An Assessment of the Absolute Accuracy of the AIRS and IASI Precipitable Water Vapor Products at Tropical, Mid-Latitude, and Arctic Ground-Truth Sites

Robert Knuteson, Sarah Bedka,
Jacola Roman, Dave Tobin,
Dave Turner, Hank Revercomb

University of Wisconsin-Madison
Space Science & Engineering Center
Cooperative Institute for Meteorological Satellite Studies

Satellite PWV Topics

- Ground-truth at DOE ARM sites using a Microwave Radiometer (MWR)
- AIRS Ver. 5 - MWR Bias using six years of measurements (Sep 2002 - Aug 2008)
- NOAA IASI and EUMETSAT IASI Bias wrt MWR using two years of measurements (Jan 2008 - Dec 2009)
- Significance of differences and conclusions.

Why Validate Precipitable Water Vapor (PWV)?

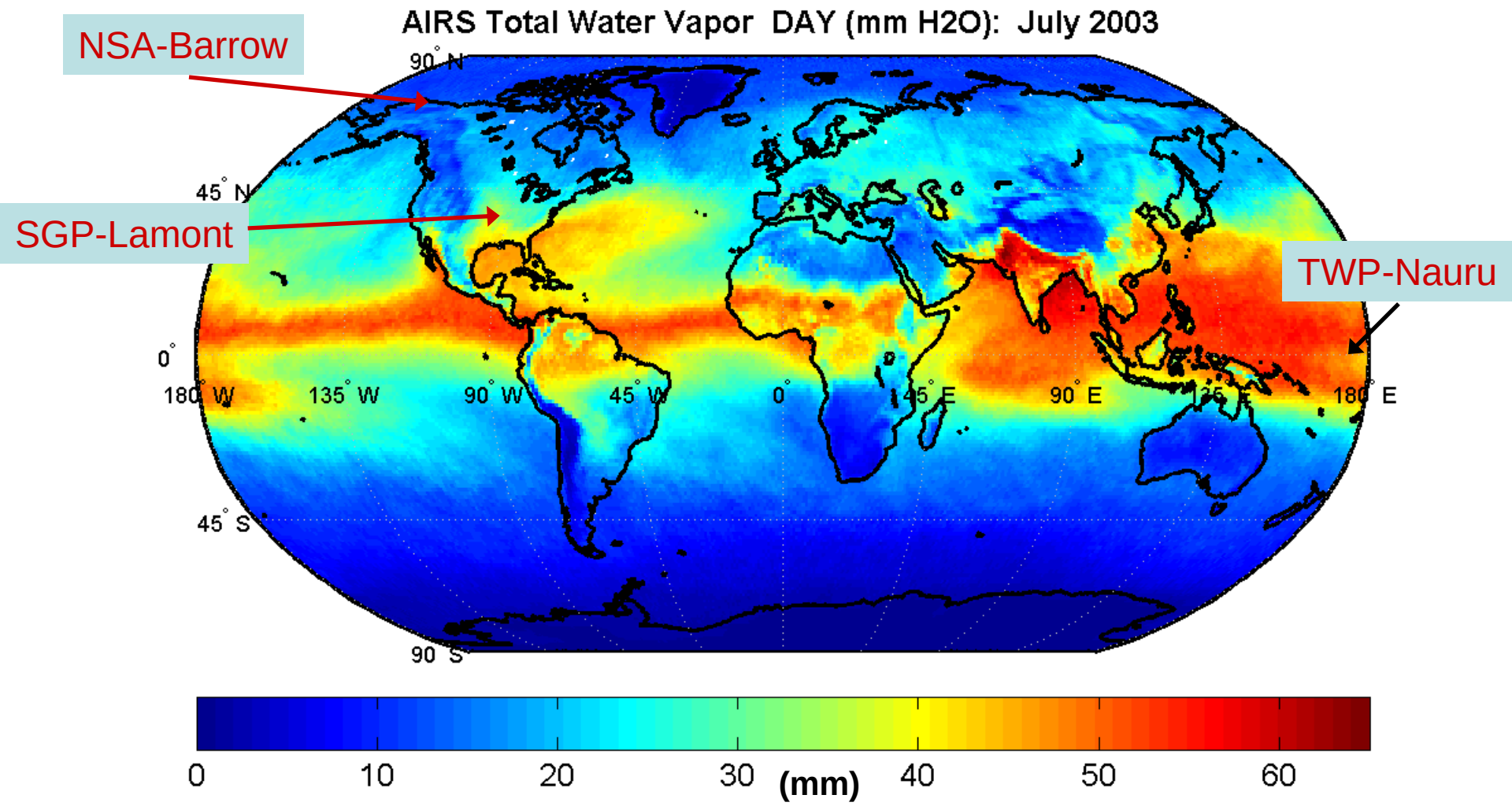
• Total column water vapor can be validated to a high percentage accuracy at selected ground sites (< 3% 2-sigma) using Microwave Radiometers operated by DOE ARM.

• Total column water vapor constrains the accuracy of the water vapor profile retrieval because it is defined here as the vertical integral of the retrieved vertical profile. Errors in the total column water vapor can be attributed to errors in the retrieved profile.

• Global warming implies an increase in the global atmospheric water vapor. Over OCEAN the satellite microwave SSMI precipitable water vapor has been shown to be strongly correlated with SST (a rate of 7% per degree Kelvin) similar to that predicted by climate models using the *Clausius–Clapeyron* relation. Over LAND both the theoretical expectation and the satellite measurements are more uncertain.

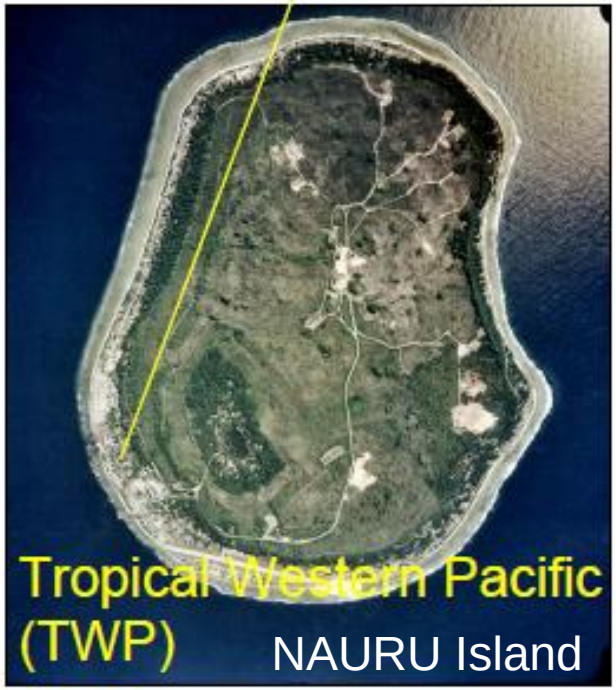
• Can we use AIRS, IASI, and CrIS to accurately measure water vapor trends over both OCEAN and LAND?

U.S. ARM Sites: SGP, TWP-Nauru, NSA-Barrow



- We use ground-based observations from three ARM sites for validation in the Southern Great Plains, Tropical Western Pacific, and North Slope of Alaska

DOE ARM Sites



22 GHz MWR Retrieval of TPW (built by Radiometrics, Inc.)

PWV absolute accuracy is better than 3% (95% confidence)

- 22 GHz line strength is known to high precision

  Clough, S. A., Y. Beers, G. P. Klein, and L. S. Rothman, "Dipole moment of water from Stark measurements of H2O, HDO, and D2O," *J. Chem. Phys.*, vol. 59, pp. 2254-2259, 1973.

- Improved PW retrieval method by Dave Turner of UW-SSEC.

  *Turner, D.D., S. A. Clough, J. C. Liljegren, et al., 2007: Retrieving liquid water path and precipitable water vapor from the Atmospheric Radiation Measurement (ARM) microwave radiometers. IEEE Trans. Geosci. Remote Sens., **45**.*

- MWR B.T. calibration accuracy estimated at < 0.3 K RMS.

- Verified MWR column using Raman Lidar/Chilled Mirrors (1%)

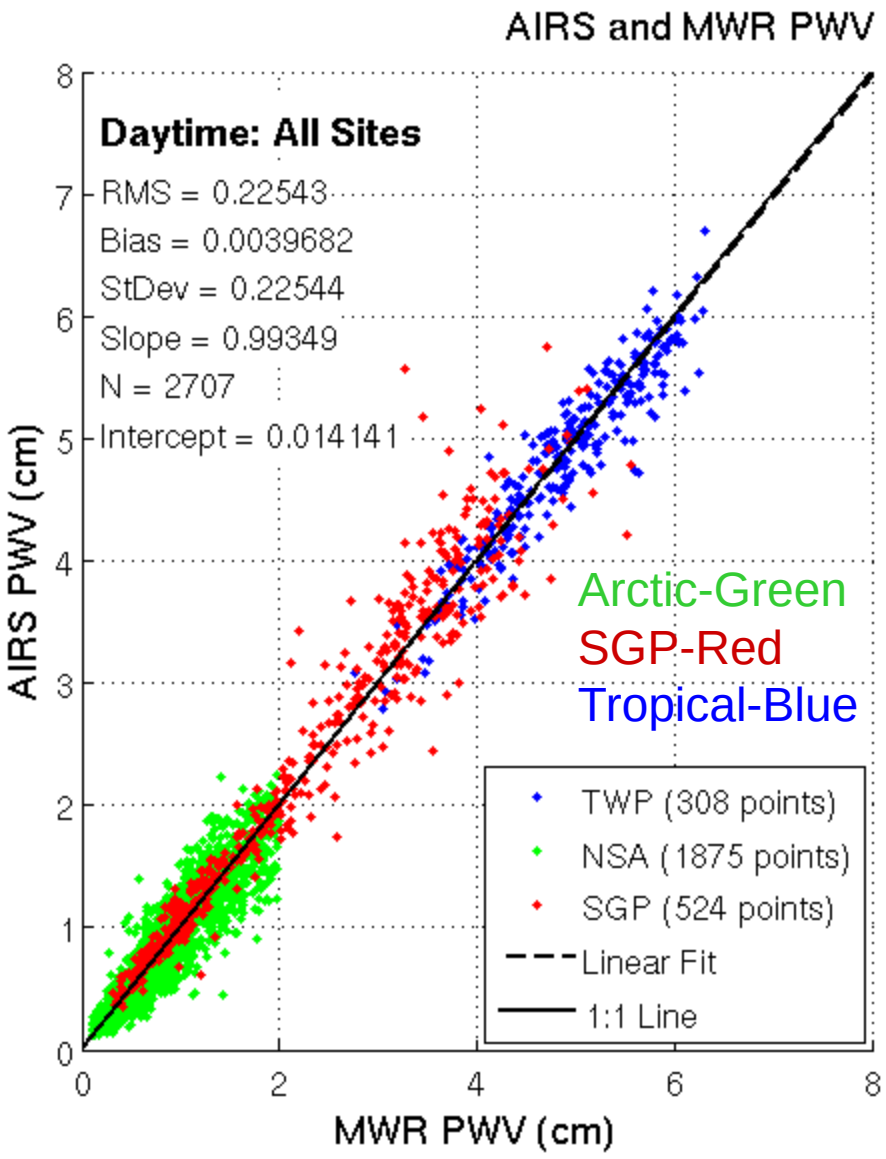
  *Revercomb, H.E., D.D. Turner, D.C. Tobin, et al., 2003: The Arm Program's Water Vapor Intensive Observation Periods. Bull. Amer. Meteor. Soc., **84**, 217.*

