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

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CIRA Cooperative Institute for Research in the Atmosphere

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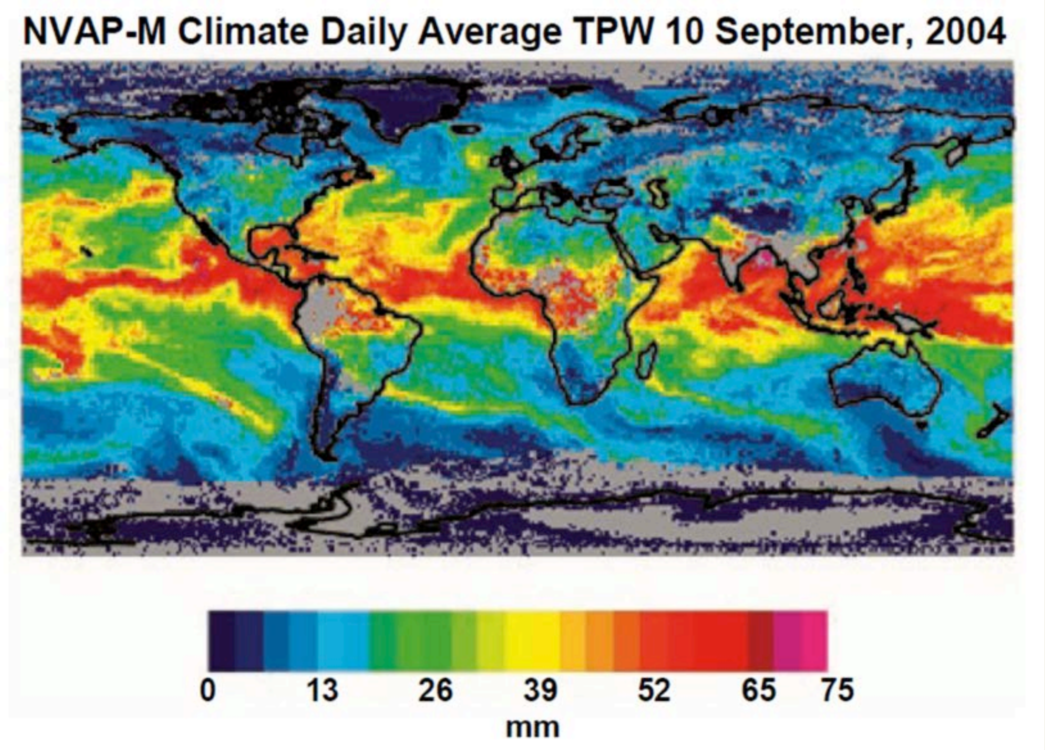
NASA Water Vapor Project – MEaSUREs

- **Reanalysis**, **extension** (1988-2009) **and replacement** of the heritage NVAP (1988-2001) dataset
- **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

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

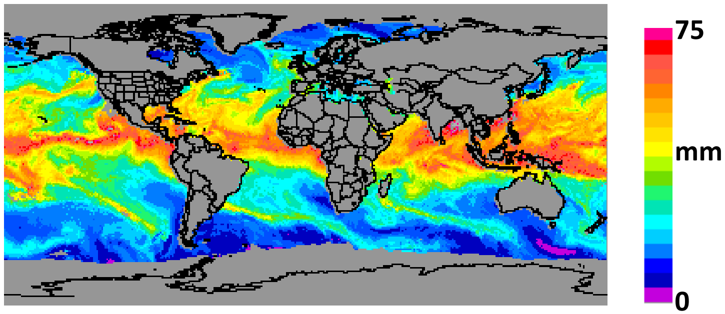


Vonder Haar et al. 2012: Weather and climate analyses using improved global water vapor observations. *Geophys. Res. Lett.*, **39**, L15802. doi:10.1029/2012GL052094.

"NVAP-M" refers to the new NVAP-MEaSUREs data set. "Heritage NVAP" refers to the existing dataset described by Randel et al., 1996

NVAP-M: Input Datasets

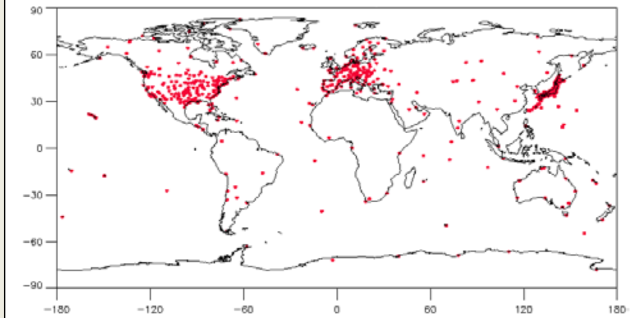
SSM/I Average TPW September 10, 2004
Retrieved from microwave Tbs intercalibrated by Sapiano et al



SSM/I

Sapiano et al. (2012) intercalibration; Elsaesser et al. (2008) retrieval.

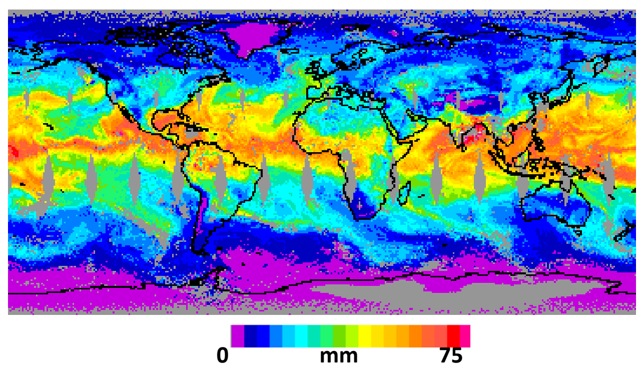
GPS TPW Data Points (beginning 1997)
(Wang et al. 2007)



GPS

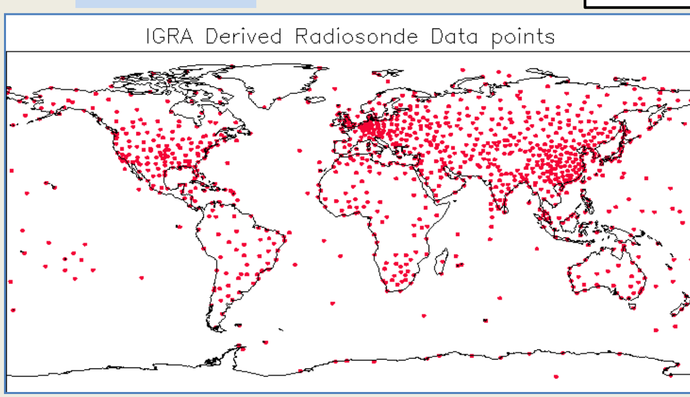
AIRS V5

AIRS Version 5 Level 3 Average TPW September 10, 2004



Sonde

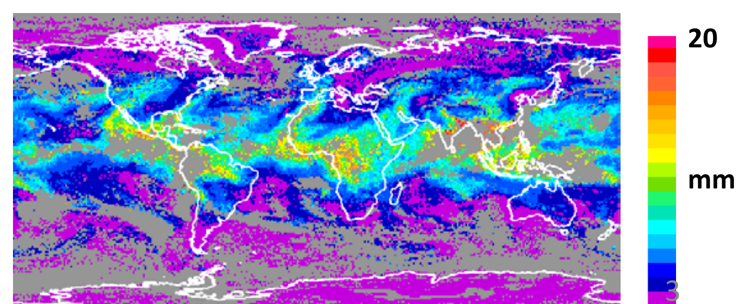
(IGRA, Durre et al.)



HIRS

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

HIRS September 10, 2004 500-700 mb layer
Retrieved from clear-sky radiances



NVAP-M: A Three-Tiered Product Approach

Heritage NVAP begun in early 1990's was "one size fits all" approach.

NVAP-Weather

Used for weather case studies on timescales of days to weeks

- SSM/I Level 1 C intercalibrated radiances
- HIRS cloud cleared radiances
- Radiosonde, GPS since 1997
- AIRS Level 3 TPW and Layered PW

- Maximizes spatial and temporal coverage
- Not driven by reduction of time-dependent biases

- 4x daily
- ½ degree resolution
- TPW and layered precipitable water
  - surface to 700 hPa
  - 700 to 500 hPa
  - 500 to 300 hPa
  - < 300 hPa.

NVAP-Climate

Used for studies of climate change and interannual variability

- SSM/I Level 1 C intercalibrated radiances
- HIRS cloud cleared radiances, + AIRS since 2002
- Radiosonde

- Consistent inputs through time.
- Consistent, high quality retrievals.
- Less emphasis on spatial and temporal coverage

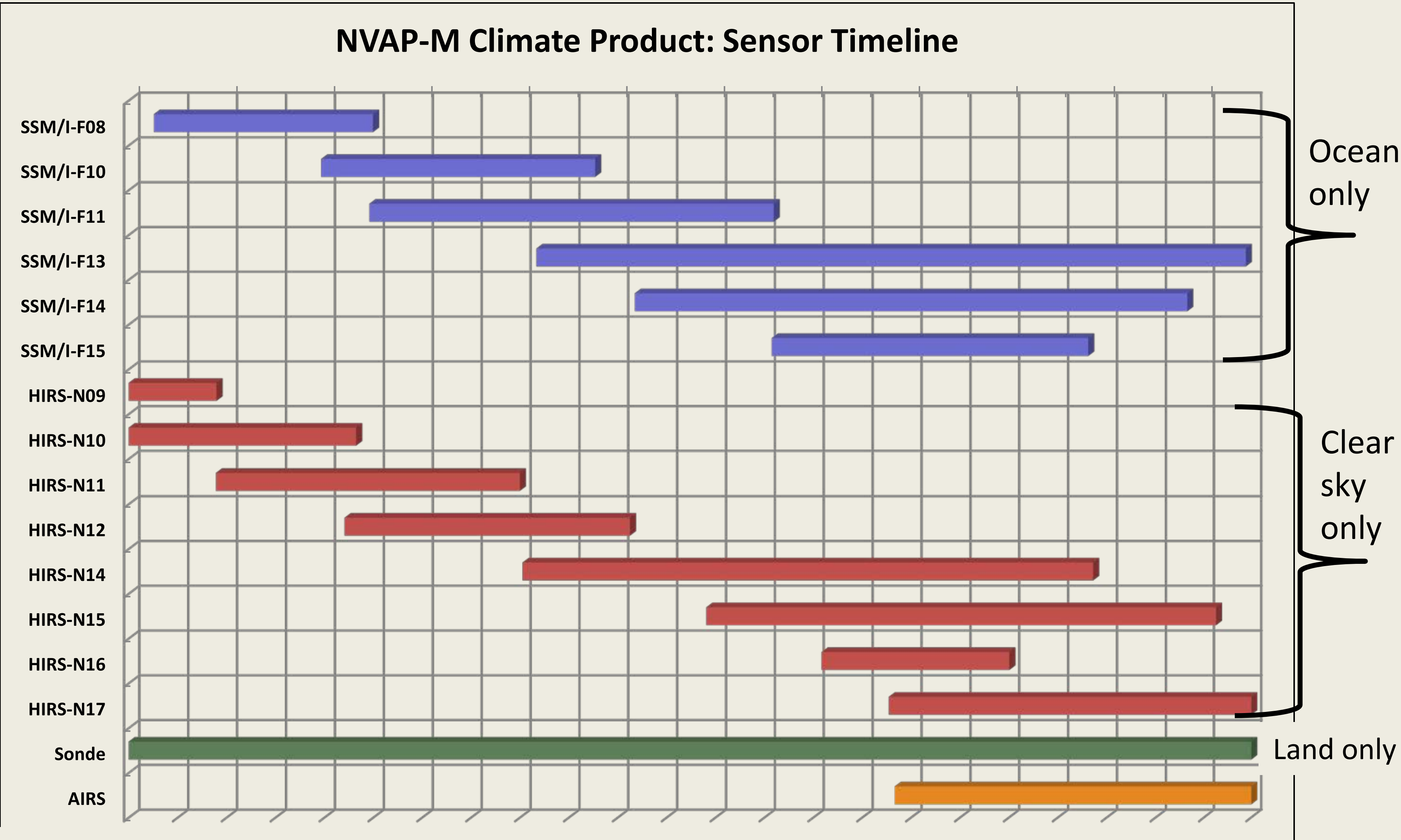
- Daily
- 1-degree resolution
- TPW
- layered precipitable water
  - surface to 700 hPa
  - 700 to 500 hPa
  - 500 to 300 hPa
  - < 300 hPa

NVAP-Ocean

SSM/I-only.

