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THE INITIAL JOINT POLAR-ORBITING OPERATIONAL SATELLITE SYSTEM VERIFICATION AND VALIDATION PROGRAM

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1. Introduction

The National Oceanic and Atmospheric Administration (NOAA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) have agreed to share their resources in establishing an Initial Joint Polar-orbiting Operational Satellite System (IJPS). Per the agreement, NOAA and EUMETSAT have agreed to share their resources in establishing the IJPS. The IJPS is a global meteorological remote sensing satellite and ground data processing system. The satellite constellation comprises a morning and an afternoon satellite, both in polar orbits. The ground system is primarily comprised of satellite operational control centers, data processing facilities, data archiving centers and end user services. Each agency will procure space and ground systems, operate satellites, and collect, process, share, archive environmental data for mutual benefit.

In support of IJPS, NOAA and EUMETSAT will build, integrate, verify, and validate their respective space and ground systems. NOAA will provide the NOAA-N and N' afternoon orbit satellites for the space segment and will upgrade the operational Polar-orbiting Operational Environmental Satellite (POES) ground segment (PGS). EUMETSAT will provide Metop-1 and -2 for the morning polar satellites and the EUMETSAT Polar System (EPS) including the Core Ground Segment (CGS) for satellite operations and primary data processing.

The NOAA POES operational ground system has evolved over 30 years. NOAA's Environmental Satellite, Data and Information Service (NESDIS) division is primarily responsible for upgrading the ground operational entities or functional elements that constitute the PGS and those affected by the IJPS system requirements. NESDIS, during its process of system upgrading for the PGS, will conduct numerous verification and validation (V&V) activities at various build stages with the goal of building its operational capabilities in compliance with assigned IJPS requirements.

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This paper provides the NOAA, philosophy and process adopted for the V&V activities related to the PGS functional upgrade. Included in this paper are discussions of the PGS V&V activities as well as the NOAA/EUMETSAT "joint system tests" activity. The joint system tests include IJPS system end-to-end (ETE) verifications to ensure functional, performance and interface compatibilities, and validate selected operational scenarios as practicable.

2. Purpose

With the introduction of the IJPS services, the existing system will be upgraded to meet the new requirements. Various functional elements in the existing operational facilities will be modified to support new functions and services.

The primary purpose of this paper is to present the overall philosophy and approach adopted for the NOAA IJPS V&V program. However, to establish the context for the discussion, adequate background system information is also included preceding the discussion on V&V.

3. Scope

The scope of the NOAA IJPS V&V Program is to verify all of the IJPS System requirements and validate operational scenarios as time and cost permitted. The scope covered all the PGS Element and System level verification activities including joint system end-to-end verification with EUMETSAT.

4. IJPS Overview

Figure 1 shows the IJPS System overview. The space segment essentially comprises the NOAA and Metop satellites. The ground segment includes the satellite command and data acquisition stations, the satellite operations control centers, data processing centers, archive centers and the users. In the figure, for simplicity, the satellite operations control centers, data processing centers and archive centers are grouped as one physical unit, labeled as satellite control. For IJPS, NOAA and EUMETSAT each have independent ground systems and each control and operate their own satellites. However the satellite instrument data is exchanged via a dedicated communications link. Each also has the capability for providing cross support for satellite control and data reception from the partner satellite.

