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 [LAI_{max}]

  - additional parameters with no impact on FAPAR [Q10]

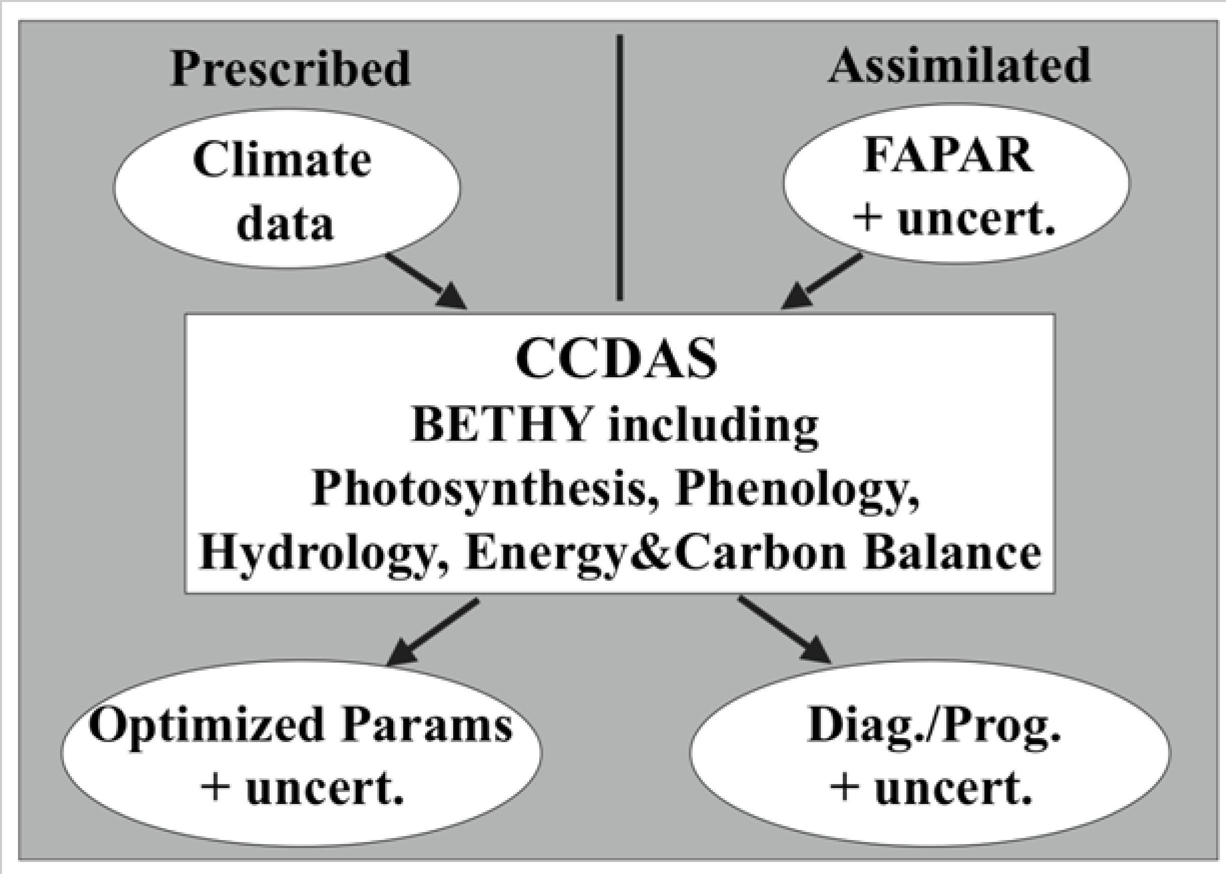
Assimilation of MERIS FAPAR at site scale

