

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

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Outline



- Motivation
- Climate Measurement Requirements
- Satellite Matchup Method and Results
- Time-To-Detect with Current IR Instruments
- Conclusions



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



Flash Floods are a Major Global Threat

- Flash floods results 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



Guatemala



French Riviera



South Carolina Event

- More than 20 inches of rain fell in some locations Friday October 2nd through Sunday October 4th.
- 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

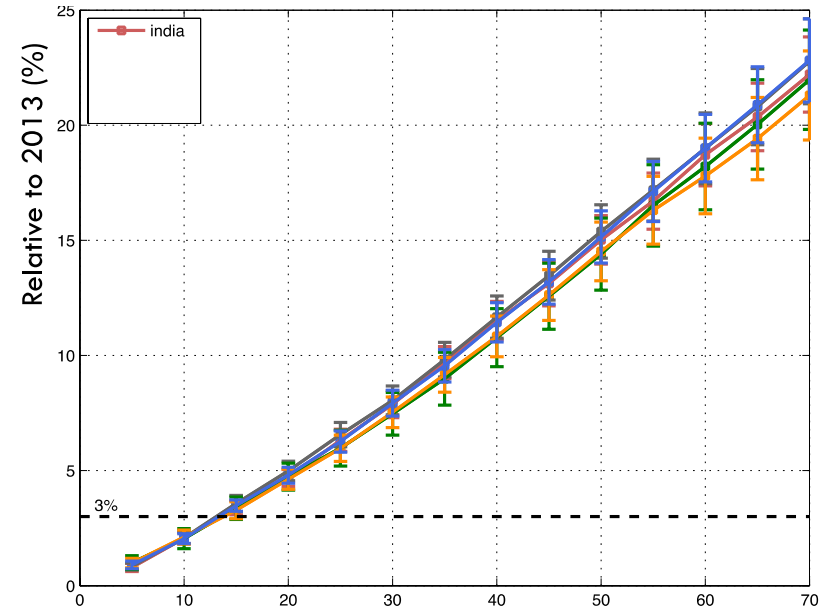
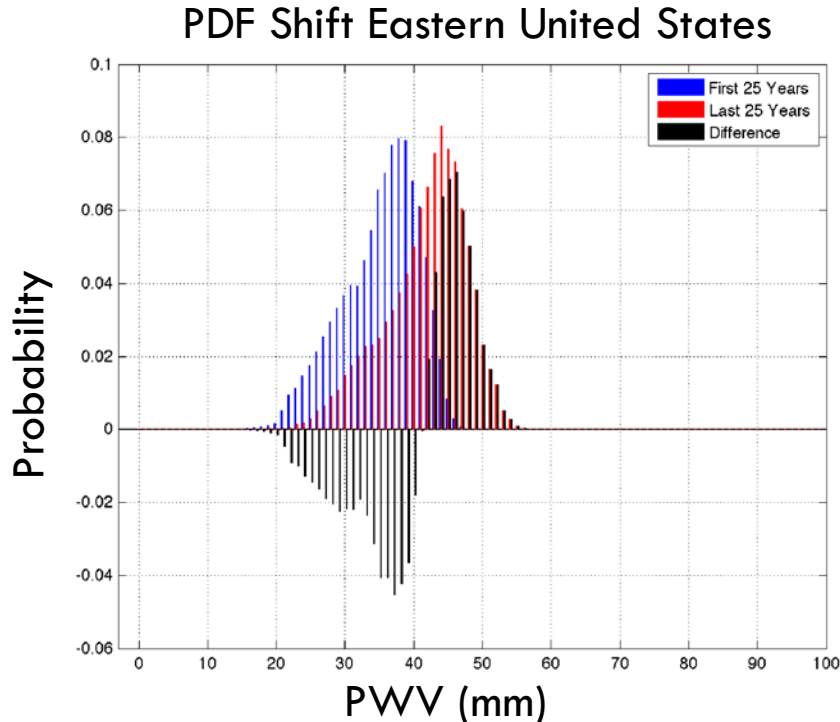
GCM X-Factor: 5 (2050),
15 (2075), 20 (2100)



