The ESA GlobAlbedo project for mapping the Earth’s land surface albedo for 15 years (1995-2010) from European sensors: Role of 10 years of MODIS

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Uwe Krämer, Carsten Brockmann, Brockmann Consult
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• With contributions from Crystal Schaaf (BU) and Gabriela Schaapman-Strub (University of Zürich)

Overall Aims

• Production of a 15 year record (1995-2010) of Land Surface BroadBand Albedo (BBA) from European space assets to provide an independent capability to generate this Essential Climate Variable

• Input data will consists of level 1b (radiometrically calibrated, satellite projection)
  – VGT (24.3.98-31.1.03) and VGT2 (1.2.03-12/2010)

• An estimated uncertainty (variance-covariance matrix) is produced for each output pixel using an optimal estimation framework

• Validation of final albedo products as well as intermediate products (e.g. cloud masks, aerosol retrievals, narrow-to-broadband)

• GlobAlbedo products will be freely available via ftp, http and an OGC-compliant webGIS
Product Processing and Validation

- Subset of GlobAlbedo products validated
- Focus on Pixel ID AOT SDR N-to-BB Albedo
- Validation performed by relevant producer with support from PI
- Russian Albedo validation performed by G. Schaapman-Strub

Overall GlobAlbedo processing chain

GlobAlbedo product flowchart

Processing Flow

SDR/BBDR Processor

1. Inversion of TOA reflectance
   $\rightarrow$ SDRs & NDVI

2. SDR Error Propagation
   $\rightarrow$ $\sigma_\alpha$ & $\sigma_{\text{NDVI}}$

3. Narrow-to-broadband (N2B) conversion
   $\rightarrow$ BBDRs

4. BBDR Error Propagation
   $\rightarrow$ $\sigma_A$

5. Projection to MODIS Sinusoidal Grid
   $\rightarrow$ Projected BBDRs + $\sigma_A$ + NDVI + $\sigma_{\text{NDVI}}$ + Kernels
BRDF TILE product (not currently distributed)
- 9 kernels [isotropic, geometric, volumetric] x [VIS, NIR, SW]
- 45 layers from 9 x 9 error variance/covariance matrix per pixel
- Pixel classification (land or water), Relative entropy (impact of priors), SZA
- Nsamples and Mdays used in BRDF retrieval from accumulator arrays
- 59 band product with each layer of 32-bit floating point arrays (324.09 MB)

Albedo TILE product (distributed)
- 6 albedos [DHR, BHR] x [VIS, NIR, SW]
- 6 standard errors for [DHR, BHR] for [VIS, NIR, BBA] derived from error variance/covariance matrix per pixel
- Pixel classification (water or land [snow or no-snow depending on Mdays]), Relative entropy (impact of priors), posteriori entropy
- Nsamples and Mdays used in BRDF retrieval from accumulator arrays
- 17-band product with each layer of 32-bit floating point arrays (93.37MB)

Sensor intercalibration

Jan-Peter Muller, Dale Potts*, Neville Shane

* PhD supported by NERC and NPL
Sensor intercalibration over DOME-C

- CNES have used the DOME-C in Antarctica for calibrating VEGETATION since 1998
- Cao et al (CJRS Special Issue) developed a GEOSS QA4EO-compliant scheme for inter-comparison of sensors such as MODIS vs MERIS
- Smith et al., RALspace report no. PO-RP-RAL-AT-0599 (2009) applied similar to MERIS-AATSR-MODIS
- Potts et al (ESA Bergen 2010) have applied an updated approach to MERIS-AATSR-VEGETATION
- BRDF and O3 corrections applied as O3 can change values by >30% from one day to the next

Cloud masking DOME-C observations

- Challenging problem to detect cloud over snow/ice
- VEGETATION has dead pixels in their 1.6μm CCD which makes it even more challenging as this channel is very helpful usually in distinguishing snow/ice from cloud
- GlobAlbedo PixelID applied with tweaked parameters (yellow area) and compared against cloud mask supplied with product (orange)
- Assessments performed only for cloud-free pixels in a 25 x 25km area centred on the ground tower site at DOME-C
- Results look reasonable for all input scenes although there may still be spill-over from
### Final intersensor calibration results

<table>
<thead>
<tr>
<th>AATSR vs MERIS</th>
<th>Ratio</th>
<th>StdDev</th>
<th>Offset</th>
<th>Slope</th>
<th>R-squared</th>
<th>Number of data points</th>
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</thead>
<tbody>
<tr>
<td>550/560 nm band</td>
<td>1.0374</td>
<td>0.0152</td>
<td>0.6954</td>
<td>1.0179</td>
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<td>unspecified</td>
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<tr>
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<td>0.0108</td>
<td>0.4953</td>
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<td>870/875 nm band</td>
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<td>0.0279</td>
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<td>1.0189</td>
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### How do MERIS & AATSR compare to MODIS

