

# Assimilation of MERIS FAPAR into a Terrestrial Vegetation Model and Mission Design

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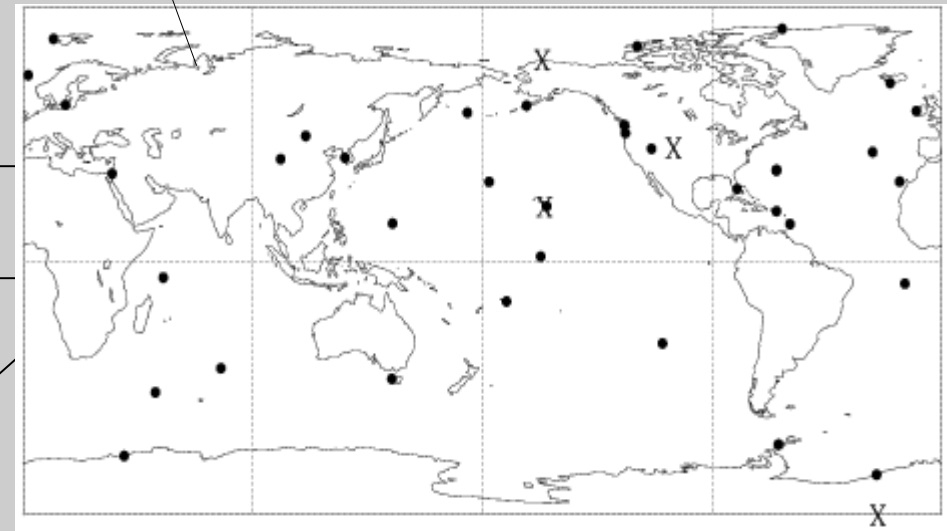
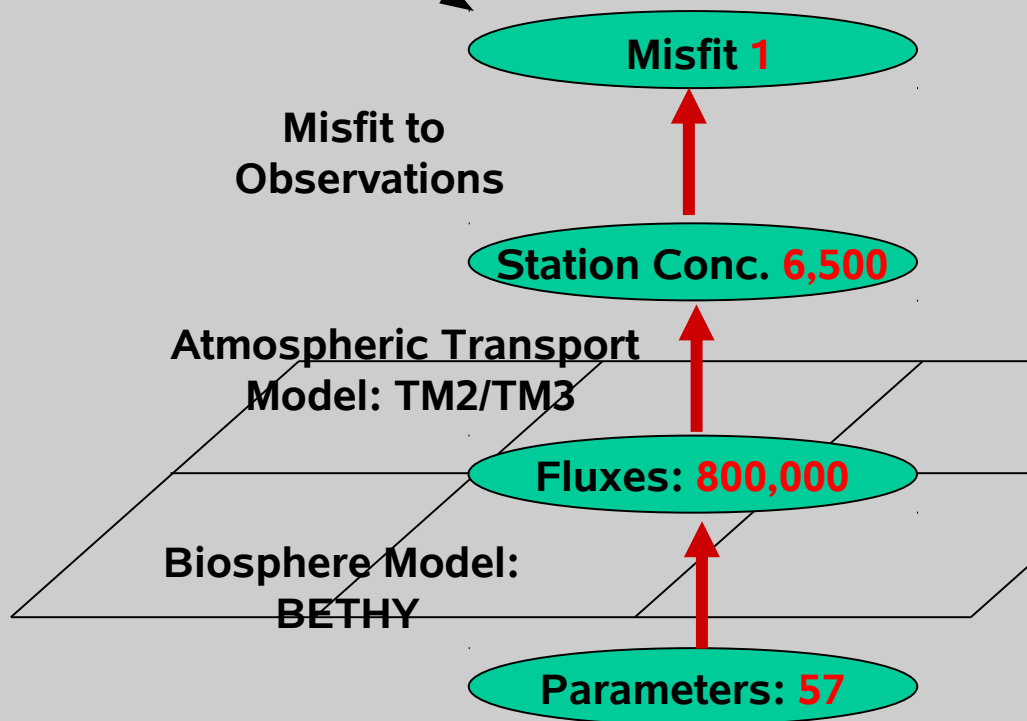
# Outline

- Methodology
- Problem
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- Global Scale
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- Summary

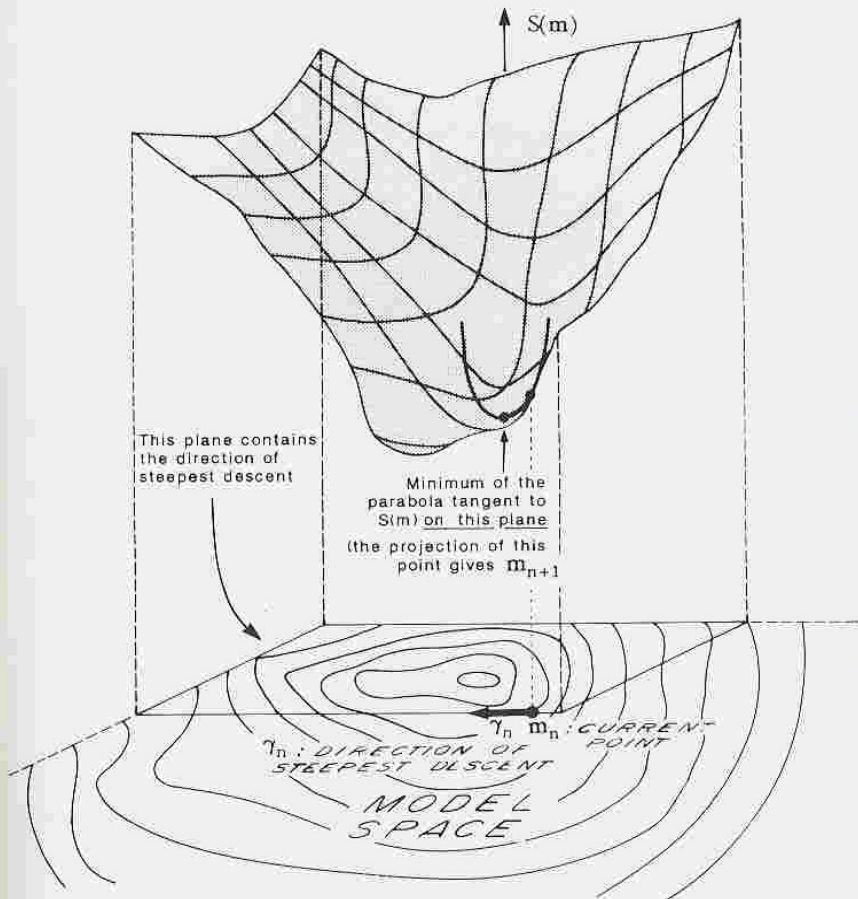
# Carbon Cycle Data Assimilation System (CCDAS)

$$J(x) = \frac{1}{2} \left( \sum_{i=1,nd} \left( \frac{M_i(x) - d_i}{\sigma_{d_i}} \right)^2 + \sum_{i=1,np} \left( \frac{x_i - p_i}{\sigma_{p_i}} \right)^2 \right)$$

Minimisation of misfit (cost function) by variation of process parameters



# Carbon Cycle Data Assimilation System



- Iterative minimisation of  $J(x)$
- $$J(x) = \frac{1}{2} [ (x-x_{pr})^T C_{pr}^{-1} (x-x_{pr}) + (M(x)-d)^T C_d^{-1} (M(x)-d) ]$$
- Uses gradient of  $J$  with respect to parameters
  - Second derivatives (Hessian) at minimum  $x_{po}$  provide approximation of parameter uncertainties (error bars)

