“Atmospheric Rivers” (AR) of Moisture:
Satellite Observations and Applications for Heavy Precipitation Analysis and Forecasting

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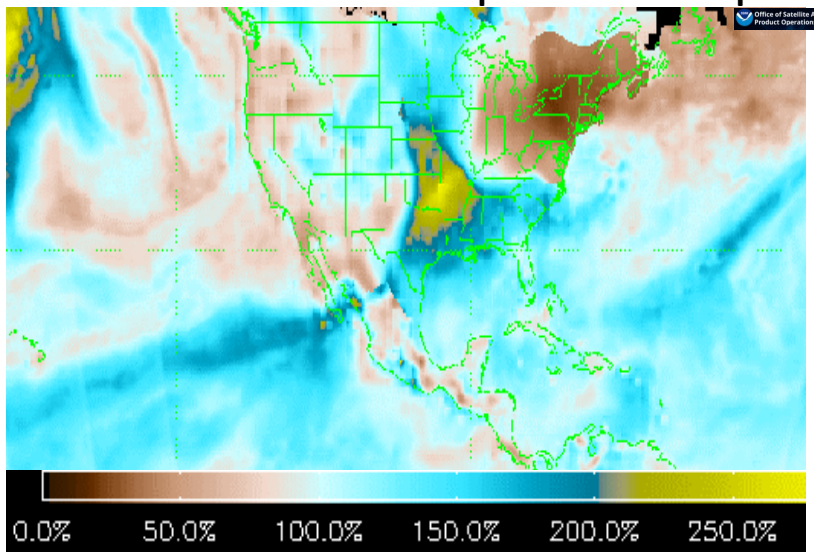
Retired, NOAA/NESDIS

with contributions from my CIRA/Colorado State University Team, John Forsythe, Stan Kidder and Dan Bikos

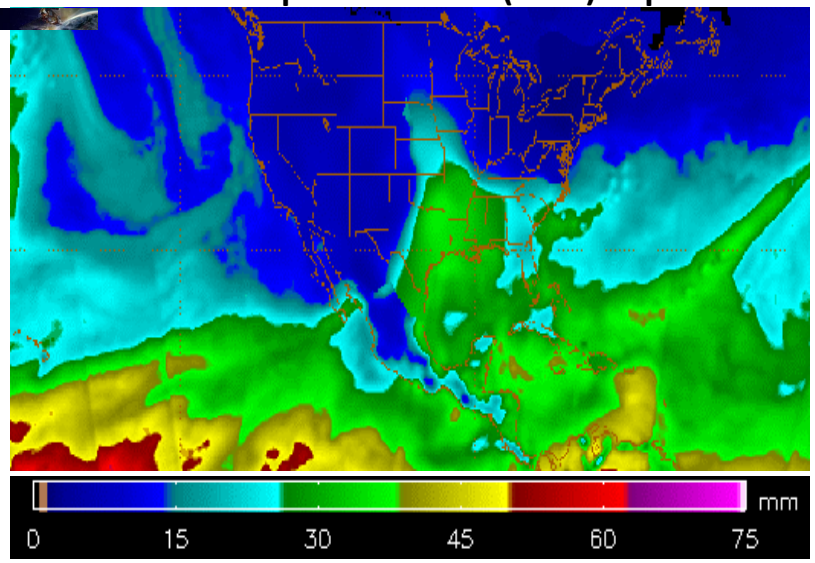
12 UTC 9 March 2019

Percent of Normal Total Precipitable Water Vapor

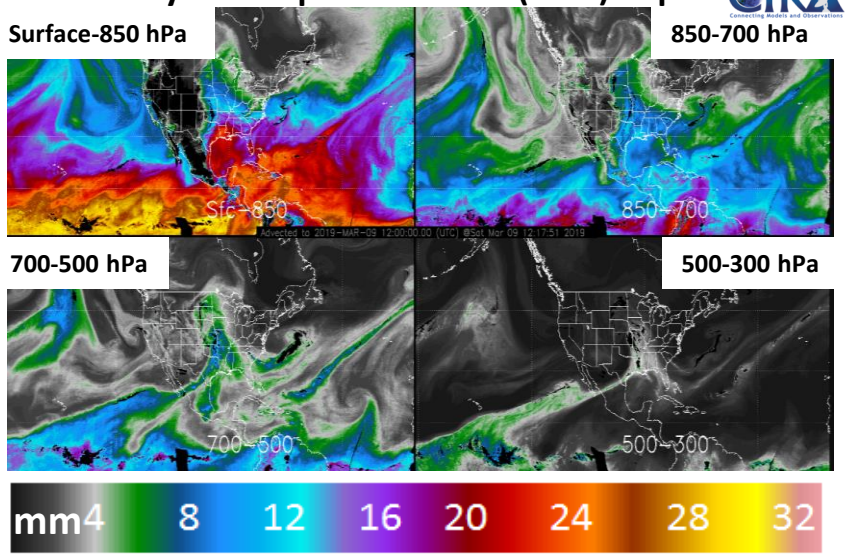


Weak el nino

Total Precipitable Water (TPW) Vapor



Layer Precipitable Water (LPW) Vapor



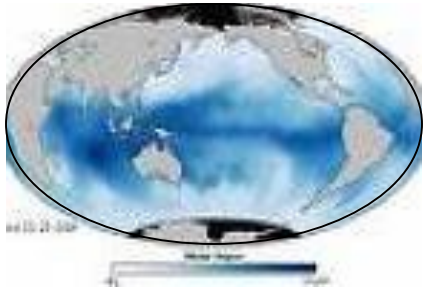
American Meteorological Society SatMOC Virtual Training

Session 2: Extreme Hydro-meteorological Forecasting and Flood Mapping

25 June 2024

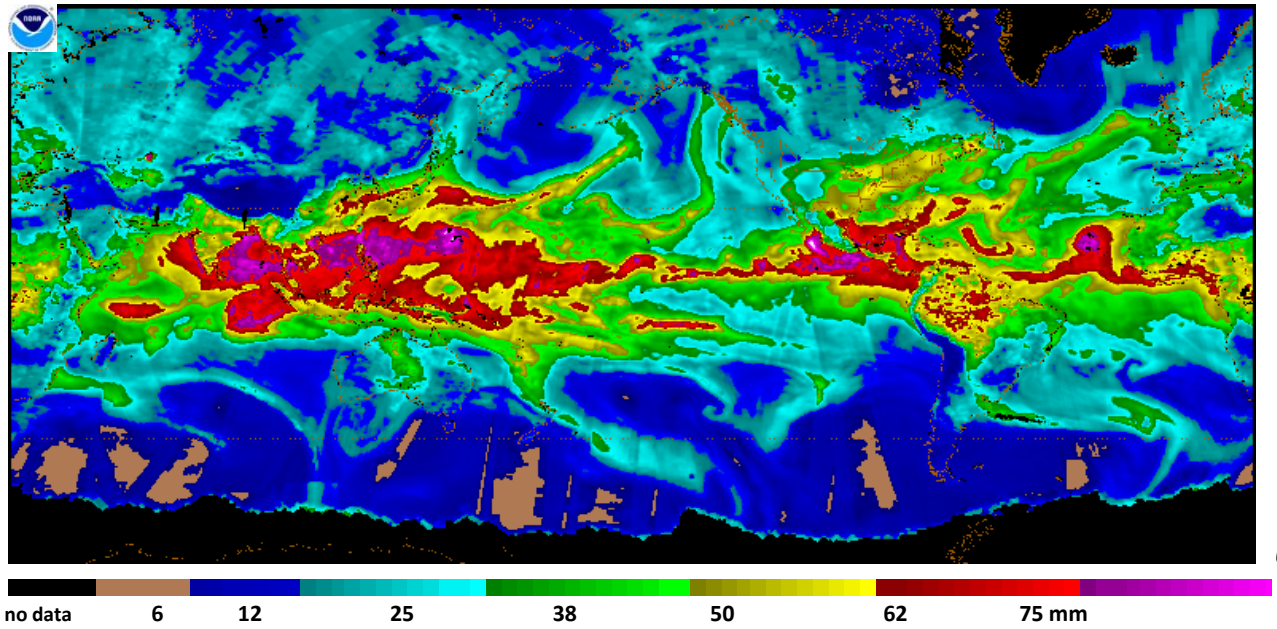
What is Water Vapor?

Answer. Water in it's gaseous state



Total Precipitable Water (TPW, PWAT, PW, Total Water Vapor) ?

Answer. The amount of water that can be obtained from the **surface** to the **"top"** of the atmosphere if all of the water and water vapor were condensed to a liquid phase.



00 UTC 12 Sep 2013

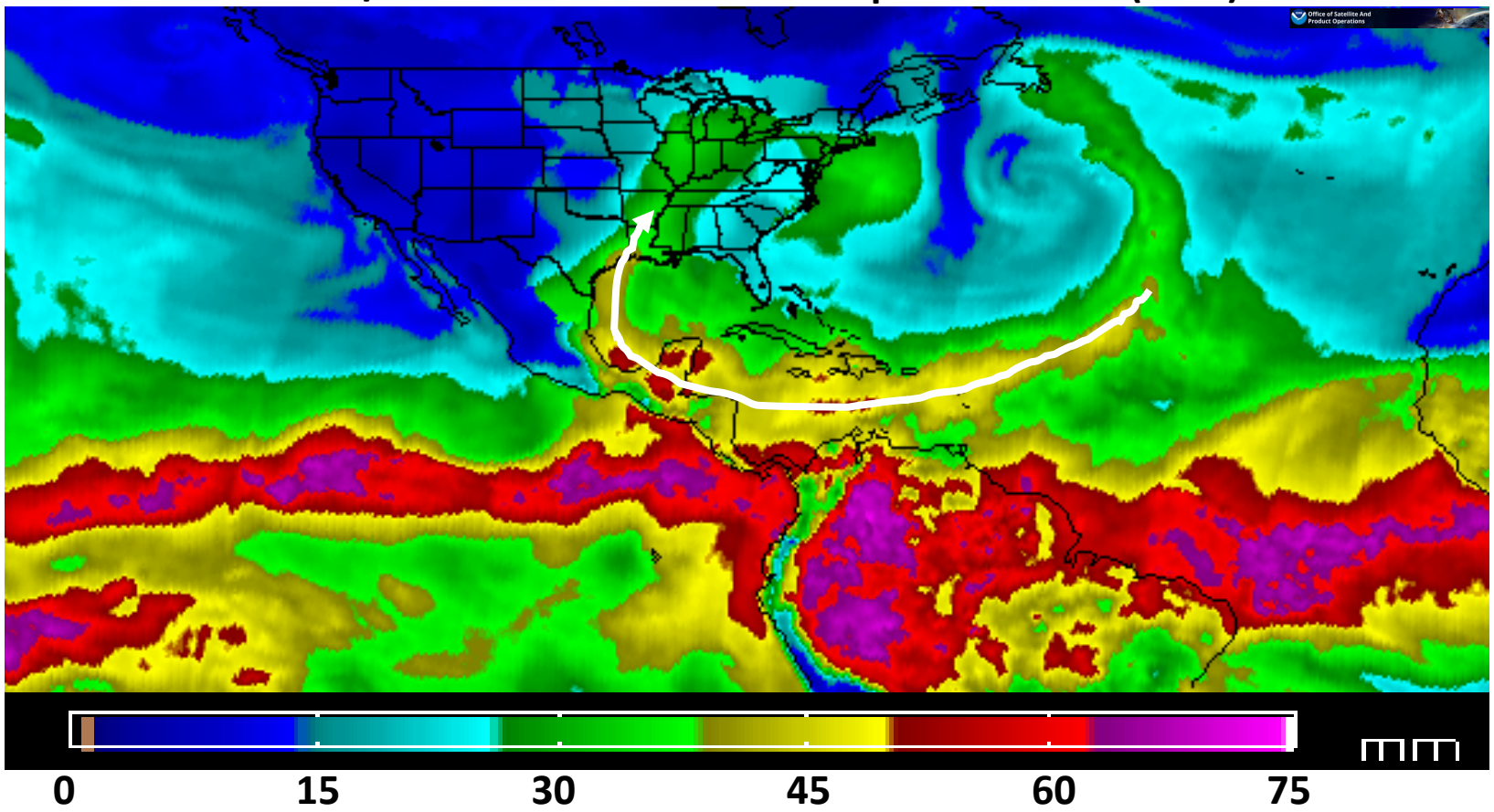
Why is water vapor important?

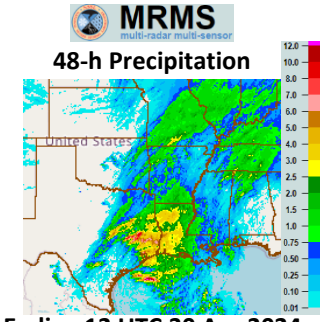
A. No clouds, no liquid droplets, no rain, no life and no weather on earth and no atmospheric rivers as we know it

What is an “Atmospheric River” (AR)?

