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T.B.D.

Wouter Peters

Anne-Wil van den Berg, Auke van der Woude, Joram Hooghiem, Ingrid Luijkx, Remco de Kok, Kim Faassen, Maarten Krol, Firmin Stroo, Marnix van de Sande, Liesbeth Florentie, Gerbrand Koren

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Carbon cycle data assimilation in support of the Copernicus Monitoring and Verification System: ~~towards~~ multi-tracer and multi-scale CarbonTracker

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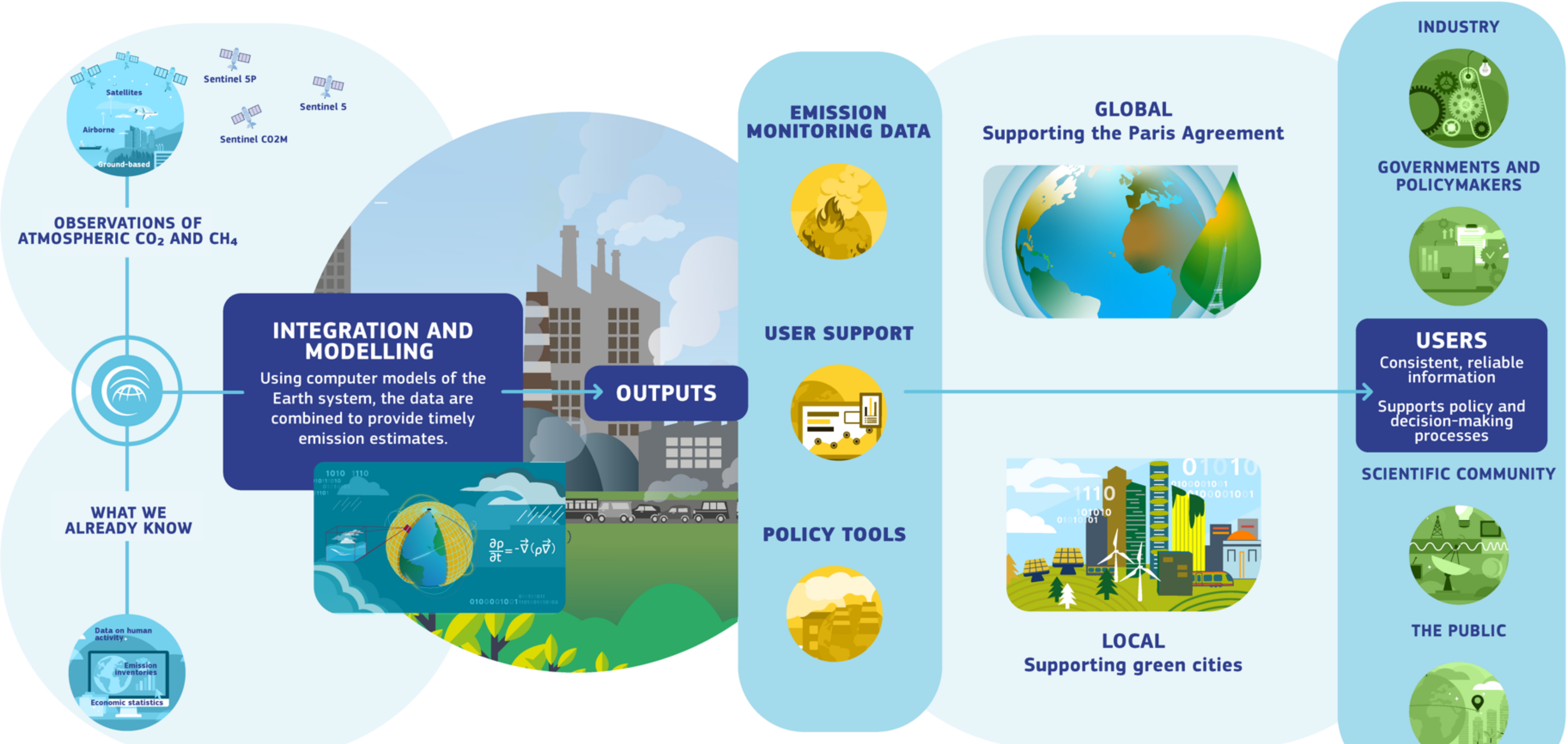
Greenhouse gas emissions monitoring capacity

Atmosphere Monitoring Service
atmosphere.copernicus.eu



PROGRAMME OF THE EUROPEAN UNION
opernicus
IMPLEMENTED BY ECMWF
EUMETSAT
esa

Ingrid

Liesbeth

Gerbrand

Remco

CO_2 Human Emissions

Anne-Wil

CoCO2

Prototype system for a Copernicus CO_2 service

Joram

Kim

CORSO

Prototype system for a Copernicus CO_2 service

Ingrid

PARIS

EU verification support system

Firmin

Marnix

Auke

CO_2 Human Emissions

Progress report on service elements for data assimilation methodology

Wouter Peters

Maarten Krol

Maarten

frontiers in Remote Sensing

METHODS
published: 30 September 2021
doi: 10.3389/frsen.2021.707247

The CO_2 Human Emissions (CHE) Project: First Steps Towards a European Operational Capacity to Monitor Anthropogenic CO_2 Emissions

Gianpaolo Balsamo[1]*, Richard Engelen[1], Daniel Thiemert[1], Anna Agusti-Panareda[1], Nicolas Bousserez[1], Grégoire Broquet[2], Dominik Brunner[3], Michael Buchwitz[4], Frédéric Chevallier[2], Margarita Choulga[1], Hugo Denier Van Der Gon[5], Liesbeth Florentie[6], Jean-Matthieu Haussaire[2], Greet Janssens-Maenhout[7], Matthew W. Jones[8], Thomas Kaminski[9], Maarten Krol[10], Corinne Le Quéré[8], Julia Marshall[11], Joe McNorton[1], Pascal Prunet[12], Maximilian Reuter[4], Wouter Peters[10] and Marko Scholze[13]

OPEN ACCESS

Edited by:
Jochen Landgraf,

CarbonTracker Europe

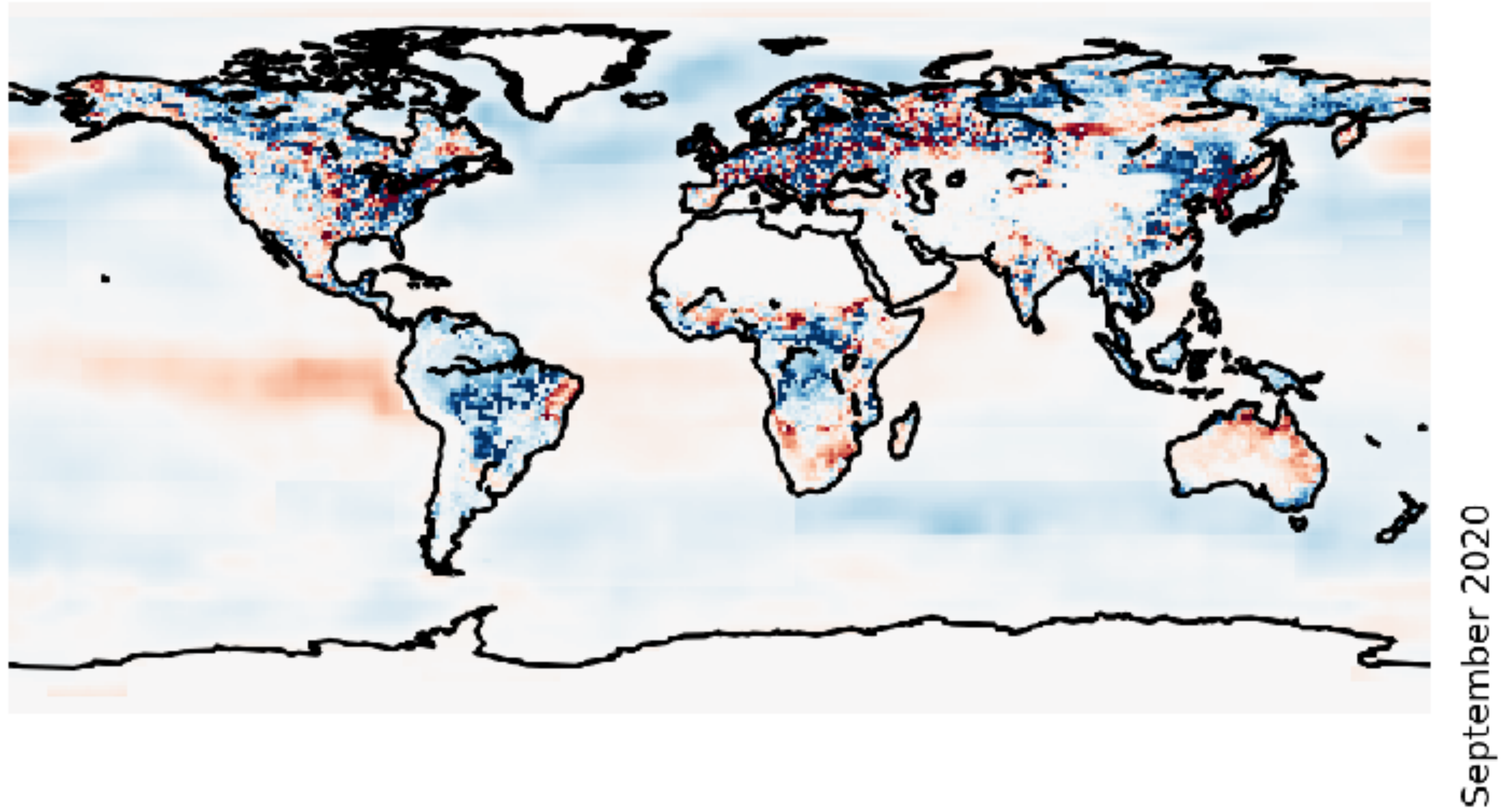
- Data Assimilation system for atmospheric CO_2 mole fraction observations
- Runs on a weekly time-step, optimizes ocean+terrestrial biosphere carbon exchange over 20+ years (1040^{+} cycles)
- 9805+30 scaling factors (λ) estimated each week (d.o.f. ~750/week)
- λ multiplies the fluxes calculated with SIB4 and with the Jena ocean inversion product (so-called flux priors)

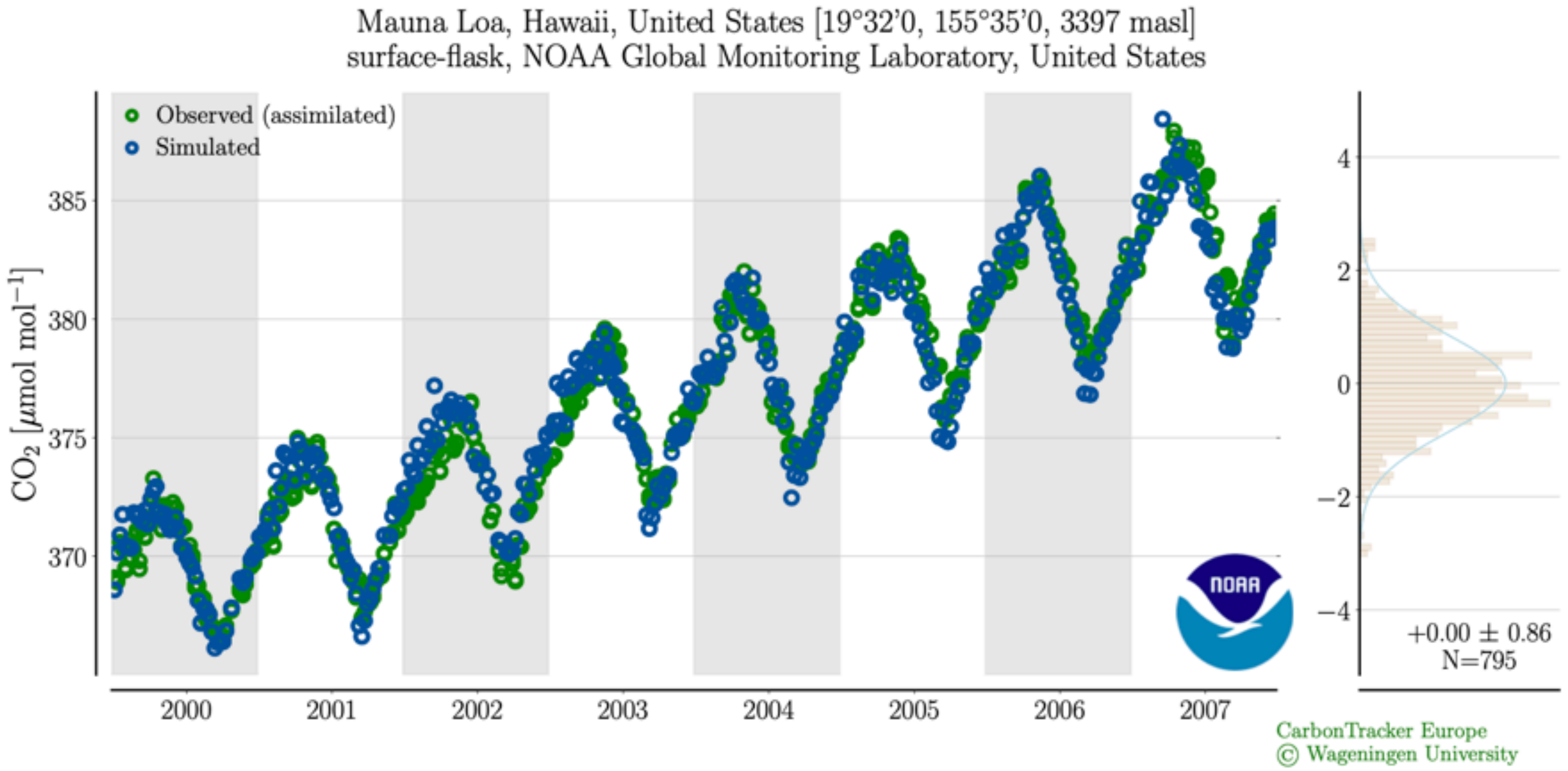
$$F_{optimized} = \lambda \cdot F_{SIB4} + \lambda \cdot F_{ocean} + F_{fossil} + F_{fire}$$

