Water Vapor Fields Via Multisensor Blended Satellite Products

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Thanks to many NOAA colleagues and forecasters for collaboration and to the NOAA MiRS team.

Winter Weather Experiment (WWE) and Precipitation Experiment for Atmospheric Rivers (PEAR) Seminar Series

Feb. 4, 2025

Some Definitions

TPW: Total Precipitable Water. The condensed depth of water from the surface to space. ***Also referred to as PWAT, TCWV, IPW, IWV…***

LPW: Layer Precipitable Water: The condensed depth in some specified pressure layer

ALPW: Advected LPW: use winds to move LPW to common time

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

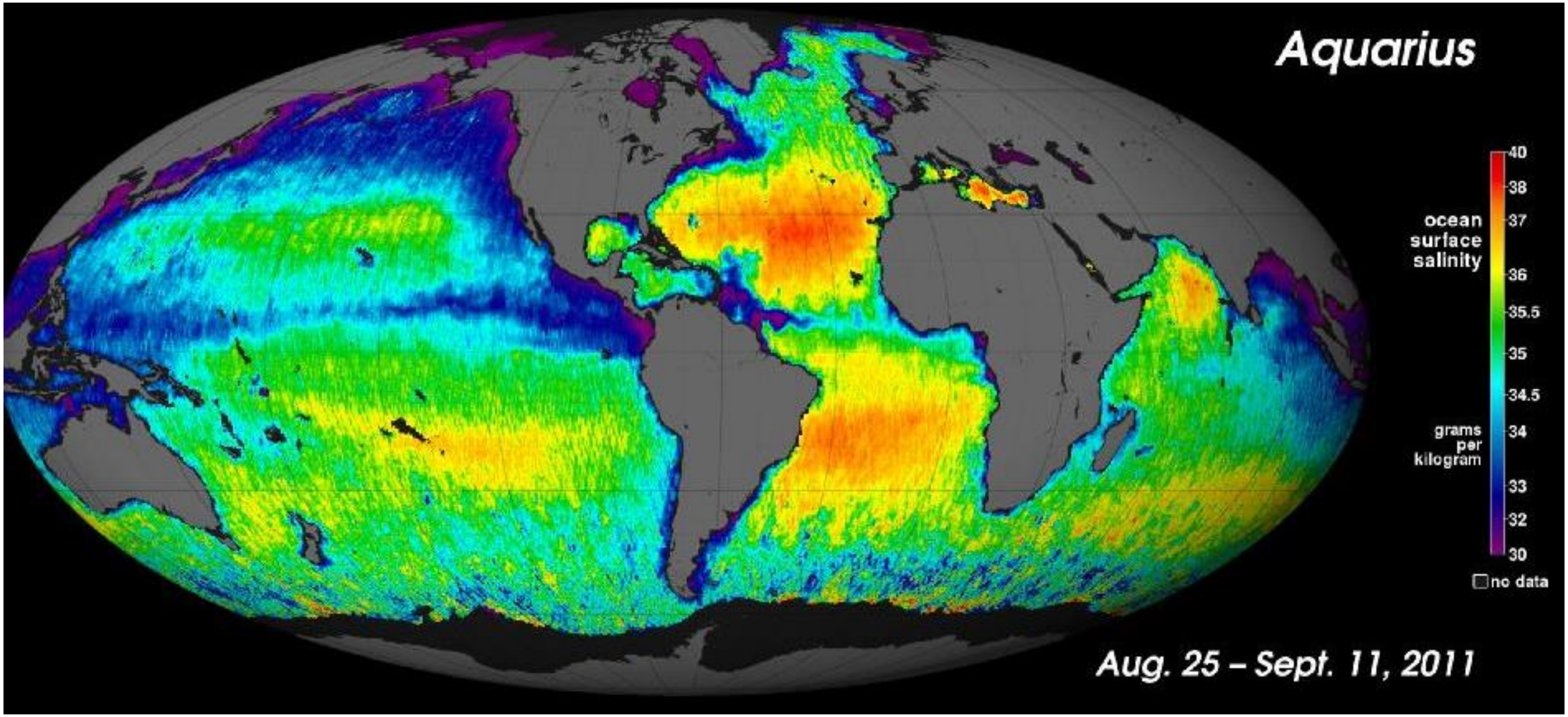
$$LPW \equiv \frac{1}{g}\int_{p_{top}}^{p_{bottom}} q\, dp$$

So LPW is proportional to layer mean mixing ratio.

Ocean Salinity a Proxy for Evaporation

The chief source of atmospheric water vapor is evaporation over the ocean, which makes conventional observations difficult.

As a result, satellite observations of atmospheric water vapor have been made since the earliest days of satellite observation.



Water Vapor is Increasing in the Troposphere

nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-021-25685-2 OPEN

Global increase in tropical cyclone rain rate

Oscar Guzm

Theoretical r
rainfall rates
been studied
general trend
observational
Precipitation
average TC r
combined eff
rate on the r
Northwestern
uniform for a
increases in

npj Climate and Atmospheric Science www.nature.com/npjclimatsci

BRIEF COMMUNICATION OPEN

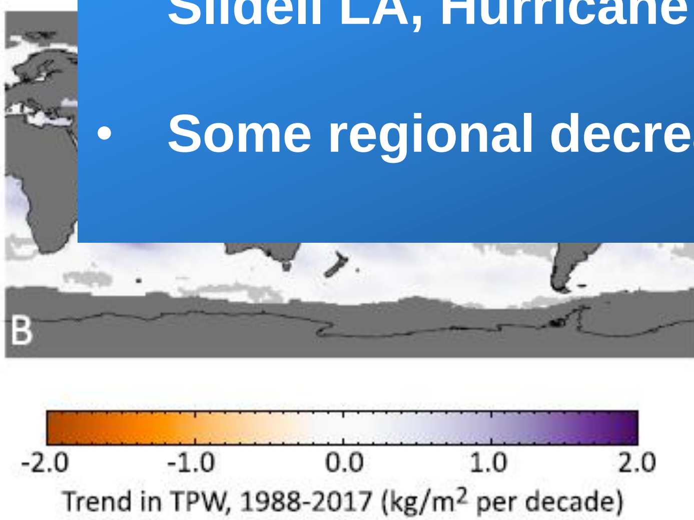
Check for updates

Increasing heat and rainfall extremes now far outside the historical climate

Alexander Robinson[1,2,3]✉, Jascha Lehmann[3], David Barriopedro[2], Stefan Rahmstorf[3,4] and Dim Coumou[3,5,6]

Over the last decade, the world warmed by 0.25 °C, in-line with the roughly linear trend since the 1970s. Here we present updated
possible
ge, 1 in 4
ies that

- Global Mean TPW is 26 mm (~1 in.)
- +1.5% / decade increase over global oceans observed
- Highest TPW I've ever observed is 91 mm (3.5", GPS site, Slidell LA, Hurricane Katrina)
- Some regional decreases



Mears et al, 2018, Earth and Space Sciences

Check for updates

winter, when sea ice is expected to recover following the melting season. It is unclear to what extent atmospheric processes such as atmospheric rivers (ARs), intense corridors of moisture transport, contribute to this reduced recovery of sea ice. Here, using observations and climate model simulations, we find a robust frequency increase in ARs in early winter over the Barents–Kara Seas and the central Arctic for 1979–2021. The moisture carried by more frequent ARs has intensified surface downward longwave radiation and rainfall, caused stronger melting of thin, fragile ice cover and slowed the seasonal recovery of sea ice, accounting for 34% of the sea-ice cover decline in the Barents–Kara Seas and central Arctic. A series of model ensemble experiments suggests that, in addition to a uniform AR increase in response to anthropogenic warming, tropical Pacific variability also contributes to the observed Arctic AR changes.

“Water vapor is a limiting factor in the amount of extreme precipitation more than the intensity of the weather causing the event” *(Kunkel et al. 2020)*

Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL086721

Observed Climatological Relationships of Extreme Daily Precipitation Events With Precipitable Water and Vertical Velocity in the Contiguous United States

Kenneth E. Kunkel[1], Scott E. Stevens[1], Laura E. Stevens[1], and Thomas R. Karl[2]

[1]North Carolina Institute for Climate Studies, North Carolina State University, Asheville, NC, USA, [2]Climate and Weather, L.L.C, Mills River, NC, USA

Key Points:

- Extreme daily precipitation is strongly correlated with and on average amplified to twice the vertically integrated water vapor
- As water vapor increases there is evidence for nonlinear scaling at lower (higher) values of *q* with decreasing (increasing) amplification
- Vertical velocity and related weather types modulate the amplification along with complex terrain and along ocean/land transitions

Abstract An analysis of 3,104 stations in the United States shows virtually every station exhibits a positive correlation between precipitable water (PW) and extreme daily precipitation (EP) with over one-third statistically significant. To first approximation, EP scales linearly with PW, but there is nonlinear

- Noted disproportionately large effect on extreme precipitation at higher Total Precipitable Water (TPW) values

"…a generally rising trend in land-falling AR activity. The latter trend is consistent with a long-term increase in vapor transport from the warming North Pacific onto the North American continent."

Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL074175

Assessing the climate-scale variability of atmospheric rivers affecting western North America

Alexander Gershunov[1], **Tamara Shulgina**[1], **F. Martin Ralph**[1], **David A. Lavers**[2], and **Jonathan J. Rutz**[3]

[1]Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California, USA, [2]European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, UK, [3]Science and Technology Infusion Division, National Weather Service, Western Region Headquarters, Salt Lake City, Utah, USA

Key Points:
- Using a new detection scheme, a 69 yearlong catalog of atmospheric rivers land-falling upon western North America is created and validated
- AR landfalls show a marked seasonal progression from the Gulf of Alaska in the early fall to northern California in early winter
- The seasonal intensity of AR landfalls varies from year to year and from decade to decade in relation to Pacific SST variability

Supporting Information:
- Supporting Information S1

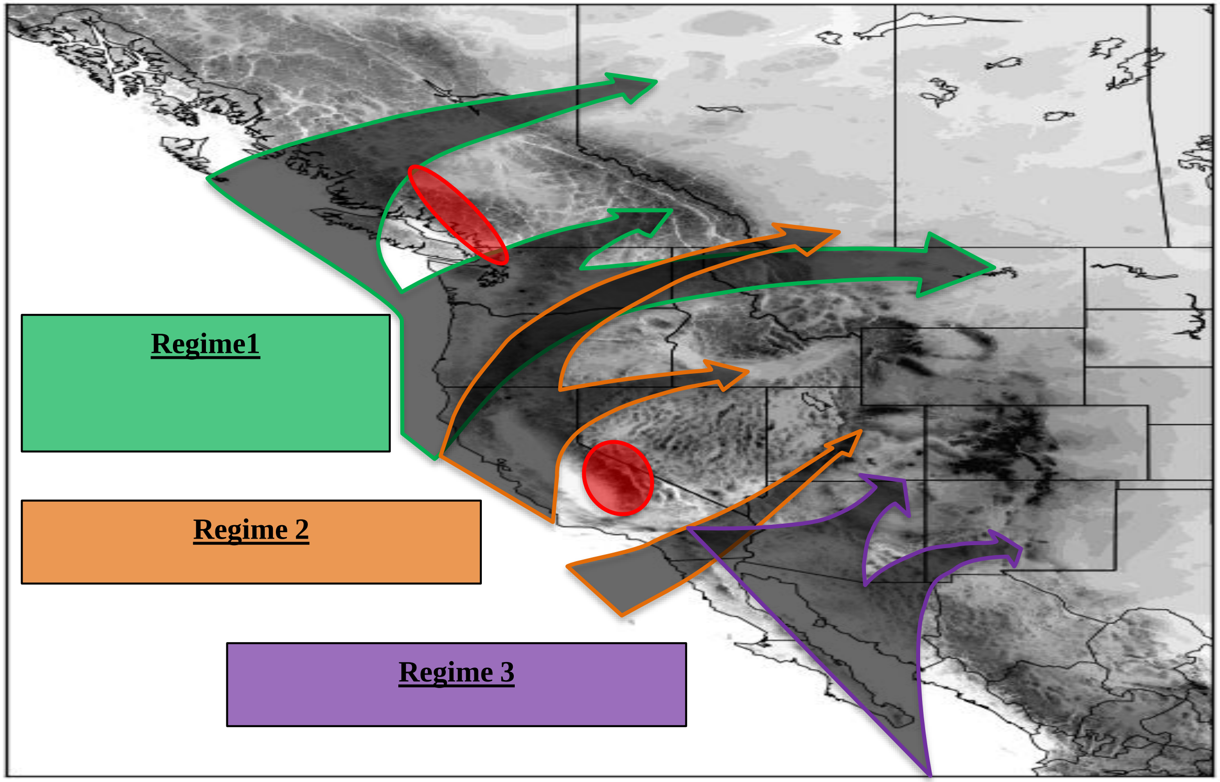
Correspondence to:
A. Gershunov,
sasha@ucsd.edu

Citation:
Gershunov, A., T. Shulgina, F. M. Ralph, D. A. Lavers, and J. J. Rutz (2017), Assessing the climate-scale variability of

Abstract A new method for automatic detection of atmospheric rivers (ARs) is developed and applied to an atmospheric reanalysis, yielding an extensive catalog of ARs land-falling along the west coast of North America during 1948–2017. This catalog provides a large array of variables that can be used to examine AR cases and their climate-scale variability in exceptional detail. The new record of AR activity, as presented, validated and examined here, provides a perspective on the seasonal cycle and the interannual-interdecadal variability of AR activity affecting the hydroclimate of western North America. Importantly, AR intensity does not exactly follow the climatological pattern of AR frequency. Strong links to hydroclimate are demonstrated using a high-resolution precipitation data set. We describe the seasonal progression of AR activity and diagnose linkages with climate variability expressed in Pacific sea surface temperatures, revealing links to Pacific decadal variability, recent regional anomalies, as well as a generally rising trend in land-falling AR activity. The latter trend is consistent with a long-term increase in vapor transport from the warming North Pacific onto the North American continent. The new catalog provides unprecedented opportunities to study the climate-scale behavior and predictability of ARs affecting western North America.