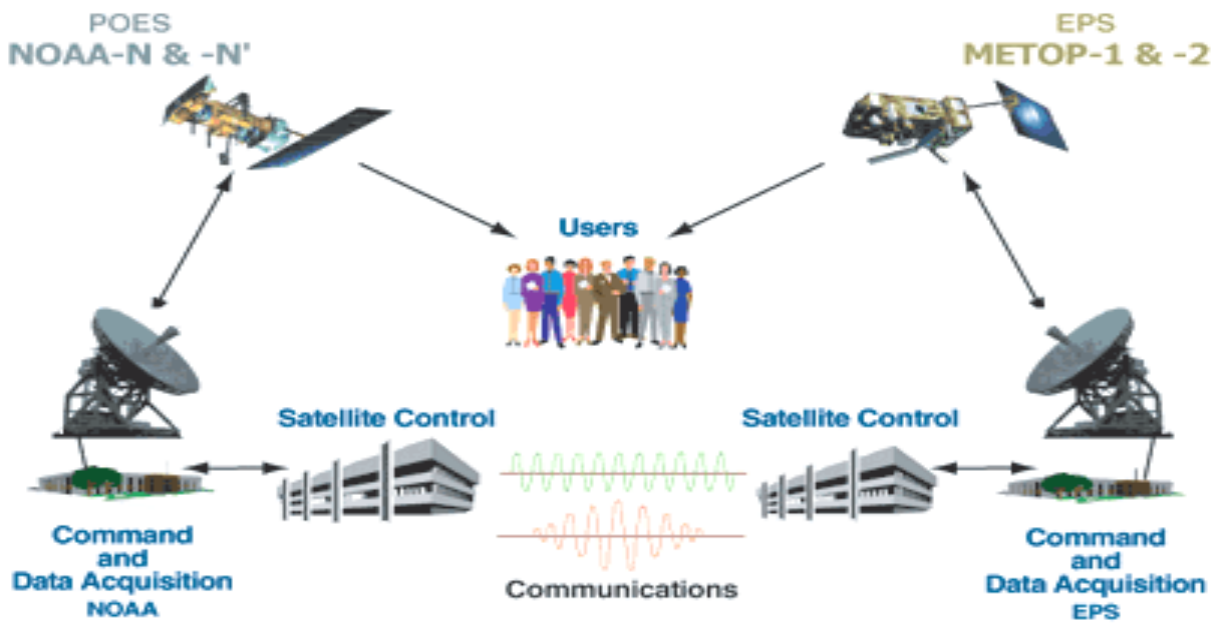


Figure 1 IJPS System Overview

Typically, each agency is the primary to receive data from their satellite and share it with the other, however both agencies independently process the instrument data from both the satellites through their respective ground segments. The processed data is made available to the end users.

5. IJPS Impact Summary

5.1 Ground Segment Impact

The ground segment (G/S) Element/entities that are affected by the IJPS requirements and require modifications in the NESDIS organization are listed in Table-1.

5.2 Data Flow Impact

The primary instrument data or science data streams, generated by the IJPS system are: NOAA satellites which generate the Global Area Coverage (GAC) and Local Area Coverage (LAC) data streams, and Metop satellites which generate the Global Data Stream (GDS). NOAA also produces broadcast data, which consists of High Resolution Picture Transmission (HRPT) and Automatic Picture Transmission (APT), while Metop broadcasts MHRPT and MLRPT (low-resolution data).

Figures 2 and 3 respectively present the NOAA and the Metop spacecraft data flow for the NOAA ground segment. Typically, in both diagrams, the data originates at the spacecraft and flows to the G/S data processing elements. In case of blind orbit data (BGAC/NOAA and BGDS/Metop), the BGAC data is received through the NOAA interface (the NOAA Gateway) located at EUMETSAT. Similarly the Metop BGDS is delivered to the EUMETSAT interface (EUMETSAT Gateway) located at the NOAA facility. Following data reception at the Gateway, that data is retrieved to NOAA G/S for processing. The NOAA SOCC processes, monitors and retains the spacecraft health and safety data, the IPS/CEMSCS ingests and preprocesses the instrument science data producing the NOAA Level 1b data sets. The PGD or product processing systems receive the 1b data sets and develop higher level products and distribute them to end users. The AAS or the NOAA archive & access system archives all data produced by NOAA. Further details of these elements' functionalities and operations may be obtained separately.

The noteworthy point of this architecture is that of the data exchange mechanism. Note that each agency makes their respective satellite instrument data available to the other via a data exchange interface located at each other's premises, referred to as either NOAA or EPS Gateway. Once the data is delivered to a Gateway, each agency is responsible to pull that data from their gateway for processing and distribution on their side.

6.0 IJPS V&V Philosophy

The NESDIS organizations/divisions (Table-1) are responsible for upgrading the PGS functional elements to support IJPS operations. Each division is also responsible for the verification and validation of their upgraded system (Element level), and supporting the NOAA G/S and the IJPS system level V&V activities, including EUMETSAT interface verifications.

