White Paper on
Continuity of NASA Satellite Climate and Earth Science Data Records into the NPP/JPSS-1 Era

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1. WHITE PAPER OBJECTIVE

This *white paper* provides recommendations to the NASA Earth Science Division (ESD) to ensure the continued generation of key long-term satellite data records over the next decade.

The satellite data records discussed in this paper were started during the Earth Observing System (EOS)-era and are being used to address Earth System Science questions and support related science analyses, including climate science and system process studies. For either of these uses, the need for datasets with known uncertainties and the removal of instrument artifacts is paramount. We refer to such satellite datasets, whether comprised of instrument or geophysical retrieval records, as *Climate and Earth Science Data Records* (CESDRs) to distinguish from the more limited scope of so-called Climate Data Records (CDRs).

Specifically, the recommendations and activities proposed herein are aimed at maximizing NASA's capability to achieve relevant EOS-era data continuity through the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project [NPP] and the first Joint Polar Satellite System (JPSS-1) missions for the benefit of NASA's research programs as well as the greater Earth science and climate change research communities. This white paper focuses on how to make the best of the near-term situation in which we find ourselves, including recommendations regarding the organization and management of instrument characterization, algorithm development/maintenance, data processing/reprocessing capabilities and archiving, and calibration/validation efforts.

This white paper *does not* address post JPSS-1 instrument capabilities/improvements required for continuation of EOS and Earth System Science Program (ESSP)/Afternoon Constellation or "A-Train" measurements that are not part of the NPP/JPSS-1 portfolio (e.g., multiangle imaging, lidar, radar), new CESDRs that should/will be initiated with Decadal Survey or other future missions, and precipitation and water storage datasets that will be continued via the Global Precipitation Measurement (GPM) and Gravity Recovery and Climate Experiment–Follow-on (GRACE-FO) missions.

> **Note on Document Organization:**
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> For ease of reference, our recommendations are succinctly stated at the beginning of **Section 2** and summarized further in **Section 2.3**. Detailed recommendations are given in **Section 3**. The Tables of **Section 4** provide a summary assessment of NPP/JPSS-1 instrument and geophysical data records relative to EOS heritage, as well as the potential for improvement; the tables represent a synthesis of the discipline-specific material provided in **Appendix A**.

2. OVERVIEW AND EXECUTIVE SUMMARY

A set of Essential Climate Variables (ECVs) have been identified by the international Global Climate Observing System (GCOS) as critical for fostering our understanding of Earth system and climate science, and improving our capability for climate prediction. The EOS data stream (1998–present) covers many ECVs, in addition to other important and unique data records. It is critical to continue these NASA records into the future using NPP/JPSS instruments to the fullest extent possible.

This white paper compares the EOS data processing system and products that now exist with our current understanding of those that will come from the NPP/JPSS system (*see Appendix A* for specific product-to-product comparisons). For a variety of historical and organizational reasons, it is shown that the operational data products in the current JPSS plan do not approach the science quality of CESDRs generated with similar instruments by the existing NASA data processing systems. **This document makes a series of recommendations that are directed at setting in place a NASA managed/coordinated organizational structure, including processing systems and significant science support, to generate CESDRs from NPP/JPSS data streams that would be comparable to those from EOS and could thus be used to extend these important data records over the next decade.**

Solar Irradiance Sensor (TSIS)). It is unlikely that all EOS missions will continue operations beyond the start of the JPSS-1 time frame.

Over the past decade, NASA's EOS program has proven the scientific value of a new generation of satellite observations. As the time length of these measurements grow, their scientific value increases disproportionately. Climate change detection requires artifact-free, multi-decadal records with well-characterized uncertainties. Establishing this long-term "climate quality" record requires both inter-calibrated instrumental data records and the use of consistent geophysical retrieval algorithms. With this experience in mind, a plan must be developed for maintaining EOS-era CESDR continuity, to the extent possible, using NPP/JPSS instrument data.

The NPP/JPSS program is focused primarily on meeting operational weather observations and forecast requirements.

Overall Recommendations

A project management and organizational structure should be established to integrate between, and provide for, the following:

1. Development of a consistent set of Level-2 and Level-3 science algorithms for use across EOS and NPP/JPSS-1 instrument records.
2. Establishment of an integrated instrument and Level-1 algorithm team.
3. Expansion of the role of the Product Evaluation and Test Elements (PEATE) to include (re)processing, archiving, and distribution of NASA-funded instrument and science team data products.
4. Establishment of discipline-specific Validation Teams to assess the NASA-funded NPP/JPSS data records.

The EOS missions of primary relevance to this white paper are Terra, Aqua, the Solar Radiation and Climate Experiment (SORCE), and Aura—launched in 1999, 2002, 2003, and 2004, respectively (*click here for a timeline of recent NASA Earth science missions*). In turn these missions built on, or continued records from, the Total Ozone Monitoring Spectrometer (TOMS), Solar Backscatter Ultraviolet (SBUV) instrument, and Sea-viewing Wide Field-of-view Sensor (SeaWiFS), among others. Collectively, EOS datasets have been reprocessed numerous times, yielding a continuously refined set of instrument and science data records. It is highly desirable to continue these data records into the coming decade and beyond using the only relevant missions that are likely to be available, i.e., NPP (launched in October 2011), JPSS-1 (to launch no earlier than first quarter FY17), and potential JPSS free-flyers (e.g., Total

However, with a few notable exceptions (see **Tables 4.x**), the instruments on NPP and JPSS-1 are expected to have the intrinsic measurement capability to continue the EOS data product stream. Strategic investments in both the NPP Science Team (acquiring early insight and knowledge of the JPSS instruments and algorithms) and the associated Product Evaluation and Test Elements (PEATE) processing infrastructure has placed NASA's ESD in a position to maximize the Nation's investment in the EOS program by continuing to produce EOS-quality data products from NPP/JPSS measurements. The issue then becomes how best to develop an infrastructure that taps the full potential of NPP/JPSS measurements.

Most of the human and technical resources required to process the NPP/JPSS-1 data into CESDRs are already

in place in some form within ESD. The recommendations in this white paper identify what is required to sustain or augment these resources to assure the continuation of the EOS-era CESDRs into the NPP/JPSS-1 era (approximately 2011-2020).

2.1 *JPSS History, Organization, and Infrastructure*

In February 2010, the Office of Management and Budget (OMB) directed that the National Polar Orbiting Environmental Satellite System (NPOESS) be split into two separate programs. With this direction, NOAA became responsible for the 1330 local time (LT) afternoon orbit by providing the requirements and resources for the Joint Polar Satellite System (JPSS). The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) will continue to be responsible for the mid-morning 0930 LT orbit. The Department of Defense (DoD)/Air Force will be responsible for the early morning 0530 LT orbit, with responsibility for satisfying the requirements and resources for the Defense Weather Satellite System (DWSS)[1].

Under direction from OMB, NASA was given the task of implementing the JPSS Program for NOAA. In this role, NASA's Goddard Space Flight Center (GSFC) will implement, subject to available resources, the JPSS Level 1 Requirements Document (L1RD). In response, GSFC formed the JPSS Program Office (Code 470). The JPSS Program Office includes: (1) the JPSS Flight Project (Code 472), responsible for the spacecraft and instruments of the large observatories; (2) the JPSS Ground Project (Code 474), responsible for the operational ground system; and (3) the Free Flyers Project (Code 476), responsible for TSIS and the Search and Rescue Satellite-aided Tracking (SARSAT)/ Advanced Data Collection System (ADCS) services requirements.

The JPSS Flight Project has responsibility for implementing the JPSS-1-4 missions. JPSS-1 is the only mission that has been defined to date, with JPSS 2–4 to be further defined when the JPSS Program budget is established in FY12 and FY13. JPSS-1 is currently defined as near clone of the NPP mission, flying the same five instruments as NPP[2]. The major difference between NPP and JPSS-1 is that the latter mission will use Ka-band communications for sending the Stored Mission Data to the ground station instead of X-band; JPSS-1 will continue to use X-band for the Direct Broadcast Data. The JPSS Flight Project will use NASA instrument scientists and the associated instrument performance teams to monitor the build, characterization, and calibration of all the JPSS instruments.

The JPSS Ground Project has the responsibility for providing the *operational* ground system for the both the NPP and the JPSS missions (primarily to meet the needs of the National Weather Service). This includes the responsibility for assuring that the JPSS data products meet the L1RD requirements. JPSS Ground also provides the Command, Control, and Communications Segment (C3S) system for controlling the spacecraft and getting data to the processing system. JPSS Ground has specific responsibility for: (1) the Interface Data Processing Segment (IDPS) system that processes the data into products for operational users; (2) calibration and validation for the operational data products; and (3) monitoring the on-orbit performance of three of the NPP (VIIRS, CrIS, OMPS) and all of the JPSS instruments. At the request of NOAA's National Environmental Satellite Data and Information Service (NESDIS), JPSS Ground will be using NESDIS Center for Satellite Applications and Research (STAR) personnel as leads for algorithm and data product calibration/validation activities (see *Section 3.4* for further details).

We believe the eventual paradigm for JPSS should be a NOAA/NASA Polar Operational Environmental Satellite (POES) program with EOS-class instruments. NASA-JPSS will build instruments and spacecraft *capable* of continuing most EOS data records, and NOAA NESDIS will run the operational data system to provide data products to the operational users in near real-time. It is expected that the JPSS data system will be turned over to NOAA NESDIS operations one year after the JPSS-1 launch (anticipated launch readiness date no earlier than November 2016). The operational data system, by design, is not capable of producing reprocessed, consistent data products that are required by the climate research community. NOAA currently plans to support the climate research community with the Climate Data Record research program at NOAA's National Climate Data Center (NCDC).

While not directly part of JPSS, NASA's ESD has made strategic investments in the computational infrastructure needed to process NPP data records. Five discipline-based PEATE processing systems have been funded to support evaluation efforts by the NPP science team. The use of these PEATEs to help achieve data record continuity is discussed in *Section 3.3*.

The gap in the above paradigm is the lack of an organization and infrastructure (as detailed in *Sec-*

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[1] We note that DWSS was recommended for cancelation by the Consolidated Appropriations Act of 2012; some resources are provided for determining the requirements for a follow-on weather satellite system.

[2] These include the Visible/Infrared Imager Radiometer Suite (VIIRS), Cross-track Infrared Sounder (CrIS), Advanced Technology Microwave Sounder (ATMS), Ozone Mapping and Profiler Suite (OMPS) and Clouds and the Earth's Radiant Energy System (CERES).
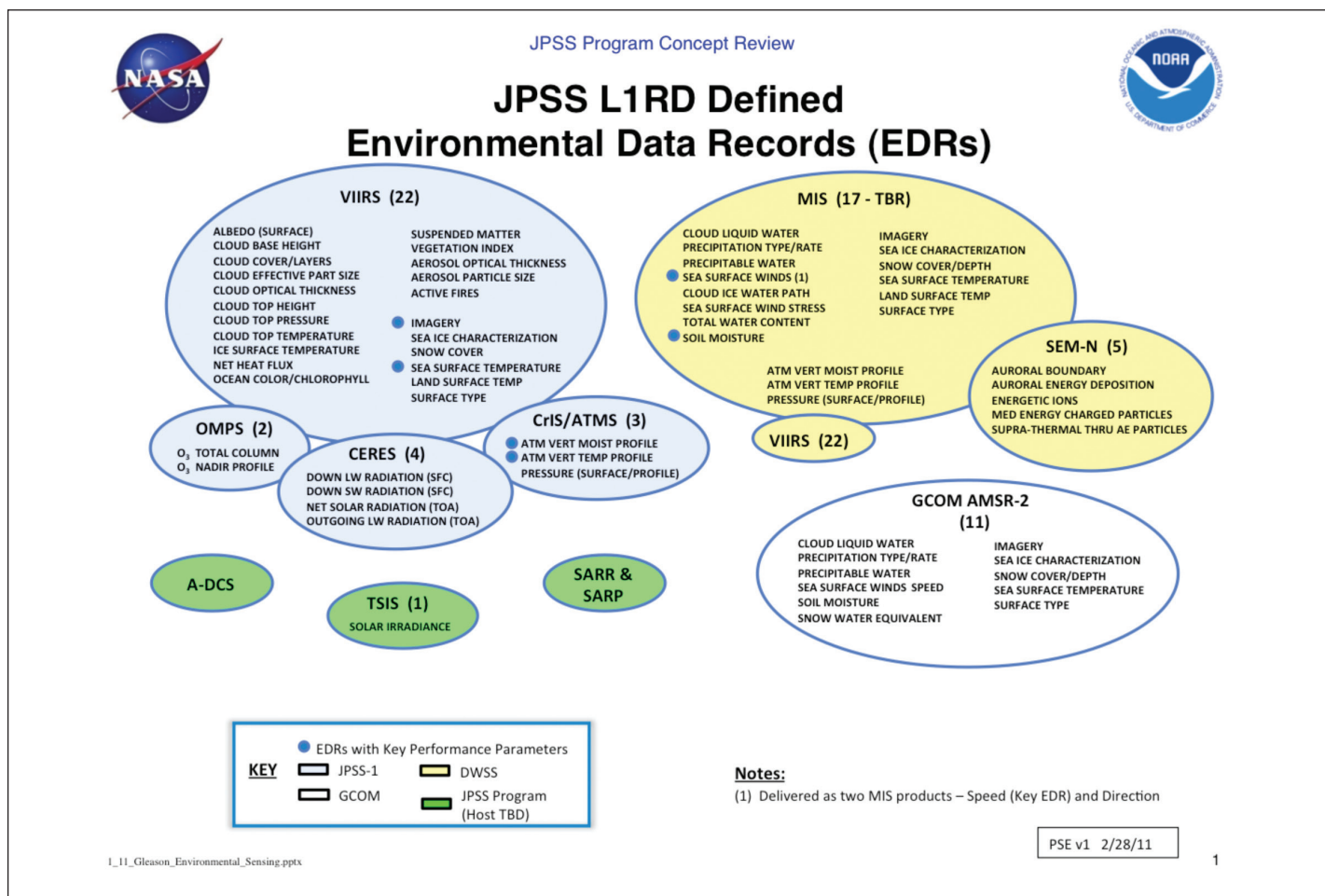
Figure 1. List of Environmental Data Records (EDRs) specified in the JPSS Level-1 Requirement Document (L1RD).

tion 3) to continue useful EOS-era CESDRs into the JPSS timeframe. However, NASA's ESD is uniquely well-positioned to fill that gap.

2.2 *Status of JPSS vs. NASA SDRs and EDRs*

In the JPSS L1RD, instrument and geophysical retrieval data are referred to as Sensor Data Records (SDRs) and Environmental Data Records (EDRs), respectively. **Figure 1** summarizes the JPSS EDRs as well as those from DWSS[3] and the Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission (GCOM) Program. Note that all GCOM data—i.e., Advanced Microwave Scanning Radiometer (AMSR2 and AMSR3), Dual Frequency Scatterometer (DFS) and Second Generation Global Imager (SGLI)—are considered Category 3 EDRs as described in the JPSS L1RD Supplement *V1.4.2*

(July 2011). **Table 1** lists the EDRs for the NPP/JPSS-1 instruments only.

In the summary tables of *Section 4*, we present a condensed assessment of our current understanding of the status of NPP instrument capabilities, SDRs, and EDRs relative to heritage NASA instruments/algorithms. The tables are broken down by discipline for EDRs, and are a synthesis of the full description of heritage EOS data records and JPSS algorithms that are given in *Appendix A.* Refer to the appendix for further details, quantitative comparisons, relevant discipline white papers, and other references.

2.3 *Overview of Recommendations*

The JPSS organization, algorithms, and data processing requirements are designed to meet operational needs first and foremost. This results in a system capable of continu-

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[3] Although some funding for DWSS was appropriated, funding for conical scanner Microwave Imager/Sounder (MIS) sensor development is uncertain.

ous processing with an emphasis on low latency through-put and tight configuration control. However, these attributes do not support a science-driven data enterprise. The EOS experience has demonstrated the need for a more flexible approach, including:

- An ongoing commitment to on-orbit calibration/characterization, including spacecraft maneuvers incorporated into continual Level-1 algorithm updates;
- evolving science-driven geophysical algorithms;
- capability for data reprocessing;
- capability for generating custom or experimental research products;
- recognition of, and responsiveness to, a diverse set of users and their needs;

- agility for reconfiguration and redirection of resources; and
- communication and coordination among the instrument calibration, science, and data processing teams.

The distinction between datasets useful for operations and those for science studies (including climate) is not a matter of semantics and is ultimately tied to the organization and management structure that must support the requirements. *Section 3* describes the four major organizational elements that must be integrated (managed) to achieve scientifically useful satellite data records (also see **Figure 2**). These elements comprise: instrument characterization coupled with Level-1 algorithm development, Level-2 and higher-order geophysical algorithm development, calibration/validation, and data (re)processing and distribution.

Table 1. Environmental Data Products (EDRs) by instrument for the NPP/JPSS-1 platforms as specified in the L1RD.

VIIRS	CERES	CrIS/ATMS	OMPS
ALBEDO (SURFACE)	DOWN LW RADIATION (SFC)	ATM VERT MOIST PROFILE	O_3 TOTAL COLUMN
CLOUD BASE HEIGHT	DOWN SW RADIATION (SFC)	ATM VERT TEMP PROFILE	O_3 NADIR PROFILE
CLOUD COVER/LAYERS	NET SOLAR RADIATION (TOA)	PRESSURE (SURFACE/ PROFILE)	
CLOUD EFFECTIVE PART SIZE	OUTGOING LW RADIATION (TOA)		
CLOUD OPTICAL THICKNESS			
CLOUD TOP HEIGHT			
CLOUD TOP PRESSURE			
CLOUD TOP TEMPERATURE			
ICE SURFACE TEMPERATURE			
NET HEAT FLUX			
OCEAN COLOR/CHLOROPHYLL			
SUSPENDED MATTER			
VEGETATION INDEX			
AEROSOL OPTICAL THICKNESS			
AEROSOL PARTICLE SIZE			
ACTIVE FIRES			
IMAGERY			
SEA ICE CHARACTERIZATION			
SNOW COVER			
SEA SURFACE TEMPERATURE			
LAND SURFACE TEMPERATURE			
SURFACE TYPE			

We stress that integration is key. A perfect instrument (should one exist) would not by itself make for a useful climate record. Likewise, a state-of-the-art retrieval algorithm does not ensure a useful science data record. The current JPSS structure does not integrate these efforts. Justifications for these statements are presented in _Section 3_.

Each of the four subsections in _Section 3_ provides a detailed overview of the system element along with lessons-learned and recommendations. While it is impossible to summarize succinctly without omitting essential aspects (we refer the reader directly to these sections for details), at the highest level they are restated in the box below.

An organizational structure and task analysis plan for implementing these recommendations can be pursued based on the reception of this white paper. However, we nominally expect required long-term resources to be comparable to EOS instrument support from current Senior Review funding, and algorithm enhancement development support from Senior Review and/or competed Research Opportunities in Space and Earth Science (ROSES) funding. There are expected to be some initial "spin-up" resource demands for most instrument and science algorithm teams. The current level of PEATE funding is also generally expected to be commensurate with the additional processing/reprocessing responsibilities discussed below. NPP EDR validation teams are small and underfunded relative to the EOS history; the means for expanding validation resources needs to be discussed across the ESD.

A management and organizational structure mirroring Figure 2 should be established to provide the following:

1. Development of a consistent set of Level-2 and Level-3 science algorithms for use across instrument records (i.e., EOS and NPP/JPSS-1) that is critical for establishing continuity of CESDRs and reaching the broader science community.

2. Establishment of an integrated instrument and Level-1 algorithm team, along with systematic reviews and inclusion of outside calibration experts for JPSS-1 pre-launch activities.

3. Expansion of the role of the PEATEs to include (re)processing, archiving, and distribution of NASA-funded instrument and science team data products.

4. Establishment of independent discipline-specific NASA Validation Teams (NVTs) to assess the NASA-funded NPP/JPSS CESDR data records, that will work closely with the algorithm teams to ensure that validation findings inform algorithm refinement.

3. RECOMMENDATIONS ON ACHIEVING CONTINUITY WITH NPP/JPSS

There are four distinct task elements and an integrating management function that provide the fundamental infrastructure necessary to establish and maintain a useful Earth science satellite data set.

These are:

1. On-orbit characterization/calibration and L1 algorithm development.

2. L2+ algorithm development and refinement/maintenance.

3. Independent validation of both sensor and geophysical products.

4. A data processing system with over-capacity capabilities for algorithm/product testing, reprocessing, product distribution, and archiving.

5. A management structure that ensures continuous efficient interaction among these four tasks for maximum scientific yield and efficient use of resources.

Collectively, with the support of management, all task elements (shown schematically in **Figure 2**) must engage the broad science and application user communities. As indicated by the arrows, communication and coordination between the elements are necessarily tightly coupled. The two-way directions found on most arrows are derived from experience and are not gratuitous.

As noted in **Figure 2**, one aspect of a processing system is the ability to manage and preserve ancillary and other non-instrument datasets to enable consistent forward processing and reprocessing. In addition, an archive and distribution system must provide users with easy and flexible access. All algorithm development (L1+) requires a close relationship with the data system. In particular, algorithm testing for climate records must be done over monthly and greater time scales so that a retrieval sensitivity assessment can be made as each algorithm refinement change is made. This in turn, informs the algorithm developers and may result in further iterations. As an example, the testing history used in the Moderate Resolution Imaging Spectroradiometer (MODIS) atmosphere team *Collection 6* (C6) development has shown climatologically significant changes (in terms of impact to the continuity of the data record) for monthly zonal aggregations when the algorithm is processed with different radiative Look-up Tables (LUTs) and cloud masks. Examples of difference images from C6 development tests can be found in the following two links: *MODIS land tests* and *MODIS atmosphere tests*.

