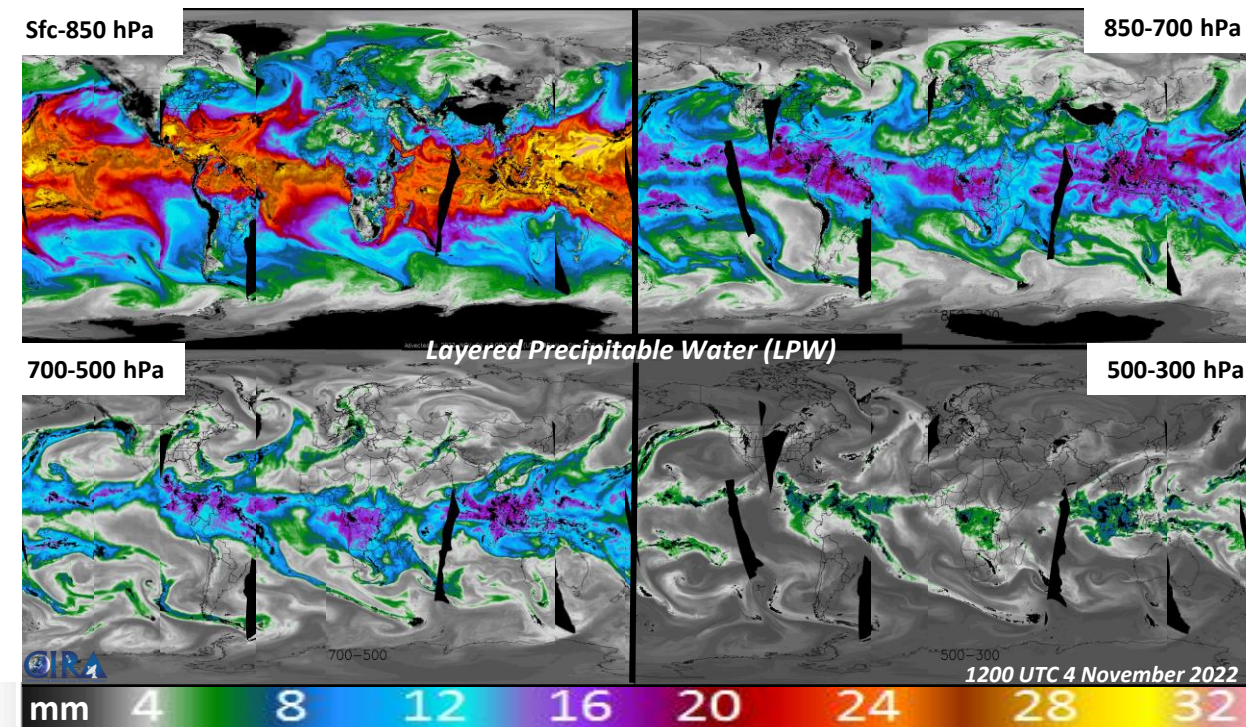
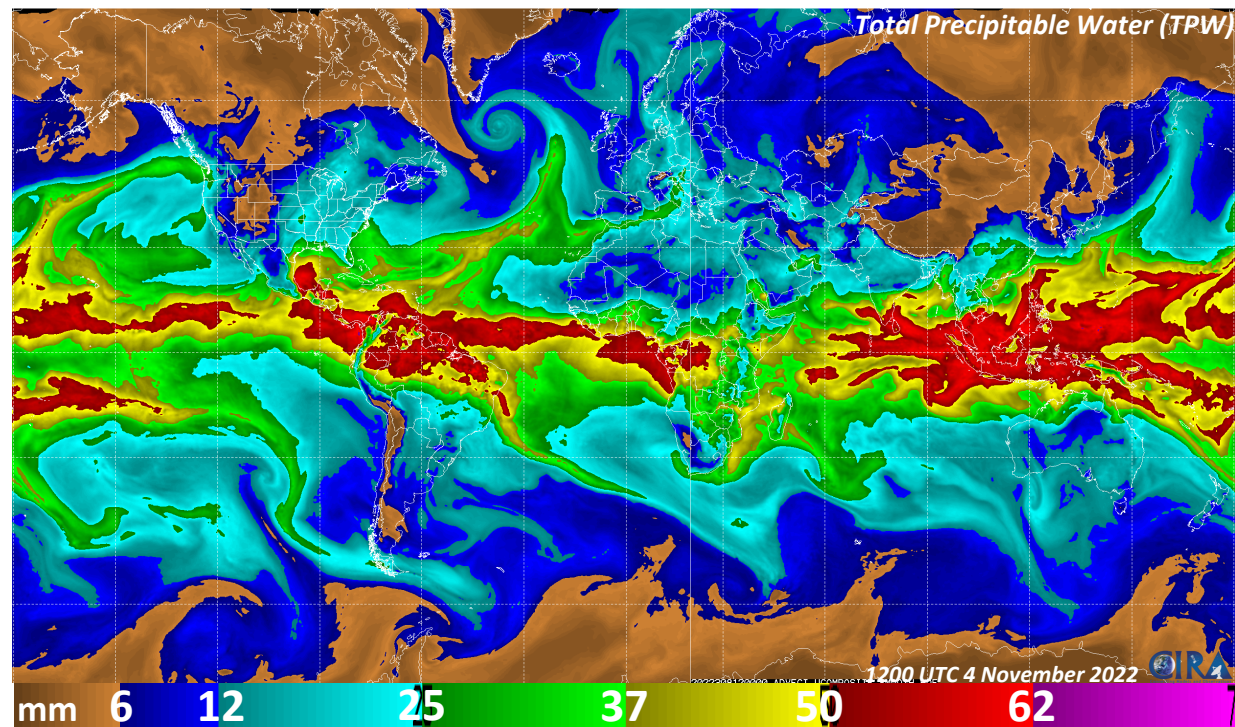


Total and Layered Precipitable Water Vapor Products – Applications for Forecasting Hazardous Precipitation Events – Part 1



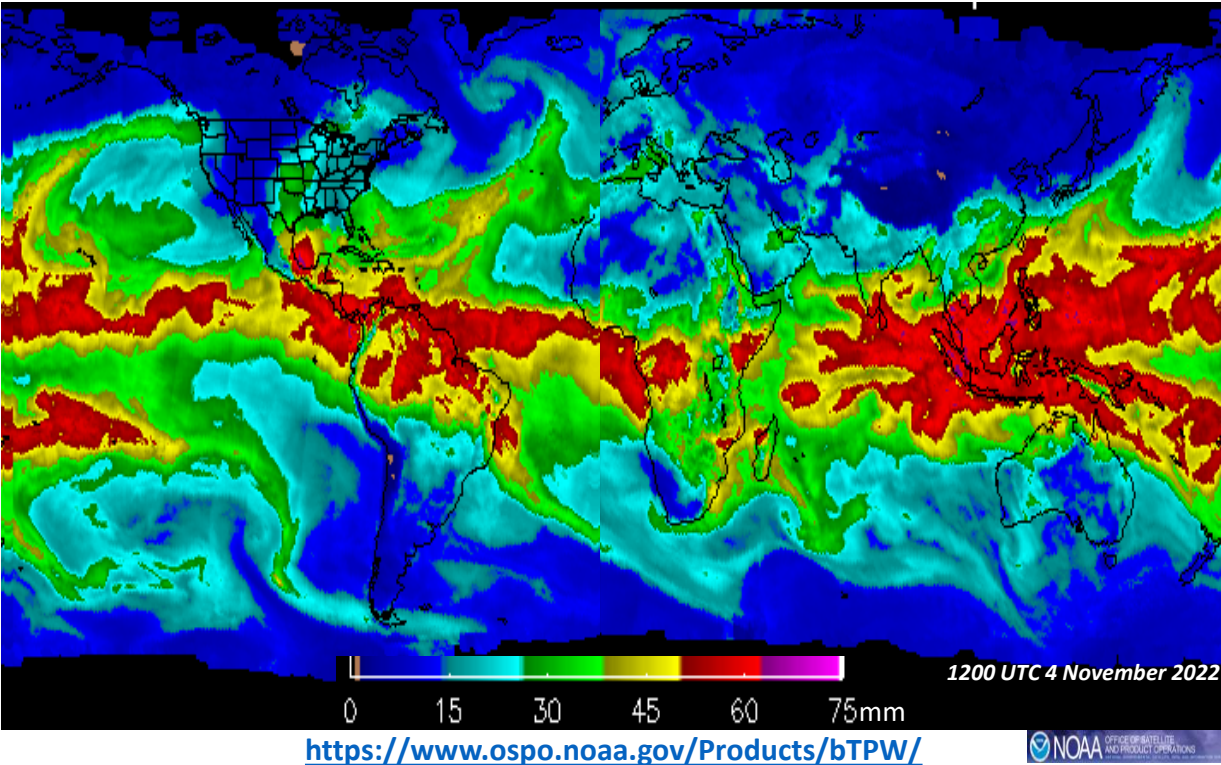
Sheldon Kusselson,
Research Associate, Cooperative Institute for Research in the Atmosphere (CIRA)/Colorado State University
Retired NOAA/NESDIS

Contributions by John Forsythe, Stanley Kidder and Dan Bikos, CIRA/Colorado State University



Blended Total Precipitable Water (bTPW) Being Upgraded to Advected Total Precipitable Water (aTPW) in 2023

