Observed Global and Regional Variation in Earth’s Water Vapor: Focus on the Weather-Climate Interface

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NASA Water Vapor Project – MEaSUREs


- **Global** (land and ocean) data designed for weather, climate and hydrology users

- Total (TPW) and layered (LPW) precipitable water

- **Removes time-dependent biases** caused by dataset and algorithm changes incurred during multi-phase processing.
  - Focus on consistent data inputs and peer reviewed processing algorithms through time.

- **Back-propagation of modern observations** through the entire data period.
  - Collaboration with AIRS water vapor project at NASA JPL. (E. Fetzer et al.)

- Highly model-independent

- **Available at NASA Langley Atmospheric Science Data Center (ASDC):**
  [https://eosweb.larc.nasa.gov/project/nvap/nvap-m_table](https://eosweb.larc.nasa.gov/project/nvap/nvap-m_table)

Similar in concept to GPCP, ISCCP, but with three products: **Climate, Weather, Ocean.**


“NVAP-M” refers to the new NVAP-MEaSUREs data set. “Heritage NVAP” refers to the existing dataset described by Randel et al., 1996.
SSM/I Average TPW September 10, 2004
Retrieved from microwave Tbs intercalibrated by Sapiano et al.

AIRS Version 5 Level 3 Average TPW September 10, 2004

GPS TPW Data Points (beginning 1997)
(Wang et al. 2007)

GPS TPW Data Points (beginning 1997)
(Wang et al. 2007)


AIRS V5

Jackson and Bates radiances; Engelen and Stephens (1999) retrieval.

SSM/I

AIRS

V5

HIRS

GPS

Sonde

(IGRA, Durre et al.)

(HIR, Engelen and Stephens (1999))

IGRA Derived Radiosonde Data Points

HIRS September 10, 2004 500-700 mb layer
Retrieved from clear-sky radiances
NVAP-M: A Three-Tiered Product Approach

<table>
<thead>
<tr>
<th>NVAP-Weather</th>
<th>NVAP-Climate</th>
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<tbody>
<tr>
<td>Used for weather case studies on timescales of days to weeks</td>
<td>Used for studies of climate change and interannual variability</td>
</tr>
<tr>
<td>• SSM/I Level 1 C intercalibrated radiances</td>
<td>• SSM/I Level 1 C intercalibrated radiances</td>
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<tr>
<td>• HIRS cloud cleared radiances</td>
<td>• HIRS cloud cleared radiances, + AIRS since 2002</td>
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<tr>
<td>• Radiosonde, GPS since 1997</td>
<td>• Radiosonde</td>
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<tr>
<td>• AIRS Level 3 TPW and Layered PW</td>
<td>• Consistent inputs through time.</td>
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<tr>
<td>• Maximizes spatial and temporal coverage</td>
<td>• Consistent, high quality retrievals.</td>
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<tr>
<td>• Not driven by reduction of time-dependent biases</td>
<td>• Less emphasis on spatial and temporal coverage</td>
</tr>
<tr>
<td>• 4x daily</td>
<td>• Daily</td>
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<tr>
<td>• ½ degree resolution</td>
<td>• 1-degree resolution</td>
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<tr>
<td>• TPW and layered precipitable water</td>
<td>• TPW</td>
</tr>
<tr>
<td>• surface to 700 hPa</td>
<td>• layered precipitable water</td>
</tr>
<tr>
<td>• 700 to 500 hPa</td>
<td>• surface to 700 hPa</td>
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<td>• 500 to 300 hPa</td>
<td>• 700 to 500 hPa</td>
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<td>• &lt; 300 hPa.</td>
<td>• 500 to 300 hPa</td>
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| NVAP-Ocean |
| SSM/I-only. |

Supplemental Fields

• Data source code (DSC) map, indicating the sources used in each grid box.

Heritage NVAP begun in early 1990’s was “one size fits all” approach.
Global mean Total Precipitable Water Vapor (TPW) from the new NVAP-M Climate Dataset:

25.3 mm
• Strong annual cycle is found in all latitude zones
• ENSO of 1997-1998 most apparent in 0-30° S
NVAP-M Climate Dataset: 1° gridded daily TPW data August 2003

Notice poleward transport of “atmospheric rivers”
Example NVAP-M climate science results

1) How total precipitable water (mm) in Pacific Ocean from 5° N to 5° S tracks the ENSO index

2) Correlation of ISCCP total cloud and NVAP-M total precipitable water vapor monthly anomalies (1988-2007)

Blue areas indicate cloud amount decreases as TPW increases
The Challenge of Time-Dependent Sampling

- Especially in the study of global and regional trends
At this time - due to time-varying sampling effects currently under study - we can neither prove nor disprove a robust trend in the global water vapor data from the NVAP-M Climate data set (over land and ocean).
Percentage of Time Data Missing from NVAP-M Climate TPW

1988

1998

2008
Summary

- NVAP-MEaSUREs reprocesses, extends and replaces the original NVAP dataset. Consistency of input datasets and algorithms with time is a main focus of NVAP-M.
- Data is available at the NASA Langley ASDC.
- NVAP-M Weather, Climate, and Ocean data components allow studies of weather and climate processes.
- Changes in satellite sampling with time continue to hinder the ability to claim a significant robust global trend in TPW.
- GEWEX GVAP effort underway to compare several global water vapor datasets, we are participating.

