An Evaluation of the NPOESS Preparatory Project (NPP)
Visible/Infrared Imager Radiometer Suite (VIIRS) and the Associated
Environmental Data Records for Land Science

The VIIRS Land Team with contributions from:
Ivan Csiszar, Evan Ellicott, Mark Friedl, Louis Giglio, Dorothy K. Hall,
Alfredo Huete, Jeffrey R. Key, Alexei Lyapustin, James Maslanik, Edward J. Masuoka,
Jaime Nickeson, Jeffrey L. Privette, George A. Riggs, Peter Romanov, Crystal B. Schaaf,
Wilfrid Schroeder, Eric F. Vermote, Yujie Wang, Robert E. Wolfe, and Yunyue Yu

Editors: Miguel O. Román and Chris Justice

Table of Contents

Executive Summary ..........................................................2
1. Background ...........................................................................6
2. VIIRS Instrument Characterization for Land Science.................8
3. EDR Evaluation for Land Science........................................10
   3.1. Land Surface Temperature EDR ..................................10
   3.2. Surface Type EDR ..................................................12
   3.3. Surface Albedo EDR .................................................14
   3.4. Vegetation Index EDR ..............................................16
   3.5. Ice Characterization EDR .........................................18
   3.6. Ice Surface Temperature EDR ..................................20
   3.7. Snow Cover/Depth EDR .........................................21
   3.8. Active Fires ARP ..................................................24
   3.9. Surface Reflectance IP .............................................26
4. EDR Land Validation and additional needs for Science Product Validation .......27
5. VIIRS Data Processing Capabilities for Land Science ..................34
6. Science Product and Processing needs beyond the VIIRS Land EDRs .......35
7. NASA Land Team Recommendations ....................................37
8. Desired Land Improvements to future VIIRS Instruments ..........39
9. References ...........................................................................40

# Support for the research activities underpinning this document was provided by the National Aeronautics and Space Administration and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO).
Executive Summary

This report presents the findings of the VIIRS Land Science Team on the utility of the VIIRS instrument, data processing system, and Environmental Data Records (EDR’s) 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 Integrated Program Office (IPO) 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 the land component of the study of Global Change. 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 time-series through the next decades will be increasingly important for NASA’s Earth System Science Program’s ability to meet the science needs of its national and international partner programs.

The NPP VIIRS instrument was intended to provide continuity for NASA’s EOS MODIS instruments and risk reduction for NPOESS. The NPOESS program was designed to provide observations through to 2026. The history of the NPOESS Program has been checkered but following thermal vacuum testing, as the first VIIRS instrument is being readied for launch, the land science community expects to have an instrument suitable for continuing and building upon much of the science currently undertaken using MODIS.

Unlike the MODIS, the VIIRS design constrains pixel growth across the scan, which could be a significantly positive advance for land products. However, the full potential of the instrument will almost surely not be known or exploited through the operational program. Alternatively, the step-jumps associated with onboard aggregation could impart undesirable impacts on the products if not accounted for. Similarly, the use of dual-gain bands has a strong potential to impart artifacts at transition radiance levels. It will be necessary to undertake significant end-to-end studies of this new instrument in the context of science data processing. For MODIS, a significant effort was given by the MODIS Calibration Support Team to understanding and monitoring instrument calibration and performance and the same will be needed for the VIIRS.

The first VIIRS instrument has been built and work has started on a second instrument. The VIIRS instrument will be a staple for NPOESS and will be used extensively by the NASA Land science and applications communities. However, improvements to the VIIRS instruments would increase the utility of the data for science use. It should be noted that the NRC Decadal Survey showed a heavy reliance on NPOESS missions for providing key climate variables in the coming decade (NRC 2007). Although the VIIRS was not considered as a new mission in the NRC Decadal Survey, funding for improving the VIIRS should be given a high priority by NASA. If the instrument performs on-orbit as expected, instrument improvements for the land community would be modest e.g. providing a higher dynamic range for fire detection. As a multidisciplinary instrument, the needs of the oceans and atmospheres science community should also be considered and would likely include reducing cross-talk and adding more bands.

A number of EDRs will be generated by the VIIRS contractor, Northrop Grumman Aerospace Systems (NGAS) supported by the IPO. These products, generated by an Interface Data
Processing Segment (IDPS), are designed and specified to meet the needs of the operational community, primarily within the DOD and the National Weather Service. We are anticipating that if the instrument performs as planned, to a large degree the EDRs will meet their specification and thus the needs of the intended operational community. The Land Team of the NASA VIIRS Science Team is evaluating the EDR algorithms in terms of their appropriateness for fulfilling NASA’s science needs. A summary of the findings from these studies to-date is presented in this report.

The Land Surface Temperature, Surface Type, Surface Albedo, Vegetation Index, Sea Ice Characterization, Ice Surface Temperature, and Snow Cover EDRs will most likely meet the target requirements of the operational users. The Snow Cover EDR as currently scoped will in general provide useful input to the cryospheric science community. The Sea Ice Characterization EDR, in its present form, is unlikely to meet specifications for correct classification of New/Young and Other ice. With only three classes (Ice free, New/Young, and Other ice), and a relatively low probability of correct classification, its usefulness in scientific research is somewhat limited. The Ice Surface Temperature (IST) algorithm, will meet the science community needs especially if it is tuned after launch, based on surface observations. 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. The identification of cloud amount and properties critical to successful ice characterization could also be improved and mapping of freshwater ice including large lakes should be included. The Snow 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 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.

The dependence of the surface reflectance IP on aerosol retrieval is provided for VIIRS by the aerosol optical thickness IP. This is in contrast to the aerosol retrieval which is integrated in the same algorithm for the MODIS Surface Reflectance product (MOD09). The VIIRS aerosol retrieval over land uses similar aerosol models and retrieval techniques to MODIS. Pre-launch testing of the VIIRS aerosol retrieval over land and comparisons to AERONET measurements has shown performance comparable to MOD09 aerosol retrieval. On the other hand, retrieval accuracies begin to decline under various surface-atmosphere conditions particularly for: the shortwave channels, where the Lambertian assumption introduces biases that depend on the view geometry and atmospheric opacity; over bright surfaces; and over regions with variable aerosol sources including dust. Planned improvements to the VIIRS aerosol retrieval over land, including the deep blue algorithm to handle bright surfaces, should provide a surface reflectance product from VIIRS as scientifically sound and useful as the MODIS surface reflectance product.

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 cor-
rected, there are blue-band discrepancies that will impact the continuity with MODIS EVI. The 
Surface Albedo EDR supplies a single broadband value which will not provide the underlying 
spectral albedos or anisotropy information currently produced by EOS. This information is in-
creasingly being utilized to improve land surface energy budget computations within global and 
mesoscale numerical prediction models. Furthermore the product, while produced at a finer reso-
lation, will only be evaluated at a 4km resolution, avoiding the impacts of fine scale variations of 
snow cover, water, ice, and surface cover. In the context of NASA science, the quality and accu-
racy 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 coded by NGAS will lack the contextual fire mask and fire radiative power data layers 
that have been present in the MODIS active fire product, and are now standard components of 
most contemporary active-fire data sets. However, an Active Fire Science Product currently in 
development by members of the VIIRS Science Team, with support from the IPO and NASA 
should provide the necessary continuity with the MODIS Active Fire product.

Finally, all land products ingest the VIIRS cloud mask which adopted a one size fits all approach 
that proved ineffective for MODIS and could potentially lead to systematic substandard 
NPOESS operational products. However, many features of cloud detection needed for the land 
products have been incorporated in the VIIRS cloud mask. The VIIRS cloud mask algorithm 
uses Imagery-resolution bands to identify ephemeral water for use with land and aerosol algo-
rithms. A geometric-based cloud shadow detection algorithm and an improved aerosol versus 
cloud discrimination algorithm have been implemented. Finally snow-cloud discrimination 
should improve with VIIRS based upon the higher resolution imagery available and mixed pixels 
should have less impact with VIIRS.

There are shortcomings in the formats associated the EDR products for science use. The 
NPOESS latency requirements prohibited some of the more time-consuming processing tasks 
integral to the MODIS Land Products, such as multi-angle and multi-temporal compositing 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 
are not gridded (i.e. Level 3) they will not be directly amenable for science and modeling use.

For the IDPS, there is no mandate or capacity for reprocessing, which has proven critical to en-
suring research-quality MODIS land products. As our understanding of the instrument perfor-
ance develops post-launch, a better knowledge of instrument calibration on-orbit and during 
the life of the instrument will be gained and changes to the calibration can be made and applied 
retrospectively, requiring data reprocessing. To-date, the MODIS Land Products have undergone 
five complete reprocessing of the archive. Similarly, upstream algorithms from Level 1B cali-
bration to clouds to aerosols will likely change frequently with no operational capability or mandate 
to develop a consistent temporal series back in time.

Based on the above findings 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 broad 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 Test Element (Land PEATE) has been developed at NASA-GSFC, managed as part of NASA’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 a VIIRS Land Science Product Suite be generated and distributed by the Land PEATE in close coordination with the VIIRS Land Science Team. A small team should be supported to conduct Quality Assessment of the products generated from the Land PEATE, in conjunction with the science QA undertaken by the VIIRS Land Science Team.

Once the VIIRS Land Science Products have stabilized, i.e., promoted from Beta to Version 1, a program of product validation should be initiated. This validation should be undertaken 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 NPOESS-funded activities and international partner programs, as is currently the case with MODIS.

It is anticipated that some of the Land Science Products from VIIRS will also be of interest to the operational community, particularly the NASA Applications partners (e.g. USDA, USFS) and once the products are of sufficiently maturity (e.g. Validated to Stage 1), a case might be made for running some of the science products in the IDPS or other operational systems. Once Land Science Products are being generated by the PEATE, discussions will be needed between NASA and the IPO on how to transition desirable NASA science products for long-term generation into the operational data chains. Given that the IPO has started a program of EDR Validation and the National Oceanic and Atmospheric Administration (NOAA) is embarking on a program of NPOESS Data Exploitation (NDE), albeit focusing on the additional needs of the operational community, it is recommended that interagency coordination be undertaken concerning roles and responsibilities for VIIRS Land Science Product Generation and Validation. Specifically, in cases where NASA research-quality algorithms are not appropriate or acceptable for generation in IDPS or other operational systems, inter-agency coordination will be needed concerning the long-term stewardship for the products in the NPOESS era e.g. with NOAA’s Climate Data Record (CDR) program in coordination with the new WMO Sustained, Co-Ordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE CM).