Supplemental Fields

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

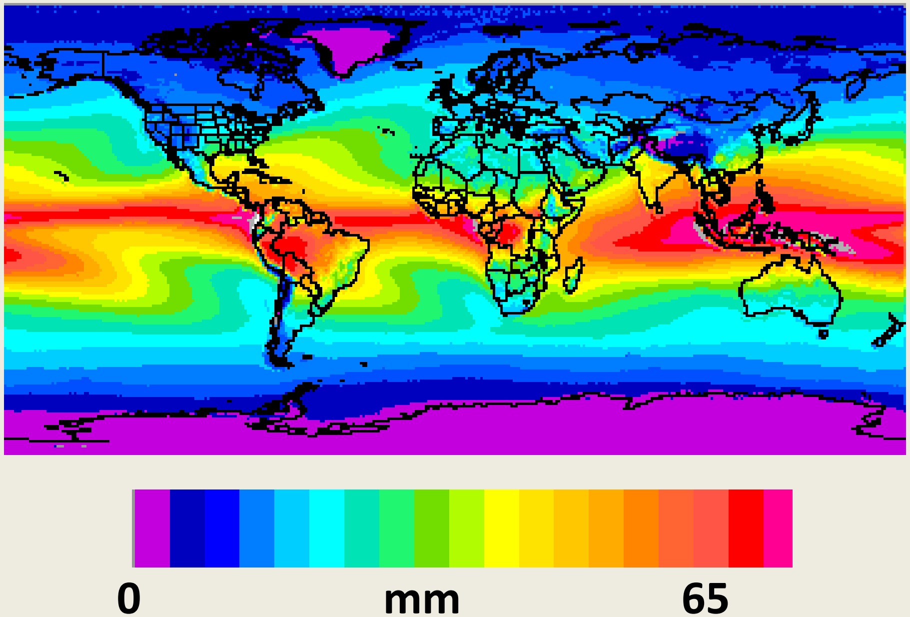


NVAP-M Climate Product: Sensor Timeline
SSM/I-F08
SSM/I-F10
SSM/I-F11
SSM/I-F13
SSM/I-F14
SSM/I-F15
HIRS-N09
HIRS-N10
HIRS-N11
HIRS-N12
HIRS-N14
HIRS-N15
HIRS-N16
HIRS-N17
Sonde
AIRS
1988
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
Ocean only
Clear sky only
Land only

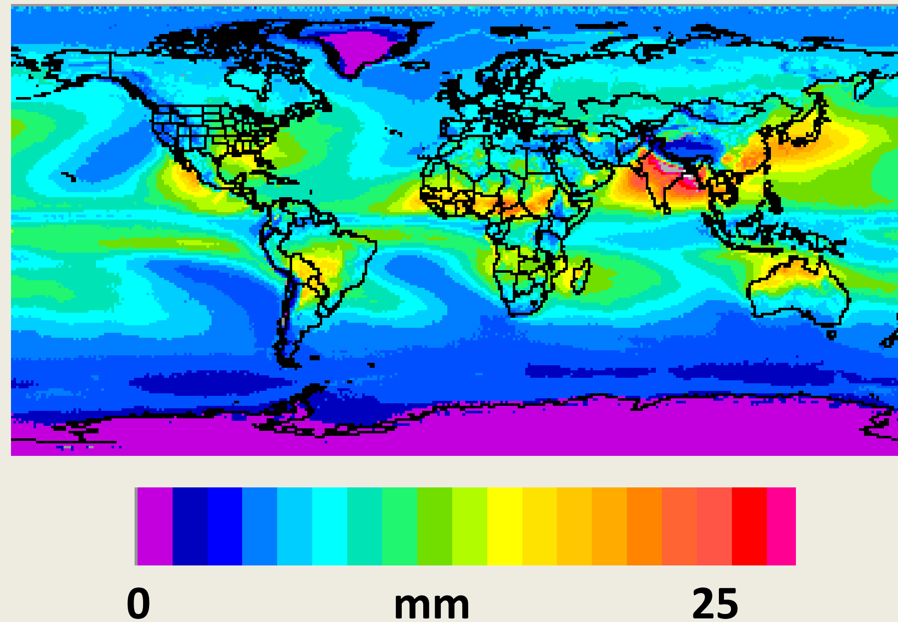
Global mean Total Precipitable Water Vapor (TPW) from the new NVAP-M Climate Dataset:

25.3 mm

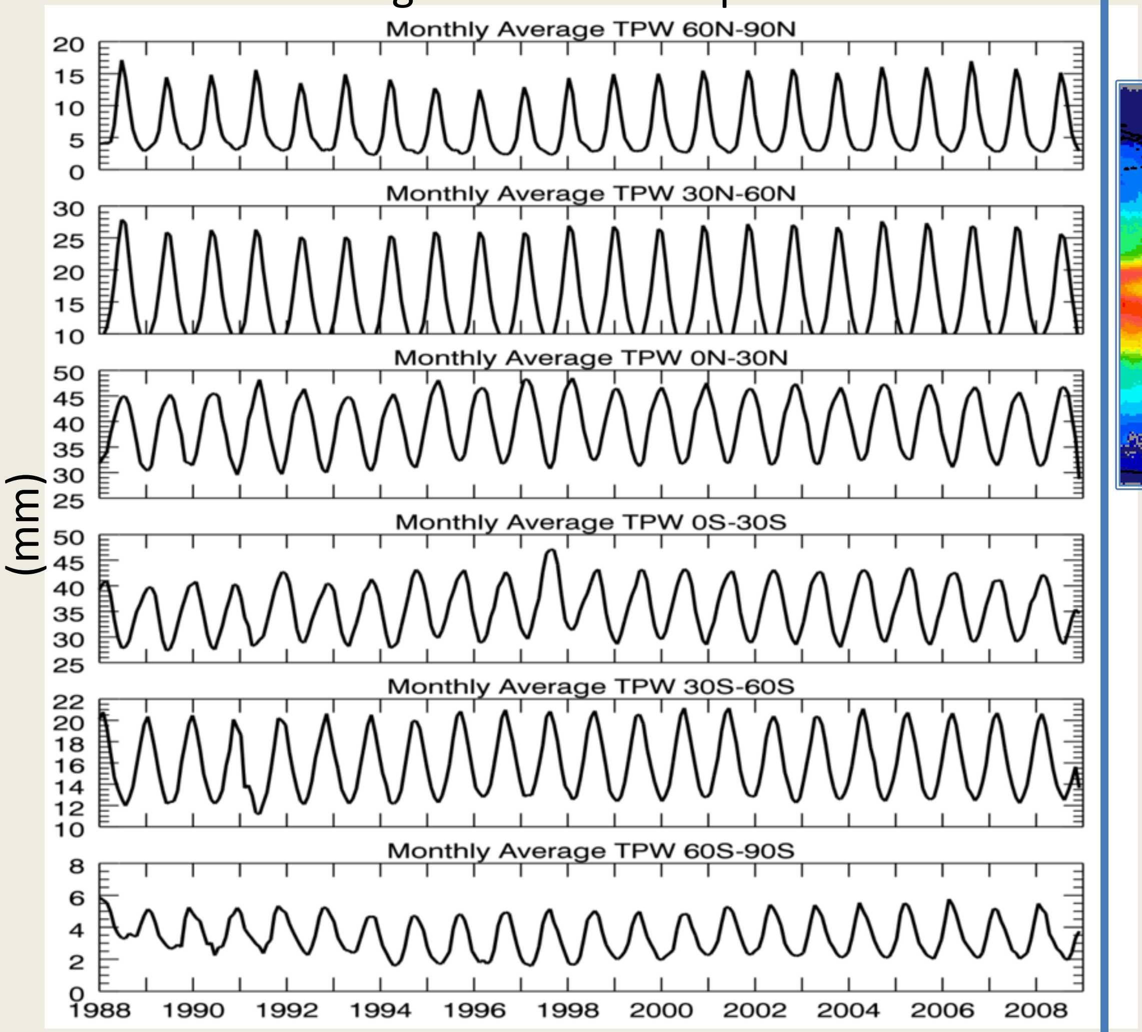
NVAP-M Climate Average TPW 1988-2009



NVAP-M Climate TPW Standard Deviation 1988-2009

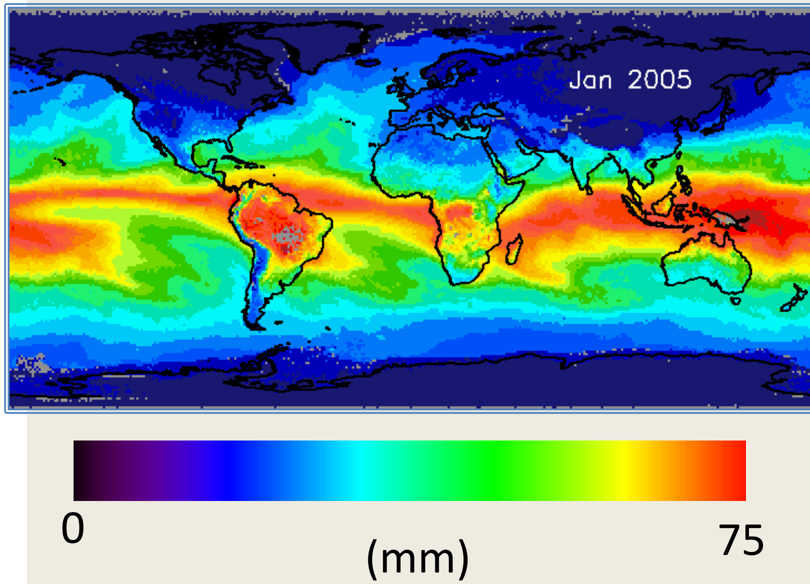


Zonal Averages of Total Precipitable Water



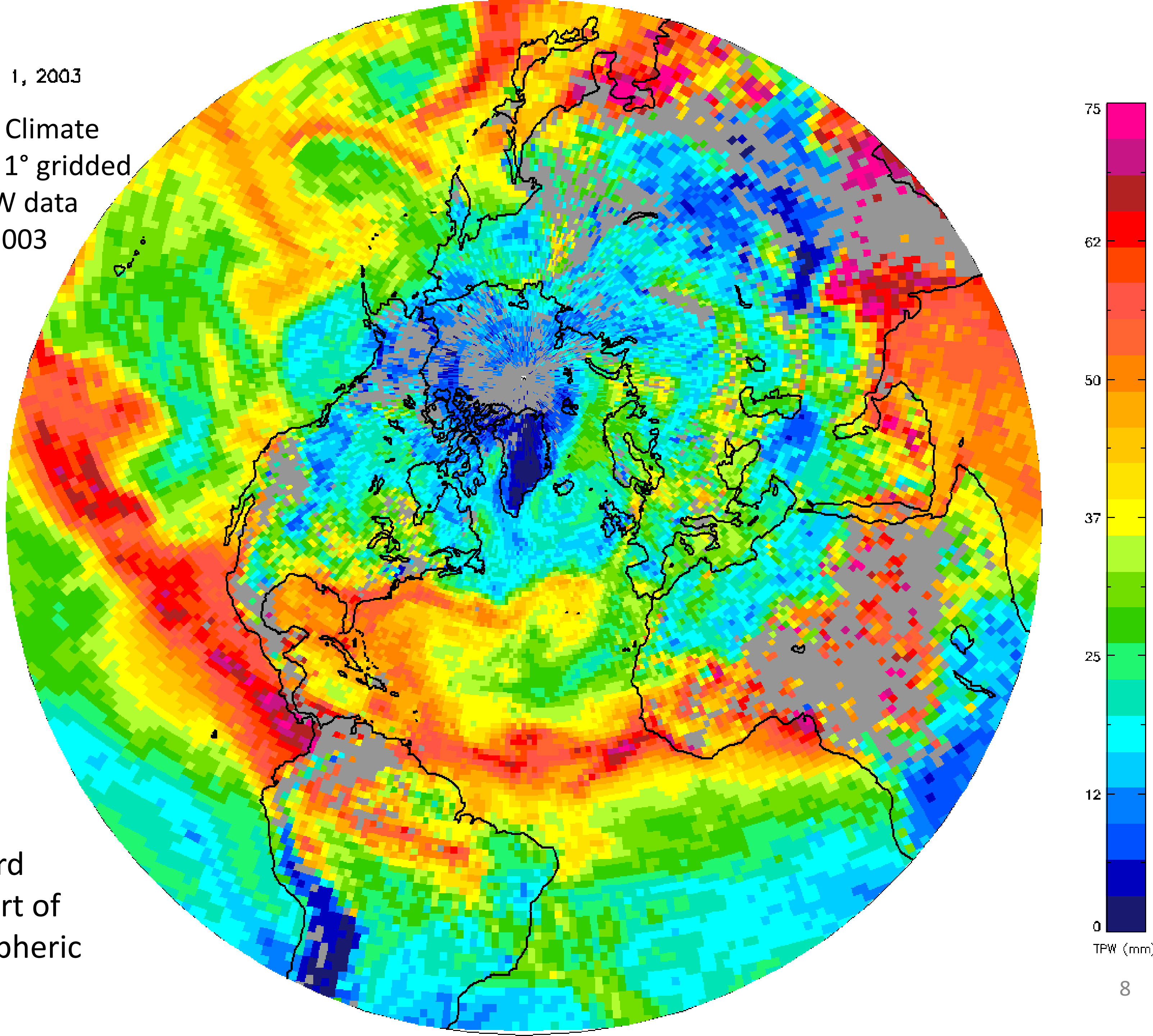
- Strong annual cycle is found in all latitude zones
- ENSO of 1997-1998 most apparent in 0-30° S

Monthly Mean TPW (mm) from NVAP-M Climate for 2005



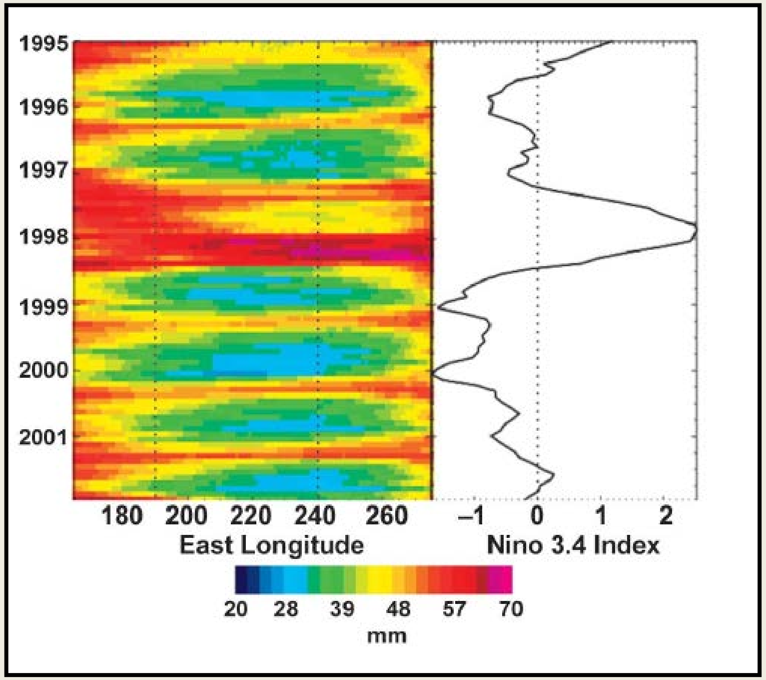
August 1, 2003

NVAP-M Climate Dataset: 1° gridded daily TPW data August 2003

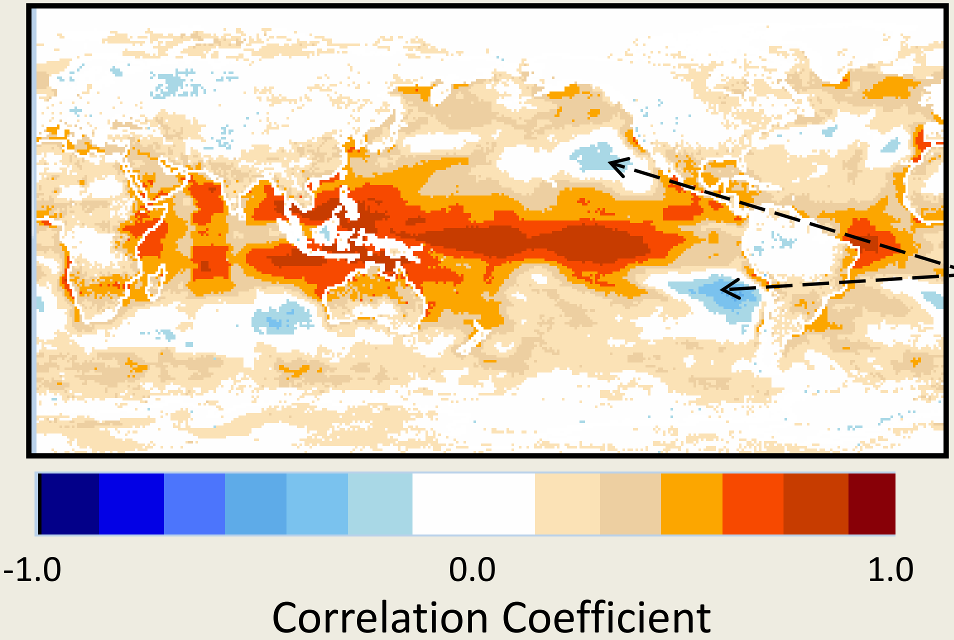


Notice poleward transport of “atmospheric rivers”

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



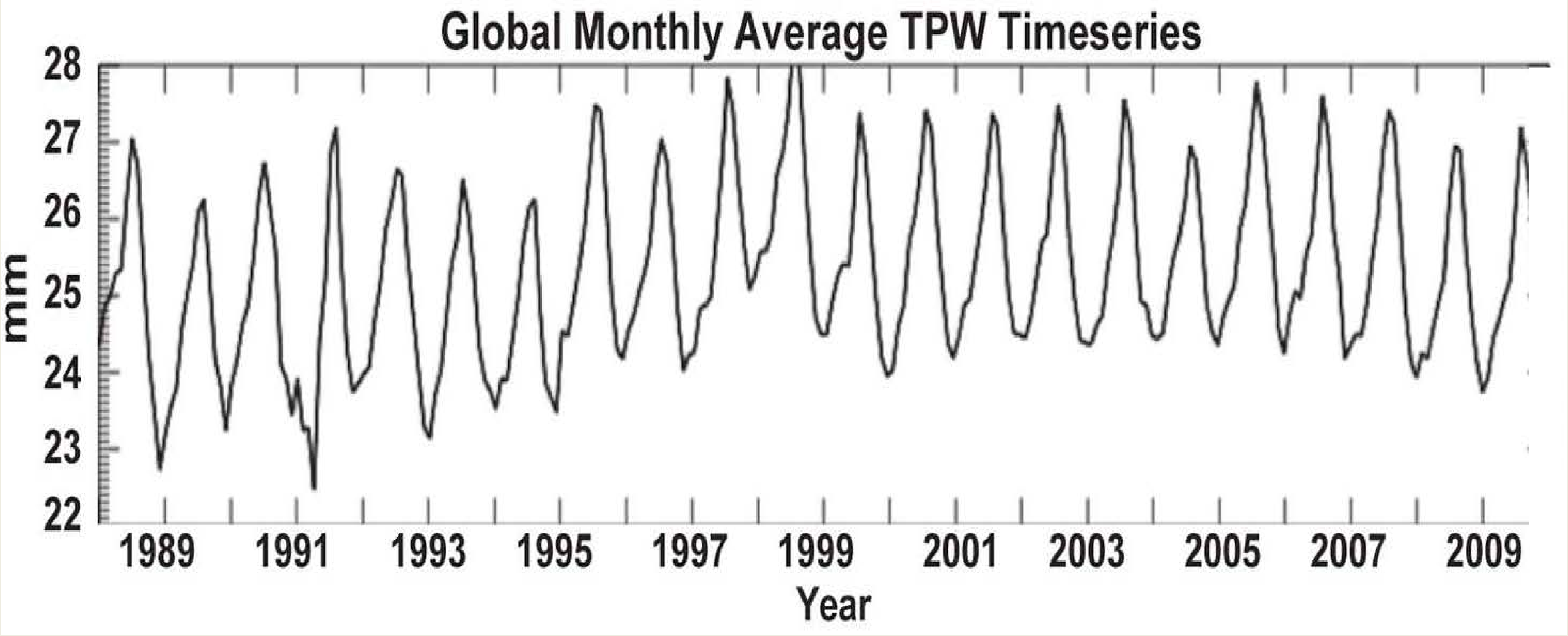
2) Correlation of ISCCP total cloud and NVAP-M total precipitable water vapor monthly anomalies (1988-2007)

Blue areas indicate cloud amount decreases as TPW increases

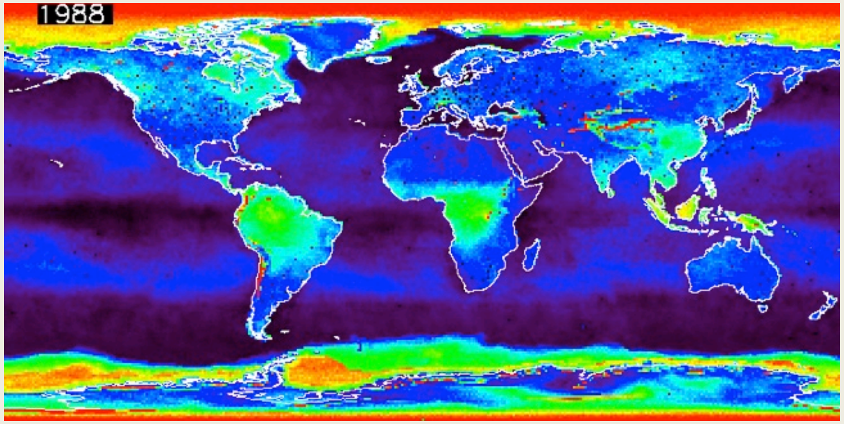
The Challenge of Time-Dependent Sampling

- Especially in the study of global and regional trends

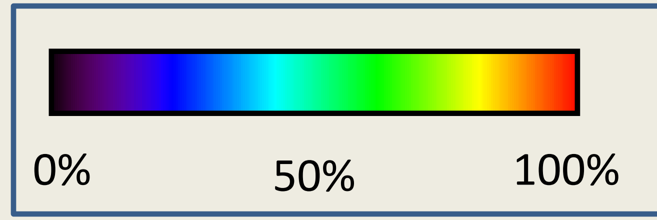
At this time
- due to time-varying sampling effects currently under study -
we can <u>neither</u> prove nor disprove a robust trend in the global water vapor data from the NVAP-M Climate data set (over land and ocean)

