Uncertainties on the land carbon reanalysis

Philippe Peylin, **Nicolas Vuichard**, Palmira Messina,
Vladislav Bastrikov, Devaraju Narayanappa
& the ORCHIDEE project team

Laboratoire des Sciences du Climat et de l'Environnement
CEA/CNRS/UVSQ, IPSL, France

Challenges

- To provide **uncertainty estimates** and bias correction **for the main input drivers** of the carbon re-analysis; eg. the land cover changes
- To provide **uncertainties of carbon fluxes and reservoirs through propagation of errors** associated with the input drivers

- *Associated Deliverables*
  - *D4.13 : Confidence intervals on net and gross carbon fluxes through the surface as well as above and below ground carbon reservoirs for major ecosystems*
  - *D4.14 : Comparison of CTESSEL and ORCHIDEE carbon flux estimates in the satellite period*

Land carbon cycle uncertainties from:

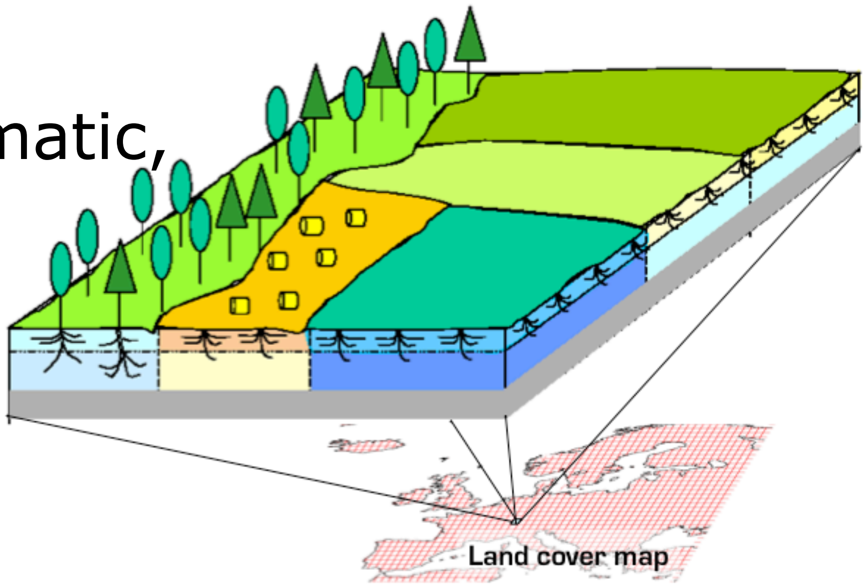
Forcing error error	Model parameter error	Model structure error
- Land Use Change scenarios - Meteo. forcing - Soil property uncertainties	- Parametric equations with Uncertain parameters (photosynthesis, respiration C allocation,…)	- Missing processes - Wrong process representation
➔ Test different scenarios From LCC & different Meteo forcing	➔ Optimize parameter using a 4D-var system with - Atm. CO2 data - FluxNet data - MODIS-NDVI	➔ Comparison between ORCHIDEE / CTESSEL and other models & approaches

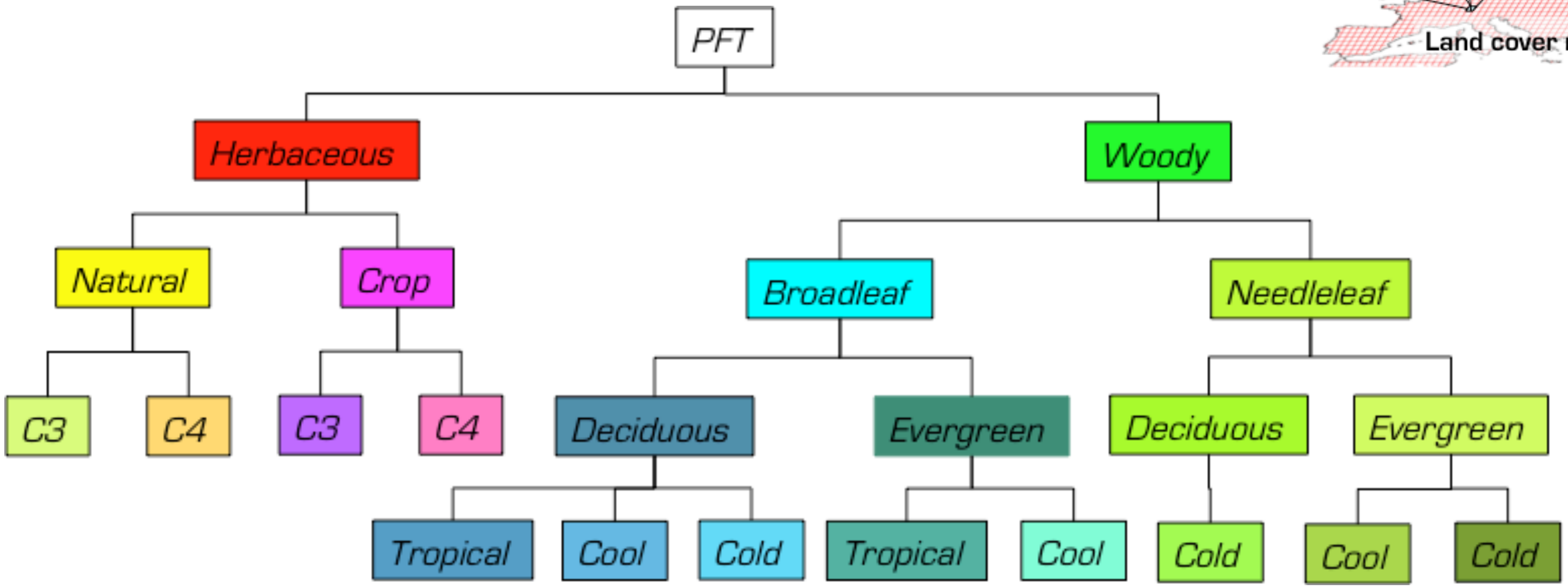
Land carbon cycle uncertainties from:

Forcing error error	Model parameter error	Model structure error
- Land Use Change scenarios - Meteo. forcing - Soil property uncertainties	- Parametric equations with Uncertain parameters (photosynthesis, respiration C allocation,…)	- Missing processes - Wrong process representation
➔ Test different scenarios From LCC & different Meteo forcing	➔ Optimize parameter using a 4D-var system with - Atm. CO_2 data - FluxNet data - MODIS-NDVI	➔ Comparison between ORCHIDEE / CTESSEL and other models & approaches

Plant functional types

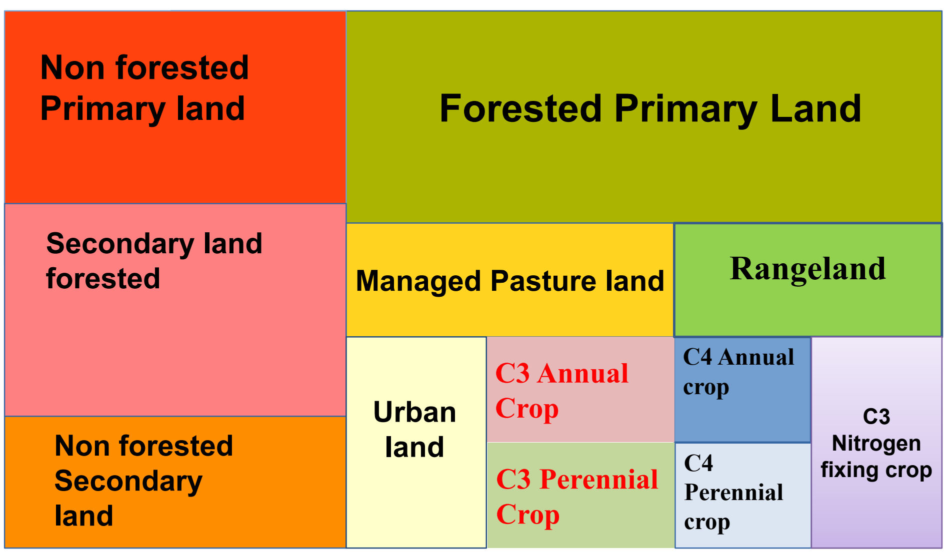
- Defined according to systematic, physiological, phenological, climatic conditions





Land-use harmonization

- LUh2: an harmonized set of land-use scenarios that connects the historical reconstructions of land-use with the future projections
  - land-use transitions
  - annually for the time period 850-2100
  - at 0.25 x 0.25 resolution

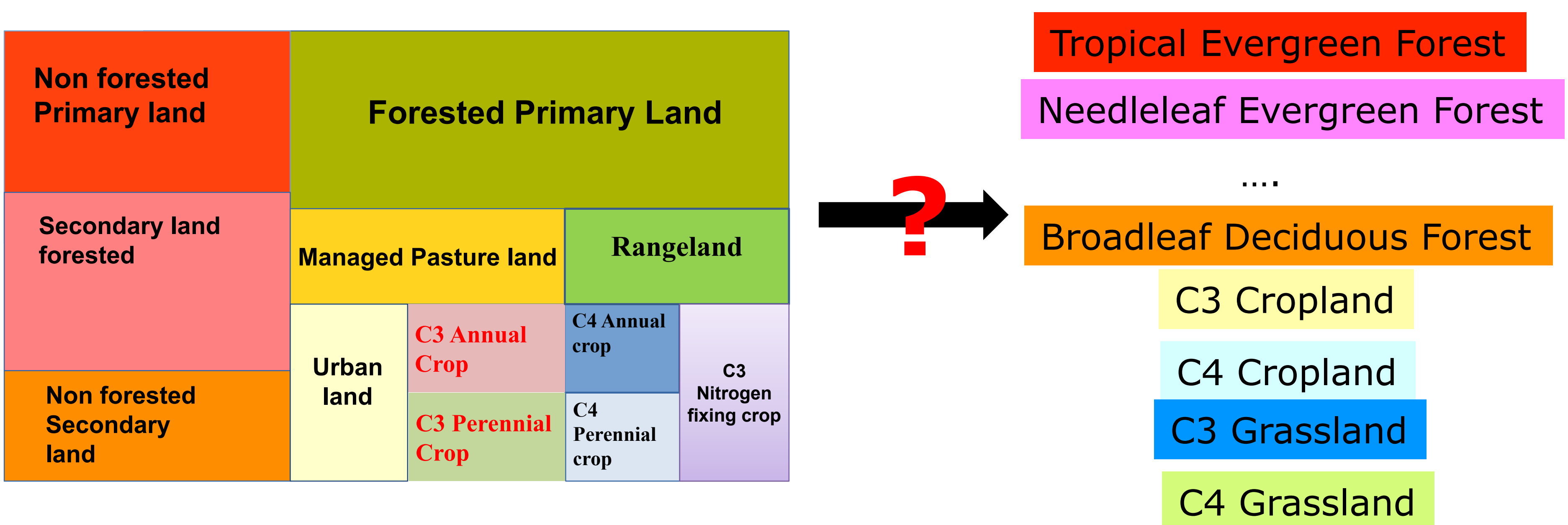


⇒ ***Land-use categories in LUh2***

Land-use harmonization

- LUh2: an harmonized set of land-use scenarios that connects the historical reconstructions of land-use with the future projections
  - land-use transitions
  - annually for the time period 850-2100
  - at 0.25 x 0.25 resolution

ORCHIDEE PFT's



ESA-CCI land cover product

- Global product
- 19 types of land categories
- At high resolution (~100m)

ESA-CCI Land Cover

Defines PFT present in each grid cell

ORCHIDEE PFT's

Tropical Evergreen Forest

Needleleaf Evergreen Forest

....

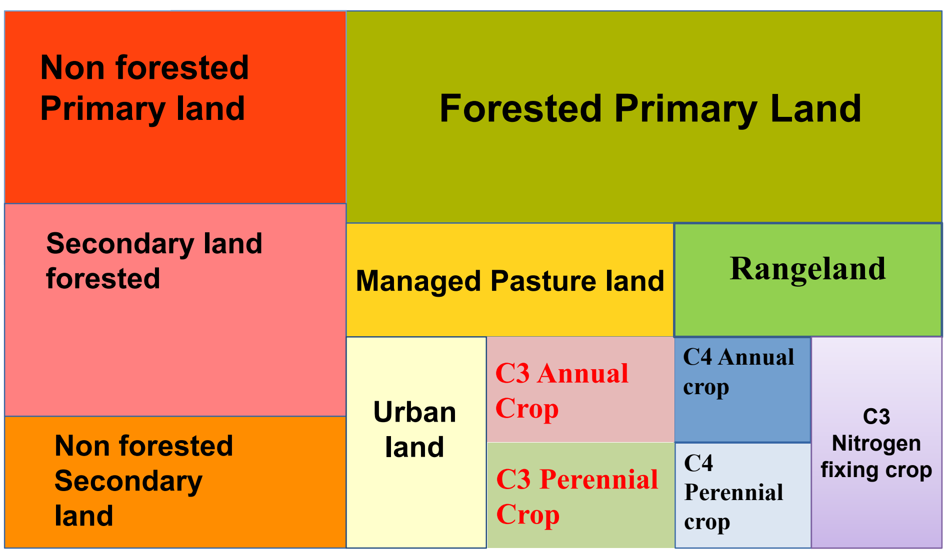
Broadleaf Deciduous Forest

C3 Cropland

C4 Cropland

C3 Grassland

C4 Grassland

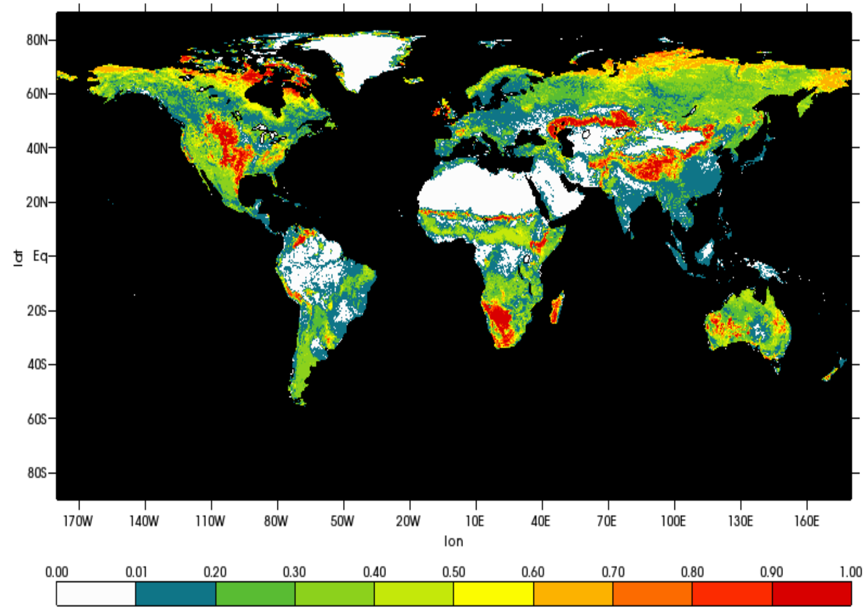


?