Climate Measurement Requirements

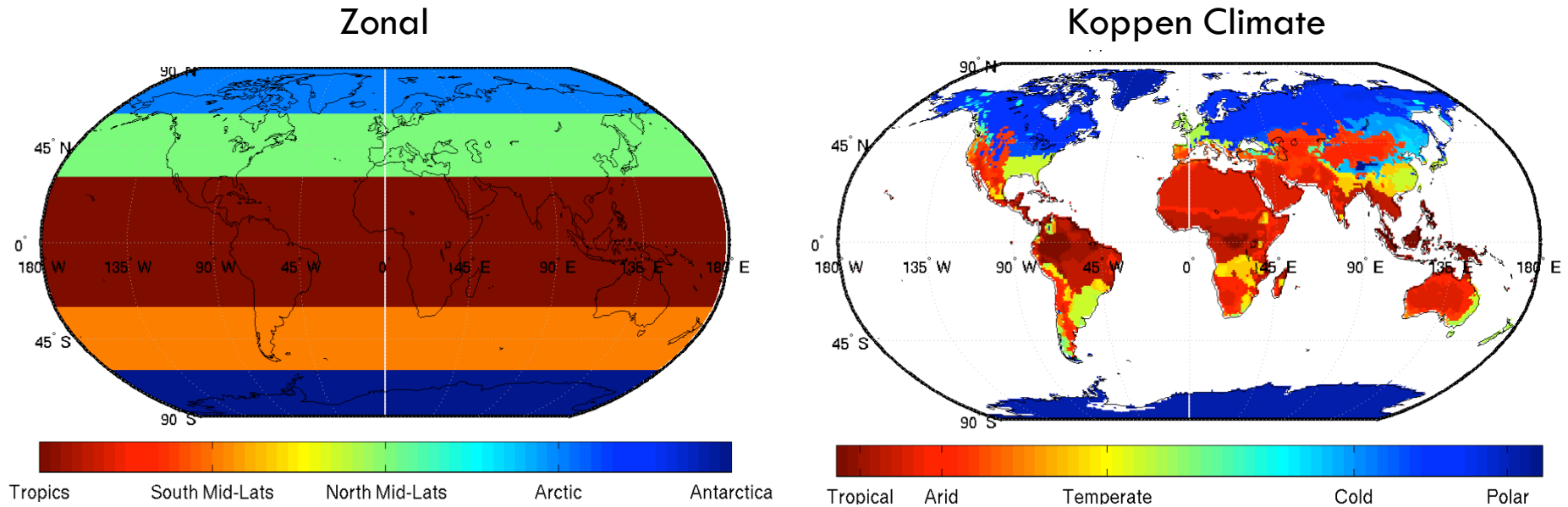
Jacola Roman, Robert Knuteson, Steve Ackerman, and Hank Revercomb, 2015:
**Predicted Changes in the Frequency of Extreme Precipitable
Water Vapor Events.** *J. Climate*, 28, 7057–7070. doi:
<http://dx.doi.org/10.1175/JCLI-D-14-00679.1>

Predicted Changes in Extreme PWV



- 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

Classification



- GCM PWV output was classified by latitude zones (5) and Koppen Climate categories (5).
- Koppen Climate categories are classified using temperature and precipitation.

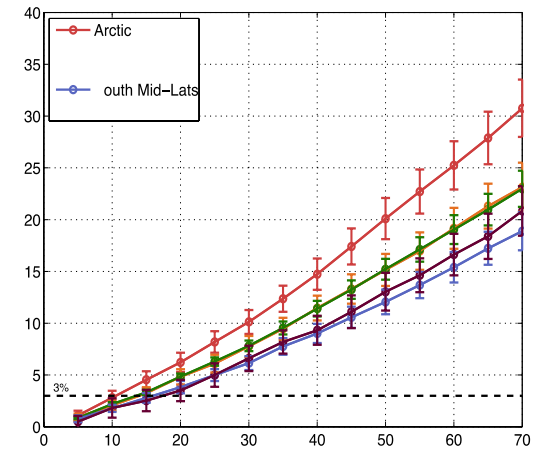
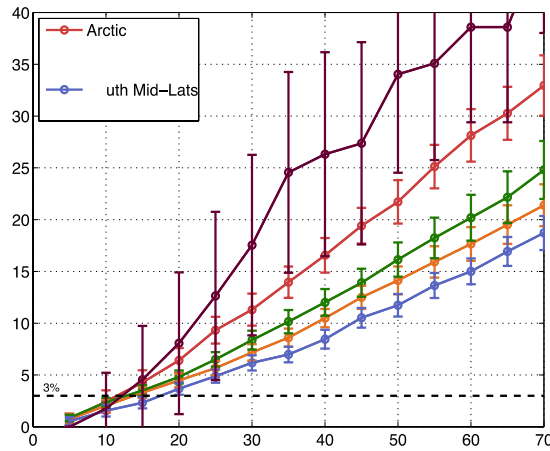
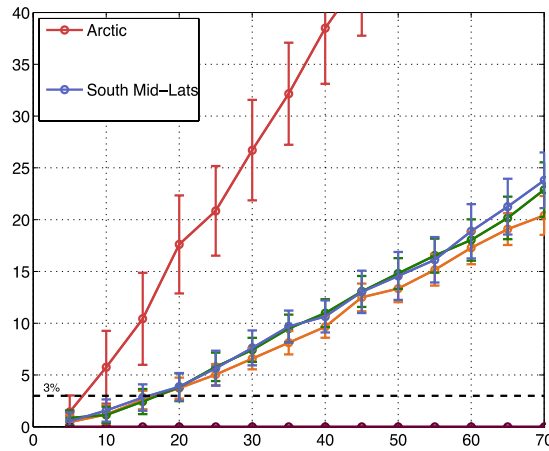
GCM PWV Fractional Change (%)

