Multi-satellite Water Vapor Products at the Weather Climate Interface

John Forsythe*, Stan Kidder, Sheldon Kusselson, Dan Bikos, Natalie Tourville, Jorel Torres (CIRA)

Thanks to many forecasters for collaboration and to the NOAA MiRS team for data!

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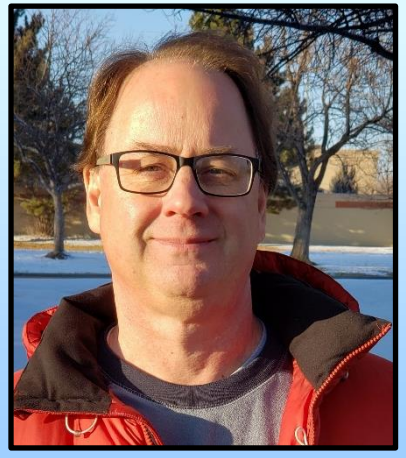
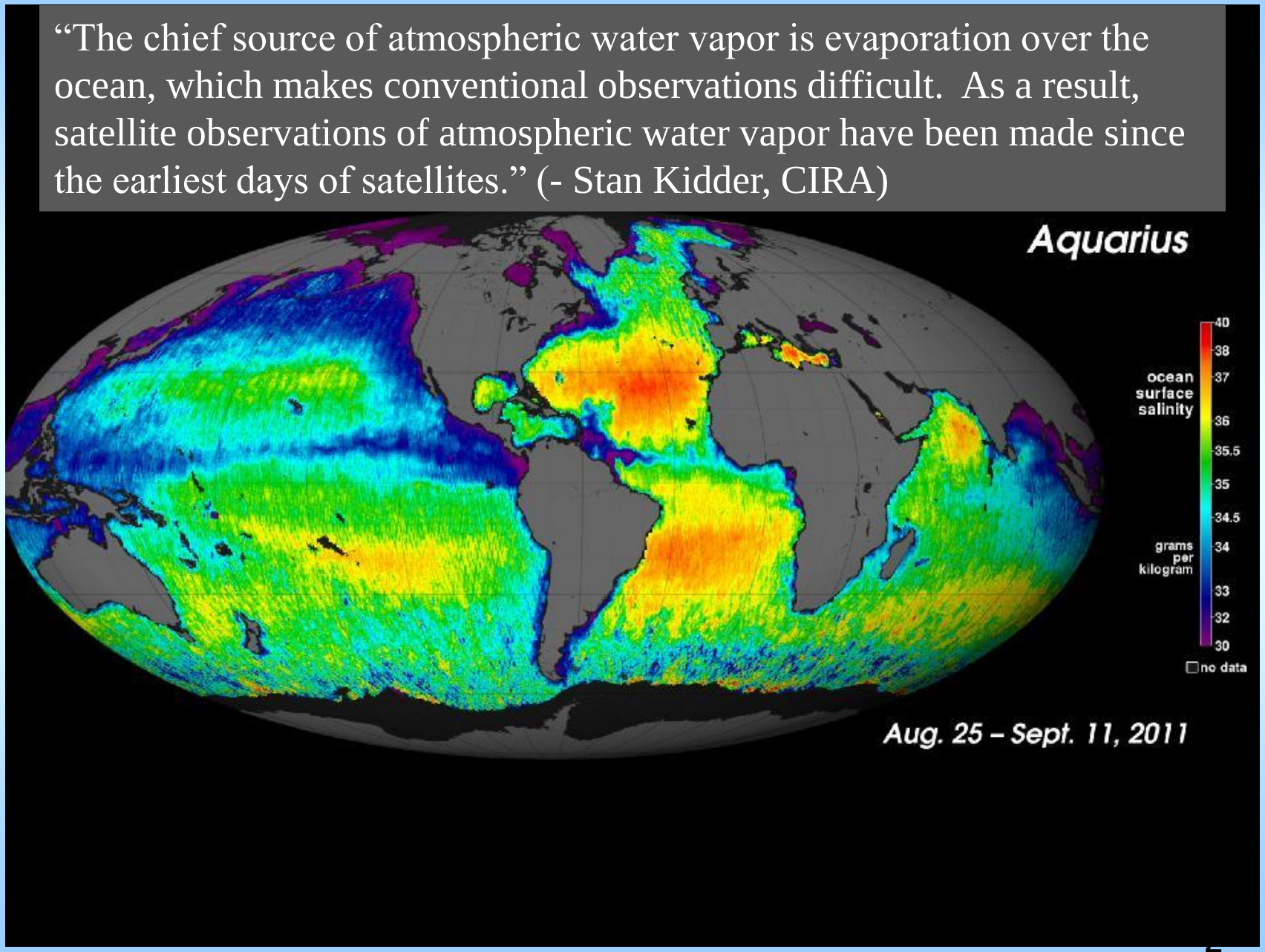


Supported by JPSS Proving Ground and NOAA Climate Program Office

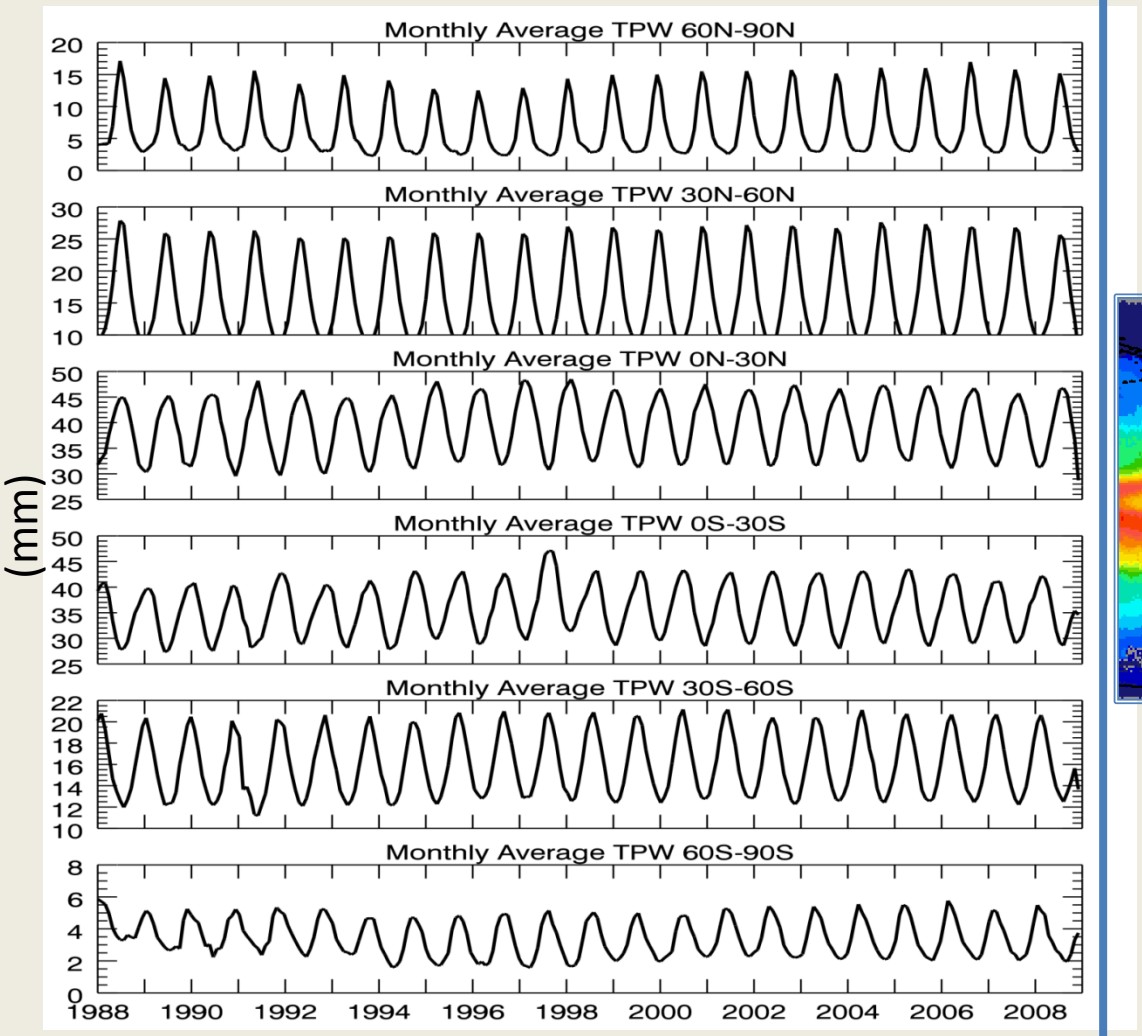
VAWS Seminar, May 29, 2024

Ocean Salinity a Proxy for Evaporation

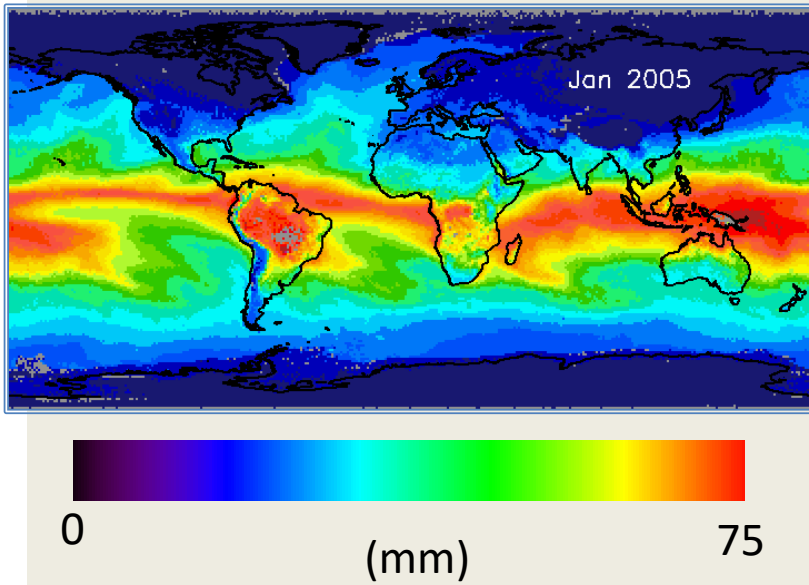
"The chief source of atmospheric water vapor is evaporation over the ocean, which makes conventional observations difficult. As a result, satellite observations of atmospheric water vapor have been made since the earliest days of satellites." (- Stan Kidder, CIRA)



Zonal Averages of Total Precipitable Water(TPW)



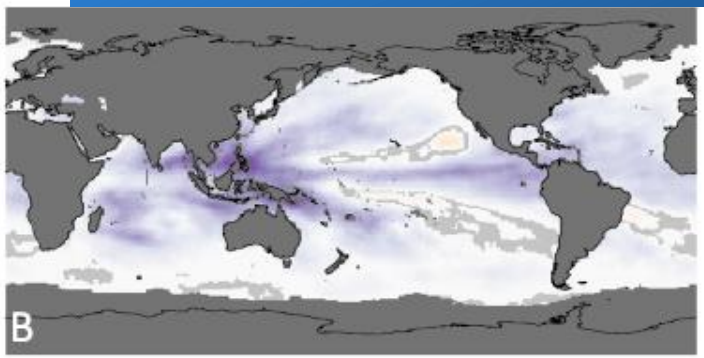
Monthly Mean TPW (mm) from NASA NVAP-M Climate dataset for 2005



- Strong annual cycle is found in all latitude zones, roughly 10% of the mean
- ENSO of 1997-1998 most apparent in 0-30° S

Water Vapor Fuels Climate Change Impacts

- **Global Mean TPW is 26 mm**
- **+1.5% / decade increase over global oceans observed (Mears et al 2018)**
- **Highest I've ever observed is 91 mm (GPS site, Slidell LA, Hurricane Katrina)**



Mears et al, 2018, Earth and Space Sciences

nature COMMUNICATIONS

ARTICLE

https://doi.o

Glob

Oscar Guz

Theoretical rainfall rates been studie general tren observationa Precipitation average TC combined et rate on the Northwester uniform for increases in

npj | Climate and Atmospheric Science

www.nature.com/npjclimatsci

BRIEF COMMUNICATION OPEN

Check for updates

t updated possible age, 1 in 4 tries that

the seasonal recovery of Arctic sea ice

Received: 21 February 2022

Accepted: 5 January 2023

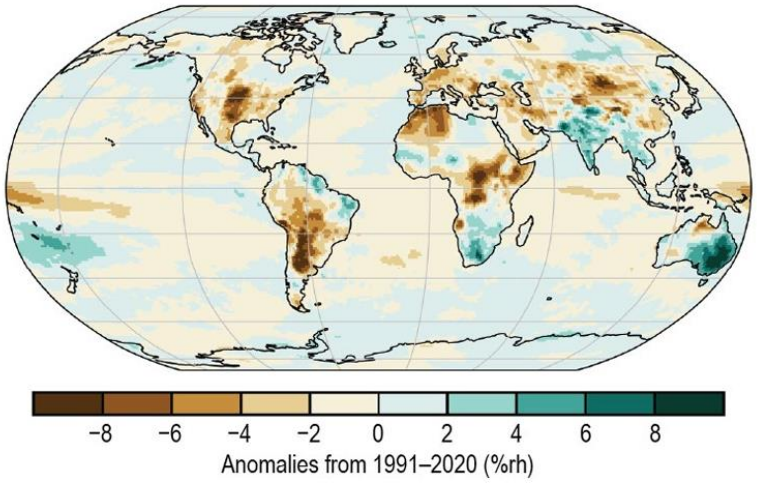
Published online: 06 February 2023

Check for updates

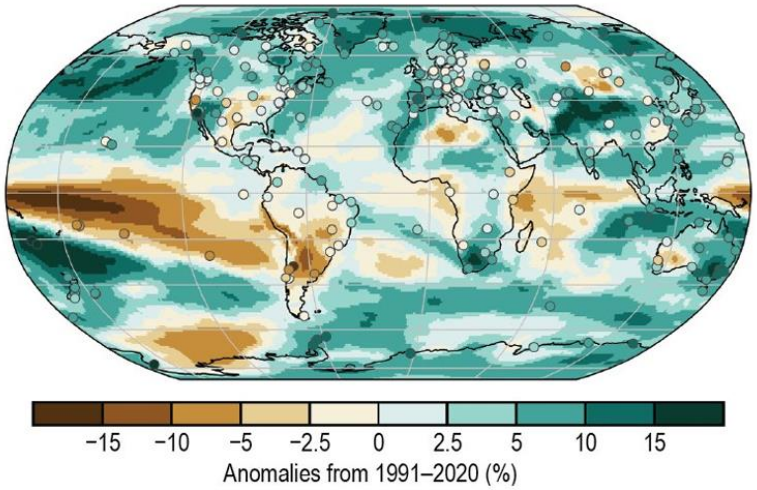
Pengfei Zhang [1], Gang Chen [2], Mingfang Ting [3], L. Ruby Leung [4], Bin Guan [5,6] & Laifang Li [1,7,8]

In recent decades, Arctic sea-ice coverage underwent a drastic decline in 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.

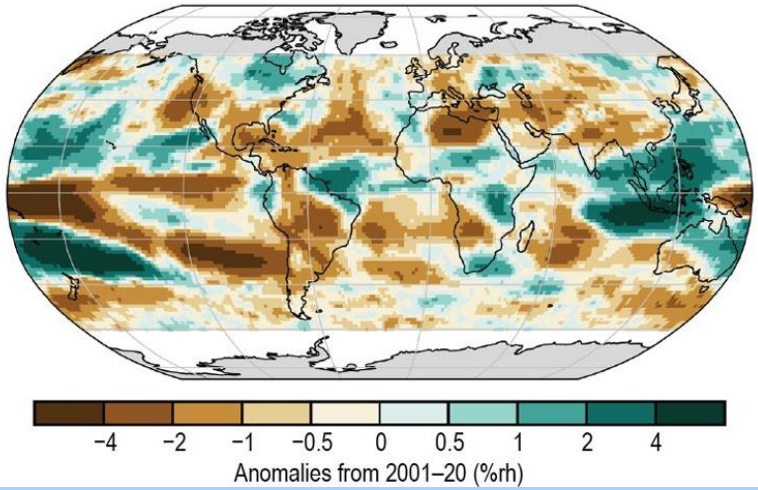
(h) Surface Relative Humidity



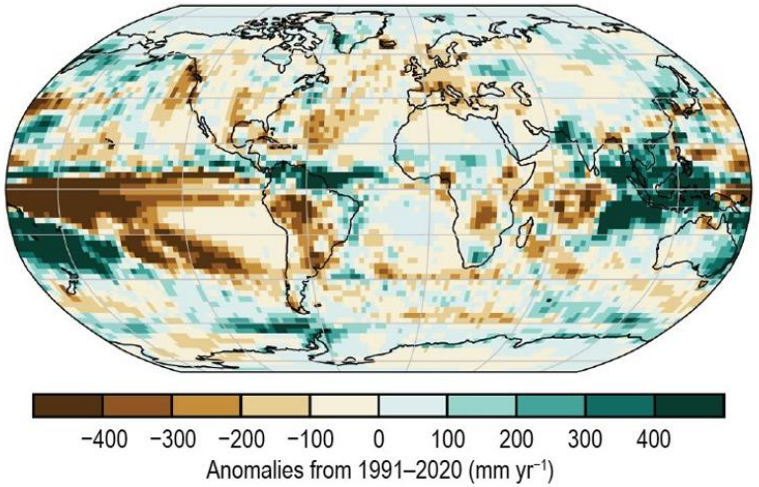
(i) Total Column Water Vapor



(j) Upper Tropospheric Humidity



(k) Precipitation



BAMS State of the Climate Year 2022

"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

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

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

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

- Compared > 3000 Co-op stations to NCEP and NASA MERRA-2 reanalysis from 1949 – present.
- Noted disproportionately large effect on extreme precipitation at higher TPW values

JGR Atmospheres

RESEARCH ARTICLE
10.1029/2023JD039294

Atmospheric Rivers in Southeast Alaska: Meteorological Conditions Associated With Extreme Precipitation

Deanna Nash[1], Jonathan J. Rutz[1], and Aaron Jacobs[2]

[1]Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, University of California San Diego, San Diego, CA, USA, [2]Weather Forecast Office, National Weather Service, Juneau, AK, USA

Key Points:

- Atmospheric rivers occur on ~120 days per year in Southeast Alaska, but ~6 days produce 68%–91% of precipitation days >95th percentile
- In six rural and indigenous Southeast AK communities, 80%–96% of days with extreme precipitation have >75th percentile moisture transport
- Extreme precipitation in Southeast Alaska is more likely during atmospheric rivers with south-southwesterly moisture transport

Correspondence to:
D. Nash,
dnash@ucsd.edu

Citation:
Nash, D., Rutz, J. J., & Jacobs, A. (2024). Atmospheric rivers in Southeast Alaska: Meteorological conditions associated with extreme precipitation. *Journal of Geophysical Research: Atmospheres*, *129*, e2023JD039294. https://doi.org/10.1029/2023JD039294

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This article was corrected on 4 MAR 2024. See the end of the full text for details.

Author Contributions:
Conceptualization: Deanna Nash, Aaron Jacobs
Data curation: Deanna Nash

Abstract Extreme precipitation events associated with atmospheric rivers (ARs) trigger floods, landslides, and avalanches that threaten lives and livelihoods in Southeast Alaska. Six rural and indigenous communities (Hoonah, Klukwan, Skagway, Yakutat, Craig, and Kasaan) identified specific needs regarding these hazards and joined the Southeast Alaska Coastlines and People (CoPe) Kutí Hub to address the shared challenge of understanding and predicting these events. This study presents a climatology (1980–2019) of synoptic, mesoscale, and local meteorological characteristics of ARs and heavy precipitation across this region. High-amplitude upper-level patterns across the northeastern Pacific Ocean favor ARs reaching Southeast Alaska, where moisture is orographically lifted, resulting in heavy precipitation. In the six communities, ARs occur 8–15 days per month, yet only 6 AR days per year account for up to 68%–91% of precipitation extremes.

Integrated Vapor Transport (IVT) well-corelated with extreme precipitation in Alaska. Does Layered Vapor Transport (LVT) add any insight for forecasters?

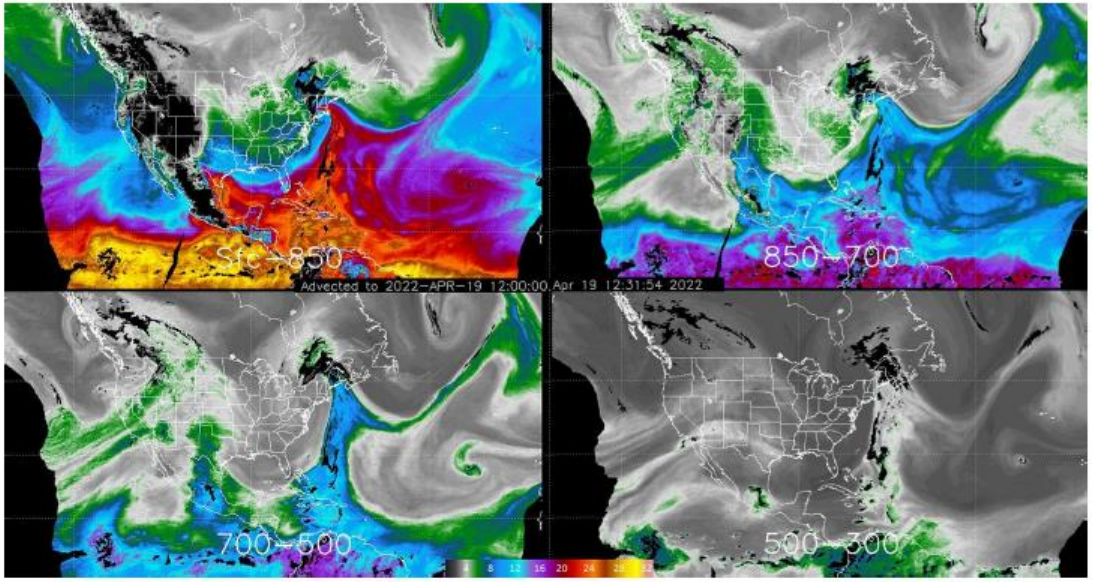
property in a region vulnerable to the impacts of climate change.

Plain Language Summary Extreme precipitation events associated with atmospheric rivers (ARs) trigger floods, landslides, and avalanches that threaten lives and livelihoods in Southeast Alaska. ARs, long and narrow regions of intense water vapor transport, reach Southeast Alaska 8–15 days per month, yet only six ARs per year account for up to 91% of precipitation extremes. This study shows that ARs that result in extreme precipitation in six rural and indigenous communities (Hoonah, Klukwan, Skagway, Yakutat, Craig, and Kasaan) are more likely to have stronger moisture transport, and that the direction of the moisture transport plays a role in precipitation outcomes in each community. Coastal communities like Yakutat experience higher

FEATURE 4

Inspecting the Atmosphere's "Plumbing" With Multi-satellite Water Vapor Products

Flooding is destructive to humans and the natural environment. Flood waters can destroy wildlife habitats, devastate crops and livestock, and spread debris and pollutants far and wide. Every year, flooding damages critical infrastructure, like roads and hospitals, and causes property damage. It impacts public health by disrupting water supplies and sewage systems, spreading infectious disease, and displacing people from their communities. Flood events can cause psychological trauma, injury, and even death. In fact, flooding is the second highest cause of weather-related fatalities in the U.S. (based on a 10-year average from 2011 to 2020).



The Advected Layered Precipitable Water (ALPW) product, derived from Microwave Integrated Retrieval System (MiRS) retrievals of moisture and temperature from six polar orbiting satellites, offers a 4-dimensional look at water vapor. Shown here is the ALPW (mm) hourly loop for April 19, 2022 at 12:31:54. Source: Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University.

These impacts add up. From 1980 to 2020 flooding in the U.S. caused more than 3,750 fatalities and $165.8 billion in losses, and annual damages are on the rise—a recent analysis estimates that losses will increase to $40.6 billion per year by 2050. In 2019, a historic flooding event across the Missouri, Arkansas, and Mississippi River basins cost $20 billion alone.

