Consistent EO Land Surface Products including Uncertainty Estimates through the Two-stream Inversion Package (TIP)

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with contributions
from the GlobAlbedo team

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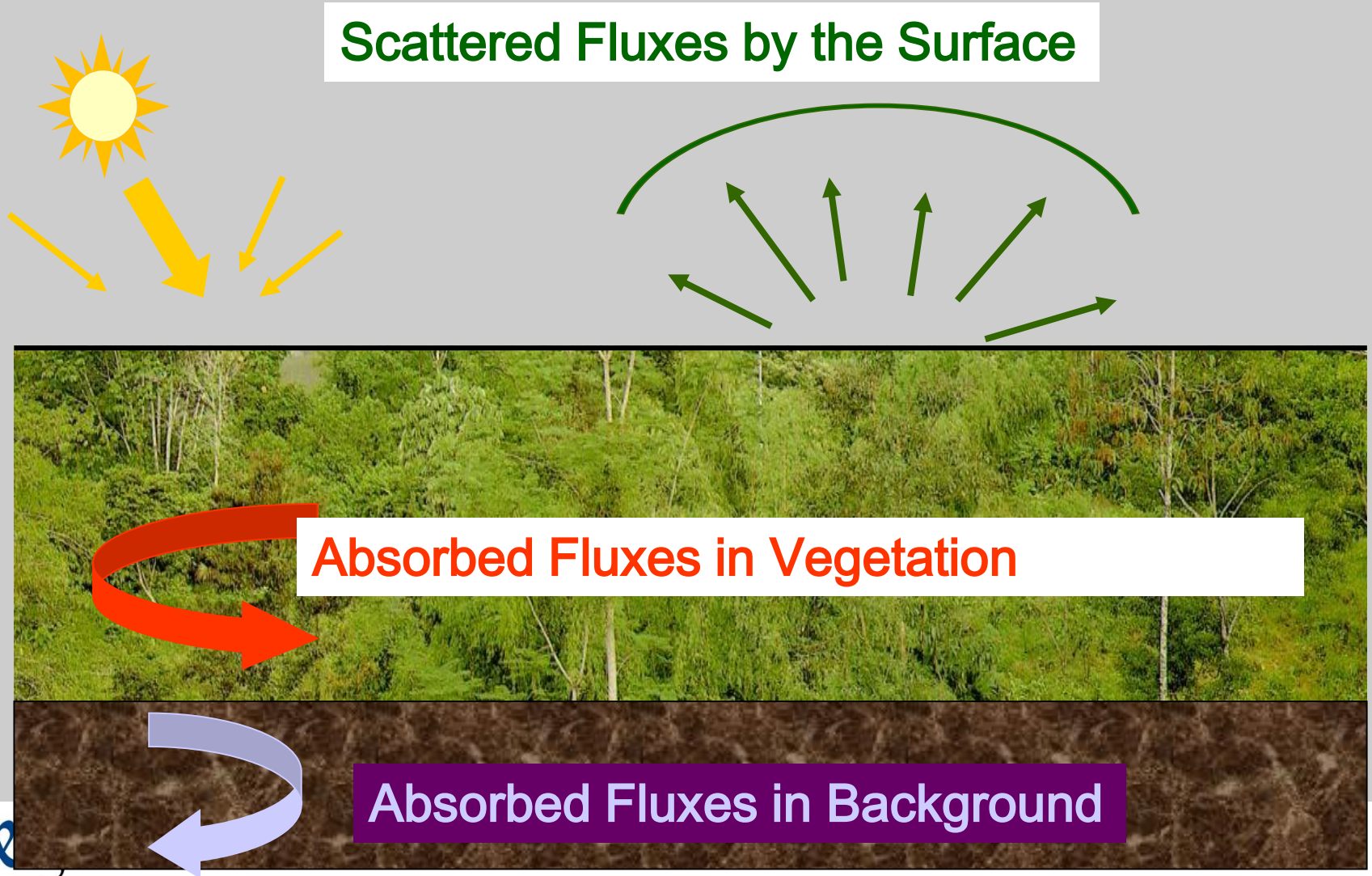
Two-stream model to distribute the Sun energy between the atmosphere, the vegetation and soil layers



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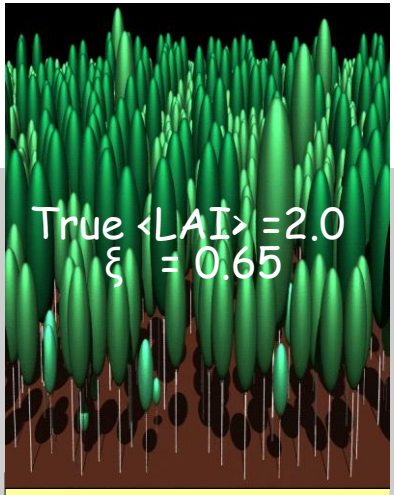
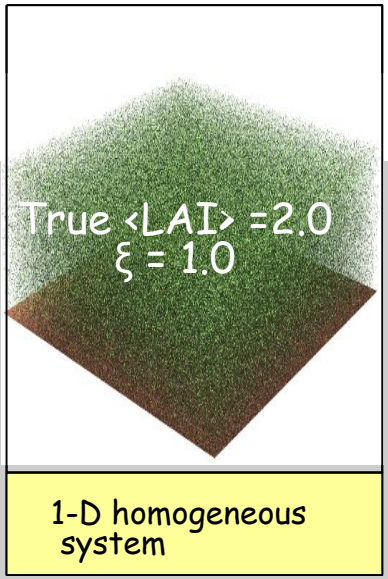
Pinty etal., (2006) Journal of Geophysical Research, doi:10.1029/2005JD005952

Two-stream model

The two-stream (Pinty et al., JGR, 2006) is a model of the radiative transfer in the vegetation canopy-soil system



3-D heterogeneous system



1-D homogeneous system

State of system characterised by 4 variables:

- *Leaf area index (LAI = ξ * <LAI>) (describes density of vegetation)*
- w_l is the *vegetation single-scattering albedo ($w_l = r_l + t_l$)*
- d_l is the *vegetation forward-scattering efficiency ($d_l = r_l / t_l$)*
- $r_{bgd,l}$, *background reflectance with or without snow*

All variables and fluxes are domain-averaged values

All 3 vegetation state variables are effective

Formulation of the inverse problem

Typically 2 broadband wavelengths (VIS, NIR)

yields 7 unknowns (parameter) and up to 6 observations:

$x = < LAI, w_l(\lambda_1), d_l(\lambda_1), r_{bgd}(\lambda_1), w_l(\lambda_2), d_l(\lambda_2), r_{bgd}(\lambda_2) >$

$d = < R(\lambda_1), T(\lambda_1), A(\lambda_1), R(\lambda_2), T(\lambda_2), A(\lambda_2) >$

Typically only a subset of the radiant fluxes are observed (R)

Task: Retrieval of model parameters x from a given set of observations d

Bayesian approach: Use prior information

covariance of uncertainty in priors for parameters

priors for model M parameters

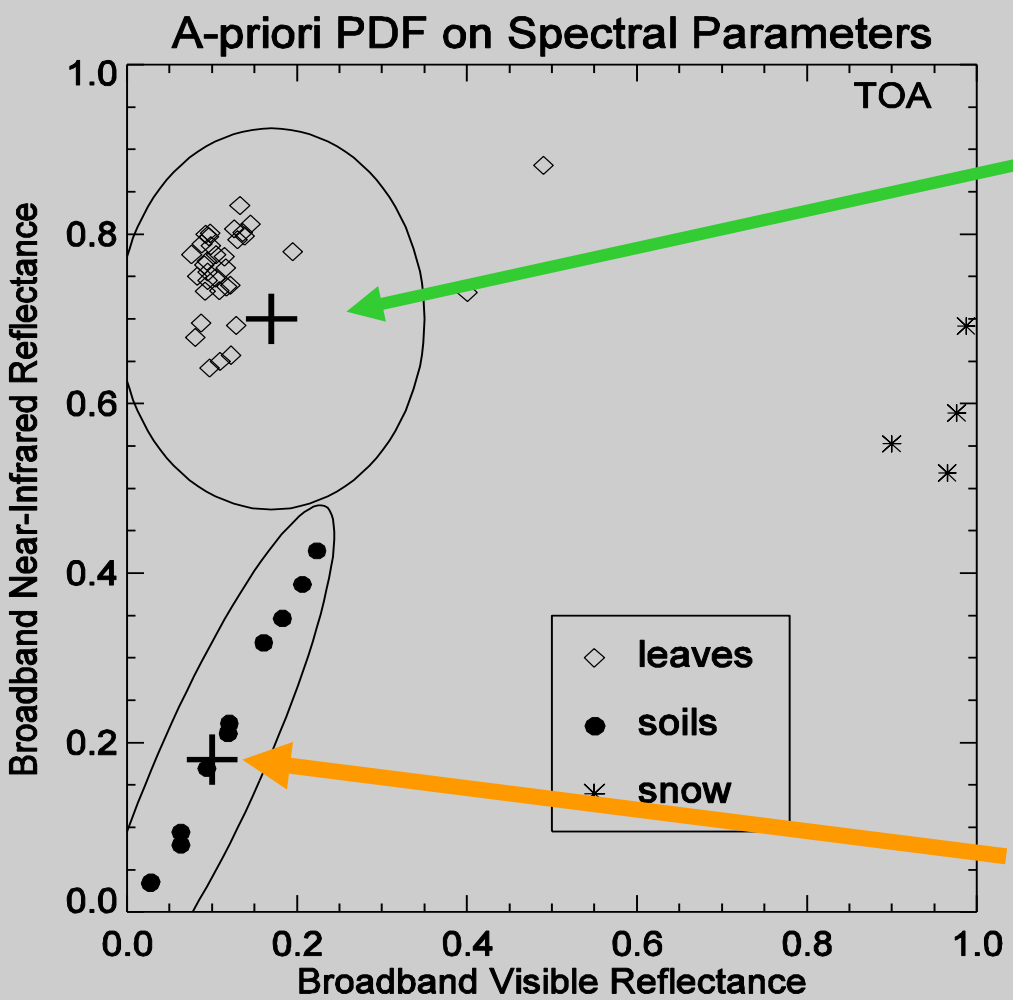
covariance of uncertainty in measurements + model

two-stream model M(x)

observed fluxes

$$J(x) = \tfrac{1}{2} \left[(x-x_{pr})^T C_{pr}^{-1} (x-x_{pr}) + (M(x)-d)^T C_d^{-1} (M(x)-d) \right]$$

