Max Planck Institute for Biogeochemistry

Sources of Uncertainty in Regional and Global Terrestrial CO2 Exchange Estimates

NOAA Global Monitoring Laboratory Virtual Global Monitoring Annual Conference (eGMAC) 2020

Ana Bastos

M. O'Sullivan , P. Ciais, D. Makowski, S. Sitch, P. Friedlingstein, F. Chevallier, C. Rödenbeck, J. Pongratz, I. Luijkx, P. K. Patra, P. Peylin, J. G. Canadell , R. Lauerwald, W. Li, N. E. Smith, W. Peters, D. S. Goll, A.K. Jain, E. Kato, S. Lienert, D. L. Lombardozzi, V. Haverd, J. E.M. S. Nabel, B. Poulter, H. Tian, A. P.Walker, and S. Zaehle

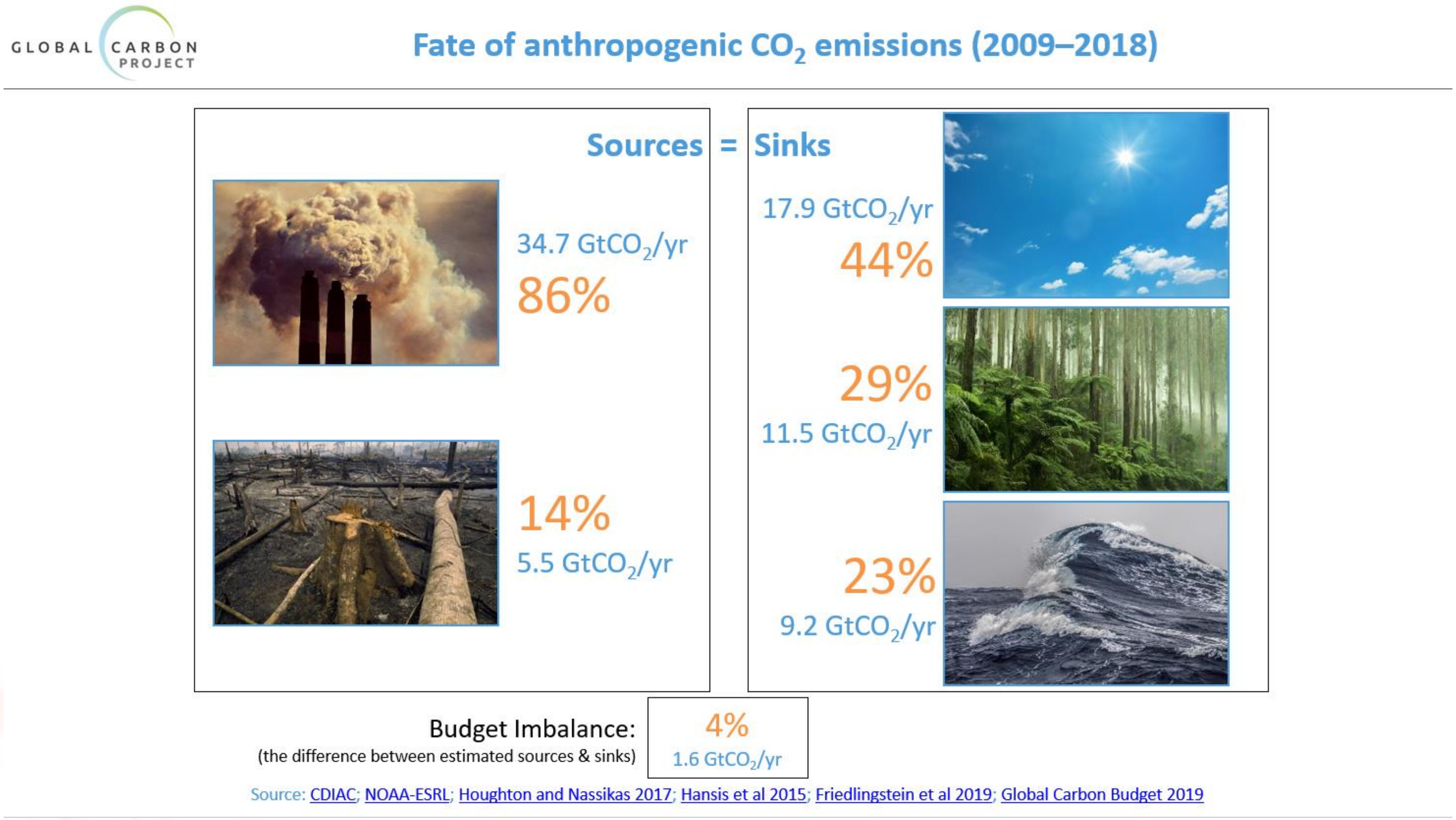
Social relevance of C budgets

*“so as to achieve **a <u>balance</u> between <u>anthropogenic emissions</u> by sources and removals by <u>sinks</u> of greenhouse gases** in the second half of this century [...]“*

Demands for the scientific community:

- Track accurately **anthropogenic** emissions AND **natural** sinks and sources at regional/country scale, <u>consistent with the global scale</u>;
- Understand and quantify **processes and feedbacks** between the carbon cycle and climate (past and future).

Global C budget and uncertainty



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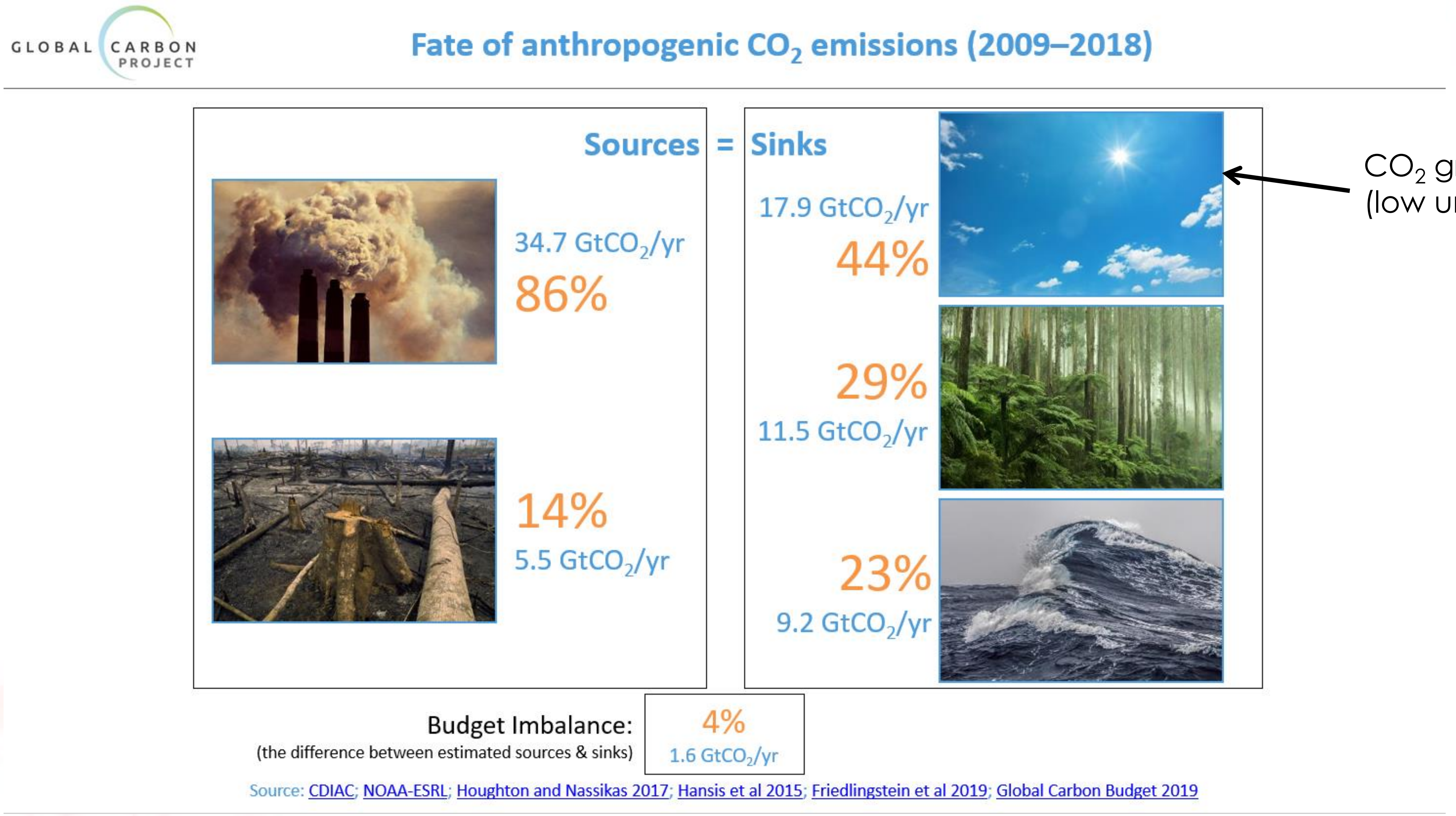
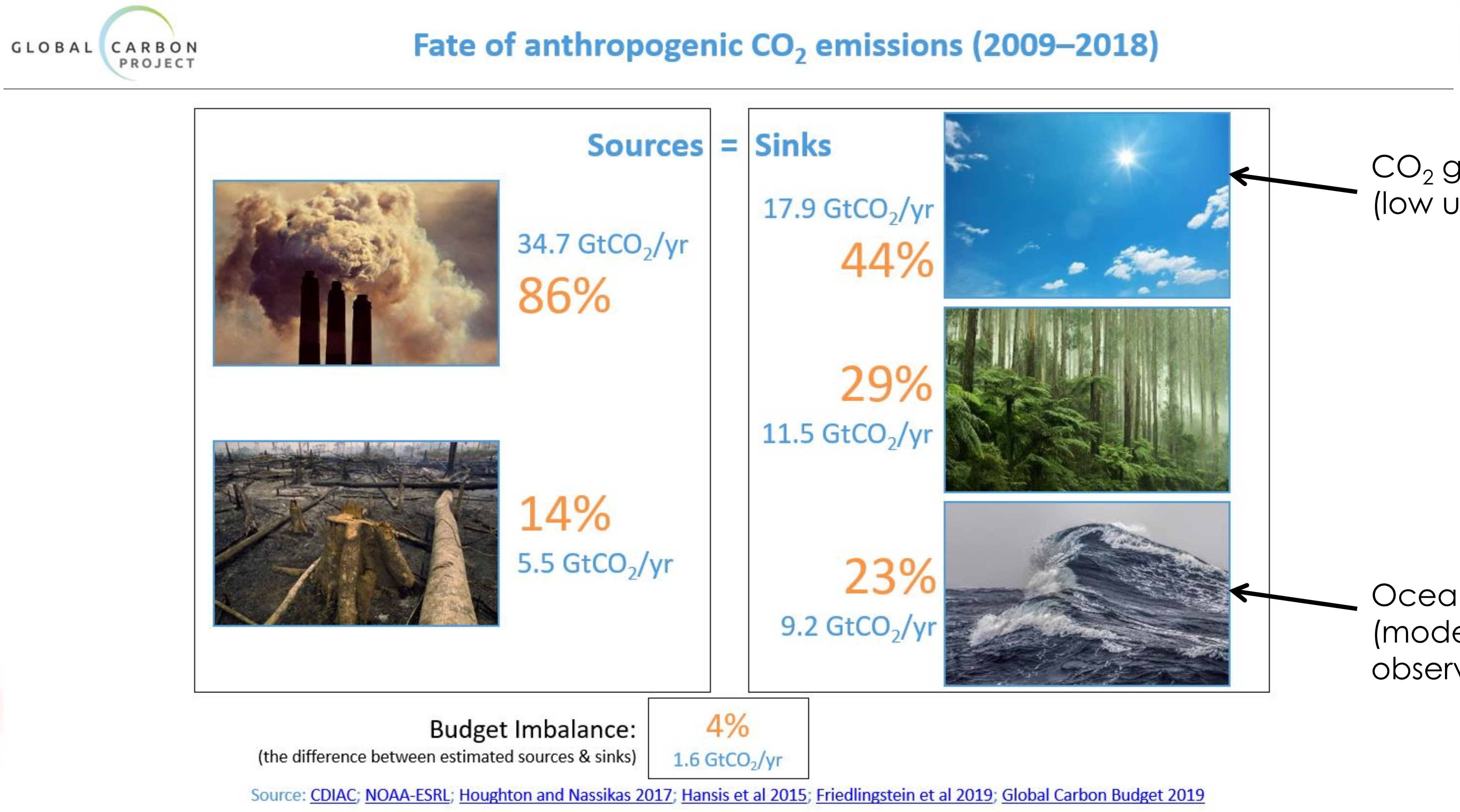