CarbonTracker Europe

Ingrid

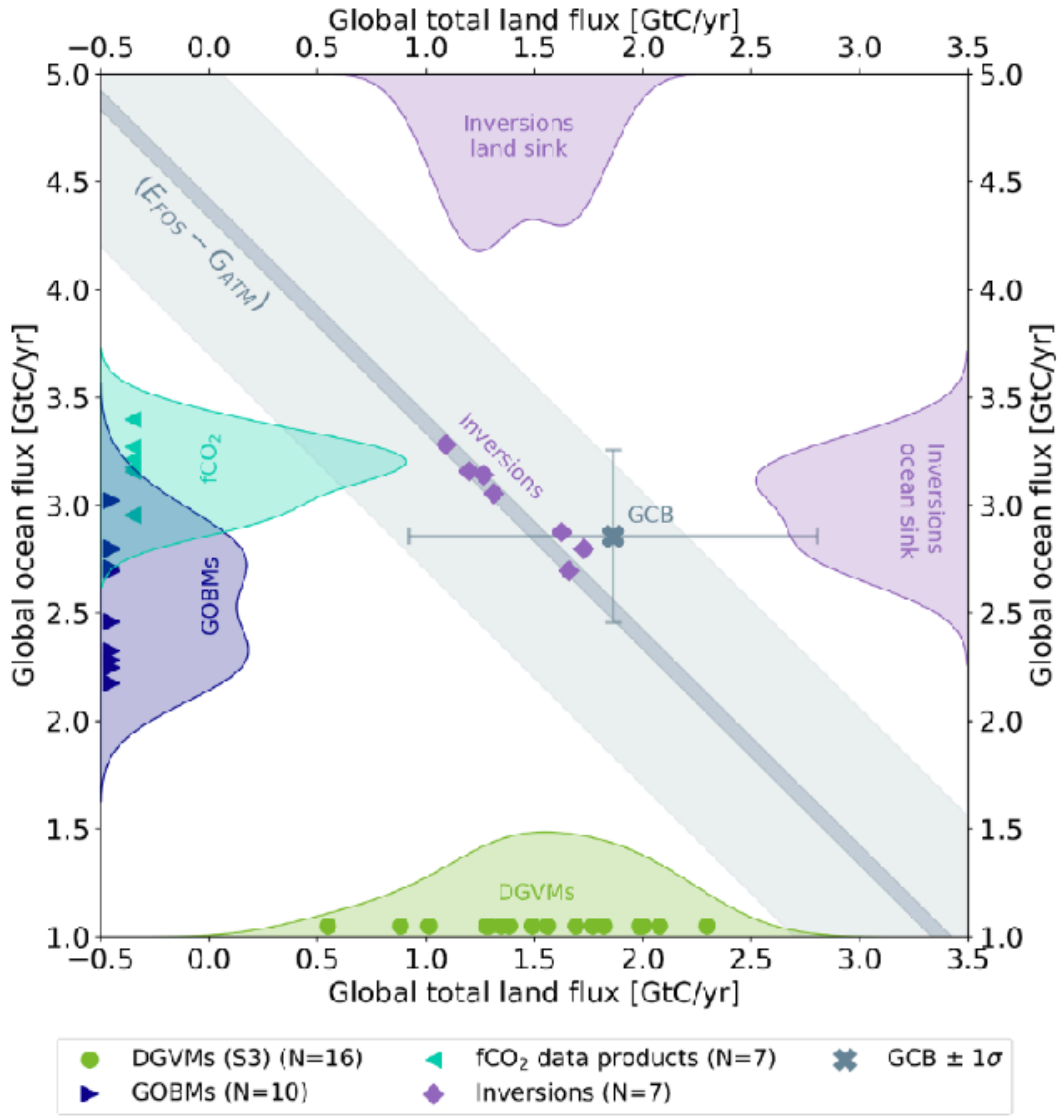
$F_{optimized} = 9835 * F_{prior}$





Global Carbon Budget 2022

Pierre Friedlingstein[1,2], Michael O'Sullivan[1], Matthew W. Jones[3], Robbie M. Andrew[4], Luke Gregor[5], Judith Hauck[6], Corinne Le Quéré[3], Ingrid T. Luijkx[7], Are Olsen[8,9], Glen P. Peters[4], Wouter Peters[7,10], Julia Pongratz[11,12], Clemens Schwingshackl[11], Stephen Sitch[1], Josep G. Canadell[13], Philippe Ciais[14],



Two branches of new development

- **Multi-tracer**
  - additional observations from $\delta^{13}C$, CO, O_2, $\Delta 14C$ can provide extra constraints on global C-cycling
  - Some of these are moreover observed at space with high-resolution (MOPITT, TropOMI, OCO-2, CO_2-M)
- **Multi-scale**
  - individual actors, sectors, or cities can be monitored locally, using high resolution (plume) models, and by resolving turbulent-to-diurnal and synoptic time+space scales (*talk by Auke van der Woude*)
  - climate feedbacks (on Amazon tropical forest, or Arctic tundra, or Southern Ocean) require synoptic to decadal time+space scales

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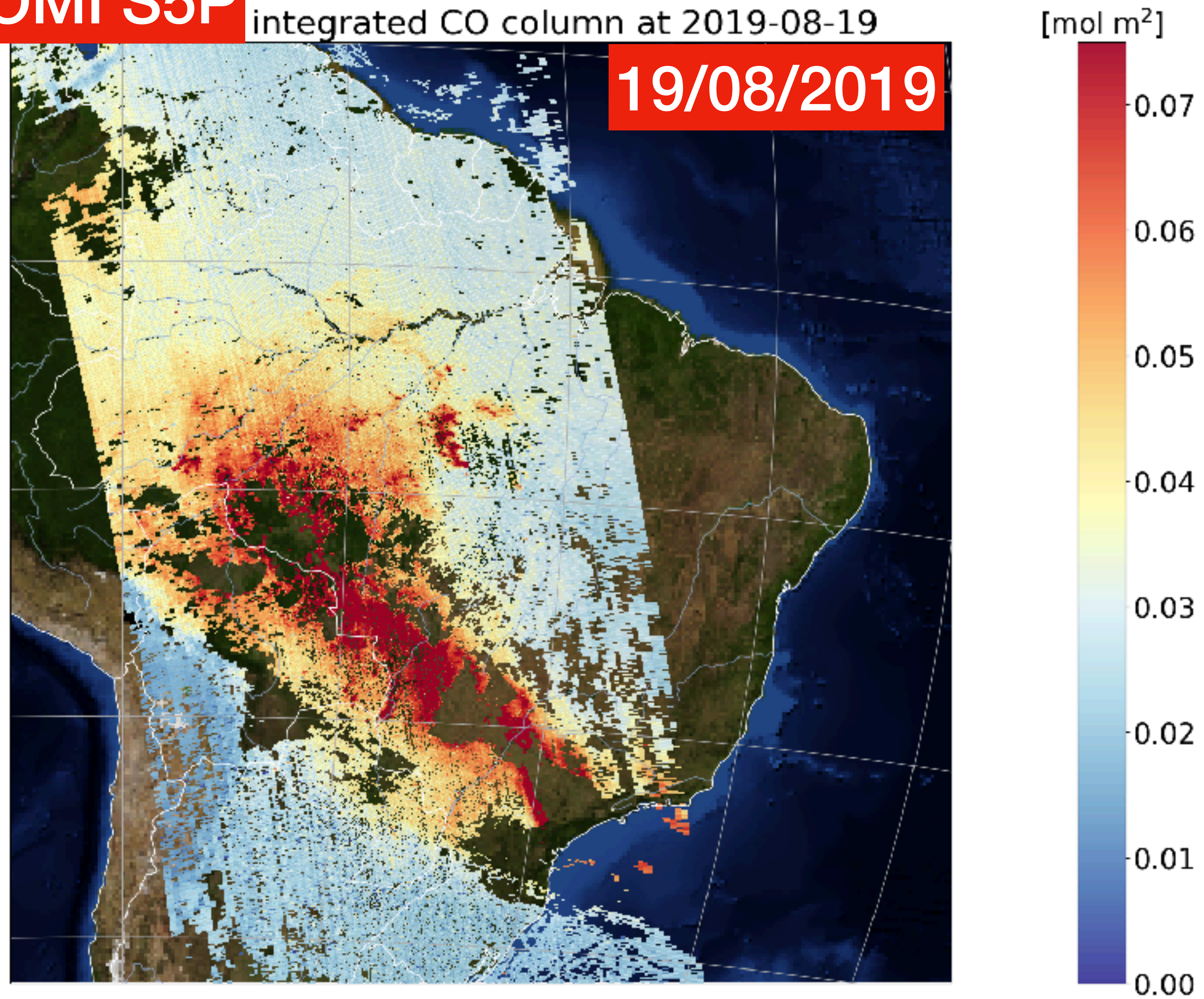
CoCO2 data assimilation (Anne-Wil)

