Stability and Interconsistency of Passive Microwave Products for Weather and Climate Users

John Forsythe, CIRA

August 11, 2016

Presentation to Global Space-Based Inter-Calibration System (GSICS) Users Workshop

CIRA Connecting Models and Observations

NOAA • NESDIS JPSS Joint Polar Satellite System

Outline

1. Differences in needs of weather and climate users
2. Blended hydrometeorological products for forecasters (Total and Layered Precipitable Water)
3. Total Precipitable Water Climate Record (NVAP-M)
4. Connections to GSICS

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Weather and Climate Users of Water Vapor Products have Different Needs

Weather	Climate
Retrieval algorithms can be updated frequently	Need constant retrieval algorithm though time
Introduce new sensors as soon as practical	New sensors might cause discontinuities in existing records
Polar orbiters in equally spaced orbits desirable	Overlapping sensors in some orbit (e.g. NASA A-Train) desirable for intercomparison
Accuracy less important, images which represent gradients and moisture flow are key.	Absolute accuracy and precision are critical for things like reanalysis/model comparison and trend analysis
Latency of less than a few hours required	Latency not a key issue

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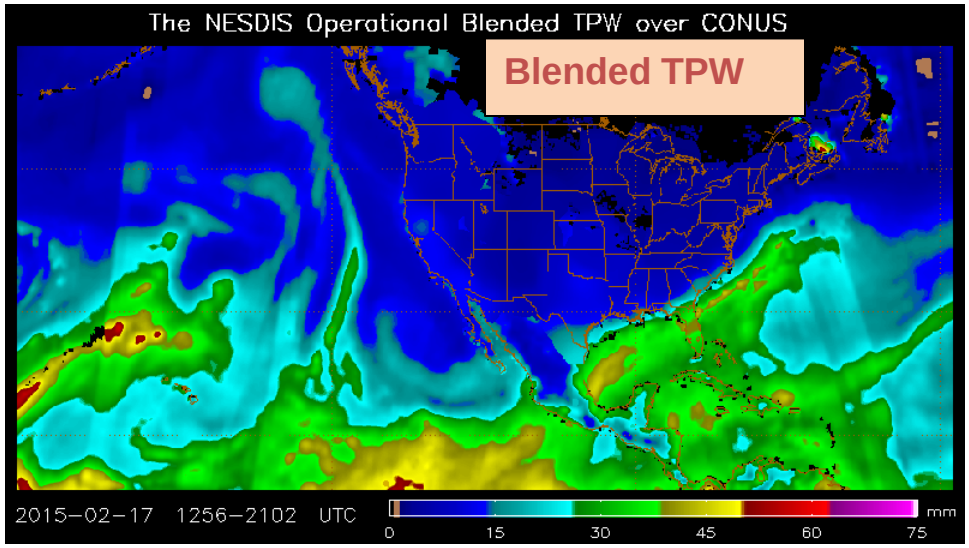
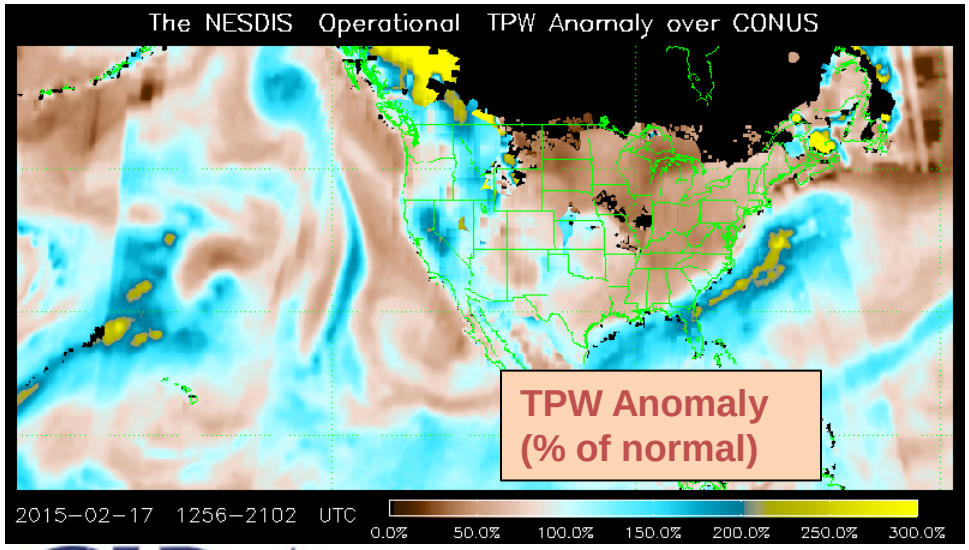
Part 1: Weather

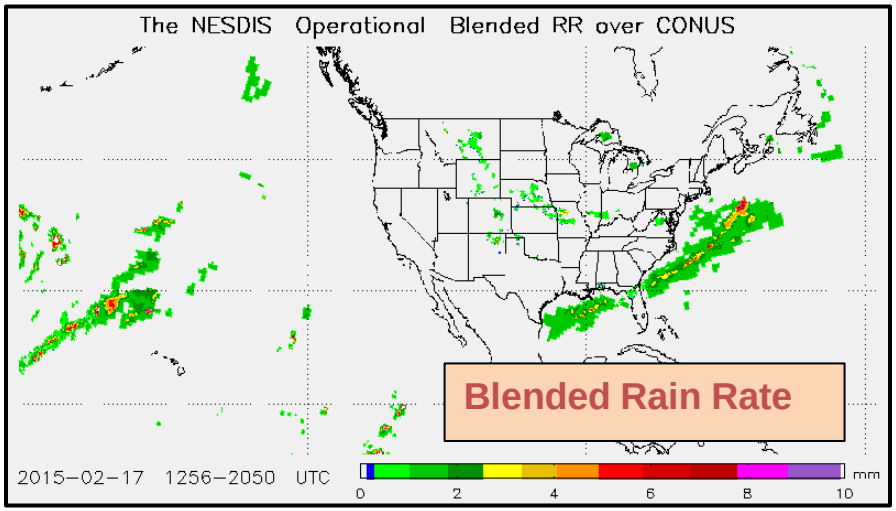
Operational NOAA Blended TPW, TPW Anomaly and Rain Rate show forecasters where the action is. Layer Precipitable Water (LPW) non-operational but being used by national centers.

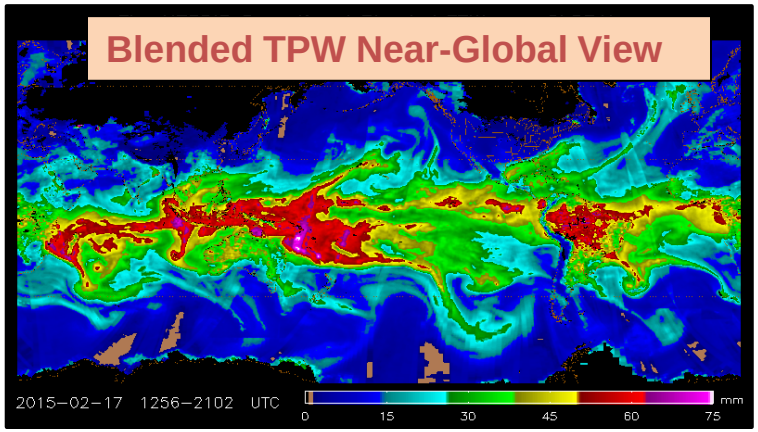




- Near-global, from 71° S to 71°N
- Moisture and rainfall can be tracked for extreme precipitation events
- Produced every hour. Mostly from NOAA MiRS retrievals (Boukabara et al.). Surface GPS and GOES Sounder also used near CONUS.

http://www.ospo.noaa.gov/Products/bTPW/index.html





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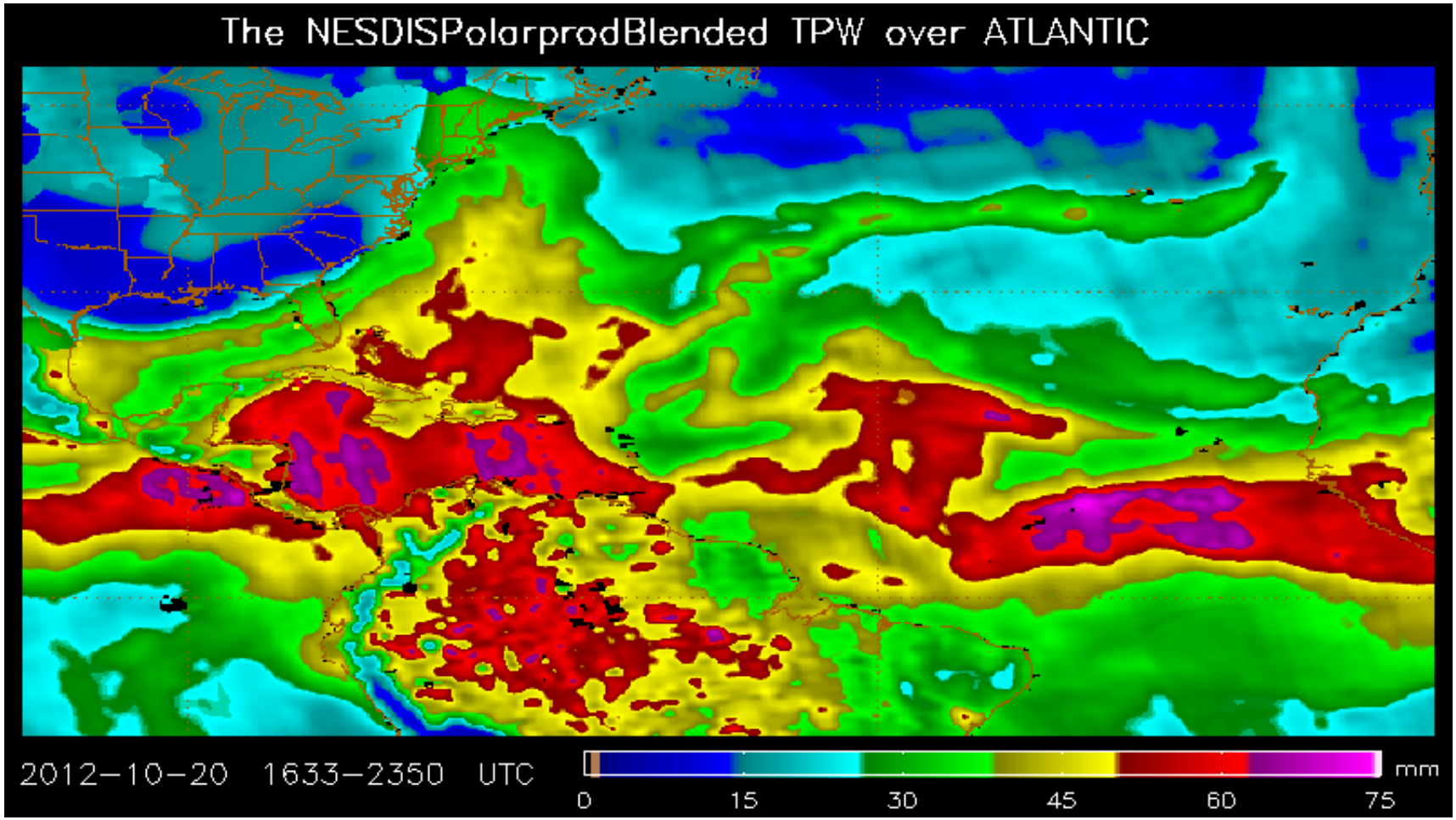
Blended Products from Polar Satellites Allow Forecasters to Track Moisture Flow