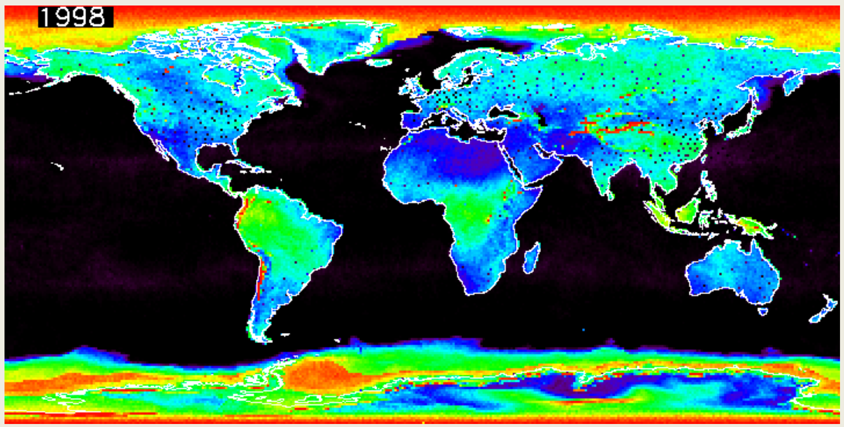


Percentage of Time Data Missing from NVAP-M Climate TPW

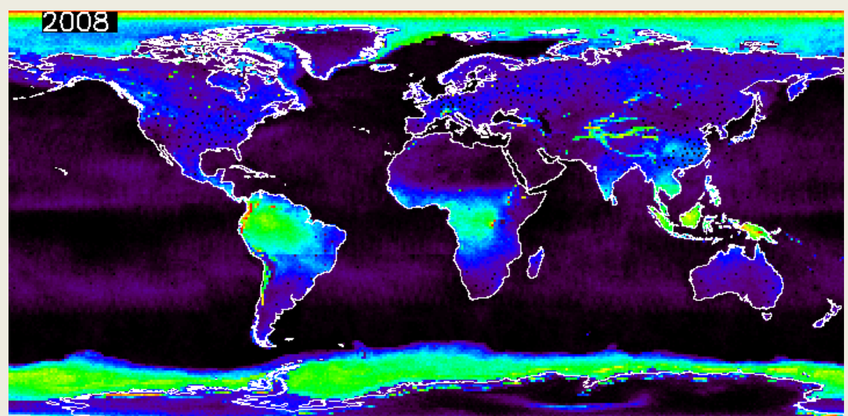


1988





1998



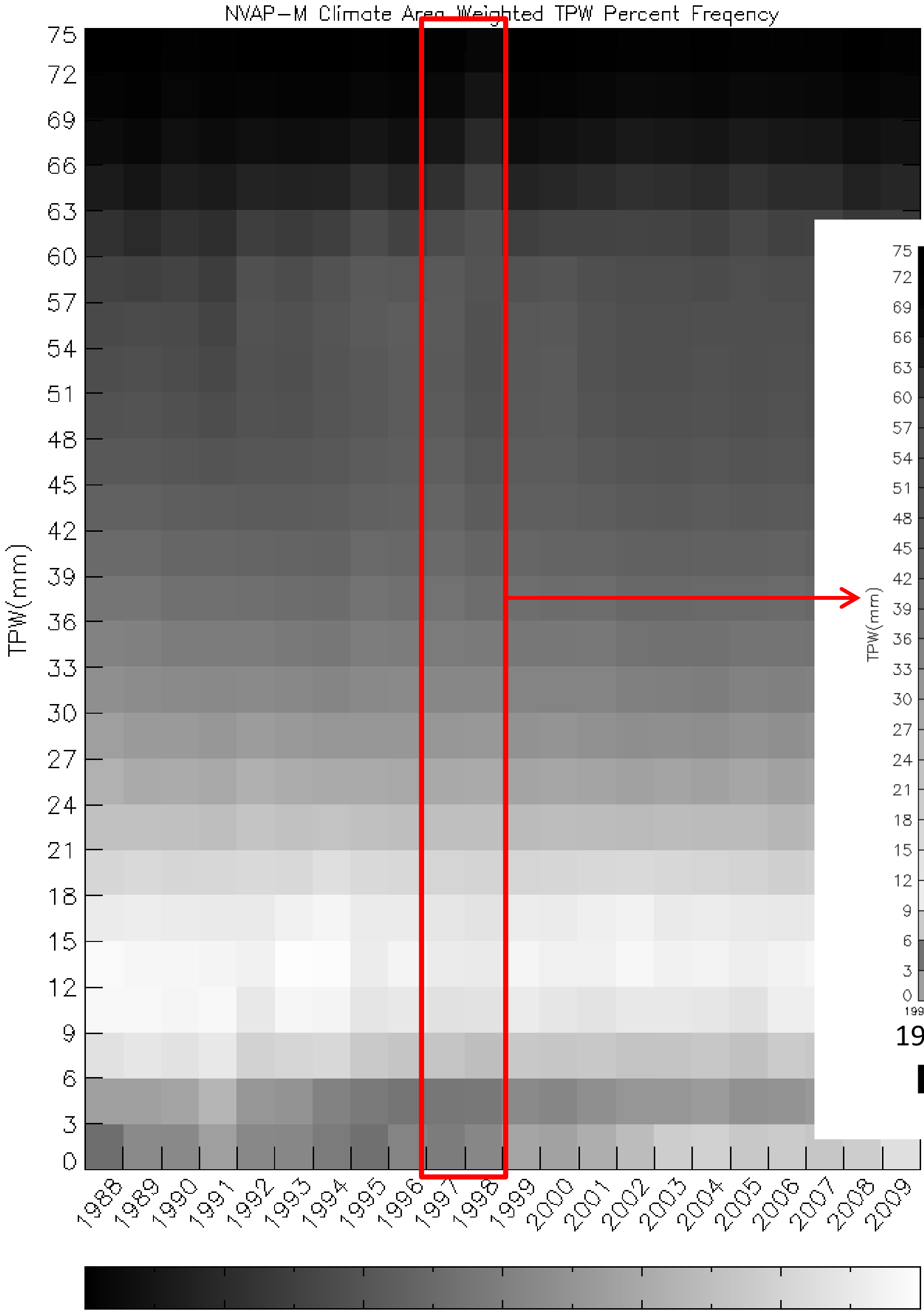
2008

Summary

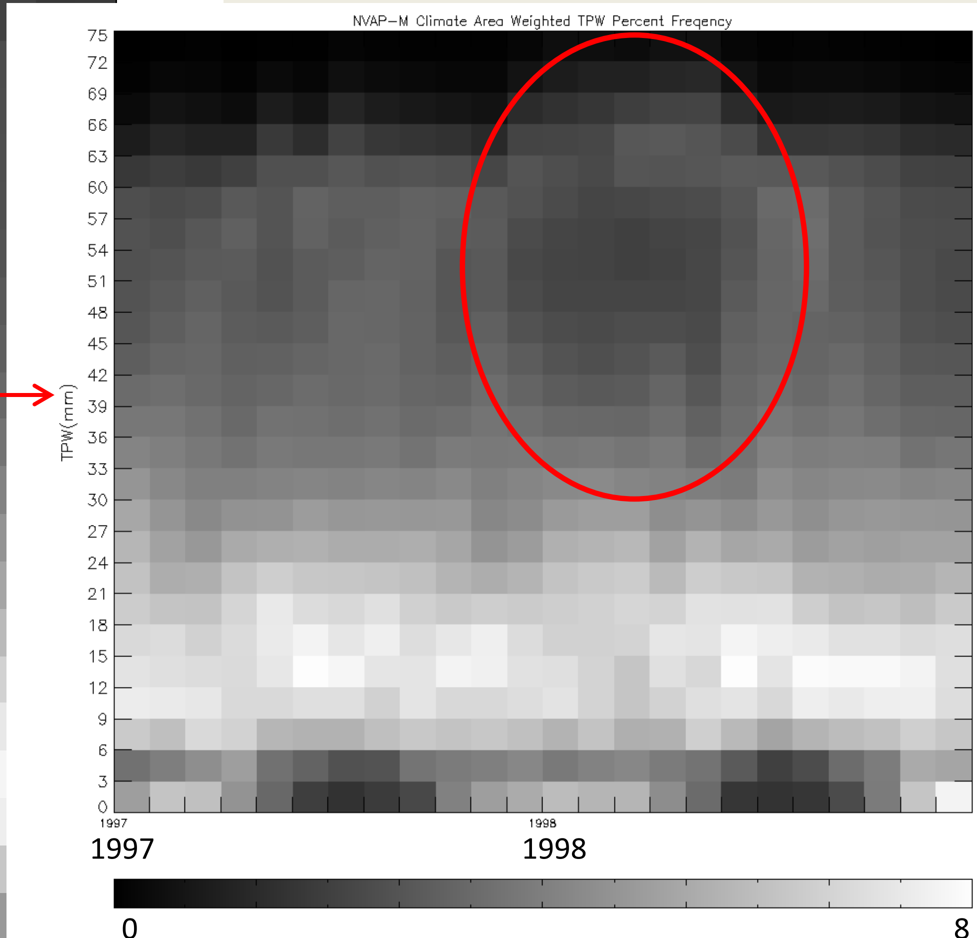
- NVAP-MEaSUREs reprocesses, extends and replaces the original NVAP dataset. Consistency of input datasets and algorithms with time is a main focus of NVAP-M.
- Data is available at the NASA Langley ASDC.
- NVAP-M Weather, Climate, and Ocean data components allow studies of weather and climate processes.
- Changes in satellite sampling with time continue to hinder the ability to claim a significant robust <u>global</u> 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

