How MiRS Retrievals Enable a Layered Water Vapor Product for Forecasters

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Outline

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

2. Forecaster usage examples

3. Work in progress

How is Blended LPW Created?

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

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

LPW is proportional to layer mean mixing ratio.

Creating the Blended LPW Product

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

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

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

Current configuration for Layer Precipitable Water: 7 satellites:

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

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

→ All of these spacecraft measure microwave radiation around the 183 GHz water vapor absorption line.
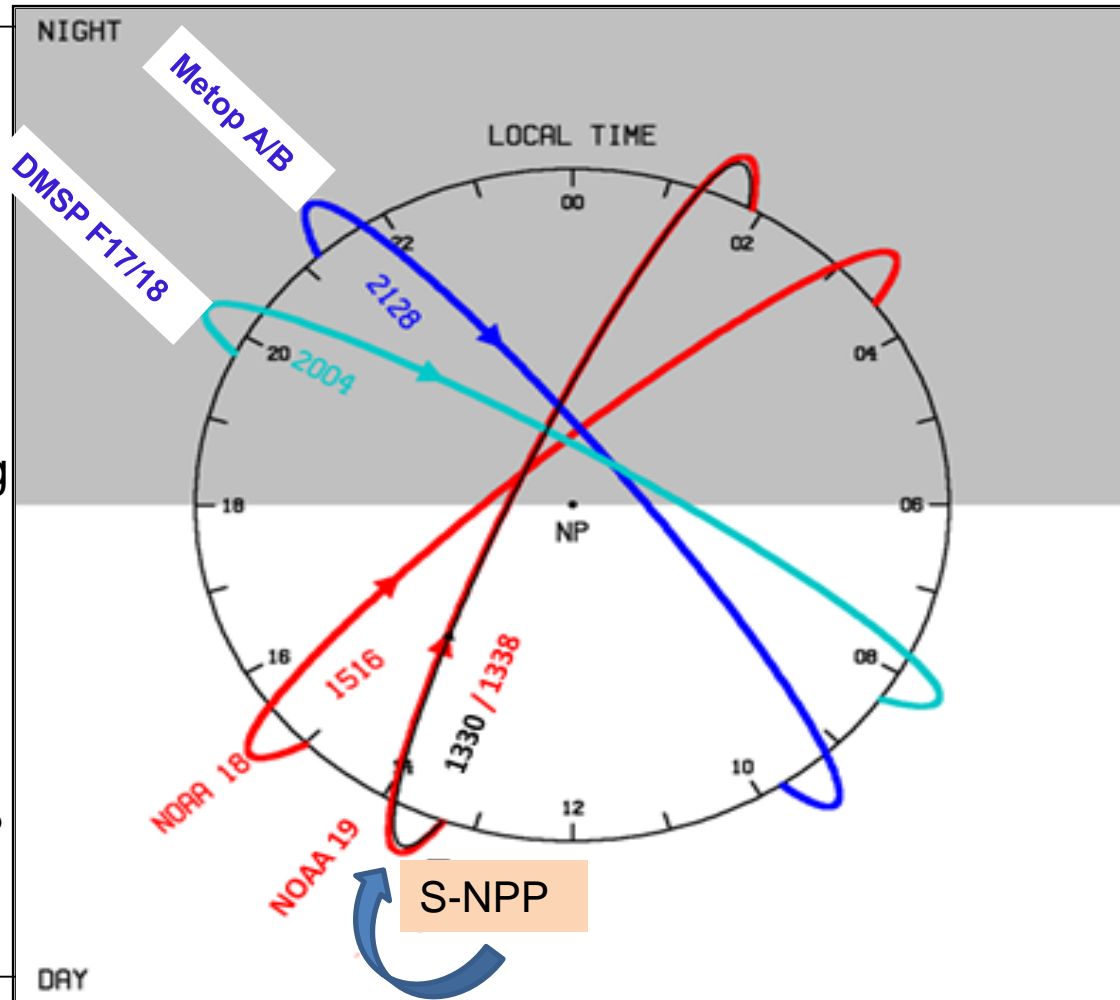
Older satellites play a valuable role in extending temporal sampling

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Creating the Overlay Product

Thu Jun 22 02:47:31 2017 (UTC)
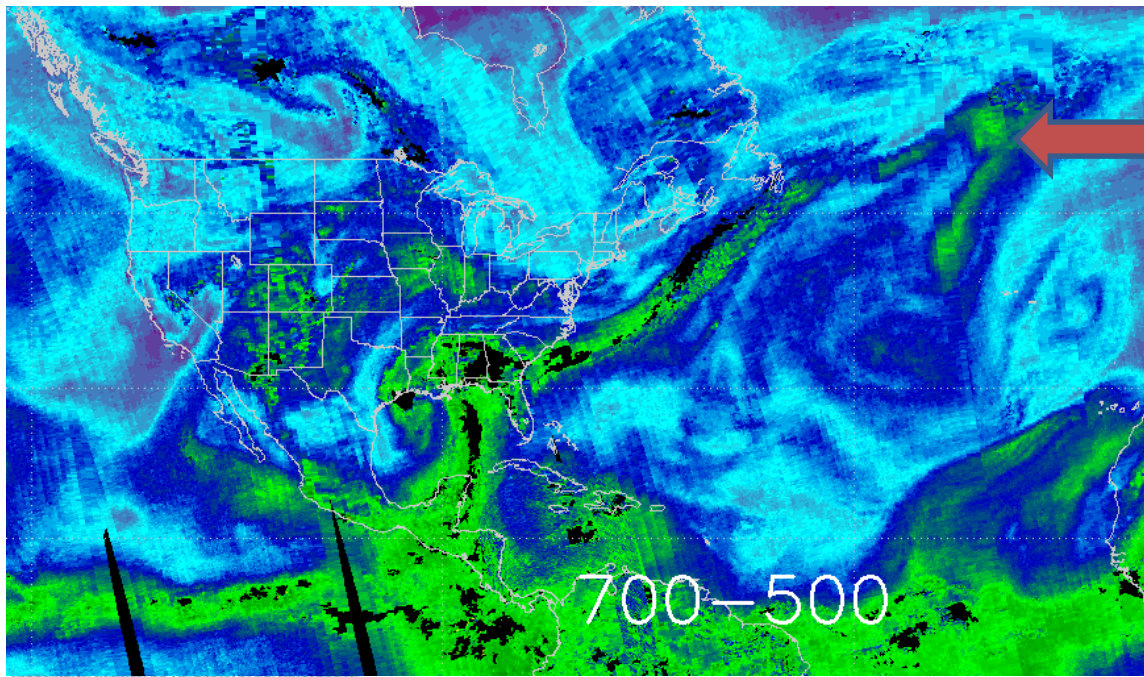
| N18 | N19 | F17 | F18 | Metop-A | Metop-B | AIRS | SNPP |

