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NPOESS Community Collaborative Calibration/Validation Plan for the NPOESS Preparatory Project VIIRS Ocean EDR

DATE: 13 March 2009 **No. 1.0**
REV. A - DRAFT

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Prepared by
NPOESS Integrated Program Office

Prepared for
U.S. Department of Commerce
National Oceanic and Atmospheric Administration (NOAA)
National Environmental Satellite, Data, and Information Services (NESDIS)
National Polar-orbiting Operational Environmental Satellite System (NPOESS)
Integrated Program Office (IPO)

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1.0 Objectives

This document provides an initial definition of a Calibration and Validation (Cal/Val) program for ocean products that will be derived from the Visible Infrared Spectrometer (VIIRS) to be flown on NPOESS Preparatory Project (NPP) and the operational NPOESS spacecrafts. There are three goals for this program: 1) validation of NPOESS program delivered ocean products, 2) evaluate the usability of VIIRS data and products for operational and scientific use by the agencies and 3) evaluate the VIIRS products in relation to the heritage instrument products with the goal of producing comparable products and combining heritage instrument and VIIRS products to assess climate variations.

Sensor Data Records (SDRs): Sensor data records are the calibrated and geolocated at-sensor radiances measured for each pixel in the scene. Highly accurate SDRs are essential for producing ocean products. Hence, the Ocean Cal/Val team will work closely with the IPO SDR Cal/Val team and the NASA PEATE to assess and improve the SDRs to achieve the highest possible accuracy.

Environmental Data Records (EDRs): The NPOESS ocean EDRs addressed in this document are Sea-Surface Temperature (SST, a key performance parameter (KPP), a Primary EDR), and Ocean Color, which consists of spectral water-leaving radiances (Lw, also known as Remote Sensing Reflectances (RSRs)) and chlorophyll.

These ocean products are currently produced from a number of sensors and used operationally by the Naval Oceanographic Office (NAVOCEANO) and National Oceanic and Atmospheric Administration (NOAA), including the NOAA Environmental Satellite Service (NESDIS), the National Ocean Service (NOS) and the National Marine Fisheries Service (NMFS). Additionally these products are used for research and applications by NASA, NOAA, Navy and university researchers. These products, and agency-unique ocean products, will be produced from VIIRS SDRs using their existing algorithms and processing capabilities. NPOESS compatible products will be compared to the NPOESS products as part of the validation process.. Both EDRs and government derived products will be calibrated and validated using a consistent Cal/Val methodology, and their relative performance will be cross-evaluated and reported side-by-side.

The present data products produced by these agencies from MODIS and AVHRR data include a suite of ocean bio-optical products and SST products required for operations and research that are not specifically in the NPOESS EDR product list, but are derived using the radiances and reflectances available from the Sensor Data Records (SDRs). These products will be produced and evaluated by the agencies as part of their operations and their results compared with the products from MODIS.

An Ocean Cal/Val team of Subject Matter Experts was assembled to help formulate a Cal/Val plan. The team members included leaders in satellite ocean color Cal/Val research and operational customers representing ocean color and SST products. The team is composed of personnel from NOAA, NASA, Navy, universities, and the NPOESS Prime Contractor Northrop Grumman Aerospace Systems (NGAS).

The purpose of this Cal/Val plan is to provide guidance on how the government agencies plan to establish and maintain the calibration and validation of NPP VIIRS Ocean EDRs. The Cal/Val procedures for ocean products and a draft plan has been described prior to this document in “NPP Cal Val Team 2001”.

The complete specifications are provided in Appendix G.

EDR Product	Temporal	GSD	Precision	Data delivery
SST (skin/bulk)	Daily	1km	>0.5 degree	~ 1 hour
Remote Sensing Reflectance	Daily	1 km	>.1	~ 1 hour
Chlorophyll	Daily	1 km	25%	~ 1hour

Table 1: Summary of EDR Requirements

2.0 APPROACH

***2.1** Overall Approach*

The Ocean Cal/Val Team (hereafter referred to as “Ocean Team”) has outlined a strategy that primarily includes:

1) Develop an integrated cross-agency Cal/Val plan for the NPP products that is based on present infrastructure and architectures used for heritage satellite sensors.

2) Ensure consistency of NPP products with heritage satellite products (from e.g. SeaWiFS, MODIS, MERIS and AVHRR) through extensive cross-evaluation and inter-comparison.

3) Construct a readiness program beginning with MODIS and MetOp-A/AVHRR FRAC (1km global) as a pathfinder to ocean calibration and validation for NPP and extending to the first two NPOESS operational satellites, named C1 and C2.

2.2 Assumptions

The work outlined in this document is planned based on the following assumptions:

- The IPO appoints the VIIRS Ocean Cal/Val Lead, who organizes the NPOESS Ocean Cal/Val Team and coordinates its activities, with IPO funding support.
- The IPO will facilitate and support a working group addressing Cal/Val archiving needs, including independent data and retained Intermediate Products (IPs).
- The Navy, NOAA and NASA are participating in the Cal/Val program and representing their needs and requirements.
- New and improved approaches of Cal/Val for NPOESS which are defined by the government team will be assessed by IPO and “quickly” integrated into VIIRS ocean product processing. IPO will define the procedures for integration of new Cal/Val methods into processing. We expect the cal/val efforts, approaches and recommendations will be adopted by the NPOESS prime contractor, NGAS.

- The required ocean operational products are expected to be of a similar quality as those from the heritage sensors, such as those derived from SeaWIFS and AVHRR.
- The calibration requirements for SDRs will include such things as 1) prelaunch system level calibration including the solar diffuser and BRDF effects and 2) On-orbit drift /stability calibration (see appendix H - Kevin Turpie)
- The IPO will organize and fund a VIIRS Sensor Data Record (SDR) Cal/Val team to evaluate and provide input to the IPO and NGAS to ensure the best possible SDRs.
- There will be a strong integration of the EDR and the SDR Cal/Val programs such that each program quickly takes advantage of the results of the other program to improve the final products. For example, the validation of clear-sky radiances associated with the ocean products is an integral part of the Ocean Cal/Val.
- The data products discussed here refer to two types of ocean products: EDRs provided by the contractors, and those based on government operational algorithms which use the VIIRS SDRs as input. For ocean color, algorithms include both atmospheric correction and in-water properties. The contractor SST EDR will be evaluated against government SST products.
- Existing or similar activities of ongoing Cal/Val efforts for ocean color and SST from MODIS, AVHRR and other satellite sensors continue. These include such activities as the AERONET network and MOBY-like ocean radiometer operations for color, and evaluations using matchups with ship-based radiometer and global buoy SSTs and global reference fields for SST.
- NASA continues to operate MODIS instruments and NOAA/Navy continue processing MODIS and AVHRR data to allow data overlap, and continue to maintain current Cal/Val operational activities for SST.
- Upon completion of the initial intensive Cal/Val campaign, when access to data may be limited, the routine Cal/Val results obtained beyond that period can be freely and openly distributed, including conference presentations, peer-reviewed publication, and other national and international forums. This includes cross-evaluation of the performance of the contractor's EDRs relative to the similar heritage products produced by participating government agencies.
- Cal/Val is carried out in a close collaboration with international Ocean Color and SST communities, including the Global High Resolution SST (GHRSST), in a spirit of free and fully open data and information exchange.

2.3 Mission Readiness - *Time Periods*

The ocean Cal/Val effort will address 3 time periods for the validation of VIIRS NPP ocean data:

a) Pre-launch readiness program for NPP, including proxy VIIRS data stream. In the prelaunch period emphasis is on building on the experience with heritage instruments AVHRR, SeaWiFS and MODIS and conducting validation prototyping activities. The Ocean Team will focus on the following activities:

- review, unify, evolve and document the methods and resources required for operational calibration and validation;
- in collaboration with the NASA's Global Change Science Team (GCST), conduct calibration and validation prototyping activities with heritage instrument SST and Ocean Color data products used as proxy data for NPP SDRs and EDRs;
- set up methodology and tools to quality-control (QC) in situ data used in validation, satellite-derived products and associated clear-sky radiances over oceans;

- set up methodology and tools for long-term monitoring of derived products and associated clear-sky radiances over oceans for stability and cross-platform consistency;
- set up procedures and protocols to effectively communicate the Cal/Val results within the Team, and between the Team, IPO, NGAS and the user Community;
- set up a near-real time data stream to generate proxy VIIRS SDRs (by reformatting MODIS or AVHRR FRAC data into NPOESS hdf5 format);
- Investigate the potential for at least two targeted prototype campaigns with strong NASA support to evaluate the credibility of operational NPOESS validation strategies. Nominal campaigns include 1) evaluation of NOAA in situ ocean color data (MOBY or similar follow-on) and scaling methodologies against heritage NASA approaches, and 2) a coastal in situ and aircraft field campaign to validate coastal products;
- develop a second-generation Marine-Atmosphere Emitted Radiance Interferometer (M-AERI) for ship-board deployment in the post-launch validation period for SST;
- ensure the NIST-traceable calibration facilities upon which MOBY and M-AERI are ultimately dependent are maintained in good condition to extend well into the NPOESS era.

b) Intensive Cal/Val program immediately post launch

In the *post-launch Intensive Cal/Val period*, the Ocean Team will:

- acquire VIIRS SDRs, generate Navy and NOAA heritage ocean products and process them through the heritage Calibration and Validation algorithms;
- acquire NGAS EDRs, and process them through the same Calibration and Validation algorithms as heritage products;
- conduct a rigorous inter-comparison and cross-evaluation of the derived products reported on the EDRs, and SDR-derived government products, against heritage products from contemporaneous AVHRR, MODIS, SeaWiFS, and MERIS data (e.g., SST, water leaving radiances and chlorophyll);
- conduct a rigorous evaluation of VIIRS clear-sky radiances associated with the ocean products, against radiative transfer models and other contemporaneous available sensors (MODIS, AVHRR, SeaWiFS, MERIS);
- suggest trouble-shooting to evaluate and fix any identified EDR/SDR problems to the IPO and, as directed by the IPO, advise contractor on implementing fixes as needed
- conduct targeted validation campaigns and demonstrate methods and use of operational field data sets.
    - at-sea deployment of the ship-based radiometers in a wide range of oceanic and atmospheric regimes, and near real-time matchups with the VIIRS data.
    - The available moored and drifting buoy data will also be used for near real-time matchups. Although the buoy thermometers measure a bulk SST, skin SSTs will be derived for the validation using the best-available skin-bulk SST models.

c) Define a long term Cal/Val monitoring system

During the *long-term monitoring phase*, the Ocean Team will

- add new data streams (EDRs and government-derived products, and associated clear-sky radiances over oceans) to the existing long-term monitoring tools maintained for the then-contemporaneous sensors and products (from AVHRR, MODIS, etc), and ensure continuity in these data records across the various sensors' missions;

- continuously monitor performance, suggest fixes to data products to IPO and assist contractor with implementation as needed;
- analyze the long-term performance of NPOESS products relative to the heritage products, and suggest improved SST and ocean color algorithms;
- use operational in situ monitoring sites such as, ship-based radiometers, NOAA buoys for SST comparisons, MOBY or follow-on for ocean color radiances, coastal sites and AERONET Ocean Sites with SeaPRISM and others with reliable validated in situ ocean data to validate long-term performance.

2.4 *Cal/Val Philosophy*

The ocean Cal/Val program is designed to address an "end to end" capability from sensor to end product. The Cal/Val program is developed based on existing ongoing government satellite ocean remote sensing capabilities that are currently in use with NASA research and Navy and NOAA operational products. Therefore, the plan focuses on the extension of known reliable methods and capabilities currently used with the heritage sensors that will be extended to the NPP and NPOESS ocean product Cal/Val effort. This is not a fully "new" approach but it is designed to be the most reliable and cost effective approach to developing an automated Cal/Val system for VIIRS while retaining highly accurate procedures and protocols.

The Ocean Team is currently evaluating EDR algorithm heritage, validation approach maturity, existing field resources, and other criteria to ensure early funding of long lead time needs and later funding of existing well-developed approaches. Our current prioritization is focused on products that characterize sensor performance (e.g., spectral water leaving radiance and SST) and/or are critical to NPOESS program performance (e.g., SST and chlorophyll).