Total grassland area comparison

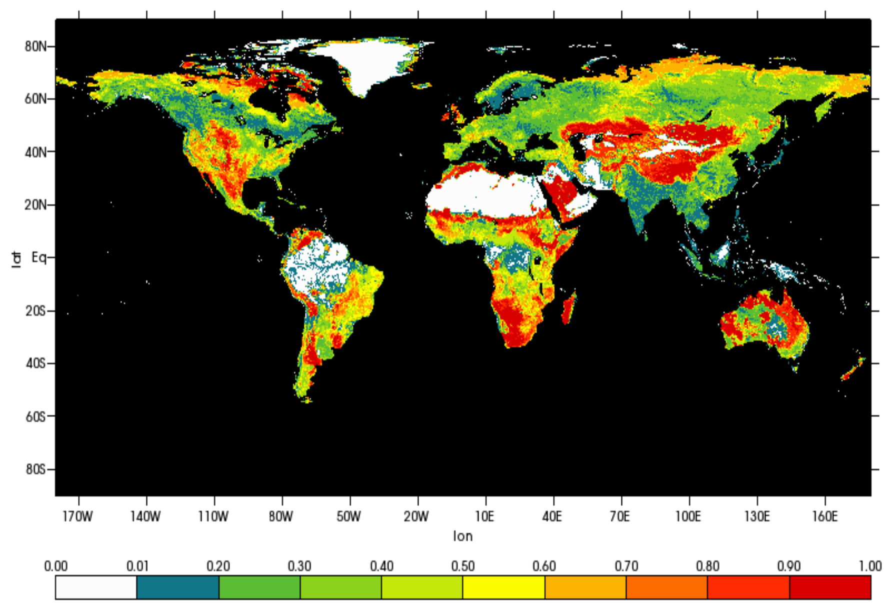
ESACCI_LC map

- Total area = **33 Mkm²**



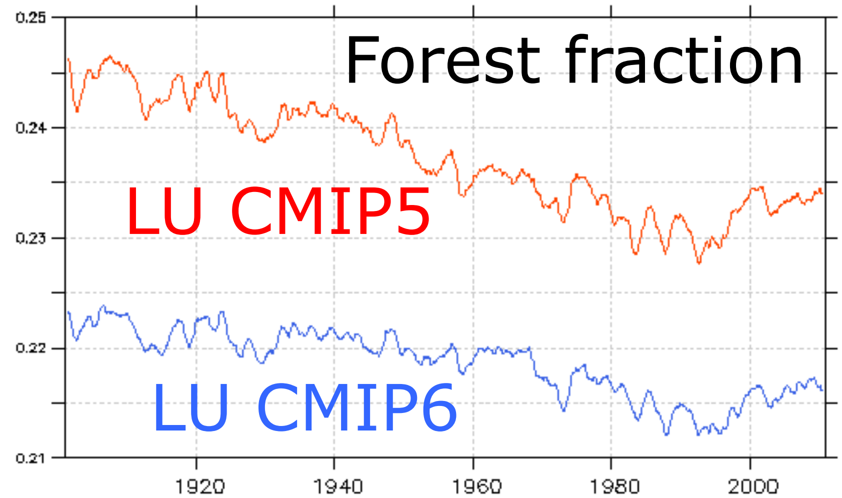
Luh CMIP6

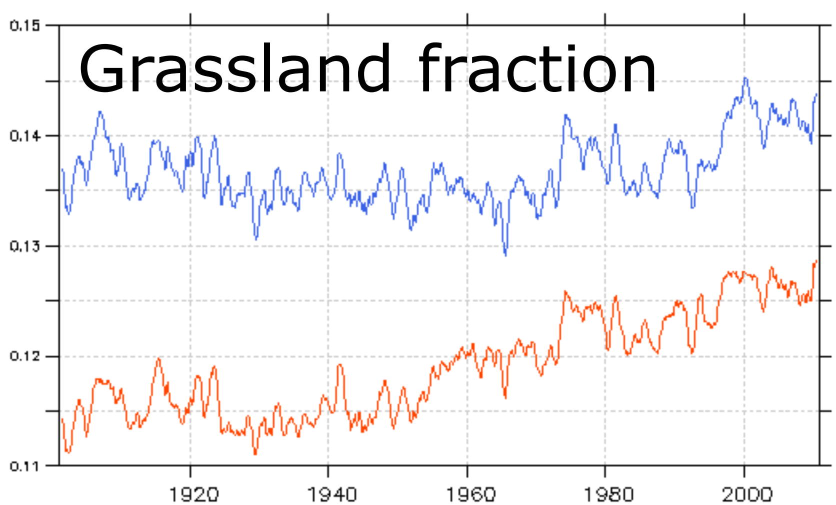
- Total area = **55 Mkm²**

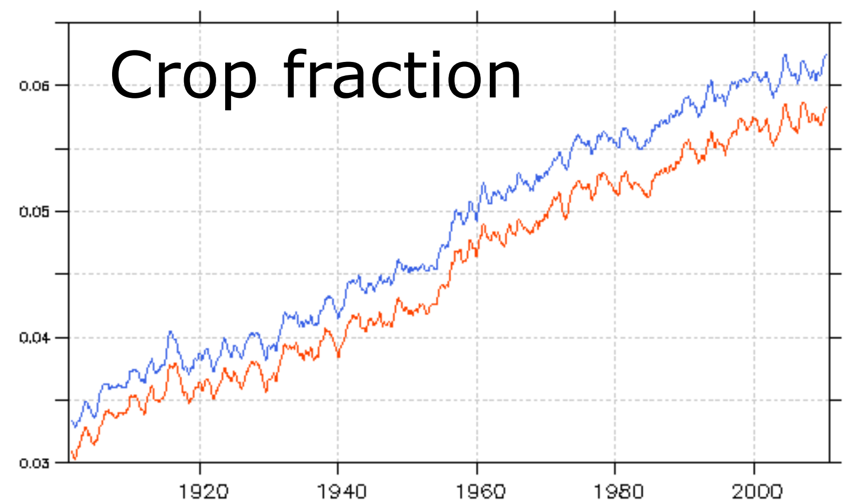


LU CMIP6 vs. LU CMIP5

- Similar trends over the 20th century
- Less forest area, more grassland area







CRUNCEP clim dataset

- An homogeneous dataset that cover all the 20th century up to now
  - CRU climatology
    - offers a good spatial resolution
    - **But** only monthly mean field are available
      $\Rightarrow$ too low resolution for modelling
  - NCEP
    - has a temporal resolution of 6 hours compatible
      $\Rightarrow$ Compatible with ecosystem models requirements
    - **But** the spatial resolution is low
    - and precipitation of such reanalysis is know to be less reliable than CRU

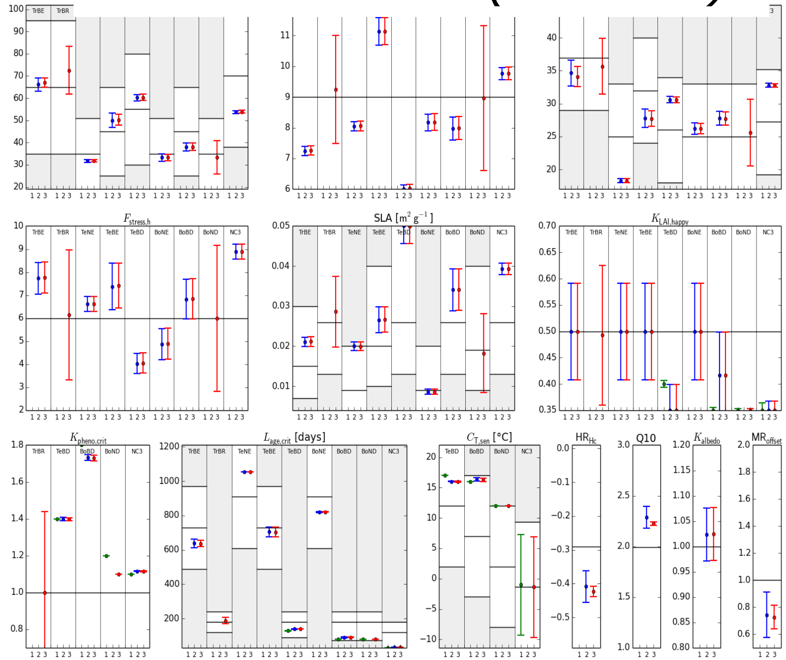
- Used in many Ecosystem Model Intercomparison Projects (such as TRENDY)

Land carbon cycle uncertainties from:

Forcing error error	Model parameter error	Model structure error
- Land Use Change scenarios - Meteo. forcing - Soil property uncertainties	- Parametric equations with Uncertain parameters (photosynthesis, respiration C allocation,…)	- Missing processes - Wrong process representation
➔ Test different scenarios From LCC & different Meteo forcing	➔ Optimize parameter using a 4D-var system with - Atm. CO2 data - FluxNet data - MODIS-NDVI	➔ Comparison between ORCHIDEE / CTESSEL and other models & approaches

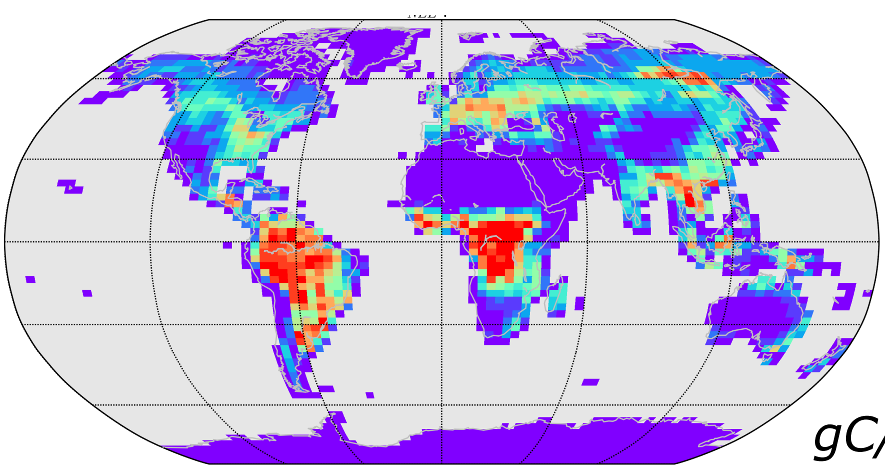
Model parameter uncertainties…

Estimated error (from DA)

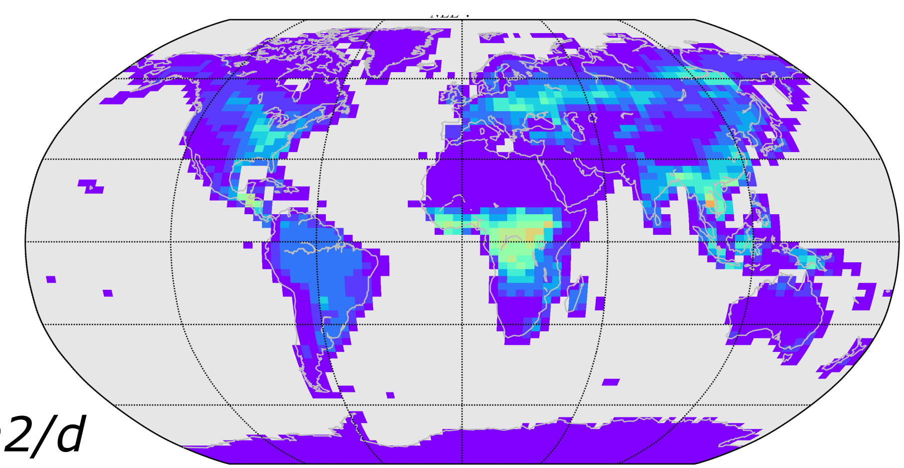


Error propagation on the fluxes

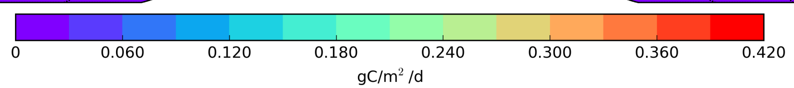
σ-NEE - Prior



σ-NEE - Posterior



gC/m2/d



Land carbon cycle uncertainties from:

Forcing error error	Model parameter error	**Model structure error**
- Land Use Change scenarios - Meteo. forcing - Soil property uncertainties	- Parametric equations with Uncertain parameters (photosynthesis, respiration C allocation,…)	**- Missing processes** **- Wrong process representation**
➔ Test different scenarios From LCC & different Meteo forcing	➔ Optimize parameter using a 4D-var system with - Atm. CO2 data - FluxNet data - MODIS-NDVI	**➔ Comparison between ORCHIDEE / CTESSEL and other models & approaches**

Model development

Implemented

Ongoing:

New Aerodynamic resistance

Nitrogen – carbon Coupled cycles

Optimized albedo (using MODIS)

Permafrost carbon

Land cover based on ESA-CCI

Forest management & forest structure

New 3 layers snow model

11-layer soil hydrology With soil freezing

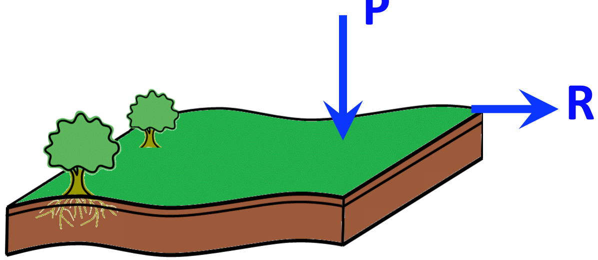
SPITFIRE and Land use gross transitions

Improved Dynamic vegetation

Model development: Hydrology

Choisnel = ORC2

Ducoudré et al., 1993; de Rosnay et al. 1998

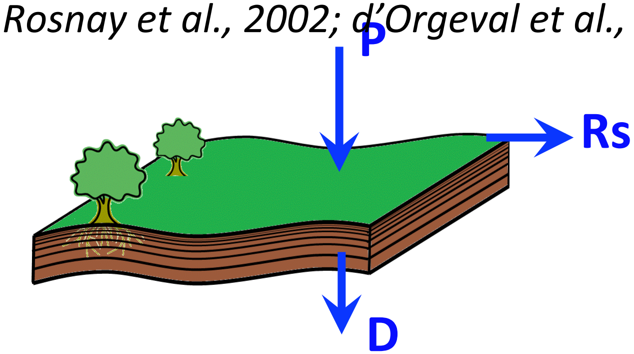


- **Conceptual description of soil moisture storage**
- **2-m soil and 2-layers**
- Top layer can vanish
- Constant available water holding capacity (between FC and WP)
- Runoff when saturation
- No drainage from the soil

  We just diagnose a drainage as 95% of runoff for the routing scheme

CWRR = ORC11

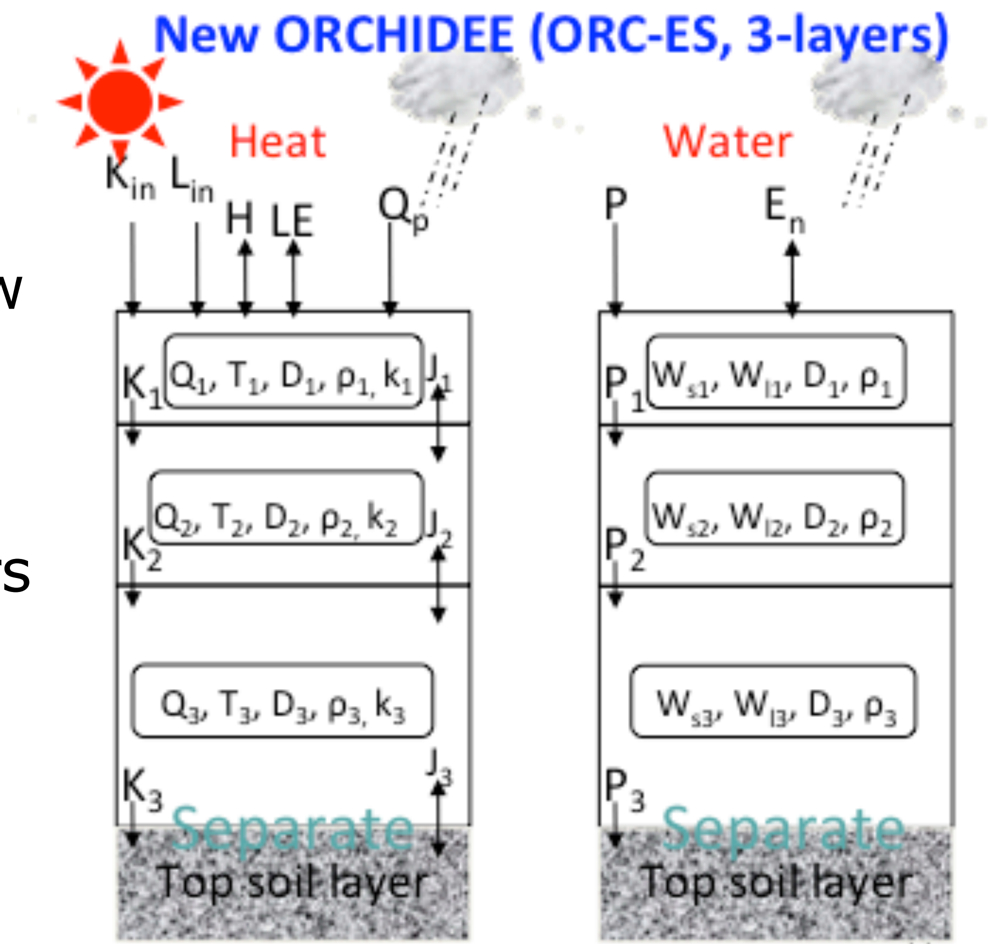
de Rosnay et al., 2002; d'Orgeval et al., 2008



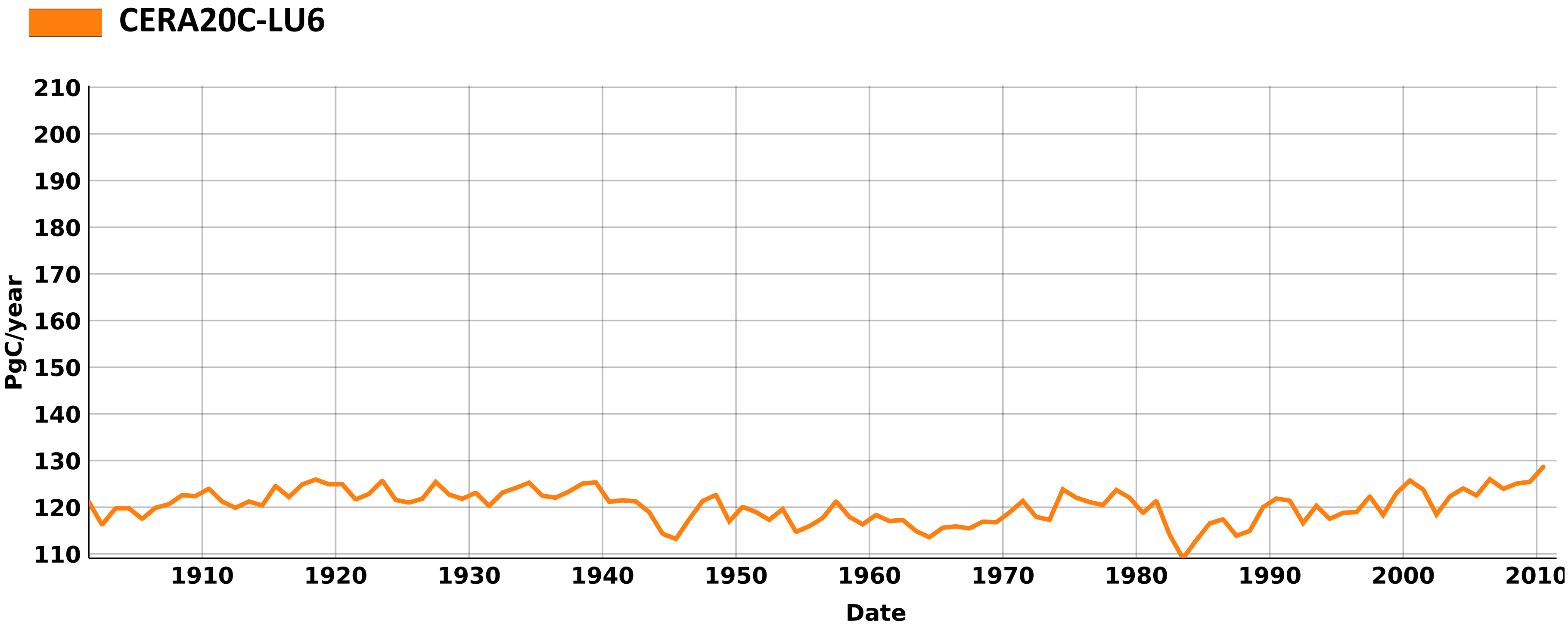
- **Physically-based description of soil water fluxes using Richards eq.**
- **2-m soil and 11-layers**
- Formulation of Fokker-Planck
- Hydraulic properties based on van Genuchten-Mualem formulation
- Parameter based on texture
- Surface runoff = P – Esol – Infiltration
- Free drainage at the bottom

Model development: Snow

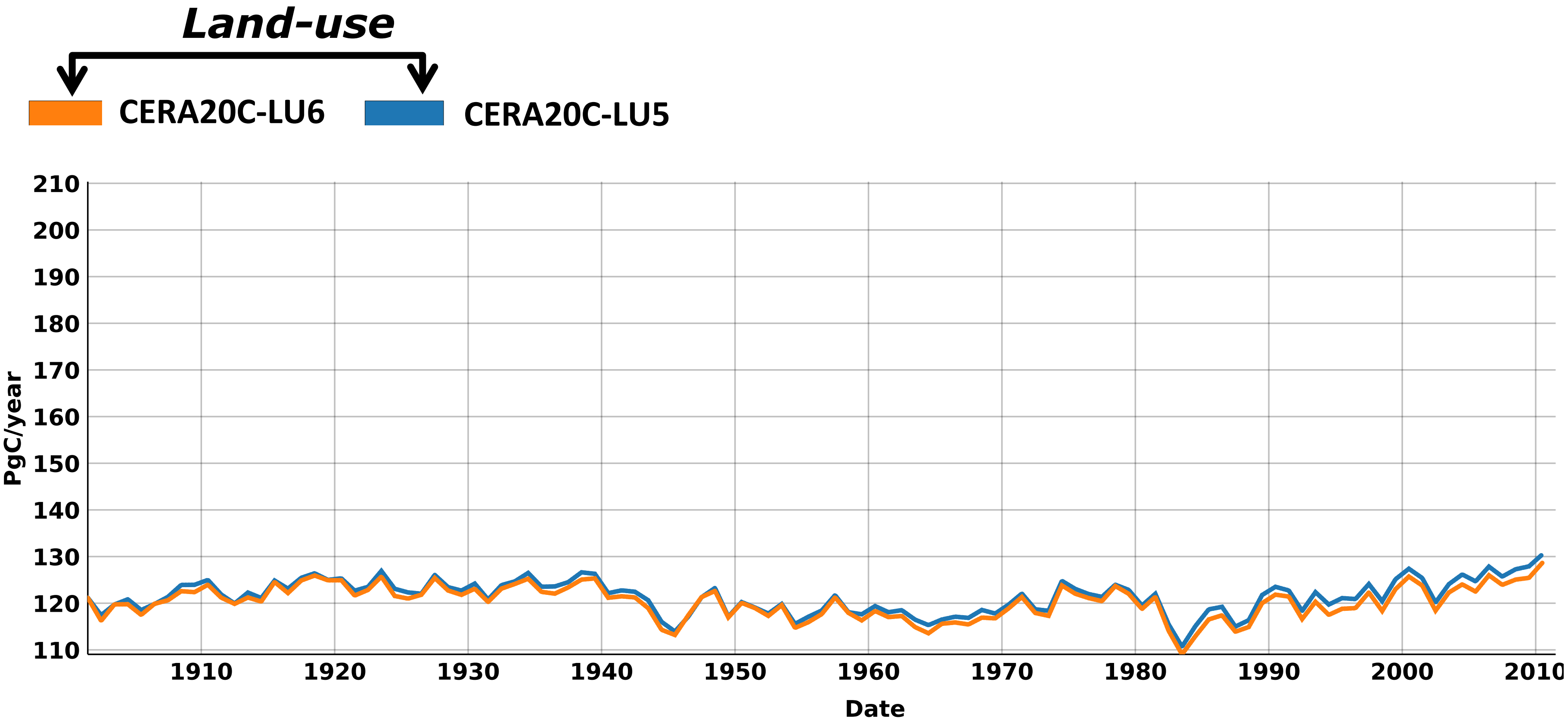
- Single layer vs. Three layers
- Composite vs. Separate snow structure
- Snow density(r) and snow thermal conductivity (k)
- Thawing and refreezing processes
- Water flow between layers
- New snow albedo parametrization
- Snow impacts on roughness length