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 systematic 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 current NASA systems. 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 NPP VIIRS and through the NPOESS 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 7.
Purpose of the White Paper

This whitepaper is intended to summarize the NASA VIIRS Land Science Team findings to-date with respect to the instrument characteristics, the pre-launch performance, the utility of the 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, NOAA and the IPO as to what is required from VIIRS to meet the needs of the global and climate change research communities.

1. Background

In 1994 a Presidential Decision Directive was given to the Department of Commerce (DOC) and the Department of Defense (DOD) to integrate the U.S. polar-orbiting systems into a single, converged, National Polar-orbiting Operational Environmental Satellite System (NPOESS). The DOC, DOD, and NASA were charged with creating an Integrated Program Office (IPO). To reduce development risk and to provide a bridging mission from the NASA EOS to NPOESS, the IPO and NASA jointly defined an NPOESS Preparatory Project (NPP), with the goal of providing continuing observations for studying global change after EOS Terra and Aqua and allowing early user evaluation of NPOESS products. The Visible/Infrared Imager/Radiometer Suite (VIIRS) instrument was defined as the NPOESS equivalent of the MODIS instrument to be included on the NPP Mission (Murphy 2006; Murphy et al. 2001). In February 2010, the Office of Science and Technology Policy (OSTP) announced the discontinuation of the NPOESS program. OSTP has assigned responsibility for the early morning and afternoon U.S. populated polar orbits to DOD and the NOAA respectively. While this decision will impact the NPOESS IPO, NPP will remain a multi-agency mission with an expected launch date of September 2011.

The VIIRS instrument design review was completed in early 2002, the instrument is built and is currently planned for launch in 2011 with a 13:30 (ascending node) overpass. The instrument has 21 bands from 0.412 µm to 11.50 µm, distributed on three focal plane assemblies, and also includes a Day/Night Band centered at 0.70 µm. The VIIRS instrument design is described by Murphy et al. (2006).

The VIIRS instrument builds on the capabilities of the AVHRR, the MODIS and the DOD Operational Line Scanner (OLS), with spectral bands selected to satisfy the requirements for generating accurate operational and scientific products (16 moderate resolution bands at 750 m nadir spatial resolution and 5 ‘imagery’ resolution bands at 375 m). The nominal altitude for NPOESS will be 833 km and the VIIRS scan will extend to +/-56 degrees on either side of nadir, giving a swath width of approximately 3000 km. Unlike MODIS, the VIIRS controls growth in spatial resolution along the scan by aggregating pixels, resulting in only a quadrupling of pixel area at c. 55 degrees for VIIRS, compared to the nine times pixel area growth for MODIS. Radiometric calibration uses an onboard solar diffuser for short wavelengths and an onboard blackbody source and a deep space view for thermal wavelengths. A stability monitor is included to track the performance of the solar diffuser.

A number of higher order products known as Environmental Data Records (EDRs) are under development by the prime VIIRS contractor Northrop Grumman Aerospace Systems (NGAS) and managed by the IPO. The requirements for the EDR’s were driven by DOD and NOAA’s traditional operational user, the National Weather Service and summarized in an Integrated Operational Re-
requirements Document (IORD). The Land EDR’s are: Albedo, Land Surface Temperature, Snow Cover and Depth, Vegetation Index, and Surface Type. Active Fire is an Applications Related Product (ARP). Surface Reflectance will be generated as an intermediate product (IP). The Land Team has also embraced the Ice Surface Temperature and Sea Ice Characterization EDRs. 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 NGAS to assist with algorithm implementation. The development of the Land EDRs by NGAS has now been completed and operational versions of the Code are being tested.

Starting in 2004, NASA supported an NPP Science Team for a three year study to evaluate the utility of the VIIRS instrument and the associated EDR’s for science use. In 2007 through a second round of three-year funding, as part of the EOS recompete, investigators were selected to continue to evaluate the EDR’s from a science perspective and compare them with science algorithms. The VIIRS Land Team has developed an open dialog with the NGAS contractors assigned to the land products, which has helped with the understanding of the EDR algorithms and suggest improvements within the contractors remit. Several improvements have been made; however, a number of improvements suggested by the Land Team were not adopted as they were either beyond the specified requirements, incompatible with the processing implementation or too costly. In some cases working through the IPO and the VIIRS Operational Algorithm Team (VOAT), improvements were accepted and additional resources provided by the IPO to the contractor to implement them. The current round of VIIRS Science Team funding is due to expire in December 2010. A new funding competition for the NASA VIIRS Science Team is anticipated in 2010.

Building on the MODIS Advance Processing System (MODAPS), NASA constructed a computing system known as the Land Product Evaluation and Test Element (Land PEATE) 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 PEATE allows 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 IPO 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 and will be required for the VIIRS EDR’s and Land Science Products. Recognizing the validation experience-base that resides within the MODIS Team and the global land community, the IPO formed an EDR Land Validation Team to augment the NGAS validation activity. Although this team has strong overlap with the NASA MODIS Land Team, its scope is currently limited to the operational specifications, algorithms, and products.
2. VIIRS Instrument Characterization for Land Science

Robert E. Wolfe (NASA); Eric F. Vermote (UMCP); Louis Giglio (SSAI)

From the Land perspective there are a number of instrument characteristics that affect the product performance and require continued attention. In general the instrument was well specified for Land needs, however, as a result of the instrument characterization and testing, the Land Science Team has identified three generic instrument characteristics which need continued attention: (1) band-to-band registration; (2) out of band spectral response; and (3) geolocation thermal correction. In addition, at various stages of the formulation of instrument specifications and review, recommendations by the Land Science Team to improve the specifications for fire characterization were unsuccessful, thus resulting in a limited Active Fires ARP.

**Band-to-band registration**

There are two issues of concern for instrument band-to-band registration (BBR). First, even though the static BBR for almost all band/detector pairs is within specification, under some high frequency vibration (jitter) conditions induced by the spacecraft, the dynamic BBR for certain bands becomes much worse than specified. Second, based on the instrument characterization, the "best" on-orbit registration between the focal planes should be determined and uploaded before launch.

The primary cause of the dynamic BBR issue is jitter introduced by the spacecraft attitude control system Reaction Wheel Assembly (RWA) when rotating at specific rates. The jitter then causes samples from bands acquired at different times but seeing the same ground location, to be shifted with respect to one-another, thus increasing the BBR errors. This is an intermittent problem as the RWA operates over a wide range of rates and the jitter-inducing frequencies only occur for brief periods during each orbit. A better understanding of the frequency and duration of these events is needed. Also, measurements of the actual RWA jitter, when mounted on the spacecraft, would help to better understand this issue and the magnitude of the impact on the Land products.

Ideally, the “best” on-orbit registration would minimize BBR errors for important algorithm band combinations. There is sufficient information from the pre-flight BBR testing and understanding of the algorithms to perform an analysis to determine the optimal set of BBR parameters before launch. This analysis should be performed and the instrument should be put into this configuration before launch, preferably, or before first light at the latest. This will ensure that the first data acquired by the instrument will be in the best configuration as determined by the pre-flight tests. If appropriate, on-orbit data can be used to further “tweak” these values during the intensive post-launch Cal/Val period.

**Out of band spectral response**

The VIS/NIR focal plane has out of band spectral crosstalk related the band-pass filters. This is primarily an issue for the Ocean algorithms which are particularly sensitive to spectral crosstalk. For Land, the algorithms used to determine aerosol optical thickness as part of the atmospheric correction are the most sensitive to the measured instrument crosstalk, specifically in
M5 (672nm). The main impact on the aerosol product occurs near sharp edges of cloud boundaries, where the cloud’s spectral response contaminates the bands used by the aerosol algorithm. Contractor simulations show that these errors impact only a small number of retrievals, so this is a topic to be assessed during the intensive post-launch Cal/Val period to better understand the impact on the Land products.

**Geolocation thermal correction**

Based on optical/thermal/mechanical models of the instrument, the VIIRS pointing is expected to have within-orbit thermal variations that if not modeled in the geolocation algorithm will cause significant geolocation errors. There is currently a minimal “placeholder” for this thermal variation model in the IDPS software. Based on the current models, the functional form of this correction and preliminary estimates of the model’s parameters are known. To minimize the work required during the early post-launch period, this algorithm should be fully “fleshed out” before launch so that only tweaking the parameters based on control point measurements is needed after launch.

**Fire band saturation and characterization**

There are two main issues of concern for the VIIRS fire bands. First, the saturation specification for band M15 is not sufficiently high for fire monitoring. This will degrade the ability of the VIIRS sensor for fire characterization, and potentially fire detection. Second, no characterization of M15 has been performed at the high radiance levels that will be routinely experienced in the presence of actively burning fires.

Band saturation is a problem because many fires will saturate M15 and prevent a full retrieval of fire intensity and smoldering ratio. A further problem is the on-board aggregation of saturated samples in the scan direction in the three- and two-sample aggregation zones near the nadir portion of the swath. Due to the logic of the on-board computation, if some aggregated samples are saturated, the sample will be marked as unsaturated; thus resulting in incorrect radiance computations. This corrupted value will then propagate through any algorithm using band M15. In the case of the active fire algorithm, the corrupted radiances, will occur frequently and will confound reliable retrieval of fire intensity and smoldering ratio. In extreme cases the simpler task of merely detecting a fire may also be compromised. Two mitigation options have been discussed with the IPO for NPP: correcting the on-board computation, or transmitting unaggregated data to ground stations (as is done for some other bands). The former option has been rejected due to impacts on cost and/or schedule. The feasibility of the latter option is still under ongoing consideration. Note that the M15 saturation issue is helped somewhat by the fact that the recently measured M15 saturation level of VIIRS/NPP (FU1) exceeds the saturation specification by a wide margin (~50%). If M15 can be calibrated over its full dynamic range, and if the same (or better) margin can be guaranteed for subsequent VIIRS instruments, then the frequency of saturation of the pre-aggregated M15 pixels will be greatly reduced. Note that testing has shown that M15 actually saturates as substantially above its spec value of 343K. In fact M15 saturates over 360K. However, a sizable fraction of detectable fires (~38%) will still saturate M15. Moreover, transmitting unaggregated data is still preferable for expanding the range of detectable fires, particularly for operational and Direct Broadcast users.
The second issue concerns characterizing the fire bands at high radiance levels (near and above saturation) due to limitations of the ground test equipment. Measurements at these values are needed to confirm that the instrument response at radiance levels above saturation does not significantly “fold over” and alias non-saturated values. This issue is ongoing and the fire team will continue to work with the contractor and government sensor characterization teams to obtain the most accurate sensor data. High temperature calibration, a well-defined saturation level, and well-understood and controlled behavior near and beyond saturation of all bands used for fire detection and characterization all require additional attention.