The Cal/Val effort will integrate into an "end to end" (sensor to product) cycle where procedures are directly traceable to "value added" to the product. This approach enables metrics for defining the impact which both calibration and validation procedures have on ocean product performance and uncertainty. Additionally, the "end to end" approach addresses the necessity for both short-term and long-term Cal/Val protocols. Lastly, it ensures a coupled science and product traceability matrix for merging multiple sensors from AVHRR to MODIS, to VIIRS on NPP, to C1 and C2, thus enabling reliable continuous, senor and product inter-comparison.

While the Cal/Val plan presented here covers both SST and ocean color products, and while there is some commonality in the approaches, there are differences. The infrared measurements from VIIRS will be calibrated on orbit using an on-board black-body calibration target and measurements of cold space (near zero radiance). However, some aspects of the instrument performance, notably any residual reflectivity-*vs*-scan angle on the Half-Angle-Mirror cannot be dealt with using the in-flight calibration procedures alone and must rely on the pre-launch characterization measurements or on-orbit calibration maneuvers. The cal/val activities for the infrared data are therefore a validation of the corrections applied to compensate for instrumental artifacts and for the atmospheric correction algorithm, rather than a vicarious calibration in the same sense as applied to the ocean color data.

2.5 "End to end" processing of Sensor to Ocean products:

Present paths of "end to end" methods for ocean products are illustrated in figures 1 and 2 for Ocean color and SST products.;

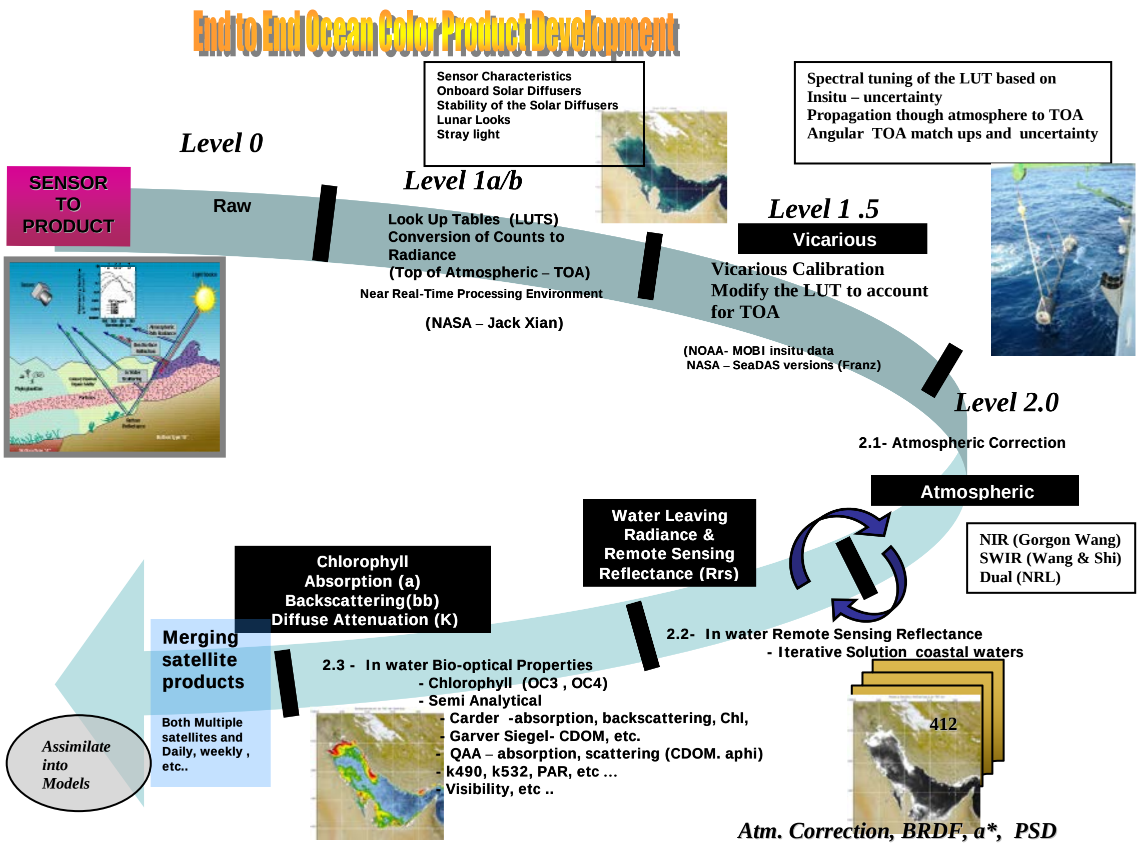

Figure 1: End to End - "Sensor to Product" Cycle for Ocean Color Products

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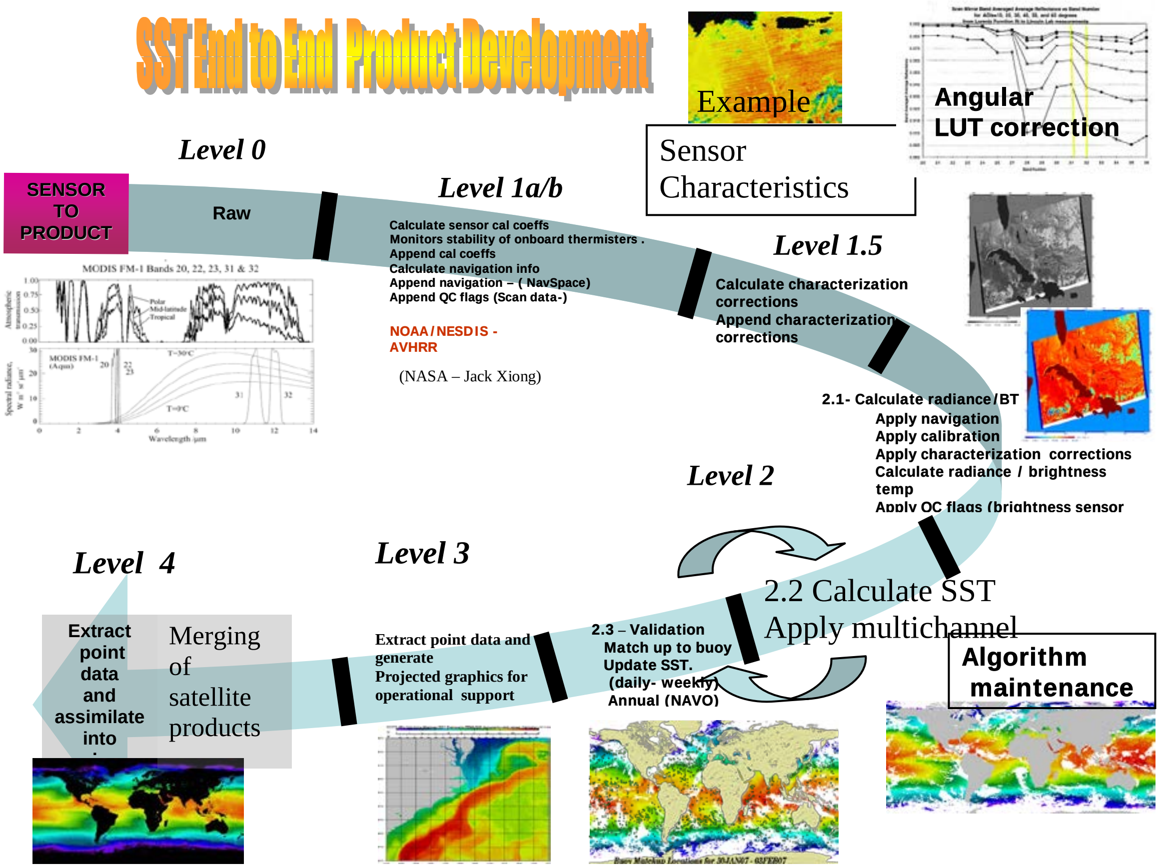

Figure 2: End to End - "Sensor to Product" Cycle for SST Products

In Figures 1 and 2 the procedures (steps) are identified that are currently performed in the generation of operational ocean products. These procedures include the integration of Cal/Val procedures into the daily processing. These steps are critical for the end product and must be performed in order to insure a reliable and accurate product.

The responsibility and expertise required to perform each of these steps will be detailed in the following sections as we define the Cal/Val plan. Additionally, improved methods and automation of these procedures are required in constructing a Cal/Val program and will be detailed in the "Investment strategy" section of this document.

Many of these procedures outlined in Figures 1 and 2 are currently in place at each of the agencies. Although slightly different at NOAA, NASA and Navy, similar procedures are performed many times leveraging across agencies to define the operational product. The procedures require better inter-agency coordination to improve connectivity to the NPOESS Cal/Val program. Present operations and research products require these procedures in the product generation. The product uncertainty increases severely if any of these steps is omitted or not completed correctly.

The ocean government team recognizes that the procedures outlined here are required in the generation of operational products and must be performed with the NPP and NPOESS program to provide viable ocean products from VIIRS.

A) Steps in Ocean Color product generation: {Figure 1}

a) **Raw Data Records (RDR):** The Level 0 digital counts (DC) at the top of the atmosphere contain both the atmospheric radiance and the water leaving radiance. For a typical ocean color scene over 90% of the at-sensor radiance comes from the atmosphere. As the ocean signal of interest is only 10% of the total signal, a 5% sensor calibration error can result in as much as a 50% error in the ocean radiances. This initial step is to convert these DC to radiances.

b) **Generation of the calibration Look up Tables (LUTs) to convert RDR digital counts to top of the atmosphere radiance SDR**. This is the responsibility of NGAS coordinated with the MODIS Characterization Support Team (MCST) program at NASA – Goddard (Jack Xiong; reference). This step converts the level 0 RDR to Level 1 data of SDRs and is critical toward ocean color product generation .The calibration Look-Up Table (LUT) must be determined routinely (i.e. weekly) and is based on monitoring the solar diffuser, lunar looks, etc., all of which effectively track the major changes in sensor calibration. Any long term tends that may be present are used to predict the changes in the LUT for spectral sensor degradation and may be used for more accurate real time SDR generation. Changes in the sensor stability and thus the SDR will affect ocean color products and must be determined on a weekly basis.
c) Sensor navigation is also integrated in Level 0 RDR to Level 1 SDR conversion based on modeling the spacecraft ephemerides with sensor geometry. Spacecraft navigation data are included in the SDR Level 1 data generation and are critical for Level 2 processing.

c) **Vicarious calibration –** This procedure is to fine-tune the Level 2 products by comparison of precise measured in-water ocean radiances with atmospheric models and the LUT. This step requires in situ measurements within a spatially stable ocean region where the in-water remote sensing reflectance is accurately measured and then theoretically propagated to the top of the atmosphere (TOA) at the satellite altitude by inverting the atmospheric correction procedure used in the generation of ocean products. (Franz, et al., 2007) These in situ-based TOA radiances are matched up with satellite TOA radiances to refine the LUT and produce a more accurate SDR. Demonstrably accurate in-water radiances are required for this fine tuning and are critical to the reduction of the level of uncertainty to that required for ocean products (Brown, et al., 2007). The frequency of vicarious calibration, the number of points required to perform a calibration, and the accuracy of in-water radiance measurements are issues which have a direct bearing on the uncertainty of the end product. The vicarious calibration and adjustment for the long-term changes in the LUT are critical toward the validation of the products and the inter-satellite comparisons.

This step requires in-situ observations at a spatially homogeneous ocean region in order to perform the calibration. The measurements of the surface ocean color radiometry are critical to sensor calibration and must be tied to NIST standards. Current methods for SeaWiFS and MODIS have used the MOBY instrument located off the coast of Hawaii (Eplee and McClain, 2000; Brown, et al., 2007).

d) **Atmospheric correction procedures**: The SDR data representing the TOA radiances include large signals from the atmospheric and ocean surface reflectances. The TOA radiances require removal of the atmospheric components (gas absorption as well as Rayleigh and aerosol scattering). These components contribute approximate 90% of the signal so that this removal step is critical for the accurate estimation of ocean color reflectances. There are several procedures that have been used in operations and research processing using bands in the SWIR and NIR (Gordon and Wang, 1994a, Gao, et al., 2007; Wang, 2007). Significant advances have been made in the last 5 years, especially for coastal atmospheric correction that are presently used in operational processing by Navy, NOAA and NASA. These methods are being applied to present satellite data (SeaWiFS and MODIS) in order to determine the remote sensing reflectance (RSR). The accuracy of the ocean product is highly dependent on the accuracy of the atmospheric removal process. There are issues in this step that are critical to the uncertainty of the product which include 1) the estimation of the aerosol optical depth, 2) the selection of the correct aerosol-type model, and 3) the ability to separate the water leaving radiance and aerosol scattering in the NIR channels.

