Towards Post-Launch Validation of GOES-R ABI SI Traceability with High-Altitude Aircraft, Small Near Surface UAS, & Satellite Reference Measurements

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ABSTRACT

The GOES-R field campaign (planned for April – June 2017) is focused to support post-launch validation of the Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM). Great emphasis has been placed in the development of methodologies to achieve the ABI GOES-R field campaign primary objective - validation of ABI L1b spectral radiance observations to ensure the SI traceability established pre-launch. An integrated approach using high-altitude aircraft, near surface UAS, and satellite reference measurements was developed to achieve the ABI validation objectives of the GOES-R field campaign. The high-altitude aircraft measurements coupled with special ABI collections are planned to provide the primary pathway (direct comparison) to validate ABI SI traceability of all ABI operational detectors. Near surface Unmanned Aircraft Systems (UAS) are planned to provide a secondary pathway to validate ABI SI traceability through coincident near surface measurements of Earth validation targets using the Earth's surface as a reference (indirect comparison). Satellite reference measurements obtained through special ABI collections and Simultaneous Nadir Overpass (SNO) of reference sensors will also provide a secondary pathway to validate ABI SI traceability. A detailed description of each validation approach, the critical components, and the preliminary expected uncertainties will be presented. The combined collections offer advanced post-launch validation capabilities and foster new perspectives for science teams during the post-launch validation and monitoring of NOAA's next generation of operational environmental satellites.

Keywords: GOES-R Advanced Baseline Imager, Field Campaign, Post-Launch Validation, SI Traceability, Hyperspectral, High Altitude Aircraft, Unmanned Aircraft Systems, Reference Measurements

1. INTRODUCTION

The United States Geostationary Operational Environmental Satellite (GOES) program began in 1974 in support of weather forecasting and environmental monitoring consisting of two operational satellites: GOES-East and GOES-West (located at 75 deg W and 60 deg W, respectively). Over the past four decades the program has evolved from providing primarily qualitative imagery products to its users to now a broad set of qualitative and quantitative imagery products with the introduction of the GOES-R next generation imaging sensor the Advanced Baseline Imager (ABI) -- scheduled to launch in the fall of 2016 [1]. The ABI will provide increased spatial, spectral, and temporal coverage, compared to the heritage GOES imaging systems with 6 calibrated Solar Reflective Bands (RSB) via an onboard solar diffuser (5% radiometric uncertainty) and 10 calibrated Thermal Emissive Bands (TEB) via an onboard blackbody (1 K radiometric uncertainty) [1, 2]. The inclusion of the 6 calibrated RSBs is significant because they are new to the GOES Program (heritage GOES imager has only 1 uncalibrated RSB).

One fundamental design change in the GOES-R ABI compared to the heritage imagers -- enabling the improvement in performance -- is a significant increase in the number of detectors per channel resulting in large Focal Plane Arrays (FPA) per channel: 2 to 8 detectors (heritage GOES O-P imagers) to 100s to 1000s of detectors (next generation GOES imager ABI). The increase in FPA size enables a decrease in scan rate which improves signal-to-noise and enables an increase in the ABI spatial swath width (~ 500 km) and temporal coverage (capable of imaging a full hemisphere of the Earth every 5 min), but also presents new post-launch validation challenges. The large number of detectors increases the system's sensitivity to image striping (detector-to-detector non-uniformities), and poses new challenges to existing operational validation methodologies and sites. These challenges are evident through a comparison of swath width (north-south direction) between the heritage and next generation GOES imagers' using an operational GOES desert validation target [Figure 1]. The current GOES imager enables the collection of multiple scans of all detectors over a

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large pseudo invariant desert validation target [Figure 1 (left)] using nominal collection modes. In contrast, applying the same collection strategy over the operational validation target for the GOES-R ABI yields only a few detectors per channel (~6%) to pass over the same target due to its much larger swath width [Figure 1 (right)]. This is a major post-launch validation challenge in the GOES-R ABI era that will require new validation strategies to ensure the post-launch performance of the instrument. The new post-launch validation methods designed to address these challenges will be discussed in Section: 2.1.2 & 2.3.

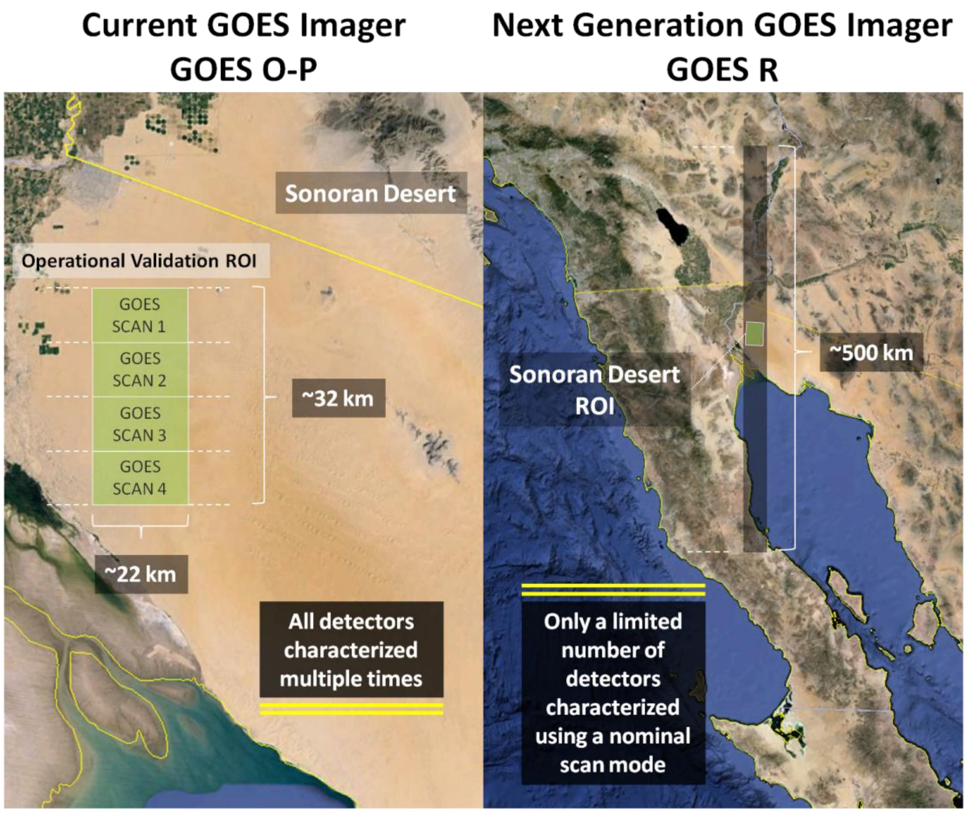

Figure 1: (Left) Current operational GOES O-P imager enables operational scan mode data to ensure all detectors are characterized multiple times through the collection of a large "uniform/stable" desert validation Region Of Interest (ROI); (Right) illustrates the current GOES operational ROI within a single GOES-R ABI swath demonstrating the validation challenge of large FPA systems.

NOAA has placed a great amount of support in the pre-launch calibration of the next generation GOES-R era instruments, in reference to the heritage instruments, which helped to ensure the SI traceability of the ABI instruments calibration was established pre-launch. Leveraging the in-depth knowledge of the system performance developed during the pre-launch calibration phase of the instrument, a dedicated GOES-R validation field campaign was planned to independently validate ABI's performance post-launch. Field campaigns are essential for collecting reference data, from well calibrated sensors [3-11], that can be directly related to satellite observations. Field campaigns are internationally recognized as a best practice by the Committee on Earth Observation Satellites (CEOS) [12] and Global Space-based Inter-Calibration System (GSICS) [13] to ensure the post-launch instrument performance.