The Inland Penetration of Atmospheric Rivers over Western North America

Rutz, J. J., W. J. Steenburgh, and F. M. Ralph,
Mon. Wea. Rev., 2015



Schematic highlighting 3 predominant regimes associated with landfalling ARs on the North American West Coast. Regimes are a function of AR quantity and likelihood of penetrating inland.

Why not just use the model water vapor?

The NOAA Joint Center for Satellite Data Assimilation (JCSDA) has six primary scientific research priority areas:

One of these is:
"Assimilation of satellite data impacted by clouds and precipitation"

The ALPW product directly uses all of the satellite microwave radiance data. Data assimilation systems for NWP are still evolving to use cloudy radiances and microwave radiances over land.

The satellite products provide a rapid update (typically hourly) without the latency, cadence of models.

- Blended Satellite Products provide an observation-driven comparison to the model moisture field

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Blended Multisensor Products

Cooperative Institute for Research in the Atmosphere

Status of Blended TPW and ALPW

- NOAA Blended TPW first became operational in 2009.
- **Operational Blended TPW enhancements ("V4.0") in early 2025 (nominally Feb. 5) include:**
  - GOES East/West TPW in clear skies
  - MIMIC (Tony Wimmers CIMSS) advected LEO microwave TPW
  - GPS data over CONUS with more limited extrapolation

  A much-improved product!

- ALPW is a new product and became operational in Fall 2024

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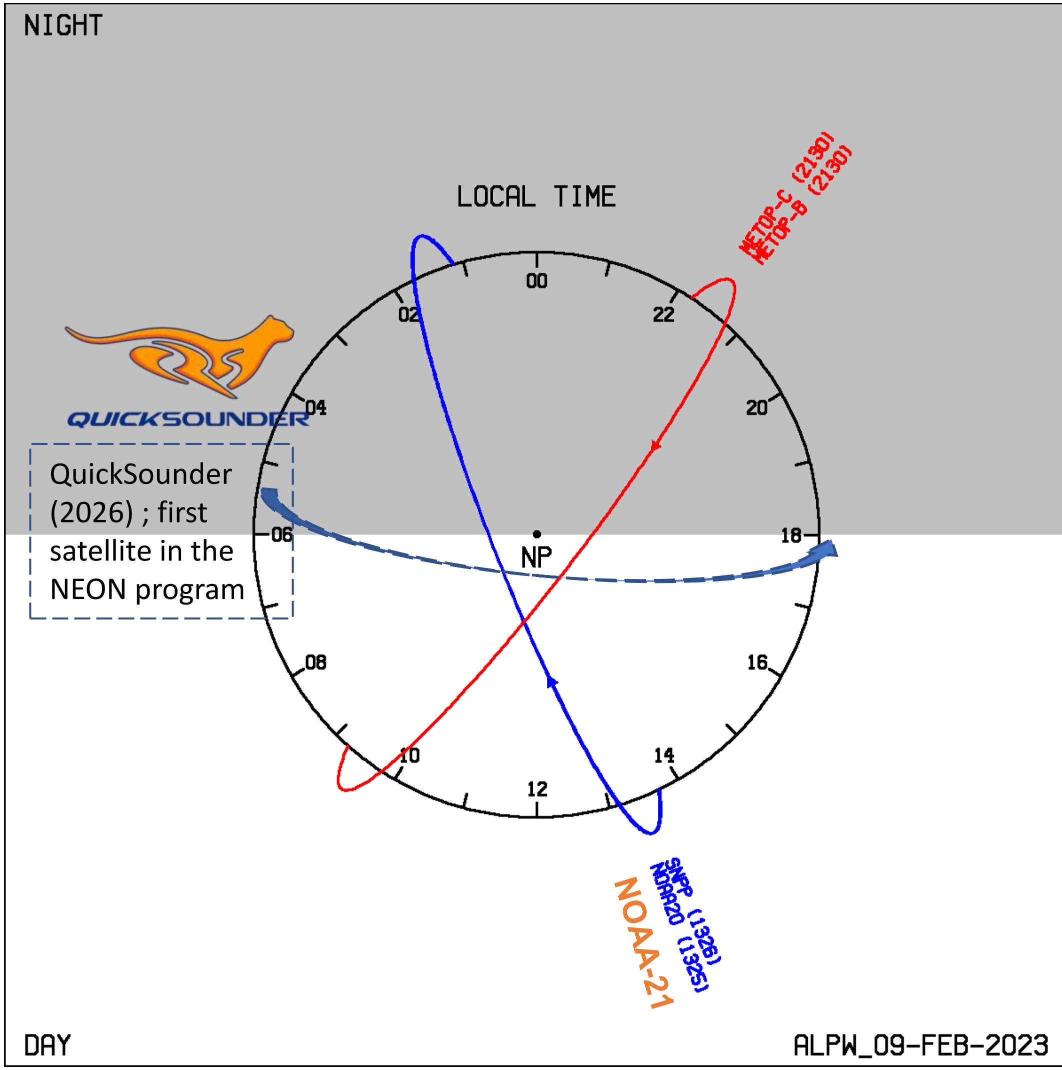
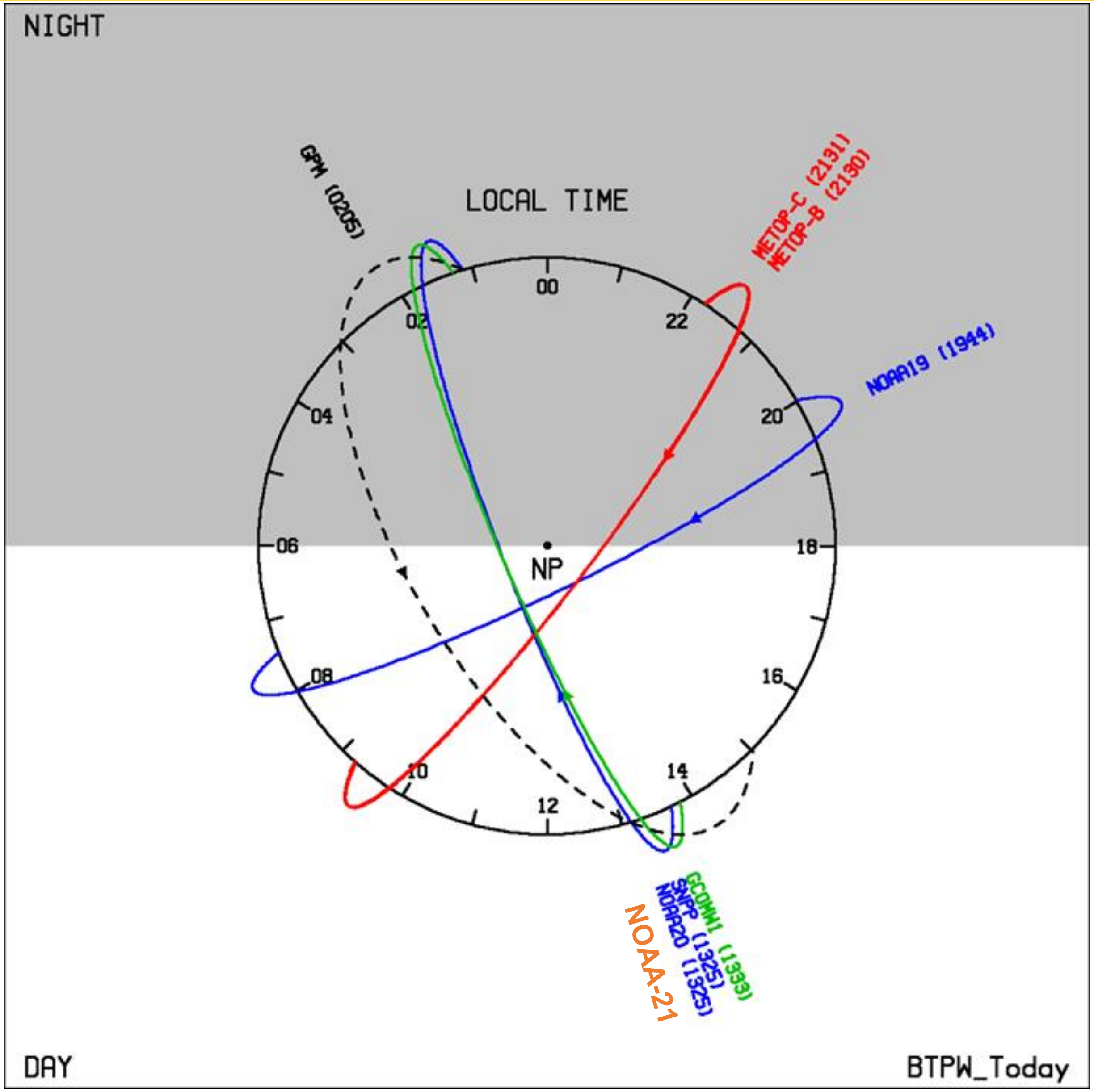
Advection Fills in Between Satellite Overpasses



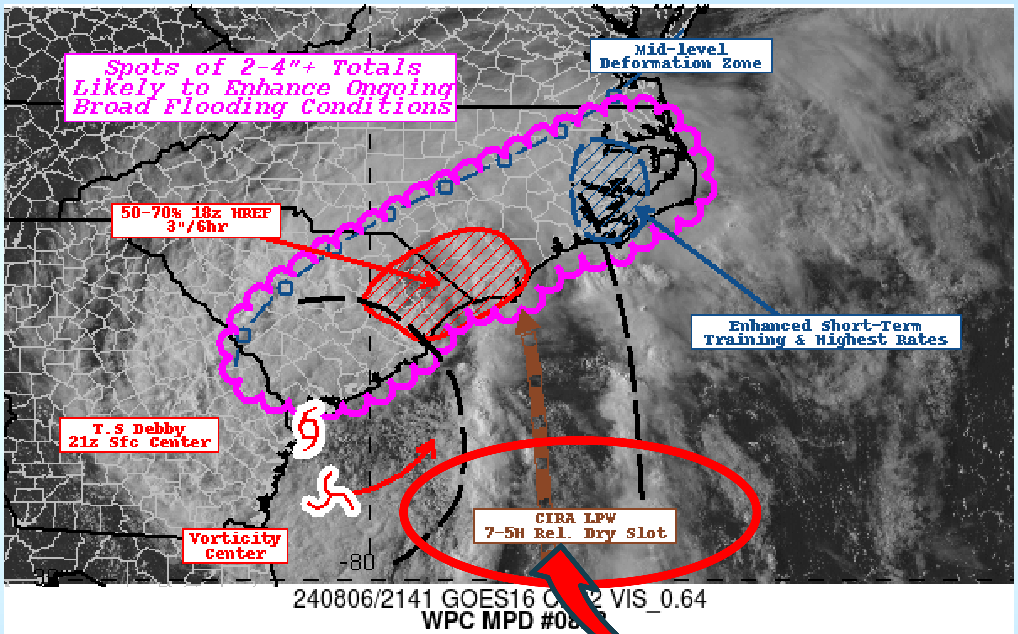
Polar MiRS constellation for ALPW

- QuickSounder will fill a key gap
- Currently, 9 hour reachback window used for each hourly analysis
- SmallSats in other planes welcome!
- This diagram is key to understanding satellite water vapor and precipitation products.