#### MODIS 0.64 μm

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Observed Bias</th>
<th>Theoretical Bias</th>
<th>Observed Bias</th>
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</tr>
</thead>
<tbody>
<tr>
<td>OrbView/SeaWiFS</td>
<td>-2.74% ±1.32%</td>
<td>1.95%</td>
<td>-2.09% ±1.57%</td>
<td>-1.46%</td>
</tr>
<tr>
<td>METOP-A/AVHRR</td>
<td>-8.74% ±1.60%</td>
<td>-0.43%</td>
<td>-10.14% ±1.58%</td>
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<tr>
<td>Envisat/MERIS</td>
<td>0.74% ±2.28%</td>
<td>0.66%</td>
<td>+1.22% ±2.28%</td>
<td>0.20%</td>
</tr>
<tr>
<td>ENVISAT/AATSR</td>
<td>1.76% ±2.83%</td>
<td>1.07%</td>
<td>+1.90 ± 2.92%</td>
<td>0.43%</td>
</tr>
<tr>
<td>Landsat 7/ETM+</td>
<td>1.03% ±0.52%</td>
<td>1.17%</td>
<td>1.35% ±1.24%</td>
<td>-3.22%</td>
</tr>
<tr>
<td>EO-1/Hyperion</td>
<td>+2.63 ± 0.48%</td>
<td>n/a</td>
<td>+4.35 ± 0.18%</td>
<td>n/a</td>
</tr>
</tbody>
</table>

#### MODIS 0.86 μm

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<th>Theoretical Bias</th>
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Processing: Innovations in Albedo retrieval

Prof. P. Lewis, UCL

Prior knowledge constraint

- Regularisation is form of prior knowledge constraint
  - Yesterday, likely to be same as today, with given tolerance
- MODIS backup algorithm, another example
  - Assume knowledge of BRDF shape
  - But sharp transition – not within optimal estimation framework
- Geiger et al. (2008) (MSG)
  - Weak (constant) prior to condition solution
- GlobAlbedo:
  - Dynamic (per 8-day time period), spatial prior
    - To condition solution in case of weak sampling
    - To ‘gap fill’
Rationale

- Prior allows solution even when sampling weak (or non-existent)
  - Obviate need for backup algorithm
- Part of Optimal estimation framework
  - Can estimate uncertainty
  - Can estimate impact of new observations
    - Relative entropy
- Prior here is MODIS climatology:
  - Based on 500m BRDFs
  - But need uncertainty
    - Conservative estimate

Priors and treatment of Snow

- Impact of snow great
  - Develop 2 priors (snow/no snow)
  - Each associated with different inputs (snow/no snow)
  - N.B. in future could use distance from prior to aid cloud/snow retrievals
- Snow can have strong fwd scattering peak
  - Can claim kernels not appropriate
  - But no suitable replacement model available
    - Attempts e.g.:
      - Klein and Stroeve, 2002; Stroeve and Nolin, 2002; Liang et al., 2005
      - Separation of snow/no snow allows route for possible replacement of snow model
Generation of priors

• Input: MODIS Collection V005 BRDF-Albedo model parameters product
  – MCD43A1, MCD43A2 at 500m*

• Same kernel models as used here

• Estimate climatology and uncertainty in parameters
  – Uncertainty to include actual variation: conservative

• Product has no uncertainty info, but 4 QA states
  – Apply weighting to QA states: relative uncertainty

\[
W_{r0} = \frac{1}{\alpha_{QAC0,0.1}}
\]

<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>best quality, full inversion (WoDs, RMSE majority good)</td>
</tr>
<tr>
<td>1</td>
<td>good quality, full inversion</td>
</tr>
<tr>
<td>2</td>
<td>Magnitude inversion (numobs &gt; 2)</td>
</tr>
<tr>
<td>3</td>
<td>Magnitude inversion (numobs &gt; 3 &amp; &lt; 7)</td>
</tr>
<tr>
<td>4</td>
<td>Fill value</td>
</tr>
</tbody>
</table>

* Thanks to Dave Obler and Robert Wolfe for supply of data on USB2 disks

Generation of priors

• Mean:

\[
\bar{f}_k(i,j) = \frac{1}{N_{(i,j)}} \sum_{c=0}^{C} \sum_{y_{QAC}} W_{r0,0,0,c}(i,j)
\]

\[
N_{(i,j)} = \sum_{c=0}^{C} \sum_{y_{QAC}} W_{r0}
\]