1.1 GOES-R Validation Field Campaign Overview

The purpose of the GOES-R field campaign (planned for April – June 2017) is to support post-launch validation of the Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM). The campaign will provide dedicated collections of reference data in support of the comprehensive post-launch validation strategy of each instrument, while also addressing several validation challenges presented by these next generation systems. A six week campaign is planned with the high altitude NASA ER-2 platform (~100 flight hours) [14], integrated with a host of both passive and active sensors [Table 1] coordinated with ground based, near surface, and satellite reference data over several Earth targets in support of the validation of L1b & L2+ products.

Table 1. GOES-R Field Campaign ER-2 Based Instruments: Next-Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRISng) [15]; Scanning High-resolution Interferometer Sounder (S-HIS) [16]; Fly's Eye GLM Simulator (FEGS) [17]; Lightning Instrument Package (LIP) [18]; Cloud Physics Lidar (CPL) [19]; Cloud Radar System (CRS) [20]; GeoCAPE Airborne Simulator (GCAS) [21].

Instrument	Type	Spectral Range	Spectral Res.	GSD	FOV	Swath Width
AVIRISng	HSI	380 – 2510 nm	5 nm	0.3 m to 20 m	34 deg	~11 km
S-HIS	Hyperspectral	3.3 - 18 µm	0.5 cm^{-1}	2 km	40 deg	40 km
FEGS	Passive EO	near-infrared (777.4 nm)	10 nm			~10 km
LIP	Passive Electrical					
CPL	Lidar	1064, 532, & 355 nm		30x200 m		
CRS	Doppler Radar	94 GHz (W-band; 3 mm wavelength)		na		
GCAS	Hyperspectral	300 – 490 nm; 480 -900 nm	0.6 nm; 2.8 nm	350 x 1000 m; 250 x 250 m	45 deg; 70 deg	

The ER-2 campaign will be executed in a two phased approach. During the first phase the ABI validation missions will be the primary focus with the ER-2 based out of Palmdale, CA (~2 weeks) for best access to desert validation targets; phase 2 the GLM validation missions will be the primary focus with the ER-2 based out of Warner Robins Air Force Base for best access to lightning producing storms over both land and ocean (~6 weeks). During this time the GOES-R satellite will be located at its checkout location of 89.5 W providing data for all desired validation targets.

The GOES-R ABI field campaign primary objective is to provide validation of ABI L1b spectral radiance observations to validate the SI traceability established pre-launch. The secondary objective of the campaign is to provide surface and atmospheric geo-physical measurements to support L1b & L2+ product validation. For this discussion we will focus solely on the methodologies developed to achieve the GOES-R ABI field campaign primary objective. To achieve this objective a comprehensive approach was developed that leverages high-altitude aircraft based reference measurements, (primary validation approach), and near surface Unmanned Aircraft System (UAS) reference measurements & satellite reference measurements (secondary validation approaches). In the following sections each of the developed approaches and primarily set of uncertainties will be discussed in support of the post-launch validation of the GOES-R ABI.

2. METHODS TO VALIDATE ABI SI TRACEABLITY POST-LAUNCH

There are two fundamental paths to validate SI traceability post-launch [Figure 2]: 1) through direct comparison of observations from an SI traceable reference sensor; 2) through Earth surface reference observations. The direct comparison method employs well calibrated sensors intended to match the satellite sensor view geometry to enable a radiance-to-radiance comparison between sensors. Alternatively the Earth's surface can be used as an SI traceable reference. This method relies on the measurement of the primary physical state variables at the time of the satellite image acquisition over a uniform target area and Radiative Transfer Modeling (RTM) to predict the satellite observation and make comparisons against the observed data.

The direct (radiance based) approach is widely used and mature in the TEB through the use of reference sensors integrated onto high-altitude aircraft platforms [3-5, 16] with demonstrated measurement uncertainties of better than ~0.2 K. However, this approach is less mature in RSB and is not regarded as the heritage approach as previous work demonstrated biases between 2 to+12% [6, 7, 15]. The heritage approach in the RSB uses the Earth's surface as a reference, with demonstrated uncertainties of ~3-5% over well characterized and uniform target sites [16-19]. This

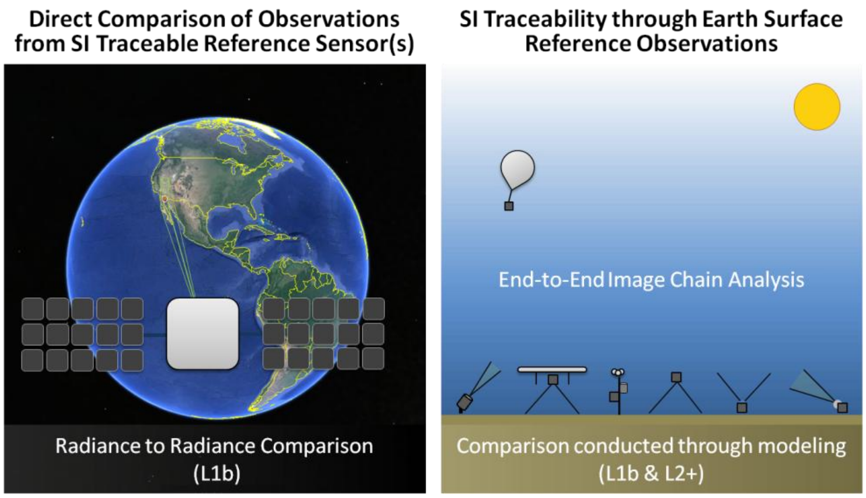

Figure 2: Two main paths to validate SI traceability post-launch.

approach, however, has been largely limited to high to moderate resolution sensors (spatial resolutions of a few meters to tens of meters) where human operator(s) or distributed stationary sensors provide reference observations of a representative region of interest with modular spectrometer(s). Due to the low resolution of environmental sensors (~375 m to 2 km) the heritage RSB methodologies have not been used operationally, due largely to limitations of collecting high quality reference data over large areas representative of environmental satellite sensor footprints.

The GOES-R ABI validation field campaign will employ two unique direct comparison methods (high-altitude aircraft & satellite inter-comparison) for the validation of all ABI detectors, and a third approach, regarded as a research to operations effort, investigating the feasibility of utilizing modular RSB spectrometers from small near surface UAS to obtain reference data to enable using the Earth surface as an SI traceable source. These methods will be discussed in detail in the following sections.

2.1 High-Altitude Aircraft Validation

The high-altitude ER-2 aircraft based AVIRISng and S-HIS hyperspectral observations will be used as the primary SI traceable reference observations for the GOES-R ABI field campaign. Two high-altitude aircraft missions coordinated with ABI special collections will be conducted over cloud-free validation targets: 1) ABI RSB validation mission over the Sonoran Desert, Mexico (near local noon); 2) ABI TEB validation mission over the central portions of the Gulf of Mexico (night). These collections will be coordinated, with coincident and collocated S-NPP VIIRS/CrIS instrument nadir overpasses for additional reference and inter-comparison datasets. This approach has three critical components that must be addressed for successful collections of these targets: 1) development of a methodology to match the aircraft based-sensors with the view geometry of ABI; 2) development of a methodology to optimally collect coincident and collocated aircraft-based sensor data with ABI (all detectors); and 3) ensure the calibration of aircraft reference sensors. This validation approach provides an absolute validation capability of all ABI detectors and is the primary pathway to validate SI traceability for the GOES-R ABI field campaign.

