ESTIMATING COLUMN WATER VAPOR TIME-TO-DETECT (TTD) USING CLARREO RETRIEVALS

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CLARREO Science Team Meeting: April 10, 2012

Outline

- Motivation
- Data
- Methodology
- Results
  - GPS/GCM Comparison
  - AIRS/AMSR-E/GCM Comparison
  - CLARREO-Proxy Comparison
  - TTD GCM Precipitable Water Vapor (PWV)
  - TTD PWV using “CLARREO” versus “AIRS” sounder
- Conclusions

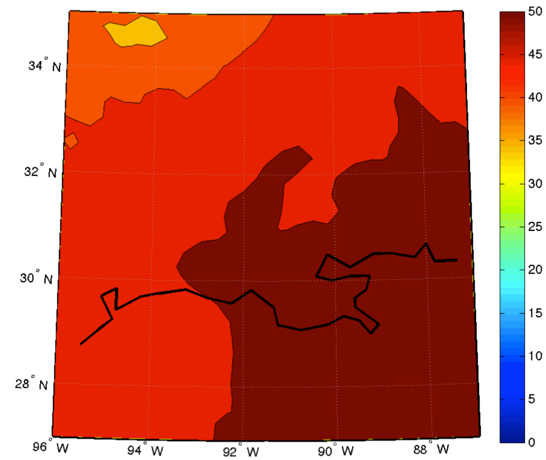
Motivation

Climate Change

- The Intergovernmental Panel on Climate Change (IPCC et al. 2007) fourth assessment concluded that the warming of the climate system is "unequivocal".
- The consequences of a changing climate will effect everyone in many ways including social and economic consequences.

Societal Impacts- Flooding

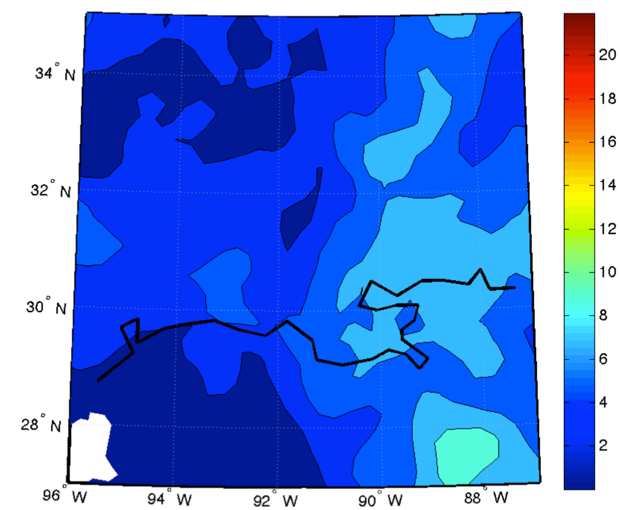
- Flooding events are likely to increase in certain regions around the world.
- This increase in precipitation is largely due to increase water vapor in the atmosphere (IPCC).
- Damages due to flooding are large. 1inch of flooding for a 1000 square foot home is estimated to cost $10,600 (FEMA).
  - The average annual flood loss in the U.S. for the last ten years (2001-2010) has exceeded $2.7 billion



PWV (mm)

Louisiana August 2005 (Hurricane Katrina)

Total Precipitation (kg/m^2)



Societal Impacts- Flooding

- Flooding also causes public health issues.
  - In developing countries especially, water borne diseases can have a severe impact due to poor sanitation and drinking water.
  - The July 2005 Maharashtra flooding in Mumbai India killed 1,000 people with over 3,000 people hospitalized for various diseases, many due to contaminated water.

Epidemiological Survey for 2005 Floods

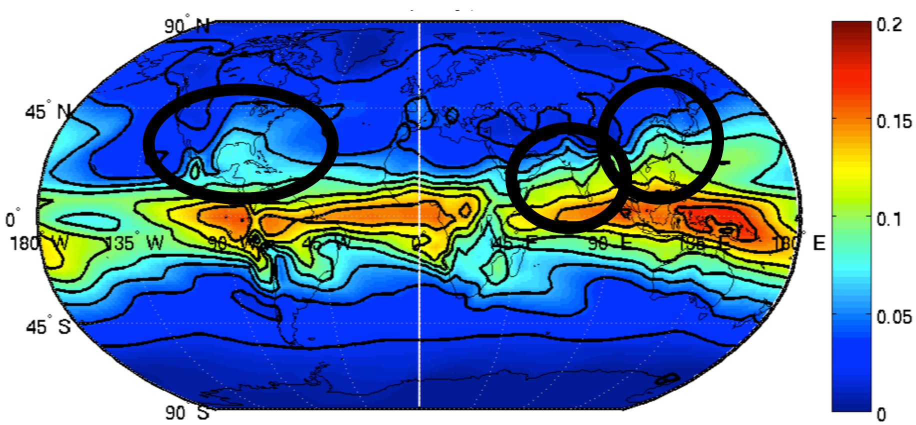
Name of the disease	Admission in last 24 hrs.	Total admissions since 29th July	Number of deaths
Gastroenteritis	154	1318	1
Hepatitis	27	194	--
Enteric fever, Typhoid	5	53	--
Malaria	62	406	2
Dengue	5	49	--
Leptospirosis	56	197	10
Fever (Unknown cause)	597	1,044	45
Total	**906**	**3,261**	**57**

Societal Impacts- Drought

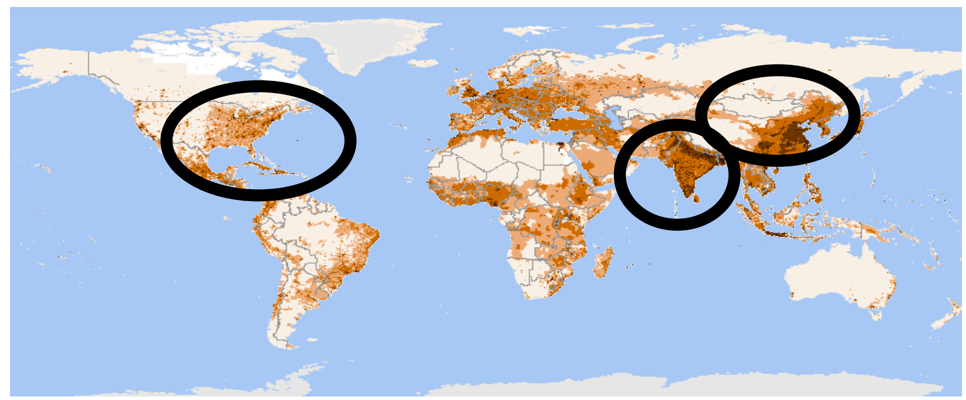
- Drought can cause damage to the ecosystem as well as the agriculture, which in turn can effect the local economy and public health.
- The IPCC concluded that droughts are expected to increase over low latitudes and mid-latitude interior regions during summer.
- Possible protection strategies include dams, rainwater harvesting, and recycled water, but understanding where the highest areas of threats are could reduce the costs implementation.
- One example is the China drought during 2010 and 2011 that effected 8 proveniences in the North.
  - This drought was due to lack of rain and snow. Anomalously low precipitation caused low amounts of snow cover. In turn putting the wheat crops at risk of being killed by frost.
  - Over 35 million people were effected, 4.2 million faced a drinking water shortage.
  - The economic damage was about 15 billion yuan or 2.3 billion dollars.
  - Many people resorted to cloud seeding to induce artificial rain.

Societal Impacts- Drought

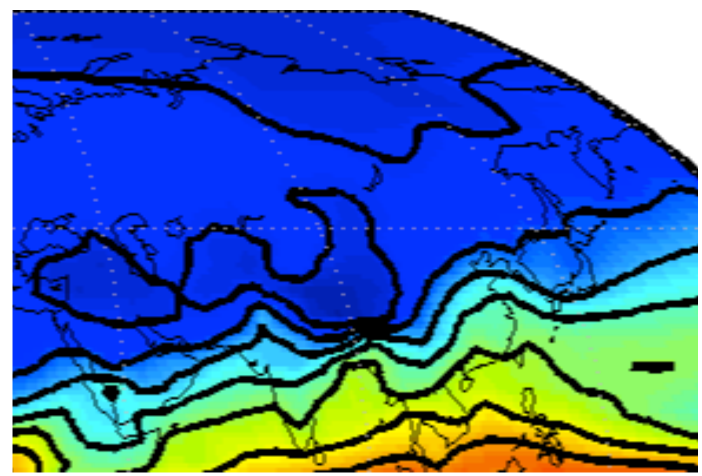
PWV Trend (mm/yr)



Projected Population Density



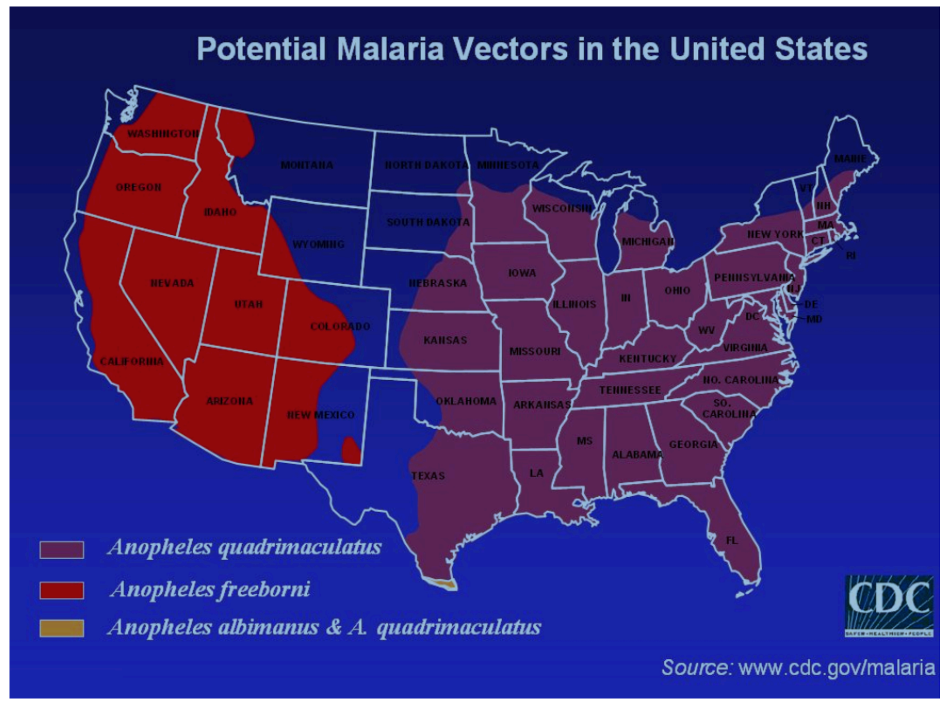
- PWV trends in the circled region indicates areas that lie on a boundary where the PWV increase could be substantial or not. These regions also have significant projected population density increases.
- The area on the right shows the region over China. More droughts, like that of 2010-2011 could occur in the future if the PWV decreases.



Societal Impacts- Vector-Borne Illness

- A vector-borne disease is one in which a pathogenic microorganism is transmitted from a infected individual to a non-infected individual by an agent.
- For example, Malaria is a vector-borne disease transported by mosquitos that causes fevers and chills.
  - Reasons for resurgence include biological, population movements, agricultural, and deforestation
  - To understand the the diseases many factors need to be examined, however, without certain atmospheric conditions the host will not survive (i.e. certain temperature or relative humidity requirements).

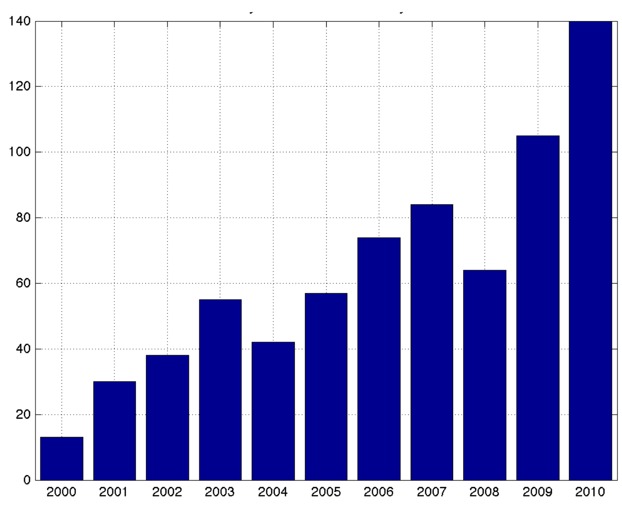
The United States has the potential for Malaria and the disease is expected to return. What steps will be taken to resist this disease? If atmospheric factors are better observed/understood, focuses on areas with greatest potential risk could be handled first.



Societal Impacts- Vector-Borne Illness

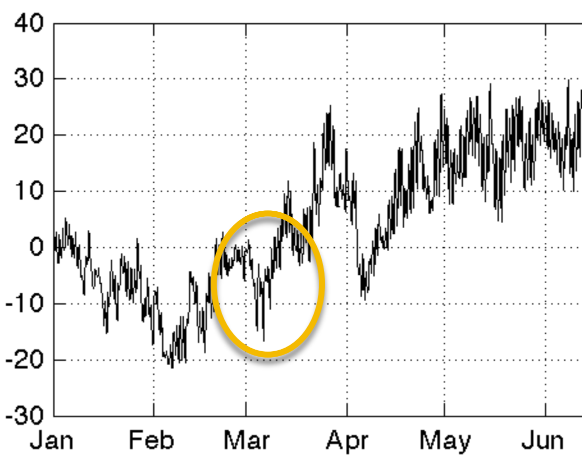
- Lyme disease is an infectious disease transmitted by ticks that causes rash, swelling, and joint pain.
- This is an enormous problem in Minnesota and Wisconsin, as well as several states on the East Coast including Maine, Virginia, and Delaware.
- Ticks need certain temperatures and relative humidity to survive. By better understanding these requirements, we could better represent the areas potentially threatened by the disease.

Societal Impacts- Vector-Borne Illness

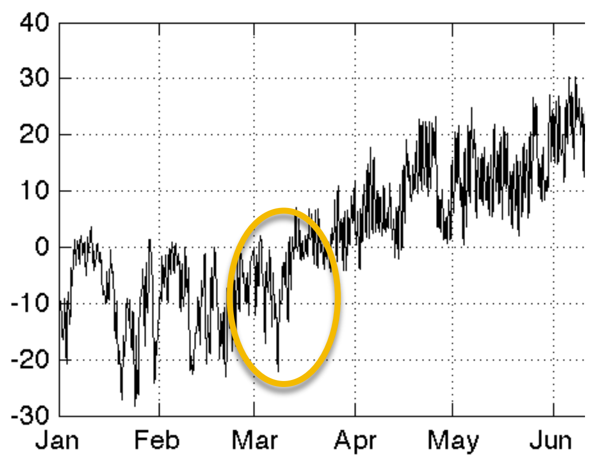


- On the left, the number of cases of Lyme disease in Dane County Wisconsin are shown for 2000-2010.
  - In 2008 there was a substantial decrease in the number of cases.
- Below surface temperature at 3 hourly intervals are shown for 2007, 2008, and 2009.
  - Note the cooler temperatures in march for 2008 and the anomalously warm temperatures of 2009 which effect the number of ticks that survive with the disease during winter and spring, which lead to the outbreaks in summer.

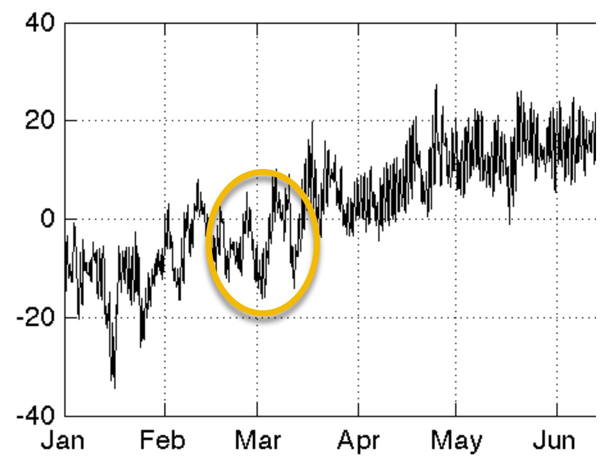
2007



2008



2009

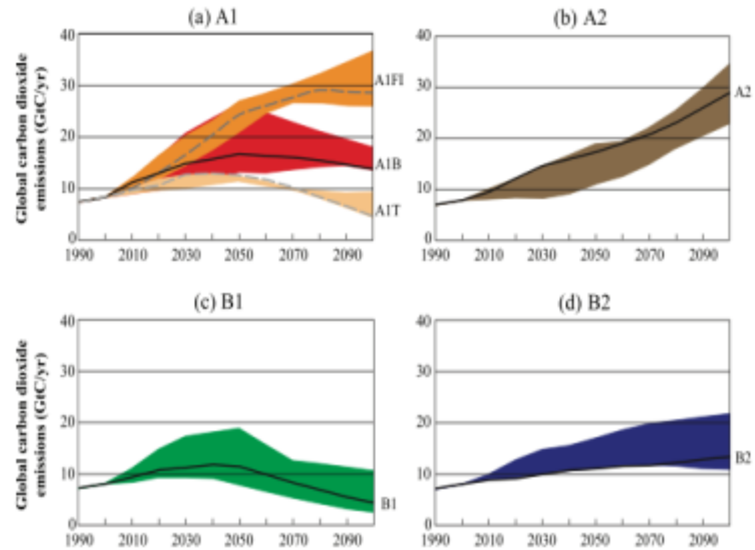


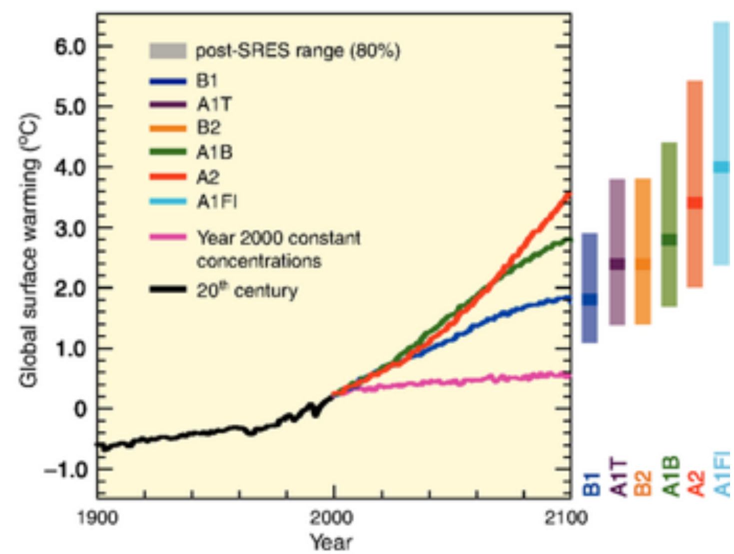
Climate Models

- Global Climate Models (GCMs) provide a way for scientists to assess our current climate system and project the future climate system.
- The modeling world is complex, with over 15 different models in the CMIP3 archive from all over the world, each with different scenarios.
- As one can expect, different models have different results. This becomes even more prominent when you move away from global averages.