• Standard error (incl. small number bias correction):

\[
\sigma_{1,2}^2 = \frac{\sum_{i=1}^{n} \sum_{c=1}^{n} W_{QAC}(x_{i,j} - \bar{x}_j)(x_{i,j} - \bar{x}_j)}{\left( \sum_{i=1}^{n} W_{QAC} \right)^2 - \sum_{i=1}^{n} W_{QAC}^2}
\]

\[
\sigma_{2,3}^2 = \sigma_{1,2}^2 / \sum_{i=1}^{n} W_{QAC}
\]

• Examined temporal-weighting of priors:
  – Very similar to a weighting of climatology priors
MODIS-derived prior for tile h18v04 for 2005 – FCC SW f0, NIR f0, VIS f0 (RGB) and standard error model parameter f0 VIS, image scaled 0:0.25

MODIS-derived prior for tile h19v08 for 2005 – FCC SW f0, NIR f0, VIS f0 (RGB) and standard error model parameter f0 VIS, image scaled 0:0.25
Relative Entropy - assessment of impact of MODIS on GlobAlbedo

2005 Prototype Products

Gerardo Lopez & Jan-Peter Muller, UCL-MSSL
2005 Prototype products:
BRDF/Albedo examples for tile h18v04 (Europe) – DoY 153

BRDF isotropic parameter:
SW, NIR, VIS (R,G,B)

BHR SW

BHR SW SD

2005 Prototype products: Global 50km SIN BHR

Monthly Bi-hemispherical reflectance - SW, NIR, VIS (RGB)
Validation - Albedo Prototype products

Jan-Peter Muller, Gerardo López, Neville Shane

Albedo validation

• Focusing on 3 aspects
  – Intercomparison of Blue-Sky Albedo with tower albedometer measurements for representative sites which are homogeneous at 1-3km scale (Roman et al., 2009)
  – Assessment of BroadBand Albedo (VIS, NIR, SW) at the global scale on monthly time-steps with MISR and MODIS
  – Assessment of GlobAlbedo with MCD43

• Tower albedometer data obtained from C. Schaaf of Boston University who has processed such data for a wide variety of North American sites. Dr Schaaf is in charge of MODIS albedo validation and Co-Chair of CEOS-WGCV-LPV task on albedo as well as a consultant on GlobAlbedo

• Intercomparison with University of Amsterdam tower sites in Siberia performed by Gabriela Schaapman-Strub (University of Zurich)

• These data were processed to obtain averages over 11-13h Local Time along with Direct-to-Diffuse (SURFRAD) or MODIS 1° x 1° look-up of AOD, Cloud Fraction and Snow cover.
Assessment of blue-sky broadband albedo

- For worldwide test sites where tower-based albedo values have been acquired, spatial geostatistics (semi-variance) have been employed by Boston University to assess the homogeneity of the site.
- 20 ARM, 16 AmeriFLUX, 13 CRN and 7 SURFRAD sites have been processed to date.
- For homogeneous sites, BU provided blue-sky tower albedometer values from the sites for leaf-on and leaf-off conditions.
- Where sites coincide with BSRN/SURFRAD, direct-to-diffuse measurements obtained, elsewhere AODs taken from MODIS 0.5 degree climatology.

Roman et al., RSE (2009)

North American test sites (12 Ameriflux, 1 ARM, 7 SURFRAD)
North American test sites (12 Ameriflux, 1 ARM, 7 SURFRAD)

Russian test sites (Yakursk, Chokurdah)

*Poor snow albedos, X missing DEM value*
Russian test sites (Yakursk, Chokurdah) Results provided by Gabriela Schaapman-Strub (U of Zurich)

GlobAlbedo BRDF comparison with Priors & MCD43 for h08v05

Prior vs MCD43 of BRDF parameters

GlobAlbedo vs MCD43 of BRDF parameters
Global 50km albedo (DHR) inter-comparison datasets

Global 50km Albedo (DHR) inter-comparisons
What next?

- MODIS prior to be extended back to 1995 using LTDR and forward using MODIS (3/10-3/11)
- 15 year processing to start in 7/11 and due to be completed by 10/11
- Validation datasets need to be established for global BSRN sites for entire time period
- Inter-comparisons with MISR, POLDER, METEOSAT Land-SAF
- ECMWF, Météo-France, MPI Hamburg testing impact of uncertainties on NWP forecasts