Validation of the MERIS FAPAR L2 Products against Independent Estimates Derived from the MODIS and MISR Surface Albedo Operational products

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with contributions from
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Complex land-surface RT effects on short term climate: the snow case with ECMWF/NCEP

Ref: Viterbo and Betts, 1999, JGR

Everyone Complains About the Weather...

Betts and his BOREAS colleagues observed that, in the spring, daily weather forecasts significantly underestimated air temperatures over the boreal forest, sometimes by as much as 10—15°C (18—27°F) (Viterbo and Betts, 1999). Additionally, the BOREAS team found that predictions of cloud cover over the boreal region were often far off the mark. Everyone complains about the weather, but how could the forecasts be so wrong so often?

"...weather forecasts significantly underestimated air temperatures over boreal, sometimes by as much as 10-15 C..."
Everyone Complain About the Weather...

Betts and his BOREAS colleagues observed that, in the spring, daily weather forecasts significantly underestimated air temperatures over the boreal forest, sometimes by as much as 10–15°C (18–27°F) (Viterbo and Betts, 1999). Additionally, the BOREAS team found that predictions of snow cover over the boreal region were often far off the mark. Everyone complains about the weather, but how could the forecasts be so wrong so often?

Ref: Viterbo and Betts, 1999, JGR

Ref: http://eobglossary.gsfc.nasa.gov/

“…—the BOREAS team found that the models were overestimating albedo (the amount of light reflected by the surface). ...”
How does radiation redistribute energy between the atmosphere and the biosphere?

- Scattered Fluxes by the surface
- Absorbed Fluxes in Vegetation
- Absorbed Fluxes in Soil
What do we measure at global scale that we should model as well?

Albedo of the surface in the VIS and NIR (MODIS and MISR)

Absorbed Flux by green Vegetation in the VIS (FAPAR)
How do we model the absorbed fluxes in vegetation and soil?

Correct partitioning between the flux that is absorbed:

1- in the vegetation layer

\[ A_{\text{veg}} = 1 - \text{ALB}_{\text{sfc}} - A_{\text{ground}}^{\text{VIS+NIR}} \]

2- in the background

\[ A_{\text{ground}} = T_{\text{veg}}(1 - \alpha_{\text{ground}}) \]

Assessment of the fraction of solar radiant flux that is scattered (albedo) by, transmitted through and absorbed in the vegetation layer

What are the needs?

• Update/improve the current Land Surface schemes describing the radiation transfer processes in vegetation canopies
  
  see 2-stream model by Pinty et al. JGR (2006).
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- Improve the radiation transfer flux models in vegetation canopies
  
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Requirements from a 2-stream model

• 3 (effective) state variables:
  1. Optical depth: LAI amount of leaf material
  2. single scattering albedo:
     Leaf reflectance+ Leaf transmittance leaf color
  3. asymmetry of the phase function
     Leaf reflectance/transmittance

• 2 boundary conditions:
  1. Top: Direct and Diffuse atmospheric fluxes (known)
  2. Bottom: Flux from background Albedo (unknown) soil color

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The concept of effective LAI

True $\langle \text{LAI} \rangle = 2.0$

3-D heterogeneous system

Direct transmission at 30 degrees Sun zenith angle,

$$T_{3-D}^{\text{direct}} (\langle \text{LAI} \rangle) = 0.596$$

1-D system representation

Direct transmission at 30 degrees Sun zenith angle,

$$T_{1-D}^{\text{direct}} (\langle \text{LAI} \rangle) = \exp \left( -\frac{\langle \text{LAI} \rangle}{2 \mu_0} \right) = 0.312$$

Effects induced by internal variability of LAI
The concept of effective LAI

Direct transmission at 30 degrees Sun zenith angle,

\[ T_{3-D}^{direct} \langle LAI \rangle = 0.596 \]

\[ T_{1-D}^{direct} \langle LAI \rangle = \exp \left( - \frac{\langle LAI \rangle}{2 \mu_0} \right) = 0.312 \]

\[ T_{1-D}^{direct} (LAI_{eff}) = \exp \left( - \frac{LAI_{eff}}{2 \mu_0} \right) = \exp \left( - \frac{\langle LAI \rangle \xi(\mu_0)}{2 \mu_0} \right) = T_{3-D}^{direct} \langle LAI \rangle \]

Structure factor
What are the needs?

