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NPOESS Community Collaborative Calibration/Validation Plan for the NPOESS Preparatory Project Cloud and Aerosol EDRs

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Calibration and Validation of the NPP/NPOESS VIIRS Atmospheric Environmental Data Records

Version 1.2

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5.1 OBJECTIVES

This plan describes a coordinated strategy for the validation of the Visible Infrared Imager Radiometer Suite (VIIRS) atmospheric Environmental Data Records (EDRs) for the National Polar-orbiting Operational Environmental Satellite System (NPOESS), beginning with its risk reduction mission, the NPOESS Preparatory Project (NPP).

The key objectives for the Atmosphere EDR Validation Plan are:

- Develop executable approaches for efficient validation of the VIIRS Aerosol and Cloud EDRs in close coordination with the VIIRS Cloud Mask/Imagery validation group
- Facilitate the socialization of the plan with members of the Customer/User community to improve the plan and to increase the likelihood of acceptance.

The NPP VIIRS Atmospheric EDRs consist of the following:

CLOUDS

- Cloud Optical Properties (COP)
  - Cloud Optical Thickness (COT)
  - Cloud Effective Particle Size (CEPS)
- Cloud Top Properties (CTX)
  - Cloud Top Temperature (CTT)
  - Cloud Top Height (CTH)
  - Cloud Top Pressure (CTP)
- Cloud Base Height (CBH)
- Cloud Cover/Layers (CC/L)[1]

AEROSOLS

- Aerosol Optical Thickness (AOT)
- Aerosol Particle Size Parameter (APSP)
- Suspended Matter (SM)

An Intermediate Product (IP), the VIIRS Cloud Mask (VCM*)*, is an integral component in generating the cloud EDRs. The VCM contains two other additional parameters that are integral to the success of the cloud products: (1) Cloud Thermodynamic Phase and (2) a Multilayered Cloud detection flag. The detection of multilayered clouds in a given pixel is especially useful for those cases in which an optically thin ice cloud (e.g., cirrus) overlies a lower-level water cloud. The VCM will be validated by the VIIRS Cloud Mask/Imagery team, in close collaboration with the Atmospheres EDR team.

5.1.1 VIIRS Atmospheric EDR Validation Philosophy

[1] Cloud Cover/Layers EDR will be validated by the VIIRS Cloud Mask/Imagery team.

The goals of the government team and the Northrop Grumman Aerospace Systems (NGAS) team are closely related, but not identical. The government team seeks to establish the bounds of accuracy and precision for the EDRs, characterizing performance as a function of scene characteristics. The foundation of this effort is comparison of the pixel-level Intermediate Products (IPs) to independent correlative data, so-called truth data. The NGAS team has the explicit responsibility to demonstrate whether or not the operational data products at the specified Horizontal Cell Size (HCS) meet the System Specification. There are a large number of attributes that must be met; key among them are the Accuracy, Precision and Uncertainty (APU). There are also explicit stratification requirements, allowable degradation conditions, and exclusion conditions. The government team is responsible for advising the IPO on the acceptability of the NGA demonstration that they have (or have not) met the specification.

The government part of the Atmosphere Team strongly emphasizes pixel-level validation as an integral part of the validation of NPP VIIRS Aerosol and Cloud Properties EDRs. Pixel-level validation will provide validation of the fundamental physical reality of the algorithm performance, and is most closely traceable to the Sensor Data Record (SDR) performance and characteristics. The primary result of the government team validation will be statements about the accuracy and precision of the pixel level products (IPs) compared to various truth measurements.

The NGAS portion of the Atmosphere Team will focus on the validation of the EDR data products, which are aggregated from the IPs into the larger HCS, as specified in the System Specification. The NGAS members of the team will perform the aggregation of truth data to the cell level and use that to validate performance against the system specification. These activities are more fully detailed in Appendix 5A. The government team is not isolated from this activity. The NGAS team will rely on data resources and expertise of the government team during its assessment. Moreover, the government team will independently assess the validity of the implementation of the aggregation process for selected subsets of the data. Our expectation is that significant interaction and cooperation will occur between the government and NGAS components of the overall Validation team.

Validation of atmospheric EDRs will be accomplished using existing ground truth networks, specialized field campaigns, airborne and space-borne sensors, and the computational and analysis capabilities of the NASA Atmosphere Product Evaluation and Test Element (PEATE).

The basic premises of the Atmospheric EDR validation activities are summarized as follows:

- Excellent ground-truth data for AOT and APSP are available. Field data are needed to understand error characteristics, especially for APSP and SM.
- COT and CEPS ground-truth data are problematic for many cloud types since adequate quality correlative data for direct comparison is scarce. For COT, high-value ground-truth data can be acquired from the few existing sites with high-spectral-resolution LIDAR (HSRL), or Raman LIDAR, especially for optically thin clouds. CEPS is particularly challenging for ice and mixed-phase clouds. Consequently, alternative approaches, such as radiative closure assessments, are needed.
- Heritage data from CALIPSO (Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observations), CloudSat, and MODIS (Moderate Resolution Imaging Spectroradiometer) are key for CTP and CC/L. Multilayered clouds are a significant challenge, even for CBH.

- The validation and characterization of the VCM is critical for VIIRS EDRs; the availability of quality match-up data from MODIS and CALIPSO are presently transforming cloud mask science, and NPP is in an excellent position to take advantage of these findings for which MODIS may serve as a transfer standard.
- If MODIS and CALIPSO are not available, significantly more *in-situ* data will be necessary. In addition to data from the Department of Energy Atmospheric Radiation Measurements Clouds and Radiation Testbed (DoE ARM CART) sites that are integral to the closure approach, the utility of the Micropulse LIDAR Network (MPLNET) sites, which are collocated with NASA Aerosol Robotic Network (AERONET) sites, is currently being investigated.
- The Atmosphere team is collaborating with the Cross Track Infrared Sounder/Advanced Technology Microwave Sounder (CrIS/ATMS) SDR team on planning an early aircraft campaign that could include a VIIRS-like instrument to obtain cloud data. This plan will be available Summer 2009 and details will be incorporated into this plan as they become available. Additional requirements for field campaign data will be incorporated into this plan as those requirements are defined for the intensive EDR validation phase.

The availability of heritage data notwithstanding, it cannot be stated strongly enough that satellite-based data are not in and of themselves *truth.* Only by combining these satellite data with correlative ground-truth data can the facts be determined. The Atmospheric EDR validation plan, therefore, has significant components for both satellite-derived and ground-truth data.

5.2 REQUIREMENTS SUMMARIES

5.2.1 Cloud EDR Requirements from the NPOESS System Specification

The Cloud EDR specifications are described in detail in Appendix 5A. The key parameters are tabulated in Table 5.1 below. In some cases the validation approach will be discussed by subgroup, rather than by individual EDR. COP refers to the Cloud Optical Properties, comprised of Cloud Optical Thickness (COT) and Cloud Effective Particle Size (CEPS). CTX stands for Cloud Top Properties, which consist of Cloud Top Height (CTH), Cloud Top Temperature (CTT) and Cloud Top Pressure (CTP).

The CTX & CBH EDRs are produced by aggregating pixel-level data IPs that are identified in the Cloud Mask as being non-Heavy Aerosol and Confidently Cloudy. The government team will concentrate on validating these pixel-level IPs. NGAS will validate the EDR products, aggregated from the IPs to the specified grid cell size (6 Km) for each cloud layer identified in the CC/L EDR. All of the cloud products, with the exception of the VCM are specified relative to a vertical path. Thus, a parallax correction is performed for the cloud IPs prior to aggregation into the EDRs.

NGAS plans to validate each cloud EDR primarily for single-layer overcast cloud cases using a comparison to correlative data sets across a variety of meteorological conditions and background types, e.g., ocean, land, complex terrain. The NGAS team will use a statistical approach to characterize algorithm performance. Extensions must be made to assess performance as a function of HCS cloud cover, and for cases where two cloud layers are identified in a vertical column (note: this involves assessment of the multilayered cloud detection in the VCM). Consideration of these more challenging conditions will involve a higher level of cooperation between the NGAS and government teams and strongly leverages the government team findings for IP validation.

Table 5.1: Cloud EDR Specifications

EDR Group/EDR	Horizontal Cell Size (Nadir)	Precision	Accuracy	Uncert
Cloud Optical Properties (COP)				
Cloud Optical Thickness (COT)	6 ± 1 km	Greater of 5% or 0.025	Greater of 10% or 0.05	
Cloud Effective Particle Size (CEPS) Water	6 ± 1 km	Greater of 2 µm or 10%	Greater of 2 µm or 5%	
Cloud Effective Particle Size (CEPS) Ice	6 ± 1 km	Greater of 3.5 µm or 10%	Greater of 2 µm or 5%	
Cloud Top Properties (CTX)				
CT Temperature (CTT): $\tau \geq 1$	6 ± 1 km	1.5 K	2 K	
CT Temperature (CTT): $\tau < 1$	6 ± 1 km	1.5 K	6 K	
CT Height (CTH): $\tau \geq 1$	6 ± 1 km	0.3 km	1 km	
CT Height (CTH): $\tau < 1$	6 ± 1 km	0.3 km	2 km	
CT Pressure (CTP): $t \geq 1$	6 ± 1 km		100 mb at <3 km to 25 mb at 7 km	
Cloud Base Height (CBH)	6 ± 1 km			2 km

5.2.1.1 COP Requirements

The stratification of COT and CEPS can be defined for ice and water clouds corresponding to the measurement range of $1 < \tau < 10$ and $1 < \tau < 30$, respectively. The COP validation by NGAS will be carried out in these ranges.

For both COT and CEPS the degraded condition is that of optically thin clouds at $\tau < 1$. The excluded condition is defined as the sun glint condition produced when the viewing zenith and solar zenith angles have nearly the same values in the principle plane. The COP EDRs will be produced under the exclusion and degraded conditions but without performance specifications.

5.2.1.2 CTX and CBH Requirements

The EDR retrievals are based on computing the CTT and then using an atmospheric profile to compute the CTH and CTP. CBH is then computed from deducing a cloud thickness that is then subtracted from the CTH. In the case of validation, the process is somewhat reversed with correlative data generally providing a CTH and CTB, from which the CTP and CTT must be derived.

5.2.2 Aerosol EDR NPOESS System Specification Requirements

The Aerosol EDR specifications are described in detail in Appendix 5A. They consist of AOT, Aerosol Particle Size Parameter (ASPS) and Suspended Matter (SM). The key parameters are tabulated in Table 0-2 below.

Table 5.2: Aerosol EDR Specifications

EDR Group/DR	Horizontal Cell Size (nadir)	Precision	Accuracy	Uncert
Aerosol Optical Thickness (AOT) Over Ocean	6 km	.02 + .03 Tau		.03 + .05 Tau
Aerosol Optical Thickness (AOT) Over Land	6 km	.04 + .10 Tau		.05 + .15 Tau
Aerosol Particle Size Parameter (ASPS) Over Ocean	6 km		.3 alpha units	.3 alpha units
Aerosol Particle Size Parameter (ASPS) over Land	6 km		.6 alpha units	.6 alpha units
Suspended Matter (SM)	1.6 km	Prob. of correct typing 80 – 85%		

The only stratifications are land and ocean where very different techniques are used. The government and NGAS teams will each focus on comparison of EDRs to ground-truth data derived from AERONET and similar network resources, such as the Baseline Surface Radiation Network (BSRN) and SURFRAD. As with the cloud EDRs, NGAS will apply a robust statistical approach to validation of the EDR end products. The government investigators (2) will independently consider these same comparisons, but also expand into characterization of the dependencies of the assessment, such as height and/or depth of the aerosol layer and aerosol type, especially for ASPS and SM. Such a characterization is important to the customers and many users. Consequently, data resources such as MPLNET and other LIDAR remote sensing ground sites (ARM) will be important. Indeed, toward this end, the government validation team will take advantage of highly-focused field campaigns on aerosols, e.g., NRL (Naval Research Laboratory) and NASA airborne in-situ sampling, to the extent permitted by resources. The NGAS team will require extra effort to determine validation in the twilight region. The viewing geometry of VIIRS and AERONET is significantly different for high solar zenith angles; therefore, care must be taken in the interpretation of these results. The difficulty in requirements validation for SM arises from the high AOT value of the typing exclusion. This limits the amount of data available for validation.

Key to the approach used by the NGAS and government team is the fact that AOT spatial gradients are usually quite small over the scales of interest here, HCS to multiple HCS. Consequently, temporal averaging of AERONET observations, and other "point" measurements, will be used to match the HCS of the EDRs. Differences in viewing geometries need to be taken into account. The validity of this approach will be documented by comparing aerosol EDRs for adjacent cells. Explicit consideration of the aerosol IPs will be made by the government team only if deemed necessary to understand specific findings at the HCS resolution.

5.3 APPROACH

The key strategic activities necessary to accomplishing the Plan's objectives are as follows:

(1) Build a team of subject matter experts (SMEs) calling on representatives from the Customer/User and science communities to leverage heritage knowledge and tools and to assure understanding and implementation of customer mission success criteria.
(2) Coordinate with the VIIRS Cloud Mask/Imagery Validation team to ensure efficient validation of all products.
(3) Coordinate and collaborate closely with the SDR team to assess/validate SDRs in the mission's Early Orbit Checkout Phase.
(4) Identify and develop ground-truth field data resources necessary for activities in the Intensive Validation and Long-term Monitoring Validation phases of the mission, where the latter overlaps NPOESS.
(5) Develop strong collaborative relationships with the NASA Atmosphere PEATE for pre-launch assessment and post-launch validation.
(6) Partner with other agencies to plan post-launch field campaigns to target needed measurements that are not currently available from field sites.

A mission-phased summary of activities necessary to parley this strategic approach into attainment of the earlier-stated objectives is presented below.

5.3.1 Team Organization

The Atmosphere EDR Validation Team has been assembled to leverage on-going activities within the government that are applicable to the validation effort. The team leader is David Starr, from NASA/GSFC. He provided leadership for the EOS validation effort, including coordination of teams, plans and resources. The present team includes investigators from NASA, NOAA, the Air Force Weather Agency (AFWA), the Naval Research Laboratory (NRL) and universities. The NASA team is experienced with MODIS aerosol and cloud algorithm development and validation. University of Wisconsin investigators bring extensive MODIS experience and are leading the NASA PEATE development. The University of Utah has developed a sophisticated system for bringing together and efficiently analyzing a wide range of observations and data products generated by the ARM Program with coincident satellite observations such as MODIS. We plan to couple this capability with the activities at the PEATE and take advantage of Dr. Mace's extensive experience and capabilities with manipulating complex multi-sensor ARM data for satellite validation purposes, including application of closure calculations for validation of COT and CEPS EDRs, a capability also present in the PEATE team (Robert Holz).

Operational experience comes from the NOAA/NESDIS/STAR investigators. Members from the VIIRS Imagery/Cloud Mask team at AFWA provide insight into the cloud mask validation and provide additional insight into customer needs. NRL provides insight into aerosol validation from the perspective of an operational customer with an emphasis on data assimilation and field measurements. The NGAS team provides the expertise with the operational algorithms and the IDPS (Interface Data Processing Segment) system that produces the operational products.

The team communicates via telecons and face-to-face workshops to exchange ideas and resolve issues as they occur.

Table 5.3: VIIRS Atmosphere EDR Team Members

Subject	Name	Organization	Sponsor
Lead	David Starr	NASA/GSFC	IPO
Aerosol	Istvan Laszlo	NOAA/NESDIS	IPO
Aerosol	Christina Hsu	NASA/GSFC	IPO/NASA
Cloud	Bryan Baum	SSEC	NASA/IPO
Cloud	Andrew Heidinger	NOAA	IPO
Cloud	Robert Holz	SSEC	IPO/NASA
Cloud	Paul Menzel	SSEC	IPO
Cloud	Jay Mace	U. Utah	IPO
Cloud/Aerosol	Mike Plonski	NGAS	NGAS
Cloud/Aerosol	Eric Wong	NGAS	NGAS
Aerosol	Sid Jackson	NGAS	NGAS
Cloud	Tom Kopp	Imagery/VCM Lead, Aerospace Corp.	IPO
Aerosol	Alexei Lyapustin	Land Surface EDR Team, UMBC	IPO
Aerosol	Jeffrey S. Reid	NRL	NRL
Cloud/Aerosol	John Eylander	AFWA	AFWA
Cloud	Steve Platnick	NASA/GSFC	NASA EOS

Coordination with other VIIRS discipline teams is ongoing and achieved through team leader face-to-face meetings facilitated by the IPO, and by overlapping memberships. The Atmosphere EDR Validation team is working with Frank DeLuccia, the VIIRS SDR government team lead, and Tom Kopp, the VIIRS Imagery/Cloud Mask team lead, to coordinate activities affecting both teams.

The roles and responsibilities of the team members vary by organization. The IPO Lead is responsible for coordinating all team members to accomplish the IPO Cal/Val objectives as stated in section 1.1 of the Overview Volume of this document. The NGAS team members are focused on compliance assessment, or showing that the operational EDRs produced by the IDPS system meet the contract specification (NSS). The NASA NPP Team, mostly concentrated in the PEATE activity has primary responsibility to their NASA mission of evaluating the EDRs for climate applicability. The Atmosphere Validation Team is leveraging their activities to accomplish this mission by funding the PEATE to perform supplemental studies, extending their work to validation and performance characterization of the EDRs, off-line data products produced using proposed changes to the NPP/NPOESS algorithms, and other data products deemed useful to the team against the needs of the Customer. Moreover, the PEATE is highly engaged in collecting, processing and utilizing much of the same correlative data planned here, especially including the CALIPSO-CloudSat-MODIS match-up data sets that are the focus of the pre-launch phase effort here. The IPO funded team members at various institutions have varying responsibilities, but their objectives are those of the IPO.

5.3.2 Critical Capabilities

There are 4 ongoing externally funded activities that are critical to the success of the atmospheres validation plan.

5.3.2.1 NASA PEATE

A key component of the atmosphere EDR validation chain is the Atmosphere Product and Evaluation and Test Element (PEATE), developed by NASA as a part of its Science Data Segment (SDS). The Atmosphere PEATE, located at the University of Wisconsin-Madison, will enable the NPP Science Team to (a) assess the impact of on-orbit instrument performance on SDRs and subsequently on Atmosphere EDRs; (b) evaluate the quality of Atmosphere EDRs at sensor resolution over a wide range of environmental conditions; (c) validate Atmosphere EDRs against ground-based and satellite-based measurements; (d) develop improved Atmosphere EDR algorithms; and (e) evaluate the climate quality of the Atmosphere EDRs.