Future VIIRS Instruments

The VIIRS Flight Unit 2 (F2) is currently being built with a number of improvements including reduced Cross-Talk. The NASA VIIRS Science Team has submitted a prioritized list of instrument improvements to program management that would make the instrument and data more useful to the science community. The status of this list is unknown and the question of VIIRS enhancements needs to be revisited by NASA. Discussions with the IPO concerning improvements to Flight Unit 3 (F3) should also be initiated in this context (see Section 8).

3. EDR Evaluation for Land Science

3.1. Land Surface Temperature EDR

EDR Team: Jeffrey L. Privette (Team Lead, NOAA-NCDC); Zhengming Wan (UCSB); Simon Hook (JPL); Yunyue Yu (NOAA-STAR)

Summary of the EDR requirement, algorithm and the contractor approach

The VIIRS LST EDR provides the radiometric LST values over land and larger inland waters in swath format (equivalent to MODIS Level 2). The dynamic range extends from 213 K to 343 K, and will be produced 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 accuracy and precision values are 2.4 K and 0.5 K, respectively. Accuracy and precision will be evaluated individually for each International Geosphere-Biosphere Programme (IGBP) surface type. There is no global “all land” accuracy specification. Further, the product must only meet specifications over confidently clear cloud conditions.

The NPOESS LST EDR algorithm deviates substantially from its MODIS counterpart in three areas as described below. First, the VIIRS algorithm is actually an algorithm suite composed of a 1) main daytime algorithm 2) main nighttime algorithm, and 3) backup algorithm. It is likely that, under normal circumstances, each of these three algorithmic forms will be employed through each VIIRS orbit. Ideally, only the main algorithms will be used, however the backup algorithm – which most resembles the heritage MODIS algorithm – is available if the primary algorithm experiences degraded input (e.g., in sun-glint regions) or produced unexpected outcomes. Potential artifacts in jumping from one algorithm to another are currently not well known.
The second main difference from the MODIS LST algorithm is the functional form of the main LST algorithms (for both day and night). NPOESS employs a new algorithmic approach, the so-called dual split window, which is an adaptation of the well-known split window algorithm used with MODIS. The dual split window attempts to improve upon the split window by using both thermal infrared bands (10.8 and 12.0 µm, similar to split window) and middle-infrared bands (3.75 and 4.005, not used in split window). The new bands potentially offer improvements in atmospheric correction; however, they also introduce uncertainties absent from the split-window approach. To our knowledge, the dual split window has never been used for a global product by any space agency. Due to the above concerns and the potential impacts from BBR, the prime contractor has implemented an algorithmic switch for allowing the backup split-window algorithm to be the fulltime algorithm. The decision on the final algorithm selection will be evaluated during Cal/Val.

Finally, the NPOESS LST algorithm deviates from its MODIS counterpart in its functional dependency with surface type. Specifically, the NPOESS algorithm relies on previously-generated surface type dependent coefficient rather than generic coefficients as well as land emissivity data (as an independent variable per MODIS). The NPOESS technique was adapted from the ATSR/AATSR algorithm. It is notable that the prime contractor attempted to include likely surface type mixtures in the coefficient development process. Like MODIS, the NPOESS LST algorithm uses view zenith angle to improve the atmospheric correction. However, unlike MODIS, it also uses the solar zenith angle to reduce errors associated with using the middle-IR bands (which, in contrast to the thermal IR bands, are subject to atmospheric contamination). The prime contractor expects to meet accuracy specifications for all surface types, and precision specifications for all but two surface types based on the performance analyses with global synthetic data and MODIS proxy data.

**Evaluation of the resultant LST EDR in the context of NASA science needs**

NASA evaluated the VIIRS LST algorithm against a variety of split window algorithms in two ways: with output of radiative transfer models and with a large number of MODIS scenes. The tests exposed the weakness of the NPOESS algorithm in meeting the precision specification. The problem is primarily associated with the greater uncertainty in land emissivity knowledge for the middle-infrared bands compared to the thermal infrared (emissivity is a key input to the generation of NPOESS surface type dependent algorithm coefficients). Specifically, middle infrared emissivity varies significantly more within and across surface types than does thermal emissivity. It is also varies significantly with vegetation phenological stage. Given the relative immaturity of global emissivity data in general, the NPOESS algorithm’s need for accurate middle infrared information is extremely hard to satisfy. Indeed, NASA’s evaluation revealed that the NPOESS “backup” algorithm (split window) is more stable and would likely provide superior results to the main algorithm when using actual on-orbit VIIRS data and will have robustness given normal errors in the cloud mask, mixed surface types, shortcomings of “training data” developed from radiative transfer codes, etc.

The consistency of the VIIRS LST product across the different algorithms (day, night and back-up) was not studied, however it remains a major concern. Currently, there is no attempt by the NPOESS program to ensure smooth cross-over from one algorithm form to another. Therefore, it is possible that the so-called sun glint exclusion zone will be visible in LST imagery, since the
algorithm will systematically jump from the main to backup algorithm, and back, as a function of the view/solar angle difference.

Finally, a structural shortcoming of the NPOESS algorithm is its indirect relationship with surface emissivity. Surface emissivity is known to change under many circumstances, including rainfall in arid regions, phenological changes, and intra-surface type changes (e.g., fractional overstory cover in woodlands). Because MODIS and nearly all other split window formulations rely explicitly on emissivity as an independent variable, they can easily accommodate these changes by spatially- and temporally-adjusted emissivity values. The NPOESS algorithm, in contrast, cannot respond to such variability or dynamics due to its fixed surface type coefficients.

**What is needed in addition to the LST EDR with respect to the product?**

In addition to the shortcomings outlined above, the VIIRS operational product does not provide dynamic land emissivity per the current MODIS “day-night” algorithm. Although this product was experimental at the onset of EOS, it is now recognized as a valuable and viable product and should be continued in the NPOESS era.

### 3.2. Surface Type EDR

**EDR Team:** Mark Friedl (Team Lead) and Damien Sulla-Menashe (Boston University)

**Summary of the Surface Type EDR requirement, algorithm and the contractor approach**

The Surface Type Environmental Data Record (EDR) will be produced at 1 km spatial resolution based on the previous 12 months of VIIRS data. The VIIRS Surface Type EDR is a swath product built by reprojecting the Gridded Quarterly Surface Type IP and added layers of Active Fire APR, Snow Cover EDR and Vegetation Fractional Greenness (a qualitative variable defined deterministically from the current and past 12 months of Vegetation Index values). The EDR will provide 17 surface type classes following the IGBP classification scheme. The requirement for this EDR is 70 overall percent correctly classified.

The contractor is using off-the-shelf commercial software to generate the surface type EDR. Specifically, the VIIRS Quarterly Surface Type IP algorithm will be run in a supervised classification mode, using global training data selected to be representative of IGBP surface types. Input features will include spectral information and temporal metrics developed from 12 months of VIIRS visible and infrared band information. The C5 ensemble decision tree classifier (www.rulequest.com) is used to perform the classification.

**Evaluation of the resultant Surface Type EDR in the context of NASA science needs**

The Surface Type EDR will likely (but not definitely) meet its target requirement of 70 percent classification accuracy. This may support the general needs of the meteorological forecasting community for land boundary conditions. However, even this community may find the required accuracy insufficient. Equally important, the surface type EDR will probably be of insufficient quality to support many current and future NASA science needs. In particular:
• While the overall accuracy requirement may be met, this will likely occur at the expense of specific land cover classes, which will have substantially lower accuracies. Uniform land cover types that are more easily classified such as the barren and sparsely vegetated, water, permanent snow and ice, and even some of the forest classes are likely to have much higher classification accuracies (75-90 percent correctly classified) than more complex and less separable classes such as open and closed shrublands, savannas and agricultural mosaics.

• The Surface Type EDR is used as input to other NPP products, including the Cloud Mask and Land Surface Temperature. Hence, surface type errors will be propagated to these other products.

• The quality and accuracy of the surface type EDR will not be sufficient to support meaningful land cover change detection. 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 unacceptable levels of spurious differences (i.e., apparent but not real land cover change) between EDR data sets in successive time periods.

**What is needed in addition to the Surface Type EDR with respect to the product?**

The EDR product needs for surface type fall into two categories: (1) changes to the current surface type EDR algorithm to address shortcomings identified above, and (2) additions to the EDR to address critical information that is currently not included.

• **Changes to the current surface type EDR algorithm:** The use of off-the-shelf commercial software is fundamentally limiting for algorithm refinement and improvement. The inability to access source code, and by extension, tune the algorithm to address problems, is a critical weakness of the EDR algorithm. As a result, once the EDR becomes operational, it will be very difficult to correct problems.

• **Additions to the EDR:** NASA and science community needs for land cover needs go well beyond provision of quarterly maps of IGBP land cover. Specifically:

1. In addition to IGBP, the EDR should provide surface type characterization that is consistent with the now widely used FAO-Land Cover Classification System.

2. The 500m MODIS Vegetation Continuous Fields (VCF) product representing proportional estimates of cover is widely used by the science community and continuation of the product will be needed from VIIRS.

3. Land cover change is an essential variable that is not currently included in the Surface Type EDR. While 1-km data is not well-suited for detailed change monitoring, VIIRS data and an associated change product designed to identify potential change regions could be very valuable to the broad community working in land cover, ecosystems, and terrestrial carbon budgets. A quarterly or annual change product should therefore be included as part of the VIIRS Land Science Product suite.

4. Land surface phenology has emerged in the last decade as a key control of surface energy, water and carbon budgets, and more generally, as an important diagnostic of ecosystem response to climate change. The Surface Type EDR currently includes the Vegetation Greenness Fraction. However, this quantity does not provide the type of information desired by bioclimatologists interested in interannual to decadal scale
ecosystem responses to climate forcing and also by ecosystem modelers interested in regional to global carbon and water budgets. A quarterly land surface phenology product that identifies land surface phenological activity during each quarterly period should therefore be added as Land Science Product.