These events are not going away. Satellite data shows that the amount of water vapor in the atmosphere fueling heavy rain is increasing globally at a rate of about 1.5% per decade as the climate warms (based on the 30-year passive microwave record of Total Precipitable Water over the ocean). Supporting this are decades of research that suggest an increase in extreme rainfall events from rising global surface temperatures and worsening storm surge from sea level rise. Case in point: 2021 was the fifth consecutive year

Source: NOAA National Severe Storms Laboratory, https://www.nssl.noaa.gov/education/svrwx101/floods/.

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.

Two Blended Satellite Water Vapor Products for Forecasters

Product	Operational?	Inputs	Details
Blended TPW and TPW anomaly	**Yes (since 2009)**	**Microwave retrievals from 7 spacecraft.** **~ 400 surface GPS stations each hour.** **No GOES-16/18 currently**	**Hourly** **16 km near-global** **Polar data non-advected**
Advected Layered Precipitable Water	**No*** ***CIRA distributes in NRT to WPC, NHC, and 27 WFO's** ***Should become operational late summer 2024**	**MiRS retrievals from 5 polar orbiters**	**Hourly** **Four layers:** **sfc-850 mb** **850-700** **700-500** **500-300 mb** **16 km spatial**

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 49, NO. 9, SEPTEMBER 2011 3249

MiRS: An All-Weather 1DVAR Satellite Data

Key Feature: MiRS does not use a dynamic NWP model and retrieves in cloudy conditions

Fuzhong Weng, Ralph Ferraro, Thomas J. Kleespies, and Huan Meng

NOAA operational MiRS retrieval system used to produce TPW and LPW

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

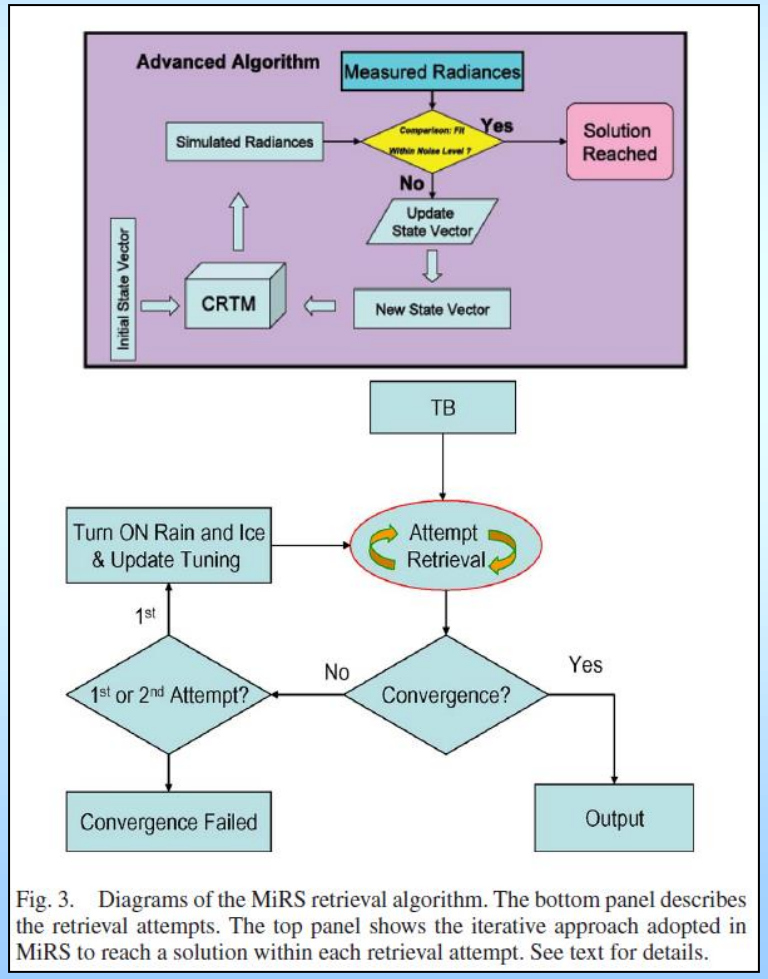
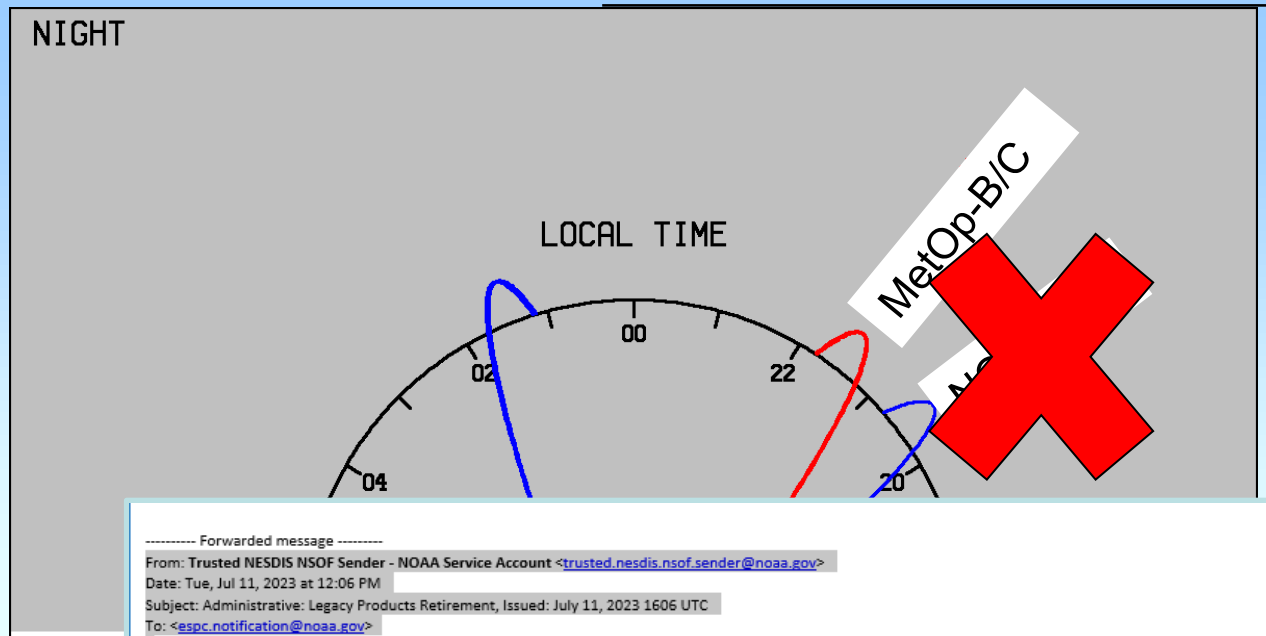


Fig. 3. Diagrams of the MiRS retrieval algorithm. The bottom panel describes the retrieval attempts. The top panel shows the iterative approach adopted in MiRS to reach a solution within each retrieval attempt. See text for details.

Current ALPW Constellation – 5 Satellites



The battle to keep older spacecraft operating goes on...

---------- Forwarded message ---------
From: **Trusted NESDIS NSOF Sender - NOAA Service Account** <trusted.nesdis.nsof.sender@noaa.gov>
Date: Tue, Jul 11, 2023 at 12:06 PM
Subject: Administrative: Legacy Products Retirement, Issued: July 11, 2023 1606 UTC
To: <espc.notification@noaa.gov>

Topic: Legacy Products Retirement

Date/Time Issued: July 11, 2023 1606 UTC

Product(s) or Data Impacted: See details below

Date/Time of Initial Impact: April 3, 2024

Date/Time of Expected End: Permanent

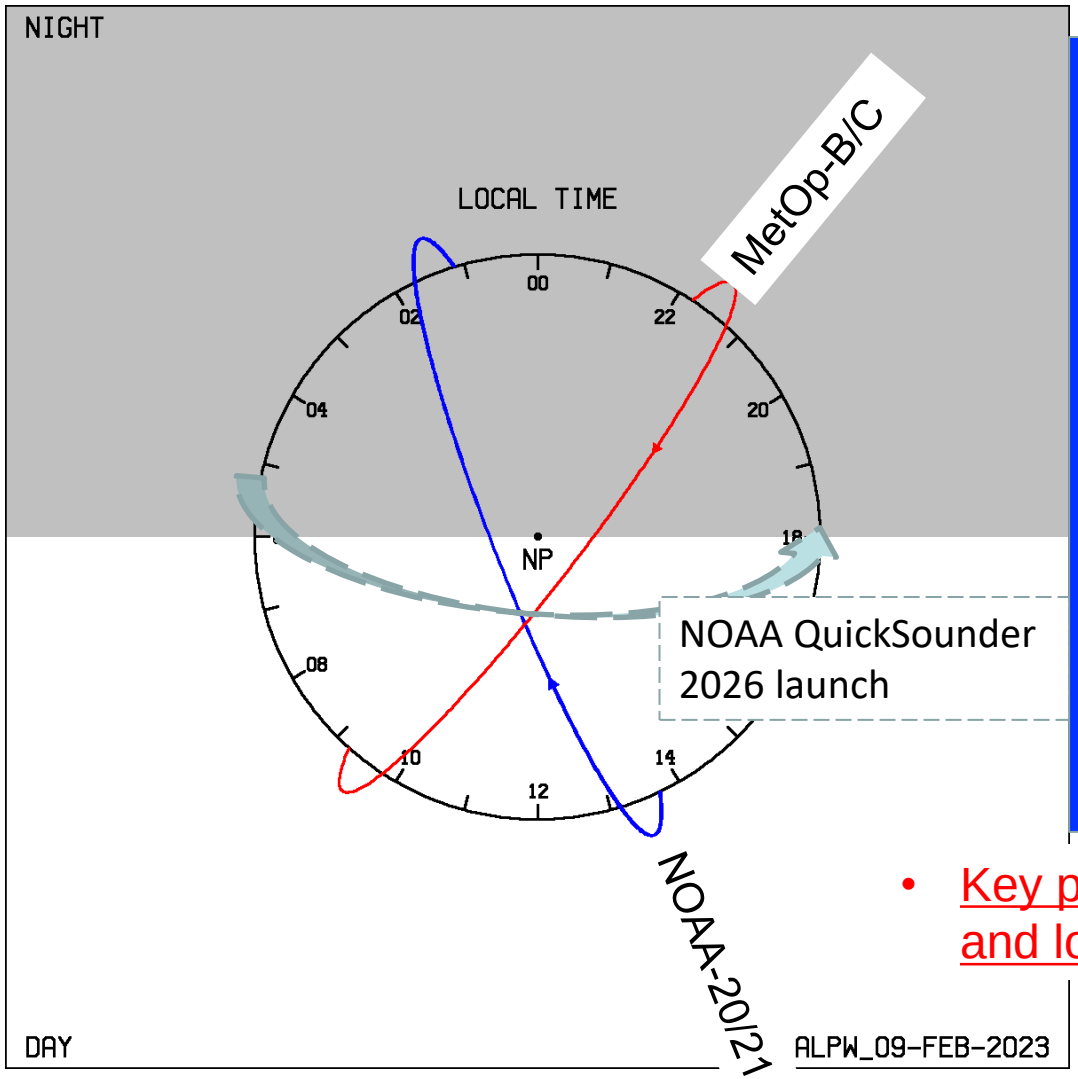
Details/Specifics of Change:

ESPC plans to terminate the legacy satellite capabilities for the following products (see table below) on April 3, 2024.

NESDIS will collect user feedback for at least 30 days following the issuance of this notification. If you have any concerns, please provide your feedback and comments to the corresponding Product Area Leads (PALs) (contact info listed in the table below) and User Services via email: (spsd.userservices@noaa.gov) by August 31, 2023. User feedback will be evaluated by PALs and the NESDIS Satellite Products and Services Review Board (SPSRB).

Algorithms/Products	Data Source to be Retired	Existing Missions /Mitigation	PALs (POC)
Microwave Integrated Retrieval System (MIRS)	NOAA 19, DMSP 17/18	SNPP and N20, Metop-B/C and GPM MIRS Products	liqin.ma@noaa.gov
Blended Hydrometorological Products - Blended Rain Rate & Blended TPW	NOAA 19, DMSP 17/18 MIRS	SNPP, N20,Metop-B/C, GPM, GCOM-W1	liqin.ma@noaa.gov
Ensemble Tropical Rainfall Potential (eTRaP)	NOAA 19, DMSP 17/18 MIRS	MetOp-B/C, GOES-16, GOES-17/18, METEOSAT-9/11,Himawari-8/9, S-NPP, NOAA-20,GCOM-W,GPM	Aiwu.Li@noaa.gov
AVHRR Cloud Drift Polar Winds	NOAA 15/18/19	SNPP and N20 VPW (NDE) Metop-B/C AVHRR Winds (NCCF)	Hongming.Qi@noaa.gov
AMSU TC	NOAA 19 MIRS	MetOp-B/C AMSU	Aiwu.Li@noaa.gov
Ocean Heat Content	SARAL	JASON-CS/MF Sentinel-6A Poseidon 4	David.Donahue@noaa.gov

Advection Fills in Between Satellite Overpasses



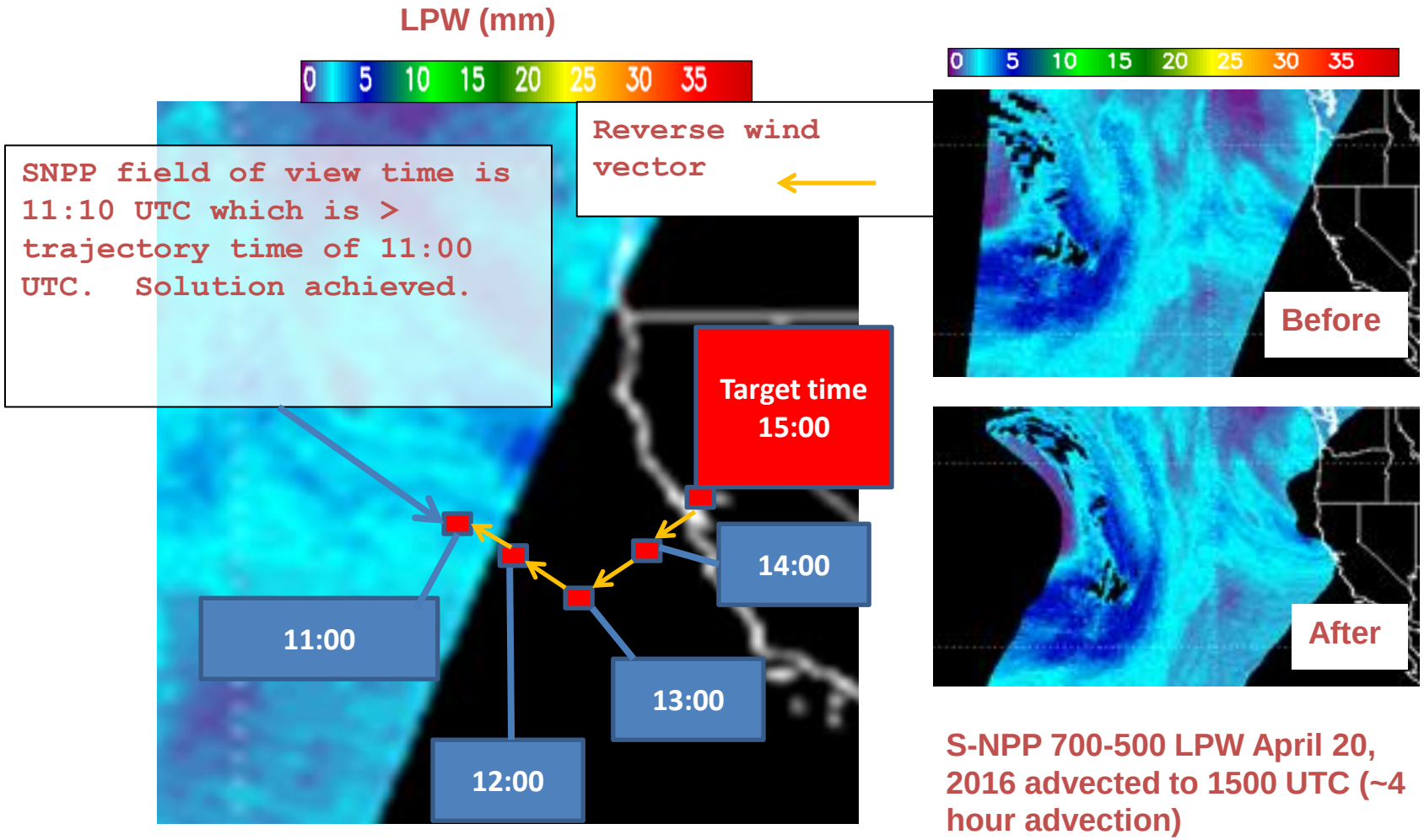
NOAA QuickSounder
2026 launch

Polar MiRS constellation when ALPW operations commence (expect late summer 2024)

- QuickSounder will fill a key gap
- Currently, 9 hour reachback window used for each hourly analysis
- SmallSats in other planes welcome!

- Key point – undesirable periods of high and low sampling throughout the day

Schematic of how the back-trajectory method works for advection

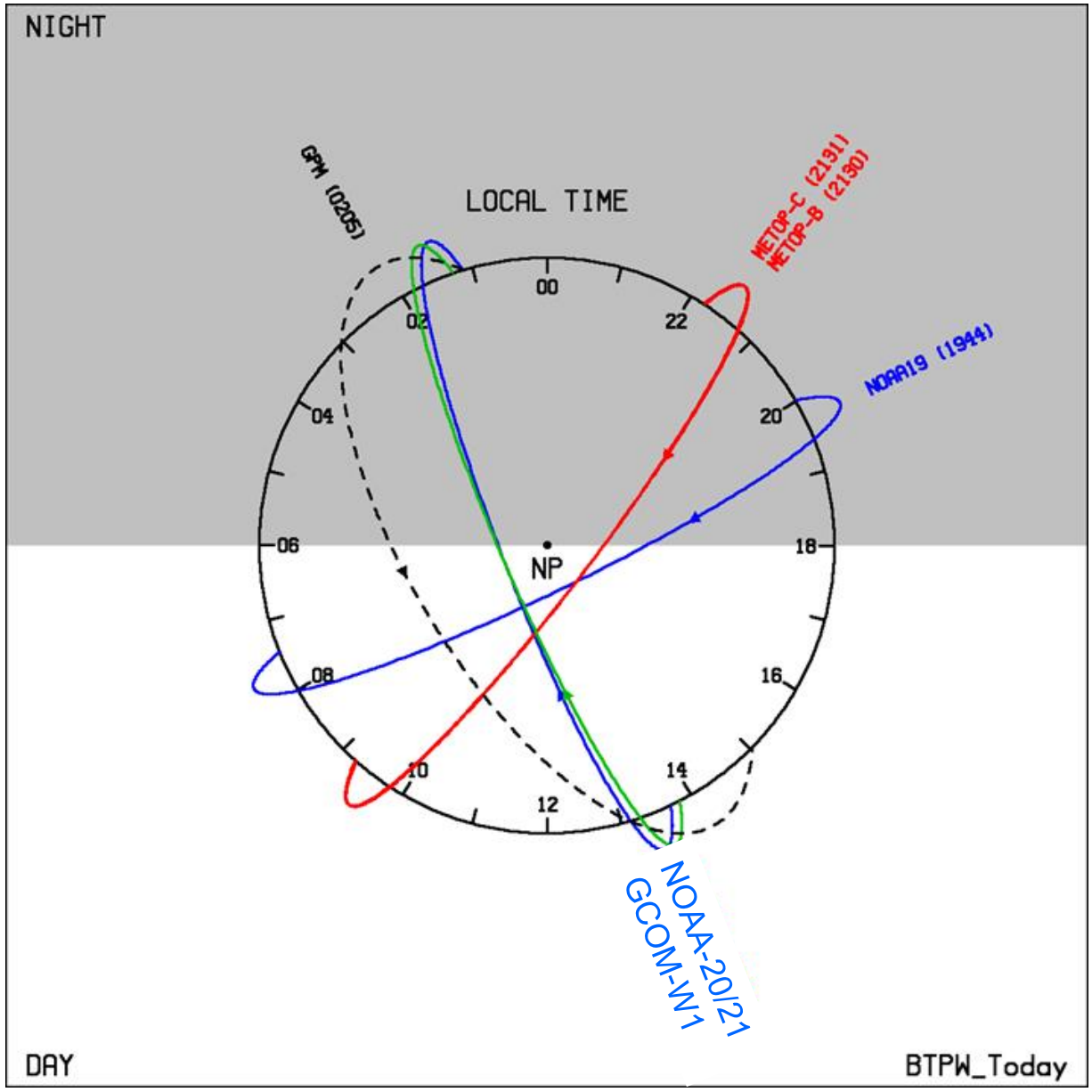


S-NPP 700-500 LPW April 20, 2016 advected to 1500 UTC (~4 hour advection)

Winds are from the GFS

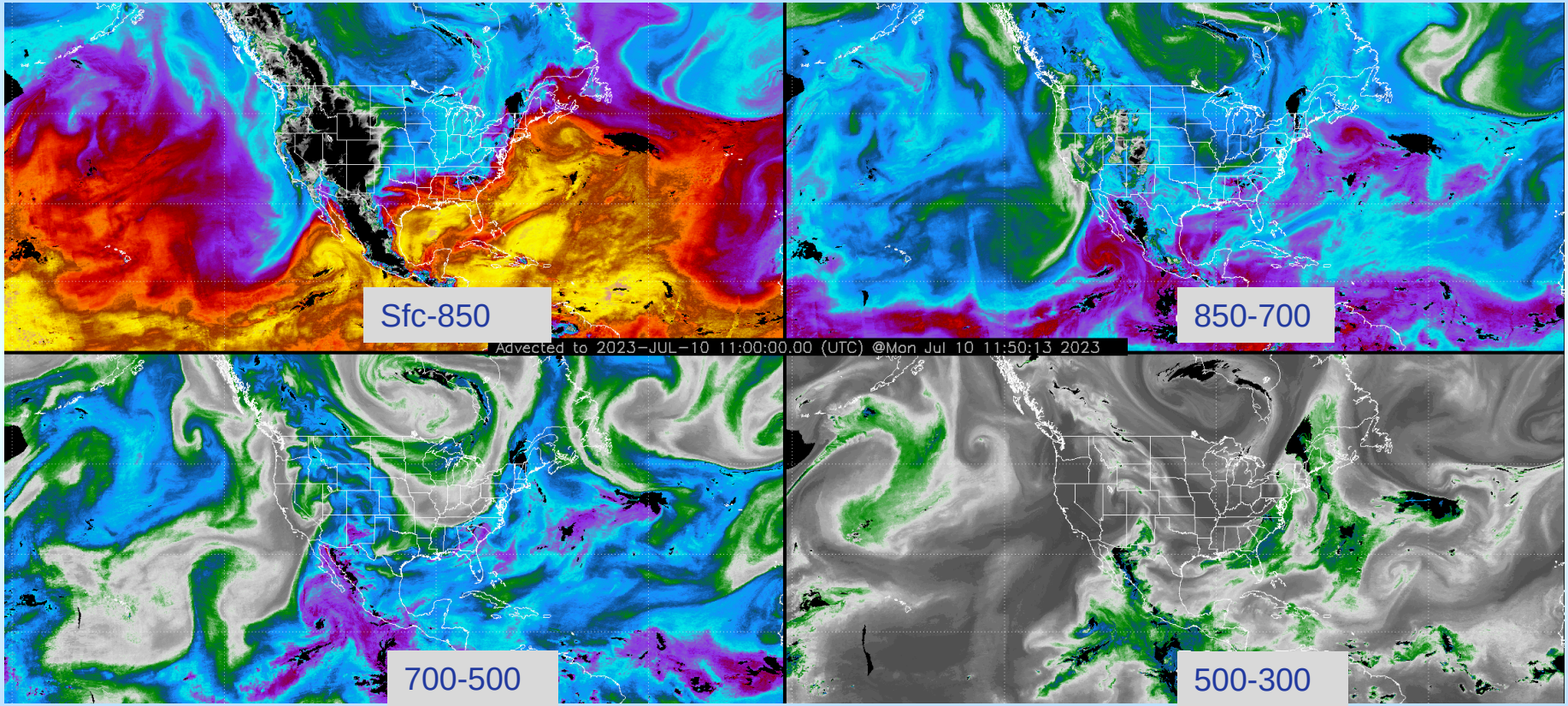
Gitro et al. JOM 2018

Current Blended TPW Leo Constellation



A Weather Product: Hourly Advected Layer Precipitable Water (ALPW)

- 5 satellites with microwave sensors, MiRS retrieval system, GFS winds
- Transitioning to NWS operations in 2024
- MiRS can be run for both weather and climate applications



New England Flood (10 July 2023)

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

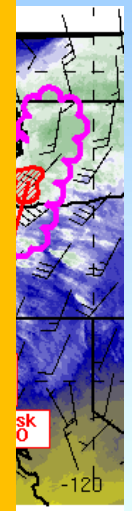
ALPW products have proven to be a very useful diagnostic tool at WPC for operational forecasters at WPC's Quantitative Precipitation Forecast (QPF), Rainfall Hazards and MetWatch desks...