Prior knowledge on model parameters (snow free)



$$LAI_{prior} = 1.5$$

$$\sigma_{prior}(LAI) = 5$$

Pinty etal., (2007) Journal of Geophysical Research, doi:10.1029/2006JD008105

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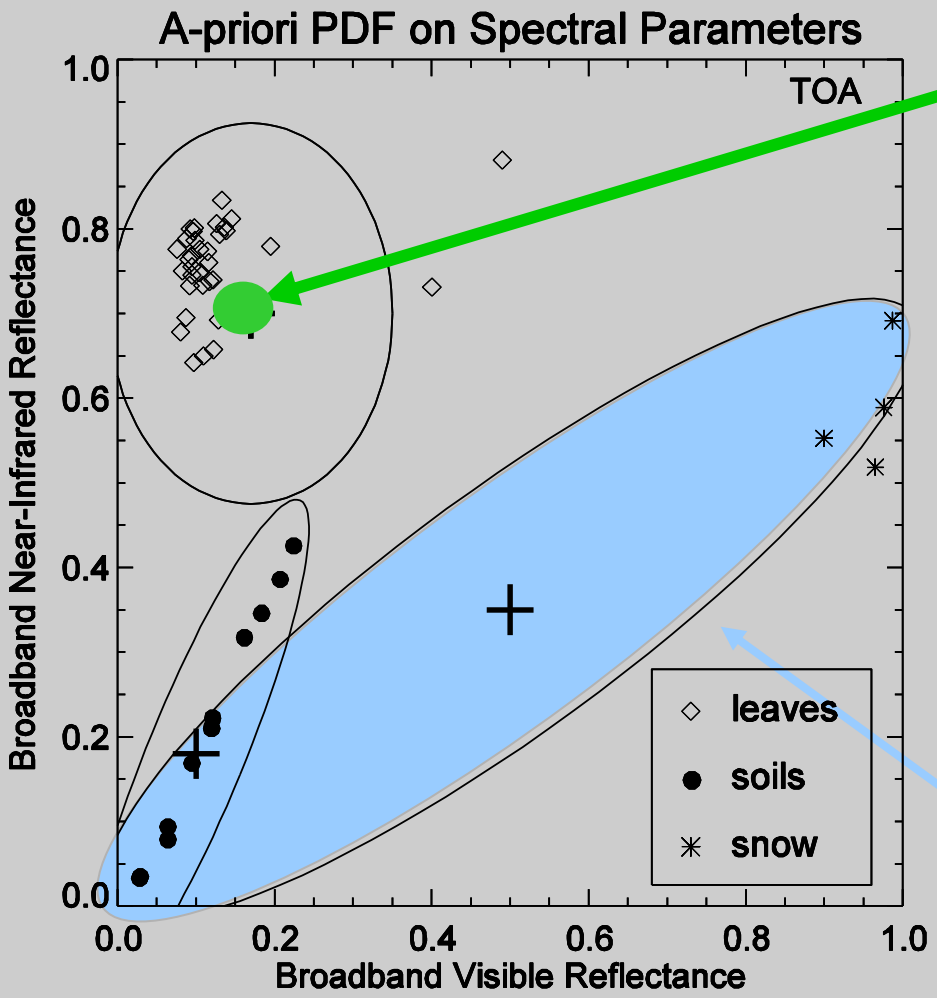
Prior knowledge on model parameters (with snow)



with ‘green’ leaves

$$LAI_{prior} = 1.5$$

$$\sigma_{prior}(LAI) = 5.0$$

in case snow occurs

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Pinty etal., (2007) Journal of Geophysical Research, doi:10.1029/2006JD008105

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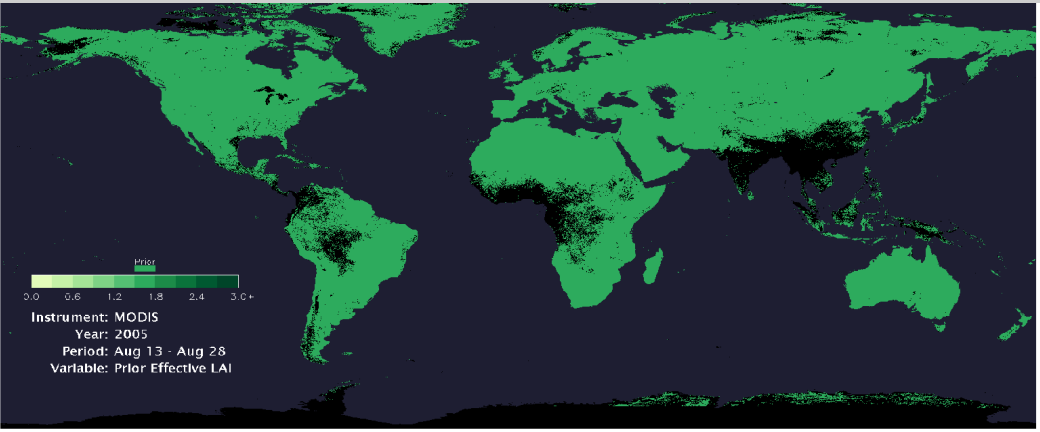
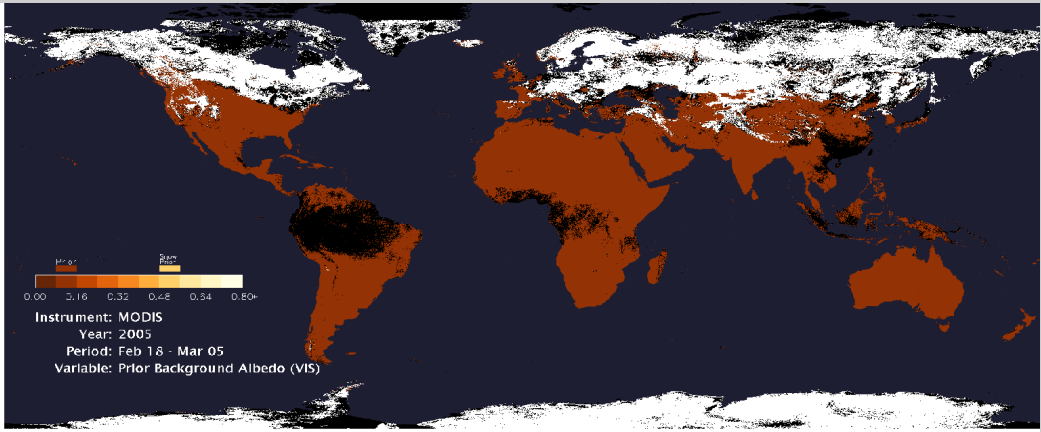
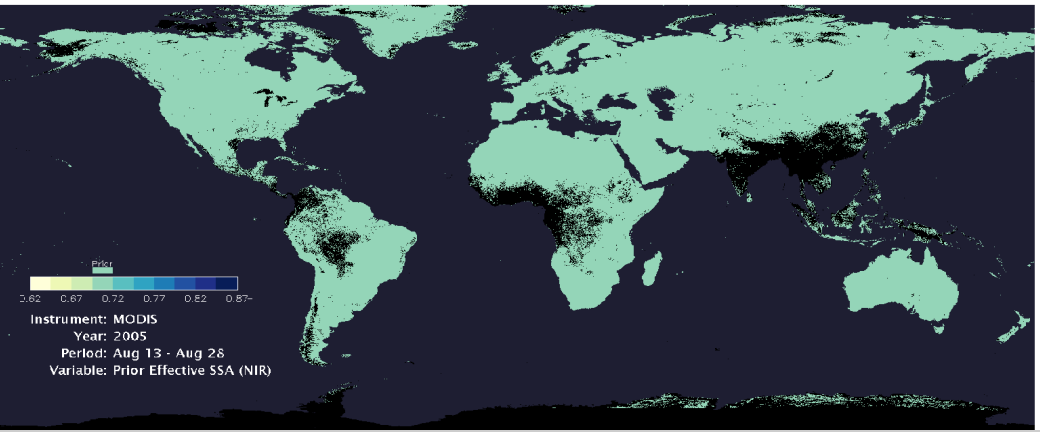
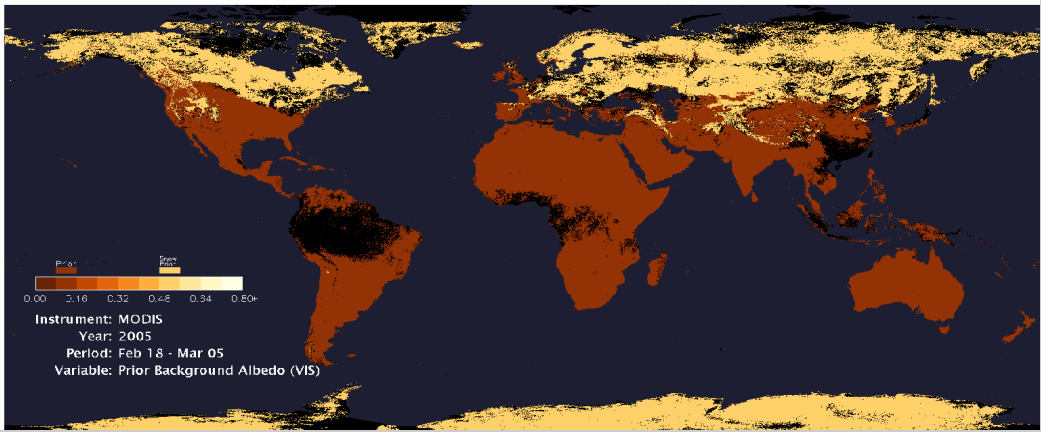
Prior knowledge on model parameters

TIME and SPACE INVARIANT









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Pinty etal., (2011): Journal of Geophysical Research, doi:10.1029/2010JD015373