For MODIS, there are several examples of the L2 algorithm developers providing input to the instrument characterization team that resulted in changes to the L1B code—most recently, investigation of the use of Committee on Earth Observing Satellites (CEOS) desert sites to de-trend Terra MODIS Visible/Near-Infrared channels as a function of view angle. Independent validation (i.e., accuracy assess-

Coordinated System/Infrastructure Elements Required for Production and Sustainability of Climate Quality Data Records
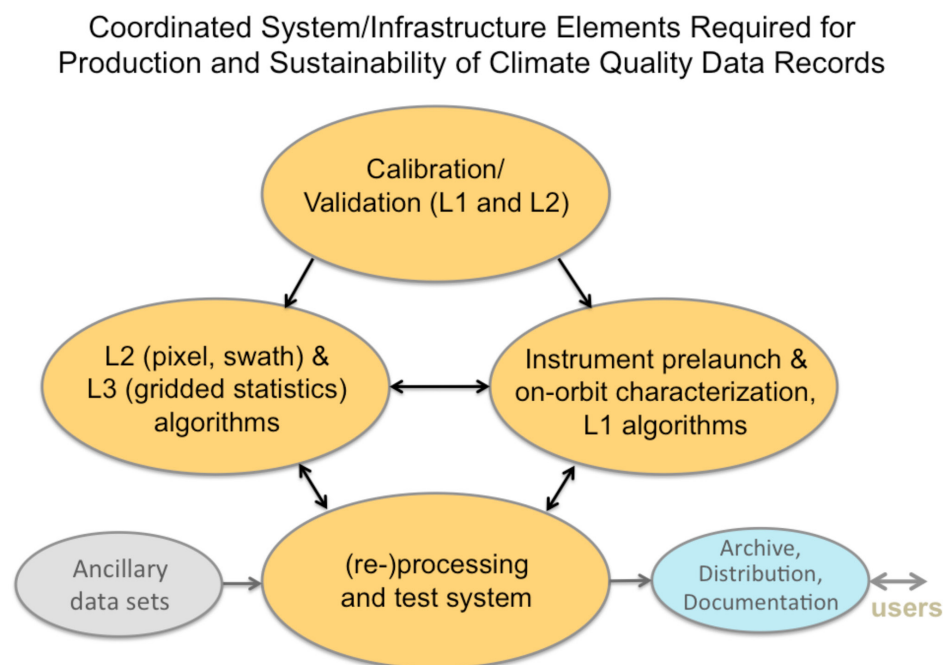
Fig. 2. Integrated elements required for production and sustainability of CESDRs.

ment using an independent data source) is critical to all sensor and geophysical products. Initial validation is best handled through direct mission/instrument control though piggybacking on scientific field campaigns is possible. Ultimately, the entire effort must be responsive to feedback from the users of the data products.

The NASA EOS and PI instrument/mission experience indicates that all these elements must be integrated and adequately supported before even beginning to consider the possibility of a dataset becoming useful for multi-decadal climate studies. **Conversely, it is extremely difficult to build quality climate records if these elements are treated as independent, distinct efforts occurring with little or no coordinating oversight. Unfortunately this latter approach was inherent to NPOESS and will continue into JPSS unless corrective action is taken.**

Development and ownership of these elements is a significant undertaking, and NASA has learned how to organize these elements to produce science quality data records. This capability cannot be reproduced quickly or cheaply. The structure shown in **Figure 2** has become the basic model for EOS, ESSP, and ocean color heritage datasets. **NASA has made significant capital and human investment in developing these products, and they are only now beginning to be sufficiently long enough be considered useful CESDRs. It would be a crippling loss to the national and international climate community if NASA stewardship was abandoned without a credible alternative in place.** It is also in the direct interest of NASA's internal climate research efforts that these records continue to be managed and produced by NASA.

Along these lines, a summary list of lessons-learned follows[4]:

- Algorithm development teams must have ownership of the entire effort—including responsibility for the code. Retrieval methodologies and concepts cannot be handed off from the scientists to another group that independently implements the code.

- L2+ algorithm developers must have a close working relation with the instrument characterization team and L1B developers. The two groups need to be embedded together from the start and the relationship must be on-going throughout the life of the instrument. Experience has shown that L2 and L3 data analysis can inform and affect L1B approaches.

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[4] The satellite element of the Global Climate Observing System *(GCOS) Monitoring Principles* gives a complimentary statement of needs for effective climate studies.

- Algorithm developers must have a close working relation with the management of the processing system. The processing system must be sufficiently flexible to respond to the needs of the algorithm development, testing, and reprocessing. Ownership of an algorithm without a voice in the processing system leads to inefficiencies in re-processing activities and potential disconnects in the provenance of algorithm code and ancillary data sources.

- The role of the algorithm team is to make sure that the product is well-characterized and uncertainties are established. Validation is concerned with the establishment of uncertainties and is an ongoing process that has a lifespan as long as the dataset.

- Level-3 spatial/temporal aggregations are absolutely necessary for climate studies but are not trivial to produce.

- Both algorithm developers and the data system need to communicate with and engage/assist the user community. This includes providing well-documented quality assessment metadata and algorithm technical background documents, and may also result in the availability of different file formats—e.g., *netCDF* Climate and Forecast (CF) convention for Intergovernmental Panel on Climate Change (IPCC) Coupled Model Intercomparison Project (CMIP5), the development of model instrument simulators, and updating algorithm output based on user feedback.

- Documentation is critical for climate studies. In particular, information on the design and performance of the instrument, algorithms, and validation efforts must be detailed for future generations. User guides to data products are important. An appreciation for the wide range of expertise among the user community is needed to make these documents effective.

- Periodic independent scientific reviews of the algorithms and data products are useful for ensuring transparency and continuous improvement of the science. To be responsive to evolving science data needs, a process is needed for incorporating new products into the data production system.

3.1 *Retrieval Algorithm Development*

There is a distinction between algorithms adequate for operational needs and those needed for climate and physical process studies. Climate studies require, at an absolute minimum, a consistent algorithm across the full time record (including LUTs, ancillary sources, etc.). Therefore, bridging an EOS and NPP/JPSS data record requires a common algorithm that can be applied to both. A redi-

rection of the current NPP Science Team (which to date has been directed to focus on evaluating the operational JPSS products for science use) to work on the development of common algorithms is recommended to achieve this. We recognize that, given the original narrower focus of the NPP solicitation, such a change of priorities would likely require an expansion of science team expertise. In addition, explicit support would be needed for algorithms that produce climate products outside of the NPP science team purview (e.g., CERES/JPSS-1, TSIS, ASMR-2/GCOM-W1).

3.1.1 *The Importance of Consistent Algorithms*

The two main inherent obstacles to generating climate data records across missions are instrument differences (e.g., on-orbit characterization capabilities, sampling) and algorithm differences (e.g., model assumptions, ancillary datasets). Unraveling the impact of instrument versus algorithm variances in a data record is extremely challenging. It is not clear that there is any meaningful process that can be developed to adjust the operational EDRs in a way that achieves continuity to meet the multi-decadal climate signal requirement [*Ohring et al.*, 2005]. **However, while instrument differences are a given, geophysical product algorithm differ-**

ences can be eliminated (or at least minimized) by the use of a single consistent algorithm that is applied across the series of instruments.

Applying a consistent algorithm across instruments rephrases the nature of data record comparisons. The questions become: *To what extent do the operational algorithms incorporate retrieval approaches adopted by current data records and what are the consequences of having made different algorithm choices?* An advantage to this approach is that identifying algorithm sensitivities provides a means for attributing data record differences at the algorithm level as well as for identifying pathways for improving the NPP and/or EOS algorithms.

Significant algorithm differences can arise from differences in algorithm methodologies (e.g., LUT, iterative approaches), use of spectral channels, choice of forward models (e.g., aerosol and ice cloud particle radiative models), ancillary datasets (e.g., surface emissivity, spectral albedo, meteorological data), retrieval uncertainty, and/or Quality Assurance (QA) assessments. **Figure 3** illustrates these challenges with an example of cloud fraction from the Global Energy and Water Cycle Experiment (GEWEX) Cloud Assessment [*Stubenrauch et al.*, 2011]. A further example is discussed in **Figure A1** and associated text.
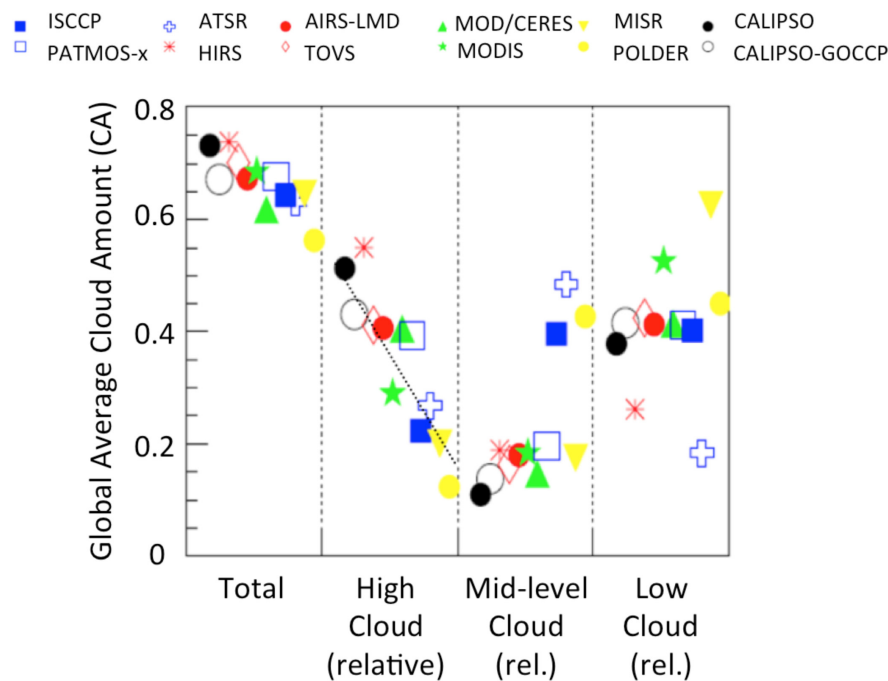
Fig. 3. Cloud amount (fraction) averaged globally for 12 different datasets over various time periods. The two green data types (triangles and stars) represent results for the same instrument but using two different algorithms (MODIS CERES and the MODIS Science Team). Climate data record continuity is not possible without the use of consistent algorithms. Differences among the other data points are due to a combination of algorithm and instrument/sampling effects. From *Stubenrauch et al.* [2011].

Below we give a couple of general examples that encompass all JPSS algorithms.

Absence of Level-3 Products

There are no Level-3 requirements for NPP/JPSS despite the fact that the vast majority of users require gridded spatial/temporal statistics for climate studies. It should go without saying that this is an obvious need for climate models. Nevertheless, as an example, we note that a number of NASA Earth Science datasets are being published to the Earth System Grid (ESG) for use in IPCC CMIP5 assessments [These include Atmospheric Infrared Sounder (AIRS)/Microwave Limb Sounder (MLS) temperature and humidity profiles, AMSR-E Sea Surface Temperature, CERES Top of Atmosphere fluxes, MODIS cloud mask and land surface products (Leaf Area Index, Net Primary Productivity, Global Primary Production), Tropospheric Emission Spectromter (TES) ozone, and Tropical Rainfall Measuring Mission (TRMM) precipitation]. In all cases, the ESG datasets required 1° gridded statistics on a monthly time scale.

Without Level-3 aggregations, the utility of even perfect algorithm continuity among Level-2 products is of little value for climate studies. This is a huge gap in the current JPSS algorithm design, and will severely limit the utility of the JPSS data for NASA climate science. That said, the EOS experience is that proper design of a Level-3 code is far from trivial. Statistics are affected by choices regarding aggregation strategies (e.g., use of multiple orbits, daily-to-multiday weighting approaches, QA weighting/filtering—described below). By adopting similar aggregation strategies as used for the EOS legacy instruments, a set of JPSS aggregation products could be developed that would allow for a direct comparison against EOS.

Filtering of Pixels: Masking and Quality Assurance

All algorithms filter the set of pixels for which retrievals are provided. This is typically done in one of three ways:

1. By outright elimination of the pixel from consideration (e.g., assigning it as cloud-contaminated for land retrievals or sun-glint contaminated for ocean aerosol retrievals, excessive cloud fraction for sounder cloud-cleared radiance retrievals, screening of noisy detectors);

2. by assigning Quality Assurance (QA) or Quality Control levels as a guide to users on the usefulness of the retrieval; and

3. by attempting a retrieval, but allowing the algorithm to return a "failed" result due to an inconsistency between the forward model and/or ancillary data and the measurements (e.g., a retrieval that cannot match multispectral radiances to model LUTs).

The first two methods are explicit choices made by the algorithm developers; the last one represents an implicit filtering imposed by the physics. Further, for many products, QA assignments are used to weight and/or eliminate pixels for aggregation in Level-3 products. This is based on an attempt to provide the best quality product for a common user[5]. However, it is unlikely that a fixed set of filtering satisfies all users. Regardless, choices made in filtering at the pixel level along with the success rate of attempted retrievals can affect Level-3 aggregation statistics.

Therefore, even for identical instruments, differences in filtering between algorithm developers can make direct comparisons of retrievals and statistics ambiguous. A notable example of this that is likely to affect MODIS vs. VIIRS comparisons is the Interface Data Processing Segment's (IDPS) mandated use of the VIIRS Cloud Mask (VCM).

The VCM – a so-called "intermediate product" (IP) in that it is input to all VIIRS EDRs – is modeled after the MODIS mask, providing 48 bits of information detailing results from various spectral and spatial tests. Being clear-sky conservative, MODIS provides an overall assessment (2 bits of information) about the likelihood of a field of view (FOV) being contaminated by cloudy radiances. The MODIS experience has been that each clear sky product team will need to define their own comfort level for cloud contamination and the means by which they want to filter potentially cloudy FOVs. Similarly, a cloud product team needs to interpret to what extent a non-clear FOV matches the expectations of overcast cloudiness needed for retrievals. As such, MODIS land (Surface Reflectance), aerosol (Dark Target and Deep Blue), and cloud optical property teams use selected tests from the MODIS cloud mask, along with specific information/masking methods brought in by the teams, as part of their filtering. This provides the best use of the cloud mask information while providing flexibility for the teams.

In contrast to MODIS, the IDPS approach requires implementing a single VCM for all EDRs [VCM Operational Algorithm Description, 2010]. This ignores the variety of mask requirements among the EDR algorithms. **The MODIS**

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[5] Note that it is unlikely that a single choice satisfies all users. Regardless, choices made in filtering at the pixel level along with the success rate of attempted retrievals, can affect Level-3 aggregation statistics.

experience suggests this is a failed approach and likely to result in ambiguity in comparing VIIRS and MODIS datasets.

3.1.2 *Recommendations Related to Retrieval Algorithms*

The directed focus of the recently competed NPP Science Team (ROSES 2010) continues to be on evaluation of contractor algorithms (as was the case for the previous two incarnations of the science team). For the benefit of NASA's research programs as well as the larger national and international climate community, we recommend that NASA Earth Science take ownership of EOS-era algorithm continuity in the following manner:

1. Refocus the NASA NPP Science Team (ST) effort towards the design and implementation of consistent EOS/NPP Level-2 algorithms (to the extent possible) with the objective of producing continuous data records across the instruments and the quantification of remaining differences.
2. Expand the NPP ST as needed. The existing team may not have the full complement of required expertise given the solicitation objectives.
3. Expand the NPP ST membership to support the development of Level-3 gridded spatial/temporal aggregation products that are compatible with relevant EOS Level-3 approaches so as to enable climate science, in particular, the use of observational data in model assessments.
4. Provide direct support of algorithms for climate products outside of the NPP ST charter (e.g., CERES JPSS-1, TSIS, GCOM-W1/AMSR2[6]—*see Section 3*).
5. Enable a process for algorithm improvement and re-processing in recognition of lessons-learned in previous Earth Science algorithm development efforts. As discussed in *Section 3.3*, expand the role of the PEATEs to work with the science team on processing, archiving, and distribution of the products.

Though the proposed re-scoping of the NPP Science Team would be at odds with the formal language in the ROSES 2010 NRA call, we are aware that this approach is an implicit part of several science team proposals. It is recognized that additional team members may have to be brought in since this would represent a change in team objectives. By default, we believe this is also the most straightforward means for evaluating operational algorithms, should this still be of value to the Research and Analysis Program.

We recognize that designing a consistent algorithm will be challenging for VIIRS products with missing spectral channels and/or spatial resolution. (e.g., clouds). Approaches for this situation have been discussed (*See Section A.1.2*).

3.2 *Instrument Calibration and Characterization*

Climate Data Records are derived using calibrated and geolocated measurements of radiance, irradiance, and/or reflectance. In EOS, these data are referred to as Level-1B (L1B) data, while in NPP/JPSS these data are referred to as Sensor Data Records (SDRs). The production of CESDRs from Earth observing satellite instruments requires the implementation of a comprehensive instrument calibration and characterization program spanning pre-launch to on-orbit timeframes to accurately assess instrument performance and quantify instrument measurement uncertainties. The quantification of instrument measurement uncertainties is key to the program, since it is required to establish calibration traceability to the national/international standards and thereby achieve the necessary level of confidence in the derived geophysical products used to produce CESDRs.

The recommendations given below related to NPP/JPSS instrument calibration and characterization are focused on post-launch instrument calibration and climate quality SDR data production for the NPP program and on pre- and post-launch instrument calibration, characterization, and climate quality SDR data production for the JPSS program.

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[6] Note: As previously mentioned, GCOM data are JPSS Category 3 Environmental Data Records (EDRs), with an agreement in place for NOAA to receive AMSR2 raw data records from JAXA. NOAA will then produce a suite of microwave imager products for operational requirement purposes only. The algorithms/methodologies with which L1 and higher-order products will be generated by NOAA are not clear at this time. There is a pressing need to manage/provide a mechanism for data continuity with GCOM-W1. On October 4, 2011, the AMSR-E antenna drive assembly spun down to zero rotation due to a torque overload anomaly. This behavior was not entirely unexpected given the design lifetime of the mechanism and occurrence of torque spikes over the last couple of years. The viability of some level

of instrument recovery is under discussion with JAXA. Regardless, the lack of overlap with GCOM-W1 is in serious doubt and therefore the ability to directly intercalibrate AMSR-E with AMSR2. However, if direct intercalibration is not viable, the AMSR-E team believes this can be accomplished indirectly by using the NASA Modern Era Retrospective-Analysis for Research and Analysis (MERRA) reanalysis as a transfer standard. For example, one year of global AMSR-E brightness temperature (T_b) data could be compared to T_b's computed from the MERRA global fields co-located in space and time, and then that relationship applied to the MERRA vs. AMSR2 data. Direct intercomparisons with Tropical Rainfall Measuring Mission (TRMM) Microwave Instrument [TMI] and Windsat are also possible.

3.2.1 Production of Climate Quality Sensor Data Records

The production of CESDRs requires SDRs generated using instrument algorithm codes controlled to allow for input data and algorithm updates and data reprocessing. An example of this is the L1B processing approach used for MODIS with instrument performance validation and L1B data production functions being performed by the MODIS Characterization Support Team (MCST). MCST was established early in the EOS Program to directly support the NASA EOS MODIS Project and Science Team, and is responsible for developing, implementing, and controlling the MODIS L1B algorithm and code, generating and updating calibration parameters used for the L1B LUTs, and maintaining and verifying the quality of MODIS calibration data products. The MCST also works closely with the MODIS L2 algorithm developers.

The MODIS Terra and Aqua L1B data has been reprocessed three and two times, respectively, with the next reprocessing scheduled to begin in late 2011. The MCST has direct control of all L1B code, and is also responsible for MODIS Terra and Aqua on-orbit operation and calibration, including direct participation in a number of on-orbit activities required for the production of climate quality L1B data. These on-orbit activities include event scheduling for lunar and solar calibration maneuvers, on-board calibrator operation and monitoring, command uploading, instrument health monitoring, and calibration data processing. Lastly, the MCST has benefitted in its work by close interaction with the MODIS instrument vendor on instrument calibration and characterization issues.

Another example supporting the requirement for control of the SDR code is the AIRS/Advanced Microwave Sounding Unit (AMSU) Level 1B processing system. For AIRS/AMSU, the JPL AIRS Team Leader Science Computing Facility (TLSCF) is responsible for implementation of software updates to the AIRS and AMSU Level 1B algorithms. Software updates capture changes in the instrument performance characteristics such as on-orbit polarization and linearity changes and temperature drift corrections. AIRS/AMSU L1B software updates are sent to the GSFC Data and Information Services Center (DISC) for incorporation into the processing system used to produce the data for the science community.

With respect to the NPP and JPSS SDR code, NASA's role is quite different than it was for EOS. NASA's sole role in NPP and the JPSS program to date has been to assess the climate quality of the Environmental Data Records (EDRs) produced by the IDPS from SDRs. In the process of that assessment, NASA's Science Data Segment (SDS),

the NPP Instrument Characterization Support Element (NICSE), and PEATEs will ingest subsets of the raw instrument data streams to run independent tests of operational SDRs using state-of-the art heritage algorithms to assess these data suitability for climate science. **However, there is no guarantee that improvements indicated by the NPP teams will be incorporated into the operational SDR code. There are also no plans in NPP to reprocess instrument SDRs, a critical exercise in the production of climate datasets.**

3.2.2 Communication of Instrument Calibration Issues to the Science Community

The on-orbit production of climate quality datasets requires that the instrument's calibration and science teams jointly maintain interest and ownership in the L1B algorithm. To do this, calibration workshops and frequent meetings involving an instrument's calibration personnel, science team, and the larger science community are required to evaluate the climate quality of instrument L1B data. For MODIS Terra and Aqua, the MCST has maintained its close interaction with MODIS Science Team through its calibration and science discipline representatives via weekly MODIS Sensor Working Group (MSWG) meetings. Instrument operational changes, LUT updates, and proposed algorithm improvements are reviewed by the MSWG prior to their approval and implementation. Issues identified from the calibration process or raised by the data users are also discussed. In addition to these smaller, weekly meetings, annual or semi-annual calibration workshops—with invitations extended to the larger instrument science teams and science community—are also required to evaluate the overall L1B data quality. These workshops present the status of on-orbit instrument calibration and characterization. Sensor calibration performance and quality evaluations of sensor calibration are also presented. For MODIS, calibration workshops are organized by the MCST and are held during each of the MODIS Science Team meetings on a semi-annual or annual basis and have been extremely beneficial to the science community.

The production or continuation of CESDRs requires remote sensing data provided by a series of, preferably, overlapping on-orbit instruments. Multi-instrument workshops with international participation are essential for addressing on-orbit measurement differences and resolving instrument issues experienced by remote sensing instruments used in the construction of CESDRs. These directed workshops serve as a type of informal review leading to improved measurement methodologies and techniques and lead to a clear identification of cross-cutting calibra-

tion efforts. Workshops also afford the opportunity to examine and compare the L1B algorithms.

An example from the EOS era of the benefit of a multi-instrument workshop to specifically address measurement differences was the 2005 EOS workshop at National Institute of Standards and Technology (NIST) to examine potential sources of differences in on-orbit Total Solar Irradiance (TSI) measurements [*Butler et al.,* 2009]. Participation in the workshop included representatives from all the instruments whose measurements currently constitute the TSI historical data record as well as NASA, NIST, and the Naval Research Laboratory (NRL). The recommendations from that workshop included conducting a measurement comparison of the optical areas of heritage apertures used in the TSI instruments, consideration of diffraction effects from instrument apertures and baffles, and conducting a comparison of optical power/irradiance measurements of the TSI instruments using intensity stabilized lasers and the NIST Primary Optical Watt Radiometer (POWR). Implementation of these recommendations has led to agreement in the TSI measurements of SORCE Total Irradiance Monitor, ACRIMSAT Active Cavity Radiometer Irradiance Monitor (ACRIM III), and PICARD/PREMOS to within their stated uncertainties [*Kopp,* 2011].

