Planck Weighted Transmittance and Correction of Solar Reflection for Broadband Infrared Satellite Channels

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Abstract

Three approximations methods to calculate the level-to-space transmittance, used in fast radiative transfer model, are studied for five infrared broadband channels. Two of them are Planck-weighted transmittances, in which one involves the effective layer temperature of a layer (PW1), and the other involves temperatures at the interface between layers (PW2). The third one is not including temperature at all (ORD). It is found that under all circumstances method PW1 is better than method PW2 compared to the line-by-line (LBL) calculation. Planck-weighted methods are more sensitive to atmospheric surface temperatures compared to ORD method.

Based on these simulations and comparisons, when the band correction is larger (greater than 1), PW1 method should be used to take account of the Planck radiance changing with the transmittance within the band spectral. When considering the solar contribution in daytime, correction of the solar reflection has been made for near infrared broadband channels (~3.7 µm) when using PW1 transmittance. The solar transmittance is predicted by using explanatory variables as PW1 transmittance, secant of zenith angle, and surface temperature. With the correction, the error reduces to more reasonable level.

Methodology

In order to obtain the transmittance coefficients to predict the optical depth in fast models (such as CRTM, and RTTOV), the common approach is using the transmittances which are convolved the line-by-line transmittances by the instrument SRF, referred to Ordinary Transmittance (ORD):

$$\tau_i^{ORD} = \frac{\int \phi(v)\tau_i(v)dv}{\int \phi(v)dv}$$

Uses the layer temperature to modify the Planck-weighted transmittance for the level channel transmittance (PW1):

$$\tau_i^{PW1} = \frac{\int \phi(v)\overline{B(v,T_i)}\tau_i(v)dv}{\int \phi(v)\overline{B(v,T_i)}dv}$$

Uses the level temperature instead of the layer temperature to modify the Planck-weighted transmittance for the level channel transmittance (PW2):

$$\tau_i^{PW2} = \frac{\int \phi(v)B[v,T_i]\tau_i(v)dv}{\int \phi(v)B[v,T_i]dv}$$

Band Correction for Channel Brightness Temperature

The channel center wavenumber ν_i is defined as the first spectral moment of the SRF

$$\nu_i = \frac{\int_{\Delta\nu} \phi(\nu)\nu d\nu}{\int_{\Delta\nu} \phi(\nu)d\nu}$$

Assuming the channel BT is T_e, which is linearly predicted from the spectral radiance of a blackbody at temperature T

$$T_e = b + b_1 T$$

b, and b_1 are fitting coefficients, which can be determined from

$$R = \frac{c_1\nu_i^3}{e^{c_2\nu_i/T_e}-1} = \frac{\int_{\Delta\nu} \phi(\nu)B[\nu,T]d\nu}{\int_{\Delta\nu} \phi(\nu)d\nu}$$

Results

Table 1. Characteristics of the five pseudo channels used in this study and the BT band correction coefficients for a 180-340 K temperature range.

Pseudo Channel	*Satellite Sensor*	*Spectral interval (cm⁻¹)*	*Center Wavenumber (cm⁻¹)*	*BT Band Correction Coefficients*		
				b	*b_1*	*RMS*
1	n/a	2456.0-2683.3	2563.790	4.9724E-01	9.9929E-01	2.9985E-04
2	NOAA-16 AVHRR3 channel 3	2222.7-3355.7	2697.562	2.2687E+00	9.9642E-01	1.5148E-02
3	GOES-12 Sounder channel 15	2225.8-2271.1	2248.638	2.0287E-02	9.9997E-01	2.4825E-05
4	METEOSAT-9 SEVIRI channel 4	2083.3-3289.5	2568.259	3.3855E+00	9.9540E-01	4.5146E-03
5	METEOSAT-9 SEVIRI channel 11	649.4-877.2	750.660	3.1222E-01	9.9869E-01	6.8775E-03