5th Percentile (Extreme Dry)

50th Percentile (Median)

95th Percentile (Extreme Wet)

Zonal

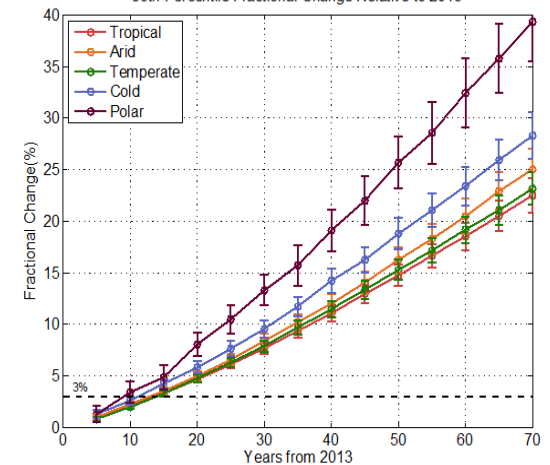
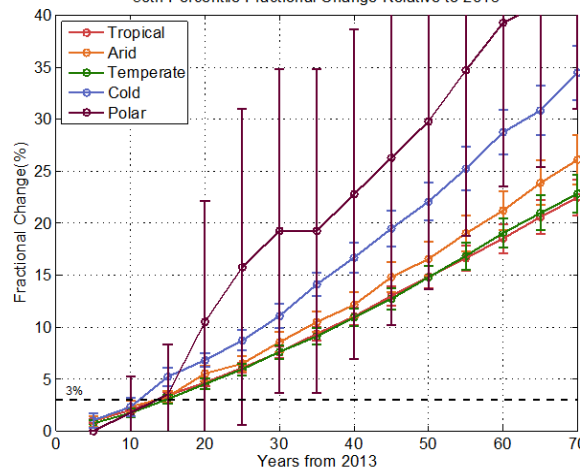
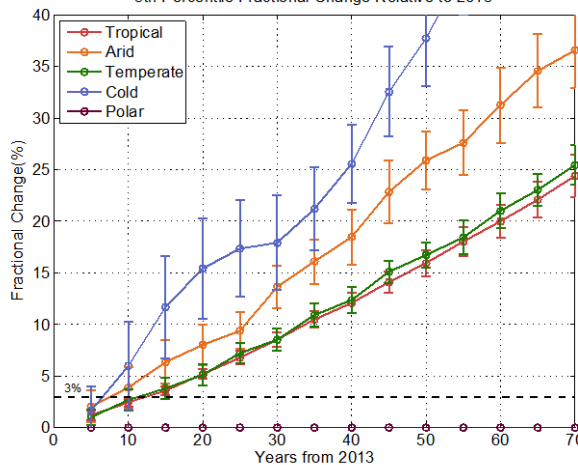


Koppen Climate

5th Percentile Fractional Change Relative to 2013

50th Percentile Fractional Change Relative to 2013

95th Percentile Fractional Change Relative to 2013



Global Assessment of AIRS and IASI PWV

Roman, Jacola, R. Knuteson, T. August, T. Hultberg, S. Ackerman, and H. Revercomb.
2016: **A Global Assessment of NASA AIRS v6 and EUMETSAT IASI v6 Precipitable Water Vapor using Ground-based GPS SuomiNet Stations.**
JGR. To Be Submitted.

Passive Advanced MW and IR Measurements of Water Vapor

Aqua



MetOp



SuomiNPP

JPSS



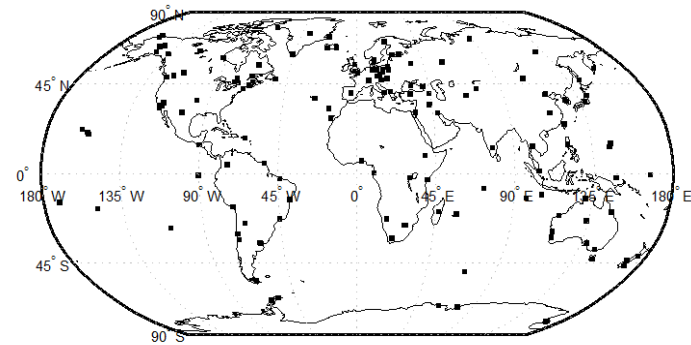
Active Radio GNSS Ground-Based Measurements of Water Vapor