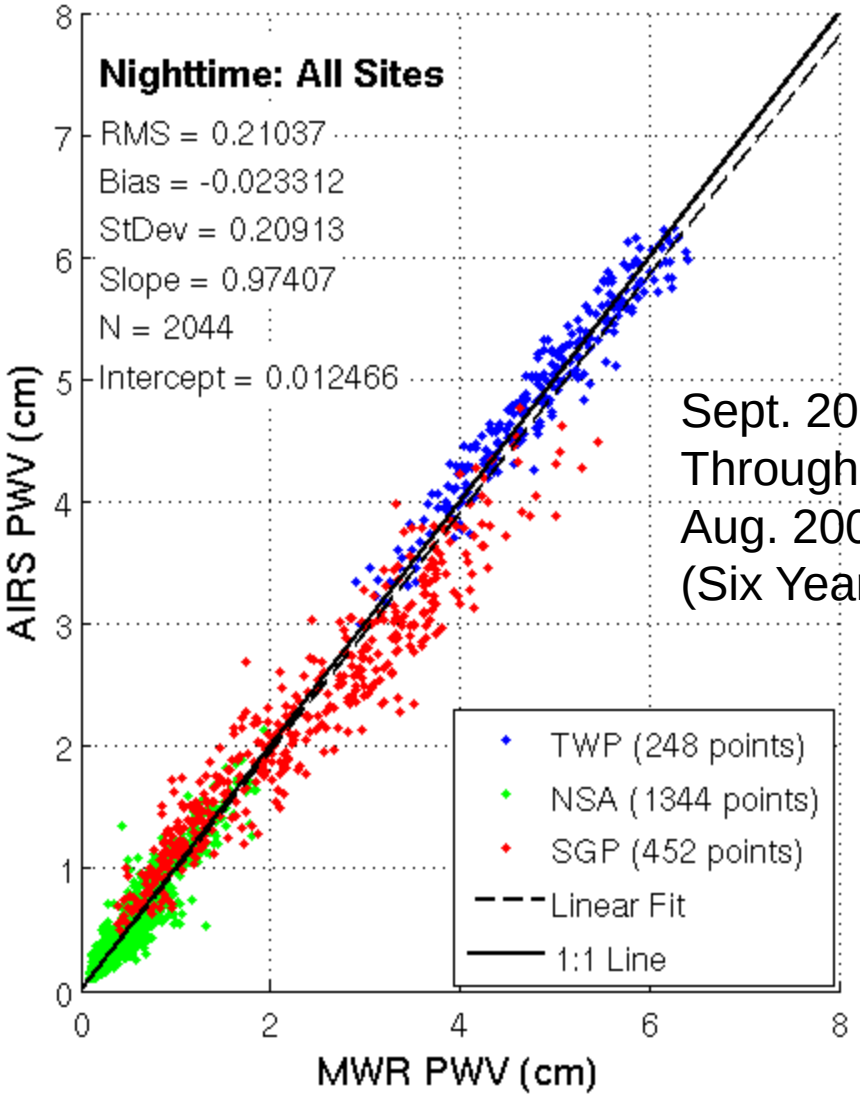
AIRS PWV Validation

Sept 2002 – August 2008

AIRS Science Team PWV Product Version 5
compared to
DOE ARM MWR PWV Product

AIRS





Sept. 2002
Through
Aug. 2008
(Six Years)

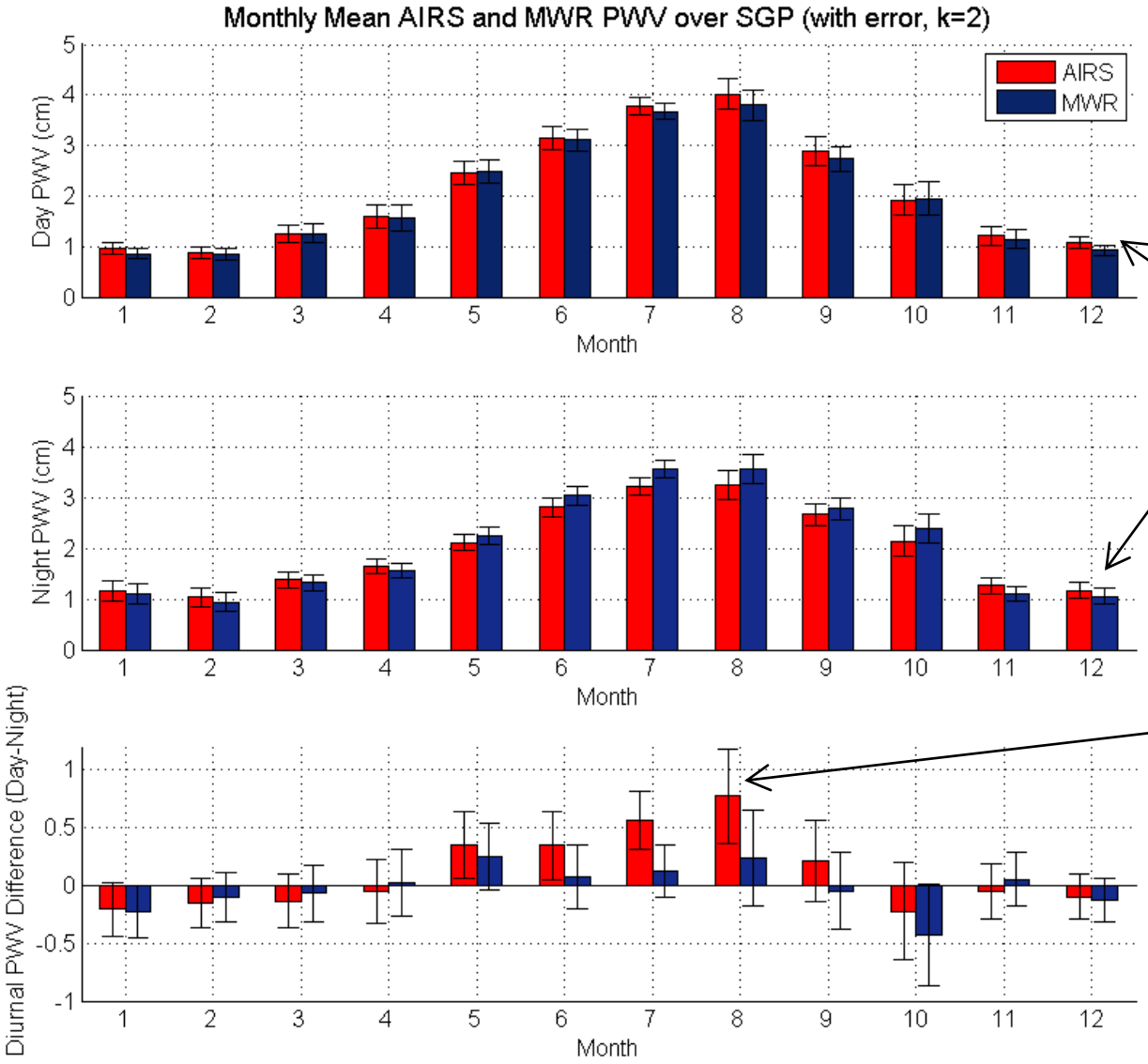
- Separate daylight and nighttime cases for independent analysis.

AIRS PWV Validation at the ARM Southern Great Plains Site

DAY

NIGHT

DAY – NIGHT

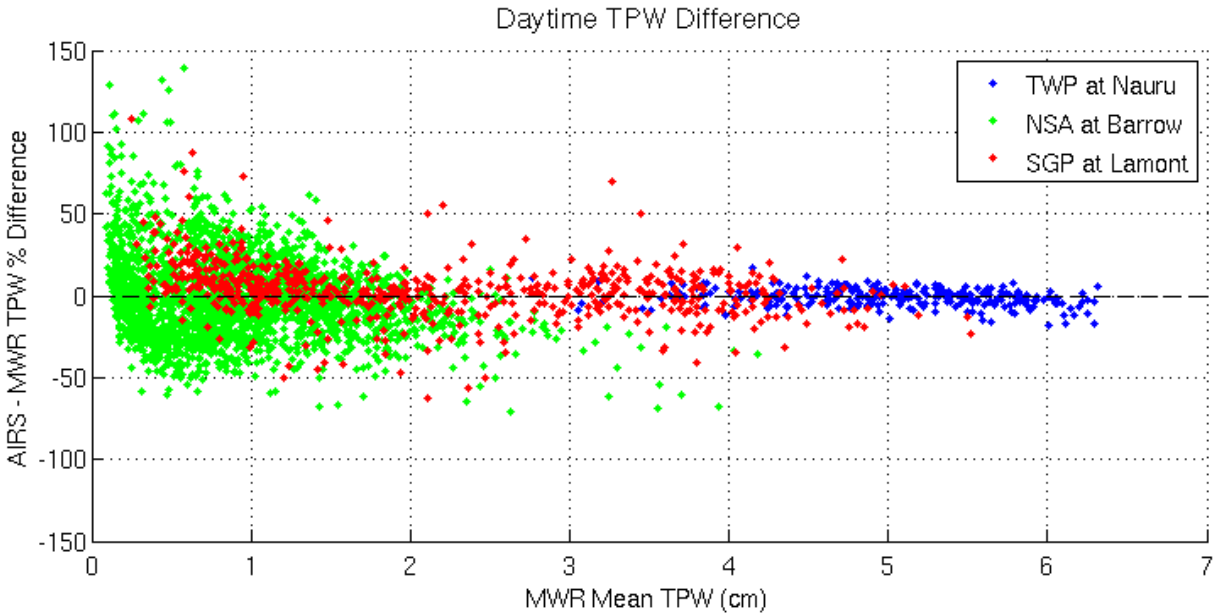


Winter "Wet" Bias?