Ten Day Animation of Blended TPW during Hurricane Sandy (2012)

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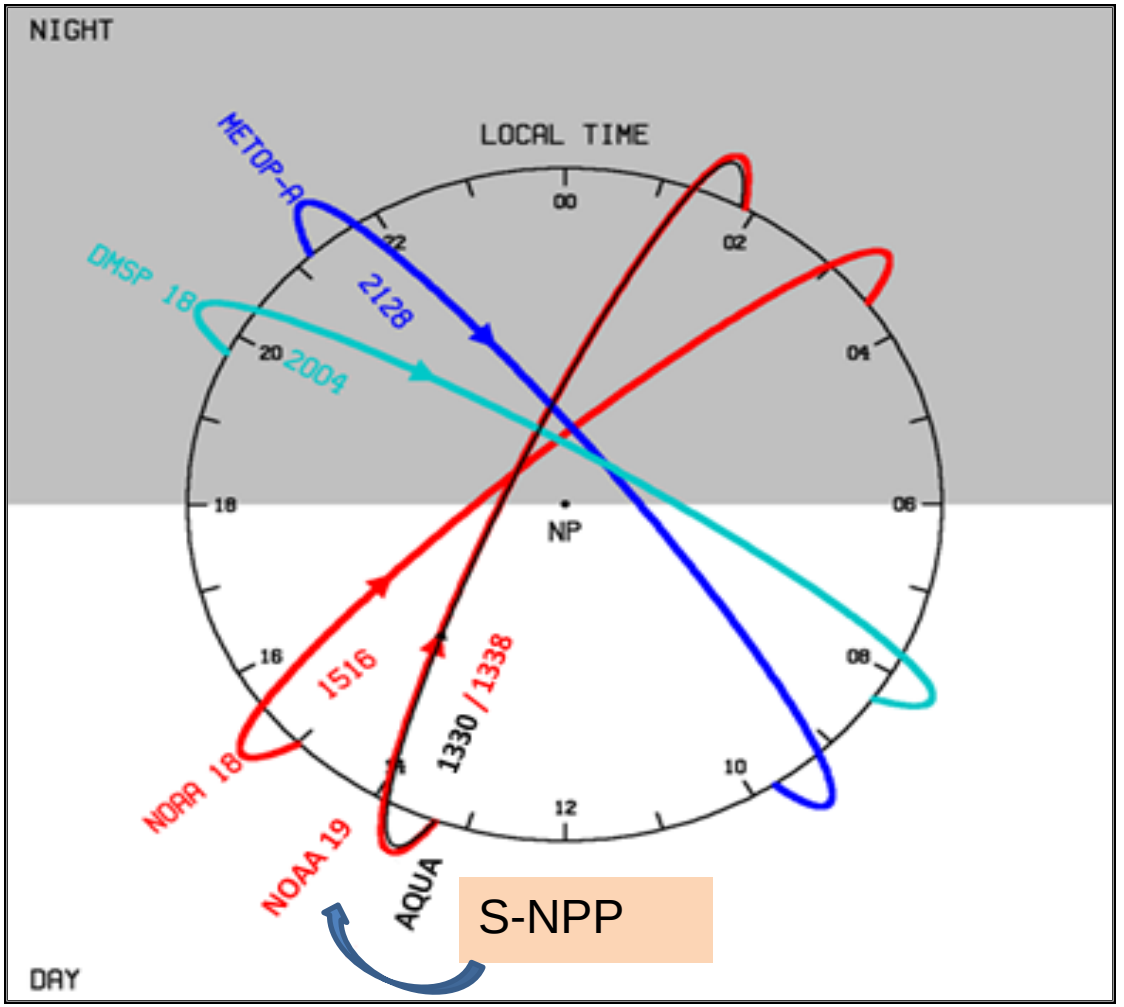
Frequent updates on intercalibration and sensor biases to NOAA MiRS group essential for quality near-realtime products.

Science Issue

- Forecasters are faced with an overwhelming variety of satellite data for analysis.
- Blended products - merging multiple sensors into one product - consolidate this data into easy-to-use observational products.
- How do we merge disparate sensors in space, time, and algorithm to create a seamless blended product? How do we know it's helping forecasters? Can we feed back anomalies to algorithm developers to inform efforts like GSICS?

“Clock Diagrams” show local time sampling of polar sensors used

Current configuration for Layer Precipitable Water: Periods of high sampling and no sampling



Older satellites play a valuable role in extending temporal sampling

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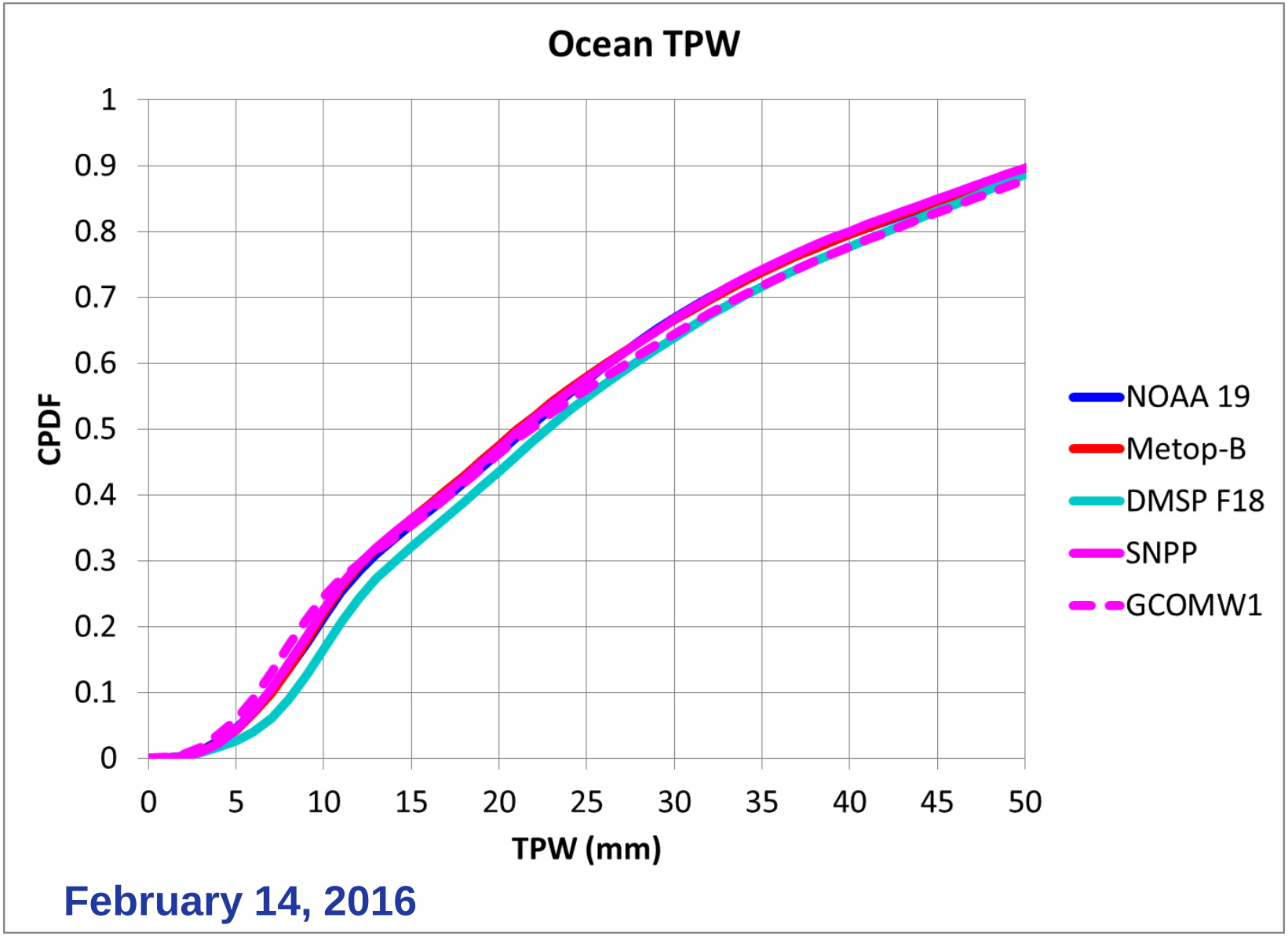

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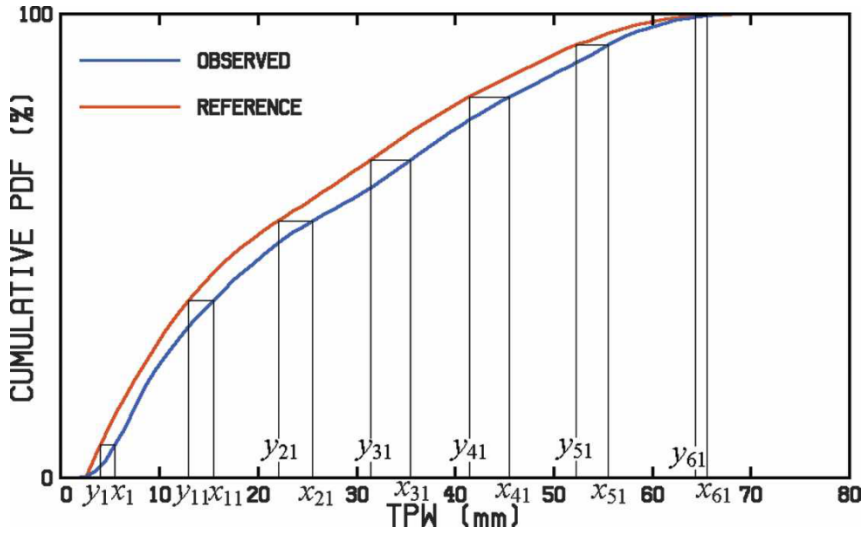
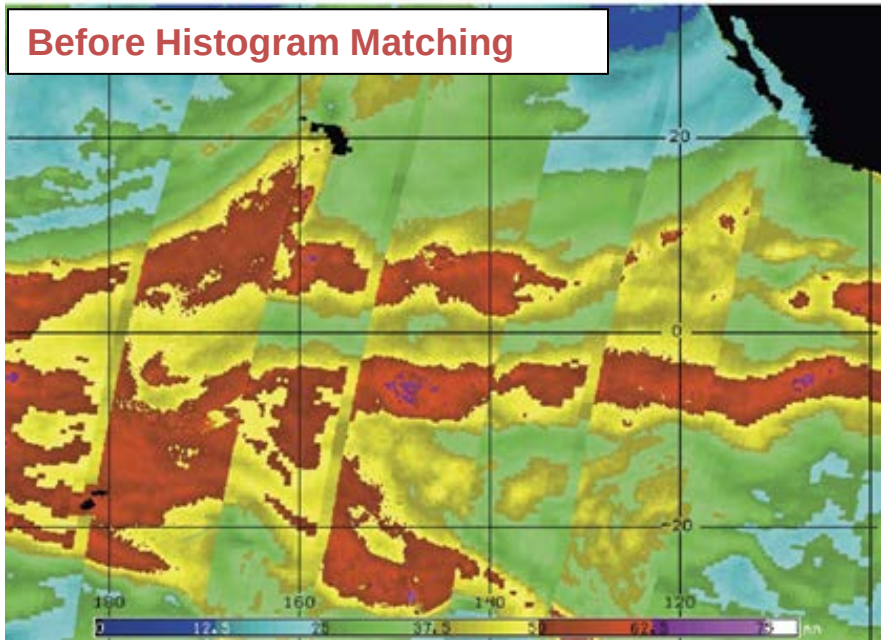
Removing Artifacts Which Distract Forecasters