- 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



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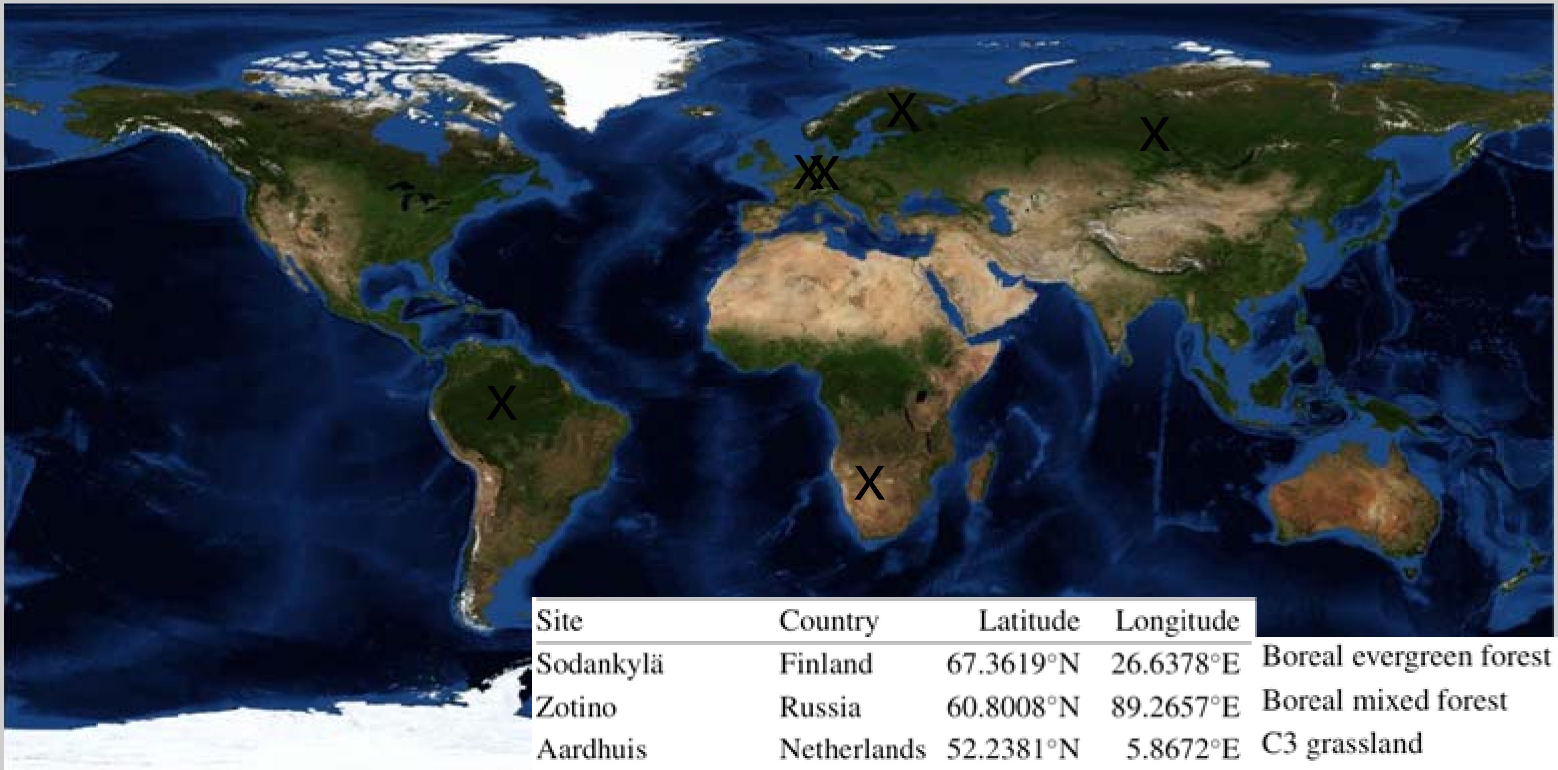
The selected sites



Site	Country	Latitude	Longitude	
Sodankylä	Finland	67.3619°N	26.6378°E	Boreal evergreen forest
Zotino	Russia	60.8008°N	89.2657°E	Boreal mixed forest
Aardhuis	Netherlands	52.2381°N	5.8672°E	C3 grassland
Loobos	Netherlands	52.1679°N	5.7440°E	Temperate pine forest
Hainich forest site	Germany	51.0793°N	10.4520°E	Temperate deciduous forest
Manaus	Brazil	2.5892°S	60.1311°W	Tropical rainforest
Maun	Botswana	19.9155°S	23.5605°E	Tropical savanna
Hainich grass site	Germany	51.0199°N	10.4348°E	C3 grassland