The IPO Community Validation plan is based upon leveraging this NASA capability with incremental funding and cooperative activities.

The Atmospheres PEATE will allow SDR and EDR product generation at more than 100 times real-time processing speed; this will allow the NPP Science Team to rapidly assess the impact of calibration and science algorithm changes on climatologically significant subsets of the NPP data record [Gumley *et al.*, 2006]. The Atmosphere PEATE is developing tools necessary to support their validation effort, including subsetting, data access and navigation, collocation, formatting, automatic processes, and visualization capabilities. A key capability is the efficient generation of match-up data sets, such as MODIS-CALIPSO-CloudSat, and MODIS for AERONET and ARM sites. They also have the capability to run the VIIRS algorithms on the MODIS data to generate VIIRS Proxy data.

The PEATE-developed tools will supplement the NGAS tools already in use for pre-launch algorithm verification described in Appendix 5A. NGAS has developed detailed error budgets for the algorithms, and performed verification studies using comparisons of MODIS aerosol results to the Aerosol Robotic Network (AERONET) data.

5.3.2.2 Existing Ground-Based Networks

Key to the validation of AOT and ASPS EDRs is comparison to coincident AERONET (AErosol RObotic NETwork, Holben et al, 2001) observations. Use of AERONET observations for validation of satellite-derived aerosol data products was well developed for MODIS. The Atmosphere PEATE is presently developing the capacity for generating aerosol match-up data sets with AERONET. AERONET is a federation of ground-based remote sensing aerosol networks established by NASA and LOA-PHOTONS (CNRS) and is greatly expanded by collaborators from national agencies, institutes, universities, individual scientists, and partners. AERONET presently comprises more than 200 sites. The program provides a long-term, continuous and readily accessible public domain database of aerosol optical, mircrophysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. The network imposes standardization of instruments, calibration, processing and distribution.

AERONET collaboration provides globally distributed observations of spectral aerosol optical depth (AOD), inversion products, and precipitable water in diverse aerosol regimes. Aerosol optical depth data are computed for three data quality levels: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (cloud-screened and quality-assured). Temperature inversions, precipitable water, and other AOD-dependent products are derived from these levels and may implement additional quality checks.

MPLNET is a NASA-supported federated network of 17 relatively standardized and automated micropulse LIDAR sensors with common data processing and public domain data products, similar to AERONET. The number of sites continues to grow and is globally distributed. The key contribution of MPLNET data, collocated with AERONET sites, is definitive information on the vertical distribution of aerosols that is typically related to their composition/type. Such information is highly useful is assessing why disagreement is found when comparing AERONET and satellite-generated data products.

The DoE ARM Program maintains extensively instrumented observing sites at locations in north-central Oklahoma (Southern Great Plains, SGP), near Barrow Alaska (North Slope of Alaska, NSA), and in the Tropical West Pacific (TWP) at Manus, Papua New Guinea (2.006° S, 147.425° E), Nauru Island (0.521° S, 166.916° E) and Darwin, Australia (12.425° S, 130.891° E) remote sensing sites. These sites, and the CloudNet sites (3) in Europe, provide a continuous and nearly complete physical measurement of the radiative environment and, via sophisticated remote sensing as well as soundings, the atmosphere and its properties. Data from these sites have been extensively used for satellite validation studies. Many field experiments, including airborne campaigns with satellite simulator instruments and in-situ instruments have been conducted around these locations over the past two decades. Thus, the remote sensing retrieval products are particularly well calibrated. The ARM data and processing systems represent a unique resource that will be leveraged for VIIRS Atmosphere EDR validation.

5.3.2.3 Airborne Sensors

NASA is currently defining a major update of the highly successful MODIS Airborne Simulator (MAS). NASA is fully committed to this activity, which is supported with stimulus funding. Steve Platnick, NASA EOS Senior Scientist, leads the science requirements aspect of this. Like MAS for MODIS, the new sensor will exceed on-orbit capabilities that are essential for validation applications. While science is the key NASA driver, the importance of VIIRS simulator capabilities is well recognized and part of the plan. Availability of a robust VIIRS simulator for the atmosphere EDRs would be highly beneficial to the atmosphere EDR validation effort, especially for cloud EDRs. The Atmospheres team (Starr) is representing the NPP/NPOESS needs to NASA in their planning activity.

Because airborne resources are high cost, the general approach has been to minimize their use. The Atmospheres team (Starr) is working with the CrIS SDR-lead (Bingham) to develop a cost effective plan for an aircraft campaign that could benefit VIIRS EDR validation. The initial effort would focus strongly on CrIS SDR validation, but also result in observations useful for EDR validation via the updated MAS and other coincident correlative data. It is fully expected that additional requirements for airborne measurements will be defined as a result of the pre-launch and early post-launch validation activities, both for aerosols and clouds. The IPO strategy is to partner with other agencies and plans of opportunity to address such data requirements. This partnering will require IPO resources, such as the funding of specific investigators/instruments to participate on a deployment. However, the hope is that the costs will be minimized. This likely will limit the selection of targets, but not overly so, as there is much commonality between the science hot spots and known issues for satellite retrievals. Note that field missions typically focus on more complex situations than a retrieval expert might otherwise choose. Nevertheless, there is a good history of accommodation and accomplishment in this regard.

5.3.2.4 Heritage Satellite Sensors

It is important to note that there are several cloud climatologies available that are based on NOAA heritage sensors. These climatologies are not static, however, and are always in a process of improvement. The advent of Calipso and CloudSat have been invaluable for assessing the cloud products globally, and this intercomparison has resulted in making great strides towards developing a more stable long-term record. Keep in mind that for a decadal climatology, it is often necessary to reprocess much, if not all, of the record many times. Thus it is critical to be able to make changes and test on global data covering month, if not years. While a coding change may seem minor, it can have unintended consequences that only come to light when inspecting a decadal record.

High-Resolution Infrared Radiation Sounder (HIRS)

At the University of Wisconsin-Madison, a long-term effort has been underway to develop a decadal high cloud climatology from the High-Resolution Infrared Radiation Sounder (HIRS) sensors on the NOAA polar-orbiting platforms. The record is now approaching 30 years duration. The HIRS sensor is a filter radiometer that takes measurements at wavelengths within the 15-μm CO_2 band among others; the cloud retrieval method that uses these bands is typically called “CO_2 slicing”. While the spatial resolution of the earlier HIRS sensors is approximately 18 km (the latest generation has a smaller field-of-view of about 10 km), these same spectal bands are on the MODIS at 1-km resolution. There is thus some heritage between MODIS and the HIRS sensors. This heritage is necessary for developing climate data records from infrared (IR) measurements. However, the HIRS instruments are evolving to advanced hyperspectral infrared instruments such as the Atmospheric Infrared Sounder (AIRS) instrument currently on the NASA Earth Observing System Aqua platform, and the Infrared Atmospheric Sounding Interferometer (IASI) on the European Meteorological Operational Satellite (METOP) platform. The HIRS cloud climatology is intended to be a precursor of cloud products available from the new generation of hyperspectral infrared instruments just listed. To assess the eventual NGAS cloud products as a climate data record, it will be important to understand how the HIRS cloud products compare to those from AIRS and IASI, and eventually from CrIS. An important step to improving our understanding of the HIRS cloud products and the associated calibration is by convolving hyperspectral IR data over the HIRS SRFs. This approach was undertaken with MODIS using AIRS hyperspectral data, and biases were noted in several of the MODIS 15-μm CO_2 bands. The same approach will be undertaken with HIRS and AIRS (on NOAA and Aqua) in the afternoon orbit as well as HIRS and IASI in the morning orbit (on METOP).

Advanced Very High Resolution Radiometer (AVHRR)

The Advanced Very High Resolution Radiometer (AVHRR) is the imager that has been on NOAA operational platforms since the late 1970’s, flying alongside the HIRS sensors. NOAA provides operational cloud products from the AVHRR through the Clouds from AVHRR (or CLAVR). The climatology component of the CLAVR methodology is called by another name: AVHRR Pathfinder Atmospheres-extended (PATMOS-x). The PATMOS-x cloud climatology provides the full suite of cloud properties (CTX, COPS) and uses much of the same methodology as used for MODIS processing such as the ice cloud bulk scattering models, surface albedo maps, and more. Additionally, both the

MODIS and PATMOS-x methodologies have been quite useful for development of the NGAS VCM, particularly the cloud typing (cloud thermodynamic phase and multilayered cloud detection). Additionally, the PATMOS-x cloud climatology is based on an IR split-window technique for inferring cloud properties that will provide consistent results regardless of solar illumination. This data set will provide an independent yardstick for comparison with NGAS cloud properties for the evaluation of climate data records.

5.3.2.5 Concurrent measurements from CrIS

To Be Provided

5.3.2.6 Other Key Assets

Other key assets include Government Resource for Algorithm Verification, Independent Testing, and Evaluation (GRAVITE), the NPOESS Science Investigator-led Processing System (NSIPS), and the expertise provided by the IPO Calibration-Validation team, the NPP Science Team, the NGAS Calibration-Validation Team, and the Centrals: the Fleet Numerical Meteorology and Oceanography Center (FNMOC), AFWA, and NOAA.

In each phase, the algorithms, tools, and data sets developed are going to be submitted to appropriate central locations (CLASS, CasaNOSA, PEATE) for access by other investigators. Documentation of tools and data sets will be prepared and submitted to the Centrals.

5.3.3 Summary of Approach in each Validation Phase

To fully characterize the EDR uncertainties requires determination of not just the total EDR uncertainty but also the individual sources contributing to EDR performance. These sources include both RDR and SDR uncertainties as well as ancillary data sources such as atmosphere thermodynamic profiles. Figure 5.1 presents the sources of uncertainties for RDR, SDR, and EDR products and the flow of these uncertainties through the EDR processing chain. The approach presented is designed to provide characterization of both RDR/SDR and EDR sources of uncertainties with the capability to modify input

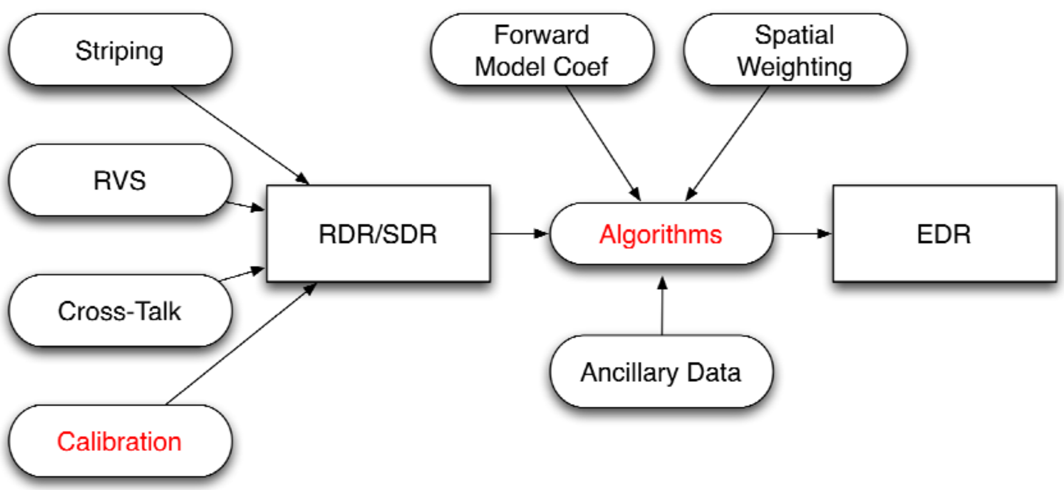

Figure 5.1: The propagation of uncertainties through the EDR processing chain is presented

data streams at the RDR/SDR level and then reprocess the EDR with the modified data source to determine the impact on the EDR product. This capability will allow for the separation of uncertainties between the EDR algorithm and instrument calibration/noise.

5.3.3.1 Pre-Launch Phase

Prior to launch, the key activity for the government team will be to fully characterize the algorithm performance. This will include identifying existing and emerging algorithm performance issues, team familiarization with the NGAS developed algorithm error budget, resolving outstanding algorithm issues, and identifying key measurement needs to address any unresolved issues.

A major aspect of these early validation activities is the tight integration with the NASA Atmosphere PEATE. Partnerships with other agencies—such as NASA, NRL, NOAA, and DoE for correlative field measurements—must be developed and fostered, especially as such measurements are required for the post-launch Intensive EDR Validation Phase.

Algorithm testing at global and selected test sites will be performed for comparison purposes. The algorithms to be addressed include the VIIRS science and operational algorithms. Such assessment and verification will focus on proxy MODIS data for VIIRS retrievals, with attention being paid to comparison with MODIS collection 5 (MODIS Collection 6 if available) and, possibly, with data from Advanced Very High Resolution Radiometer (AVHRR) Pathfinder Atmosphere-extended (PATMOS-x) Project, the MODIS-CERES (Cloud and Earth Radiant Energy System) combination from EOS-era platforms, and aerosol data from several NOAA platforms. This pre-launch activity is particularly important because of the unique set of circumstances that presently exist.

The pre-launch validation phase for the NGAS VIIRS cloud/aerosol algorithms will proceed as follows. The PEATE will facilitate the implementation of the NGAS algorithms within their facility by embedding the algorithms from the latest NGAS Operational Build into the Low Earth Orbiter Cloud Algorithm Testbed, or LeoCat. The ancillary data necessary for running the algorithms will be the same as what MODIS algorithms will be using, with other NGAS-specific LUTs also implemented. While the products will not be exactly the same as those derived from the IDPS, such an effort is necessary for global testing and validation activities pre-launch. The VIIRS algorithms will be run using MODIS as proxy data and compared to the standard MODIS products globally. This enables a wide range of conditions to be included and will likely lead to identification of various algorithm issues, possibly regional or phenomenological dependent, that otherwise might remain undiscovered until the data products are in users hands. Moreover, since every CALIPSO and CloudSat observation is taken in a MODIS pixel, usually the same pixel, analysis of the NPP VIIRS cloud and aerosol algorithm performance for the MODIS-CALIPSO-CloudSat match-up data sets can be done which provides for a very robust statistical analysis versus something very close to truth in the case of CTH and CBH, and to a lesser extent for COP. This is also a key element of VCM assessment.

The NGAS team has been actively engaged in these types of activities over the past 6 years. Their pre-launch phase cal/val activities will consist of interacting with the government teams in their efforts, developing detailed implementation plans for validation to specifications, tracking sensor characterization and calibration issues during thermal vacuum testing and incorporating them into plans where needed. In addition, the software tools that had been used for pre-launch performance predictions, based on limited test data sets, will be enhanced and automated in preparation for the post-launch data sets.

Data sets will be constructed and compared to key validation match-up data sets, such as those deriving from MODIS-CALIPSO-CloudSat combinations, the Atmospheric Infrared Sounder (AIRS), the ARM CART campaign, CloudNet, AERONET and MPLNET data, and from BSRN, SURFRAD, and UV-B data. In support of such activities, the ARM-CART relational database effort will be reactivated.

Permeating all these activities is the need for descriptive and prescriptive statistics and physical insight and understanding to help characterize geometric, geographical, seasonal, and phenomenological dependencies.

5.3.3.2 Early Orbit Check-out

During Early Orbit Check-out, the focus will be on supporting sensor calibration and preparing for the next phase, Intensive EDR Validation, discussed below.

Early in this phase, the focus will be on key products for sensor calibration; quantities using ratios and differences are especially sensitive and therefore useful. The focus on AOT and APSP and Cloud Optical Properties and Cloud Top Temperature are key here. Cloud Top Temperature activities will emphasize radiance comparisons with cold targets (warm scenes are addressed under SST validation). Activities will start with simple scenes and progress to increasingly complex scenes, with attention being paid to precision, viewing geometry, and scene dependence.

Comparisons between global VIIRS EDRs and MODIS data will be performed. Under-flights are recommended to allow radiance validation with VIIRS simulator data and key ancillary measurements for cloud mask and atmosphere products (e.g., S-HIS, CPL, HSRL). In this regard, a robust VIIRS simulator capability is a major concern. These activities will be conducted in conjunction with CrIS validation under-flights.

To prepare for the next mission phase, Intensive EDR Validation, routine satellite matchup data acquisitions (e.g., MODIS-CloudSat-CALIPSO-AIRS) and routine test site correlative data acquisitions (e.g., AERONET, MPLNET, ARM-CART) will begin. For these activities to be successful, systems and tools must be mature. Such tools include PEATE, GRAVITE, NSIPS, CLASS, etc.)

When the VIIRS has reached a stable operating configuration with consistent calibration, field data acquisition (in cooperation with the Partner Agencies) will begin in earnest.

Because the leadership of the SDR cal/val activity is with NGAS personnel, the NGAS EDR team will play an especially important role at this time. They will be the day-to-day conduit for information flow between the SDR team and the Atmospheres EDR team.

5.3.3.3 Intensive EDR Validation

During this phase of the mission, satellite and test site matchup data acquisitions and comparative analysis will continue, as will comparisons between global VIIRS EDRs and MODIS products. Validation of operational EDRs will be performed for accuracy limitations over increasingly complex scenes. In this regard, AERONET is the primary “truth” standard for aerosols, and matchup data

(CALIPSO & CloudSat) and closure analysis (ARM CART) are key "cloud truth" standards. Throughout, MODIS is the key transfer mechanism to apply techniques globally. Continuation of MODIS into the NPP operational time period is essential. If CALIPSO and/or CloudSat demise before NPP, the extensive prelaunch studies allow transference to NPP VIIRS via MODIS. While this will not be nearly as rigorous as direct comparison to CALIPSO and CloudSat with respect to truth, it will be better than the alternatives that have plagued cloud product validation prior to CALIPSO and CloudSat. In the event that MODIS fails before NPP becomes operational, the robustness of the cloud EDR validation effort will be seriously compromised. In this case, reliance on ground site observations will need to be significantly increased, albeit with a great reduction in sample size and statistical robustness and a significant cost increase as operation of such systems tends to be expensive and not in the scope of the present plan beyond leveraging of ARM.

Coordination, collaboration, and result sharing between the IPO, the NPP Science Team, and NGAS are essential. The key results will address accuracy, limitations, and the nature and resolution of complex scenes.