Case 1: Deforestation emissions in Amazonia

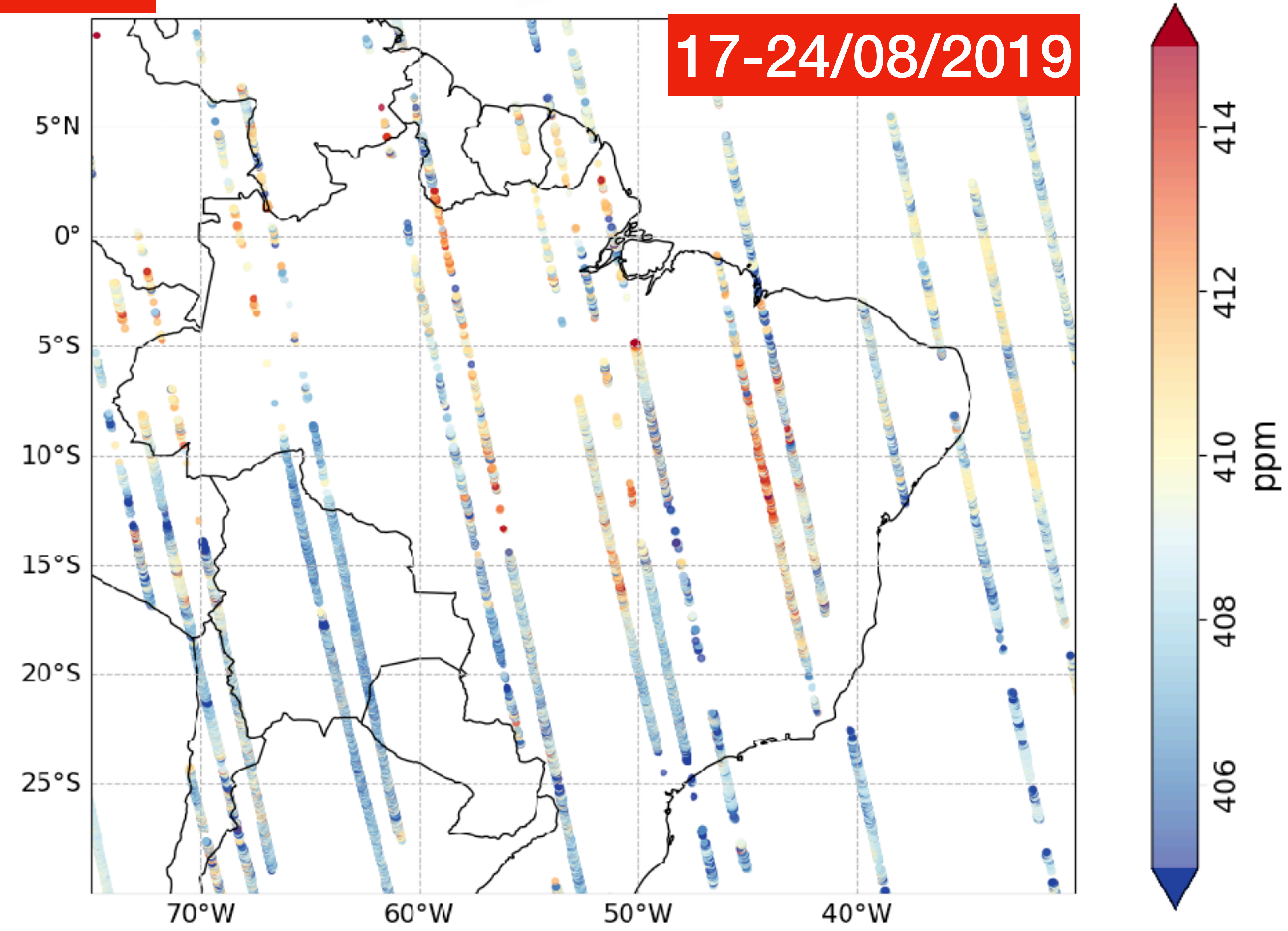

euronews.
My Europe World Business Sport Green Next Travel Culture Video Programmes
Home > News > World > Amazon burning: Smoke travels nearly 3000 km to black out Sao Paulo in middle of the day
BRAZIL
Amazon burning: Smoke travels nearly 3000 km to bl... out Sao Paulo in middle of the day
COMMENTS
By Angela Barnes with Reuters • Updated: 23/08/2019

23/08/2019

TropOMI S5P



OCO-2



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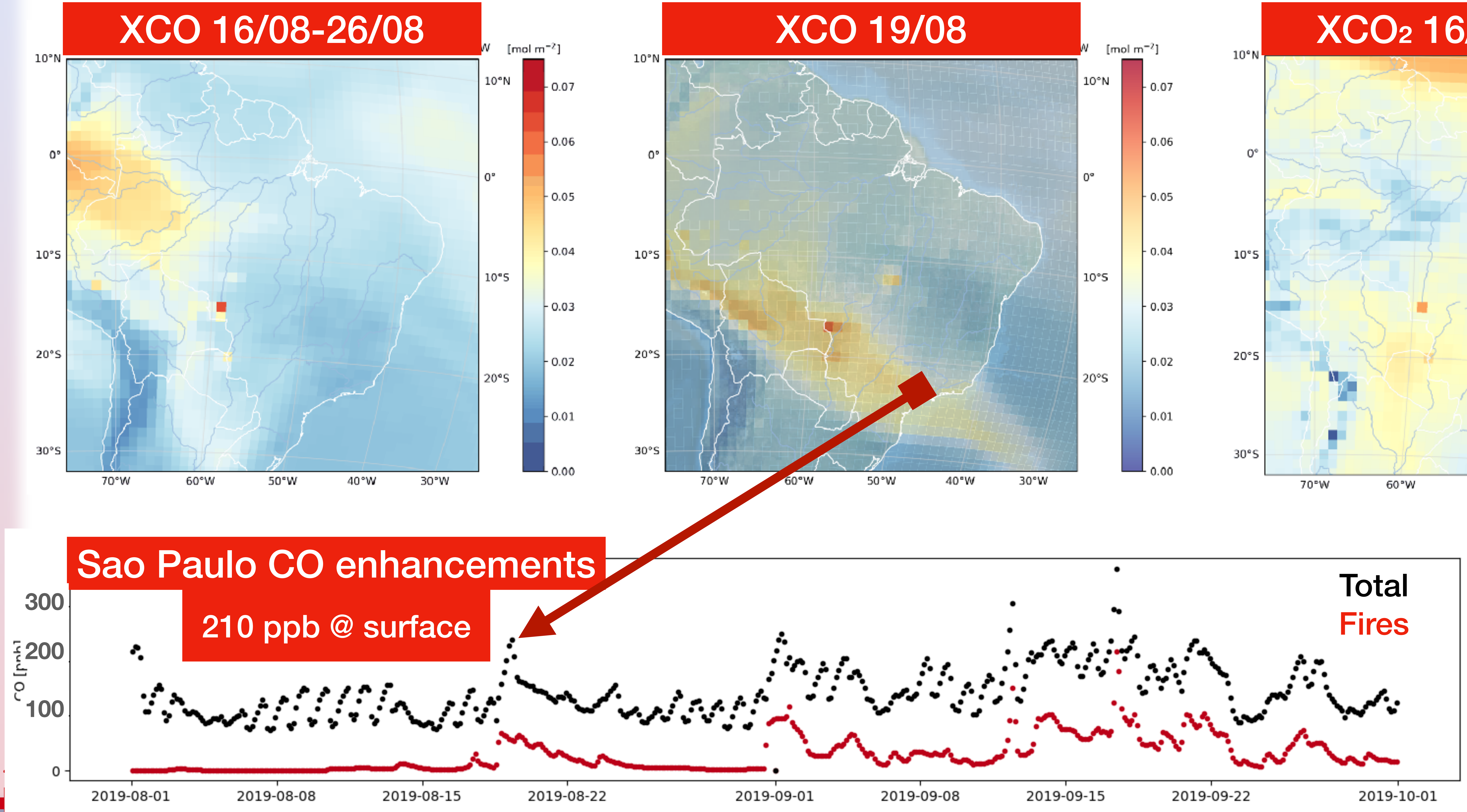

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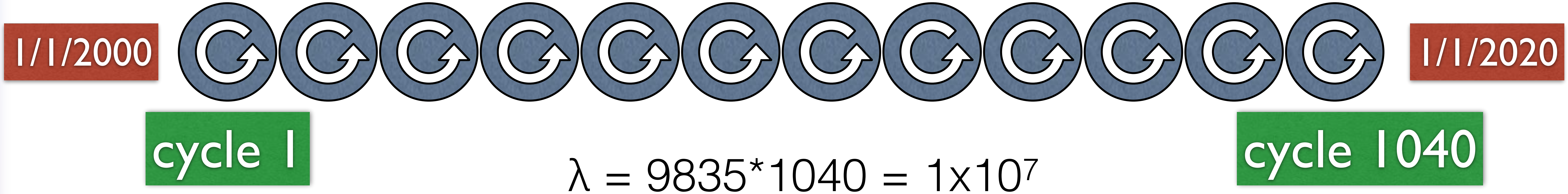
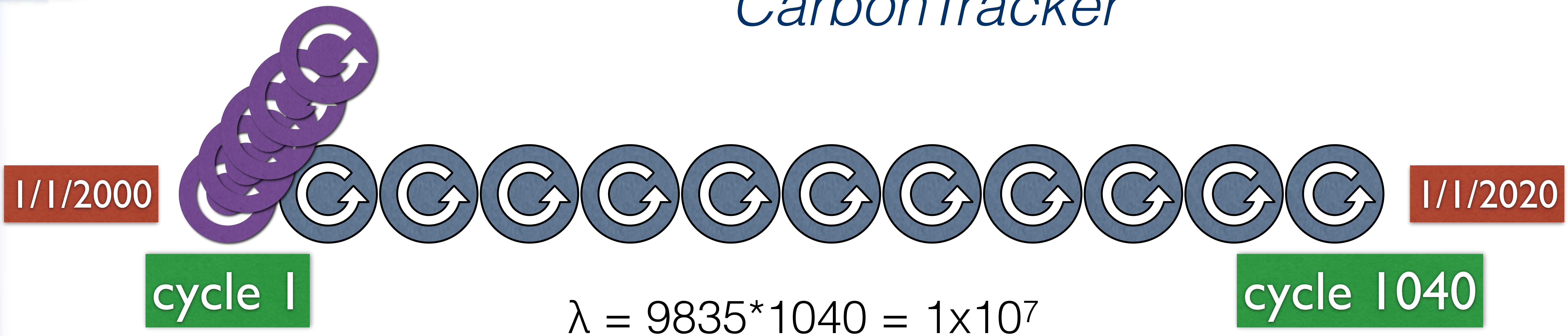
CarbonTracker



λ = 9835*1040 = 1×10^7

TM5 = 52*20*6 = 6240 weeks

CarbonTracker



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CarbonTracker long-window

1/1/2000 1/1/2020

cycle 1 cycle 1040

$\lambda = 9835*1040 = 1x10^7$

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1/1/2000 1/1/2020

1 cycle

$\lambda = 9835*(365+365+365) = 1x10^7$

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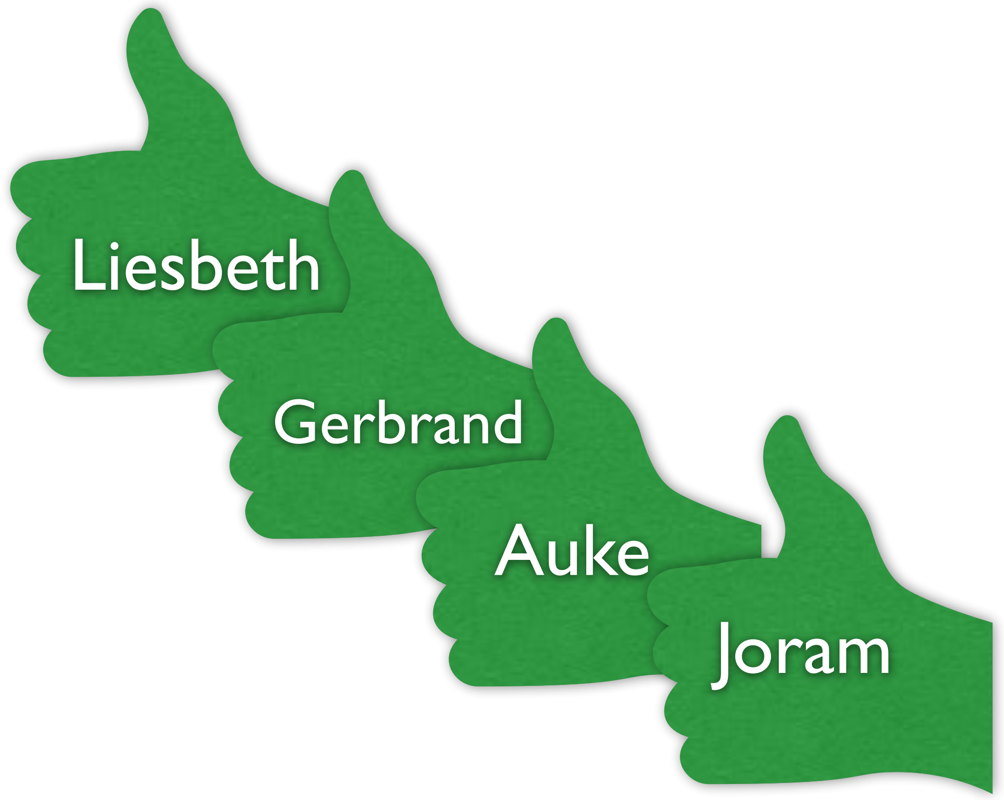

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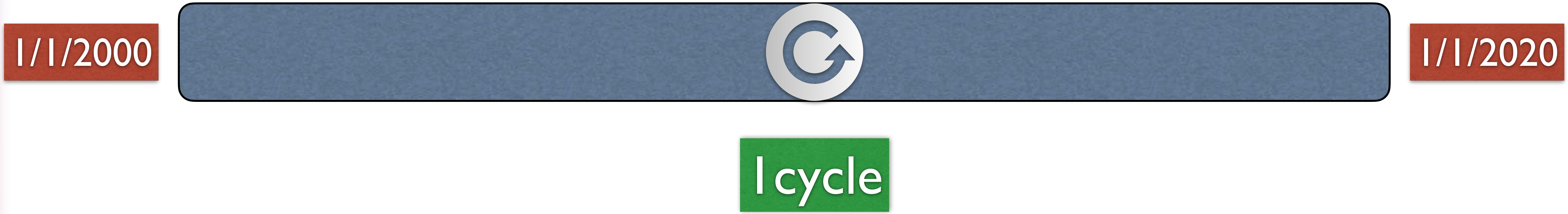

λ = 9835***(365+365+365)** = 1x10^{7}

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CarbonTracker long-window

1/1/2000

1/1/2020

cycle 1

cycle 1040

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1/1/2000

1/1/2020

1cycle

$\lambda = 9835*$**(365+365+365)** $= 1x10^7$

TM5 = 52*20 =1040 weeks

one-shot inversion resembles closely the 4dVAR approach!

