Tropospheric Moisture Retrievals from HIRS, MODIS, and VIIRS plus CrIS

E. Eva Borbas[1], Elisabeth Weisz[1], W. Paul Menzel[1], Chris Moeller[1], and Bryan Baum[2]

[1]SSEC, University of Wisconsin-Madison, [2]Science and Technology Corporation

Contact: eva.borbas@ssec.wisc.edu

Abstract

Tropospheric moisture data records derived from HIRS and MODIS are compared from 2003 to 2013 and from VIIRS plus CrIS fusion and MODIS for one year 2017. Total Precipitable Water (TPW) and Upper Tropospheric Precipitable Water (UTPW or UTH) are derived using infrared spectral bands in CO2 and H2O absorption bands (fusion with CrIS has recently added these bands to VIIRS) plus IR window bands. Retrieval of TPW and UTH uses a statistical regression algorithm performed using clear sky radiances (and brightness temperatures) measured over land and ocean for both day and night. TPW and UTH seasonal cycles of all three observing systems are found to be in synchronization with zonal mean values in good agreement.

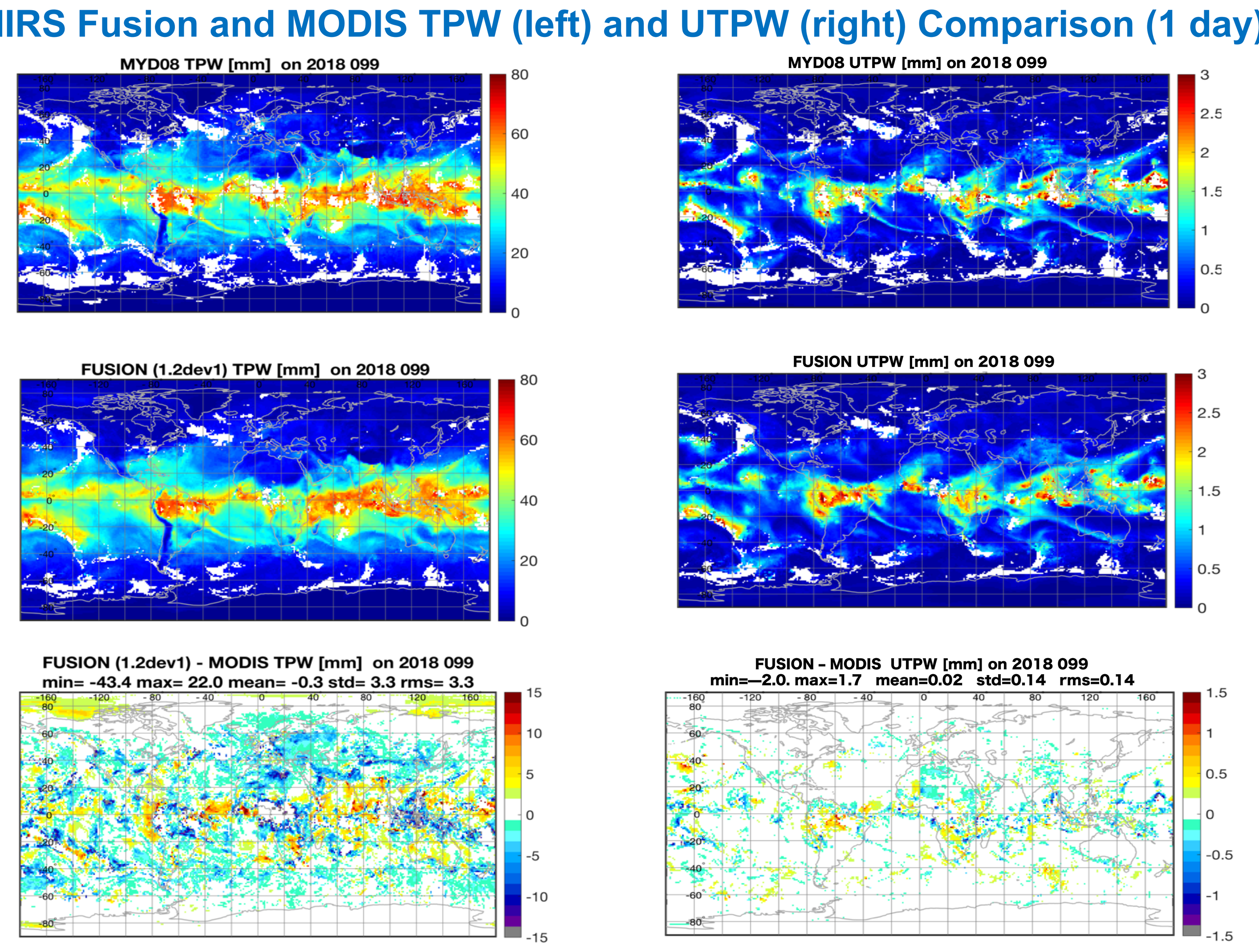
Processing Moisture Products

All three moisture records include total column precipitable water vapor (TPW) as well as integrated high (UTH), mid, and low layer tropospheric precipitable water vapor. The statistical regression is developed from an atmospheric profile database that consists of geographically and seasonally distributed radiosonde, ozonesonde, and ECMWF reanalysis data. TPW and UTH are determined for clear sky radiances (and brightness temperatures, BTs) over