An Evaluation of the Suomi-NPP Visible Infrared Imaging Radiometer Suite (VIIRS) and the Associated Environmental Data Records for Land Science after Early Evaluation on On-Orbit Performance

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Executive Summary

This report presents the findings of the VIIRS Land Science Team on the utility of the VIIRS instrument, data system, and Environmental Data Records (EDR's), based on their current status[1], for meeting the needs of the global change research community. The report addresses what is needed in addition to the current VIIRS Land related activities that are supported by the Joint Polar Satellite System (JPSS) program and NASA.

Data at coarse resolution from the AVHRR and MODIS (and at moderate resolution from the Landsat) instruments provide crucial and indispensable time-series for Global Change land science. With the recent and anticipated changes to the land surface, associated with the impacts of a warming world, increased global population pressure and rapid economic development, continuing these satellite time-series through the next decades will be important for NASA's Earth System Science Program and its ability to meet the science needs of its science community and national and international partner programs. The Suomi-NPP VIIRS instrument is intended to provide continuity for NASA's EOS MODIS instruments and a bridging mission and risk reduction for the newly-named JPSS program. **After a year of on-orbit operations, the land group of the NASA NPP Science Team has determined that the VIIRS is an instrument suitable for continuing and further developing the land science currently undertaken using MODIS and in some aspects provides an improvement over the MODIS instrument capability.** For example, unlike the MODIS instruments, the VIIRS instrument design constrains pixel growth across the scan and provides complete daily global coverage, which has proven to be an advantage for land products. Similarly the higher resolution Image-Bands and Day Night Band offer enhanced capabilities beyond MODIS. However, the full potential of the instrument for global change science and applications will not be exploited through the NOAA operational program, as currently configured. **The operational JPSS program has been designed to meet the needs of the traditional NOAA operational community,** primarily the meteorological community (e.g. NWS NCEP and AFWA) and therefore the focus is on provision of real-time data and products to these organizations, **with no requirement for developing or utilizing the consistent long-term data records needed for global change science.** Similarly, the operational products being generated by the Interface Data Processing Segment (IDPS) were designed to meet the needs of NOAA's operational users and although improvements are slowly being made to these products as problems are encountered or proposed improvements are accepted, **the fundamental design of the current algorithms and IDPS processing chain remain those developed by the contractor and therefore are not designed to meet the needs of the global change science community**. The IDPS is poorly-suited as a system to generate products for the science community. The NOAA real time users (NCEP, AFWA, NESDIS) get a real time feed of VIIRS data to their 'Centrals'. The CLASS system provides the archive for IDPS generated data and although data can be obtained from CLASS, it was not designed as a comprehensive data distribution system and is poorly suited as a system to provide products for the science community.

[1] The VIIRS instrument is in the intensive calibration phase, the IDPS is running Mx6.5 and the Land EDR's are currently being promoted to Beta status. Provisional status is planned for mid-2013.

It should be noted that the NRC Decadal Survey showed a heavy reliance on JPSS missions for providing key climate variables in the coming decade (NRC 2007) and stated that the VIIRS will be a primary instrument for generating the land climate variables. However, climate variables are not being generated by the IDPS system. **MODIS has been an unparalleled success for NASA Earth Science, in terms of science and applications-uptake, and with investment in product generation, validation and research by NASA, the VIIRS would continue this success.** For MODIS, a significant effort was made by the MODIS Calibration Support Team to understand and monitor instrument calibration and long-term performance and the same is needed for the VIIRS. Integrating data from VIIRS with those from heritage sensors to provide the long term record for climate studies will require a research investment. Successive VIIRS instruments will be used by the land science and applications communities; however, modest improvement to future VIIRS instruments, such as providing a higher dynamic range for fire detection, or providing unaggregated measurements for small cloud detection, would increase the utility of the data for both science and applications.

A number of EDRs are being generated by the IDPS to meet the needs of the operational community. The Land Team of the NASA NPP Science Team is evaluating the suitability of these EDR algorithms in terms of their appropriateness for fulfilling NASA's science needs. A summary of the findings from the evaluations to-date is outlined below and presented in this report.

In a number of cases, the Science Team are developing and testing MODIS continuity or improved algorithms on the Land Product Evaluation and Analysis Tool Element (PEATE) at GSFC. These data are made available to the Science Team and broader community by the LAADS system. Regardless of the suitability of the IDPS generated products for NASA science and applications**, for global change science there is a need for land products from VIIRS to be generated outside of the IDPS system, so that a consistent time-series can be established from the beginning of the VIIRS record.** Similarly, the upstream algorithms for the land products, from Level 1B calibration to clouds and aerosols are changing frequently with no operational capability or mandate to develop a consistent temporal series back in time. This is a consequence of there being no reprocessing capability within the IDPS. For instance, most of the VIIRS data collected on the first year after launch were affected by the VIIRS telescope mirror degradation, primarily in the NIR and Red bands; and while the adequate correction model was developed in the second half-year, no backward reprocessing was applied to correct the beginning of the mission data. **As with MODIS, the data record will need to be improved in response to better understanding of the instrument calibration and improvements to the algorithms endorsed by the science community. Periodic reprocessing of land science products from VIIRS will be vital.**[2] For efficiency of processing the production of the science products should not be constrained to the configuration or processing procedures of the IDPS.

[2] Inter-agency coordination will be needed concerning the long-term stewardship for climate data records in the JPSS era e.g. with NOAA's Climate Data Record (CDR) program in coordination with the new WMO Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE CM).

Furthermore, there are a number of land standard products from MODIS which are not currently generated by the IDPS or planned for IDPS production (i.e. LAI/FPAR, Net Primary Productivity, Vegetation Dynamics (phenology), Vegetation Continuous Fields, or Burned Area) and if product continuity is to be maintained, NASA will need to generate them.[3] In addition, identifying the science needs for the MODIS standard products was a process which was undertaken in the 1990's and 2000's. **Global change science has evolved to include impacts and adaptation science and a number of additional experimental products could be considered to meet NASA's changing earth science and applications needs (e.g. forest, urban and land use change, cropland systems, irrigation, flood and drought extent, fire return frequency).** The new VIIRS Day/Night Band (DNB) provides enhanced observation capabilities beyond the heritage DMSP products, that offer potential new insights into natural and anthropogenic sources of lunar- and emission- based phenomena. DNB products are currently being developed by NOAA NGDC and an evaluation is needed to determine the utility of these products for long-term climate and environmental change studies.

The NASA Applied Sciences Program has developed a number of partnerships with US Government Agencies, other than those whose needs are met by NOAA (e.g. USDA, EPA, USAID and FEMA). These partners are currently utilizing MODIS and their near real time needs are being met by the Land Atmosphere Near real-time Capability for EOS (LANCE). These partners are fully expecting data continuity from VIIRS although their VIIRS data needs will not be met by NOAA and the data latency of the CLASS system. **The development of a NASA near real time capability for VIIRS, equivalent to LANCE is a priority for the NASA Applied Sciences land community.** In this context discussions with NOAA on a near real time data feed to NASA would be needed.

EDR Evaluation Summaries

The Land Surface Temperature, Surface Type, Vegetation Index**,** Ice Surface Temperature, and Snow Cover EDRs will meet the target requirements of the NOAA operational users. The Albedo EDR requires additional refinement. In all cases, the current VIIRS quality assurance (QA) fields associated with each EDR do not allow users to thoroughly screen low or suspicious quality observations. Unlike the full swath data generated by MODIS, the IDPS generated land products are bow-tie deleted to reduce data volumes, resulting in data gaps off nadir. Thus, without a major revamp of the existing QA fields and formats, the products will continue to lack the rigorous consistency checks and quality controls necessary for characterizing the Earth's climate and environmental changes with high confidence and will be incompatible with MODIS products.

The Sea Ice Characterization EDR, in its present form, is not suitable for climate applications, unless the product is used strictly as an "ice vs. no-ice" classifier. With only three classes (Ice free, New/Young, and Other ice), and a relatively low probability of correct classification, its usefulness for scientific research is somewhat limited. The Ice Surface Temperature (IST) algo-

[3] The NOAA Data Exploitation (NDE) program at NESDIS is considering supporting the generation of VIIRS products beyond the EDR's and there may be an opportunity for joint-funding of some of these products using the Land PEATE for product generation.

rithm, will meet the science community needs. However, additional tuning is needed to correct for biases in ice surface temperature when compared to the MODIS IST product. The IST EDR should be enhanced by extension to coastal and land ice areas. The Ice Characterization EDR could be improved for science use by inter-use of data from passive microwave sensors; particularly with respect to ice-age during the summer periods. The Snow Cover EDR will provide continuity with the MODIS product but could be enhanced by the inclusion of fractional snow cover and daily snow albedo, as provided by MODIS, and by adopting a multi-sensor approach.

Many of the other land products including vegetation index, surface albedo, and quarterly surface type depend directly on the Surface Reflectance (SR) Intermediate Product (IP). This product is the direct heritage of the MODIS reflectance product with the associated scientific benefits demonstrated for the downstream MODIS products such as vegetation index, surface albedo, land cover type and LAI/FPAR. At this time, VIIRS Surface Reflectance is currently not stored in the long-term CLASS archive and is not available for climate analysis. Surface reflectance is required for producing higher-level land products.[4] The accuracy of the Surface Reflectance IP depends on the aerosol optical thickness IP, which is different from the VIIRS AOT EDR and not readily accessible. This differs from the MODIS processing where aerosol retrieval is integrated in the same algorithm for the MODIS Surface Reflectance product (MOD09). The VIIRS Aerosol Optical Thickness (AOT) IP over land uses similar aerosol models and retrieval techniques similar to those of MODIS. On the other hand, current VIIRS AOT validation analysis shows that it has a substantial high bias over land affecting surface retrievals. The VIIRS SR retrieval accuracies also begin to decline under various surface-atmosphere conditions particularly for: the shortwave channels, where the Lambertian assumption introduces biases that depend on the viewing geometry and atmospheric opacity; over bright surfaces; and over regions with variable aerosol sources including dust.[5]

The NDVI EDR is generated from Top-of-Atmosphere retrievals and will have very little value to the scientific and applications communities already routinely using NDVI values that are atmospherically corrected. While the enhanced vegetation (EVI) EDR is atmospherically corrected, there are blue-band discrepancies that will impact the continuity with the MODIS EVI. The Surface Albedo EDR supplies a single broadband value which does not provide the underlying spectral albedos or the BRDF anisotropy information currently produced by MODIS. This information is increasingly being utilized to improve land surface energy budget computations within global and mesoscale numerical prediction models. In the context of NASA science, the quality and accuracy of the current Surface Type EDR (70% classification accuracy) will be insufficient for most regional land cover related applications. The Active Fire Applications Related Product (ARP) as currently produced, lacks the contextual fire mask and fire radiative power data layers that have been present in the MODIS active fire product, and are now standard

[4] It should be noted that discussions are underway as part of the revision of Level 1 requirements to make the Surface Reflectance IP an EDR.

[5] It should be noted that planned improvements to the IDPS aerosol retrieval over land, including using the deep blue algorithm to handle bright surfaces, should eventually provide a surface reflectance product from VIIRS comparable to the MODIS surface reflectance product.

components of most contemporary active-fire data sets.[6] The fire products generated by the IDPS are currently not available in the formats generated by the MODIS data dissemination systems i.e. LANCE FIRMS and Rapid Response. There is an expectation from the NASA applied science user community that such fire data dissemination capabilities will be available for VIIRS.

There are shortcomings in the formats associated with the EDR products for science use. The JPSS latency requirements have continued to prohibit some of the more time-consuming processing tasks integral to the MODIS Land Products, such as multi-angle and multi-temporal binning e.g. for Albedo, VI and LST. In addition, it should be noted that the native VIIRS resolutions vary across the EDR swath products (i.e., Level 2) and that as most of the operational land products generated by the IDPS are not gridded (i.e. Level 3) they will not be directly amenable for science and modeling use.

Based on this evaluation, it is strongly recommended that NASA develop a suite of VIIRS Earth Science Data Records (ESDRs) for Land science that will at least provide continuity with the MODIS products. Each product should be under the stewardship of a scientist or group of scientists, responsible for quality and accuracy assessment (validation), product maintenance and documentation, guidance on data reprocessing and outreach to the science community.

Building on the MODIS data processing experience and collocated with the MODIS Advanced Processing System (MODAPS), a data system known as the Land Product Evaluation and Analysis Tool Element (Land PEATE or LPEATE) has been developed at NASA-GSFC, managed as part of NASA's S-NPP Science Data Segment (SDS). The current focus of this system is to run the VIIRS EDR algorithms, enabling the Land Science Team to compare them to those from MODIS and the equivalent science algorithms for VIIRS. **For the purpose of continuity it is recommended that the proposed NASA VIIRS Land Science Product Suite be generated and distributed by the Land PEATE in close coordination with the S-NPP VIIRS Land Science Team. A small team should be supported to conduct Quality Assessment of the products generated from the LPEATE, in conjunction with the science QA undertaken by the VIIRS Land Science Team.**

Once the NASA VIIRS Land Science Products have stabilized, i.e., promoted from Beta to Provisional and Validation Stage 1, a program of product validation should be initiated to take the products to at least CEOS Land Product Validation Stage 2, i.e., "independent data should be collected to assess the product accuracy over the range of conditions for which the product is generated". It is recommended that a small group be responsible for product validation coordination and liaison with both JPSS-funded EDR validation activities and international partner programs, as is currently the case with MODIS.

While the current focus of NASA's Earth Science Program is on implementing the missions outlined by the NRC Decadal Survey, **it is crucial that the agency continue and enhance the sys-**

[6] Plans are underway to make the Fire ARP an EDR and to include Fire Radiative Power in the IDPS generated product.

tematic observations from the coarse (and moderate resolution) polar-orbiting imagers, and generate and distribute validated, science-quality data and products that are consistent with the products from MODIS. Investments by NASA should continue on the development of long-term, multi-sensor data records which span decades, building on the success of EOS MODIS with S-NPP VIIRS and through the JPSS era, providing the underpinning long-term measurements for the study of the land surface in the context of Climate and Global Change Research.

The complete recommendations from this report are presented in Section 6.

Purpose of the Land Report

This discipline report is intended to summarize the NASA VIIRS Land Science Team findings to-date with respect to the instrument characteristics, the on-orbit performance after 1-year of operations, the utility of the S-NPP VIIRS EDR's for Land Science and the additional processing, science products, and validation activities that will be needed to provide the intended continuity with MODIS. It is hoped that the document will inform NASA as to what the Land Discipline group from the VIIRS Science Team believes is required from VIIRS to meet the needs of the global and climate change research communities.

1. Introduction & Background

The Visible Infrared Imaging Radiometer Suite (VIIRS) is a comprehensive multispectral imager covering the spectral range between 0.4 μm and 12.0 μm. It obtains full global coverage using a ~3000 km swath on a daily basis in 22 spectral bands at nadir spatial resolutions between 0.38 km and 0.76 km. VIIRS was launched on the Suomi National Polar-orbiting Partnership (NPP) mission from Vandenberg Air Force Base on October 28, 2011. The instrument was activated on November 10, 2011. Shortwave scene data became available immediately after the nadir aperture doors were opened on November 21, 2011, while the thermal cooler doors were opened on Jan 18, 2012. By the following day Suomi-NPP was acquiring its first active fire detections. The seven VIIRS thermal infrared bands were considered stable starting Jan. 20, 2012.

A number of higher order products known as Environmental Data Records (EDRs) are being generated by the Data Products and Algorithms (DPA) group within the JPSS Common Ground Systems and Operations Project. The VIIRS Land products are grouped into four general product categories: (1) radiation budget variables, i.e. the Surface Reflectance IP (corrected for effects of the atmosphere), Land Surface Temperature, and Surface Albedo; (2) ecosystem variables, such as Vegetation Indices; (3) land-cover characteristics i.e. Surface Type and the location of Active Fires; and (4) cryospheric products, i.e., Snow Cover, Ice Surface Temperature and Sea Ice Characterization. A number of these products, including the surface reflectance have their heritage in the MODIS product algorithms and in some cases early versions of the MODIS Code were used in the EDR algorithm development. Early in the development program, some of the MODIS science team members were supported by the form NPOESS prime contractor to assist with algorithm implementation.

Starting in 2004, NASA began supporting an S-NPP Science Team for three year study cycles to evaluate the utility of the VIIRS instrument and the associated EDR's for science use. In 2007 and 2011 through another two rounds of funding, investigators were selected to continue to evaluate the EDR's from a science perspective and compare them with science algorithms. Through this time, the NASA VIIRS Land Team developed an open dialog with the operational product teams in charge of developing, testing and maintaining the IDPS Land algorithms, which has helped with the understanding of the EDR algorithms and incorporation of some improvements within the constraints of the product specifications. Through two major baseline releases (IDPS MX5 and MX6) in the past 12 months, several improvements have been made; however, a number of improvements suggested by the Land Team have yet to be adopted as they are either considered to be of lower priority, beyond the specified requirements, incompatible with the IDPS processing implementation or too costly.

Building on the MODIS Advance Processing System (MODAPS), NASA constructed a computing system known as the Land Product Evaluation and Analysis Tool Element (Land PEATE or LPEATE) at Goddard Space Flight Center (GSFC), managed by the NPP Science Data Segment (SDS), to run the VIIRS EDR operational code for evaluation by the Land Science Team, to facilitate comparison with MODIS products and to run the Science Team generated algorithms. Funding for the LPEATE allowed for a small in-house group to continue the quality assessment function of the MODIS Land Data Operational Product Evaluation (LDOPE) for VIIRS. Bringing the MODIS experience to bear on the development of the Land PEATE has provided the JPSS project with the advantage of the lessons learned from MODIS product generation.

Product validation continues to be an important part of the MODIS Land Team activity, is required for the VIIRS Land EDR's and will be required for the Land Science Products. Recognizing the validation experience-base that resides within the MODIS Team and the global land community, the JPSS project formed an EDR Land Validation Team. Although this team has strong overlap with the NASA MODIS Land Team membership, its scope is limited to the operational specifications, algorithms, and products but benefits heavily from the MODIS validation experience.

