Geostationary Operational Environmental Satellite (GOES) – R Series

ABI L2+ Total Precipitable Water (TPW) Beta, Provisional and Full Validation Readiness, Implementation and Management Plan (RIMP)

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ABI L2+ Total Precipitable Water (TPW)
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.

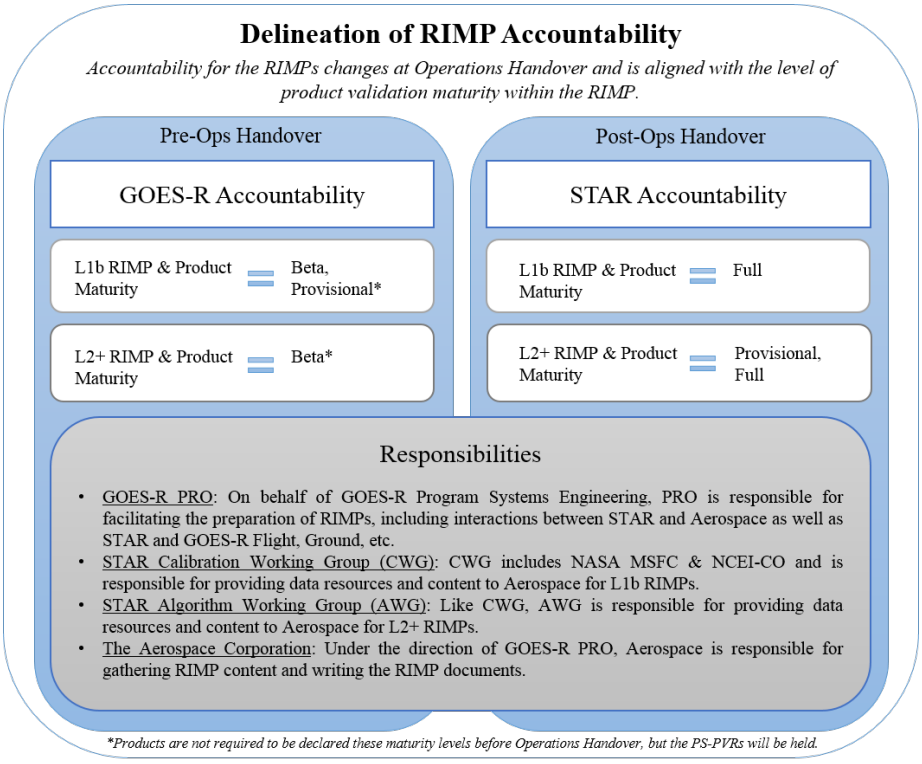

Figure 2. Delineation of accountability between GOES-R and STAR.

1. Total Precipitable Water Validation Overview

This Readiness, Implementation, and Management Plan (RIMP) covers all validation stages of the GOES-R Advanced Baseline Imager (ABI) Total Precipitable Water (TPW) Level 2 product. TPW is the integrated amount of atmospheric water vapor contained in a vertical column. There are three stages in the validation process, Beta, Provisional, and Full. Each stage is defined by Post-launch Product Tests (PLPT), which guide the overall validation process. The RIMP includes a summary of the methods and tools employed to prove TPW has met a given validation stage. Feedback from the NWS will be provided through the PS-PVR process. Other forums are being considered, but are TBD at this time. Appendices are included that present more detail on each test and detail on the different data sets employed in the validation of the TPW product. The TPW validation effort has no identified need for data from a North/South (N/S) scan. Data from field campaigns is not required for TPW validation, but high spectral IR measurements, such as from the Scanning High-resolution Interferometer Sounder, and radiosondes from field campaigns would be used if available.

Beta tests of TPW will involve quantitative comparisons between the TPW data product and various truth data sources, to validate the reasonableness of the data products. A primary source of truth data for Beta will be Numerical Weather Prediction (NWP) short-term forecasts used to initialize the TPW algorithm. While not an independent source of truth data or as high accuracy as other sources of truth data, NWP will be available for comparison with every TPW output and will be sufficient to assess the reasonableness of the data products. Comparisons may also be made to additional independent sources of truth data, including conventional radiosondes within GOES-R coverage, ground based GPS over the CONUS, and the Advanced Microwave Scanning Radiometer 2 (AMSR2) over surrounding ocean of CONUS.

The TPW product has eight PLPTs with identified success criteria for Beta maturity. Five of these tests are verifications that various products are generated at the required frequency (see Table 1 below). The other three Beta test events are an initial assessment of the accuracy and precision of the FD, CONUS, and mesoscale data products when the sensor is in Mode 3.[1] Validation of product generation test events are scheduled for 1 week, while the assessment of product accuracy and precision test events are scheduled for 5 weeks. All Beta maturity test events for TPW are scheduled to start simultaneously. PLPT events that support Beta maturity are listed below; details are in Appendix A:

- **ABI-FD_TPW01:** verify that TPW products generated at the required cadence for FD for cloud-free areas while in ABI Mode 3 fall within the expected measurement range.
- **ABI-CONUS_TPW02:** verify that TPW products generated at the required cadence for CONUS for cloud-free areas while in ABI Mode 3 fall within the expected measurement range.
- **ABI-MESO_TPW03:** verify that TPW products generated at the required cadence for mesoscale for cloud-free areas while in ABI Mode 3 fall within the expected measurement range.
- **ABI-FD_TPW04:** verify that TPW products generated at the required cadence for FD for cloud-free areas while in ABI Mode 4 fall within the expected measurement range.
- **ABI-CONUS_TPW05:** verify that TPW products generated at the required cadence for CONUS for cloud-free areas while in ABI Mode 4 fall within the expected measurement range.
- **ABI-FD_TPW06:** assess the accuracy of TPW products generated for FD in ABI Modes 3 and 4 for a very limited (i.e. not seasonally representative) number of independent measurements to convey an initial characterization of product accuracy to the user community.
- **ABI-CONUS_TPW07:** assess the accuracy of TPW products generated for CONUS in ABI Mode 3 for a very limited (i.e. not seasonally representative) number of independent measurements to convey an initial characterization of product accuracy to the user community.