Sat ID

Satellite ID

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

700-500
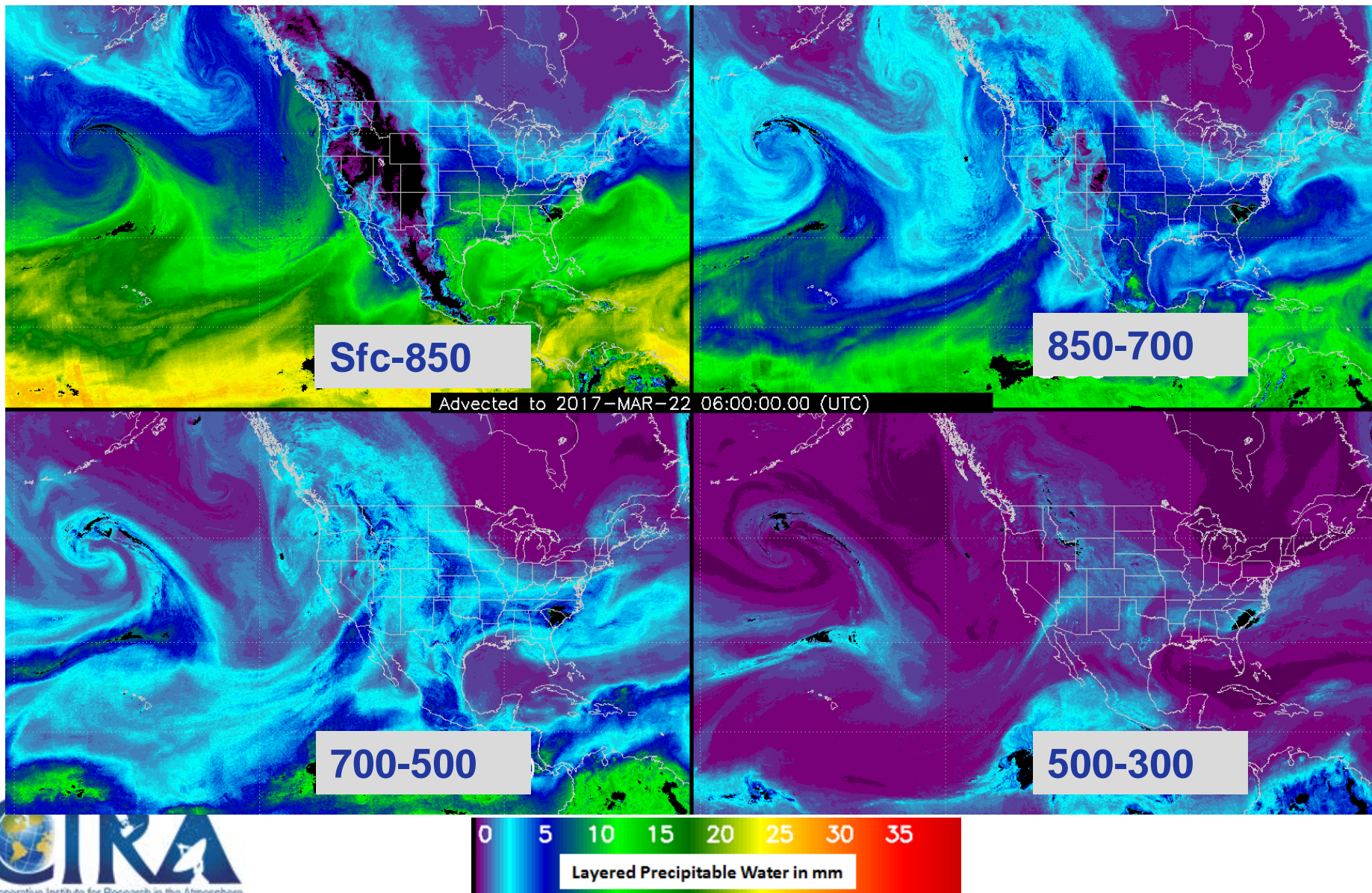
The overlay product currently being used by forecasters

700 – 500 mb LPW (mm)

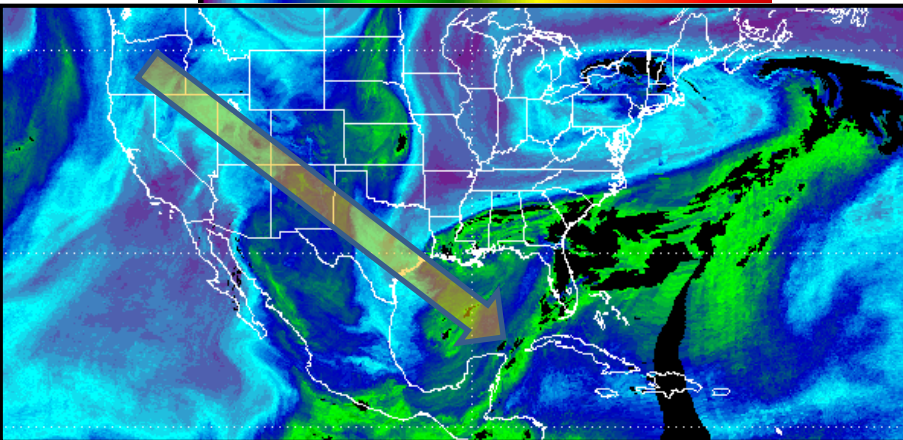| 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 |

Layered Precipitable Water in mm

New Version 01 Advected LPW, advected every three hours
- **Everything moves and is mapped to one synoptic time.**
- *Plan to switch NHC, WPC to this product within a month or two*
- *A good test of MiRS quality and interconsistency*

Sfc-850

850-700

Advected to 2017-MAR-22 06:00:00.00 (UTC)

700-500

500-300

Layered Precipitable Water in mm

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Forecaster Usage Examples

Example CIRA LPW Usage at WPC for Tracking Tropical Moisture

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

RAP32 PRECIP WATER 170605/2300f001
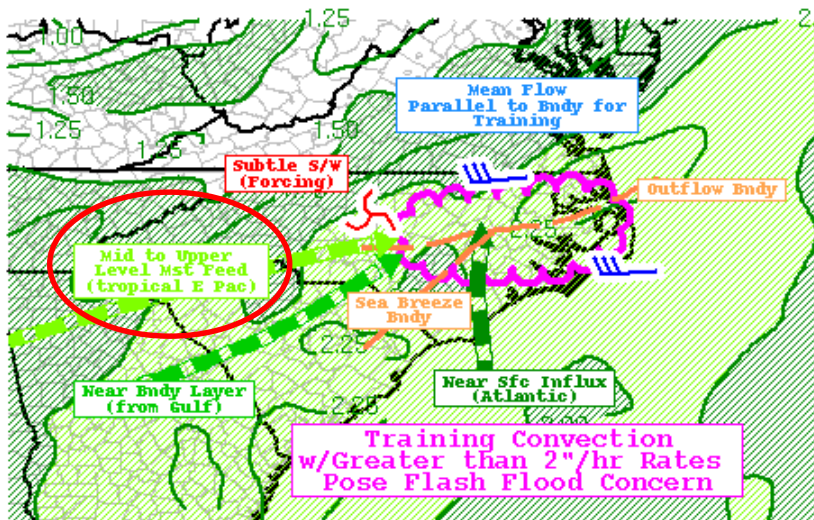**WPC MPD #0301**

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

AREAS AFFECTED...EASTERN NC

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

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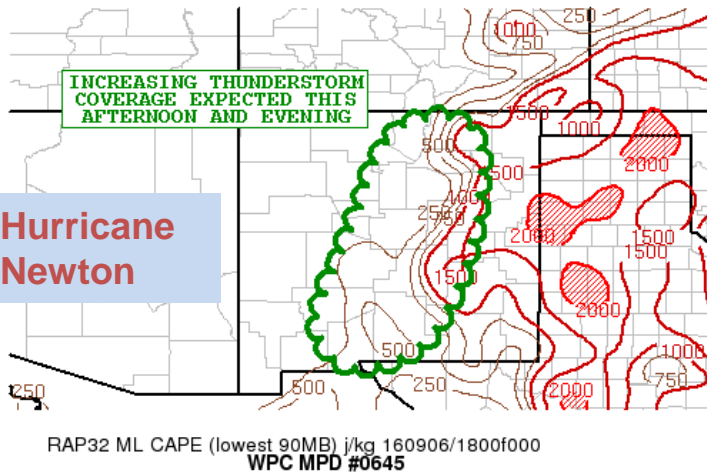
GALLINA
ATTN...WFO...AKQ...MHX...RAH... ATTN...RFC...SERFC...