CarbonTracker long-window

$$F_{optimized} = (\lambda \cdot TER_{prior} + GPP_{prior}) + \lambda \cdot F_{ocean} + \Delta F + \gamma \cdot \Delta P$$

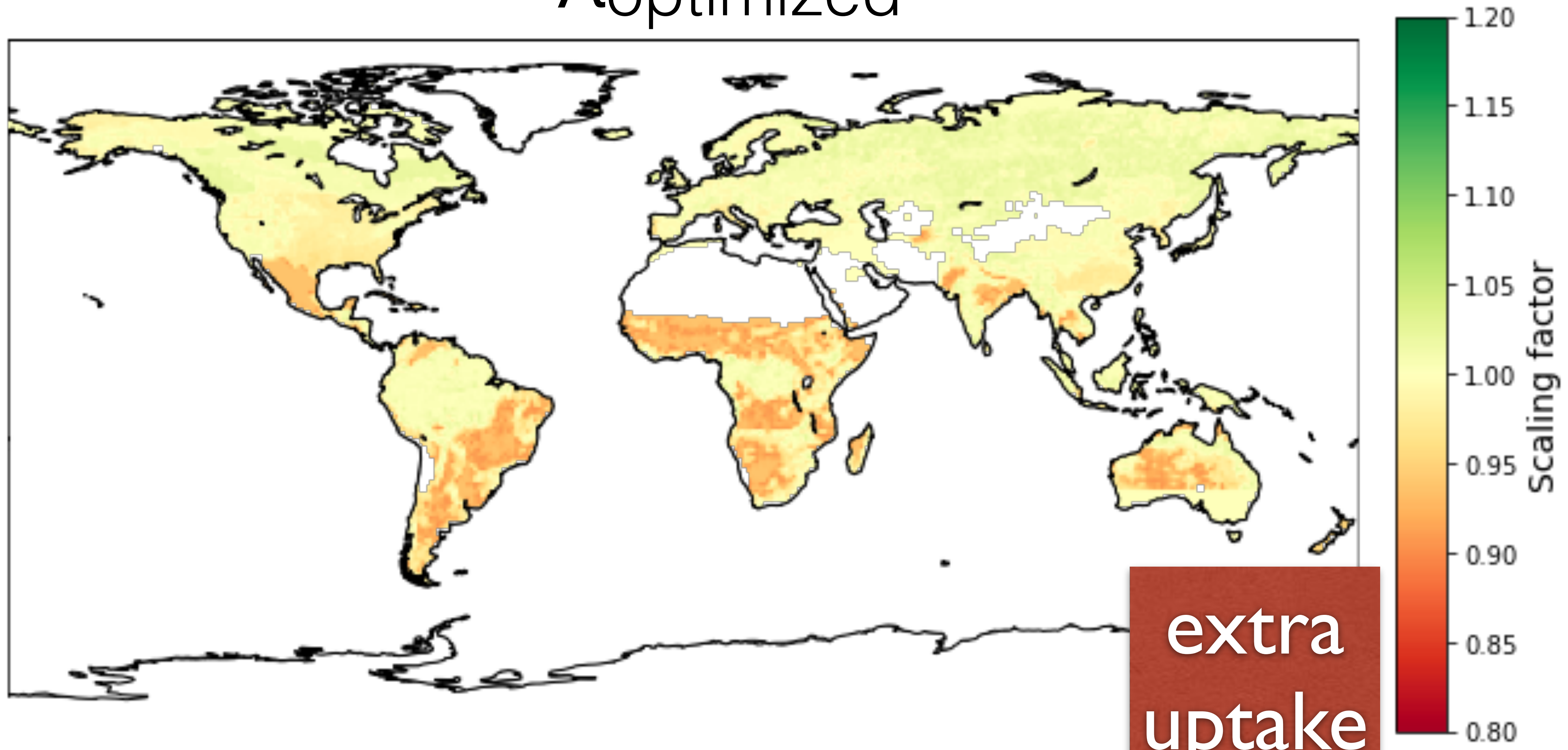
λ = 365* scaling factors to adjust the **long-term mean** flux

ΔF = 365* flux increments to adjust the **seasonal** cycle

γ = 365* multipliers to an “anomaly proxy” ΔP to create **IAV**

$$F_{optimized} = \underline{(\lambda \cdot TER_{prior} + GPP_{prior})} + \lambda F_{ocean} + \Delta F + \gamma \cdot \Delta P$$