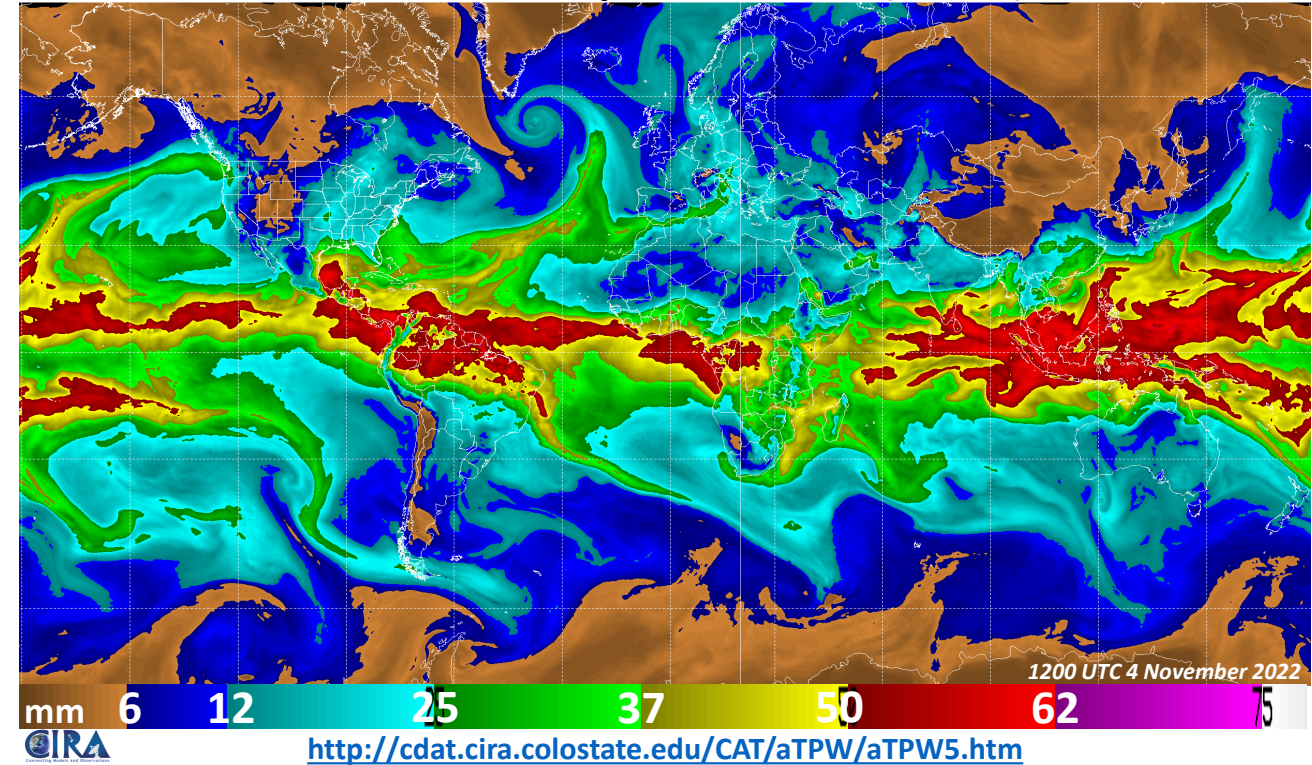
Current NOAA/NESDIS Satellite Derived Operational Blended Total Precipitable Water (bTPW) Product



Blended TPW (bTPW)

- New image passes replace old in composite, so not timely
- Operational for forecasters since 2009, so upgrade necessary
- Satellites used: N-19/20, S-NPP, Metop-B/C, GCOM-W, GPM GMI
- Over Continental US: Blend of MIRS TPW, GPS-MET, GOES ABI

Upgraded CIRA Satellite Derived Experimental Advected Total Precipitable Water (aTPW) Product



Advised TPW (aTPW)

- New image passes advected to time of composite image; more timely
- Replacing bTPW for forecasters in 2023
- Satellites used: N-20/21, Metop-B/C, GCOM-W, GPM GMI
- Over Continental US: Blend of MIRS TPW, GPS-MET, GOES ABI

“Atmospheric Rivers” (AR) of Moisture that can Result in Heavy Amounts of Precipitation

Early Season California
Heavy Rain/Flooding



Washington DC Area
76+ cms of Snow

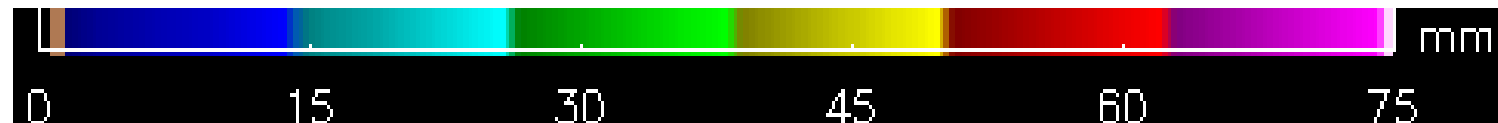
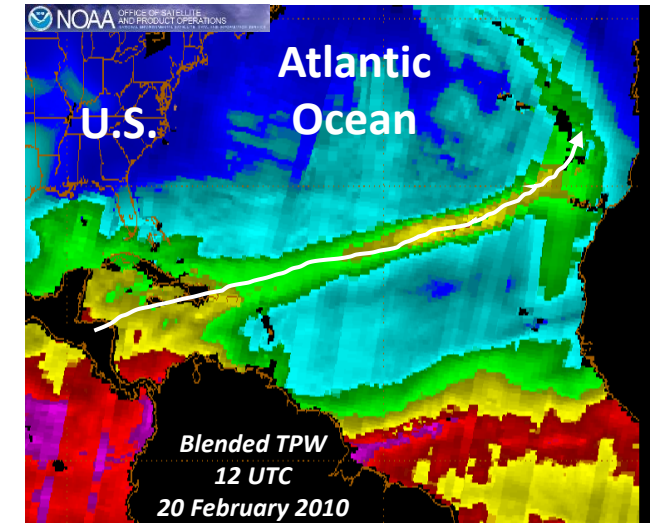
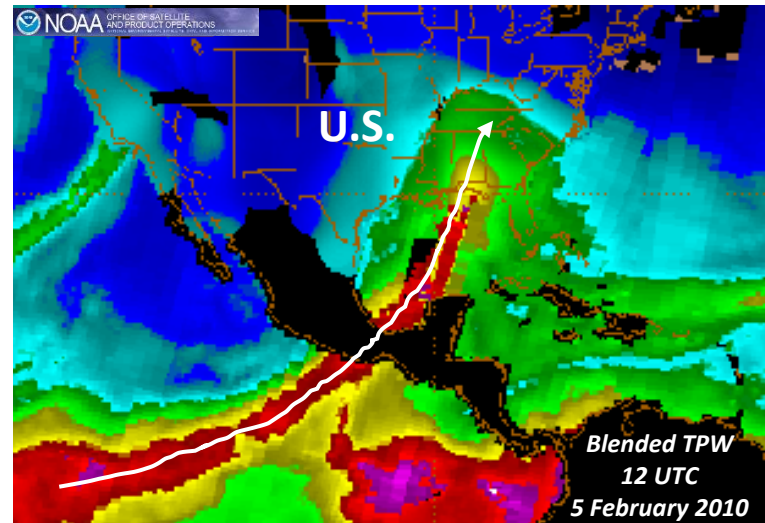
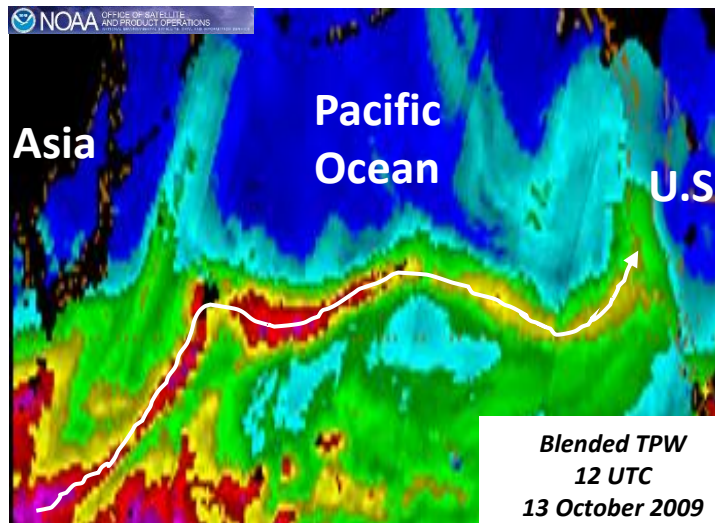


Dave Dildine/
WTOP

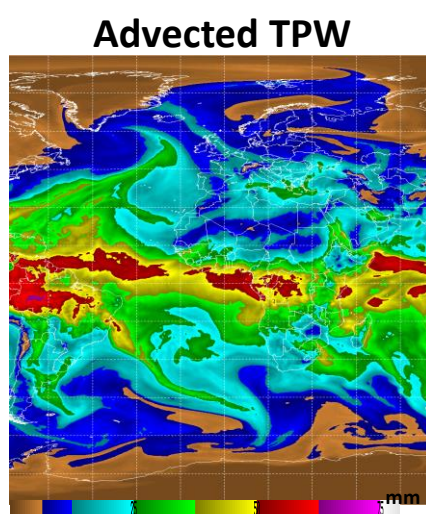
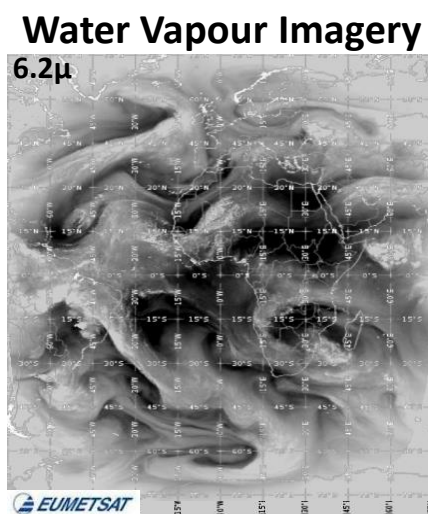
Madeira Floods
and Mudslides



