Surface Reflectance

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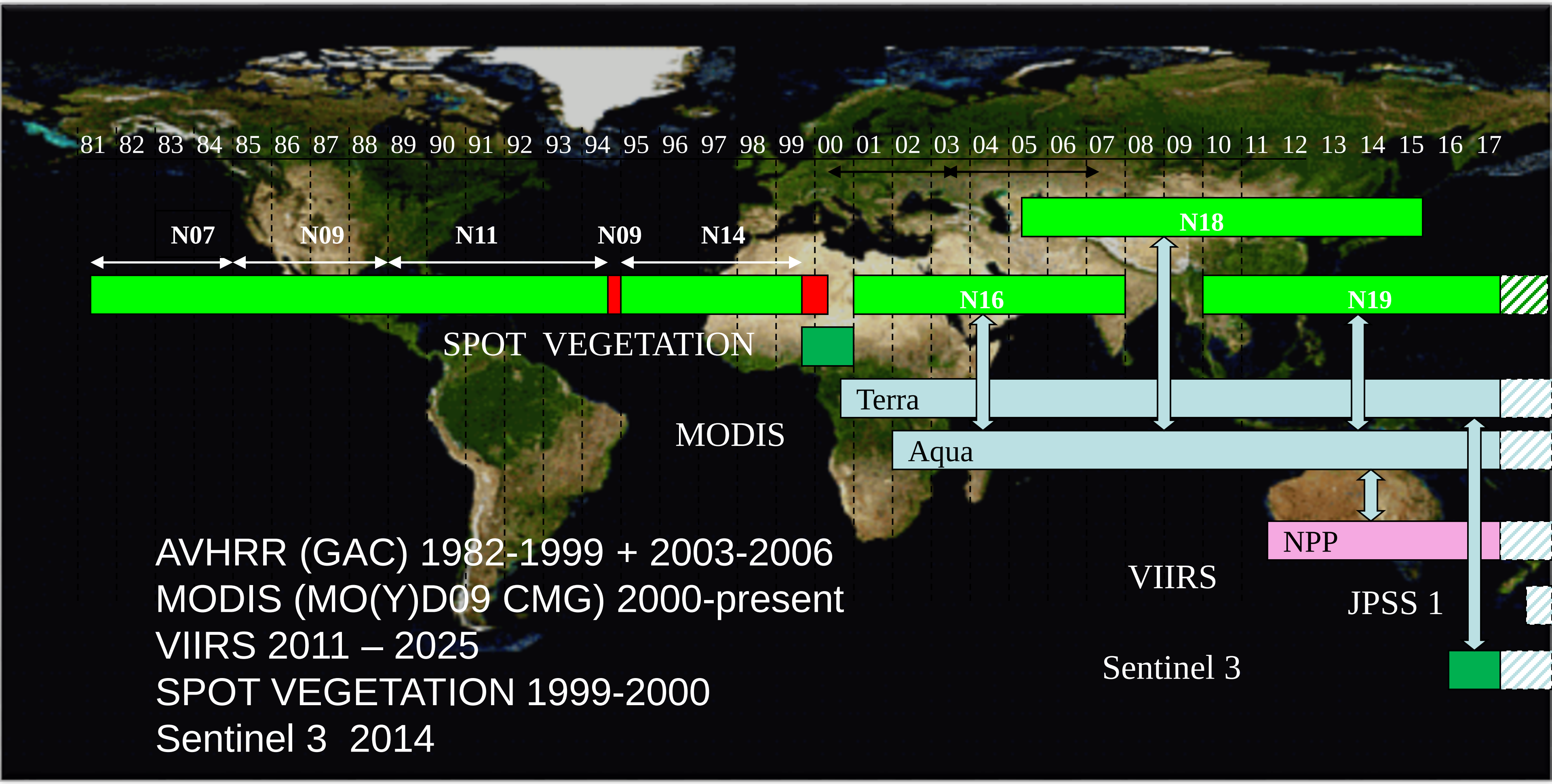
A Land Climate Data Record

Multi instrument/Multi sensor Science Quality Data Records used to quantify trends and changes



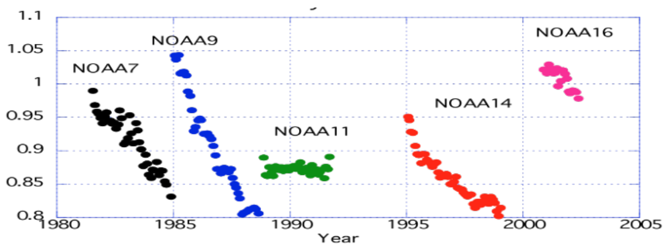
Emphasis on data consistency – characterization rather than degrading/smoothing the data

Land Climate Data Record (Approach)

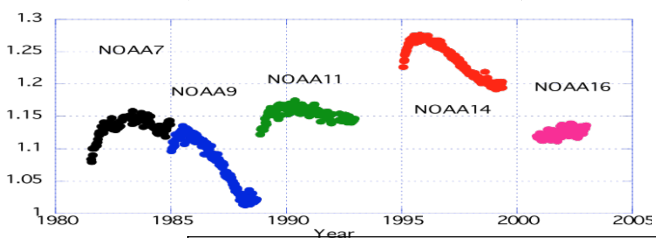
Needs to address geolocation,calibration, atmospheric/BRDF correction issues

CALIBRATION

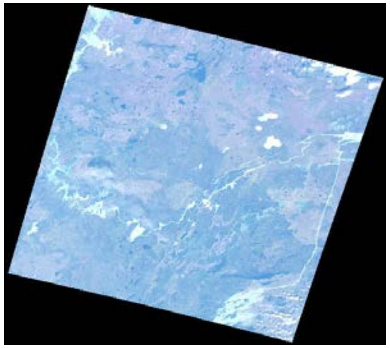
Degradation in channel 1
(from Ocean observations)

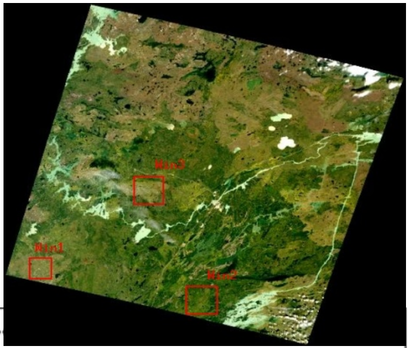


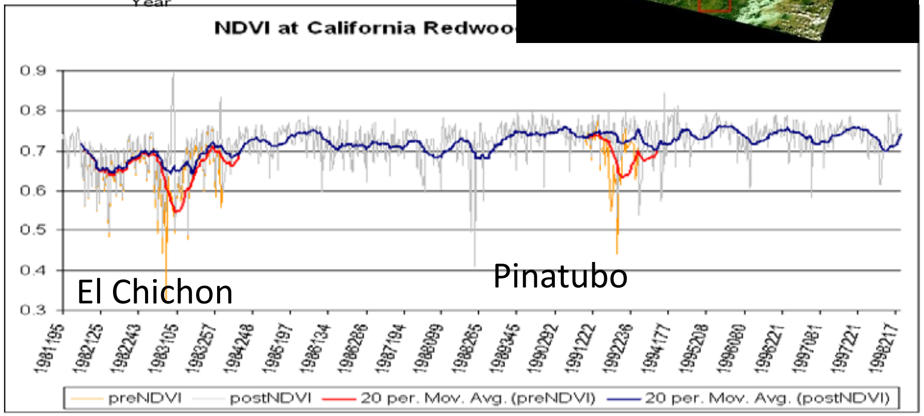
Channel1/Channel2 ratio
(from Clouds observations)



