The use of CTESSEL carbon model in the MACC-II CO_2 near real time forecast:

Towards an optimization of CTESSEL parameters to constrain the global atmospheric CO_2

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Anton Beljaars,Joaquin Muñoz, Clement Albergel, Patricia de Rosnay
Richard Engelen, Vincent-Henri Peuch

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Outline

- Components of global CO_2 forecast
- CTESSEL carbon module
- Biases in the CO_2 budget
- **How to reduce biases in CTESSEL CO_2 fluxes?**

Components of global CO_2 forecast

SURFACE FLUXES

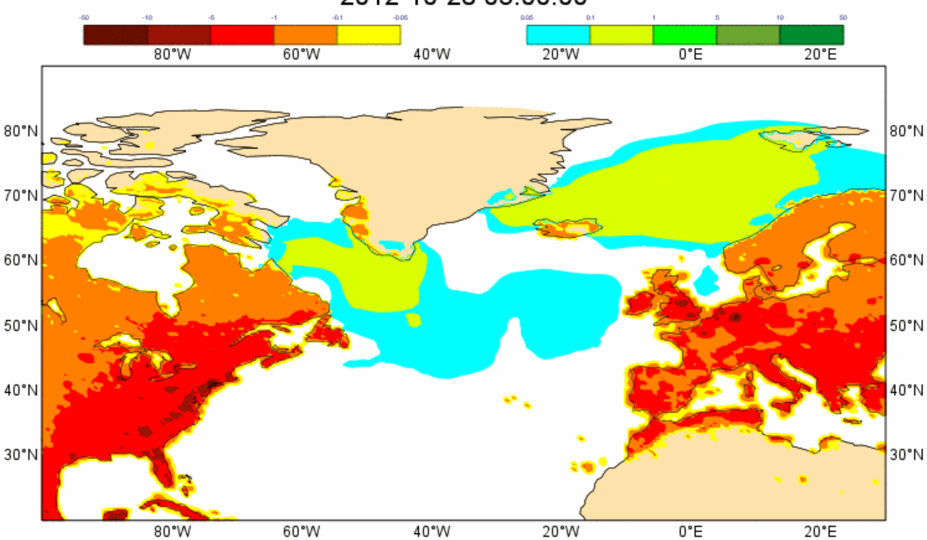
TRANSPORT

Total CO_2 surface flux
[μmol m^{-2} s^{-1}]

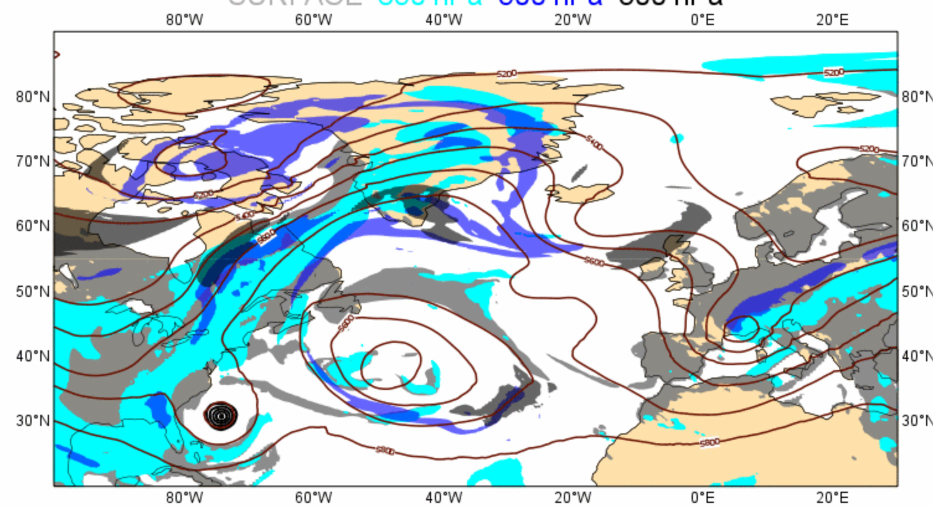
Atmospheric CO_2 anomalies above 392 ppm at different vertical levels

SOURCE **SINK**

Total CO2 flux
2012-10-28 03:00:00



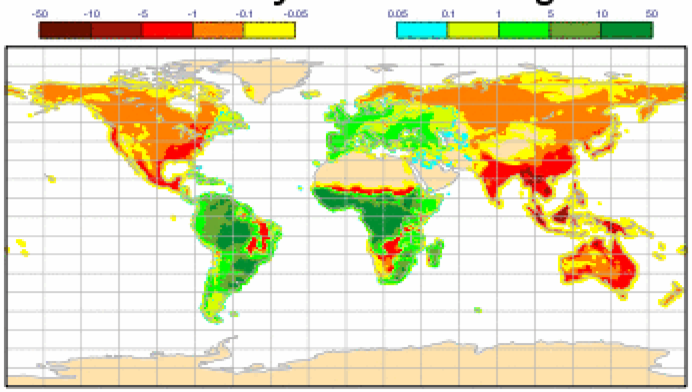
2012-10-28 03:00:00
SURFACE 850 hPa 500 hPa 300 hPa



CO_2 *fluxes*

[μmol m^{-2} s^{-1}]

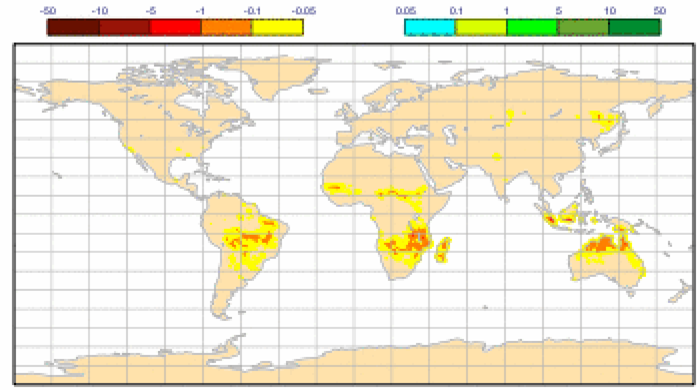
Net Ecosystem Exchange



CTESSEL (Boussetta et al. 2013)

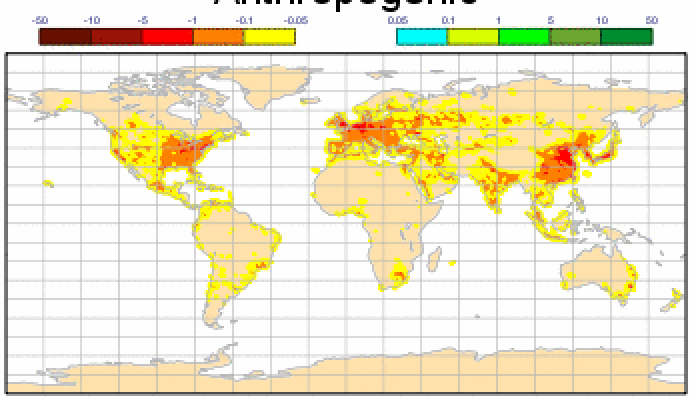
Fires

2012-10-28 12:00:00



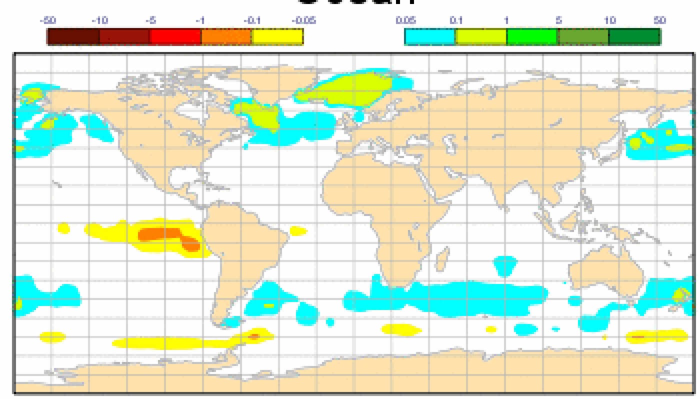
GFAS (Kaiser et al. 2012)

Anthropogenic



EDGARv4.2 (JRC)

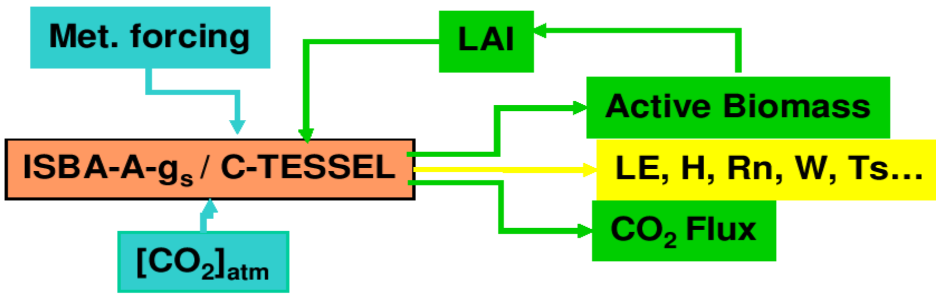
Ocean



Takahashi et al., (2009) climatology

The CTESSEL Carbon module

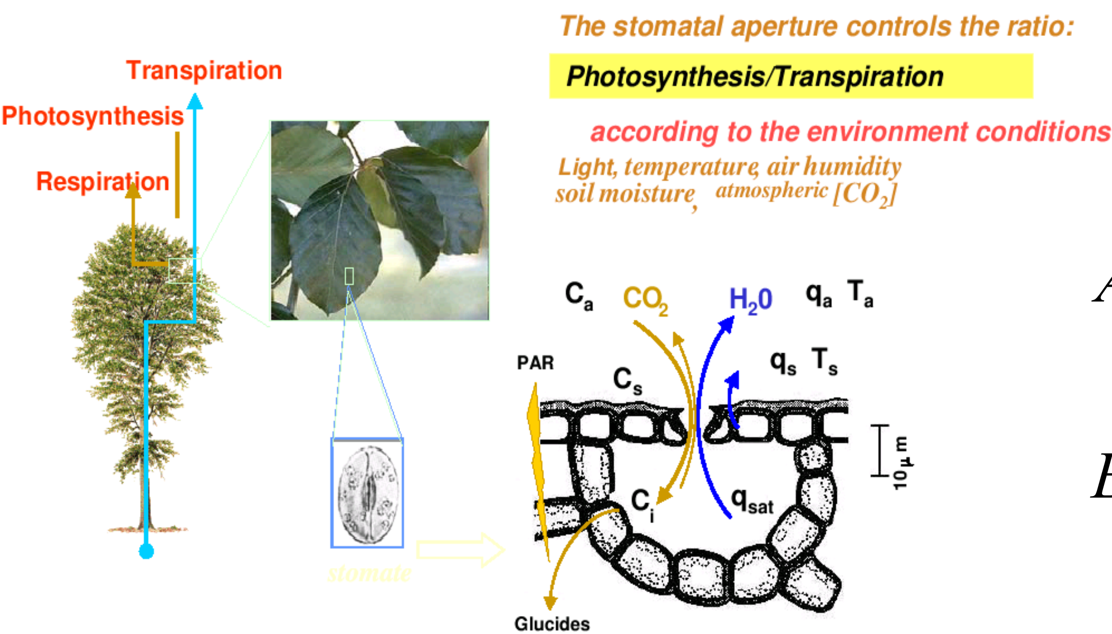
(Calvet et al. 2005)