CO_2 growth rate
(low uncertainty)

Global C budget and uncertainty



CO_2 growth rate (low uncertainty)

Ocean sink (models and observations)

Global C budget and uncertainty

GLOBAL CARBON PROJECT

Fate of anthropogenic CO_2 emissions (2009–2018)

Sources = Sinks

Fossil fuel emissions (5-10% uncertainty)

34.7 $GtCO_2$/yr
86%

14%
5.5 $GtCO_2$/yr

17.9 $GtCO_2$/yr
44%

CO_2 growth rate (low uncertainty)

29%
11.5 $GtCO_2$/yr

23%
9.2 $GtCO_2$/yr

Ocean sink (models and observations)

Budget Imbalance: 4% 1.6 $GtCO_2$/yr
(the difference between estimated sources & sinks)

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Friedlingstein et al 2019; Global Carbon Budget 2019

Global C budget and uncertainty

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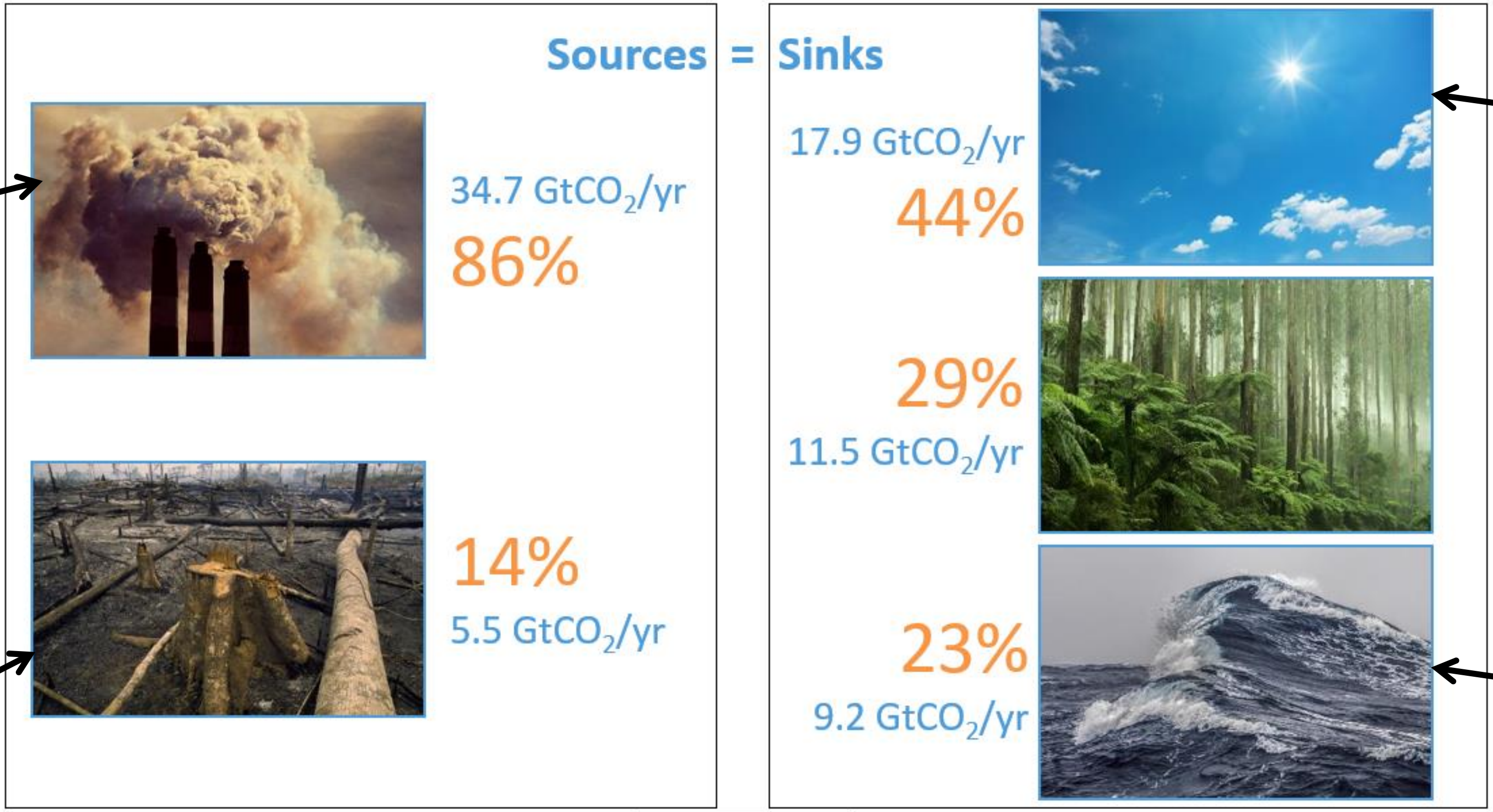
Land use change emissions (Bookkeeping models)



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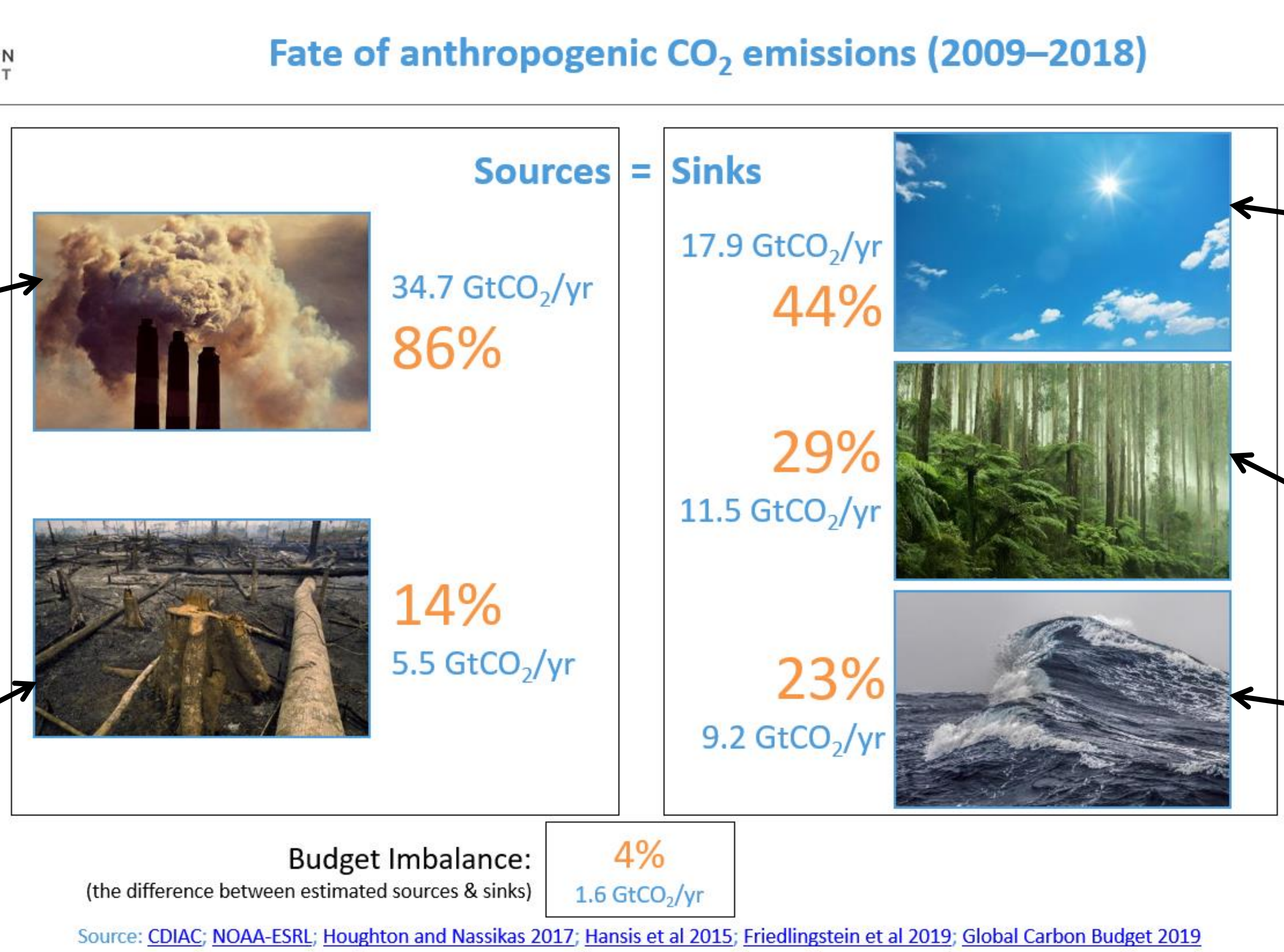


Fossil fuel emissions (5-10% uncertainty)

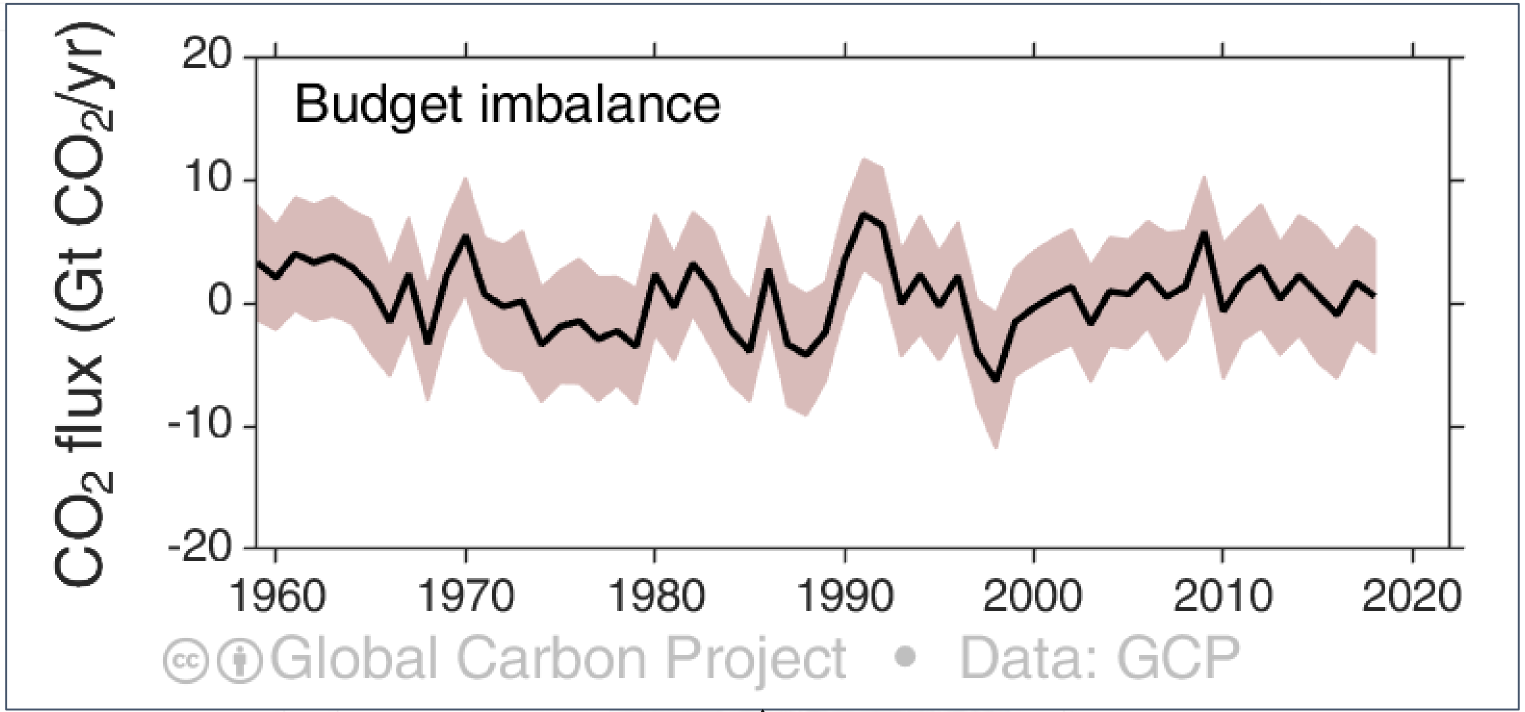
Land use change emissions (Bookkeeping models)