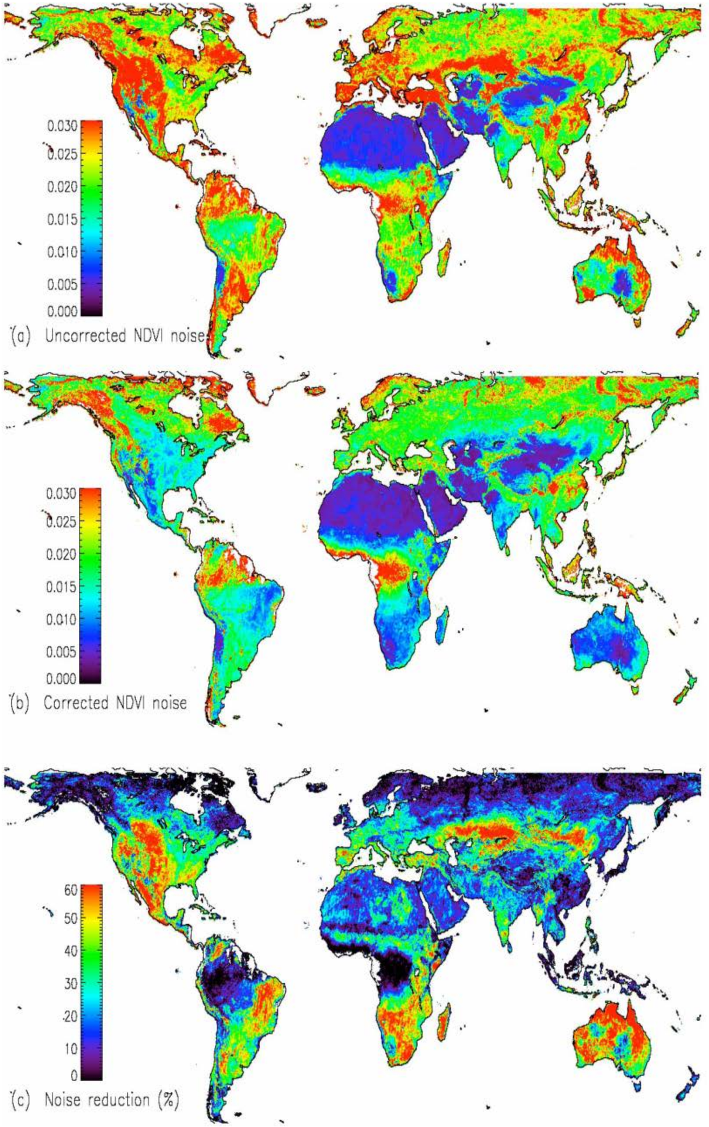
ATMOSPHERIC CORRECTION







BRDF CORRECTION



Generic Surface Reflectance Algorithm for VIIRS, MODIS Landsat 8…

The surface reflectance algorithm relies on:

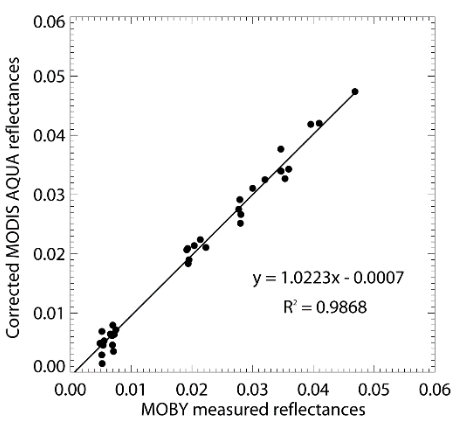
- the use of very accurate (better than 1%) vector radiative transfer modeling of the coupled atmosphere-surface system
- the inversion of key atmospheric parameters (aerosol, water vapor)

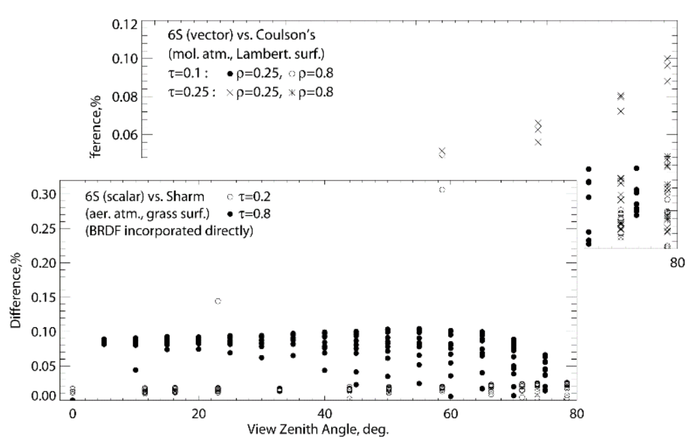
Home page: http://modis-sr.ltdri.org

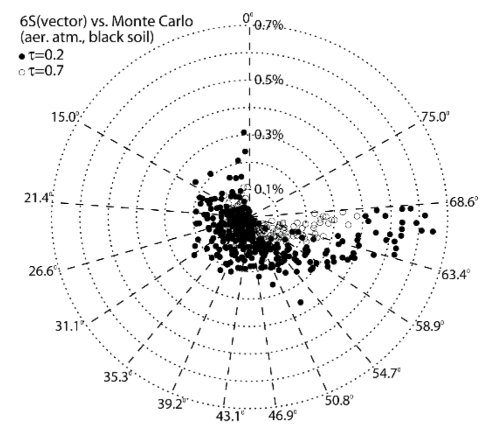
6SV Validation Effort

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

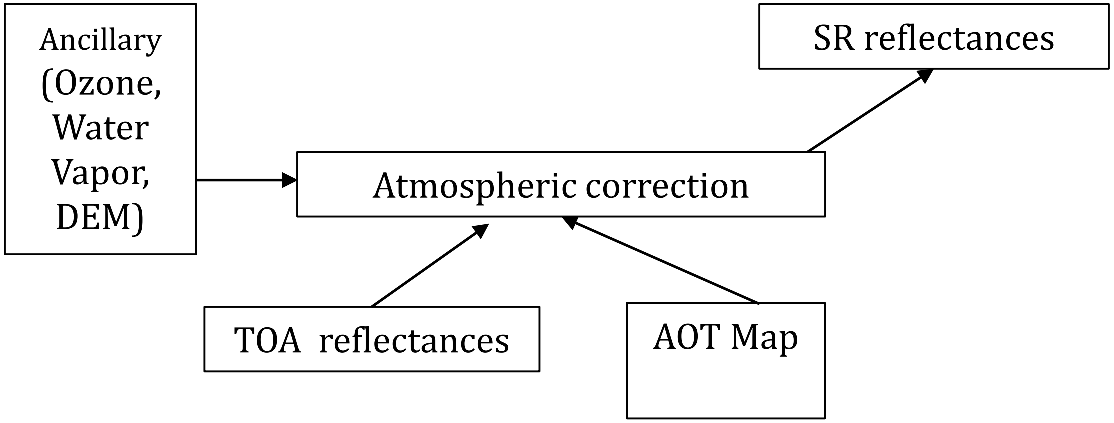
- Kotchenova, S. Y., Vermote, E. F., Matarrese, R., & Klemm Jr, F. J. (2006). Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part I: Path radiance. *Applied Optics*, *45*(26), 6762-6774.
- Kotchenova, S. Y., & Vermote, E. F. (2007). Validation of a vector version of the 6S radiative transfer code for atmospheric correction of satellite data. Part II. Homogeneous Lambertian and anisotropic surfaces. *Applied Optics*, *46*(20), 4455-4464.
- Kotchenova, S. Y., Vermote, E. F., Levy, R., & Lyapustin, A. (2008). Radiative transfer codes for atmospheric correction and aerosol retrieval: intercomparison study. *Applied Optics*, *47*(13), 2215-2226.







Generic flowchart for atmospheric correction



Aerosol inversion

Reading **Inputs, LUT** and **Ancillary data**

ρ_{surf} determined (*) using ρ_{atm}, T_{atm} and S_{atm} **from LUT** <u>assuming</u> AOT, Aerosol model and knowing pressure, altitude, water vapor, ozone…

Aerosol Opt. Thick. and **Aerosol model** for each pixel

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 $(\rho_{surf}\text{ blue} / \rho_{surf}\text{ red})_{MSI} = (\rho_{surf}\text{ blue} / \rho_{surf}\text{ red})_{MODIS}$

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.

$$residual = \frac{\sum_{i=1}^{2}\left(\rho_{surf}^{i} - Ratio_{665}^{i} * \rho_{surf}^{665}\right)}{2}$$

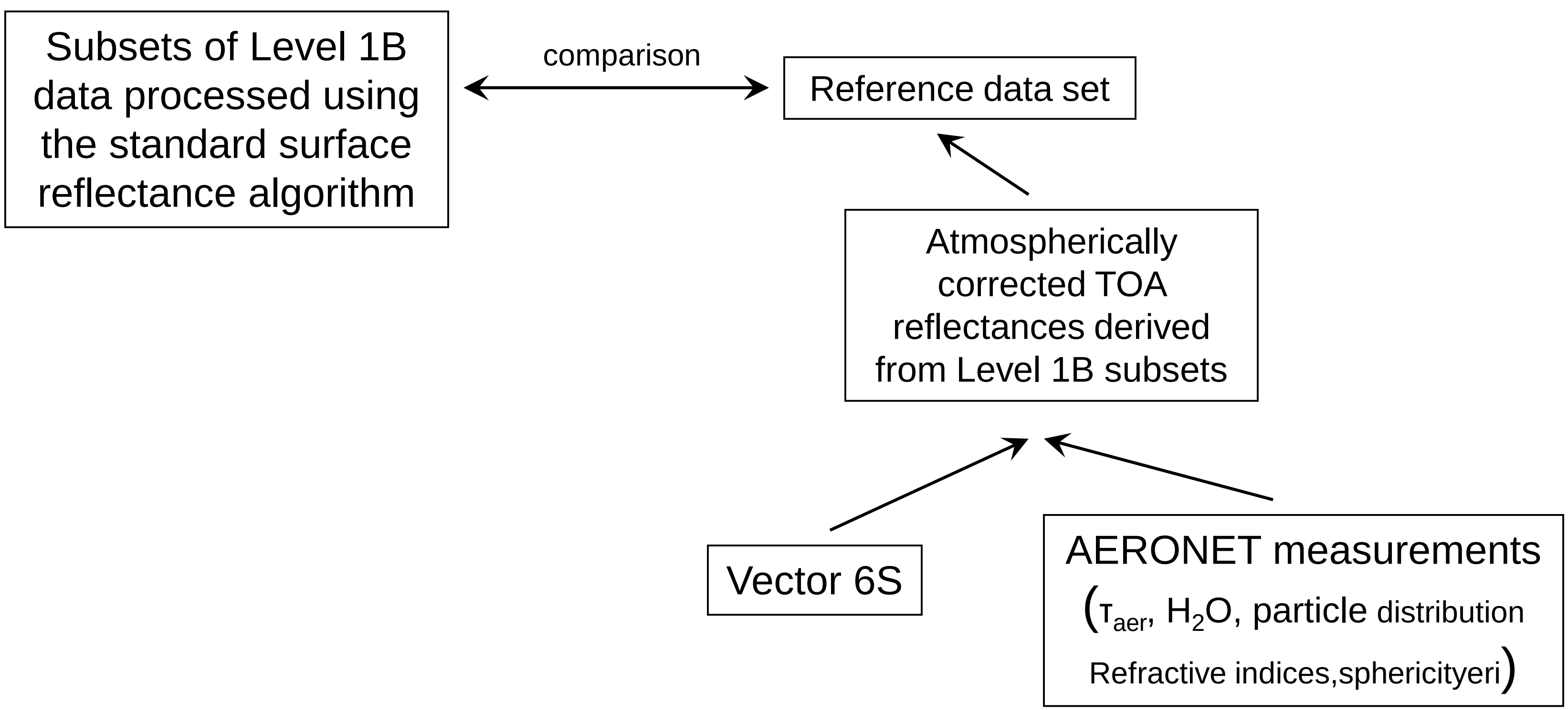
Surface reflectance for each pixel and each band

