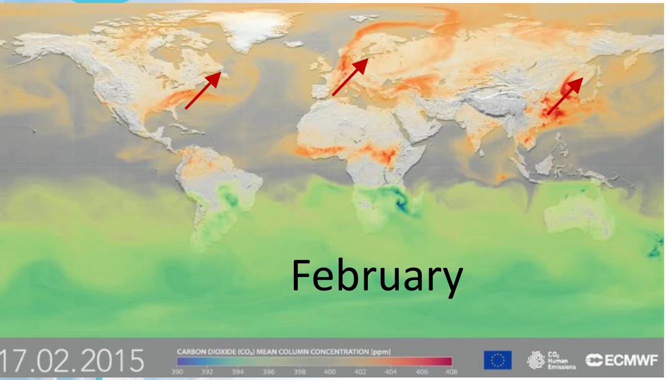
CO_2 (ppm) OBSERVATIONS

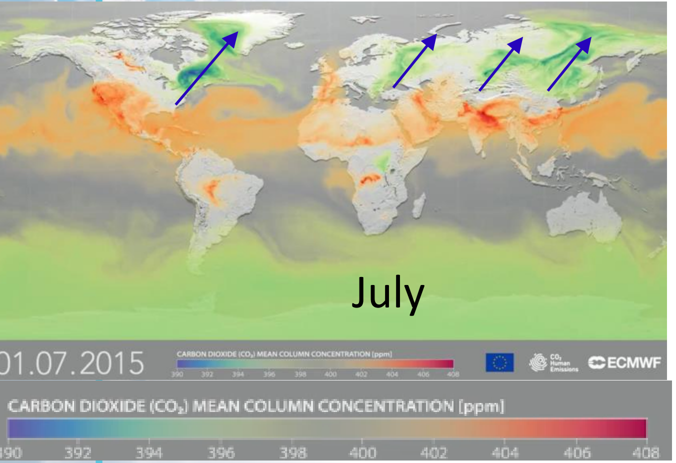


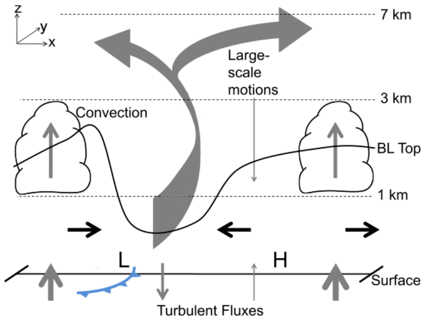
Agusti-Panareda et al. (ACP, 2016)

Atmospheric tracer transport

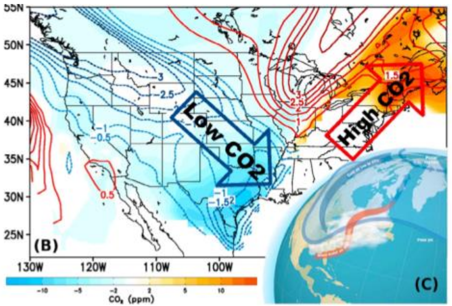
Atmospheric transport by weather systems bring high CO_2 from lower latitudes to high latitudes in the winter and low CO_2 in the summer



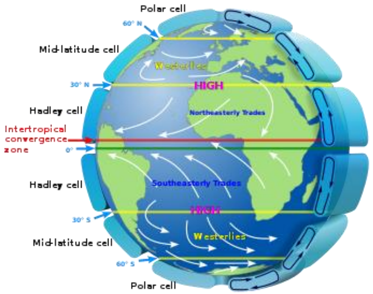




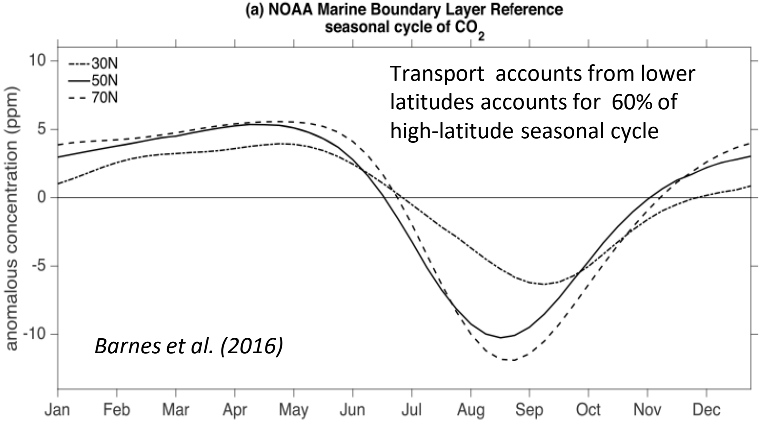
From Boutle et al. (2010)



Parazoo et al. (2011)



https://en.wikipedia.org/wiki/Atmospheric_circulation



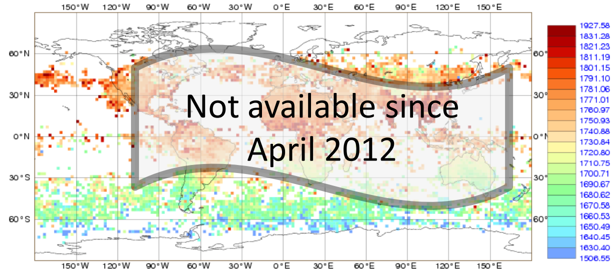
Transport accounts from lower latitudes accounts for 60% of high-latitude seasonal cycle

Barnes et al. (2016)

Atmosphere Monitoring

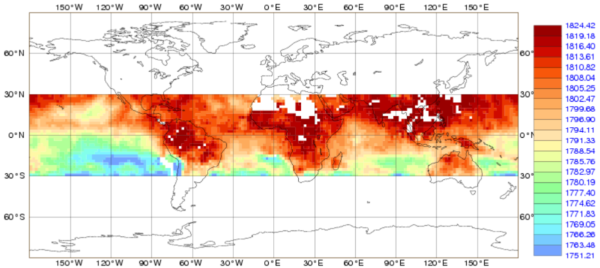
Assimilation of observations

ENVISAT/SCIAMACHY
CO_2 and CH_4 Total column

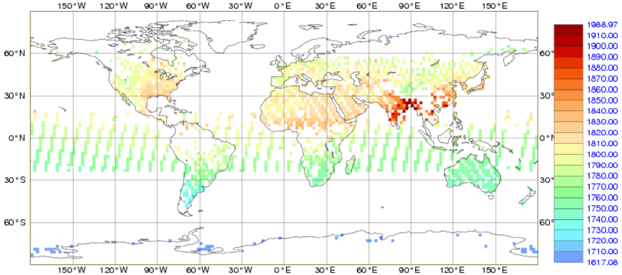


Not available since April 2012

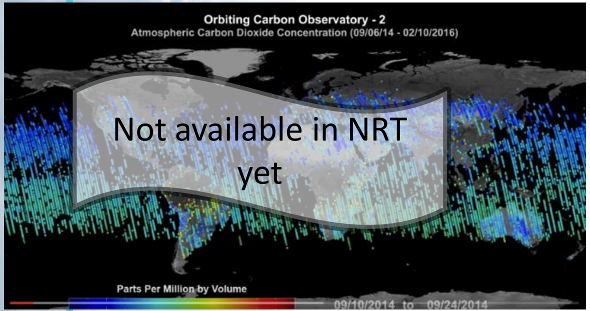
METOP/IASI CO_2 and CH_4
Middle troposphere



GOSAT/TANSO CO_2 and CH_4
Total column

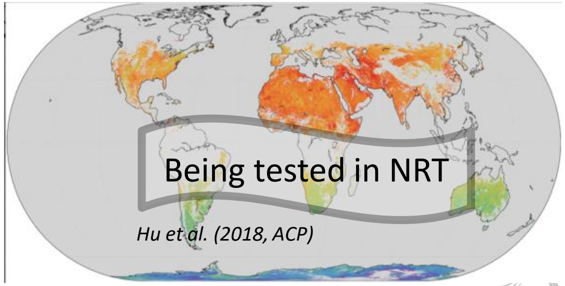


OCO-2 CO_2
Total column



Not available in NRT yet

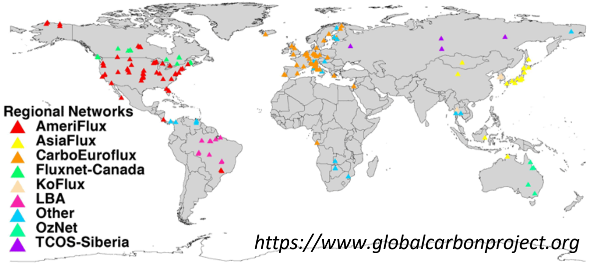
S5-P/TROPOMI CH_4
Total column



Being tested in NRT

Hu et al. (2018, ACP)

Eddy Covariance fluxes **FLUXNET** NEE, GPP, R_{eco}
Used to calibrate vegetation model parameters