2. EDR Evaluation for Land Science

2.1. Land Surface Temperature EDR

EDR Team: Simon Hook; Glynn Hulley (JPL);
Robert Radocinski (JPL); Christopher Hughes (JPL)

Overview

The VIIRS Land Surface Temperature (LST) EDR provides radiometric LST values over land and larger inland waters in swath format, equivalent to the MODIS Level 2 MOD11_L2 product. The EDR deviates from its MODIS counterpart in four major areas: (a) It employs an algorithm suite comprised of a main dual split-window day- and night-time algorithm, and a backup algorithm that most resembles one of the heritage MODIS MOD11_L2 algorithm (Wan and Dozier 1996); (b) it uses both thermal and middle-infrared bands based on the so-called dual split window approach; (c) it has a functional dependency on previously-generated surface type dependent coefficients; and (d) it does not provide dynamic land emissivity per the current MODIS day-night product (MOD11B1) (Wan and Li 1997) or MODIS Temperature Emissivity Separation (TES) product (MOD21) (Hulley et al. 2010). Surface emissivity is known to change under many circumstances, including rainfall in arid regions, phenological changes, and intra-surface type changes or fires. This variation is not fully captured in the VIIRS product. Work over the last decade has shown that for arid and semi-arid regions the best approach is an algorithm with dynamically varying emissivity such as MOD11B1 or MOD21 algorithms. The MOD11B1 or day/night algorithm is only available at coarse resolutions (5 km) while the MOD21 product, which uses the TES algorithm, is available at 1 km resolution.

The accuracy and precision values specified for the VIIRS LST product are 2.4 K and 0.5 K, respectively. The dynamic range for the product extends from 213 K to 343 K, and the product will be generated over all land pixels under all conditions except for "confident cloudy" as categorized by the cloud mask. The spatial resolution of the LST product is 0.75 km at nadir and 1.3 km at the edge of the swath. The aim is to evaluate the accuracy and precision for each of previously-generated surface type dependent coefficients, however, absolute validation will be limited to sites where in situ measurements are available. There is no global "all land" accuracy specification and the product must only meet specifications over confidently clear cloud conditions.

Current Status and Quality of the Land Surface Temperature EDR

Since S-NPP's launch, NASA's Land PEATE has distributed three versions of the VIIRS LST EDR, which are archived in three archive sets (AS) in LAADS. For the purpose of this study, AS 3001 (products produced by Land PEATE using the IDPS software) and AS 3002 (products produced by Land PEATE using NASA science team adjusted version of the IDPS software) were used in the evaluation of the EDR. Note that the LST code being run in AS 3002 is using a different coefficient file that causes it to use the split window instead of the dual split window. Our validation effort has focused on the AS 3001 products, which are closest to the IDPS product.

The AS 3001 product is being validated using three different approaches: 1) Cross comparison with the Aqua MOD11 product when the Aqua and NPP overpasses were within 30 minutes of each other; 2) Absolute temperature validation using the Lake Tahoe and Salton Sea automated validation approach (Hook et al. 2007) and 3) Radiance based LST validation over a set of pseudo-invariant sand dune sites (Wan and Li 2008; Hulley et al. 2009).

Table 1: VIIRS LST (VLST) and MODIS-Aqua LST (MLST) and differences between TOA brightness temperatures for VIIRS bands (14, 15 and 16) and corresponding MODIS bands (29, 31 and 32) are also shown.

Date & Time	VLST	MLST	V-M (LST)	14-29	15-31	16-32
09/20/2012 10:06	18.20	17.73	0.47	0.44	0.28	0.46
09/26/2012 09:54	17.79	17.47	0.31	-0.08	0.18	0.30
09/26/2012 21:15	18.75	18.32	0.43	-0.38	-0.10	-0.03
10/01/2012 10:00	17.48	17.52	-0.04	-0.54	-0.33	-0.18
10/01/2012 21:22	20.41	19.84	0.57	-1.54	-0.45	-0.55
10/03/2012 20:44	18.81	18.66	0.15	-0.79	-0.21	-0.16
10/06/2012 10:06	17.33	17.11	0.22	0.43	0.38	0.49
		Mean	0.30	-0.35	-0.04	0.05
		Stdev	0.21	0.70	0.32	0.38

Initial cross validation with MODIS-Aqua over the Lake Tahoe and Salton Sea sites revealed that the emissivity for the water surface dependent coefficient was incorrect. This resulted in unrealistic temperatures for water and was first reported at the S-NPP meeting in May 2012. The JPSS project took an action to fix this problem and the lookup table was updated and went into IDPS operations with Mx6.2, on 8/09/12. The same fix was implemented in the LPEATE code on 9/20/12. Figure 1 shows the matchups between the MODIS-Aqua LST and VIIRS LST at Lake Tahoe after 9/20/12. Examination of this table indicates that the MODIS-Aqua LST is typically within 0.30 +/- 0.21 K with VIIRS being slightly warmer and well within the VIIRS accuracy and precision requirement. Although a very short data record, this suggests that the operational IDPS product will provide accurate LST's over inland waters.

Figure 1 shows a plot of the validation results using the MOD11, MOD21 and VIIRS main algorithm over one of the pseudo-invariant sites. This figure highlights the problem of using a static map for the emissivity coefficients seen with both MOD11 and VIIRS (Hulley and Hook 2009). In both cases the retrieved MOD11 and VIIRS LSTs are too low by 2-3 K (emissivity set too high) whereas the dynamic emissivity approach MOD21 gives the correct answer. As a result, the VIIRS LST-EDR retrieval does not meet the accuracy requirement.

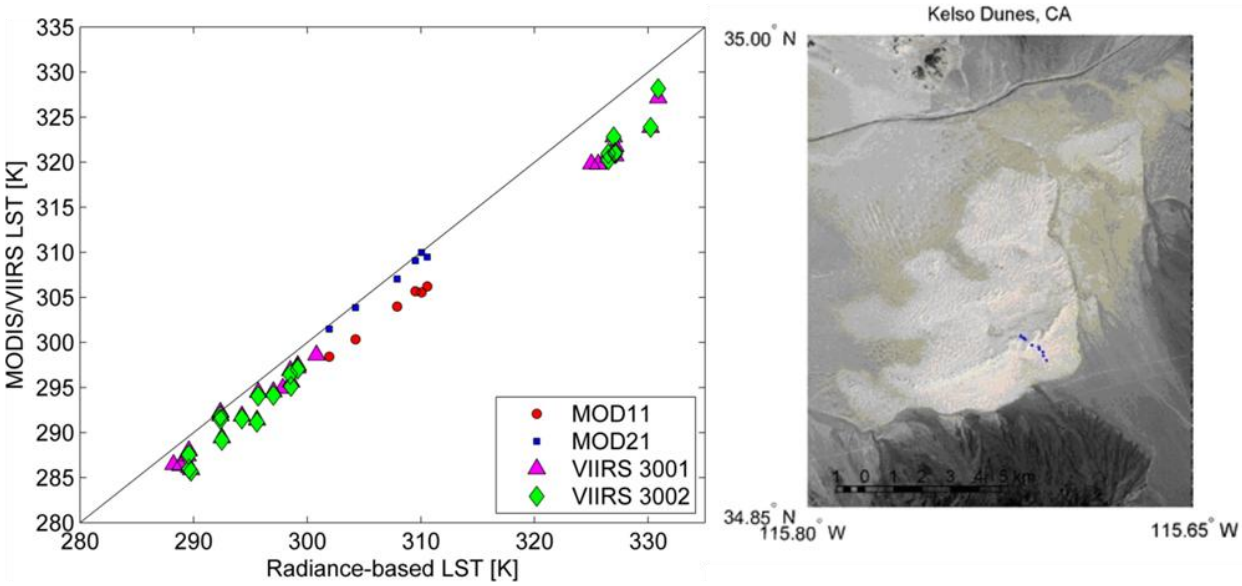

Figure 1: Plot of MODIS/VIIRS LST at the Kelso Dunes, CA pseudo invariant site versus radiance-based LST.

What climate/global change science can be done with the Land Surface Temperature EDR? The existing product is suitable for climate science over water and dense vegetation canopies. Example studies include measuring the change in inland water temperatures or measuring the evapotranspiration over dense canopies.

What climate/global change science can't be done with the Land Surface Temperature EDR? The existing product should not be used for climate science over semi-arid and arid regions or any science requiring accurate emissivities. Examples studies include estimating water vapor profiles from sounders where the surface emissivity is needed as an input or energy balance models over arid and semi-arid regions used for drought monitoring.

What would it take to get the Land Surface Temperature EDR in the shape needed to do the science that can't be done now? A science-quality LST product needs to be offered that includes accurate and physically retrieved temperatures and emissivities over arid and semi-arid regions. This product would then be merged with the IDPS product which is suitable for areas with dense vegetation cover or areas of water. The product shall be made available in daily and monthly earth gridded formats at full spatial resolution and on various climate grids.

Suitability of the VIIRS Sensor Data Records as it applies to the Land Surface Temperature EDR: The radiance at sensor product has also been validated at the Lake Tahoe and Salton Sea sites and shows good agreement with MODIS aqua (see Table 1). The difference between the MODIS Aqua band and equivalent VIIRS bands are (14-29) = -0.35, (15-31) = -0.04 and (16-32) = 0.05 K. These differences are reasonable but further work is required to evaluate performance over a range of viewing geometries.

2.2. Surface Type EDR

EDR Team: Mark Friedl (BU); Damien Sulla-Menashe (BU); Josh Gray (BU)

Overview

The VIIRS Surface Type EDR is a swath product built by re-projecting the Gridded Quarterly Surface Type IP and overlaying it with the Active Fire ARP, Snow Cover EDR, and Vegetation Fractional Greenness product. It is produced at 1 km spatial resolution based on the previous 12 months of VIIRS data. The EDR will provide 17 surface type classes following the IGBP classification scheme. The requirement for this EDR is 70 percent correctly classified. Off-the-shelf commercial software is used to generate the Gridded Quarterly Surface Type IP, which provides the foundation for the EDR. Specifically, the VIIRS Quarterly Surface Type IP algorithm uses the C5 ensemble decision tree classifier (www.rulequest.com) to perform a supervised classification of global VIIRS data using a set of global training sites. Input features include spectral information and temporal metrics developed from 12 months of VIIRS visible and infrared band information.

The team responsible for the Surface Type EDR includes Xiwu Zhan at NOAA/NESDIS/STAR, who provides oversight and management, Chengquan Huang and Kuan Song at UMD, who are responsible for algorithm implementation, and Mark Friedl and Damien Sulla-Menashe at BU, who provide data sets, input regarding algorithm implementation, and EDR validation. Note that because the Gridded Quarterly Surface Type IP requires a full year of input data from VIIRS, evaluation of the IP and EDR currently relies on prototype results from MODIS.

Current Status and Quality of the Surface Type EDR

The Surface Type EDR is expected to meet its target requirement of 70% overall classification accuracy. However, uniform land cover types (e.g., barren/sparsely vegetated; permanent snow and ice) are likely to have much higher classification accuracies than more complex and less separable classes. Results generated at STAR and UMD using MODIS data demonstrate that the algorithm is working, but also indicate significant challenges related to confusion among specific classes that are also problematic in the MODIS MCD12Q1 land cover product (e.g. shrublands, savannas, and mixture classes such as agricultural mosaic) (Friedl et al. 2010). The agriculture class, because of its global extent and diversity, is also challenging to map. It is unlikely that these issues will be resolved when the IP and EDR are generated from VIIRS data. We therefore expect that EDR accuracy will be below the 70% target for some classes. In this context, the use of commercial software places substantial constraints on the ability of the team at STAR and UMD to implement algorithm fixes such as those implemented in the MODIS land cover product. Differences in classification results across time will introduce spurious land cover changes that are also difficult to address in the current algorithm implementation.

What climate/global change science can be done with the Surface Type EDR? Once generated, the surface type EDR will support climate modeling activities by providing land cover boundary conditions. Most climate models require coarse resolution (i.e., 1-2 degree) representation of land surface properties; thus, spatial aggregation of Surface Type EDR data will likely reduce local-scale errors in classification results. At this scale and for this purpose, the

Surface Type EDR has good probability of providing continuity with the MODIS land cover product in support of climate science research and operations.

What climate/global change science can't be done with the Surface Type EDR? Climate science studies that require finer scale (< 1.0 km) information related to land cover and land cover change at local, regional, and in some cases even at global scales will not be well-served by the surface type EDR. The quality and accuracy of the surface type EDR will not be sufficient to support meaningful land cover change detection. This issue is especially relevant to studies that require local-to-regional land cover change products to quantify dynamics in terrestrial carbon and energy budgets. Part of this issue is attributable to the use of incremental and independent quarterly classifications that do not explicitly account for change, part is related to the 1 km spatial resolution of the IP and EDR, and part is related to limitations of the classification algorithm and the IGBP classification scheme. Further, the current EDR algorithm includes no mechanism to stabilize classifier results from one period to the next. Classifier errors and uncertainty will likely lead to substantial levels of spurious land cover change (i.e., land cover change that are not real) between EDR data sets in successive quarterly or annual time periods. This issue is not unique to the VIIRS product and is also an issue for the MODIS land cover product.

What would it take to get the Surface Type EDR in the shape needed to do the science that can't be done now? Surface Type (land cover) is a unique variable in context of climate science because it provides the basis for parameterizing land surface properties that are not directly observable from existing remote sensing assets (e.g., surface roughness, biomass, etc). Within this framework, two issues are critical to improving the science quality and utility of the Surface Type EDR:

(1) Improvements to the overall quality of the EDR, especially for the problematic classes identified above, will improve the science utility of the surface type EDR. For this to happen, the algorithm will need to migrate from the commercial software currently being used, to software developed in-house that can be tuned and refined to address errors in the Surface Type IP and EDR.

(2) Algorithm refinements are required that explicitly detect, characterize, and incorporate land cover change processes in the EDR. In addition, replacing the IGBP classification scheme with a system that is more appropriate for global land cover and land cover change mapping (and that is consistent with international land cover mapping conventions, e.g., based on the FAO LCCS system), would improve the science utility of the EDR.

Suitability of the VIIRS Sensor Data Records as it applies to the Surface Type EDR: Current evaluations suggest that the VIIRS SDRs (and associated calibration) are suitable for the surface type EDR. Current EDR limitations are much more dependent on (1) the 1 km spatial resolution of the EDR, (2) constraints imposed by the use of commercial software to perform the classification, (3) use of the IGBP classification system to represent land cover types, and (4) lack of an explicit strategy for integrating land cover change processes.

2.3. Surface Albedo EDR

EDR Team: Crystal B. Schaaf (UMB); Zhuosen Wang (UMB); Miguel Román (NASA GSFC)

Overview

Albedo, the quantity that specifies the proportion of the shortwave radiative flux that is reflected by the surface, is one of the primary VIIRS EDR's required by JPSS and S-NPP as well as being a GTOS Essential Climate Variable (ECV) (Schaaf et al. 2009). The VIIRS specification calls for only a broadband (0.3- 4.0 μm) value, retrieved on a daily basis under cloud-free conditions.

Two algorithms were originally implemented by the contractor to fulfill this operational requirement. The first (designated as a Dark Pixel Surface Albedo or DPSA) is derived from the well-validated MODIS heritage (Schaaf et al. 2002; Román et al. 2009; Román et al. 2010; Cescatti et al. 2012) and relies on the periodic multi-day retrieval of narrowband anisotropy models to estimate the Bidirectional Reflectance Distribution Function (BRDF) of each field of view. These periodic models are then coupled with the surface reflectance retrieved on any single day to obtain an estimate of the daily shortwave albedo at the overpass time. Similar approaches have been employed with data from MISR, Meteosat, MSG/Seviri and MERIS GLOBAlbedo. The second approach (designated as a Bright Pixel Surface Albedo or BPSA) relies on single-day top-of-atmosphere radiances and pre-computed radiative transfer model information to estimate daily broadband surface albedos (Liang et al. 2005; He et al. 2012).

Originally, the NPOESS prime contractor had implemented a strategy of providing two albedo retrievals (DPSA and BPSA) at each location. However, the contractor then designated the BPSA approach as the primary land albedo algorithm (despite the MODIS heritage of the DPSA approach). They did insist however that they would continue to produce the DPSA as an ancillary method. The contractor indicated that this decision to favor the BPSA algorithm was been made in part because both the sea ice and ocean albedo algorithms were going to use approaches similar to BPSA. Unfortunately, the only product that has been produced since launch has been the BPSA.

Current Status and Quality of the Surface Albedo EDR

The VIIRS broadband albedo that has been produced since launch has been plagued by large flaws and errors. At some point immediately prior to launch, the DPSA algorithm was completely turned off and only the BPSA output has been produced by the IDPS since launch. After the concern over the VIIRS telescope mirror degradation had subsided, the BPSA product was investigated over several field sites. The data were extremely noisy and variable, a condition ascribed to poor cloud clearing or atmospheric correction. However, investigation over a location in the Sahara revealed that this extreme variability continued over what should have been a stable calibration location (see Figure 2). A look-up table correction over the summer (IDPS MX 6.2 build) just exacerbated the problem. Current LUT updates seem to indicate that angular effects remain in the product. Investigation of recent papers using the BPSA approach seem to indicate that averaging (both spatially and temporally) must be used to derived a stable product. On the other hand, when daily VIIRS data are tested though the MODIS daily algorithm code (Wang et al. 2012), the results are very stable and very similar to what is achieved with

MODIS data. Therefore we conclude that the VIIRS input spectral data is behaving well, but the BPSA algorithm itself continues (one year after launch) to be unusable. Further evaluation of albedo over sea ice will be conducted by the Cryosphere Team, and albedo over land by the Surface Albedo EDR team.