AP

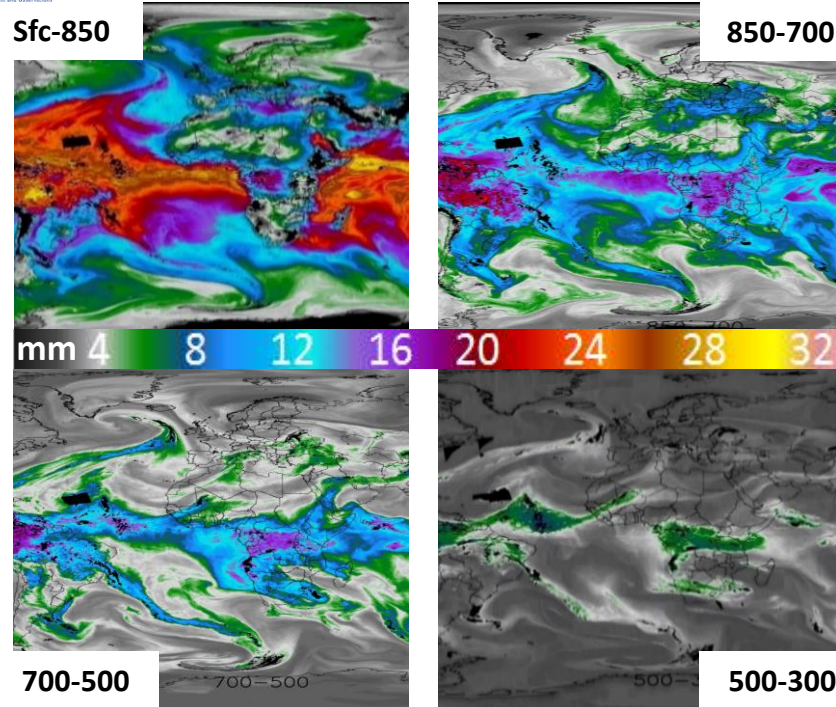


With Destructive Effects



0300 UTC 19 November 2022

CIRA Advectioned Layered Precipitable Water (ALPW) for 0300 UTC 19 November 2022



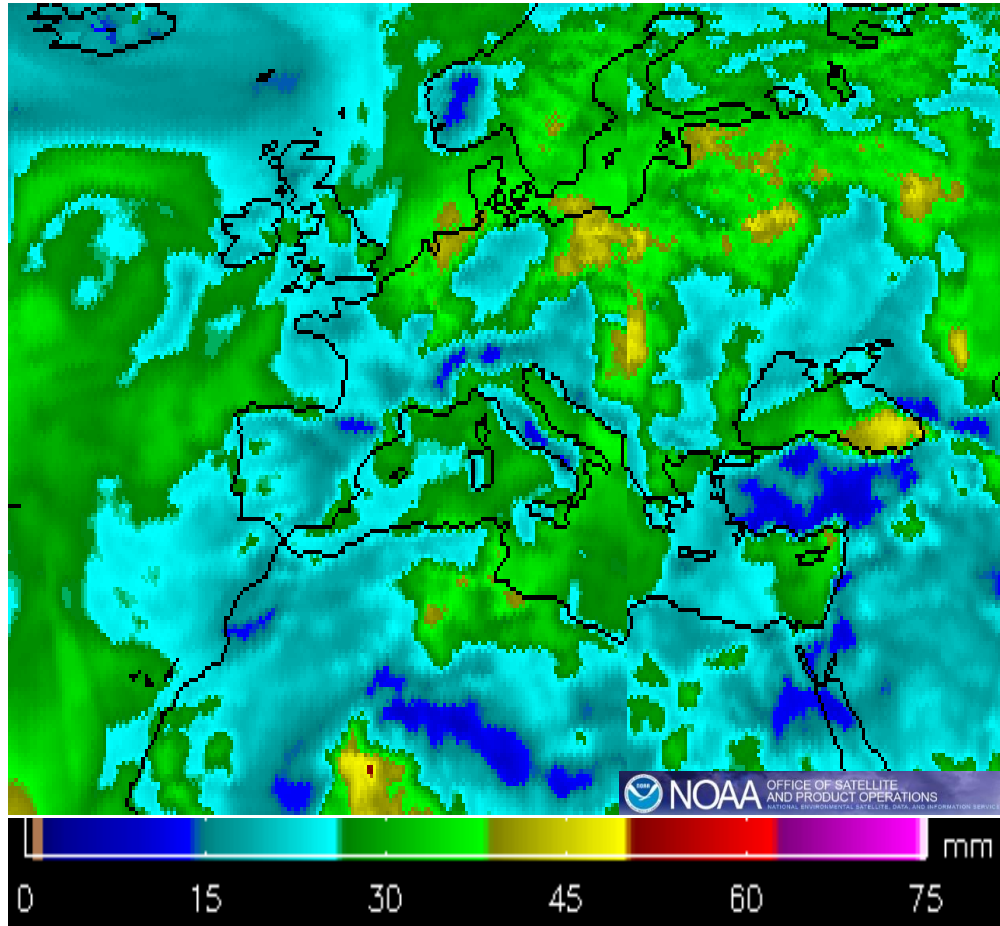
Blended total, layered water vapor products fill a void in observations

Moisture Product	Spatial Resolution and Coverage	Temporal Resolution	Strengths	Limitations
Radiosondes	~ 500 km over land None over ocean	12 hours	Trusted. High vertical resolution.	Spatial and temporal coverage
Water Vapor channel (6.3 and 7.3 μm) imagery	2 km, near-hemispheric coverage	15 minutes or less	Very high spatial & temporal resolution. Animations show flow.	Upper level moisture only. No vapor signal in clouds. Variable sensing depth
Advectioned TPW Advectioned Layered PW	16 km, global	1-3 hours (varies based on time of day), but <u>advection improves latency</u>	Retrievals in clouds Near-global coverage Multiple input types including Metop-B and Metop-C	No retrievals in heavy precipitation

For the future, interested in working with the Meteosat Third Generation (MTG) Hyperspectral Sounder to see how it compares, perhaps could be blended

Sometimes Satellite Total Precipitable Water (TPW) and GEO Imagery Are Not Enough

Satellite Total Precipitable Water (TPW)
for 00 UTC 15 July 2021

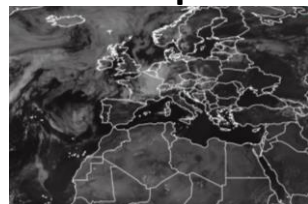
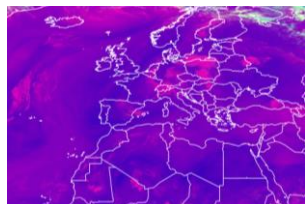
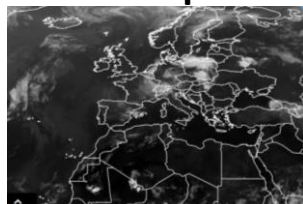
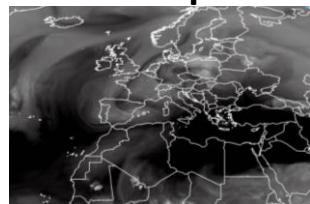