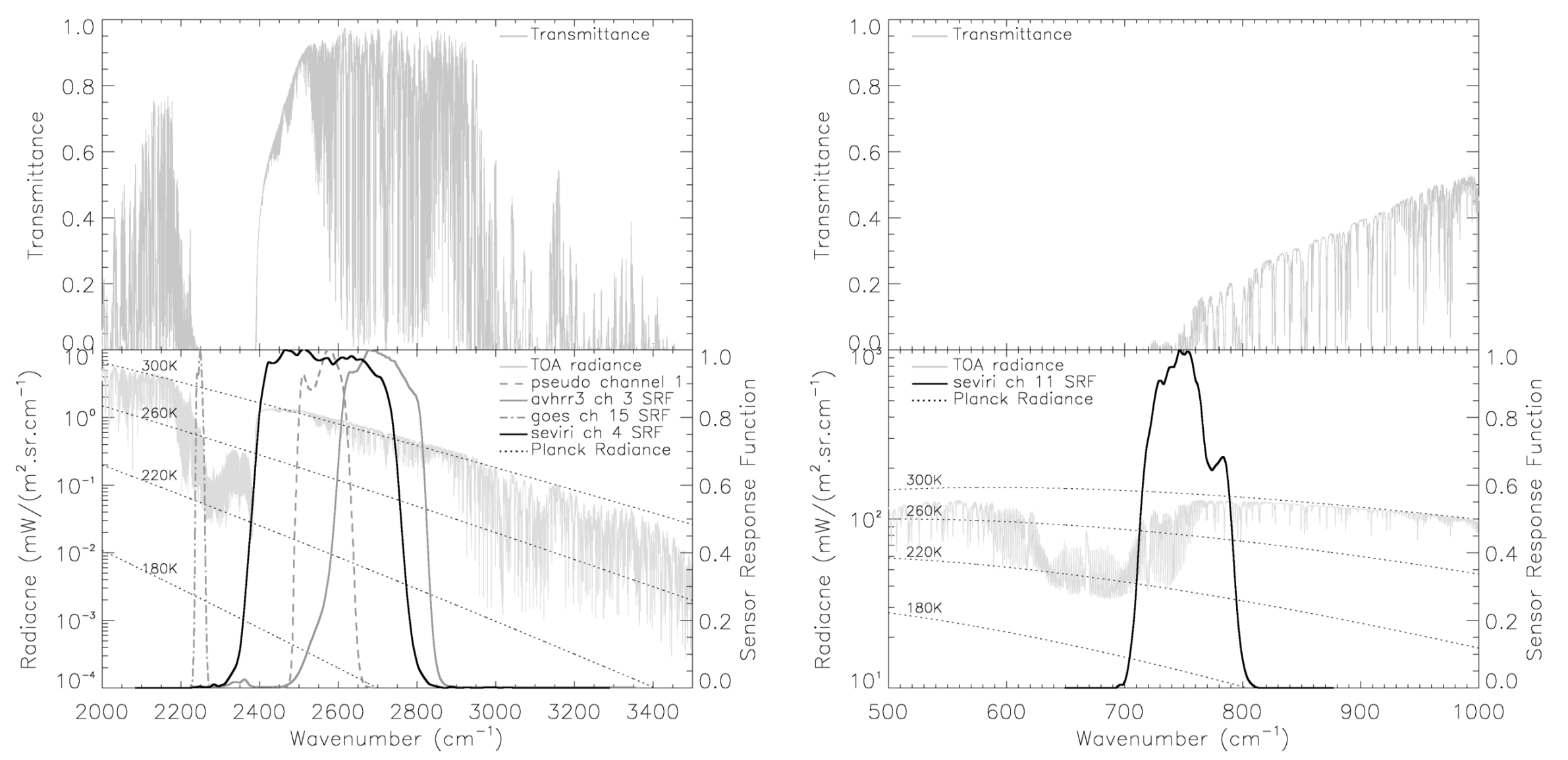

Figure 1. Channel sensor response functions, surface-to-space transmittance, TOA radiance for tropical model atmosphere, and theoretical Planck radiance curves for a number of atmospheric temperatures.

The Line-By-Line Radiative Transfer Model (LBLRTM) version 11.3 was employed to realistically simulate the monochromatic level-to-space transmittance. The spectral resolution for all the channels is set to 1×10^{-3} cm^{-1}. The variable gases for the input profiles include H_2O, CO_2 and O_3, and all other gases are treated as fix gases. Based on the above three convolved transmittances, the clear sky channel radiances can be calculated.