We acknowledge the support of the NOAA NEAT Program (Fuzhong Weng technical lead) and the NASA MEaSUREs program.
Backup Slides
• NVAP-M Climate Dataset
• Annual frequency
• 3mm bins
• Area-weighted bin count

El Niño causes a higher frequency of high TPW values and a lower frequency of mid-level TPW values as compared to surrounding years.
Water vapor transport occurs at the weather-climate interface: A single weather event might heavily influence the regional climate.
Daily Total Precipitable Water (TPW) Animation Beginning January 2004
Monthly Zonal TPW Anomaly Over Land and Ocean

Dotted lines: Known time-dependent biases due to processing changes

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<tr>
<td>Heritage</td>
<td>25.12</td>
<td>24.62</td>
<td>24.18</td>
<td>24.01</td>
<td>24.17</td>
<td>24.01</td>
<td>24.82</td>
<td>-</td>
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Heritage: 24.5 mm

Global Mean TPW

NVAP-M: 25.3 mm

Heritage NVAP

NVAP-M Climate
The challenge of creating a multisensor, multidecadal, global water vapor climate record

Sensors preferentially sample ocean or clear regions.
NVAP-M Climate Dataset: 1º gridded daily TPW data
Global water vapor tracks temperature and ENSO, but can vary regionally.

- MSU Monthly Ocean Only Lower Tropospheric Temperature Anomaly 50N – 50S
  - Base period 1979-1998

- NVAP-M Climate monthly ocean only water vapor anomaly 50N – 50S
  - Base period 1987-2009

- Nino 3.4 monthly ENSO index
This equation links surface water exchange to the flux of moisture throughout the depth of the atmosphere. The moisture flux (transport) is a cross-cutting term connecting the water cycle and energy budget due to latent heat transport.

\[
\frac{\partial w}{\partial t} + \nabla \cdot \left( \frac{1}{g} \int_0^P \nabla q \, dp \right) = E - P
\]

where
- \( w \) is the total precipitable water
- \( q \) is the specific humidity profile
- \( \nabla \) is the wind vector
- \( E \) and \( P \) are evaporation and precipitation

\( g \) is the gravitational acceleration.
Microwave Absorption Spectrum

SSM/I 22 GHz radiance (V-pol)

22 GHz H$_2$O vapor absorption line sensed by SSM/I

15°N Annual Atmosphere

HIRS Infrared Sounding Channels

HIRS 8.16 µm radiance in cloud-free regions

Infrared Absorption Spectrum
Ground-based GPS sensing of total precipitable water – high accuracy

- Geodesists developed techniques to model these delays as “nuisance parameters” and remove them to improve their survey accuracy.

- In 1992, Bevis et al. proposed that these errors could be used to retrieve integrated (total atmospheric column) precipitable water vapor (TPW) for weather forecasting and climate studies.

GPS sensor with precision barometer
Water vapor is Earth’s most important variable greenhouse gas

- Source for precipitation, dominates diabatic heating structure in troposphere; typical scale height ~ 2 km.
- Trenberth (1999) estimates for extratropical cyclones, on average 70% of precipitation comes from moisture already in the atmosphere at the time the storm formed.
- “Feedback from the redistribution of water vapor remains a substantial source of uncertainty in climate models” (IPCC).
- Expect ~ 7% TPW / K increase (C-C eqn); (current mean ~25 mm)
- Upper tropospheric water vapor especially important for climate change
- Better representation of water vapor in forecast models improves fields of high-impact weather (precip, clouds).

So important NASA dedicated a satellite to it (Aqua)
Fig. 2.11. (a) Anomaly time series of TCWV over ocean from satellite-borne microwave radiometers and COSMIC. The reference period for both measurements is 2007–12. (b) Anomaly time series of TCWV over land from radiosondes, ground-based GPS, and COSMIC. Except for COSMIC, the reference period is 1997–2012. The COSMIC land anomalies are calculated relative to a 2007–12 COSMIC land climatology. For (a) and (b) the time series have been smoothed to remove variability on time scales shorter than 6 months.
Satellite Sensor Inputs to NVAP-M

SSM/I on board DMSP Satellite Series

Reflector size:
61 x 66 cm

Source: http://podaac.jpl.nasa.gov/SSMI

HIRS on board NOAA Satellite Series

Physical Size of HIRS:
41 x 46 x 69 cm

Source: https://directory.eoportal.org/web/eoportal/satellite-missions/n/noaa-poes-series-5th-generation

Physical size of AIRS:
140 x 78 x 76 cm (stowed)
140 x 151 x 76 cm (deployed)

Source: http://aqua.nasa.gov/about/instrument_airs.php

Physical size of HIRS:
41 x 46 x 69 cm

Source: https://directory.eoportal.org/web/eoportal/satellite-missions/n/noaa-poes-series-5th-generation