Validated Maturity Science Review for VIIRS Polar Winds

Presented by Jeff Key and Jaime Daniels

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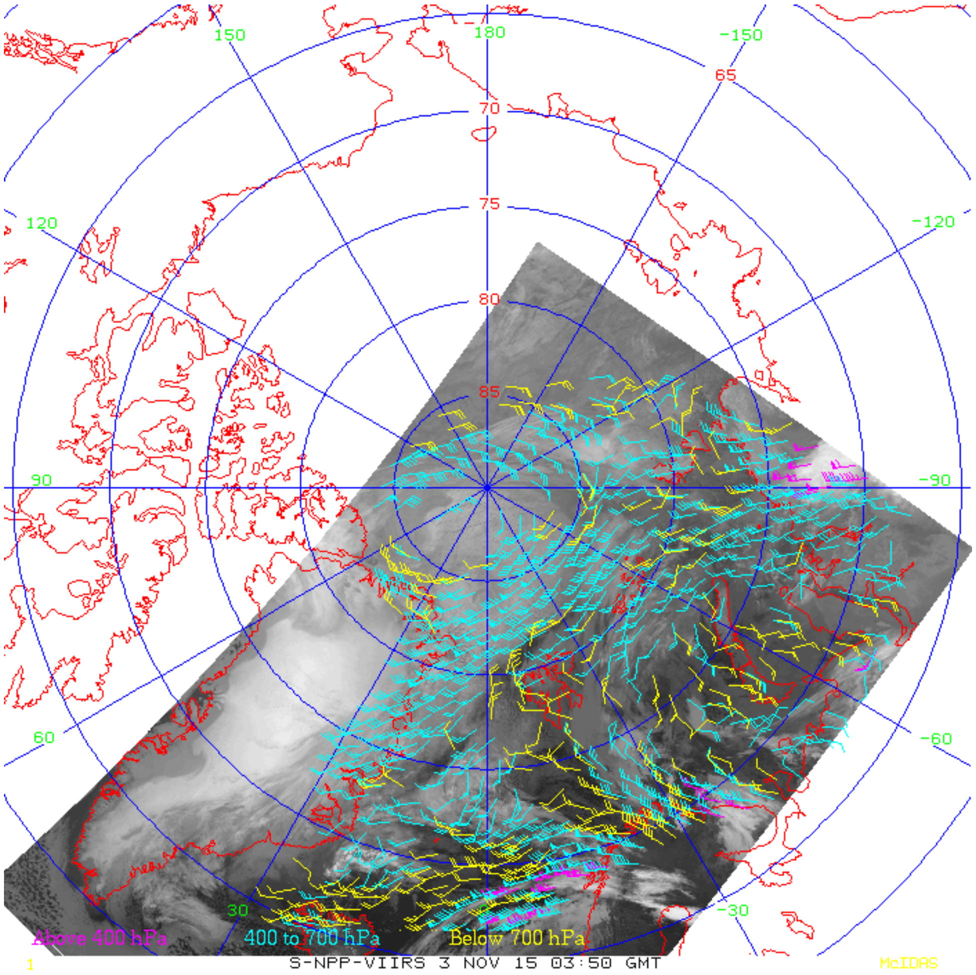
VIIRS Polar Winds (VPW) in Brief

VIIRS Polar Winds are derived by tracking clouds features in the VIIRS longwave infrared channel (Band M15, 10.8um)

- Wind speed, direction, and height are measured throughout the troposphere, poleward of approximately 65 degrees latitude, in cloudy areas only
- Wind information is generated in both the Arctic and Antarctic regions
- The product includes observation time, data quality flags, and metadata



Previous Reviews and Current Status

- Critical design review for VIIRS Polar Winds – April 27, 2011
- Algorithm Readiness Review/Maturity Review – March 27, 2014
- **The VIIRS Polar Winds product has been operational since May 2014.**
- VPW is also generated at direct broadcast sites and delivered to NWP centers.
- Algorithm changes since ARR: none

VIIRS Polar Winds Team

Name	Organization	Major Task
Jeff Key	STAR	Project management, DB winds
Jaime Daniels	STAR	Project management, algorithm development and testing
Wayne Bresky	IMSG	Algorithm development and testing
Andrew Bailey	IMSG	Algorithm development and testing
Dave Santek	CIMSS	Algorithm and product testing
Steve Wanzong	CIMSS	Algorithm and product testing
Hongming Qi	OSPO	Operations
Walter Wolf and others	STAR, AIT	Implementation