3.3. Surface Albedo EDR

**EDR Team:** Crystal B. Schaaf (Team Lead), Alan H. Strahler and Zhuosen Wang (Boston University); Shunlin Liang (UMCP)

**Summary of the Surface Albedo EDR requirement, algorithm and the contractor approach**

Albedo, the quantity that specifies the proportion of the shortwave radiative flux that is reflected by the surface, is one of the primary Visible Infrared Imaging Radiometer Suite (VIIRS) Environmental Data Records (EDR) required by the National Polar Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) as well as GTOS Essential Climate Variable (ECV) (Schaaf et al., 2009). The VIIRS specification calls for only a broadband value, retrieved on a daily basis under cloud-free conditions. Two algorithms have been 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; Lucht et al., 2000; Gao et al., 2005; Jin et al., 2003a;b; Salomon et al., 2006; Strove et al., 2005; Schaaf et al., 2008; Román et al., 2009a;b;) 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 (Martonchik et al., 1998a;b), POLDER (Leroy et al., 1997; Hautecoeur and Leroy, 1998; Bicheron and Leroy, 2000; Maignan et al., 2004; Bacour and Breon, 2005), Meteosat (Pinty et al., 2000a;b; Govaerts et al., 2004; 2006) and MSG (van Leeuwen and Roujean, 2002; Geiger et al., 2008). 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., 1999; Liang, 2003; Liang et al., 2005; Strove et al., 2005; 2006).

**Evaluation of the resultant Surface Albedo EDR in the context of NASA science needs**

From the outset, in our role as members of the 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 multispectral bands. While the DPSA approach actually calculates these quantities (and the BPSA approach easily could as well), the specification only guarantees that a single broadband albedo appropriate for a single illumination condition is actually provided to the operational user.
Moreover, since the operational user has no access to the underlying spectral anisotropy models (the BRDF Intermediate Product or IP) for each location, they are precluded from computing spectral albedos for themselves as well as computing albedo under other illumination conditions, specifying the surface boundary conditions, or 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 implemented the MODIS 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. Note also that the Direct Broadcast MODIS code is run in a daily fashion in keeping with the VIIRS requirement for a daily product. This represents a temporal improvement over the MODIS collection V005 product (which is currently retrieved every 8 days based on 16 days worth of directional surface reflectance data). This enhancement is of particular interest for monitoring snow and ice albedos, and vegetation phenology at times of rapid growth or senescence.

An additional concern continues to involve the contractor’s strategy of providing two albedo retrievals (DPSA and BPSA) at each location without any immediate assessment of which retrieval was more likely to be closer to reality at any particular location. To our disappointment, at present, the contractor has designated the BPSA approach as the primary land albedo algorithm (despite the MODIS heritage of the DPSA approach). The contractor has indicated that this decision has been made in part because both the sea ice and ocean albedo algorithms will also use approaches similar to BPSA.

Another lesson learned from MODIS is that the quality of the underlying BRDF retrievals increase with an increase in the number and distribution of high-quality cloud-free observations obtained over a multi-day period. This is achieved in the operational MODIS algorithm by using observations from both the Aqua and the Terra MODIS. Unfortunately with the retrenchment of the NPOESS program, it is no longer possible to use both morning and afternoon VIIRS data to increase the number of the directional observations.

As 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 is now actually producing BRDF and albedo quantities at an increased spatial resolution (500m in Collection V005 data) 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) as subpixel snow cover, open water and thin ice in the ice pack, residual water pooling and the variety of surface types typical in natural system would all only be represented by coarse averages. Therefore, at present, the VIIRS albedo product will continue to be generated at the higher spatial resolution although it will only be evaluated at a coarser 4km resolution. –This suggests that the product will not be as rigorous as it should be given that regional and mesoscale numerical weather prediction models are increasingly moving to land surface energy budget computations at a 1 or 2km spatial resolution (e.g. UK Met Office) and high quality accuracies at that resolution should still be achievable.

What is needed in addition to the Surface Albedo EDR with respect to the product?

As indicated above, the loss of spectral anisotropy and albedo products from VIIRS represents a major setback from the MODIS era. Access to the underlying spectral BRDF IP is
required to compute both spectral and broadband 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 particularly by the climate and numerical modeling com-
munity (e.g. Lawrence and Chase, 2007 (NCAR-CLM); Zhan et al., 2007 (GISS-GCM); J.-J.
Morcrette et al, 2008 (ECMWF); Houldcroft et al., 2009 (Hadley Centre HadGEM)). Gap-filled
products (Moody et al., 2005; 2008) are also being extensively utilized by the MODIS Cloud
Team, GMAO, GISS, ECMWF, and the UK Met. Office. 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 important MODIS measurements into the VIIRS era. These
modeling and monitoring needs will not be met by the single broadband albedo value currently
provided by the VIIRS EDR.

3.4. Vegetation Index EDR

**EDR Team:** Alfredo Huete (Team Lead), Ramon Solano, and Zhangyan Jiang (University of
Arizona); Alexei Lyapustin (UMBC); Eric F. Vermote (UMCP)

**Summary of the Vegetation Index EDR requirement, algorithm and the contractor approach**

The Vegetation Index EDR consists of two products that will be generated daily at 375 m
spatial resolution over land: the Normalized Difference Vegetation Index (NDVI, Top of the
Atmosphere) and the Enhanced Vegetation Index (EVI, Top of the Canopy):

\[
\text{NDVI} = \frac{(I_2_{\text{TOA}} - I_1_{\text{TOA}})}{(I_2_{\text{TOA}} + I_1_{\text{TOA}})}
\]  

(1)

\[
\text{EVI} = \frac{(1 + L)\times(I_2_{\text{TOC}} - I_1_{\text{TOC}})}{(I_2_{\text{TOC}} - C1\times M3_{\text{TOC}} + C2\times I1_{\text{TOC}} + L)}
\]  

(2)

where spectral bands I1 and I2 are 600 - 680 nm and 845.5 - 884.5 nm, respectively; L, C1 and
C2 are constants; M3 is the band between 478 - 498 nm; and the TOA and TOC subscripts indi-
cate that the values used are Top-of-Atmosphere and Top-of-Canopy reflectances, respectively,
in the respective bands. The M3 band has twice the cell size of the I1 and I2 bands, so its value is
applied to 4 horizontal cells. The Vegetation Index EDR is bidirectional, representing measure-
ments for actual sensor view and sun angle conditions. There is planned latency period for this
EDR of 28 minutes for NPOESS.

The contractor is using an early EVI algorithm from MODIS VI ATBD v.1 to generate
the EVI EDR that results in a different equation with different dynamic range of EVI values rela-
tive to MODIS. Thus, first EVI equation in ATBD v.1 used a gain factor of 2, while the revised
and currently implemented EVI equation has gain factor of 2.5. Due to the nature of equation (2)
above, the gain factor of \((1 + L)\) cannot be reconciled with MODIS.

There is a measurement accuracy specification of 0.016 NDVI units, a measurement pre-
cision of 0.02 NDVI units, and a long term stability specification of 0.01 NDVI units. The mea-
surement uncertainty for EVI is 0.11 units and a measurement exclusion condition for aerosol
optical thickness > 1.0.
Evaluation of the resultant Vegetation Index EDR in the context of NASA science needs

The Vegetation Index EDR has several issues related to the contractor supplied algorithm (listed below), but overall the VIIRS data will be of sufficient quality to generate atmosphere-corrected surface reflectance values in support of NASA science objectives.

- The Top-of-Atmosphere NDVI EDR 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).
- The specifications for the Top-of-Atmosphere NDVI encompass atmosphere contamination and adjacency effects as ‘signal’ and thereby result in very high accuracies, despite poor relationships to surface vegetation dynamics.
- The uncertainty specification for EVI is so loose (0.11 units) that the atmosphere correction IP is essentially non-constrained and the EVI specification will be accomplished even with poor atmospheric correction.
- The VIIRS sensor has a spectrally different blue bandpass (from the heritage MODIS sensor), and requires an adjustment to the EVI coefficient, C1, for optimal EVI performance.
- The altered dynamic range in the VIIRS EVI EDR will result in confusion and discontinuity to the modeling and phenology communities who may be expecting more MODIS-like values.

What is needed in addition to the Vegetation Index EDR with respect to the product?

The quality of VIIRS data will be adequate for many of the constraints mentioned above to be removed or minimized. The VIIRS atmosphere correction intermediate (IP) product can potentially provide higher quality surface reflectances for use in the NDVI EDR.

- Required changes to the current Vegetation Index EDR include, (1) conversion of the Top-of-Atmosphere NDVI to a Top-of-Canopy NDVI through implementation of the atmosphere correction IP; (2) adjustment of the EVI equation to the same structure as in the MODIS EVI equation; (3) adjustment of EVI blue band coefficient, C1, to reflect the different VIIRS blue bandpass; (4) provision of more realistic accuracy and uncertainty specifications; and (5) a sensitivity analysis study to determine the benefits and weakness of eliminating the blue band in EVI and using a two-band EVI.
- Additions to the EDR include (1) higher-level temporal compositing of daily VI values to cloud-free and BRDF-adjusted values; (2) gap-filled temporal composites; (3) spatially gridded values to 500 m, 1 km, and CMG resolutions; (4) validation data for assessment of EDR performance and limitations; and (5) document and characterize continuity assessments with heritage sensors across a range of applications.
3.5. Ice Characterization EDR

**EDR Team** Jeffrey R. Key (Team Lead - NOAA/NESDIS/STAR); James Maslanik (U. Colorado)

**Summary of the IC-EDR requirement, algorithm and the contractor approach**

The VIIRS Sea Ice Characterization (IC) EDR includes the Sea Ice Age EDR and Sea Ice Concentration as an intermediate product (IP). The Sea Ice Age EDR is an ice age classification map that contains classifications for Ice-free, New/Young ice and All Other ice categories. It 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. Horizontal cell size is 2.4 km. There are constraints on the range of conditions under which retrievals are performed, including the thermal contrast between ice and open water and snow depth. 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. Note that the Sea Ice Concentration IP is a retained IP for Calibration and Validation (Cal/Val) and is not a deliverable product. This implies that product may not be available after Cal/Val.

The VIIRS ice age 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. It has been tested with MODIS, AVHRR, GOES, and SEVERI data.

**Evaluation of the resultant IC-EDR in the context of NASA science needs**

The Sea Ice Characterization EDR in its present form, believed to be unlikely to meet specifications for correct classification of New/Young and Other ice. Current testing by NGAS with MODIS Proxy data has identified performance issues with the heat balance algorithm results. A technical committee report (TCR) has been submitted with regards to the potential of not meeting the 70% probability of correct typing for new, young, and other ice classification categories.