Table-1. PGS Element, Entity and Upgrade Relationship

PGS Functional Element	NESDIS Organization	Major Upgrade Activity
FCDAS and WCDAS upgrade and verification	OSD Office of Satellite Operations (OSO)	Reception of Metop RF (X- and S-bands) satellite downlinks & command uplink Process CCSDS packet protocol
SOCC upgrade and verification	OSD OSO	Managing and controlling the Suitland communications interface and the interface at EPS CGS for data transfer Command capability of NOAA satellite via EPS CGS Coordinate cross support activities
IPS functions/ CEMSCS (Level 1 Product) upgrade and verification	OSDPD/IPD Office of Research and Applications (ORA)	Receiving and Preprocessing Metop CCSDS formatted science data packets Ingesting and preprocessing Metop and NOAA global data in “pipeline” mode Upgrade NOAA earth location software to accommodate Metop “in-plane” and “out-of-plane” maneuvers Applying calibration parameters to new instrument data
Product Generation and Distribution (PGD) systems (Level 2 & higher products) NEW systems development and verification	OSD OSDPD/IPD and Satellite Systems Division (SSD) ORA	Processing AVHRR 1 km global data New/modified product processing for IJPS instrument data such as HIRS/4, MHS, IASI 1c, GOME 1b, ASCAT 1b and GRAS 1b Product processing in “pipeline” mode Applying calibration parameters to new instrument data.
AAS upgrade and verification	National Climatic Data Center (NCDC)/CLASS Project OSDPD/IPD, OSDPD/SSD	Increase communications and data storage capacity to accommodate Metop data Implement metadata management, user access controls, and retrieval capabilities for IJPS data
Communications Infrastructure upgrade and verification	OSD OSO OSDPD	Implement communication links between PGS and EPS CGS interfaces New communication links between Fairbanks CDA station and SOCC to meet IJPS timeliness requirements