SuomiNet GPS

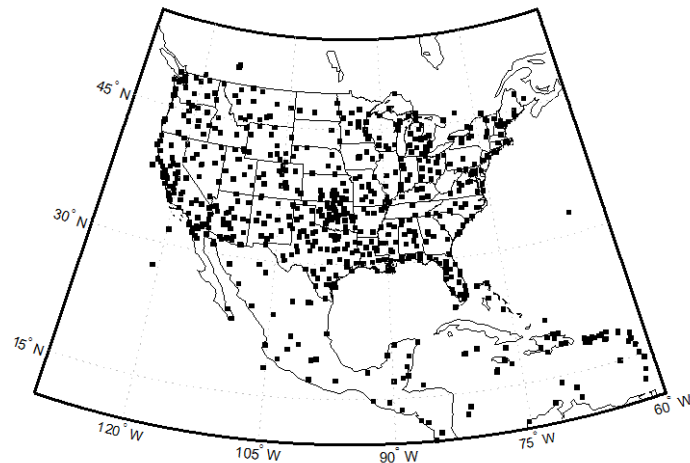


SuomiNet GPS Stations Matchup Criteria and QC

International Stations



North America Stations



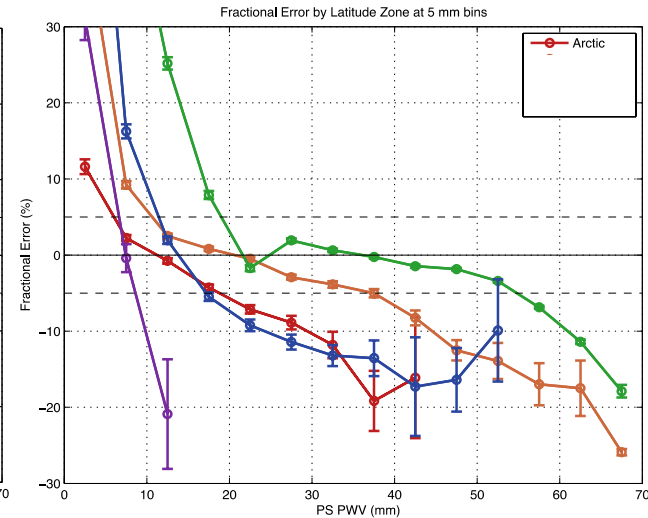
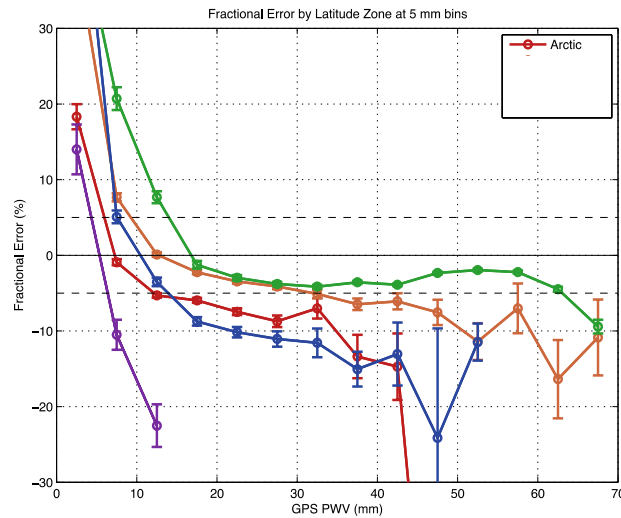
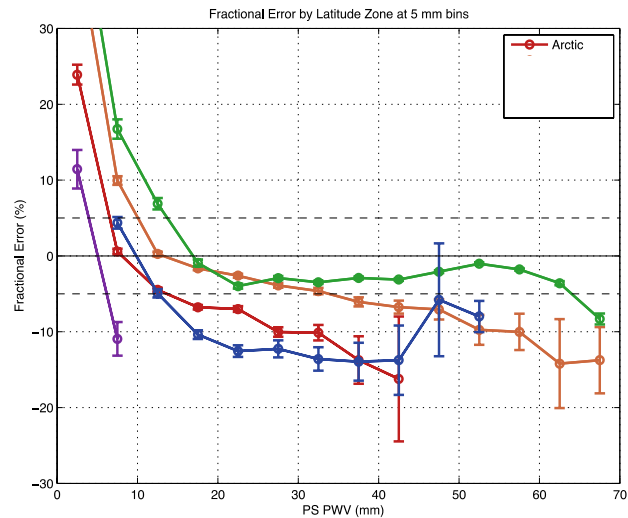
- IASI A, IASI B, and AIRS L2 PWV products were elevated corrected to matchup with SuomiNet GPS Stations.
- IASI A matchups to ground-based observations were made from 2013-2014
- IASI B matchups to ground-based observations were made from 2013-2014
- AIRS matchups to ground-based observations were made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

