Geostationary Operational Environmental Satellite (GOES) – R Series

Advanced Baseline Imager (ABI) L2+ Land Surface Temperature (LST) Beta, Provisional, and Full Validation Readiness, Implementation, and Management Plan (RIMP)

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ABI L2+ Land Surface Temperature (LST)
Beta, Provisional, and Full Validation
Readiness, Implementation, and Management Plan (RIMP)

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Preface

The evolving calibration and validation (cal/val) maturity of Geostationary Operational Environmental Satellite R-Series (GOES-R) products throughout the beginning of the mission is described by three levels: Beta, Provisional, and Full validation. The Flight Project is responsible for producing the Level 1b (L1b) products according to the Level III requirement documents. Once Beta Maturity of the L1b products is achieved, the Level 2+ (L2+) will begin analysis towards Beta maturity. Further levels of maturity (Provisional and Full validation) require additional and often long-term activities. A detailed description of the three product maturity levels is given in Figure 1, but brief descriptions of the three maturity levels are:

Beta: the product is minimally validated and may still contain significant errors; based on product quick looks using the initial calibration parameters.
Provisional: product performance has been demonstrated through a large, but still (seasonally or otherwise) limited, number of independent measurements. The analysis is sufficient for limited qualitative determinations of product fitness-for-purpose, and the product is potentially ready for testing operational use.
Full: product performance has been demonstrated over a large and wide range of representative conditions, with comprehensive documentation of product performance, including known anomalies and their remediation strategies. Products are ready for operational use.

Assessment and declaration of maturity levels is performed during Peer Stakeholder–Product Validation Reviews (PS-PVRs). At each PS-PVR, the status of products will be presented by members of the cal/val science teams. For L2+ products, Beta maturity PS-PVRs are held in close proximity with and prior to Operations Handover. The review panel at the PS-PVRs will include the GOES-R Operational Readiness Working Group (GORWG), GOES-R Program System Engineering (PSE), NOAA Office of Satellite and Product Operations (OSPO), and GOES-R Product Readiness and Operations (PRO). The Readiness, Implementation, and Management Plans (RIMPs) have been created to document the analysis techniques, methodology, duration, tools, data, resources, staffing, and schedule of the Post-Launch Product Tests (PLPTs) to be used by the cal/val science teams to demonstrate the different levels of product maturity. The primary purpose of the RIMPs is to act as a planning resource for the cal/val teams as they prepare for Launch. Additionally, the RIMPs can be used by other members of the GOES-R Program to prepare for cal/val activities, to assess the suitability of the cal/val test plans, and to understand the data and resource requirements the science teams have. Cal/val testing is likely to reveal necessary algorithm changes to evolve the product quality through the maturity levels. The Algorithm Change Management Plan (ACMP) will be used to track and implement these algorithm changes.

The introspection necessary to create these RIMPs has led to extensive consultations between the cal/val teams and other groups within the GOES-R Program, including the Flight Project, the Ground Segment, and a team of experts from The Aerospace Corporation under contract from GOES-R PSE to help improve the cal/val mission. Figure 2 below describes the responsibilities and accountability of each of the main parties involved in the creation of the RIMPs. This delineation is required because GOES-R operations are to be handed over from the GOES-R Program to NOAA OSPO at the end of the PLT period, yet the process of validating product maturity will continue. This changing nature of accountability during the process must be acknowledged. Accountability of the RIMPs changes at Operations Handover from NASA to NOAA and is aligned with the level of each RIMPs' validation maturity objective. Accountability determines which organization owns documentation, process, and procedures. Responsibility determines which organization creates, executes, and maintains specific activities.

GOES-R Product (L1b and L2+) Maturity Levels

Beta Validation

Preparation Activities
- Initial calibration applied (L1b).
- Rapid changes in product input tables, and possibly product algorithms, can be expected.
- Product quick looks and initial comparisons with ground truth data (if any) are not adequate to determine product quality.
- Anomalies may be found in the product and the resolution strategy may not exist.

End state
- Products are made available to users to gain familiarity with data formats and parameters.
- Product has been minimally validated and may still contain significant errors.
- Product is not optimized for operational use.

Provisional Validation

Preparation Activities
- Validation and quality assurance (QA) activities are ongoing, and the general research community is now encouraged to participate.
- Severe algorithm anomalies are identified and under analysis. Solutions to anomalies are in development and testing.
- Incremental product improvements may still be occurring.
- Users are engaged in the Customer Forums (L2+ products only), and user feedback is assessed.

End state
- Product performance (L1b or L2+) has been demonstrated through analysis of a small number of independent measurements obtained from selected locations, periods, and associated ground-truth/field program efforts.
- Product analysis are sufficient to communicate product performance to users relative to expectations.
- Documentation of product performance exists that includes recommended remediation strategies for all anomalies and weaknesses. Any algorithm changes associated with severe anomalies have been documented, implemented, tested, and shared with the user community.
- Testing has been fully documented.
- Product ready for operational use and for use in comprehensive calibration/validation activities and product optimization.

Full Validation

Preparation Activities
- Validation, QA, and anomaly resolution activities are ongoing.
- Incremental product improvements may still be occurring.
- Users are engaged and user feedback is assessed.

End state
- Product performance for all products is defined and documented over a wide range of representative conditions via ongoing ground-truth and validation efforts.
- Products are operationally optimized, as necessary, considering mission parameters of cost, schedule, and technical competence as compared to user expectations.
- All known product anomalies are documented and shared with the user community.
- Product is operational.

Figure 1. GOES-R product maturity levels.