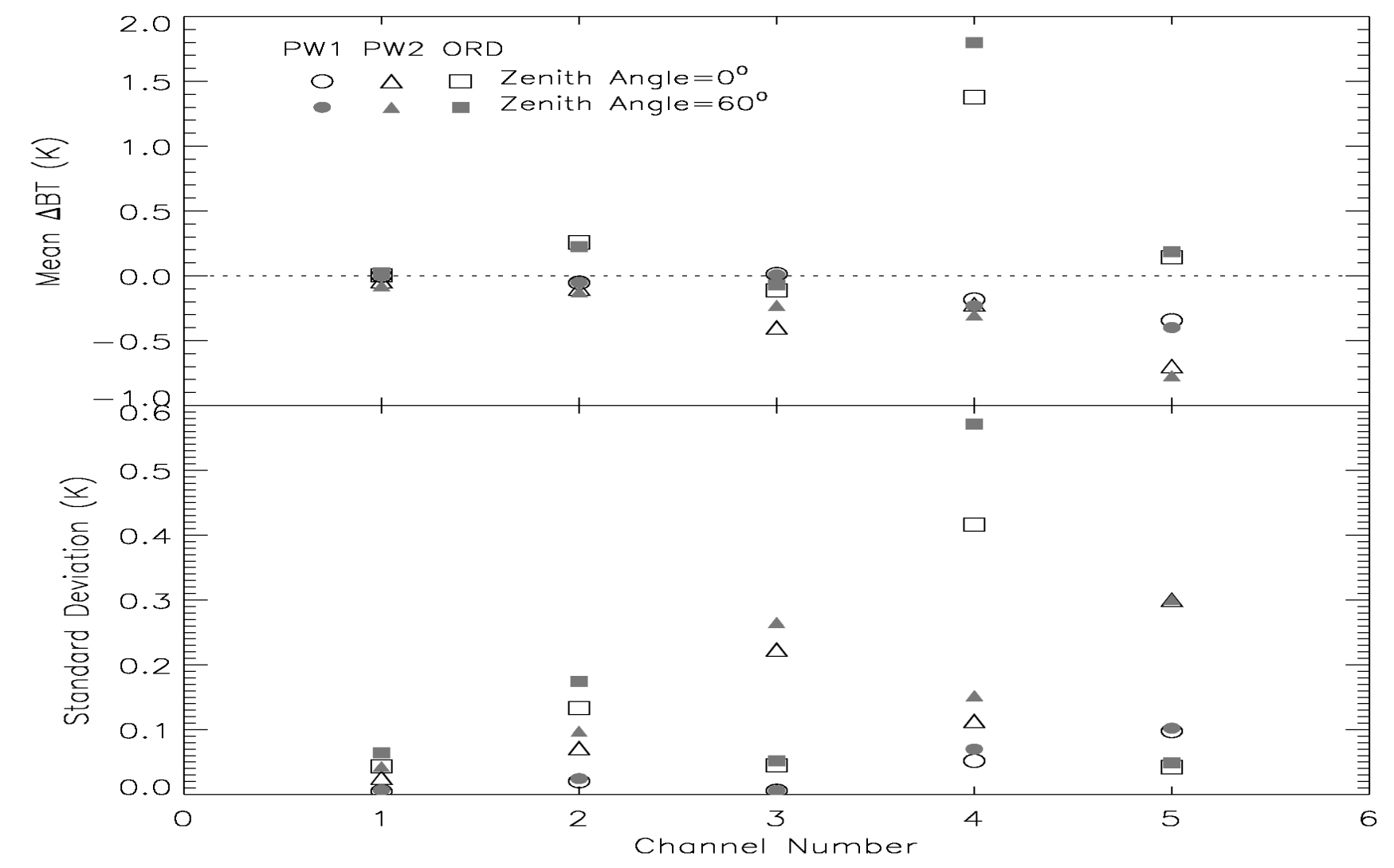

Figure 2. Mean brightness temperature differences and standard deviation for methods PW1, PW2, and ORD compared to LBL results for UMBC 48 diverse atmospheric profiles at nadir.