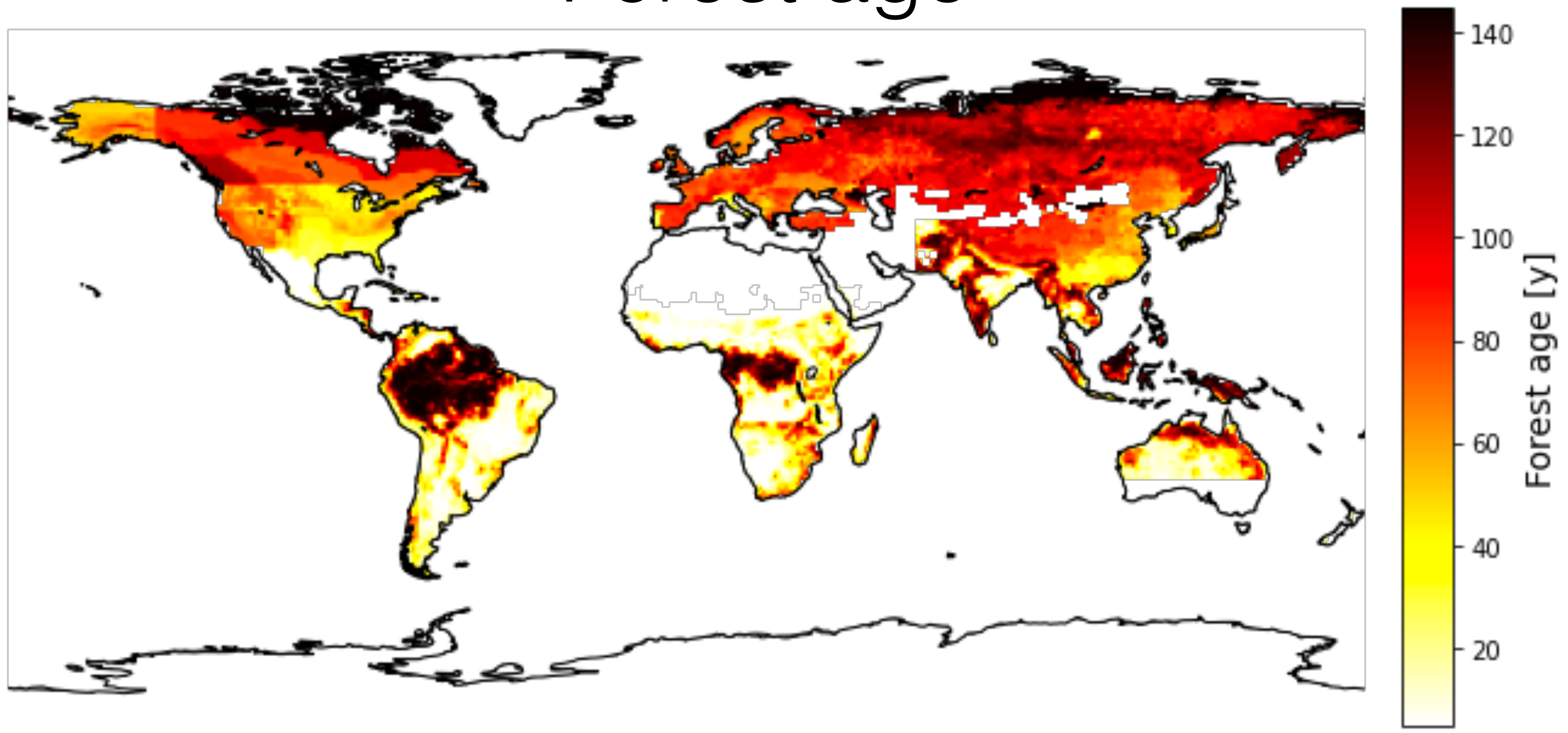
λoptimized

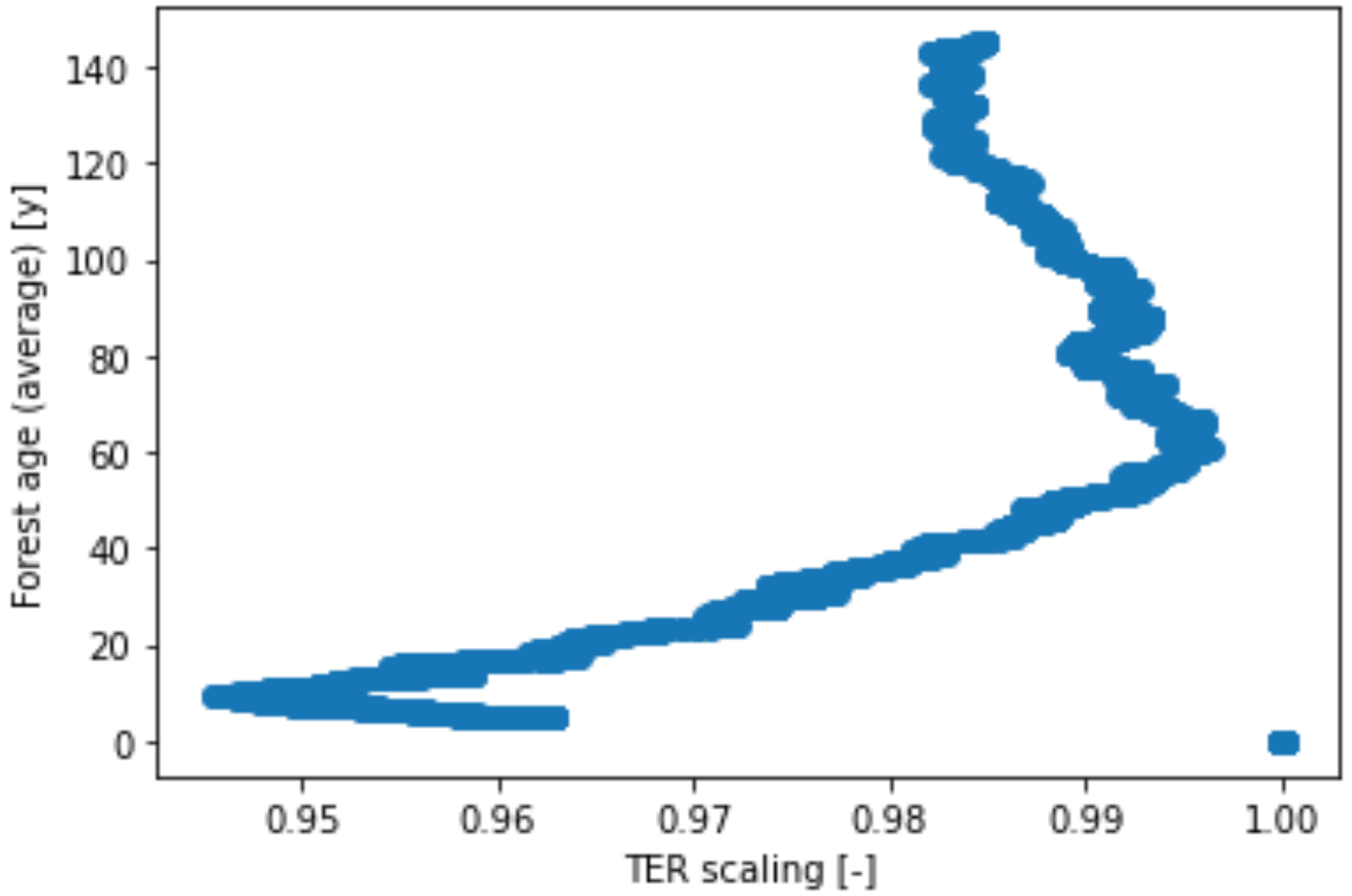


extra uptake

old

Forest age



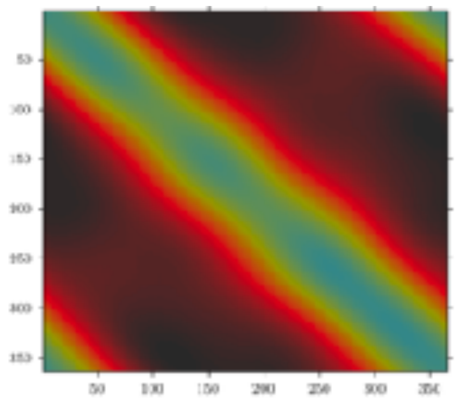


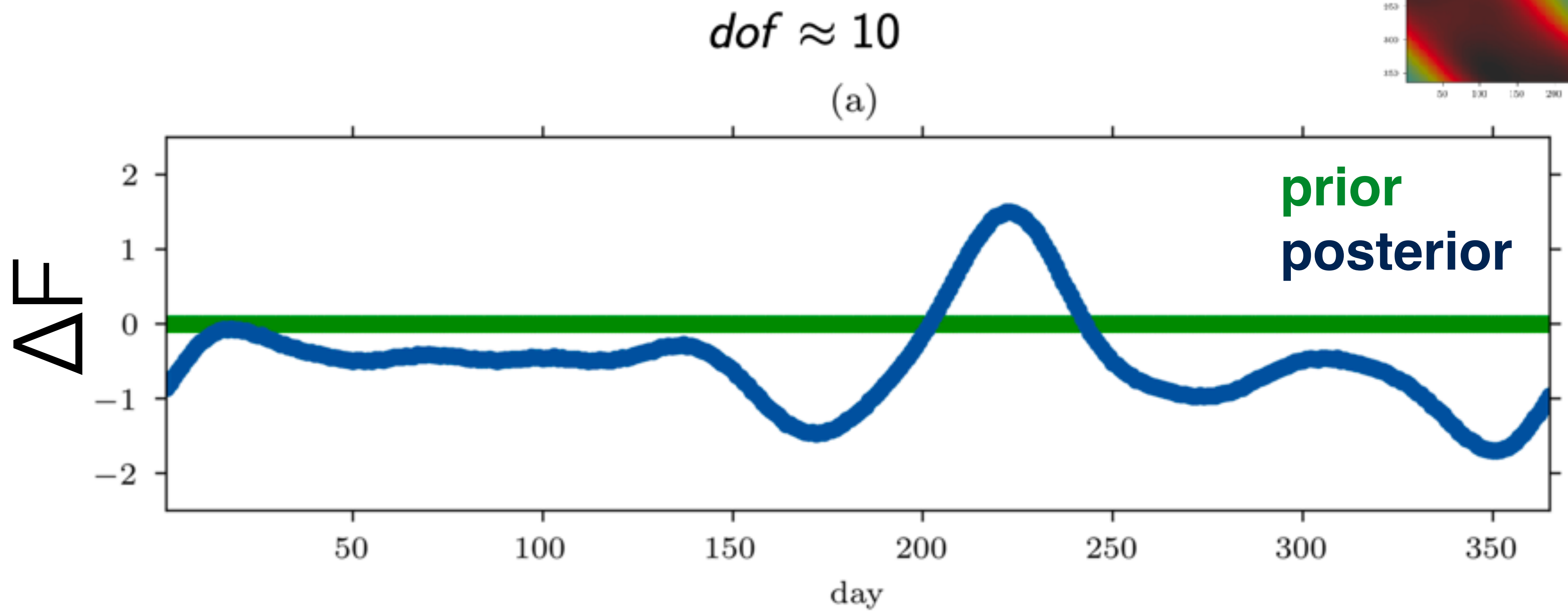
Forest age was used in the covariance structure of λ (9805x9805 matrix)

Auke

$$F_{optimized} = (\lambda \cdot TER_{prior} + GPP_{prior}) + \lambda F_{ocean} + \Delta F + \gamma \cdot \Delta P$$

ΔF is a daily flux adjustment to SIB4
every DOY (1,…,365) gets one ΔF
ΔF is thus repeated each year (!)
a covariance time-scale makes the adjustment smoother





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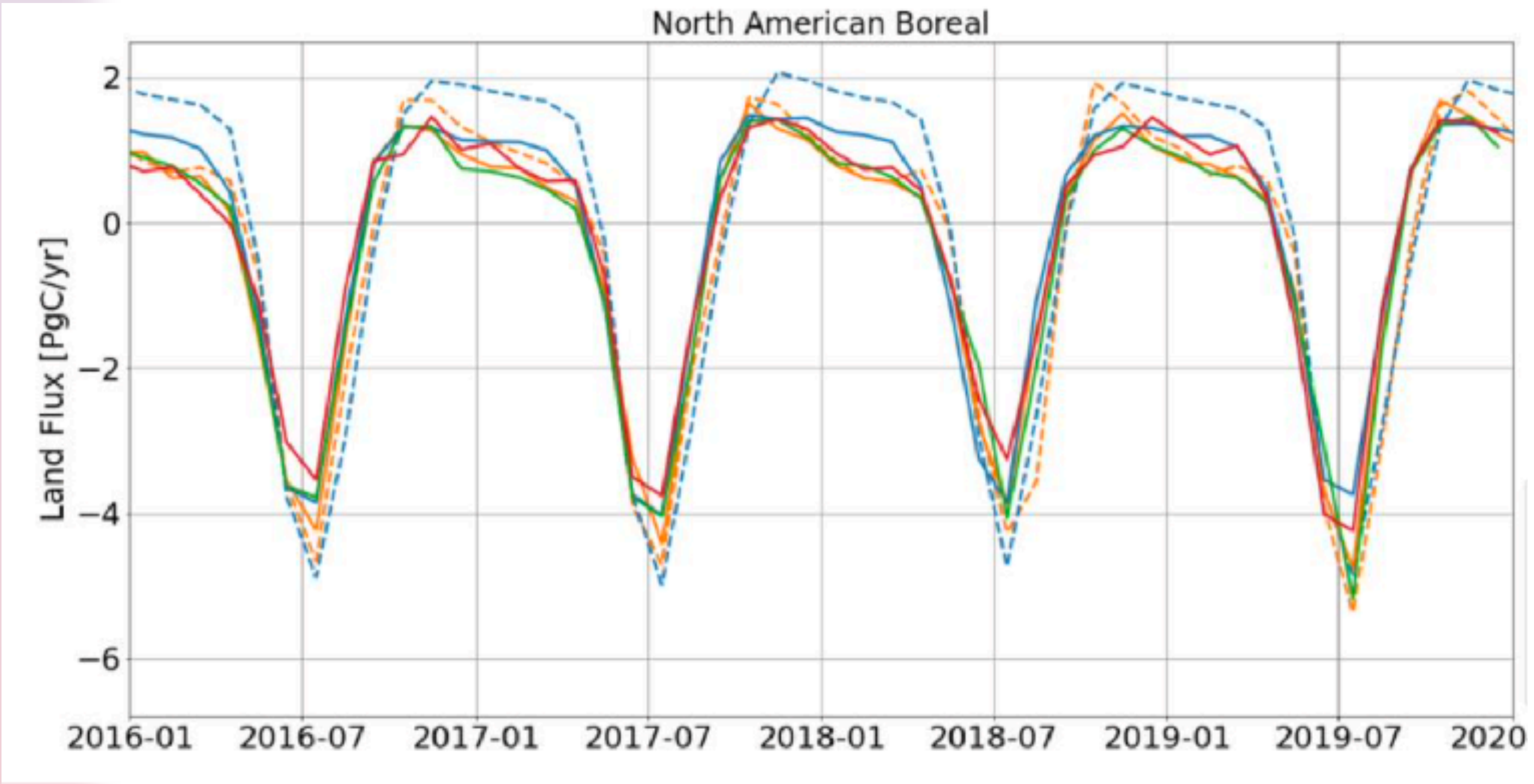
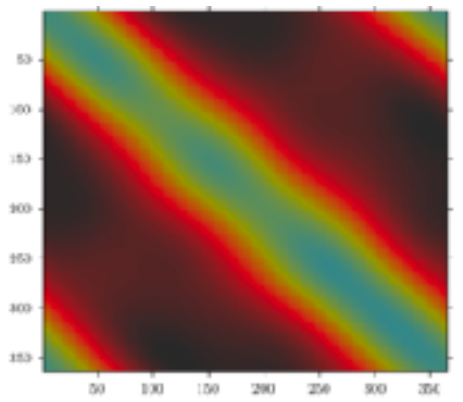
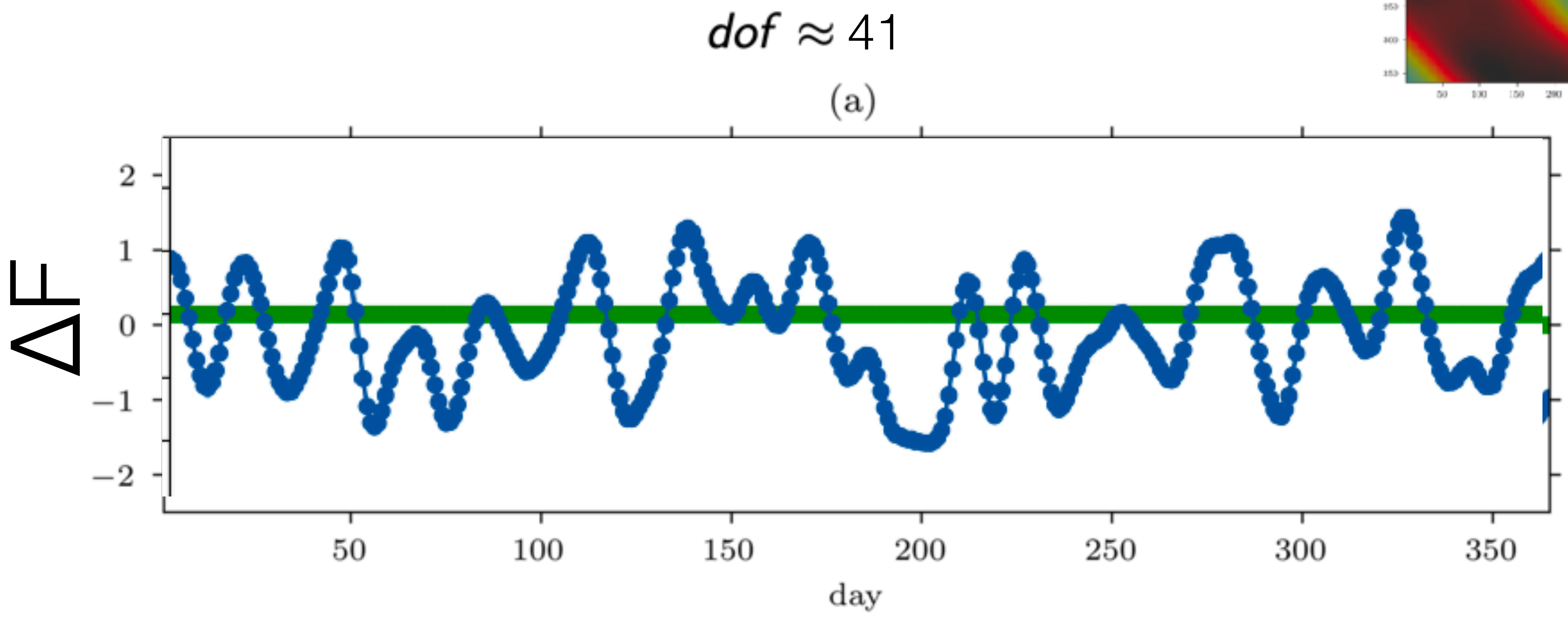