Climate Models

- The top panel shows carbon dioxide emissions (GtC/yr) for different scenarios (IPCC et al. 2007).
- The bottom panel shows projected global SST (°C) for the different scenarios.
- Validation of GCMs is a necessity to create confidence in the results, especially when the results are used for political policies.





Regional Validation Location

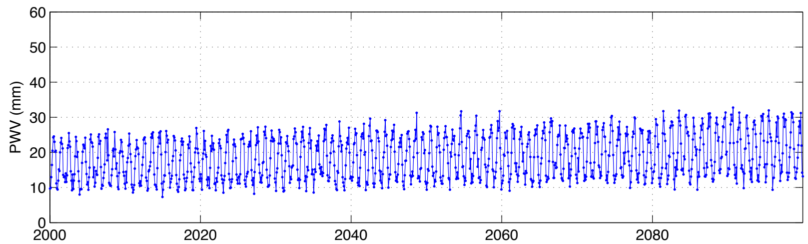
Fig 1. Map from the University of Texas, Austin

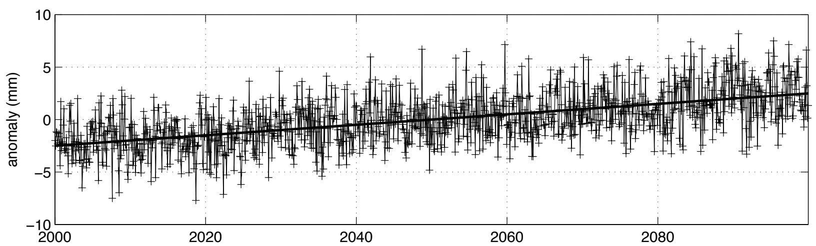
- Precipitable Water Vapor (PWV) is a key climate feedback in GCMs.
- For this study, we will focus in on the Great Plains and Midwest region in the United States where PWV has a key role not only in the long term climate system but in severe weather, making it an important region to better understand the current PWV cycle and future trends.

GCM Model Predictions in Great Plains

CCSM3 100 PWV Trend OK/KS

- 0.050 +- 0.008 mm/yr

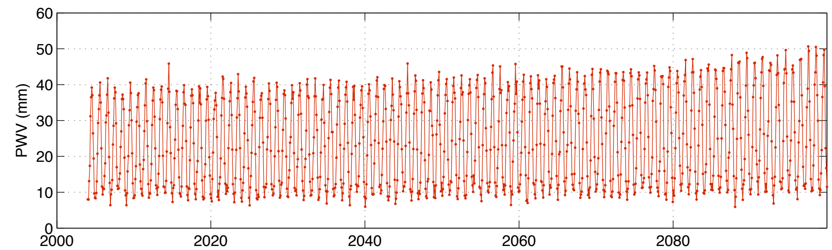


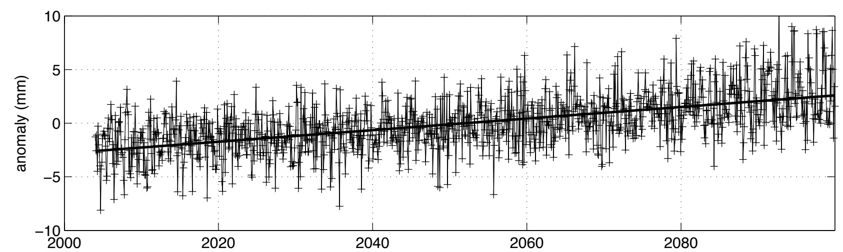


2000 2100

GISS 100 PWV Trend OK/KS

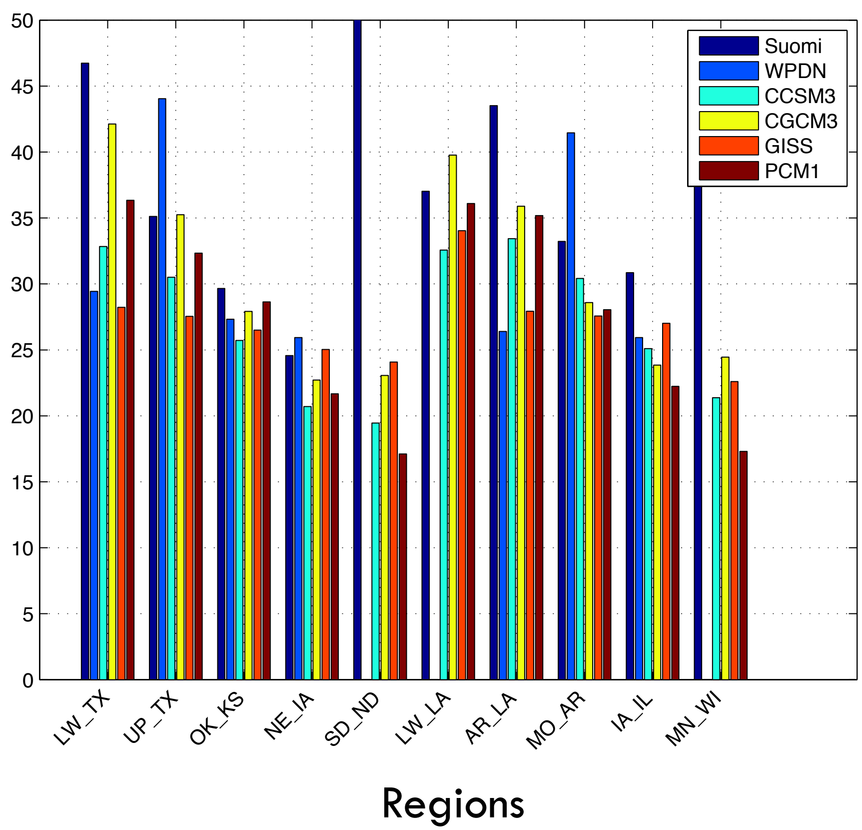
- 0.054 +- 0.009 mm/yr

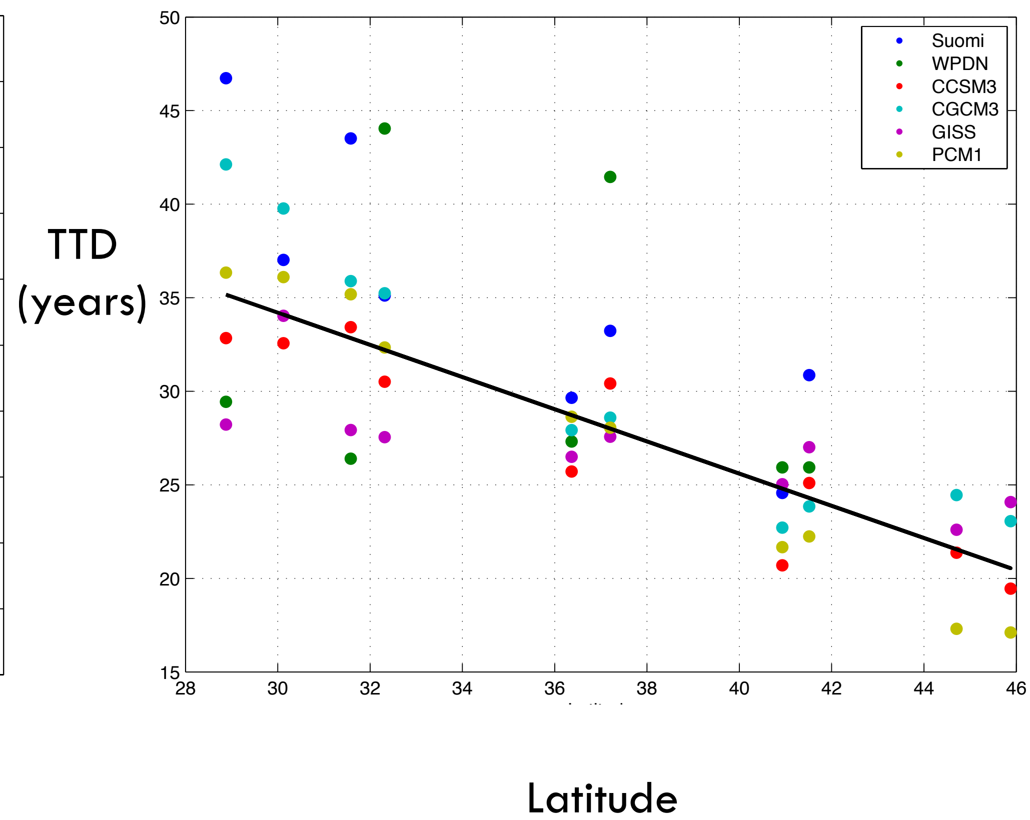




2000 2100

Time to Detect (TTD) PWV Trend





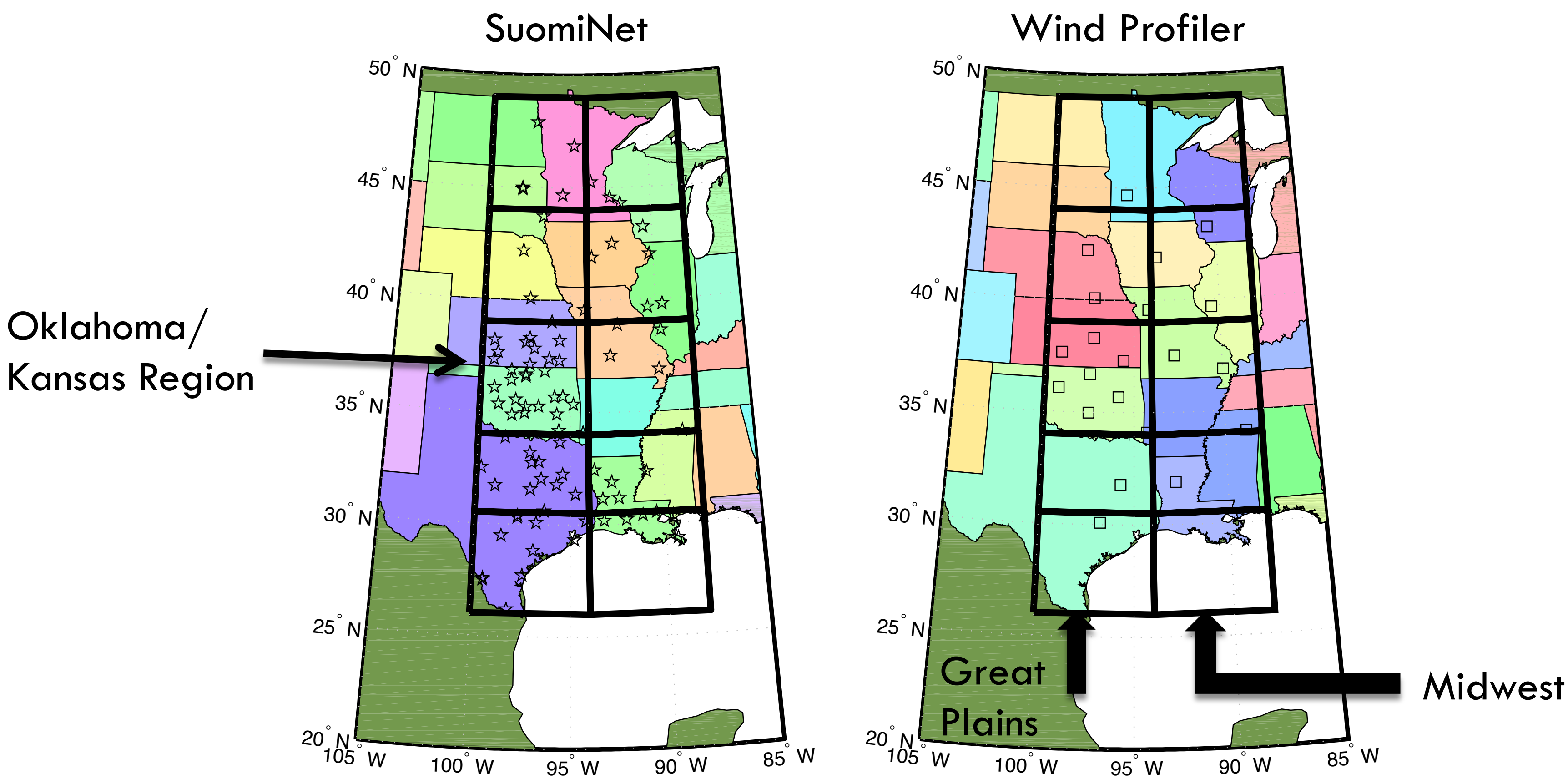
- Time to Detect a trend of 0.05 mm/yr
- Latitude dependence? – Much more on this later!

Data

Data Sets

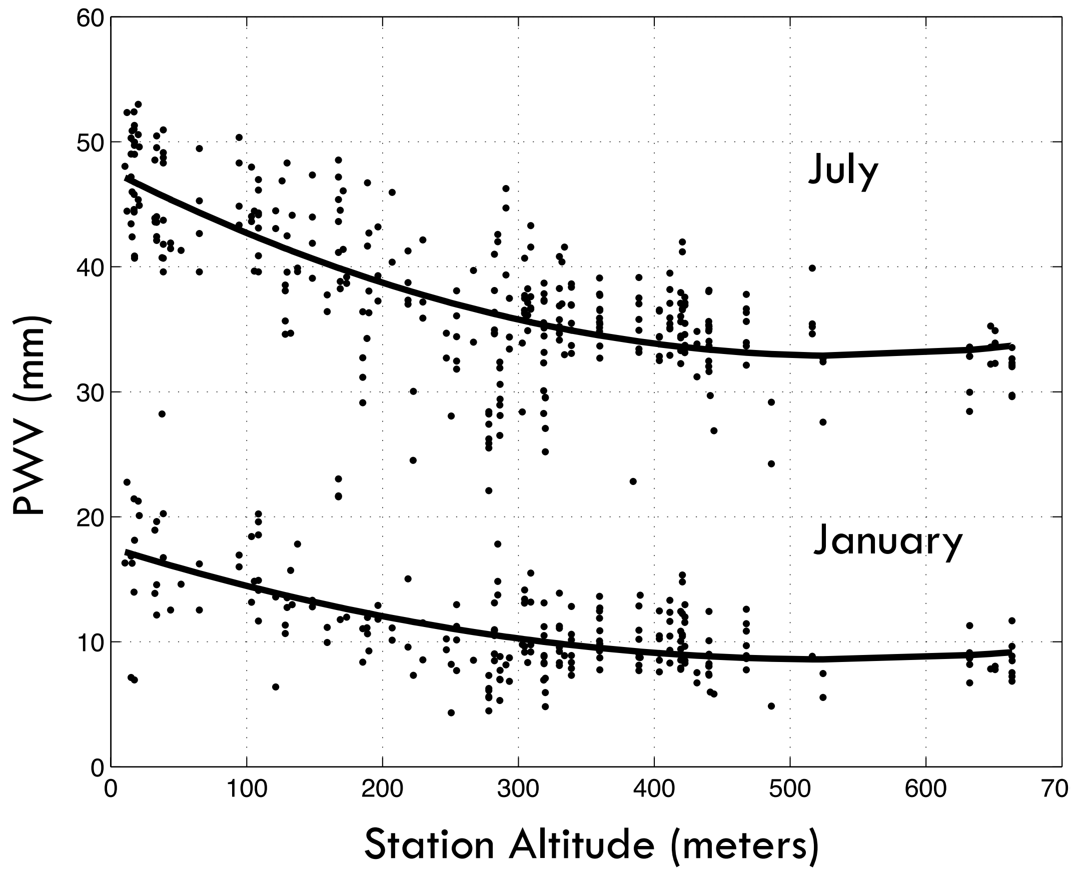
- There are three observational data sets used in this study
  - Ground-Based GPS
  - AIRS
  - AMSR-E
- There are four GCMs used from the CMIP3 archive
  - CCSM3- NCAR
  - CGCM3- Environment Canada
  - GISS- NASA
  - PCM1- DOE
- There is one reanalysis
  - NCEP North American Regional Reanalysis (NARR)
- CLARREO Proxy Data (Bill Smith's Product)

GPS: Regional PWV Estimation



- Ground-based networks of GPS receivers measure Total Column WV
  - Growing networks provide increasing spatial coverage
  - 30 minute time sampling provides continuous diurnal coverage

GPS: Station Altitude Correction



- Ground-based GPS PWV are corrected for site altitude variation
  - A quadratic function was fit to SuomiNet data for each month
  - Each GB-GPS station data is adjusted to the region mean altitude

AIRS and AMSR-E

- NASA's AIRS L3 V5 provides a monthly mean global gridded product (1°x1°) of PWV
- AMSR-E L3 V2 provides a monthly mean gridded product (0.25°x0.25°) of PWV over the ocean
  - Both products have Ascending and Descending times, meaning the temporal sampling is only twice a day