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

INCREASING THUNDERSTORM COVERAGE EXPECTED THIS AFTERNOON AND EVENING

Hurricane Newton

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

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

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

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

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

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

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

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

Ramos

LPW also has Utility for Heavy Snow Forecasting

Advected to 2016-NOV-21 09:00:00.00 (UTC)

Sfc-850

850-700
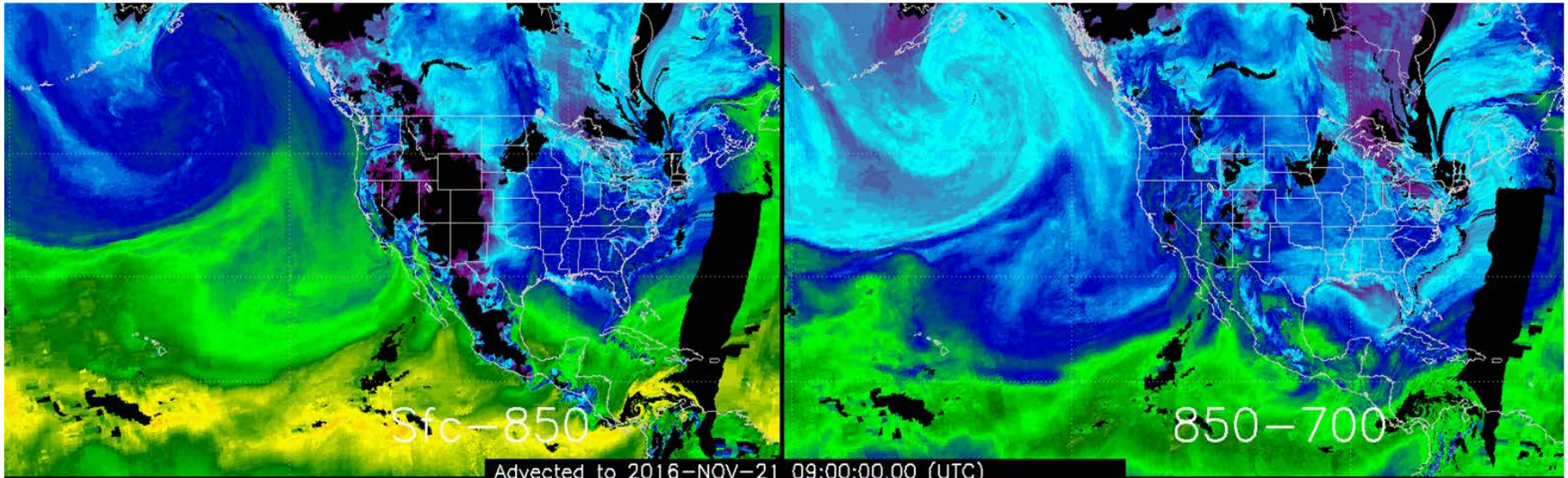
700-500

"A pretty amazing lake-effect/lake-enhanced event is unfolding for western/central NY tonight. LPW data shines again, as the 700-500 mb panels show a lengthening moisture inflow, from the southeast coastal waters, all the way around the comma-head of the storm over northern New England/southern Ontario. Mid-level moisture is normally the achilles heel of many otherwise good lake-effect events, but not so this time."
-- Michael Jurewicz, NWS Binghamton NY, 11/20/16

0   5   10   15   20   25   30   35
Layered Precipitable Water in mm

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

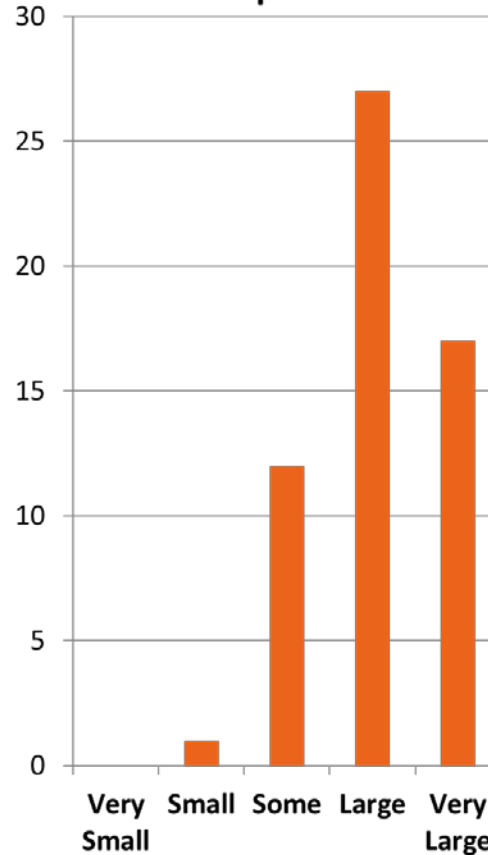**"Using the Multi-sensor Layered Precipitable Water Advection Product in the Operational Forecast Environment"**

SPoRT-led NWS forecaster survey of Alaska and Puerto Rico NWS offices during 2013 demonstration of Layered Precipitable Water
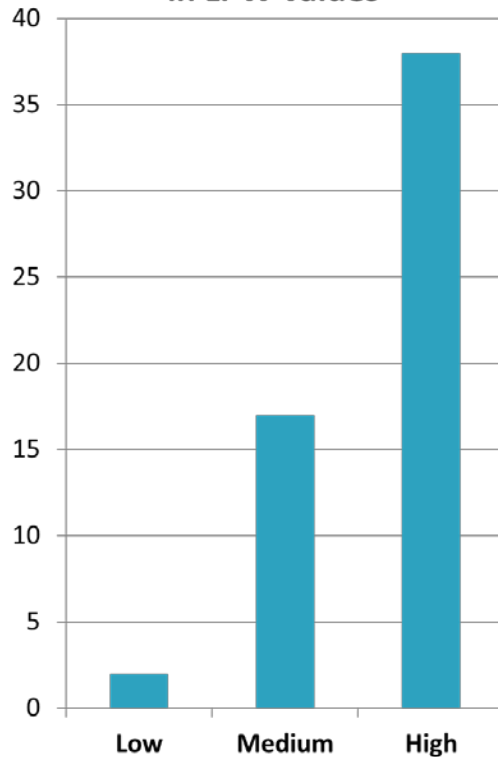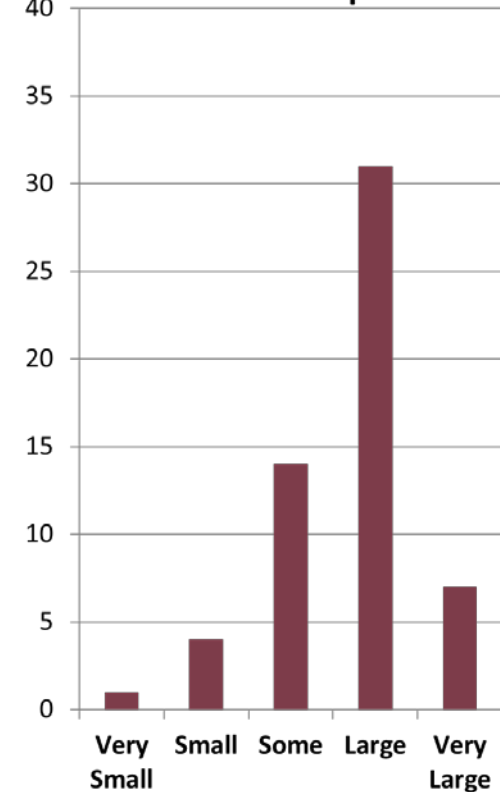
LeRoy et al. 2016, J. Operational Meteorology