To date, plans for NPP/JPSS instrument on-orbit performance reviews and cross-instrument workshops have not been formulated. Under the current paradigm, information exchanges with calibration and characterization personnel from similar on-orbit instruments currently producing and/or continuing NASA CESDRs will be confined to the comparison of retrieved geophysical products, such as those afforded by Simultaneous Nadir Overpasses (SNOs).

3.2.3 *Reviews in Support of Prelaunch Instrument Calibration and Characterization*

Pre-launch reviews play a critical role in ensuring the most efficient production of climate quality SDRs. The EOS experience underscores the value of having calibration and characterization experts from NASA, NIST, and universities included from the earliest phase of the process—namely the derivation of instrument performance specifications from science requirements. Review of instrument performance specifications by the instrument calibration community provides important early feedback that is crucial to the formulation of achievable, verifiable instrument specifications. Review of instrument calibration plans at instrument builder facilities by experts in the calibration and instrument testing field should be held at the time of each instrument's Preliminary Design Review (PDR) and again during the Critical De-

sign Review (CDR). These reviews should be held a sufficient amount of time before instrument hardware testing begins to ensure timely implementation of review recommendations. In order to formulate a comprehensive set of recommendations, material to be presented at these reviews should be made available to all participants one week prior to the review. Lastly, review panel members should be encouraged and invited to participate in all follow-on reviews where the results of instrument subsystem, system, and instrument observatory level tests are presented.

In the NPP program, formal instrument calibration reviews were not held during PDR or CDR, and at this time, it appears that none are planned for JPSS instruments. For NPP, instrument calibration test plan reviews were conducted piecemeal as instrument test plans were released. These reviews consisted of a series of technical interface meetings involving NOAA, NASA, and university representatives working on NPP with review material often being released a day or two in advance of the meeting. This approach made it very difficult for key subject matter experts (SME) to participate and to make optimal recommendations. This approach also led to several calibration issues (e.g., visible/near infrared/shortwave infrared calibration methodology of the VIIRS spherical integrating source, redesign of the VIIRS polarization responsivity test equipment, errors in Bidirectional Reflectance Distribution Function (BRDF) measurements of VIIRS on-board diffusers, unacceptably low emissivity of the CrIS on-board blackbody) related to testing shortfalls, improper measurement methodologies, and poorly designed ground support equipment. Unfortunately, these issues were often discovered or flagged late in the test program with significant schedule and cost implications.

3.2.4 *Direct Government/University Analysis of Prelaunch Instrument Calibration, Characterization, and Test Data*

The direct participation of government and university calibration experts in the processing of ambient and thermal vacuum instrument test data at the instrument vendor's facility provides the most efficient, independent validation of instrument performance versus specification. Such participation also provides insight and guidance on necessary corrections and updates to the instrument L1B algorithm. For example, during the EOS program, NASA, NIST, and university calibration personnel were routinely welcomed into the instrument vendors' cleanroom and non-cleanroom facilities and directly participated in calibration and characterization of EOS instruments. Government participation at this level proved to be extremely valuable to the

instrument vendor in a number of ways. Participation of instrument vendors and government and university metrology labs provided a direct validation of instrument calibration scales—including the key scales for irradiance, radiance, reflectance, temperature, and emissivity that form the basis for all CESDRs. Participation also led to a number of suggested improvements to the instrument vendor's calibration approaches and hardware. These suggestions would not have been made if the hardware and test setup were not directly viewed.

We emphasize that a constructive working relationship that includes information sharing between contractor and government significantly benefits both the science community and instrument vendor. The science community benefits by regular acquisition of accurate sensor development and test information necessary to produce climate-quality SDRs; the instrument vendor benefits by ready access to quick, independent, and more complete data analysis support and review.

For NPP, access to instrument vendor cleanroom or non-cleanroom facilities containing calibration equipment was not granted to government or university calibration personnel. It is anticipated that a similar approach will be taken for JPSS instruments, and suggestions to improve calibration methodologies and hardware setups will need to be made via responses to written test plans provided serially at technical interface meetings. To the NPP Project's credit, and partially due to schedule and cost-driven reasons, government and university calibration personnel were requested and indeed played a critical role in processing pre-launch ambient and thermal vacuum data for the VIIRS instrument in particular.

3.2.5 *Recommendations Related to Instrument Calibration and Characterization*

Based on the above discussion, the following recommendations are made with respect to the pre-launch instrument calibration and characterization.

1. Implement NASA control of NPP/JPSS instrument SDR algorithms and code to enable necessary calibration parameter updates, methodology improvements, data uncertainty assessments, and data reprocessing.
2. Conduct NASA-led, post-launch NPP/JPSS instrument calibration and characterization meetings with open invitation to instrument calibration and

science teams. In accordance with International Traffic in Arms (ITAR) restrictions, support NASA-led, multi-instrument calibration and characterization workshops to address fundamental instrument measurement differences.

3. Conduct a formal pre-launch review of JPSS instrument calibration and characterization plans at least eight months before an instrument's Test Readiness Review (TRR) with an additional formal review at the time of the TRR. Conduct additional calibration and characterization reviews following completion of ambient testing and thermal vacuum testing, before thermal vacuum is broken.
4. Support the participation of NASA and university calibration experts in the on- and off-site testing/analysis of the JPSS instruments. This includes accessing instrument cleanroom and non-cleanroom test facilities for purposes of review and evaluation.

3.3 *Data Reprocessing and Archiving*

Given the historical uncertainty on the actual performance of the contributed instruments on NPP, the NASA Science Mission Directorate (SMD) and ESD has been unwilling to commit the resources necessary for data product reprocessing. Therefore, data reprocessing and subsequent data product archiving are explicitly not part of the NPP L1RD. Nevertheless, while reprocessing is not a requirement, ESD has made strategic investments in both the scientific and computational assets needed to create merged EOS/NPP data records.

The NPP Science Team, having just completed its third recompetition, has the charter to evaluate the NPP data for its ability to produce products that continue the EOS data records. In particular, the science team members are to assess the quality of the operational data products against the EOS data continuity standard. To support the science team in their efforts, the NPP Project has supported the development of the SDS which consists of five discipline-based PEATEs; Ocean, at MODIS/SeaWIFs data processing group (further details in *Section A.3*); Land, at the MODIS land processing group (further details in *Section A.2*); Ozone, at the TOMS/OMI data processing group; Earth Radiation Budget, at the CERES data processing group; and Atmospheres at the University of Wisconsin, Madison Space Science and Engineering Center. Four of the five PEATEs are contained in active EOS data processing/reprocessing centers.

The current plan is to have an NPP Science Team evaluation review 18 months after launch. After that review, ESD

will determine the path forward for combining NPP and EOS data records.

3.3.1 *Recommendations for Data Reprocessing and Archiving*

As part of an integrated approach to CESDR continuity, we recommend that the charter of the PEATEs evolve so that these facilities take on the role of Science Investigator-led Processing System (SIPS) facilities. This involves the processing and reprocessing of NASA supported NPP/JPSS-1 products, as well as providing for an algorithm development test system. Some PEATEs are already positioned to take on the task of archiving and public distribution. ESD should begin planning for this capability now, including an assessment of required resources. Specifically, as part of this evolution ESD should:

1. Task the PEATE discipline teams to use the 18 month evaluation period to assess the infrastructure design and resources needed to provide for EOS-like algorithm testing, data production and reprocessing of relevant NPP data products, including working with the science teams and HQ to scope a complete list of products from those presented in the CESDR summary tables (See **Tables 4.1-4.7**).

2. Work with current EOS DAACs and the PEATEs to plan for archiving of NPP products.

3.4 *Environmental Data Record (EDR) Validation*

Validation is the establishment of satellite product uncertainties via independent measurements and/or retrievals that have known errors characteristics.

In this section, we are primarily concerned with assessing EDR uncertainties. This inherently requires validation across large spatial and temporal scales, and as such is extremely challenging—typically requiring a combination of ground networks and instrumented surface sites, airborne in situ and remote observations (including instruments with independent capabilities/methodologies), inter-satellite comparisons, and research and modeling efforts. A diversity of approaches are required for the suite of products that can be generated from NPP/JPSS. Some products have an infrastructure of established and community-accepted approaches for product validation (e.g., aerosol optical depth from AERONET sunphotometers) while others lack an infrastructure and/or a robust methodology for validation.

For this discussion, we consider on-orbit intercomparison of EDRs from similar satellite instruments (e.g., VIIRS vs. MODIS, etc.) to be product "evaluation" and not strictly validation since it does not invoke an independent type of measurement or methodology. That is, even in the ideal situation where both instruments are without measurement error and identical algorithms can be used (*Section 3.1*), agreement does not directly establish retrieval uncertainties; an exception under these circumstances is when uncertainties for the older satellite record are already established and well understood.

For completeness, and as discussed in *Section 3.3*, we note that an integrated pre- and post-launch program is essential for validating SDRs, including the quantification of errors that can be used to establish instrument-related EDR retrieval uncertainties. For climate studies, time-series assessments of space-borne instruments are essential. Post-launch validation of SDRs takes many forms, and may rely on a combination of on-board systems and comparisons against ground and airborne observations (e.g., vicarious calibration) as well as other satellite instruments.

3.4.1 *NOAA/JPSS EDR Validation*

The JPSS Program, specifically the JPSS Ground Project, has the responsibility for ensuring the quality of the data products produced by the operational system from NPP and JPSS-1 observations.

Prior to JPSS, the NPOESS Integrated Program Office (IPO) had developed extensive calibration and validation (cal/val) plans for both NPP and NPOESS data products. These plans had the prime contractor, Northrop Grumman Aerospace Systems (NGAS), primarily focused on instrument SDR cal/val, with the IPO having the EDRs as their primary focus. To implement their portion of the cal/val tasks, the IPO appointed discipline-specific *Validation Leads* (also referred to as Validation Scientists), to help plan and coordinate EDR validation efforts.

After the IPO/JPSS transition, NOAA/NESDIS STAR personnel have assumed responsibility for the operational (contractor) algorithms and been designated as *Application Leads*. They will be supported in this endeavor by select members of the former NGAS contractor team though, due primarily to budget limitations, the level of such support remains uncertain at this time. Subject to budgetary constraints, the JPSS Ground Project has attempted to retain the Validation Leads and other personnel from the heritage IPO cal/val program. In most cases,

the current STAR Application Lead was a member of the EDR discipline validation team and would remain so with this model. However, it is expected that the Application Leads are likely to become the Validation Leads as well, potentially resulting in a further depletion of validation focus and resources.

Both before and after the transition, the NPP/JPSS cal/val program has prioritized their activities as follows:

1. All Sensors: Archiving of Raw Data Records (RDRs) including all relevant sensor, telemetry, and housekeeping data downloaded from the spacecraft.

2. All Sensors: Thorough evaluation of SDRs to ensure that on-orbit instrument data is consistent with the sensor performance as determined in pre-launch testing.

3. All Sensors: Off-line processing to support SDR production (e.g., calibration coefficients).

4. Examination of EDRs that help characterize the on-orbit sensor performance available by no other means, including:
   – Key Performance Parameters (KPPs): Imagery (band-to-band registration, noise, striping), SST (radiometric performance of infrared bands at warm brightness temperatures)
   – Cloud Top Temperature (radiometric performance of infrared bands at cold brightness temperatures)
   – VIIRS Cloud Mask (band-to-band registration)
   – Ocean Color (performance of VIIRS visible bands)
   – Other KPP EDRs (e.g., CrIMSS temperature and moisture profiles)

5. Other EDR validation.

The previous FY11 continuing resolution and an uncertain FY12 fiscal environment resulted in a NPP cal/val program focused on the first four items with only marginal levels of support for the last item that encompasses the vast majority of the EDRs.

As mentioned, the current NPP EDR Validation program is organized into traditional discipline-based groups. These are Land, Ocean (Physical and Biological), Atmospheres (Clouds and Aerosols), Ozone, and Sounder (CrIMSS temperature and moisture profiles). The CERES NPP data products are handled separately as NASA data products (but not JPSS-1, see *Section A.1.5*). Additional details on specific validation issues can be found in some of the *Appendix A* data product sections.

For budgetary reasons, the current EDR validation plan emphasizes the use of proven networks (surface-based systems) and comparison to existing satellite data products (i.e., product "evaluation" in most cases).

The EDR Validation teams have/will use the following available surface networks and infrastructure:

Aerosols:	AERONET, MPLNet, Sea Prisms, SURFRAD (NOAA)
Clouds:	DoE ARM sites, MPLNet
Ozone:	Dobson/Brewer Network, Ozonesondes (NOAA)
SST:	Buoys (NOAA)
CrIMSS profiles:	Operational Radiosondes, DoE ARM sites (NOAA)
Ocean Color[1]:	In-situ data, SeaPRISM, MOBY (NASA, NOAA, Navy)
Land[2]:	NOAA-CRN, DoE-ARM, SurfRad/BSRN, AERONET
Cryo[2]:	Greenland Climate Network, Antarctic automated station networks

[1]Also, see *Hooker et al.* [2007]
[2]Discussed in *Appendix A.2*

However, at the present time, funding for the cal/val infrastructure, in particular the above surface-based networks, is not part of the JPSS cal/val program. Limited financial contributions were made by JPSS in FY11 to the AERONET network. There are plans by NOAA to initiate MOBY support in FY12 (NASA funding ended in FY06). These surface-based networks have provided objective standards for comparison with satellite data products. Their key attributes are robust sample size (many sites observed daily by satellite) with consistent and reliable data products. For federated sites such as AERONET and MPLNet having common instrumentation, this means uniform site-to-site data protocols and product algorithms; similarly, the DoE Atmospheric Radiation Measurement (ARM) facility uses common standards. The continuation of these networks is critical for the validation of NPP CESDRs.

The most dramatic change from the EOS era is that comparisons with existing satellite observations are expected to be a major source of evaluation/validation for NPP/JPSS. While these are not perfect or "truth" references, the level of validation and characterization achieved with the EOS data products and the inherent statistical robustness and coverage capability, make this a key pathway. The

fact that NASA has invested significant resources in developing the PEATE facilities is also a significant enabling factor. We are already seeing the impact of the cloud/aerosol PEATE that supports validation of MODIS Collection 6 algorithm development. Although NPP is not in the A-Train, NPP is in the same orbital plane and has the same notional (1330 LT) equator-crossing time as the other A-train assets. Approximately one-third of the time, NPP will be within the A-Train nominal criteria of ±15 minutes between EOS Aqua and NPP observations. This physical and temporal overlap will be essential for identifying any systematic differences in the data products produced from both the EOS and NPP platforms. The major risk to this approach is the possibility that A-Train sensors may not last sufficiently into the NPP and JPSS era. This is particularly true of the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission, which has had a major impact on the assessment of cloud mask performance and consequently on knowledge of various other downstream products including, of course, cloud and aerosol EDRs. Failure of CALIPSO prior to stage-2 validation of the NPP SDRs would be a major problem, retarding the development and validation of quality CESDRs.

Plans for airborne campaigns focused on validation have been limited solely to CrIS and VIIRS SDR validation. For CrIS, this is to tie CrIS observations firmly to IASI and AIRS (JPSS funding with NASA aircraft assets and primarily NASA instrument PIs). Discussions about other possible endeavors have been severely limited by the perception that there will be no funds available. The various disciplines do have notions about what measurements they would like to see if such resources were available—e.g., observations of aerosol composition as a function of height, ice cloud composition (particle size and ice water content), land surface properties, ice/snow surface properties. While such activities could make significant contributions to EDR quality, the current reliance on networks and satellite product intercomparisons, largely enabled by the PEATEs, is the optimal pragmatic path in the present fiscally-constrained environment.

Given the validation priorities and approaches, our assessment of the individual instrument EDR validation status follows:

CrIS and ATMS: The current JPSS approach for validation appears satisfactory. This is due to the maturity of the existing team (STAR Application Lead and validation team), its extensive experience, the reality that these data are essential to the NOAA operational mission, and the fact that this team was sufficiently engaged in other

sounder missions that the lessons-learned have come through loud and clear. The major issue will be in developing the necessary expertise to actually tune/revise the algorithms post-launch in response to validation findings. The team has the expertise, but will need to have greater familiarity with the sounding algorithm code.

OPMS: Given the maturity of the existing team and its extensive experience over a long history of ozone sensors, the current JPSS approach for validation seems satisfactory.

VIIRS: VIIRS is the most problematic sensor with regard to EDR validation. It is here that algorithm expertise and familiarity is a problem. Some of the operational algorithms are not based on heritage algorithms, while others do not reflect science developments over the past decade. The situation varies by discipline (see Appendix and product summary tables). The lack of ownership of the contractor-developed algorithms by the newly appointed Application Leads is a very significant hurdle, especially in the year following launch when resources necessary to develop the required expertise are definitely lacking. Moreover, the widespread EDR dependence on the VIIRS Cloud Mask (VCM) performance and application across all EDRs is a major issue (*see Section 3.1.1*).

3.4.2 *Recommendations Related to EDR Validation*

To summarize the previous section, the current situation is that the JPSS EDR Validation Teams are typically rather small and underfunded. In most instances, their resources have been further depleted by assignment of algorithm responsibility to a STAR member of the team. Moreover, the JPSS Validation Teams are charged to validate the EDRs with respect to the system requirements that were largely defined by the operational user community in the mid-1990s, and that consequently may not transfer into climate and science uses.

If NASA wishes to achieve CESDRs from NPP sensors, the resources must be found to increase the manpower and observational resources focused on validation. We believe that it is beneficial to create discipline-specific validation teams that are funded independently from, but coordinate closely with, the CESDR algorithm teams. This has several advantages, including practical issues associated with having a separate resource stream and an inherently broader inclusion of the community. Of course, in forming effective validation teams it will be critical to ensure that the review process include those with expertise regarding the algorithms, processing, products, and key validation issues.

Based on the above discussion, we recommend that ESD:

1. Establish a NASA Validation Team (NVT) for each discipline to provide a robust effort to validate NASA-funded CESDRs (*Section 3.1*) and/or JPSS EDRs by comparison to independent "ground-truth" measurements to the maximum extent possible.
   a. The NVT interacts closely with, but is independent from, the CESDR algorithm leads.
   b. Take steps to ensure that the NVTs operate as closely knit teams and not as independent entities.

2. Ensure that the NVTs routinely and substantively engage with the JPSS algorithm/validation teams.

3. Encourage the NVTs to establish interactive working relationship with the JPSS sensor teams and sensor-related NASA activities (*Section 3.2*).

4. Maintain robust support of the discipline PEATEs as these ultimately will be crucial to achieving CESDR quality (*Section 3.3*). The PEATEs should support appropriate NVT activities, in addition to CESDR development and testing.

5. Continue support of the various networks and other ground truth observations that are the bedrock of validation for many of the disciplines.

6. Consider convening community workshops, by discipline, to achieve consensus on observation requirements and approaches that are necessary for CESDR validation.

We note that a validation team approach is different from EOS where the algorithm lead had resources within his/her team to plan and implement a validation strategy. External investigators were also supported via NASA Research Announcements, but the integration of these investigators into the algorithm teams was variable and sometimes, as in the case of the MODIS land products, ineffective. A more integrated team approach is necessary. In particular, having a discipline Validation Lead/Team can help to foment a more robust validation effort. This will help maintain validation as high priority regardless the circumstances of the NASA-funded algorithm leads (*Section 3.1*) or JPSS Algorithm Leads whose attention span is typically overwhelmed in the first year or two after launch as well as during reprocessing/testing efforts. We also note that this approach is different than the more broadly integrated science-driven field campaign work that dominates ROSES efforts and is not always well suited to addressing algorithm-specific retrieval questions.

Finally, to get the full utility out of a validation program, NASA needs an integrating organization to coordinate and link the algorithm developers and validation teams (**See Figure 2**). This should be designed/managed to be a cooperative relationship and not adversarial.

4. SUMMARY TABLES: JPSS VS. RELATED NASA DATA RECORDS

The following tables represent a high-level assessment of the current status of the NPP/JPSS instrument capability and Sensor Data Records (SDR) algorithms (**Table 4.1**) and Environmental Data Records (EDRs) relative to heritage NASA EOS instruments and algorithms (**Tables 4.2–4.7**). The tables, broken down by discipline for EDRs, are a synthesis of the full description of the heritage EOS data records and our current understanding of the JPSS algorithms that are given in *Appendix A*. Please refer to the appendix for further details, quantitative comparisons, and relevant discipline white papers and other references.

In the EDR tables, JPSS Level-1 requirements are shown first, followed by climate-relevant EOS standard products for which there are no JPSS requirements. In some cases,

potentially important EOS research-level products worth further study as CESDRs are mentioned. EDRs considered Essential Climate Variables (ECVs) by the international Global Climate Observing System (GCOS) are designated by bold-face in the tables.

The color-coding assignments given to the JPSS column are meant to be qualitative in the sense of conveying the relative status among the various SDRs and EDRs (again, see appendix for details). The color key is as follows – Green: no anticipated issues or minor algorithm corrections/approaches needed; Yellow: some concern; reasonably straightforward approaches can be taken to evaluate and/or correct problems; Red: serious concern regarding lack of data continuity; approaches for remediation (if feasible) involve substantial efforts.

Table 4.1. Summary assessment of current status of **JPSS Sensor Data Records** (SDRs) relative to the heritage NASA data records.

L1 SDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			JPSS	**Potential Improvements**
VIIRS	MODIS	Accuracy	Some concern about VisNIR out of band response and crosstalk. Concern about how onboard characterization feeds back to L1 algorithm.	Need to sustain onboard characterization, especially lunar observations for VisNIR-SWIR. Need to continually feed updates to L1 algorithm for forward and reprocessing efforts.
		Stability	VisNIR-SWIR: On board solar diffuser and solar diffuser stability monitor similar to MODIS. Concern about how onboard characterization feeds back to L1 algorithm.	
		Spectral coverage	CO_2 slicing and IR water vapor channels are absent. Lacks 2.13 µm channel for cloud re continuity and aerosol Dark Target land algorithm. Lacks Chl fluorescence channels.	No remediation possible.
		Spatial Res.	Lacks 250m channels. Has selected 375m "imager" channels but typically with much larger bandwidth.	