Diurnal Bias in Summer?

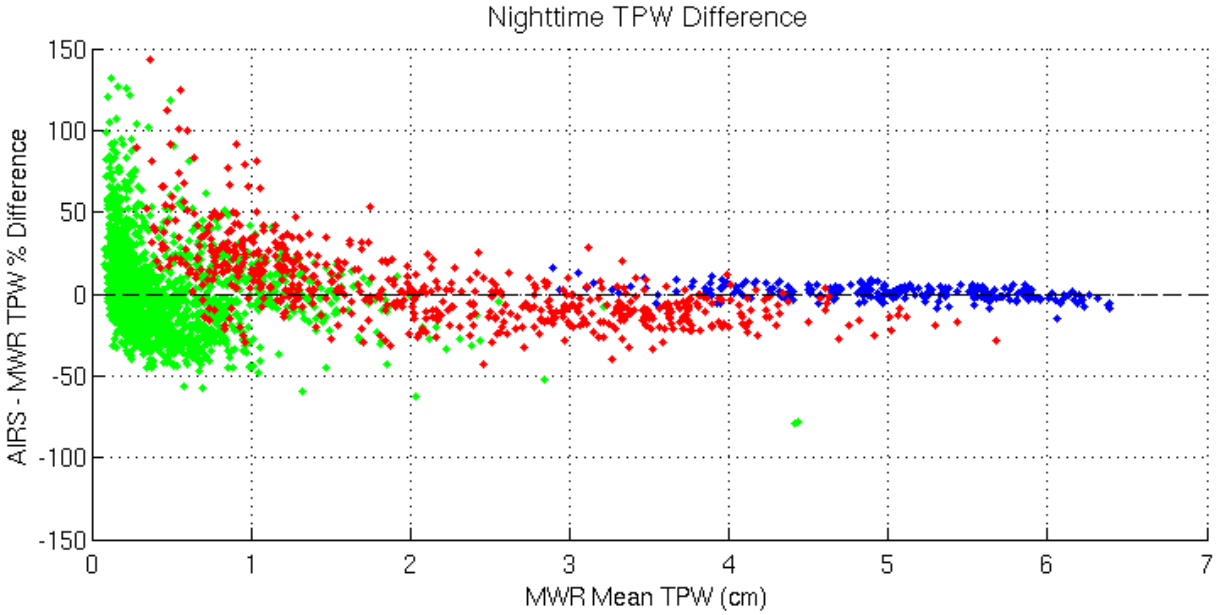
- Each month shows the mean and 2 x the uncertainty in the mean over the period of six years (Sept 2002 – August 2008).

DAY



ARM MWR PWV (cm)

NIGHT



ARM MWR PWV (cm)

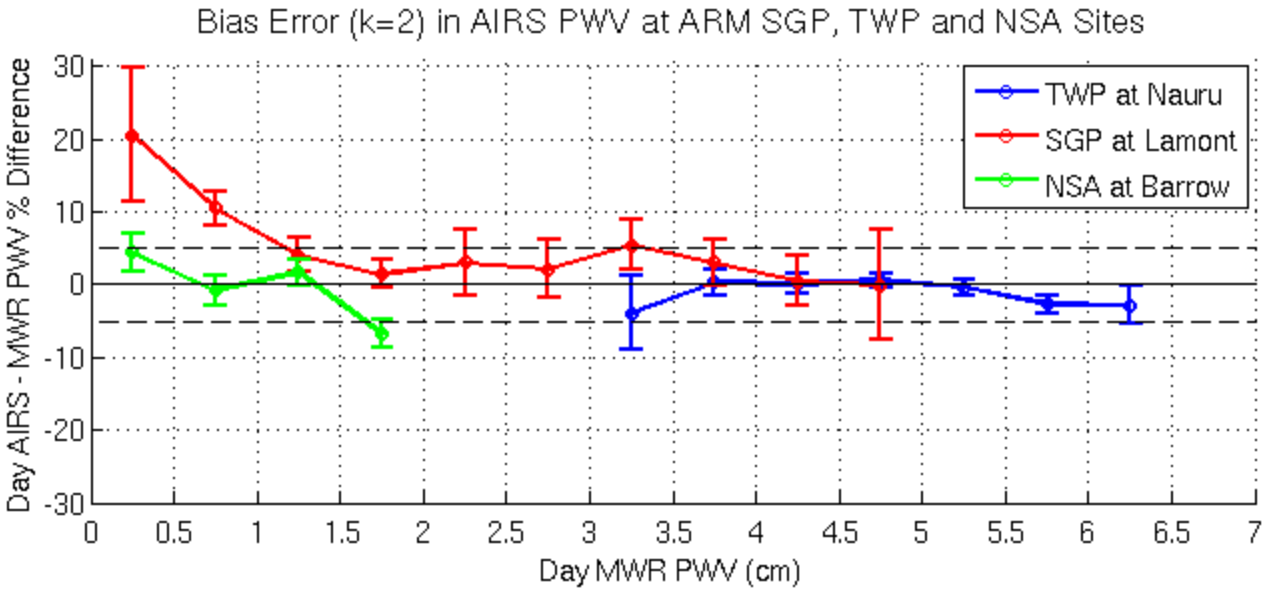
AIRS

All the data from the period September 2002 to August 2008

To quantify the bias we Estimate the Error in 0.5 cm PWV bins (next slide)

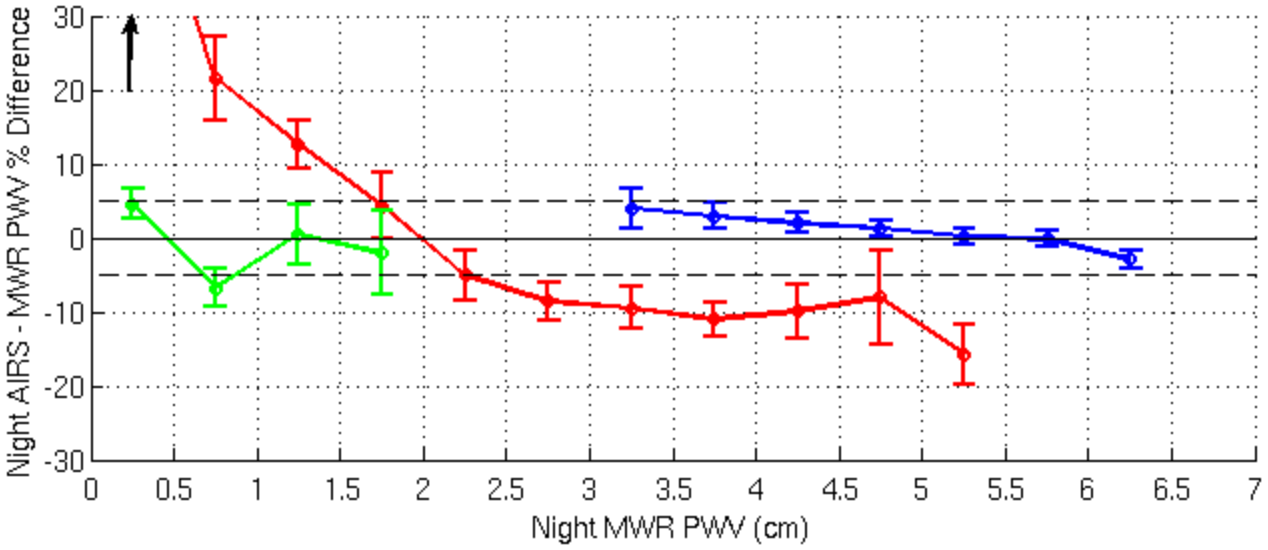
AIRS

DAY



± 5%

NIGHT



± 5%

ARM MWR PWV (cm)

U. Wisconsin Validation of AIRS V5 Total Water

- **AIRS PWV is within the stated 5% accuracy:**
  - **NSA < 5% (1 – 25 mm pw)**
  - **SGP < 5% (10 – 50 mm pw; daytime only)**
  - **TWP < 5% (35 – 65 mm pw)**

- **AIRS 10-30% too wet for pwv < 1 cm for Southern Great Plains LAND site both day and night.**

- **AIRS 10% too dry for pwv > 1 cm for the Southern Great Plains LAND site at nighttime only.**

[Bedka et al., An Assessment of the Absolute Accuracy of the Atmospheric Infrared Sounder (AIRS) v5 Precipitable Water Vapor Product at Tropical, Mid-Latitude, and Arctic Ground-Truth Sites: September 2002 through August 2008, JGR, 2010, in press]

Comparison of

AIRS V5 PWV

Sept 2002 – August 2008

with

NOAA IASI

&

EUMETSAT IASI

Jan 2008 – Dec 2009

Relative to

DOE ARM MWR PWV

At Mid-Latitude, Arctic, and Tropical Sites

EUMETSAT vs NOAA Algorithms

- IASI L1C radiances are input to both algorithms

- Regression first guess followed by physical iterative retrieval is common to both although channel selection may be different. NOAA uses a modified version of AIRS team algorithm (Chris Barnet)