...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

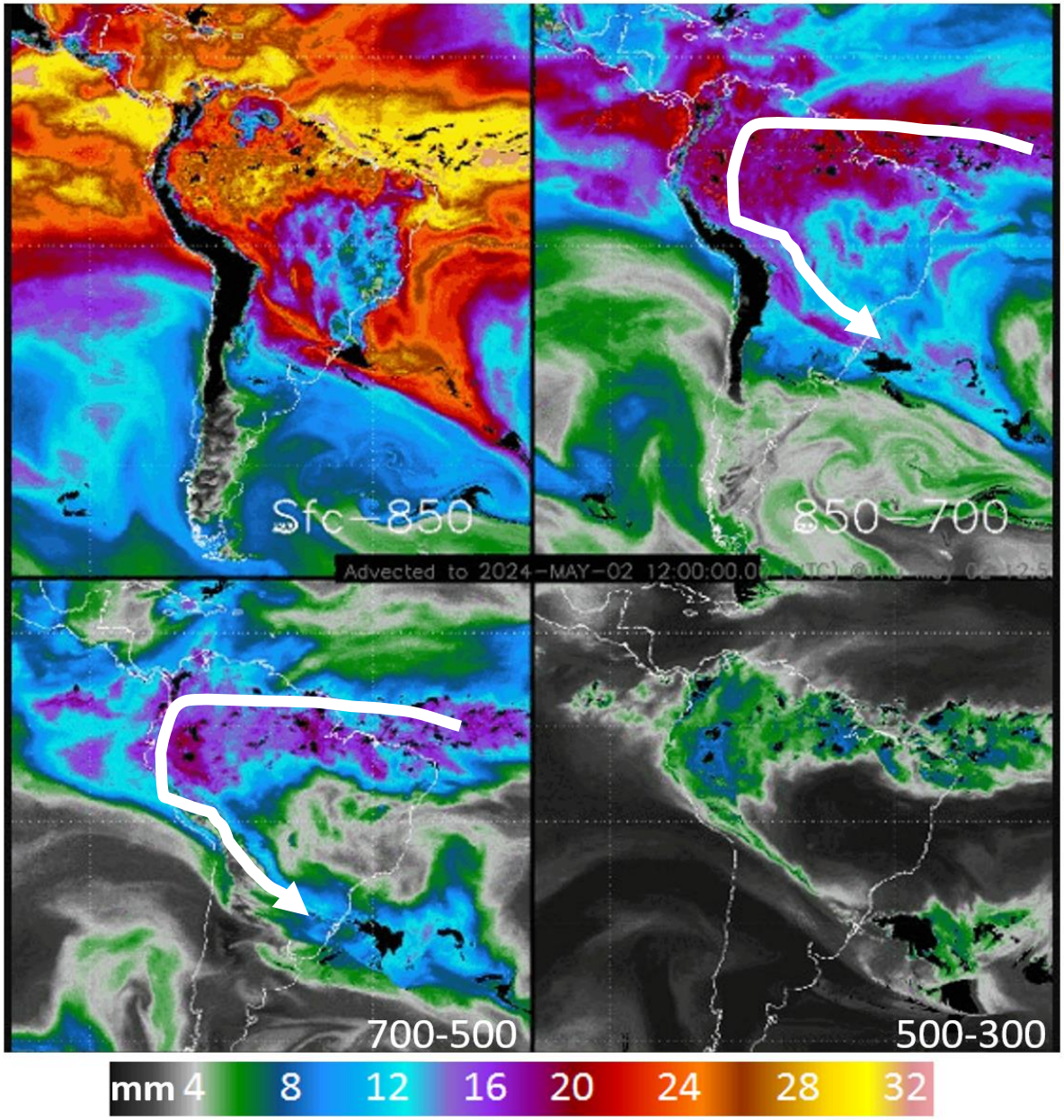


latitude (arcing northeast to about halfway between Hawaii and California)... This level of tropospheric
moisture is also at or above the max moving average of the
associated OAK sounding climatology.

ALPW reveals long-distance trajectories of water vapor for heavy precipitation.

Brazil floods early May 2024.

Main moisture source is tropical Atlantic.



SmallSat missions with microwave sensors for water vapor:

- **NASA TROPICS (4 satellites launched, data not released)**
- **NASA INCUS (~2025) – One MW radiometer**
- **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.**

Status of Blended TPW and ALPW for Operations

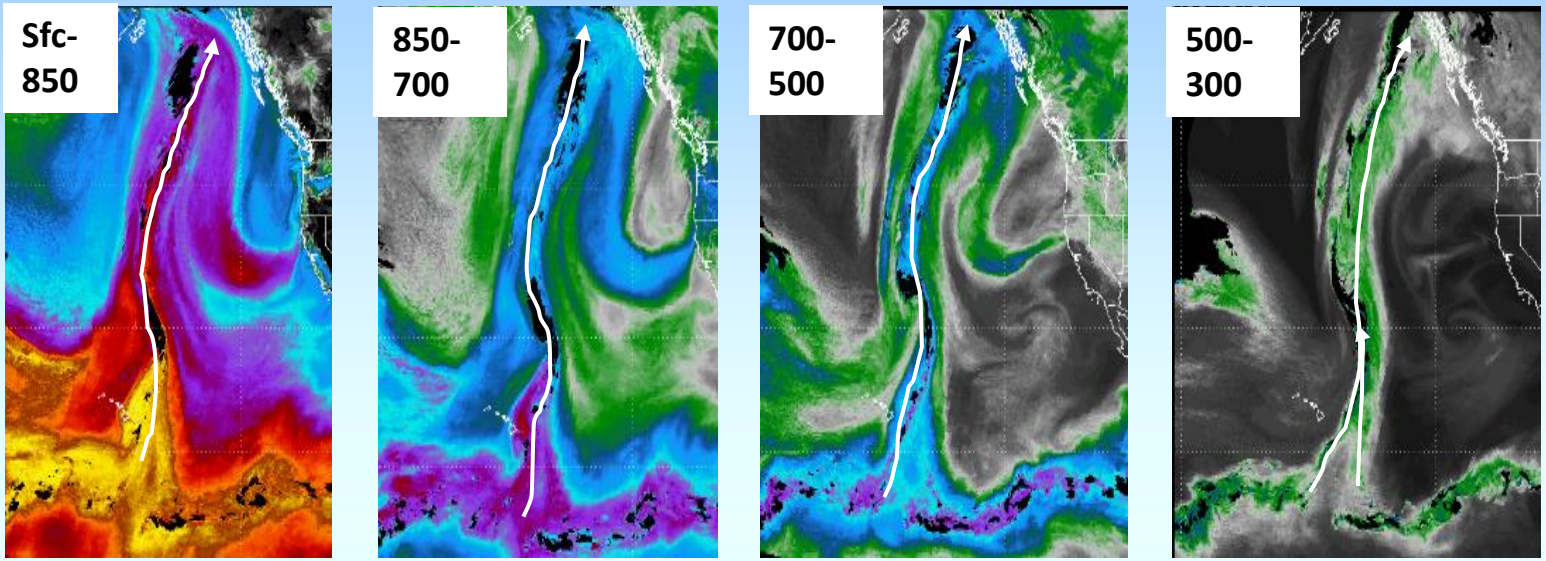
- ALPW is running in the NESDIS Common Cloud Framework (NCCF). **Should become operational in late Summer.**
- In the interim, CIRA distributes hourly ALPW in AWIPS-2 format in NRT to 27 WFO's and NHC, WPC.
- Blended TPW became operational in 2009.
- Operational Blended TPW enhancements ("V4.0") **should become operational in second half of 2024** include:
  - GOES East/West TPW in clear skies
  - MIMIC (Tony Wimmers CIMSS) advected LEO microwave TPW
  - GPS data over CONUS with more limited extrapolation
  - Always seeking more GPS networks, any in Alaska?

Cooperative Institute for Research in the Atmosphere

Alaska ALPW Examples

One of the first cases: Atmospheric Rivers of High Concentrated Moisture into Alaska at 4 layers For Excessive Rainfall & Flooding – 26-27 October 2017

CIRA/Colorado State University Advected Layered Precipitable Water (ALPW) for 18 UTC 26 October 2017

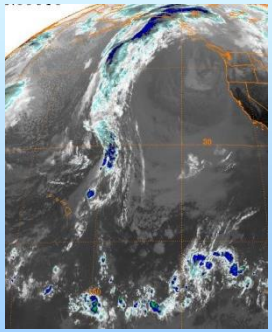


Avg Wind flow at layer

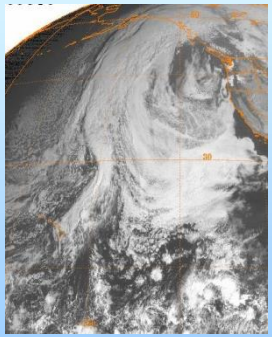
18 UTC 26 October 2017

Juneau, AK Total Rainfall 26-27 October 2017 = 3.37”

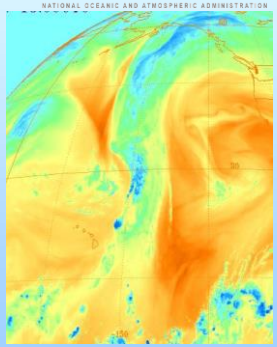
Long fetch moisture advection/transport along atmospheric river of moisture at 4 layers;Moist boundary also provides the focus for excessive rains



GOES-15 IR

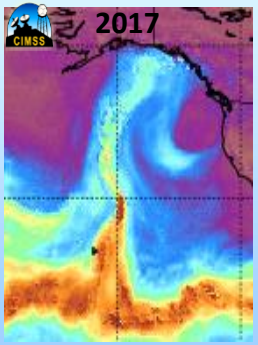


GOES-15 VIS

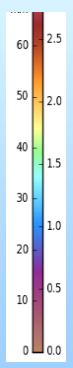


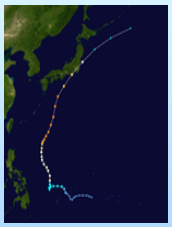
GOES-15 Water Vapor

18 UTC 26 October 2017



CIMSS MIMIC TPW2.0



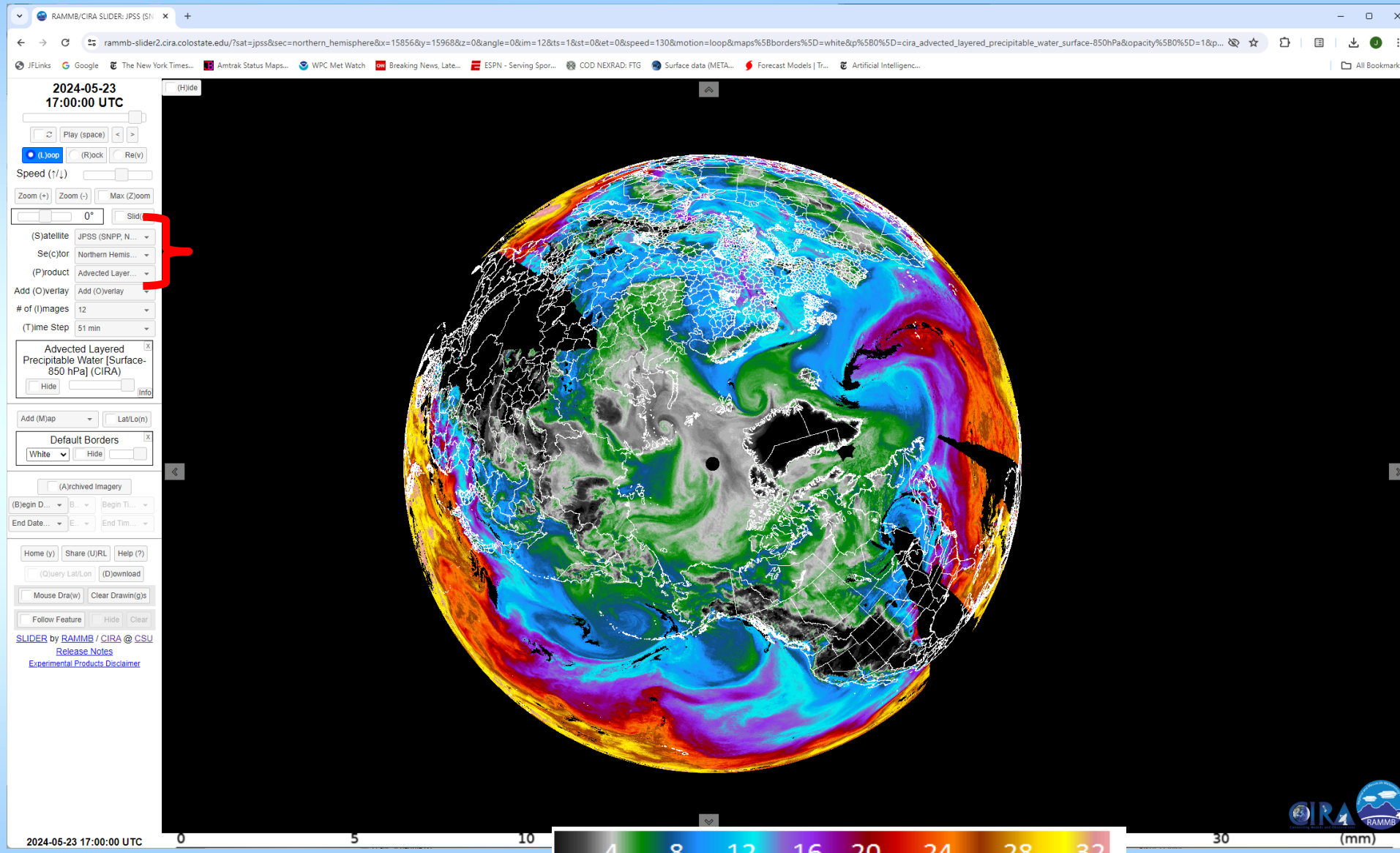


Helped along by the remnants of Typhoon Lan

Photos by Adelyn Baxter/KTOO)

Analysis Prepared by Sheldon Kusselson

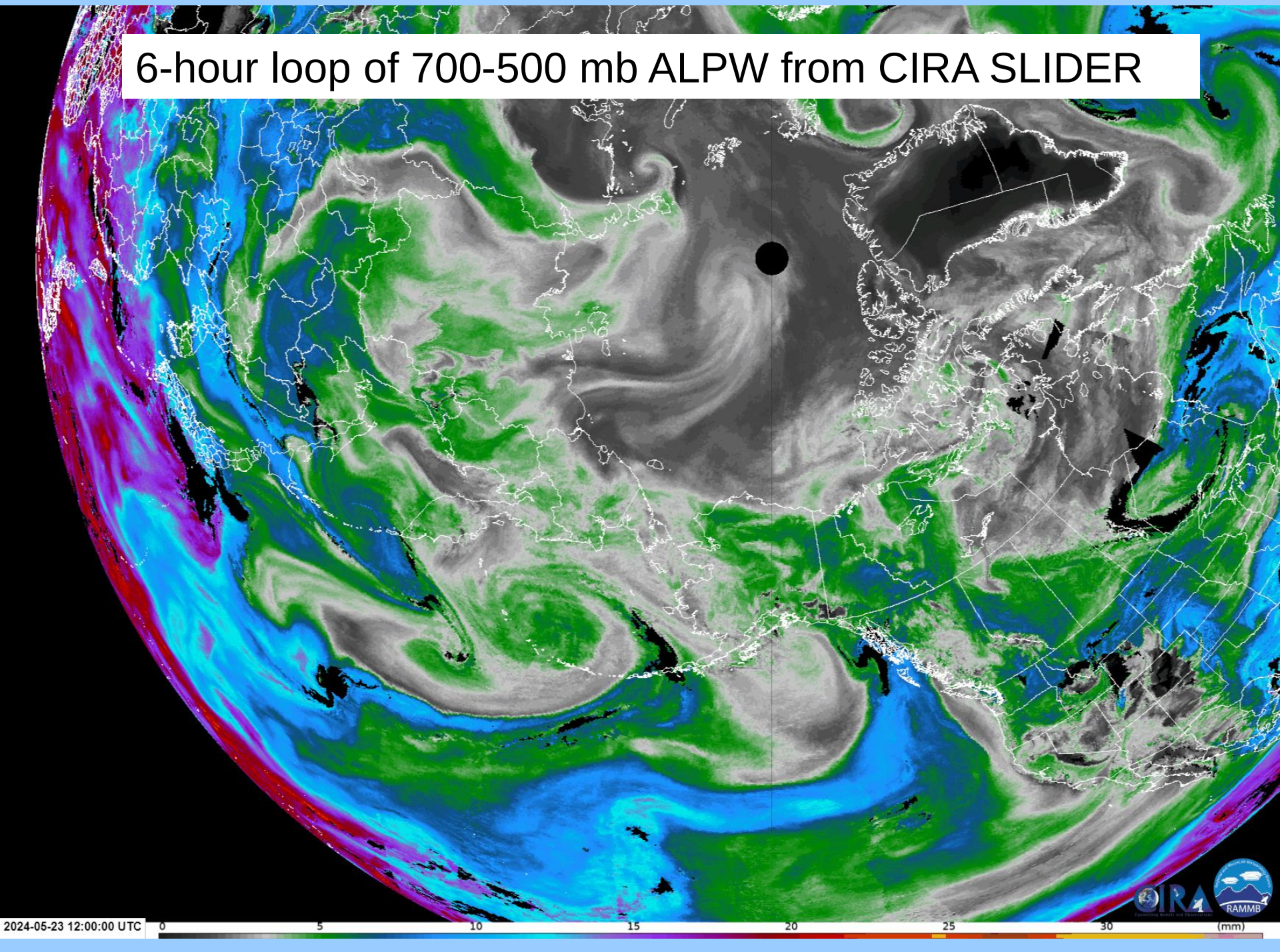
Polar view of Blended TPW and ALPW available at https://rammb-slider.cira.colostate.edu/

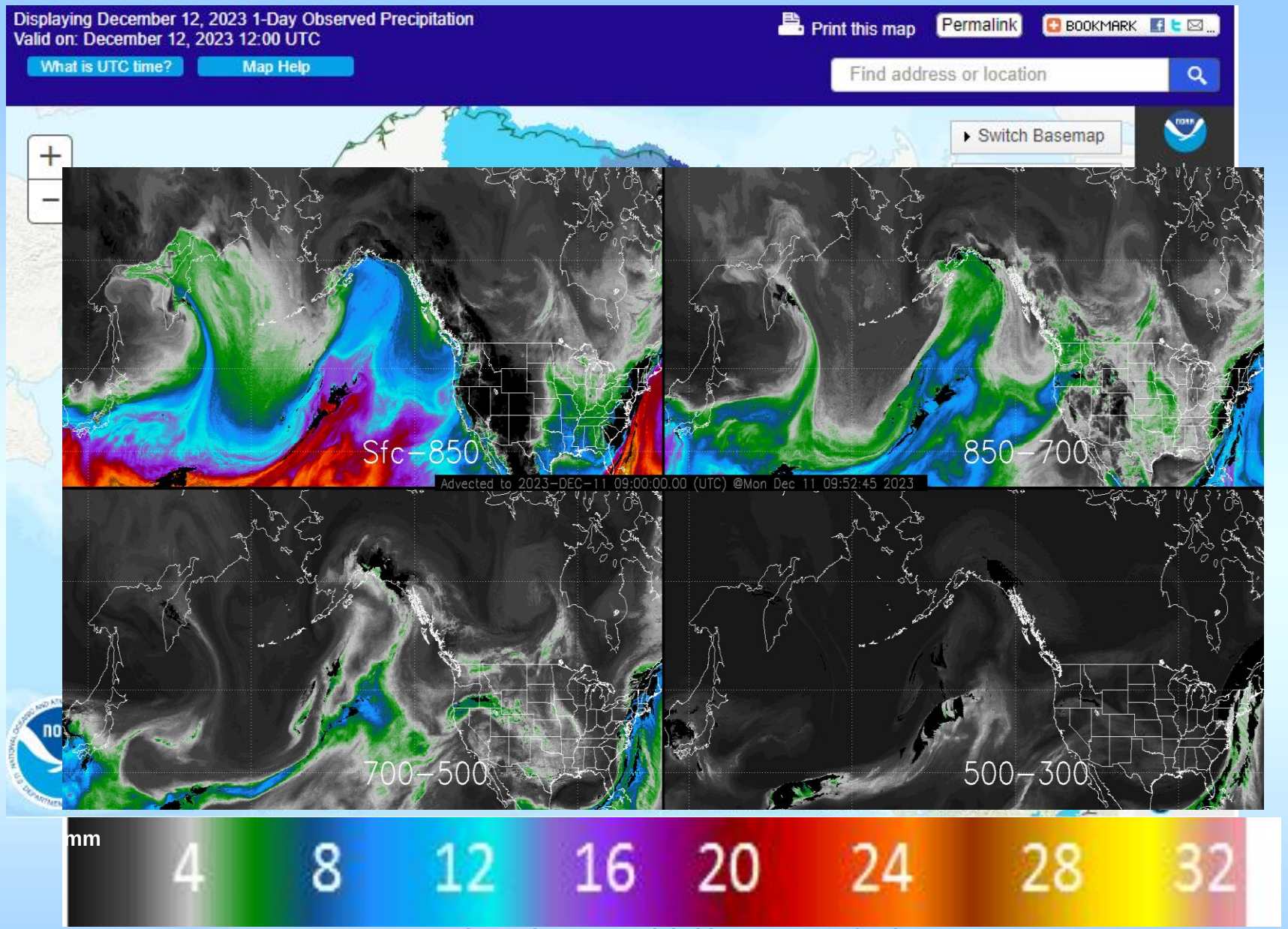


Sfc-850 mb layer

Layer Precipitable Water (mm)