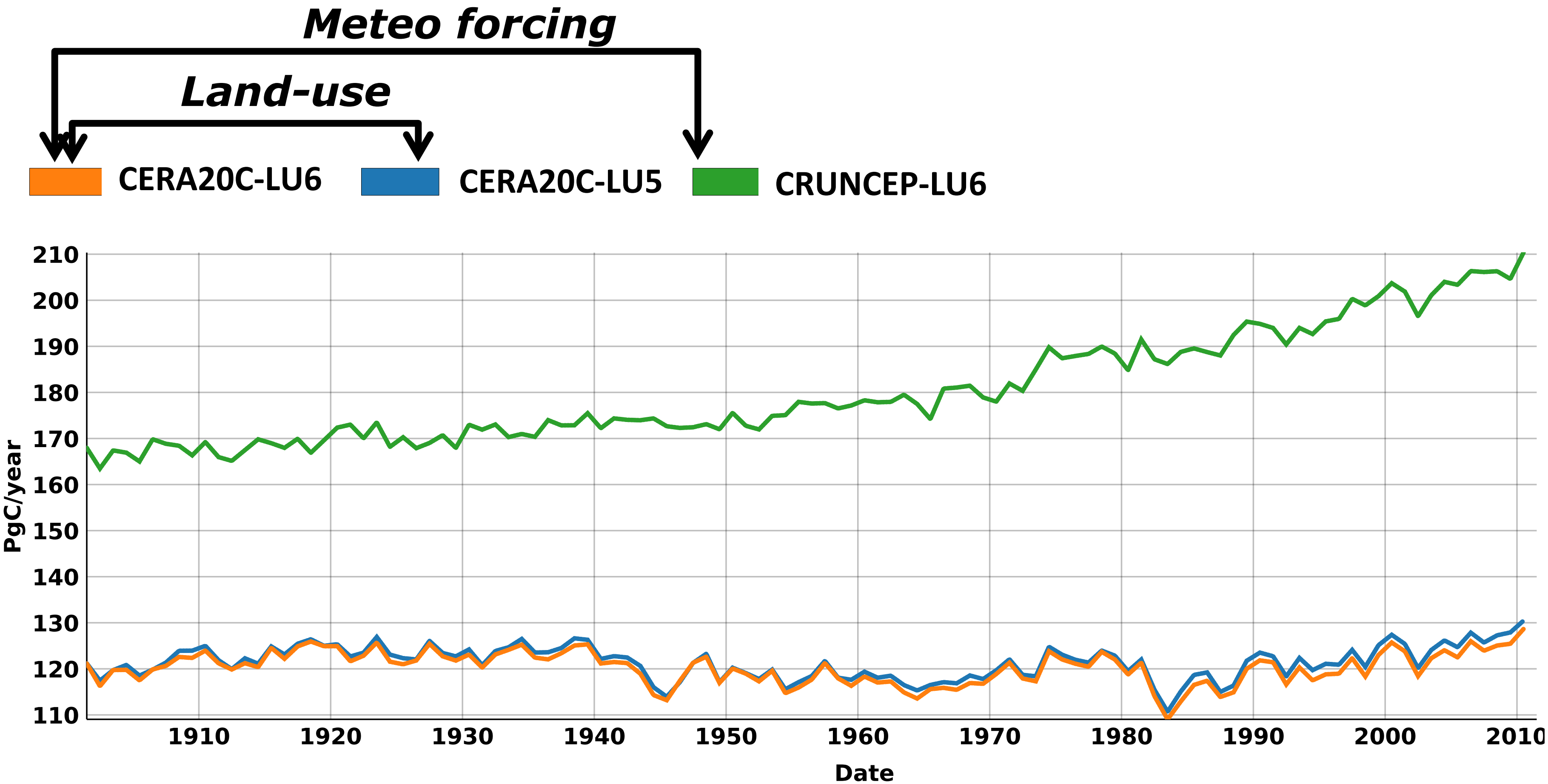
Gross Primary Production (Photosynthesis)



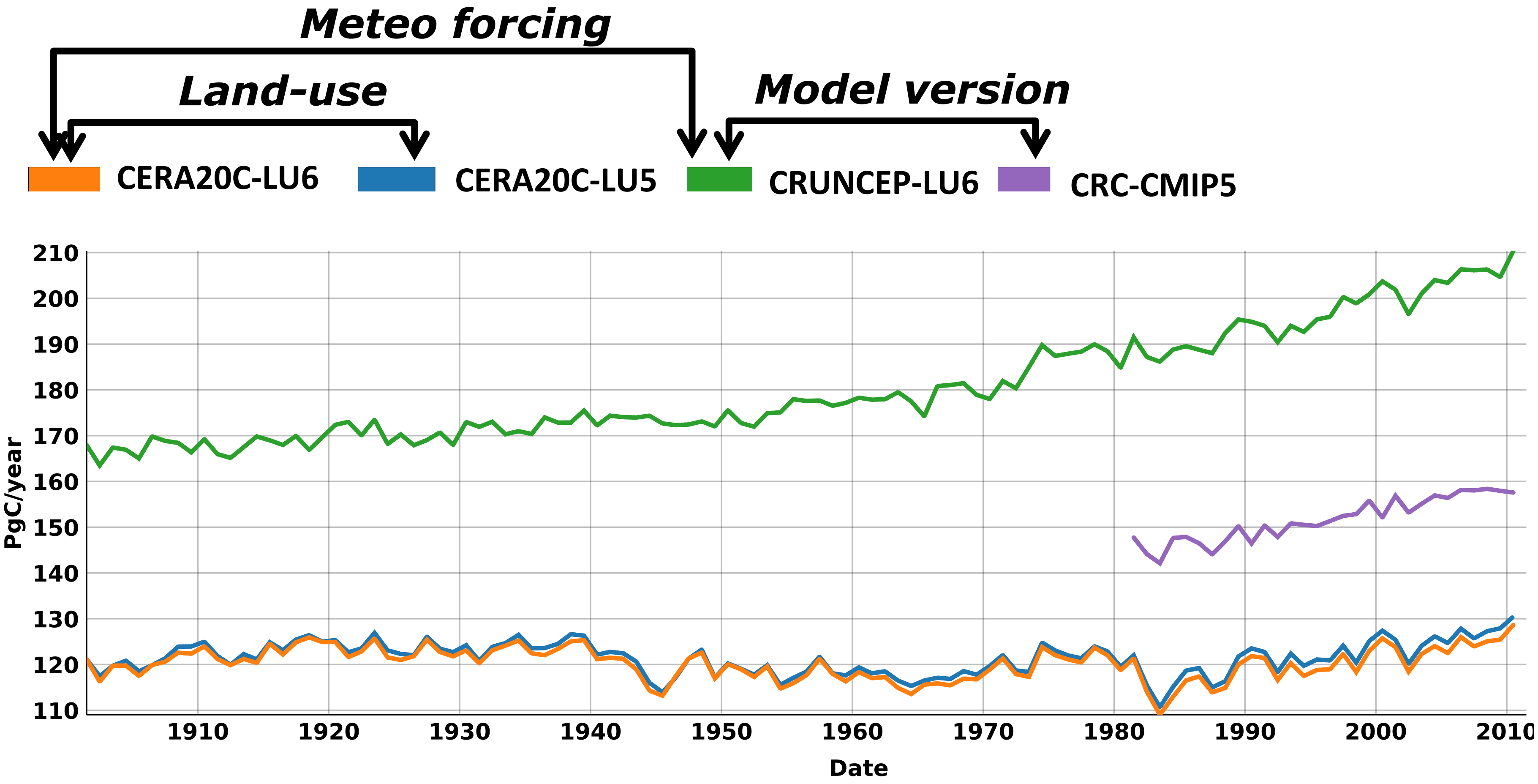
Gross Primary Production (Photosynthesis)



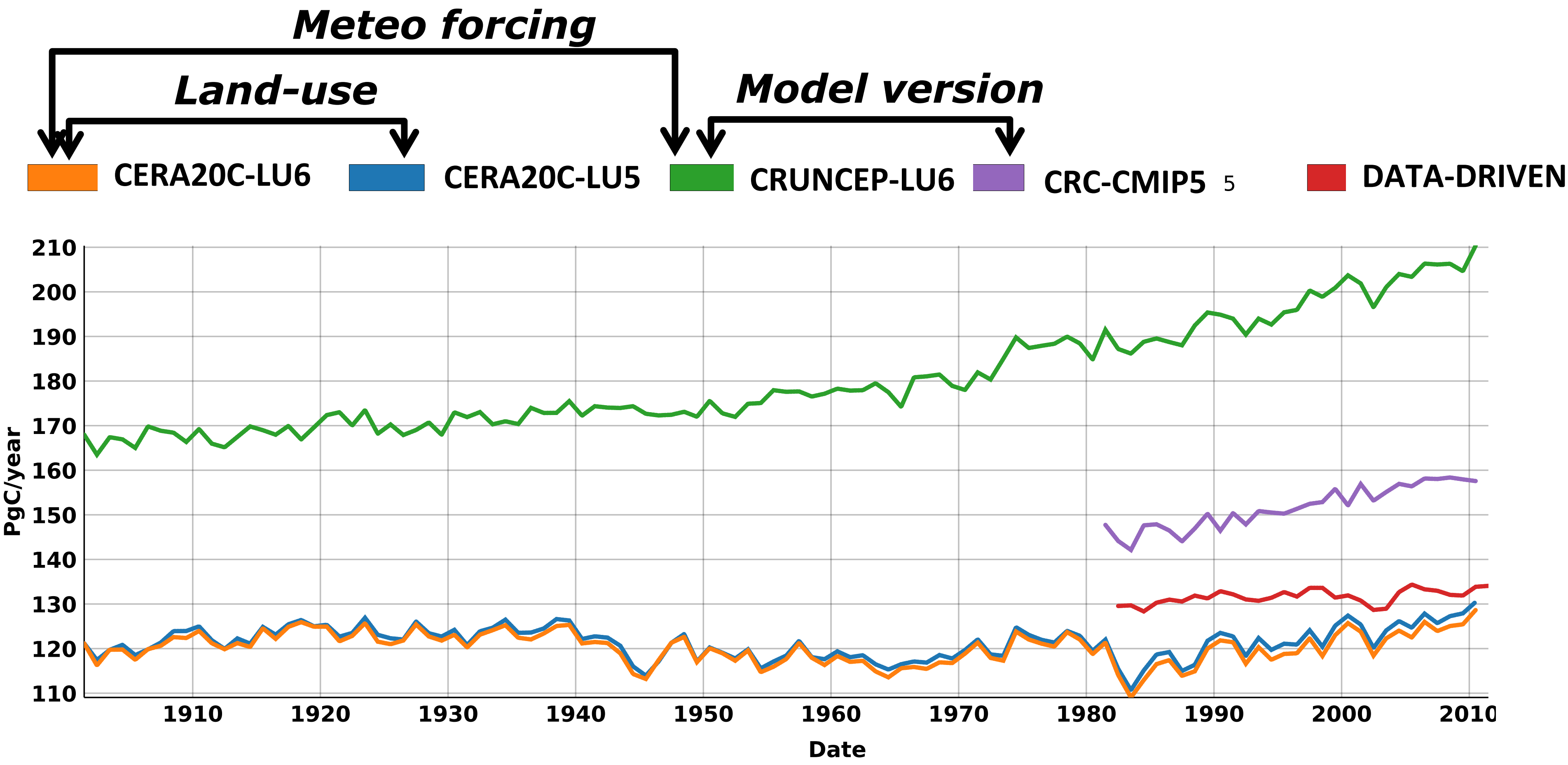
Gross Primary Production (Photosynthesis)



Gross Primary Production (Photosynthesis)

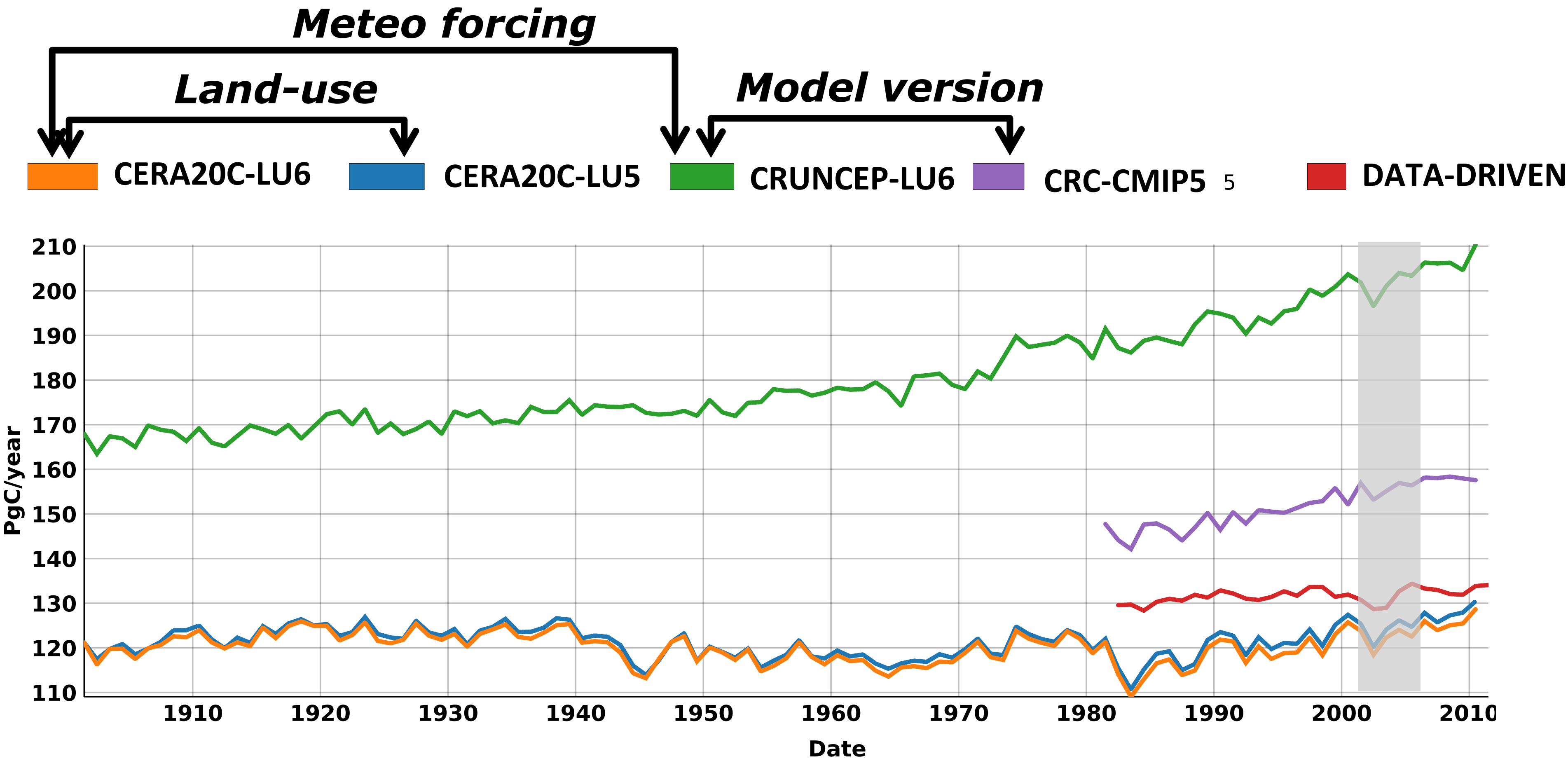


Gross Primary Production (Photosynthesis)

