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The Importance of Flight Operations Involvement During the Early Phases of the Systems Development Lifecycle for Enterprise Multi-mission Ground System Upgrades

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In recent years, there has been an industry-wide push for the development and application of Enterprise Architecture (EA) solutions. When it comes to spacecraft operations, the EA initiative has been most evident in ground system development where multi-mission flight operation and dataflow capabilities are now favored over stovepipe solutions that often only support single mission flight operations. With the promise of increased efficiency, higher agility, and improved operations and sustainment, it's easy to see why Enterprise Architecture Multi-mission (EAMM) solutions systems are so alluring. However, those benefits can easily be erased if system operators/users are not involved during the early phases of the Systems Development Lifecycle (SDLC) thus resulting in an end product with many operational challenges. End user involvement early in the SDLC can help improve overall project management, shape a more realistic Concept of Operations (CONOPS), ensure system requirements are written and interpreted correctly by the development teams, and prevent suboptimal system acceptance, integration, and qualification testing. This paper examines two recent EAMM ground system upgrades performed at the National Oceanic and Atmospheric Administration (NOAA) looking side-by-side at the early SDLC phases, how they were managed, and how the level of involvement of flight operations systems personnel impacted each phase.

I. Introduction

IN early 2015, NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) Office of Satellite Ground Services (OSGS) released a CONOPS for how it was going to apply EA to the ground systems that NOAA operates in support of its flagship constellations, Geostationary Environmental Operational Satellites (GOES) and Joint Polar Satellite System (JPSS), as well as its space weather mission Deep Space Climate Observatory (DSCOVR), legacy Polar Operational Environmnental Services (POES) mission, and international partner missions, Jason-2/3 (collectively referred to as Jason) and EUMETSAT's Metop-A/B/C. This OSGS effort was coined the Ground Enterprise Architecture Services (GEARS) initiative, see Figure 1, and has the core purpose of instituting an integrated EA that provides more cost-effective, agile, and sustainable systems to serve the NESDIS mission. Previously, many of NOAA's ground systems ended up being developed as stovepipe solutions limiting opportunities to share common resources, services, and functionality. This approach has historically resulted in high acquisition and Operations & Maintenance (O&M) costs, which is not ideal in an era of uncertain Federal budgets and constantly changing policies. Two major ground system upgrades that have occurred in the past 5-7 years were performed for the Jason and JPSS missions. These two relatively concurrent upgrades served as NOAA's first push towards EAMM systems and were developed and intergrated into operations with contrasting degrees of success. The ensuing sections of this paper will help lay a background of the Jason and JPSS missions, go over a customized version of the standard SDLC engine that is utilized by NOAA operations, compare the early SDLC phases of both missions stressing the differences in how involved (or not involved) Flight Operations Systems Engineers (FOSEs) were, and summarize how FOSEs can impact the overall success of a system's development and operations.

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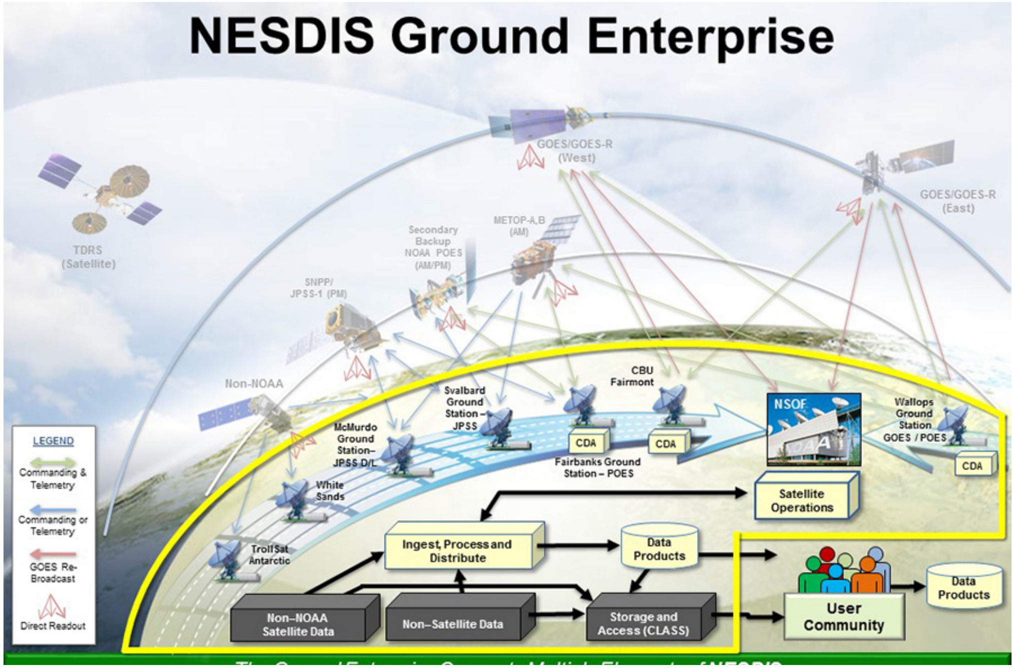

Figure 1: NOAA GEARS Initiative

II. A Brief History: Jason & JPSS

In order to compare the Jason and JPSS missions, one must look at the missions individually and understand their overall mission objectives, some historical context, and how the ground system of each mission has evolved over the years.

A. Jason

1. Mission Overview

Figure 2: Jason-2 and Jason-3 Spacecraft

The Jason-2 mission, also referred to as Ocean Surface Topography Mission (OSTM) and its follow-on Jason-3 were launched June 20, 2008 and January 17, 2016, respectively. Both missions provide measurement of ocean surface topography, surface wind speed, and average wave height which are key in monitoring the rise of the global sea level and understanding behavior of deep and surface ocean currents. The missions are part of an international partnership between NOAA, the Centre National d'Etudes Spatiales (CNES), the EUropean Organisation for the Exploitation of METeorological SATellites (EUMETSAT), and the National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA JPL). The Jason missions are unique to NOAA satellite operations and follow a different concept of operations then the rest of the missions operated by NOAA. One of the key differences with the Jason missions is that while NOAA handles command and control of the spacecraft and a portion of data product generation and distribution, it is not responsible for the health and safety of the spacecraft and instruments beyond real-time and back-orbit alarm monitoring and the execution of select contingency procedures. This is primarily due to how the concept of operations and operational responsibilities are delineated between the Jason 4-Partners. Table 1 covers the high-level core operational responsibilities of each of the Jason 4-Partners during the routine phase of the missions.