The validation of this step requires satellite match-ups with the aerosol optical depth from in situ observations in order to assess if the correct aerosol model is being used for atmospheric correction. The uncertainty of the aerosol optical depth and the aerosol models used in the atmospheric correction are critical toward determine in the uncertainty of the final ocean products (RSR and bio-optical products). This can be performed using the MICROTOPS or the AERONET instruments over water (reference?).

e) **Remote Sensing Reflectance (RSR):** The spectral water leaving radiances (Lw) or RSRs are the fundamental EDRs from which all other ocean color products are generated. The RSRs are generated as part of the atmospheric correction by including corrections for the surface reflectance, bidirectional reflectance, surface glint and whitecap contamination. There are several research programs underway that will improve these corrections with will result in better RSR retrievals which will in turn improve the quality of all ocean products.

Validation of the RSRs requires observation of spectral RSR which can be obtained using either in-water or above-water radiometers. These measurements come from ship surveys, AERONET sites equipped with SeaPRISM (reference?), and moorings.

f) **Bio-optical products** are generated from the RSRs. These products are based on evolving algorithms to include Chlorophyll, Inherent Optical Properties (IOPs) including beam attenuation, absorption, scattering and backscattering) diffuse attenuation coefficient, 1% light level, Photosynthetically Available Radiation (PAR), diver visibility, and others. (Kopp et al. 2007)

B) Steps in SST product generation: (Figure 2)

Steps in SST product generation:

a) **Sensor Data Records (SDRs) –** Sea surface temperature retrieval generation begins with reliable and accurate SDRs. A sensor's Raw Data Records (RDRs) must be properly converted into SDR channel radiances. This requires accurate onboard calibration information to be properly applied when converting counts to radiance for the SDRs. In addition, radiance data must be quality controlled and geolocated within the SDRs. Navigation, time and data gap errors must be correctly identified and flagged in order for SST processing to determine if SDR pixels and/or scans are acceptable for product generation. NESDIS performs these functions for AVHRR, NASA for MODIS, and European and Japanese agencies for various foreign satellite data streams (AATSR, MSG, MTSAT, etc.). Data used for this include onboard sensor calibration information including blackbody radiances. The SDRs also have to be free of instrumental artifacts which can propagate and quantitatively magnify into SST retrieval errors. For MODIS this activity is performed by the NASA MCST group (Jack Xiong). Information used for this activity includes results from both pre-launch characterization and on-board calibration procedures.

b) **Sensor Characterization Corrections –** Sensor anomaly characteristics can introduce errors in the count to radiance conversion obtained from onboard calibration information (e.g. MODIS, and to a lesser extent AVHRR). Typically, studies are conducted to determine the characterization anomaly and the necessary correction to be applied. Next, a procedure to implement the correction into the operational processing stream must be developed. Implementation can occur either in the SDR or post-SDR generation processing depending on the anomaly to be corrected. E.g. for MODIS, calibration Look up Tables (LUTs) are utilized to correct for instrumental artifacts when converting digital counts to radiance. Data used for this activity include those from pre-launch calibration information; an on-orbit deep space roll maneuver used for scan mirror characterization, onboard sensor calibration information, and measured ocean radiances.

c) **Atmospheric correction procedures –** Corrections are applied on a pixel by pixel basis using the multiple channel SDR information and measurement geometry. Several forms of algorithms exist to derive SST from satellite data. The most popular forms of SST algorithms include regressing satellite channel brightness temperatures to either in situ SST measurements or against atmospheric transmission model results. Proper application of cloud detection and removal algorithms is very important for obtaining accurate SST coefficients.

   Experience with Terra MODIS indicates that the speed and accuracy with which a usable SST algorithm may be derived is significantly improved by using coefficients derived from comparisons with daily SST fields from other spacecrafts' radiometers which have previously undergone rigorous algorithm development. These coefficients provide the real time products until sufficient matchups have been generated over time to permit the independent derivation of matchup-based coefficients. Data used for this activity include satellite channel brightness temperatures, in situ ocean measurements and/or atmospheric model outputs.

d) **Validation of SST –** Satellite SST retrievals are compared to accurately measured in situ ocean measurements to determine the accuracy and uncertainty over time and at different locations around the globe. Typically, the SST retrievals are analyzed relative to numerous influential factors including view angles, water temperature, atmospheric water vapor content, atmospheric dust content, etc. These investigations normally lead to improvements in the calculation of SST coefficients in (c) above. The investigations can also identify issues in (a) and (b) when studied over long periods of time. Data used for this include satellite channel brightness temperatures, satellite view angles, geolocation information, a variety of different kinds of in situ SST measurements, atmospheric model outputs, ancillary atmospheric data sets and onboard calibration information.

e) **Skin SST –** The skin SST is generally cooler than the bulk temperature beneath by several tenths of a degree due to the heat flow from ocean to atmosphere. The thermal skin effect is variable, dependent on wind speed, heat fluxes and other variables, and is of a sufficient magnitude to introduce a significant fraction of the anticipated uncertainty in the VIIRS SST products. The use of highly-accurate ship-based radiometers to validate VIIRS skin SSTs is a valid and desirable approach, but they are relatively few in number and thus cannot easily provide samples from a large enough variety of atmospheric and oceanographic conditions to be considered the sole validation source. The larger data base of subsurface SSTs measured from drifting and moored buoys can be used to validate the VIIRS skin SSTs providing the thermal skin effect is adequately modeled. For MODIS, this is presently done using an average skin effect, but in the VIIRS era it is anticipated that a physical model based on our improving understanding of the skin layer will be used.

3.0 Ocean product "Calibration – Validation" Major Component Areas

We have structured the ocean calibration and validation in 6 investment areas which will enable the effective organization of the Cal/Val program. This is aimed at identifying the needs for research/development which will lead directly to operational improvements. These investment areas have been identified by the government team as "needs to be done". Within each of these areas there are some established Cal/Val activities which have been identified which are ongoing within the agencies or universities. We believe these or similar activities need to continue as stated in Section 2, Assumptions.

In the resource requirements sections we will identify current activities by agencies and indentify activity gaps that must be filled to have a coherent and effective Ocean Cal/Val program for VIIRS.

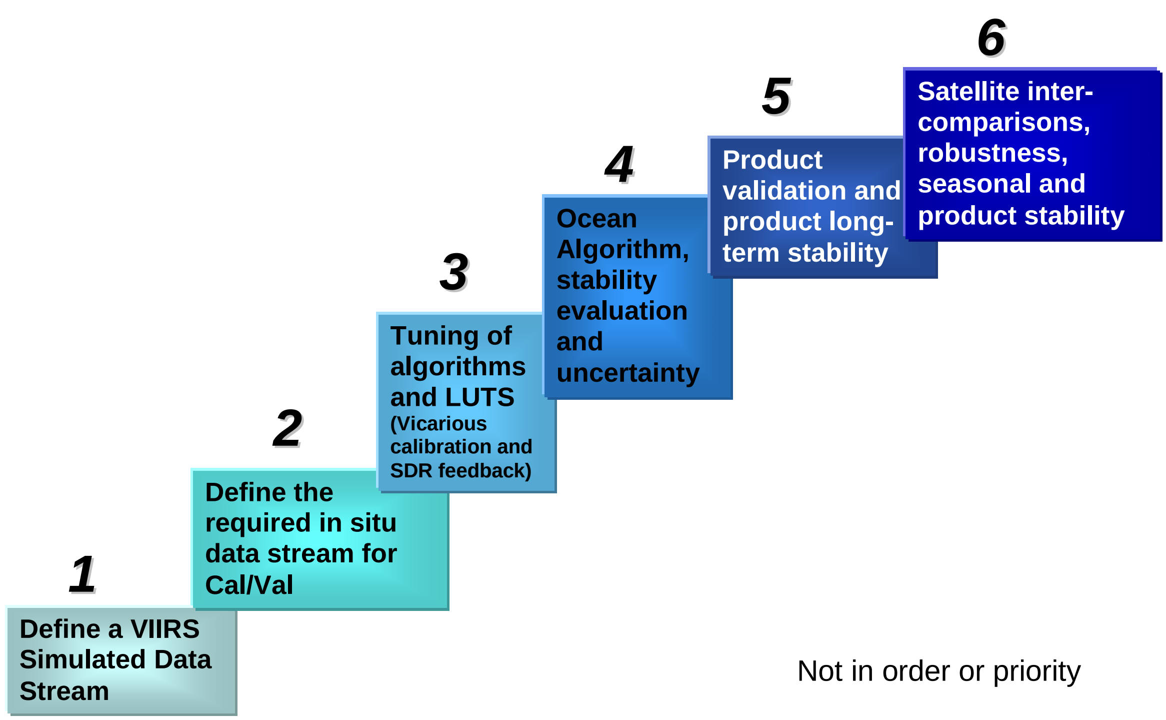

Figure 3: Major Components to a "Calibration-Validation" for VIIRS Ocean Products

1) **Define and developDevelop a Proxy VIIRS Data Stream and the sensor uncertainties (see Appendix A)..**
   - The sensor characterization of VIIRS will be used to establish a proxy data stream using re-cast MODIS data.
   - The proxy data will include realistic estimates of errors based on laboratory calibration data to estimate SDR uncertainty prior to launch.
   - The real-time data stream will be established for proxy VIIRS data in which sequential software updates to the Proxy data simulation will be performed as our characterization of VIIRS and the data formats becomes better defined.
   - The proxy data stream will be in the VIIRS format and made available in real time for operational and research evaluation.
2) **Define and develop the required *in-situ* data stream for Cal/Val (see Appendix B).**
   - Define 2 types of in situ data - one for vicarious calibration and a second for product validation.
   - Define where and what in situ data are required and how they are integrated into the “end-to-end” product cycle.
   - Define the critical validation site locations and ocean extremes required for validation.
   - Define the spatial and temporal uncertainty of the observations and the measurement protocols for both calibration and validation.
   - Determine protocols and the NIST traceability which are required for each in situ data set.
   - Identify the data base manager for these in situ data.
   - Define the data delivery time and protocols for delivery.
   - These data will be used by different groups as stated in the calibration and validation stages.
   - Develop a capability to collect insitu data for automated calibration and product validation using Aeronet/ SeaPRISM and MOBY data sets.
3) **Refining algorithms and Look Up Tables: (LUTS) for Vicarious calibration and SDR feedback (See Appendix C).**
   - Uses the results of the comparisons with the at-sea measurements to refine the Look up Tables that are introduced at the SDR level with ocean observations for both ocean color and SST.
   - Define the timeliness and update cycle by defining the temporal uncertainty and stability of the sensor and the algorithms.
   - Develop capability to perform rapid matchups of satellite and ocean parameters to optimize the ocean products.
   - Automate the vicarious calibration procedures and integrate within the SDR - EDR processing system.
   - Define vicarious calibration strategy for initialization (address immediately post-launch) and for long-term.
   - Address multiple approaches for initial vicarious calibration. Address the needs for short-time scales (Climatology, satellite matchup and in situ.)

- Develop new approaches for automated vicarious calibration and validation. Evaluate these approaches using insitu data sets from MOBY, A-MERI, AERONET SeaPRISM, Ship data etc. with existing satellites. Demonstrate a capability now (prelaunch) that will be used with NPP and C1.

4) Ocean Algorithm, stability evaluation and uncertainty (See Appendix D)

- Evaluate all aspects of the algorithm performance with the VIIRS proxy data and post-launch sensor data. This includes the definition of the expected algorithm performance in product development (e.g. the atmospheric correction algorithms in ocean color products).
- Examine the algorithms over the full range of expected conditions and define the limitations and uncertainties associated with seasonal variations, meridional variations, coastal vs. open ocean differences, cloud/land boundary effects, and impacts of varying atmospheric types (aerosols and Total Precipitable Water (TPW)).
- Determine the impact of sensor stability (LUT and vicarious calibration) on the algorithms' stability and on product uncertainty. What is the impact of changes in the sensor stability on algorithms and operational products?
- Demonstrate the algorithm uncertainty of the EDR using Proxy VIIRS data stream now (FY09Fy09-11) in preparation for NPP and C1.