- **ABI-MESO_TPW08:** assess the accuracy of TPW products generated for mesoscale in ABI Mode 3 for a very limited (i.e. not seasonally representative) number of independent measurements to convey an initial characterization of product accuracy to the user community.

The following Table identifies the frequency of each scan type for Modes 3 and 4. It includes the required cadence of the TPW products as defined by both the GOES-R Functional and Performance Specification (F&PS)[7] and the Product User's Guide (PUG)[10]. The PUG is a forward-looking document and may not match the F&PS. The TPW team will validate to whatever cadence TPW products are derived.

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

Mode	Mode 3			Mode 4		
Scan Type	FD	CONUS	Mesoscale	FD	CONUS	Mesoscale
Scan Freq	15 min	5 min	30 sec	5 min	5 min*	N/A
F&PS	60 min	30 min	5 min	60 min	30 min	N/A
PUG	15 min	5 min	5 min	5 min	5 min	N/A

Table 1. Total Precipitable Water documented product and verification cadences

Provisional tests of TPW will involve quantitative comparisons between the TPW data product and various truth data sources, to provide an initial statistical assessment of data accuracy and precision. Numerical Weather Prediction (NWP) short-term forecasts used to initialize the TPW algorithm will continue to be used, although these are not truly independent data sets. For Provisional maturity, a greater emphasis will be placed on comparisons to additional independent sources of truth data, including conventional radiosondes within GOES-R coverage, ground based GPS over the CONUS, and AMSR2 over surrounding ocean of CONUS.

Three additional tests have been defined to attain Provisional maturity. The success criteria for the Provisional tests are that the TPW product, generated over a large and wide range of representative (except seasonally representative) conditions for all required modes (see Table 1 for cadences), are:

1) Assess sufficiently to characterize its accuracy and precision as well as the product limitations and to identify the potential fixes and improvements needed to satisfy the F&PS specifications.

2) Establish needed fixes to the ABI sensor performance for the TPW product to be ready for operational use.

3) Establish needed fixes to the TPW algorithm for the product to be ready for operational use. Provisional events are planned to begin at the end of the PLPT, immediately after Beta maturity has been obtained and last 24 weeks.

PLPT events that support Provisional maturity are listed below; details are in Appendix A:

- **ABI-FD_TPW09:** assess the accuracy and precision of TPW product generated for FD in ABI Modes 3 and 4 for an extended period that includes some but not all seasonal variability, to facilitate user decision on operational readiness.
- **ABI-CONUS_TPW10:** assess the accuracy and precision of TPW product generated for CONUS in ABI Mode 3 for an extended period that includes some but not all seasonal variability, to facilitate user decision on operational readiness.
- **ABI-MESO_TPW11:** assess the accuracy and precision of TPW product generated for mesoscale in ABI Mode 3 for an extended period that includes some but not all seasonal variability, to facilitate user decision on operational readiness.

Full maturity tests of TPW will involve quantitative comparisons between the TPW data product and various truth data sources over an extended period of time, to provide a statistical assessment of data accuracy and precision. Numerical Weather Prediction (NWP) short-term forecasts used to initialize the TPW algorithm, conventional radiosondes within GOES-R coverage, ground based GPS over the CONUS, and AMSR2 over surrounding ocean of CONUS will continue to be used. Additional sources of independent ground truth, such as radiosondes from ARM sites, microwave radiometer data from ARM sites, and European Centre for Medium-Range Weather Forecasts (ECMWF) analyses will also be used.

Three tests have been defined to attain Full maturity. The success criteria for the Full tests are that the TPW product meets accuracy and precision specifications for a large and wide range of representative conditions (i.e., seasonal) over a period of at least a year for all required modes. Full tests are planned to begin after PLPT, immediately after the completion of Provisional PLPTs and last 36 weeks.

PLPT events that support Full maturity are listed below; details are in Appendix A:

- **ABI-FD_TPW12:** assess the accuracy and precision of TPW products generated for FD in ABI Modes 3 and 4 for an extended period of at least one year that includes seasonal variability, to facilitate user decision on operational readiness.
- **ABI-CONUS_TPW13:** assess the accuracy and precision of TPW products generated for CONUS in ABI Mode 3 for an extended period of at least one year that includes seasonal variability, to facilitate user decision on operational readiness.
- **ABI-MESO_TPW14:** assess the accuracy and precision of TPW products generated for mesoscale in ABI Mode 3 for an extended period of at least one year that includes seasonal variability, to facilitate user decision on operational readiness.

