MICROWAVE INTEGRATED RETRIEVAL SYSTEM (MIRS): RECENT VALIDATION, FUTURE ENHANCEMENTS, AND PLANS FOR JPSS-1/ATMS

Chris Grassotti

CICS-MD and NOAA/NESDIS/STAR

MiRS Team: S. Liu, J. Chen, Q. Liu

Help from: C. Perez Diaz, K. Garrett, P. Liang, H. Meng, B. Sun, G. Chirokova, J. Knaff

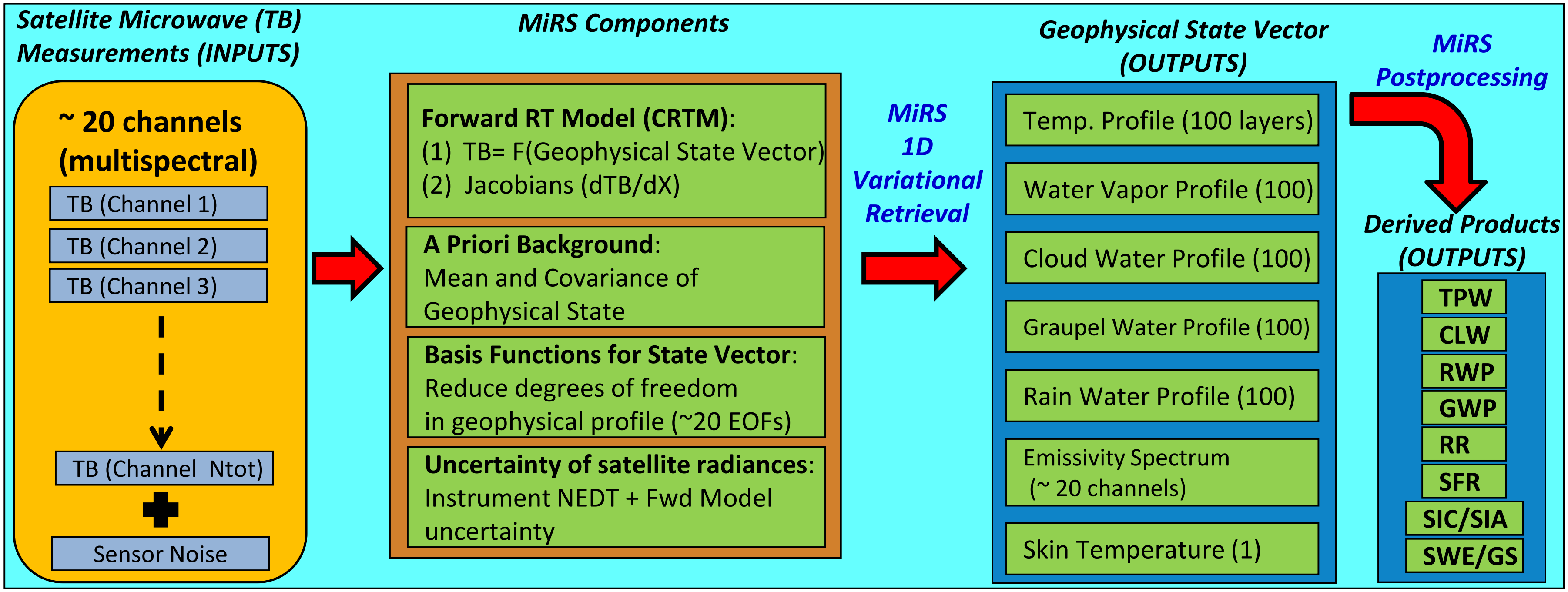
christopher.grassotti@noaa.gov

16 August 2017

Outline

- Algorithm Overview
- S-NPP Product(s) Overview
  - Standard validation: global performance for T, WV Sounding
  - Validation maturity status/plans
  - Targeted validation: in situ reference data (SURFRAD) for LST
- New Activities/Science Improvements
  - Precipitation: Rain rate and Snowfall Rate
  - Air mass-dependent radiometric bias correction
  - Tropical Cyclone Adaptation (MiRS-TC)
- JPSS-1 Readiness
  - Algorithm changes
  - Pre-launch activities
  - Post-launch cal/val
- Summary and Path Forward

Algorithm Overview

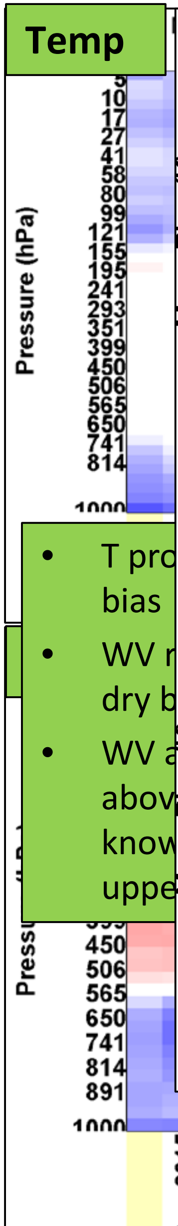


- MW Only, Variational Approach: Find the "most likely" atm/sfc state that: (1) best matches the satellite measurements, and (2) is still close to an a priori estimate of the atm/sfc conditions
- At NDE: Currently running v11.1 on SNPP/ATMS data, on J1/ATMS (v11.3) in early 2018.
- At OSPO: Initial capability delivered in 2007. Running v11.2 since Jan 2017 on N18, N19, MetopA, MetopB, F17, F18, GPM/GMI, Megha-Tropiques/SAPHIR. (eventually MetopC…)
- External Users/Applications: **(1) CIRA TC Analysis/Forecasting (G. Chirokova), (2) Layer PW (J. Forsythe), (3) MIMIC TPW Animations (T. Wimmers)**, CSPP (Direct Broadcast), NFLUX model (NRL, Stennis), CMORPH (CPC, precipitation), …

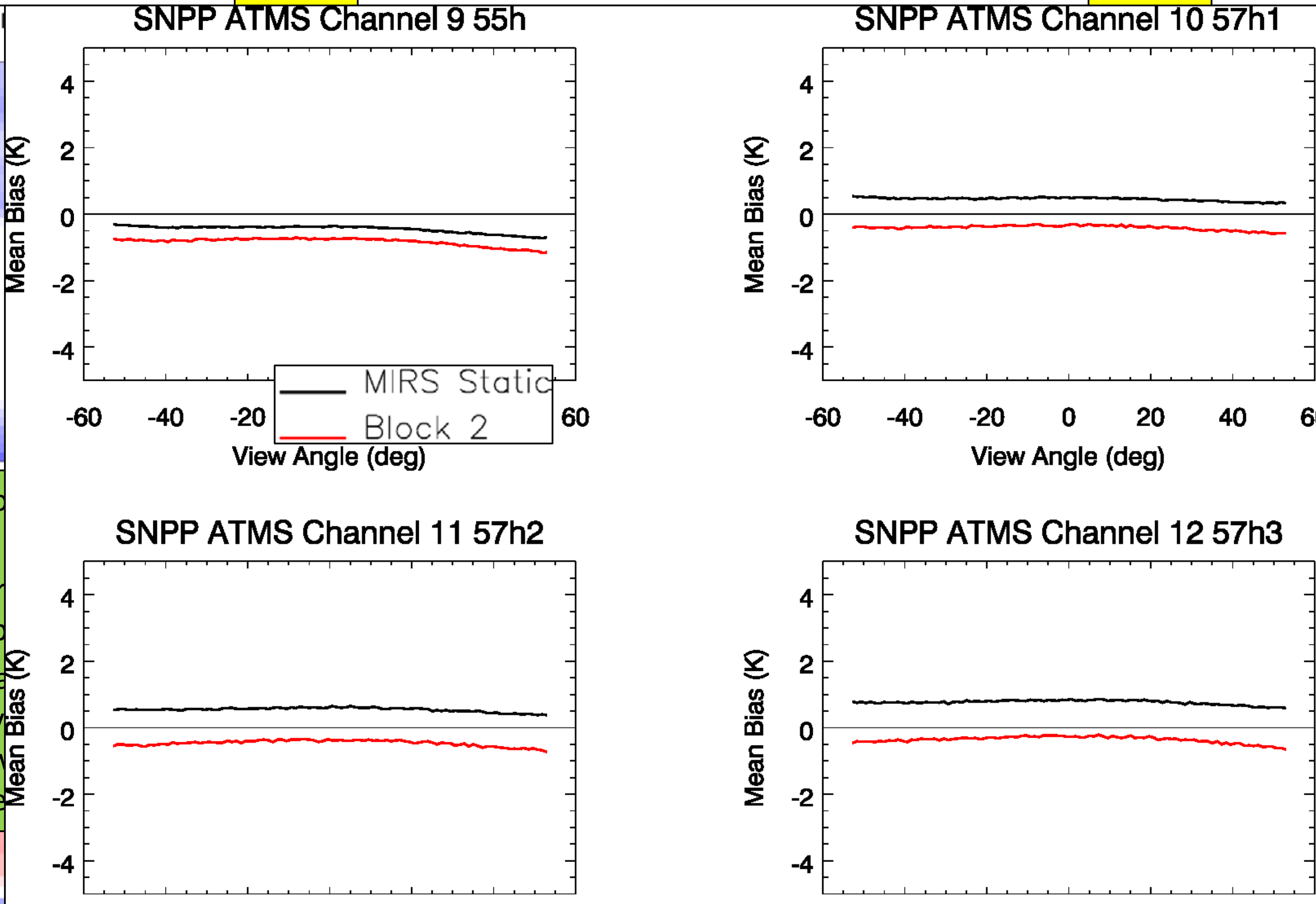
MiRS SNPP/ATMS Temperature and WV Bias vs. Raobs (NPROVS): Aug 2015 – June 2017

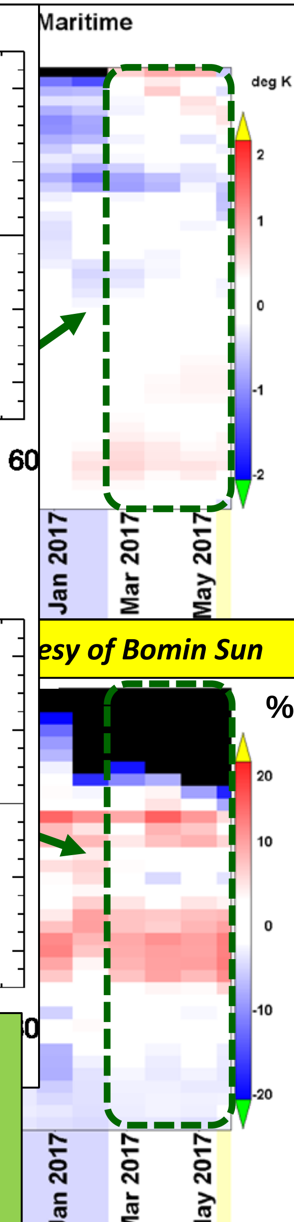
Land **Sea**

Temp



- T pro… bias
- WV r… dry b…
- WV a… abov… know… uppe…





…esy of Bomin Sun

- MiRS radiometric bias corrections for T sounding channels (5-12): Block 1 (Static) and Block 2, OBS-SIMULATED
  - These corrections are subtracted from observed TBs prior to retrieval (i.e. negative means correction increases TB)
  - Block 2 corrections generally ~0.5 to 1 K lower than Block 1

MiRS SNPP Validation Status/Plans

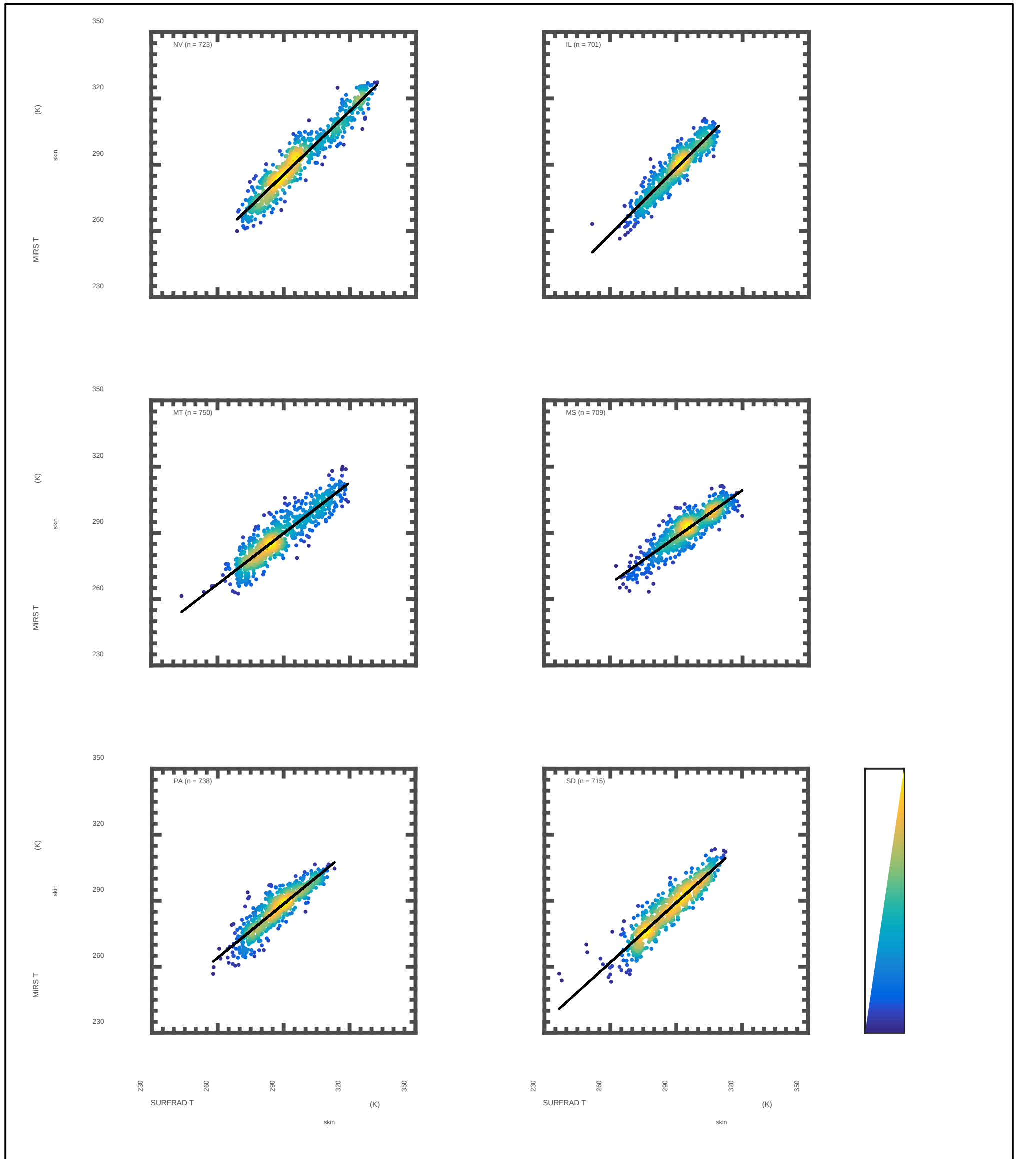
- Validated Maturity Reviews:
  - Two reviews in last 12 months:
    - October 2016 (T, WV, TPW, RR)
    - April 2017 (SIC, SWE, SCE, LST, LSE, CLW)
  - Status: All products validated maturity, except LST, LSE, CLW provisional maturity, with recommendations to utilize additional reference data, both in situ and satellite-based.
- Current Validation Activity Status for LST, LSE, CLW:

EDR	Plans/Activity	Status
LST	(1) 13-month collocation with in situ SURFRAD data (7 sites over CONUS). Performance characterized by location, season, day/night, scan position. (2) global collocation with VIIRS LST for single day (more days planned). **See next slides, and poster by C. Perez-Diaz et al.**	Nearly complete.
LSE	Global collocation with analytic emissivities derived from VIIRS LST+ECMWF atmosphere. One day complete, additional days planned (seasonal cycle). **(J. Chen)**	Ongoing. Expected completion Nov 2017.
CLW	Collocation with ARM surface-based MW radiometers in Tropical Western Pacific (3+ years), and Eastern N. Atlantic (10 months to date). Plan to process entire record of ENA (4+ years). Challenge to find non-tropical ocean sites. **(S. Liu)**	Ongoing. Expected completion Nov 2017.

Validation of Land Sfc Temperature

- Daily Comparisons:
  - Automated global comparisons with both ECMWF and GDAS; results posted daily
  - Advantage: Global coverage, all sfc and weather conditions, large sample sizes
  - Disadvantage: LST from NWP analyses may have large errors depending on obs available and land surface assimilation model.
- Targeted collocations with in situ data:
  - Collocations with SURFRAD LST (IR Flux Based): May 2016-May2017, 7 stations over the CONUS
  - Advantage: in situ, direct measurement (need to convert from flux to LST using Stefan-Boltzmann law), IR emissivity assumed=0.97
  - Disadvantage: IR LST, not same as MW LST (vertical penetration depth), representiveness error (point vs. IFOV average)
  - SURFRAD stations used:
    - Desert Rock, NV
    - Bondville, IL
    - Fort Peck, MT
    - Goodwin Creek, MS
    - Penn State, PA
    - Sioux Falls, SD
    - Boulder, CO

Validation of Land Sfc Temperature: Collocation with SURFRAD



Validation Parameter	All SURFRAD stations and overpasses				
	Spring	Summer	Autumn	Winter	13 months
R	0.91	0.90	0.90	0.81	0.92
Bias (K)	-2.21	-2.55	-0.58	-2.05	-1.84
Std. dev. (K)	5.21	4.66	5.25	5.98	5.26
RMSE (K)	5.65	5.31	5.28	6.32	5.58
Slope	0.96	0.74	0.92	0.89	0.92

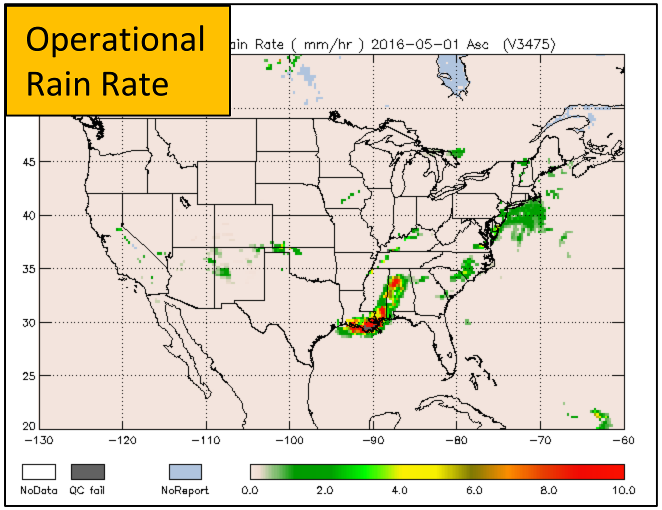
Requirements	Bias/ Accuracy (K)	StDev/ Precision (K)	RMS/ Uncertainty (K)
Threshold	**4.0**	**7.0**	**8.0**
Objective	**3.4**	**6.3**	**7.1**

Meets threshold
Meets objective

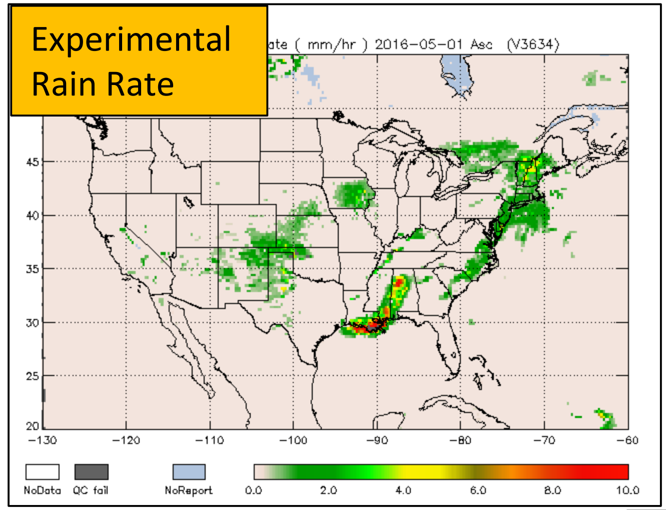
Many more results in poster by C. Perez-Diaz et al.

Path Forward: Rainfall Rate, Incorporating CLW over Land

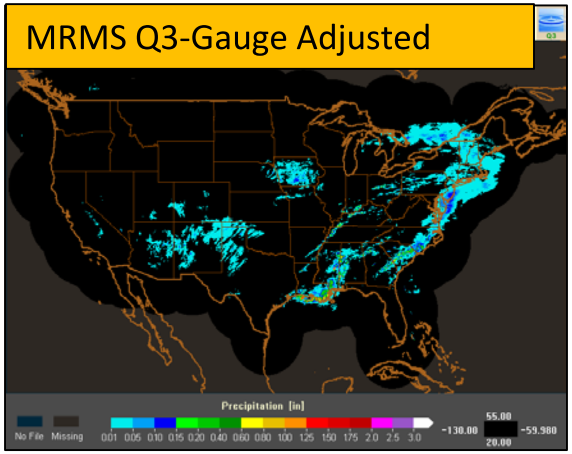
Operational Rain Rate



Experimental Rain Rate

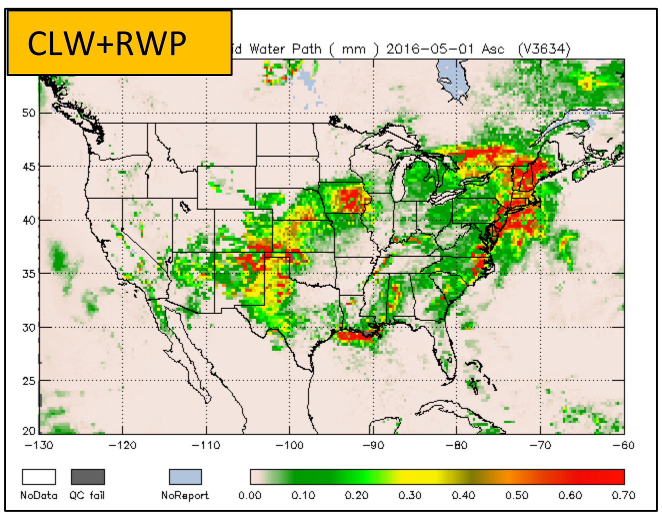


MRMS Q3-Gauge Adjusted

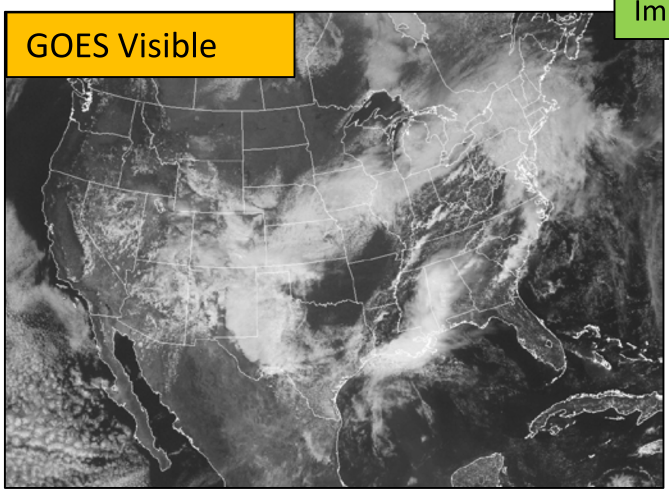


Improved detection of light rain (< 2 mm/h)

CLW+RWP

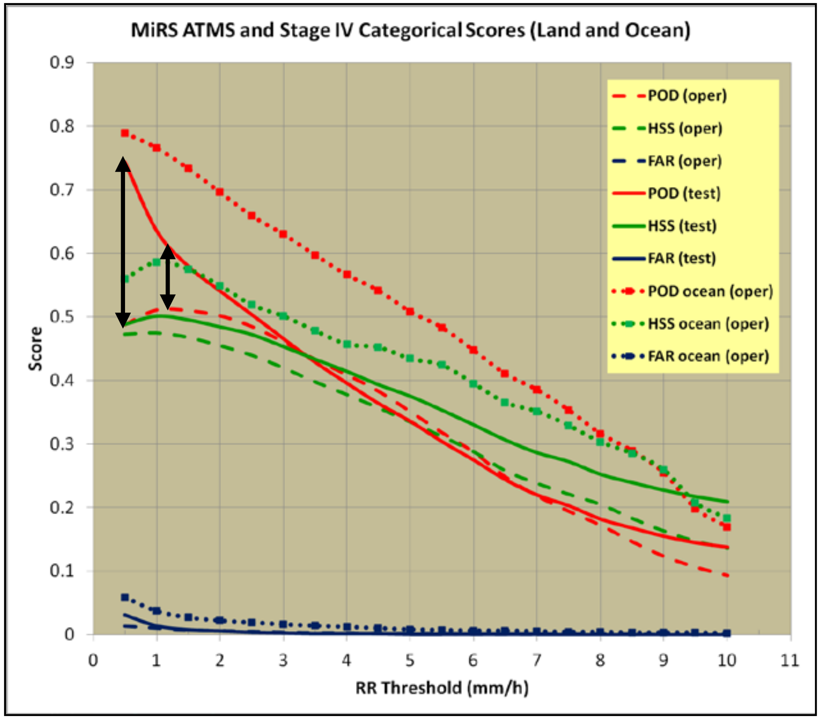


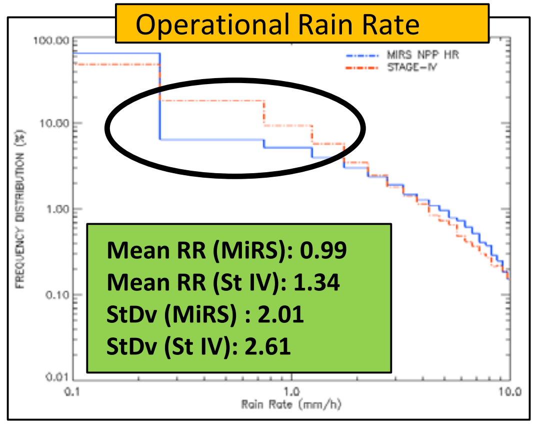
GOES Visible

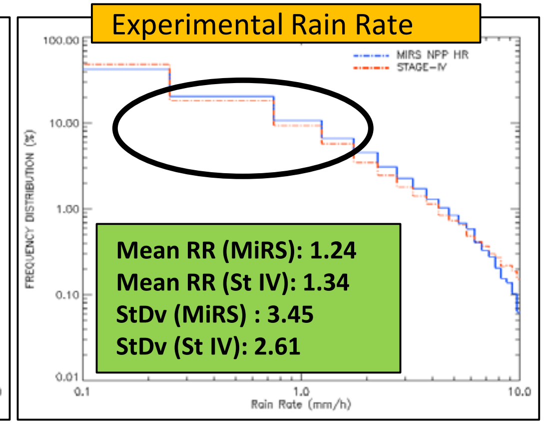


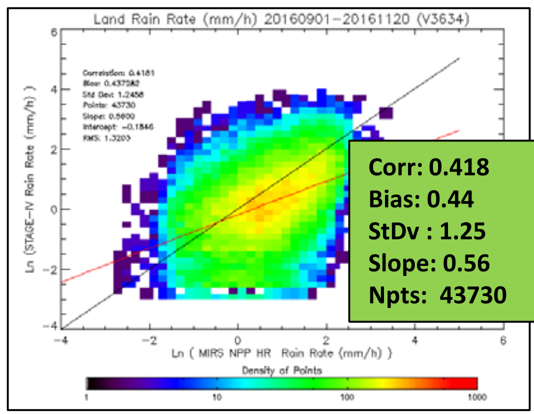
Path Forward: Rainfall Rate, Incorporating CLW over Land

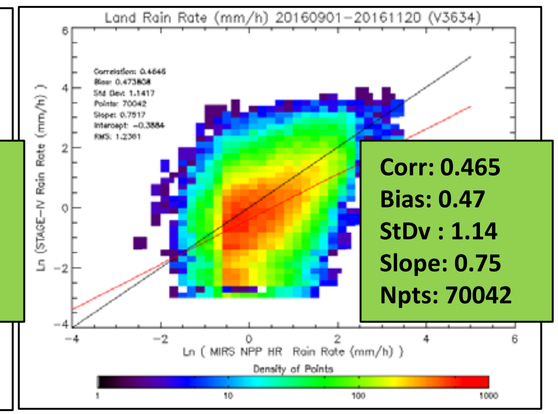
MiRS ATMS RR Performance Relative to Stage IV: 1 Sept-20 Nov 2016











MiRS
Stage IV

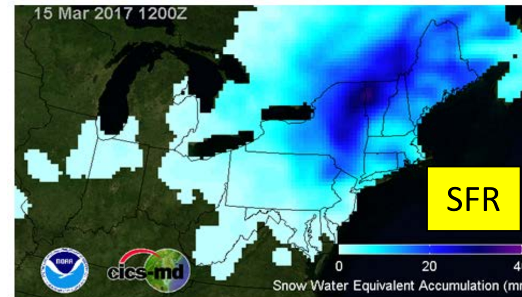
- Over land POD and Heidke Score significant increase
- Better PDF match with Stage IV for both low and high rain rates
- Increased correlation and slope closer to 1
- Plan to incorporate in next version of MIRS (v11.3)

ATMS Snowfall Rate (SFR)

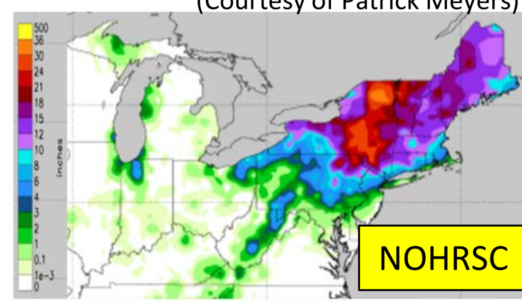
- POES and Metop AMSU/MHS SFR product is operationally produced inside MiRS
- SNPP ATMS SFR algorithm developed with the JPSS PGRR support; to be integrated into MiRS in FY18 pending PSDI support
- ATMS SFR initial cal/val indicates ATMS SFR outperforms AMSU/MHS SFR
- Development of SFR algorithms for DMSP SSMIS and NASA GMI with the JPSS PGRR support; significantly improves temporal coverage and enhances product utility with four additional satellites (nine in total)
- Applications: hydrology and weather forecasting

ATMS and MHS SFR from the intense Nor'easter on March 14-15, 2017

24-hour snowfall accumulation ending March 15, 2017 12 UTC



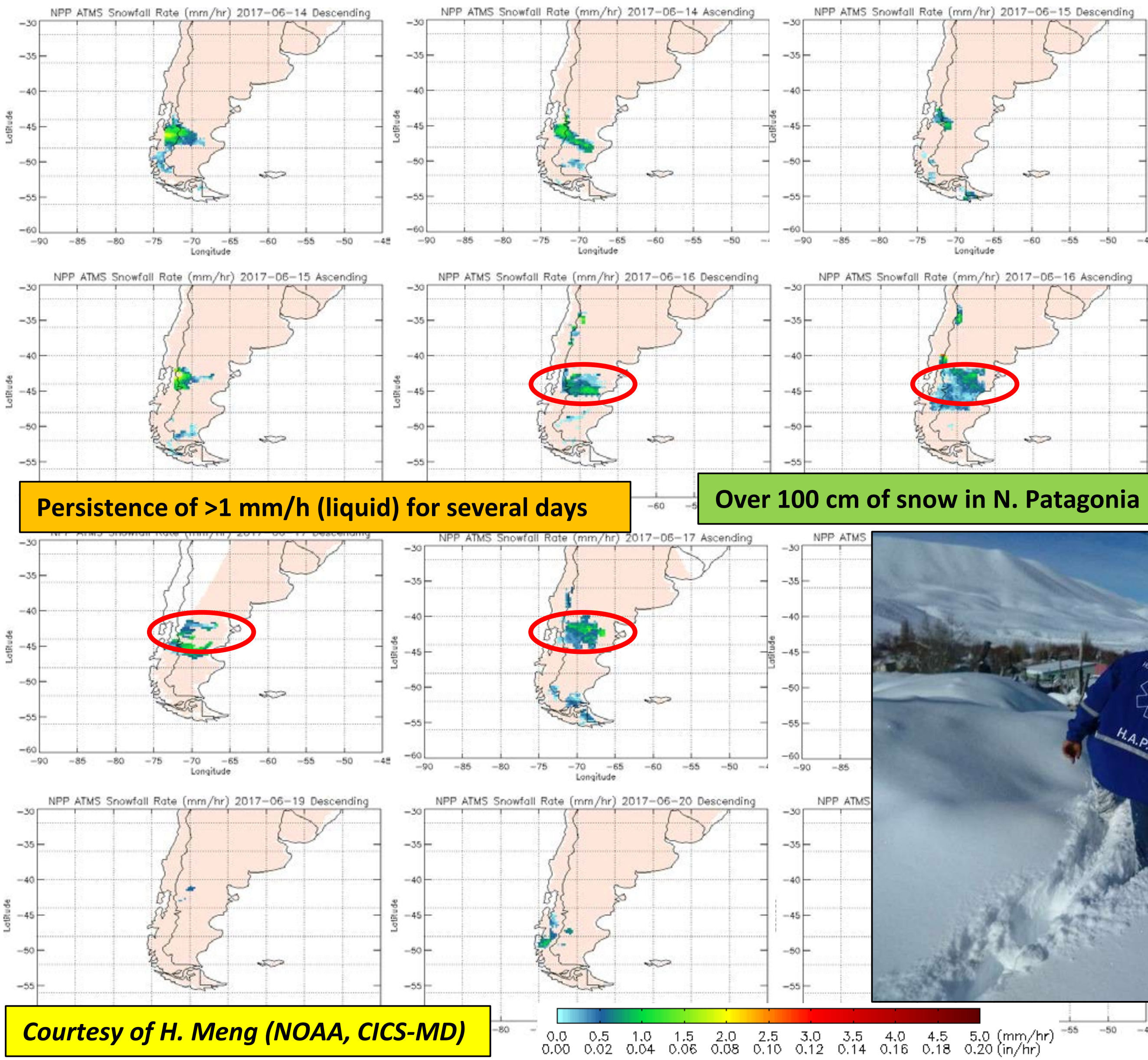
(Courtesy of Patrick Meyers)



- Entering Intensive Calibration/Validation (ICV) phase
  - ✓ Snowfall Detection (SD) cal/val with gauge observations and potentially radar snowfall detection data
  - ✓ Snowfall Rate cal/val with radar estimates (MRMS) and gauge snowfall accumulations (SNOTEL, USCRN)

Courtesy of H. Meng (NOAA, CICS-MD)

ATMS SFR Captures Record South American Snowfall (14-21 June 2017)



Persistence of >1 mm/h (liquid) for several days

VIIRS Snow Cover Fraction

Over 100 cm of snow in N. Patagonia

Courtesy of H. Meng (NOAA, CICS-MD)

Development of an Air Mass-Based Radiometric Bias Correction

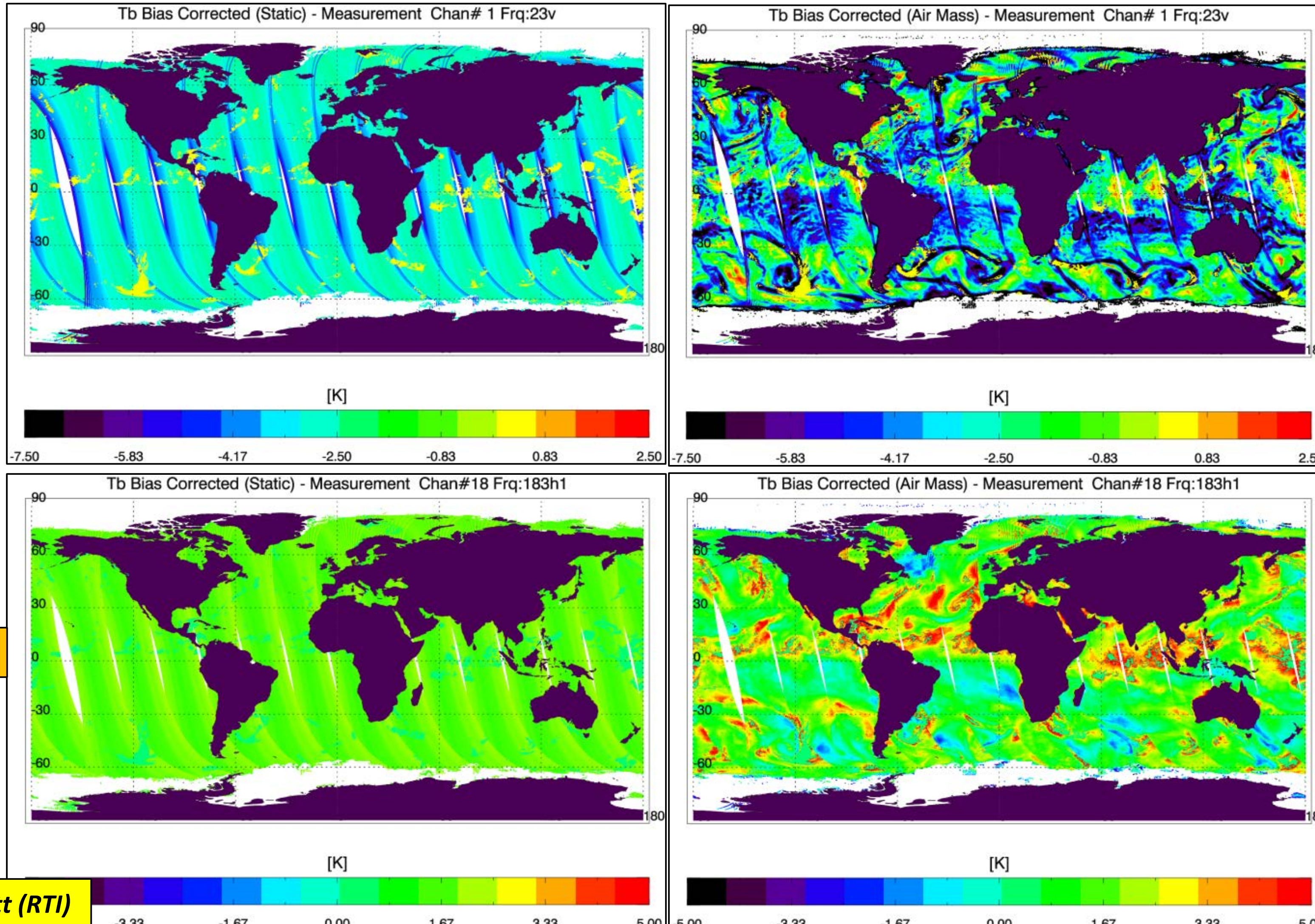
- Motivation:
  - Current operational MiRS uses Histogram Adjustment Method. Derived over oceanic/clear scenes. Bias specified as function of channel and scan position.
  - Advantages: Stable, reduces impact of outliers/cloud/rain contamination, good at characterizing the average global differences between measurements and model.
  - Disadvantages: Systematic errors in forward model due to over/underestimation of absorber effects (e.g. water vapor, non-precip cloud) not accounted for. (also assumes atmospheric and ocean emissivity models are accurate).
- Testing air mass dependent bias correction (ocean only)
  - Regression-based, 2-steps
    - **Step 1: CLW using uncorrected TBs**
    - **Step 2: dTB(iChan, iscanpos)=f(CLW, TPW, Tskin, TB(iChan)), TPW and Tskin from operational "Dynamic Background" (f(lat,lon,time,month)). Scan position dependent.**
    - **Applied to all channels except T sounding channels 4-15 (static bias correction used)**
  - Applied over ocean only, using Block 2 SDRs
    - **Quantify impact on retrieved parameters (e.g. T, WV, ocean emissivity, CLW, TPW, chi-square, iterations)**

Testing an Air Mass-Based Radiometric Bias Correction

Static Correction (operational) | **Air-mass Correction**

Ch 1 (23 GHz)