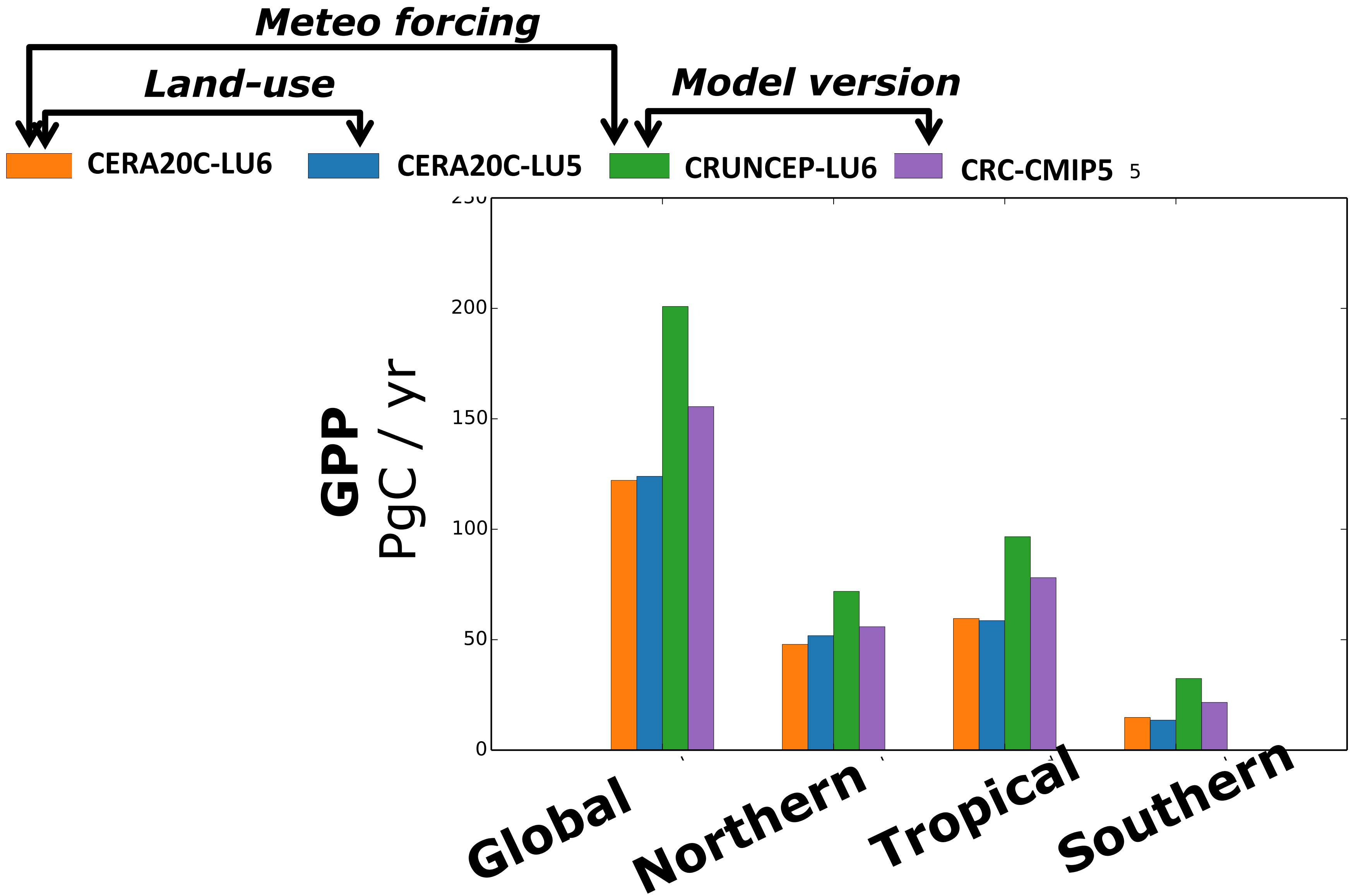


5

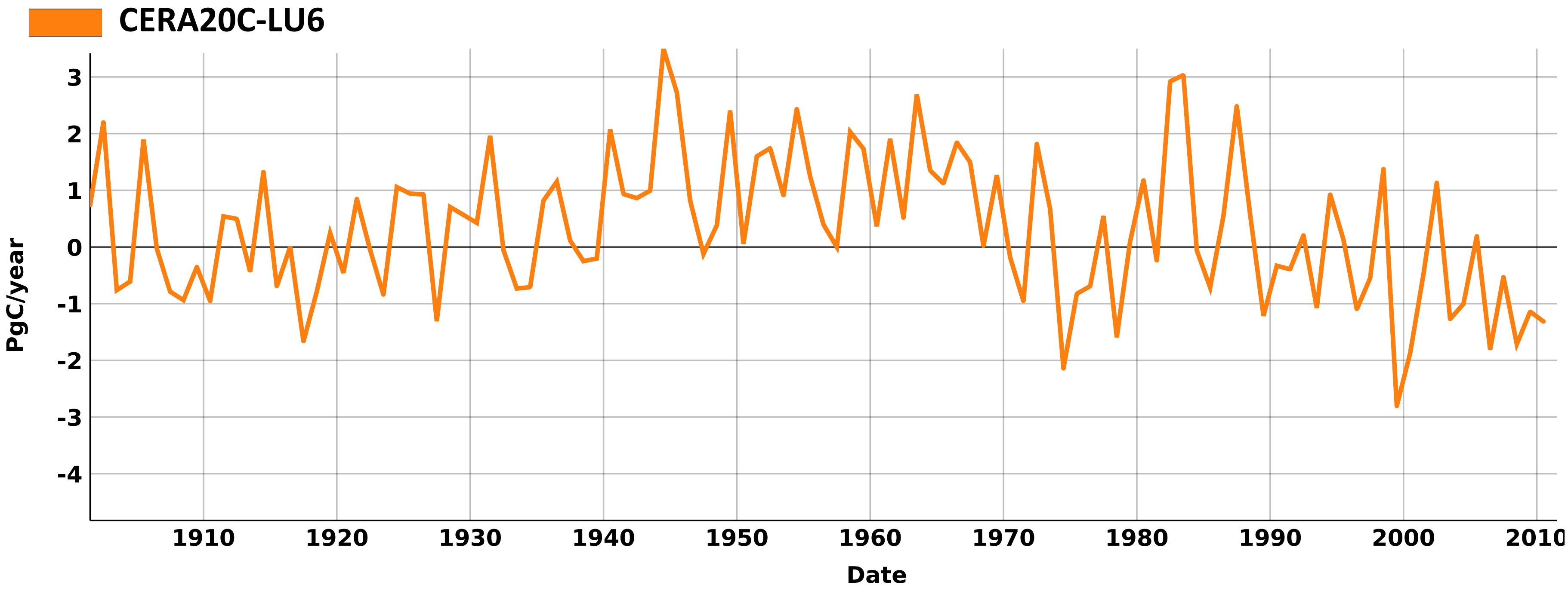
Gross Primary Production (Photosynthesis)



Annual Mean 2001-2004

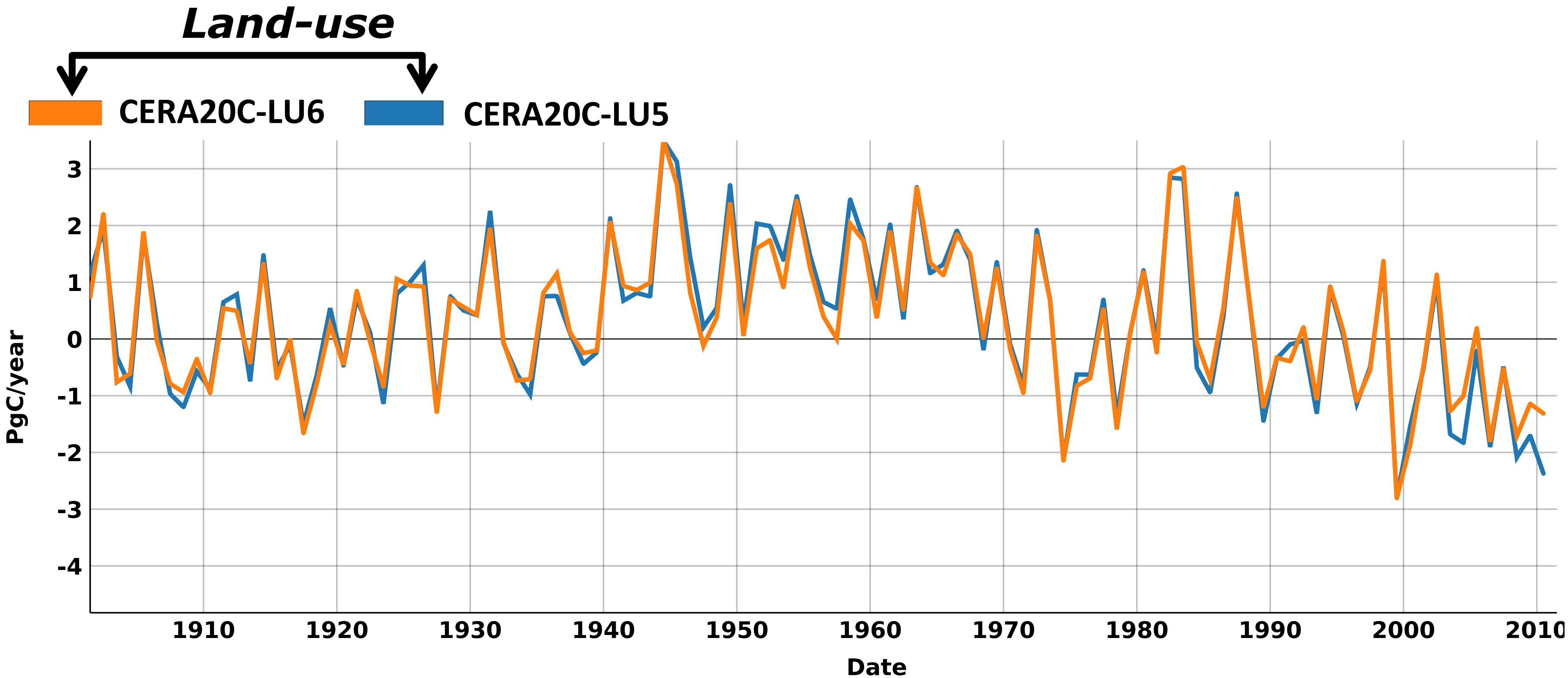


Net CO_2 flux



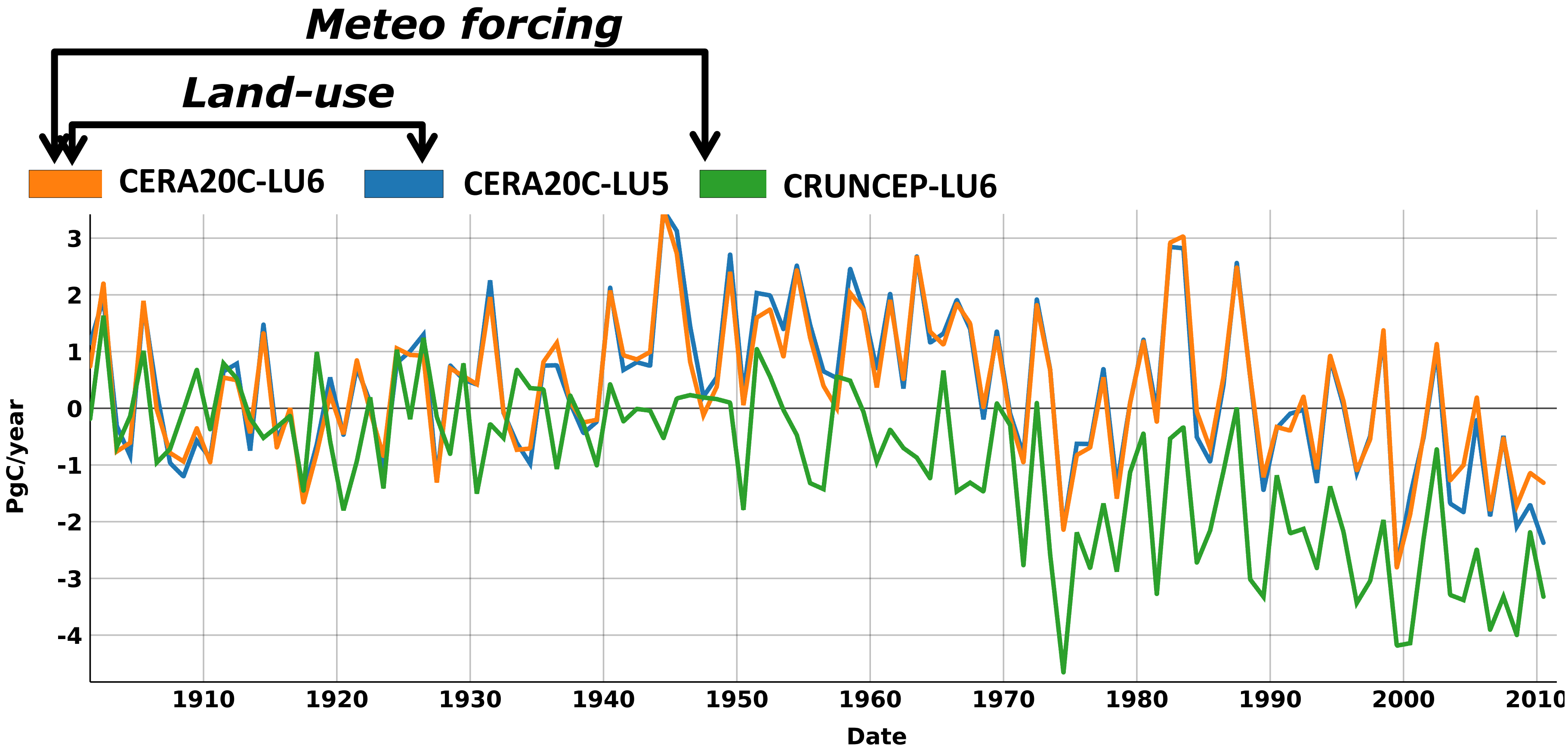
CERA20C-LU6
3
2
1
0
-1
-2
-3
-4
PgC/year
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Date