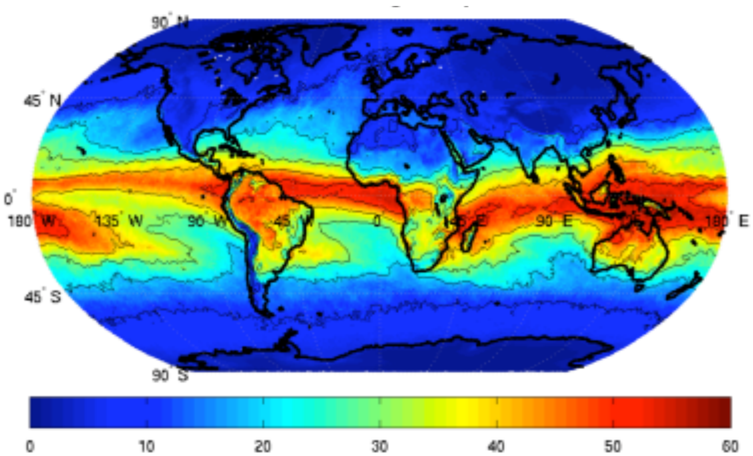
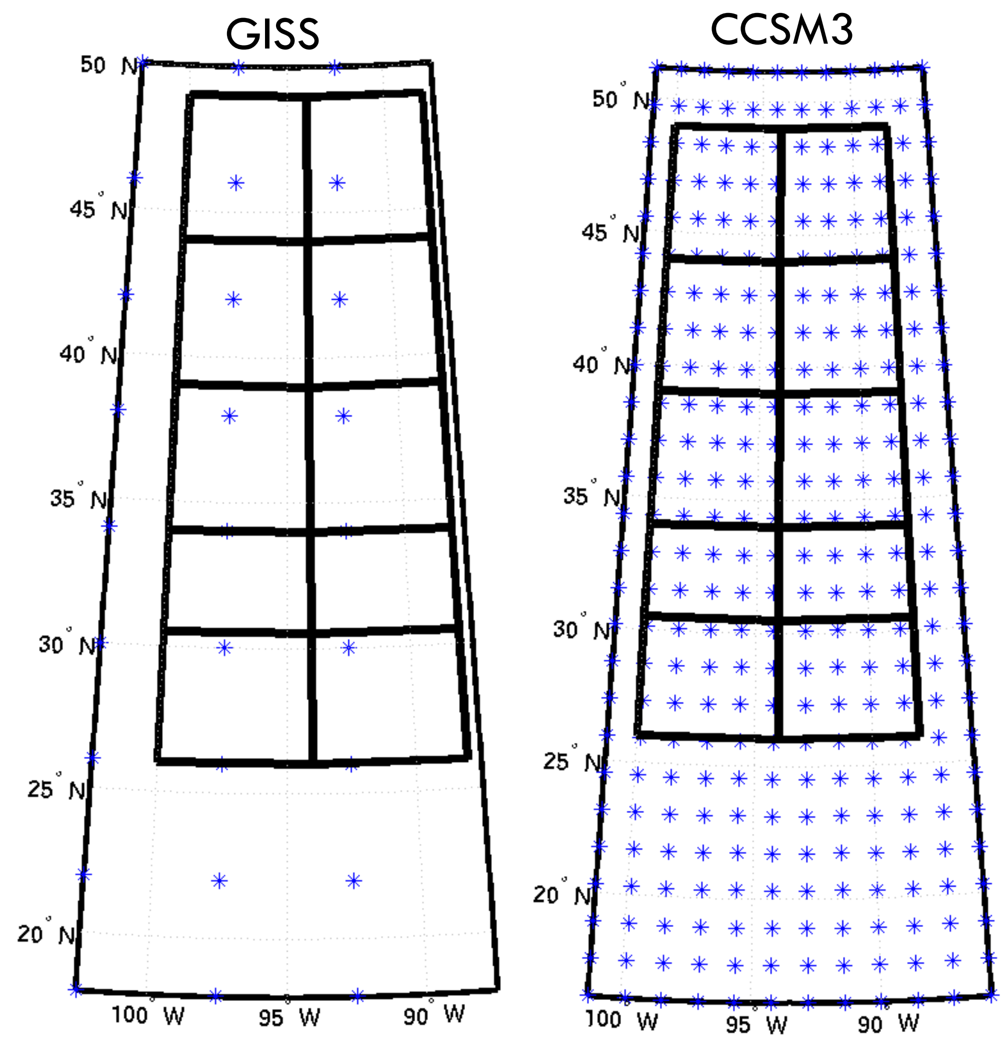


Fig 1. AIRS L3A PWV January 2006


Fig 2. AQUA

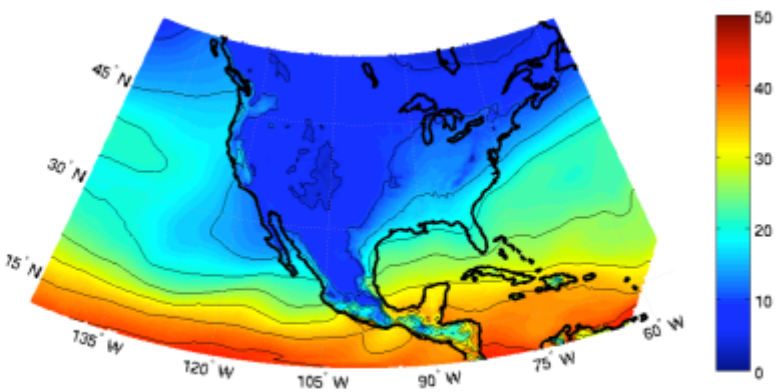
GCMs

- The four GCMs used in this study were from the CMIP3 archive
- The SRES A2 Scenario run 1 monthly mean PWV was used
- Resolutions varied
  - GISS was the most coarse, while CCSM3 had the highest resolution

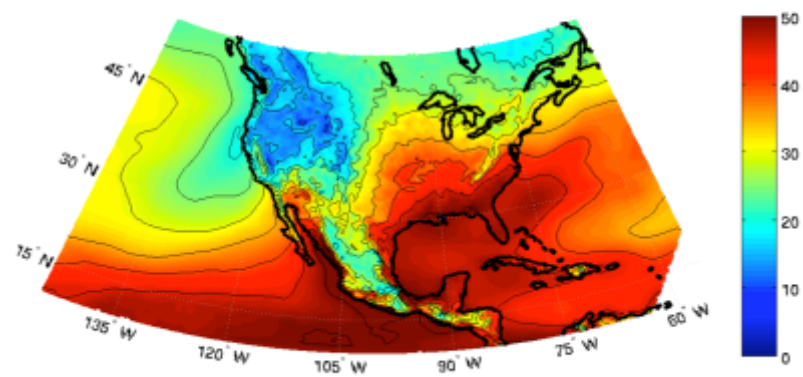


NARR

- NCEP NARR is an assimilation of multiple datasets with with a high resolution model
- The NCEP NARR product contains monthly means of PWV for North America starting from 1979 to present
- The inputs include rawisondes, dropsondes, surface observations, geo-stationary satellites, etc.



January 2006



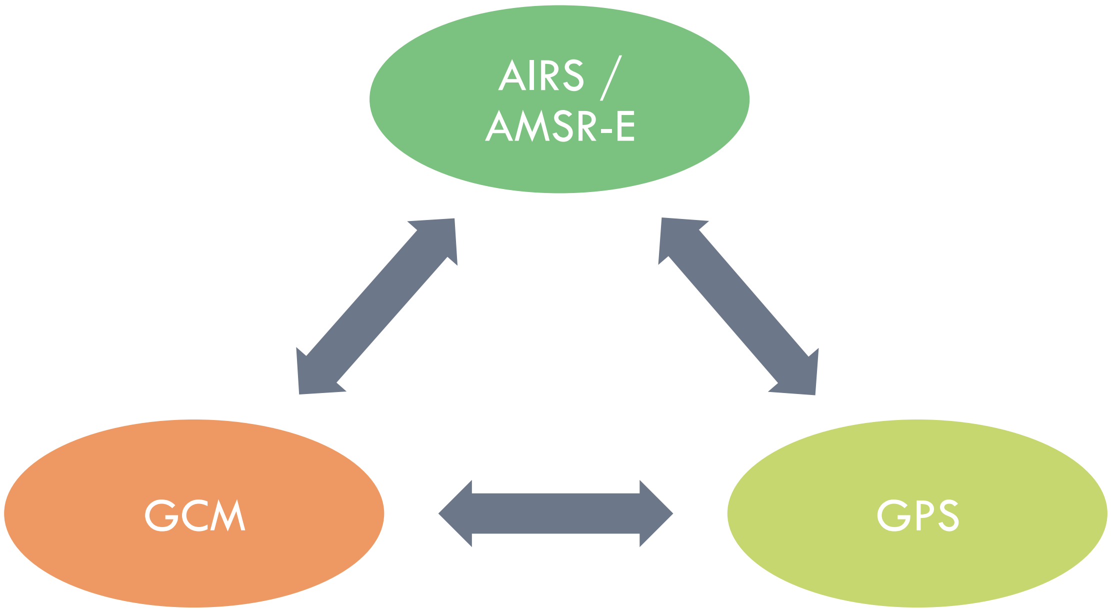
August 2006

Methodology

Approach:

1) Assess regional GCM model differences using multiple sources of validation data, both Ground & Satellite.
2) Apply TTD analysis to investigate CLARREO regions of interest, i.e. Can we go beyond zonal averages?

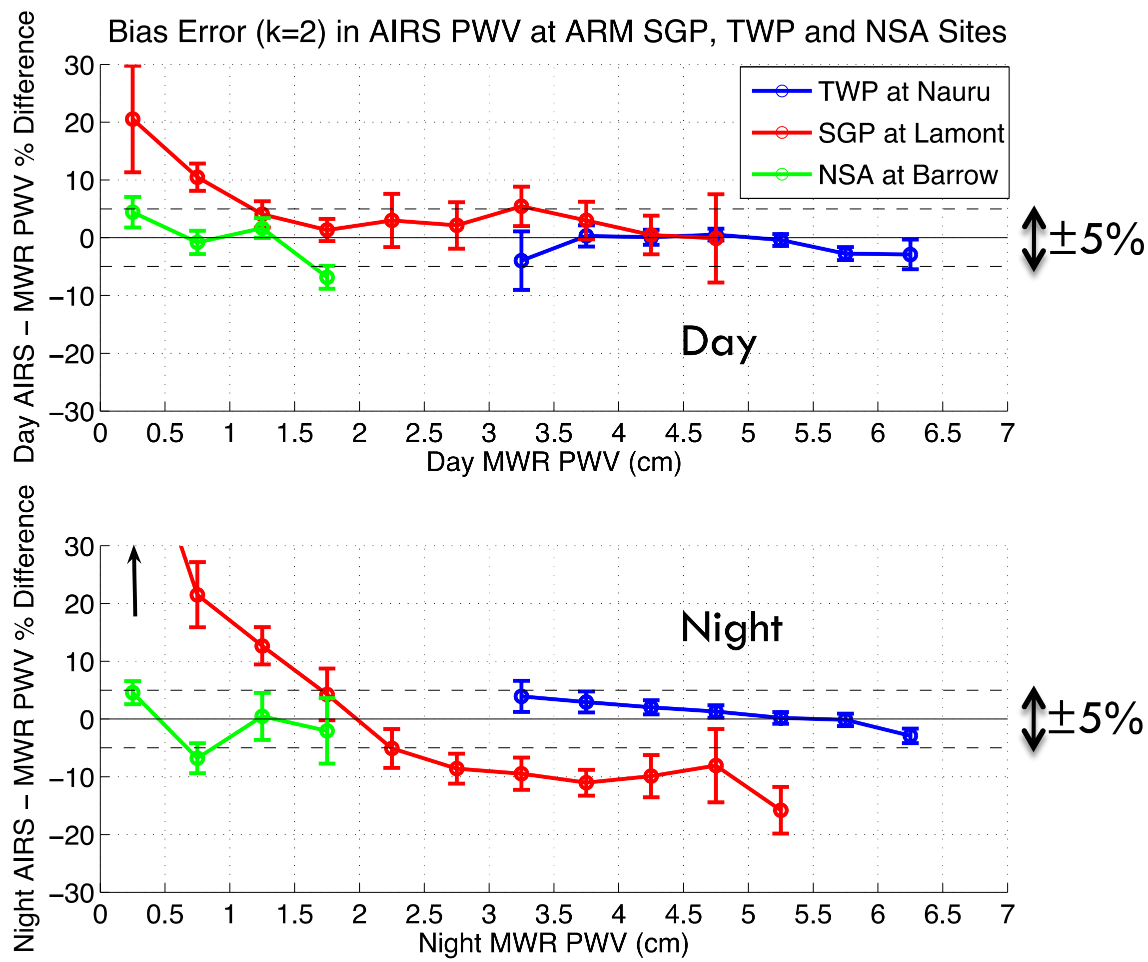
Overview



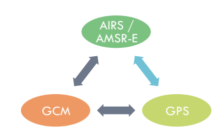
- Created regional monthly mean PWV climatology
- Ground-based GPS and AIRS/AMSR-E satellite
- Profile validation at ARM sites (not discussed here)

AIRS PWV Level 2 Validation

- The AIRS L2 v5 product accuracy at ARM sites is within about 5% (Bedka et al. 2010)
- The AIRS L3 product is a 1°x1° monthly composite of NASA AIRS L2 moisture retrievals.

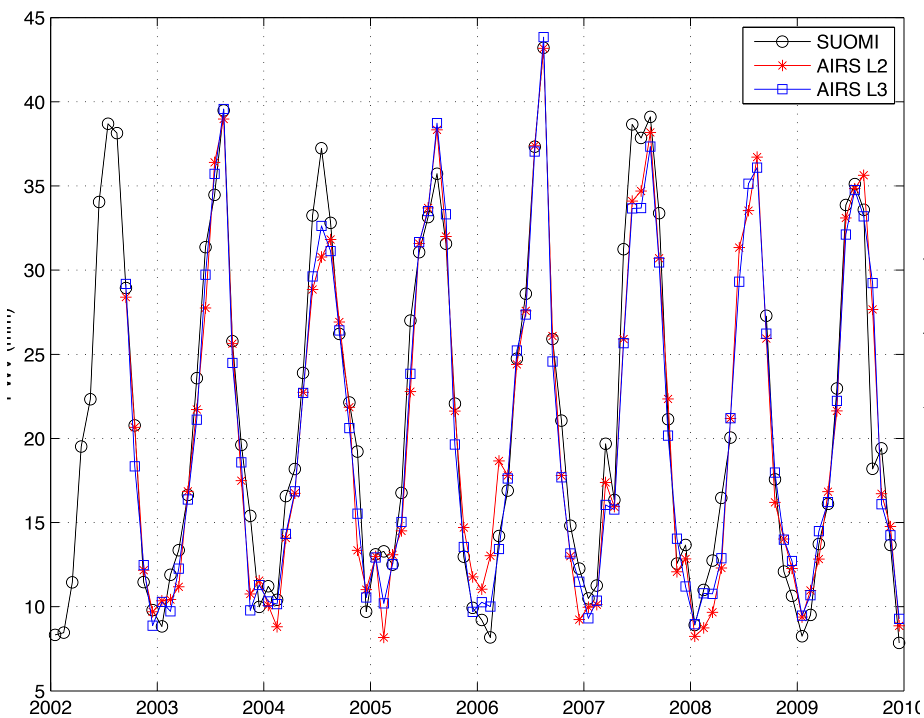


Percentage Error of AIRS L2 Product



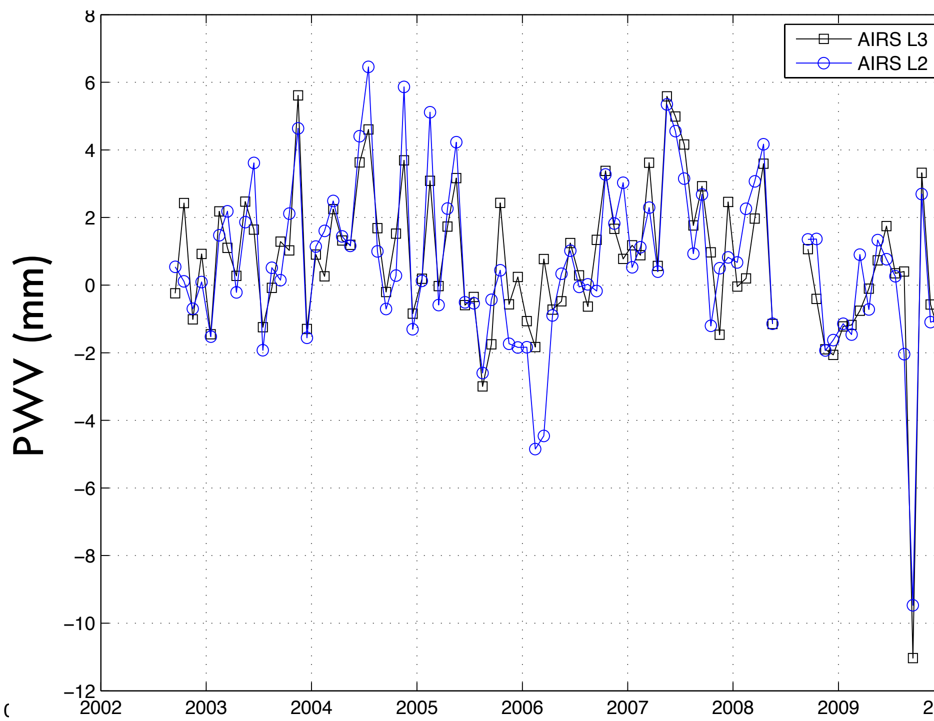
AIRS PWV L3 Validation

Suomi and AIRS (L2 and L3) PWV Time series



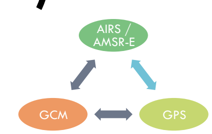
2002 2010

PWV Difference (Suomi-AIRS) at SGP CF



2002 2010

- AIRS L3 is a global gridded product (2003-2012+)
- Quality check provided by SuomiNet GPS



Results

Review Recent Publication

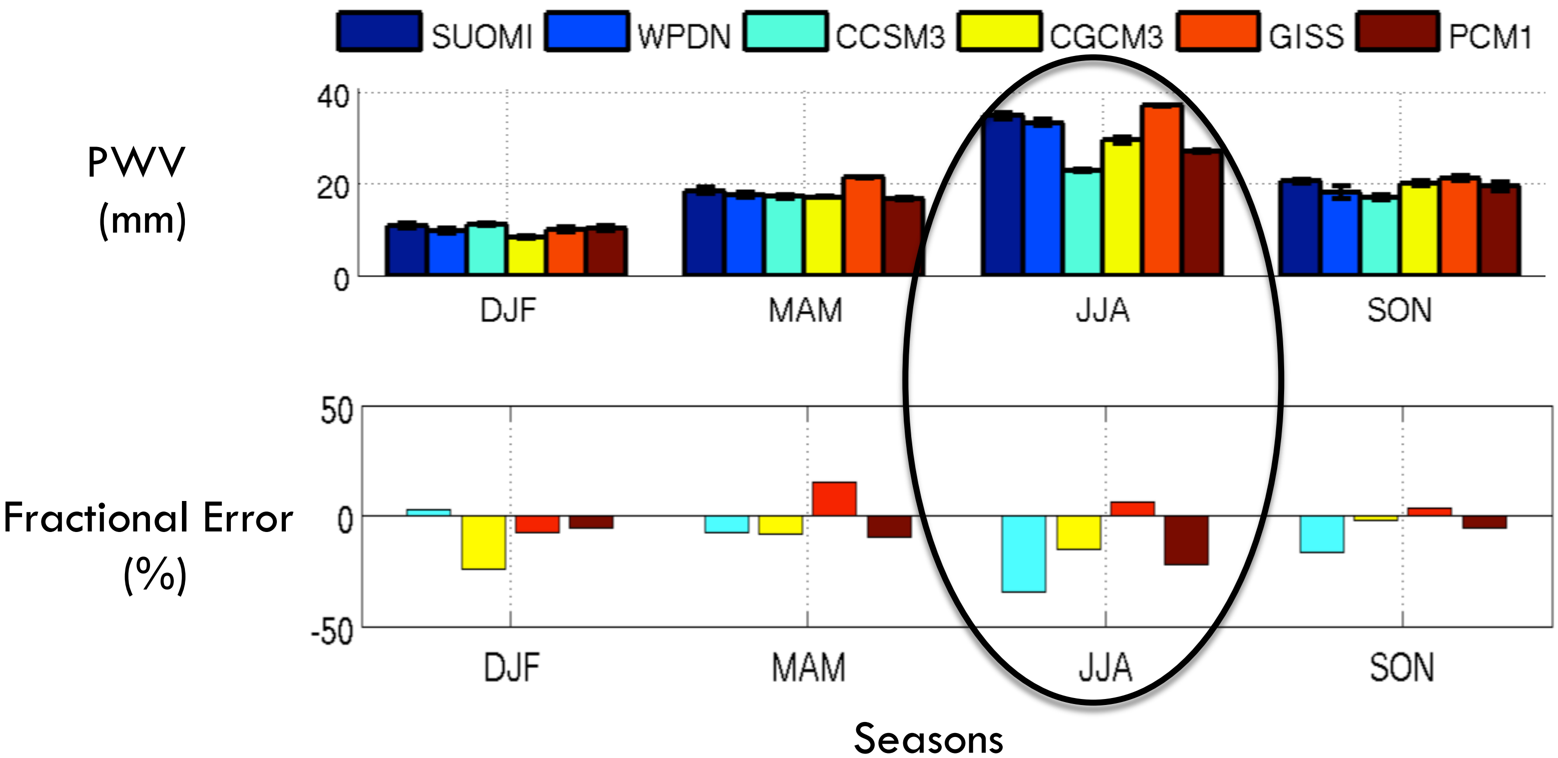
Validation of Regional Global Climate Model (GCM) Water Vapor Bias and Trends Using Precipitable Water Vapor (PWV) Observations from a Network of Global Positioning Satellite (GPS) Receivers in the U.S. Great Plains and Midwest

Jacola A. Roman, Robert O. Knuteson, Steven A. Ackerman, David C. Tobin, and Henry E. Revercomb

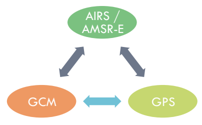
Journal of Climate, 2012 (In Press)
doi:10.1175/JCLI-D-11-00570.1

This talk includes additional material on satellite validation and time to detect trends.