Zonal Classification Fractional Error (%) by GPS PWV

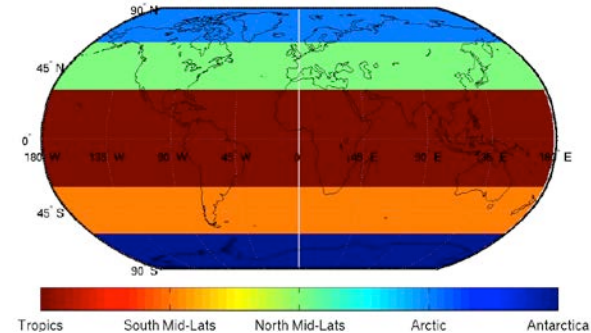
IASI A

IASI B

AIRS



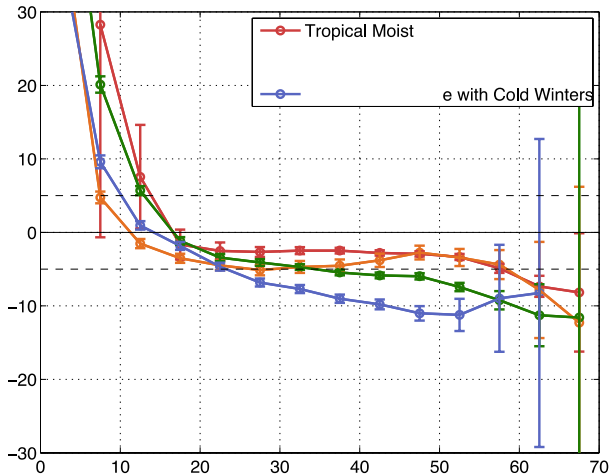
- IASI A, IASI B, and AIRS show consistent results.
- The greatest fractional error occurs in cold climates (i.e Arctic, Antarctica).