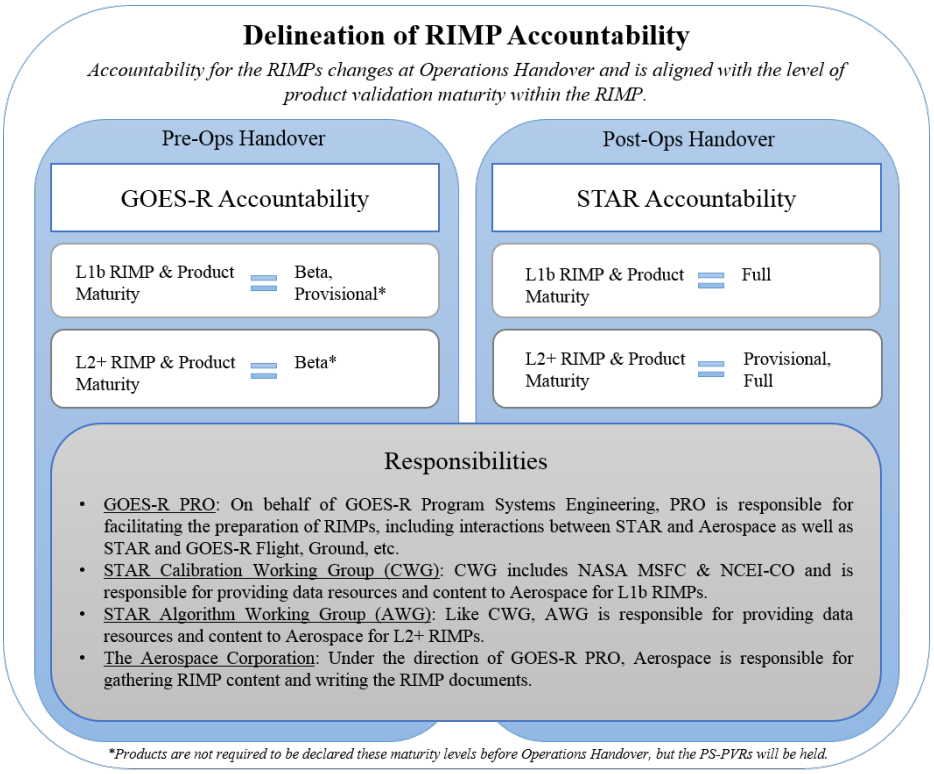

Figure 2. Delineation of accountability between GOES-R and STAR.

1. Land Surface Temperature Validation Overview

This Readiness, Implementation, and Management Plan (RIMP) covers validation stages of the GOES-R Advanced Baseline Imager (ABI) Land Surface Temperature (LST) Level 2 product. There are three stages in the validation process: Beta, Provisional, and Full. Each stage is defined by Post-Launch Product Tests (PLPTs), which guide the overall validation process. The RIMP includes a summary of the methods and tools employed to prove that LST has met a given validation stage. Appendices present more detail on each PLPT and detail on the different data sets employed in the validation of the LST product.

Eight PLPTs test have been defined to attain Beta maturity.[1] The first five events verify that: when the sensor is in Mode 3, the Full Disk (FD), CONUS, and mesoscale products are generated within the expected measurement ranges; and when the sensor is in Mode 4, that FD and CONUS products are within range. Assuming both Mode 3 and Mode 4 data are available, these initial tests will occur in parallel for each mode, and be accomplished during the first week of PLPT. The remaining three Beta tests provide an initial performance assessment in terms of accuracy of the FD, CONUS, and mesoscale products when the sensor is in Mode 3. These performance assessments for Beta maturity get underway in the second week of PLPT, and are conducted in parallel over a 5-week period. The two criteria for declaring Beta maturity are to: quantitatively assess performance with limited set of data available during PLPT; and identify issues with product.

Three tests have been defined to attain Provisional maturity to: assess the performance of the LST products for an expanded number of independent measurements sufficient to address diurnal and cloud cover, but not necessarily seasonal, dependence; and to establish that the products are ready for operational use. The GOES-R operations phase begins at the end of PLPT and marks the start of the three Provisional tests (for FD, CONUS, and mesoscale) which occur concurrently over 24 weeks. While the products do not have to meet accuracy and precision specifications to reach Provisional maturity, if they don't, such rationale must be identified with remediation strategies in place when feasible.

Three tests have been defined to attain Full maturity by further extending the conditions under which the LST product accuracy and precision performance are quantified to include a seasonally representative number of independent measurements. The three Full tests (FD, CONUS, and mesoscale) occur concurrently over a 36 week period at the end of which performance must be shown to meet, or nearly meet, the accuracy and precision specifications in order for the products to have reached Full maturity. If the performance does not meet the specifications, the product can still be declared to have reached Full maturity if the cause is due to non-algorithm errors and the reason is documented. In addition, users must concur Full maturity has been demonstrated.

The PLPTs for all validation stages are identified below and the details are provided in Appendix A.

Beta validation Tests:

- **ABI-FD_LST01:** verify that Mode 3 hourly FD products are within range.
- **ABI-CONUS_LST02:** verify that Mode 3 hourly CONUS products are within range.
- **ABI-MESO_LST03:** verify that Mode 3 hourly mesoscale products are within range.
- **ABI-FD_LST04:** verify that Mode 4 hourly FD products are within range.
- **ABI-CONUS_LST05:** verify that Mode 4 hourly CONUS products are within range.
- **ABI-FD_LST06:** initial assessment of FD product accuracy and precision.
- **ABI-CONUS_LST07:** initial assessment of CONUS product accuracy and precision.

- **ABI-MESO_LST08:** initial assessment of mesoscale product accuracy and precision.

Provisional validation Tests:

- **ABI-FD_LST09:** FD product accuracy and precision assessment.
- **ABI-CONUS_LST10:** CONUS product accuracy and precision assessment.
- **ABI-MESO_LST11:** mesoscale product accuracy and precision assessment.