2.1.1 Matching the View Geometry of ABI with the ER-2 Based AVIRISng & S-HIS

Matching the view geometry of the high-altitude aircraft based sensors with the space-based sensors in geostationary orbit presents unique validation challenges, compared to the much more established Low Earth Orbit (LEO) validation efforts. In general, LEO aircraft validation campaigns will typically seek satellite nadir track overpasses of the validation target of interests to ensure the best matches of the view geometry of the satellite sensor(s) and the nadir pointing integrated aircraft sensors. This approach enables greatest value to the field collections because the ER-2 can fly flat and level coincident and collocated with the satellite sensor(s). For geostationary validation campaigns this methodology is often not available as the targets of interest are generally not located at the nadir location of the space-based instruments [Figure 2 (left)] resulting in more challenging off-nadir view geometry. These view geometries are dependent upon the location of the validation target of interest resulting in a dynamic set of collection requirements to match with the aircraft sensors. To assess the radiometric impacts of view geometry differences of the aircraft-based sensors compared to the satellite, Padula et al. (2015) [22] presented an initial RTM simulation of representative Sonoran Desert and Wagner Basin (ocean) validation targets. The study simulated an aircraft-based ABI sensor flying at 20 km (spanning view geometries: looking from nadir to matching the ABI view geometry of each target) and compared the results to the simulated observations of the ABI in geostationary orbit. The results of the study [Figure 3] demonstrated the importance of matching the view geometry of the ER-2 aircraft sensors and ABI for both AVIRISng & S-HIS, with

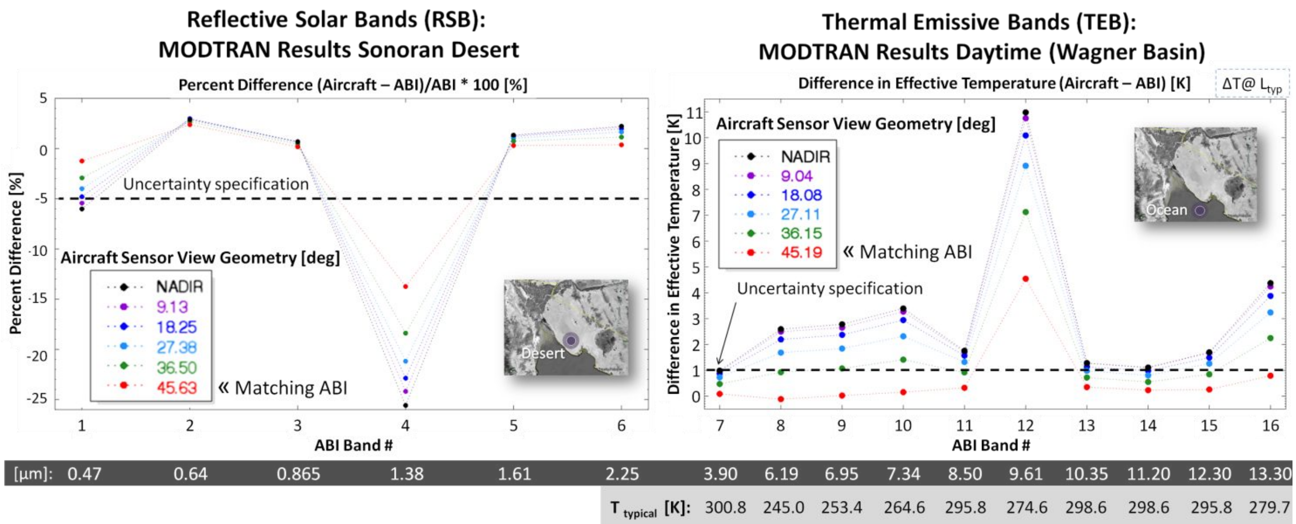

Figure 3: Initial MODTRAN simulations of view geometry impacts from a 20 km aircraft-based sensor (nadir to matching the ABI view geometry – in ~9 degree steps) compared to the view geometry of ABI.

the TEB demonstrating greater sensitivity to view geometry than the RSB. Note ABI RSB 4 (1.38 um) and TEB 12 (9.61 um) are more challenging to validate using such an approach due to atmospheric water vapor and ozone content above the ER-2 flight altitude.

The ER-2 based AVIRISng and S-HIS sensors will be able to achieve matching ABI view geometry in both zenith & azimuth angles in the designed approach. Matching the zenith angles is the most challenging and will be achieved by having the ER-2 aircraft fly consecutive circles holding a 30^{o} bank (roughly the largest bank that can be held stable) and utilizing the off-nadir aircraft sensor field of view of each instrument to achieve the desired view geometry. The azimuth angle is achieved by simply orienting the consecutive circle maneuvers perpendicular to the ABI azimuth angle line of sight. This collection was demonstrated by the NASA ER-2 and AVIRIS teams [23, 24] in the spring of 2016 and provided to the GOES-R Program as proxy data in preparation for the 2017 campaign [Figure 4].

The Sonoran Desert validation collection will introduce the most challenging view geometry conditions (ABI view geometry from 89.5 W - Zenith: ~45°, Azimuth: ~41° (counter-clockwise from north) though the RSB are largely insensitive to small view geometry differences. The Sonoran Desert was selected because it is the largest and most uniform desert in the GOES-R field of view and is easily accessible by the ER-2 aircraft. Due to the greater sensitivity to view geometry in the TEBs the Gulf of Mexico (ABI view geometry from 89.5 W - Zenith: ~30°, Azimuth: 0°) was selected over alternative sites in the Wagner Basin south of the Sonoran Desert, to more easily match the ABI view geometry (as discussed in Section 2.1.4).

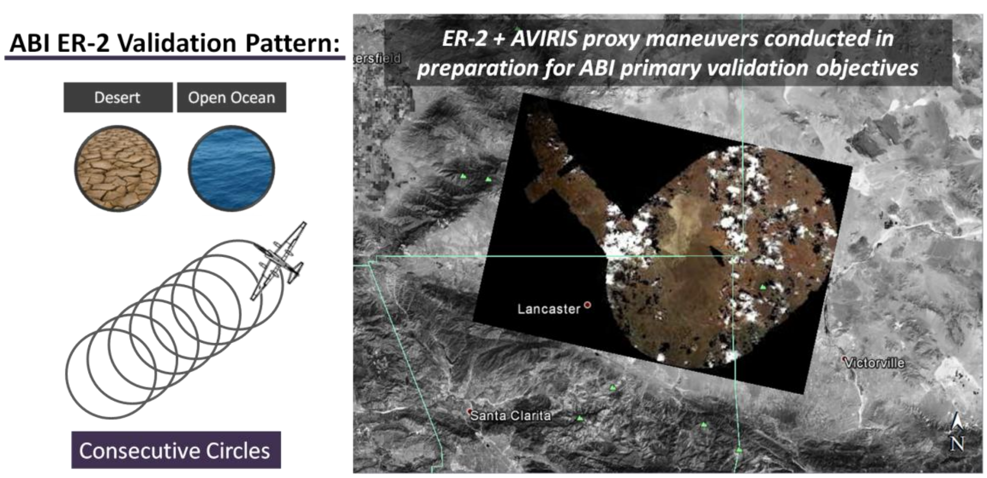

Figure 4: Schematic illustration of the high-altitude ER-2 aircraft validation flight pattern: consecutive circle maneuver (left) and GOES-R ABI field campaign ER-2 + AVIRIS proxy data proof of concept demonstration [23, 24] (right).

2.1.2 ABI Collection Strategy (All Detectors) Coincident & Collocated with AVIRISng & S-HIS

Coincident and collocated aircraft reference observations (nominal swath width of: ~11 km for AVIRISng and 40 km for S-HIS) compared to the large swath width of ABI (~500 km) is a major challenge being addressed in the development of the GOES-R validation collection planning. The performance validation challenges of large FPAs has been identified and addressed in the pushbroom sensing Low Earth Orbit (LEO) community by conducting a 90 degree yaw maneuver of the spacecraft to enable all detectors to collect over the same effective target area, referred to as side-slither maneuver (SSM), providing an ideal method of on-orbit relative calibration or flat fielding [25, 26, 27]. This methodology enables the large swath width of the FPA to be constrained to a much smaller area effectively the size of its projected FPA width [Figure 5]. SSM over stable uniform scenes provide an all detector relative calibration within each channel and the ability to diagnose & mitigate image striping issues via flat fielding. If the target area radiance is known during the SSM then this methodology could be utilized as an absolute vicarious radiometric calibration of all detectors. It is this methodology that will be leveraged for the validation of ABI.