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

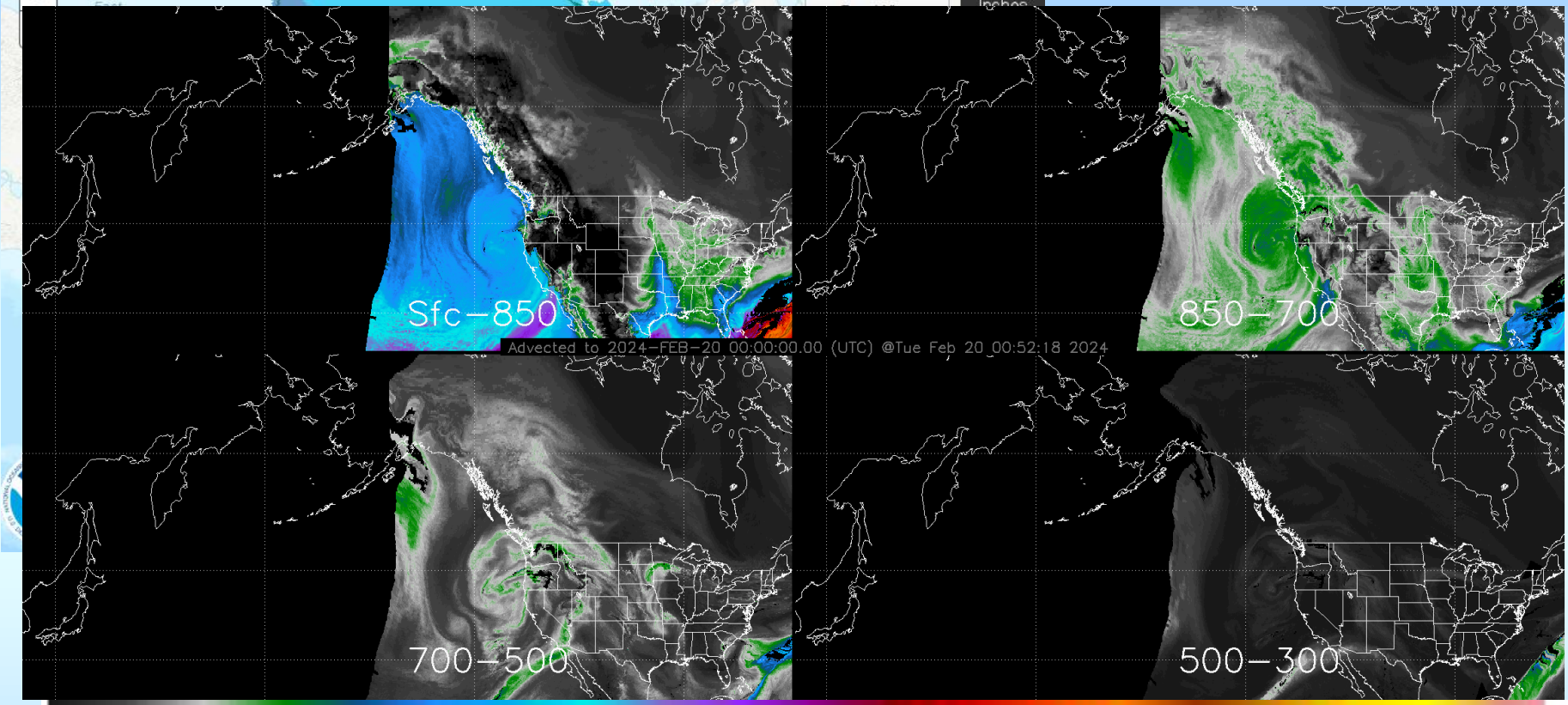




Advected Layer Precipitable Water Loop for the Period 0900 UTC 11 Dec to 1500 UTC 12 Dec 2023

https://cat.cira.colostate.edu/CAT/FTP/2023Dec1218Advect_LPW_AK_ALT_anim.gif

Advected Layer Precipitable Water Loop for the Period 0000 UTC 20 Feb to 0600 UTC 21 Feb 2024

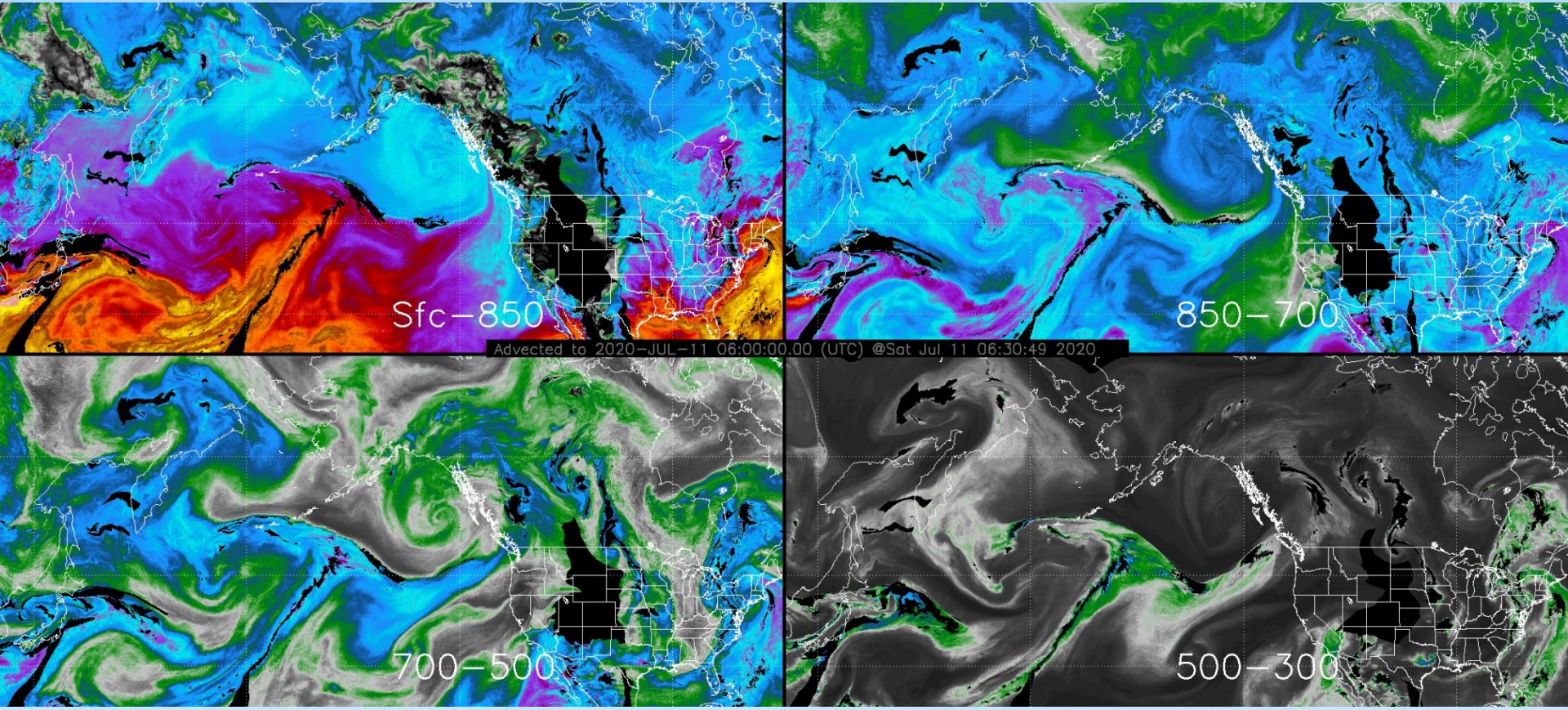


https://cat.cira.colostate.edu/CAT/FTP/2024Feb2109Advect_LPW_AK_ALT_anim.gif

NOAA • NESDIS
JPSS
Joint Polar Satellite System

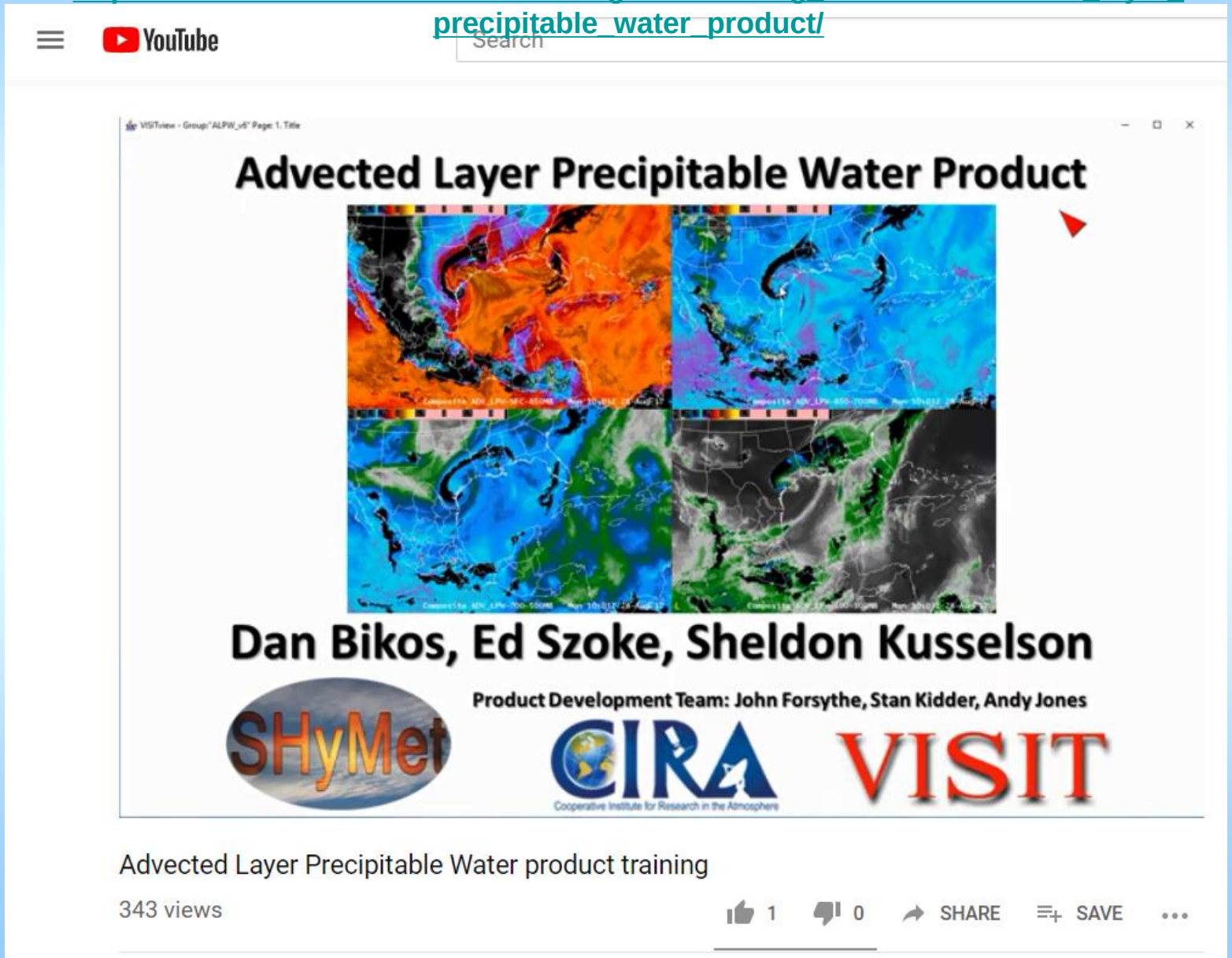
Alaska and North Pacific Sector

http://cat.cira.colostate.edu/SPoRT/Layered/Advected/LPW_Alaska.htm



ALPW VISIT Training Session Available in Commerce Learning Center.

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



Getting the Research Data to Forecasters

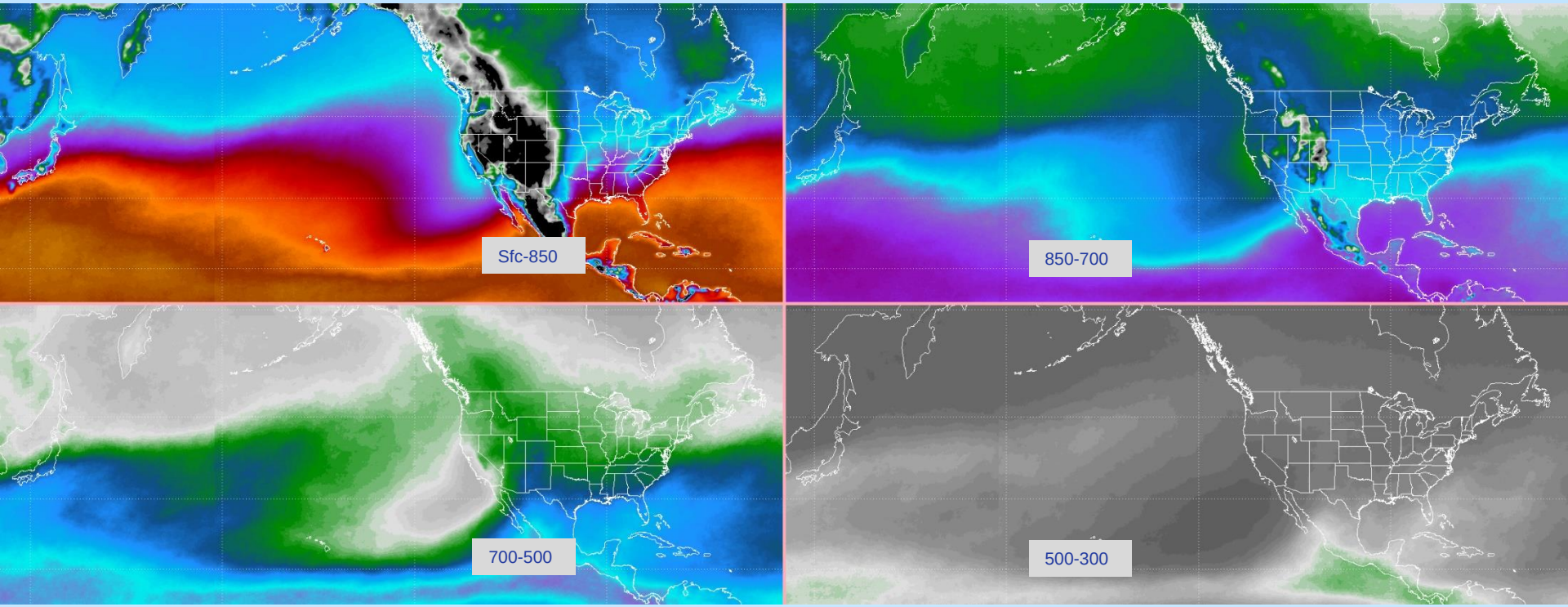
- As a NOAA cooperative institute at a university, with 5 federal employees, CIRA has long-standing data flows to the National Weather Service.
- The ALPW product is provided to forecasters on **their** display system (very important). CIRA-developed **training**.

A lead forecaster at NWS WFO Tucson mentioned, "we look at the ALPW product religiously, especially during the Southwest Monsoon season".

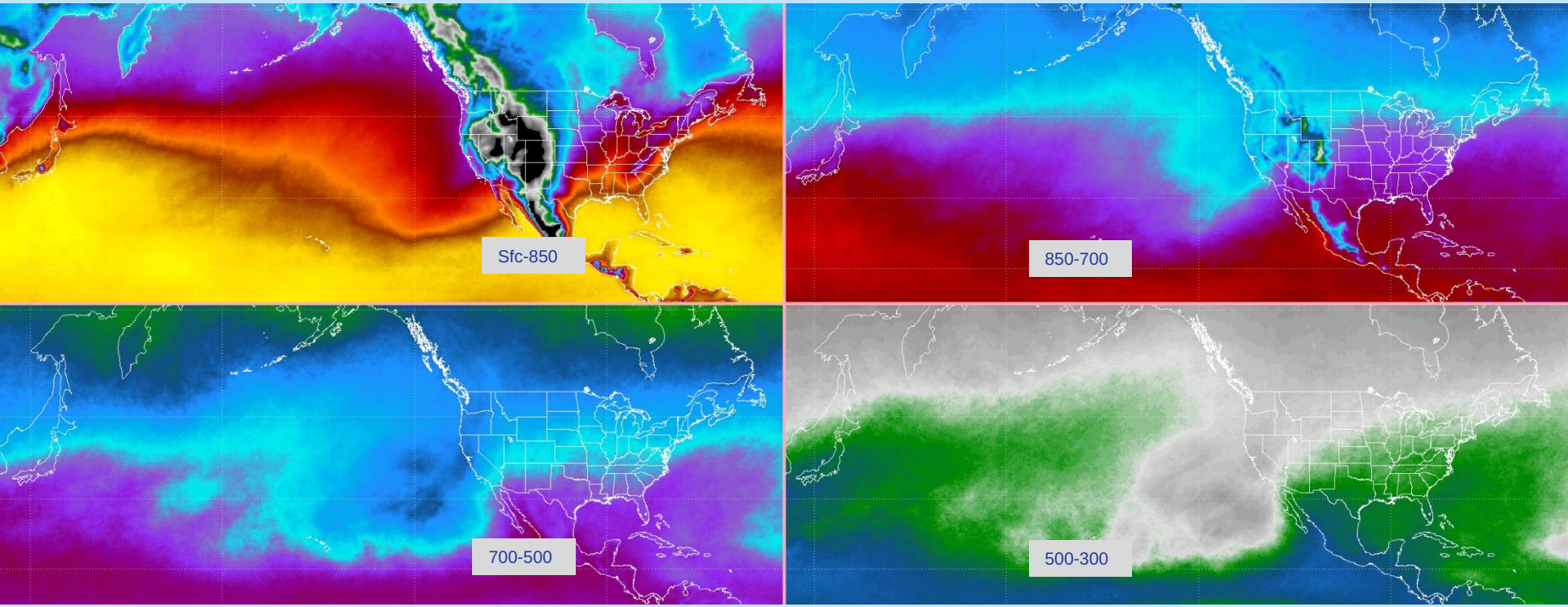
http://rammb.cira.colostate.edu/training/visit/training_sessions/advected_layer_precipitable_water_product/

Recent Historical Record of ALPW

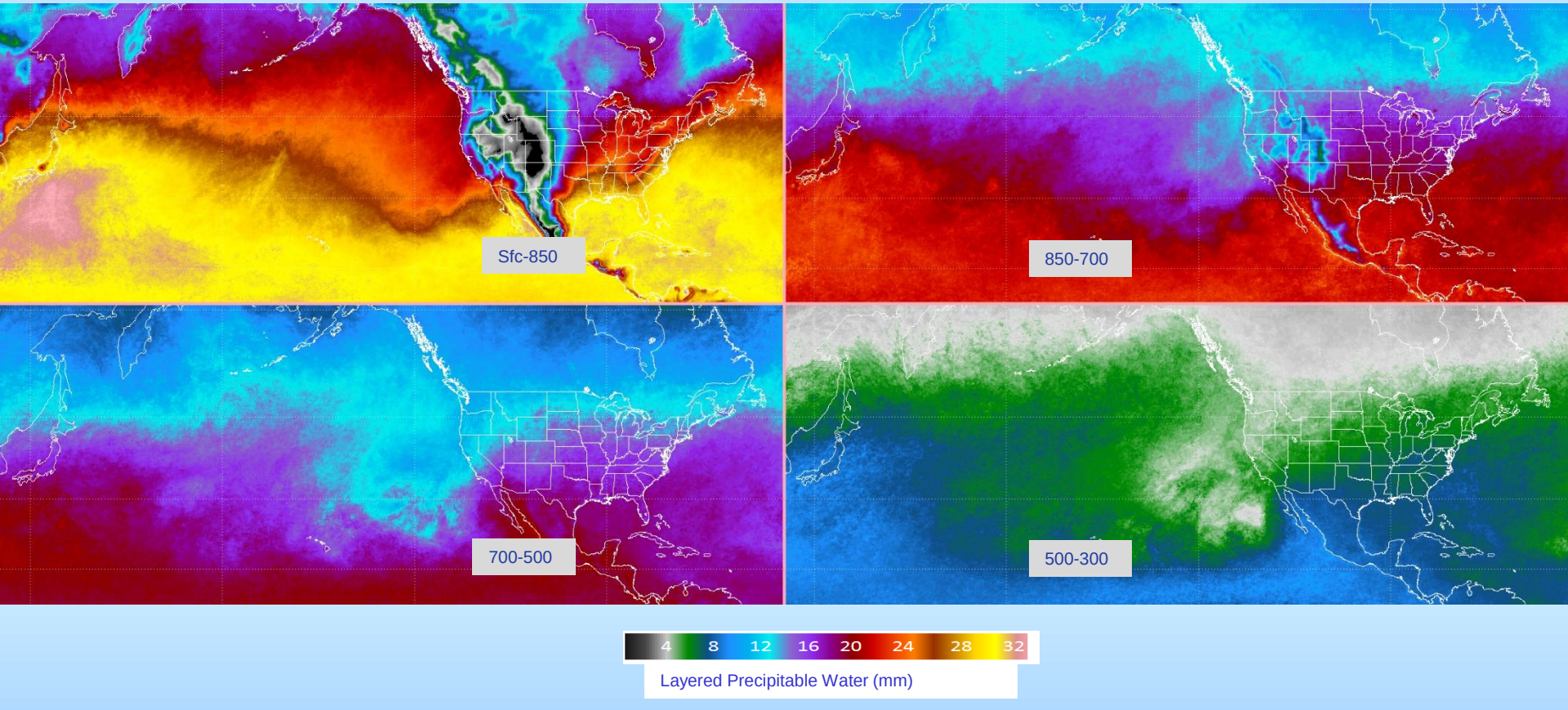
September 2013 – 2023 Median LPW from LPW data



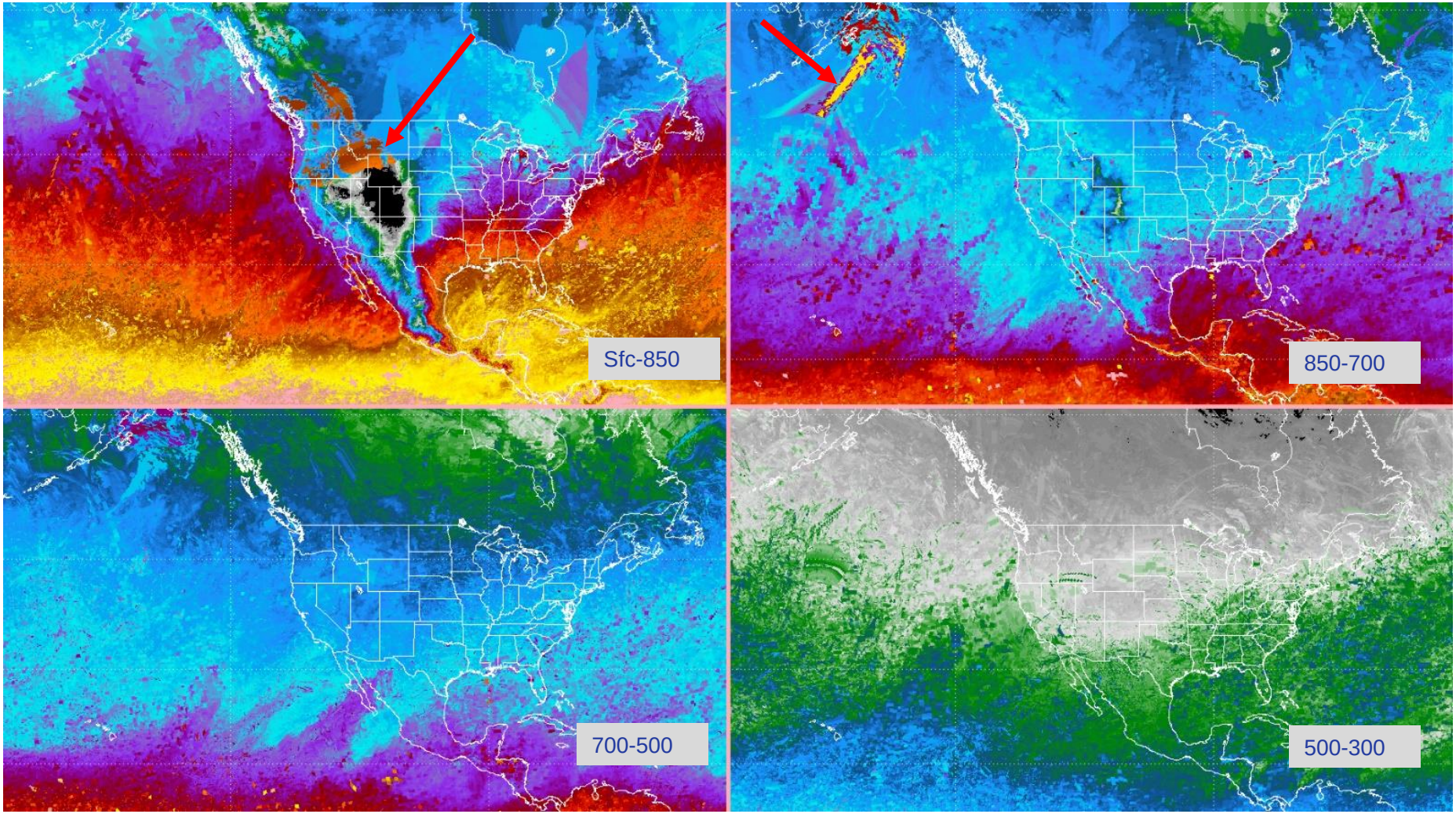
September 2013 – 2023 95th percentile LPW