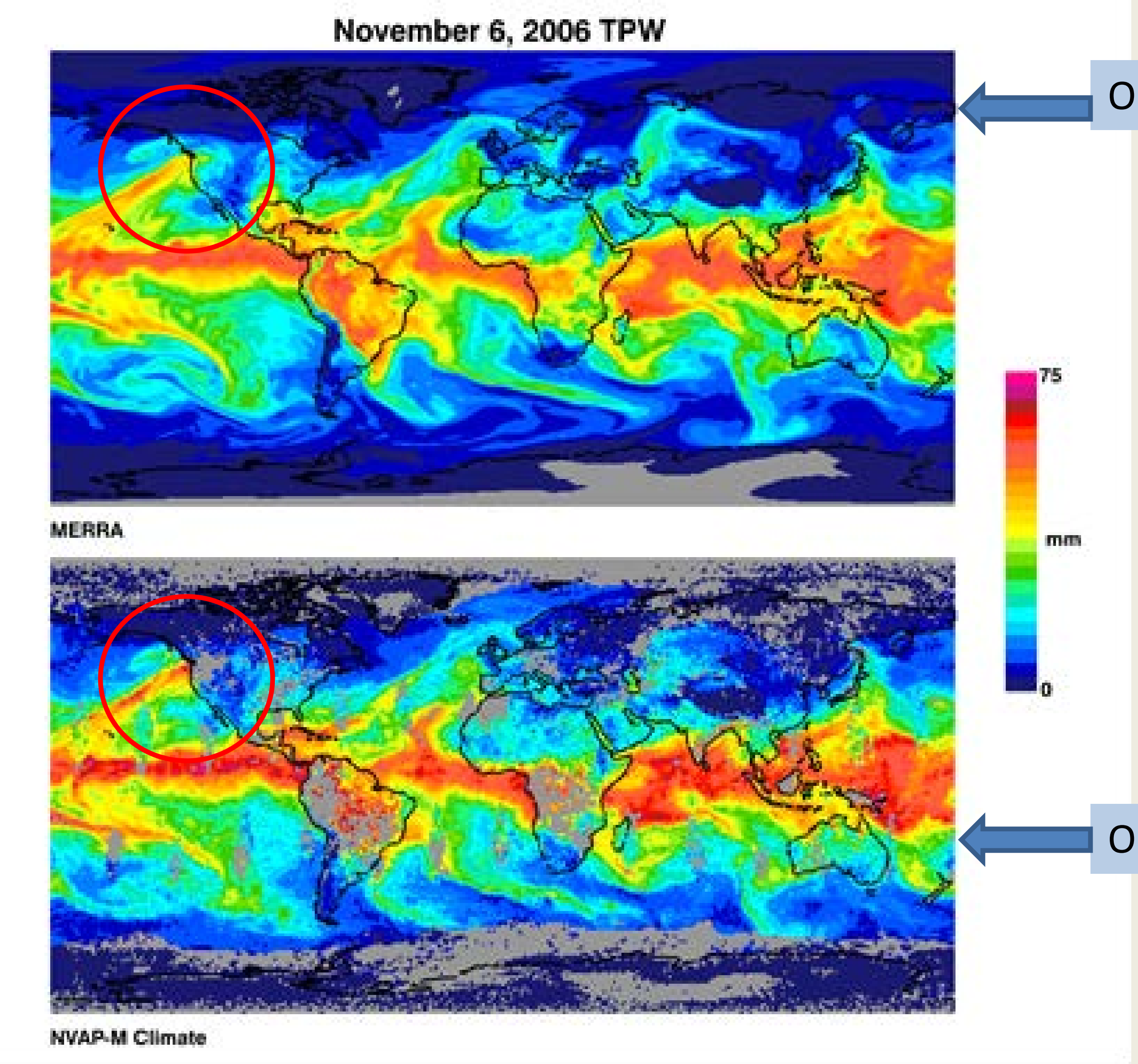
Backup Slides



- 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



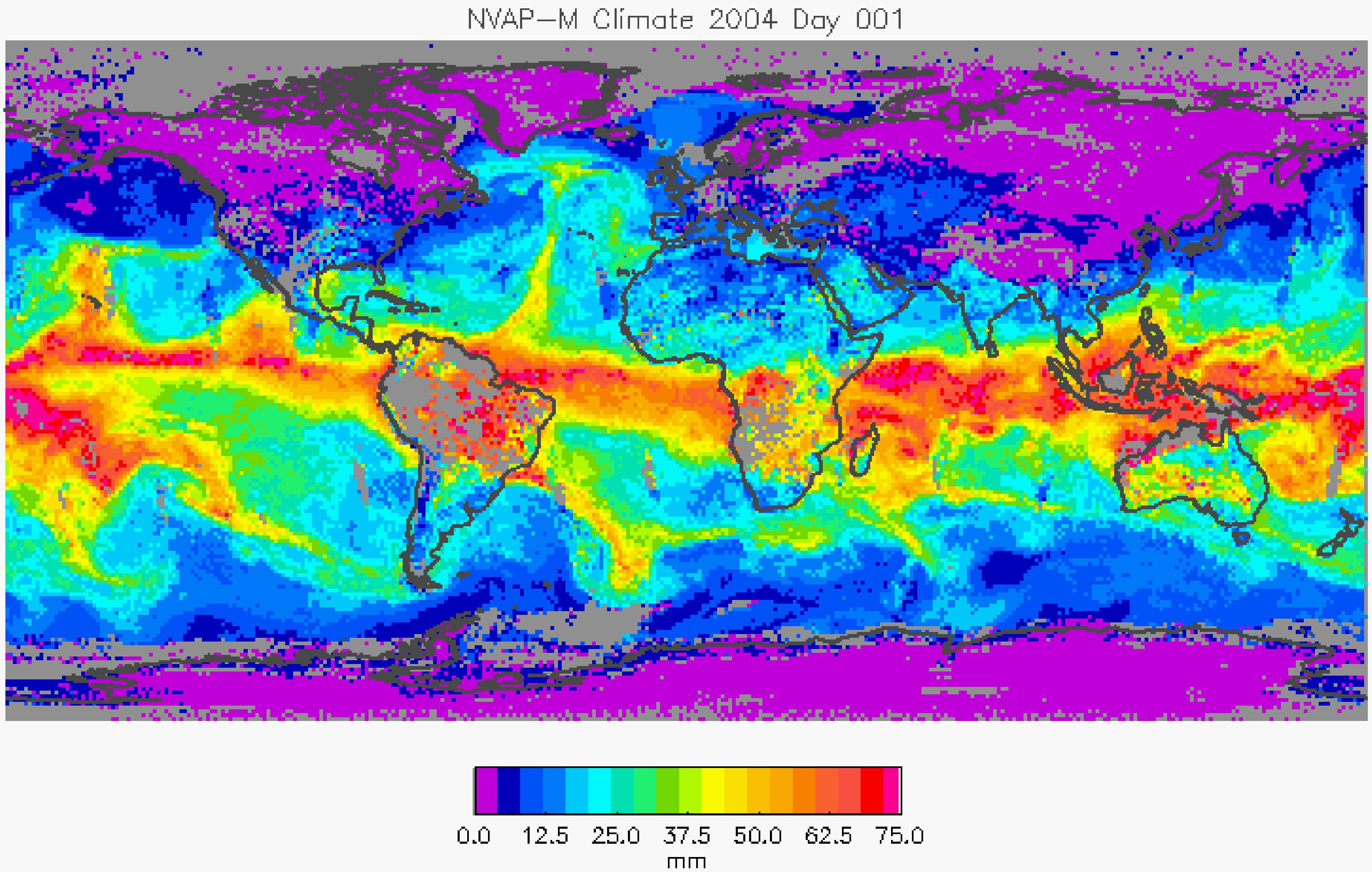
Observations + A Model

Observations Only

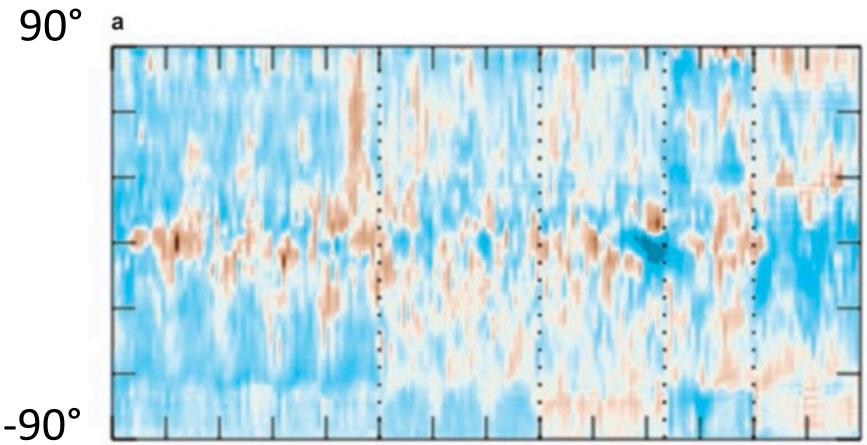
NASA MERRA (top) and NVAP-M Climate (bottom) total precipitable water (mm) for November 6, 2006. Devastating floods from an atmospheric river impacted the Pacific Northwest.

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

Heritage NVAP

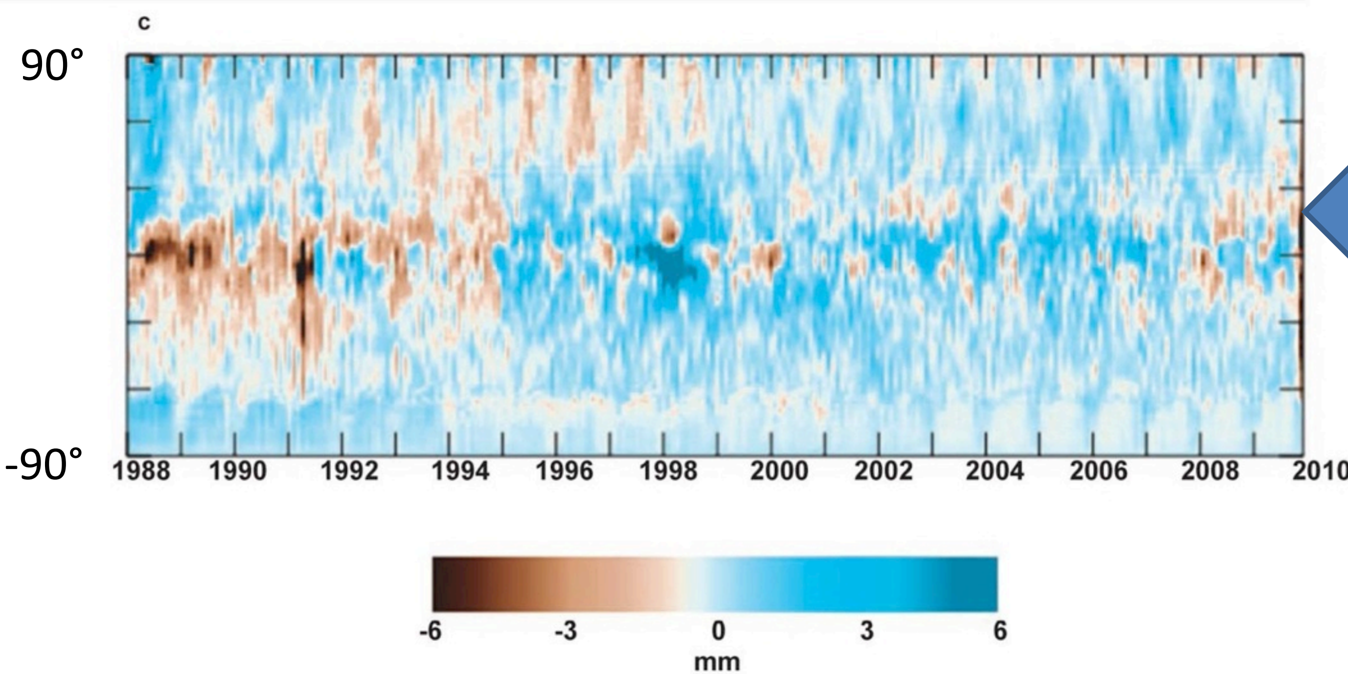
b

	1988	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008
Heritage	25.12	24.62	24.18	24.01	24.17	24.01	24.82	-	-	-	-
NVAP-M	25.06	24.93	25.06	24.56	25.38	26.31	25.51	25.56	25.41	25.60	25.12