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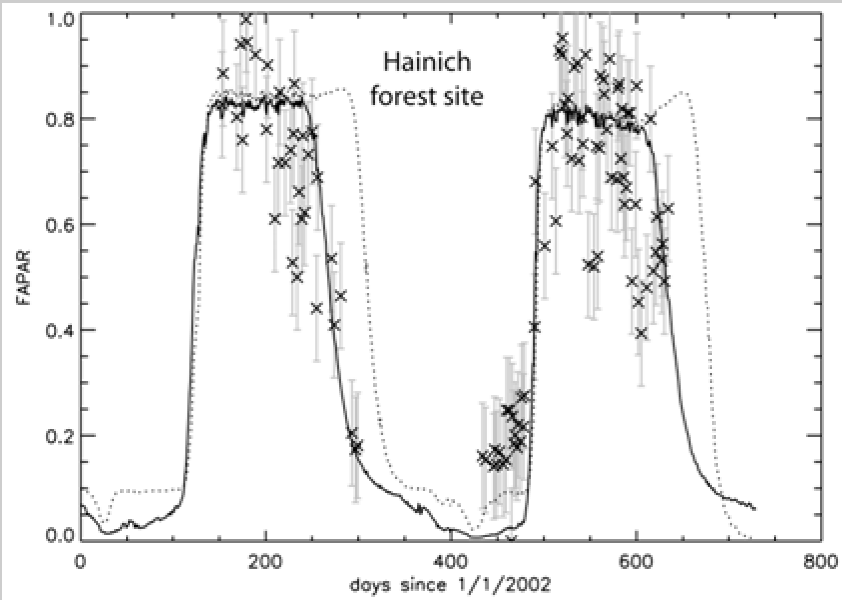
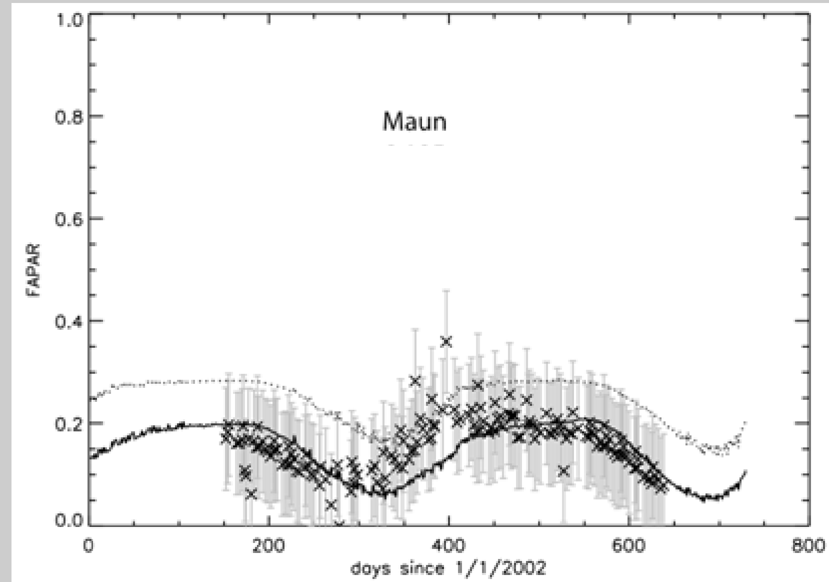
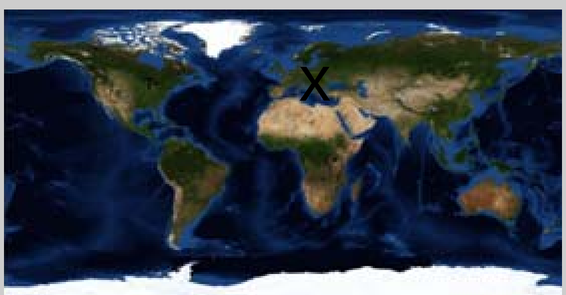
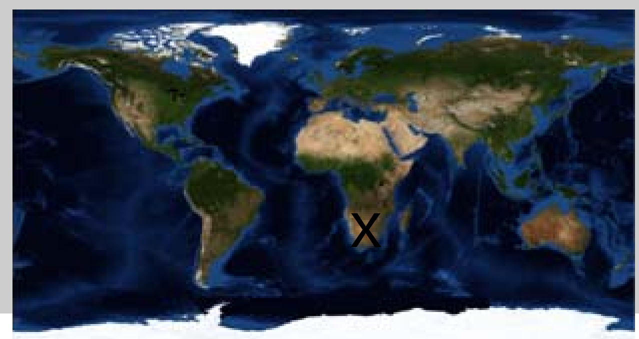
Assimilation of MERIS FAPAR at site scale





Dotted: prior; solid line: posterior FAPAR; crosses with error bars: MERIS FAPAR.





Reduction in Uncertainty of NPP

Site	prior NPP	post. NPP	rel. change	prior unc.	post. unc.	unc. reduction [%]
Sodankylä	137	151	0.68	112	98	5
Zotino	201	216	0.54	28	28	0
Aardhuis	853	842	-0.07	164	101	38
Loobos	449	424	-0.40	62	59	5
Hainich forest	689	657	-0.29	112	98	13
Manaus	1465	964	-1.96	255	168	34
Maun	350	346	-0.10	50	46	8
Hainich grass	619	786	0.97	172	89	48

Prior: without FAPAR assimilation

Posterior: after FAPAR assimilation

NPP: Net Primary Productivity

Assimilation of MERIS FAPAR and atmospheric CO_2

Perform first **simultaneous** assimilation of two data streams in fast global test configuration:

– Very coarse 8 x 10 degree global grid

– **Monthly CO_2** from two sites: MLO and SPO over five years (120 observations)