• Update/improve the current Land Surface schemes describing the radiation transfer processes in vegetation canopies
  see 2-stream model by Pinty et al. JGR (2006).

• Prepare for the ingestion/assimilation of RS flux products into Land Surface schemes
  Retrieve 2-stream model parameters from RS flux products
What are the needs?

- Improve the radiation transfer flux models in vegetation canopies
  see 2-stream model by Pinty et al. JGR (2006).

- Solve the inverse problem using operational scattered flux products i.e., Surface Albedos
  Retrieve 2-stream model parameters from RS flux products
Retrievals of model Parameters for Land surface schemes

The inverse problem can be formulated in order to find solutions optimizing all the available information i.e., inferring statistically the state of the system.

Towards an integrated system for the optimal use of remote sensing flux products.
JRC-Two-stream Inversion Package: JRC-TIP

- RS flux products from various sources + uncertainties
- Prior knowledge on model parameters + uncertainties
- Ancillary information, e.g. occurrence of snow and water

Time-independent operating mode

Radiation transfer model

Diagnostic fluxes + uncertainties

Posterior model parameters + uncertainties
**INPUTS : prior knowledge**

- RS Flux products, e.g., Albedo Vis/NIR and/or FAPAR noted $d$

- Updated/benchmarked 2-stream model from Pinty et al. JGR (2006) noted $M(X)$

- A priori knowledge/guess on model parameters noted $X_{prior}$

  uncertainty on the RS products is specified in the measurement set covariance matrix $C_d$

  uncertainty associated the model parameter is specified via a covariance matrix $C_{X_{prior}}$
The core of the JRC-TIP

\[ J(X) = \frac{1}{2} \left[ (M(X) - d)^T C_d^{-1} (M(X) - d) + (X - X_{prior})^T C_{X_{prior}}^{-1} (X - X_{prior}) \right] \]

- Computer optimized Adjoint and Hessian model of cost function from automatic differentiation technique
- Assume Gaussian theory
- Posterior uncertainties on retrieved parameters are estimated from the curvature of \( J(X) \)

• PDFs of all 2-stream model parameters:

\[
PDF(X) \approx \exp\left(-\frac{1}{2}(X - X_{\text{post}})^T C^{-1}_{X_{\text{post}}} (X - X_{\text{post}})\right)
\]

(a posteriori uncertainty covariance matrix)

• Assessment of all fluxes predicted by the 2-stream model and their associated uncertainty:

\[
C_{\text{Flux}_{\text{post}}} = GC_{X_{\text{post}}} GT
\]

prior knowledge on model parameters

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

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

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prior knowledge on model parameters

A-priori PDF on Spectral Parameters

Broadband Visible Reflectance

Broadband Near-Infrared Reflectance

TOA

leaves

soils

snow

prior knowledge on model parameters

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

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

in case snow occurs

Application over Yakustk Forest: a deciduous needle-leaf larch forest

Courtesy of Dr. R. Suzuki
Application over Yakutsk: Measurements

Input Broadband White-Sky Albedo

Specified uncertainty on BHRs is 5% relative
Application over Yakustsk: model parameters

Application over Yakutsk: model parameters

Application over Yakutsk: model parameters

Application over Yakustk: radiant fluxes

YAKUTSKspas R1R2

- VIS (MODIS, MISR)

Application over Yakutsk: radiant fluxes

\[
\text{Fraction Absorbed in Vegetation [VIS]}
\]

\[
\text{Input Broadband White-Sky Albedo}
\]

\[
\text{YAKUTSKspas R1R2}
\]

\[
\text{VIS (MODIS, MISR)}
\]

\[
\]

\[
a \textit{priori} 'green' leaves
\]
Application over Yakustk: radiant fluxes

Operational products from MERIS-MODIS-MISR and SeaWiFS
Application over Yakustk: radiant fluxes