Current Blended TPW LEO Constellation – more satellites than ALPW



ALPW is Used for a Variety of Purposes



Mesoscale Precipitation Discussion 0823
NWS Weather Prediction Center College Park MD
547 PM EDT Tue Aug 06 2024

Areas affected...Coastal Plains of the Carolinas...

Concerning...Heavy rainfall...Flash flooding likely

Valid 062145Z - 070345Z

DISCUSSION... GOES-Visible and RAP analysis denote a broad area of generally stable with relative vertical lapse rates in an southwest of the center generally aligned with CIRA LPW suite of highest values and totals near 2.5-2.75". However, a mid-level 700-500mb dry slot is detected along the southeast and eastern quadrants lifting northward across the Gulf Stream. GOES-E Visible delineates this very well…

The most important ALPW product validation:

It makes sense when viewed by forecasters and compared to other data

Typical Uses of Blended TPW (Total Precipitable Water) and ALPW (Advected Layer Precipitable Water)

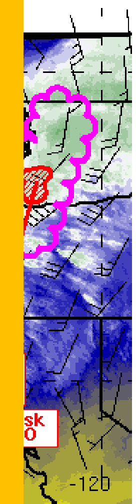
ALPW products have proven to be a very useful diagnostic tool at WPC for operational forecasters at WPC's Quantitative Precipitation Forecast (QPF), Rainfall Hazards and MetWatch desks…

…ALPW products have been utilized operationally at the MetWatch desk to identify areas of enhanced rainfall efficiency (e.g. warm rain and "seeder-feeder" processes) and to query the depth of Pacific atmospheric river events.

-Andrew Orrison
NOAA WPC Oct. 2022

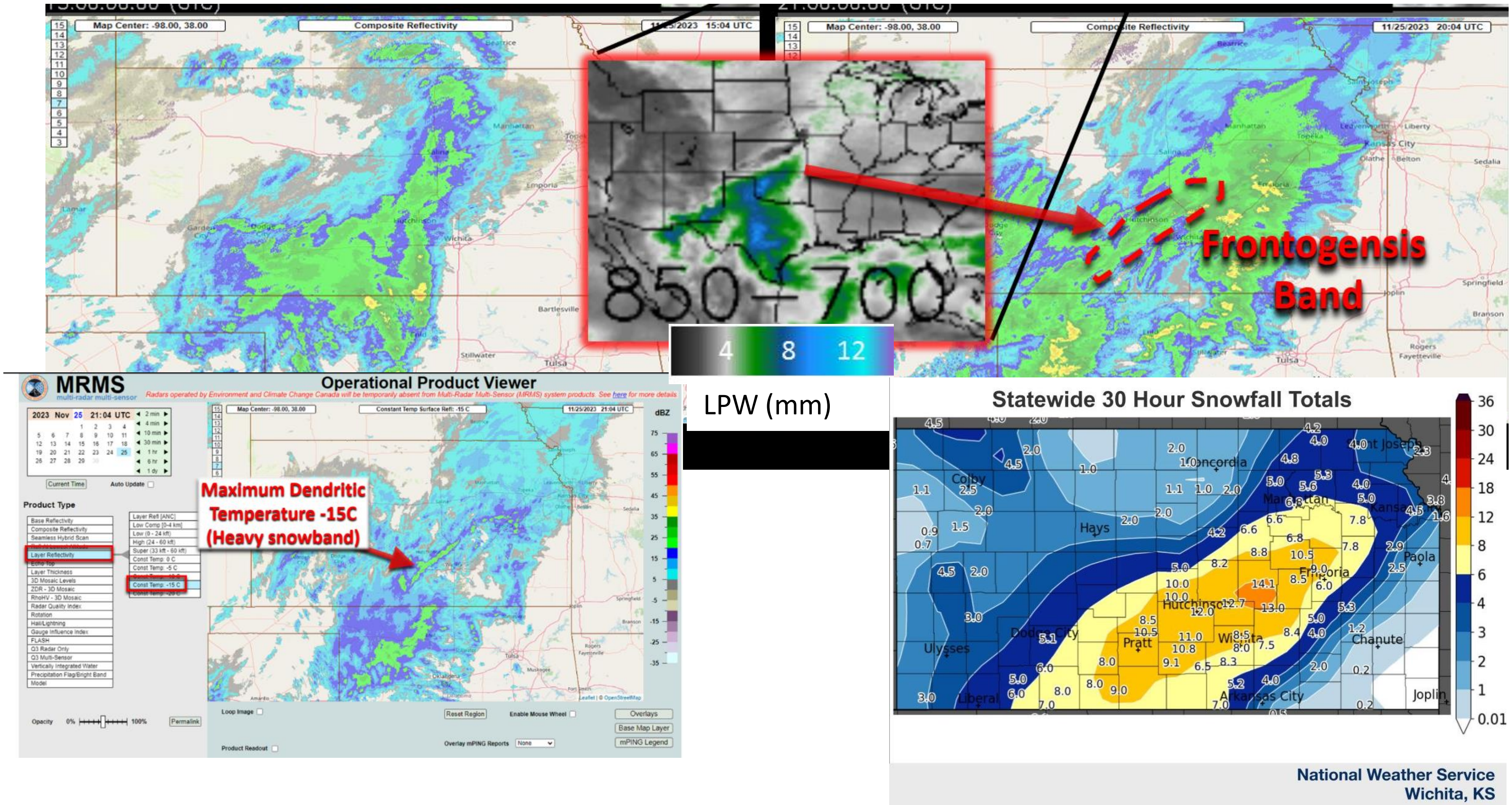
"So many uses, especially for mesoscale analysis and supporting our partners' needs in the critical first 12 hours of the forecast. I did a quick search and we have mentioned ALPW in our Area Forecast Discussion 7 times in the last year."

- WFO Norman, OK
June 2023



latitude (arcing northeast to about halfway between Hawaii and California)... This level of tropospheric moisture is also at or above the max moving average of the associated OAK sounding climatology.

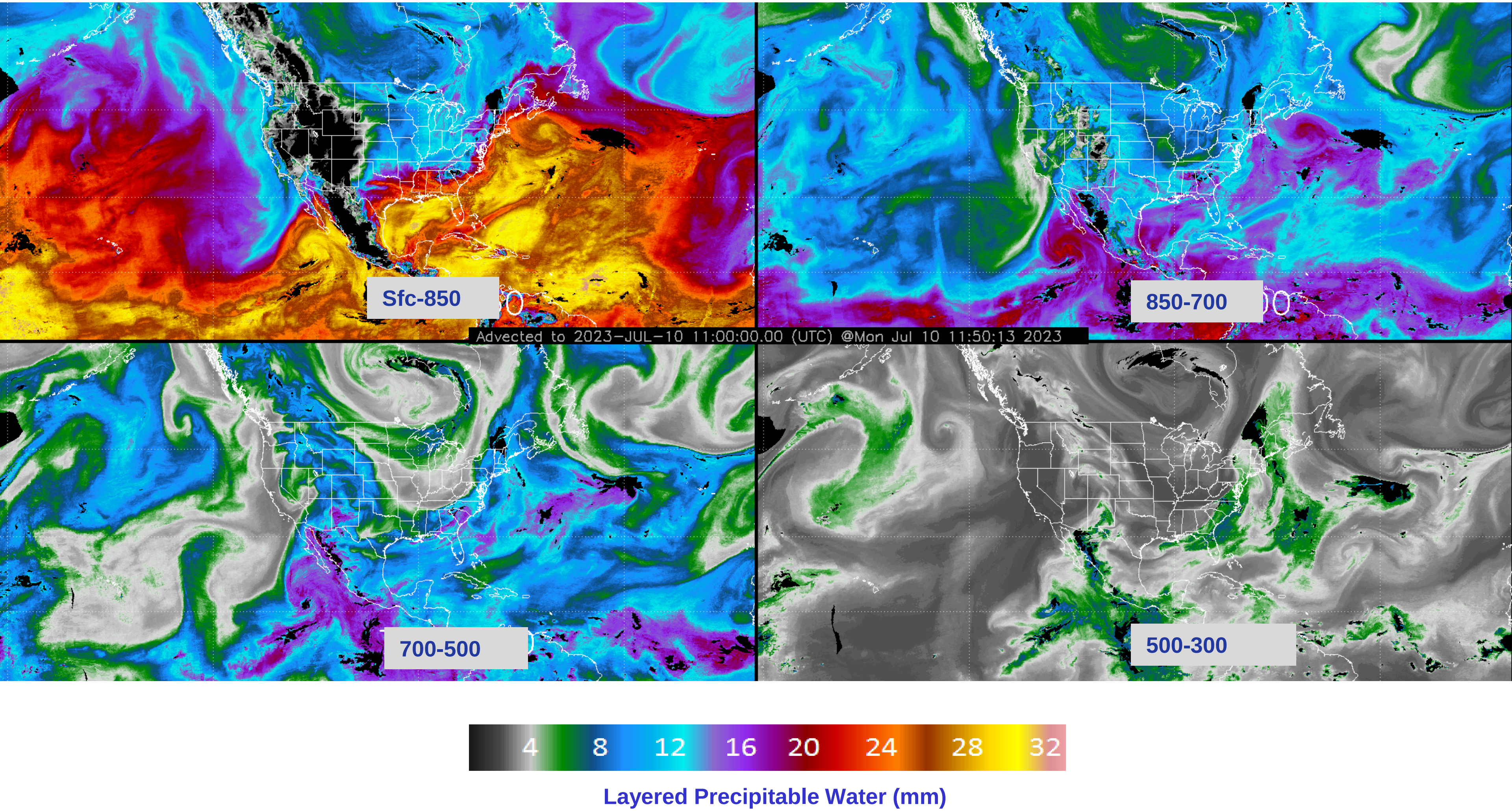
"I am finding these ALPW/Layer vapor transport products very helpful in detecting real-time frontogensis in the atmosphere." -- Chris Jakub, NWS Wichita , Nov. 2023.



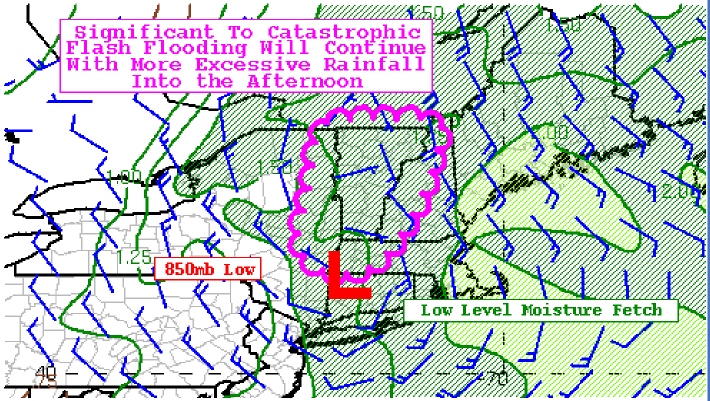
https://www.youtube.com/watch?v=_z-hFd5d3X8&t=786s

FDTD Applications Webinar on November 4, 2020

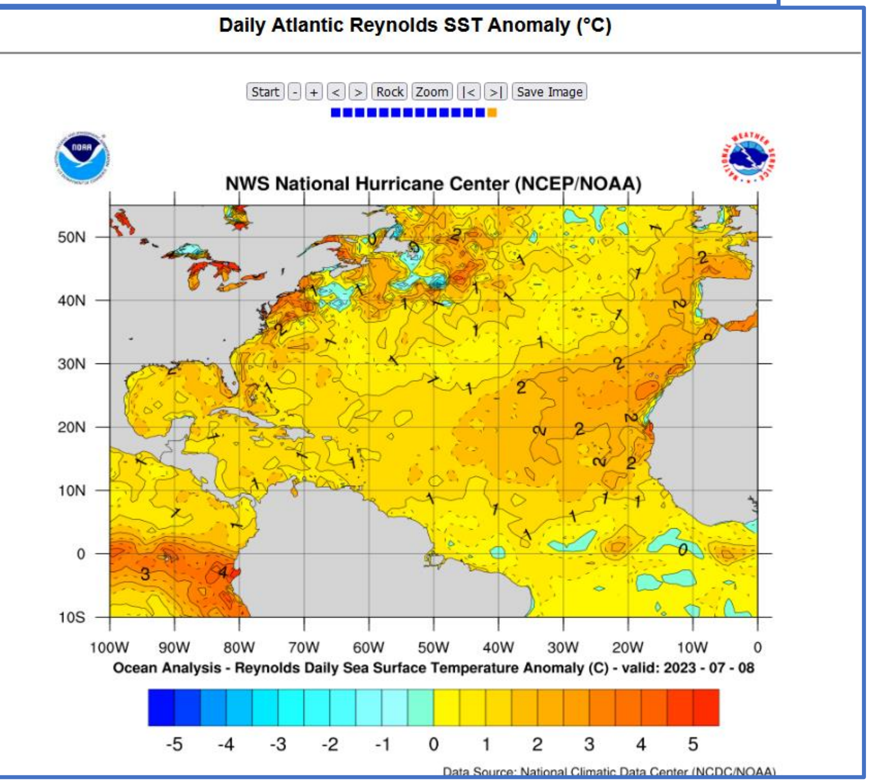
Hourly ALPW for New England Flood 10 July 2023