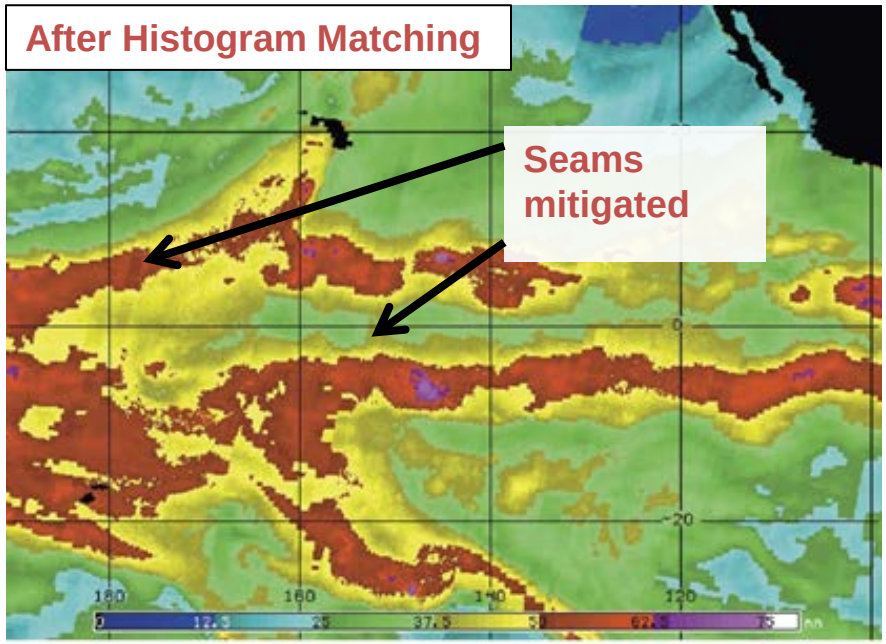
5-day scan angle-dependent histogram matching is applied to the NOAA operational blended Total Precipitable Water vapor product (over ocean).

SNPP MiRS V11 is current reference product. Makes the other sensors look more like it.



TPW example of histogram matching





Kidder and Jones, J. Atmos Ocean. Tech. 2007

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Adding the Vertical Dimension to Water Vapor

CIRA and NASA completed an initial demonstration of a near-realtime Layer Precipitable Water (LPW) product (4 layers; every 3 hours) in 2013. Science development continuing under JPSS Proving Ground.

- **NASA AIRS and six MiRS sounding spacecraft used (NOAA-18/19,Metop-A/B, DMSP F18, S-NPP)**
- **Forecast applications include moisture flow for heavy precipitation, tropical cyclone genesis and intensification**

Further details in Forsythe, J. M., S. Q. Kidder, K. K. Fuell, A. LeRoy, G. J. Jedlovec, and A. S. Jones, 2015: A multisensor, blended, layered water vapor product for weather analysis and forecasting. J. Operational Meteor., 3, 41-58.

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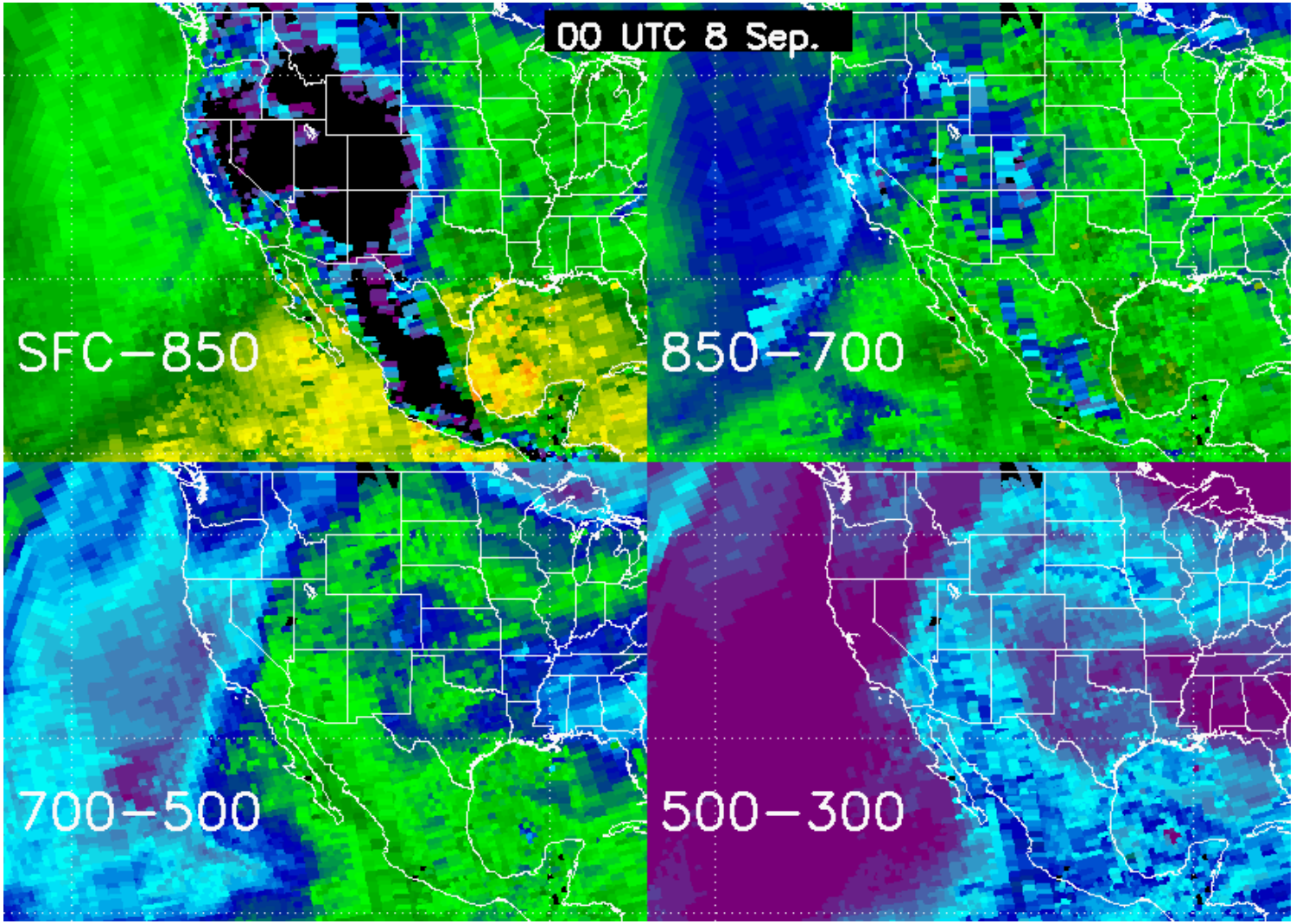
Four-layer LPW leading up to the Colorado Front Range floods in September 2013



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Delivering Existing Layer Precipitable Water Product to National Centers

MESOSCALE PRECIPITATION DISCUSSION 0530
NWS WEATHER PREDICTION CENTER COLLEGE PARK MD
1016 AM EDT TUE SEP 29 2015

CONCERNING...HEAVY RAINFALL...FLASH FLOODING LIKELY

SUMMARY...A TROPICAL AIRMASS WITH NEAR RECORD PRECIPITABLE WATER WILL RESULT IN A CONTINUED FLOOD AND FLASH FLOOD THREAT INTO THIS AFTERNOON.

...

FORCING FROM THE SHORTWAVE IN GA AND A GENERALLY DIVERGENT PATTER ALOFT IS HELPING FORCE ASCENT ON THE LARGE SCALE...WITH 20-30 KTS OF LOW LEVEL UPSLOPE FLOW AIDING IN LIFT. LAYERED PRECIPITABLE WATER PRODUCTS SHOW AN IMPRESSIVE COMBINATION OF FACTORS CONTRIBUTING TO THE NEAR RECORD PRECIPITABLE WATER VALUES ACROSS THIS REGION. A CONNECTION TO THE PACIFIC AND TROPICAL STORM MARTY CAN BE SEEN IN THE MID/UPPER LEVELS...WITH A DEEP LAYER CONNECTION TO THE GULF OF MEXICO AND ALSO TROPICAL STORM JOAQUIN IN THE ATLANTIC. THIS IS ALL RESULTING IN A VERY EFFICIENT ATMOSPHERE FOR HEAVY RAIN RATES. THE ONE THING LACKING IS INSTABILITY...BUT AT LEAST SOME DOES EXIST ACROSS THE AREA AS NOTED BY SOME LIGHTNING AND COLDER CLOUD TOPS…

Example NOAA WPC usage of LPW for flooding in New England

AXNT20 KNHC 301212
TWDAT

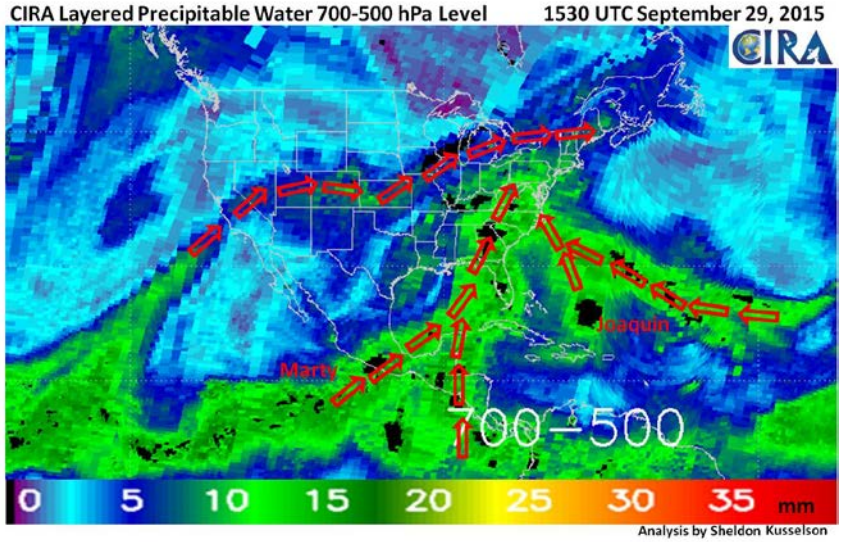
TROPICAL WEATHER DISCUSSION
NWS NATIONAL HURRICANE CENTER MIAMI FL
805 AM EDT WED SEP 30 2015

...