The validation processes and procedures, monitoring and analysis methods, tools, and expected output artifacts are described in the following sections. The details of each test are contained in Appendix A and of each reference data set are 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 should be declared Beta maturity by L+87. One day later, the GOES Rebroadcast (GRB) will be populated with that data. The L2 product must reach Beta maturity by Handover at L+197, the same time that ABI L1B and CMI must reach Provisional. Given that L2 Beta tests require at least 6 weeks, L2 Beta testing must get underway by L+155, but can begin as soon as the ABI L1B and CMI reach Beta (L+87).

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 month period for the L2 products to reach Full maturity, 15 months after Handover. TPW validations are expected to require the entire allocated period.

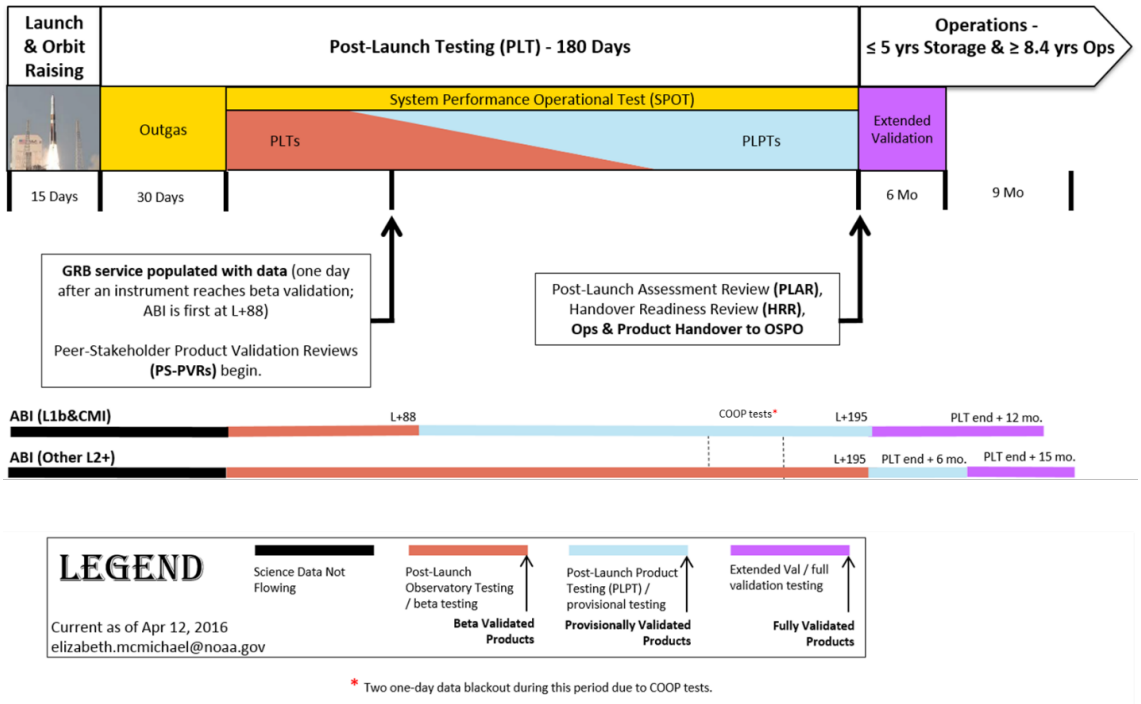

Figure 3. Schedule of events.

All Beta TPW tests will commence at the start of PLPT and progress in parallel. Inspection of TPW products to ensure data are produced at the specified cadence in each mode and will be the responsibility of OSPO personnel and any failures will be reported to the product analyst. In parallel, the product analyst will perform checks that the data outputs are within the expected range and begin initial quantitative assessments of TPW quality. These quality assessments continue over the first five weeks of PLPT. Comparisons will be made on an ongoing basis with summaries made approximately weekly, so as to identify unreasonable data products as early in PLPT as possible. Provisional TPW validation events are planned to begin at the end of the PLPT period, immediately after the Beta evaluation events are complete, and they are planned to last 24 weeks. Finally, Full TPW validation events will be carried out immediately after the Provisional stage for another 36 weeks.

3. Roles and Responsibilities

3.1 Primary Point of Contact

The primary point of contact (POC) for managing the TPW validation effort and coordinating algorithm updates is Tim Schmit, with Jun Li (CIMSS) as secondary POC.

3.2 GOES-R Point of Contact

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

3.3 Test Analyst/Engineer

The test analyst is Yong-Keun Lee. If Yong-Keun Lee is unavailable, the primary backup analyst is Zhenglong Li.

3.4 GOES-R Feedback

Formal feedback to the GOES-R program regarding TPW products will be provided by the TPW product lead Tim Schmit.

3.5 Level of Effort

The first five product generation Beta TPW tests (checking that TPW values are within range) are each budgeted 0.08 FTE (0.08 person-weeks), for a total of 0.4 FTE (0.4 person-weeks).

The remaining three product assessment tests, to be worked in parallel over the first five weeks, are each budgeted 0.13 FTE (0.65 person-weeks), for a total of 0.39 FTE (1.95 person-weeks). Note that the same analyst is responsible for nearly identical tasks for the Derived Stability Indices data products, with identical allotments of time. Thus the total LAP commitment for this analyst during PLPT is nearly 0.8 FTE per week for six weeks.