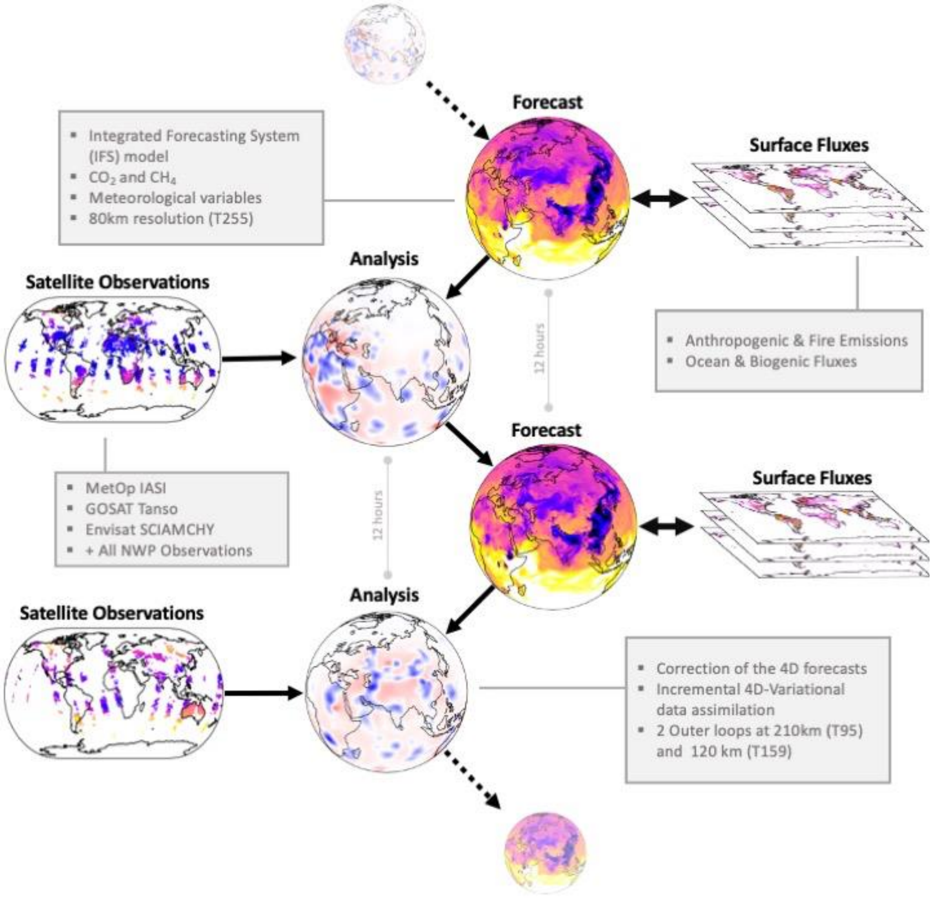


https://www.globalcarbonproject.org

European Commission | Copernicus Europe's eyes on Earth ECMWF

SRON Netherlands Institute for Space Research Universität Bremen LMD

CAMS IFS CO_2 and CH_4 reanalysis (egg4)

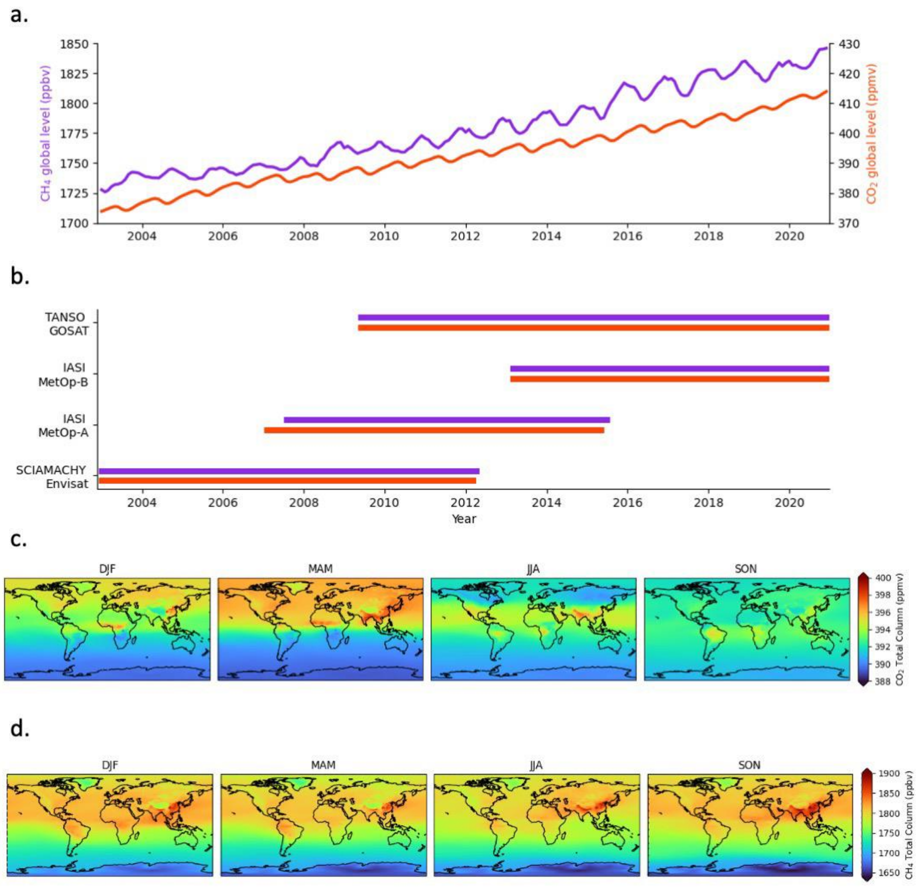


- Integrated Forecasting System (IFS) model
- CO_2 and CH_4
- Meteorological variables
- 80km resolution (T255)

- Anthropogenic & Fire Emissions
- Ocean & Biogenic Fluxes

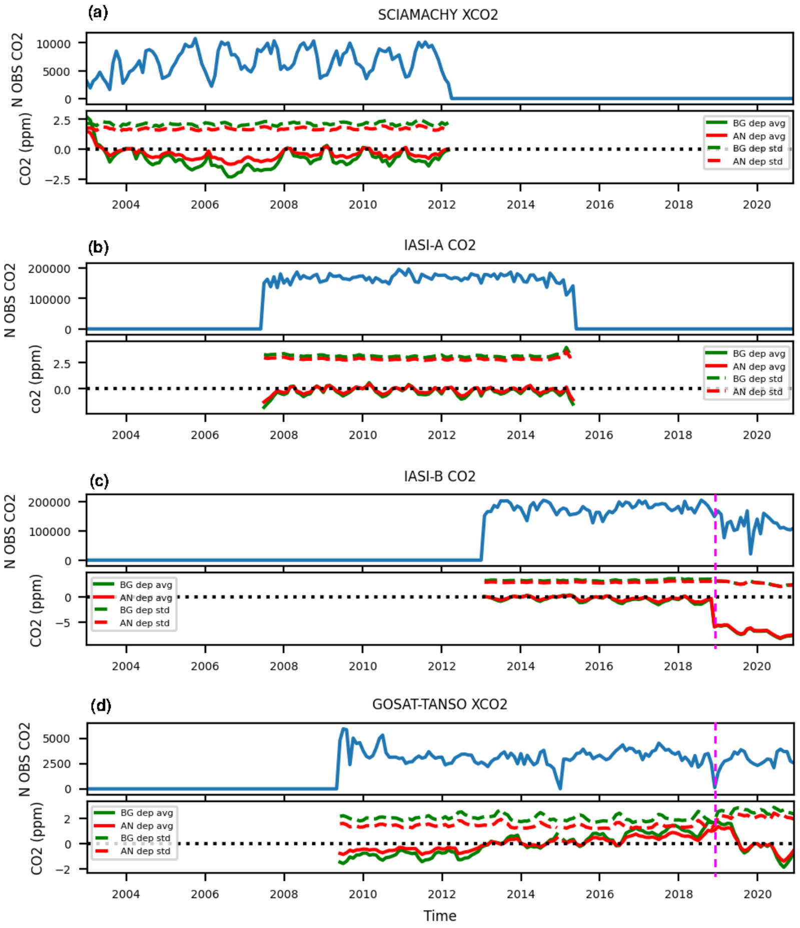
- MetOp IASI
- GOSAT Tanso
- Envisat SCIAMCHY
- + All NWP Observations

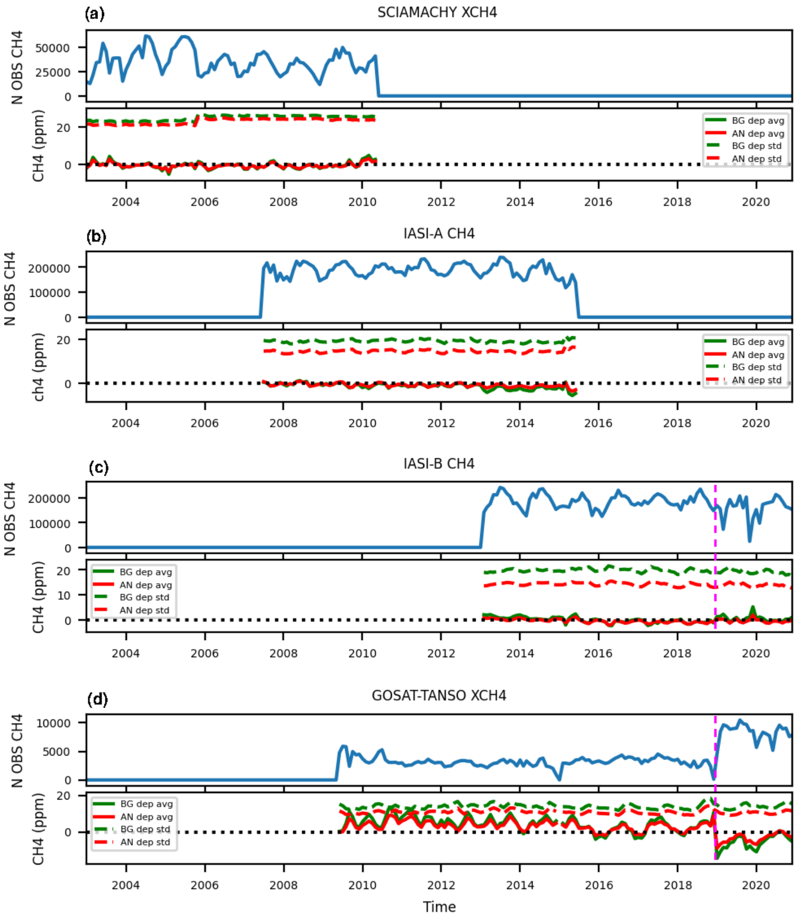
- Correction of the 4D forecasts
- Incremental 4D-Variational data assimilation
- 2 Outer loops at 210km (T95) and 120 km (T159)



CAMS GHG reanalysis data available from Copernicus Atmosphere Data Store (ADS) https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-ghg-reanalysis-egg4