NOAA	CNES	EUMETSAT	NASA/JPL
• Lead the Jason-3 program with EUMETSAT • Provide support to overall systems engineering • Provide and operate a command and control center for the satellite, command, and data acquisition stations • Perform near real-time data processing for data collected at NOAA ground stations • Disseminate all near real-time data products and offline products • Archive all near real-time and offline data products	• Perform overall systems engineering and mission management • Provide nominal and anomaly spacecraft and European instrument expertise	• Lead the Jason-3 program with NOAA • Provide support to overall systems engineering • Perform near real-time data processing for data collected at European ground stations • Disseminate all near real-time data products	• Provide nominal and anomaly US instrument expertise

Table 1: Jason 4-Partner Routine Phase Operations Core Responsibilities

2. *Ground System Evolution*

The Jason-2 Ground System (J2GS) that supported Jason-2 pre-launch testing, launch and early orbit operations, and routine operations was designed as a single mission, stovepipe ground system utilizing legacy telemetry, command, and control software developed by NASA JPL for the Jason-1 mission. When the follow-on Jason-3 mission came along, it was decided that instead of starting from scratch with a new ground system, the existing J2GS would be upgraded to support both Jason-2 and Jason-3. This upgraded multi-mission ground system would be rebranded the NOAA Jason Ground System (NJGS) and NOAA's Office of Satellite Ground Services (OSGS) would be responsible for the development, Integration and Test (I&T), and the Transition To Operations (TTO). For the most part, the NJGS architecture mirrored that of the J2GS, just with upgraded hardware, software, mission-specific interfaces, and a simplified network. Most of the key differences reside in the additional ground station resources acquired to support two missions, which were instrumental to the launch and early orbit and assessment phases of Jason-3 when the spacecraft was closely following the Jason-2 spacecraft in order to calibrate the payload instruments. At the request of CNES, the plan for TTO of Jason-2 onto NJGS was after Jason-3 launch however delays in Jason-3's launch allowed TTO of Jason-2 to NJGS ~4 months prior to launch. This timeline was NOAA preference due to the hardware age and security posture of the J2GS and it allowed for any issues in the ground system to be addressed before Jason-3 launch.

B. JPSS

1. Mission Overview

JPSS has a long and very complicated history. JPSS is ultimately the end result of the dissolution of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) that occurred in early 2010 after years of cost overruns and schedule delays. NPOESS, established in 1994, was intended to consolidate the next generations of NOAA's Polar Operational Environmental Satellites (POES) and the Department of Defense's (DoD) Defense Meteorological Satellite Program (DMSP) constellations into one program with NASA being responsible for the acquisition and development of both the ground and flight segments. The overall planning and management of the NPOESS program was performed by an Integrated Program Office (IPO) formed under NOAA that consisted of representatives from each of the three agencies. Unfortunately, the IPO and its tri-agency structure never gelled together into a united program and each agency's differing objectives, acquisition processes, and project management philosophies led to dysfunction and the aforementioned cost overruns and numerous schedule delays. After NPOESS was cancelled and the new NOAA JPSS program was formed with NASA handling all the acquisition, development, and launch responsibilities and NOAA performing mission operations, sustainment, and decommissioning responsibilities. While the distribution of these core responsibilities was similar to what was previously employed for the NOAA POES program, it differed in that NASA was responsible for both the flight and ground segment acquisition and development, the latter previously being handled by NOAA OSGS for POES. This difference is worth pointing out now, as it will be reoccurring point of emphasis later.

In the midst of the independent team reviews, congressional hearings, and program cancellation and subsequent rebirth, the NPOESS Preparatory Project (NPP) was close to being completed. NPP was conceived by the IPO as a risk reduction mission for the NPOESS program and to provide data continuity for NASA's Earth Observing System (EOS). NPP, later rebranded to the Suomi National Polar-orbiting Partnership (S-NPP) mission in the post-NPOESS era, was launched October 28, 2011. Even though S-NPP is considered a part of the JPSS program and constellation, its rebranding as a partnership makes it unique to JPSS in that the spacecraft is still owned by NASA, but mission operations are carried out by NOAA.

S-NPP's successor is the JPSS-1 spacecraft and launched November 18, 2017. JPSS-1 has since been renamed NOAA-20 after achieving its final orbit following a NOAA naming tradition that dates back to the Improved Television Infrared Observation Satellite (TIROS) days. NOAA-20 is considered a clone of the S-NPP mission; however, it has many differences that were the result of lessons learned from S-NPP and other heritage missions along with technological advances that were incorporated, some being attributed to obsolescence. The NOAA-20 payload instruments are the same as NOAA-20 with the exception of the Ozone Mapping and Profiler Suite (OMPS) not being equipped with a limb sensor.

The JPSS-2/3/4 spacecraft will be similar to NOAA-20 in terms of instrument payload except they will not be hosting the Radiation Budget Instrument (RBI), which is a successor to the Clouds and the Earth's Radiant Energy System (CERES) instrument. The spacecraft bus will be completely different from NOAA-20 though, with Orbital ATK being the spacecraft manufacturer instead of Ball Aerospace who manufactured the spacecraft bus for S-NPP and NOAA-20.

