The use of CTESSEL carbon model in the MACC-II CO₂ near real time forecast:

Towards an optimization of CTESSEL parameters to constrain the global atmospheric CO₂

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Acknowledgements:
Anton Beljaars, Joaquin Muñoz, Clement Albergel, Patricia de Rosnay
Richard Engelen, Vincent-Henri Peuch
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 CO₂ forecast

SURFACE FLUXES

Total CO₂ surface flux
[µmol m⁻² s⁻¹]

SOURCE
SINK

TRANSPORT

Atmospheric CO₂ anomalies above 392 ppm at different vertical levels

2012-10-28 03:00:00

SURFACE 850 hPa 500 hPa 300 hPa
**CO₂ fluxes**

- **CTESSEL** (Boussetta et al. 2013)
- **GFAS** (Kaiser et al. 2012)
- **EDGARv4.2** (JRC)
- **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

\[ \text{NEE} = GPP - R_{\text{eco}} \]

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

Optimization of model parameters using GPP and REC FLUXNET observation
**Evaluation of CTESSEL fluxes**

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

<table>
<thead>
<tr>
<th>Model</th>
<th>GPP RMSE [μmol m⁻² s⁻¹]</th>
<th>GPP Bias [μmol m⁻² s⁻¹]</th>
<th>GPP Corr</th>
<th>NEE RMSE [μmol m⁻² s⁻¹]</th>
<th>NEE Bias [μmol m⁻² s⁻¹]</th>
<th>NEE Corr [μmol m⁻² s⁻¹]</th>
<th>Reco RMSE [μmol m⁻² s⁻¹]</th>
<th>Reco Bias [μmol m⁻² s⁻¹]</th>
<th>Reco Corr</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHTESSEL</td>
<td>2.2</td>
<td>0.6</td>
<td>0.80</td>
<td>1.6</td>
<td>-0.1</td>
<td>0.65</td>
<td>1.8</td>
<td>-0.7</td>
<td>0.79</td>
</tr>
<tr>
<td>CTESSEL</td>
<td>2.0</td>
<td>0.3</td>
<td>0.82</td>
<td>1.6</td>
<td>-0.2</td>
<td>0.68</td>
<td>1.8</td>
<td>-0.6</td>
<td>0.80</td>
</tr>
<tr>
<td>CASA-GFED3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.8</td>
<td>0.7</td>
<td>0.37</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Flux observations:**
- have very small footprint
- have sparse global coverage for sampling high spatial and temporal heterogeneity of CO₂ fluxes.
- cannot constrain on global CO₂ budget

**This result in global CO₂ biases, unlike atmospheric flux inversions!!!**
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)

\[
\text{total flux in model} = \text{atmospheric growth in model}
\]
MODEL: total flux = anthropogenic + ocean + fire + vegetation

- Anthropogenic emissions (EDGARv4.2)
- GFAS biomass burning (MACC, Kaiser et al. 2011)
- Ocean climatology (Takahashi 2009)
- Observed atmospheric growth (NOAA, Conway et al., 2012)
- Land sink (CTESSEL, Boussetta et al., 2013)

Global bias in atmospheric CO2 background
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 CO₂ fluxes as a reference

**TOTAL OPTIMIZED FLUX**
(vegetation + anthropogenic + fire + ocean)

**PREScribed FLUXES**
- Ocean
- Anthropogenic
- Fires

**Residual vegetation flux**
TOTAL OPT. FLUX – PREScribed FLUXES

“OPTIMIZED NEE“
Using optimized CO₂ fluxes as a reference

TOTAL OPTIMIZED FLUX
(vegetation + anthropogenic + fire + ocean)

PREScribed fluxes
Ocean
Anthropogenic
Fires

CTESSEL NEE

10-day budget for each CTESSEL dominant vegetation type

Residual vegetation flux
TOTAL OPT. FLUX – PREScribed fluxes

"OPTIMIZED NEE"

CTESSEL NEE budget

OPTIMIZED NEE BUDGET
BIASES IN GLOBAL C TESSEL NEE BUDGETS
10-day budget with vegetation type

OPTIMIZED FLUXES (F Chevallier)

Comparison with clim. CO2 budget 9_Tundra 10day window

Comparison with clim. CO2 budget 1_Crops 10day window

Comparison with clim. CO2 budget 2_ShortGrass 10day window

GLCC_1.2; Low vegetation type; T511_0.25x0.25
BIASES IN GLOBAL CTESSEL NEE BUDGETS
10-day budget with vegetation type