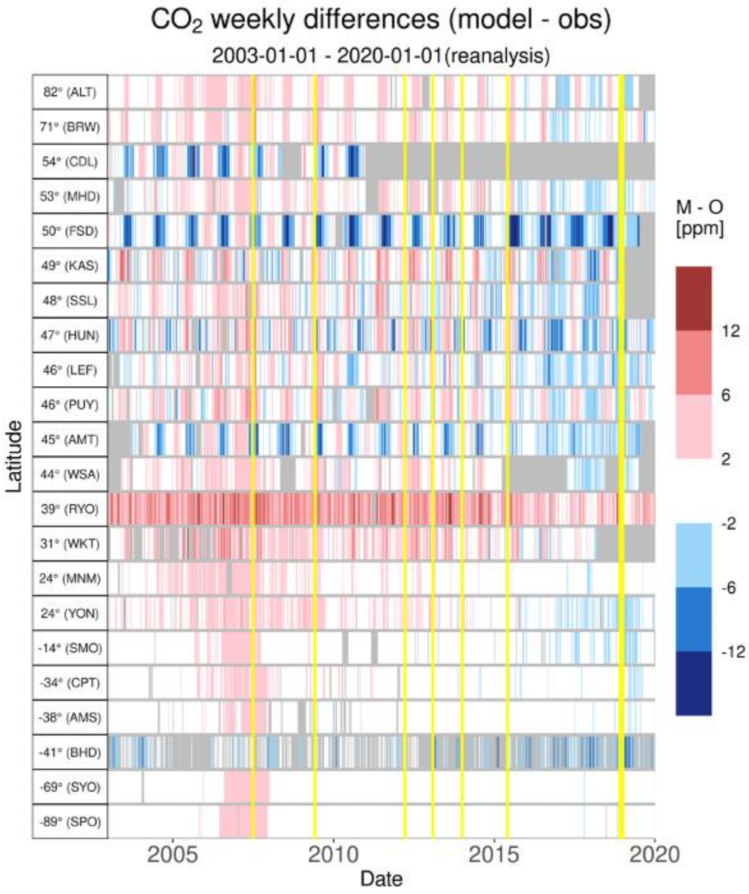
Monitoring departures in CAMS IFS CO_2 and CH_4 reanalysis (egg4)

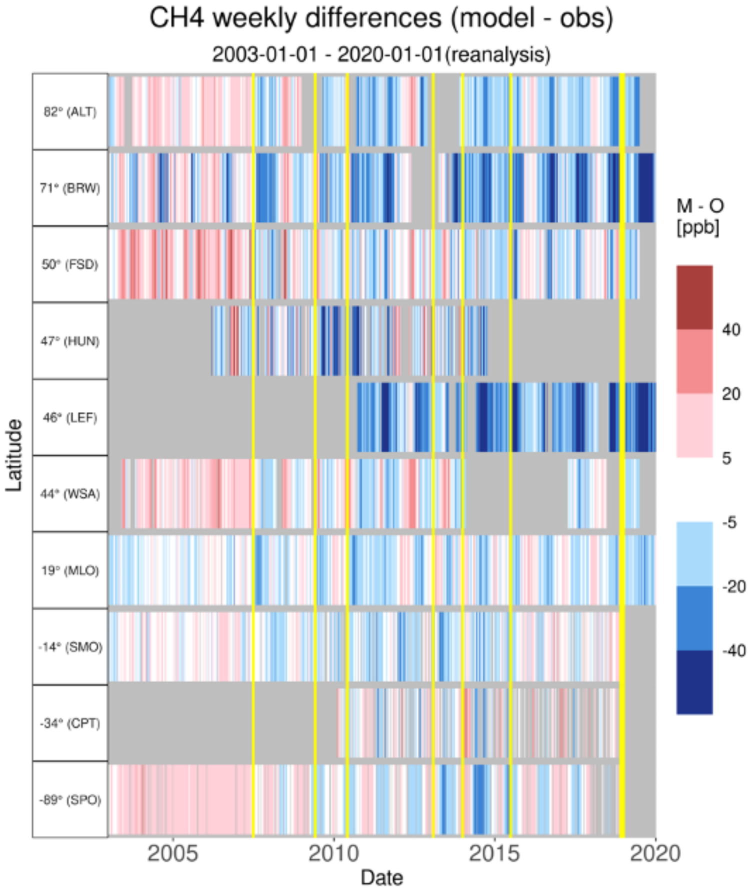




Atmosphere Monitoring

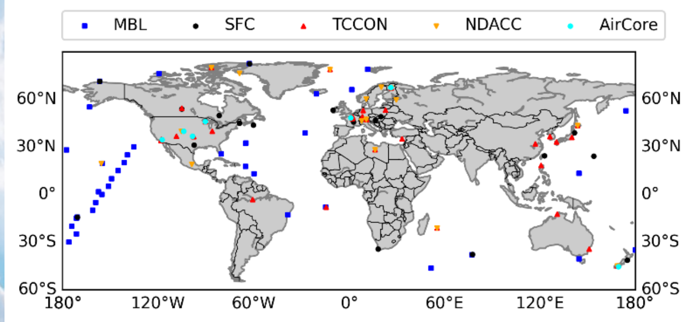
Evaluation of CAMS IFS CO_2 and CH_4 reanalysis (egg4)



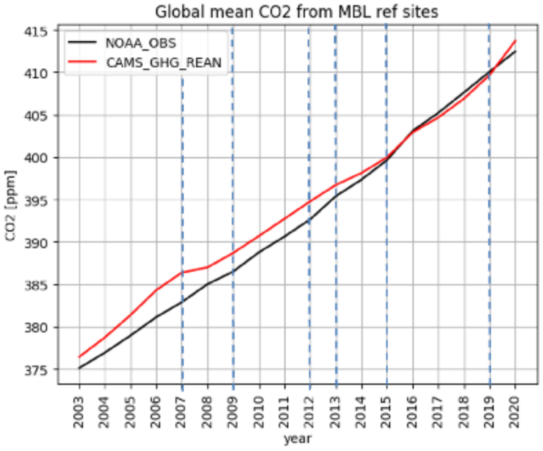


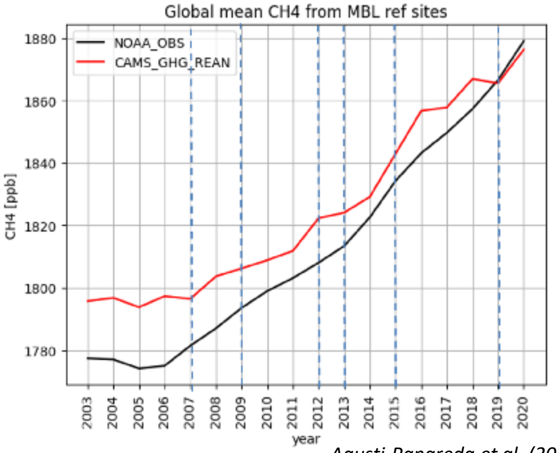
Evaluation of CAMS IFS CO_2 and CH_4 reanalysis (egg4)

Atmosphere
Monitoring



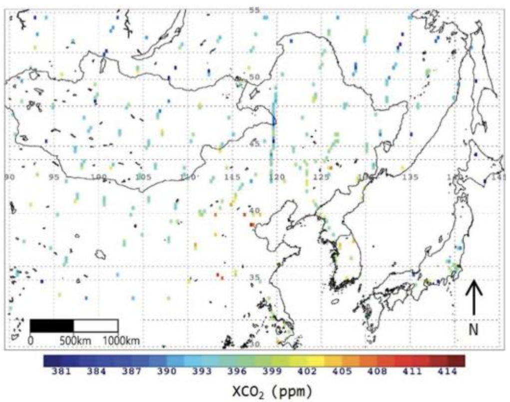
- The global trend in the CAMS IFS re-analysis at Marine Boundary Layer sites (MBL) is sensitive to changes in observing system
- Issues constraining global mass with current observing system and 12-hour data assimilation window with sparse observations of CO_2 and CH_4

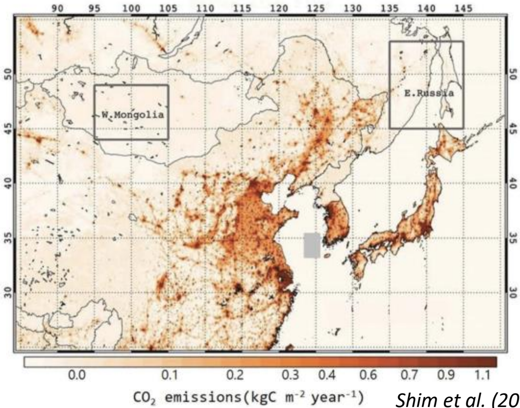




Agusti-Panareda et al. (2023)

Example: Spatial coverage of GOSAT XCO_2 and CO2 emissions in NE Asia (February)





Shim et al. (2018)

Atmosphere
Monitoring

Challenges and plans for future CAMS CO_2 and CH_4 reanalyses

Challenges faced in current CAMS CO_2 and CH_4 re-analyses:

- Presence of systematic errors in satellite observations, emissions/surface fluxes, CH_4 chemical sinks and initial conditions
- Sparse and changing observing system

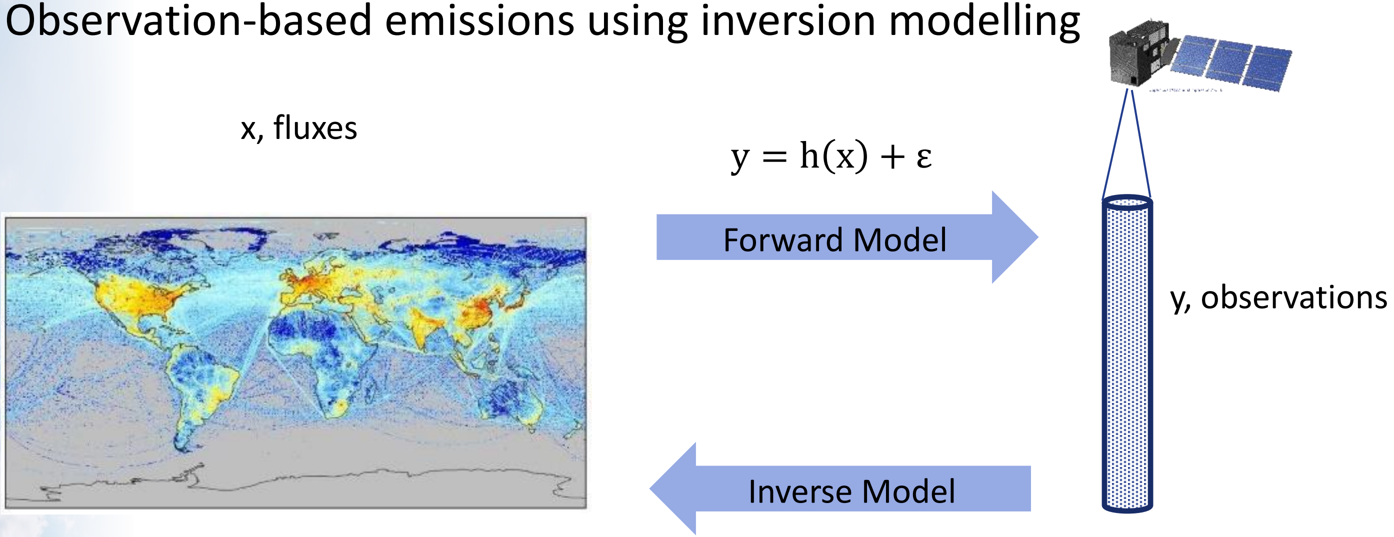
Plans/requirements for next CAMS CO_2 and CH_4 re-analyses:

- Improvement of emission dataset in near-real time and natural flux processes in model
- Use CH4 chemical sink from CAMS air quality analysis (IFS-CB05-BASCOE)
- High spatial resolution
- Flux inversion capability (CHE, CoCO2, CORSO projects) for emission monitoring will also lead to a reduction of major sources of model biases

European Commission | Copernicus Europe's eyes on Earth ECMWF

Developing the inversion system to estimate surface fluxes in the IFS

Observation-based emissions using inversion modelling



x, fluxes

$y = h(x) + \varepsilon$

Forward Model

y, observations

Inverse Model

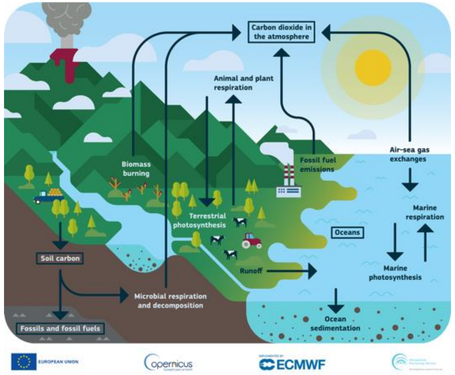
$$J(\mathbf{x},\mathbf{p}) = (\mathbf{x}-\mathbf{x}_b)^T \mathbf{B}_{\mathbf{x}}^{-1}(\mathbf{x}-\mathbf{x}_b)+(\mathbf{p}-\mathbf{p}_b)^T \mathbf{B}_{\mathbf{p}}^{-1}(\mathbf{p}-\mathbf{p}_b)+(\mathbf{y}-h(\mathbf{x},\mathbf{p}))^T \mathbf{R}^{-1}(\mathbf{y}-h(\mathbf{x},\mathbf{p}))$$

state (prognostic)

parameter (e.g., emission scaling factors)

Towards monitoring CO_2 and CH_4 emissions

Prior information: forward model with emissions, natural fluxes and atmospheric chemistry and transport



CO_2 and CH_4 and other co-emitted chemical species (NOx, CO)

CO_2 Human Emissions

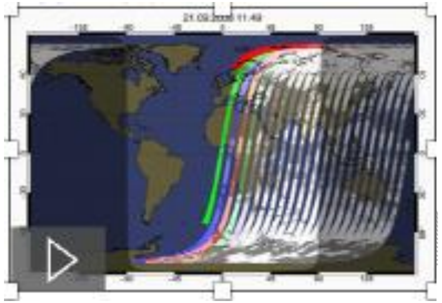
CoCO2
Prototype system for a Copernicus CO_2 service

CORSO
CO2MVS Research on Supplementary Observations

EU-funded projects

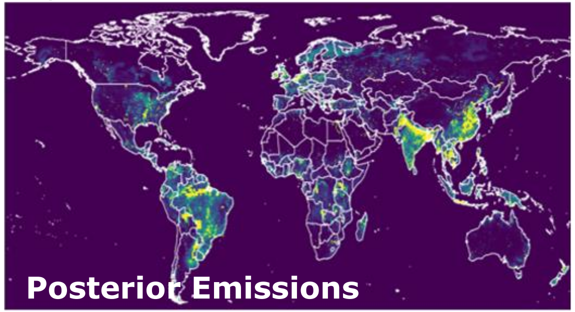
IFS

Observations: TROPOMI S5P, GOSAT, IASI, OCO-2, CO2M etc.

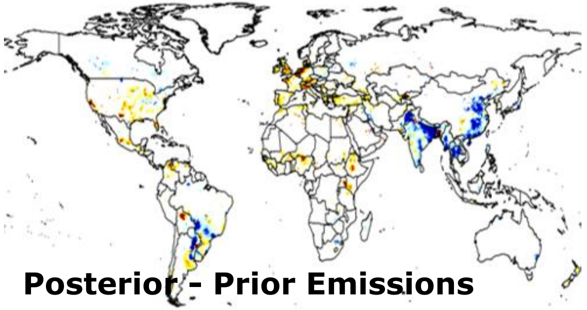


Michael Buchwitz, IUP, Bremen

Optimised Fluxes and Uncertainties



Posterior Emissions



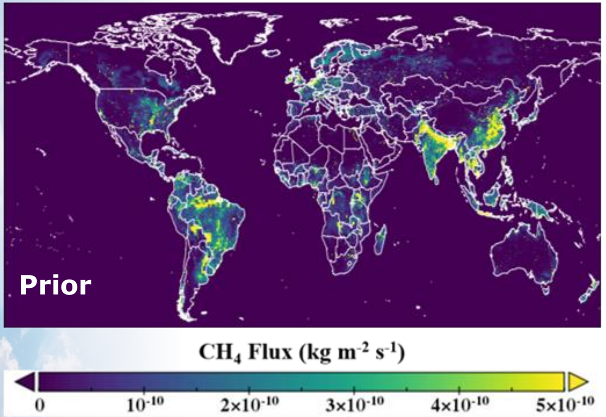
Posterior - Prior Emissions

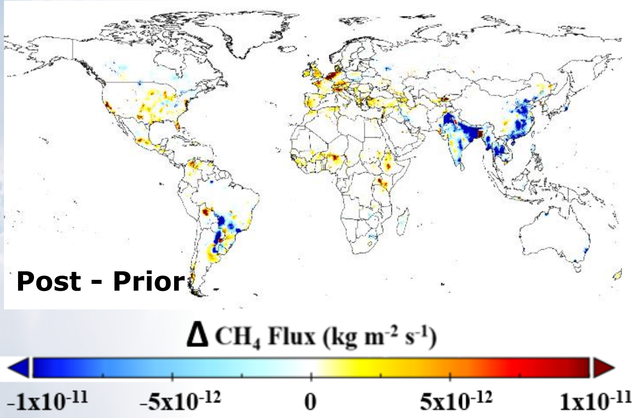
Consolidated Country/Regional Emissions for End User

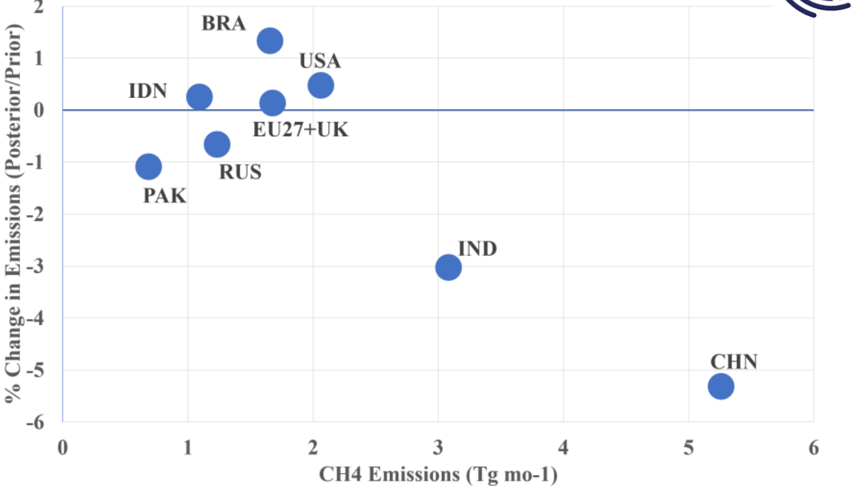
Atmosphere
Monitoring

First results from IFS flux inversion system

CoCO2
Prototype system for a Copernicus CO_2 service



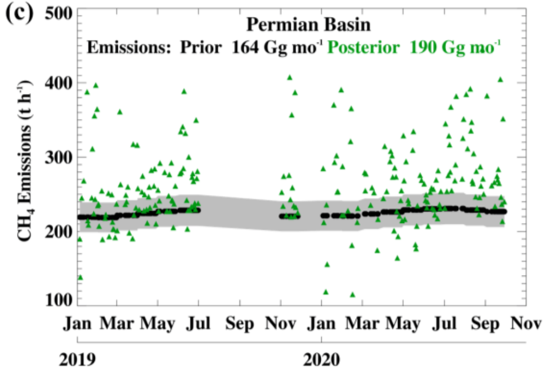




Change in emissions from prior to posterior CH_4 for Jan-Jun 2019

McNorton, Bousserez et al. (2022, ACP)

