Surface Reflectance

Eric Vermote
NASA GSFC Code 619
eric.f.vermote@nasa.gov

Ivan Csiszar
STAR

Mike Wilson
STAR ASSIST

STAR JPSS Science Team Meeting, August 14 – 18, 2017, NCWCP, College Park, MD
A Land Climate Data Record
Multi instrument/Multi sensor Science Quality Data Records used to quantify trends and changes

Emphasis on data consistency – characterization rather than degrading/smoothing the data

STAR JPSS Science Team Meeting, August 14 – 18, 2017, NCWCP, College Park, MD
Land Climate Data Record (Approach)

Needs to address geolocation, calibration, atmospheric/BRDF correction issues

**CALIBRATION**

Degradation in channel 1 (from Ocean observations)

Channel1/Channel2 ratio (from Clouds observations)

**ATMOSPHERIC CORRECTION**

**BRDF CORRECTION**

- Uncorrected NDVI noise
- Corrected NDVI noise
- Noise reduction (%)
The surface reflectance algorithm relies on:

- the use of very accurate (better than 1%) vector radiative transfer modeling of the coupled atmosphere-surface system
- the inversion of key atmospheric parameters (aerosol, water vapor)
6SV Validation Effort

The complete 6SV validation effort is summarized in three manuscripts:

Generic flowchart for atmospheric correction

- Ancillary (Ozone, Water Vapor, DEM)
- TOA reflectances
- SR reflectances
- Atmospheric correction
- AOT Map
Aerosol inversion

**Reading Inputs, LUT and Ancillary data**

Using the relationship between the blue surface reflectance (490 nm) and the red surface reflectance (665 nm) known from MODIS, we are able to retrieve the **AOT**.

We loop the AOT until \(\frac{\rho_{\text{surf \ blue}}}{\rho_{\text{surf \ red}}}_{\text{MSI}} = \frac{\rho_{\text{surf \ blue}}}{\rho_{\text{surf \ red}}}_{\text{MODIS}}\)

The retrieved AOT is used to compute the surface reflectance at 443 and 2190 nm.

The **aerosol model** is then derived by minimizing the residual.

\[
\text{residual} = \frac{1}{2} \sum_{j=1}^{\tilde{j}} \left( \rho_{\text{surf}}^j - \text{Ratio}_{665}^j \cdot \rho_{\text{surf}}^{665} \right)
\]

**Computation of surface reflectances for all channels**

\[
\rho_{\text{surf}} = \frac{Y}{1+S_{\text{atm}} \cdot Y} \quad \text{with} \quad Y = \frac{1}{T_{\text{atm}} \cdot \text{tg}^{\text{wv}}} \left[ \left( \rho_{\text{TOA}} - \rho_{\text{atm}} \cdot \text{tg}^{\text{o3}} \cdot \text{tg}^{\text{others}} \right) - \left( \rho_{\text{atm}} - \rho_{\text{ray}} \right) \cdot \text{tg}^{\text{wv/2}} - \rho_{\text{ray}} \right]
\]

\(\rho_{\text{surf}}\) determined (*) using \(\rho_{\text{atm}}, T_{\text{atm}}\) and \(S_{\text{atm}}\) from LUT knowing AOT, Aerosol model, pressure, altitude, water vapor, ozone…

**Surface reflectance for each pixel and each band**
Methodology for evaluating the performance of surface reflectance

Subsets of Level 1B data processed using the standard surface reflectance algorithm

comparison

Reference data set

Atmospherically corrected TOA reflectances derived from Level 1B subsets

AERONET measurements ($\tau_{aer}$, H$_2$O, particle distribution
Refractive indices, sphericity)

Vector 6S

http://mod09val.ltdri.org/cgi-bin/mod09_c005_public_allsites_onecollection.cgi

STAR JPSS Science Team Meeting, August 14 – 18, 2017, NCWCP, College Park, MD
quantitative assessment of performances (APU)

**COLLECTION 5**: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (the line in magenta), that was derived from the theoretical error budget. Data collected from Terra over 200 AERONET sites from 2000 to 2009.
Improving the aerosol retrieval in collection 6 reflected in APU metrics

**COLLECTION 6:** accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (the line in magenta), that was derived from the theoretical error budget. Data collected from Terra over 200 AERONET sites from 2003.
Aerosol retrieval also shows improvement.

Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for East Coast sites selection: GSFC (top left), Stennis (top right), Walker Branch (bottom left) and Wallops (bottom right).
Aerosol retrieval also shows improvement

Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for the West Coast sites selection: UCLA (top left), La Jolla (top right), and Fresno (bottom left) and Table Mountain (bottom right).
Aerosol retrieval also shows improvement

Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for a very bright site in Saudi Arabia (Solar Village)
Aerosol retrieval also shows improvement

Scatterplot of the Landsat 8 AOT at 550nm versus the AERONET measured AOT at 550nm for all AERONET matchups since Landsat 8 activation
VIIRS Surface reflectance

- the VIIRS SR product is directly heritage from collection 6 MODIS and that it has been validated to stage 1-2

- MODIS algorithm refinements from Collection 6 have been integrated into the VIIRS algorithm and are included in the operational product (NDE) equivalent of NASA VIIRS Version 1.
Evaluation of VIIRS SR Algorithm Performance (example Red band)

IDPS version

NASA C1.1

NDE, NASA Version 1

Improvement is clearly visible from IDPS to current NDE version
Use of BRDF correction for product cross-comparison

Comparison of aggregated FORMOSAT-2 reflectance and MODIS reflectance. No BRDF correction. Density function from light grey (minimum) to black (maximum); white = no data.

Comparison of aggregated FORMOSAT-2 reflectance and BRDF corrected MODIS reflectance. Corrections were performed with Vermote al. (2009) method using for each day of acquisition, the angular configuration of FORMOSAT-2 data.
Cross comparison with MODIS over BELMANIP2

The VIIRS SR is now monitored at more than 400 sites (red losanges) through cross-comparison with MODIS.
Results over BELMANIP2 (IDPS and C1.1)
Cross comparison results of the VIIRS and MODIS-Aqua SR product on a monthly basis for the BELMANIP sites reprocessed version NDE/NASA SIPS Version 1 for the near infrared band (M7).
Transitioning from MODIS to VIIRS

- **VIIRS** was launched, in part to provide **continuity** with **MODIS**

- The **VIIRS** will eventually **replace MODIS** for both land science and applications, and add to the coarse-resolution, **long term data record**

- It is, therefore, important to provide the user community with an **assessment of the consistency** of equivalent products from the two sensors

Spectral adjustment:

\[
\rho^M_{\text{red}} = a_{\text{red}} \rho^V_{\text{red}} + b_{\text{red}} \rho^V_{\text{NIR}},
\]

\[
\rho^M_{\text{NIR}} = a_{\text{NIR}} \rho^V_{\text{red}} + b_{\text{NIR}} \rho^V_{\text{NIR}},
\]

where \(\rho^M_{\text{red}}, \rho^M_{\text{NIR}}, \rho^V_{\text{red}}, \rho^V_{\text{NIR}}\) are surface reflectance values in red and NIR for MODIS (superscript \(M\)) and VIIRS (superscript \(V\)), and \(a_{\text{red}}, b_{\text{red}}, a_{\text{NIR}}, b_{\text{NIR}}\) are conversion coefficients.

Relative spectral response functions for MODIS/Aqua and VIIRS sensors in the red and NIR spectral domain.
Transitioning from MODIS to VIIRS

Comparison (in terms of APU) of NDVI's derived from MYD09CMG and VNP09CMG surface reflectance products at global scale (approximately $2 \times 10^9$ pixels) for 2012–2016 without (a) and with (b) spectral adjustment of red and NIR bands. The light blues bars show the number of points used in each bin of NDVI values from MODIS (used as a reference). The APU values are computed for points in each bin and being shown in red (accuracy), green (precision) and blue (uncertainty). The pink line represents the specified uncertainty based on theoretical error budget.
Corn growth dynamics derived from MODIS/Aqua and VIIRS in 2012 in Iowa (US) compared to the median NDVI values for 2002–2016 derived from MODIS/Aqua. Due to a drought, corn growth started to decrease significantly from June which resulted in a 25% yield reduction.
Transitioning from MODIS to VIIRS

- Spatial consistency

NDVI anomalies at 0.05° spatial resolution for the state of Iowa (US) derived from MODIS/Aqua (a), and adjusted VIIRS (b) data on August 21, 2012. Anomalies were computed by subtracting NDVI values from the median NDVI values for 2002–2016 derived from MODIS/Aqua.
Surface Reflectance Conversion from IDPS to NDE

• The main issues in the conversion of the surface reflectance code from the IDPS system to NDE were as follows:

  1) The code was designed to read and write in HDF-EOS format. NDE does not support HDF-EOS, so NASA developers added HDF-5 capability.