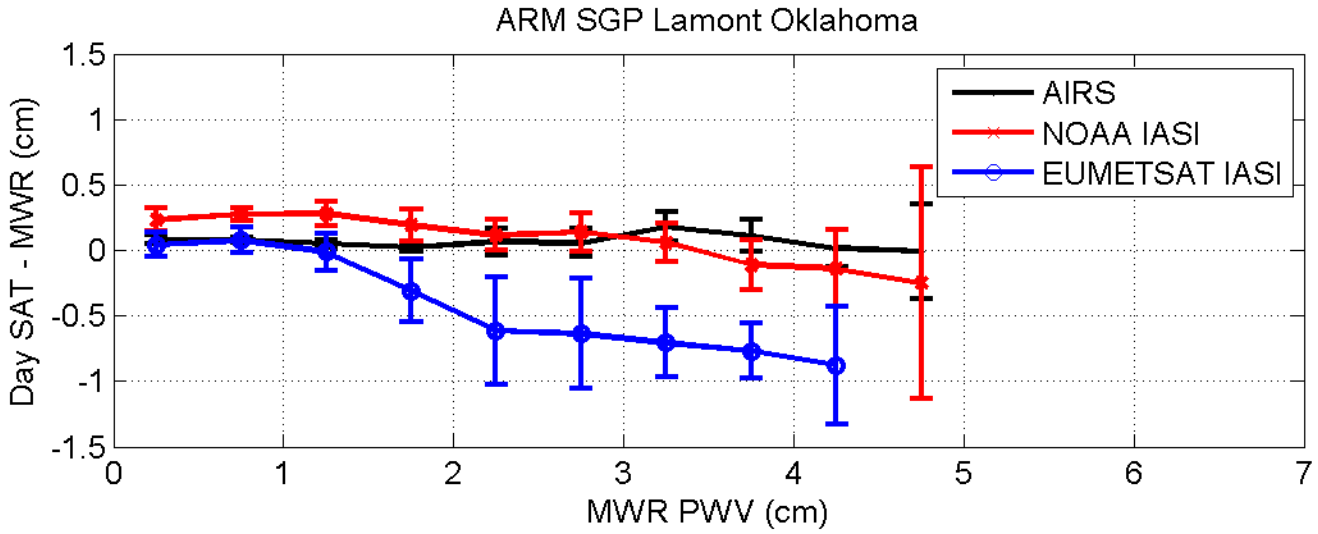
- RT-IASI versus UMBC IASI RTM

- Radiance tuning in EUMETSAT algorithm
  UMBC IASI RTM not tuned (unlike for AIRS SARTA)

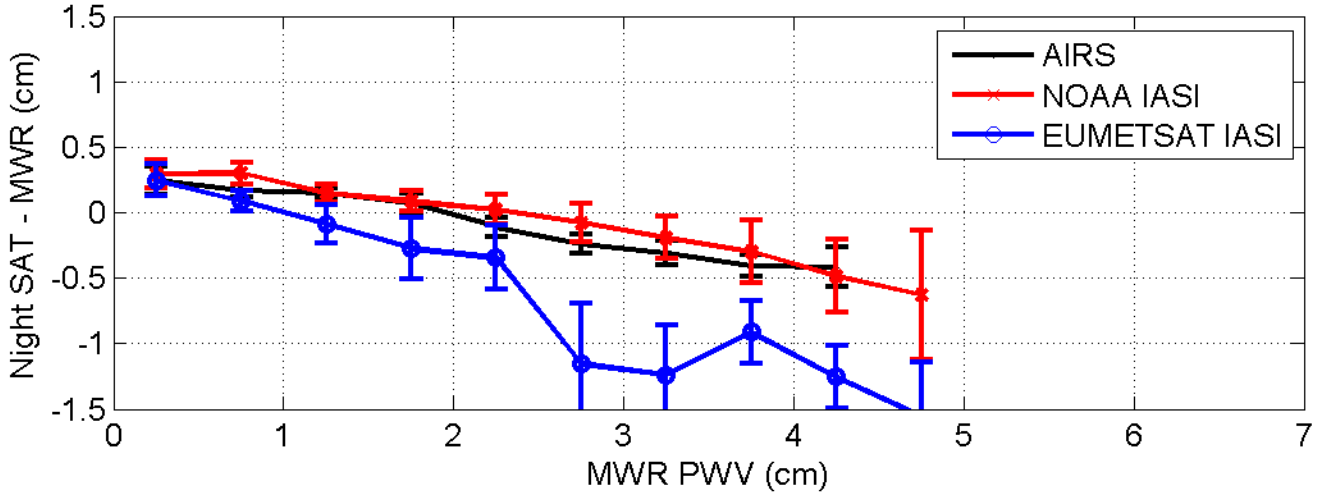
- FOV cloud “detection” versus 2x2 cloud “clearing”

ARM South Great Plains Lamont, OK (in cm)

DAY

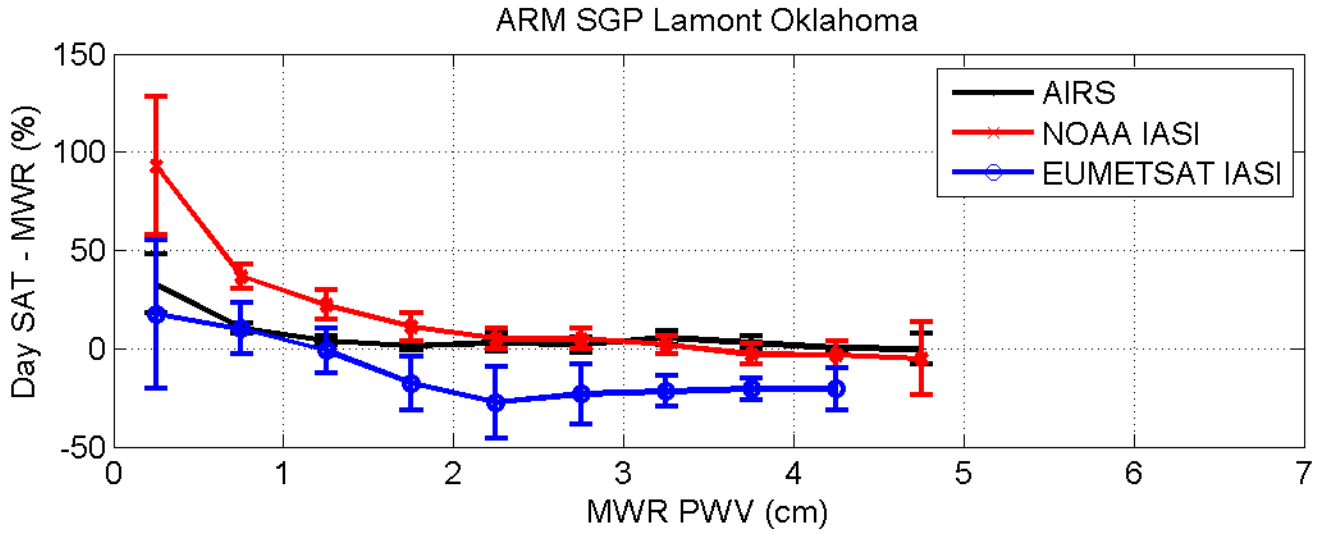


NIGHT

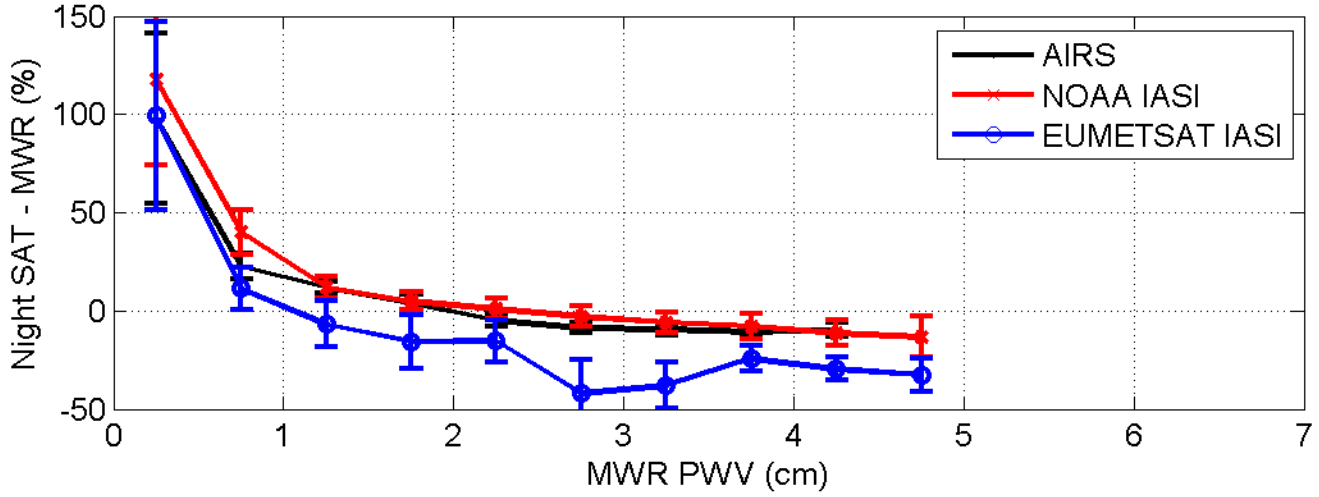


ARM South Great Plains Lamont, OK (in %)