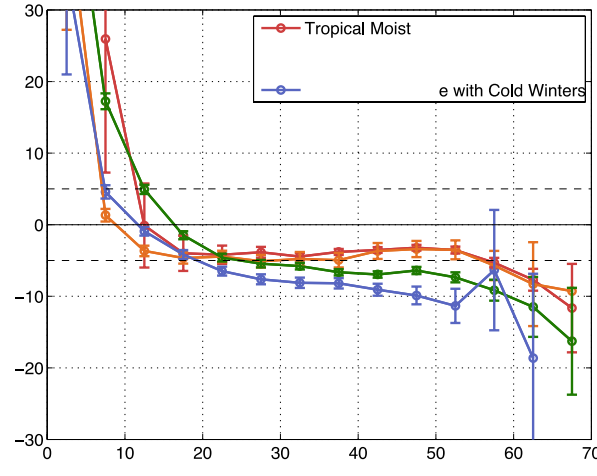
Koppen Climate Classification

Fractional Error (%) by GPS PWV

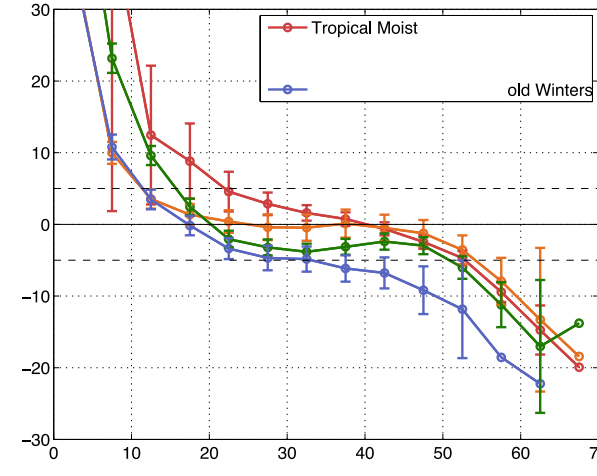
IASI A



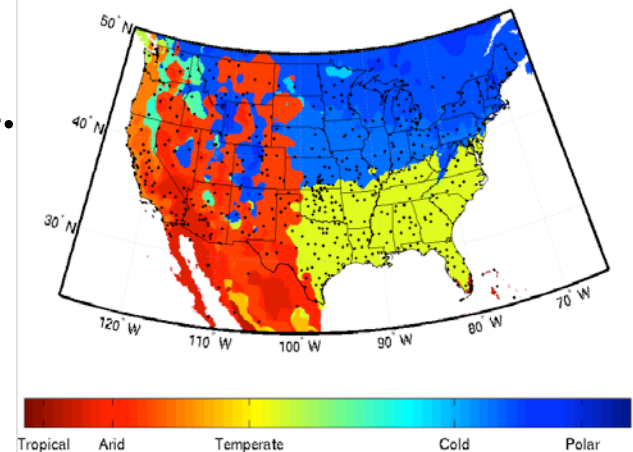
IASI B



AIRS

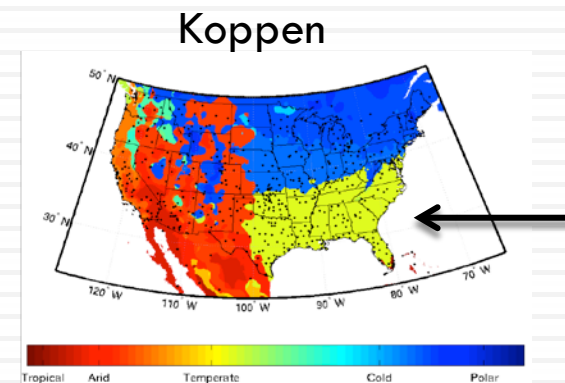
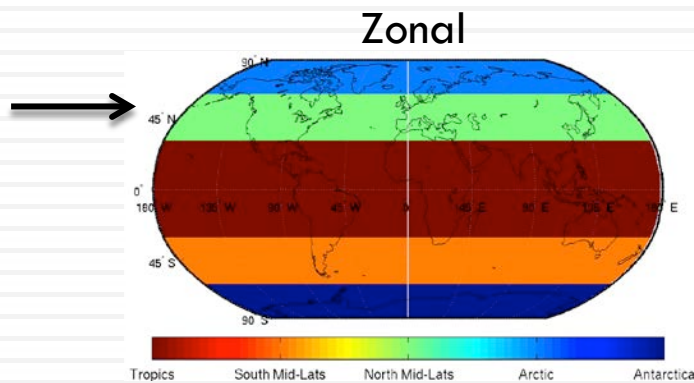


- IASI A, IASI B, and AIRS show consistent results.
- Again, the greatest fractional error occurs in cold climates (Moist Mid-Latitudes with Cold Winters).

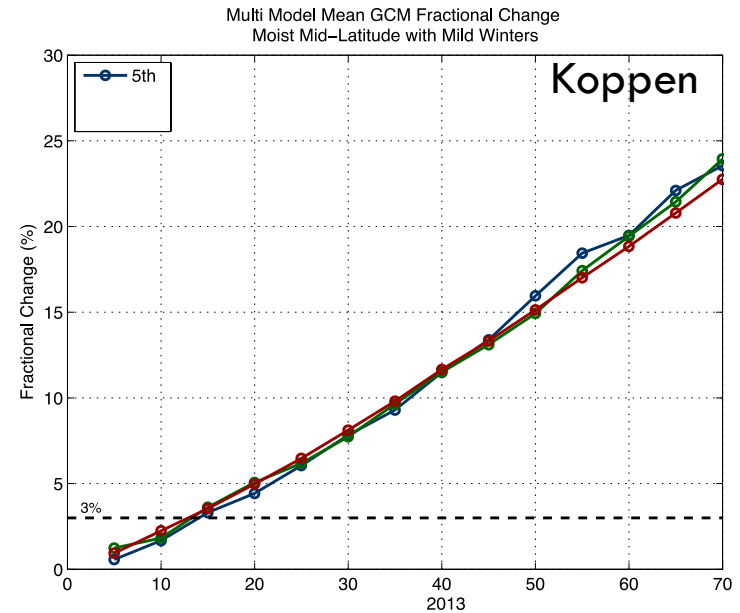
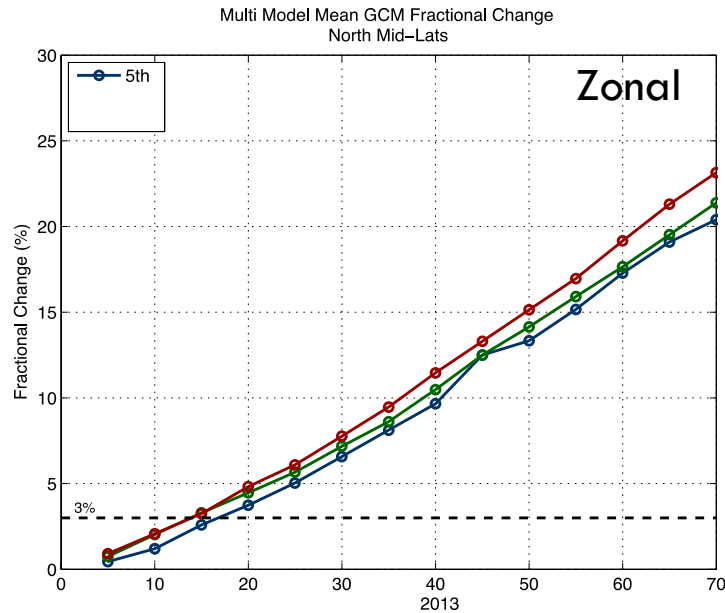