The TPW Provisional tests should be budgeted for 0.4 FTE (0.4 person-weeks) per week, for a total of 9.6 FTE (9.6 person-weeks). In addition to the TPW Provisional test, this analyst will be the analyst for the DSI Provisional tests, budgeted for the same effort. Therefore the total commitment for this analyst during the Provisional stage is 0.8 FTE (0.8 person-weeks) per week, for a total of 19.2 FTE (19.2 person-weeks).

The TPW Full tests should be budgeted for 0.4 FTE (0.4 person-weeks) per week, for a total of 14.4 FTE (14.4 person-weeks). In addition to the TPW Full tests, this analyst will be the analyst for the DSI Full tests, budgeted for the same effort. Therefore the total commitment for this analyst during the Full stage is 0.8 FTE (0.8 person-weeks) per week, for a total of 28.8 FTE (28.8 person-weeks).

4. Tools

The TPW validation effort utilizes a set of two tools: colocation and statistical analysis. The colocation tool compares Latitude, Longitude and time between TPW data and "truth" data sets to establish matched pairs of data for comparison. The statistical analysis tool will calculate bias, standard deviation, and RMS error between truth data sets and collocated ABI TPW products as well as visualization tools for such comparisons. Each of these tools is detailed in Appendix C.

5. Analysis Methods

There are 3 analysis methods used for the PLPTs which are listed below.

Only the first two of the listed Visualization and Software Tools are likely to be used during Beta of the TPW. The other Tools will be required for later stages of product validation. Similarly, the only Datasets used during Beta will be NWP forecast used in the LAP retrieval, Radiosondes (conventional), AMSR2 TPW over oceans, GPS-Met TPW, and ABI IR brightness temperatures.

5.1 Routine Analysis[4]

Capabilities: Monitoring the quality of TPW products in near-realtime.

Datasets used: NWP forecast used in the LAP retrieval; Radiosondes (conventional); ABI IR brightness temperatures.

Visualization and Software Tools:

- Animation of RTVL images (TPW).
- Animation of FCST images (TPW).
- Animation of difference (RTVL-FCST) images (TPW).
- Time series of TPW from GOES-R RTVLs, FCSTs, and GPS sites for single location.
- Statistics of retrievals against conventional radiosondes.
- Statistics of retrievals against GPS-Met TPW.
- Statistics of retrievals against AMSR2 over ocean.
- Monitor Product quality.

5.2 Deep-Dive Validation Tools[4] (Not used for Beta test events)

Capabilities: Monitor any anomalies of any GOES-R LAP product and identify the cause. Quantify the error/uncertainty of GOES-R LAP products for better applications.

Datasets used: Radiosondes (conventional); ABI IR brightness temperatures;

Visualization and Software Tools:

- Full and/or zoomed difference (TPW) between RTVLs and FCSTs images.
- Full and/or zoomed (TPW) RTVL images.
- Full and/or zoomed (TPW) FCST images.
- Vertical (temperature and water vapor) profiles can be shown where both ground truth and retrieval are available.

5.3 Long-term performance Analysis (Not used for Beta test events)

Capabilities: Monitoring the quality of TPW products.

Datasets used: the LAP retrieval; Radiosondes (ARM site); ARM site microwave radiometer TPW; ECMWF analysis.

Visualization and Software Tools:

- Statistics of retrievals against ARM site radiosondes and microwave radiometer.
- Statistics of retrievals against ECMWF analysis.

6. Output Artifacts

6.1 Beta Maturity Artifacts

At the end of the first week of PLPT, the results from the range testing will be summarized in a report that will be made available for review by the Program. During the weeks 2-6 of PLPT the validation results from the Analysis methods in Section 5 will be made available in the Web-based display. The success criterion for Beta is the successful characterization of product accuracy and precision regardless of scene type or season. At the completion of the Beta phase, a report will be prepared and presented detailing the methods used and the results in terms of mean (accuracy), standard deviation (precision), and root mean square, minimum and maximum values and probability distribution will be reported.

6.1.1 These tests of priority 1 all must pass in order to achieve Beta maturity:

- ABI-FD_TPW01
- ABI-CONUS_TPW02
- ABI-MESO_TPW03
- ABI-FD_TPW04
- ABI-CONUS_TPW05
- ABI-FD_TPW06
- ABI-CONUS_TPW07
- ABI-MESO_TPW08

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

6.2 Provisional Maturity Artifacts

The success criteria for the Provisional PLPTs are: 1. the product, generated over a large and wide range of representative (except seasonally representative) conditions for all required frequencies (see Table 1) has been assessed sufficiently to characterize its accuracy and precision as well as the product limitations. 2. Potential fixes and improvements needed to satisfy the Functional and Performance Specification (F&PS) have been identified; 3. Necessary fixes to the ABI sensor performance for the TPW products to be ready for operational use have been established; and 4. Necessary fixes to the TPW algorithms for the products to be ready for operational use have been established.

At the completion of the Provisional analysis, a report will be prepared and presented detailing the methods used and the results in terms of mean (accuracy), standard deviation (precision), and root mean square, minimum and maximum values, and probability distribution will be reported for TPW. Results will be presented showing dependencies on time (diurnal cycle), and region.

6.2.1 The following test of priority 1 must pass in order to achieve Provisional maturity:

- ABI-FD_TPW09
- ABI-CONUS_TPW10
- ABI-MESO_TPW11

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

6.3 Full Maturity Artifacts

The success criteria for the Full PLPTs are that the TPW product meets accuracy and precision specifications for a large and wide range of representative conditions (i.e., seasonal) over a period of at least a year for all required frequencies (see Table 1). Accuracy and precision specifications for each product are described in Appendix A.