September 2013 – 2023 99th percentile LPW



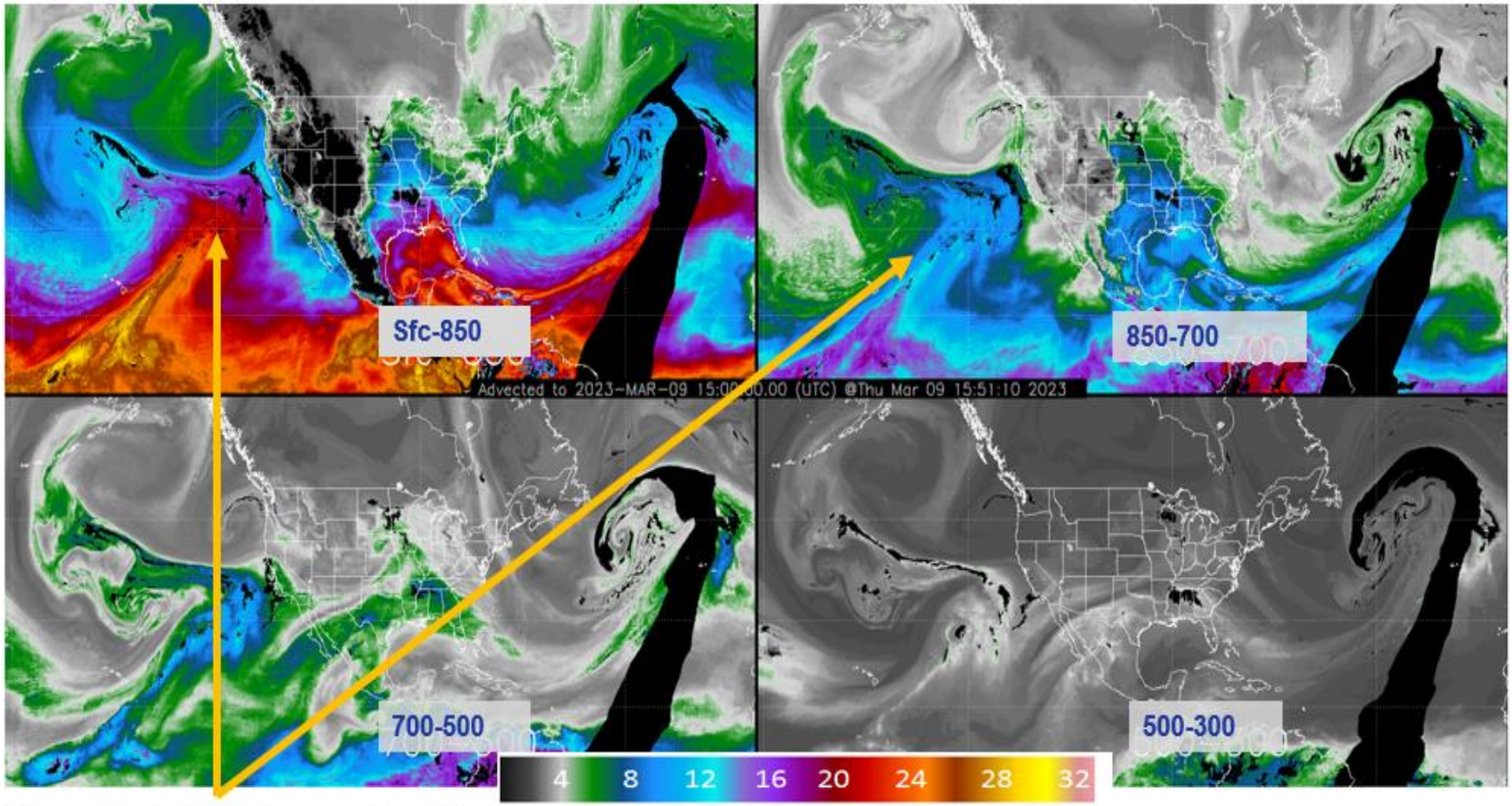
March 2013 – 2021 Maximum LPW



New Derived Products Being Evaluated

- Percentile Ranking
- Layered Vapor Transport (LVT)
- Reanalysis records

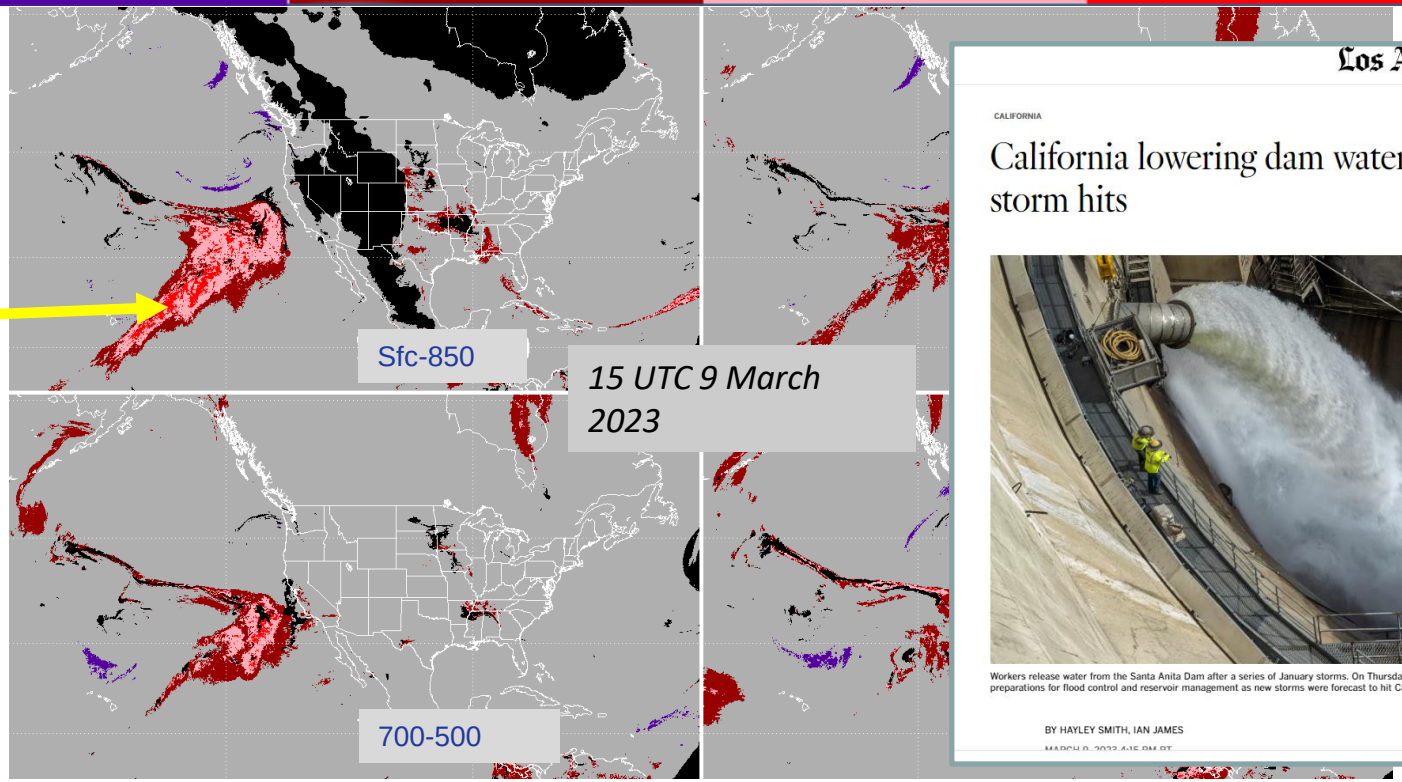
March 9,2023 California Atmospheric River



Large Atmospheric River Approaching CA

ALPW Percentile Ranking for 10-year Record

Highest values in record



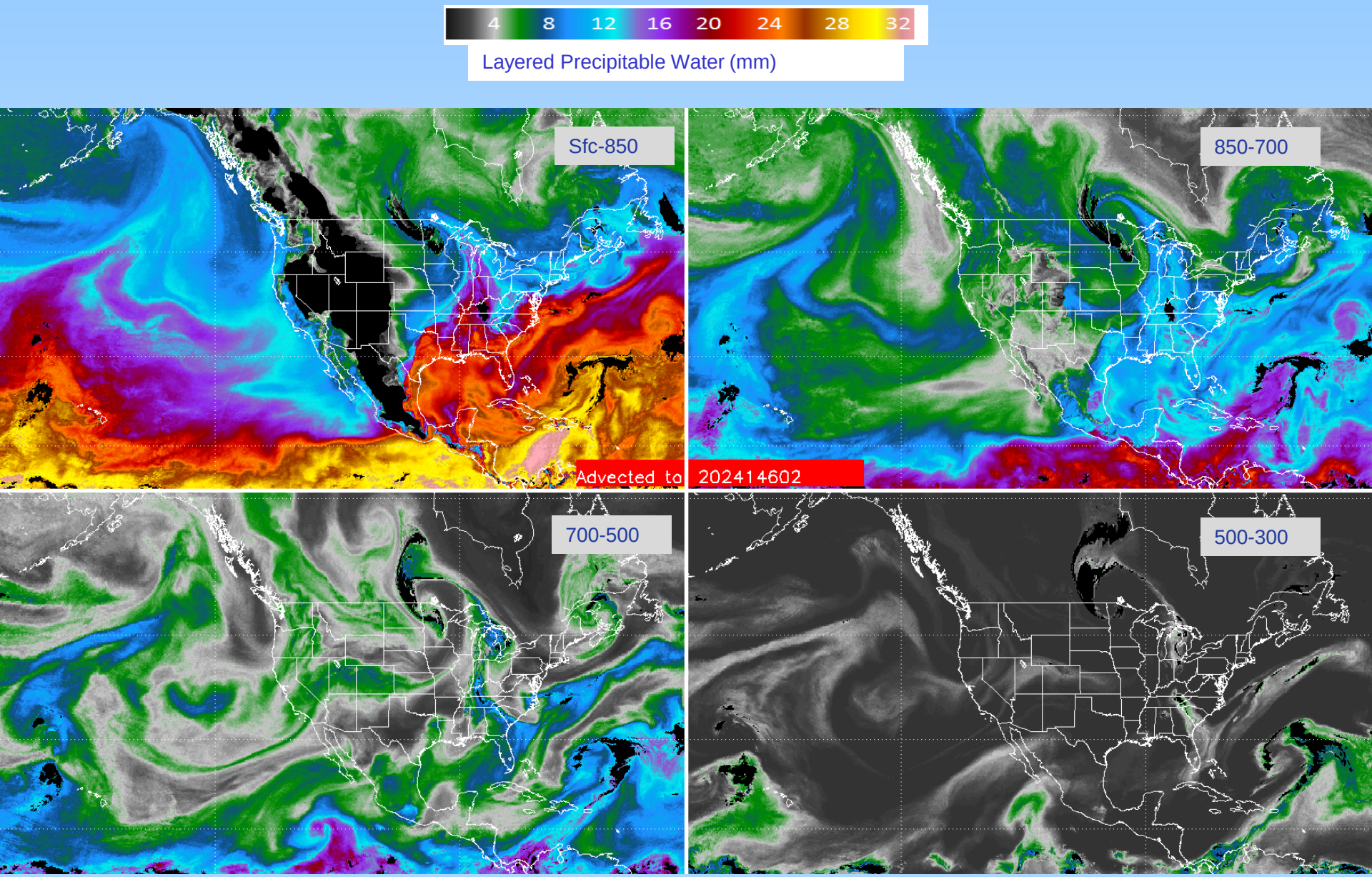
Los Angeles Times

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)

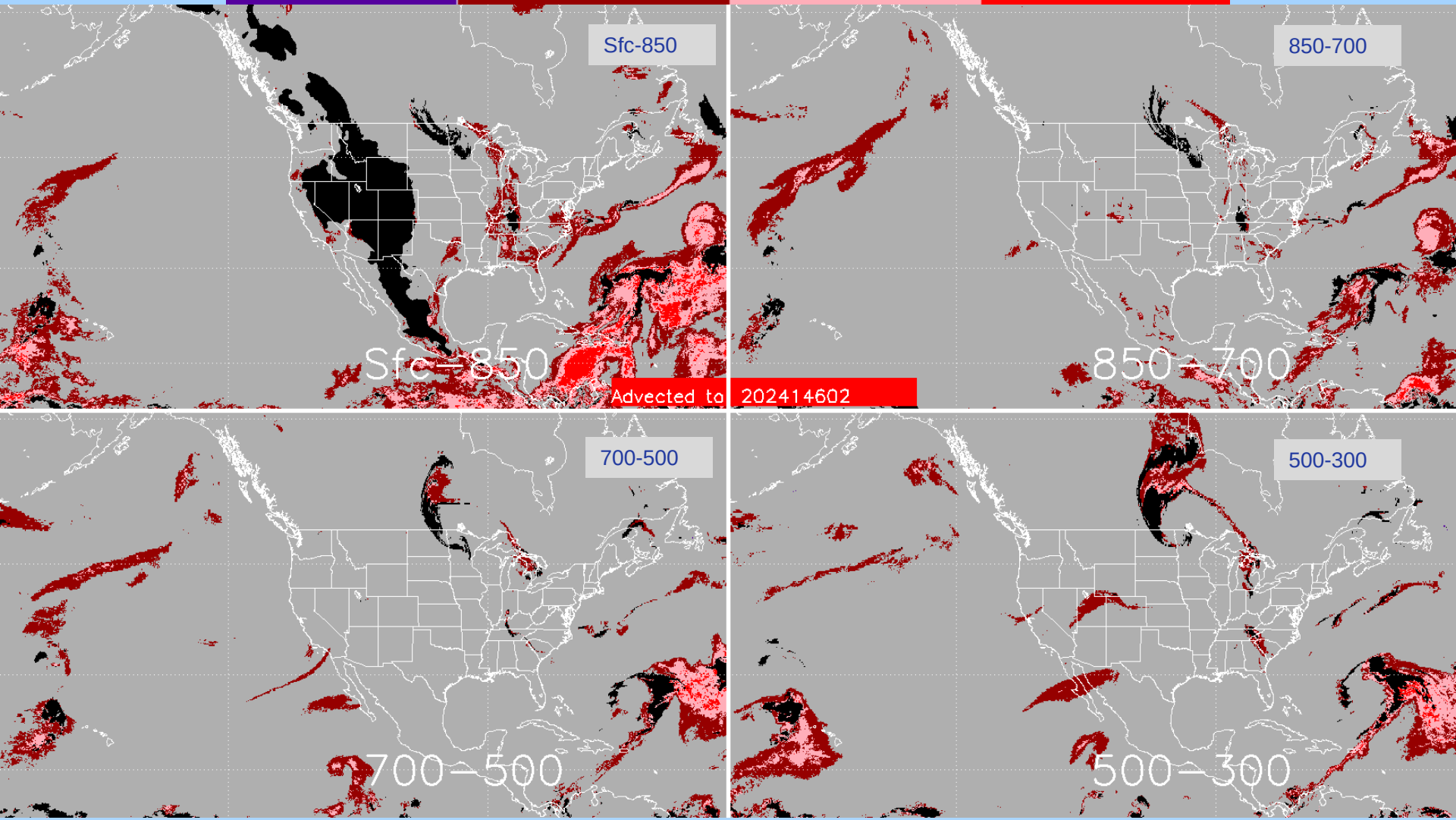
BY HAYLEY SMITH, IAN JAMES



02 UTC 25 May 2024

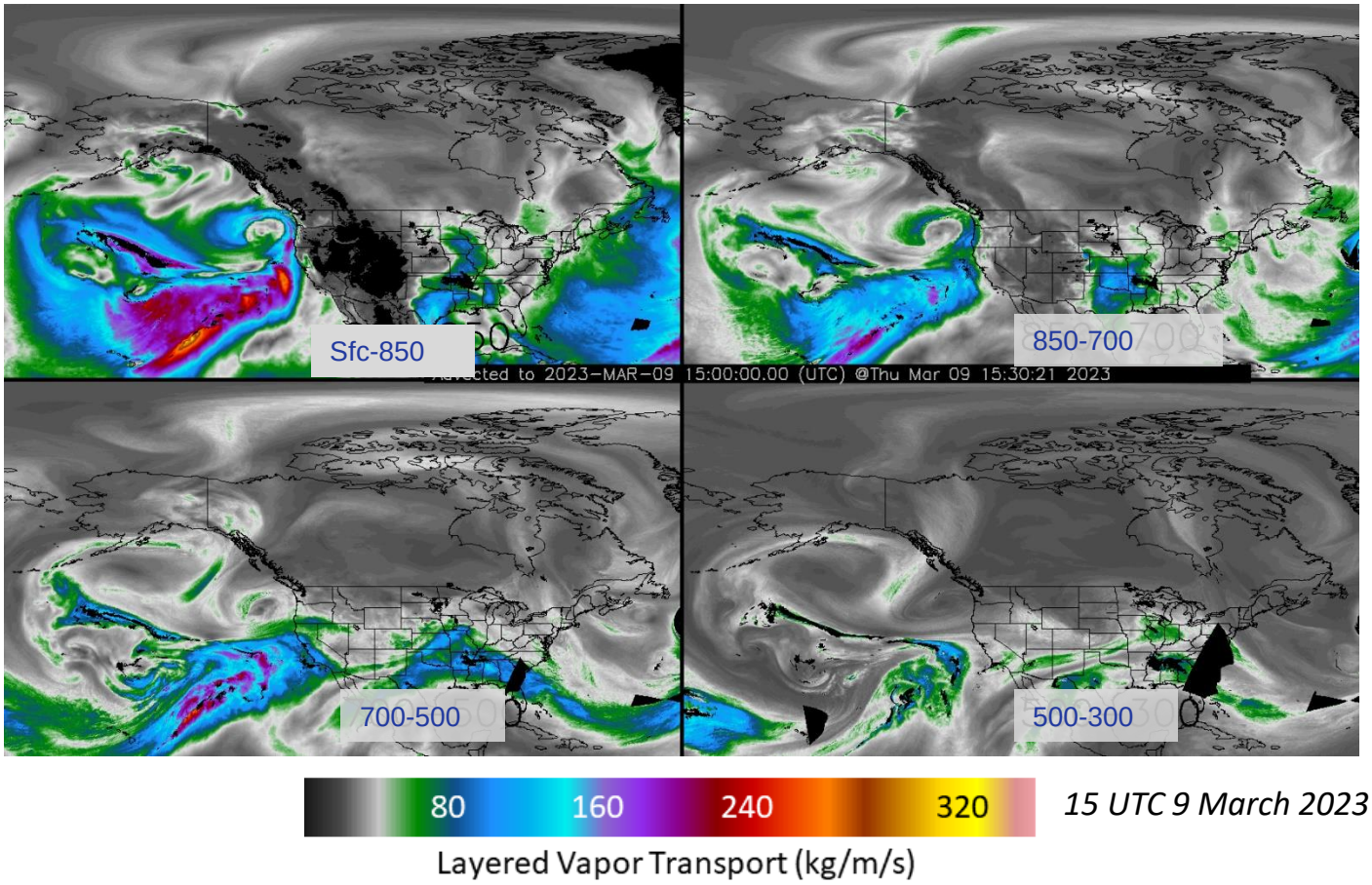
Percentile Ranking

< 5th | > 95th | > 99th | Maximum



02 UTC 25 May 2024

New Layered Vapor Transport (LVT) evaluated at WPC FFaIR* Experiment (Jun. – Aug. 2023)
Waiting for final evaluation
NWS Alaska Region has also looked at this product



- Derived using GFS winds
- Work in progress on comparing to IVT

15 UTC 9 March 2023

**Flash Flood and Intense Rainfall Experiment*

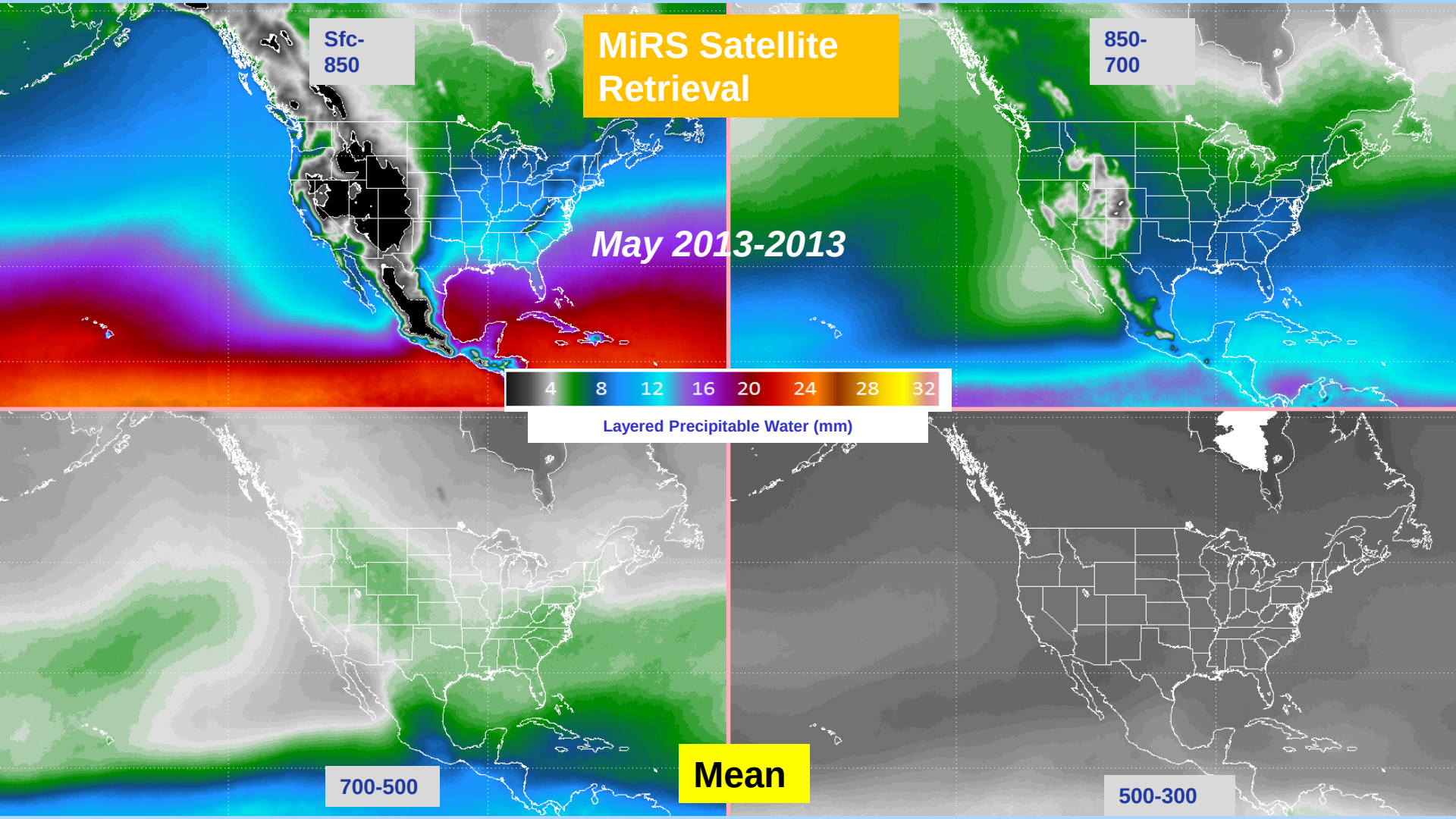
Sample of Questions Being Posed to NWS Alaska Forecasters