DAY

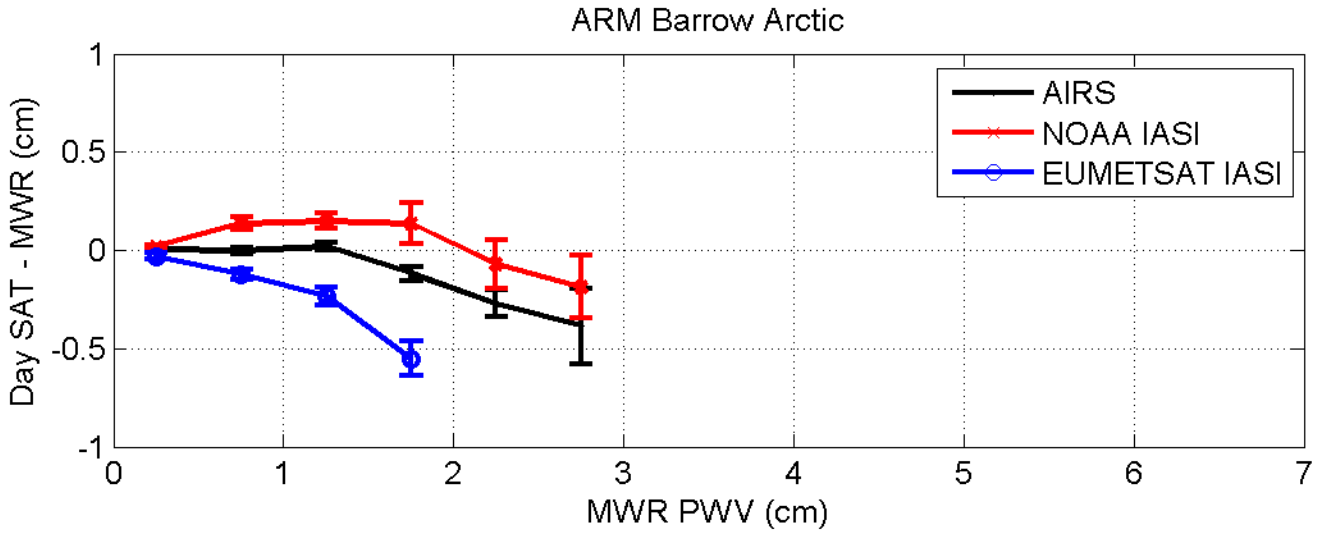


NIGHT

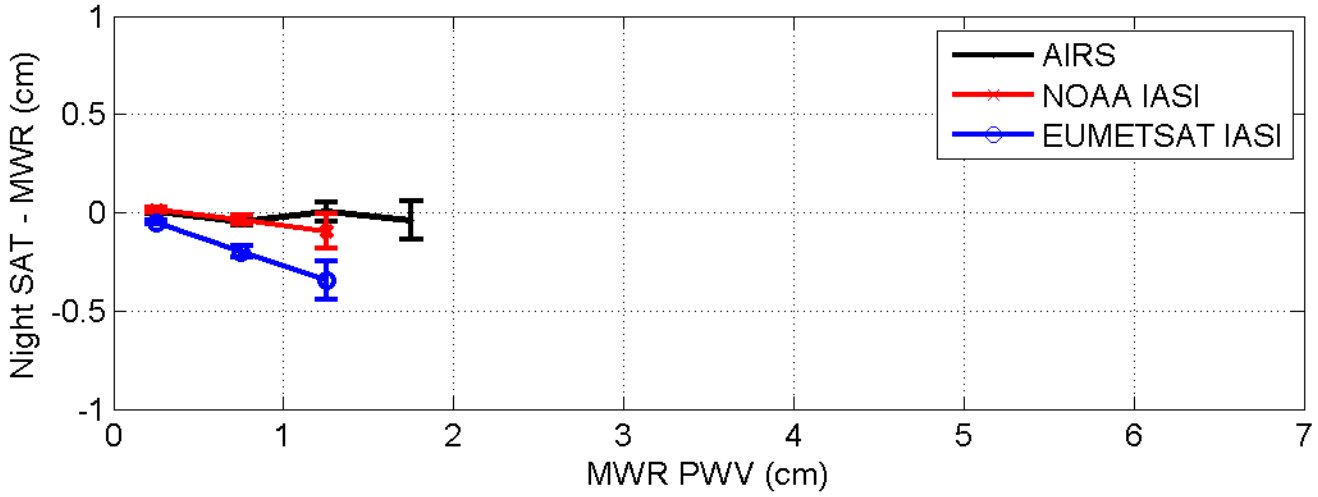


ARM NSA Barrow, Alaska (in cm)

DAY

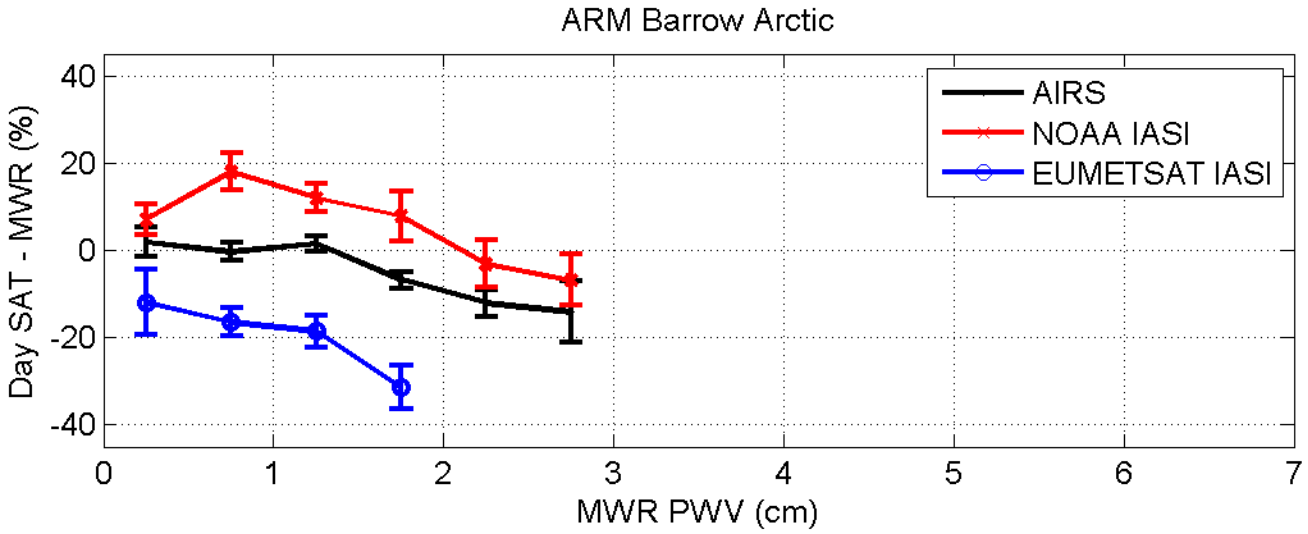


NIGHT

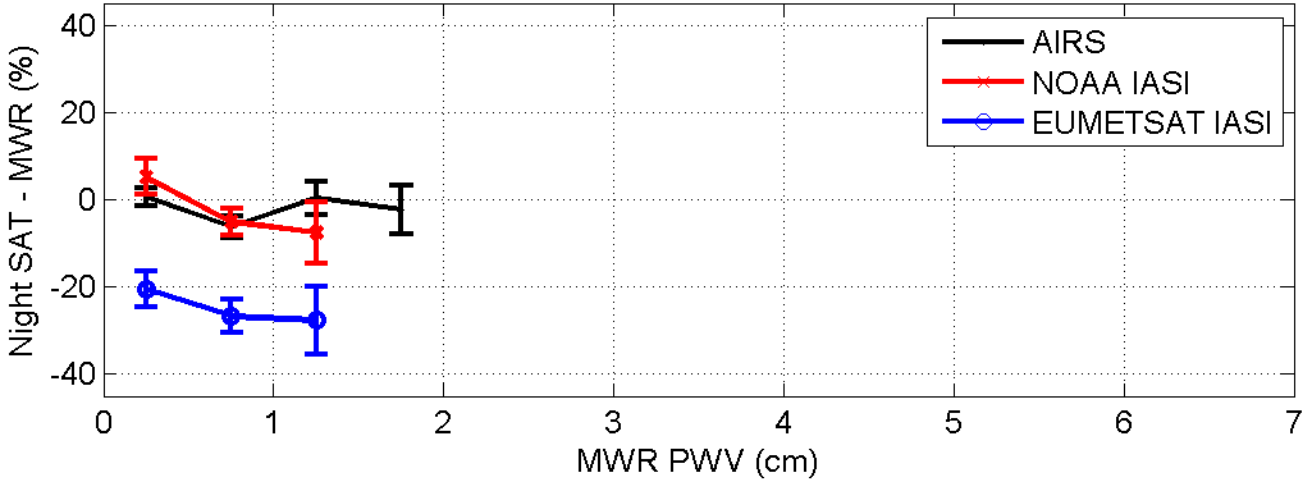


ARM NSA Barrow, Alaska (%)

DAY

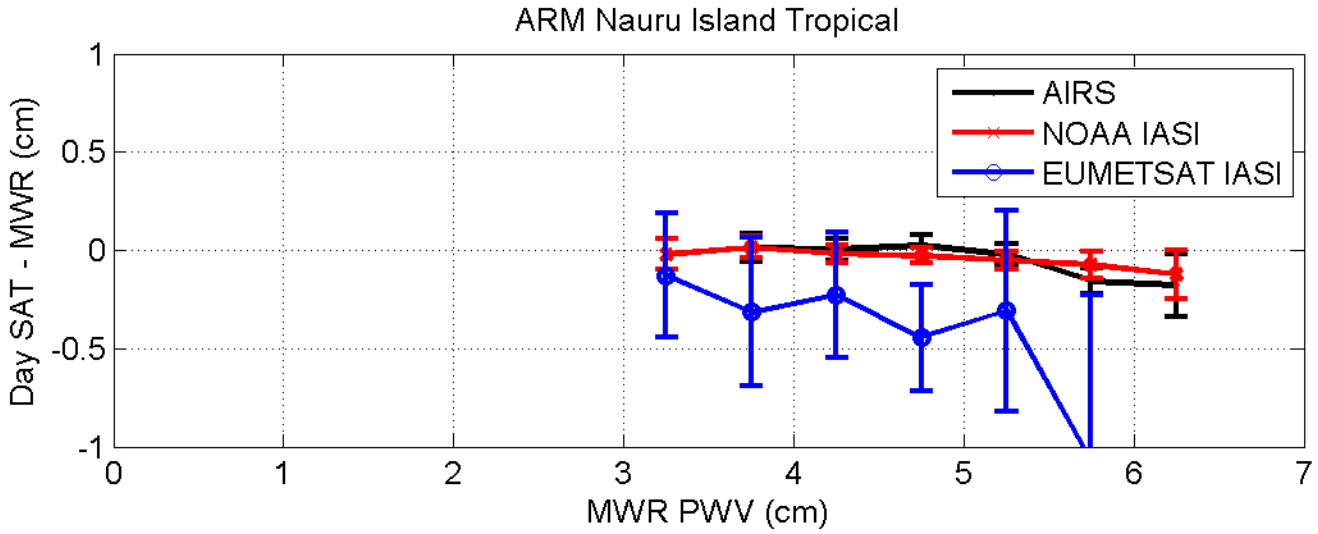


NIGHT

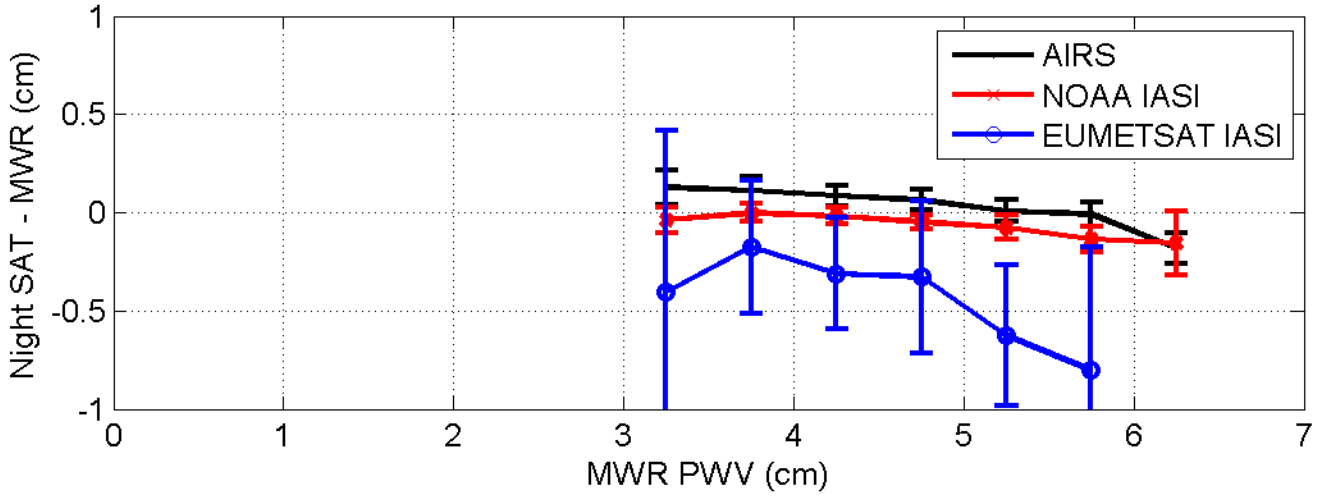


ARM Tropical Western Pacific Nauru Island (in cm)