Net CO_2 flux

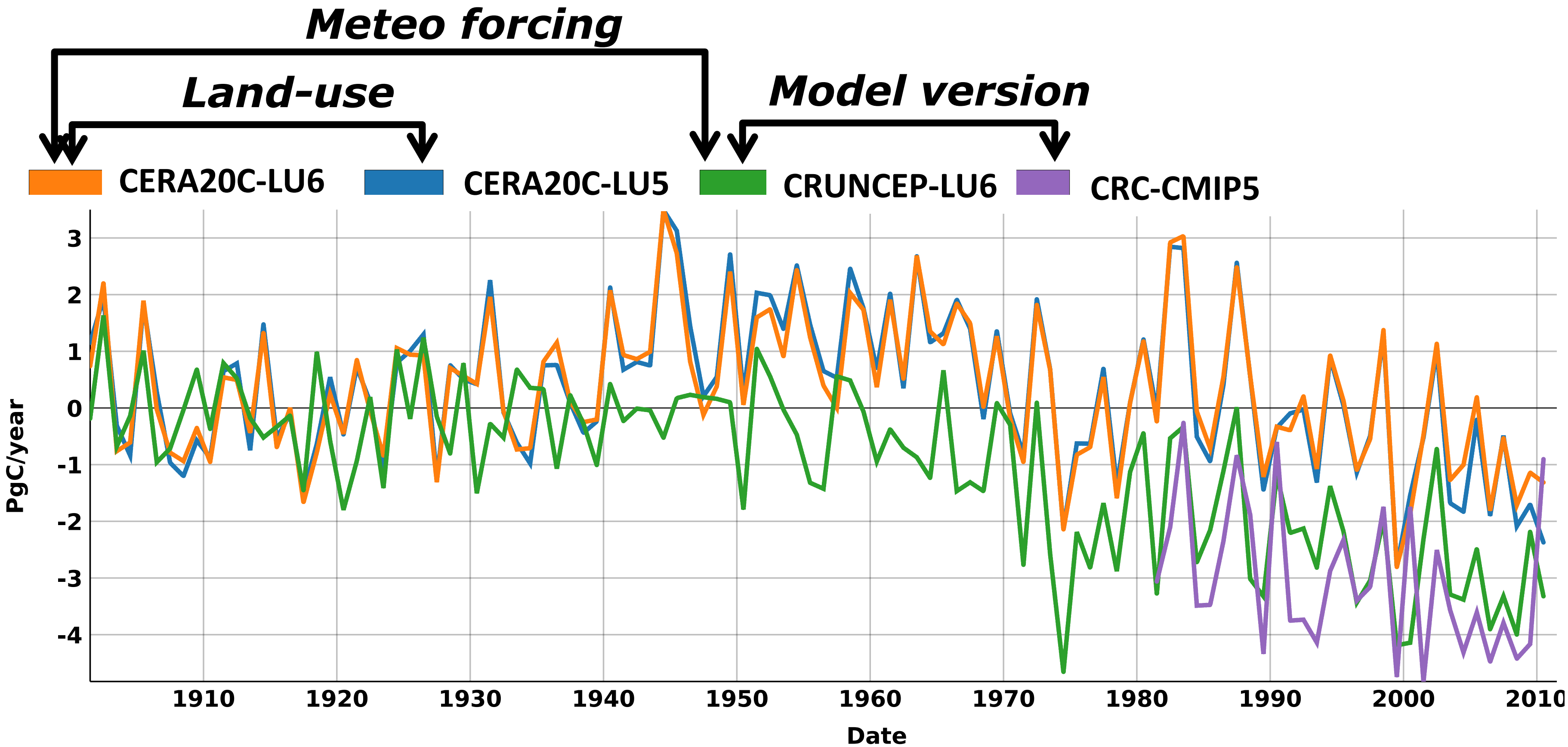


Land-use
CERA20C-LU6
CERA20C-LU5
3
2
1
0
-1
-2
-3
-4
PgC/year
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Date

Net CO_2 flux

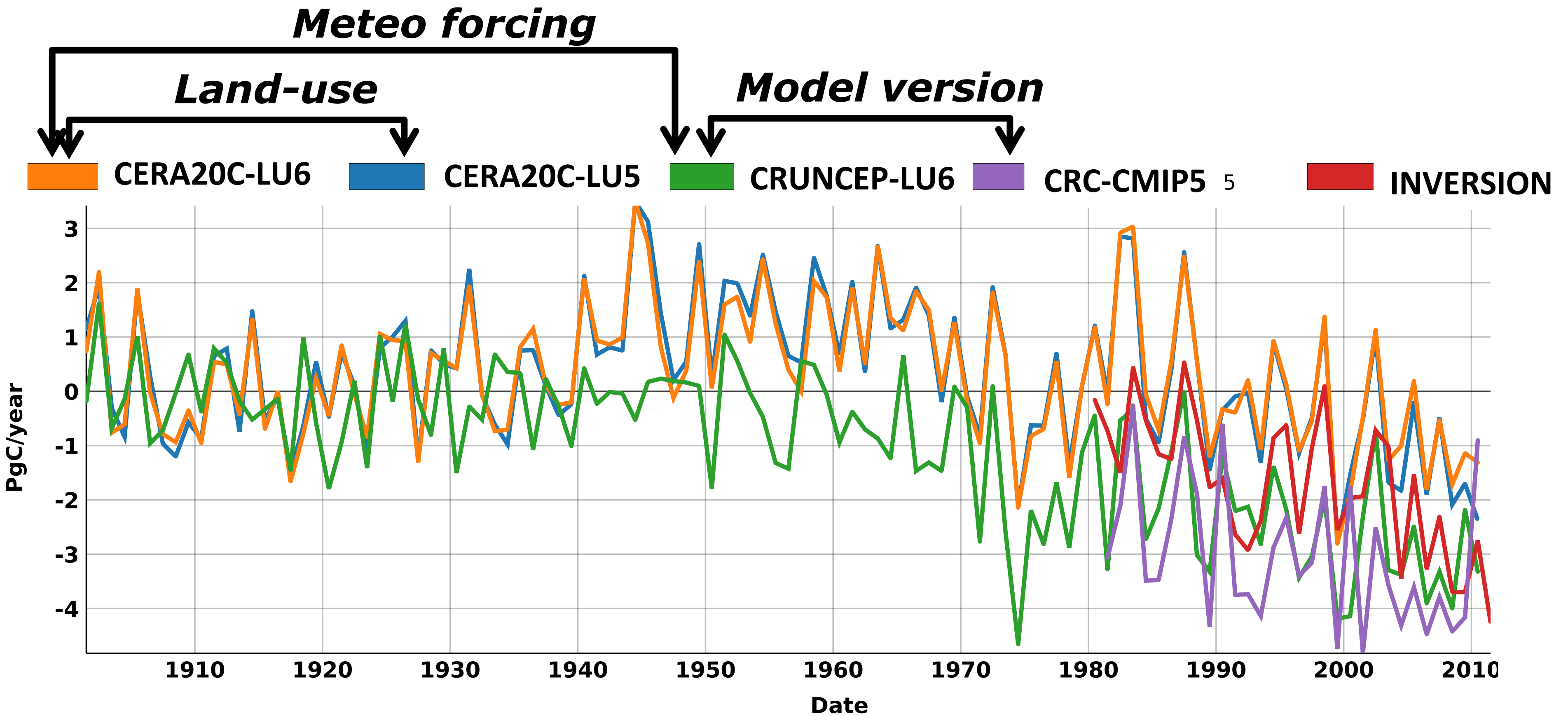

Meteo forcing
Land-use
CERA20C-LU6
CERA20C-LU5
CRUNCEP-LU6
3
2
1
0
-1
-2
-3
-4
PgC/year
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Date

Net CO_2 flux

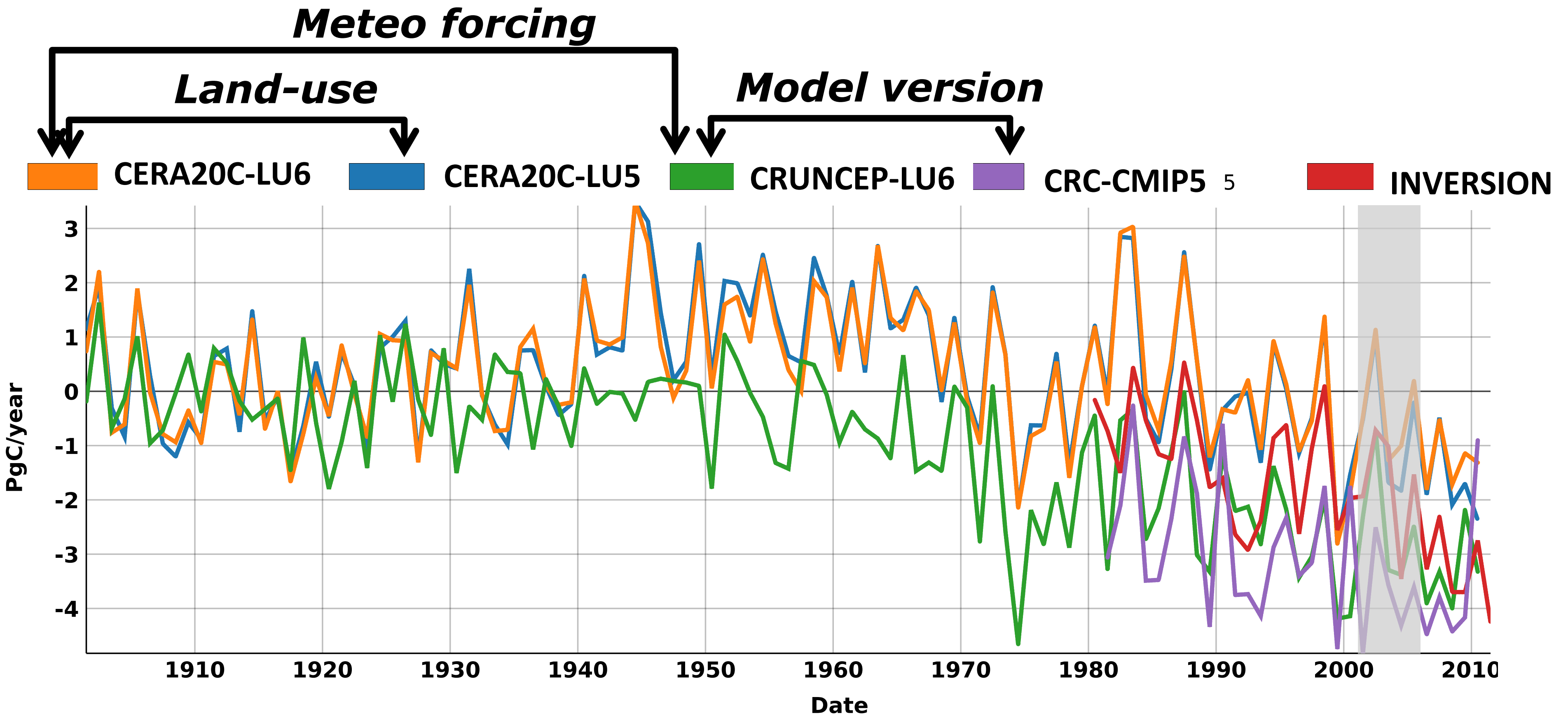


Meteo forcing
Land-use
Model version
CERA20C-LU6
CERA20C-LU5
CRUNCEP-LU6
CRC-CMIP5
3
2
1
0
-1
-2
-3
-4
PgC/year
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Date

