MODIS AP (MOD07) Webinar #7

Clear Sky Atmospheric Profiles

The Retrieval Problem and Profile Solution

Algorithm Adjustments - Resolving Some Early Issues

C6 TPW and TOZ Validation

Moisture Trends

Contents of MOD07 Output File

29 October 2014

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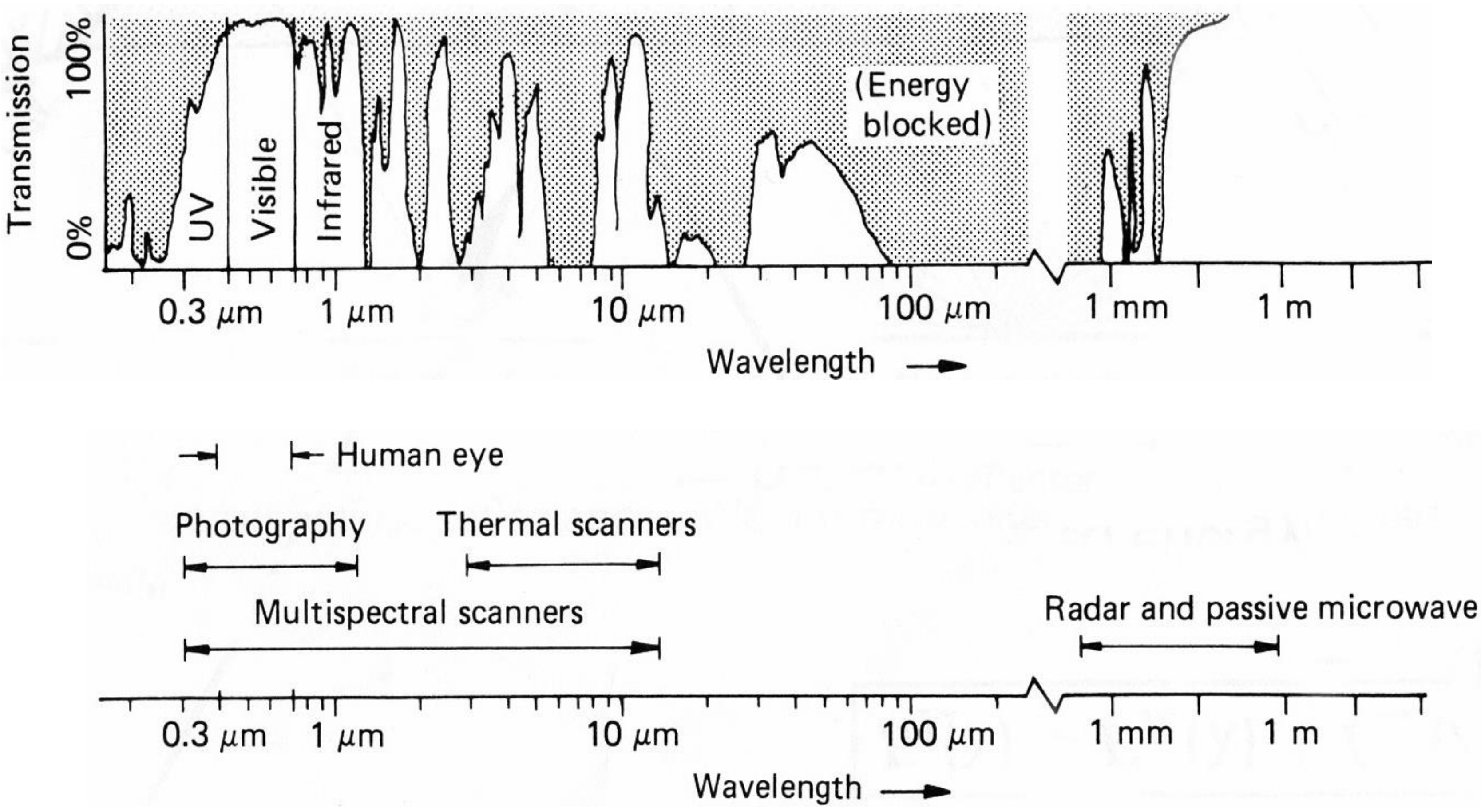
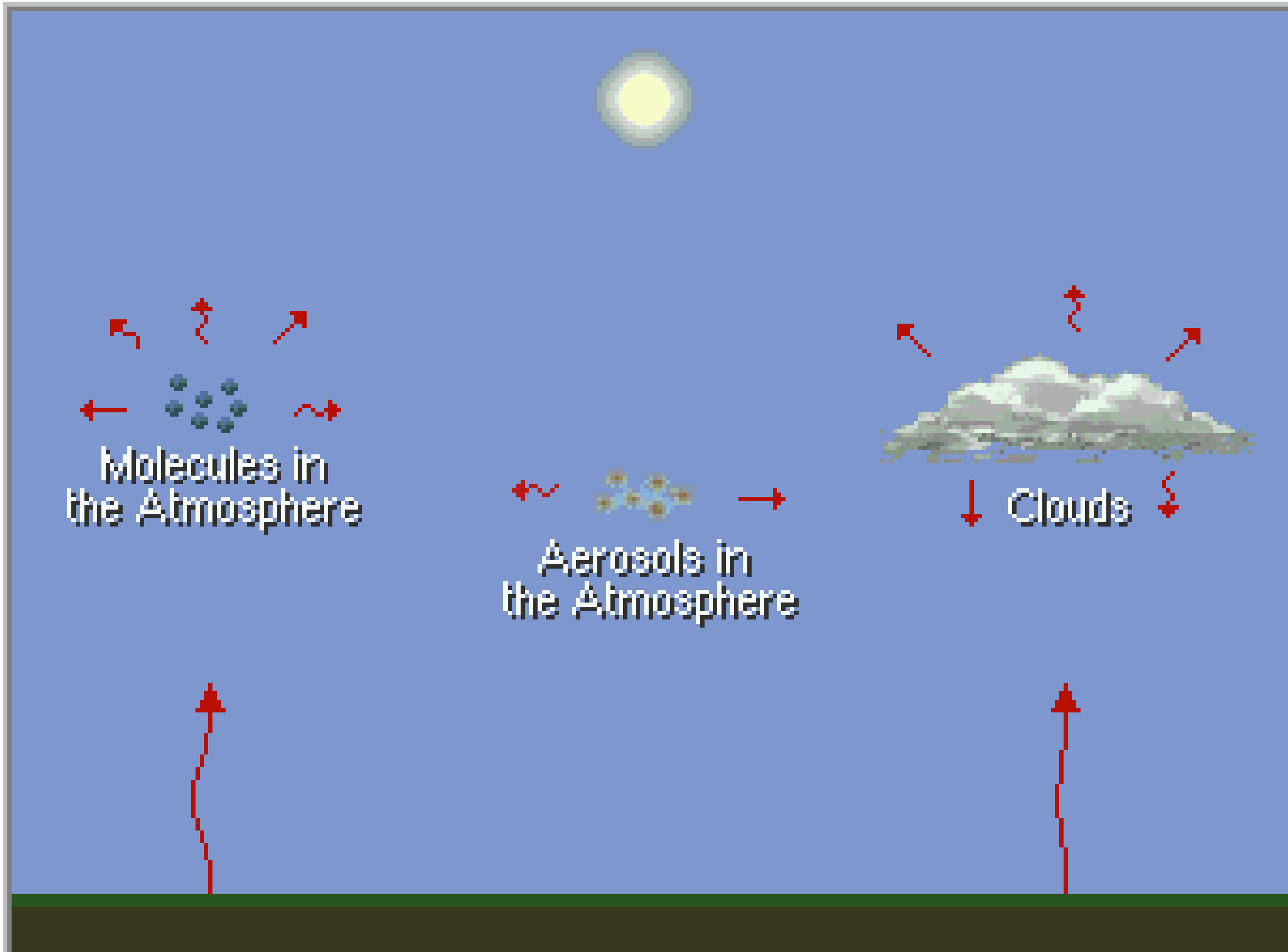
RTE and Profile Retrieval

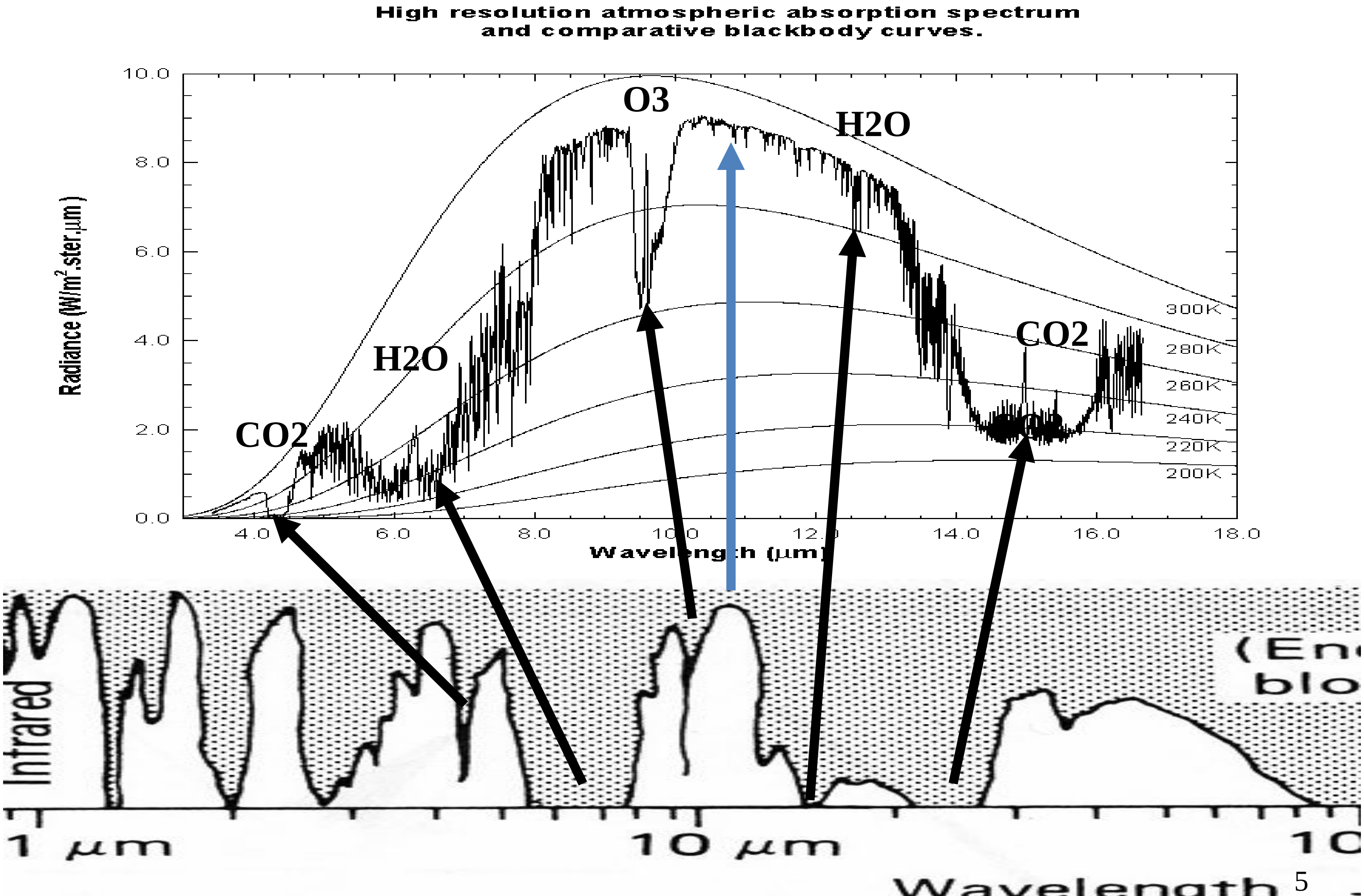
Spectral Characteristics of Atmospheric Transmission and Sensing Systems



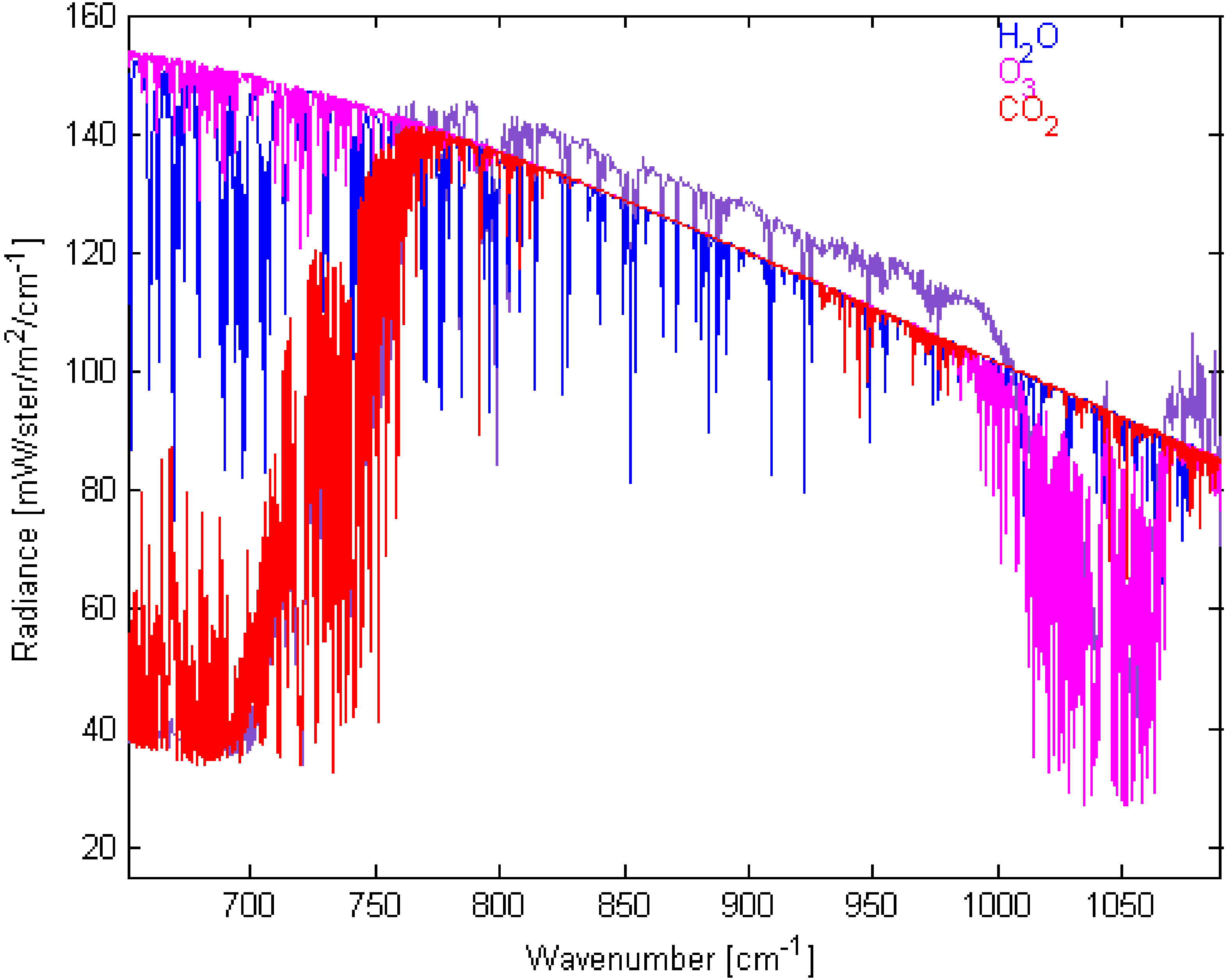
Re-emission of Infrared Radiation



Earth emitted spectra overlaid on Planck function envelopes



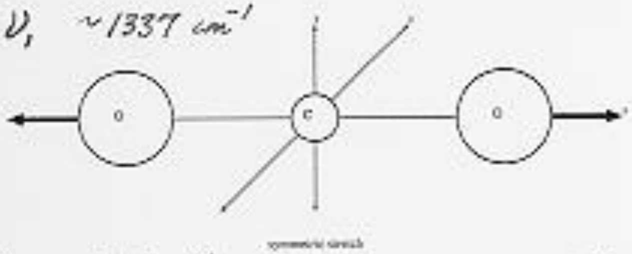
IR absorption Spectra due to CO2, H2O, O3 vibrations and rotations



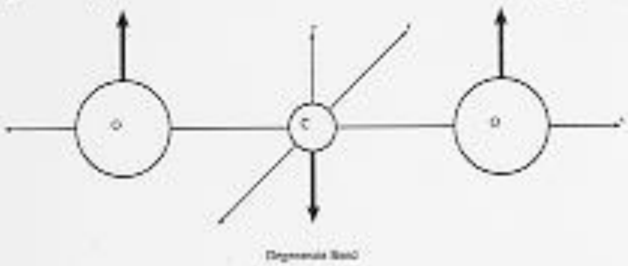
CO_2 Vibration - Rotation Spectra

$$E(v,J) = \underbrace{h\nu(v+\frac{1}{2}) - xh\nu(v+\frac{1}{2})^2 + \ldots}_{\text{vibration}} + \underbrace{B_\nu[J(J+1)-\ell^2] - D_\nu[J(J+1)-\ell^2]^2 + \ldots}_{\text{rotation}}$$

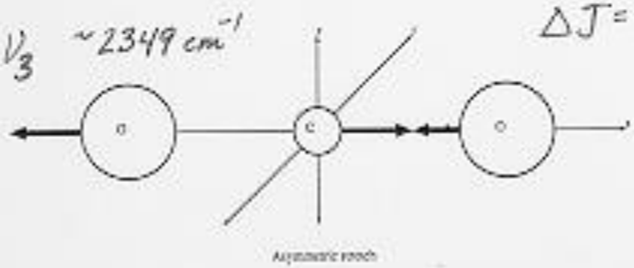
ν_1 ~1337 cm^{-1}

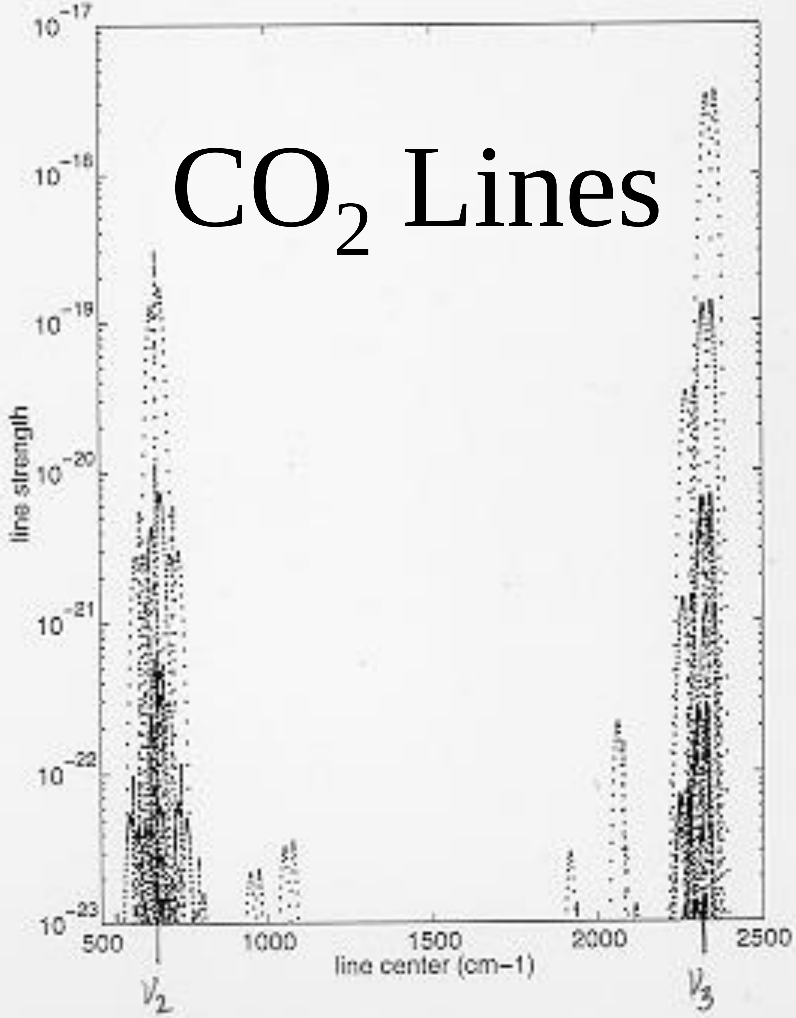


ν_2 ~667 cm^{-1} $\Delta J = 0, \pm 1$

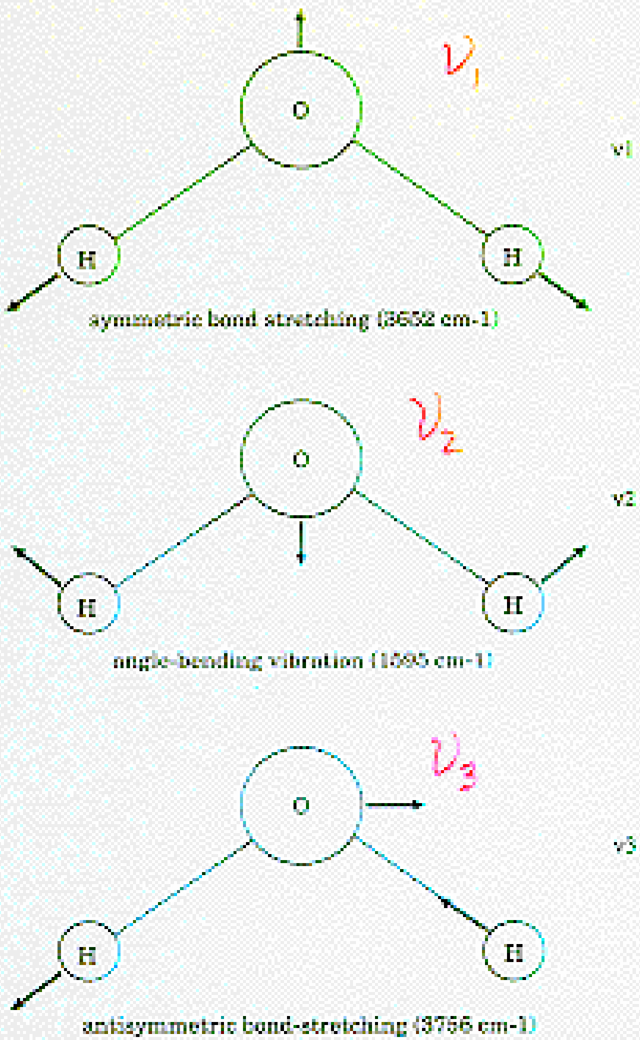


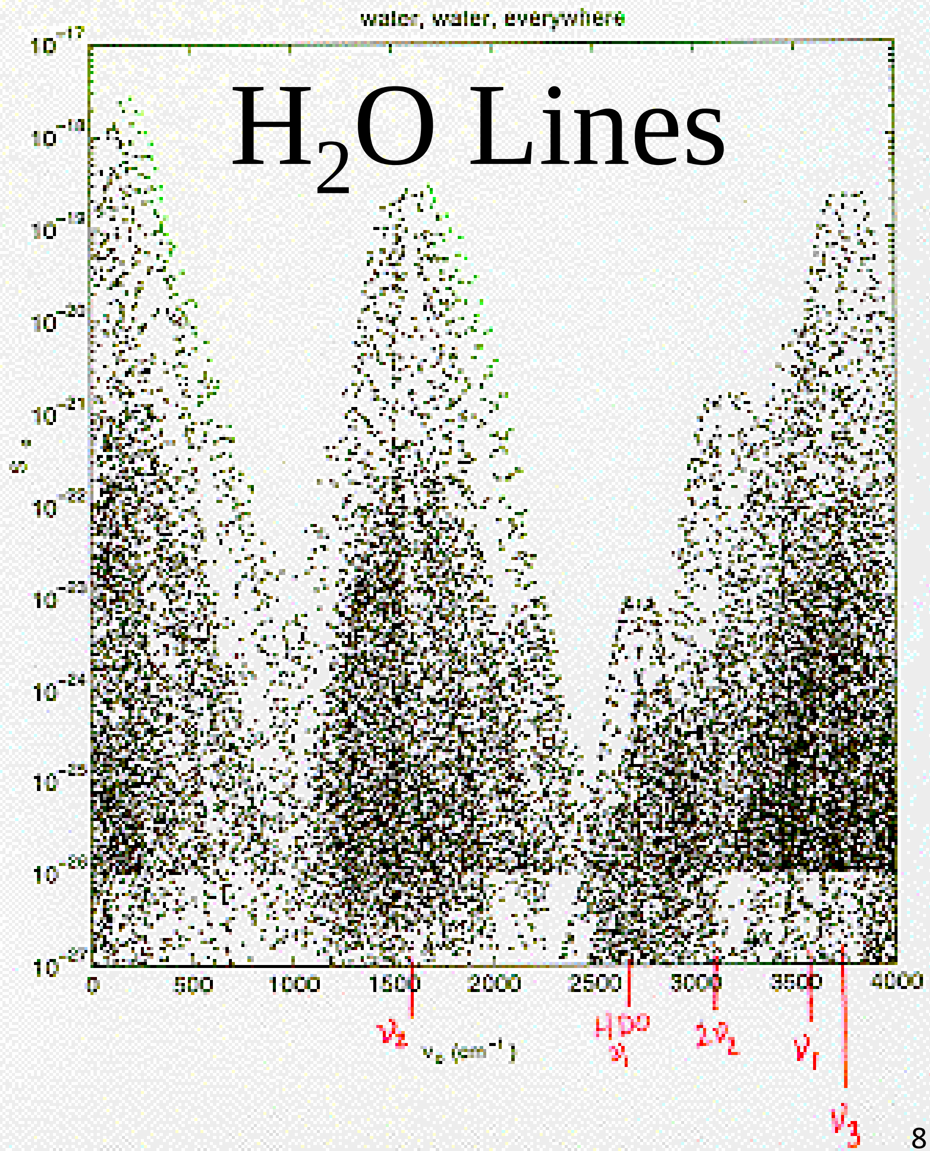
ν_3 ~2349 cm^{-1} $\Delta J = \pm 1$





H_2O Vibration – Rotation Spectra





$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T_{sfc}) \tau_\lambda(sfc - top) + \sum_{layers} \varepsilon_\lambda^{layer} B_\lambda(T_{layer}) \tau_\lambda(layer - top)$$