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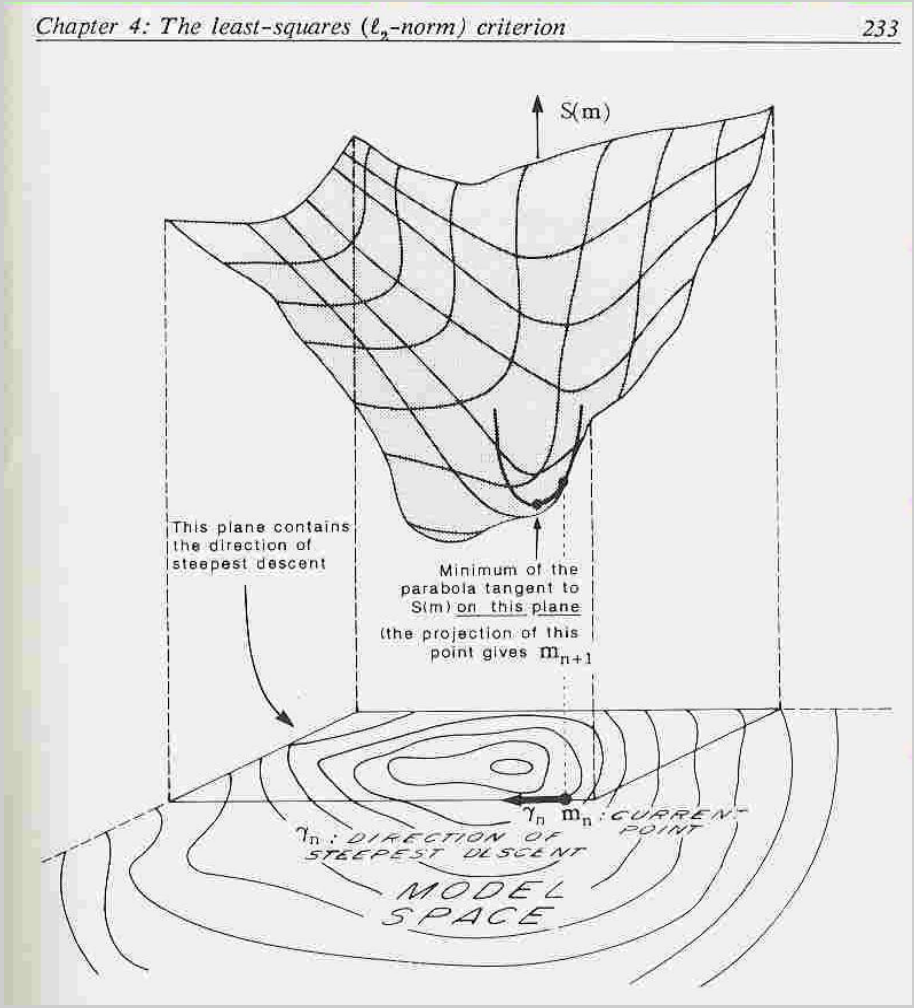
Technical Solution to the inverse problem



- Iterative minimisation of **J(x)**

$$J(x) = \tfrac{1}{2} [(x-x_{pr})^T C_{pr}^{-1} (x-x_{pr}) + (M(x)-d)^T C_d^{-1} (M(x)-d)]$$

- Uses gradient of J with respect to parameters
- Second derivatives (Hessian) at minimum x_{po} provide approximation of parameter uncertainties (error bars)

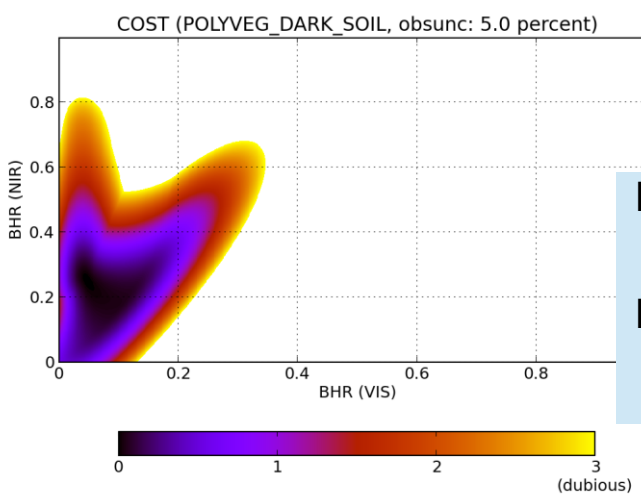
$$C_{po}^{-1} = \partial^2 J(x_{po}) / \partial x^2$$

- Uncertainties on simulated fluxes (e.g. FAPAR) via linearisation of model (Jacobian matrix)

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

- All derivatives provided via automatic differentiation of model code (TAC++), see Vossbeck et al. (2008)
- Figure taken from Tarantola (1987)

