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:

<table>
<thead>
<tr>
<th>Forcing error error</th>
<th>Model parameter error</th>
<th>Model structure error</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Land Use Change scenarios</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Meteo. forcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Soil property uncertainties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Parametric equations with Uncertain parameters (photosynthesis, respiration C allocation,…)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Missing processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Wrong process representation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 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:

<table>
<thead>
<tr>
<th>Forcing error</th>
<th>Model parameter error</th>
<th>Model structure error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use Change</td>
<td>Parametric equations</td>
<td>Missing processes</td>
</tr>
<tr>
<td>scenarios</td>
<td>with Uncertain parameters</td>
<td>Wrong process</td>
</tr>
<tr>
<td>Meteo. forcing</td>
<td>(photosynthesis, respiration</td>
<td>representation</td>
</tr>
<tr>
<td>Soil property</td>
<td>C allocation,…)</td>
<td></td>
</tr>
<tr>
<td>uncertainties</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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
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

<table>
<thead>
<tr>
<th>Non forested Primary land</th>
<th>Forested Primary Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary land forested</td>
<td>Managed Pasture land</td>
</tr>
<tr>
<td>Urban land</td>
<td>C3 Annual Crop</td>
</tr>
<tr>
<td>Non forested Secondary land</td>
<td>C3 Perennial Crop</td>
</tr>
<tr>
<td></td>
<td>C4 Annual crop</td>
</tr>
<tr>
<td></td>
<td>C4 Perennial crop</td>
</tr>
<tr>
<td></td>
<td>C3 Nitrogen fixing crop</td>
</tr>
</tbody>
</table>

⇒ *Land-use categories in LUh2*
What will we get in terms of land-cover & use information?

- Non forested
- Forested
- Managed Pasture land
- Rangeland
- Urban land
- C3 Annual Crop
- C4 Annual crop
- C3 Perennial Crop
- C4 Perennial crop
- C3 Nitrogen fixing crop

**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**

- Tropical Evergreen Forest
- Needleleaf Evergreen Forest
- Broadleaf Deciduous Forest
- C3 Cropland
- C4 Cropland
- C3 Grassland
- C4 Grassland
What will we get in terms of land-cover & use information?

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

**ESA-CCI land cover product**

**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

<table>
<thead>
<tr>
<th>Non forested Primary land</th>
<th>Forested Primary Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary land forested</td>
<td>Managed Pasture land</td>
</tr>
<tr>
<td>Urban land</td>
<td>Rangeland</td>
</tr>
<tr>
<td>C3 Annual Crop</td>
<td>C4 Annual crop</td>
</tr>
<tr>
<td>C3 Perennial Crop</td>
<td>C4 Perennial crop</td>
</tr>
<tr>
<td>C3 Nitrogen fixing crop</td>
<td></td>
</tr>
</tbody>
</table>

**Non forested Secondary land**

- Managed Pasture land
- Rangeland
- C3 Annual Crop
- C4 Annual crop
- C3 Perennial Crop
- C4 Perennial crop
- C3 Nitrogen fixing crop
Total grassland area comparison

ESACCI_LC map
- Total area = 33 Mkm$^2$

Luh CMIP6
- Total area = 55 Mkm$^2$
• Similar trends over the 20\textsuperscript{th} 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
      ⇒ too low resolution for modelling
  - NCEP
    - has a temporal resolution of 6 hours compatible
      ⇒ 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:

<table>
<thead>
<tr>
<th>Forcing error</th>
<th>Model parameter error</th>
<th>Model structure error</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Land Use Change scenarios</td>
<td>- Parametric equations with Uncertain parameters (photosynthesis, respiration C allocation,…)</td>
<td>- Missing processes</td>
</tr>
<tr>
<td>- Meteo. forcing</td>
<td>- Optimize parameter using a 4D-var system with</td>
<td>- Wrong process representation</td>
</tr>
<tr>
<td>- Soil property uncertainties</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

→ Test different scenarios From LCC & different Meteo forcing

→ Compare ORCHIDEE / CTESSEL and other models & approaches
Estimated error (from DA)

Model parameter uncertainties...

Error propagation on the fluxes

\( \sigma \)-NEE - Prior

\( \sigma \)-NEE - Posterior

\( gC/m^2/d \)

\( gC/m^2/d \)
### Land carbon cycle uncertainties from:

<table>
<thead>
<tr>
<th>Forcing error error</th>
<th>Model parameter error</th>
<th>Model structure error</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Land Use Change scenarios</td>
<td>- Parametric equations with Uncertain parameters (photosynthesis, respiration C allocation, …)</td>
<td>- Missing processes</td>
</tr>
<tr>
<td>- Meteo. forcing</td>
<td></td>
<td>- Wrong process representation</td>
</tr>
<tr>
<td>- Soil property uncertainties</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 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**
- Optimized albedo (using MODIS)
- Land cover based on ESA-CCI
- New 3 layers snow model
- 11-layer soil hydrology With soil freezing
- New Aerodynamic resistance