Requirements

JPSS L1RD supplement (threshold) requirements versus observed

Attribute	Threshold	Observed/validated
Geographic coverage	~70º latitude to poles	~65º to poles
Vertical Coverage	Surface to tropopause	same
Vertical Cell Size	At cloud tops	same
Horizontal Cell Size	10 km (should be ~19 km, CCR Aug 2015)	same
Mapping Uncertainty	0.4 km (nadir); 1.5km (edge of scan)	0.57 km
Measurement Range	Speed: 3 to 100 m s^{-1}; Direction: 0 to 360 degrees	same
Measurement Accuracy	Mean vector difference: 7.5 m/s	5.7-7.0 m/s (w/raobs)
Measurement Precision	Mean vector difference: 4.2 m/s (was 3.8 m/s)	2.7-3.8 m/s (w/raobs)
Measurement Uncertainty	Not specified	Not applicable

AMV Performance Metrics

AMVs (QI>60) are matched and compared against RAOBS or GFS model analysis winds. Metrics:

$$Accuracy = \frac{1}{N}\sum_{i=1}^{N}(VD_i)$$

$$\Pr ecision = \sqrt{\frac{1}{N}\sum_{i=1}^{N}((VD_i) - (MVD))^2}$$

where:

$$(VD)_i = \sqrt{(U_i - U_r)^2 + (V_i - V_r)^2}$$

U_i and V_i ---> AMV
U_r and V_r ---> “Truth”

JERD Requirements

JPSS ESPC Requirements Document (JERD) requirements:

Requirement ID	Requirement Text
JERD-2139	The algorithm shall produce a polar winds product that has vertical coverage from the surface to the tropopause.
JERD-2140	The algorithm shall produce a polar winds product that has a horizontal resolution of 10 km.
JERD-2141	The algorithm shall produce a polar winds product that has a vertical reporting interval at cloud tops.
JERD-2142	The algorithm shall produce a polar winds product that has a mapping uncertainty (3 sigma) of 5 km.
JERD-2143	The algorithm shall produce a polar winds product that has a measurement range of: 3 to 100 m/sec for speed and 0 to 360 degrees for direction.
JERD-2144	The algorithm shall produce a polar winds product that has a measurement precision mean vector difference of 3.8 m/sec.
JERD-2145	The algorithm shall produce a polar winds product that has a measurement accuracy mean vector difference of 7.5 m/sec.

Validation Strategy

- Derive winds over both poles using overlapping NPP/VIIRS orbits

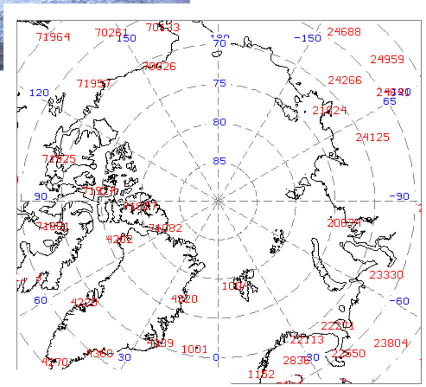
- Derive winds with full product precedence in place
  - Official NPP cloud mask product is used
  - Cloud Products (cloud-top temp, pressure, phase, type) are generated as part of the product precedence chain

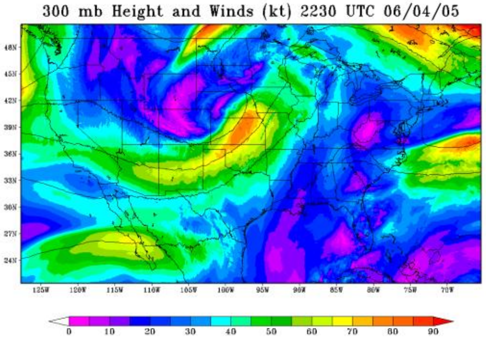
- Collocate (in space and time) derived satellite winds with reference (“truth”) winds
  - Radiosonde wind observations (Land)
  - Aircraft wind observations (Land & Ocean)
  - GFS analysis winds (Ocean)

- Generate comparative statistics (satellite winds minus reference winds)
  - Accuracy
  - Precision

Derived Motion Winds Test Plan – Offline Validation: Truth Data

- Radiosonde wind observations serve as a key validation data source for derived motion wind products
  - Used by all operational satellite processing centers that generate satellite derived motion winds
- Aircraft wind observations
- GFS Model Analysis Wind Fields