The original EDR specification called for classification of thick ice into first-year and multiyear ice. This distinction is particularly valuable for climate studies as well as use for operational activities such as shipping. However, this classification was dropped due to the inability to meet specifications using VIIRS data alone. Even so, the EDR does provide 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 with, or replace, passive microwave ice age during the summer, when the low microwave emissivity of melting ice makes ice typing difficult.

Knowing the difference between 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. Unfortunately, ice thickness information is currently underutilized in numerical weather prediction and climate modeling.
What is needed in addition to the IC-EDR with respect to the product?

The primary limitations to the accuracy of the sea ice age EDR are not the model or the algorithm, but rather the model inputs. Tests indicate that the ice thickness estimation and the ice age classification are most 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 no reliable method of determining the depth of snow on ice from space, though there is at least one experimental method using passive microwave data with applications to first-year ice (only). Research in this area should be pursued.

Surface albedo is critical for daytime retrievals. Small errors in the albedo translate into significant errors in ice thickness, compounded by the complexity of incorporating solar radiation into the ice thickness energy budget model. The bidirectional reflectance function of snow at the large solar zenith angles typical of the high latitudes needs to be better understood in order to improve snow/ice albedo estimation.

Uncertainty in cloud cover (amount and properties) is also relatively large for the polar regions. While this has been an area of active research with MODIS and AVHRR for many years, additional research with new satellites and sensors (CloudSat and CALIPSO) should provide information to help improve cloud detection with visible/infrared imagers.

The effects of interdependencies among the EDR and IPs will require additional research beyond that included in the IPO’s existing Cal/Val plan. The focus of that plan is on evaluating whether individual EDRs meet specifications, but this may not be sufficient for understanding why the algorithms do not meet specifications (if that indeed proves to be the case).

Improvements to these and other products that are used as input to the sea ice age algorithm would allow for a more robust sea ice characterization EDR. The probability of correct typing would be increased, and additional ice types could be identified.

Although excluded from the Ice Characterization EDR, mapping of fresh-water ice is also feasible using simple algorithm approaches. This has been discussed with the IPO but resources are not available to implement it in the current EDR. It is a logical addition for future algorithm upgrades however. 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.

In summary, there are several promising routes for improving the EDRs that would benefit from further research, including the testing of existing, alternative algorithms, developing new approaches, and extending the Cal/Val activities in cost-effective ways. In many cases, this would involve taking greater advantage of fusion of various satellite data and model-derived fields, including many such data sets already provided by NASA.
3.6. Ice Surface Temperature EDR

**EDR Team** Jeffrey R. Key (Team Lead - NOAA/NESDIS/STAR); James Maslanik (U. Colorado)

**Summary of the IST-EDR requirement, algorithm and the contractor approach**

The VIIRS Ice Surface Temperature EDR provides a “skin temperature” for sea-ice covered areas (note the excluded areas below). In this context, “sea ice” is considered to be ice plus any overlying snow rather than just sea ice alone. The EDR has dependencies on the ice characterization and related IPs, as well as the VIIRS Cloud Mask (VCM) IP. The IST EDR is produced both day and night over the oceans. Horizontal cell size is 0.8 km at nadir, degraded to 1.6 km at the edge of the scan. The EDR is to be generated over ice-covered oceans only, thus excluding areas of fresh-water ice and also excluding coastal waters. For these areas, surface temperatures will be provided by the Land Surface Temperature (LST) EDR. IST will be produced under “confidently clear” and “probably clear” VCM conditions, but with no performance specifications imposed for the latter. An aerosol optical thickness exclusion (AOP > 1.0) is also applied. The measurement accuracy is specified as 0.5 K for areas that do not fall within the exclusion conditions above.

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.

**Evaluation of the resultant IST-EDR in the context of NASA science needs**

IST is critical for long-term change detection, estimating ice thickness and characterizing the ice into new/young vs. 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 all the IPs that the IST EDR depends upon 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.

The only temperature products comparable to the IST EDR are temperatures determined from passive microwave data and temperatures estimated using an energy balance approach. Other than for first-year ice with no snow cover, the former relates to snow/ice column temperatures rather than skin temperature. The passive microwave ISTs had been generated as an operational product from AMSR-E but have since been discontinued (although it probably should be resurrected as a research product).

**What is needed in addition to the IST-EDR with respect to the product?**

The main limitations to the IST EDR accuracy are likely to be the availability of good observations for algorithm tuning, and the accuracies of the supporting IPs. For the former, given that the EDR algorithm is a regression approach, the IST accuracy will depend on the availability
of accurate surface observations. These are much more limited for sea ice areas than is the case for open-ocean SST, so the IST EDR will be affected accordingly. In terms of dependencies on other products, the VCM might have the greatest effect in this regard – particularly for nighttime conditions. Potential improvement in the VCM for polar regions is therefore a good route for improving the IST EDR. As noted in the above Sea Ice Characterization EDR summary, while cloud retrieval improvements have been an area of active research with MODIS and AVHRR for many years, additional research with new satellites and sensors (CloudSat and CALIPSO) should provide information to help improve cloud detection with visible/infrared imagers.

Some IST applications such as ice thickness determination and energy balance calculations also use sea-ice albedo. The accuracy of the albedo product is therefore important and needs to be considered (as mentioned in the Surface Albedo EDR write-up).

It is also worth noting that while not included within the IST EDR, surface temperatures over coastal sea ice (which will potentially include significant portions of land-fast ice), freshwater ice, and land ice (glaciers, etc.) are critical for climate investigations. The LST algorithm will not be specifically tuned for these conditions, so it will be important to determine the degree to which this affects accuracy. In particular, the algorithms may not be well tuned high-altitude ice sheet areas.

Depending on the land mask used to define coastal areas, it may be feasible to refine the mask coverage so that as much land-fast ice as possible is included in the IST EDR coverage. There is also no reason why an appropriate IST calculation cannot be applied in the future 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.

For many climate studies, it is useful to treat the pack ice IST, coastal ice IST and land IST as a single data set. For VIIRS, this would require merging the IST and LST products, or as noted above, refining the areas for which the IST algorithm is applied.

In summary, the planned IST EDR should meet researcher needs for sea ice studies in most cases, but depends on the availability of observations for algorithm tuning and on performance of other VIIRS products. The planned EDR also excludes some coastal sea ice areas as well as fresh-water ice, which could be addressed relatively easily by refining the locations for which IST is calculated.

3.7. Snow Cover/Depth EDR

**EDR Team:** Peter Romanov (Co-Lead; CICS/UMD); Dorothy K. Hall (Co-Lead; NASA); Igor Appel (IMSG); George A. Riggs (SSAI); Jeffrey R. Key (NOAA/NESDIS/STAR); James Maslanik (U. Colorado)

**Summary of the Snow Cover EDR requirement, algorithm and the contractor approach**

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. An external cloud mask is used to exclude cloudy pixels from the classification process. The similarity of the algorithms and products will also permit the production of snow-cover climate-data records (CDRs) using MODIS and VIIRS.

Many researchers have used the MODIS snow products for science and modeling research. Time series of MODIS snow cover and albedo data may be used for monitoring dates of snowpack onset and melt progression. Additionally, the snow-cover products are used for modeling studies, both as input to models and to compare model-calculated snow with MODIS-derived snow from the products.

**Evaluation of the resultant Snow Cover EDR in the context of NASA science needs**

The Binary Snow Map product will likely (but not definitely) meet its target requirement of 90 percent probability of correct classification. A similar algorithm applied to MODIS data provides about 92 to 97 percent snow/no snow classification accuracy. The accuracy of classification should be expected to vary depending on the vegetation cover type. Due to the masking effect of trees, the probability of correct typing in forests will be lower than over grasslands and croplands. It is important to note that even with the 90% classification accuracy the product value for the user community (NWP, hydrological and climate modeling) will be limited because of gaps in the area coverage due to clouds. Generation of spatially continuous snow cover product on a daily basis is possible only through synergy of VIIRS snow retrievals with information on snow cover derived from the future MIS microwave sensor. In terms of NASA and user needs, the current VIIRS snow cover binary snow map EDR is adequate because it is essentially a continuation of the MODIS snow cover data product. The expectation is that the VIIRS snow cover EDR will have accuracies similar to those reported for the MODIS snow cover products. We further expect that the community will apply the VIIRS EDR in ways similar to those which the MODIS snow product is used.

The current VIIRS snow cover EDR is inadequate because the MODIS fractional snow cover algorithm is not included in the EDR. The need for the VIIRS Snow Fraction Product is not very clear. This is not a value-added product and most potential users can easily reproduce it by averaging snow/no snow classification results within 2x2 pixel blocks of the VIIRS Binary Snow Map.
Fig. 1 Snow cover map for July 12, 2003 derived from VIIRS simulate data at land PEATE (a) and produced through interactive analysis of satellite imagery at NOAA (b). Snow is shown in red in (a) and in white in (b).

At this time the accuracy of the Binary Snow Cover Map product derived from simulated VIIRS data and available from Land PEATE is poor. Evaluation of snow products for the 51 Day Global Test period in July-August 2003 has shown a substantial overestimation of snow cover. Most false snow identifications apparently occur due to inaccurate cloud masking. Fig. 1 presents an example of a snow map derived from simulated VIIRS data for July 12, 2003 and corresponding NOAA interactive snow cover map for the same day. It is seen, that numerous false snow identifications in the VIIRS snow map occur almost everywhere including tropical and equatorial areas. All other Land PEATE snow products for July 2003 are of the same quality. It is expected that improvements already implemented in the cloud mask may improve the quality of this product.

The snow EDR probably will have snow errors of commission and omission similar to that observed in the MODIS snow products. However some of the data filters in the VIIRS snow algorithm may reduce the frequency of snow errors. The current MODIS snow cover product suite provides daily snow albedo while the VIIRS EDR does not. Daily snow albedo should also be provided in addition to the VIIRS snow EDR.

**What is needed in addition to the Snow Cover EDR with respect to the product?**

Considering a very poor quality of the current Snow Cover Product, the primary need at this time consists of verification of the current EDR algorithm and auxiliary datasets used. The latter concerns, first, the cloud mask, which is applied to restrict the snow/no snow identifications to cloud clear pixels only. The cloud mask should be incorporated in the snow map as an additional pixel category similar to the MODIS Level 2 product. The lack of information on the cloud cover in the product leads to confusion between pixels labeled as “snow free” due to the lack of snow cover and with those due to an inability to identify snow because of clouds. The cloud mask included with the snow cover product would also help to better understand the reasons for snow misclassification.