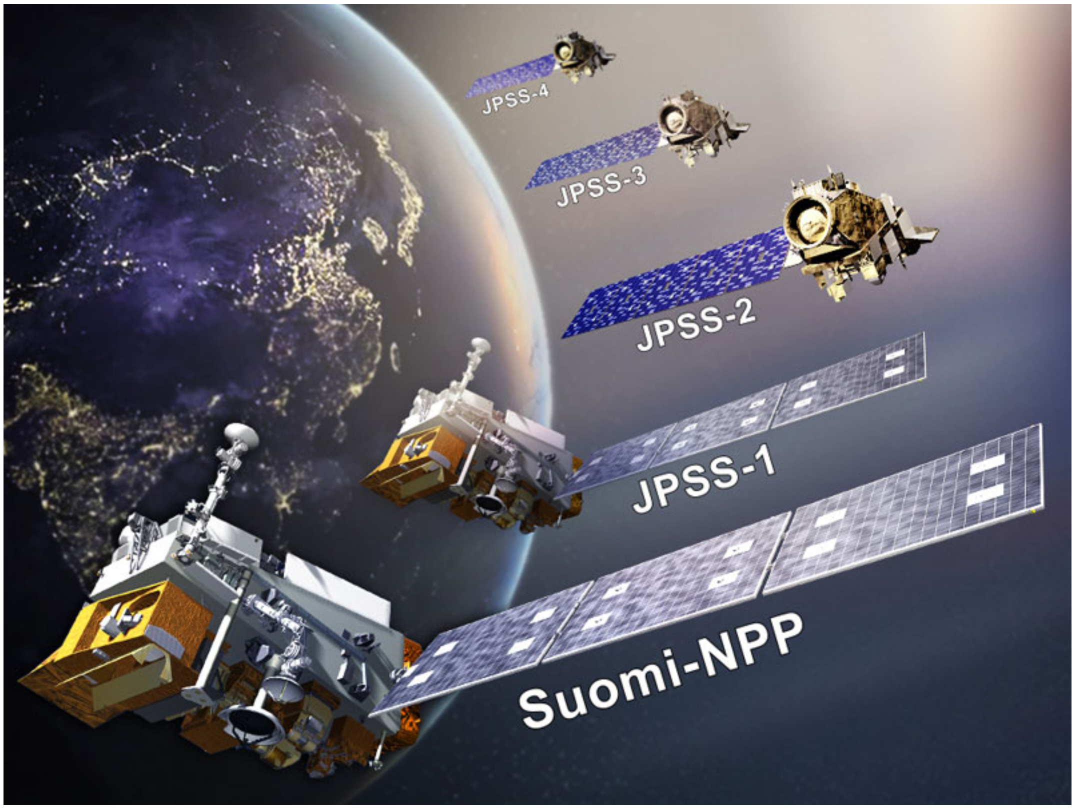

Figure 3: NOAA JPSS Constellation

2. Ground System Evolution

Much like the ground system that supports the Jason missions, the JPSS Ground System (JPSS GS) started out as a single mission ground system that only supported the S-NPP mission. The NASA JPSS Ground Project, the organization responsible for the development, I&T, TTO, and sustainment of the JPSS GS, coined the initial build of the ground system Block 1.0 and eventually upgraded it incrementally to Block 1.2 to accommodate data routing and resource scheduling for other missions like DMSP and GCOM-W1. To add NOAA-20 and truly make the JPSS GS multi-mission, the NASA JPSS Ground Project conceived the next major build of the ground system called Block 2.0. This build included a complete technical refresh of the JPSS GS and rebuild of nearly the entire core ground subsystems and software, a tremendous undertaking. The magnitude of this overhaul, led to many delays in the ground system development, to the point where the JPSS Program Office, the management entity overseeing the JPSS Flight and Ground Projects, adjusted priorities and target milestones in order to prevent delays that would impede the launch of NOAA-20. In 2014, it was decided that ground development would focus on Minimum Essential Capability (MEC) and get the ground system ready for NOAA-20 launch and postpone any multi-mission development efforts until after launch. This meant that the S-NPP mission would not transition from the old Block 1.2 GS until after the launch and checkout of NOAA-20. This also meant that NOAA Mission Operations Team (MOT) would have to operate two spacecraft on two separate ground systems, which would be inefficient and could introduce operator error. Even with this change in management guidance towards MEC, ground system development struggled to meet schedule and was threatening to impact NOAA-20's launch readiness date. Finally, in late 2016 after JPSS-1 launch was delayed, it was decided that the MEC would be revised and the multi-mission aspects of the ground system development would be prioritized higher. This decision meant that the S-NPP mission would transition to the new Block 2.0 GS prior to the launch of NOAA-20 with the idea that it would help serve as risk reduction for NOAA-20 launch readiness. This change in direction thrust the NOAA MOT into ground system assessment, checkout and TTO readiness activities. Through extensive testing, the NOAA MOT revealed many problems with the ground system, particularly with S-NPP and multi-mission aspects of the ground system that had been neglected due the previous MEC declaration that focused purely on NOAA-20. After 9 months of testing, the NOAA MOT and JPSS Ground Project teams got the ground system into a stable configuration that allowed the Block 2.0 GS to finally TTO in August 2017, although the ground system had to be heavily augmented with additional personnel in order to sustain operations. To this date, the ground system is still augmented with additional personnel to help keep operations going. The next couple of builds are expected to help reduce the need for additional manpower and help alleviate a lot of the manual burdens and workarounds the NOAA MOT has taken on to keep mission operations as safe and efficient as possible. Starting with Block 2.2, functionality will be added to accommodate JPSS-2 pre-launch readiness testing and Block 3.0 will constitute another complete tech refresh of the JPSS GS.

III. The Early SDLC and Operations Engineering Impacts

The System Development Lifecycle (SDLC) engine utilized by NOAA operations is tailored version of the typical industry standard SDLC to give it an operational flavor. Figure 4 illustrates this tailored SDLC engine. The classical phases, Pre-Phase A and Phases A through F, are still represented in this engine; however they are now augmented with separate set of supplemental phases that mirror the classical phases, except for Phase F, but in a more operational way. These supplemental phases are Pre-Phase EA and Phases EA through EE in Figure 4 and are detailed further in Table 2. The supplemental phases are naturally under the purview of the operations teams while the classical SDLC phases are associated with the development teams. These two teams and portions of the SDLC engine are bridged by a Flight Operations Systems Engineer (FOSE) with flight operations experience and systems engineering expertise. The role and responsibilities of the FOSE will be covered shortly.