Leaf Area Index:
MODIS climatology

Meteorological forcing:
- Solar radiation
- Soil temperature
- Soil moisture
- Snow

Atmospheric CO2 (C_s)



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

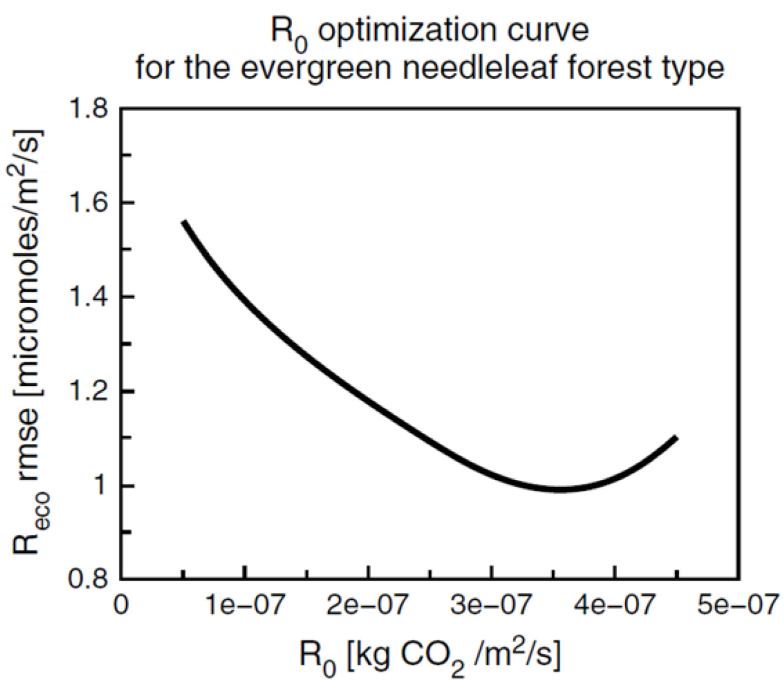
$$E = \frac{\beta}{r_c + r_a}(q_a - q_{sat}),\, r_c = f(r_{cc})$$

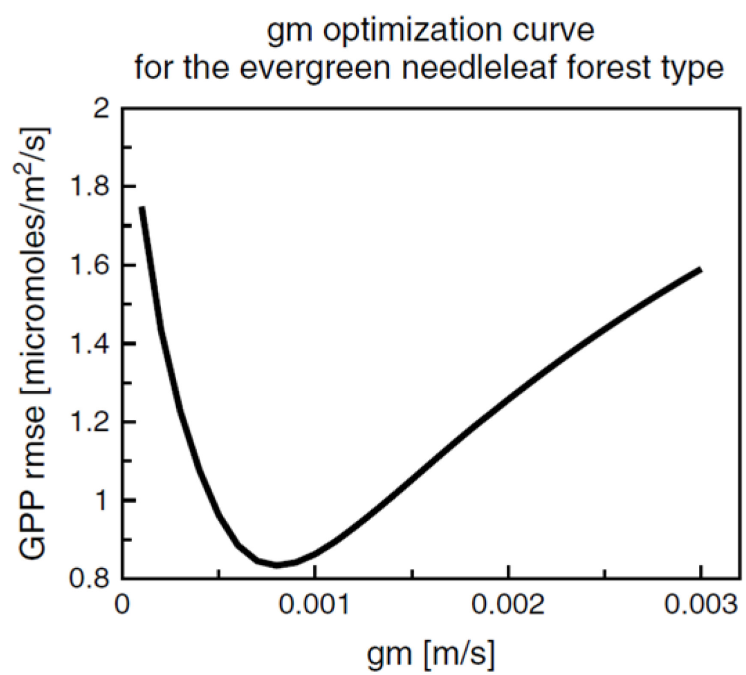
Optimization of CTESSEL parameters

$$NEE = GPP - R_{eco}$$

- **Model parameters** dependent on vegetation type:
  - mesosphyll conductance (**g_m**) ⟶ **GPP**
  - reference respiration (**R_o**) ⟶ **R_{eco}**

Optimization of model parameters using GPP and REC FLUXNET observation





Evaluation of CTESSEL fluxes

BOUSSETTA ET AL.: LAND CO_2 WITHIN THE ECMWF SYSTEM

Table 6. Average Performance Metrics for 2004 of the 10 Day Averaged Carbon Fluxes Simulated With CTESSEL and CHTESSEL for the 34 Sites

Model	GPP RMSE [μmol m^{-2} s^{-1}]	GPP Bias [μmol m^{-2} s^{-1}]	GPP Corr	*NEE* RMSE [μmol m^{-2} s^{-1}]	*NEE* Bias [μmol m^{-2} s^{-1}]	*NEE* Corr [μmol m^{-2} s^{-1}]	Reco RMSE [μmol m^{-2} s^{-1}]	Reco Bias [μmol m^{-2} s^{-1}]	Reco Corr
CHTESSEL	2.2	0.6	0.80	1.6	−0.1	0.65	1.8	−0.7	0.79
CTESSEL	2.0	0.3	0.82	1.6	−0.2	0.68	1.8	−0.6	0.80
CASA-GFED3	-	-	-	1.8	0.7	0.37	-	-	-

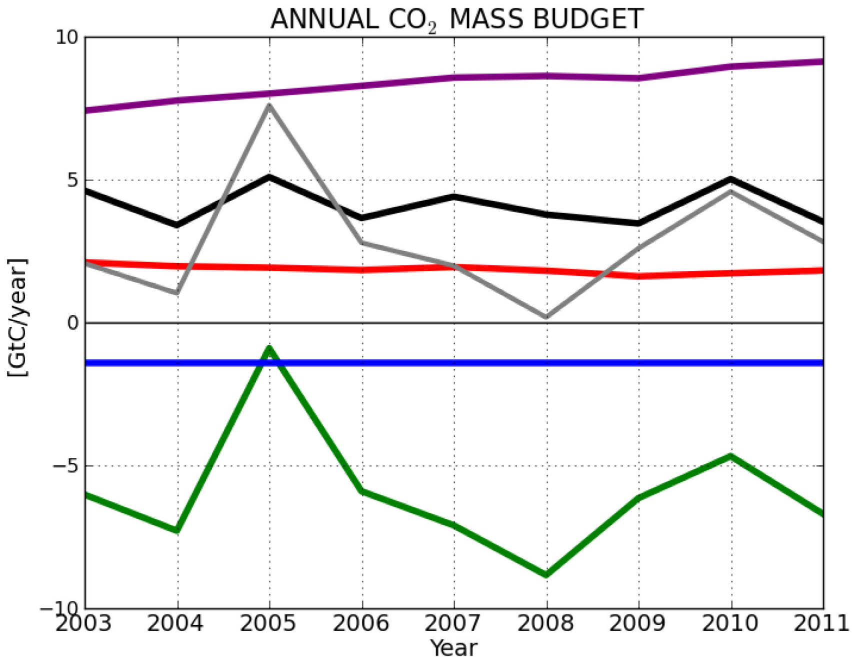
Flux observations:

- have very small footprint
- have sparse global coverage for sampling high spatial and temporal heterogeneity of CO_2 fluxes.
- cannot constrain on global CO_2 budget

This result in global CO_2 biases, unlike atmospheric flux inversions!!!