In support of the Intensive Validation phase, field campaigns will be instituted and/or supported. This will require partnerships with existing or planned Partner Agency science field experiments, with contributions of instrument investigators and flight-hour support, constrained to opportunities that align with VIIRS EDR Validation requirements. Targets for major issues must be prioritized, but phasing may not be of our choosing. Targets that are priorities for atmosphere EDR validation include:

- Aerosol composition and height dependence
    - Dust, smoke, urban, sea salt
    - Open ocean, coastal, dark vegetation, bright land, mixed land, ice
- High (ice) clouds
    - Cumulonimbus, cirrus, mixed phase, especially with open ocean background and inhomogeneous land backgrounds. It is important to assess synoptic cirrus as well as convectively-generated cirrus such as tropical anvils, which are very different.
- Low clouds
    - Stratus, stratocumulus, cumulus, with open ocean background, and inhomogeneous land backgrounds

The key concern during this phase is the availability of robust VIIRS simulator instruments and aircraft lidar observations (CPL/HSRL).

Lastly, given the challenges of COP validation, IPO should take advantage of available observational capabilities not presently included in the scope of the program. Specifically, routine acquisition of well-calibrated HSRL and Raman LIDAR observations coincident with VIIRS cloud observations would serve to provide a definitive independent truth measurement for COT in the case of optically thin ($\tau_{vis} <$ ~3) clouds which are an important and especially difficult target of high value to some customers. Other emerging capabilities, such as observations of the angular pattern of aureoles, should also be explored. COP is an area where truth is difficult to measure and where the validity of existing satellite retrievals is not yet mature.

5.3.3.4 Long-term Monitoring

Long-term monitoring will be the subject of a separate NGAS generated plan; however there are important insights to be gained during the initial cal/val activities. At the root of long-term monitoring is the stability of the SDRs. During the Long-term Monitoring Phase for EDRs, routine monitoring and algorithm improvement should be the focus. Trends and changes will be monitored and suggestions made for corresponding calibration/algorithm/processing adjustments. Given the many requests that will undoubtedly be made, some thought must be given for prioritizing the suggested requests, and a process for doing this efficiently should be initiated. Satellite and test site match-up data acquisitions and comparative analysis must continue, maximizing automation, generating statistics, and extending the overall reach of the mission. Periodic field campaigns to continue support of algorithm validation and improvement should be undertaken as opportunities arise and resources permit. This is best accomplished through continuing partnerships with other agencies that are conducting field experiments. The IPO/NGAS should be prepared to make funding and technical contributions to such activities.

5.4 ACTIVITIES, SCHEDULE, AND MILESTONES

In this version of the document, general activities needed and capabilities of the team members are described. Schedules and Milestones will be detailed as the team matures their tasks during the pre-launch verification phase prior to NPP launch. Critical logistical details defining data distribution, team communication and reporting strategies post-launch are currently under development.

The Cloud EDR Validation Team encompasses a diverse set of capabilities and interests. We have significant connections to the SDR validation efforts for VIIRS. These aspects are briefly detailed here. We are also strongly connected to the VIIRS Cloud Mask (VCM) and Cloud Layers (CCL) Team. The activities here, more directly focused on COPS and CTx, and CBH validation, are described below.

5.4.1 SDR Focused Activities

Validation of the VIIRS radiance calibration will be performed and the impact of any changes on products will be assessed. Studies will be performed with CrIS high spectral resolution measurements to create highly accurate comparisons with VIIRS moderate-band sensor observations. Initially AIRS and MODIS measurements will be used as surrogates; IASI and HIRS inter-comparison will also be performed. Previous work done with AIRS and MODIS (Tobin et al., JGR 2006) has proven the utility this approach.

We also plan to participate in the Early Orbit Check underflight field campaign that is primarily focused on SDR validation. Plans for this activity are presently in development. A CrIS simulator instrument(s) will be flown along with a cloud LIDAR system for cloud height truth and a VIIRS simulator. An effort to develop a replacement instrument for MAS is underway, but it may not be ready for VIIRS early orbit checkout (assuming VIIRS launch sometime in early 2011); rather, a refurbished MAS would likely be available for any campaign in that timeframe. Data from the CrIS simulator will be used similarly to that just described for CrIS. The purpose of acquiring the VIIRS simulator data is to provide context for the CrIS simu lator data and underflight (VIIRS data) to support the CrIS SDR validation effort; and to acquire VIIRS-like data to be analyzed for cloud and aerosol EDR validation.

For SDR evaluation, aircraft based instruments collect unique data. As an example, Tobin et al. (2007) developed global MODIS/AIRS global radiance comparisons that pointed towards some MODIS IR calibration issues. Was the problem with AIRS or MODIS? Subsequent aircraft observations employing the S-HIS provided confidence that AIRS was well calibrated, so that led to closer inspection of MODIS. However, aircraft based comparisons alone were not able to tell us what the global comparisons did. The combination of aircraft and global comparisons is very powerful. Aircraft deployments need to have multiple, independent objectives (e.g. SDR validation, aerosol validation, COP,CTX validation) so that the time in the field is always of use (i.e. on a given day if you can't do SDR validation, you can probably do cloud validation). It will be very important to try to track SDR anomalies downstream to assess EDR impact. The Atmosphere PEATE science team will need a good understanding of exactly what is happening in the VIIRS sensor to be effective in this (e.g. cross talk, RVS (response versus scan of the mirror), nonlinear calibration effects, etc.). The NGAS EDR team may not be an ideal conduit of day-to-day information on this since their objective may be very different from NASA's. We think NASA needs to be have an independent capability, and will maintain close contact with DeLuccia as SDR lead for the government team.

5.4.2 Cloud EDR Activities

The cloud EDR validation approach is derived from past experience with similar data products. There are 4 types of cloud validation studies, comparisons with heritage satellite cloud data products, comparisons to independent ground-based correlative data mostly focused on CBH and CTx, closure studies mostly focused on COP and CEPS, and use of field campaign observations as available. The closure studies significantly expand the types of correlative data acquisitions and their use. Error budget studies are an inherent component of each of these approaches, but especially enabled by the closure approach.

5.4.2.1 Inter-Satellite Comparison Studies

In the pre-launch time frame, extensive global comparisons will be done between cloud property retrievals using the NGAS science and operational algorithms using MODIS data as a VIIRS proxy. These data will be rigorously compared to available heritage cloud products derived from MODIS (collection 5 and collection 6 when available) and AVHRR. In particular, these comparisons will focus on the MODIS observations from NASA's Aqua satellite, which is part of the afternoon A-Train satellite constellation. This allows other A-Train data (such as CALIPSO, CloudSat, AIRS and MLS), to be used, as deemed necessary, to provide further definition to the analyses.

The matchup data sets being constructed at the Atmosphere PEATE in Wisconsin are of great value. MODIS pixel data are being pulled for every CALIPSO and CloudSat "pixel". Because of the existence of the A-Train, a huge sample of such near-coincident observations now exist. In comparison to cloud property retrievals from passive instruments, such as MODIS and VIIRS, these data provide a much closer approximation to truth and serve as high standard against which to validate the VIIRS EDR products. This is particularly true for the cloud top EDR (CTx) where CALIPSO observed cloud top altitude is definitive. In this realm, the connection to the VIIRS cloud mask (VCM) team is explicit since CALIPSO also provides a definitive measure of the existence, or not, of cloud, albeit with differences in pixel size and sampling. Taken together with the collocated CloudSat radar observations, C&C provide an excellent measure of the existence of multiple cloud layers and the altitude of cloud base in all but the densest cloud situations (e.g., heavy precipitation). Thus, these matchup data are also essential for examining the performance of the CBH and CCL EDR algorithms. These matchup data sets are very well navigated and nearly coincident. A key point is that they are extensive and global, something never before available. In the past, the satellite validation community has relied on twice daily views of a few ground truth sites where necessary LIDAR and radar observations are available. The statistical robustness of what is and can be done with the A-Train matchup data sets is truly unprecedented and is presently transforming cloud retrieval science.

As part of the atmospheric PEATE, computationally efficient and accurate collocation software has been developed to merge the active (CALIOP/CloudSat) and passive observations (MODIS/VIIRS) (Ref Nagel and Holz). The matchup data products produced for the VIIRS evaluation will use these collocation methods accounting for both spatial sampling and cloud parallax effects caused by the different viewing geometries as presented in Figure 5.2. The collocation and parallax correction will also be applied to ground based evaluation products.

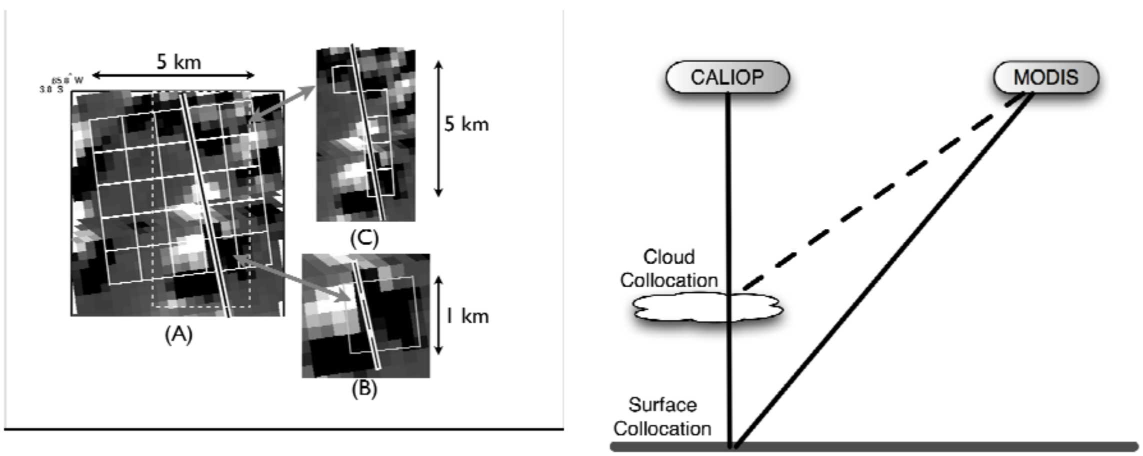

Figure 5.2: The MODIS(VIIRS) sampling compared to CALIOP/CloudSat sampling is presented for a 5 km (Cell) FOV (A), and a 1 km pixel level FOV (B and C). Real MODIS 250 meter visible cloud imagery is presented in the background. The right figure presents the parallax effect due to the different viewing geometries of the sensors.

An additional activity that is currently being planned is to generate a library of scenes where AQUA/MODIS and NOAA-18/19/AVHRR are colocated. Since VIIRS lacks many of the IR channels that MODIS has, such as the water vapor and CO_2 15-μm wavelengths, the CTH and COPS algorithms will have more similarity to those now implemented with PATMOS-x. This activity will allow for a direct comparison of MODIS/AVHRR and PEATE generated VIIRS cloud products. Demonstration of improvement of VIIRS over AVHRR is a critical element for NPOESS. A second similar activity will be to conduct comparisons of VIIRS (generated using MODIS as proxy) COPS products with those generated from SEVIRI to determine the angular characteristics, i.e., the behavior of the COPS products at higher viewing and solar zenith angles. This activity will continue in the post-launch phase with the goal of building a library of collocations between MODIS, AVHRR, and SEVIRI.

This activity will be continued into the NPP post-launch period if MODIS, CALIPSO and CloudSat do not demise. In the event that CALIPSO does demise before NPP launch, MODIS will serve as the comparative transfer standard to apply what is learned in the pre-launch studies to the validation of VIIRS. The present situation (since 2006) provides a much more powerful validation approach than has ever existed before. In the less likely event that CloudSat also demises, we proceed as planned with direct global comparison of MODIS products versus VIIRS EDRs. However, if MODIS also ceases to operate prior to NPP launch, our job gets much more difficult. In the present plan, we provide only a scetch of alternatives in such a worst-case scenario (Section 5.5). However, we can say here that, in that scenario, VIIRS cloud EDR validation would necessarily depend on acquisition and analysis of correlative data from ground-based observing systems. In comparison to what we describe below, this activity would have to be significantly expanded at major expense to IPO so that a credible validation of the cloud EDRs could be made. It would also take longer than planned here.

The focus of cloud properties EDR validation effort will be initially on selected cloud-top properties (water and ice cloud height/pressure/temperature, particle size, and optical thickness) that have never been tested globally. The specific focus will be on the performance of the NGAS algorithms for daytime cirrus initially, and subsequently nighttime cirrus. The validation of the NGAS ice cloud properties will be made in light of ongoing work being performed as part of MODIS pre-Collection 6 studies, specifically with regards to the use of new ice bulk scattering models currently being developed by Ping Yang, Bryan Baum, and Andy Heymsfield – these new models will incorporate advances in light scattering models as well as include surface roughening, new habits such as hollow bullet rosettes, and a wealth of recent (over last five years) *in situ* microphysical data obtained in various field campaigns. Additionally, a new scattering database will include an updated database of the ice refractive index by Warren and Brandt (*J. Geophys. Res.*, *113*, D14220, doi:10.1029/2007JD009744) that necessitates updating the scattering calculations. The NGAS look-up tables of ice cloud radiance and transmission properties, which are used in the ice cloud retrievals, do not include these recent advances, and in fact were developed based primarily on data from a single FIRE campaign.

Experience to date with the NGAS algorithm theoretical basis documents (ATBDs) and resulting software indicates that the inference of ice cloud properties will stand out as a major deficiency in the NGAS products. The validation effort will focus on this aspect with specific tasks listed below. This validation effort involves working closely with the Atmosphere PEATE. As part of the Atmosphere PEATE activities, the NGAS Build 1.5 cloud and aerosol algorithms are being ported into the PEATE system for testing and evaluation in support of the NASA Science Team. The PEATE is responsible for applying the NGAS operational software to global data. For the purposes of evaluating the NGAS cloud and aerosol products, MODIS data will be used as a proxy. Additionally, the PEATE will be generating match-up files of MODIS products with pertinent products from active sensors on the A-Train platform, specifically CALIPSO and CloudSat. Given the current availability of both MODIS Collection 5 and pre-Collection 6 cloud products, products generated from other sensors such as AVHRR and HIRS, and the imminent availability of cloud products derived using NGAS algorithms, a significant validation effort is required to evaluate and understand the performance of the products, both from heritage sensors and NGAS operational code.

5.4.2.2 Correlative Data Studies

As noted previously, COT and CEPS ground-truth data are problematic for many cloud types since adequate quality correlative data for direct comparison is scarce. Accurate direct measurements of cloud optical thickness are difficult to acquire. COT products derived from existing heritage satellite missions have significant uncertainty and likely errors. Even CALIPSO COT retrievals for optically thin clouds suffer from significant assumptions made in the algorithms that have not been adequately validated. For

COT, high-value ground-truth data can be acquired from the few existing sites with high-spectral-resolution LIDAR (HSRL), or Raman LIDAR, especially for optically thin ($\tau < 3$) clouds. At this point, IPO has not planned to invest in acquisition of such data or the analysis thereof. We recommend that IPO consider such investments, subject to mission priorities and available funding. CEPS is particularly challenging for ice and mixed-phase clouds. Consequently, alternative approaches, such as closure assessments, are needed.

5.4.2.3 Closure Studies

For MODIS cloud property validation, NASA funded an innovative approach at the University of Utah. Correlative data and cloud property retrievals from operational ground-observing sites are combined with MODIS retrievals in an online relational database that allows for comparison over many of the relevant degrees of freedom. To date, the data source is the DoE ARM Southern Great Plains (SGP) site in Oklahoma, the most extensively instrumented of the ARM sites, including cloud radar profiles, cloud LIDAR profiles, Raman LIDAR profiles, AIRS-like infrared spectra, microwave radiometer spectra, and sun photometer measurements along with radiosonde support and many other measurements. ARM has developed techniques to generate geophysical products (Value-Added Products, or VAPs) from these data streams. Of special interest here are those generated from multiple sensors that maximize what each provides and, together, minimize their deficiencies. Thus, this NASA investment leveraged the huge investments made by DoE and ARM. We will build off that effort.

For VIIRS Cloud EDR validation, the database will be expanded to also ingest comparable data streams from the North Slope of Alaska (NSA) site at Barrow, and the Tropical West Pacific (TWP) sites at Manus and Darwin. The greatly expands the utility of this effort for VIIRS validation in terms of the sampling of different climate/cloud regimes under a wide range of environmental conditions. It may also be possible, to extend this effort to include data from CloudNet in Europe. This will be explored, though the CloudNet data streams may not be nearly as mature as for ARM.

Besides direct data product comparison, the relational database provides sufficient observational data to allow calculation of the radiance streams that an independent satellite or ground-based sensor would observe. Thus, if the retrieved cloud properties, when combined with high-quality surface and atmospheric observations lead to an estimate of downwelling or upwelling radiances, or fluxes, that agree with the independent observations, there is consistency or closure, and some quantitative measure of validation for the cloud products. This approach is very powerful when TOA and surface fluxes are predicted.

In the present plan, we will develop an interface (TBD) between the software and data streams to University of Utah and the PEATE. Defining this interface and working relationship is an immediate priority. In addition to expansion of the online relational database to include the data collected at additional ground sites in the tropics (TWP) and the NSA, we will continue to update the database as new ground-based results (new data products or retrievals) become available, and work closely with algorithm developers to address specific issues as they are known.

The science/validation team is leveraging the significant processing capabilities of the atmospheric PEATE, including the implementation of the radiative closure capability on a globally scale using CloudSat/CALIOP/MODIS that is currently being developed. The system uses a line-by-line clear sky radiative transfer model (LBLRTM) combined with a cloudy radiative transfer model DISORT (Discrete Ordinates Radiative Transfer Program for a Multi-Layered Plane-Parallel Medium) to compute top-of-atmosphere (TOA) high spectral resolution IR cloudy radiances. These computed radiances are compared to both MODIS and AIRS measured radiances providing an independent source for validation of COT. At launch, the PEATE will have this capability globally for both the NASA Aqua (MODIS/AIRS) and the NPP (VIIRS/CrIS) observations. Even without the active observations (CALIOP/CloudSat), the radiative closure provides a valuable global evaluation of COT.

5.4.2.4 Field Campaigns

It is anticipated that focused field observations will be needed to resolve issues identified via the other validation approaches, specifically for COT and CEPS. Field study data can be used in closure approach if adequate independent data types are acquired. IPO has not planned budget or resources to engage in major field campaigns that might satisfy this requirement. However, it is likely that such campaigns will occur nevertheless, driven by science goals and led by other agencies, especially NASA. Such campaigns would provide a valuable opportunity for IPO supplement and leveraging to acquire the necessary observations in the proper context. Development of a prioritized list of likely cloud EDR validation issues that could be addressed via field data and definition of the corresponding measurement requirements/strategies is a key early priority for the cloud EDR validation team. This will allow identification of possible partnership opportunities for post-launch field activity.