ANSWER: “***Flowing column of condensed water vapor in the atmosphere responsible for producing significant levels of rain and snow...”***

NOAA/NESDIS Blended Total Precipitable Water (TPW) ***12 UTC 29 April 2024***





weakening el nino

https://www.ospo.noaa.gov/Products/bTPW/Product_Animation.html

https://cdat.cira.colostate.edu/CAT/aTPW/aTPW5.htm

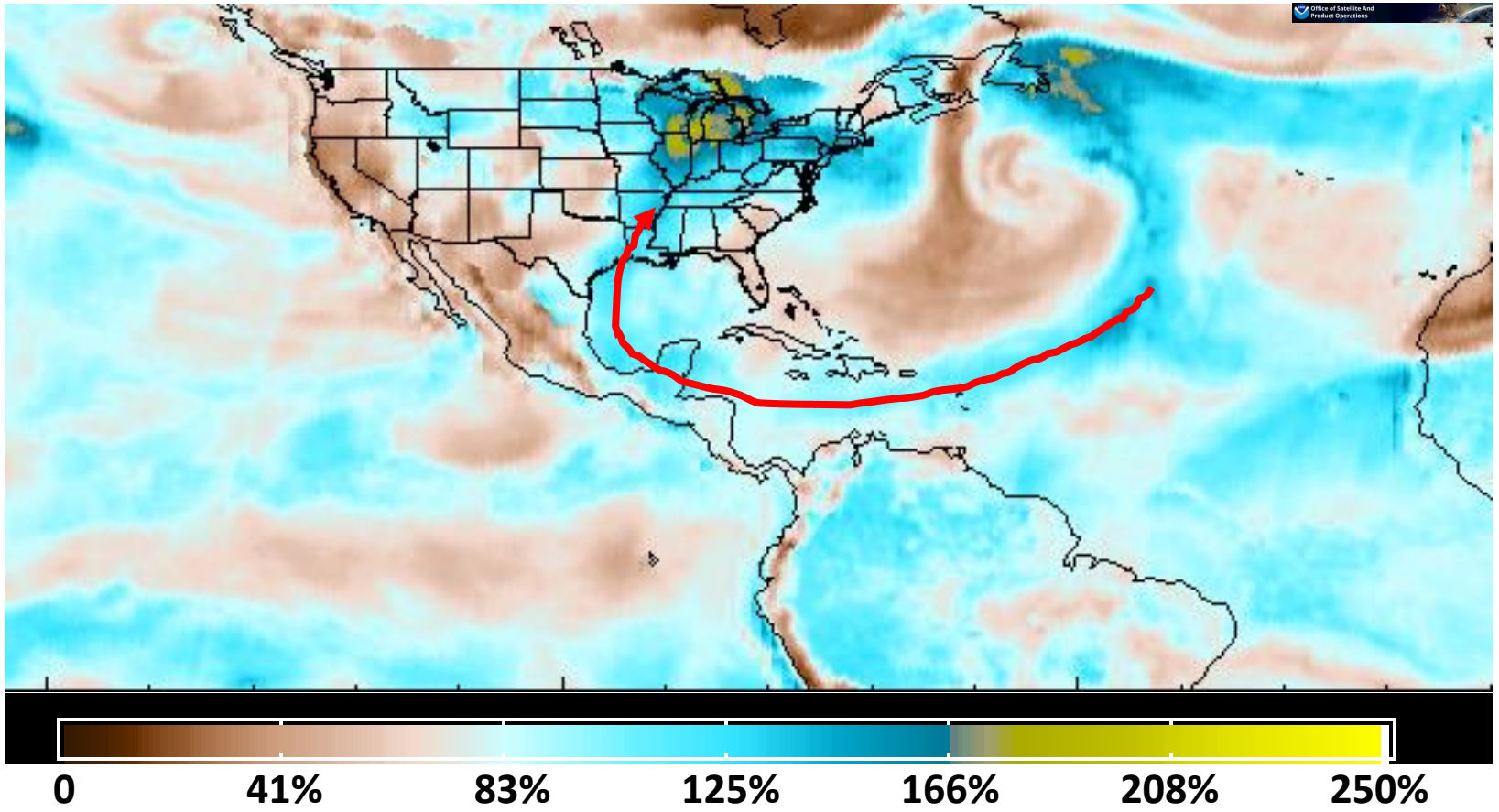
https://tropic.ssec.wisc.edu/real-time/mtpw2/product.php?color_type=tpw_nrl_colors&prod=global2&timespan=24hrs&anim=html5

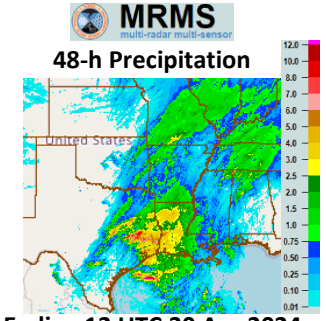
Even Better

An "Atmospheric River" that has MOSTLY <u>ABOVE Normal</u> Total Atmospheric Precipitable Water Vapor

NOAA/NESDIS Percent of Normal TPW

12 UTC 29 April 2024





weakening el nino

https://www.ospo.noaa.gov/Products/bTPW/Product_Animation.html

under Product & Region
select Global_PCT

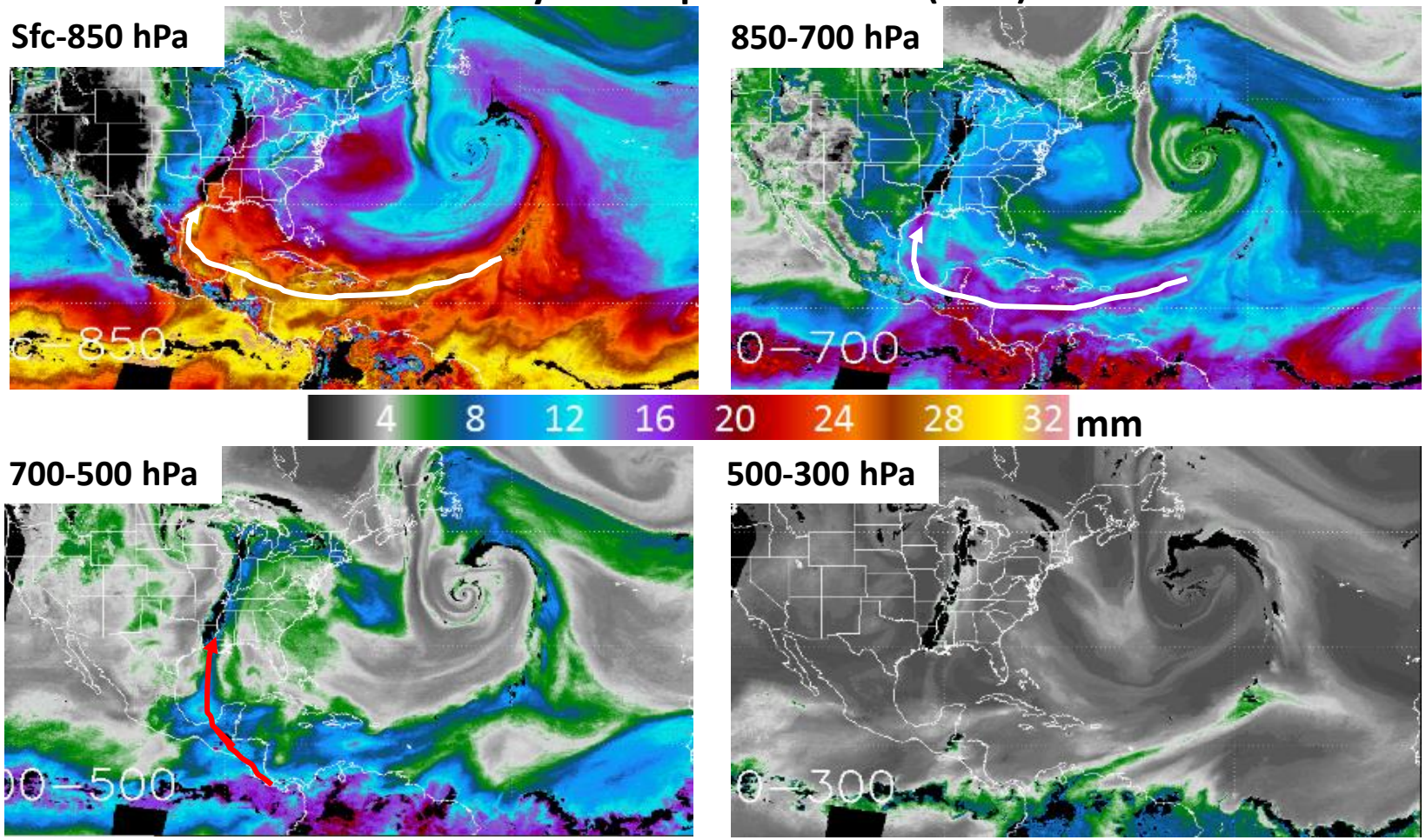
Even Better

Now, we have the ability to <u>see</u> atmospheric rivers of precipitable water vapor at four distinct layers of the troposphere (up to 300 hPa)

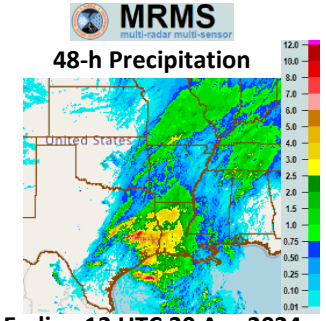
CIRA Layer Precipitable Water (LPW)

12 UTC 29 April 2024

Low layer atmospheric river for best moisture transport



How layer atmospheric river for best moisture transport



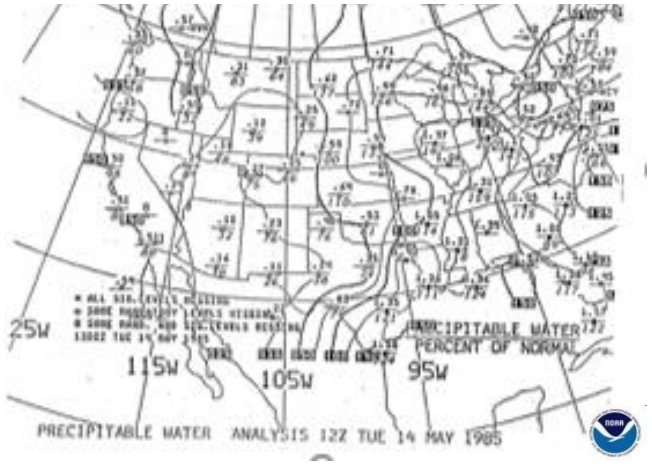
weakening el nino

https://cat.cira.colostate.edu/SPoRT/Layered/Advected/ALPW_Hourly.htm **N and W Hemisphere**

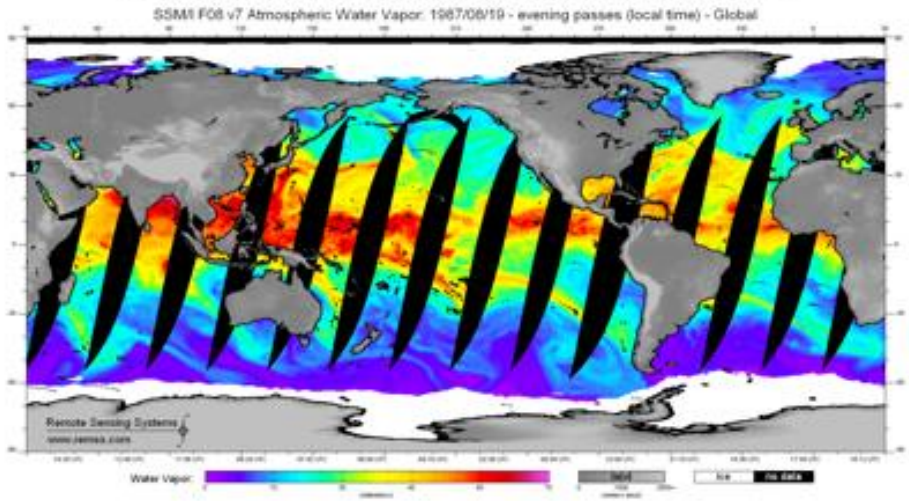
https://cat.cira.colostate.edu/ALPX/ADVLUT/ALPX_hourly.htm **global**

Historical Perspective As To Why We Better See the "Atmospheric River" Today

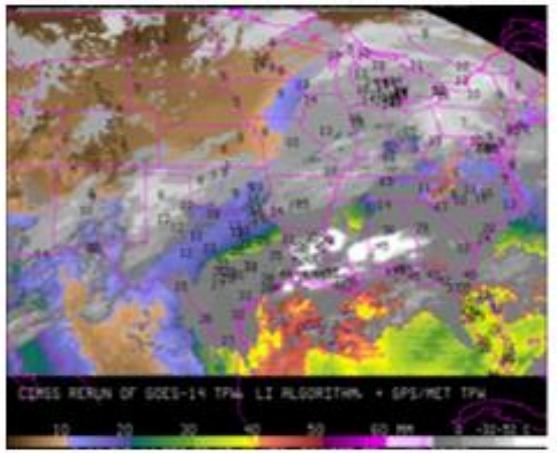
Only Precipitable Water data available before 1987



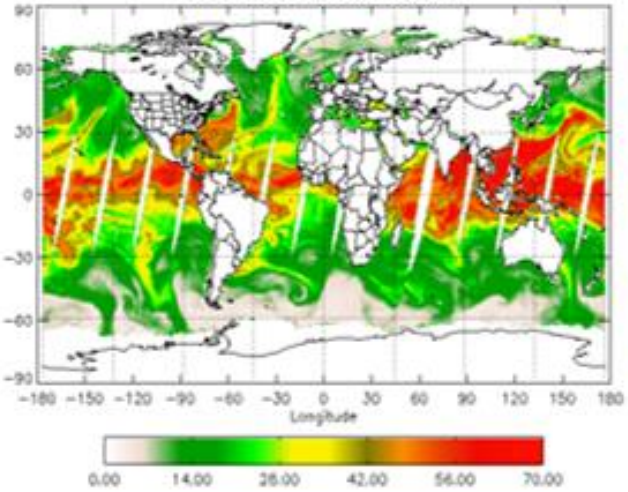
First microwave Imager (SSMI) TPW available in 1987



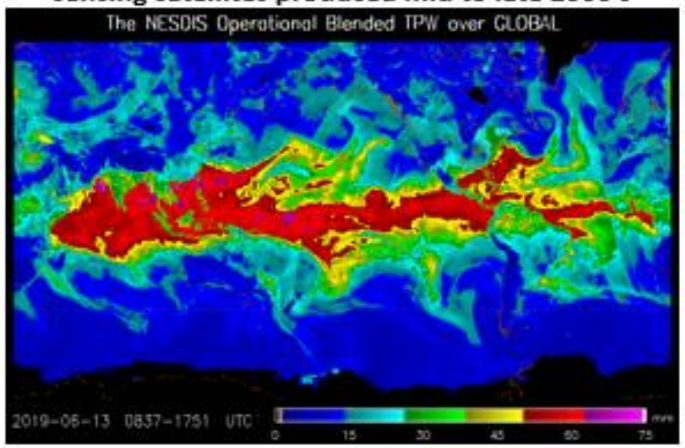
First GOES Sounder TPW produced in mid-1990's; First GPS TPW mid/late 1990's



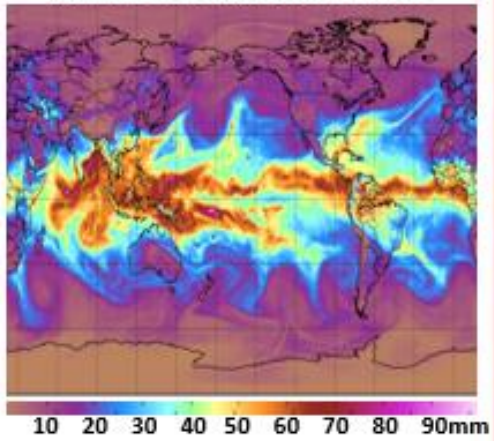
First NOAA microwave imager (AMSU) TPW available in 1998



First Blended TPW (land/ocean) from many remote sensing satellites produced mid to late 2000's

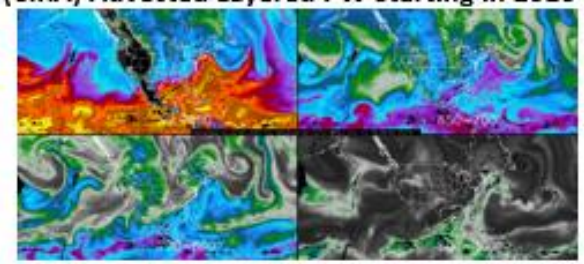


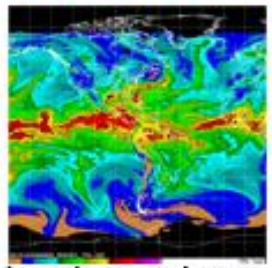
First advected blended TPW (MIMIC) from many P-O MW satellites produced early to mid 2010's



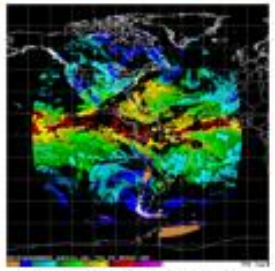
Latest developments in TPW

(CIRA) Advected Layered PW Starting in 2016





(CIRA) Merged TPW starting in 2019



GOES 16 ABI TPW started in 2018

Some Precipitable Water History

P3.12

Reprinted from the preprint volume of the **13th Conference on Weather Analysis and Forecasting including Symposium on Flash Floods,** August 2-6, 1993, Vienna, VA. Published by the American Meteorological Society, Boston, MA.