A TROPICAL WAVE IS IN THE CENTRAL ATLC WITH TILTED AXIS EXTENDING FROM 16N36W SW TO A 1009 MB LOW PRESSURE CENTER EMBEDDED IN THE MONSOON TROUGH NEAR 11N39W...MOVING W AT 5-10 KT. CIRA LAYER PRECIPITABLE WATER IMAGERY SHOW THE WAVE IS EMBEDDED IN A MODERATE MOIST ENVIRONMENT FROM THE SURFACE TO 850 MB. HOWEVER...SOME DRY AIR INTRUSION IS ALSO DEPICTED IN THE N-NW WAVE ENVIRONMENT...WHERE METEOSAT ENHANCED IMAGERY SHOW DRY AIR AND DUST.

Example NHC usage of LPW

Five streams of moisture fuel flooding in SC



Part 2: Climate

Featuring the NASA Water Vapor-MEaSUREs Global Total and Layered Water Vapor Record (1988-2009)

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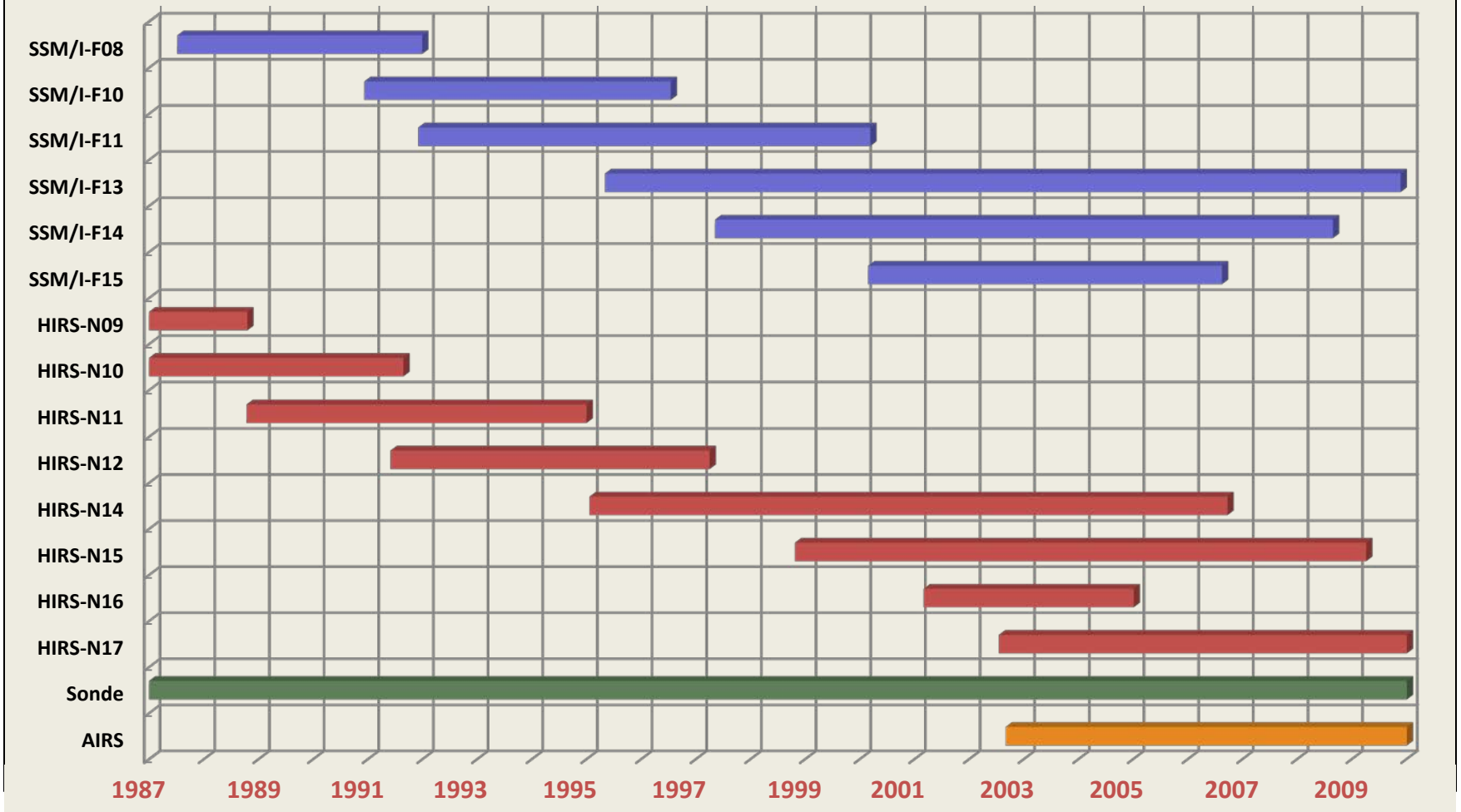
NASA Water Vapor (NVAP-M) Climate Product: Sensor Timeline



More confidence in later period due to increased observations

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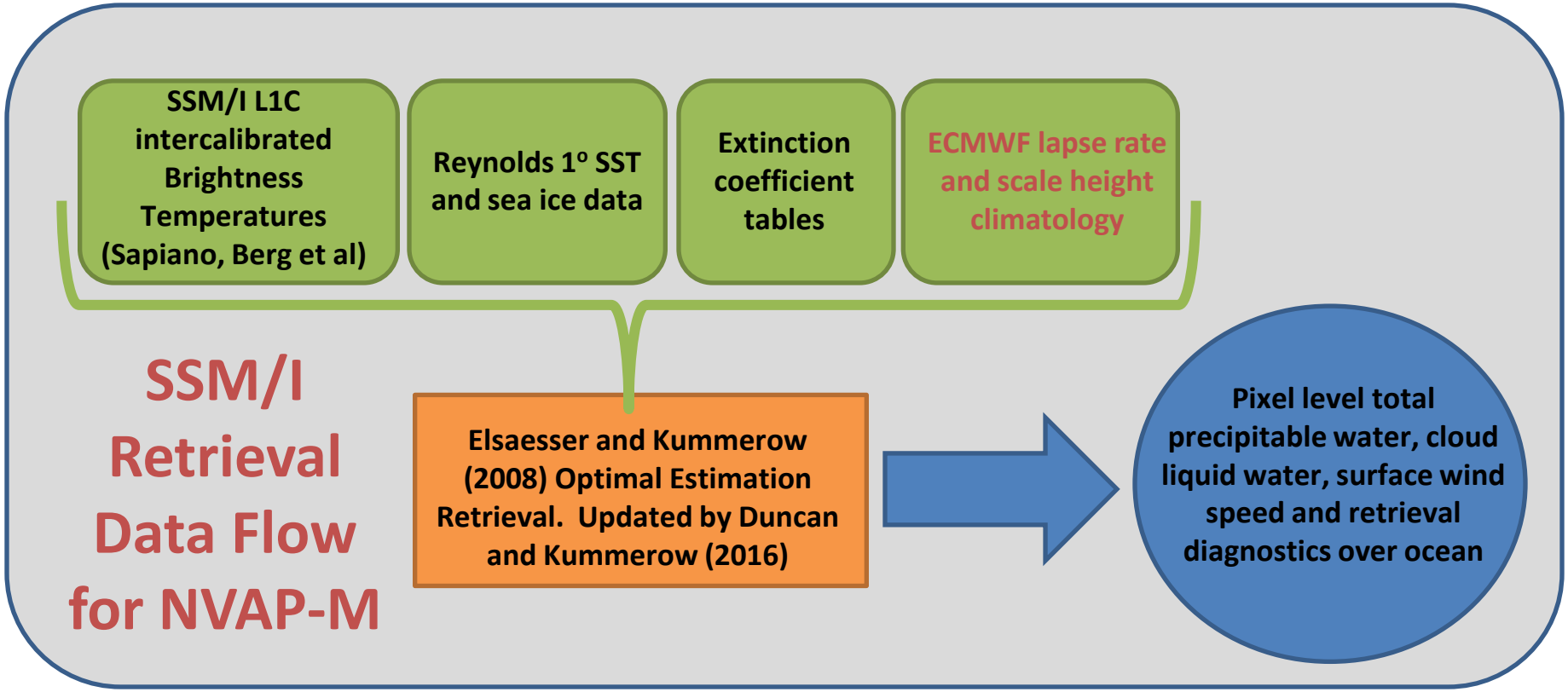
SSM/I is the backbone sensor of NVAP-M; efforts in Intercalibration have paid off



At the time of NVAP-M production (2012), we did not judge the 183 GHz radiance record (AMSU-B, SSM/T-2) to be sufficiently intercalibrated to consider for this climate record.