5) Product validation and product long-term stability (See Appendix E) .

- Comparisons of at-sea- mooring, AERONET SeaPRISMAeronet/SeaPrism, M-AERI, MOBY) measurements (SST and RSR – Color products) with derived satellite products including their associated uncertainties.
- Define the spatial and temporal uncertainty of the match-up of in situ data and the satellite-retrieved geophysical parameters.
- Evaluate the ocean products in a range of environmental conditions which are defined by the availability of the required data sets. Ocean product evaluation should include atmospheric correction uncertainty (aerosols and TPW) and the ocean product uncertainty.
- Define the error estimates of the products in different conditions to include: sensor configurations, measurement geometry, illumination variability, coastal vs. open ocean, and environmental conditions (wind speed, air-sea temperature difference, etc.).
- Determine how the ocean product validation is influenced by the sensor stability.
- Demonstrate a capability for long term monitoring of Ocean EDR product validation. Track products trends for seasonal, latitudinal and environmental variability.

6) Satellite inter- comparisons, robustness, seasonal and product stability (See Appendix F)

- Define the protocols to compare the VIIRS ocean products with ocean products from different satellites.
- Determine the uncertainties introduced by spatial and temporal variability of the oceanic and atmospheric parameters into the match-ups between the at-sea measurements and the satellite products. This defines the acceptable temporal and spatial coherence scales of the matchups.
- Demonstrate the ability to maintain satellite ocean product continuity in near-real time.
- Demonstrate the methods which VIIRS will be evaluated against heritage instrument ocean products from MERIS, MODIS, AVHRR,

- Integrate present research cal/val procedures used for tracking continuity between satellites products (e.g. MODIS etc.) into Navy and NOAA operations. This is to prepare "operations" to accept VIIRS data from NPP and C1 for data continuity with current operational products used today.

4.0 Schedule and Milestone Plan by Product

These six components have been separated for specific tasks for each EDR by schedule and milestones. Within each schedule period, the numbers in this section refer to the major components for Cal/Val listed in the previous section.

Sensor Data Records SDRs. Note that the ocean team does not have primary responsibility for the SDRs but they will work closely with the SDR calibration team and the NASA PEATE to assure the best possible SDRs. The schedule and milestones will be set by the SDR team.

4.1 Sea Surface Temperature Primary EDR

Pre-launch: (Note: numbers represent the investment areas listed above.)

1. Proxy Data: Develop VIIRS Proxy data stream using MODIS data. Demonstrate VIIRS Proxy data stream to users so that they can prepare to use VIIRS data immediately after launch.

2. In Situ: Develop the next generation M-AERI, test and develop a deployment plan to be in place by launch. Develop techniques for automated comparison with M-AERI, buoy and other in situ SST as well as with other remotely-sensed SSTs (AVHRR, MODIS, AATSR, etc.)

3. Vicarious calibration: Integrate automated tuning of SST scheme with VIIRS proxy data stream.

4. Algorithm performance: Evaluate SST algorithms with VIIRS proxy data. Compare VIIRS proxy data with SST from radiative transfer models.

Intensive Calibration during First 90 days On-Orbit:

4. Algorithm Performance: Evaluation of SST algorithms with real VIIRS data.

5. Product validation: Comparison against, M-AERI, Buoy and radiative transfer model data

6. Inter-satellite comparison: Comparison with MODIS and AVHRR SST products including evaluating temporal, seasonal and meridional variations. Establish protocols for SST product continuity to add VIIRS products to the current time series of SST. Work with primary users to evaluate VIIRS SST data for their operational use.

Long term Cal/Val monitoring system:

4. Algorithm Performance: Evaluation of SST algorithms with VIIRS data.

5. Product validation: Comparison against, M-AERI, Buoy and radiative transfer model data

6. Inter-satellite comparison: Comparison with MODIS and AVHRR SST products including evaluating temporal, seasonal and meridional variations. Validate the SST product to add VIIRS products to the current time series of SST. Work with primary users to evaluate VIIRS SST data for their operational use.

Notes

Algorithm has extensive heritage from MODIS and AVHRR.
Candidate subject matter experts: Doug May (Navy), Peter Minnett (UMiami), Bob Evans (UMiami), Sasha Ignatov (NOAA-STAR), Ed Kearns (NOAA-NCDC)
Primary users: Navy, NOAA and TBD (pending IPO document in preparation)
Primary Comparisons: MODIS/AVHRR products

4.2 Ocean Color water leaving radiances EDRs

Pre-launch:

This is the product of applying the atmospheric correction to the SDRs.

1 Proxy Data: Prototyping with MODIS-based proxy VIIRS data

2 In Situ: Vicarious calibration uses in situ measured water leaving radiances (e.g. MOBY data) and inverts the atmospheric correction to calculate the at-sensor radiances. Establish automatic procedures for using MOBY data and creating match ups with the proxy VIIRS data.

3 Vicarious calibration: Establish the protocols for this using the VIIRS proxy data, MOBY data and the atmospheric correction algorithms to perform the vicarious calibration.

4 Algorithm performance: Test run the atmospheric correction algorithms using proxy VIIRS data and evaluate the product using MOBY and other data.

6 Inter-satellite comparison: Establish the protocols and algorithms for comparison of VIIRS data with MODIS and MERIS data in preparation for VIIRS flight data.

Intensive Calibration during First 90 days On-Orbit:

4 Algorithm performance: Assess mean values and distributions of remote sensing reflectances for central ocean gyres against theoretical predictions as well as mean values from a decade of SeaWiFS data collection.

5 Product validation: Validate products using data from optical calibration cruises, and AERONET SeaPRISM sites and other in situ data. Validate open ocean data against mean values from the blue waters of central gyres.

6 Inter-satellite comparison: Conduct direct comparisons with MODIS, MERIS or other available ocean color sensor remote sensing reflectance data.

Notes

Primary Comparisons: MODIS/SeaWiFS/MERIS and in situ data from MOBY and other sources

On-orbit Focus with MODIS: Comparison with MODIS products

On-orbit Focus without MODIS: Comparison against MERIS, SeaWiFS and in situ data

Long term Cal/Val monitoring system:

4 Algorithm performance: Assess seasonal and year-to-year trends relative to mean distributions estimated from SeaWiFS. Look for changes or differences that may stem from the sensor calibration/performance and report results back to the SDR Cal/Val team.

5 Product validation: Validate products using data from optical calibration cruises, AERONET SeaPRISM sites and other in situ data. Validate open ocean data against mean values collected from the central gyres.

6 Inter-satellite comparison: The primary comparison is with the MODIS products, or if without MODIS will be a comparison against MERIS, SeaWiFS or other contemporaneous satellite data.

Candidate experts: Menghua Wang, Mike Ondrusek, Curt Davis, Bob Arnone, P. Lyon, Karen Patterson, Linda Stathoplos, Paul DiGiacomo, Rick Stumpf, Chuck McClain, Kevin Turpie, Stan Hooker, Dave Siegel,

Primary users: Navy, NOAA and TBD (pending IPO document in preparation)

4.3 Ocean chlorophyll EDR

Pre-launch:

1 Proxy Data: Prototyping with MODIS-based proxy data at NGAS and in Navy and NOAA operational processing systems.

2 In Situ: Focus on the development of open ocean and coastal validations sites that include the full suite of optical measurements and HPLC chlorophyll for validation. Coordinate with on-going activities and sharing data with those endeavors.

Intensive Calibration during First 90 days On-Orbit:

4 Algorithm performance: Compare NPOESS chlorophyll product to the Navy and NOAA products produced with VIIRS SDRs and their operational data systems.

5 Product validation: Validate against open ocean and coastal ocean in-situ validation data.

6 Inter-satellite comparison: Compare against MODIS, MERIS or other contemporaneous ocean color satellite data. On-orbit will focus with MODIS, MERIS, and SeaWiFS products as well as aircraft and in situ data.

Long term Cal/Val monitoring system:

4 Algorithm performance: Assess seasonal and year-to-year trends relative to mean distributions as measured from SeaWiFS. Look for changes that could be related to the sensor calibration/performance and report results back to the SDR Cal/Val team.

5 Product validation: Validate products using data from optical calibration cruises, AERONET SeaPRISM sites and other in situ data for sites that include HPLC chlorophyll measurements. Validate open ocean data against mean values for the central gyres.

6 Inter-satellite comparison: The primary comparison is with MODIS products, or if without MODIS will be a comparison against MERIS, SeaWiFS or other contemporaneous satellite data.

Candidate experts: Curt Davis, Ricardo Letelier, Rick Stumpf, Chuck Trees, S. Hooker, C. McClain

Primary users: TBD (pending IPO document in preparation)

5.0 Resource Requirements and Tasking Strategy

To accomplish these pre- to post-launch Cal/Val activities for the SST and Color EDRs, we have identified ~28 tasking areas which are based on the six major component areas for cal/val (Table 1). This investment strategy has been developed to address an "*end-to-end*", sensor-to-product capability leading to operational capability, readiness and automation of Cal/Val procedures. The tasking is based on a coordinated interagency (NOAA, NAVY, and NASA, supported by academic researchers) plan with the IPO beginning with the Preparatory project for NPP ocean products. Although there is uncertainty in the funding and therefore participation by several agencies, we have identified Cal/Val collaborations which will build a sound interagency program. This plan is designed to define an "*end-to-end*" plan to identify and leverage ongoing activities and capabilities and recognize scientific and operational gaps which must be addressed for continuity of ocean products within operations. The plan initially will address the NPP instrument, but is expected to be extended to C1 and C2 and thus establish a long-term Cal/Val program. The investment tasking identifies a prelaunch sensor risk reduction activity, beginning with MODIS-based VIIRS proxy data and extending through inter - satellite comparisons with a goal of enabling the long-term continuity of existing SST and Ocean color operational products.

All of these identifying tasks are required in order for the VIIRS ocean products to meet present operational capabilities and requirements**. Additionally, these tasking provide the necessary backbone for "minimal" Cal/Val requirements that are necessary to meet the present requirements for operational products.** Successfully meeting these requirements will provide the validated VIIRS data stream which can be the basis of future ocean operational and research needs.

The activities are identified as 28 tasks broadly outlined in Table 1 and cover the broad Cal/Val plans required for the NPOESS era. These tasks are identified as the minimal set needed for a viable Cal/Val program for VIIRS ocean products. This tasking is linked to the end to end system and can be linked to both the operational and research programs. Note that many of the "28" tasking investments are cross threaded to all of the products (example: in-situ data collection and product validation). (Throughout the text these items are referred to in notation as #1 - #28 .)

Science and Operational Investments					
		Components			
1	2	3	4	5	6
Proxy VIIRS Data Stream	"Insitu" data collection	Vicarious calibration and LUT tuning	Algorithm Performance	Product Validation	Inter-satellite calibration
1. Software versions - MODIS to VIIRS	6. Moby or AHAB calibration in situ data	12. Evaluation of Vicarious cal using MOBY, AERONET, Open Ocean Gyre water	17. Evaluation of ocean color Algorithms with VIIRS Proxy Data and after launch VIIRS data	21. Automated match up of ocean color imagery products with in situ data	25. Establish protocols for ocean color products continuity (VIIRS with MODIS/MERIS/ SeaWIFS) Seasonal/ Temporal evaluation
2. Integrate Sensor characteristics into Software versions (Crosstalk, Polarization, etc)	7. AERONET - SeaPRISM data stream	13. Automated tuning of the SST algorithms	18. Evaluation of SST algorithms with VIIRS Proxy data and after launch VIIRS data	22. Automated matchup of SST (Bulk/Skin) with VIIRS data	26. Establish protocols for SST product continuity- MODIS/AVHRR/ METOP, Seasonal/ Temporal evaluation
3. Integrate Proxy software into NRTPE	8. Ship Cruise Data - field data stream , bio-optical and M-AERI- buoy measurements	14 Coupling skin and bulk (M-AERI and Buoy) SST measurements with VIIRS products	19. Evaluation of the Atmospheric Correction methods	23. Ship cruise data (SST and Color) match up with VIIRS imagery	27. Demonstrate real time continuity of Ocean Color products
4. Demonstrate VIIRS data stream to users.	9. Insitu data management tools	15 Develop methods to automate Vicarious Calibration of color and SST data	20 Comparison of VIIRS SST and radiative transfer SST models	24. Determine if the available insitu data can validate products spatial/ temporal variations	28. Demonstrate real time Continuity of SST products
5. Model VIIRIS proxy data using MODIS Lw to TOA	10. Buoy match ups of SST	16. Generation of Rayleigh Look up tables for atmospheric correction			
	11. Instrument upgrades and NIST traceability				

Table 2: Tasking Elements

The required activities are supported in four ways:

1. Calibration and validation of the SDRs will be performed by the IPO SDR Cal/Val program.
2. **Activities currently ongoing within the different agencies are assumed to continue (NASA PEATE and VIIRS science team, NOAA MOBY, Navy NAVOCEANO data processing, etc.).**
3. Activities currently performed through existing IPO-funded programs that are assumed to continue to support the program.
4. The remaining critical pieces will require additional support from the IPO. In FY09 some additional tasks have been identifies to address this table and are explained and included in Appendix I.