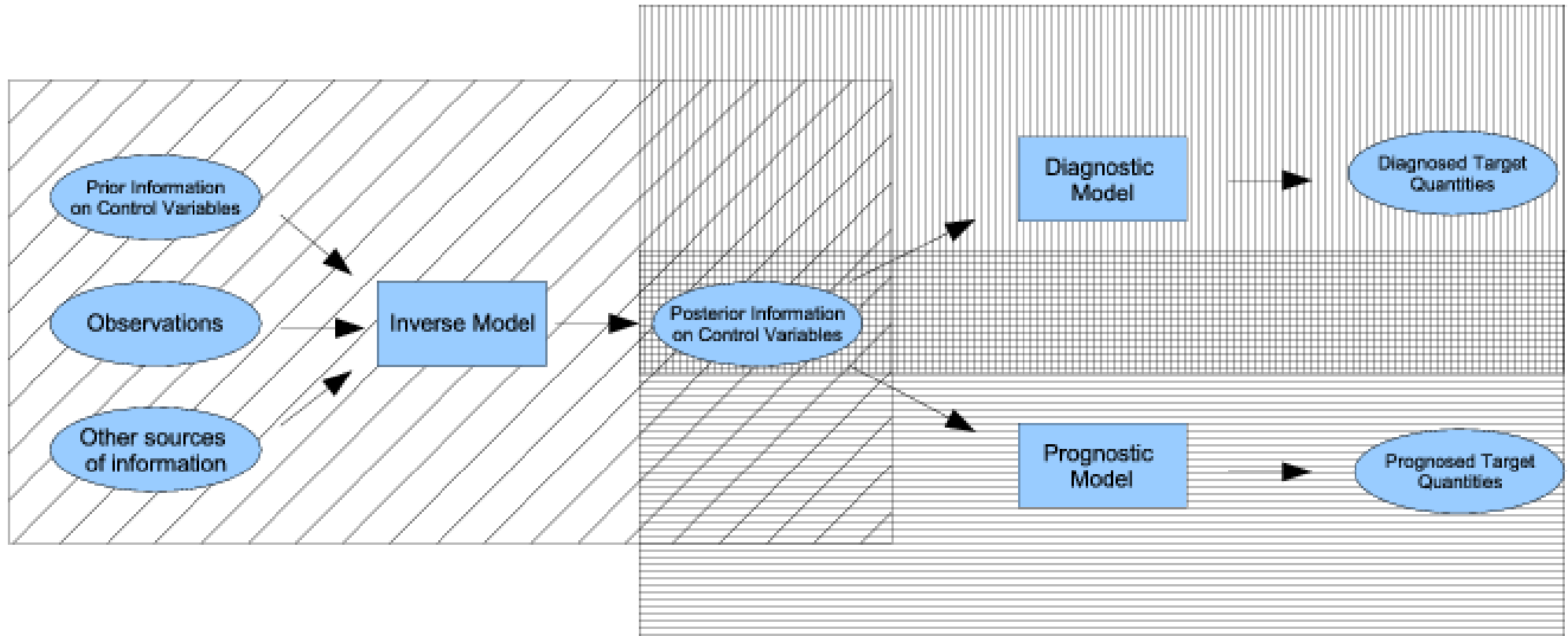
$$C_{po}^{-1} = \partial^2 J(x_{po}) / \partial x^2$$

- Uncertainties on current of future target quantities (e.g. net flux, NEP) via linearisation of model (Jacobian matrix)

$$C_{NEP} = \partial M / \partial x C_{po} \partial M / \partial x^T$$

- All derivatives provided via automatic differentiation of model code (TAF), see Kaminski et al. (2003)
- Figure taken from Tarantola (1987)

# CCDAS scheme



Scholze et al. (2007)

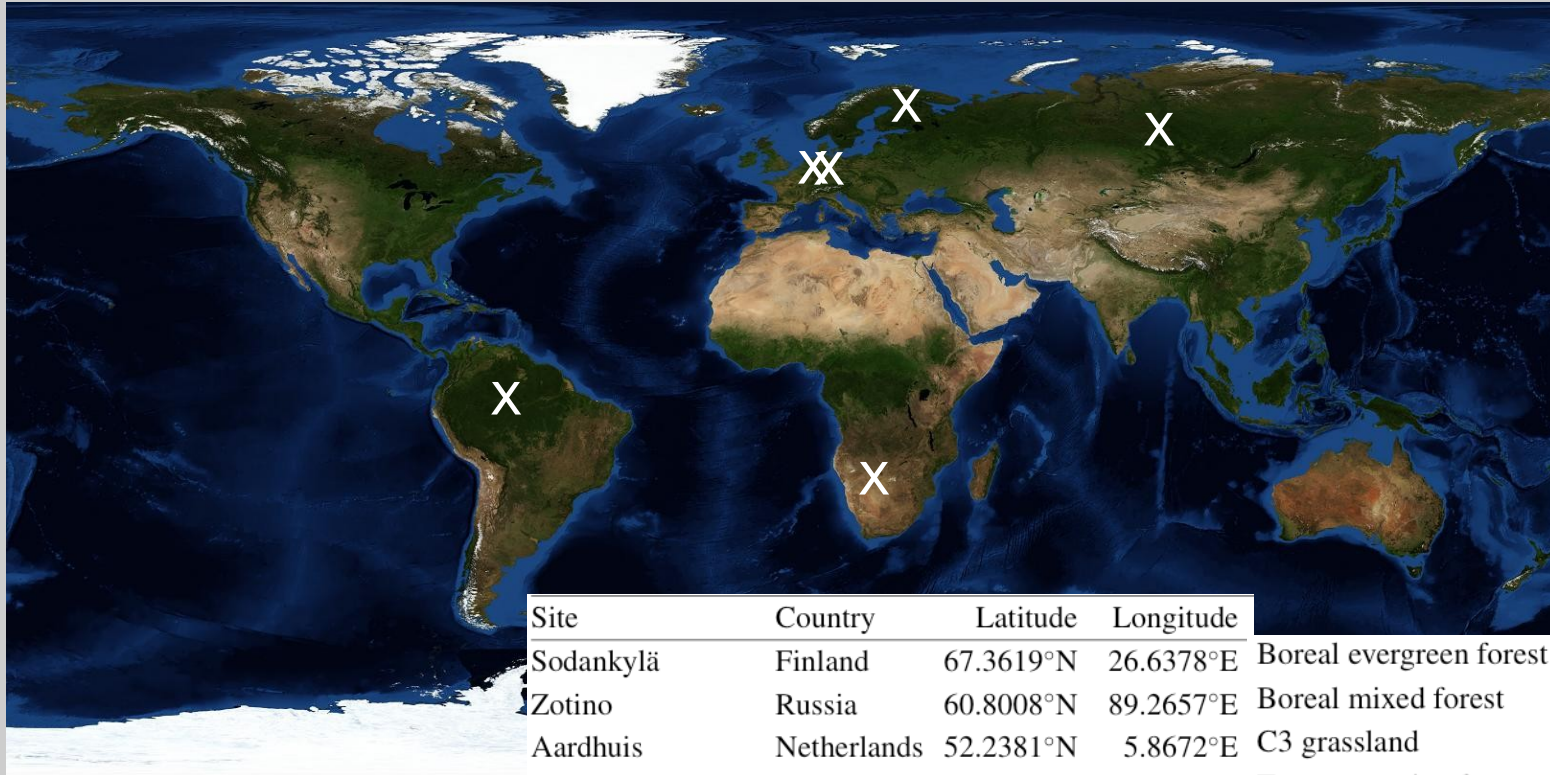
# Problem Statement

- 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 daily 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]