Net CO_2 flux

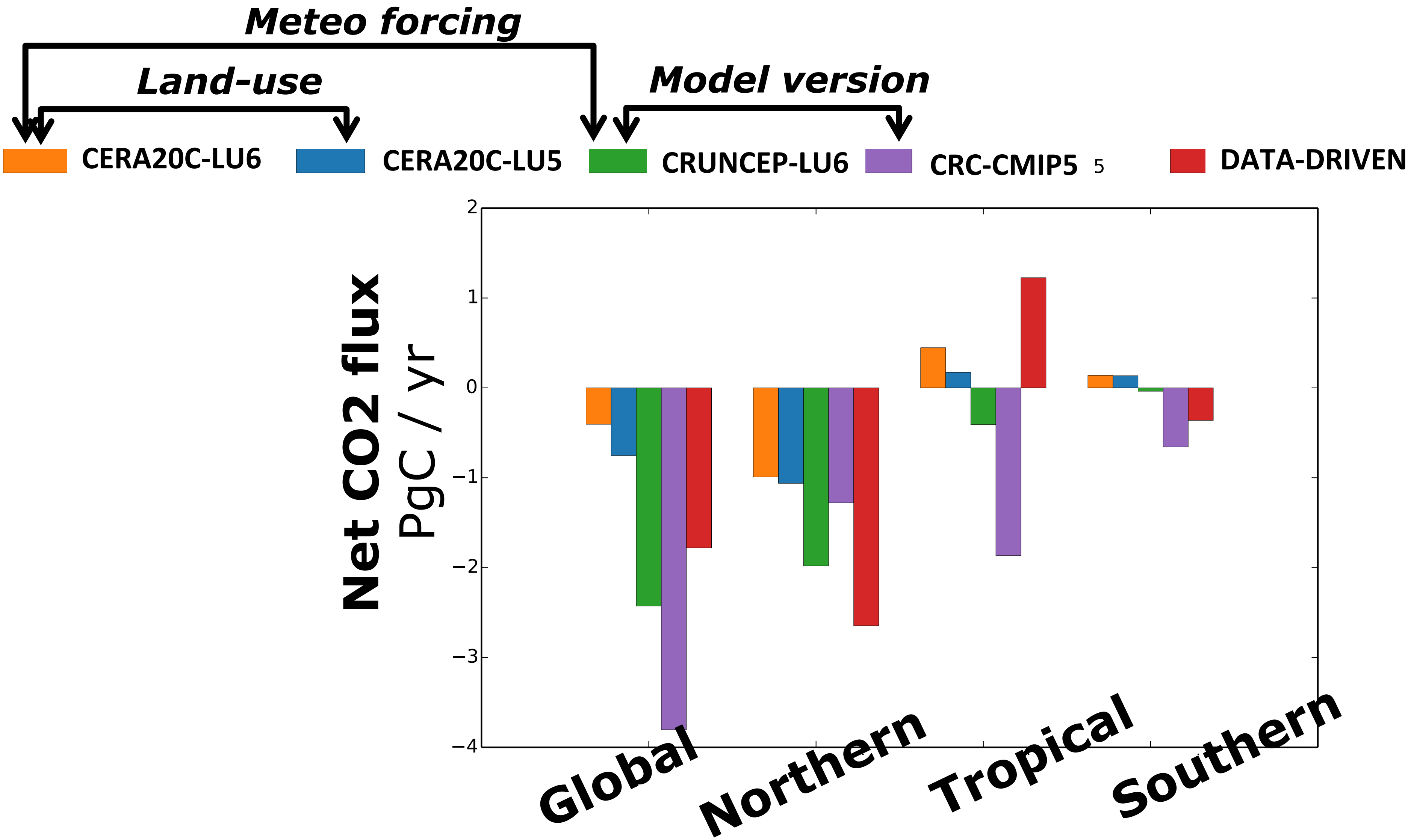

Meteo forcing
Land-use
Model version
CERA20C-LU6
CERA20C-LU5
CRUNCEP-LU6
CRC-CMIP5
5
INVERSION
3
2
1
0
-1
-2
-3
-4
PgC/year
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Date

Net CO_2 flux

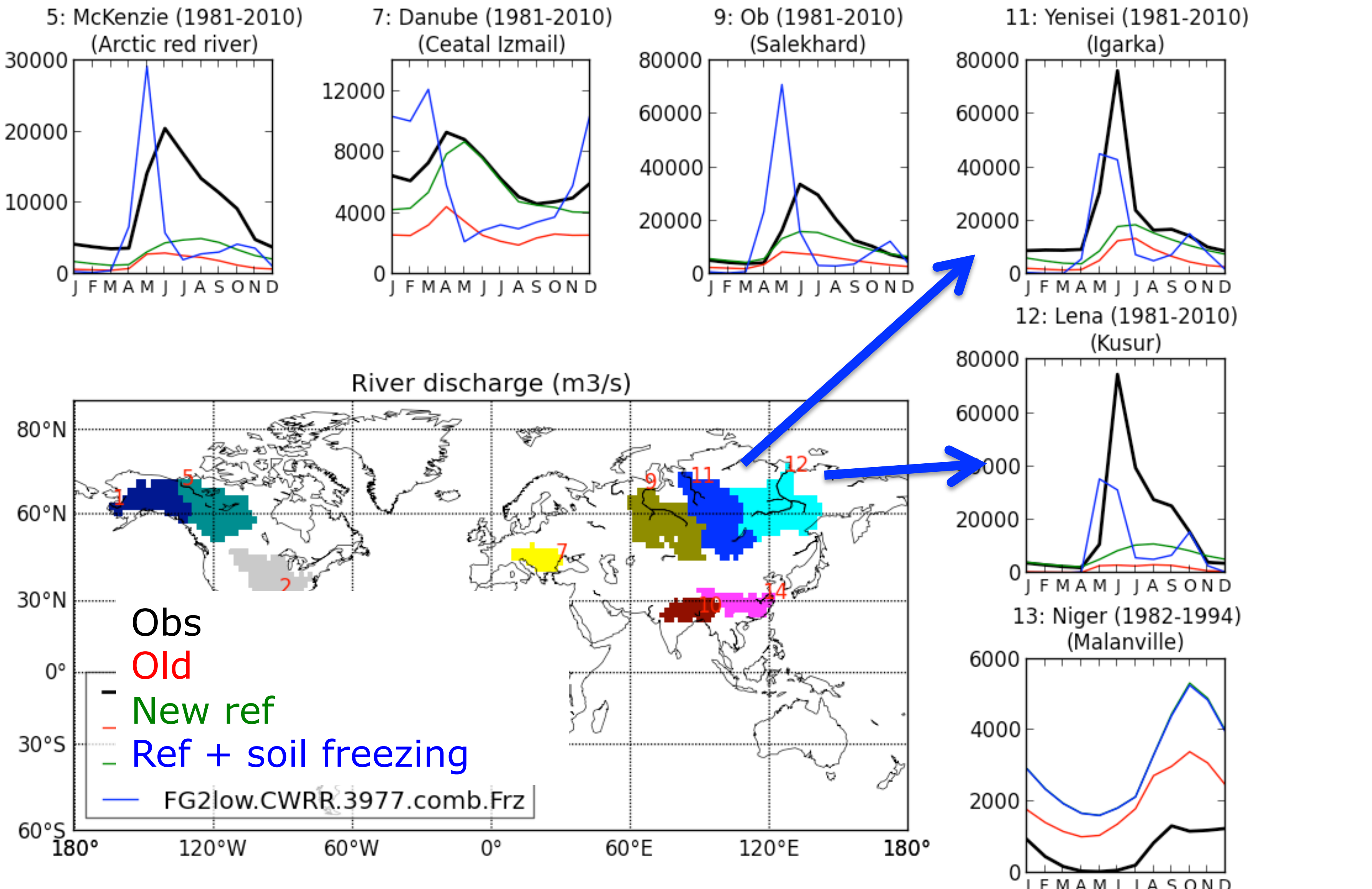


Meteo forcing
Land-use
Model version
CERA20C-LU6
CERA20C-LU5
CRUNCEP-LU6
CRC-CMIP5 5
INVERSION
3
2
1
0
-1
-2
-3
-4
PgC/year
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Date

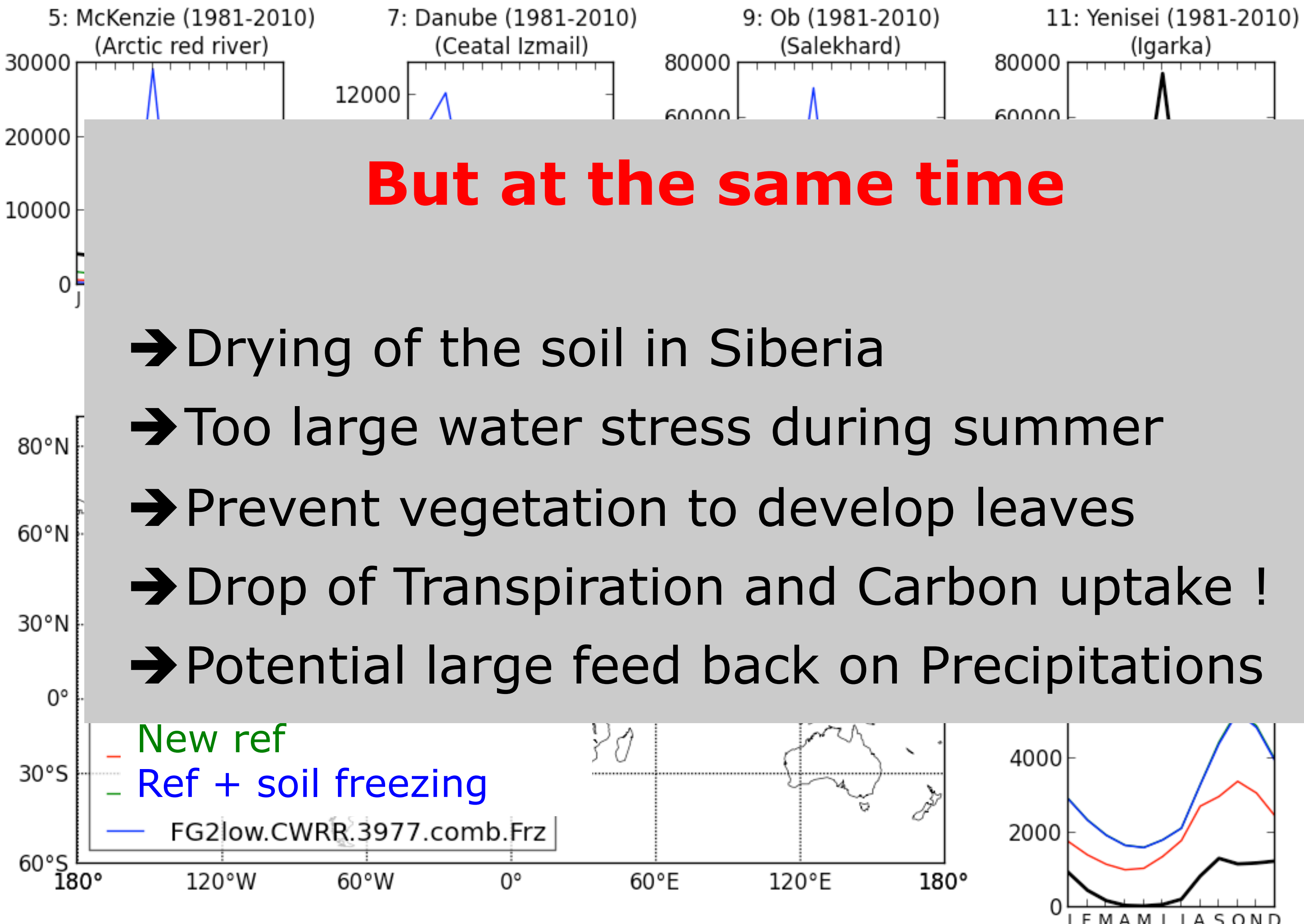
Annual Mean 2001-2004



Impact of soil freezing on river discharge



Impact of soil freezing on river discharge

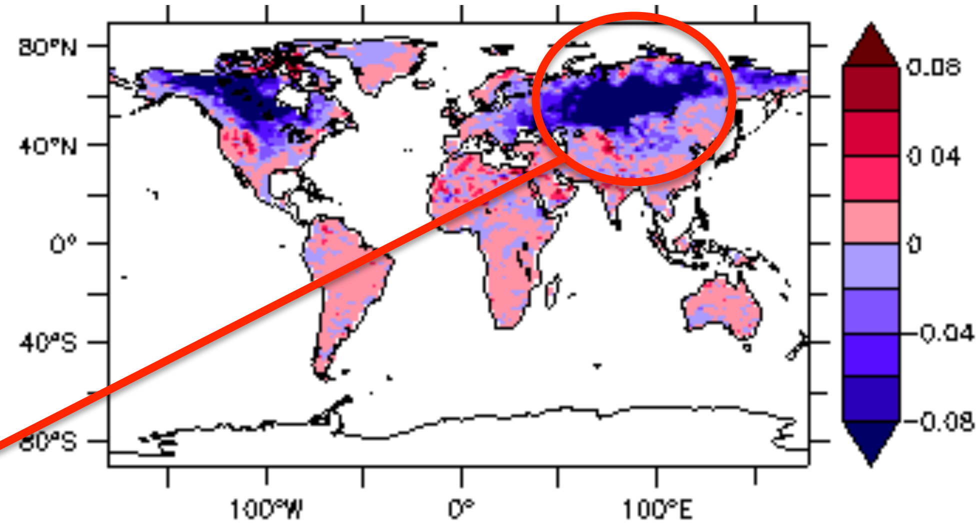


But at the same time

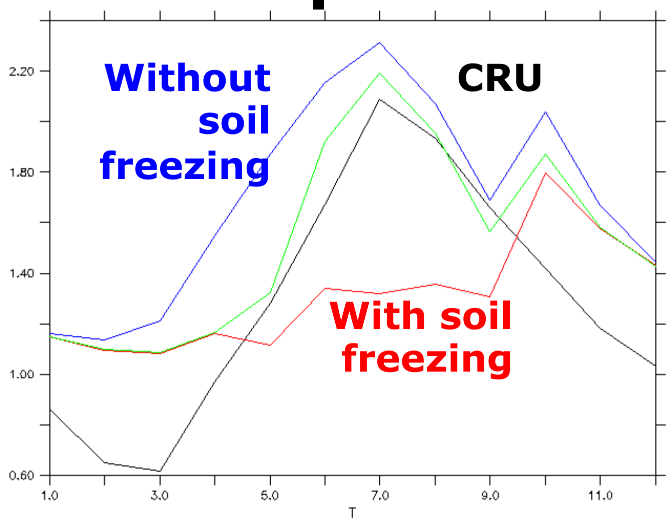
- ➔ Drying of the soil in Siberia
- ➔ Too large water stress during summer
- ➔ Prevent vegetation to develop leaves
- ➔ Drop of Transpiration and Carbon uptake !
- ➔ Potential large feed back on Precipitations