CO_2 growth rate (low uncertainty)

Global land sink (vegetation models)

Ocean sink (models and observations)

Global C budget and uncertainty



Budget Imbalance:
(the difference between estimated sources & sinks)

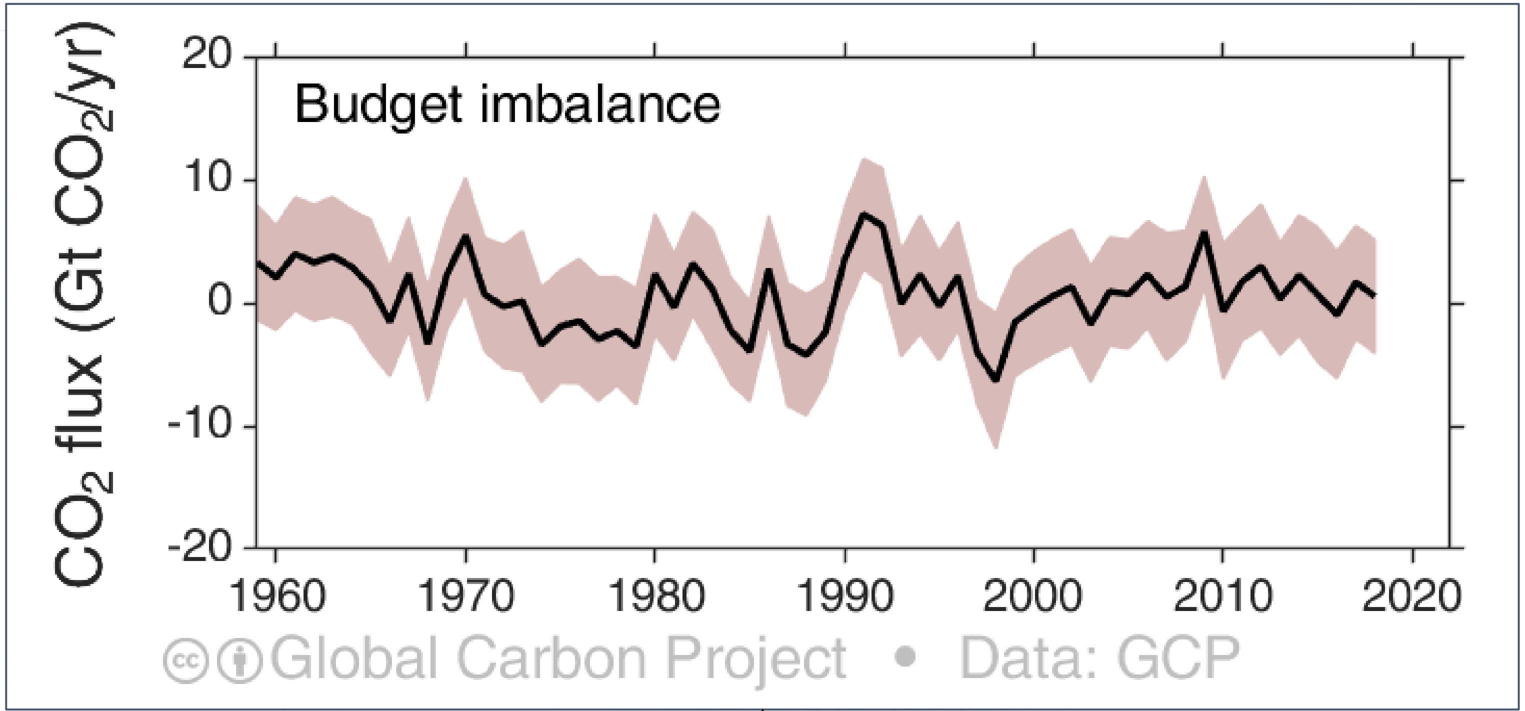
4%
1.6 $GtCO_2$/yr

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Friedlingstein et al 2019; Global Carbon Budget 2019

Global C budget and uncertainty

Budget imbalance 1960 - 2018:

- No significant trend
- Mean slightly positive, but not significantly ≠ 0
- High year-to-year and decadal variability



Budget Imbalance: 4% 1.6 $GtCO_2$/yr

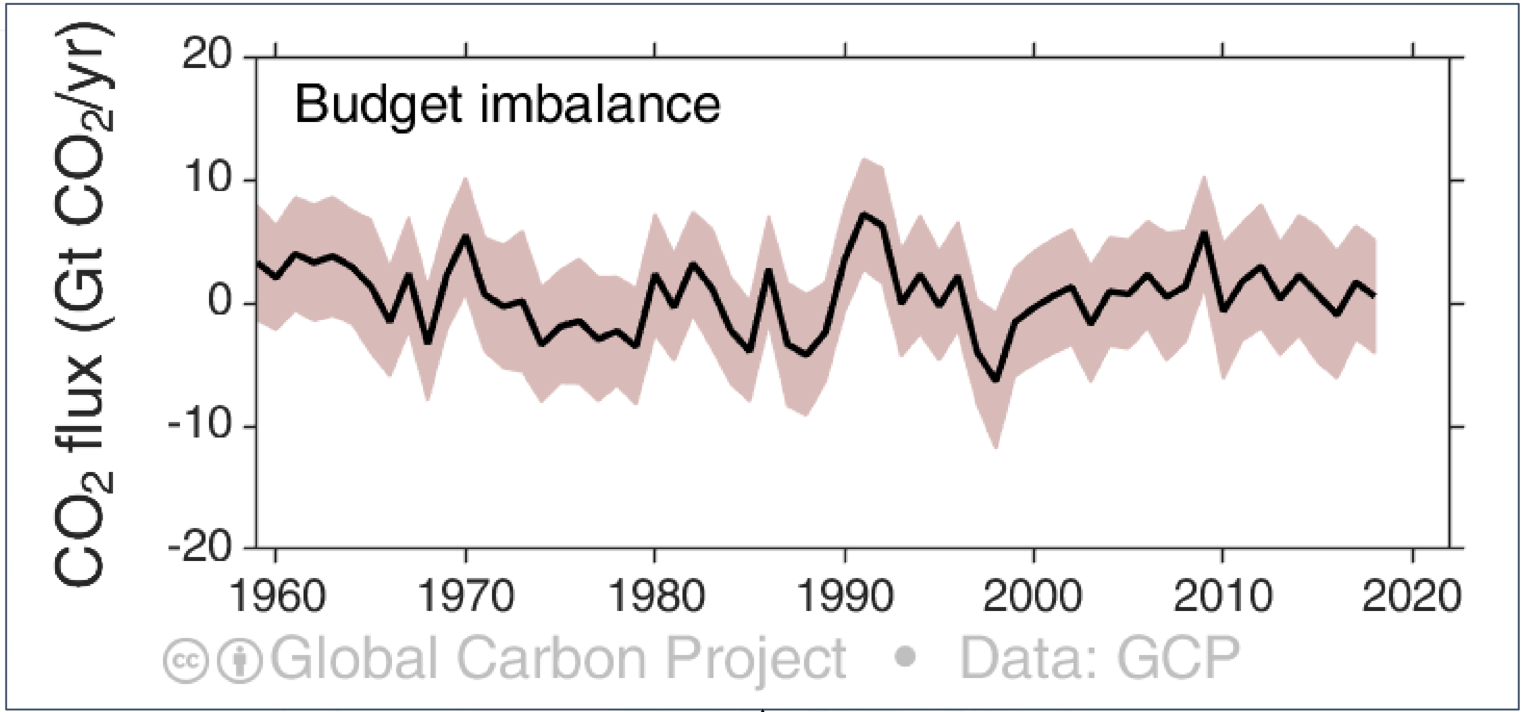
(the difference between estimated sources & sinks)

Source: CDIAC; NOAA-ESRL; Houghton and Nassikas 2017; Hansis et al 2015; Friedlingstein et al 2019; Global Carbon Budget 2019

Global C budget and uncertainty

Can we identify the sources of uncertainty in global C budget estimates?

- Specific regions?
- Specific datasets?
- Specific processes?



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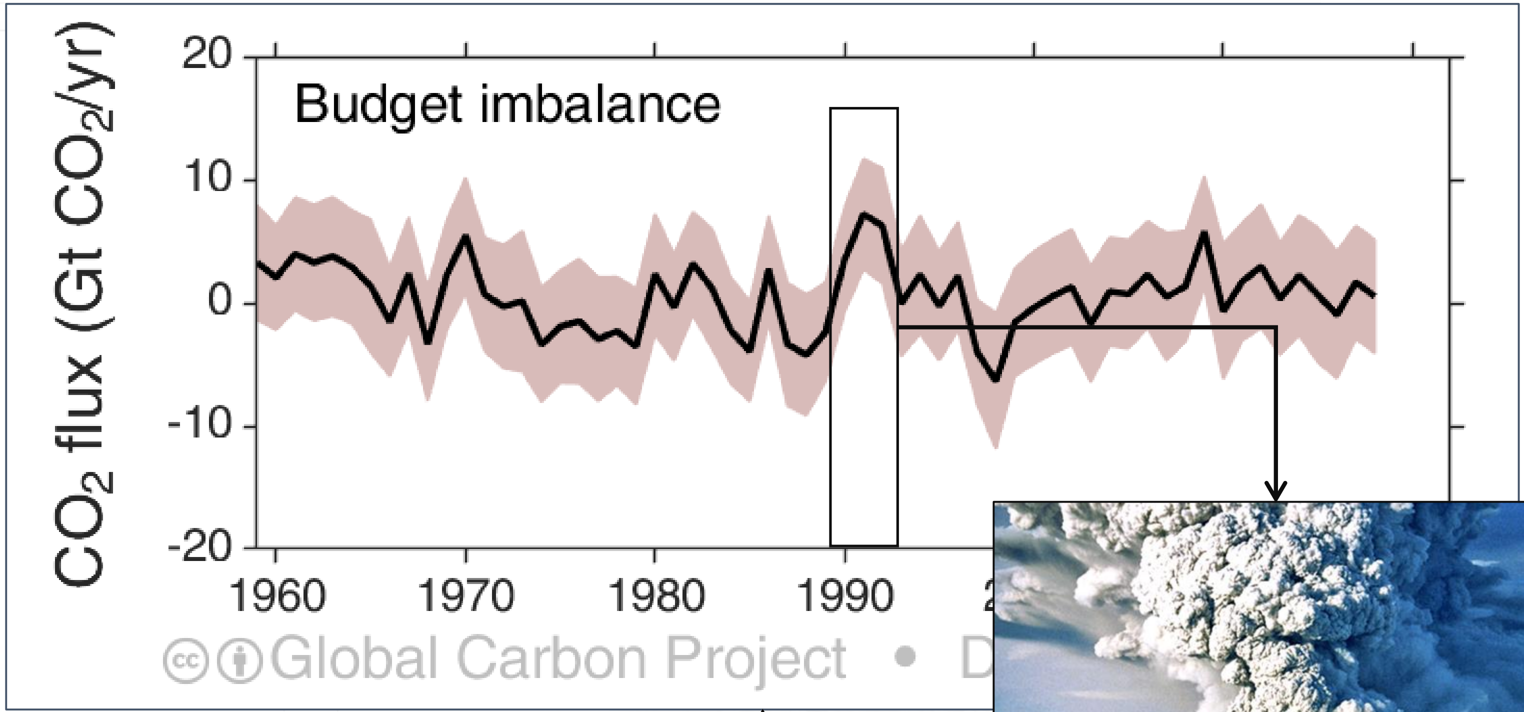