Leveraging the lessons learned from previous & existing large FPA systems a similar collection capability was identified for ABI. Due to ABI's unique scanning capabilities offered by two scan mirrors, the East-West (EW) and North-South (NS) scan mirrors, it can acquire collections equivalent to the LEO SSM collections without the need of a spacecraft maneuver by using a special scan pattern called an ABI North South Scan (NSS) [Figure 5]. In simplest terms an ABI NSS is achieved by holding the EW scan mirror fixed and moving the NS scan mirror; though in practice both ES and NS mirrors are moved to ensure a true north-south footprint is collected. To acquire all 16 ABI bands over the same validation target (which takes only 10s of seconds to complete) 16 unique NSSs are required using a unique shift in the EW scan mirror to position a given band's FPA over the desired region of interest before each NSS. The ABI NSS collections provide a means to validate all ABI detectors using existing operational validation methodologies and sites. The ABI NSS collection strategy has been recognized as a critical capability of the GOES-R post-launch validation strategy.

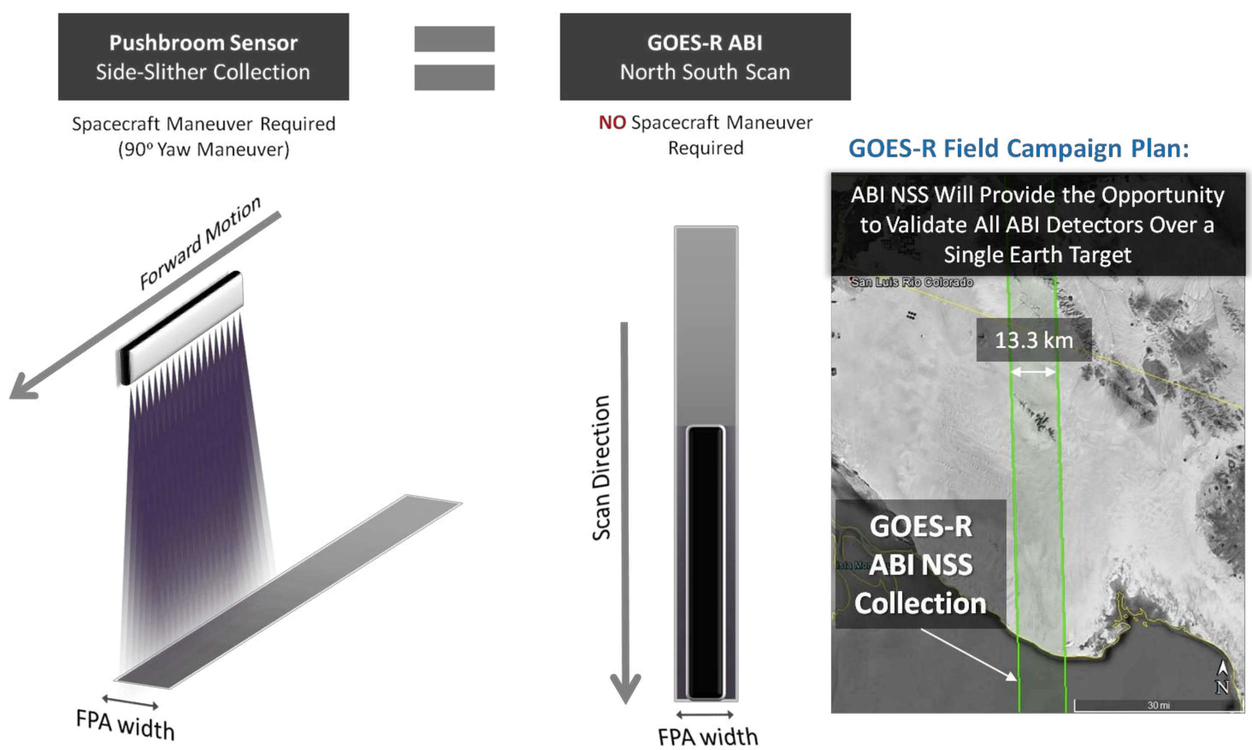

Figure 5: Illustration of the LEO pushbroom slide-slither collection and the equivalent ABI NSS collection strategy enabled by using its two (east-west & north-south) scan mirrors.

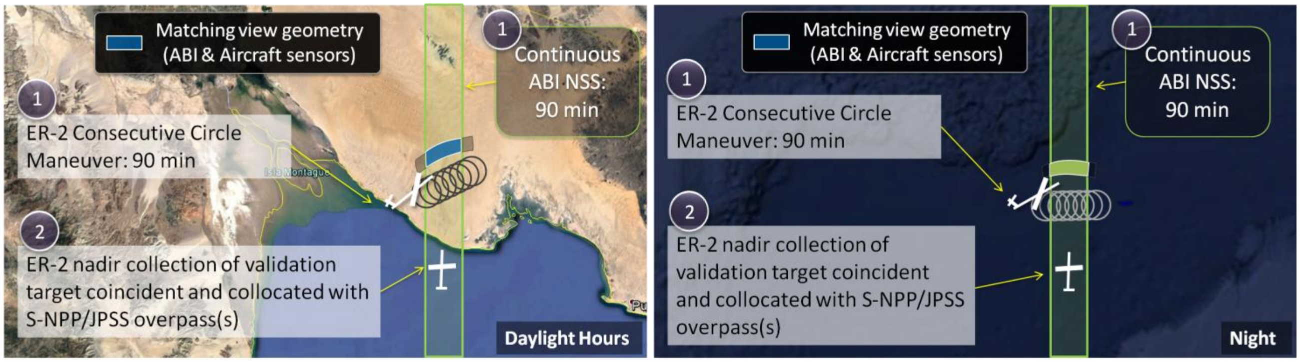

Figure 6: GOES-R ABI field campaign primary validation objective activities using high-altitude aircraft based sensors and ABI special collections.

2.1.3 High-Altitude Aircraft Validation Approach

GOES-R ABI field campaign primary validation objective activities using high-altitude aircraft based sensors and ABI special collections can be achieved in two successful missions [Figure 6]. For each validation flight the ER-2 will conduct continuous circle collections of the validation target to ensure the aircraft based sensors view geometry matches ABI. During this time 90 minutes of coincident and collocated continuous ABI NSS collections will be conducted over an identified cloud-free and uniform validation target (Sonoran Desert and Gulf of Mexico). Upon completion of the 90 minute ABI NSS collections, the ER-2 will collect over the validation target, flying flat and level, coincident and collocated with S-NPP/JPSS VIIRS/CrIS sensors (ideally a nadir overpass) for additional reference and inter-comparison datasets. To augment the ABI validation data sets during the nadir ER-2 collections of the validation target (i.e. aircraft flying flat and level), ABI will be tasked to collect 30 minutes of ABI Mode 3 Meso collection (1000 km x 1000 km imagery every 1 min or 30 sec).

2.1.4 Preliminary Uncertainty: High-Altitude Aircraft Validation Approach

A preliminary uncertainty budget for the high-altitude aircraft validation approach is provided [Figure 7] illustrating that both methods are expected to provide uncertainties that meet the GOES-R field campaign validation objectives. These estimates are a result of literature review, modeling & simulation, and consultation with instrument principle investigators; however, note that these initial estimates will be refined as new measurements and modeling and simulation studies become available.