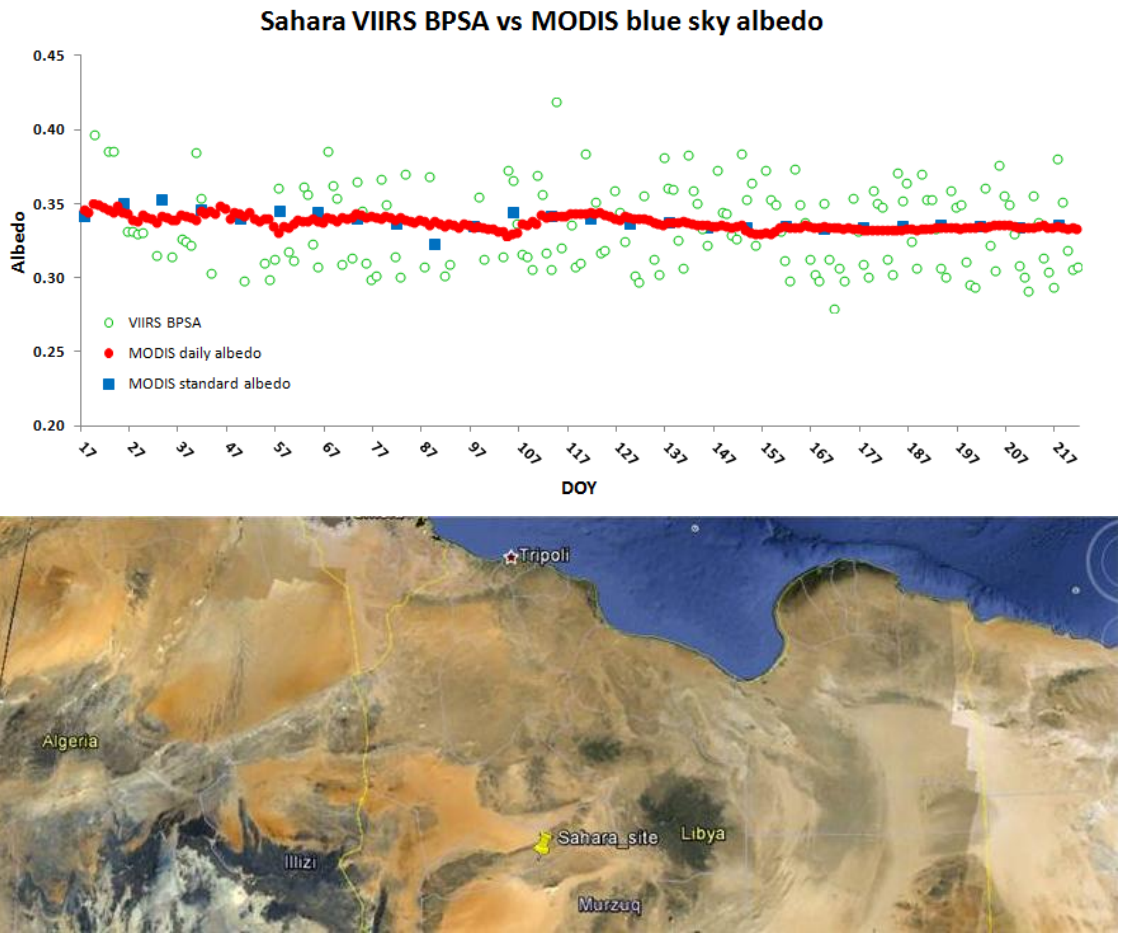

Figure 2: Comparison between VIIRS BPSA (black), MODIS V005 8day standard product (blue), and MODIS V006 daily albedo (analogous to DPSA) over the Sahara site (a stable desert location).

As long time NPP science team members, we have always vigorously opposed efforts by the contractor to reduce the spatial resolution of the VIIRS albedo product. Note that the MODIS algorithm (MCD43A) produces BRDF and albedo quantities at a spatial resolution of 500m in Collection 5 and this was implemented in response to user feedback. We have argued that coarser resolution albedos would only represent mixed surfaces (particularly in times of ephemeral snow fall or melt). Thus subpixel snow cover, open water and thin ice in the ice pack, residual water pooling and the variety of surface types typical in natural systems would all only be represented by coarse averages. Because of our strident objections, the VIIRS albedo product has continued to be generated at a higher spatial resolution, although the contractor did insist in the documentation that it only be evaluated at a coarser 4 km resolution (presumably to stabilize the BPSA algorithm through spatial averaging). This averaging evaluation requirement en-

sures that the product will not be as rigorous as the MODIS daily algorithm values. Furthermore, a 4km evaluation is not appropriate given that regional and mesoscale numerical weather prediction models are increasingly moving to land surface energy budget computations at higher and higher resolutions (e.g., 1 km spatial resolution at the UK Met Office)[7].

What climate/global change science can be done with the Surface Albedo EDR? In its present state, the VIIRS Surface Albedo EDR is not suitable for climate applications. While efforts are underway to reactivate the DPSA algorithm code, the current DPSA IDPS algorithm version (MX6) is not as advanced as the MODIS C6 product, which quantifies retrieval uncertainties on a daily basis through the use of the Root Mean Squared Error (RMSE) and angular weights of determination (WoD). Furthermore periodic reprocessing of the entire VIIRS record will be required to maintain a climate quality product.

What climate/global change science can't be done with the Surface Albedo EDR? From the outset, in our role as members of the S-NPP Science team, we have identified several significant problems, both with the original specification and with the approach implemented by the contractor. A primary difficulty is that the original specification only called for a single broadband value whereas most (if not all) numerical prediction models (and global climate and biogeochemical models) currently in use call for a representation of the surface radiation in terms of both the photosynthetically active radiation (shortwave radiation less than 0.7μm) and the near and mid-wave radiation (0.7- 4.0 μm). Many applications are relying on even more than two broad multispectral bands. While the DPSA approach actually calculates these quantities on a per band basis, the JPSS specification only guarantees that a single broadband albedo appropriate for a single illumination condition is actually provided to the operational user.

Since the operational user has no access to the underlying spectral anisotropy models (the DPSA BRDF Intermediate Product or IP) for each location, they are also precluded from computing spectral albedos for themselves, from computing albedo under other illumination conditions, from specifying the surface atmospheric boundary conditions, or from correcting surface reflectances to a common view-angle. Note that reflectances corrected to a nadir view (Nadir BRDF-Adjusted Reflectances or NBAR) are the primary input for the MODIS land cover and phenology products and a number of Direct Broadcast localities have already implemented the MODIS daily BRDF anisotropy model retrieval code so that they can generate view angle corrected data to monitor local land cover change, assess rangeland capacity and estimate agricultural productivity. NBAR values are also required by VIIRS to assist in the cloud algorithms. Furthermore, note that the MODIS C6 standard product will be now produced on a daily basis as well. This daily enhancement is of particular interest to the user community for monitoring snow and ice albedos, as well as vegetation phenology at times of rapid growth or senescence.

What would it take to get the Surface Albedo EDR in the shape needed to do the science that can't be done now? As indicated above, the loss of spectral anisotropy and albedo products from the VIIRS EDR already represents a major setback from the MODIS era. Access to the underlying spectral BRDF IP for DPSA would be required to compute both spectral and broad-

[7] It should be noted that the science team member will evaluate the Albedo EDR at the native 1km spatial resolution.

band albedo under other illumination conditions, to specify the surface boundary conditions, or to correct surface reflectances to a common view-angle for various monitoring and modeling activities. The spectral MODIS surface albedo and BRDF products have been embraced by the climate and numerical modeling community (NCAR-CLM; GISS-GCM; ECMWF; Hadley Centre HadGEM). Gap-filled products are also being extensively utilized by the MODIS Cloud Team, GMAO, GISS, ECMWF, and the UK Met Office for model initialization and data assimilation. MODIS albedo and anisotropy products are also being used as a-priori information for ESA's GLOBAlbedo project and are being coupled with Landsat for both high resolution albedo values and for the WELD data processing effort (Roy et al. 2010). Continued access to the underlying BRDF information at an increased number of spectral channels (and at a spatial resolution of 1km or better) is required to extend these important MODIS measurements into the VIIRS era. These modeling and monitoring needs will not be met by the single broadband albedo value currently specified for the VIIRS Albedo EDR.

Suitability of the VIIRS Sensor Data Records as it applies to the Surface Albedo EDR: The fact that we can run the VIIRS surface reflectances through the MODIS algorithms and achieve a high quality product gives us confidence that the VIIRS instrument is operating as it should and producing excellent SDRs. Therefore, from the point of view of the operational IDPS stream, it is the albedo algorithm itself and its implementation that continues to be a problem.

2.4. Vegetation Index EDR

EDR Team: Tomoaki Miura (U. Hawaii); Alfredo Huete (UA/UTS)

Overview

The VIIRS Vegetation Index (VI) EDR currently consists of two vegetation index products generated daily at the Imagery resolution (0.375 km at nadir) over land in swath/granule form: the Normalized Difference Vegetation Index (NDVI) from top-of-atmosphere (TOA) reflectances and the Enhanced Vegetation Index from atmospherically-corrected, top-of-canopy (TOC) reflectances:

$$NDVI = (I2TOA - I1TOA) / (I2TOA + I1TOA) \quad [1]$$

$$EVI = (1 + L)*(I2TOC - I1TOC)/(I2TOC + CI1*I1TOC - CM3*M3TOC + L) \quad [2]$$

where the spectral bands I1 and I2 are 600 - 680 nm and 845.5 - 884.5 nm, respectively; L, CI1, and CM3 are constants; M3 is the spectral band over 478 - 498 nm. The M3 band (0.750 km at nadir) has twice the cell dimension of the I1 and I2 bands (0.375 km at nadir), and its value is applied to 4 equivalent-area array cells. The VI EDR is based on bidirectional reflectance factor estimates, representing intrinsic measurements for actual sensor view and sun angle conditions (Schaepman-Strub et al. 2006).

Current Status and Quality of the Vegetation Index EDR

In general, VIIRS VI EDR is radiometrically performing well. Both TOA NDVI and TOC EVI depict spatial variations of global vegetation cover well without any noticeable sensor noise. VIIRS TOA NDVI and TOC EVI compare consistently well with those derived from Aqua MODIS for good observations obtained along their overlapped ground tracks (i.e., near-nadir, cloud-, cloud shadow-, and snow/ice-free, and clear atmosphere), and their differences show consistent patterns since February 2012. Temporal profiles of VIIRS TOA NDVI and TOC EVI show seasonal evolutions that correspond to vegetation growths over a wide variety of land cover conditions, which are comparable to those depicted in Aqua MODIS VI time series (Figure 3).

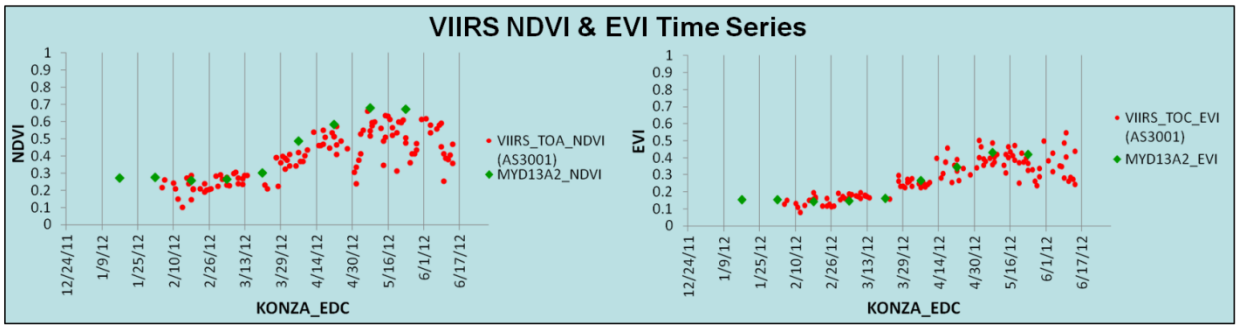

Figure 3: Comparison between VIIRS vegetation indices (red) and the MODIS V005 16-day standard product (green) over the Konza Prairie LTER (39.08N, -96.56E).

In detail, the current EDR contains several types of erroneous observations and retrievals. First, both the TOA NDVI and TOC EVI are subject to cloud contaminations. Recurrent instances of cloudy pixels that were undetected by the upstream processing or that could not properly be screened with the current set of VI quality flags have been found. Second, the current VI EDR also contains observations that are of low or suspicious quality. These include cloud shadow, adjacency cloud, snow/ice cover, and fire, all of which are not flagged with the current VI algorithm or the current set of VI QFs. Without a major revamp of the existing VI quality assurance fields (as proposed in Table 2), as well as compositing to reduce these contaminations to a standard view and solar geometry, the VIIRS VI temporal profiles (and thus, any long term data records derived from this product) will continue to show secondary variations that can be higher than the seasonal changes, in particular, in moderately- to low-seasonal forested areas.

For the VIIRS TOC EVI retrieval, many spatial gaps in the data have been found; particularly due to unavailability of M3 TOC reflectance. These conditions frequently occur over bright pixels (desert areas), and are likely a result from overcorrection of the atmosphere associated with overestimation of the VIIRS AOT retrieval. The TOC EVI product often contains unrealistically high or small values over snow/ice cover and also over cloud-contaminated pixels. Due to the adoption of a different gain factor from the heritage MODIS sensor, the dynamic range of VIIRS EVI is systematically reduced by ~20%.

Table 2: Comparison of the current, original quality assurance flags (QFs) to the proposed, new QFs. New QFs are colored in red.

	Current			Requested, New		
Byte	**Bits**	**VIIRS VI Quality Flag**	**Value**	**Bits**	**VIIRS VI Quality Flag**	**Value**
0	0	Overall NDVI Quality	0: Low 1: High	0	Overall NDVI Quality	0: Low 1: High
	1	Overall EVI Quality	0: Low 1: High	1	Overall EVI Quality	0: Low 1: High
	2	I1 TOA Reflectance	0: Available 1: Not available	2	I1 TOA Reflectance	0: Available 1: Not available
	3	I2 TOA Reflectance	0: Available 1: Not available	3	I2 TOA Reflectance	0: Available 1: Not available
	4	I1 Surface Reflectance	0: Available 1: Not available	4	I1 Surface Reflectance	0: Available 1: Not available
	5	I2 Surface Reflectance	0: Available 1: Not available	5	I2 Surface Reflectance	0: Available 1: Not available
	6	M3 Surface Reflectance	0: Available 1: Not available	6	M3 Surface Reflectance	0: Available 1: Not available
	7	EVI Range	0: In range 1: Out of range	7	EVI Range	0: In range [-0.2, 1.2] 1: Out of range
1	0-2	*Land/Water	000: Land & desert 001: Land/no desert 010: Inland water 011: Sea water 100: *not used* 101: Coastal 110: *not used* 111: *not used*	0-2	*Land/Water	000: Land & desert 001: Land/no desert 010: Inland water 011: Sea water 100: *not used* 101: Coastal 110: *not used* 111: *not used*
	3-4	*Cloud Confidence	00: Confidently clear 01: Probably clear 10: Probably cloudy 11: Confidently cloudy	3-4	*Cloud Confidence	00: Confidently clear 01: Probably clear 10: Probably cloudy 11: Confidently cloudy
	5-6	*Sun Glint	00: None 01: Geometry based 10: Wind speed based 11: Geometry * Wind	5-6	*Sun Glint	00: None 01: Geometry based 10: Wind speed based 11: Geometry * Wind
	7	*Thin Cirrus (Reflective)	0: False (no) 1: True (yes)	7	*Thin Cirrus (Reflective)	0: False (no) 1: True (yes)
2	0	Stratification – Solar Zenith Angle	0: SZA < 65 or > 85 1: 65 ≤ SZA ≤ 85	0	Stratification – Solar Zenith Angle	0: SZA < 65 or > 85 1: 65 ≤ SZA ≤ 85
	1	*Excl – AOT > 1.0	0: AOT ≤ 1.0 1: AOT > 1.0	1	*Snow/Ice	0: False (no) 1: True (yes)
	2	Excl – Solar Zenith Angle > 85 Deg	0: SZA ≤ 85 1: SZA > 85	2	Excl – Solar Zenith Angle > 85 Deg	0: SZA ≤ 85 1: SZA > 85
	3	*spare bit*	*set to 0*	3-4	*Aerosol Quantity	00: Climatology 01: Low 10: Average 11: High
	4	*spare bit*	*set to 0*			
	5	*spare bit*	*set to 0*	5	*Adjacency Clouds	0: False (no) 1: True (yes)
	6	*spare bit*	*set to 0*	6	*Cloud Shadows	0: False (no) 1: True (yes)
	7	*spare bit*	*set to 0*	7	*Fire	0: False (no) 1: True (yes)

* Copied from Surface Reflectance IP

What climate/global change science can be done with the Vegetation Index EDR? A wide range of the Earth science and applications user community groups are using VI time series in natural resource management, agriculture, invasive species monitoring, and public health. A near real-time VI consistent with that from MODIS data as currently being entrained into the LANCE would be useful for several near real-time operational monitoring and prediction applications, including phenological monitoring and forecasting, drought monitoring, famine early warning, yield production prediction, and weather forecasting.

These operational monitoring applications compare the latest values against historical records and, therefore, the need for VIIRS VI EDR compatibility with MODIS is of significant importance. Likewise, most of these operational systems have adopted TOC NDVI which are either composited on-site or generated via rolling composites and gap-filled image data (Gao et al. 2008).

What climate/global change science can't be done with the Vegetation Index EDR? Vegetation Indexes are among the most widely used satellite products, providing key measurements to climate studies addressing inter-annual variability and/or long-term changes of terrestrial ecosystems, climate-vegetation interactions, and biogeochemical and hydrological cycle models that ingest the VI data records.