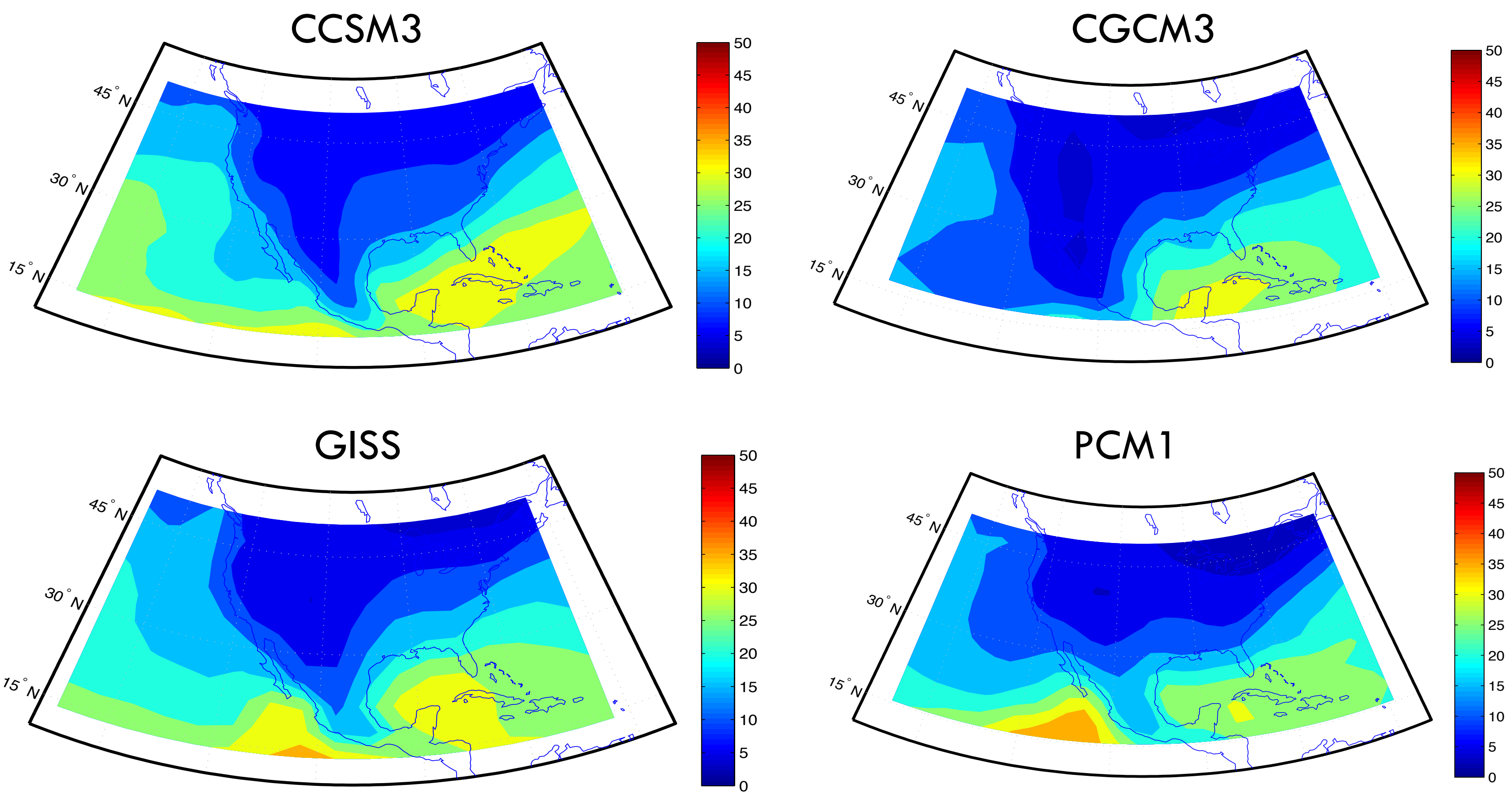
Seasonal Dependence



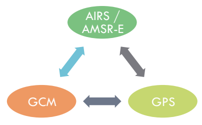
- Seasonal PWV in the OK/KS region
  - Large differences in summer time among models



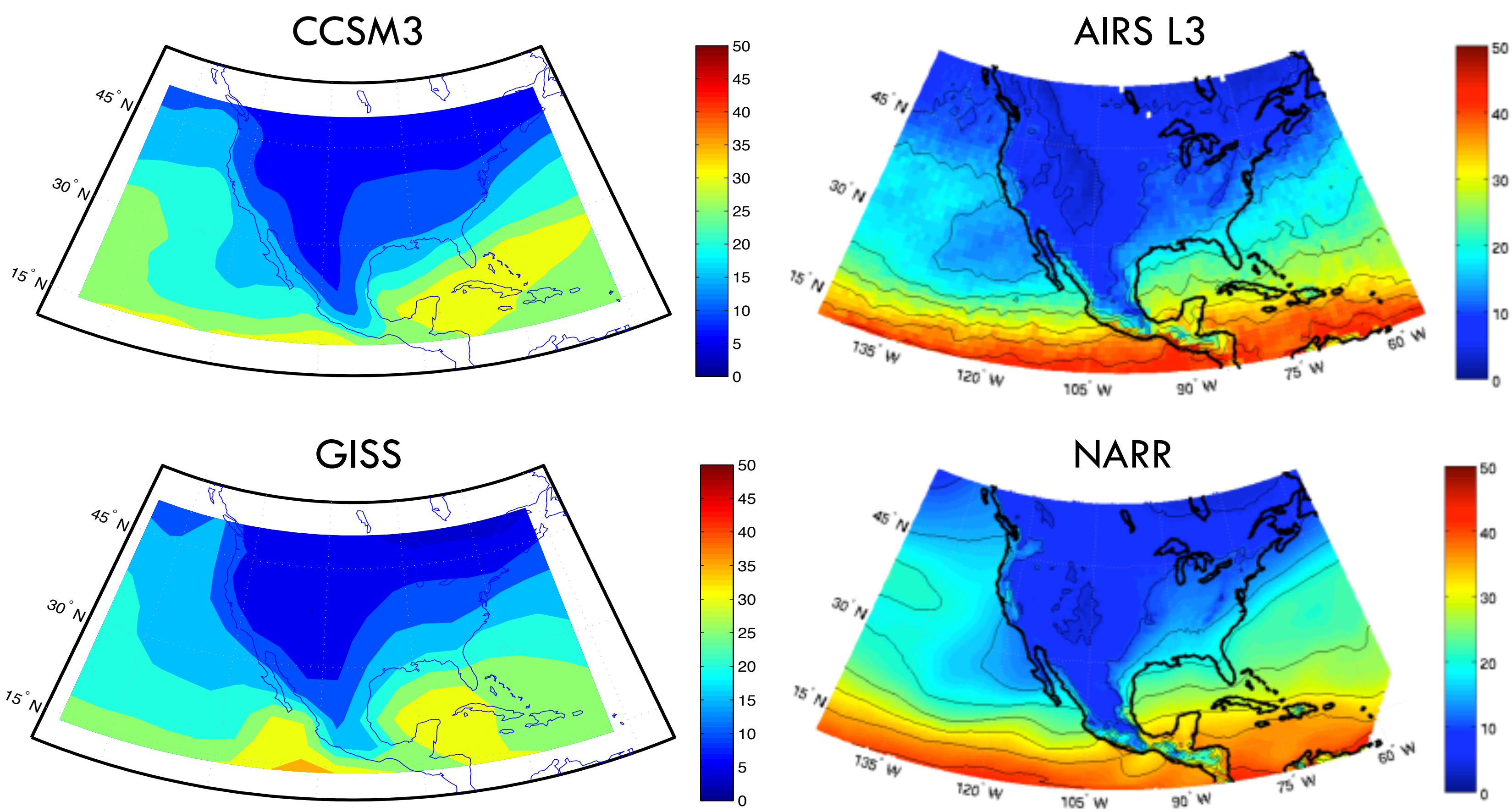
North America PWV Winter



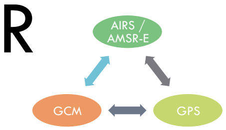
- North America monthly mean PWV for GCMs in January 2006
  - Good agreement among all four



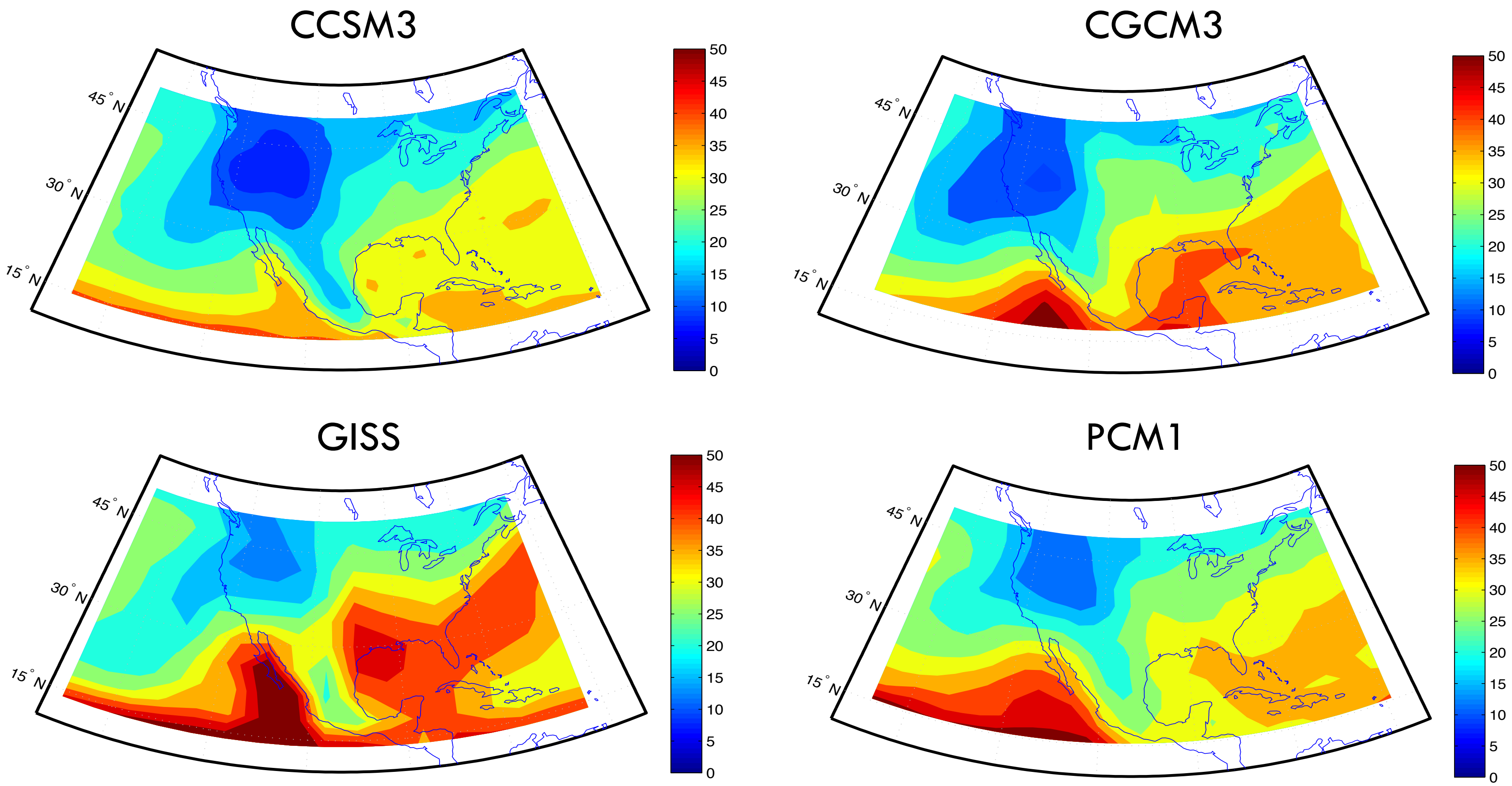
North America PWV Winter



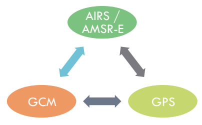
- Good agreement between models, AIRS and NARR



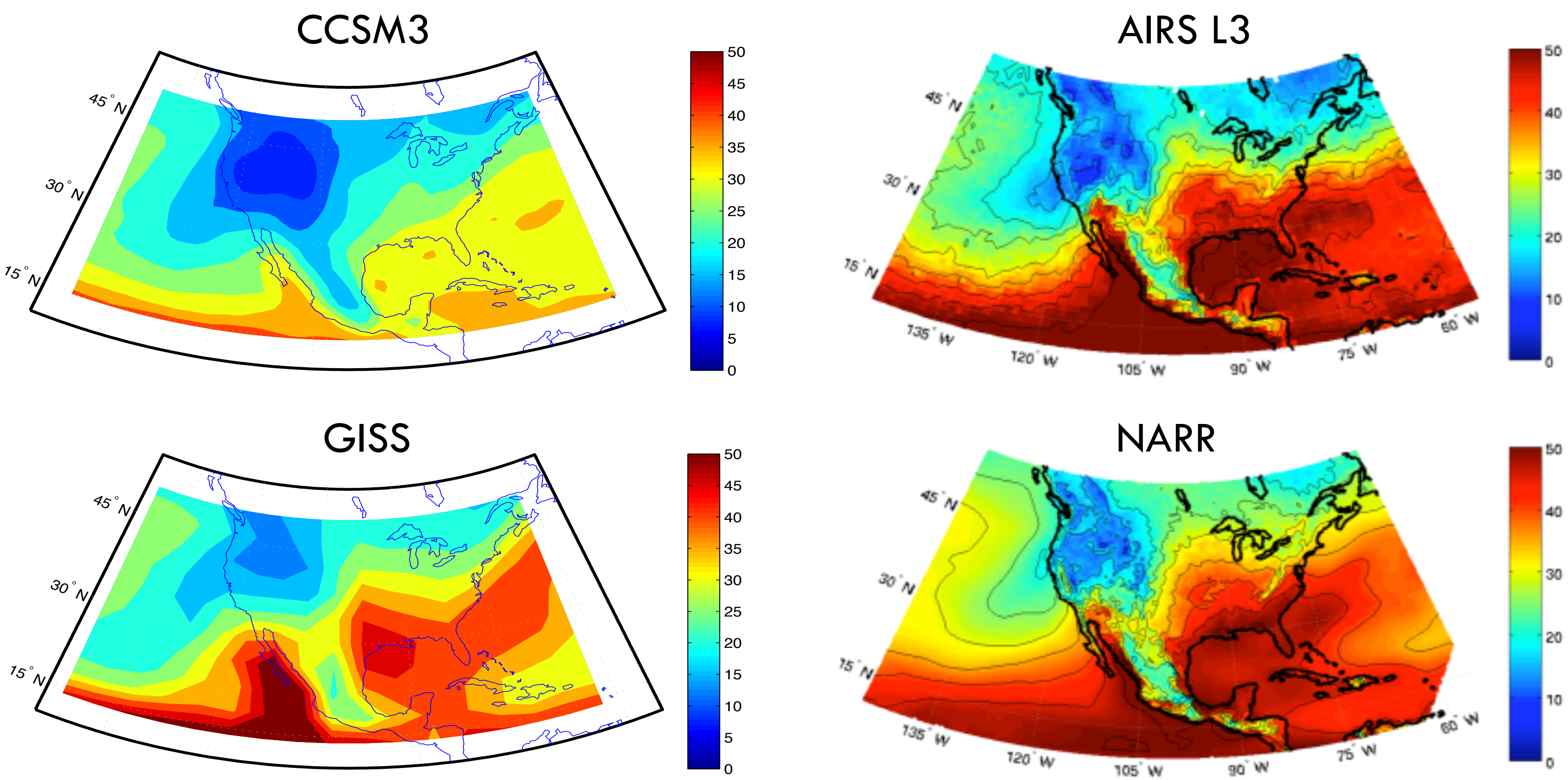
North America PWV Summer



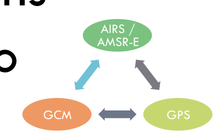
- North America monthly mean PWV for GCMs in August 2006
  - All four are distinctly different, especially in the Gulf of Mexico