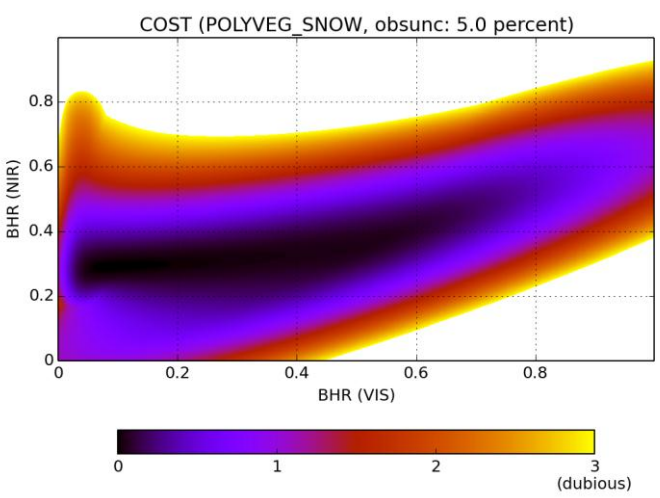
TIP Tables: Robustness and Speed

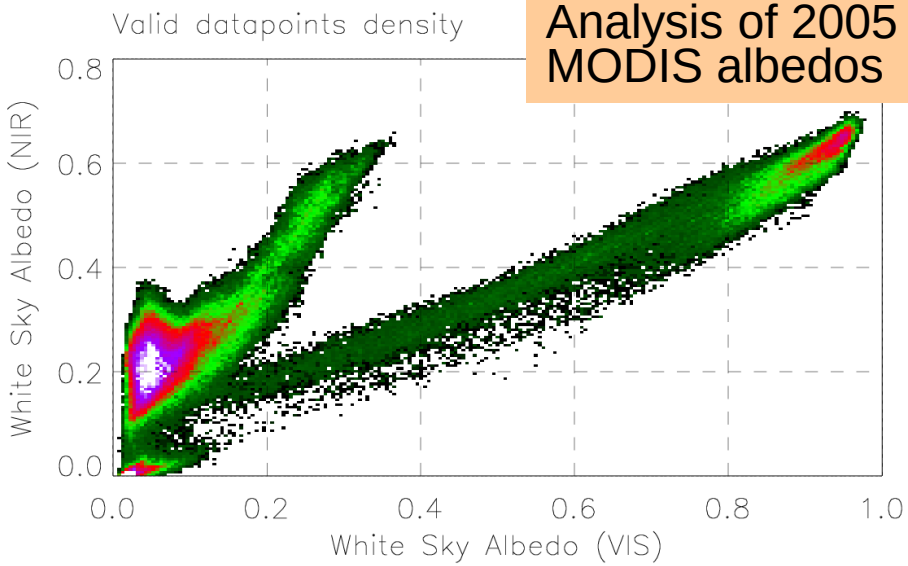


TIP table

Retrieval is **dubious** :=
finalcost > 3

Retrieval is **trusted** :<=>
not dubious and
within physical bounds





Analysis of 2005
MODIS albedos

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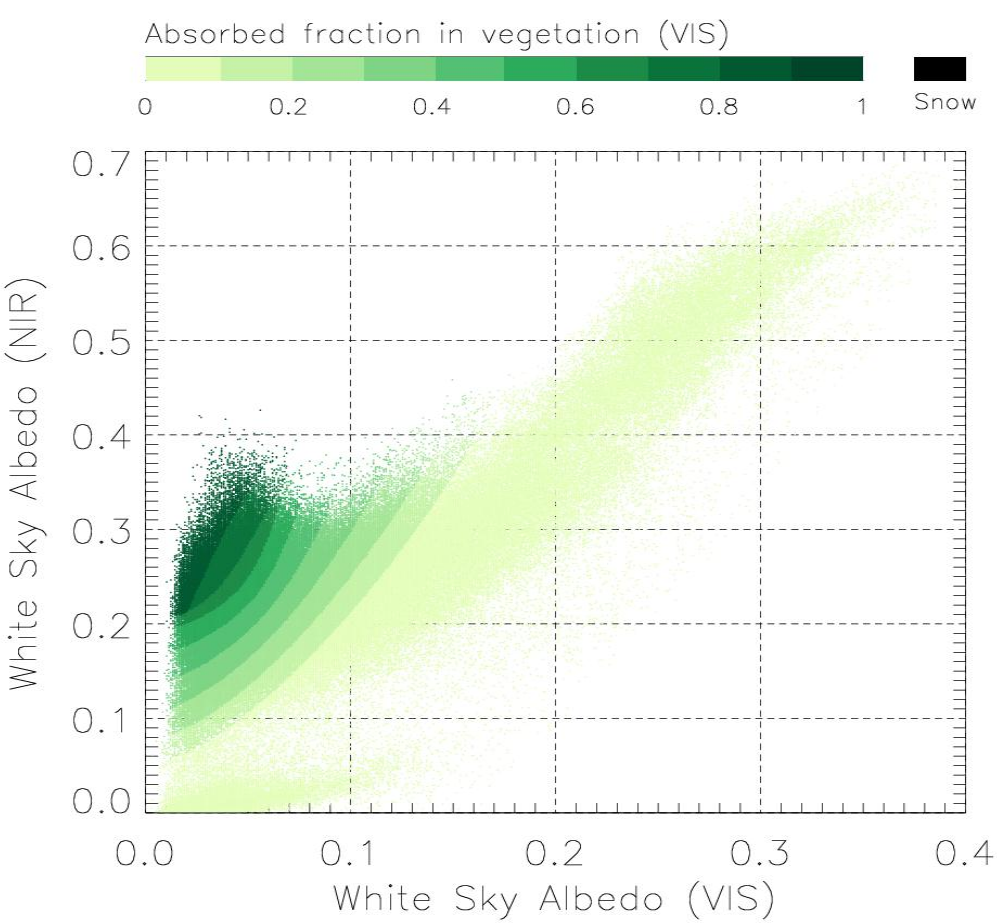
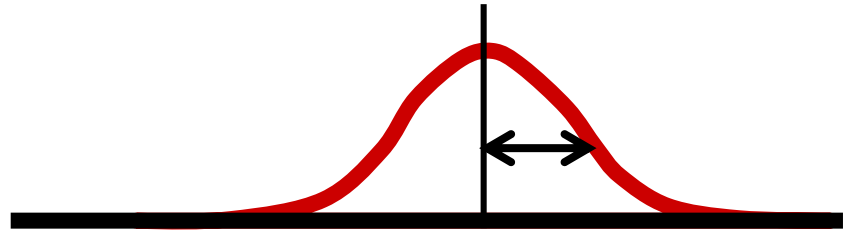
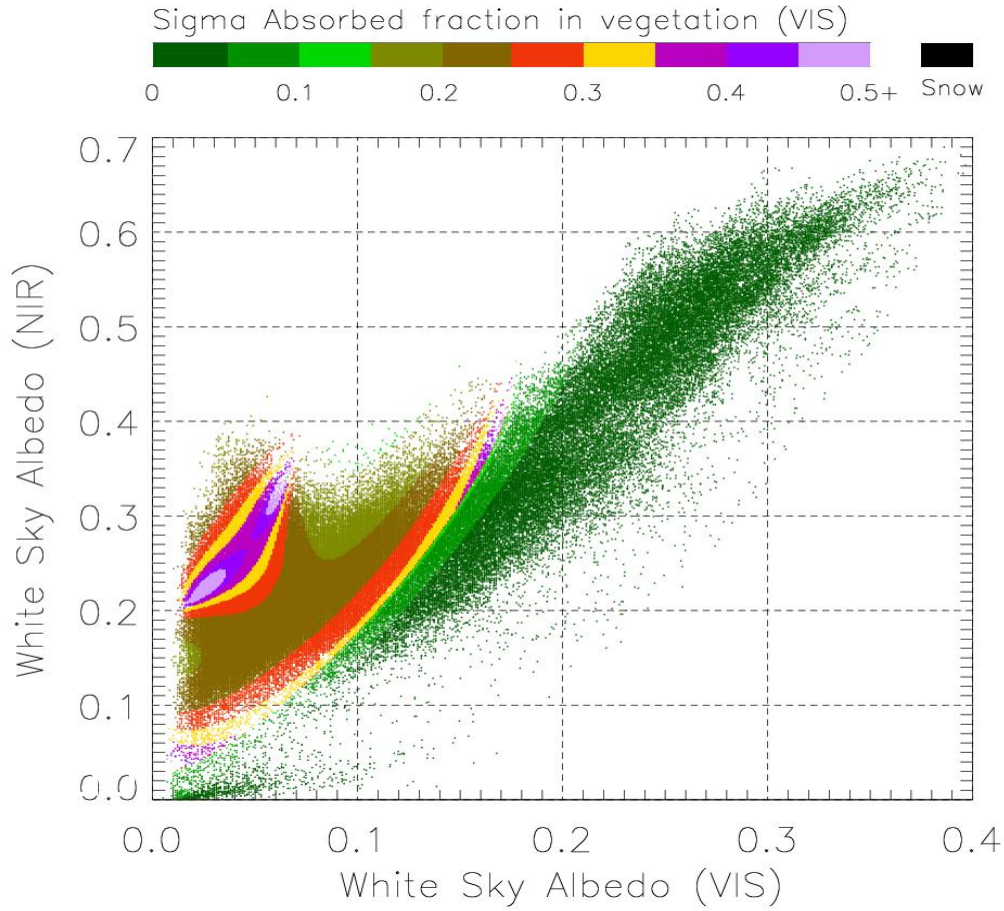
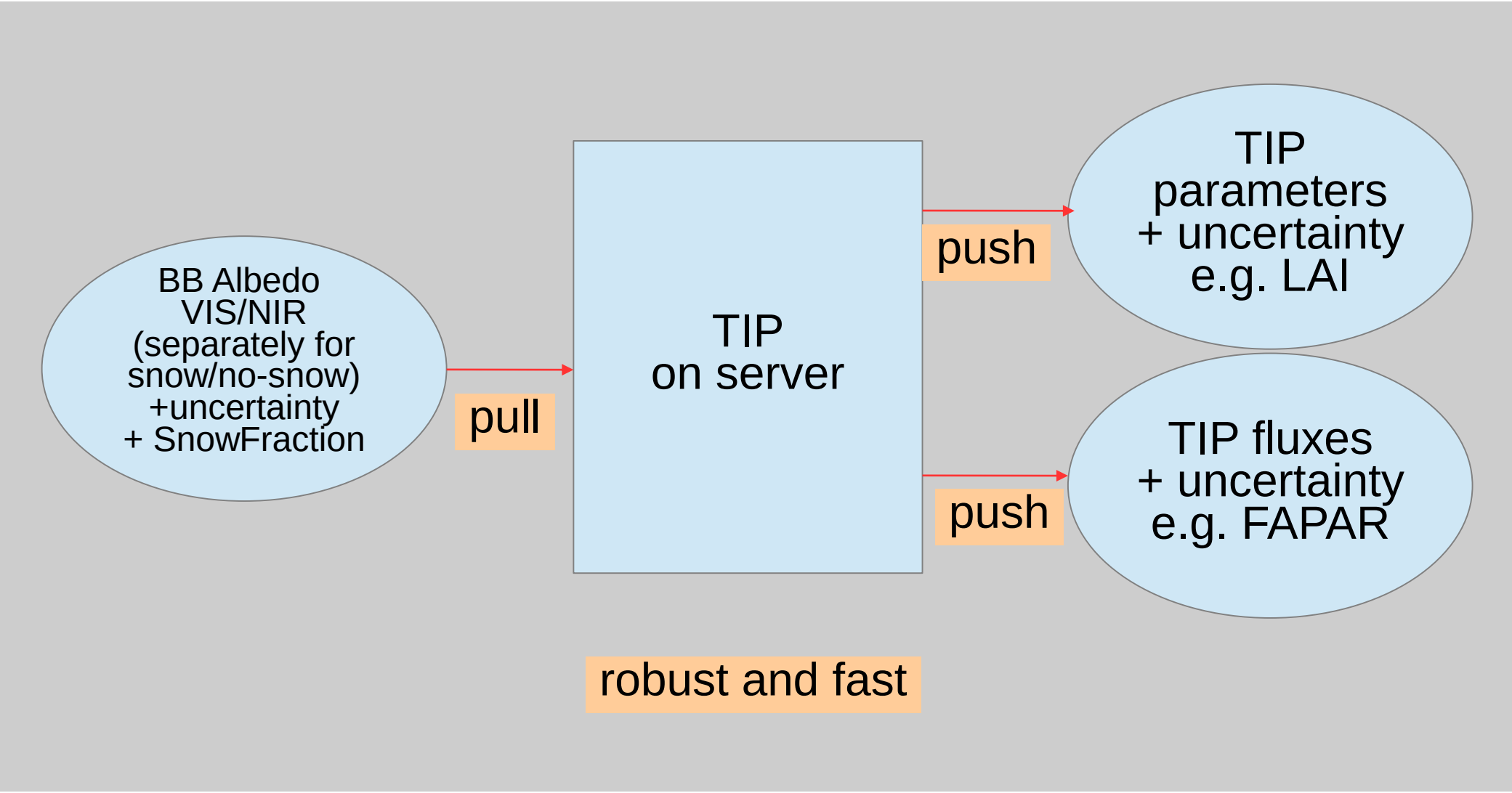
PDFs of retrieved FAPAR (absorption by vegetation in the VIS)







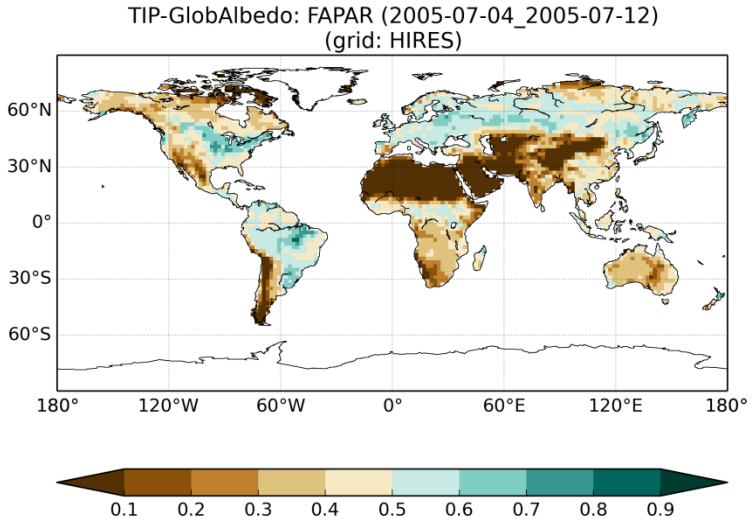
Two-stream Inversion Package (TIP) processing chain for GlobAlbedo