CO_2 budget

- **MODEL: total flux = anthropogenic + ocean + fire + vegetation**

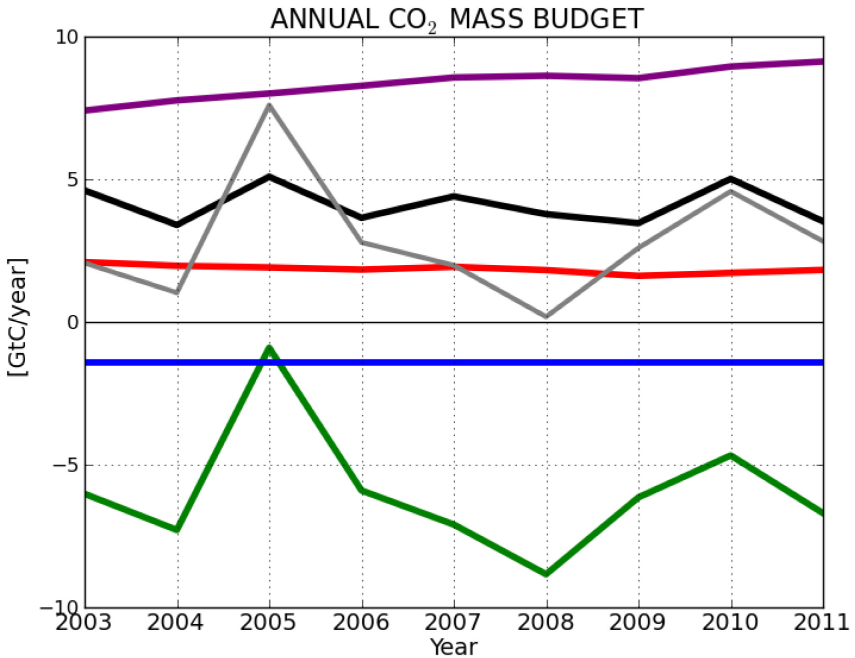


- **Anthropogenic emissions** **(EDGARv4.2)**
- GFAS biomass burning (MACC, Kaiser et al. 2012).
- Ocean climatology (Takahashi 2009).
- **Observed atmospheric growth** **(NOAA, Conway et al., 2012)**
- **Land sink** **(CTESSEL, Boussetta et al., 2013)**

total flux in model = atmospheric growth in model

CO_2 budget

- **MODEL: total flux = anthropogenic + ocean + fire + vegetation**



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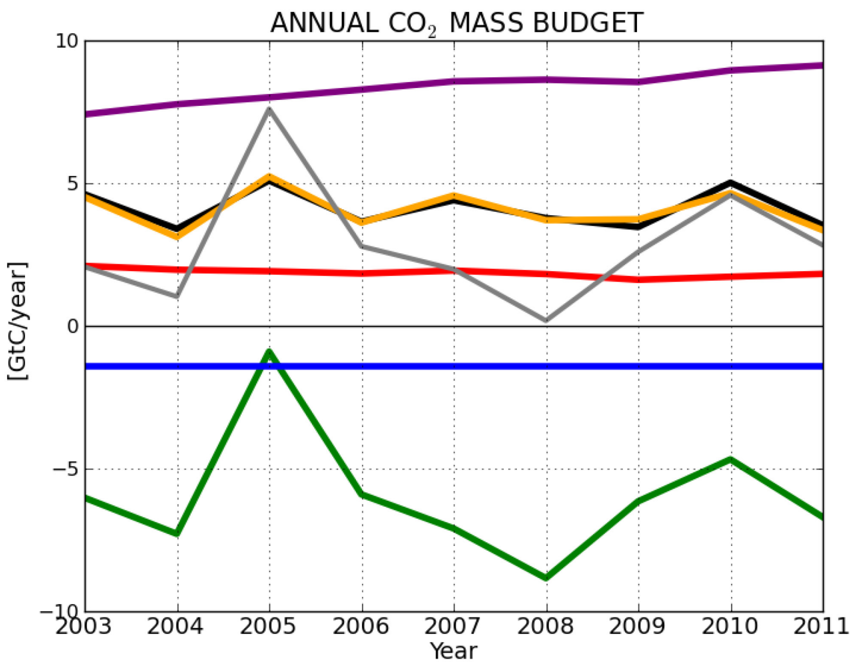
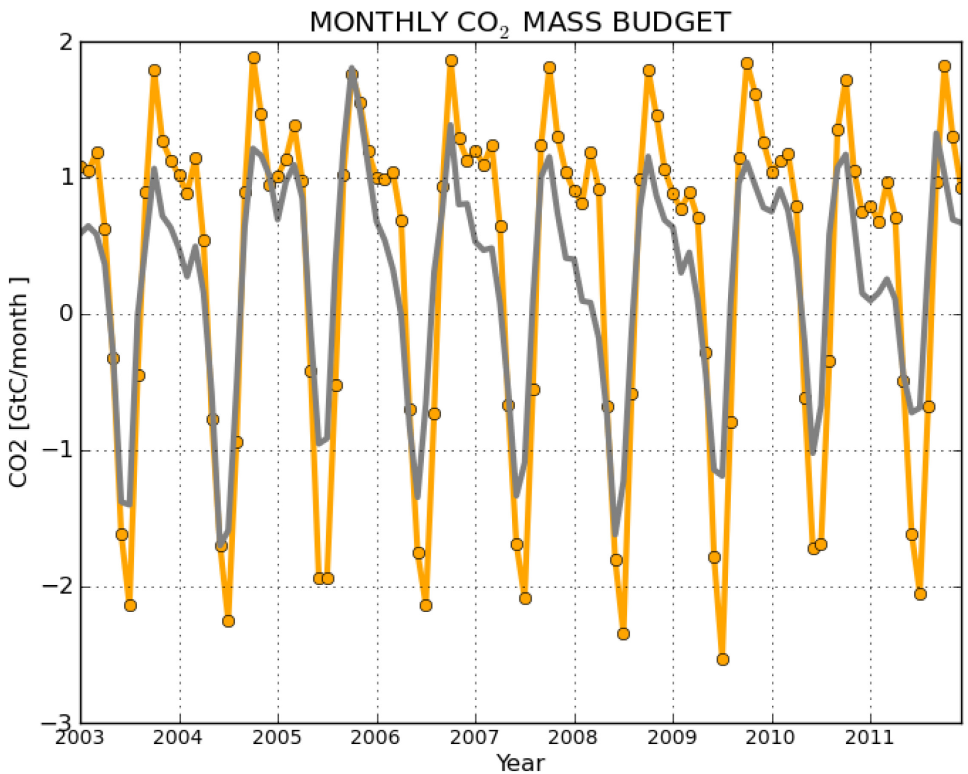
- **Land sink** **(CTESSEL, Boussetta et al., 2013)**

total flux in model ! = observed atmospheric growth → Global bias in atmospheric CO2 background