THE OPERATIONAL USE OF PASSIVE MICROWAVE DATA TO ENHANCE PRECIPITATION FORECASTS

Sheldon J. Kusselson
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
Washington, D.C. 20233

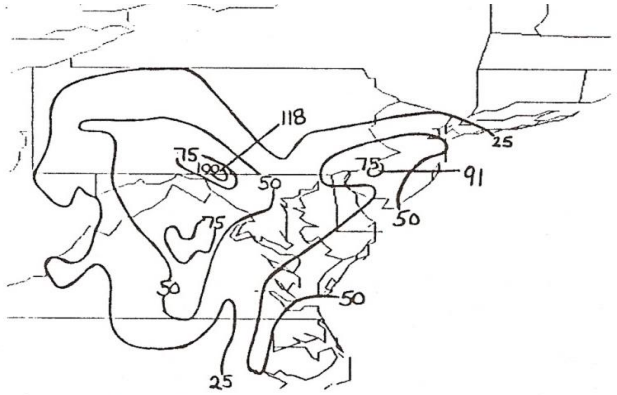


Figure 1b. Observed Precipitation (mm) for the 24-hour Period Ending at 1200 UTC on Dec. 11, 1992.

ENSO Neutral

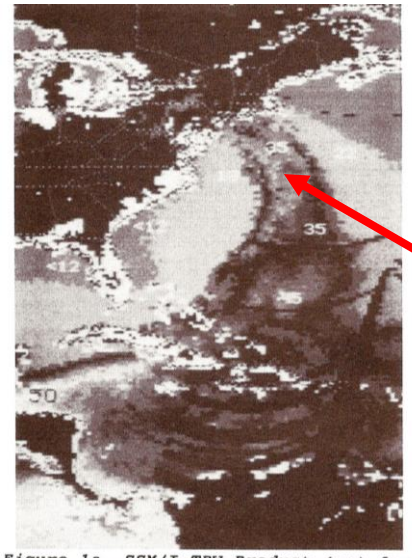


Figure 1a. SSM/I TPW Product (mm) for the Morning Polar Orbiting Pass on Dec. 11, 1992.

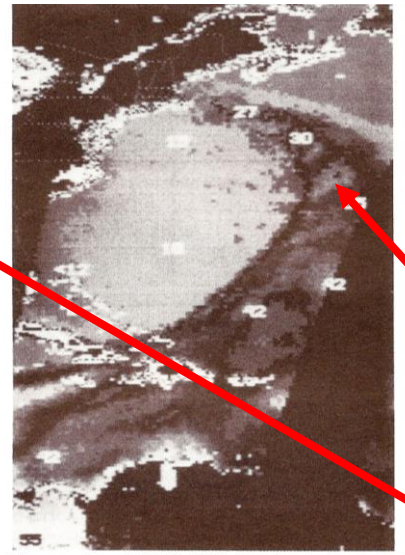


Figure 2a. SSM/I TPW Product (mm) for the Morning Polar Orbiting Pass on Dec. 12, 1992.

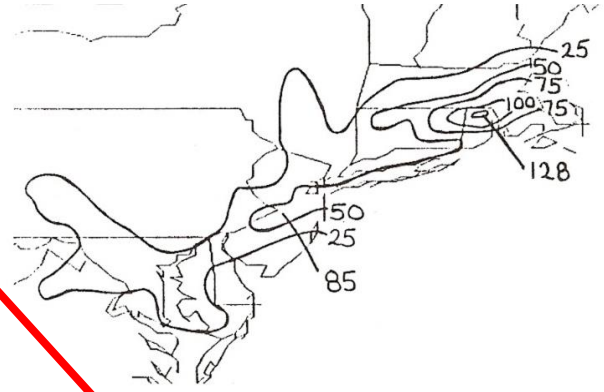


Figure 2b. Observed Precipitation (mm) for the 24-hour Period Ending at 1200 UTC on Dec. 12, 1992.

1993 First Paper Mention of a Satellite Moisture Plume Now Called "Atmospheric River"

2. SSM/I PRODUCTS AND APPLICATIONS

2.1 Total Precipitable Water (TPW) Product

The SSM/I TPW Product (Hollinger, 1991) provides additional information over ocean areas and is used to complement other conventional and satellite data and NESDIS techniques (Scofield, 1993) for the analysis and

3. SUMMARY AND FUTURE

This paper has presented an overview of experimental applications of SSM/I products for operational use by NOAA meteorologists. TPW, and Experimental Wind Speed and Rain Rates, provide additional information over data sparse ocean areas and are primarily used to complement and confirm conventional and other satellite data and NESDIS techniques for the analysis and forecast of precipitation. The usefulness of SSM/I products from applications in this paper are summarized

SSM/I TPW PRODUCT

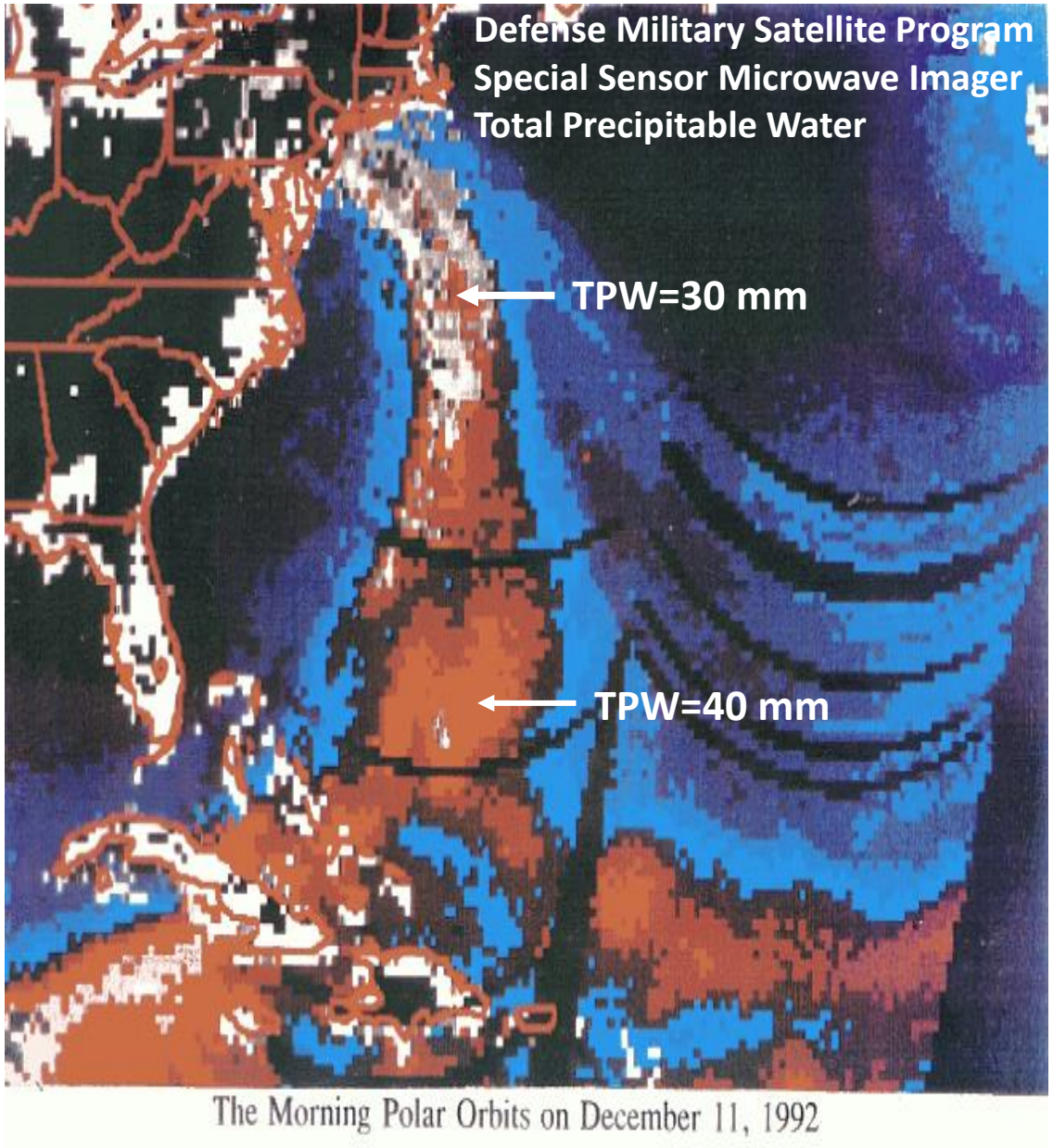
Analysis Applications:
- Locating maximum TPW areas and following their trends
- Analyzing moist axes of TPW (TPW plumes)

Forecast Applications:
- TPW plumes with subtropic origins relate well to the generation of heavy precipitation

December 1992 NYC Atmospheric River Event

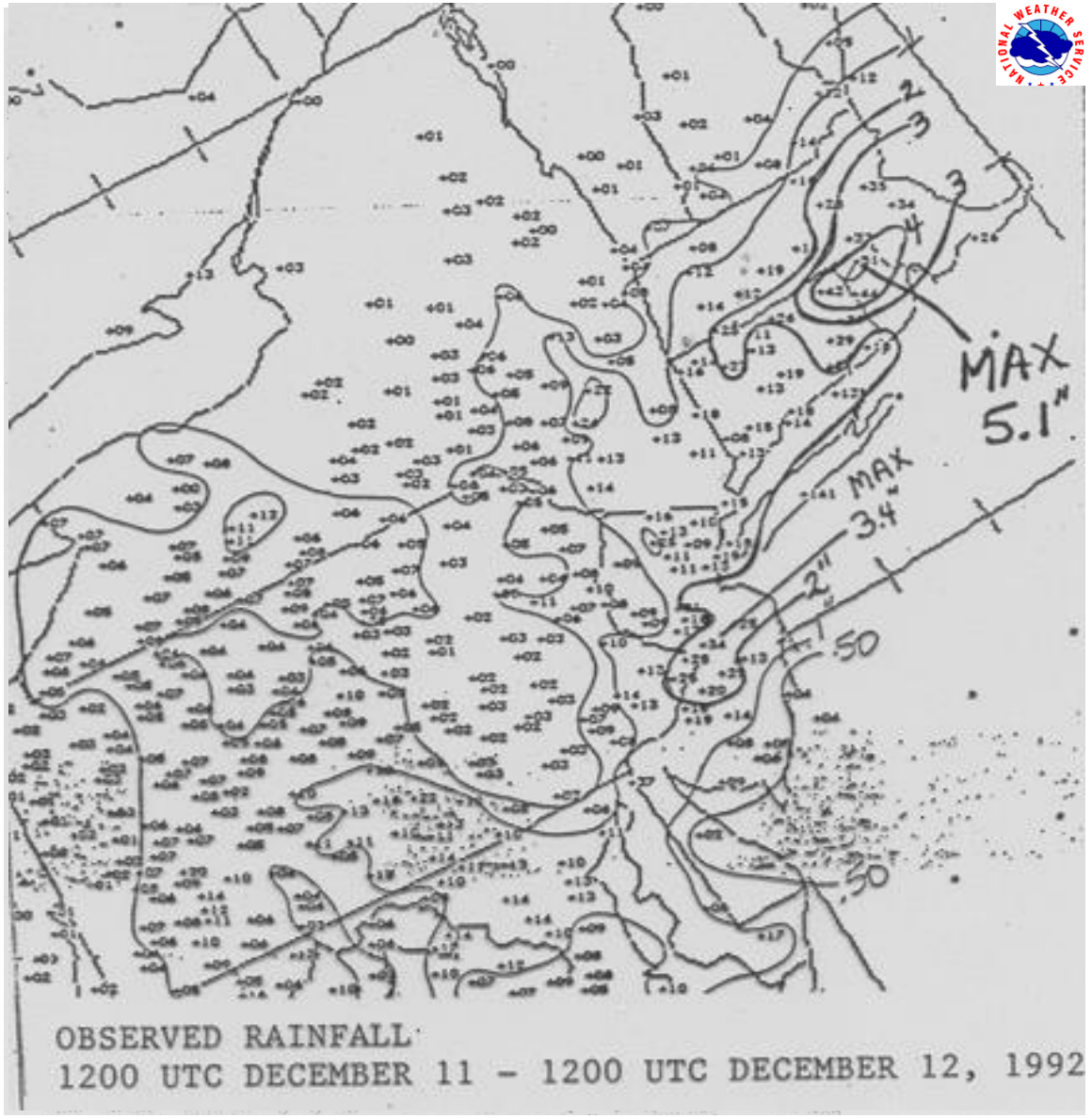
Neutral ENSO – December 1992

cause



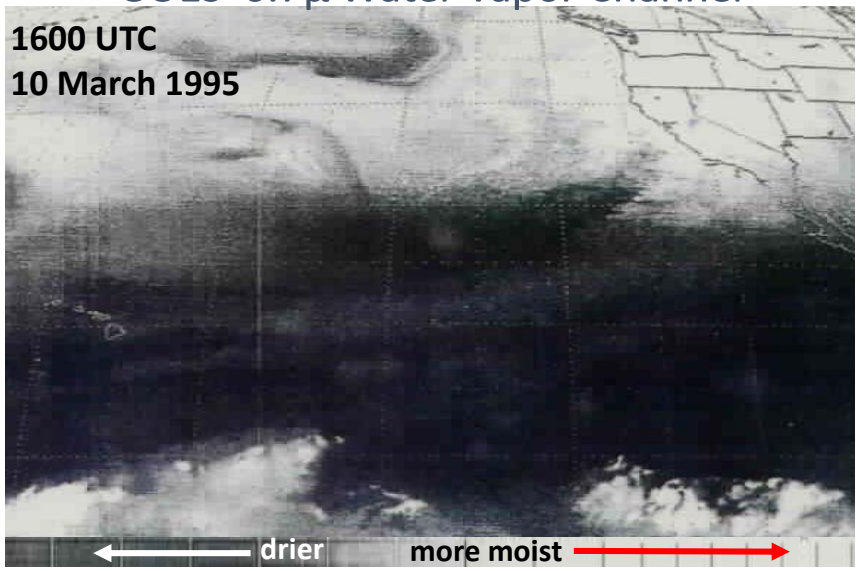
The Morning Polar Orbits on December 11, 1992