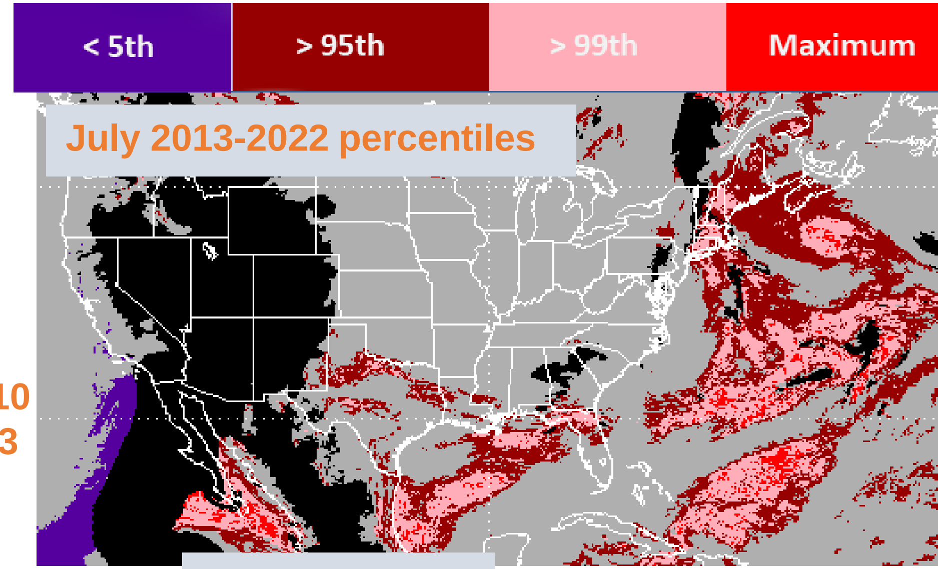
New England Floods, July 10 2023

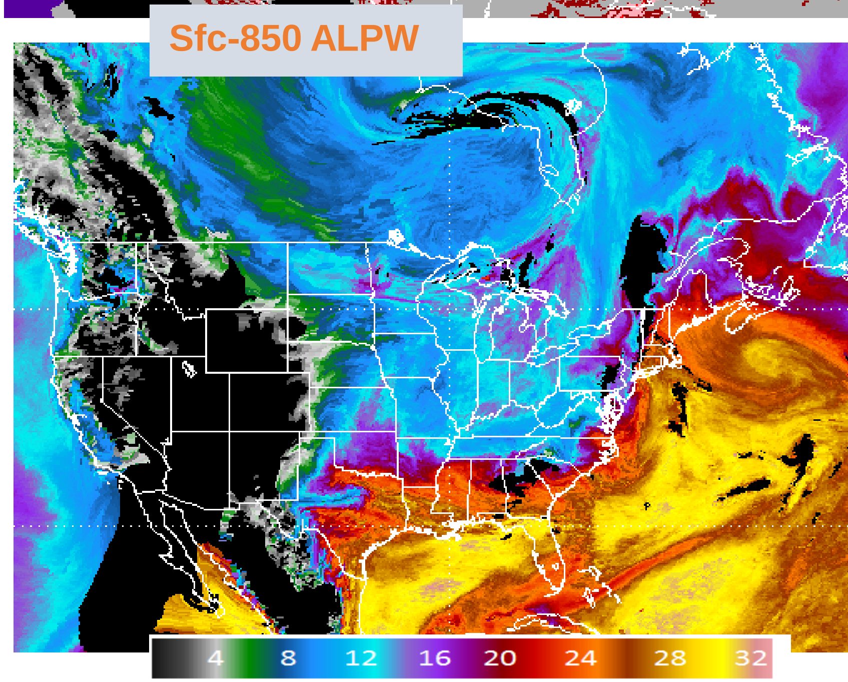


RAP32 PRECIP WATER 230710/1300f005
RAP32 850 MB WINDS 230710/1300f005
WPC MPD #0690



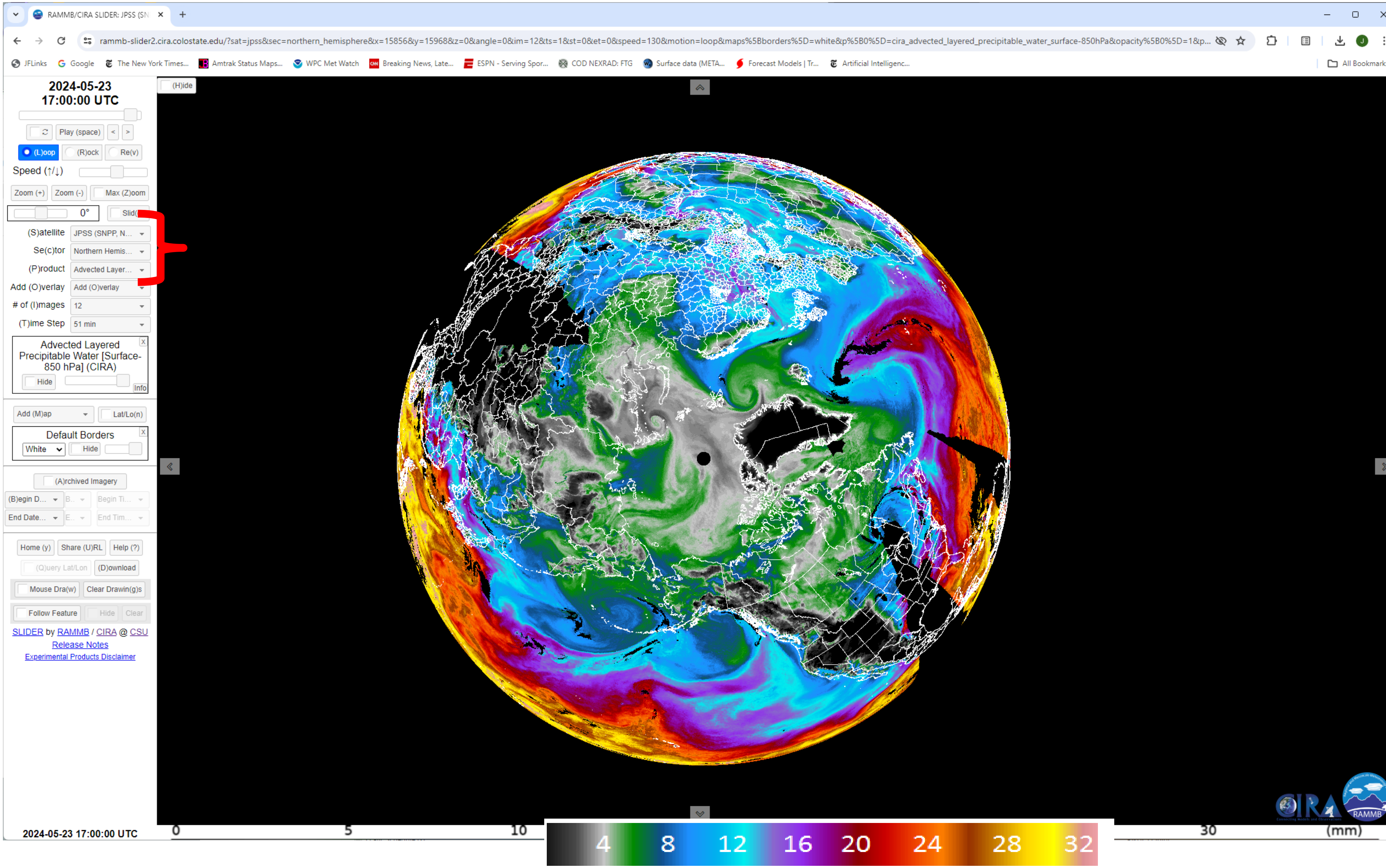
15 UTC 10 July 2023





Layered Precipitable Water (mm)

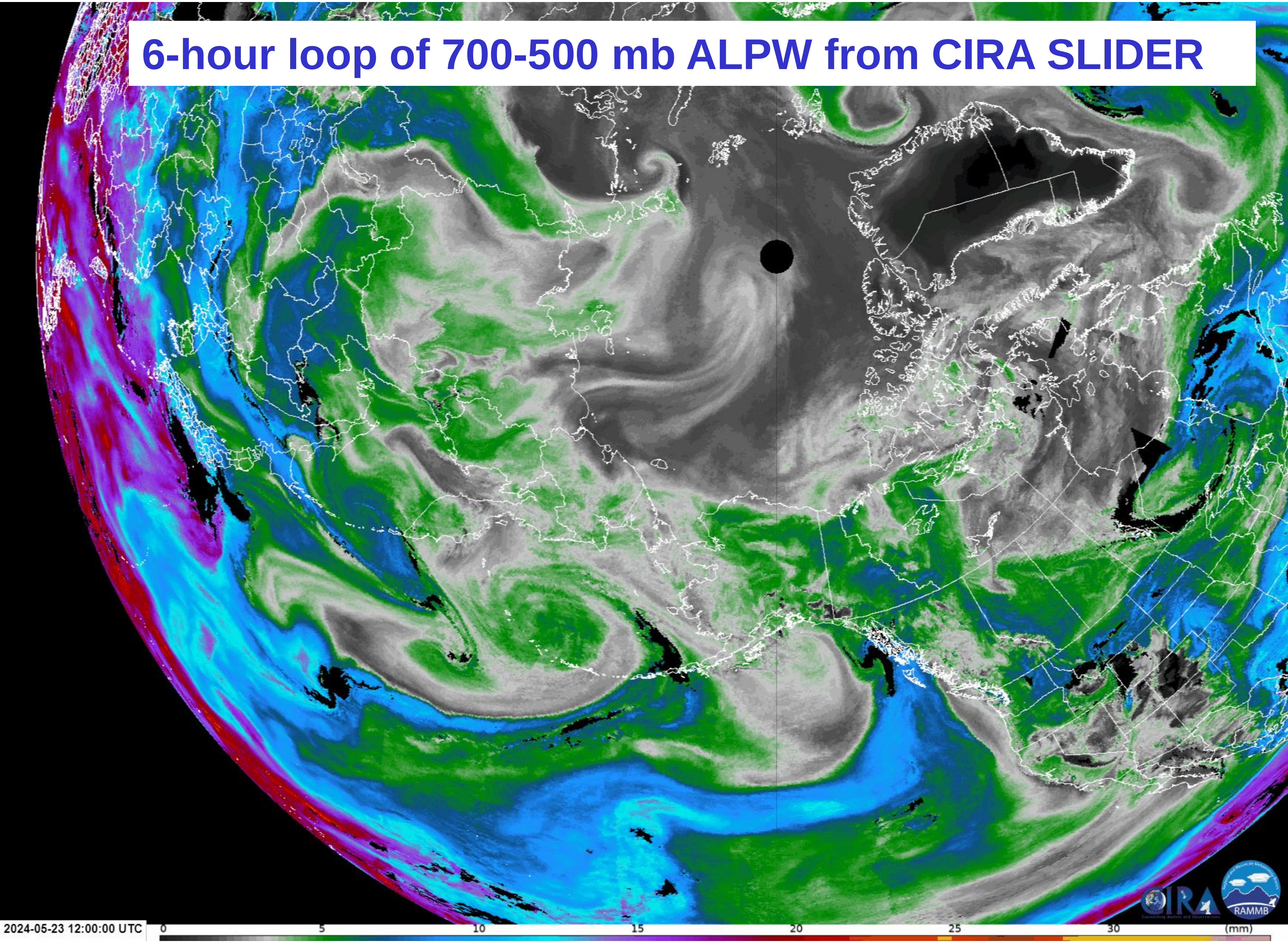
Polar view of Blended TPW and ALPW available at https://rammb-slider.cira.colostate.edu/



Sfc-850 mb layer

Layer Precipitable Water (mm)

6-hour loop of 700-500 mb ALPW from CIRA SLIDER



Constructing the ALPW and Blended TPW Products

Much of what we are doing with blended products is trying to mimic the functionality of a geostationary microwave sounder.