DAY

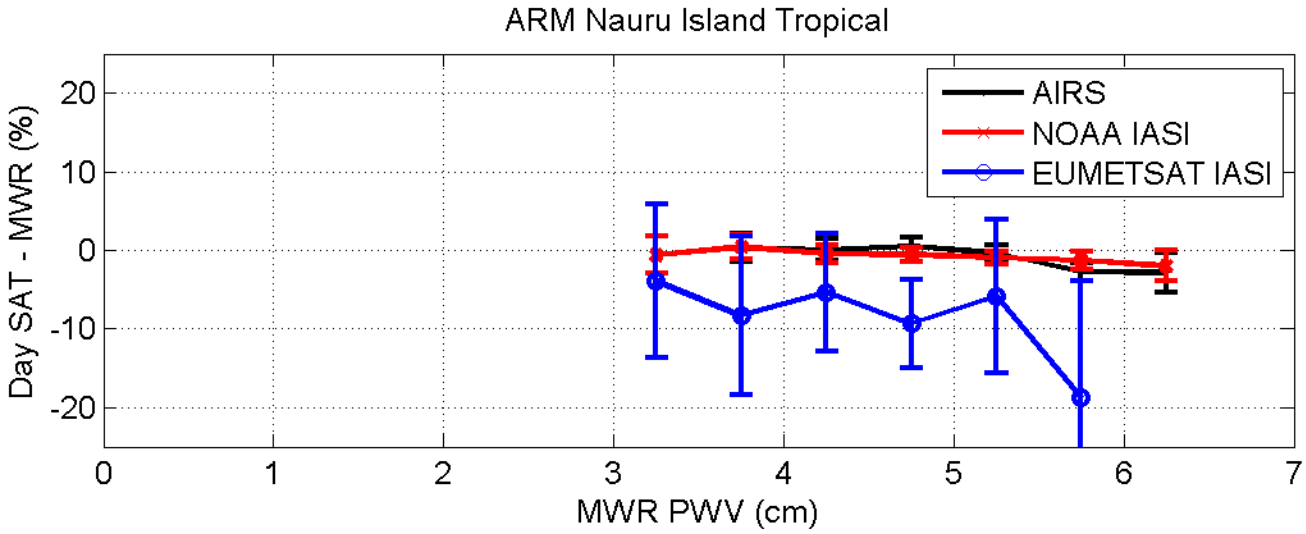


NIGHT

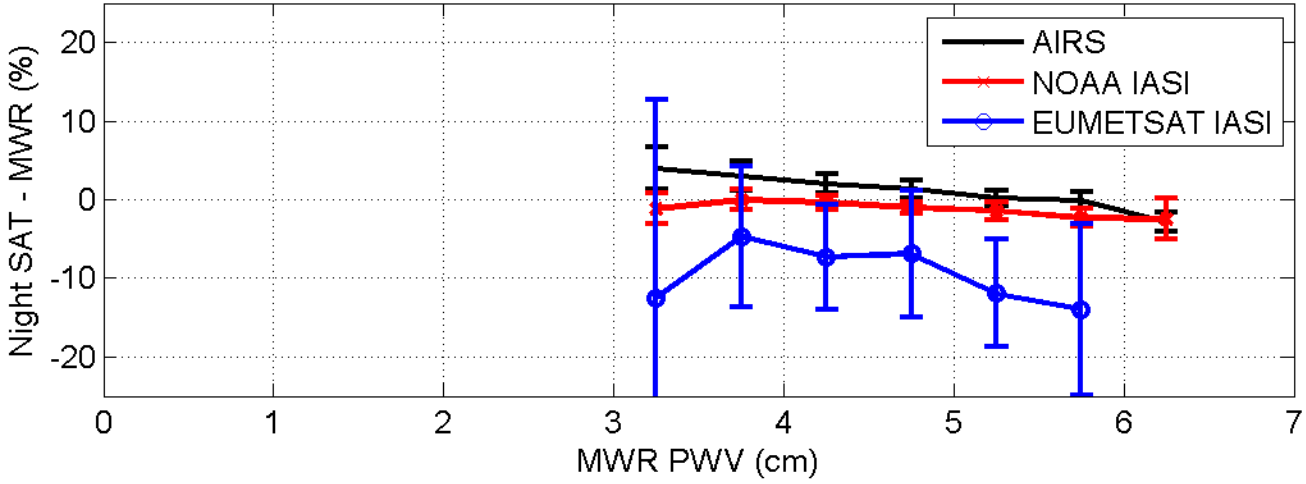


ARM Tropical Western Pacific Nauru Island (%)

DAY



NIGHT



Significance of Results

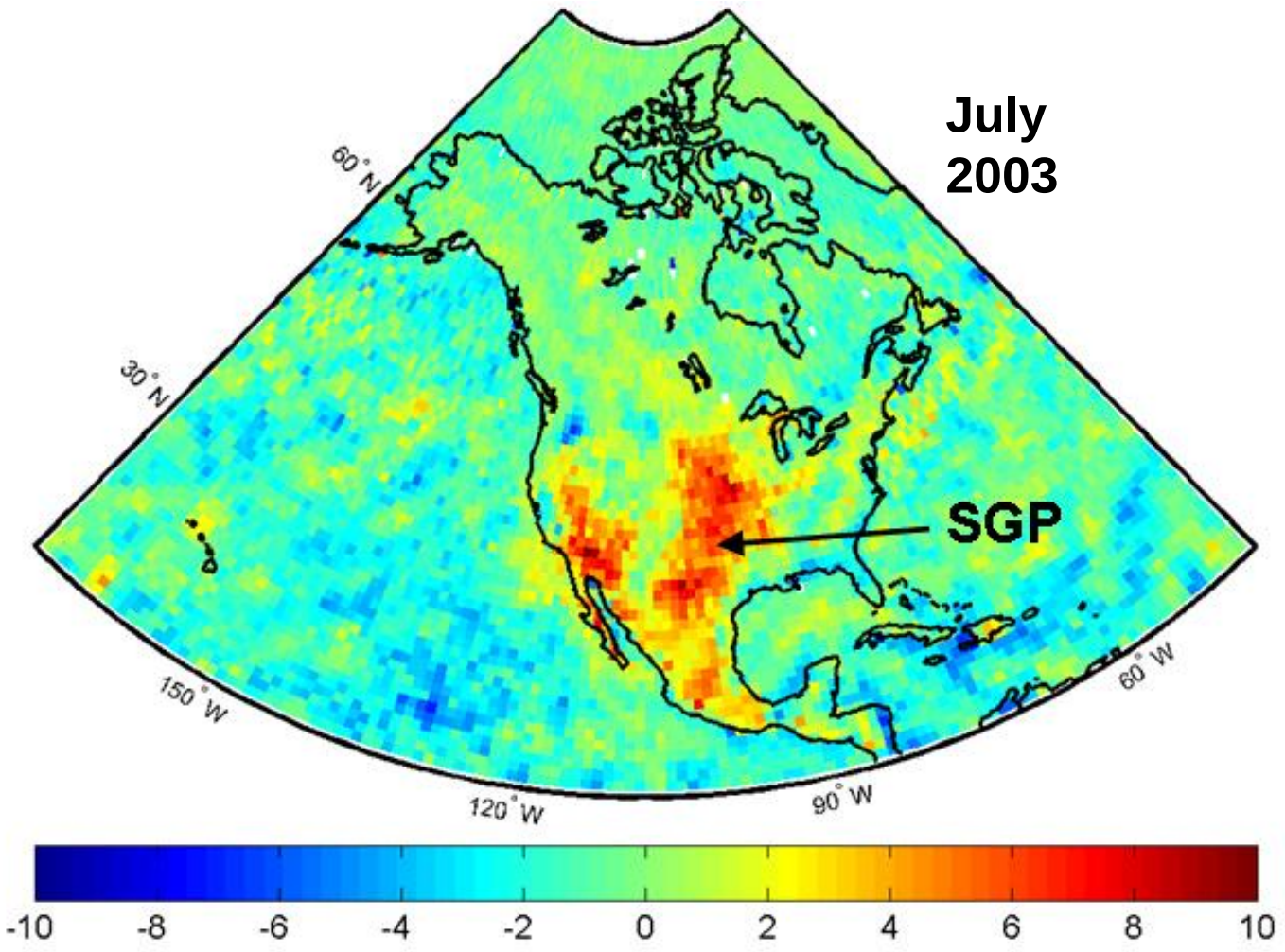
- What is cause of the Diurnal Error in PWV at the Southern Great Plains site?

- Why is there a wet bias for low water amounts at SGP?

- Why is the satellite product have greater variability than the comparable sonde PWV compared to the same ground truth?

The following slides will highlight these questions.

Diurnal PWV Error of AIRS Retrieval at the Southern Great Plains Oklahoma site?