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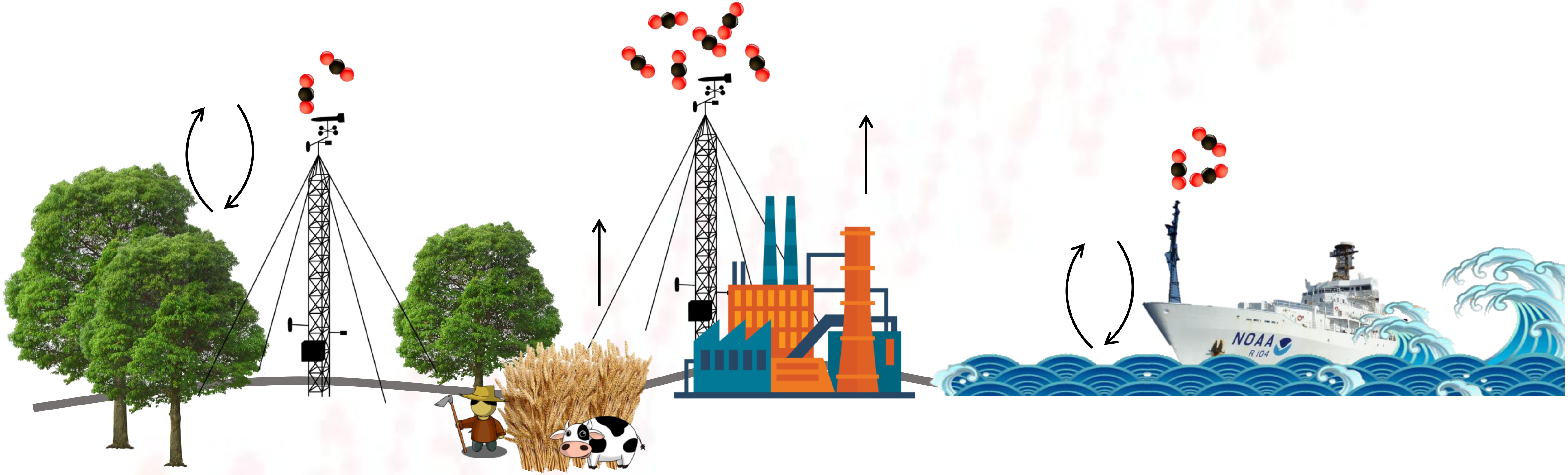
Quantifying C fluxes

Atmospheric inversions from CO_2 concentration measurements
(top-down: what the atmosphere "sees")



Process based vegetation / ocean models, inventories
(bottom-up estimates)

Quantifying C flux uncertainty

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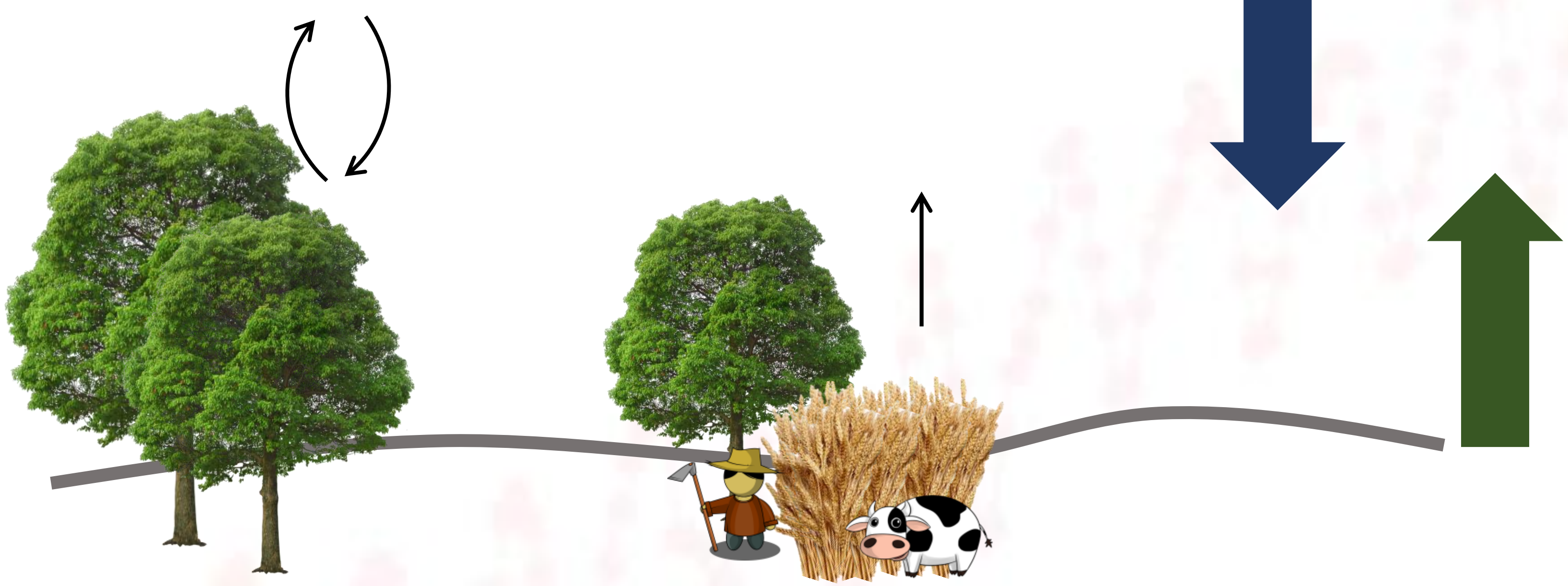


5 Atmospheric inversions
- Net land-atmosphere CO2 flux
- Corrected for fossil fuel emissions & lateral fluxes

16 Land Surface Models
- Net land-atmosphere CO2 flux (NBP)
- models simulate natural sink + land-use change fluxes
- miss lateral C transport, disturbances

Process based land-surface models
(bottom-up estimates)

Quantifying C flux uncertainty

LSMs

Inversions

5 Atmospheric inversions

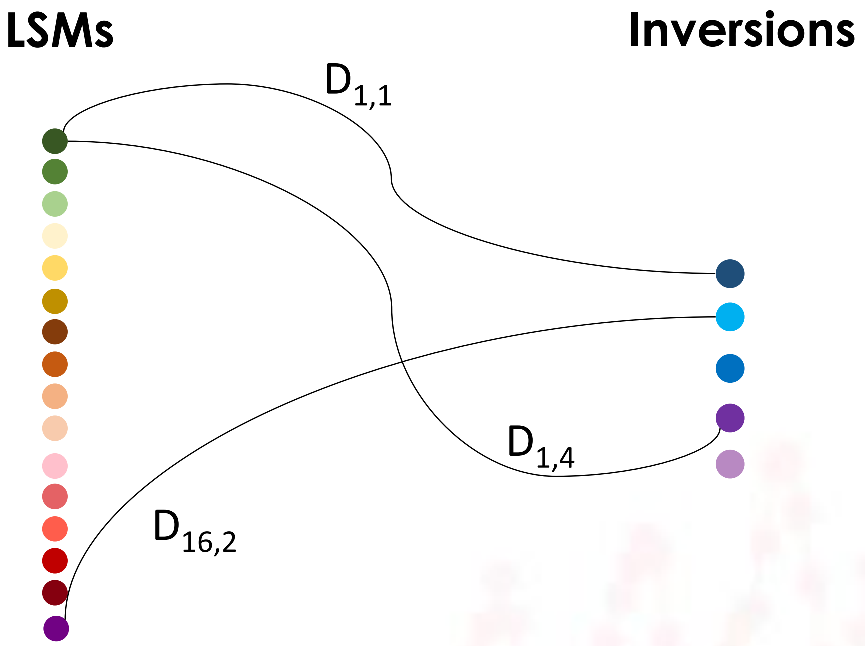
CAMS
CarboScope s76, s85
MIROC
CarbonTracker Europe

16 Land Surface Models (LSMs)

TRENDYv7 (GCB2018)

Bastos et al. 2020, GBC

Quantifying C flux uncertainty



5 Atmospheric inversions

CAMS
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16 Land Surface Models (LSMs)

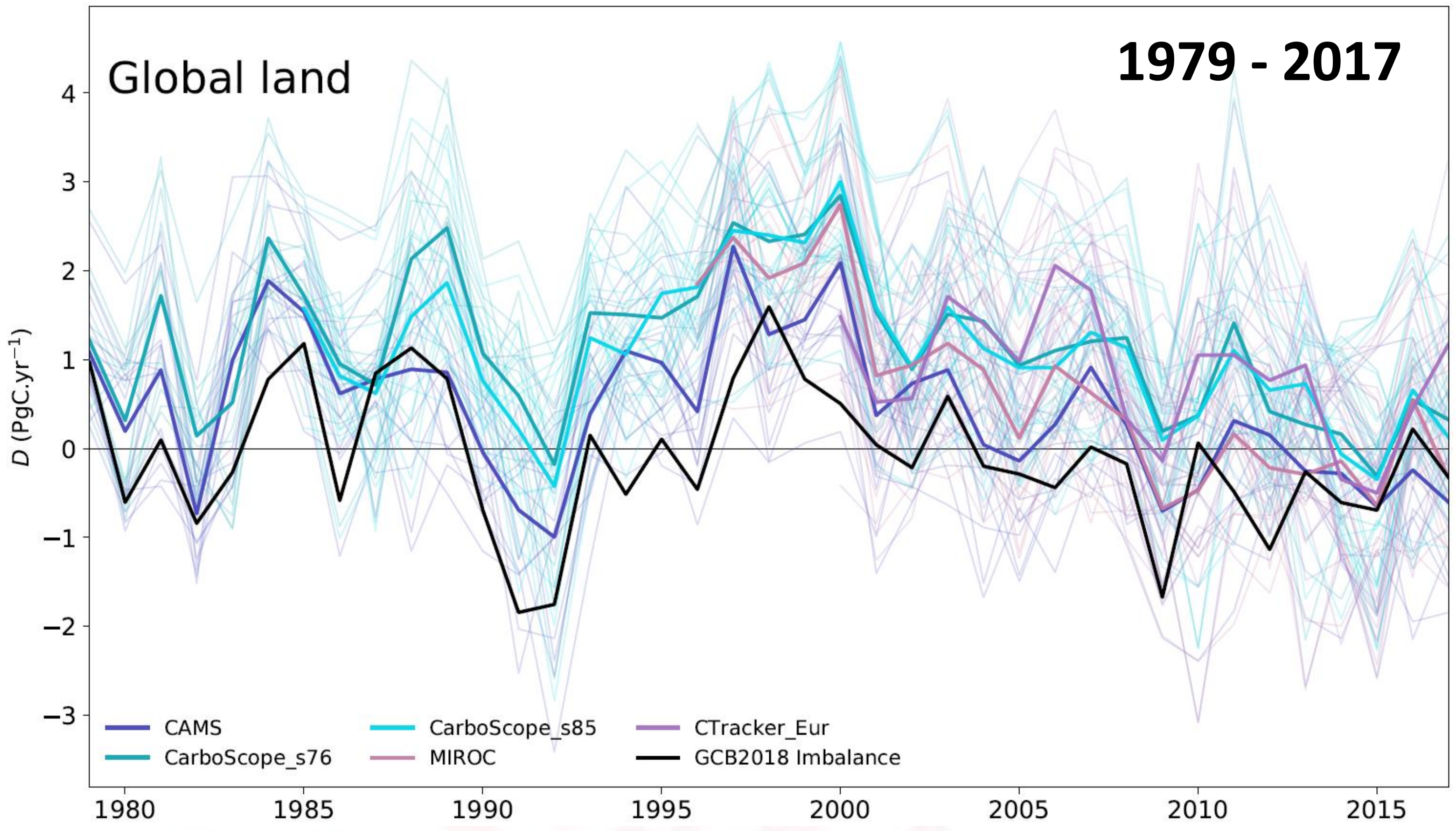
TRENDYv7 (GCB2018)