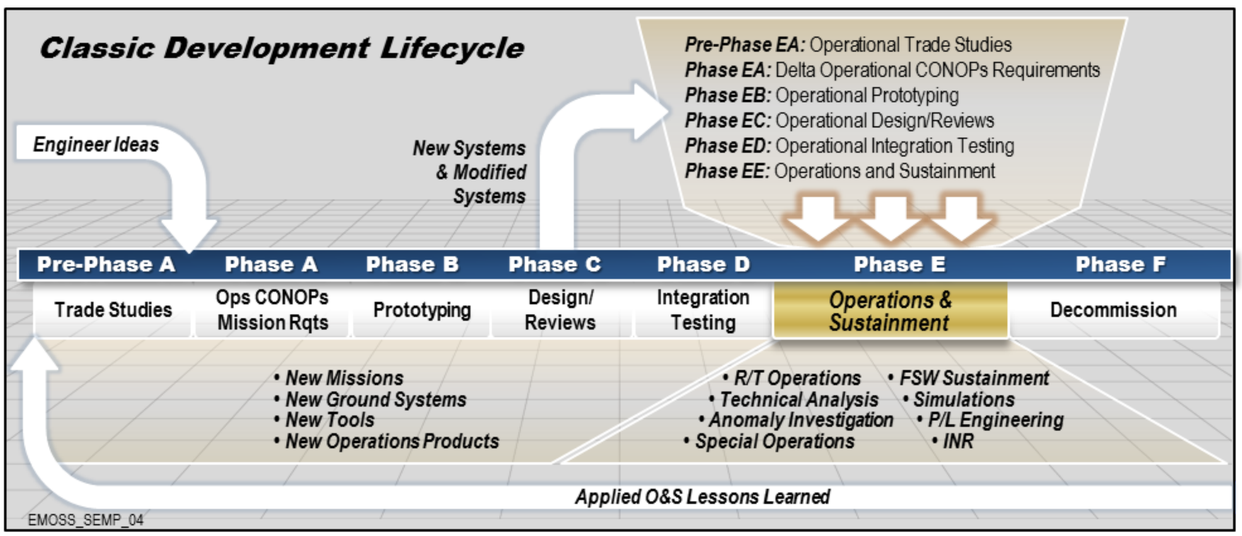

Figure 4: SDLC Engine with Supplemental Phases for NOAA Operations

Supplemental Phase	Purpose	Typical Output
Pre-Phase EA: Operational Trade Studies	To produce ideas and alternatives from expertise and lessons learned for current mission. Determine feasibility of desired system/solution, develop Operations concepts, generate system-level requirements, and identify potential technical needs.	Feasibility reports; system concepts in the form of simulations, analysis, study reports, models, and mockups
Phase EA: Delta Operations Concept & Operations Requirements	To determine the feasibility of a proposed change to operations and establish an initial baseline compatibility with NOAA's ongoing operations. Develop final operations concept, operations requirements, and operations structure technology developments, as needed.	Delta operations concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition. Updates to Operations Requirements documents as needed.

Supplemental Phase	Purpose	Typical Output
Phase EB: Operational Prototyping	To establish an initial baseline capable of meeting operational needs. Develop required structure and product(s), as well as enabling product(s) for evaluation. Generate a preliminary design for each operational structure or end product.	Prototype End Products in the form of demonstrations, detailed requirement specifications and updated interface documents.
Phase EC: Operational Design/Reviews	To complete the detailed, comprehensive design of the system, fabricate hardware, and code software. Generate final designs for each operational structure or end product.	End product detailed designs, end product component fabrication, and software development
Phase ED: Operational Integration Testing	To assemble, integrate, and create the system while developing confidence in the ability meet operations requirements. Deploy changes and prepare for operations. Perform operations end product implementation, assembly, integration and test, and transition to operations.	Operations-ready system end product with supporting related enabling products. Parallel Operations Testing results showing no adverse response to the changes.
Phase EE: Operations & Sustainment	To conduct operations and meet the identified need and maintain support for that need. Implement the mission operations plan.	Desired operations changes

Table 2: SDLC Supplemental Phases for NOAA Operations

Within each of the supplemental phases the activity types are essentially the same to those found in the classical SDLC phases (detailed in Table 3), there are some distinct differences between the mission-level undertaking found in the classical SDLC phases and the supplemental phases specifically tailored to operations.

The first and most obvious is speed. The operations environment inherently requires rapid response to real-time events, such as anomalies or critical weather events like hurricanes, forest fires, blizzards, etc. Another aspect related to the speed of operations is how changes are made. Changes to operations to either fix deficiencies or improve performance needed to be implemented as soon as possible with little impact to the natural cadence of mission operations. Considering both of these two time-related variables, it is clear that that the operations lifecycle runs on timescales of hours for anomalies and critical events, days for simple improvements, and weeks for complex improvements. This contrasts greatly with the phases of the classical SDLC which are much more complex, much less defined, and involve many more people, ultimately resulting in a lifecycle that can last months to quarters to years.

Another major difference is in the size of the organizations involved in the classical SDLC phases versus those found in the supplemental phases. The supplemental SDLC phases for operations requires fewer personnel than needed for the classical mission-level SDLC. The smaller workforce allows for a more rapid response when needed. The number of people involved could be as small as a Flight Operations Systems Engineer (FOSE), a Constellation Lead, a Tester (often a Ground System or Flight Subsystem Engineer), a Program Manager and a NOAA Office of Satellite and Product Operations (OSPO) management representative for relatively simple modifications, but will generally not involve more than 20 people for even the most complex changes.

Phase	Purpose	Typical Output
Pre-Phase A: Trade Studies	To produce ideas and alternatives from expertise and lessons learned for new missions, programs, and projects. Determine feasibility of desired system/solution, develop mission concepts, generate system-level requirements, and identify potential technical needs.	Feasibility reports; system concepts in the form of simulations, analysis, study reports, models, and mockups
Phase A: Operations Concept & Mission Requirements	To determine the feasibility of a proposed new major system and establish an initial baseline compatibility with NOAA's strategic plans. Develop final mission concept, system-level requirements, and needed system structure technology developments	System operations concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition. Mission and System Requirements documents.
Phase B: Prototyping	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure and product, as well as enabling product, requirements. Generate a preliminary design for each system structure end product.	End products in the form of mockups, trade study results, specification and interface documents, and prototypes
Phase C: Design/Reviews	To complete the detailed, comprehensive design of the system, fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
Phase D: Integration Testing	To assemble, integrate, and create the system while developing confidence that it will be able to meet system requirements. Launch system and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to operations.	Operations-ready system end product with supporting related enabling products
Phase E: Operations & Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system

Table 3: Classical SDLC Engine Phases

A. Flight Operations Systems Engineer (FOSE)

The FOSE, under NOAA OSPO, functions as a liaison between the classical mission-level portion of the SDLC and the supplemental operations-level portion to bridge the development and operations teams. To be the most effective, FOSEs are embedded within NOAA Program or Project Offices, like the aforementioned OSGS and JPSS Program Office, to ensure the application of lessons learned from operations early in the SDLC, perform trade studies, develop feasibility analyses, provide input for system and/mission requirements, and generate concept of operations for proposed systems being developed. FOSEs also attend product demonstrations and design reviews and provide necessary feedback and participate heavily in integration and test activities to assess system/product functionality and perform verification and validation of whether the system/product meets mission requirements and operational needs.