➢ CO_2 budget

- **MODEL:** total flux = anthropogenic + ocean + fire + vegetation

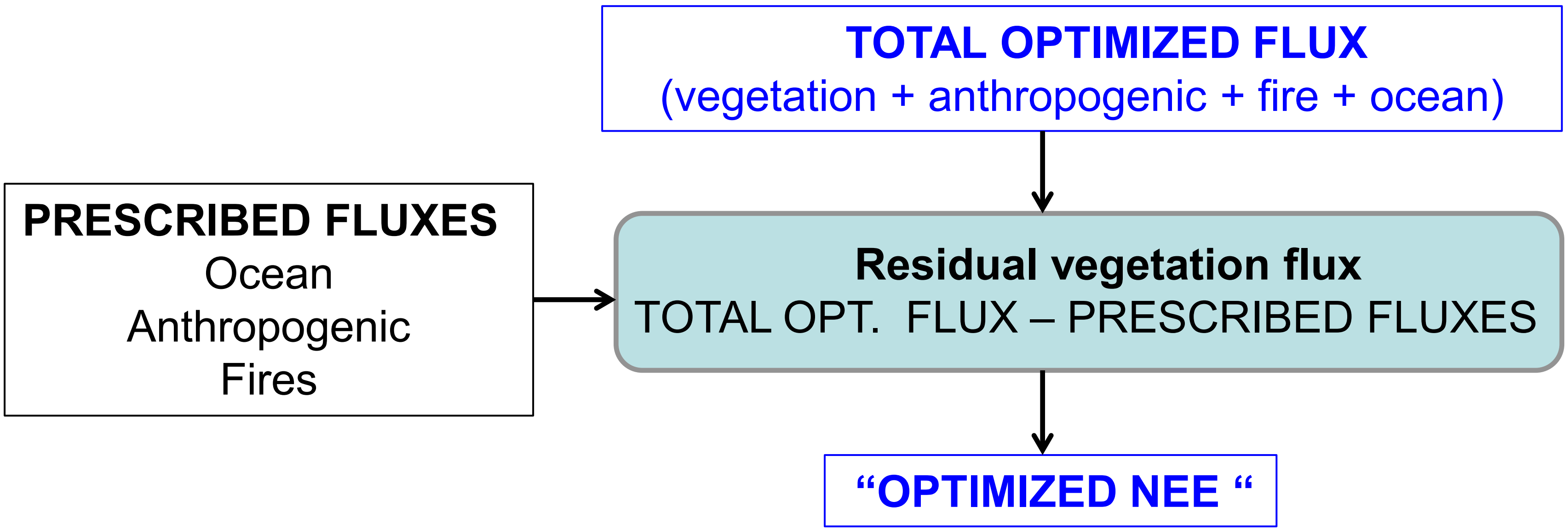




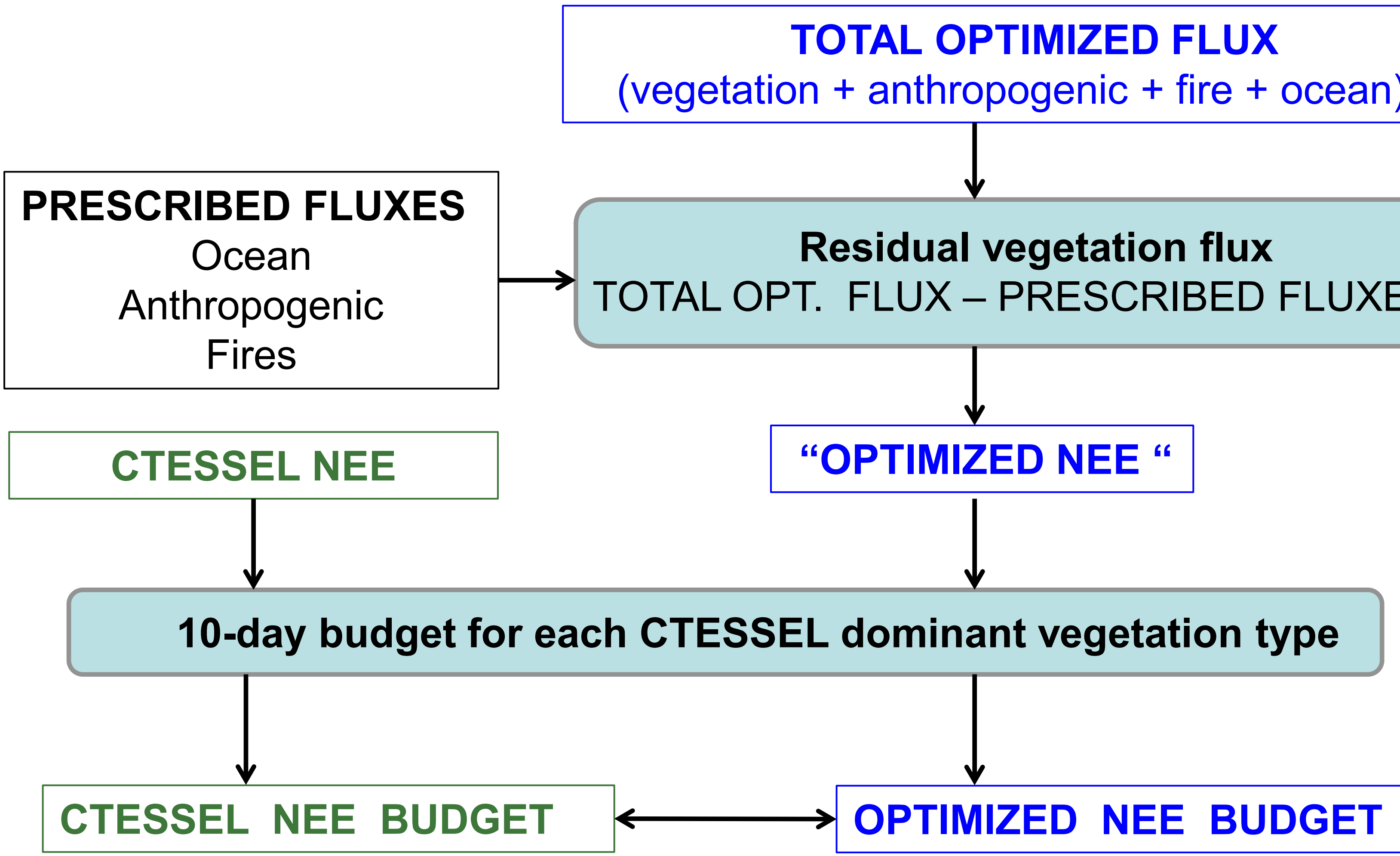
- ➢ Anthropogenic emissions
- ➢ GFAS biomass burning.
- ➢ Ocean climatology.
- ➢ **Observed atmospheric growth**
- ➢ Land sink from

- ➢ Total flux in model
- ➢ Optimized fluxes (MACC PYVAR) (Chevallier et al., 2011)

Using optimized CO_2 fluxes as a reference



Using optimized CO_2 fluxes as a reference



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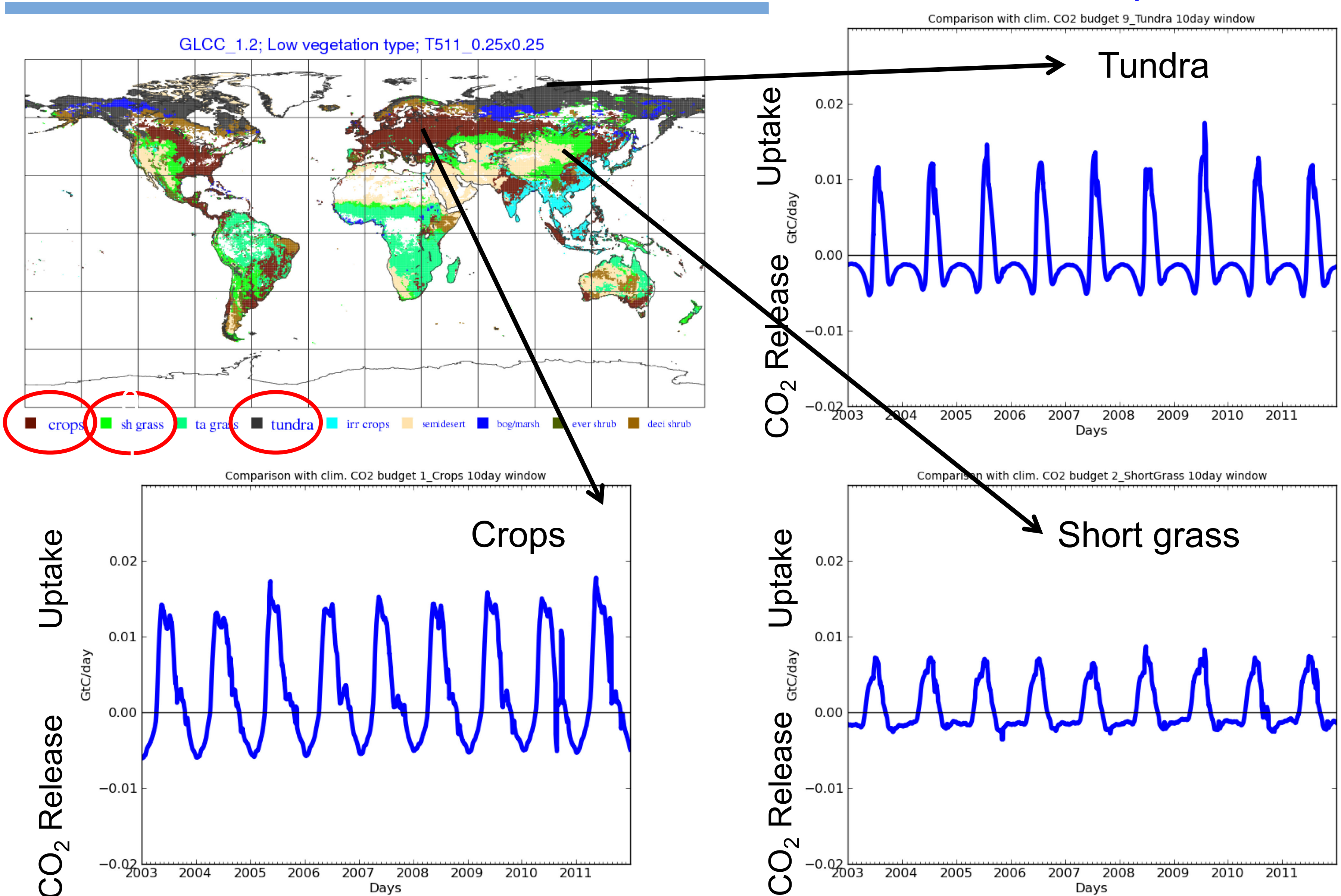
BIASES IN GLOBAL CTESSEL NEE BUDGETS

10-day budget with vegetation type

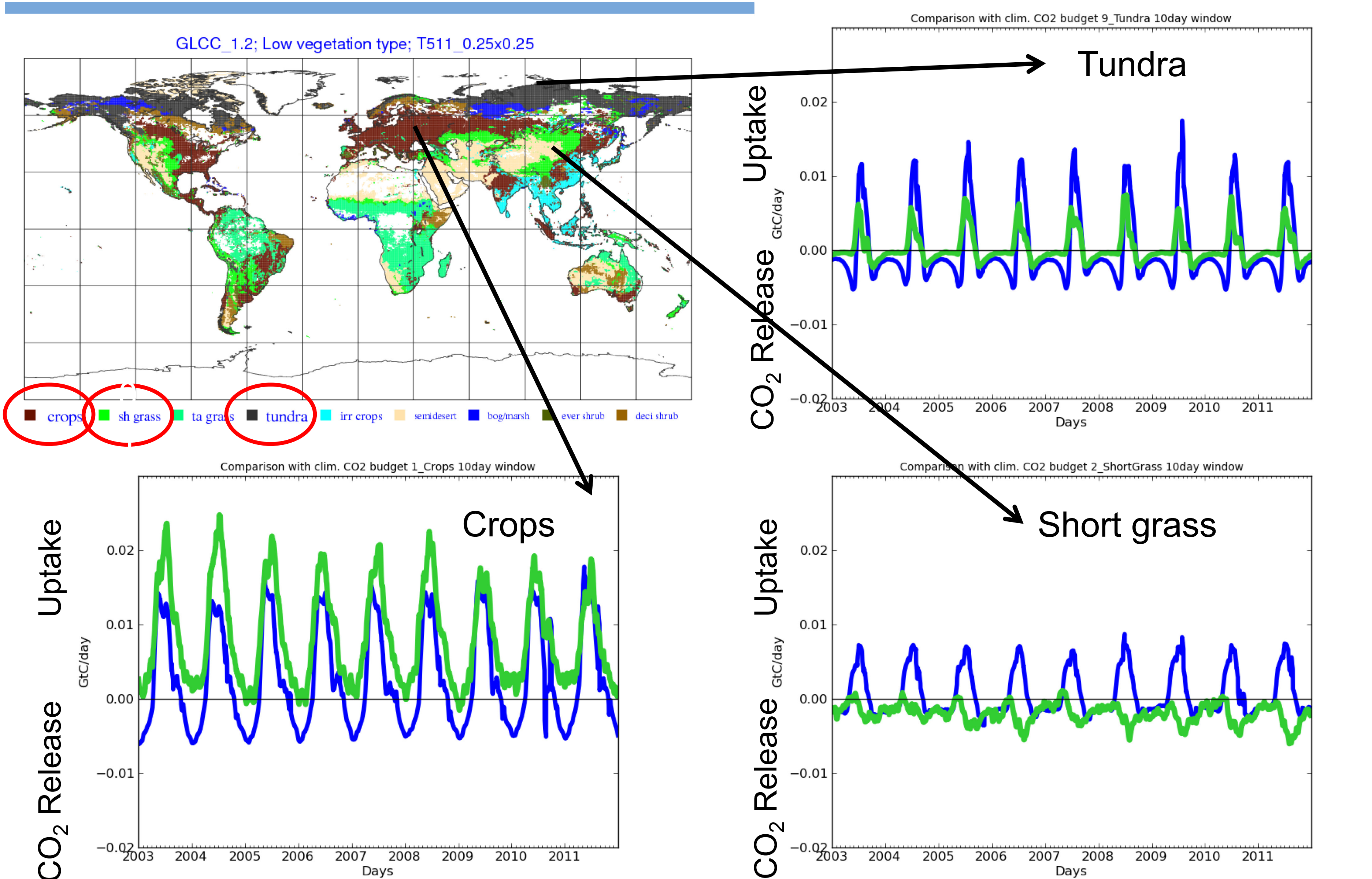
OPTIMIZED FLUXES (F Chevallier)