At the completion of the Full analysis, a report will be prepared and presented detailing the methods used and the results in terms of mean (accuracy), standard deviation (precision), and root mean square, minimum and maximum values, and probability distribution will be reported for TPW.

Results will be presented showing dependencies on diurnal cycle, region (east or west CONUS, ocean), and season.

6.3.1 The following test of priority must pass in order to achieve Full maturity:

- ABI-FD_TPW12
- ABI-CONUS_TPW13

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

6.4 Key Artifacts

Key artifacts for the TPW validation effort are reports generated at the end of each validation stage.

6.5 More Output Artifacts

None.

6.6 Delivery Schedule

The delivery schedule of artifacts for the TPW validation effort is tied to the schedule for completing beta, provisional, and full validation as given in section 2. The generation of reports will the responsibility of the Test Lead, working in conjunction with the Test Analyst.

7. Pre-launch

The following activities have been completed during pre-launch.

- Software tools are 90% Complete. All validation tools have been developed and web tools are now available at http://soundingval.ssec.wisc.edu/.
- Testing of colocation and analysis tools with GOES-R proxy data, Southern Great Plains radiosonde data, CONUS standard radiosonde sites, and archived AMSR-E data from 2011 have been successfully completed.[5] Data Operations Exercises (DOEs) 1, 2, and 3 data have been provided and the TPW team has responded with comments. Additional data from DOE 4 are anticipated by the end of September 2016. Remaining tests of the tools require routine files to be produced and run through the system, staged and accessed by the PDS in real time. Future test data must contain forecast TPW products which are needed in the GOES-R ABI LAP validation tool. Software tools are expected to be fully tested by October 2016.

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] CalValPlan_Vol2_L2_v1-1-draft-redlines_inc-ERB_comments_v2a - Clean - BobEdits.docx.
[3] Derived_LAP_TPW_Stability_Validation_Table_v2_rico.docx.
[4] GOES-R_LAP_Validation_final_final.ppt.
[5] GOES-R_ABI_Validation_Tools_LAP_v1.3.docx.
[6] GOESR-CVCT-PLPT_BriefingToNOAA-IAC_2015-02-03_FINAL.pptx – Shortcut.
[7] GOES-R_GS_FPS.pdf.
[8] GOES-R_Field_Campaign_Plan_IAC_bds.pptx.
[9] MRD_v3_17.pdf.
[10] SE-16_CGS_7035538_PUG_V5_L2_RevD.pdf.

A. Appendix A: Validation Events

A.1 PLPT Events that Support Beta Maturity

A.1.1 Event Name: ABI-FD_TPW01

Objective: Verify that product is generated at the required cadence for FD.
Start Time: Start of PLPT.
Duration: 1 week.
ABI Mode: 3.
GOES-R Data Type(s): Bands 8-16, FD.
Beta Success Criteria: Range assessment results reported. Analyst will inspect products to assess whether product is generated at the required cadence (see Table 1) for FD and falls within expected range (0–100 mm)[7,10]. The monitoring of the product generation cadence will primarily be the responsibility of OSPO (not the test analyst) and the results conveyed to the test analyst. If there are issues with data products not being produced on time or falling outside expected values, a root cause and path forward should be identified prior to Beta being achieved.
Dependencies: Any issues with data access to TPW products will directly impact the schedule of TPW validation activities. Analyst requires access to near-real-time data through PDA.
PLPT Lead: Tim Schmit
PLPT Analyst: Yong-Keun Lee; 0.08 FTE; 0.08 Person weeks
Comparison / Reference Data: None.
Monitoring and Analysis Method: Product inspection.

A.1.2 Event Name: ABI-CONUS_TPW02

Same as for ABI-FD_TPW01, except for:
Objective: Verify that product is generated at the required cadence for CONUS.
GOES-R Data Type(s): Bands 8-16, CONUS.
Beta Success Criteria: Range assessment results reported. Analyst will inspect products to assess whether product is generated at the required cadence (see Table 1) for CONUS and falls within expected range (0–100 mm)[7,10]. The monitoring of the product generation cadence will primarily be the responsibility of OSPO (not the test analyst) and the results conveyed to the test analyst. If there are issues with data products not being produced on time or falling outside expected values, a root cause and path forward should be identified prior to Beta being achieved.

A.1.3 Event Name: ABI-MESO_TPW03

Same as for ABI-FD_TPW01, except for:
Objective: Verify that product is generated at the required cadence for mesoscale.
GOES-R Data Type(s): Bands 8-16, mesoscale.
Beta Success Criteria: Range assessment results reported. Analyst will inspect products to assess whether product is generated at the required cadence (see Table 1) for mesoscale and falls within expected range (0–100 mm)[7,10]. The monitoring of the product generation cadence will primarily be the responsibility of OSPO (not the test analyst) and the results conveyed to the test analyst. If there are issues with data products not being produced on time or falling outside expected values, a root cause and path forward should be identified prior to Beta being achieved.

A.1.4 Event Name: ABI-FD_TPW04

Same as for ABI-FD_TPW01, except for:
ABI Mode: 4.

A.1.5 Event Name: ABI-CONUS_TPW05

Same as for ABI-CONUS_TPW02, except for:
ABI Mode: 4.