$$D_{ikj} = LSM_{ij} - INV_{kj}$$

→ **80 combinations of *(inversion, LSM)* differences**

Bastos et al. 2020, GBC

Global differences



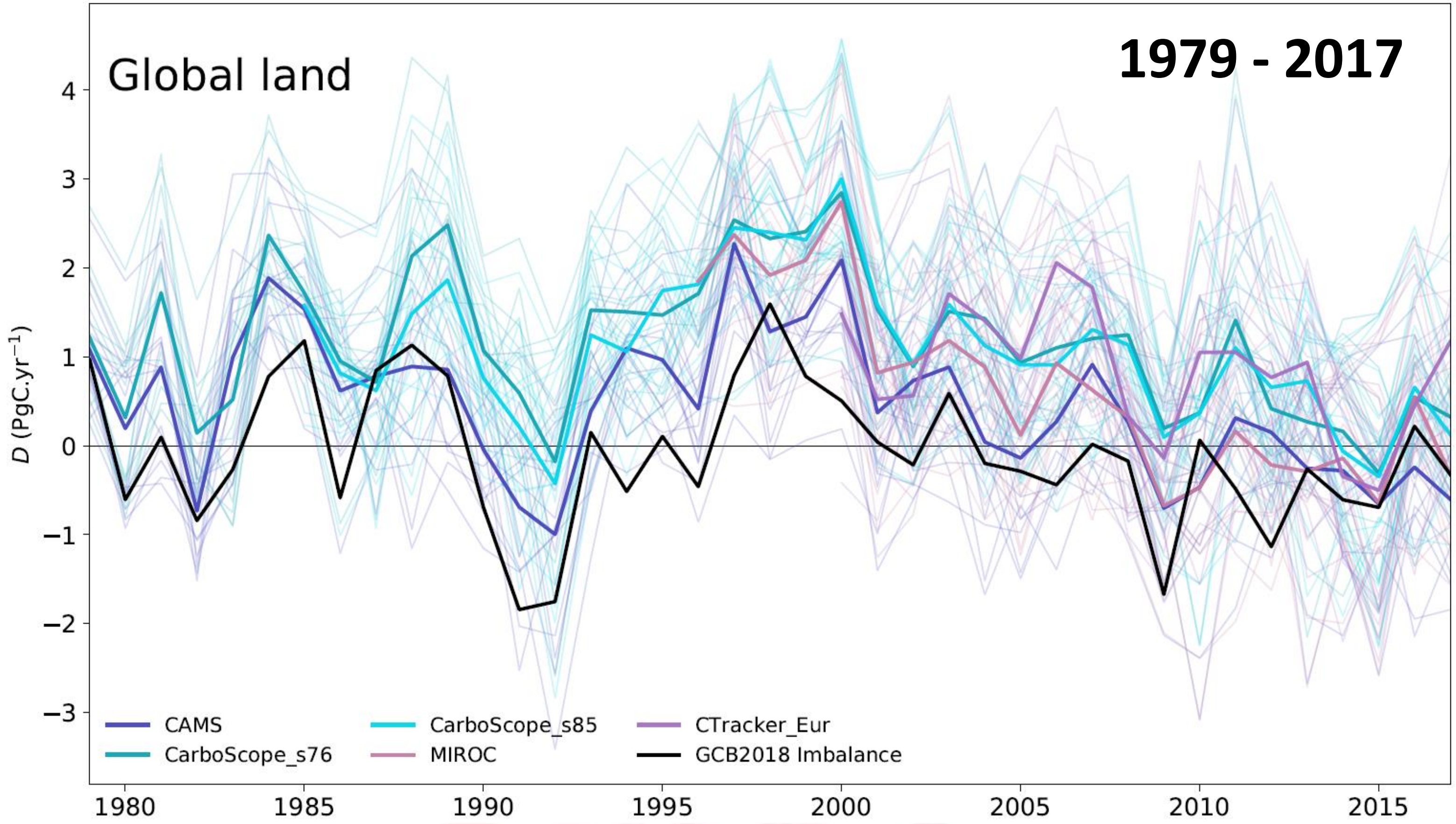
CAMS
CarboScope_s76
CarboScope_s85
MIROC
CTracker_Eur
GCB2018 Imbalance

Positive D:
LSMs stronger sink / smaller source than inversions

Negative D:
LSMs weaker sink / stronger source than inversions

Bastos et al. 2020, GBC

Global differences



CAMS | CarboScope_s85 | CTracker_Eur
CarboScope_s76 | MIROC | GCB2018 Imbalance

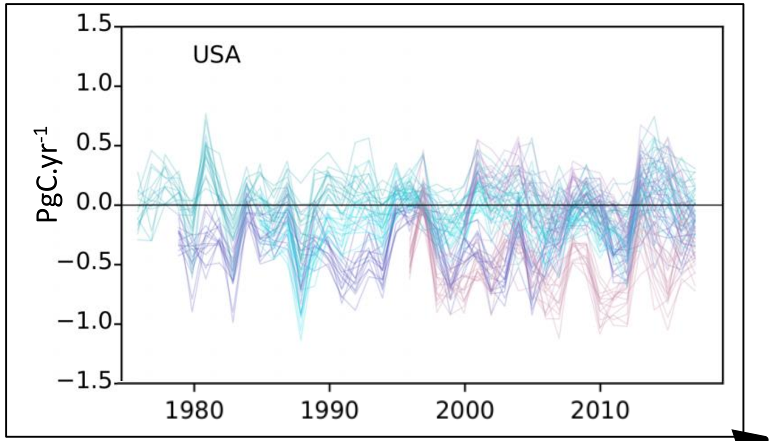
No significant trends for most pairs

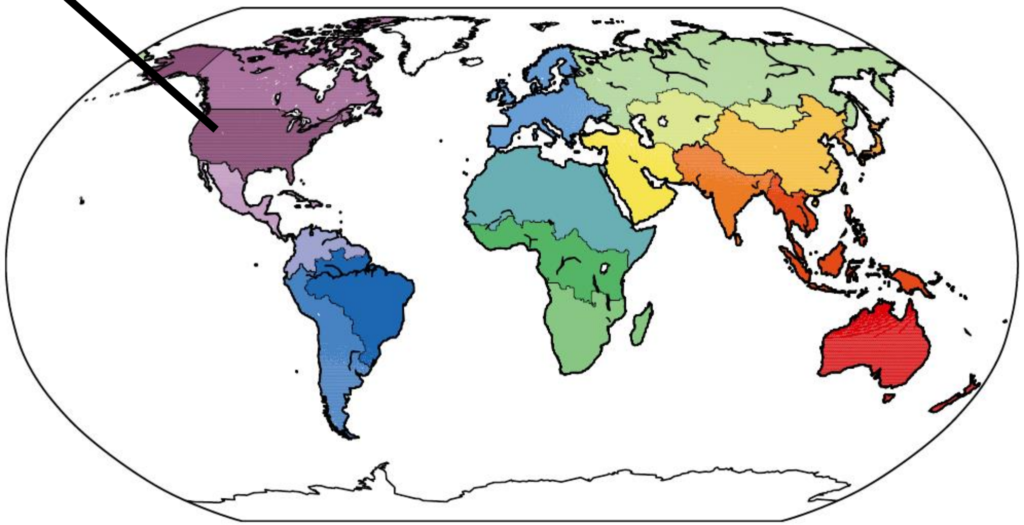
Similar variability to the "budget imbalance" term in GCB2018 (black)