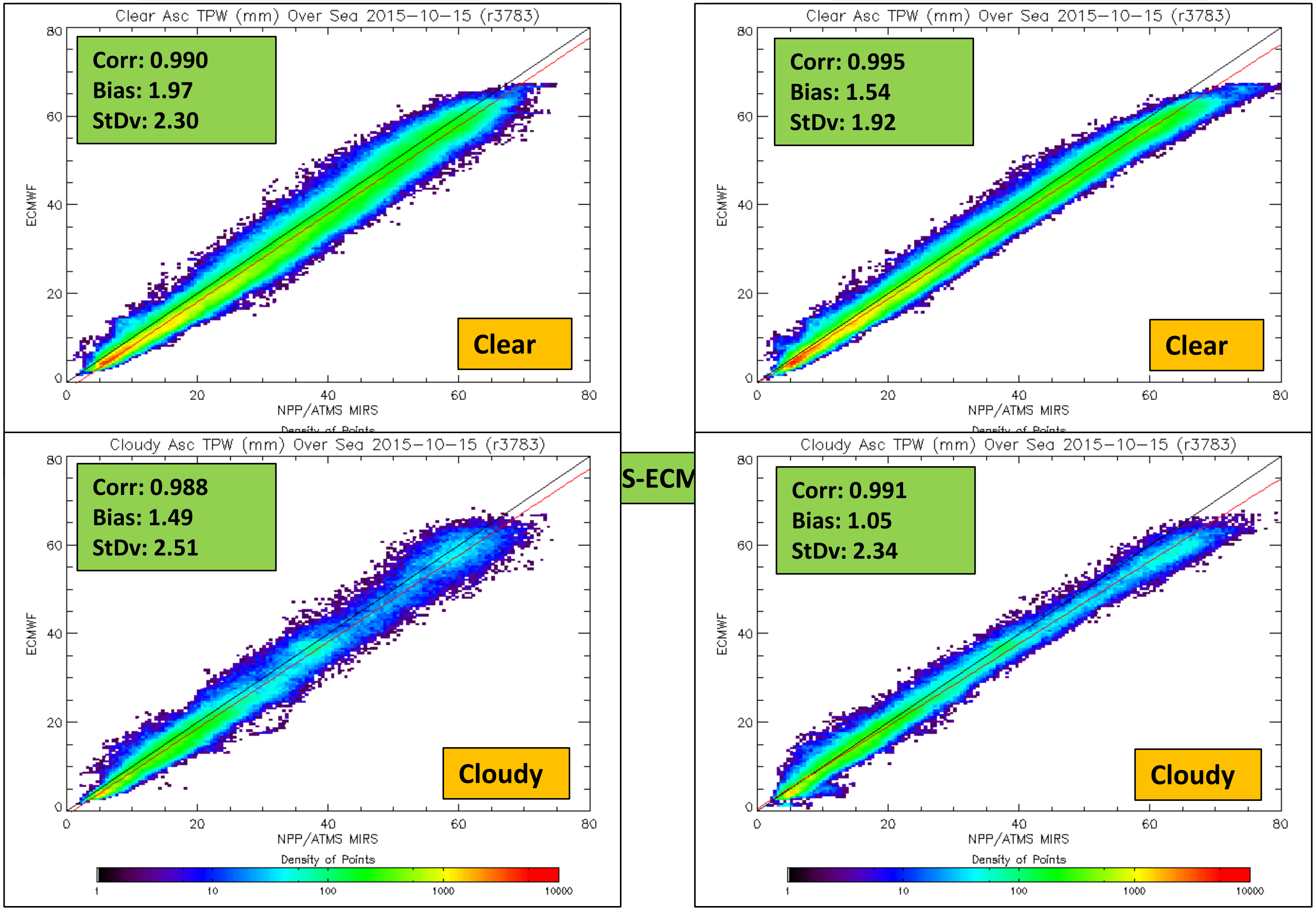
Ch 18 (183+/- 7 GHz)



Courtesy of K. Garrett (RTI) and P. Liang (AER)

Testing an Air Mass-Based Radiometric Bias Correction: Ocean TPW

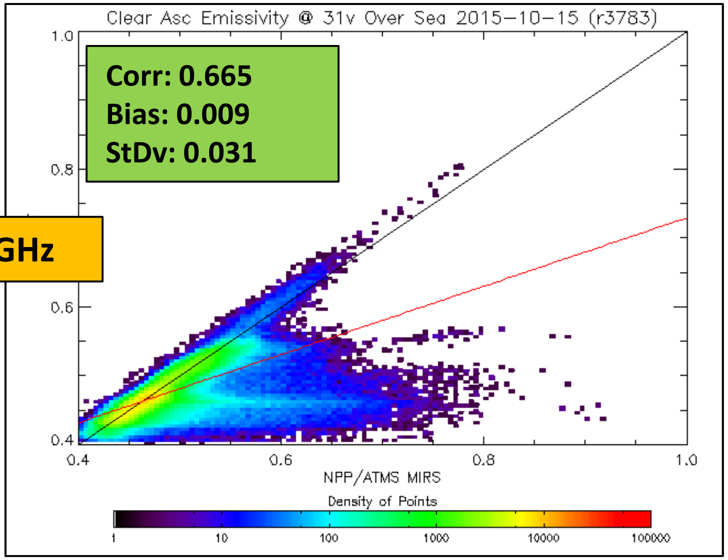
TPW (Static Correction) | **TPW (Air-mass Correction)**

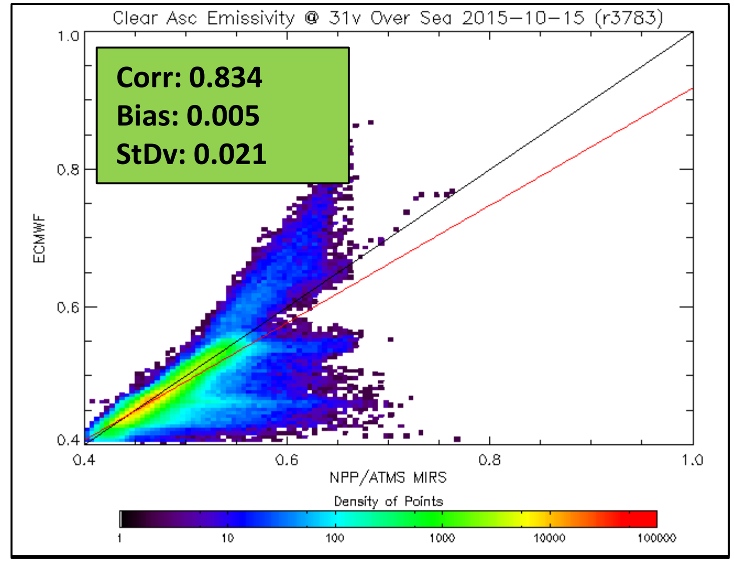


Testing an Air Mass-Based Radiometric Bias Correction: Ocean Emissivity

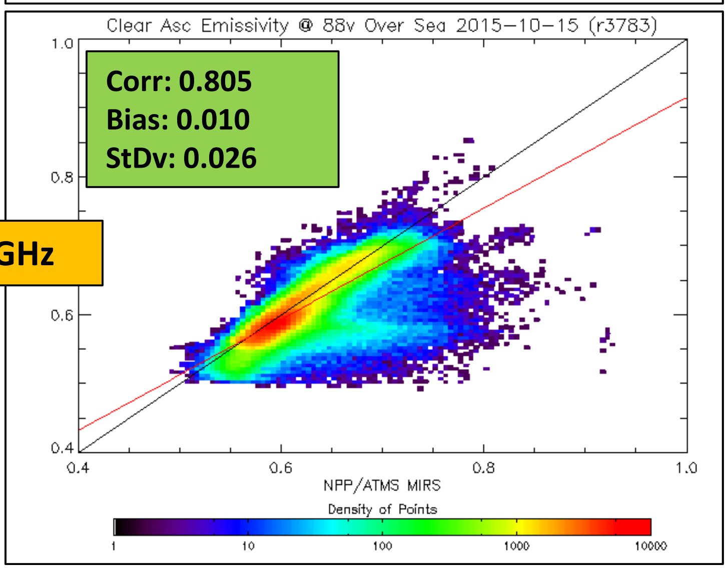
MIRS-FASTEM (Static Correction) | **MiRS-FASTEM (Air-mass Correction)**

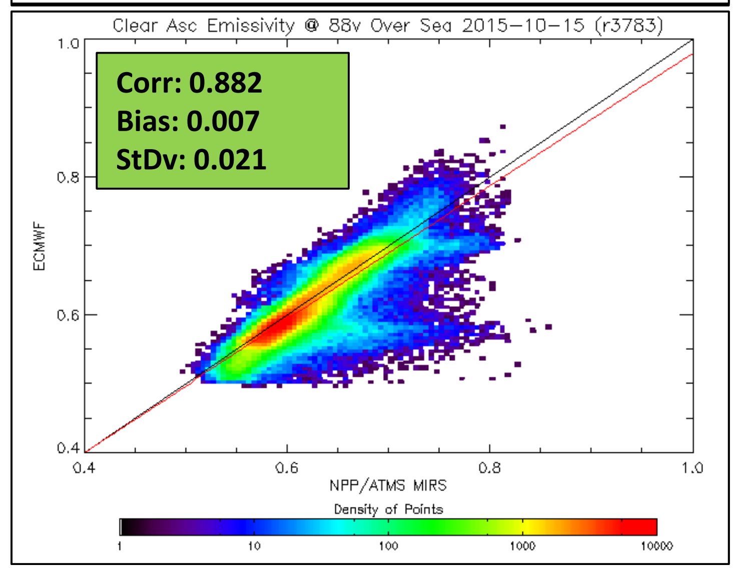
31 GHz





88 GHz

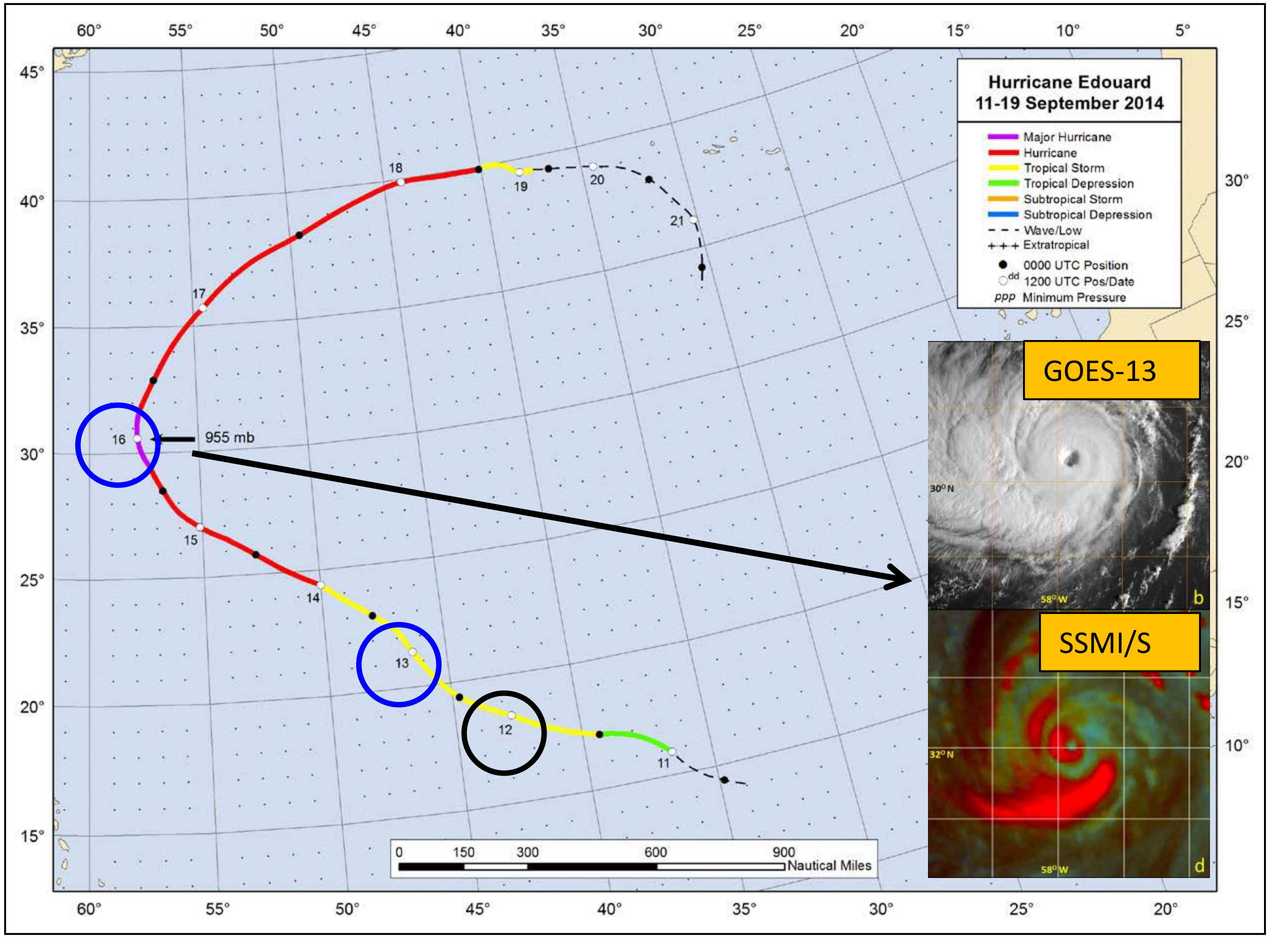




Developing a TC-Specific Version of MiRS

- Motivation:
  - MiRS data currently used in the operational TC Intensity Algorithm (developed at CIRA). Utilizes T and WV sounding to estimate warm core structure combined with statistical/dynamic model to predict future intensification.
  - Challenge: (1) retrieval of warm core structure complicated due to presence of hydrometeors; scattering signal in TBs can interfere with retrievals (2) hurricane warm core structure is anomalous relative to "global climatology" currently used as a priori constraint in MIRS.
- Experiments with SNPP/ATMS (3 control parameters)
  - Modify use of higher frequency channels in scenes likely to have large amounts of scattering
    - **(A) Oper: Use all 22 channels, (B) Turn off WV channels (18-22) when rain detected, (C) Turn off all high-frequency channels when rain detected (16-22).**
  - Test varying sources of First Guess/Background constraints:
    - **(A) Oper: Climatology f(lat,lon,time,month), (B) TC-Climatology based on COSMIC RO data (from CIRA)**
  - Vary number of EOF basis functions for T and WV profiles:
    - **(A) Oper: nEOFT=7, nEOFWV=5, (B) nEOFT=9, nEOFWV=4 when rain detected**

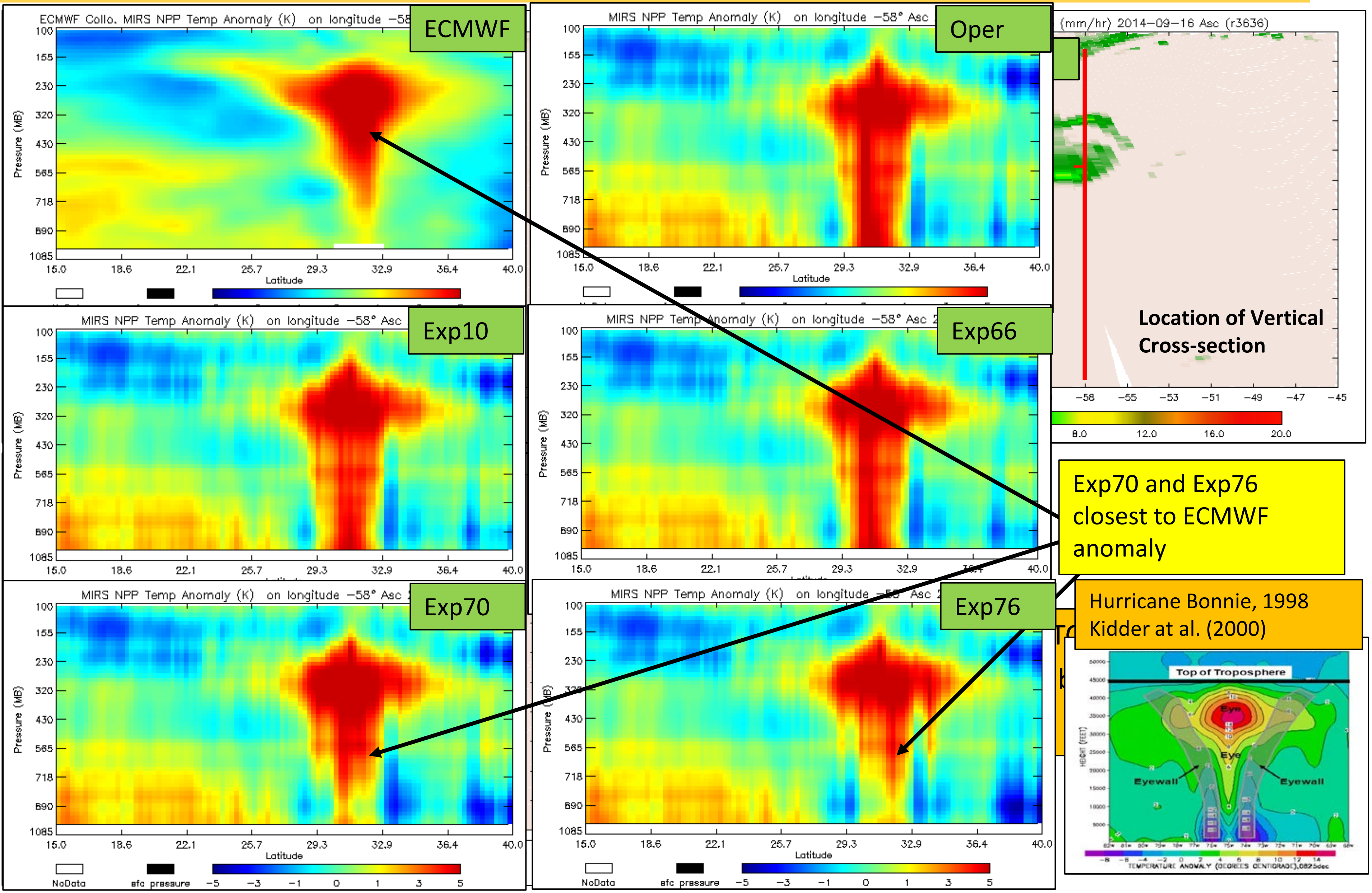
Case Study: Hurricane Edouard, Sept 2014



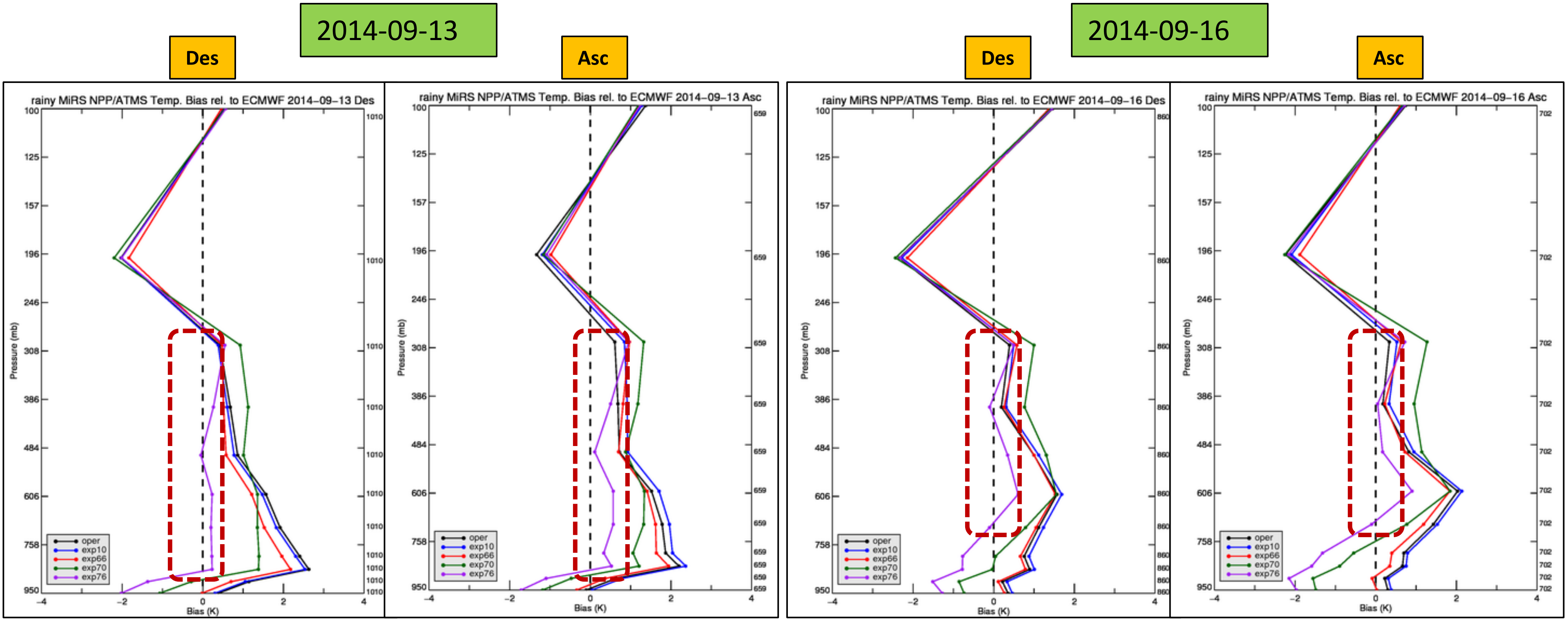
- 11-19 Sept 2014
- Maximum strength: 105 knots, 955 mb (16 Sept)
- Retrievals performed:
  - 12 Sept
  - **13 Sept**
  - **16 Sept**

Experiment	2nd att BG T	2nd att BG WV	WV Chans 18-22 On/Off	Chans 16-17 On/Off	2nd att nEOF T and WV
OPER	Oper	Oper	ON	ON	Oper
Exp 10	Oper	Oper	OFF	ON	Oper
Exp 66	Oper	TC	OFF	ON	Oper
Exp 70	Oper	TC	OFF	ON	nEOFT=9,nEOFWV=4
Exp 76	Oper	TC	OFF	OFF	nEOFT=9,nEOFWV=4

Temperature Anomaly Along -58 deg Lon: 2014-09-16



Temperature Bias Statistics in Rainy Conditions (wrt ECMWF)



- **Best result mid,upper-trop**: TC climatology for WV BG + chans 16-22 off (cold bias below 800-850 hPa); but ECMWF may also have errors
- Use of TC-specific WV BG critical when all WV sounding channels turned off
- **Future:** FG/BG from forecast, TC-specific covariance/EOFs, additional TCs (Joaquin 2015, Matthew 2016), validation w/dropsondes, continue collaboration with CIRA

Exp	2nd att BG T	2nd att BG WV	WV Ch 18-22 On/Off	Ch 16-17 On/Off	2nd att nEOF T and WV
OPER	Oper	Oper	ON	ON	Oper
Exp 10	Oper	Oper	OFF	ON	Oper
Exp 66	Oper	TC	OFF	ON	Oper
Exp 70	Oper	TC	OFF	ON	nEOFT=9,nEOFWV=4
Exp 76	Oper	TC	OFF	OFF	nEOFT=9,nEOFWV=4

JPSS-1 Readiness

- Significant Algorithm changes from V11.2 to V11.3:
  - **Addition of SFR for ATMS**: will require access to GFS forecasts (will work with NDE during integration and testing; already done for AMSU/MHS).
  - Vegetation correction for SWE (improved estimation over forested regions).
  - CLW retrieved over land (improved light rain detection)
- Pre-launch Characterization
  - **All software now extended to J1**: End to end testing on previous proxy data completed, also plan to process 8-day data. Daily processing codes in STAR now complete and ready for near real-time data after launch.
- Post-Launch Cal/Val Plans
  - Data Sets: Radiometric bias characterization (ECMWF), T and WV sounding (ECMWF, GDAS, raobs), rain rate (Stage IV, MRMS, GPROF), CLW (GPROF, ARM), snow (SNODAS, AMSR2, IMS), ice (IMS, OSI-SAF, VIIRS), LSE/LST (ECMWF, SURFRAD, VIIRS),
  - Milestones: (1) preDAP delivery in Feb 2018, ~L+6 months (initial cal/val for T, WV and TPW) (2) official DAP ~L+12 months. Possible delivery to CSPP/DB after preDAP complete.
- Risks and Mitigation: None at this time.
- Collaboration with Stake Holders: Feedback from OSPO, NDE to identify bugs/issues, other external users/applications. Explore pathway to AWIPS2.
- Science improvements in testing: Air-mass bias correction, TC-specific applications. Website: www.star.nesdis.noaa.gov/mirs

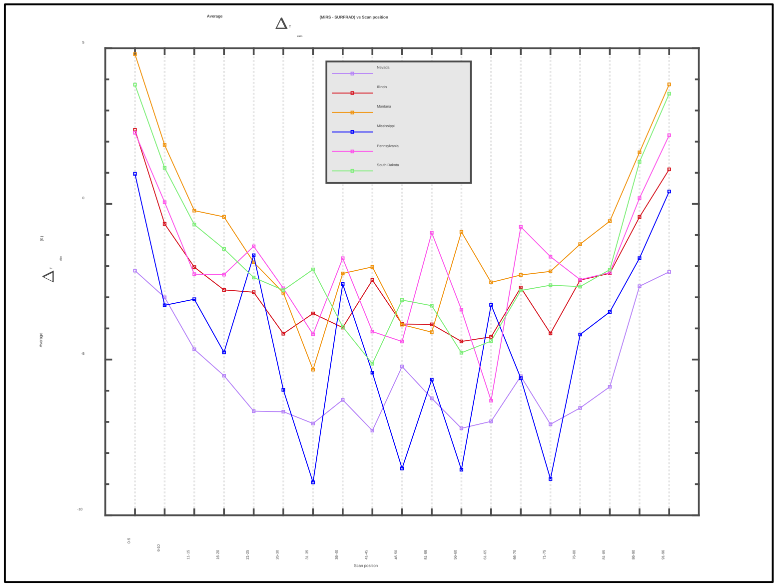
Summary & Path Forward

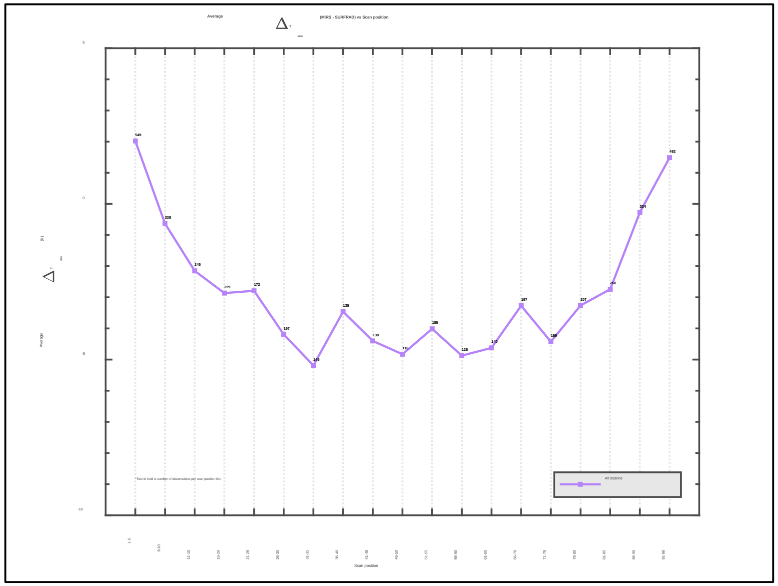
- MiRS is relatively mature algorithm; evolution and improvement since SNPP launch (v9.2 -> v11.2); more improvements possible!
- Next version (v11.3): Biggest change from data flow/dependence perspective is integration of SFR requiring GFS data.
- Path Forward
  - FY18 Milestones: (2) preDAP delivery in Feb 2018, (3) official DAP ~L+6 months (initial cal/val).
  - Future Improvements:
    - **Snow (vegetation correction to emissivity), included in v11.3**
    - **CLW over land to improve light rain detection, included in v11.3**
    - Air mass-dependent bias corrections
    - Rainy condition sounding (update a priori constraints)
    - TC-specific applications (FG/BG a priori based on TC climo or 6-h fcst)
    - Stakeholders/user needs…

Backup

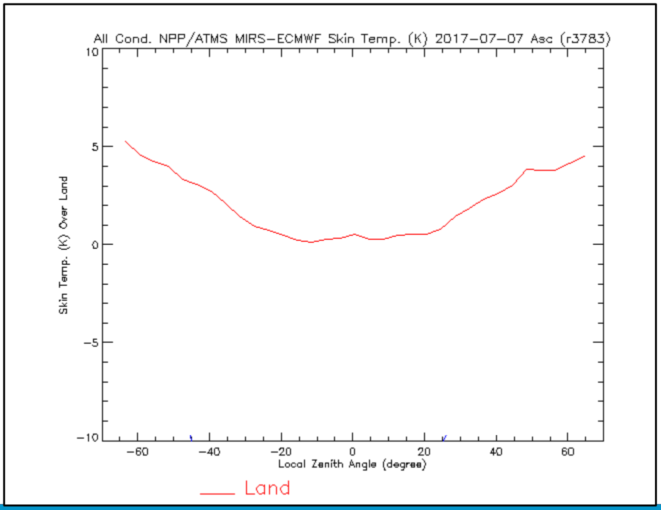
Validation of Land Sfc Temperature: Scan Dependence wrt SURFRAD and ECMWF

Scan Dependence wrt SURFRAD



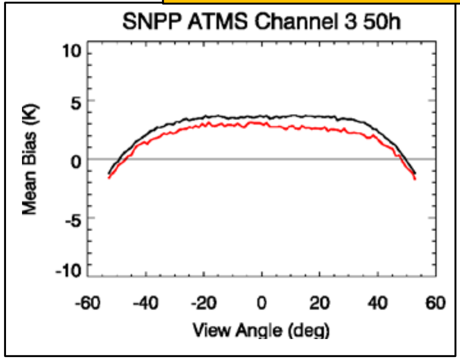


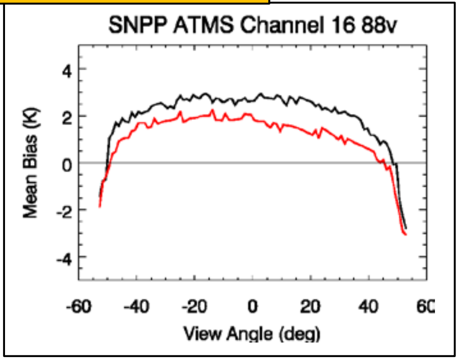
Scan Dependence wrt ECMWF



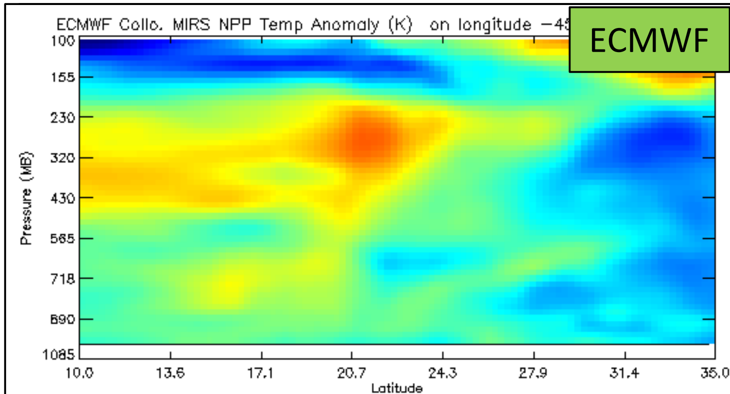
- Relative scan dependence seen wrt both SURFRAD and ECMWF
- Absolute biases different
- Likely due to radiometric bias correction (trained over ocean)

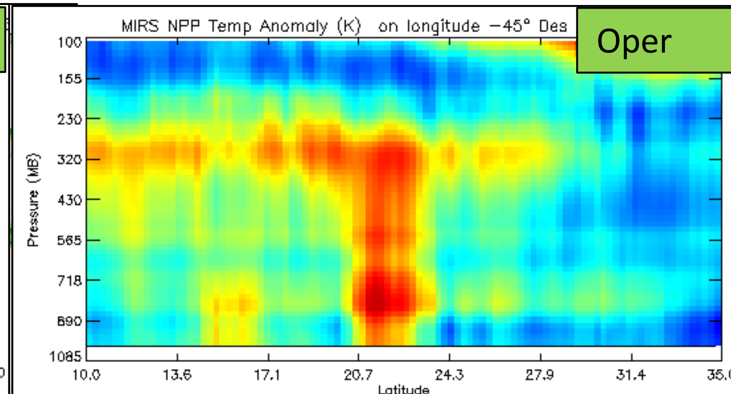
Block1 and Block 2 Bias corrections

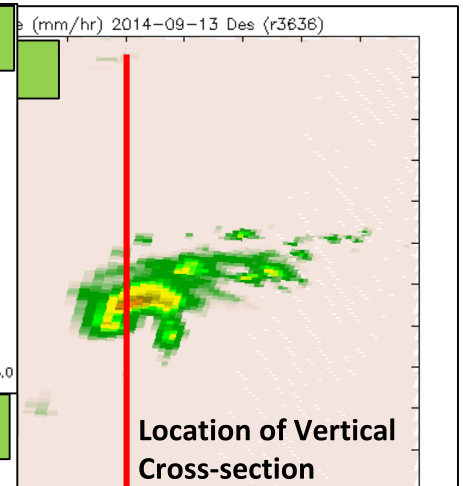


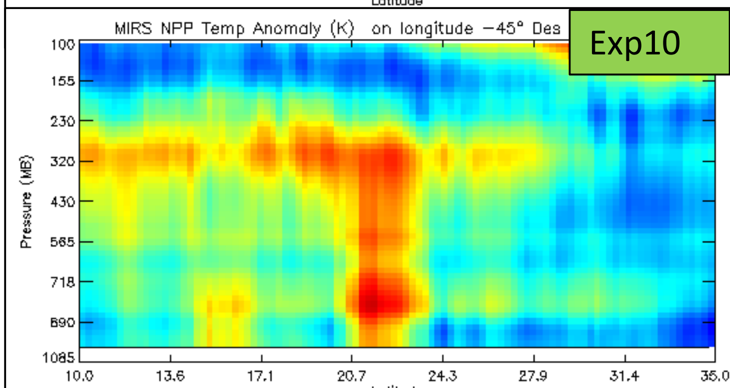


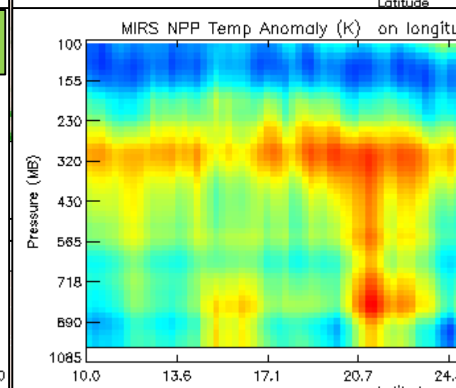
Temperature Anomaly Along -45 deg Lon: 2014-09-13



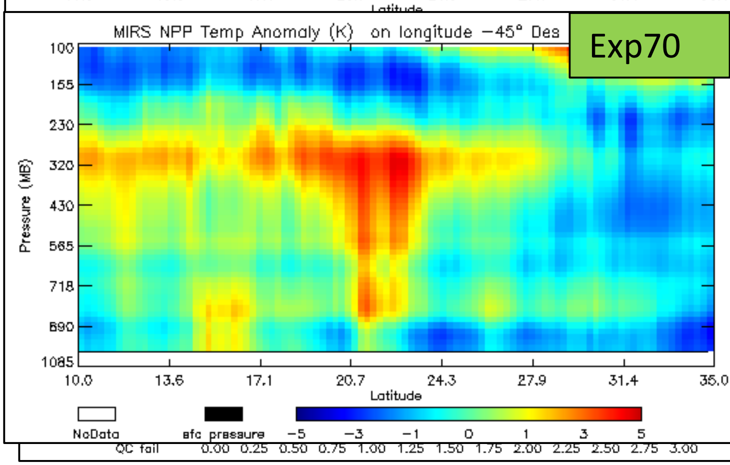


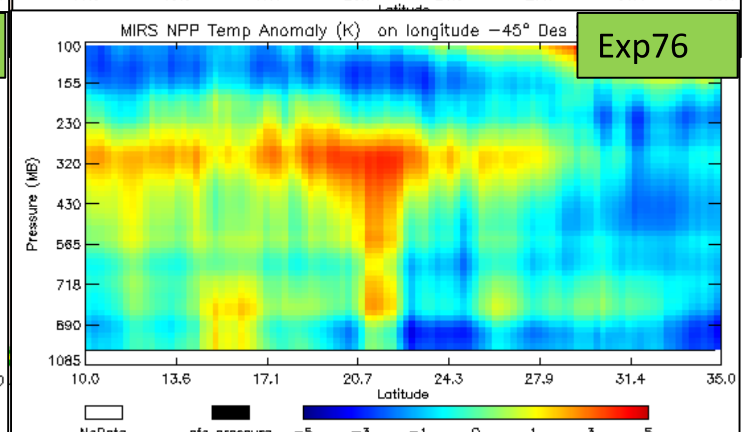




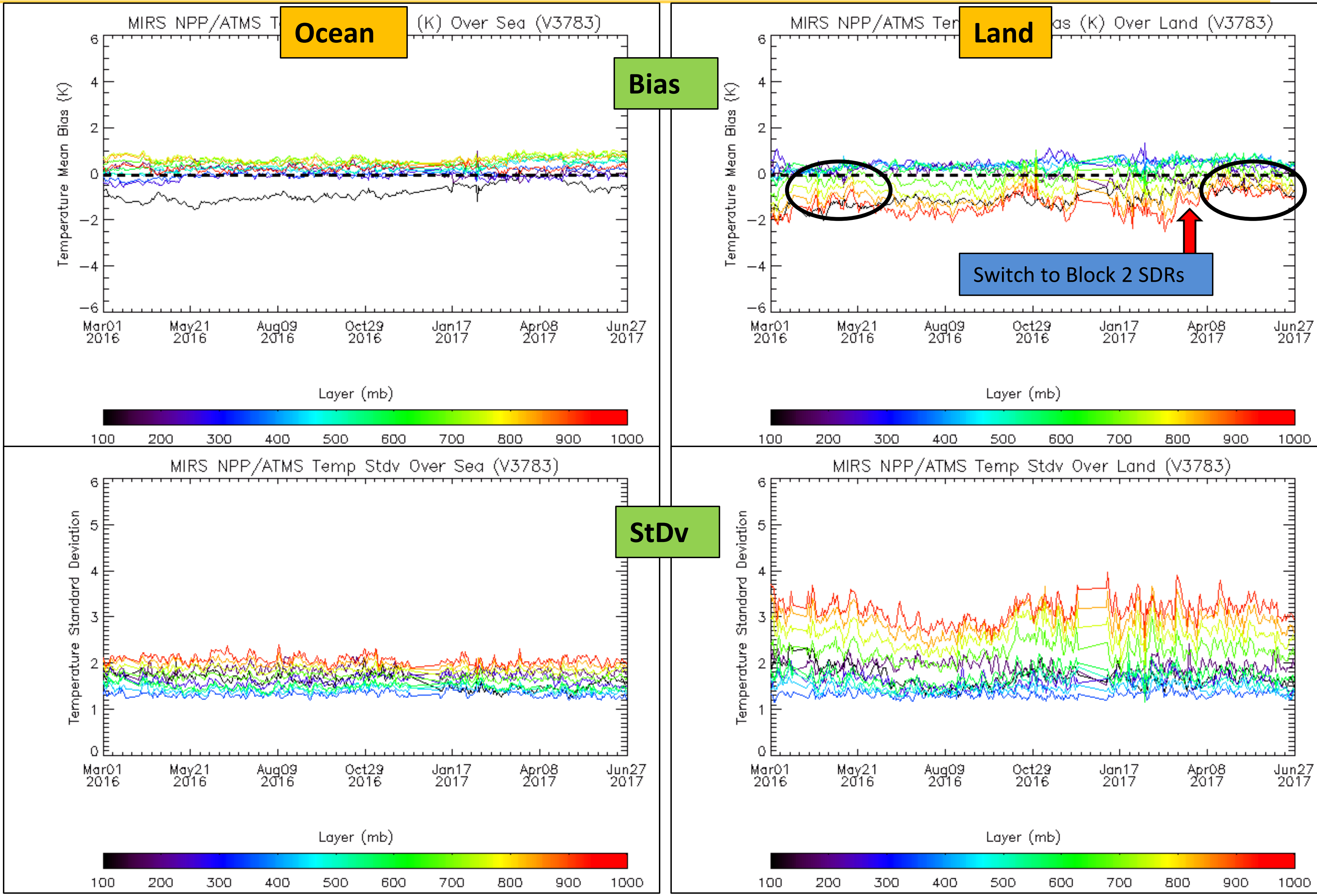


Exp	2nd att BG T	2nd att BG WV	WV Ch On/Off	Ch 16-17 On/Off	2nd att nEOF T and WV
OPER	Oper	Oper	ON	ON	Oper
Exp 10	Oper	Oper	OFF	ON	Oper
Exp 66	Oper	TC	OFF	ON	Oper
Exp 70	Oper	TC	OFF	ON	nEOFT=9,n EOFWV=4
Exp 76	Oper	TC	OFF	OFF	nEOFT=9,n EOFWV=4