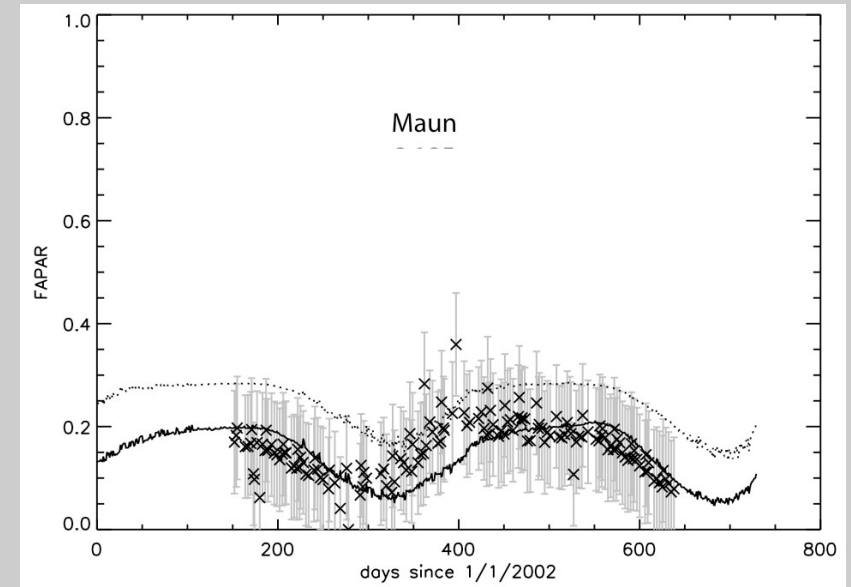
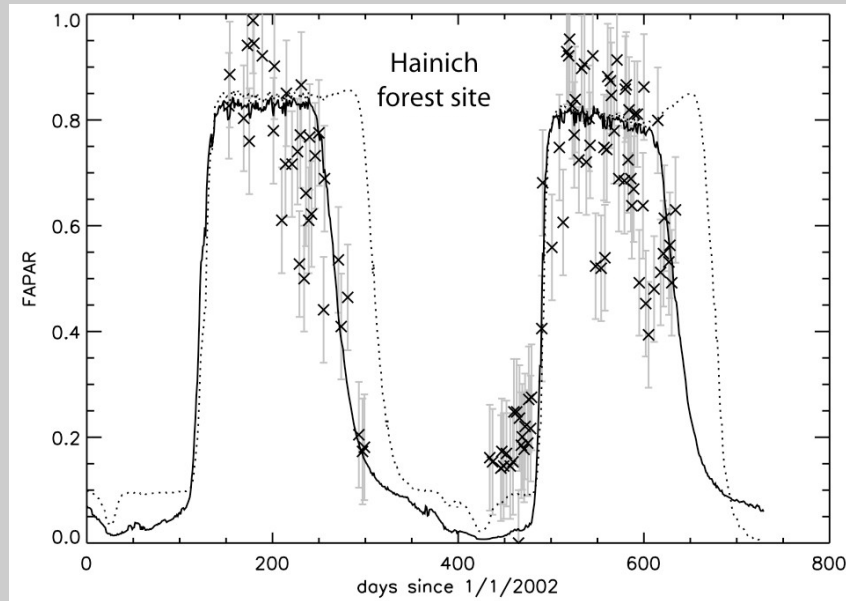
# The selected sites



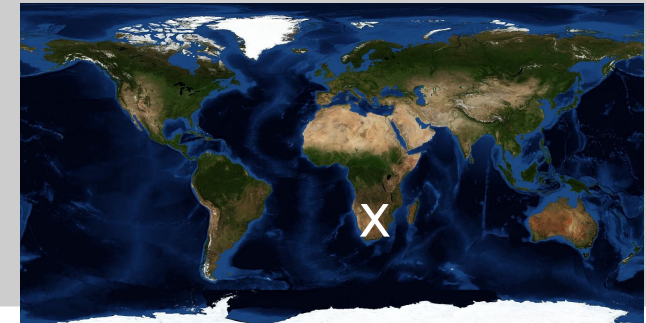
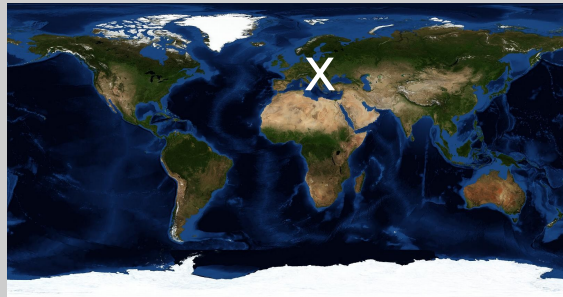
Site	Country	Latitude	Longitude	
Sodankylä	Finland	67.3619°N	26.6378°E	Boreal evergreen forest
Zotino	Russia	60.8008°N	89.2657°E	Boreal mixed forest
Aardhuis	Netherlands	52.2381°N	5.8672°E	C3 grassland
Loobos	Netherlands	52.1679°N	5.7440°E	Temperate pine forest
Hainich forest site	Germany	51.0793°N	10.4520°E	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

Not included for assimilation →

# 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

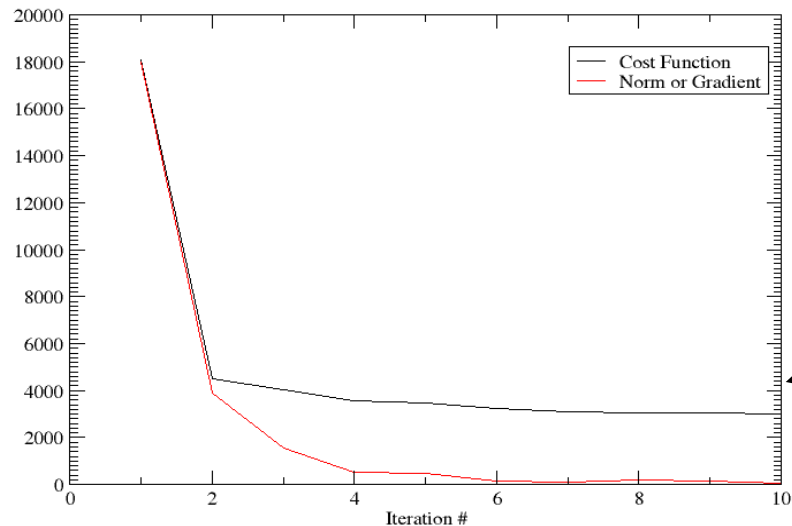
Details on site scale study:  
Knorr et al., JGR, 2010

# Assimilation of MERIS FAPAR and atmospheric CO<sub>2</sub>

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

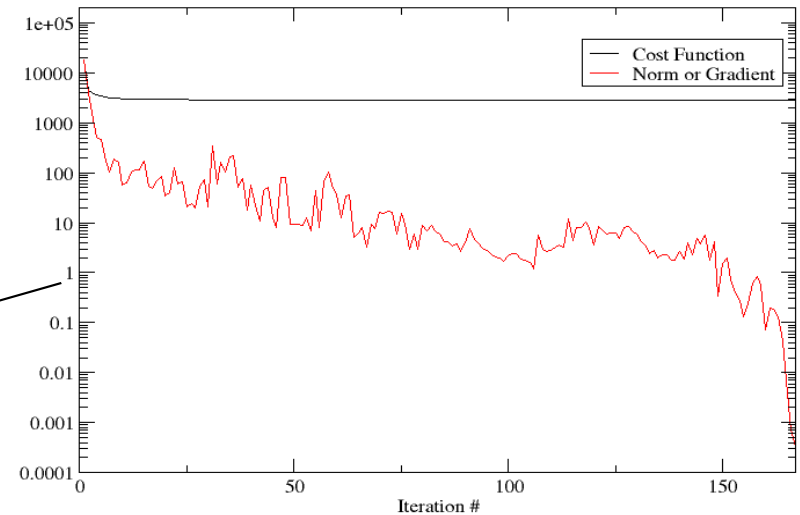
- Very coarse 8 x 10 degree global grid
- **Monthly CO<sub>2</sub>** from two sites: MLO and SPO over five years (120 observations)
- MERIS **FAPAR** monthly means over 170 grid cells and 18 months (~ 3000 observations)
- Now (almost) 71 terrestrial parameters plus 1 atmospheric parameter
- Land cover scaled to match long term FAPAR