Comparisons to Radiosondes

September, 2013 – January, 2014

Comparison statistics of VPW product computed using the M15 band (10.76um),

All Levels (100-1000 hPa)	VIIRS Polar Wind vs. Radiosonde Winds (m/s)		GFS Forecast Winds vs. Radiosonde Winds (m/s)	
	NHEM	SHEM	NHEM	SHEM
Accuracy	5.67	5.71	4.54	4.77
Precision	3.41	3.25	3.06	2.99
Speed bias	0.38	-0.04	-0.30	-0.57
Speed	17.61	14.22	16.93	13.69
Sample	9650	866	9650	866
High Level (100-400 hPa)	**NHEM**	**SHEM**	**NHEM**	**SHEM**
Accuracy	6.21	6.81	5.08	5.56
Precision	3.55	3.36	3.23	3.14
Speed bias	-0.06	-0.23	-0.69	-0.55
Speed	23.62	18.05	22.99	17.73
Sample	3054	301	3054	301
Mid Level (400-700 hPa)	**NHEM**	**SHEM**	**NHEM**	**SHEM**
Accuracy	5.65	5.24	4.48	4.48
Precision	3.40	3.12	3.04	2.87
Speed bias	0.56	0.07	-0.32	-0.75
Speed	16.69	12.51	15.81	11.69
Sample	4468	471	4468	471
Low Level (700-1000 hPa)	**NHEM**	**SHEM**	**NHEM**	**SHEM**
Accuracy	4.95	4.55	3.90	3.70
Precision	3.08	2.39	2.69	2.40
Speed bias	0.64	0.04	0.32	0.28
Speed	10.91	10.52	10.58	10.76
Sample	2128	94	2128	94

Specifications:

Measurement Accuracy	7.5 m/s
Measurement Precision	3.8 m/s

Comparisons to Radiosondes, cont.

June, 2014 – September, 2016

Comparison statistics of VPW product computed using the M15 band (10.76um),

All Levels (100-1000 hPa)	*VIIRS Polar Wind vs. Radiosonde Winds (m/s)*		*GFS Forecast Winds vs. Radiosonde Winds (m/s)*	
	NHEM	SHEM	NHEM	SHEM
Accuracy	6.07	NA	4.89	NA
Precision	3.75	NA	3.36	NA
Speed bias	0.74	NA	-0.02	NA
Speed	21.79	NA	21.01	NA
Sample	72363	NA	72363	NA
High Level (100-400 hPa)	**NHEM**	**SHEM**	**NHEM**	**SHEM**
Accuracy	6.59	NA	5.40	NA
Precision	3.77	NA	3.40	NA
Speed bias	0.61	-NA	-0.12	NA
Speed	26.64	NA	25.89	NA
Sample	34710	NA	34710	NA
Mid Level (400-700 hPa)	**NHEM**	**SHEM**	**NHEM**	**SHEM**
Accuracy	5.85	NA	4.55	NA
Precision	3.64	NA	3.19	NA
Speed bias	0.96	NA	0.00	NA
Speed	19.19	NA	18.23	NA
Sample	28540	NA	28540	NA
Low Level (700-1000 hPa)	**NHEM**	**SHEM**	**NHEM**	**SHEM**
Accuracy	4.82	NA	3.99	NA
Precision	3.62	NA	3.44	NA
Speed bias	0.51	NA	0.22	NA
Speed	11.44	NA	11.14	NA
Sample	9113	NA	9113	NA

Specifications:

Measurement Accuracy	7.5 m/s
Measurement Precision	3.8 m/s

Comparisons to Aircraft

January 29, 2014 – February 23, 2014

Comparison of the VPW product with aircraft data.

There were insuffient data from the Southern Hemisphere for reliable statistics for different height bins.