After all integration and test activities for a given system/product are performed, the FOSE handles all Transition To Operations (TTO) communication and coordination and manages the development of transition strategies and plans. Activities associated with TTO that the FOSE coordinates include Operational Readiness Reviews (ORRs), system configuration freeze management, Parallel Operations (POps), and the actual TTO event (including roll-back contingencies). In instances where FOSEs, especially dedicated, are not utilized, equivalent personnel can be a Constellation Lead, Program Manager, or an Operations Subject Matter Expert (OSME).

IV. Early SDLC Phase Analysis: Jason vs. JPSS

The following sections will compare the early, classical SDLC phases of the Jason and JPSS missions to see how the FOSE was or was not used to apply the supplemental, operations part of the engine in Figure 4 and Table 2 and how that translated to the overall operability and usability of each system. Additionally, the majority of this analysis focuses on the Command, Control, and Communications System (C3S) portions of each of the ground systems as opposed to the Product Data Processing portions since C3S required the most work to become multi-mission capable.

A. Pre-Phase A: Trade Studies

	Jason	JPSS
Operational Trade Studies	• The FOSE participated in trade studies and provided an operations perspective to help assist management and project development decision-makers, in the case of Jason this was NOAA's OSGS.	• No FOSE or equivalent supported trade studies for JPSS. • NOAA OSPO management participated in trade studies, but attendance was limited due to the nature of operations and they were often too far removed from working level operations to effectively influence development decision-makers at the NASA JPSS Ground Project.

Table 4: Pre-Phase A Comparison of Jason vs. JPSS

For the Jason missions, the FOSE supported trade studies providing inputs to decision-makers on such things as ground system architecture, ground station loading and scheduling, ground system failover philosophies, security patching policy and cadence, and ground network design. These inputs, as well as operational lessons learned from the J2GS and other NOAA missions, helped setup CONOPS development and helped establish more operationally conscious mission and ground system requirements.

The same cannot be said for JPSS when looking at Table 4. There was no FOSE or equivalent involved in this early SDLC phase. NOAA OSPO management did limitedly participate in trade studies, but were often attending to higher priority operational activities or too far removed from working level operations to effectively influence project development decision-makers at the NASA JPSS Ground Project. While the NASA JPSS Ground Project had their own systems engineers with science mission operations experience, they did not have any NOAA weather mission operations expertise. This resulted in the JPSS being shaped more like NASA's Earth Observing System missions than NOAA's POES and GOES constellations. This philosophical difference in how operations is performed has resulted in the implementation of a ground system and associated processes that require additional labor, workarounds, and monitoring to sustain operations.

B. Phase A: CONOPS & Mission Requirements

	Jason	JPSS
CONOPS	• The FOSE functioned as 'book boss' and was responsible for updating the existing Jason-2 CONOPS to include Jason-3 and updates for new multi-mission NJGS ground operations. • With the FOSE in the 'book boss' role, it guaranteed that operational needs would be addressed, applicable lessons learned would be incorporated, working level personnel across all facets of operations would be solicited for review and inputs, and that NOAA OSPO would be a signatory of approval for the document.	• JPSS Program and the NASA JPSS Ground Project were responsible for developing the JPSS-1 CONOPS, which included baseline S-NPP CONOPS content and additional updates for the new multi-mission JPSS Block 2.0 GS operations. • No FOSE or equivalent nor NOAA OSPO management representation reviewed the CONOPS developed and there was no NOAA OSPO signatory for approval of the document and its content. As a result, operational lessons learned were not incorporated and operational needs were not addressed.
Operational Mission Requirements	• The FOSE and other working level operations personnel reviewed and provided inputs to requirements documents, both at the Jason 4 Partner level (overall mission requirements) and for the NOAA Jason Ground System. • The FOSE and other NOAA operations personnel wrote supplemental requirements to address operational needs not covered in the core requirements documents.	• No FOSE or equivalent was solicited for review of core mission level and ground system documents. • NOAA OSPO management did have designees assigned to review requirements documents, but they were too high above the working level to understand the intricacies, needs, and challenges of operations.

Table 5: Phase A Comparison of Jason vs. JPSS

When examining Table 5 above, it is evident that the Jason FOSE, and subsequently NOAA operations, contributed greatly to this core, fundamental phase of the SDLC whereas the opposite was the case for JPSS. The mission CONOPS, a crucial, foundation document that provides the overarching vision for how mission operations will be executed, had significant input from NOAA operations purely through the fact that the FOSE served as the document's 'book boss'. This helped ensure that operational needs would be addressed and that lessons learned from Jason-2 and other NOAA missions were incorporated within the CONOPS.

In the case of JPSS, with JPSS Program and the NASA JPSS Ground Project as the prime authors and contributors to the JPSS-1 CONOPS, the document ended up being an evolution of the S-NPP CONOPS, which never fit the mold for NOAA OSPO conducted mission operations and contained many NPOESS era misconceptions. The lessons learned and challenges from how S-NPP was integrated into NOAA operations were never addressed in the JPSS-1 CONOPS and thus the JPSS Block 2.0 GS and accompanying ground operations were developed with the many of the problems that plagued the early days of the S-NPP mission on the JPSS Block 1.0 GS. History unfortunately repeated itself. Many of the problems that plague JPSS mission operations, can be traced back to the inadequacies of the mission CONOPS and how the document developed and approved by personnel that had no NOAA operations background or expertise.