Work in Progress and Future Work

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

GFS moister

Excellent agreement
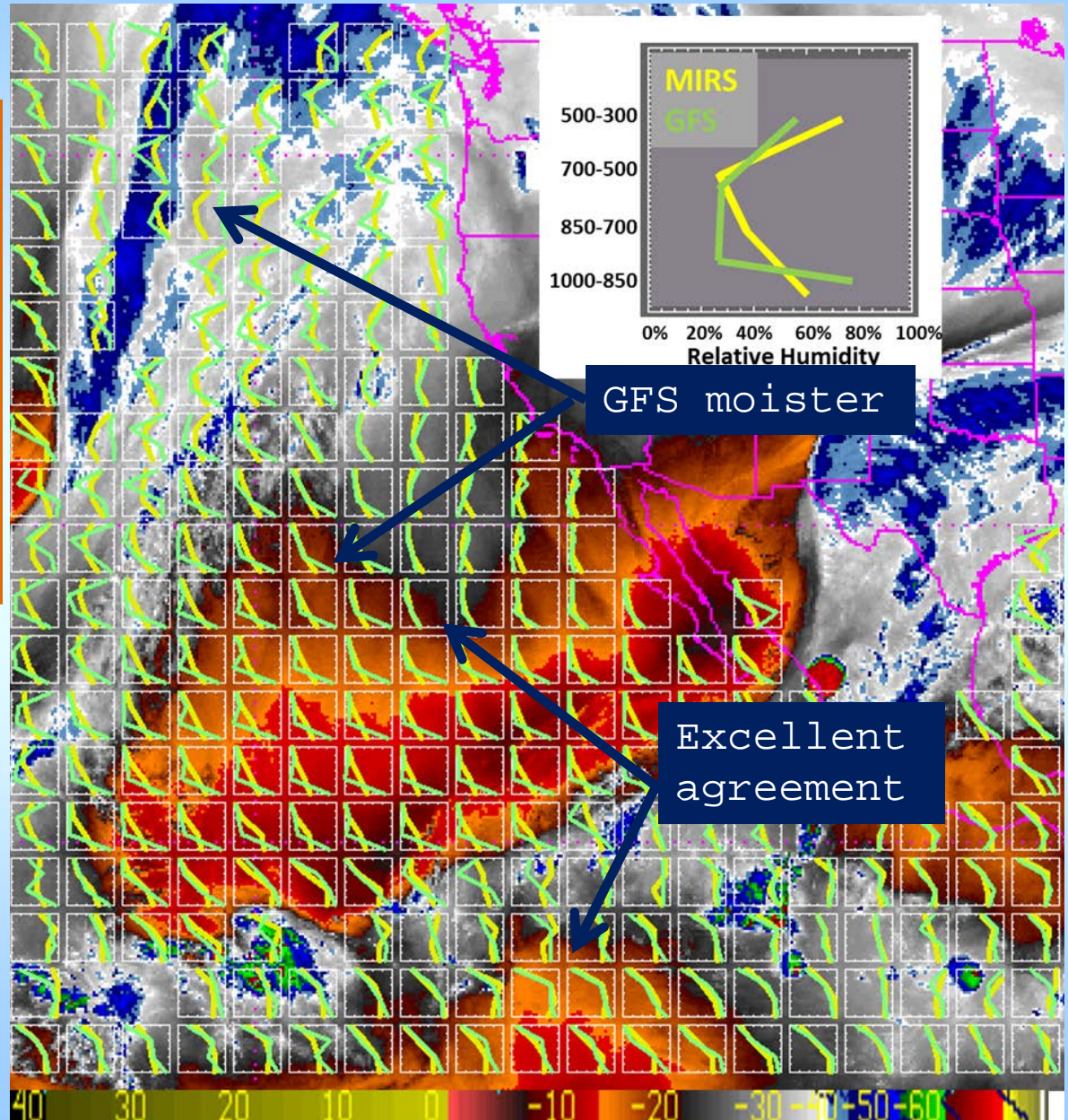
Prototype 6.5 μm Cloud-Free Water Vapor Imagery
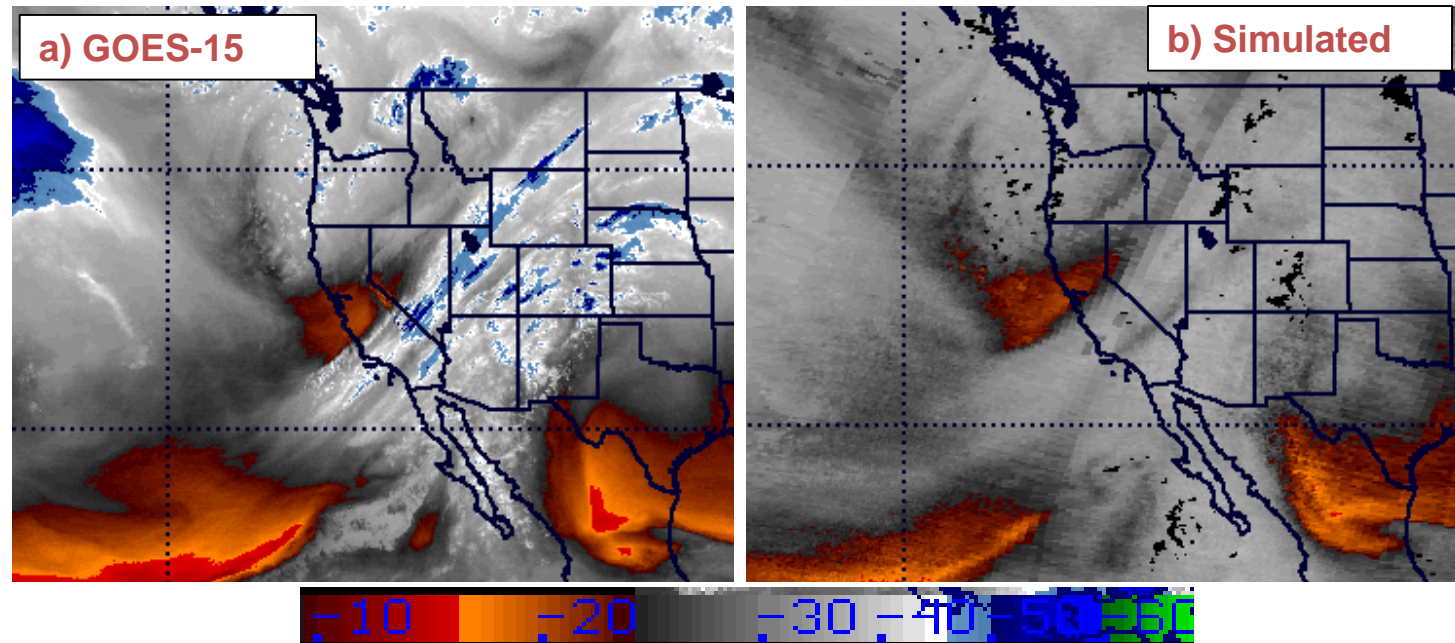
(a) GOES-15 water vapor channel brightness temperature at 1500 UTC 16 November 2016 and (b) Prototype simulated brightness temperature derived from CIRA LPW.