MiRS SNPP/ATMS Temperature Bias and Std Dev vs. GDAS: 1 March 2016 – 1 July 2017



MiRS Cal/Val Team Members

Team Member	Organization	Roles and Responsibilities
Q. Liu (Project Manager)	NESDIS/STAR/SMCD	Project management
C. Grassotti (Technical Lead)	NESDIS/STAR/SMCD (U. MD./ESSIC)	Coordination of technical activities; review/deliverable planning
S. Liu	NESDIS/STAR/SMCD (CIRA/CSU)	Precipitation cal/val, SFR integration, DAP preparation
J. Chen	NESDIS/STAR/SMCD (U. MD./ESSIC)	Sounding and emissivity cal/val, J1 extension, Sounding improvements

MIMIC-TPW and lessons learned from a lifelike verification of MiRS

Tony Wimmers

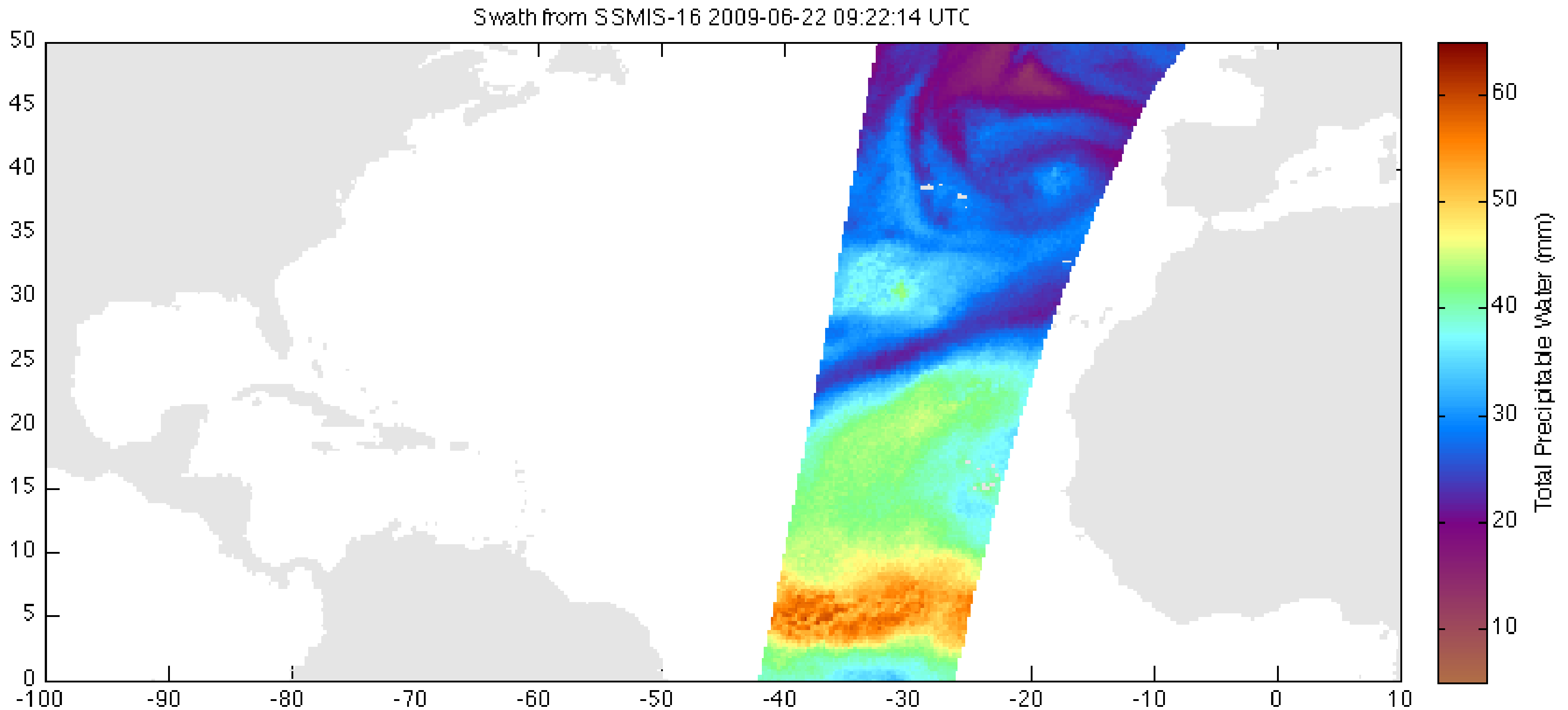
With contributions from Chris Velden, Jordan Gerth and Scott Bachmeier

Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin - Madison

R&D supported by JPSS Risk Reduction, and the Naval Research Lab and Office of Naval Research

Data advected from 09:22 UTC

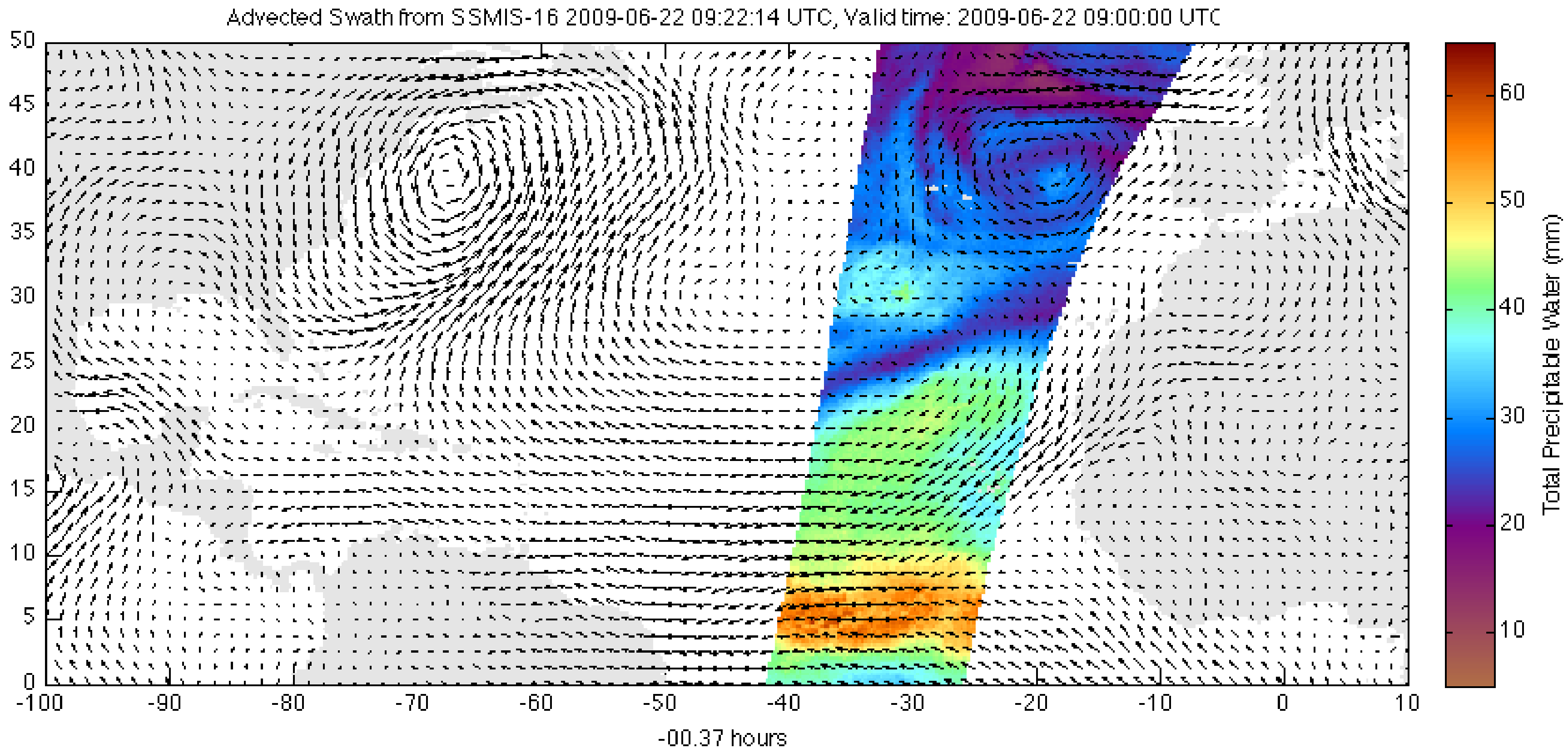
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

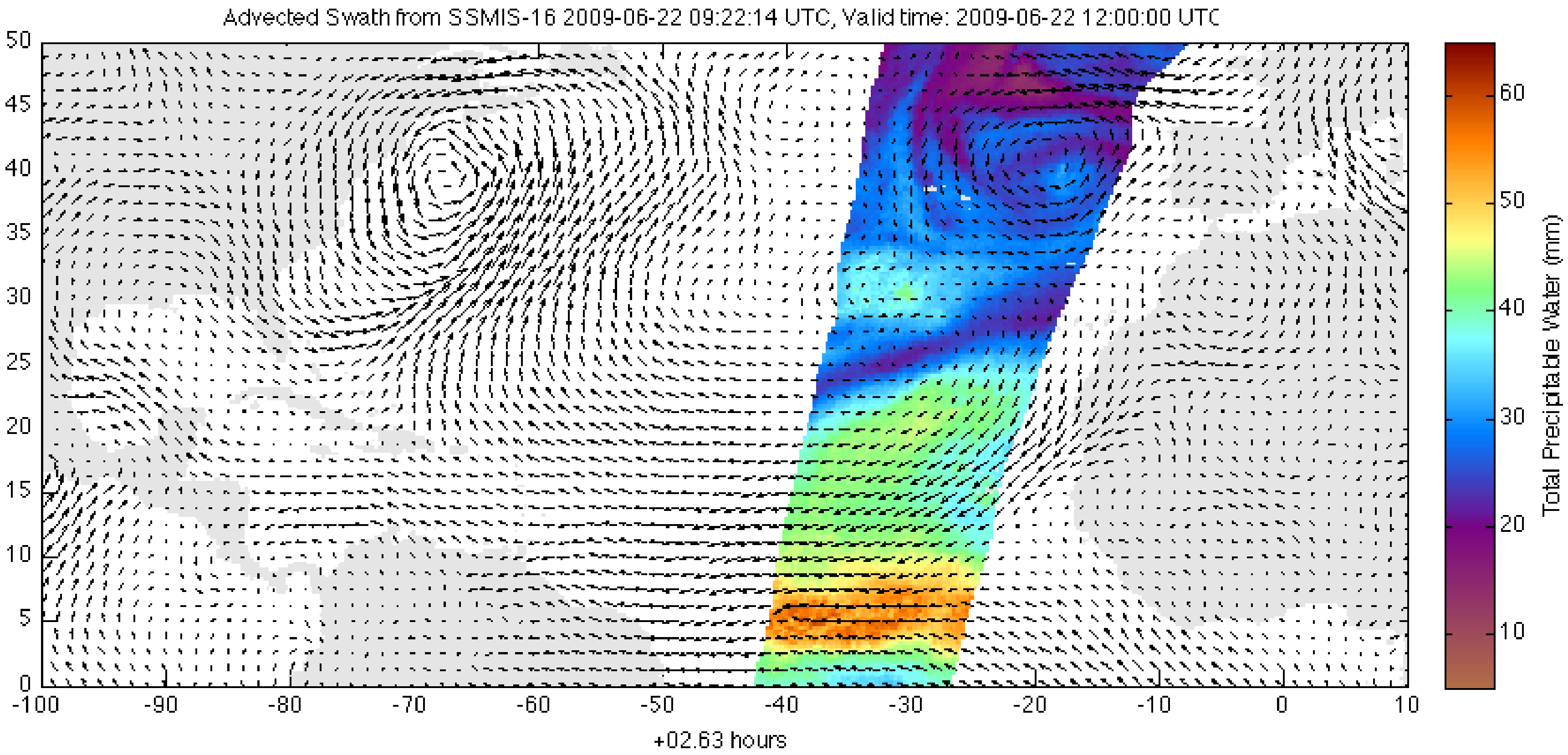
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · **09** · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

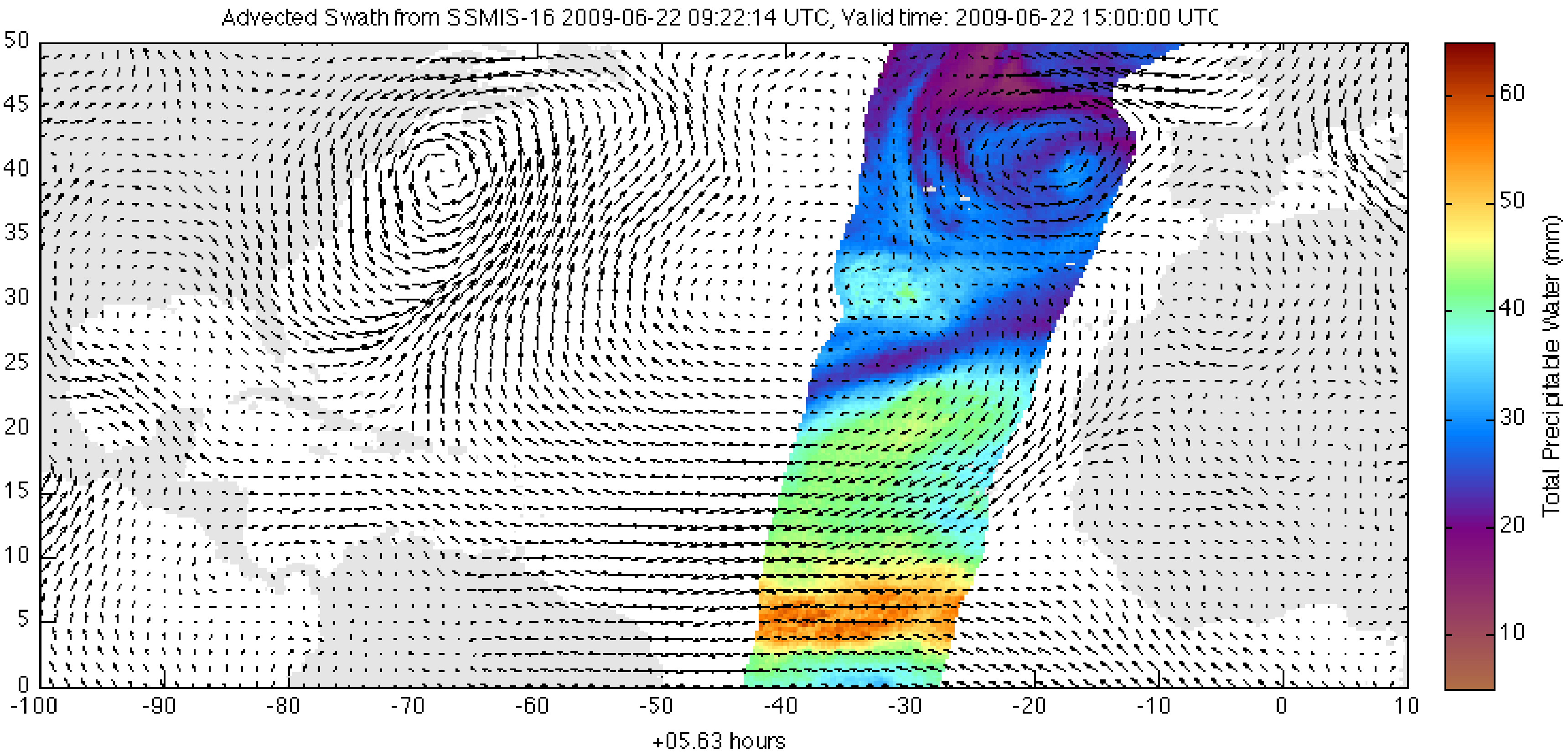
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

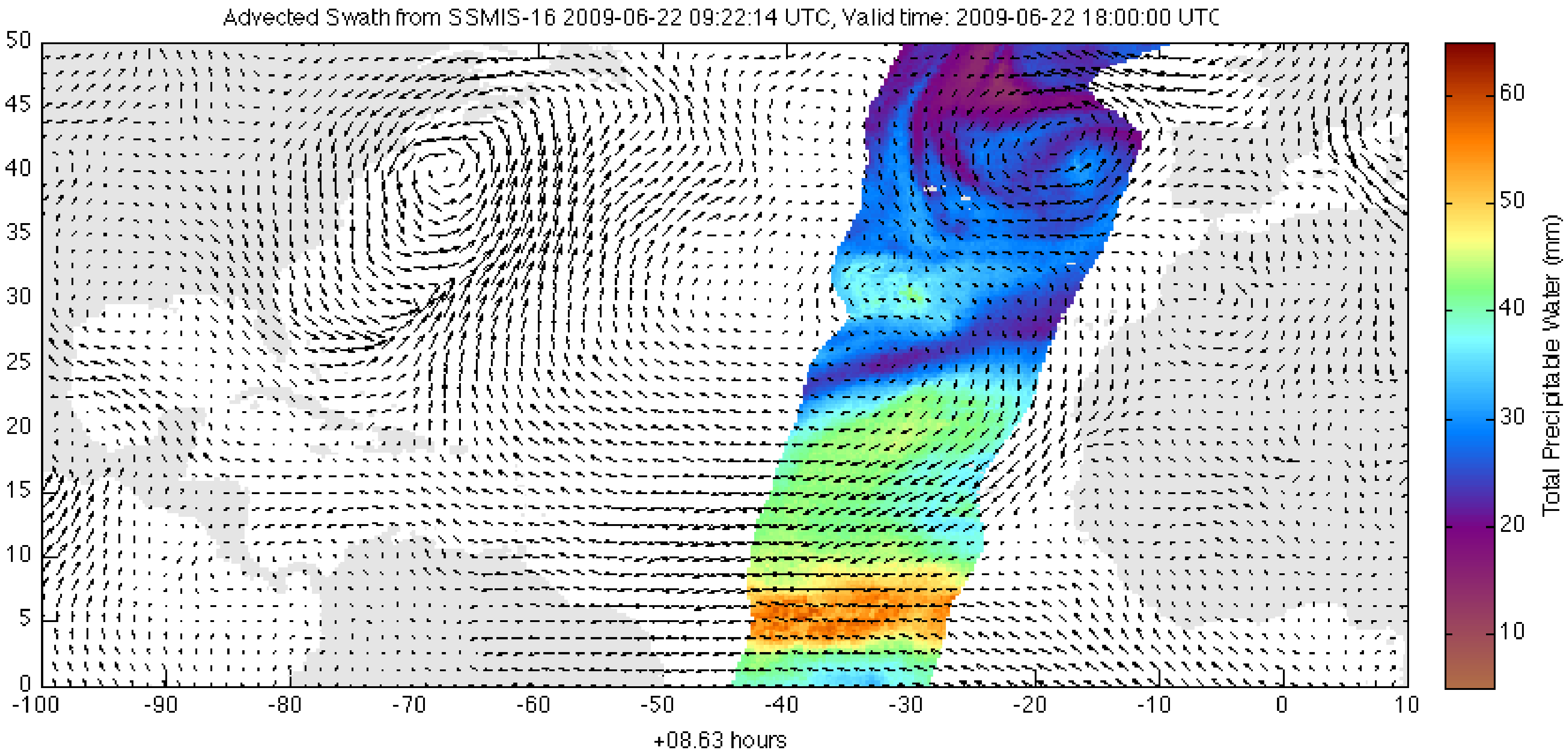
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

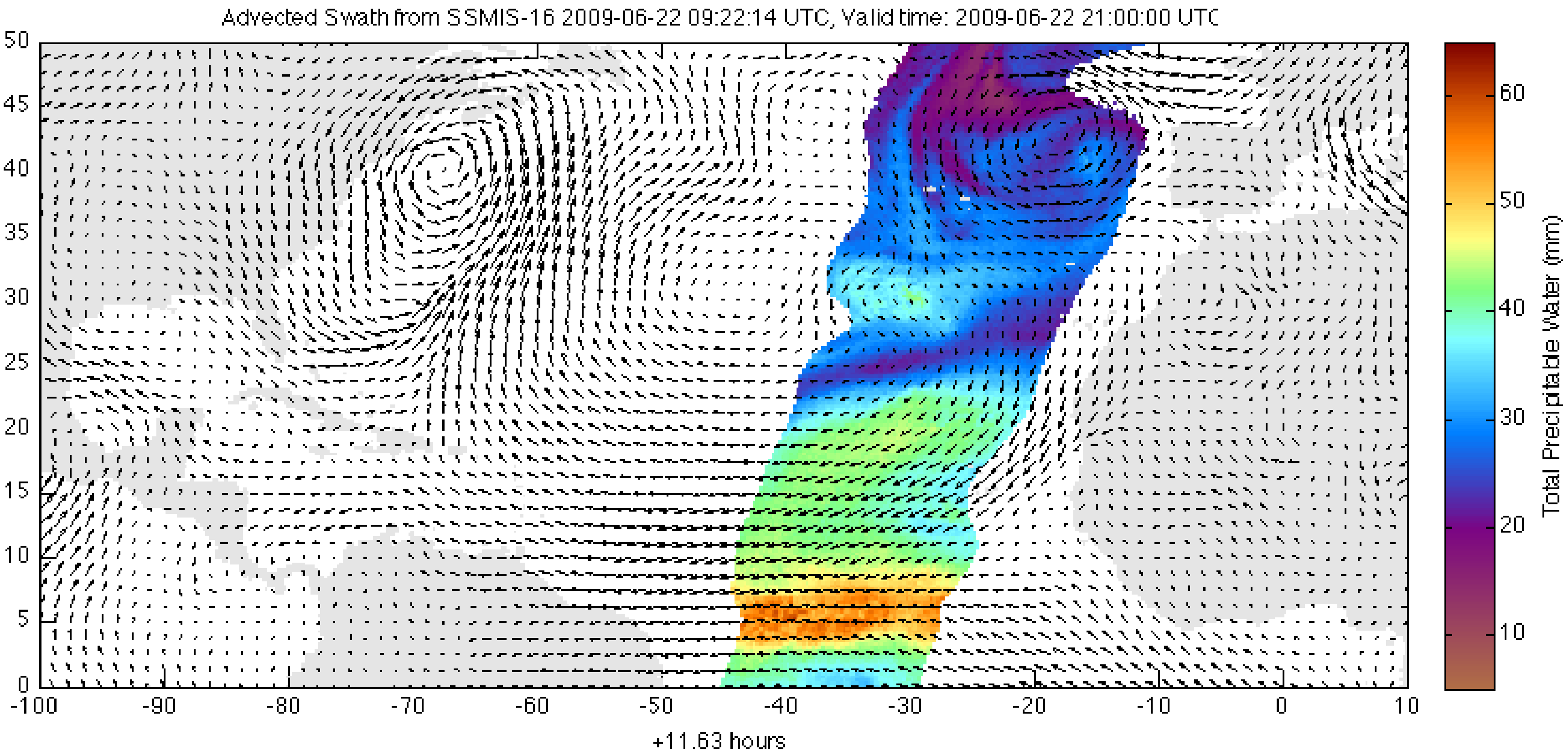
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

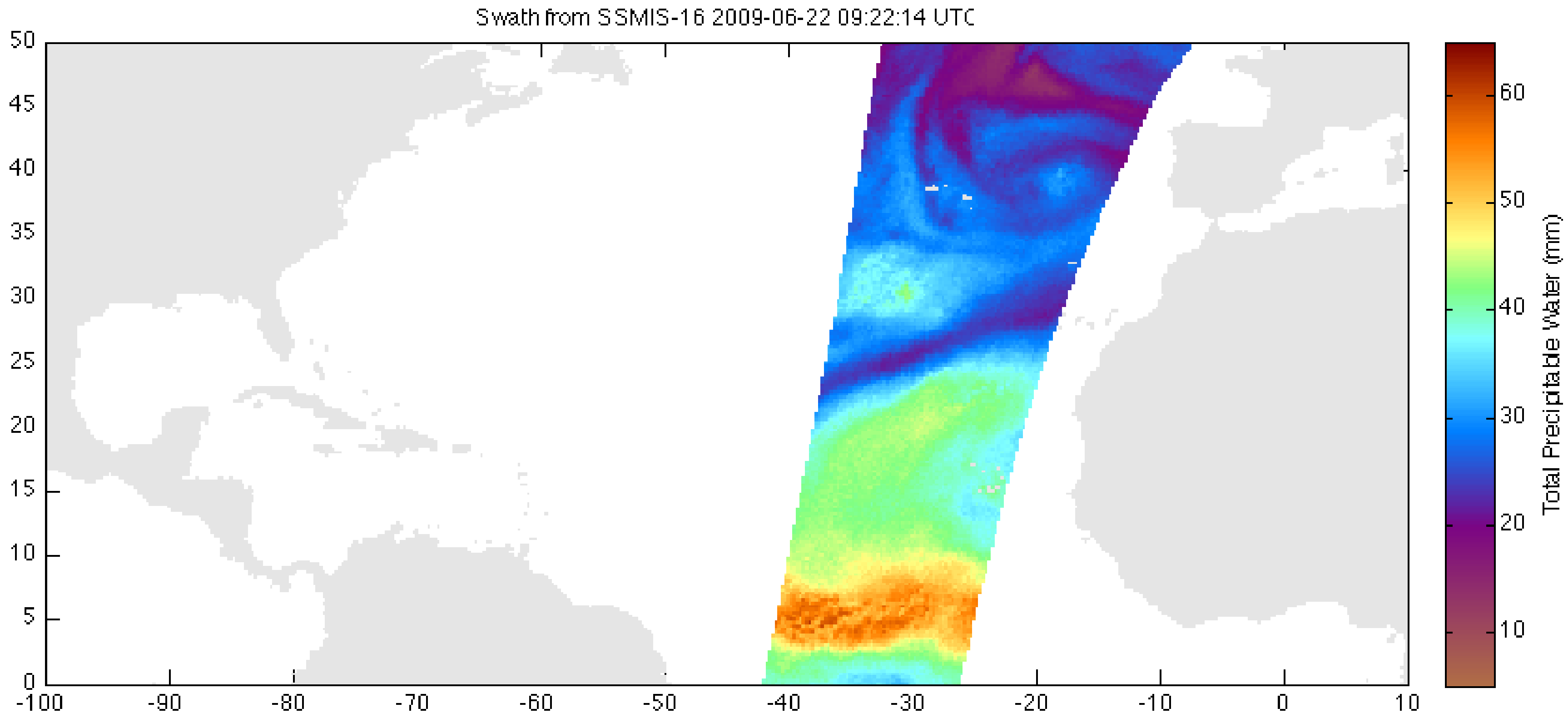
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

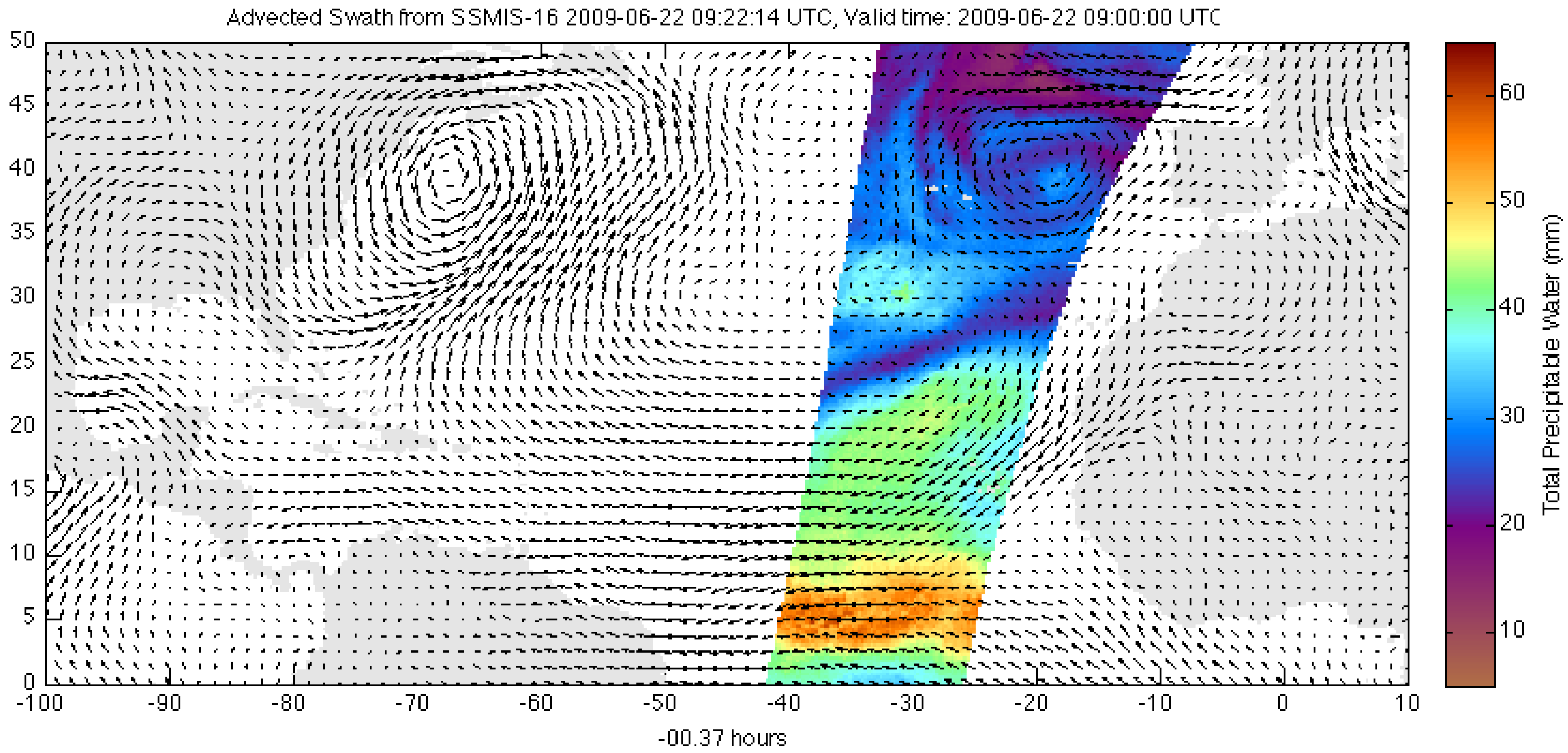
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

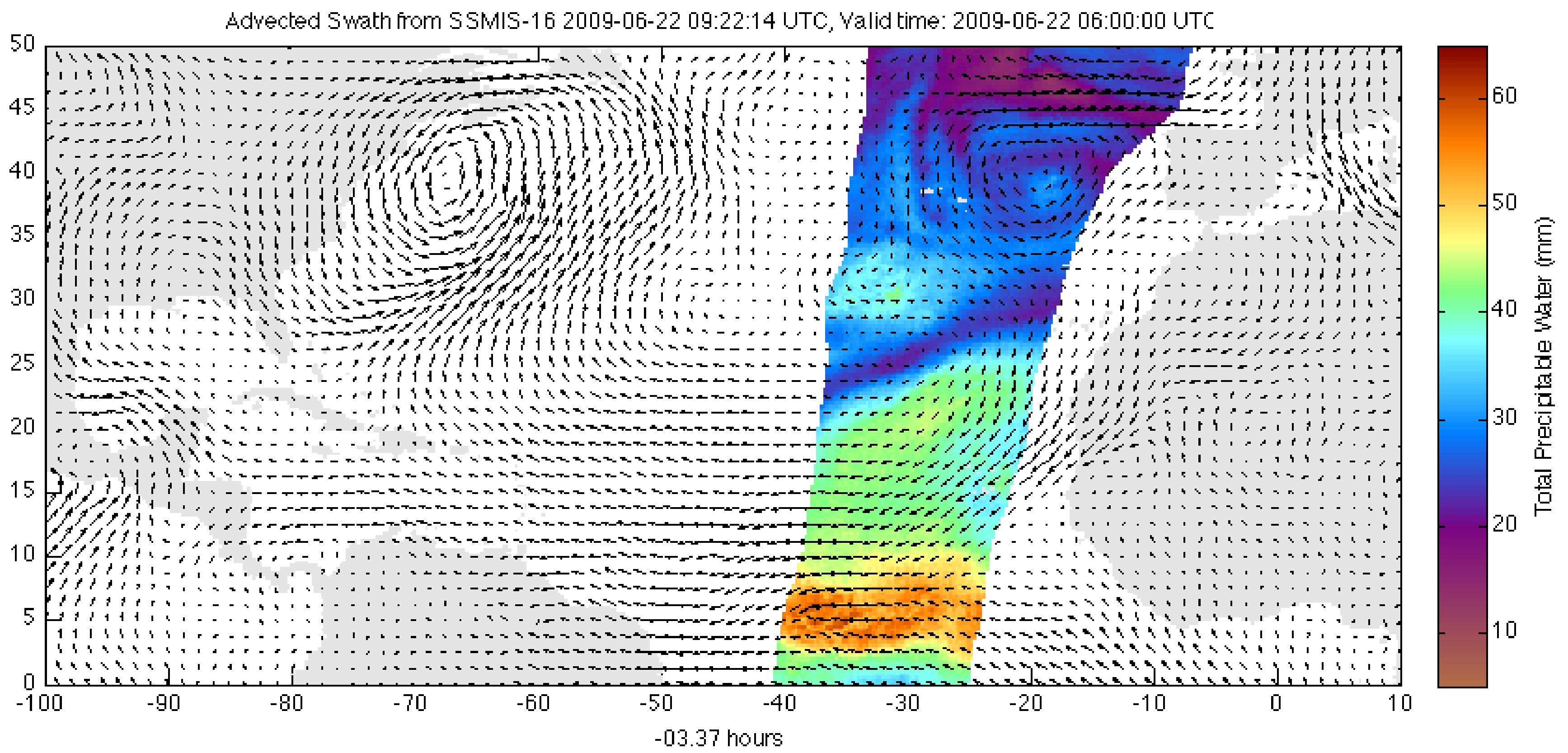
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

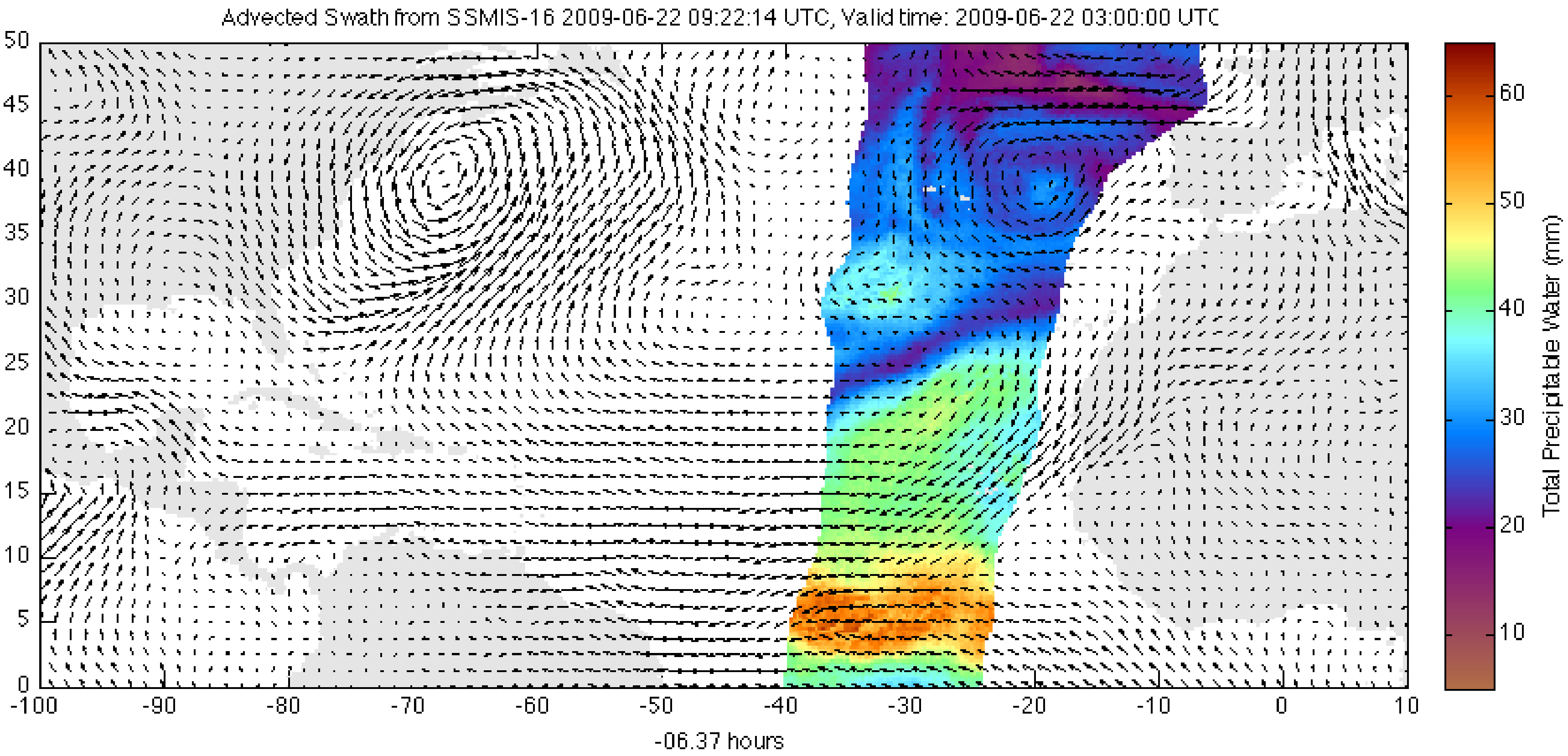
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

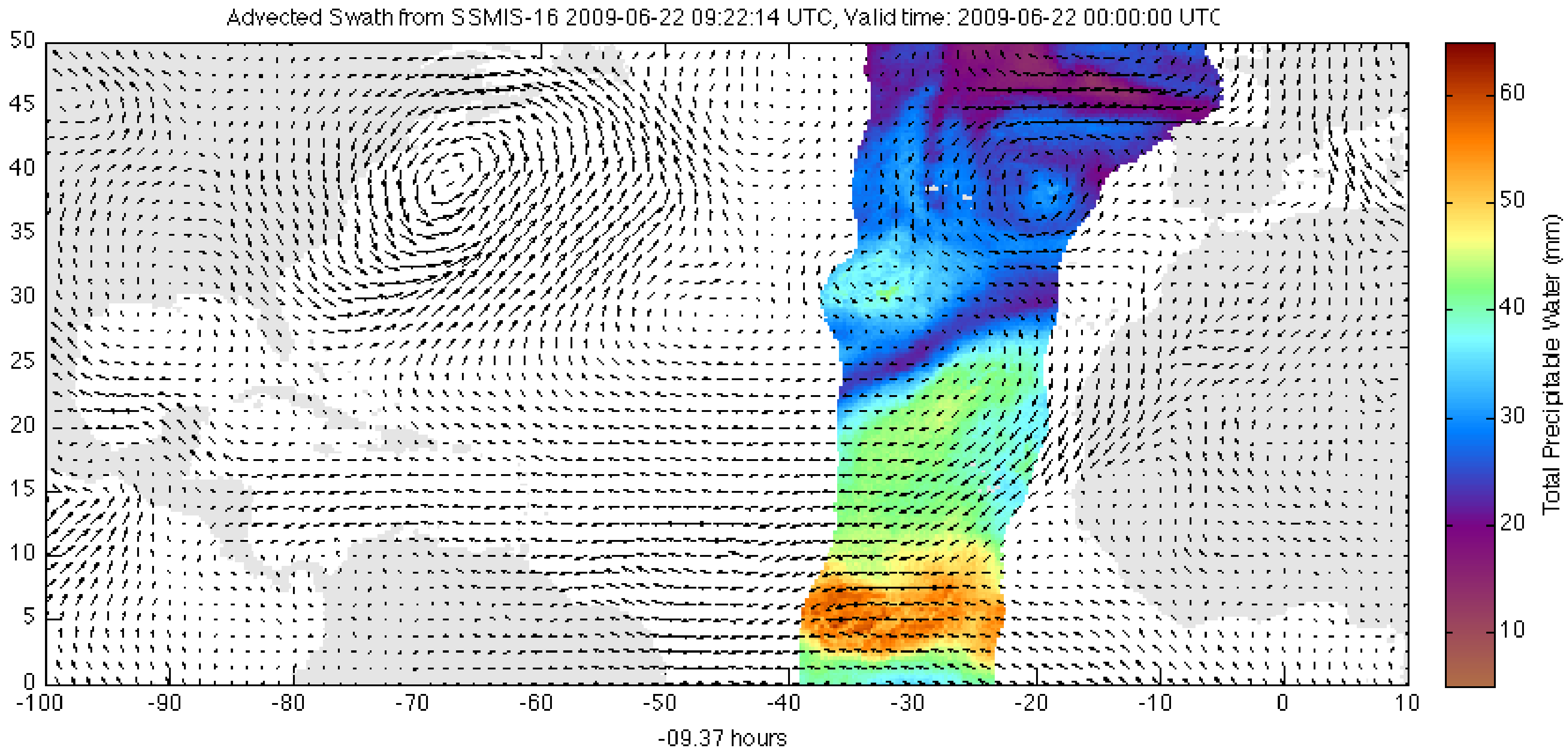
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