All Levels (100-1000 hPa)	*VIIRS Polar Wind vs. Aircraft Winds (m/s)*	*VIIRS Polar Wind vs. Aircraft Winds (m/s)*
	NHEM	SHEM
Accuracy	6.10	7.02
Precision	3.27	2.74
Speed bias	0.36	-0.98
Speed	18.76	
Sample	3225	81
High Level (100-400 hPa)	**NHEM**	**NHEM**
Accuracy	6.56	
Precision	3.36	
Speed bias	-0.34	
Speed	20.24	
Sample	2082	
Mid Level (400-700 hPa)	**NHEM**	**NHEM**
Accuracy	5.37	
Precision	3.22	
Speed bias	1.57	
Speed	17.37	
Sample	945	
Low Level (700-1000 hPa)	**NHEM**	**NHEM**
Accuracy	4.77	
Precision	2.00	
Speed bias	1.93	
Speed	9.81	
Sample	198	

Specifications:

Measurement Accuracy	7.5 m/s
Measurement Precision	3.8 m/s

Comparisons of the algorithm's derived winds against raob and aircraft winds at all levels (100-1000 hPa), high level (100- 400 hPa), mid level (400-700 hPa), and low level (700-100 hPa) in the northern hemisphere. In each case, the observed precision meets the requirement. The accuracy and precision of the VIIRS winds fall well within the accuracy and precision specifications.

Comparisons to Aircraft, cont.

June, 2014 – September, 2016

Comparison of the VPW product with aircraft data.

There were insuffient data from the Southern Hemisphere for reliable statistics for different height bins.

All Levels (100-1000 hPa)	*VIIRS Polar Wind vs. Aircraft Winds (m/s)* NHEM	*VIIRS Polar Wind vs. Aircraft Winds (m/s)* SHEM
Accuracy	5.77	6.77
Precision	3.56	3.83
Speed bias	1.08	-1.67
Speed	21.62	29.97
Sample	34998	354
High Level (100-400 hPa)	**NHEM**	**SHEM**
Accuracy	6.48	6.77
Precision	3.70	3.83
Speed bias	0.45	-1.67
Speed	27.27	29.97
Sample	14781	354
Mid Level (400-700 hPa)	**NHEM**	**SHEM**
Accuracy	5.50	NA
Precision	3.64	NA
Speed bias	1.52	NA
Speed	19.59	NA
Sample	14775	NA
Low Level (700-1000 hPa)	**NHEM**	**SHEM**
Accuracy	4.59	NA
Precision	3.04	NA
Speed bias	1.57	NA
Speed	11.75	NA
Sample	5442	NA

Specifications:

Measurement Accuracy	7.5 m/s
Measurement Precision	3.8 m/s

Comparisons of the algorithm's derived winds against raob and aircraft winds at all levels (100-1000 hPa), high level (100- 400 hPa), mid level (400-700 hPa), and low level (700-100 hPa) in the northern hemisphere. In each case, the observed precision meets the requirement. The accuracy and precision of the VIIRS winds fall <u>well within</u> the accuracy and precision specifications.

Requirement ID	Requirement Text
JERD-2139	The algorithm shall produce a polar winds product that has vertical coverage from the surface to the tropopause.

- The winds derivation method is based on tracking clouds. Wind vectors are derived wherever a cloud target can be tracked. Therefore, the vertical coverage of the winds is equivalent to the vertical distribution of clouds that are tracked. Given that clouds can occur anywhere in the troposphere (and can, in fact, extend into the stratosphere), the derived wind vectors can and do occur at all vertical levels throughout the troposphere.
- The validation results tables shown earlier clearly indicate that the vertical coverage is throughout the troposphere.

Requirement ID	Requirement Text
JERD-2140	The algorithm shall produce a polar winds product that has a horizontal resolution of 10 km.

- This requirement is not being met. The horizontal resolution is inherent in the algorithm. It is simply the size of the “target box” that is used for tracking. The target box size is 19 km, not 10 km. We believe that the 10 km value was inherited from an early GOES-R requirement and never changed. The requirement should be 19 km.
- A CCR for this item was submitted in August 2015. Its status is unknown.

Requirement ID	Requirement Text
JERD-2141	The algorithm shall produce a polar winds product that has a vertical reporting interval at cloud tops.

- The winds derivation method is based on tracking clouds. The VIIRS and GOES-R winds algorithms use an externally-generated cloud product, which includes the cloud heights. The algorithm dictates that the height of the derived wind vector is the cloud top height. No further verification is needed.