In terms of NASA and user needs, the VIIRS snow EDR should include fractional-snow cover (FSC), currently an important part of the MODIS snow-product suite. FSC is needed, for example, to monitor the snowmelt process in mountainous areas.

In the majority of the literature, the reported accuracy of the MODIS snow product is 90% or greater under clear-sky conditions. The VIIRS snow cover EDR should be generated using the heritage MODIS techniques to produce a snow product that investigators and modelers can use to continue their research, and to enable the production of CDRs.
Blending or fusion of optical sensor data with microwave sensor data or data products to generate a single snow product providing snow cover extent and snow water equivalent (SWE) is an active area of research to enable monitoring of both the extent and volume of snow. A blended snow product using the MODIS snow products and AMSR-E SWE products has been developed. The VIIRS snow EDR, and forthcoming MIS snow EDR, should be used to develop multisensor snow data products.

The initial validation should focus on comparing MODIS and VIIRS snow maps, which should produce similar results. Further validation of the VIIRS snow-cover products will be needed by comparing the VIIRS products with snow-cover results from higher-resolution products and from ground-station data, to determine the errors inherent in the VIIRS snow products.

3.8. Active Fires ARP

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

**Summary of the Active Fires ARP requirement, algorithm and the contractor approach**

The 2002 NPOESS System Specification (SY15-0007, page 145) reads as follows:

*Active surface fires are natural or anthropogenic fires. This EDR provides (a) geolocation of the pixels in which active fires are detected, (b) the sub-pixel average temperature of each active fire, and (c) the sub-pixel area of each active fire. A global, binary "fire/no fire" map is neither required nor desired. The products for this application are desired during both day and night time for clear-sky conditions and within clear areas under conditions of broken clouds.*

The sub-pixel fire characterization requirements (fire temperature and area) have since been eliminated for various reasons (among other issues, the accuracy specification in most cases would not be met). This change will be reflected in the forthcoming NPOESS Capability Production Document.

The current contractor algorithm is the Collection 4 MODIS active fire algorithm. As far as we can tell, no significant changes have been made to account for the spectral and spatial differences between the MODIS and VIIRS instruments.

**Evaluation of the resultant Active Fires ARP in the context of NASA science needs**

In the context of NASA science needs (and indeed, *most* science needs), the current Active Fire ARP is inadequate for a number of reasons. These include:

- The current algorithm implementation, which was based on the MODIS Collection 4 fire code, produces many obvious false fires over arid surfaces when tested with proxy input data. It is not yet clear whether these false alarms are an unintended result of intentional algorithm
changes, or are instead the result of bugs introduced in rewriting portions of the original MODIS code.

- The output product lacks the contextual fire mask and fire radiative power (FRP) data layers that have been present in the MODIS active fire product since inception, and are now standard components of most contemporary active-fire data sets (e.g., GOES, SEVIRI, VIIRS, and several forthcoming sensors). Among other problems, the absence of these data layers confounds production of a VIIRS active fire CDR suitable for long term fire monitoring.

- No attempt is made to identify the corrupted M15 radiances that will often occur when fires are present within an aggregated VIIRS pixel. While such corrupted radiances are expected to have little effect on fire detection, they have the potential to severely degrade the ability to perform fire characterization.

**What is needed in addition to the Active Fires ARP with respect to the product?**

Our efforts to encourage the IPO remedy the limitations of the VIIRS active fire ARP over the past seven years have been overwhelmingly ineffective due to cost constraints and the extremely low priority (the lowest possible, in fact) assigned to the active fire ARP in the NPOESS System Specification. Further constraints are imposed by the IDPS, which severely limits the quantity of output data that may be produced by any one algorithm, to meet the stringent NPOESS SDR and EDR latency requirements. It was clear that there was little prospect of improving the current VIIRS active fire ARP in this environment. Instead, we recommended the development of an alternative VIIRS active fire EDR that will better satisfy the needs of both the science and operational communities. In response to the growing concerns of both communities, the IPO and the NASA Direct Readout Laboratory are sponsoring the VIIRS Fire Team in a modest, Science Team effort to produce an improved VIIRS active fire product (based on the Collection 6 MODIS active fire algorithm) which will fully exploit the capabilities of the sensor. This builds on the NASA VIIRS Science Team support and the work being undertaken by the Fire sub-team.

The output required from the VIIRS fire product to meet the needs of the NASA science and applications communities should effectively continue the current capabilities of MODIS, with a selection of higher level, temporally-composited daily, 8-day, and monthly fire products, including a subset on a global, climate modeling grid. In addition it is recommended that the fire capabilities provided by the MODIS Rapid Response System, which are currently being incorporated within the NASA LANCE System and the Fire Information for Resource Management Systems (FIRMS) to meet the needs of the NASA Earth Science Applications Program, should be continued in the VIIRS era.

While we believe the above algorithmic and software-based recommendations represent a major step forward, they cannot adequately compensate for certain design features of the VIIRS sensor that are problematic for fire monitoring. Recognizing the current timeline and financial situation of the NPP program, we therefore suggest the following hardware-related modifications. For NPP:

- The IPO provide pre-launch characterization of the fire bands (M13 and M15) over their full dynamic range, in particular the nonlinear behavior above saturation, and to make the test data easily accessible.
For NPOESS Flight Unit 2 (C2) and beyond:

- Provide unaggregated M15 observations in both the standard data streams and direct broadcast.

- Increase the M15 saturation specification from 343 K to approximately 420 K.

Finally, it should be noted that there is currently no requirement for a Burned Area EDR. The science community addressing global fire emissions, air quality, aerosol studies, and ecosystem processes are currently utilizing the MODIS Burned Area products. It is recommended that a comparable burned area product, which continues the MODIS data record, should be included in the VIIRS Science Product suite.

3.9. Surface Reflectance IP

**IP Team:** Alexei Lyapustin (Team Lead; UMBC) and Eric F. Vermote (UMCP), co-PIs; Yujie Wang (UMBC), co-I; Alfredo Huete (University of Arizona) and Crystal B. Schaaf (Boston University), collaborators

**Summary of the Surface Reflectance IP requirement, algorithm and the contractor approach**

Surface Reflectance (SR) is the main product of atmospheric correction (AC) required for different land downstream products including top of canopy vegetation index, surface albedo, snow fraction etc. SR is defined as a reflectance with the atmosphere removed, and it is fully equivalent to the bidirectional reflectance factor (BRF) (Schaepman-Strub et al., 2006). The current version of the NGAS AC algorithm was developed based on the operational MODIS AC algorithm (Vermote and Kotchenova, 2008) which uses a Lambertian assumption to derive SR. Apart from the latest changes to the MODIS Collection V006 algorithm, the main difference with the contractor's version is that in the MODIS code, cloud/cloud shadow mask and aerosol parameters are retrieved internally, whereas in the VIIRS code these parameters come as ancillary data produced by separately maintained algorithms. SR will be produced at 0.375 km for imagery bands and at 0.75 km for moderate resolution bands. The derived uncertainty requirement is 0.01.

**Evaluation of the resultant Surface Reflectance IP in the context of NASA science needs**

The current contractor's VIIRS processing obligations and product suite are less than they were for MODIS which is a serious setback from the EOS era:

- The Surface Reflectance product is considered an Intermediate Product (IP). Thus, it is not stored in the long-term archive, and it will not be available to the science community except for limited validation purposes by the Science Team.

- Surface BRDF is also not a part of the current VIIRS product suite. The BRDF parameters are produced internally but they are not archived.
The VIIRS will not provide spectral surface reflectance, BRDF and albedo product continuity with MODIS (and AVHRR), effectively severing the long-term record needed for climate research. Surface reflectance is currently one of the most requested land MODIS products, both for applications and science analysis and is used as an input to higher-order MODIS Land products. Surface reflectance along with cloud mask is also often required for the evaluation and validation of higher level products. The lack of a SR product from VIIRS will 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 products.

Even if the SR IP was archived by the contractor, the accuracy of SR product may be insufficient in the following conditions:

- In the shortwave channels (blue-green part of spectrum) where the Lambertian assumption introduces biases that depend on the view geometry and atmospheric opacity. Our current analysis conducted for vegetated validation sites such as Konza and Walker Branch (USA), shows that the magnitude of Lambertian biases may be higher than 0.01 (e.g., 0.01-0.02 in the green band);
- Over bright surfaces (semi-arid, arid and desert regions) due to biases of aerosol retrievals or the lack thereof in the current VIIRS code;
- Over regions with variable aerosol sources including dust, because the current selection of an aerosol model within the contractor's algorithm has not yet demonstrated reliable performance.

**What is needed in addition to the Surface Reflectance IP with respect to the product?**

Repeated efforts over the past several years by the VIIRS Operational Algorithm Team (VOAT) and NASA science team to raise SR, BRDF, and spectral albedo to EDR level within NPP/NPOESS program were not successful. An independent development of the AC algorithm for these products and processing of the VIIRS measurements by the NASA team will provide the only cost-effective alternative. To satisfy climate research needs, we will thus need to improve and reprocess the SR-IP to make it consistent with Surface Reflectance products from MODIS and AVHRR. This will require additional storage, processing and reprocessing capabilities.

4. **EDR Land Validation and additional needs for Science Product Validation**

*Miguel O. Román (NASA), Jeffrey L. Privette (NOAA-NCDC), and Chris Justice (UMCP)*

Building on the experience of the NASA MODIS and VIIRS Science Team, the IPO is currently supporting a VIIRS Land and Cryosphere Validation Team (hereafter “Land Validation Team”) (Table 1) to help validate a total of 14 different products within nine general EDR product categories. This team also includes experts to provide guidance on several “upstream” algorithms critical to successful Land Products (i.e., Calibration, Geolocation, Aerosols, and Cloud Mask). Validation is defined as the quantitative determination of product accuracy using independent data. Each VIIRS land product (EDRs, ARPs, and IPs) has quantitative requirements determined by NPOESS System Specifications (see Table 2). Note that while the contractor is
working to demonstrate that the products will meet the contractual requirements, the Integrated Program Office (IPO) must further ensure that the delivered products are operationally viable. Accordingly, the operational users have identified a different set of Cal/Val requirements in the Interagency Operational Requirements Document 2 (IORD2) (http://www.osd.noaa.gov/rpsi/IORDII_011402.pdf). Some IPs (e.g. Surface Reflectance), while without quantitative specifications, are of sufficient importance and interest to current operational user communities that their uncertainties must also be determined. The Land Validation Team will assess the operational viability and compliance of Land EDRs, IPs, and ARPs with the VIIRS System Specification and the IORD2. The latter involves a more rigorous comparison of EDRs with independent datasets (e.g. field, airborne, and other satellite measurements), as well as including estimated uncertainties of the comparison. Achieving this level of validation is the primary goal of the Land Validation Team’s planned activities. However, the NPOESS land validation program’s funding resources are small relative to those expended by EOS, and therefore the team is where possible emphasizing use of existing measurement networks and resources, rather than dedicated campaigns and aircraft flights. The Land Validation Team is charged with working closely with the contractor (NGAS) to coordinate EDR validation activities.