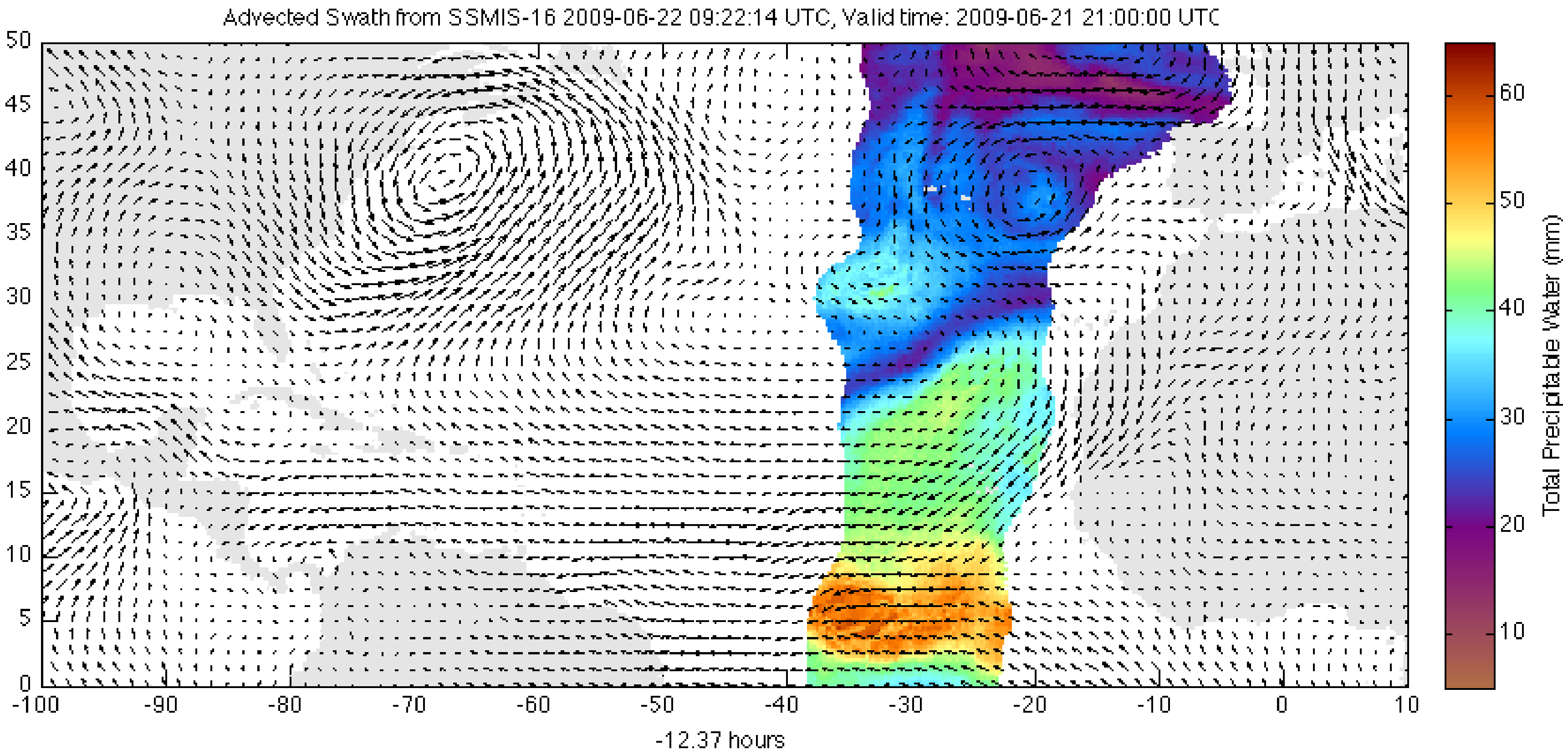
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

Data advected from 09:22 UTC

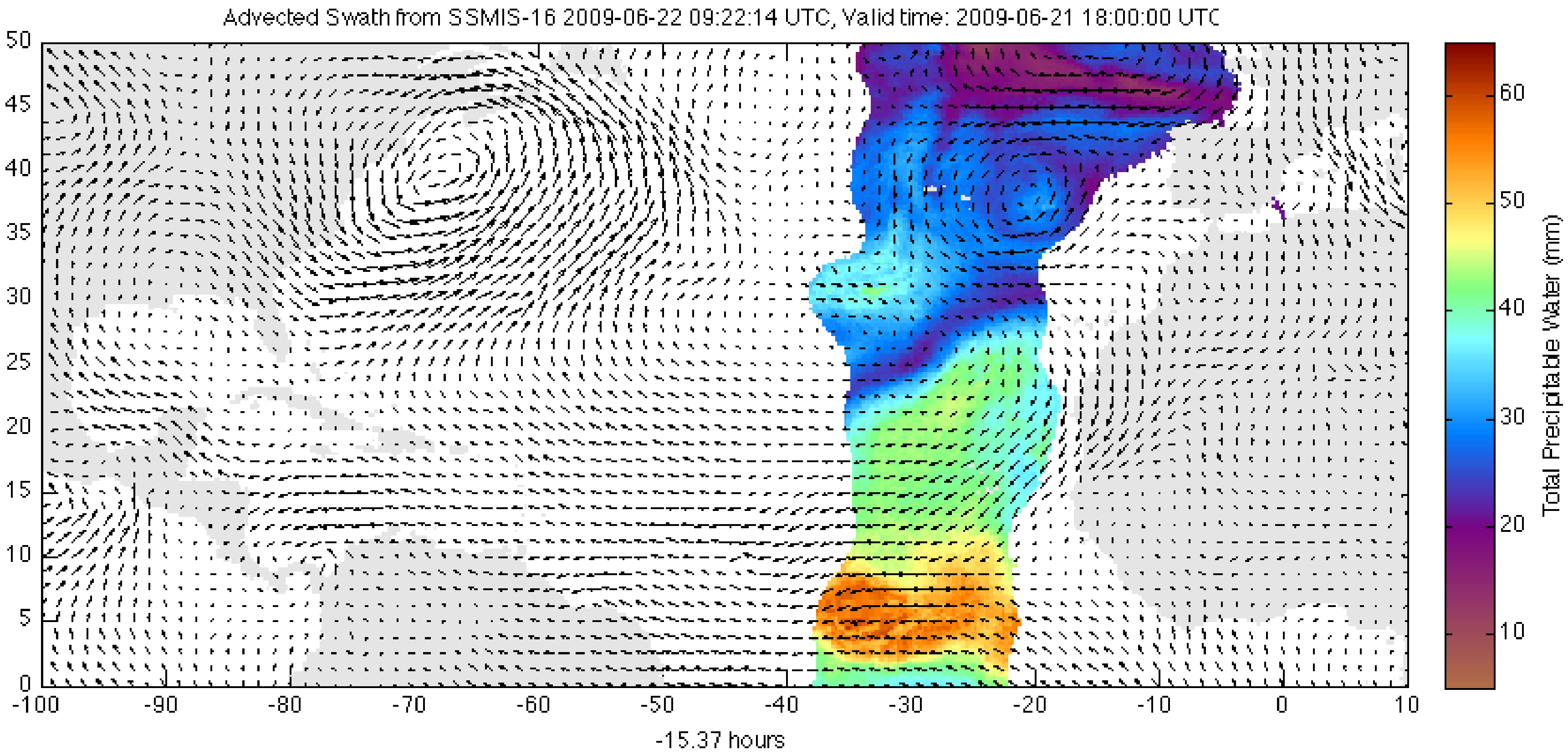
2009 / 06 / 22



18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

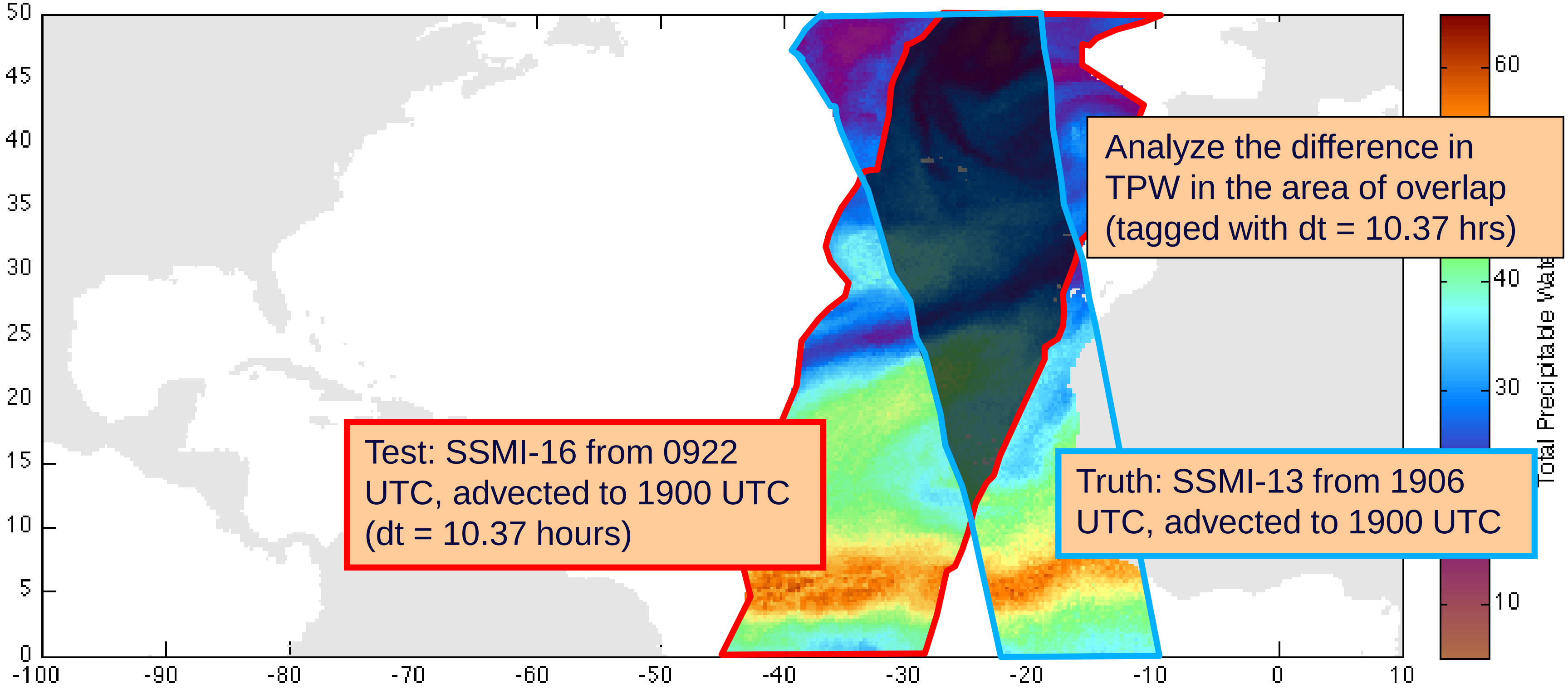
Data advected from 09:22 UTC

2009 / 06 / 22



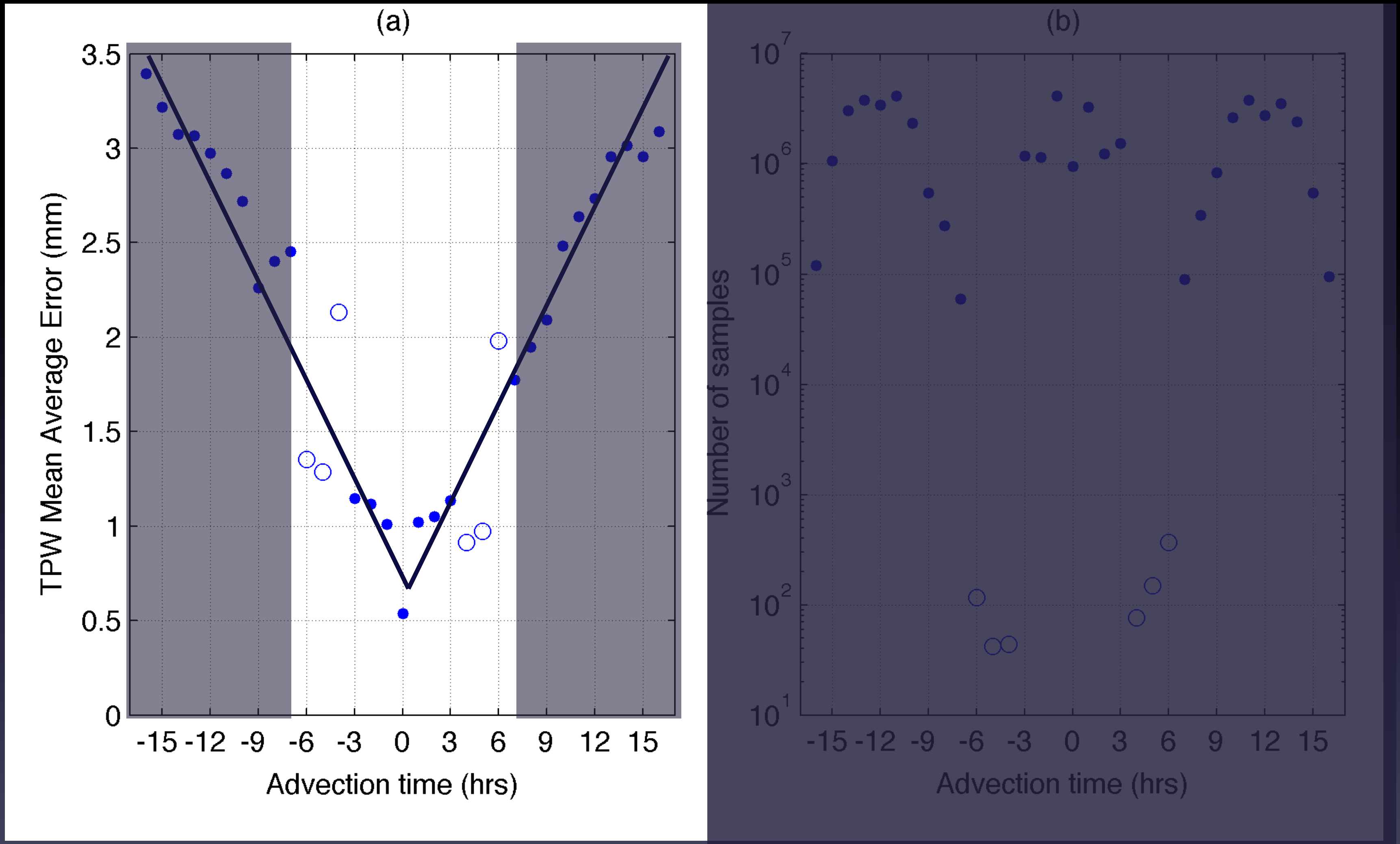
18 · · 21 · · 00 · · 03 · · 06 · · 09 · · 12 · · 15 · · 18 · · 21

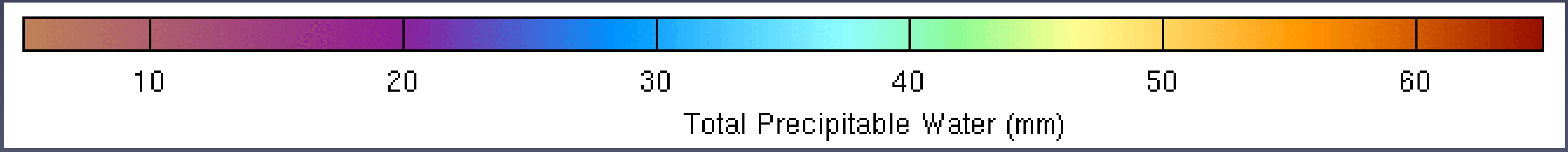
Validation



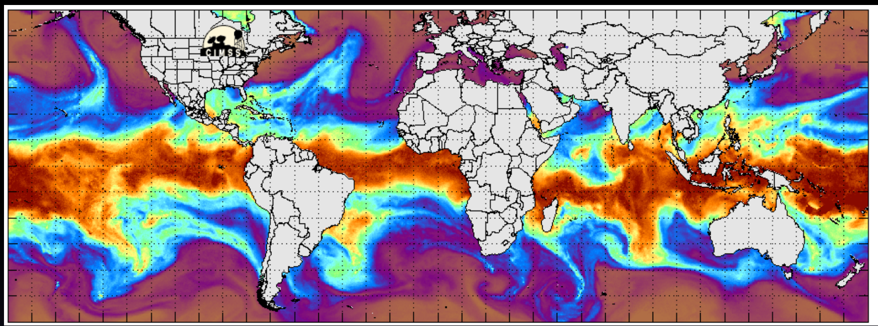
Valid 2009/06/22 1900 UTC

Error statistics binned by advection time



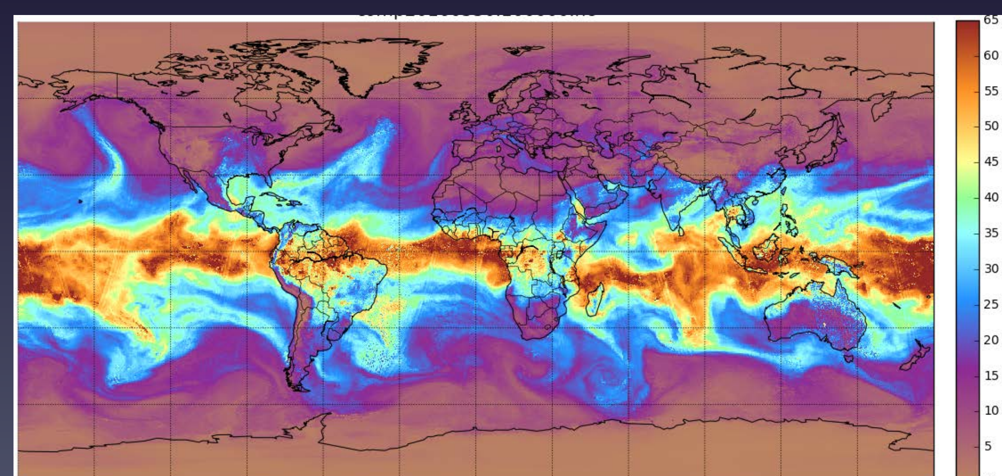


MIMIC-TPW: Background



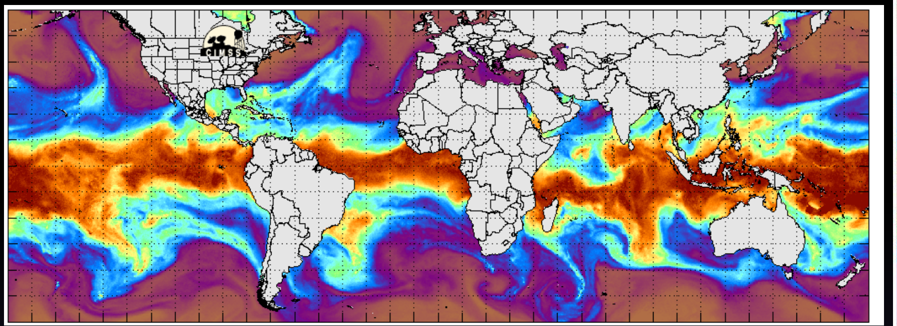
Version 1: 2008-present

- 2004: CMORPH demonstrates morphed advection on MW precip
- 2007: CIMSS supported by the Office of Naval Research to create real-time morphological composites of TPW from SSMI/S, AMSR sensors (4 conical scanners)
  - Retrieval only over liquid water (not a problem for the Navy!)
- ~2014: DoD indicates end of DMSP (SSMIS) program
- 2015: CIMSS supported by JPSS RR program to switch over to ATMS and AMSU-B/MHS, and improve the algorithm
  - <u>Now uses the MIRS retrieval</u>, which is valid over water, ice *and land*.
- 2016: Version 2 product goes online

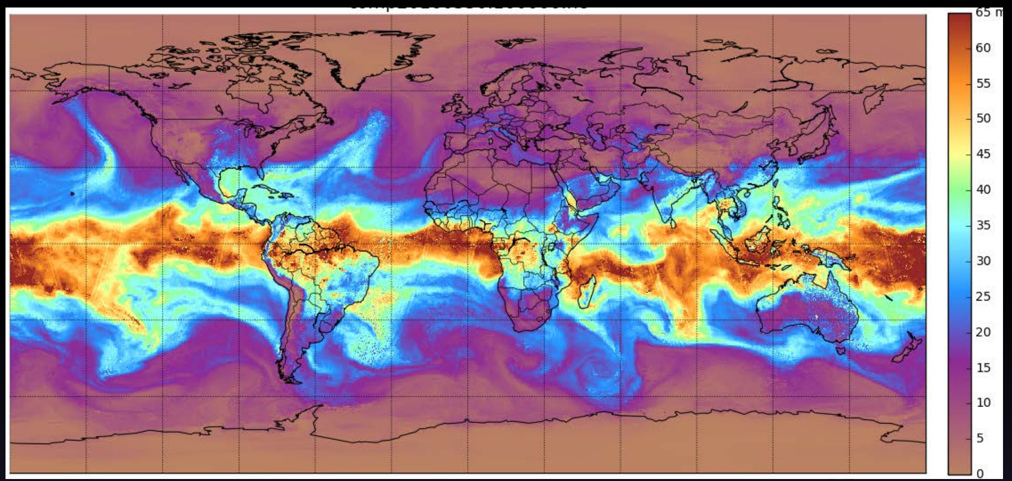


Version 2: 2016-present

Benefits of using MIRS

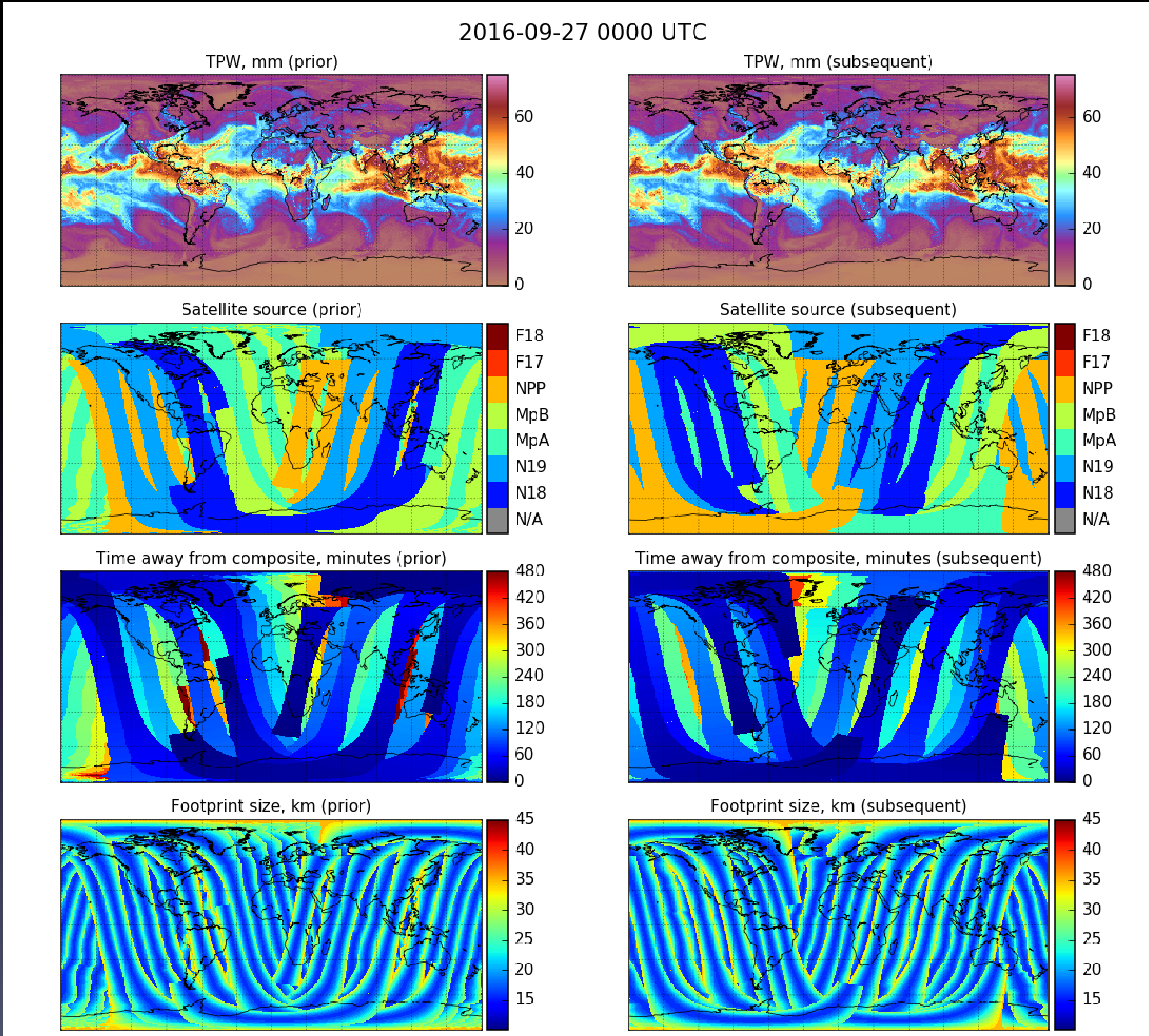


Version 1: No MIRS

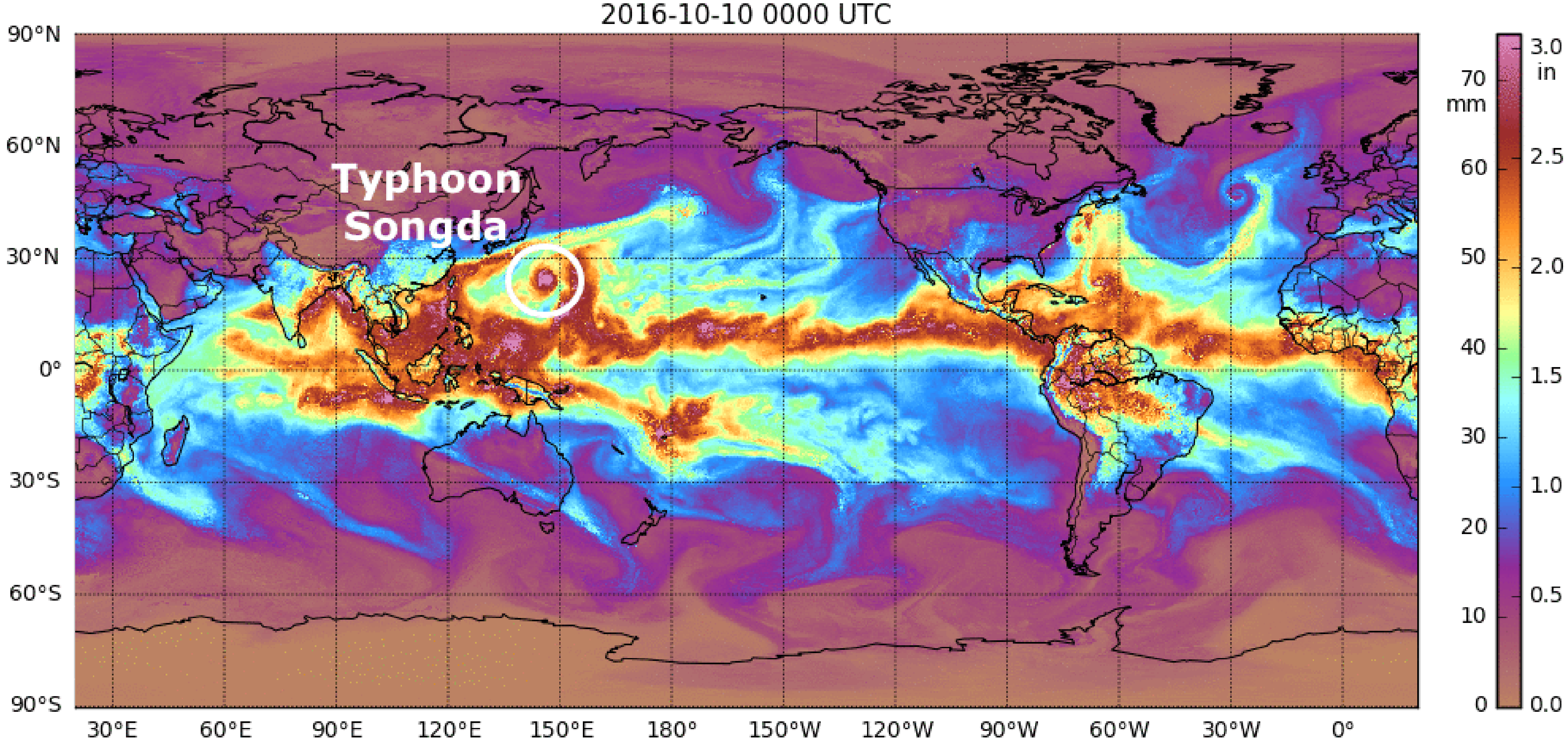


Version 2: Uses MIRS

- *Full global coverage* (versus over-water only)
- *Continuity*: We can be sure that this will continue after the DMSP program is over
- *Accuracy*: MIRS is well-validated and actively maintained
- *Big surprise benefit*: Morphed data also works well over land

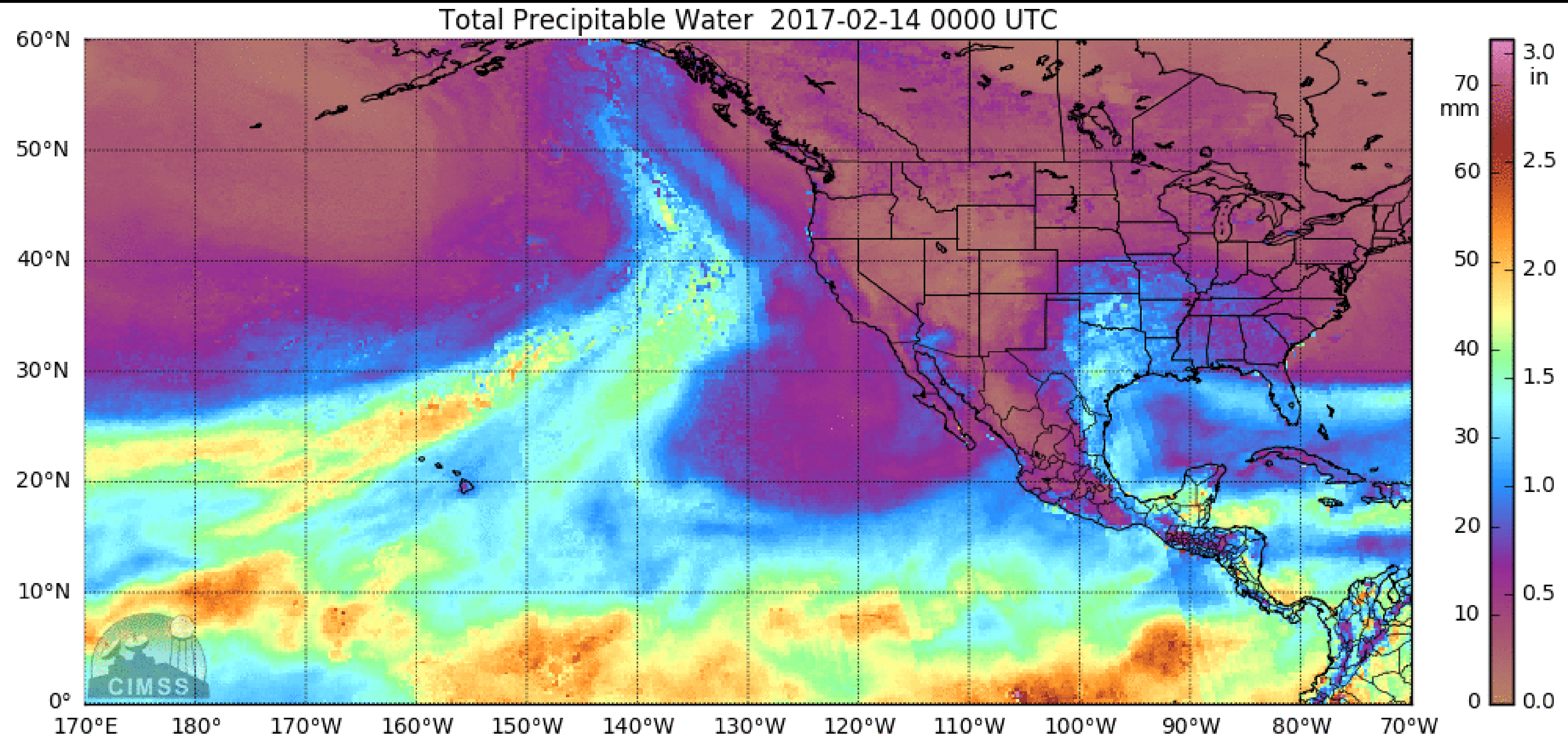

2016-09-27 0000 UTC
TPW, mm (prior)
TPW, mm (subsequent)
0 20 40 60
Satellite source (prior)
Satellite source (subsequent)
F18 F17 NPP MpB MpA N19 N18 N/A
Time away from composite, minutes (prior)
Time away from composite, minutes (subsequent)
480 420 360 300 240 180 120 60 0
Footprint size, km (prior)
Footprint size, km (subsequent)
45 40 35 30 25 20 15

MIMIC-TPW: Examples



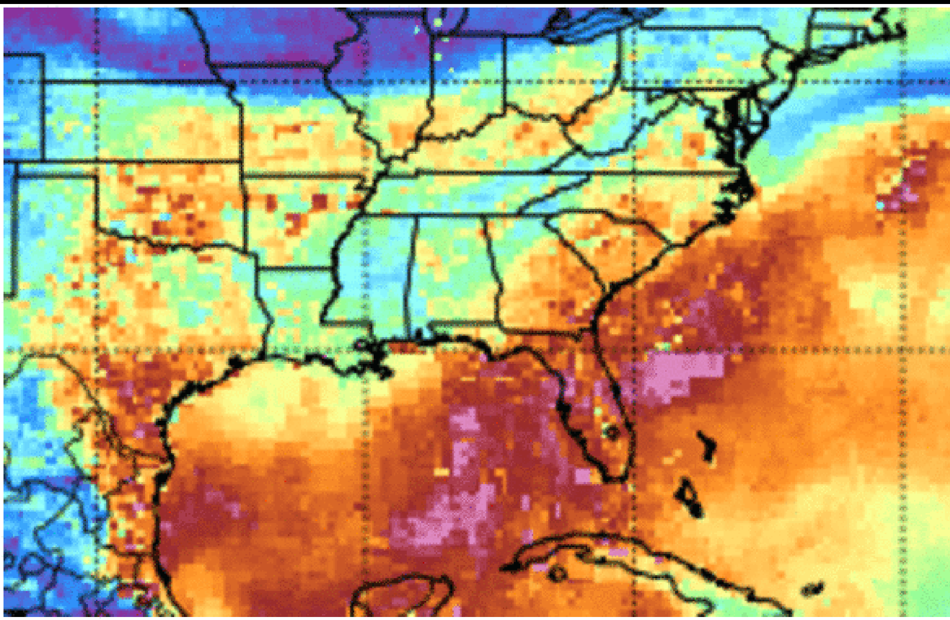
- Oct 2016: Remnants of Typhoon Songda hit U.S. west coast

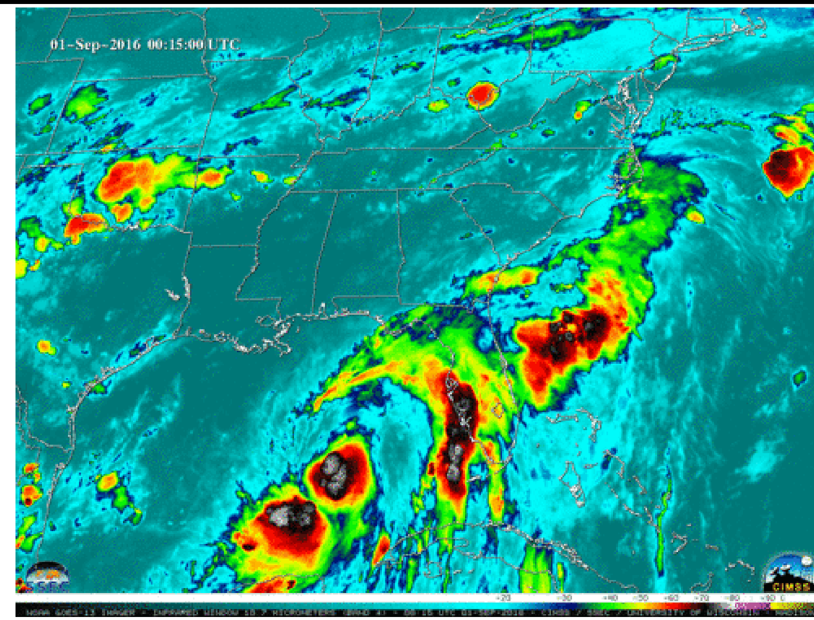
MIMIC-TPW: Examples



- Feb 2017: Atmospheric rivers cause flooding in California, Pacific northwest

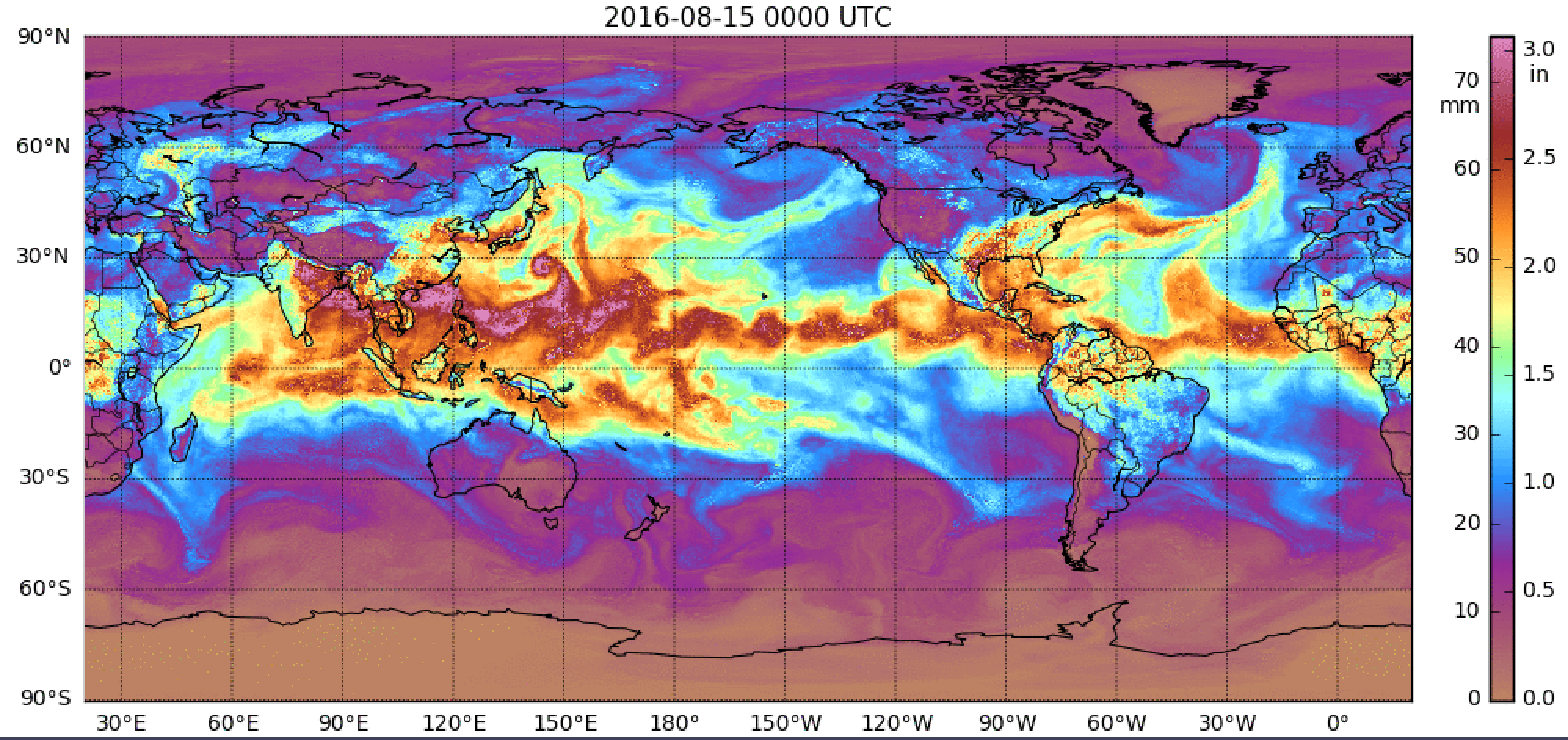
MIMIC-TPW: Examples





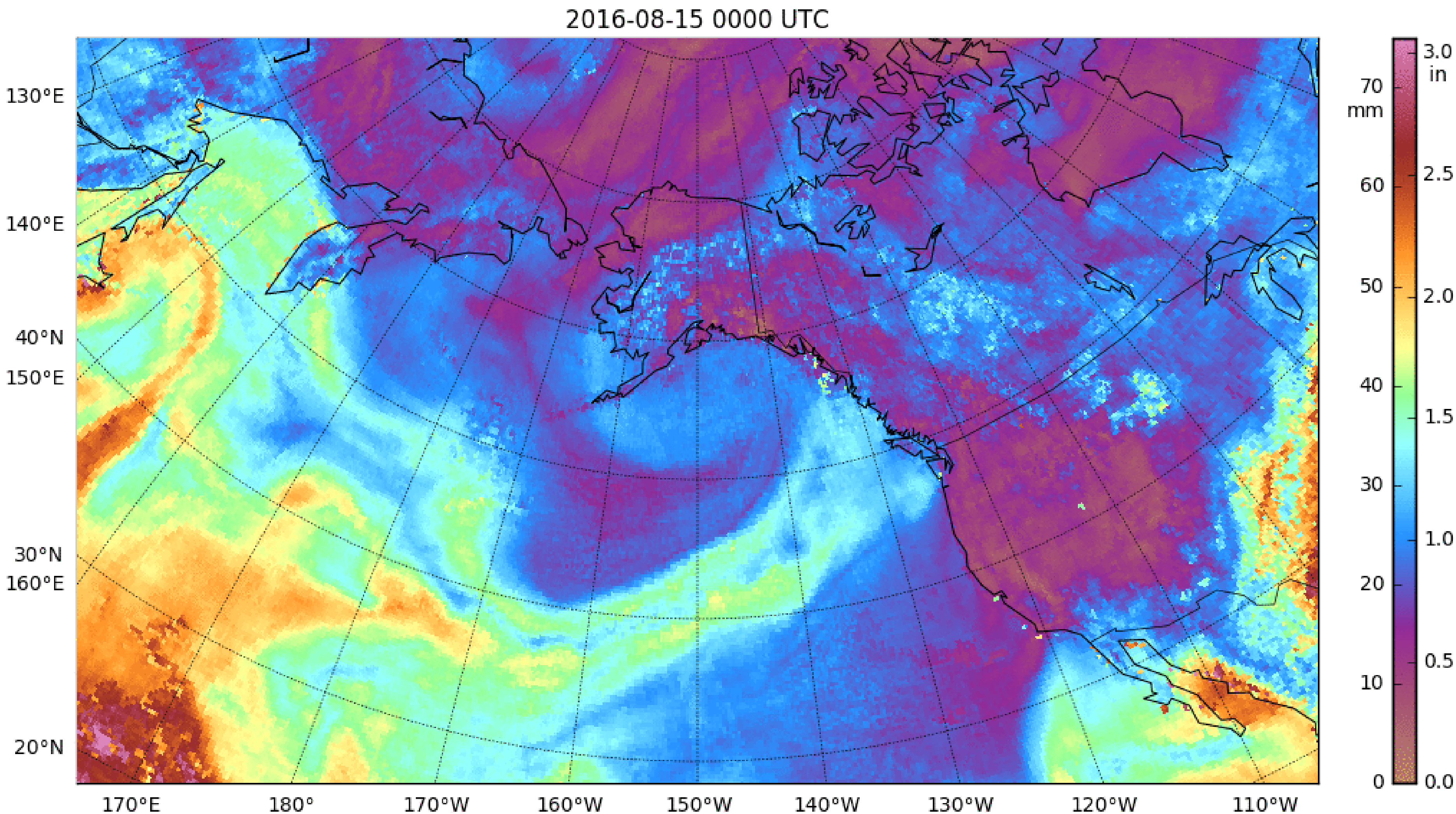
- Landfall of TS Hermine (2016)