The emission of an infinitesimal layer of the atmosphere at pressure p is equal to the absorption (1 - transmission). So,

$$\varepsilon_\lambda(layer)\, \tau_\lambda(layer\ to\ top) = [1 - \tau_\lambda(layer)]\, \tau_\lambda(layer\ to\ top)$$

Since transmission is multiplicative

$$\tau_\lambda(layer\ to\ top) - \tau_\lambda(layer)\, \tau_\lambda(layer\ to\ top) = -\Delta\tau_\lambda(layer\ to\ top)$$

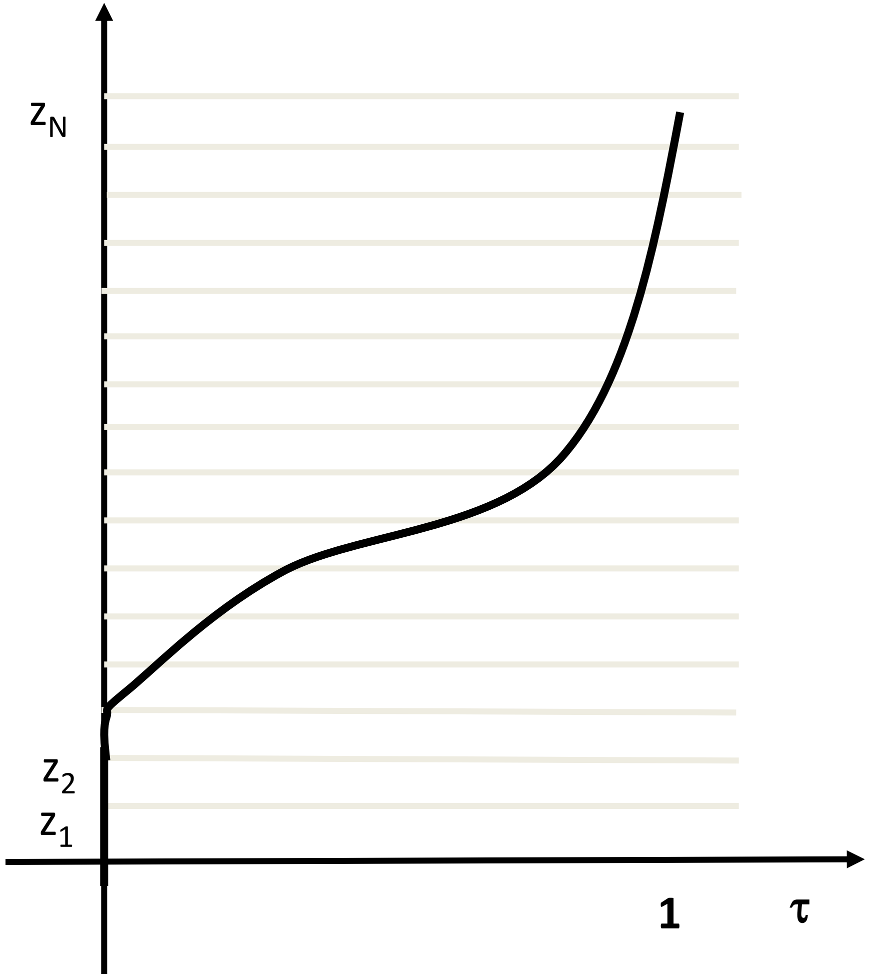
So we can write

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) - \sum_{p} B_\lambda(T(p))\, \Delta\tau_\lambda(p)\ .$$

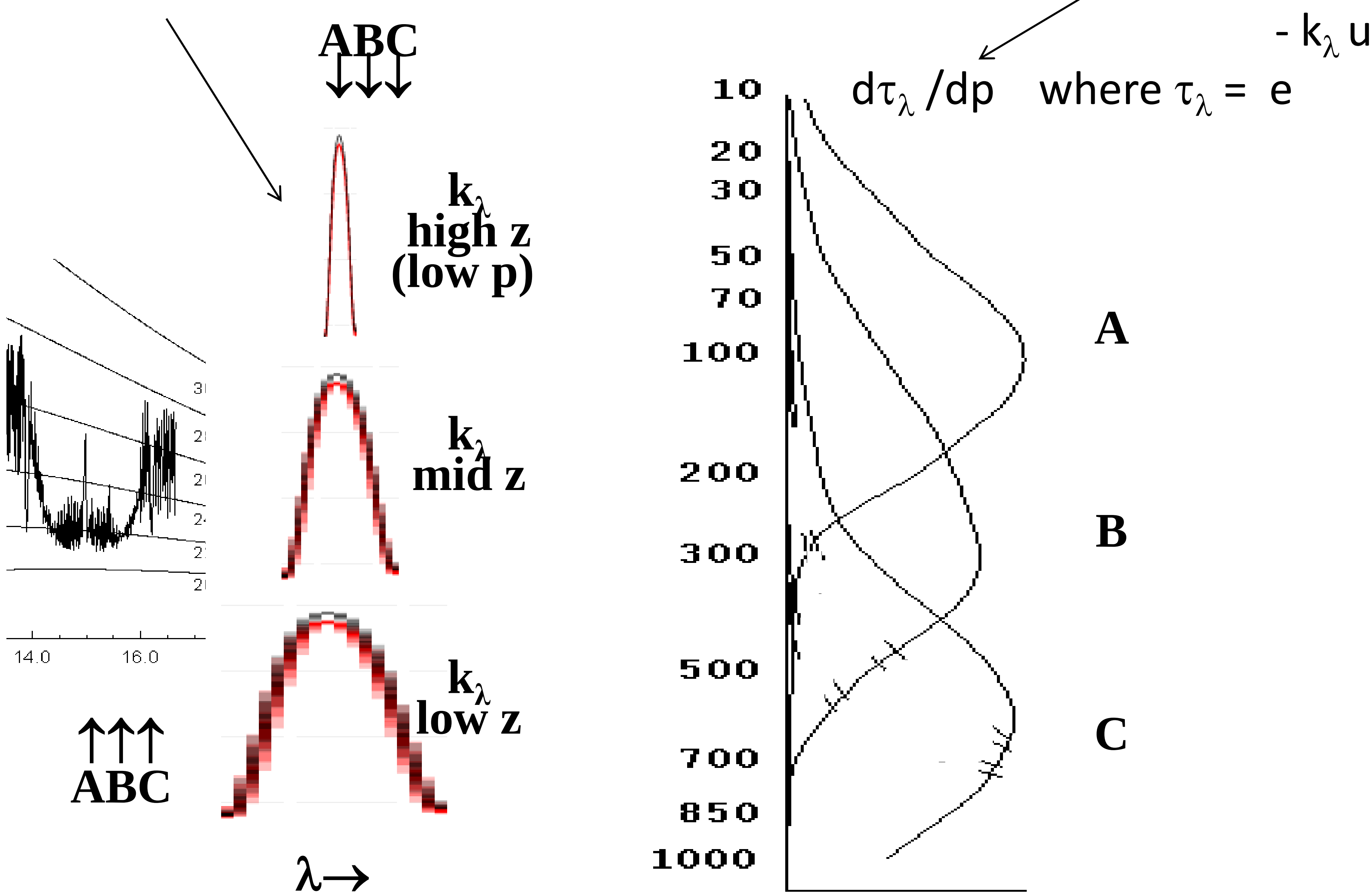
which when written in integral form reads

$$I_\lambda = \varepsilon_\lambda^{sfc} B_\lambda(T(p_s))\, \tau_\lambda(p_s) - \int_{o}^{p_s} B_\lambda(T(p))\, [\, d\tau_\lambda(p) / dp \,]\ dp\ .$$

Weighting Functions

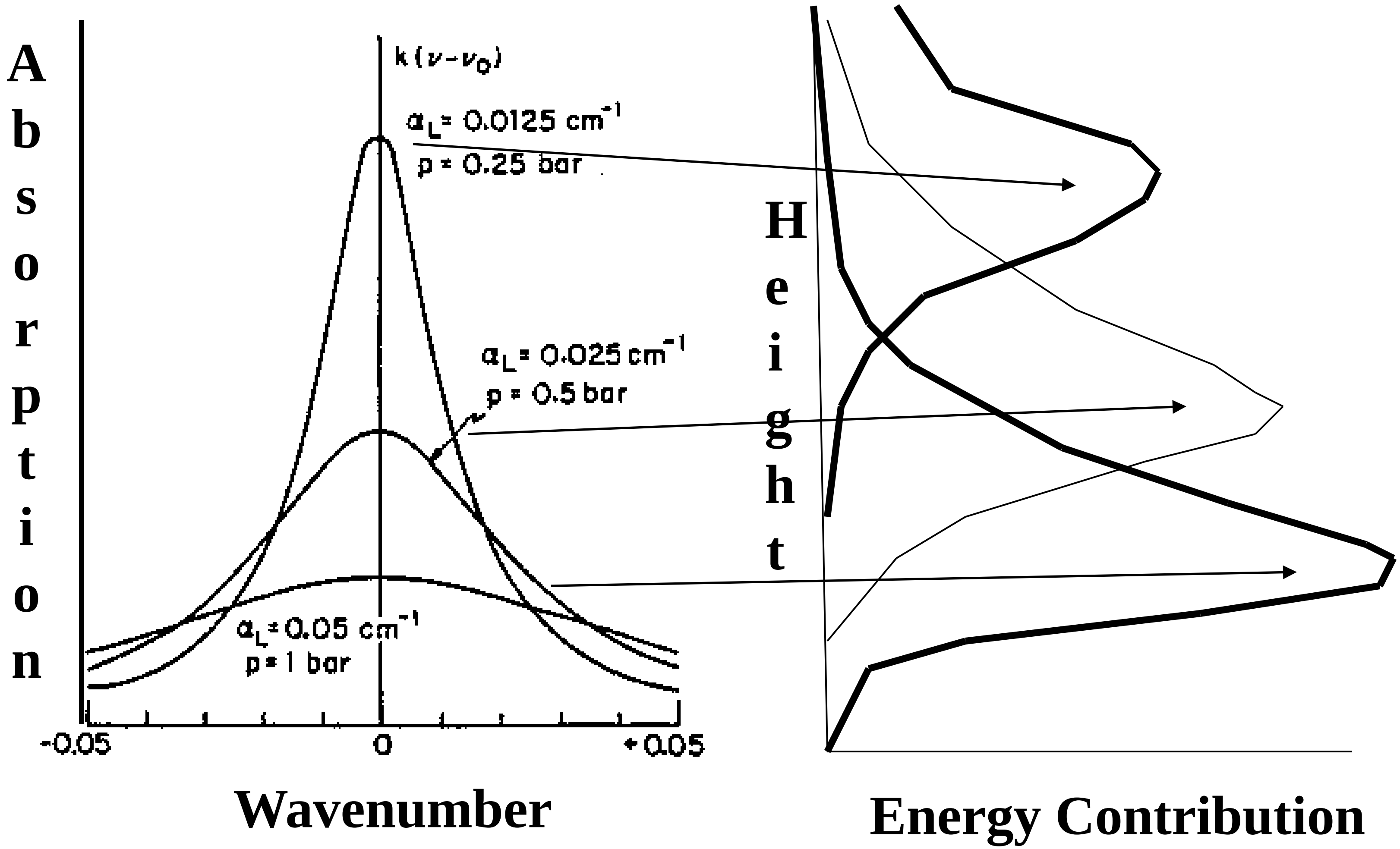


line broadening with pressure explains weighting function locations

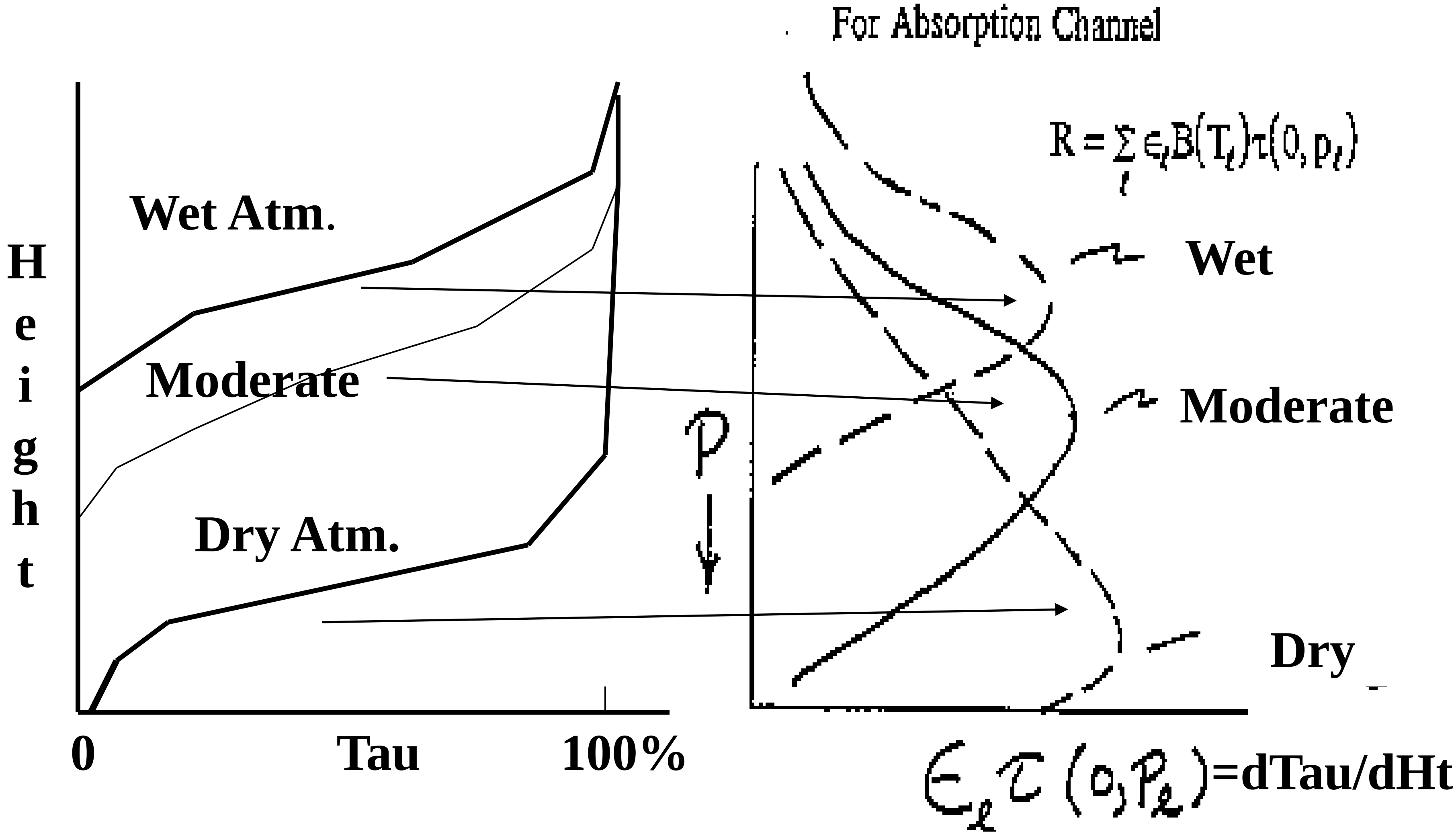


line broadening with pressure helps to explain weighting functions

$$\tau_\nu (z \rightarrow \infty) = e^{-k_\nu u(z)}$$

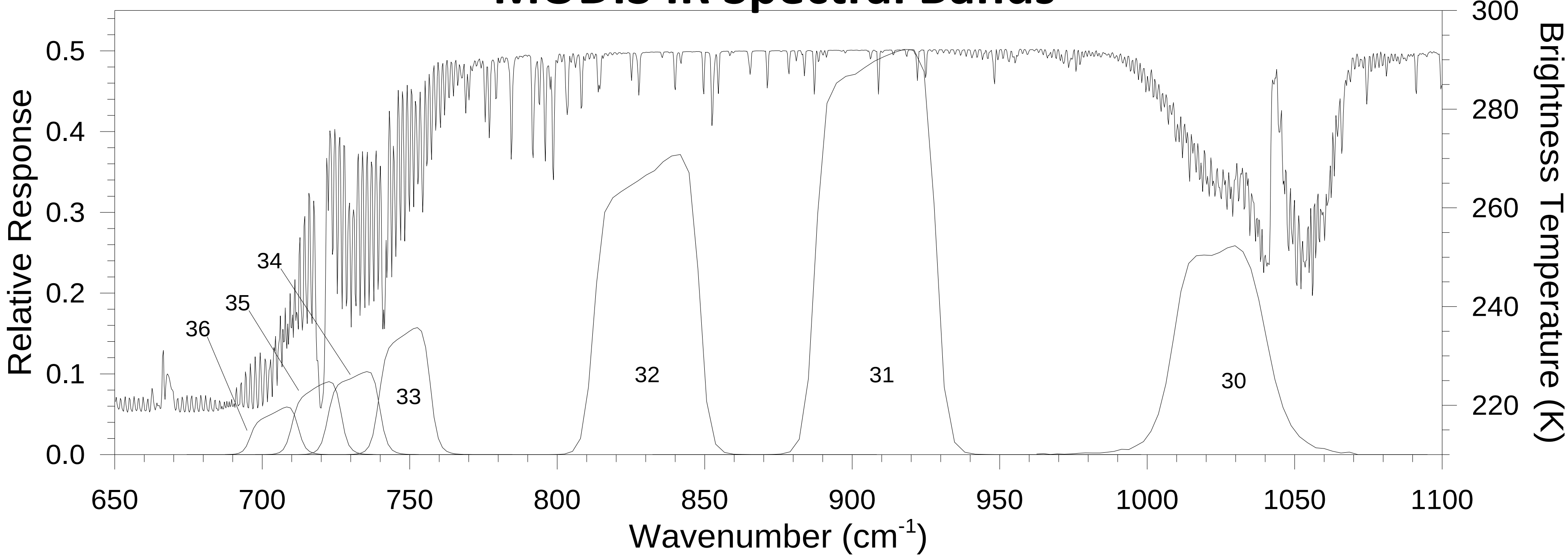


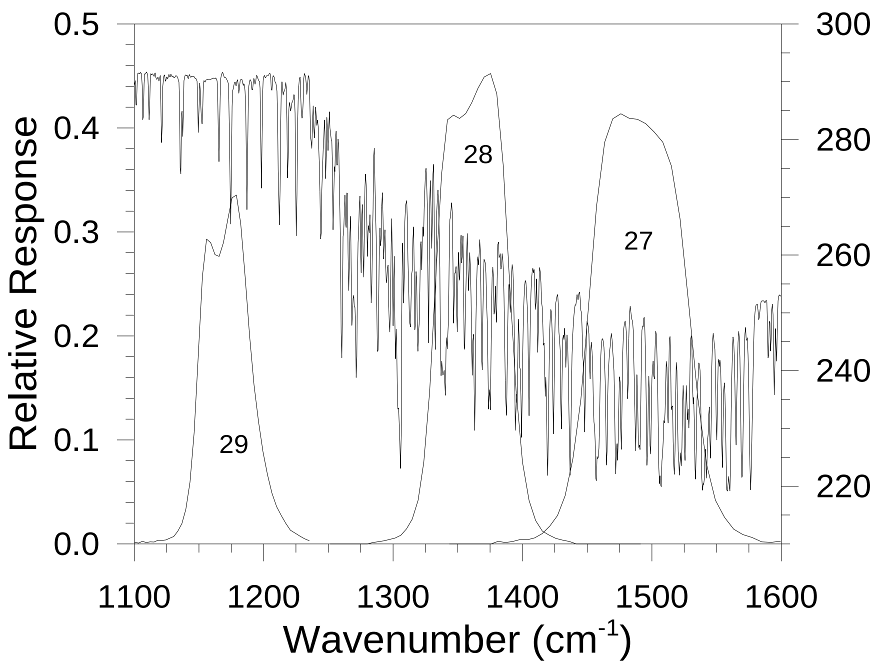
For a given water vapor spectral channel the weighting function location depends on the amount of water vapor in the atmospheric column

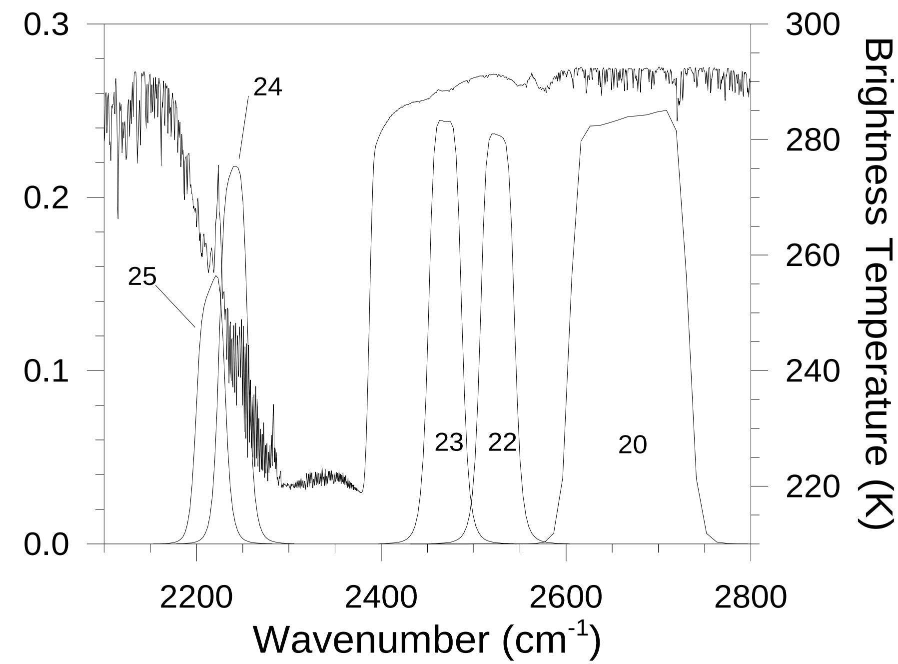


CO2 is about the same everywhere, the weighting function for a given CO2 spectral channel is the same everywhere