The Land Validation Team’s current emphasis is on establishing the infrastructure to validate the EDR’s and to develop automated validation procedures which can be implemented easily post-launch and applied throughout the NPOESS era. For instance, recent progress has been made towards the implementation of a global sample design for surface type EDR validation (see Fig. 2). The plan (developed in coordination with a NASA-funded, GOFC/GOLD coordinated project led by Dr. Curtis Woodcock) includes a global stratified sampling, based on a combination of climate and land use criteria. Using this stratification, 500 random site locations have been identified that will be used for surface type EDR validation. This method provides a statistically valid basis for land cover validation. Preliminary analyses using MODIS and GlobCover datasets show that the sample design adequately captures the range and diversity of global land cover and land use types.

Additional pre-launch validation efforts include site-level characterizations of all field network sites of potential interest for validation of surface albedo and land surface temperature EDRs. The geostatistical method to be employed was recently developed and demonstrated by Román et al (2009). The procedure quantifies the spatial and seasonal representativeness of tower measurements relative to the VIIRS pixel area, given (among other variables) the existing tower height and instrument field of view (see Fig. 3). By conducting this study at the onset, the Land Validation Team will be able to concentrate its post-launch Intensive Cal/Val activities only on those sites for which success in scaling is likely.

In the immediate post-launch period, emphasis will be given to product inter-comparison with validated MODIS data. Once the EDR’s are generating stable data products, emphasis will be on achieving Stage 1 Validation using a small number of well characterized targets of opportunity. The ultimate goal will be to determine the quantitative uncertainties of EDR, IPs, and ARPs at CEOS Stage 3 Validation (statistically valid over comprehensive range of environmental conditions). This task involves identifying the uncertainties as a function of several variables, including surface-atmospheric regime, scaling effects, phenological stage, sun-view geometry, etc.

For NASA, the NPP mission will provide an important benchmark to test the assumption that a VIIRS land product suite can be generated that is suitable for climate research applications
and will provide continuity with the EOS MODIS instrument. This will require a more extensive set of activities and expertise including Cal/Val analysis, coordination between dependent products and science research in support of the generation of Land Science Products. These include assessments of consistency with long term data records (e.g. Surface Reflectance, NDVI), temporally smoothed and gap-filled land products (e.g. annual phenology, LAI/FPAR), as well as other EOS-era products that have been embraced by the climate and numerical modeling communities (e.g. spectral surface albedo, burned area, and BRDF products) but go beyond the current VIIRS Land algorithm development and Cal/Val team efforts.

To meet the above objectives, the community needs expedited access to site-level ancillary information and higher resolution satellite remote sensing data (e.g., Quickbird, Landsat, ASTER) over the EOS Core Sites as well as additional NPP validation sites (e.g. NOAA-CRN, DOE-ARM, SurfRad/BSRN, AERONET, Greenland Climate Network, and Antarctic automated station networks). While still in its early planning and development stages, the National Ecological Observatory Network (NEON) will also provide long-term products and airborne observations over 20 major field stations across the US. Access to these correlative datasets could enable comparisons with in-situ data collected over a distributed set of field sites, comparisons with data and products from other sensors (e.g., ASTER, AVHRR, MISR, TM/ETM+), intercomparison of trends derived from independently-obtained reference data and analysis of process model results.

Another key prerequisite in support of the VIIRS Land product validation will be ensuring continued access to ongoing platforms and NASA sensor resources for which dedicated airborne campaigns or campaigns of opportunity are available. Airborne sensors such as NASA’s Cloud Absorption Radiometer (CAR) and the MODIS Airborne Simulator (MAS) continue to be essential validation data sources to improve model parameterization of reflectance-based Land science products and to address upscaling needs for comparison with in-situ measurements and VIIRS observations. For example, NASA airborne sensor data are needed for the validation of the VIIRS Active Fire Products.

The Land Validation Team also seeks to contribute to the definition of internationally accepted validation protocols as defined by the CEOS Working Group on Calibration and Validation (WGCV) subgroup on Land Product Validation (LPV). NASA is currently directly supporting the CEOS LPV in the development of international validation protocols for land products, which will facilitate the validation of global products from international satellite assets. Shared development of validation data sets that allow a CEOS Stage 3 Validation of similar products generated by different space agencies will be advantageous to all parties. Continuous commitment on NASA’s part to these efforts will ensure that an international mechanism for coordinating global validation activities is available throughout the NPP-NPOESS era. This will provide a medium for expanded validation community outreach, as well as insights into state of the art methods, tools, data handling and collaboration opportunities.
### Table 1. VIIRS Land EDR Validation Team

<table>
<thead>
<tr>
<th>EDR Validation Lead</th>
<th>Role</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeffrey L. Privette</td>
<td>Team Lead</td>
<td>NOAA NCDC</td>
</tr>
<tr>
<td>Chris Justice</td>
<td>Team Co-Lead</td>
<td>University of Maryland</td>
</tr>
<tr>
<td>Miguel O. Román</td>
<td>Land Cal/Val Coordinator</td>
<td>NASA GSFC</td>
</tr>
<tr>
<td>Ivan Csiszar</td>
<td>Active Fire SME</td>
<td>NOAA/NESDIS/STAR</td>
</tr>
<tr>
<td>Mark Friedl</td>
<td>Surface Type SME</td>
<td>Boston University</td>
</tr>
<tr>
<td>Alfredo Huete</td>
<td>Vegetation Index SME</td>
<td>University of Arizona</td>
</tr>
<tr>
<td>Jeffrey R. Key</td>
<td>Cryospheric Products SME</td>
<td>NOAA/NESDIS/STAR at University of Wisconsin</td>
</tr>
<tr>
<td>Alexei Lyapustin</td>
<td>Surface Reflectance SME</td>
<td>UMBC at NASA GSFC</td>
</tr>
<tr>
<td>James Maslanik</td>
<td>Cryospheric Products SME</td>
<td>University of Colorado</td>
</tr>
<tr>
<td>Peter Romanov</td>
<td>Snow Cover SME</td>
<td>University of Maryland at NOAA/NESDIS/STAR</td>
</tr>
<tr>
<td>Crystal B. Schaaf</td>
<td>Surface Albedo SME</td>
<td>Boston University</td>
</tr>
<tr>
<td>Eric F. Vermote</td>
<td>Cloud Mask SME</td>
<td>University of Maryland</td>
</tr>
<tr>
<td>Robert E. Wolfe</td>
<td>Geolocation/SDR SME</td>
<td>NASA GSFC</td>
</tr>
<tr>
<td>Yunyue (Bob) Yu</td>
<td>Land Surface Temperature SME</td>
<td>NOAA/NESDIS/STAR</td>
</tr>
<tr>
<td>Joanne Nightingale</td>
<td>CEOS-WGCV LPV Liaison</td>
<td>Sigma Space Corporation (NASA GSFC)</td>
</tr>
</tbody>
</table>
Table 2. The Land EDR’s and their associated performance metrics from the VIIRS System Specification. Note that additional specifications typically apply to each EDR, such as Revisit Time, Coverage, Long Term Stability and Mapping Uncertainty; for brevity, these are not listed here. Further, each EDR has an associated Exclusion Conditions (e.g., high solar zenith angles) for which its specifications are relaxed.

<table>
<thead>
<tr>
<th>EDR</th>
<th>Horizontal Cell Size (nadir) [km]</th>
<th>Precision</th>
<th>Accuracy</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Surface Temperature (LST)</td>
<td>0.75</td>
<td>0.5 K</td>
<td>2.4 K</td>
<td>N/S</td>
</tr>
<tr>
<td>Surface Type</td>
<td>1.0</td>
<td>N/S</td>
<td>N/S</td>
<td>70% (PCT*)</td>
</tr>
<tr>
<td>Albedo</td>
<td>0.75^</td>
<td>0.02</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Active Fires (ARP)</td>
<td>0.75</td>
<td>N/S</td>
<td>N/S</td>
<td>50 K (subpixel temperature) 30% (subpixel area)</td>
</tr>
<tr>
<td>Vegetation Index</td>
<td>0.375**</td>
<td>0.02**</td>
<td>0.016 (NDV) 0.11 (EVI)</td>
<td>0.11 (TOC EVI)</td>
</tr>
<tr>
<td>Surface Reflectance IP &amp;&amp;</td>
<td>0.375 (#), 0.75 (M)</td>
<td>N/S</td>
<td>N/S</td>
<td>&lt;0.01#</td>
</tr>
<tr>
<td>Snow Cover/Depth</td>
<td>0.4 (binary) 0.8 (% cover)</td>
<td>N/S</td>
<td>N/S</td>
<td>90% (binary PCT*) 10% (% cover)</td>
</tr>
<tr>
<td>Ice age</td>
<td>2.4</td>
<td>N/S</td>
<td>N/S</td>
<td>70% PCT (ice free, new/young, other)</td>
</tr>
<tr>
<td>Ice concentration (MIS)</td>
<td>20</td>
<td>N/S</td>
<td>N/S</td>
<td>1/10</td>
</tr>
<tr>
<td>Ice surface temperature (IST)</td>
<td>0.8</td>
<td>N/S</td>
<td>N/S</td>
<td>0.5 K</td>
</tr>
<tr>
<td>Ice motion</td>
<td>3</td>
<td>N/S</td>
<td>N/S</td>
<td>1 km/day</td>
</tr>
</tbody>
</table>