Convergence of Minimisation

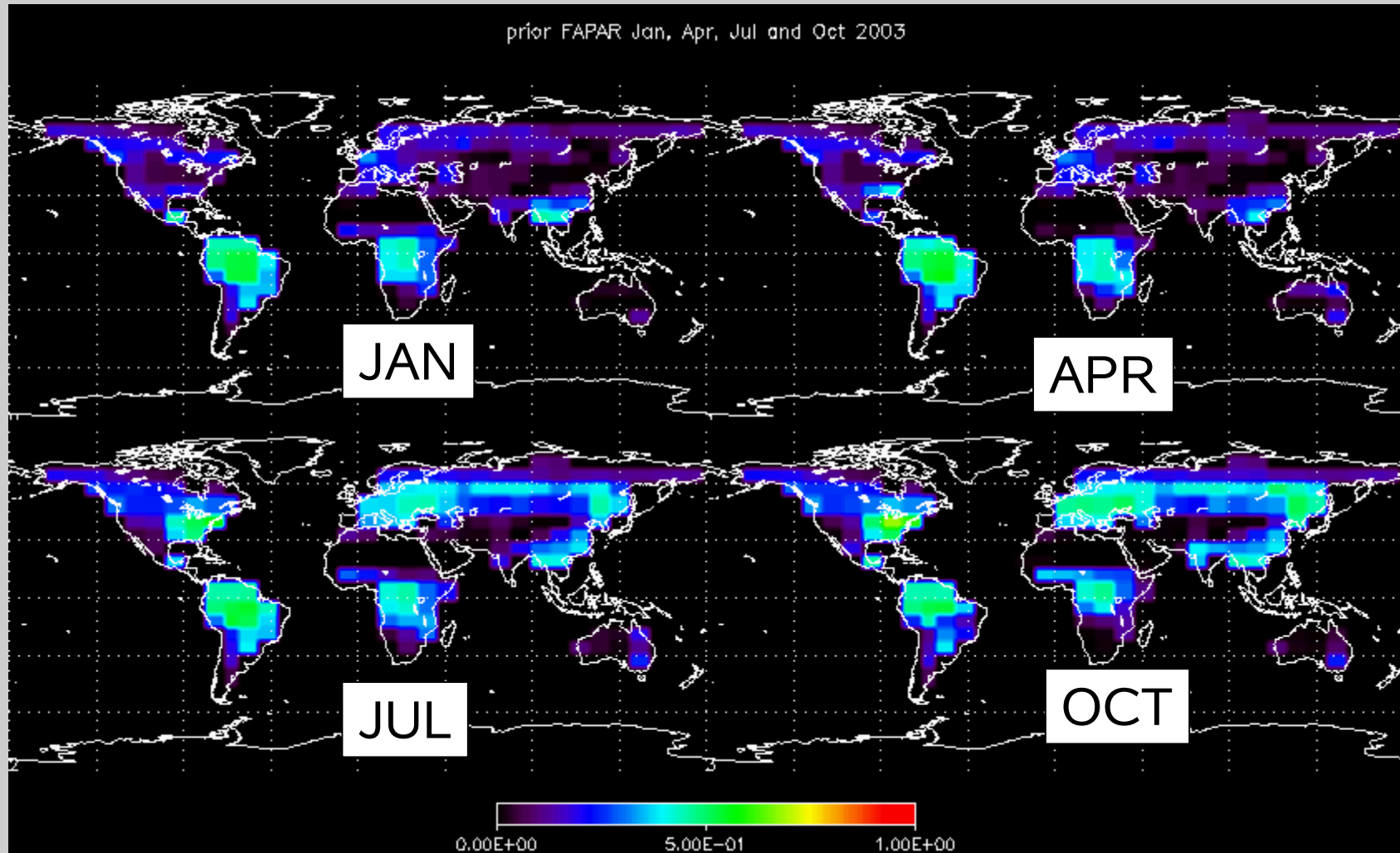


Zoom

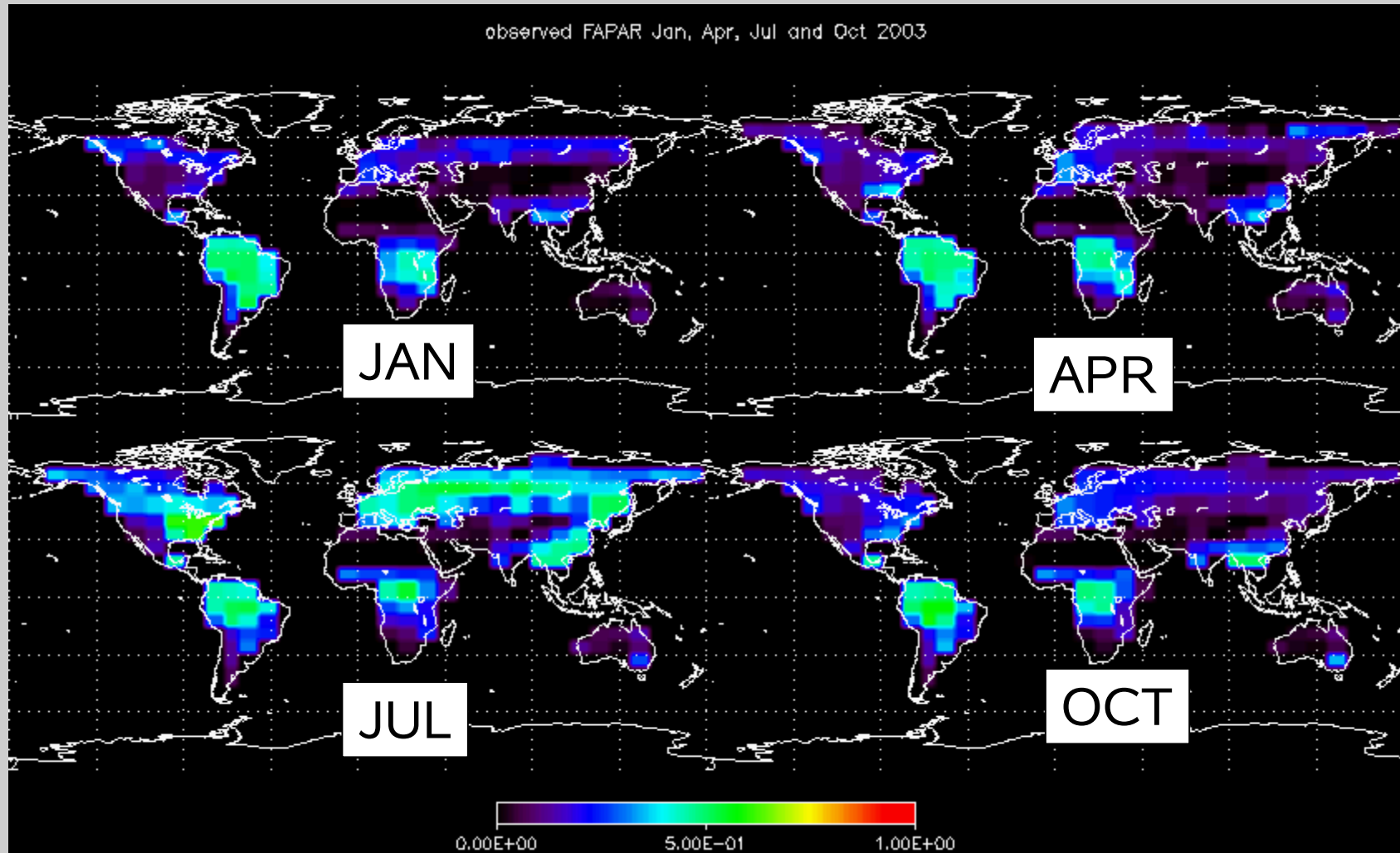
Convergence of Minimisation