L1 SDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			JPSS	Potential Improvements
CrIS/ATMS	AIRS/ AMSU	Accuracy	CrIS: Smaller S/N spec in critical 4 μm sounding bands affects yield and lower tropospheric sensitivity.	
		Stability	CrIS: Noncompliant NPP On-Board Blackbody affects radiometric stability	Replace blackbody with 3-bounce design on JPSS-1
		Spectral Res.	CrIS: Roughly 2x lower than AIRS on NPP impacts CO and spectral calibration.	Download entire interferogram. LW still 2x lower than AIRS.
		Spatial Res.	Similar to AIRS/AMSU	
OMPS	OMI, TOMS, SBUV	Accuracy	OMPS sensors capable of providing the accuracy, stability, spectral coverage, and spatial resolution needed for ozone nadir and limb retrievals, but the IDPS operational SDR algorithm is not flexible enough to properly handle changes in sensor data (i.e., changes in timing, spectral or spatial resolution, etc.) that may be required to optimize performance.	Processing of cal/val SDR data now being performed with an alternative SDR algorithm by the OMPS Science Operations Center, utilizing resources of the ozone PEATE. SDRs generated by the algorithms in this facility contain all information needed by the EDR algorithms to reprocess the data.
		Stability		
		Spectral coverage		
		Spatial Res.		
CERES NPP/FM5		Accuracy	LaRC CERES has responsibility for instrument build and SDRs.	
		Stability		
		Spectral coverage		
		Spatial Res.		
CERES JPSS-1/FM6	CERES (TRMM, Terra, Aqua)	Accuracy	LaRC team oversees instrument build only. No post-launch SDR involvement at this time.	Place all CERES SDRs under JPSS Program Office
		Stability		
		Spectral coverage		
		Spatial Res.		
TSIS	SORCE TIM, SIM	Accuracy	JPSS pursuing a free-flyer. TSI data gap a concern. TSIS team believes use of LASP team for product development is likely, but contract for effort not yet in place with JPSS Program Office.	Place SORCE TIM and SIM SDRs under JPSS Program Office.
		Stability		
		Spectral		
		Spatial Res.		

L1 SDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			JPSS	Potential Improvements
AMSR2 (GCOM-W1)	AMSR-E	Accuracy	Methodology/algorithm for generating L1B not expected to be public. Not conducive to CDR development.	Provide access to AMSR2 L1A data or equivalent
		Stability		
		Spectral	AMSR2 has additional low frequency channel for RFI mitigation	
		Spatial Res.	AMSR2 has larger antenna than AMSR-E	

Table 4.2. Summary assessment of current status of JPSS **Land** Environmental Data Record (EDR) algorithms and related products relative to the heritage NASA data records. EDRs considered Essential Climate Variables (ECVs) by GCOS are designated by bold-face.

Land L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			JPSS Plan	Potential Improvements
Land Surface Temperature	MODIS (MOD11)	Accuracy/ continuity	Comprised of two daytime/ nighttime algorithms (split window thermal and mid-IR), and backup algorithm that resembles heritage MODIS algorithm. Uses previous surface type dependent coefficients. Does not provide dynamic surface emissivity.	Use heritage algorithms
		QA/filtering/ sampling	Uses VIIRS Cloud Mask (VCM), not optimized for land products	Develop heritage cloud masking specific to land retrievals
Emissivity, LST (hyperspectral)	AIRS standard product	Accuracy/ continuity	*Intermediate Product (IP).*	Use AIRS-like algorithm. Retain as EDR.
Surface type	MODIS (MOD12)	Accuracy/ continuity	From re-projected Gridded Quarterly Surface Type IP. Follows IGBP classifications. Complex and less separable classes (e.g., open and closed shrubland, savanna, urban, agricultural mosaics) expected to have reduced accuracies.	A quarterly or annual product consistent with the FAO-Land Cover classification system should also be included.
		QA/filtering/ sampling	– as for T_{sfc} –	– as for T_{sfc} –

Land L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			JPSS Plan	Potential Improvements
Surface Spectral Reflectance	MODIS (MOD09)	Accuracy/ continuity	*Intermediate Product (IP).* One of the most requested MODIS land products. Several land EDRs depend directly on this IP. As an IP, VIIRS will not provide product continuity with MODIS (and AVHRR); effectively severing the long-term data record. Will limit assessment of existing products, development of new products, and/or result in duplication of effort to re-generate.	Access to spectral reflectance information is required to extend the MODIS data record. Retain as EDR.
		QA/filtering/ sampling	– as for T_{sfc} –	– as for T_{sfc} –
Vegetation Indices (NDVI, EVI)	MODIS (MOD13), AVHRR	Accuracy/ continuity	Several issues related to JPSS algorithm design for NDVI and EVI, but VIIRS data expected to be of sufficient quality for data continuity.	Update algorithms to achieve product continuity.
		QA/filtering/ sampling	– as for T_{sfc} –	– as for T_{sfc} –
Surface Albedo	MODIS (MOD43)	Accuracy/ continuity	Requirement is for broadband surface albedo (0.3-5.0 μm) only. No shortwave (PAR) or near/midwave IR for model use; no spectral albedo for other retrieval efforts. Lack of access to underlying spectral anisotropy models (in the BRDF IP) precludes computation of spectral albedos and albedo under varying illumination conditions.	Access to the underlying spectral BRDF information at an increased number of spectral channels is required to extend MODIS spectral data records.
		QA/filtering/ sampling	– as for T_{sfc} –	– as for T_{sfc} –
Active Fires	MODIS (MOD14)	Accuracy/ continuity	*Application Required Product* (ARP). Currently based on MODIS Collection 4. Product lacks fire mask and fire radiative power (FRP) data layers available from MODIS. No requirement for VIIRS Burned Area EDR product.	Update algorithm and data layers.
		QA/filtering/ sampling	– as for T_{sfc} –	– as for T_{sfc} –

Land L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			JPSS Plan	Potential Improvements
CESDR-relevant EOS Standard Product w/out Associated JPSS L1 Requirement				
LAI/fPAR	MODIS (MOD15)	Accuracy/ continuity	N/A	Adopt MOD15 to achieve product continuity.
Burned Area (ECV is "fire disturbance")	MODIS (MCD45)	Accuracy/ continuity	N/A	Adopt MCD45 to achieve ECV and EOS product continuity. Should be included along with Active Fires (see above)
Other: Veg. Continuous Fields	MODIS (MOD14)	Accuracy/ continuity	N/A	
Other: NPP/ GPP	MODIS (MOD17)	Accuracy/ continuity	N/A	

Table 4.3. Summary assessment of current status of JPSS **Atmosphere Cloud and Aerosol** Environmental Data Record (EDR) algorithms and related products relative to the heritage NASA data records. EDRs considered Essential Climate Variables (ECVs) by GCOS are designated by bold-face. For clouds, the ECV is "Cloud Properties" which we interpret to be inclusive of heritage products; the aerosol ECV is not specified by algorithm, so all types/capabilities are highlighted below.

Cloud/Aerosol L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPS/S Plan	Potential Improvements
Cloud masking/detection	MODIS (MOD35)	Accuracy/ continuity	JPSS algorithm similar to MODIS	
		QA/filtering/ sampling		
Cloud-top properties (p_c, T_c)	MODIS (MOD06)	Accuracy	VIIRS lacks CO_2 slicing channels	No direct remediation. Apply VIIRS-like algorithm to MODIS is best chance for achieving an algorithm-consistent data record.
		QA/filtering/ sampling	Uses similar cloud mask as MODIS	Threshold adjustments for MODIS data continuity may be required.
Cloud thermo-dynamic phase	MODIS (MOD06)	Accuracy/ continuity	Improved skill with 2.25 μm channel (vs. MODIS 2.13 μm), but less capable T_c sanity checks (see above)	
		QA/filtering/ sampling		
Cloud optical properties (τ, r_e, WP)	MODIS (MOD06)	Accuracy/ continuity	VIIRS lacks channel for continuity of 2.1 μm derived r_e	No direct remediation for that spectral retrieval.
		QA/filtering/ sampling	No additional filtering of "non-clear" pixels by VIRS Cloud Mask	Add additional filtering/QA output as needed for product consistency.

Cloud/Aerosol L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPS/S Plan	Potential Improvements
Cloud Liquid Water Path (LWP)	AMSR-E (ocean product suite)	Accuracy/ continuity	Algorithms to be used by NOAA? Continuity depends critically on L1B continuity.	Independent L1B (see **Table 4.1**) and ocean product evaluation and/or development.
		QA/filtering/ sampling		
Aerosol Dark Target (over ocean)	MODIS (MOD04)	Accuracy/ continuity		
		QA/filtering/ sampling	VIIRS Cloud Mask (VCM) not optimized for aerosol retrievals	Develop heritage cloud masking specific to aerosol retrievals
Aerosol Dark Target (over land)	MODIS (MOD04)	Accuracy/ continuity	VIIRS algorithm based on MODIS land atmospheric correction algorithms (not MOD04). Continuity will be difficult to establish because algorithm not based on publicly available predecessor.	Develop MOD04-like algorithm (not directly portable due to spectral mismatch: 0.47 μm to 0.49 μm, 2.13 μm to 2.25 μm). Level of achievable product continuity is TBD.
		QA/filtering/ sampling	VIIRS Cloud Mask (VCM) not optimized for aerosol retrievals	Develop heritage cloud masking specific to aerosol retrievals
CESDR-relevant EOS Standard Product w/out Associated JPSS L1 Requirement				
Cloud-top properties (p_c, T_c), cloud phase and ice cloud properties	AIRS standard products	Accuracy/ continuity	No JPSS CrIS cloud algorithms	Develop CrIS cloud algorithms for improved low spatial resolution p_c, T_c and ice cloud properties via IR observations.
Aerosol Deep Blue (bright surfaces)	MODIS (MOD04)	Accuracy/ continuity	N/A	Develop Deep Blue algorithm to expand land surfaces for which retrieval can be made.
Aerosol Index, smoke, ash, dust detection	OMI, TOMS	Accuracy/ continuity	N/A	Develop OMI aerosol algorithms to complement existing VIIRS EDRs.

Table 4.4. Summary assessment of current status of JPSS **Atmosphere Sounding and Trace Gases** Environmental Data Record (EDR) algorithms and related products relative to the heritage NASA data records. EDRs considered Essential Climate Variables (ECVs) by GCOS are designated by bold-face. ECVs are not broken down by specific type of information (e.g., column vs. profile) so all occurrences are highlighted below.

Clear Sky Atmospheric L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPS/S Plan	**Potential Improvements**
Cloud Cleared IR Radiances	AIRS/ AMSU	Accuracy/ continuity	*Intermediate Product (IP)* only: Not retained or supported by NOAA.	Add MW products and retain as EDR.
		QA/filtering/ sampling	More extensive cloud clearing with AIRS algorithm.	Improve cloud clearing sampling, yield and accuracy
Temperature Profile	AIRS/ AMSU	Accuracy/ continuity	Reduced accuracy requirements in cloudy areas	Improvements required post-launch
		QA/filtering/ sampling	– as for *Cld. Cleared* –	
Water Vapor Profile	AIRS/ AMSU	Accuracy/ continuity	Reduced accuracy requirements in cloudy areas	Improvements required post-launch
		QA/filtering/ sampling	– as for *Cld. Cleared* –	
O$_3$ Profile (tropopause/stratosphere) & Total Column	AIRS standard product	Accuracy/ continuity	*Intermediate Product (IP)*	Improvements required post-launch. Retain as EDR.
O$_3$ total column (TC), nadir profiles (NP)	OMI, TOMS, SBUV	Accuracy/ continuity	TC algorithm similar to NASA V8 algorithm, but IDPS implementation has degraded performance. NP algorithm based on NASA V6 SBUV/2 algorithm while current standard retrievals is V8, making continuity of datasets problematic.	The ozone PEATE has adapted NASA's V8 TC retrieval for use with OMPS data. Similarly, ozone PEATE has adapted the V8 SBUV/2 algorithm for use with OMPS NP.
		QA/filtering/ sampling		
O$_3$ limb profiles	MLS standard product	Accuracy continuity	Development of OMPS limb profile retrieval algorithm currently being done by NASA; product not yet fully validated or considered operational	NASA funding effort needed to validate and improve the algorithm and the resulting product.
		QA/filtering/ sampling	Spatial coverage as good or better than MLS	

Clear Sky Atmospheric L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPS/S Plan	Potential Improvements
CESDR-relevant EOS Standard Product w/out Associated JPSS L1 Requirement				
Total Precipitable Water	AIRS/ AMSU	Accuracy/ continuity	N/A	Easily generated from profile product
CO	AIRS, TES	Accuracy/ continuity	N/A	Requires downlink of full interferogram and modifications to algorithm
CO_2	AIRS, TES	Accuracy/ continuity	N/A	Product possible but w/reduced accuracy
CH_4	AIRS, TES	Accuracy/ continuity	N/A	Requires downlink of full interferogram and modifications to algorithm
SO_2	OMI standard products	Accuracy/ continuity	N/A	NASA's algorithms for SO_2 can be adapted for use with OMPS data; the NPP science team is currently funding this effort.
NO_2	OMI standard products	Accuracy/ continuity	N/A	NASA's algorithms for NO_2 could be adapted for use with OMPS data. NASA algorithms need to be optimized for OMPS spectral range and reduced spectral resolution. The OMPS spectral range 340 nm-380 nm will increase the sensitivity to the *a-priori* profile. The larger (8x) OMPS footprint will decrease sensitivity.
NH_3, HDO/H_2O ratio	TES	Accuracy/ continuity	N/A	Product possible but w/reduced accuracy
Potentially Important EOS Research Products Worth Further Study				
Tropospheric O_3 profiles	TES	Accuracy/ continuity	N/A	Possible to obtain using combination of CrIS 9.6 μm and OMPS UV. TES/OMI algorithm prototyped, demonstrated, and has been initially validated with sondes.
Cloud Optical Centroid Pressure (OCP)	OMI	Accuracy/ continuity	N/A	Algorithm to determine cloud OCP is straightforwardly adapted for use with OMPS data; the NPP science team is currently funding this effort.

Table 4.5. Summary assessment of current status of JPSS **Radiation Budget** Environmental Data Record (EDR) algorithms relative to the heritage NASA data records. EDRs considered Essential Climate Variables (ECVs) by GCOS are designated by bold-face. ECVs are not broken down by specific type of information or retrieval approach, so all occurrences are highlighted below.

Rad Budget L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPSS Plan	**Potential Improvements**
TOA, atmo, surface fluxes (*NPP/FM5*)	CERES	Accuracy/continuity	As for EOS, CERES LaRC team has responsibility for instrument and all products.	
		QA/filtering/sampling		
TOA, atmo, surface fluxes (*JPSS-1/FM6*)	CERES	Accuracy/continuity	No post-launch SDR involvement at this time. Current NOAA approach is to produce their own Level-2/-3 products using to-be-determined portions of the existing EOS-era code developed by the CERES LaRC team.	Retain LaRC CERES expertise for maintaining FM6 Level-1 through Level-3 data products, otherwise considerable risk to the continuity of CERES ERB CDRs into the JPSS era.
		QA/filtering/sampling	N/A	
Solar irradiance, Total and Spectral	SORCE	Accuracy/continuity	See TSIS SDRs	See TSIS SDRs
CESDR-relevant EOS Standard Product w/out Associated JPSS L1 Requirement				
OLR (from hyperspectral retrievals)	AIRS standard product	Accuracy/continuity	N/A	Use of AIRS heritage algorithm

Table 4.6. Summary assessment of current status of JPSS **Ocean** Environmental Data Record (EDR) algorithms and related products relative to the heritage NASA data records. EDRs considered Essential Climate Variables (ECVs) by GCOS are designated by bold-face. ECVs are not broken down by specific type of information or retrieval approach, so all occurrences are highlighted below.

Ocean L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPSS Plan	**Potential Improvements**
Chl-a (ECV is "ocean color")	SeaWiFS, MODIS	Accuracy/continuity	Out-of-date: improvements incorporated into atmospheric correction and bio-optical algorithms over the past decade not captured in current VIIRS algorithms.	Need updated algorithms that allow for consistent processing across Sea-WiFS, MODIS, and VIIRS.
		QA/filtering/sampling	Uses VIIRS Cloud Mask (VCM), not optimized for ocean products. Will impact product continuity.	Develop additional cloud masking specific to ocean retrievals
SST (window IR)	MODIS	Accuracy/ continuity	Product likely to be comparable to MODIS.	
		QA/filtering/sampling	–as for *Chl-a* –	–as for *Chl-a* –

Ocean L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPSS Plan	Potential Improvements
SST4 (midwave IR, nighttime)	MODIS	Accuracy/continuity	Concern about extending the more accurate MODIS SST4 time series (relative to SST-IR) due to differences in VIIRS mid-IR channel location and bandpass.	Needs further study
		QA/filtering/sampling	–as for *Chl-a* –	–as for *Chl-a* –
SST (µwave)	AMSR-E	Accuracy/ continuity	No instrument issues. However, no plan to continue NASA-legacy L2A+ data product continuity with GCOM-W1/AMSR2 obs.	Access to ASMR-2 L1A data or equivalent
		QA/filtering/sampling		
Sea surface wind speed		Accuracy/continuity	No instrument issues. However, no plan to continue NASA-legacy L2A+ data product continuity with GCOM-W/AMSR2 obs.	Access to ASMR-2 L1A data or equivalent
		QA/filtering/sampling		
CESDR-relevant EOS Standard Product w/out Associated JPSS L1 Requirement				
Chl-a fluorescence		Accuracy/continuity	Not possible w/VIIRS (see **Table 4.1**)	No remediation possible
SST (hyperspectral)	AIRS standard product	Accuracy/continuity	N/A	Use of AIRS heritage algorithm

Table 4.7. Summary assessment of current status of JPSS **Cryospheric** Environmental Data Record (EDR) algorithms relative to the heritage NASA data records. EDRs considered Essential Climate Variables (ECVs) by GCOS are designated by bold-face.

Cryo L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPSS Plan	**Potential Improvements**
Snow Cover	MODIS (MOD10)	Accuracy/continuity	Similar algorithm as MODIS (NDSI) but substitutes red channel for green. Product includes snow cover binary and fraction from 2x2 spatial aggregation of 375m bi-nary map. Recent evaluation shows substantial over-estimation of snow cover, likely due to VCM; new VCM improvements expected to reduce bias.	Change binary snow cover map to a thematic map, similar to MODIS snow map.\n\nUse a MODIS like fractional snow cover algorithm.\n\nDevelop high-resolution gridded product.
		QA/filtering/sampling	Uses VIIRS Cloud Mask (VCM). MODIS product uses similar MOD35 cloud mask. Differences will need to be evaluated (see above).	Use individual tests from VCM. Output a general QA flag as byte in addition to QA bits.
Snow Cover/ Depth over ice	AMSR-E (AE_SI12) QA/filtering/ sampling	Accuracy/continuity	Team is uncertain as to JAXA or NOAA intentions.	NASA AMSR-E algorithm can be used (product is over sea ice only).
		QA/filtering/sampling	Not known at this time, but not expected to be an issue.	Can be made equivalent to AMSR-E heritage if differences exit.
Snow Water Equivalent	ASMR-E (AE_Sno), and SMMR, SSM/I heritage QA/ filtering/ sampling	Accuracy/continuity	JAXA will generate AMSR2 product. Uncertain as to NOAA intentions. Algorithm details not know.	NASA AMSR-E algorithm can be used (product is over land only).
		QA/filtering/sampling	Not known at this time, but not expected to be an issue.	Can be made equivalent to AMSR-E heritage if differences exit.
Sea Ice Charac-teriz-ation: ice concentration	AMSR-E (AE_SI) QA/filtering/ sampling	Accuracy/ continuity	JAXA AMSR2 product uti-lizes the Bootstrap algorithm for the standard product (cf. A.4). Uncertain as to NOAA intentions.	NASA standard product is NT2 (cf. A.4)
		QA/filtering/sampling	Not known at this time, but not expected to be an issue.	NASA AMSR-E algorithm can be used (product is over land only).
Sea Ice Charac-teriz-ation: age	*None*	Accuracy/ continuity	No heritage from previous programs	No heritage from previous programs

Cryo L2 EDRs	EOS/ heritage	JPSS (relative to heritage)	Notes	
			NPP/JPSS Plan	**Potential Improvements**
Sea Ice Surface Temperature	*None*	Accuracy/ continuity	VIIRS algorithm. "Sea ice" is considered ice plus overlying-snow. Availability of validation datasets for algorithm development a fundamental limitation on accuracy.	No heritage
		QA/filtering/sampling	N/A w.r.t. heritage	N/A
CESDR-relevant EOS Standard Product w/out Associated JPSS L1 Requirement				
Greenland Ice Surface Temperature	MODIS	Accuracy/continuity	N/A	The MODIS IST algorithm can be adapted for use with VIIRS.
Snow Cover Albedo (Terrestrial Albedo ECV interpreted as inclusive of snow)	MODIS (MOD43)	Accuracy/continuity	N/A	Adapt MODIS algorithm. See notes in Surface Spectral Albedo (MOD43) in **Table 4.2**.

APPENDIX A: CURRENT STATUS OF THE JPSS VS. NASA DATA RECORDS

This appendix provides an overview assessment of pixel-level JPSS Environmental Data Records (EDRs) vs. equivalent NASA Level-2 (L2) data products. We limit the discussion to the role of the instrument and EDR algorithms as we currently understand them. We also mention existing NASA L2 standard products that have a direct use in climate studies but are not part of the JPSS L1 requirement set. The intention is to provide the current snapshot of the situation as it currently is. A high-level summary of the products considered in this appendix is given in the tables of _Section 4_.

A.1 _Atmospheric Data Records_

A.1.1 _Aerosol data records (MODIS)_

EOS

It is recognized by the scientific community that aerosols have direct and indirect roles in Earth's radiative energy budget and that aerosol perturbations have a likely impact on the hydrological cycle. However, accurate estimates of long-term aerosol trends cannot be achieved without high fidelity long-term aerosol climate data records, which in turn rely on high quality sensor calibration, validation and algorithm continuity.

Legacy sensors providing long-term data records of aerosol properties include AVHRR and TOMS. Although these records span three decades, limited sensor channels or large spatial resolution limit the quantitative value of their aerosol products. AVHRR does not retrieve operationally over land, and the TOMS product is an aerosol index, not a quantitative aerosol optical depth. In addition, these sensors have been flown aboard a series of platforms with

drifting equator crossing times, so the aliasing of diurnal sampling into the aerosol data record from these instruments makes it extremely difficult to eliminate artificial from actual trends. In contrast, with adequate spectral/spatial capability and orbit control, the SeaWiFS and MODIS measurements have provided an important first step towards obtaining a critically needed global aerosol climate data record, including both land and ocean for more than a decade.

Overview of MODIS Aerosol Products

The current version (Collection 5.1) of MODIS aerosol products for Terra and Aqua include the Dark Target algorithm that provides _aerosol optical thickness_ over land and ocean, as well as particle size information over ocean (i.e., _fine mode fraction_ or _Ångström exponent_). In addition, aerosol absorption properties such as _single scattering albedo_ values for dust particles are now provided by the Deep Blue algorithm that was added into the MODIS processing stream during this collection. There are in fact five separate MODIS aerosol algorithms used in processing (see **Table A1**). The first three entries in the table are publicly available products. The last two are atmospheric correction algorithms that derive aerosol properties, but do not provide an archived product.