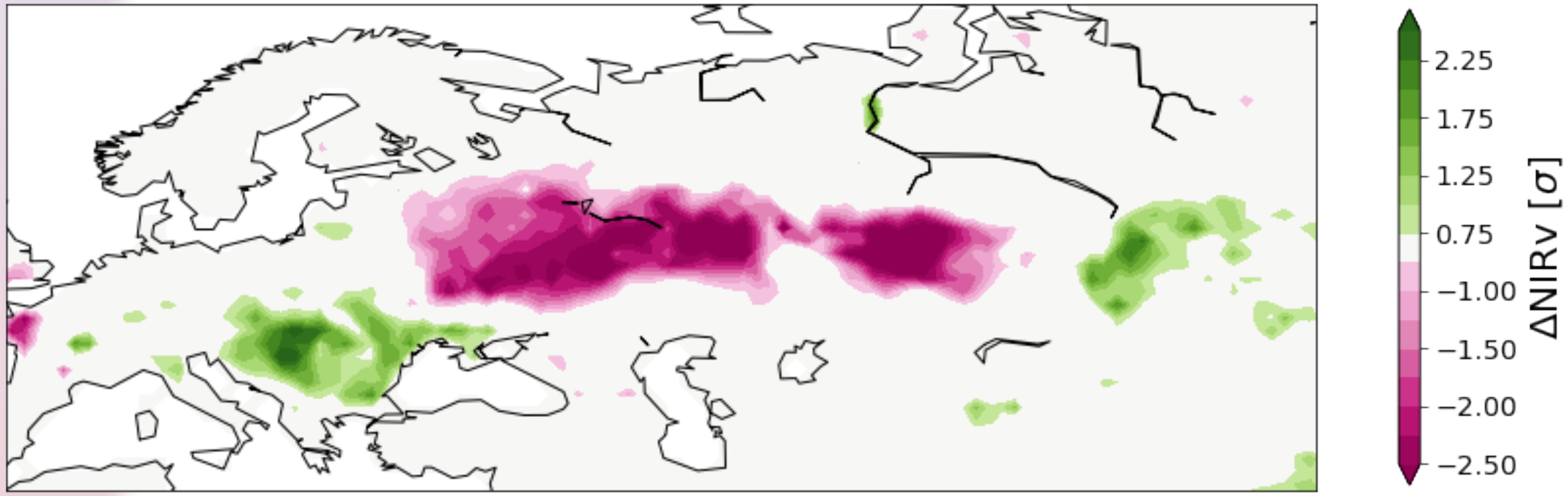
—- prior SIB4/SIBCASA



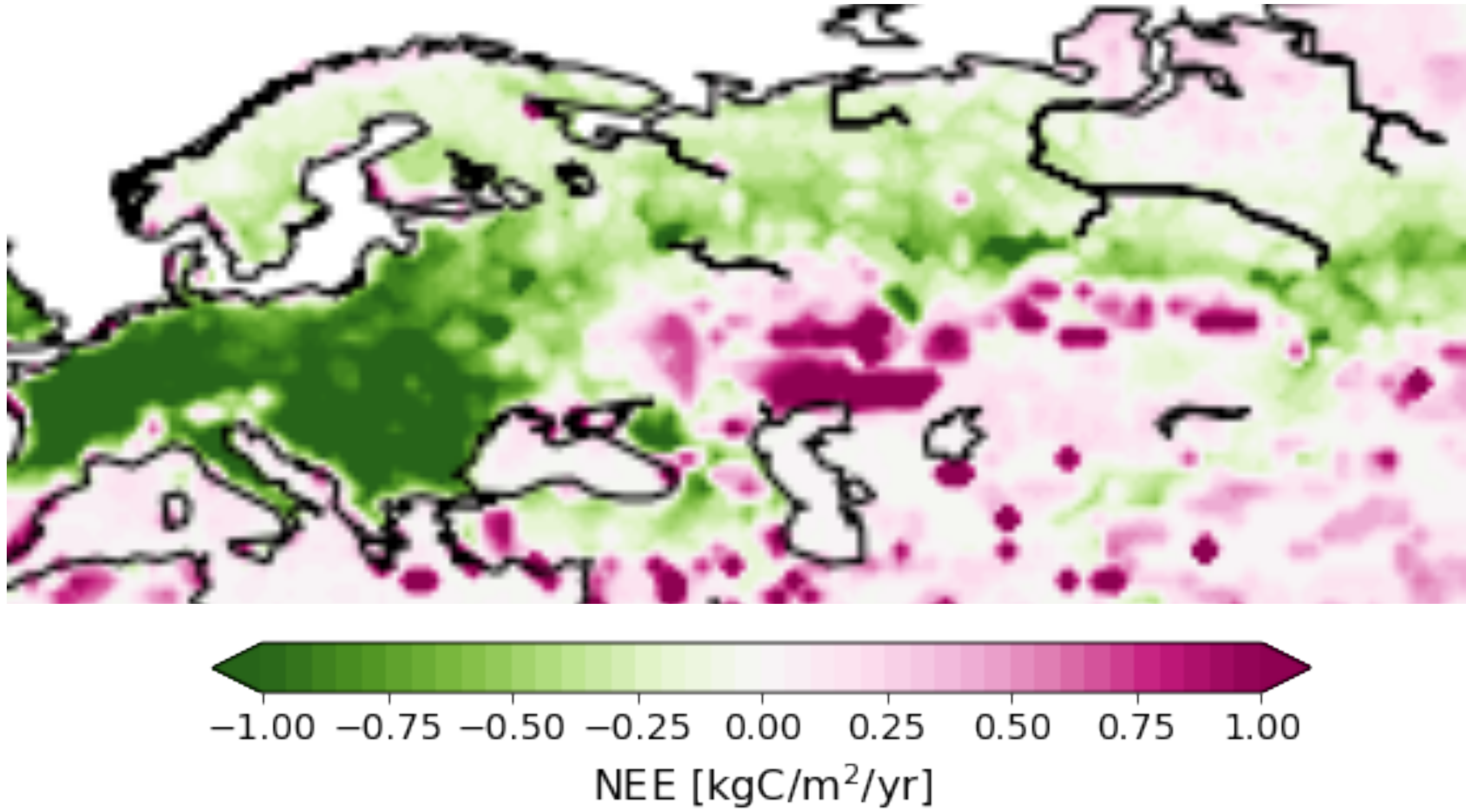


$$F_{optimized} = (\lambda \cdot TER_{prior} + GPP_{prior}) + \lambda F_{ocean} + \Delta F + \gamma \cdot \Delta P$$

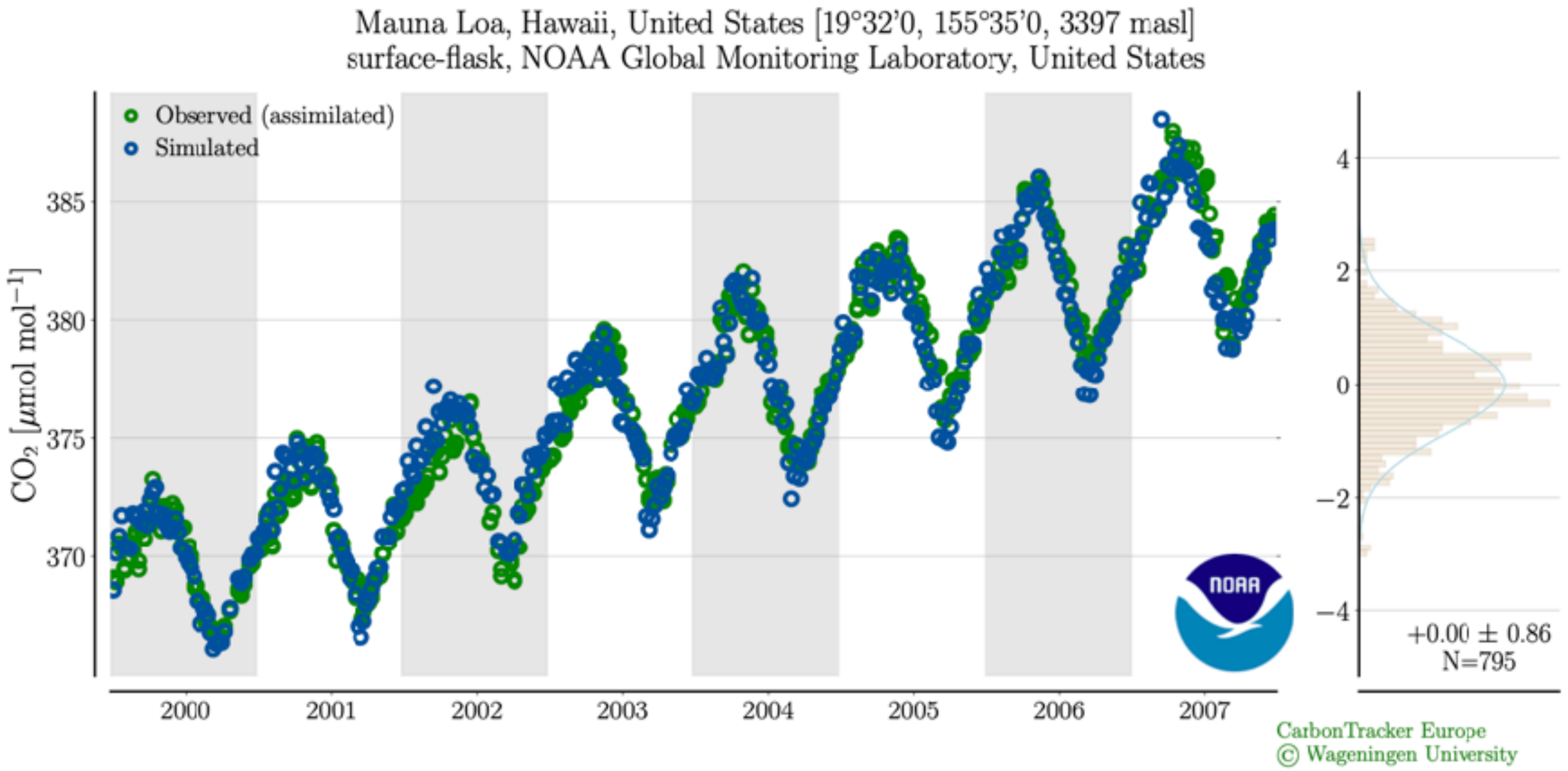
γ is the linear relation between an observed anomaly (ΔP) and a change in flux.
e.g. for ΔT its units would be (μmol/m2/s)/K
γ is estimated for each DOY (with covariance, like ΔF)
ΔT is relative to the multi-year average T for each day
Proxies we will test: T, VPD, SPEI, **NIRv**, SM, …