Why don’t we have one?

(NASA-TM-86185) THE RATIONALE AND SUGGESTED APPROACHES FOR RESEARCH GEOSYNCHRONOUS SATELLITE MEASUREMENTS FOR SEVERE STORM AND MESOSCALE INVESTIGATIONS (NASA) 37 p HC A03/MF A01 CSCL 04B G3/47 N85-18532 Unclas 13507

NASA

Technical Memorandum 86185

THE RATIONALE AND SUGGESTED APPROACHES FOR RESEARCH GEOSYNCHRONOUS SATELLITE MEASUREMENTS FOR SEVERE STORM AND MESOSCALE INVESTIGATIONS

W. E. Shenk, R. F. Adler, D. Chesters, J. Susskind and L. Uccellini
(AD HOC Severe Storms and Mesoscale Requirements Committee)

JANUARY 1985

- Concepts for a geostationary microwave sensor have been around since the 1980’s
- Programmatic and technical reasons have kept it from happening so far
- But with a mixture of larger LEO’s, Smallsats and advection where warranted we can begin to approach this capability

1985

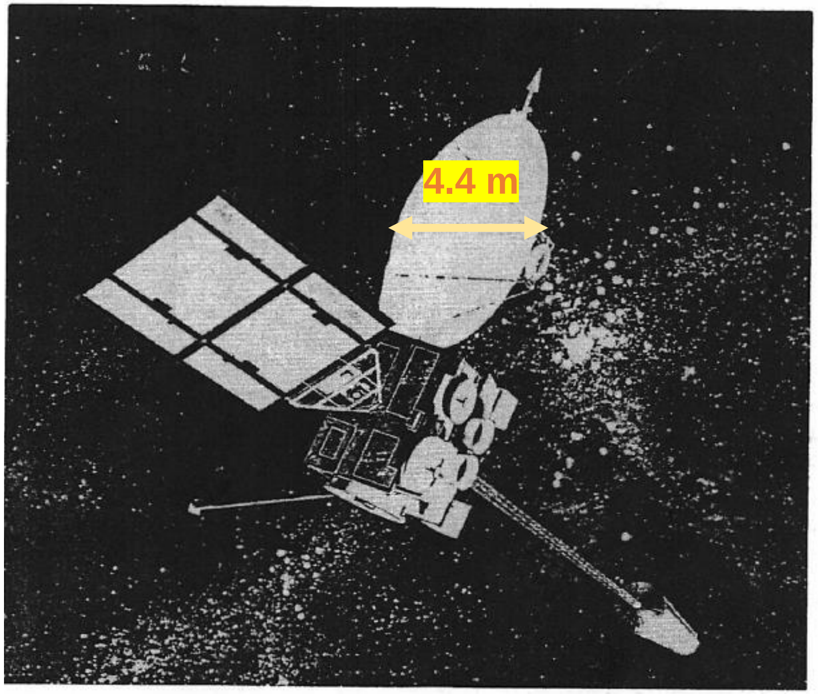


Fig. 1. Artist's conception of the PMR on a GOES satellite.

"Plans and budgets were in place for the instrument on at least one satellite in the GOES - NEXT series. And then came the Challenger disaster (1986)... NOAA had to move on with the operational GEO satellites and arranged for conventional launch vehicles for all the GOES-NEXT. We thus lost the opportunity to fly a sizeable antenna on those spacecraft due to smaller payload shrouds".
(Tom Vonder Haar, pers. comm.)

2022

IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 15, 2022 623

A Geostationary Microwave Sounder: Design, Implementation and Performance

Bjorn Lambrigtsen, Pekka Kangaslahti, Oliver Montes, Noppasin Niamsuwan, Derek Posselt, Jacola Roman, Mathias Schreier, Alan Tanner, Longtao Wu, and Igor Yanovsky

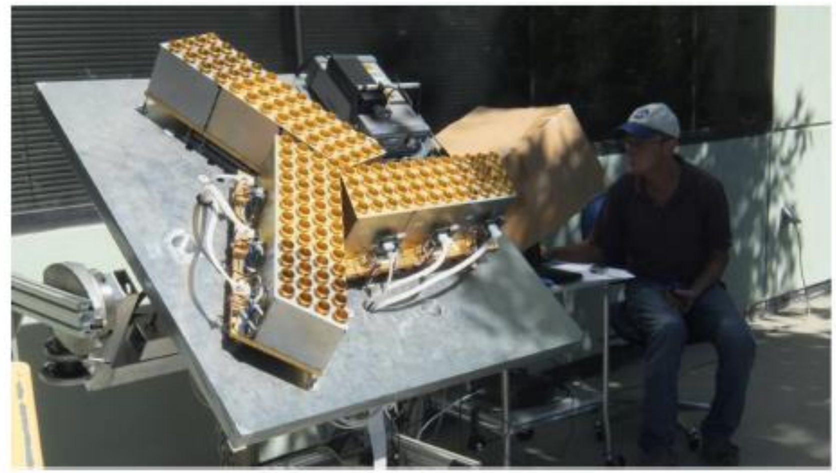


Fig. 4. GeoSTAR prototype, operating at 183 GHz.

JPL developed and tested the GeoSTAR synthetic aperture instrument concept (smaller).

No launch plans as of now.

MiRS: An All-Weather 1DVAR Satellite Data Assimilation and Retrieval System

Sid-Ahmed Boukabara, Kevin Garrett, Wanchun Chen, Flavio Iturbide-Sanchez, *Member, IEEE*, Christopher Grassotti, Cezar Kongoli, Ruiyue Chen, Quanhua Liu, Banghua Yan, Fuzhong Weng, Ralph Ferraro, Thomas J. Kleespies, and Huan Meng

NOAA operational MiRS retrieval system is the backone used to produce TPW and LPW

- **Uses passive microwave data including 183 GHZ spectral region**
- **Forecast model independent**

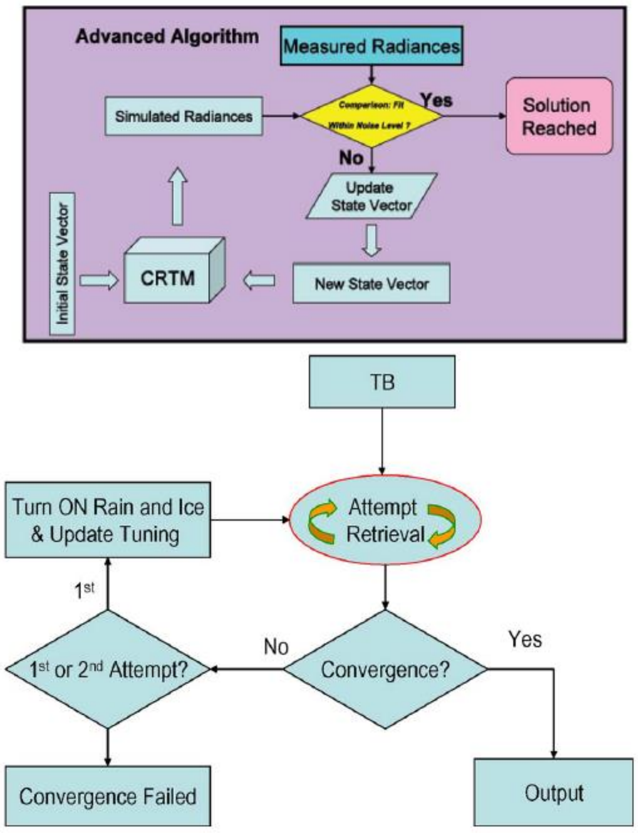
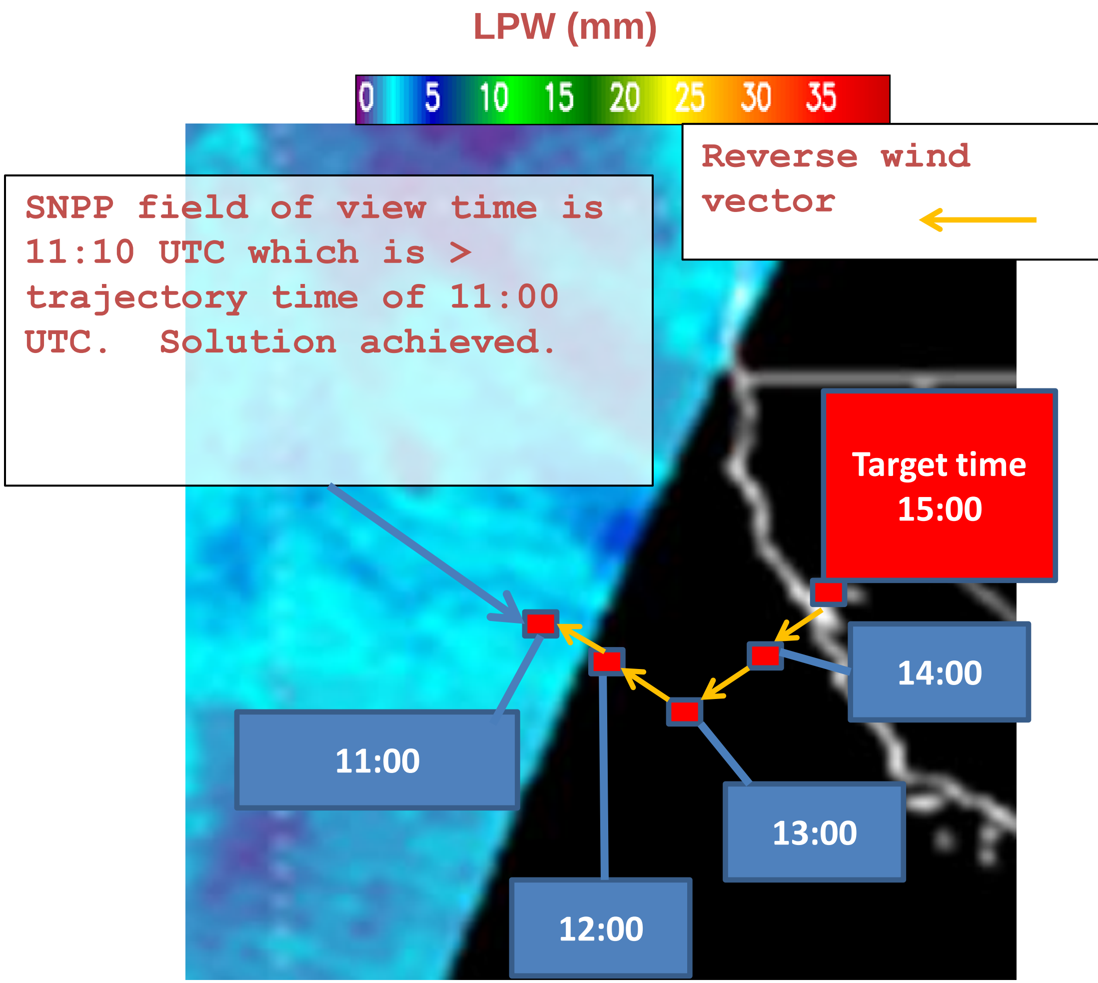
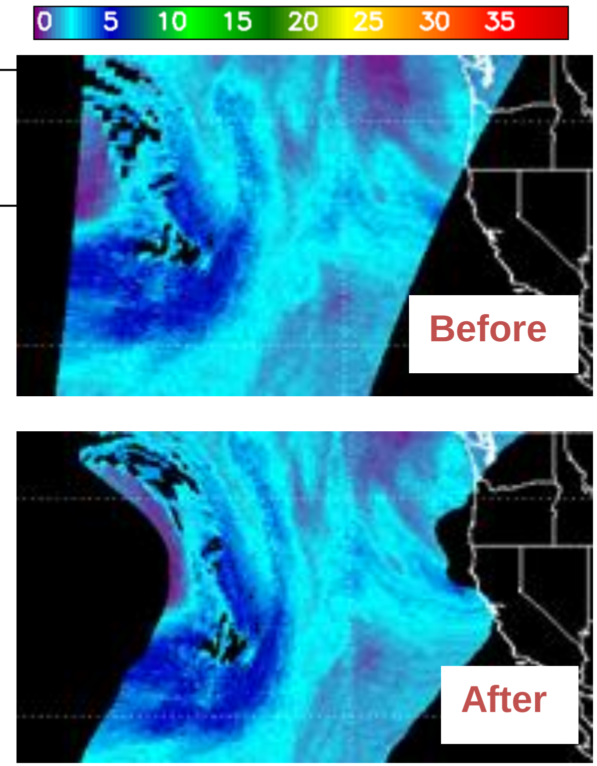


Fig. 3. Diagrams of the MiRS retrieval algorithm. The bottom panel describes the retrieval attempts. The top panel shows the iterative approach adopted in MiRS to reach a solution within each retrieval attempt. See text for details.