MIMIC-TPW: Examples



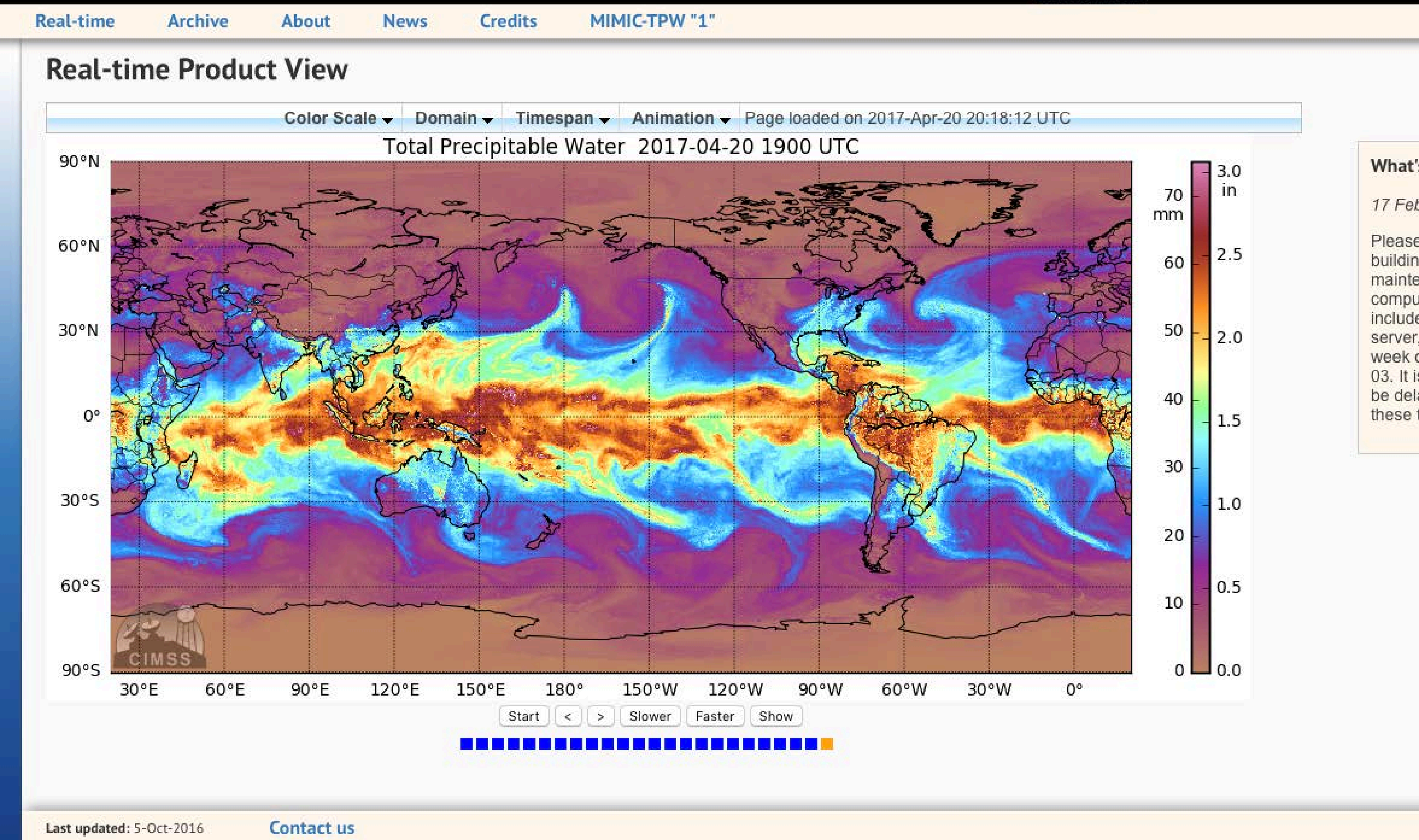
- Tropical wave development

MIMIC-TPW: Examples

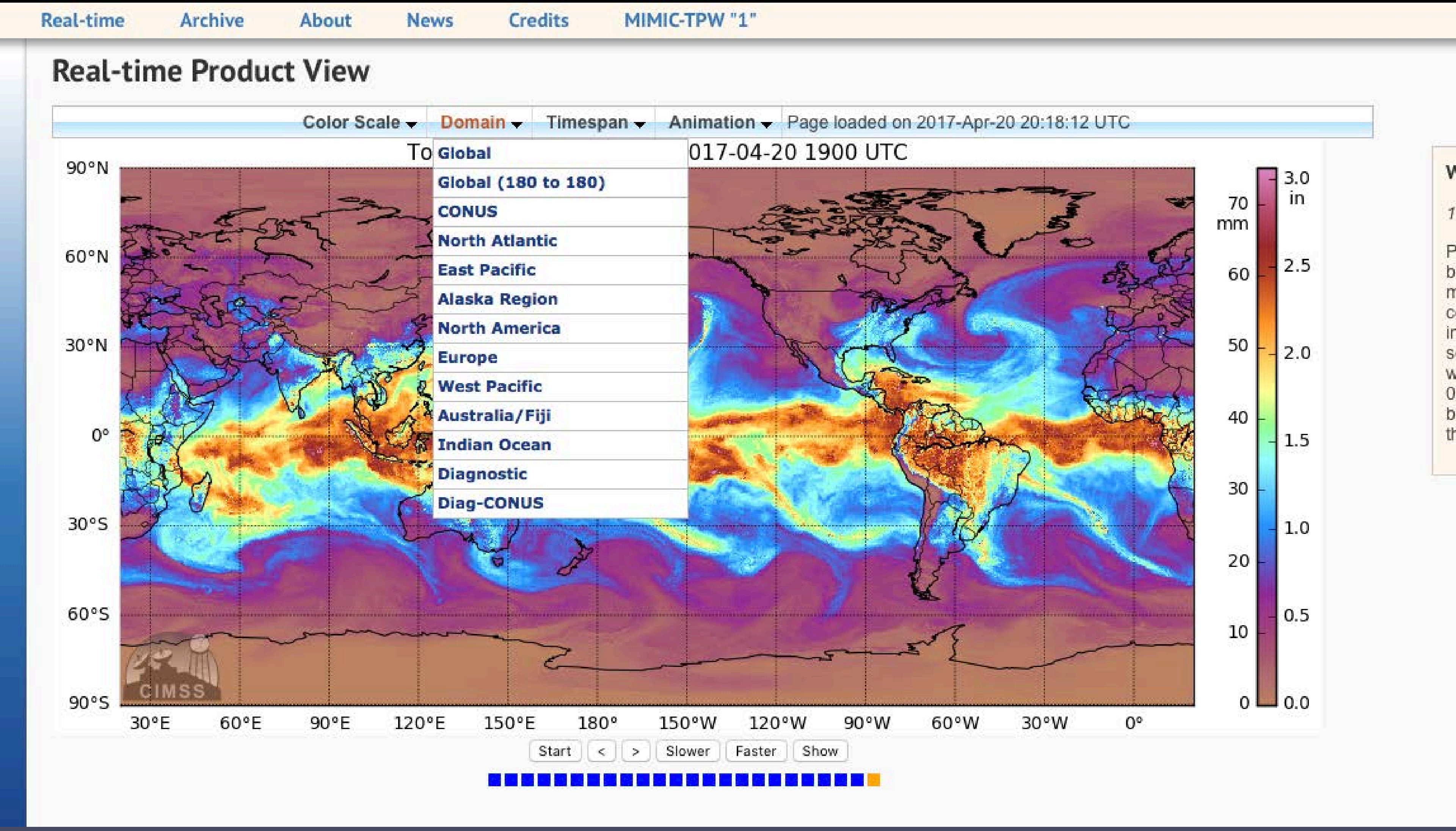


- Tropical moisture hitting Alaska

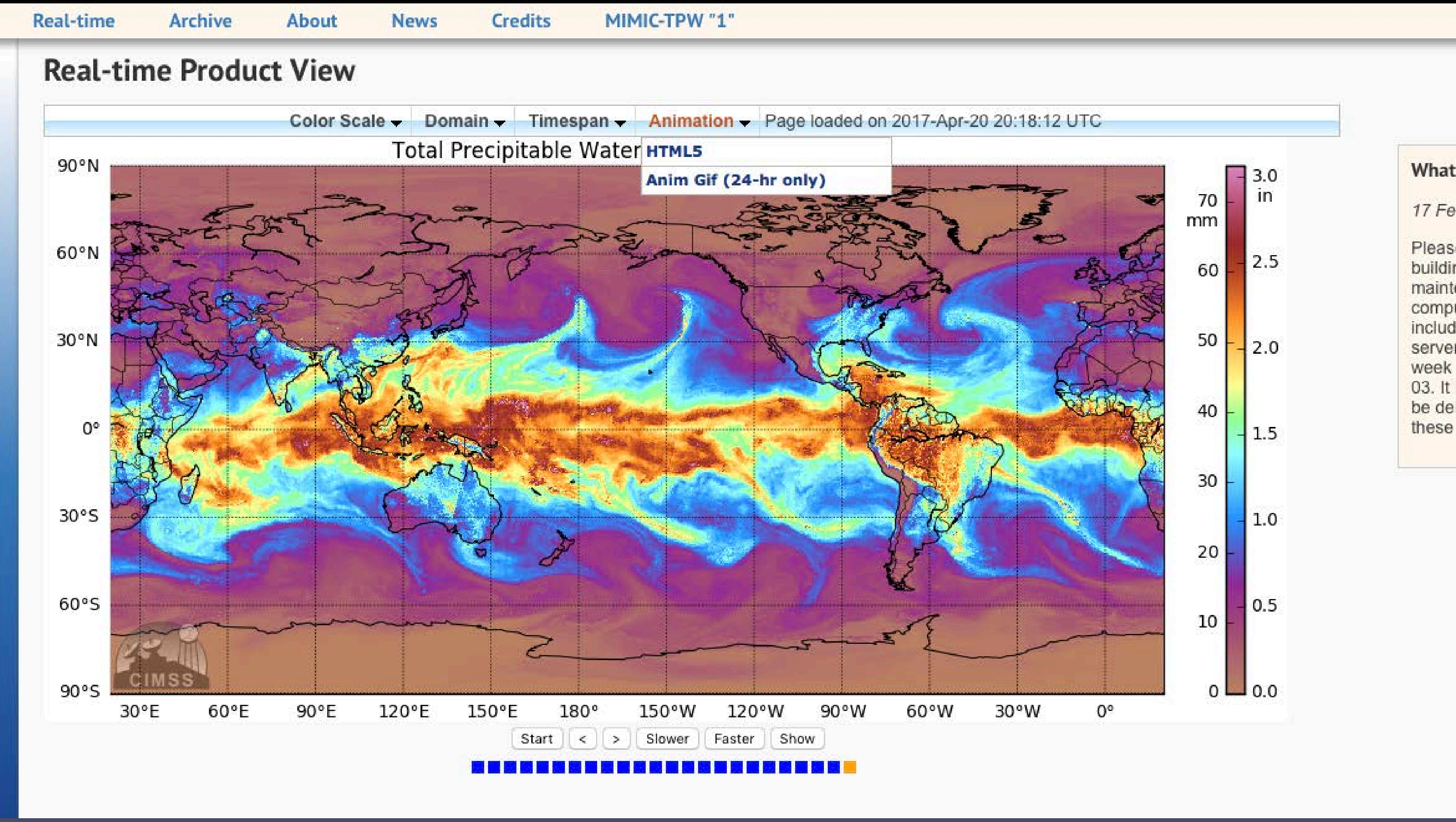
MIMIC-TPW2: Website



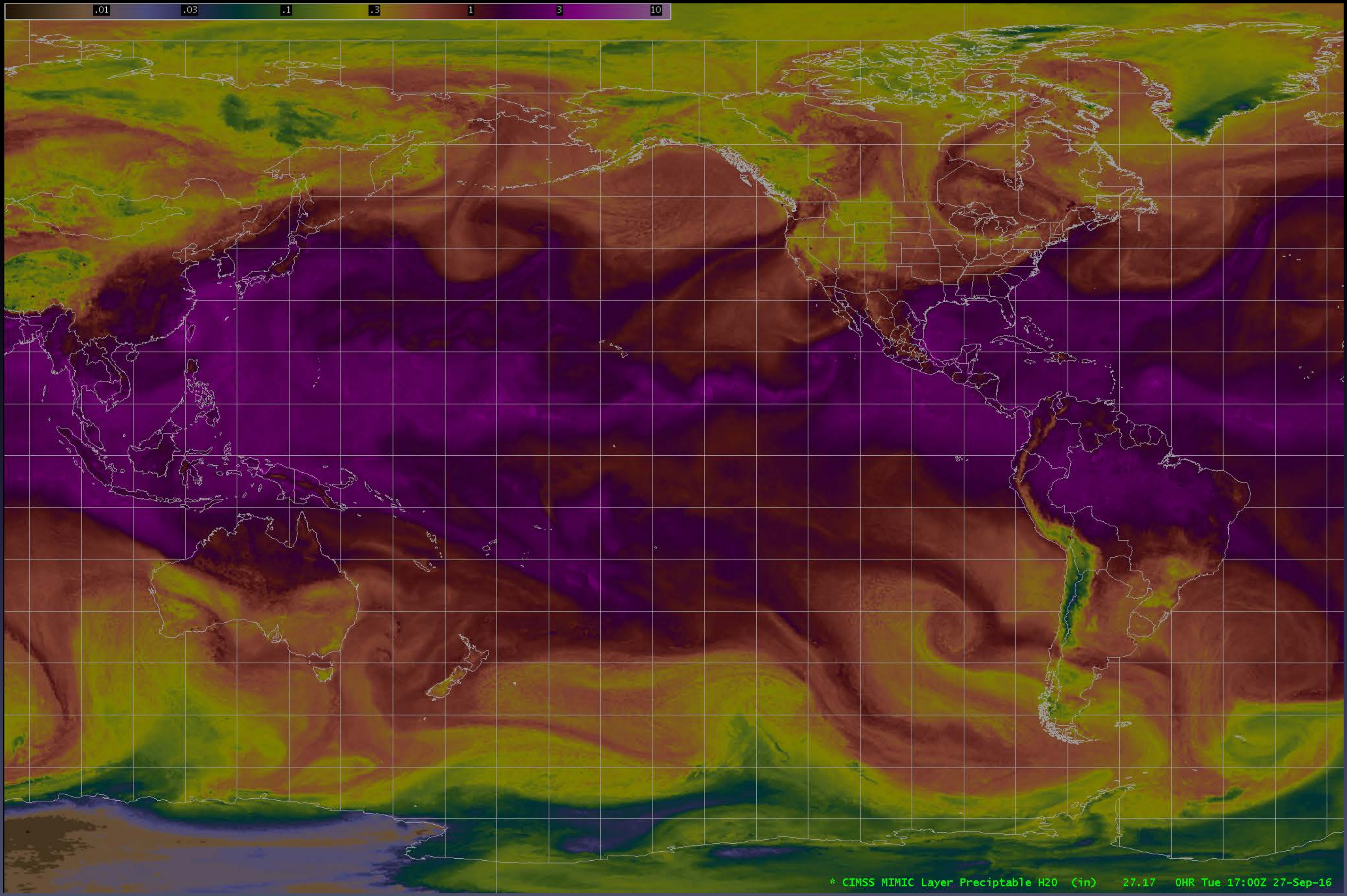
MIMIC-TPW2: Website



MIMIC-TPW2: Website

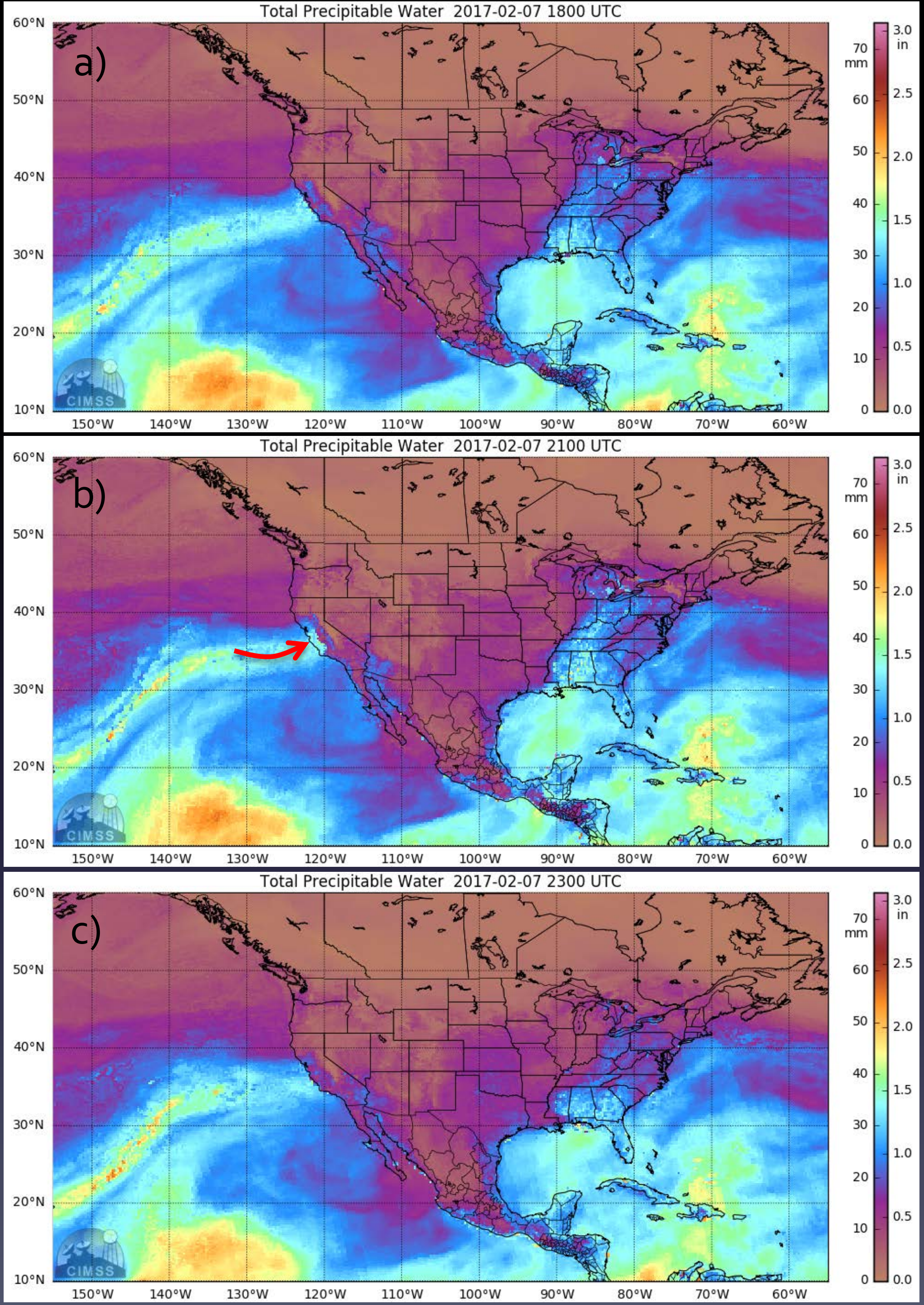


MIMIC-TPW2: AWIPS

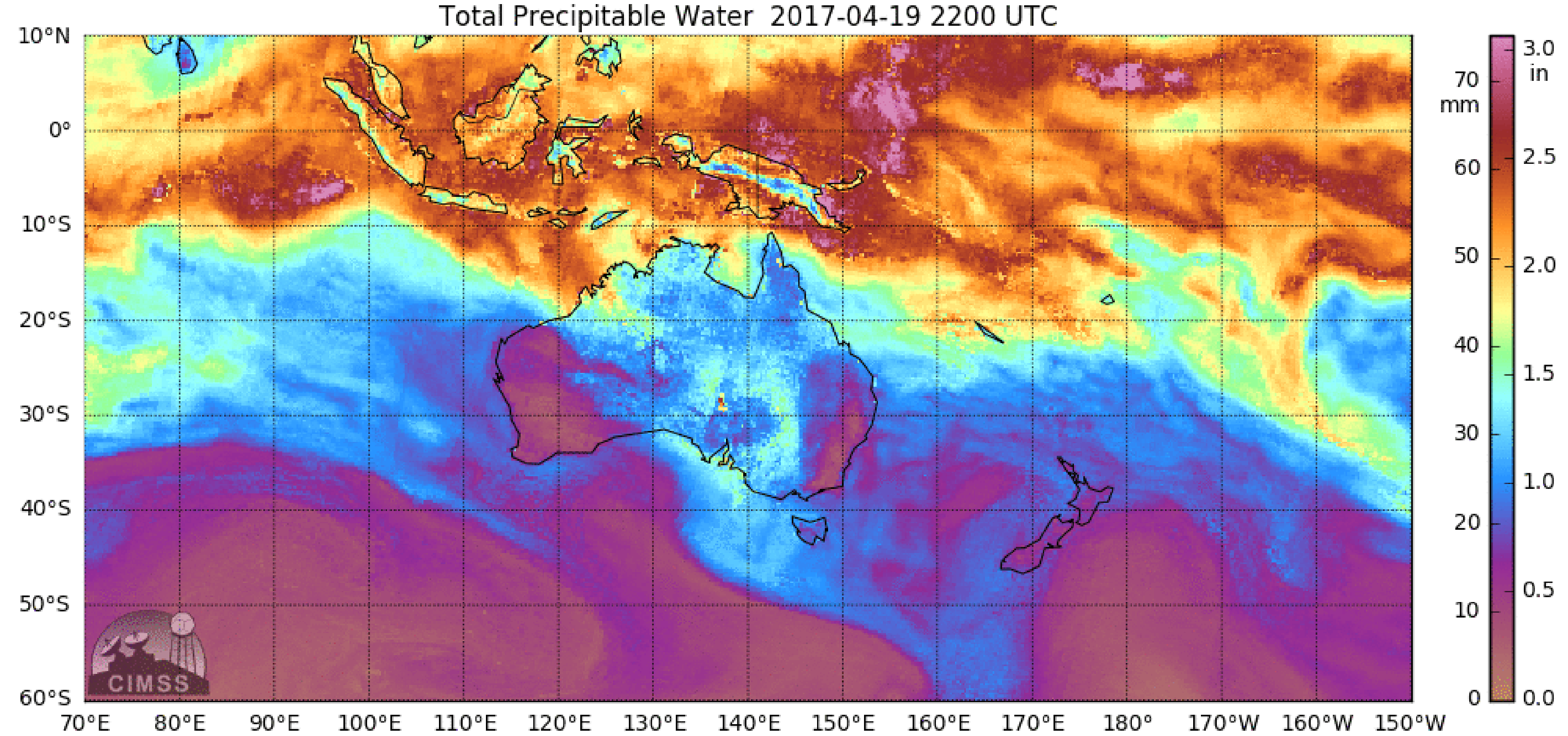


Remaining issue: Advection over land and across coasts

- Simple one-level advection causes moisture to be depicted crossing the coastal boundaries even when it should not (due to trapping from an inversion or other discrepancies).