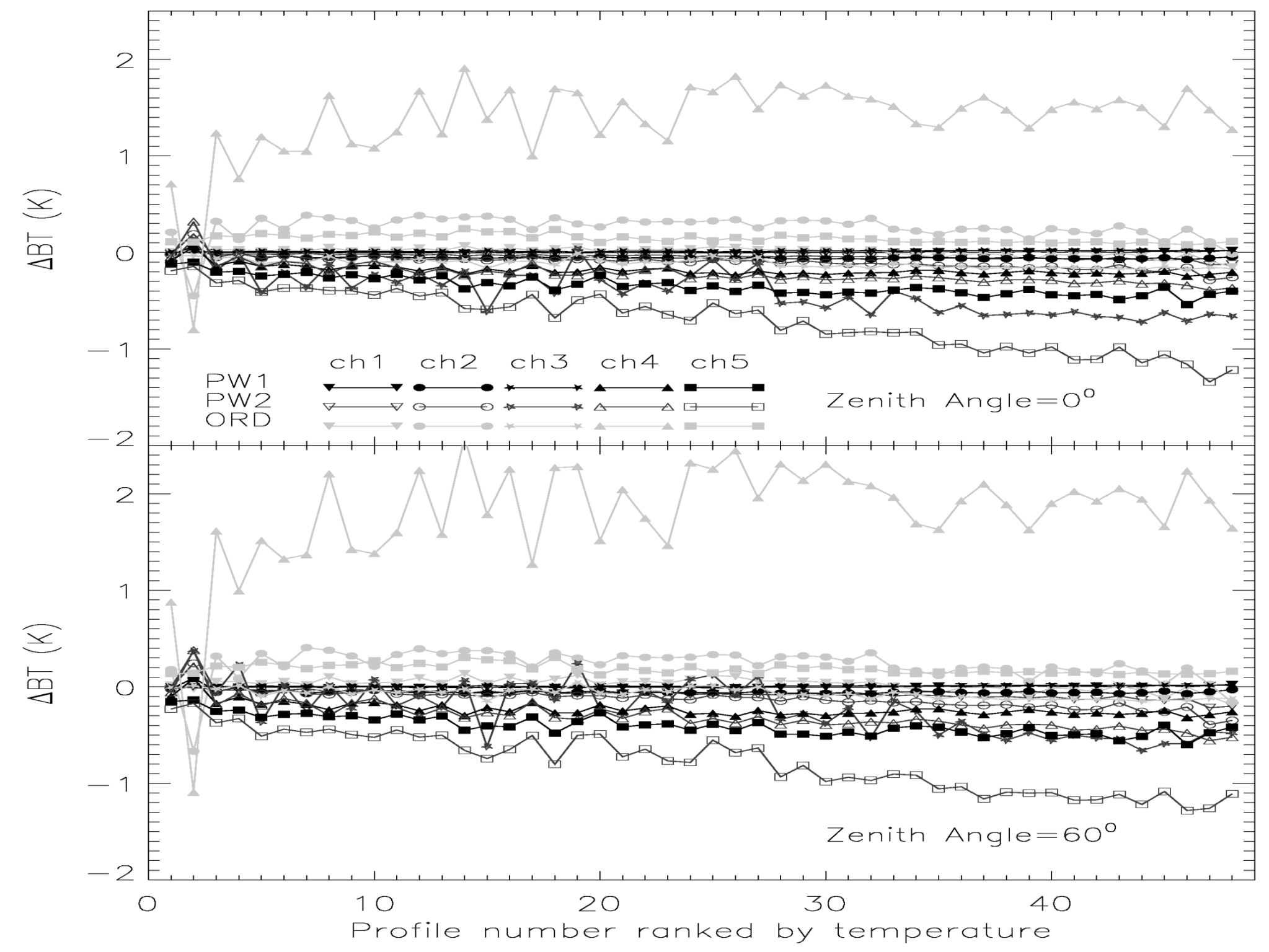

Figure 3. The brightness temperature differences for methods PW1, PW2, and ORD compared to LBL calculation as a function of profile number ranked by temperature by using UMBC 48 diverse atmospheric profiles at nadir (top panel) and 60° (bottom panel).

Correction of Solar Reflection for NIR

Correction of solar reflection for NIR channels when using PW transmittance

Solar transmittance

$$\tau_i^s = \frac{\int \phi(v)R_s(v)\tau_i(v)dv}{\int \phi(v)R_s(v)dv}$$

is not the same as

$$\tau_i^{PW1} = \frac{\int \phi(v)\overline{B(v,T_i)}\tau_i(v)dv}{\int \phi(v)\overline{B(v,T_i)}dv}$$

Solar contribution for clear sky:

$$R_{sol} = r\mu_0 F_* \tau^s(\mu_0)\tau^s(\mu)/\pi$$

We need account for the difference between using PW transmittance and solar transmittance