**Ongoing:**
- Nitrogen – carbon Coupled cycles
- Permafrost carbon
- Forest management & forest structure
- Improved Dynamic vegetation
- SPITFIRE and Land use gross transitions
Model development: Hydrology

**Choisnel = ORC2**
*Ducoutré 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 = $P – E_{sol} – I_{infiltration}$
- 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)

Date:


PgC/year:

110 120 130 140 150 160 170 180 190 200 210

CERA20C-LU6
Gross Primary Production (Photosynthesis)

**Land-use**

- CERA20C-LU6
- CERA20C-LU5
Gross Primary Production (Photosynthesis)

**Meteo forcing**

**Land-use**

- CERA20C-LU5
- CERA20C-LU6
- CRUNCEP-LU6

<table>
<thead>
<tr>
<th>Date</th>
<th>Gross Primary Production (PgC/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1910</td>
<td>110</td>
</tr>
<tr>
<td>1920</td>
<td>115</td>
</tr>
<tr>
<td>1930</td>
<td>120</td>
</tr>
<tr>
<td>1940</td>
<td>125</td>
</tr>
<tr>
<td>1950</td>
<td>130</td>
</tr>
<tr>
<td>1960</td>
<td>135</td>
</tr>
<tr>
<td>1970</td>
<td>140</td>
</tr>
<tr>
<td>1980</td>
<td>145</td>
</tr>
<tr>
<td>1990</td>
<td>150</td>
</tr>
<tr>
<td>2000</td>
<td>155</td>
</tr>
<tr>
<td>2010</td>
<td>160</td>
</tr>
</tbody>
</table>
Gross Primary Production (Photosynthesis)

**Meteo forcing**

**Land-use**

**Model version**

- CERA20C-LU6
- CERA20C-LU5
- CRUNCEP-LU6
- CRC-CMIP5


**PgC/year**: 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210

**Graph**

- ORC CERA LU5 / gpp / 05 Global Land / Yearly mean
- ORC CERA LU6 / gpp / 05 Global Land / Yearly mean
- ORCHIDEE / gpp / 05 Global Land / Yearly mean
Gross Primary Production (Photosynthesis)

Meteo forcing

Land-use

Model version

ORC CERA LU5 / gpp / 05 Global Land / Yearly mean

ORC CERA LU6 / gpp / 05 Global Land / Yearly mean

ORC CRUNCEP LU6 / gpp / 05 Global Land / Yearly mean

MTE JUNG / gpp / 05 Global Land / Yearly mean

ORCHIDEE / gpp / 05 Global Land / Yearly mean

DATA-DRIVEN
Annual Mean 2001-2004

Meteo forcing

Land-use

Model version

CERA20C-LU6
CERA20C-LU5
CRUNCEP-LU6
CRC-CMIP5

GPP PgC / yr

Global
Northern
Tropical
Southern
Net CO$_2$ flux

CERA20C-LU6
Net CO$_2$ flux

Land-use

CERA20C-LU6
CERA20C-LU5
Net CO$_2$ flux

Meteo forcing

Land-use

CERA20C-LU6
CERA20C-LU5
CRUNCEP-LU6

Date

Pgc/year

Net CO$_2$ flux

Meteo forcing

Land-use

Model version

CERA20C-LU6
CERA20C-LU5
CRUNCEP-LU6
CRC-CMIP5
INVERSION

Net CO$_2$ flux over time with different land-use and model version scenarios.
Net CO$_2$ flux

Meteo forcing

Land-use

CERA20C-LU6

CERA20C-LU5

Model version

CRUNCEP-LU6

CRC-CMIP5

INVERSION

Net CO$_2$ flux over time with different land-use and model version categories.
Annual Mean 2001-2004

Meteo forcing

Land-use

CERA20C-LU6
CERA20C-LU5

Model version

CRUNCEP-LU6
CRC-CMIP5
DATA-DRIVEN

Net CO₂ flux

PgC / yr

Global
Northern
Tropical
Southern
Impact of soil freezing on river discharge

5: McKenzie (1981-2010) (Arctic red river)
7: Danube (1981-2010) (Ceatal Izmail)
9: Ob (1981-2010) (Salekhard)
11: Yenisei (1981-2010) (Igarka)
12: Lena (1981-2010) (Kusur)
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
Impact on the Month-to-month correlation
Of modeled vs. CRU 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 fertilisation 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

<table>
<thead>
<tr>
<th>Date</th>
<th>PgC/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>February</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td></td>
</tr>
<tr>
<td>August</td>
<td></td>
</tr>
<tr>
<td>September</td>
<td></td>
</tr>
<tr>
<td>October</td>
<td></td>
</tr>
<tr>
<td>November</td>
<td></td>
</tr>
<tr>
<td>December</td>
<td></td>
</tr>
</tbody>
</table>

- Large amplitude differences at high latitudes
- Large phase differences in the Tropics

**11 models (TRENDY)**
Net Carbon flux still highly variable.

**Net C. Flux**

- **N. Hemisphere**
- **Tropics**

11 models (TRENDY)
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 CO2 flux at regional and global scale