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

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

State of system characterised by 4 variables:

- Leaf area index \( (LAI = \xi * <LAI>) \) (describes density of vegetation)
- \( w_\parallel \) is the vegetation single-scattering albedo \( (w_\parallel = r_\parallel + t_\parallel) \)
- \( d_\parallel \) is the vegetation forward-scattering efficiency \( (d_\parallel = r_\parallel / t_\parallel) \)
- \( r_{bgd,l} \), 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:
\[ x = \langle \text{LAI}, w_l(\lambda_1), d_l(\lambda_1), r_{bgd}(\lambda_1), w_l(\lambda_2), d_l(\lambda_2), r_{bgd}(\lambda_2) \rangle \]
\[ d = \langle R(\lambda_1), T(\lambda_1), A(\lambda_1), R(\lambda_2), T(\lambda_2), A(\lambda_2) \rangle \]

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

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

Prior knowledge on model parameters (snow free)

\[ \text{LAI}_{\text{prior}} = 1.5 \]

Prior knowledge on model parameters (with snow)

\[ LAI_{prior} = 1.5 \]
\[ \sigma_{prior}(LAI) = 5.0 \]

in case snow occurs

Prior knowledge on model parameters

TIME and SPACE INVARIENT

Technical Solution to the inverse problem

• Iterative minimisation of $J(x)$

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

• Uses gradient of $J$ with respect to parameters

• Second derivatives (Hessian) at minimum $x_{po}$ provide approximation of parameter uncertainties (error bars)

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

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

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

• 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

Retrieval is **dubious** := finalcost > 3
Retrieval is **trusted** :\(\Longleftrightarrow\) not dubious and within physical bounds

Analysis of 2005 MODIS albedos
PDFs of retrieved FAPAR (absorption by vegetation in the VIS)
Two-stream Inversion Package (TIP) processing chain for GlobAlbedo

- BB Albedo VIS/NIR (separately for snow/no-snow) + uncertainty + SnowFraction
  - pull

- TIP on server
  - push

- TIP parameters + uncertainty e.g. LAI
  - push

- TIP fluxes + uncertainty e.g. FAPAR
  - push

- robust and fast

FastOpt
Fast Opt

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

(grid: HIRES)

(grid: HIRES)

TIP-GlobAlbedo: FAPAR (2005-12-27_2005-12-31)
(grid: HIRES)

TIP-GlobAlbedo: Sigma_FAPAR (2005-12-27_2005-12-31)
(grid: HIRES)
Global results: effective LAI
TIP-FAPAR@Loobos (NL)

TIP-MODIS: $\bar{\theta}=0.384$ $\sigma=0.087$
TIP-GA : $\bar{\theta}=0.429$ $\sigma=0.076$

probably due to cloud-cover!
TIP-FAPAR@Tumbarumba (Australia)

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

TIP-MODIS: $\bar{\theta}=0.550$ $\sigma=0.098$
TIP-GA      : $\bar{\theta}=0.514$ $\sigma=0.045$
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

TIP-MODIS: $\bar{c}=0.602$, $\sigma=0.237$
TIP-GA : $\bar{c}=0.479$, $\sigma=0.173$
assuming 5% uncertainty in albedo
PDFs of retrieved effective LAI

assuming 5% uncertainty in albedo
Globalbedo vs in situ @ Hainich

TIP-GlobAlbedo vs. LAI2000 Random Forest, DE-Hai, 2005

Absorbed Fraction (VIS)

Globalbedo vs in situ @ Hainich