Heritage: 24.5 mm

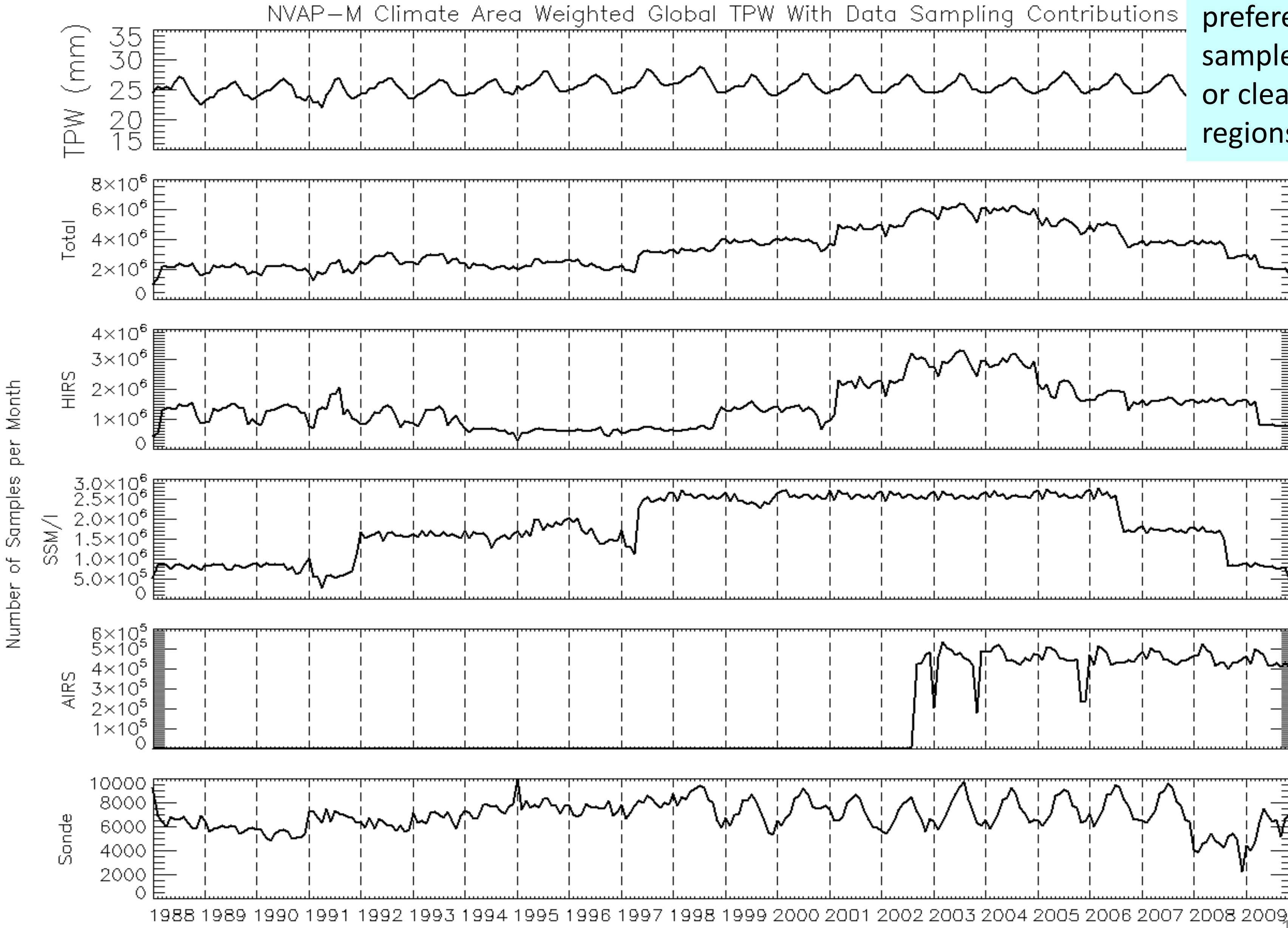
Global Mean TPW

NVAP-M: 25.3 mm

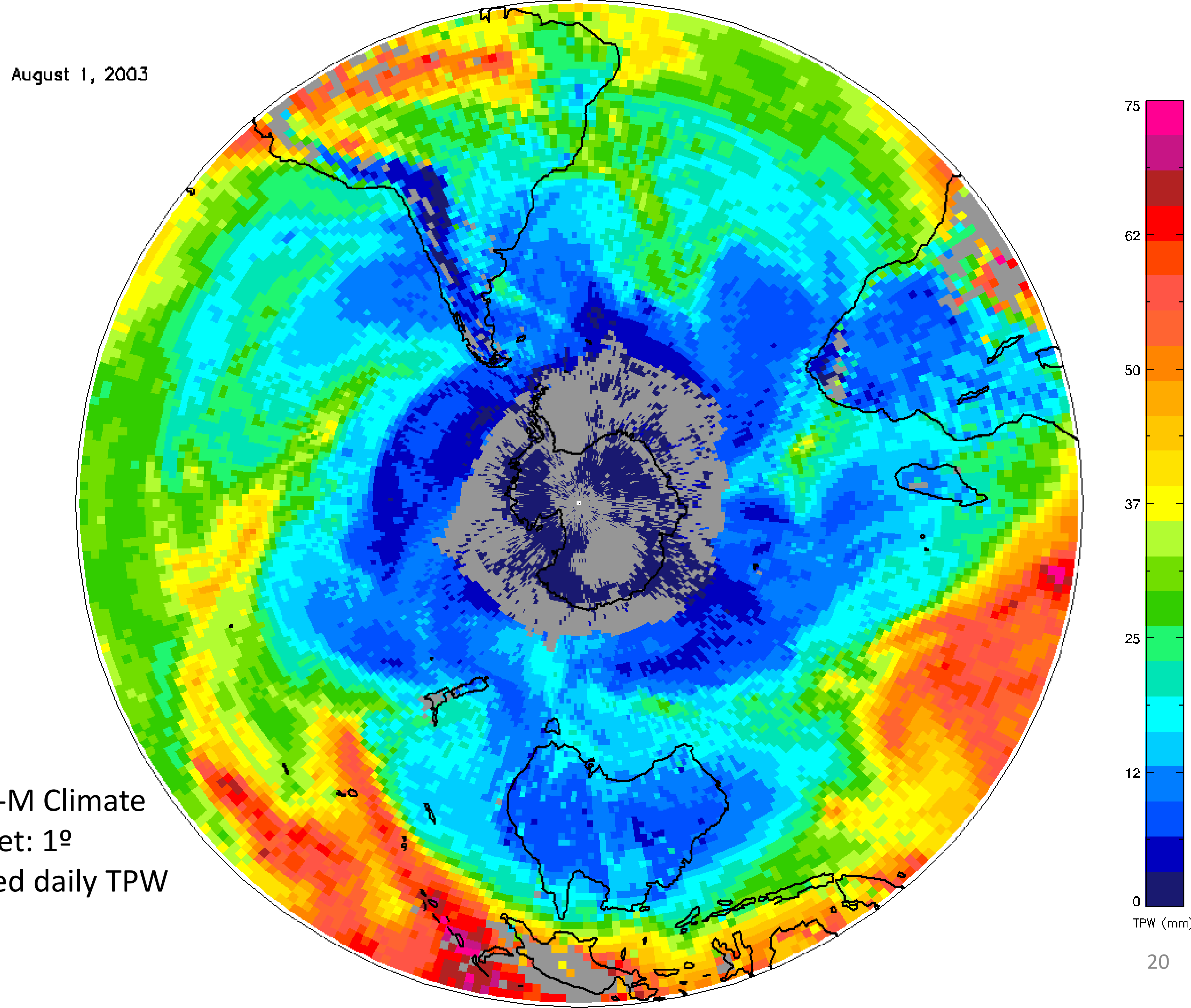


NVAP-M Climate

The challenge of creating a multisensor, multidecadal, global water vapor climate record

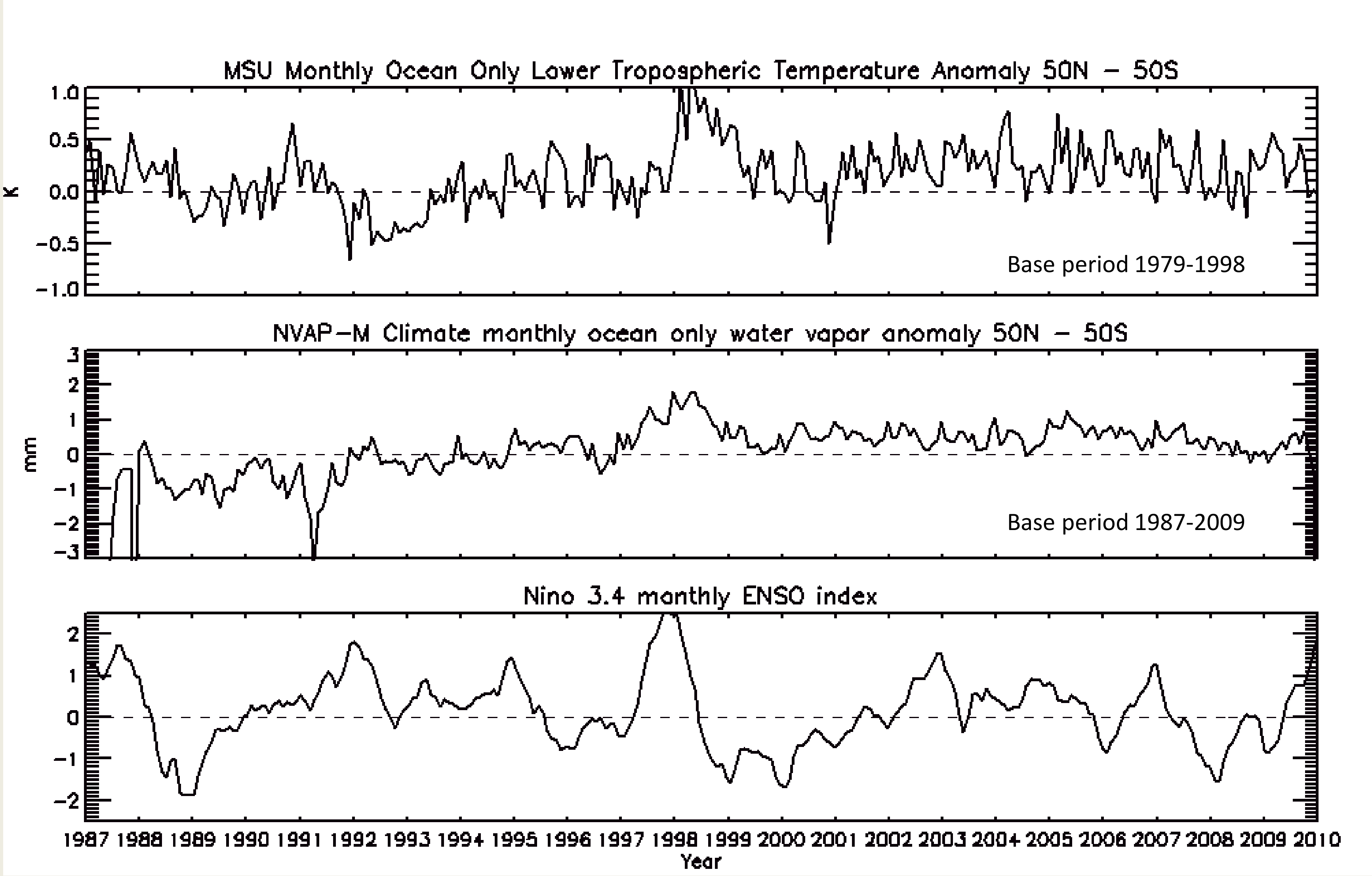


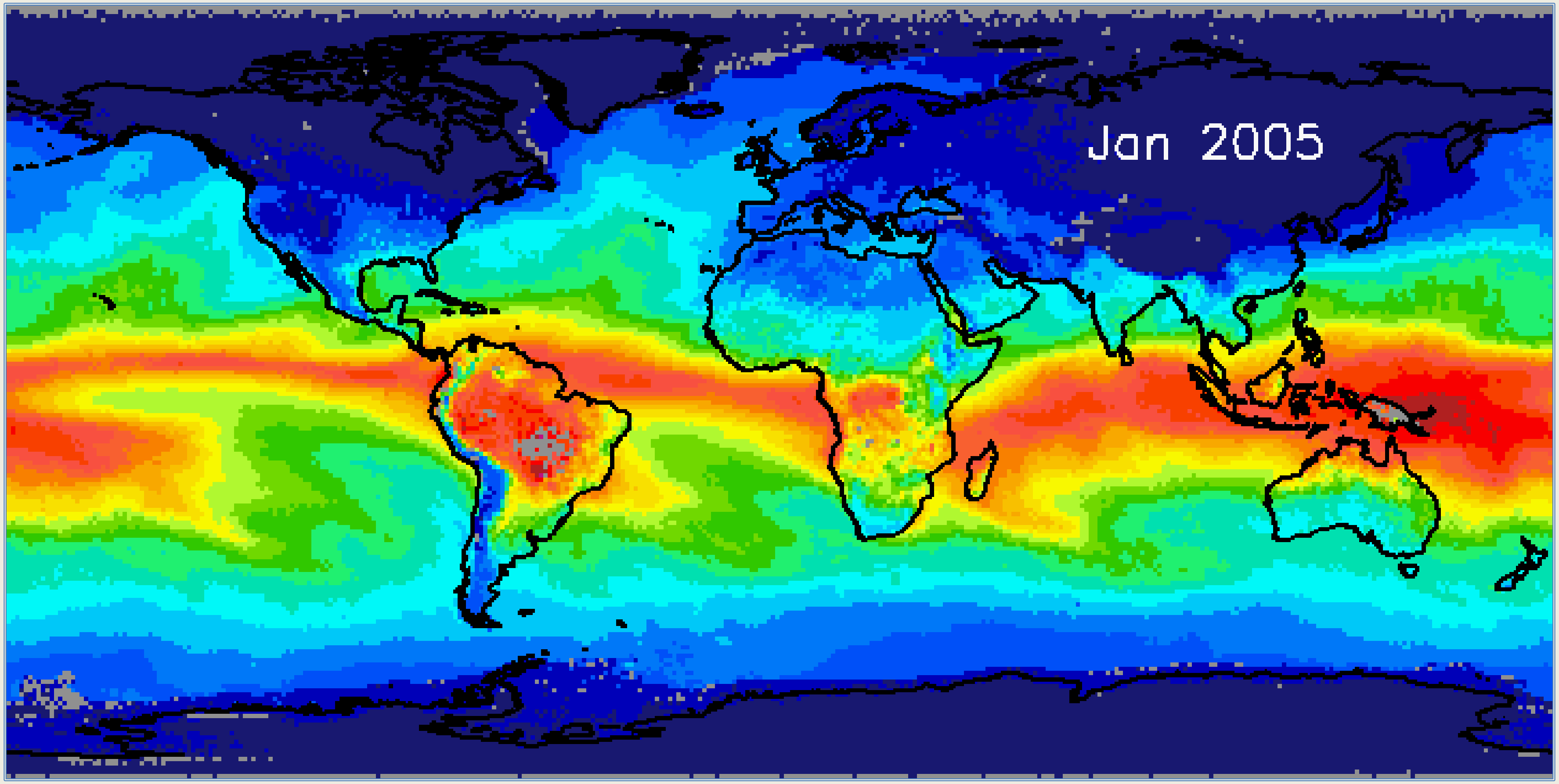
Sensors preferentially sample ocean or clear regions.