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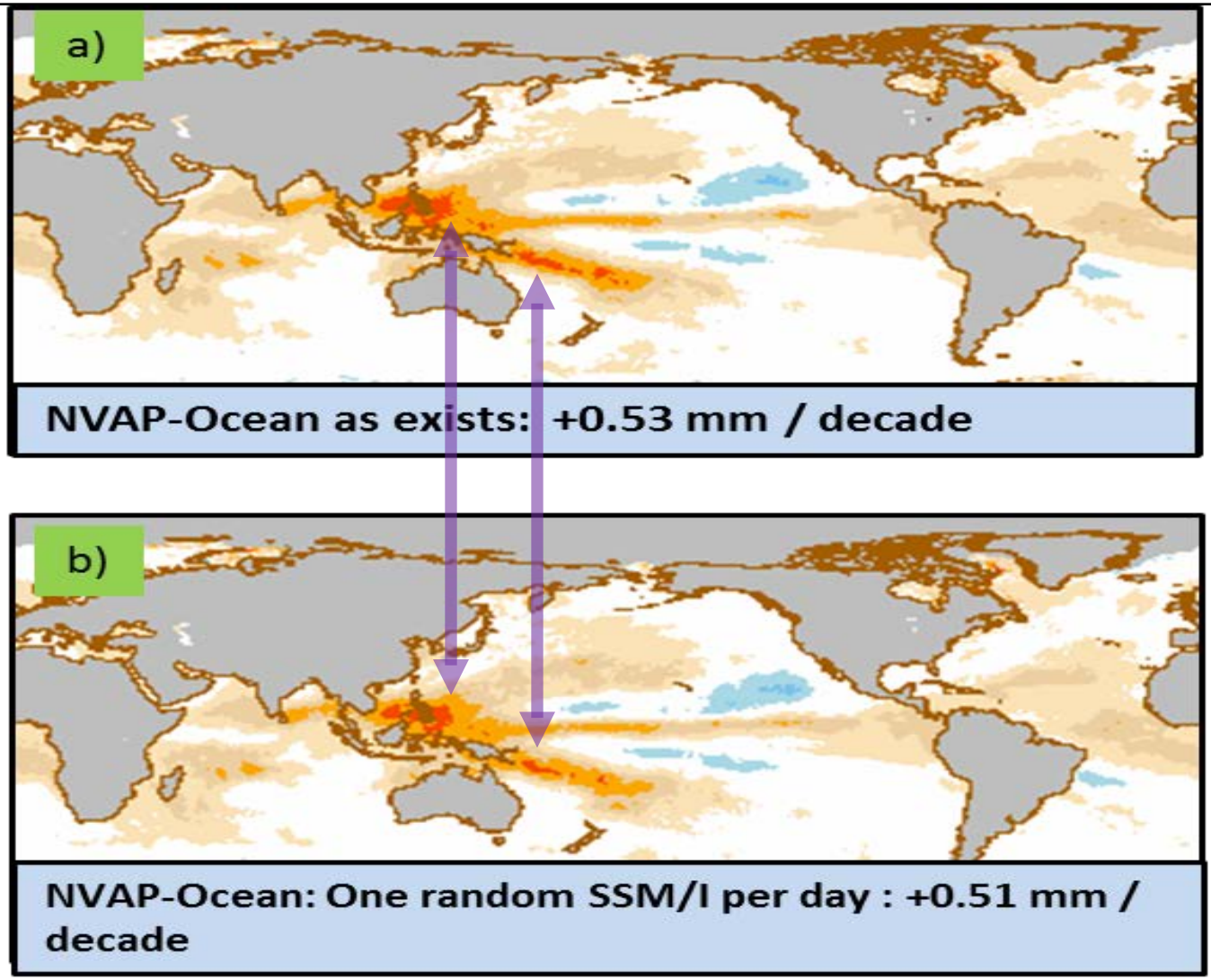
TPW Trend in NVAP-M Ocean (1988 – 2009 data)



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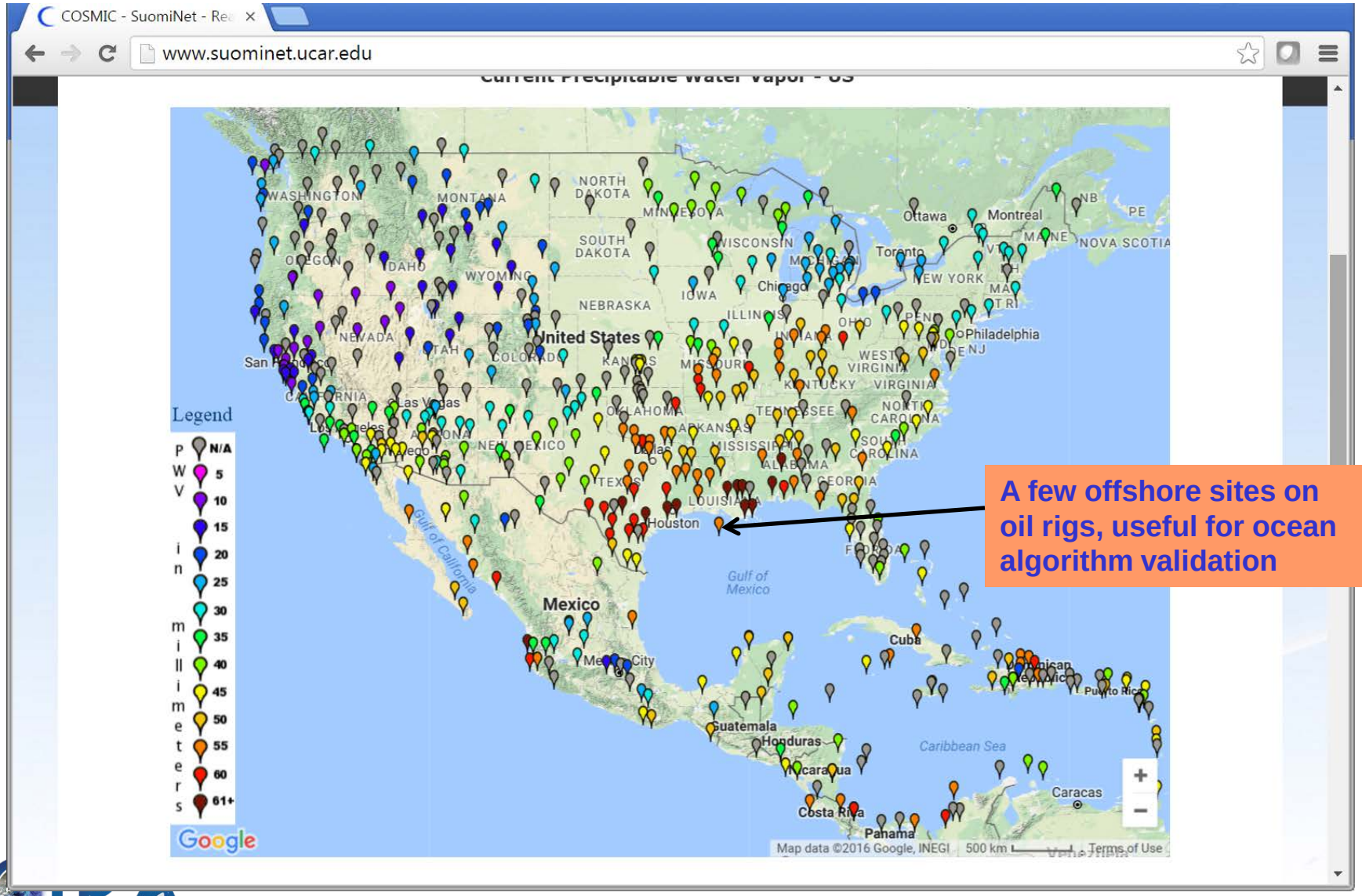
Surface GPS sites measure TPW every half hour within better than 2 mm or 5%, we consider them as the best validation source



Suominet GPS TPW, 1900 UTC July 28, 2016

Connecting Models and Observations

Atmos. Meas. Tech., 9, 2207–2221, 2016
www.atmos-meas-tech.net/9/2207/2016/
doi:10.5194/amt-9-2207-2016

Atmospheric Measurement Techniques
Open Access
EGU

- Recent sensor radiances compare to < 1 K
- Spectroscopy and cloud clearing likely causing observed up to 3 K differences

2015 workshop on 183 GHz uncertainties

A review of sources of systematic errors and uncertainties in observations and simulations at 183 GHz

Hélène Brogniez[1], Stephen English[2], Jean-François Mahfouf[3], Andreas Behrendt[4], Wesley Berg[5], Sid Boukabara[6], Stefan Alexander Buehler[7], Philippe Chambon[3], Antonia Gambacorta[8], Alan Geer[2], William Ingram[9], E. Robert Kursinski[10], Marco Matricardi[2], Tatyana A. Odintsova[11], Vivienne H. Payne[12], Peter W. Thorne[13], Mikhail Yu. Tretyakov[11], and Junhong Wang[14]

[1]LATMOS (IPSL/UVSQ/UPMC/CNRS), 78280, Guyancourt, France
[2]ECMWF, Reading, RG2 9AX, UK
[3]CNRM/GAME, Météo-France/CNRS, Toulouse, 31057, France
[4]University of Hohenheim, Institute of Physics and Meteorology, 70599 Stuttgart, Germany
[5]Colorado State University, Fort Collins, CO, USA
[6]NOAA, USA, Camp Spring, MD, USA
[7]Meteorological Institute, Center for Earth System Research and Sustainability, University of Hamburg, Hamburg, Germany
[8]Science and Technology Corporation, Columbia, MD, USA
[9]MetOffice, Hadley Centre, Exeter, UK and AOPP, Department of Physics, Oxford, UK
[10]Space Sciences and Engineering, Boulder, CO, USA
[11]Institute of Applied Physics of the Russian Academy of Science, Nizhny Novgorod, Russia
[12]JPL, California Institute of Technology, Pasadena, CA, USA
[13]Department of Geography, Maynooth University, Maynooth, Ireland
[14]State University of New York, Albany, NY, USA

Opportunities exist to add passive microwave water vapor profile to climate record

Needs From and Feedback To GSICS

- **NOAA MiRS team continue to receive updated Level 1 radiance regularly so that Level 2 products and blended products have artifacts minimized.**

- **SSM/I L1C radiance intercalibration very useful for climate, allows trend studies.**

- **183 GHz record in particular is important for weather applications, and for climate records of water vapor (upper tropospheric moisture feedback). Noted inconsistencies among measurements / RTM's at 183 GHz (Brogniez et al. 2016)**

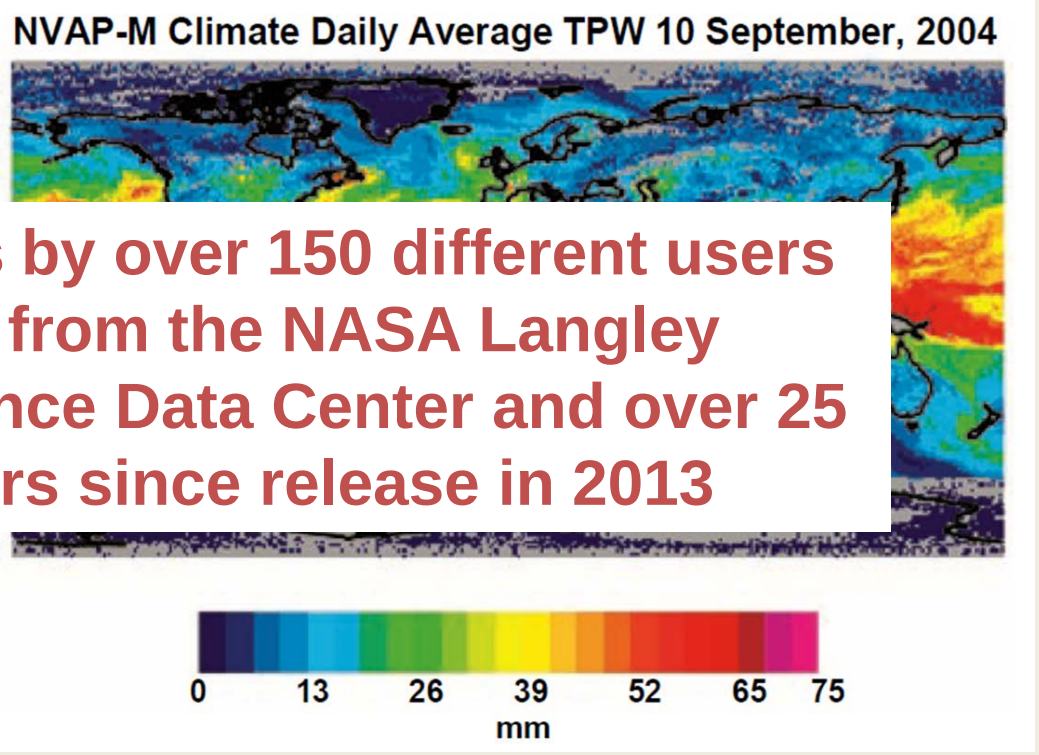
- **"Image validation" from near-realtime weather is a useful form of determining product quality throughout all seasons and weather regimes. For example, a MiRS cold land TPW artifact was noticed and reported.**

Backup Slides

NASA Water Vapor Project – MEaSUREs

- **Reanalysis**, **extension** (1988-2009) **and replacement** of the heritage NVAP (1988-2001) dataset
- **Global** (land and ocean) data designed for weather, climate and hydrology users
- Total (TPW) and layered (LPW) precipitable water
- **Removes time-dependent biases** caused by
  - dataset and
  - multi-phase
    - Focus
      review
      time.
- **Back-propag**
  through the
    - Collaboration with AIRS water vapor project at NASA JPL. (E. Fetzer et al.)
- Highly model-independent
- **Available at NASA Langley Atmospheric Science Data Center (ASDC):** https://eosweb.larc.nasa.gov/project/nvap/nvap-m_table

Similar in concept to GPCP, ISCCP, but with three products: Climate, Weather, Ocean.