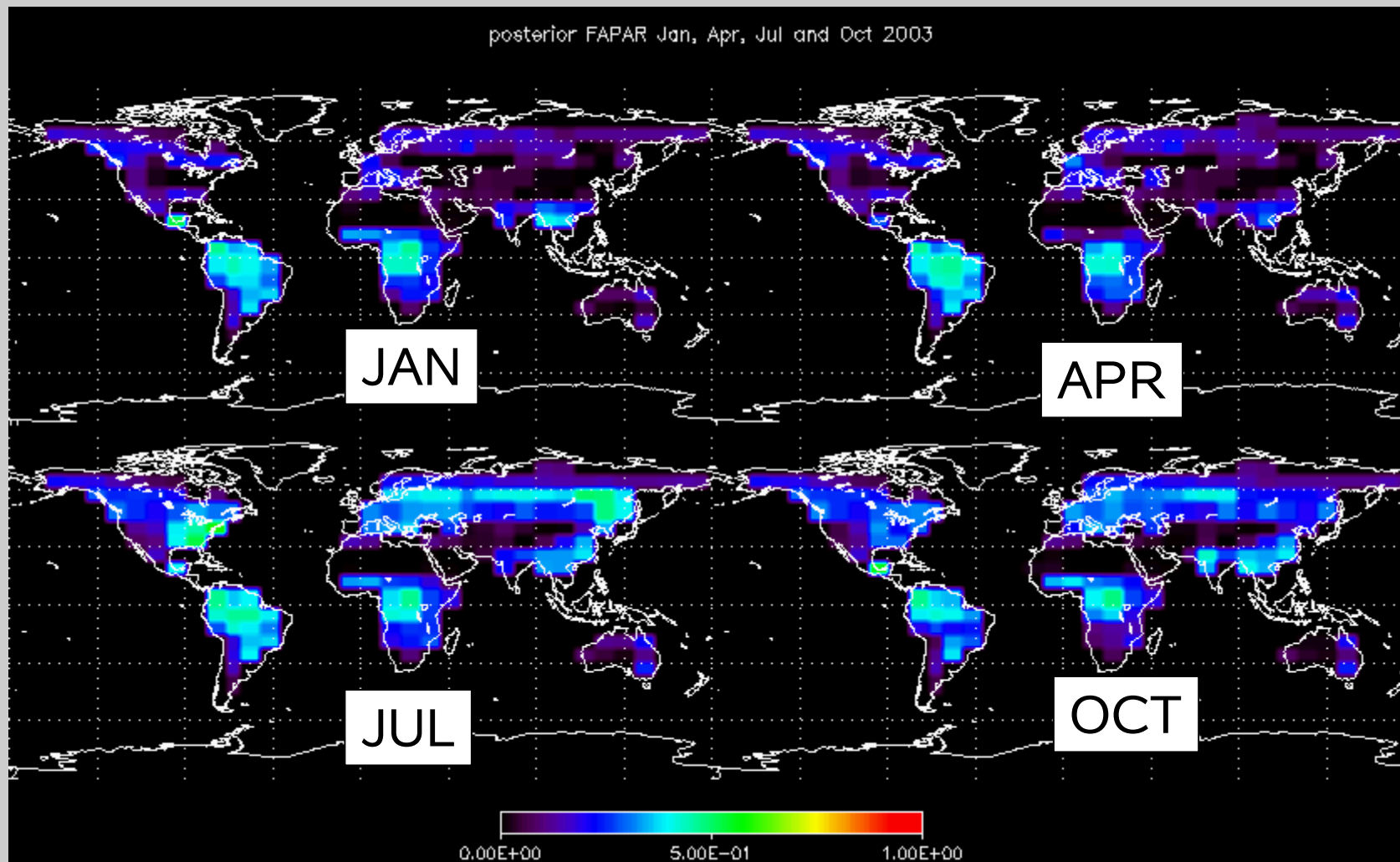
# 1<sup>st</sup> global results: prior



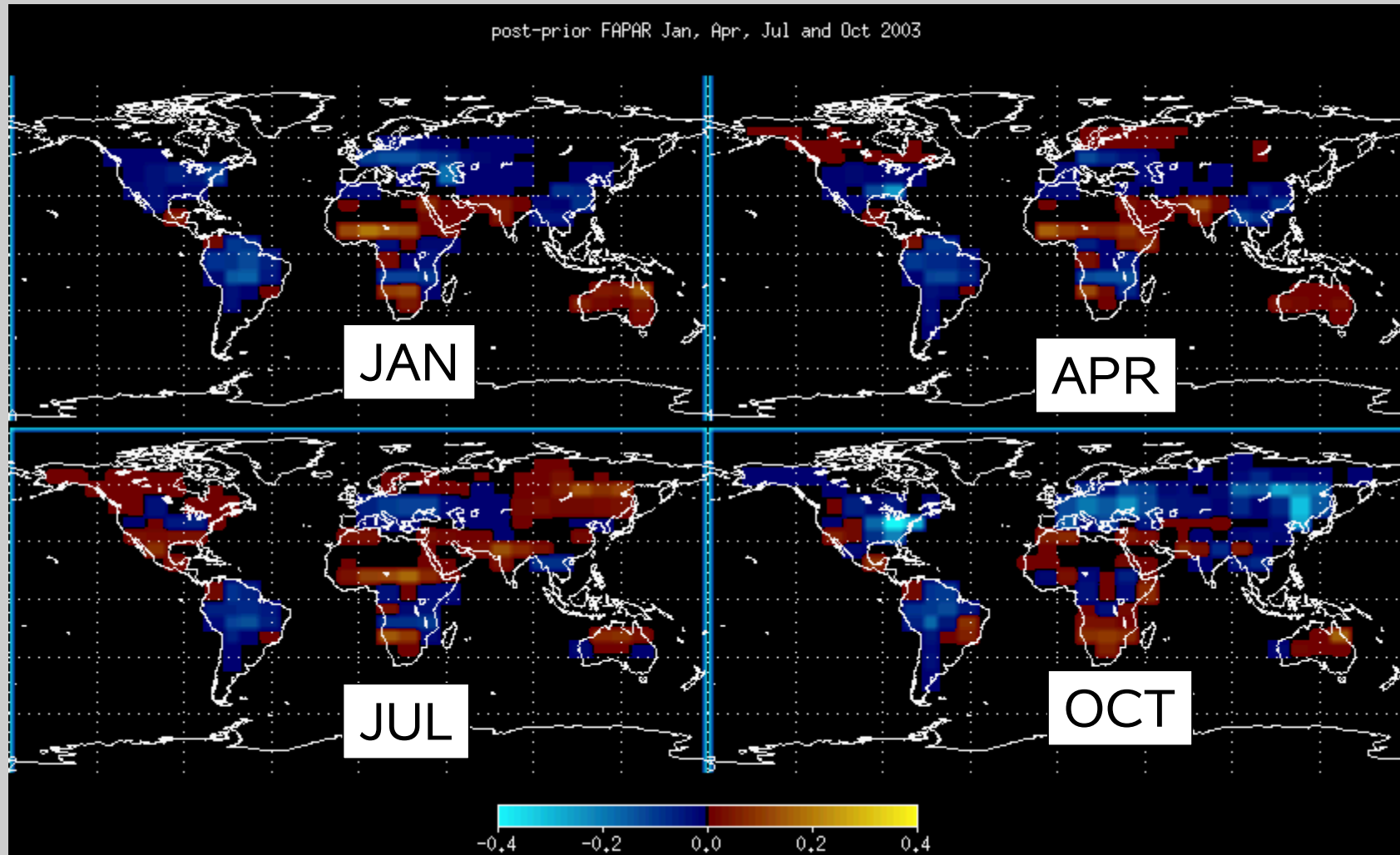
# 1<sup>st</sup> global results: satellite