Full validation Tests:

- **ABI-FD_LST12:** FD product accuracy and precision assessment.
- **ABI-CONUS_LST13:** CONUS product accuracy and precision assessment.
- **ABI-MESO_LST14:** mesoscale product accuracy and precision assessment.

The following Table identifies the frequency of each scan type for Modes 3 and 4. It includes the required cadence of the LST product as defined by both the GOES-R Functional and Performance Specification (F&PS) and the Product User's Guide (PUG). The bottom line reflects, for each appropriate scan type, the frequency of that product used for verification purposes.

**There is no CONUS scan type for Mode 4, but required CONUS products are derived from the FD output*

Mode	Mode 3			Mode 4		
Scan Type	FD	CONUS	Meso	FD	CONUS	Meso
Freq	15 min	5 min	30 sec	5 min	5 min*	N/A
LST – F&PS Freq	60 min	60 min	60 min	60 min	60 min	N/A
LST – PUG Freq	60 min	60 min	60 min	60 min	60 min	N/A
LST Verification Freq	Random sampling	Random sampling	Random sampling	Random sampling	Random sampling	NA

Table 1. LST product and verification cadences.

Validation data include: SURFace RADiation Budget (SURFRAD) in-situ observations, Suomi National Polar-orbiting Partnership (SNPP) Visible Infrared Imaging Radiometer Suite (VIIRS) LST product, with Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua LST as a fall back. A weekly or monthly emissivity data set generated at Center for Satellite Applications and Research (STAR) will be used in deriving the relevant parameters from the SURFRAD reference data for comparison. During the Provisional and Full validation analysis periods, field campaign data will be used if available. The details of the validation reference data are provided in Appendix B.

2. Schedule of Events

Figure 3 shows the GOES-R validation schedule. System Performance Operation Test (SPOT) begins 44 days after launch when ABI L1b and the L2 Cloud and Moisture Imagery (CMI) Key Performance Beta evaluation begins and these data should be declared Beta maturity by L+87 days. One day later, the GOES Rebroadcast (GRB) will be populated with that data. The L2 products must reach Beta maturity by handover at L+197 days, the same time that ABI L1b and CMI reach Provisional. Given that L2 Beta tests require at least 6 weeks, L2 Beta testing must get underway by L+155 days, but can begin as soon as the ABI L1b and CMI reach Beta (L+87 days).

The GOES-R operations phase begins after handover marking the start of a 12 month Extended Validation period for ABI L1b and CMI, which is coincident with the start of the 6 month L2 Provisional evaluation, followed by another nine months period for L2 products to reach Full maturity, 15 months after handover.

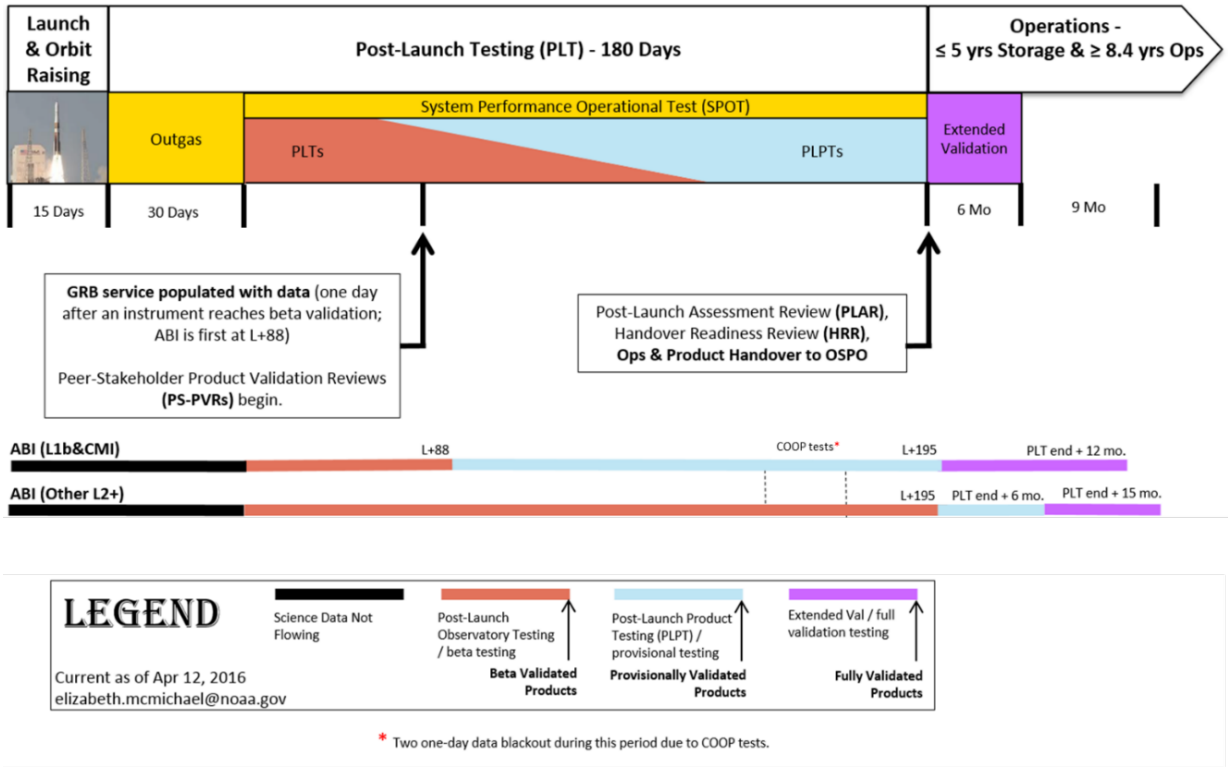

Figure 3. Schedule of events.