All aerosol algorithms in **Table A1**, including the atmospheric correction algorithms, have undergone significant evaluations and validation using airborne and surface-based "ground truth" provided by AERONET and other sources. Although individual algorithm groups have conducted various independent assessments on the MODIS aerosol products using the ground based AERONET measurements, an international project called "AEROCOM"

Table A1. Five MODIS aerosol algorithms and their related products.

MODIS algorithm	Geophysical products	MODIS L2 product name	References
Dark Target aerosol over ocean	AOT, fine fraction	MOD04, MYD04	Tanré et al. (1997)
Dark Target aerosol over land	AOT	MOD04, MYD04	Kaufman et al. (1997); Levy et al. (2007a, b)
Deep Blue aerosol over land	AOT, ω_o	MOD04, MYD04	Hsu et al. (2004, 2006)
Ocean atmospheric correction	Water leaving radiances	MOD18, MYD18	Gordon and Wang (1994)
Land atmospheric correction	Surface reflectance	MOD09, MYD09	Vermote et al. (1997); Vermote and Kotchenova (2008)

AOT is aerosol optical thickness
ω_o _is aerosol single scattering albedo_

Table A2. VIIRS and MODIS spectral configuration and aerosol algorithm use of channels. "Fine" refers to the VIIRS higher spatial resolution channels.

VIIRS band (µm)	VIIRS aerosol algorithm	MODIS band (µm)	MODIS aerosol algorithm	Other MODIS purpose
0.412	Land	0.411	Deep Blue	Ocean color
0.445	Land	0.442		Ocean color
		0.466	Dark Target land	
0.488	Land	0.487	Deep Blue	Ocean color
		0.530		Ocean color
		0.547		Ocean color
0.555	Ocean	0.554	Dark Target ocean	
0.640 (fine)	Alternative for Land and Ocean	0.666		Ocean color
0.672	Land and Ocean	0.646	Deep Blue and Dark Target land and ocean	NDVI+
		0.677		Ocean color
0.746		0.746		Ocean color
0.865 (fine)	Alternative Ocean	0.866		Ocean color
0.865	Ocean	0.857	Dark Target ocean	NDVI+
0.7				
		0.904		Water vapor
		0.936		Water vapor
		0.935		Water vapor
1.24	Ocean and Snow/ Sediment/Cirrus mask	1.242	Dark Target ocean and snow sediment/cirrus mask	
1.378	Cirrus mask land and ocean	1.383	cirrus mask land and ocean	
1.61 (fine)	Alternative for Ocean			
1.61	Ocean	1.629	Dark Target ocean	
2.25	Land and Ocean	2.114	Dark Target land and ocean	

has been making significant contributions to systematically evaluate the performance of the publicly available aerosol products derived from all relevant sensors including MODIS, SeaWiFS, MISR, OMI, AASTR, and POLDER. All products are associated with well-understood and verifiable uncertainties.

NPP/JPSS

There are several obstacles to creating a merged aerosol climate data record from MODIS and NPP VIIRS including:

- sensor differences
- algorithm differences
- cloud mask differences (used to screen clear sky pixels used in aerosol retrievals)
- calibration/characterization differences

Sensor differences

VIIRS was designed to have similar visible and NIR/SWIR channels with MODIS and thus is nominally suitable to provide measurement continuity for the current aerosol time series. **Table A2** summarizes the VIIRS and MODIS channel configuration for aerosols.

VIIRS is missing the 0.47 µm channel used for retrieving Dark Target (DT) aerosol properties over land. Although,

0.49 μm can be substituted, because surface reflectances increase sharply from 0.47 μm to 0.49 μm over most of the land types (particularly deserts), the surface reflectance databases as well as the reflectance relationship between 2.1 μm and 0.47 μm surface applied to MODIS DT algorithm are not valid for VIIRS. This problem is exacerbated by moving the 2.13 μm channel to 2.25 μm. Therefore, direct porting of the MODIS aerosol algorithm to the VIIRS instrument without the involvements of algorithm expertise will not produce the high quality of aerosol products that are comparable to MODIS to continue the time series.

Algorithm differences

The JPSS VIIRS algorithms are based on the MODIS Dark Target Ocean and the Land Atmospheric Correction algorithms. **Therefore, at the onset, continuity will be difficult to establish because the JPSS VIIRS algorithm will NOT be producing an aerosol product over land that has a publicly available predecessor.** The JPSS VIIRS land algorithm is NOT based on either Dark Target or Deep Blue. In **Table A2** we see that the JPSS VIIRS algorithm will make use of the same six comparable channels used by Dark Target Ocean, but uses five channels over land, which are different than the three used by Dark Target Land or the three used by Deep Blue.

The current state of operational EDR's for meeting NASA science needs was presented at the IGARSS meeting in July 2011 (*Hsu et al*., 2011). The bottom line is that the algorithms are out-of-date. By not including a Deep Blue-based algorithm, there will be large data gaps over desert and semi-desert regions in the VIIRS products. Furthermore, many improvements have been developed and incorporated into the current Collection 5.1 and upcoming collection 6 MODIS surface reflectance determination and aerosol retrieval algorithms, and this new knowledge is not captured in the current operational VIIRS aerosol EDR algorithms.

Cloud mask differences

The single most likely impediment to product continuity will be the cloud mask, or the selection of pixels that are deemed appropriate for aerosol retrievals. Currently, all five MODIS aerosol algorithms each use a different cloud mask. There is no one-size-fits-all (see also Section 3.1.1 **with regard to other products).** The cloud mask is an inherent part of the aerosol retrieval, controlled by the aerosol algorithm developers to compensate for the assumptions inherent in their algorithms. *Kahn et al.* (2009) report that both the MODIS and MISR aerosol algorithms select only ~15% of

all possible scenes to attempt an aerosol retrieval, and yet the selections are different in that only ~7% of all possible scenes result in a collocated retrieval. With JPSS VIIRS there will be one universal cloud mask (the VCM or VIIRS Cloud Mask) developed by an independent team that is separate from the aerosol algorithm team. The VCM will not resemble the internal cloud masks used by the MODIS algorithms that JPSS VIIRS is imitating. This will certainly cause discontinuity in the aerosol CESDRs.

Calibration/Characterization differences

A number of potential issues with radiometric performance (e.g., optical cross-talk and gain transition anomaly) have been identified (*Hsu et al.*, MODIS/NPP joint Science Team Meeting, January 2010), but no major impacts are expected. This does not rule out potential discontinuities due to calibration/characterization differences.

A Way Forward

To summarize the previous discussion, continuity of MODIS aerosol products into the VIIRS era within the current environment is challenging due to:

- an over land algorithm based on a MODIS atmospheric correction product that does not currently produce a publicly available aerosol data set;

- no Deep Blue algorithm that extends retrievals over deserts and bright surfaces;

- a one-size-fits-all cloud mask that does not resemble any of the cloud masks used by the current algorithms that the JPSS VIIRS algorithms are imitating;

- the lack of a 0.47 μm channel that is key to the over land retrievals, the shifting of the 2.1 μm channel to 2.25 μm, and other small spectral shifts;

- no structure linking aerosol algorithm development teams with instrument characterization teams to facilitate maintaining long-term consistency in instrument calibration.

The way forward requires systematic comparison of the JPSS VIIRS aerosol product with MODIS products. Some of this is being done before launch by applying the JPSS VIIRS aerosol algorithm to sanitized MODIS radiance inputs (i.e., a data set that has already been cloud-cleared and corrected for gaseous absorption). This test eliminates all issues connected with pixel selection and cloud mask. Even this highly controlled test results in unexplained differences between algorithms (see example figures at *www.star.nesdis.noaa.gov/smcd/emb/aerosols/ research_NPP_NPOESS_VIIRS.php*). There are notable

differences over both land and ocean. VIIRS AOT over the Atlantic is higher than in MODIS, while in the center of the African biomass burning over the continent it is lower. These differences arise despite having exactly the same input reflectances on the same grid. In a similar manner, the impact of the VIIRS cloud mask needs to be investigated. To complete the circle, the standard MODIS algorithm should be run on VIIRS radiances, using the VIIRS cloud mask. From these tests the differences between the resulting aerosol products from MODIS and VIIRS should be able to be quantified and causes identified.

The NPP Science Team and members of the JPSS team, including the PEATE and NOAA STAR, are already working towards this direction. However, the end goal of the NPP Science Team study is a quantification of the differences and identification of the cause of those differences without expending any effort to "fix" the problem or draw the two aerosol data streams and time series closer together.

To create a consistent climate data record, an aerosol development team will need to continually adjust and maintain the algorithm. On-going validation against ground-truth such as AERONET is essential to identify artificial trends introduced from sensor calibration drift. From the MODIS experience we know that adjustments are generally not minor, but require major overhauls of algorithms, introduction of new important products such as Deep Blue, development of internal cloud masks, and strong interaction with instrument characterization teams.

Like other Earth observation measurements, aerosol loadings and properties are subject to large seasonal and inter-annual variability. As a result, teasing out long-term trends among these short-term fluctuations is a challenging task, thus making the continuation of EOS aerosol climate data record into the VIIRS era critical for establishing sufficient data record length to undertake global climate change studies. A lesson-learned is that construction of multi-instrument CESDRs requires consistent aerosol algorithms across the missions, in addition to an integrated team consisting of algorithm expertise and calibration groups to iterate efficiently on data reprocessing. **Figure A1** shows an example of this successful team structure. As a result of data reprocessing and collaborative efforts between the MODIS calibration and aerosol teams to account for Terra MODIS sensor radiometric degradation, the Terra MODIS Deep Blue aerosol time series now has comparable trends to those from MISR

(*Jeong et al.*, 2011). A similar example from Terra for both the MODIS Dark Target aerosol and cloud optical property products is given by *Levy et al.* (2011).

These examples demonstrate that multiple data reprocessing efforts by an integrated team are required to establish product accuracy and stability. Such highly collaborative team structure for periodic data reanalysis and reprocessing is currently beyond the scope of JPSS mission, but critical to the extension of aerosol climate data records into the VIIRS era.
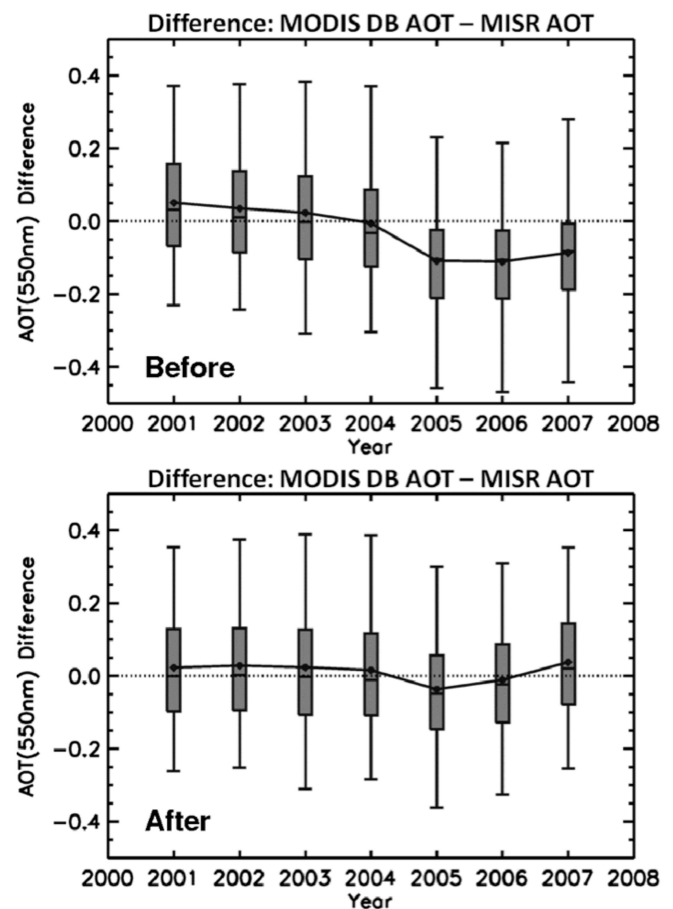
Fig. A1. The impact of improved MODIS radiometric calibrations on MODIS Deep Blue (DB) aerosol trend estimates against those from MISR. This figure shows that there were strong temporal trends occurred in AOT differences (MODIS DB AOT – MISR AOT) between Terra/MODIS and MISR over North Africa using the previous MODIS calibration (top panel), which disappear in the new time series after applying the re-calibrated reflectances (bottom panel).

A.1.2 *Cloud data records (MODIS, AIRS, AMSR-E)*

MODIS Cloud Products

EOS

The MODIS imager provided a major step forward in spectral, spatial, and radiometric capability relative to the polar orbiting AVHRR observations that began in 1978. The AVHRR cloud observations are an important climate resource due to the 3+ decade record length, e.g., NOAA's PATMOS-x product [*Heidinger et al*., *cimss.ssec.wisc.edu/patmosx*] and the International Satellite Cloud Climatology Project (ISCCP). While an 11-year record is available from MODIS Terra, and a 9-year record from Aqua, these data records are of insufficient length to establish statistically significant cloud trends of the expected level or to separate trends from natural interannual climate oscillations, especially on the regional level; the record is also too short to understand the significance of cloud property correlations to interannual climate variability (*Platnick et al.*, MODIS Science Team Meeting, 2011, *click here for presentation*).

As with many climate records, natural variability results in cloud trend detection being a multi-decadal endeavor. The length of the MODIS cloud record is only now becoming meaningful. The loss of imager cloud data continuity, to the extent that it can be maintained into the VIIRS era, would be a major setback for NASA climate observations and studies. **Unfortunately, the lack of important spectral channels on VIIRS makes direct continuity problematic for some of the MODIS cloud products (discussed below), advocating for a concerted algorithm development effort to achieve the maximum possible level of continuity possible for NASA science needs.**

Overview of MODIS Cloud Products

The MODIS Terra and Aqua cloud products include cloudy FOV detection/masking and cloud product that includes both cloud-top (temperature, pressure, effective emissivity) and optical/microphysical properties (thermodynamic phase, optical thickness, effective particle radius, water path, multilayer detection and other QA) datasets. The only JPSS EDR not included in the MODIS standard product suite is cloud base height (see **Fig. 1**). MODIS processing streams based on a consistent set of algorithms are referred to as data "collections". The implementation and evaluation of code refinements for Collection 6 reprocessing is ongoing, with production nominally expected to begin in early 2012.

An assessment of the MODIS cloud products has been undertaken by a number of investigators including the MODIS algorithm team. The team has also participated in the continuing GEWEX cloud assessment study [e.g., *Stubenrauch and Kinne*, 2009; *Stubenrauch et al.*, 2011]. While such assessments will continue, the uncertainties and/or issues for most of these products are understood and have been documented. An assessment of cloud retrieval accuracies from a MODIS-like imager is given in Appendix 2 of the ACE Cloud Science White Paper [*Mace et al.*, 2010]. Instrument stability, consistent (re-processed) algorithms and ancillary data are recognized as key to establishing a climate quality data set.

NPP/JPSS

Instrument Data Continuity

VIIRS lacks several key spectral channels compared to MODIS (namely, the 6.7, 7.3 μm water vapor channels and 13.3-14.2 μm CO_2 bands used for high cloud properties), and a significant change in the spectral location for the key shortwave infrared band (from 2.13 μm to 2.25 μm) used for retrieving cloud effective particle radius that results in a reversal in the relative absorption between liquid water and ice phase particles. In addition, a near-infrared water vapor band (0.94 μm) used for multilayer cloud detection and optical retrieval quality flagging is not available on VIIRS. Direct comparison with many MODIS products is therefore futile, e.g., the cloud-top information content of MODIS observations will be superior to VIIRS [*Heidinger et al.*, 2010]. With respect to the 2.2 μm window channel location, the shift towards longer wavelengths is not necessarily without merit for phase detection, but meaningful comparisons with MODIS are unlikely [*Zhang and Platnick*, 2011]. For the same reasons, direct porting of the MODIS cloud algorithms to the VIIRS instrument is not possible to achieve EDR continuity.

JPSS Algorithms

The current state of the operational EDR's for meeting NASA science needs was previously provided to HQ in a white paper [*Baum et al.*, 2010]. A summary is given below.

Only two orbits of MODIS proxy data retrievals were made available by the end of 2009. The team (consisting of university, NASA, and NOAA personnel) was therefore unable to provide an in-depth assessment. However, large differences were noted, though little can be said about the role of LUTs vs. other algorithm components/approaches. Based on the limited comparisons with MODIS, it was concluded: **"From our preliminary assessment of the**

two orbits of data that have recently been made available from the mini-IDPS at NASA GSFC, there is increasing evidence to suggest that except for the cloud mask and cloud typing product, the other cloud products (specifically, cloud top height/temperature/pressure, optical thickness, and effective particle size) will have deficiencies that will preclude them being acceptable for EOS continuity."

A later briefing by NGAS personnel in 2010 discussed a major change in the algorithm wherein NGAS discussed implementing a radiative transfer model to calculate clear-sky radiances, and also expressed their intention to re-work their treatment of water/ice clouds (resulting in the development of new LUTs). The status of this update and its details are unknown at the time of this writing.

A Way Forward

Continuity of MODIS cloud products into the VIIRS era within the current environment is challenging due to missing spectral channels and/or spatial resolution. From knowledge of the JPSS algorithm, it is unlikely that these products will be of much use to the Research and Analysis programs; it is extremely unlikely that the products can be used to extend MODIS observation for climate record studies.

A first approach is to develop a less capable MODIS algorithm that can run on the subset of spectral channels/resolutions available to both instruments. **This latter approach of bridging MODIS heritage data records is a "lowest common denominator approach" in the sense that a common algorithm is developed for the instrument having the more limited measurement capability (VIIRS in this case).** This will provide algorithms that are designed to run on both VIIRS and MODIS measurements. With a consistent algorithm running on VIIRS and MODIS Aqua (for example), the resulting products can be used to generate a consistent 1330 LT data record that bridges the two instrument time periods. An IR-based cloud top property approach that used only the available VIIRS channels has been developed as part of GOES-R ABI studies, and its skill vs. MODIS has been evaluated against CALIOP [*Heidinger et al.*, 2010].

A follow-on approach is to reduce the differences caused by the absence of VIIRS CO_2 slicing channels by combining VIIRS and CrIS measurements. Based on the MODIS team's experience, it is believed that the CrIS high cloud-top pressure record will be superior to that generated by an imager as will it's ability to detect thin cirrus. However, for cirrus microphysics the imager resolution becomes important because of heterogeneity in optical thickness and

particle size (including vertical structure). This argues for a merged VIIRS/CrIS approach (CrIS resolution ~15km). Work has progressed on combining high spatial and spectral radiance measurements for improved cloud-top property retrievals with what is called a "merging gradients" [*Weisz et al.*, 2011].

Both of these approaches are beyond the scope of the current JPSS structure as well as the current science team. While both approaches were part of two awarded NPP ROSES 2010 proposals, the proposals had to be clear that a development of algorithms in this manner was the only meaningful way to make an apple-to-apple evaluation of the operational algorithms without aliasing in instrument differences. Still, in one instance, the panel expressed concern that such an effort "is not entirely consistent with the NRA's focus on evaluation and improvement of the existing operational VIIRS retrieval algorithms".

Data Processing Capabilities: These are discussed in more detail in *Section 3.3*. However, we note that the necessary processing infrastructure to support a cloud team has been developed at UW/SSEC PEATE, though further infrastructure support would be necessary to expand the scope of that facility for the role described above. The MODIS team is currently working to develop and deliver software for the upcoming Collection 6 reprocessing effort, so the organizational experience in working with MODIS-like algorithms is already in place.

AIRS Cloud Products

EOS

With over 2300 spectral channels and state of the art on-board calibration, the AIRS IR grating spectrometer has significantly improved sounding capability over previous generation sensors (e.g., HIRS). In addition, hyperspectral IR observations provide important cloud information. The AIRS standard cloud products include cloud-top temperature, pressure, and effective emissivity and have been validated against independent observations from CloudSat and CALIPSO [*Kahn et al*., 2008]. In the Version 5 algorithm, up to two cloud layers are inferred from fitting observed AIRS radiances to calculations. Cloud-top pressure and temperature are reported at the AMSU resolution (~40 km at nadir), whereas effective emissivity is reported at the native AIRS resolution (13.5 km). Spatially matched IR-derived cloud products from AIRS and MODIS have been shown to be radiatively consistent to each other [*Nasiri et al.*, 2011]. Differences in the individual cloud fields (cloud top pressure and effective emissivity) are primarily due to compensating errors induced by algorithm and instrument

differences. More research is required to determine if the instrument and algorithm differences between AIRS and MODIS will lead to fundamentally different cloud trends, even for the same geophysical parameter.

The AIRS team's most recent algorithm release and reprocessing effort is Version 5 (V5). however, the V6 algorithm development is progressing (currently scheduled release in late 2011) with some potentially important changes and additions to the suite of cloud products. Given the obvious need for higher spatial resolution cloud fields, the AIRS Team is considering reporting the cloud top temperature and pressure fields at the native AIRS resolution. Furthermore, three new cloud fields will be added to the Level 2 (L2) Support product: (1) ice cloud optical thickness, (2) ice cloud effective diameter, and (3) cloud-top thermodynamic phase. The new cloud fields are obtained using Standard L2 fields from the cloud-clearing retrieval [*Susskind et al.,* 2003] to calculate clear-sky radiances. Error estimates and scalar averaging kernels are reported for the retrieved cloud parameters.

Ongoing comparisons and validation of AIRS cloud fields with other A-train sensors is necessary, and similarities and differences must be better understood for any interpretation of observed climate variability and trends. Similarly, development towards multi-sensor cloud products (e.g., AIRS, MODIS, CloudSat and CALIPSO) would yield important insights on single-sensor obtained cloud fields (e.g., from AIRS alone) as individual constraints and observational fields can be arbitrarily added and/or subtracted to demonstrate its importance on single cloud parameter estimation.

NPP/JPSS

There are no CrIS EDR cloud products as part of the JPSS Level-1 requirements (see **Fig. 1**). This, despite as mentioned above, the understanding that the CrIS high cloud-top pressure record will be far superior to the VIIRS imager as will it's ability to detect thin cirrus which also provides useful information for other products.

Instrument Data Continuity

While there are unlikely to be fundamental CrIS instrument differences that preclude the direct implementation of the existing AIRS cloud product algorithms, cloud product continuity also requires continuity of the cloud-clearing approach from AIRS/AMSU to CrIMSS (CrIS and ATMS). The viability of this continuity is discussed in *Section A.1.2*. Continuity with new AIRS V6 cloud products is less certain. Further study is needed. Once again,

we argue for a merged VIIRS/CrIS approach to obtain the best possible cloud-top data record from the NPP/JPSS system. This would include a CrIS-only data record as continuity for AIRS.

AMSR-E Liquid Cloud Water Path over the Ocean

EOS

Being a JAXA instrument, a separate EOS AMSR-E U.S. team was funded to provide a suite of products, separate from JAXA product development, that are archived at NSIDC.