NVAP-M Climate Dataset: 1º gridded daily TPW data

Global water vapor tracks temperature and ENSO, but can vary regionally





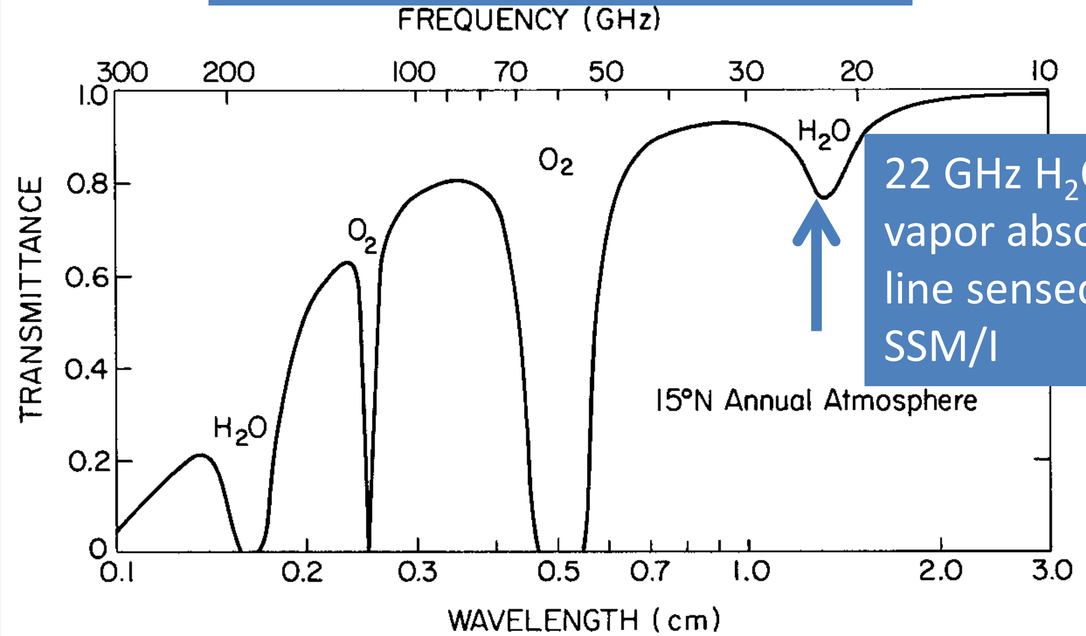
Monthly Mean TPW (mm) from
NVAP-M Climate for 2005

$$\frac{\partial w}{\partial t} + \nabla \cdot \frac{1}{g}\int_0^{p_s} \mathbf{v}q \, dp = E - P$$

where
w is the total precipitable water
q is the specific humidity profile
v is the wind vector
E and P are evaporation and precipitation

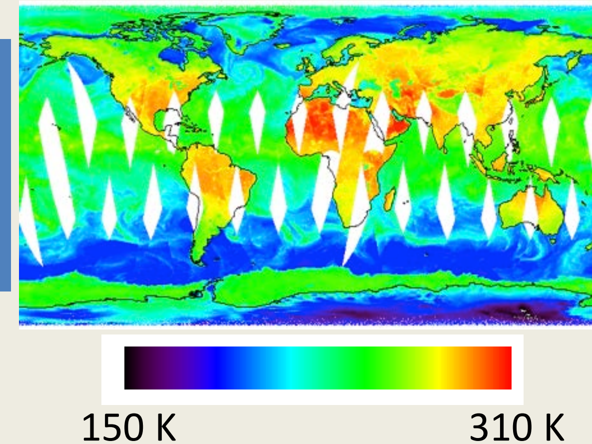
This equation links surface water exchange to the flux of moisture throughout the depth of the atmosphere. The moisture flux (transport) is a cross-cutting term connecting the water cycle and energy budget due to latent heat transport.

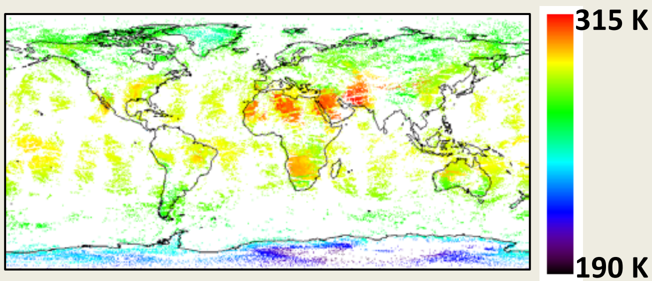
Microwave Absorption Spectrum



22 GHz H_2O vapor absorption line sensed by SSM/I

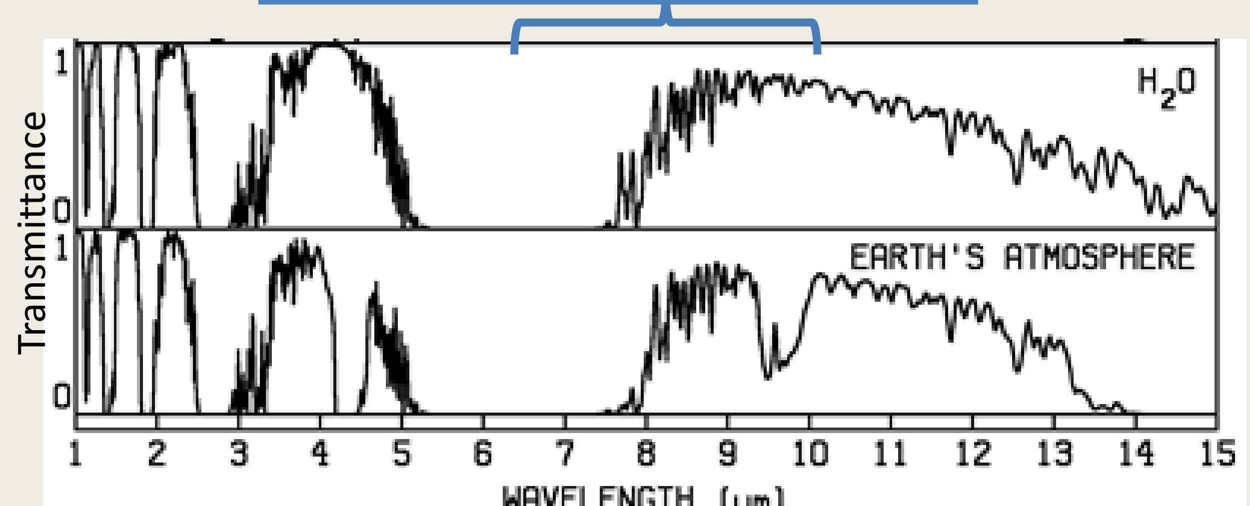
SSM/I 22 GHz radiance (V-pol)





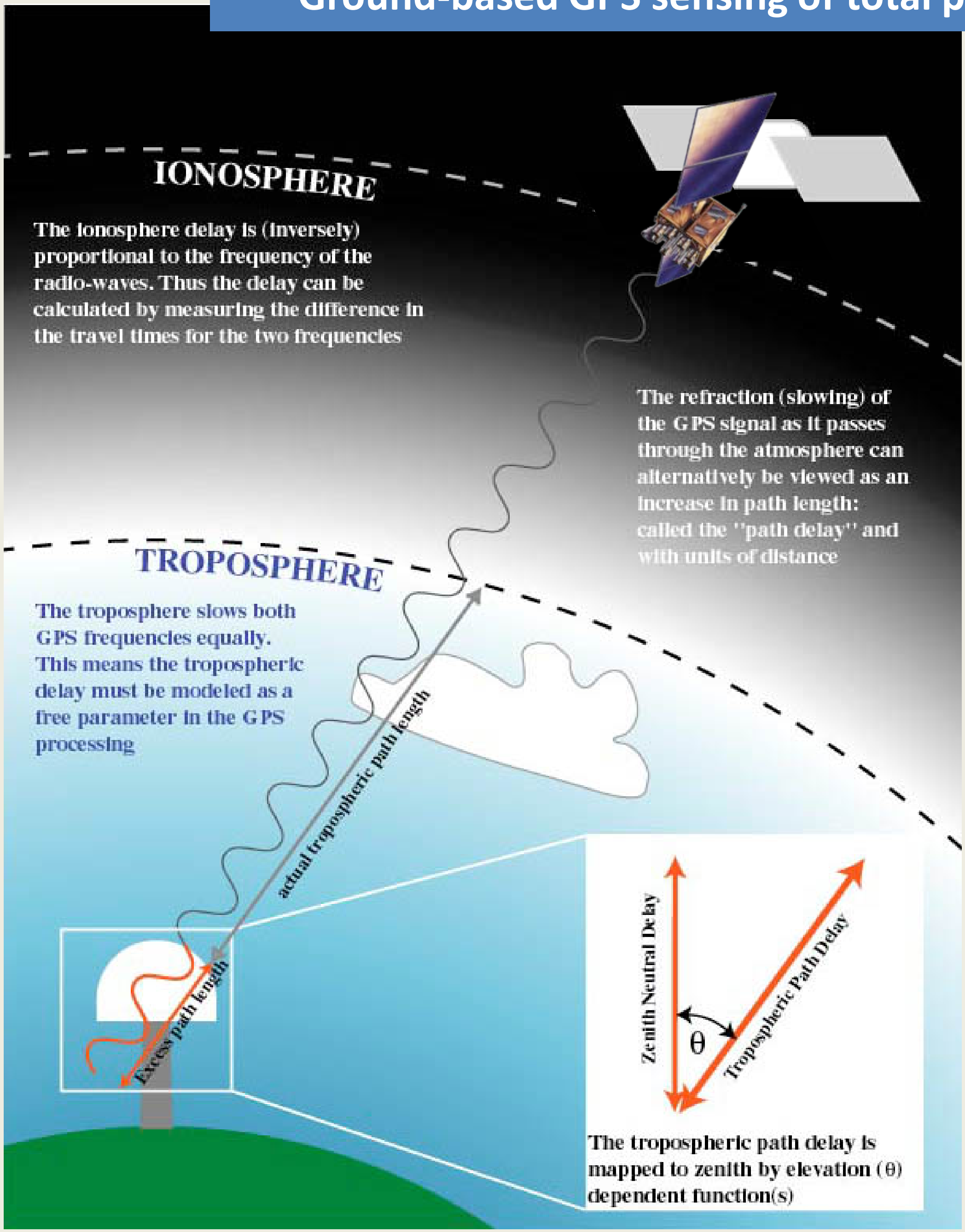
HIRS 8.16 µm radiance in cloud-free regions