Time-To-Detect with Current IR Instruments

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

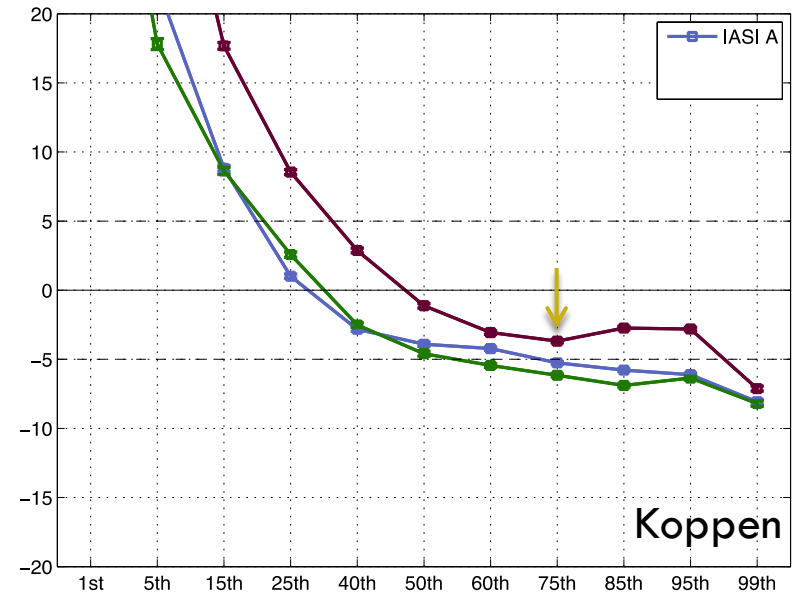
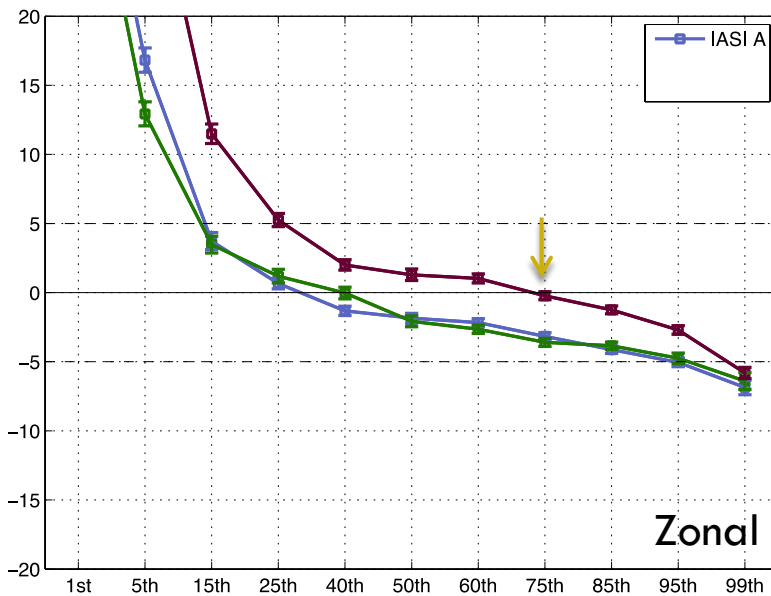


GCM PWV Fractional Change (%)



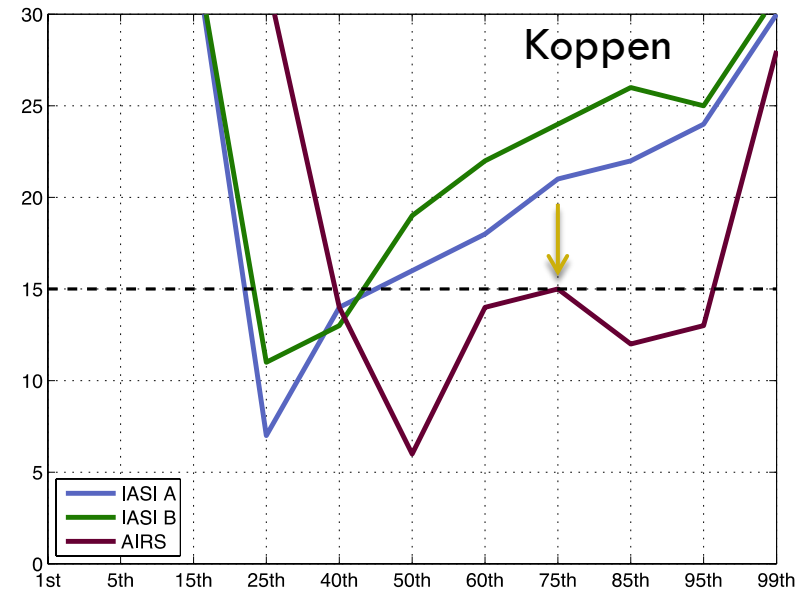
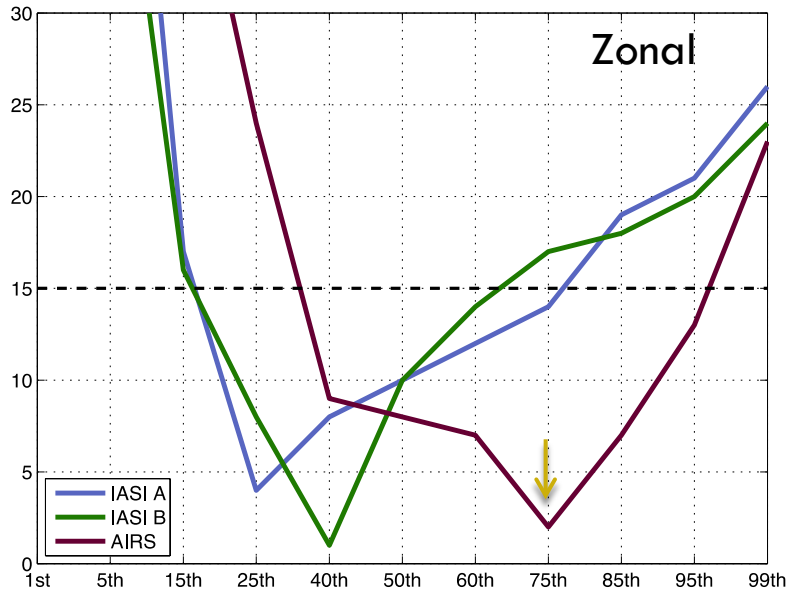
- The measurement error of the IR instrument must be smaller than the climate signal to detect the PDF shift.
- GCM fractional change with time for Zonal (ocean+land) and Koppen (land) is equivalent.