MODIS IR Spectral Bands







When reflection from the earth surface is also considered, the Radiative Transfer Equation for infrared radiation can be written

$$I_\lambda = \boldsymbol{\varepsilon_\lambda^{sfc}}\, B_\lambda(T_s)\, \tau_\lambda(p_s) + \int_{p_s}^{o} B_\lambda(T(p))\, F_\lambda(p)\, [d\tau_\lambda(p)/\, dp]\, dp$$

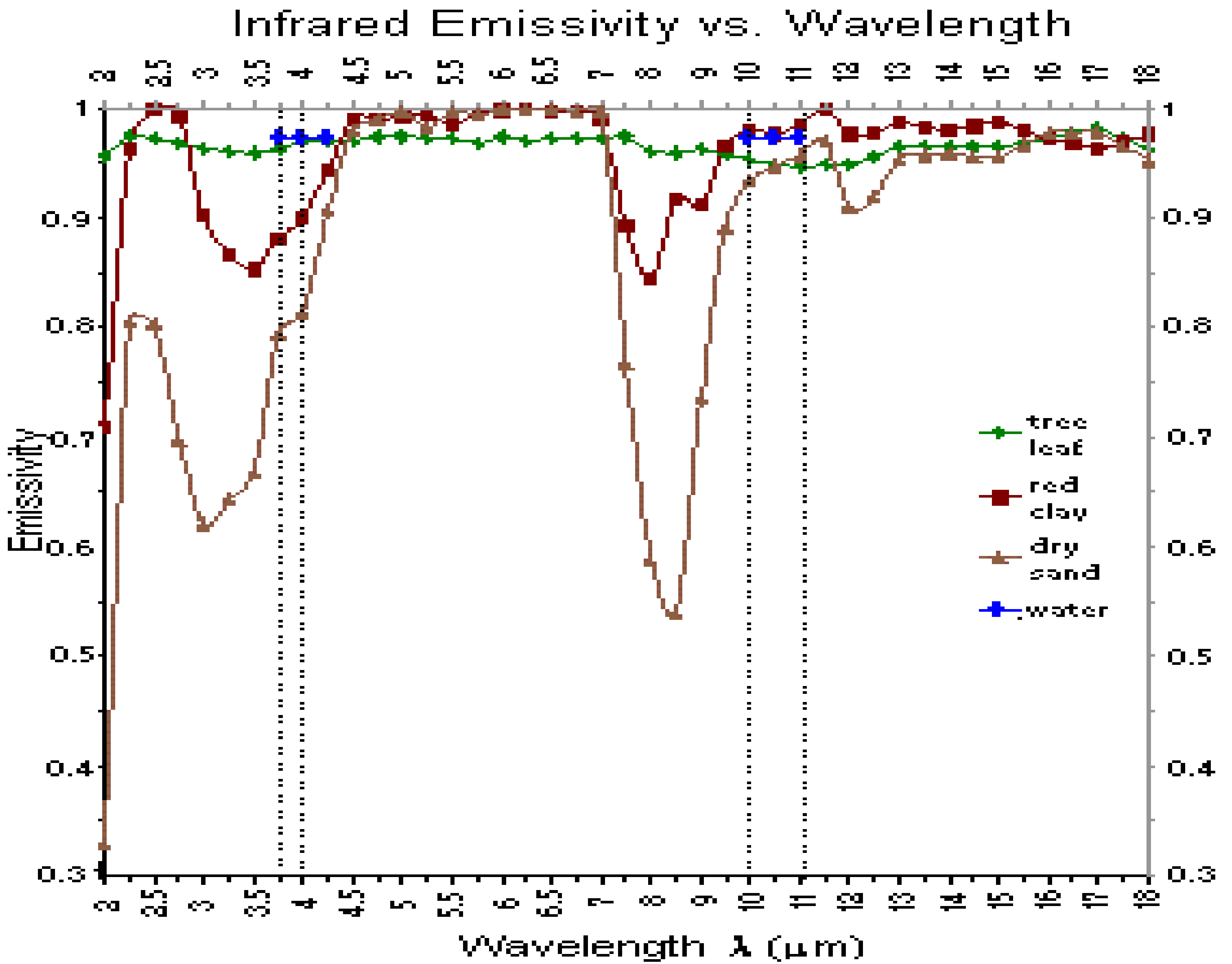
where

$$F_\lambda(p) = \{ 1 + (\mathbf{1 - \varepsilon_\lambda^{sfc}})\, [\tau_\lambda(p_s) / \tau_\lambda(p)]^2 \}$$

since $\tau\downarrow(a,b) = \tau\uparrow(a,b)$ commutative
and $\tau(a,b) * \tau(b,c) = \tau(a,c)$ associative

The first term is the spectral radiance emitted by the surface and attenuated by the atmosphere, often called the boundary term and the second term is the spectral radiance emitted to space by the atmosphere directly or by reflection from the earth surface.

The atmospheric contribution is the weighted sum of the Planck radiance contribution from each layer, where the weighting function is [$d\tau_\lambda(p) / dp$]. This weighting function is an indication of where in the atmosphere the majority of the radiation for a given spectral band comes from.


Infrared Emissivity vs. Wavelength
Emissivity
Wavelength λ (µm)
tree leaf
red clay
dry sand
water
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
8
9
10
11
12
13
14
15
16
17
18

PND/COMET

Primary Atmospheric Application	Band	Bandwidth[1]	$T_{typical}$ (K)	Radiance[2] at $T_{typical}$	NE∆T (K) Required
Temperature profile	25	4.482-4.549	275	0.59	0.25
Moisture profile	27	6.535-6.895	240	1.16	0.25
	28	7.175-7.475	250	2.18	0.25
	29	8.400-8.700	300	9.58	0.05
Ozone	30	9.580-9.880	250	3.69	0.25
Surface Temperature	31	10.780-11.280	300	9.55	0.05
	32	11.770-12.270	300	8.94	0.05
Temperature profile	33	13.185-13.485	260	4.52	0.25
	34	13.485-13.785	250	3.76	0.25
	35	13.785-14.085	240	3.11	0.25
	36	14.085-14.385	220	2.08	0.35

MODIS TPW, UTH, & TOZ

- MODIS TPW, UTH, and TOZ retrievals are based on a statistical regression developed from the SeeBor data base (Borbas et al. 2005) that consists of geographically and seasonally distributed radiosonde, ozonesonde, and ECMWF ReAnalysis data.

- Retrievals are determined for clear sky radiances measured by MODIS over land and ocean both day and night (Seemann et al. 2003, Seemann et al. 2008).

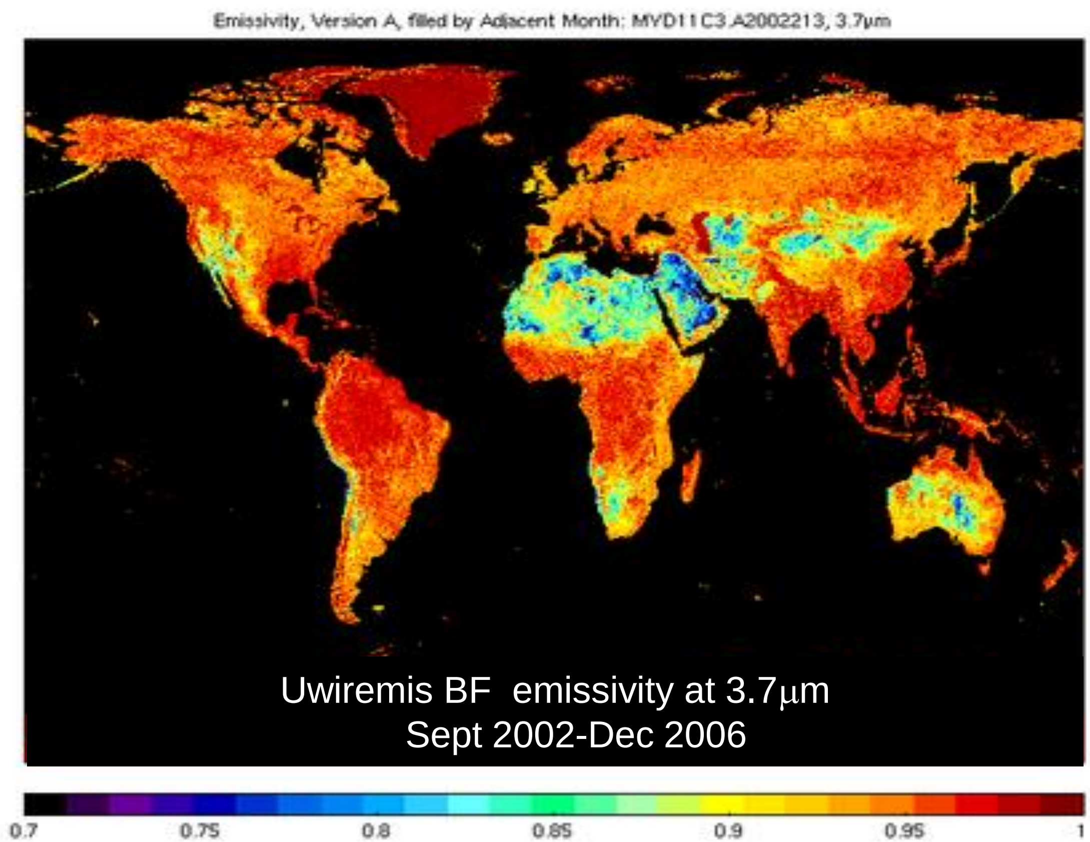
* MOD35 cloud mask algorithm (Ackerman et al. 1998) is used to identify pixels that are cloud free. The operational retrieval algorithm averages the clear pixels in a 5x5 field-of-view (at least 5 of the 25 pixels must be clear).

Algorithm Adjustments

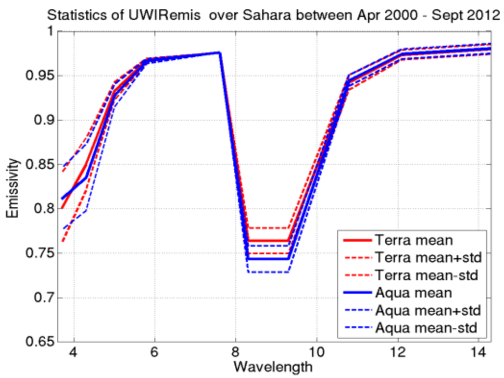
Current status of the UW Global Infrared Land Surface Emissivity Database

- Time coverage: Monthly: Oct 2002 - Dec 2006 - 4.2 years (based on MYD11 V4.0)
- Jan 2007–Dec 2013 – 7.0 years (based on MYD11 V4.1)
- Spatial Resolution: 0.05 degree ~ 5 km;
- Spectral Resolution: 10 hinge points (3.7 and 14.3 μm)
- Available: **http:/cimss.ssec.wisc.edu/iremis**

Applications/Users:
MODIS Atmospheric Retrievals (UW,NASA)
IMAPP/AIRS retrievals (UW)
GEOCAT (NOAA/CIMSS)
Climate Monitoring SAF (EUMETSAT)
AIRS Retrieval of Dust Optical Depths (UMBC/ASL)
IASI-Metop Cal/Val (CNES, France)
IASI retrieval (EUMETSAT, UW, Neteo-France))
Retrieval of hot spot data from AATSR (ESA)
Energy balance from ASTER over glacier (Univ of Milan)
AIRS trace gas retrieval (Stellenbosch University, South-Africa, JCET-UMBC)
Education (Seoul National Univ.; NTA, Konstantin)
SEVIRI water vapor retrievals (UW, EOS)
SEVIRI aerosol retrieval (Univ Oxford)
SEVIRI cloud and ozone retrieval (EUMETSAT)
SEVIRI cloud phase, cloud top parameter retrievals (KNMI)
LST retrievals from GOES-R (NOAA NESDIS)
OSS calculations (AER)
AIRS NWP model assimilation (UKMO)



Ten years of the UW high spectral resolution global IR land surface emissivity (UWIREMIS) database



The UW BF emissivity database is available at:

http://cimss.ssec.wisc.edu/iremis/

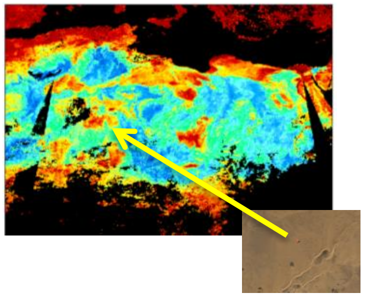
It covers the time from early postlaunch onwards

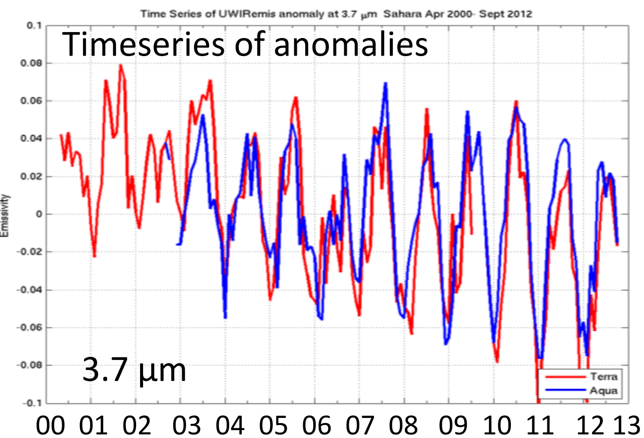
Terra: Apr 2000 – Sept 2012 / Aqua: Sept 2002– Sept 2012

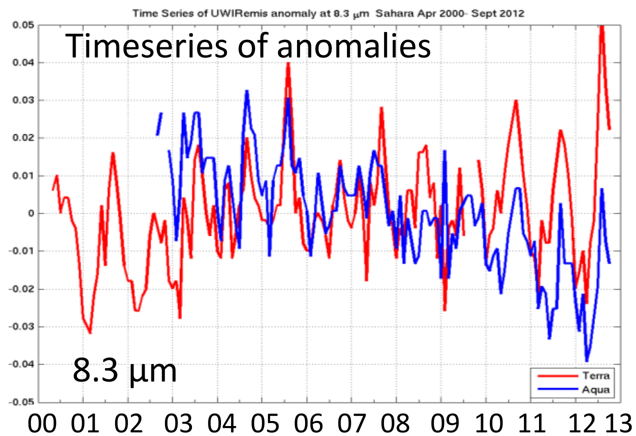
Collection 6 updated in 2013.

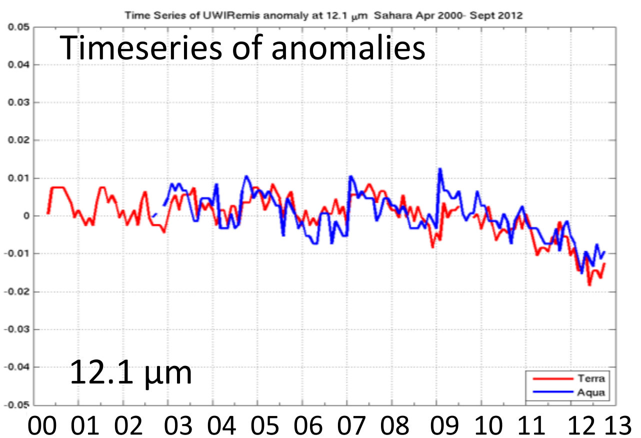
Over 160 users are internationally distributed

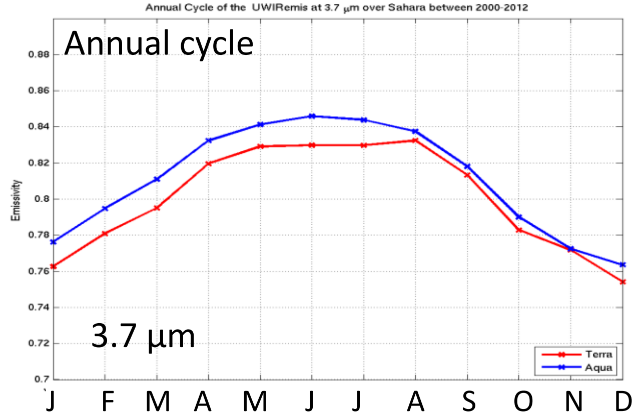
The UWIREMIS module was implemented into RTTOV10 and has been available since Jan 2012.

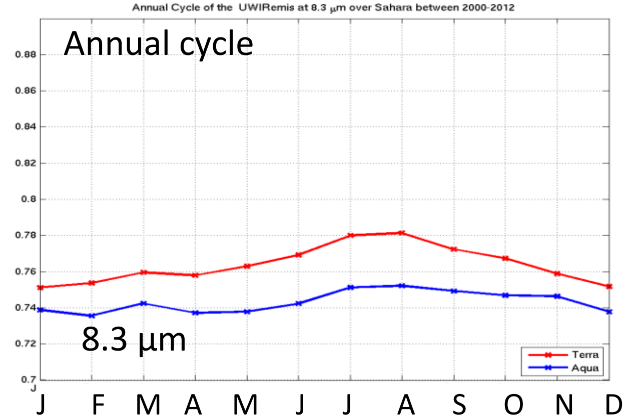


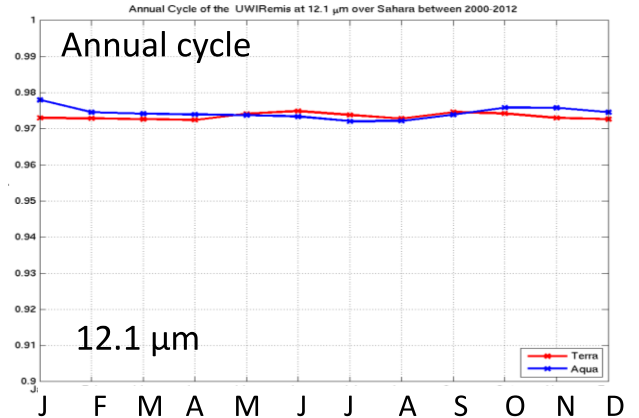










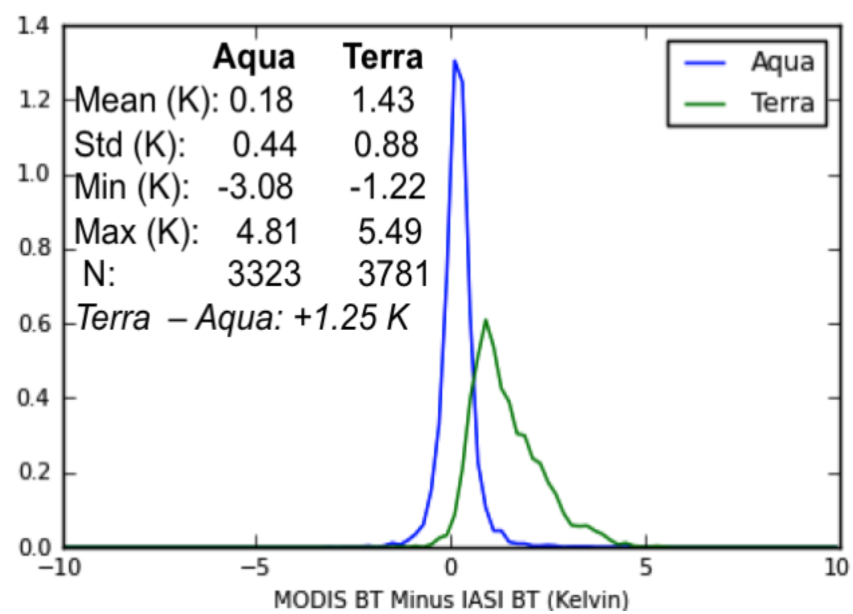


Predictor	Noise used in MOD07 algorithm (Terra)	Noise used in MOD07 algorithm (Aqua)
Band 25 BT(4.52mm)	0.063 ^{o}K	0.055 ^{o}K
Band 27 BT (6.7mm)	0.411^{o}K	0.145 ^{o}K
Band 28 BT (7.3mm)	0.184^{o}K	0.129 ^{o}K
Band 29 BT (8.55mm)	0.035^{o}K	0.043 ^{o}K
Band 30 BT (9.73mm)	0.139^{o}K	0.110 ^{o}K
Band 31 BT (11mm)	0.041^{o}K	0.026 ^{o}K
Band 32 BT (12mm)	0.047^{o}K	0.039 ^{o}K
Band 33 BT (13.3mm)	0.151 ^{o}K	0.082 ^{o}K
Band 34 BT (13.6mm)	0.234 ^{o}K	0.115 ^{o}K
Band 35 BT (13.9mm)	0.266 ^{o}K	0.146 ^{o}K
Band 36 BT (14.2mm)	0.428^{o}K	0.209 ^{o}K
Surface Pressure	5 hPa	5 hPa
Latitude	0.0	0.0
Month	0.0	0.0
Percent Land	0.0	0.0

Band	Terra Shift (cm-1)	Aqua Shift (cm-1)
27	4	5
28	2	2
30	1	0
34	0.8	0.8
35	0.8	0.8
36	1	1

SRF shifts
suggested by
IASI intercomparisons

Band 30
MODIS minus IASI BT
Intercomparisons
before shift

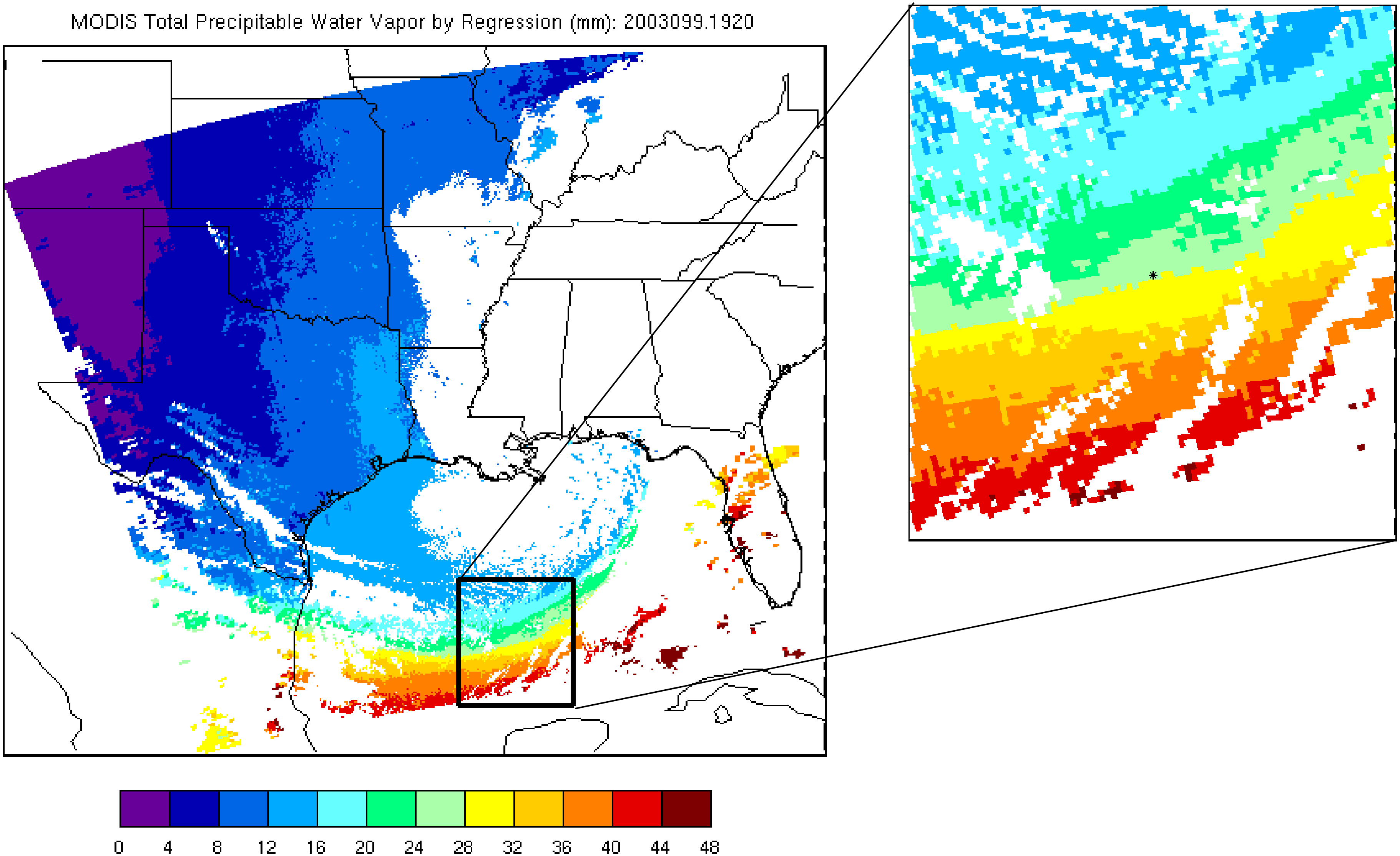


Product Validation

Total Precipitable Water (TPW)