The current VIIRS VI EDR is not optimized for these science applications. The current VI EDR algorithm has several issues restricting its applicability and utilities for climate sciences:

1. The TOA NDVI contains atmosphere variations as part of its signal, and thereby can result in poor relationships to surface vegetation dynamics and poor continuity with the TOC-based MODIS NDVI (Miura et al., 2013);

2. VI time series provided by the current EDR is subject to variations unassociated with surface vegetation changes due to incomplete screening of low quality observations;

3. While VIIRS TOC EVI shows sensitivity comparable to that of MODIS EVI, the VIIRS sensor has a spectrally different blue band from the heritage MODIS sensor, and requires an adjustment to the EVI coefficient for optimal EVI performance;

4. The altered dynamic range in the VIIRS EVI (a systematic 20% reduction in values relative to MODIS EVI) will result in confusion and discontinuity to the modeling and phenology communities who may be expecting more MODIS-like values;

5. TOC EVI can produce unrealistically low or high values over snow/ice surfaces and residual cloud-contaminated pixels for a lack of a backup algorithm;

6. The current set of QFs contained in the VI EDR does not allow users to thoroughly screen low or suspicious quality observations.

What would it take to get the Vegetation Index EDR in the shape needed to do the science that can't be done now? The quality of VIIRS VI EDR will be adequate if many of the constraints mentioned above are removed or minimized. Required changes to optimize the current VI EDR include:

1. Addition of a Top-of-Canopy NDVI. The TOA NDVI product will have very little value to the scientific and applications communities that already routinely ingest NDVI values that are partially (as in AVHRR-NDVI) or completely atmosphere-corrected (as in MODIS-NDVI).

2. Incorporation of an EVI backup algorithm over snow/ice cover (and residual clouds).

3. Provision of spatially gridded values at moderate (375 m – 1 km) and Climate Modeling Grid (CMG) resolutions.

4. Provision of temporally-composited products (based on 'intrinsic' measurements or nadir BRDF-adjusted reflectance) that minimize residual contaminations, and standardize measurements to nadir viewing, and fill gaps.

5. Adjustment of the EVI blue band coefficient to reflect the different VIIRS blue bandpass.

6. Adjustment of the EVI equation to the same structure as in the MODIS EVI equation.

7. Revision of quality assurance fields to allow for more thorough screening of VI data.

8. Establishment of product continuity with heritage sensors across a range of applications.

9. Revision of Level 1 Requirements Document (L1RD) supplement to more realistic accuracy and uncertainty specifications.

10. Improvement in the upstream processing algorithms, including cloud mask and atmospheric correction.

It is also desirable to conduct a sensitivity analysis study to determine the benefits and weakness of eliminating the blue band in EVI and using a two-band EVI (Jiang et al. 2008).

Suitability of the VIIRS Sensor Data Records as it applies to the Vegetation Index EDR: Overall, the VIIRS SDR data will be of sufficient quality to generate atmosphere-corrected surface reflectance values in support of NASA science objectives. However, it is of crucial importance that the VIIRS SDRs provide well-calibrated radiance or TOA reflectance throughout the entire mission so that calibration errors would not potentially be mistaken as climate signals in VI time series analysis. Studies conducted on the scan mirror degradation so far found little or no significant impacts on the VIIRS VI EDR performance. The potential impact of VIIRS along-scan pixel size changes need to be thoroughly assessed.

2.5. Ice Characterization EDR

EDR Team: James Maslanik (U. Colorado); Mark Tschudi (U. Colorado); Dan Baldwin (U. Colorado); Jeffrey R. Key (NOAA/NESDIS/STAR); Xuanji Wang (U. Wisconsin); Yinghui Liu (U. Wisconsin)

Overview

The VIIRS Sea Ice Characterization (SIC) EDR uses the VIIRS Sea Ice Concentration intermediate product (IP) as a primary input. There is no heritage MODIS product for the SIC EDR. The Sea Ice Concentration IP is not a deliverable product, although we are evaluating its accuracy vs. MODIS sea ice extent products.

The SIC EDR is an ice age classification map that contains classifications for Ice-free, New/Young Ice and All Other Ice categories. New/Young ice has a maximum thickness of 30cm, while All Other Ice is thicker than 30cm. The EDR does not include fresh-water ice and may also exclude some shore-fast ice areas, depending on the land mask used. It is produced both day and night over the oceans. The requirement for this EDR is 70% probability of correct typing. In addition to the ice concentration IP, the EDR also has dependencies on the surface temperature and surface reflectance IPs.

The VIIRS SIC algorithm is essentially a one-dimensional ice thickness model based on the surface energy budget. Inputs such as cloud properties, near surface wind speed, vapor pressure, surface temperature, albedo, and snow depth are used to solve the energy budget for ice thickness. The nighttime algorithm does not utilize albedo as input, relying more on the Ice Surface Temperature EDR to determine ice growth and subsequent thickness.

Current Status and Quality of the Ice Characterization EDR

The SIC EDR in its present form is unlikely to meet the specification of 70% probability for correct classification. Although the Sea Ice Concentration IP agrees well with the MODIS sea ice extent product for comparisons performed in the Beaufort Sea region (shown in Figure 4), the classification of ice type by the Sea Ice Characterization EDR can be highly inaccurate. The SIC EDR is thus likely to be useful for identification of ice vs. ice-free areas, but there is no specification for this capability.

During winter, ice misclassifications have been found that are likely due to atmospheric effects, such as surface inversions, low opacity clouds or ice fog, which likely result in errors to the ice surface temperature EDR that are in turn passed to the SIC EDR. During the melt season, the lower reflectance of melting sea ice appears to cause the SIC EDR to indicate New/Young Ice, although this type of ice cannot be present this time of year. Errors in snow depth parameterization also appear to contribute to this misclassification.

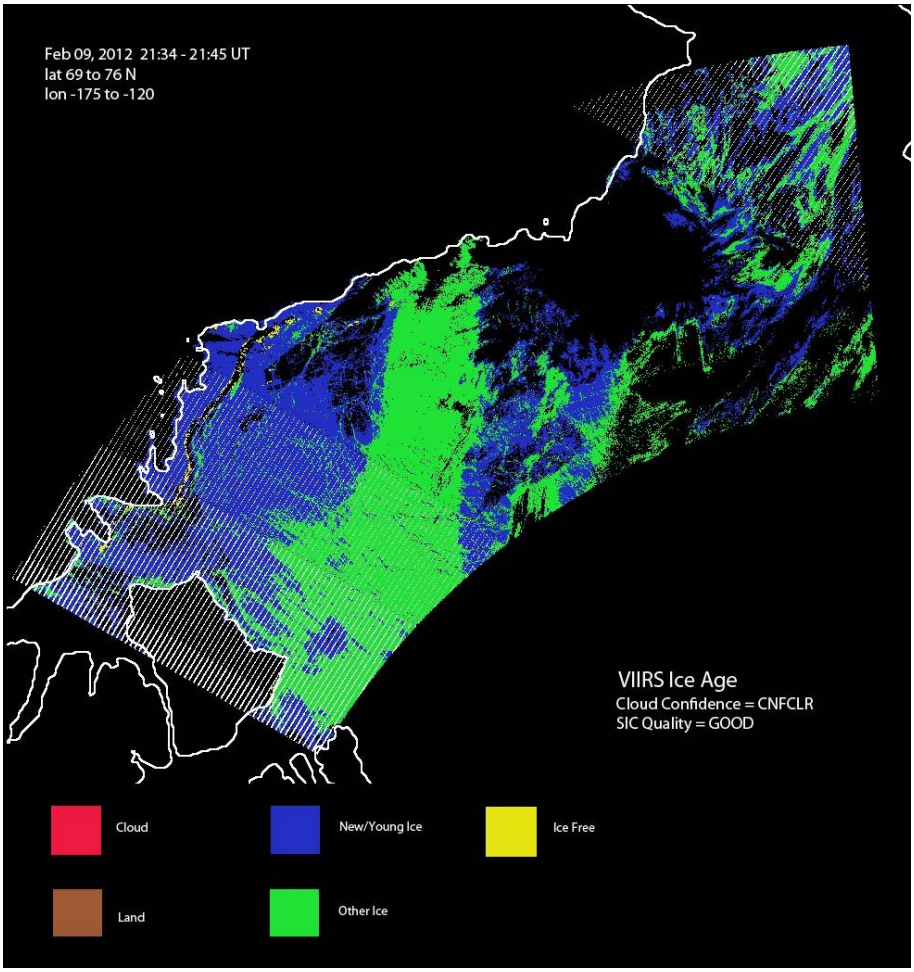

Figure 4: VIIRS SIC on Feb 9, 2012 in the Beaufort Sea for VIIRS cloud mask confidently clear and good SIC quality flag data. New/Young ice on left is misclassified, likely due to atmospheric effects on ice surface temperature. Figure by D. Baldwin.

What climate/global change science can be done with the Ice Characterization EDR? In its present state, the VIIRS Sea Ice Characterization EDR is not suitable for climate applications, unless the product is used strictly as an "ice vs. no-ice" classifier. Note that this classification could also be achieved by using the Sea Ice Concentration IP.

What climate/global change science can't be done with the Ice Characterization EDR? The VIIRS Sea Ice Characterization EDR is not currently useable for climate applications. Although the EDR algorithm appears physically sound, our analysis to-date has found that its accuracy is affected adversely by errors in the algorithm's inputs. The routine's estimate of ice thickness is sensitive to errors in the depth of the snow and the surface albedo. Uncertainties in these quantities are currently large, particularly for snow depth. There is currently no reliable method of determining the depth of snow on ice from satellite, so the snow accumulation must be determined by using snowfall rates over the time of ice presence, which introduces significant error, particularly in areas where new ice growth is inaccurately computed.

This EDR potentially provides a valuable comparison to ice age from passive microwave sensors, which can distinguish between first-year and multi-year sea ice, and in some cases, between thick first-year and new/young ice. The VIIRS EDR could be blended, or replaced with, passive microwave ice age during the summer, when the low microwave emissivity of melting ice makes ice typing difficult.

Classification of new/young ice and older ice is also useful in modeling, as it provides some indication of the ice thickness, which is critical for the surface energy budget. Ice thickness information is currently underutilized in numerical weather prediction, but is becoming more utilized in some climate models, such as NCAR's CCSM.

Although excluded from the Sea Ice Characterization EDR, mapping of fresh-water ice is recommended. A fresh-water ice product is important for climate research investigating trends in lake freeze-up and break-up, which are good indicators of large-scale temperature changes. It is also important for studies of trends in ice coverage over large lakes such as the Great Lakes.

Note that the Sea Ice Concentration IP may not be available after Cal/Val tasks are completed. However, we recommend that this product be maintained, as it serves as a continuity product for MODIS ice extent, and is more accurate in resolution than passive microwave sea ice concentration products. In addition, this IP likely performs better than the passive microwave products during the melt season.

What would it take to get the Ice Characterization EDR in the shape needed to do the science that can't be done now? Challenges with providing precise algorithm input as described above suggest that this algorithm may need to be simplified or replaced, but our evaluation is not yet complete to recommend this course of action. Plans to likely improve algorithm sea ice classification accuracy include modifying and testing updated snow albedo values over sea ice, particularly during melt, which is not currently accounted for although it is a time when albedo changes dramatically. Sea ice albedo is not currently included as a Level 1 product, although it is provided as an auxiliary lower-resolution (4km) product. Since sea ice albedo can vary considerably (from 0.4 to 0.9) over a small area, especially during the melt season, we recommend that it be included in the albedo EDR product at the higher (750m) resolution (*cf.*, Section 2.3).

Uncertainty in cloud cover (amount and properties) is also relatively large for polar regions. The VIIRS Cloud Mask algorithm should also be updated to identify some polar clouds not currently detected, but due to the lack of certain channels available in the MODIS instrument, identifying optically thin clouds and other atmospheric phenomena (such as ice fog) will be more challenging.

2.6. Ice Surface Temperature EDR

EDR Team Jeffrey R. Key (NOAA/NESDIS/STAR); Xuanji Wang (U. Wisconsin); Yinghui Liu (U. Wisconsin); James Maslanik (U. Colorado); Mark Tschudi (U. Colorado); Dan Baldwin (U. Colorado)

Overview

The VIIRS Ice Surface Temperature (IST) EDR provides a "skin temperature" for sea-ice covered areas. In this context, sea ice is considered to be ice and any overlying snow, given that bare ice exists for only a short period during the summer or when new ice is forming. The IST EDR is produced for clear skies both day and night over the oceans. It does not include areas of fresh-water ice (see Figure 5a). For these areas, surface temperatures are provided by the Land Surface Temperature (LST) EDR. The VIIRS IST algorithm is basically the same type of statistical (linear multi-channel regression) approach as the LST EDR. This uses the "split window" approach, regressing VIIRS channels 11 and 12 vs. observed IST, and thus depends on the use of available IST observations.

Current Status and Quality of the Ice Surface Temperature EDR

Validation of IST has been done primarily through comparisons to MODIS IST (similar algorithm) and KT-19 measurements from NASA IceBridge aircraft. Results suggest that VIIRS IST underestimates the surface temperature by 1 to 2 degrees C (see Figure 5b). Differences between VIIRS IST and drifting ice buoys are greater, though the buoy temperatures are air temperatures rather than skin temperatures. Updating the regression coefficients with more robust training data may reduce this bias. However, this process is limited by the availability of good observations for algorithm tuning, and the accuracies of the supporting intermediate products (IPs). Given that IST retrievals are only done in clear sky conditions, there is a strong dependence on the VIIRS cloud mask (VCM). Validation of both the IST and the Sea Ice Characterization EDRs indicates that errors in the VCM at high latitudes are common and problematic. Potential improvement in the VCM for polar regions is therefore essential for improving the IST EDR.

What climate/global change science can be done with the Ice Surface Temperature EDR?
IST is critical for long-term change detection, estimating ice thickness and characterizing the ice into new/young versus thick ice, either through simple algorithms or through energy balance modeling. It also provides a comparison data set for analyses of climate and forecast models. The VIIRS IST EDR appears likely to meet the science community needs for these purposes. Based on the performance of its heritage AVHRR and MODIS algorithms, the IST EDR should meet its accuracy specification for the conditions that do not fall within the exclusion categories. This also assumes that the IPs upon which the IST EDR depends also meet specification, or if not, that the effects of the IP accuracies are not critical. The accuracy of the IST product therefore will vary by region, conditions and time of year.

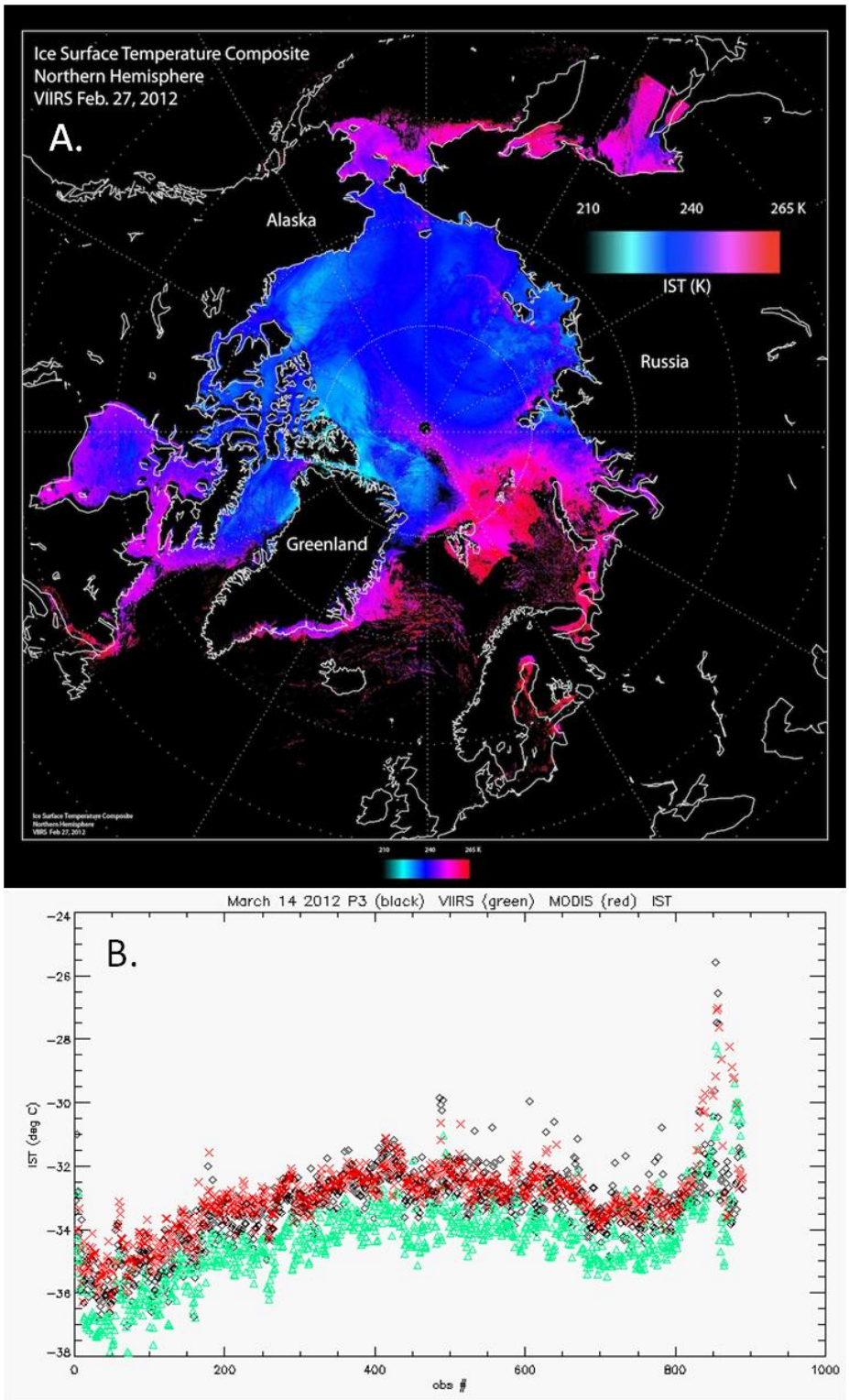

Figure 5: (A) Composite of VIIRS IST over the Arctic on 27 February 2012. (B) Comparison of VIIRS IST (green) with MODIS IST (red) and skin temperatures measured by aircraft (NASA P3, IceBridge), 14 March 2012 (black).