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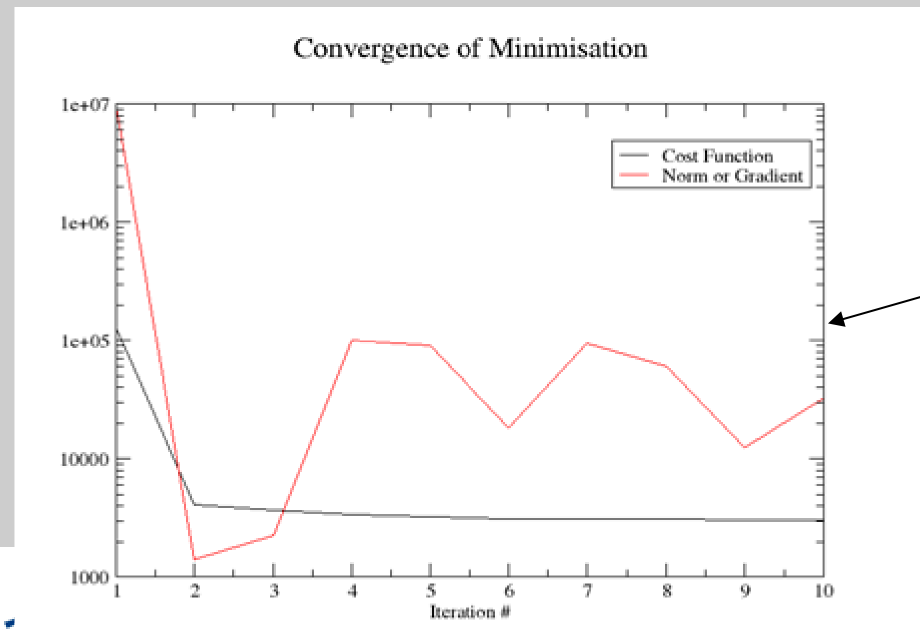
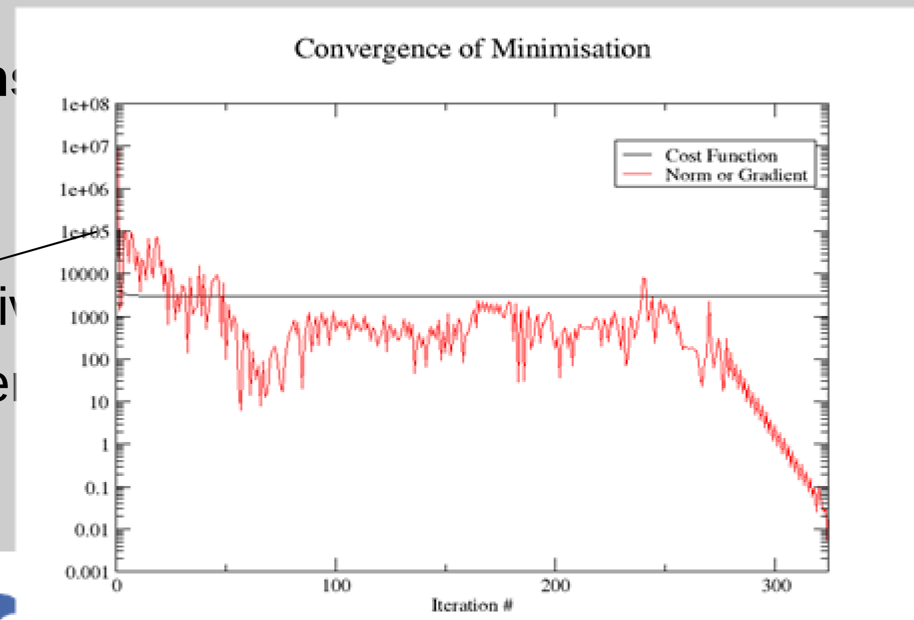
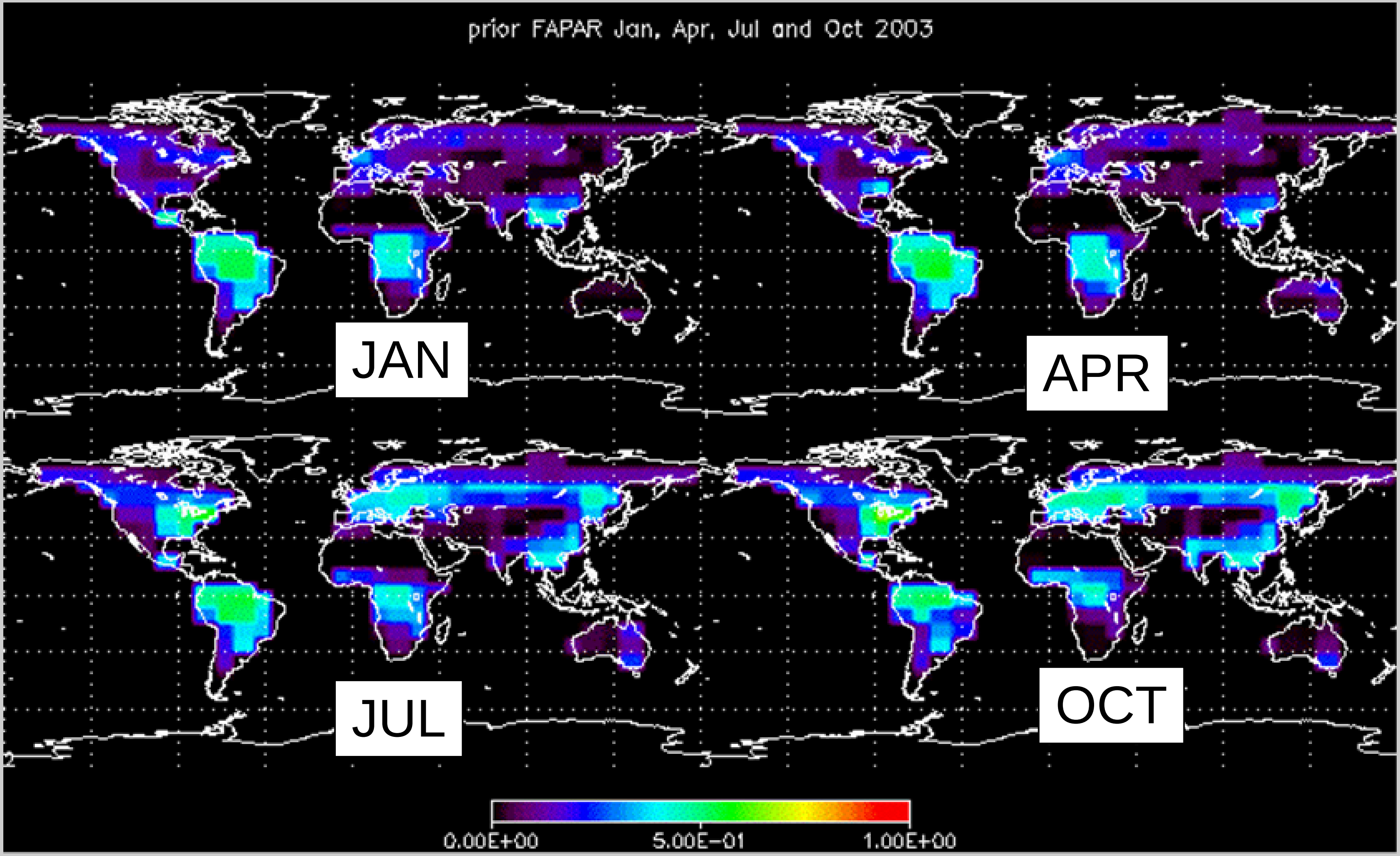