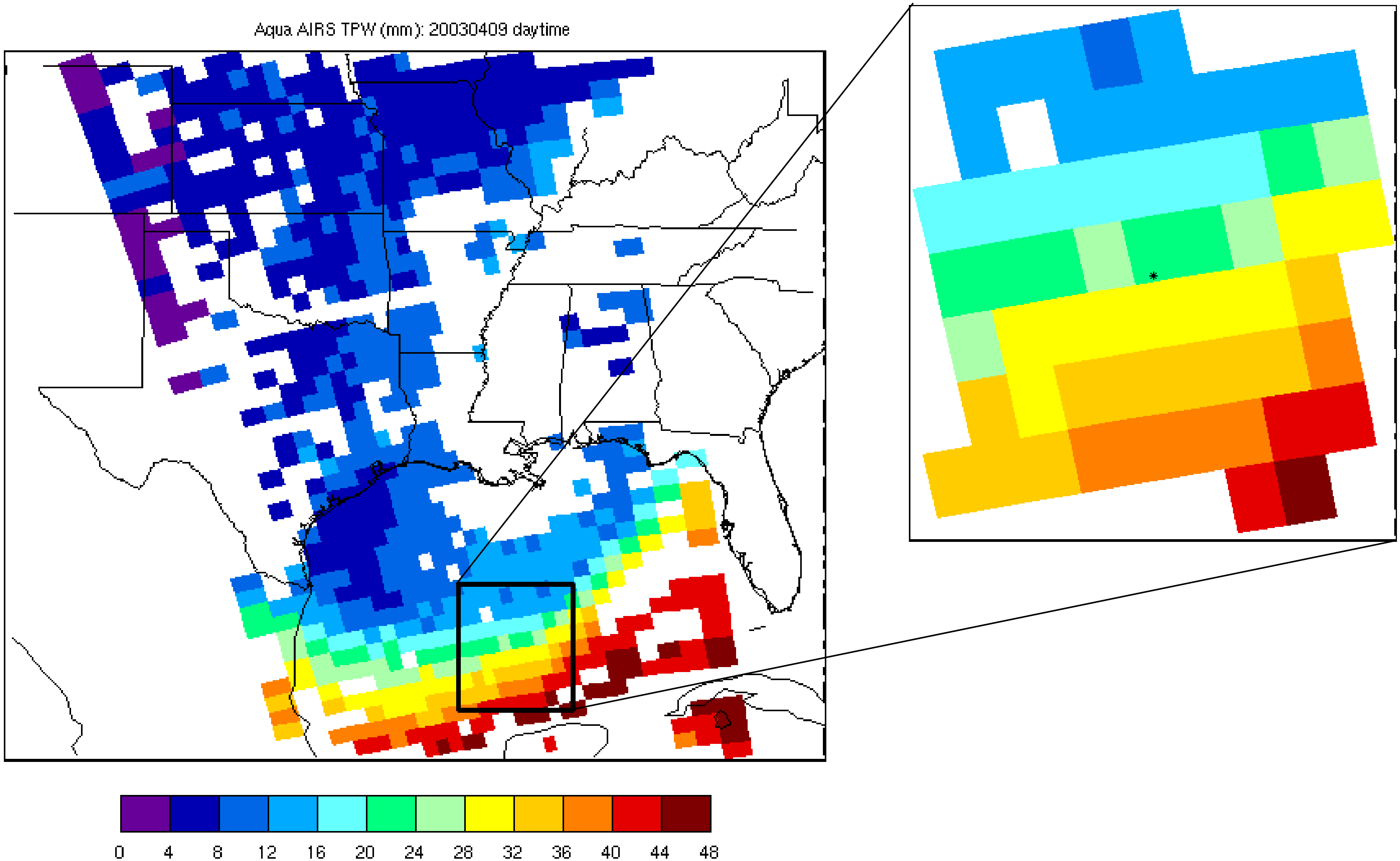
Total Ozone (TOZ)

Aqua AIRS / MODIS MOD07 Comparison



MOD07 Collection 5 TPW

AIRS TPW (Granule #s 193 & 194)



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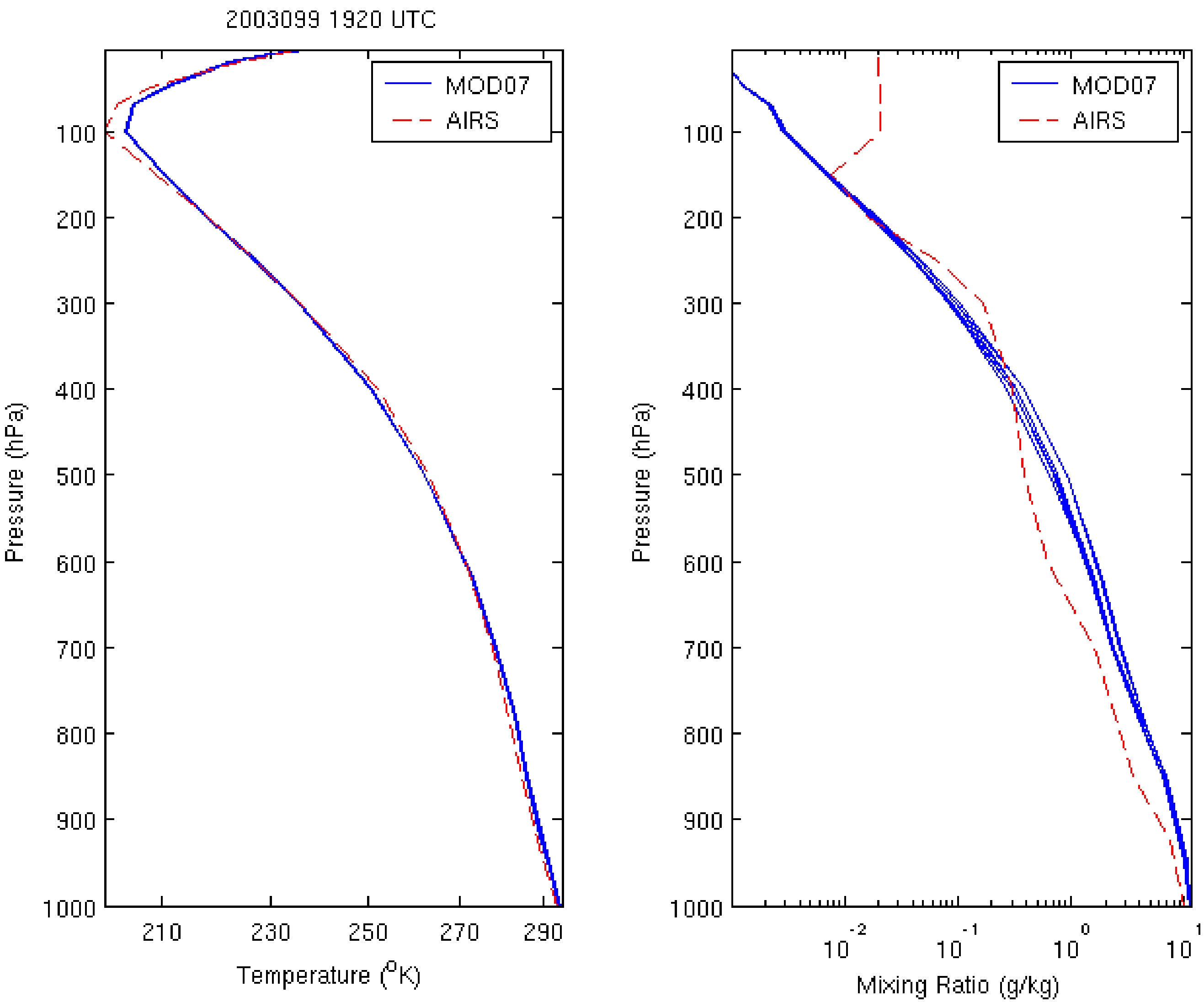
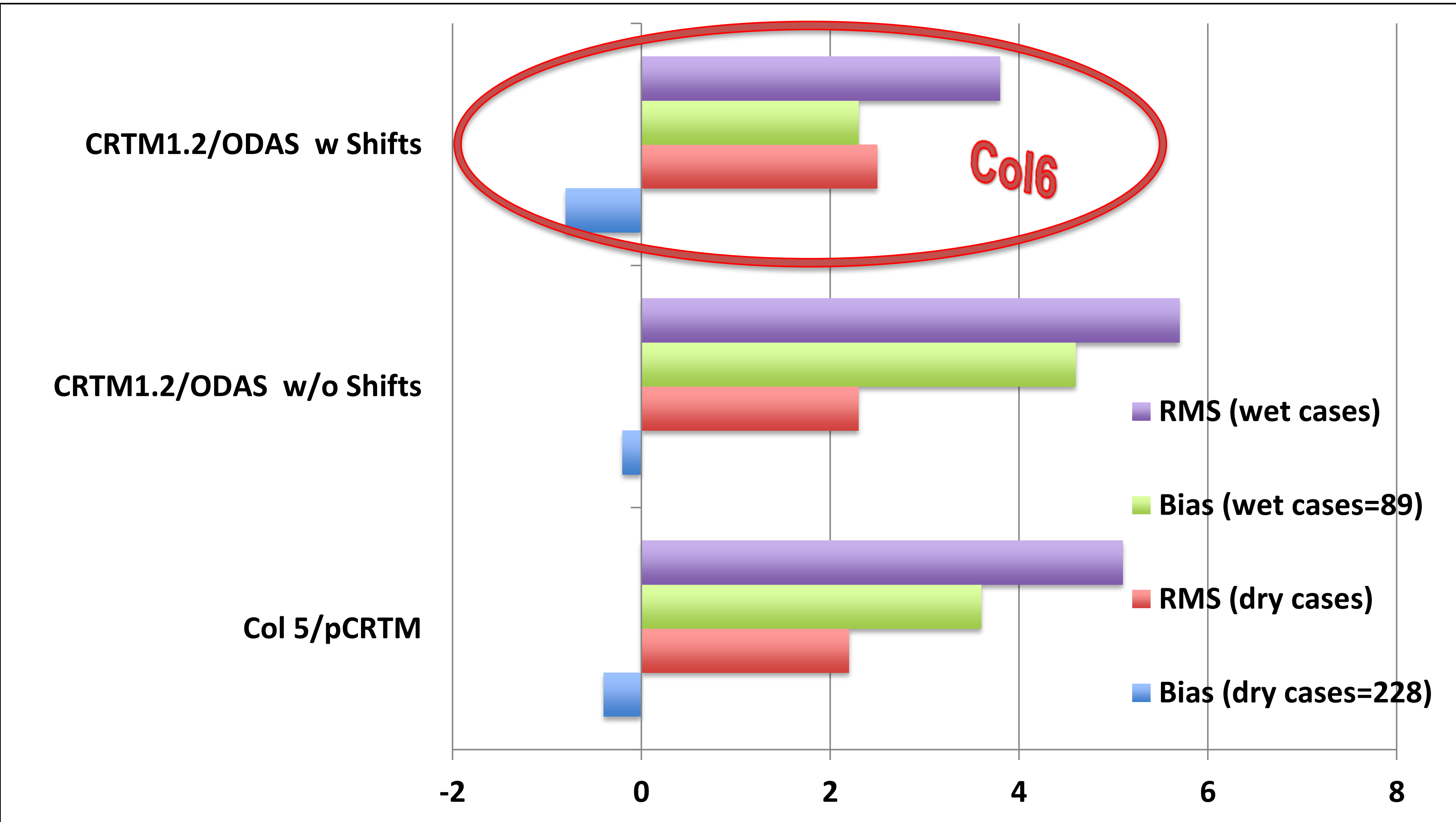
airs_file194 = 'AIRS.2003.04.09.194.L2.RetStd.v3.0.8.0.G04114143117.hdf';

AIRS and collocated MOD07 profiles



Aqua/MYD07 TPW comparison with ground-based observations at the SGP CART site

Comparison of total precipitable water (mm) at the ARM SGP site from MODIS, with the ground-based ARM SGP microwave radiometer for 317 clear sky Aqua cases from 4/2001 to 8/2005.



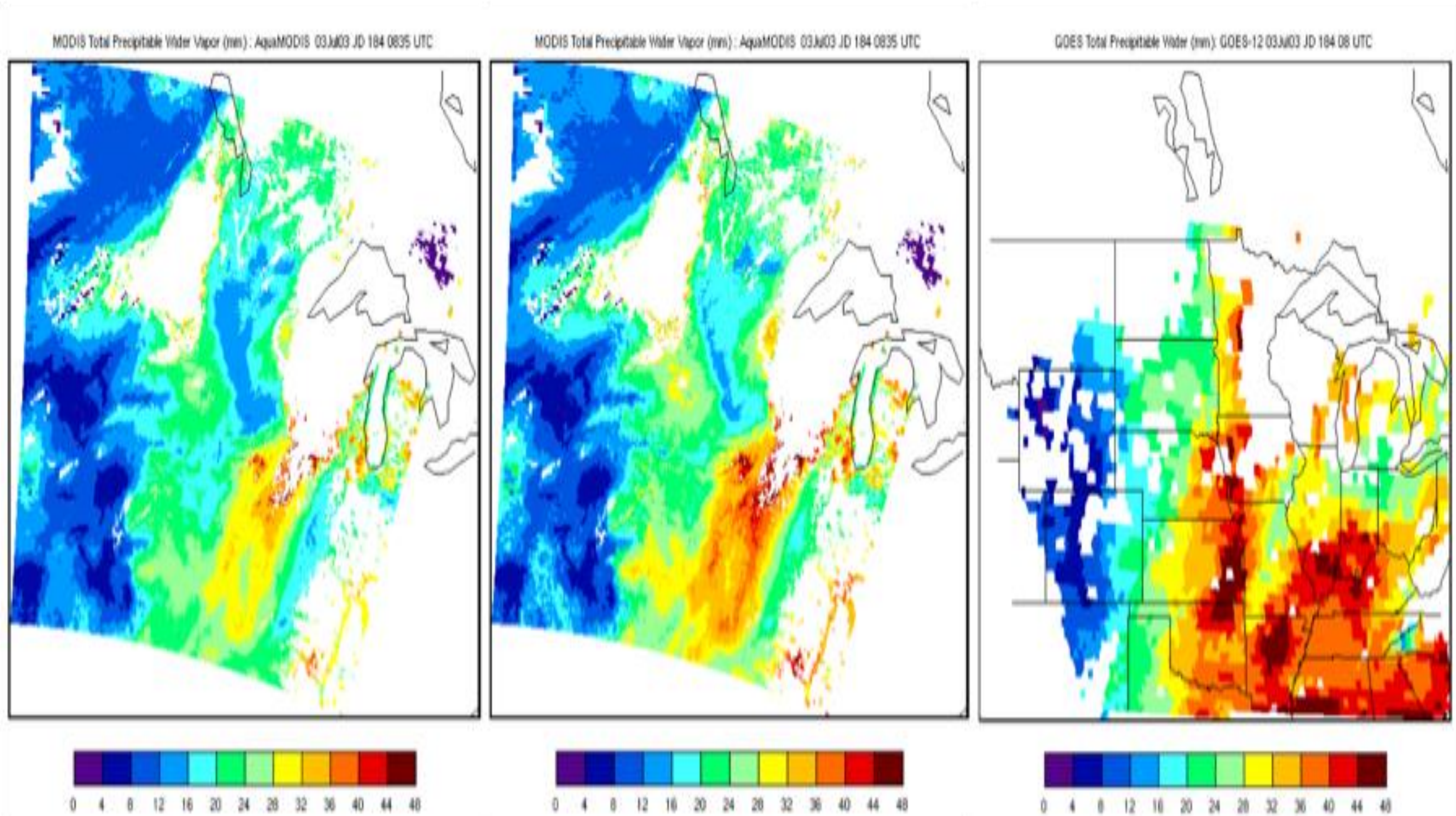
Global Aqua MYD07 TPW and AIRS L2 operational TPW products separated by scene (sea/land and day/night)

Aqua TPW [mm] BIAS land/ocean	AIRS-MOD07 (Col. 5) Day	AIRS-MOD07 (Col. 5) Night	AIRS-MOD07 (Col. 6) Day	AIRS-MOD07 (Col. 6) Night
2004336: no shift	1.2/-2.8	1.5/-1.7	1.3/-0.9	1.3/1.0
: with shifts	-	-	0.1/-2.4	0.6/-0.5
2006240: no shift	-0.9/-2.3	1.4/-1.0	0.5/-0.7	1.8/1.1
: with shifts	-	-	-1.6/-2.7	0.0/-0.6
2007032: no shift	-0.2/-1.9	1.0/-0.8	1.0/-1.1	1.2/0.7
: with shifts	-	-	0.2/-2.7	0.4/-0.5

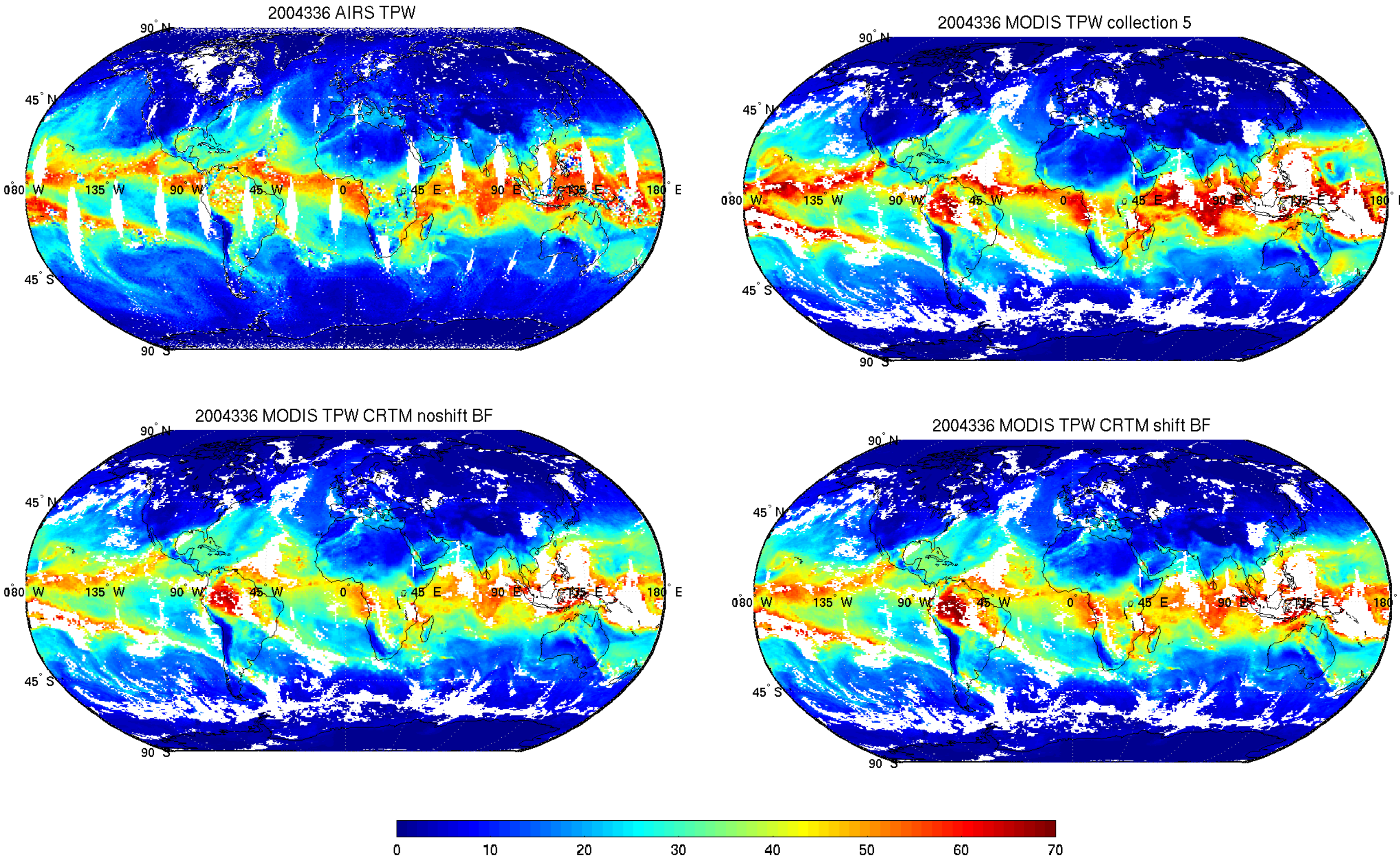
Aqua TPW [mm] RMS (land/ocean)	AIRS-MOD07(Col. 5) Day	AIRS-MOD07(Col. 5) Night	AIRS-MOD07 (Col. 6) Day	AIRS-MOD07 (Col. 6) Night
2004336: no shift	3.4/5.8	3.0/4.8	4.0/4.8	2.8/3.9
: with shifts	-	-	3.5/5.4	2.6/4.1
2006240: no shift	4.6/4.7	4.2/3.7	4.8/4.2	4.1/3.5
: with shifts	-	-	5.1/5.1	4.4/3.3
2007032: no shift	3.6/5.1	2.6/4.4	4.2/4.5	2.9/4.0
: with shifts	-	-	3.8/5.3	2.7/3.9

Total Precipitable Water from 3 July 2003 at 08:00 UTC

MYD07 TPW without shifts | MYD07 TPW with shifts | GOES TPW

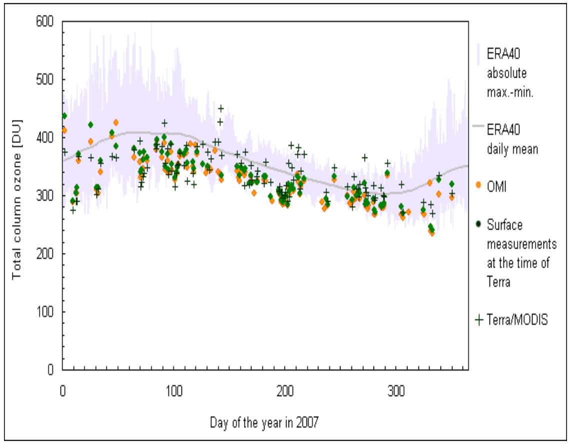


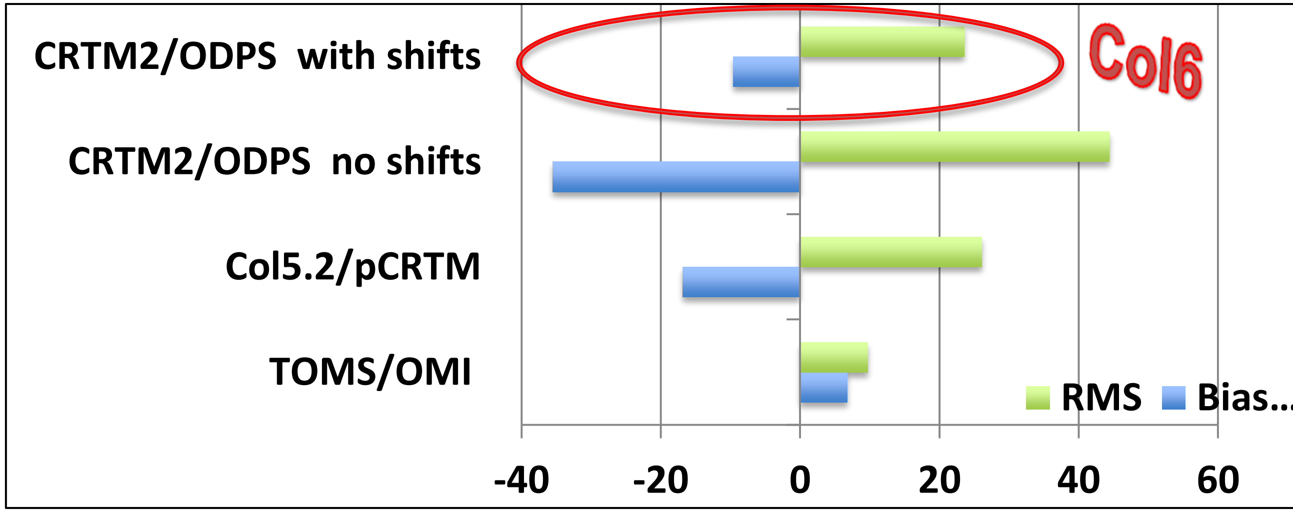
AIRS versus MODIS TPW



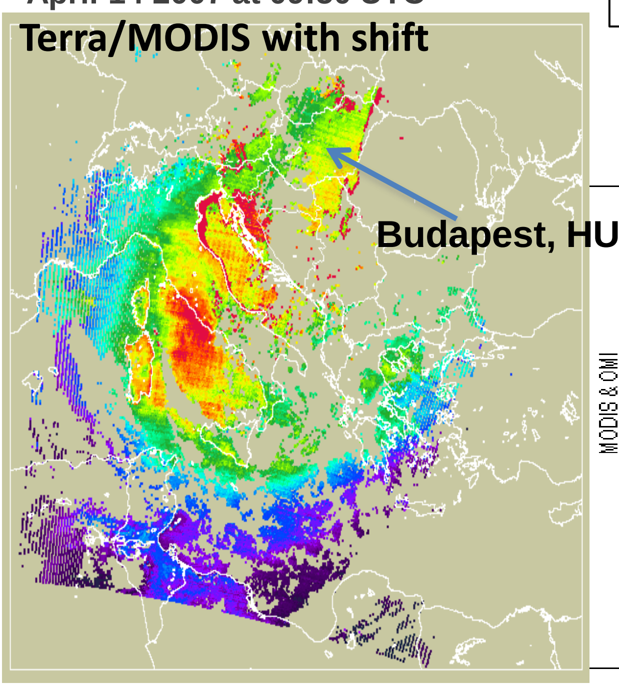
Total Ozone

The impact of the Terra H2O/CO2/O3 channel spectral shifts on MOD07 TOZ over Budapest, HU over 2007: Comparison with ground-based Brewer Spectrophotometer measurements