effect

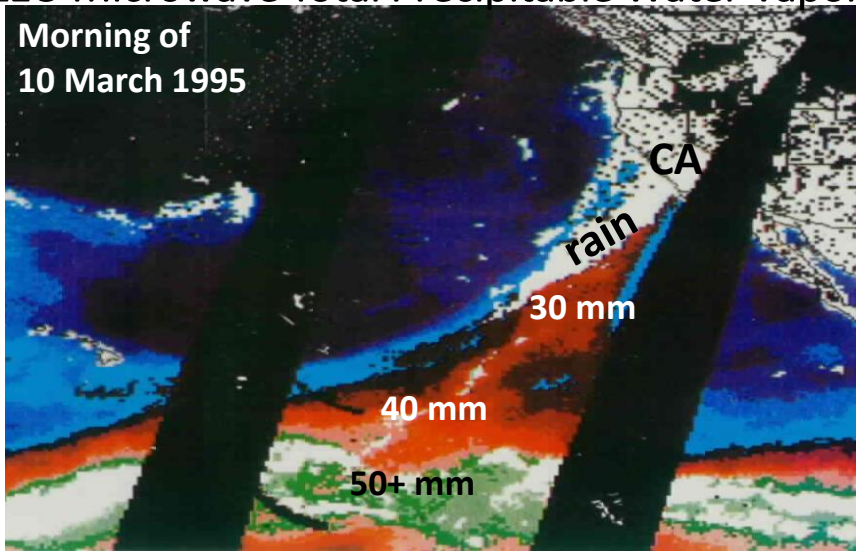


Satellite Microwave Imager Detects “Atmospheric Rivers” Better

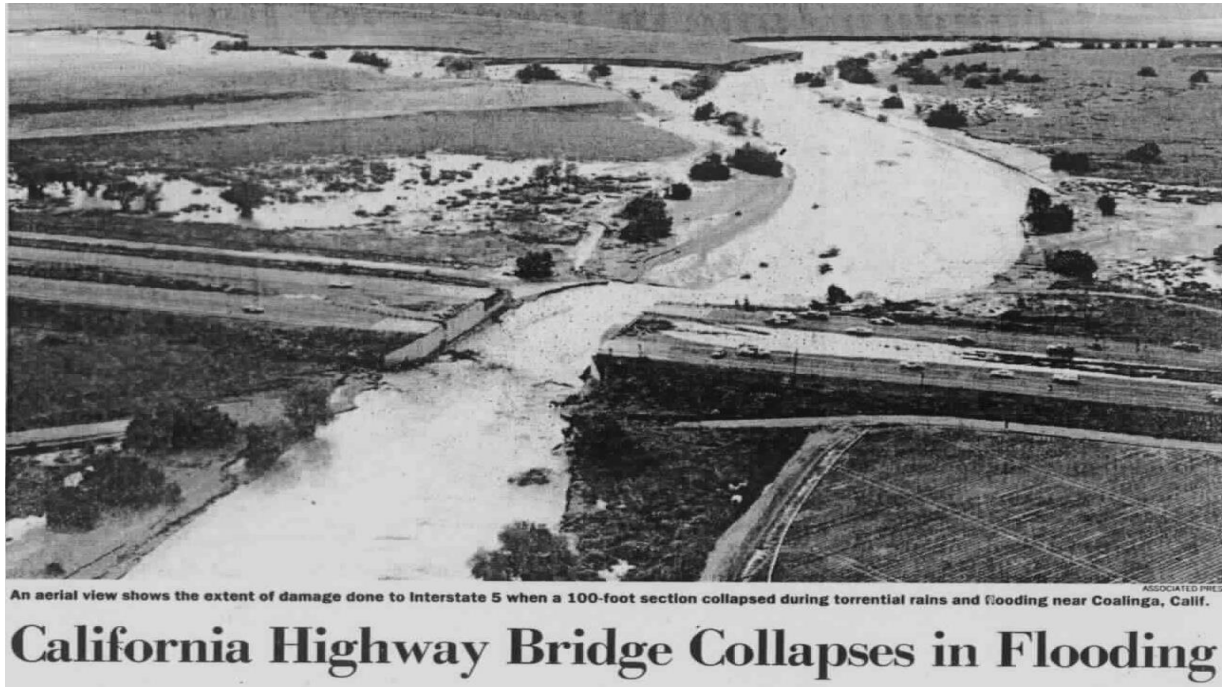
GOES 6.7µ Water Vapor Channel



LEO Microwave Total Precipitable Water Vapor



11 March 1995 Results

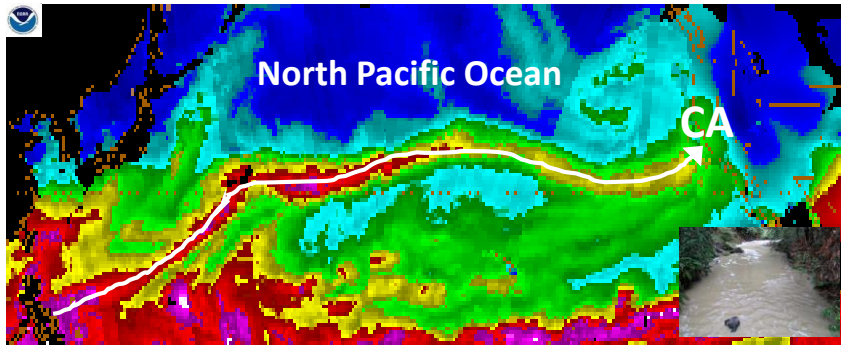


An aerial view shows the extent of damage done to Interstate 5 when a 100-foot section collapsed during torrential rains and flooding near Coalinga, Calif.

California Highway Bridge Collapses in Flooding

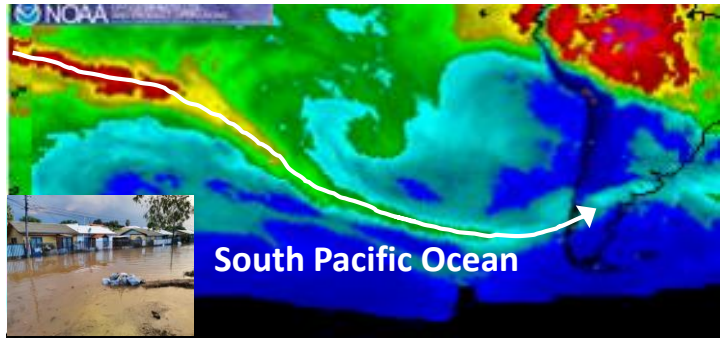
"Atmospheric Rivers" Are Seen in MANY Parts of the GLOBE?

1500 UTC 13 October 2009



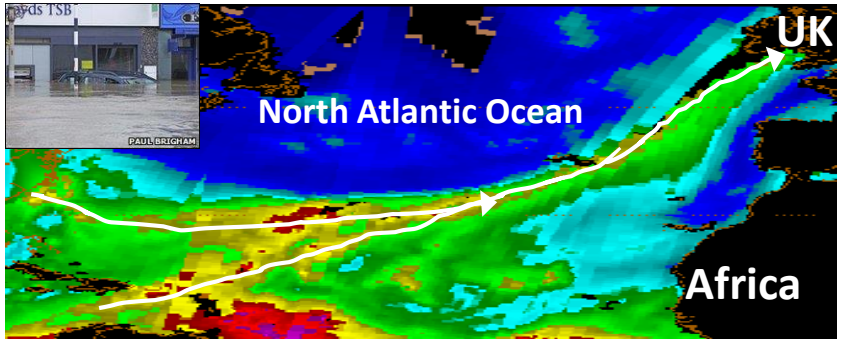
6 12 25 38 50 62 mm

1800 UTC 25 October 2021



6 12 25 38 50 62 mm

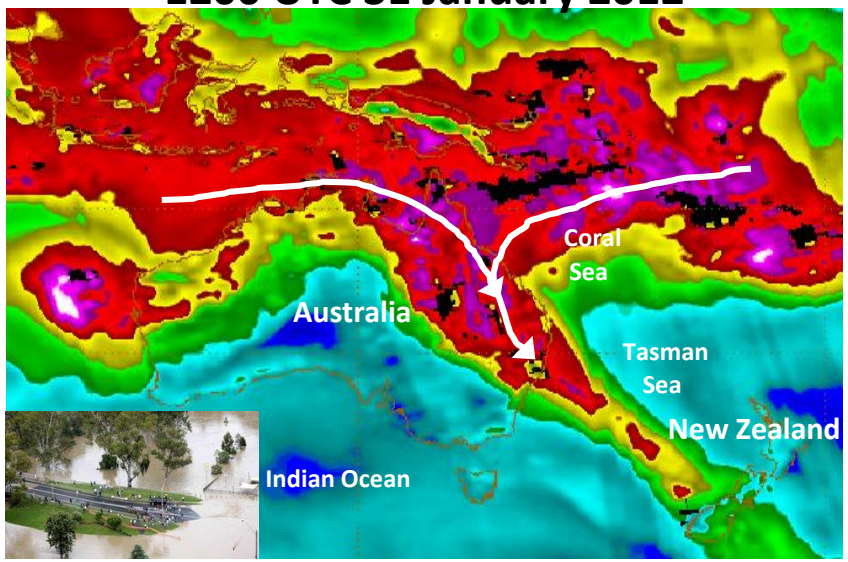
1200 UTC 19 November 2009



6 12 25 38 50 62 mm

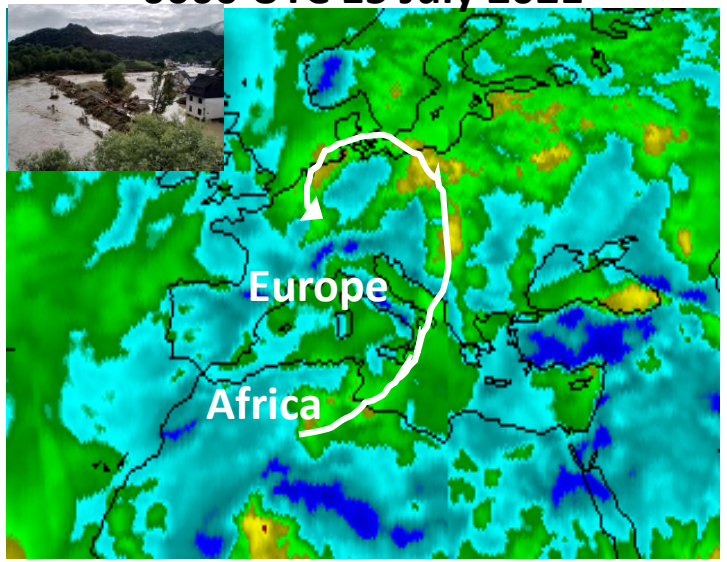
atmospheric river

1200 UTC 31 January 2012



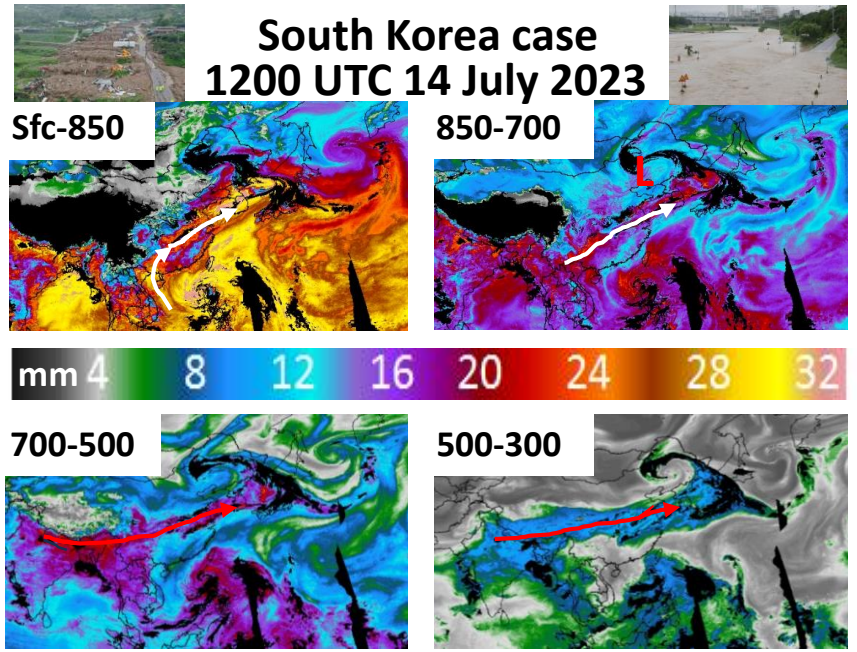
6 12 25 38 50 62 mm

0000 UTC 15 July 2021



6 12 25 38 50 62 mm

South Korea case 1200 UTC 14 July 2023



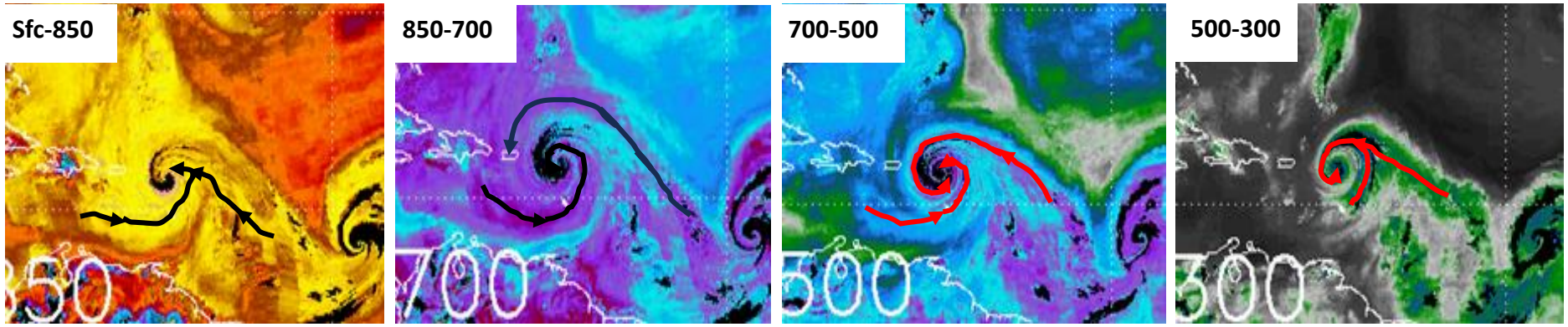
Different Atmospheric Rivers for this case
Best Seen with the Layer Precipitable Water

