# Validated Maturity Science Review for AMSR2 Snow Products

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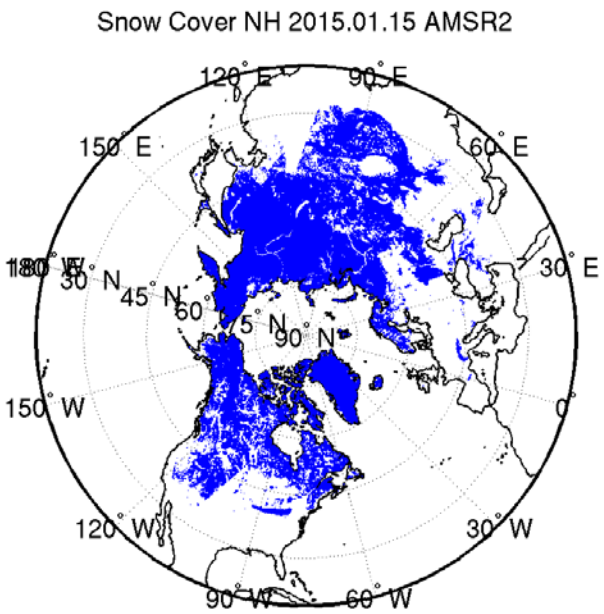
# Sea Ice Cal/Val Team

## Algorithm Cal/Val Team Members

| Name | Organization | Major Task |
|---|---|---|
| Yong-Keun Lee | UW/CIMSS | Snow product development and validation |
| Cezar Kongoli | CICS | Snow algorithm consultation |
| Jeff Key | NOAA | Team lead |