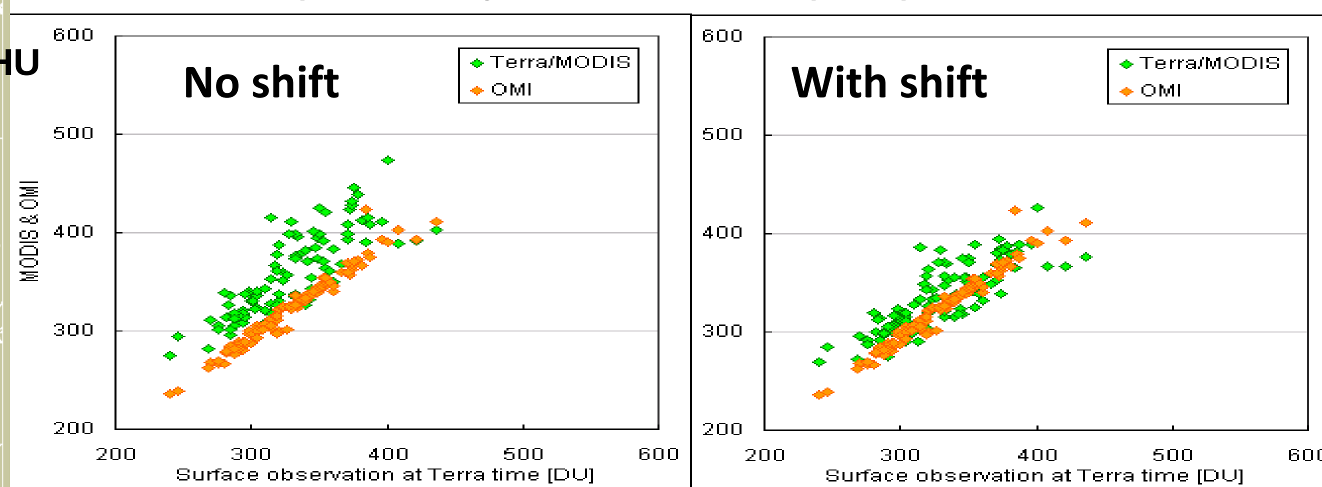




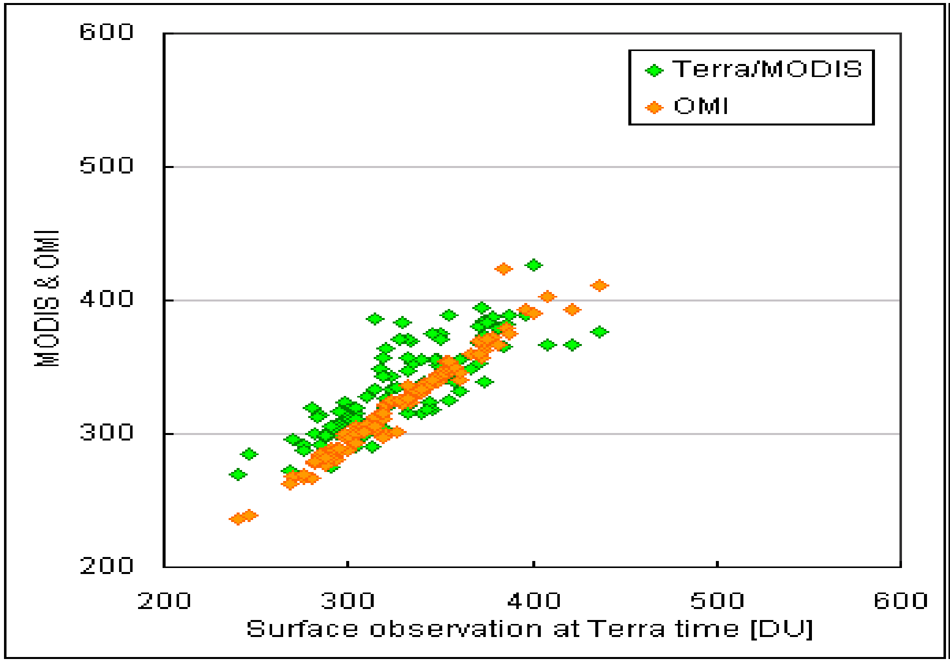
April 14 2007 at 09:50 UTC



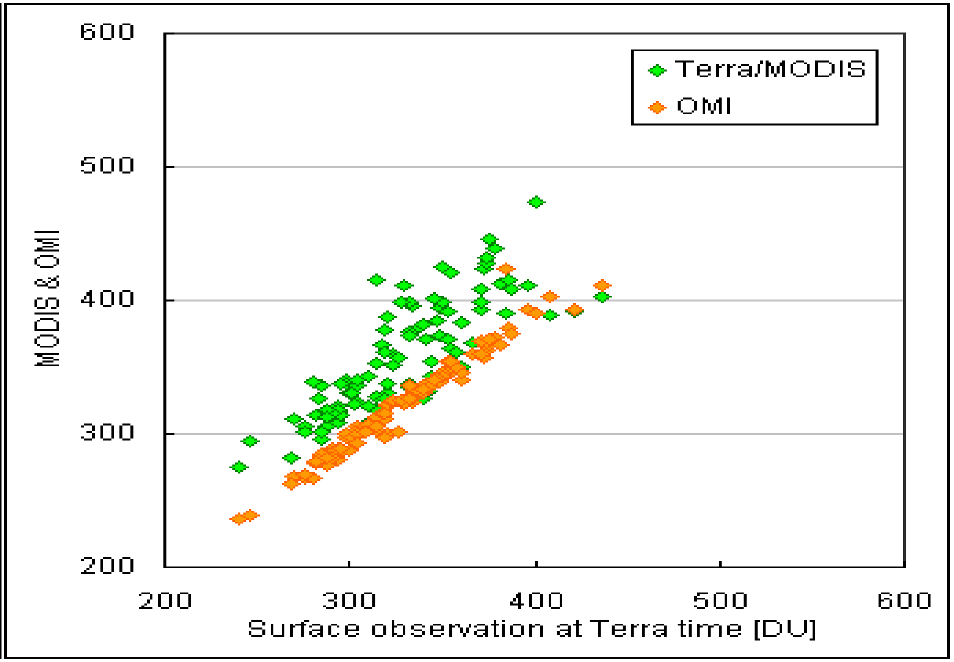
The impact of the Terra H2O/CO2/O3 band spectral shifts on MOD07 TOZ over Budapest, HU for 2007: Comparison with ground-based Brewer Spectrophotometer measurements



MODIS and OMI vs. ground-based Brewer TOZ for 2007 at Budapest, Hungary

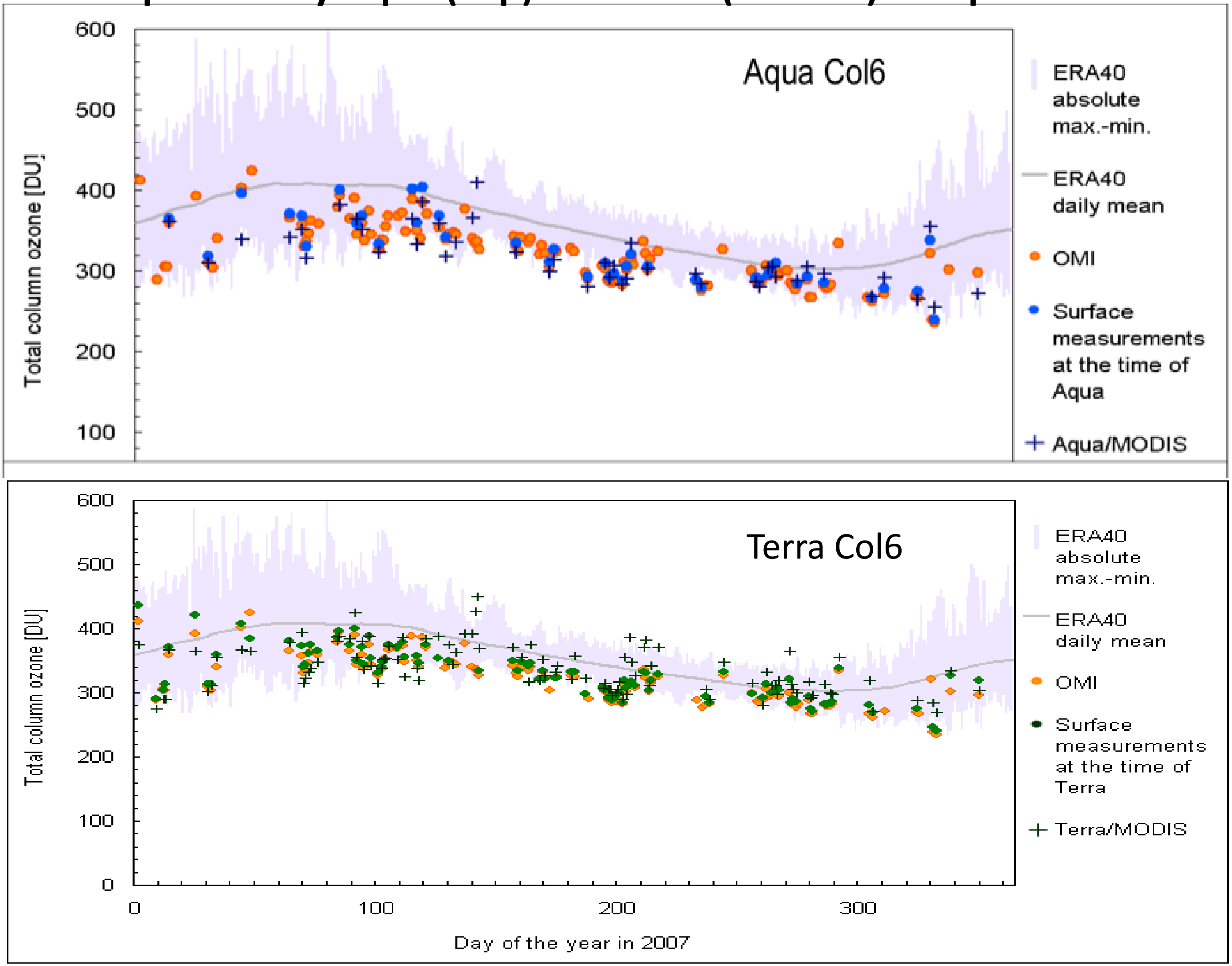


with SRF shift



wo SRF shift

Total Ozone observations for the year 2007 over Budapest, Hungary separated by Aqua (Top) and Terra (bottom) overpass times.

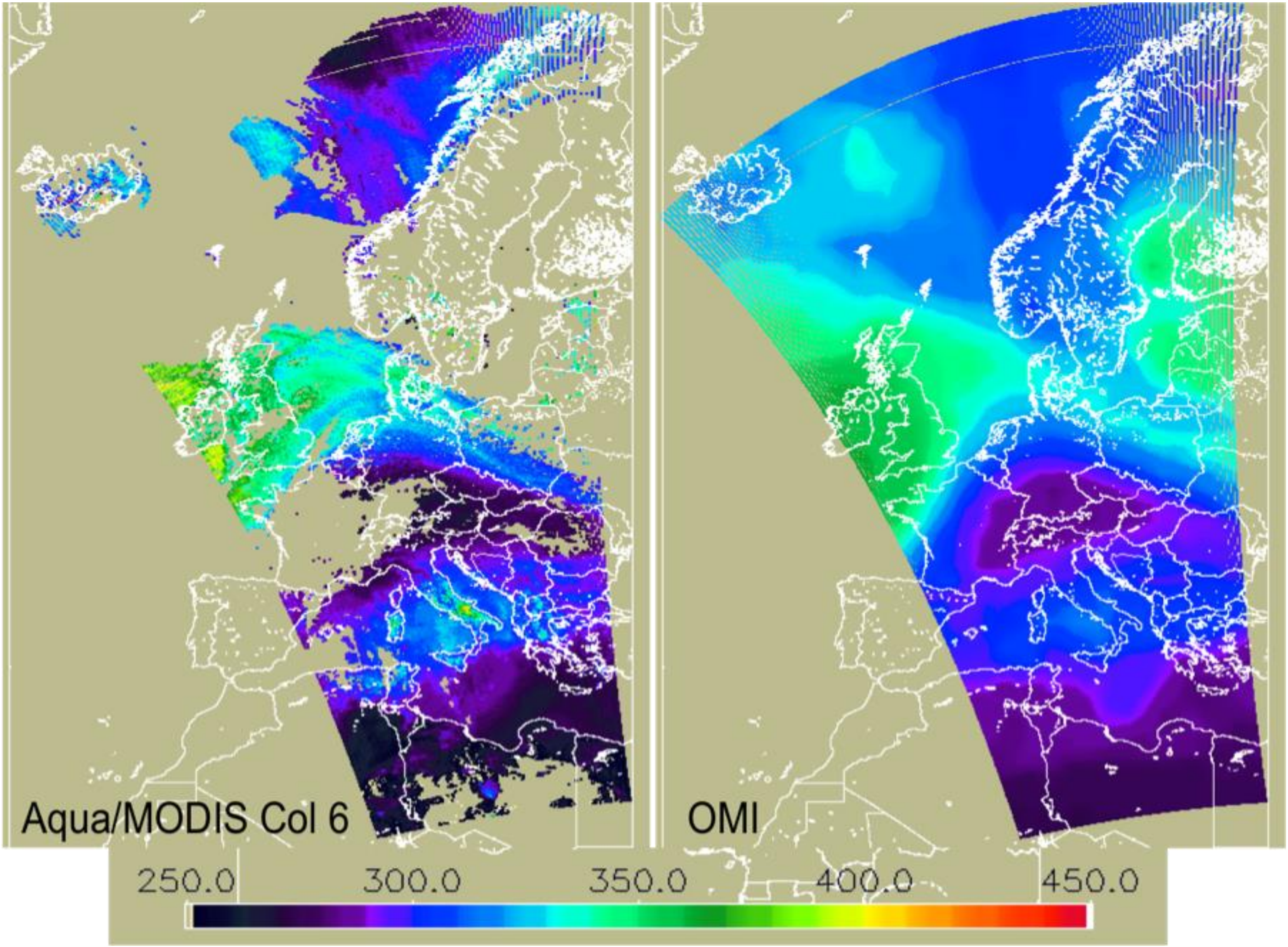


2007 ECMWF ERA40 daily mean and absolute maximum and minimum TPW shown in grey.

Comparison of TOZ measured by OMI and MODIS (Terra and Aqua) vs surface Brewer measurements for year 2007 over Budapest, Hungary.

Satellite-based TOZ vs. Surface Brewer Measurements	Bias [DU]	Stdev [DU]	RMSE [DU]
OMI at Terra overpass times	6.8	6.9	9.7
MOD07/Terra Col 5	-16.8	20.0	26.1
MOD07/Terra Col 6 without spectral shifts	-35.5	26.7	44/4
MOD07/Terra Col 6 with spectral shifts	-9.6	21.6	23.6
OMI at Aqua overpass times	0.6	7.5	7.6
MYD07/Aqua Col 5	6.0	20.8	21.6
MYD07/Aqua Col 6 without spectral shifts	-1.2	17.6	17.7
MYD07/Aqua Col 6 with spectral shifts	4.0	16.0	16.5

Total Ozone by Aqua/MODIS (left) and OMI (right) on July 8, 2007 at 12:18:55 UTC.

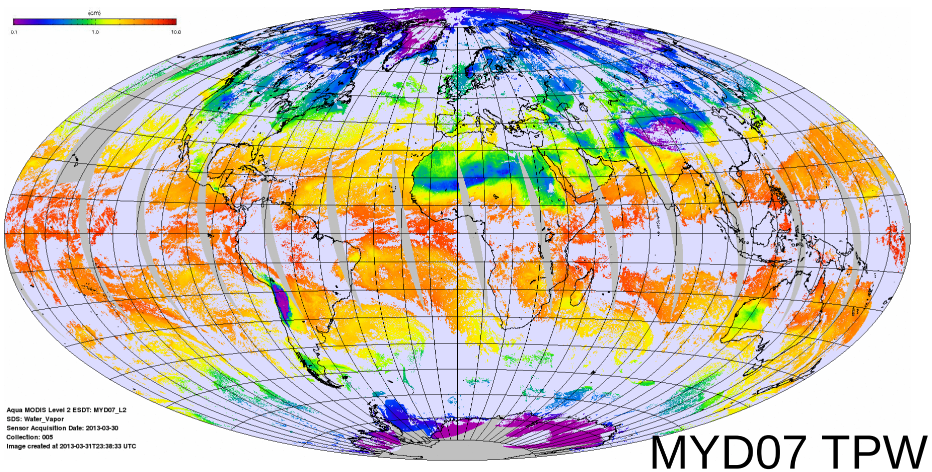


Conclusions

TOZ: Overall, application of Terra spectral shifts shows ***significant improvement*** (reduced bias and rms) for MOD07 TOZ products in both the local (Budapest, Hungary) and global validation studies. The Aqua TOZ is also positively effected on the global scale by the H20/CO2 spectral shifts.

TPW: Application of Aqua spectral shifts (using CRTM V1.2/ODAS) a ***significant positive improvement*** was realized for the Aqua/MODIS TPW over the SGP Cart site by applying the Band 27 & 28 spectral shifts. Comparing to the Col5 product, the dry bias for the wet cases has been reduced by 1.1mm!

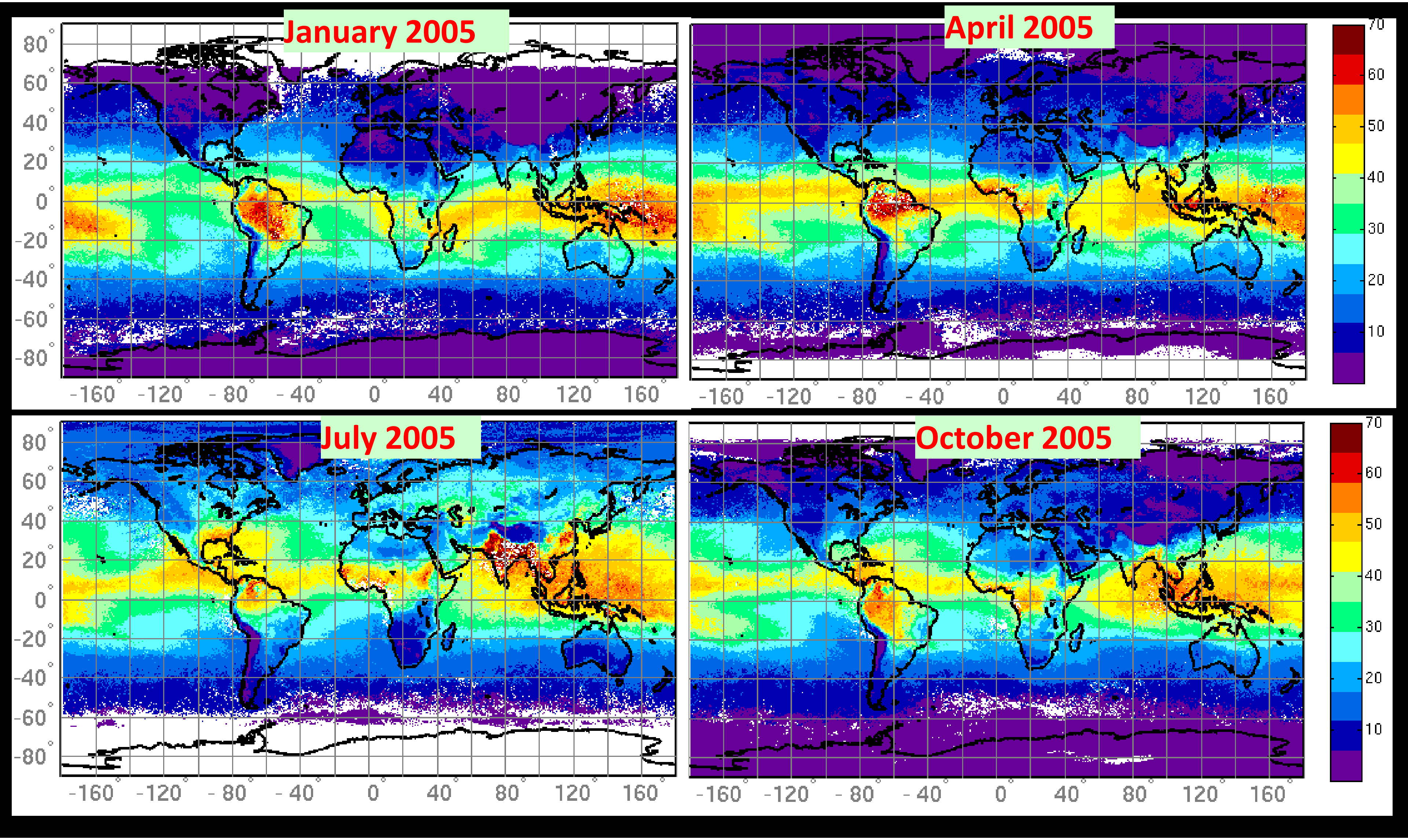
For application of Terra spectral shifts show a positive effect for the dry cases (the wet bias is reduced by 0.5 mm), but have a negative effect for the wet and overall cases (0.7 mm bias increase). The overall rms differences are not changed significantly.