WV6.2 μ m

IR10.8 μ m

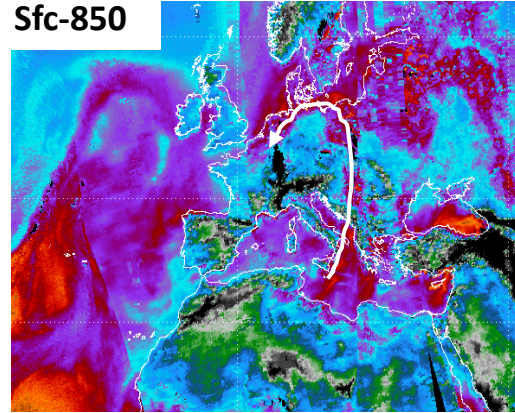
Conv RGB

VIS.6 μ m

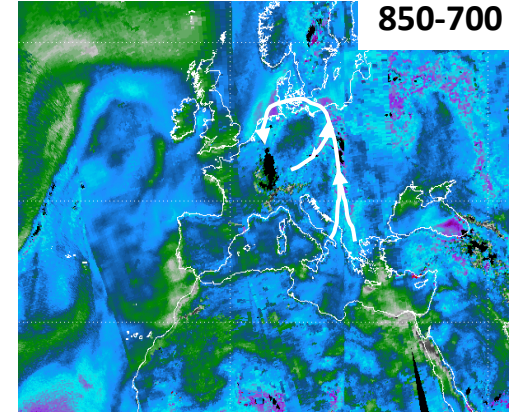


CIRA Advected Layered Precipitable Water (ALPW)
for 00 UTC 15 July 2021

Sfc-850

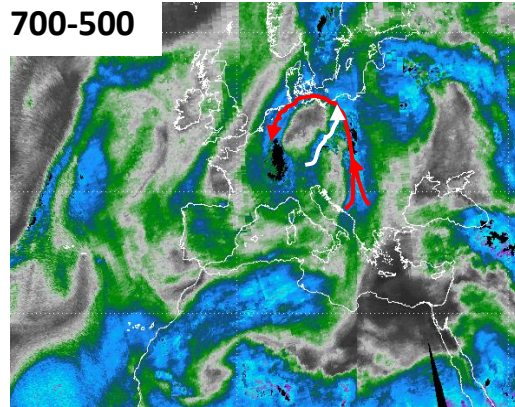


850-700

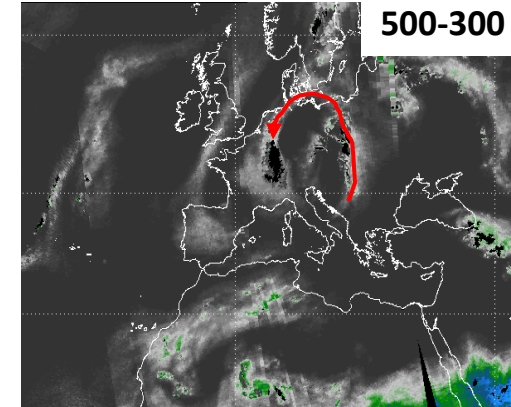


Average wind
flow in layer
below 700 hPa

700-500



500-300



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

Average wind
flow in layer
above 700 hPa

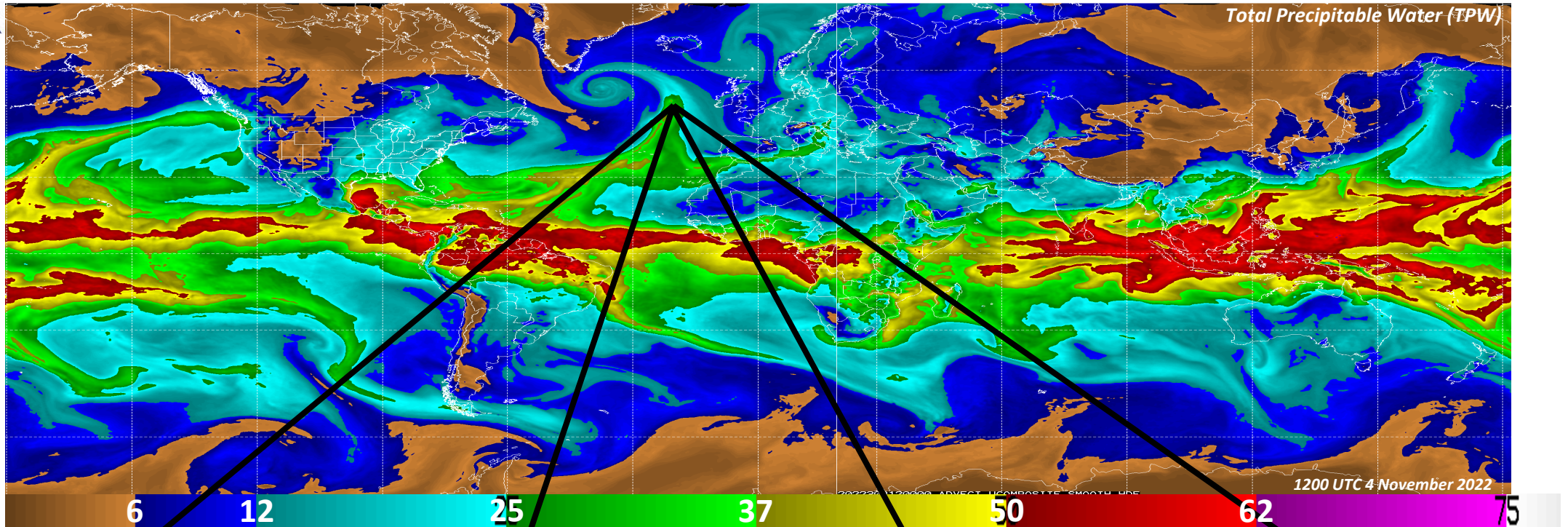
mm 4 8 12 16 20 24 28 32



00 UTC 15 July WV & IR
00 UTC 15 July Conv RGB
14 UTC 14 July VIS

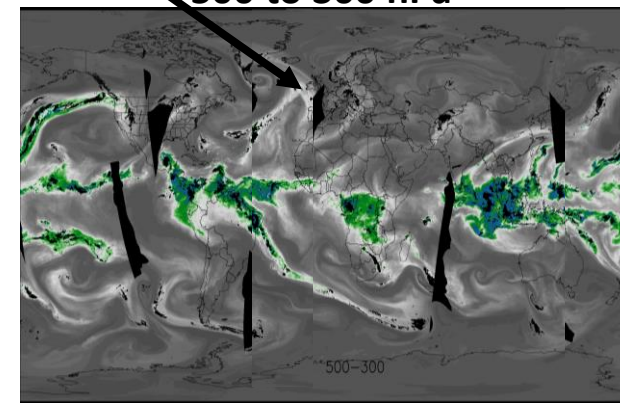
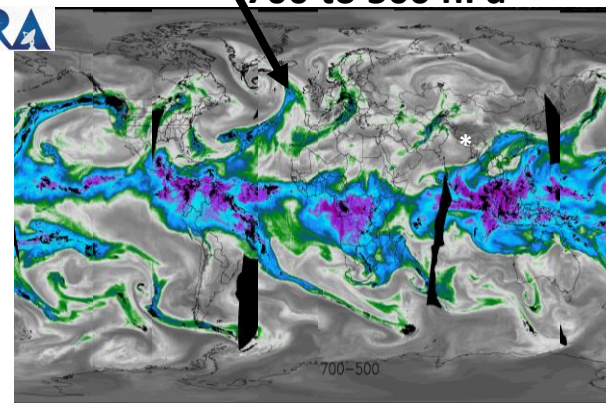
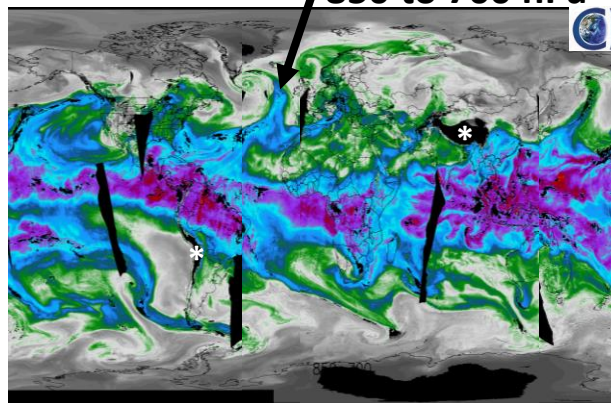
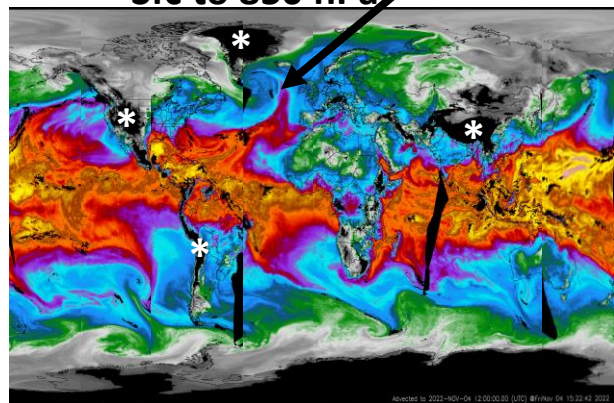
***This is why the layered PW
was an important addition
to the TPW Product***

How the CIRA Experimental Advected Layered Precipitable Water (ALPW) is Made



Total Precipitable Water separated into four distinct layers

Sfc to 850 hPa 850 to 700 hPa 700 to 500 hPa 500 to 300 hPa



* **Note:** No PW data as layer below surface



Note: GFS winds are only model used to produce product

Some Applications of the Advection Layered Precipitable Water (ALPW) for Various Cases

- **Synoptic Conveyor Belt**
- **Developing/Deepening Coastal Winter Storm**
- **Severe Weather**
- **Out of Season, Hazardous Weather Events**
- **Remnant Tropical Storm Moisture**

TROugh of Warm air ALoft (TROWAL) – Warm Moist Conveyor Belt into Cold Air

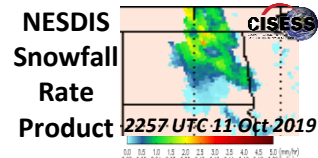
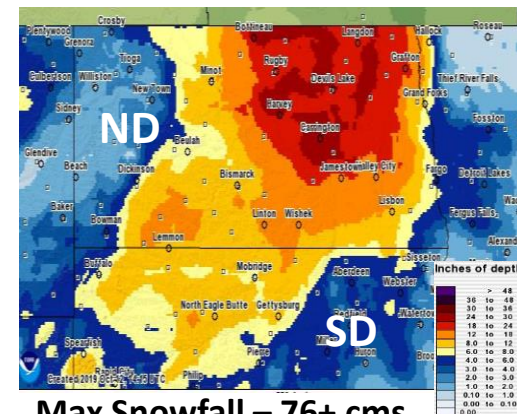
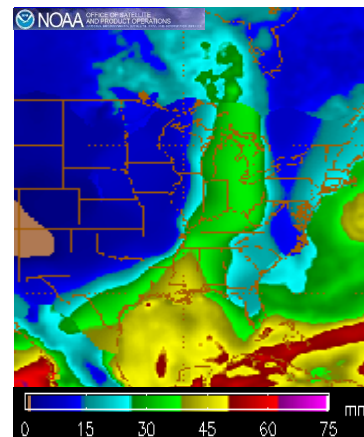
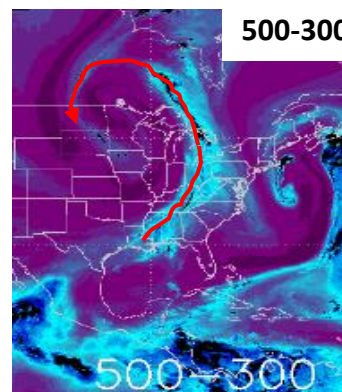
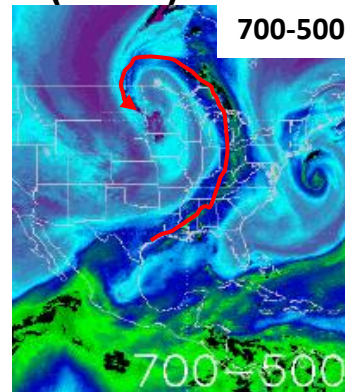
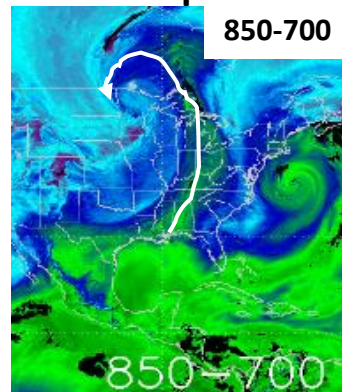
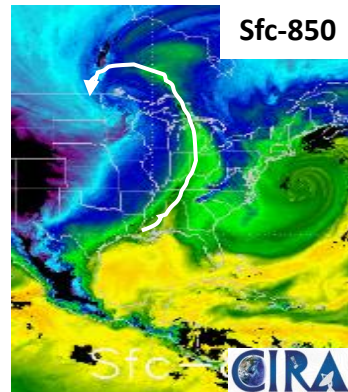
ALPW and TPW Comparisons over the U.S.



CIRA Advected Layered Precipitable Water (ALPW) for 00 UTC 12 October 2019

Total PW
00 UTC 12 Oct 2019

72-h Snowfall Through
12 UTC 12 October 2019



average wind flow in layer below 700 hPa for moisture advection

average wind flow in layer above 700 hPa for moisture advection

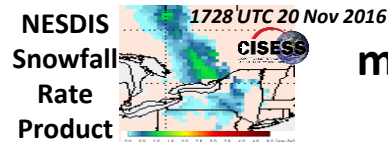
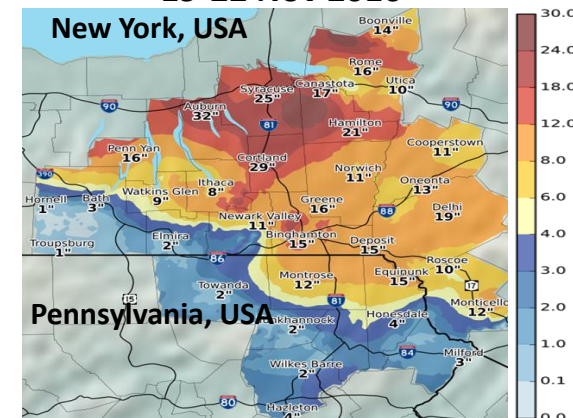
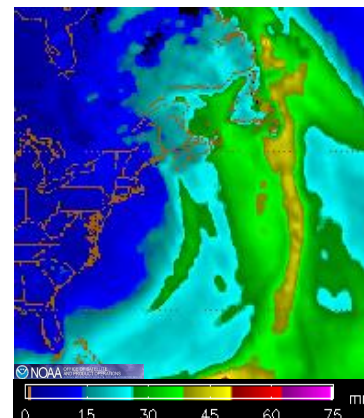
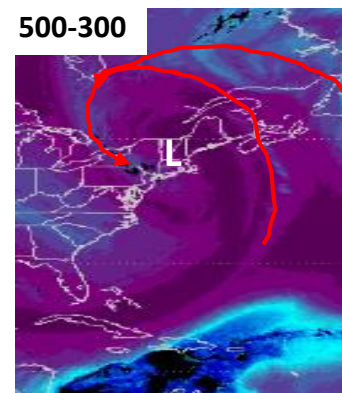
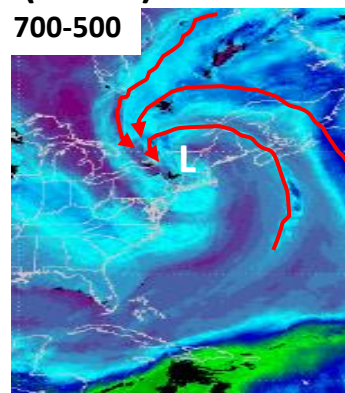
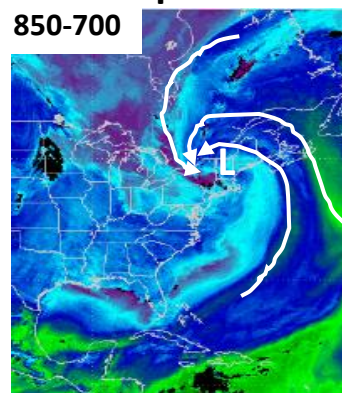
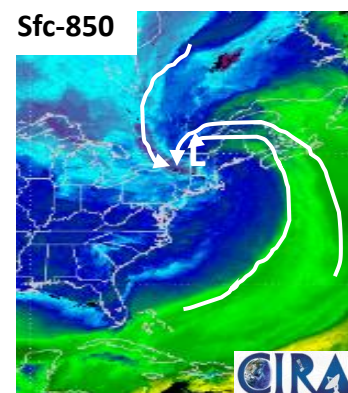
Max Snowfall – 76+ cms
North Dakota, USA