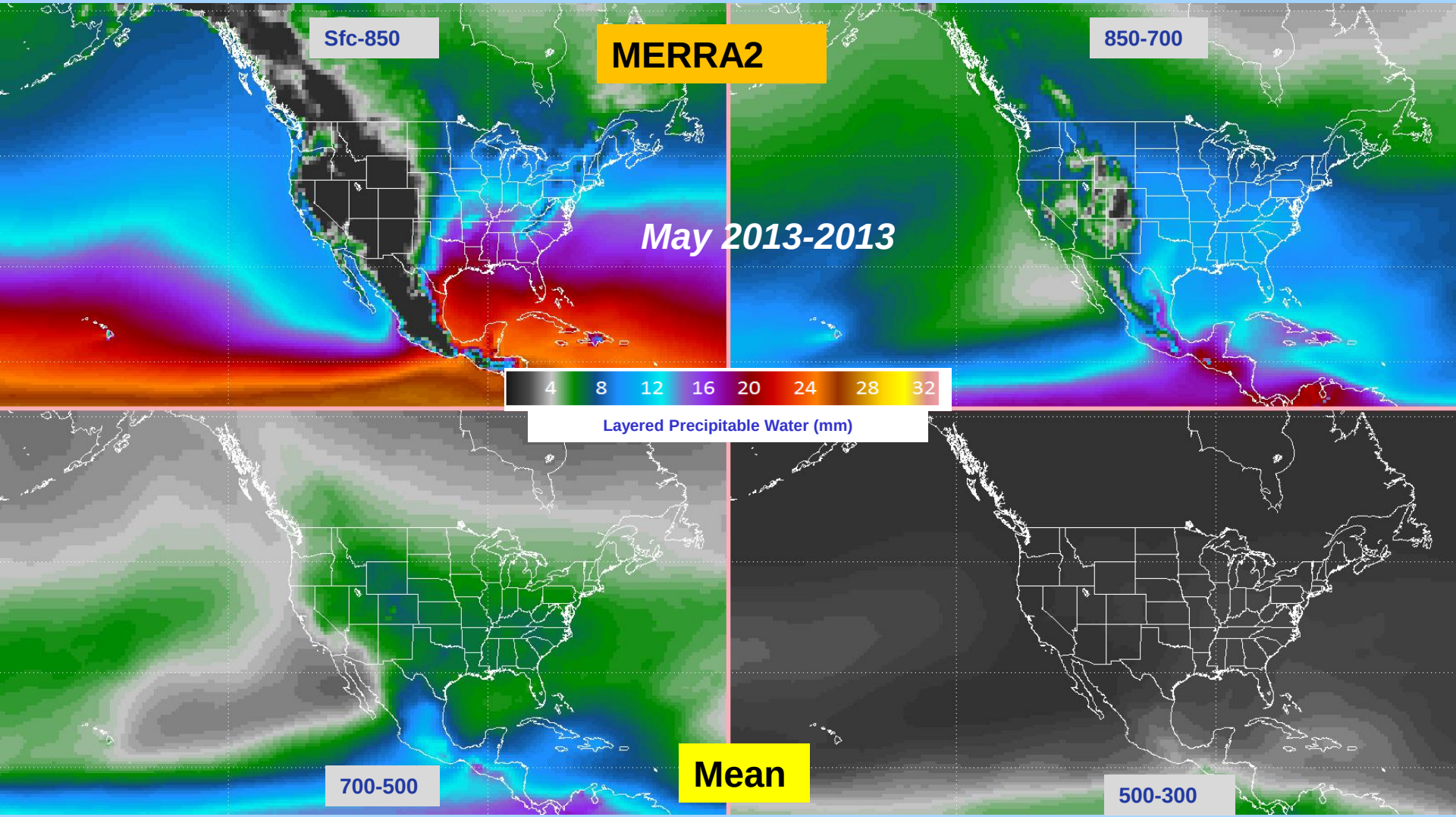
1. Did the percentile ranking focus your attention on areas which received heavy rain?
   - *"The areas which were shown as being around the 95th percentile or greater did coincide with areas that reported moderate to heavy rain"*

2. Do you think the percentile ranking tool could be useful in communicating threats to the public?
   - *"…when communicating to the public we can more confidently draw comparisons to previous extreme events and thus be more proactive in communicating potential impacts…"*

3. Did the LVT product help you see how much moisture was being transported over mountains?
   - *"Moisture that was being transported over the mountains was only viewable for heights above 700mb while everything below was blocked by the terrain of the Coast mountains."*

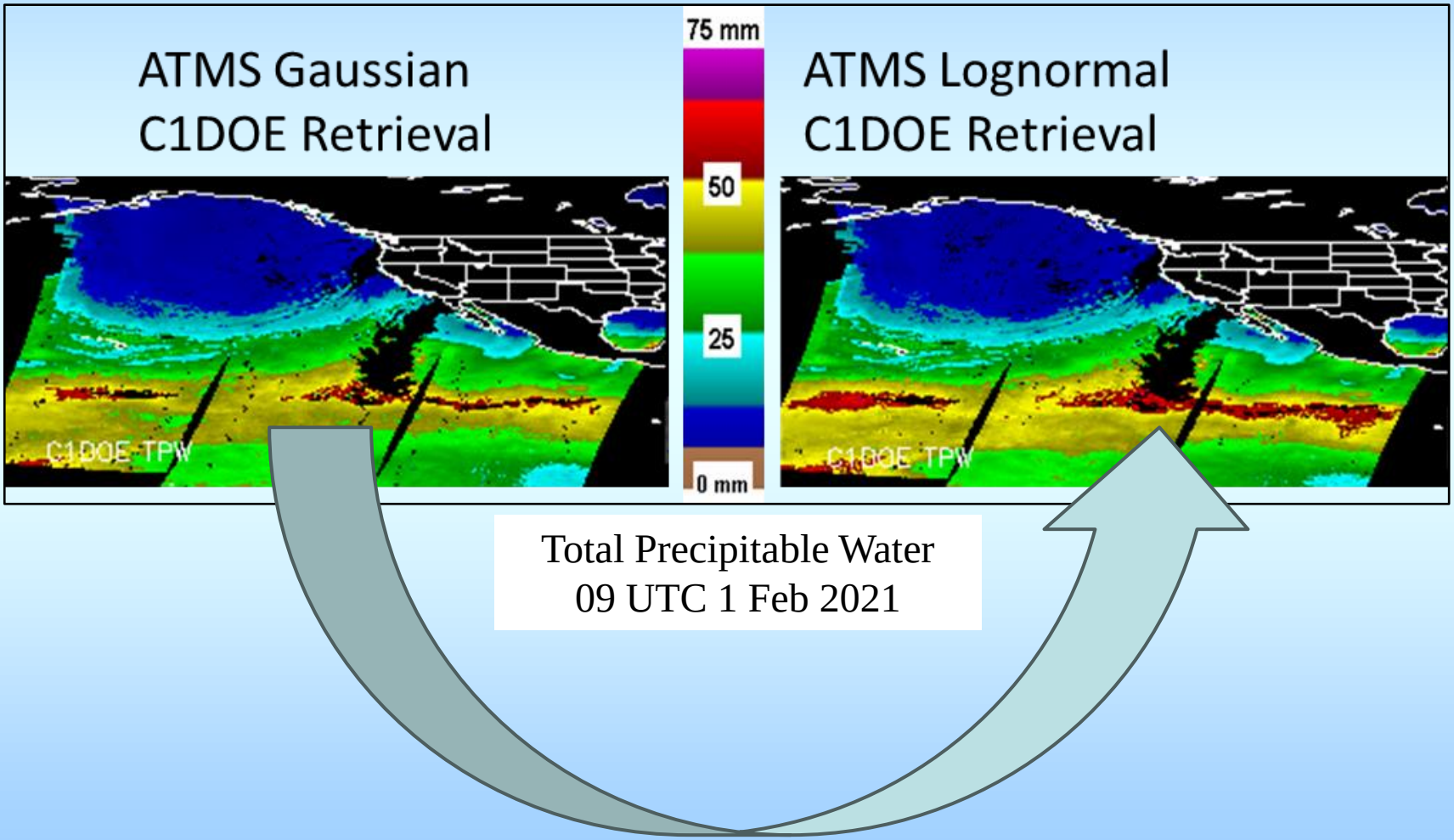
Related Work in Progress


Sfc-
850
MiRS Satellite
Retrieval
850-
700
May 2013-2013
4 8 12 16 20 24 28 32
Layered Precipitable Water (mm)
700-500
Mean
500-300


Sfc-850
MERRA2
850-700
May 2013-2013
4 8 12 16 20 24 28 32
Layered Precipitable Water (mm)
700-500
Mean
500-300

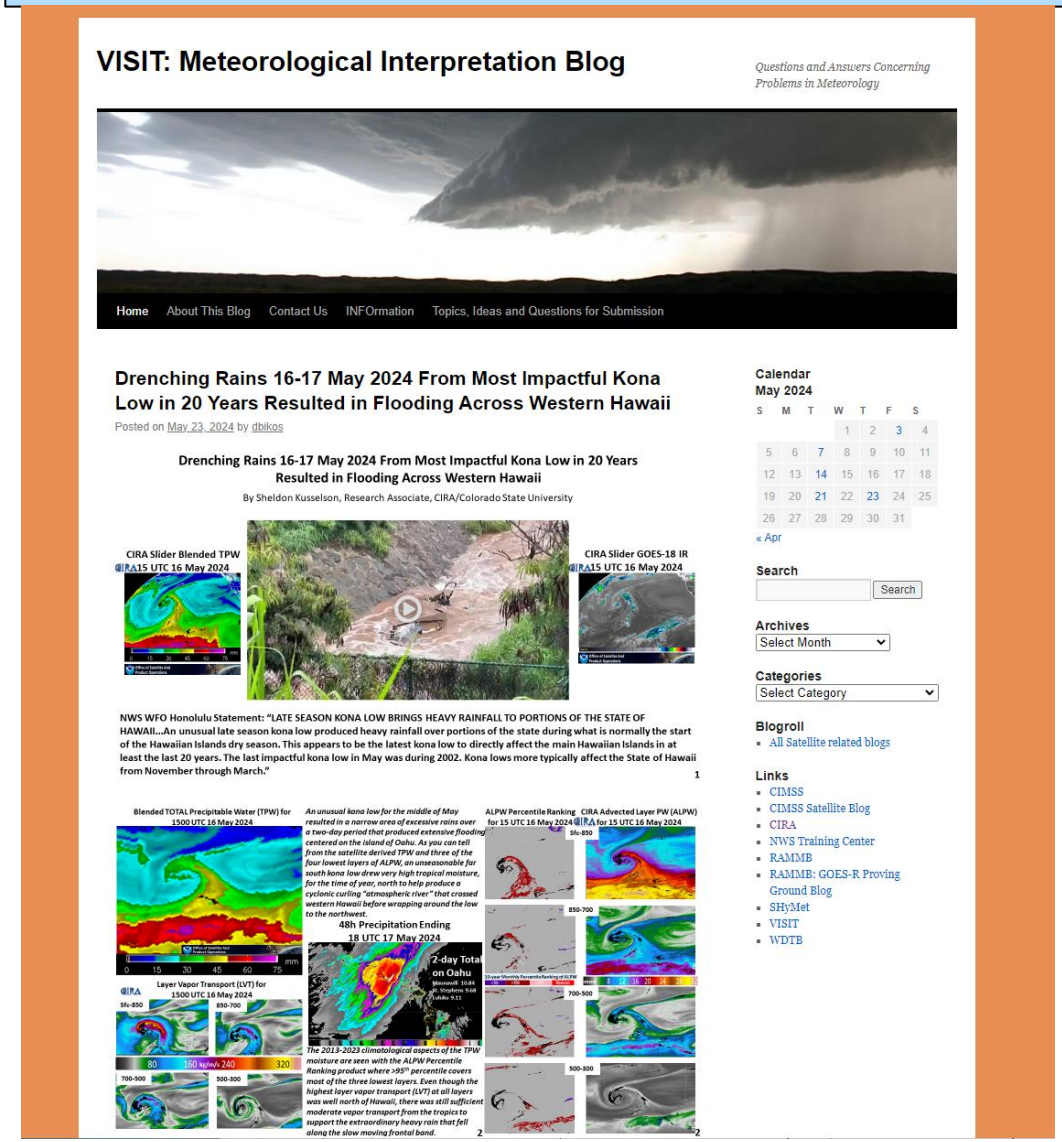
CIRA will run a non-Gaussian framework microwave retrieval (C1DOE: Fletcher, Kliewer et al. 2016) for NASA NVAP project (40-year instrumental record)

- ❑ 1DVAR retrieval similar to NOAA MiRS
- ❑ Should better retrieve extreme values
- ❑ Will also run MiRS (Gaussian) and validate the two



Total Precipitable Water
09 UTC 1 Feb 2021

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



VISIT: Meteorological Interpretation Blog

Questions and Answers Concerning Problems in Meteorology

Home | About This Blog | Contact Us | INFOrmation | Topics, Ideas and Questions for Submission

Drenching Rains 16-17 May 2024 From Most Impactful Kona Low in 20 Years Resulted in Flooding Across Western Hawaii

Posted on May 23, 2024 by dbikos

Drenching Rains 16-17 May 2024 From Most Impactful Kona Low in 20 Years Resulted in Flooding Across Western Hawaii

By Sheldon Kusselson, Research Associate, CIRA/Colorado State University

CIRA Slider Blended TPW 15 UTC 16 May 2024

CIRA Slider GOES-18 IR 15 UTC 16 May 2024

NWS WFO Honolulu Statement: "LATE SEASON KONA LOW BRINGS HEAVY RAINFALL TO PORTIONS OF THE STATE OF HAWAII...An unusual late season kona low produced heavy rainfall over portions of the state during what is normally the start of the Hawaiian Islands dry season. This appears to be the latest kona low to directly affect the main Hawaiian Islands in at least the last 20 years. The last impactful kona low in May was during 2002. Kona lows more typically affect the State of Hawaii from November through March."

Blended TOTAL Precipitable Water (TPW) for 1500 UTC 16 May 2024

An unusual kona low for the middle of May resulted in a narrow area of excessive rains over a two-day period that produced extensive flooding centered on the island of Oahu. As you can tell from the satellite derived TPW and three of the four lowest layers of ALPW, an unseasonable for south kona low drew very high tropical moisture, for the time of year, north to help produce a cyclonic curling "atmospheric river" that crossed western Hawaii before wrapping around the low to the northwest.

ALPW Percentile Ranking for 15 UTC 16 May 2024

CIRA Advected Layer PW (ALPW) for 15 UTC 16 May 2024

48h Precipitation Ending 18 UTC 17 May 2024

2-day Total on Oahu

Layer Vapor Transport (LVT) for 1500 UTC 16 May 2024

The 2013-2023 climatological aspects of the TPW moisture are seen with the ALPW Percentile Ranking product where >95th percentile covers most of the three lowest layers. Even though the highest layer vapor transport (LVT) at all layers was well north of Hawaii, there was still sufficient moderate vapor transport from the tropics to support the extraordinary heavy rain that fell along the slow moving frontal band.

Calendar
May 2024

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

« Apr

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- RAMMB: GOES-R Proving Ground Blog
- SHyMet
- VISIT
- WDTB

Many examples of applications of satellite products around the world.

If you have a specific heavy precipitation case you'd like us to look at please let us know.

Links

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

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

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

https://cat.cira.colostate.edu/ALPX/ADVLUT/ALPX_Hourly.htm <- reduced size global 4-panel loop

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

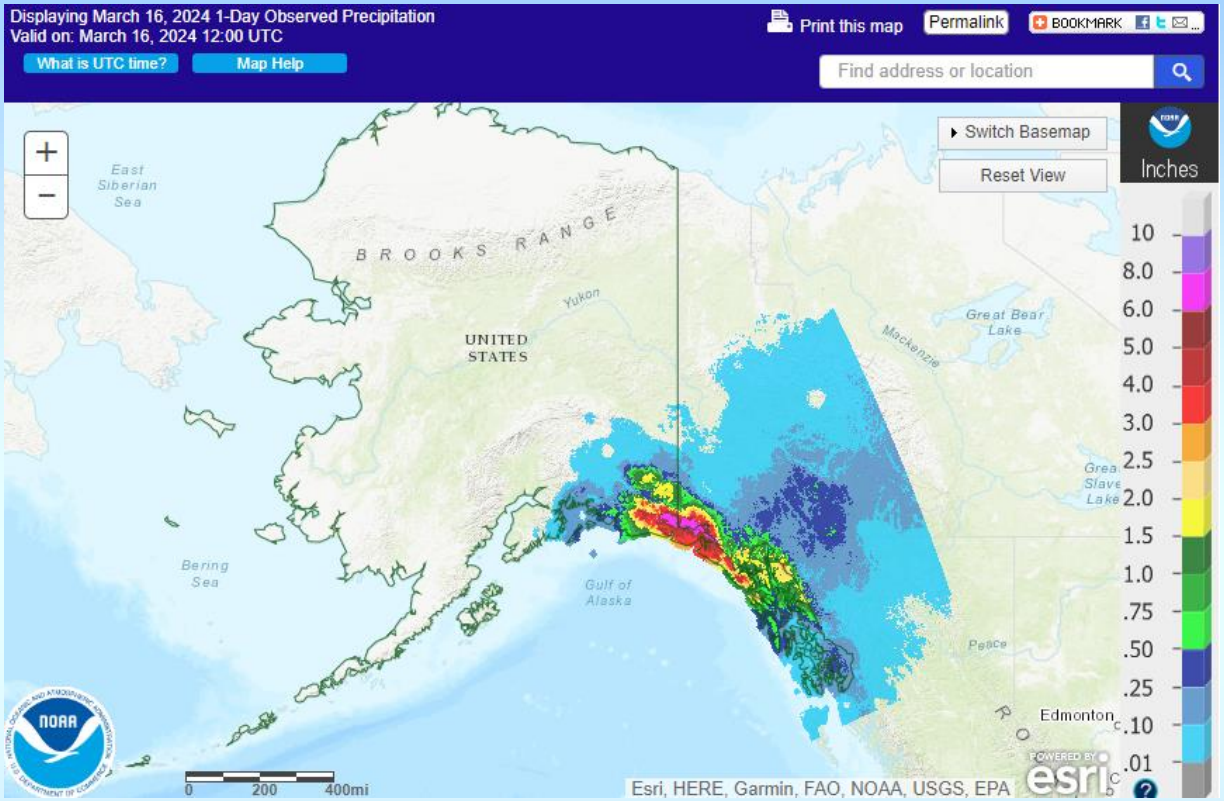
https://cat.cira.colostate.edu/SPoRT/Layered/Advected/LPW_Alaska.htm <- Alaska / N.Pacific ALPW sector

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 2024.
- Historical records provide forecasters new context for water vapor amounts in advance of flood threats.
- Sheldon Kusselson and Dan Bikos have created many application examples (floods, winter weather...), on VISIT blog.
- New efforts at CIRA underway to examine radiosonde, reanalysis LPW and TPW records for flood forecasting and historical perspective. A nearly 40-year record will be created.

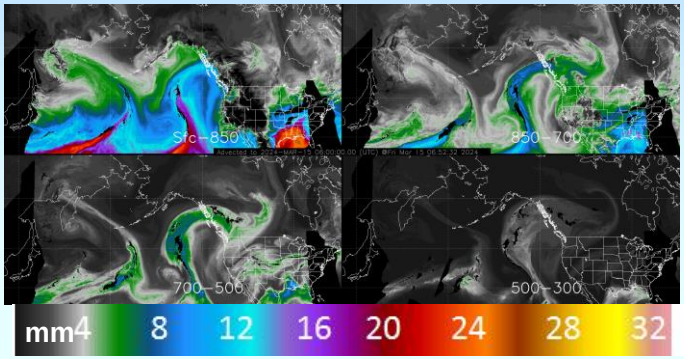
Always happy to have feedback and questions!
(John.Forsythe@colostate.edu)

Backup Slides



https://cat.cira.colostate.edu/CAT/FTP/2024Mar1615Advect_LPW_Alf_ALT_anim.gif

Advected Layer Precipitable Water Loop for the Period 0600 UTC 15 Mar to 1200 UTC 16 Mar



CIRA

A REMOTE SENSING PRECIPITABLE WATER PRODUCT FOR USE IN HEAVY PRECIPITATION FORECASTING

R. A. Scofield [1], D. Zaras [2], S. Kusselson [3], R. Rabin [4]

1. Office of Research and Applications (NOAA/NESDIS)
2. NOAA/NSSL/CIMMS
3. Synoptic Analysis Branch (NOAA/NESDIS)
4. NOAA/NSSL/CIMSS

First attempt at blended TPW: 1996

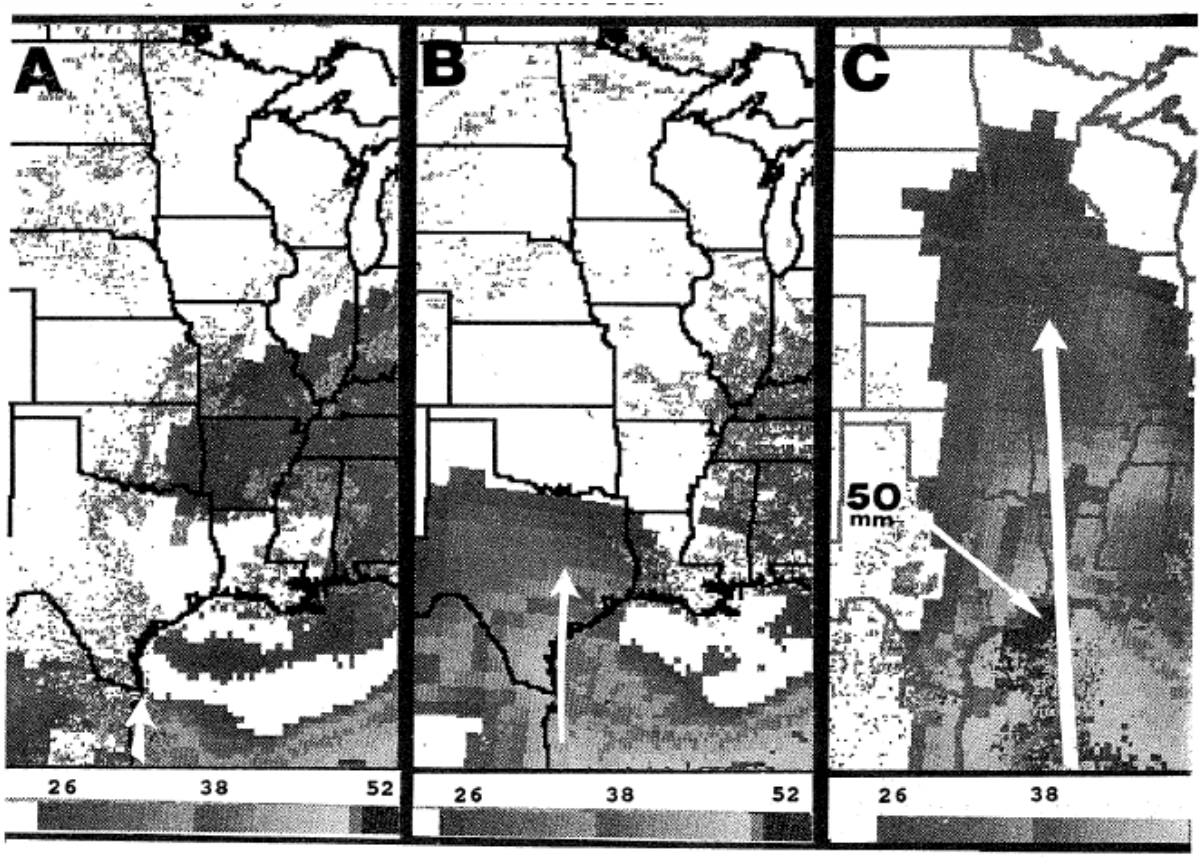


Figure 2a. *Blended Precipitable Water (mm) Product for October 14, 1994, 0000 UTC*
Figure 2b. *Blended Precipitable Water (mm) Product for October 15, 1994, 0000 UTC.*
Figure 2c. *Blended Precipitable Water (mm) Product for October 15, 1994, 1200 UTC.*

Used GOES-8 Sounder, Two SSM/I's over ocean, Eta model

29" rainfall event near Houston!

Radiosonde matchups over CONUS: March 21, 2020 – June 12, 2020

Source	n	r^2	RMS (mm)	Bias (mm)	
Advected Microwave:	17485	0.92	4.3	0.17	
GOES:	3951	0.96	2.7	-0.40	
GPS short range:	710	0.96	2.4	-0.67	
Operational Blended TPW:	17632	0.91	4.6	-0.99	←
BTPW2020:	17632	0.94	3.7	0.20	←

24% improvement in RMS error in new blended TPW

Why not just use the model water vapor?