Atmospheric Rivers In the Tropics

Feeder bands around and into Tropical Cyclone Irma

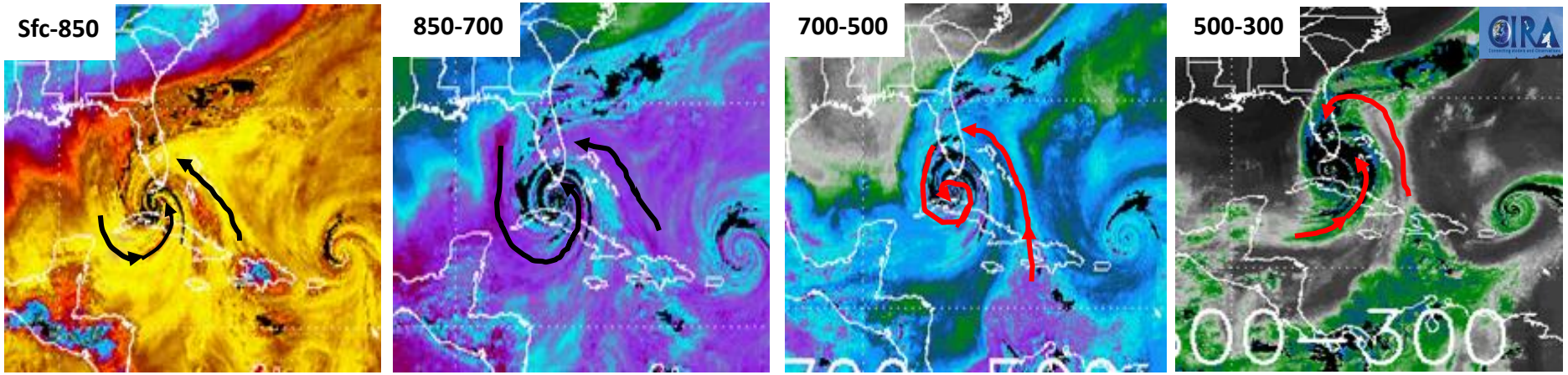
Neutral ENSO
September 2017

CIRA Advected Layer Precipitable Water (ALPW) for 06 UTC 6 Sep 2017



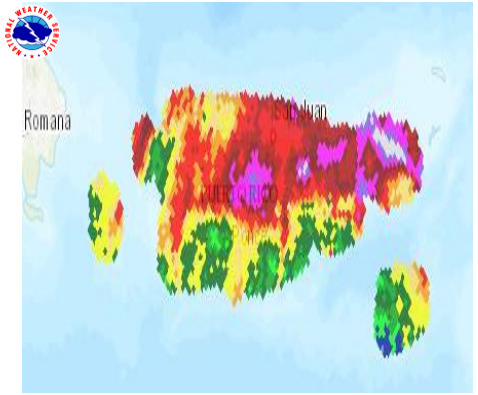
Advection of atmospheric river layer moisture below 700 hPa

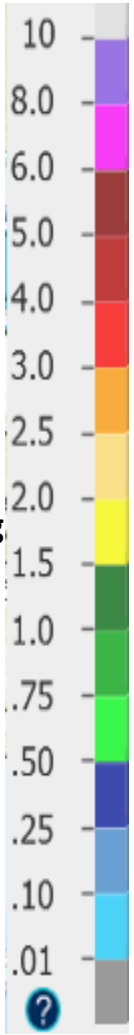
Advection of atmospheric river layer moisture above 700 hPa



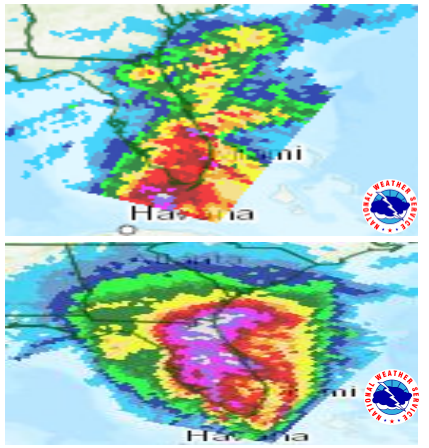
CIRA Advected Layer Precipitable Water(ALPW) for 06 UTC 10 Sep 2017: Irma

Puerto Rico 24-h Rainfall ending 12 UTC 7 September 2017





South Florida: 24-h Rainfall ending 12 UTC 10 September 2017



FL/SE US 24-h Rainfall ending 12 UTC 11 September 2017

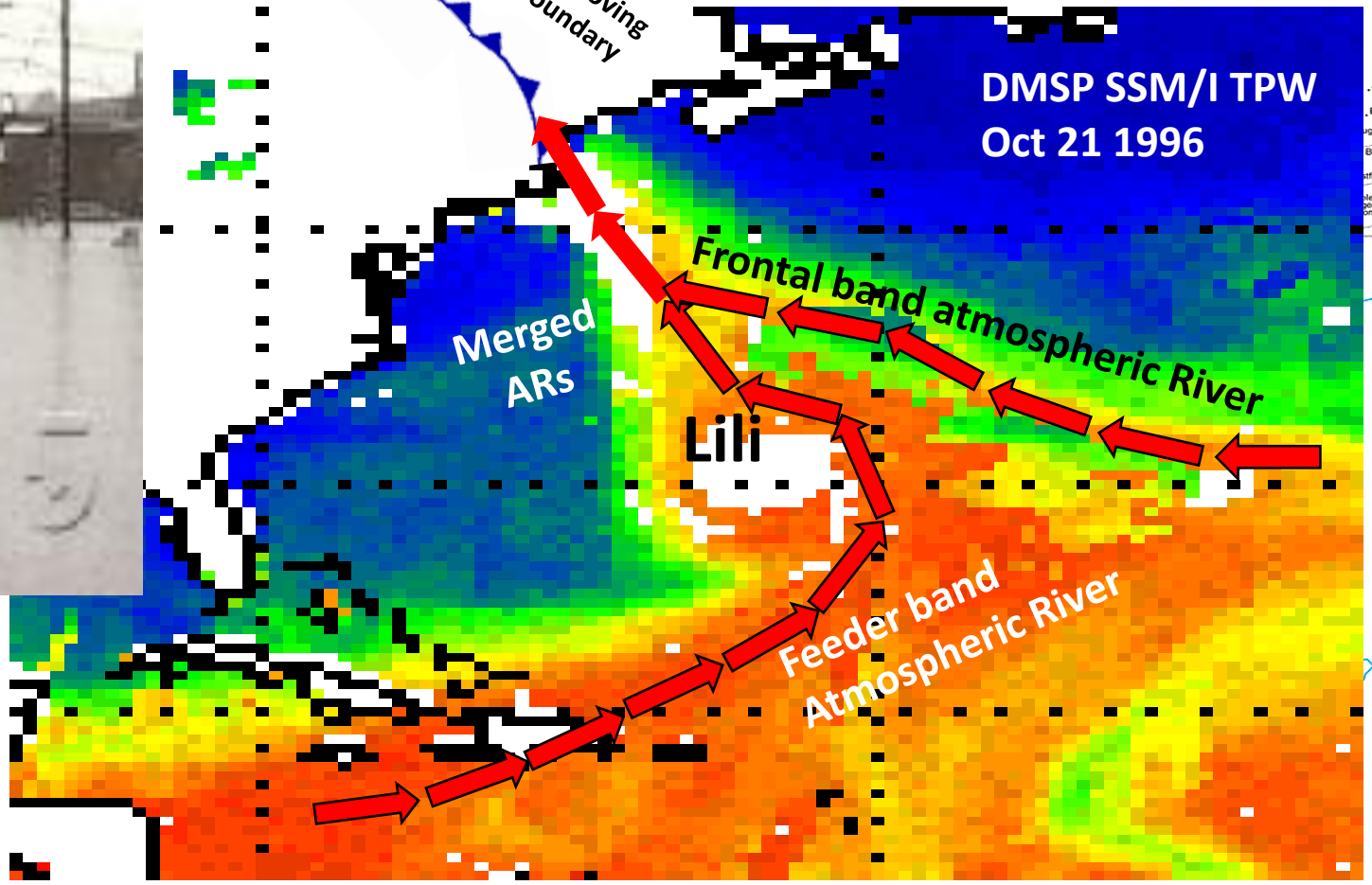
Graphics and analysis prepared by Sheldon Kusselson

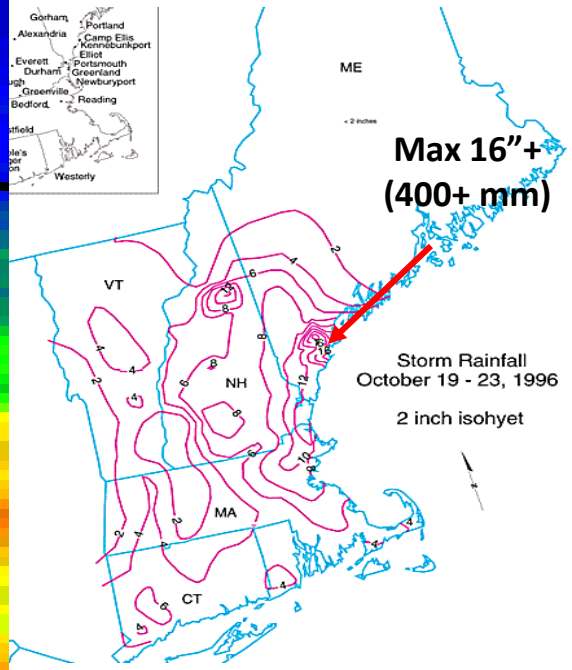
Interaction of Hurricane TPW Moisture and Slow Moving Front

A different kind of "Atmospheric River" (AR)

Neutral ENSO
Oct 1996

The Catastrophic Results



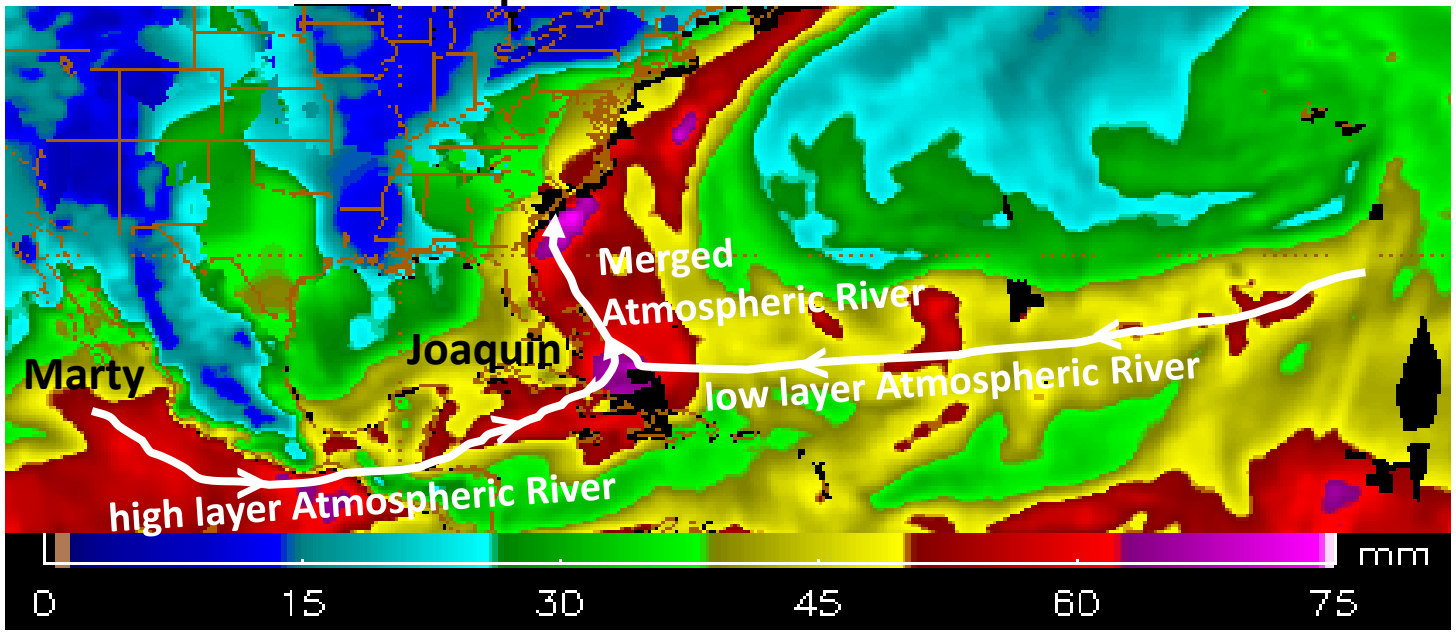


5-day Rainfall Results

Converging Atmospheric Rivers (ARs) Including Tropical Cyclone Joaquin's Moisture in October 2015 Resulting in South Carolina's 1000-yr flood

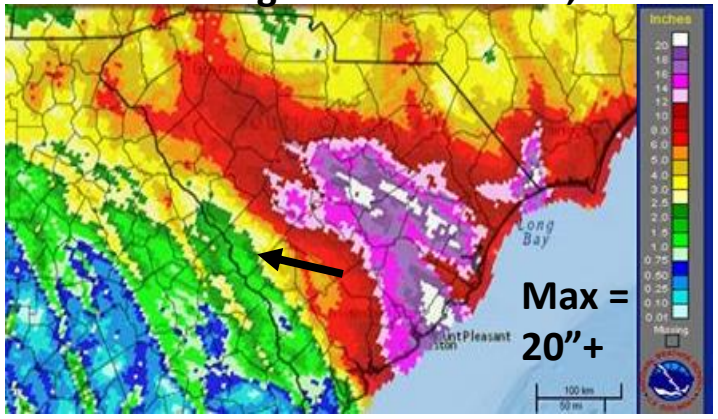
strong el nino
Oct 2015

Satellite Total Precipitable Water at 0600 UTC 2 October 2015



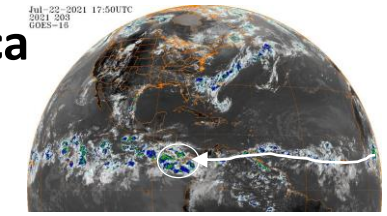
Atmospheric River Moisture Transport and Convergence for Exceptional Moisture Transport into South Carolina

Radar Rainfall Estimates
48-hr ending 2300 UTC Oct 4, 2015

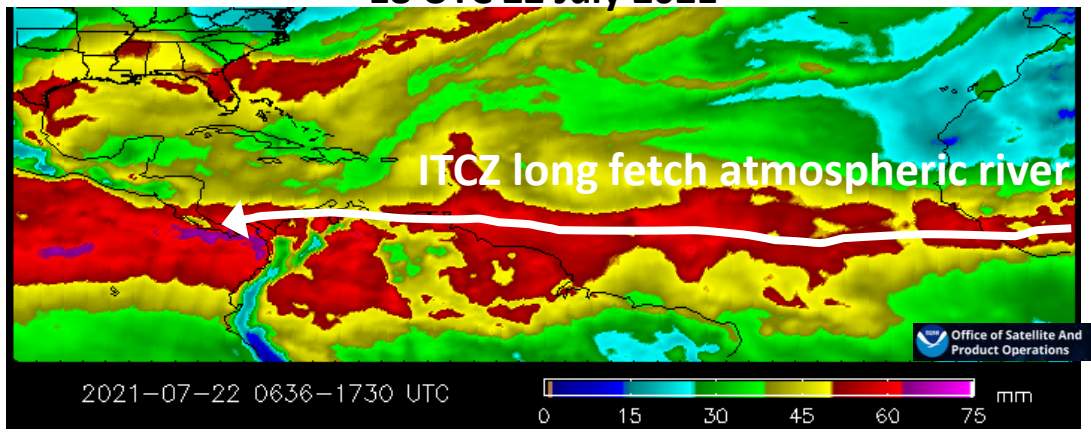


Devastating Results

Long Fetch Tropical Atmospheric River Giving Heavy Rain and Flooding to Costa Rica