Computation of **surface reflectances** for all channels

ρ_{surf} determined (*) using ρ_{atm}, T_{atm} and S_{atm} **from LUT** <u>knowing</u> AOT, Aerosol model, pressure, altitude, water vapor, ozone…

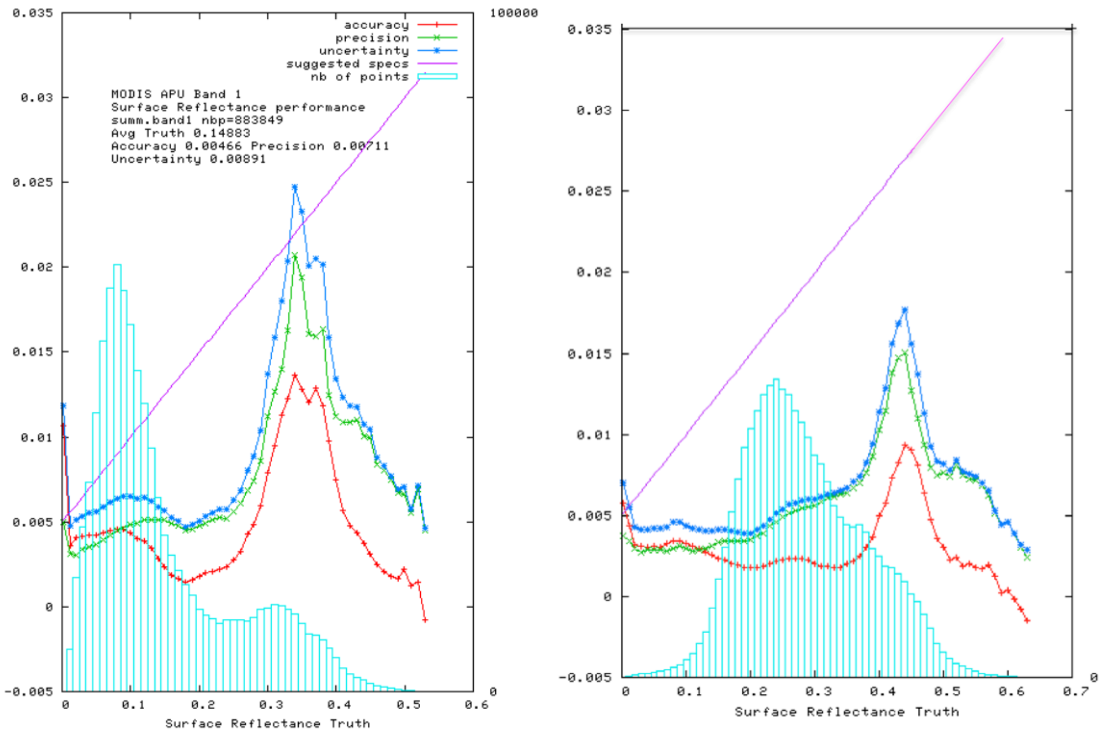
$$(*) \quad \rho_{surf} = \frac{Y}{1 + S_{atm}.Y} \quad \text{with} \quad Y = \frac{1}{T_{atm}.tg^{wv}}\left[\left(\frac{\rho_{TOA}}{tg^{O3}.tg^{others}} - \right) - \left(\rho_{atm} - \rho_{ray}\right).tg^{wv/2} - \rho_{ray}\right]$$

Methodology for evaluating the performance of surface reflectance



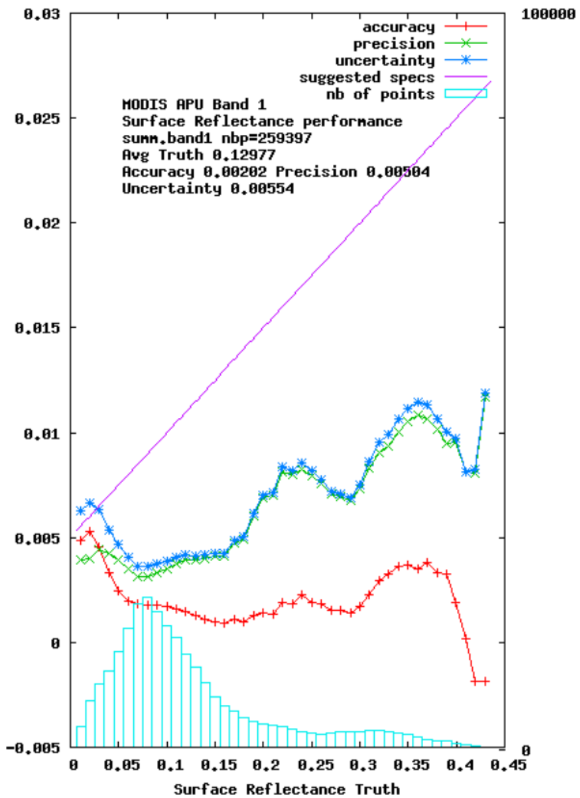
http://mod09val.ltdri.org/cgi-bin/mod09_c005_public_allsites_onecollection.cgi

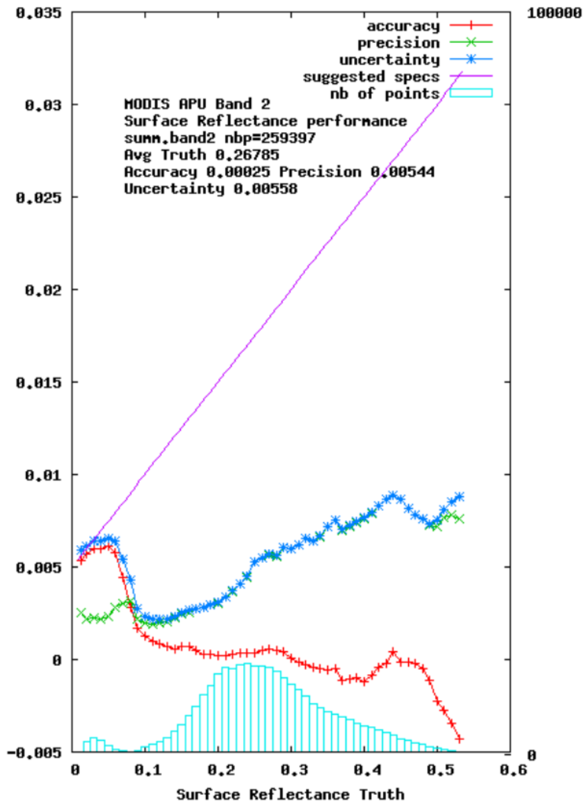
quantitative assessment of performances (APU)

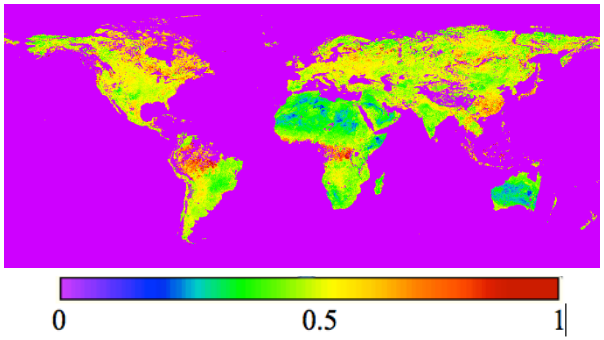


COLLECTION 5: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (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