Liquid water path (LWP) retrievals are part of the AMSR-E ocean product suite. It is derived from the signal that remains after retrieval of other ocean products (SST, near surface wind speed, and vertically integrated water vapor). The AMSR-E conical scanning heritage algorithm comes from the SSM/I [*Wentz*, 1997] and TRMM TMI instruments. AMSR-E has 5-60 km spatial resolution (depending on frequency) with a 1.6 m antenna. RMS accuracy is expected to be about the 0.025 mm or 25 g-m^2 [*Wentz*, 1997] for homogeneous scenes (note: a homogeneous cloud with optical thickness 10 and effective radius 10 μm gives LWP=67 g-m^2). However, as cloud fraction decreases within the microwave FOV, the retrievals have been found to overestimate higher resolution optical retrievals [*Horváth and Gentemann*, 2007].

JPSS

GCOM-W1 will fly AMSR2 in the A-Train constellation. This newer instrument will have higher spatial resolution (2m antenna) than AMSR-E and an additional low frequency channel for RFI mitigation. Launch is scheduled for no earlier than February 2012. According to the draft JPSS Level-1 requirements supplement ("JPSS L1RD Supplement v1.4.2_post_Mgmt_Red"), all GCOM data (AMSR2 and AMSR3, DFS and SGLI) are considered JPSS "Category 3" Environmental Data Records (EDRs). NOAA has an agreement in place to receive from JAXA AMSR2 raw data records (RDRs) from which a suite of microwave imager products will be produced for operational requirement purposes only. The algorithms/methodologies with which L1B and higher order products will be generated by NOAA are not clear to us at this time, though we understand them to be legacy SSM/I, SSMIS algorithms.

Producing climate records from microwave imagery requires extensive radiometric analysis to produce stable brightness temperature calibrations across multiple instruments. In the EOS approach, AMSR-E L1A data

(containing separate counts and calibration coefficients) were made available by JAXA to the U.S. science team who created their own L2A product (similar to L1B but with additional information). Early JAXA versions (2005) had brightness temperatures approximately 1K warmer than the U.S. team's calibrated brightness temperatures, though this difference was not constant (e.g., scan-to-scan and scan position variations, non-linear differences at high brightness temperature). The U.S. team's L2A data were used in all NASA geophysical retrieval products that are archived at NSIDC. More recently, the JAXA AMSR-E team has worked on higher-level radiometric characterization including the use of non-linear corrections (e.g., _www.eorc.jaxa.jp/en/hatoyama/amsr-e/amsr-e_format_l1_e.pdf_). While AMSR-E U.S. investigators have proposed for membership on the Japanese science team, there is no independent means for continuity of AMSR-E team products, including access to L1A or equivalent data.

With the same frequency selection (other than an additional low frequency channel), no disruption in AMSR-E LWP measurement continuity capability is expected. However, for climate data continuity, access to ASMR-2 L1A data or equivalent information is required to evaluate/establish radiometric continuity among instruments. Regardless, no infrastructure exists to continue NASA-legacy L2A and higher data product continuity with GCOM-W observations.

A.1.3 _Atmospheric State (AIRS)_

EOS

AIRS/AMSU, the atmospheric sounder suite on Aqua, provides spectrally resolved upwelling infrared and microwave observations with twice daily coverage. This coverage was driven by the primary observing requirement for global fields of atmospheric temperature profiles from the surface to the stratosphere, and water vapor profiles from the surface to the upper troposphere. The AIRS radiance products are assimilated directly into operational forecast systems at National Weather Prediction (NWP) centers worldwide [e.g. _Le Marshall et al._ 2008] to characterize and understand specific physical processes related to the atmospheric hydrologic cycle, to generate Climate Data Records for the study of climate processes and to characterize variability at scales ranging from days to nearly a decade.

The GES DISC processes AIRS/AMSU radiances to generate products using the AIRS Science Team Version-5 (V5) retrieval algorithm [_Susskind et al._, 2010]. The AIRS V5 re-

trieval algorithm generates quality-controlled soundings of atmospheric temperature and water vapor for up to 90% fractional cloud cover. The accuracy and precision of the AIRS/AMSU temperature and water vapor retrievals are well established through validation studies [e.g., _Pu et al._, 2010; _Ferguson et al._, 2010]. They are within the nominal pre-launch specified root-mean-square uncertainties of 1K in 1km thick layers for temperature and 15% absolute in 2km layers for water vapor. The AIRS V5 products all include layer error estimates that are a critical component of the Quality Control procedure referred to above. The AIRS Science Team Version-6 retrieval algorithm is expected to produce further improved soundings using AIRS/AMSU observations under almost all cloud conditions.

A number of important products, aside from temperature and water vapor profiles, are currently being archived as Level-2 and Level-3 products using AIRS/AMSU observations and have the potential for constituting a CESDR: land and ocean surface skin temperature and surface spectral emissivity; stratosphere and troposphere ozone burden; mid-tropospheric CO, CH_4 and CO_2; spectrally resolved Outgoing Longwave Radiation (OLR), and clear sky OLR. The AIRS/AMSU retrieval algorithm also generates cloud properties including cloud-top temperature and cloud fraction. Version 6 processing will enable more advanced cloud products (see _Section A.1.2_).

NPP/JPSS

Instrument Continuity

CrIS will fly on NPP and JPSS-1 alongside the microwave ATMS sounder. Together, CrIS and ATMS make up the CrIMSS package (analogous to AIRS/AMSU). CrIS instrument performance is expected to be similar to that of AIRS but with degraded spectral resolution (roughly twice as coarse as that of AIRS), and with a higher specified radiometric noise in the shortwave portion of the spectrum (critical for obtaining accurate soundings under more cloudy conditions). Radiometric instabilities related to a noncompliant on-board calibrator on CrIS on NPP, and loss of data in certain cloud regimes as seen in IASI [_Elliott et al._, 2011] will also limit its value for climate applications and must be fully characterized and corrected where possible. ATMS is expected to have better performance than AMSU in terms of spatial resolution (35km vs 50km) and spectral resolution (more water vapor channels), though radiometric sensitivity is similar to AMSU. The CrIS and ATMS are not co-aligned and synchronized as they are for AIRS and AMSU on Aqua which impacts the accuracy of cloud clearing and combined products.

Techniques used for in-flight validation of AIRS/AMSU L1B will also be used for CrIS/ATMS SDR's to establish product accuracy and stability for climate applications. Spectral frequencies of CrIS will be calculated precisely from the preflight and inflight calibration and analysis of the upwelling Earth spectra, an essential part of the process [*Strow et al*., 2006]. Calibration of the CrIS radiances will be performed in window channels by comparison to NIST traceable ocean buoy's [*Aumann et al.*, 2004] and for the entire spectrum using simultaneous aircraft and inter-satellite observations [*Tobin et al.*, 2006]. AIRS radiances have been shown to be calibrated to 0.1-0.2K 3, depending on band, under clear uniform conditions and stable to better than 10mK/year using these methods. The JPSS Cal/Val program as currently configured is inadequate in comparison to the AIRS/AMSU efforts and it is highly recommended that NASA invest in this area.

JPSS Algorithms

JPSS will generate sounder products using the CrIMSS EDR algorithm originally designed by Atmospheric and Environmental Research (AER). The CrIMSS EDR algorithm is required to generate RMS uncertainties comparable to AIRS/AMSU, but only for clear conditions and for the lower troposphere. Less stringent lower tropospheric requirements are set for 50% fractional cloud cover, and considerably higher uncertainties under the remaining cloud conditions. At altitudes from the middle troposphere and above, the performance requirements are less stringent than for AIRS/AMSU with concomitant degradation in performance with cloud fraction.

The CrIMSS EDR algorithm only retains temperature, water vapor and pressure profiles and is not required to retain any of the other very important L2 products currently being derived from AIRS/AMSU observations. It does not retain error estimates that are critical for the potential use of CrIS retrieved profiles in a data assimilation mode to improve operational forecasting skill. The NASA Science Community Workshop on Polar Orbiting IR and MW Sounders recommends that an AIRS science team-like algorithm be used to generate data from CrIS retrievals when they become available (R 1.2.1) [Fetzer ed., 2011]. **NOAA has started this process and has modified the AIRS Science Team V5 algorithm to work with CrIS/ATMS data and plans to deliver "NOAA Unique Products" that include most of the AIRS Version 5 products. While it is a step in the right direction, it is unclear as to the level of continued support NOAA will provide for these products in terms of algorithm enhancement, validation and reprocessing, documentation and input from the scientific com-**

munity. NOAA's primary investment at this time is in the operational CrIMSS EDRs. Numerous enhancements implemented in the AIRS Version6 retrieval algorithm as well as plans for improved error characterization in Version7 are also necessary to achieve the next level of weather and climate utilization of CrIMSS and AIRS/AMSU data products. The NASA AIRS and Sounder PEATE teams have excellent relationships with NOAA and the scientific sounding community and are capable of leading in the development of a single set of CrIMSS and AIRS/AMSU algorithms and products that will provide for CESDR continuity between instrument suites.

A.1.4 *Atmospheric chemistry data records/gaps (OMI, AIRS, TES)*

OMI Data Records

The Ozone Mapping and Profiling Suite on NPP has three instruments, a total ozone mapper, a nadir backscatter ultraviolet profiler and a limb scattering profiler. OMPS will continue the total ozone data records from TOMS/OMI and the low vertical resolution profiles from the SBUV/SBUV-2 instruments. The OMPS limb instrument is intended to continue the high resolution ozone profile data records from SAGEI-SAGEII-Aura MLS .

Ozone Profile

The OMPS-Limb instrument is intended to continue the high vertical resolution ozone profile data record started by the SAGE I instrument and continued by the EOS Aura MLS instrument. The current algorithms are based on the limb scattering data from the SAGE II instrument. The ozone profile data product is a research effort funded by the NPP science team and the data products are produced and distributed by NASA research data systems. Although there are several limb scattering instruments, ENVISAT/SCIMACHY, ODIN/OSIRIS, and SAGE II, OMPS-Limb has a different design and will have its own unique features. After the ozone profile data product quality has been demonstrated, NOAA may choose to create operational data products to support the operational community. The OMPS-Limb instruments are on NPP and manifested for the JPSS-J2 mission in late 2021. Currently, OMPS-Limb is NOT manifested on the JPSS-J1 mission in late 2016.

Total Ozone

OMPS will continue the total ozone record started by Nimbus7 TOMS that continue with the EOS OMI data. Although OMPS has a larger footprint (50 km x 50 km) compared to EOS OMI (13 km x 24 km) the total ozone data

should be similar quality. The current operational algorithm is at least one version behind the current state of the art.

Other trace gases: Compared with the EOS OMI and the METOP GOME2 instruments, OMPS has a more limited spectral coverage (250nm–380 nm vs. 240nm–800 nm) and lower spectral resolution (1.0 nm vs. 0.2/0.4 nm). This has a direct effect on the quality of the trace gas retrievals. There are some NO_2 absorption lines in the OMPS spectral range they are less sensitive than the line in the 405nm and 460 nm region used by OMI and GOME2. In addition the blue shifting of the window makes the retrieval more sensitive to the *a-priori* NO_2 profile used in the retrieval. HCHO and BrO are usually retrieved in the OMPS region, but the reduced spectral resolution will make the retrieval more difficult. Both the OMI and GOME2 instruments have a break in their spectral coverage in the 310 nm region, transitioning from one detector to another. OMPS has continuous spectra in this region, which is the most sensitive region for SO_2 retrievals. For SO_2, OMPS may have an advantage over the current instruments.

AIRS Trace Gas Data Records

Though there are no JPSS CrIS L1 trace gas requirements, there is considerable value in continuing the advancement of the trace gas products from AIRS via CrIS where possible.

EOS

The AIRS Version 5 retrieval system produces global atmospheric composition products including O_3, CO, CO_2 and CH_4. With its wide swath and global daily coverage, AIRS retrievals complement those from other EOS instruments. Since the observations are acquired in the infrared they are obtained day and night and during polar winter. The observations are primarily weighted in the mid-troposphere. So while not well suited for air quality observations they are ideal for examining the global transport of greenhouse gases and validation of global circulation and chemistry in climate models. Derived from cloud-cleared products, they provide high yield, making them ideal for transport studies.

Ozone: AIRS retrieves the total column and profile of ozone in the boundary between the tropopause and the stratosphere, making the product ideal for studies of stratospheric-tropospheric exchange during severe convection events and the global transport of ozone through the Brewer-Dobson circulation. AIRS ozone data have undergone rigorous validation using aircraft data and ozonesondes [Bian et al, 2007]. More recently AIRS Ozone data have been validated

with aircraft and compare well with IASI and OMI. In particular all three capture the vertical and horizontal variability well in the UTLS [*Pitman et al*., 2009].

Carbon Monoxide: CO is currently produced from both the EOS AIRS and METOP IASI instrument. With a 1600 km cross-track swath and cloud-clearing retrieval capabilities, AIRS provides daily global CO maps over approximately 90% of the Earth. Validation studies indicate that AIRS CO retrievals are approaching the 15% accuracy target set by pre-launch simulations [*McMillan et al.*, 2005]. AIRS has become a regular source for CO data along with MOPITT, TES and SCIAMACHY and was used to estimate the global emissions of CO at approximately 1350 Tg/Year which is much higher than bottoms up estimates [*Kopacz et al.*, 2010].

The NPP CrIS will not send down spectra with sufficient resolution to retrieve a CO data product. This is a data handling, spacecraft data rate issue not a technical issue related to the CrIS instrument. The native CrIS resolution is sufficient for CO retrievals. The JPSS Program is studying the options to bring down the full resolution data from the J1 CrIS instrument.

Carbon Dioxide: The AIRS mid-tropospheric CO_2 data have proven to be of high value for observation of vertical transport and seasonal variability in the CO_2 distribution. Validation studies show AIRS retrievals to be accurate to ±1.20 ppmv when compared to aircraft observations at the same altitude [*Chahine et al.*, 2008, *Bai et al.*, 2011]. Recent analysis suggests that the influences of El Niño events and polar vortex on the CO_2 concentration are apparent in the AIRS data [*Jiang et al*., 2010].

Methane: The accuracy of AIRS CH_4 is about 1.2-1.5%, with peak sensitivity around 200 mb, which provides the capability to map seasonal variation of CH_4 and provide valuable information on the global methane distribution in the mid-upper troposphere [*Xiong et al*., 2008]. Scientists have observed a significant enhancement of methane in the mid-to-upper troposphere in the summer season associated with upwelling caused by the Asian Monsoons [*Xiong et al*., 2009]. The results obtained with AIRS data are consistent with model predictions.

NPP/JPSS

Continuity of the AIRS O_3 and CH_4 products with CrIS should be relatively straightforward, however, small differences may result due to spectral resolution and shortwave sensitivity differences. Retrieval of CO will not be possible unless the full spectral resolution of CrIS is downloaded. The second over-

arching recommendation from the NASA Science Community Workshop on Polar Orbiting IR and MW Sounders [Fetzer, Editor, 2011] recommends "The JPSS enable the full spectral resolution possible with the Flight Model 1 (FM1) CrIS on NPP as soon as possible." **The ability to retrieve mid-tropospheric CO_2 from CrIS will depend on the stability obtained from the instrument calibration.** The stated accuracy requirement of 1-2ppm corresponds to a radiometric stability of 30-50 mK. The non-compliant In-Flight Calibration Blackbody and lack of temperature control of the CrIS will make continuity of this product extremely difficult.

TES Trace Gas Data Records

TES vertical profiles of tropospheric trace gasses (O_3, CO_2, CH_4, CO, HDO, H_2O, CO, and NH_3) are critical for understanding the processes controlling atmospheric chemistry, the water, carbon, and nitrogen cycles and their interactions. **Currently, there are no new satellites with the capability to continue the record begun by TES of these critical trace gasses at the same vertical resolution. Nevertheless, CrIS will be capable of continuing some of these records with an accuracy sufficient to support climate studies and provide some measure of data continuity (details in Table 4.1).** Moreover, new Aura ozone products that combine TES and OMI IR and UV bands should be pursued with a combination of CrIS and OMPS.

A.1.5 Radiation budget (CERES, SORCE)

The Earth radiation budget (ERB) is fundamental to climate science. The balance between absorbed solar and emitted longwave radiation determines the equilibrium temperature of the Earth. Accurate observations of the Earth's radiation and the factors that influence it (e.g., solar irradiance, clouds, aerosols, surface properties, and temperature/humidity) are essential for determining the causes of climate variability and change. NASA's expertise in ERB observations is acknowledged by the IPCC (2007), the NRC Decadal Survey (2007), and the WMO's GCOS implementation plan (2004).

CERES

The EOS era:

The first CERES instrument flew on TRMM in 1997; observations continue on the Terra and Aqua satellites. The primary goal of the CERES team is to produce integrated CESDRs of the ERB from the surface to the top-of-atmosphere (TOA). The resulting CERES CESDRs account for the regional and global diurnal cycle of radiative fluxes and include coincident cloud, aerosol, surface, and meteorological properties so that changes in ERB and climate system components can be investigated in an integrated manner. This requires a high level of data fusion involving 11 instruments on 7 spacecraft. A total of 25 unique input data sources are used to produce 18 CERES data products.

Instrument calibration efforts are critical for ensuring that CERES CESDRs reflect real changes in the climate system as opposed to artifacts associated with the input stream. This includes monitoring gain and spectral response using onboard sources, vicarious techniques, comparisons between CERES sensors on the same platform and between Terra and Aqua, and intercomparisons with other well calibrated satellite instruments (e.g., SeaWiFS, MODIS, AIRS). A recent milestone has been characterization of the temporal spectral degradation of the CERES optics. Corrections are being used in the current Edition 3 reprocessing effort. Validation results now show consistency between CERES Terra and Aqua records to better than 0.3Wm^{-2}/decade for SW and 0.5Wm^{-2}/decade for LW, a factor of 3-4 better than sensor requirements set prior to launch.

CERES validation includes comparisons of satellite-derived products with surface cloud and radiation measurements at sites around the world, including the CERES Ocean Validation Experiment (COVE) site. Activities also include comparisons with the Geostationary Earth Radiation Budget (GERB) instrument, use of CALIPSO and CloudSat for quantifying scene identification errors, and combined use of CERES, MODIS, and MISR for quantifying instantaneous TOA flux errors. Validation efforts indicate where algorithm improvements are needed, thereby improving future editions.

NPP:

Since the NPP CERES FM5 instrument is NASA's, the CERES LaRC team will have the same responsibilities as they had for Terra and Aqua. This includes instrument operations, calibration/algorithm maintenance/validation for all Level-1 through Level-3 products. The LaRC Atmospheric Sciences Data Center (ASDC) will continue to be responsible for processing, archiving, and distributing FM5 data products. The Land PEATE at GSFC will provide subsetted VIIRS radiances and aerosol properties (similar to the current process of MODIS data being obtained through the MODAPS production system). The Global Modeling and Assimilation Office (GMAO) will continue to provide meteorological assimilation data using a special frozen version of GEOS-5.

The JPSS era:

The situation for CERES FM6 on JPSS-1 is entirely different than for NPP. Currently, the LaRC CERES Project team is responsible for overseeing the instrument build only. Though NOAA recognizes the NASA team as the logical choice to provide post-delivery support through launch + 90 days, this is not yet an official responsibility. There is planning underway to establish a CERES sensor science team that would be responsible for instrument operations, calibration, and production of Sensor Data Records (SDRs), i.e., Level-1 calibrated radiances. The team is working with the JPSS Sr. Project Scientist (J. Gleason) to have the SDR effort fall under the auspices of the JPSS Program office.

Discussions with NOAA about NASA participation in FM6 CERES Level-2/-3 products have been limited. The current NOAA position is that they will produce their own Level-2/-3 products using to-be-determined portions of the existing EOS-era code developed by the CERES LaRC team. A white paper detailing the particularly high level of integration required for CERES CESDRs (algorithms, instrument characterizations, cal/val, ancillary datasets, data processing, etc.) has been provided to NOAA (*Loeb et al*., 2011).

Without retaining NASA CERES expertise and maintaining responsibility for FM6 Level-1 through Level-3 data products, there is considerable risk to the continuity of CERES ERB CESDRs into the JPSS era. NASA has made a major investment in building the expertise and infrastructure to produce ERB climate-quality data records. Transitioning wholesale responsibility (algorithm through production) to NOAA involves substantial cost and risk to both NASA and NOAA, jeopardizing science for NASA's own research and climate studies as well as the larger user community.

SORCE

Launched in early 2003, SORCE has achieved its primary goal of measuring total solar irradiance (TSI) and solar spectral irradiance (SSI) with unprecedented accuracy and precision. It is now four years past its prime mission lifetime of 5 years.

The TSI satellite climate record, dating back to 1978, has been improved with SORCE Total Irradiance Monitor (TIM) observations. A highlight has been in determining that TSI during the 2008 solar minimum period was 1360.8 ± 0.5 W m^{-2} using observations from the TIM and a series of new radiometric laboratory and field measurements with other TSI instruments. This value is significantly lower than the previously established value of 1365.4 ± 1.3 W m^{-2} (Kopp and Lean, 2011). New composite records of TSI will provide insight into long-term irradiance changes.

The Spectral Irradiance Monitor (SIM) has provided the first ever satellite spectral observations from 200–2400 nm. SIM observations show that irradiance variations in discrete spectral wavelengths are considerably greater than TSI itself and some wavelengths vary out of phase with the solar cycle (*Harder et al*., 2009).

Models of solar irradiance variability have been improved through SORCE TIM and SIM observations (*Kopp and Lean*, 2011; *Fontenla et al*., 2009), providing insight into the physical causes, and enabling investigations of solar influence on climate and atmospheric changes (*Kopp and Lean,* 2011; *Haigh et al.*, 2010; *Cahalan et al*., 2010).

SORCE battery anomalies reached a critical point in May 2011, requiring power cycling on all instruments other than TIM during the eclipse period of each orbit. The impact on the quality of SIM observations has not yet been determined.

The Total and Spectral Solar Irradiance Sensor (TSIS) and JPSS:

The NOAA-NASA Joint Polar Satellite System (JPSS) office is currently pursuing a free-flyer option for the Total and Spectral Solar Irradiance Sensor (TSIS), but even under optimistic budgetary scenarios, a launch is not expected before 2014. With the loss of the Glory mission, **the probability of a data gap in the TSI record increases with every day the TSIS launch remains unresolved, threatening the 33-year data record. The eight-year solar spectral irradiance record that commenced with SORCE SIM is already in jeopardy.**

For total and spectral irradiance data continuity, the recommended approach to TSIS science data processing is to continue with the model developed for SORCE TIM and SIM. **While the TSIS team believes this approach is likely to be adopted, a contract for the effort is not yet in place** (through the GSFC JPSS program office with reimbursable NOAA funding). The processing system functionality, if funded, is detailed below.