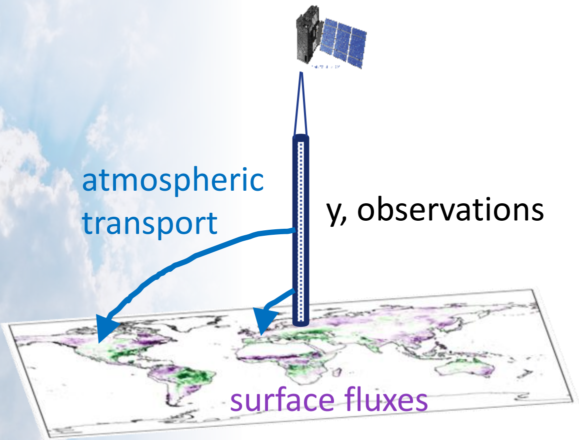
European
Commission

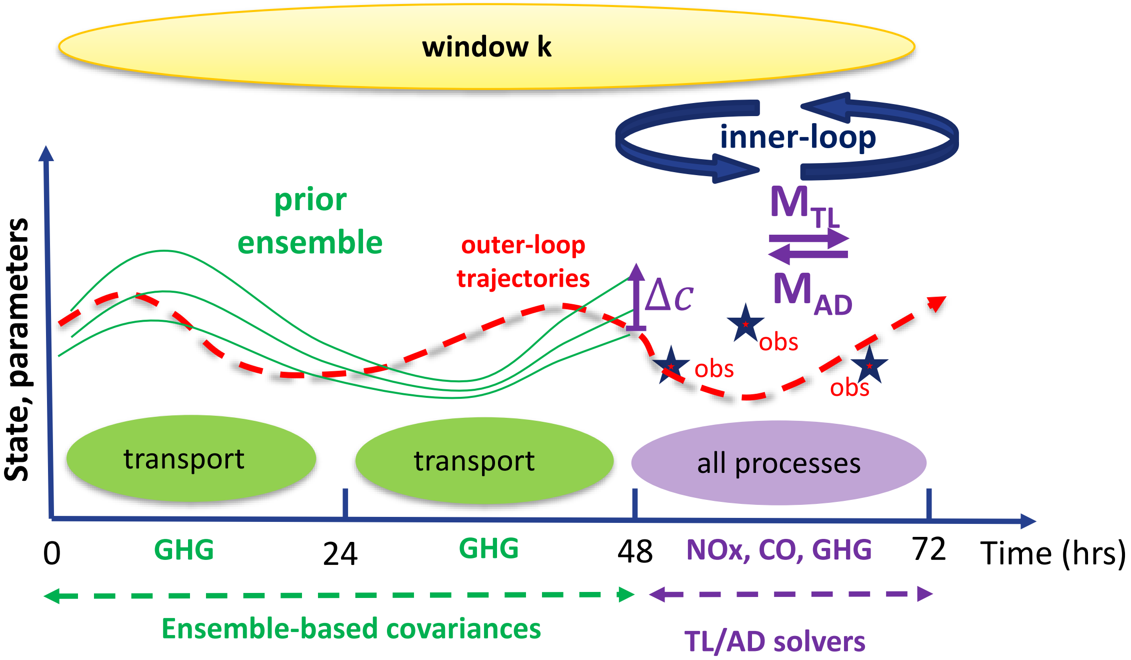


Atmosphere
Monitoring

Extended 4D-Var window for CO_2 and CH_4 inversion – Nicolas Bousserez (ECMWF)

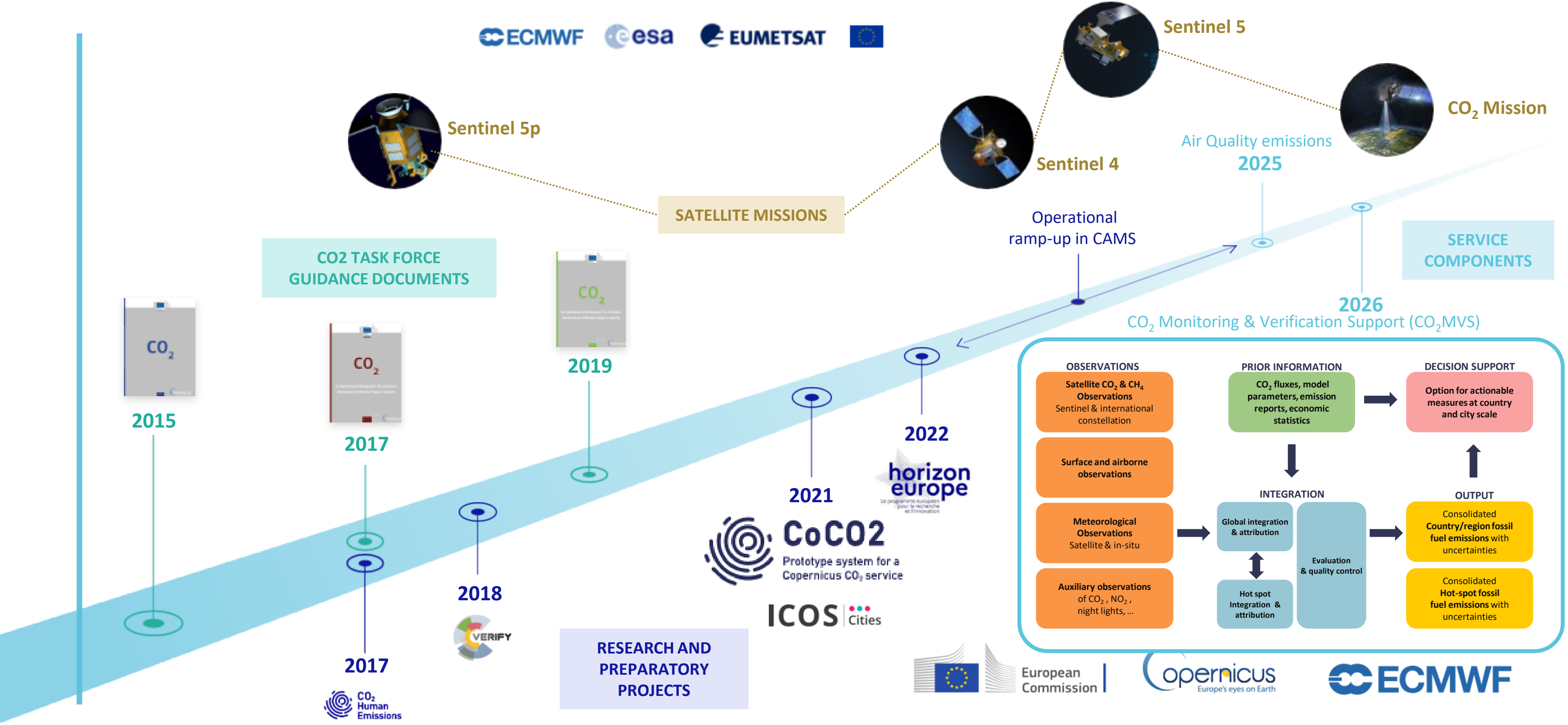
- Long data assimilation window is required to constrain the global mass and trends of CO_2 and CH_4
- Tangent-linear/adjoint models used for short-window containing current observations
- Ensemble-based covariances used for previous days
- Short-window state increment (Δc) propagated backward to update past emissions


atmospheric transport
y, observations
surface fluxes


window k
inner-loop
M_{TL}
M_{AD}
prior ensemble
outer-loop trajectories
Δc
obs
obs
obs
State, parameters
transport
transport
all processes
0
GHG
24
GHG
48
NOx, CO, GHG
72
Time (hrs)
Ensemble-based covariances
TL/AD solvers

CoCO2
Prototype system for a Copernicus CO_2 service

Timeline of CAMS Emission Services



SATELLITE MISSIONS

Sentinel 5p

Sentinel 4

Sentinel 5

CO_2 Mission

CO2 TASK FORCE
GUIDANCE DOCUMENTS

2015

2017

2019

RESEARCH AND
PREPARATORY
PROJECTS

2017

CO_2 Human Emissions

2018

VERIFY

2021

CoCO2
Prototype system for a Copernicus CO_2 service

ICOS Cities

2022

horizon europe

Operational
ramp-up in CAMS

Air Quality emissions
2025

2026
CO_2 Monitoring & Verification Support (CO_2MVS)

SERVICE
COMPONENTS

OBSERVATIONS

- **Satellite CO_2 & CH_4 Observations** Sentinel & international constellation
- **Surface and airborne observations**
- **Meteorological Observations** Satellite & in-situ
- **Auxiliary observations** of CO_2, NO_2, night lights, …

PRIOR INFORMATION

- **CO_2 fluxes, model parameters, emission reports, economic statistics**

INTEGRATION

- **Global integration & attribution**
- **Hot spot Integration & attribution**
- **Evaluation & quality control**

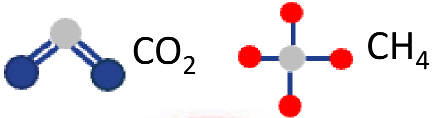
OUTPUT

- Consolidated **Country/region fossil fuel emissions** with uncertainties
- Consolidated **Hot-spot fossil fuel emissions** with uncertainties

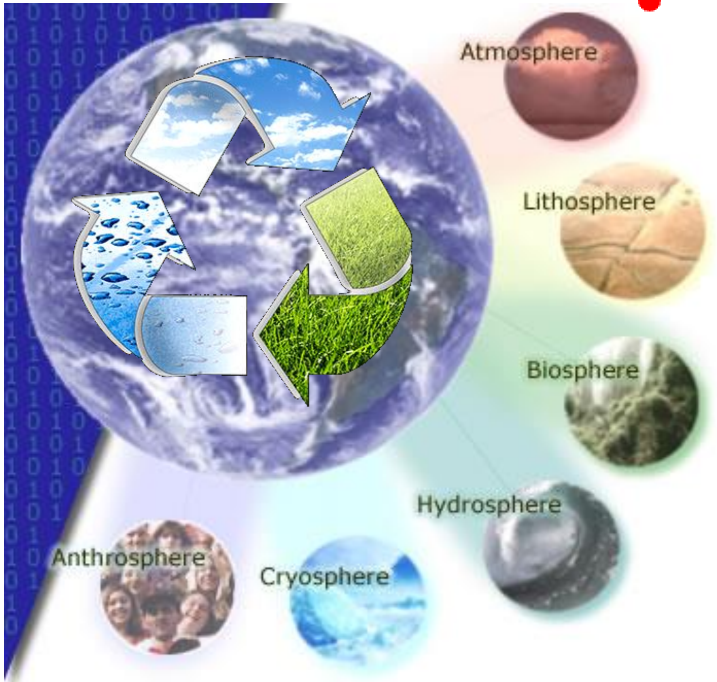
DECISION SUPPORT

- **Option for actionable measures at country and city scale**

Integrated carbon cycle in reanalyses



- What is the carbon cycle and why is it important?
- Current representation of carbon cycle in the Integrated Forecasting System at ECMWF
  - ✓ Modelling
  - ✓ Observations
- Current CAMS IFS re-analysis of CO_2 and CH_4
- The development of an inversion system in the IFS to monitor emission of CO2 and CH4 (new Copernicus Service).
- **Recent model developments and use of new observations**
- Exploring synergies between composition and NWP
- Benefits of integrating the carbon cycle in Earth System re-analysis

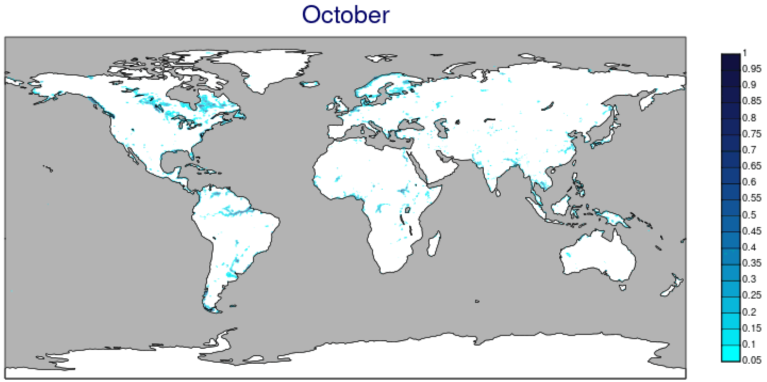


A simple CH_4 wetland model in IFS (CY49R1)