CIRA Advected Layered Precipitable Water (ALPW) for 21 UTC 20 November 2016

Total PW
21 UTC 20 Nov 2016

Snowfall Totals
19-22 Nov 2016



moist conveyor belt shows better in each of the four distinct layers of ALPW

Max Snowfall – 76+ cms
New York, USA

Prepared by Sheldon Kusselson

CIRA Advected Layered Precipitable Water (LPW) for 00 UTC 15 July 2021

Bruno Fahy/AFP/
Getty Images

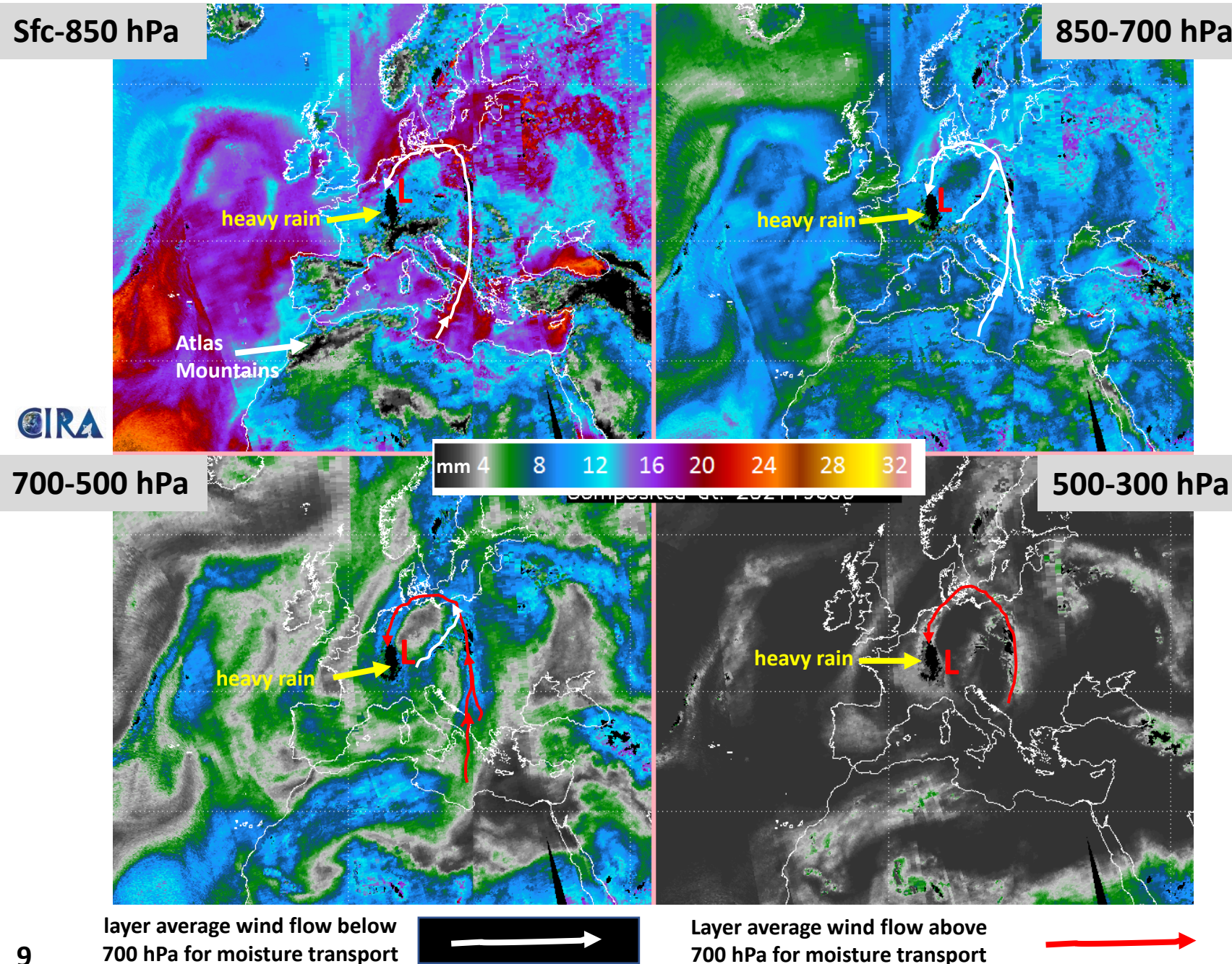


Sebastian Schmitt/dpa/AP

Some Notes on this Central Europe

TROWAL/Flood Case:

- Sfc-850 hPa layer - “atmospheric river” of moisture not continuous because of terrain effects; still has the effect of a continuous moist long-fetch conveyor belt transport.
- Converging moisture at 850-700 and 700-500 hPa layers provides added depth to total column.
- “Atmospheric rivers” of moisture at three layers originating in Mediterranean and aligned with each other for deep moisture transport.
- Though 500-300 hPa layer moisture low, still helpful when aligned with other moisture layers
- Low provides instability to act on deep moisture to produce excessive rainfall



Analysis by Sheldon Kusselson

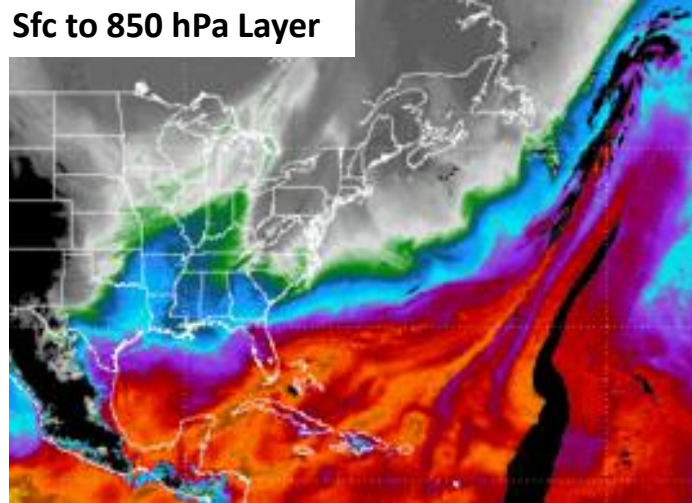
Application of Advected Layered Precipitable Water: Conveyor Belt

Finding the Best Dendritic Growth for Heavy Winter Snowfall – US East Coast Snow Storm of Jan 2022

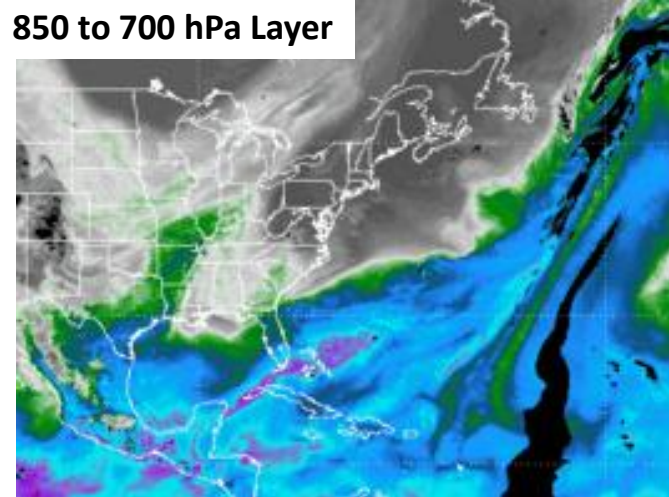
CIRA Advected Layered Precipitable Water Loop for the Period
1400 UTC 27 January to 12 UTC 30 January 2022



Sfc to 850 hPa Layer

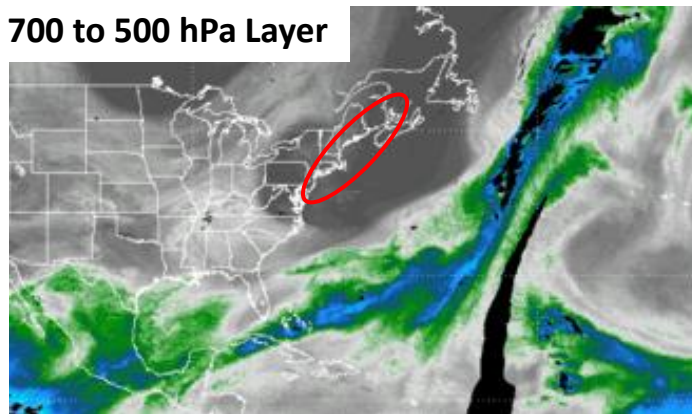


850 to 700 hPa Layer

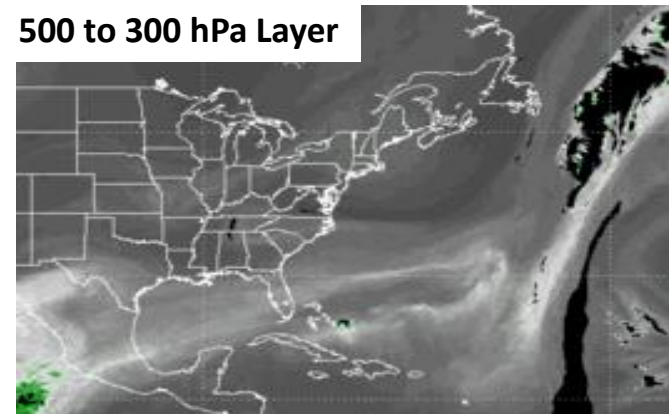


mm 4 8 12 16 20 24 28 32

700 to 500 hPa Layer

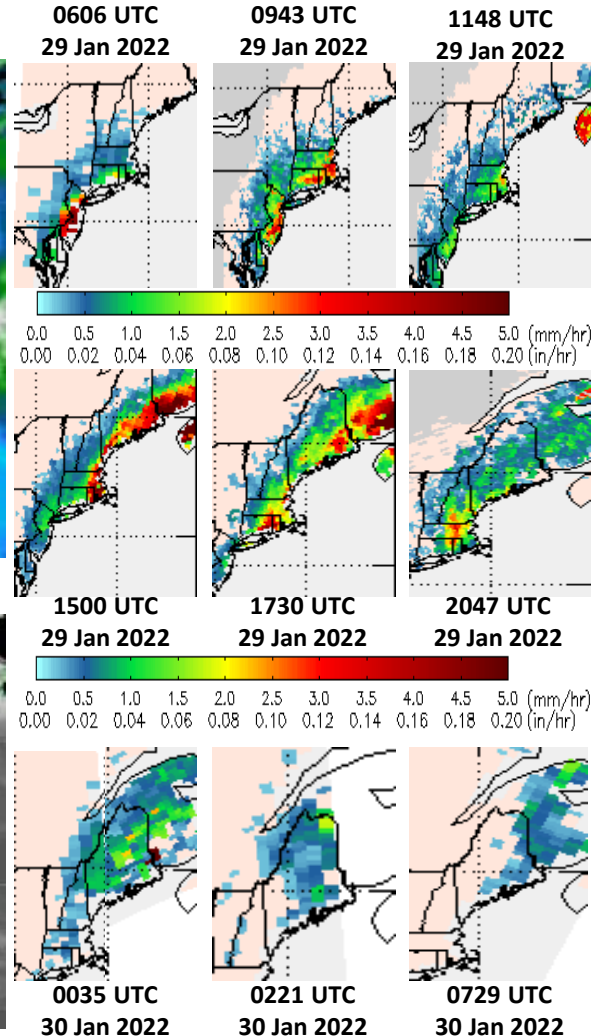


500 to 300 hPa Layer



Advected to 2022-JAN-27 14:00:00.00 (UTC) @Thu Jan 27 14:31:20 2022

Satellite Snowfall Results



<http://cics.umd.edu/sfr>

Highest precipitable water values in the favored 700-500 hPa dendritic growth rate layer marks area of **very heavy snow** along the US East Coast.