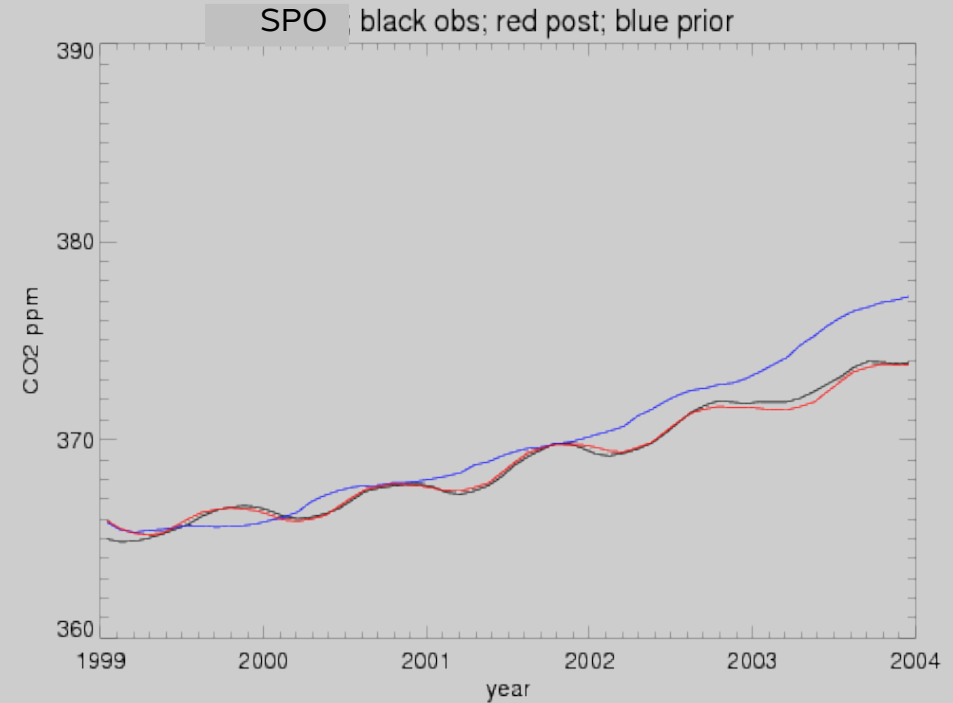
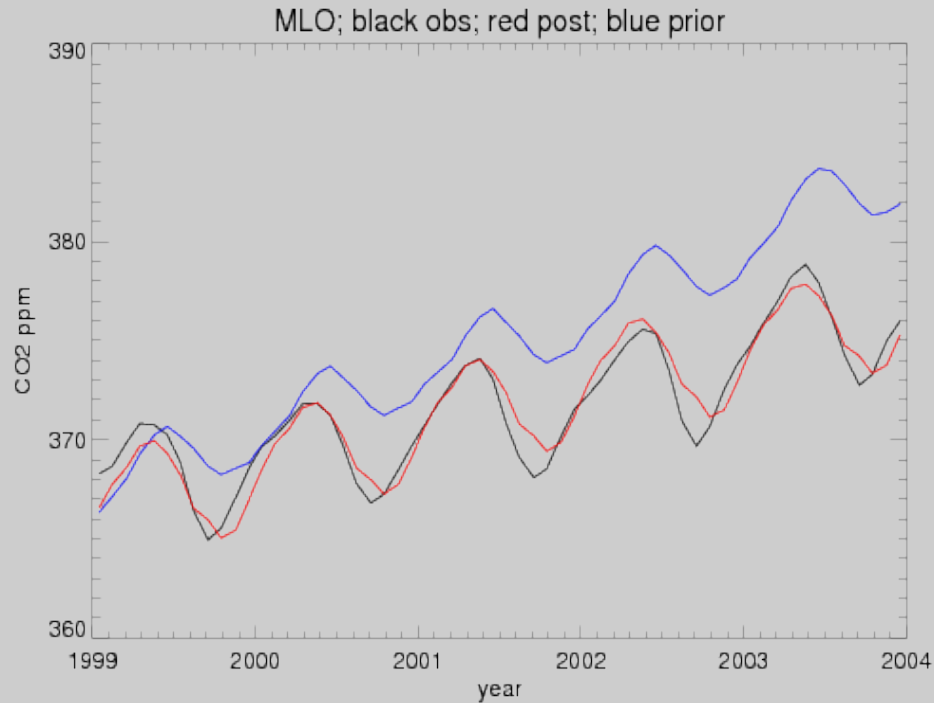
# 1<sup>st</sup> global results: posterior



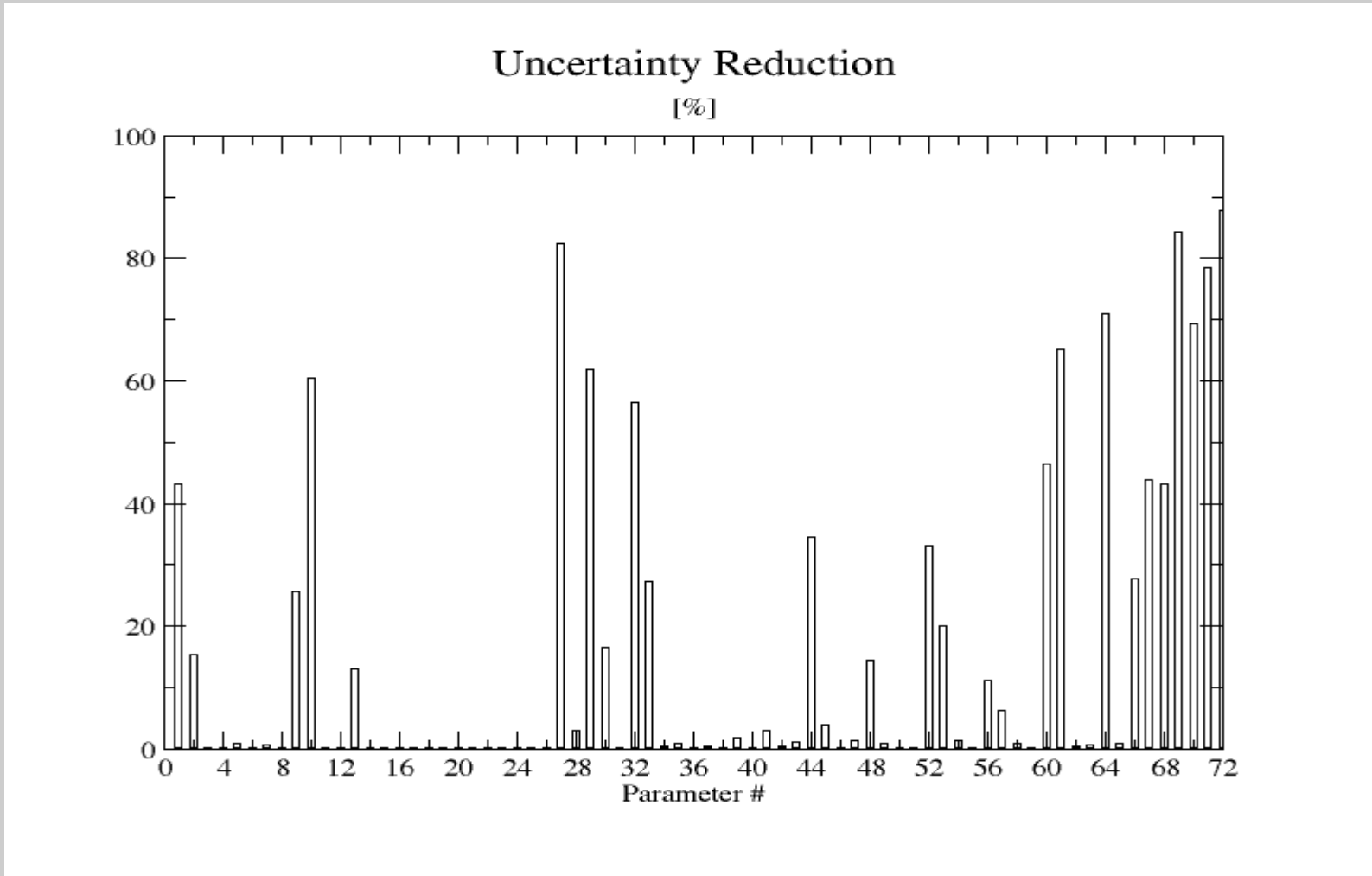
# 1<sup>st</sup> global results: Difference posterior - prior