PWV Fractional Error (%) in AIRS and IASI



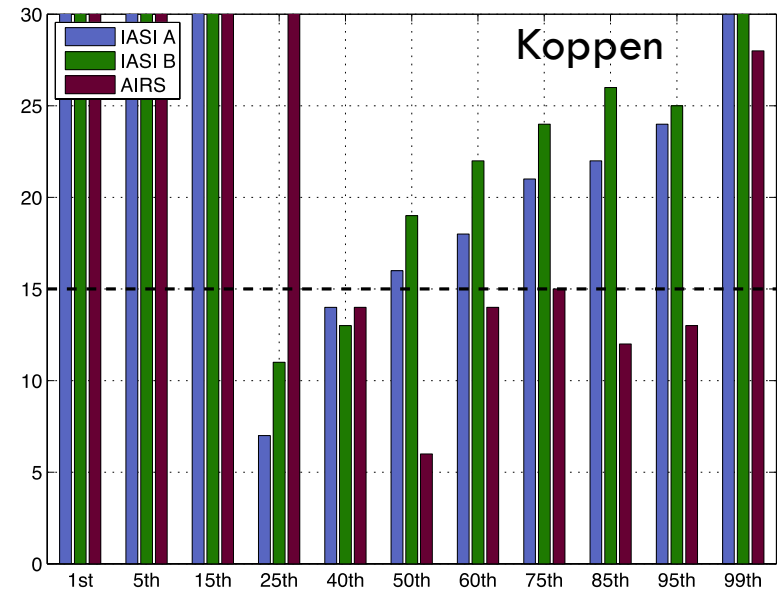
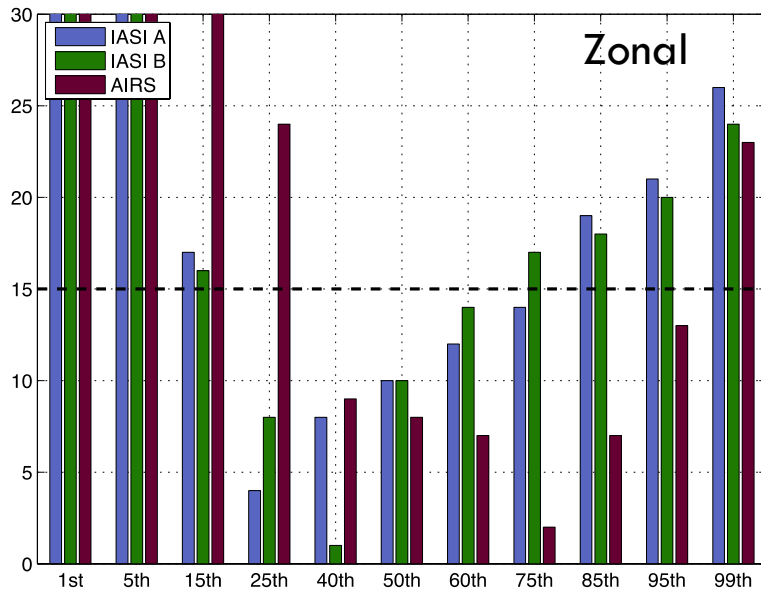
- AIRS, IASI A, and IASI B are within 5% fractional error over the range 25th-95th percentile.
- Extreme dry has the largest fractional error (> 10%).

PWV Time-To-Detect



- 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.

PWV Time-To-Detect



- Both AIRS and IASI are about 3% drier for the southeast United States land region.
- This leads to increased detection times for moist cases ($> 50^{\text{th}}$ 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 (50th to 99th 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.