For the RSB validation, the measurement uncertainty of AVIRISng is expected to be the greatest source of uncertainty in the method, while the remaining components are expected to be minimized by the designed collection strategy through the selection of a uniform desert region of interest and supplemental information from coincident LEO instruments during collection. Since the AVIRIS & AVIRISng instruments have been primarily used for Earth observing missions, with only limited demonstrations for validation purposes - a more comprehensive calibration approach has been developed in reference to other Earth application campaigns. To ensure the calibration/validation of the AVIRISng in support of the GOES-R field campaign, pre and post-flight hanger calibrations, as well as, a vicarious field campaign collection during the validation flight(s) have been added to the operational plan. Additionally, during the GOES-R field campaign validation flights, an independent vicarious calibration is planned by the Remote Sensing Group at the College of Optical Sciences, University of Arizona (using the heritage approach) to ensure the performance of AVIRISng is well understood.

The TEB measurement uncertainties of S-HIS are well documented and demonstrated [16]. By utilizing the central Gulf of Mexico as a validation target uncertainties in matching the view geometry are assumed to be negligible as the S-HIS will be collecting nadir imagery (relative to the banked aircraft). This enables optimal post-selection of matching ABI and S-HIS pixels, resulting in the largest source of uncertainty being accounting for the atmospheric path above the aircraft. Again, as a result of the collection strategy LEO instrument observations will be utilized to bound the parameters needed for the intended RTM correction. These preliminary uncertainty estimates will be refined as new measurements and modeling and simulation studies become available.

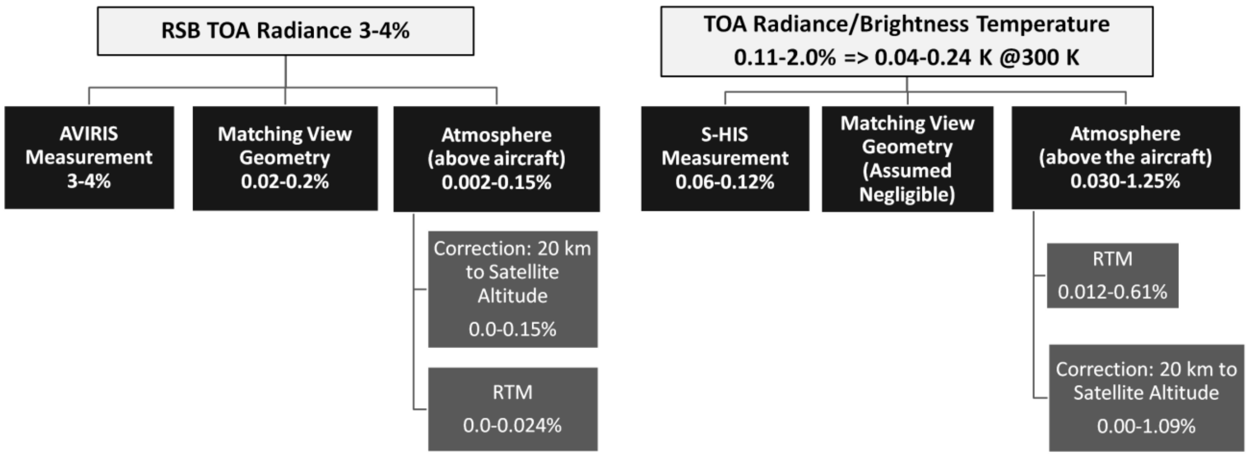

Figure 7: Preliminary uncertainty budget for the constructed high-altitude aircraft validation approach. These estimates will be refined as new measurements and modeling and simulation studies become available. Note ranges denote variability as a function of ABI band. Radiative Transfer Modeling (RTM) uncertainties estimates were obtained from MODTRAN through collaboration with SSI [28].

2.2 Near Surface Unmanned Aircraft System

High quality surface reference data that can be directly compared to satellite observations without gross uniformity assumptions are challenging to provide for environmental remote sensing satellite systems, especially in the case of the GOES-R ABI with pixel sizes of 500 m, 1 km, and 2 km. Heritage methods of reference data collection, commonly used in the high to moderate spatial resolution Earth observation community, are typically not considered feasible at these scales due to technical, financial and logistical constraints. The result is that no routinely used operational capability exists to acquire reference data of the Earth surface in support of environmental satellite validation. Additionally, there is no operational capability to measure goniometric observations of the surface over regions comparable to environmental satellite observations to cover the diverse set of validation targets within the GOES-R field of regard. As previously mentioned, reference in the RSB is critically important (new to the GOES Program) where the heritage post-launch absolute validation methodologies rely on such reference data. These fundamental validation challenges must be overcome in order to best characterize system performance in the post-launch calibration phase of the GOES-R ABI era.

2.2.1 Overview of the Prototype Near Surface UAS & Payloads

Leveraging the technological advances in both the UAS and small modular sensor communities, a GOES-R near surface UAS feasibility demonstration study was established by the GOES-R program to develop prototype UASs to assess the feasibility of near surface validation reference measurement capabilities in support of GOES-R Field Campaign advanced validation capability development efforts (partners include: GOES-R Program, NOAA/NESDIS/STAR, NOAA UAS Program Office, and NOAA Cooperative Institute for Climate & Satellites - University of Maryland). An end-to-end validation strategy was developed for the acquisition of high quality reference data, at the scales of environmental satellite sensors, using a combined approach of both fixed-wing and rotary UAS's. The following priorities were developed: 1) RSB hyperspectral hemispheric directional reflectance measurements (0.35 – 2.5 µm) -- includes observations upward of the total sky (hemisphere) and downward of the surface (directional); 2) ability to operate near the surface ~10 m above ground level (i.e. assumption – atmosphere between ground and 10 m is negligible); 3) ability to autonomously control the view geometry of the sensor payload(s) for oblique angle data collection: range: 0° (nadir) to 90° (horizon); 4) broadband IR (8 – 14 µm) measurements directional surface observations (ideally filtered to match ABI spectral bands of ABI TEB surface channels); and 5) high resolution georeferenced context imagery & Digital Elevation Model (DEM) generation. Common requirements for the UAS included that all validation payload measurements have documented SI traceable paths and measurement uncertainties; UAS is capable of autonomous flight through pre-programmed mission planning; and meta data are collected & stored (such as image acquisition times, sensor look angles, GPS data). The developed prototype systems encompassing the above capabilities are illustrated [Figure 8].

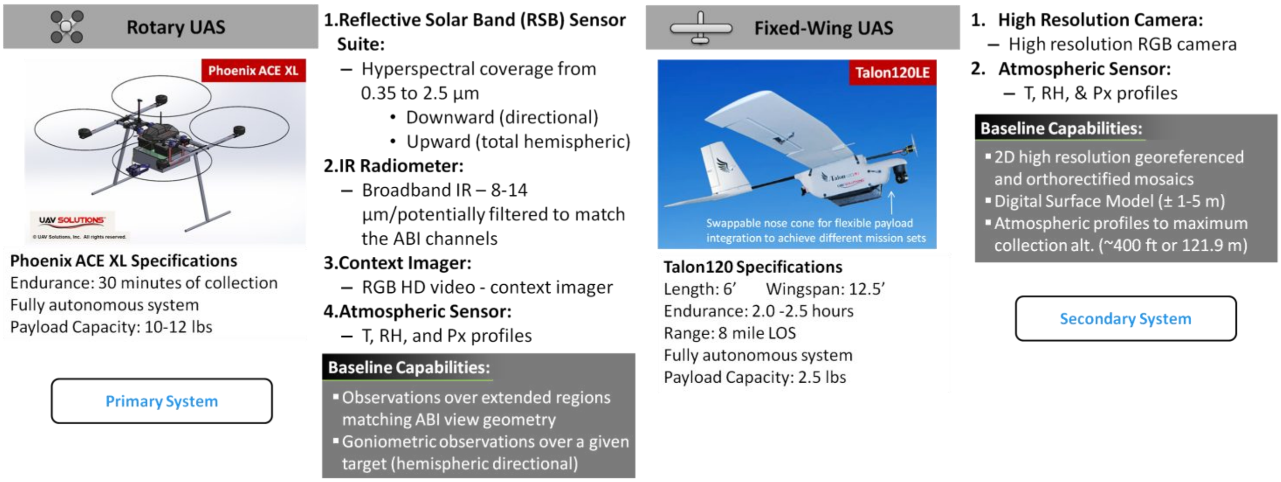

Figure 8: Depiction of the prototype rotary UAS and payloads (left) and prototype fixed-wing UAS and payloads (right). (UAS platforms and images courtesy of UAV Solutions, Inc.)