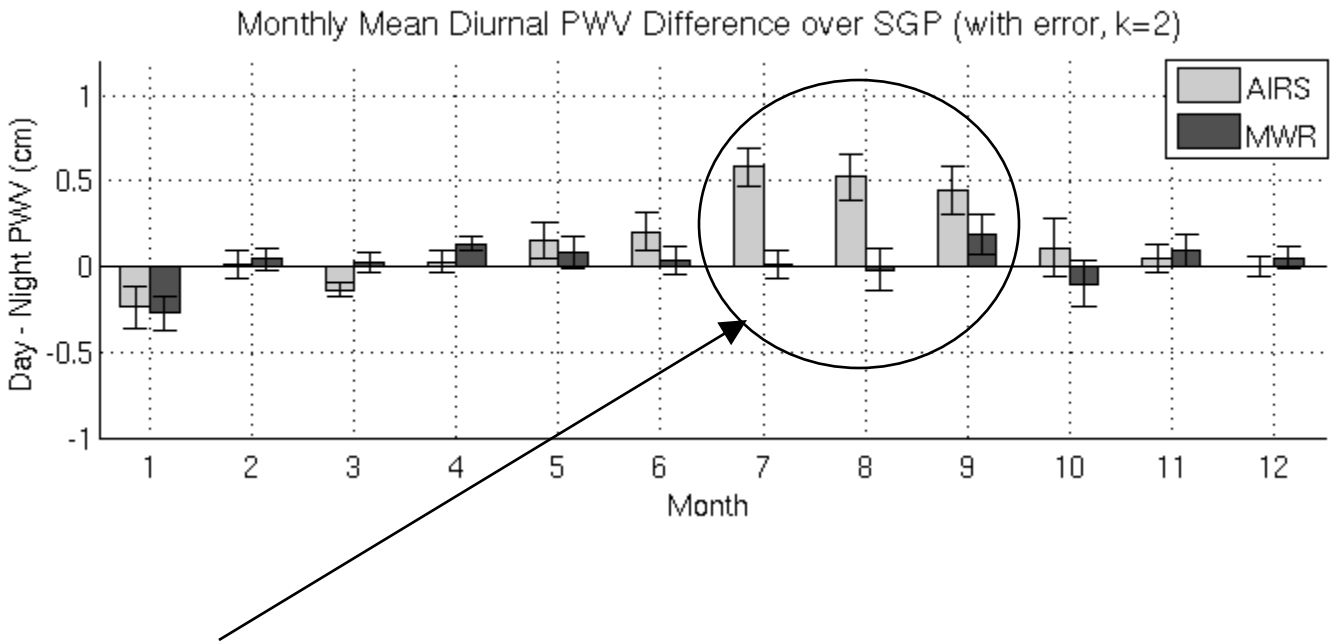


AIRS Day minus Night Diurnal PWV in mm

AIRS v5 Level 3 product exhibits a large day minus night difference for the monthly means during each summertime throughout the U.S. Great Plains and in the Desert Southwest.

This diurnal difference is a retrieval artifact as shown in the next figure.

Diurnal PWV Error of AIRS Retrieval at the Southern Great Plains Oklahoma site?

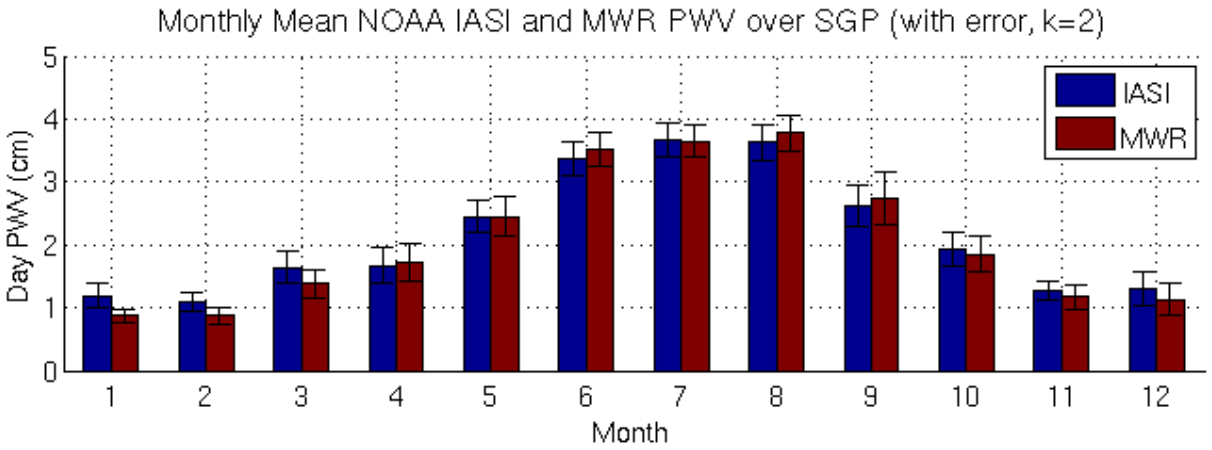


AIRS v5 Processing

Summer months of July, August, and September show a **statistically significant** difference (at the 95% confidence level) between the AIRS day minus night estimate of PWV compared to the Microwave Radiometer which shows nearly zero diurnal signal. This is an AIRS artifact of the version 5 product.

Note that this subset of the data contains only day/night "matched" pairs which are within 13 hours of each other, so that they represent an equal number of day and night samples and for the same day.