Field campaigns, such as CRYSTAL-FACE (2002), the Atmospheric Radiation Measurements (ARM) program (begun in 1989), and CloudNet (begun in 2001), and the Cabauw Experimental Site for Atmospheric Research (CESAR), a European effort based in The Netherlands, all use various combinations of satellite, aircraft, and ground-based sensors to measure cloud properties and, in so doing, provide validation for newer remote sensing instruments. The Atmosphere team is participating in the planning process for NPP/NPOESS field campaigns using available aircraft, ground sites, and satellite data.

5.4.3 Cloud EDR Activities Schedule

5.4.3.1 Pre-Launch

FY 09 (June 2009 start)

1. Further develop unified "Team" approach to VIIRS cloud validation, including IPO, NASA NPP and NGAS team members, and partnerships with other interested parties, such as the Fleet Numerical Meteorology and Oceanography Center (FNMOC), the Air Force Weather Agency (AFWA), and NOAA. Update plan as required.

2. Define relative roles and required interfaces between NASA Atmosphere PEATE, "native" systems (e.g., Aeronet, MPLnet, University of Utah), Government Resource for Algorithm Verification, Independent Testing, and Evaluation (GRAVITE) and IDPS, the NPOESS Science Investigator-led

Processing System (NSIPS) facilities, especially with regard to data, computer and tool resources. Develop an integrated approach that maximizes efficiency.

3. Define access to IDPS-generated EDRs and IPs for post-launch period (need pixel-level products and cell products).

4. Develop protocols to transfer the most current IR calibration look-up tables, developed algorithms, tools, and data sets to appropriate central locations (CLASS, CasaNOSA, PEATE), with appropriate documentation, for access by other investigators.

5. Reactivate and update relational database build at the University of Utah.

**6. Critical need to have delivered two full months of cloud/aerosol EDRs from the mini-IDPS (based on the most current operational NGAS build) for February 2008 and August 2008. The choice of these months is to focus on time periods after Calipso went to off-nadir pointing at the end of 2007. We need this ASAP so that the products can be evaluated by our team using the PEATE. Both the cell (EDR) products as well as the underlying pixel-level IPs are essential for the evaluation.

FY 10 – launch in early 2011

7. Based on 2 months of NGAS cloud products, use CALIPSO to characterize algorithm performance for all cloud products regardless of solar illumination (day & night). Evaluate impact of VIIRS cloud mask on downstream cloud EDRs.

Subtasks could include
- comparison of CTH to Calipso
- evaluation of VCM (including multilayer cloud flag)
- evaluation of VIIRS cloud phase (part of VCM)
- evaluation of COT (optical thickness)

8. Integrate CloudSat with existing MODIS/CALIOP/AIRS, and with MODIS as a proxy for VIIRS, into Collocation/Matchup UW processing system in collaboration with Jay Mace (U. Utah).

9. Construct MODIS (and VIIRS EDR run on MODIS Proxy) matchup data sets for static surface sites such as ARM CART, Eureka (HSRL), SSEC (HSRL; currently running) and Beltsville/GSFC (Raman) sites.

10. Develop capability at Atmosphere PEATE to use solely Cloudsat cloud products for comparison with pre-launch cloud products.

11. Develop system to perform radiative transfer closure studies.

Subtasks could include:
- use of line-by-line RTM + Disort
- using measured radiances as a way to determine adequacy of products

12. Intercompare mini-IDPS cloud products with those produced at the PEATE using Leocat and the same operational build of EDR cloud algorithms.

13. Once cloud products from mini-IDPS effort are intercompared with products from Atmosphere PEATE so that we have good-faith comparison and think we have replicated the NGAS products adequately, then repeat evaluation of cloud properties globally, but over lengthier periods of data (at least one year of CALIPSO/CloudSat/MODIS), focusing on problem areas such as clouds over snow/mountains, data from low-sun conditions (terminator).

14. Prepare summary of problem areas that need additional focus for validation activities
By this time, there will be more clarity as to whether the NGAS algorithms will be of sufficient quality to meet required specifications pre-launch

5.4.3.2 Early Orbit Check-out

1. SDR activity: The PEATE will provide Simultaneous Nadir Overpass (SNO) observations between VIIRS and both AIRS and IASI hyperspectral sounder observations with the goal of providing an early assessment of the VIIRS IR channel calibration. This analysis will be transitioned to CrIS observations once the CrIS has completed its initial validation period. The AIRS/IASI/CrIS radiances will be integrated over the VIIRS spectral response functions for appropriate IR bands, and subsequently compared to the VIIRS measured radiances. This activity will provide insight to the VIIRS SDR evaluation effort and also be critical for understanding the behavior of the VIIRS cloud products.

2. The PEATE will provide SNO match-ups of cloud EDRs between VIIRS and other polar-orbiting imagers such as AVHRR and MODIS. At same time, intercompare shortwave radiances/reflectances, with focus on dark and bright targets.

3. The PEATE will run, in parallel, the NGAS and other science team algorithms on MODIS data and compare to VIIRS EDRs and IPs. One issue to evaluate is the NGAS treatment of cloud parallax corrections in going from pixel-level results to cell product.

4. Conduct global comparison of VIIRS CTx and COPS products with those generated from MODIS and AVHRR PATMOS-x.

5.4.3.3 Intensive Validation Phase (mid-FY 11 – FY 13)

1. Ongoing evaluation of performance of products from new/revised algorithms. Repeat global pre-launch analysis in post-launch timeframe. Look for anomalies between cloud products based on heritage algorithms and data sets (e.g., HIRS, AVHRR, MODIS) and those from VIIRS

2. High quality LWP retrievals from ATMS can be used as a contraint to LWP derived from VIIRS in restricted regimes (related to product of particle size and optical thickness)

3. If both VIIRS data become available and CALIPSO is alive, the PEATE should provide NPOESS/CALIPSO matchup files as has been done with MODIS (POES) and CALIPSO.

4. If both VIIRS data become available and Cloudsat is alive, the PEATE should provide NPOESS/Cloudsat matchup files for evaluation.

5. Focused field campaign would be very valuable for evaluation of IR calibration. Also would be valuable to have coincident depolarization lidar (HSRL)/radar from aircraft for cloud profiling of cloud phase and cloud-top height. Need to determine whether HSRL has both upward and downward viewing capability on aircraft.

6. Perform final EDR assessment based on cells (pixel aggregation)

7. Keep track of global IR radiance comparisons between CrIS and VIIRS

8. Keep track of comparisons between VIIRS cloud products and surface sites

9. Prepare summary of evaluation results for each cloud EDR

5.5 Contingency Plans

Some thought is being given to making contingency plans in case expected data streams unexpectedly terminate. The following list is not exhaustive by any means, and will be expanded over time.

Early termination of MODIS Aqua:

Option 1: Compare VIIRS cloud products to those from AVHRR (based on PATMOS-x) and MODIS Terra (in addition to the regular MODIS products, should also apply VIIRS-like algorithms to MODIS Terra data stream)

a. look for anomalies in global properties, probably using either weekly or monthly averages
b. derive simple statistical metrics that we could use for automated comparisons (e.g., percentage of cloud cover in broad low, mid, and high-level cloud categories)

Option 2: Potential use of SEVIRI (geostationary) as daily transfer point

a. prelaunch: compare Calipso/Cloudsat to SEVIRI cloud products, using set of algorithms prepared by GOES-R Cloud Working Group (Heidinger, Pavolonis, Platnick, Minnis, Yang). These algorithms are already available and ready for use.
b. Mechanism has been developed to intercompare Calipso products to SEVIRI-based cloud products. If this was pushed farther and sufficient statistics with SEVIRI-Calipso/Cloudsat matchups were available, then we could compare VIIRS to SEVIRI on a daily basis.

Early termination of Calipso:

a. fly more aircraft with HSRL or CPL package
b. rely more heavily on MPLnet (lidar network) and ARM CART sites
c. rely more heavily on Cloudsat data for global coverage

If Calipso and Cloudsat are unavailable after the launch of VIIRS,

a. fly more aircraft with HSRL or CPL package
b. rely more heavily on MPLnet, ARM CART sites, and other ground sites of opportunity (e.g., SSEC has a HSRL)

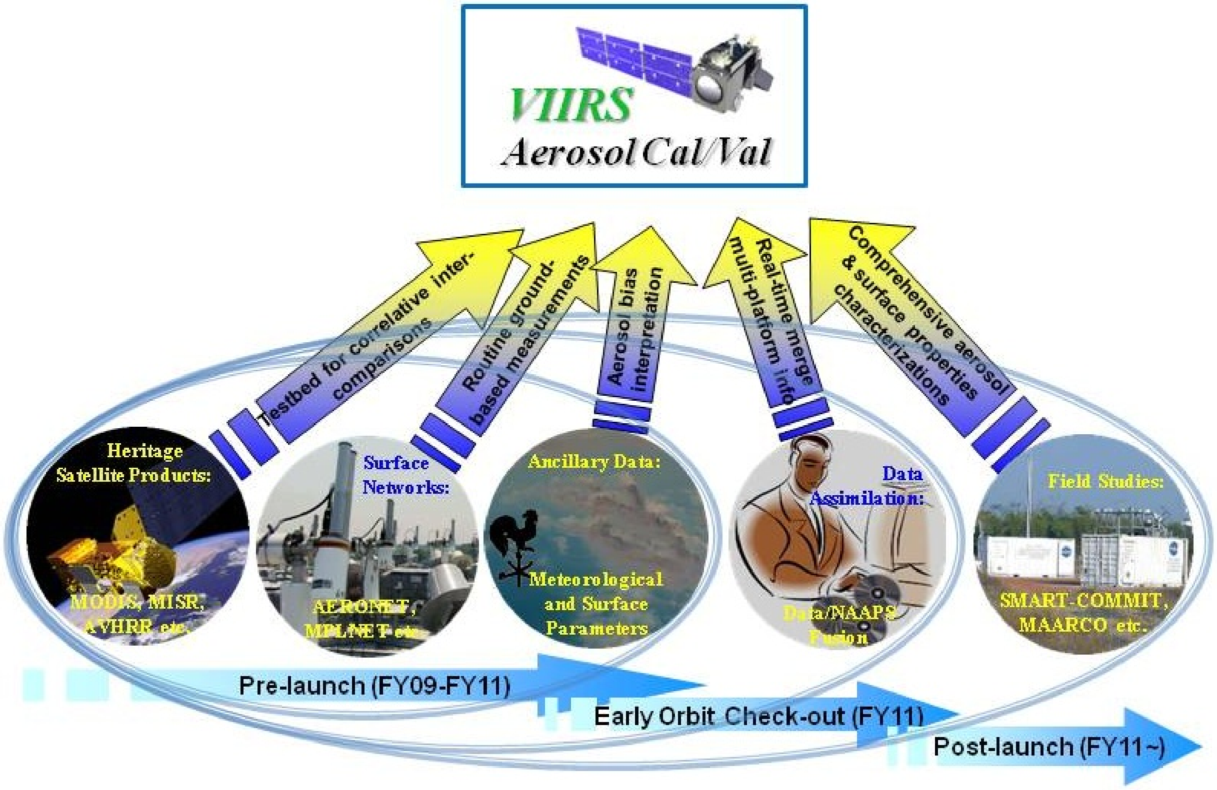

Figure 5.3. VIIRS Aerosol EDR Validation Strategy

5.4.4 Aerosol EDR Validation Activities

The VIIRS aerosol EDRs addressed in this document include aerosol optical thickness (AOT) and aerosol particle size parameter (APSP), as well as the aerosol suspended matter (SM). In order to build a cost efficient and productive team structure, significant efforts will be made by leveraging on existing resources and will be coordinated closely between NASA, NOAA, and Navy teams. Figure 1 summarizes the major components of aerosol EDR validation activities in this plan, including (1) long-term ground network monitoring, (2) intercomparisons with heritage satellite aerosol products, (3) data assimilation, and (4) field campaigns.

The primary efforts of validating the VIIRS aerosol EDRs will focus on evaluating and testing the VIIRS operational and science aerosol algorithm and characterizing errors in the resulting aerosol products with emphasis on the identification of error sources, with the expectation of a detailed estimate of the error budget, and understanding of error sources. In order to achieve this goal, we will not only utilize the correlative aerosol EDR products from satellite, ground and aircraft measurements, but also various important ancillary data such as ocean surface wind speed, land surface reflectance, and meteorological parameters to provide insight on the sources of discrepancy in the aerosol retrieval processes.

The aerosol validation plan encompasses both NPP pre-launch and post-launch activities and builds on the extensive experience with validating AVHRR and MODIS aerosol data products. The approach includes a wide range of independent coincident correlative data so that sufficient sampling statistics can be achieved, both temporally and spatially. Established ground networks such as AERONET and ARM provide long-term consistent benchmarks for validating VIIRS aerosol EDRs, but they suffer from geographic bias; in particular, they lack ocean coverage and are often not able to capture the episodic events in regions of interest. Accordingly, we will also make daily comparisons of VIIRS products with other satellite aerosol products from MODIS, MISR, APS, and AVHRR, as well as with CALIPSO retrievals. This multi-platform approach will allow comprehensive assessments in terms of regional, seasonal and phenomenological dependencies that will be essential to maximize the utility of the EDRs for operational customer applications.

For the satellite component of the correlative measurements, we will heavily rely on the heritage aerosol products of MODIS in particular from Aqua satellite because of their similarity of equator crossing time and spatial coverage. However, in the event of demise of MODIS/Aqua sensor, the use of aerosol products from APS, on Glory, will become a key element to continue providing independent satellite information acquired close to the VIIRS overpass time. Another alternative approach is using data assimilation. Various satellite products taken at different time and locations such as from AVHRR, MISR, and MODIS/Terra can be ingested through data assimilation technique and generate aerosol information collocated for VIIRS.

The lessons learned from these simulation activities will help identify algorithm issues and expected performance characteristics, as well as provide a basis for improvement of the aerosol retrieval algorithm and thus the efficacy of VIIRS aerosol EDR products. These results will also provide important guidance for focusing and developing strategies to perform any necessary validation field campaigns during the Intensive Validation Phase.

Details of major validation components targeted by the aerosol validation plan are described in this section. Many categories of activities listed below will be performed starting from pre-launch period and continue into the early checkout and intense validation phase as part of the post-launch activities.

5.4.4.1 Comparison to Heritage Satellite Aerosol Products

Heritage aerosol data products derived from MODIS sensors on the EOS-era Terra and Aqua satellites, launched in 1999 and 2002, respectively, will play a major role in comparing and characterizing the VIIRS aerosol EDRs. Another key heritage sensor for aerosols is the AVHRR that is currently flying on NOAA-18 and NOAA-19. Other important EOS-era satellite-based sensors, which provide heritage aerosol products, include MISR, also aboard Terra satellite, SeaWiFS on SeaStar satellite, as well as the OMI onboard Aura satellite.

During the pre-launch period, the performance of NGAS's VIIRS operational aerosol algorithm will be evaluated by generating aerosol EDRs from it using MODIS radiance data as a VIIRS proxy data set. The lookup tables used by the operational algorithm will be modified to account for the differences between the MODIS and VIIRS bands. Post launch, the actual VIIRS aerosol EDRs will be similarly evaluated globally. We plan to compare these simulated products of aerosol optical thickness and size parameter over both land and water with those retrieved from MODIS as well as other heritage aerosol products mentioned above.

Regional and global statistics (mean, standard deviation, probability density function, etc.) of the comparisons will be calculated and analyzed. The results of these analyses will be further divided into subgroups based upon aerosol type, such as smoke, dust, urban pollution and sea salt, as well as different underlying surfaces including water, vegetated dark land, and bright dry land. Such detailed characterization is particularly imperative in order to provide in-depth evaluations of NGAS versus MODIS heritage algorithm performances in terms of aerosol model selections and surface reflectance parameterizations, two of the most important key elements in retrieving aerosol properties from space. The results will also be categorized in terms of the level of consistency (low, medium, high) between the VIIRS and MODIS AOT retrievals. Regions with low consistency will be further examined for causes by analyzing the flow of processing in the VIIRS algorithm, especially the selection of aerosol models. The routine processing will permit capture of episodic events (e.g., volcanic eruptions, smoke and dust plumes) and to test the SM retrievals by comparing it with independently identified (known from ground and aircraft reports) and geographically localized events and to the retrieved aerosol models and particle size.

5.4.4.2 Evaluation with CALIPSO and APS Data Products

We also plan to merge heritage MODIS products and VIIRS EDRs derived from the NGAS operational algorithm using MODIS radiances with CALIPSO measurements. Since its launch in 2006, CALIPSO has provided invaluable information on the vertical structure of aerosols and clouds. CALIPSO observations (extinction profiles) will be used to investigate the sensitivity to assumptions about aerosol vertical distribution. Combining MODIS with CALIPSO information will allow us to better separate stratospheric aerosols from tropospheric aerosols, such as volcanic plumes. It will also help improve the cloud mask/screening determination in the aerosol algorithm, particularly over thin cirrus.

With the launch of NPP currently scheduled for 2011, it is possible that CALIPSO measurements will not overlap with actual VIIRS observations. Nevertheless, the lessons and knowledge learned from the merged data sets of MODIS and CALIPSO, and the NGAS-like products (pre-launch products generated using MODIS proxy data as described above), can be directly applied to the VIIRS operational EDRs.

Data from APS on Glory, planned for launch in early 2010, will also be used to assess the effect of assumptions on composition (especially biomass burning smoke) and particle shape (mineral dust). However, both APS and CALIPSO have very narrow swath (i.e., small spatial coverage) compared to that of VIIRS. The sampling sizes of correlative measurements from such sensors is a major concern for validating VIIRS aerosol EDRs, especially for larger view angles.

5.4.4.3 Comparison to Ground-based Correlative Measurements

For validation of the AOT EDR, a wealth of high-quality ground-truth observations are available, including measurements from the AERONET and SURFRAD observing network, among others. These will be used in combination with highly valuable correlative data from the MPLNET and ARM sites to provide insights into understanding the efficacy of algorithm performance over different atmospheric and underlying surface conditions on long-term regular basis. These observations also provide a foundation for comprehensive evaluation of APSP EDR. While the approach for validation of the SM EDR has not yet been finalized, it is clear that such field data can be used to indirectly infer information on SM, by combining the retrieved AERONET products of single scattering albedo and size distribution.