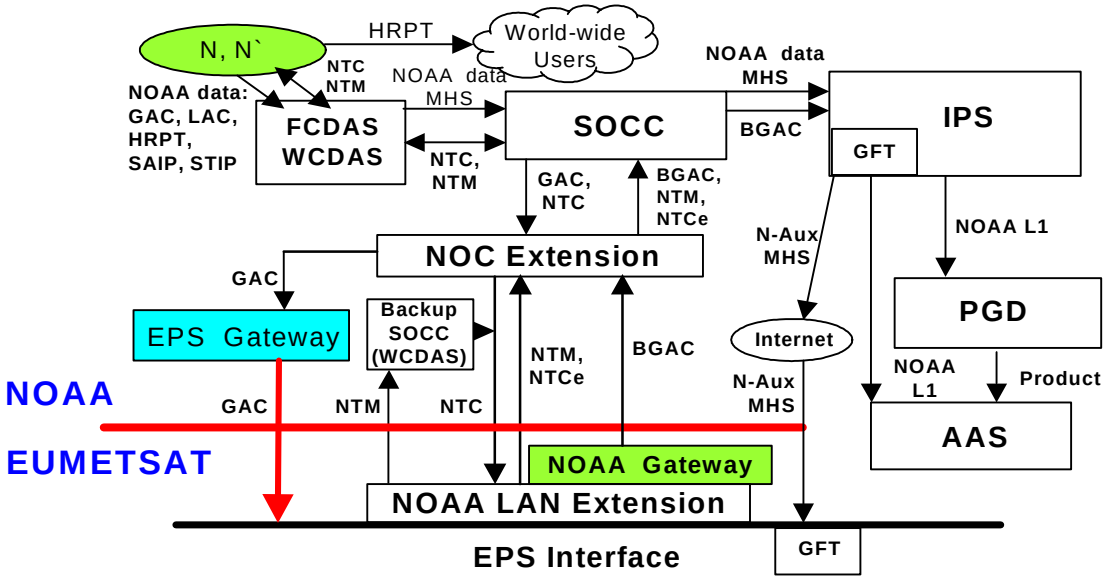


Figure 2 NOAA Satellite Data Flow

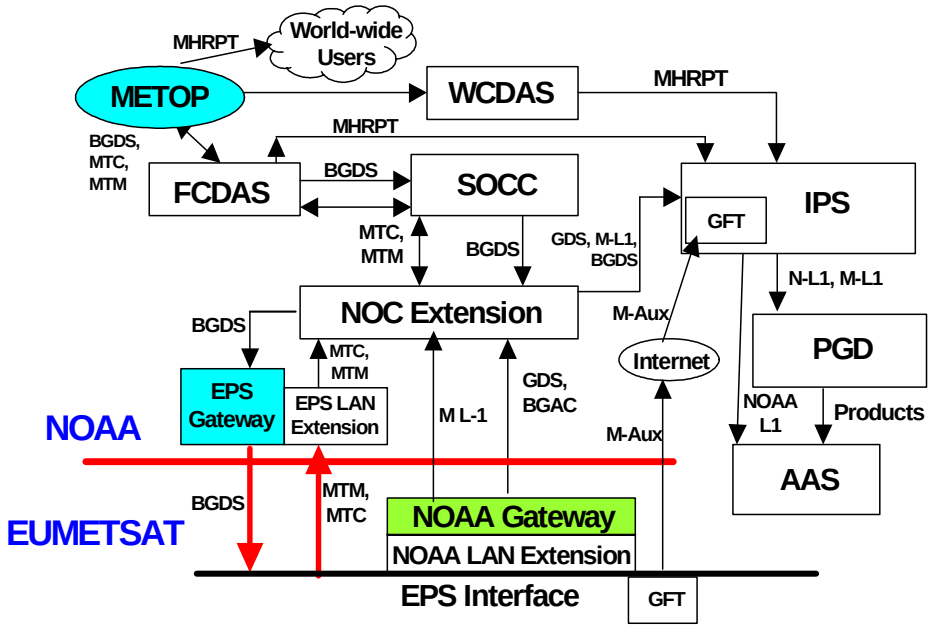


Figure 3 METOP Satellite Data Flow

The general philosophy for all of the V&V activities, within the limitations of available resources are:

- Testing shall be the preferred method of verification for all new system upgrades/ modifications and interfaces.
- Ascertain that new upgrades have not impacted the old operational systems, by testing the old process after upgrades.
- Verify all types of spacecraft and instrument data that would be operationally processed by the system. If available, the test data types should include real spacecraft and instrument data. Data sets should emulate operational configurations with respect to formats, rates and quantities. Simulated test data and test tools may be used to supplement actual data.
- Testing interfaces shall be performed as early as possible in the build cycle.
- Test operational hardware and software at least once, more if practicable.
- Simulate operational environment for conducting tests, as practicable.
- Verify stand-alone subsystems prior to integrating into a system.

Definitions

Verification is defined as the process that determines whether component hardware or software comply with prescribed functional, design, and performance requirements. The objective of verification activity is to determine the extent to which the system can reliably support ETE system functionality and operations and the extent to which the system complies with the system requirements. Verification may be conducted at various stages of a system development and integration with the objective of establishing compliance at all levels. The four methods of verification are inspection, analysis, demonstration and test. Further, tests may be classified as integration test, qualification test, acceptance test and operational scenario test.

Validation is proof of the system, that a verified system accomplishes its designed end-user and mission goals. Hence, validation is typically accomplished at the integrated system level ETE testing. Selected operational scenarios are planned to be validated.

7. Verification Methodology

The overall goal of the V&V activity is to verify and validate NOAA POES System Requirements for IJPS. The V&V of components and systems are accomplished at the four build levels and tests may be repeated at higher integrated levels as deemed necessary by the project manager.

The four build levels for IJPS are:

- Unit Level (Upgrade component procurement and acceptance)
- Element Level (Integrated Element V&V)
- Ground Segment Level (Integrated G/S V&V)
- IJPS System Level (Integrated NOAA G/S with EPS CGS V&V)

Figure 4 presents build level flow schematic.

Referring to Figure 4, Element level verifications are performed during the integration of the newly procured and verified components in building the operational element to support IJPS service. The verifications primarily focus on the internal interface requirements, integrated element ETE specifications and performance, and external interface requirements. The tests validate

requirements at the Element level and prepare for ground segment level integration and tests. These verifications are also internal to the implementation process of each NESDIS organization

Once the “element level” upgrade verifications are completed, the “ground segment level” verifications are performed, which primarily includes satellite data flow through the NOAA ground segment.

Ground Segment Level refers to the integrated NOAA ground elements with all the inter- and intra-element interfaces completed and upgraded to support IJPS services. Ground segment level V&V activity constitutes the ETE performance assessments of the upgraded NOAA IJPS ground segment. The G/S level V&V activities will verify all G/S level requirements; system interfaces and validates selected nominal ETE requirements as prescribed in the NOAA POES System Requirements for IJPS. The activities will verify inter element and ground segment end-to-end (ETE) compatibility with respect to communication interfaces and satellite data flows. Successful completion of this verification phase will qualify the G/S for joint system level testing with EUMETSAT.

The activity includes IJPS system ETE functional validation including satellite data exchange and cross-support satellite commanding capabilities. Joint testing will also validate that the satellite data can be shared between systems while satisfying product processing timeliness requirements. Selected nominal and contingency operational scenarios will be verified as defined in joint documents. The activities will establish the ETE system compliance with the IJPS functional requirements and validate operational performance parameters.