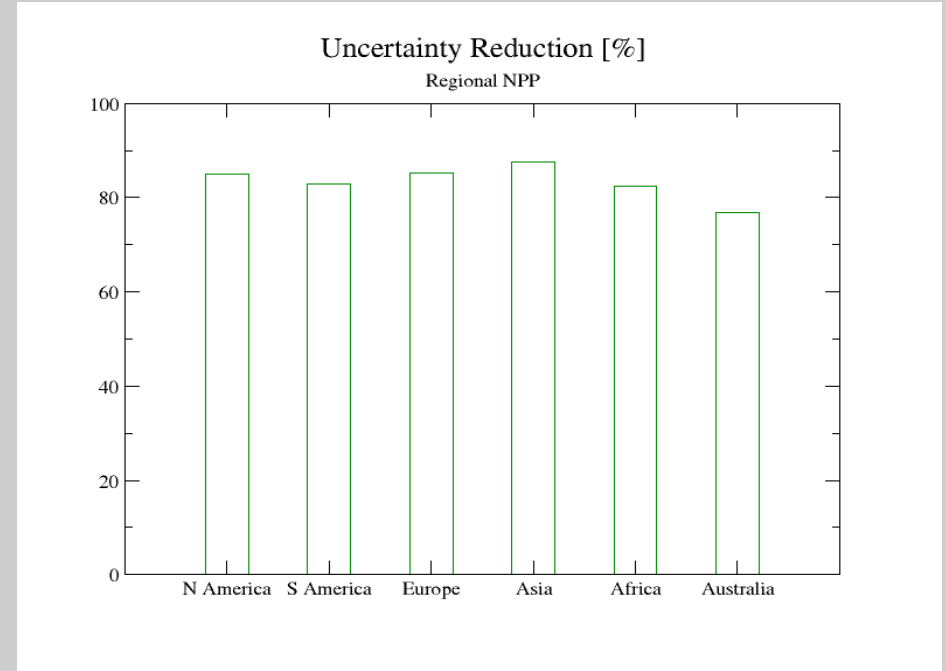
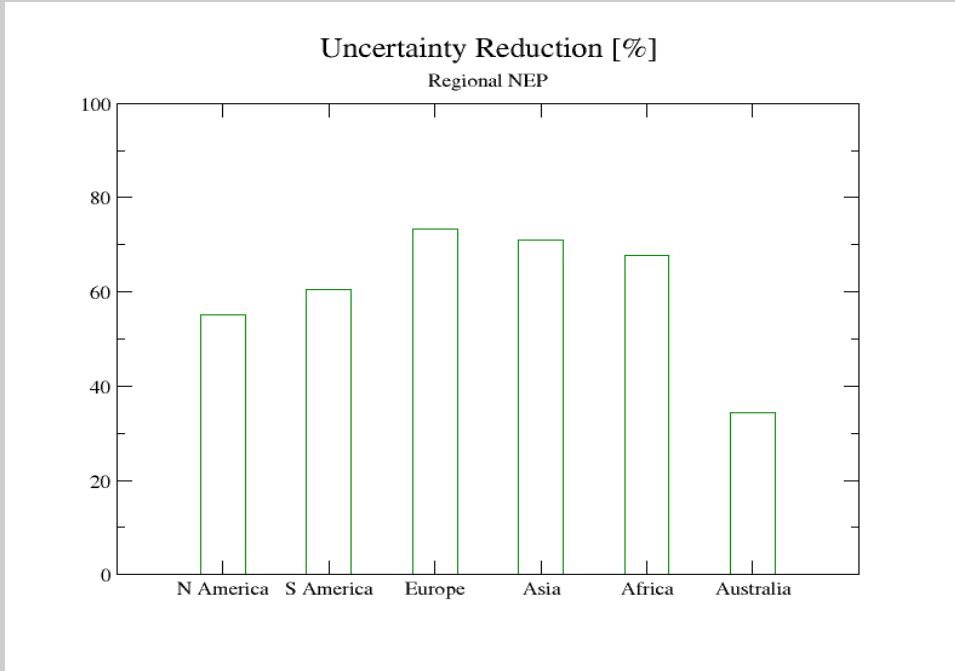
# 1<sup>st</sup> global results: Fit to atmospheric CO<sub>2</sub>