1st global results: prior



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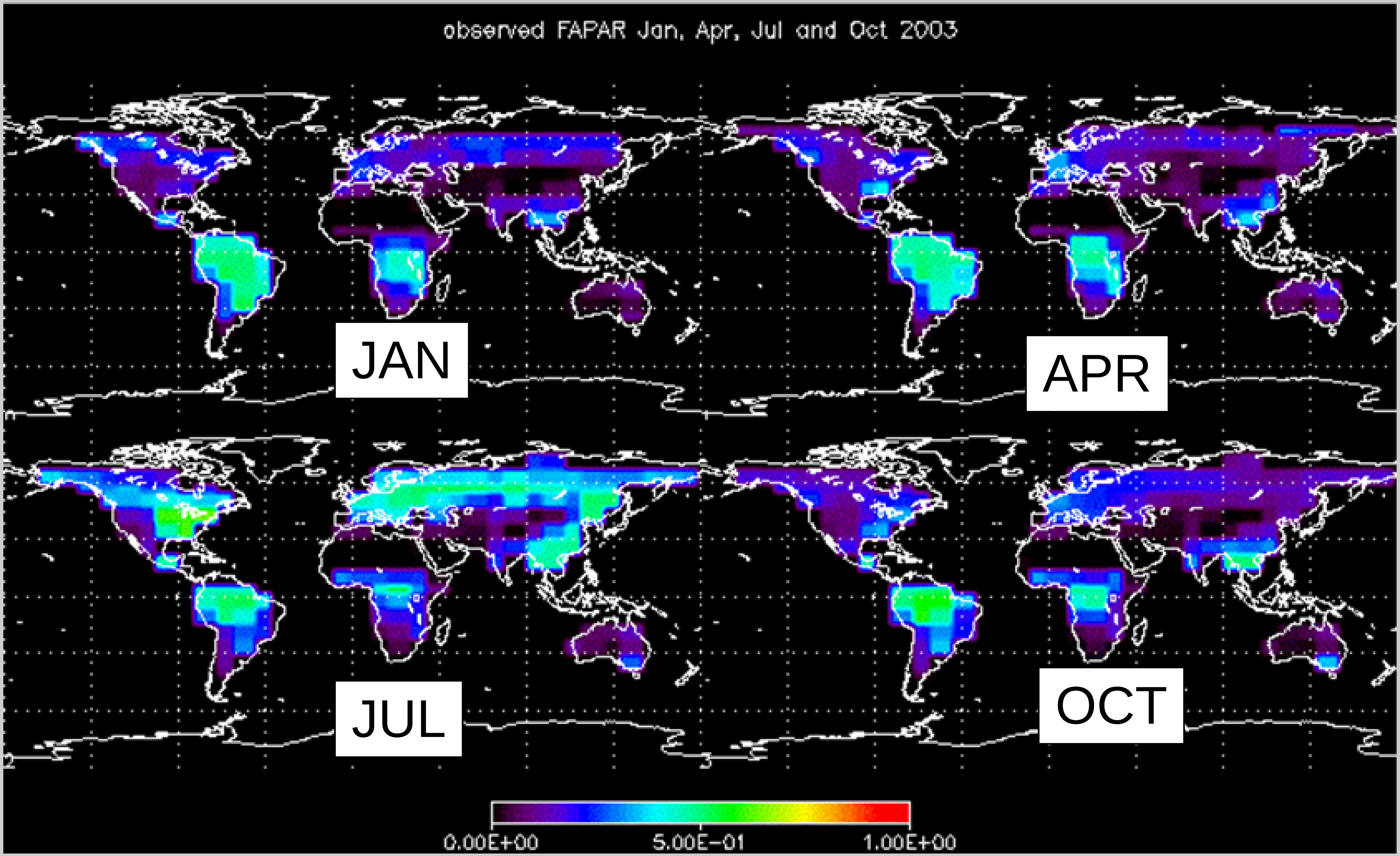
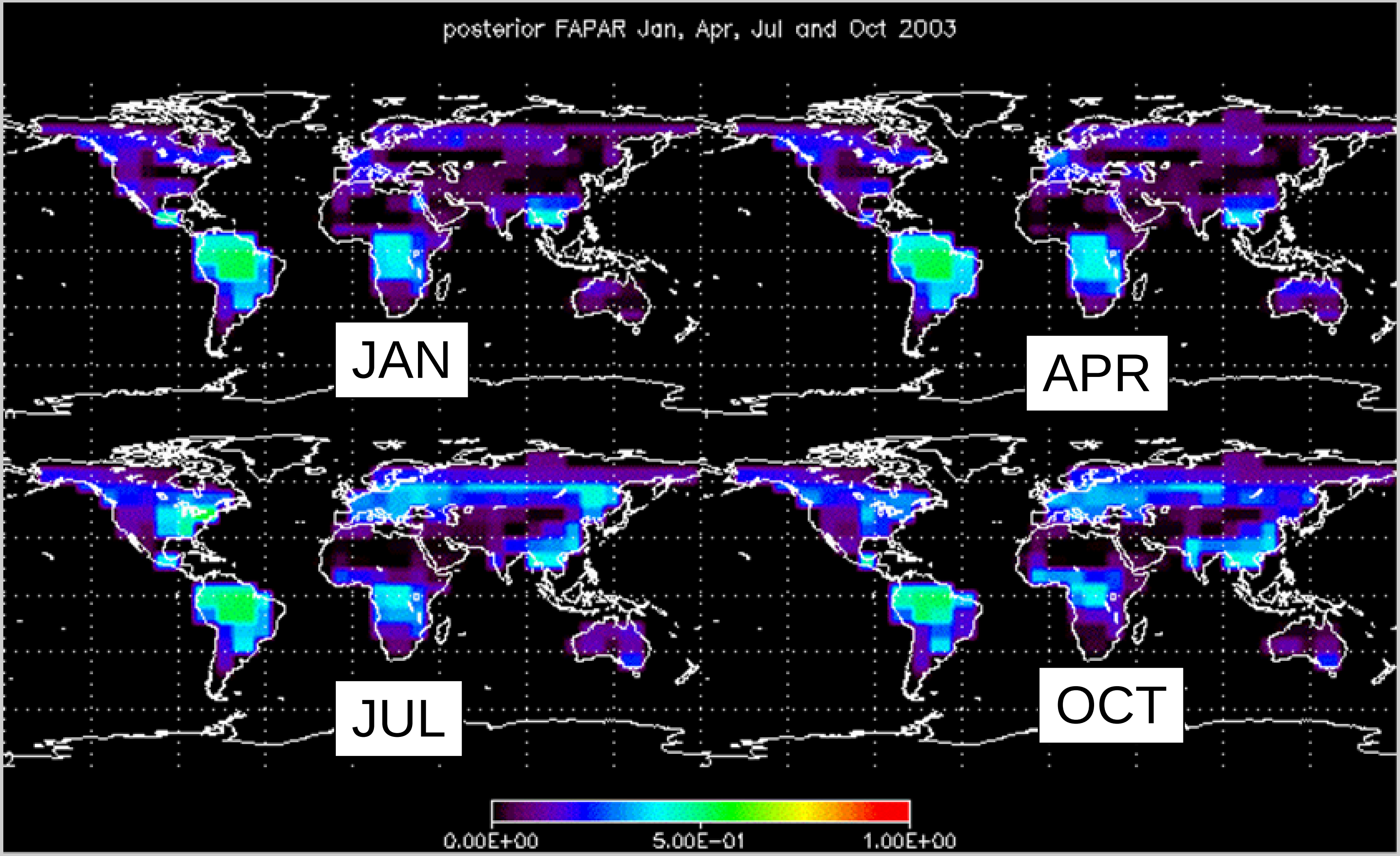
1st global results: satellite