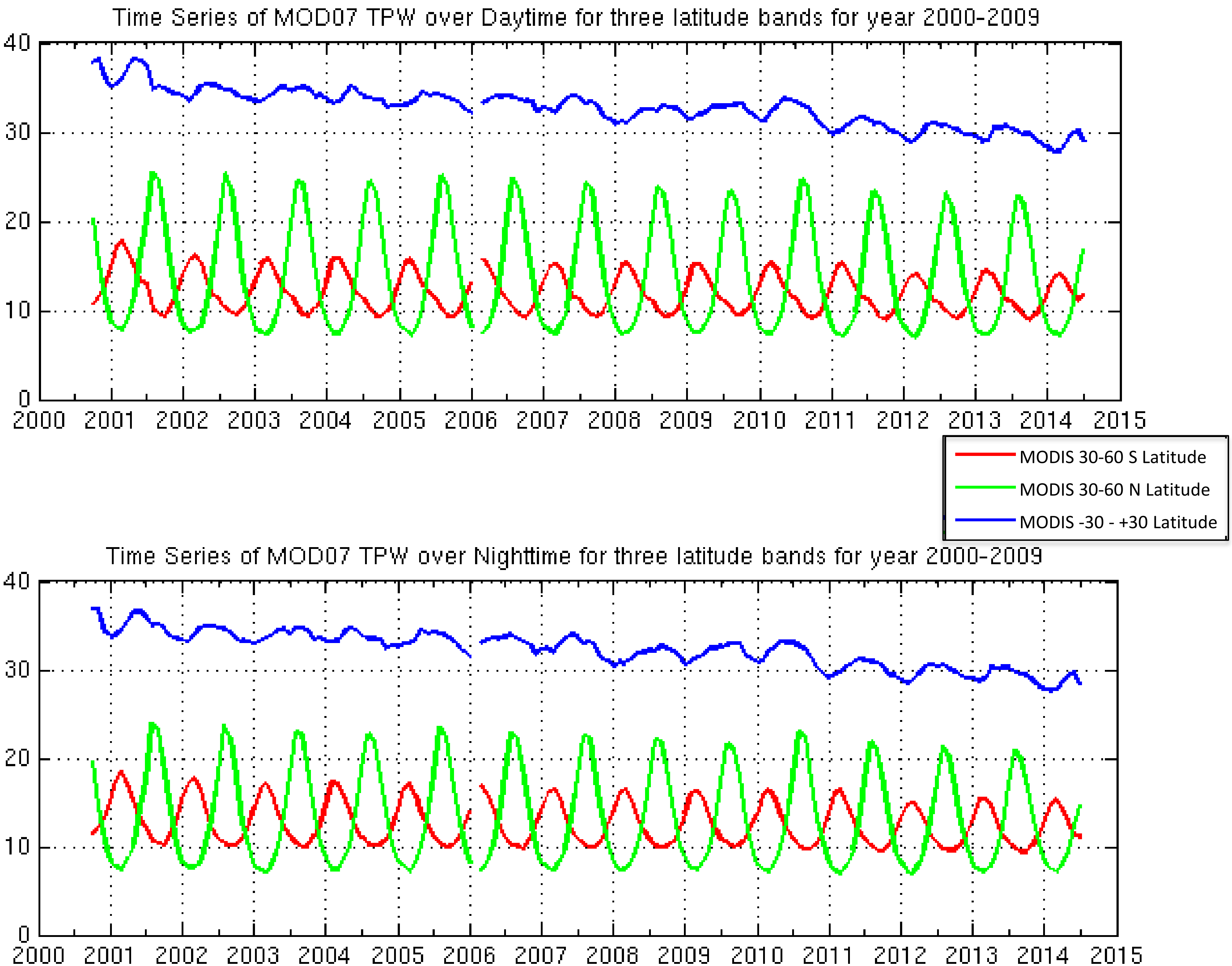
MYD07 TPW

Recent Trends

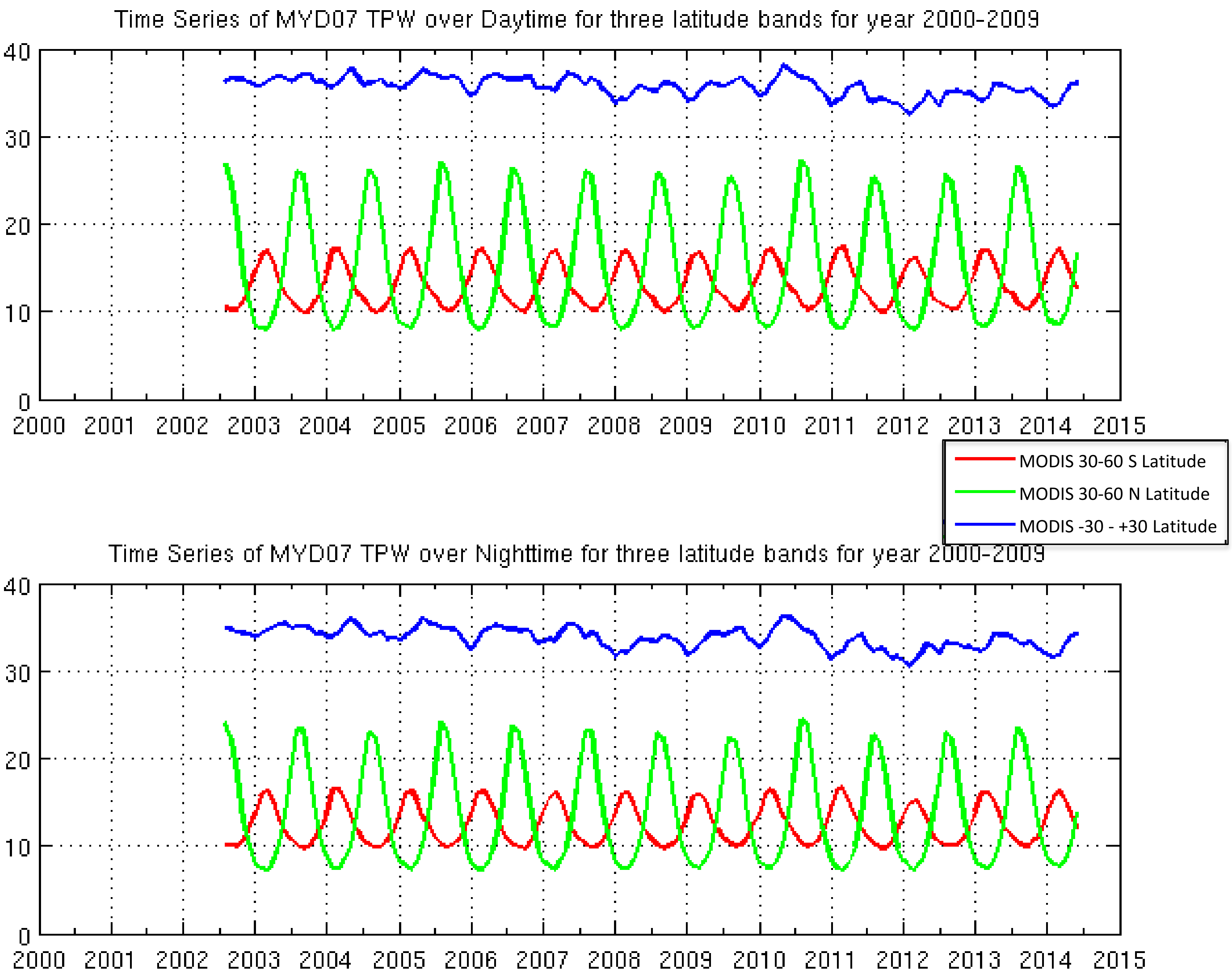
MOD07 monthly mean TPW (mm) (day)



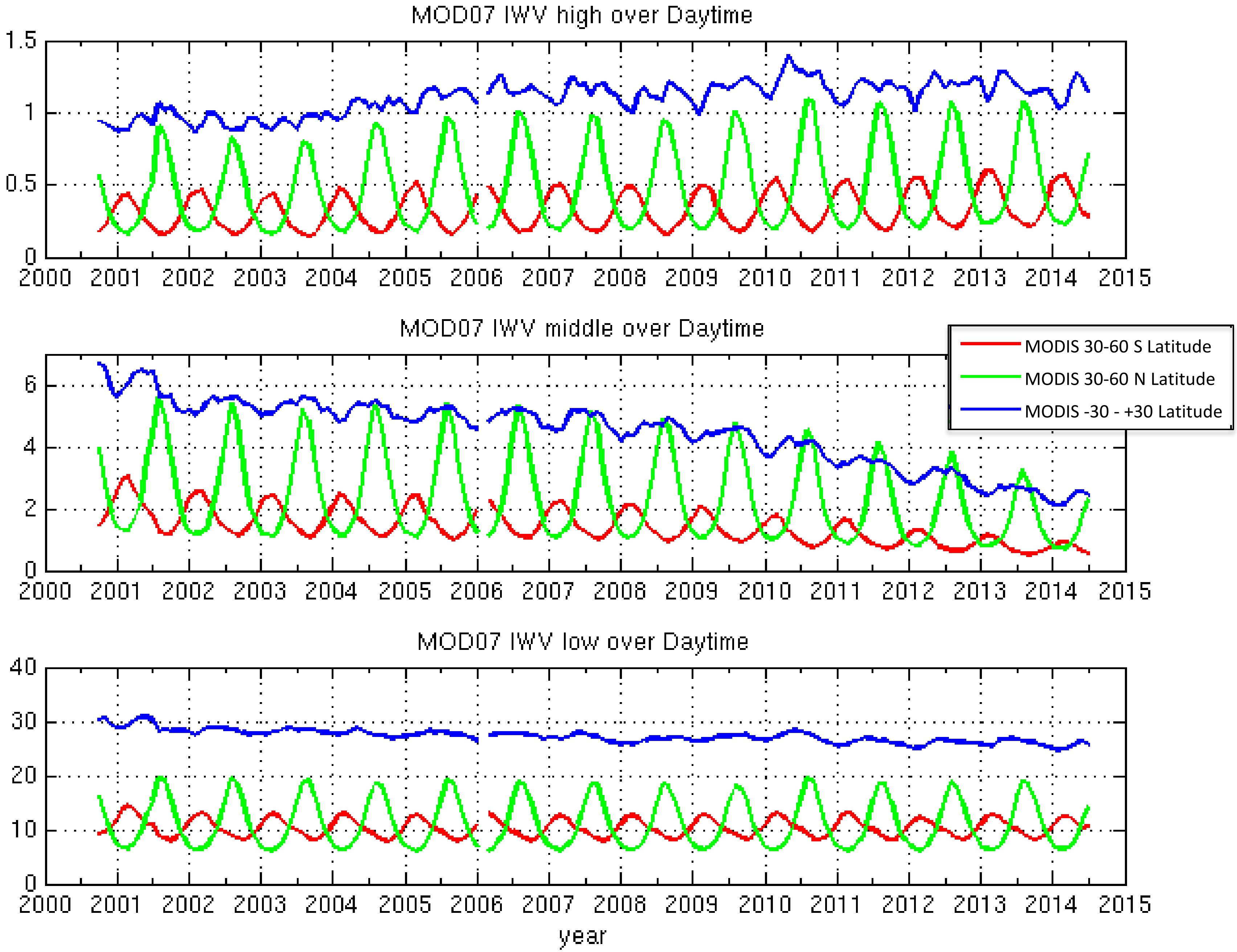
(Borbas and Menzel)



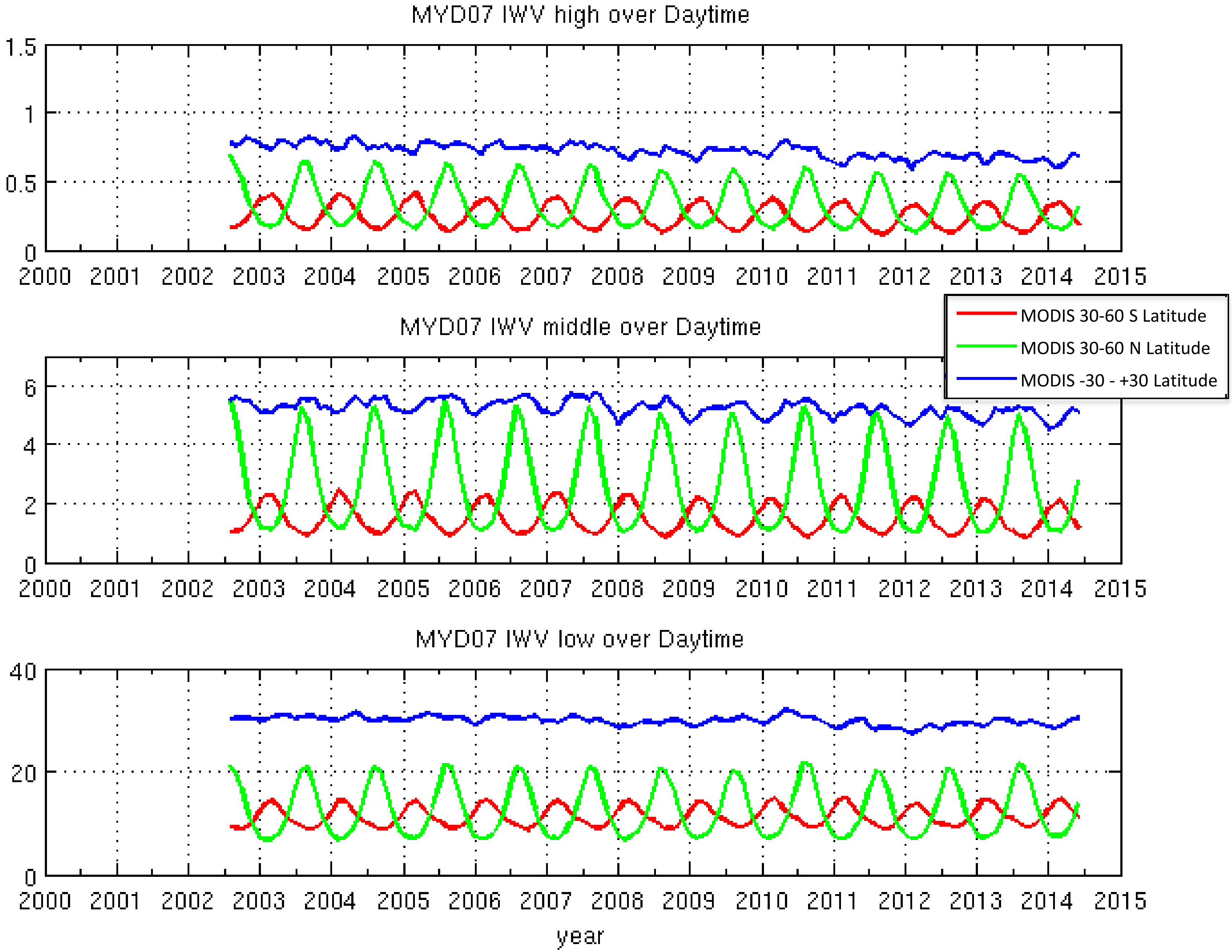
Time Series of MOD07 TPW over Daytime for three latitude bands for year 2000-2009
40
30
20
10
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
MODIS 30-60 S Latitude
MODIS 30-60 N Latitude
MODIS -30 - +30 Latitude
Time Series of MOD07 TPW over Nighttime for three latitude bands for year 2000-2009
40
30
20
10
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015


Time Series of MYD07 TPW over Daytime for three latitude bands for year 2000-2009
0
10
20
30
40
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
MODIS 30-60 S Latitude
MODIS 30-60 N Latitude
MODIS -30 - +30 Latitude
Time Series of MYD07 TPW over Nighttime for three latitude bands for year 2000-2009
0
10
20
30
40
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

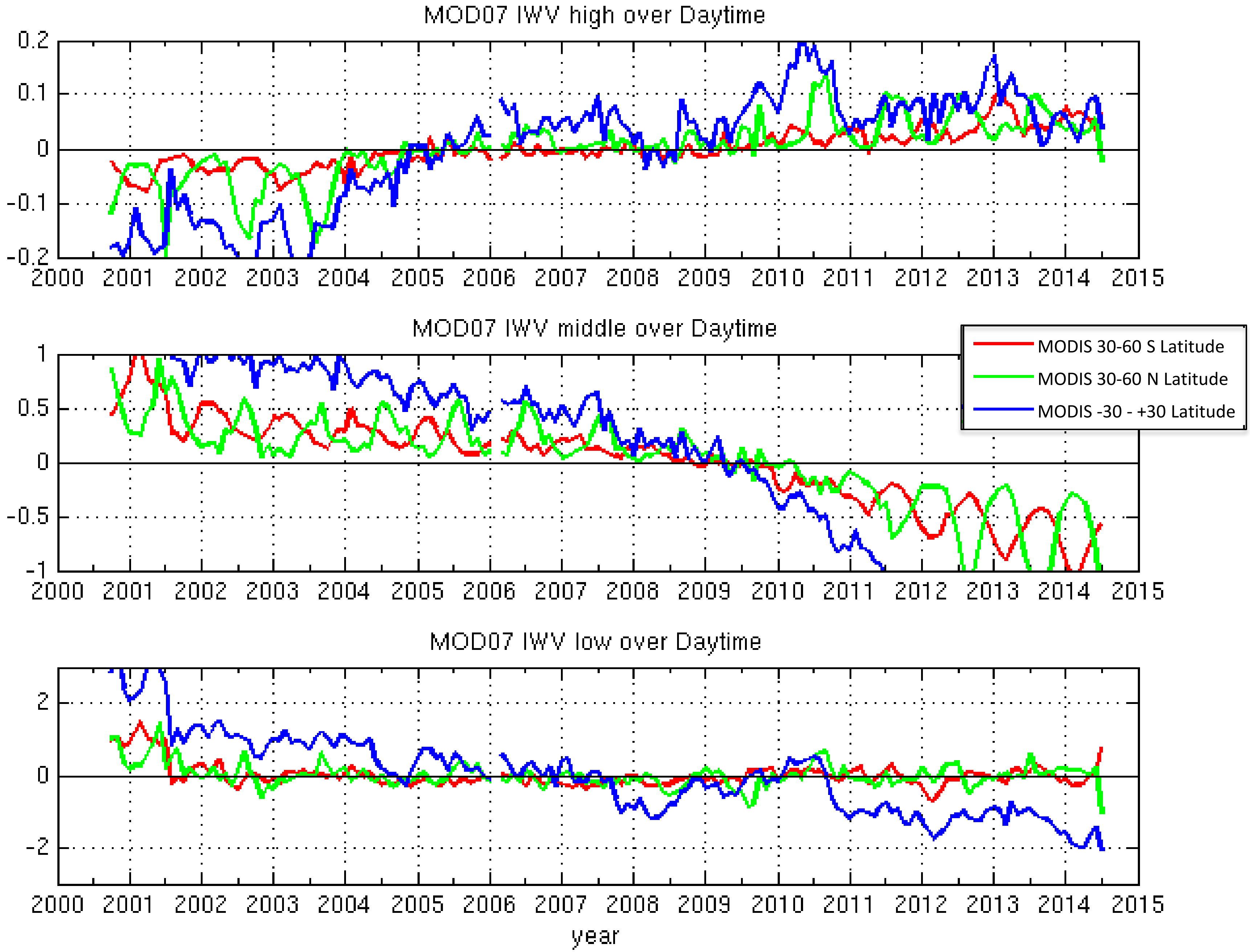
Timeseries of MOD07 IWV high, middle and low over Daytime



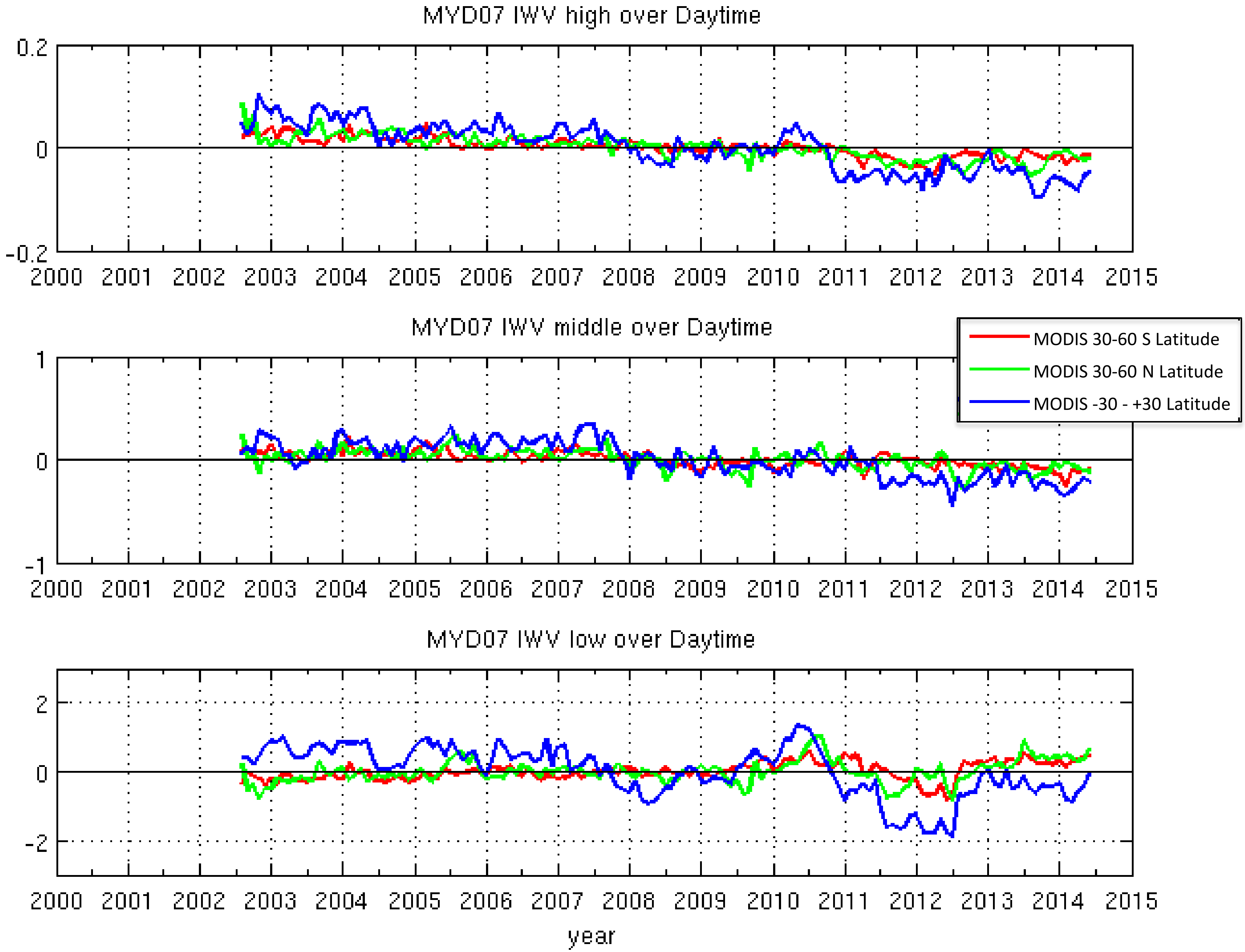
Timeseries of MYD07 IWV high, middle and low over Daytime

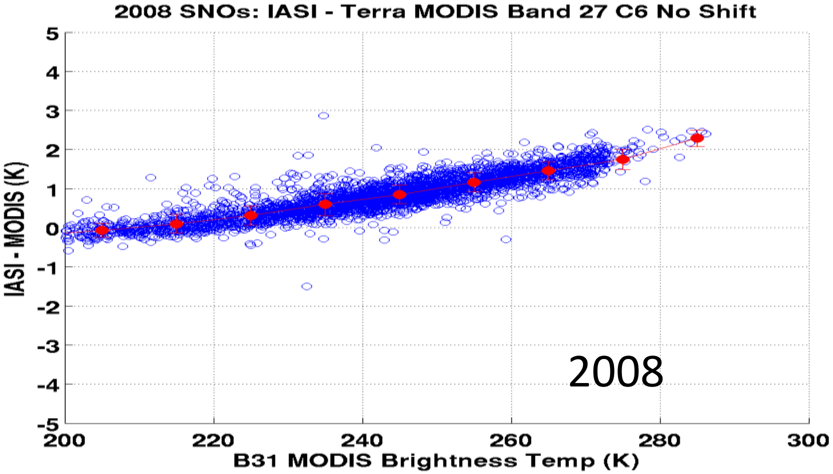


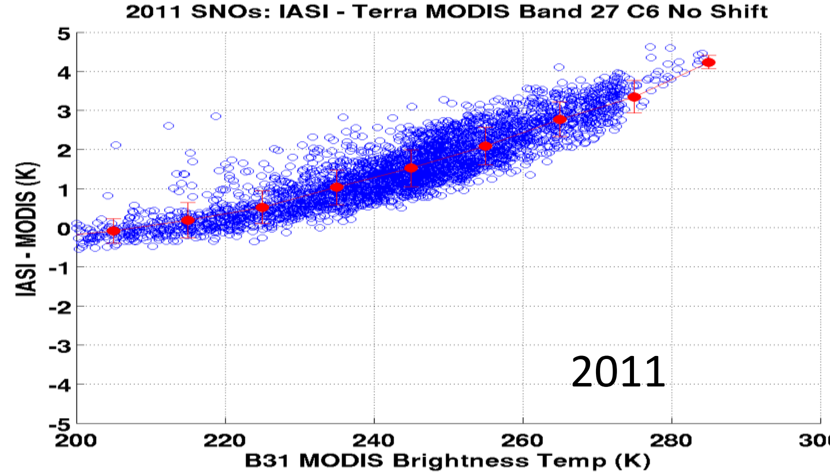
Timeseries of MOD07 IWV high, middle, and low anomaly over Daytime