Wetland model is a simple parameterisation from CAMS41 based on
- Temperature (Q_{10} function : 2.337 and soil Temperature : T)
- A proxy for substrate (PFT dependent soil respiration : Re0)
- Wetland fraction (f_{wet} 0-1)
- Fluxes are globally scaled using a global methanogensis rate (S)

$$f_{CH_4} = S \cdot f_{wet} \cdot \mathrm{Re0} \cdot q_{10}^{\frac{T-25}{10}}$$

WETLAND FRACTION f_{wet}: GIEMSv3.1 (Pringent et al., 2007) +CAMA-Flood (Yamazaki et al., 2011)



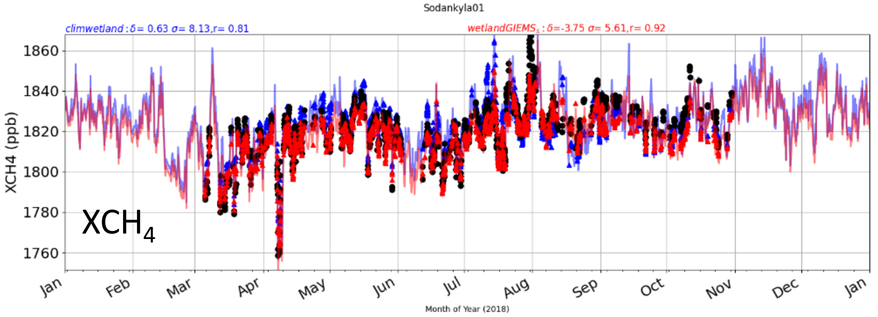
Climatology
LPJ-WHyMe
Inversion.

IFS wetland model
(GIEMS+CaMaFlood)

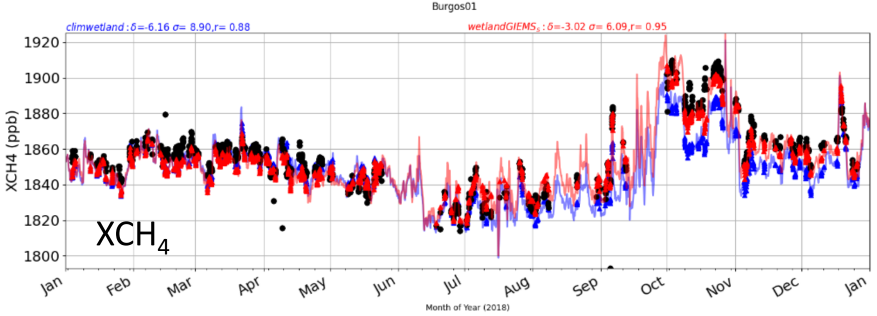
TCCON OBS

(Spanhi et al., 2011) **(Pringent et al. 2007, Yamazaki et al. 2014)**

Sodankyla (Finland) 67.37°N 26.63°E



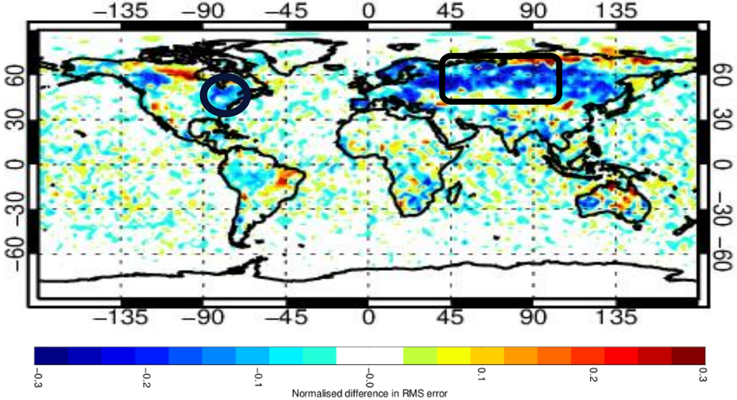
Burgos (Philippines) 18.53°N 120.65°E



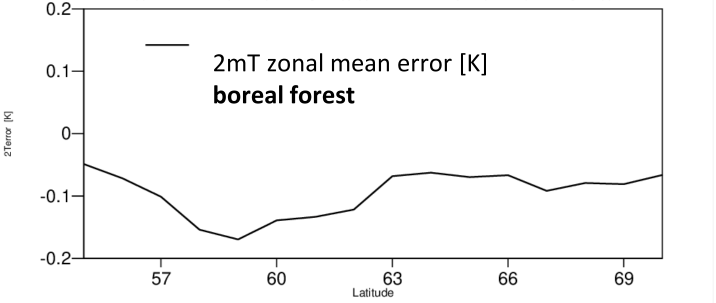
Thanks to CAMS41 (Vlad Bastrikov, Philippe Peylin, Fabienne Maignan),
Catherine Pringent, Margarita Choulga, Joe McNorton, Gianpaolo Balsamo, Souhail Boussetta

New LAI climatology in CY49R1 improves 2mT and CO_2

Change in RMSE for MAM 2m temperature fc (T+60) when using the new ESACCI LULC and new LAI climatology with oper analysis as reference



2T Total zonal mean error for EUBor_West
|(48r1_CTL(hut7)-analysis)|-|(48r1_LU_opt1(hwf1)-analysis)|

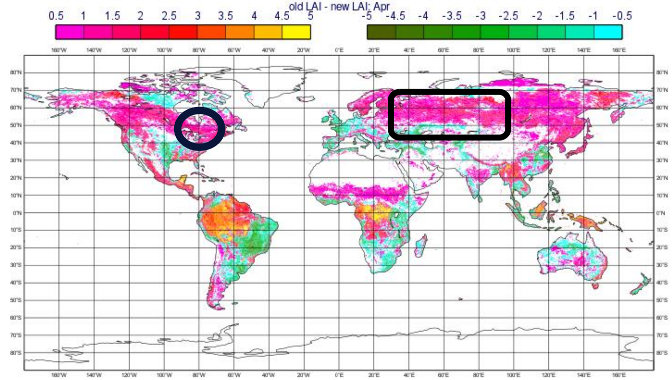


Souhail Boussetta (ECMWF)

April: Current LAI climatology (CY48R1) – New LAI climatology (CY49R1)

LAI is increased
with new climatology

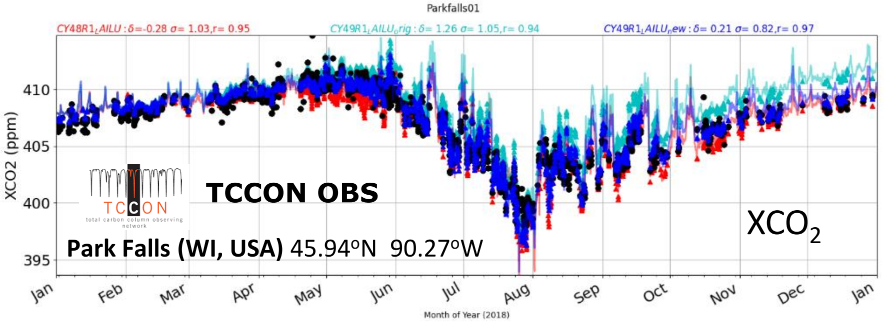
LAI is reduced
with new climatology



CY48R1
climate.v020

CY48R1
climate.v021

CY49R1
climate.v021



Coupling urban scheme in IFS with CO_2 emissions from residential heating

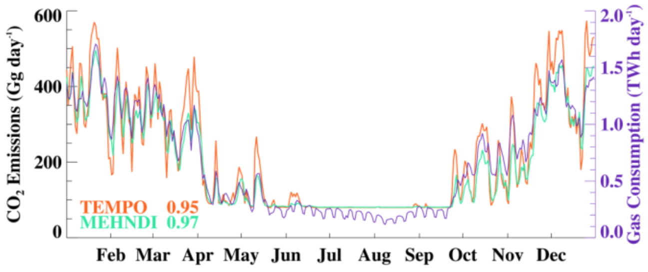
Modelling residential CO2 emissions within **urban scheme in IFS (McNorton et al., 2021, 2022)**

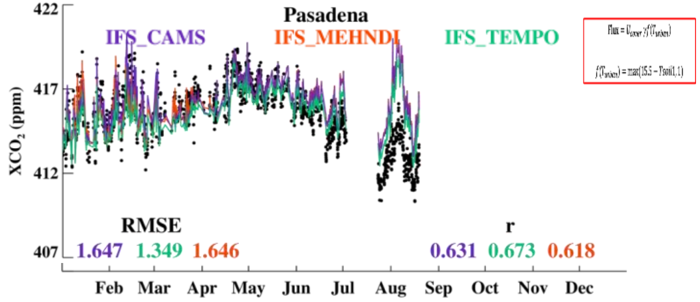
MEHNDI works by taking the annual nationally reported residential sector emissions and spatial and temporally disaggregating those using urban cover used in the IFS. At least 20% of those are assumed constant (cooking etc.) and the remaining up to 80% are derived using the top soil layer temperature in a similar way to the traditional heating degree day. A nationally constant emission factor is calculated to preserve the budget of each country.

$$\text{Flux} = U_{cover}\,\gamma f(T_{urban})$$

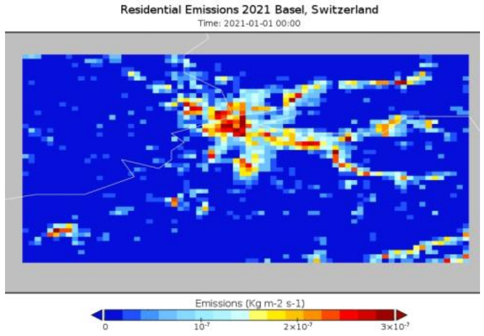
$$f(T_{urban}) = \max(15.5 - Tsoil1, 1)$$

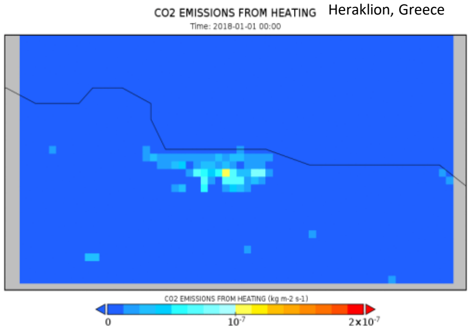
γ, is a national scaling factor based on annual residential heating.
U_{cover} is the urban cover.
$f(T_{urban})$ is the heating degree day function.