The AERONET sites will be selected to cover the major tropospheric aerosol types (such as mineral dust particles, biomass burning smoke, urban/industrial pollutions, and marine aerosols). The spectral AOT derived from the AERONET sun photometers will be interpolated or extrapolated to the satellite retrieval channels for proper comparison. Both level 1.5 and level 2.0 AERONET observations will be used. Because of the delay in the availability of AERONET data, satellite retrievals will have to be archived and comparison statistics computed when the ground data become available. Similar to CALIPSO, MPLNET provides a measure of the vertical distribution of aerosols at selected AERONET sites.

During the pre-launch phase, infrastructure and software will be developed, building on the MODIS and AVHRR heritage, to provide routine global statistics of aerosol EDR performance against the benchmark provided by ground based AERONET observations. The performance of VIIRS operational algorithm will be tested by using MODIS aerosol products derived from the NGST-like algorithm as a proxy to compare against the AERONET observations. These results will be compared with those based upon the MODIS heritage products region by region as well as on global basis. The infrastructure to merge satellite data with ground-based measurements built during the pre-launch activities will be used as the framework for post-launch validation.

5.4.4.4 Error Budgets and Algorithm Evaluation

Initially in the pre-launch phase with MODIS proxy data simulations of VIIRS EDRs and continuing on into the post-launch phase with the actual EDRs, the VIIRS science and operational algorithms will be evaluated by comparing them with MODIS (and other satellite)-derived and ground-observed (mainly AERONET and SURFRAD) aerosol optical thicknesses and particle size, as well as vertical distribution information at MPLNET and ARM sites. This will permit thorough testing of the algorithm under a large variety of realistic conditions, and establish a detailed time and space (surface type), and aerosol-model dependent error budget. This also ensures statistically robust sampling, and permits characterization of the quality of aerosol retrievals for different “classes” of aerosol types and surface reflectance. The data will also be analyzed in terms of geometry, geographical region, season, and aerosol type. Special emphasis will be on understanding the physical reasons of the observed dependences. The techniques applied for this type of analysis will include computation of statistics describing various aspects of the retrievals (e.g., mean, RMS and mean absolute differences, probability distributions) as well as Kolmogorov-Smirnov statistics.

Our initial focus will be on addressing known issues. The dynamic determination of aerosol model over land used in the VIIRS algorithm is a relatively new concept and therefore not well tested. Thus, there is need to check 1) whether the dynamic method is robust enough in the presence of measurement and numerical uncertainties; 2) whether the eight aerosol models are sufficiently representative of possible situations, 3) how frequently the retrieval is ambiguous due to the fact that different aerosol models with different AOT can produce very similar spectral TOA reflectance, and 4) whether the retrieval “favors” any size mode (small or large) over ocean or any particular aerosol model over land. These will be done by a detailed examination of results obtained from applying the statistical techniques.

In summary, the validation of the VIIRS AOT and APSP EDRs will focus heavily on comparisons with AERONET and SURFRAD data, supplemented by MPLNET aerosol profiles, and with comparisons to available heritage satellite retrievals, especially those produced from MODIS and AVHRR, and making heavy use of CALIPSO observations.

5.4.4.5 Ancillary Data

In order to provide sufficient insight in understanding the discrepancy between VIIRS aerosol EDRs and independent correlative measurements, the acquisition of ancillary data, which are relevant on aerosol retrieval processes, will also need to be addressed. These supplementary parameters include various land, ocean, and atmosphere products, as summarized in Table 5.4. The use of ancillary data can be categorized into two parts: one is based on the known science, from which we can validate the meaningfulness of the VIIRS aerosol EDRs in comparison to existing scientific results; the other is based on new research exploration, from which we can conduct detailed data analysis of independently retrieved weather and climate datasets and find their coherent relationships. Such relationships could either tell us any possible error sources of aerosol data biases or lead us to new scientific discoveries based on the use of VIIRS aerosol EDRs.

Table 5.4. Relevant ancillary data for aerosol retrieval processes

Parameters	Datasets	Temporal coverage	Data sources	Relevance
Precipitation	GPCP V2	1979-	http://precip.gsfc.nasa.gov/	Changes in surface reflectance; Wash out effect; Modulation of aerosol emission and transport
	CMAP	1979-	http://www.cdc.noaa.gov/data/gridded/	
	ECMWF	1979-	http://data.ecmwf.int/data/	
	TRMM	1988-	http://daac.gsfc.nasa.gov/data/datapool/TRMM/	
Water vapor	AIRS (Aqua)	2002-	http://daac.gsfc.nasa.gov/data/datapool/AIRS/index.html	Water vapor absorption correction for some of sensor bands; Aerosol physical and hygroscopic characteristics
	SSM/I	1987-	http://www.ssmi.com/ssmi/ssmi_browse.html	
	NCEP Reanalysis I and II	1948-	http://www.cdc.noaa.gov/data/gridded/reanalysis/	
	MODIS (Terra and Aqua)	1999-	http://modis.gsfc.nasa.gov/	
Cloud	CloudSat	2006-	http://www.nasa.gov/cloudsat	Aerosol retrieval near clouds; Aerosol-cloud interaction
	ISCCP	1983-	http://isccp.giss.nasa.gov/	
	MODIS (Terra and Aqua)	1999-	http://modis.gsfc.nasa.gov/	
Surface wind	NCEP Reanalysis I and II	1948-	http://www.cdc.noaa.gov/data/gridded/reanalysis/	Ocean reflectance; Sun glint
	SSM/I	1987-	http://www.ssmi.com/ssmi/ssmi_browse.html	
	SeaWinds (QuikSCAT)	1999-	http://podaac.jpl.nasa.gov/	
	AMI (ERS-1 and ERS-2)	1991-	http://cersat.ifremer.fr/data	
Relative humidity, air temperature and pressure	AIRS (Aqua)	2002-	http://daac.gsfc.nasa.gov/data/datapool/AIRS/index.html	Aerosol physical and hygroscopic characteristics; Aerosol transport
	MODIS (Terra and Aqua)	1999-	http://modis.gsfc.nasa.gov/	
	NCEP Reanalysis I and II	1948-	http://www.cdc.noaa.gov/data/gridded/reanalysis/	
Land surface reflectance	LandSat (MSS, TM, ETM+)	1972-	http://landsat.gsfc.nasa.gov/	Land reflectance; Aerosol source identification
	MODIS (Terra and Aqua)	1999-	http://modis.gsfc.nasa.gov/	
	ASTER (Terra)	1999-	http://asterweb.jpl.nasa.gov/	
Land surface elevation	ASTER (Terra)	1999-	http://asterweb.jpl.nasa.gov/	Terrain pressure correction for Rayleigh scattering

5.4.4.6 Data Assimilation

Another important tool for validating VIIRS aerosol EDRs is through data assimilation by ingesting various satellite and ground measurements into the model. This effort is currently led by the NRL team in Monterey, California. The outcome of data assimilation will provide valuable mean to bridge aerosol information derived from VIIRS and other satellite observations (such as AVHRR) taken at different time and location. This capability is in particular imperative in the event of demise of the A-train constellation satellite sensors, when nearly coincident / collocated measurements both temporally and spatially are no longer possible between VIIRS and MODIS or APS. In addition, the assimilation outputs will provide, on real-time basis, a suite of supplementary information such as meteorological and cloud conditions from Navy's NOGAPS model to aid interpretation of the intercomparison results between VIIRS and other ground and satellite products. The data assimilation approach is particularly well-suited to rapid day-1 assessment of post-launch EDRs.

5.4.4.7 SDR Focused Activities

Compared to the cloud products, aerosol retrievals are much more sensitive to the uncertainty in both absolute as well as inter-wavelength (i.e., band-to-band) radiometric calibrations, in particular for APSP EDR. Therefore, SDR validation activity will also be an imperative element of the VIIRS aerosol EDR validation efforts.

Vicarious calibration approach will be implemented to provide routine monitoring of the characteristics of anomaly in SDR that are relevant to the accuracy of VIIRS aerosol EDRs. We will in particular evaluate the magnitudes of SDR anomaly due to the potential sensor issues related to (1) IFA cross talk; (2) stray light; (3) polarization; and (4) transition between high and low gains. Since the magnitudes of VIIRS IFA cross talk are wavelength dependent, they may impact the performance of aerosol optical thickness and, in particular, size parameter. We will also examine aerosol products retrieved around the bright objects (such as pixels near cloud edge and coastal zone) where the quality of aerosol EDRs may be susceptible to the stray light issue. Thorough pre-launch characterization of the polarization impact on SDR will also be highly valuable to account for its effect particularly for shorter wavelength bands. Since VIIRS has dual gain capability, the transition between high and low gain needs to be well characterized to avoid uncertainty of SDR within this radiance range where medium aerosol loading usually resides.

5.4.4.8 Field Campaigns

While the intercomparison efforts with heritage satellite products and ground based AERONET and MPLNET observations will serve as the bedrock for systematic long-term monitoring of NPP/NPOESS VIIRS algorithm performance for aerosol EDRs, well-focused field campaigns undoubtedly play a key role in providing in-depth information which are needed to address the root causes of the problematic areas identified by the routine network validation processes. The chemical composition measurements collected during the field experiments will also provide an important piece of puzzles to validate the SM product, which is otherwise not available through either AERONET or heritage satellite observations.

Ground-based in-situ and remote-sensing measurements acquired from Navy's MAARCO and NASA/GSFC's SMART-COMMIT mobile facilities will allow detailed comprehensive information of aerosol microphysical, optical and chemical properties made directly underneath the track of VIIRS. They will also provide valuable link between aerosol optical thickness and mass concentration, which is critically needed for improving the skill and accuracy of aerosol transport model as well as data assimilation forecast. In addition, data from lidar not only reveal the aerosol vertical profiles, when in conjunction with hyperspectral IR sensors, they can also distinguish elevated dust layer from thin cirrus, which is well known to impact the accuracy of both satellite aerosol EDRs as well as the AERONET products. Measurements from these types of ground super-site field operations are essential elements in better understanding the efficacy of the VIIRS aerosol EDRs.

5.4.4.9 Collaboration with other Validation Teams

The relationship to the VIIRS Cloud Mask (VCM) and Cloud Validation Team is very clear, since the quality of the aerosol retrievals depend strongly on the quality of the cloud mask as described elsewhere in this document. Also, cloud retrievals, especially in the aerosol-cloud transition domain, are important since for closure the aerosol and cloud retrievals should closely lead to the satellite-observed reflectance in a forward calculation.

The activities of the Aerosol Team are also closely related and linked to those of the Land Validation Team. Alexei Lyapustin (Table 3) is the appointed bridge between aerosol and land validation teams. Retrieval of land surface reflectance, an internal (by-) product of the aerosol retrieval, is one of the main sources of uncertainties in the VIIRS aerosol algorithm. On the other hand, the quality of the aerosol data affects the quality of atmospheric correction and the accuracy of surface reflectance, vegetation index, albedo and other land EDRs. This interdependence demonstrates the need for close collaboration between the Atmospheres and Land teams in sharing common test datasets and results of analysis of products that are intermediate for the aerosol and land algorithms (surface reflectance for aerosol, and aerosol for surface reflectance).

The Land Team will initially use the AERONET-based Surface Reflectance Validation Network (ASRVN) for evaluating the retrieved surface reflectance. This network was developed as part of the EOS MODIS validation program. The ASRVN is an automated system that receives 50x50 km^2 subsets of operational MODIS and MISR data for about 160 AERONET sites globally and performs accurate atmospheric correction using AERONET aerosol and water vapor data. Currently, the ASRVN provides comprehensive 9-year MODIS/TERRA and 7-years MODIS/AQUA statistics for surface reflectance validation, including spatial, spectral, temporal and angular domains. The global AERONET infrastructure allows characterization of major ecosystems and surface types. For the VIIRS-related work, the ASRVN will receive VIIRS subsets of L1B data as well as cloud mask and aerosol products. The latter products are required for detailed error analysis of surface reflectance. In this regard, the aerosol analysis by the Land and Atmospheres Teams will be complementary but not necessarily identical. The ASRVN will contribute to the aerosol analysis by the Atmospheres team. ASRVN data over different land surface types will also be used to assess the surface reflectance retrievals in the aerosol algorithm. In the immediate post-launch period, the ASRVN will also provide algorithm and sensor calibration support analysis by studying trends in the time series of the VIIRS products and their consistency with the MODIS data record.

5.4.5 Aerosol EDR Activities Schedule

5.4.5.1 Pre-Launch (FY09 – FY11)

MODIS data will be used as proxy input to the operational VIIRS aerosol algorithm to produce NGAS-like EDRs for AOT, APSP, and SM. These will be evaluated by direct comparison with MODIS (and other satellite)-derived heritage aerosol data products and ground-based remote sensing observations (mainly AERONET and SURFRAD) of aerosol optical thicknesses and particle size. This will permit thorough testing of the algorithm under a large variety of realistic conditions, and establish a detailed time, space, and aerosol-model dependent error budget. This also ensures statistically robust sampling, and permits characterization of the quality of aerosol retrievals for different "classes" of aerosol types and surface reflectance. Analysis of match-up CALIPSO aerosol extinction profile observations, and MPLNET profiles, will be used to help understand the role of aerosol vertical profile assumptions in the error retrieval budgets.

Both the AOT and APSP algorithms will be configured for routine runs with MODIS data. This effort will benefit from the existing access to near real-time MODIS data. Level-0 MODIS data are transmitted to the NASA/NOAA Near Real Time (NRT) Processing System and Goddard Space Flight Center (GSFC). The "bent pipe" approach allows the generation of selected products with 24 hours of observation. This system was designed to provide NOAA with "rapid" access to MODIS data from the Terra and Aqua satellites while providing risk reductions for future high data rate satellite systems. However, we plan to transition portions of this activity to the Atmospheric PEATE, as appropriate.

Using MODIS data as proxy allows the evaluation of aerosol retrievals under a large number of realistic varying surface and atmospheric conditions. It is noted, however, that the above approach cannot test the VIIRS algorithm in its entirety; surface reflectance retrieval and gas-absorption correction developed for the VIIRS channels are necessarily replaced with ones developed for MODIS. Therefore, the precision and accuracy EDR assessment must be done after the launch of NPP, but strongly benefiting from the lessons learned during the pre-launch phase.

(FY 09) – June 2009 start

1. Further develop unified "Team" approach to VIIRS aerosols validation, including IPO, NASA NPP and NGAS team members, and partnerships with other interested parties, such as the Fleet Numerical Meteorology and Oceanography Center (FNMOC), AFWA, and NOAA. Update plan as required.

2. Define relative roles and required interfaces among between NASA PEATE, "native" systems, Government Resource for Algorithm Verification, Independent Testing, and Evaluation (GRAVITE), the NPOESS Science Investigator-led Processing System (NSIPS) facilities, especially with regard to data, computer and tool resources. Develop an integrated approach that maximizes efficiency.

3. Develop protocols to transfer the developed algorithms, tools, and data sets to appropriate central locations (CLASS, CasaNOSA, PEATE), with appropriate documentation, for access by other investigators.

4. Begin the FY 10 activities.

(FY 10)

5. Conduct sensitivity tests using the operational VIIRS aerosol retrieval algorithm applied to MODIS proxy data and cross validate with MODIS and /or MISR aerosol retrievals to explain differences between the VIIRS and MODIS heritage aerosol retrievals.

6. Finalize system for routine retrieval of AOT, APSP, and SM from the VIIRS algorithm driven by MODIS data.

7. Collect independent satellite-retrievals of aerosol properties (MODIS, MISR, APS).
Analyze the EDRs for consistency with independent aerosol products.

8. Develop a prototype version of the VIIRS aerosol verification and validation system. The validation procedures and dataset for each aerosol EDR will be defined and initial ground truth data (AERONET) will be collected. Test the system and evaluate the aerosol EDRs.

9. Finalize the verification and validation system. Develop active QC/QA analysis and validation operations for the NPP/VIIRS observations. Derive, archive, and deliver a concise match-up dataset for the algorithm and calibration re-evaluation as well as for algorithm inter-comparison. Continue collection and analysis of MODIS, MISR, CALIPSO, and APS observations. Make adjustments to the QC/QA methodology. Perform validation using the developed verification and validation system.

10. Finalize schedule and milestones for Intensive Validation Phase, and define the EXIT CRITERIA.

11. Document and report on the performance of the VIIRS aerosol retrieval algorithm, and provide assessment of the error budget.

5.4.5.2 Early-Orbit Checkout (FY11)

Because the retrieval of small aerosol optical thickness over a dark surface is very sensitive to the calibration and stability of the sensor, it can potentially be used to monitor the radiometric performance of the sensor. Thus, the quality of retrieved aerosol optical properties can potentially serve as indicators of sensor performance (e.g., calibration accuracy and stability), if algorithm assumptions are well characterized and verified. The aerosol products from A-train satellites will provide important basis for validating NPP VIIRS aerosol EDR during this phase.

1. Monitor sensor performance by analyzing quality of aerosol data from the verification and validation system. Perform forward radiative transfer calculations to assess consistency of VIIRS EDRs.

5.4.5.3 Intensive Validation (FY11 – FY13)

In the first six months following the launch of NPP, extensive data will be collected to validate VIIRS aerosol EDRs through comparisons with the ground-based AERONET and SURFRAD data as well as through satellite-to-satellite intercomparison with MODIS, Glory and, hopefully, CALIPSO data products. Global and regional statistics of VIIRS aerosol EDR performance scores can be swiftly generated using the systems developed during the pre-launch validation efforts. For the purpose of validating VIIRS SDR, a handful of targeted AERONET sites with most favorable environments, such as stable surface and atmospheric conditions, will be selected for detecting absolute bias, angular dependence of viewing geometry, and trend in the differences between VIIRS aerosol EDRs and ground truth. The robustness of the VIIRS cloud mask used in the aerosol algorithm will also be tested with other existing satellite products and ground based measurements from AERONET and ARM sites.

Through these comprehensive intercomparison efforts of VIIRS aerosol EDR products with AERONET and other satellite products, we will confirm the regions where the performance of aerosol EDRs meets the specified requirements. In addition, we will identify critical areas and situations where the aerosol retrieval scheme is deficient in producing aerosol data records, and further focused in-depth investigations are needed. Thus, these validation studies will provide guidance in defining crucial science questions and measurement requirements for VIIRS post-launch field validation campaigns.