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

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

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

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

ALL Soundings for DNR
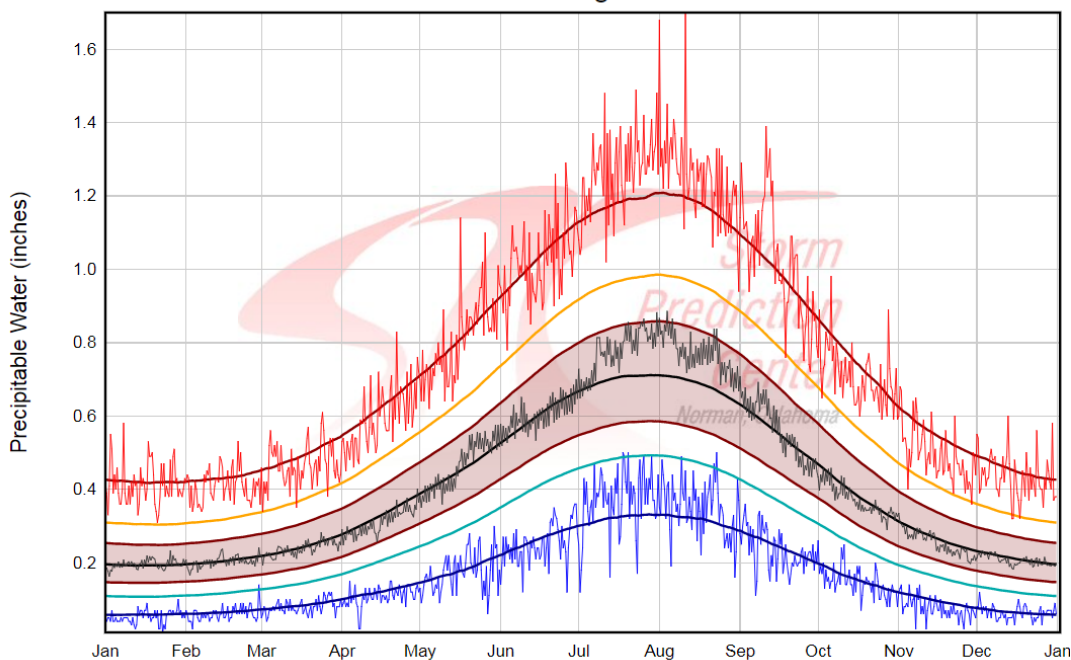
07 Aug 12 UTC

Daily Min (Thin Line): 0.34
Min Moving Average: 0.33
10% Moving Average: 0.49
25% Moving Average: 0.58

Median Moving Average: 0.71
Daily Mean (Thin Line): 0.78

75% Moving Average: 0.85
90% Moving Average: 0.98
Max Moving Average: 1.20
Daily Max (Thin Line): 1.30

Summary

- **MiRS retrievals from seven spacecraft** drive the Blended Layer Precipitable Water product, which fills a void in moisture analysis for forecasters. Currently being evaluated at National Centers and select WFO's.

- **Advectively blended** products using MiRS V11 will be distributed in coming months.

- Provides **unique monitoring capability for MiRS**, with feedback to developers.

- Eventually Blended LPW **could become operational** using the same data processing framework as blended TPW.

- Most usage of LPW to date has been qualitative (unlike TPW). Work in progress to compare LPW to model moisture fields and generate cloud-free infrared imagery.

Backup Slides

Summary

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

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

Science Issue

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

Current Status

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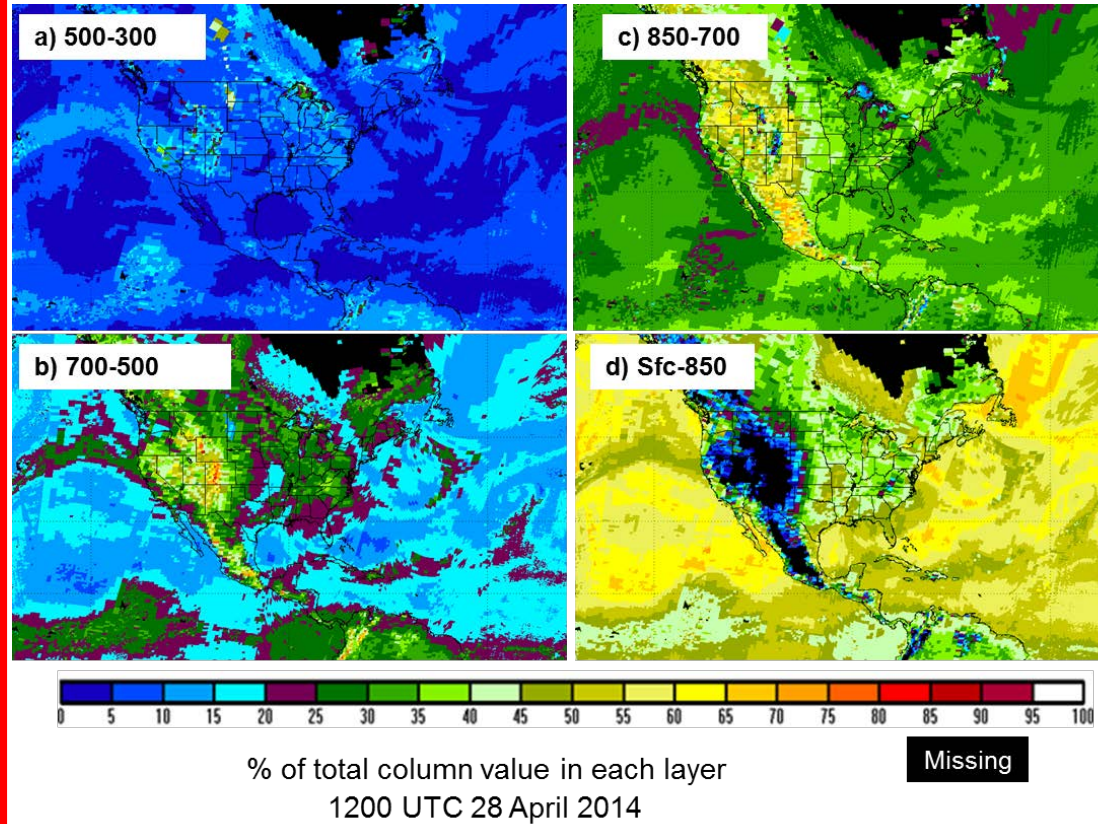- **Work in progress under NOAA JPSS Proving Ground / Risk Reduction to perform "advective blending". *Could become operational…***

Explore Other Derived Variables to Assist Forecasters

Prototype % of normal using AIRS climatology
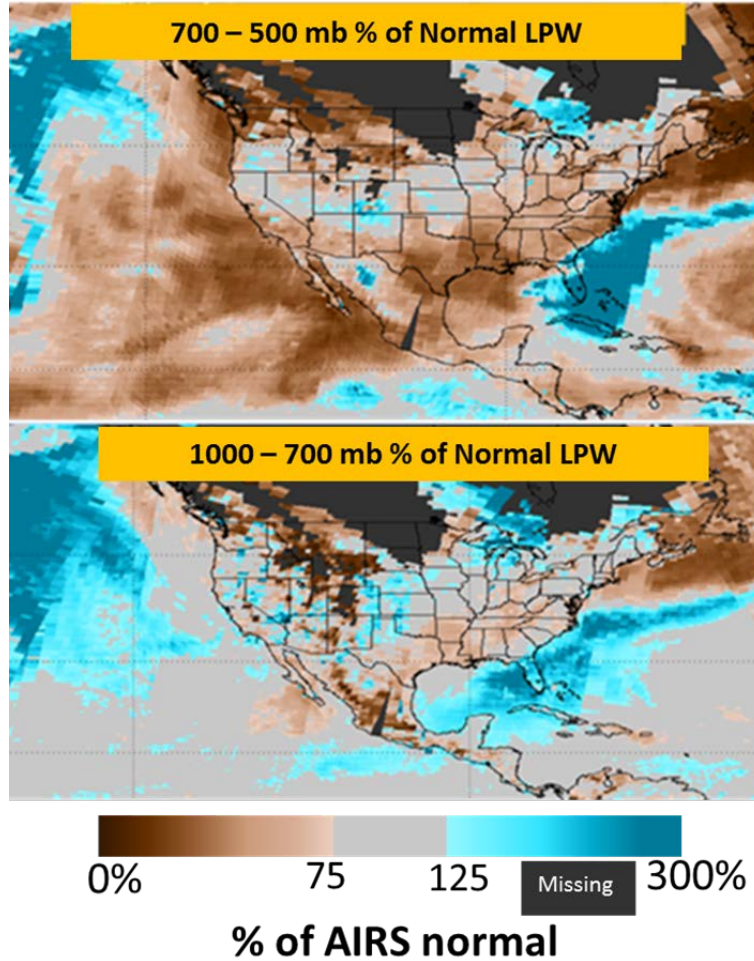
% of TPW in each layer