3. Roles and Responsibilities

3.1 Primary Point of Contact

The primary point of contact (POC) for leading the LST validation effort is Yunyue Yu.[2]

3.2 GOES-R Point of Contact

The primary POC at GOES-R for the LST validation effort is Wayne MacKenzie.

3.3 Test Analyst/Engineer

Peng Yu is the primary test analyst.

3.4 GOES-R Feedback

Formal feedback to the GOES-R Program regarding the LST validation will be provided by Jaime Daniels.

3.5 Level of Effort

Yunyue Yu will coordinate with the Calibration Working Group (CWG) to keep abreast of ABI L1b status and relay any potential issues resulting from the LST analysis. He is also responsible for coordinating, through the Algorithm Working Group (AWG), with the GOES-R L2 cloud mask, water vapor leads on status and/or issues with these LST dependent upstream products.

Peng Yu is responsible for tool development which is 90% complete and tested with Data Operations Exercise (DOE) test data sets. A small effort (0.2FTE over 4 weeks) remains to add and test a capability to routinely access, store, and process the 4-level cloud mask interim product.

For the 1st week, 0.4 x 5 = 2.0 FTE is needed; for the following five weeks, it should be 0.667 x 3 = 2 FTE effort, which includes full time from Peng Yu, half time from Yuhan Rao, and another half time FTE is going to be recruited.[1] This 2 FTE level of effort is expected to continue throughout the Provisional and Full validation assessments after handover.

4. Tools

For the LST validation, one tool—Landval—will be used. Landval is a set of Interactive Data Language (IDL) functions and procedures. Automated IDL routines perform co-location/-time match ups, additional cloud filtering, and visualization.[3] The components of Landval are comprised of a preprocessing module and a validation module. The pre-processing module includes data readers (satellite, ground-truth/reference, ancillary) and spatial and temporal collocation. The validation module is an interactive capability (with a Graphical User Interface (GUI) option) that enables additional cloud filtering, and the generation and output of comparison statistics and graphics. Details of this tool can be found in Appendix C.

5. Analysis Methods

The validation strategy is to discriminate between the multiple sources of error through the use of real time reference data from other satellite products to identify problem cascades (instrument noise > cloud detection > LST) and to quantify performance by comparison to ground truth observations.[4] Some research error budget analysis might be initiated during PLPT, though it is not required to declare Beta maturity. For the most part this type of performance analysis will get underway during the Provisional and Full validation assessments after handover.

5.1 Inspection

Automated processing determines if all valid retrieval values from the three (FD, CONUS, and mesoscale) LST products are within the required LST retrieval range.

5.2 Routine Analysis

The tool will be used to routinely acquire matchup data sets with stringent cloud filtering, and to make multiple direct and indirect comparisons: satellite vs. satellite and satellite vs. ground station.

The validation relies highly in the cloud filtering step. Under different cloud conditions, the LST performance varies with uncertainty of cloud contamination, which can easily lead to a difference of 10-20 K between the LST retrieval and its in-situ counterpart. For precise validation results, the cloud mask information of clear and probably clear must be differentiated; however, the LST and Clear Sky Mask outputs contain only binary cloud/no cloud information. Access to the 4-level indication of presence/absence of clouds, an interim product generated by the ABI Cloud Mask Algorithm, is needed.

The satellite to satellite comparisons are used to provide a comparative assessment while the ground SURFRAD data serves as truth data. The accuracy and precision specifications for the FD product are the same as for the CONUS, so similar validation procedures will be applied to it. However, as explained in the GOES-R LST Algorithm Theoretical Basis Document (ATBD)[6], since extra aggregation process is involved in the generation of the FD product, additional error may be introduced which might have a negative impact on both the FD accuracy and precision. In particular, when in-situ point observations are compared with the coarse resolution satellite LST, it is more difficult for the SURFRAD measurements to be representative of the 10 km by 10 km FD satellite pixel. On the other hand, mesoscale LST covers such a small area and it is unlikely to cover any of the SURFRAD ground stations. One option to mitigate the risk is to validate it through FD product, since it is a small portion of the FD, though the resolution is different. The match-up and cloud filtering process is illustrated in Figure 4.[4]

The GOES-R algorithm was designed to input GOES-R emissivity, but that product will likely not be available, so the default is the emissivity product being developed by the LST AWG. If that is not available, the fall back will be the CIMSS (MODIS) ancillary data set. Direct comparison statistics from each SURFRAD site will be generated throughout the validation as routine monitoring output. Changes that appear in the the observed differences between satellite and surface LST will serve as an “early warning” indicator of problems that warrant deep dive analysis.

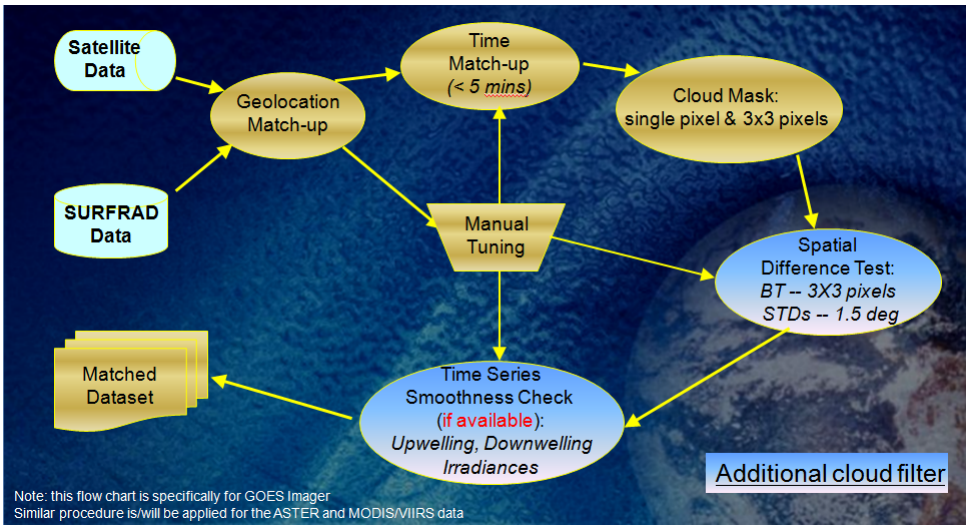

Figure 4. Matchup and cloud filtering process.