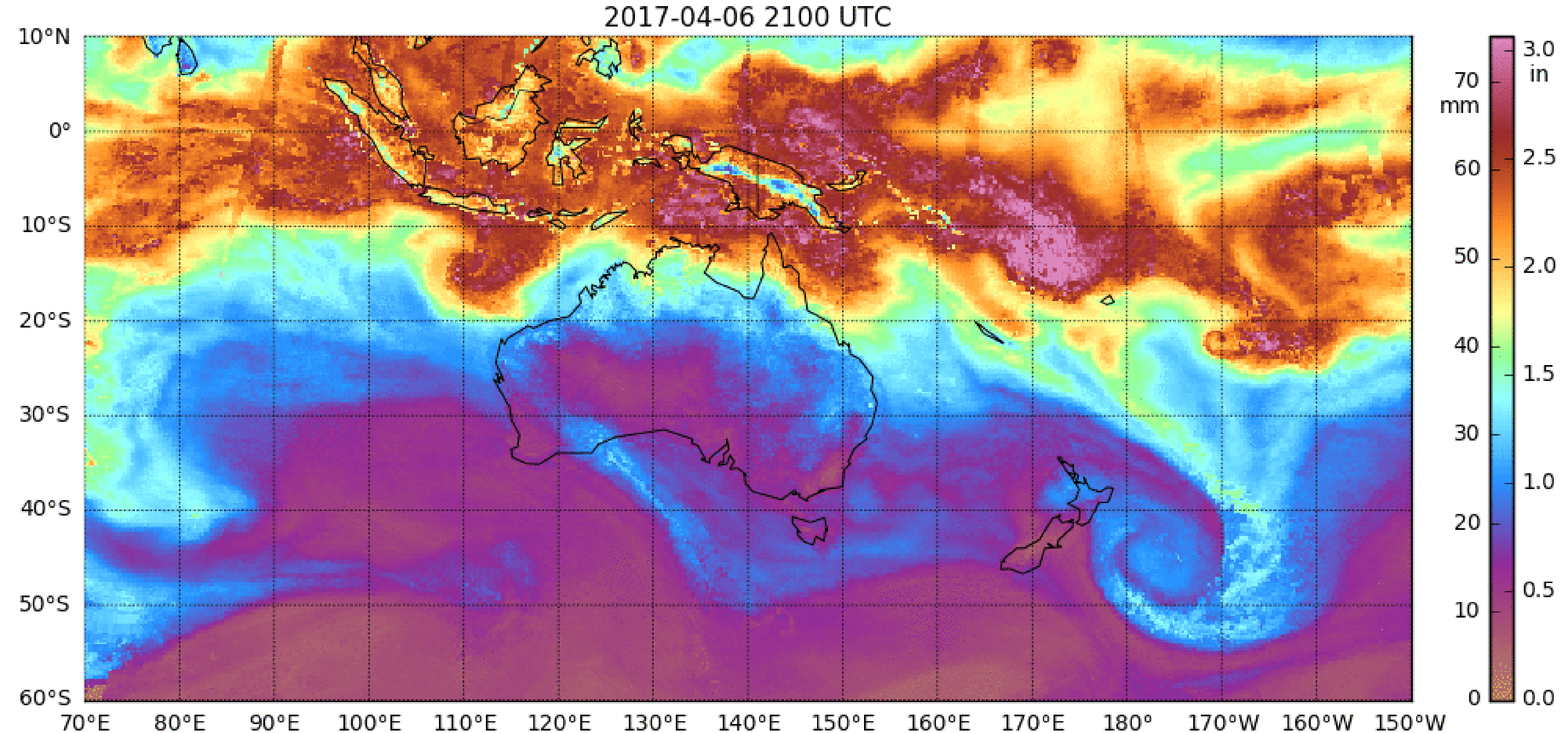


Remaining issue: Adjusting for AMSU-B



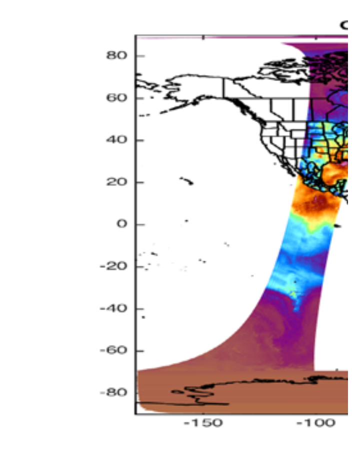
- MIMIC-TPW2 from all sensors

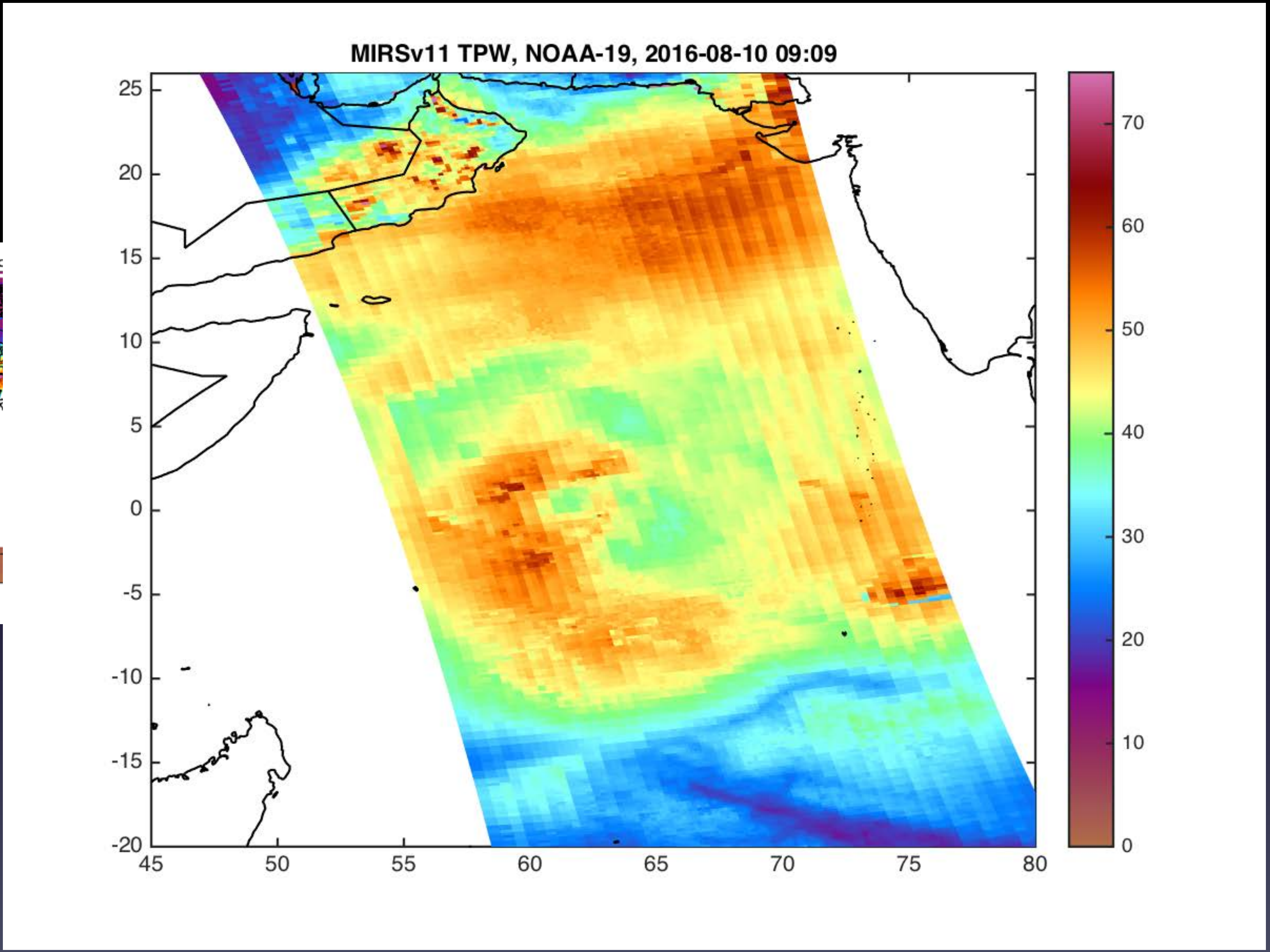
Remaining issue: Adjusting for AMSU-B



- MIMIC-TPW from Suomi ATMS only

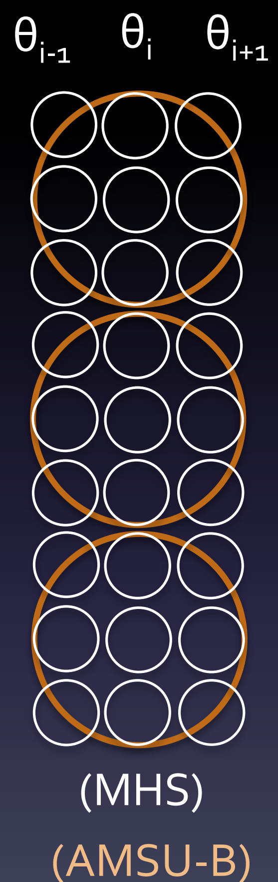
Nearly solved issue: MIRS striping

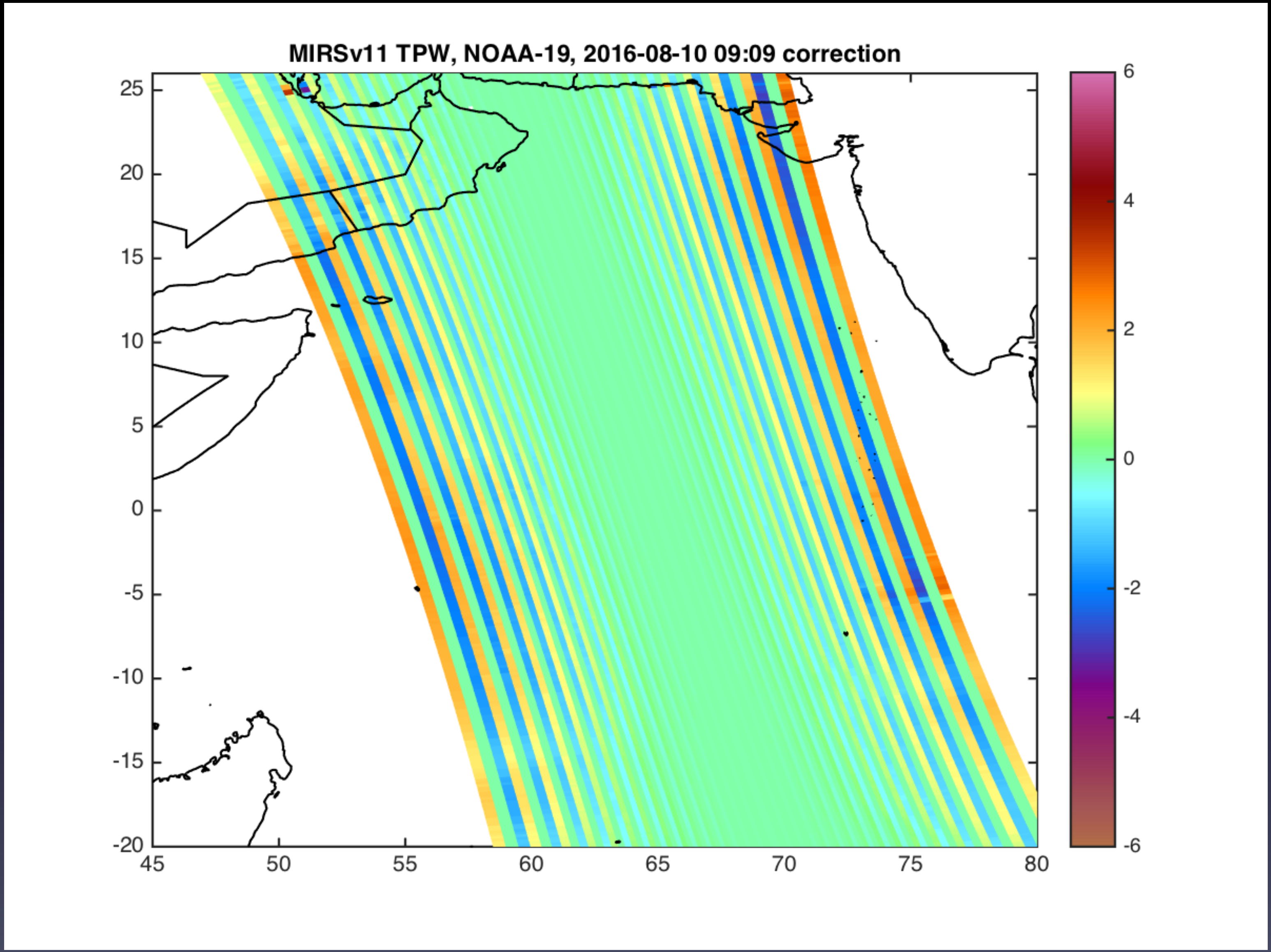




- Original MIRS v11.2 TPW

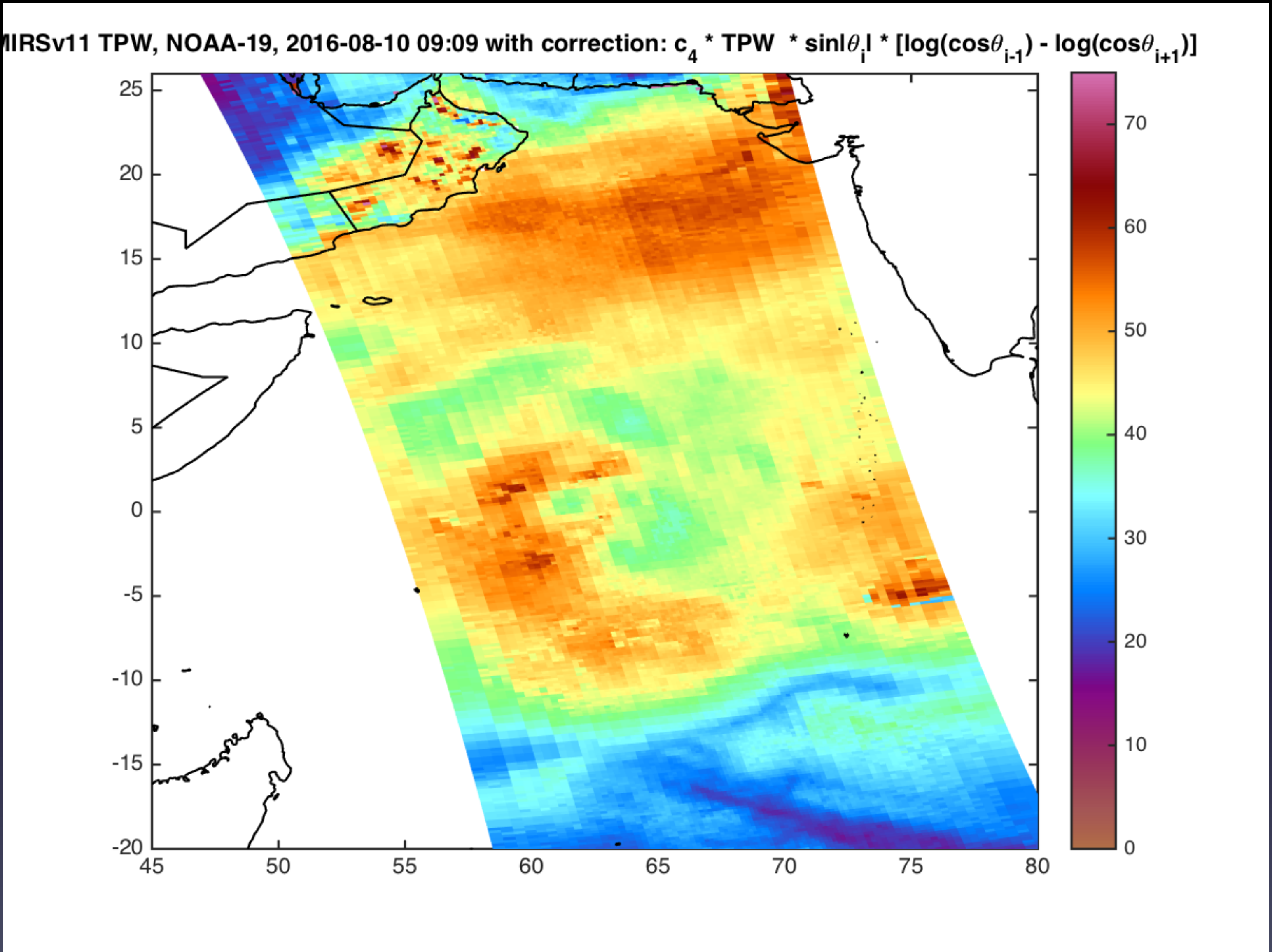
Nearly solved issue: MIRS striping





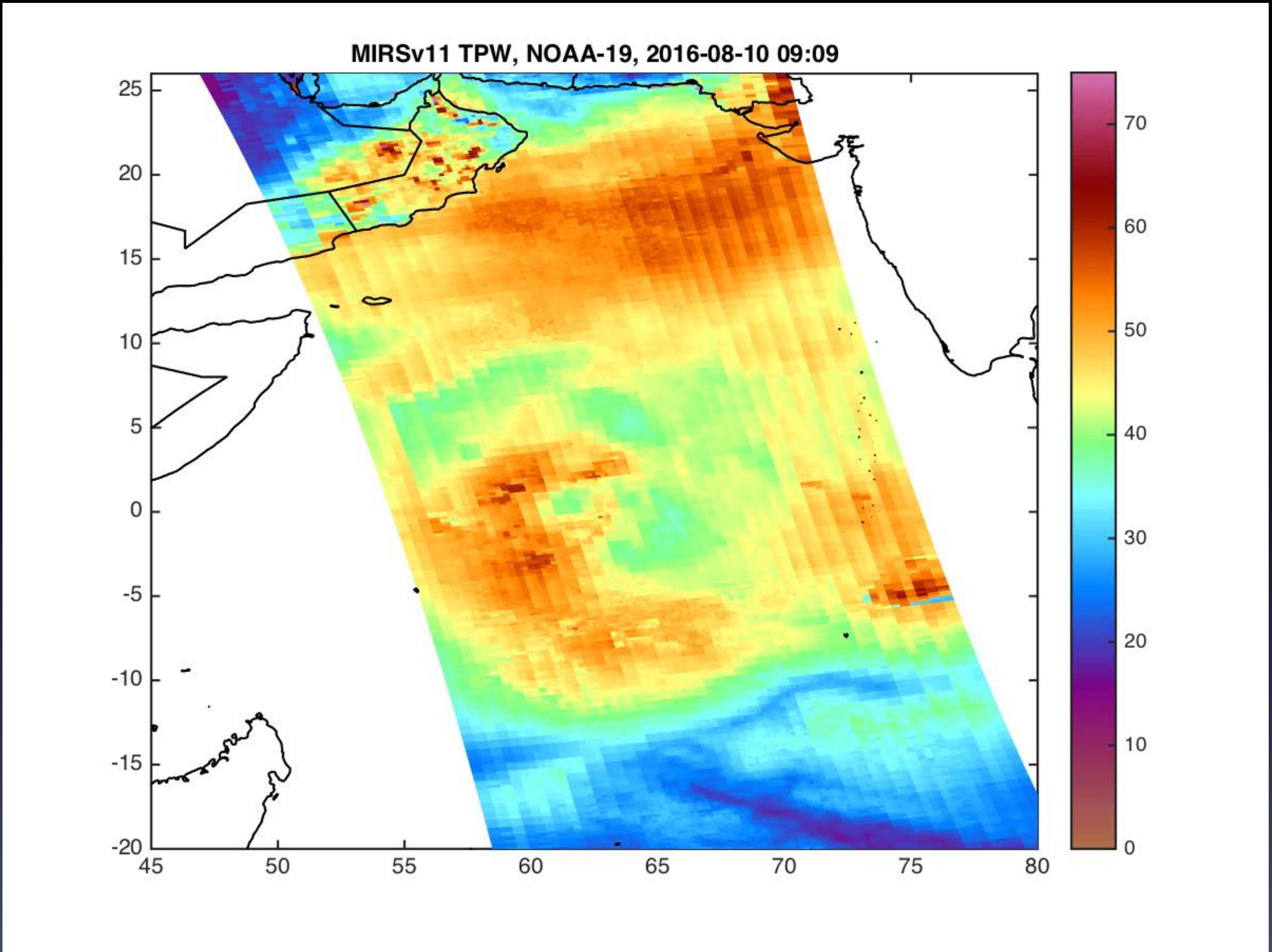
- Correction: $c * TPW * \sin|\theta_i| * [\log(\cos\theta_{i-1}) - \log(\cos\theta_{i+1})]$

Nearly solved issue: MIRS striping



- TPW with correction

Nearly solved issue: MIRS striping



- TPW without correction

Final Remarks

General benefits of morphological compositing of MIRS retrievals

- Use polar orbiters like geo
- Increase the temporal resolution of satellite products
  - Regular time-stepping
  - Better matching with in-situ data
  - Improve satellite temporal interpolation
  - **Natural, fluid motion matches with users' intuition**

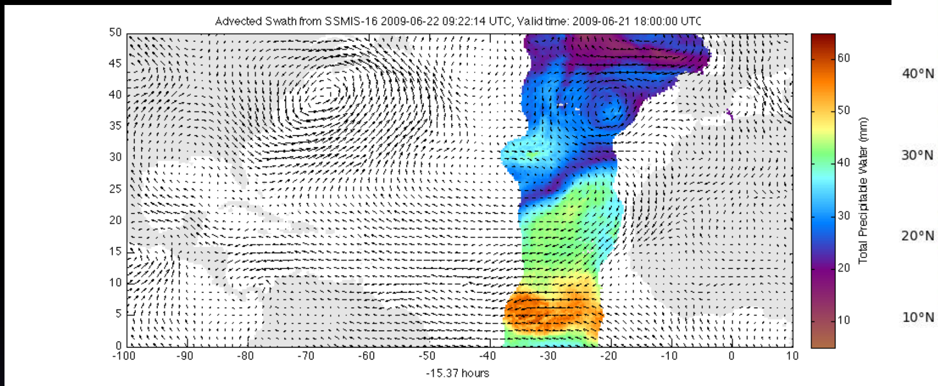
Lessons Learned

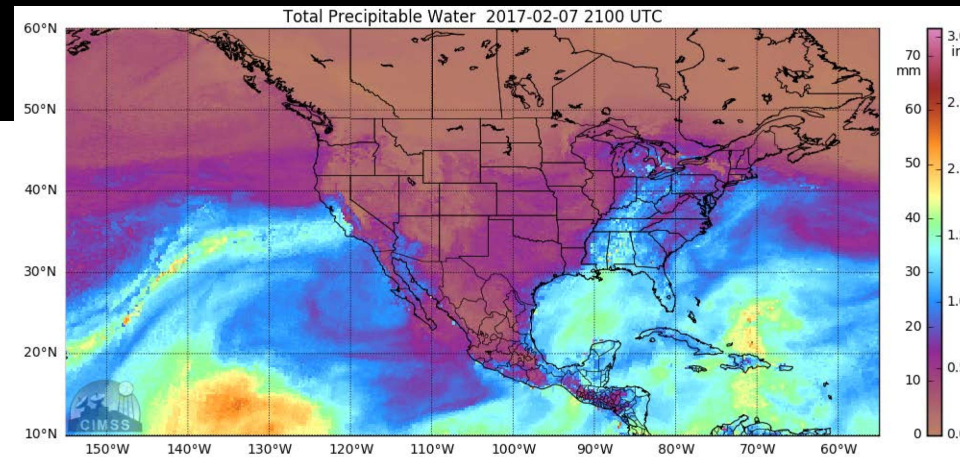
- Morphological compositing is successful where the tracer lifetime exceeds the sampling rate. Integrated Water Vapor is nearly ideal for this.

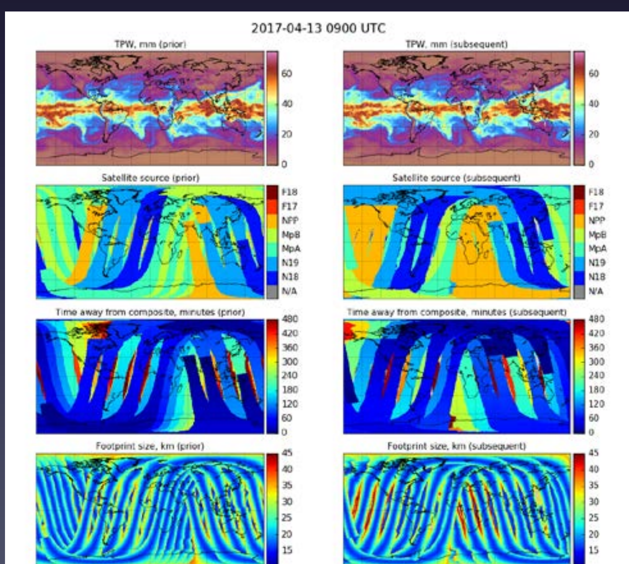
- Accuracy:
  - 1-2mm error (negligible)
  - Also accurate in more subjective ways, such as temporal continuity

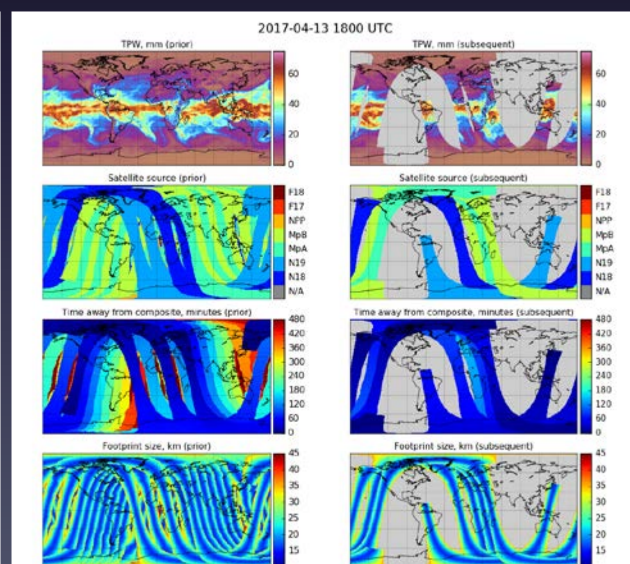
- The biggest obstacles for general use are the new requirements for incorporation into AWIPS

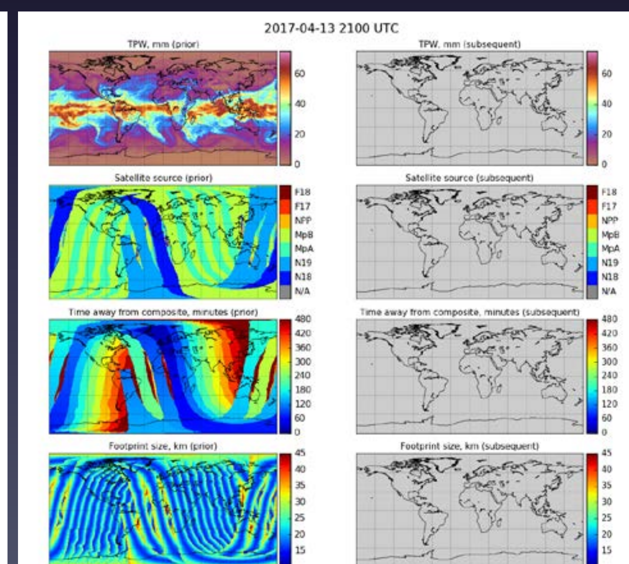
Q/A


Advected Swath from SSMIS-16 2009-06-22 09:22:14 UTC, Valid time: 2009-06-21 18:00:00 UTC
Total Precipitable Water (mm)
-15.37 hours


Total Precipitable Water 2017-02-07 2100 UTC
mm
in
CIMSS


2017-04-13 0900 UTC
TPW, mm (prior)
TPW, mm (subsequent)
Satellite source (prior)
Satellite source (subsequent)
Time away from composite, minutes (prior)
Time away from composite, minutes (subsequent)
Footprint size, km (prior)
Footprint size, km (subsequent)
F18
F17
NPP
MpB
MpA
N19
N18
N/A


2017-04-13 1800 UTC
TPW, mm (prior)
TPW, mm (subsequent)
Satellite source (prior)
Satellite source (subsequent)
Time away from composite, minutes (prior)
Time away from composite, minutes (subsequent)
Footprint size, km (prior)
Footprint size, km (subsequent)


2017-04-13 2100 UTC
TPW, mm (prior)
TPW, mm (subsequent)
Satellite source (prior)
Satellite source (subsequent)
Time away from composite, minutes (prior)
Time away from composite, minutes (subsequent)
Footprint size, km (prior)
Footprint size, km (subsequent)

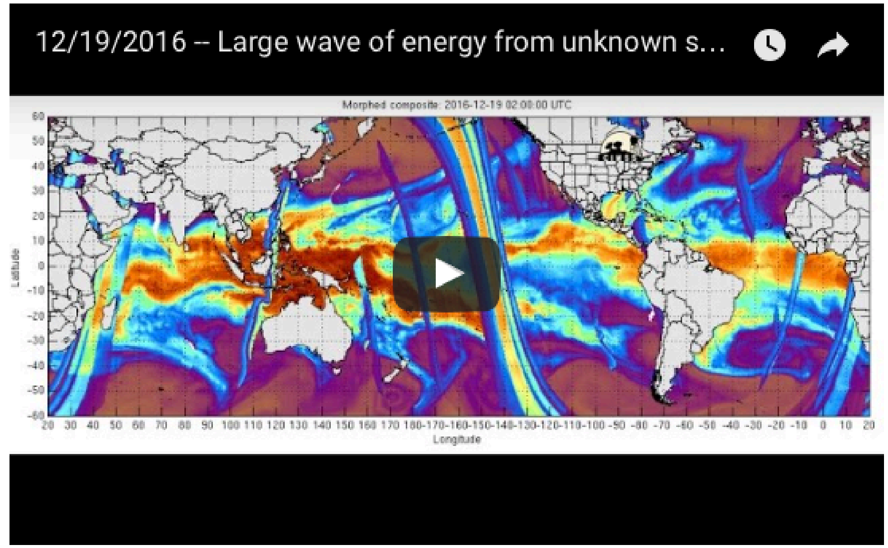
Extras

Required adapt

But some people may never understand how to read it…

Dutchsinse 12-19-16… "Large wave of energy from unknown source hitting Earth now – Possible effects?"

Posted on 2016/12/22



https://youtu.be/fCyLWFZoAlE

[Kp update: I've downloaded the gif from 12-19-16 that Dutchsinse talks about. Click here to view or download.]

This has been flying around and a few have contacted about it, but finally I had chance to view it… and I've never heard Dutchsinse so astounded by something. Anyway, to me it definitely indicates something major (huge) going on energetically.

Published on Dec 18, 2016 (December 18th into 19th, 2016)

Update : 457pm Dec 19, 2016 – MIMIC has issued a statement via twitter saying this is a mistake, an error in their system… hmm..

A large wave of energy impacting the entire planet has UNINTENTIONALLY been detected by the MIMIC TPW microwave background imagery. Currently ONGOING as of 12/19/2016 at 1:20am US central time)

Points to argue over

- We can do better than standard composites of polar orbiter data
- Imagery is much more popular if it fits into the viewer’s intuition
- The weather community’s software and forecasting systems are poor at accommodating polar-orbiter products that fit with intuition
- Error has more than one dimension

MIMIC-TPW2: Upgrades

Software:

- Version 1:
  - Matlab code (requires license, not supported in NOAA operations.)
  - Runs on a desktop server

- Version 2:
  - Python code, using standard libraries (portable, supported)
  - Runs on a cluster system at CIMSS (can live forever)
  - Outputs netCDF data, .png images and anim'd gifs
  - 10x faster

Questions

1. Is morphing just about making pretty pictures?
    - No, it really does correct our bad habits of how we look at satellite imagery.
2. Is this just a stopgap until we have better satellites and models?
    - No, because there will always be temporal and spatial scales to exploit.
3. Is this actually science?
    - Not sure!

Required adaptations (esp. from NOAA)

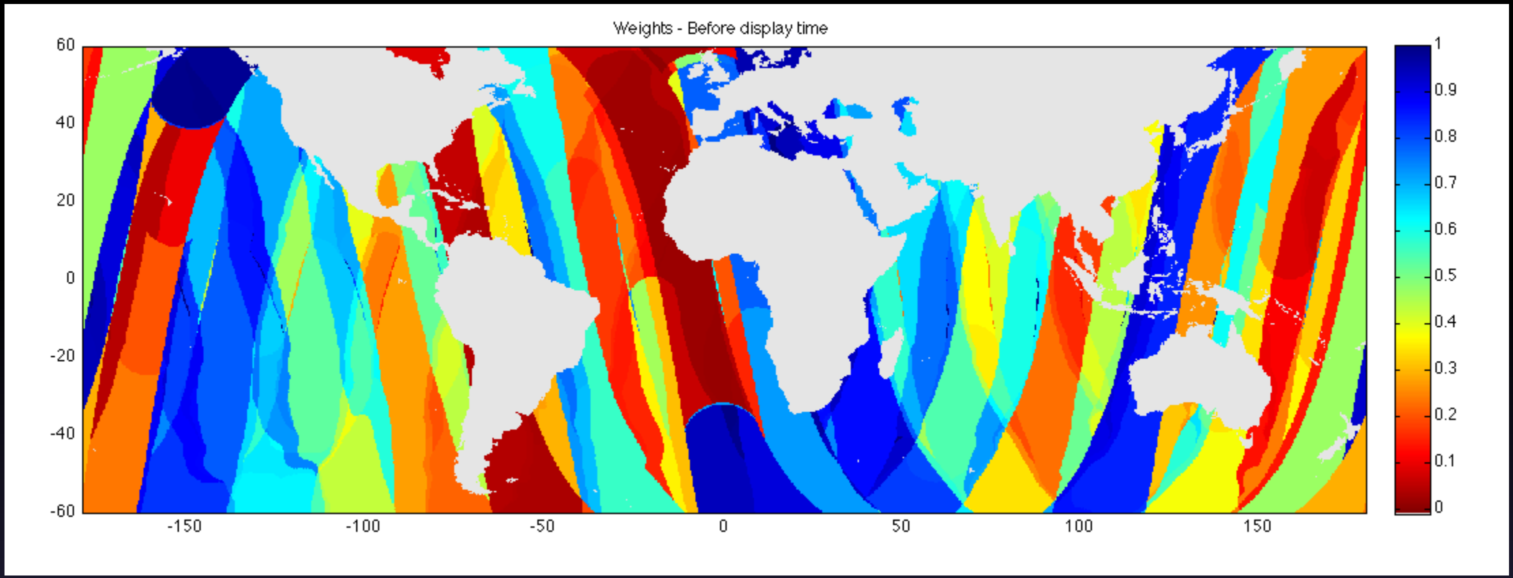
- * We need a new file updating system on AWIPS2 that allows overwriting image sets
  - Do not just keep the first image you find!

- We need increased user awareness of the particulars of morphed compositing
  1) Understanding the difference between displacement error and other forms of error
  2) Recognizing new kinds of artifacts in morphed composites
  3) Using the diagnostic images to immediately recognize (1) and (2)

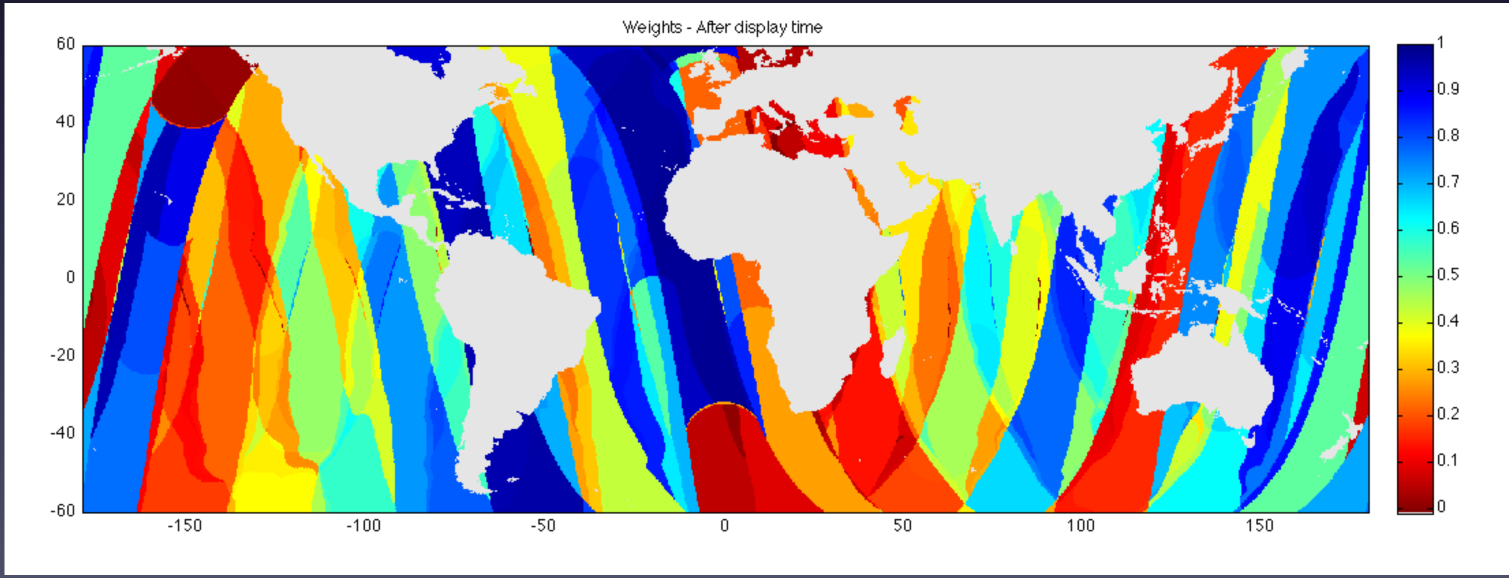
Compute prior/subsequent weights proportional to dt:

w(prior) = dt(subsequent) / [dt(prior)+dt(subsequent)]

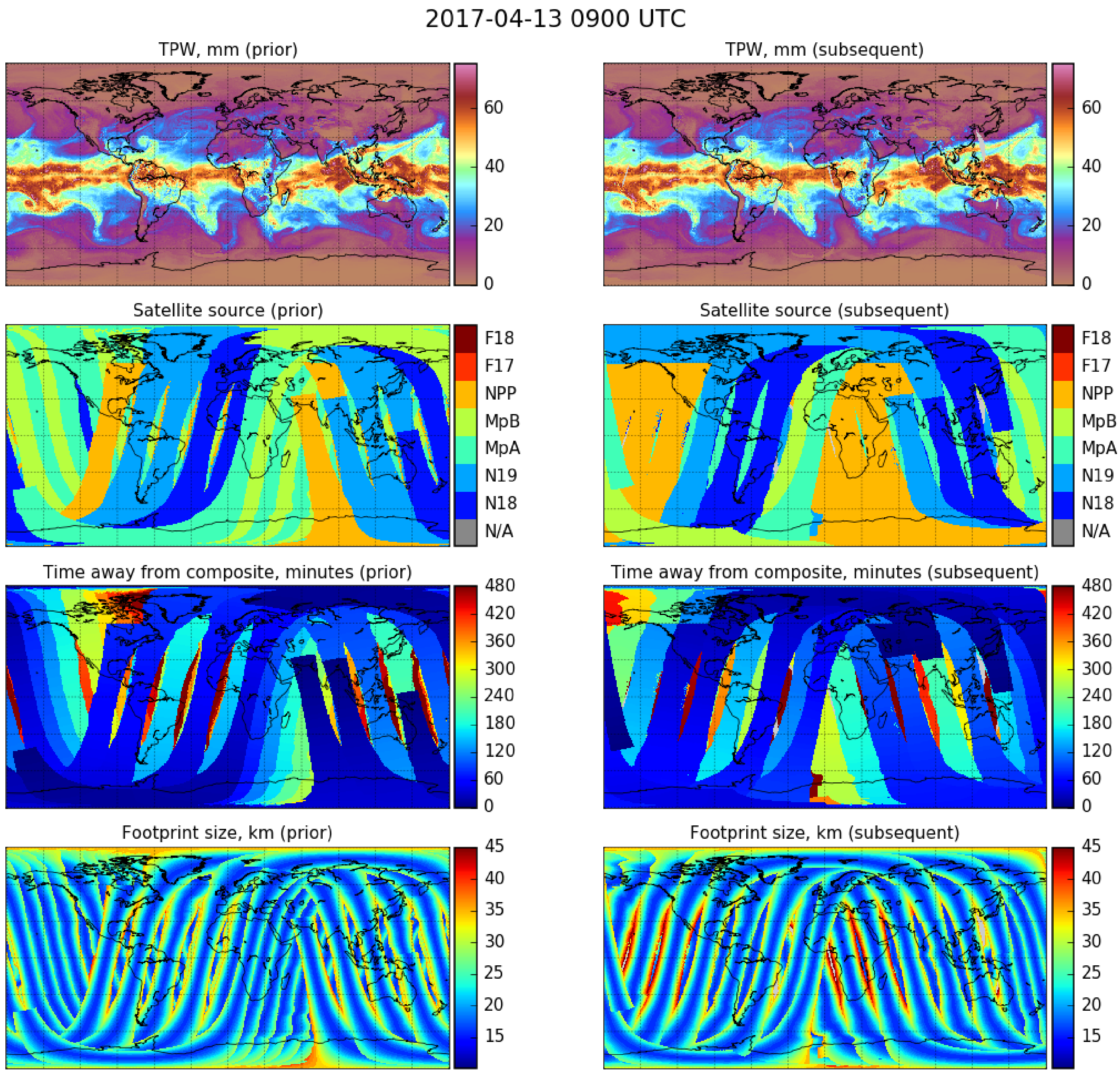
w(prior)



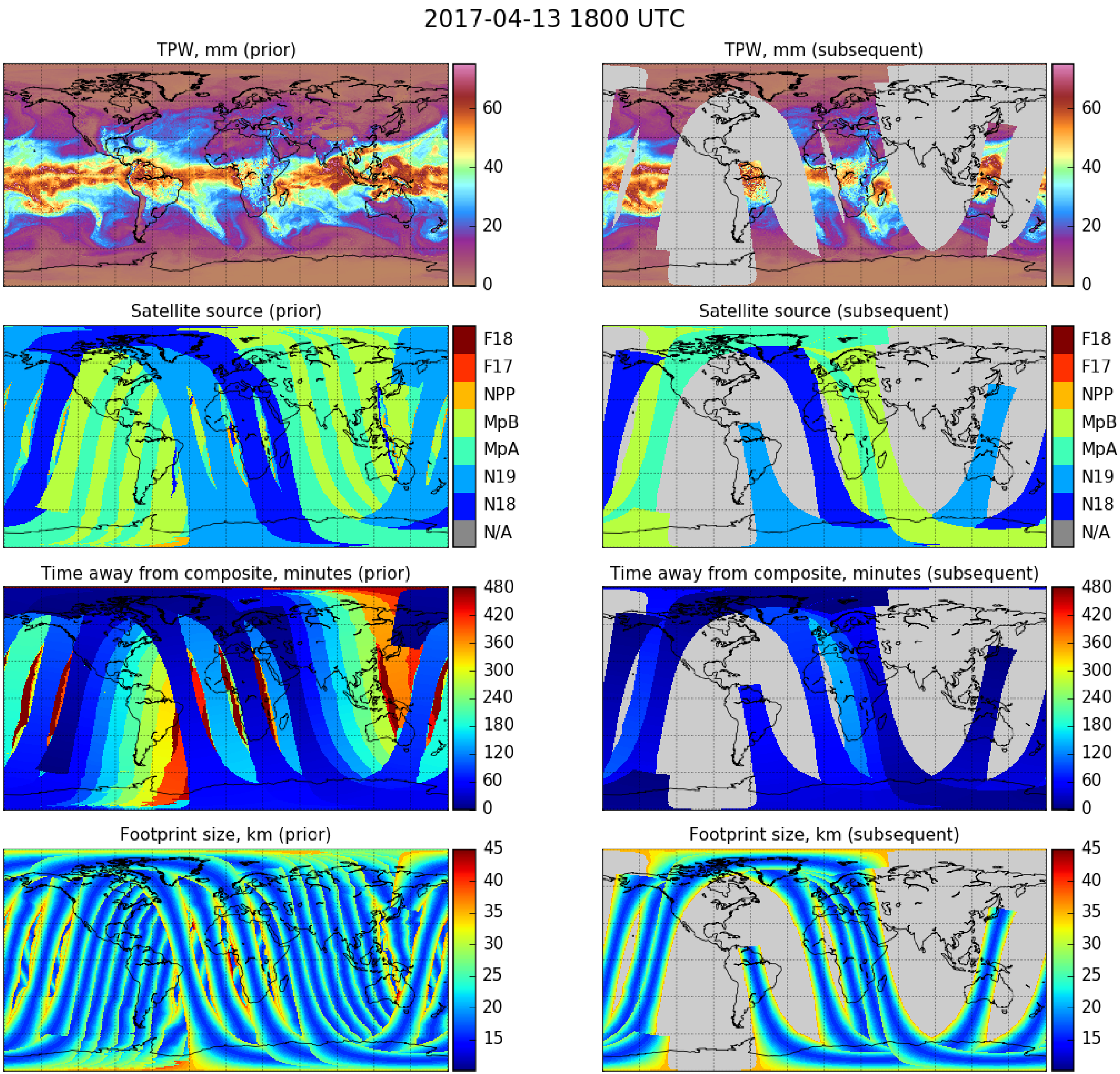
w(subseq.)

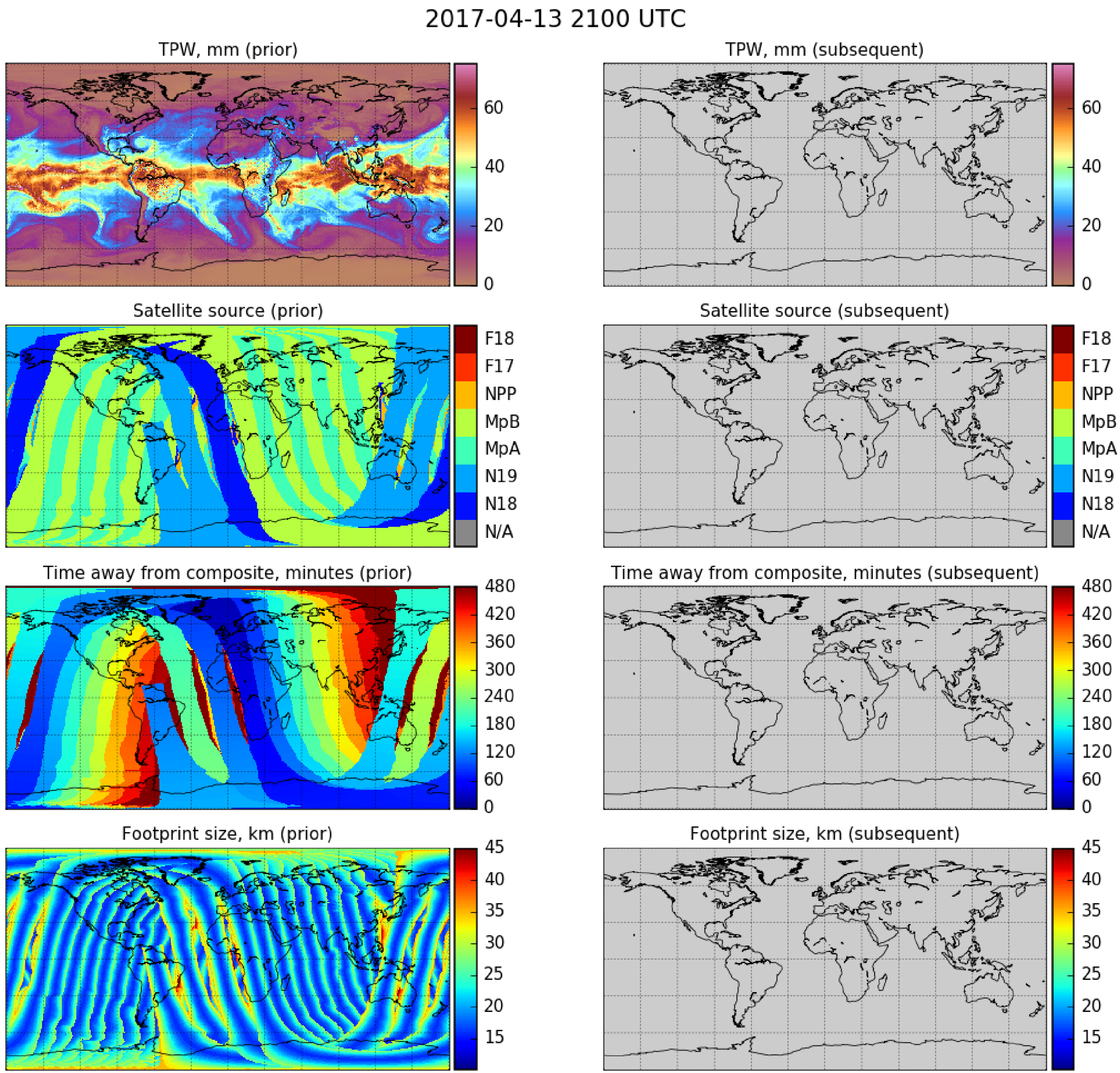


Valid time: 2009/06/22 1800 UTC



2017-04-13 0900 UTC
TPW, mm (prior)
TPW, mm (subsequent)
0
20
40
60
Satellite source (prior)
Satellite source (subsequent)
F18
F17
NPP
MpB
MpA
N19
N18
N/A
Time away from composite, minutes (prior)
Time away from composite, minutes (subsequent)
480
420
360
300
240
180
120
60
0
Footprint size, km (prior)
Footprint size, km (subsequent)
45
40
35
30
25
20
15

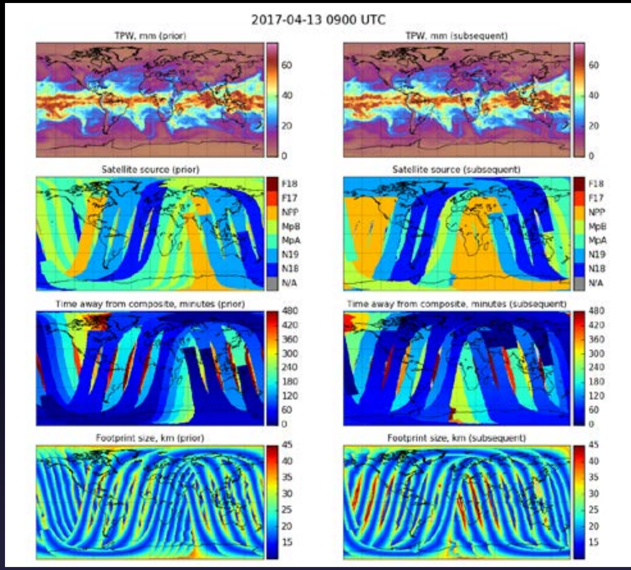

2017-04-13 1800 UTC
TPW, mm (prior)
TPW, mm (subsequent)
0
20
40
60
Satellite source (prior)
Satellite source (subsequent)
F18
F17
NPP
MpB
MpA
N19
N18
N/A
Time away from composite, minutes (prior)
Time away from composite, minutes (subsequent)
480
420
360
300
240
180
120
60
0
Footprint size, km (prior)
Footprint size, km (subsequent)
45
40
35
30
25
20
15



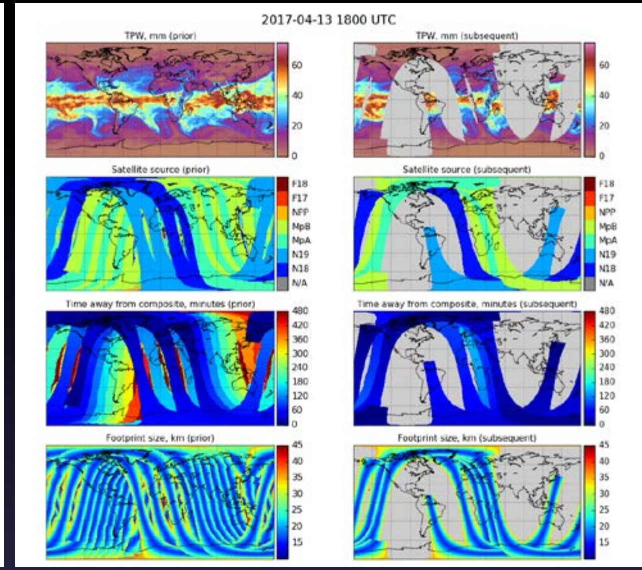
2017-04-13 2100 UTC
TPW, mm (prior)
TPW, mm (subsequent)
0
20
40
60
Satellite source (prior)
Satellite source (subsequent)
F18
F17
NPP
MpB
MpA
N19
N18
N/A
Time away from composite, minutes (prior)
Time away from composite, minutes (subsequent)
0
60
120
180
240
300
360
420
480
Footprint size, km (prior)
Footprint size, km (subsequent)
15
20
25
30
35
40
45

Product updating

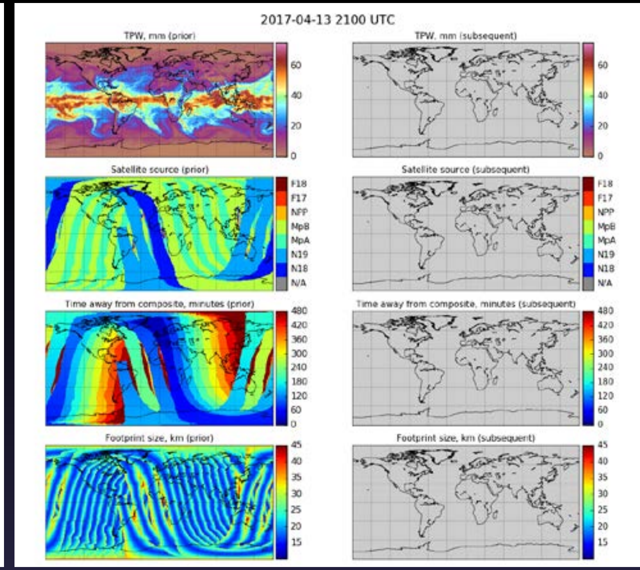
"Archive-ready"



Near real time



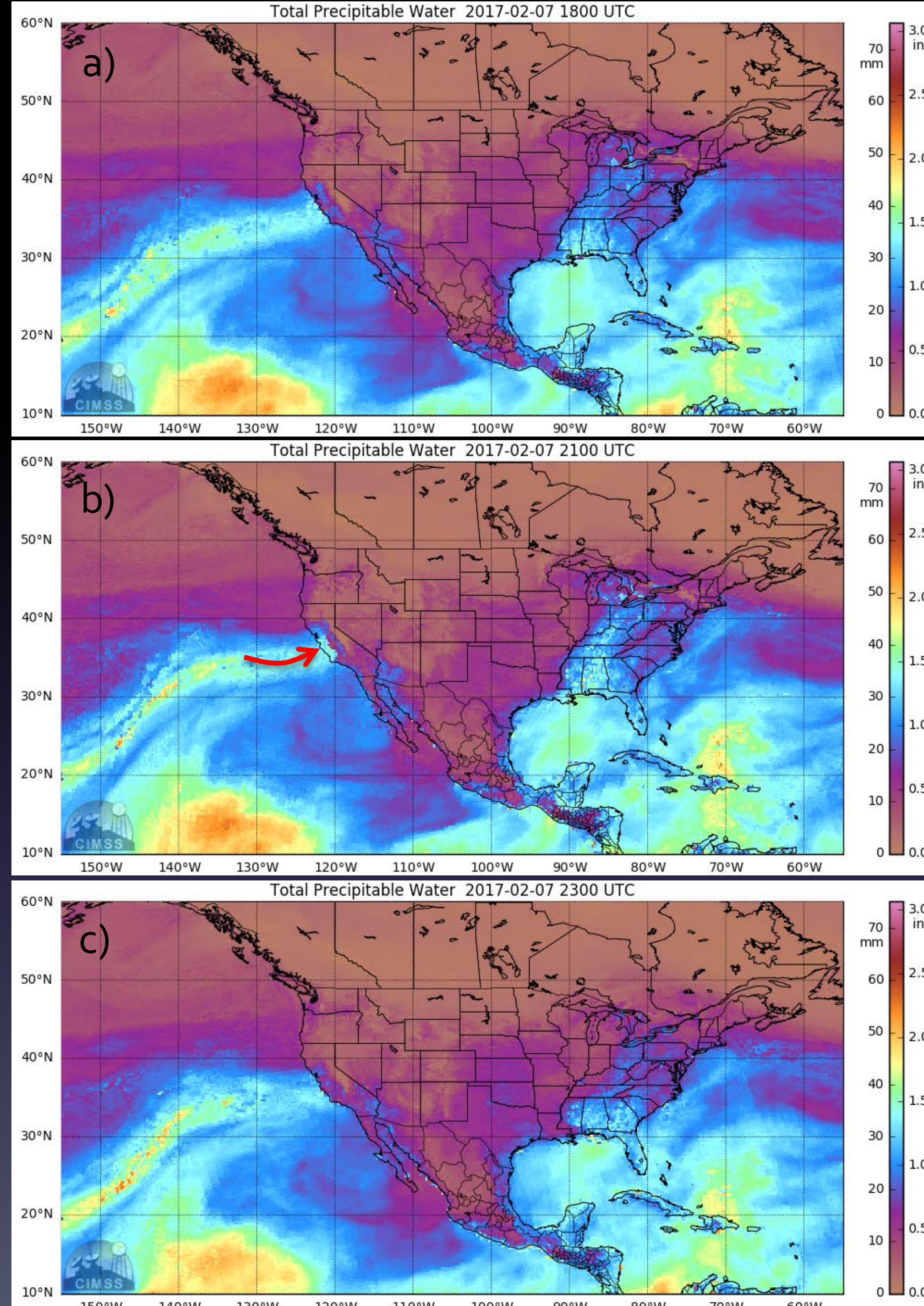
Real time



- A product that begins at "real time" is gradually overwritten by more data over the next 12 hours.
- A single product may be revised 20-40 times until it is "finished" and archive-ready. Every revision is necessary to maintain a fluid transition.
- Therefore, you can't simply make an animation of the first images that were created in real-time, like with other satellite images. You have to "refresh" the last 12 hours of data every time. Is your AWIPS station set up to do this?