1st global results: posterior



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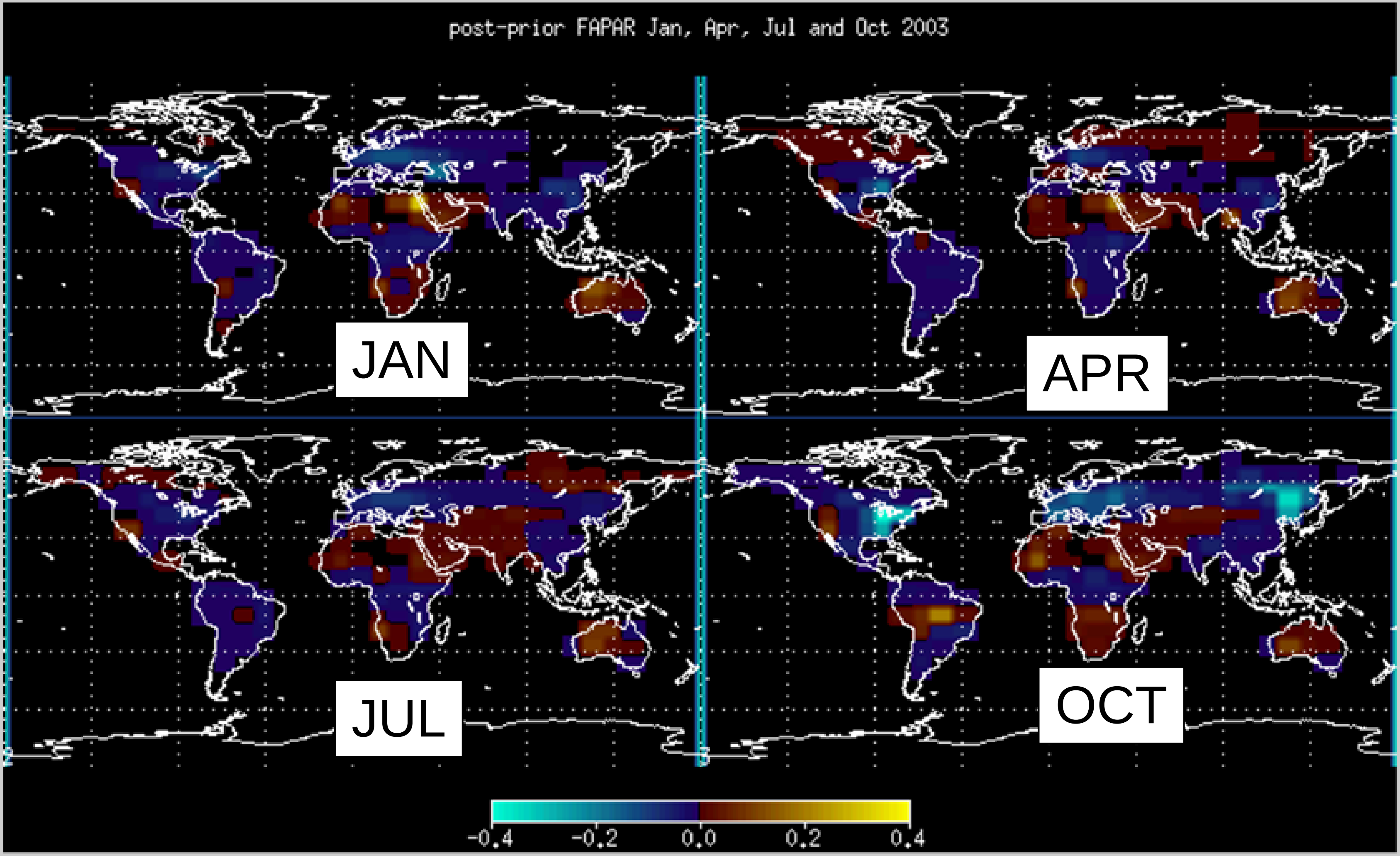
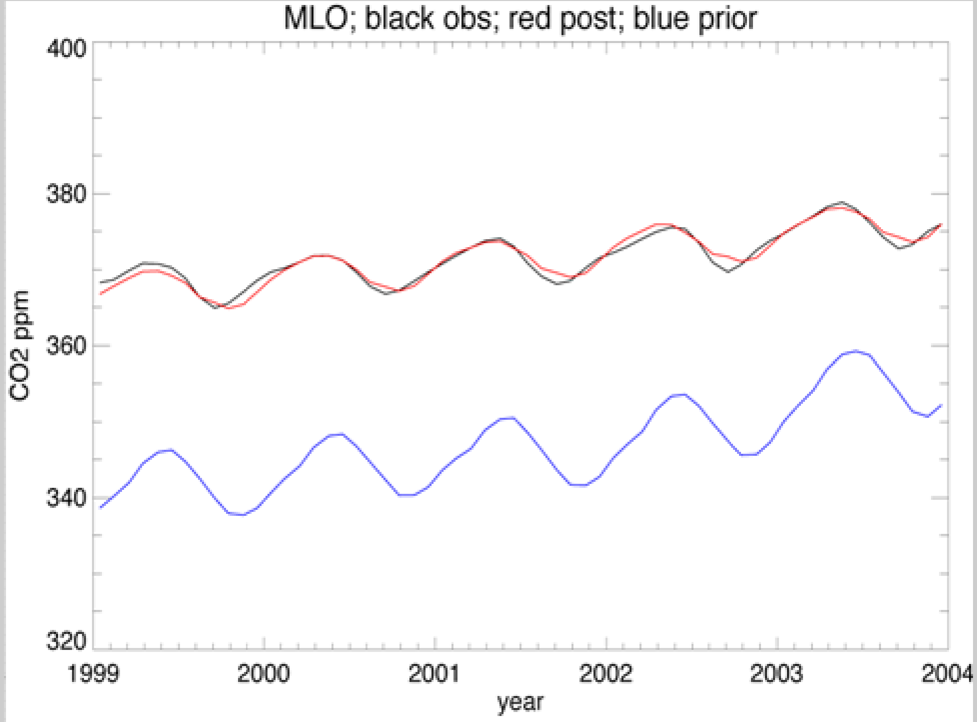