N/S=No value specified.
*PCT=Probability of Correct Typing
^ Product is reported and delivered at 0.75 km, however the performance is specified at 4 km resolution.
## I=Imagery band, M=Moderate resolution band
**Accuracy and precision apply to NDVI only. EVI does not have these specifications.
&& Derived requirements for Intermediate Products are not contractually binding.
# Surface Reflectance IP requirements are derived as specified in VIIRS Chain Test Report – The VIIRS Land Algorithms Document, Number: D44204: 30 March 2007
Fig. 2. Global Land Cover Validation: Global stratification and sample sites based on a combination of climate/vegetation biomes (modified from Koppen) and population data.
Fig. 3. Top-of-Atmosphere shortwave reflectance composites (ETM+ Bands 7-4-2), and the corresponding variogram plots, centered over Bartlett Experimental Forest for three time periods, illustrating conditions of greenness (A - 26 August, 2000), early senescence (B - 27 September, 2000), and dormancy (C - 20 October, 2000). Trees and bushes are in shades of green (both light and dark tones) and bare areas are seen in light-lavender, magenta, and pale-pink.
5. VIIRS Data Processing Capabilities for Land Science

Edward J. Masuoka and Robert E. Wolfe (NASA)

The VIIRS Land Product Evaluation and Test Element (Land PEATE) has a number of capabilities to support Land science in the NPP and NPOESS era. These include support for evaluation against MODIS science products, support for validation and as a test bed for algorithm changes. 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 PEATE will receive VIIRS products from the NESDIS IDPS. The products include not only Land EDRs but the upstream Level 0 RDR, Level 1 SDR and atmosphere EDRs. The PEATE will produce a set of Diagnostic Data Records (DDRs) that are 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 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 PEATE 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 will enable 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 will support validation of VIIRS Land products by producing subsets over validation sites. These subsets will be of the EDRs and IPs as well as the DDRs. The PEATE will also have a capability to reproduce the standard products for time periods and key locations where validation sets have been collected. This capability will enable the most recent versions of the standard algorithms (and/or improved algorithms) to be assessed against valuable validation data that may have been acquired before the newer versions of the algorithms were run in the IDPS.

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 PEATE. The PEATE has the capability to produce the IDPS operational products in parallel with products based on algorithms from the VIIRS Science Team and land science community at a rate of 12 data-days per day (for each stream). The PEATE’s processing rate can be easily increased to facilitate multi-month and multi-year comparisons of the two product streams. The evaluation tools mentioned above can then be used to assess the improved Land products against
the current operational products, MODIS products and validation data. This capability will enable the Science Team to assess the value of algorithm updates or new algorithms in order to determine if they should be submitted to the IPO or other operational systems for consideration as operational products. The PEATE will be capable of running science-based MODIS continuity products from VIIRS.

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 at-launch processing rate of 12 data-days per day (for two product streams) 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 PEATE 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.

6. Science Product and Processing needs beyond the VIIRS Land EDRs

Chris Justice, Jeffrey L. Privette, Eric F. Vermote, and Robert E. Wolfe

The VIIRS EDR’s were designed to meet the operational needs of 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 is to be provided then product consistency is needed; and will not be met by the EDR’s (Surface Albedo, Vegetation Index, Land Cover, 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 Active Fire Product that will be generated by the Fire Science Team will be designed to complement the Collection 6 MODIS Active Fire Product (MOD14) and will undoubtedly be used by the MODIS Fire user community. Whether this product can be transitioned into the IDPS as the official Fire EDR has yet to be determined. 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 improvement from combining the VIIRS with the METOP AVHRR (1km), which provides AM data, albeit at 09.30.

It should also be noted that the EDR’s represent a sub-set of the current MODIS Land Product Suite. In particular, there are no EDRs for LAI/FPAR, Net Primary Productivity, Vegetation Dynamics (phenology) 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 the NPP VIIRS, providing full data continuity. The initial MODIS product suite was essentially agreed upon in the mid-1990’s based on an understanding at that time of global
change research needs, strongly driven by the needs of the global modeling communities. New Land products such as LAI/FPAR and Vegetation Continuous Fields were later included the product suite through various recompetitions. The MODIS products have had significant uptake by both the science and applications communities and there is some expectation from these communities that the data stream will continue with VIIRS.

With international focus on climate change, efforts have been made to identify the observation variables needed to monitor climate change. A number of Essential Climate Variables (ECV’s) have therefore been identified by the International Global Climate Observing System (GCOS) to meet the needs of the UN Framework Convention on Climate Change. In response to such initiatives, additional products could be considered for the VIIRS. Similarly, as new operational users have fully adopted MODIS data in their decision support systems (DSSs), it is recommended that a broader community of operational users be consulted in the formulation of additional products from NPOESS VIIRS e.g. USDA, USFS, EPA. In this context it would make sense for the IPO to revisit the IORD2 that was last revised in 2002.

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 (Townshend and Justice 2002). 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 launches, 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 DOS or NWS operational communities. As a result any improvements to the EDR’s made by the contractor to meet the operational specifications will 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.
7. NASA Land Team Recommendations

For NASA Land science, the NPP VIIRS instrument will provide continuity with the EOS MODIS, with some notable exceptions identified in this report, which could with additional resources be resolved. In addition to guiding the instrument build and testing, emphasis from the IPO 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 VIIRS Project Science Office and the VIIRS Science Team has been on understanding the VIIRS performance pre-launch and likely utility of the EDRs from an Earth Science perspective. The VIIRS Land Team have identified that the snow and ice EDRs will largely meet the needs of the cryospheric science community. However, if all the Land EDRs are to serve the needs of the science community, then a significant number of changes to the other Land EDR algorithms and the IDPS processing system will need to be made, as identified in this report. In addition, other land products which are currently generated from MODIS (e.g. LAI, NPP, and Burned Area) will also need to be added to the VIIRS EDRs, to extend the MODIS land data record. As the NASA research program explores new global change research areas, the VIIRS could provide the polar-orbiting imager data from which new science products could be developed. However, it is our understanding that for the foreseeable future, such changes and additions will be beyond the scope and means of the NPOESS IPO.

Based on this understanding and the above assessment, the VIIRS Land Team has the following seven 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 community and at least provides continuity with the current suite of MODIS Land products.**
   
   a. The suite of VIIRS Land ESDRs could consist of a combination of modified or enhanced EDRs and stand-alone ESDRs
   
   b. As with MODIS, these products should start to be generated in Beta mode, immediately following instrument testing (i.e. 60 days post-launch).
   
   c. With respect to instrument testing, in the immediate pre-launch period, attention should be given to on-orbit instrument performance, calibration and evaluation of the new VIIRS functionality, e.g. on-board aggregation and dual gain steps.

2. **For consistency and continuity with the MODIS Land products, these products should:**
   
   a. utilize the same algorithmic theoretical basis as their MODIS counterparts.
   
   b. be generated by the Land PEATE, following guidance from and in close cooperation with the VIIRS Land Science Community. 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 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 result 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 PEATE.

3. **Support should be provided for Quality Assessment of the products and Validation for each VIIRS Land science product to at least Stage 2, building on the approaches developed for MODIS.**

   a. A program of science product validation should be designed pre-launch and start in earnest once the science products have stabilized and have been promoted beyond Beta to Version 1. It should be recognized that validation of the EDR’s will contribute to the validation of science products.

   b. A small group should be supported to coordinate VIIRS land product validation, as is currently the case for MODIS.

4. **Discussions should be held between NASA, NOAA and the IPO on the roles and responsibilities for supporting VIIRS Land science products in the NPOESS era, identifying pathways for the eventual entrainment of desired science products into operational production streams (IDPS or NDE), once the Land science products have been validated to Stage 2.**

   a. If the science products are not appropriate for NPOESS or NOAA operational streams, NASA and NOAA should discuss roles and responsibilities for continuity e.g. via a NASA Land ESDR or the NOAA CDR program.

5. **A mechanism should be set up by NASA in collaboration with the IPO for identifying, assessing the cost-benefit and funding improvements to the follow-on VIIRS instruments to meet the needs of the Land science community.**

   a. NASA should consider funding improvements to the VIIRS F2 and F3 instruments to meet specific science community needs.

6. **A mechanism should be set up to allow the prototyping and testing of new VIIRS land products as new products and algorithms come on-line to meet the needs of the science community. Also the NPOESS IORD should be revisited after L+6 months to include the EDR needs of the operational ‘land’ agencies e.g. USDA, USFS.**

7. **Given the well-known fragility of the post-Nunn McCurdy NPOESS program (i.e., compared to robustness of two functioning MODIS sensors providing daytime observations), NASA should work with NOAA to develop data agreements and pathways with international partners to assure access to substitute global coarse resolution multispectral satellite observations in the NPOESS timeframe (e.g. Sentinel 3). These should be pursued now, to allow algorithm testing and minimize possible disruptions to downstream users.**

   a. 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.
8. Desired Land Improvements to future VIIRS Instruments

The following is a list of recommended improvements for VIIRS FU3 in the context of Land Science Use. It should be noted that these action items have been selected under the assumption that ongoing efforts to improve the technical baseline of FU1 and FU2 will continue and transition into FU3 activities. Among these assumptions, the Land Team anticipates: (1) improvements in the optical design in SWIR, MWIR and LWIR bands to address the dewar window ghosting features; (2) noise removal in the gain switch regions of the VIIRS dual gain bands; (3) improved requirements (i.e. exclusion zone) testing, and data analysis of near field and far field stray light VIIRS response; and (4) resolving crosstalk and saturation issues in VIIRS M2 and M5 bands.

It is our understanding that some minor improvements can be considered for FU2. Our hope is that for FU2 and subsequent instruments that it will be possible to increase the M15 band saturation specification from 343 K to approximately 420 K and to provide unaggregated M15 observations in both the standard data streams and direct broadcast.

Desired Land Improvements to VIIRS FU3:

1. Improve saturation handling for single gain bands (i.e. on-board aggregation) and resolve the saturation rollover effect

2. A limited empirical determination of out-of-band response needs to be conducted to determine if any impacts on Land products require mitigation.

3. Report well defined sub-scene statistics of the impact of crosstalk and near field response; particularly in regions of technical interest (e.g., coastlines and cloud edges). Currently, only full-scene statistics are reported. The instrument’s sensitivity to polarization (albeit small) strongly depends on the detector’s position by 0.0-2.0%. Recent modeling studies have been unable to characterize these differences.

Furthermore, if any opportunities to revisit the current design of the VIIRS instrument arise in the near-future, then a number of changes to the technical baseline should be considered (e.g. aggregation over the swath; band selection, improved dynamic range, platform consideration, etc.).
9. References