Schematic of how the back-trajectory method works for advection





S-NPP 700-500 LPW April 20, 2016 advected to 1500 UTC (~4 hour advection)

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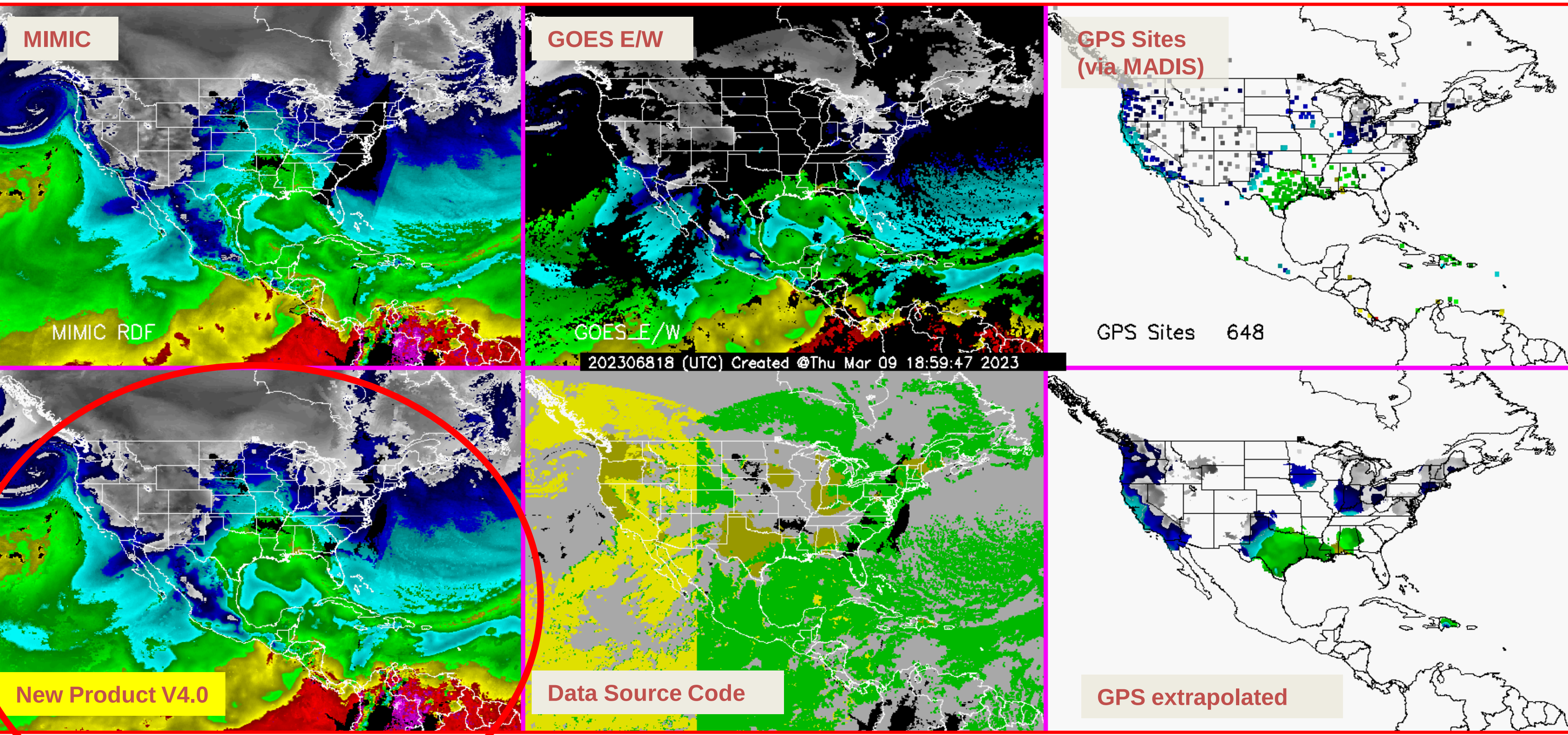
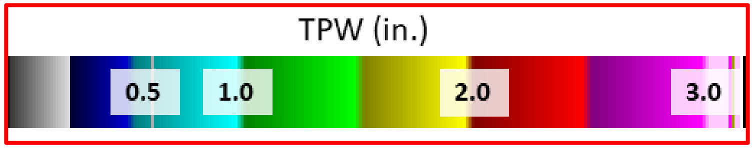
Winds are from the GFS

New Version of Blended TPW to go Operational in Early 2025

While ALPW is Microwave-Only, Blended TPW Uses Microwave, GOES infrared and Surface GPS Data.

Blends inputs according to hierarchy. 1st GOES, 2nd GPS, 3rd Advected Microwave





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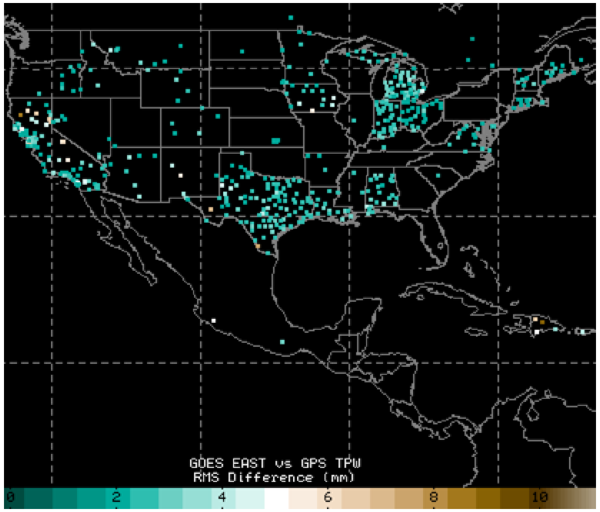
Hourly Loop at https://cat.cira.colostate.edu/btpw_2020/

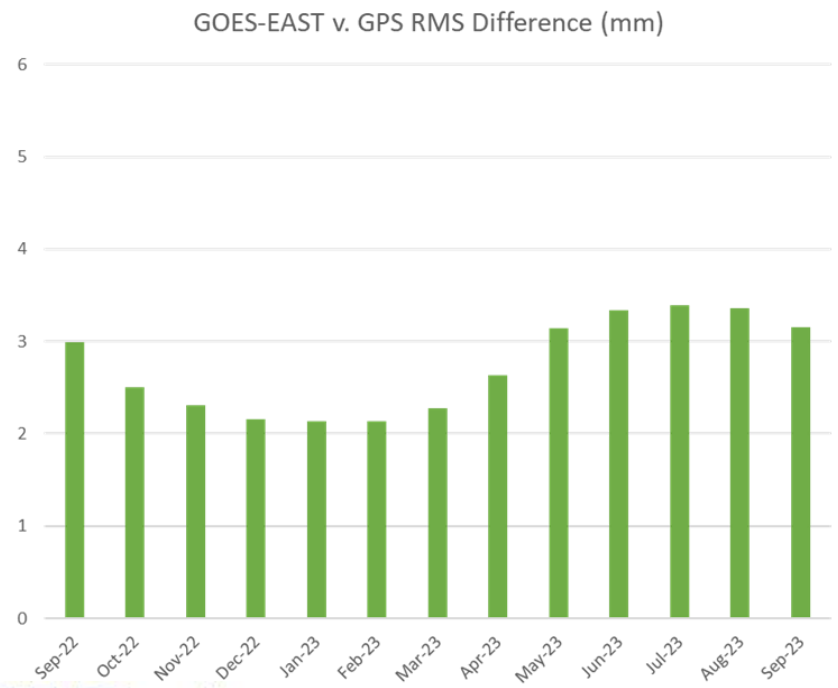
Validation of Advected LEO (MIMIC) and GOES TPW versus Surface GPS

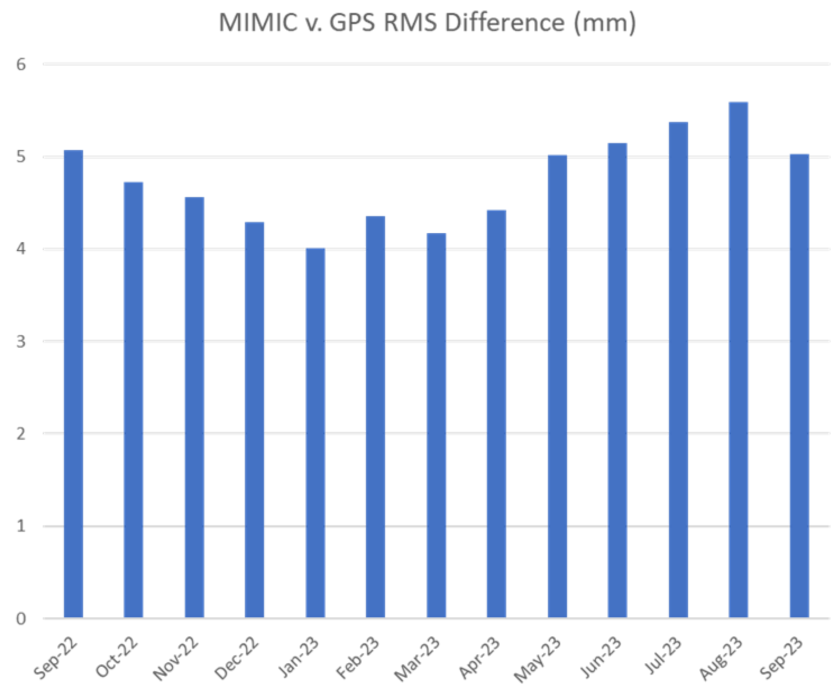
13 months of hourly data:

September 2022 through September 2023

- GOES TPW very consistent, no penalty for advection







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NWS Forecaster Surveys of the New “Merged” Total Precipitable Water Product

Question	2019 HWT (severe wx experiment)	2019 FFaIR (flash flood experiment)
1. Did the new Merged TPW product perform better than the operational blended TPW?	(responses – 79) 68% YES 32% NO	(responses – 80) 70% - much better 12% - better 14% - same 4% - worse

Independent Radiosonde Validation Supports Forecaster Evaluation

00 and 12 Radiosonde TPW Data in CONUS domain Feb 1 – March 22, 2022

	number	r^2	rms (mm)	bias (mm)	
MIMIC:	4180	0.86	3.5	0.93	-- From using Wimmers RDF files
GOES-16:	2229	0.96	1.7	-0.37	-- Clear skies only
New Blended TPW:	4392	0.93	2.4	-0.34	-- What will be the new operational product
Current Operational:	4392	0.90	2.9	0.76	-- 20 % RMS improvement

SmallSat missions with microwave sensors for water vapor profiling:

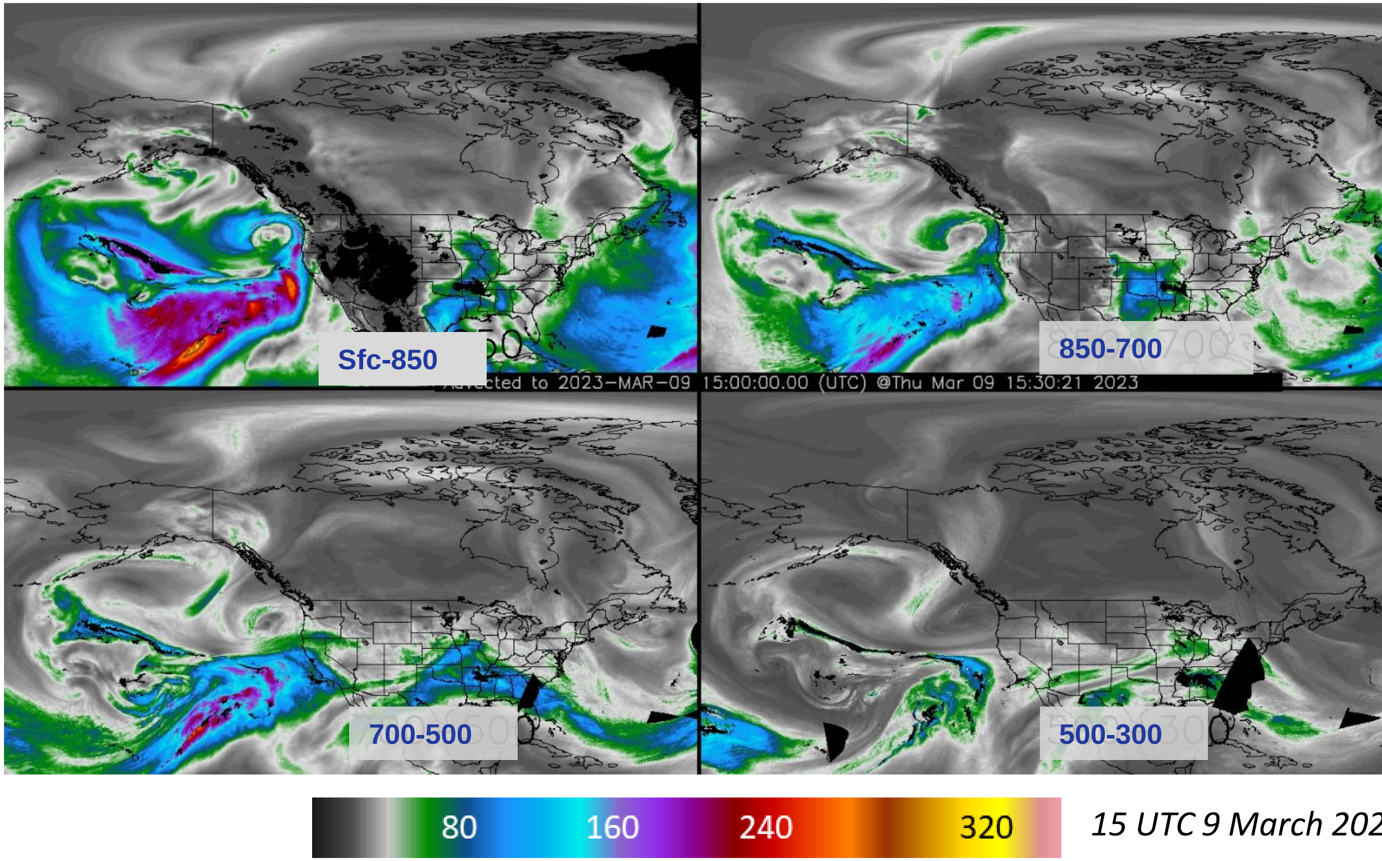
- **NASA TROPICS (2023 – 4 satellites launched)**
- **NASA INCUS (~2027)**
- **EUMETSAT Arctic Weather Satellite / Sterna Program**
- **Commercial (Tomorrow.io)**

➢ **Data access in near real time and rapid integration into operational products are needed to realize potential.**

New Layered Vapor Transport Currently Evaluated at WPC

AWIPS-2 files being distributed hourly to WPC

https://cat.cira.colostate.edu/ALPX/LVT/lvt.htm



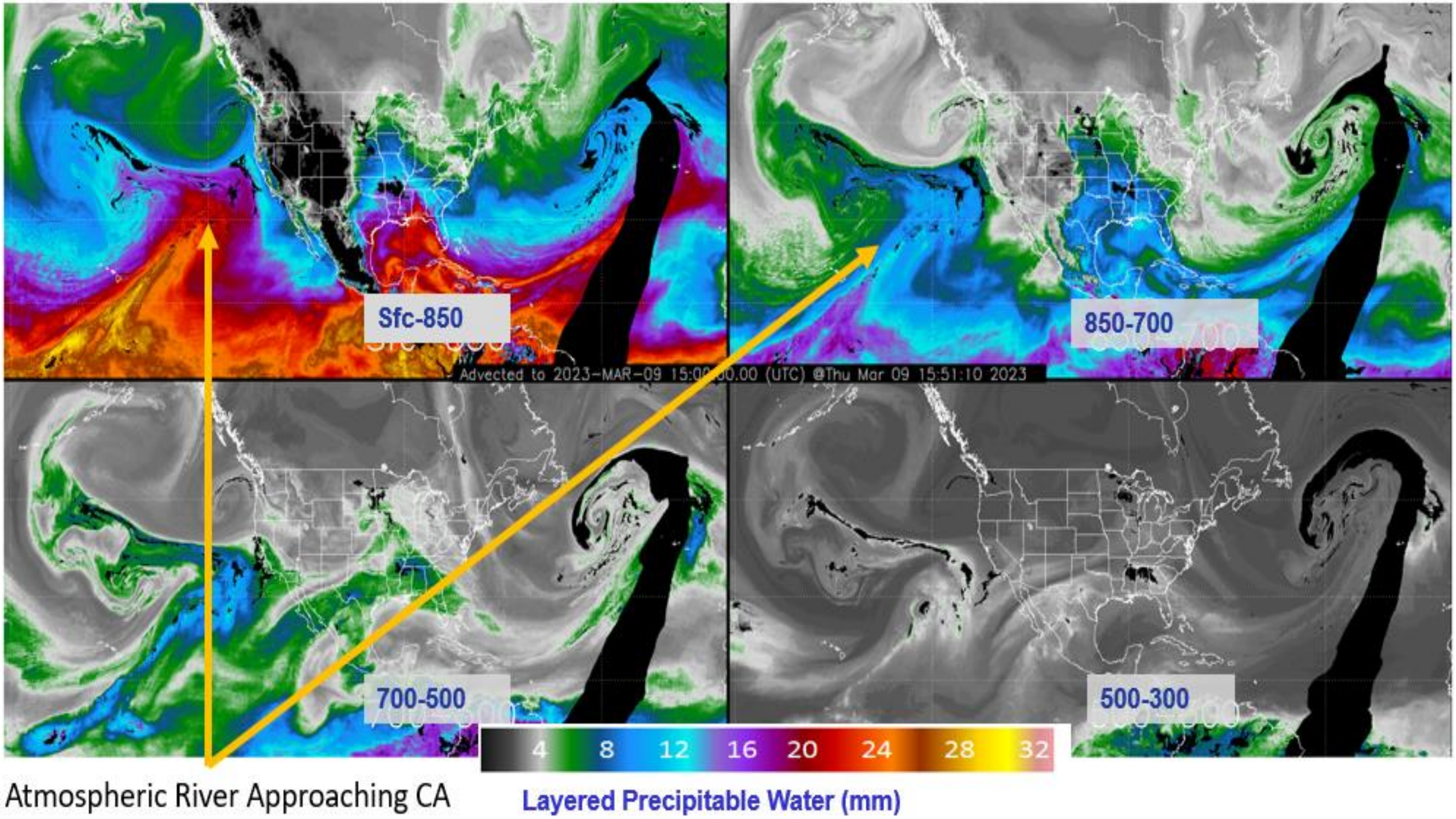
Layered Vapor Transport (kg/m/s)

15 UTC 9 March 2023

- Derived using ALPW and GFS winds
- Work in progress on comparing to commonly used Integrated Vapor Transport (IVT)

Applied Climatology Products for Forecasters

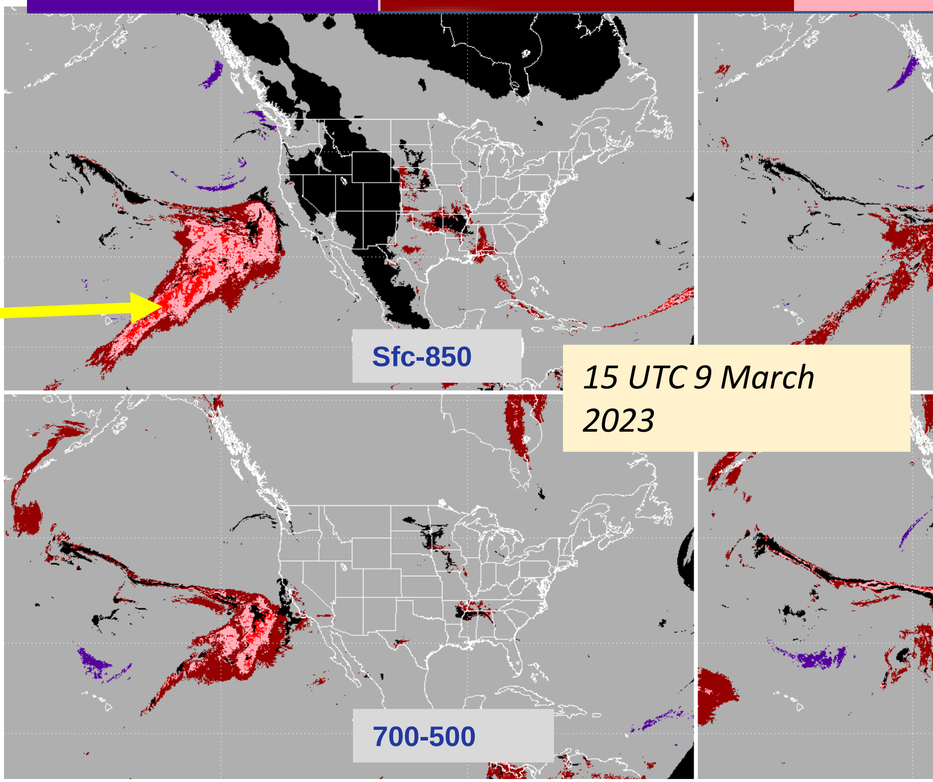
March 9, 2023 California Atmospheric River