Remaining issue: Advection over land and across coasts

- Simple one-level advection causes moisture to be depicted crossing the coastal boundaries even when it should not (due to trapping from an inversion or other discrepancies).
- In this example, moisture is improperly advected to central California in (b), through the same process that correctly captures the advection of moisture-laden air from the Gulf in the eastern U.S.



How MiRS Retrievals Enable a Layered Water Vapor Product for Forecasters

John Forsythe

Cooperative Institute for Research in the Atmosphere (CIRA)
Colorado State University, Fort Collins CO

(John.Forsythe@colostate.edu)

CIRA Team: Stan Kidder, Andy Jones, Dan Bikos, Ed Szoke

Collaborators: Kevin Fuell, Anita LeRoy (NASA SPoRT)
Michael Folmer, Ralph Ferraro (NOAA)

Special thanks to Sheldon Kusselson (NESDIS SAB (retired))

Connecting Models and Observations

August 16, 2017 JPSS Science Team Meeting

Outline

1. How blended Layer Precipitable Water (LPW) is created

2. Forecaster usage examples

3. Work in progress

How is Blended LPW Created?

Layered precipitable water is defined as the integral of the mixing ratio *q* profile through a pressure layer, divided by gravity:

$$LPW \equiv \frac{1}{g}\int_{p_{top}}^{p_{bottom}} q\, dp$$

LPW is proportional to layer mean mixing ratio.

Creating the Blended LPW Product

- LPW is analogous to Total Precipitable Water (TPW), but on layers.
- Blended LPW is created from NOAA Microwave Integrated Retrieval System (MiRS) 1DVAR retrieval (Boukabara et al. 2011).
- Four layers created (sfc-850,850-700,700-500,500-300 mb).
- MiRS retrievals are independent of dynamic NWP models, allowing comparison. NWP winds (GFS) used for advection.
- Produced every 3 hours and mapped onto a 16 km resolution grid.
- New MiRS V11 is now available, forecasters have been mostly using V07. Better retrievals physics, and higher spatial resolution (16 km vs 48 km).

View Near-Realtime Layer Precipitable Water (LPW):
http://cat.cira.colostate.edu/sport/layered/blended/lpw.htm <-- Old way
http://cat.cira.colostate.edu/sport/layered/advected/lpw.htm <-- New way

CIRA
Cooperative Institute for Research in the Atmosphere

More details: 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 (5), 41–58. http://dx.doi.org/10.15191/nwajom.2015.0305

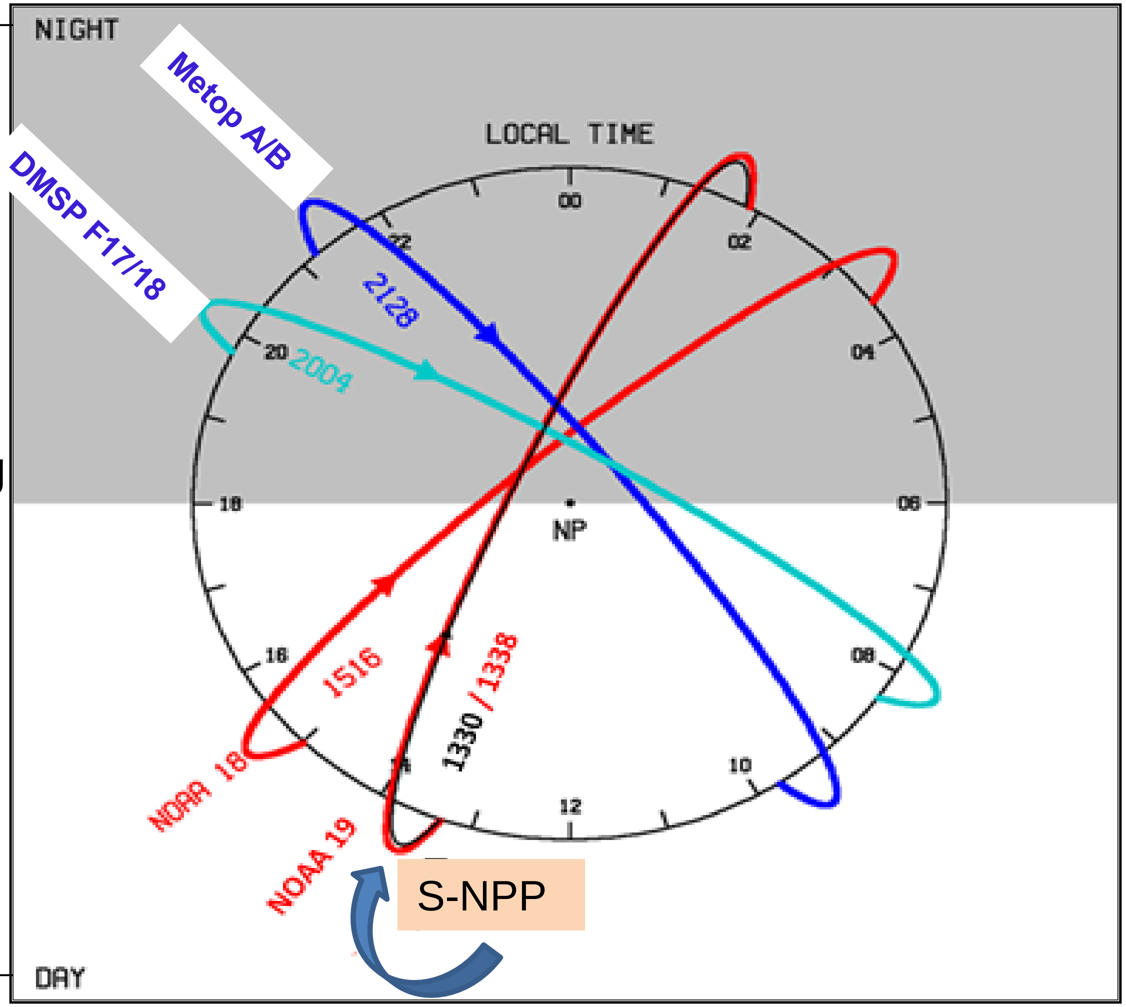
"Clock Diagram" shows local time of sunsynchronous polar orbiting spacecraft

Current configuration for Layer Precipitable Water: 7 satellites:

S-NPP, NOAA-18/19, Metop-A/B, DMSP F17/18

→ Periods of high sampling and no sampling make animations challenging.

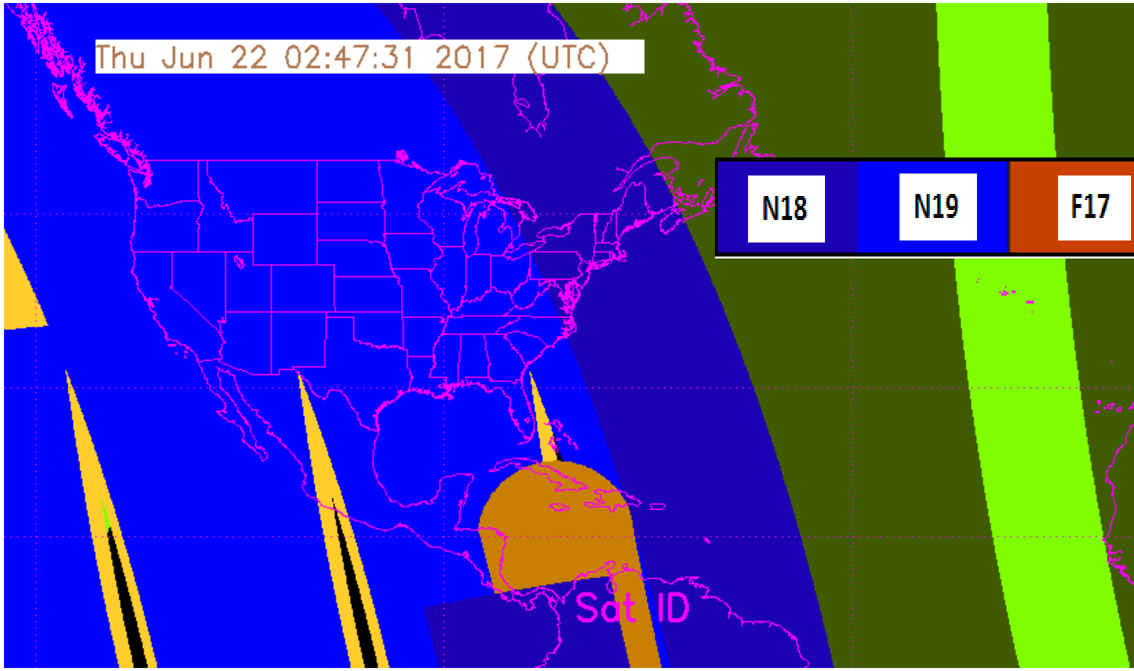
→ All of these spacecraft measure microwave radiation around the 183 GHz water vapor absorption line.

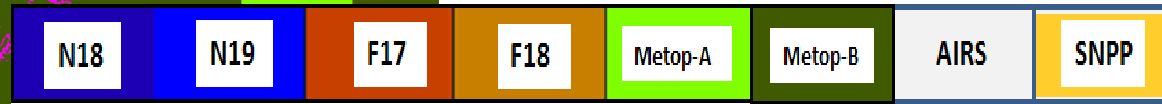


Older satellites play a valuable role in extending temporal sampling

Cooperative Institute for Research in the Atmosphere

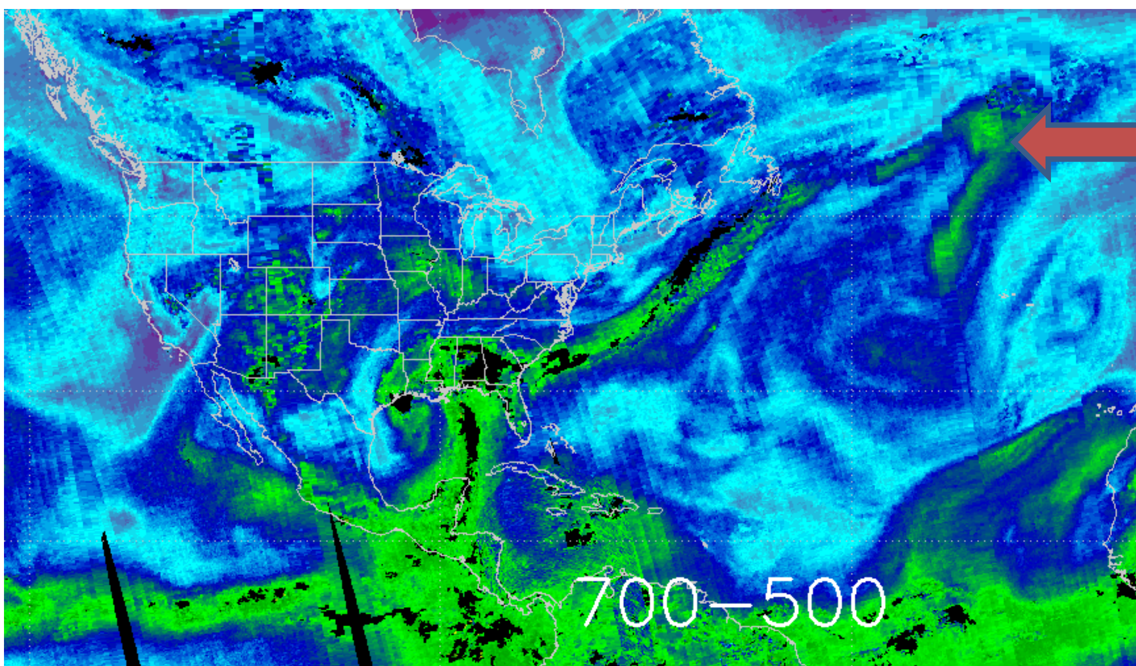
Creating the Overlay Product





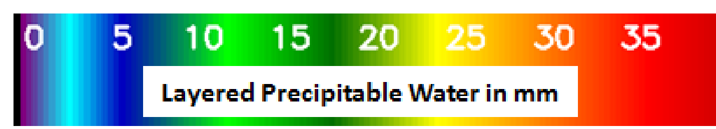
Satellite ID

- Note that each of these overpasses are at different, non-synoptic times. Advective blending solves this problem.



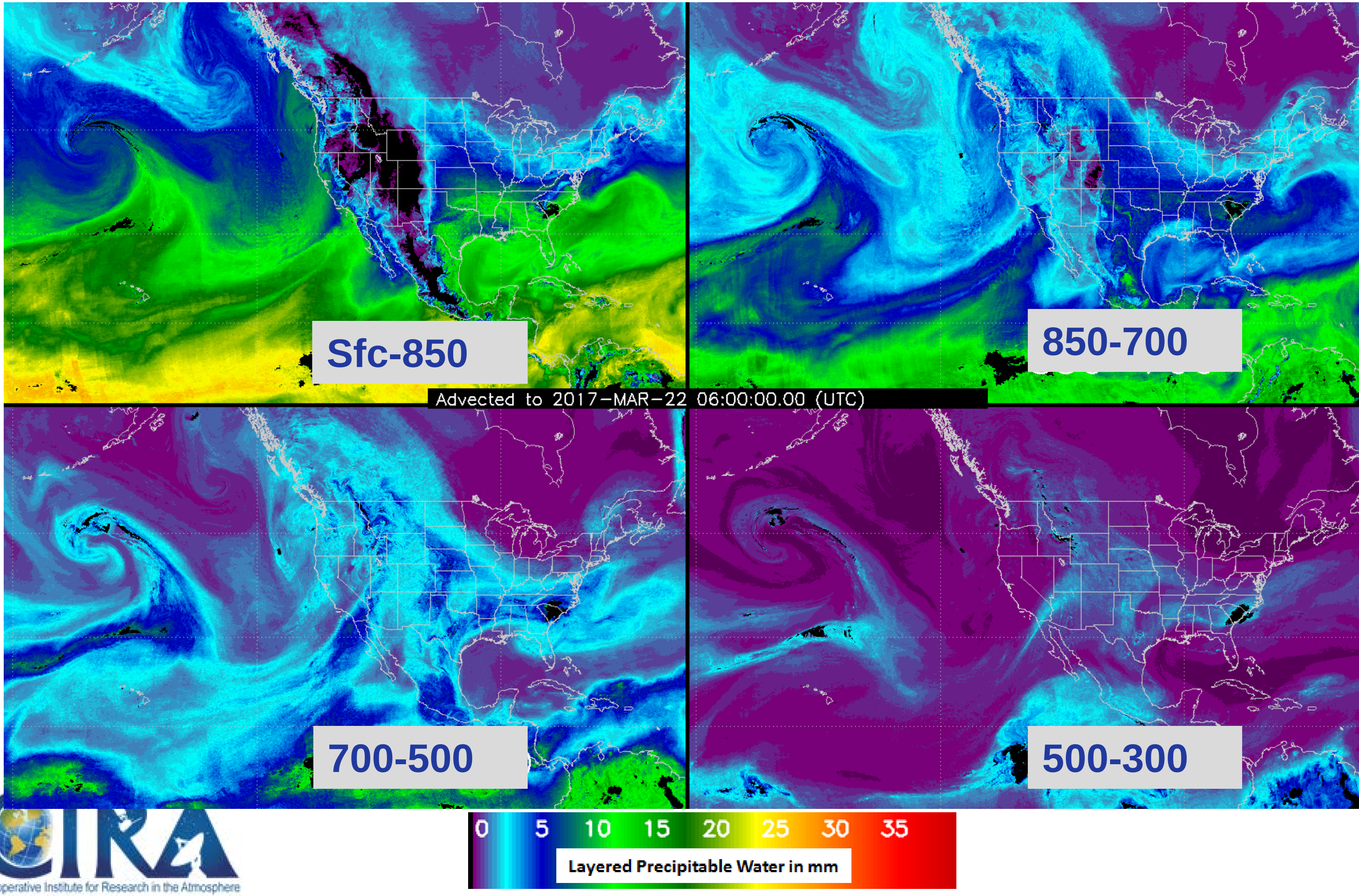
The overlay product currently being used by forecasters

700 – 500 mb LPW (mm)



New Version 01 Advected LPW, advected every three hours

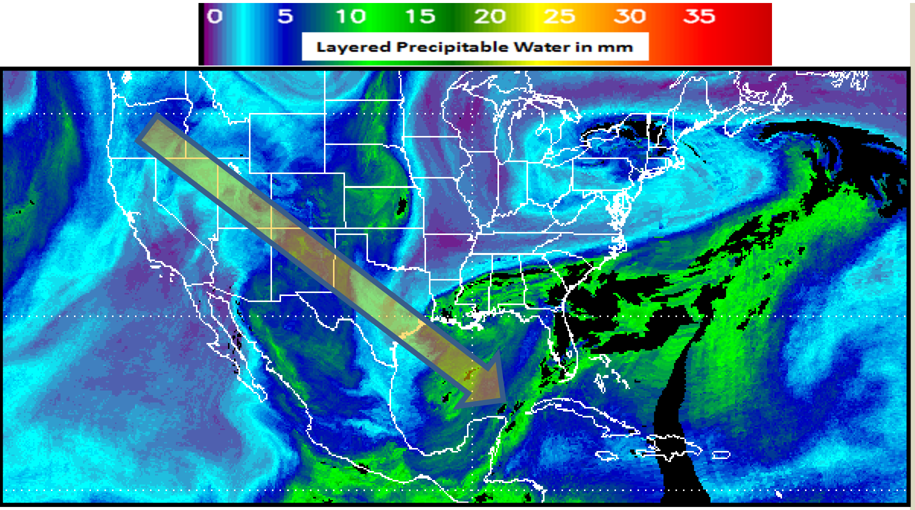
- **Everything moves and is mapped to one synoptic time.**
- ***Plan to switch NHC, WPC to this product within a month or two***
- ***A good test of MiRS quality and interconsistency***



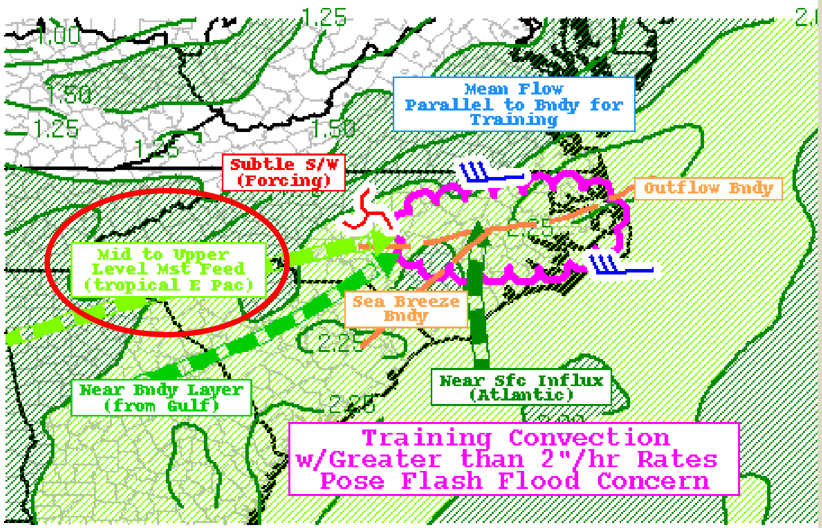
Cooperative Institute for Research in the Atmosphere

Forecaster Usage Examples

Example CIRA LPW Usage at WPC for Tracking Tropical Moisture



CIRA 700-500 mb LPW June 6, 2017 00 UTC



RAP32 PRECIP WATER 170605/2300f001
WPC MPD #0301

MESOSCALE PRECIPITATION DISCUSSION 0301
NWS WEATHER PREDICTION CENTER COLLEGE PARK MD
824 PM EDT MON JUN 05 2017

AREAS AFFECTED...EASTERN NC

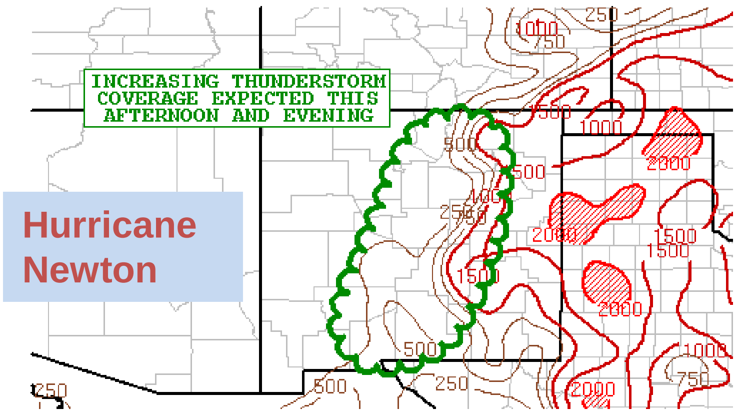
CONCERNING...HEAVY RAINFALL...FLASH FLOODING POSSIBLE VALID 060023Z - 060323Z

….UNSEASONABLY DEEP MOISTURE AVAILABILITY HAS SATURATED THE ENTIRE COLUMN ORIGINATING FROM **THREE STREAMS**...LOWER LEVEL INFLOW EAST OF SEA BREEZE FROM SELY FLOW...NEAR BOUNDARY LAYER MOISTURE FROM THE GULF (SSWLY) **AND CIRA LAYERED TPW SHOWING 700-300 TPW TRACING FROM EASTERN TROPICAL PACIFIC AND FORMER TROPICAL CYCLONE BEATRIZ.** THIS HAS LEAD TO HIGHER RAINFALL EFFICIENCY ACROSS THE EASTERN PIEDMONT (FROM VA TO SC) THROUGHOUT THE DAY GENERALLY HIGHER THAN EVEN LOCAL RADARS ARE ESTIMATING IN THE 2.5-3"/HR RANGE. AS SUCH EVEN WITH THE HIGHER FFG VALUES IN THE REGION...RAINFALL TOTALS OF 2-4" IN QUITE SHORT TERM PERIOD ARE POSSIBLE SUPPORTING FLASH FLOODING CONCERNS.

GALLINA
ATTN...WFO...AKQ...MHX...RAH... ATTN...RFC...SERFC...

Blended LPW being used in operations by WPC, NHC, SAB and a few WFO's which receive it via SPoRT (Tucson, Corpus Christi, Binghamton for example).

LPW used to analyze the moisture flow into heavy rain scenarios and fusion of moisture from multiple streams.



RAP32 ML CAPE (lowest 90MB) j/kg 160906/1800f000
WPC MPD #0645

MESOSCALE PRECIPITATION DISCUSSION 0645
NWS WEATHER PREDICTION CENTER COLLEGE PARK MD 341 PM EDT TUE SEP 06 2016

THE **LATEST CIRA-LPW PRODUCT SHOWS A WELL-DEFINED AXIS OF MOISTURE EMANATING FROM NEWTON IN THE 700/300 MB LAYER...**AND THE TRENDS IN SHOW AN EXPECTED INCREASE IN THE LEVEL OF MOISTURE CONCENTRATION IN THIS LAYER MOVING THROUGH THE LATE DAY AND EARLY EVENING HOURS. **THE RESULT OF THIS WILL BE AN INCREASE IN RAINFALL EFFICIENCY**...WITH INCREASED WARM LAYER RAIN PROCESSES...AND THUS AN ENHANCEMENT IN RAINFALL RATES.

In July 2017, in the NHC Atlantic Tropical Weather Discussion (TWDAT), **CIRA LPW mentioned 53 times**. Widely used to assess the environment around tropical waves. Passive microwave retrievals perform around clouds, unlike GOES water vapor imagery or the Saharan Air Layer product.

Tropical Weather Discussion...
NWS National Hurricane Center Miami FL
747 AM EDT Thu Jun 22 2017
...TROPICAL WAVES...

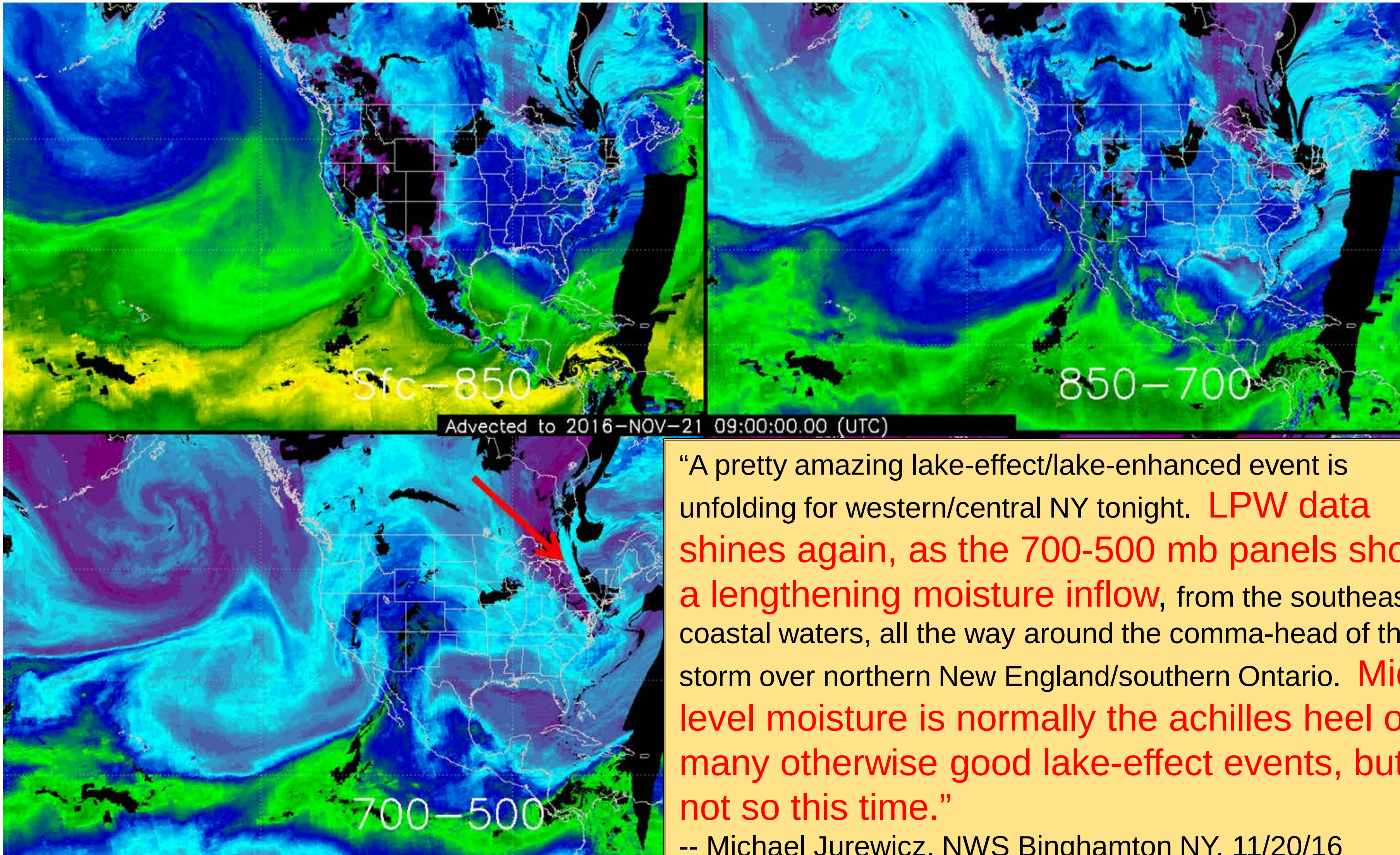
A tropical wave came off the west coast of Africa last night. The wave is in a region of favorable wind shear, **is in moderate moist environment with patches of dry air according to CIRA LPW,** and is under a region of upper level divergence.

A tropical wave is in the central Atlc with axis extending from 11N38W to 0N41W, moving west at 10 to 15 knots within the last 24 hours. The wave is in a region of favorable wind shear**, is in a mostly very moist environment with some patches of dry air according to CIRA LPW, …**

A tropical wave is in the central Caribbean with axis extending from 20N74W to 10N76W, moving west at 10 to 15 knots. The wave is entering a region of unfavorable wind shear. **CIRA LPW imagery show patches of dry air in the northern wave environment…**

Ramos

LPW also has Utility for Heavy Snow Forecasting



"A pretty amazing lake-effect/lake-enhanced event is unfolding for western/central NY tonight. LPW data shines again, as the 700-500 mb panels show a lengthening moisture inflow, from the southeast coastal waters, all the way around the comma-head of the storm over northern New England/southern Ontario. Mid-level moisture is normally the achilles heel of many otherwise good lake-effect events, but not so this time."

-- Michael Jurewicz, NWS Binghamton NY, 11/20/16

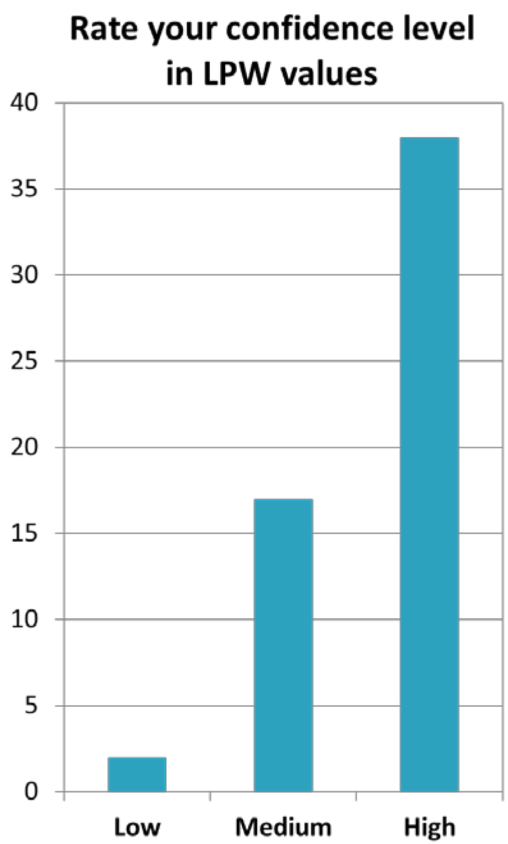
CIRA
Cooperative Institute for Research in the Atmosphere

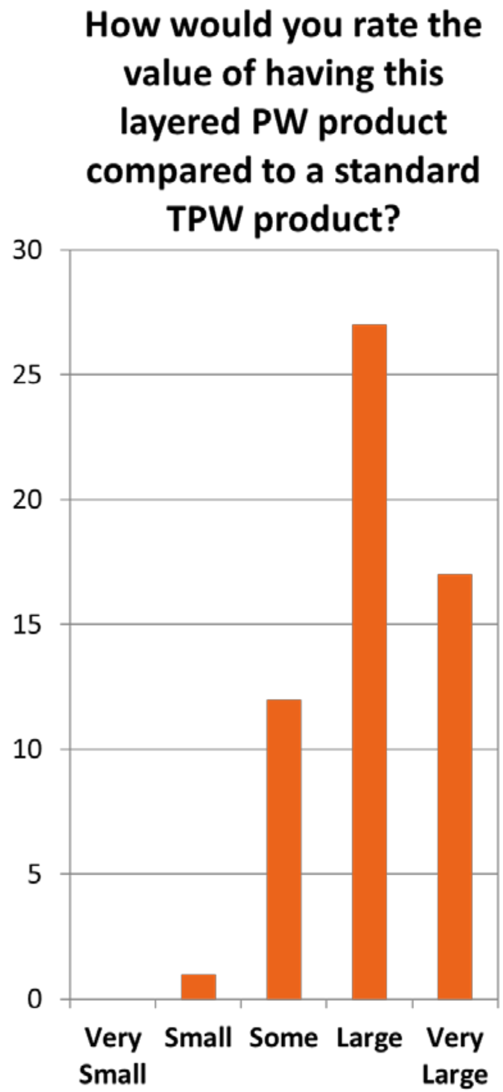
Paper in Progress for *J. Oper. Meteor.*, led by Chris Gitro (NWS Kansas City):

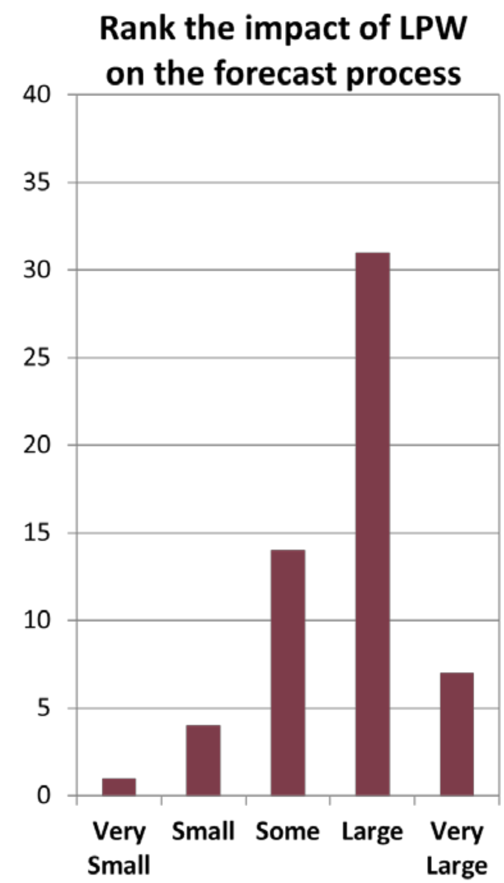
"Using the Multi-sensor Layered Precipitable Water Advection Product in the Operational Forecast Environment"

CIRA
Cooperative Institute for Research in the Atmosphere

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







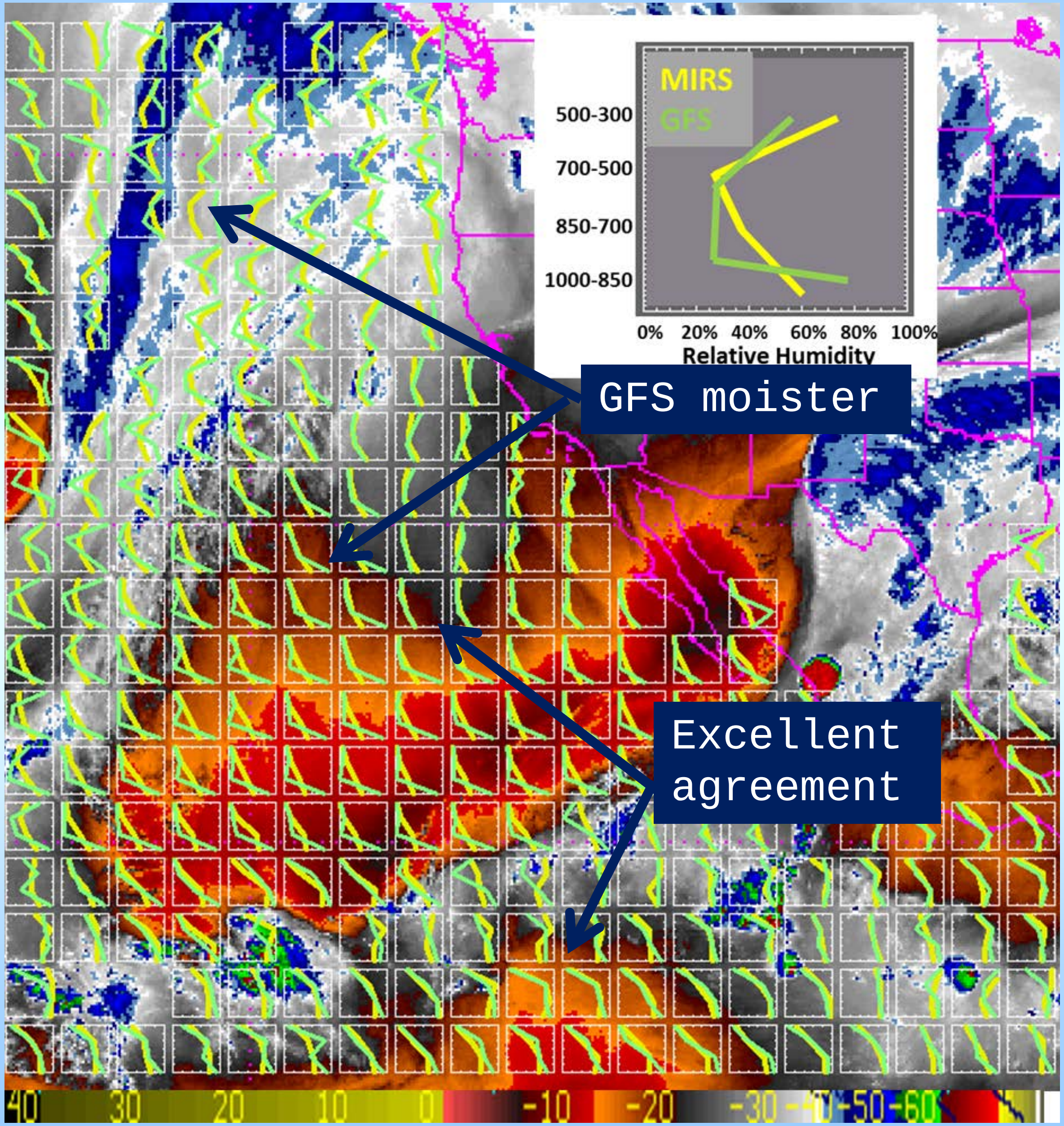
LeRoy et al. 2016, J. Operational Meteorology

Work in Progress and Future Work

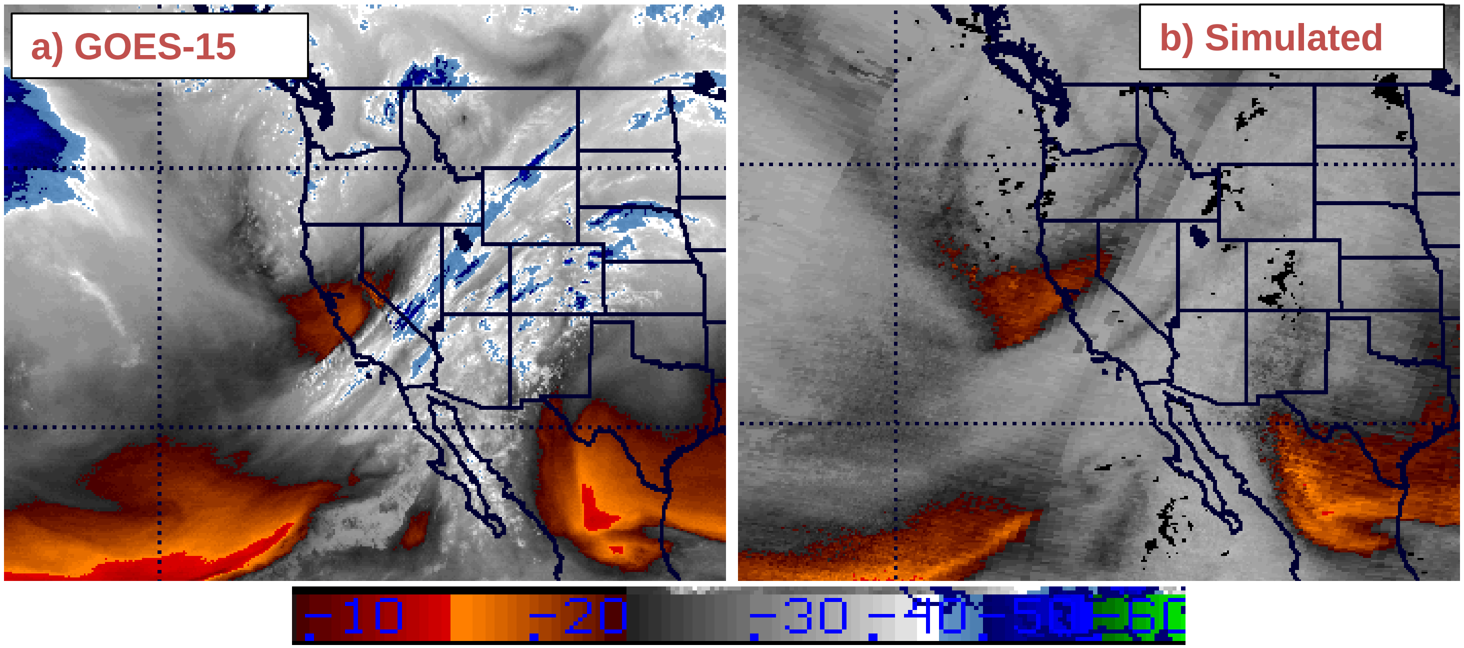
Cooperative Institute for Research in the Atmosphere

How blended products may be fused with other datasets such as NWP and geostationary data

NOAA Hydrometeorology Testbed project just begun to compare model moisture to CIRA LPW



Prototype 6.5 µm Cloud-Free Water Vapor Imagery



(a) GOES-15 water vapor channel brightness temperature at 1500 UTC 16 November 2016 and (b) Prototype simulated brightness temperature derived from CIRA LPW.