land and ocean for both day and night at 1 deg spatial resolution with monthly average values for one of four possible time periods daily (night before and after midnight and day before and after noon), compiled for the operational months of each satellite. The regression coefficients are generated using calculated synthetic radiances and the matching atmospheric profile. The regression seeks a "best-fit" atmospheric profile that is computed using least squares methods applied to actual measurements; integration over the total column yields the TPW water and integration from 400 to 10 hPa gives the UTH. The Aqua MODIS and S-NPP VIIRS equator crossing time have been maintained at 13:30 Local Time (LT); HIRS on NOAA-16, -18, and -19 cross from 14:00 to 15:00 LT during their operational lifetimes. VIIRS plus CrIS fusion products are compared to MODIS for one year in 2017 (below) and HIRS and MODIS are compared from 2003 to 2013 (right).

VIIRS plus CrIS Fusion Creating MODIS-like Radiances

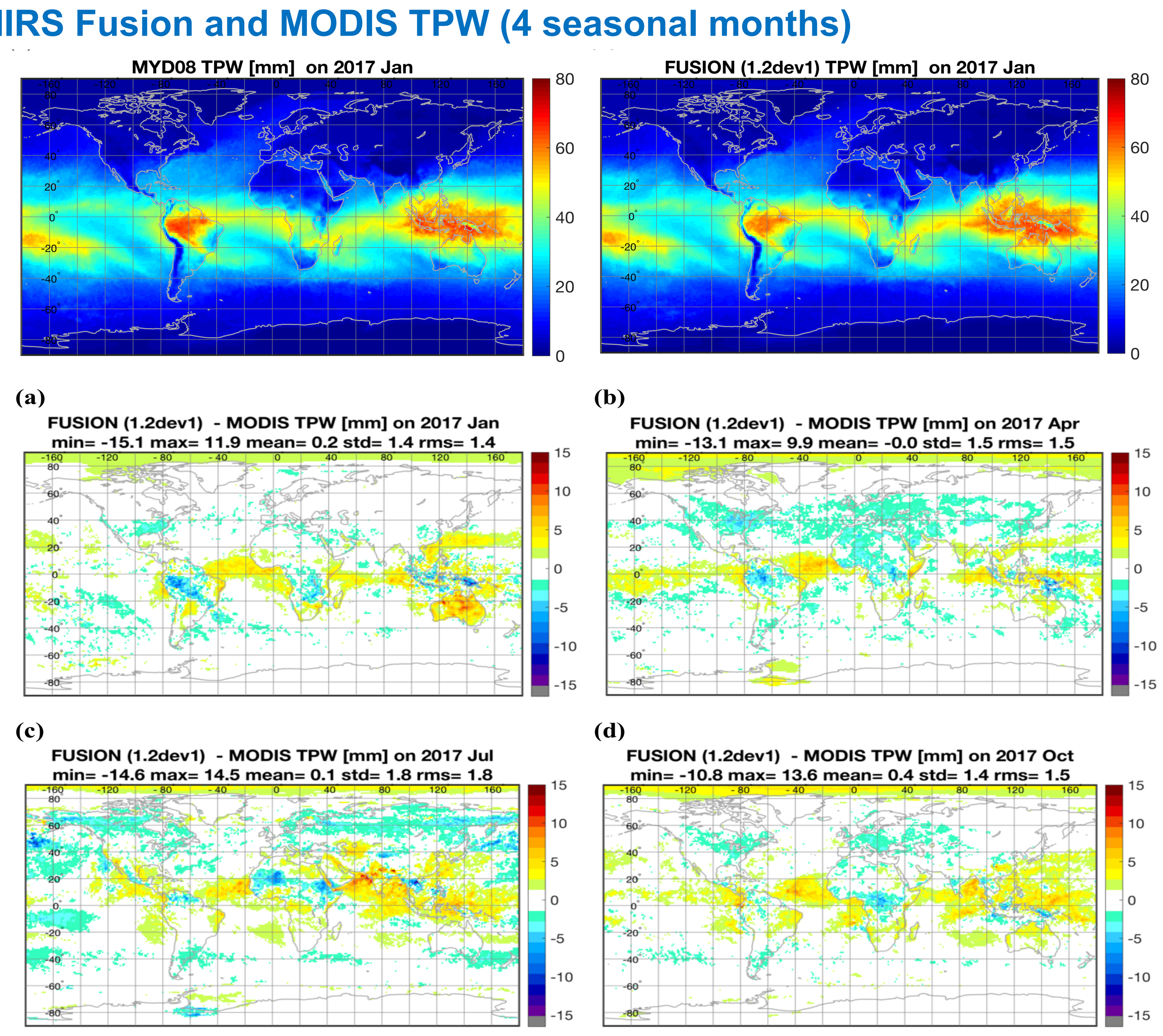
Retrieval of atmospheric WV properties from VIIRS measurements from S-NPP is accomplished using IR absorption bands constructed through fusion with the CrIS data. Weisz et al. (2017) demonstrated a fusion method to construct IR water vapor and carbon dioxide absorption band radiances for VIIRS at 750m spatial resolution. Mean clear-sky VIIRS+CrIS fusion minus MODIS BT differences are found to less than 0.5 K (1.0 K) for MODIS CO2 (H2O) for IRW BTs ranging from 200 to 280 K.