BIASES IN GLOBAL CTESSEL NEE BUDGETS

10-day budget with vegetation type

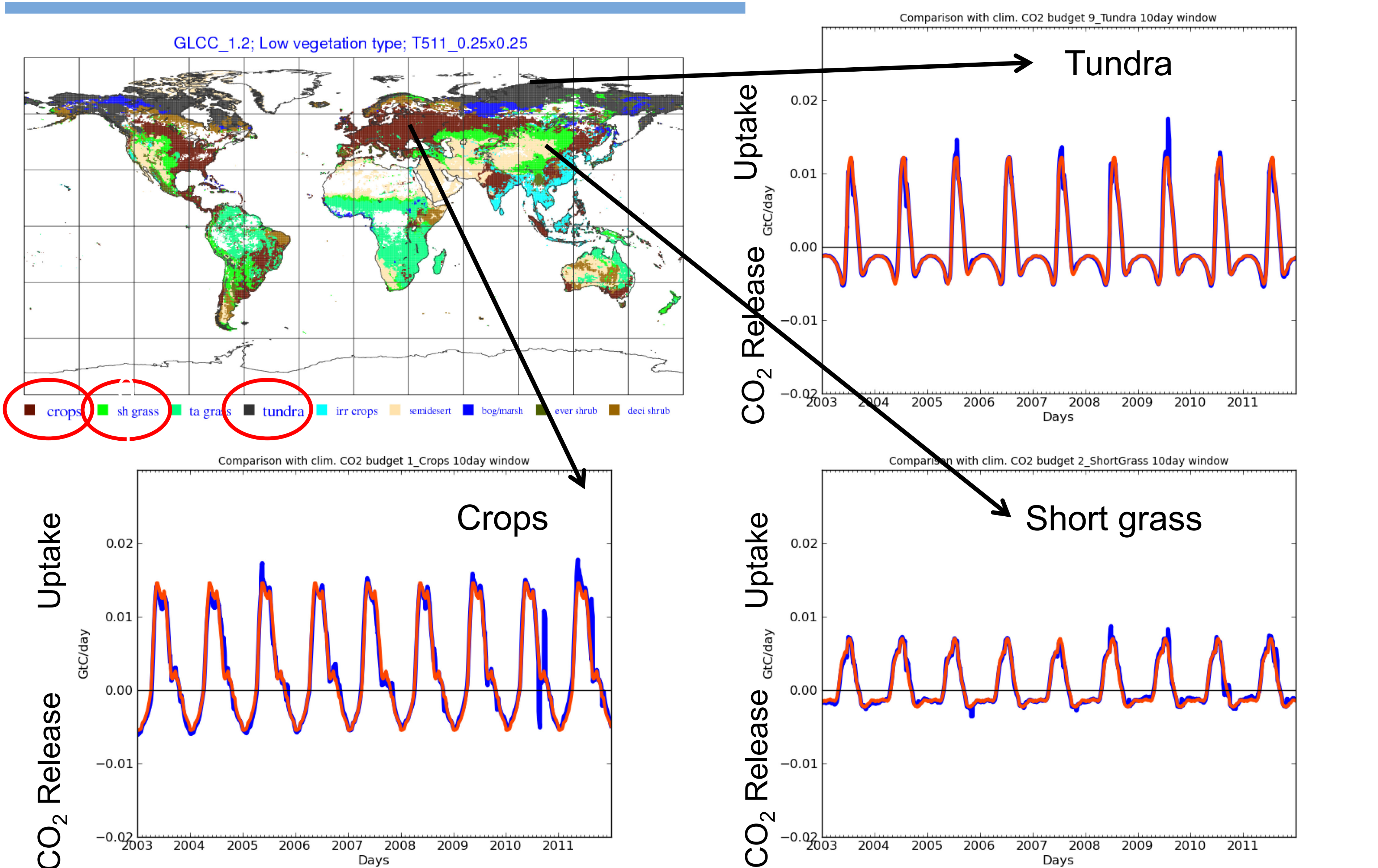
OPTIMIZED FLUXES **CTESSEL**



BIASES IN GLOBAL CTESSEL NEE BUDGETS

10-day budget with vegetation type

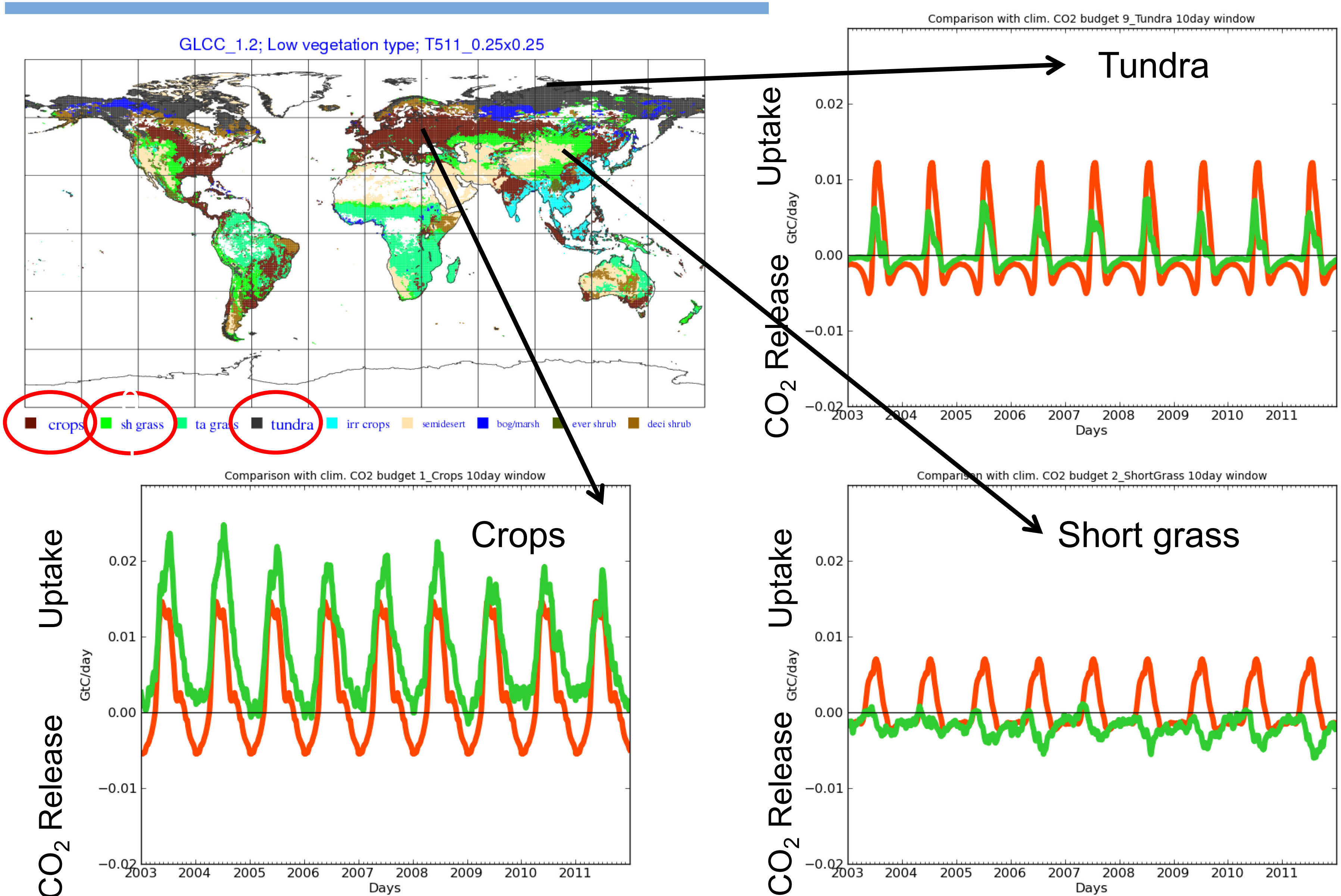
OPTIMIZED FLUXES **OPTIMIZED FLUX CLIMATOLOGY**



BIASES IN GLOBAL CTESSEL NEE BUDGETS

10-day budget with vegetation

CTESSEL OPTIMIZED FLUX CLIMATOLOGY



NEE bias correction for vegetation type

$$\alpha = \frac{(NEE_{optclim} + IAV * STD(NEE_{optclim}))}{NEE_{ctessel}}$$

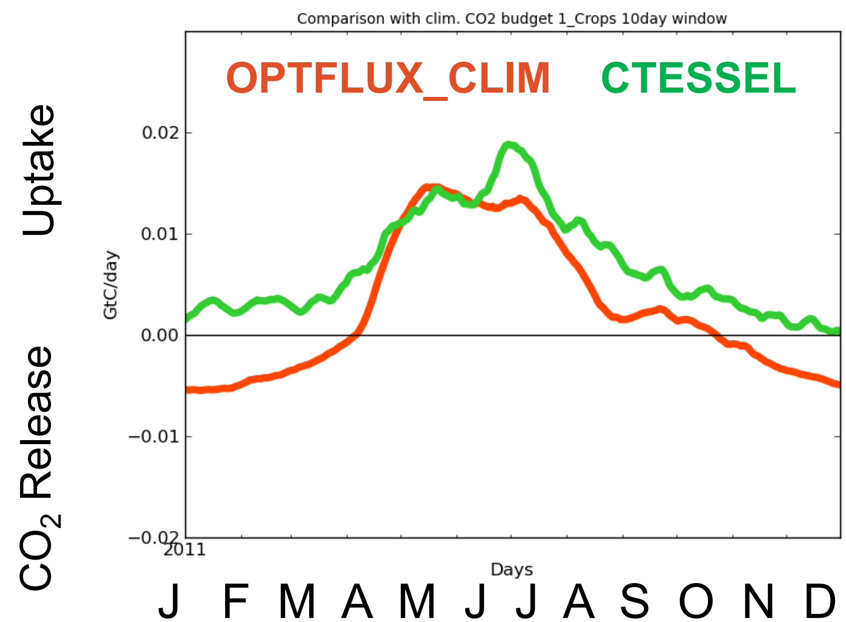
$$IAV = \frac{(NEE_{ctessel} - NEE_{ctesselclim})}{STD(NEE_{ctessel})}$$