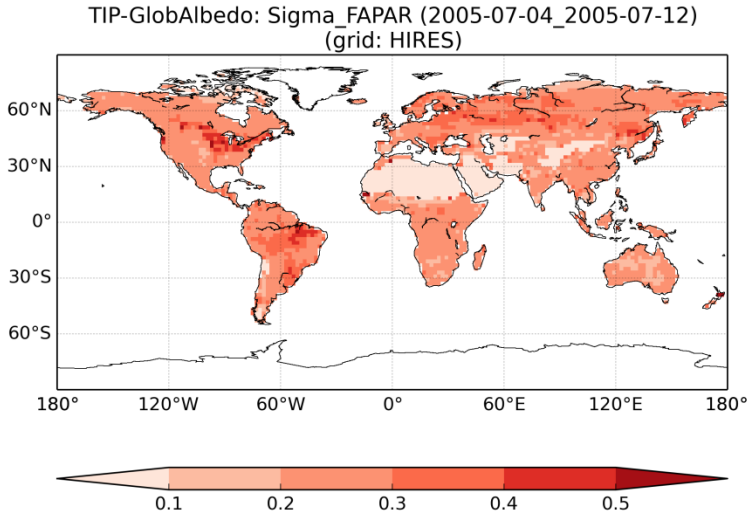


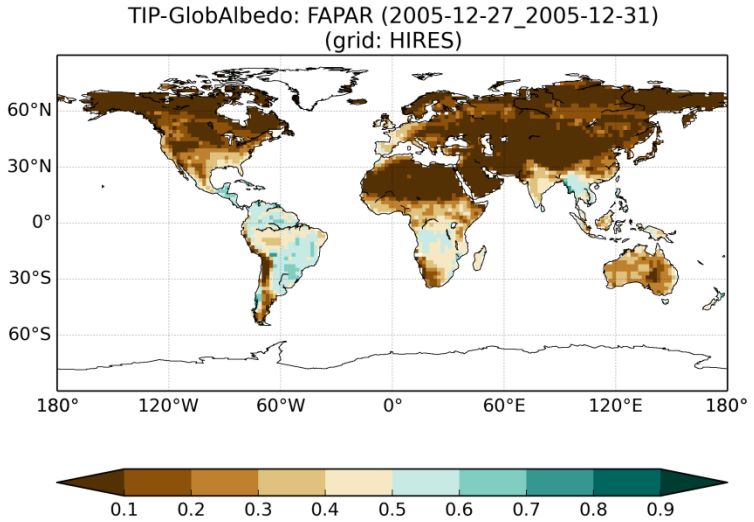
Processing

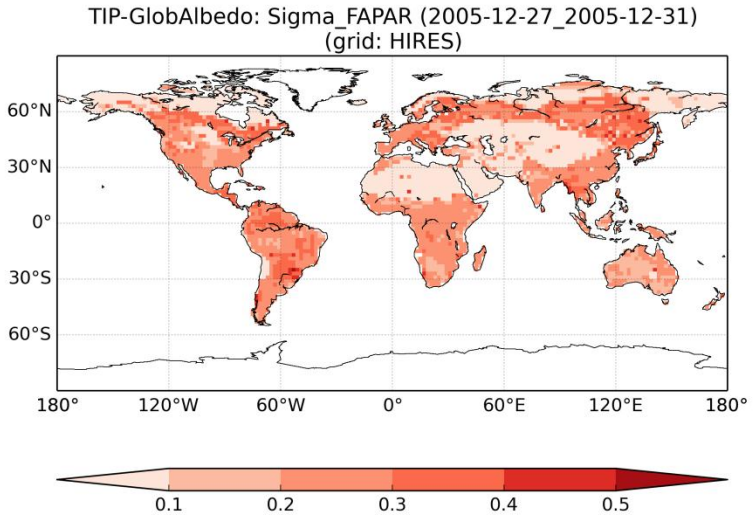
- 2002 - 2011
- globally
- 1km native resolution
- processing of aggregated albedos on 5, 25 km, and coarser grids
- exploiting albedo uncertainty information (currently within large bins)
- TIP-retrievals are derived as weighted mean according to snow fraction from distinct retrievals for snow/nosnow albedo conditions (for each pixel / grid-cell)

Global results: FAPAR









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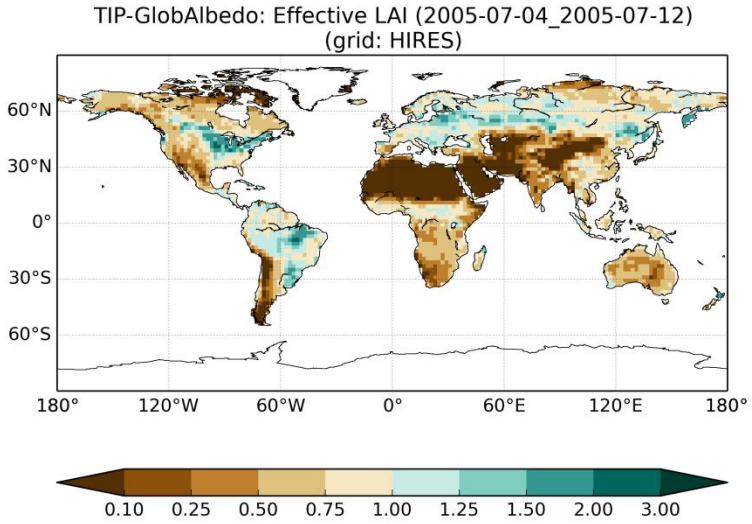
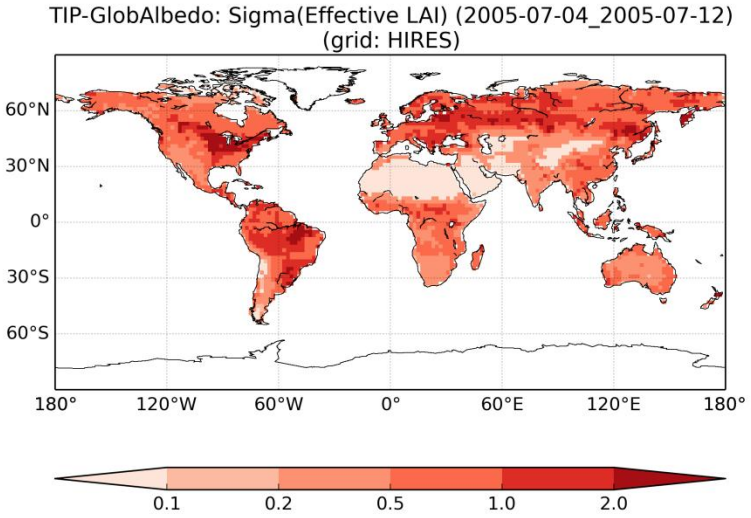
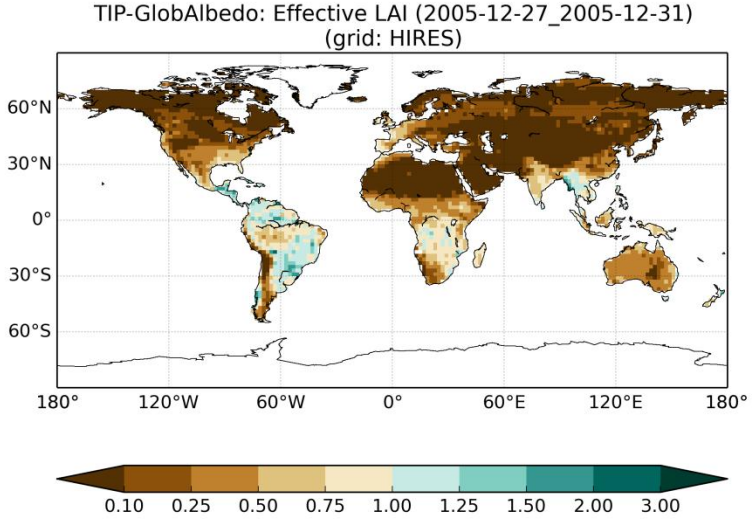
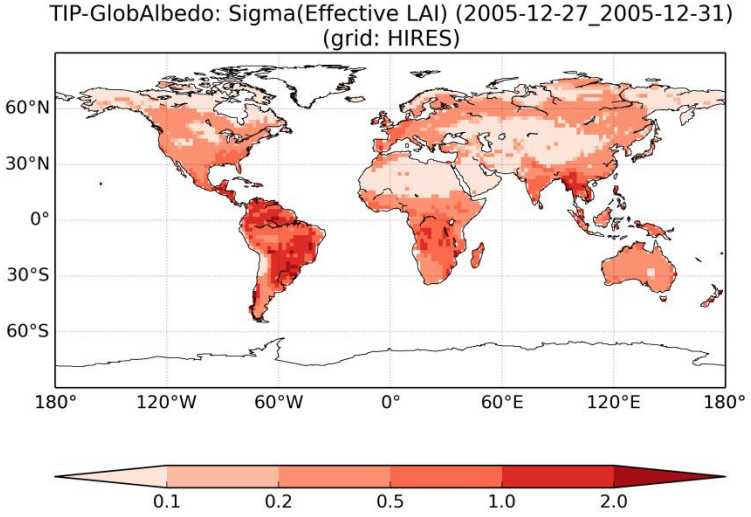
Global results: effective LAI









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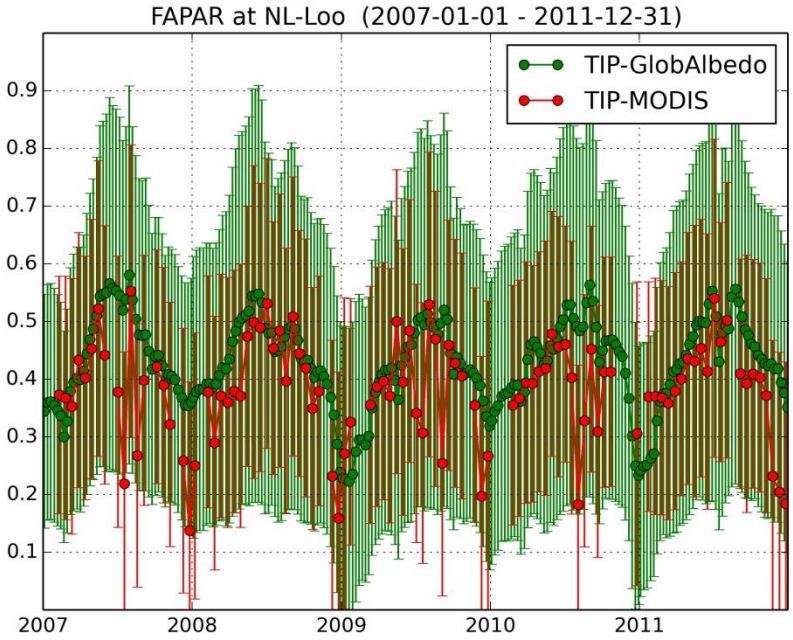
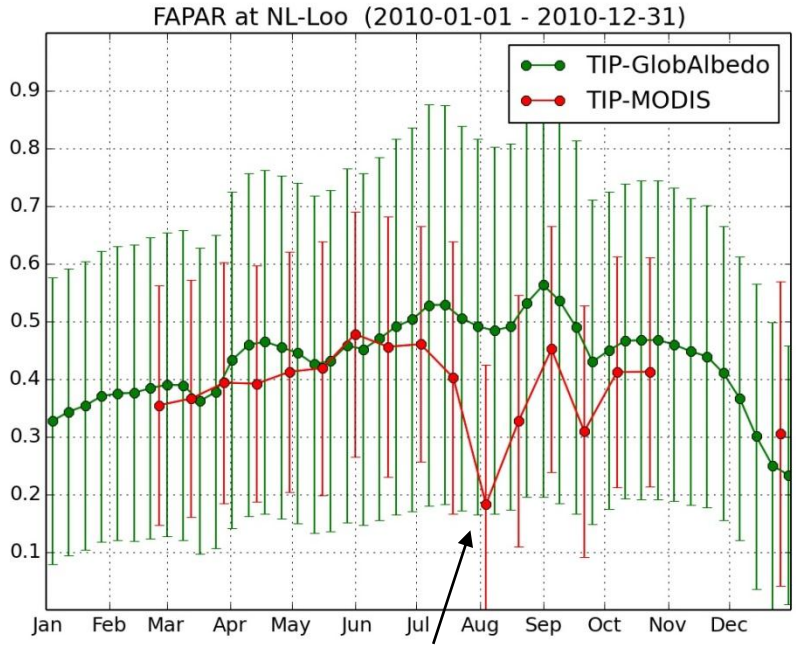
TIP-FAPAR@Loobos (NL)





probably due to cloud-cover!