1800 UTC 22 April 2013

% of total column value in each layer
1200 UTC 28 April 2014

Revise Orographic Rain Index Using LPW

Historic Flooding in South Carolina in 2015

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

CONCERNING...HEAVY RAINFALL...FLASH FLOODING LIKELY

SUMMARY...A TROPICAL AIRMASS WITH NEAR RECORD PRECIPITABLE WATER
WILL RESULT IN A CONTINUED FLOOD AND FLASH FLOOD THREAT INTO THIS
AFTERNOON.
...
FORCING FROM THE SHORTWAVE IN GA AND A GENERALLY DIVERGENT PATTERN
ALOFT IS HELPING FORCE ASCENT ON THE LARGE SCALE...WITH 20-30 KTS
OF LOW LEVEL UPSLOPE FLOW AIDING IN LIFT. LAYERED PRECIPITABLE
WATER PRODUCTS SHOW AN IMPRESSIVE COMBINATION OF FACTORS
CONTRIBUTING TO THE NEAR RECORD PRECIPITABLE WATER VALUES ACROSS
THIS REGION. A CONNECTION TO THE PACIFIC AND TROPICAL STORM MARTY
CAN BE SEEN IN THE MID/UPPER LEVELS...WITH A DEEP LAYER CONNECTION
TO THE GULF OF MEXICO AND ALSO TROPICAL STORM JOAQUIN IN THE
ATLANTIC. THIS IS ALL RESULTING IN A VERY EFFICIENT ATMOSPHERE FOR
HEAVY RAIN RATES. THE ONE THING LACKING IS INSTABILITY...BUT AT
LEAST SOME DOES EXIST ACROSS THE AREA AS NOTED BY SOME LIGHTNING
AND COLDER CLOUD TOPS...

CIRA Layered Precipitable Water 700-500 hPa Level   1530 UTC September 29, 2015

700-500

0 5 10 15 20 25 30 35 mm

Analysis by Sheldon Kusselson
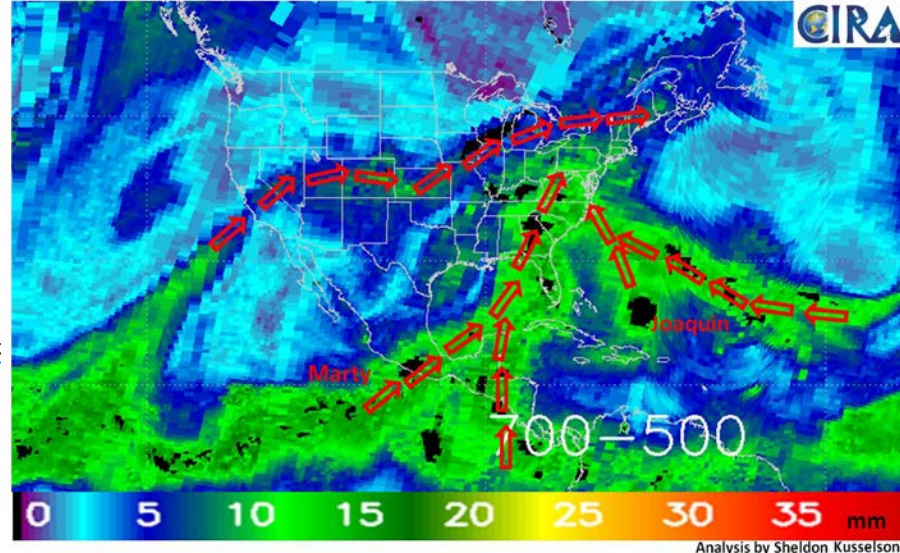
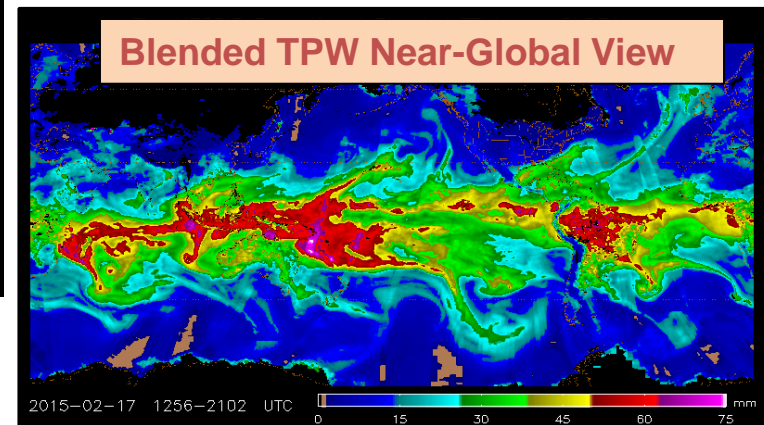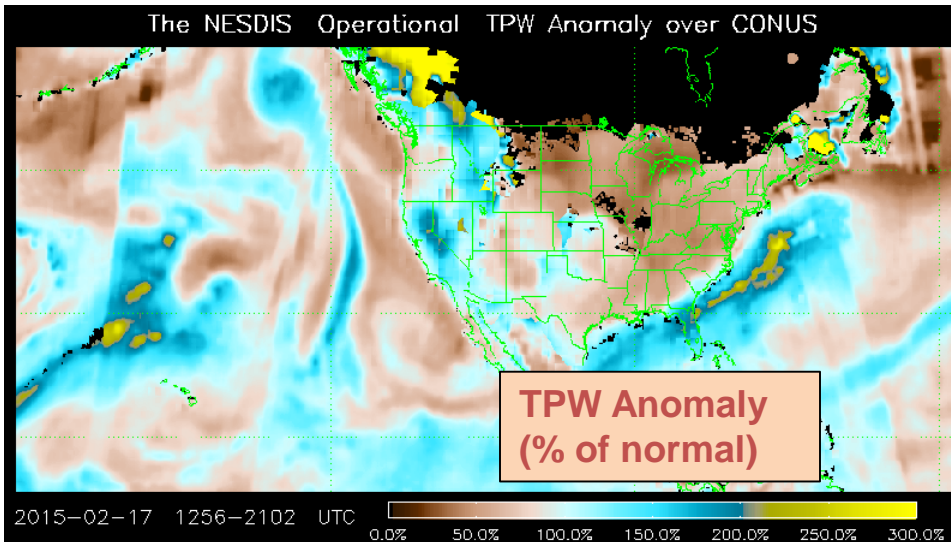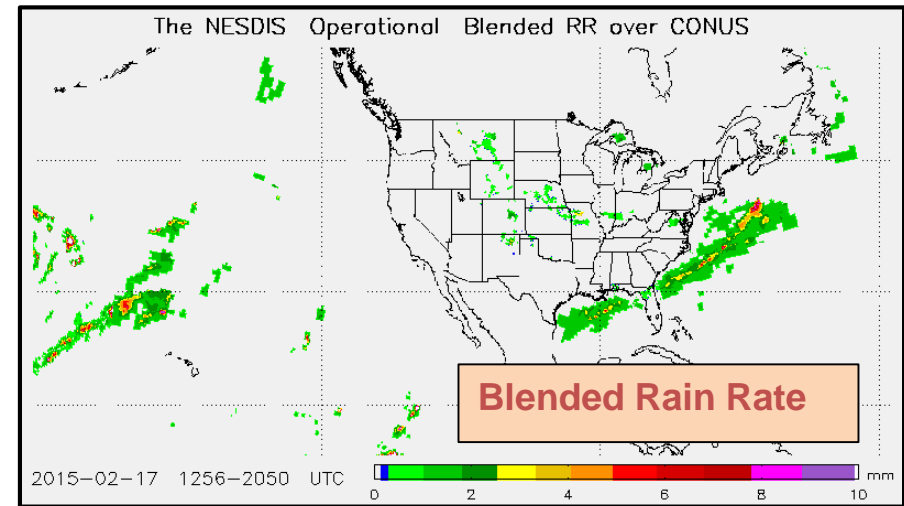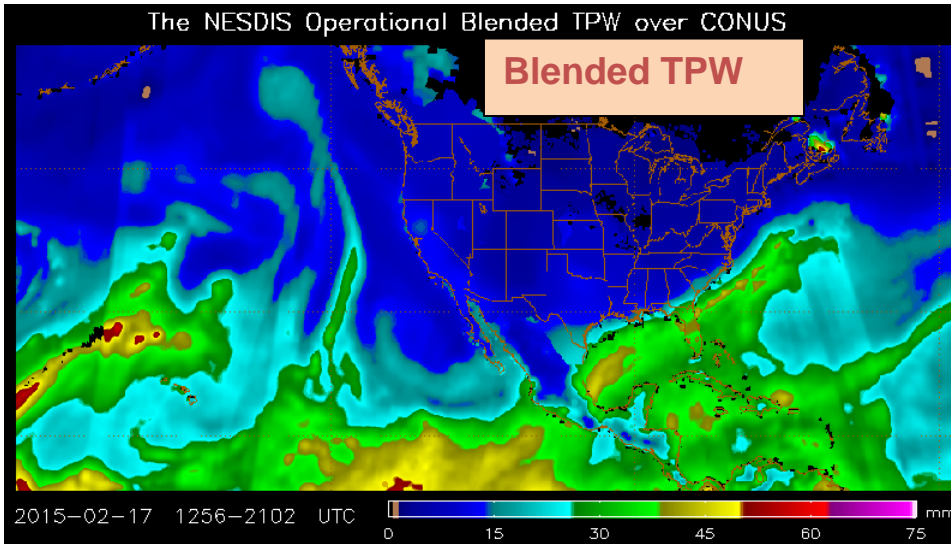**Five streams of moisture fuel flooding in SC**