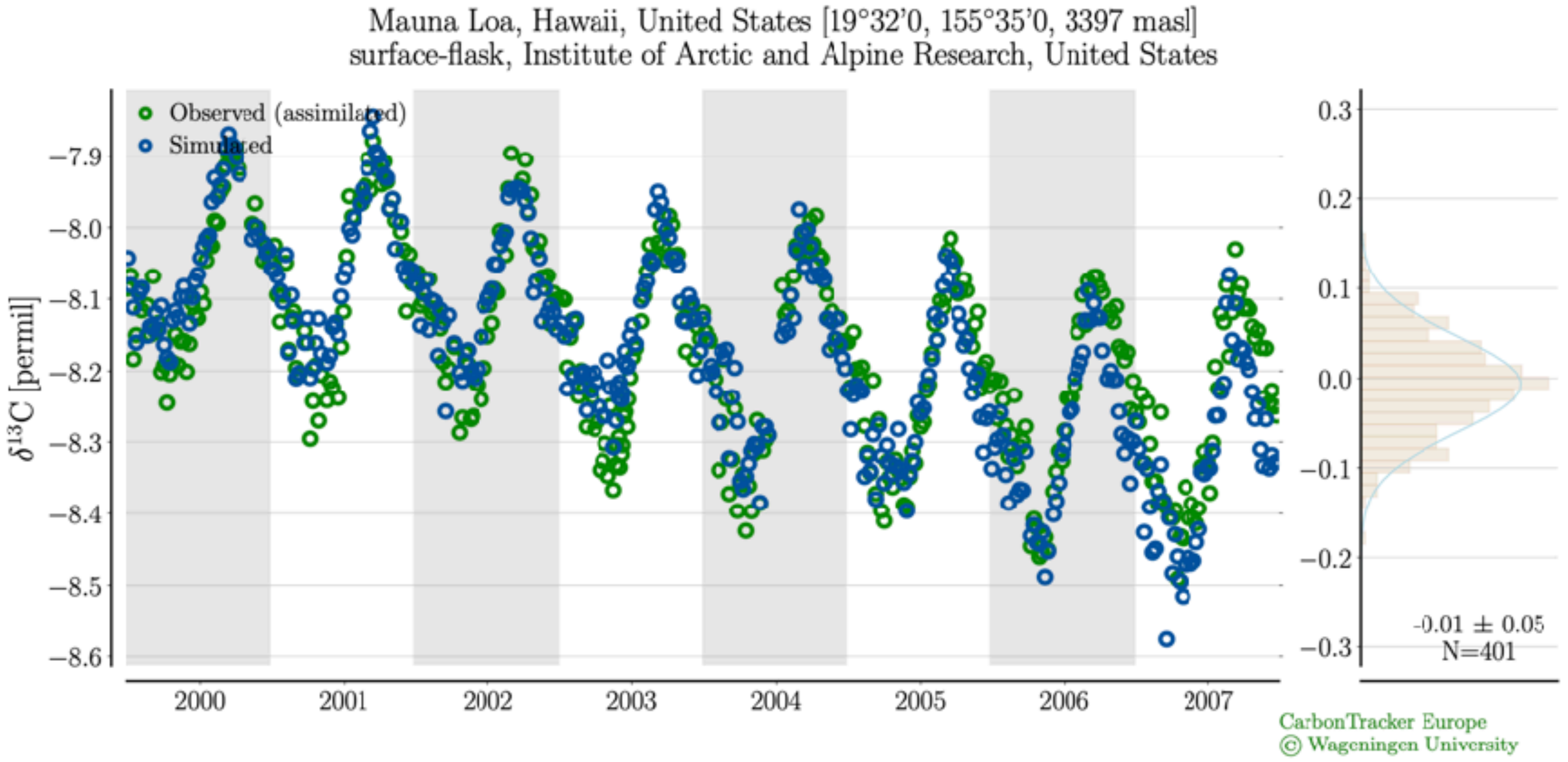


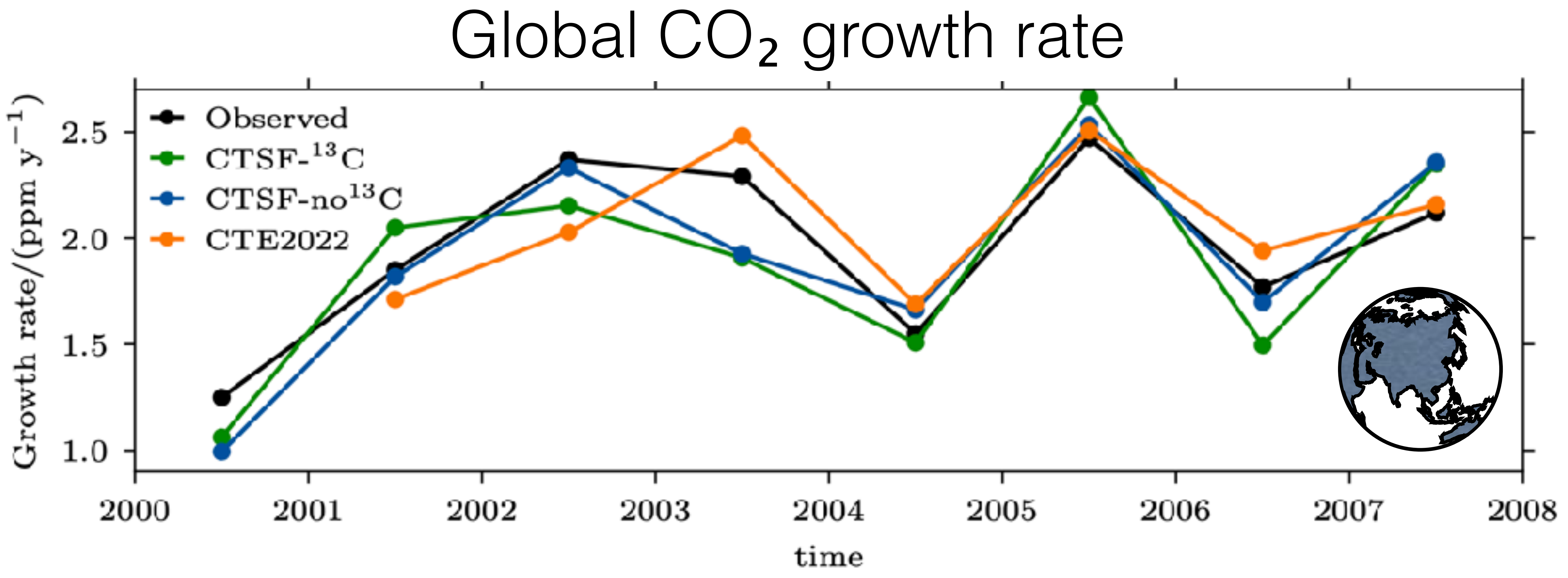
Anomaly in NIRv (photosynthesis) during 2010 July drought in Russia

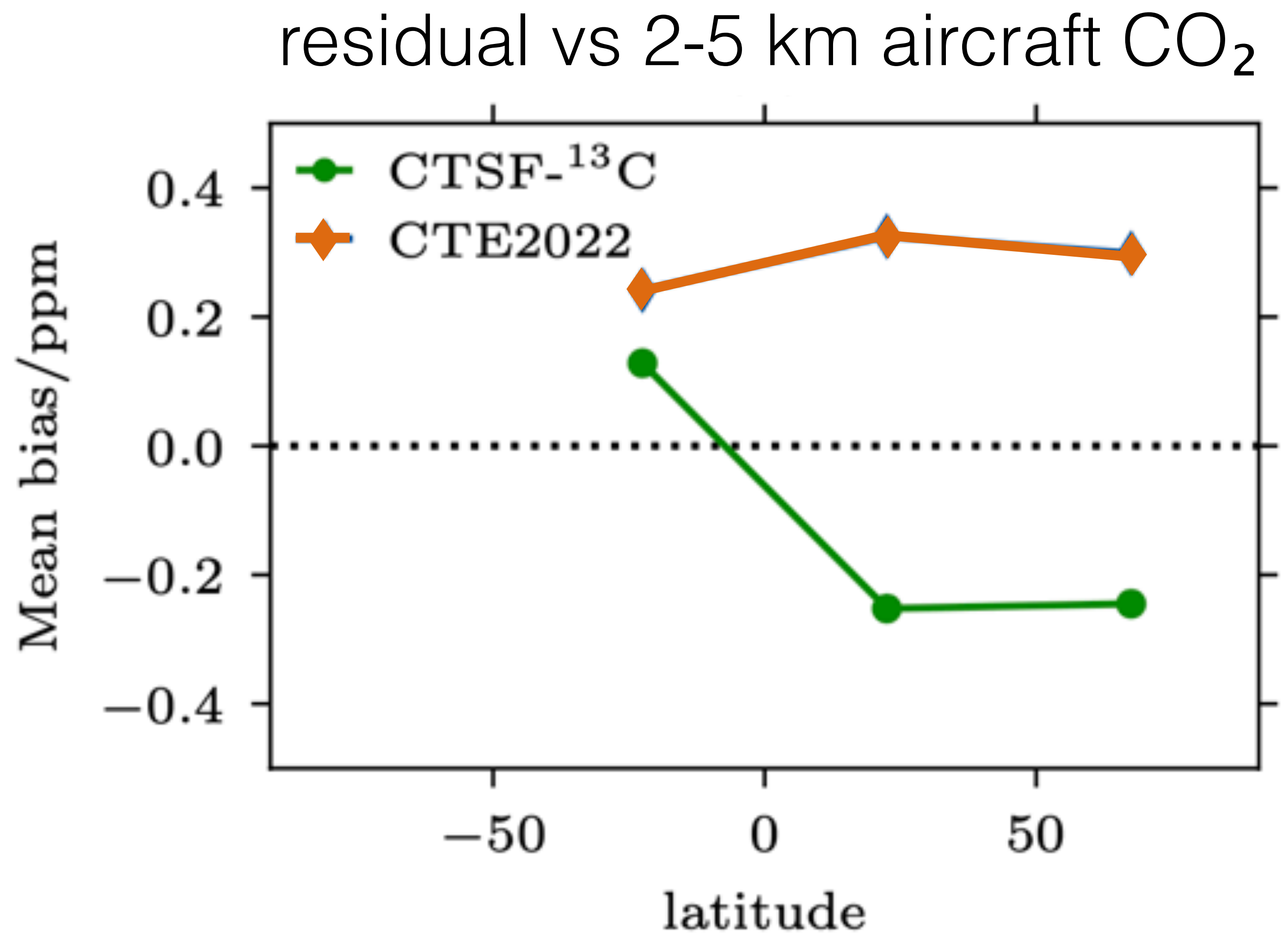


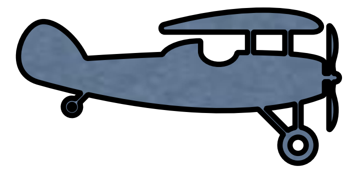
Does it work as well as CT-Europe?











Developments towards Copernicus

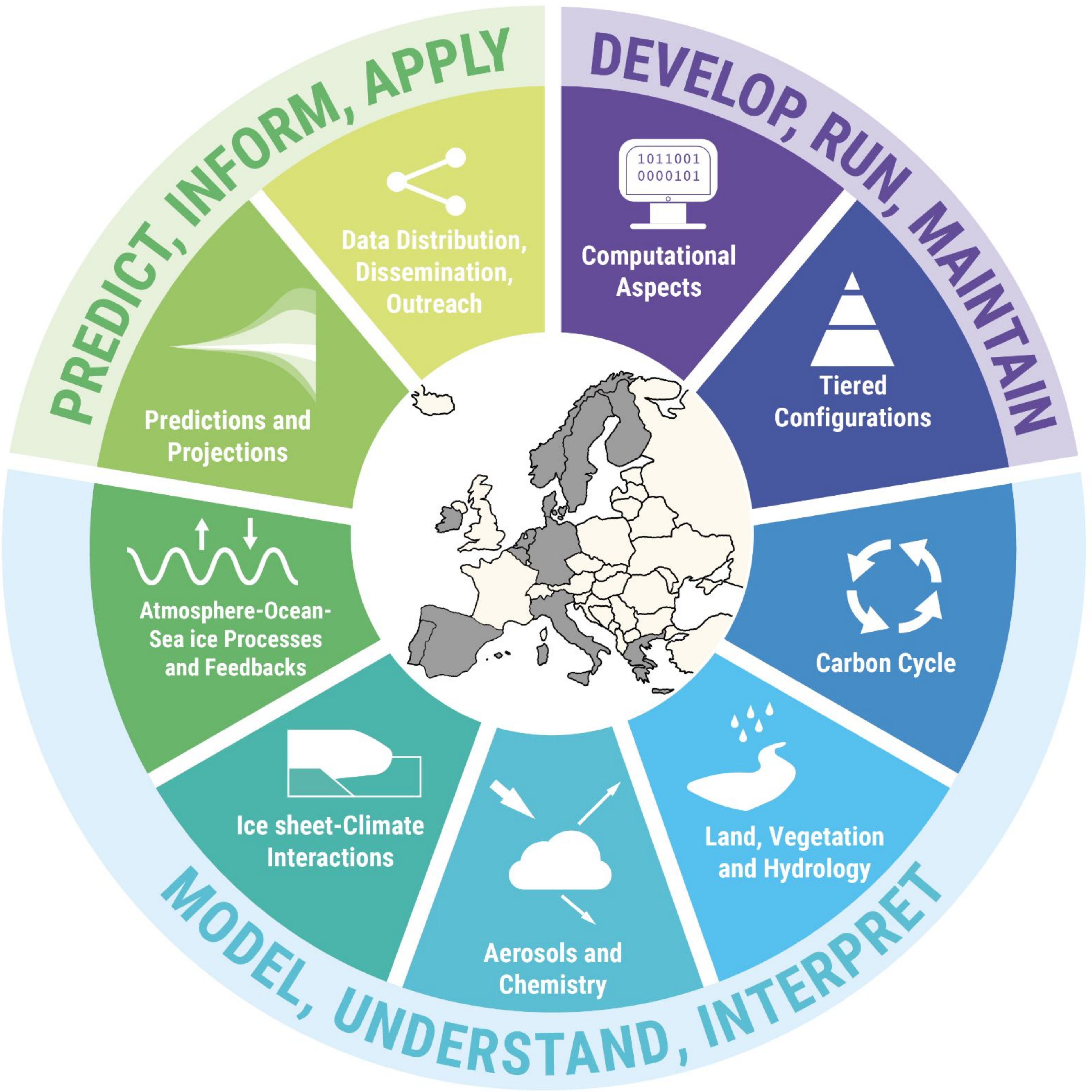
- With the long-window system we cover time scales that will never be captured in CT-Europe, or in the IFS-based MVS (24-hour 4dVAR)
- It is suited for long-term reanalyses and seasonal-to-decadal carbon exchange studies
- It is 6x cheaper than CT-Europe (runtime -3 days/decade)
- It can use spatial data and observations not easily integrated into CT-Europe or IFS-MVS
- Its use frees up resources to focus satellite-based inversions and multi-tracer runs on smaller time+space scales (Anne-Wil van den Berg)
- CT-Europe and CT-long window are integrated in the ongoing design of a global MVS…
- … + collaboration on OpenIFS (20 km global) and EC-Earth4-CC-lite