Residential emissions at 1km from MEHNDI model



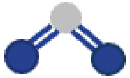


- One-way coupling between urban tile and emissions.
- Two-way coupling to include effect of heating on urban temperature.

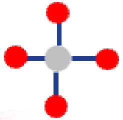
Joe McNorton (ECMWF)

Atmosphere
Monitoring

Integrated carbon cycle in reanalyses



CO_2



CH_4

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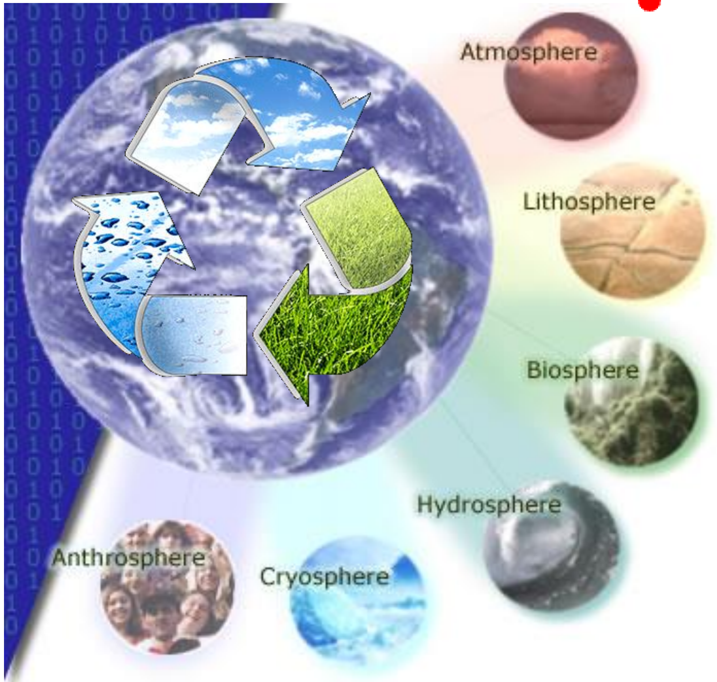


European Commission | Copernicus Europe's eyes on Earth | ECMWF

Coupling water and carbon cycles

Modelling canopy resistance: empirical vs mechanistic approaches

$$\boxed{E = \frac{\beta}{\enclose{circle}{r_c} + r_a}(q_a - q_{sat})}$$

The photosynthesis (mechanistic) approach
CTESSEL (ECLand) in IFS

$$r_c = f(r_{cc})$$

$$r_{cc} = \frac{\alpha}{A_n}(C_s - C_i)$$

- Coupling with carbon cycle:
  CO_2 fluxes in atmospheric CO_2 model
- Vegetation feedbacks.
- Carbon observations to constrain carbon and water/energy fluxes
- Complex feedbacks and uncertainty in model parameters

The Jarvis (empirical) approach
HTESSEL in IFS (operational)

$$r_{\mathrm{c}} = \frac{r_{\mathrm{S,min}}}{LAI} f_1(R_{\mathrm{s}}) f_2(\bar{\theta}) f_3(D_{\mathrm{a}})$$

- No coupling with carbon cycle: No CO_2 fluxes (no coupling with atmospheric CO_2).
- Simpler one-way feedback with fewer parameters to adjust/tune.
- Weaker coupling/variability with vegetation? Static vegetation in FC. E.g. semi-arid regions, droughts, etc.

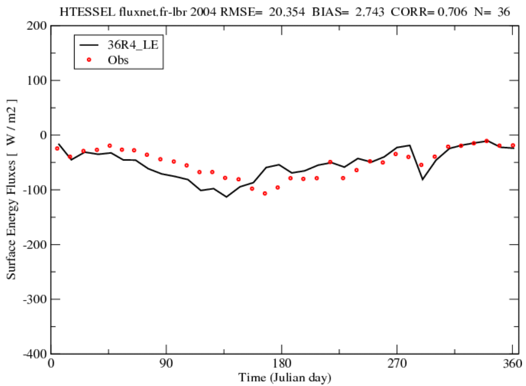
Jarvis versus photosynthesis-based evapotranspiration

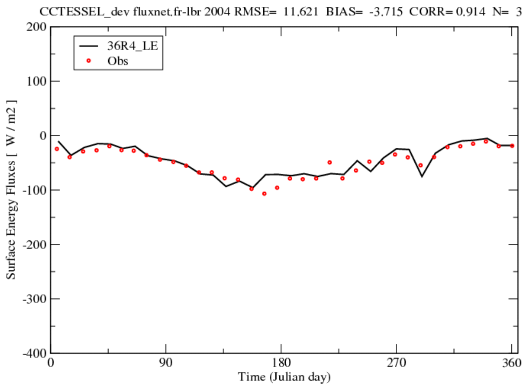
Atmosphere
Monitoring

HTESSEL

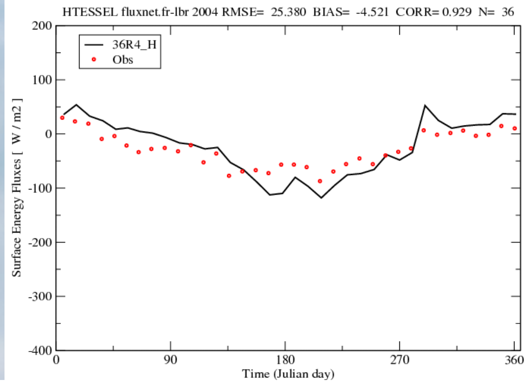
CTESSEL

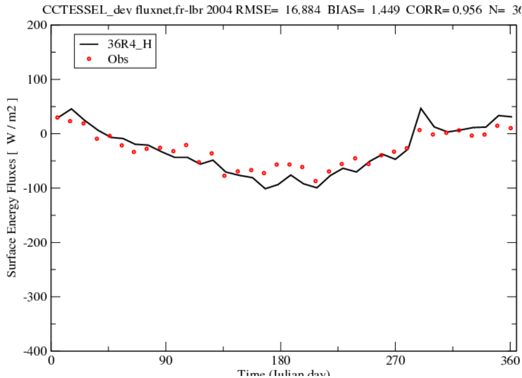
LE



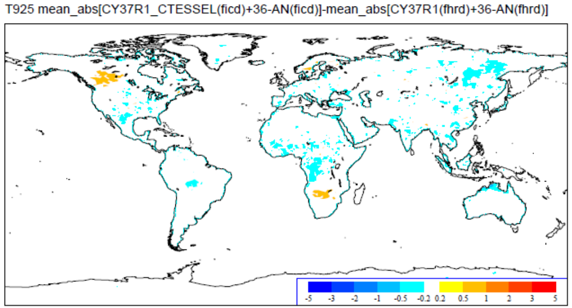


H

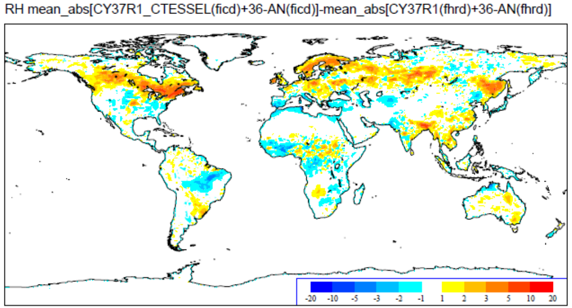




2m T Error differences from the CTL



2m Rh Error differences from the CTL



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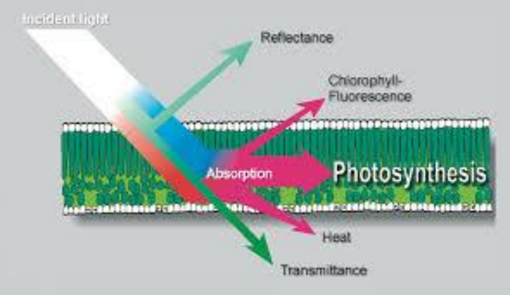
- **CTESSEL improves the LE/H simulations (photosynthesis-based vs Jarvis approach)**

Boussetta et al. (2013)

Atmosphere Monitoring

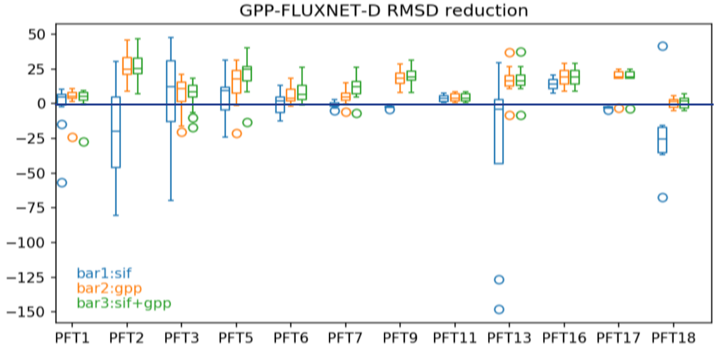
Using Solar Induced Fluorescence (SIF) observations



ESA Bulletin 11/2003 116:34-37.