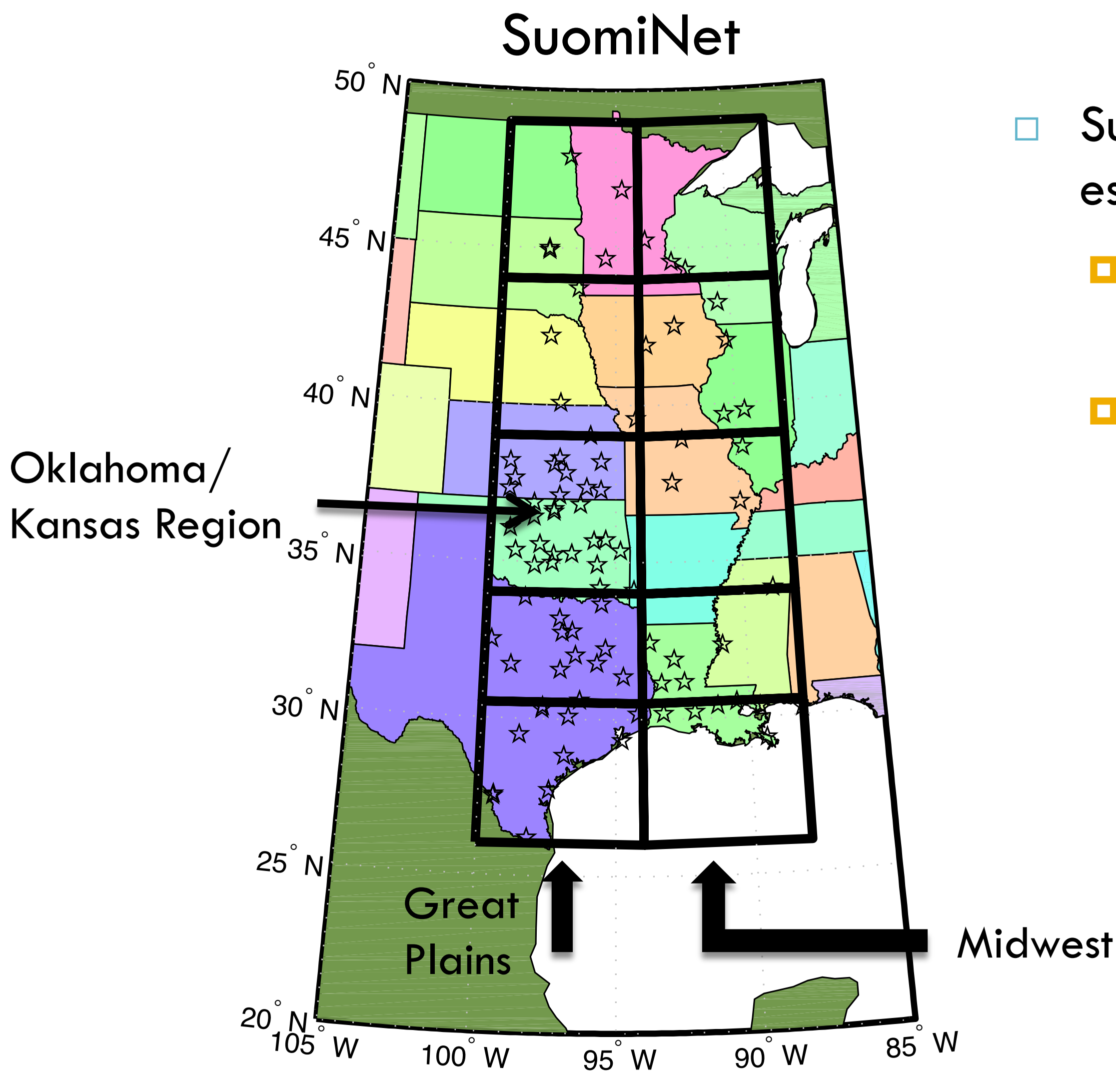
North America PWV Summer



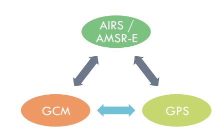
- There are large discrepancies between the models and observations
  - Only the GISS captures the moisture transport from the Gulf of Mexico into the U.S. Great Plains and Midwest



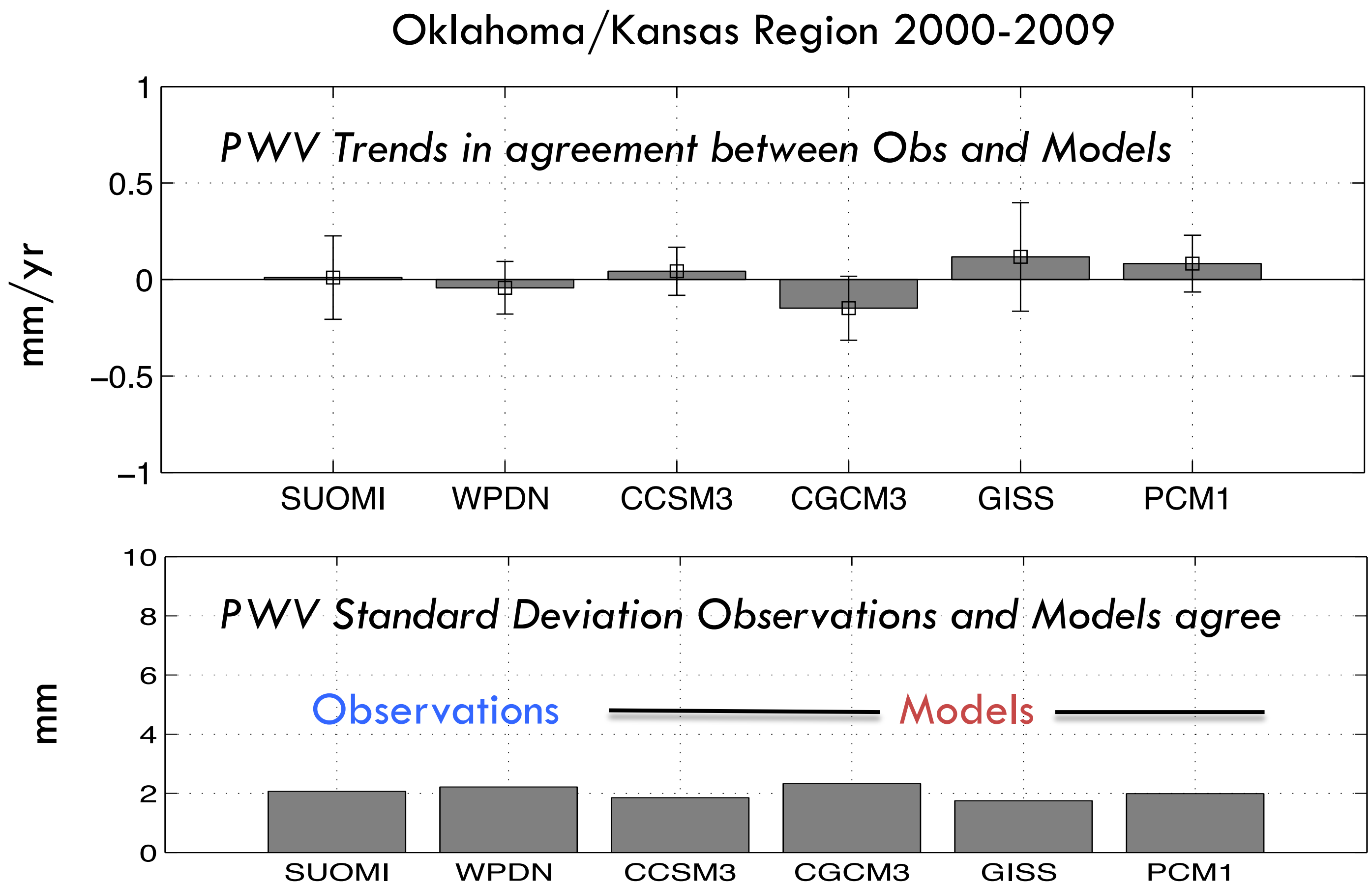
Validation Regions



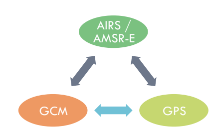
- SuomiNet GPS PWV regional estimates
  - 10 regions span the U.S. Great Plains and Midwest
  - The DOE ARM Southern Great Plains (SGP) site in Lamont, Oklahoma is at the center of the OK/KS region



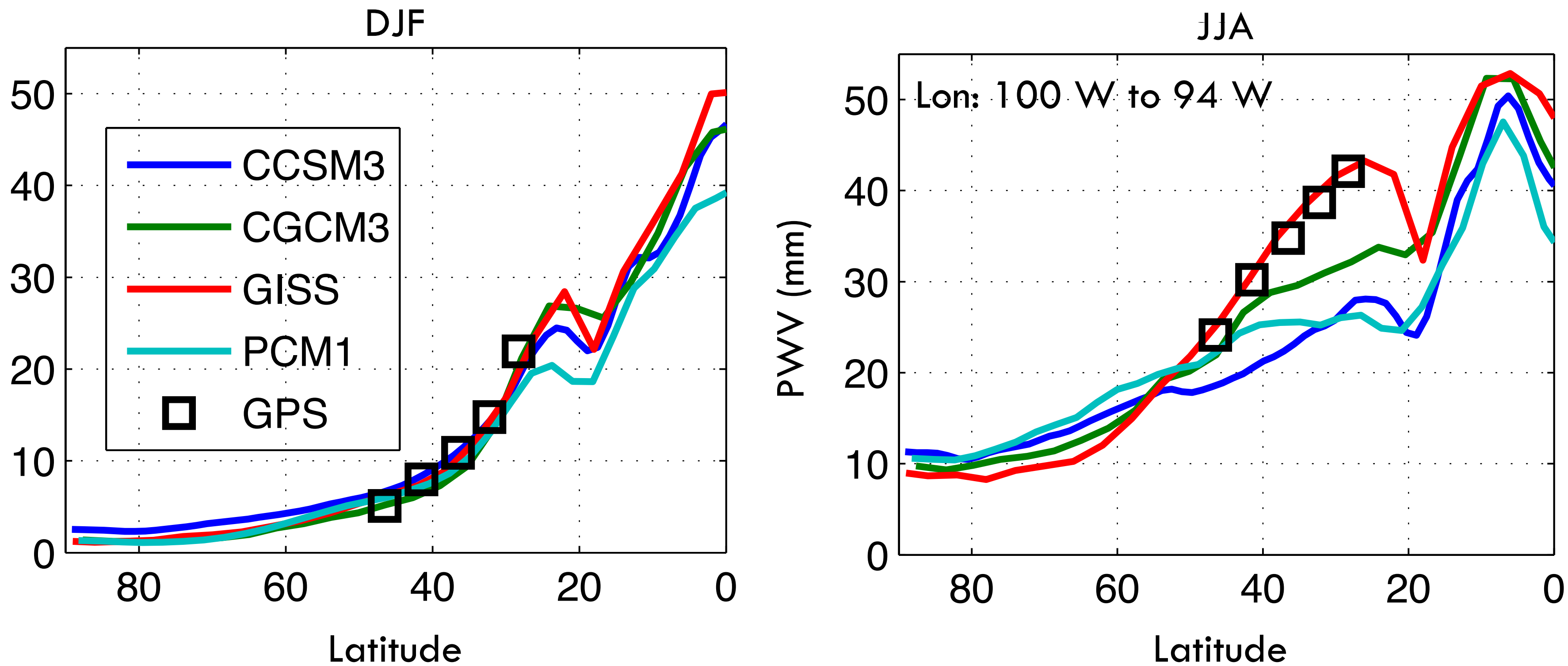
PWV Trends in U.S. Great Plains



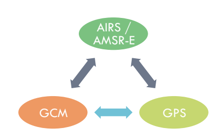
- PWV Trend and Variability consistent between models and observations for 2000-2009.



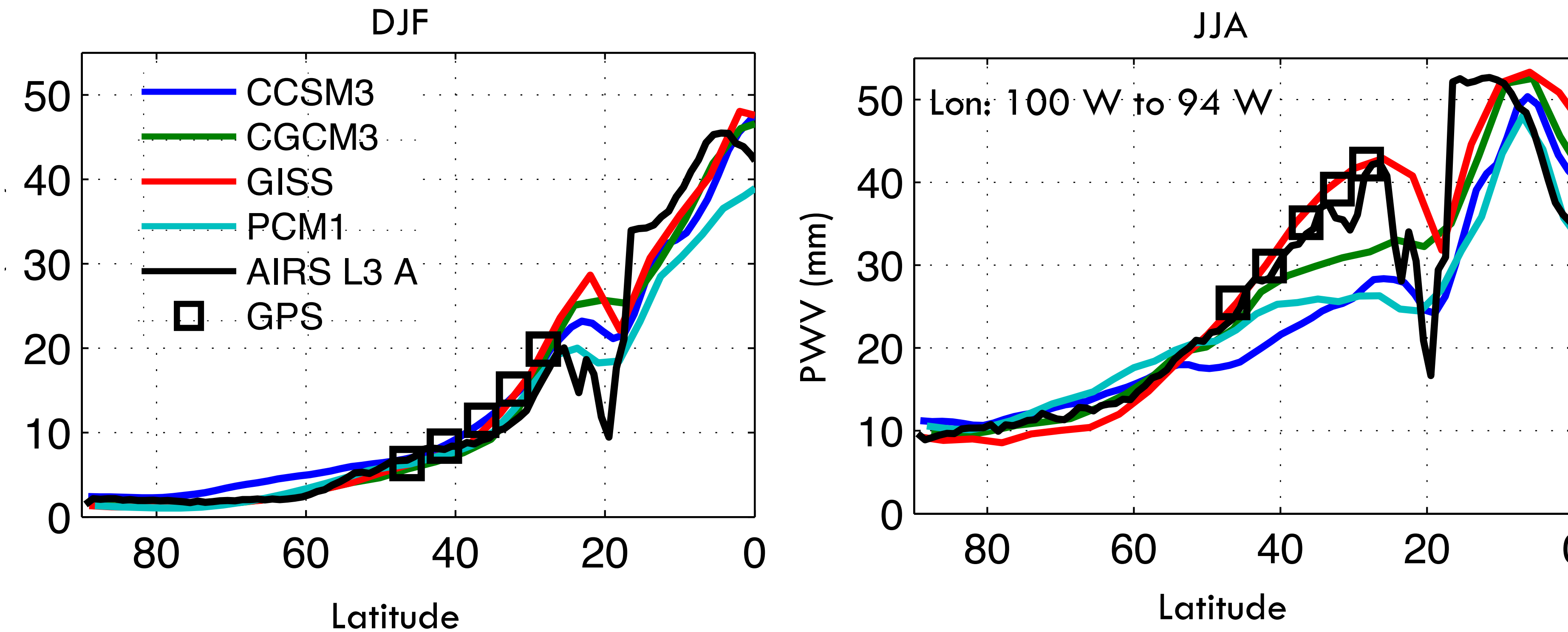
Northern Hemisphere PWV



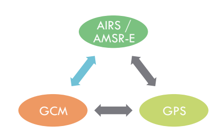
- GPS SuomiNet confirms winter time model PWV
- The large summer time GISS model PWV is validated by the GPS SuomiNet PWV climatology



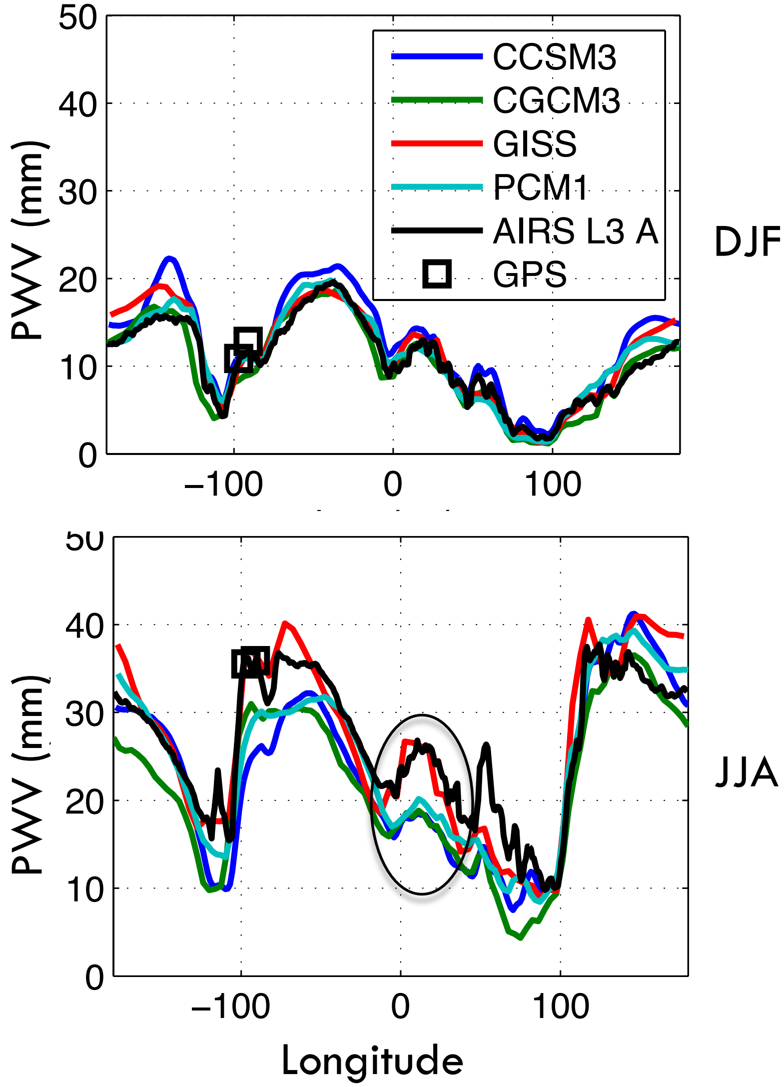
Northern Hemisphere PWV

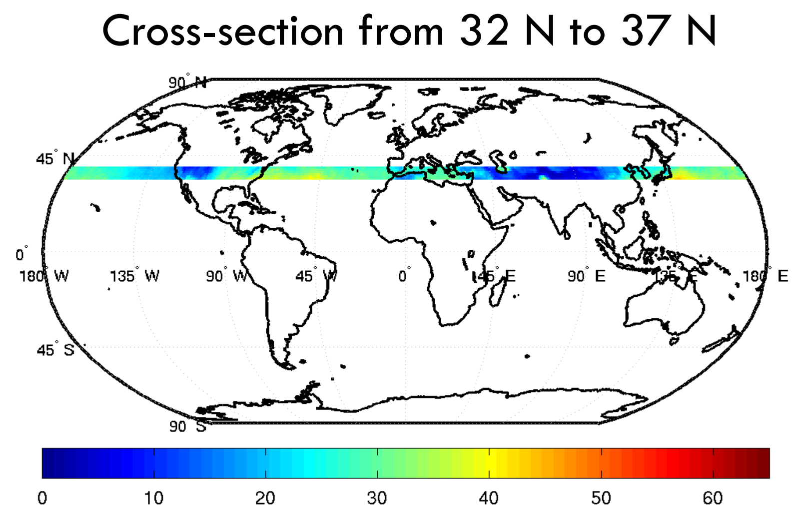


- AIRS confirms winter time model PWV
- The large summer time GISS model PWV is validated by both the AIRS PWV and the SuomiNet climatology