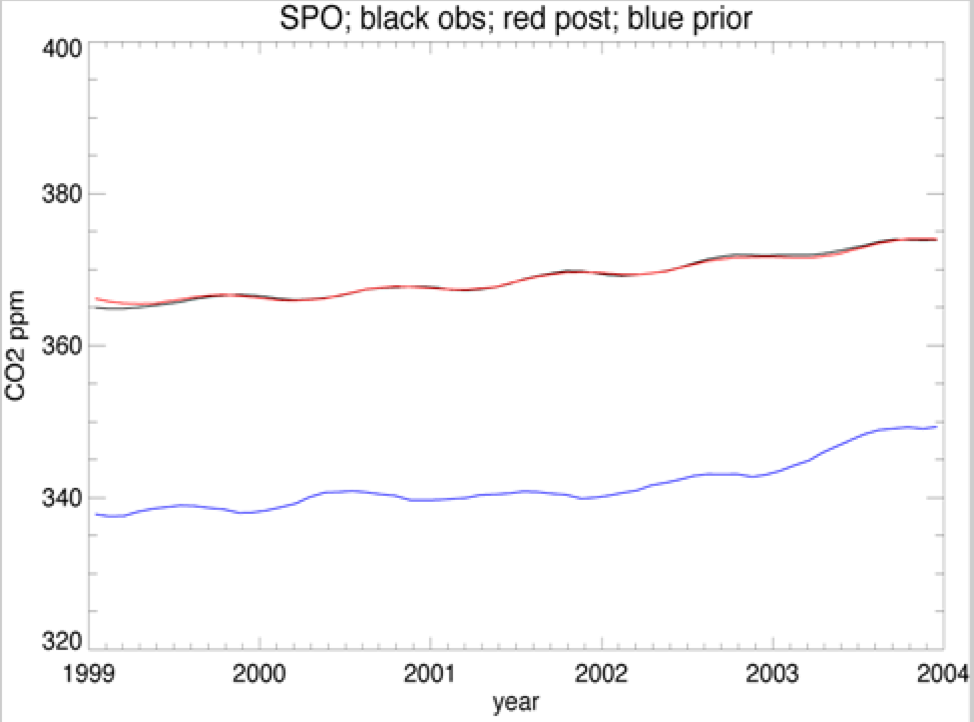
1st global results: Difference posterior - prior



1st global results: Fit to atmospheric CO_2





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**