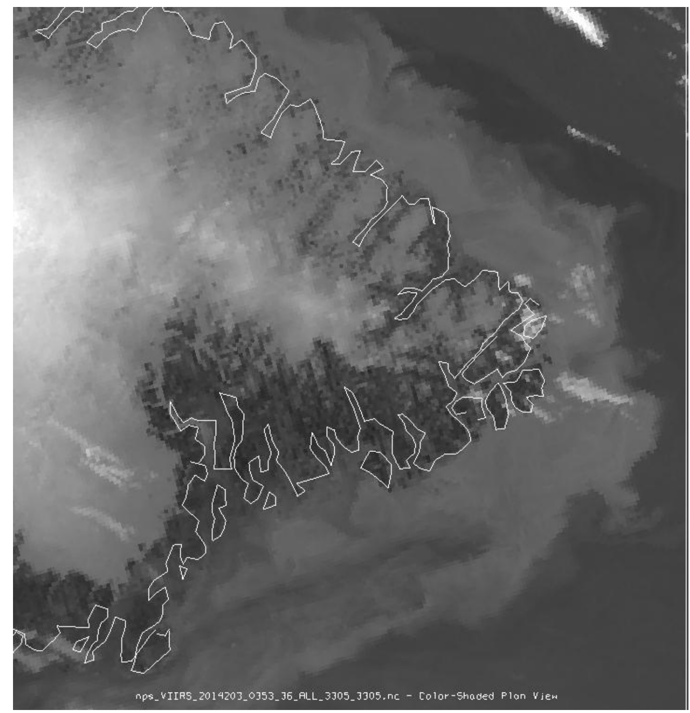
Requirement ID	Requirement Text
JERD-2142	The algorithm shall produce a polar winds product that has a mapping uncertainty (3 sigma) of 5 km.

- The location accuracy of the VIIRS winds is dependent upon (a) the geolocation accuracy of the SDRs, (b) the mapping accuracy of the map projection software (MODIS Swath to Grid Toolbox, MS2GT), and (c) the retransformation from line/element back to latitude/longitude (McIDAS functions).

- To quantify the overall accuracy, control points on coastlines in the VIIRS imagery used for wind retrievals were identified. Their locations were compared to a high resolution land database.

- The mean mapping error is 1.55 km with a standard deviation of 0.57 km. The 3-sigma value (3 x standard deviation) is 1.72 km.

- Mapping accuracy therefore meets the requirement of 5 km.



Requirement ID	Requirement Text
JERD-2143	The algorithm shall produce a polar winds product that has a measurement range of: 3 to 100 m/sec for speed and 0 to 360 degrees for direction.

- There is no limit to the wind speed and direction inherent in the algorithm, though quality control would reject winds outside of a reasonable range.
- The validation tables shown earlier summarize the results of comparisons with radiosondes and aircraft data and show the wind speeds for the samples. Typical wind speeds are in the range 5-20 m/s, though lower and higher speeds are obtained (not shown in these summary statistics).
- The range in wind directions cannot be seen in the tables because U and V components are used to derive the statistics. The range in derived wind direction can easily be seen in the plotted wind vectors. An example was shown earlier.

Evaluation of the effect of required algorithm inputs

- Required Algorithm Inputs
  - VIIRS SDR granule files containing science data (radiances) for 16 Moderate Resolution Bands over north and south polar region. Each polar pass has 14 ~ 18 granules.
  - VIIRS granule files containing geolocation data.
  - VIIRS granule files containing cloud data over polar region.
  - The 0.25 degree global AVHRR only Daily OISST.
  - GFS 6-hour global forecast data at 0.5 degree in GRIB2 format from NCEP (Vertical profiles of NWP temperature, wind, and pressure; NWP level for the surface and tropopause)
- Upstream algorithms: Cloud detection (VCM) and properties (Cloud phase/type and top pressure)
- Evaluation of the effect of required algorithm inputs: Sensitivity to input cloud products. As an example, see the NDE 1.0 vs 2.0 Southern Hemisphere case later.

Quality Indicators

- All derived winds are subject to the following quality assurance checks and are flagged if test thresholds are exceeded
  - SSD correlation check (threshold = 0.60)
  - Correlation match occurs on the boundary of the search scene
  - u- and v-component acceleration checks (threshold = 10 m/s)
  - Minimum speed check (threshold >= 3 m/s)
  - Directional (threshold = 50 deg) and speed checks (threshold = 8 m/s) against forecast
- Quality indicators are computed and appended to each derived wind vector
  - Quality Indicator (QI)
  - Expected Error (EE)

Quality Indicators, cont.

- QI Component Tests:
  - AMV Direction Consistency Check
  - AMV Speed Consistency Check
  - Vector Consistency Check
  - Spatial Consistency Check
    - Test of the spatial wind consistency of the AMV with its closest neighbor.
  - Forecast Check (Optional)
    - Comparison of AMV against NWP wind interpolated to AMV location and time.
- Expected Error (EE)
  - Originally developed at the Australian Bureau of Meteorology (LeMarshall et al., 2004) as an alternative to the QI.
  - Based on a linear regression of collocated AMV – RAOB vector differences using predictors that include the QI consistency tests and other vector and NWP information
  - Regression produces an error estimate in m/s rather than a normalized score.