Coupling of Water – Carbon - Energy

⇒ Impact on the Month-to-month correlation Of modeled vs. CRU Precipitation



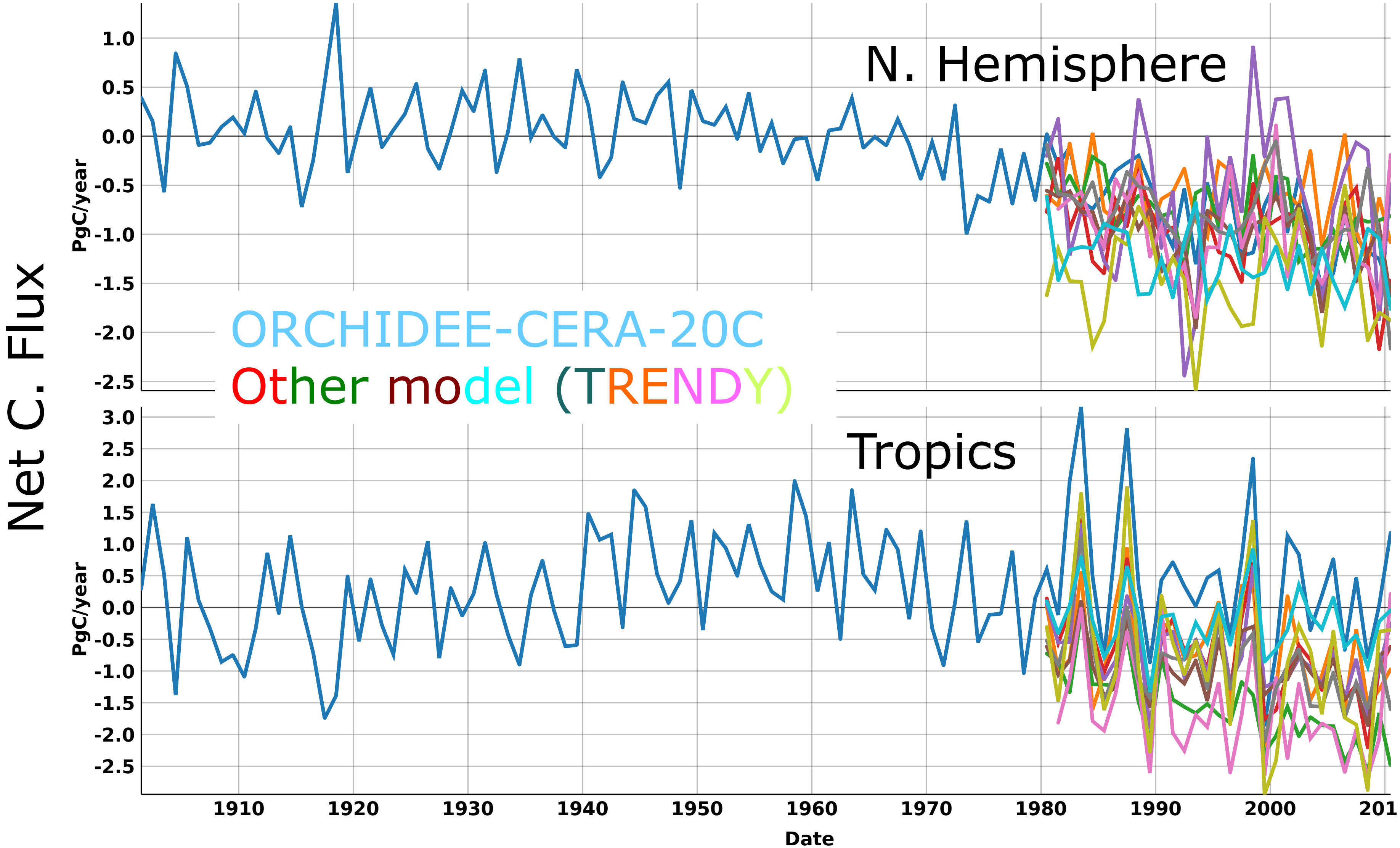
Precipitation



Perspectives

- Model uncertainties based on CTESSEL & ORCHIDEE comparison
- Propagation of model parameter errors to Carbon modelled flux and stocks uncertainties
- To account for new processes:
  - **Carbon-Nitrogen interactions**: atm. CO2 and N fertilsation may enhance or limit photosynthesis and the Net CO2 flux
  - **Permafrost carbon**
  - **Forest and agricultural management**: Harvest and logging impact on Net CO2 flux
  - **Gross vs. Net land-use changes**

Net Carbon flux still highly variables..

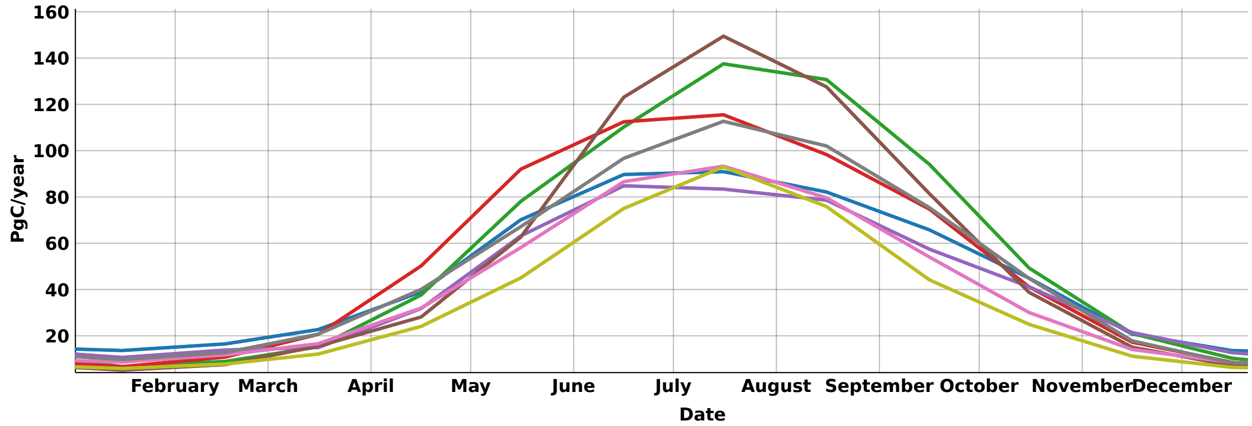


Gross Carbon flux still highly variables

Gross Primary Production

N. Hemisphere

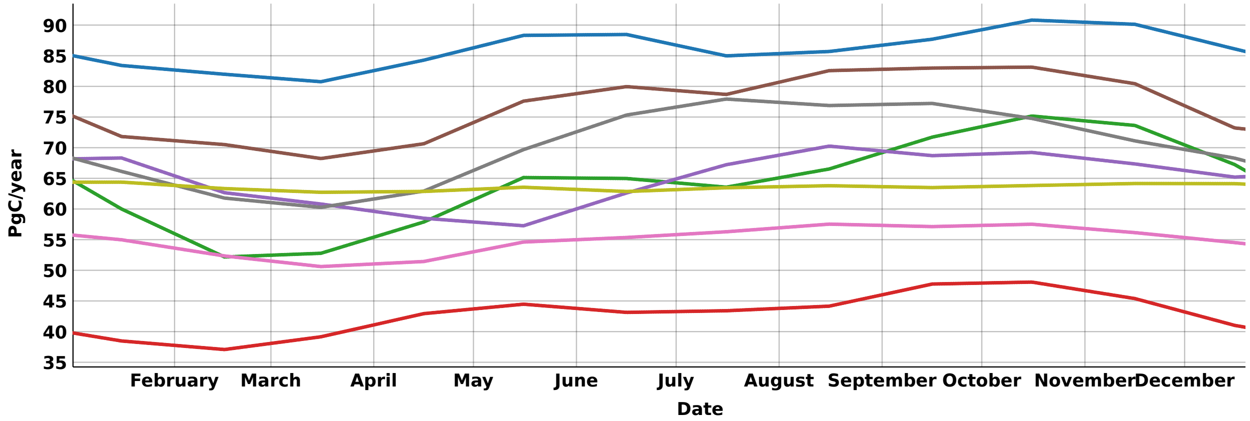
Large amplitude differences at high latitudes



11 models (TRENDY)

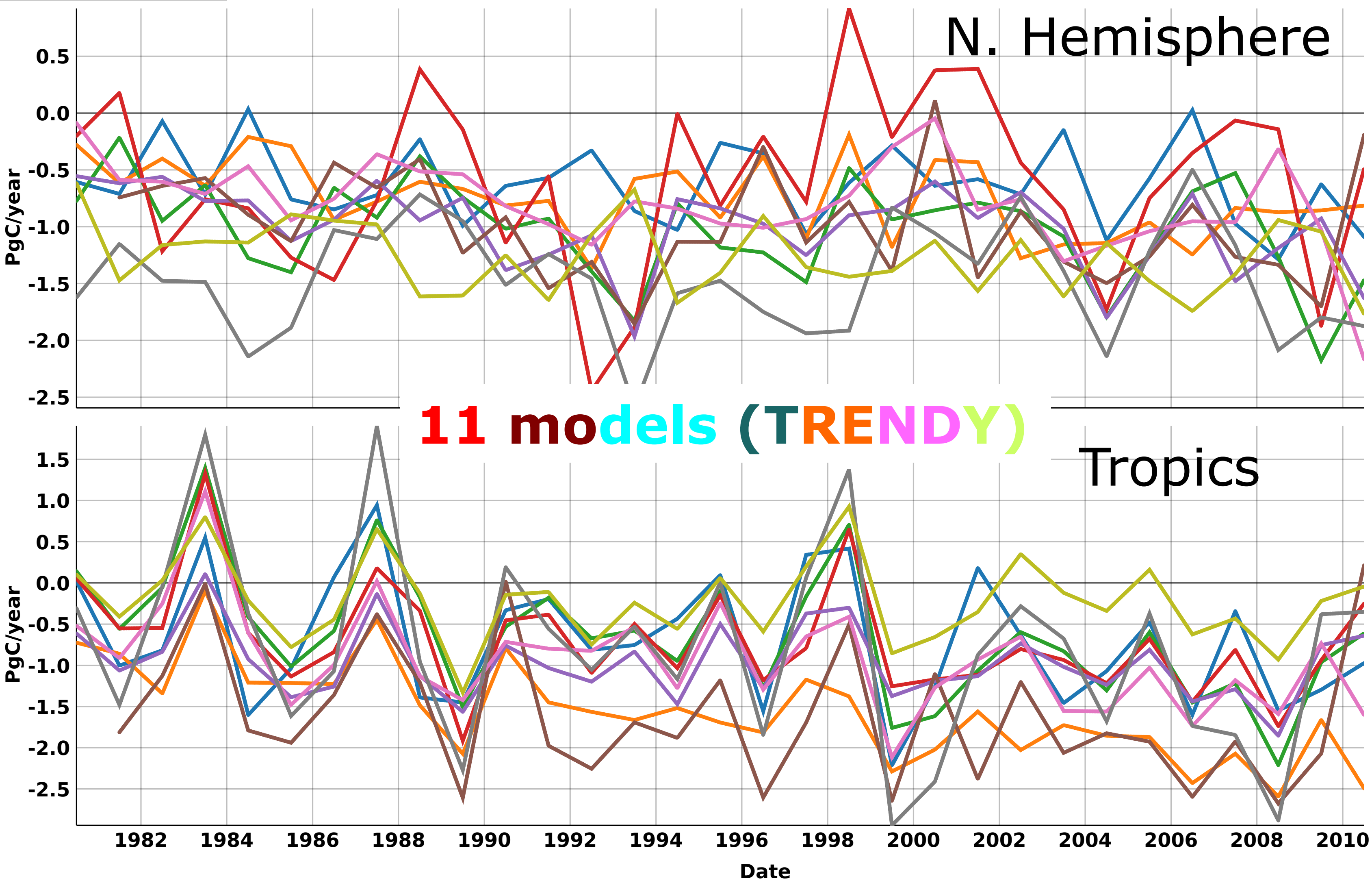
Tropics

Large phase differences in the Tropics



Net Carbon flux still highly variables..

Net C. Flux



Objectives

- **To account for recent developments** regarding
  - Land-use reconstruction
  - Climate Reanalysis
  - Model process developments

- **To evaluate their respective contributions to modelled estimates** of Gross (here GPP) and Net CO_2 flux at regional and global scale