The TSIS Science Data System would be a straightforward adaptation of the operational data system currently running for the SORCE TIM/SIM instruments. LASP would process, manage, analyze, and distribute data products, and have responsibility for on-orbit instrument

monitoring, calibration/characterization efforts, etc. All data processing would occur locally at LASP in the TSIS Science Operations Center. Raw Telemetry (Level-0) data would be provided to LASP for production of daily and 6-hourly mean Level-3 TSI, and daily and 12-hourly SSI. All products would be retained online for the life of the mission. In addition, data products would be delivered to the NOAA National Climatic Data Center (NCDC) for archival and dissemination.

LASP is highly experienced with this type of scientific data processing, management, and distribution. TSIS would leverage an existing, highly optimized data system inherited from the SORCE system and the Glory TIM processing system. Existing procedures and tools at LASP to support on-orbit calibration/characterization maintenance and processing system updates make this the most efficient and low risk means of maintaining CESDR data quality and usability. Separately, the LASP team is currently funded by the NOAA CESDR program to produce a multi-instrument irradiance record.

A.2 *Land data records*

EOS vs. NPP/JPSS

The MODIS Land Standard Products were developed based on the heritage global AVHRR products (e.g. Surface Reflectance, Vegetation Index, Land Cover, Active Fire) and new products requested or adopted by the Global Change Community, which were possible given the much expanded capability of MODIS over the AVHRR and advances in algorithm development (i.e. BRDF/Albedo, Land Surface Temperature, LAI, Snow Cover, Burned Area, Vegetation Continuous Fields).

The NPP VIIRS instrument will be used by NASA and the Earth Science community to provide observational continuity with MODIS in the context of global change research. **Although VIIRS was designed specifically to meet the needs of the DOD and NOAA operational communities, the full suite of land products developed from MODIS could be generated from VIIRS with varying degrees of fidelity.**

The Integrated Operational Requirements Document (IORD) for VIIRS identified a number of higher order products required by the operational community (primarily the Weather Service) known as Environmental Data records (EDRs). These products were designed to meet the product specifications developed by the operational user communities. The at-launch code for these EDR's was developed by the VIIRS contractor (NGAS). The land EDRs are:

albedo; land surface temperature; snow cover and depth; vegetation index; surface type; and active fire. Surface reflectance will be generated as an *intermediate product* (IP). In some cases the contractor used the MODIS code available at the time as a basis for the EDR development. At the time the EDR code was developed, the MODIS land code was at Collection V4. The latest reprocessing (Collection V6) is currently being tested in the MODAPS system. We are anticipating that if the instrument and data system perform as planned, then to a large degree, the Land EDRs will meet their accuracy specifications and thus the needs of the intended operational community.

A program of validation was designed to evaluate whether the EDR's would meet IORD specifications that included input from a number of MODIS Science Team Members. The NASA VIIRS Land Science Team is tasked with evaluating the EDR's for science use and developing continuity products with MODIS. A procedure is currently being tested to see how proven improvements to the EDR's could be integrated into the operational chain. However there are serious reservations as to the effectiveness of this procedure for making science team improvements or changing the contractor-developed algorithms. The following is a summary evaluation of the current state of the EDR's for meeting NASA science needs (see the VIIRS Land White Paper, *Roman et al.*, 2011).

A.2.1 *Land Surface Temperature EDR*

The VIIRS Land Surface Temperature (LST) EDR will provide radiometric LST values over land and larger inland waters in swath format (equivalent to MODIS Level 2). The EDR deviates from its MODIS counterpart in three major areas: (a) It employs an algorithm suite comprised of two main daytime/nighttime algorithms, and a backup algorithm that resembles the heritage MODIS algorithm; (b) it uses both thermal and middle-infrared bands based on the so-called dual split window approach [1]; and (c) it has a functional dependency on previously-generated surface type dependent coefficients. Finally, the LST EDR 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 JPSS era.

A.2.2 *Surface Type EDR*

The Surface Type EDR is a swath product built by reprojecting the Gridded Quarterly Surface Type IP and other ancillary layers. The EDR will provide 17 surface type classes following the IGBP classification scheme. While it

is expected that this EDR will meet its target requirement, this will likely occur at the expense of specific land cover classes, which will have substantially lower accuracies. Uniform land cover types (e.g., barren, water, permanent snow and ice) are likely to have much higher classification accuracies (75-90 percent correctly classified) than more complex and less separable classes (e.g., open and closed shrublands, savannas, urban areas, and agricultural mosaics).

While 1.0 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 consistent with both IGBP as well as the FAO-Land Cover classification system [2] should therefore be included as part of the VIIRS Land Science Product suite.

A.2.3 *Surface Albedo EDR*

The VIIRS Albedo EDR will provide broadband surface albedo (0.3-5.0μm) on a daily basis under cloud-free conditions. Two algorithms will be used to fulfill this operational requirement. The first (designated as a Dark Pixel Surface Albedo or DPSA) is derived from the well-validated MODIS BRDF/Albedo heritage [3]. 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 [4].

A primary difficulty with this EDR is that the original specifications call 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 0.7 μm) and the near and mid-wave radiation (0.7-4.0 μm). Since the operational user will have no access to the underlying spectral anisotropy models (the BRDF Intermediate Product or IP) for each location, they are further precluded from computing spectral intrinsic 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. Continued access to the underlying BRDF information at an increased number of spectral channels is thus required to extend important MODIS measurements into the JPSS era.

A.2.4 *Vegetation Index EDR*

The Vegetation Index (VI) EDR consists of two products that will be generated daily at 0.375 km spatial resolution over land: the Normalized Difference Vegetation Index (NDVI, Top of the Atmosphere) and the Enhanced Vegetation Index (EVI, Top of the Canopy). While the VI EDR has several issues related to the algorithm design (e.g., a spectrally different blue bandpass and altered dynamic range), the VIIRS data will, in general, be of sufficient quality to generate atmosphere-corrected surface reflectance values in support of NASA science objectives.

A.2.5 *Surface Reflectance IP*

Surface Reflectance (SR) is currently one of the most requested MODIS land products, both for applications and science analysis. For VIIRS, several Land EDRs depend directly on the SR-IP. However, the current VIIRS Land EDR suite will not provide spectral surface reflectance product continuity with MODIS (and AVHRR); effectively severing the long-term data record needed for climate research. This data gap will also limit development of new applications and science data products, or result in duplication of effort to generate surface reflectance as an intermediate step to new higher-order (Level 3) products.

A.2.6 *Active Fires ARP*

The current Active Fires Application Required Product (ARP) provides geolocation of the pixels in which active fires are detected. 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. Note that the sub-pixel fire characterization requirements (i.e., fire temperature and area) have since been eliminated for various reasons (among other issues, the accuracy specification in most cases would not be met). The ARP is currently in the process of becoming a full EDR.

In the context of NASA science needs, the current Active Fire ARP is inadequate for a number of reasons. First, the current algorithm implementation, which is based on the MODIS Collection 4 fire code, produces false fires over arid surfaces when tested with VIIRS proxy input data. Second, 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 datasets (e.g., GOES, SEVIRI, VIRS, and several forthcoming sensors). Third, no attempt is made to identify

the corrupted M15 channel 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. Finally, it should be noted that there is currently no requirement for a VIIRS Burned Area product. 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 should be included.

The Way Forward

The Land Component of the NPP Science Team has been selected to continue to evaluate the operational products. As part of the selected proposals, some of the PI's proposed to develop MODIS continuity products from VIIRS. Since the transfer of responsibilities for algorithms from the contractor back to the government, there appears to be less rigid adherence to the product specifications but the degree to which the JPSS Program will accept science team recommended improvements to the operational products beyond the current product specification is yet to be determined. NOAA also has a small program known as NPOESS Data Exploitation (NDE) to increase the number of products beyond the current EDRs.

Although there is overlap between some MODIS products and VIIRS EDR's at least in name, there is no EDR equivalent for some of the current MODIS Land products: LAI, Burned Area, NPP, ET or Vegetation Continuous Fields. It should be noted that the MODIS products as generated today represent science needs largely articulated at the outset and during the EOS Program. **Global change science has evolved since the formulation of EOS and consideration should be given by NASA to additional long term land products from JPSS relevant to the next phase of global change science, associated not only with the physical climate system but also to include mitigation and adaptation science, with a focus on products for monitoring managed ecosystems e.g. drought, flooding/irrigation extent, agricultural production.**

EDR Land Validation and Additional Needs for Science Product Validation

In the current pre-launch Cal/Val period, the VIIRS Land and Cryosphere validation team's current emphasis has been on establishing the infrastructure to evaluate the EDRs and to develop automated validation procedures which can be implemented easily post-launch and applied throughout the JPSS era. In the immediate post-launch period, emphasis will be given to product inter-comparison with validated MODIS data. Once the EDRs are generating stable data products, emphasis will be on achieving Stage 1 Validation using a small number of well-characterized targets of opportunity. The next step will be to determine the quantitative uncertainties of the VIIRS Land EDR, IPs, and ARPs at CEOS Stage 2 Validation (statistically valid over comprehensive range of environmental conditions) [5]. This involves identifying the uncertainties as a function of several variables, including surface-atmospheric regime, scaling effects, phenological stage, sun-view geometry, etc. To meet the above objectives, the community will need expedited access to site-level ancillary information and high resolution satellite remote sensing data (e.g., WorldView, 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 well-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 will be ensuring continued access to ongoing platforms and NASA sensor resources for which dedicated airborne campaigns or campaigns of opportunity are available. Currently active airborne sensors such as NASA's Cloud Absorption Radiometer (CAR) [6, 7] and the MODIS Airborne Simulator (MAS/eMAS) will continue to be critical sources of validation data to improve model parameterization of land products and to address upscaling needs for comparison with in-situ measurements and VIIRS observations.

Data Processing Capabilities for Land Science

Building on the MODIS data processing experience and collocated with the MODIS Advanced Processing System (MODAPS), 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) [8]. The current focus of this system is to run the VIIRS Land and Cryosphere EDRs, enabling the Land Science Team to evaluate them to those from MODIS and the equivalent science algorithms for VIIRS.

As our understanding of the VIIRS instrument performance 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. 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 PE-ATE. 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 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.

Finally, all land products ingest the VIIRS cloud mask, adopting 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 algorithms. 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.

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 ensuring research-

quality MODIS land products. To-date, the MODIS Land Products have undergone five complete reprocessings of the archive. Similarly, algorithms downstream from Level-1B will likely change frequently with no operational capability or mandate to develop a consistent temporal series back in time.

Based on the above, it is strongly recommended that NASA develop a suite of VIIRS Climate and Earth Science Data Records (CESDRs) 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.

A.3 *Ocean Data Records*

A.3.1 *Ocean Color*

#### EOS and Ocean Color Processing Infrastructure

The MODIS imager extended and enhanced the continuous ocean color data record that started with the launch of Sea-viewing Wide Field-of-view Sensor (SeaWiFS) in 1997. SeaWiFS was a significant enhancement over the Coastal Zone Color Scanner (CZCS), a highly successful technology demonstration mission (1978-1986) that first verified the utility of satellite ocean color for measuring phytoplankton chlorophyll concentrations and marine primary productivity. Ocean color products from MODIS, SeaWiFS, CZCS, and various international missions are all processed and distributed by the Ocean Biology Processing Group (OBPG) at NASA/GSFC. In 2011, the National Research Council stated: "*To develop quality ocean color products requires highly specialized skill and expertise. Currently, the NASA Ocean Biology Processing Group (OBPG) at Goddard Space Flight Center (GSFC) is internationally recognized as a leader in producing well-calibrated, high-quality ocean color data products from multiple satellite sensors.*"

The OBPG is a highly integrated team skilled in instrument calibration, atmospheric correction and bio-optical algorithm development, processing and data distribution, and product validation for satellite remote sensing of ocean biology. This end-to-end capability and discipline-oriented (rather than mission-oriented) structure has been critical to the success of the OBPG at producing a consistent ocean color time-series from multiple missions. Notably, the co-location of sensor calibration and algorithm expertise

with the processing system allows for rapid assessment of calibration and algorithm changes on the global time-series, thus making it possible to detect and correct for temporal variations in instrument calibration, and to reprocess and redistribute the ocean color products in a timely and efficient manner. Recently, the OBPG completed a full, multi-mission reprocessing of CZCS, Ocean Color and Temperature Scanner (OCTS) on ADEOS, SeaWiFS, MODIS-Terra, and MODIS-Aqua. This demonstrated that the SeaWiFS and MODIS-Aqua ocean color time-series are now highly consistent in the 2002-2010 overlapping period (**Fig. A2**), suggesting that the time-series that started with SeaWiFS can be maintained through MODIS. **This success could not have been achieved without the integrated team structure**, as dozens of intermediate mission reprocessing tests and global analyses were required to understand and separate sensor radiometric degradation and changes in the polarization sensitivity from algorithm issues and real, geophysical variability.

Furthermore, since common software and methods are employed, the ocean color products produced by the OBPG are consistent in data format, which minimizes the effort required by the research community to utilize data products
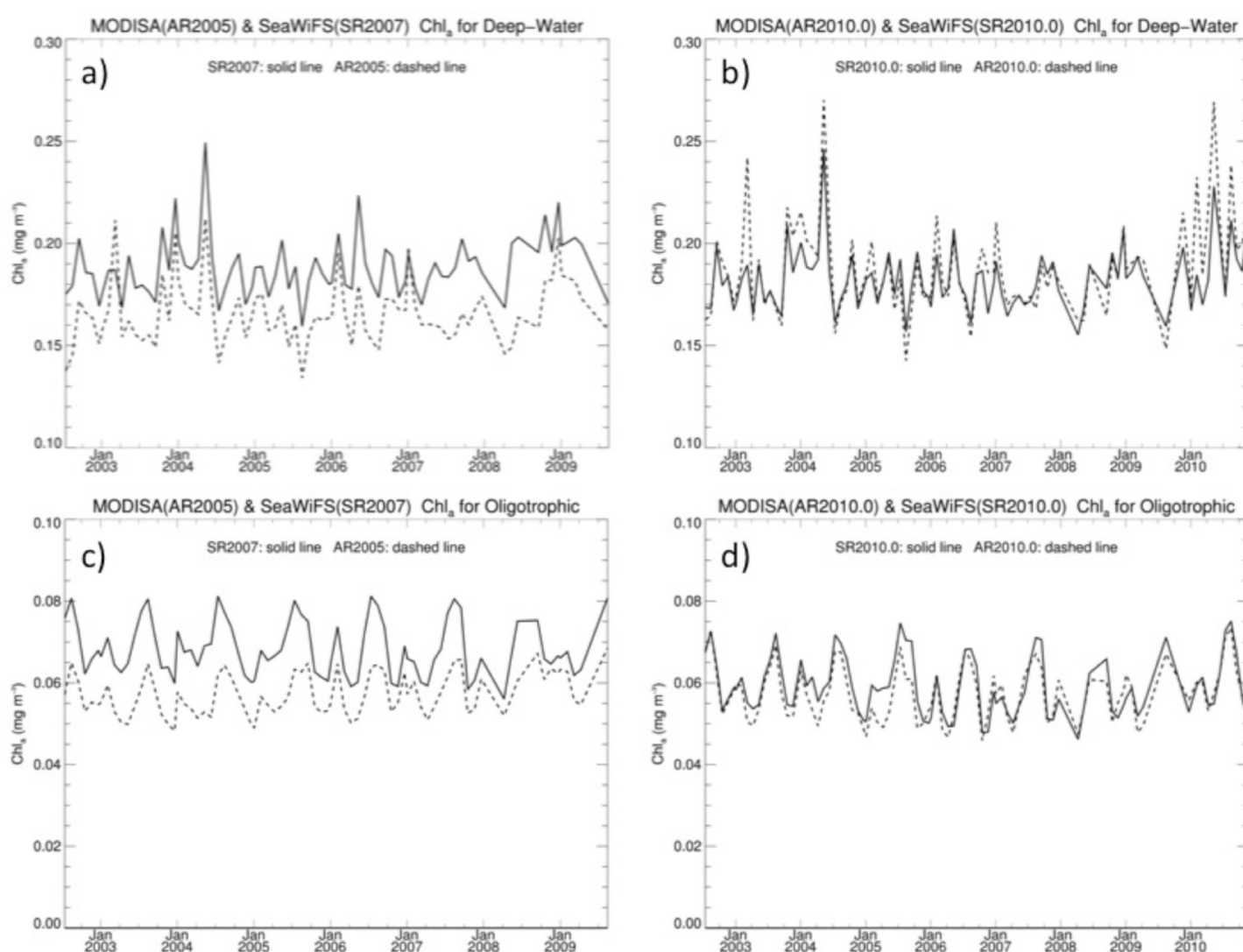
Fig. A2. Comparison of SeaWiFS and MODIS-Aqua Chlorophyll-a time-series over the common mission lifespan, showing improved agreement over time through periodic reprocessing. Top panels show mean Chlorophyll-a time-series over all deep water for a) the 2005-2007 reprocessing, and b) the 2010 reprocessing. Bottom panels show same for clearest ocean waters. Agreement was achieved through consistent processing, common vicarious calibration, and rigorous assessment and correction for changes in instrument radiometric performance.

from multiple missions. This consistency of data format and quality has allowed for a smooth transition from SeaWiFS to MODIS, and thus the continuation of on-going research and applications following the demise of SeaWiFS in 2010.

Co-location of end-to-end expertise has also served to maximize the use of MODIS ocean color products, as the OBPG provides comprehensive support and education through a highly active on-line forum monitored by all Project staff. The OBPG also provides the community with the SeaDAS package, which allows for the processing, display, and analysis of all NASA and most international ocean color (and SST) products, enables the community to produce hundreds of additional products from MODIS and other sensors for evaluation and regional applications, and provides a common base for advanced algorithm research and development. In fact, NOAA currently relies on SeaDAS to support near real-time applications of MODIS ocean color (e.g., Coast Watch).

Overview of MODIS Ocean Color Products

As for SeaWiFS and CZCS, MODIS Terra and Aqua ocean color products produced by the OBPG include the water-leaving reflectances at all sensor wavelengths within the visible spectral regime, as well as various water column constituent concentrations and optical properties that can be inferred from the spectral distribution of the upwelling reflectance. The derived products currently produced for MODIS include chlorophyll concentration, spectral and integrated diffuse attenuation and euphotic depth, particulate organic and inorganic carbon concentrations, and inherent optical properties (total and constituent absorption and scattering). All of these products are also produced for SeaWiFS using common software and algorithms. In addition, the OBPG produces chlorophyll-a fluorescence and supporting products that allow for the derivation of fluorescence quantum yield estimates (which can be related to phytoplankton physiology, e.g., nutrient stress).

NPP/JPSS

Instrument Data Continuity

The VIIRS design provides a sufficient set of spectral bands, spatial sampling, and on-orbit calibration capabilities to maintain the existing ocean color time-series for all products currently produced for SeaWiFS and for the majority of products currently produced for MODIS (all but fluorescence). A number of potential issues with radiometric performance (e.g., optical cross-talk) have been identified [*Turpie et al.*, 2010]. Mitigation strategies have also been identified, provided there is a team in place with

the expertise to implement those strategies. The sensor is not ideal for ocean color, and it does not advance the state-of-the-art in satellite remote sensing of ocean biology, but it likely can provide continuity for the current ocean color time-series, and the resulting 15-20 year continuous record of consistent ocean color measurements would serve to advance our knowledge of global change and decadal-scale marine ecosystem dynamics.

Ocean Color JPSS Algorithms

The current state of the operational EDR's for meeting NASA science needs was previously provided to HQ in a white paper [*Turpie et al.*, 2010]. The bottom line is that the algorithms are out-of-date. Many improvements have been developed and incorporated into the current ocean color atmospheric correction and bio-optical algorithms over the past decade, and these advancements are not captured in the current VIIRS EDR algorithms for ocean color. Consistency of processing algorithms is a first-order requirement for generation of a multi-mission CESDR.

Furthermore, the current plan is for the NPP/VIIRS temporal calibration to be updated in discrete steps (forward processing stream only), with no capability for mission-long reprocessing to incorporate knowledge gained from retrospective analysis of on-board (lunar, solar) calibration measurements. **Thus, the VIIRS EDR is unlikely to provide a consistent data record even within the duration of the NPP mission. Periodic reanalysis and reprocessing is a requirement for CESDR generation.**

Ocean Color: The Way Forward

We now have a continuous ocean color data record spanning over 13 years, but both MODIS instruments are beyond their design lifetime, and substantial degradation in radiometric performance is now evident. When the MODIS instruments fail or radiometric performance becomes inadequate, VIIRS will be the only US asset in orbit with global ocean color capabilities. A recent paper by *Henson et al.* (2010) concluded that 40 years of observations will be required to sort out the effects of natural modes of climate variability from trends related to long-term climate change. Clearly, a consistent ocean color data record from SeaWiFS, MODIS, VIIRS, and beyond is needed if NASA is to pursue global change research (e.g., marine primary productivity, carbon flux, impacts to ocean acidification). Based on experience with SeaWiFS and MODIS, we know that the production of a consistent multi-mission time-series requires:

1. consistent processing algorithms;

2. end-to-end expertise and infrastructure to separate instrument calibration error and algorithm error from geophysical variability;

3. reprocessing capabilities to incorporate revised calibration and enhanced algorithms, and to facilitate global calibration and algorithm testing.

These capabilities, consistent with the discussion in *Section 3.3*, exist today within NASA. The ocean NPP/VIIRS PEATE (OBPG) is prepared to support VIIRS processing using the same software and infrastructure currently employed for MODIS and other sensors. As it was for MODIS and SeaWiFS, however, the primary challenge to the production of climate-quality data from VIIRS rests in the ability to detect and correct for instrument radiometric and polarization sensitivity errors, and specifically to separate these effects from algorithm issues and the geophysical variations that we seek to measure. The PEATE is uniquely suited to this task. PEATE staff already possess detailed knowledge of the VIIRS instrument design, prelaunch calibration, and on-orbit calibration strategy, and have been active in ensuring that the characterization knowledge is complete. The expertise, software, and infrastructure exists.

With minimal additional investment in hardware and staffing, the PEATE processing infrastructure can incorporate end-to-end calibration, processing, and distribution of ocean color products from NPP/VIIRS, and provide the same level of support to the research community that is currently maintained for MODIS. This would also enable the relationship between NASA and NOAA ocean color to continue into the VIIRS era, as NOAA currently relies on the OBPG for software and calibration updates to support near real-time applications for MODIS.

A comprehensive long-term plan on satellite ocean color calibration and validation, based on lessons-learned during previous satellite missions, is presented in *Hooker et al.* (2007).

A.3.2 *Sea Surface Temperature*

Sea Surface Temperature (SST) can be inferred from both passive infrared and microwave measurements. We begin with a discussion of infrared products.