2.2.2 Near Surface UAS RSB Validation Approach

Our primary validation focus is on the collection of reference data in support of ABI RSB validation as a secondary pathway to validate SI traceability. The heritage RSB reference measurements made by human observers or distributed autonomous stations are typically obtained from ~1-2 m above the surface under the assumption that the atmospheric contributions within the ~1-2 m path are negligible; thus a fundamental measurement of the surface is obtained. Using a similar approach the UAS will fly at ~10 m above the Earth's surface (i.e. near surface) under the same assumption, validated through RTM [29, 30], matching the field of view of the ABI sensor – obtaining a fundamental surface measurement in support of GOES-R ABI SI traceability validation [Figure 9]. A second fundamental collection strategy with the rotary UAS is goniometric target collection [Figure 9] which is enabled by the autonomously controlled payload gimbal and UAS flight maneuvers about a given target point which supports both L1b and L2+ products.

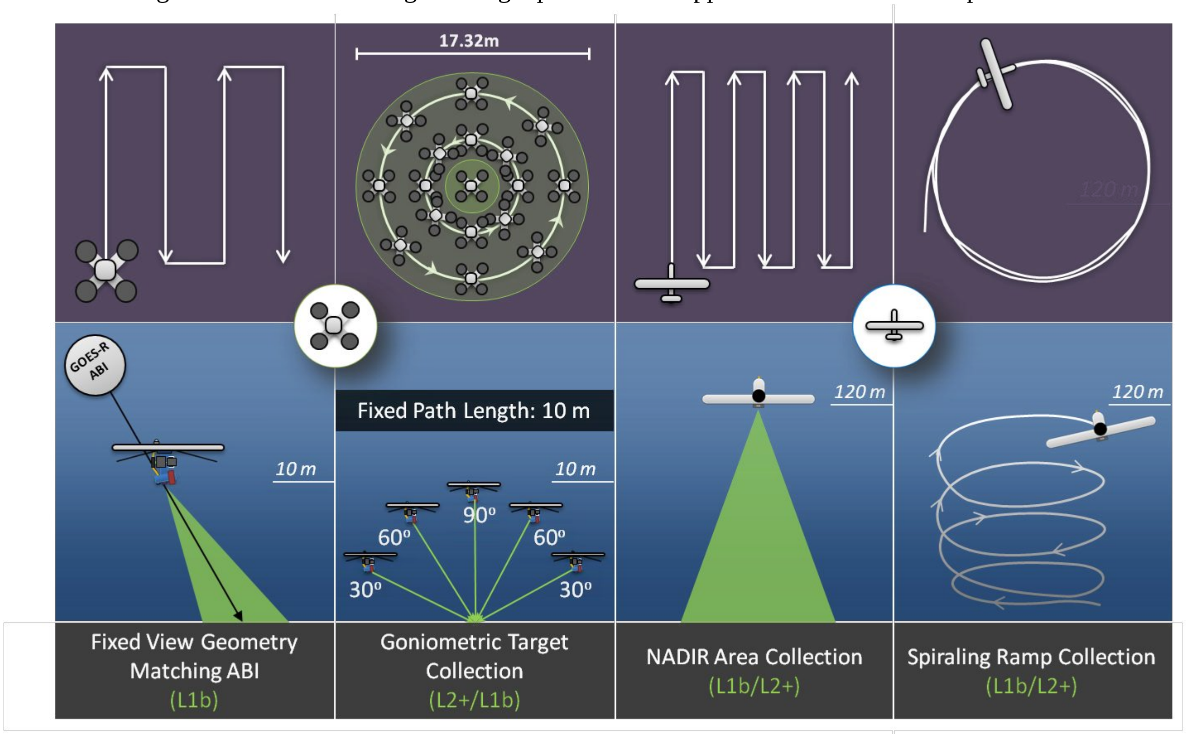

Figure 9: Baseline UAS collections types.

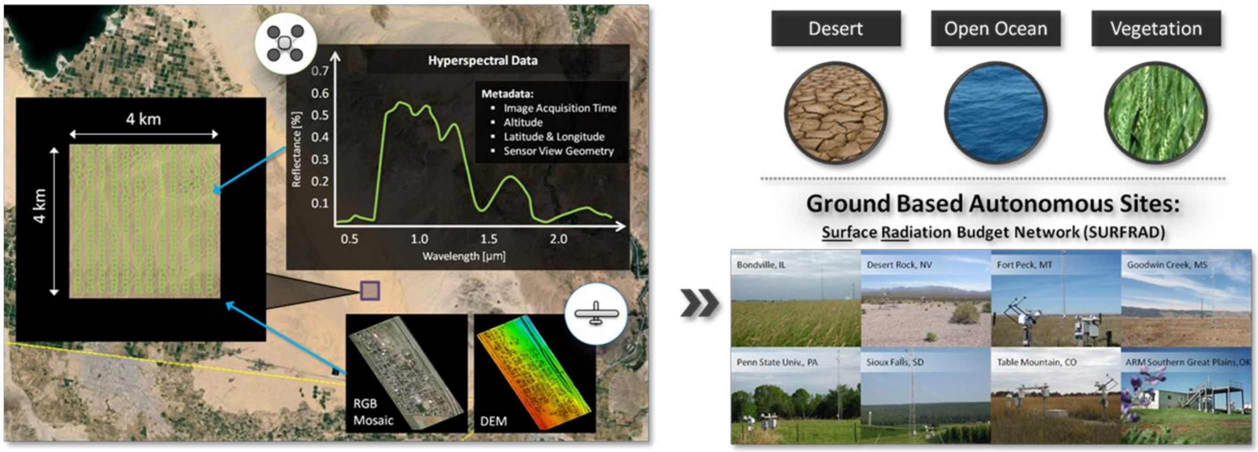

Figure 10: Near surface UAS reference measurement approach to provide improved validation capabilities to the post-launch validation of L1b data & the support of enhanced L2+ product uncertainty capabilities.

A validation target area of 4 km by 4 km is needed to ensure representative reference data is collected over at least one pixel in all GOES-R ABI RSBs. The fixed-wing UAS collections will be conducted to generate complete 2D & 3D geo-referenced products of the target site to provide context imagery products prior to the rotary UAS collections. Validation collections with the rotary UAS will be conducted over the target area with the UAS payload view geometry matching that of ABI [Figure 9]. During this time ABI will be tasked to collect imagery every 30 sec for roughly 45 minutes to ensure large validation datasets are provided. The designed reference data collections provide enhanced information of the targets that can be utilized during analysis. The context imagery products provide both qualitative (2D map products) and quantitative (3D digital surface model) insights in conjunction with the non-imaging hyperspectral observations, from the rotary UAS, enabling a comprehensive near surface reference measurement capability in support of post-launch GOES-R L1b/L2+ product validation [Figure 10]. This approach facilitates an absolute validation capability for the use as a secondary pathway to validate ABI RSB SI traceability.

2.2.3 Preliminary Uncertainty Budget: Near Surface UAS RSB Validation Approach

The preliminary uncertainty budget [Figure 11] shows the expected uncertainties are adequate to meet the needs of GOES-R ABI field campaign validation objectives. The measurement uncertainty of the hyperspectral instruments is the greatest source of uncertainty in the method, which is greatest in the shortwave infrared. The UAS-based surface reflectance measurements will be supplemented by ancillary measurements (optical depth and atmospheric profile measurements) to convert to top-of-atmosphere radiance using RTM. Since we will be collecting both incoming (hemispheric sky) and surface radiance this collection strategy is not reliant on any field calibration collections (i.e. calibration tarps), which enables large area collection under changing solar and sky conditions. These preliminary uncertainty estimates will be refined as new measurements and modeling and simulation studies become available.