Classic Severe Weather Signature in the Advected Layered Precipitable Water Product

Middle of the U.S. Tornadoes and Damaging Winds

layer average wind flow
below 700 hPa for
moisture transport



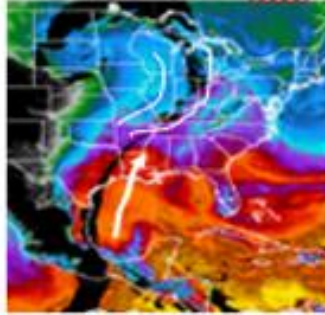
Boundary or front



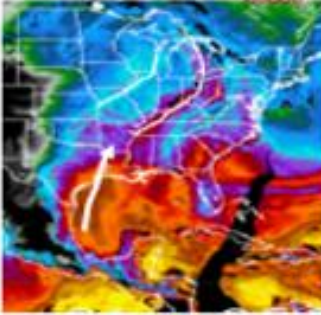
layer average wind flow
above 700 hPa for
moisture transport



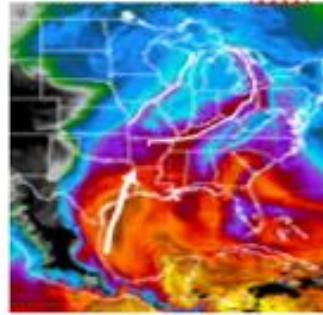
18 UTC 22 May 2019
ALPW Sfc-850 hPa



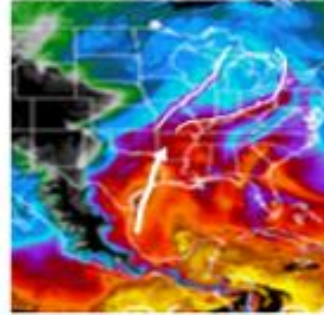
21 UTC 22 May 2019
ALPW Sfc-850 hPa



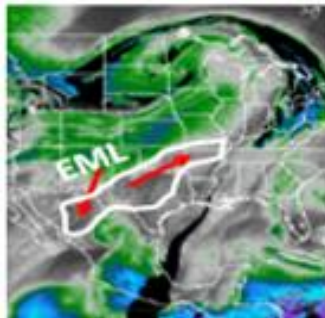
00 UTC 23 May 2019
ALPW Sfc-850 hPa



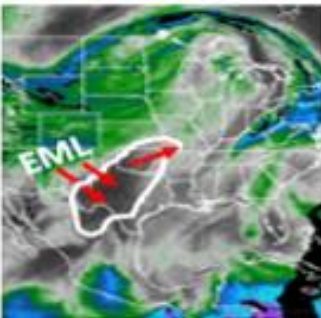
03 UTC 23 May 2019
ALPW Sfc-850 hPa



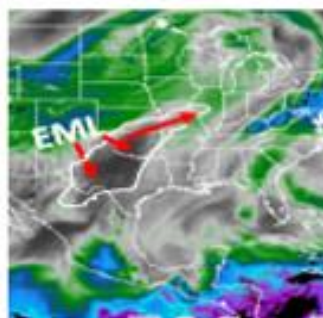
mm 4 8 12 16 20 24 28 32



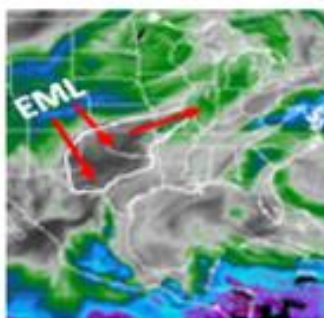
ALPW 700-500 hPa



ALPW 700-500 hPa



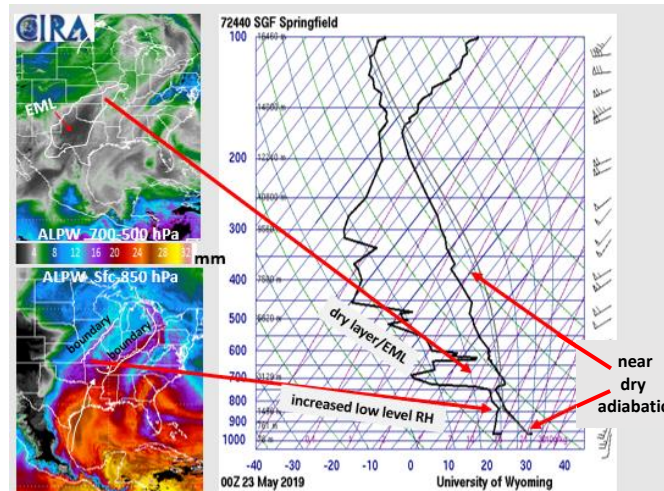
ALPW 700-500 hPa



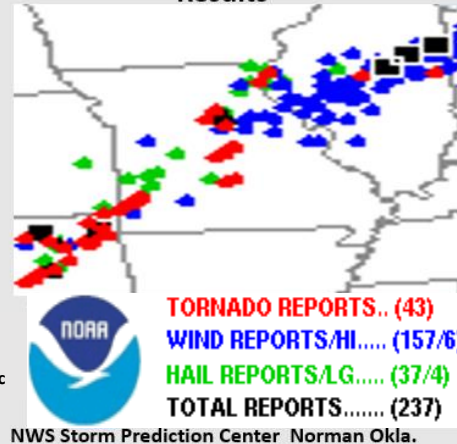
ALPW 700-500 hPa

Elevated Mixed Layer (EML)

is a layer of warm, dry air advected from a high terrain region to another location, characterized by a capping inversion and well mixed air above it.



Results



Key ALPW Points for this Severe Weather

- Persistent low-layer max amount moisture advection
- Dry air/EML middle-layer signature and advection
- EML origins C Mexico
- Boundary helpful to focus area for severe
- Confirmation with a RAOB sounding

Classic Severe Weather Signature in the Advected Layered Precipitable Water Product

The Derecho Storms of 18 August 2022...what did the ALPW product show ?

layer average wind flow
below 700 hPa for
moisture transport

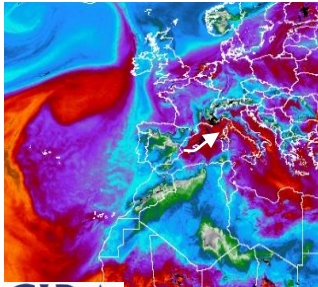


layer average wind flow
above 700 hPa for
moisture transport

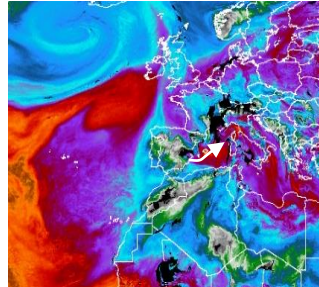


EML= Elevated Mixed Layer

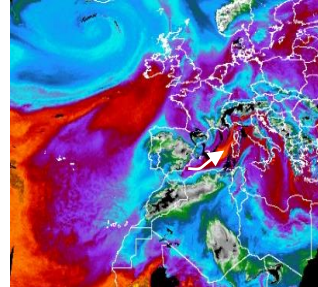
18 UTC 17 Aug 2022
ALPW Sfc-850 hPa



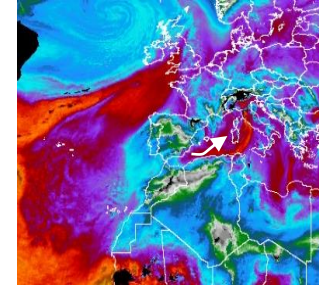
03 UTC 18 Aug 2022
ALPW Sfc-850 hPa



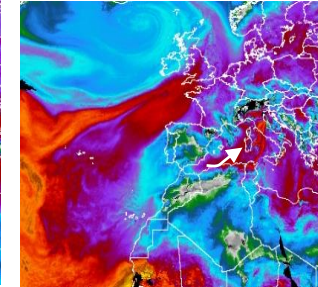
09 UTC 18 Aug 2022
ALPW Sfc-850 hPa



15 UTC 18 Aug 2022
ALPW Sfc-850 hPa



18 UTC 18 Aug 2022
ALPW Sfc-850 hPa

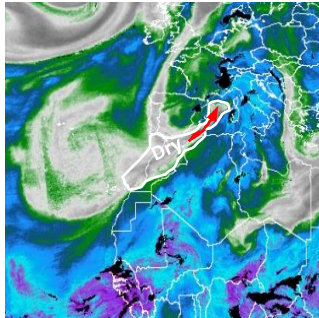


CIRA

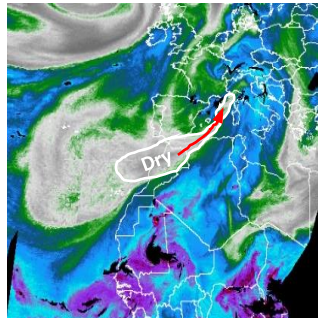
mm 4 8 12 16 20 24 28 32



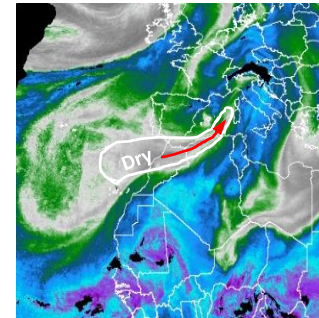
ALPW 700-500 hPa



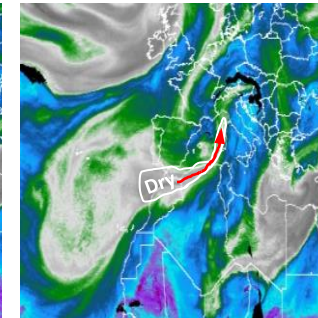
ALPW 700-500 hPa



ALPW 700-500 hPa



ALPW 700-500 hPa

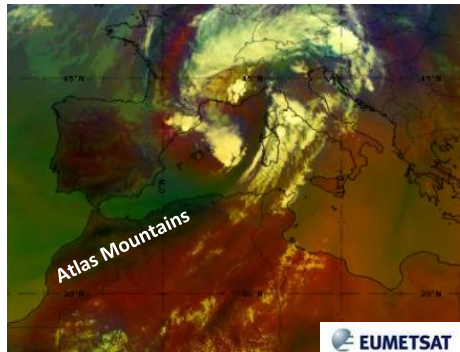


ALPW 700-500 hPa

Key ALPW Points

- Small, but persistent low-layer max amount moisture advection
- Dry air/EML middle-layer signature and advection
- EML origins NW Africa/Atlas Mtns
- Confirmation with a RAOB sounding
- What about 700-500 moisture connection from Africa ahead of EML?