The comparative analysis of data will be performed on global and local (test site) scales and temporal domains (daily, monthly, and seasonal). The data will also be analyzed in terms of viewing geometry, geographical region (surface type) and aerosol type. Special emphasis will be on understanding the physical reasons of the observed dependences. The techniques applied for this type of analysis will include computation of statistics describing various aspects of the retrievals (e.g., mean, RMS and mean absolute differences). Kolmogorov-Smirnov statistics will be used to quantify the differences between different estimates (or measurements) of AOT, APSP and SM.

1. Perform automated statistical regional and global comparisons of VIIRS Aerosol EDRs versus heritage satellite data products and available ground-based “truth” observations.

2. Provide definitive assessment of error characteristics of VIIRS Aerosol EDRs with emphasis on the identification of error sources and dependencies, with the expectation of a detailed estimate of the error budget, and understanding of error sources.

3. Demonstrate that EXIT CRITERIA are satisfied.

5.4.5.4 Long-Term Monitoring

TBD

5.5 RESOURCE REQUIREMENTS

Personnel -TBS

Satellite Data:
MODIS (on Aqua and also on Terra)
AVHRR
CALIPSO
CloudSat
MISR (on Terra)
GOES
SEVIRI
APS (to be launched on Glory)
AIRS and IASI

Ground and Campaign-based Data:
AERONET
ARM sites (SGP, TWP, NSA)
MPLNET
SURFRAD
HSRL and Raman sites (1-2 each)

5.6 REPORTING

TBS

5.7 AREAS OF CONCERN

This validation program is critically dependent on being able to participate in timely field and aircraft campaigns that are largely funded externally. It is also dependent on NASA-funded upgrades to the MAS. Funding of ground networks is also a great concern. IPO has adequately addressed this for AERONET, but additional support may be needed for MPLNET and especially the HSRL and Raman sites.

5.8 REFERENCES (TBR)

Gumley, L, H. Revercomb, P. Antonelli, B. Baum, and R. Holz, **The NPP Atmosphere Product Evaluation and Test Element (PEATE),** Abstract for the 12th Conference on Atmospheric Radiation (2006) published online at http://ams.confex.com/ams/Madison2006/techprogram/paper_112298.htm, accessed October 14, 2008.

5A. APPENDICES

5A.1 Validation of NPOESS System Specification

NGAS Draft Input to Community Cal/Val Plan, Michael Plonski, 3/24/09, Version 1.0

The objective of this section is to identify activities and procedures needed to conduct calibration/validation (Cal/Val) of the Atmosphere EDRs against requirements levied in the NPOESS System Specification (Sys Spec) for the NPP and NPOESS programs.

The EDR Cal/Val effort is a team activity that involves expertise from members of the government, research institutions, academia, as well as the NPOESS Contractor. Since the overall EDR Cal/Val tasks envisaged by the team cover a broader range of activities than those needed solely to assess EDR performance against the NPOESS System Specification [NSS], this section shall focus only on those tasks necessary to validate the NPOESS Sys Spec. As a result, this plan (1) leverages on the activities benefiting the larger community and identified in other sections of this plan, and (2) identifies any additional tasks needed to accomplish this objective.

General Requirements and Assumptions are described in section 1.4, the Overview Volume of this document. EDR definitions and specific specifications are detailed in section 5.2 of this Volume.

5A.1.1 EDRs in the Atmosphere Product Group

The specific list of EDRs covered by the Atmosphere product group are shown below. The specific performance parameters for each EDR are discussed in more detail in the following sections.

Table 1: Atmosphere EDR Horizontal Cell Sizes and Grids

Category	Acronym	SS sec.	Name	HCS	Granule Grid
AEROSOLS		40.3.1			
	AOT	40.3.1.1	Aerosol Optical Thickness	6 km / 12.8km (nadir/EOS)	96x400
	APS	40.3.1.2	Aerosol Particle Size Parameter	6 km / 12.8km (nadir/EOS)	96x400
	SM	40.3.1.3	Suspended Matter	1.6 km	768x3200
CLOUDS		40.4.			
	CBH	40.4.1	Cloud Base Height	6 +/- 1 km	96x508
Not in this CVP	CC/L*	40.4.2	Cloud Cover/Layers	6 +/- 1 km (0.8km BCM @nadir)	96x508 BCM is 768x3200
	COP		Cloud Optical Properties (COT, CEPS)	6 +/- 1 km	96x508
	CEPS	40.4.3	Cloud Effective Particle Size	6 +/- 1 km	96x508
	COT	40.4.6	Cloud Optical Thickness	6 +/- 1 km	96x508
	CTX		Cloud Top Properties (CTH, CTP, CTT)		96x508
	CTT	40.4.9	Cloud Top Temperature	6 +/- 1 km	96x508
	CTH	40.4.7	Cloud Top Height	6 +/- 1 km	96x508
	CTP	40.4.8	Cloud Top Pressure	6 +/- 1 km	96x508

*** CC/L will be addressed in VCM/Imagery CVP as discussed in this document**

VIIRS data is processed on a granule basis, which each data granule consist of 48 scans of data (approximately 85.75 seconds). The Moderate resolution bands have 16 detectors, while the imagery bands have 32 detectors, yielding 768x3200 M-bands "pixels" per granule. This document will use the term "pixel" to refer to the M-band resolution that is also the resolution at which many Cloud IPs are produced. The term grid cell will refer to the Horizontal Cell Size (HCS) called for in the above table. The Cloud EDRs use a variable pixel aggregation to achieve a near constant HCS across the scan, while the Aerosols use a fixed aggregation resulting in a variable HCS. The aggregation approach was based on the required HCS size in the NSS.

5A.1.1.1Cloud EDRs

The cloud EDRs are first computed as IPs at the moderate resolution pixel resolution. The IPs are then aggregated into (as many as four) cloud layers before forming the gridded EDRs. The [CC/L_OAD] has a description of this gridding process which uses a variable aggregation from 8x8 IP pixels at nadir to 4x4 pixels at edge of scan (EOS) to maintain the HCS within the required 6 +/- 1km called for in the NSS. Each NPOESS data granule contains 96 x 508 cloud EDR grid cells that contain the measured values along with various quality control (QC flags) [CDFCB Vol4p2 Sec 5.3], with a fixed mapping of cloud IP pixels to EDR grid cells for each granule. This mapping also accounts for overlapping IP pixels as you move towards the edge of scan that are discarded in the aggregation. All of the cloud EDRs requirements are defined on this grid aggregation, with the exception of the Binary Cloud Map (BCM) which is addressed in the VCM CVP. While there are no formal requirements on IPs, additional insight into the algorithm performance can be gained by looking at the IP products. The core plan addresses the analysis of IP products as a synergistic effort to EDR cal/val.

Note that the CC/L EDR consist of two parts: A Binary Cloud Map (BCM), which is at IP pixel resolution and a 4 layer gridded Cloud Cover % at the 6 km HCS. The BCM is defined by NGAS to be a subset of the bits in the VIIRS Cloud Mask (VCM) that indicate confidently cloudy and confidently clear conditions. The BCM will be validated as part of the VCM [VCM_VCP] and is outside the scope of this document. The remaining part of the CC/L is the cloud layering and the HCS cloud coverage %. An agreement has been reached between the VCM/Imagery and Atmosphere cal/val teams that the CC/L cloud layering should be handled as part of the VCM/Imagery CVP. It is proposed that the remainder of the CC/L EDR validation (% HCS cloud cover) also be handled in the VCM/Imagery CVP since it is essentially an aggregation of the BCM with some adjustments from a %slant view to %vertical view coverage. In this document we will use the term cloudy to refer to the condition where the VCM indicates confidently cloudy conditions with the Heavy Aerosols flag not set, unless otherwise specified. Cloud EDRs are only made under this condition since many users view the cloud flag as an indication of an obscured view and may not care if the obscuration is cloud or heavy aerosol. It is simply a design decision on how things are flagged and has no bearing on performance.

Figure 0-0 shows the basic cloud geometry used in the cloud processing. Figure 0-1 shows the overall process flow. The cloud is detected in the slant path along the satellite view angle by the VCM algorithm. The cloud optical properties are used to determine the cloud top properties (slant path IPs) that are used to perform the parallax correction. The parallax algorithm uses the lat-long of the cloud intercept to compute the closet slant path IP location on the geoid to that lat-long. The parallax corrected IPs are then constructed by overwriting the geoid IP with the cloud intercept IP parameters at that location. All the parallax corrected IPs that fall within a 3x3 neighborhood of EDR grid cells are then clustered using the COP and CTT to assign pixels to up to 4 cloud layers. The IPs that fall within the center EDR grid cell are then aggregated to compute the cloud EDR properties for that grid cell as shown in Figure 0-2.   Many cloud properties are computed as a slant path IP, a parallax corrected IP and as a gridded EDR product as shown in Figure 0-1, so that it important to be clear which particular product is discussed when referring to a cloud property. Unless otherwise stated, the assumption in this EDR validation section is that the property being referred to (e.g. CTT) is the EDR product.

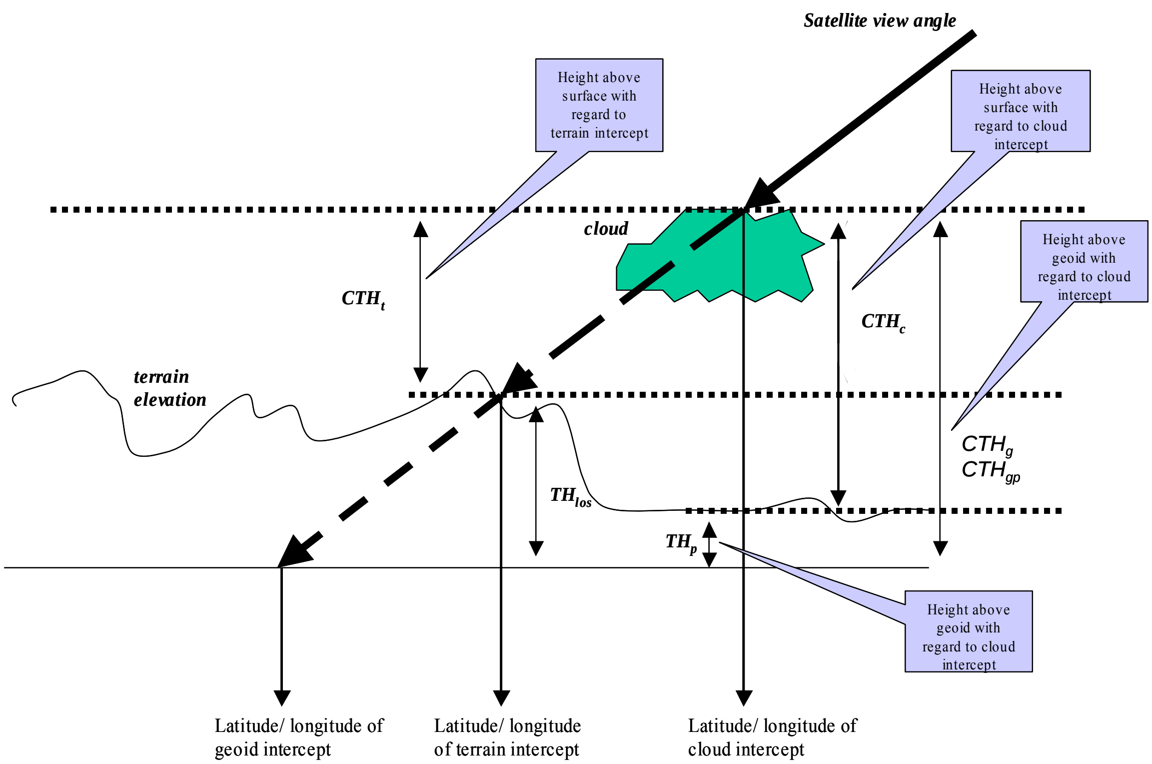

Figure 0-1 Cloud Geometry (from CTP_OAD Fig. 7)

Figure 0-2 VIIRS Cloud Processing Flow (from CC/L_ATBD Fig. 8)

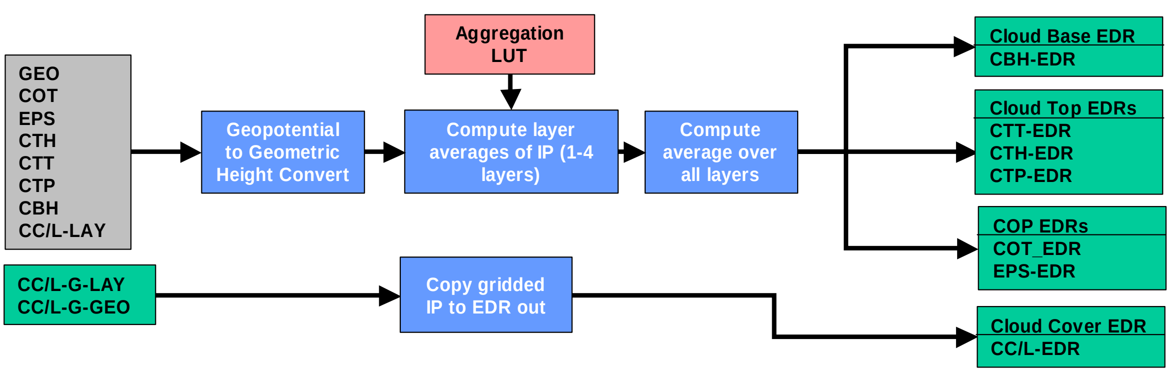

Figure 0-3 Conceptual Process to Generate Layered Cloud EDRS (from OAD_CC/L Fig. 6)

5A.1.1.2 Aerosol EDRs

The Aerosol EDRs are processed in a single module and produced in the following order: AOT IP (Moderate resolution pixel resolution), APSP IP (Moderate resolution pixel resolution), AOT EDR (8x8 Moderate resolution pixel aggregation), APSP EDR (8x8 Moderate resolution pixel aggregation) and SM EDR (Moderate resolution pixel resolution). Note that because the Aerosol EDRs use a fixed aggregation, the HCS increases as one goes from nadir to EOS. There are no Sys Spec requirements for the IPs, only the EDRs. Therefore, the performance of the EDRs will be validated and the performance of the IPs will to characterized. Because cloud clearing is so important to the quality of the Aerosol EDRs, outliers in the AOT IP, which are flagged as high quality, will be investigated for possible cloud contamination. The results of this investigation will be provided to the VCM Cal/Val team and used to improve VCM performance if required.

5A.1.2 Reference Documents for Atmosphere Product Group

In general this plan will refer to other documents as needed rather than duplicating the information. The [Ref Name] will be used in the plan to indicate a specific document from this list.

Table 2: NGAS Reference Documents for Atmosphere Cal/Val Plan

Ref Name	Document Title	Document Number/Revision	Revision Date
CCL_OAD	Operational Algorithm Description Document for VIIRS Cloud Cover/Layers (CC/L) and Generate Cloud EDR (GCE)	D39590 rev A18	24 Oct 2007
CTP_OAD	Operational Algorithm Description Document for VIIRS Cloud Top Parameters (CTP) EDR	D39568_B6	19 June 2008
COP_OAD	Operational Algorithm Description Document for VIIRS Cloud Optical Properties (COP) EDR	D39298_A5	19 June 2008
CBH_OAD	Operational Algorithm Description Document for VIIRS Cloud Base Height (CBH) EDR	D39589_A8	24 Oct 2007
CCL_ATBD	Cloud Cover/Layers Algorithm Theoretical Basis Document (ATBD)	D43317	Latest Revision Date
VCM_CVP	NPOESS Community Correlative Calibration/Validation Plan for the NPOESS Preparatory Project. VIIRS Cloud Mask (VCM)	TBD ver 1.0	Latest Revision Date
VCM_IM	NPOESS Community Correlative Calibration/Validation Plan for the NPOESS Preparatory Project. VIIRS Imagery EDR	TBD ver 1.0	Latest Revision Date
EDRPR	NPP EDR Production Report	D37005 Rev. B	28 Mar 2006
EDRIR	EDR Interdependency Report	D36385 Rev. A	30 Jun 2006
CDFCB	NPOESS Common Data Format Control Book External numerous volumes	D34862 Rev. A [TBR-001]	Latest Revision Date
CDFCBv3	NPOESS Common Data Format Control Book External Vol. 3 SDR/TDR Formats	D34862-03 Rev. A [TBR-001]	Latest Revision Date
CDFCBv4p1	NPOESS Common Data Format Control Book External Vol. IV-Part I – Ips, ARPs, and Geolocation Data	D34862-04-01 Rev. A [TBR-001]	Latest Revision Date
CDFCBv4p2	NPOESS Common Data Format Control Book External Vol. IV-Part II (D34862-04-02) is Atmosphere EDRs	D34862-04-02 Rev. A [TBR-001]	Latest Revision Date
CDFCBv8	NPOESS Common Data Format Control Book External Vol. VIII Look Up Table Formats	D34862-04-02 Rev. A [TBR-001]	Latest Revision Date
MDFCB	NPP Mission Data Format Control Book (MDFCB)	GSFC 429-05-02-42 {rev tag}	Latest Revision Date
CCL6drop	VIIRS Cloud Cover / Layers (CC/L) and Grid Cloud EDRs (GCE) Algorithms. Version 6 Code Drop to IDPS by AER & NGAS	Version 6 Code Drop to IDPS	14 Jan 2005
CCL_ATBD_sup	Cloud Cover / Layers Performance TestData Compendium, Supplement to ATBD	P1187-TR-I-007	
SVP	NPOESS System Verification Plan- Sec H discusses EDR	D35851-B	31 Oct. 2008
Aero_OAD	Operational Algorithm Description Document For Viirs Aerosol Products (AOT, APSP & SM) IP/EDR	D39292 Rev B11	18 Feb 2009
AOT_APSP_ATBD	VIIRS Aerosol Optical Thickness and Particle Size Parameter Algorithm Theoretical Basis Document ATBD	D43313 Rev E	10 Dec 2008
SM_ATBD	VIIRS Suspended Matter Algorithm Theoretical Basis Document ATBD	D43315 Rec C	10 Dec 2008
	Operational Algorithm Description Document for the VIIRS Cloud Mask Intermediate Product (VCM IP) Software	D36816	Latest Revision Date
	VIIRS Cloud Mask (VCM) OAD Update (Technical Memo)	NP-EMD.2004.510.0050	3 December 2004
	Operational Algorithm Description Document for VIIRS Geolocation (GEO) Sensor Data Record (SDR) and Calibration (Cal) SDR Software	D39300	Latest Revision Date
NSS	NPOESS System Specification	SY15-0007-N	Latest Revision Date
	Operational Algorithm Description Document for the VIIRS Perform	D40382	Latest Revision Date

Ref Name	Document Title	Document Number/Revision	Revision Date
	Parallax Correction (PPC) Software		
	Cross-granule Algorithm Processing	NP-EMD.2005.510.0038	7 March 2005
glossary	D35836_E_NPOESS_Glossary	D35836_E	Latest Revision Date
acro	D35838_E_NPOESS_Acronyms	D35838_E	Latest Revision Date

5A.1.3 Atmosphere EDR Requirements and Assumptions

Cloud and Atmosphere EDR Requirements from the NPOESS Sys Spec are detailed in section 5.2 of this Volume.