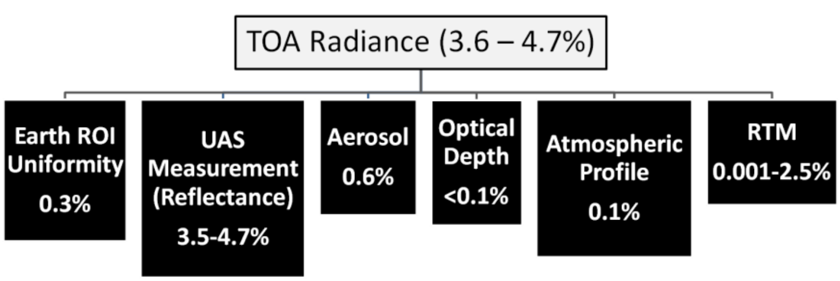

Figure 11: Preliminary uncertainty budget for the near surface UAS RSB validation approach. These estimates will be refined as new measurements and modeling and simulation studies become available. The ranges denote variability as a function of ABI band.

2.3 Satellite Reference Validation Approach

As a secondary pathway to validate the performance of all ABI detectors, an idealized satellite inter-comparison method has been developed. The approach is based on the Simultaneous Nadir Overpass (SNO) approach [31, 32] but uses ABI NSS collections during SNO events of reference LEO instruments to inter-compare the radiance values of all detectors of both ABI and the reference instrument(s). This methodology ensures matching the view geometry of all detectors of the reference sensors through successive ABI NSS collections dependent upon the reference instrument under consideration. Post-processing of the data will determine the best set of matching validation pixels of both instruments for analysis. The results of this approach can be used as a "gold" standard in support of ABI post-launch inter-comparisons with LEO references instruments.

Our focus for the GOES-R field campaign will be to collect a single optimal inter-comparison between ABI & S-NPP/JPSS VIIRS (day), and CrIS (night), & MetOp IASI (night) under clear sky conditions. The ABI NSS + SNO collection events are expected to have 3 minute duration ABI NSS collections for VIIRS events, and 3.5 minute duration CrIS/IASI events. The duration of collection is driven by the size of the area to be covered by the ABI NSSs in the east-west directions. This methodology enables the legacy SNO methods, widely used in the operational post-launch validation of the heritage systems, to be collected in an idealized manner (i.e. all detectors) suitable for the validation of large FPA next generation systems.

2.3.1 Preliminary Uncertainty Budget Satellite Reference Validation Approach

The preliminary uncertainty budget [Figure 12] shows the expected uncertainties are adequate to meet the GOES-R ABI field campaign validation objectives. The uncertainty of this approach is dominated by the reference instrument measurement uncertainties [33, 34, 35] and the spectral response differences between the instruments [36]. As a result of the ABI NSS collection methodology (i.e. consecutive ABI NSS collections are conducted to ensure the entire Instantaneous Field Of View (IFOV) of the reference sensor is collected) the uncertainty in the scene uniformity, time differences, and view geometry can be assumed negligible. These preliminary uncertainty estimates will be refined as new measurements and modeling and simulation studies become available.

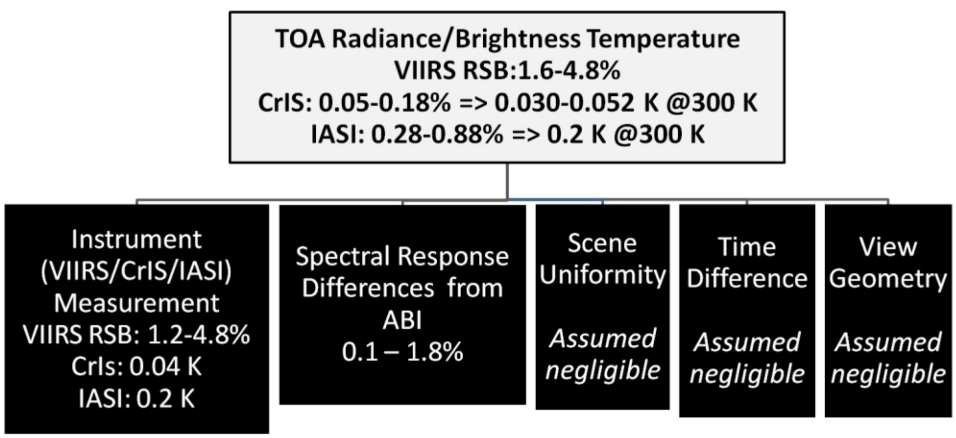

Figure 12: Preliminary uncertainty budget for satellite reference validation approach. These estimates will be refined as new measurements and modeling and simulation studies become available. The ranges denote variability as a function of ABI band.

3. DISCUSSION

The post-launch validation of SI traceability for geostationary satellite sensors is challenging and thus redundancy has been built into this approach. The high-altitude aircraft validation approach in-conjunction with the ABI NSS collections provides a unique post-launch capability to absolutely validate all ABI detectors post-launch. This validation would provide a great step forward in the validation methodologies of large FPA systems, as only relative calibration/validation approaches are commonly obtained due to the lack of representative reference data of the validation target at the time of image acquisition.

The near surface UAS validation efforts are currently focused solely on the ABI surface RSBs, and provide a secondary pathway to validate SI traceability (only for a very limited number of detectors), however, this data used in conjunction with the aircraft validation (all detector) approach will enable enhanced insights to the validation effort. Enabling the routine and mobile collection of surface reference measurements, at the scales of environmental satellite sensors, would be a significant improvement to the current post-launch validation capabilities of operational environmental satellites. This approach facilitates an absolute validation capability for the use as a secondary pathway to validate SI traceability (RSB & TEB surface channels) and capability for the use in L2+ product performance uncertainties. A major advantage of this reference collection approach is that the near surface UAS campaigns can be replicated numerous times throughout the year at significantly reduced costs in comparison to heritage approaches. The UAS deployments can also support the characterization of the degree of uniformity within a given satellite footprint -- ideally, for all reference calibration/validation sites (i.e. fixed ground instruments) in different seasons. This in combination with goniometric surface measurements can be used to develop and check components of model values used in retrieval algorithms of L2+ products. A status of the feasibility of this approach will be documented and reported at the end of the GOES-R feasibility demonstration study (planned completion - late 2016 following an operational environment test collection in the U.S. Southwest desert) for its potential use during GOES-R post-launch validation. The utility of UAS near surface reference data will likely become a critical asset in support of post-launch validation of satellite sensors enabling science validation teams to respond faster to data quality issues and performance anomalies, while enabling attainable, low cost, and on-demand field experiments in response to fundamental post-launch performance questions.

4. SUMMARY

Three unique methods were presented designed specifically for the post-launch validation of the SI traceability of the GOES-R ABI - the GOES-R ABI field campaign primary objective. The approach ensures an absolute independent validation of all ABI detectors using hyperspectral sensors over ideal calibration/validation Earth targets. These approaches leveraged heritage methodologies, unique scanning capabilities of ABI, ideal Earth validation targets, and best available reference instruments to ensure the successful of the GOES-R field campaign validation objectives. The GOES-R ABI represents the next 20 years of GOES Earth imaging and these methods will support efforts to ensure its data quality and foster new perspectives for science teams during the post-launch validation and monitoring of NOAA's next generation of operational environmental satellites.

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REFERENCES

[1] GOES-R website, "Advanced Baseline Imager," http://www.goes-r.gov/spacesegment/abi.html (August 2016).

[2] Schmit, T. J., Paul Griffith, Mathew M. Gunshor, Jaime M. Daniels, Steven J. Goodman and William J. Lebair, "A Closer Look at the ABI on the GOES-R Series," Bull. Am. Meteor. Soc., doi: 10.1175/BAMS-D-15-00230.1 (2016).