The interagency activities and investments listed in (2.) above are critical to the success of the cal/val program and, since they are outside of the IPO's direct influence, must be fostered through significant interagency interactions and cooperation. We have identified efforts ongoing at Navy, NOAA and NASA which contribute to this table and are working to coordinate those activities into the overall plan.

A. Immediate Investment Requirements.

Through a comparison of the pre-launch requirements and the currently funded activities, the following activities are identified as having the highest priority for immediate funding:

1) Establish a VIIRS proxy data stream (minimum length of 2 days) and make it available to both the research evaluation team and the operational community. A team is required to implement a proxy VIIRS data stream including NASA, Navy, NOAA-NCDC and GRAVITE as participants.
2) Couple the ocean requirements and measurements into the AERONET network design including adding SeaPRISM measurements at additional coastal sites. Automate the ability to use the AERONET network for aerosol and ocean product validation.
3) Develop a cross-agency ship cruise plan for validation for ocean products within 90 days of launch, and secure the necessary ship time and other required resources.
4) Automate the vicarious calibration methods for SST and ocean color.
5) Establish international coordination for Cal/Val programs (through GlobColour and CoastColour/ GHRSST)

B. Additional investments:

6) Identify the probable impact of VIIRS sensor characteristics by comparing VIIRS proxy data products of Color and SST against MODIS data products. This should include variations across a swath and seasonal and meridional uncertainties.
7) Identify the requirements and data streams necessary for vicarious calibration. Outline the activities, and establish a plan for automation for vicarious re-calibration of the sensor calibrated radiances using in situ measurements of the spectral water leaving radiances.
8) Evaluate the utility of one or more coastal product validation sites, e.g. AERONET/SeaPRISM sites with additional in situ data for chlorophyll and other products and develop an inter-agency plan for the operation of and use of data from these sites.
9) Determine the utility of present satellite SST Cal/Val program for VIIRS on NPP and develop a plan for validation of VIIRS SST products using match-ups with MODIS data, NOAA buoy/drifter data, M-AERI and other bulk and surface SST data.
10) Support, link with and expand existing programs for quality control of the in situ data. This should include tracking sensor and platform metadata, measurement performance metrics, and automated generation of a comprehensive match-up database.
11) Develop and deploy the next generation of the M-AERI instrument for SST validation.
12) Automate the integration of skin temperature data from M-AERI and other sources with near surface SST models for use in cal/val procedures.
13) Evaluate the possible spatial and seasonal influences on the SST algorithm using VIIRS Proxy data, and compare with those from existing sensors. Investigate implications that result from different atmospheric conditions, and prepare corrections as needed for implementation when VIIRS data are available.
14) Investigate possible impacts on the regional vs. the global SST retrievals using VIIRS Proxy data as derived from MODIS data.
15) Implement a real–time Radiative Transfer Model for SST with appropriate forecast field and ancillary datasets to simulate TOA radiances.
16) Determine the methods and protocols for global and regional inter-comparisons of multiple satellite products (MODIS, SeaWiFS and MERIS).
17) Assess the in situ SST data availability, including the spatial and temporal requirements for each type of Ocean Cal/Val from real-time to CDR-level activities.
18) Investigate the anticipated number and type of of buoys, drifters, and ship-based measurements that are expected to be supported by the larger ocean research community throughout the out years of the project.
19) Integrate the MODIS-derived VIIRS proxy SST data into the GHRSST data stream to test possible impacts on blended and merged SST products.
20) Characterize the diurnal response associated with the skin-bulk temperature relationship, including influences of buoyancy and momentum fluxes on the relationship.
21) Develop and distribute open-source community tools for satellite comparison validation using in situ data from a variety of open ocean and coastal environments, including techniques for the distribution of data required for the comprehensive matchup database (satellite, in situ, and anciallary data) among the community members using the latest Server Oriented Architectures.

-(May 2009) Last year these 21 efforts were the keystones that we believe important toward initializing the (FY09 – 10) the cal val programs. These efforts are the focus of our FY09 – 10 milestones (listed on the 1498 Forms included in Appendix I).

C. Ongoing Cal/Val activities and investments: (updates May 2009)

We have identified ongoing investments from NOAA, NASA, Navy and the IPO that support aspects of this Cal/Val investment strategy (Table 1). These interagency efforts address not only the EDRs but also the SDRs which are tightly linked to ocean Cal/Val activities and many times are difficult to separate. We are now linking these interagency activities with the investment strategy to identify both the personnel, level of effort and responsibility.

Table 2 identifies many pertinent NPOESS ocean Cal/Val activities for both the SST and ocean color activities. The personnel identified are included in the list of Subject Matter Experts that are included in the ocean Cal/Val team. Note: Additional programs and contributions are expected from outside agencies and universities as the Cal/Val efforts evolve, however it is not our intent to identify ALL ocean research activities, but to assemble a coordinated plan that meets the minimal requirements for IPO.

Organization	Sponsor	Contact	Objective
SST			
NRL	SPAWARS	Rowley	Data assimilation / diurnal variability
Navy	IPO	May	SST algorithms evaluation
NOAA	IPO	Ignatov	SST algorithms evaluation
U. Miami	IPO	Minnett, Evans	SST algorithms evaluation
NOAA	NOAA	STAR	Research activities
NASA	NASA	Feldman, Patt	NASA PEATE / prepare for the NPP
U/ Wisconsin	IPO	Gunther	upgrade the M-AERI instrument
NAVY	NAVO	May, Coulter	prepare for NPOESS, IDPS etc
NOAA	NOAA - NDE	Stathoplos	Data formats for VIIRS
Ocean Color			
NRL	SPAWAR	Lyon	Gap fillers, Automated validation sites, APS upgrade
NAVO-	NAVO	Matulewski	identify data stream, IDPS setup at NAVO
NOAA	IPO	Wang	Atmospheric correction - Rayleigh tables
NOAA	NOAA	Ondrusek	Moby buoy, AHAB
Oregon State	IPO	Davis	cal val plan, coastal product validation
NASA	NASA	Feldman . Patt	NASA PEATE / prepare for the NPP
NASA	NASA - NPP	Turpie	Evaluation of VIIRS sensor and product
NOAA	NESDIS	DiGiacomo	Research for VIIRS into Coast Watch
NOAA	NOAA Operations	Stathoplos	Preparing VIIRS for NOAA Operations

NOAA	NOAA - NDE	Stathoplos	Data formats for VIIRS
NIST	IPO	Johnson	Sensor characterization
NRL	IPO	Lucke, Snyder, Gao	Sensor characterization and impact on atmospheric correction
NASA	IPO	Esaias	Ocean color
NRL	IPO	Arnone	Cal/Val team leader

Table 3: Current funded interagency activities in Ocean Cal/Val

Presently we have identified Subject Matter Experts (SMEs) listed in Table 3, who will be involved with the Cal/Val and exploitation of the VIIRS sensor EDR products into research and operational products. Additional SMEs will be added as the Cal/Val program evolves.

(May 2009) Update: additional SME have been added based on tasking by the IPO to address the thrust areas.

Subject Matter Experts

	Navy		NOAA		NASA		Academic		IPO		Others
1	R. Arnone	11	P .DiGiacomo	21	C.McClain	31	C. Davis	41	J. Zajic	51	C. Johnson
2	P. Lyon	12	M. Wang	22	K. Turpie	32	P. Minnett				
3	Matalewski	13	M Ondrusek	23	W. Esaias	33	C. Trees/ Alverez				
4	D. May, Caylula Cayloga	14	R. Stumpf	24	Feldman	34	B. Emery				
5	R. Lucke -	15	S. Ignatov	25	S. Hooker	35	R. Letelier				
6	W. Snyder	16	L. Stathoplos	26.	Franz	36	R. Evans				
7	Gao	17	E. Kearns	27.	Werdell	37	P. Lee				
8.	Gould					38	Zibordi				
						39	Ahmed				
						40	Jones				

Table 4: Subject Matter Experts involved in VIIRS Ocean Cal/Val

D. Reprocessing of Ocean products:

Operational products do require some degree of short term reprocessing for stability and to maintain a time series. Some current operational ocean products at both NOAA and NAVY products are constructed with a dependence upon a consistent and continuous time series. Requirements to meet these specific needs should be integrated into Cal/Val procedures in order to support these types of operational products. Additionally there are specific needs for reprocessing that have been identified for the NASA and NOAA research applications, such as the construction of Climate Data Records. (Reference needed here.)

Examples of current operational reprocessing needs:

1) Navy- Ocean color products (e.g. diver visibility) are required on a daily basis to meet specific operational requirements. To meet the requirements for this product in highly cloudy areas, the most recent cloud free valid retrieval is used. For these daily products the latest pixel composite of the last 2-3 weeks or at times extending to several months of image products is used to fill in bad or cloudy pixels. In addition ,the mean and variance of the daily images are generated to provide the user with an estimate of the product validity. This product requires that the satellite is properly calibrated and stable for this time period and that the changes in the LUT are not highly variable. If necessary and substantial calibration and corresponding LUT changes do occur, than additional reprocessing is required to account for these changes and produce a consistent data set.
2) NOAA- Harmful Algal Bloom (HAB) products similarly require that analogous water leaving radiance and chlorophylls field be generated on a daily basis, and compared to regional statistics for the previous several months. The HAB product requires that the ocean color products be computed using a stable satellite calibration for several months in order to determine the anomaly field. If satellite calibration changes occur in the LUT during this period, than reprocessing is required to account for the variability before statistics can be recalculated and the real-time data can be used to detect anomalous blooms.
3) Navy – SST retrievals are validated against in situ measurements every day using the latest 30 days or more of matchups. Improvements in the calculation of SST are derived from these matchups. When a LUT update or other retrieval improvement is implemented into operations, reprocessing of previously collected SST retrievals is necessary to generate an updated 30 day matchup data set. Otherwise, the Navy validation analysis cannot be accurately performed until the improvement has been operational for 30 days.

The NOAA-NESDIS National Climate Data Center (NCDC) is the NOAA center for the stewardship of long-term data sets required for climate analysis. In addition to serving as the long-term archive of all RDRs from the NPP and NPOESS platforms, NCDC is developing plans for engaging the research community in instrument-related investigations. The results from these studies will be used to routinely reprocess NPP and NPOESS datasets to obtain climate-quality SST and ocean color data sets from VIIRS. These data will be merged with data from other sensors to create decadal-scale global time series which are consistent across missions, and are largely free from instrument-related biases and trends. These so-called Climate Data Records (CDRs) will be subject to periodic reprocessing as the knowledge of the sensors' behavior and improvements in radiative transfer modeling, aerosol detection, and other technical details are advanced by the research community. These CDRs will form the basis of the generation of climate analyses and Climate Information Records (CIRs) which can be utilized by entities well beyond the remote sensing community. Discussions are ongoing with NOAA's Ed Kearns through the "Climate data record and Scientific Data Stewardship" program led by John Bates and Jeff Privette at NCDC.