Optimization of Farquhar photosynthesis parameters and simplified SIF radiative model parameters in ECLand using SIF observations from TROPOMI and FLUXNET GPP observations

CAMS_2-52a : Maignan, Bastrikov, Bacour, Peylin, (LSCE, Science Partners)

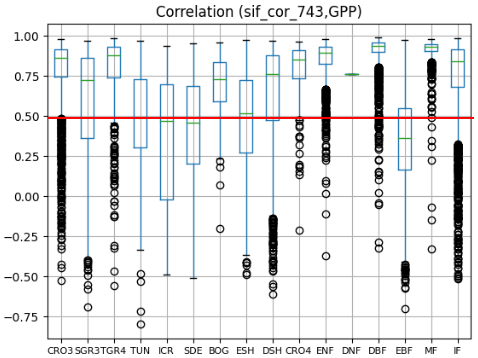


Plant Functional Types (PFT)

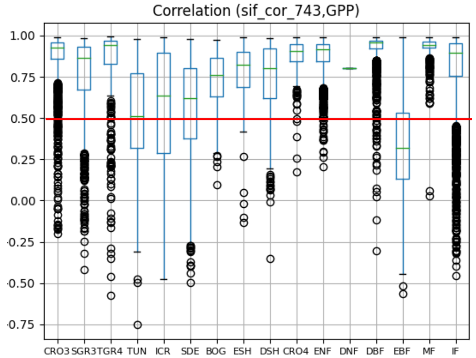
LSCE

Evaluation of CO_2 uptake from photosynthesis

CY48R1 clim LAI_LUC



CY49R1 clim LAI_LUC



Plant Functional Types (PFT)

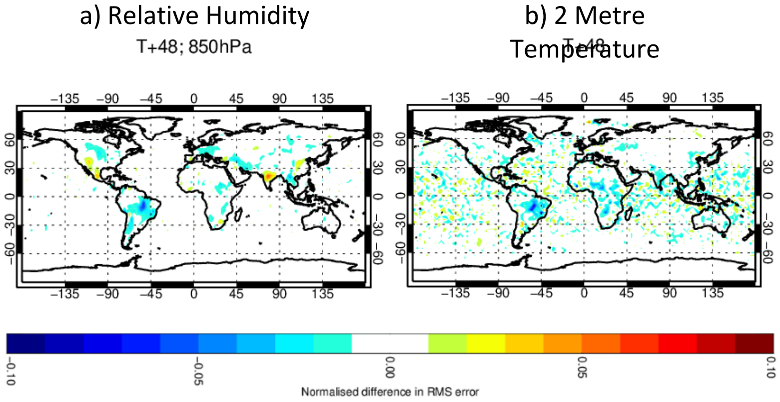
Data assimilation

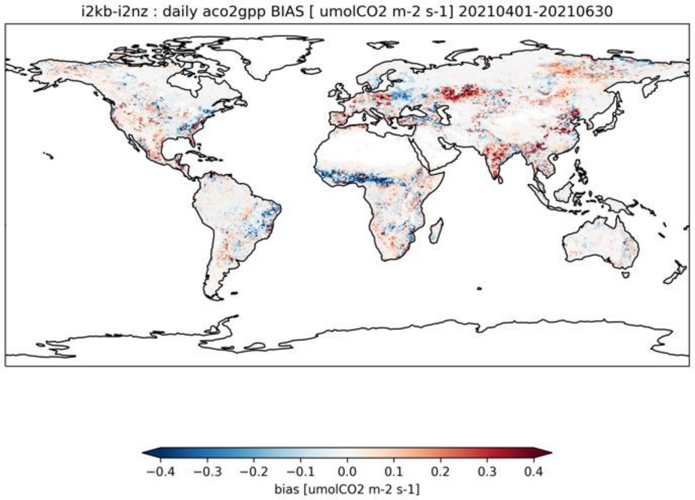
- to constrain photosynthesis **model parameters**
- to constrain the **CO_2 flux** using machine learning techniques to build an observation operator (Sebastien Garrigues, ECMWF).

CORSO
CO2MVS Research on Supplementary Observations

Assimilation of VOD to analyse LAI – Pete Weston, ECMWF

- Currently the IFS uses a monthly climatology for LAI (no inter-annual variation)
- AMSR2 & SMOS VOD products have been assimilated offline to produce a dynamic daily LAI analysis, which has been used instead of the climatology in IFS experiments





- NWP results show improved forecasts of near surface relative humidity and 2 metre temperature especially over forested areas e.g. Amazon
- The carbon flux results are more mixed with reduced biases of GPP against FLUXCOM over tropical Africa but increased biases over Asia
- Future work (CORSO project) will focus on observation operator development for L1 observation assimilation

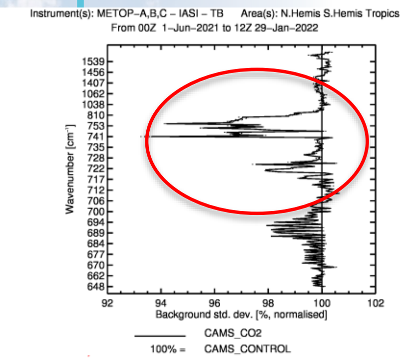
Exploitation of CAMS variable CO_2 in RTTOV – Marco Matricaldi (ECMWF)

Control : Fixed CO2 profile in RTTOV (operational configuration)
Experiment : CAMS global CO_2 fields are passed to RTTOV

Results from assimilation trials – Seven months worth of data: 1-6-2021 to 29-1-2022

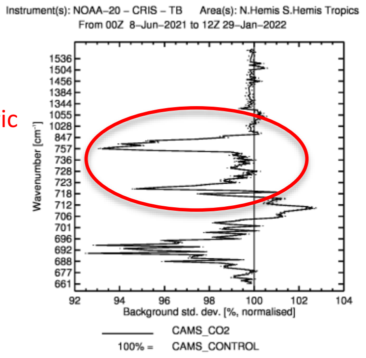
IASI

Hyperspectral sounders



Tropospheric sounding channels

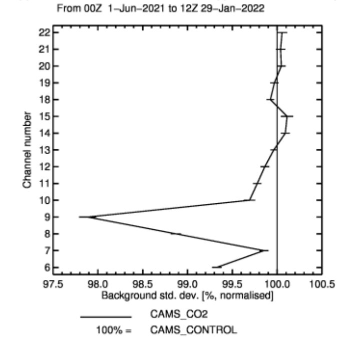
CrIS



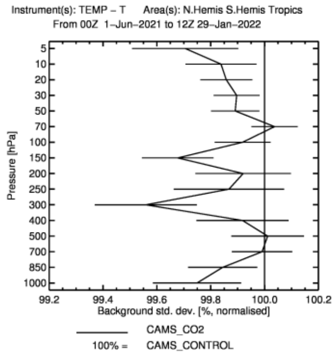
- Use of CAMS CO_2 model data improves NWP analysis of temperature
- Forecast scores with respect to own analyses show small neutral impact overall

ATMS

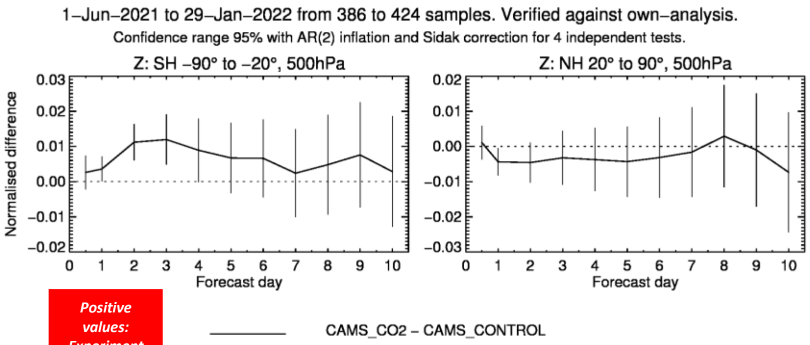
Microwave



Temperature



Forecast scores: 500 hPa geopotential



Positive values: Experiment worse than Control

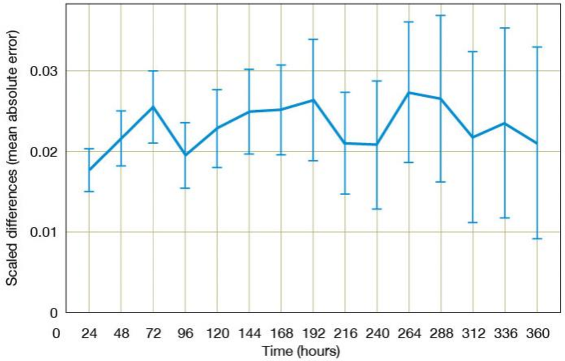
Other synergies with NWP

Improving atmospheric transport in IFS :

Mass conservation error in IFS Semi-Lagrangian advection scheme:
The same type of mass fixer first implemented for CO_2 and CH_4 in CAMS IFS GHG AN/FC in 2017 (Diamantakis and Agusti-Panareda, 2017) is now used operational in NWP (IFS cycle 48r1) for humidity and hydrometeors:

- Improves skill of ENS
- Improves precipitation scores
- Eliminates water budget error and almost eliminates energy imbalance

See Becker et al. (2022): https://www.ecmwf.int/en/newsletter/172/news/fixing-water-and-energy-budget-imbalances-integrated-forecasting-system



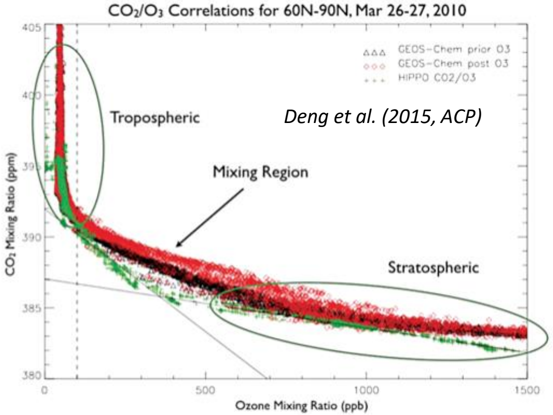
Difference between forecasts with and without global water conservation with respect to the mean absolute error in precipitation against rain gauge measurements over the northern hemisphere, as a function of lead time.

New HE project (CATRINE, 2024-2026) aims to improve improve tracer transport for the Copernicus CO_2 and CH_4 emission monitoring Service and explore the use of a range of atmospheric tracers CO_2, Rn_{222}, SF_6, idealized tracers, humidity and other chemical tracers to diagnose systematic errors in tracer transport

CATRINE
Carbon Atmospheric Tracer
Research to Improve
Numerics and Evaluation

European
Commission

Example: Transport across tropopause



Deng et al. (2015, ACP)

Atmosphere
Monitoring

Benefits of integrating the carbon cycle in NWP/reanalysis

- Integral part of climate system: Information on CO_2 and CH_4 concentration as well as emissions/fluxes is of great interest to scientist/policy makers/citizens
- Consistency and interaction/coupling between Earth system components in the model and also data assimilation (vegetation model, radiative transfer, flux inversion system)
- Synergy with NWP model developments and evaluation. e.g., urban scheme, photosynthesis model and wetland model.
- Supporting evaluation of atmospheric transport errors (e.g. tracer-tracer correlations) and surface energy and water fluxes (through its correlation with CO_2 fluxes from land ecosystems)

European Commission | Copernicus Europe's eyes on Earth ECMWF

Many thanks for your attention!