5.3 Deep Dive Analysis

Deep dive analyses will be conducted when a more detailed analysis is warranted based on routine monitoring results; however, deep-dive processes are mostly geared toward calibrating for algorithm coefficients and testing of different retrieval algorithm(s) for potential algorithm improvement (e.g., calibrating the algorithm coefficients).[4] Using automated and interactive components of the deep dive tool, which is an expansion of the routine monitoring software, the analysis will accomplish detailed point analyses which may later involve multiple years of clear radiances coincident with ground LSTs. Indirect comparisons might be made for selected ground site vs. ground site climatology over years. While very limited deep dive analyses might be conducted during PLPT, this analysis procedure will primarily be used during the program operational phase for the Provisional and Full validation assessments.

6. Output Artifacts

6.1 Beta Maturity Artifacts

A Beta report will be provided documenting issues and summarizing the qualitative assessment of the product, including time series plots of satellite LST retrieval, its in-situ counterpart, and the difference between the two for selected coincident LST and ground LST resulting from routine validation monitoring during PLPT. Suggestions for algorithm improvements might be included, though it is unlikely that algorithm coefficient updates will be produced during Beta PLPTs.

6.1.1 All Beta tests listed in Appendix A are priority 1 which means their success criteria must be met to reach Beta maturity.

6.1.2 The Beta maturity validation effort does not include any priority 2 tests.

6.2 Provisional Maturity Artifacts

At the conclusion of the Provisional validation stage, results will be presented at Peer Stakeholder - Product Validation Reviews (PS-PVRs) detailing the methods used and the product performance results in terms of accuracy and precision of LST out to at least 70 degrees Local Zenith Angle (LZA) over a large and wide range of representative conditions, stratified by geographic area, time of day, and clear vs. various levels of cloud cover, etc. If the product does not meet a performance specification, the reason will be documented along with remediation strategies. Algorithm changes made, in work, and/or recommended, to include tuning and coefficient updates will be described and challenges with upstream dependencies will be identified. Finally, the Provisional validation presentations will include a summary of user feedback received during the respective validation periods.

6.2.1 All Provisional tests listed in Appendix A are priority 1 – their success criteria must be met to reach Provisional maturity.

6.2.2 The Provisional maturity validation effort does not include any priority 2 tests.

6.3 Full Maturity Artifacts

At the conclusion of the Full Maturity validation stage, results will be presented at Peer Stakeholder - Product Validation Reviews (PS-PVRs) covering the same information as reported at the Provisional PS-PVR, but with the inclusion of seasonal stratification of the results.

6.3.1 All Full tests listed in Appendix A are priority 1 – their criteria must be met to reach the Full validation stage.

6.3.2 The Full maturity validation effort does not include any priority 2 tests.

6.4 Key artifacts

The key artifact for the LST validation effort is the statistical analysis of accuracy and precision which will be covered in the Beta report and the Provisional and Validated presentations described above.

6.5 More Output Artifacts

There are no other artifacts besides those noted in sections 6.1 through 6.4.

6.6 Delivery Schedule

The delivery schedule of artifacts for the LST validation effort is tied to the schedule for completing beta, provisional, and full validation as given in section 2. All statistical analysis necessary to prove a given validation stage will be included in a power point presentation in time for the appropriate PS-PVR.

7. Pre-launch

The ABI algorithm has been tested with SURFRAD in-situ observations using data from SNPP VIIRS, MODIS Aqua and Terra, and MSG SEVIRI as proxies. The routine validation tool to validate the ABI retrieval using proxy with SURFRAD data has been completed. The automated system to validate the GOES data as GOES-R proxy has been completed. The tool has also been adapted to enable processing of the CIMSS MODIS global emissivity data set; allow inter-sensor comparison between GOES-R LST proxy (GOES and Himawari AHI) and LST from the reference VIIRS and MODIS data. Validation of the tool capability to ingest GOES-R data format was accomplished using test data from Data Operations Exercises (DOEs). Pre-launch work remaining includes developing the capability to routinely access, store, and process the GOES-R 4-level cloud mask interim product and conducting additional tool testing as more DOE data sets are made available.

8. References

The references listed below were used to generate this document, augmented with written and/or verbal feedback with the STAR product team. Superscripts are invoked within the text of this document to indicate a reference that can provide additional detail for the reader.

[1] PLPT_VE_List_L2_v1_0_20141022.xlsx.
[2] GOES-R Series Ground Segment Project Algorithm Change Management Plan, G416-R-ALGCMP-0285.
[3] L2 Product Validation Tools_05-12-2015.xlsx.
[4] CV Workshop charts: Application_Team_Validation_LST_v1.ppt.
[5] GOES-R F (MRS), 410-R-MRD-0070, Version 3.17.
[6] GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Land Surface Temperature.