Infrared SST retrievals

There are two distinct SST fields derived from MODIS infrared observations, each using a different combination of wavelengths in spectral intervals where the cloud-free at-

mosphere is relatively transparent. In the thermal infrared these are in the 10-12 μm window, and in the mid-infrared from 3.5-4.2 μm, referred to as the MODIS SST and SST4 retrievals, respectively. A major cause for uncertainties in both retrievals is imperfections in atmosphere corrections, especially for the effects of water vapor; this has a bigger and more variable influence on the top-of-atmosphere radiances measured in the thermal infrared than the mid-infrared. In addition, the temperature dependence of emitted radiance is greater at the mid-infrared, so even though the intensity of the emission is much smaller, the SST4 retrievals should be more accurate than those in the thermal infrared. This is indeed the case, but during the day, surface reflectance and atmospheric scattering of sunlight contaminates the mid-infrared radiances, so SST4 can generally only be retrieved at night. The bands used to derive SST4 are an innovation of MODIS, whereas the 10-12 μm bands are similar to, but narrower than, those flown on the "heritage" AVHRR instruments. VIIRS includes two bands in the thermal infrared, comparable in spectral response to those of the AVHRRs, and two in the mid-infrared, but different (spectral location/bandpass) from the three of MODIS. **So, while the VIIRS SST retrievals in the thermal infrared are likely to be comparable to those from MODIS and AVHRR (unexpected instrument artifacts not withstanding), it is not clear that the more accurate MODIS mid-infrared SST4 time series can be extended by VIIRS.**

The MODIS atmospheric correction algorithm is based on the well-established Non-Linear SST (NLSST) equation (*Walton et al.*, 1998) that is also used in the AVHRR SST retrievals (*Kilpatrick et al.*, 2001). Several groups have been working on alternative approaches to the atmospheric correction, but thus far none has produced consistently better results than the NLSST approach. The at-launch VIIRS thermal atmospheric correction algorithm is now based on the heritage NLSST equation. The atmospheric correction can only be applied to multi-spectral measurements to areas of the images that have been identified as being clear of clouds, and experience with MODIS, built on that with AVHRR, indicates that a series of simple threshold tests (*Kilpatrick et al.* 2001) is as effective as other approaches.

The key to the success of the NLSST algorithm is in the correct selection of coefficients, and this can be done by robust regression analyses of the satellite radiometer measurements of top-of-atmosphere brightness temperatures and collocated, simultaneous measurements of the SST, usually taken from sub-surface thermometers on drifting buoys. These are numerous, but have relatively poor accuracy (~0.25K; *O'Carroll et al.* 2008), are irregularly distributed in the world's oceans, and measure a subsurface

temperature. Other approaches, using simulated brightness temperatures derived by radiative transfer modelling through a wide selection of atmospheric state vectors have been tried, but have other sources of uncertainties and thus far have not been demonstrated to produce more accurate SST retrievals.

We note that AIRS has also a SST standard product that is derived in conjunction with the sounding algorithm (see **Table 4.6**).

Microwave Imager SST retrievals

SST can also be derived from the surface emission in the microwave, such as measured by AMSR-E on Aqua. The microwave SST measurements are largely immune to contamination by clouds, unless they are raining heavily, but have a much poorer spatial resolution (~25km retrieval grid, but this is an oversampling of the native resolution) and suffer from side-lobe effects that are very pronounced in the vicinity of coasts, leading to no useful SSTs being derived within 50-100km of a coastline. The continuance of microwave SSTs is entirely reliant on the AMSR2 on the Japanese GCOM-W satellite(s). The ASMR-2 instrument and JAXA/NOAA roles and responsibilities for GCOM-W1 data have previously been described (see _Section A.1.2_/AMSR-E).

With the same frequency selection (other than an additional low frequency channel), no disruption in AMSR-E SST measurement continuity capability is expected. However, for climate data continuity, access to ASMR-2 L1A data or equivalent information is required to evaluate/establish radiometric continuity among instruments. Regardless, no infrastructure exists to continue NASA-legacy L2A and higher data product continuity with GCOM-W observations.

The Meaning and Validation of SST

A layer of large temperature gradient exists on the aqueous side of the air-sea interface, often referred to as the thermal skin layer, resulting from conductive heat flow from the ocean to the atmosphere. This results in the surface being cooler than the underlying water. Estimates of the thickness of the thermal skin layer vary, ranging from a few mm to a few tenths of a mm, or less (_Katsaros et al._ 1977; Hanafin 2002). The relationship between skin and bulk SSTs just below the surface (at ~5cm) is reasonably well behaved (_Minnett et al._ 2011), having an asymptote of about -0.13K at high winds and exceeding -0.6K at low winds. The relationship with deeper bulk temperature

at depths of a few meters, where many subsurface SST measurements are taken, is the same on average during the night and during the day for surface wind speeds of >~6ms^{-1} (_Donlon et al._ 2002). But under low winds the relationship is quite variable (vertically, horizontally and temporally – see Minnett 2003; Ward 2006; Gentemann and Minnett 2008). In conditions of low wind speed, the heat generated in the upper ocean by the absorption of solar radiation is not well mixed through the surface layer, causing thermal stratification with temperature differences between the uppermost layer of the ocean and the water below. There is a strong diurnal component to the magnitude of these temperature gradients, as well as a dependence on cloud cover which modulates the insolation and, importantly, wind speed which influences the turbulent mixing (e.g. Price et al. 1986; _Fairall et al._ 1996; Gentemann and Minnett 2008). The difference between the skin temperature and that measured by a sub-surface, in situ thermometer in the presence of diurnal heating is strongly dependent on the depth of the sub-surface measurement, and has been measured up to 4K (Minnett 2003). When the amplitude of the diurnal heating at the sea surface is determined by comparisons with SSTs measured during the previous night, multiple cases of amplitudes in excess of 5K have been identified (_Gentemann et al._ 2008).

The accuracy of the MODIS SST and SST4 retrievals, and those of other infrared radiometers and AMSR-E, are determined by comparison with drifting buoy measurements (withheld from the coefficient derivation process) or by less numerous measurements of the skin SST derived from well-calibrated ship-board radiometers. **The radiometric validation is in principle superior in that it is comparing the satellite retrieval with the source of the radiation before it is modified by propagation through the atmosphere**, but they are much less numerous than drifter measurements.

SST CESDRs

Of the many applications of MODIS SST(4) fields, the one with the most stringent accuracy requirement is climate research and CESDR generation where an absolute accuracy of ±0.1K and a stability of 0.04K-decade^{-1} has been stated (_Ohring et al._ 2005). These are not yet demonstrably achieved, but at these levels of accuracy the meaning of the SST needs clarification.

The generation of multi-decadal time series of SST to constitute a CESDR requires utilizing measurements from several satellite radiometer missions, and must be extended into the VIIRS and AMSR2 era. Because temperature is

one of the seven fundamental base units of the International System of Units (SI), the production of CESDRs of SST is a feasible proposition. **Due to shortcomings in the thermometer calibrations and consequent uncertainties in the temperature measurements from buoys, achieving consistency in satellite-derived SST accuracy over multiple missions is best achieved using ship-board radiometers.**

In a series of workshops held at the University of Miami, ship-board radiometers have been calibrated against laboratory blackbody targets that are characterized by the NIST EOS Transfer Radiometer (TXR; Rice and Johnson 1998). Participation in the workshops has included many groups, encompassing nearly all who are involved in satellite SST validation (*Barton et al.* 2004; *Rice et al.* 2004) and the most recent one, conducted under the auspices of CEOS, included a component at the National Physical Laboratory in the UK (Theocharous and Fox 2010). The outcome of these workshops is an unbroken chain of links from the determination of the uncertainties in the satellite-derived SSTs to SI standards, which is a requirement for an SST CESDR. Extending the SST CESDRs into the future requires continuing deployments of the ship-board radiometers and periodic re-establishment of traceability to the SI standards.

Another advantage of radiometer validation is that it inherently provides information on the physics of the ocean-atmosphere interface. For example, data provided by the ship-borne campaigns, especially those from the hyper-spectral Marine—Atmospheric Emitted Radiance Interferometers (M-AERI; *Minnett et al.* 2001), have been analysed to reveal characteristics of the sea-surface and atmosphere that influence the accuracy of the satellite SST retrievals. These include the skin layer, diurnal heating, air-sea temperature differences, sea-surface emissivity, lower tropospheric structure and surface radiative forcing.

SST international collaboration

As well as involvement in Infrared Radiometry Workshops, international collaboration extends to the free exchange of ship-board data between the various groups and their utilization in the validation of SSTs from multiple satellite sensors. This is anticipated to extend into the VIIRS and AMSR2 era with validation of the SLSTR (Sea and Land Surface Temperature Radiometer) to be flown on the ESA satellites Sentinel-3 A and B.

Much of the international coordination of research into the SST and satellite measurements is done through the GHRSST (Group for High Resolution SST; see *https://*

www.ghrsst.org/); the U.S. component of which has recently had its funding renewed through National Ocean Partnership Program (NOPP), a collaboration of federal agencies that provides leadership and coordination of national oceanographic research initiatives.

SST: The Way Forward

The newly formed NASA SST Science Team (ROSES 2009) is responsible for the quality and integrity of NASA's measurements of global sea surface temperatures, and will interact with the wider international satellite oceanography community. This team, which first met in November 2010, augments former instrument science teams, specifically the SST components of MODIS, ASTER, and AMSR-E Science Teams, and will include VIIRS SST activities. An overview of the science team efforts is given at *http://depts.washington.edu/uwconf/sst2010/*.

To ensure SSTs are of sufficient quality to contribute to the SST CESDR, effort must be directed in identifying and correcting possible instrumental artifacts (VIIRS and AMSR2), in addition to using sensors with unbroken traceability to SI standards to understand uncertainties in SSTs derived from top-of-atmosphere radiance measurements. Learning from the MODIS SST experience, this requires close collaboration between NASA-supported NPP/JPSS instrument characterization teams (which don't yet exist, see *Section 3.2*) and scientists funded to establish the uncertainties in the SST retrievals (potentially via NASA SST Science Team assuming sufficient directed funding). It also requires interaction with a reprocessing group (e.g., OBPG at NASA GSFC) to implement algorithm improvements. Finally, it also requires willingness of the National Metrology Institutes (NIST in the U.S.) to continue to involvement in the efforts to provide traceability to SI standards of the ship-board radiometers used in the validation of the IR-derived SSTs from VIIRS.

A.4 *Cryosphere*

A.4.1 *MODIS Records*

Snow-cover CESDR

EOS

The MODIS Terra and Aqua snow-cover product suite is produced as a sequence of products beginning with the Level-2 swath product. A daily Level-3 gridded and projected product at 500m resolution is made from the swath product. Then a daily global product is made, followed by eight-day tiled and global products. A complete descrip-

tion of the MODIS products is found in the snow products user guide [*Riggs et al.*, 2006]. Of all of the MODIS cryosphere products, the daily projected 500m resolution snow cover has been the most-frequently requested and used product by the user community. The products have been validated extensively by the user community (see listing of published papers utilizing the MODIS cryosphere products: *modis-snow-ice.gsfc.nasa.gov*, click on "Publications," and then "Listing of papers that use MODIS cryosphere products.")

The core of the MODIS snow cover algorithms is the Normalized Difference Snow Index (NDSI) that is based on the characteristic of snow being highly reflective in the visible and very absorptive in the shortwave-IR. The binary snow algorithm uses a threshold technique based on the NDSI and other spectral tests are used to detect snow cover; the output is a thematic snow cover map which designates snow cover, snow-free land, clouds, lakes and other surface features. The fractional snow cover is made from a regression algorithm using the NDSI; the output is a thematic fractional snow cover map. The MODIS Level-2 Cloud Mask Product [*Ackerman et al.*, 2010] is used as input to the snow algorithms.

EOS vs. JPSS

The VIIRS JPSS Snow Cover EDR has a Snow Cover Binary Map and a Snow Fraction. The binary snow cover algorithm is based on the MODIS snow-cover algorithm. The VCM is used to mask clouds (*c.f. Sec 3.1.1*). The snow fraction is based on a spatial aggregation of the binary snow map. Only a Level 2 EDR is made, there are no NPP/JPSS Level-3 products (*c.f. Sec 3.1.1*).

The discussion presented in *Section A.2 Land data records* also applies to the snow cover data records as the EOS cyrospheric products are produced by the land products processing system.

Binary Snow Cover EDR: The NPP/JPSS Binary Snow Cover EDR uses the same NDSI algorithm as MODIS but with a different visible wavelength (VIIRS 0.640 μm vs. MODIS 0.555 μm), necessitated by the differences between the VIIRS and MODIS sensors. The difference in visible bands may have an effect on sensitivity or threshold selection of the NDSI for snow cover-mapping; that potential affect has not been investigated.

Fractional Snow Cover EDR: The NPP/JPSS Fractional Snow Cover EDR is made by aggregating the Binary Snow Cover EDR. There is no similarity in the Level-2 fractional snow cover algorithms of EOS (based on a NDSI regression) and NPP/JPSS.

The Way Forward

Evaluation of the operational products and development of continuity product with MODIS will follow the way presented for the land products (c.f. *Section A.2 Land data records*) as the cryospheric products are generated in the land processing system. A major hindrance to evaluation is that the EDRs are produced only at Level-2, there are no Level-3 EDRs; the MODIS Level-3, gridded land and cryospheric products are used predominately in evaluation and validation activities and by the user community.

Errors resulting from problems with snow/cloud confusion are a problem in the EOS products and have appeared as a significant problem in the snow cover EDRs. Improvement in reducing snow-cloud confusion in the snow products may be realized by using cloud spectral tests from the VCM. Some work by *Riggs and Hall* [2003] demonstrated that improvement in snow cloud discrimination is possible if individual cloud spectral tests from the MODIS cloud mask product were used. Differences between the MODIS and VIIRS cloud masks discussed in *Section A.1.2* are applicable to snow-cloud confusion between the EOS and NPP/JPSS snow products.

Greenland Ice-Surface Temperature (IST) CESDR

EOS

Though Land Surface Temperature (LST) is a JPSS EDR, Ice Surface Temperature (IST) over land is not. The LST and IST algorithms are closely related, but there are also many differences. NASA has funded an IST climate-data record to be produced over Greenland. The IST record utilizes both Terra and Aqua MODIS data and is suitable for continuation in the VIIRS era. MODIS IST of Greenland was developed and is produced as a special product at GSFC using the algorithm developed for the MODIS sea ice product (MOD29).

The MODIS IST split window algorithm derives its heritage from the IST algorithm of *Key and Haefliger* [1992] developed for use with AVHRR data, and as implemented by *Hall et al.* [2004].

Daily and monthly Terra MODIS ISTs of the Greenland Ice Sheet are available beginning on 1 March 2000 and continuing through 31 December 2010 at 6.25-km spatial resolution on a polar stereographic grid (*Hall et al.*, submitted). Aqua data are used to fill in instrument data gaps in

the Terra record that are longer than one day. This MODIS IST data record is useful for monitoring temperature and melt trends on the surface of the ice sheet and as input to models that calculate ice sheet mass balance. Data-assimilation modelers may also be able to take advantage of the data for validation and possibly for input.

Preliminary validation of the ISTs at Summit Camp, Greenland, during the 2008-09 winter, shows that there is a cold bias using the MODIS IST which underestimates the measured surface temperature by ~3°C when temperatures range from ~-50°C to ~-35°C [*Hall et al.*, submitted]. Additional validation is planned using automatic-weather station data from ice sheet locations.

The MODIS IST algorithm can be adapted for use with VIIRS data to ensure continuation of the data record. It is expected that there may be some issues related to differences in cloud masks between the MODIS-derived Greenland IST and a comparable VIIRS-derived IST product.

Sea Ice Surface Temperature EDR

The VIIRS Ice Surface Temperature EDR provides a "skin temperature" for sea-ice covered areas. In this context, sea ice is considered to be "ice-plus-any-overlying-snow" rather than just sea ice alone. 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. 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. 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 refining the areas for which the IST algorithm is applied. This could be addressed relatively easily by refining the locations for which IST is calculated.

A.4.2 *AMSR-E Records*

The AMSR-E cryosphere records include sea ice concentration (areal fraction), snow cover /depth over ice, and snow water equivalent. The ASMR-2 instrument and JAXA/NOAA roles and responsibilities for GCOM-W1 data have previously been described (see *Section A.1.2*/AMSR-E).

The AMSR2 JPSS Level-1 EDR requirements supplement includes sea ice characterization, consisting of ice concentration as well as an age (young vs. old) estimate. Other EDRs are snow cover/depth and snow water equivalent.

With the same frequency selection (other than an additional low frequency channel), no disruption in AMSR-E SST measurement continuity capability is expected. However, for climate data continuity, access to ASMR-2 L1A data or equivalent information is required to evaluate/establish radiometric continuity among instruments. Regardless, no infrastructure exists to continue NASA-legacy L2A and higher data product continuity with GCOM-W observations.

EOS/pre-EOS Heritage

Because the AMSR-E instrument was provided by JAXA and because there was also an AMSR on ADEOS-2, two parallel Science Teams exist with separate responsibility for the NASA and JAXA cryosphere products.

For NASA, the Snow Water Equivalent (SWE) product algorithm follows *Kelly* [2009] while the JAXA SWE algorithm was developed by JAXA scientists. For sea ice concentration NASA provides two products. The standard product is the NASA Team 2 (NT2) algorithm [*Markus and Cavalieri*, 2000] and an alternative algorithm called the AMSR-E Bootstrap algorithm [*Comiso et al.*, 2003]. A detailed description of those algorithms and its implementation can be found in *Comiso et al.* [2003] and *Markus and Cavalieri* [2009]. The NASA product also has a snow depth on sea ice product that follows *Markus and Cavalieri* [1998].

While snow depth on sea ice is a relatively new algorithm, the retrieval of SWE and sea ice concentrations dates back to Nimbus-7 SMMR and have been continued with SSM/I on the DMSP satellite into the EOS era. The SMMR and SSM/I data form the baseline for the SWE and ice concentration CESDRs with their 30+ year time series. While AMSR-E standard products for ice concentration and SWE utilize improved algorithms that take advantage of the additional channels available on AMSR-E, cryospheric CESDRs that use satellite passive microwave data employ algorithms developed originally for SMMR or SSM/I. Those are specifically the SMMR SWE algorithm [*Chang et al.*, 1987], the NASA Team sea ice concentration algorithm [*Cavalieri et al.*, 1984] and the Bootstrap sea ice concentration algorithm [*Comiso*, 1995].

JPSS

Since it was not clear over most of the Aqua era that the additional channels available on AMSR-E would be continued in the future, there was some reluctance by the community to use the improved AMSR-E algorithms as the baseline for the CESDRs and to adjust algorithms

backwards in time. Instead, heritage algorithms (channels) were used for CESDR algorithms, i.e., those that only require the channels available for the entire SMMR-SSM/I-AMSR-E period.

While JAXA has a clear plan to continue its AMSR series within the GCOM-W satellite series, we note that the channel selection for DWSS MIS (not part of JPSS) remains unclear at the time of this document. The JAXA AMSR2 SWE algorithm will be provided by Japanese sci-entists. The JAXA AMSR2 sea ice concentration products utilize the Bootstrap algorithm for the standard product and the NT2 algorithm for the research product. Drs. Comiso and Markus are both PIs on the JAXA GCOM-W1 Science Team.

As previously mentioned (*Section A.1.2*/AMSR-E), the algorithms with which L1B and higher order products will be generated by NOAA are not clear to us at this time. ∎

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Important/Common White Paper Acronyms

AIRS	Atmospheric Infrared Sounder (on Aqua satellite)		JPSS-1	First JPSS mission
AMSU	Advanced Microwave Sounding Unit		KPP	Key Performance Parameters (JPSS)
AMSR-E	Advanced Microwave Scanning Radiometer 2 (on Aqua satellite)		L1	Level-1 (sensor) product
			L1B	Level-1B (calibrated/geolocated Level-1) product
AMSR2	Advanced Microwave Scanning Radiometer 2 (advanced version of AMSR-E on Aqua)		L2	Level-2 (geophysical) product
			L3	Level-3 (gridded) product
ARP	Application Required Product (JPSS)		L1RD	Level-1 Requirements Document (JPSS)
ATMS	Advanced Technology Microwave Sounder (JPSS)		LUT	Look-up Table
			MIS	Microwave Imager/Sounder (DWSS)
CDR	Climate Data Record		MODIS	Moderate Resolution Imaging Spectroradiometer (on Aqua and Terra)
CERES	Clouds and the Earth's Radiant Energy System instrument			
CESDR	Climate and Earth Science Data Records (EOS-era records used for general science analysis, including process and climatology studies)		NESDIS	National Environmental Satellite Data and Information Service (NOAA)
			NICSE	NPP Instrument Characterization Support Element
			NPOESS	National Polar-orbiting Operational Environmental Satellite System
CrIMSS	Synergistic use of CrIS and ATMS for soundings		NPP	NPOESS Preparatory Program
			NIR	Near-Infrared
CrIS	Cross-track Infrared Sounder (JPSS)		NVT	NASA Validation Team (see _Section 3.4_)
DAAC	Distributed Active Archive Center		OMI	Ozone Monitoring Instrument
DWSS	Defense Weather Satellite System		OMPS	Ozone Mapping and Profiler Suite (JPSS)
ECV	Essential Climate Variable (as defined by GCOS)		PEATE	Product Evaluation and Test Elements
			QA	Quality Assurance
EDR	Environmental Data Record (JPSS Level-2 product)		RDR	Raw Data Records (JPSS)
			SBUV	Solar Backscatter Ultraviolet instrument
EOS	Earth Observing System		SeaWiFS	Sea-viewing Wide Field-of-view Sensor
ESD	Earth Science Division (NASA)		SDR	Sensor Data Record (JPSS Level-1 product)
ESSP	Earth System Science Pathfinder			
FOV	Field of View		SDS	Science Data Segment (JPSS)
GCOM	Global Change Observation Mission (JAXA)		SORCE	Solar Radiation and Climate Experiment
			STAR	Satellite Applications and Research (NOAA NESDIS)
GCOM-W1	First GCOM "Water" mission w/AMSR2 instrument			
			SWIR	Shortwave Infrared
GCOS	Global Climate Observing System		TES	Tropospheric Emission Spectromter (on Aura satellite)
GSFC	Goddard Space Flight Center			
HQ	Head Quarters (NASA)		TOMS	Total Ozone Monitoring Spectrometer
IASI	Infrared Atmospheric Sounding Interferometer (on MetOp)		TRMM	Tropical Rainfall Measuring Mission
			TSIS	Total Solar Irradiance Sensor (JPSS)
IDPS	Interface Data Processing Segment (JPSS)		VCM	VIIRS Cloud Mask
IP	Intermediate Product (JPSS)		VIIRS	Visible /Infrared Imager/Radiometer Suite (JPSS)
JAXA	Japan Aerospace Exploration Agency			
JPSS	Joint Polar Satellite System			