What climate/global change science can't be done with the Ice Surface Temperature EDR? While not included within the IST EDR, surface temperatures over coastal sea ice (which will potentially include significant portions of land-fast ice), fresh-water ice, and land ice (glaciers, etc.) are critical for climate investigations. The LST or IST algorithms are not specifically tuned for these conditions, so it will be important to determine the degree to which this affects accuracy. There is no reason why an appropriate IST calculation cannot be done over fresh-water ice. This would be useful for climate researchers and operational users investigating areas such as the Great Lakes, for example, and is also valuable for long-term climate change studies investigating patterns of Arctic and sub-Arctic lakes.

What would it take to get the Ice Surface Temperature EDR in the shape needed to do the science that can't be done now? Analysis of the IST EDR to date by the Cryosphere Team suggests that the IST EDR algorithm is currently suitable to perform the climate science summarized above; with the exception that modification to regression coefficients is likely needed to correct for biases in ice surface temperature when compared to the MODIS IST product. Note also the desired additional capability for the VIIRS IST EDR to map surface temperature over freshwater ice. This may require additional adjustments to some parameters for this application.

2.7. Snow Cover EDR

EDR Team: George Riggs (SSAI); Dorothy Hall (NASA GSFC)

Overview

The VIIRS Snow Cover suite of products includes the Snow Cover Binary Map and the Snow Cover Fraction Map. The Snow Cover Binary Map is a swath product. It will be produced at 375m maximum spatial resolution in the daytime. Snow will be identified only in pixels defined as confidently clear. The requirement for this EDR is 90% probability of correct typing.

The VIIRS snow EDR is designed after the snow MODIS algorithm, and thus the VIIRS snow product will permit continuity in research using VIIRS and MODIS together, and ultimately only using VIIRS. It employs a threshold-based decision-tree algorithm to separate snow free and snow covered pixels. The VIIRS cloud mask is used to exclude cloudy pixels from the classification process.

Evaluation of the IDPS VIIRS snow cover EDRs is done using the Land PEATE versions of the IDPS EDRs in MODIS product-like form and format (HDF-EOS). The LAADS archive and VIIRS data reprojection tools provided by LPEATE are used. Note that using LPEATE-supported products allowed for reuse of existing SCF tools and software for evaluation of MODIS to be used with VIIRS EDRs, thus maximized all existing resources for evaluation of the VIIRS Snow Cover EDR. Evaluation of the IDPS HDF5 snow cover EDRs obtained from the CLASS was initiated, then abandoned because of difficulties encountered in using that format.

Current Status and Quality of the Snow Cover EDR

The VIIRS Binary Snow Cover EDR (VSCM) is very similar in quality to the MODIS snow cover product MYD10_L2 (*cf.*, Figure 6). Our results show that the VSCM and MYD10_L2 are very similar in accuracy in mapping snow cover extent. Confusion between clouds and snow that decreases accuracy in snow extent exists in both products. The VSCM has lesser extent of snow/cloud confusion (e.g. around snow covered Plains in Nebraska to Iowa in Figure 6a and b). The VSCM EDR uses the same NDSI algorithm as MODIS to map snow cover, but using a different wavelength (VIIRS 0.640 µm vs. MODIS 0.555 µm). The difference in visible bands may have an effect on sensitivity or threshold selection of the NDSI for snow cover-mapping. This effect has not been investigated. Since the VSCM and MODIS are very similar, the working assumption is that the VSCM has an overall accuracy of ~90%, which is similar to that of MODIS in clear conditions. The VSCM accuracy and quality has been observed to be static over seasons and many situations compared to the MYD10_L2 and other snow cover maps.

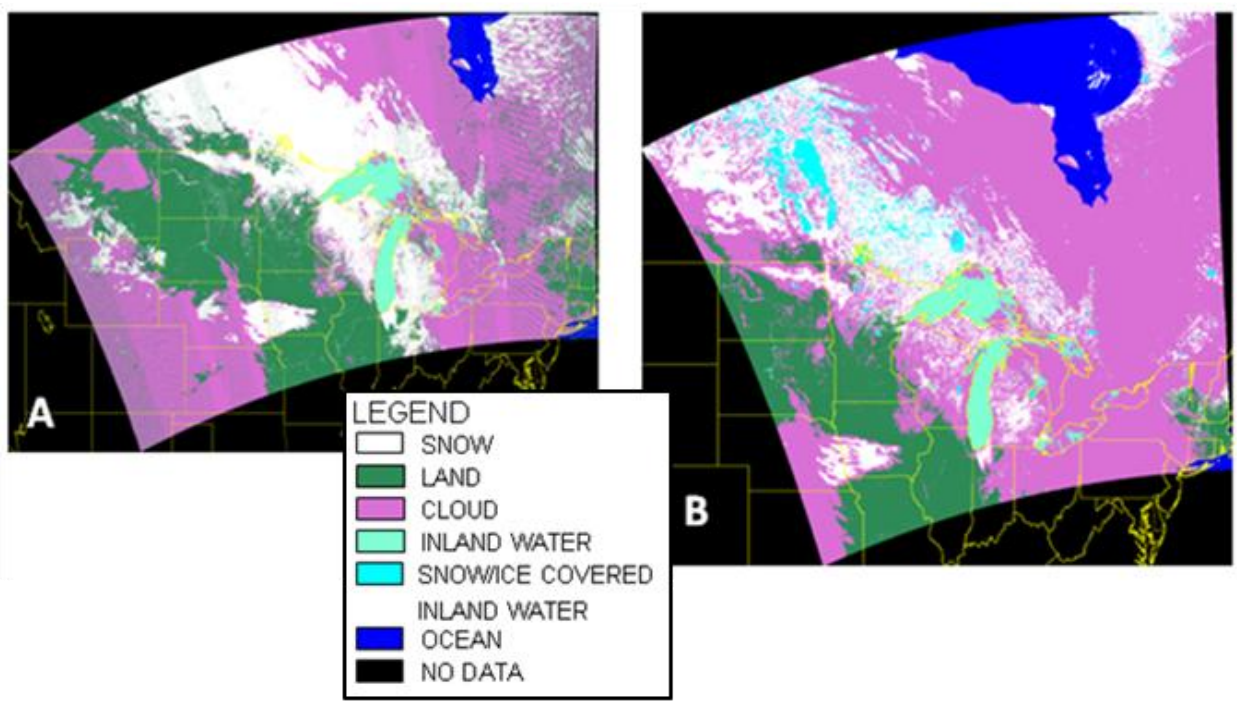

Figure 6: (A) VIIRS VSCM Snow Cover Binary map, 12 February 2012, 1850 GMT, 375 m resolution, rendered to a thematic map with land/water mask and cloud ask overlaid. (B) MODIS thematic snow cover map, 12 February 2012, 1845 GTM, 500 m resolution.

The VIIRS Snow Fraction EDR (VSCD) is made by spatially aggregating four adjacent pixels in the Binary Snow Cover EDR (VSCM). The pixel aggregation algorithm of the VSCD outputs fractional snow cover in four discrete classes, 25%, 50%, 75%, 100% (Figure 7b) There is no similarity between the VSCD and the MODIS Level-2 fractional snow cover algorithms, which is based on a NDSI regression using reflectance for input to estimate fractional snow cover continuously over the 1-100% range (Salomonson and Appel 2004). The VSCD maps the same snow extent as VSCM but at a coarser resolution (Riggs and Hall 2012). Quality of the VSCD is less than the corresponding VSCM because of the lower spatial resolution. Thus VSCD does not have continuity with MODIS and cannot be quantitatively assessed against MODIS fractional snow product.

What climate/global change science can be done with the Snow Cover EDR? While the VIIRS Snow Fraction EDR (VSCD) is unlikely to be useful for climate science, the VIIRS Binary Snow Cover EDR (VSCM) is useful for characterizing and understanding change in the Earth system. Specifically, we anticipate that the VSCM can be used to quantify changing distributions of snow cover that may result from climate change at regional to global scales. The VSCM also provides continuity with the MODIS snow cover product(s). In the near term these products can be used to detect seasonal and/or annual anomalies from the long term (30 year) snow cover climatology. Changes in snow cover extent and/or temporal occurrence have impacts on the hydrologic cycle and energy balance.

What climate/global change science can't be done with the Snow Cover EDR? While climate science can be done with the IDPS VIIRS Binary Snow Cover EDR (VSCM) product, the product format discourages its use. The IDPS product exists only as a Level-2 swath product in HDF5; a product level and format that are challenging, for users to access and use in climate change research.

The IDPS VIIRS Snow Fraction EDR (VSCD) is not usable in climate research because it does not provide estimates of fractional snow cover at the pixel level necessary to perform assessments at a local or regional scales. Climate modelers working at coarser spatial scales could possibly use the VSCD; but the IDPS product exists only as a Level-2 swath product in HDF5 a product level and format that are challenging, for users to access and use in climate change research where data inputs are commonly in gridded and projected formats.

What would it take to get the Snow Cover EDR in the shape needed to do the science that can't be done now? The IDPS VSCM product needs to be produced as a sequence of products similar to the MODIS snow cover products (Riggs et al. 2006) and in HDF-EOS format for the community. A lesson learned from the EOS-era, is that users prefer daily, gridded, projected products for use in research. The vast majority of science done with the MODIS snow products has been with the daily tiled product (MOD10A1) or daily climate modeling global product (CMG).

Investigation of sources of snow/cloud confusion emanating from the VIIRS Cloud Mask (VCM) algorithm must be done to alleviate, if possible, that snow/cloud confusion so that more accurate VIIRS snow EDRs can be made. Recent investigations have found that some situations of confusion could be alleviated if individual cloud mask flags (MOD35_L2) were used in the snow algorithm (Riggs and Hall 2002). Collaboration with the JPSS VCM group would be necessary to such an investigation.

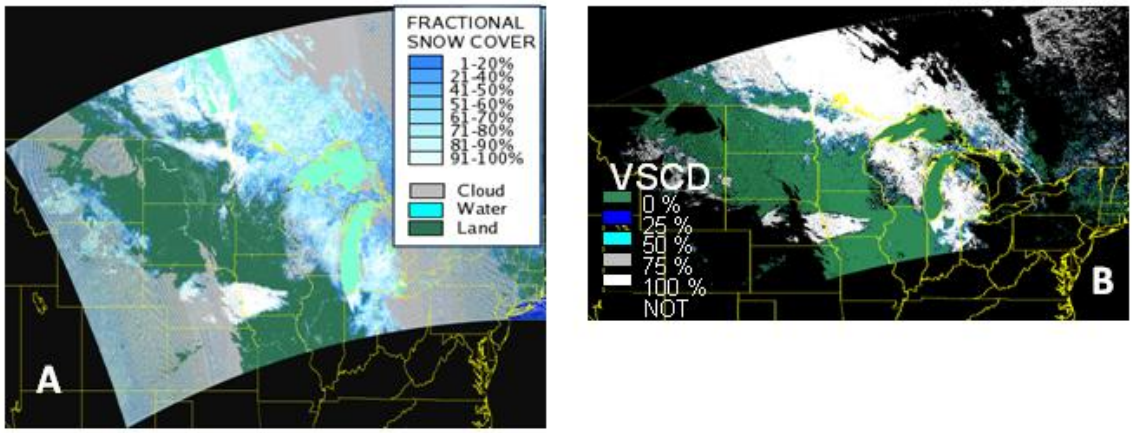

Figure 7: (A) VIIRS Fractional Cover map made using the MODIS FSC algorithm with VIIRS TOA SDR imagery (VIAE) data (12 February 2012, 1850 GMT 375 m resolution). (B) VIIRS VSCD Snow Cover Fraction (12 February 2012, 1850 GMT 750 m resolution.)

A fractional snow cover algorithm based on a technique using spectral reflectance input is required to address issues surrounding the VIIRS Snow Fraction EDR (VSCD). The MODIS fractional snow algorithm has been applied to VIIRS data with excellent results. Fractional snow cover using the MODIS FSC algorithm with VIIRS inputs (Figure 7a) is compared to the VSCD (Fig. 2B) to demonstrate the detail and variation in snow cover that can be captured using the MODIS algorithm with VIIRS data input (Riggs and Hall 2012).

The success of this effort will depend on continuing support and availability of Land PEATE expertise and resources to develop fractional snow cover algorithms for VIIRS; specifically to enable baselining and production of higher level gridded products. LPEATE has demonstrated to have the flexibility to make and/or revise algorithms and perform global science test runs, which the current IDPS, GRAVITE, and ADL environment have not.

Suitability of the VIIRS Sensor Data Records as it applies to the Snow Cover EDR: The VIIRS SDR Imagery Resolution product (VIAE) is suitable for the snow cover EDRs. A capability for long-term monitoring of VIIRS sensor calibration stability is essential to the snow cover EDRs.

2.8. Active Fires ARP

ARP Team: *Ivan Csiszar (NOAA/NESDIS/STAR); Chris Justice (UMCP), Louis Giglio (UMCP); Wilfrid Schroeder (NOAA/NESDIS/STAR)*

Overview

The Suomi-NPP VIIRS Active Fires (AF) baseline product was built on the EOS MODIS Collection 4 Fire and Thermal Anomalies algorithm. The main tests designed to identify fire-affected pixels in the image swath data mimic the MODIS algorithm with no specific tuning or considera-

tion of unique spectral and/or spatial characteristics involving the primary VIIRS fire channels used (i.e., the 3.9-4.1μm [M13] and 10.2-11.2μm [M15] bands).

Current Status and Quality of the Active Fires ARP

In terms of algorithm performance, the current IDPS MX6.3 product shows satisfactory results with good overall correlation with near-coincident Aqua/MODIS active fire product data (*cf.*, Figure 8). However, false alarms leading to large clusters of spurious fire pixels occasionally occur due to inappropriate handling of the input SDR quality flags. This and earlier quality issues have been documented. Most recently, the JPSS Algorithm Engineering Review Board (AERB) approved the release of the Active Fires ARP to the public with a Beta level quality as of May 2012 (Csiszar et al. 2012).

What climate/global change science can be done with the Active Fires ARP? If accepted by the JPSS, the changes proposed for the IDPS-based VIIRS AF will improve the product's utility in support of climate science applications as they provide a baseline for the development of several important higher level products, including VIIRS versions of the widely used "tiled" MODIS Level 3 8-day and daily fire products.

What climate/global change science can't be done with the Active Fires ARP? Currently, the IDPS version of the AF product provides a single one-dimensional list of fire pixel coordinates and therefore lacks key information about image-wide areas where no fires were detected and about the corresponding fire pixel characteristics (e.g., FRP). This is inconsistent with the MODIS product and by and large prevents use of the data by the climate science community, since models fundamentally require 2D fire input data and the associated metadata information (including fire pixel characteristics) to operate.

Another remaining issue is that the swath-level MODIS active fire product contains additional data layers that facilitate production of the MODIS Climate Modeling Grid (CMG) 8-day and monthly product suite. If the inclusion of the equivalent layers in the proposed VIIRS AF EDR is deemed unfeasible, production of compatible VIIRS CMG fire products will be a major challenge due to the enormous data volumes required to acquire these additional layers retrospectively. Differences in the spatial sampling between MODIS and VIIRS (pixel size, along-scan aggregation scheme, swath width) will result in differences in the spatially and temporally aggregated fire statistics in CMG products that will require the development of methodologies to establish a data record for climate monitoring purposes.

New Level 1 requirements are currently being set for the Active Fire Products and even if these are all implemented there will be a need to reprocess the entire archive up to that point and periodically as the algorithm is improved.

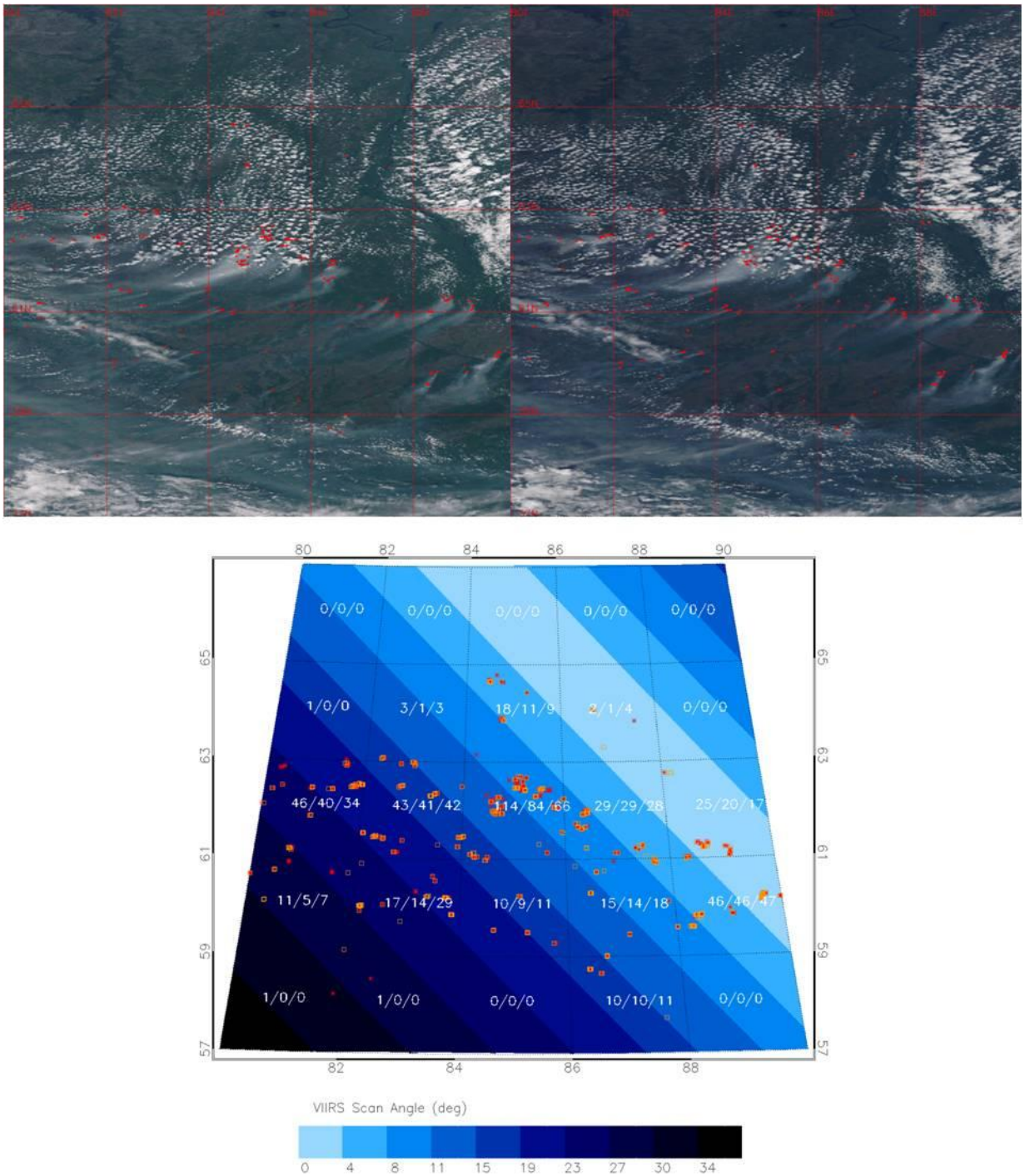

Figure 8: Comparison of Suomi NPP VIIRS and Aqua MODIS fire detections in Western Siberia. Upper left: VIIRS detections from the IDPS product over M5-M4-M3 RGB imagery on June 16 2012 6:15 UTC. Upper right: MODIS detections (MYD14) over bands 1-4-3 RGB imagery at 6:42 UTC. Fire detections are indicated by red dots. Bottom: number of VIIRS fire pixels/number of VIIRS fire pixels overlapping with MODIS fire pixels/number of MODIS fire pixels within each 2x2° grid cell.