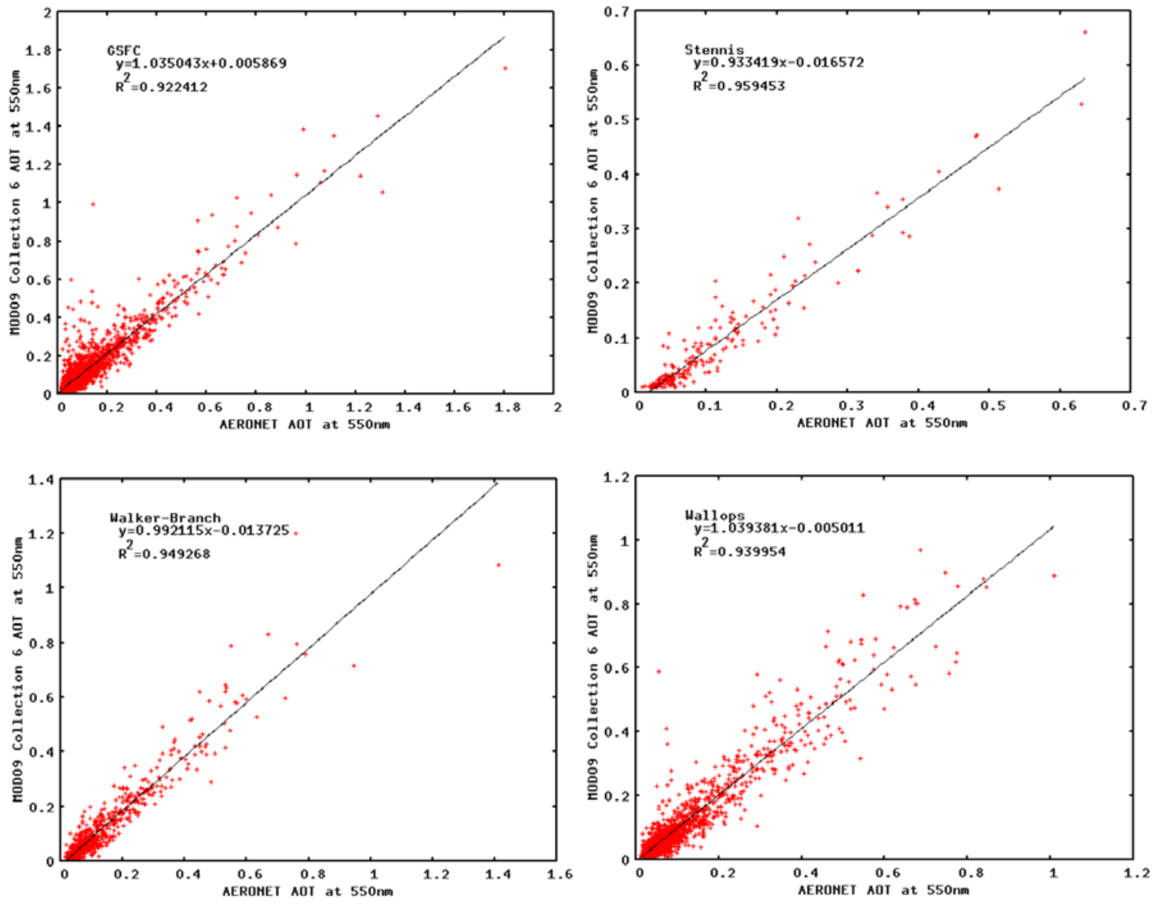




ratio band3/band1 derived using MODIS top of the atmosphere corrected with MISR aerosol optical depth

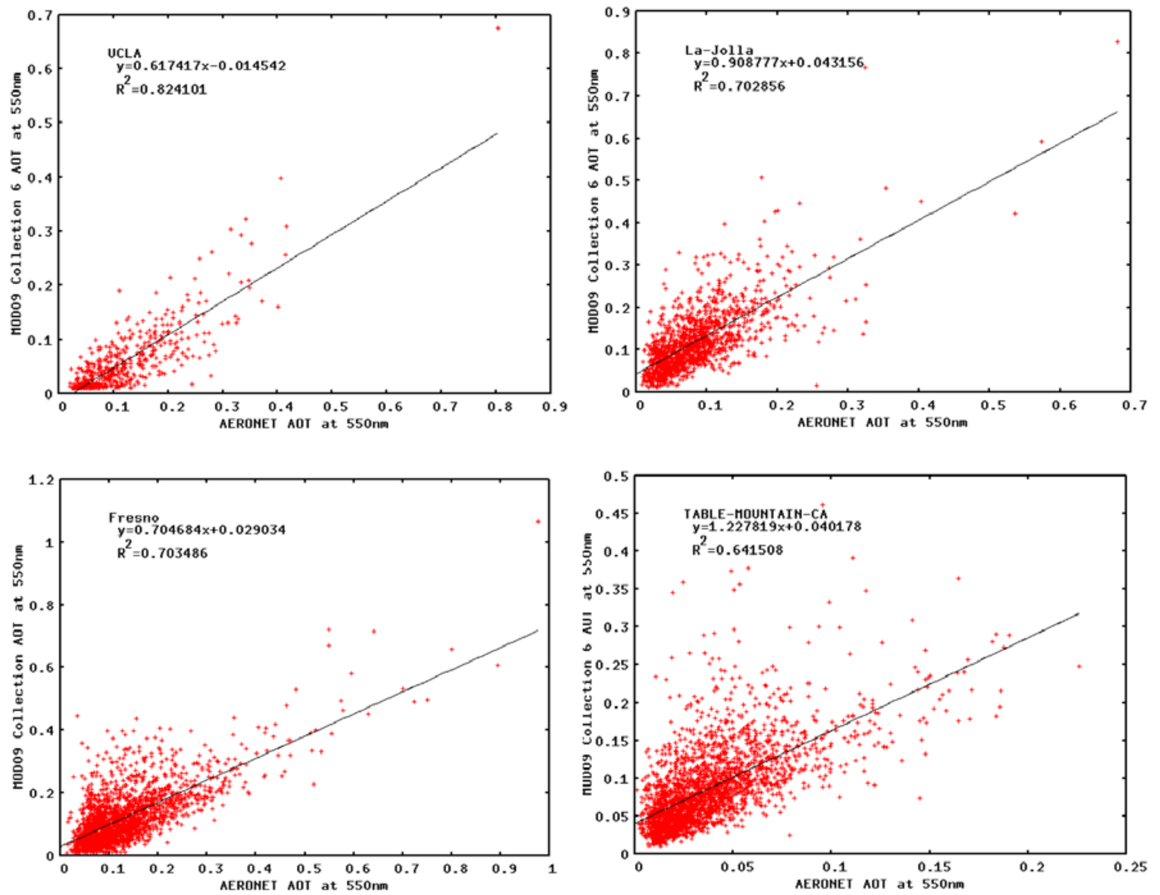
COLLECTION 6: accuracy or mean bias (red line), Precision or repeatability (green line) and Uncertainty or quadratic sum of Accuracy and Precision (blue line) of the surface reflectance in band 1 in the Red (top left), band 2 in the Near Infrared (top right also shown is the uncertainty specification (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



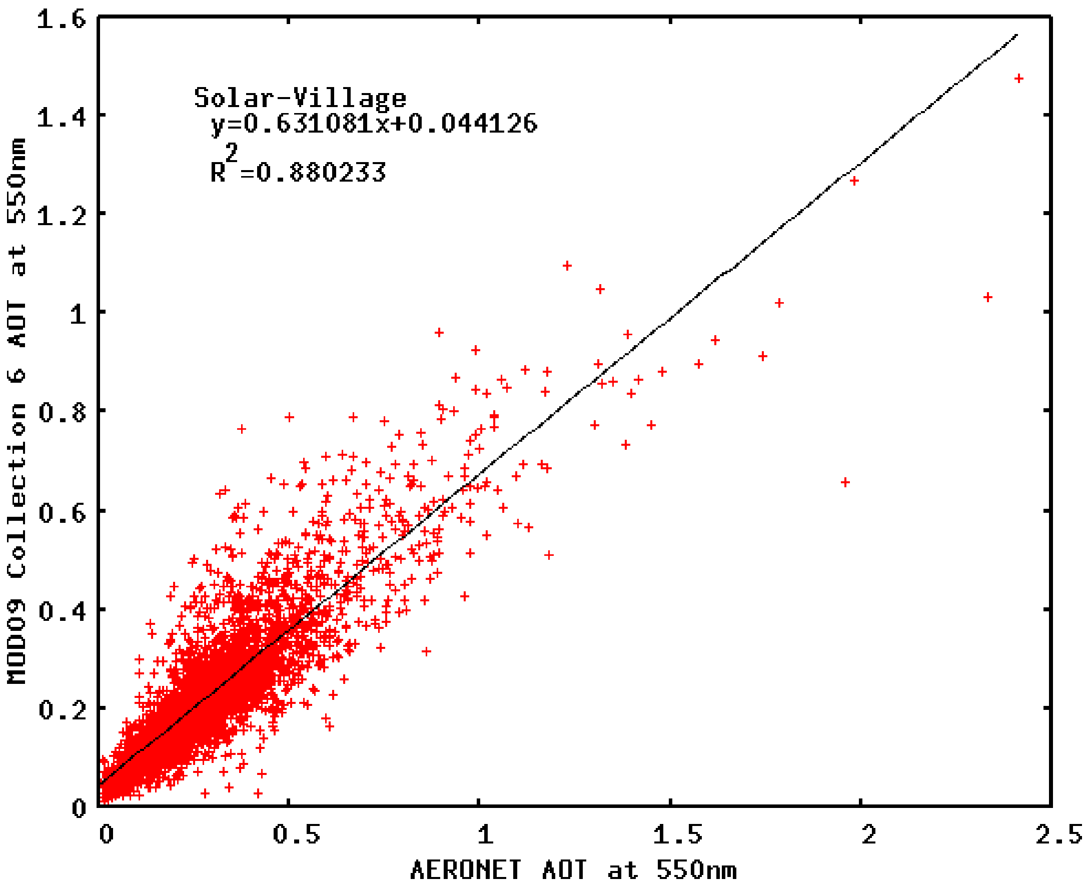
Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for East Coast sites selection: GSFC (top left), Stennis (top right), Walker Branch (bottom left) and Wallops (bottom right).