TIP-MODIS: Ø=0.384 σ=0.087
TIP-GA : Ø=0.429 σ=0.076

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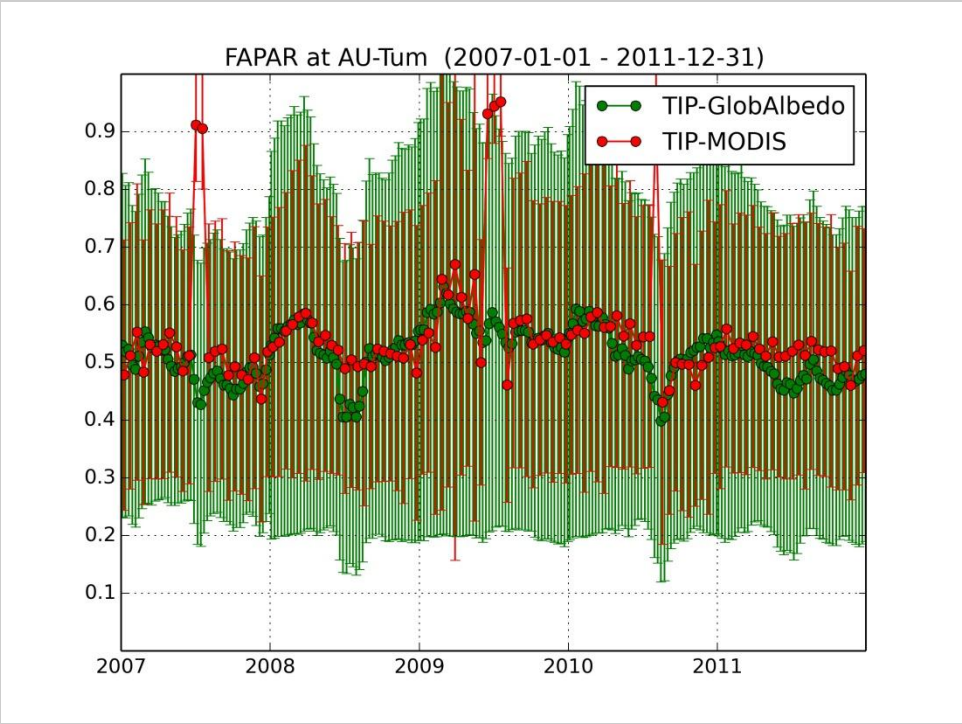
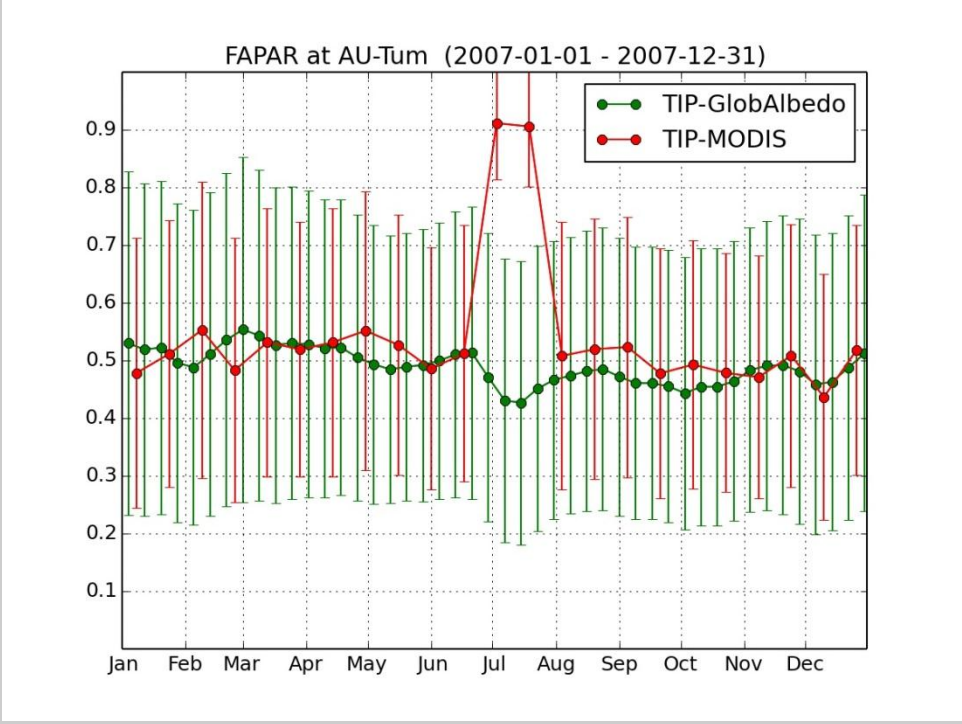
TIP-FAPAR@Tumbarumba (Australia)



TIP-MODIS: Ø=0.550 σ=0.098
TIP-GA : Ø=0.514 σ=0.045



the atypical jumps of FAPAR seen in TIP-MODIS do not appear in TIP-GlobAlbedo

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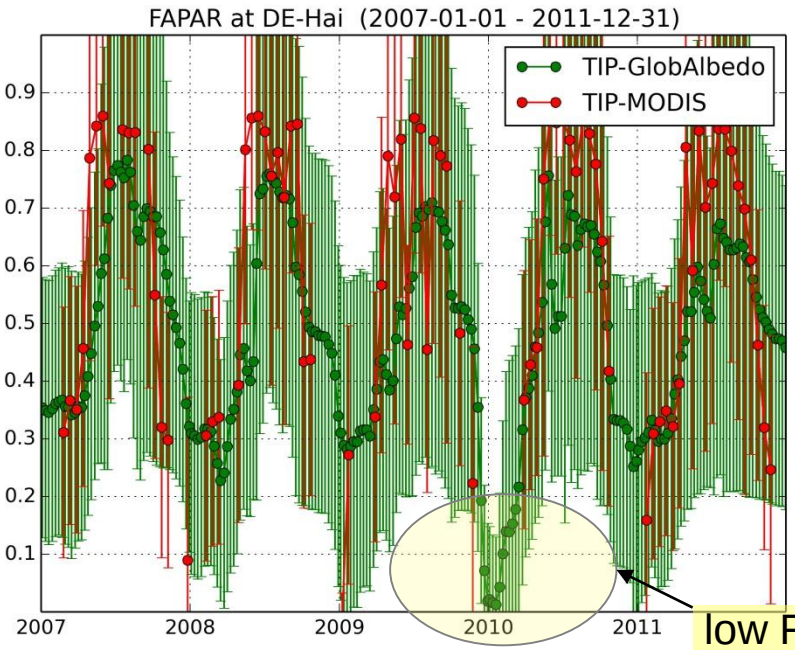
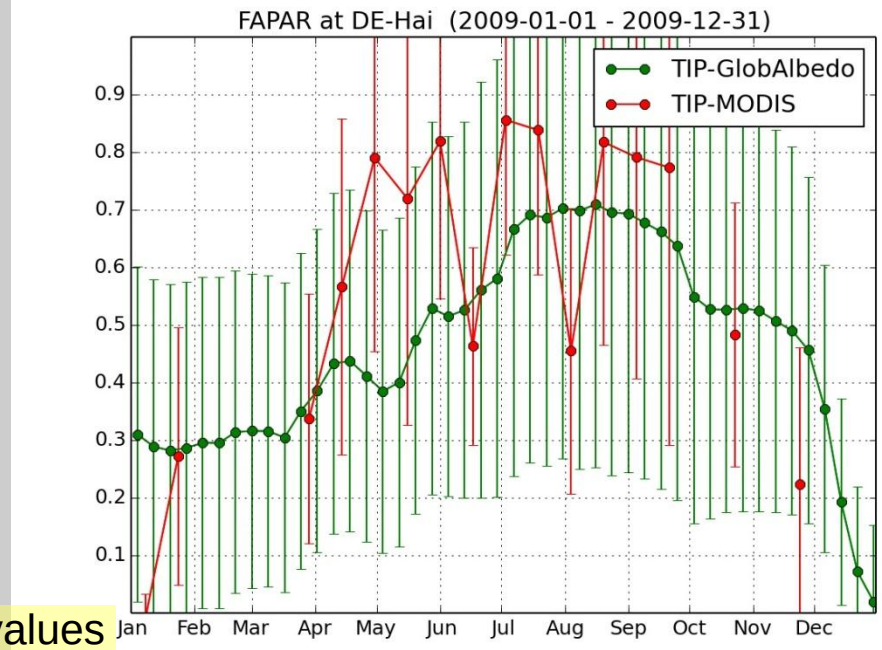
TIP-FAPAR@Hainich (DE)





low FAPAR values
(to be anlyzed)

TIP-MODIS: Ø=0.602 σ=0.237
TIP-GA : Ø=0.479 σ=0.173

- **FAPAR derived from GlobAlbedo shows significantly less variability than from MODIS**
- **only very few missing input albedos (probably attributed to using prior BRDF information)**
- **in general slightly increased uncertainty**