Spread of D = 0.9 $PgC.yr^{-1}$

Bastos et al. 2020, GBC

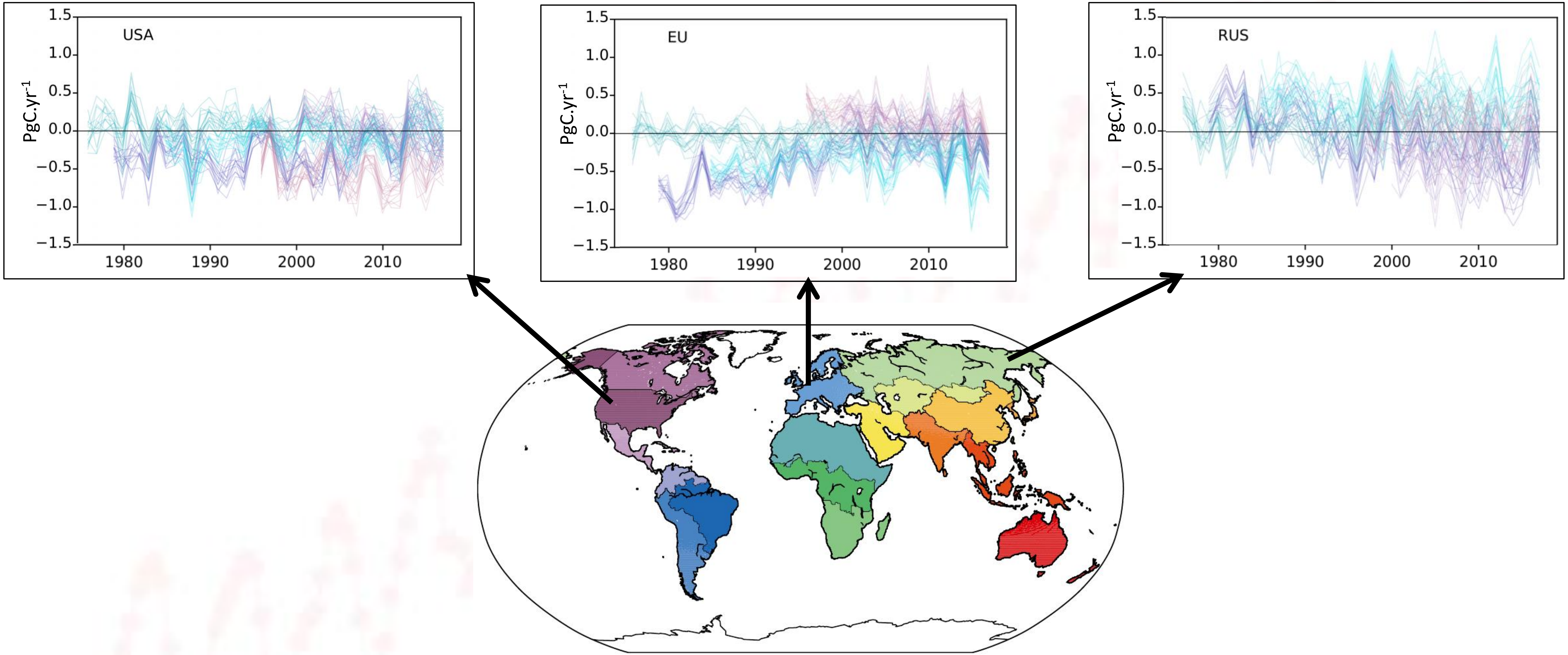
Regional differences





Bastos et al. 2020, GBC

Regional differences



Bastos et al. 2020, GBC

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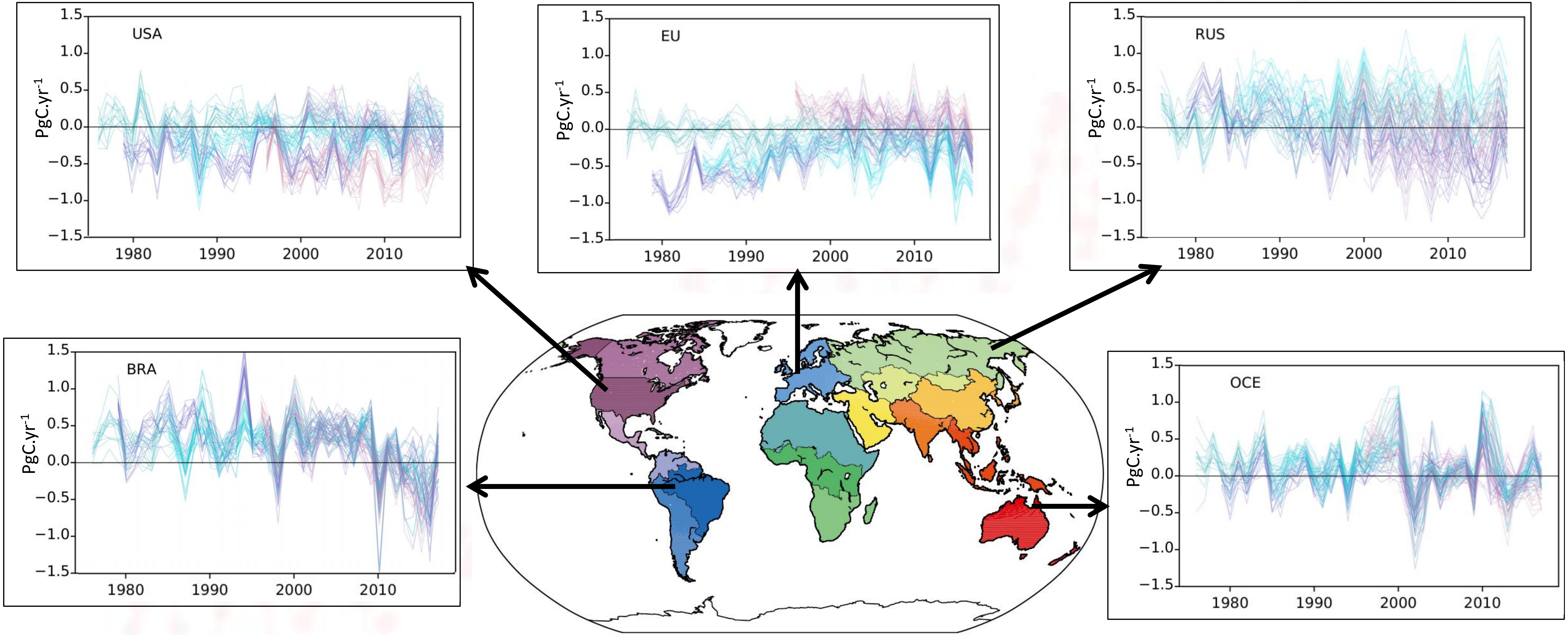


Bastos et al. 2020, GBC

Modelling LSM-inversion differences

For each region and globe, we fit a linear mixed effects statistical model:

$$D_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \epsilon_{ijk}$$

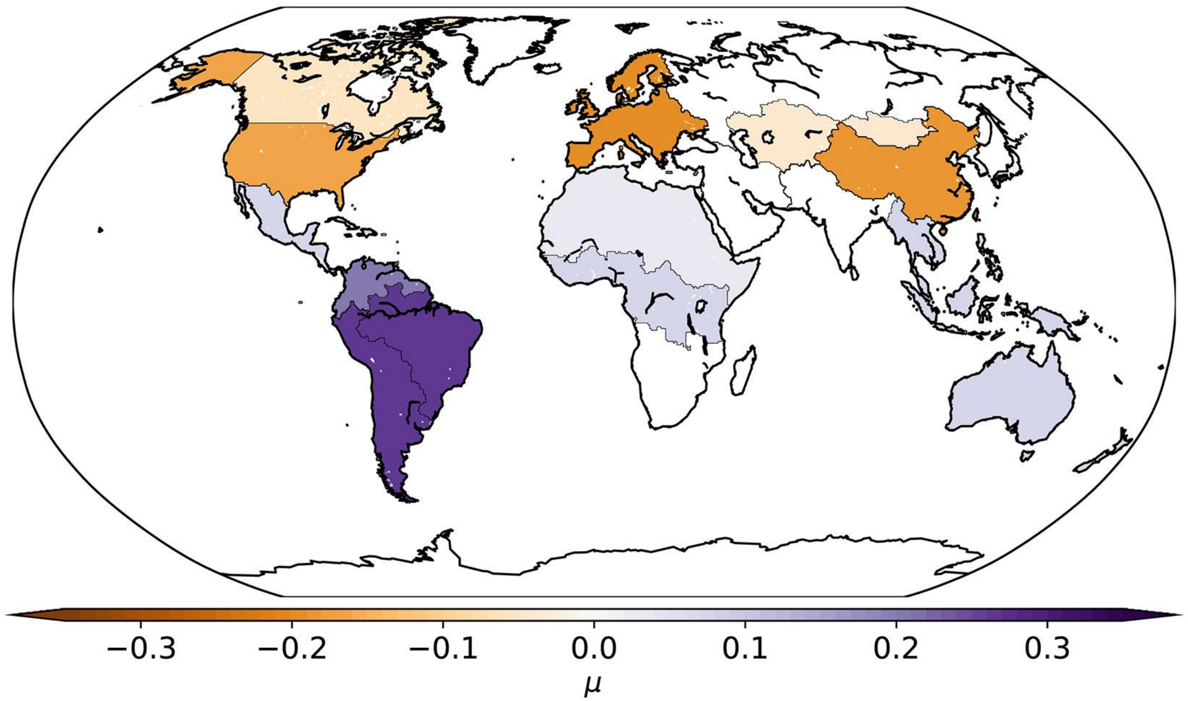
- μ: **Bias (average error)**
- α_i: **Model variability**
- β_j: **IAV**
- γ_{ij}: **Model:IAV**
- ϵ_{ijk}: **Inversion variability**

+ Time (trend)
+ ENSO
+ Land-use change emissions

For each region choose the best model (lowest AIC)

Bastos et al. 2020, GBC

Modelling LSM-inversion differences



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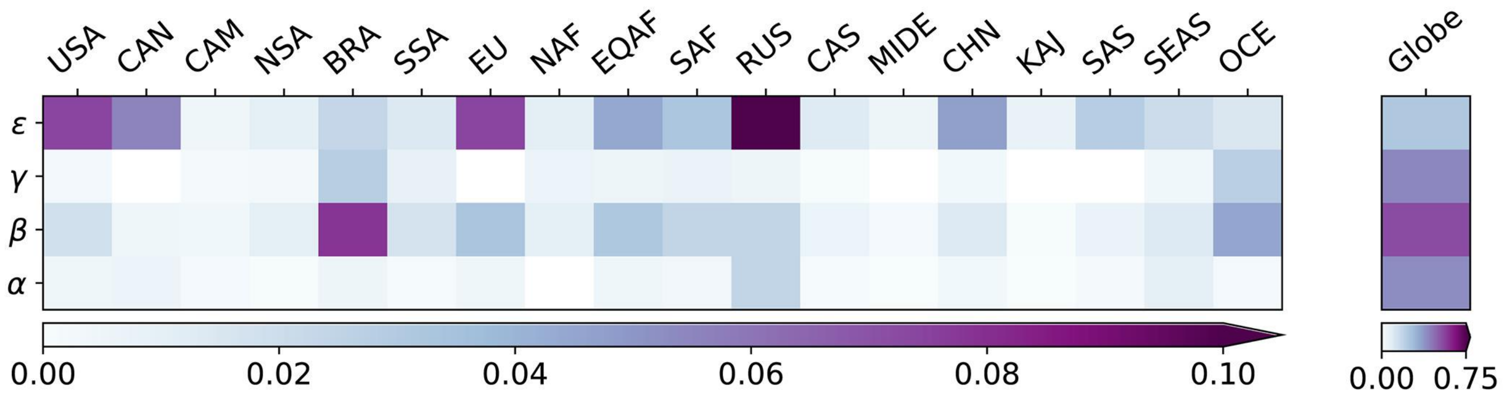
Bias (average error)

Model variability

IAV

Model:IAV

Inversion variability

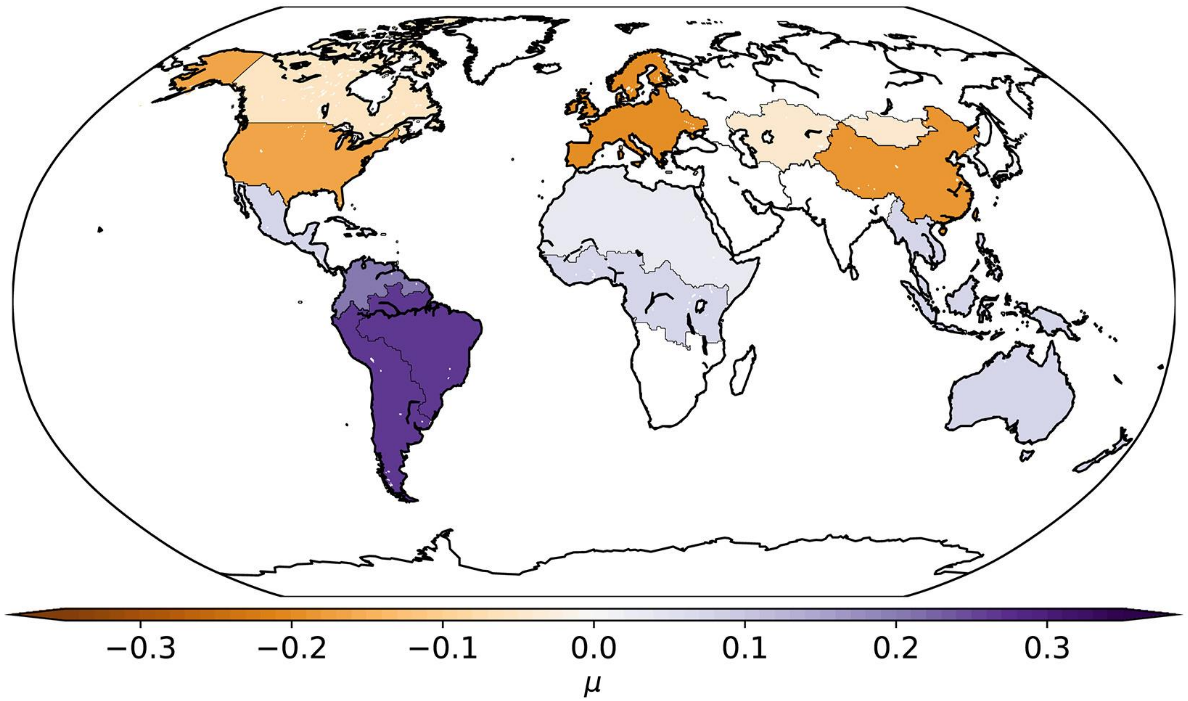


Large differences in regions well constrained by observations

- Fossil fuel emissions?
- Spatial resolution?
- N-deposition?
- Other?