# AMSR2 Snow Product Examples

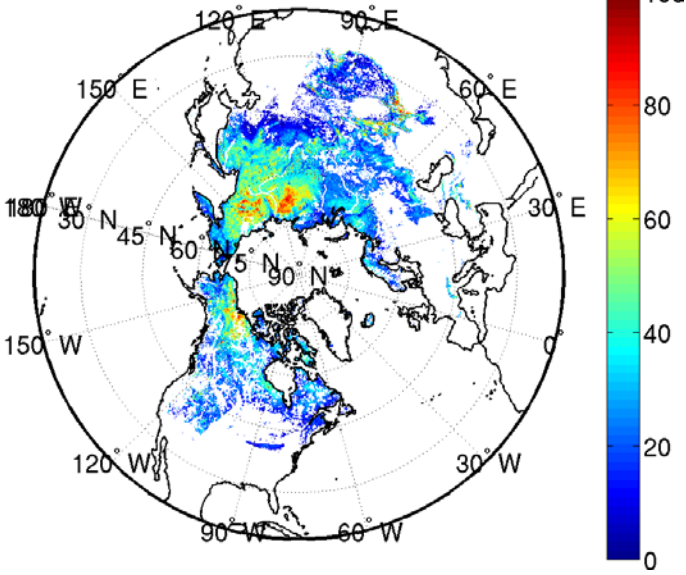
## Snow Cover



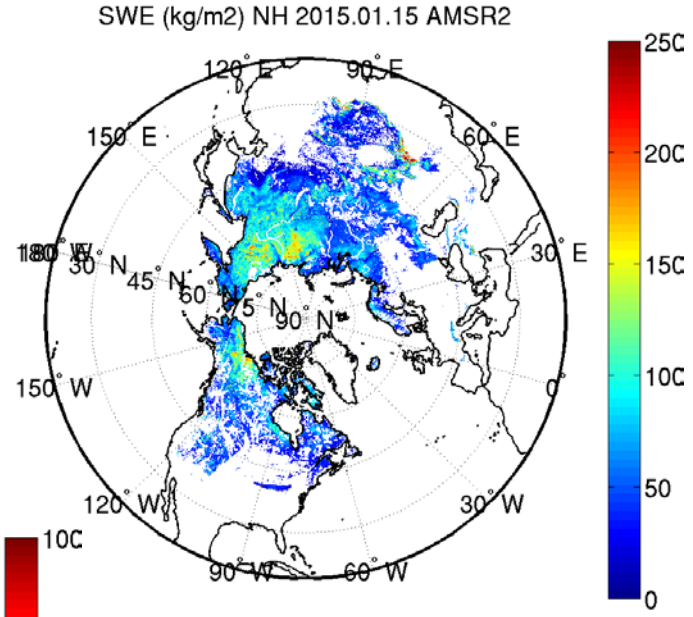

The **Snow Cover** product provides the presence/absence of snow cover for every pixel.

The **Snow Depth** product provides the depth of the snow cover (cm).

## Snow Depth




## SWE




The **Snow Water Equivalent** (SWE) product provides the water equivalent (mm) of the snow cover.

# Requirements: Snow Cover/Depth

- Product performance requirements from JPSS L1RD supplement (threshold) versus observed/validated

| Table 6.1.8 GCOM Snow Cover/Depth | | |
|---|---|---|
| EDR Attribute | Threshold | Observed/Validated |
| Applicable conditions | Delivered under "all weather" conditions | Delivered under "all weather" conditions |
| Sensing depth | 0 – 60 cm | same |
| Horizontal cell size | 10 km | same |
| Mapping uncertainty, 3 sigma | 5 km | n/a |
| Snow depth ranges | 5 – 60 cm | same |
| Measurement uncertainty | | |
| -- Clear | | |
| -- Cloudy | 80% probability of correct snow/no snow classification; Snow Depth: 20 cm | 90+% correct classif. (no wet snow); < 20 cm depth uncertainty (no alpine areas) |
| Refresh | At least 90% coverage of the globe about every 20 hours (monthly average) | same |

**Note:** Uncertainty requirements do not apply to (1) mountainous areas (2) melting snow condition.

# Requirements: Snow Water Equivalent

- Product performance requirements from JPSS L1RD supplement (threshold) versus observed/validated

| Table 6.1.9 GCOM Snow Water Equivalent | | |
|---|---|---|
| EDR Attribute | Threshold | Observed/Validated |
| Applicable conditions | Delivered under "all weather“ conditions | Delivered under "all weather“ conditions |
| Horizontal cell size | 10 km | same |
| Mapping uncertainty, 3 sigma | 5 km | n/a |
| Measurement range | 10 – 200 mm | same |
| Measurement uncertainty | | |
| -- Shallow to moderate snow packs (10 – 100 mm) | 20 mm or 50% | |
| -- High snow accumulation (above 100 mm) | 70% | 20-22% |
| Refresh | At least 90% coverage of the globe about every 20 hours (monthly average) | same |

**Notes:**
1. Uncertainty requirements do not apply to (1) mountainous areas (2) melting snow condition. Relaxed accuracy requirement should be specified for densely forested areas. Formulated uncertainty requirements are based on past results of validation of other SWE products derived from the data of SSMI and AMSR-E. Retrievals with algorithms utilizing only satellite data (no RT model involvement) were considered.
2. This SWE Refresh requirement is consistent with the AMSR-2 Cross-track Swath Width design of 1450 km for a single orbit plane.

# Snow Cover/Depth and SWE Requirements: JERD vol 2

- Additional requirements from JPSS ESPC Requirements Document (JERD) Volume 2 - Science Requirements

- Snow Cover is defined to be the horizontal extent of snow cover. It does not include snow hidden by vegetation or other obstructions when viewed from above. Snow cover data at specified values are required to determine background conditions for electro-optical sensors. Forecasts of weather, trafficability, river stage, flood, air rescue conditions, and other phenomena also utilize snow cover information.

- Snow-Water Equivalent (SWE) is the product of snow depth and snow relative density (with respect to the density of liquid water), a measure of the amount of water stored in a snowpack per unit area; it is expressed in units of length (e.g., cm or inches), being a quantity of type surface density, normalized by water density. It is the depth of water in the snowpack, if the snowpack were melted. SWE is extremely useful to the hydrological community to estimate runoff and stored water.