Consistent with its archive-based program, the Ocean Team will facilitate development of data flow architecture and tools necessary to ensure NPOESS Cal/Val data, including that from other disciplines, can be stored and redistributed in a low-cost and efficient fashion. This will include tools for near real time routine comparison of NPOESS EDRs with operational field measurements and EDRs from other sensors.

6.0 Status

The government ocean Cal/Val team conducted 2 meetings with participation from subject matter experts. The SST group met on August 11, 2008 at Stennis Space Center and the Ocean Color group met on August 16, 2008 in Silver Spring, Md. A draft of the Cal/Val plan was distributed at these meetings and the groups discussed their concerns and present involvement in the Cal/Val activities.

The plan received comments from several members of the group and the plan was rewritten and expanded based on comments from the group members and the IPO. The present plan will be distributed to the community and the IPO for comment prior to implementation.

(May 2009) –

Substantial progress has been made in the development of the cal/val plan in the last 5 months. Additional SME, have been selected to address requirements #1-28 (table 1) of the 6 thrust areas. These SME have written milestones and deliverables in the form of DD1498's which address the requirements and investments outlined above within this cal/val plan.

These 1498 plans of many of the SME's are included as Appendix I. Their milestone and delieverables specifically identify the components (#1 – 28) of the for cal val plan (Table 1 above). The plan calls for theseThese milestones and deliverables to be accomplished in FY 09 and FY10. Our goal was to try to address ALL aspects of the 28 blocks and identify short – falls and gaps. Based on these inputs we have identified SME addressing the topics in Table 1 in Table 2 (below).

1	2	3	4	5	6
Proxy VIIRS Data Stream	***"Insitu" data collection***	***Vicarious calibration and LUT tuning***	***Algorithm Performance***	***Product Validation***	***Inter-satellite calibration***
1. Software versions - MODIS to VIIRS	**6. Moby or AHAB calibration insitu data**	**12. Evaluation of Vicarious cal using MOBY, AERONET, Open Ocean Gyre water**	**17. Evaluation of ocean color Algorithms with VIIRS Proxy Data**	**21. Automated match up of ocean color imagery products with insitu data**	**25. Establish protocols for ocean color products continuity (MODIS/MERIS/ SeaWIFS) Seasonal/Temporal evaluation**
30, 2, 3, 46	**12, 11**	**2, 12,11 ,**	**1,13, 2, 13, 40,**	**2, 7,12, 13, 40,44, 47**	**13, 2,**
2. Integrate Sensor characteristics into Software versions (Crosstalk, Polarization, etc)	**7. Aeronet - SeaPrism data stream**	**13. Automated tuning of the SST algorithms**	**18. Evaluation of SST algorithms with VIIRS Proxy data**	**22. Automated matchup of SST (Bulk/Skin) with matchup**	**26. Establish protocols for SST product continuity- MODIS/AVHRR/ METOP , Seasonal/Temporal evaluation**
2.,11, 46	**2, 40, 47,49, 51,53**	**3, 10, 42**	**3, 10,**	**3, 42, 49**	**13, 42, 41, 3,**
3. Integrate Proxy software into NRTPE	**8. Ship Cruise Data - field data stream , bio-optical and MERIS- buoy measurements**	**14. Coupling skin and bulk measurements MERI and Buoys comparison and analyses for SST**	**19. Evaluation of the Atmospheric Correction methods**	**23 Ship cruise data (SST and Color) match up with satellite imagery**	**27. Demonstrate real time continuity of Ocean Color products**
30, 3, 14, 46	**7, 13, 48, 45,40**	**41,42, 5**	**11, 6, 13**	**2, 12,13,40,49, 44,7, 53**	**14, 4,**
4. Demonstrate VIIRS data stream to users.	**9. Insitu data management tools**	**15. Develop methods for automated Vicarious Calibration**	**20. Comparison of radiative transfer SST models**	**24. Determine if the available insitu data can validate products space/temporal**	**28. Demonstrate real time Continuity of SST products**
3, 14, 4, 50	**45, 48**	**2, 11, 12**	**10, 41,**	**44, 45,48**	**3,**
5. Model VIIRIS proxy data using MODIS Lw to TOA	**10. Buoy match ups of SST**	**16. Generation of Rayleigh Look up tables**			
20, 21	**3, 42**	**11,**			
	11. Instrument upgrades and NIST traceability				

NAVY	NOAA	NASA	IPO	Academic	Others
1 Arnone	10 Ignatov	20 McClain	30 Zijak	40 Davis (OSU)	50 Johnson (NIST)
2. Lyon ***	11 Wang	21 Turpie		41 Evans (RSMAS)	51. Jones (USC)
3. May, Mckenzie, CayulaCayolga	12 Ondrusek	22 Franz		42 Minnett (RSMAS)	52. Robinson (UK)
4. Metaluski	13 Stumpf	23 Hooker		43.	53. Ahmed (CUNY)
5, Rowley	14. Stapholopous	24 NASA Aeronet		44 Letcher (OSU)	
6. Gao	15, E. Kearns	25 Werdell		45 Trees /Allverez (NURC)	
7. Gould	16. DiGiacomo'	26 Feldman		46 Lee (MSU)	55. Zibordi
				47 Jones (USC)	
				48 Fargion (CHORES)	
				49 Emery (U Col)	

Table 5: List of Task Areas Addressed by Subject Matter Experts (Additional details for FY09 and FY10 available in Appendix I)

The details of each of these tasks and deliverables are beyond the scope of this plan however they are directly tied to the goals of the plans tasking statements. Some "Highlights" of these plans for FY09 – 10 are: .

1) Developing VIIRS proxy data stream
2) Installation of 3 AERONET SeaPRISM SeaPrism Sites for cal val activities.
3) Automation of match – up insitu and satellite products and determining the uncertainty.
4) Demonstrating methods for defining continuity of ocean products
5) Developing Web based data products / tools (insitu & satellite)
6) International coordination of cal/val activities.
7) Determining how the distribution of in situ datainsitu availability influences ocean product uncertainty.

7.0 Summary

This document provides an initial definition of a Calibration and Validation (Cal/Val) program for ocean products that will be derived from the Visible Infrared Spectrometer (VIIRS) to be flown on NPOESS Preparatory Project (NPP) and the operational NPOESS spacecrafts. The three goals for this program are: 1) to validate NPOESS program-delivered ocean products, 2) to evaluate the usability of VIIRS data and products for operational and scientific use by the agencies and 3) to evaluate the VIIRS products in relation to the heritage instrument products with the goal of producing consistent global time series from combinations of heritage instrument and VIIRS products to enable the assessment of climate variations.

This plan is meant to be a living document. We have begun implementation and it is expected that with implementation we will discover ways to improve the approach to be more accurate and efficient. We will instigate version control and add changes to the plan roughly every 6 months by issuing a new version of the plan. The goal is to provide the most cost effective and efficient Cal/Val program for the IPO and to assure the best possible VIIRS ocean products.

8.0 Schedule:

August 2008 Workshop with team members and primary EDR users (as provided by the IPO), modified and adapted the plan as necessary
August 2008 Initial Plan to IPO – coordination with other Cal/Val disciplines
September 2008 Updated Ocean Validation Plan delivered to IPO for review
October 2008 IPO accepts version 1 of the Cal/Val Plan and initiates funding for the program.
January 2011 – NPP Launch

9.0 References

S. W. Bailey, S. B. Hooker, D. Antoine, B. A. Franz, and P. J. Werdell, "Sources and assumptions for the vicarious calibration of ocean color satellite observations," Appl. Opt. **47**, 2035-2045 (2008)

R. E. Eplee, W. D. Robinson, S. W. Bailey, D. K. Clark, P. J. Werdell, M. Wang, R. A. Barnes, and C. R. McClain, "Calibration of SeaWiFS. II. Vicarious Techniques," Appl. Opt. **40**, 6701-6718 (2001)

R. E. Eplee, Jr. and C. R. McClain, "MOBY data analysis for the vicarious calibration of SeaWiFS bands 1–6," in SeaWiFS Postlaunch Calibration and Validation Analyses, Part 1, NASA Tech. Memo. 1999–206892 9, S. B. Hooker and E. R. Firestone, eds. (NASA Goddard Space Flight Center, Greenbelt, Md., 2000).

B. A. Franz, S. W. Bailey, P. J. Werdell, and C. R. McClain, "Sensor-independent approach to the vicarious calibration of satellite ocean color radiometry," Appl. Opt. **46**, 5068-5082 (2007)

Gao, B-C., M. J. Montes, R-R. Li, H. M. Dierssen, and C. O. Davis, 2007, An atmospheric correction algorithm for remote sensing of bright coastal waters using MODIS land and ocean channels in the solar spectral region, IEEE *Trans. on Geoscience and Remote Sensing*, V. 45(6): 1835-1843.

Giuseppe Z , B. Holben, I. Slutsker, D. Giles., D. D'Alimonte., F. Mélin, J. Bertho, D. Vandemark, H Feng, G. Schuster, B. Fabbri, S.Kaitala, J. Seppälä, 2009 "AERONET-OC: a network for the validation of Ocean Color primary radiometric products", Submitted to JAOT-O

H. R. Gordon and M. Wang, "Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: a preliminary algorithm," Appl. Opt. 33, 443–452 (1994a).

H. R. Gordon and M. Wang, "Influence of oceanic whitecaps on atmospheric correction of ocean-color sensors," Appl. Opt. 33, 7754–7763 (1994b).

Holben B. N., Eck T. F., Slutsker I., Tanré D., Buis J. P., Setzer A., Vermote E., Reagan J. A.,Kaufman Y. J., Nakajima T., Lavenu F., Jankowiak I. and Smirnov A. (1998). AERONET—A federated instrument network and data archive for aerosol characterization. *Remote Sens.Environ.*, **66**, 1–16.

Hooker S. B., Lazin G., Zibordi G. and McClean S. (2002). An evaluation of above- and inwater methods for determining water leaving radiances. *J. Atmos. Oceanic Technol.*, **19**,486–515.

Hooker S. B., Zibordi G., Berthon J.-F. and Brown J. W. (2004). Above-Water Radiometry in shallow coastal waters. *Appl. Opt.*, **43**, 4254–4268.

Kopp, et al 2007

Lucci et al, 2008

Lyon, P.E., R. A. Arnone, R.W. Gould, Z.P. Lee, P.M. Martinolich, S. D. Ladner, B. Casey. Automated Validation of Satellite Derived Coastal Optical Products. 2007 SPIE Optics and Photonics Meeting, San Diego, CA, 26-30 August 2007.

May et al, 2XXX

Mobley C. (1999). Estimation of the remote-sensing reflectance from above surface measurements. *Appl. Opt.*, **38**,7442–7455.

K. D. Moore, K. J. Voss, and H. R. Gordon, “Spectral reflectance of whitecaps: their contribution to water-leaving radiance,” J. Geophys. Res. 105, 6493–6499 (2000).

J. L. Mueller, D. K. Clark, V. S. Kuwahara, G. Lazin, S. Brown, G. S. Fargion, M. A. Yarbrough, M. Feinholz, S. Flora, W. Broenkow, Y. S. Kim, B. C. Johnson, M. Yuen, P. G. Strutton, T. D. Dickey, M. R. Abbott, R. M. Letelier, M. R. Lewis, S. McLean, F. P. Chavez, J. R. M. A. Barnard, A. Subramaniam, D. Manov, X. Zheng, J. L. W. Harding, R. A. Barnes, and K. R. Lykke, “Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 4: Special topics in ocean optics protocols and appendices,” NASA Tech. Memo. 2004-211621, NASA, Goddard Space Flight Center, Greenbelt, MD (2003)

P. J. Werdell, S. Bailey, and G. S. Fargion, “SeaBASS data protocols and policy,” in Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 2, NASA Tech. Memo. 2000–209966, G. S. Fargion and J. L. Mueller, eds. (NASA Goddard Space Flight Center, Greenbelt, Md., 2000).

Appendix A: Proxy VIIRS Data Stream and the sensor uncertainty.

VIIRS proxy data stream is required to provide a pathway to preparing for the NPP data stream. These data are required to:

1) prepare the operational customers used to using MODIS, AVHRR, etc. for handling the new data formats and processing issues that are associated with VIIRS data and

2) to assess the uncertainties based on the VIIRS sensor characteristics with existing operational algorithms.