Aerosol retrieval also shows improvement



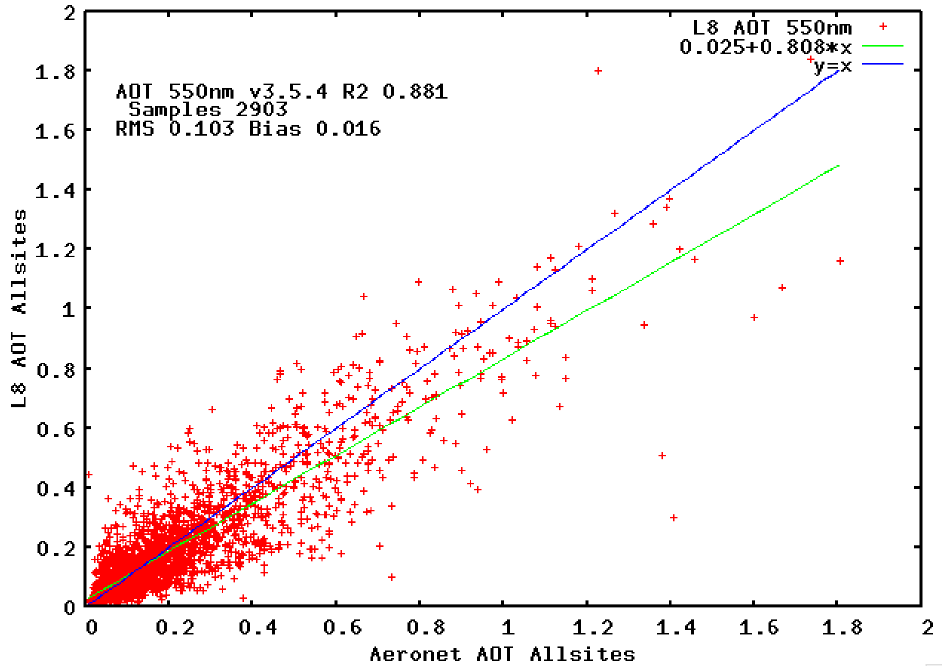
Scatterplot of the MOD09 AOT at 550nm versus the AERONET measured AOT at 550nm for the West Coast sites selection: UCLA (top left), La Jolla (top right), and Fresno (bottom left) and Table Mountain (bottom right).

Aerosol retrieval also shows improvement



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

Aerosol retrieval also shows improvement



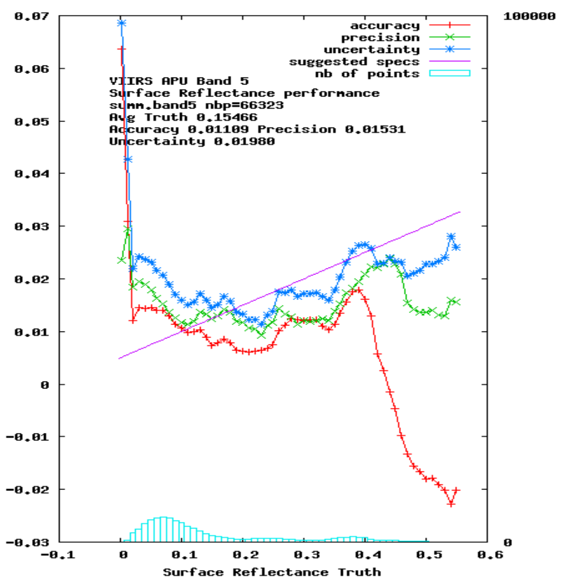
Scatterplot of the Landsat 8 AOT at 550nm versus the AERONET measured AOT at 550nm for all AERONET matchups since Landsat 8 activation

VIIRS Surface reflectance

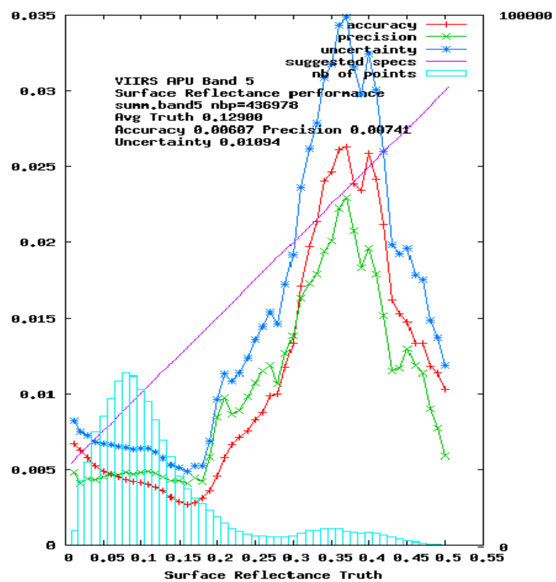
- the VIIRS SR product is directly heritage from collection 6 MODIS and that it has been validated to stage 1-2
- MODIS algorithm refinements from Collection 6 have been integrated into the VIIRS algorithm and are included in the operational product (NDE) equivalent of NASA VIIRS Version 1.

Evaluation of VIIRS SR Algorithm Performance (example Red band)