# Snow Cover/Depth Requirements: JERD vol 2

The algorithm shall produce a snow cover/depth product under all-weather conditions.

The algorithm shall produce the snow cover/depth product that has a sensing depth of 0 – 60 cm.

The algorithm shall produce the snow cover/depth product that has a horizontal cell size of 10 km.

The algorithm shall produce the snow cover/depth product that has a mapping uncertainty (3 sigma) of 5 km.

The algorithm shall produce the snow cover/depth product that has snow depth ranges of 5 – 60 cm.

The algorithm shall produce the snow cover/depth product that has a measurement uncertainty (note 1) of:

- 80% probability of correct snow/no snow classification – snow depth: 20 cm (30 cm if forest cover exceeds 30%) for clear scenes and
- 80% probability of correct snow/no snow classification – snow depth: 20 cm for cloudy scenes.

Notes:
1. Uncertainty requirements do not apply to (1) mountainous areas (2) melting snow condition. Formulated uncertainty requirements are based on past results of validation of other snow depth products derived from the data of SSMI and AMSR-E. Retrievals with algorithms utilizing only satellite data (no Radiative Transfer (RT) model involvement) were considered.
2. This Refresh requirement is consistent with the AMSR-2 Cross-track Swath Width design of 1450 km for a single orbit plane.

# SWE Requirements: JERD vol 2

The algorithm shall produce a snow water equivalent product under all-weather conditions.

The algorithm shall produce the snow water equivalent product that has a horizontal cell size of 10 km.

The algorithm shall produce the snow water equivalent product that has a mapping uncertainty (3 sigma) of 5 km.

The algorithm shall produce the snow water equivalent product that has a measurement range of 10 – 200 mm.

The algorithm shall produce the snow water equivalent product that has a measurement uncertainty (note 1) of:

- 20 mm or 50% for shallow to moderate snow packs (10-100 mm) and
- 70% for high snow accumulation (above 100 mm).

Notes:
1. Uncertainty requirements do not apply to (1) mountainous areas (2) melting snow condition. Formulated uncertainty requirements are based on past results of validation of other snow depth products derived from the data of SSMI and AMSR-E. Retrievals with algorithms utilizing only satellite data (no Radiative Transfer (RT) model involvement) were considered.
2. This Refresh requirement is consistent with the AMSR-2 Cross-track Swath Width design of 1450 km for a single orbit plane.

# Evaluation of algorithm performance to specification requirements

- Improvements since Algorithm Readiness Review (ARR, Provisional)
  - No algorithm improvements since ARR
  - No LUT / PCT updates
- Cal/Val Activities for evaluating algorithm performance since ARR have been focused on
  - automating the comparison to in situ data on a monthly basis
  - SWE validation