What would it take to get the Active Fires ARP in the shape needed to do the science that can't be done now? The current VIIRS AF product merely provides vector layers containing the geographic coordinates of fire-affected pixels with no additional fire information and no swath-wide classification mask. However, as a result of input from the VIIRS AF team and the user communities of the MODIS AF product, the proposed new JPSS L1 requirements now include elements to make the next generation of the VIIRS AF product more compatible with the MODIS fire product. These requirements include a full fire mask and a fire radiative power layer, and promoting the Active Fires product to a true EDR.

Development of a revised VIIRS AF algorithm that complies with the new L1 requirements is ongoing with the Land PEATE and provisionally includes the following: (1) a code upgrade to the MODIS Collection 6 algorithm, which implements ocean processing for gas flares, a new false-alarm rejection test over tropical regions, and dynamic potential fire thresholds; (ii) inclusion of a fire radiative power retrieval; and (iii) inclusion of an additional two-dimensional image classification layer (mask) discriminating between fire-affected and fire-free pixels (e.g., land surfaces, water, clouds). Additional tuning will follow to optimize the algorithm for the spectral and spatial characteristics of the VIIRS sensor. This would provide L2 Swath Product equivalent to that from MODIS.

An improved active fire science code is being tested by the Land PEATE for comparison with the EDR. The output from this code will enable the current suite of MODIS Active Fire Products, (i.e. Level 2G, Level 3 Tile Products, the CMG (8 day and monthly) and Monthly Fire Information (MCD14ML)) to be generated. None of these can be generated by the IDPS as currently configured and therefore will need to be generated outside of the IDPS. Also for science use these would need to be generated from the beginning of the satellite record.

Suitability of the VIIRS Sensor Data Records as it applies to the Active Fires ARP: Overall, the VIIRS SDR data sets are considered of satisfactory quality leading to good fire detection performance and compatibility with the MODIS time series. No major/long-standing calibration issue has been identified or associated with deviations from nominal fire detection performance. However, the AF team does have two main recommendations to make involving the generation of current and/or future SDR data files. These are:

(1) SDR data reprocessing: provisions for data reprocessing and testing are missing and that is a key limitation of the current system preventing the development of climate data records from VIIRS. Data processing systems must incorporate that capability and also support proper testing of algorithm upgrades (e.g., providing parallel processing of two algorithm versions to allow adequate assessment of modifications made to the product).
(2) SDR file content: the adoption of floating point data format for the primary SDR layers (radiance, reflectance, brightness temperature) has proven to be overwhelmingly inadequate when it comes to resource management. File sizes are disproportionally large placing a burden on both the science and user community. Likewise, the option to store redundant information on each SDR file must be revised. For example, L1B data should only provide radiance data and not include reflectance or brightness temperature data since those two extra layers can be easily derived from former. Lastly, both science and user community should provide feedback on the adequacy of the chosen 85sec data

segments stored in each SDR file (e.g., as opposed to using 5min data segments) and whether groups of channels should share the same file (e.g., as opposed to having single band SDR files). The MODIS Fire products are provided to NASA science data users through the SCF, LP DAAC, LANCE Rapid Response and FIRMS. Active Fire data users are expecting continuity of data products and services from VIIRS. The NOAA JPSS Proving Ground is funding a project for user readiness of the VIIRS AF product, with USFS RSAC as a key partner, and there is a website with product and distribution information http://viirsfire.geog.umd.edu/ Given the broad interest in meeting the needs of operational fire data users, discussion is needed between NASA and NOAA as to how ensure Active Fire product continuity and distribution most efficiently.

2.9. Surface Reflectance IP

SR-IP Team: Alexei Lyapustin (NASA GSFC); Eric Vermote (NASA GSFC); Yujie Wang (UMBC)

Overview

Surface Reflectance (SR) is currently one of the most requested land products, both for applications and science analysis. For VIIRS, as well as for MODIS, a number of Land EDRs depend directly on the SR. However, SR has an intermediate product (IP) status, and it is not available as a standard dataset through the NOAA/CLASS archive, except for limited validation purposes by the NASA Science and JPSS Cal/Val and Product teams. Due to the recent effort on the part of the NOAA-NASA land community to promote SR from IP to the EDR, deliberations continue in the framework of the new EDR Requirements. It is not clear presently if and when SR will be promoted to the full EDR status with possible implications for the long-term SR storage in the CLASS and availability to the community. Regardless of the outcome of this effort, the NOAA data processing and storage structure does not allow reprocessing. As problems with the instrument are encountered there is a need to reprocess the full data record. For instance, most of the VIIRS data collected on the first year after launch were affected by the VIIRS telescope mirror degradation, primarily in the NIR and Red bands; and while the adequate correction model was developed in the second half-year, no backward reprocessing has been applied.

Current Status and Quality of the Surface Reflectance IP

The quality and character of surface reflectance depends on the accuracy of cloud mask (CM) and aerosol algorithms. For this reason, we are conducting a complex evaluation of SR together with CM and aerosol products. At this stage, our evaluation shows that:

1) VIIRS cloud mask (VCM) correctly detects large, bright and cold clouds and significantly underestimates small and low cumulus clouds. In part, this is a consequence of VCM being designed to satisfy all EDR algorithms, and thus provide an average performance in terms of omission and commission errors, in contrast to more conservative MODIS cloud mask. The leakage of small clouds creates large biases in the VIIRS SR, which are not currently captured

by the quality flags. It is not clear whether this issue can be remedied within a single orbit processing paradigm as even MODIS CM has the same issues as shown in the recent analysis over tropics (Hilker et al. 2012).

2) The quality of VIIRS aerosol retrievals is still being evaluated by the aerosol and SR teams and the detailed picture has yet to emerge. Presently it is clear that VIIRS cannot provide aerosol type (model) information and its aerosol optical depth (AOD) product is worse, often significantly, than that from MODIS. The deficiencies are most apparent over the bright surfaces, where VIIRS often shows high AOD when in fact it is clear. Over moderately bright and dark surfaces, VIIRS AOD rather unpredictably may show a substantial bias which, according to our analysis, may stem from adopted flexible selection of the aerosol model on a pixel basis.

Table 3: Average surface reflectance and bias of VIIRS SR for selected sites

Site Name	M2 (436 - 454nm)		M4 (545 - 565nm)		M5 (662 -682nm)		M7 (846 -885nm)	
	Refl.	Bias	Refl.	Bias	Refl.	Bias	Refl.	Bias
GSFC	0.038	-0.026	0.063	-0.018	0.053	-0.019	0.295	-0.008
Railroad Valley	0.123	-0.018	0.183	-0.015	0.229	-0.014	0.273	-0.010
KONZA_EDC	0.039	-0.004	0.077	-0.006	0.084	-0.007	0.302	-0.014
Evora	0.058	-0.004	0.106	-0.005	0.157	-0.007	0.300	-0.009
Ispra	0.029	-0.013	0.055	-0.009	0.045	-0.006	0.297	-0.006
Lille	0.042	-0.015	0.081	-0.011	0.074	-0.009	0.355	-0.001
UCSB	0.042	-0.007	0.070	-0.006	0.084	-0.005	0.230	-0.005
BONDVILLE	0.027	-0.010	0.059	-0.004	0.052	-0.005	0.348	0.012
Alta Floresta	0.036	-0.003	0.078	-0.005	0.094	-0.003	0.321	-0.008
Beijing	0.058	-0.032	0.086	-0.022	0.086	-0.022	0.255	-0.009
CUIABA-MIRANDA	0.033	0.004	0.069	0.000	0.084	-0.002	0.254	-0.006
Hamburg	0.032	-0.012	0.071	-0.011	0.060	-0.010	0.345	-0.007
TABLE_MOUNTAIN_CA	0.082	-0.017	0.123	-0.014	0.156	-0.011	0.250	-0.008
Dakar	0.079	-0.028	0.132	-0.037	0.147	-0.028	0.328	-0.086
Banizoumbou	0.066	0.021	0.174	-0.005	0.298	-0.029	0.467	-0.049
XiangHe	0.039	-0.019	0.072	-0.017	0.062	-0.011	0.326	-0.007

3) Even under the best conditions, the Lambertian assumption, used to derive VIIRS SR, introduces low biases that depend on the view geometry and atmospheric opacity (Wang et al. 2010). Our current assessment is based on the AERONET-based Surface Reflectance Validation Network (ASRVN) (Wang et al. 2009), which uses AERONET aerosol and water vapor information as well as extensive QA analysis to derive SR. The evaluation of the cumulative performance of the VIIRS SR IP, based on weighted average spectral reflectance over 50×50 km^2 areas and bias for several AERONET sites is summarized in Table 3. These results show the best VIIRS performance as they generally represent low AOD conditions and no cloud contamination due to AERONET and ASRVN cloud filters. The data are color coded to indicate an average

performance level. The green color indicates a relatively good performance with the bias across all spectral bands below 0.015. Table 3 shows that these sites are characterized by abundance of vegetation and relatively dark surface with the exception of UCSB. The blue color indicates a marginal performance, and yellow color shows sites of poor performance. Of these, the high bias for the Beijing and XiangHe is due to the high aerosol levels, and Dakar and Banizoumbou have bright surfaces where the VIIRS aerosol retrievals are problematic.

What climate/global change science can be done with the Surface Reflectance IP? In its present state, the Surface Reflectance IP is not suitable for climate applications. Furthermore, the current VIIRS Land EDR suite does not provide continuity with MODIS (and AVHRR) for the spectral surface reflectance as well as for a number of other land products produced from SR, effectively severing the long-term data record needed for climate research. This data gap will also limit development of new applications and science data products, or result in duplication of effort to generate surface reflectance as an intermediate step to new higher-order (Level 3) products.

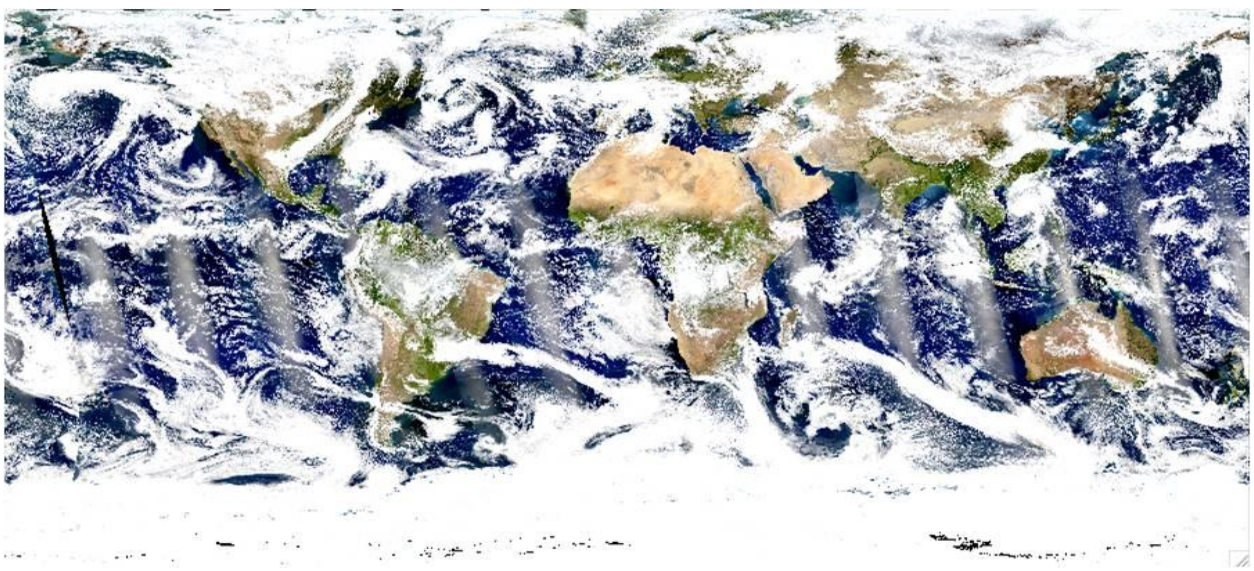

Figure 9: VIIRS Level 3 Global 0.05Deg Global Climate Modeling Grid (CMG) Surface Reflectance Intermediate Product (Land PEATE- adjusted version of the SR-IP IDPS algorithm) for October 26 2012.

What climate/global change science can't be done with the Surface Reflectance IP? Without an official designation of surface reflectance as an EDR, a number of important climate research products and activities will be terminated. For example: (1) vegetation characterization via LAI/FPAR; (2) global assessments of vegetation disturbance and recovery which is a large component of the terrestrial carbon balance currently known with equally high uncertainty; (3) SR is required to compute spectral surface albedo. In the current VIIRS specification, the albedo EDR represent a broadband value which has long became an obsolete requirement. The broadband albedo is no longer used by the modern climate models which require spectrally resolved data to satisfy increasing accuracy demands for the climate simulations (*cf.*, Section 2.3

on Albedo). For example, NASA Goddard model GEOS-5 currently has 2 and is moving towards 14 spectral bins.

What would it take to get the Surface Reflectance IP in the shape needed to do the science that can't be done now? The VIIRS Surface Reflectance IP must be designated as an EDR, and all spectral and QA fields must be retained for long-term archiving and distribution for climate analysis. This critical step will enable data continuity for a number of high level land products and procedures used by the climate research community. Furthermore, the vast majority of global climate science done with MODIS has been with climate modeling global products (CMG) (*cf.*, Figure 9). Provision of spatially gridded VIIRS-SR values at both moderate (500 m – 1 km) and CMG resolutions is thus needed to ensure data continuity for Surface Reflectance, as well as the whole suite of radiative and biophysical products derived from SR. A long-term SR data record over stable bright deserts (North Africa) is also required to monitor sensor calibration stability. This approach has been developed and successfully used by the MODIS calibration team complementing the lunar calibration data, and became particularly important to correct calibration degradation of MODIS Terra for the Collection 6 re-processing (MCST, MODIS science team meeting presentations, May 7-9, 2012).

Suitability of the VIIRS Sensor Data Records as it applies to the Surface Reflectance IP: Current evaluations suggest that the VIIRS SDRs (and associated calibration) are suitable for the Surface Reflectance IP. Analysis based on aerosol retrievals did not reveal noticeable issues in the calibration, but further work is required to evaluate performance through a cross-calibration with MODIS SR.

The VIIRS SDRs and particularly the associated calibration are being closely monitored on a continuous basis by cross-comparison of the VIIRS and MODIS SR product over dedicated sites. We are confirming that the SDRs are suitable for the Surface reflectance IP; however continuous monitoring of the SDRs is necessary, and data generated prior to the VIIRS SDR provisional status (Launch +1 year) might not be suitable for the Surface Reflectance IP.

3. New Products for Advancing Climate and Global Change Science

The VIIRS EDR's were designed to meet the operational needs of the DOD and the National Weather Service and as a result, the individual EDR's fall short of the science needs in ways outlined in the previous section. If continuity with MODIS products is to be provided then consistency is needed and will not be met by the EDR's (Surface Albedo, Vegetation Index, Surface Reflectance and Active Fire, for example). In addition it should be noted that the IDPS will not be generating temporally composited or spatially re-sampled (Level 3) forms of the products currently used by the science community. In particular 8 day and 16 day surface reflectance and VI will be needed, as well as Climate Modeling Grid versions of the products. The MODIS Albedo and LST products currently take advantage of and are much improved by using both AM and PM observations from Terra and Aqua. With the absence of an AM orbit, it has yet to be determined whether there is sufficient continuity of multi-sensor products (e.g. LAI, Al-

bedo) from combining the VIIRS with the METOP AVHRR (1km), which provides AM data, albeit at 09.30.

In the context of global change research, the most important aspect of the coarse resolution data sets from MODIS and VIIRS is their time-series. In developing comparable long-term data records (aka. climate data records) it is important for there to be an overlap of the MODIS and VIIRS data records. By the time VIIRS completes 2-years of operations, MODIS will have been through 5 major reprocessing cycles to develop a consistent 'science quality' data record. It should be noted that there is currently no plan to reprocess data in the IDPS and no demand for such from the DOD or NWS operational communities. As a result, any improvements to the EDR's made by the JPSS project to meet the operational specifications will continue to be applied only to current data. The agencies concerned with science data use will need to provide the capability for data reprocessing. It should be noted that NOAA through its NPOESS Data Exploitation (NDE) is tasked to deliver POES equivalent products from NPP in a phased approach and has already integrated three new algorithms into its Science and Algorithm Integration Environment (SAIE). NDE will in some cases repackage EDR's and in other cases develop new products designed to meet the needs of operational users. However, NDE will not provide reprocessing of either IDPS or NDE-generated products, and therefore its output will have limited climate applicability.