Timeseries of MYD07 IWV high, middle and low anomaly over Daytime



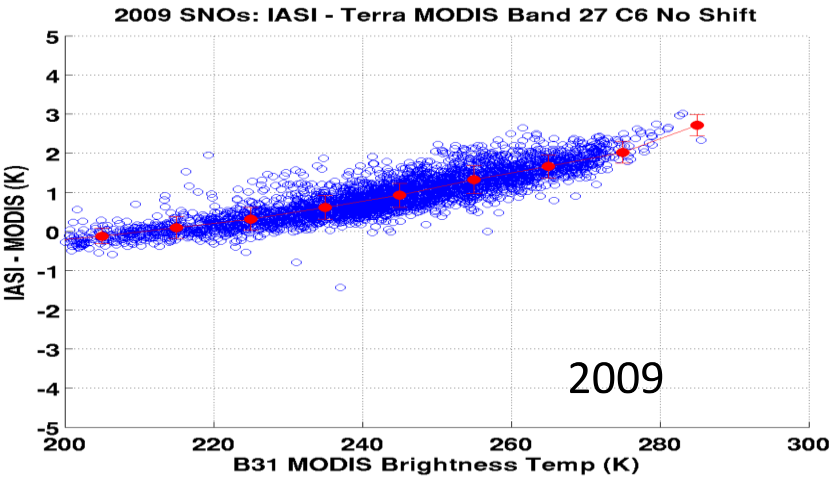


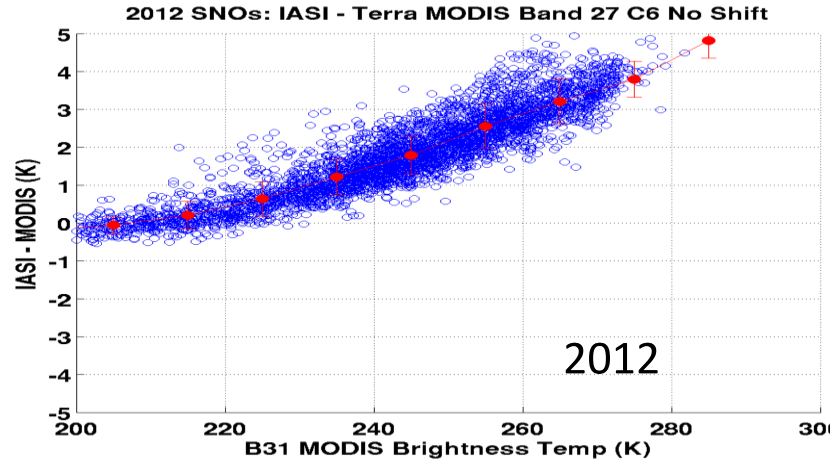


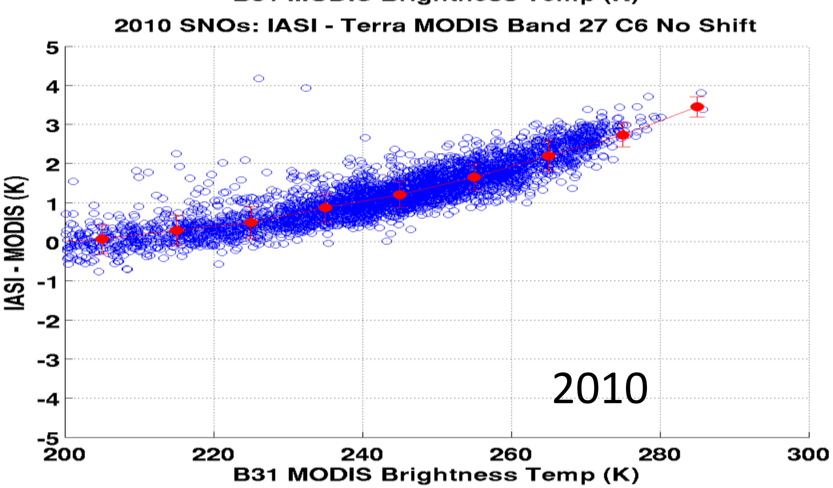
CH27

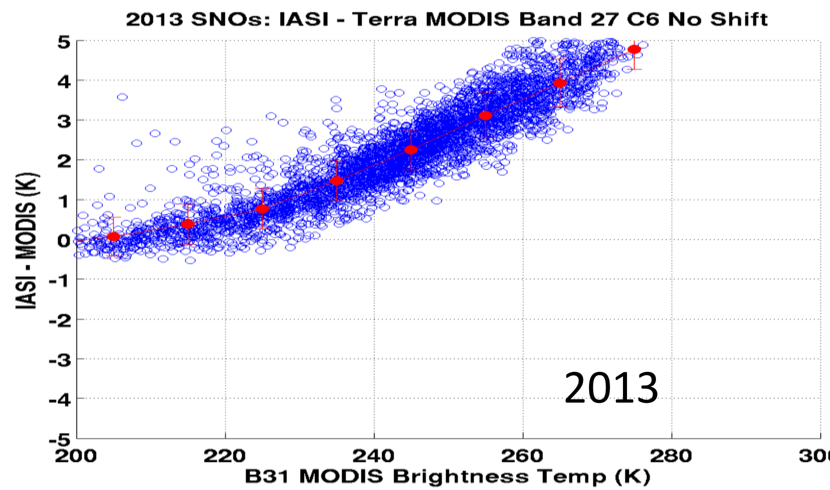
TERRA

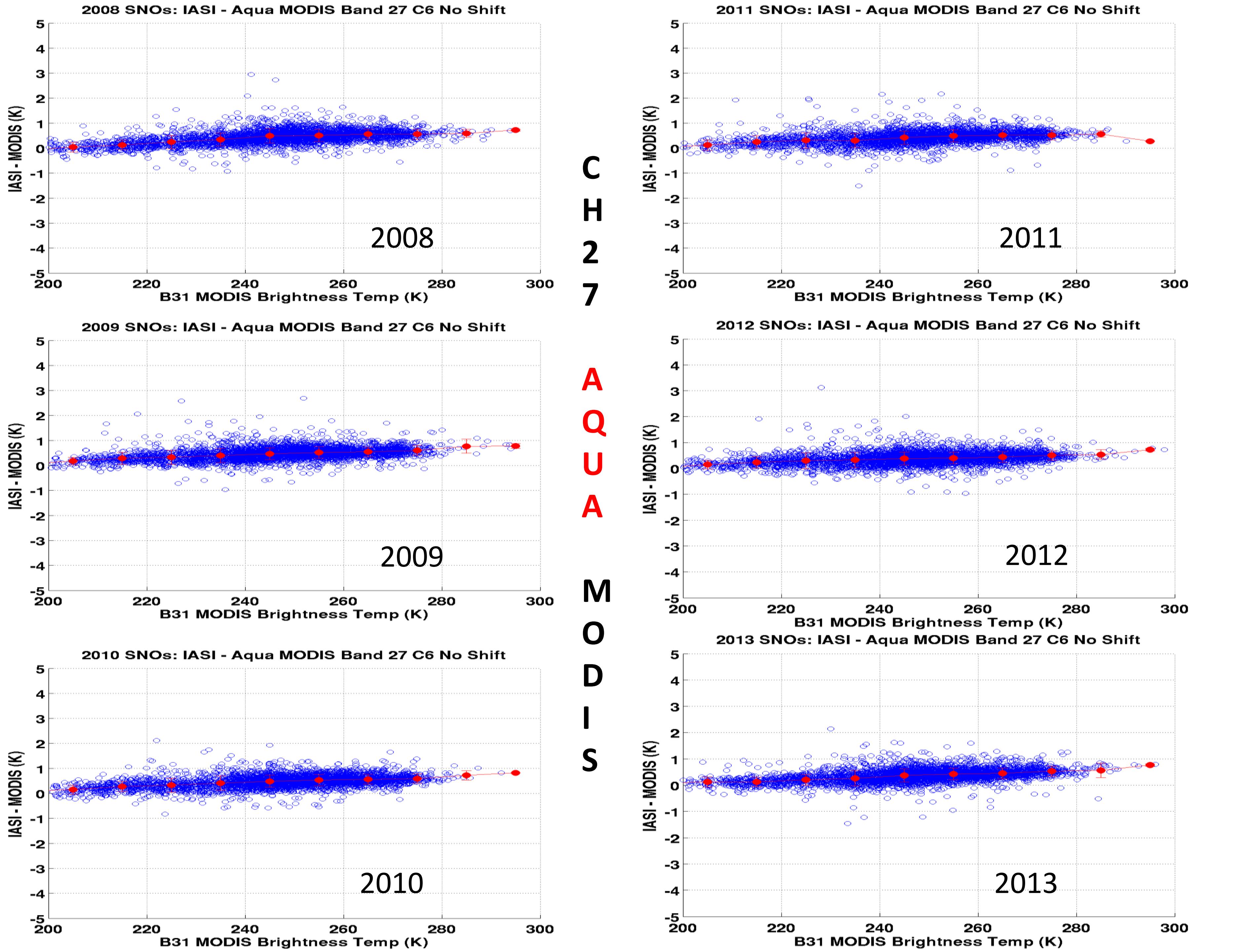
MODIS

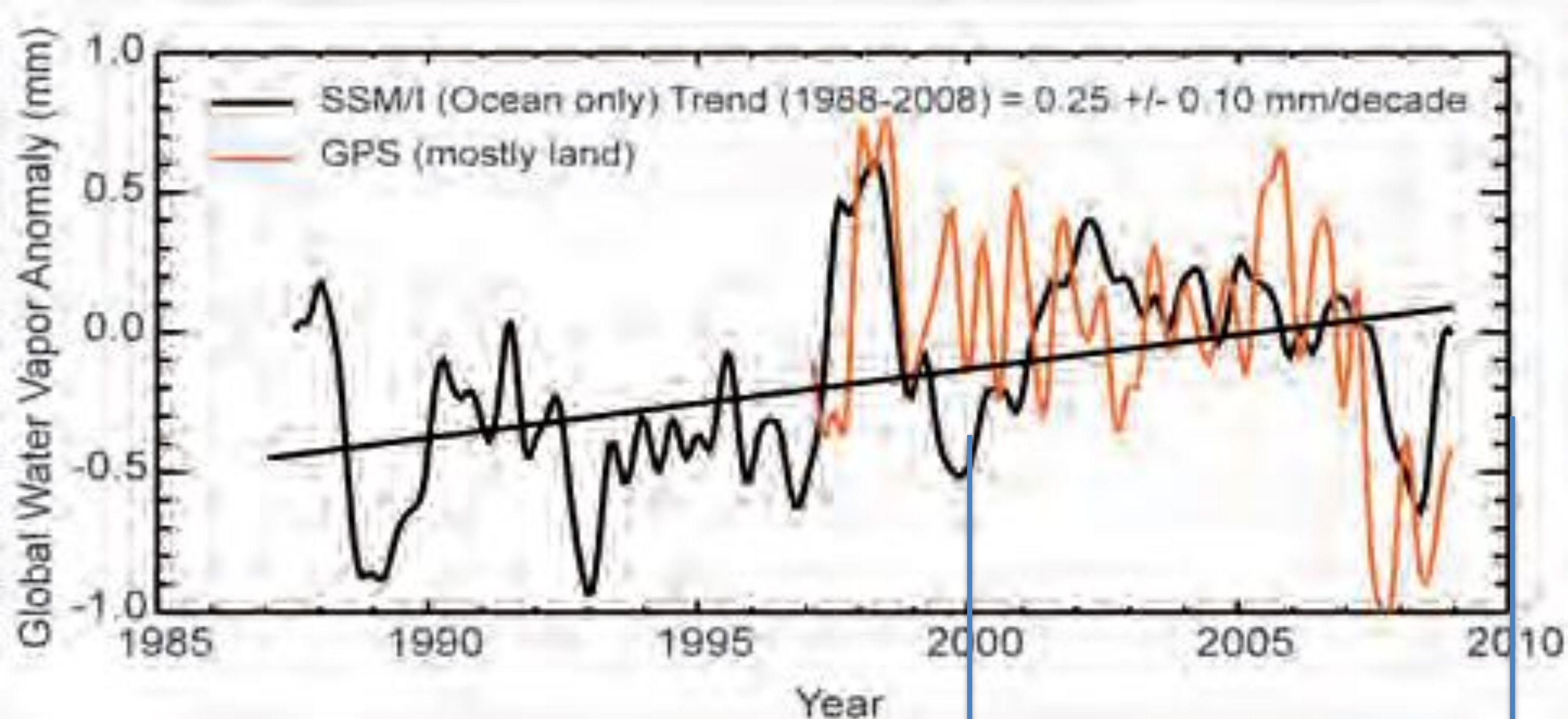


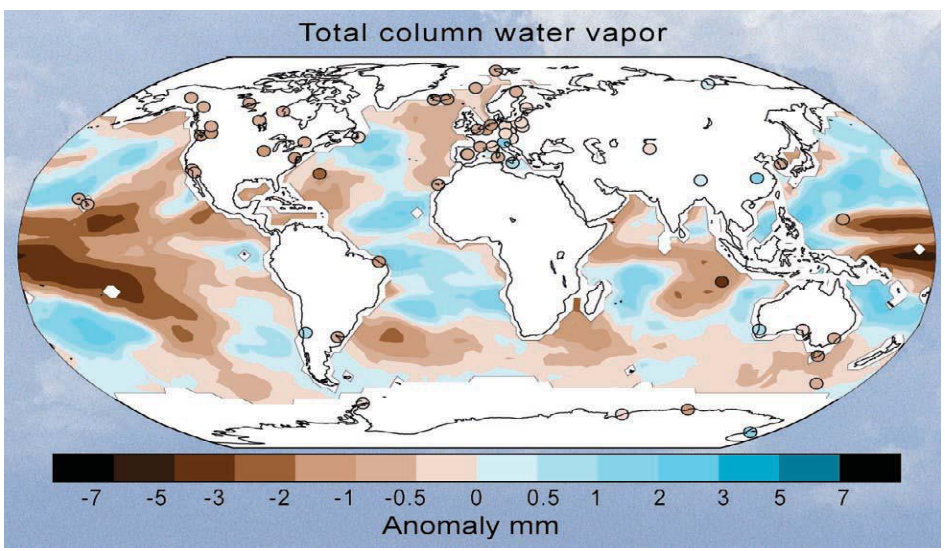




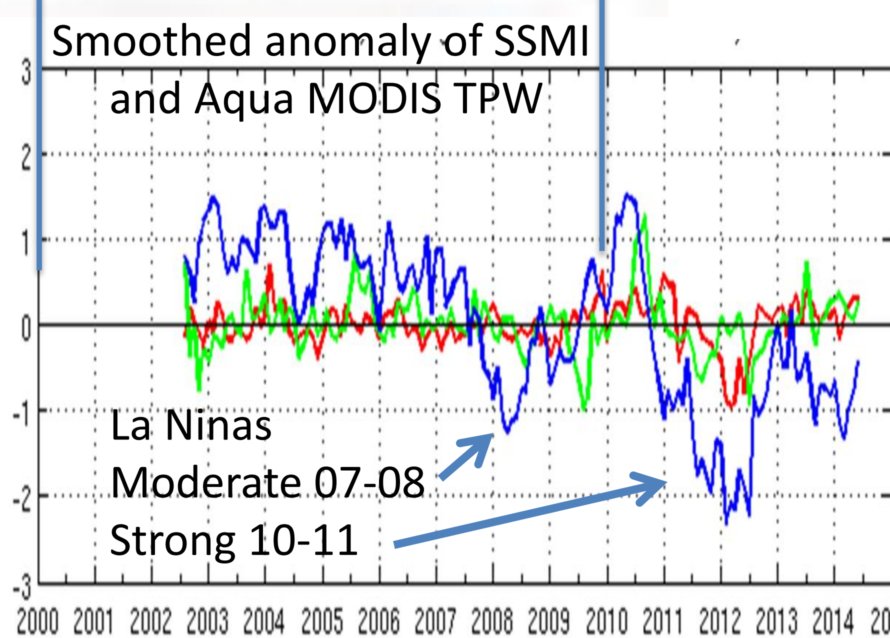



2008 SNOs: IASI - Aqua MODIS Band 27 C6 No Shift
IASI - MODIS (K)
B31 MODIS Brightness Temp (K)
2008
2009 SNOs: IASI - Aqua MODIS Band 27 C6 No Shift
IASI - MODIS (K)
B31 MODIS Brightness Temp (K)
2009
2010 SNOs: IASI - Aqua MODIS Band 27 C6 No Shift
IASI - MODIS (K)
B31 MODIS Brightness Temp (K)
2010
CH27
AQUA
MODIS
2011 SNOs: IASI - Aqua MODIS Band 27 C6 No Shift
IASI - MODIS (K)
B31 MODIS Brightness Temp (K)
2011
2012 SNOs: IASI - Aqua MODIS Band 27 C6 No Shift
IASI - MODIS (K)
B31 MODIS Brightness Temp (K)
2012
2013 SNOs: IASI - Aqua MODIS Band 27 C6 No Shift
IASI - MODIS (K)
B31 MODIS Brightness Temp (K)
2013





2008 La Nina Water Vapor 10 yr Anomaly



Weak (<0.5C), moderate ,or strong (>1.5C) for at least 3 consecutive overlapping 3-month periods.

	El Niño			La Niña	
Weak	Mod	Strong	Weak	Mod	Strong
1952-53	1951-52	1957-58	1950-51	1955-56	1973-74
1953-54	1963-64	1965-66	1954-55	1970-71	1975-76
1958-59	1968-69	1972-73	1956-57	1998-99	1988-89
1969-70	1986-87	1982-83	1964-65	2007-08	1999-00
1976-77	1991-92	1987-88	1971-72		2010-11
1977-78	1994-95	1997-98	1974-75		
2004-05	2002-03		1983-84		
2006-07	2009-10		1984-85		
			1995-96		
			2000-01		
			2005-06		
			2008-09		
			2011-12		

Conclusions

Regarding Atm Profiles

* Surface emissivity data base offers good retrievals over land and ocean
* TPW within 2 (4) mm rms for dry (wet) retrievals wrt ground microwave
* TOZ within 25 DU rms of OMI

Regarding Recalibration

* MODIS recalibration using IASI offers suggestions for SRF shifts
* Sensor calibration drift over time needs to be monitored and may need further correction to be useful for long term trend analyses

Regarding H2O Trends

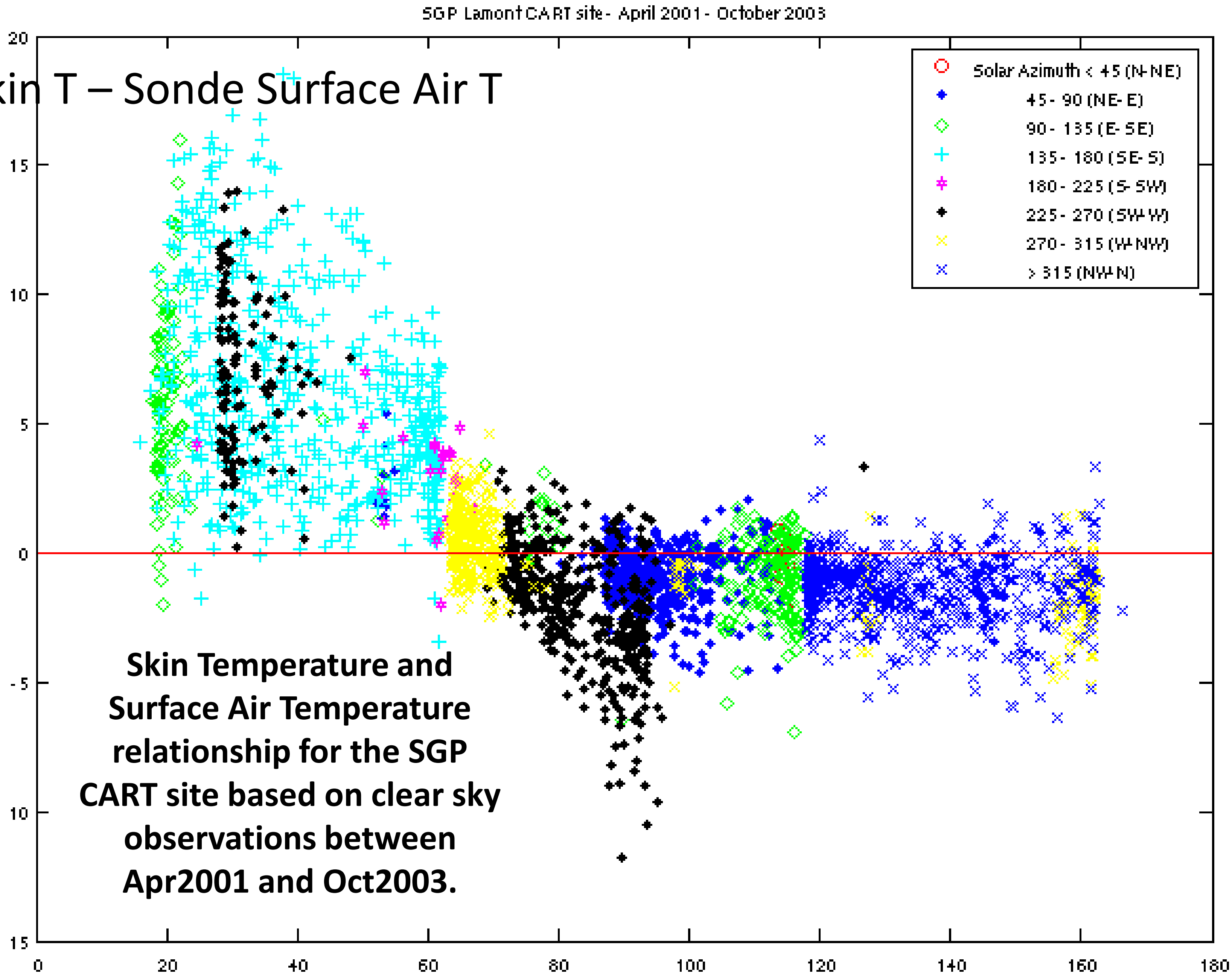
* Terra and Aqua MODIS TPW trends are in good agreement; Terra MODIS UTH is out of family due to Ch 27 calibration drift
* Seasonal TPW cycle is strongest in northern mid-latitudes and weakest in tropics
* Seasonal TPW cycle is stronger in the afternoon than at night
* La Nina decrease in tropical TPW evident in all sensor trends
* Decrease in tropical TPW from 2002 to 2008 and increase after 2008 is evident Terra & Aqua MODIS

Contents of MOD07 Output File

Time, Lat, Lon, SZA, SatZA
BTs of IR bands
Cloud Mask
Sfc Skin T & p
Retrieved T(p), Q(p) at 20 levels
TOZ, TPW, TPW (440-10 hPa), TPW(sfc-680 hPa)
Stability Indices (LI, Total Totals, K-Index)