A.1.6 Event Name: ABI-FD_TPW06

Objective: Assess accuracy and precision of FD product.
Start Time: Start of PLPT.
Duration: 5 weeks.
ABI Mode: 3 and 4.
GOES-R Data Type(s): Bands 8-16, FD.
Beta Success Criteria: Quantitatively assess performance with limited set of data. Identify issues with TPW product. Document performance and issue in the Beta report.
Dependencies: Any issues with data access to TPW products will directly impact the schedule of TPW validation activities. Analyst requires access to near-real time data through TPW. Any issues with access to Global Forecast System profiles of moisture and temperature will also impact TPW accuracy and precision validation activities.
PLPT Lead: Tim Schmit.
PLPT Analyst: Yong-Keun Lee (primary), 0.13 FTE, 0.65 person-weeks; Zhenglong Li (backup).
Comparison / Reference Data: Numerical Weather Prediction (NWP) inputs to algorithm; NWS Radiosondes; GPS TPW measurements; AMSR2 TPW measurements.[1]
Monitoring and Analysis Method: Colocation tools and statistical analysis tools. Colocation tools will extract TPW data matched in time and space with reference "truth" data. Statistical analysis tools will calculate accuracy and precision metrics relative to reference data.

A.1.7 Event Name: ABI-CONUS_TPW07

Same as for ABI-FD_TPW06, except for:
Objective: Assess accuracy and precision of CONUS product
GOES-R Data Type(s): Bands 8-16, CONUS.
ABI Mode: 3.

A.1.8 Event Name: ABI-MESO_TPW08

Same as for ABI-FD_TPW06, except for:
Objective: Assess accuracy and precision of mesoscale product.
GOES-R Data Type(s): Bands 8-16, mesoscale.
ABI Mode: 3.

A.2 PLPT Events that Support Provisional Maturity

A.2.1 Event Name: ABI-FD_TPW09

Objective: Assess accuracy and precision of FD products for an adequate number of independent measurements to characterize accuracy and precision adequately for the user to determine if the product is ready for operational use.
Start Time: At completion of Beta Analysis and start of Operational phase.
Duration: 24 weeks.
ABI Mode: 3 and 4.
GOES-R Data Type(s): Bands 8-16, FD.
Provisional Success Criteria:

- Accuracy and precision determined over a large and wide range of representative conditions for all required modes. Accuracy and precision requirements do not have to be met to attain Provisional status, however, if they do not do so, the reasons behind not meeting these requirements must be documented

- Accuracy[7,9,10]: 1 mm
- Precision[7,9,10]: 3 mm
- Horizontal Resolution[7,9,10]: 10 km
- Mapping Accuracy[7,9,10]: 2 km

- Remediation strategies are in place for known issues;
- Impacts from challenges with upstream dependencies are documented;
- Feedback from the primary user (NWS) is documented;
- Product is ready for potential operational use (user decision) and for use in scientific publications.

Dependencies: Any issues with data access to TPW products will directly impact the schedule of TPW validation activities. Analyst requires access to near-real time data through TPW. Any issues with access to Global Forecast System profiles of moisture and temperature will also impact TPW accuracy and precision validation activities.
PLPT Lead: Tim Schmit.
PLPT Analyst: Yong-Keun Lee (primary), 0.13 FTE, 3.2 person-weeks; Zhenglong Li (backup).
Comparison / Reference Data: Numerical Weather Prediction (NWP) inputs to algorithm; NWS Radiosondes; GPS TPW measurements; AMSR2 TPW measurements.[1]
Monitoring and Analysis Method: Colocation tools and statistical analysis tools. Colocation tools will extract TPW data matched in time and space with reference "truth" data. Statistical analysis tools will calculate accuracy and precision metrics relative to reference data.

A.2.2 Event Name: ABI-CONUS_TPW10

Same as for ABI-FD_TPW09, except for:
Objective: Assess accuracy and precision of CONUS products for an adequate number of independent measurements to characterize accuracy and precision adequately for the user to determine if the product is ready for operational use.
GOES-R Data Type(s): Bands 8-16, CONUS.
ABI Mode: 3.

A.2.3 Event Name: ABI-MESO_TPW11

Same as for ABI-FD_ TPW09, except for:
Objective: Assess accuracy and precision of mesoscale products for an adequate number of independent measurements to characterize accuracy and precision adequately for the user to determine if the product is ready for operational use.
GOES-R Data Type(s): Bands 8-16, mesoscale.
ABI Mode: 3.

A.3 PLPT Events that Support Full Maturity

A.3.1 Event Name: ABI-FD_TPW12

Objective: Assess accuracy and precision of FD products for an adequate number of independent measurements to characterize accuracy and precision over a range of conditions, including seasonal variability.
Start Time: At completion of Beta Analysis and start of Operational phase.
Duration: 36 weeks.
ABI Mode: 3 and 4.
GOES-R Data Type(s): Bands 8-16, FD.
Full Success Criteria: Accuracy and precision determined over a large and wide range of representative conditions for all required modes. Accuracy and precision requirements should be met to attain Full maturity status. However, if they do not do so, the reasons behind not meeting

these requirements must be documented and remediation strategies must be in place for known issues.