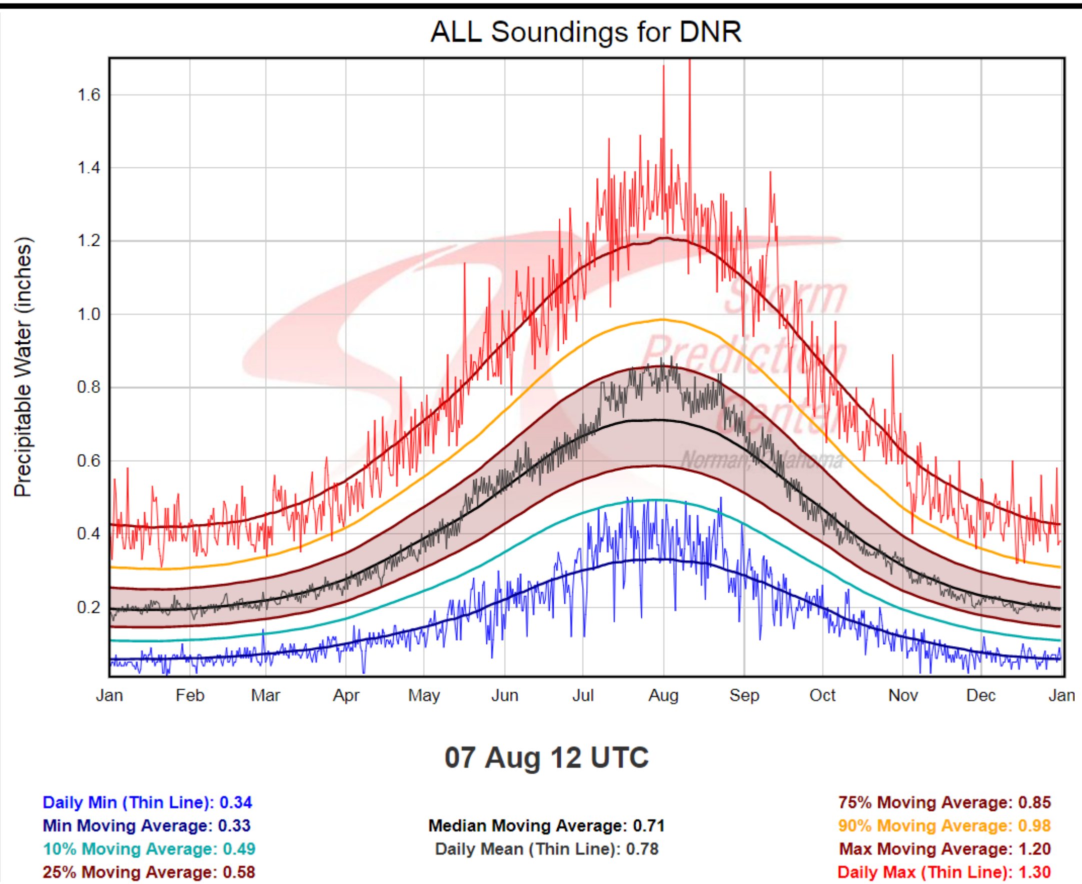
***GOES-R Risk Reduction Project just begun to perform comparisons and create synthetic imagery with CRTM.**

Cooperative Institute for Research in the Atmosphere

Have not yet achieved much quantitative usage, climatology and rules of thumb for LPW, unlike for TPW.

Area Forecast Discussion
National Weather Service Denver/Boulder CO
814 PM MDT Mon Aug 7 2017
…
A moisture plume stretched over the forecast area is contributing to TPW values near an inch, above the 90th percentile for the area for the day…

SPC Sounding Climatology Page for Denver TPW (1956 – 1998 reference)



Cooperative Institute for Research in the Atmosphere

Summary

- **MiRS retrievals from seven spacecraft** drive the Blended Layer Precipitable Water product, which fills a void in moisture analysis for forecasters. Currently being evaluated at National Centers and select WFO's.
- **Advectively blended** products using MiRS V11 will be distributed in coming months.
- Provides **unique monitoring capability for MiRS**, with feedback to developers.
- Eventually Blended LPW **could become operational** using the same data processing framework as blended TPW.
- Most usage of LPW to date has been qualitative (unlike TPW). Work in progress to compare LPW to model moisture fields and generate cloud-free infrared imagery.

Backup Slides

Cooperative Institute for Research in the Atmosphere

Summary

Product	Status	Training	Comments
Blended TPW, TPW Anomaly, and Rain Rate	Operational since 2009. Runs at OSPO, distributed throughout NWS	None recently. VISIT and teletraining will occur via GOES-R project.	New 3-year GOES-R Risk Reduction Project just begun to add GOES-R and perform advection
CIRA Layer Precipitable Water (LPW)	Non-operational, but used routinely by WPC and NHC ***(referenced 53 times in July 2017 by NHC).*** Distributed to about 15 WFO's via SPoRT.	Need to start distributing new advected product, requires training and quick guide. Will create a VISIT session in September.	Seeking an advocate from NWS to initiate the SPSRB process to transition to operations. WPC good candidate. Also exploring ORI (Orographic Rain Index) with LPW.

Also, new Hydrometeorology Testbed project just begun (July 2017) to compare CIRA LPW to model moisture fields. Opens the door towards more quantitative uses of the product (like with TPW).

Cooperative Institute for Research in the Atmosphere

Science Issue

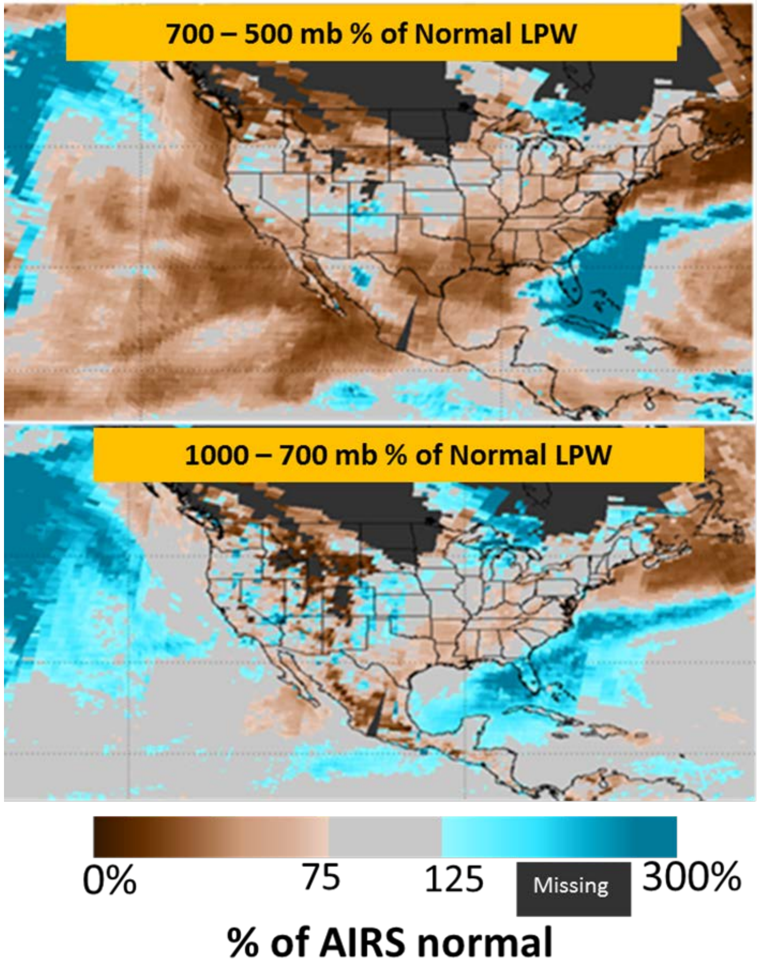
- Forecasters are faced with an overwhelming variety of satellite data for analysis.
- Blended products - merging multiple sensors into one product - consolidate this data into easy-to-use observational products.
- Science Questions: How do we merge disparate sensors in space, time, and algorithm to create a seamless blended product? How do we know they are helping forecasters?

Current Status

- Blended rain rate and blended total precipitable water (TPW) are operational in AWIPS for forecasters.
- Blended Layer Precipitable Water (LPW) was demonstrated in a CIRA project completed with NASA SPoRT in 2014. Blended LPW being distributed to National Centers every three hours.
- Work in progress under NOAA JPSS Proving Ground / Risk Reduction to perform "advective blending". *Could become operational…*

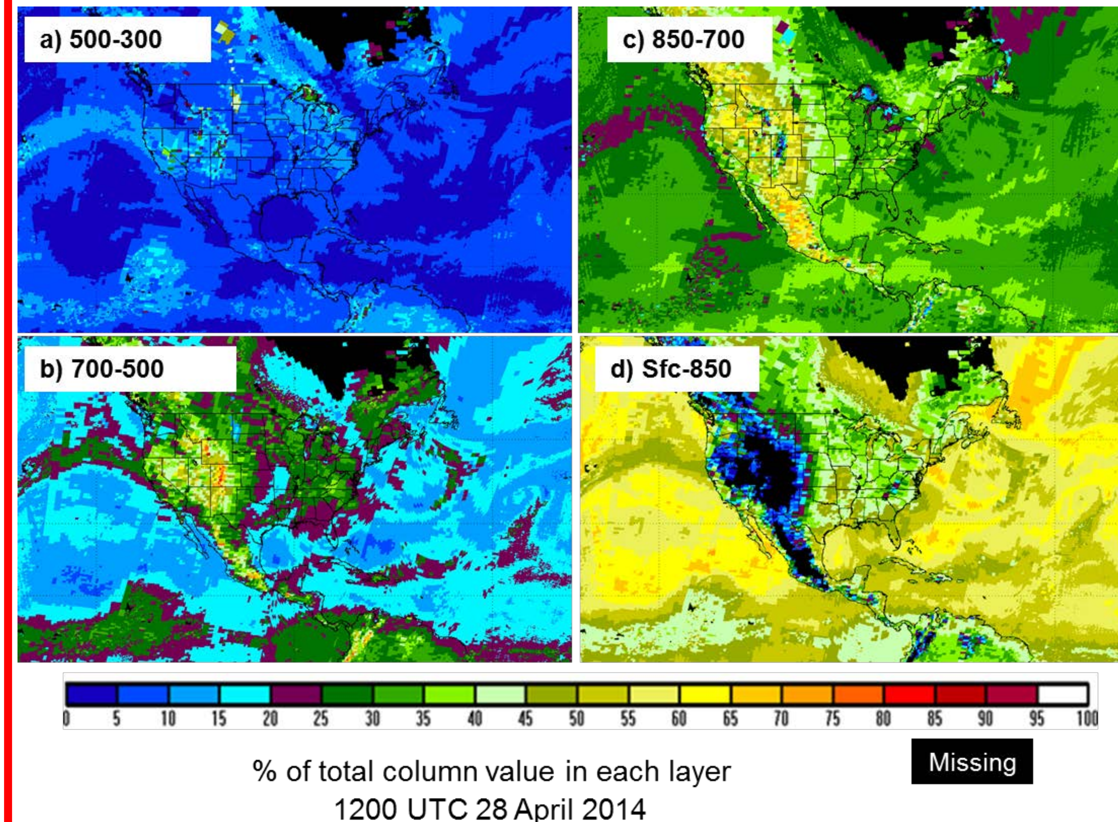
Explore Other Derived Variables to Assist Forecasters

Prototype % of normal using AIRS climatology



1800 UTC 22 April 2013

% of TPW in each layer



Revise Orographic Rain Index Using LPW

Cooperative Institute for Research in the Atmosphere

Historic Flooding in South Carolina in 2015

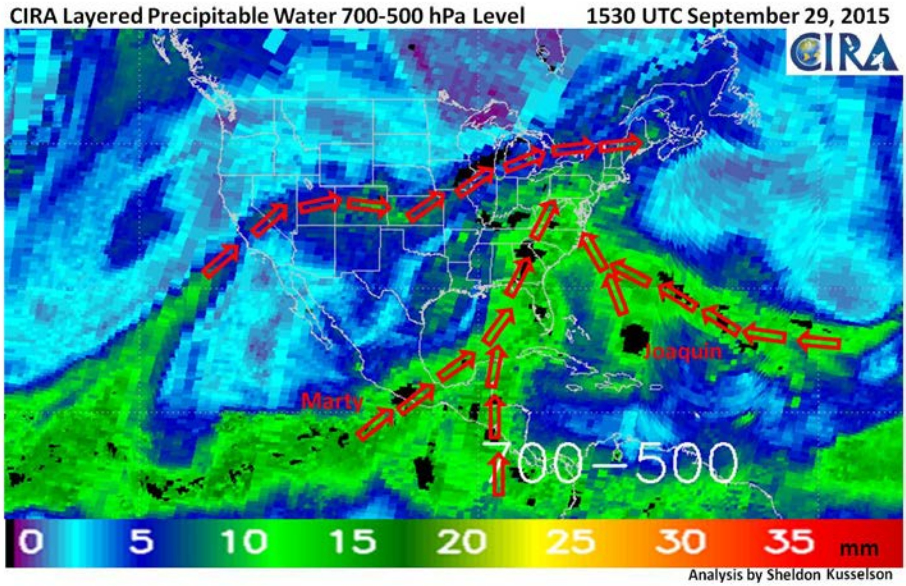
MESOSCALE PRECIPITATION DISCUSSION 0530
NWS WEATHER PREDICTION CENTER COLLEGE PARK MD
1016 AM EDT TUE SEP 29 2015

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...

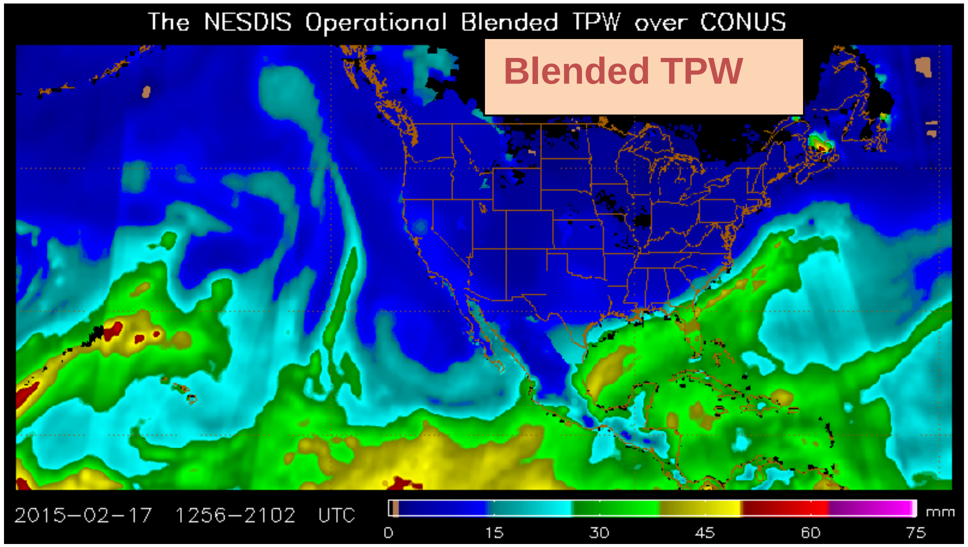


Five streams of moisture fuel flooding in SC

VISIT Satellite Chat on October 7, 2015 hosted by CIRA focused on blended LPW and historic floods in SC. 8 WFO's and WPC participated.

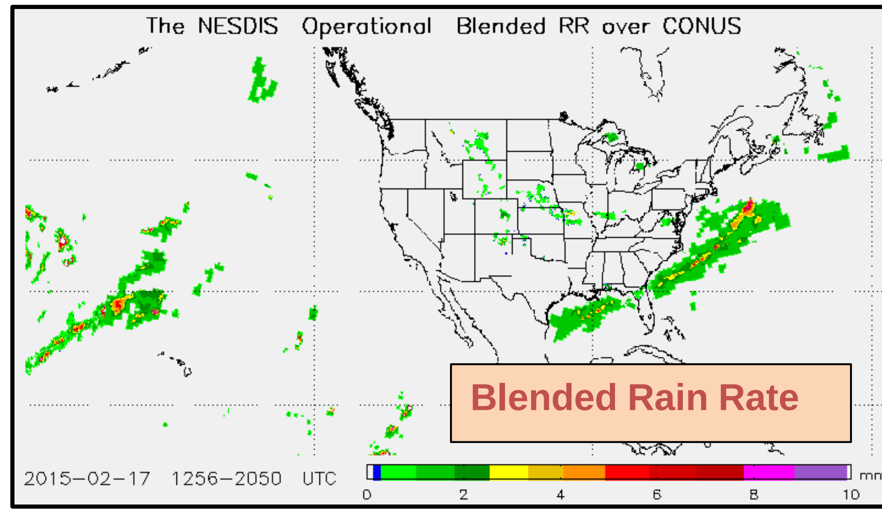
http://rammb.cira.colostate.edu/training/visit/satellite_chat/20151007/

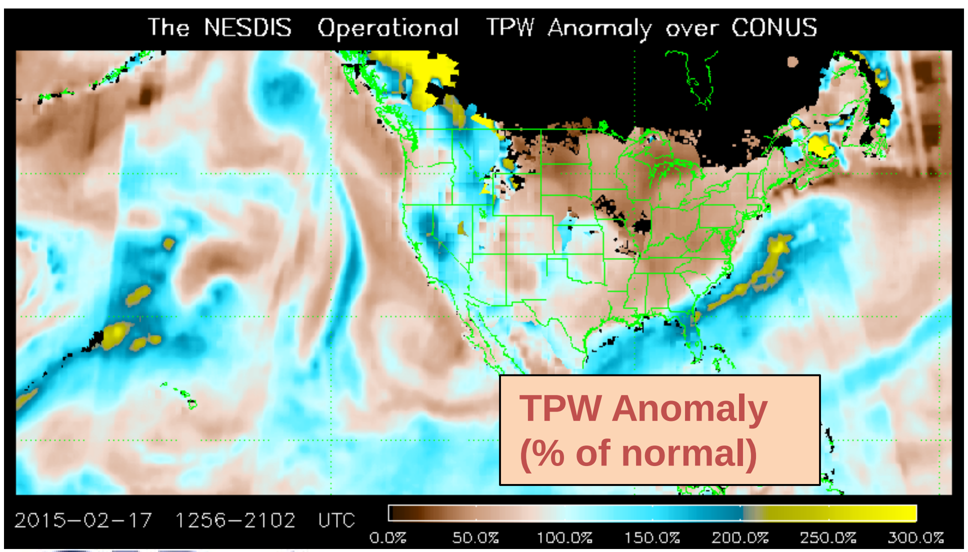
Operational NOAA Blended TPW, TPW Anomaly and Rain Rate show forecasters where the action is. Layer Precipitable Water (LPW) non-operational but being used by national centers.

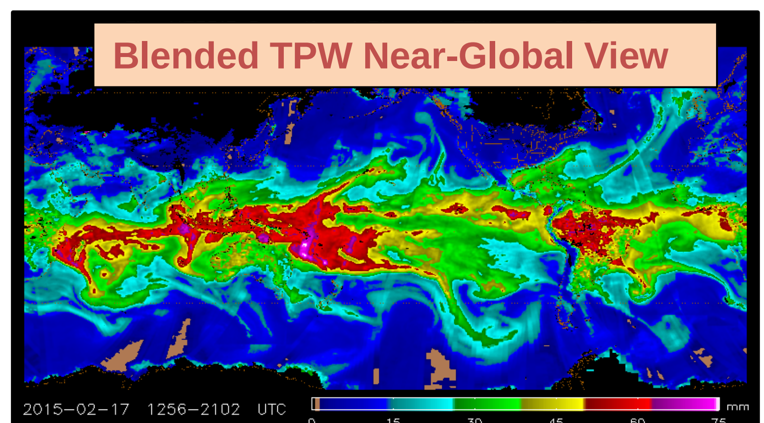


- Near-global, from 71° S to 71°N
- Moisture and rainfall can be tracked for extreme precipitation events
- Produced every hour. Mostly from NOAA MiRS retrievals (Boukabara et al.). Surface GPS and GOES Sounder also used near CONUS.

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







Cooperative Institute for Research in the Atmosphere

	AIRS V6	MIRS
Number of reported water vapor levels	12	100
Number of Independent Water Vapor Levels Retrieved	Varies from 3 to 6	No more than 4
Uncertainty	15% of mixing ratio in 2 km layers from surface to tropopause. (Olsen et al. 2013)	15-20% at 950 hPa 25-40% at 800 hPa 40% at 500 and 300 hPa Uncertainty over land is about 10-20% higher than over ocean at 950 and 800 hPa. (Boukabara et al. 2011 – Table V) Reale et al. (2012 – Fig. 9) indicates seasonally varying 10-20% Metop-A mixing ratio error versus radiosondes at 700 hPa

Boukabara, S.-A., et al., 2011: MiRS: An All-Weather 1DVAR Satellite Data Assimilation and Retrieval System. *IEEE Trans. Geosci. Remote Sens.*, 49, 3249-3272.

The NOAA Products Validation System (NPROVS) Tony Reale, Bomin Sun, Franklin H. Tilley, Michael PetteyJournal of Atmospheric and Oceanic Technology Volume 29, Issue 5 (May 2012) pp. 629-645

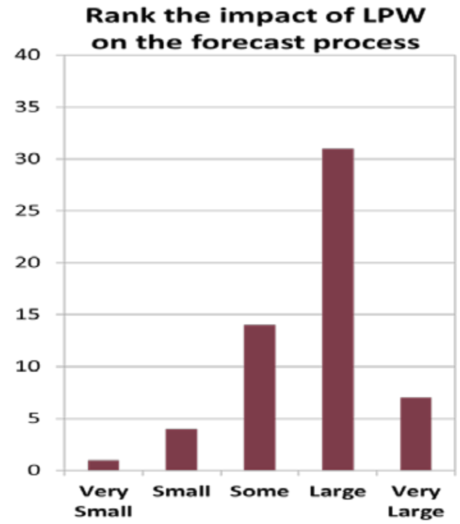
Cooperative Institute for Research in the Atmosphere

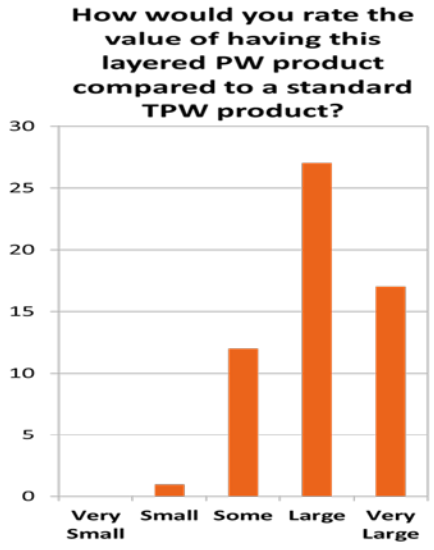
Current/Planned User Interactions

- Heritage overlay LPW product created at CIRA and being delivered for AWIPS every three hours to NHC, WPC, OPC, SAB. NASA SPoRT currently serving data via existing pathway.
- Expect large user impacts based on NWS evaluations in 2013

VISIT Satellite Chat on October 7 hosted by CIRA focused on Blended LPW and historic floods in SC. 8 WFO's and WPC participated.

http://rammb.cira.colostate.edu/training/visit/satellite_chat/20151007/



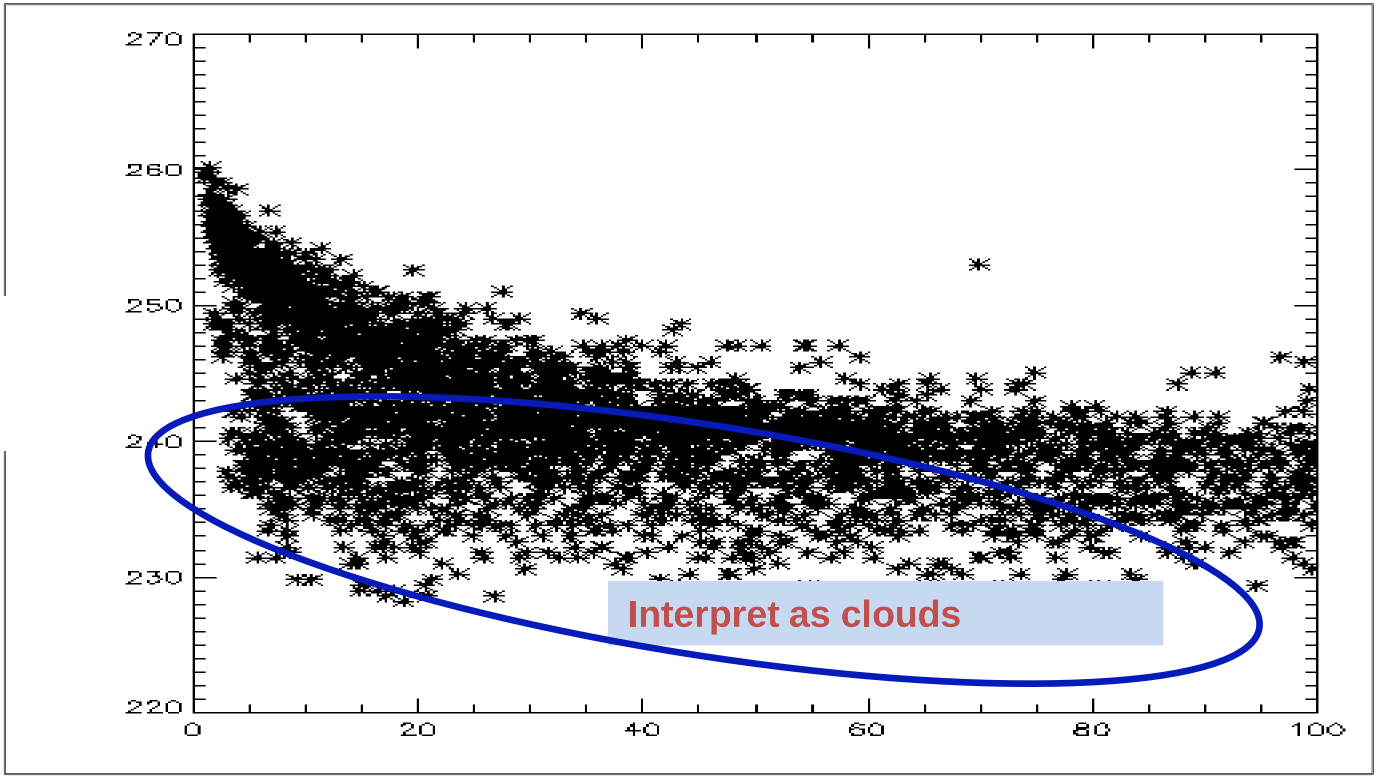


LeRoy et al. 2016

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

GOES-West
6.7 µm TB
(K)



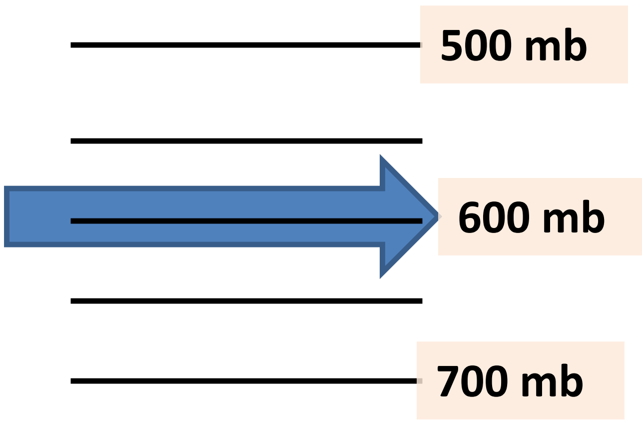
MIRS 500-300 hPa RH (%)

Cooperative Institute for Research in the Atmosphere

New Product:
Advectively Blended LPW

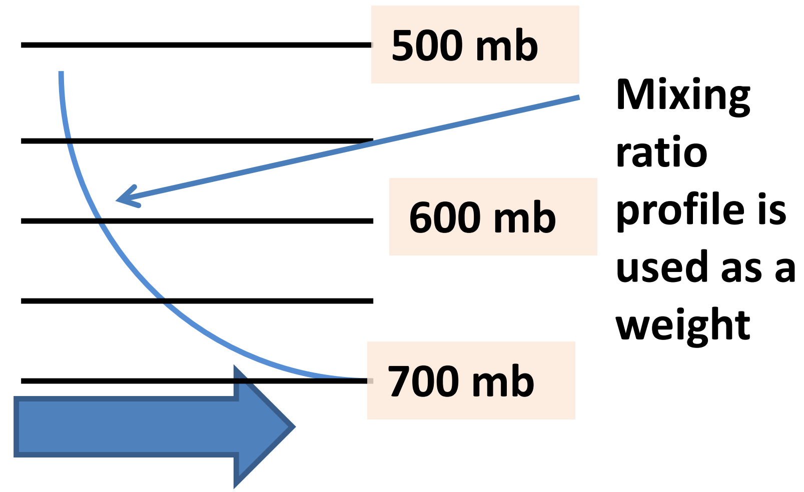
Advective Blending Aproaches

a) Current Advection Approach – use single mid layer wind



700 – 500 mb layer is advected with the 600 mb wind.

b) Alternate Advection Approach – use wind weighted by moisture profile



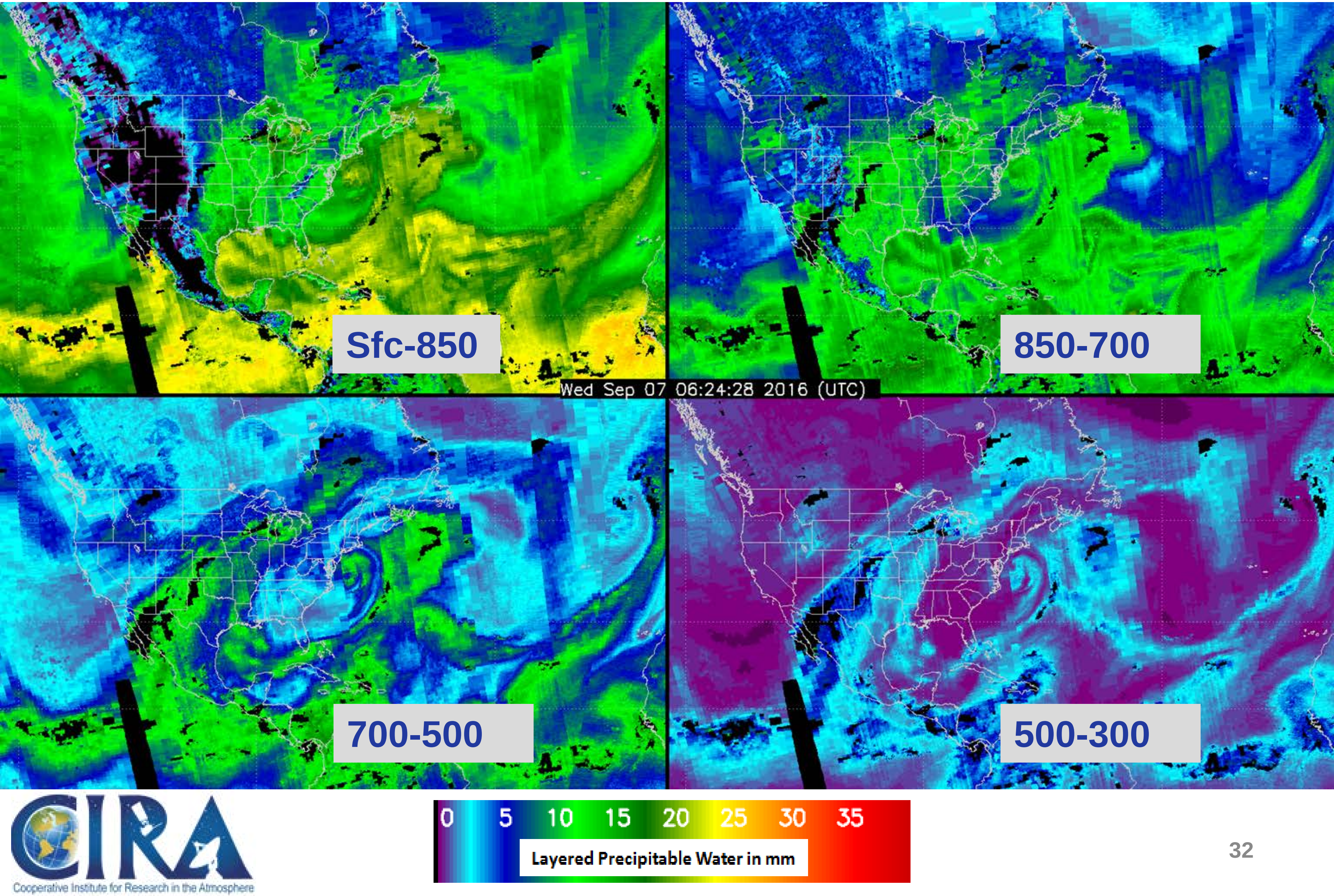
700 – 500 mb layer is advected with the vertically weighted wind.

- **Similar to the CIMSS MIMIC TPW product approach**

Both of these techniques are currently being advected over radiosonde sites to quantify performance as a function of advection time.

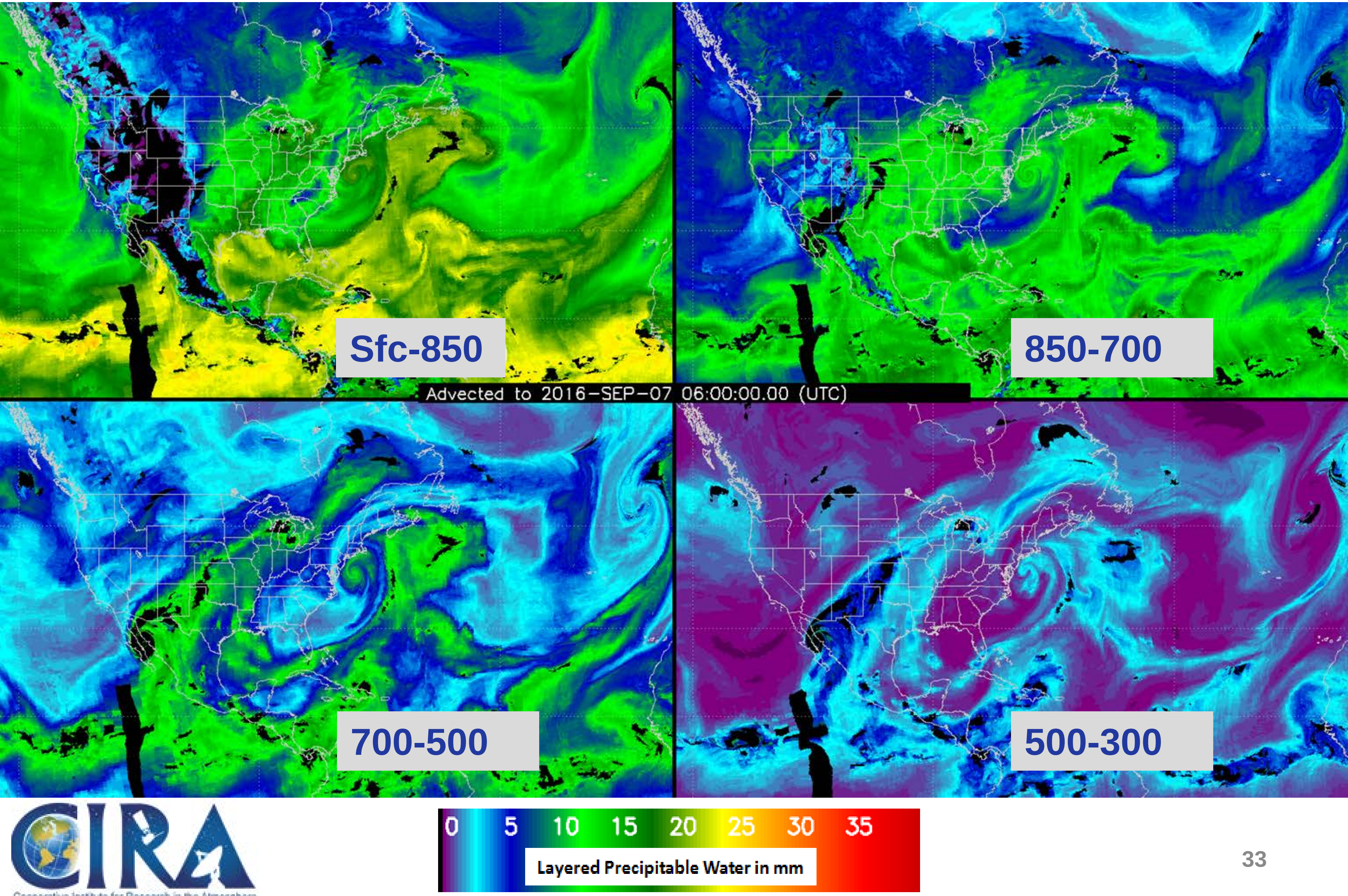
Cooperative Institute for Research in the Atmosphere

Non-advected heritage version



Cooperative Institute for Research in the Atmosphere

Version 01 Advected LPW, advected every three hours. Uses MiRS V11, fewer artifacts and better spatial resolution



Cooperative Institute for Research in the Atmosphere