CLIMATE MEASUREMENT REQUIREMENTS AND CURRENT CAPABILITIES FOR SATELLITE REMOTE SENSING OF PRECIPITABLE WATER VAPOR

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Motivation
Cost of Floods

- Floods have many negative socio-economic impacts.
- In 2014, there were 32 documented flash floods, killing over 1000 people, affecting over 1 million people, and costing $1.6 billion.
- The cost of floods could exceed $500 billion globally by 2030.

Courtesy: http://gideonmendel.com/drowning-world-curators-words/
Flash Floods are a Major Global Threat

- Flash floods result from extreme precipitation events, fueled by extreme moisture availability. As PWV increase, the potential for extreme precipitation will increase.
- Devastating flash floods during October in France, Guatemala, and South Carolina has highlighted the socio-economic cost of such events.
- Head of the UN Office for Disaster Risk Reduction (UNISDR) called for further investment to reduce the risk from flash floods in urban areas.
South Carolina Event

- More than 20 inches of rain fell in some locations Friday October 2\textsuperscript{nd} through Sunday October 4\textsuperscript{th}.
- At least 15 people killed and over 18 dams were breached causing mandatory evacuations.
- Moisture was continuously ‘pumped’ into the area.
- The GCM X-Factor is the predicted change in the frequency of events with respect to the period 2000-2025.

- PWV event: 3/decade
  - GCM X-Factor: 5 (2050), 15 (2075), 20 (2100)
Climate Measurement Requirements

Jacola Roman, Robert Knuteson, Steve Ackerman, and Hank Revercomb, 2015: *Predicted Changes in the Frequency of Extreme Precipitable Water Vapor Events*. J. Climate, 28, 7057–7070. doi: http://dx.doi.org/10.1175/JCLI-D-14-00679.1
The largest PWV X-Factor occurs in India, a country extremely vulnerable to natural disasters due to high population density and poor infrastructure development.

The comprehensive CMIP5 study has shown a model median predicted a X-Factor range of 8-10 (Global) and 8-48 (Regional/Seasonal).

The fractional change is statistically the same for all regions.

For all regions and the globe, the average rate of fractional change is 3%/decade, suggesting a 3% measurement error or better is needed to detect shifts in extreme PWV within 10-15 years.
GCM PWV output was classified by latitude zones (5) and Koppen Climate categories (5).

Koppen Climate categories are classified using temperature and precipitation.
GCM PWV Fractional Change (%)

5th Percentile (Extreme Dry)  50th Percentile (Median)  95th Percentile (Extreme Wet)

Zonal Climate

5th Percentile Fractional Change Relative to 2013

Koppen Climate

5th Percentile Fractional Change Relative to 2013

95th Percentile Fractional Change Relative to 2013
Global Assessment of AIRS and IASI PWV

SuomiNet GPS Stations Matchup Criteria and QC

- IASI A, IASI B, and AIRS L2 PWV products were elevated corrected to matchup with SuomiNet GPS Stations.
- IASI A matchups to ground-based observations were made from 2013-2014
- IASI B matchups to ground-based observations were made from 2013-2014
- AIRS matchups to ground-based observations were made from 2012-2014

Matchup criteria:
- Within 1° radius of the station
- Within 1 hour of the observations

Quality control:
- PWV greater than 80 mm were discarded
- GPS PWV measurements with errors greater than 5% were discarded
- AIRS PWV QC =2 discarded
IASI A, IASI B, and AIRS show consistent results.

The greatest fractional error occurs in cold climates (i.e. Arctic, Antarctica).
IASI A, IASI B, and AIRS show consistent results.

Again, the greatest fractional error occurs in cold climates (Moist Mid-Latitudes with Cold Winters).
Use the region containing South Carolina to illustrate the predicted shift in the PDF of PWV from GCMs to determine whether the measurement error of the current IR instruments is small enough to detect the predicted shift.

Time-To-Detect with Current IR Instruments
The measurement error of the IR instrument must be smaller than the climate signal to detect the PDF shift.

GCM fractional change with time for Zonal (ocean+land) and Koppen (land) is equivalent.
AIRS, IASI A, and IASI B are within 5% fractional error over the range 25th-95th percentile.

Extreme dry has the largest fractional error (> 10%).
**Zonal:** Between the 40th-75th percentile, IASI A, IASI B, and AIRS require less than 15 years of observations to detect the GCM predicted PWV shift.

**Koppen:** Degraded regional performance leads to longer TTDs.

**AIRS 3% error at the 75th percentile causes a 10 year increase in TTD.**
Both AIRS and IASI are about 3% drier for the southeast United States land region.

This leads to increased detection times for moist cases (> 50th percentile).
Conclusions
Current IR Capabilities

- To detect the shift in 15 years, the zonal and Koppen measurement requirement is about **3-5%**.
  - The greatest challenge occurs at the Poles and extreme dry end where little change is predicted to occur, suggesting an expansion of the PDF instead of a shift.

- IASI A, IASI B, and AIRS show consistent results suggesting that measurements are within **5%** for the middle of the PDF (**25th-75th** percentile).

- The South Carolina Flash Flood event had a coinciding extreme moisture event that is predicted to increase in frequency by a factor of 5 in the next 30 years.

- The TTD the predicted PDF shift of extreme PWV for the region containing South Carolina was at least **25 years** for AIRS and IASI.
Recommendations

- Recommend satellite product providers place emphasis on achieving better than 3% (goal) and 5% (threshold) fractional error in PWV over ocean and land and in each global climate zone.

- Recommend satellite product providers place additional emphasis on the absolute accuracy of PWV measurements for higher than average water amounts (50\textsuperscript{th} to 99\textsuperscript{th} percentile).

- Recommend that weather analysis centers perform routine validation of NWP and satellite PWV products with GPS ground-based PWV stations, e.g. SuomiNet, to provide a continuous record of PWV product accuracy assessment that is publicly available.

- Recommend that climate analysis centers perform routine trending of operational satellite and ground-based validation PWV products using the Koppen Climate Classification system according to probability density function percentile and make the results publicly available.