Note: Generally each stage of build is independently verified prior to proceeding to the next stage. As such, in some cases, it may be acceptable to use the results of an earlier stage testing to substitute a later stage test provided the test criteria and parameters are identical. At times this approach may become necessary and cost-effective.

8. Test Process Flow

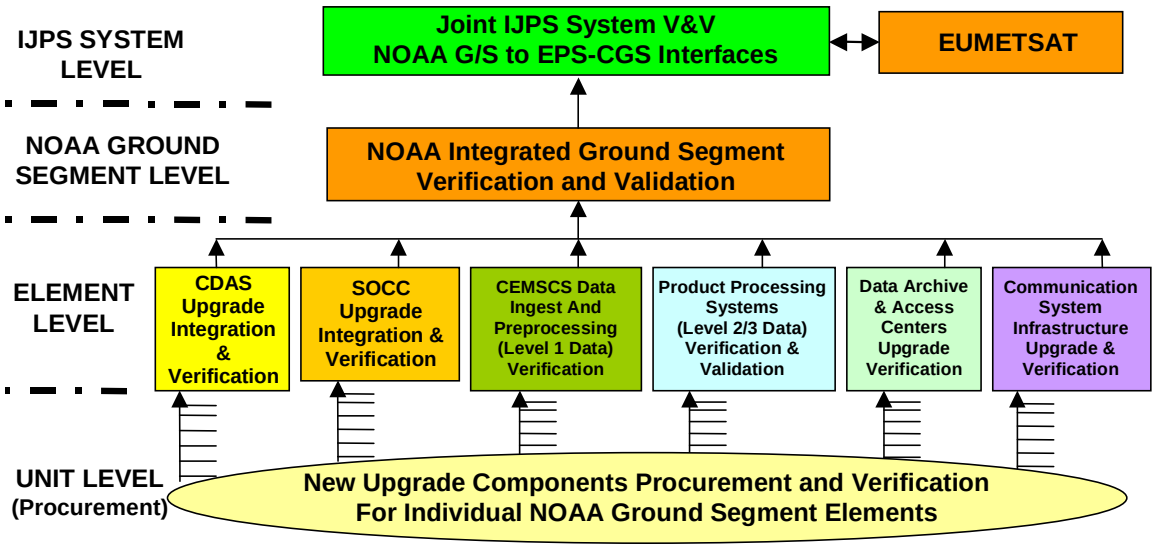
A general test process flow for V&V activities is comprised of planning, execution, reporting, and certification activities, as illustrated in Figure 5.

9. Test Documentation

Test-related documents that are produced as part of the V&V activity include the following:

- Test Plans
- Test specifications
- Test Procedures
- Test Reports
- Analysis Reports
- Anomaly Resolution Form

For maintaining content conformity among documents produced by various NOAA elements, an outline for each of the above document was provided. Modifications to the outline were applied as necessary. The set of documents is required to conduct, report, and record, at each level, the performance of each test in the verification process.



Arrowheads indicate the system build direction (Bottom to Top)