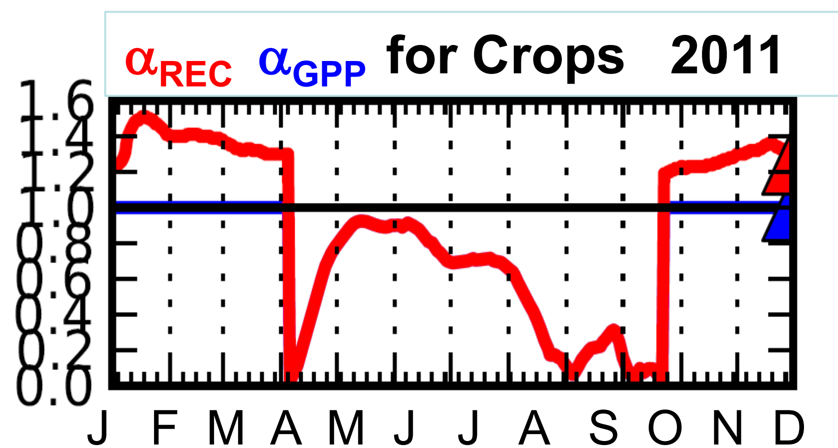
$NEE = GPP + REC$

if $\alpha > 0$ then both GPP and REC are re-scaled

$$\alpha_{GPP} = \alpha_{REC} = \alpha$$

else if $\alpha < 0$ then the largest of GPP or REC are re-scaled.

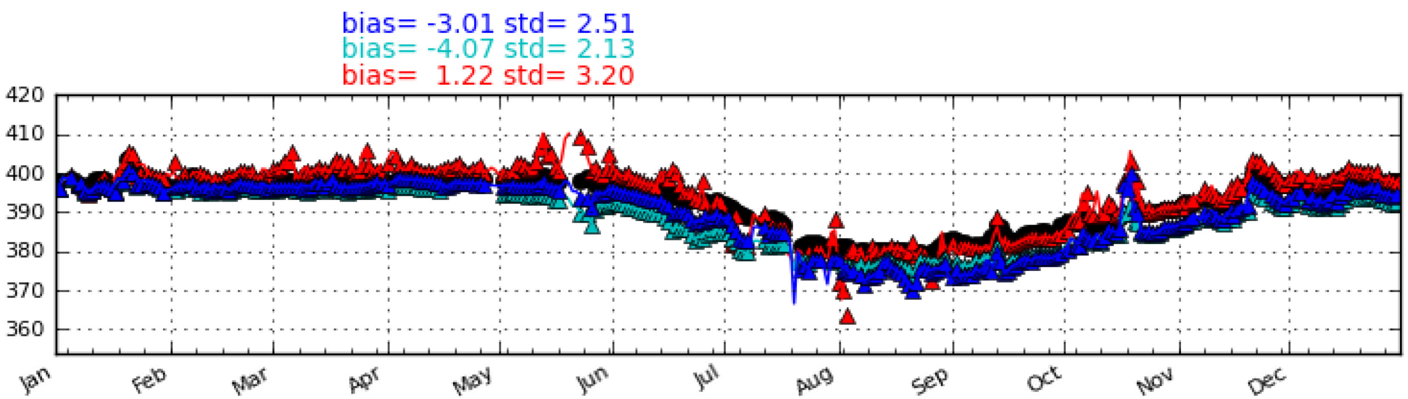




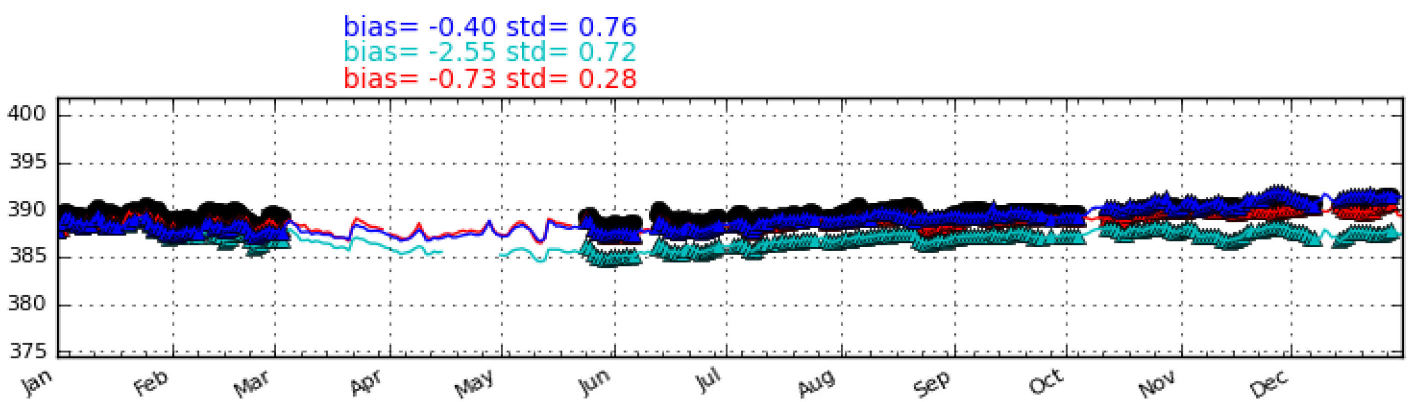
CTESSEL NEE bias correction evaluation

- Daily mean CO_2 at background insitu continuous NOAA stations (2011):

OBS **OPT.FLUXES** **CTESSEL** **BC_CTESSEL**



Barrow, Alaska
71.3 °N
156.6 °W
27.5 m a.s.l.



Tutuila Island, American Samoa
14.25 °S
170.56 °W
60.3 m a.s.l.

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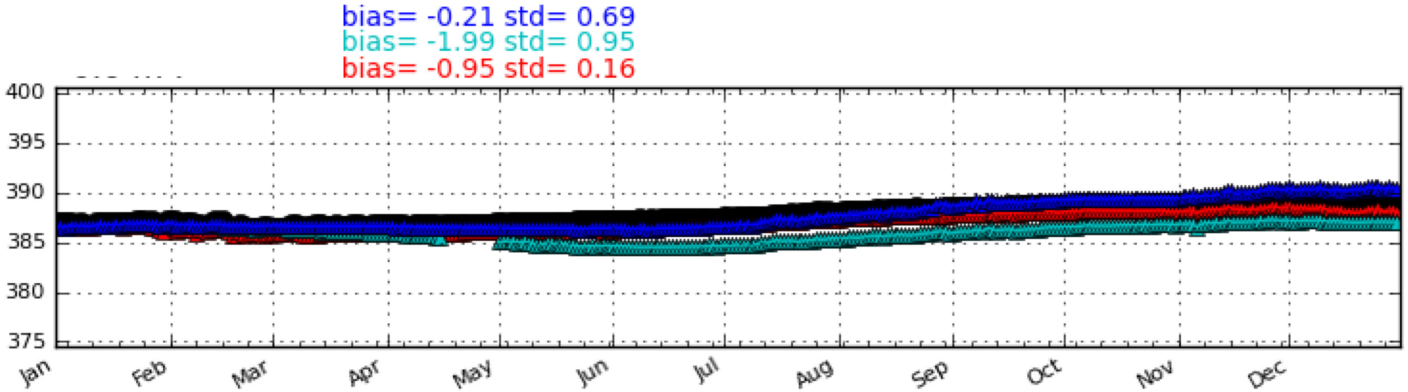
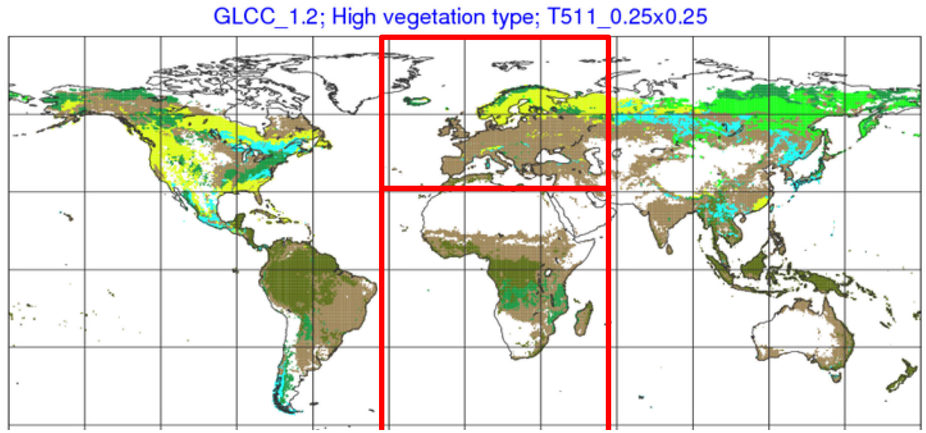
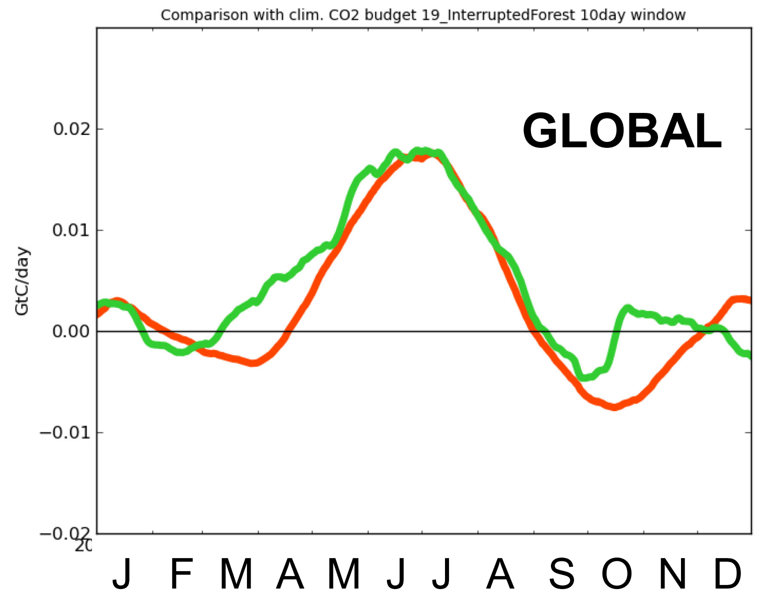


South Pole
89.98 °N
89.96 °W
2821 m a.s.l.