Regarding mission requirements, a similar contrast is observed between Jason and JPSS. For Jason, the mission-level Jason 4 Partner requirements were mostly reworked Jason-2 mission requirements, just with the addition of Jason-3. These overall mission requirements trickled down to the lower level requirements for the NJGS. For both the Jason 4 Partner and NJGS requirement sets, they had a substantial amount of review from both the FOSE and working level operations personnel. This helped ensure that lessons learned previously from Jason-2 development and operations were incorporated in requirements space, going hand-in-hand with the CONOPS vision. In certain cases, the FOSE and NOAA operations personnel wrote supplemental requirements where significant gaps in system capability were found.

With JPSS, the requirements held many carryovers from the NPOESS era. This was especially evident in the ground system requirements where the primary contributor was NASA JPSS Ground Project, thus resulting in newer multi-mission requirements for both the mission and the JPSS Block 2.0 GS that contained many misconceptions about NOAA operations. With no FOSE or equivalent representation from NOAA operations to review the requirements, there was no opportunity to course correct the requirements prior to implementation. This ultimately resulted in requirements gaps and operational needs not being captured, which is why the ground system has many inefficiencies and requires a high degree of maintenance, manpower, and monitoring to sustain operations.

C. Phase B: Prototyping

	Jason	JPSS
Operational Prototyping	• The FOSE was involved in ground system architecture decisions and developed use case scenarios to assist decision-making. • The FOSE updated and reviewed operational Interface Control Documentation (ICD) to ensure that all operational data flows, exchanges, and types were captured and consistent with governing Jason 4 Partner documentation.	• No FOSE or equivalent was involved in ground system architecture decisions or interface control development. NOAA OSPO personnel designated to review architecture documentation and ICDs were at a higher management level and did not have working level expertise. • NOAA OSPO management not included as signatories for any architecture or ICD documentation.

Table 6: Phase B Comparison of Jason vs. JPSS

Table 6 clearly illustrates a contrast between Jason and JPSS pertaining to the level of involvement NOAA operations had during this phase of the SDLC. For Jason, the FOSE was a key participant in reviewing ground system architecture concepts and provided use case scenarios to help justify adjustments in architectural decisions and reinforce the vision of the CONOPS. This was critical in that it helped layout data flows, network connections, and interfaces between the Jason 4 Partners. Much of the work that associated with this phase setup the remaining phases for success, particular system design and operational qualification testing.

In the case of JPSS, there was no FOSE or equivalent involved in any of the JPSS Block 2.0 GS architecture decisions. Additionally, there was no NOAA OSPO management signatory for any of the major architecture or ICD documents. Unfortunately, without any NOAA operations input, this has resulted in many issues once the JPSS Block 2.0 GS was operational, especially multi-mission aspects such as differences in interfaces between S-NPP and JPSS-1, system user account roles and permissions and problems, mission scheduling performance problems, and inadequate file transfer interfaces for both mission operations and external mission partners.

D. Phase C: Design/Reviews

	Jason	JPSS
Design Reviews	• A FOSE or equivalent participated in all design reviews at the Jason 4 Partner level and for the NOAA Jason Ground System. • Participation assured that vendor and development teams were deriving and interpreting requirements correctly and that designs fell in line with operational needs, processes, and procedures where applicable. • Most reviews were held at the NOAA Satellite Operations Facility (NSOF), helping ensure that NOAA operations personnel were able to participate.	• NOAA OSPO management often provided representation for all major mission and ground system reviews. • The disadvantage is that NOAA OSPO management do not have the working level operations knowledge. • Most reviews were not local so a FOSE or working level personnel were often unable to travel and participate due to operational obligations and travel budget restrictions.

	Jason	JPSS
System Design	• NOAA operations personnel and the FOSE participated in all demonstrations that served as checkpoints in development efforts to gauge whether hardware and software were satisfactory with end user expectations and needs. • Since NOAA's OSGS was responsible for ground system development, there was easy access and less hoops to go through to access the vendor. Also, the vendor factory and personnel were local to the NSOF area.	• NOAA operations personnel occasionally supported demonstrations of system hardware and software, but they were few and far between and often required travel to factory development locations. • No FOSE supported demonstrations. • Access to the JPSS Block 2.0 GS vendors were not as readily available as Jason since communication had to go through the NASA JPSS Ground Project which was not local to the NSOF. Also, the vendor factory and personnel were not local to the NSOF area.

Table 7: Phase C Comparison of Jason vs. JPSS

When examining Table 7, it's clear that both Jason and JPSS had NOAA operations representation at all major reviews, both at the mission-level and for each of the respective ground systems. This helped guarantee that vendor and development teams were interpreting and implementing requirements correctly and that designs were consistent with NOAA operational needs, processes, and procedures. For JPSS though, a FOSE or equivalent working level personnel did not participate, often due to operational obligations or travel budget restrictions since most reviews were to the vendor site as opposed to the customer site. Thus in the case of JPSS, NOAA OSPO management were often the ones critiquing design reviews and were at a disadvantage of not being able to provide working level, end user operations knowledge. Having a FOSE or equivalent would have been able to make up for that gap in operations expertise.

Much of what has been said above for design reviews can be said of system design and associated demonstrations. The FOSE and NOAA operations personnel heavily supported demonstrations of the NJGS and its accompanying processes and procedures. This helped infuse working level operations knowledge into development efforts and facilitated changes in hardware and software to meet user expectations and needs. JPSS had a similar type of participation, just at a different level. JPSS Block 2.0 GS design demonstrations were less frequent and often required travel to the factory location, which was not local to the operations facility. Not having a FOSE to witness these demonstrations was also a drawback for JPSS. This restricted JPSS from benefiting from the same type of involvement and feedback that Jason was able to achieve.