VIIRS Fusion and MODIS TPW (left) and UTPW (right) Comparison (1 day)



Global one day mean of TPW derived from the VIIRS+CrIS is found to be 0.3 mm too low with a scatter of 3.3 mm when compared to the MYD08 TPW; VIIRS+CrIS is a bit higher in the tropics and lower in the mid-latitudes. UTPW derived from the VIIRS+CrIS is found to be 0.02 mm higher with a scatter of 0.14 mm when compared to the MYD08 UTPW. Local differences of ±1 mm are found in the tropics.

VIIRS Fusion and MODIS TPW (4 seasonal months)



VIIRS+CrIS TPW differences with respect to MYD08 TPW are shown for January, April, July, and October 2017. Mean agreement ranges from 0.0 mm in April and 0.4 mm in October; the standard deviation is largest in July at 1.8 mm. Local VIIRS+CrIS overestimations occur over Australian deserts in January and during the Indian monsoon in July; underestimation is found in the Brazilian rainforest and the ITCZ in January and the Saharan desert in July. Overall VIIRS+CrIS TPW agrees very well with MODIS TPW for all four months representing the four seasons.

References:

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Acknowledgements:

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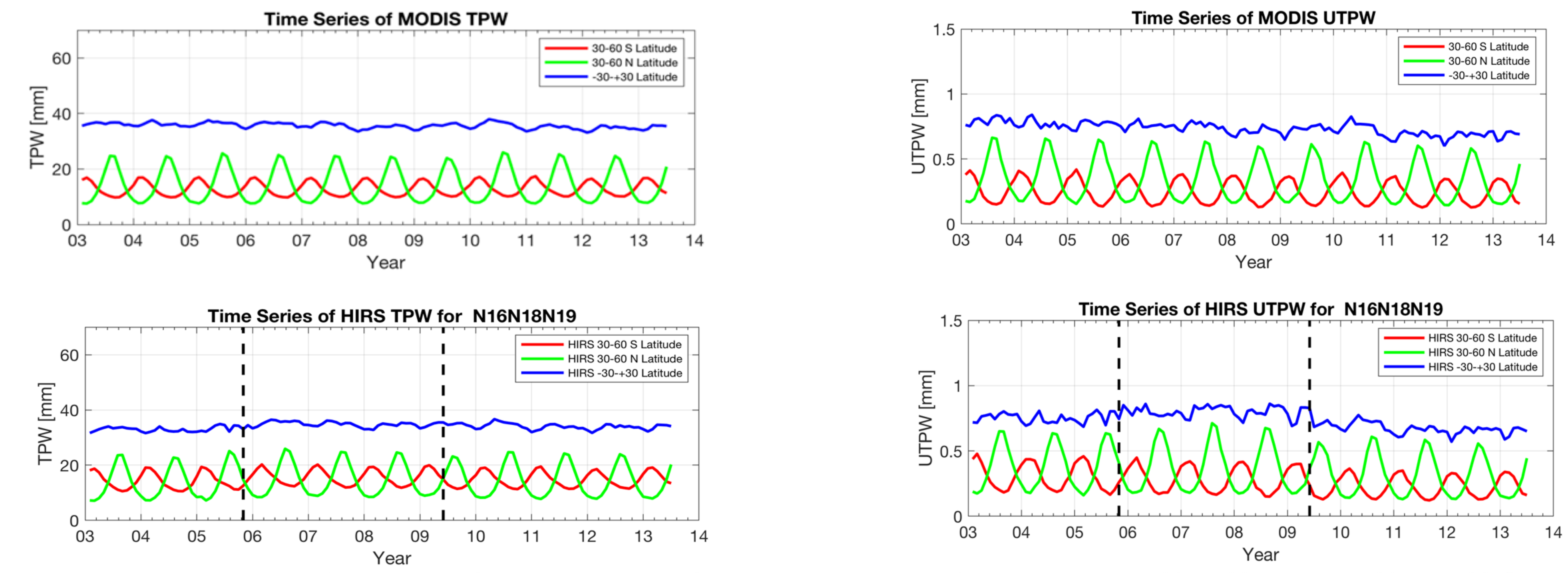
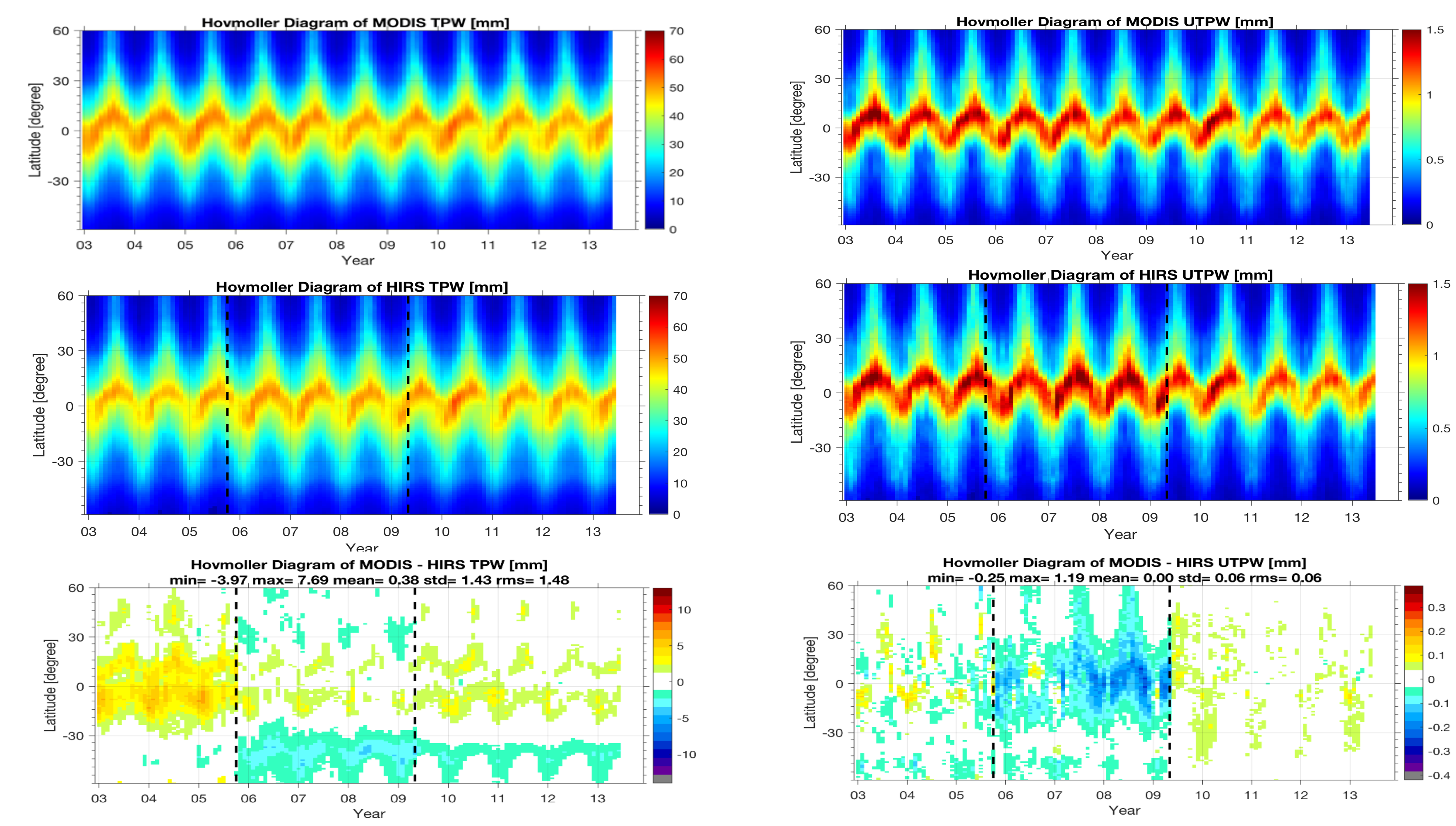
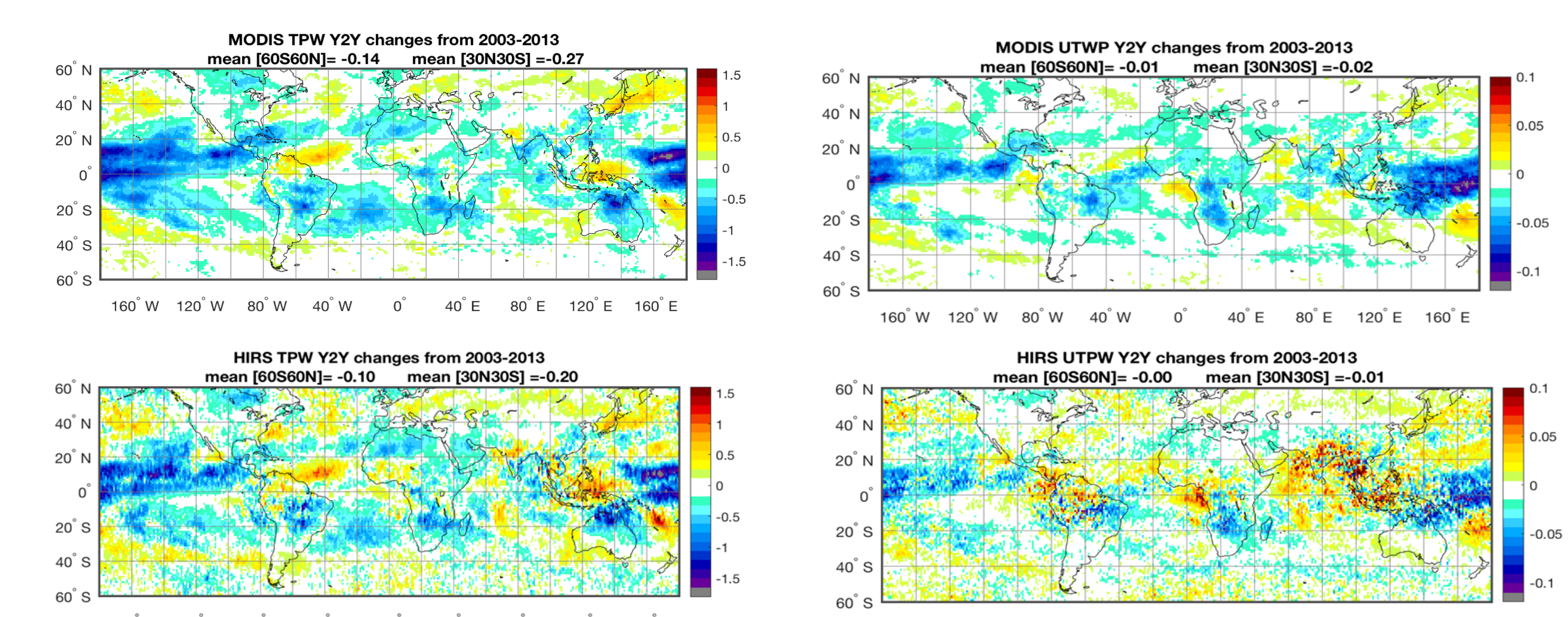
HIRS and MODIS TPW (left) and UTPW (right) Comparison (11 yrs)