Bastos et al. 2020, GBC

Modelling LSM-inversion differences



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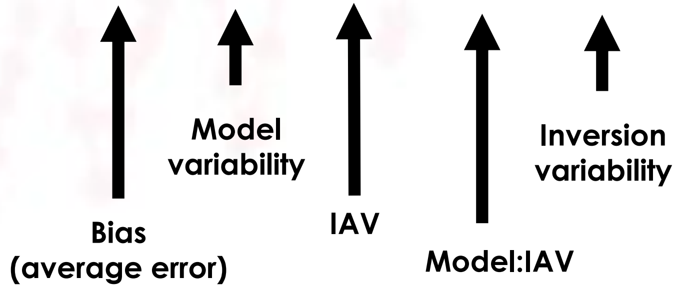

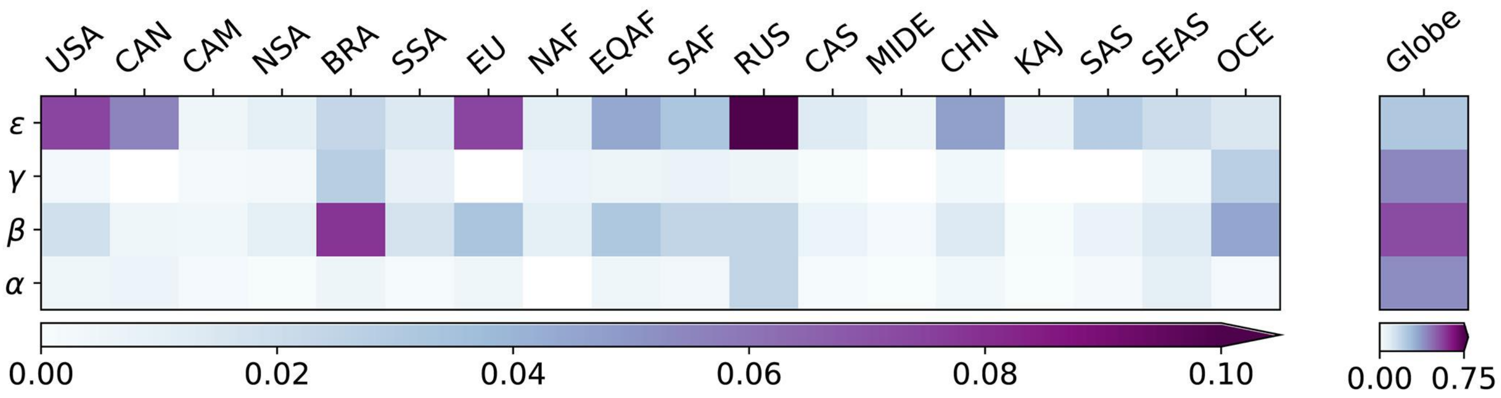

Bastos et al. 2020, GBC

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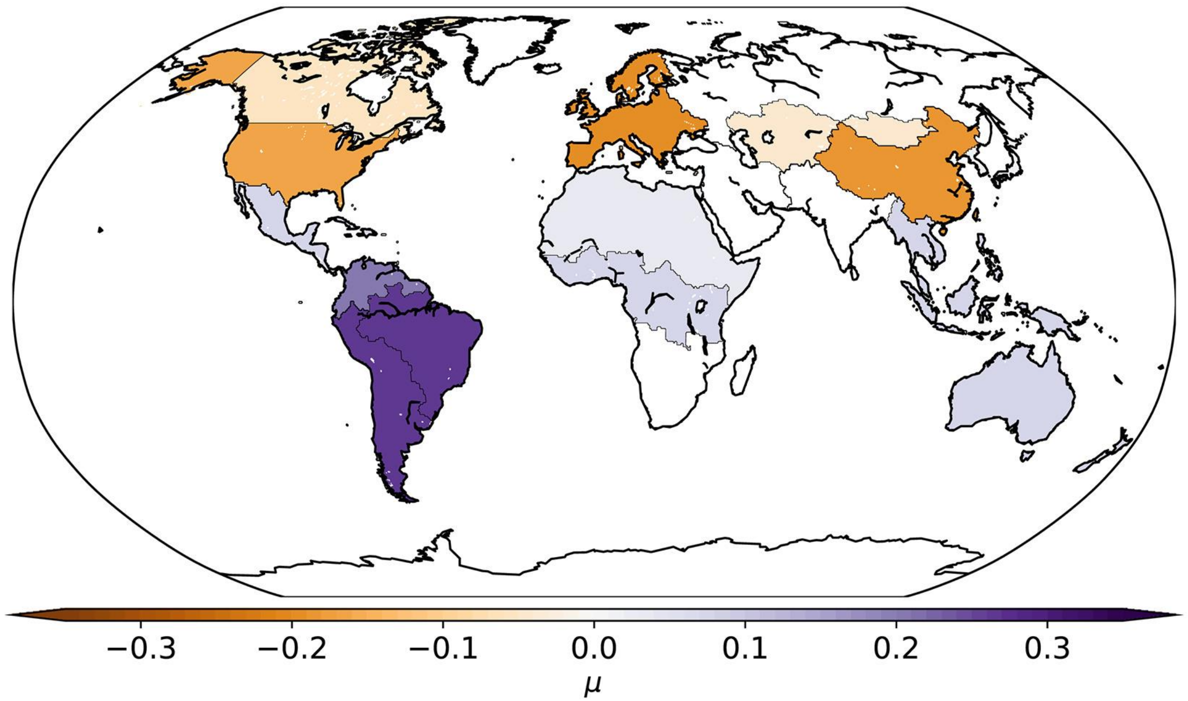

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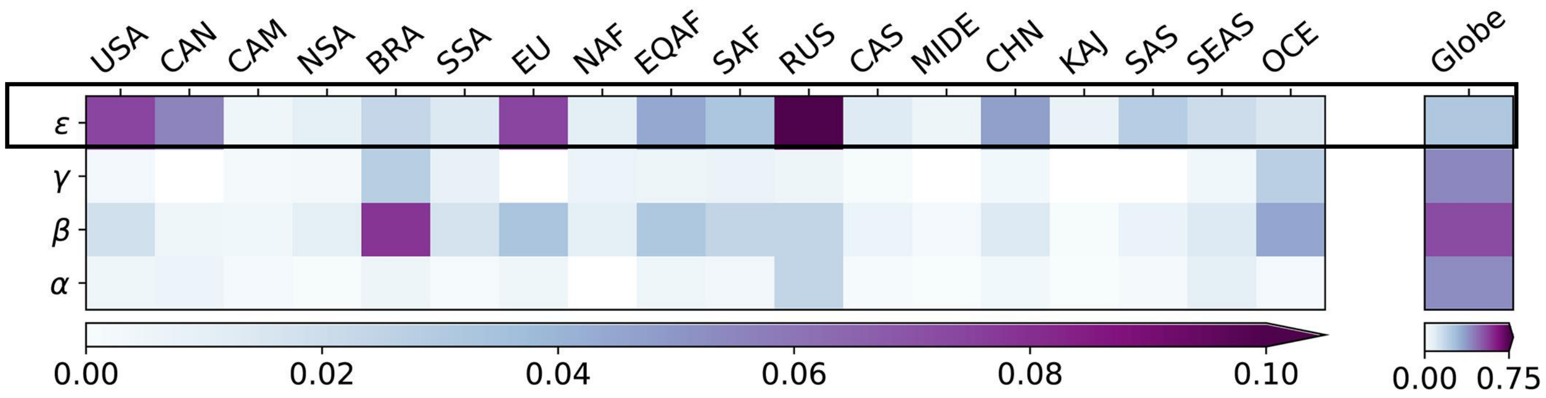
Bias (average error)

Model variability

IAV

Model:IAV

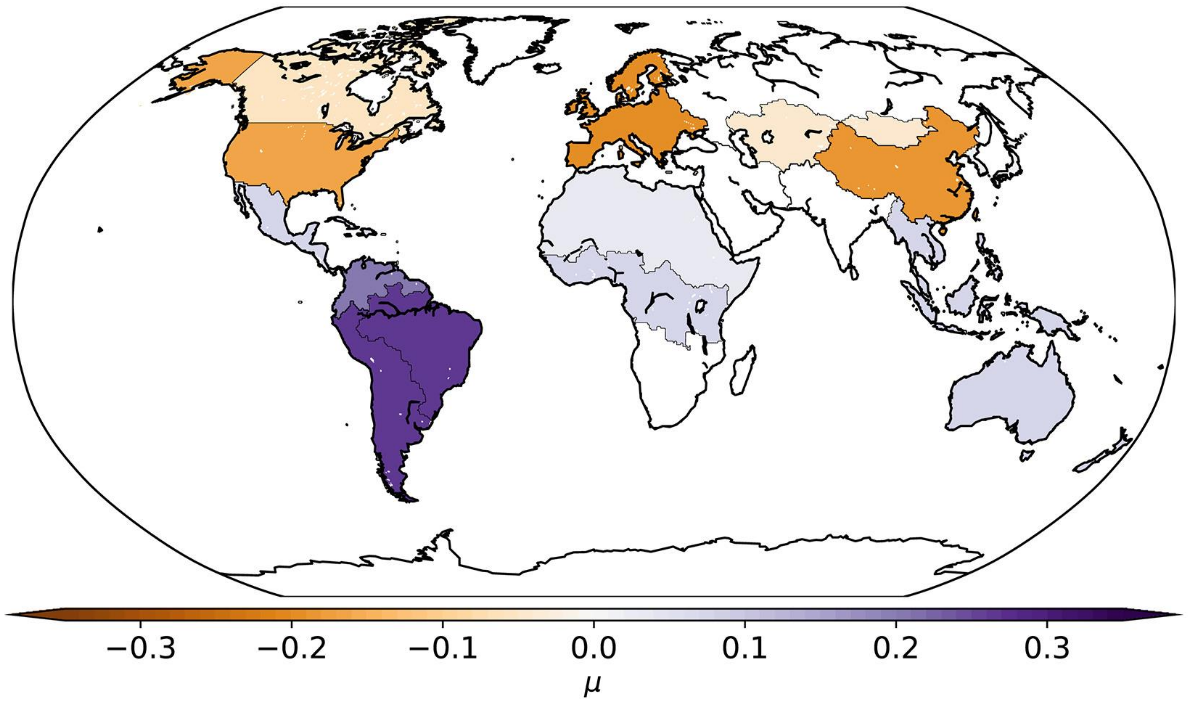
Inversion variability



Inversion uncertainty dominates at regional scale, but global well constrained

Bastos et al. 2020, GBC

Modelling LSM-inversion differences



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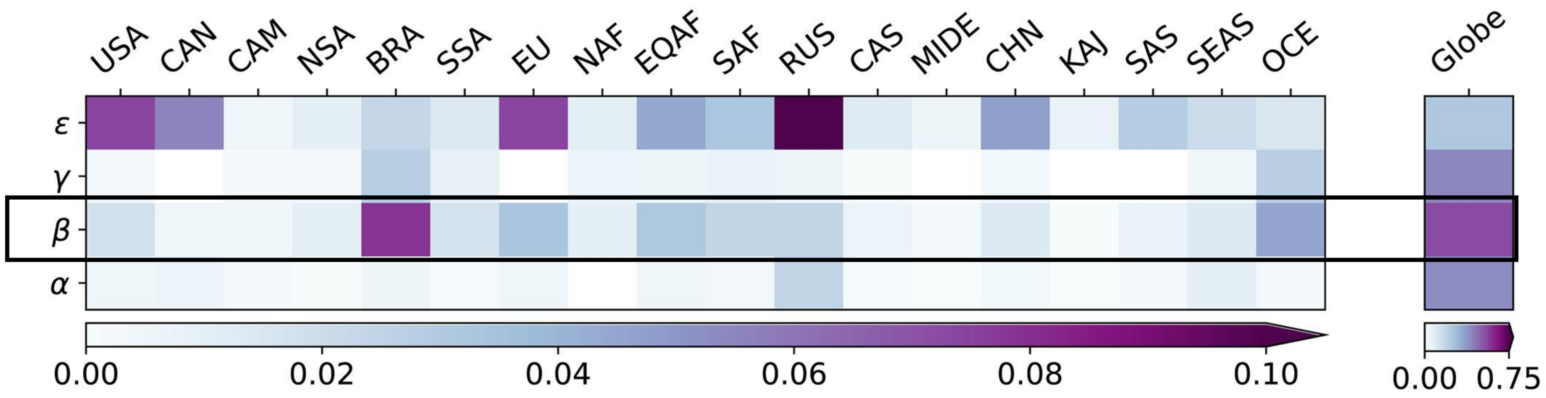
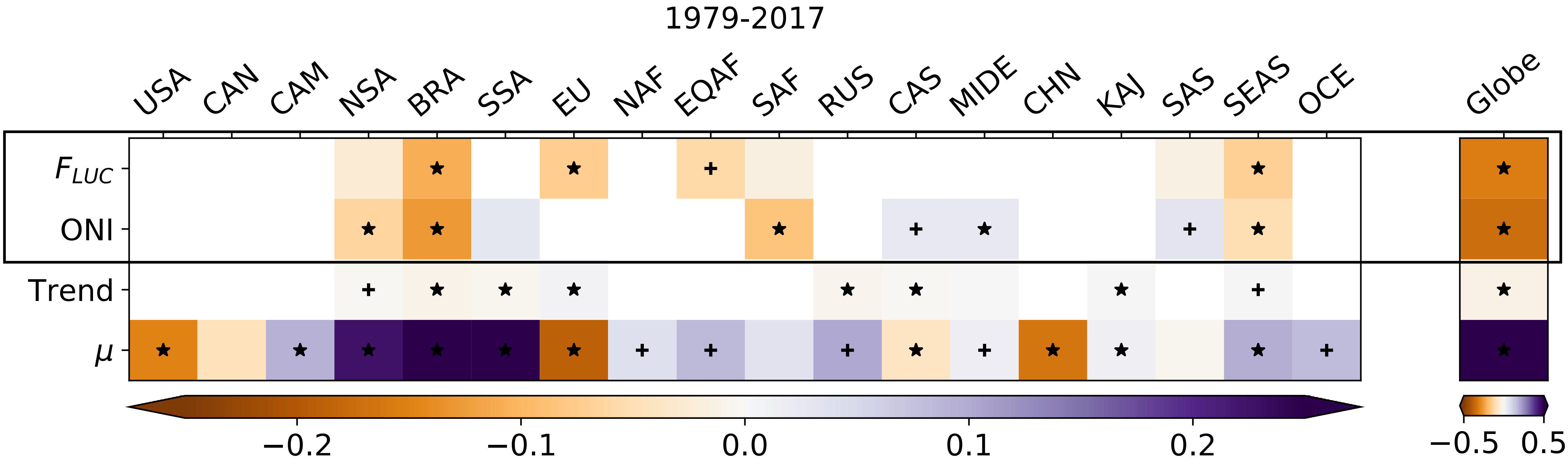