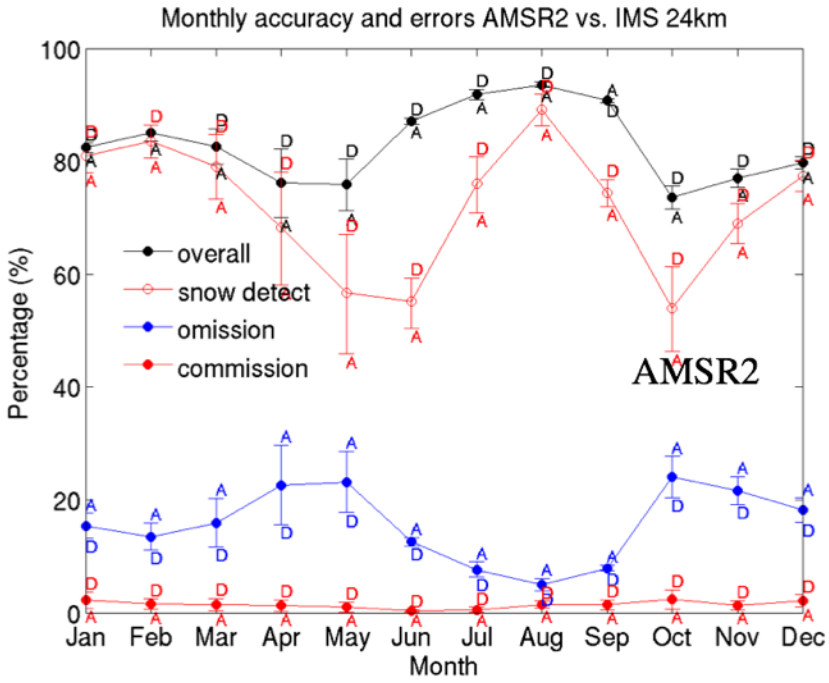
# Validation Strategy

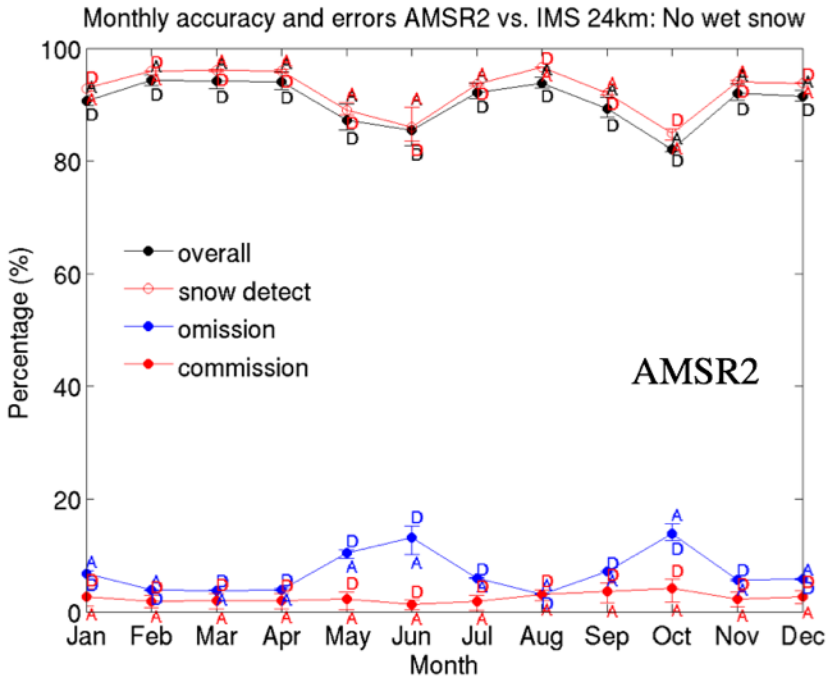
Snow cover: daily comparison with the Interactive Multisensor Snow and Ice Mapping System (IMS) 24 km.

Snow depth: daily comparison with ground station measurements including the World Meteorological Organization (WMO) and the US National Weather Service (NWS) Cooperative Observer Program (COOP) Network.

Snow Water Equivalent (SWE): comparison with the National Operational Hydrologic Remote Sensing Center (NOHRSC) Snow Data Assimilation System (SNODAS).