YAKUTSKspas R1R2

Fraction Absorbed in Vegetation [VIS]

0.00 0.20 0.40 0.60 0.80 1.00

Jan, Mar, May, Jul, Sep, Nov, Jan

Year 2005

VIS (MODIS, MISR)

JRC-TIP results based on TERRA albedos

a priori ‘green’ leaves

MERIS FAPAR

Application over BOREAS NSA-OBS
Application over BOREAS: Measurements

Specified uncertainty on BHRs is 5% relative.
Application over BOREAS: Measurements

**NSAOBS R1R2**

- **VIS**
- **NIR** (MODIS, MISR)

Specified uncertainty on BHRs is 5% relative

*Priori* 'green' leaves

Input Broadband White-Sky Albedo

Year 2005

Specified uncertainty on BHRs is 5% relative
Application over NSAOBS: model parameters

a priori 'green' leaves

Year 2005

LAI (MODIS, MISR)
Application over NSAOBS: model parameters

NSAOBS  R1R2

MODIS /Terra FAPAR
MISR /Terra FAPAR

a priori 'green' leaves
Application over NSAOBS: model parameters

Application over NSAOBS: model parameters

Effective LAI

MODIS /Terra FAPAR
MISR /Terra FAPAR

Year 2005

Jan
Mar
May
Jul
Sep
Nov
Jan
Application over NSAOBS: model parameters

Ground Albedo

a priori 'green' leaves
Application over NSAOBS: model parameters

Application over NSAOBS: radiant fluxes

N  

\[\text{Fraction Absorbed in Vegetation [VIS]}\]

\[\text{Input Broadband White-Sky Albedo}\]

Application over NSAOBS: radiant fluxes

**Fraction Absorbed in Vegetation [VIS]**

**Input Broadband White-Sky Albedo**

Application over NSAOBS: radiant fluxes

a priori 'green' leaves
Application over NSAOBS: radiant fluxes

**NSAOBS R1R2**

- **VIS (MODIS, MISR)**

- **MODIS FAPAR**
- **MERIS FAPAR**
- **MISR FAPAR**
- **SeaWiFS**
- **JRC-FAPAR**

*a priori* ‘green’ leaves

JRC-TIP results based on TERRA albedos
Application over NSAOBS: radiant fluxes

**NSAOBS R1R2**

- **VIS (MODIS, MISR)**

**Fraction Absorbed in Vegetation [VIS]**

- **NSAOBS**
- **R1R2**

**Year 2005**

- **DOY:** 0
- **100**
- **200**

**a priori 'green' leaves**

**current inversion based on TERRA albedos**

**MERIS FAPAR**
Application over NSAOBS: radiant fluxes

**NSAOBS R1R2A1**

- **VIS (MODIS, MISR)**
- Original MERIS FAPAR products
- Re-analysed MERIS FAPAR with MODIS/MISR surface albedos

Assimilation of the MODIS and MISR surface albedos
Deciduous broadleaf beech forest

Shrubland-woodland
**Evergreen needleleaf pine forest**

**Deciduous needleleaf larch forest**
The polychrome solution

The GREEN solution
Evergreen forest

Coniferous forest
Broadleaf forest

Agriculture
Concluding remarks

1. Computer efficient inversion package has been designed and tested: estimate of uncertainty on all retrievals.

2. This integrated package can be used for various purposes: retrieval of parameters from RS products, validation of RS products, assimilation of RS products into Land surface schemes.

3. Capability to generate global surface model parameters ensuring full consistency with measured (uncorrelated) fluxes from various sources: spectral albedos from MODIS-MISR (and any other sources).

Concluding remarks

1. Remarkable consistency between the MERIS FAPAR and the MODIS –MISR surface albedo operational products.

2. Computer efficient inversion package has been designed and tested: estimate of uncertainty on all retrievals.

3. This integrated package can be used for various purposes: retrieval of parameters from RS products, validation of RS products, assimilation of RS products into Land surface schemes.