Proxy VIIRS data should be generated using MODIS data modifying it to the data formats and sensor characteristics of the VIIRS sensor. Software development of VIIRS proxy data is required which includes software updates (versions) to properly replicate VIIRS sensor characteristics as we get additional information on VIIRS performance closer to launch. These sensor characteristics include: 1) VIIRS data format, 2) spectral channel convolution, 3) dynamic range, 4) Spectral cross talk (dynamic, electronic and other), 5) Stray light, 6) spatial sampling, 7) sensor polarization sensitivity and 8) other.

Many of the sensor response characteristics are being characterized now and will not be available until launch. However, we require a baseline VIIRS proxy data stream be available now to allow for EDR evaluation and for operational users to prepare for the VIIRS data characteristics.

There are several methods which Proxy data can be generated. NASA plans to use MODIS ocean water leaving radiances and propagating these radiances to the top of atmosphere by including the VIIRS sensor characteristics and the surface and the atmospheric component.

A second simpler approach involves modifying level 1 MODIS data to represent the VIIRS "type' proxy data. We suggest developing MODIS to VIIRS software which can be run on MODIS granules to represent the VIIRS data. We suggest applying this software to a MODIS data stream. We suggest using the available MODIS real time data stream (NRTPE) where Navy and NOAA are currently extracting MODIS data for operational products as the data distribution center for the VIIRS proxy data stream. Here VIIRS proxy data can be ordered in near real time for evaluation. The MODIS-VIIRS software should be available to users (research and operational) so that time series of VIIRS data like products can be evaluated in different ocean regions. .

We expect the MODIS to VIIRS software to change as the sensor characteristics become better known and that the software be available to the users.

Appendix B: In situ data measurement requirements

There are several types of in situ data required for Cal/Val.

1) Radiometrically calibrated data for vicarious calibration.
    a. Precise in-water water laving radiance (Lu) is requires at one or more sites with stable ocean and atmospheric conditions. The Marine Optical Buoy (MOBY) is the system currently used by NASA and NOAA for this purpose for MODIS and SeaWiFS (REFXXX). The in-situ instrument and the characteristic of this system have been described in the MOBY documents (References) in addition the location and the traceability to NIST. (Carol Please help here)
    b. The stability and scan characteristics of the VIIRS sensor may require the use of additional vicarious calibration sites. Presently concerns with the VIIRS sensor suggest that additional vicarious calibration sites are required to monitor the stability and provide sufficient "match ups" to perform more routine updates of the vicarious calibration. However, these sites are expensive to maintain and depending on availably the government team is exploring foreign bio-optical sites to augment a US site. A minimum of one US vicarious calibration site is required but the addition of additional foreign sites (such as the French BOUSOLE mooring) will be used if available.
    c. These instrument and the protocol standards have been established in the following documents (References – carol help)

2) In situ measurements for ocean product validation
    a. For SST these include:
        i. Buoy bulk measurements which are typically collected and maintained by the NAVO (Doug, references)
        ii. Skin SST measurements from M-AERI sensors which are ship based on ships of opportunity. The proposed plan is to regularly collect M-AERI data similar to what is being performed now. This entails several cruise ships equipped with M-AERI. (Peter, references)
    b. For Ocean Color these include:
        i. SeaPRISM and AERONET network for measurement of the Remote Sensing reflectance. (Holben et al., 1998; Hooker et al, 2002, 2004) These measurements are from platforms typically near the coast and automatically report back several times per day and include both the above water remote sensing reflectance (RSR) which is an EDR and the aerosol optical depths which are used in validating the atmospheric correction algorithms which have a direct bearing on the EDR. Currently there are ~ 7 AERONET/SeaPRISM systems deployed (see map) and additional sites are required for validation particularly of US coastal regions. Initial recommendations for sites are: Gulf of Mexico, West Coast. (Paul Lyon please add in here.)
        ii. Ship cruises to collect Cal/Val data are required especially during the intensive period during the first 90 days after launch. At a minimum, measurements that are required include: in-water radiometric profiles of water leaving radiance (e.g. with a Satlantic Hyperpro) for the remote sensing reflectance, spectral backscattering,

spectral absorption, spectral beam attenuation coefficient, spectral aerosol optical depth and chlorophyll. These measurements and protocols have been described in references (Mueller, et al., 2003).

iii. A data base of the SST and Bio-optical data is required to assemble and Quality Control (QC) the in-situ data which will be used in both the calibration and the validation. These data are difficult to assemble as they require maintaining the calibration and uncertainty of the in-situ measurement in addition to the spatial and temporal distribution of the measurements. A requirement is that these data streams be available in near real time (daily) which requires automation of the availably of these data. (reference)

1. Currently the in situ data bases are maintained at several locations. NAVO currently assemble approximated 10,000 buoy SST on a weekly basis which are used for SST match ups. We expect this capability to continue for the NPOESS program.
2. SeaBAM data base of bio-optical data is assemble by NASA and is populated primarily with data by NASA funded PI's (Werdell et al., 2000). We do not know if this data base will continue as it is dependent on NASA support and funded NASA investigators.
3. The AERONET network with SeaPRISM provides a continued data stream. Both Navy and NASA are planning on exploiting these data stream with automated procedures for matchup ups and data base managements.
4. The MOBY data set are maintained at Moss Landing Marine Laboratory supported by NOAA and NASA. These data are required in real time though a FTP site. (Mike Ondrusek add in here with reference.)

Appendix C: Tuning of algorithms and LUTS (Vicarious calibration and SDR feedback)

Vicarious calibration is presently performed on ocean color sensors such as SeaWiFS and MODIS to improve the calibration performed using moon looks and the onboard solar diffusers. Similarly, in SST products a type of vicarious calibration in performed to improve the SST product by modifying the coefficients. Both vicarious methods require in situ ocean data which are matched with the satellite products.

Ocean Color:

In ocean color processing the vicarious calibration tunes the calibration Look up tables (LUT) that are used to generate the SDRs. There are a number of references on ocean color vicarious calibration and the necessary for the procedure (references). Vicarious calibration is essential to ocean color product generation and must be performed similarly to what is being performed with SeaWiFS and MODIS sensors today.

The methods used to generate the LUT are discussed in the generation of the SDR's (Lucci et al. 2008) based on onboard solar diffusers etc. and are outside the scope of this discussion. However, it is critical that the LUT used for the SDRs be monitored for stability and predictability if the sensor is to be used for real time applications. The LUT significantly affect the ocean products and changes can occur depending of the sensor stability. These updates to the LUT should be monitored and updated weekly in order to use the SDRs and EDRs for real time products. Based on the weekly LUT used to generate the SDRs, a vicarious calibration is performed to "tune" these coefficients. The vicarious calibration is performed based on propagating the in-situ measured water leaving radiance that are obtained from NIST traceable in water instrument through the atmosphere to produce Top Of the Atmosphere (TOA) radiances and than matching those radiances with the satellite TOA radiances. The procedure and selection criteria are outlined in (Eplee and McClain, 2000; Brown, et al., 2007). A tuning of the calibration LUT is performed which is the vicarious calibration and brings the calibration coefficients into specification so that reliable ocean color products can be produced. The location of the NIST traceable in situ site is critical in addition to the quality of the in-water spectrometer. The quality of the instrument and site selection has also been described in referenced on the MOBY buoy installation (Brown, et al., 2007).

The frequency of the vicarious calibration is dependent on a) availability of the in situ and satellite data used in the matchup and b) stability of the VIIRS sensor. (Others???) In the initial phases following launch, vicarious calibration should be performed more frequency (with every good matchup) to track the stability. Methods to automate vicarious procedures are required so that real-time products can be produced with high confidence.

The ocean team will work with NOAA to assure collection of highest quality water leaving radiances for vicarious calibration of the VIIRS data. They will provide daily updates of the MOBY data for vicarious calibration and process that data through the atmospheric correction algorithm to provide at sensor radiances for direct comparison with the VIIRS measured radiances.

SST calibration:

There are several procedures for vicarious calibration of SST data. The Naval Oceanographic Office assembles SST (bulk temperature) reports daily which are used to match up with the SST derived from thermal satellite radiances. The satellite radiances come from the SDR with updated LUT based on board thermisters (again this calibration procedures are defined through the SDR calibration of the Look up Tables (LUT) (Lucci et al 2008). NAVO buoy reports are obtained globally with a well defined cloud screening process (the procedure are outline in May et al 2XXX). The uncertainty of the SST retrievals of buoys and satellite are used to monitor the algorithms coefficients for deriving the SST. The evaluation is done on a weekly basis to track any variability in the satellite bulk SST.

Additionally, the skin SST measurements are obtained from M-AERI ship data (REF XXX). The M-AERI provides precise NIST traceable radiation temperatures which are used to perform a vicarious tuning of the satellite brightness temperatures for the thermal IR channels. The frequency the skin temperature vicarious calibration needs to be defined and is dependent on the sensor stability.

Appendix D: Ocean Algorithm, stability evaluation and uncertainty

The EDR ocean products algorithms for the VIIRS sensor need to be validated for a full range of open ocean and coastal regions. This element of the Cal/Val activity addresses assessing the uncertainty of the ocean product based on the specifics of the VIIRS sensor and evaluating the expected results in different ocean regions and conditions. The activity will define algorithms' limitations based on such things as seasonally, latitudinal affects, coastal vs. open ocean and atmospheric conditions. The activity is initially based on using the VIIRS proxy data stream to evaluate how algorithms will perform compared with similar MODIS products. This activity is critical for preparing for post launch activities to evaluate the ocean products under limiting conditions.

Ocean color:

The algorithms used for ocean color products (atmospheric correction to produce Water leaving Radiance/Remote Sensing Reflectance and Chlorophyll) include both the atmospheric correction methods (Gordon and Wang, 1994a), and foam and glint removal (, Gordon and Wang, 1994b; Moore, et al., 2000) in addition to the in-water (bio-optical algorithms). Existing operational software for ocean color algorithms at NASA, NOAA and Navy to generate these ocean products are available and need to be modified to evaluate the performance of these algorithms based on differences between the MODIS and VIIRS sensor. Additionally, changes are required for addressing the specifics of the VIIRS data formats and specifics of the sensor. The VIIRS proxy data stream is planned to provide a capability to address these issues prior to the launch of VIIRS.

Atmospheric correction methods are critical to removing a major "noise" component to ocean color. Assessment of the limitations of the VIIRS sensor and the capability to effectively remove the atmosphere components are required in different conditions. Some of these conditions include 1) different aerosol types including maritime and continental with varying humidity conditions. This should also include absorbing aerosol conditions. 2) Different water type to include high backscattering water as in coastal waters or coccolithophore bloom, highly absorbing waters and open ocean and blue water conditions.

The evaluation of the water leaving radiance and the bio-optical algorithms is also required for different limiting conditions. This must also include the different atmospheric condition and different water types ranging from coastal to open ocean. In addition these algorithms need to be evaluated for seasonal and latitudinal variations such as the Southern ocean and the central gyres.

The evaluation of the performance of algorithms on VIIRS sensor proxy data can be compared with heritage sensor products such as the existing MODIS ocean products.

SST:

The performance of the VIIRS SST algorithms will be evaluated in a number of different ocean conditions representing seasonal and latitudinal affects. This includes using both the VIIRS proxy data and the Radiative Transfer Model (RTM) SST to assess the errors in full resolution global data sets. The activity will utilize MODIS data sets to estimate/assess accuracy of NGAS VIIRS bulk SST EDR algorithm and its suitability for assimilation into operational ocean analyses and models.

The RTM approach can be used for a comprehensive evaluation of the robustness and accuracy of the NGAS SST against simpler heritage techniques using synthetic and MODIS radiances.

These approaches are aimed at examining the SST algorithms over the full range of expected conditions (seasonal variations, latitudinal variations, coastal vs. open ocean, cloud/land boundary affects, varying atmospheric types (aerosols and Total Perceptible Water).

Appendix E: Product validation and product long-term stability

This element of the Cal/Val effort is directed at developing the protocols, methods and procedures where the VIIRS EDR products can be validated. Product validation is aimed at defining the limitations and conditions where the products are valid and under what conditions they fail. Product validation addresses different approaches to determining the uncertainty of the product some from match up with insitu data and others with aircraft, and other satellite products.