Month to month changes in TPW detection for each instrument for three latitude bands (mid latitude north 30 to 60 N, tropics 30 N to 30 S, and mid latitude south 30 to 60 S). Tropical TPW stays relatively constant in time (for MODIS ~36 mm and for HIRS ~34 mm). In both, northern mid-latitude TPW maxima occur in sync with southern mid-latitude TPW minima; the northern mid-latitudes have a wetter maximum as well as a drier minimum each year (seasonal change of 17 mm) compared to the southern mid-latitudes (seasonal change of 7 mm). Month to month changes in UTPW detected by MODIS and HIRS show similar features. Tropical UTPW has no discernible seasonal change, northern mid-latitude UTPW seasonally varies (seasonal change of 0.45 mm) out of synchronization with the southern mid-latitude UTPW (0.22 mm). Dotted lines show HIRS transition years.



The largest TPW values are found in the tropics, with a seasonal maximum in the northern hemisphere in the mid-year (June–July–August, JJA) that shifts to the southern hemisphere six months later (December–January–February, DJF). Both MODIS and HIRS show a strong seasonal fluctuation, with the mid-year northern hemisphere maximum somewhat stronger than the southern hemisphere maximum six months later. Differences between HIRS and MODIS TPW are found to be as large as 5 mm (roughly 10%); this is mostly occurring for NOAA-16 where the larger HIRS/3 18 km FOV is introducing more of a dry bias (by roughly 2 mm) with fewer clear sky determinations in and around clouds than the NOAA-18 and -19 HIRS/4 10 km FOV, especially in the tropics. Differences in the Hovmoller plot of less than 6 mm are within the expected standard deviation. Topical UTPW shows a strong seasonal movement north in JJA and south in DJF. MODIS UTPW is greater than HIRS for NOAA-16 and -19 by 0.1 mm (roughly 7%) and too dry for NOAA-18 by 0.3 mm (~20%) . Dotted lines show the HIRS transition years.



Year-to-year TPW and UTPW changes for the twelve months are averaged to produce maps of mean changes over the time period of the study. TPW decreases as large as 1.0 mm per year are noticeable (Figure 9) in the equatorial Pacific Ocean with increases of 0.5 mm per year in the Indonesian region; more decrease is apparent in the southern hemisphere than the northern hemisphere. HIRS sees mostly the same pattern, but is noisier because of the larger HIRS FOV and more possible cloud contamination (with the less accurate cloud mask). The average TPW decrease in the Tropics is 0.27 mm for MODIS and 0.20 mm for HIRS. UTPW, following the lead of TPW, shows a similar geographical distribution of decrease and increase. The HIRS UTPW year to year changes are again noisier than those from MODIS; both show a mean UTPW decrease of about 0.01 mm. As has been pointed out in the literature, the clear sky constraint imposed on infrared TPW and UTPW determinations is necessarily introducing a dry bias by avoiding the cloudy regions associated with higher humidity.

Conclusions

- TPW & UTPW retrieved from hyperspectral sounder CrIS measurements and provided at VIIRS high spatial resolution (750m) from Suomi-NPP compare favorably with collocated operational Aqua MODIS moisture products.
- For January 2017, global mean of VIIRS+CrIS fusion TPW is 0.2 mm too high with a scatter of 1.4 mm when compared to the MYD08 TPW. TPW results are similar for a month in each season of 2017 (Jan, Apr, Jul, & Oct).
- VIIRS+CrIS UTPW, now possible with the addition of the fusion radiances, is within 10% of the MYD08 UTPW in mean and scatter for the same four months.
- While limited in scope, these one year findings demonstrate fusion IR absorption spectral bands enable generation of moisture products that offer record continuation from MODIS and previous generations of polar orbiting satellite sensors.
- HIRS and MODIS Hovmoller plots for 2003 to 2013 suggest overall good qualitative agreement in the seasonal changes with max disagreements of 5 mm in TPW and 20% in UTPW amounts
- MODIS and HIRS tropospheric moisture records compare very well implying that HIRS TPW and UTPW determinations from the MODIS years can be a bridge to the years of HIRS data that go back to 1980.
- TPW and UTPW seasonal cycles of all three observing systems are in synchronization with zonal mean values for 1 deg latitude bands within 2.0 mm and 0.07 mm, respectively. Combining HIRS, MODIS, and VIIRS+CrIS offers a moisture record that will eventually span more than sixty years.