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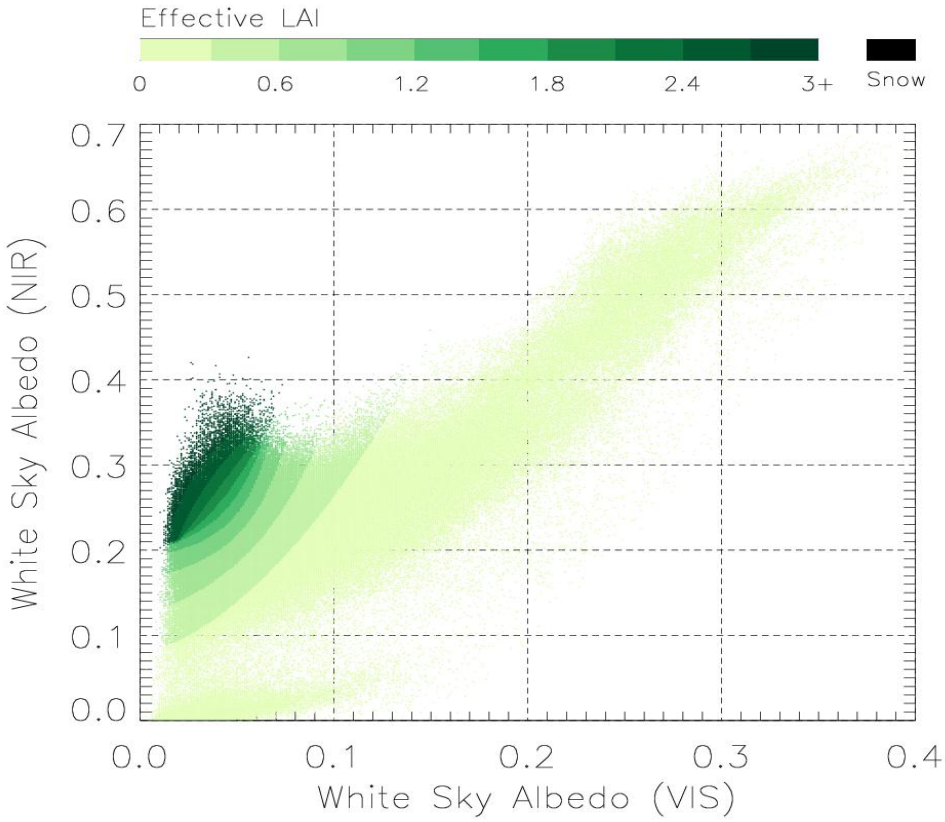
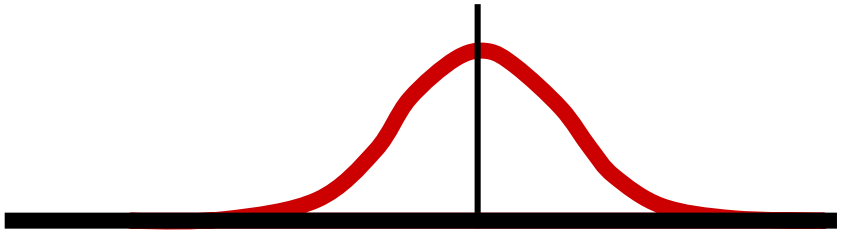
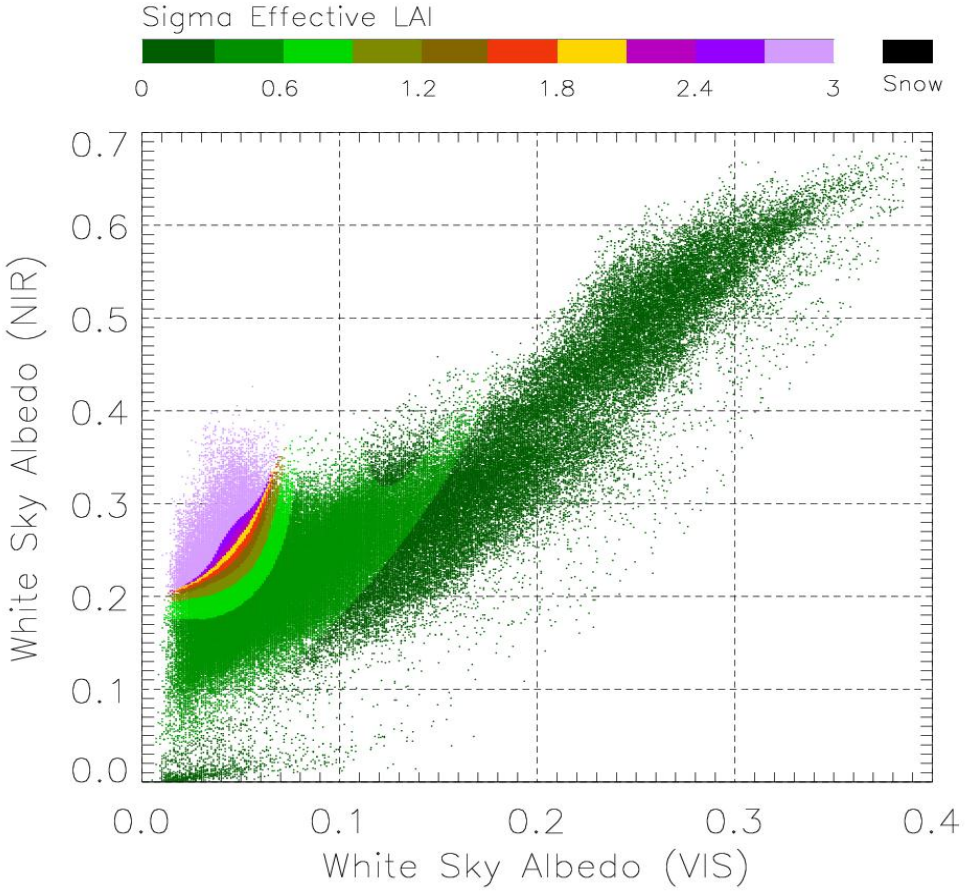
PDFs of retrieved effective LAI