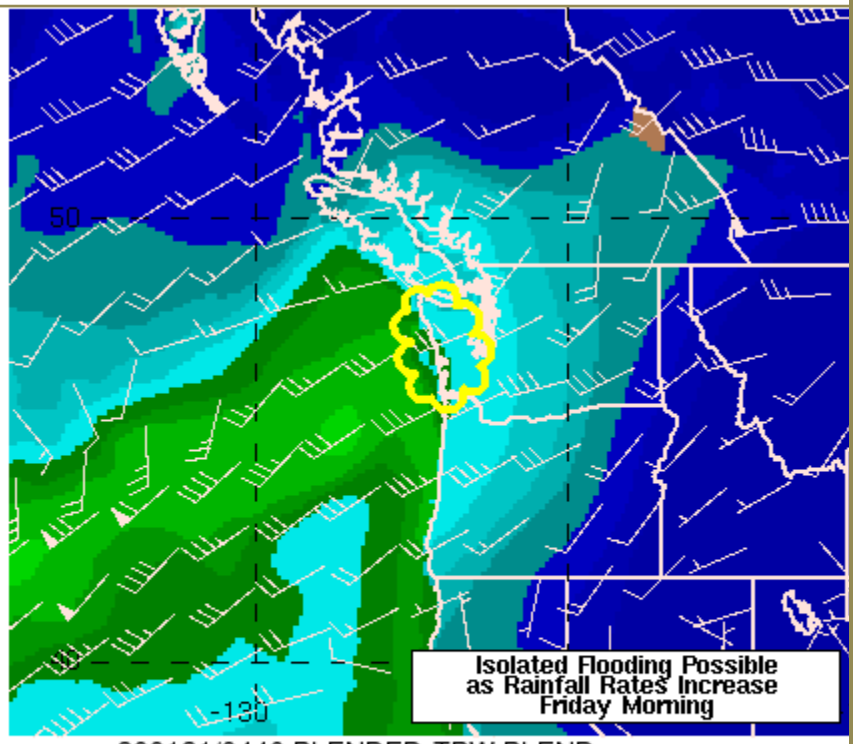
The NOAA Joint Center for Satellite Data Assimilation (JCSDA) has six primary scientific research priority areas:

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

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

- Satellite-only products not be affected by model initialization / missing data issues like a model cycle.

Typical Use of Blended TPW – Atmospheric Rivers



200131/0446 BLENDED-TPW BLEND
RAP32 850 MB WINDS 200131/0400f003
WPC MPD #0030

Mesoscale Precipitation Discussion 0030
NWS Weather Prediction Center College Park MD
148 AM EST Fri Jan 31 2020

Areas affected...Coastal Washington

Concerning...Heavy rainfall...Flash flooding possible

Valid 310647Z - 311800Z

Summary...Rainfall rates are expected to increase later tonight and Friday morning as increasingly deep moisture associated with an atmospheric river gets directed into...and interacts with...the Coastal Ranges of western Washington.

An atmospheric river, with connections extending to at least 145 West longitude, has become established and southwest winds in the lower atmosphere has been directing the moisture plume into the Washington coastal ranges since late Thursday evening. Computer models have been showing that the southwest winds will be increasing to speeds approaching 50 kts along the coast and Integrated Transport Vectors will be increasing in magnitude by 12Z and continuing into mid-Friday morning. Instability will not be particularly strong, but even marginal instability combined with deep onshore flow into the terrain may lead to rainfall rates exceeding 0.5 inch per hour as early as 12Z.

The models have been in agreement with the large scale synoptics although the higher resolution guidance seems to have a better depiction of the interaction between the moisture plume and the terrain...and there has been a growing consensus of a brief lull in the rainfall rates during the latter part of the morning in conjunction with low level winds taking on a more westerly component. Through 18Z, WPC is expecting between 2 and 4 inches of rain with locally higher amounts that could lead to isolated problems due to run-off. With the height of the wet bulb 0 level increasing to nearly 10 kft, snow melt could exacerbate any problems from rainfall runoff.

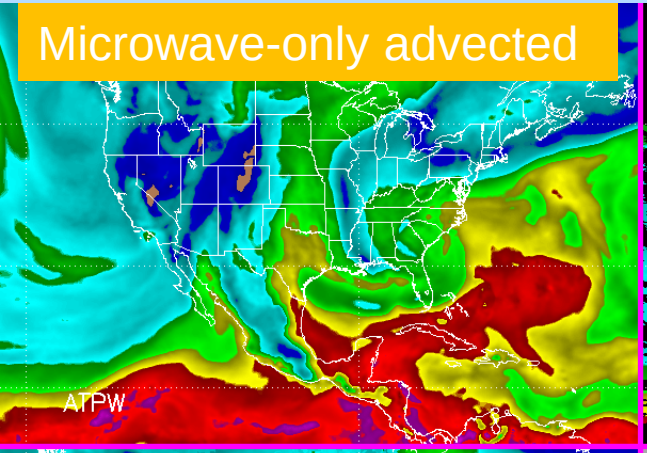
Bann

Also commonly used by NHC / TAFB to analyze tropical waves, Saharan Air Layer

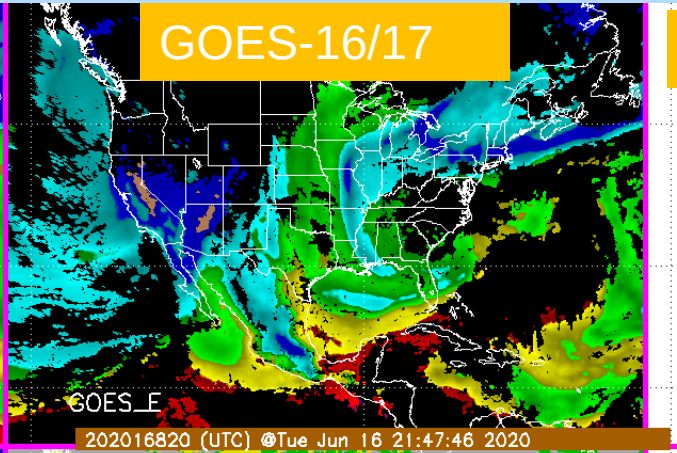
Towards the Next Generation of Blended TPW Products

http://cat.cira.colostate.edu/btpw_2020/

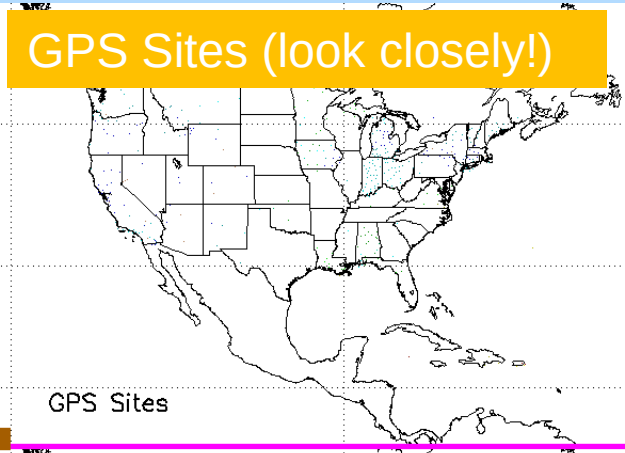
Microwave-only advected



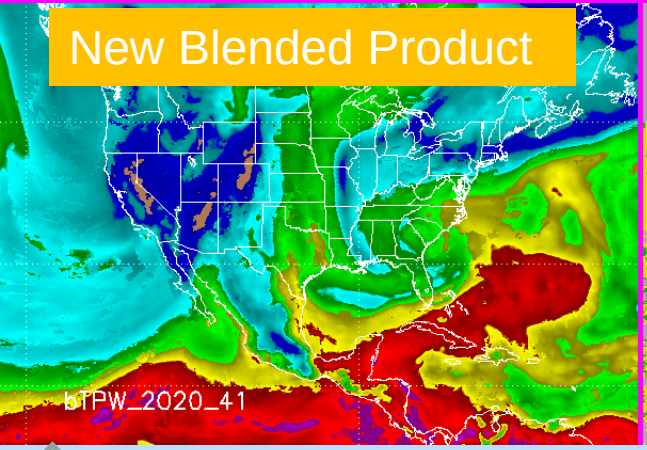
GOES-16/17



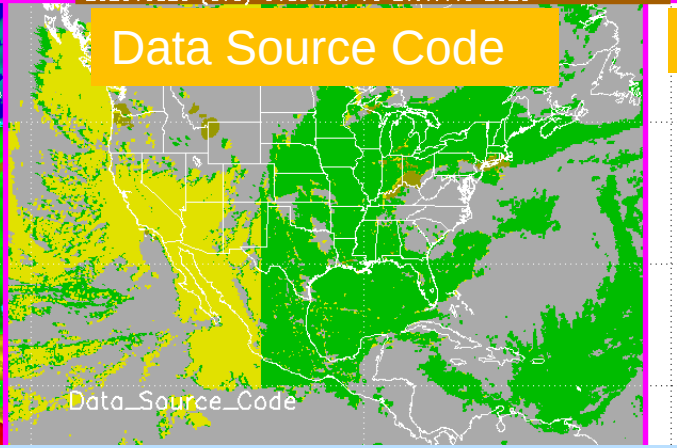
GPS Sites (look closely!)



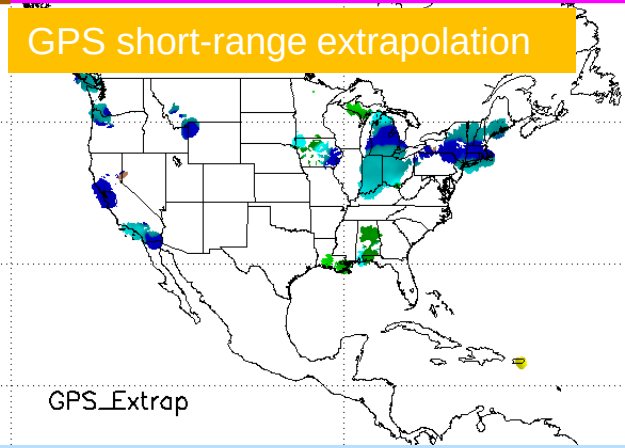
New Blended Product



Data Source Code



GPS short-range extrapolation

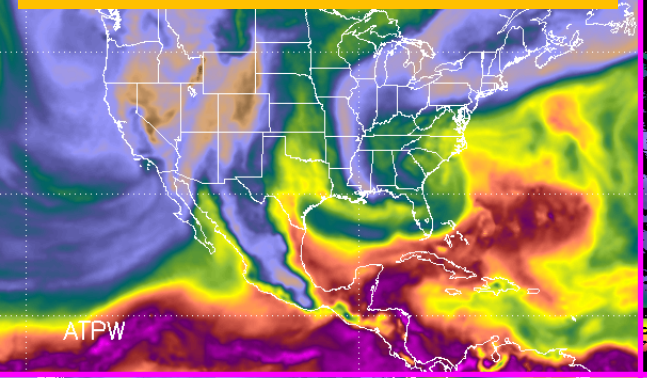


Blends inputs according to hierarchy. Version 2.0: GOES > GPS > Advected Microwave

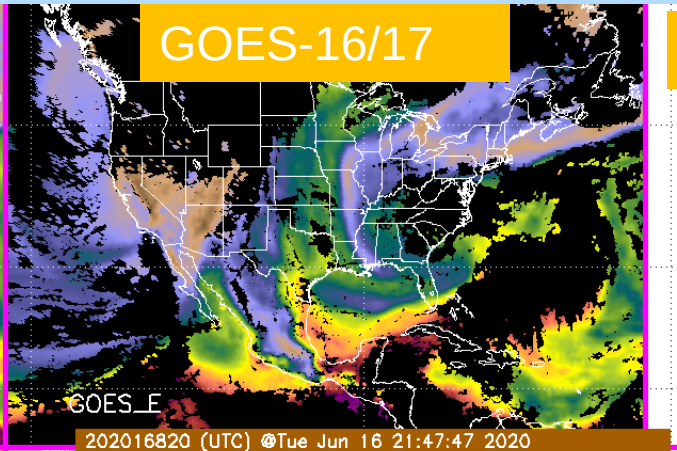
Alternative AWIPS Color Table

http://cat.cira.colostate.edu/btpw_2020/

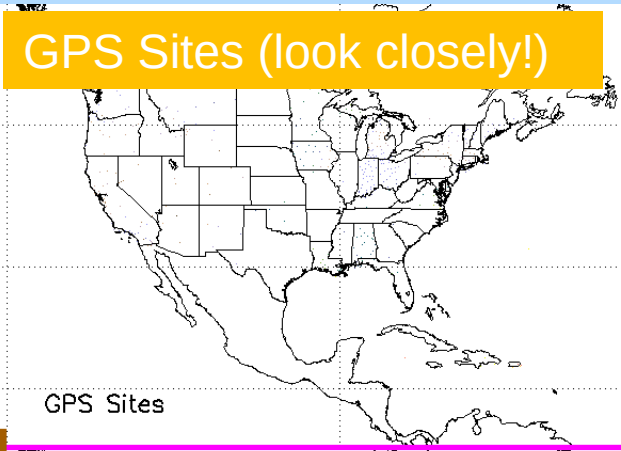
Microwave-only advected



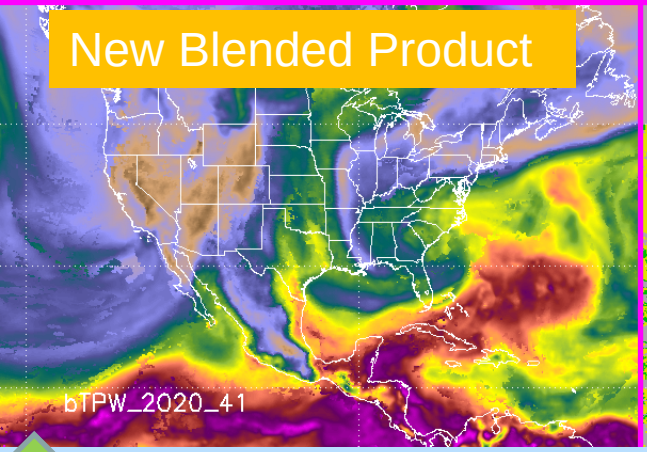
GOES-16/17



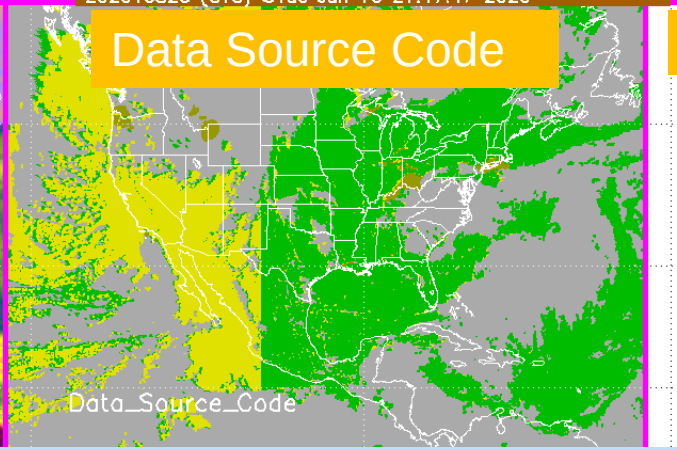
GPS Sites (look closely!)



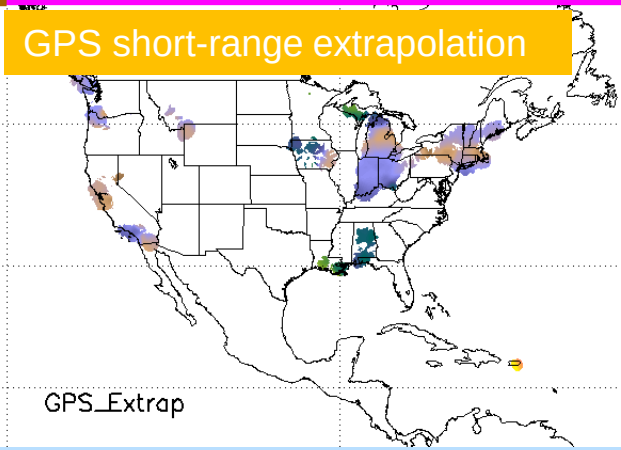
New Blended Product



Data Source Code

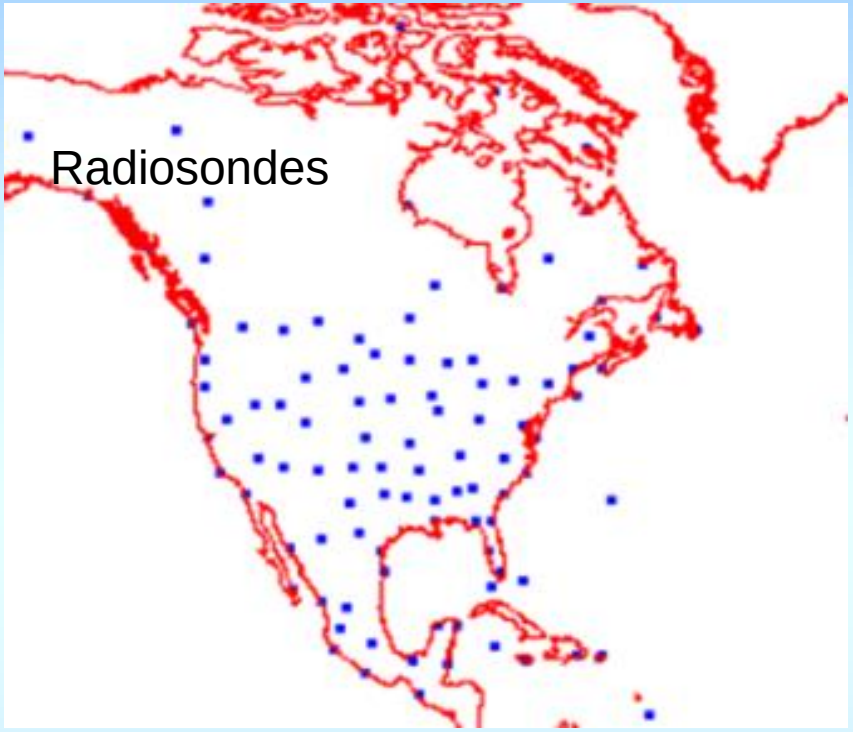


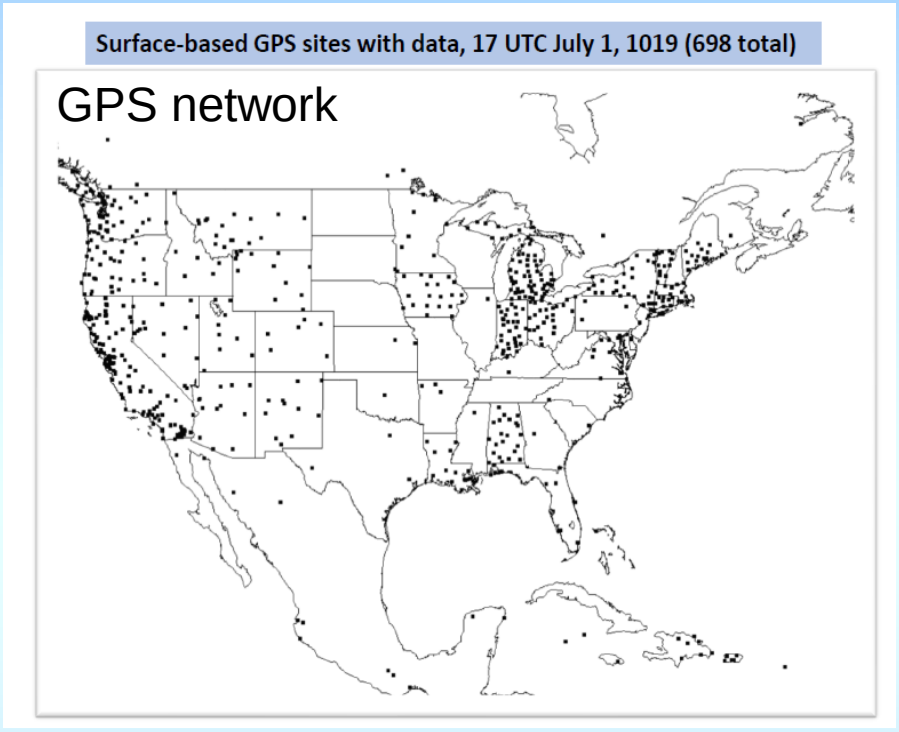
GPS short-range extrapolation



Blends inputs according to hierarchy. Version 2.0: GOES > GPS > Advected Microwave

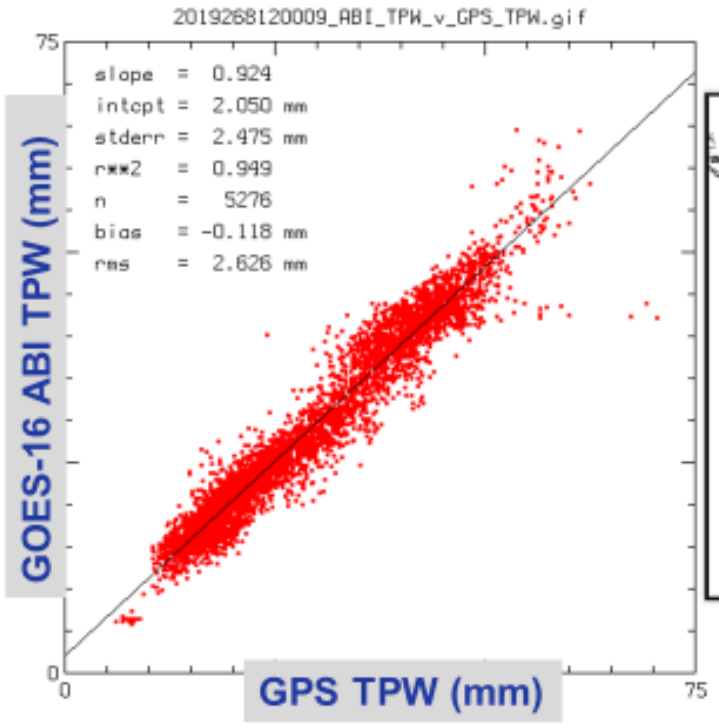
Independent Validation: Radiosondes over CONUS





- GPS is typically a great validation source (hourly, accurate, all weather), but since we want to use it in the product need another source.