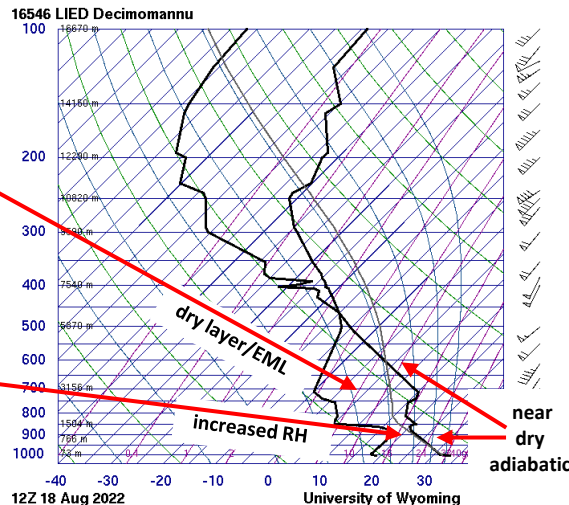
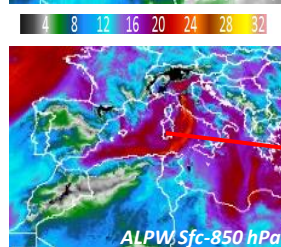
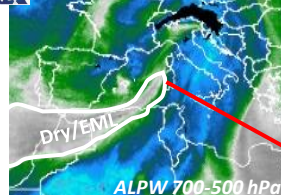
MSG Air Mass RGB



1500 UTC 18 Aug 2022

EUMETSAT

CIRA 15 UTC 18 Aug 2022



Results



Clash of Subtropical Moisture and Surface Cold to Help Produce Extraordinary Out-of-Season Weather

CIRA Advected Layered Precipitable Water for 06 UTC 29 Sep 2019

Sfc to 850 hPa

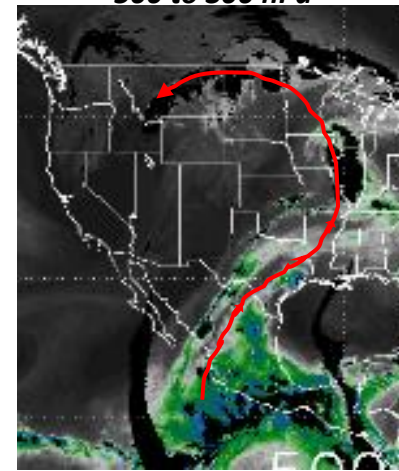
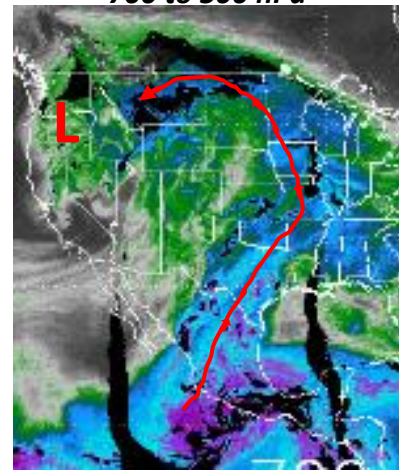
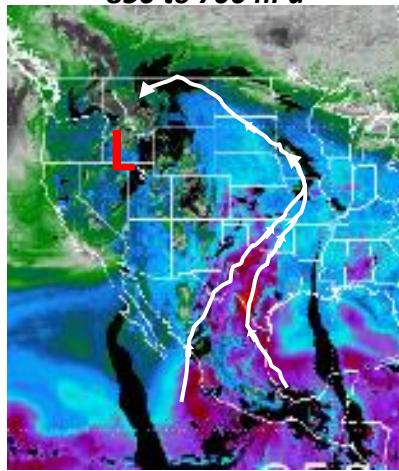
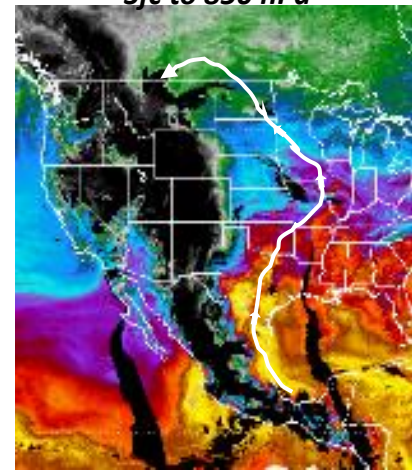
850 to 700 hPa

700 to 500 hPa

500 to 300 hPa



Snow Reports, Sept. 28-30, 2019



layer average wind flow
below 700 hPa for moisture transport

layer average wind flow
above 700 hPa for moisture transport

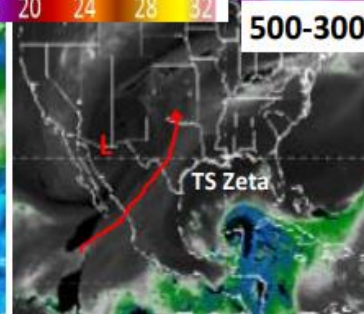
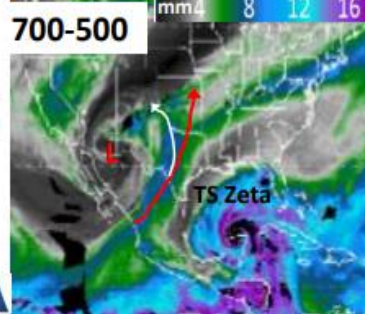
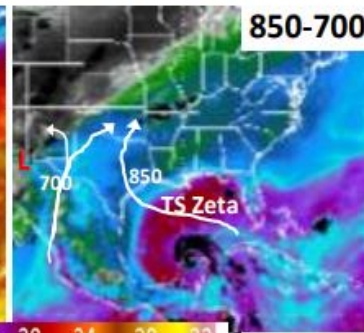
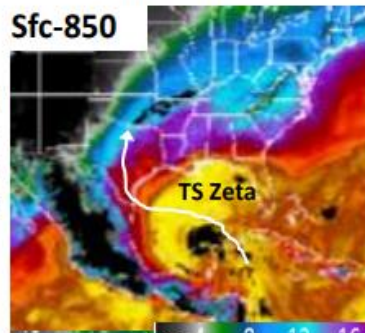
Oklahoma Ice Storm – 27 October 2020



12 UTC
27 Oct 2020

wind at layer
below 700 hPa
for moisture
advection

wind at layer
above 700 hPa
for moisture
advection



Advected Layered Precipitable Water

Important Points Forecasters Need to Know

- At surface, cold air advecting in; above surface, milder air advecting over ice storm area
- High PW moisture from late season TS Zeta in Gulf of Mexico advecting into ice storm area
- Additional PW moisture above 700 hPa advecting from tropical East Pacific; helping to deepen moist column over below freezing surface of ice storm area
- Moist deformation/diffuence at 850-700 and 700-500 hPa layers helped increase precipitation rates and amounts over ice storm area leading to devastating results

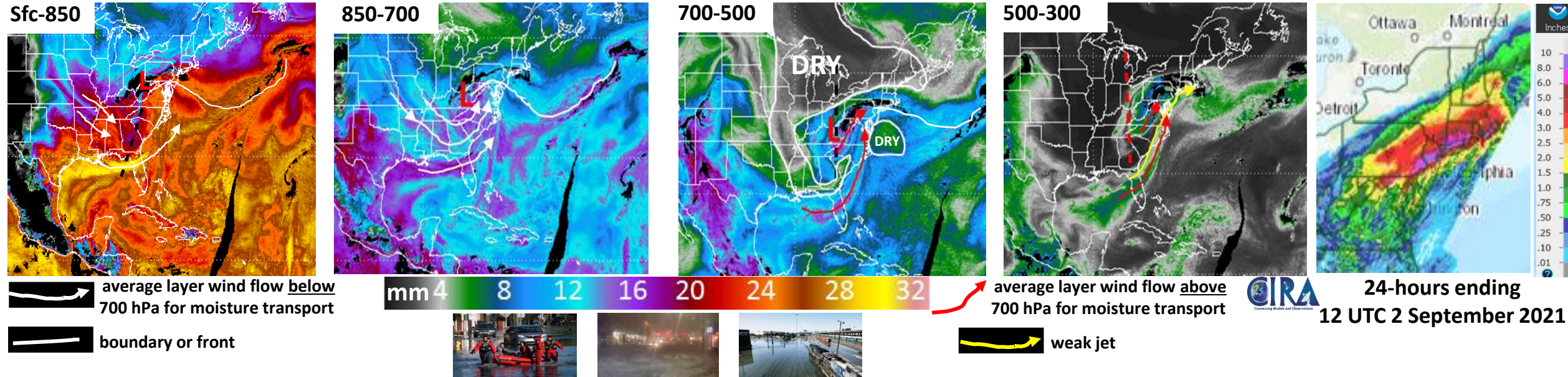


Photo courtesy of Southeastern Electric Cooperative providing mutual aid assistance to Southwest Rural Electric Association in Tipton, Oklahoma.

Excessive Rainfall from the Remains of Tropical Storms – Analysis of the ALPW – Compare and Contrast

CIRA Advected Layered Precipitable Water for 1500 UTC 1 September 2021 (9 hours before excessive rain in NYC)

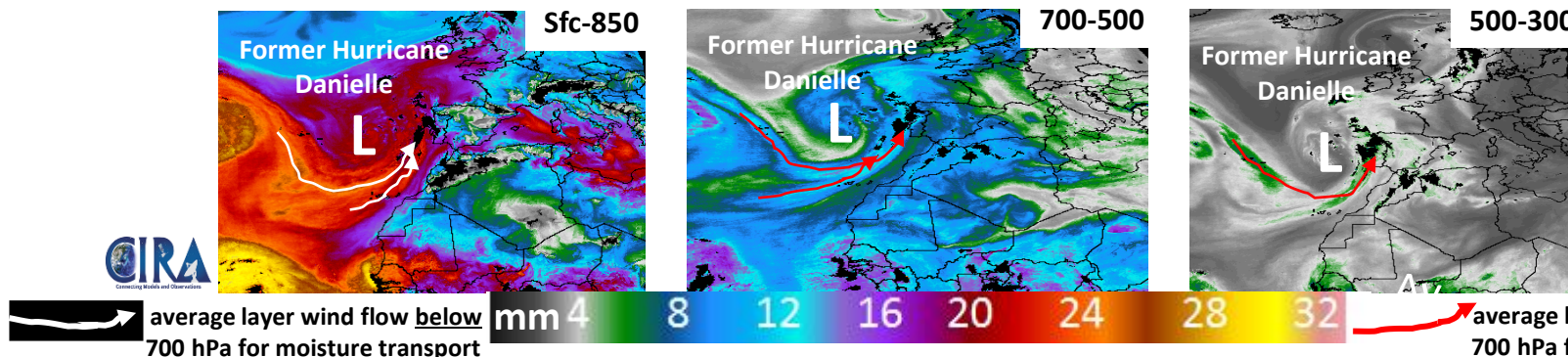
Former Hurricane Ida
Rainfall Results



METEORED
“Extratropical storm Danielle batters Portugal: floods, chaos and landslides”
 What did the Advected Layered Precipitable Water product show?