[3] Tobin, D.C., Revercomb, H.E., Moeller, C.C., Pagano, T.S.," Use of Atmospheric Infrared Sounder high–spectral resolution spectra to assess the calibration of Moderate resolution Imaging Spectroradiometer on EOS Aqua," J. Geophys. Res. (111), D09S02 (2006).

[4] Taylor, J., Tobin, D., Revercomb, H., Best, F., Garcia, R., Motteler, H., and Goldberg, M., "Suomi NPP/JPSS Cross-track Infrared Sounder (CrIS): Calibration Validation With The Aircraft Based Scanning High-resolution Interferometer Sounder (S-HIS)," in Fourier Transform Spectroscopy and Hyperspectral Imaging and Sounding of the Environment, OSA Technical Digest (online) Optical Society of America, paper FW1A.3. d (2015).

[5] Larar, A.M., Zhou, D.K., Liu, X., Tian, J., Smith, W.L., "Advanced sounder validation studies from recent NAST-I airborne field campaigns," Proc. *SPIE* 9880, Multispectral, Hyperspectral, and Ultraspectral Remote Sensing Technology, Techniques and Applications VI, 988004 (2016).

[6] Pavri, E.B. & Green, R.O., "AVIRIS/SeaWIFS Cross-Calibration for 1999," Proceedings on AVIRIS: http://aviris.jpl.nasa.gov/proceedings/ (2000).
[7] Green, R.O., Pavri, B.E., and Chrien, T.G., "On-Orbit Radiometric and Spectral Calibration Characteristics of EO-1 Hyperion Derived With an Underflight of AVIRIS and In Situ Measurements at Salar de Arizaro, Argentina," IEEE Transactions on Geoscience and Remote Sensing, 41(6), 1194-1203 (2003).
[8] Thome, K., "Absolute radiometric calibration of Landsat 7 ETM+ using the reflectance-based method," Remote Sensing of Env. (2001).
[9] Czapla-Myers, J., McCorkel, J., Anderson, N., Thome, K., Biggar, S., Helder, D., Aaron, D., Leigh, L., and Mishra, N., "The Ground-Based Absolute Radiometric Calibration of Landsat 8 OLI," Remote Sens. (7) 600-626 (2015).
[10] Czapla-Myers, J., Ong, L., Thome, K., and McCorkel, J., "Validation of EO-1 Hyperion and Advanced Land Imager Using the Radiometric Calibration TestSite at Railroad Valley, Nevada," IEEE Journal Of Selected Topics In Applied Earth Observations And Remote Sensing 9(2), 816-826 (2016).
[11] McCorkel, J., Thome, K. and Ong, L., "Vicarious calibration of EO-1 Hyperion. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing," 6(2), 400-407 (2013).
[12] Committee on Earth Observation Satellites (CEOS) Working Group on Calibration & Validation (WGCV), CEOS, http://ceos.org/ourwork/workinggroups/wgcv/ (August 2016).
[13] Global Space-based Inter-Calibration System (GSICS), GSICS, http://gsics.wmo.int/ (August 2016).
[14] NASA ER-2 High Altitude Aircraft: https://www.nasa.gov/centers/armstrong/aircraft/ER-2/index.html (August 2016).
[15] AVIRISng, Next-Generation Airborne Visible/Infrared Imaging Spectrometer – Jet Propulsion Laboratory: http://airbornescience.jpl.nasa.gov/instruments/avirisng (August 2016).
[16] S-HIS, Scanning High-resolution Interferometer Sounder – University of Wisconsin https://airbornescience.nasa.gov/instrument/S-HIS (August 2016).
[17] FEGS - Fly's Eye GLM Simulator – NASA MSFC.
[18] LIP – Lightning Instrument Package – NASA MSFC: https://espo.nasa.gov/trmmlba/lip.html (August 2016).
[19] CPL - Cloud Physics Lidar – NASA GSFC: http://cpl.gsfc.nasa.gov/ (August 2016).
[20] CRS - Cloud Radar System – NASA GSFC: http://har.gsfc.nasa.gov/index.php?section=12 (August 2016).
[21] GCAS – GeoCAPE Airborne Simulator – NASA GSFC.
[22] Padula, F., Goodman, S., Cao, C., & Wu, X., "GOES-R Field Campaign: Addressing the Validation Challenges of Geostationary Satellite Observations," Oral Presentation, Conference on Characterization and Radiometric Calibration for Remote Sensing (CALCON), (August 2015).
[23] Personal correspondents Timothy Williams (NASA AFRC) & Ian Mccubbin (NASA JPL): June 13, 2016.
[24] AVIRIS Data, NASA JPL, http://aviris.jpl.nasa.gov/alt_locator/ (August 2016).
[25] Bradley G. Henderson and Keith S. Krause, "Relative Radiometric Correction of QuickBird Imagery Using the Side-Slither Technique On-Orbit", SPIE (2004).
[26] Godard, Enrico Stoll, Cody Anderson, Roland Schulze, and Brian D'Souza, "Integrating Advanced Calibration Techniques into Routine Spacecraft Operations", Conf.Proc. SpaceOps (2012).
[27] Aaron Gerace, John Schott, Michael Gartley, and Matthew Montanaro, "An Analysis of the Side Slither On-Orbit Calibration Technique Using the DIRSIG Model", Remote Sens., 6, (2014).
[28] Personal correspondents Alexander Berk (Spectral Sciences, Inc.): February 25, 2016.
[29] Padula, F., Cao, C., Laszlo, I., Yu, Y., Goodman, G., "Evaluation of Near Surface UAV Capabilities for the GOES-R Field Campaign," Poster Presentation - NOAA Satellite Conference: Preparing for the Future of Environmental Satellites (2015).
[30] Pearlman, A., Padula, F., Shao, X., Cao, C., Goodman, S., "Initial Design & Performance of the Near Surface Unmanned Aircraft System Sensor Suite in support of the GOES-R Field Campaign," Proc. SPIE – submitted for publication (2016).
[31] Cao, C., Weinreb, M., and Xu, H., "Predicting Simultaneous Nadir Overpasses among Polar-Orbiting Meteorological Satellites for the Intersatellite Calibration of Radiometers," Journal of Atmospheric and Oceanic Technology, 21, 537-542 (2004).
[32] Cao, C. and Heidinger, A., "Intercomparison of the longwave infrared channels of MODIS and AVHRR/NOAA16 using simultaneous nadir observations at orbit intersections," Proc. Of SPIE (2002).
[33] Cao, C., J.Xiong, S. Blonski, Q. Liu, S. Uprety, X. Shao, Y. Bai, F. Weng, "Suomi NPP VIIRS sensor data record verification, validation, and long-term performance monitoring," Journal of Geophysical Research- Atmosphere, 118(20), 664–678 (2013).

[34] Tobin, D., Revercomb, H., Knuteson, R., Taylor, J., Best F., Borg, L., DeSlover, D., Martin, G., Buijs, H., Esplin, M., Glumb, R., Han, Y., Mooney, D., Predina, J., Strow, L., Suwinski, L., Wang, L., "Suomi-NPP CrIS radiometric calibration uncertainty," J. of Geophys Res: Atmospheres, 118, 10,589–10,600 (2013).
[35] Larar, A.M., Smith, W.L., Zhou, D.K., Liu, X., Revercomb, H., Taylor, J.P., Newman, S.M., and Schlussel, P., "IASI spectral radiance validation inter-comparisons: case study assessment from the JAIVEx field campaign," Atmos. Chem. Phys., 10, 411–430 (2010).
[36] Padula, F. and Cao, C., "Using S-NPP VIIRS as a Transfer Radiometer to Inter-compare GOES-R ABI and Himawari-8 AHI," Oral Presentation, AMS Annual Meeting (2014).