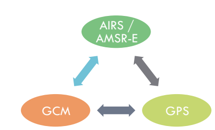


Seasonal Longitudinal Cross-section



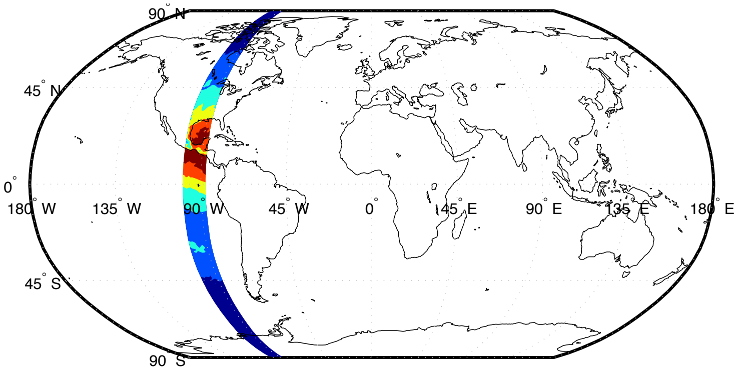


- AIRS L3 A validates the GISS model PWV in the circled area

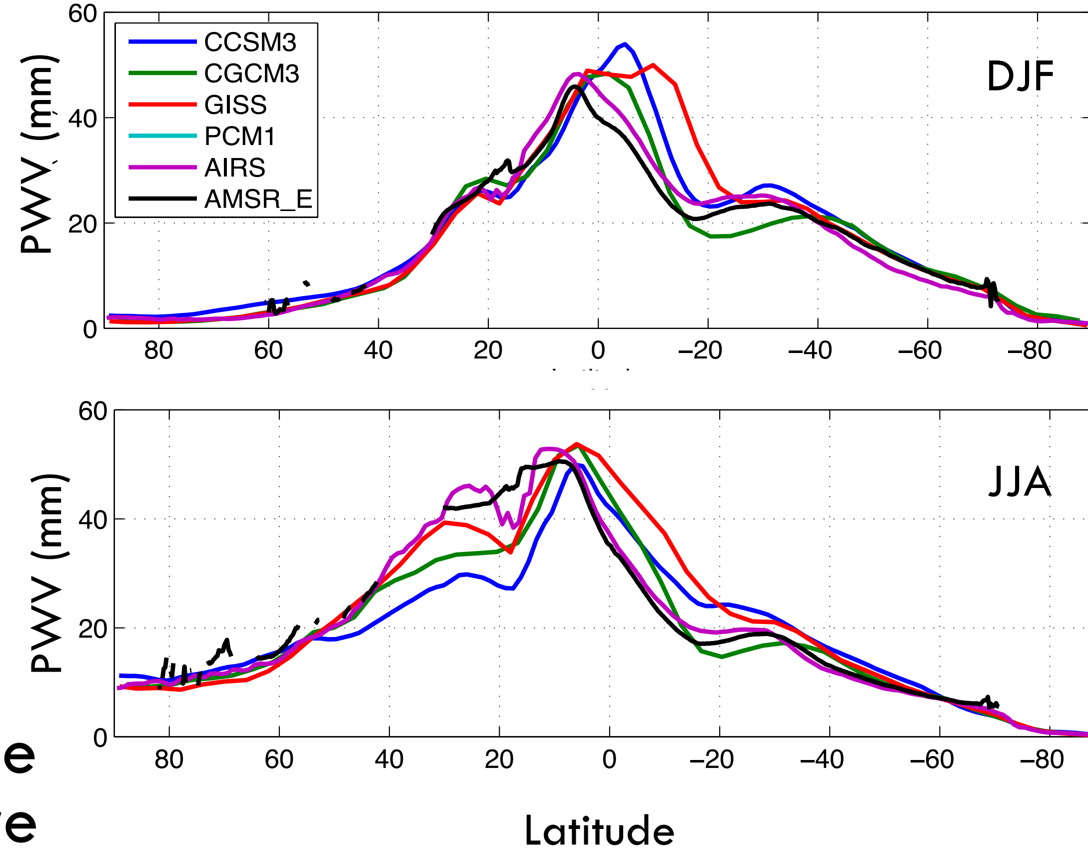


Work in Progress: AMSR-E

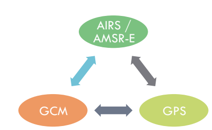
Cross-section from 87 W to 100 W



Models, AIRS, and AMSR-E 3 Year Seasonal PWV

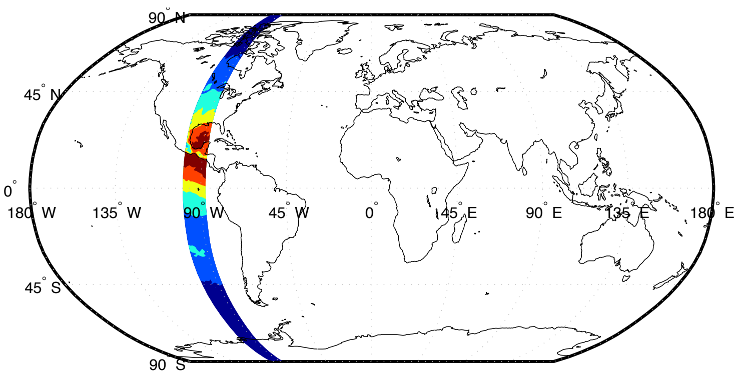


- AMSR-E generally agrees well with AIRS L3 over the oceans
- Model differences in the southern hemisphere are large and disagree with observations

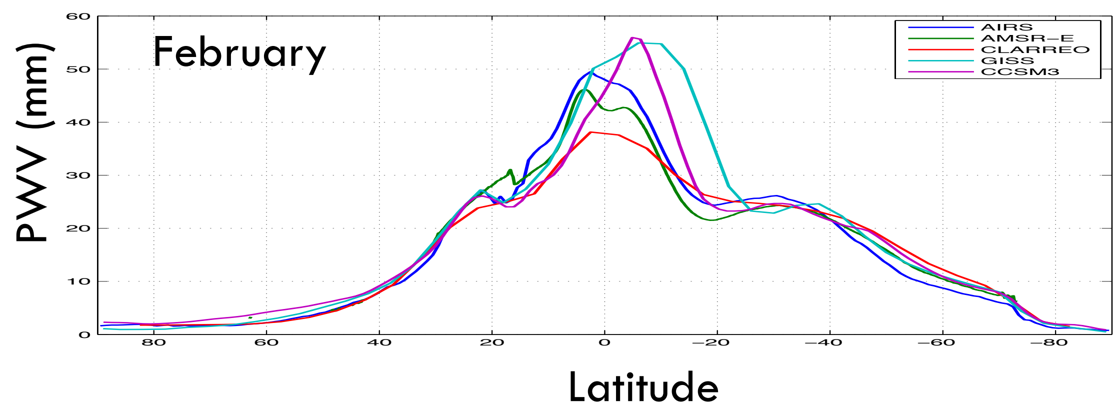


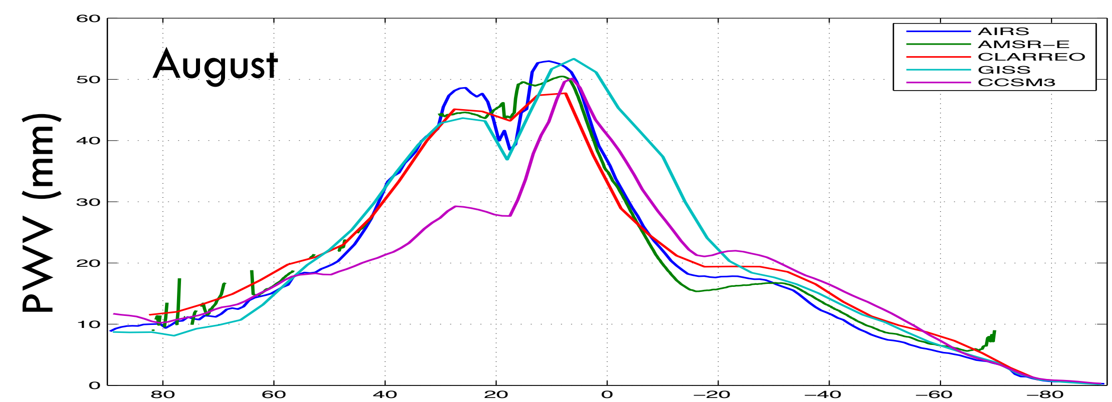
Work in Progress: CLARREO-Proxy

Cross-section from 87 W to 100 W

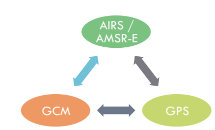


Models, AIRS, CLARREO-Proxy and AMSR-E



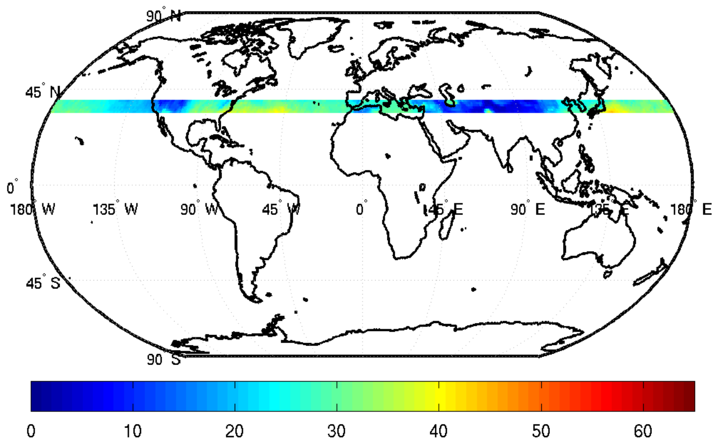


- CLARREO-Proxy shows both regions of agreement and disagreement with AIRS L3 and AMSR-E. Further analysis is required.

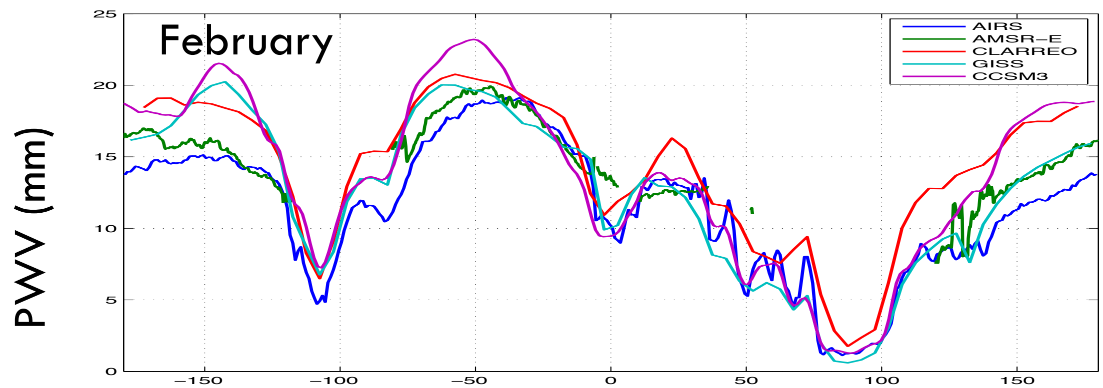


Work in Progress: CLARREO-Proxy

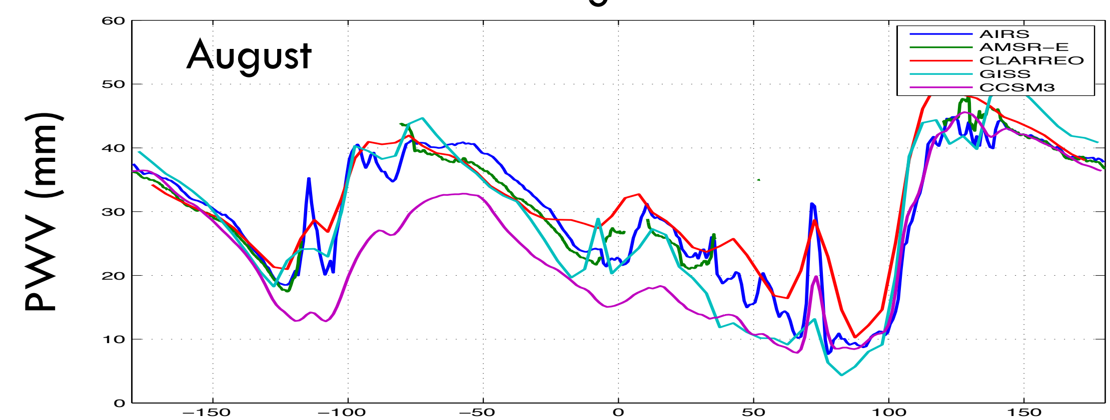
Cross-section from 32N to 37N



Models, AIRS, CLARREO-Proxy and AMSR-E

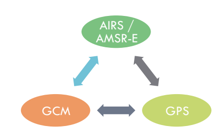


Longitude



- CLARREO-Proxy goal is to achieve 1% accuracy with short trace-ability path to radiance standards.

PWV accuracy remains to be verified



Time to Detect (TTD) Trends

Weatherhead et al. modified to include measurement error; $\sigma_N = (\sigma^2_{NatVar} + \varepsilon^2_m)^{1/2}$

$$n^* = (3.3 \times (\frac{\sigma_N}{\omega_0}) \times \sqrt{\frac{1+\Phi}{1-\Phi}})^{2/3} \quad \text{(years)}$$

<u>Nomenclature:</u>

"Natural Variability": GCM Trend & GCM variability with zero measurement error

"CLARREO PWV" : GCM Trend & GCM variability with 1% measurement error

"AIRS PWV" : GCM Trend & GCM variability with 5% measurement error

CLARREO-Proxy Retrievals (Bill Smith)

AIRS Level 2 Algorithm Theoretical Basis Document Version 2.2

NASA AIRS L2 Processing Flow

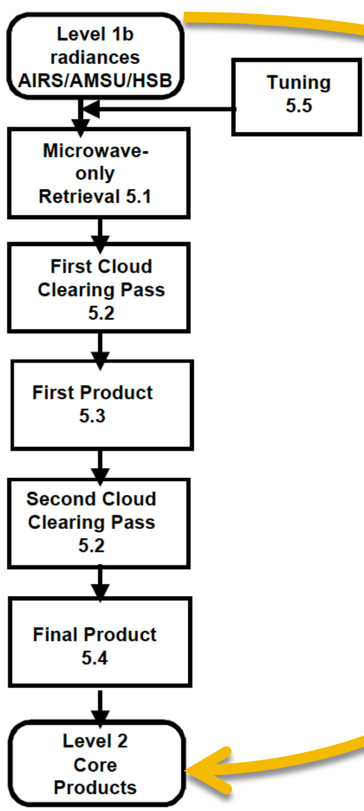


FIGURE 5.1.1 SIMPLIFIED ALGORITHM FLOW CHART

CLARREO-proxy retrievals "by-pass" algorithm complexity.

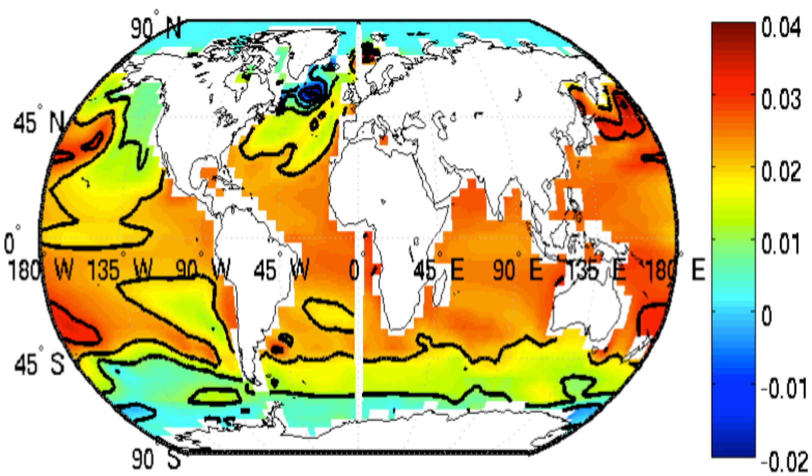
"CLARREO-Proxy"

Linear Matrix Operator

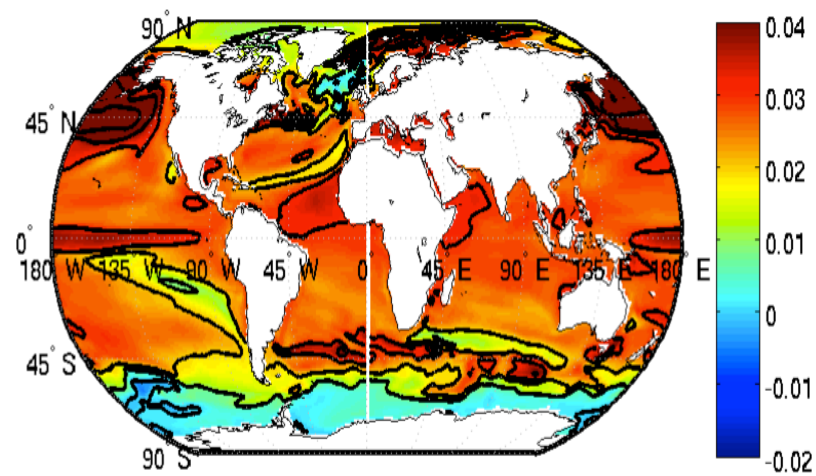
Linear operator provides a simpler traceability path between retrieved products and observed radiances with SI traceability.

100yr GCM SST Trends

GISS



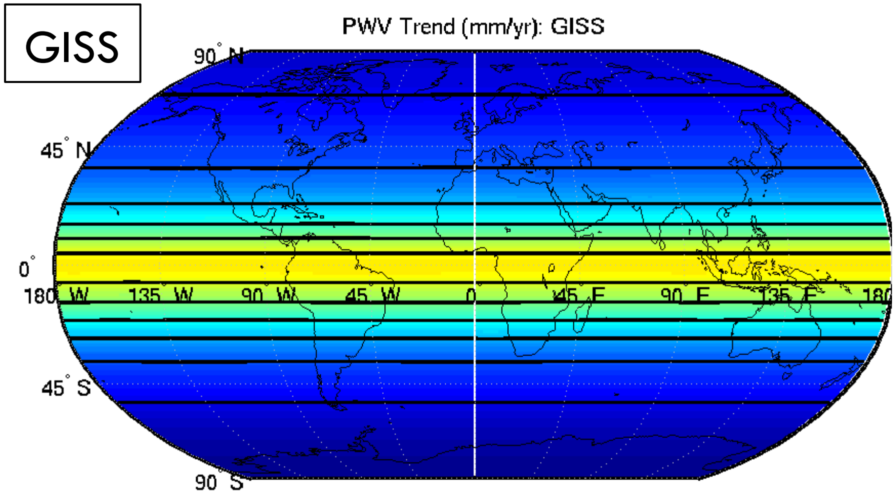
CCSM3

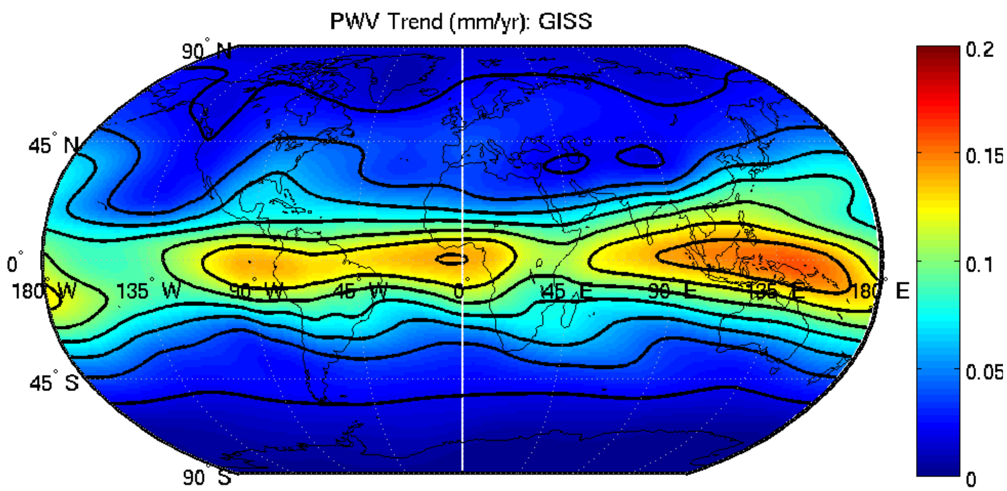


- 1x1 Degree Grid
- Differences between the models are most prevalent in the northern hemisphere.
- The magnitude of the increase is generally greater in the CCSM3 than the GISS.