# Uncertainty Reduction on Process Parameters

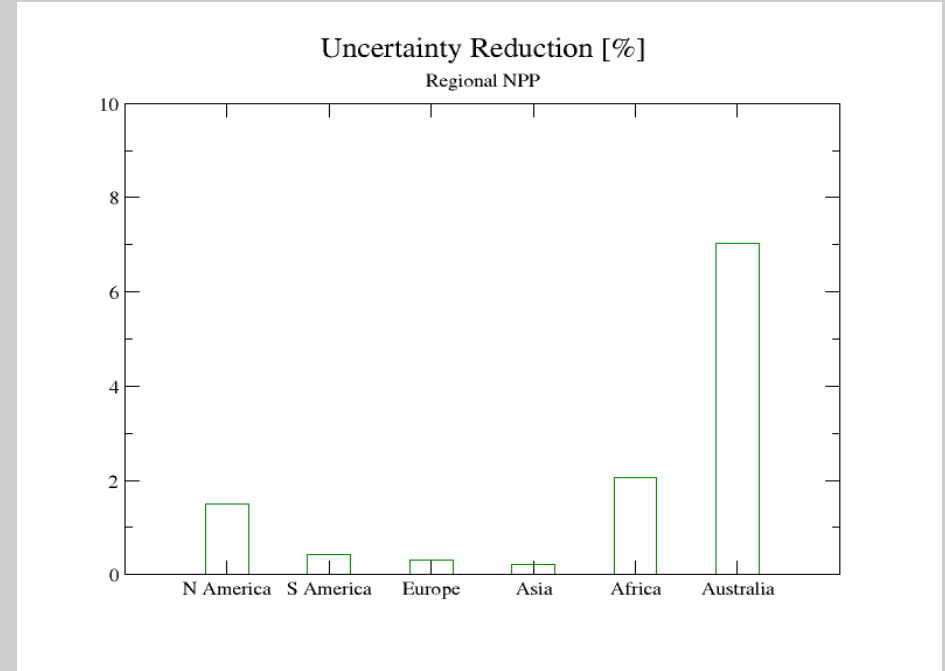
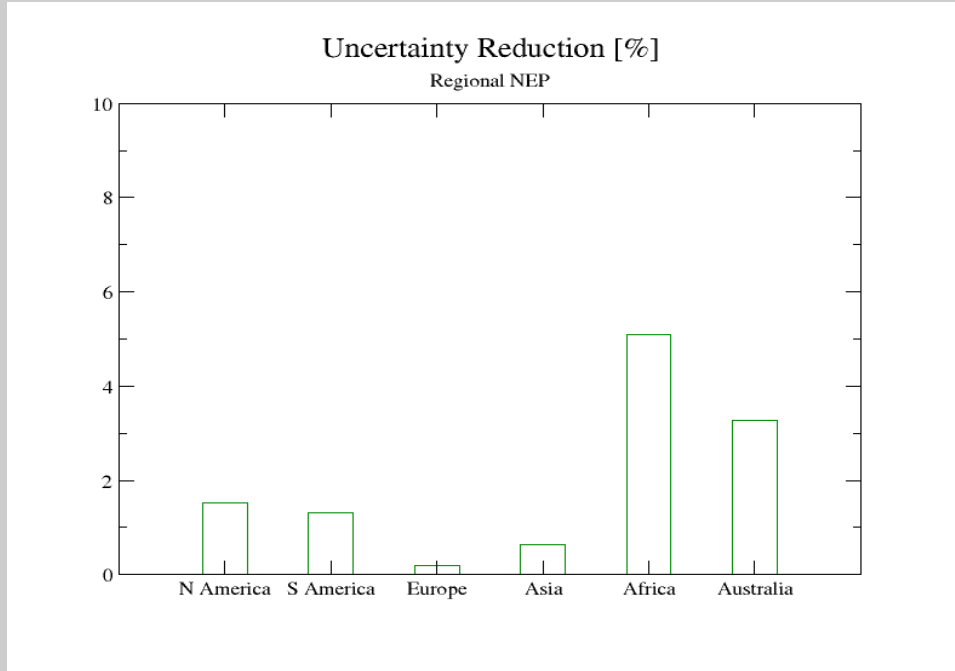


# Uncertainty Reduction on Simulated Fluxes MERIS + Atmospheric CO2



Results have to be confirmed in high resolution

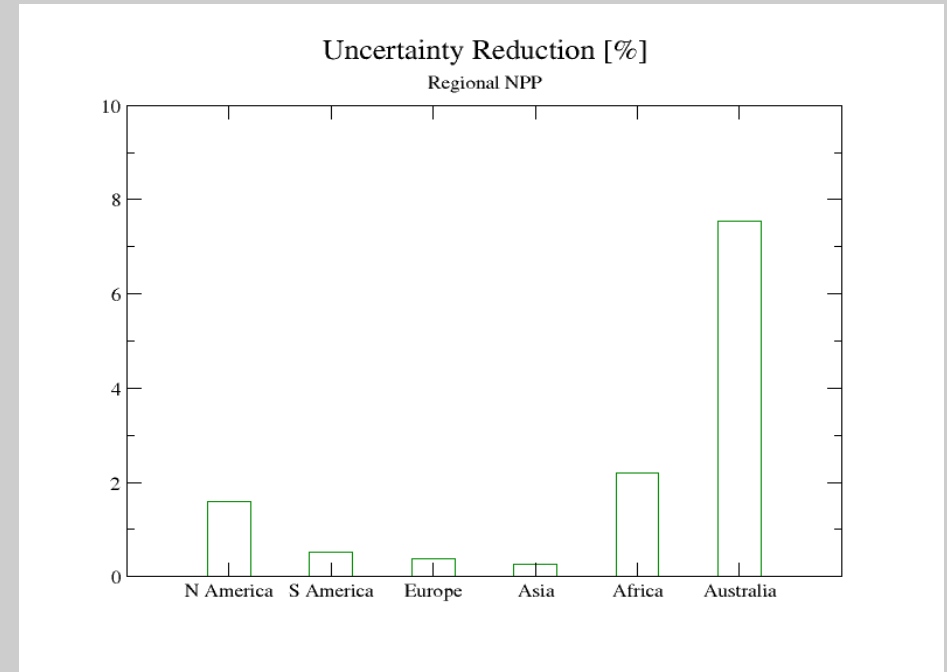
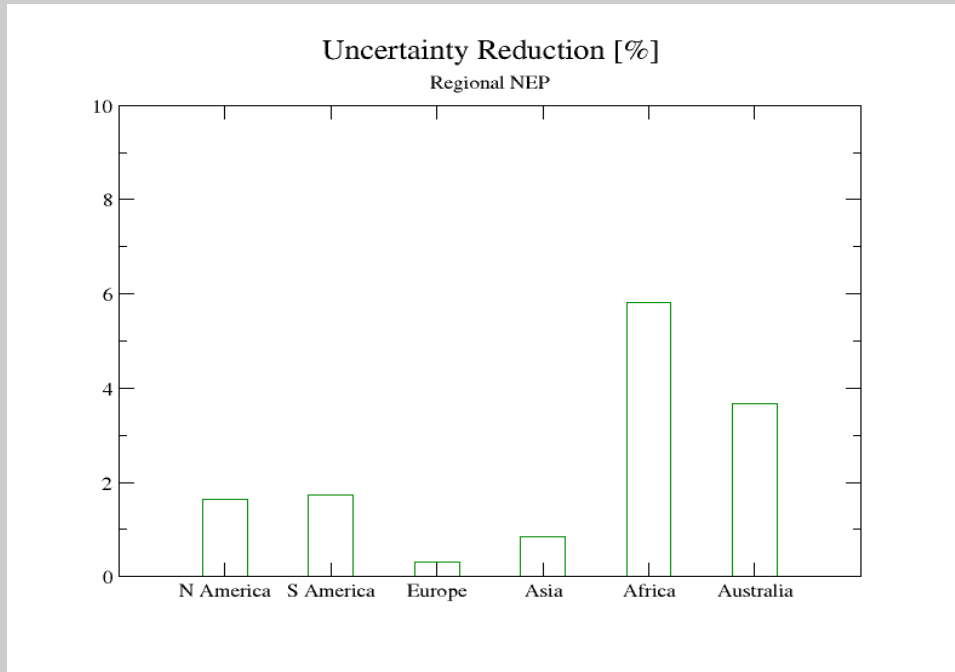
# Uncertainty Reduction on Simulated Fluxes MERIS only



Note: Uncertainty Propagation can be decoupled from optimisation (Kaminski and Rayner, 2008):  
Mission Design Local scale: Knorr et al., Proceedings of 2nd MERIS/(A)ATSR User Workshop, 2008

# Uncertainty Reduction on Simulated Fluxes

## Hypothetical MERIS like, with observational uncertainty halved



Principle of a tool to evaluate **hypothetical sensors to support mission design**

# Summary

- **Simultaneous** assimilation of MERIS FAPAR product at seven sites with **revised phenology scheme**
- **Simultaneous** assimilation of **global scale MERIS FAPAR product and atmospheric CO2**
- Impact of observations quantified by **uncertainty reduction**, e.g. in simulated surface fluxes
- Uncertainty propagation decouples from optimisation: Allows to evaluate **benefit of hypothetical instruments, i.e. support mission design**
- Currently evaluating strategies to include a **bias model** and **calibrate it jointly** with the terrestrial **vegetation model**

Acknowledgement: **Study supported by ESA**

More info: <http://rs.ccdas.org>