It should be noted that the VIIRS Land EDR's represent a subset of the current MODIS Land Product Suite. In particular, there are no EDRs for LAI/FPAR, Net Primary Productivity, Vegetation Dynamics (phenology), Vegetation Continuous Fields or Burned Area. It is strongly recommended that the full suite of MODIS Land Products which were designed to meet the needs of the science community be adapted for VIIRS, providing full data continuity. The following sections provide examples of both current and potential Land Science products that meet these criteria:

3.1. LAI and FPAR Product Continuity Needs

Science Team: *Ranga Myneni (BU)*

The primary goal of Suomi NPP VIIRS instrument is continuation of the EOS record of climate-quality observations in the post-EOS sensor era. However, not all of the new science data products being produced by EOS were included in the S-NPP and JPSS programs when they were first planned. Some of these products may have been new and untested at the start of the EOS program, but now more than a decade-long experience of the EOS program has led to mature algorithms and research-quality versions of these data products. Amongst the vegetation data products, two key variables for monitoring and modeling vegetation condition and functioning - leaf area index (LAI) and fraction of vegetation absorbed photosynthetically active radiation (FPAR) - were not included in the original NPP and NPOESS programs.

Recognizing (a) the scientific success and wide community user base of MODIS LAI and FPAR data products, (b) the recommendation by the Committee on Earth Observation Satellites (CEOS) to include LAI and FPAR in the list of "Essential Climate Variables" for vegetation, (c) the LAI and FPAR data product series may be limited to the EOS MODIS sensor period and (d)

the real possibility that the land community may be limited to a vegetation index time series for all of its long-term monitoring and modeling science needs, NASA has decided to fund a proposal (PI: Myneni) to explore production of LAI and FPAR products from the Suomi NPP VIIRS instrument that will continue the EOS MODIS LAI and FPAR product stream.

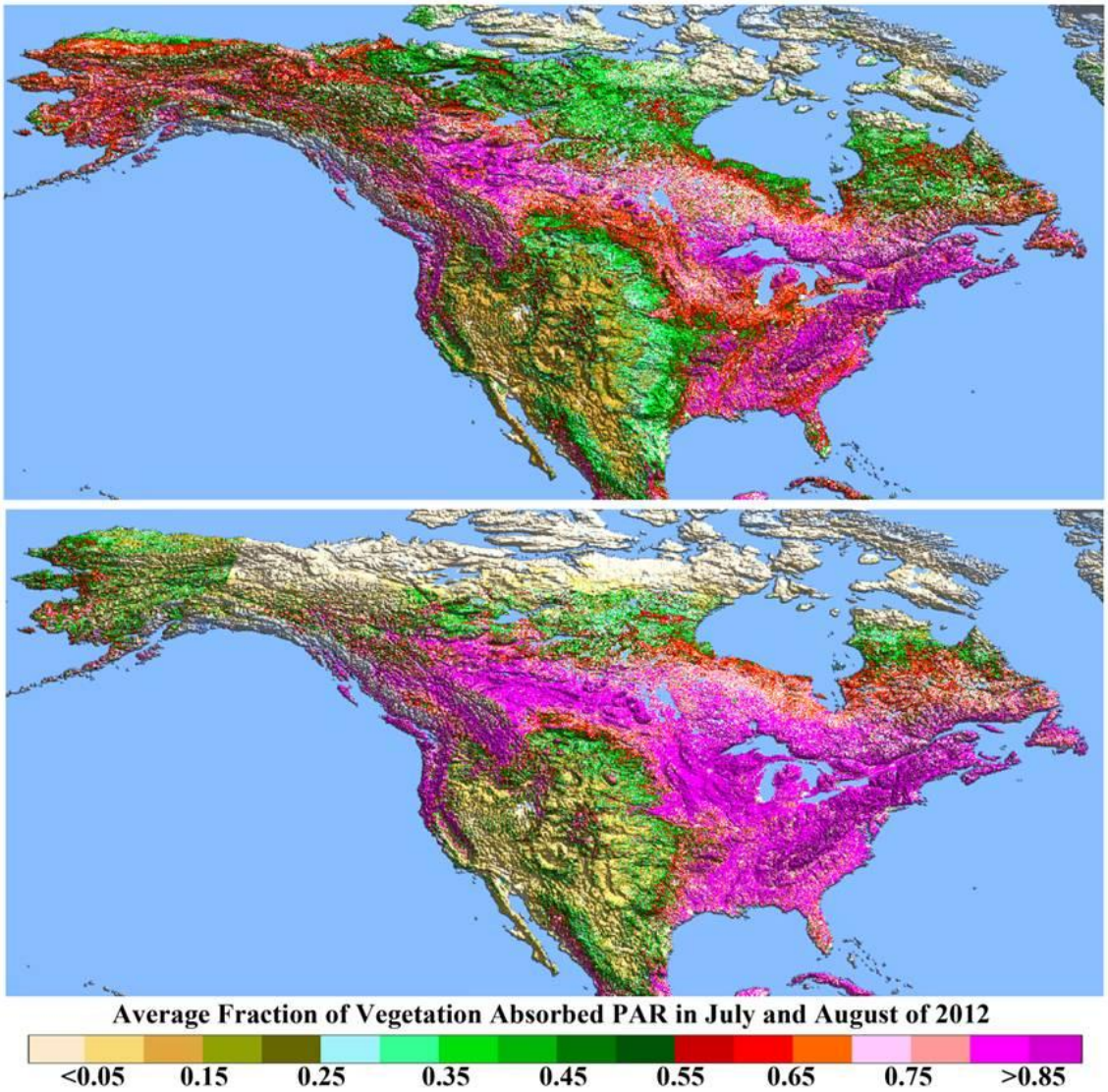

Figure 10: (Top panel) Terra MODIS FPAR. (Bottom Panel) Suomi-NPP VIIRS FPAR.

The primary objective of Myneni's Suomi NPP VIIRS project is *to extend the MODIS LAI and FPAR product series through the term of the Suomi NPP VIIRS mission*. This objective is to be realized through three sets of research activities:

- VIIRS LAI/FPAR algorithm development, prototyping and implementation
    - Task 1: Ensuring Continuity Between MODIS and VIIRS
    - Task 2: Refinement of Algorithm Theoretical Formulation for Continuity
    - Task 3: Adjustment for VIIRS Spatial and Spectral Features

    - Task 4: Algorithm Coding, LPEATE Integration and Prototyping
- Evaluation of VIIRS LAI/FPAR ESDRs for accuracy, precision, uncertainty, spatial coverage and continuity
    - Task 5: Spatial Coverage
    - Task 6: Continuity and Consistency
    - Task 7: Precision
    - Task 8: Accuracy and Uncertainty
- VIIRS project activities
    - Task 9: Quality Assessment and Project Activities
    - Task 10: Community-Support and Outreach Activities
    - Task 11: ATBD and User Guide

The tangible end product of these activities is a continuous, well-characterized, long time series of global LAI and FPAR products, spanning the EOS and Suomi NPP VIIRS era, suitable for research in climate and global change science and applications.

Taking advantage of simultaneous availability of MODIS and VIIRS atmosphere-corrected surface reflectances, we have acquired requisite data for the summer months of June through August, 2012. We are now performing LAI and FPAR algorithm runs in-house and generating 8-day composite LAI and FPAR products from VIIRS and these products are being compared to concurrent products from both Terra and Aqua MODIS sensors. Figure 10 shows the Terra MODIS and the Suomi NPP VIIRS FPAR product. The average difference between the two products is low (<0.1) for certain land covers (forests) but high for non-woody vegetation (about 0.2). While these preliminary results are encouraging, there is considerable amount of research effort required in order to meet the stated objective of this activity (*cf.* the Task list above). The differences between the two products are clear even from simple visual inspection.

3.2. VIIRS Day/Night Band SDR: Status and Needs for Land Science

Science Team: Miguel Román (NASA GSFC); Robert Wolfe (NASA GSFC); ShihYan Lee (Sigma Space); Dorothy Hall (NASA GSFC); George Riggs (SSAI); James Foster (NASA GSFC)

Overview

The next generation of low-light visible sensors, represented by the VIIRS Day/Night Band (DNB), offers enhanced nighttime observation capabilities over heritage instruments through improved dynamic range, higher signal-to-noise, long-term sensor calibration, superior temporal sampling, and complementary information from other VIIRS products (Lee et al. 2004). For Land research and applications, the VIIRS-DNB will advance the study of urbanization dynamics at regional and global scales. The availability of multi-temporal nighttime light data will be of particular value to improve our understanding of urbanization trajectories through the explicit representation of urban land cover, urban population, and urban economic activities. The great potential of this new channel has also been highlighted in recent NASA studies that

have used the operational IDPS DNB product for several purposes; from near real time monitoring of urban light outages (Román et al. 2012), to efforts to detect bioluminescent blooms in Arctic and Antarctic regions (Foster et al. 2012).

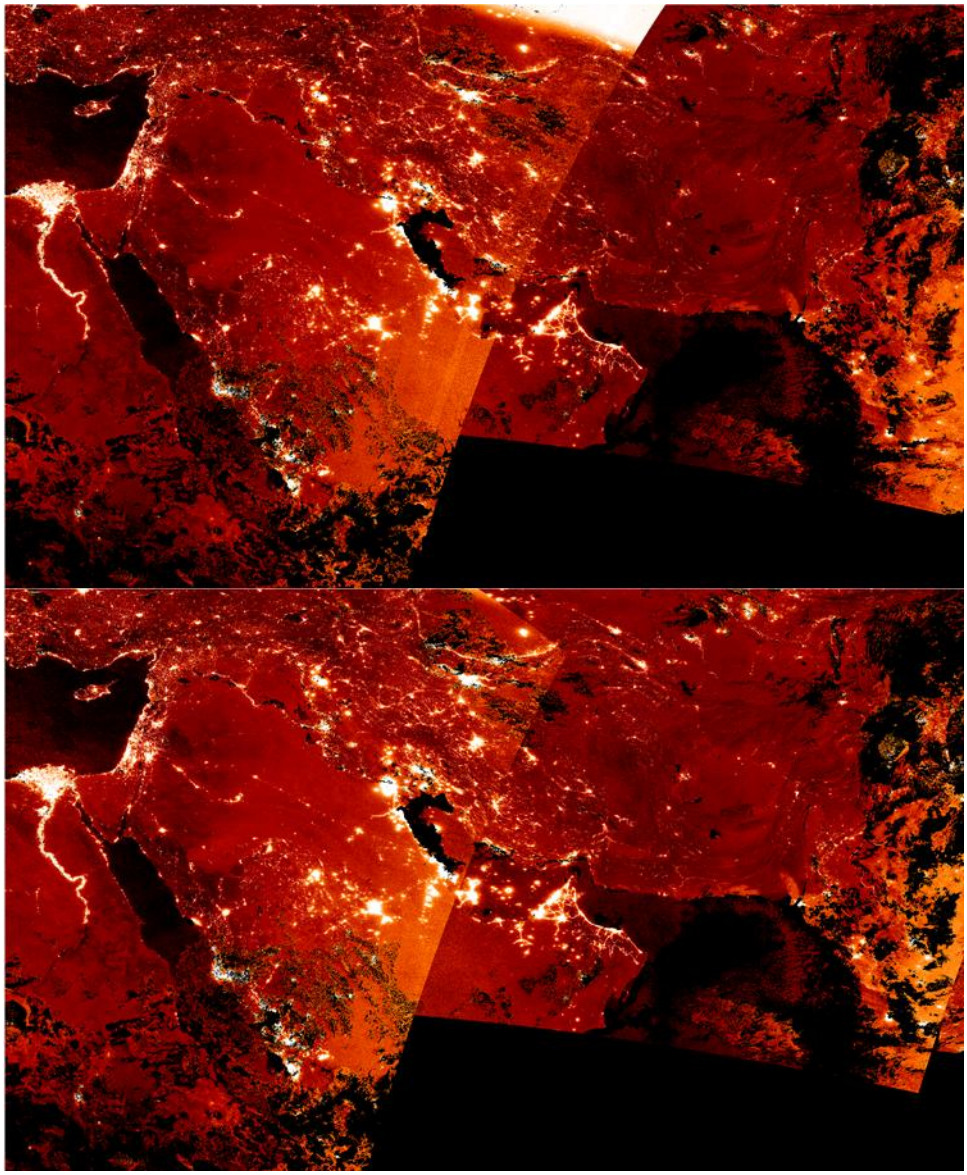

Figure 11: (Above) Original DNB Image from Aug 10, 2012 – Middle East Arabian Peninsula. The bright region at the top shows the transition region (penumbra) when the spacecraft goes into eclipse. (Below) Same DNB Image corrected for stray light and scan angle effects.

Unlike the VIIRS Land EDR's, it is important to note that the Suomi-NPP Project Office (through the supporting role provided by the SDS Land PEATE) has not established measures for evaluating the quality of the VIIRS Day Night Band to meet NASA's scientific objectives. Without support from the SDS-PEATEs, and a basic infrastructure for retaining the nighttime observations beyond a 60-day period, both current and future research efforts will confront numerous chal-

lenges in tracking the quality and status of the DNB and the operational IDPS algorithms. Likewise, the NASA VIIRS Characterization Support Team (VCST) has not been asked or tasked to characterize or evaluate DNB performance. A few members of the team have provided limited support on some specific DNB issues, but not as extensively as efforts made for other VIIRS spectral bands.

While the JPSS-VIIRS Sensor Data Record (SDR) and Imagery teams are proceeding with the analysis and calibration of the DNB to meet NOAA's operational needs, a dedicated and focused scientific development effort is required on the part of NASA to enable the Land user community to leverage the VIIRS Day/Night Band in long-term climate and environmental change studies. In principle, future NASA research announcements would open the opportunity to propose activities to both evaluate and improve the VIIRS-DNB for scientific use, and propose new applications. Realizing these scientific opportunities are contingent upon maintaining a core set of capabilities, NASA should support the overall coordination of algorithm testing, refinement, QA, and validation activities surrounding the VIIRS DNB SDR product; preferably through the Land PEATE.

Current Status and Quality of the VIIRS Day/Night Band SDR

The current JPSS radiometric requirements for the VIIRS Day Night Band (DNB) Sensor Data Record (SDR) are defined at the minimum radiance of $3x10^{-9}$ W/(cm^2·sr); although recent work has estimated noise equivalent radiances to be in the range of ~$1x10^{-10}$ W/(cm^2·sr) at nadir to $3x10^{-10}$ W/(cm^2·sr) at scan edge (Miller et al. 2012). Note that this specification is not required to be correct for all retrieval conditions (e.g., it excludes moonless scenes at mid-to-high latitudes).

VIIRS DNB scenes are currently affected by solar stray light artifacts (Figure 11). This seasonal trend contaminates about 2 orders of magnitude of the DNB's dynamic range. If the current product continues to be uncorrected with stray light, this will reduce the DNB's sensitivity down to 10^{-8} W/(cm^2·sr) at mid-to-high latitudes, yielding retrievals of insufficient quality for scientific research purposes. Moreover, for VIIRS Flight Unit #2 on JPSS-1, it is of utmost importance to understand the root cause of the stray light and implement the appropriate instrument correction plans.

What would it take to get the VIIRS Day/Night Band in the shape needed to do the science that can't be done now? The VIIRS Land Science team recommends that NASA establish new radiometric requirements and detection thresholds for estimating different lunar- and emission- based phenomena from VIIRS DNB radiances. In order to meet such rigorous requirements, NASA would need to undertake the following core activities in close coordination with the NASA Land PEATE and the S-NPP Science Team:

(1) Support the development, refinement, and implementation of approaches for cloud-clearing, noise removal, and terrain correction of VIIRS-DNB radiances: If the Land Science community is to fully leverage the VIIRS DNB for climate and environmental change studies, a sensitivity down to 10^{-10} W/(cm2·sr) is required to observe key phenomena and natural processes with high confidence (e.g., scattering of city lights through clouds, dim lights in rural areas and suburbs, and observations of snow and ice during times of polar darkness). This activi-

ty would include development of tools and methods for detecting and excluding noise originating from instrument dynamics (e.g., stray light), external light contamination sources (e.g., zodiacal light and faint stars), as well as other atmospheric emission signals that could give false-positive signals (e.g., Earth's aurora in high latitude regions and air glow in other regions).

Work is also needed to address and leverage the use of other VIIRS channels and products at night for compositing purposes. For instance, the VIIRS Active Fire Product could be used to distinguish between gas flares and fires from other light emission sources (e.g. urban/city lights). While preliminary results have shown that the VIIRS Cloud Mask is quite stable over most regions, its performance at night is still being investigated and is expected to be lower than its performance during daytime.

To use the full DNB's sensitivity, an improved High Gain Stage (HGS) dark offset subtraction method should be implemented. One option would be to use a pitch maneuver (based on a dark space view) as reference point, and then track the DNB's offset drift over time. This method would further minimize impacts due to stray-light contamination. Note that the DNB RSR modulation due to mirror degradation is projected to result in ~4% radiance biases. This will also affect the DNB's sensitivity (S/N ratio), thus limiting the usefulness of the VIIRS-DNB for scientific studies.

For land applications, terrain corrected geolocation should also be implemented in the DNB SDR algorithm as soon as possible and should be done in any product reprocessing. This algorithm change is particularly critical for land applications (e.g., mapping urban city lights). This will enhance the DNB's scientific applications and help the DNB reach calibrated and validated status. The S-NPP VIIRS Geolocation team (Wolfe et al.) have come up with a correction approach for the DNB (cf., ftp://landsc1.nascom.nasa.gov/outgoing/mroman/DR_4924.pptx). However, as this report was being prepared, the proposed fix had yet to be considered for inclusion in the two upcoming IDPS SDR revisions (Mx6 or Mx7.0).