E. Phase D: Integration Testing

	Jason	JPSS
Acceptance Testing	• The FOSE and other working level NOAA operations personnel were heavily participated in all acceptance testing of the NJGS. This included both Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT). • The FOSE and participating NOAA operations personnel wrote Discrepancy Reports (DRs) for issues note during FAT and SAT testing and helped track them to resolution. • As part of the acceptance testing, requirements verification was also performed by the FOSE and other NOAA operations personnel.	• No FOSE or NOAA operations personnel participated in acceptance testing for the JPSS Block 2.0 GS. • NASA JPSS Ground Project was responsible for requirements verification and witnessing acceptance testing. • Since the JPSS Block 2.0 GS was behind schedule and incurring more cost, the FAT was eliminated as a key milestone leaving only the SAT as the primary requirements event. This was also around the point in development where the JPSS Program declared the Minimum Essential Capability (MEC) of the JPSS Block 2.0 GS would focus on supporting JPSS-1. • The SAT was rescoped to just focus on operations based test procedures to verify requirements and was heavily JPSS-1, with minimal multi-mission and S-NPP testing. This essentially took the teeth out of SAT and forced the creation of other specialized requirements verification test events that are still occurring to this day even though the JPSS Block 2.0 GS is operational.
Technical Integration and Qualification Testing	• The FOSE, and occasionally other NOAA operations, participated heavily in Technical Integration and Qualification Testing (TIQT) of the NJGS, both at the Jason 4 Partner level and internally to the NOAA aspects of the ground system. • This frequently involved End-To-End (ETE) data flows tests with Jason-2/3 simulators and test data. On the occasional, live data from the on-orbit Jason-2 spacecraft was used. • Other compatibility tests with the Jason-3 spacecraft at factory occurred as part of TIQT.	• Again, no FOSE or NOAA operations personnel participated in acceptance testing for the JPSS Block 2.0 GS. • Similar to Acceptance Testing, NASA JPSS Ground Project was responsible for TIQT. • Outside of compatibility testing with JPSS-1 spacecraft and ETE data flow tests like those performed for Jason, TIQT was a repeat of the operations based SAT previously executed and did not cover much new ground.

	Jason	JPSS
Operational Qualification Testing	• The FOSE and other NOAA operations personnel were highly involved with all Operational Qualification Testing (OQT) of the NJGS which were nearly all at the Jason 4 Partner level. • OQT included a lot of the TIQT aspects, but is executed in a more operational manner, typically simulating Launch & Early Orbit Phase (LEOP) and Routine Phase (RP) operations with spacecraft and ground system anomalies.	• With JPSS-1 and JPSS Block 2.0 GS further behind schedule, mainly the latter, it was decided by JPSS Program that MEC would be revised to prioritize S-NPP and multi-mission over JPSS-1. • As part of that declaration, it was determined that the FOSE and NOAA operations teams would support pre-OQT discovery testing to find as many operational issues with the JPSS Block 2.0 GS and document them in Discrepancy Reports (DRs). • The FOSE and NOAA operations teams participated side-by-side with NASA JPSS Ground Project personnel to execute OQT. This included shadow and parallel operations between the legacy JPSS Block 1.2 GS and the new JPSS Block 2.0 GS which was the primary OQT event.

Table 8: Phase D Comparison of Jason vs. JPSS

Phase D was ultimately the most crucial phase of development for both Jason and JPSS and it is where the FOSE and NOAA operations have arguably the biggest opportunity to make an impact on development efforts. When looking at the Acceptance Testing (AT) for both Jason and JPSS, there is a definite contrast as to the level of involvement by the FOSE and other NOAA operations personnel. For Jason, the FOSE and other operations team members were highly involved in FAT and SAT events documenting DRs for issues found and verifying requirements alongside the NOAA OSGS project development team. The opposite was the case for JPSS. The NASA JPSS Ground Project witnessed AT and solely performed requirements verification. It is important to note that due to development schedule delays and cost overruns, AT for the JPSS Block 2.0 GS was rescoped to just a SAT, no FAT was performed. Another variable to consider was that since development was behind schedule, JPSS Program declared that the MEC for the JPSS Block 2.0 GS would focus purely on supporting JPSS-1 and that S-NPP and other multi-mission efforts would be delayed until after JPSS-1 launch. As a result, the SAT was rescoped to just focus on operations based test procedures to verify requirements and was heavily JPSS-1, with minimal multi-mission and S-NPP testing. This hindered the effectiveness of the SAT in terms of multi-mission requirement verification and delayed verification to later test events, many of which are still be verified to this day or continually being deferred to later builds and iterations of the JPSS GS.

When comparing the TIQT between the two missions, the differences are similar to what was identified for AT. For JPSS, TIQT was almost wholly a re-execution of SAT with the exception of compatibility tests with the JPSS-1 spacecraft at factory and some ETE data flow testing, all of which was carried out by the NASA JPSS Ground Project with no FOSE or NOAA operations involvement. Conversely, for Jason, the FOSE and other NOAA operations personnel were highly engaged in TIQT which covered testing local to NJGS environments and at the higher Jason 4 Partner level. Jason TIQT differed significantly from AT and frequently involved End-To-End (ETE) data flows tests with Jason-2/3 simulators and test data. Jason TIQT occasionally used live data from the on-orbit Jason-2 spacecraft and also involved compatibility testing with the Jason-3 spacecraft.

OQT was a significant event for Jason and JPSS and served as the final gate for transitioning the system to operations. Like TIQT, the FOSE and NOAA operations personnel participated in every OQT event, which were at the Jason 4 Partner. Jason OQT included a lot of what was executed previously during TIQT, but was executed in a more operational manner, typically simulating Launch & Early Orbit Phase (LEOP) and Routine Phase (RP) multi-mission operations with both Jason-2 and Jason-3 spacecraft. This included simulating spacecraft and ground system anomalies to fully exercise all operational scenarios. OQT for JPSS became an amalgamation of things that should have been tested previously in AT and TIQT. Before OQT began, it was decided by JPSS Program that MEC would be revised again to prioritize S-NPP and multi-mission over JPSS-1 since both the JPSS-1 and JPSS Block 2.0 GS were further behind schedule, primarily the latter. Coinciding with this direction, the FOSE and NOAA operations teams were tasked with executing pre-OQT discovery testing to find as many operational issues with the JPSS Block 2.0 GS and document them in Discrepancy Reports (DRs). After the roughly 2+ months of discovery testing and a new build of the ground system to address some of the DRs, OQT began in earnest. The FOSE and NOAA operations teams participated side-by-side with NASA JPSS Ground Project personnel to execute OQT. This included shadow and parallel operations between the legacy JPSS Block 1.2 GS and the new JPSS Block 2.0 GS which was the primary OQT event leading up to TTO. It is important to note that while the NOAA operations teams were involved in OQT and performing day-to-day operations of the S-NPP spacecraft, they were also validating all S-NPP and ground system operational products that had to be updated and converted to work with the new JPSS Block 2.0 GS. This was an incredible undertaking given to the FOSE and operations team, especially considering that it limited their ability to prepare for integration JPSS-1 into operations, but they were able to endure the strain and were able to get the JPSS Block 2.0 GS to a state where it could be transitioned to operations.