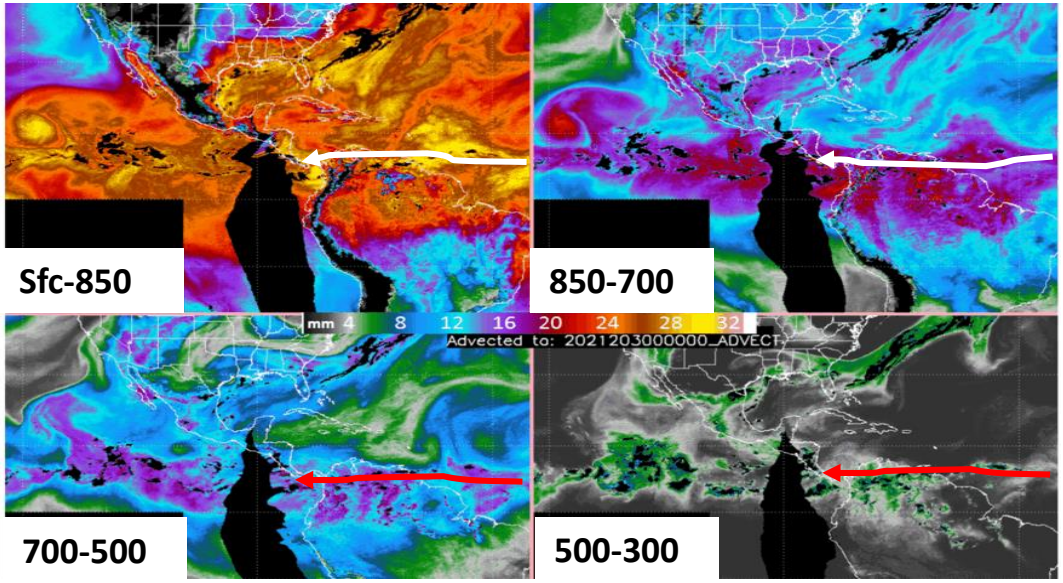


Blended Total Precipitable Water (TPW) for 18 UTC 22 July 2021



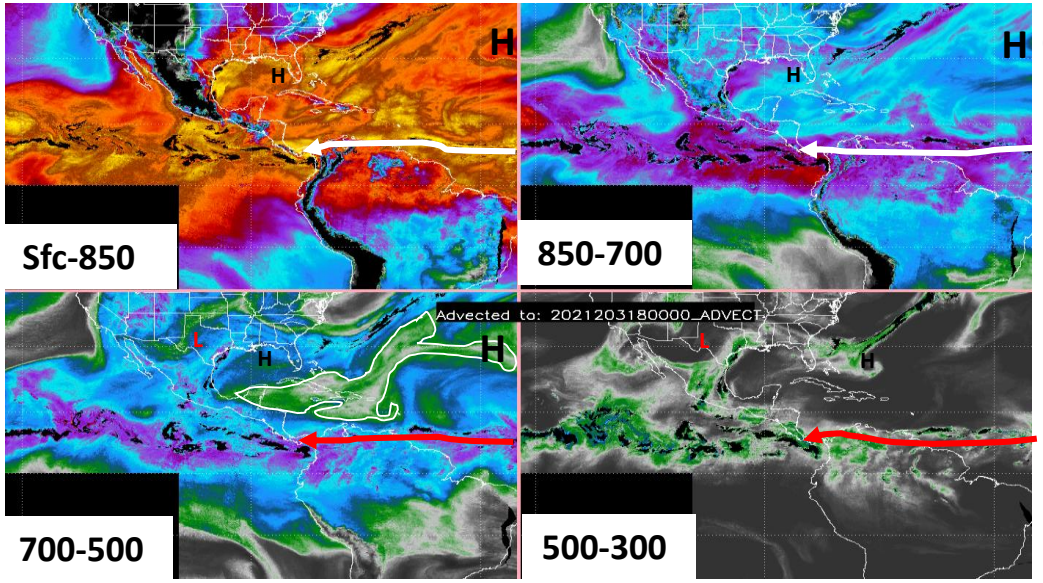
Blended TPW Pecent of Normal for 18 UTC 22 July 2021

00 UTC to 23 UTC 22 July 2021 Layer Precipitable Loop



Precipitable Water Moisture Transport below 700 hPa

Layer Precipitable Water for 18 UTC 22 July 2021



Precipitable Water Moisture Transport above 700 hPa

Neutral ENSO July 2021

CIRA Connecting Models and Observations

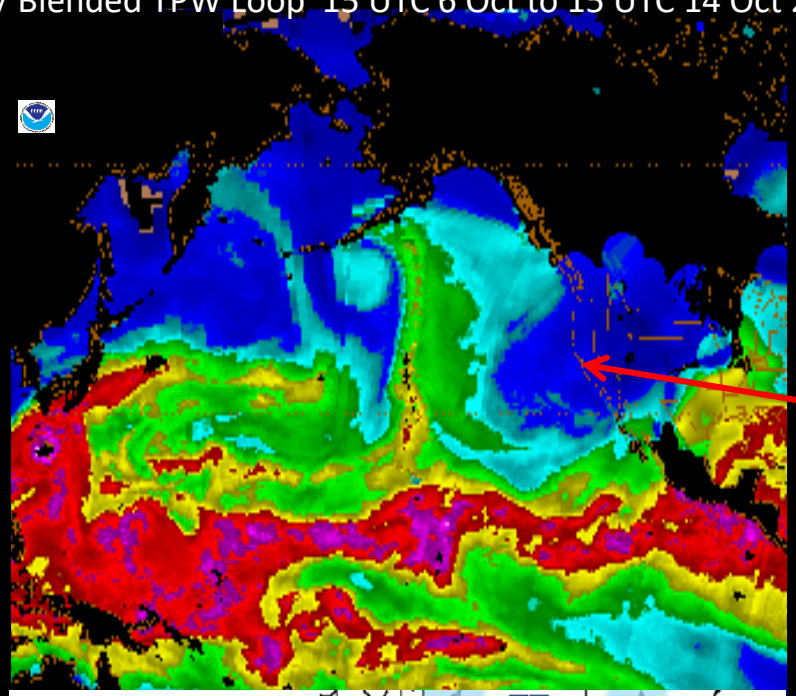
Atmospheric River Across the Pacific Pond

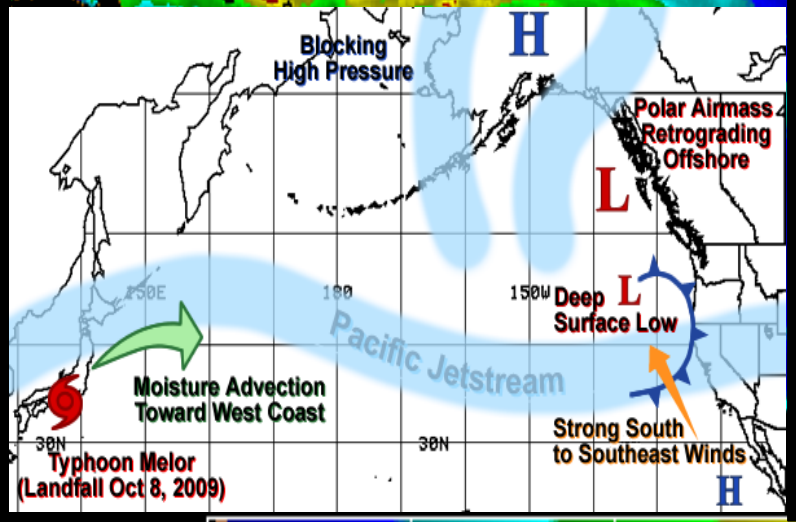
El Nino – October 2009

NOAA/ Blended TPW Loop 15 UTC 6 Oct to 15 UTC 14 Oct 2009

Preparation

NOAA OFFICE OF SATELLITE AND PRODUCT OPERATIONS





results

2009-10-06 0707-1431 UTC

0.0mm 15.0mm 30.0mm 45.0mm 60.0mm 75.0mm

Satellite-derived Blended Total Precipitable Water @ 1500 UTC 13 October 2009

NOAA OFFICE OF SATELLITE AND PRODUCT OPERATIONS

CA

6 12 25 38 50 62 mm

Here is another way to look at it!

Primary Moisture Plume or “atmospheric river”

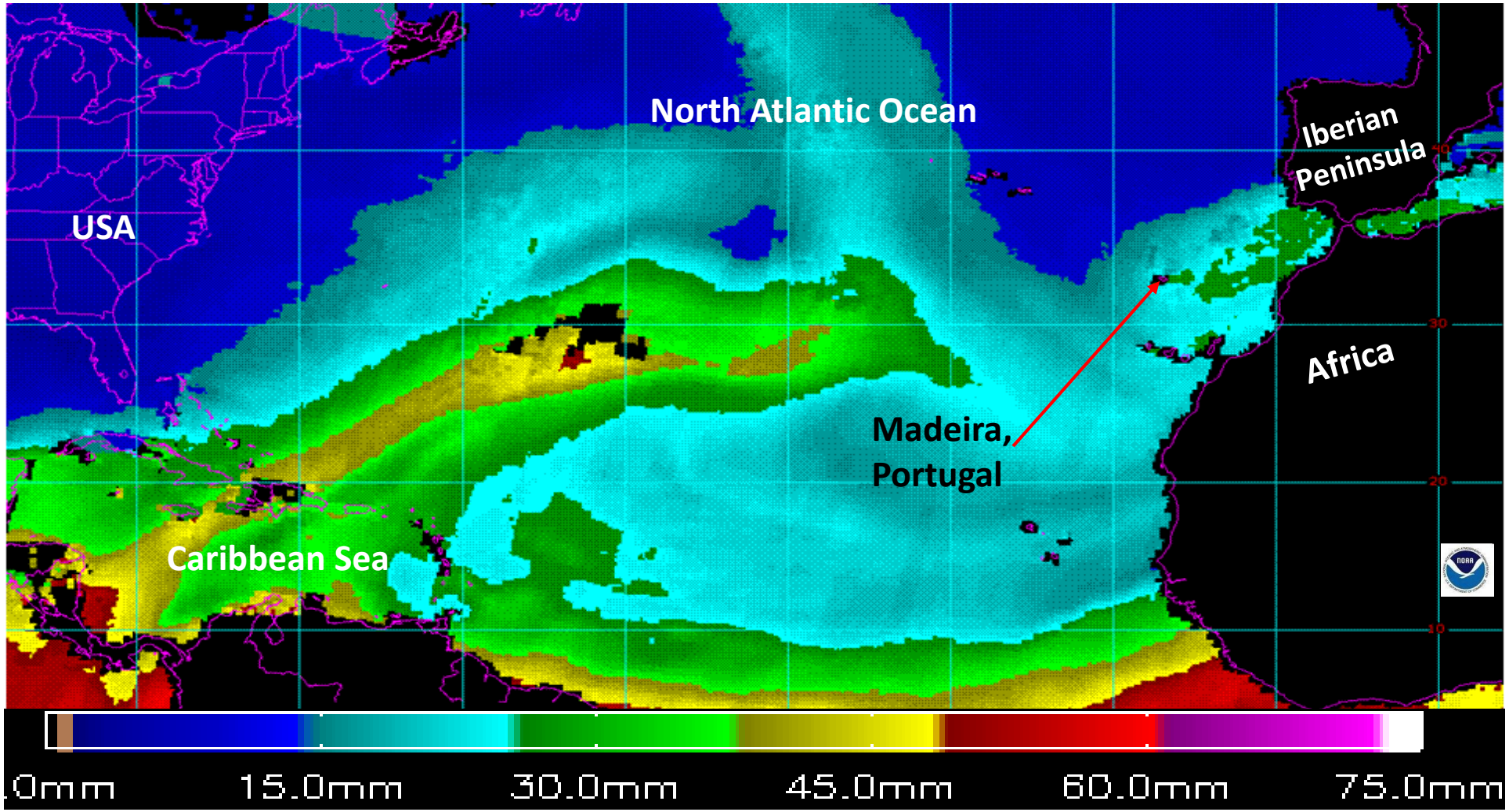
Secondary, but just as Important Second Moisture Plume or “atmospheric river”

The Results

24hr Rainfall ending
12 UTC 14 October 2009

Atmospheric River Across the Atlantic Pond – The Madeira Flood Event of 2010

NOAA Blended Total Precipitable Water (TPW) Loop for 1800 UTC 18 Feb to 1800 UTC 20 Feb 2010



Devastating Results

Atmospheric River Across the Atlantic Pond – The Madeira Flood Event of 2010

Total Precipitable Water (TPW) Concepts and Applications

TPW Satellite Signature

Moisture plume or "atmospheric river"

