How MiRS Retrievals Enable a Layered Water Vapor Product for Forecasters

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Special thanks to Sheldon Kusselson (NESDIS SAB (retired))

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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/adveced/lpw.htm <-- New way

“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
Satellite ID

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

Creating the Overlay Product

The overlay product currently being used by forecasters

700 – 500 mb LPW (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
Forecaster Usage Examples
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...
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.

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
“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
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

How would you rate the value of having this layered PW product compared to a standard TPW product?

Rate your confidence level in LPW values

Rank the impact of LPW on the forecast process

LeRoy et al. 2016, J. Operational Meteorology
Work in Progress and Future Work
How blended products may be fused with other datasets such as NWP and geostationary data

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

Excellent agreement

GFS moister
Prototype 6.5 \textmu m 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, above the 90th percentile for the area for the day...

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

<table>
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<tr>
<th>Product</th>
<th>Status</th>
<th>Training</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Blended TPW, TPW Anomaly, and Rain Rate</td>
<td>Operational since 2009. Runs at OSPO, distributed throughout NWS</td>
<td>None recently. VISIT and teletraining will occur via GOES-R project.</td>
<td>New 3-year GOES-R Risk Reduction Project just begun to add GOES-R and perform advection</td>
</tr>
<tr>
<td>CIRA Layer Precipitable Water (LPW)</td>
<td>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.</td>
<td>Need to start distributing new advected product, requires training and quick guide. Will create a VISIT session in September.</td>
<td>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.</td>
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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 observational 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

700 – 500 mb % of Normal LPW

200 – 500 mb % of Normal LPW

1000 – 700 mb % of Normal LPW

% of AIRS normal

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 PATTEI ALLOFT 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...

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.

- 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
<table>
<thead>
<tr>
<th></th>
<th>AIRS V6</th>
<th>MIRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of reported water vapor levels</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>Number of Independent Water Vapor Levels Retrieved</td>
<td>Varies from 3 to 6</td>
<td>No more than 4</td>
</tr>
</tbody>
</table>
| 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 |


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

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

Interpret as clouds

MIRS 500-300 hPa RH (%)

CO-OP
New Product:
Advectively Blended LPW
Advective Blending Approaches

a) Current Advection Approach – use single mid layer wind

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

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

- 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.
Non-adveected heritage version

Sfc-850

850-700

700-500

500-300

Layered Precipitable Water in mm
Version 01 Advected LPW, advected every three hours. Uses MiRS V11, fewer artifacts and better spatial resolution.