  2) The code requires the VIIRS Cloud Mask, Aerosol Optical Depth product, total precipitable water, total column ozone, and surface pressure in order to run. The algorithms that produce these are different in the NDE system. NOAA-STAR developers wrote codes to convert the NDE products into a format that mimics the IDPS version for compatibility.

  3) The naming convention of the files is different between NDE and IDPS, so NOAA-STAR developers wrote scripts to design unique file names.

  4) Global attributes are different between NDE and IDPS, so NOAA-STAR developers wrote scripts to create both static and dynamic global attributes.
NOAA-STAR Contribution

• NASA provided the main algorithm, while NOAA-STAR provided ancillary codes and scripts to allow the system to run at NDE. These codes/scripts include:
  • Preprocessor: converts the NDE versions of cloud mask, cloud height (which includes the cloud shadow mask), aerosol optical depth, and GFS (which contains surface pressure, total precipitable water, and total column ozone) into HDF-5 files that resemble the IDPS versions of these masks.
  • PERL Global Attribute Conversion: creates both static and dynamic global attributes to append to the final NDE output file.
  • Postprocessor: names the final output file, writes the output, appends the global attributes and designs variable attributes.

• A flow chart of these algorithms follows on the next slide.
Surface Reflectance Algorithm Overview

**Preprocessor**
- Populated Templates (HDF5)
- VNP09.*.h5 (HDF5)
- PERL Global Attribute Conversion
  - VNP09.*.h5 (HDF5)
    - plus list of NDE global attributes

**Main Algorithm**
- NDE Framework: (NetCDF4)
  - NDE Aerosol Model
  - Enterprise Cloud Mask
  - NDE Cloud Height
  - GFS Data
- IDPS: (HDF5)
  - VIIRS SDR/Geolocation: SVI*.h5 and GITCO*.h5
  - SVM*.h5 and GMTCO*.h5
- IDPS: (HDF5)
  - VIIRS Geolocation: GITCO*.h5 and GMTCO*.h5

**PerL Global Attribute Conversion**
- NDE Static Attribute Text
  - VNP09.*.h5 (HDF5)

**Postprocessor**
- SR_v1-0-8_npp.*.nc (NetCDF4)
  - Contains Surface Reflectance for: I1, I2, I3, M1, M2, M3, M4, M5, M7, M8, M10, M11
  - Contains QC values.
- Templates to mimic IDPS: (HDF5)
  - Aerosol Model
  - VIIRS Cloud Mask / Height
  - GFS Data
- Static LUTs: (binary)
  - Optical depth, reflectivity, transmittance, viewing zenith, solar zenith, spherical albedo, scattering angle, transmittance coefficients
Known Differences in Surface Reflectance

• Slight variations occur for surface pressure, total column ozone, and total precipitable water, due to upstream algorithm differences.

• Slight variations occur for aerosol optical depth due to upstream algorithm differences.

• Larger variations occur in the cloud mask because of large algorithm differences. Impacts are:
  • The NDE cloud mask does not provide a quality (high, medium, poor, etc.), which impacts the surface reflectance retrieval itself.
  • Quality Flags are impacted by differences in sun glint, snow categorization, and the lack of a thin cirrus flag or a cloud adjacency flag. This affects downstream products.
Conclusions

• Surface reflectance (SR) algorithm is mature and pathway toward validation and automated QA is clearly identified.

• Algorithm is generic and tied to documented validated radiative transfer code so the accuracy is traceable enabling error budget.

• The use of BRDF correction enables easy cross-comparison of different sensors (MODIS, VIIRS, AVHRR, LDCM, Landsat, Sentinel 2, Sentinel 3…)

• AERONET is central to SR validation and a “standard” protocol for its use is being defined (CEOS CVWG initiative)