A. Appendix A: Validation Events

A.1 PLPT Events that Support Beta Maturity

A.1.1 ABI-FD_LST01:

Objective: Verify that hourly FD products are within range.
Start Time: Start of PLPT.
Duration: 1 week.
ABI Mode: Mode 3.
GOES-R Data Type(s): FD, Band 14 and Band 15.
Beta Success Criteria: LST including Quality Control (QC) are consistent with expectations.
Dependencies: No gross errors in upstream depended products: ABI L1, cloud mask, and water vapor.
PLPT Lead: Yunyue Yu.
PLPT Analyst: Peng Yu, Yuhan Rao, and Jingjing Peng; 0.4 FTE (0.2 + 0.1 + 0.1); person weeks 0.4.
Validation Data: None.
Monitoring and Analysis Method: Product inspection.

A.1.2 ABI-CONUS_LST02:

Same as for ABI-FD_LST01 except for:
Objective: Verify that hourly CONUS products are within range.
GOES-R Data Type(s): CONUS, Band 14 and Band 15.

A.1.3 ABI-MESO_LST03:

Same as for ABI-FD_LST01 except for:
Objective: Verify that hourly LST Mesa products are within range.
GOES-R Data Type(s): Mesoscale, Band 14 and Band 15.

A.1.4 ABI-FD_LST04:

Same as for ABI-FD_LST01 except for:
ABI Mode: Mode 4.

A.1.5 ABI-CONUS_LST05:

Same as for ABI-CONUS_LST02 except for:
ABI Mode: Mode 4.

A.1.6 ABI-FD_LST06:

Same as for ABI-FD_LST01 except for:
Objective: Provide an initial characterization of overall product accuracy and precision.
Start Time: Right after the completion of ABI-CONUS_LST01—ABI-CONUS_LST05.
Duration: 5 weeks.
Beta Success Criteria:

- LST accuracy and precision performance are quantified for as many of the following conditions as the data support during PLPT support:
- Day and night out to at least 70 degrees LZA (qualitative at larger LZA).
- Over specified geographic area.
- The accuracy specification is 2.5 K with known emissivity and atmospheric correction and 80% channel correlation; 5 K otherwise. The precision specification is 2.3 K. Specification compliance is not required to reach Beta maturity.

- Issues with the product are identified.

Dependencies: GOES-R L1b, L2 cloud mask and water vapor, and ancillary emissivity being sufficient quality.
Test Analyst: Peng Yu, Yuhan Rao, and Jingjing Peng; FTE 0.667
Validation Data: SURFRAD in-situ observations will be used as truth; SNPP VIIRS LST product, with MODIS Aqua LST as a fallback will be used as reference data for comparative analysis.
Monitoring and Analysis Method: Routine and deep dive.

A.1.7 ABI-CONUS_LST07:

Same as for ABI-FD_LST06 except for:
GOES-R Data Type(s): CONUS, Band 14 and Band 15.

A.1.8 ABI-MESO_LST08:

Same as for ABI-FD_LST07 except for:
GOES-R Data Type(s): Mesoscale, Band 14 and Band 15.

A.2 PLPT Events that Support Provisional Maturity

A.2.1 ABI-FD_LST09:

Objective: Assess accuracy and precision of FD product for an extended period that includes some but not all seasonal variability, to demonstrate operational readiness (a user decision).
Start Time: at completion of Beta analysis and start of operational phase.
Duration: 24 weeks.
ABI Mode: Mode 3.
GOES-R Data Type(s): FD, Band 14 and Band 15.
Provisional Success Criteria:

- LST accuracy and precision performance are quantified out to at least 70 degrees LZA (qualitative at larger LZA) for a range of representative conditions including time of day and clear vs. various cloud cover. LST accuracy and precision specifications are listed below[5]:
- **Accuracy:** 2.5 K with known emissivity, known atmospheric correction, and 80% channel correlation; 5 K otherwise.
- **Precision:** 2.3 K.
- Performance will be assessed for a range of conditions; however these specifications only apply during daytime, LZA less than 70 degrees, and in clear conditions. Since extra aggregation process is involved in the generation of the FD product, additional error may be introduced which might have a negative impact on FD accuracy and precision. Accuracy and precision do not have to be met to attain Provisional status, however, if they don't, the reasons behind not meeting these specifications must be documented and remediation strategies in place for known issues.
- Impacts from challenges with upstream dependencies are documented.
- User feedback is summarized and documented.
- Product is ready for potential operational use (user decision based on the user's established criteria) and for use in scientific publications to document product performance.

Dependencies: No gross errors in upstream depended products: ABI L1, cloud mask, and water vapor.
PLPT Lead: Yunyue Yu.
PLPT Analyst: Peng Yu, Yuhan Rao, and Jingjing Peng; FTE 0.667.
Validation Data: SURFRAD in-situ observations will be used as truth; SNPP VIIRS LST product, with MODIS Aqua LST as a fallback will be used as reference data for comparative analysis.
Monitoring and Analysis Method: Routine and deep dive.

A.2.2 ABI-CONUS_LST10:

Same as for ABI-FD_LST09 except for:

Objective: Assess accuracy and precision of CONUS product for an extended period that includes some but not all seasonal variability, to demonstrate operational readiness (a user decision).

GOES-R Data Type(s): CONUS, Band 14 and Band 15.

A.2.3 ABI-MESO_LST11:

Same as for ABI-FD_LST09 except for:

Objective: Assess accuracy and precision of mesoscale product for an extended period that includes some but not all seasonal variability, to demonstrate operational readiness (a user decision).

GOES-R Data Type(s): Mesoscale, Band 14 and Band 15.

Validation Data: While the specifications for FD and CONUS apply both day and night, the specs only apply for day with LZA to 67 degrees for the mesoscale product. Since the geographic area of this product is TBD, it is hard to predict if the product will cover at least one of the ground sites used for the validation. In case no in-situ observation is available, the validation will focus on ABI-CONUS_LST10, as this product is a subset of the CONUS product. Otherwise, similar procedures will be carried out as CONUS LST.