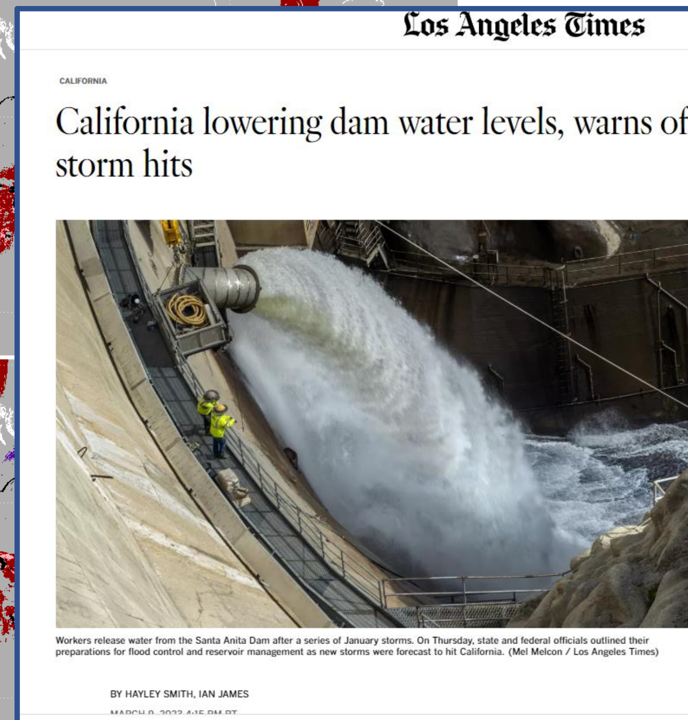


Large Atmospheric River Approaching CA

ALPW Percentile Ranking for 10-year Record

Highest values in record





Los Angeles Times

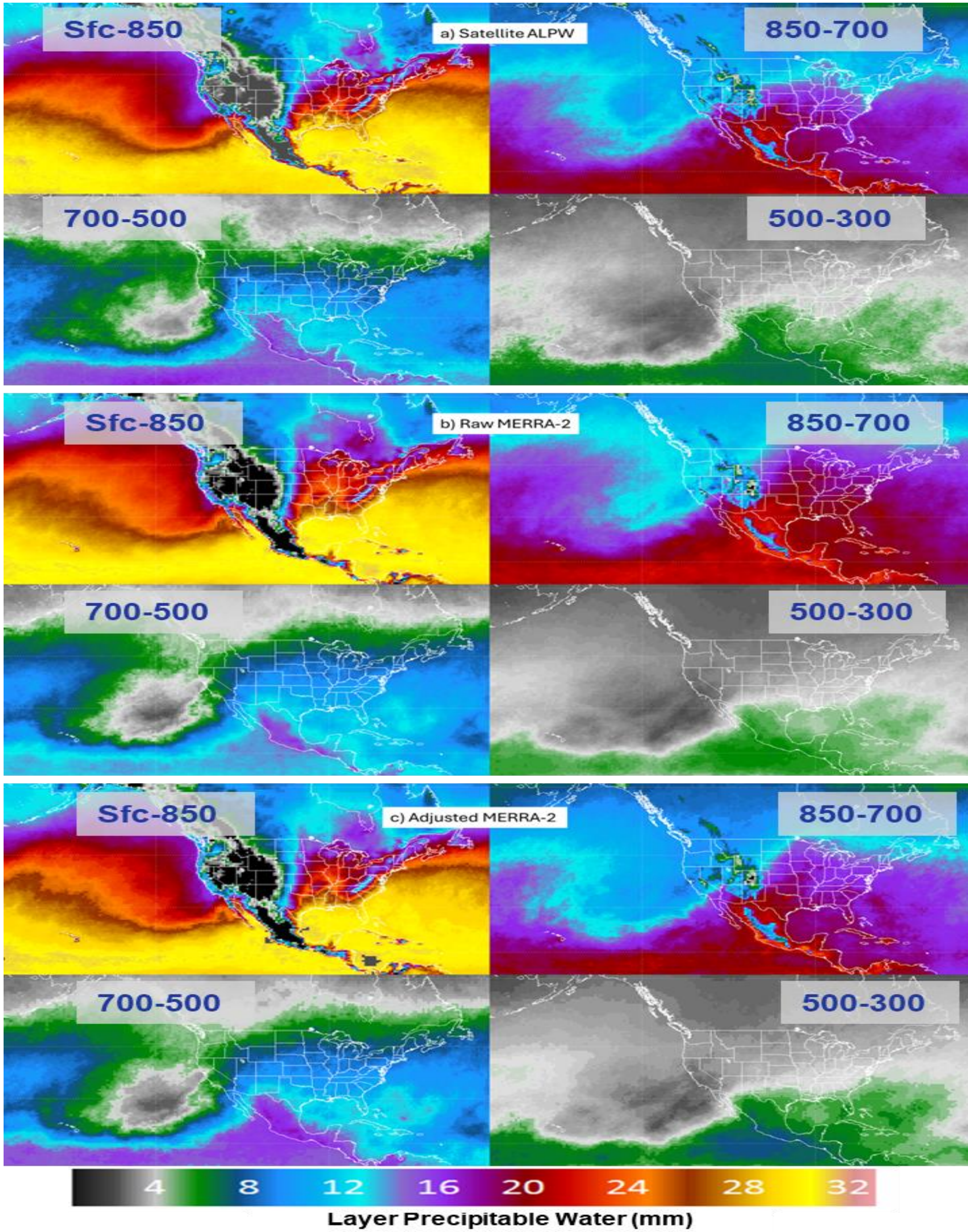
CALIFORNIA

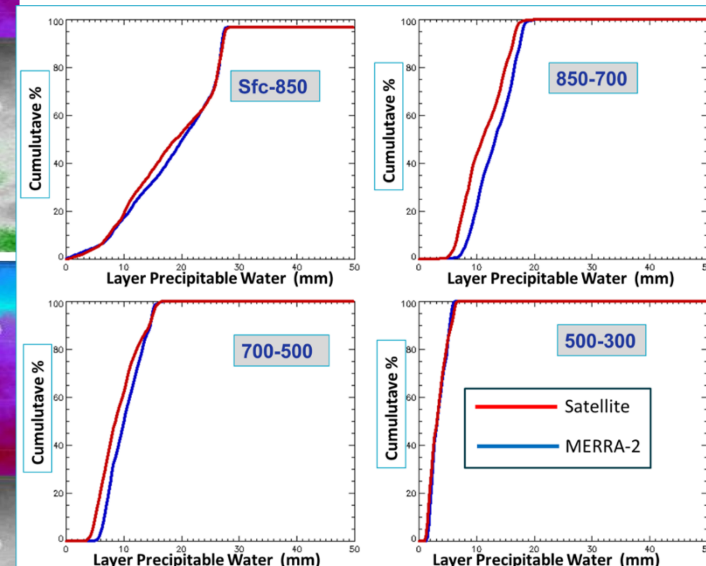
California lowering dam water levels, warns of
storm hits

Workers release water from the Santa Anita Dam after a series of January storms. On Thursday, state and federal officials outlined their preparations for flood control and reservoir management as new storms were forecast to hit California. (Mel Melcon / Los Angeles Times)

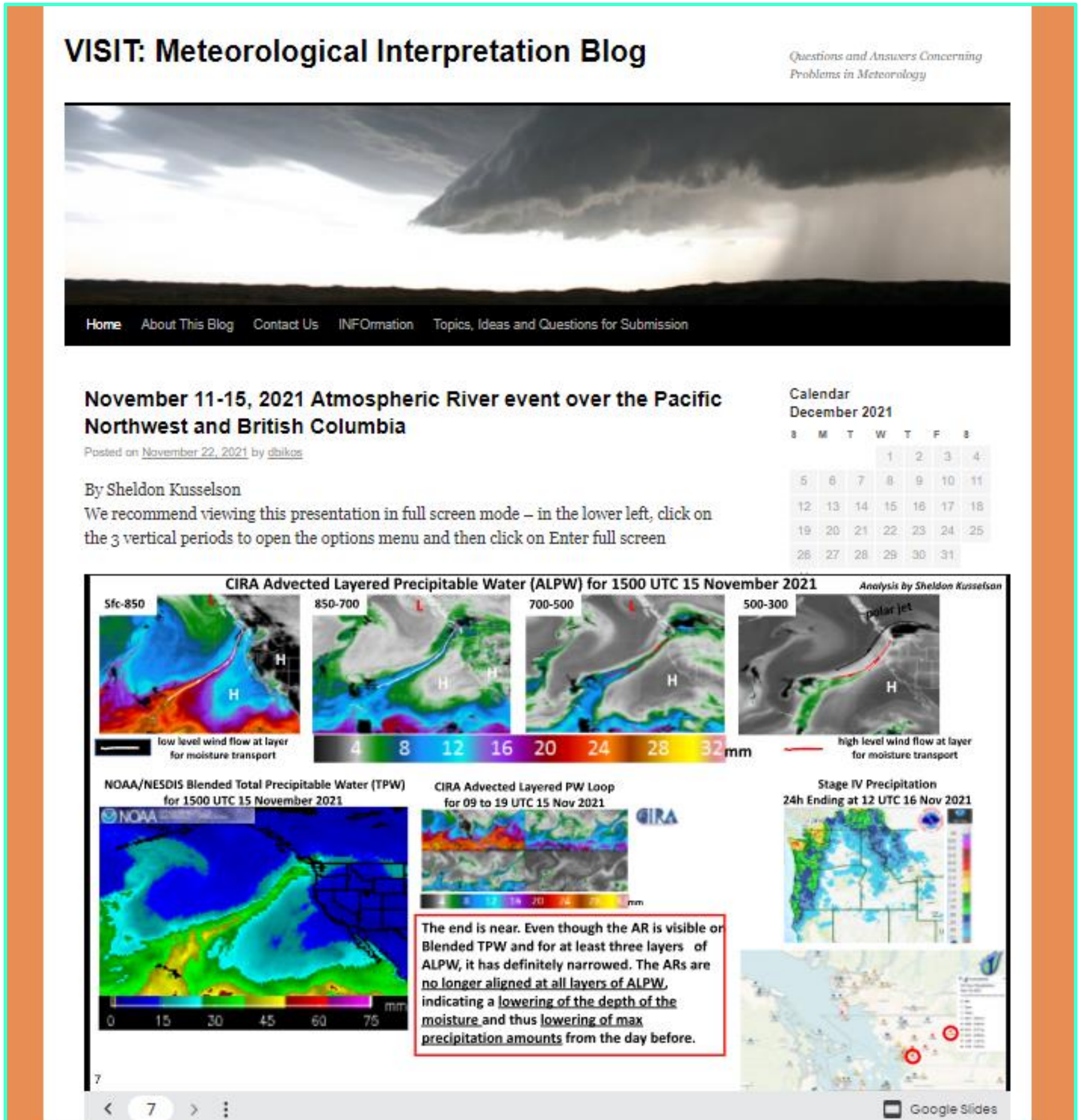
BY HAYLEY SMITH, IAN JAMES

95^{th} percentile
September 2013-2023





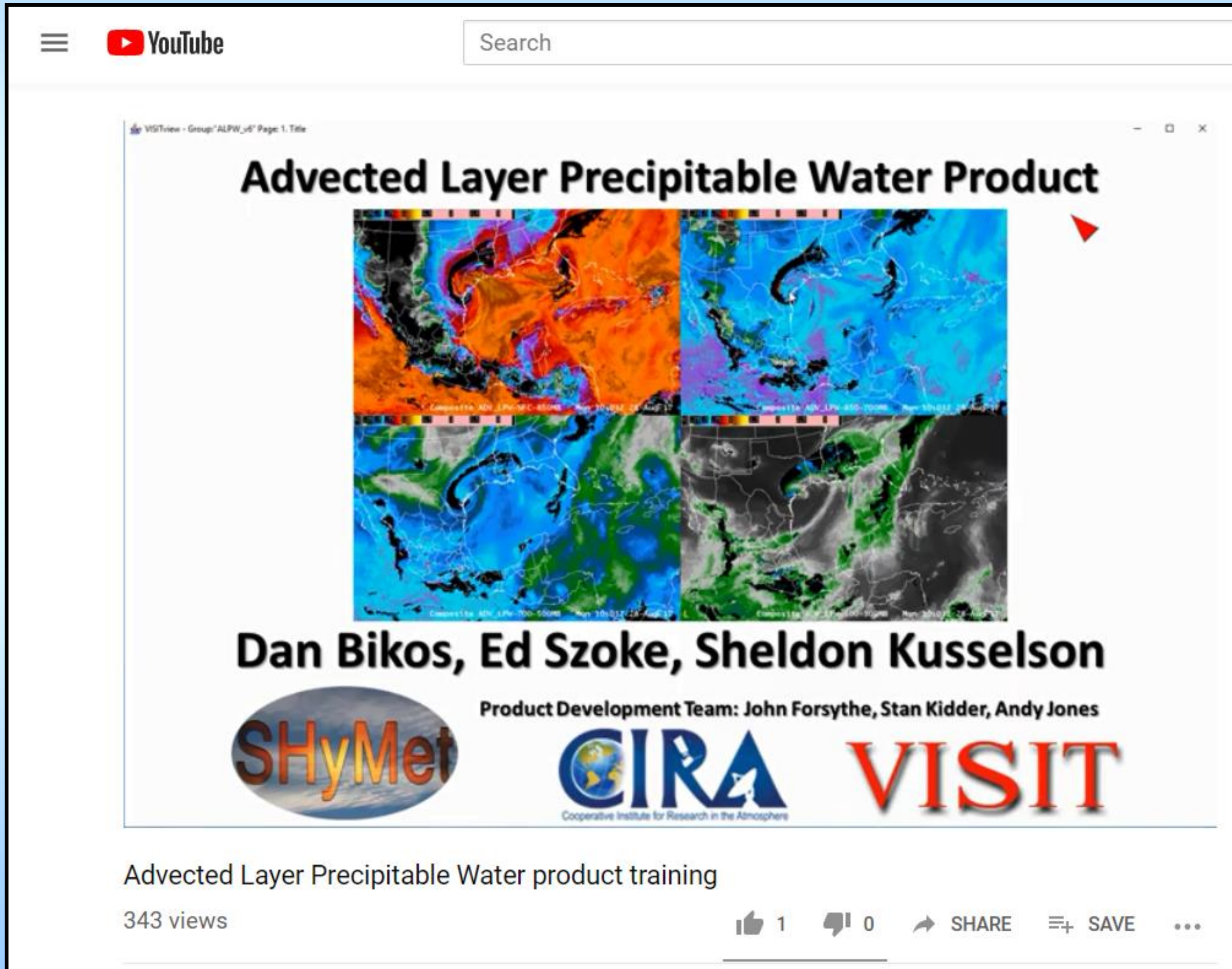
Resources



https://rammb.cira.colostate.edu/training/visit/blog/

ALPW VISIT Training Session Available in Commerce Learning Center.

http://rammb.cira.colostate.edu/training/visit/training_sessions/advected_layer_precipitable_water_product/



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The Operational Use and Assessment of a Layered Precipitable Water Product for Weather Forecasting

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A Multisensor, Blended, Layered Water Vapor Product for Weather Analysis and Forecasting

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Using the Multisensor Advected Layered Precipitable Water Product in the Operational Forecast Environment

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Summary:

- Observationally-driven blended water vapor datasets are useful for forecasters, show “plumbing” of the atmosphere.

- TPW is increasing over oceans ==> extreme precipitation events.

- New ALPW product and upgraded blended TPW available in operations in early 2025.

- Historical records provide forecasters new context for water vapor amounts in advance of flood threats.

- Sheldon Kusselson and Dan Bikos have created <u>many</u> application examples (floods, winter weather...), on VISIT blog.

Links

https://cat.cira.colostate.edu/SPoRT/Layered/Advected/ALPW_Hourly.htm <- ALPW CONUS Hourly

http://cat.cira.colostate.edu/ALPX/ALPW_Percentile/index.html <- LPW 5th, 95, 99th and max percentiles

http://cat.cira.colostate.edu/ALPX/LVT/lvt.htm <- ALPW vapor transport (GFS winds)

http://cat.cira.colostate.edu/ALPX/ADVLUT/ALPX_ADVLUT_212.png <- full resolution global 4-panel image (Large)