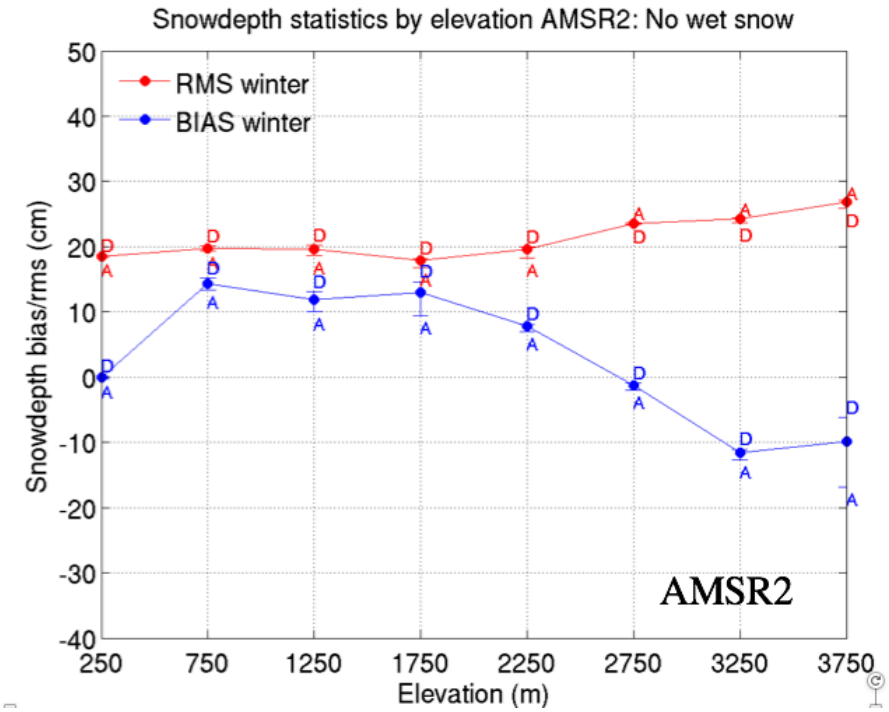
# Snow Cover Validation

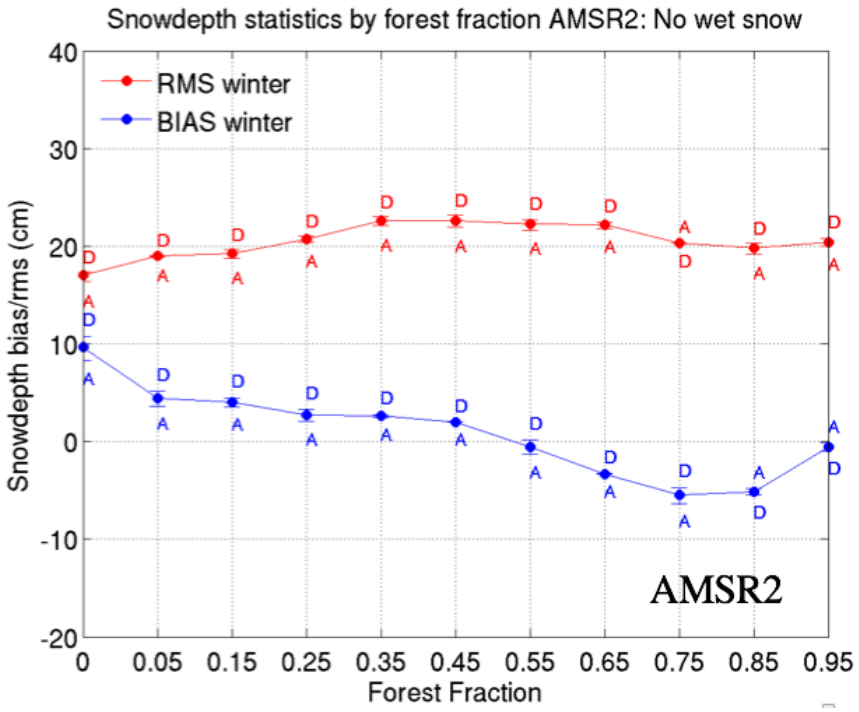



| | Tundra | Taiga | Maritime | Ephemeral | Prairie | Alpine |
|---|---|---|---|---|---|---|
| Overall Accuracy | 94.6% | 97.4% | 80.9% | 71.7% | 74.0% | 86.9% |

# Snow Depth Validation




| | Tundra | Taiga | Maritime | Ephemeral | Prairie | Alpine |
|---|---|---|---|---|---|---|
| RMSE (cm) | 18.77 | 20.96 | 19.37 | 14.95 | 18.93 | 21.97 |
| Bias (cm) | 4.51 | 3.77 | -5.34 | 6.05 | 2.75 | -4.45 |
| Mean (cm) of in-situ obs | 25.10 | 19.18 | 20.20 | 8.40 | 18.49 | 25.14 |