A.3 PLPT Events that Support Full Maturity

A.3.1 ABI-FD_LST12:

Objective: Assess accuracy of FD products to characterize accuracy and precision for a wide range of conditions including seasonal variability.

Start Time: At completion of Provisional analysis.

Duration: 36 weeks.

ABI Mode: Mode 3.

GOES-R Data Type(s): FD, Band 14 and Band 15.

Full Success Criteria:

- FD LST accuracy and precision performance are quantified out to at least 70 degrees LZA (qualitative at larger LZA) and stratified by day/night and clear vs. various cloud conditions.
- Product performance meets or is close to meeting accuracy and precision specifications[5]:
- **Accuracy:** 2.5 K with known emissivity, known atmospheric correction, and 80% channel correlation; 5 K otherwise.
- **Precision:** 2.3 K.
- Performance will be assessed for a range of conditions; however these specifications only apply during daytime, LZA less than 70 degrees, and in clear conditions. Since extra aggregation process is involved in the generation of the FD product, additional error may be introduced which might have a negative impact on both the FD accuracy and precision. If a specification is not met, the product can still be declared Full maturity if the cause is due to non-algorithm errors and the reason is documented.
- User concurs with Full maturity.

Dependencies: No gross errors in upstream depended products: ABI L1, cloud mask, and water vapor.

PLPT Lead: Yunyue Yu.

PLPT Analyst: Peng Yu, Yuhan Rao, and Jingjing Peng; FTE 0.667.

Validation Data: SURFRAD in-situ observations will be used as truth; SNPP VIIRS LST product, with MODIS Aqua LST as a fallback will be used as reference data for comparative analysis.

Monitoring and Analysis Method: Routine and deep dive.

A.3.2 ABI-CONUS_LST13:

Same as for ABI-FD_LST12 except for:

Objective: Assess accuracy of CONUS products to characterize accuracy and precision for a wide range of conditions including seasonal variability.

GOES-R Data Type(s): CONUS, Band 14 and Band 15.

A.3.3 ABI-MESO_LST14:

Same as for ABI-FD_LST12 except for:

Objective: Assess accuracy of mesoscale products to characterize accuracy and precision for a wide range of conditions including seasonal variability.

GOES-R Data Type(s): Mesoscale, Band 14 and Band 15.

Validation Data: While the specifications for FD and CONUS apply both day and night, the specs only apply for day with LZA to 67 degrees for the mesoscale product. Since the geographic area of this product is TBD, it is hard to predict if the product will cover at least one of the ground sites used for the validation. In case no in-situ observation is available, the validation will focus on ABI-CONUS_LST13 as this product is a subset of the CONUS product. Otherwise, similar procedures will be carried out as CONUS LST.

B. Appendix B: GOES-R and Validation Reference Data

B.1 Data Set #1: SURFRAD

Description: U.S. SURFRAD; radiometer measuring broadband radiation every minute; available within a day or two of observation.
Instrument calibrated annually and well maintained; American Standard Code for Information Interchange (ASCII) format. Hourly SURFRAD climatology will also be used.[5]
Storage Location: U.S. Surface Radiation Network: http://www.esrl.noaa.gov/gmd/grad/surfrad/ which links to the data archiving FTP site at ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/.
Access Process: 332 MB/station. The data will be downloaded from the FTP site on a daily basis and stored in local storage.
POC: TBD
Spatial Coverage: 7 stations.
Temporal Coverage: Measurements every minute accessed every 30 min; climatology: hourly.
Contingency: High likelihood of availability. High impact if not available. Based on the previous analysis, this network is required for the LST validation purpose, and cannot be replaced by other data set. We have been using data from this source for a few years and our past experience indicated that it is very reliable. If it were not available, the performance assessments would be provided in terms of comparative analysis between GOES-R LST and that from VIIRS and MODIS.

B.2 Data Set #2: SNPP VIIRS LST Product

Description: VIIRS LST has is a moderate spatial resolution (750 m at nadir) product measured during the satellite over-pass times both day and night.
Storage Location: Comprehensive Large Array-data Stewardship System (CLASS) http://www.nsof.class.noaa.gov/saa/products/welcome).
Access Process: 139 GB. The primary way to access it is through STAR Central Data Repository (SCDR) within STAR, the fallback plan is via NOAA CLASS. The data will be accessed on a daily basis and data for one day will be stored at the local storage.
POC: TBD
Spatial Coverage: Global.
Temporal Coverage: Daily.
Contingency: High likelihood of availability. High impact if not available. MODIS data will be the replacement if there are availability issues with VIIRS.

B.3 Data Set #3: EOS/MODIS

Description: MODIS LST product and a CIMSS emissivity ancillary data set based on MODIS monthly emissivities. This MODIS LST is a fallback data set for inter-sensor comparison if VIIRS LST data are not available for optional comparative analysis.
Storage Location: NASA Distributed Active Archive Center (DAAC): ftp://ladsftp.nascom.nasa.gov/
Access Process: 50 GB/day. It is accessed to the File Transfer Protocol (FTP) server provided by NASA. The data will be accessed on a daily basis and data for one day will be stored at the local storage.
POC: TBD
Spatial Coverage: Global.
Temporal Coverage: Coverage every 1-2 days.
Contingency: Medium likelihood of availability. Medium impact if not available.

B.4 Data Set #4: Field Campaign

Description: Near surface NOAA UAS hyperspectral and filtered IR radiometer LST observations
Storage Location: TBD
Access Process: TBD
POC: TBD
Spatial Coverage: Desert (e.g. White Sands), Vegetation (ARM site)
Temporal Coverage: ~6 week field campaign (~100 flight hours) Apr – Jun 2017
Contingency: None - no impact. L2 product validation is a secondary objective of the GOES-R Field campaign scheduled about 8 months after launch. If the data are made available they will be used in LST validation.