- Accuracy[7,9,10]: 1 mm
- Precision[7,9,10]: 3 mm
- Horizontal Resolution[7,9,10]: 10 km
- Mapping Accuracy[7,9,10]: 2 km

Dependencies: Any issues with data access to TPW products will directly impact the schedule of TPW validation activities. Analyst requires access to near-real time data through TPW. Any issues with access to Global Forecast System profiles of moisture and temperature will also impact TPW accuracy and precision validation activities.
PLPT Lead: Tim Schmit.
PLPT Analyst: Yong-Keun Lee (primary), 0.13 FTE, 4.8 person-weeks; Zhenglong Li (backup).
Comparison / Reference Data: Numerical Weather Prediction (NWP) inputs to algorithm; NWS Radiosondes; GPS TPW measurements; AMSR2 TPW measurements; ARM radiosondes and microwave radiometer; European Centre for Medium-Range Weather Forecasts (ECMWF) analyses.[1]
Monitoring and Analysis Method: Colocation tools and statistical analysis tools. Colocation tools will extract TPW data matched in time and space with reference "truth" data. Statistical analysis tools will calculate accuracy and precision metrics relative to reference data.

A.3.2 Event Name: ABI-CONUS_TPW13

Same as for ABI-FD_TPW12, except for:
Objective: Assess accuracy and precision of CONUS products for an adequate number of independent measurements to characterize accuracy and precision over a range of conditions, including seasonal variability.
GOES-R Data Type(s): Bands 8-16, CONUS.
ABI Mode: 3.

A.3.3 Event Name: ABI-MESO_TPW14

Same as for ABI-FD_TPW12, except for:
Objective: Assess accuracy and precision of mesoscale products for an adequate number of independent measurements to characterize accuracy and precision over a range of conditions, including seasonal variability.
GOES-R Data Type(s): Bands 8-16, mesoscale.
ABI Mode: 3.

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

B.1 Data Set #1: GFS Forecast products[3]

Description: Vertical profiles of temperature and water vapor calculated four times daily. Short-term Numerical Weather Prediction (NWP) input is used to initialize ABI TPW generation, and therefore will be available for every TPW product generated. While not a truly independent source of "truth" data, should be sufficient to assess the reasonableness of the TPW products.
Access Process: ftp.ncep.noaa.gov.
POC: NCEP.
Spatial Coverage: FD coverage.
Temporal Coverage: 00, 06, 12, and 18 UTC daily.
Contingency: N/A (cannot produce TPW products without GFS Forecast products).

B.2 Data Set #2: GPS Met TPW measurements[3]

Description: GPS measured TPW is available every 30 min.
Access Process: ESRL (gpsftp.fsl.noaa.gov).
POC: NOAA.
Spatial Coverage: Distributed network over CONUS land.
Temporal Coverage: Every 30 min.
Contingency: GFS Forecast.

B.3 Data Set #3: Conventional (NWS) radiosonde observations[3]

Description: Vertical profiles of temperature, pressure, and water vapor collected from a distributed network of CONUS locations at 00 UTC and 12 UTC daily.
Access Process: OSPO McIDAS ADDE server NCEP prep BUFR files (ftp .ncep.noaa.gov).
POC: NOAA.
Spatial Coverage: Network distributed fairly evenly over CONUS. Colocation and analysis tools testing used 57 locations in eastern CONUS.[5]
Temporal Coverage: 00 UTC and 12 UTC daily.
Contingency: GFS Forecast, SGP ARM Site MWR, GPS Met TPW, AMSR2 TPW product.

B.4 Data Set #4: AMSR2 TPW product over ocean[3]

Description: Data product from microwave sensor aboard LEO satellite producing TPW measurements over the ocean.
Access Process: (http://www.jpss.noaa.gov).
POC: JPSS.
Spatial Coverage: Nearly FD coverage.
Temporal Coverage: Twice daily.
Contingency: GFS Forecast.

B.5 Data Set #5: Southern Great Plain (SGP) ARM Site Radiosondes

Description: Vertical profiles of temperature, pressure, and water vapor collected from the ARM-CART site at SGP (CONUS) location every six hours. The quality of the RAOB data from SGP has been shown to be of higher quality than conventional RAOB[5]. Instability indices will be derived from the vertical profiles.
Access Process: Data available for download.
POC: ARM-CART at SGP.
Spatial Coverage: Latitude 36.61º N and longitude 97.47° W**.**
Temporal Coverage: Once every 6 hours.
Contingency: Conventional (NWS) radiosonde observations, ECMWF forecasts.

B.6 Data Set #6: Southern Great Plain (SGP) ARM Site Microwave Radiometer (MWR)

Description: MWR measured TPW is considered as the truth and available every 5 min after averaging.[5]
Access Process: Data available for download.
POC: ARM-CART at SGP.
Spatial Coverage: Latitude 36.61º N and longitude 97.47° W**.**
Temporal Coverage: Every 5 min.
Contingency: GPS TPW, SGP ARM Site Radiosondes, Conventional (NWS) radiosonde observations, ECMWF analyses.

B.7 Data Set #7: ECMWF analyses

Description: Forecasts of temperature, pressure, and water vapor calculated by the European Centre for Medium-Range Weather Forecasts (ECMWF).
Access Process: Ordered as needed.
POC: The CIMSS POC for obtaining ECMWF data is Kevin Baggett..
Spatial Coverage: Calculations performed globally at grid points.
Temporal Coverage: 00 UTC to 24 UTC daily at 6 hour intervals.
Contingency if Not Available: GFS forecast, radiosonde observations.