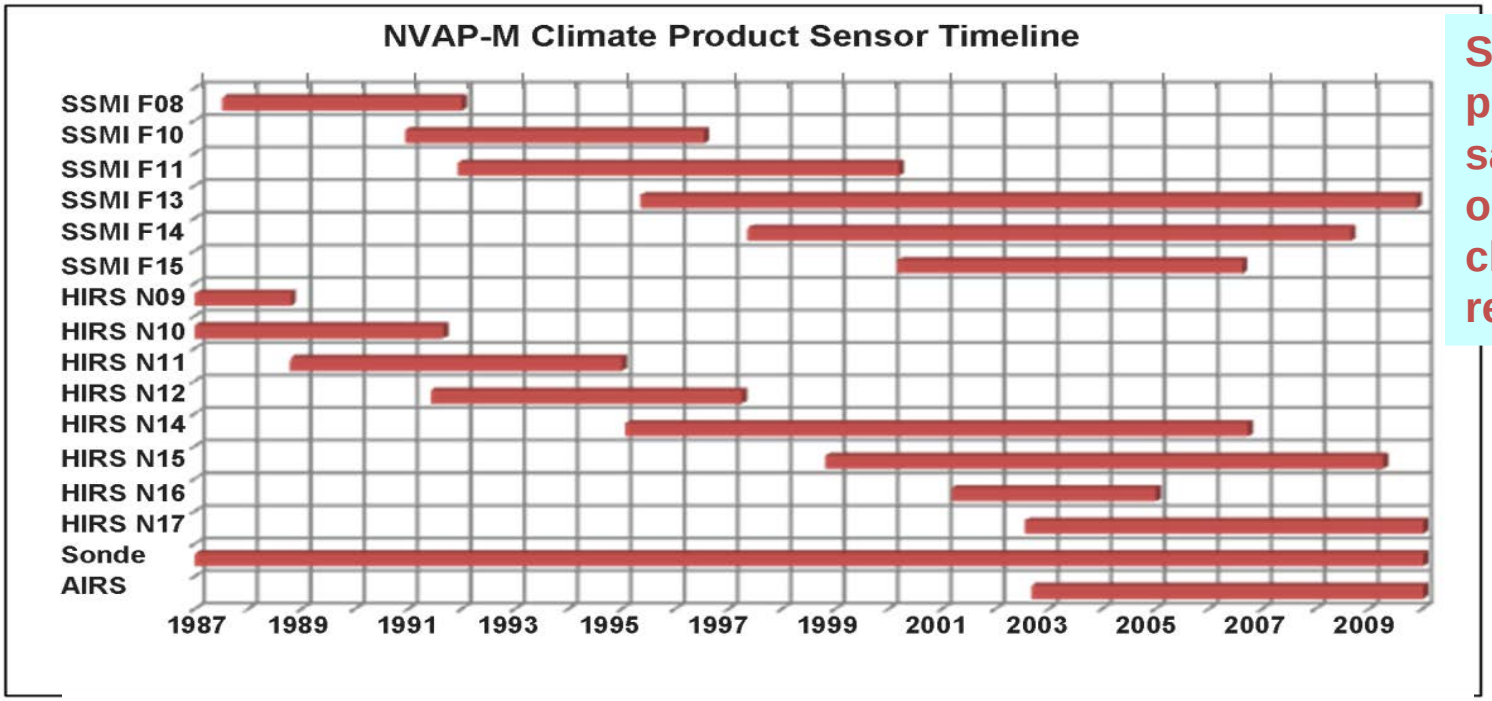


> 300 withdrawals by over 150 different users of the dataset from the NASA Langley Atmospheric Science Data Center and over 25 refereed papers since release in 2013

Vonder Haar et al. 2012: Weather and climate analyses using improved global water vapor observations. *Geophys. Res. Lett.*, **39**, L15802. doi:10.1029/2012GL052094.

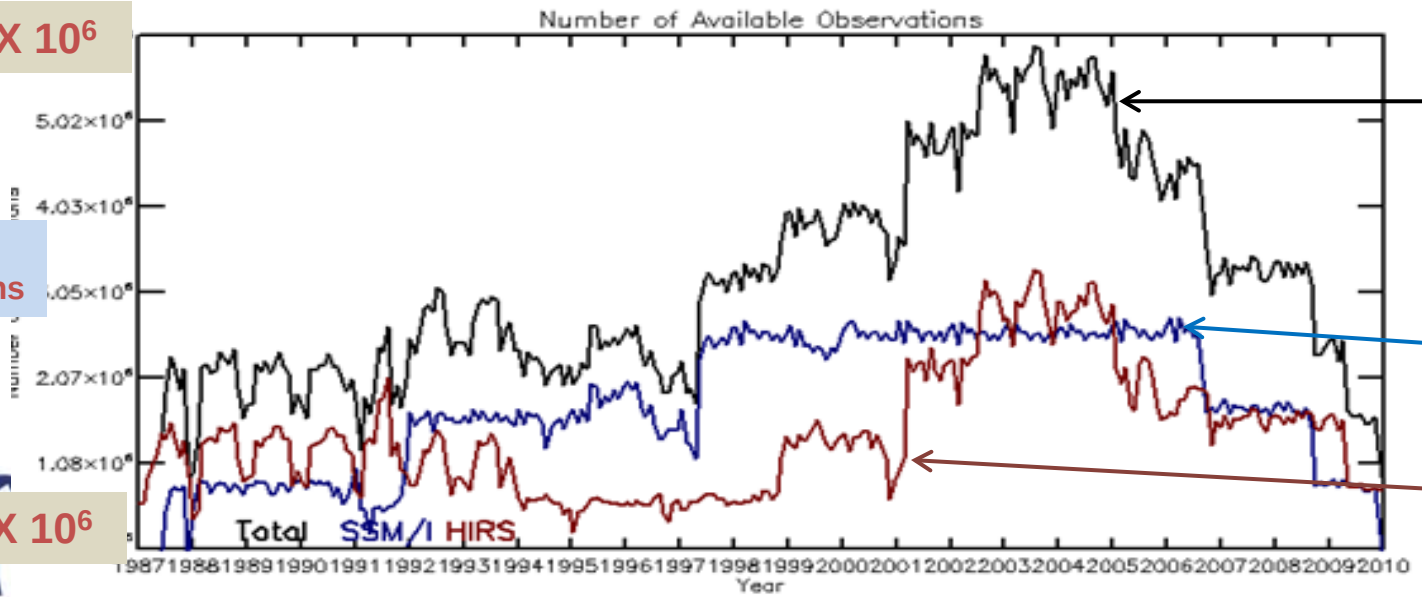
"NVAP-M" refers to the new NVAP-MEaSUREs data set. "Heritage NVAP" refers to the existing dataset described by Randel et al., 1996

The challenge of creating a multisensor, multidecadal, global water vapor climate record



Sensors preferentially sample ocean or clear regions.

6 X 10^6



Number of Observations

Total

SSM/I (ocean only)

HIRS (clear only)

1 X 10^6

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Creating the Product

- **LPW Product is created from NOAA Microwave Integrated Retrieval System (MIRS) soundings, and NASA AIRS soundings.**
- **Retrievals are independent of dynamic NWP models, allowing comparison**
- **Produced every 3 hours and mapped onto a 16 km resolution Mercator projection.**
- **Four layers created (sfc-850,850-700,700-500,500-300 hPa)**
- **NASA AIRS and Six MIRS sounding spacecraft currently used (NOAA-18/19,Metop-A/B, DMSP F18, Suomi-NPP).**

Strengths of surface-based TPW from GPS:

1. Low-cost
2. All weather
3. High temporal resolution (~ 20 minute, 24 h / day)
4. Accuracy
5. Untapped networks for seismology/volcanology exist
6. A few very dense networks (Japanese GEONET ~ 800 stations)

Limitations:

1. Sparse spatial coverage (centered on developed world, few ocean sites).
2. Climate record begins in 1995 at ~ 100 sites.