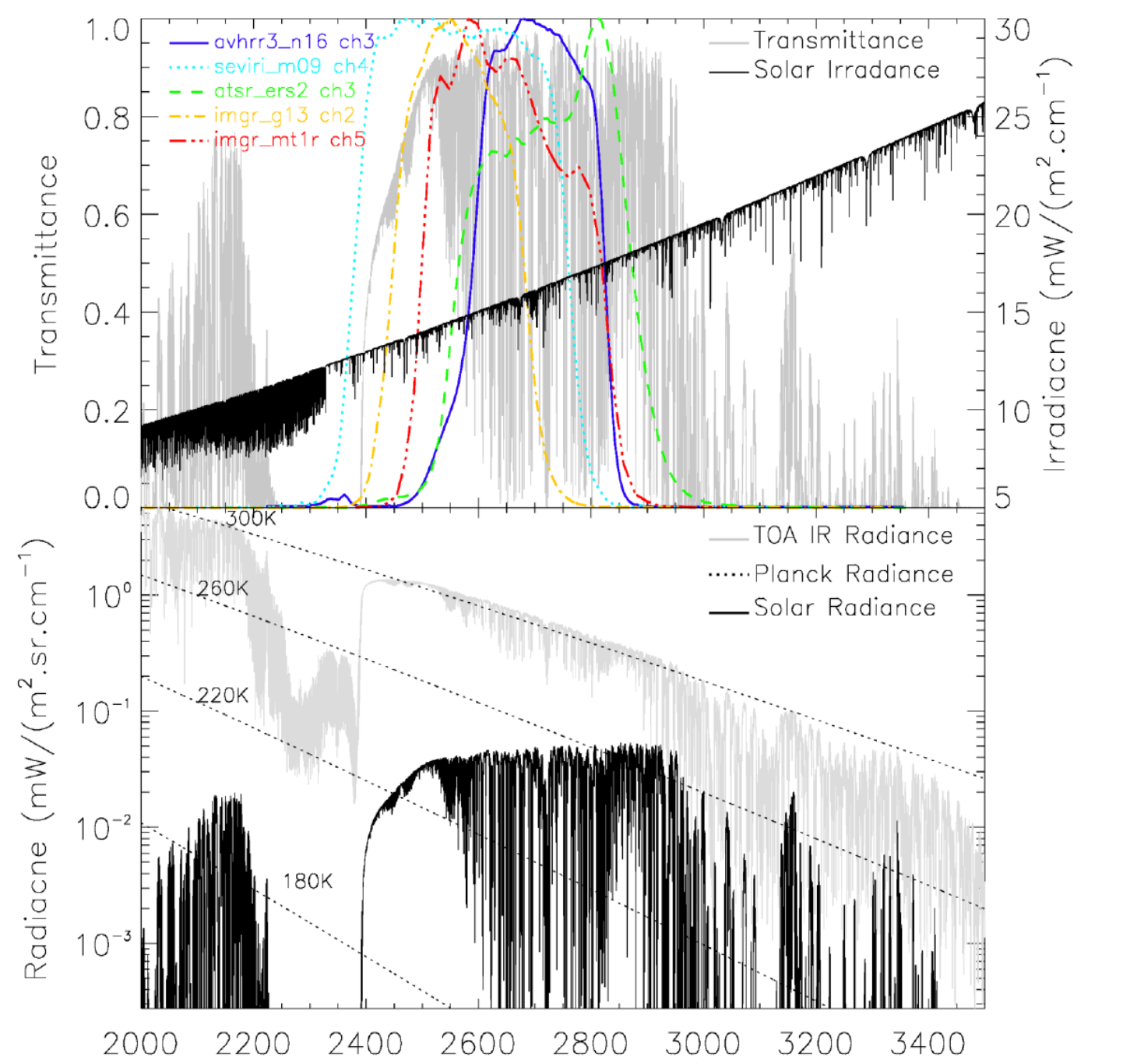

Figure 4

$$\Delta R_{sol} = r\mu_0 F_* \tau^{PW1}(\mu_0)\tau^{PW1}(\mu)/\pi - r\mu_0 F_* \tau^s(\mu_0)\tau^s(\mu)/\pi$$

Predicting solar transmittance with PW transmittance

$$\tau_m^s = \beta_0 + \beta_1\tau_m^{PW1} + \beta_2\mu_m + \beta_3(T_s)_m,\ \text{for } m = 1,2,\ldots M$$

(1) Ten pairs of solar zenith angles and sensor zenith angles are used:
μ = (1.0, 1.25, 1.50, 1.75, 2.0, 2.25, 3.0, 6.0, 9.0, 12.0)
μ_0 = (1.0, 1.25, 1.50, 1.75, 2.0, 2.25, 3.0, 6.0, 9.0, 12.0)

(2) Calculated the solar transmittances and PW transmittances for UBMC 48 profiles

(3) For each channel, we have 480 (10 angles X 48 profiles) total transmittances pairs

(4) Multiple linear regression method is used to predict the solar transmittance with explanatory variables as: PW transmittance, surface temperature, and secant of zenith angle.

