Carbon cycle data assimilation using satellite-derived FAPAR and a revisited phenology scheme for global applications

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Problem Statement

• Satellite observations of the plant **absorbed fraction of photosynthetically active radiation (FAPAR)** are available for many years globally, and through an appropriate model may provide an indirect constraint on carbon and water fluxes.

• Predictive models of the terrestrial biosphere are needed that simulate FAPAR, water and carbon fluxes. This requires a (sub-) **model of leaf phenology** of all major global biomes.

• Challenge is to design a terrestrial model such that:
  – its process parameters can be estimated by means of a gradient-based optimisation algorithm, which requires **smooth dependency on process parameters**
  – it satisfies **simultaneously multiple observational constraints**
Assimilation of MERIS FAPAR at site scale

• **Revised original phenology** scheme to render the model suitable for gradient-based optimisation (e.g. avoid sudden changes of leaf status by allowing spatial variability within a grid cell).

• Assimilation of MERIS FAPAR product at seven sites **simultaneously**.

• A single set of process parameters to match observations over all sites composed of a mix of seven Plant Functional Types (PFTs).

• Optimization of:
  - 14 parameters related to phenology
  - 24 related to photosynthesis - not all are PFT specific \([\text{LAI}_{\text{max}}]\)
  - additional parameters with no impact on FAPAR \([\text{Q10}]\)
Assimilation of MERIS FAPAR at site scale

- Gradient information from automatically generated adjoint model code (using the automatic differentiation tool TAF)

- At optimum, curvature of cost function (automatically generated 2nd derivative) yields posterior uncertainty of parameters

- Parameter uncertainties are projected onto diagnostic quantities (e.g. carbon fluxes) using a model linearization around optimum.
The Carbon Cycle Data Assimilation System at site scale

Prescribed
Climate data

Assimilated
FAPAR + uncert.

CCDAS
BETHY including Photosynthesis, Phenology, Hydrology, Energy & Carbon Balance

Optimized Params + uncert.

Diag./Prog. + uncert.
The selected sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Country</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Vegetation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodankylä</td>
<td>Finland</td>
<td>67.3619°N</td>
<td>26.6378°E</td>
<td>Boreal evergreen forest</td>
</tr>
<tr>
<td>Zoīno</td>
<td>Russia</td>
<td>60.8008°N</td>
<td>89.2657°E</td>
<td>Boreal mixed forest</td>
</tr>
<tr>
<td>Aardhuis</td>
<td>Netherlands</td>
<td>52.2381°N</td>
<td>5.8672°E</td>
<td>C3 grassland</td>
</tr>
<tr>
<td>Loobos</td>
<td>Netherlands</td>
<td>52.1679°N</td>
<td>5.7440°E</td>
<td>Temperate pine forest</td>
</tr>
<tr>
<td>Hainich forest site</td>
<td>Germany</td>
<td>51.0793°N</td>
<td>10.4520°E</td>
<td>Temperate deciduous forest</td>
</tr>
<tr>
<td>Manaus</td>
<td>Brazil</td>
<td>2.5892°S</td>
<td>60.1311°W</td>
<td>Tropical rainforest</td>
</tr>
<tr>
<td>Maun</td>
<td>Botswana</td>
<td>19.9155°S</td>
<td>23.5605°E</td>
<td>Tropical savanna</td>
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<tr>
<td>Hainich grass site</td>
<td>Germany</td>
<td>51.0199°N</td>
<td>10.4348°E</td>
<td>C3 grassland</td>
</tr>
</tbody>
</table>
Assimilation of MERIS FAPAR at site scale

Dotted: prior; solid line: posterior FAPAR; crosses with error bars: MERIS FAPAR.
# Reduction in Uncertainty of NPP

<table>
<thead>
<tr>
<th>Site</th>
<th>prior NPP</th>
<th>post. NPP</th>
<th>rel. change</th>
<th>prior unc.</th>
<th>post. unc.</th>
<th>unc. reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodankylä</td>
<td>137</td>
<td>151</td>
<td>0.68</td>
<td>112</td>
<td>98</td>
<td>5</td>
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<tr>
<td>Zotino</td>
<td>201</td>
<td>216</td>
<td>0.54</td>
<td>28</td>
<td>28</td>
<td>0</td>
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<tr>
<td>Aardhuis</td>
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<td>842</td>
<td>-0.07</td>
<td>164</td>
<td>101</td>
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<td>Loobos</td>
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<td>424</td>
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<td>62</td>
<td>59</td>
<td>5</td>
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<tr>
<td>Hainich forest</td>
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<td>657</td>
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<td>13</td>
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<tr>
<td>Manaus</td>
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<tr>
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<td>346</td>
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<td>50</td>
<td>46</td>
<td>8</td>
</tr>
<tr>
<td>Hainich grass</td>
<td>619</td>
<td>786</td>
<td>0.97</td>
<td>172</td>
<td>89</td>
<td>48</td>
</tr>
</tbody>
</table>

**Prior**: without FAPAR assimilation  
**Posterior**: after FAPAR assimilation  
**NPP**: Net Primary Productivity
Perform first **simultaneous** assimilation of two data streams in fast global test configuration:

- Very coarse 8 x 10 degree global grid

- **Monthly CO₂** from two sites: MLO and SPO over five years (120 observations)
1st global results: prior
1st global results: satellite

![Map showing observed FAPAR for Jan, Apr, Jul, and Oct 2003](image-url)
1st global results: posterior
1st global results: Difference posterior - prior

post-prior FAPAR Jan, Apr, Jul and Oct 2003

JAN

APR

JUL

OCT
1st global results: Fit to atmospheric CO₂
Summary

• **Simultaneous** assimilation of MERIS FAPAR product at six sites with *revised* phenology scheme

• Impact of observations quantified by uncertainty reduction

• First tests indicate that **simultaneous** assimilation of global scale MERIS FAPAR and atmospheric CO$_2$ is feasible