CIRA Advected Layered Precipitable Water for 0300 UTC 12 September 2022

Results



Alignment of very high precipitable water

- multi-layer long fetch moisture
- multi-layer converging moisture

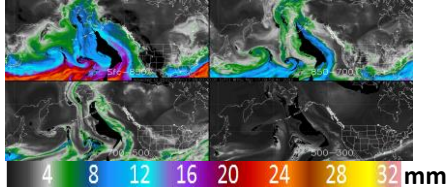
For deep moisture transport ahead of heavy rain/tragic floods

References for Layered Precipitable Water and TPW Products

Current Advected Layered Precipitable Water (ALPW) Sectors

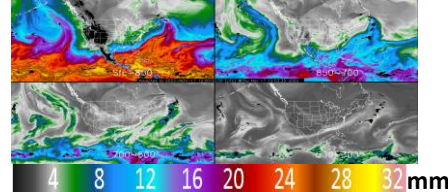
http://cat.cira.colostate.edu/SPoRT/Layered/Advected/LPW_Alaska.htm

Alaska and North Pacific

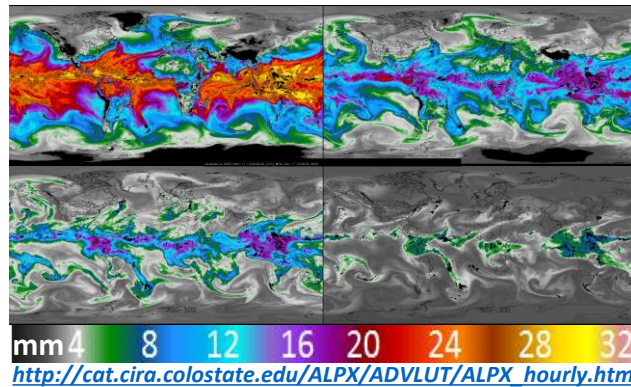


http://cat.cira.colostate.edu/SPoRT/Layered/Advected/ALPW_Hourly.htm

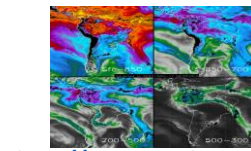
Western & Northern Hemisphere



Global

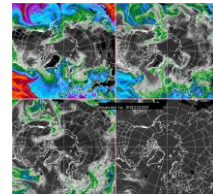


South America



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

Europe
(polar centric)



http://cat.cira.colostate.edu/ALPX/PS_NH/301.htm

Training for ALPW Product

Advected Layer Precipitable Water Product

Instructors: Den Bikos | Ed Szoke | Sheldon Kusselson | Topic: Satellite | Developed: 2017 | Last Updated: 2021

Introduction

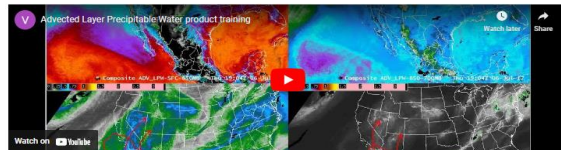
This training introduces the Advected Layer Precipitable Water (LPW) product. Strengths/limitations are discussed along with operational applications. We also let you know how to receive this product in AWIPS from CIRA since it is currently non-operational (experimental).

Training Session Options

NOAA/NWS students - to begin the training, use the web-based video, YouTube video, or audio playback options below (if present for this session). Certificates of completion for NOAA/NWS employees can be obtained by accessing the session via the [Continuing Learning Center](#).

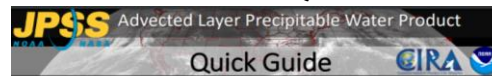
1. Live VIST training session led by an instructor (20 minutes). Check the [VIST Training Calendar](#) to see the current schedule and sign up. Upon registering for a teletraining session, you will receive an email with a link (GoToMeeting or WebEx) to connect to the session.

2. YouTube video:



https://rammb2.cira.colostate.edu/trainings/visit/training_sessions/advected_layer_precipitable_water_product/

ALPW Product Quick Guide



Why is the Advected Layer Precipitable Water (ALPW) product important?

The ALPW product offers a 4D structure of water vapor. Water vapor values are not dependent on the model. Retrieval is done in clear and cloudy (not precipitating) regions.

How is the ALPW product made?

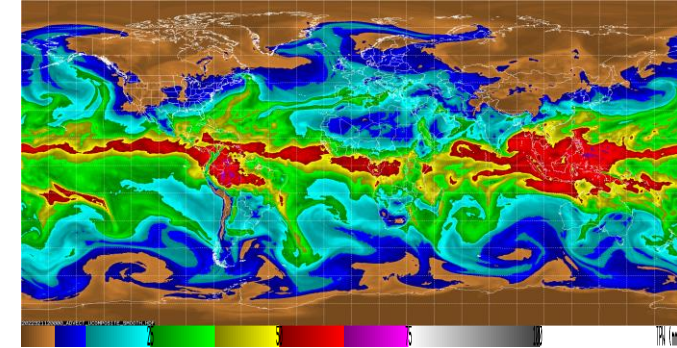
Microwave Integrated Retrieval System (MIRS) retrievals of moisture and temperature derived from 7 polar orbiting satellites. Data swaths are advected up to 10 hours before a common time via GFS wind forecasts and averaged. 4 layers are created (see vertical resolution).

Time resolution	Spatial resolution	Vertical resolution	Moisture Variables
Produced every three hours at 00, 03, ..., 21. No data older than 10 hours is used.	16 km on a Mercator projection.	4 layers: Surface-850 mb 850-700 mb 700-500 mb 500-300 mb	Layer precipitable water vapor (in)

https://rammb.cira.colostate.edu/training/visit/quick_guides/QuickGuide_LPW_Advected_20180223.pdf

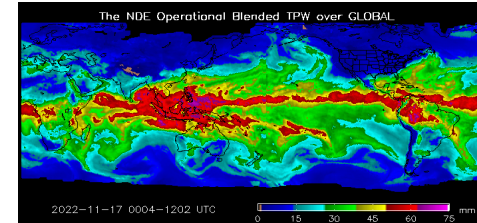
Global Advected Total Precipitable Water (ATPW)

<http://cdat.cira.colostate.edu/CAT/aTPW/aTPW5.htm>

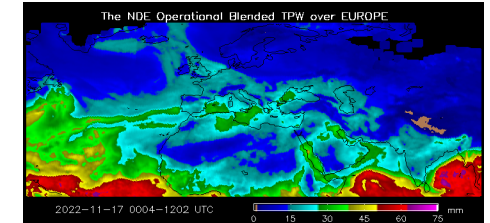


To be
operational
by mid 2023

Current Blended (non-advected) Total Precipitable Water (bTPW)



https://www.ospo.noaa.gov/Products/bTPW/TPW_Animation.html?product=GLOBAL_TPW



https://www.ospo.noaa.gov/Products/bTPW/TPW_Animation.html?product=EUROPE_TPW

bTPW Product Quick Guide



Why is the Blended Total Precipitable Water (TPW) Important?

Total precipitable water represents the liquid water equivalent if all the water vapor within a column of the atmosphere were condensed. The Blended TPW product is derived from microwave data sources over water and Global Positioning System (GPS) and geostationary data sources over land. It is important in identifying areas of high moisture that can lead to heavy precipitation and flooding events, such as those associated with atmospheric rivers.

What are the data sources and resolutions of Blended TPW?

Data Sources for TPW Over Land and Water	Data Range and Resolutions
<ul style="list-style-type: none">TPW from the NOAA Microwave Integrated Retrieval System (MIRS) from polar and low earth orbiting satellitesSurface-based Global Positioning System (GPS) TPWGOES-15 TPW; GOES-16 / 17 to be added in the future	<ul style="list-style-type: none">Range: 0-3 inchesSpatial resolution: 16 kmTemporal resolution: 1 hNear-global coverage (71°N to 71°S)

ATPW Product
Quick Guide
Coming in Future

My email address:
Sheldon.Kusselson@gmail.com

https://rammb.cira.colostate.edu/training/visit/quick_guides/Blended_TPW_Quick_Guide_20180727.pdf

Reference Material for Satellite Derived Water Vapour Products

- Additional training, presentation sessions, plus case studies

<https://rammb.cira.colostate.edu/training/visit/blog/> CIRA Search ALPW, TPW  

<https://www.meted.ucar.edu/index.php> NCAR COMET 

https://www.meted.ucar.edu/education_training/lesson/10139 Satellite Applications for Winter Weather: Mesoscale Snow Banding 

https://www.meted.ucar.edu/satmet/microwave_topics/clouds_precip_wv_v2/navmenu.php?tab=1&page=2-5-0&type=flash
Microwave Remote Sensing: Applications for Water Vapor, Clouds and Precipitation 

<https://cimss.ssec.wisc.edu/satellite-blog/?s=Total+Precipitable+Water> CIMSS Search Total Precipitable Water  

https://www.youtube.com/watch?v=ddJHPWauPPM&list=PLJzZC8w9vPV3kIBVNmQYzZfHO6vGZeNhN&index=38&ab_channel=KashaudBowman-NOAAAffiliate
Satellite Book Club presentation, “Multisatellite Water Vapor Products for Forecasters – 24 February 2022” 

- Reference Papers

Gitro, C. M., and Coauthors, 2019: A demonstration of modern geostationary and polar-orbiting satellite products for the identification and tracking of elevated mixed layers. *J. Operational Meteor.*, Vol. 7, Issue 13, Dec. 2019, 180-192 .

<https://objects-us-east-1.dream.io/nwafiles/jom/articles/2019/2019-JOM13/2019-JOM13.pdf>

Gitro, C. M., and Coauthors, 2018: Using the multisensory advected layered precipitable water product in the operational forecast environment. *J. Operational Meteorology*, 6 (6), 59-73, doi: <https://doi.org/10.15191/nwajom.2018.0606>

Forsythe, J. M., S.Q.Kidder, K.K.Fuell, A.LeRoy, G.J.Jedlovec, and A.S.Jones, 2015: A multisensory, blended, layered water vapor product for weather analysis and forecasting. *Journal of Operational Meteorology*, 3, 41-58 .

Thanks for your attention!

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