GOES-16 TPW Continues to Validate Well Against Surface GPS Network



September 25, 2019

Surface GPS network – station density varies greatly

http://cat.cira.colostate.edu/GPS_TPW_stats/

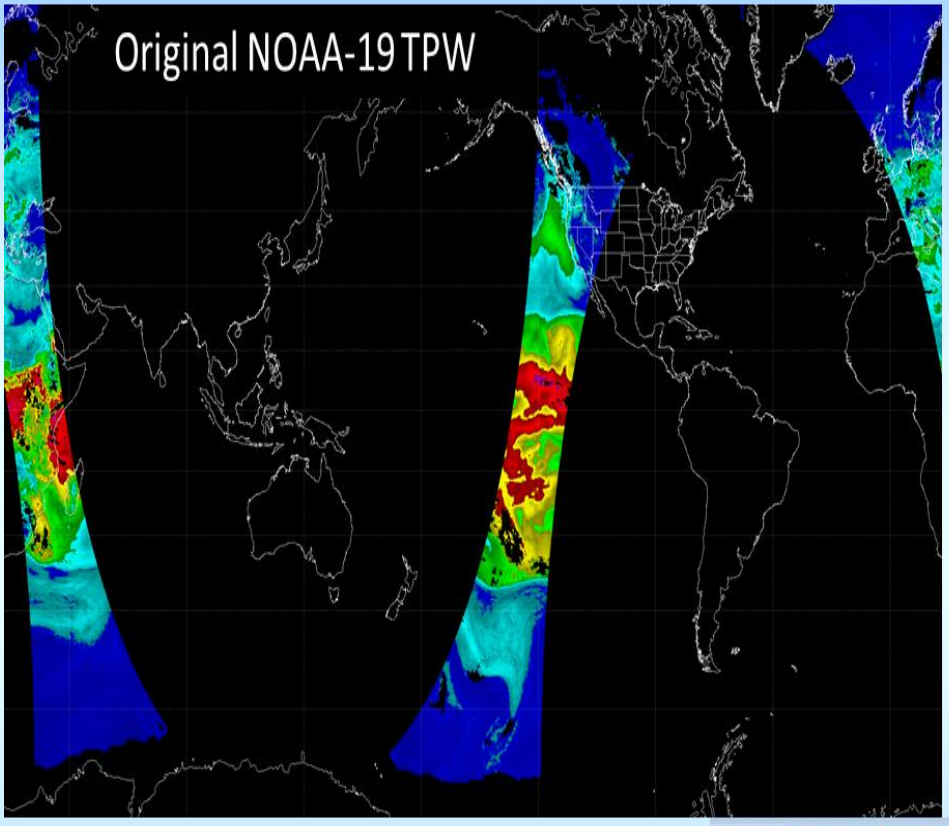
Supports results in:

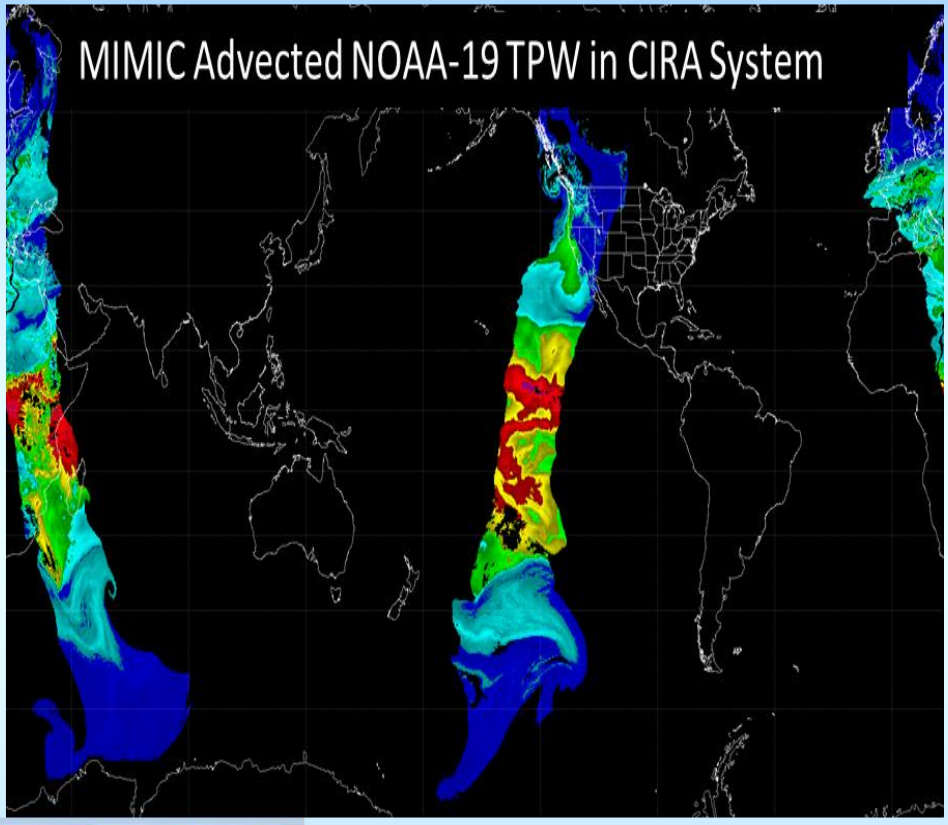
Schmit, T. J., Li, J., Lee, S. J., Li, Z., Dworak, R., Lee, Y.-K., et al. (2019). Legacy atmospheric profiles and derived products from GOES-16: Validation and applications. Earth and Space Science, 6, 1730–1748. https:// doi.org/10.1029/2019EA000729

2019 Forecaster Surveys of the New Total Precipitable Water Product (without GPS at the time)

Question	2019 HWT (severe wx experiment)	2019 FFaIR (flash flood experiment)
1. Did the new Version 1.0 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
2. Is hourly temporal resolution sufficient?	(responses = 35) 60 % Yes 40 % No	responses = 25) 68% Yes 12 % No (20 % N/A)
3. Would you like a TPW product that is completely independent of model moisture fields?	(responses = 35) Yes, but - 45% No, but - 40% No definitive answer - 15%	(responses = 15) Yes - 60% No - 7% Yes and No - 7% No position - 26%

Before / After Advection of TPW using MIMIC algorithm (Wimmers and Velden,2011)



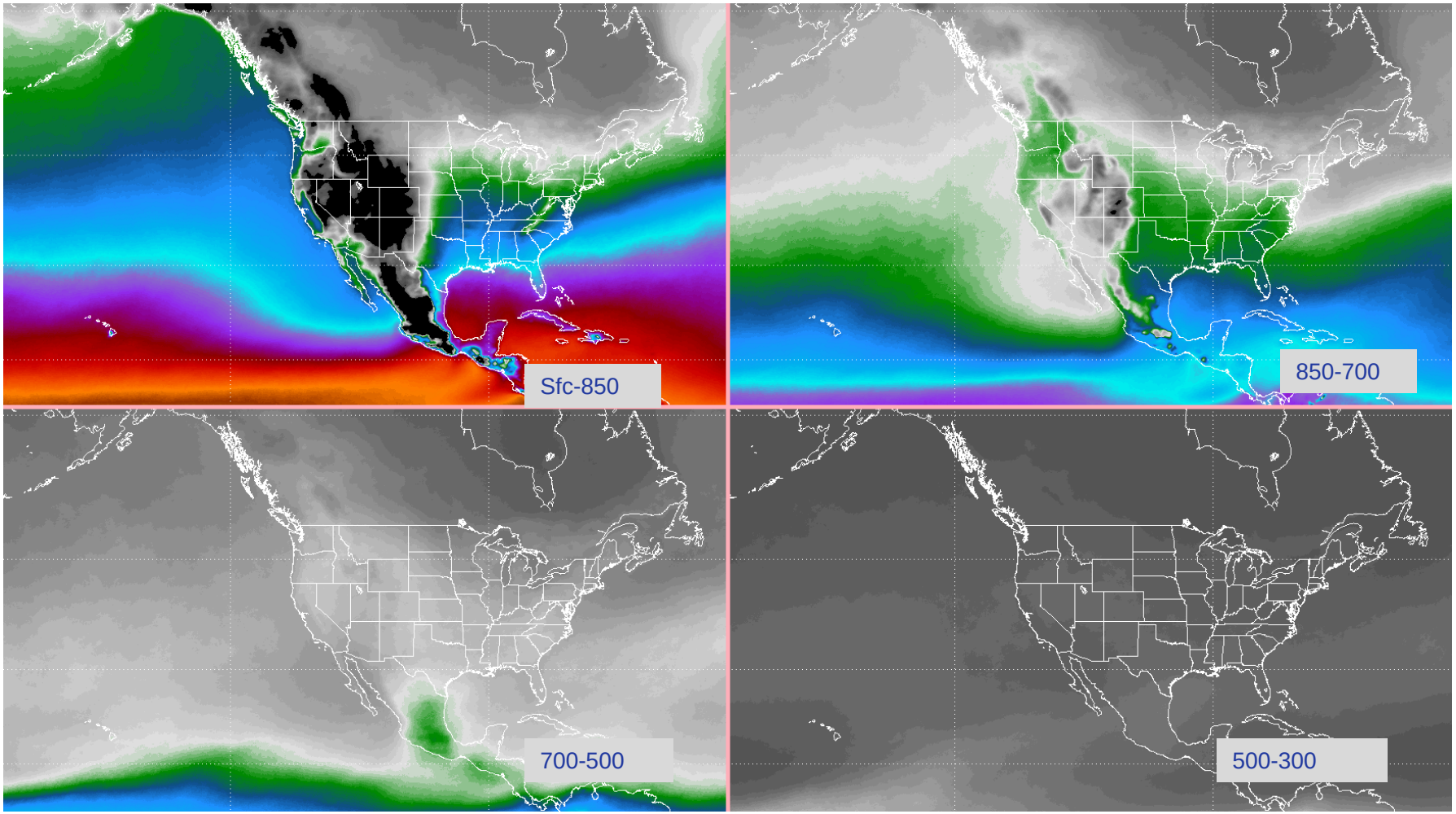


0 12 25 37 50 62 75

TPW (mm)

14 UTC 29 April 2020

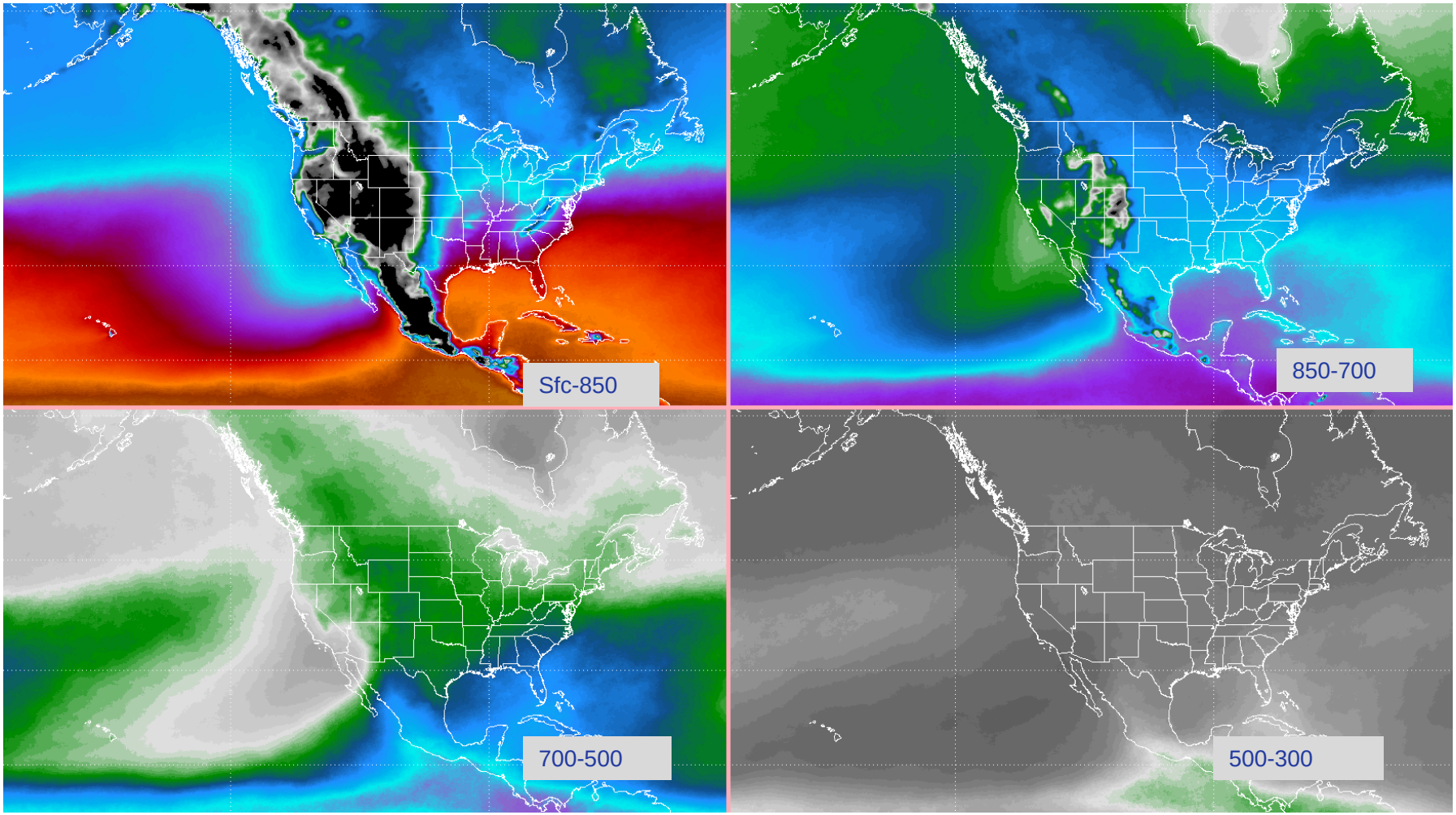
March 2013 – 2021 Median LPW



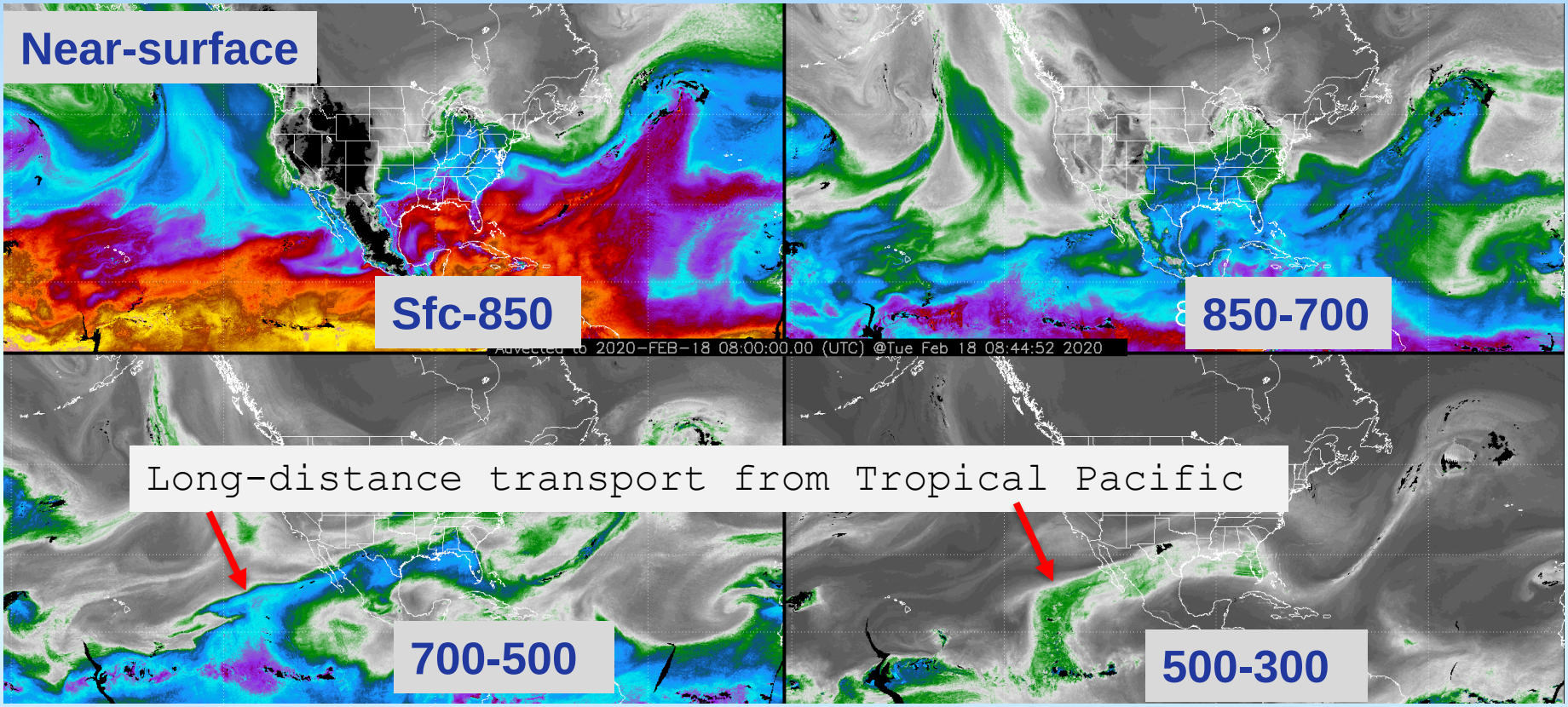
4 8 12 16 20 24 28 32

Layered Precipitable Water (mm)

June 2013 – 2021 Median LPW

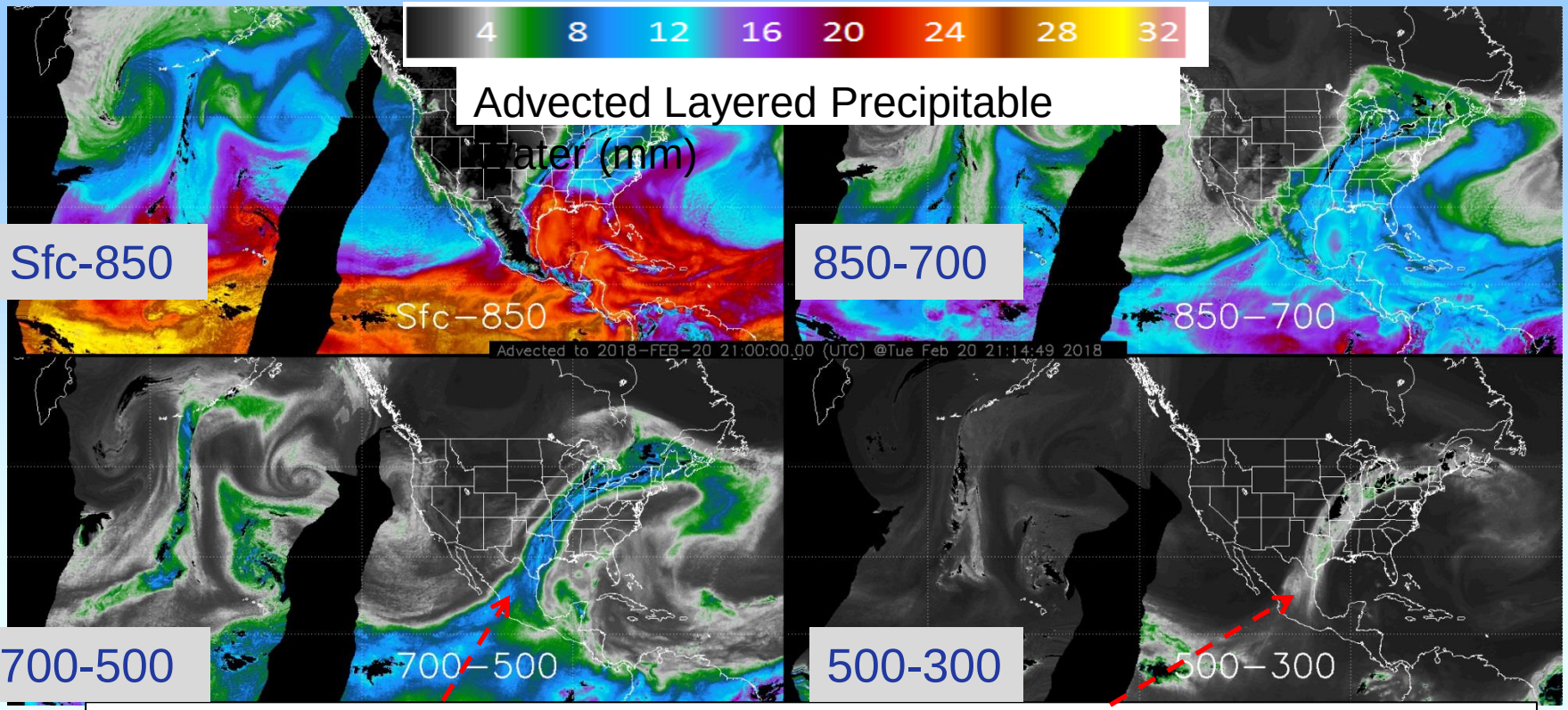


Now Forecasters Can See Four Layers of Water Vapor



Advected Layered Precipitable Water (mm)

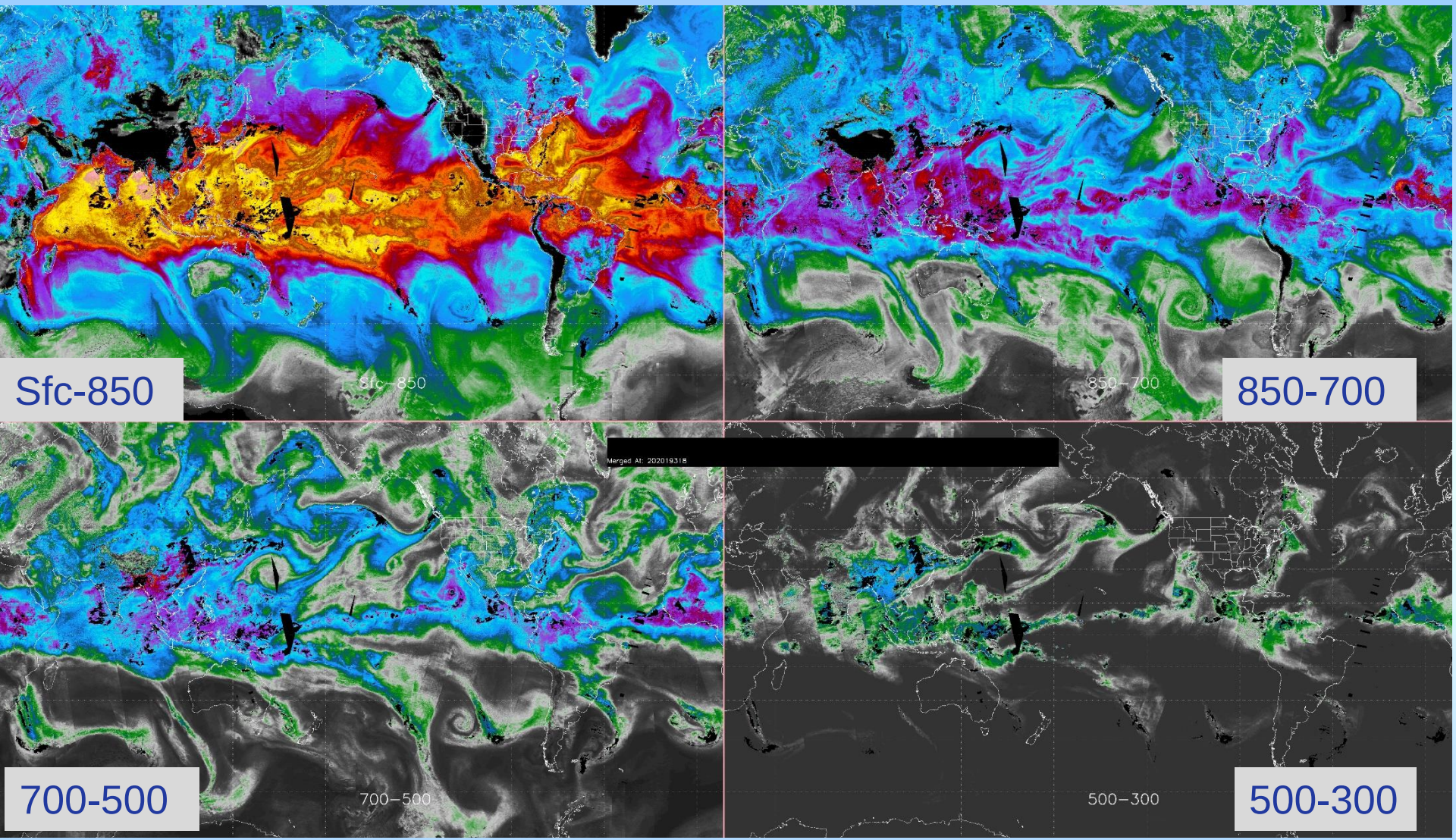
http://cat.cira.colostate.edu/sport/layered/advected/lpw_alt.htm



MESOSCALE PRECIPITATION DISCUSSION 0020
NWS WEATHER PREDICTION CENTER COLLEGE PARK MD 847 PM EST TUE FEB 20 2018 AREAS CONCERNING...HEAVY RAINFALL...FLASH FLOODING POSSIBLE VALID 210145Z - 210745Z

…DISCUSSION...A DEEP FETCH OF MOISTURE EXTENDED INTO THE ARKLATEX REGION ALONG A SLOWLY ADVANCING COLD FRONT...WITH PRECIPITABLE WATER VALUES NEAR THE UPPER ECHELONS OF WHAT HAS BEEN OBSERVED AT SOUNDING SITES IN THE MONTH OF FEBRUARY. IN FACT...THE 00Z SOUNDING FROM SHREVEPORT LA RECORDED 1.72 INCH PW...WHICH BROKE THE FEBRUARY RECORD (1.69 IN. **CIRA LAYER PW** PRODUCTS REVEAL A PLUME OF SUBSTANTIAL MOISTURE THAT EXTENDS INTO THE MID-UPPER LEVELS (BOTH THE 700-500MB AND 500-300MB LAYERS)...AND THIS DEEP MOISTURE PLUME ORIGINATED AS FAR SOUTH AS 10N IN THE TROPICAL EASTERN PACIFIC. THE DEEP MOISTURE PROFILE AND RECORD PWATS SHOULD FAVOR EFFICIENT RAINFALL PRODUCTION IN CONVECTIVE BANDS THIS EVENING AND INTO THE OVERNIGHT HOURS.

Near-Global View of LPW in Near Realtime



4 8 12 16 20 24 28 32

Layered Precipitable Water (mm)

18 UTC 11 July 2020