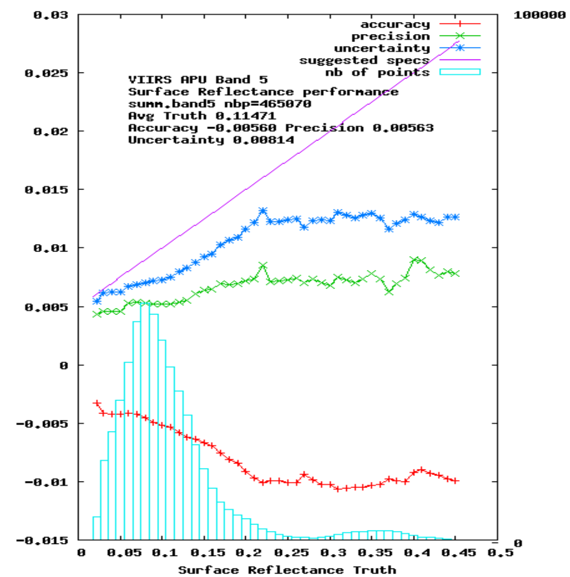
IDPS version



NASA C1.1

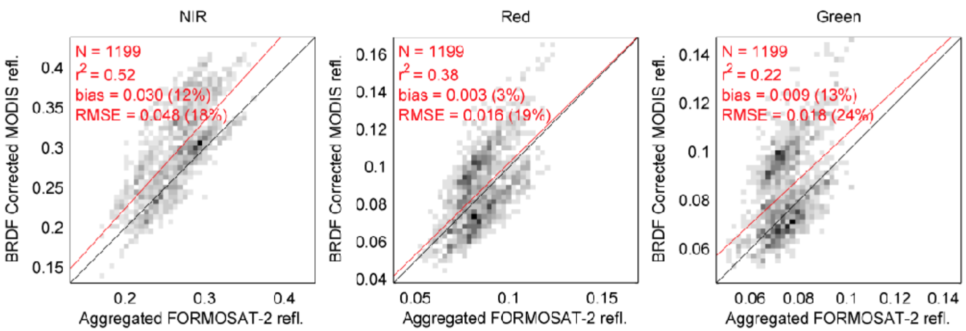


NDE, NASA Version 1

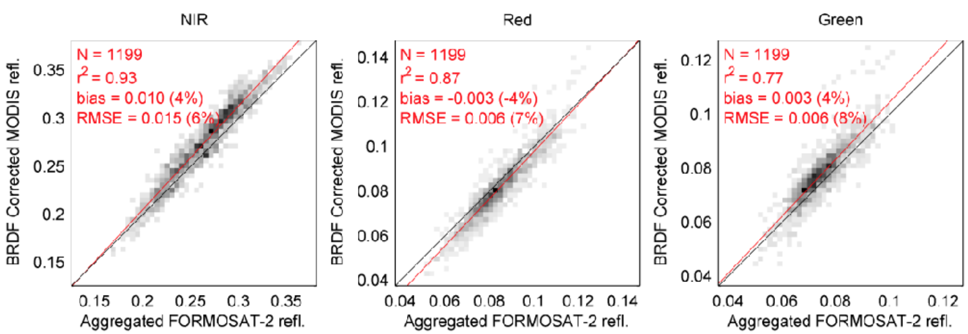


Improvement is clearly visible from IDPS to current NDE version

Use of BRDF correction for product cross-comparison



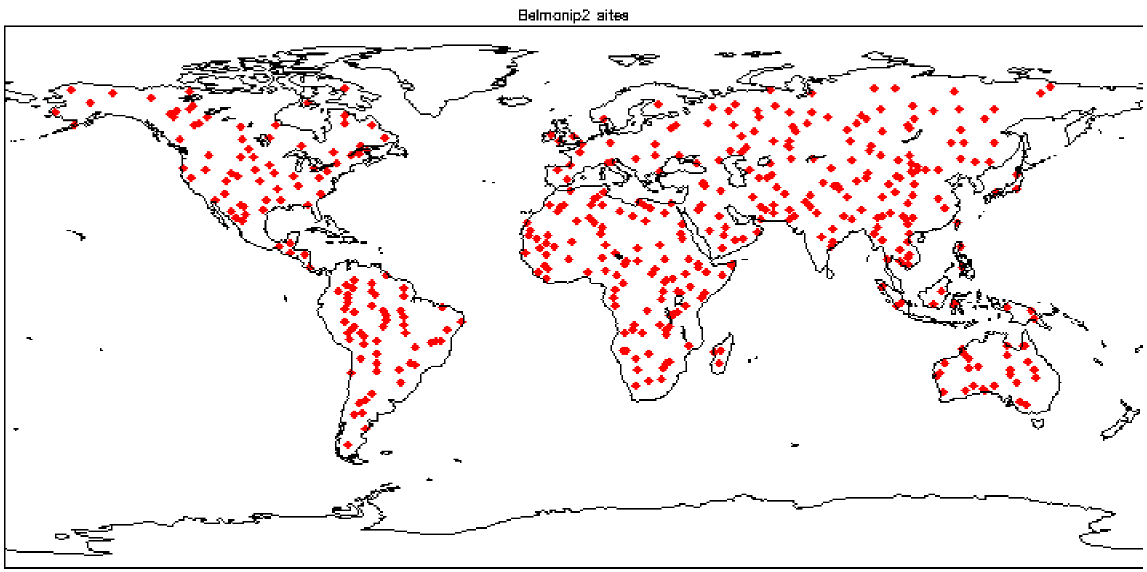
Comparison of aggregated FORMOSAT-2 reflectance and MODIS reflectance. No BRDF correction. Density function from light grey (minimum) to black (maximum); white = no data.



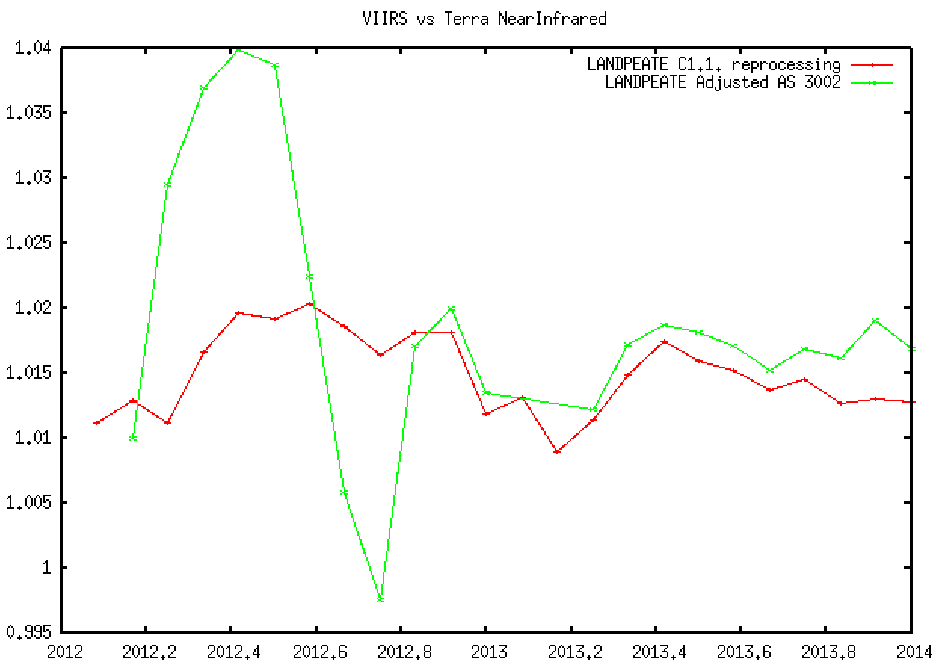
Comparison of aggregated FORMOSAT-2 reflectance and BRDF corrected MODIS reflectance. Corrections were performed with Vermote al. (2009) method using for each day of acquisition, the angular configuration of FORMOSAT-2 data.

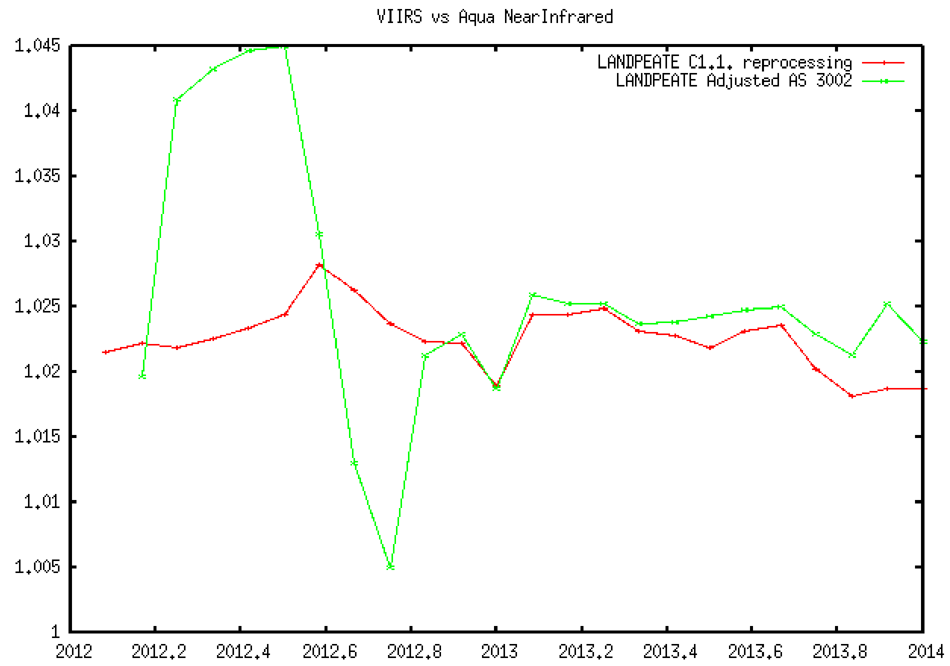
Cross comparison with MODIS over BELMANIP2

The VIIRS SR is now monitored at more than 400 sites (red losanges) through cross-comparison with MODIS.