Overlapping .vs. non-Overlapping Multi-Layer Cloud Layers

The vertical resolution is not described in NSS requirement tables for all the cloud EDRs, but in general the cloud EDRs performance is specified for each layer with up to 4 layers in a grid cell. There are some exceptions such as CBH is only specified for the top & bottom layer [SS 40.4.1-4]. It has been assumed that the specified performance for multiple layers in a grid cell only applies to the case where these layers are non-overlapping. For the purposes of cal/val we define a grid cell as an excluded multi-layer overlapping condition if any IP pixel used in the grid aggregation has been flagged as overlapping. An individual IP pixel can be flagged as overlapping either by the VCM overlapping flag [CFDCB4p1 QF6_VIIRSCMIP] or if a ground truth source (e.g. Calipso) indicates overlapping cloud layers for that pixel or grid cell. The performance of the VCM overlapping flag will need to be characterized to determine if this is a reliable flag to indicate an overlapping condition. Note that this does not mean that the cloud algorithm does not make multiple layers in a grid cell when the layers overlap, but simply that these cells will be excluded from performance calculations. It is well understood that it is not practical to compute accurate cloud information from space based IR sensors for a lower cloud layer, when it is obscured from above by a higher cloud layer.

Based on this understanding of excluding overlapping multi-layer clouds from EDR grid cell performance estimates, an agreement was reached between the Atmosphere and VCM/Imagery cal/val teams that the cloud layering process would be validated in the VCM/Imagery CVP. The reason for this is that the manual cloud analysis performed as part of that plan will identify up to 14 required cloud types [SS 40.2.3.2.1.2]. This manual cloud typing will be compared to the layer information in the CC/L EDR to validate that up to 4 layers are produced in a EDR grid cell. Note that the VCM cloud types are computed at 2x I-band resolution (0.8km @ nadir), while the manual cloud typing is required at 3x I-band resolution (1.2 km @ nadir). These cloud types will be aggregated to determine the number of layers and cloud cover for the EDR grid cell. The assumption is that the different cloud types correspond to different cloud layers. It was agreed that it was more appropriate to handle this analysis in the VCM/Imagery CVP than in the Atmosphere CVP. Correlative truth sources (e.g. Calipso) can provide information on cloud layers; however care must be taken to account for a co-location and Field of View (FOV) issues. In general Calipso can indicate the presence of multi-layer clouds in a grid cell, but may not be a reliable indicator of single cloud layers. The Calipso FOV does not cover the entire EDR HCS so multiple layers may not always be detected in the grid cell.

AFWA mission needs are the origin of the 4 ("floating") cloud layer grid cell requirement for NPOESS. The VIIRS cloud-layering algorithm is an enhancement (adds cloud optical properties) to the CDFS II

(Cloud Depiction and Forecast System II) layering algorithm that has been successfully meeting AFWA's needs for many years. No issues with cloud layering are expected as there are no explicit requirements on how well the grid cell is divided into non-overlapping layers. Cloud layering errors would manifest as a degradation of the other cloud EDRS since pixels from inconsistent cloud layers would be aggregated. Validation of the cloud layering (correctly assigning a pixel to the appropriate layer) is not considered a risk item since it has no explicit requirements and is based on the legacy approach that already meets the user's needs.

Note that in the core CVP, the government team may still look at the performance of overlapping cloud layers in IP pixels which is an important issue since we do make layered cloud information in those cases. At the pixel level, the term non-overlapping cloud layers lose its distinction from single layer cloud unless you are comparing a pixel to its neighbor. However from a SS compliance and NGAS task issue, overlapping cloud layers within a grid cell will not be considered to be in scope of this plan. When this is combined with the fact that non-overlapping cloud layering will be validated in the Imagery/VCM CVP, the scope of this NGAS plan will only focus on single layer clouds in a grid cell.

Use of single layer clouds for validation

Performance of a single layer in a grid cell or the equivalent non-overlapping layer in a grid cell should be roughly identical, with the only difference being the number of IP pixels used in the aggregation. Note that the core plan looks at the performance of the various cloud EDRS (COP, CTX, CBH) at the pixel level. This is equivalent to looking at the performance of a small cloud layer consisting of a single cloudy pixel in the grid cell. Pre-launch performance estimate made by NGAS using synthetic data also looked at pixel level performance in developing the algorithm. Aggregation of pixels in a grid cell would reduce the errors in individual pixels according to the number of pixels aggregated and the correlation of the errors across pixels. Correlated errors would not be reduced, uncorrelated errors would reduce by the 1/sqrt(# pixels) and anti-correlated errors would reduce more quickly.

Since the core effort is focusing on the performance of the cloud EDRs for individual IPs, we can use these results to determine how the error is reduced by pixel aggregation. This would be a joint NGAS – government effort with the government taking the lead since they have all the results at the pixel level available. The individual pixels can be aggregated by using a variable number of pixels (max of 8x8) to simulate partially cloud layers. A plot can then be generated for each EDR to determine the performance benefit associated with aggregation. This can be used to characterize the performance of partially covered HCS layers (less than 100% coverage) as a scale factor that can be applied to the EDR performance calculated for 100% cloud cover.

Note that the current CC/L process does not identify which specific pixels where used in which layer and it is not necessary to have this information since we will not attempt to validate individual partially cloud layers. Validating individual partially cloud grid cells can be fraught with co-location problems associated with looking at cloud edge associated with partially cloudy cells. We simply can identify those EDR grid cells that have 100% cloud cover and grab all of the IPs that were aggregated. 100% cloud cover means by definition all IPs in that grid cell were used in the aggregation. We can then manually aggregate smaller numbers of IPs to determine a statistical relationship between the %cloud cover in a grid cell and the degradation in each of the cloud EDRs (e.g. COP, CTX, CBH). It would be easy to stratify this degradation according to scan position and various other criteria; however this is considered a low priority task. This could also be used to give a good idea of expected performance for different HCS sizes (e.g. 3km or the current 25 km), which may be of interest to users.

Grid cells that are not 100% cloud covered (CC/L) will be excluded from the performance estimation. Since we will only be working with single layer cloud cover grid cells, we can now develop uniformity constraints, such as local variance in 3x3 or 5x5 neighborhoods, in order to assure that we only draw matchups from the center of large cloud fields. This will reduce any error associated with cloud motion or time/position offset with truth sources. The plan is to validate SS performance using 100% cloud cover layers and characterize the reduction in performance for partially cloudy layers as described above. Note that the 100% coverage approach may need to be adjusted for some cloud types, such as popcorn Cu, as they might not produce 100% cloud cover in a 6 km grid.

COP Assumptions

COP algorithms retrieve COT and CEPS for the clouds. These cloud properties are then used as input to retrieve cloud top temperature, cloud top pressure, cloud top height, cloud base height and cloud cover layer. Thus, the consideration of COT and EPS requirements should include simultaneous considerations of the various requirements specified for all of the downstream algorithms. With that we assume the following:

- The COT validation of ice and water clouds will focus in the ranges of $1 < \tau < 10$ and $1 < \tau < 30$ respectively
- The CEPS validation will focus in the range of 1-50 micron.
- “Although not explicitly mentioned in the System Spec for COT and EPS we assume that the degraded conditions of mixed phase and overlapping multilayer clouds for Cloud Base Height (CBH) EDR also apply to COP EDRs. The reasons for this assumption are the following: First, the current state-of-art COT and EPS algorithms are not applicable to these conditions; Secondly, the physics in retrieving the COT and EPS under these conditions is still a research topic, not mature enough to be incorporated in the operational environments. However, the EDRs will be produced under these degraded conditions without performance specifications.

5A.1.4 Cloud EDR Validation Approach

5A.1.4.1 COP Validation

The COT and CEPS validation will be carried out in the pre- and post- launch phases:

5A.1.4.1.1 Pre-launch validation activities

1. During the pre-launch phase the performance of the COP algorithm will be qualitatively verified using MODIS and CERES products. While MOIDS06 cloud products will be used primarily for daytime EDR product comparisons CERES will be used primarily for nighttime products.

2. At the same time, inter-comparison of VIIRS with CloudSat and Calipso cloud products will be performed. For comparisons, the VIIRS products will be generated using MODIS L1 B radiances. This effort will provide a quantitative estimate of the VIIRS cloud EDR performance. Included in this effort is the quantification of error estimates in the CloudSat and Calipso retrieved products.

3. In addition, ARM site Value Added Products for clouds derived from a combination of ground-based radiometer and microwave measurements will also be used to estimate the VIIRS cloud EDR performance. Again, the VIIRS products will be generated for comparisons using MODIS L1 B radiances.

4. The Cloud validation team will leverage on all existing ground based measurements produced at fixed ground sites in and out of the US. These fixed ground sites include the three ARM sites at North Slope Alaska (NSA), Oklahoma Southern Great Plain (SGP) and Tropical Western Pacific (TWP), and the European's CloudNet sites in France, Netherlands, and United Kingdom. However, these ground sites do not cover all the climate regions in which validation is required according to the System Spec. Thus field campaign(s) may be necessary to cover these climate regions. Therefore, planning for future campaigns will be initiated.

5A.1.4.1.2 Post-launch validation activities

1. Immediate after launch, the VIIRS SDR, once available, will be used to generate cloud products for comparisons with MODIS, CERES, CloudSat, Calipso, CloudNet and ARM site VAP cloud products. This will provide a quicklook of the quality of the VIIRS sensor data as well as the quality of the EDR performance.

2. A more extensive datasets will then be processed and compared to historical data records in COT and CEPS generated either by legacy cloud products such as MODIS, CloudSat, Calipso and/or the records generated during pre-launch validation. The comparison with historical data records may quickly reveal problems in the sensor data or COP algorithms.

3. Assuming that ARM site, CloudSat and Calipso are still available after C1 launch, the VIIRS cloud products will be continued to be processed and compared to products generated by measurements from these ground based and space-borne sensor. A more long-term validation will be needed to assure enough samples for statistical evaluations.

4. Lastly, campaign(s) or other means of making "truth" measurements will be further defined and planned. The goal is to carry out as few field campaigns as needed to validate the System Spec. A study of the locations of all the ARM and CloudNet sites shows that field campaigns may be needed to cover the mid-latitude ocean, high latitude ocean and tropical land climate regions.

5A.1.4.2 CTX and CBH Validation

It is easier to obtain direct measures of correlative data for CTH and CTB. CTP and CTT will then be derived from these for validation.

5A.1.4.3 Correlative Truth Needed

Error! Reference source not found. describes the basic process of comparisons with correlative data sets. The core plan has a significant discussion of data sources so only a brief summary will be provided here. Estimates of truth are need for both cloud top and base EDRs validation. The basic cloud processing uses COP to compute CTT from which the other cloud top and base properties are derived as shown in Figure 0-1. Many of the truth sources take a measurement of cloud top / base height using a LIDAR or RADAR.
The time delay between MODIS and the A-train sensors on Calipso/CloudSat is less than 80 seconds as shown in the Figure below. NPP is at a different altitude than the A-train so there will not be a variable

time offset between VIIRS and the A-train sensors. While the time offsets could extend out to 30 minutes (TBR), there should still be extended periods where the VIIRS - A-train ground tracks will overlap with very short time differences of less than several minutes. This should still provide a plethora of matchups that can be used for validation, however some additional QC flags should be put in place to track the time offsets.

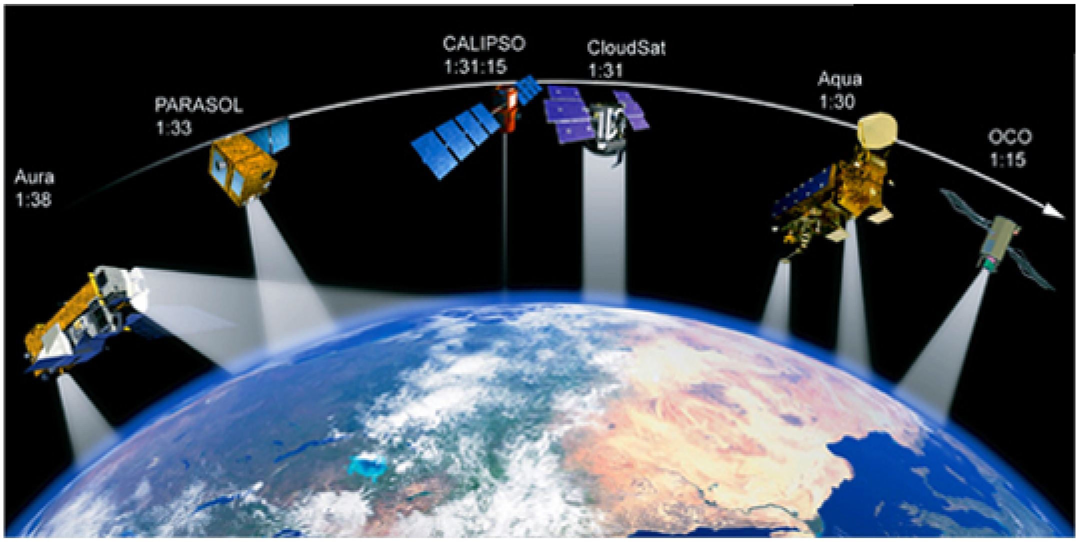

Figure 0-1 A-train constellation (from www-calipso.larc.nasa.gov/about/atrain.php)

Figure 0-2 shows the relative size of the Calipso and CloudSat Fields of View (FOV) relative to 1km MODIS footprints. Recall that VIIRS Cloud EDRs are being produced on a 6km grid from nominal 0.8km IPs. **Error! Reference source not found.** provides additional details on the Calipso resolution for Aerosol and Cloud Products. Note the extremely fine vertical structure that is available from the Cloud-Aerosol LIDAR with Orthogonal Polarization (CALIOP) sensor that has a native along track resolution of 333m. The Cloud Profiling Radar (CPR) on the CloudSat system has a native horizontal IFOV resolution of 1.4 km x 1.1 km with a vertical resolution of 500m. The main plan addresses how individual correlative measurements are aggregated to determine the truth estimate for the IPs. A different aggregation scheme may be needed for the EDR comparisons.
Clouds are in constant motion with a wide range of clouds speeds. Even with only a 2-minute delay and 100 knots winds, the matchups could be off by several pixels. This means that it is extremely important for the EDR QC matchup to impose some uniformity constraints in order to minimize the errors associated with cloud motion. The CALIOP/CloudSat orbit is designed to remain away from MODIS pixels that are impacted by sun glint. This is accomplished by allowing having the CALIPO/CloudSat orbits slightly inclined relative to MODIS. The result is CALIOP/CloudSat precess across the MODIS swath through an orbit. Because CALIOP/CloudSat are approximately nadir observations, an accraute collocation procedure needs to account for parallax between observations systems as presented in **Error! Reference source not found.**. The PEATE collocation system accounts for this parallax as function of cloud top height. Similar issues occur for ground-based observations. This will also be accounted for in the evaluation process.

Clouds have discrete edges; so that one would not necessarily have a gradual degradation in the comparison as the co-location criteria was relaxed. EDR match-ups will be designed to avoid any cloud edges within several grid cells. This becomes far more important when we look at ground based sources

that will have much larger time offsets with the cross comparisons. In theory some of the sensors have co-bore sighted VIS/IR sensors (e.g. Calipso WFC/IIR) that you could use to try and track any cloud shifts – but it is beyond the scope of this plan to attempt this.
A uniformity QC constraint will be used to make sure that matchups are not drawn from the edges of large cloud fields. It is anticipated that the initial version of this will simply be the local variance of various EDR neighborhood sizes. We will also exclude any grid cells in which the cloud cover is not 100% as discussed in Section 0on multi-layer clouds. In the case of Calipso and CloudSat, there is a plethora of matchups available, so that discarding matchups does not pose any concern.

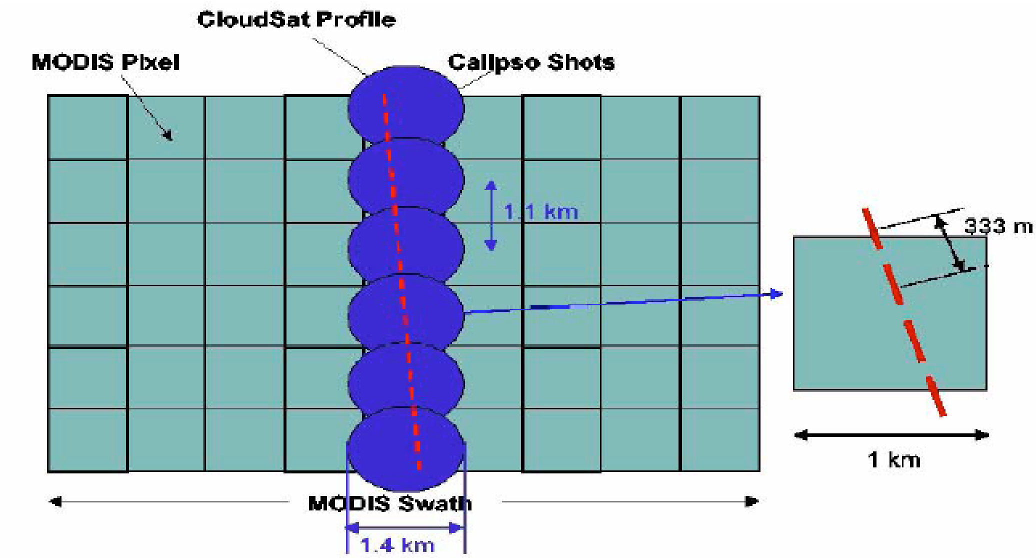

Figure 0-2 CloudSat and MODIS Resolutions (/science.larc.nasa.gov/ceres/STM/2008-11/presentations/14_kato_coI_c3m_status.pdf slide 3)

Table 3:Table 16: Calipso Aerosol & Cloud Product Resolutions (Table 1 from www.calipso.larc.nasa.gov/prodcucts)

Table 1. CALIPSO Level 2 Aerosol and Cloud Measurements			
Data Product	**Measurement Capabilities and Uncertainties**	**Data Product Resolution**	
		Horizontal	**Vertical**
	Aerosols		
Height, Thickness	For layers with $\beta > 2.5 \times 10^{-4}$ km^{-1} sr^{-1}	5 km	60 m
Optical depth, τ	40% *	5 km	N/A
Backscatter, &beta$_a$(z)	20 - 30%	40 km 40 km	Z < 20 km 120 m Z ≥ 20 km: 360 m
Extinction, σ_a	40% *	40 km 40 km	Z < 20 km 120 m Z ≥ 20 km: 360 m
	Clouds		
Height	For layers with $\beta > 1 \times 10^{-3}$ km^{-1} sr^{-1}	1/3, 1, 5 km	30, 60 m
Thickness	For layers with $\tau < 5$	1/3, 1, 5 km	60 m
Optical depth, τ	within a factor of 2 for $\tau < 5$	5 km	N/A
Backscatter, &beta$_c$(z)	20 - 30%	5 km	60 m
Extinction, σ_c	within a factor of 2 for $\tau < 5$	5 km	60 m
Ice/water phase	Layer by layer	5 km	60 m

Ice cloud emissivity, ε	±0.03	1 km	N/A
Ice particle size	±50% for ε > 0.2	1 km	N/A
Note: * assumes 30% uncertainty in the aerosol extinction-to-backscatter LIDAR ratio, S_a			

The table below shows the list of correlative data that would be beneficial to the cloud EDR validation effort.