F. Phase E: Operations & Sustainment

	Jason	JPSS
Transition to Operations	• The FOSE crafted the Transition Plan for moving Jason-2 operations to the new NJGS. With the FOSE as the primary author of this document, it made sure that NOAA operations personnel had significant as to how the transition would occur and all the logistics associated with it, both local to NOAA and at the Jason 4 Partner level. • The FOSE or equivalent carried out the coordination and execution of the transition with the support of other NOAA operations team members and the ground system vendor as needed.	• The NASA JPSS Ground Project was the primary author of the JPSS Block 2.0 GS Transition Plan. This plan covered the transition of S-NPP operations to the new ground system in addition to other missions that utilize resources of the JPSS Block 2.0 GS for data capture and routing. • The Transition Plan included minimal input from the FOSE and other NOAA operations personnel. • The FOSE and other NOAA operations personnel scoped out the augmented support required to transition and sustain operations of the JPSS Block 2.0 GS due to many outstanding DRs, manual workarounds, and intensive system monitoring. • The NASA JPSS Ground Project and FOSE or equivalent carried out the coordination of the transition of S-NPP operations and other supported, data routing missions to the JPSS Block 2.0 GS. • The NASA JPSS Ground Project and ground system vendor performed the execution of the transition of S-NPP operations with FOSE and NOAA operations support.

	Jason	JPSS
Operations & Maintenance	• The FOSE or equivalent personnel helped iron out Jason-2 operations after the transition to NJGS. • The addition of Jason-3 upon its launch was another key event that the FOSE was highly involved with to ensure a smooth transition to multi-mission operations. • The FOSE and other NOAA operations personnel also made sure all relevant historical data was migrated from the legacy J2GS prior to decommissioning that system. • The FOSE or equivalent helped document lessons learned from the development and operation of NJGS to flow into future Jason efforts.	• The FOSE and other NOAA operations personnel smoothed over JPSS Block 2.0 GS operations. • JPSS-1 launch was handled by NASA JPSS Flight and Ground Projects. A FOSE or equivalent was involved to help assure S-NPP and multi-mission operations were not adversely impacted. • The FOSE and other NOAA operations personnel oversaw the migration of all relevant historical S-NPP mission data from the old JPSS Block 1.2 GS prior to its decommissioning. • The FOSE and other NOAA operations personnel helped document lessons learned from the development, TTO, and operation of the JPSS Block 2.0 GS so that they are incorporated in future JPSS development efforts.

Table 9: Phase E Comparison of Jason vs. JPSS

Of all the activities and events that are a part of the Operations & Sustainment (O&S) phase, TTO is probably the biggest, most significant event. For Jason, TTO was a major responsibility of the FOSE. The FOSE authored the Transition Plan for moving Jason-2 operations to the new NJGS. NOAA operations personnel had significant amount of inputs to this document since the FOSE was the author of the document. The Jason FOSE was the primary coordinator of the transition and all the logistics associated with it, both local to NOAA and at the Jason 4 Partner level. Additionally, the transition leveraged the NOAA OSGS NJGS development team and vendor as needed. Within NOAA OSPO, the transition of Jason-2 operations from J2GS to NJGS is considered one of the most successful and seamless transitions performed in NOAA operations and it would not have been possible without the efforts of the FOSE not only in this phase, but across the early SDLC phases. Also, moving Jason-2 over to NJGS prior to the launch Jason-3 helped serve as a confidence builder that the ground system and multi-mission operations were ready.

TTO for JPSS was executed a bit differently. For one, after the completion of OQT, the FOSE and other NOAA operations personnel were tasked with scoping out the level of augmented support required to transition and sustain operations of the JPSS Block 2.0 GS due to the many outstanding DRs, manual workarounds, and intensive system monitoring that was identified during OQT. This additional augmented support is still in place to this day, although to a lesser extent as DRs and workarounds have permitted a reduction in the staffing level of this support. Another difference for JPSS is that the NASA JPSS Ground Project authored the JPSS Block 2.0 GS Transition Plan. Additionally, the scope of the transition was a bit more involved compared to Jason. The transition of S-NPP operations to the new ground system was accompanied with move of other missions that utilize resources of the JPSS Block 2.0 GS for data capture and routing. The NASA JPSS Ground Project, along with the ground system vendor, carried out the transition with support from NOAA operations as necessary.

When examining the Operations & Maintenance portion of Phase E, there is not a significant difference between Jason and JPSS for once. For both missions, the FOSE and NOAA operations personnel ironed out routine operations of both ground systems after transition, assured that historical mission data from the legacy ground systems was migrated and archived on the newer systems, and document lessons learned from each of the SDLC phases leading up this point. The only difference between Jason and JPSS was how multi-mission responsibilities were delegated during the launches of Jason-3 and JPSS-1.

V. Conclusion: Summary of Comparison Analysis & Recommended Paths Forward

Through the side-by-side analysis, it is rather clear to see how the Jason mission and NJGS benefitted from having a FOSE embedded in throughout the early SDLC phases and how that translated into a more mature, stable, user friendly, and operationally sound ground system. JPSS, on the other hand, could have stood to benefit from having at least one FOSE embedded in the development of the JPSS Block 2.0 GS. Had a FOSE been utilized in Pre-Phase A and Phases A-C more, a lot of the issues and problems that were discovered in Phase D could have been addressed or limited in their impact to mission operations. FOSE support in the earlier SDLC phases would have likely helped drive down costs both in the development and operation of the JPSS Block 2.0 GS, especially in reducing or eliminating the need of augmented vendor support to sustain day-to-day operations.

The path forward for future of each mission is evident. Jason simply needs to continue to utilize the FOSE and while JPSS needs to embed one into its development team, or preferably team of FOSEs considering the breadth of the ground system and mission. With the dynamic of having NASA JPSS Ground Project responsible for the development of the JPSS GS, for the FOSE(s) to be most effective the position(s) will likely have to be sponsored by the JPSS Program along with NOAA OSPO and given the right amount of authority to influence decision-making. JPSS is embracing the benefit of utilizing an FOSE in the future and has begun exploring that possibility for future JPSS missions and ground systems.

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VII. References

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