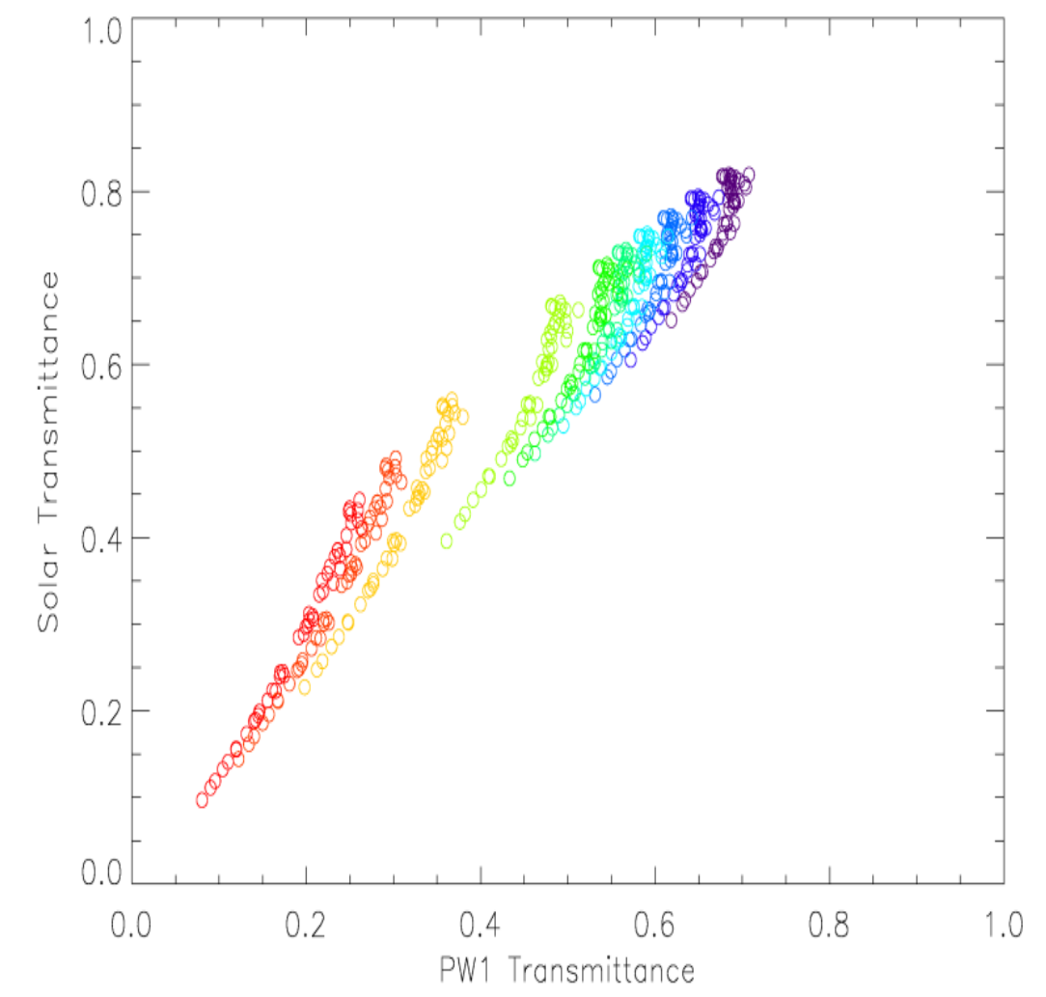

Figure 5. Relationship between PW1 total transmittance and solar total transmittance for METEOSAT-9 SEVIRI channel 4.