100yr GCM Trends: Zonal and Regional

GISS

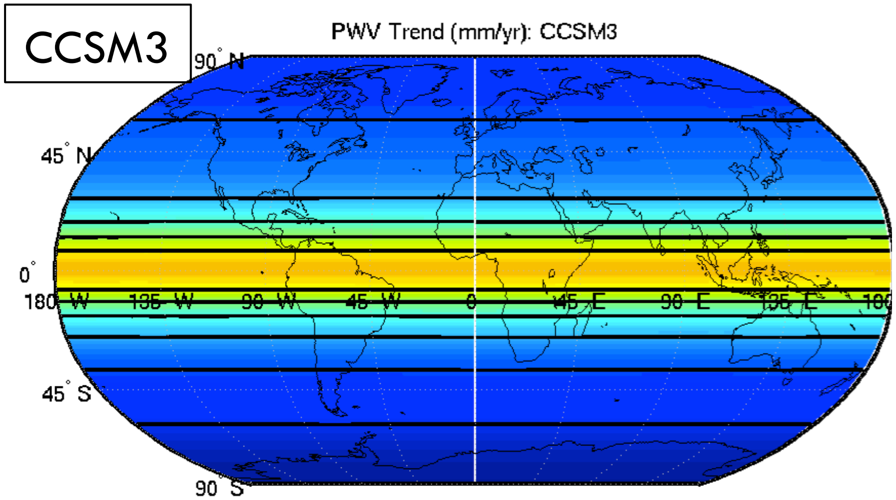


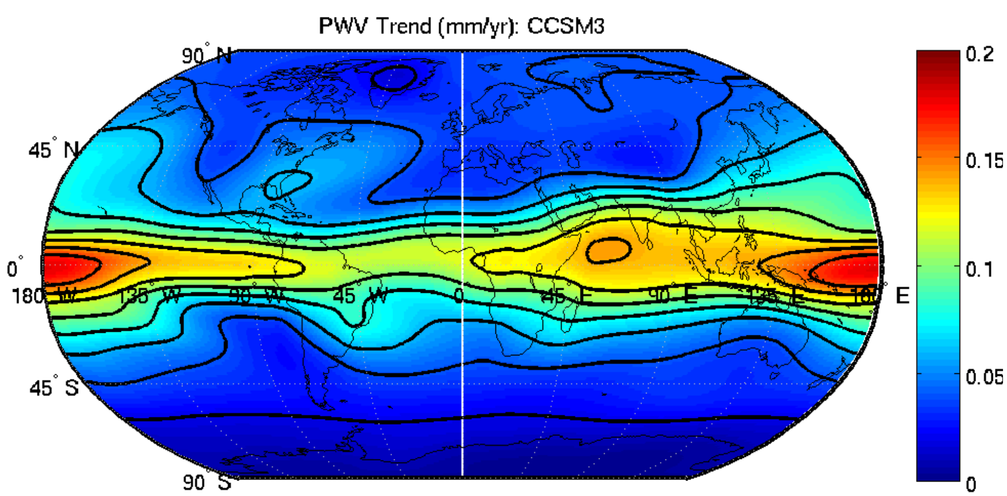


15°x360° Zonal PWV Trend

15°x30° Regional PWV Trend (mm/yr)

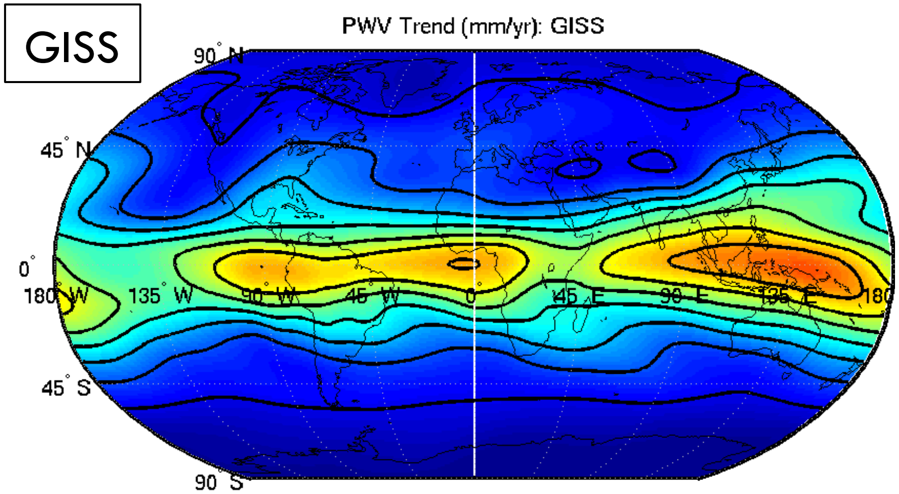
CCSM3

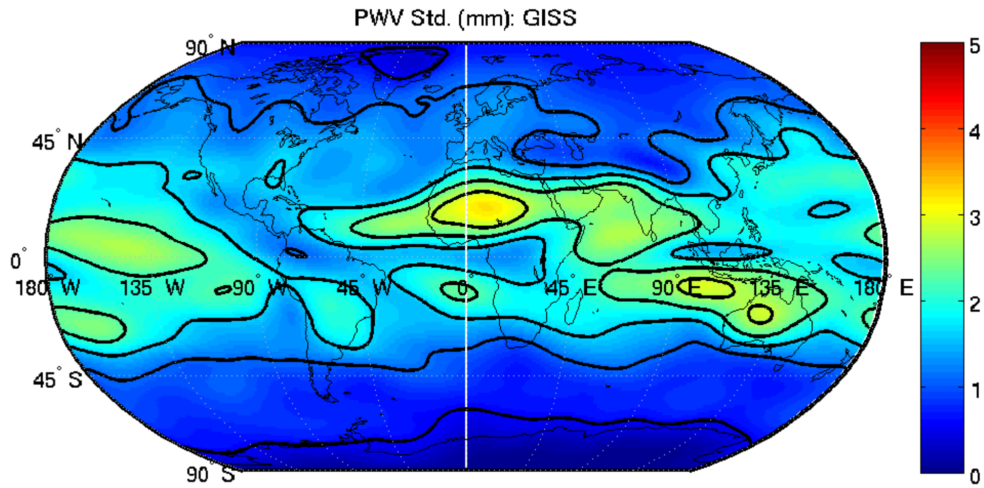




100yr GCM Trend & Natural Variability

GISS

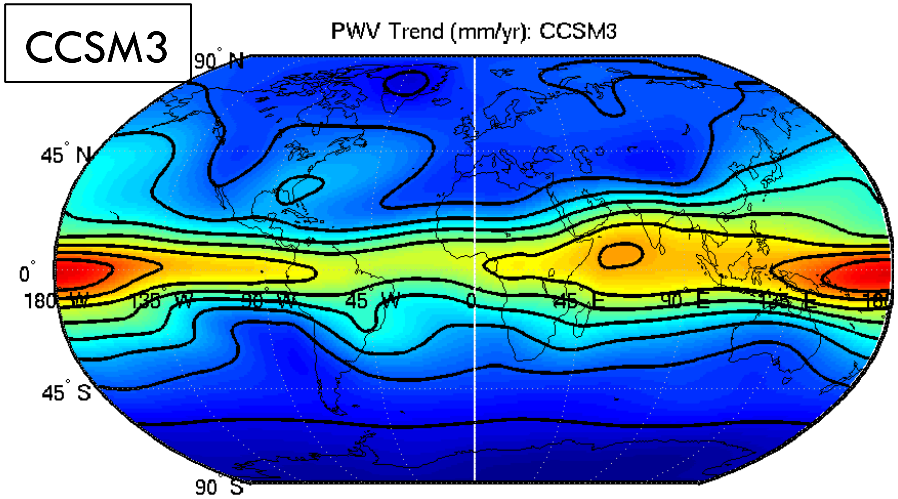


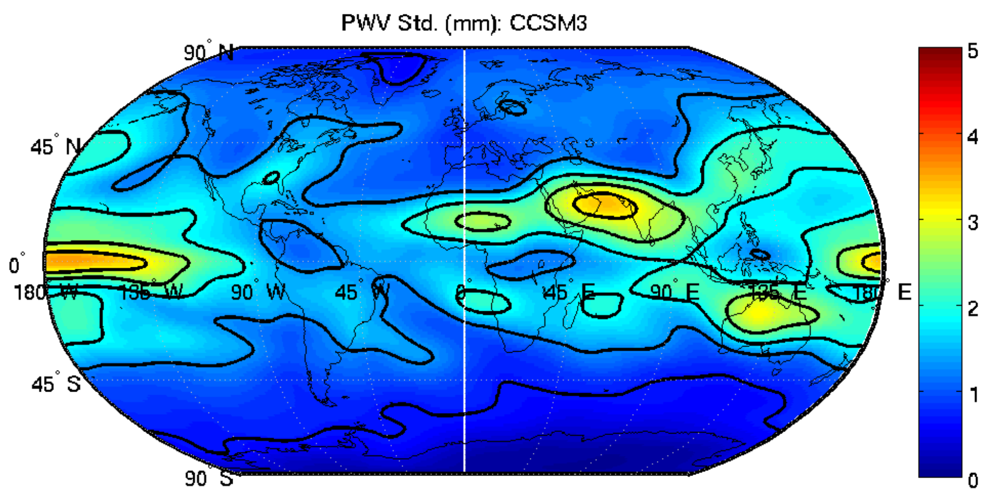


15°x30° Regional PWV Trend (mm/yr)

15°x30° Regional σ (mm/yr)

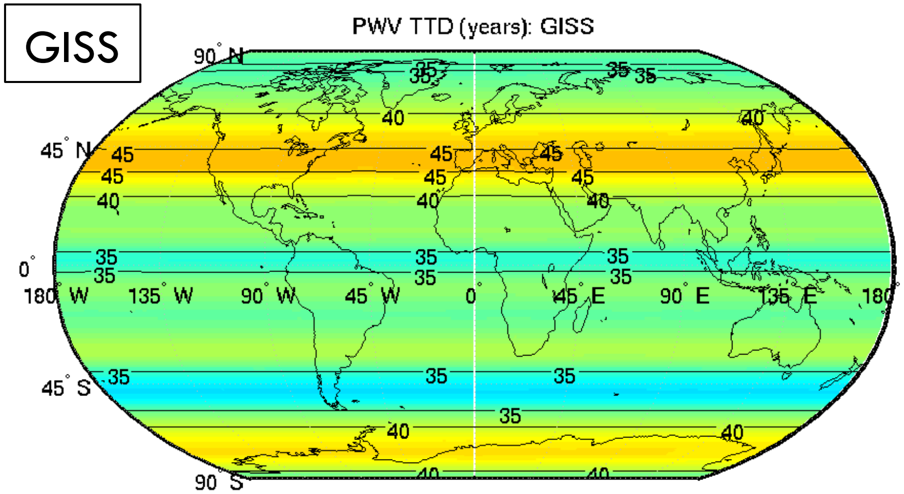
CCSM3

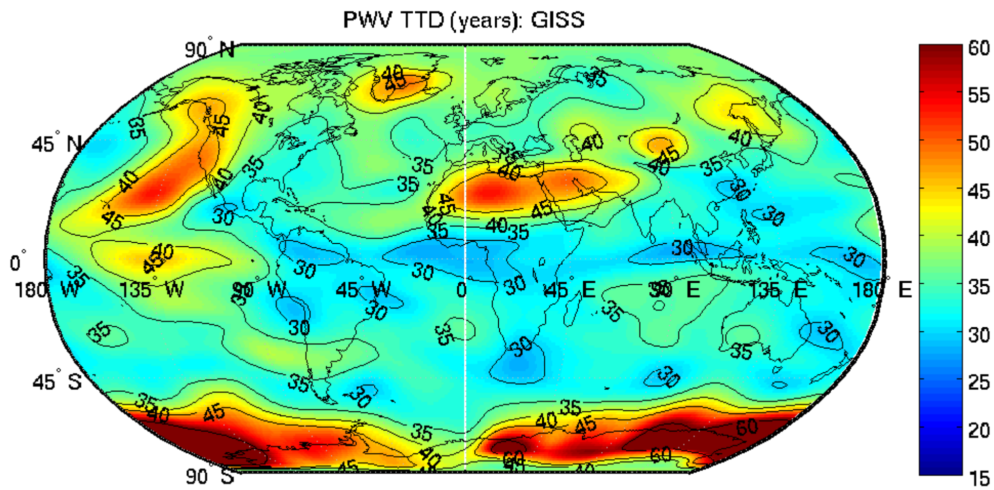




100yr GCM PWV TTD: Zonal & Regional

GISS

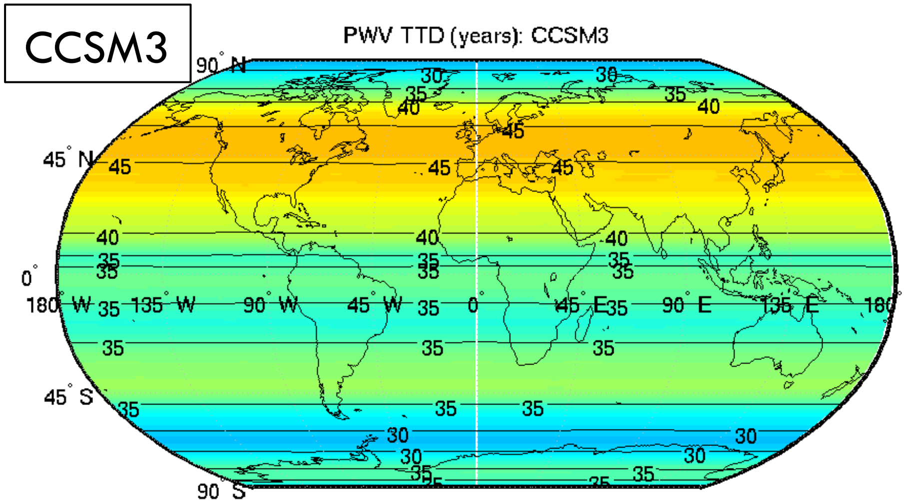


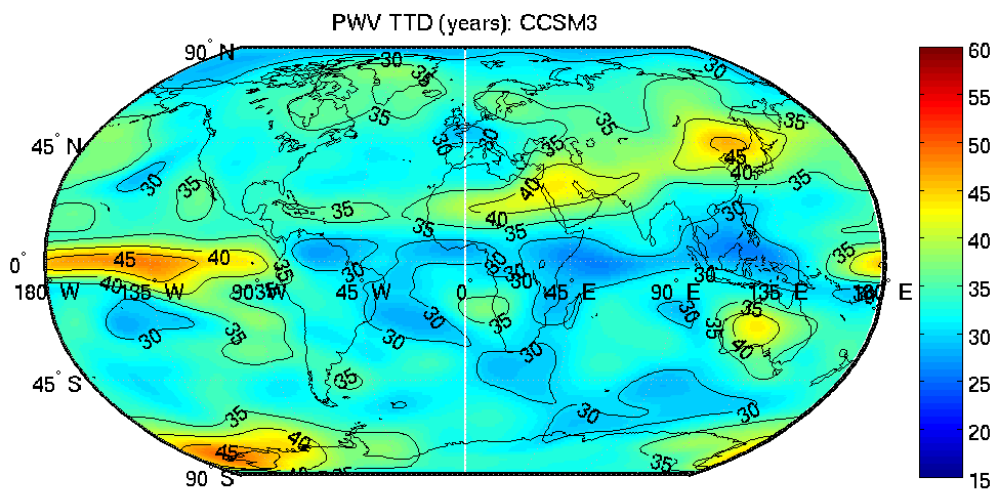


15°x360° Zonal PWV TTD

15°x30° Regional TTD (years)