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Blended, layered water vapor products fill a void in observations

Moisture Product	Spatial Resolution and Coverage	Temporal Resolution	Strengths	Limitations
Radiosondes	~ 500 km over CONUS land, none over ocean	12 hours	Trusted High vertical resolution	Spatial and temporal coverage
GOES Water vapor channel (6.7 µm) imagery	4 km, near-hemispheric coverage	15 minutes or less	Very high spatial and temporal resolution Animations show flow	Upper level moisture only No vapor signal in high clouds Variable sensing depth
GOES Sounder retrievals	20 km, CONUS, Hawaii, Puerto Rico and adjacent waters only	1 hour	High spatial and temporal resolution Limited vertical structure	Clear sky only Forecast model dependence
Blended TPW	16 km, near global	1-3 hours (varies based on time of day)	Retrievals in clouds Near-global coverage Multiple types of inputs including very accurate GPS TPW	No profile information No retrievals in heavy precipitation

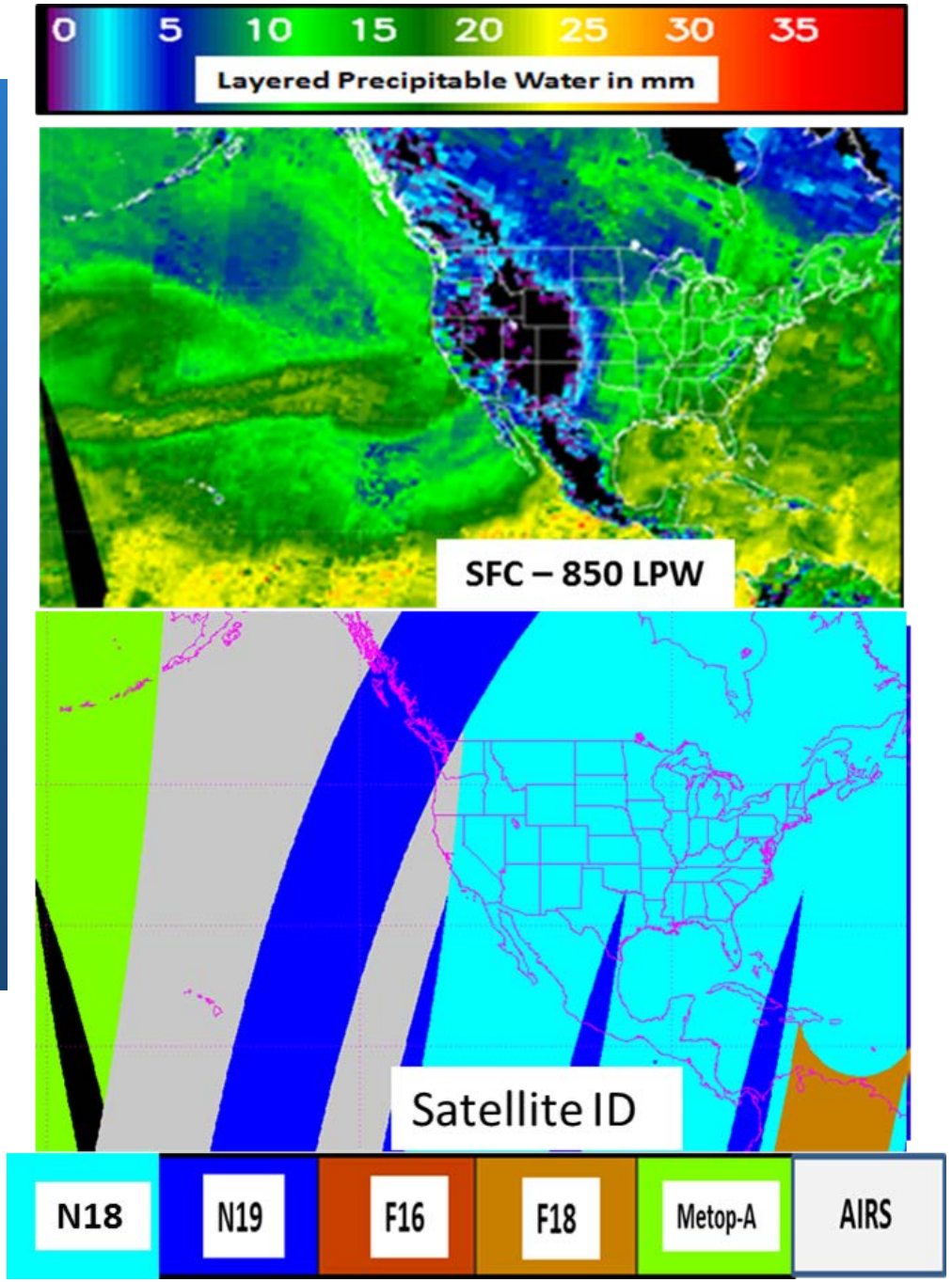
"…This is likely our most highly analyzed product in AWIPS during the monsoonal surges. The associated percent of normal graphics are also very useful" (NWS Albuquerque, NM)

"…This has been a fantastic product for monitoring trends since observation coverage from RAOB and aircraft over Mexico and Gulf of Mexico is poor." (NWS San Antonio, TX)

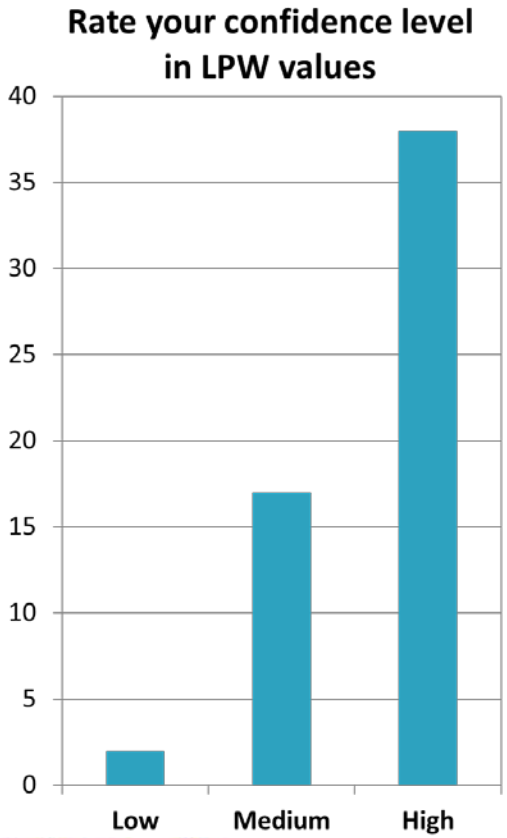
Passive microwave sensors allow a multitude of atmospheric and surface variables to be observed.

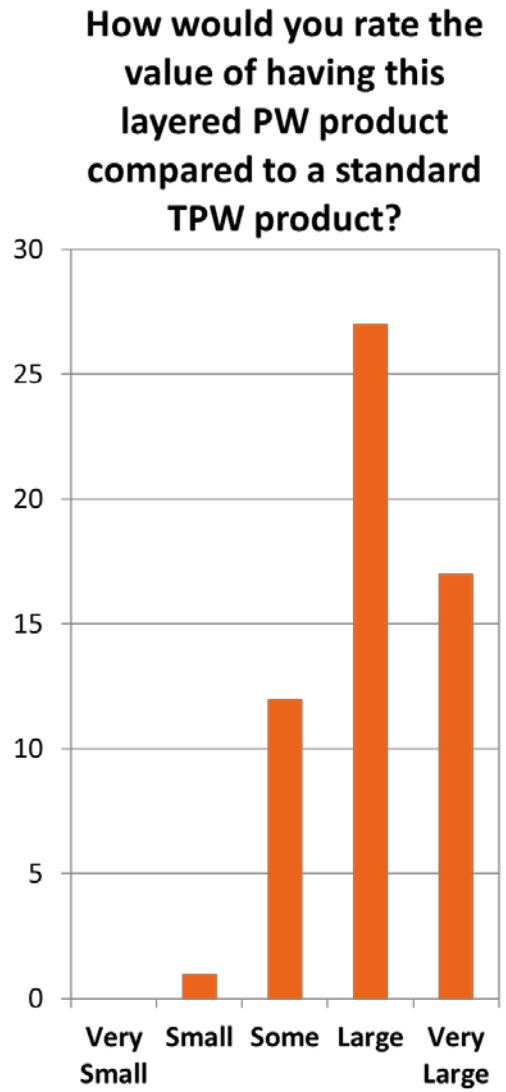
Key sensor in climate record of:

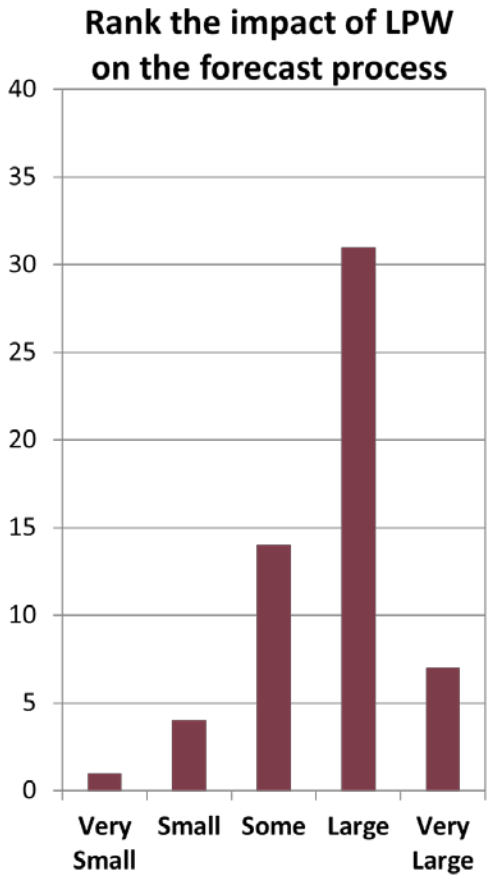
Precipitation
Sea ice
Water vapor
Ocean winds



NASA-led NWS forecaster survey of Alaska and Puerto Rico NWS offices during 2013 demonstration of Layered Precipitable Water







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Spacecraft and instruments used in blended TPW and Rain Rate:

Suomi-NPP

NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-19 (AMSU/MHS)

Metop-A, Metop-B (AMSU/MHS)

DMSP F18 (SSMIS)

Surface-based GPS TPW

GOES-W & E Sounder TPW

Currently merging 10 polar orbiters

New satellites are demonstrated at CIRA and added to operations

Major source of retrievals from polar spacecraft is the NOAA Microwave Integrated Retrieval System (MiRS)

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NVAP-M: A Three-Tiered Product Approach

Heritage NVAP begun in early 1990's was "one size fits all" approach.

NVAP-Weather

Used for weather case studies on timescales of days to weeks

- SSM/I Level 1 C intercalibrated radiances
- HIRS cloud cleared radiances
- Radiosonde, GPS since 1997
- AIRS Level 3 TPW and Layered PW

- Maximizes spatial and temporal coverage
- Not driven by reduction of time-dependent biases

- 4x daily
- ½ degree resolution
- TPW and layered precipitable water
  - surface to 700 hPa
  - 700 to 500 hPa
  - 500 to 300 hPa
  - < 300 hPa.

NVAP-Climate

Used for studies of climate change and interannual variability

- SSM/I Level 1 C intercalibrated radiances
- HIRS cloud cleared radiances, + AIRS since 2002
- Radiosonde

- Consistent inputs through time.
- Consistent, high quality retrievals.
- Less emphasis on spatial and temporal coverage

- Daily
- 1-degree resolution
- TPW
- layered precipitable water
  - surface to 700 hPa
  - 700 to 500 hPa
  - 500 to 300 hPa
  - < 300 hPa

NVAP-Ocean

SSM/I-only.

Supplemental Fields

- Data source code (DSC) map, indicating the sources used in each grid box .