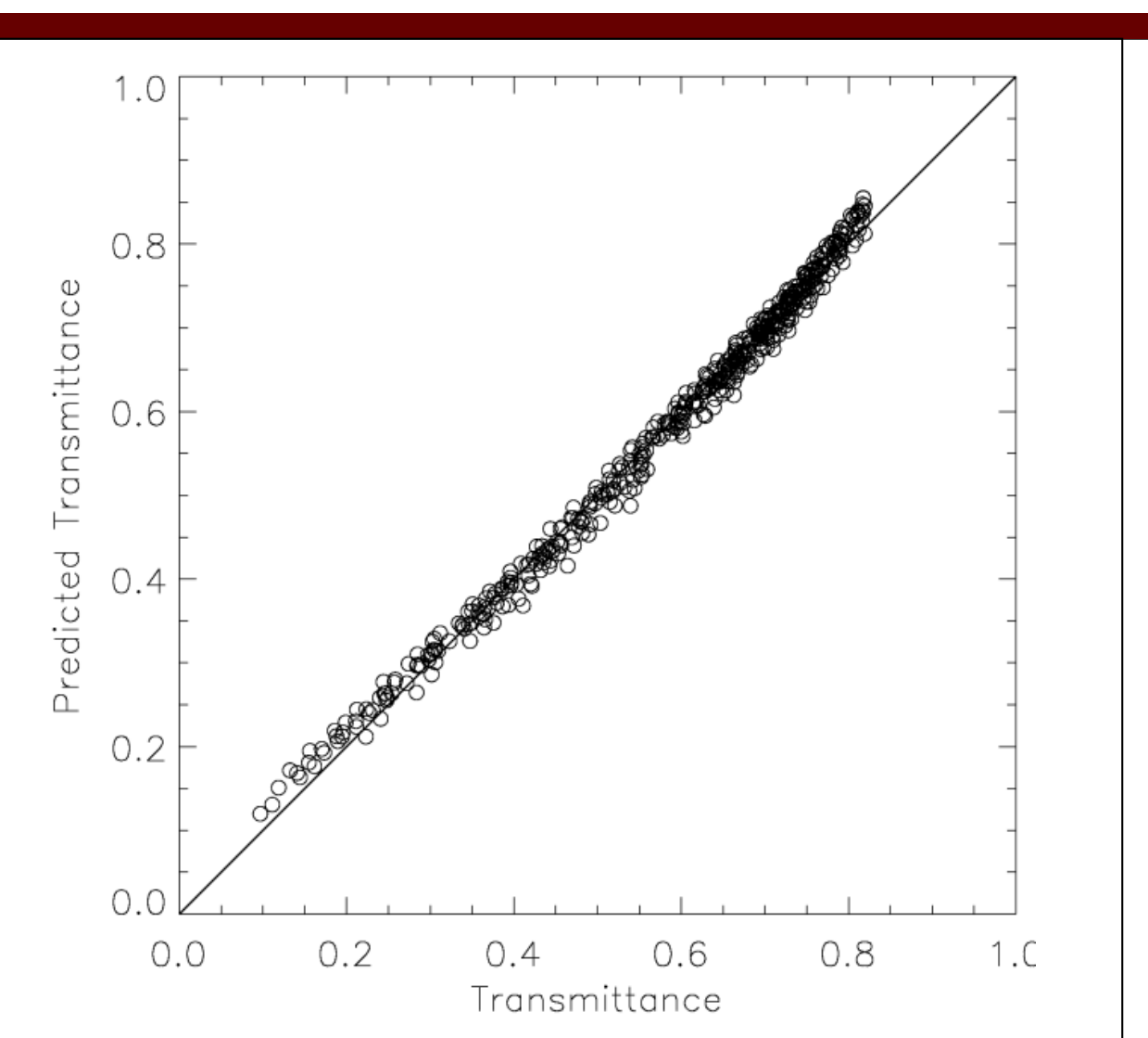

Figure 6. Predicted solar transmittance from PW1 transmittance versus solar transmittance for METEOSAT-9 SEVIRI channel 4.

Table 2. Satellite sensor channels (~3.7 µm) for Planck-weighted transmittance.

Satellite Sensor/channel	*Spectral interval (cm⁻¹)*	*Center Wavenumber (cm⁻¹)*	*BT Band Correction Coefficients*		
			b	*b_1*	*Rank*
avhrr3_n16 ch3	2222.7-3355.7	2697.562	2.2687E+00	9.9642E-01	09
avhrr3_n17 ch3	2418.4-2947.2	2670.800	1.7251E+00	9.9771E-01	05
avhrr3_n18 ch3	2406.2-2977.9	2663.004	1.7627E+00	9.9767E-01	06
avhrr3_n19 ch3	2418.4-3034.9	2671.660	1.7074E+00	9.9773E-01	04
avhrr3_metop-a ch3	2382.1-3041.3	2689.894	2.1320E+00	9.9720E-01	08
seviri_m08 ch4	2224.1-2913.2	2566.019	3.3476E+00	9.9540E-01	15
seviri_m09 ch4	2083.3-3289.5	2568.259	3.3855E+00	9.9540E-01	16
seviri_m10 ch4	2213.8-2947.1	2565.885	3.3204E+00	9.9547E-01	14
aatsr_envisat ch1	2176.1-3120.5	2680.398	1.8322E+00	9.9747E-01	07
atsr1_ers1 ch3	2426.1-3099.8	2693.365	2.3416E+00	9.9693E-01	10
atsr2_ers2 ch3	2251.2-3293.9	2727.513	2.8438E+00	9.9614E-01	13
imgr_g12 ch2	2419.1-2670.0	2564.822	6.9902E-01	9.9902E-01	01
imgr_g13 ch2	2002.5-3333.5	2563.957	1.4800E+00	9.9794E-01	02
imgr_g14 ch2	2227.1-2852.0	2573.925	1.5567E+00	9.9783E-01	03
imgr_mt1r ch5	2381.7- 3029.1	2653.665	2.3479E+00	9.9697E-01	11
imgr_mt2 ch4	2466.0- 2908.9	2684.116	2.4637E+00	9.9678E-01	12