Figure 4 PGS Upgrade Build Levels Schematic

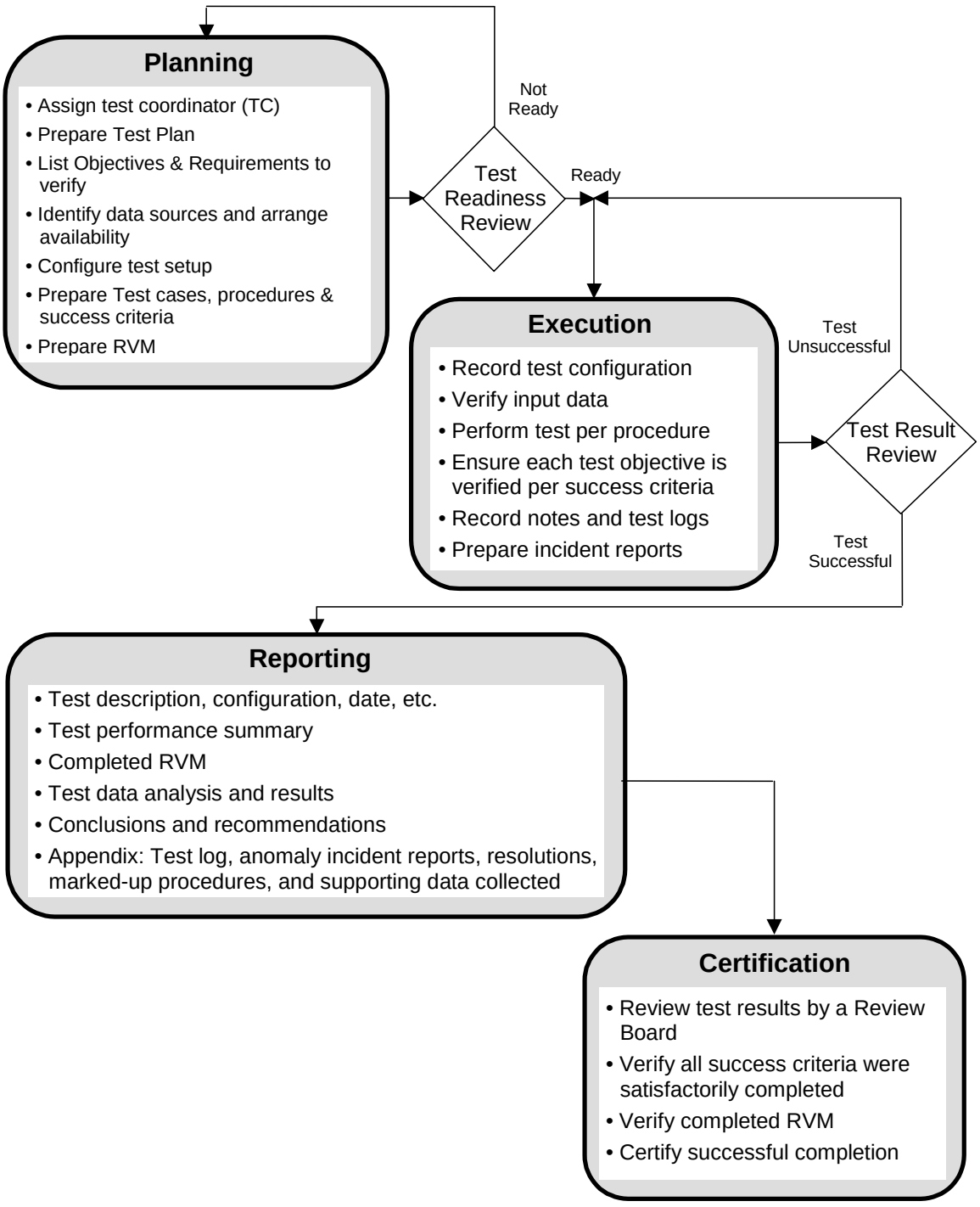


Figure 5 General Test Process Flow

10. IJPS G/S Test Information Tables

Test Cases

The test cases were categorized in to groups. Each test group has a particular Test Case ID number, Test Title, Purpose, and Reference Test identification. Test Group (G1), for example, consists of tests G1C1 through G1C8. For illustration, Table 2 presents a sample of the test case table format for two cases, G1C1 and G1C2. CSU refers to the CDA and SOCC upgrades, and CE refers to the communications element.

Test Specifications

For each test case a test specification table was prepared. This table essentially included all the characteristics of the test case. Information includes Test Case ID number, Test Case Title, Objectives, Description Configuration, Prerequisites, Required Resources, Entities, Required Test Tools, Required Test Data (Input), Required Output Data, Entry Conditions, Pass / Fail Criteria, and Requirements. Table 3 shows an example of a Test Specification for one of the test case (Test Case G1C1), which was shown in Table 2.

Table 2. Test Group (G1) Data Flow: NOAA to EPS

Test Case ID#	Test Title	Purpose	"CSU/CE Ref. Test"
G1C1	GAC from FCDAS/SOCC to EPS Gateway Simulator Test	Verify GAC data flow delivery to EPS Gateway Simulator at NOAA	– CSU Test SOCC-003, SOCC POES GAC/STIP/SAIP to EPS Processing – CSU Test ETE-013, FCDAS POES GAC/SAIP/STIP to EPS
G1C2	GAC from WCDAS/SOCC to EPS Gateway Simulator Test	Verify GAC data flow delivery to EPS Gateway Simulator at NOAA	– CSU Test SOCC-003, SOCC POES GAC/STIP/SAIP to EPS Processing – CSU Test ETE-014, WCDAS POES GAC/STIP/SAIP to EPS

Table 3. Test Case Specification (Example)