OPTIMIZED FLUXES CTESSEL

Comparison with clim. CO2 budget 9. Tundra 10 day window

Comparison with clim. CO2 budget 1. Crops 10 day window

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BIASES IN GLOBAL CTESSEL NEE BUDGETS

10-day budget with vegetation type

OPTIMIZED FLUXES

OPTIMIZED FLUX CLIMATOLOGY

GLCC_1.2; Low vegetation type; T511_0.25x0.25

Comparison with clim. CO2 budget 9. Tundra 10day window

Comparison with clim. CO2 budget 1. Crops 10day window

Comparison with clim. CO2 budget 2. ShortGrass 10day window

Tundra

Crops

Short grass
BIASES IN GLOBAL CTEESSEL NEE BUDGETS
10-day budget with vegetation

CTESSEL OPTIMIZED FLUX CLIMATOLOGY

GLCC_1.2: Low vegetation type; T511_0.25x0.25

Comparison with clim. CO2 budget 9_Tundra 10day window

Comparison with clim. CO2 budget 1_Crops 10day window

Comparison with clim. CO2 budget 2_ShortGrass 10day window
NEE bias correction for vegetation type

\[
\alpha = \frac{(\text{NEE}_{\text{optclim}} + \text{IAV} \times \text{STD}(\text{NEE}_{\text{optclim}}))}{\text{NEE}_{\text{ctessel}}}
\]

\[
\text{IAV} = \frac{(\text{NEE}_{\text{ctessel}} - \text{NEE}_{\text{ctesselclim}})}{\text{STD}(\text{NEE}_{\text{ctessel}})}
\]

\[
\text{NEE} = \text{GPP} + \text{REC}
\]

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

\[
\alpha_{\text{GPP}} = \alpha_{\text{REC}} = \alpha
\]

else if \( \alpha < 0 \) then the largest of GPP or REC are re-scaled.
CTESSEL NEE bias correction evaluation

- Daily mean CO₂ at background insitu continuous NOAA stations (2011):

<table>
<thead>
<tr>
<th>OBS</th>
<th>OPT.FLUXES</th>
<th>CTESSEL</th>
<th>BC_CTESSEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>bias= -3.01 std= 2.51</td>
<td>bias= -4.07 std= 2.13</td>
<td>bias= 1.22 std= 3.20</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing bias and standard deviation for Barrow, Alaska and Tutuila Island, American Samoa](image)

- 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.
CTESSEL NEE bias correction evaluation

- Daily mean CO$_2$ at background insitu continuous NOAA stations (2011):

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</table>

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

- Bias:
  - OBS: -0.21, std: 0.69
  - OPT.FLUXES: -1.99, std: 0.95
  - BC_CTESSEL: -0.95, std: 0.16
Issues: regional differences

INTERRUPTED FOREST (25.4% land points)

GLOBAL

AFRICA

EUROPE
Bias correction coefficients for vegetation types over 6 regions

20110101

GPP re-scaling factor

$R_{\text{eco}}$ re-scaling factor
CTESSEL NEE bias correction evaluation using 6 regions

- Daily mean CO₂ 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.  

  Bias = 1.22  std = 2.54  
  Bias = 1.22  std = 3.20  
  Bias = -4.07  std = 2.13  

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

  Bias = -0.40  std = 0.71  
  Bias = -0.73  std = 0.28  
  Bias = -2.55  std = 0.72
CTESSEL NEE bias correction evaluation

- Daily mean CO₂ at background insitu continuous NOAA stations (2011):

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South Pole
89.98 °N
89.96 °W
2821 m a.s.l.
Hovmoeller plots of background CO$_2$: Seasonal cycle and Latitudinal gradient
Hovmoeller plots of background CO$_2$: Seasonal cycle and Latitudinal gradient
CO2 bias correction: summary

- CO₂ 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.
1. CTESSEL parameter optimization

CO₂ FC

2. CTESSEL bias correction

CO₂ FC with reduced background bias

3. Atmospheric data assimilation

Atmospheric CO₂ analysis

FLUXNET observations

Optimized fluxes of CO₂.

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

Satellite data of column averaged atmospheric CO₂.
1. CTESSEL parameter optimization

CO₂ products: future configuration?

2. CTESSEL bias correction

CO₂ FC with reduced background bias

Bias correction coefficients

3.1. Land surface data assimilation: Adjust CO₂ fluxes locally

3.2. Atmospheric data assimilation

CO₂ FC

Optimized fluxes of CO₂.

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

In situ atmospheric surface observations (ICOS network)

Satellite data of column averaged atmospheric CO₂.

FLUXNET observations

Atmospheric CO₂ analysis