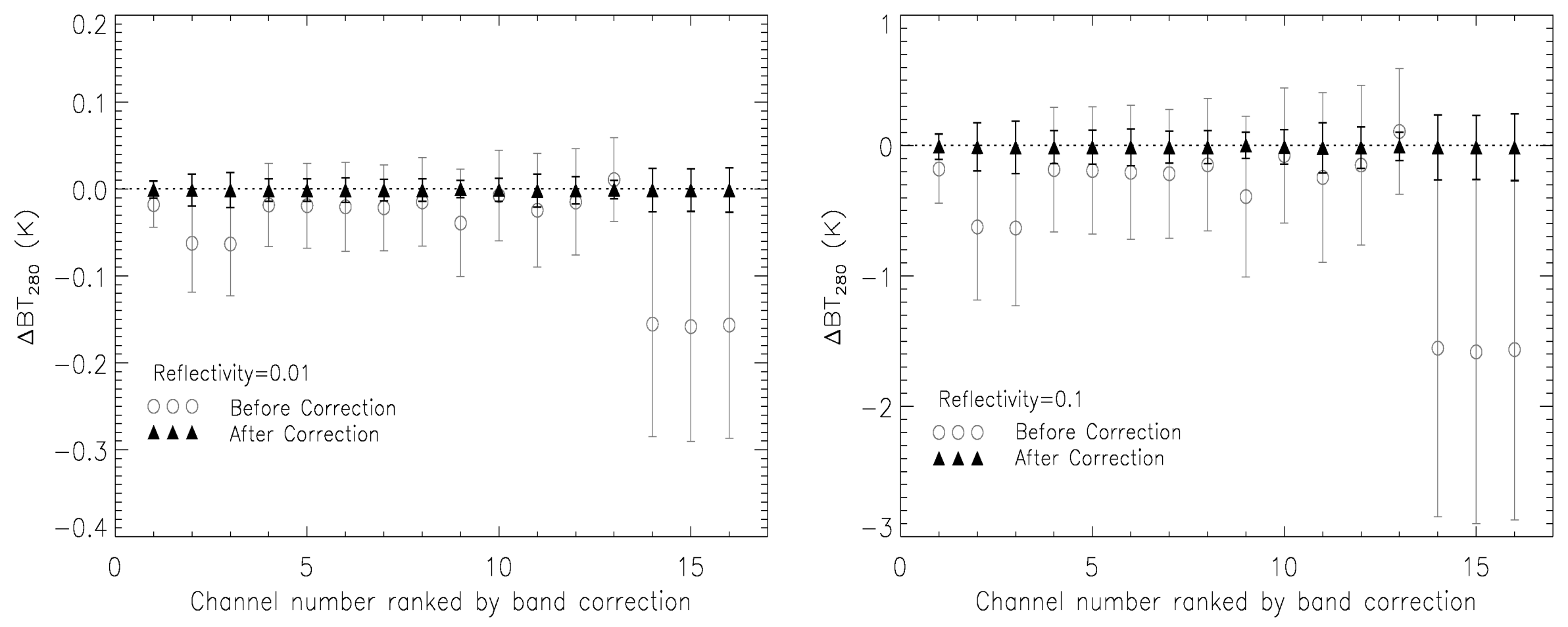

Figure 7. Statistics for solar reflection before and after correction for reflectivity 0.01 (top) and 0.1 (bottom). The symbol open circles and solid triangles are biases for before correction and after correction, respectively. The standard deviations are also shown with vertical bar.

Concluding Remarks

Based on these simulations and comparisons, when the band correction for channel brightness temperature is smaller, especially coefficient *b* is less than 1, method ORD should be used to calculate the transmittance instead of Planck-weighted transmittances due to the consistent BT differences to LBL. When the band correction coefficient *b* is great than 1, PW1 method should be used to take account of the Planck radiance changing with the transmittance within the band spectral to reduce the larger BT differences when using method ORD.

The solar reflection correction and PW transmittance are significant to accurately simulate the NIR broadband channel radiances from the sensors on the future national operational environmental satellite systems, in particular the Joint Polar Satellite System (JPSS) and the Geostationary Operational Environmental Satellite R-Series (GOES-R).