Quality Indicators, cont.

- Both the QI and EE have their strengths. The EE estimated vector reliability values have a closer 1-to-1 relationship with actual RMS errors measured against raobs. The QI tends to rank more vectors as reliable, especially fast AMVs.
- Both methods are used as AMV quality flags. Users can selectively employ the flags in their local quality control.
- AMVs that pass both EE and QI thresholds are kept.

Exception Handling

- The algorithm checks whether the time interval is valid and that the temporal data has been loaded properly.
- The algorithm checks that the search region is larger than the target scene.
- The algorithm checks the sensor data flags to see if channel data is valid.
- If the AMV retrieval is not performed, the retrieved parameters are set to a missing value and the quality flags are set to the lowest quality value.

Error Budget

Compare analysis/validation results against requirements, present as a table. Error budget limitations should be explained. Describe prospects for overcoming error budget limitations with future improvement of the algorithm, test data, and error analysis methodology.

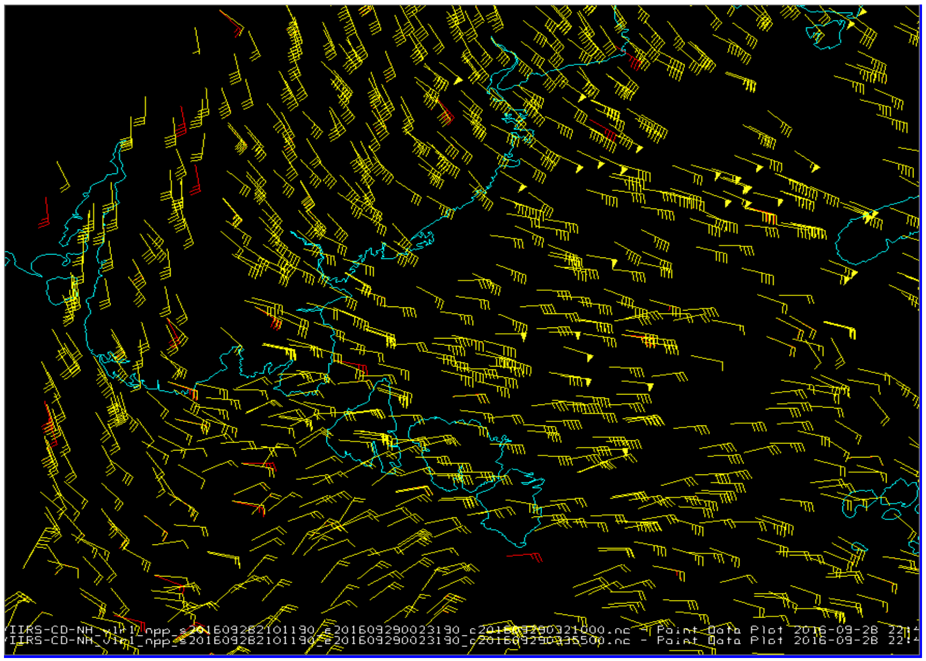
Attribute Analyzed	L1RD Threshold	Analysis/Validation Result	Error Summary	Support Artifacts
Accuracy	7.5 m/s	5.7-7.0 m/s	-	Raob, aircraft val tables
Precision	4.2 m/s	2.7-3.8 m/s	-	Raob, aircraft val tables
Horizontal cell size	10 km	19 km (inherent to the algorithm)	Change the requirement as it is an error	
Mapping uncertainty	0.4 km nadir; 1.5 km EOS	0.57 km		MS2GT and McIDAS

Identification of Processing Environment

- ESPC (e.g., NDE, Okeanos) build (version) number: NDE 1.0 (see next slide for NDE 2.0 test)
- Algorithm version: v1r1
- Environment used to achieve validated maturity stage: NDE 1.0