Test Description/Specification	
Test Case ID#	G1C1
Test Case Title:	GAC from FCDAS/SOCC to EPS Gateway Simulator Test (CSU SOCC-003, CSU ETE-013)
Objectives:	Verify the GAC data flow: (1) Verify GAC data delivery to SOCC from FCDAS (2) Verify GAC data delivery to EPS Gateway Simulator from SOCC via NOC Extension (3) Verify the communications element (CE) between FCDAS and EPS Gateway Simulator (4) Verify all requirements contained in the "Requirements" section per this Test Case
Description Configuration:	General: Diagram: Refer to "NOAA S/C Data Flow" diagram (Fig. 2-1)
Prerequisites:	Successful completion of CE integration and test, and SOCC database completed.
Required Resources, Entities	FCDA with support personnel, SOCC with support personnel, and CE support personnel
Required Test Tools:	TBD with Integral Systems, Inc.
Required Test Data: (Input)	GAC data (two orbits total)
Required Output Data:	GAC data delivery to EPS Gateway Simulator
Entry Conditions:	Nominal CDAS and SOCC conditions/routines
Pass / Fail Criteria:	All defined objectives must be met. Successful completion of IJPS-CSU tests SOCC-003 (SOCC POES GAC/STIP/SAIP to EPS Processing) and ETE-013 (FCDAS POES GAC/SAIP/STIP to EPS). This section will be revised after reviewing CSU/CE Test Plans/Procedures.
Requirements:	PGSL-3.2.2.1-010, PGSL-3.2.2.1-150, PGSL-3.2.2.1-160(a), PGSL-3.2.2.3-030(a)
Comments:	

Requirements Verification Matrix

The requirements verification matrix (RVM) provides the reverse mapping of the test specification, that is, this table shows the mapping of requirements to the test cases where they are verified.

An example of the reverse mapping of just one of the IJPS G/S requirements to the G1C1 Test Case is shown in Table 4.

11. IJPS Joint System Test Information Tables

The joint system V&V refers to the verification jointly conducted by NOAA and EUMETSAT. The objectives of these tests were to verify that the two side ground segment interfaces are operating as a cohesive compatible system, for satellite data and communication exchanges. The V&V activities entail the assessment of the ETE functional, performance and operational compatibility between the ground segments. Selected nominal operational scenario validations are also envisioned. Tests have been separated into two groups. Group 1 Tests will evaluate the system interfaces. Group 2 Tests evaluates system operations.

Table 5 shows the joint test case table with two examples each of the many test cases. Table 6 shows a single Group 1 IJPS Joint System Test Specification for illustration purposes. It is an example, for one Group 1 test case, presented to illustrate the format and type of data assembled in these specifications.

Table 4. IJPS Ground Segment Requirement Traceability

Segment Requirements	Requirement Verification Method	Test ID
3.2.2 POES Ground Segment (PGS)		
3.2.2.1 Functional		
PGSL-3.2.2.1-010 The PGS shall collect, exchange, store and disseminate global environmental data to users for application to operational meteorological and environmental forecasting and global climate monitoring in support of the IJPS mission. [PSYS-3.1.1-010]	Test	G1C1, G1C2, G1C5, G1C7, G1C8, G2C11, G5C1

Table 5. Joint System Test Cases

#	Test Case ID No.	Test Title	Purpose
[M] = Mandatory Test [O] = Optional Test			
GROUP 1 (System Interface)			
1	01-02l [M]	Nominal Real-time Central Site Functionality using real NOAA N satellite data. Exercising of Cal/Val functionality at central site using real NOAA data	To test completeness, timeliness and archiving of central NRT and GTS products generation and dissemination with use of real, and live, NOAA N satellite data received via EPS CDA and live ECMWF dynamic auxiliary data. To test use of the NRT products in the CVF to exercise Cal/Val functions
15	01-27g: [M]	Sending and processing of simulated NOAA GAC data from the NOAA	To test the nominal case for NOAA data sent from the NOAA GS via the Eumetsat WAN to the CGS.
GROUP 2 (Operational)			
1	02-15a: [M]	Behaviour of system in case of Metop in-plane manoeuvre and further assessment of resulting performance and product quality effects in TEC, CVF and SAFs.	To test the operational procedures related to a Metop in-plane (IPM) manoeuvres and the assessment of impact on instrument performance and product quality in TEC, CVF and SAFs. In addition the impact is assessed by OSE/OBSWM-As including NOAA GS for ATOVS.
2	02-15b [O]	Optional to 02-15a	- Behaviour of system (CGS) in case of Metop in-plane manoeuvre - Including required mission planning and monitoring - Provision of updated aux data (Operational System Validation (OSV), etc.) to various entities and use by these - Use of alert from Collision Warning Service as triggering event