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

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

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

Blended TPW

The NESDIS Operational Blended TPW over CONUS
2015-02-17 1256-2102 UTC

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

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

The NESDIS Operational Blended RR over CONUS
Blended Rain Rate
2015-02-17 1256-2050 UTC

The NESDIS Operational TPW Anomaly over CONUS
TPW Anomaly (% of normal)
2015-02-17 1256-2102 UTC

Blended TPW Near-Global View
2015-02-17 1256-2102 UTC

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

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

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

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Current/Planned User Interactions

– Heritage overlay LPW product created at CIRA and being delivered for AWIPS every three hours to NHC, WPC, OPC, SAB. NASA SPoRT currently serving data via existing pathway.

– Expect large user impacts based on NWS evaluations in 2013

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

**http://rammb.cira.colostate.edu/training/visit/satellite_chat/20151007/**
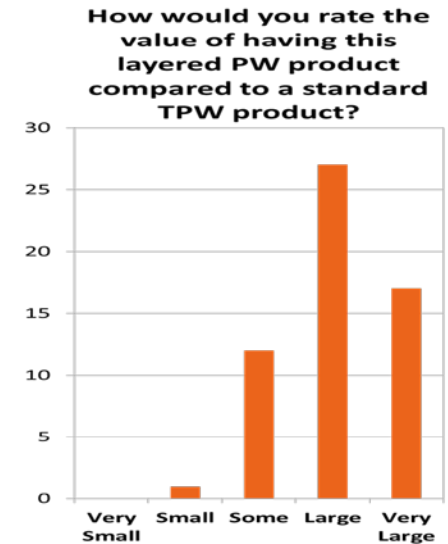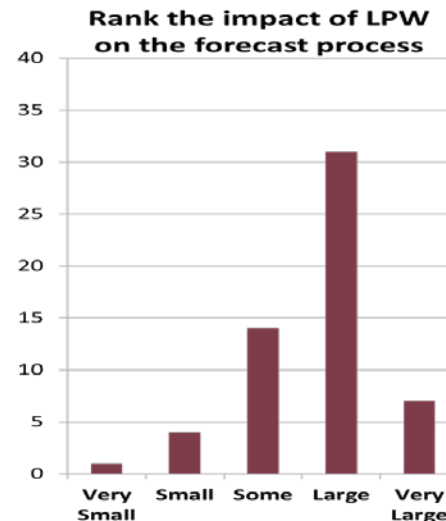
LeRoy et al. 2016

Blended, layered water vapor products fill a void in observations

| Moisture Product	Spatial Resolution and Coverage	Temporal Resolution	Strengths	Limitations
Radiosondes	~ 500 km over CONUS land, none over ocean	12 hours	Trusted High vertical resolution	Spatial and temporal coverage
GOES Water vapor channel (6.7 µm) imagery	4 km, near-hemispheric coverage	15 minutes or less	Very high spatial and temporal resolution Animations show flow	Upper level moisture only No vapor signal in high clouds Variable sensing depth
GOES Sounder retrievals	20 km, CONUS, Hawaii, Puerto Rico and adjacent waters only	1 hour	High spatial and temporal resolution Limited vertical structure	Clear sky only Forecast model dependence
Blended TPW	16 km, near global	1-3 hours (varies based on time of day)	Retrievals in clouds Near-global coverage Multiple types of inputs including very accurate GPS TPW	No profile information No retrievals in heavy precipitation

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GOES-West 6.7 μm TB (K) *(y-axis label)*

MIRS 500-300 hPa RH (%) *(x-axis label)*

Interpret as clouds
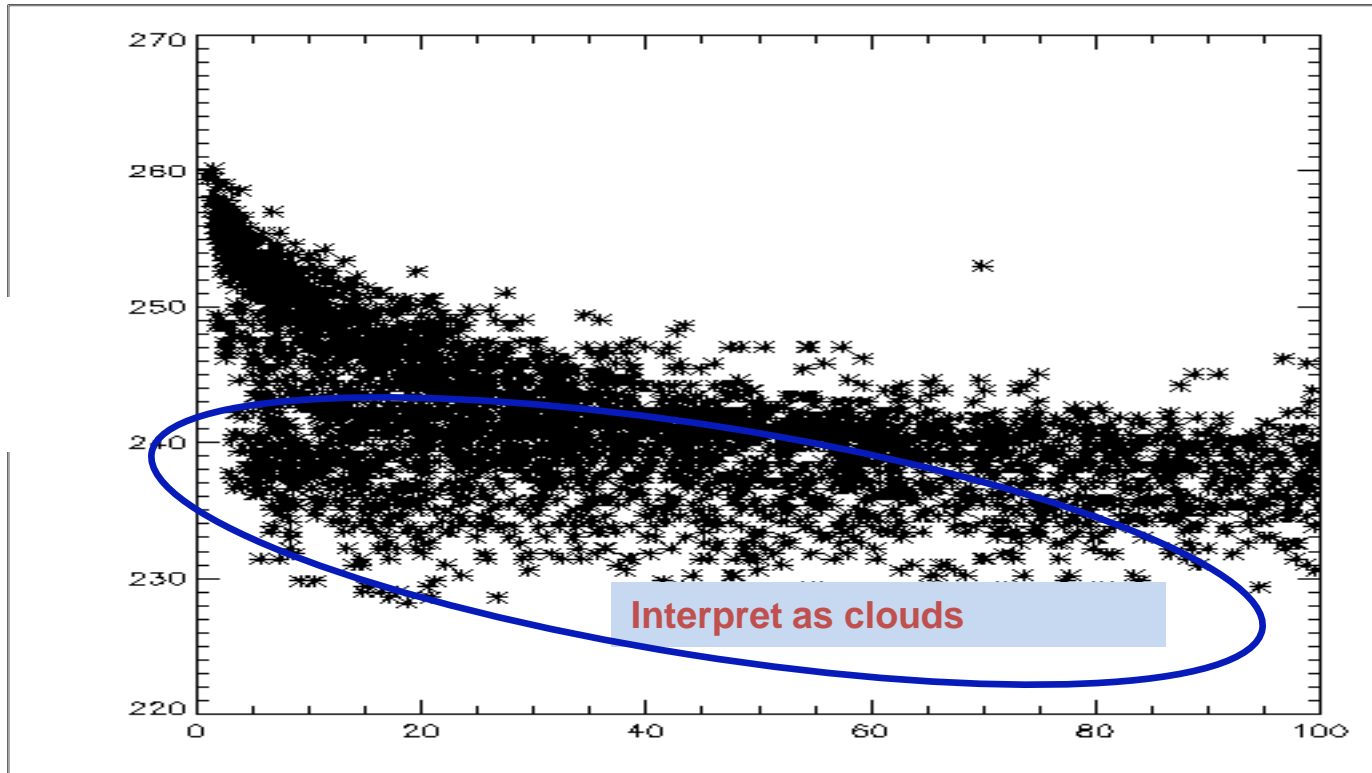
New Product: Advectively Blended LPW