Concentration of highest amount of low level moisture - pattern recognition

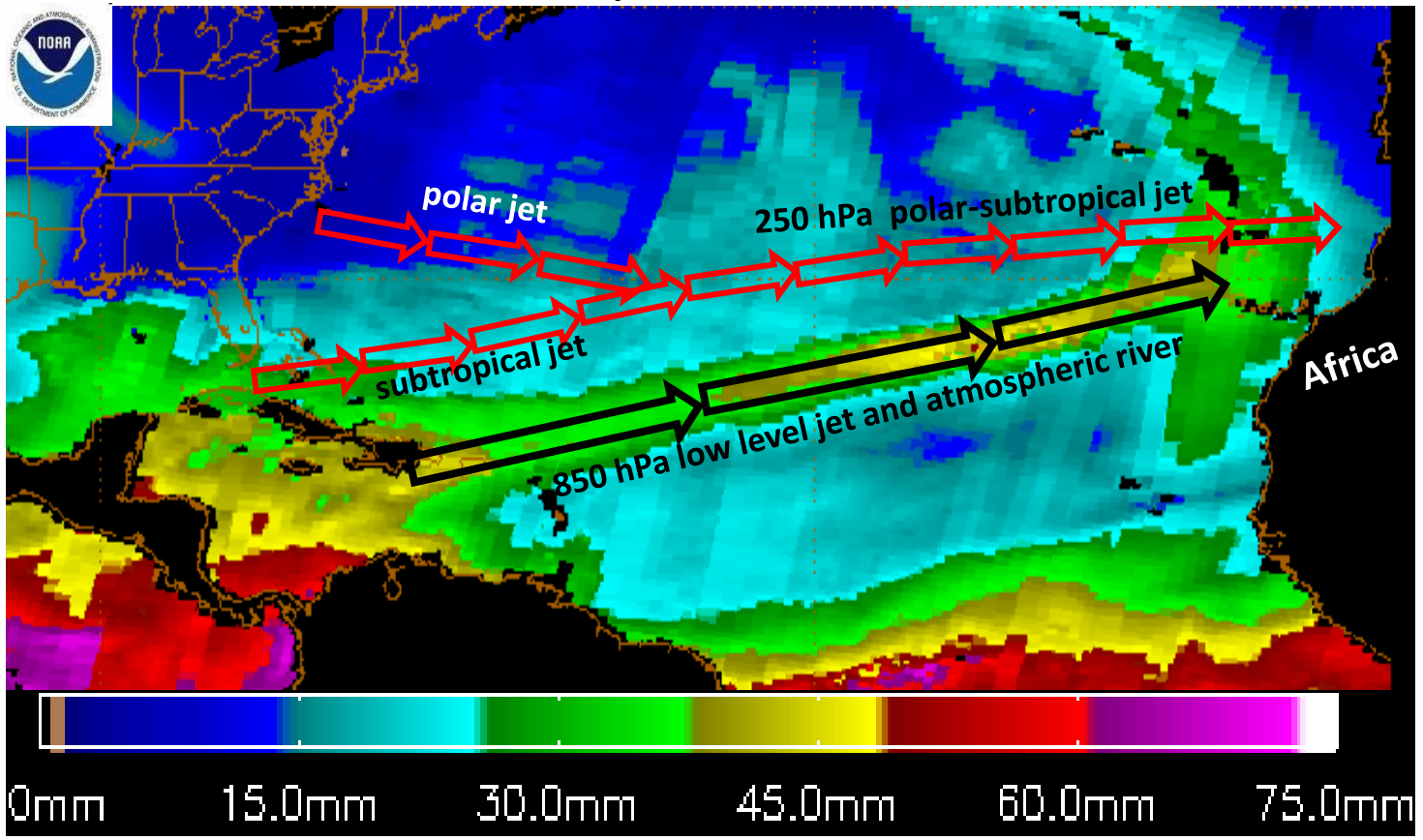
TPW Applications

- Low level flow parallel through highest moisture for longest distance can lead to heavy precipitation
- Stronger the low level flow, the stronger chance of heavy precipitation

Most ideal for heavy precipitation:

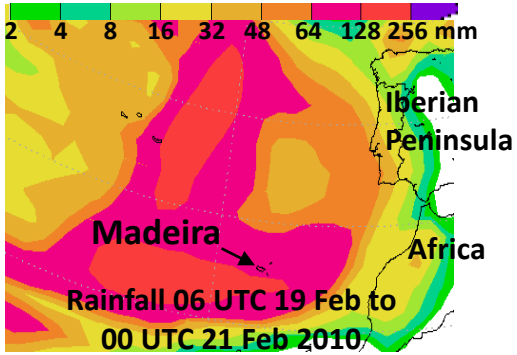
- long fetch of low level winds parallel the moisture plume; upper level forcing and strong orographics along or at end of plume

NOAA Blended Total Precipitable Water for 12 UTC 20 Feb 2010



Unusually strong high level jet crossing moisture plume

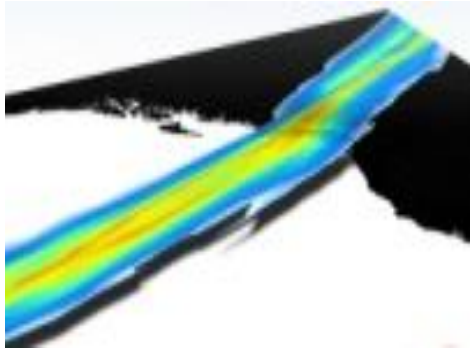
Unusually strong low level jet parallel highest moisture for maximum moisture transport



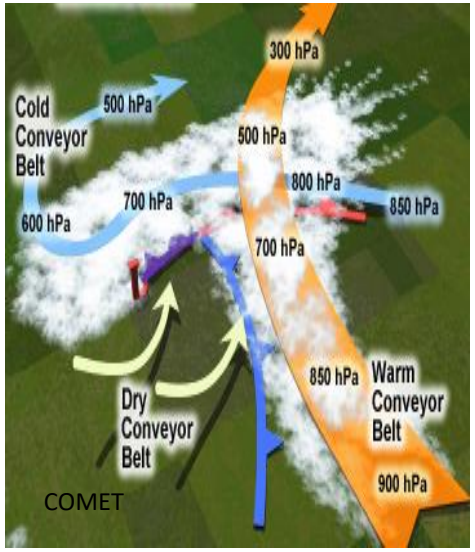
The Results

Pattern Recognition and Satellite Signatures for Record Breaking Atmospheric River Snow: Comparing the Moscow and Montreal Events

Atmospheric Blizzards

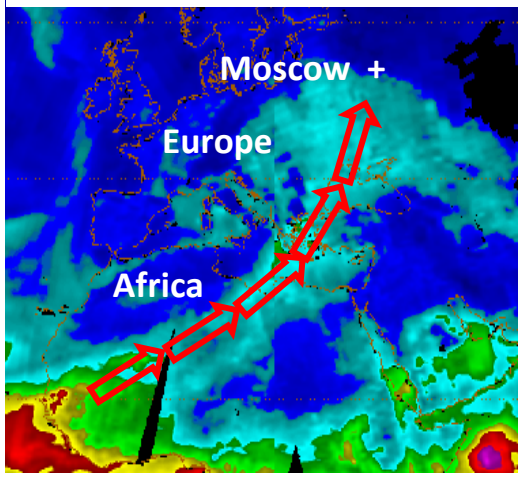


Conceptual Models



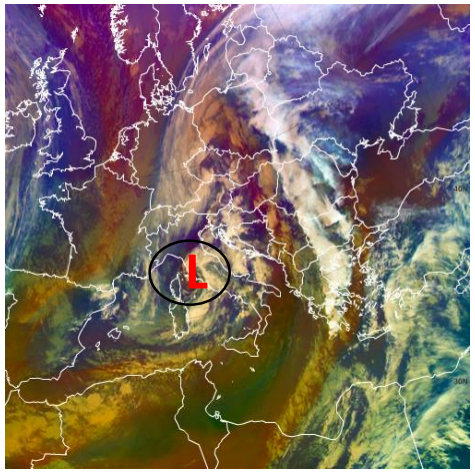
Moist conveyor belt

Blended TPW
12 UTC 29 Nov 2012

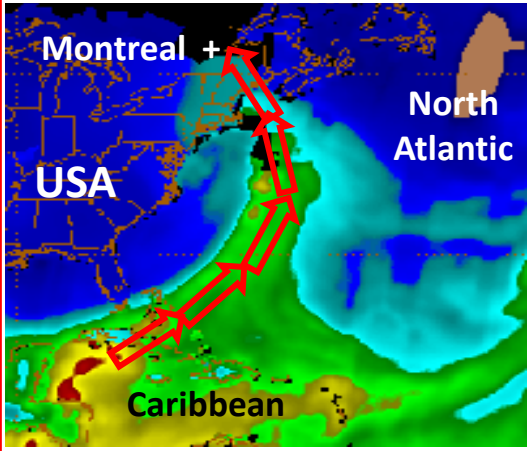


22 cm snow
Moscow Record

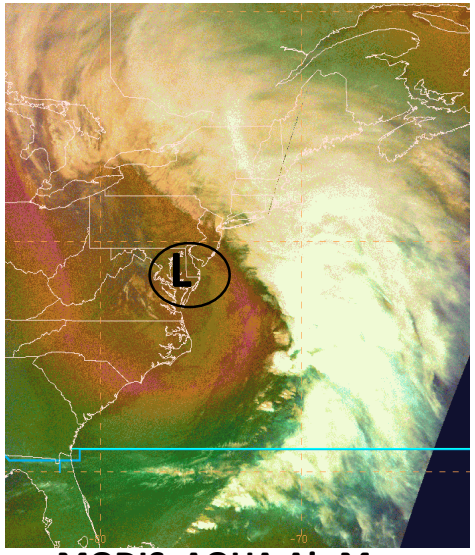
METSAT-9 RGB Air Mass
1200 UTC 29 Nov 2012



Blended TPW
12 UTC 27 Dec 2012



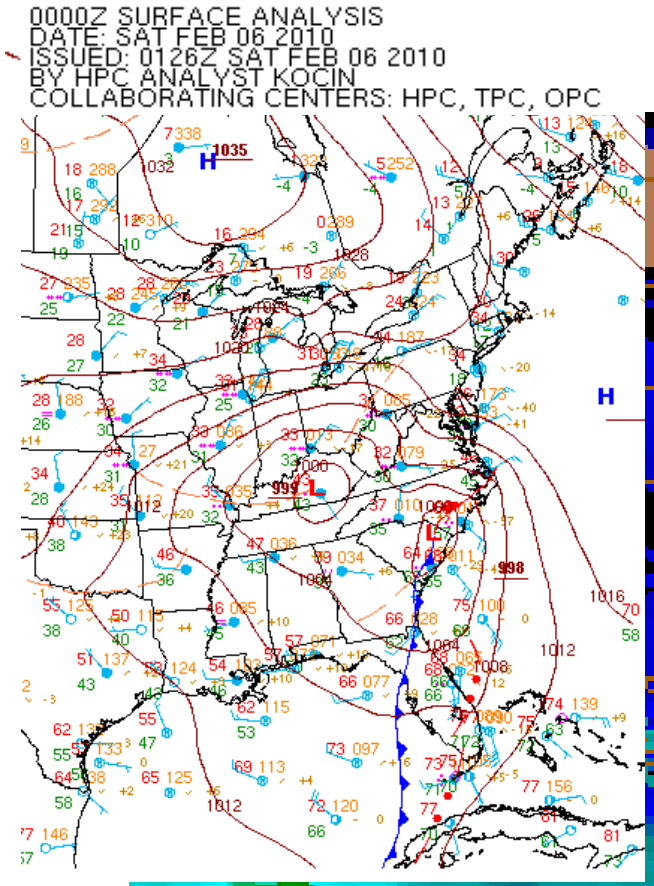
45 cm snow
Montreal Record



MODIS AQUA Air Mass
0651 UTC 27 Dec 2012

Tropical Atmospheric River Meets Mid-Winter Frigid Cold

El Nino – Winter of 2009-10

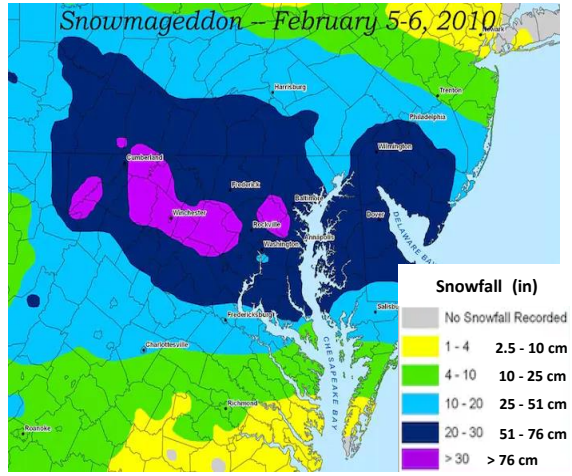


0000 UTC 6 February 2010


The Washington Post

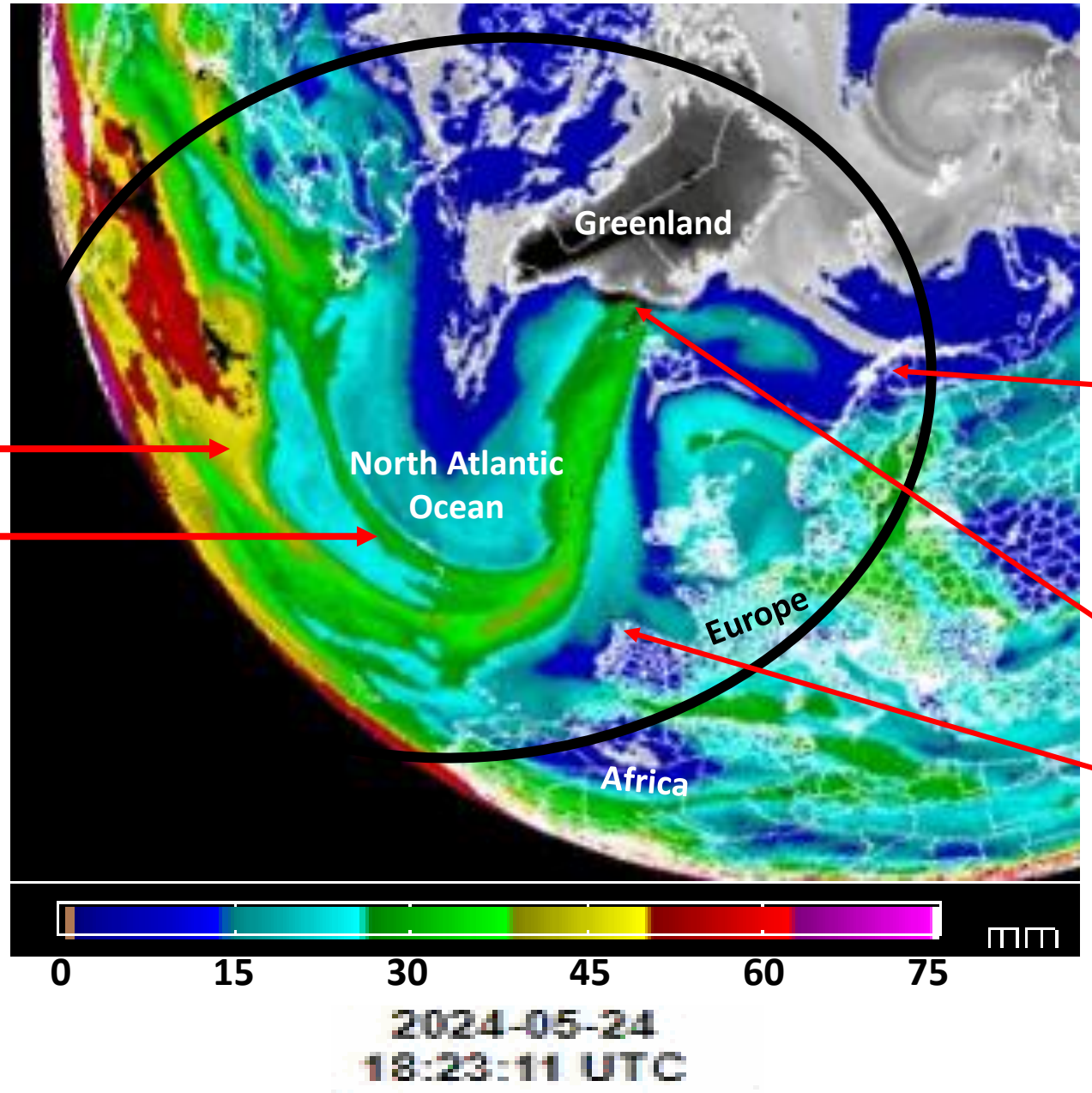
A HISTORIC MESS

POWERLESS: Officials across area consider opening shelters for tens of thousands without heat. | **STALLED:** 32 inches of snow shutters Dulles; other airports, rail and roads still struggling to dig out.