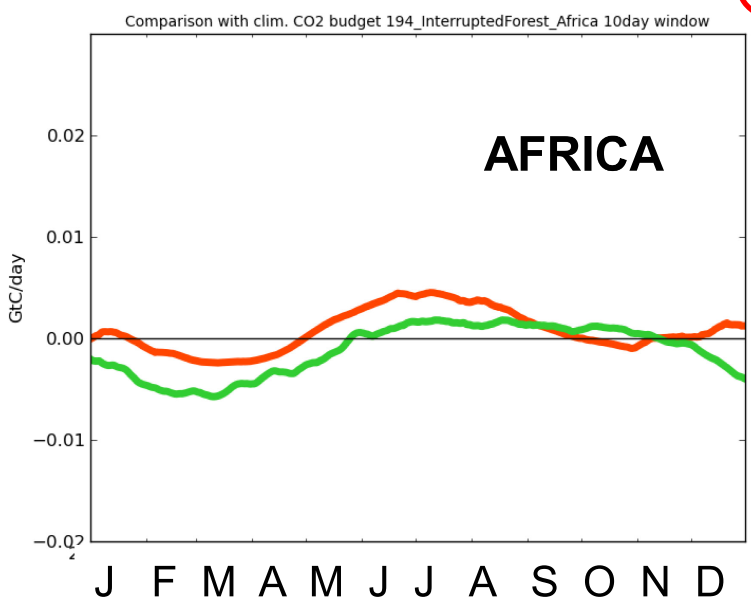
Issues: regional differences

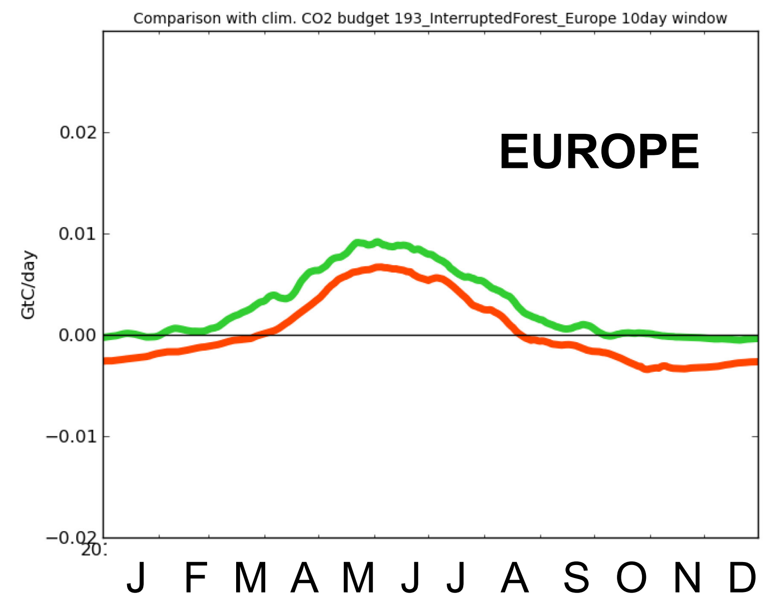




INTERRUPTED FOREST (25.4% land points)

ever needle | deci needle | deci broad | ever broad | mix forest | int forest





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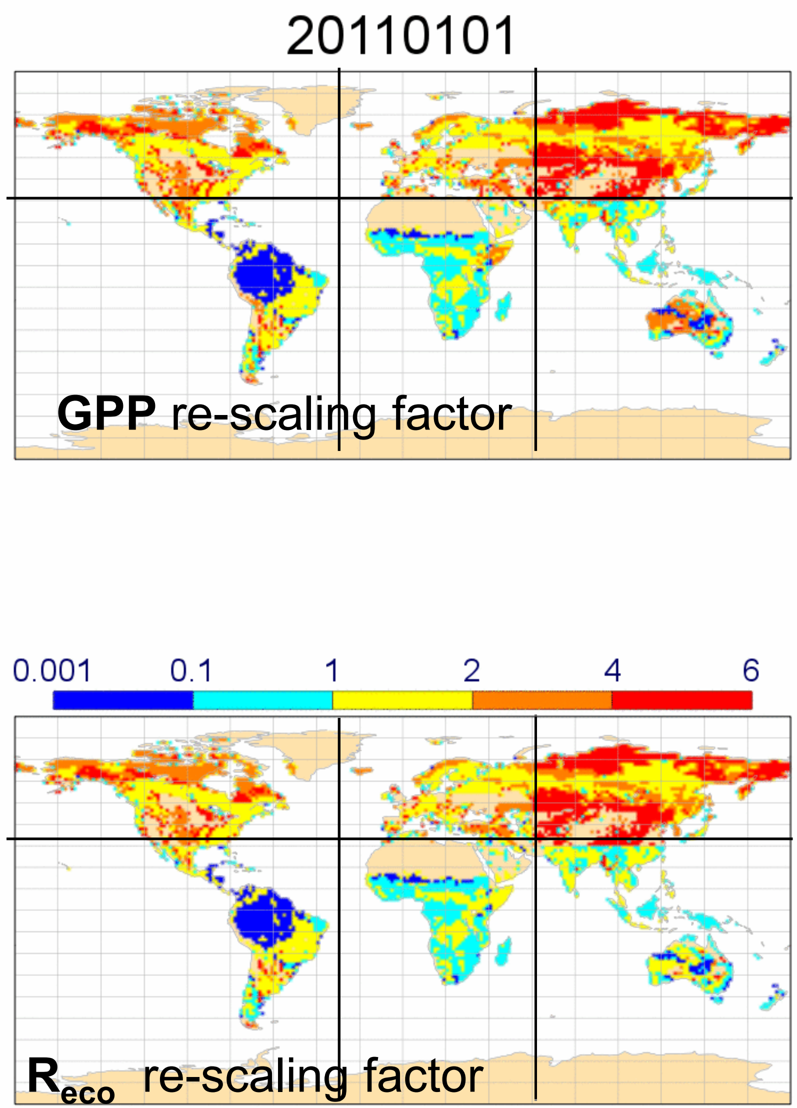
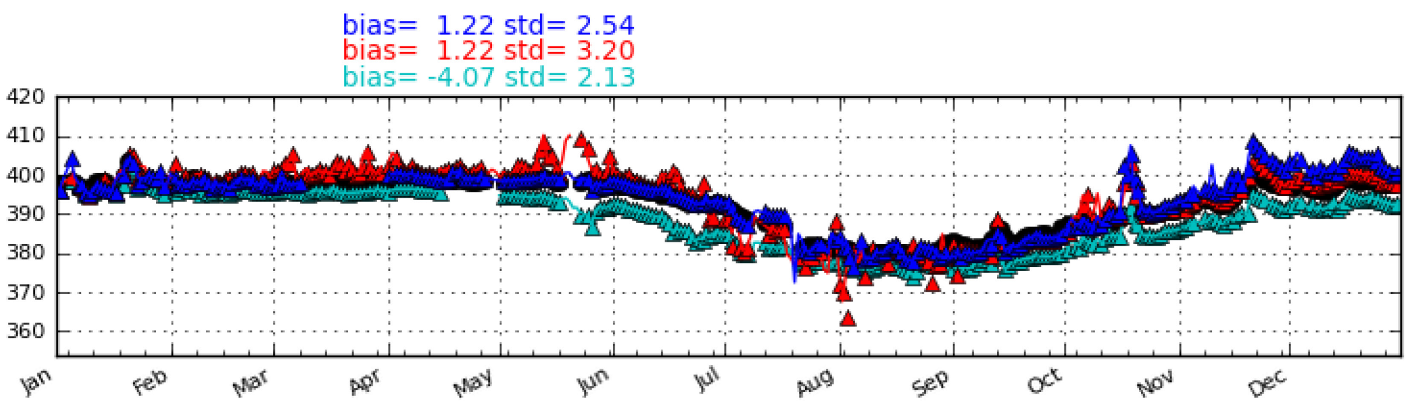
Bias correction coefficients for vegetation types over 6 regions



CTESSEL NEE bias correction evaluation using 6 regions

- Daily mean CO_2 at background insitu continuous NOAA stations (2011):

OBS **OPT.FLUXES** **CTESSEL** **BC_CTESSEL**



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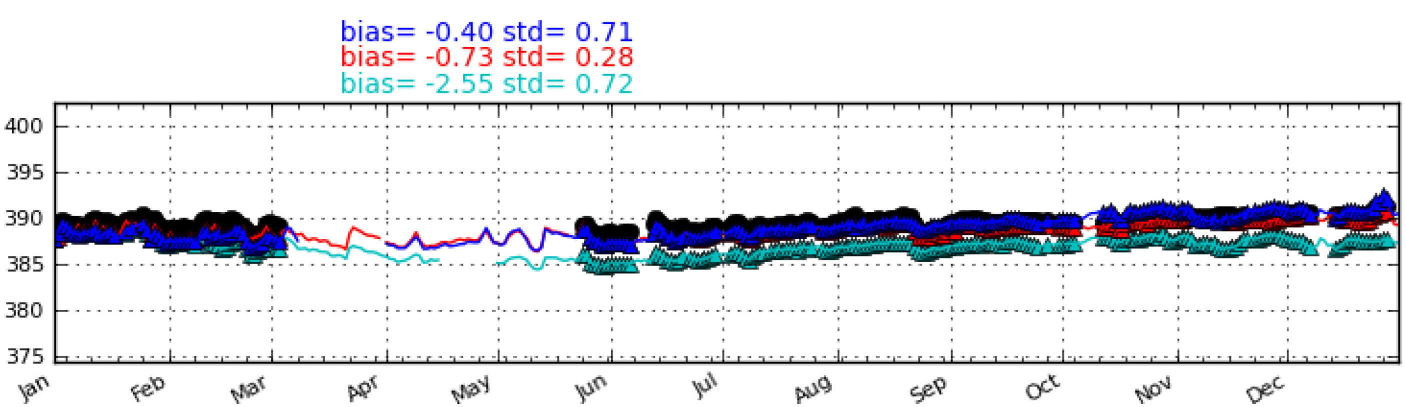