Advective Blending Aproaches

a) Current Advection Approach – use single mid layer wind

500 mb

600 mb

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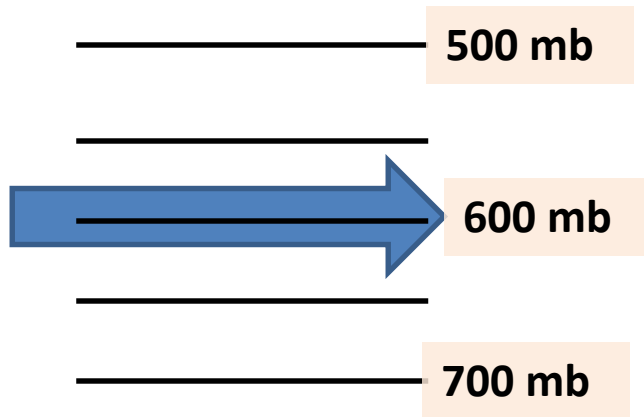
700 – 500 mb layer is advected with the 600 mb wind.

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

500 mb

600 mb

700 mb
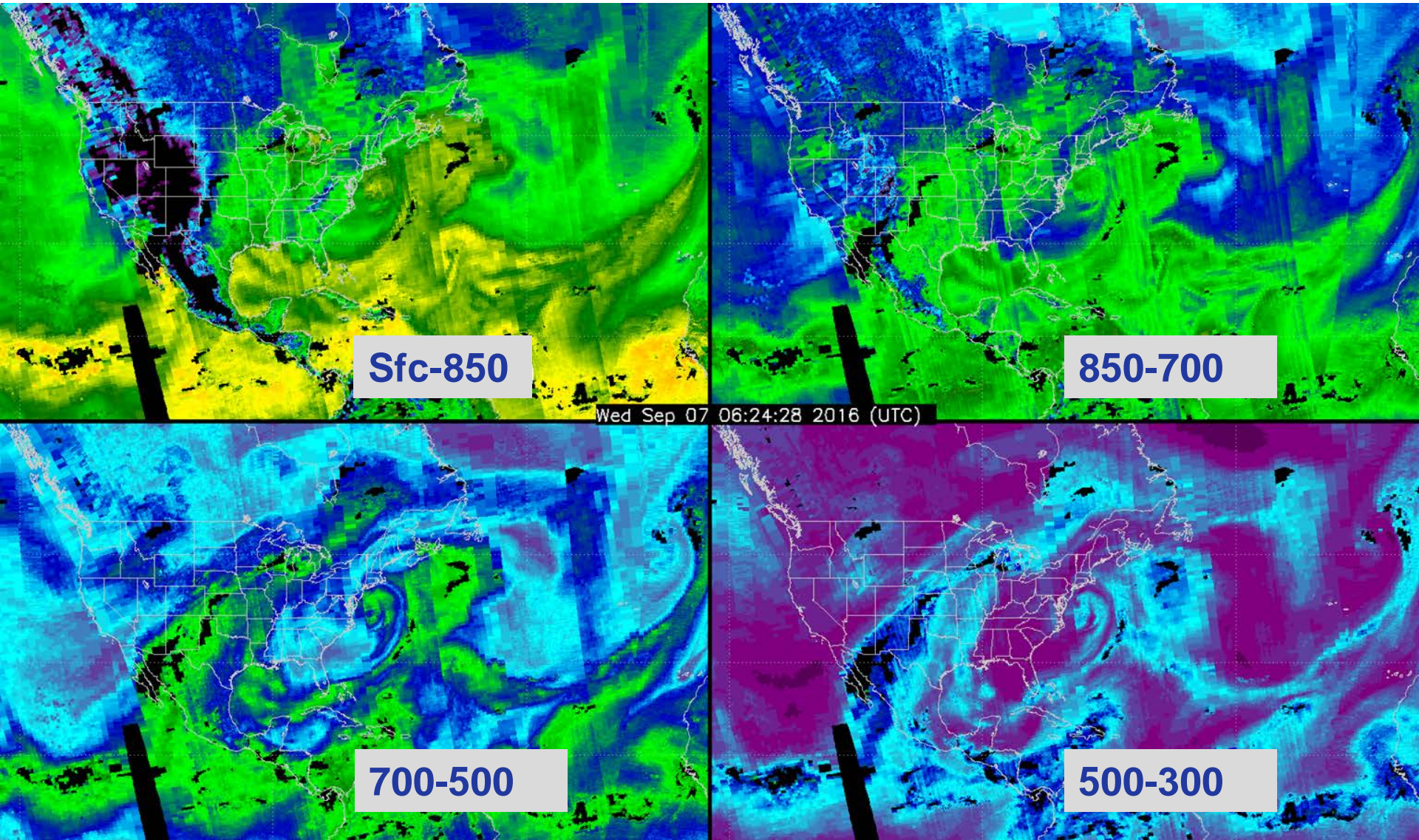
Mixing ratio profile is used as a weight
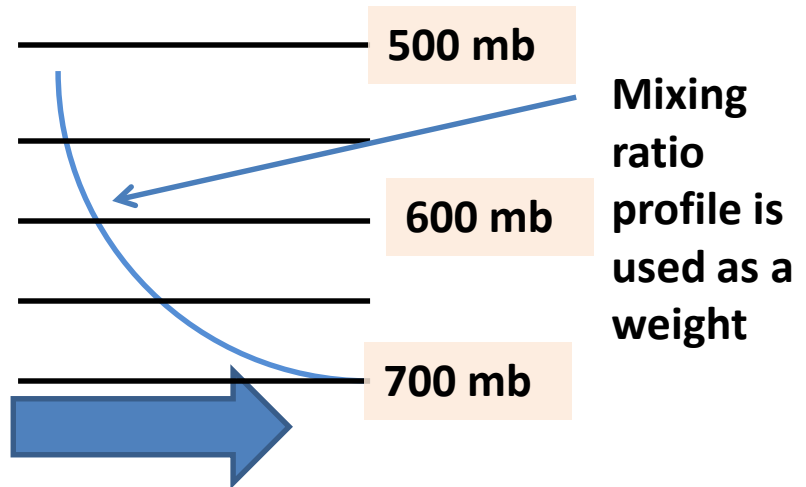
700 – 500 mb layer is advected with the vertically weighted wind.

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

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

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Non-advected heritage version

Sfc-850

850-700

Wed Sep 07 06:24:28 2016 (UTC)

700-500

500-300

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0   5   10   15   20   25   30   35
Layered Precipitable Water in mm

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

Sfc-850

850-700

Advected to 2016-SEP-07 06:00:00.00 (UTC)

700-500

500-300

Layered Precipitable Water in mm

0 5 10 15 20 25 30 35

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