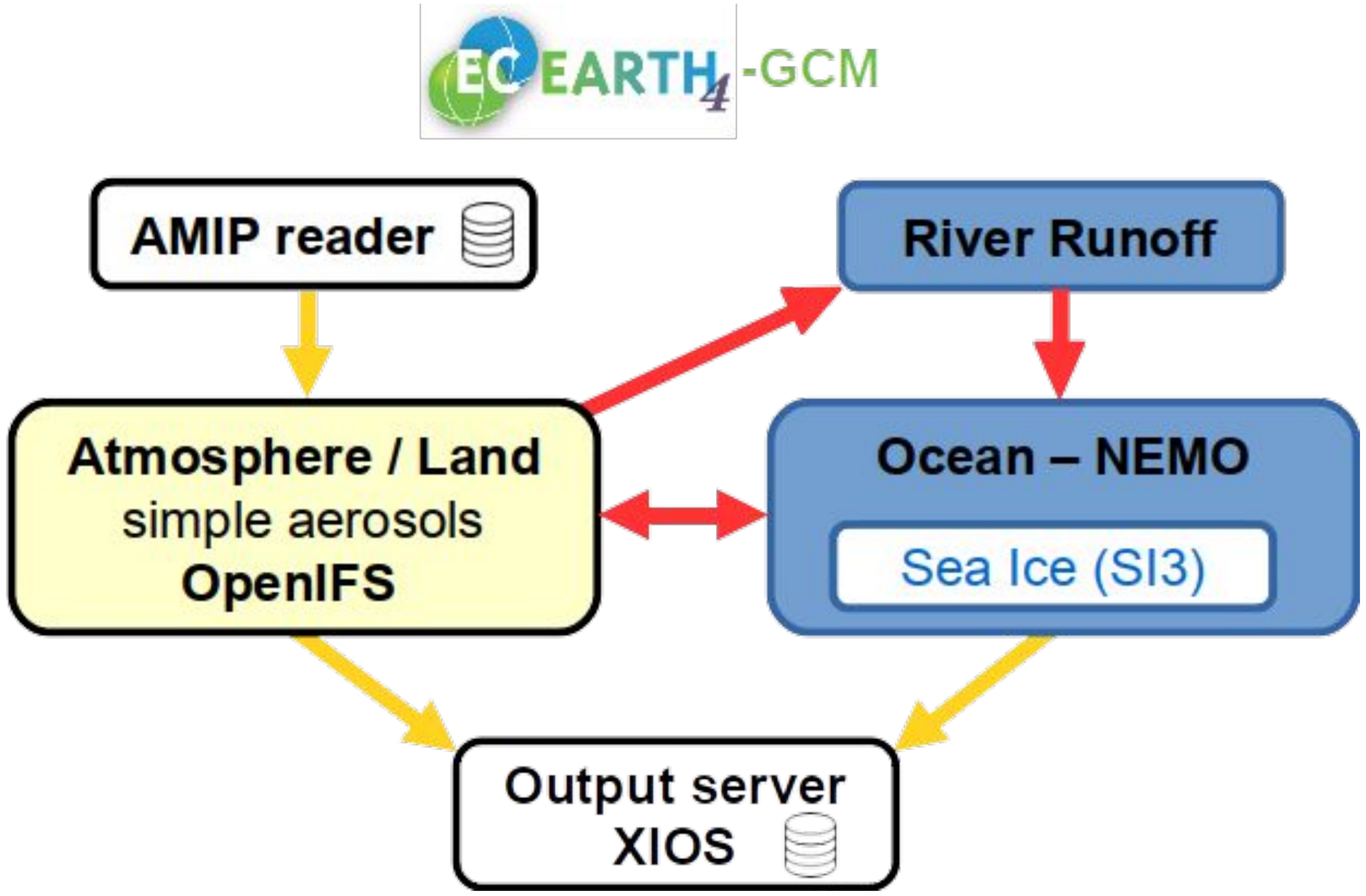
OpenIFS/CC Members

- **BSC** : Etienne Tourigny, Iria Ayan, Raffaele Bernardello
  - Etienne & Raffaele developed the c-cycle version of EC-Earth3 with TM5 for CO2 transport, linking CO2 to LPJ-GUESS (land/vegetation) and PISCES (OBGC)
  - Etienne & Iria working on CO2 transport in OpenIFS for EC-Earth4
  - OptimESM project: building EC-Earth4 for high resolution applications, to start production end 2024
- **WUR** : Wouter Peters,Anne-Wil van den Berg, Joram Hooghiem
  - CO2 transport for flux inversion with in OpenIFS to replace system using TM5 (nudged to ERA5)
  - CORSO global modeling project starting 1/1/2023
- **UU** : Gerbrand Koren
  - development of a set of simple biosphere fluxes at regional scale currently in testing
  - PhD-project with focus on tropical carbon exchange starting mid-2023
- **MPI BGC** : Alexander Winkler
  - OpenIFS to replace TM3 used to study atmospheric CO2 transport and sensitivity to land fluxes
- **AWI** : Judith Hauck, Christopher Danek
  - AWI-ESM3, similar to EC-Earth4 with FESOM
  - Interested in CO2 transport in OpenIFS, links to FESOM/REcoM for Ocean fluxes

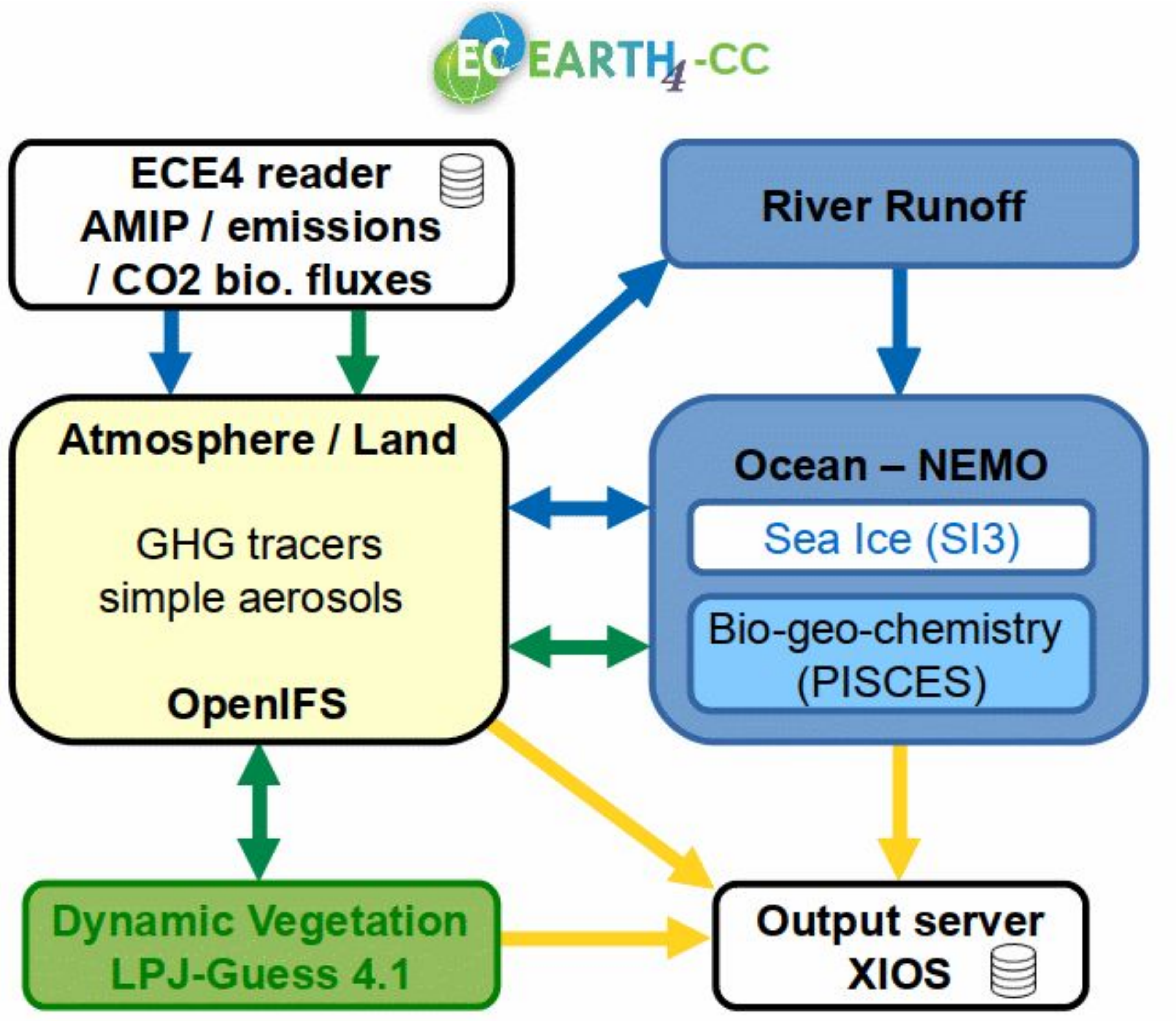
EC-Earth4

Earth System Model to advance process understanding and deliver evidence-based support for climate applications





EC-Earth4 roadmap / EC-Earth4-CC



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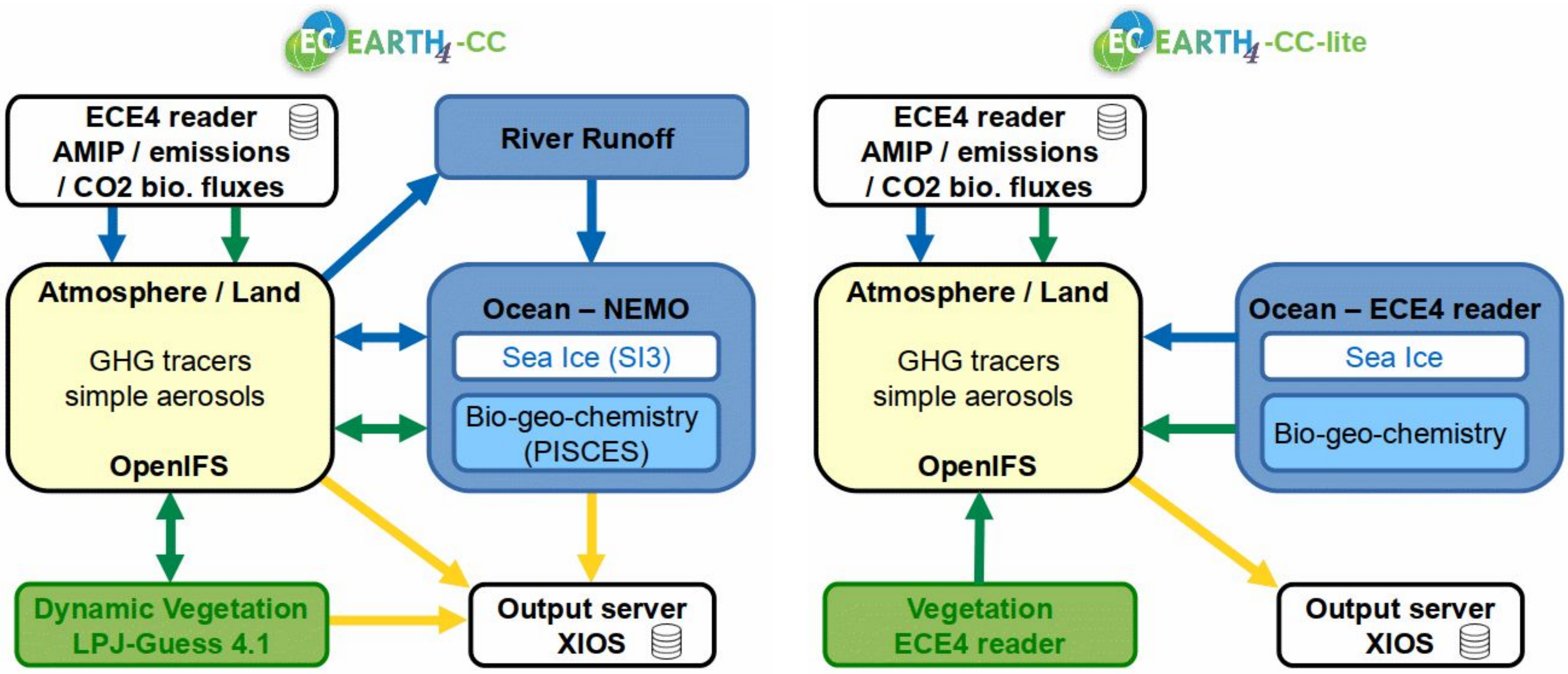

OpenIFS/CC Update

- EC-Earth4:
  - Currently runs on a few machines e.g. ECMWF HCP2020 (aka ATOS), BSC Marenostrum4
  - Simple AOGCM/AMIP setups without CMIP6 forcings
  - CMIP6 forcings and simplified aerosols to be available soon
  - contains updates to oifs43r3v2 (improved mass fixer), nemo 4.2 and oasis3-mct5 with python interface
  - Initial plan was to run on Tco95L91 grid, but this will probably change to Tl159 / Tl255
  - Hosted on SMHI github, access requires a licence for OpenIFS and is restricted to EC-Earth consortium members

- Nudging:
  - AWI has scripts & methods to do spectral nudging
  - need to be tested on other setup (e.g. ATOS)
  - BSC can download data and copy it to ATOS
  - need volunteer from OpenIFS/CC to test conversion and