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CTESSEL NEE bias correction evaluation

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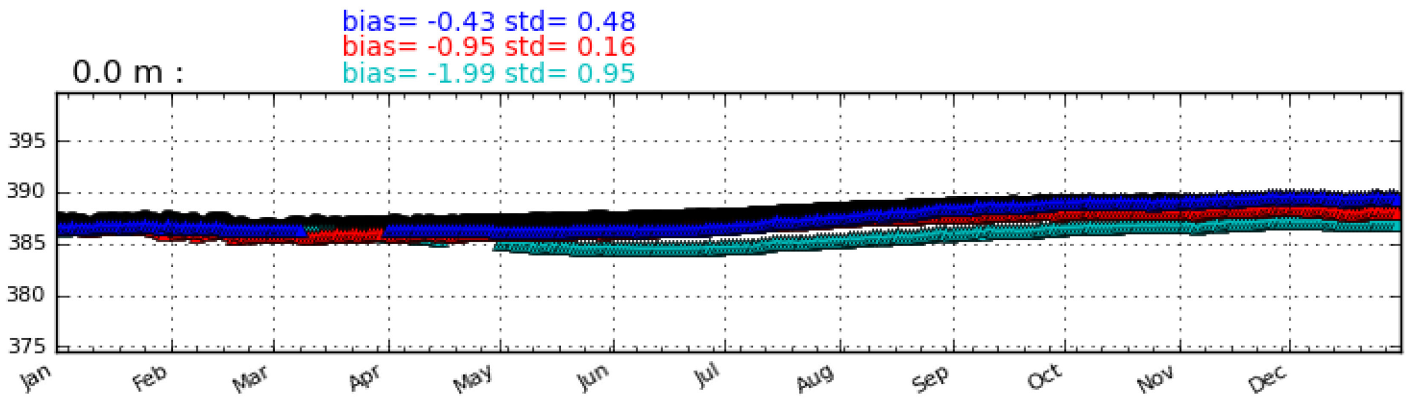

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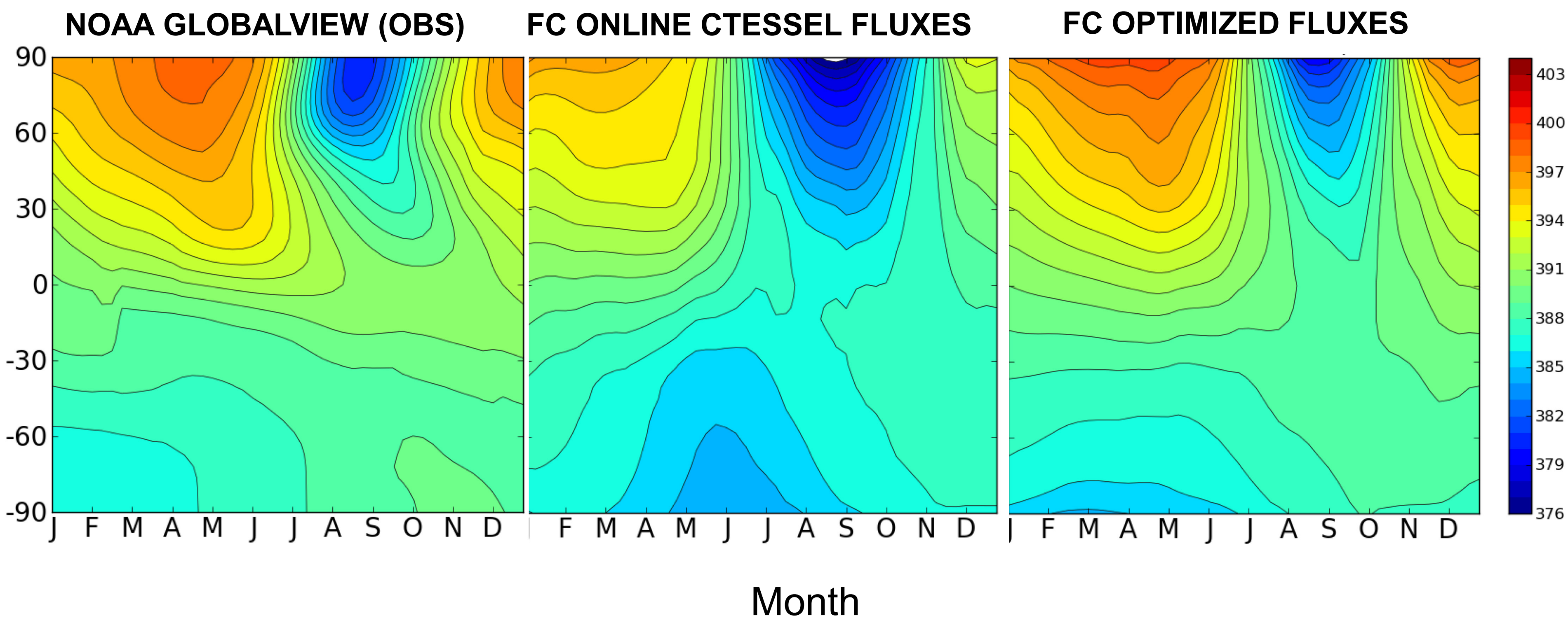
Near Real Time CO2 forecast EVALUATION 2011

- Hovmoeller plots of background CO_2: Seasonal cycle and Latitudinal gradient



Near Real Time CO2 forecast

EVALUATION 2011

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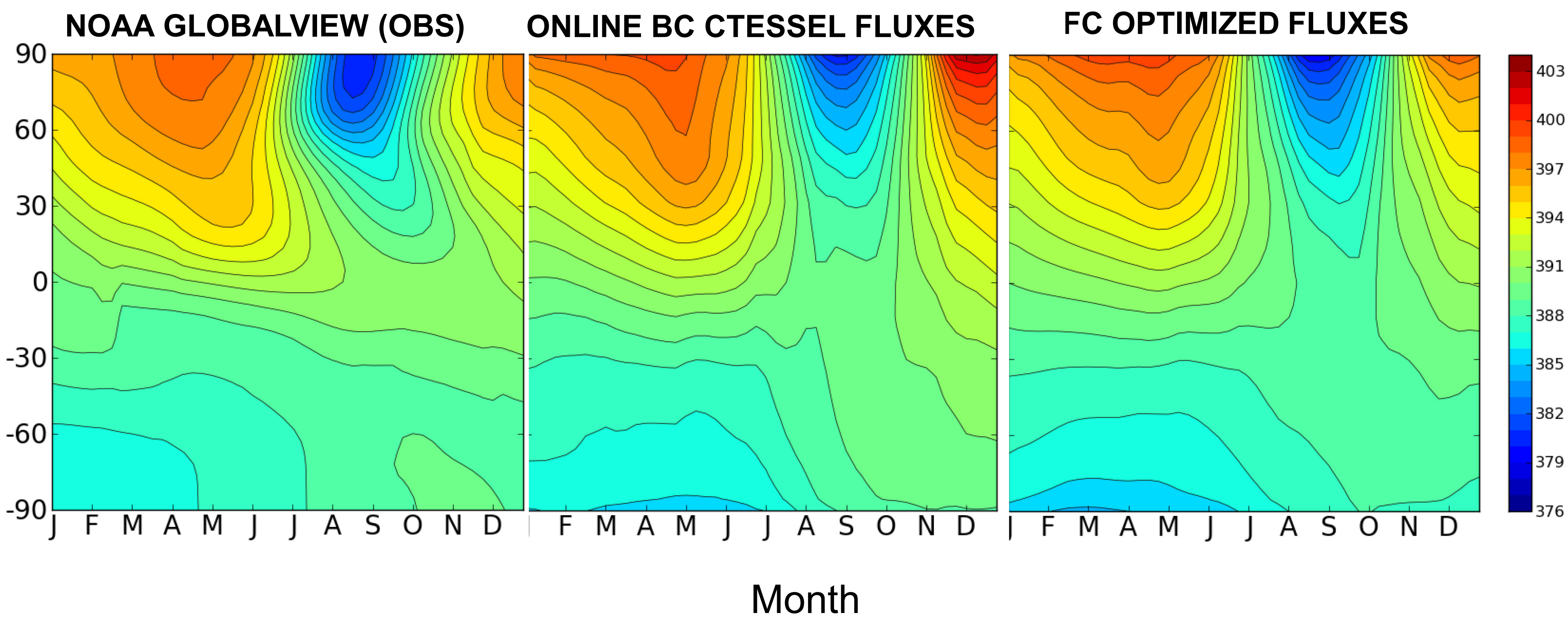

CO2 bias correction: summary

- CO_2 flux bias correction works well when vegetation types share the same errors. It is easy to implement, it adapts with model cycle and it can be a useful diagnostic to improve CTESSEL.
- Use a map for the GPP and REC correction coefficients to address other error sources (e.g. climate forcing, vegetation classification, missing processes).
- Test assumptions when deciding whether to correct REC and GPP.

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CO_2 products: configuration

1. CTESSEL parameter optimization ← **FLUXNET observations**

↓

CO_2 FC

↓

2. CTESSEL bias correction ← **Optimized fluxes of CO_2.**

Mask map with areas characterized by
- **Climate forcing errors**:
  soil moisture, 2mT, radiation
- **LAI errors**
- **New vegetation classes**
- **Missing processes**

↓

CO_2 FC
with reduced background bias

↓

3. Atmospheric data assimilation ← **Satellite data of column averaged atmospheric CO2.**

↓

Atmospheric CO_2 analysis

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CO_2 products: future configuration?