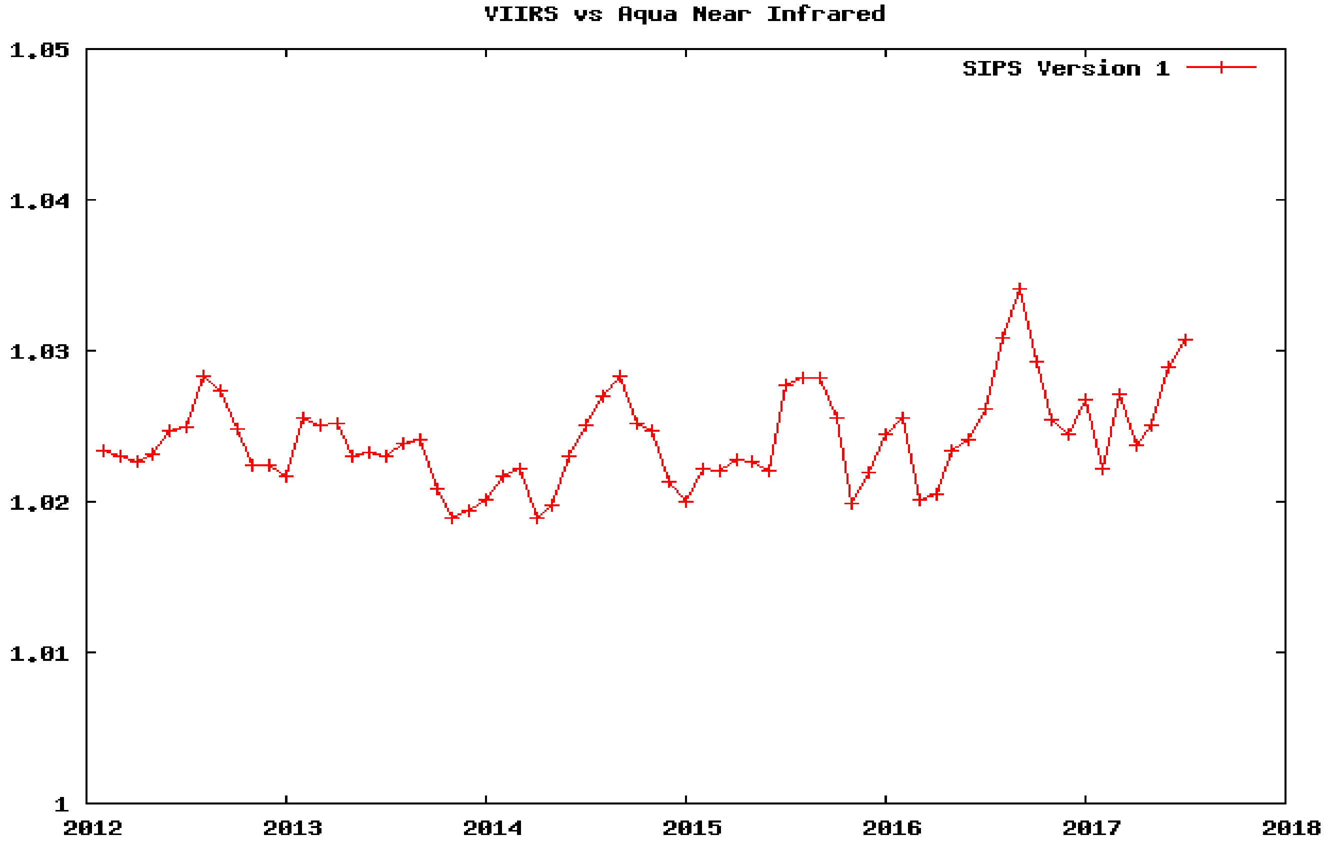


Results over BELMANIP2 (IDPS and C1.1)





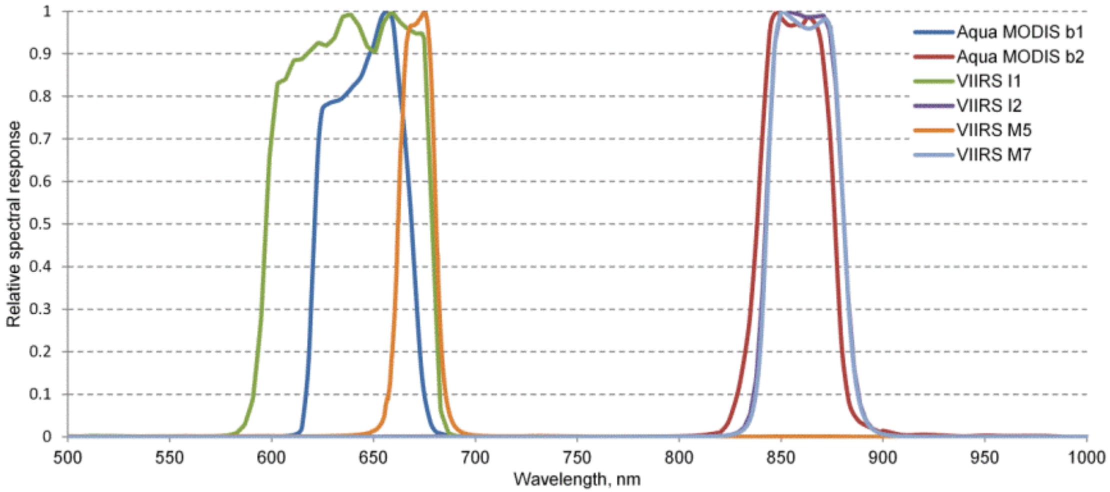
Results over BELMANIP2 (NDE/NASA Version1)



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



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

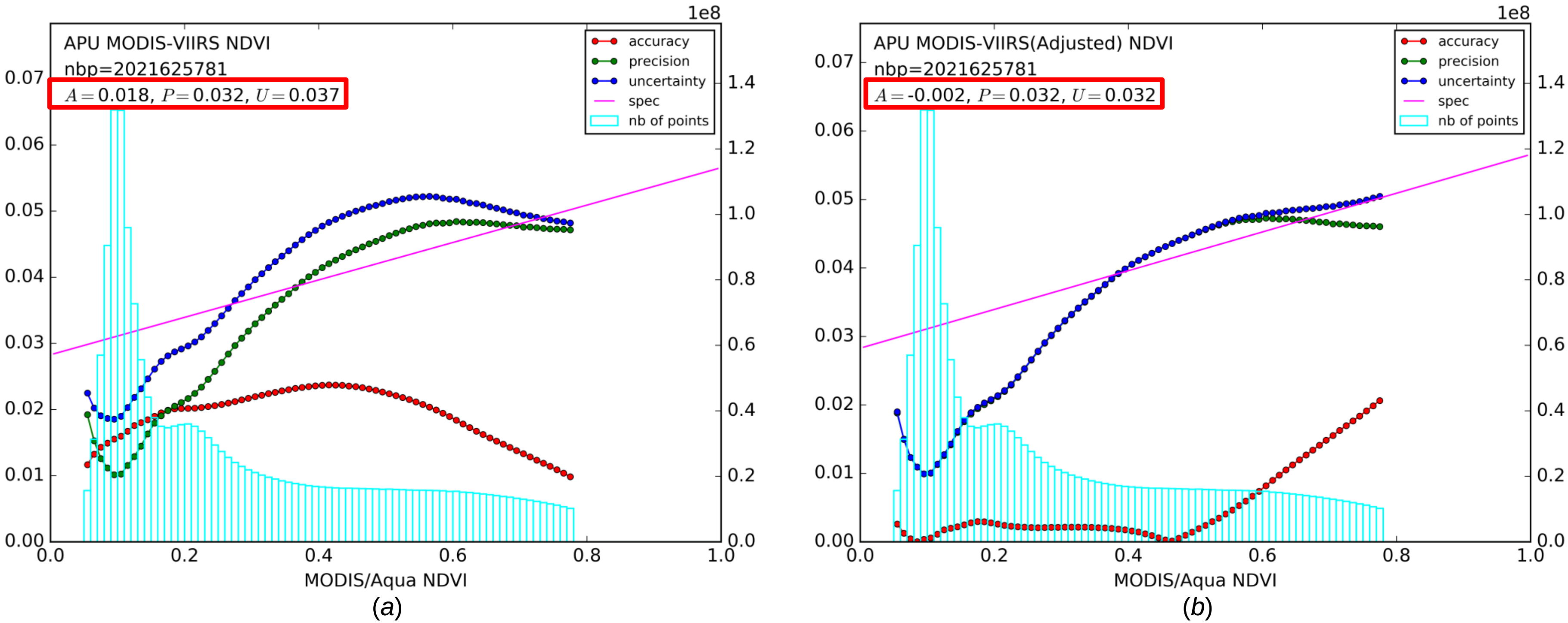
Spectral adjustment:

$$\rho^M_{red} = a_{red}\rho^V_{red} + b_{red}\rho^V_{NIR},$$

$$\rho^M_{NIR} = a_{NIR}\rho^V_{red} + b_{NIR}\rho^V_{NIR},$$

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

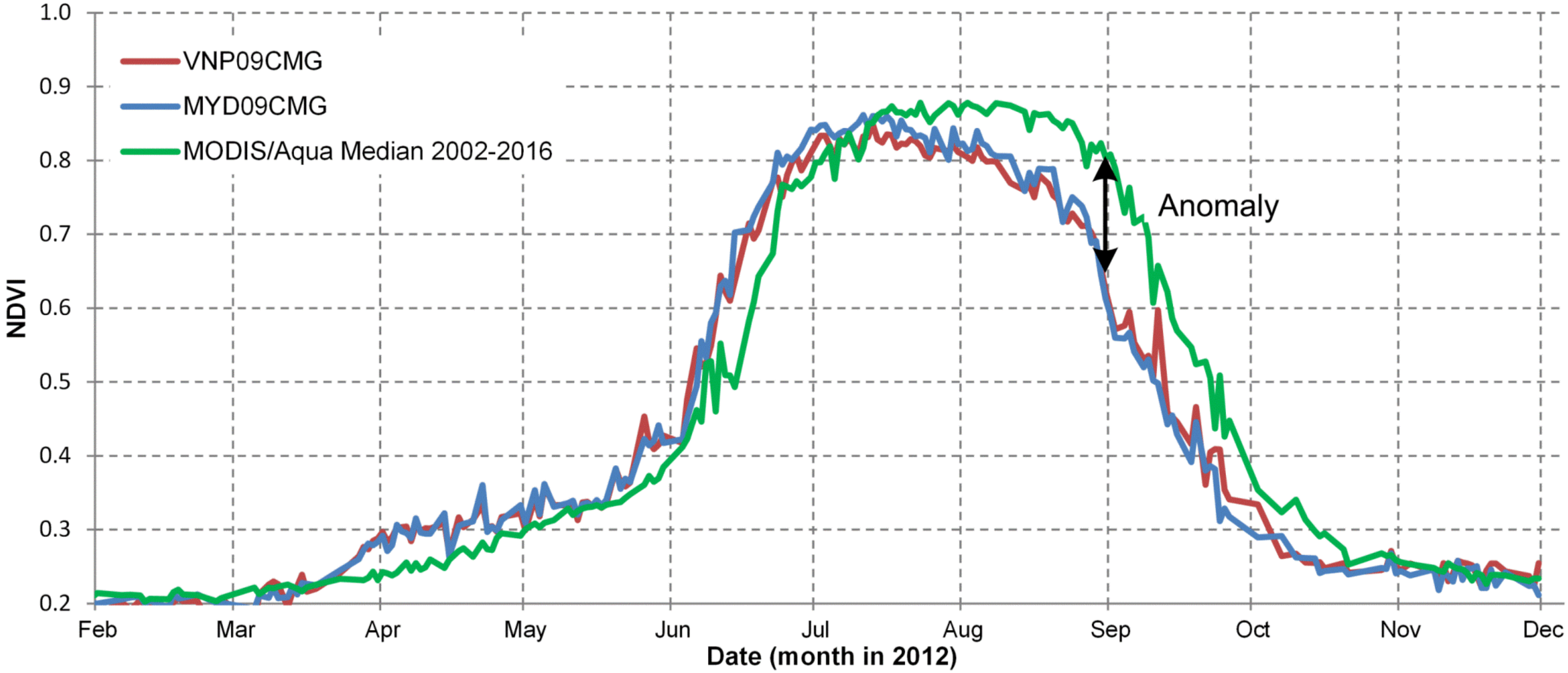
Transitioning from MODIS to VIIRS



Comparison (in terms of APU) of NDVI's derived from MYD09CMG and VNP09CMG surface reflectance products at global scale (approximately 2×10^9 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.

Transitioning from MODIS to VIIRS

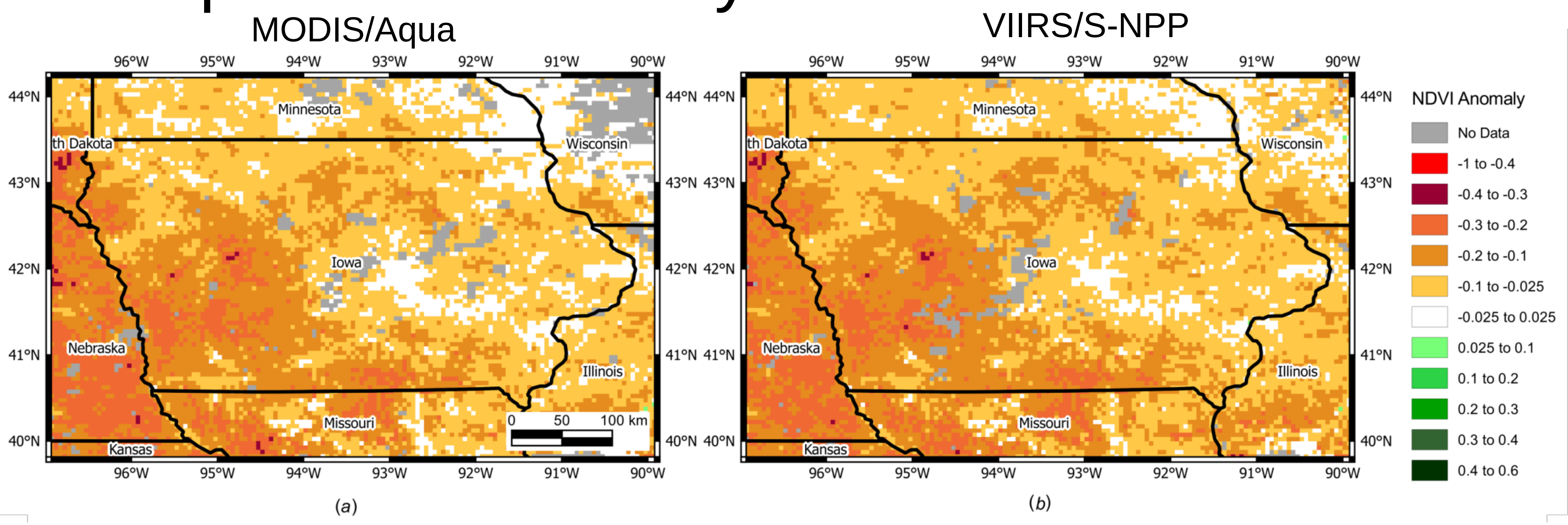
- Temporal consistency



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.

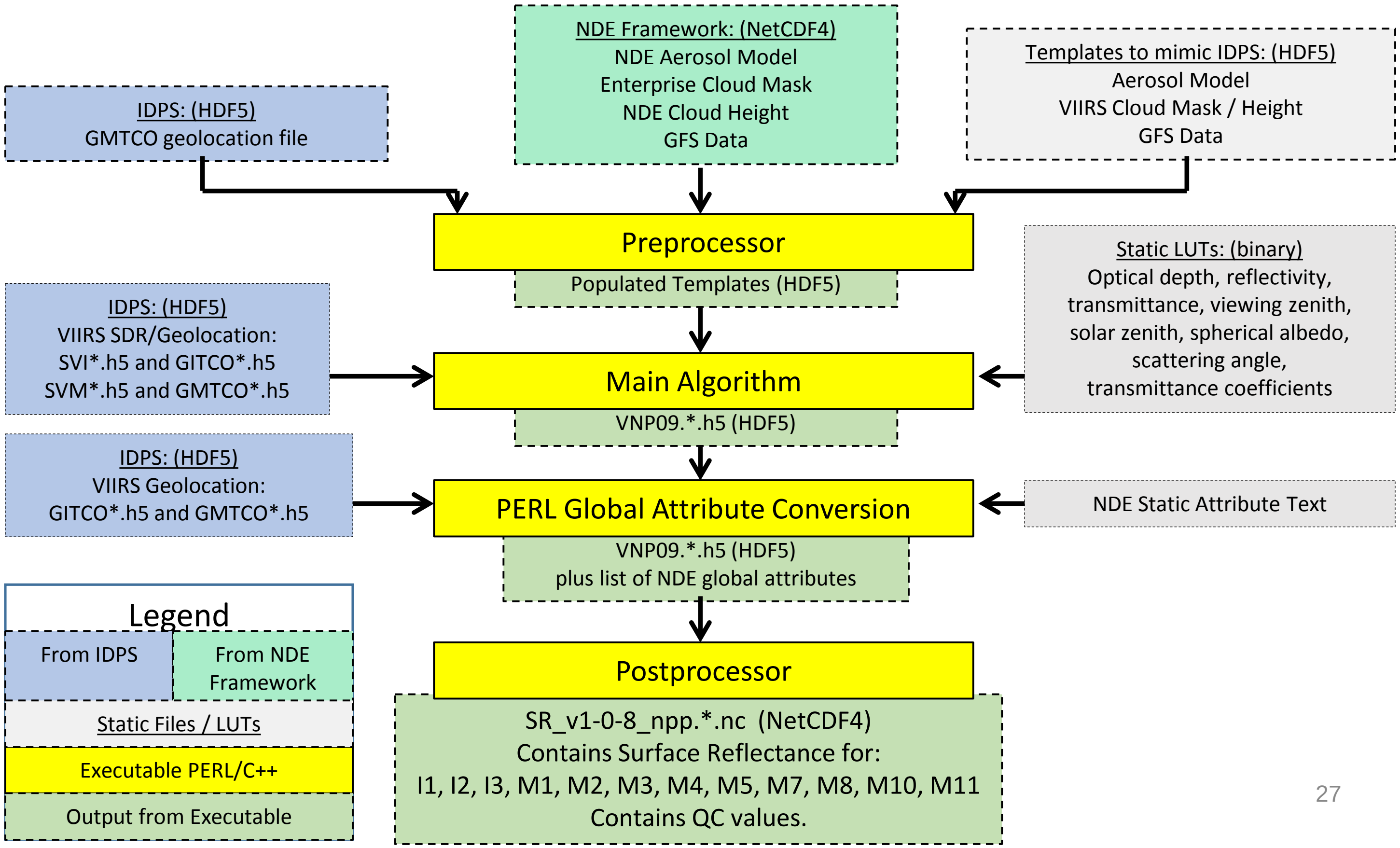
  4) Global attributes are different between NDE and IDPS, so NOAA-STAR developers wrote scripts to create both static and dynamic global attributes.

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



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)