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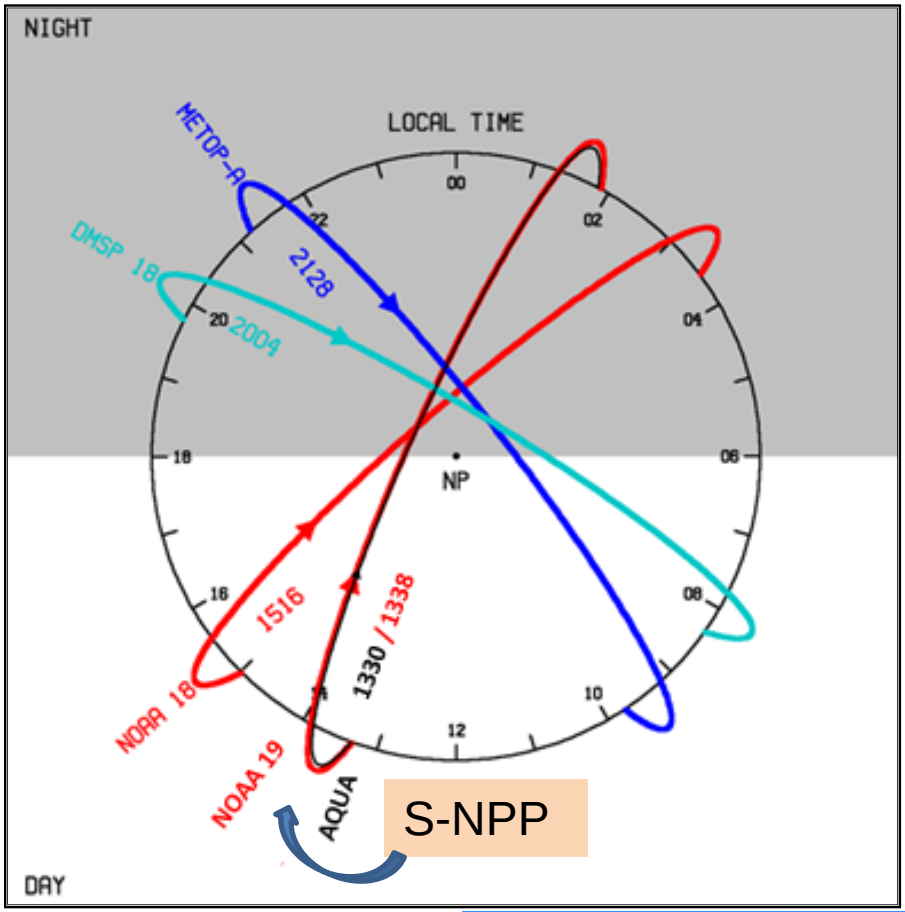
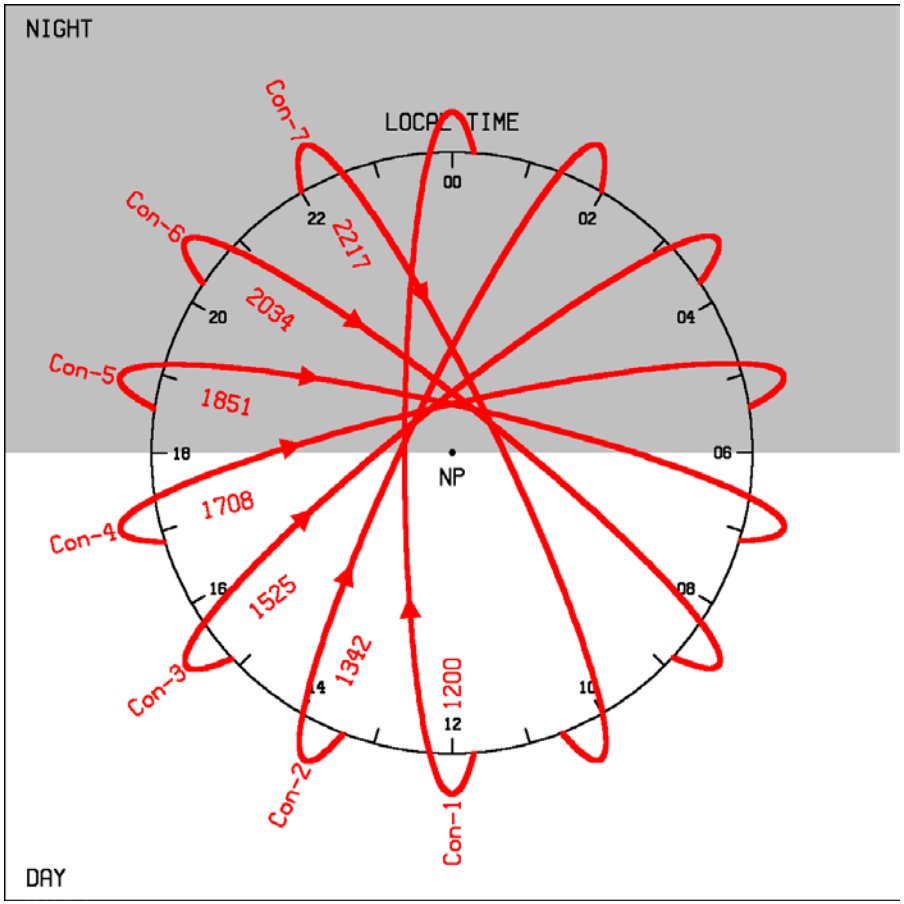
"Clock Diagrams" show local time sampling of polar sensors used

Current configuration for Layer Precipitable Water:
Periods of high sampling and no sampling

Conceptual future system for blended products: Two satellites in 7 orbital planes would provide hourly sampling globally.





Older satellites play a valuable role in extending temporal sampling

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Summary

- Blended products have proven to be successful at leveraging NOAA investments, particularly polar orbiter data, to add an observations-based, time-resolved view of weather that complements model fields.

- Weather and climate uses of the same products benefit both. For instance, seasonal biases have been noted in weather products which are reported to developers.

- Microwave Imager climate records (i.e. SSM/I) have benefited greatly from intercalibration efforts

- Microwave sounder radiance record (183 GHz) is making progress but needs more exploration

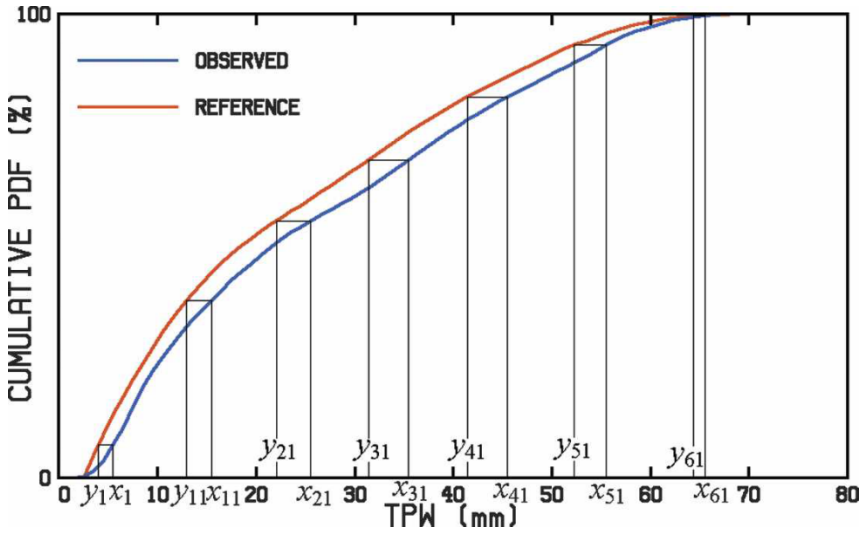
- “Image validation” is a useful form of determining product quality from a weather-oriented product.

- CIRA makes new and experimental products available on it’s website, with feedback from NWS forecasters.

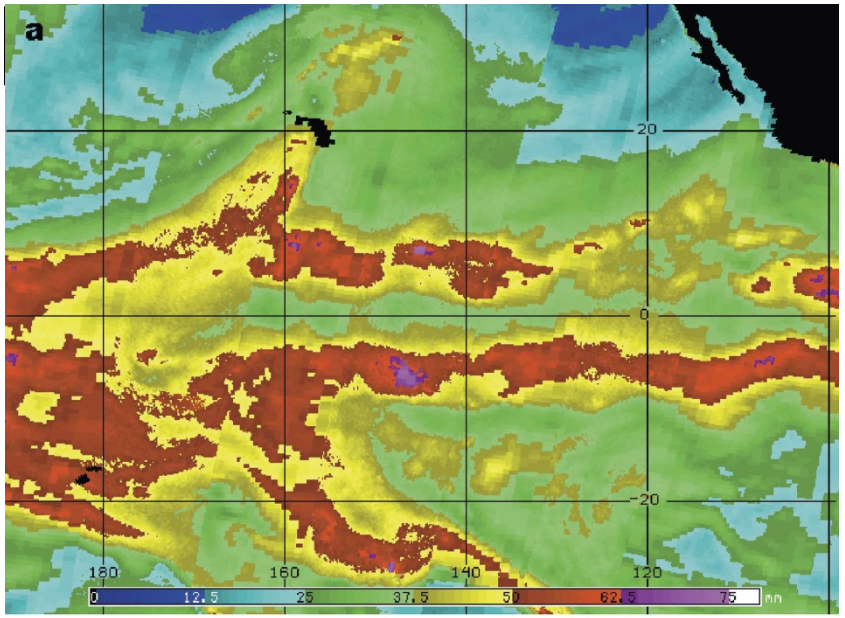
Removing Artifacts Which Distract Forecasters

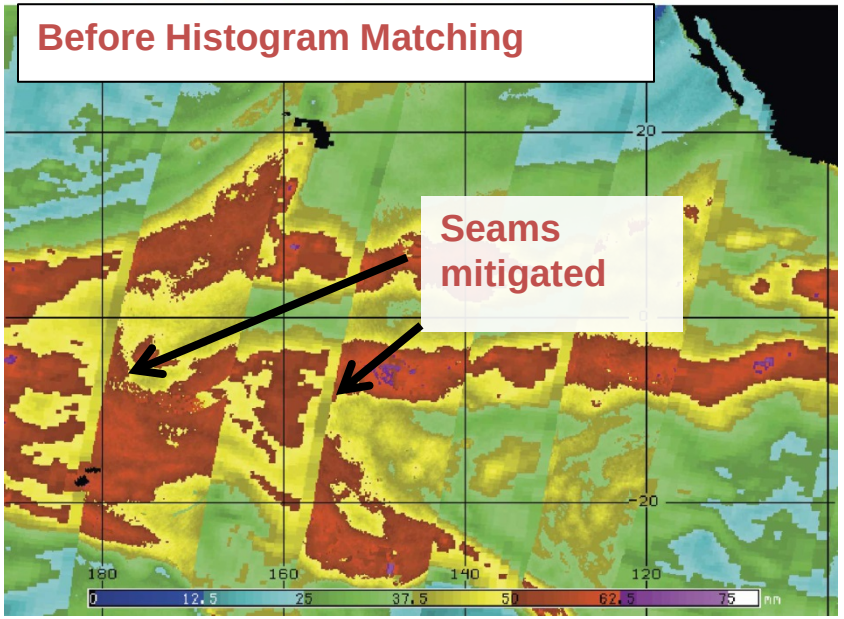
5-day scan angle-dependent histogram matching is applied to the NOAA operational blended Total Precipitable Water vapor product (over ocean).

SNPP MiRS V11 is current reference product. Makes the other sensors look more like it.



TPW example of histogram matching





Kidder and Jones, J. Atmos Ocean. Tech. 2007

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