Table 6. Joint System Test Case Specification

Name:	01-27g: PLV-X-VV-LP-GAC_FROM_NOAA_SIM
Test Title:	Sending and processing of simulated NOAA GAC and GDS data from the NOAA GS
Purpose:	To test the nominal case for NOAA data sent from the NOAA GS via the DEW at Suitland (EPS Gateway) and EUMETSAT WAN to the CGS and the functionality to send Metop GDS over the WAN (at a reduced data rate)
Description:	General: Data ingestion / Data processing / Product generation: Dissemination: Archiving: Link to services: Constraints: Procedures Used:
Requirements:	EPS System Requirements: Interface Requirements Document (s): NOAA Requirements:
Pre-requisites:	None
Required Resources:	Internal External
Required Test Tools:	EUMETSAT Test Tools
Required Test Data:	Metop: NOAA:
Required Input Data:	None
Required Output Data:	
Entry Conditions:	NOAA GS in nominal/standby mode
Exit Conditions:	GS-A in standby mode
Test Sequence:	
Pass / Fail Criteria:	
Operator roles:	CGS Operator at EUMETSAT. NOAA GS Operator at Suitland
Expected Duration:	TBD
Comments:	Note: Currently the WAN does not have sufficient bandwidth to send Metop GDS in real-time.

12. IJPS Organizational Roles and Responsibilities

The IJPS Project Manger has the overall responsibility for the entire IJPS Project including V&V activities conducted by NOAA. The IJPS Project Manager has oversight of all V&V activities at NOAA and the joint activities with EUMETSAT. The Project Manger controls the V&V budget, monitors the V&V schedule, participates in reviews and provides final approvals. The Project Manger's responsibilities also include interacting with all the NOAA organizations, NASA, EUMETSAT, and the system users. The Project Manager will assign project and V&V activity milestones, approve V&V funding, and ensure the availability of facilities, personnel, and resources for the G/S and System-Level V&V activities.

13. Summary and Lessons Learned

- Four-tier approach for a comprehensive V&V program
- Ground segment ETE data flow will be verified
- Joint system tests with EPS will verify NOAA / EPS Interfaces and validate IJPS operational scenariosIt is very essential that the test case identification and planning be done well in advance.
- Careful consideration should be given to obtain good matching formatted test data sets.
- Test should be performed to verify for all types data flow.
- Note that it always take more time to integrate and test than previously assessed!

14. Reference Documents

IJPS V&V Ground Segment Test Plan

NOAA IJPS V&V Master Plan, 23 December 2002

NOAA IJPS System Concept of Operations, March 2004

NOAA POES System Requirements for the IJPS (RDN4), 21 June 2002

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15. Acronyms

AAS	Data Archive and Access System
AVHRR	Advanced Very High Resolution Radiometer
BGAC	Blind GAC
BGDS	Blind Global Data Stream
CDAS	Command and Data Acquisition Stations
CE	Communication Element
CEMSCS	Central Environmental Satellite Computer System
CGS	Core Ground Segment (EUMETSAT)
CLASS	Comprehensive Large Array-data Stewardship System
CSU	CDA & SOCC Upgrade
EPS	EUROMETSAT Processing System
ETE	End-To-End
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDAS	Fairbanks Command and Data Acquisition Station
GAC	Global Area Coverage
GDS	Global Data Stream
GFT	Generic File Transfer
HRPT	High Resolution Picture Transmission
IJPS	Initial Joint Polar-orbiting Operational Satellite System
IPS	Ingest and Preprocessing System
LAC	Local Area Coverage
METOP	Meteorological Operational Polar satellites
MHS	Microwave Humidity Sounder
NASA	National Aeronautics & Space Administration
NESDIS	NOAA's Environmental Satellite, Data and Information Service
NOAA	National Aeronautics and Space Administration
OSD	Office of Systems Development
OSDPD	Office of Satellite Data Processing and Distribution
OSO	Office of Satellite Operations
PGD	Product Generation & Distribution
POES	Polar-orbiting Operational Environmental Satellite
SOCC	Satellite Operations Control Center
V&V	Verification and Validation
WCDAS	Wallops Command and Data Acquisition Station