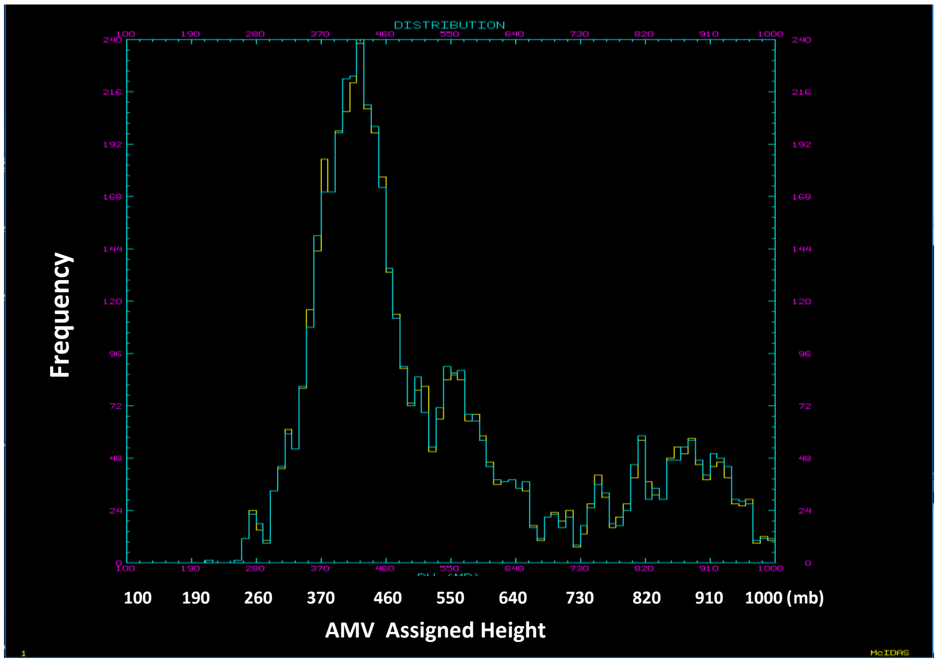
NDE 1.0 vs 2.0: Northern Hemisphere

VIIRS Winds from NDE 1.0 VIIRS Winds from NDE 2.0



Nearly all of the yellow and red wind barbs fall exactly on top of each other. There a few red wind barbs where corresponding yellow wind barbs don't exist, but this is not a concern.

AMV Heights from NDE 1.0 AMV Heights from NDE 2.0

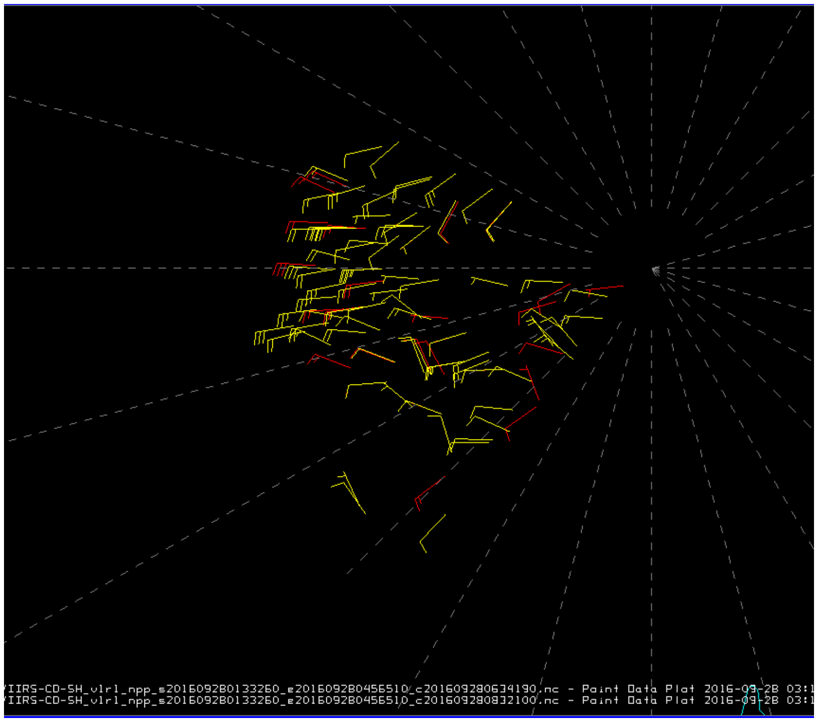


The histograms of heights assigned to the winds in both systems agree very, very well.

In the NH case, the vast majority of winds (location, speed, direction, height) from NDE 1.0 and NDE 2.0 matched up exactly for the cases examined.