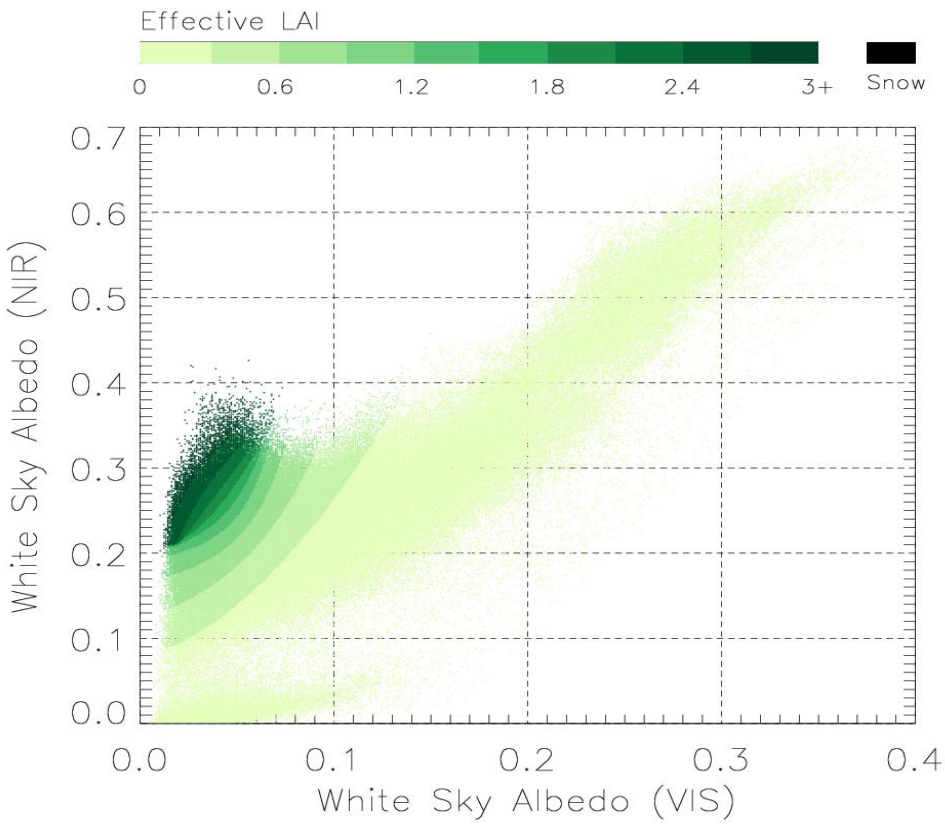


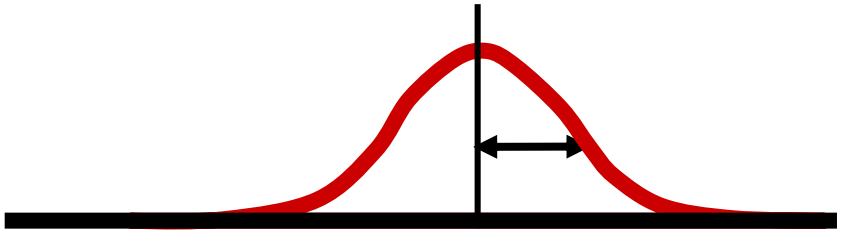


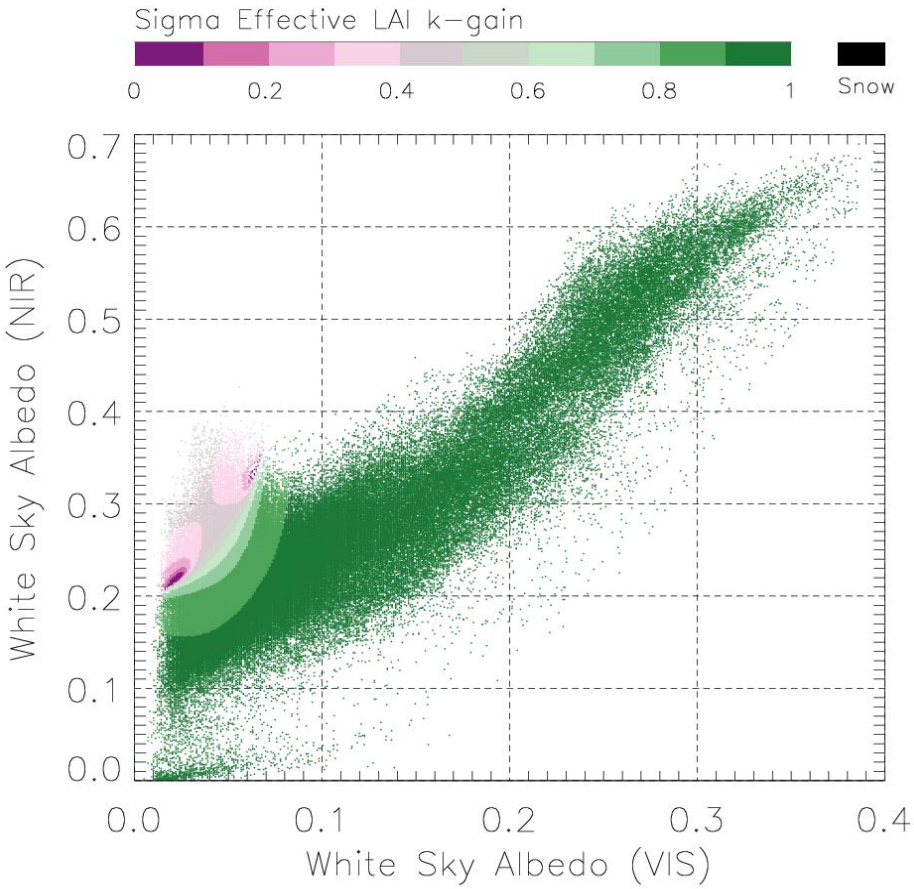


assuming 5% uncertainty in albedo

PDFs of retrieved effective LAI

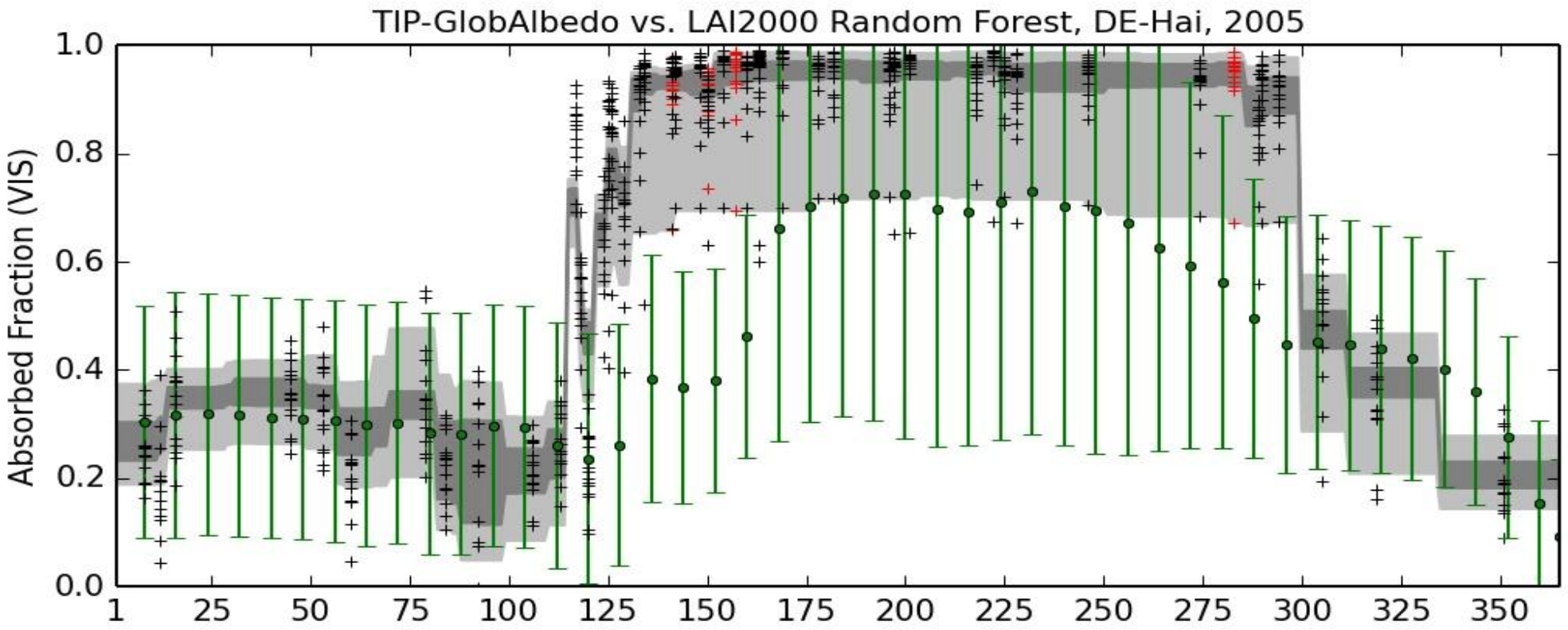






assuming 5% uncertainty in albedo

Globalbedo vs in situ @ Hainich



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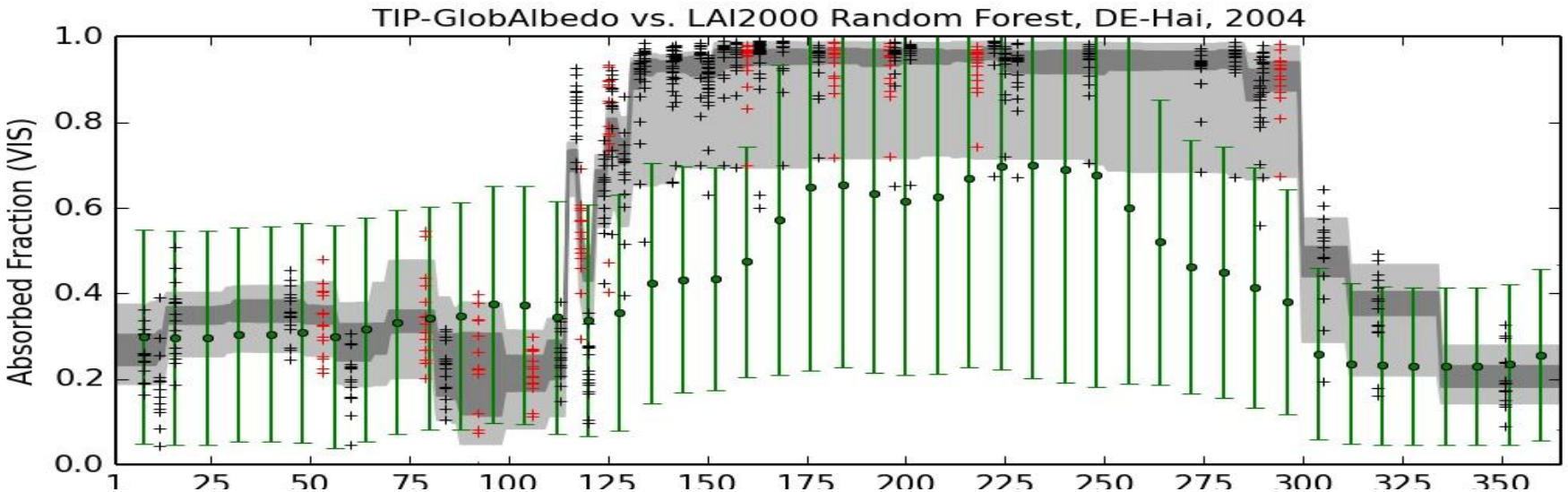
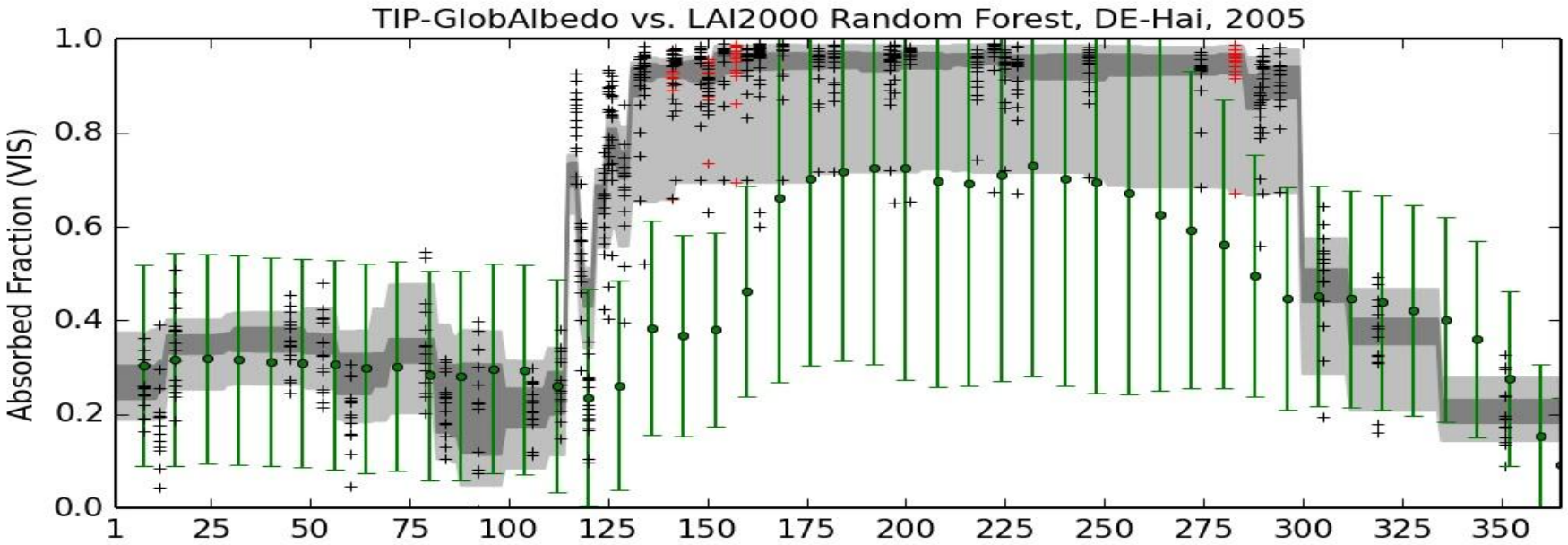
Data: Pinty etal., (2011): Remote Sensing of Environment

Globalbedo vs in situ @ Hainich





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