C. Appendix C: Tools

C.1 Tool #1: "Landval" Interactive Data Language (IDL) routine and deep dive validation tool.

Location: STAR.

Description: The components of the Landval validation tool are depicted in Figure 6.[4] Automated IDL routines perform co-location/-time match ups, additional cloud filtering, and visualization.[3] The components of Landval are comprised of a preprocessing module and a validation module. The pre-processing module includes data readers (satellite, ground-truth/reference, ancillary) and spatial and temporal collocation. The validation module is an interactive capability (with a Graphical User Interface (GUI) option) that enables additional cloud filtering and the generation and output of comparison statistics and graphics.

Developer: Landval/Peng Yu.

Development Schedule: The GOES-R LST and SNPP VIIRS LST inter-sensor comparison component will be treated as a stand-alone system. The component has been tested with proxy and DOE test data sets, but not all the validation tasks can be anticipated pre-launch; once data is flowing post launch, the need for other capabilities might be identified and incorporated.

For deep dive analyses, Landval has been expanded to: handle data sets consisting of multiple years of clear radiances coincident with ground LSTs and the validation results will be used to calibrate LST algorithm coefficients if needed. Functionality to support deep-dive analysis is incorporated into the routine validation tools, but will be exercised primarily during the Provisional and Full assessment periods.

Data Dependencies: SURFAD, MODIS, and VIIRS LST products. GOES-E and W LST will be used as a proxy data set for testing routine monitoring functions.

Testing Accomplished or Planned: Tools to routinely validate GOES-R LST with in-situ observations have been completed. The ABI algorithm has been tested with SURFRAD in-situ observations using data from SNPP VIIRS, MODIS Aqua, MODIS Terra, and Meteosat Second Generation (MSG) Spinning Enhanced Visible and Infrared Imager (SEVIRI) as proxy. Testing of Himawari Advanced Himawari Imager (AHI) data as ABI proxy has also been carried out. Pre-launch Data Operations Exercise (DOE) test data will be used to make sure tools can read in real GOES-R LST data with diagnostics from the ground system. While DOE data is exact format, real brightness temperature values might be unrealistic, so the need for additional tool check out once real data is flowing is anticipated.

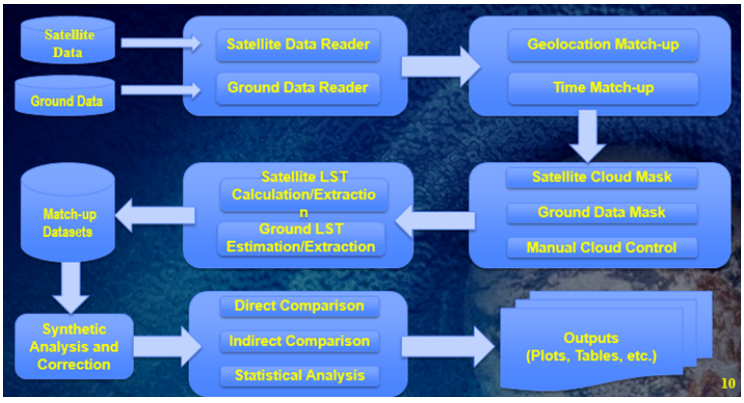

Figure 5. Components of Validation Tools.

D. Appendix D: Acronyms

Acronym	Definition
ABI	Advanced Baseline Imager
AHI	Advanced Himawari Imager
ASCII	American Standard Code for Information Interchange
AWG	Algorithm Working Group
Cal/Val	Calibration and Validation
CCR	Configuration Change Request
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CLASS	Comprehensive Large Array-data Stewardship System
CMI	Cloud and Moisture Imagery
CONUS	Continental United States
CWG	Calibration Working Group
DAAC	Distributed Active Archive Center
DOE	Data Operations Exercise
EOS	Earth Observing System
FD	Full Disk
F&PS	Functional and Performance Specification
FTE	Full-Time Equivalent
FTP	File Transfer Protocol
GOES	Geostationary Operational Environmental Satellite
GOES-E	GOES-East
GOES-R	GOES R-Series
GOES-W	GOES-West
GORWG	GOES-R Series Operational Requirements Working Group
GRB	GOES Rebroadcast
GUI	Graphical User Interface
HRR	Handover Readiness Review
IDL	Interactive Data Language
L1b	Level 1b
L2	Level 2
LST	Land Surface Temperature
LZSS	Level Zero Storage Solution
MODIS	Moderate Resolution Imaging Spectroradiometer
MOST	Mission Operations Support Team
MRD	Mission Requirements Document
MRS	Mission Requirements Specification
MSFC	Marshall Space Flight Center
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration

Acronym	Definition
NCEI	National Centers for Environmental Information
NCEI-CO	NCEI - Colorado
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OSPO	Office of Satellite and Product Operations
PLAR	Post-Launch Assessment Review
PLPT	Post-Launch Product Test
PLT	Post-Launch Test
POC	Point of Contact
PRO	Product Readiness and Operations
PSE	Program System Engineering
PS-PVR	Peer Stakeholder-Product Validation Review
PUG	Product User's Guide
QA	Quality Assurance
QC	Quality Control
RIMP	Readiness, Implementation and Management Plan
SCDR	STAR Central Data Repository
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SNPP	Suomi National Polar-orbiting Partnership
SPOT	System Performance Operational Test
STAR	Center for Satellite Applications and Research
SURFRAD	Surface Radiation Budget
TBD	To Be Determined
VIIRS	Visible Infrared Imaging Radiometer Suite