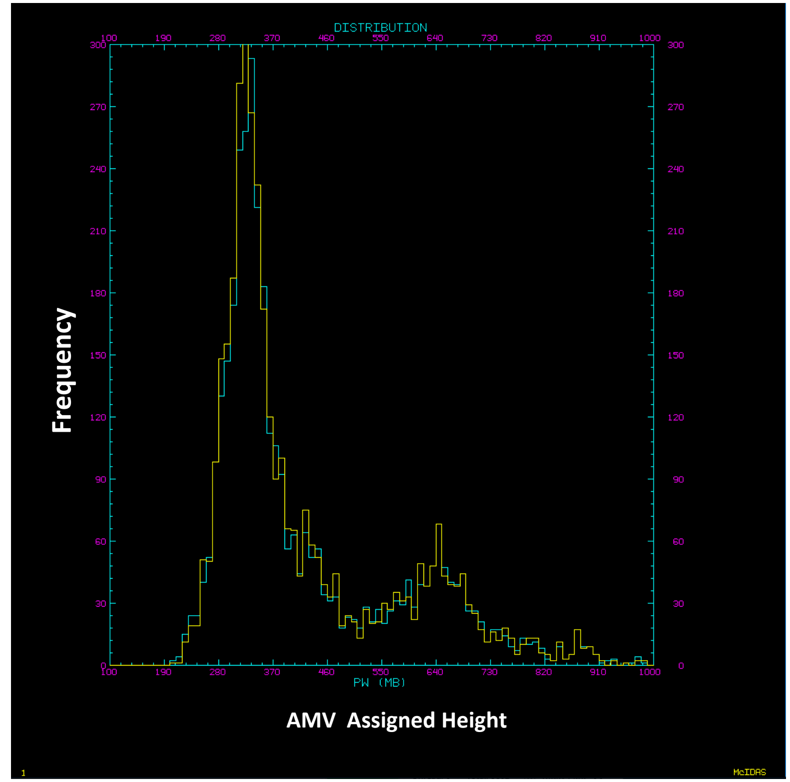
NDE 1.0 vs 2.0: Southern Hemisphere

VIIRS Winds from NDE 1.0   VIIRS Winds from NDE 2.0



Nearly all of the yellow and red wind barbs fall exactly on top of each other. There a few red wind barbs where corresponding yellow wind barbs don't exist.

AMV Heights from NDE 1.0   AMV Heights from NDE 2.0



The histograms of heights assigned to the winds in both systems agree very, very well.

In the SH case there are more differences between the NDE 1.0 and NDE 2.0 VPW winds, which we attribute to known errors in the cloud mask.

Users

- 13 NWP centers in 9 countries of polar winds, most using VIIRS winds operationally
- U.S. Users:
  - NCEP (Dennis Keyser)
  - NRL/FNMOC (Randy Pauley)
  - GMAO/JCSDA
- Foreign Users:
  - UK Met Office (Mary Forsythe)
  - JMA (Masahiro Kazumori)
  - ECMWF (Jean-Noel Thepaut)
  - DWD (Alexandar Cress)
  - Meteo-France (Bruno Lacroix)
  - CMC (Real Sarrazin)
  - BOM (John LeMarshall)
  - EUMETSAT (Simon Elliott)
  - Russian Hydrometcenter (Mikhail Tsyrulnikov)
  - CMA (China)

Users, cont.

Organization	Use VPW operationally	Currently monitoring	Plan to use?
NCEP		Yes	Yes (early 2017)
DWD	Yes		
Navy	Yes		
ECMWF	Yes		
Met Office		Yes	Yes
CMC	Yes		
MeteoFrance		Yes	Yes

Awaiting information from the other NWP centers.

Users & User Feedback

- Feedback from users
  - Over the last decade, model impact studies at >10 major NWP centers have demonstrated that model forecasts for the NH and SH extratropics are improved when the MODIS polar winds are assimilated. Forecasts can be extended 2-6 hrs, depending on the location.
  - NWP users have reported similar results for the VIIRS Polar Winds, as reported at the most recent International Winds Workshop (2016, Monterey) and at other venues.
  - Many NWP centers are either testing the VWP or using them in their operational system.
- Downstream product list: None

Documentation

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

Conclusion

- Cal/Val results summary:
  - Team recommends algorithm Validated Maturity
  - Caveats: None

Path Forward

- Planned further improvements for NDE 2.0:
  - The Enterprise cloud mask will be used.
  - Spatial coverage will be increased by about 5º latitude.
- Planned Cal/Val activities / milestones: See cal/val plan

Extra Slides

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.

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