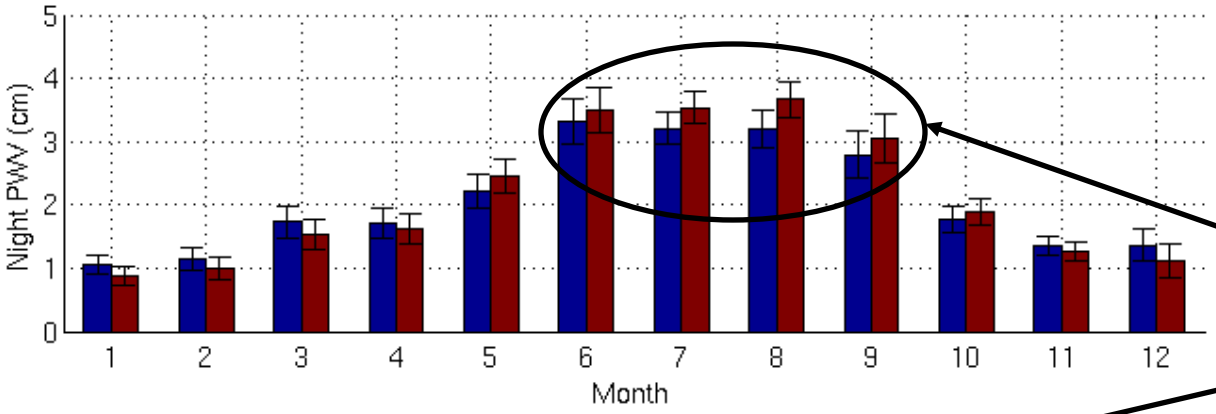
Day



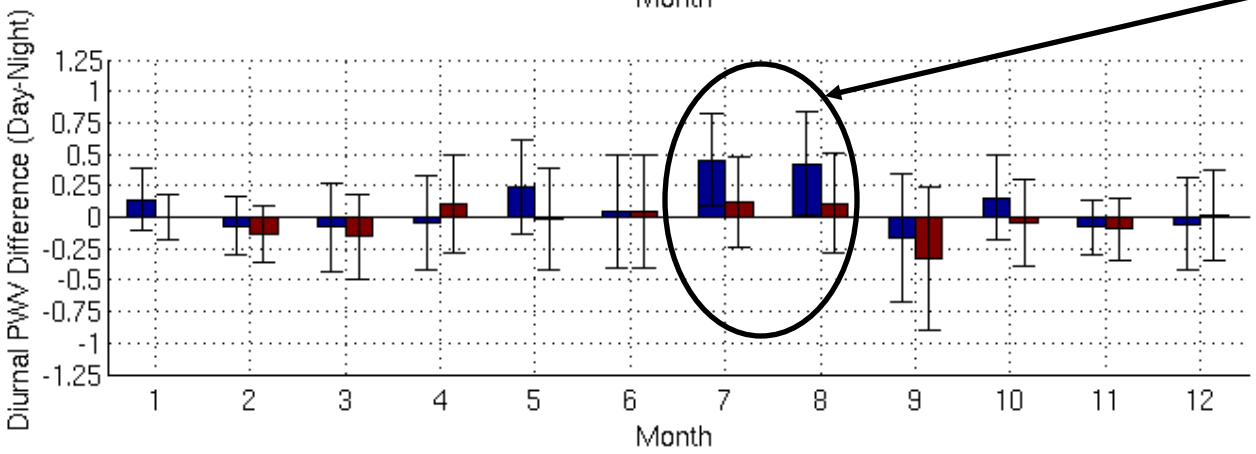
NOAA IASI Processing

2008-2009

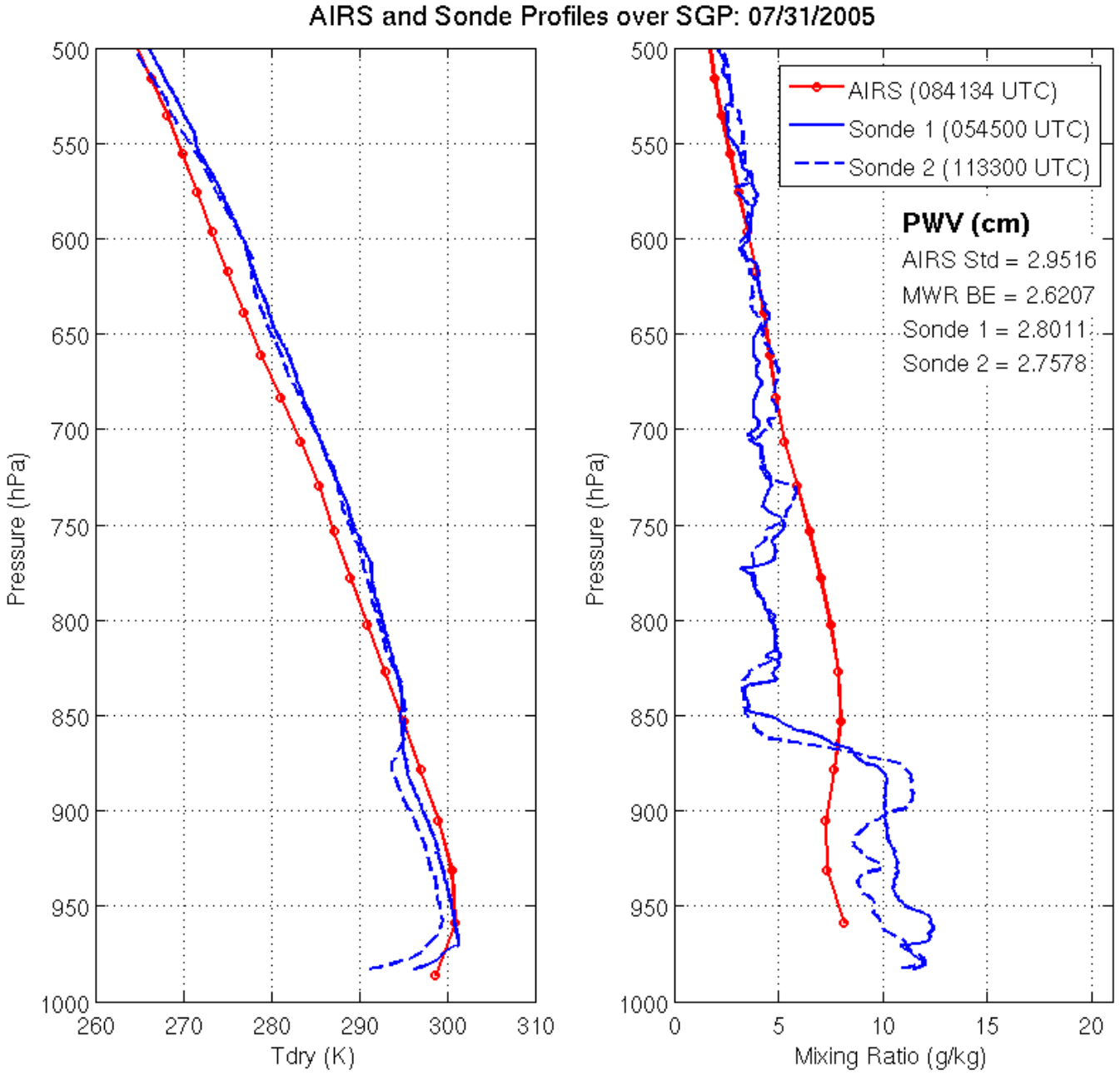
Night



Day – Night



Nighttime dry bias also present in NOAA IASI processing



AIRS

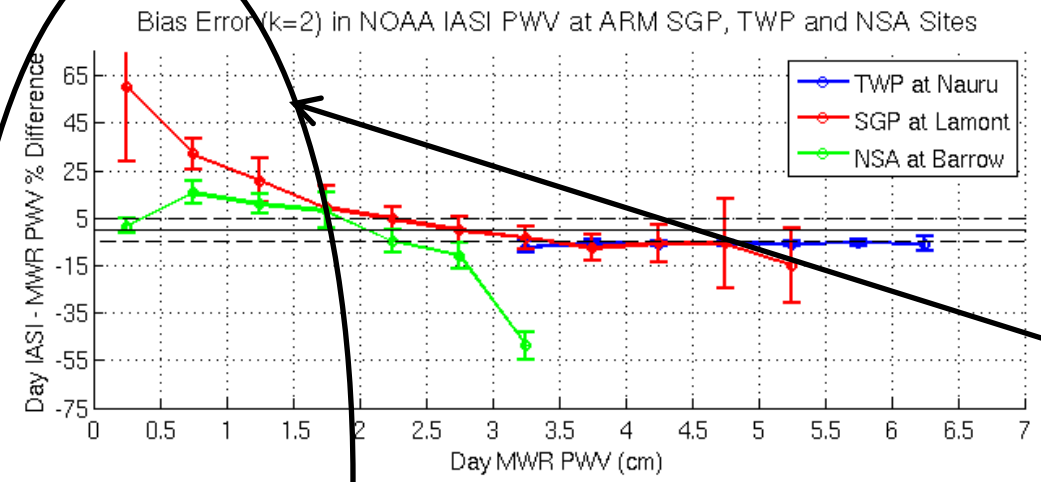
Is this evidence of Boundary Layer information loss at Night in Great Plains for high water amounts?

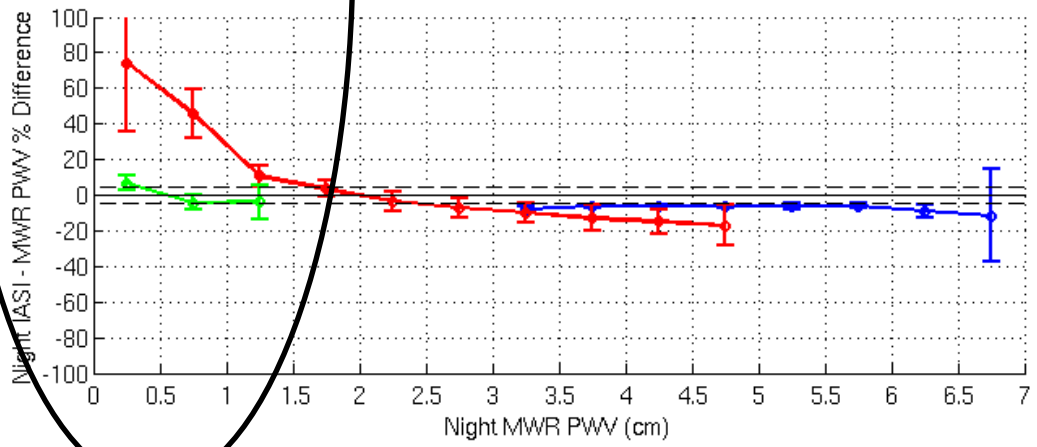
This suggests the need for a simulation study.

Wet bias for low water amounts at SGP?

DAY

NIGHT



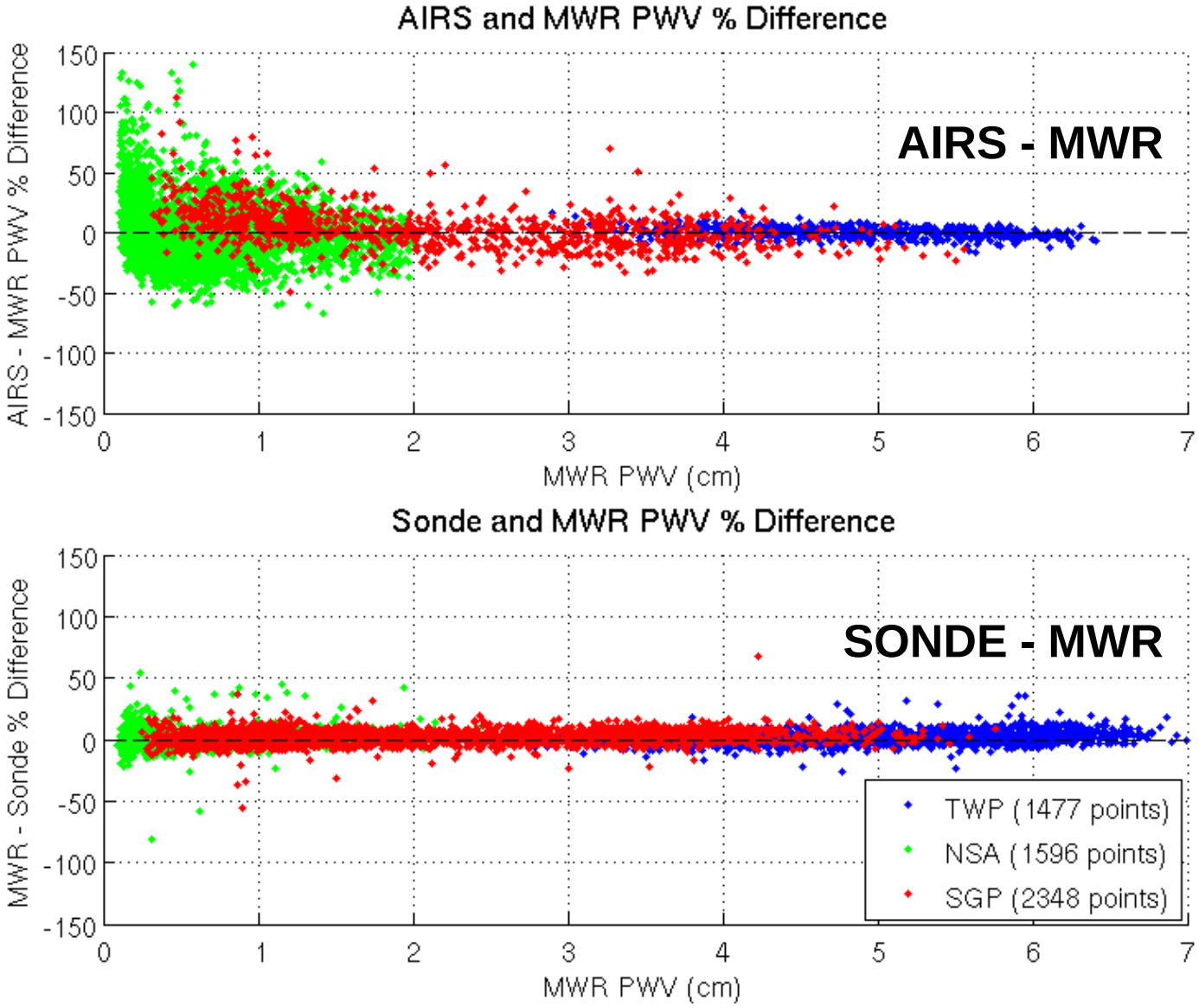


Both AIRS and IASI show a similar “wet bias” for low water amounts (< 1 cm) BUT only at the SGP land site and not at NSA.

Could this be due to a land surface emissivity effect?

The dry months are the winter months which are also the months where the bare soil is exposed in this wheat growing region.

What leads to the additional scatter in the remotely sensed data?



Point versus Satellite FOV Spatial Sampling?

The retrieval field of regard is about 45 km while the MWR is a point measurement. Note that the satellite retrievals are actually less variable in the tropics (TWP).

Preliminary Conclusions of the AIRS and IASI PWV Validation

- We were able to validate total column water vapor to 3% accuracy for nearly the entire range of terrestrial water vapor column amounts using the ARM sites for both AIRS and IASI sensors.
- *The AIRS v5 algorithm is performing well (<5%) over a wide dynamic range but with some significant diurnal biases over land which warrant further investigation.*
- IASI NOAA processing using a similar algorithm to the AIRS processing gives validation results similar to the AIRS results.
- EUMETSAT IASI operational processing produces a PWV product that has *significantly larger errors* relative to ground truth for PWV amounts for the land and arctic sites. This may be related to bias tuning and/or cloud detection methods currently used. Hopefully a reprocessing of the EUMETSAT IASI data products will bring them into closer agreement with the accuracy demonstrated by the NOAA algorithm and the AIRS science team product.
- Future work will make use of the growing groundbased GPS network to extend the analysis from point site measurements to a regional analysis.