C. Appendix C: Tools

C.1 Tool #1: Colocation Tools[5]

Location: CIMSS.
Description: MATLAB Tools to compile ABI LAP TPW data that meets matchup criteria with ground truth data sets. Designed to run on MATLAB software version 7.10.0.499 (R2010a) on 64 bit Linux machine.
Developer: Yong-Keun Lee (Tim Schmit, Jun Li, Zhenglong Li co-authors on Ref 5).
Development Schedule: 90% complete. All validation tools have been developed and web tools are now available at http://soundingval.ssec.wisc.edu/.
Tools are internal to STAR and shared within the team. No handover plan is required.
Data Dependencies: ABI TPW products. Latitude, Longitude, and time of reference ("truth") data sets.
Testing Accomplished and Planned: Testing of Statistical Analysis Tools performed with GOES data and ROAB data collected between April 7, 2010 and March 26, 2011. Data Operations Exercises (DOEs) 1, 2, and 3 data have been provided and the TPW team has responded with comments. Additional data from DOE 4 are anticipated by the end of September 2016. Remaining tests of the tools require routine files to be produced and run through the system, staged and accessed by the PDS in real time. Future test data must contain forecast TPW products which are needed in the GOES-R ABI LAP validation tool. Software tools are expected to be fully tested by October 2016.
POC: Yong-Keun Lee and Zhenglong Li.

C.2 Tool #2: Statistical Analysis Tool[5]

Location: CIMSS.
Description: MATLAB Tools to calculate bias, standard deviation, and RMS error between ground truth data sets and collocated ABI temperature profiles as well as visualization tools for such comparisons. Designed to run on MATLAB software version 7.10.0.499 (R2010a) on 64 bit Linux machine. Should work on newer versions as well.
Developer: Yong-Keun Lee (Tim Schmit, Jun Li, Zhenglong Li co-authors on Ref 5).
Development Schedule: 90% Complete. All validation tools have been developed and web tools are now available at http://soundingval.ssec.wisc.edu/.
Tools are internal to STAR and shared within the team. No handover plan is required.
Data Dependencies: NWP inputs to the LAP retrievals. TPW from the ARM CART site: Microwave Radiometer (MWR), Global Positioning System, and the integration of the radiosonde measured water vapor profiles. MWR measured TPW is considered as the truth and available every 5 min after averaging. NWS conventional radiosonde data. AMSR-E TPW data over oceans. ABI LAP retrieval products temporally and spatially matched for each of these sites by the Colocation Tools.
Testing Accomplished and Planned: Testing of Statistical Analysis Tools performed with GOES data and ROAB data collected between April 7, 2010 and March 26, 2011. Data Operations Exercises (DOEs) 1, 2, and 3 data have been provided and the TPW team has responded with comments. Additional data from DOE 4 are anticipated by the end of September 2016. Remaining tests of the tools require routine files to be produced and run through the system, staged and accessed by the PDS in real time. Future test data must contain forecast TPW products which are needed in the GOES-R ABI LAP validation tool. Software tools are expected to be fully tested by October 2016.
POC: Yong-Keun Lee and Zhenglong Li.

D. Appendix D: Acronym List

Acronym	Definition
ABI	Advanced Baseline Imager
ACMP	Algorithm Change Management Plan
AMSR2	Advanced Microwave Scanning Radiometer 2
AMSR-E	Advanced Microwave Scanning Radiometer - Earth Observing System
ARM	Atmospheric Radiation Measurement
AWG	Algorithm Working Group
BUFR	Binary Universal Form for the Representation of meteorological data
Cal/Val	Calibration and Validation
CART	Cloud and Radiation Testbed
CCR	Configuration Change Request
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CMI	Cloud and Moisture Imagery
CONUS	Continental United States
CWG	Calibration Working Group
DOE	Data Operations Exercise
DSI	Derived Stability Index
ECMWF	European Centre for Medium-Range Weather Forecasts
ESRL	Earth System Research Laboratory
F&PS	GOES-R Functional and Performance Specification
FCST	Forecast
FD	Full Disk
FTE	Full-Time Equivalent
FTP	File Transfer Protocol
GOES	Geostationary Operational Environmental Satellite
GOES-R	GOES R-Series
GORWG	GOES-R Series Operational Requirements Working Group
GPS	Global Positioning System
GRB	GOES Rebroadcast
HRR	Handover Readiness Review
IR	Infrared
L1b	Level 1b
L2	Level 2
LAP	Legacy Atmospheric Profile
LEO	Low Earth Orbit
McIDAS	Man-computer Interactive Data Access System
McIDAS ADDE	McIDAS Abstract Data Distribution Environment
MOST	Mission Operations Support Team

Acronym	Definition
MSFC	Marshall Space Flight Center
MWR	Microwave Radiometer
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information
NCEI-CO	NCEI - Colorado
NCEP	National Centers for Environmental Prediction
NWP	Numerical Weather Prediction
NWS	National Weather Service
OSPO	Office of Satellite and Product Operations
PDA	Product Dissemination and Access
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
RAOB	Radiosonde Observation
RIMP	Readiness, Implementation and Management Plan
RTVL	Retrieval
SGP	Southern Great Plains
STAR	Center for Satellite Applications and Research
TBD	To Be Determined
TPW	Total Precipitable Water