HIRS Infrared Sounding Channels



Infrared Absorption Spectrum

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



NOAA Earth Science Research Lab

- 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

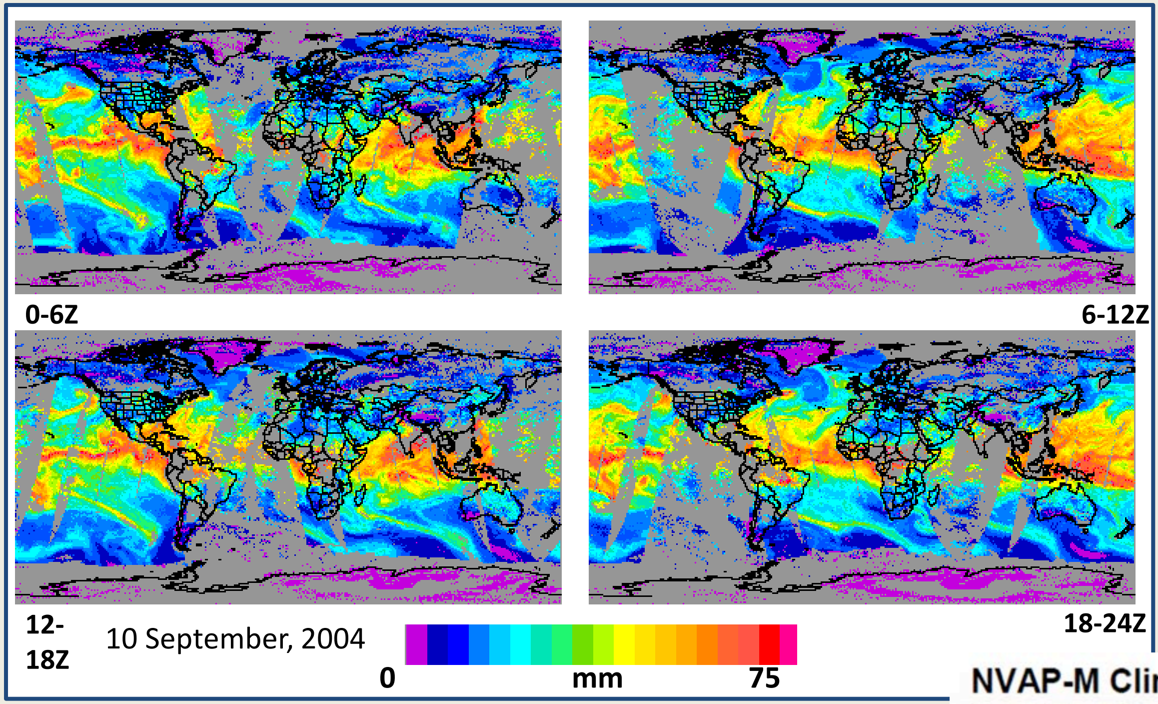
Total Delay = Dry Delay + Wet Delay

Water vapor is Earth's most important variable greenhouse gas

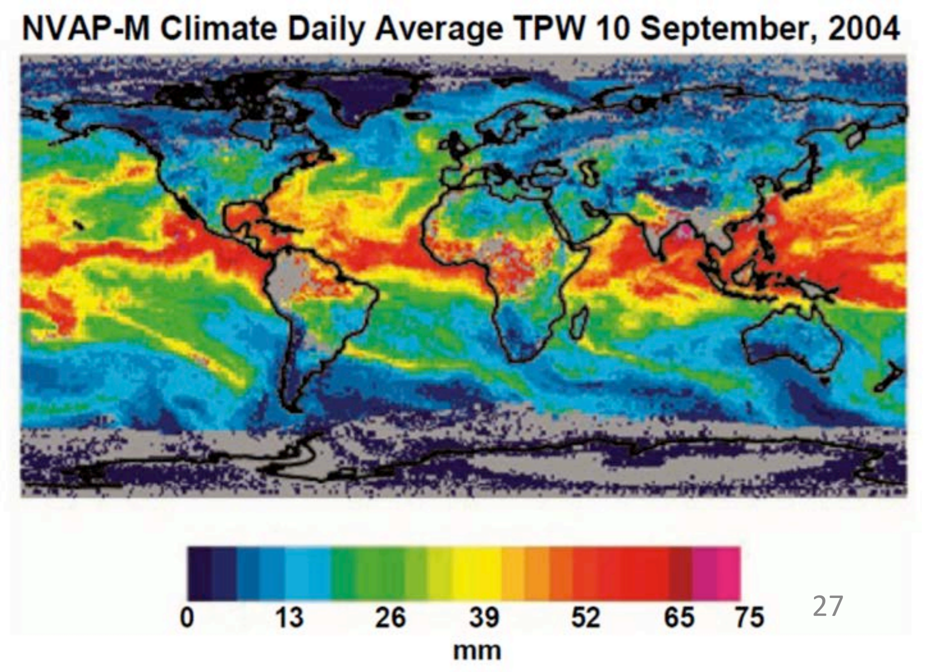
- Source for precipitation, dominates diabatic heating structure in troposphere; typical scale height ~ 2 km.
- Trenberth (1999) estimates for extratropical cyclones, on average 70 % of precipitation comes from moisture already in the atmosphere at the time the storm formed.
- "Feedback from the redistribution 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)

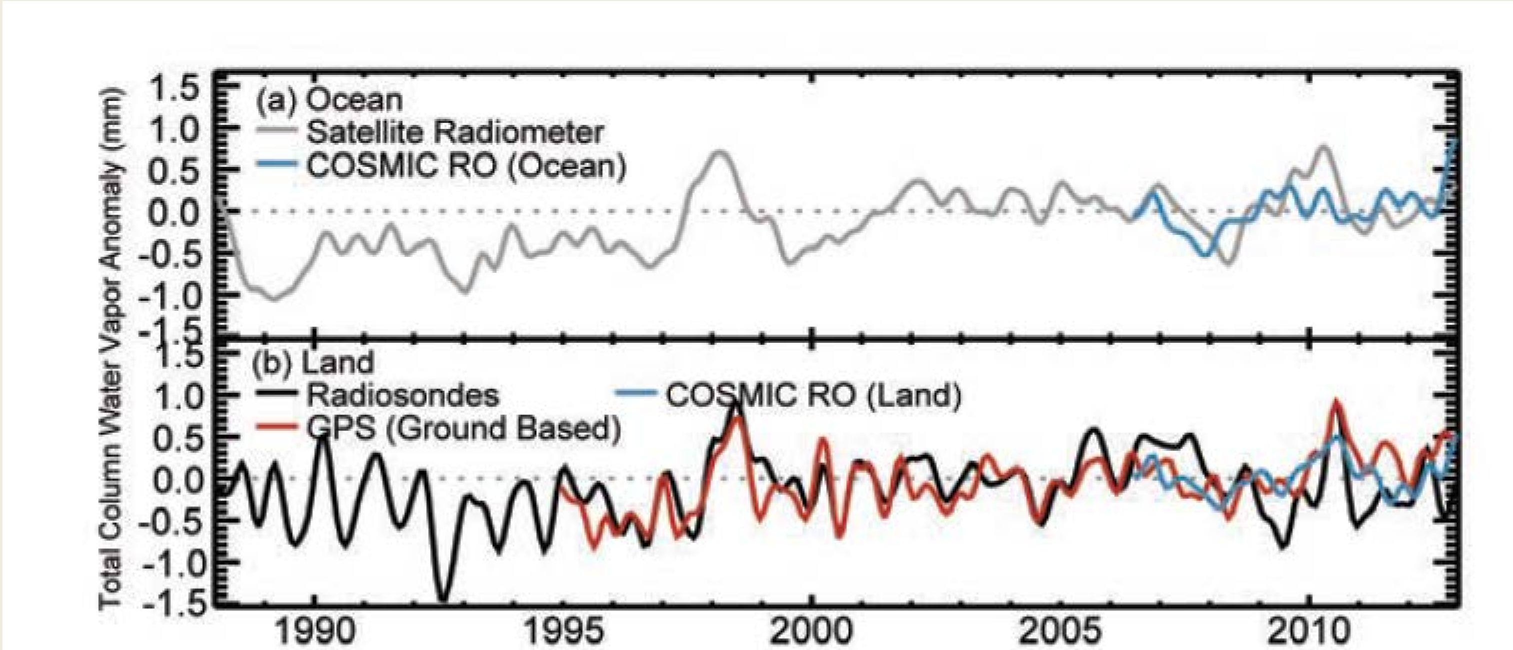
NVAP-M Weather vs. Climate Product



Weather Product



Climate Product



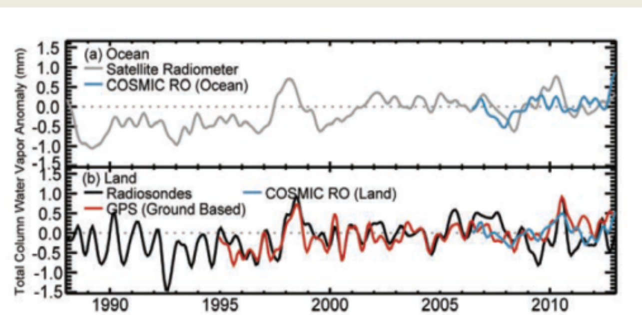
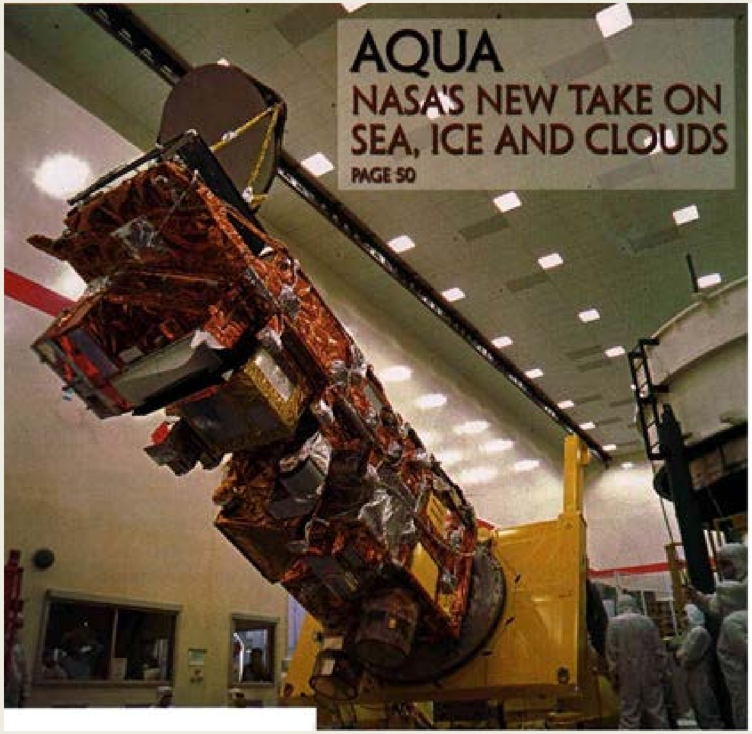
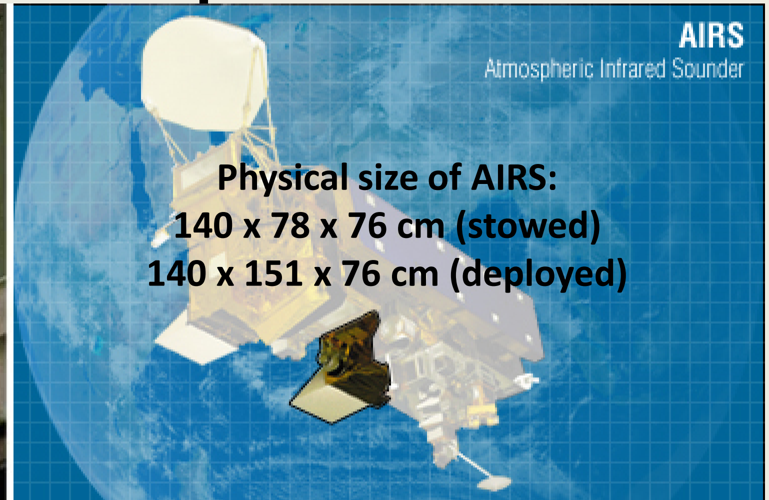


FIG. 2.11. (a) Anomaly time series of TCWV over ocean from satellite-borne microwave radiometers and COSMIC. The reference period for both measurements is 2007–12. (b) Anomaly time series of TCWV over land from radiosondes, ground-based GPS, and COSMIC. Except for COSMIC, the reference period is 1997–2012. 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.

BAMS State of Climate 2012

Satellite Sensor Inputs to NVAP-M





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

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