# Snow Water Equivalent Validation

Monthly SWE comparison between AMSR2 retrievals and SNODAS

| Month | Bias (cm) | Prec. (cm) | Uncertainty (RMSE, cm) | Mean1 (cm) | Mean2 (cm) | % Error | # pixels |
|---|---|---|---|---|---|---|---|
| 11/2016 | -4.9 | 8.8 | 10.1 | 29.4 | 45.4 | 22.2 | 92846 |
| 12/2016 | -3.5 | 7.1 | 7.9 | 29.6 | 36.4 | 21.7 | 1124420 |
| 01/2017 | -5.2 | 9.6 | 11.0 | 45.5 | 53.9 | 20.4 | 1681461 |
| 02/2017 | -6.6 | 14.1 | 15.6 | 68.8 | 75.2 | 20.7 | 1334818 |
| 03/2017 | -10.9 | 17.8 | 20.8 | 75.9 | 103.3 | 20.1 | 975439 |

Bias: AMSR2 - SNODAS
Prec: Precision (standard deviation of differences)
mean1: Mean of AMSR2 SWE
mean2: Mean of SNOWDAS SWE
% Error: RMSE/Mean2

# Evaluation of the effect of required algorithm inputs

- Required Algorithm Inputs
  - Primary Sensor Data: L2A TBs
  - Ancillary Data:
    - Land/water mask
    - Snow climatology
    - Forest fraction and vegetation
    - Global snow classification
  - Upstream algorithms: None
  - LUTs / PCTs: Snow density climatology
- Evaluation of the effect of required algorithm inputs:
  - Without the snow climatology, the false snow detection rate can be large
  - Differences in retrievals due to other ancillary data were seen in the stratified validation results (previous slides)

# Quality flag analysis/validation

- Defined Quality Flags
  - Surface type: land, water, snow-free, wet snow, dry snow
  - Snow climatology: snow/no snow/wet snow in climatology
  - Snow depth: no retrieval due to glaciers, out of range value, etc.
  - Surface scattering: precip, cold desert, rain+cold desert, frozen ground, etc.
- Quality flag analysis/validation
  - Wet snow flag is very important as wet snow degrades detectability (see validation results for snow cover)
  - Out-of-range values occur a small percentage of the time
  - Other exclusion conditions such as precipitation and cold desert areas improve results
  - Analysis/validation plan - ?

# Error Budget

| Attribute Analyzed | L1RD Threshold | Validation Result | Error Summary | Support Artifacts |
|---|---|---|---|---|
| Snow cover | 80% prob of correct snow/no-snow classification | 72-97% correct classification | If wet snow is excluded, 90+% correct | Comparison with IMS for snow cover. Manuscript published. |
| Snow depth | 20 cm snow depth | 15-22 cm depth uncertainty | If alpine excluded, depth uncertainty < 20 cm | Comparison with in situ data. Manuscript published. |
| SWE | 50-70% accuracy (shallow to thick snowpacks) | ~20-22% | Larger validation dataset would improve reliability of results. More thin snowpack cases needed. | Comparison with snow data assimilation system (SNODAS) |