Product validation will address both the uncertainty of the insitu measurements (related to the temporal and spatial variability of the environment and the uncertainty of the protocols of the measurements.) For ocean color products, the protocols for chlorophyll and RRS have been established for SeaWIFS and MODIS (reference). For SST validation this includes both the skin and the bulk temperature measurement (reference).

Validation of ocean products must also be determined for different environmental conditions. For ocean color products validation this includes both the ocean and atmospheric correction methods:

1) Coastal waters and open ocean waters (turbid and clear) optically shallow and optically deep. Highly scattering and highly absorpting waters.
2) Varying aerosols types, absorbing aerosol and marine and continental aerosol types.
3) Different seasonal solar elevations.

For SST products, the environmental condition require:

1) Seasonal and latitudinal variability
2) Different temporal and spatial scales
3) Different atmospheric column - total precipitable water content, aerosols
4) Instrument observing conditions – cross-scan, mirror side and detector

The uncertainty of the products are required both on a short term (days to weeks) and a long term (months and years), Time series of the specific products are required.

For ocean color the Aeronet / SeaPRISM network provides both a validation of the atmospheric correction and the in water radiance (RRS) that can be used for validation. Currently ~ 7 Aeronet SeaPRISM stations are distributed in near coastal waters which provide an initial data stream for validation (Giuseppe et al, 2009). This network must be increased with additional sites to include different ocean and atmospheric conditions.

Additionally, the automated use of these data stream for validation is required to perform matchup and determine product uncertainty is required. Near real time product uncertainty of required for real time operational products to determine both the short and long term stability of products in the coastal water. Additional , SeaPRISM sites are required in open waters.

Ocean color ship cruises are required for validation. The instruments and protocols measured on the ship have been established and include a suite of optical and inwater measurements. (reference) .

The SST products require validation with match up buoys for bulk temperatures. A network real time buoy data is requires on a continuous bases to define the global and regional uncertainty of the product (May et al. 2006) . This is required on a weekly based for real time operations. Additionally, skin temperatures from the M-AERI are required from a ship based program to improved product validation. The coverage of the ship and frequency where data is required needs to be better defined.

Appendix F: Satellite inter- comparisons, robustness, seasonal and product stability

The heritage of both ocean color and SST products is based on ongoing ocean products from present satellites. MODIS and SeaWIFS provide ocean color products to operations with a defined uncertainty. This same product uncertainty is required from VIIRS . Similarly, SST products from MODIS, AVHRR sensors are used in operations and a product uncertainty on VIIRS is required to match these existing products.

To assess the capability of VIIRS to match these existing satellite ocean products, protocols are required to inter-compare ocean satellite products. Satellite ocean products comparison can be performed on daily weekly and annual times series based on different location and seasonal time scales. Additionally, these product comparison should be performed at different spatial scales in different environmental conditions. These include satellite products comparisons of:

1) **coastal and open ocean waters turbid / clear**
2) **Different atmospheric conditions**
3) **Different seasonal changes and solar elevations**

Appendix G: **EDR Specifications**

SST:

Subject	Specification (skin)	Specification (bulk)
Horizontal Cell Size	.75km	.75km
Horz. Cell Size (worst case)	1.3km	1.3km
Temperature Range	271-313K	271-313K
Mapping Uncertainty (3sd) (nadir)	0.4km	0.4km
Mapping Uncertainty (worst case)	1.5km	1.5km
Max revisit time	6 hrs	6 hrs
Long Term Stability	0.1K	0.1K
Latency (NPP)	140 min	140 min
Measurement Accuracy	0.1K	0.1K
Measurement Uncertainty		
SATZ < 40	0.4K	0.5K
40 < SATZ < 53	0.7K	0.7K
SATZ > 53	0.7K	0.7K
SST > 305	0.8K	0.8K
0.6 < AOT < 1.0	1.0K	1.0K
AOT > 1.0	Excluded	Excluded

Ocean Color:

Units:
Ocean Color : W m^{-2} μm^{-1} sr^{-1}, Ocean Optical Properties: m^{-1}, Chlorophyll: mg m^{-3}

	a. Horizontal Cell Size		
	1. Worst case	1.6 km	0.1 km
	2. Nadir	0.75 km	0.1 km
40.7.6-3	b. Horizontal Reporting Interval	HCS	HCS
40.7.6.7-29	c. Horizontal Coverage	Oceans	Oceans
40.7.6-4	Deleted		
40.7.6-5	Deleted		
	d. Measurement Range		
40.7.6-13	1. Ocean Color	1.0 - 10 W m^{-2} μm^{-1} sr^{-1}	0. 05-10 W m^{-2} μm^{-1} sr^{-1}
	2. Optical Properties		
40.7.6-14	a. Absorption	0.01 – 10 m^{-1}	0.005 – 20 m^{-1}
40.7.6-15	b. Scattering	0.01 – 50 m^{-1}	0.005 – 75 m^{-1}
40.7.6-16	c. Chlorophyll Fluorescence	N/A	Detectable signals in waters with chlorophyll from 0.1 to 50 mg m^{-3} at 1 km resolution.
40.7.6-6	3. Chlorophyll	0.05 – 50 mg/m^3	0.001 - 100 mg/m^3
	e. Measurement Accuracy		
	1. Ocean Color		
40.7.6-17	a. Operational	10 %	5 %
40.7.6-18	b. Deleted.		
	2. Optical Properties		
40.7.6-19	a. Operational	40 %	30 %

40.7.6-20	b. Deleted.		
	3. Chlorophyll		
40.7.6-7	a. Operational	15% Chl <1.0 mg/m^3 30% 1.0 <Chl <10 mg/m^3 50% Chl >10 mg/m^3	20 %
40.7.6-21	b. Deleted.		
	f. Measurement Precision		
	1. Ocean Color		
40.7.6-22	a. Operational	5 %	2 %
40.7.6-23	b. Deleted.		
	2. Optical Properties		
40.7.6-24	a. Operational	20 %	20 %
40.7.6-25	b. Deleted.		
	3. Chlorophyll		
40.7.6-8	a. Operational	20% Chl <1.0 mg/m^3 30% 1.0 <Chl <10 mg/m^3 50% Chl >10 mg/m^3	10 %
	g. Mapping Uncertainty		
40.7.6-9	1. Worst Case	0.8 km (intermediate swath)	0.1 km
40.7.6-10	2. Nadir	0.4 km	0.1 km
40.7.6-11	h. Max Local Average Revisit Time (S)	24 hrs	12 hrs
40.7.6-12	i. Deleted.		
40.7.6-26	j. Long Term Stability ($W\ m^{-2}\ \mu m^{-1}\ sr^{-1}$) (C) SEE NOTE 1	Max Chl Absorption 0.5 Min Chl Absorption 0.25 Atmospheric Correction 0.08	Max Chl Absorption 0.25 Min Chl Absorption 0.125 Atmospheric correction 0.04
	k. Latency (S)		
40.7.6-27	1. Operational	180 minutes	60 minutes
40.7.6-28	2. Deleted.		

NOTE 1: STABILITY IS FOR WATER LEAVING RADIANCE AT THE BAND OF MAXIMUM CHLOROPHYLL ABSORPTION (MEASURED AT APPROXIMATELY 445 NM), MIN CHLOROPHYLL ABSORPTION (AT APPROXIMATELY 555 NM), AND ATMOSPHERIC CORRECTION (AT APPROXIMATELY 865 NM).

Appendix H – Calibrations Needs of the generation of SDRs

EIGHT CRITICAL AREAS FOR SCIENCE QUALITY OCEAN COLOR DATA

1. INSTRUMENT DESIGN

- Spectral coverage (heritage).
- Spatial resolution (heritage for global ocean; higher for coastal).
- Band-to-band registration (heritage).
- High SNR at typical clear-sky TOA over ocean radiance (~10+3).
- High radiometric resolution for clear-sky TOA over ocean radiance range.
- Precise, stable calibration (0.3% stability; <2% accuracy).
- Band-to-band stability (1 NeDL?).
- Detector-to-detector stability (1 NeDL).
- Minimal response non-linearity.
- Minimal integrated out-of-band response.
- Good structured scene response (bright edges effects constrained to within 2-3 MODIS pixels).

2. INSTRUMENT KNOWLEDGE

- Thorough testing and charactization of radiometric characteristics:
  Gain, dynamic range, resolution, and linearity.
  SNR and noise.
  Temperature response (3 or more T/VAC points).
  Polarization (0.5% uncertainty).
  Relative spectral response.
  Near-field response and spatial response.
  Stray light rejection.
  Response verses scan.
- Evaluate and characterized instrument behavior not foreseen in design (e.g., crosstalk).
- End-to-end testing of the calibration system.
- Timely access to above data and related documentation.
- Validated, model(s) of the instrument.
  Reconcilable with test data.
  Diagnose or explain pre and post launch anomalies.
  Provide a potential pathway to mitigation.
  Predict estimated end-of-life performance.

3. MANEUVERS

- At least one time yaw maneuver to characterize Solar Diffuser.
- Small roll (15 deg) maneuvers to increase lunar measurement frequency at limited phase angles.

Deep space roll maneuver to characterize HAM scan mirror characteristics (response vs. scan angle)

4. CALIBRATION PROCESSING

- Ability to process on-orbit calibrator data.
- Solid working relationship between ocean and calibration teams.
- Frequent, consistent lunar calibration to assess degradation of detector sensitivity.

5. VICARIOUS CALIBRATION

- Supported infrastructure and team.
- Protocols for vicarious calibration field data and satellite data.

- Reviewed and documented methodology for corrections.
- Mechanism to inject gain corrections into operational processing stream.
- Publication of results and distribution with software.

6 CALIBRATION ANALYSIS

- Evaluation of validation and vicarious calibration results.
- Cross-comparison with other remote sensing data.
- Identification and evaluation of trends and anomalies.
- Developing models and mitigation strategies.
- Algorithm tuning and improvements.
- Testing algorithm modifications through partial or complete reprocessing.

7. PRODUCT ANALYSIS AND IMPROVEMENT

- Supported validation infrastructure and team.
- Effective validation data protocols.
- Post-launch

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- Minimal response non-linearity.
- Minimal integrated out-of-band response.
- Good structured scene response (bright edges effects constrained to within 2-3 MODIS pixels).

2. INSTRUMENT KNOWLEDGE

- Thorough testing and charactization of radiometric characteristics:
  Gain, dynamic range, resolution, and linearity.
  SNR and noise.
  Temperature response (3 or more T/VAC points).
  Polarization (0.5% uncertainty).
  Relative spectral response.
  Near-field response and spatial response.
  Stray light rejection.
  Response verses scan.
- Evaluate and characterized instrument behavior not foreseen in design (e.g., crosstalk).
- End-to-end testing of the calibration system.
- Timely access to above data and related documentation.
- Validated, model(s) of the instrument.
  Reconcilable with test data.

Diagnose or explain pre and post launch anomalies.
Provide a potential pathway to mitigation.
Predict estimated end-of-life performance.

3. MANEUVERS

- At least one time yaw maneuver to characterize Solar Diffuser.
- Small roll (15 deg) maneuvers to increase lunar measurement frequency at limited phase angles.

Deep space roll maneuver to characterize HAM scan mirror characteristics (response vs. scan angle)

4. CALIBRATION PROCESSING

- Ability to process on-orbit calibrator data.
- Solid working relationship between ocean and calibration teams.
- Frequent, consistent lunar calibration to assess degradation of detector sensitivity.

5. VICARIOUS CALIBRATION

- Supported infrastructure and team.
- Protocols for vicarious calibration field data and satellite data.

validation data collection and archival (e.g., NOMAD).

- Analysis and publication of validation statistics.
- Stable, accepted algorithms
- Community review and update of algorithms:

Open distribution of software, data, and metadata.
Infrastructure for community interaction.
Working relationship with algorithm developers in the community.

- Access to quality ancillary data:

Surface wind speed and humidity.
Transmission for ozone or other gases as necessary.
Data for other derived-product algorithms.

8. REPROCESSING

- Provide consistent data record necessary for climate research.
- Needed for both calibration analysis and vicarious analysis.

The criteria are identified to produce climate data products (Kevin Turpie)