Extra Slides
From the MOD07 ATBD

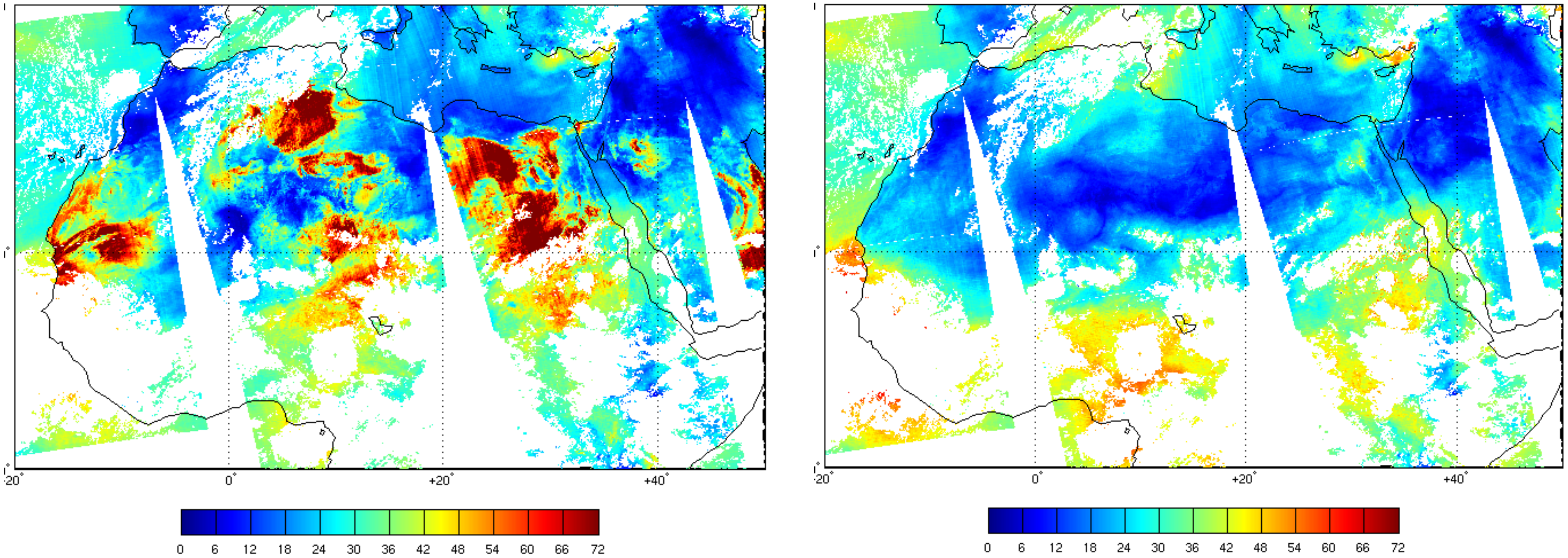
IRT Skin T – Sonde Surface Air T

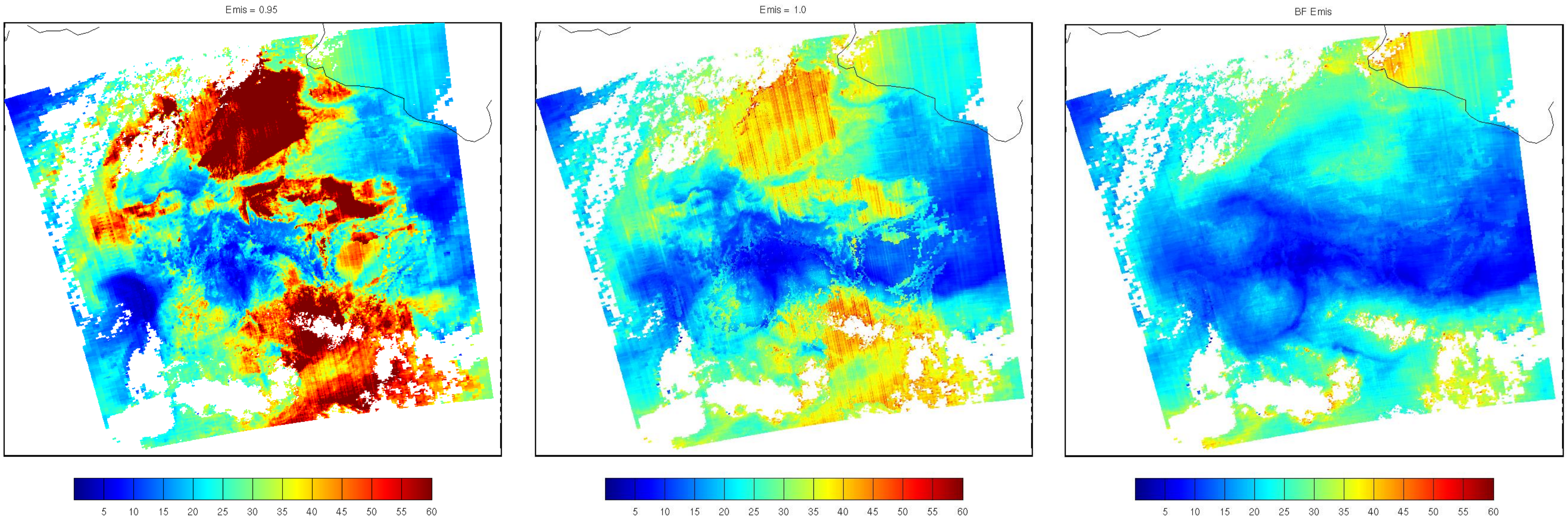


Skin Temperature and Surface Air Temperature relationship for the SGP CART site based on clear sky observations between Apr2001 and Oct2003.

Solar Zenith Angle

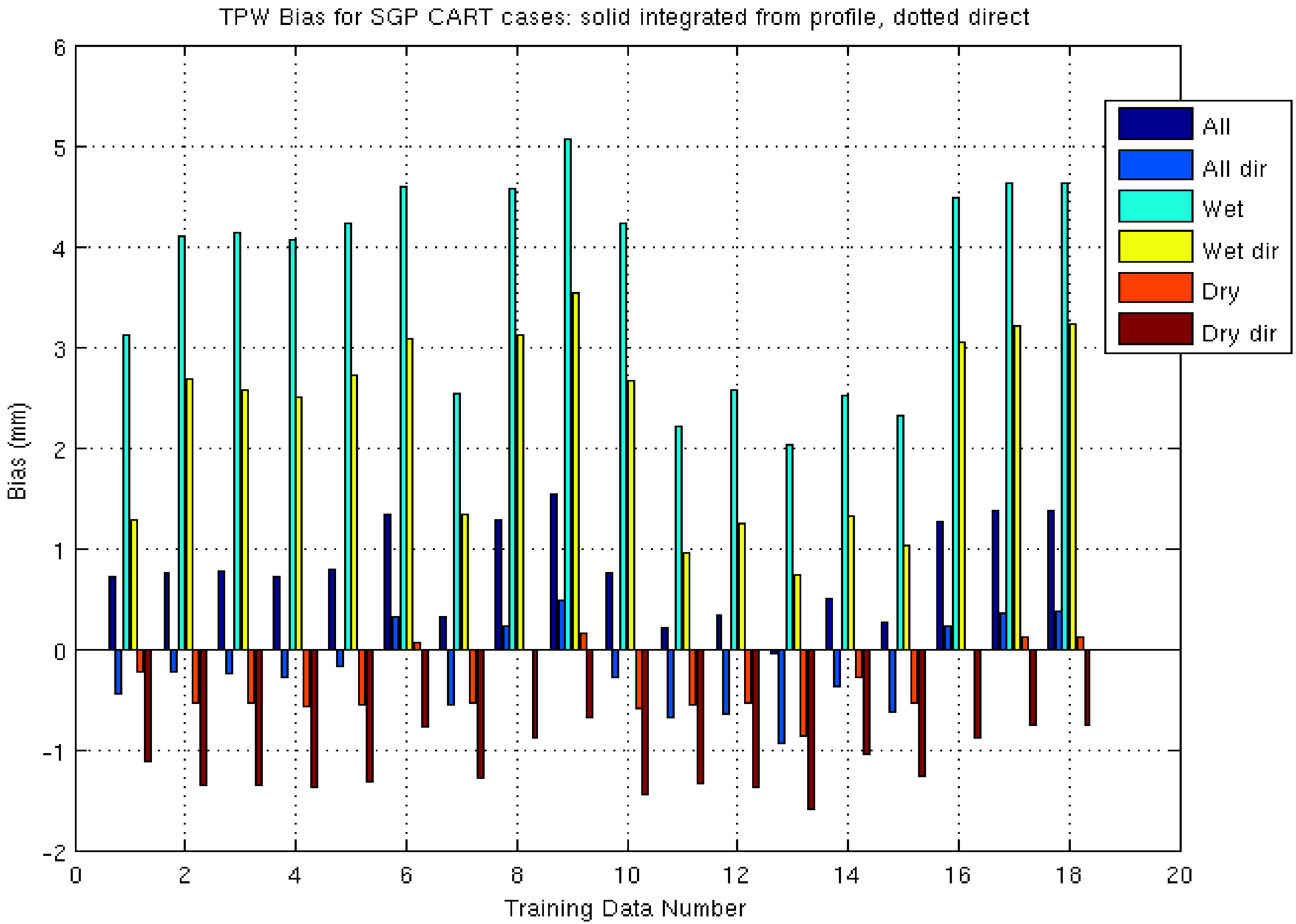
(left) 1 Aug 2005 TPW retrieved from MOD07 with two different surface emissivities used in the training data (0.95 left, BF center) for all Terra MODIS ascending (nighttime) passes over the Sahara Desert .
(right) 00 UTC NCEP-GDAS TPW analysis from 2 August 2005



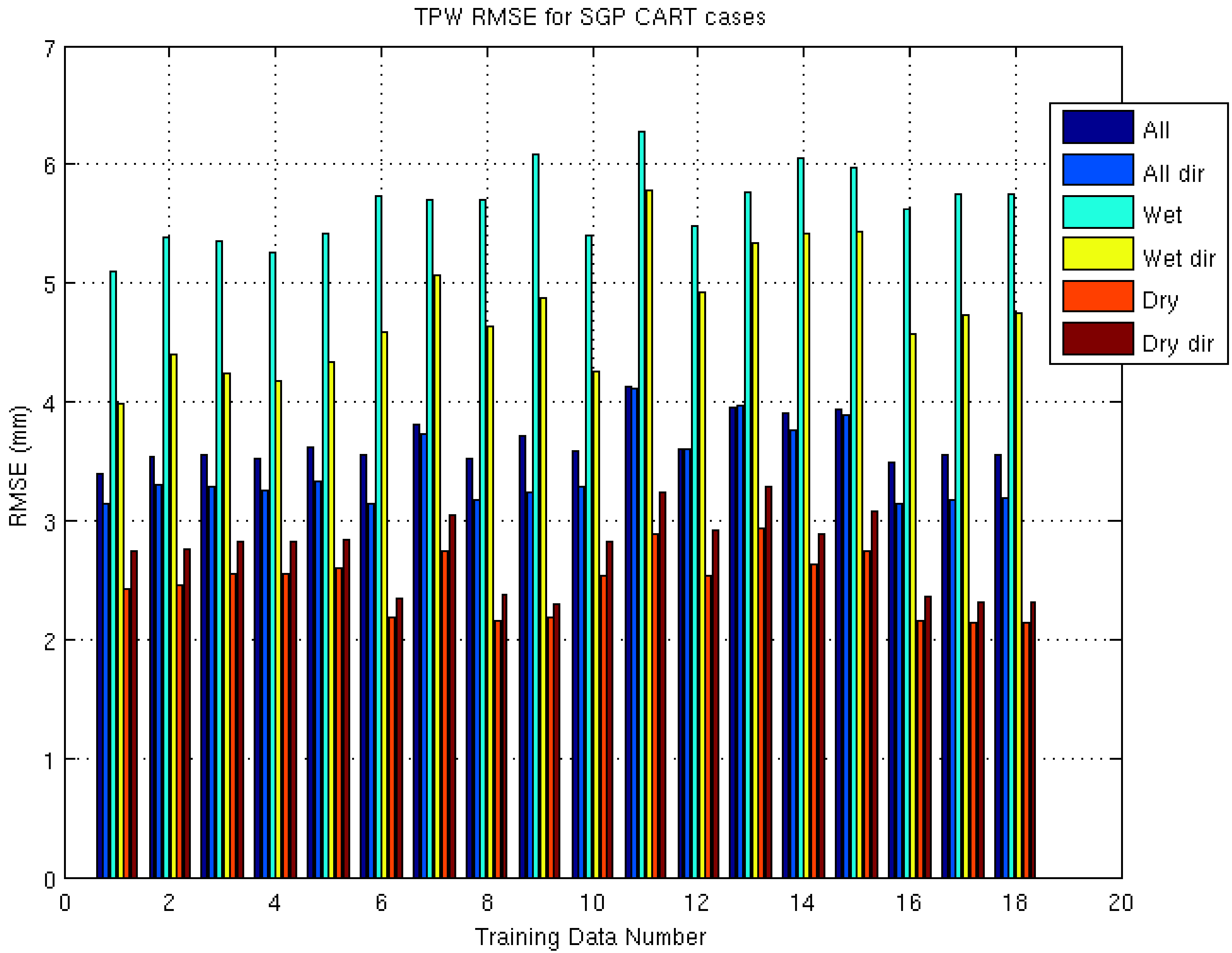


MODIS MOD07 TPW for 21:40 UTC on August 1, 2005. Emissivities of 0.95 (left), 1.0 (center), and the baseline fit emissivity (right) were applied to the training data used in the regression retrieval algorithm.

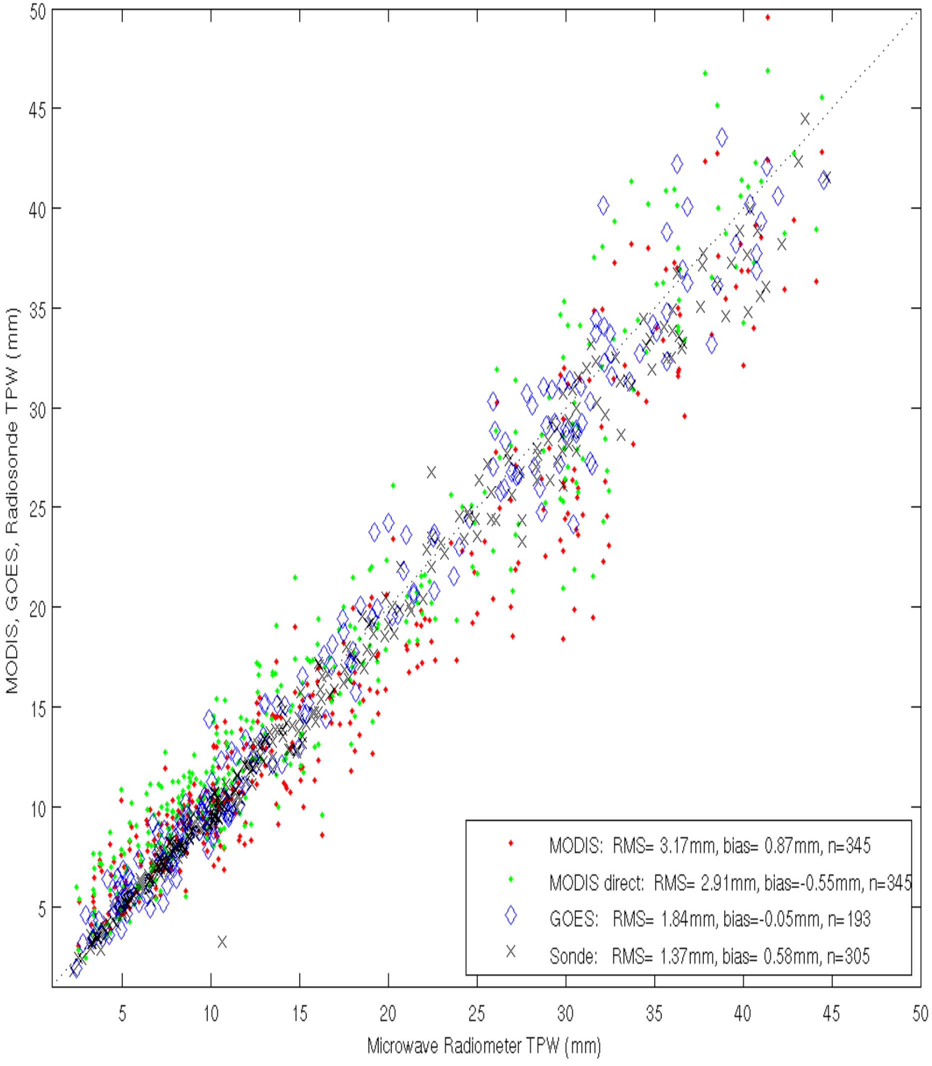
TPW Bias (ARM SGP MWR minus MODIS MOD07) in mm for 18 different training data configurations. The statistics are shown for all cases (All), but also separated into "dry" (TPW < 15 mm) and "wet" (TPW >= 15mm) cases

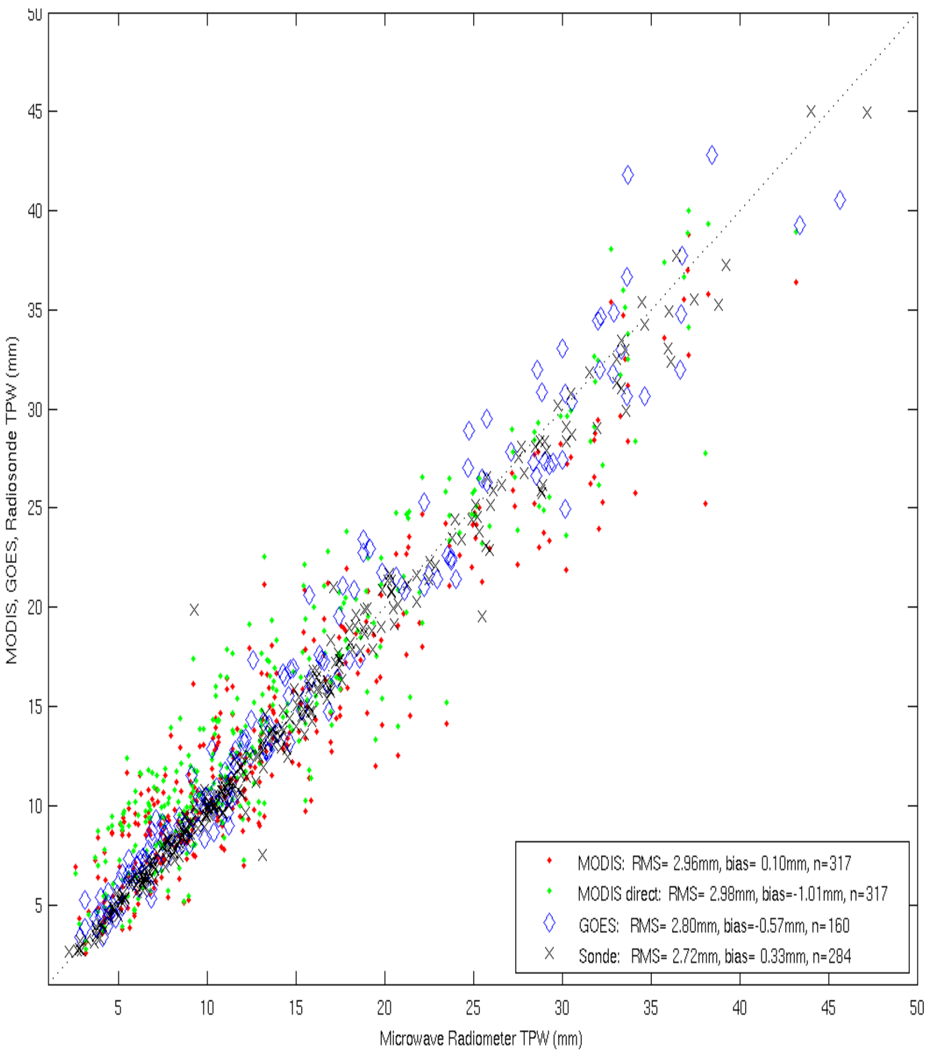


Derived from integration of vertical layers regression or total column regression (dir)

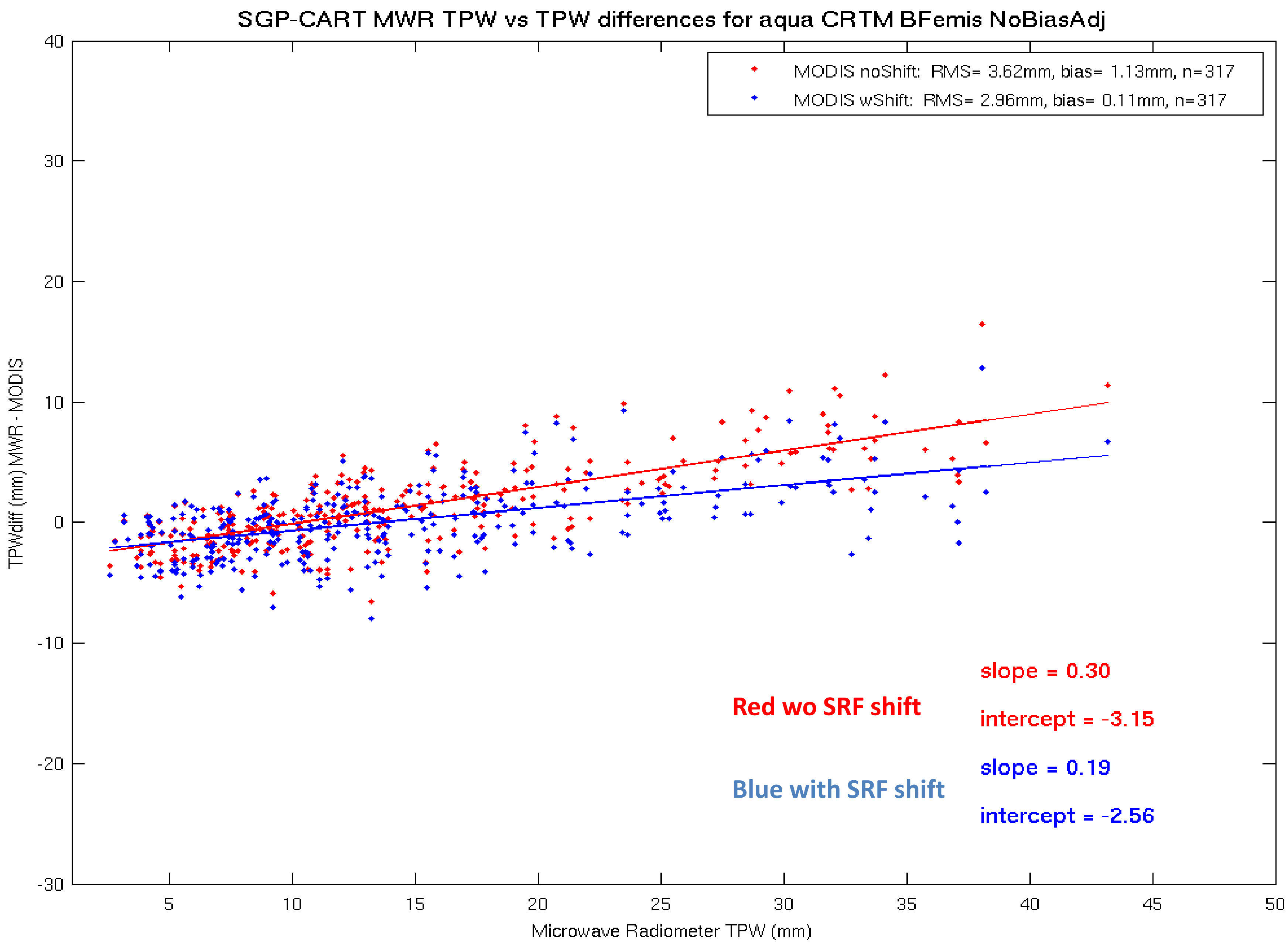

TPW RMSE for SGP CART cases
RMSE (mm)
Training Data Number
All
All dir
Wet
Wet dir
Dry
Dry dir
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
16
18
20

Comparison of MODIS TPW (mm) and MWR at the ARM SGP site from MODIS (y-axis, red dots original, green dots "direct"): Aqua (left) and Terra (right)





Also shown are GOES-8 and -12 (blue diamonds) and radiosonde (black x's) TPWs


SGP-CART MWR TPW vs TPW differences for aqua CRTM BFemis NoBiasAdj
MODIS noShift: RMS= 3.62mm, bias= 1.13mm, n=317
MODIS wShift: RMS= 2.96mm, bias= 0.11mm, n=317
TPWdiff (mm) MWR - MODIS
Microwave Radiometer TPW (mm)
40
30
20
10
0
-10
-20
-30
5
10
15
20
25
30
35
40
45
50
Red wo SRF shift
Blue with SRF shift
slope = 0.30
intercept = -3.15
slope = 0.19
intercept = -2.56