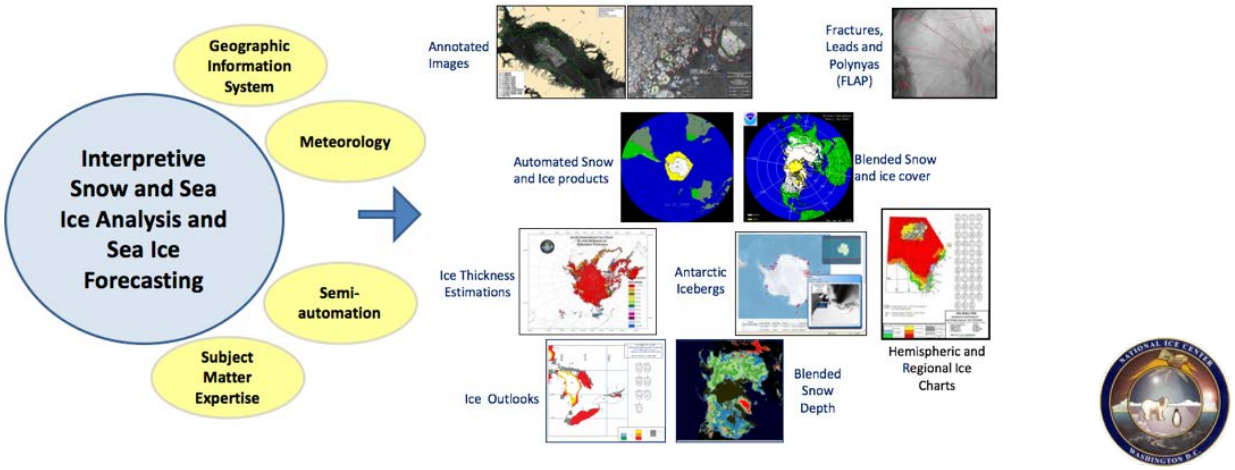
# Identification of Processing Environment

- ESPC (e.g., NDE, Okeanos) build (version) number: NDE 1.0.10; effective date: September 30, 2016
- Algorithm version – 1.0 (DAP delivery v2r0)
- Version of LUTs used – n/a
- Version of PCTs used – n/a
- Description of environment used to achieve validated maturity stage – Linux server

# Users & User Feedback

- Primary user: National Ice Center (NIC; Sean Helfrich). Others: Air Force, NWS Alaska, NCEP (TBD)

- Feedback from users
  - NIC plans to add AMSR2 snow depth to the IMS blended snow depth product. SWE can also be used in IMS.
  - The Air Force has requested the product but is not yet using it.



# Documentations (Check List)

| Science Maturity Check List | Yes ? |
|---|---|
| ReadMe for Data Product Users | Yes |
| Algorithm Theoretical Basis Document (ATBD) | Yes |
| Algorithm Calibration/Validation Plan | |
| (External/Internal) Users Manual | Yes (README files with software) |
| System Maintenance Manual (for ESPC products) | |
| Peer Reviewed Publications<br>(Demonstrates algorithm is independently reviewed) | Yes (2015) |
| Regular Validation Reports (at least. annually)<br>(Demonstrates long-term performance of the algorithm) | As requested |

# Conclusion

- Cal/Val results summary:
  - Snow cover/depth
    - **Team recommends algorithm maturity status as “validated”**
    - Manuscript published in 2015
    - Larger errors when wet snow is included (melting snow is excluded in requirements)
    - Larger errors in alpine regions (excluded in requirements)
  - Snow water equivalent (SWE)
    - **Team recommends algorithm maturity status as “validated” (possibly provisional)**
    - More thin snowpack cases are needed

# Path Forward

Algorithm improvements:

- Further investigation of wet snow detection and tests for precipitation, cold desert, and frozen ground
- Atmospheric correction may improve snow products
- The improvement of snow cover detection by adjusting the criteria in the detection algorithm

Other:

- Improvement of AMSR2 snow depth by blending it with in-situ snow depth using optimal interpolation (new product potential)
- Work with NWP on the use of AMSR2 snow products

# JPSS Data Products Maturity Definition

**JPSS/GOES-R Data Product Validation Maturity Stages – COMMON DEFINITIONS (Nominal Mission)**

## 1. Beta

- Product is minimally validated, and may still contain significant identified and unidentified errors.
- Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose.
- Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.

## 2. Provisional

- Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts.
- Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.
- Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.
- Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.

## 3. Validated

- Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).
- Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.
- Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.
- Product is ready for operational use based on documented validation findings and user feedback.
- Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.