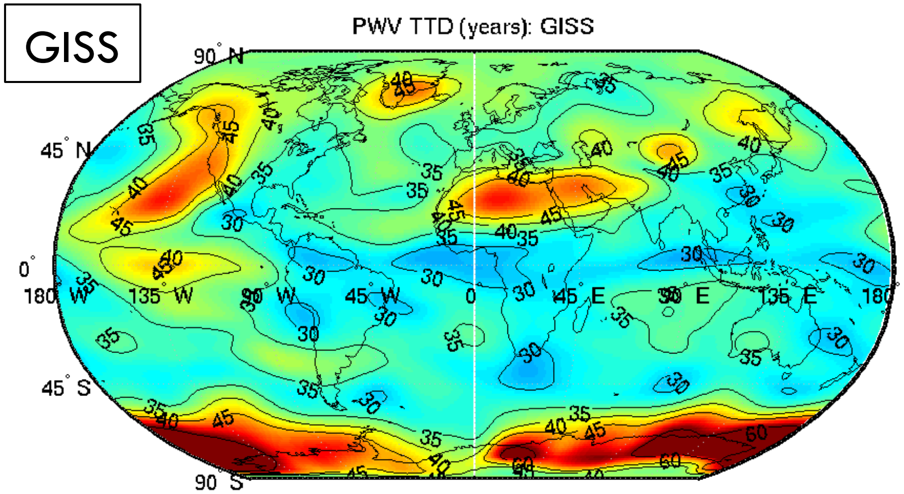
CCSM3

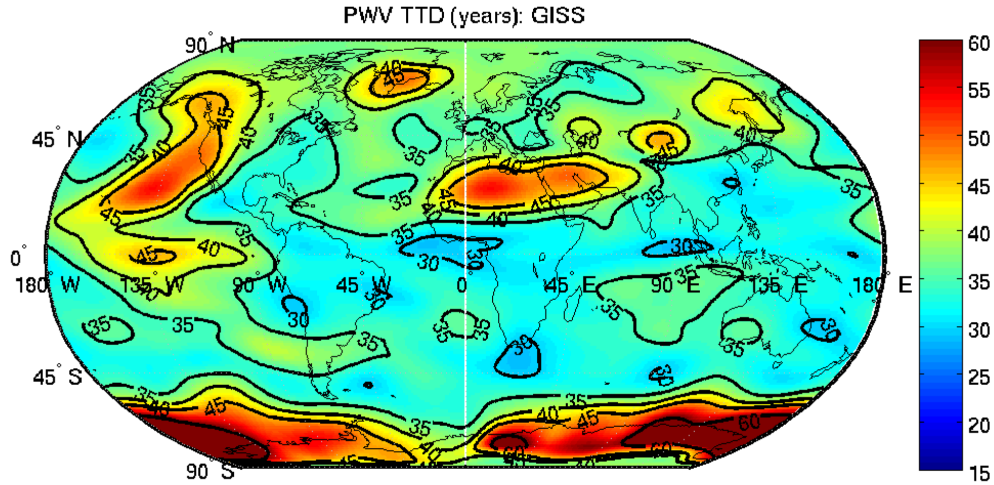




100yr GCM PWV TTD: 0% vs 1% error

GISS

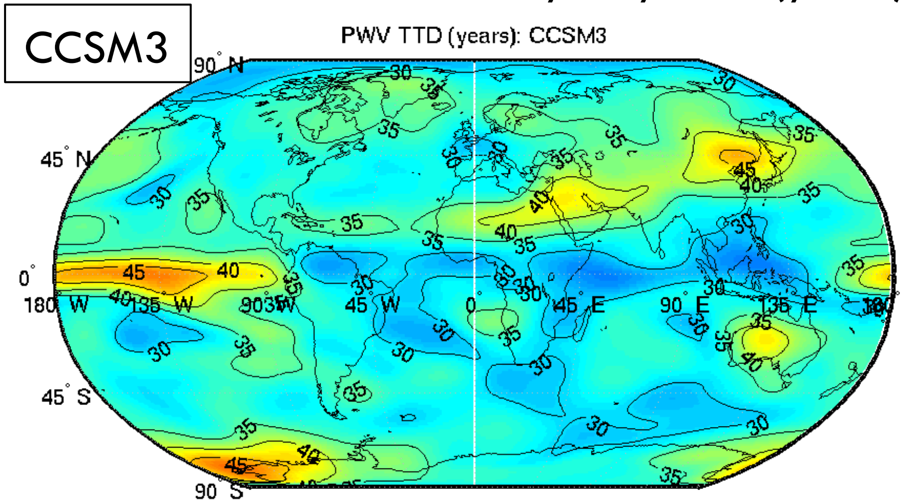


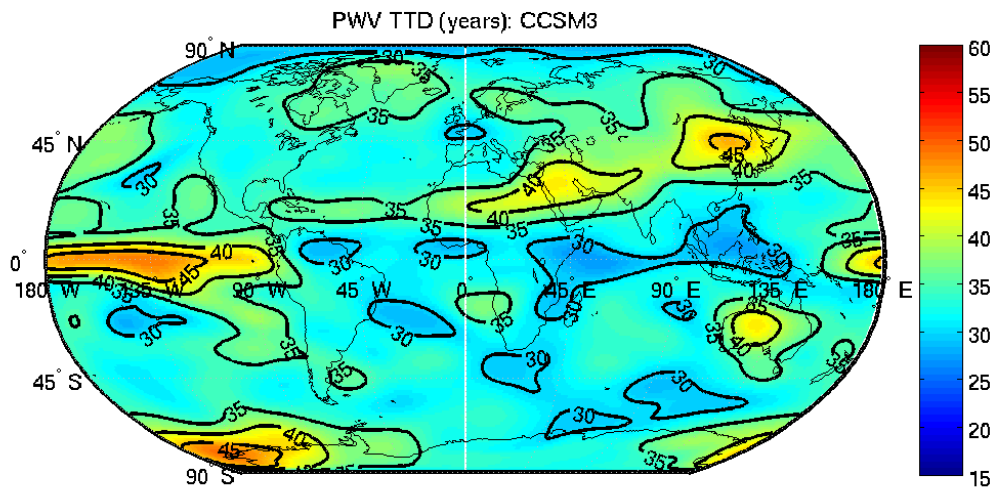


Natural Variability only- TTD (years)

Natural Variability + 1% of PWV- TTD (years)

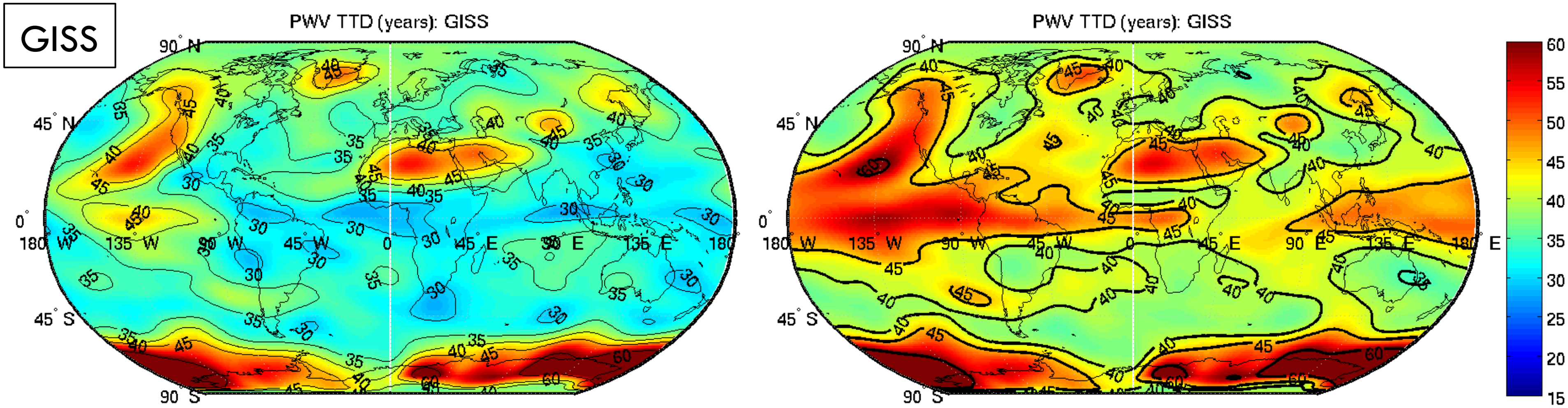
CCSM3





100yr GCM PWV TTD: 0% vs 5% error

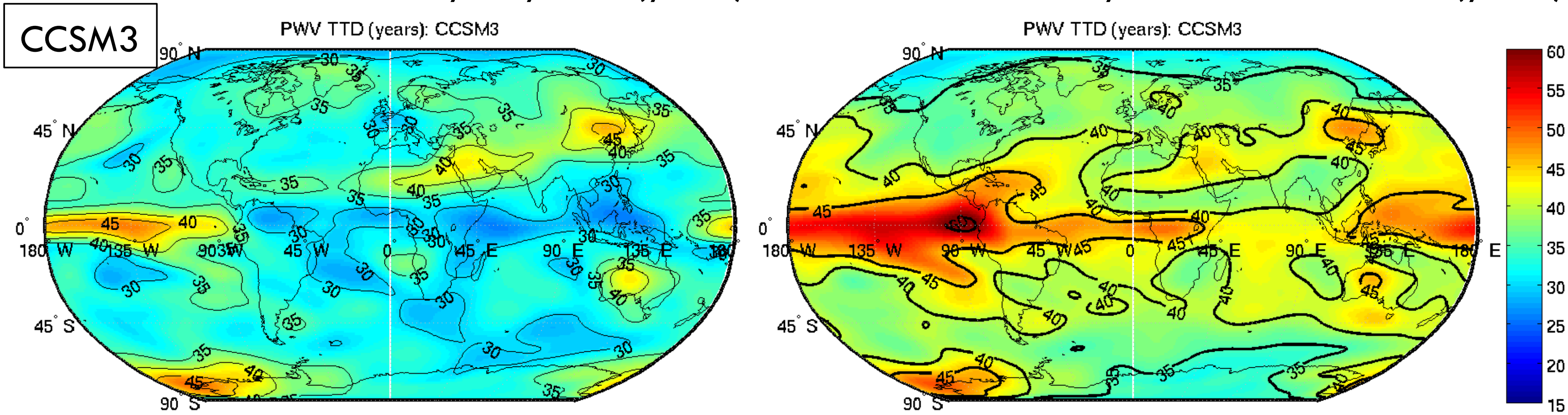
GISS



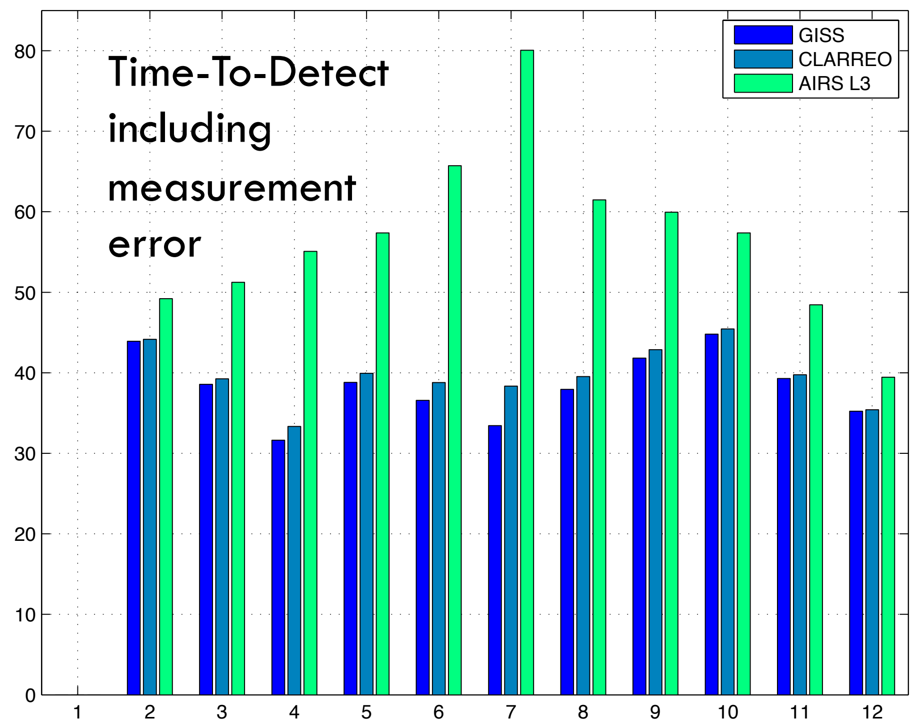
Natural Variability only- TTD (years)

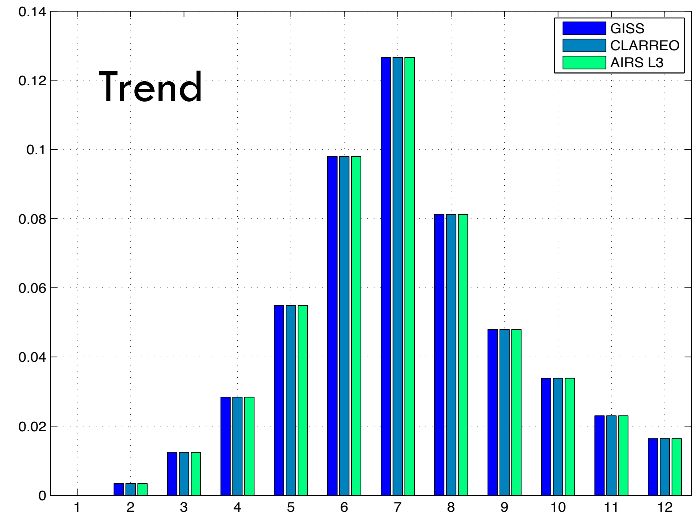
Natural Variability + 5% of PWV- TTD (years)

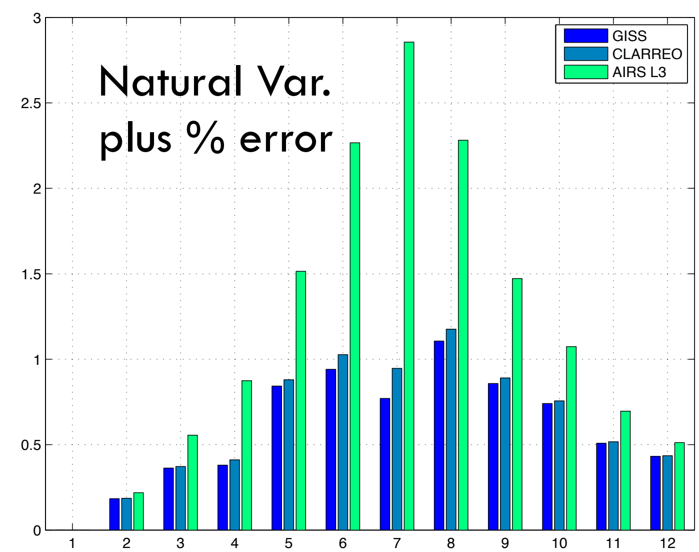
CCSM3



TTD: GISS Zonal Summary (15°x360°)

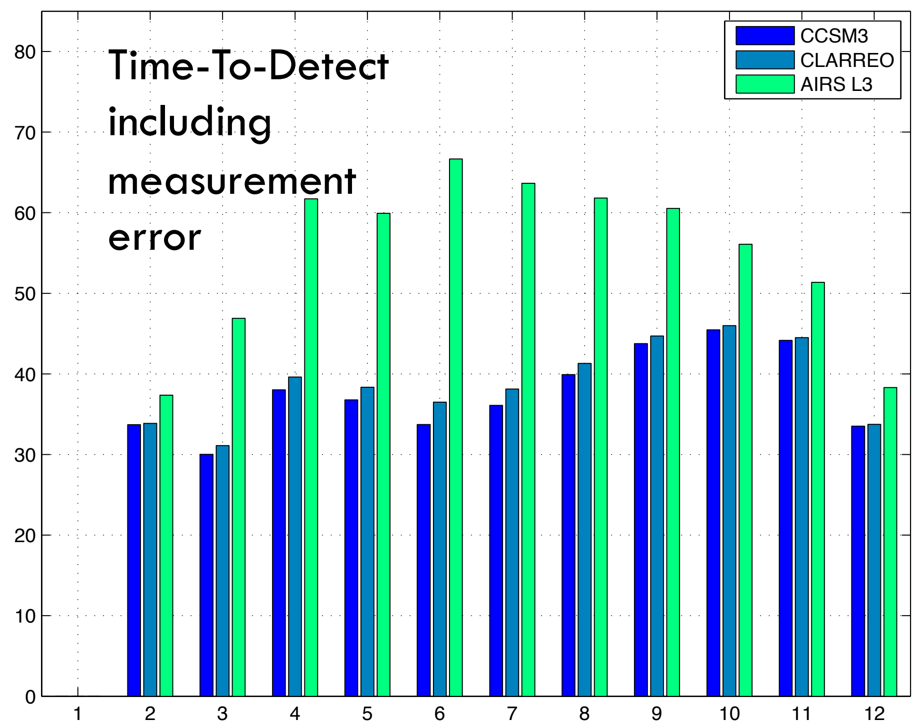


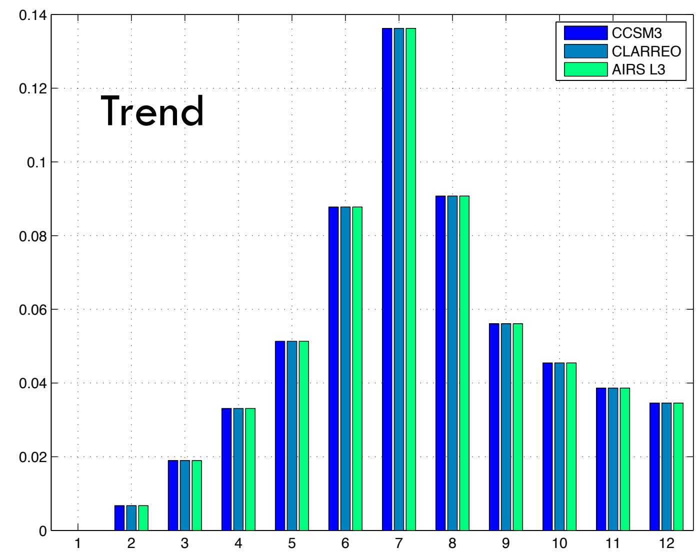


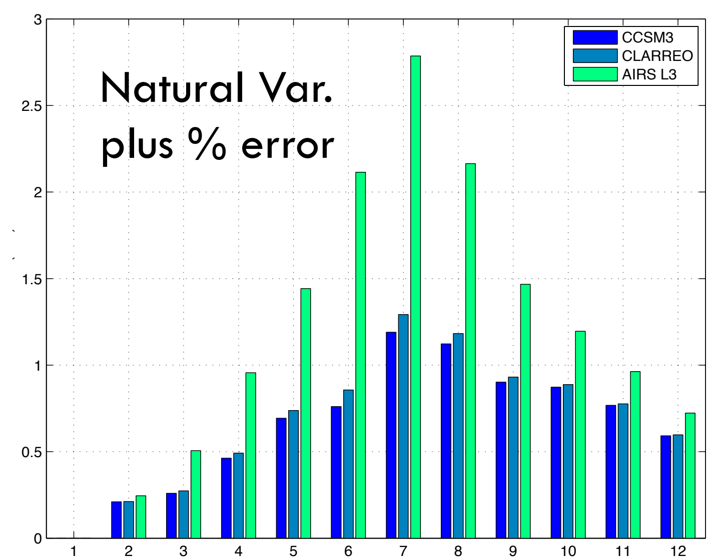


- “CLARREO” error = GCM Natural Variability + 1% PWV; “AIRS L3” error = Nat. Var. + 5% PWV
- “CLARREO” TTD is 30 to 45 years; “AIRS” TTD is 40 to 70+ years.

TTD: CCSM3 Zonal Summary (15°x360°)







- "CLARREO" error = GCM Natural Variability + 1% PWV; "AIRS L3" error = Nat. Var. + 5% PWV
- CCSM3 TTD shows similar strong dependence on measurement error.

Conclusions

Models and Observations

- Roman et al. (2012) demonstrates the use of ground-based GPS PWV for the regional validation of GCM models.
- We have begun assessing global GCM model fields with satellite "sounder" (AIRS and AMSR-E) products with large differences apparent at some latitudes.
- We have included Bill Smith's CLARREO-Proxy in the comparison. Good agreement with validation data is seen in North America. More validation is needed in the Southern Hemisphere. (Work in progress.)

TTD PWV Trends

- 15°x30° regions show promise to provide TTDs comparable to or better than zonal averages.
- GISS and CCSM3 models both show similar PWV trends in Eastern North America (U.S.) and Eastern Asia (China) with TTDs less than about 35 years.
- GISS and CCSM3 models show quite different trends in the Eastern North Pacific which are correlated to SST trend differences in each model.
- A "CLARREO" 1% accuracy has a significant TTD advantage over an "AIRS" 5% accuracy level.

Future Work

- Continue the inter-comparison of official NASA satellite climatology's to characterize observational uncertainties on a global and seasonal basis.
- Continue to work with Bill Smith in estimating the ultimate CLARREO retrieval product accuracy.
- Transition to evaluation of the CMIP5 GCM results using the tools developed under this project.
- Develop further connections to the societal impact of climate predictions on health, safety, and the global economy.

Thank You!