Atmospheric River Penetrating into the Arctic

CIRA Polar Centric NOAA/NESDIS Satellite Total Precipitable Water (TPW)



main atmospheric river originating subtropics

secondary atmospheric river

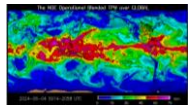
possible end of atmospheric river in NW Norway

single previously merged atmospheric river brushing Greenland's East Central Coast

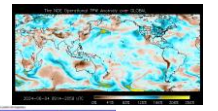
merged atmospheric river brushing Northwest Spain

Satellite Moisture Products on the Internet to Monitor Atmospheric Rivers

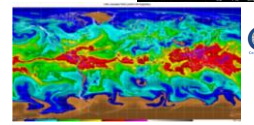
TOTAL Precipitable Water (TPW) Vapor

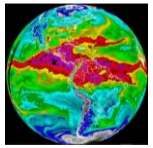
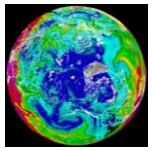
https://www.ospo.noaa.gov/Products/bTPW/Product_Animation.html NOAA/NESDIS TPW Loop




https://cdat.cira.colostate.edu/CAT/aTPW/aTPW5.htm CIRA Advected TPW Loop

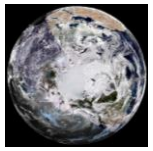


https://tropic.ssec.wisc.edu/real-time/mtpw2/product.php?color_type=tpw_nrl_colors&prod=global2&timespan=24hrs&anim=html5 CIMSS MIMIC TPW Loop

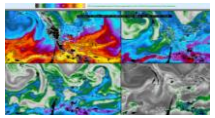
https://rammb-slider.cira.colostate.edu/ CIRA Slider where you can overlay satellite TPW Imagery on GEO imagery

https://rammb-slider.cira.colostate.edu/?sat=jpss CIRA Slider where you can overlay satellite TPW on LEO imagery

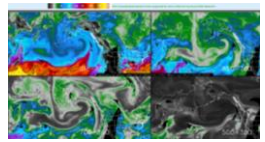



Sheldon.Kusselson@gmail.com

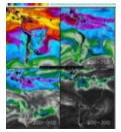
LAYER Precipitable Water (LPW) Vapor



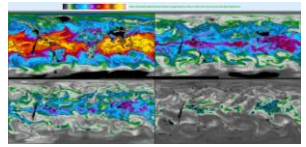
https://cat.cira.colostate.edu/SPoRT/Layered/Advected/ALPW_Hourly.htm Sector includes Eastern N Pacific, CONUS and N Atlantic



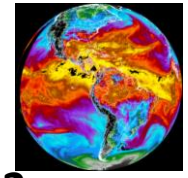
https://cat.cira.colostate.edu/SPoRT/Layered/Advected/LPW_Alaska.htm Sector includes N Pacific, Alaska and CONUS



https://cat.cira.colostate.edu/sport/layered/advected/LPW_SAm.htm Sector centered on South America

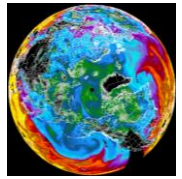
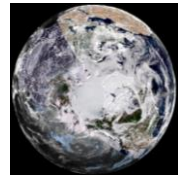


https://cat.cira.colostate.edu/ALPX/ADVLUT/ALPX_hourly.htm Global sector

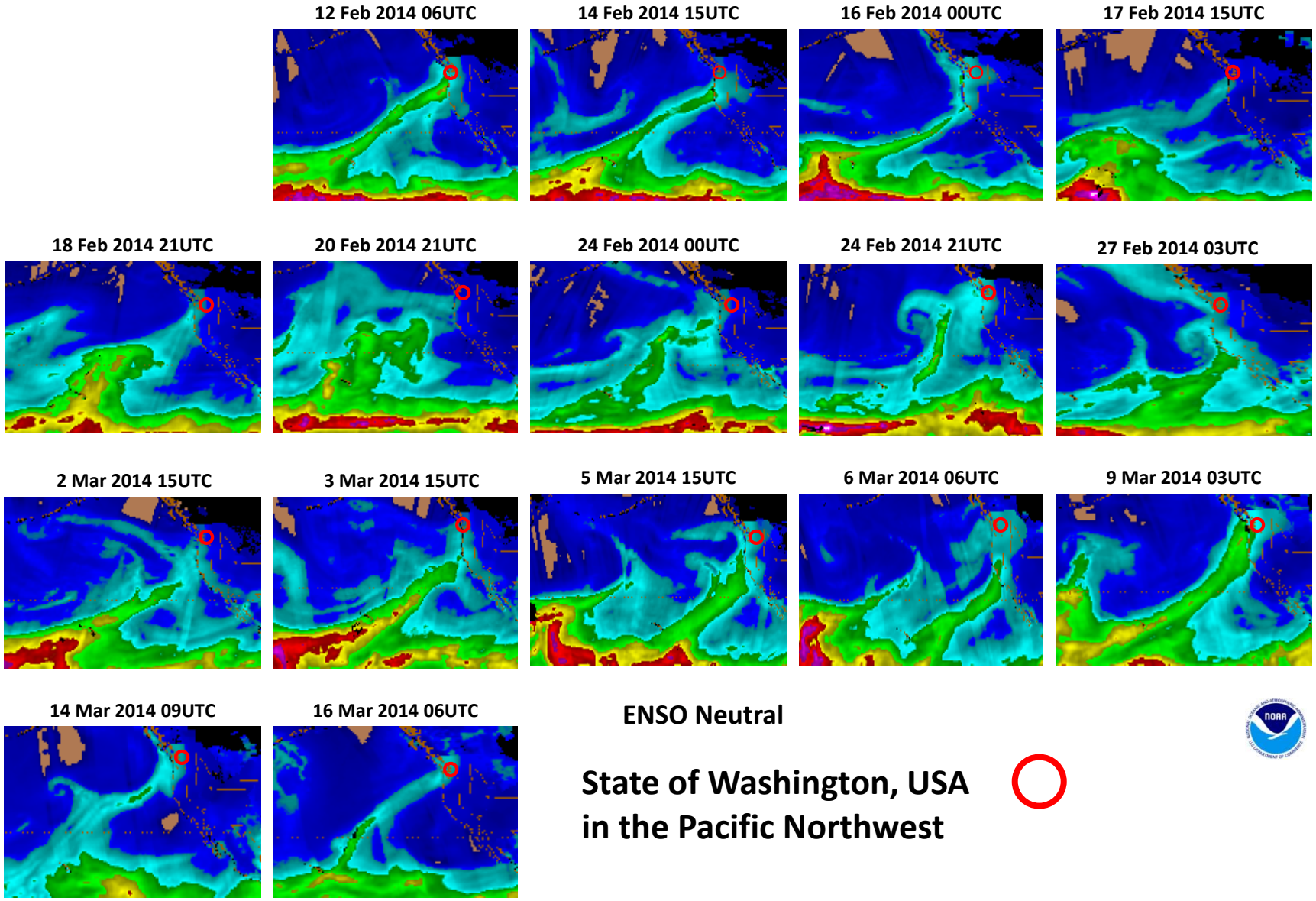



https://rammb-slider.cira.colostate.edu/ and https://rammb-slider.cira.colostate.edu/?sat=jpss

CIRA Slider where you can overlay satellite LPW on GEO and LEO imagery

Individual "Atmospheric Rivers" that affected Washington State, USA February 12 to March 16, 2014

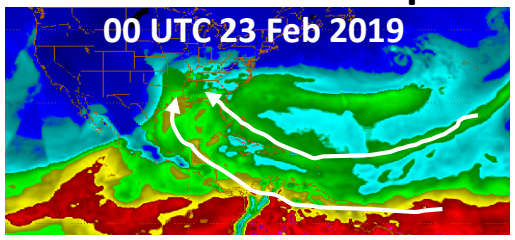


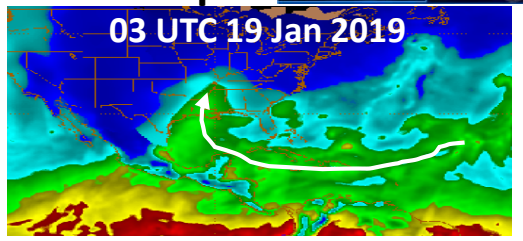
What Happened on 22 March 2014

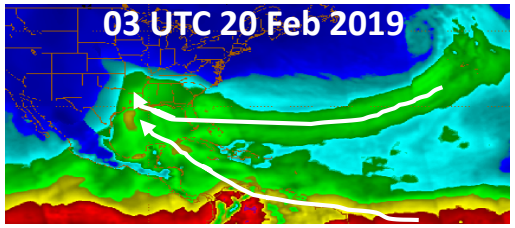
Landslide **Flooding**

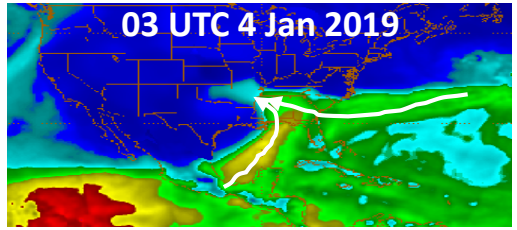
Winter 2018-19 “Atmospheric River” Events that Increased Inundation on Mississippi River During Spring 2019

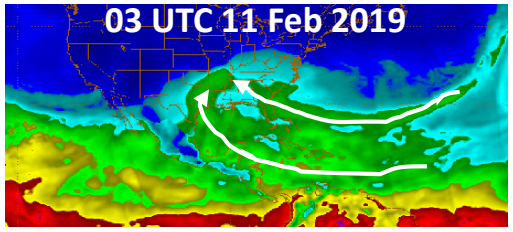
Total Precipitable Water Vapor

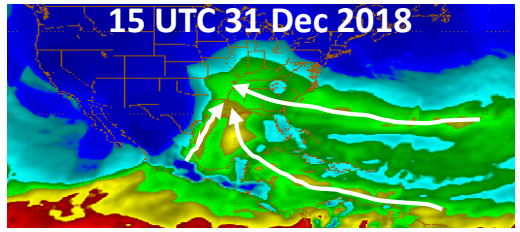


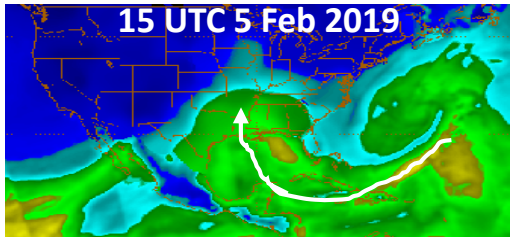


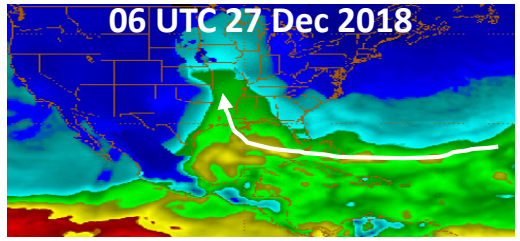


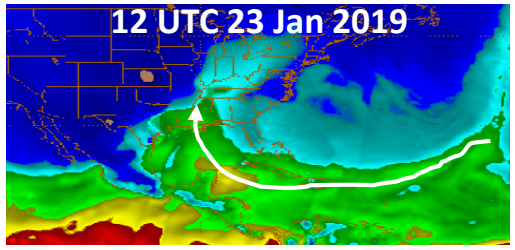


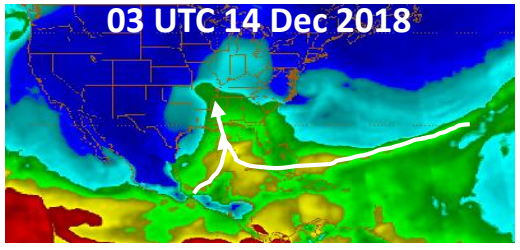










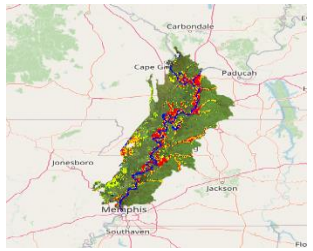


Atmospheric river and good moisture transport

One “atmospheric river” event does not result in inundation.

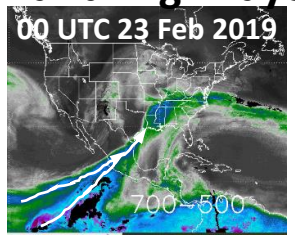
But many over a span of weeks, months, even a season can result in inundation.

Like the el nino winter of 2018-19

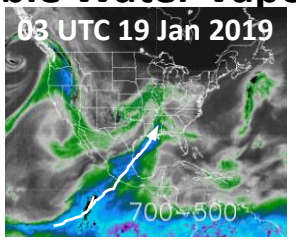


24

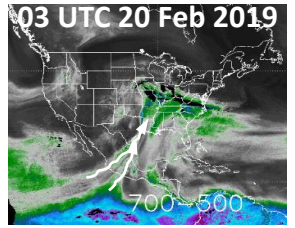
Low and High Layer Precipitable Water Vapor



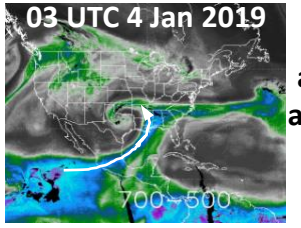
700-500 hPa

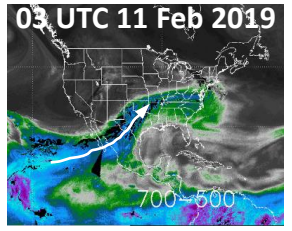


To better see the atmospheric rivers at the 700-500 layer

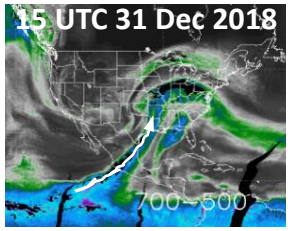


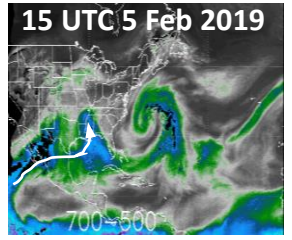
700-500 hPa



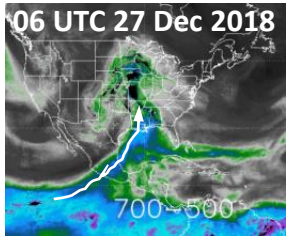


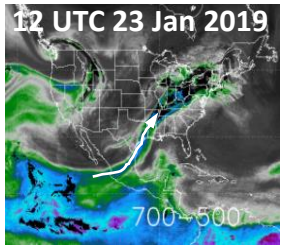
700-500 hPa





700-500 hPa





700-500 hPa