Inversion uncertainty dominates at regional scale, but global well constrained

Inter-annual variability dominant at the global scale and some regions

Bastos et al. 2020, GBC

LSM-inversion differences attribution

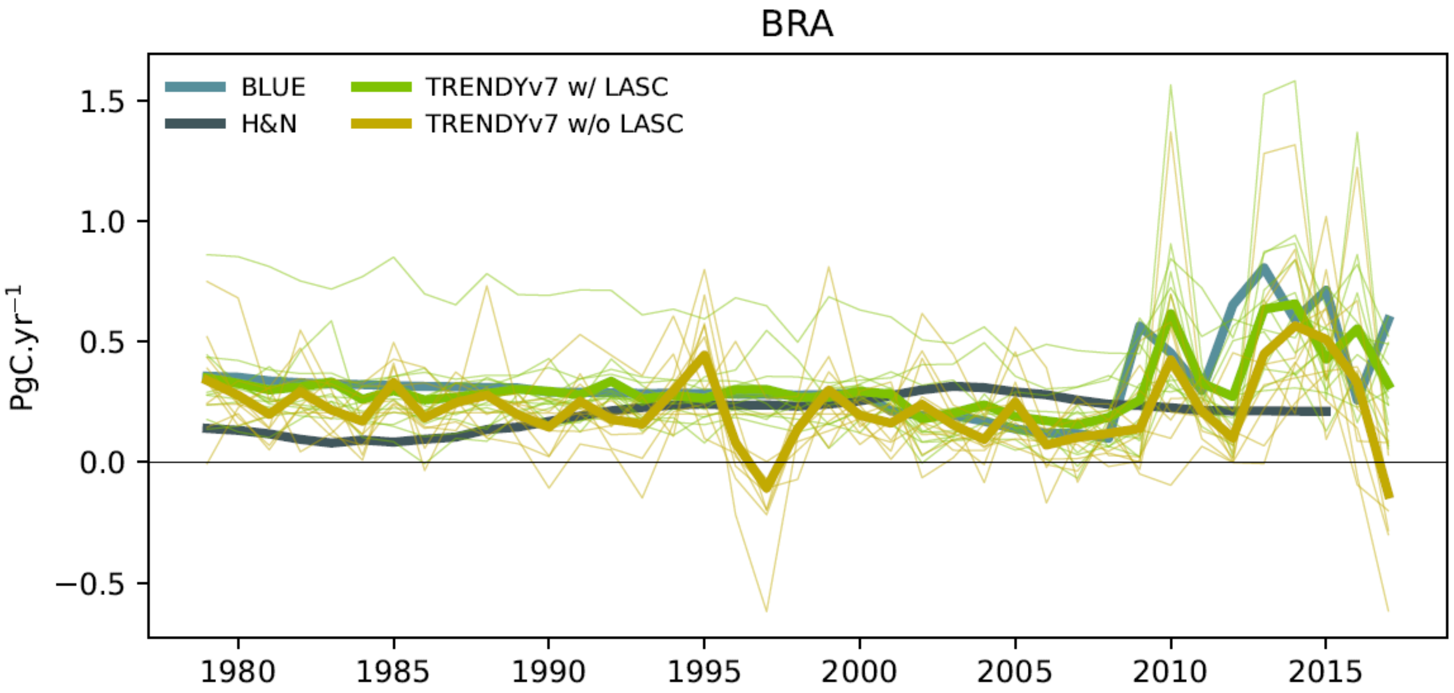


LSMs smaller sink / stronger source than inversions

LSMs stronger sink / smaller source than inversions

Bastos et al. 2020, GBC

Example: emissions from land use change



ELUC estimated by LSMs (yellow, green) compared to 2 bookkeeping models (blue)

- BLUE (Hansis et al. 2015)
- HN2017 (Houghton & Nassikas 2017)

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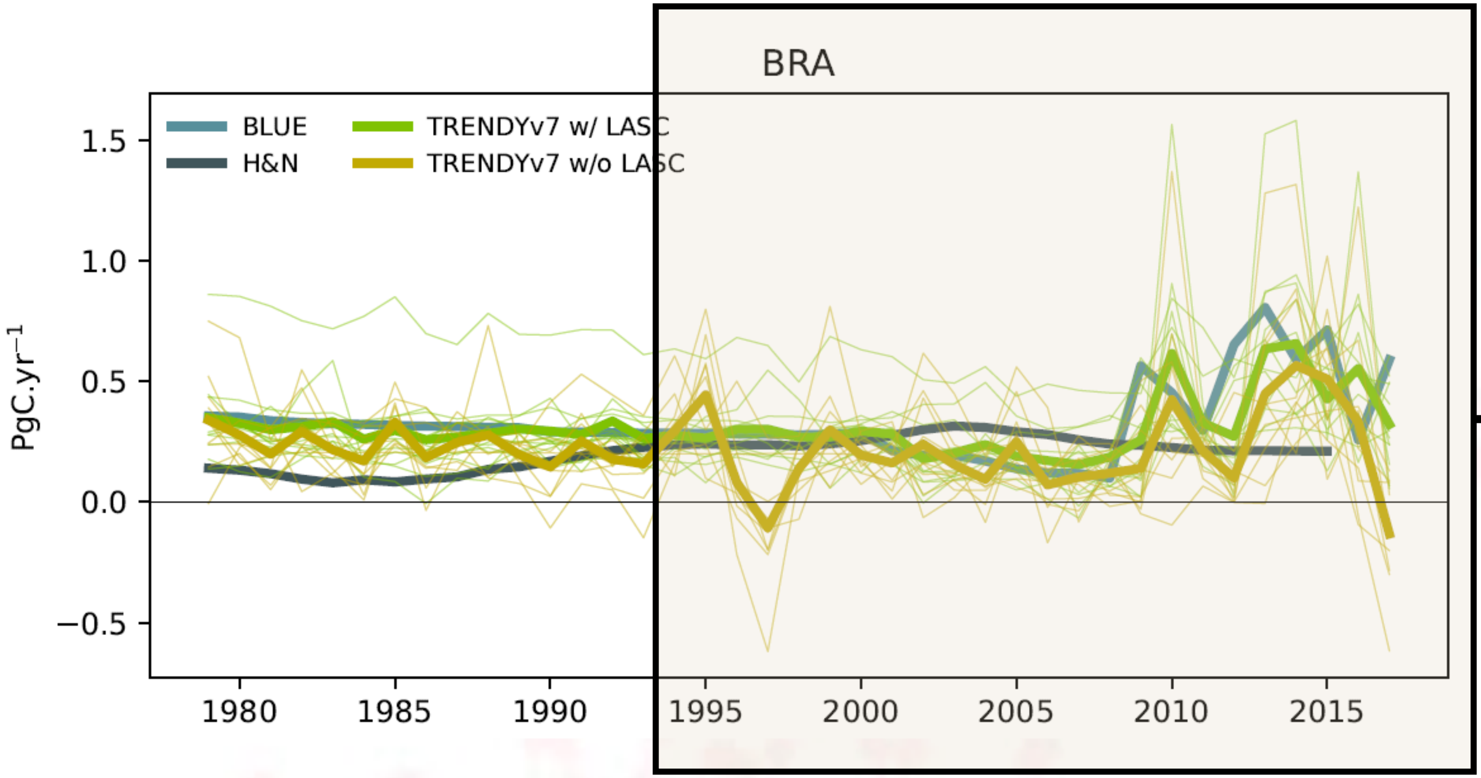
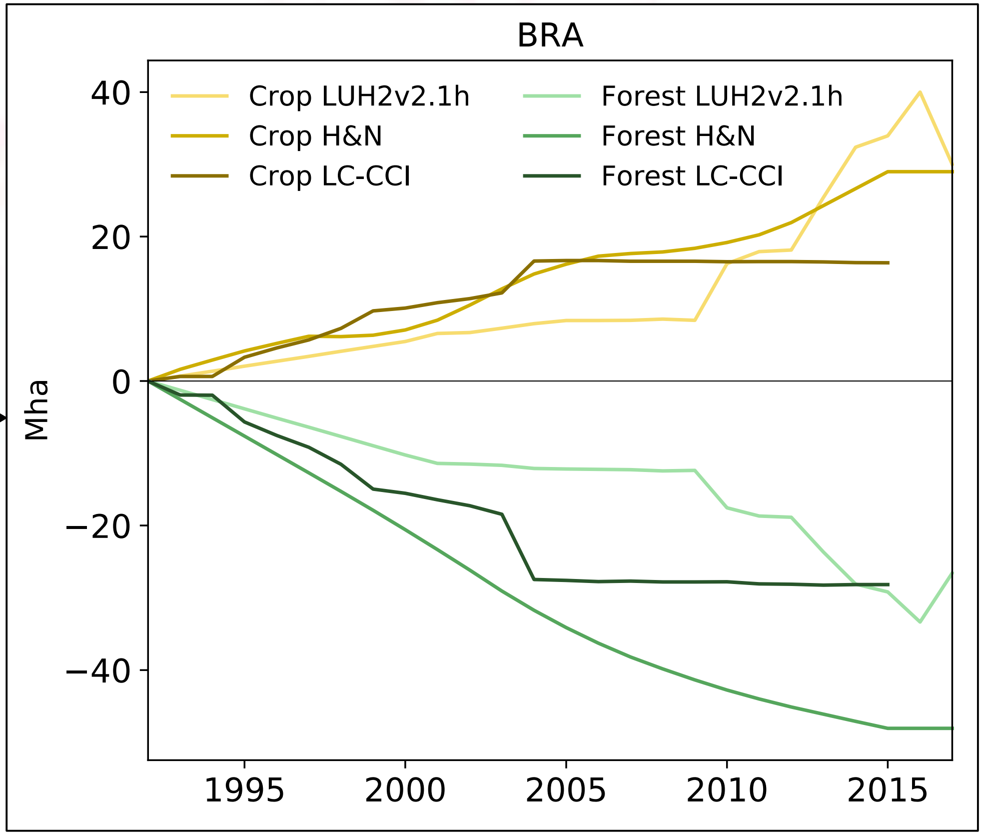
Example: emissions from land use change



Changes in forest vs crop area 1992-2017



Bastos et al. 2020, GBC

RECCAP2

- **Constraining regional C-budgets** consistently with the global scale is **still challenging:**
  - Uncertainty in observation-based datasets (inversions)
  - Process representation in LSMs
  - Uncertainty in land-use change reconstructions

- **RECCAP-2** involves a large number of teams from all continents and diverse scientific fields to provide new insights about regional C-budgets, uncertainties, trends & processes

- **RECCAP-2** will deliver fundamental information for the **global stocktaking process**

RECCAP-2:https://www.globalcarbonproject.org/global/pdf/meetings/Justification_and_Objectives_of_RECCAP2.pdf

RECCAP(1):https://www.globalcarbonproject.org/reccap/

RECCAP2 North America: Ben Poulter (benjamin.poulter[at]nasa.gov)

Thanks!

abastos[at]bgc-jena.mpg.de