Table 4: Correlative Data for NGAS Cal/Val Activities

#	Correlative Data	Use	Comment
1	Calipso	CTX, COP	A_Train Space LIDAR
2	CloudSat	CTX	A-Train Space Radar
3	ARM sites		Atmosphere Radiation Measurement- 3 sites. : MPL (LIDAR) , MMCR (Radar), ceilometer, TSI (Sky imager)
4	MPLNet	CTX, CBH, COP, AOT, APSP	Micropulse LIDAR Network. 10 sites, co-located with Aeronet?
5	CloudNet		European Cloud monitoring network, Doppler Cloud radar, LIDAR ceilometer, uwave radiometer- 3 sites?
	RAOBs	CTH, CBH	Use profile data to located the clouds vertically
	ASOS Ceilometer	CC/L, CBH	Automated Surface Observing System. Identify Cloud Bases (limited to 4km??), other ASOS info?
	AF surf network	CBH	Get ref to network of AF ceilometer data
	CRIMSS Profiles	CTX, CBH	Use sounding profiles (e.g.) AVMP / AVTP to locate the clouds vertically. Use CrIS with RTM models.
	SURFRAD	AOT, CC/L	Surface Radiation Budget observing network (7 sites)
	BSRN		Baseline Surface Radiation Network
	AERONET	AOT, APSP	Aerosol Robotic Network
	CPL	COP	Cloud Physics LIDAR on ER-2
	SHEBA		Surface Heat Budget of Artic (part of ARM?)
	EarthCare		European Follow-on to Calipso – CloudSat. Not available for NPP – but available for NPOESS
	Campaign data		Aircraft and other ground campaigns that can be leveraged. e.g. CPI,CIN, CAPS, 2D probes
	Model Comparisons		Compare MODIS, SEVERI, CDFS II cloud products with VIIRS
	SSEC/ARM/NOAA SEARCH	AOT,COT,COP	HSRL/RAMAN Lidar measurements

The best data for CTX and CBH validation would be the A-train CloudSat and Calipso data. They provide high quality data with numerous matchups that would allow global comparisons in a short period of time. However there is some risk that they may not still be available during NPP ICV. The ARM sites provide the best source of long-term high quality data, though they only cover a limited number of geographic conditions and only provide a few matchups per day. The 3 ground based LIDAR networks (ARM, MPLnet and CloudNet) would be the primary sources of data to validate the LTS requirements. Calipso and CloudSat would be the primary source for the APU validation, with the ground LIDARs serving as the backups. While the ground based LIDARS provide high quality data, they would require many months (TBR) of data to acquire sufficient data for a statistical analysis of the cloud EDRs.

The other correlative data sets will be used as available and collected under the larger effort. The current AFWA processing uses ceilometer data to override the satellite based cloud bases so that from a mission perspective it would be beneficial to characterize the satellite cloud base heights relative to the ceilometers. The other correlative data sources can also be used to identify outliers in the data. Cross-Comparisons to other satellite cloud models (MODIS, SEVERI, CDFS II) would be handled under the core program

It is assumed that the equivalent MODIS EDRs will also be stored off with the correlative truth sources. The intent would be to use comparisons to MODIS as a QC flag for the other correlative sources. It is assumed that under the core plan all of the matchup data will be made available on NSIPS to support the EDR validation. In general, all cloud EDRs in **Error! Reference source not found.**, as well as the parallax corrected VCM (retained IP) will be stored off whenever there is any correlative data matchup. It is likely that coordination with the CC/L CVP will lead to the non-parallax corrected VCM (Delivered IP) to be stored off as well.

In general a nXm (TBR) set of grid cells from the granule will be stored for each match-up in order to provide content for the matchup. In the case of ground track matchups (e.g. Calipso) a process will be used to extract a narrow swath of data from the granule similar to the current process used for MODIS at the A-train depot

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5A1.4.3.1 COP Truth

The primary sources of correlative data are the matchup datasets of CloudSat and Calipso immediately after VIIRS COP products are produced. These data are needed in near-real time to provide a quicklook at COP performance and quality of VIIRS sensor data.

Collection of matchup datasets of CloudSat and Calipso will continue until at least after IDPS has produced sufficient VIIRS COP data for the purpose of comparing with historical data records. Based on the past experience of the CERES cloud validation team one month worth of VIIRS COP data may be enough to provide a more quantitative estimate of COP performance, support anomaly resolution, and identify additional granules for algorithm enhancements and more accurate performance verification.

In the event that both CloudSat and Calipso are no longer operational to produce cloud products the ARM site VAP for COT and CEPS are required. To increase the data volume tools must be developed during the period of pre-launch validation to process CloudNet data to produce the equivalent version of VAP in COT and CEPS as from ARM sites.

Based on the 3-year mission lives of CloudSat and Calipso, the sensors onboard of these spacecrafts may cease to be operational one year after C1 launch. When that happens, a multi-year set of VIIRS granules will be used to address Long Term Stability requirements. These datasets must be granules in which the NPOESS C1 overflies the three ARM and the European CloudNet sites. Thus Long Term Stability requirements are validated by comparing with the VAP cloud products.

To complement the matchup datasets from ground sites and CloudSat, Calipso measurements campaign data are needed to cover the missing climate regions and the sensor shortfalls in providing accurate COT and CEPS retrievals for optically thick clouds. As in the LIDAR measurements, Calipso cloud products will not be accurate for COT larger than ~5. In addition, the campaign data can also be used to establish the uncertainties in the ground site retrieved cloud products. Specifically, Cloud Integrated Nephelometer (CIN) data will be needed to validate COT and cloud Particle Imager (CPI), or Cloud Aerosol Particle System (CAPS), or 2D-Probes or Replicator/Balloon data will be used for CEPS validation.

5A.1.4.4 QC metrics

5A.1.4.4.1 Inputs need to identify Stratification, Degraded & Excluded Conditions

There are various conditions called for in the NSS that are summarized in the requirement tables and discussion in Section **Error! Reference source not found.**. These conditions are summarized below. The Mnemonic is just a name to identify a particular condition. The source is generally a reference to a computed QC flag in the EDR table defined in the CDFCB. In some cases it may be a binary flag to indicate a condition. In other cases, it is better to store a numeric value (so that different stratifications can be used on an EDR (e.g. CTH is used to stratify CTP). The use column indicates the specific NSS table paragraph that is addressed by this parameter.

Table 5: Mnemonics used for Cloud EDR Conditions

	Mnemonic	Source	Condition	Use	Comment
	Sglint		degrade	40.4.7-16 40.4.8-22	Identify Sun Glint
	COThigh		stratify	40.4.7-16a/b 40.4.8-22a	Identify COT > 1 based on the embedded flags in the EDR.
	CTHest		stratify	40.4.8-22a	Use estimated CTH stratify other CTX EDR performance. estimated CTH will come from correlative data sources, but can use CTH EDR if no other measure is available
	GridFrame		exclude		Exclude the 4 grid cells on each side of EOS due to parallax correction
	Nlayers	CC/L EDR			This is implicitly copied over when we store off the CC/L EDR for any grid cell.
					FILL IN TABLE

5A.1.4.4.2 Computed QC metrics

This table includes QC metrics that will need to be explicitly computed to support the cal/val effort. This includes flags that maybe used to screen out outliers

This should include any QC metrics that would be produced from NPOESS data (e.g. local spatial variability about the grid point) as part of cal/val. This might include aggregation related QC metrics such as the number of IPs pixel that fall into each performance category. This could also include things like the QC metrics that you might be expected to be passed to you from a different CVP (e.g. SDRs flags).

Table 6: Mnemonics of Quality Control metrics

	Mnemonic	Source	Use	Comment
	Novrlap	VCM parallax IP	Identify overlapping clouds	# of IP pixels flagged as overlap in this grid cell.
	Nha	CC/L CVP	Identify cells with significant heavy aerosol contamination	# of IP pixels flagged as heavy aerosol in this grid cell.
	texture		Identify how homogeneous the scene is.	Measure of the local std dev about the matchup grid cell.
				FILL IN TABLE

5A.1.4.4.3 Correlative Data QC metrics

This should include what QC metrics you are expecting from the correlative matchups. This can include metrics on a per source basis (e.g. bias and variance of a particular buoy) or per matchups metrics (e.g. temporal variability, previous & next measurement in time).

For Calipso data we would want some knowledge of the variation of derived properties for all individual shots in a cell.

5A.1.4.4.4 External QC metrics

This should include any QC flags from external or ancillary data. This could include any knowledge of the ancillary data accuracy on a per source basis or internal checks for VIIRS consistency (e.g. comparison of VIIRS derived surface temp with the surface temperature ancillary data).

5A.1.4.5 Integration with other cal/val plans.

5A1.4.5.1 CC/L (VCM) CVP

Used to verify the CC/L EDR.

5A1.4.5.2 Imagery CVP

Can be used to provide a manual cloud truth image for validation.

5A1.4.5.3 VIIRS SDR

Will provide validation of many of the spatial parameters identified for cloud EDRs.

5A1.4.5.4 CrIS/ATMS CVP

The CrIMSS sounder data can be used to provide profile useful to identify cloud vertical structure.

5A1.4.5.5 CrIS SDR

The CrIS SDR can be used to generate a synthetic cloud top temperature and also feed RTM used to look at the consistency between the various cloud EDRs.

5A1.4.6 Related efforts for non-quantitative assessment

This should address related efforts that can provide insight to algorithm performance, but may not be used for quantitative assessment against the NSS. This would include cross comparisons with MODIS or other legacy products.

5A1.4.7 Performance Risk and Potential Mitigation Efforts

5A1.4.7.1 Incorrect Cloud Phase

The correct cloud phase at the VCM level is a critical component to all of the downstream cloud EDRs. An incorrect phase can lead to using the wrong branch in the processing logic and large errors that will show up as outliers. Note that there is no explicit requirement on how well one identifies the phase. We will impose a derived requirement on the VCM CVP to characterize the phase error when possible in order to identify outliers that may skew the results.

5A1.4.7.2 Mismatched layers

As described previously the validation process will use single layer gridded cloud cells to validate cloud properties. Any errors in cloud layer structure where 2 cloud layers may be reported as a single layer (e.g. cirrus cover) can cause a perturbation to the cloud properties.

5A1.4.7.3 CTH precision of 0.3 km

CTH has an extremely small precision error of 0.3 km. It will be very challenging to meet this both from an algorithm performance standpoint and in the presence of any outliers. Pre-Launch testing at NGAS showed that this could be met using a limited test data set. Recent comparisons of MODIS to Calipso showed very large tails in the MODIS – Calipso CTH distributions leading to large precision errors that went out to 15 km. A single misidentified layer that causes a 15 km error in 1 grid cell would take 2500 (15^2/0.3^2) perfect CTH grid cells (0 km error) in order to reduce the effective precision to 0.3 km. Extreme care will be used to identify outliers when trying to validate small numbers.

5A1.4.8 Cal/Val Risks

The largest risk to the CTX and CBH EDRs would be the loss of A-train Calipso and CloudSat data. As described previously the ground based LIDARS can be used as a fall back position. The risk with the ground based LIDARS as the only primary validation source is both a small number of matchups. This might lead to having to open the time offset in the match up window to a very large value that increases the noise in the correlative truth data when used as an estimate of truth.

5A1.5 Aerosol EDR Validation Approach

The requirements validation of the aerosol products relies on match-up of VIIRS EDRs with AERONET data. The match-up data is QC'd using data screening and aggregation techniques developed by the MODIS Aerosol validation team and then stratified by System Spec conditions. APU is computed using the equations defined in the Sys Spec. For AOT, which has precision and uncertainty defined as a function of tau, the data will be binned by truth AOT value and a weighted fit used to determine the best linear approximation of the AOT performance. Stratified performance for APSP will be reported. In addition, the nominal stratifications will be binned by both AOT and aNGASrom exponent, with binning determined by the volume and range of available data. APU is then computed for the binned data as well. It is anticipated that several years will be required for the necessary volume of AERONET data to be collected to validate the Sys Spec requirements. Due to the larger number of AERONET sites over land, the ocean requirements will be the more difficult to validate

The validation of SM requires that a reliable source of truth suspended matter type be available. While AERONET does not retrieve aerosol type, it does retrieve aerosol particle size distribution and spectral refractive index. It is anticipated that an algorithm for retrieving aerosol type from AERONET data can be developed and validated within a year after launch (it will require several years to collect the required volume of AERONET data). It is desired that this technique be shown to have a PCT > 95% so that it can be considered truth for Sys Spec validation. Identification of volcanic ash plumes will be based on USGS eruption data. The extent of the plume will be identified by manual imagery analysis in collaboration with the VCM Cal/Val team. The validation of smoke concentration will require field campaign data and is currently TBD.

5A1.5.1 Correlative Truth Needed

AERONET Level 1.5 retrievals are required for initial assessment. AERONET Level 2.0 retrievals are required for final validation. Global volcanic activity data is required to locate all volcanic ash plumes. Additional in-situ smoke concentration data from field campaigns is required to validate the smoke concentration requirement of SM.

5A1.5.2 QC metrics

5A1.5.2.1 Inputs need to identify Stratification, Degraded & Excluded Conditions

All stratification conditions can be properly identified from the product quality flags with the exception of coccolithophore blooms that will be identified by the VIIRS OC/C EDR.

5A1.5.2.2 Computed QC metrics

Accuracy, precision, uncertainty and probability of correct typing will be computed in accordance with the Sys Spec definitions. Metrics will be computed as match-up data becomes available. Changes over time to cumulative APU and PCT will be assessed for convergence of these parameters.

5A1.5.2.3 Correlative Data QC metrics

The AERONET level 1.5 and 2.0 retrieval contain the required QC. The variability of the retrieved AOT within +/- 30 minutes over satellite overpass will be used as an additional QC metric.

5A1.5.2.4 External QC metrics

TBD. Possible use of lidar data.

5A1. 5.3 Integration with other cal/val plans.

The requirements validation for the aerosol products is dependent of the successful requirements validation of the daytime VCM over both land and ocean backgrounds. Data from additional cloud screening tests in the AOT QC process will be provided to the VCM Cal/Val team to assist in VCM daytime performance characterization.

5A.2 List of Activities by Organization

TBD

5A.3 List of Acronyms

AERONET	Aerosol Robotic Network
AFWA	Air Force Weather Agency
AIRS	Atmospheric Infrared Sounder
AOT	Aerosol Optical Thickness
APU	Accuracy, Precision & Uncertainty
APS	Aerosol Polarimetry Sensor
ARM	Atmospheric Radiation Measurement
ASPS	Aerosol Particle Size Parameter
ATBD	Algorithm Theoretical Basis Document
ATMS	Advanced Technology Microwave Sensor
AVHRR	Advanced Very High Resolution Radiometer
BSRN	Baseline Surface Radiation Network
CALIOP	Cloud-Aerosol LIDAR with Orthogonal Polarization
CALIPSO	Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observation
CART	Clouds and Radiation Testbed
CBH	Cloud Base Height
CC/L	Cloud Cover/Layers
CEPS	Cloud Effective Particle Size
CERES	Cloud and Earth Radiant Energy System
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CLASS	Comprehensive Large Array-data Stewardship System
CNRS	Centre national de la recherché scientifique
COP	Cloud Optical Properties
COT	Cloud Optical Thickness
CPL	Cloud Physics LIDAR
CrIS	Cross-Track Infrared Sounder
CTH	Cloud Top Height
CTP	Cloud Top Pressure
CTT	Cloud Top Temperature
CTX	CTH, CTP & CTT
DoE	Department of Energy
EDR	Environmental Data Record
FNMOC	Fleet Numerical Meteorology and Oceanography Center
GRAVITE	Government Resource for Algorithm Verification, Independent Testing, and Evaluation
HCS	Horizontal Cell Size
IDPS	Interface Data Processing System
IP	Intermediate Product
MISR	Multiangle Imaging SpectroRadiometer

MODIS	Moderate Resolution Imaging Spectroradiometer
MPLNET	Micropulse LIDAR Network
NESDIS	National Environmental Satellite, Data, and Information Service
NGAS	Northrop Grumman Aerospace Systems
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NRL	Naval Research Laboratory
NSIPS	NPOESS Science Investigator-led Processing System
OMI	Ozone Monitoring Instrument
PEATE	Product and Evaluation and Test Element
SDR	Sensor Data Record
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
S-HIS	Scanning High-resolution Interferometer Sounder
SM	Suspended Matter
SSEC	Space Science & Engineering Center
STAR	Center for Satellite Applications & Research
TOA	Top of Atmosphere
VCM	VIIRS Cloud Mask
VIIRS	Visible Infrared Imaging Radiometer Suite