Global Precipitable Water Trend and its Diurnal Asymmetry based on GPS, Radiosonde and Microwave Satellite Measurements

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Motivation

1) Water vapor is the single most important greenhouse gas

2) Water vapor provides the water source for cloud formation and precipitation

3) Significant disagreements in PW trends among different datasets and reanalysis products


PW = total water vapor in the air column
IPCC Reports on PW trends

AR3 2001 (1973-1995 %/decade)


AR5 2013 (1988-2012 %/decade)
Questions:

1) What is the best estimate of global PW trends for recent years and its spatial variability over both land and ocean based on observations?

2) What is the diurnal asymmetry of PW variabilities and their relationship with T?
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<th>Spatial Coverage</th>
<th>Temporal Resolution</th>
<th>Temporal Coverage</th>
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<tr>
<td>Homogenized radiosonde data</td>
<td>Globe land ~900 stations</td>
<td>Twice daily</td>
<td>1973-2011</td>
<td>Request from June Wang</td>
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NCAR global, 2-hourly GPS-PW dataset (1995-present)

- 2 hourly (0100, 0300, ..., 2300 UTC)
- 380 IGS, 169 SuomiNet, 1223 GEONET
- Accuracy: < 3 mm
- Ps, Tm, ZHD and ZWD also available
- http://dss.ucar.edu/datasets/ds721.1/

Wang et al. (2007)
Impact of Homogenization

Dew-Point-Depression (DPD) at 500hPa at Lindenberg, Germany
(Raw & Homogenized)

Dai et al. 2011
Impact on PW Diurnal Variations (Lindenberg)

GPS

Radiosonde before corr.

Radiosonde after corr.

ERA-Interim

Japanese Reanalysis

Vaisala RS92

Wang et al. (2013)
Comparisons of Three Datasets

Bermuda

Monthly PW anomaly (mm)

Years

1995 1997 1999 2001 2003 2005 2007 2009 2011

GPS: -1.17 mm/dec
MWR: -0.34 mm/dec 0.9
RAOB: -0.21 mm/dec 0.8
Global mean time series (PW and Ts)

Land

GPS/RAOB PW monthly anomaly (mm)


Ocean

MWR PW monthly anomaly (mm)


Ts monthly anomaly (degC)
Comparisons of trends

- RAOB vs GPS (R=0.46)
- MWR vs GPS (R=0.64)
General agreements among three datasets;  
Spatial coherence in homogenized radiosonde data;  
Unique spatial patterns over Ocean, and consistency for different time records.
Diurnal cycle of PW trends

- At 66% of stations, the diurnal cycle dominates the sub-daily variability in PW trends;

- PW trends peak at night with a mean amplitude of $\sim 0.2$ mm/dec;

- On average, the diurnal cycle explains 42% of the variances (7% for semi-diurnal).
Diurnal Asymmetry of PW Trends (GPS Data)
Diurnal Asymmetry of PW vs. Ts Correlation
1. Global PW trends are analyzed using three datasets. The moistening trend is dominated over the globe, with larger trends over oceans than over land.

2. The atmospheric moistening rate is faster at night than during the day. PW has higher correlation with Tmin than Tmax as a result of clouds’ effect on Tmax.

3. The result implies that the relationship of nighttime PW and Ts is a better indicator of water vapor feedback.
Diurnal Asymmetry of PW vs. Ts Correlation
Diurnal Asymmetry in Correlation

Cloud Effects

https://www.e-education.psu.edu/mete0003/files/mete0003/image/Lesson%202/L2_surf_rad.swf
Diurnal Asymmetry in Correlation: Cloud Effects

Surface temperature

Surface specific humidity

LW & SW downward radiation

Dai et al. 1999
How does PW change with T?

\[ \frac{d \ln e_s}{dT} = \frac{L}{R_v T^2} \]

\[ q = 0.622 \times RH \times \frac{e_s}{P} \]
\[ \frac{d(RH)}{dT} \approx 0 \]
\[ \frac{d(lnq)}{dT} \approx \frac{L}{(R_v T^2)} \]

\[ PW = \frac{1}{g} \int q \ dp \]

\[ \frac{d(lnPW)}{dT} \approx \frac{L}{(R_v T^2)} \]
\[ (~7\%/K) \]

- Statistically significant over most regions
- Larger than Clausius-Clapeyron rate (~7%/K) over Ocean, but smaller over Land
Diurnal Asymmetry in PW Trends: Tmax, Tmin & RH

\[ \frac{dPW}{dt} \propto RH \frac{de_s}{dt} + e_s \frac{dRH}{dt} \]
\[ PW = \left( \frac{1}{g} \right) \int q \, dp \]
\[ q = \varepsilon \cdot RH \cdot \frac{e_s}{P} \]

RH * \frac{de_s}{dt} \quad \frac{de_s}{dt} \propto \frac{dT}{dt} \quad e_s \cdot \frac{dRH}{dt} \quad \frac{dRH}{dt} \approx 0

Global Land

Vose et al. (2005)