(2) Produce science-quality versions of the operational DNB SDR algorithm: Global Earth gridded products are required by the Science community to enable seamless integration with products from other instruments, and thus leverage the complementary information available from long term climate datasets. This effort shall include: (a) acquiring and baselining the SDR DNB operational codes utilized at the IDPS (as currently being done by the Land PEATE); and (b) generating and distributing daily gridded and multiple-day versions of the DNB SDR algorithm. The latter shall be produced in 10 degree square tiles at full spatial resolution to allow for easy ordering and distribution. In addition, for polar product evaluation, the products shall be produced in northern and southern polar grids, both in a fine resolution tiled grid and a hemispheric coarse resolution grid. A starting point for this activity will be the MODIS compositing and aggregation algorithms and software that produce the corresponding MODIS Level 2G and Level 3 gridded products. This software should be modified to work with the DNB's unique viewing geometry.

Given the considerable improvement over and heritage instruments and the broad and growing interest in VIIRS DNB capabilities, discussion is needed between NASA and NOAA on roles and responsibilities for preprocessing and generating derived products from these bands.

4. Required Data Processing and Evaluation Capabilities for Land Science

Land PEATE Team: Edward J. Masuoka; Robert E. Wolfe; Miguel Román (NASA GSFC); Sadashiva Devadiga; Carol Davidson (Sigma Space)

The VIIRS Land Product Evaluation and Analysis Tool Element (Land PEATE) has a number of capabilities to support Land science in the S-NPP and JPSS era. These include support for evaluation against MODIS science products , validation support, and as a test bed for algorithm changes (Wolfe et al. 2010; Román et al. 2011). These capabilities are collocated with existing MODIS Land production facilities and leverage NASA's experience in the production of global land measurements.

VIIRS Land Product Evaluation: The VIIRS Land PEATE is tasked with supporting the VIIRS products for the Land science community. The LPEATE currently receive VIIRS products from the NESDIS IDPS and GRAVITE systems. The products include not only Land EDRs but the upstream Level 0 RDR, Level 1 SDR and atmosphere EDRs. The LPEATE currently produces a set of Diagnostic Data Records (DDRs - namely, daily and multi-day Level 3 gridded products) that the Land science community can easily compare to the standard MODIS Level 3 products. These are produced at MODIS instrument spatial resolutions of 500 m and 1 km and at coarser global (Climate Modeling Grid or CMG) resolution of 5 km. Capabilities developed for the routine MODIS product Quality Assessment (QA) have been adapted for VIIRS including: production of global browse, trending data over golden tiles and time-series tools. The LPEATE is able to run "wrapped" versions of the IDPS software and has the capability to reproduce SDRs, EDRs and IPs to enable detailed investigations of data quality. These capabilities have enabled the Land science community to determine the quality of the operational VIIRS products and to identify areas that need improvement.

Validation Support: The Land PEATE has supported validation of VIIRS Land products by producing subsets over validation sites. A collection of more than 1000 VIIRS subsets have been extracted for field site networks of interest to the validation teams (e.g., AERONET, NOAA-CRN, EOS Core Sites, CEOS-LPV, and FLUXNET). These subsets are distributed via the LAADS public FTP area. Users can also navigate to those directories by 'Site name' using a simple Google API interface (cf., http://viirsland.gsfc.nasa.gov/Subsets.html). The VIIRS Land validation subsets (as well as the golden tiles, and n-day gridded DDRs) are retained indefinitely at the LPEATE to allow for continuous spatial/temporal coverage of the products during the intensive cal/val (ICV) and long-term monitoring periods.

The Land PEATE has also used its capability to reproduce the standard products for time periods and key locations where validation datasets have been collected (e.g., the recent IceBridge campaign deployments in support of the Ice Surface Temperature EDR – *cf.*, Section 2.6). This capability has enabled the most recent versions of the standard algorithms (and/or improved algorithms) to be assessed against valuable validation data that are usually acquired before the newer versions of the algorithms were run in the IDPS.

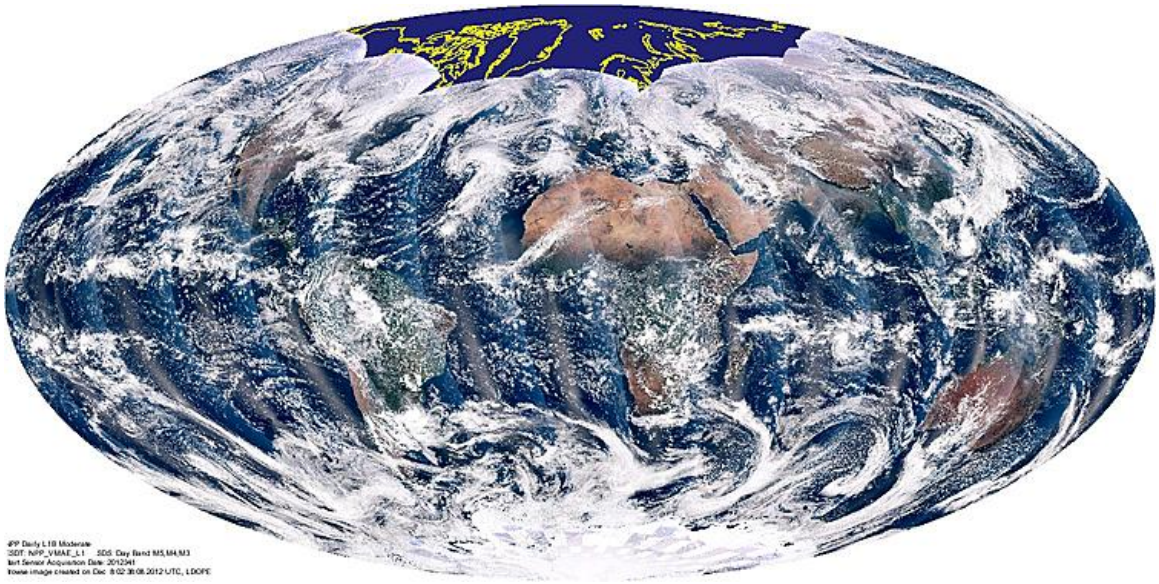

Figure 12: VIIRS Global Browse Image (NPP_VMAE_L1 – L1B SDR – RGB of M5, M4, M3), day 2012344 (12/9/2012), IDPS (AS 3000)).

Algorithm Improvement Testbed: As with past missions, there are likely to be many improvements to algorithms developed by the Land science community that will need to be assessed before running in the operational IDPS system. In addition, there may be new algorithms that are based on heritage or new algorithms that are not needed by the operational community that could be produced within the LPEATE. The Land PEATE in general has the ability to hold the VIIRS Level 0/2 data production to 100% of full capacity (1X). This includes keeping up with the incoming input stream from the IDPS, as well as local processing (or ingesting) of the Level 0/2 data. The Land PEATE can also generate products for specific time intervals at a 3-times (3X) rate, as necessary, to help evaluate any improvements in the algorithms and product codes developed by the NASA Suomi-NPP Land Science Team. The LPEATE's processing rate can be easily increased to facilitate multi-month and multi-year comparisons of the two product streams. The LPEATE is also capable of running science-based MODIS continuity products from VIIRS; and is currently supporting such efforts for multiple products, including Land Surface Temperature (emissivity based products) and Surface Reflectance. This capability has also enabled the Science Team to assess the value of algorithm updates in order to determine if new Discrepancy Reports (DRs) should be submitted to the IDPS system, or other operational systems for consideration. To date, the Land PEATE has been responsible for a large portion of the Land DRs submitted to the JPSS Ground Algorithm Engineering Review Board (AERB).

At present, changes to the operational IDPS algorithms take several months to be incorporated into the JPSS ground system. The current system is plagued with many difficulties resulting from lack of bandwidth, personnel, and the overall lack of capacity needed to handle revisions from multiple instruments. Note that this issue is not specific to the VIIRS EDRs (it has also led to significant delays in getting updates to the VIIRS SDR products). Similar challenges were encountered during the early-EOS period; which resulted in the creation of Science Investigator-led Processing Systems (SIPS) to more efficiently address the needs of each instrument team.

Reprocessing VIIRS products: As demonstrated by MODIS and the AVHRR, reprocessing of the VIIRS data record will be essential if we are to produce climate quality data records that can further research in Earth System Science. The capability to produce and distribute a suite of VIIRS science products in formats compatible with MODIS products exists in the Land PEATE. The Land PEATE's current processing rate can be easily increased by adding inexpensive Linux-based processors. The capacity to process a year of data products in a month for two versions of algorithms will facilitate converging on the best suite of algorithms for reprocessing the entire data record. Once that is established, a reprocessing campaign can be initiated using the majority of the LPEATE computing resources. The only other addition to the Land PEATE computing resources that would be required is an increase in the amount of disk storage for the online archive in order to accommodate the increased volume from storing the SDRs and full land product suite for the entire data record.

Data Distribution: NOAA's CLASS system provides the main archive for the S-NPP IDPS generated products and is the primary distribution system for these products. Note however that CLASS' primary focus is on data preservation and not on distribution, so the CLASS system offers very limited services when compared to similar NASA's ESDIS data centers. The CLASS general user ordering interface is similar to those offered by the ESDIS data centers (e.g. WIST, LAADS, LP DAAC). However, there are several limitations including a very limited number of files (100) can be selected at a time and there are very limited post-processing options. Also, at launch the archive was primarily on tape, so any data orders would take hours to days to fulfill. Recently a 90-day rolling ftp archive was established, but for users looking for long time series this is much more limiting than the current ESDIS data systems, almost all of which is directly accessible through via on-line ftp. CLASS also is able to provide some push-type capability to specific users (e.g. NASA SDS), but this is done on a special case-by-case basis and is not generally available to the research community. Finally, web-services are not available and post-processing capabilities are very limited. A standard web-service based interface is not available for ordering data. This severely limits the amount of data that can be downloaded, since the ordering requires a person to use the Web-based graphical user interface to order relatively small amounts of data. Post-processing is currently limited to band subsetting and aggregation. Other common ESDIS post-processing services such as spatial subsetting, reprojection, etc., are not available.

Some of the issues with the VIIRS data products from CLASS are not caused by CLASS *per-se*, but are caused in large part by the design of the VIIRS IDPS products. First, instead of choosing a user-friendly granule size similar to the 5-minute granules of MODIS, the IDPS latency requirements led to an 86-second granule. Other product design decisions led to storing individual bands in separate products so there are 22 individual VIIRS SDR products, one for each band. This makes ordering multiple bands much more difficult as compared to MODIS, where all bands of a single resolution can be ordered in a single file. Some of this has been mitigated by band and temporal aggregation implemented by CLASS, but this still puts an extra burden on users. Also, this doesn't mitigate the need for CLASS to store and retrieve many more individual files than MODIS. Second, there were a number of decisions regarding format (e.g. use of floats instead of integers) that lead to products that are much larger than necessary. This and a lack of internal compression (used for years for MODIS products) means the archive and transfer volumes are much larger than necessary. Third, many of the QA flags were designed for internal use and not end-user use. In some cases, overall QA summary flags are missing and in

other cases specific QA flag information (e.g. high/medium/low aerosol flags) needed to better understand the products are missing. Fourth, the standard products are almost all swath-based (L2), not gridded (L3) products. This means that users have to order a large number of products to cover their region and time of interest, and then use their own tools to grid and composite the products to produce cloud-free multi-day products that are most useful to the Land community. Finally, the meta-data model used for VIIRS products is different than for standard NASA EOS products. This means that researchers who are experienced users of NASA Land data and deal with large amounts of data have to develop special tools to deal with the metadata in these products. This is exacerbated by not using the NASA standard HDF-EOS format, but instead using a complicated variation of HDF5.

NASA Land science team members do not currently use CLASS to obtain data, instead they use data provided by LPEATE. LPEATE aggregates the IDPS 86 second granules in to standard 5 minute MODIS like granules and provides the data in a compact HDF4 format that is compatible with standard HDF4 MODIS products. LPEATE also produces daily and multi-day global gridded (L3) products that can be easily compared to the similar MODIS products.

5. NASA LANCE Capability from VIIRS

Chris Justice (LANCE UWG Chair, UMD), Edward J. Masuoka; Robert E. Wolfe (NASA GSFC)

The Land Atmosphere Near-real time Capability for EOS (LANCE) provides access to real time data from MODIS, AIRS, MLS and OMI instruments on-board the Terra, Aqua and Aura. NASA end-users utilize these products for a wide range of science and applications from weather and climate prediction to monitoring and management of natural hazards such as fires, drought and floods. LANCE is part of EOSDIS and provides near real-time capability within 2 hours of overpass. (http://earthdata.nasa.gov/data/near-real-time-data). The data can be easily downloaded and viewed in Worldview (a new tool from EOSDIS: http://earthdata.nasa.gov/labs/worldview/) and a number of web-mapping services are provided by LANCE. Data subsets are available over different areas and quality assessment by the Land Data Operational Product Evaluation team. For MODIS near real time users products are stored for 7 days and then deleted.

The NOAA operational partners get their data feed in real time at their respective Centrals (NWS, AFWA) and the NESDIS NDE system. All other users have to obtain VIIRS data from CLASS. CLASS was designed primarily as an archive system. CLASS does not have the suite of data delivery capabilities provided by the NASA DAAC's nor is it set up for NRT data delivery. CLASS currently has a latency of c. 6 hrs. and there are many other CLASS issues mentioned in Section 4 that also impact distribution to NRT users. As indicated above there is some expectation from the NASA Applied Science community that products such as Vegetation Index and Active fire will be available with the current functionality of LANCE. At the most recent LANCE UWG Meeting and the LANCE UWG Telecon, Nov. 9, 2012, there were strong requests for a LANCE- capability from VIIRS. It is recommended that NASA explore the provision of a LANCE type capability from VIIRS to meet the needs of NASA's near real time data users.

6. NASA Land Team Summary Recommendations

For NASA Land science, the Suomi-NPP VIIRS instrument will enable NASA to provide continuity with the EOS MODIS, with some notable exceptions identified in this report. In addition to guiding the instrument build and testing, emphasis from the JPSS project has been on the development of Environmental Data Records (products) from the VIIRS, which will meet the needs of the operational community and it is likely that the operational requirements will be met. Emphasis from NASA S-NPP VIIRS Project Science Office and the S-NPP VIIRS Science Team has been on understanding the VIIRS instrument performance and likely utility of the EDRs from an Earth Science perspective. The VIIRS Land Team have identified that in general, if the Land EDRs are to serve the needs of the science community, a significant number of changes to the Land EDR algorithms and the IDPS processing system will need to be made, as identified in this report. In addition, some of the current MODIS products not generated as VIIRS EDRs will be needed if we are to extend all the MODIS land data records. As the NASA Earth Science program explores new global change research areas, a new suite of 'next generation' experimental products could be envisioned from the VIIRS (e.g., forest and cropland change, irrigation extent, flooding, DNB city lights, etc.). It is our understanding that for the foreseeable future, such changes and additions will be beyond the scope and means of JPSS and the IDPS. Based on this understanding and the above assessment, the VIIRS Land Team has the following nine recommendations:

1. ***A suite of Land 'Science' products should be generated from VIIRS (i.e. VIIRS Land Earth Science Data Records –ESDRs) that meet the needs of the Land science and applications communities and at least provides continuity with the current suite of MODIS Land products.***
2. ***For consistency and continuity with the MODIS Land products, these products should:***
    a. utilize the same algorithmic theoretical basis and quality assurance (QA) interpretation logic as their MODIS counterparts.
    b. be generated by the Land PEATE, following in close cooperation with the Land Discipline Group of the VIIRS Science Team and with guidance from the NASA's Earth Science Community. As with MODIS, code integration and testing using the Land PEATE facility will need to be coordinated and sequenced.
    c. be made broadly available to the science and applications community through the LAADS system, once the products have progressed beyond the Beta (test) level.
    d. each product should have a scientist responsible for product refinement and well developed product documentation (i.e. User Guide).
    e. be reprocessed at periodic intervals following refinement of the algorithms, based on instrument performance, product QA and validation. Reprocessing should have science guidance and oversight, resulting in significant improvements to the product. Reprocessing should follow extensive testing, the results of which will be shared with the science community. Product versioning should be coordinated by the Land PEATE.

3. ***Support should be provided for Quality Assessment of the products and Validation for each VIIRS Land science product to at least CEOS LPV Stage 2, building on the approaches developed for MODIS.***
    a. A program of science product validation should be supported and start in earnest once the science products have stabilized and have been promoted beyond Beta to Provisional Status. It should be recognized that validation of the EDR's could contribute to the validation of the science products and that coordination with the JPSS EDR validation program is highly desirable.
    b. A small group should be supported to coordinate VIIRS land product validation, as is currently the case for MODIS.
4. ***A NASA LANCE capability should be developed for VIIRS to meet the needs of NASA's near real time user community***
5. **A *mechanism should be set up to allow the prototyping and testing of new VIIRS land products as new products and algorithms are proposed to meet the needs of the science community.***
6. ***If the scope of the IDPS is to be changed to accommodate the needs of the science community beyond those of NOAA's operational users, then for products to be generated in a timely and cost-efficient manner, a revamp of the IDPS system's algorithm change process is required.***
7. ***Discussions should be held between NASA and NOAA on the roles and responsibilities for supporting VIIRS Land science products in the JPSS era, identifying pathways for entrainment of desired science products into operational production streams, once the Land science products have been validated to CEOS LPV Stage 2 and the stewardship of Land climate data records.***
8. ***A mechanism should be set up by NASA in collaboration with the NOAA for identifying and assessing the cost-benefit of improvements to the follow-on VIIRS (F2 and F3) instruments to meet the needs of the Land science and applications communities.***
9. ***Analysis should be supported to evaluate the utility of combining VIIRS (PM) and Metop (AM) for Land science product generation, in the context of continuity of the current MODIS combined Aqua/Terra products.***

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