On the use of Planck-weighted transmittances in CRTM

Yong Chen
CIRA/NESDIS/STAR
11/09/2007

1. Introduction. CRTM assumes that the Planck function does not depend on wave number when simulating the satellite radiance by integrating over the width of satellite instrument spectral response function (SRF). This approximation is less valid for wide spectral bands, such as MSG SEVIRI 3.8 micron channel (Brunel and Turner, 2003). Brunel and Turner used an alternative approach in which RTTOV regression predicts convolved transmittances that are weighted by the Planck function. Comparing the performance of the RTTOV to reference line-by-line computations showed that the use of Planck-weighted transmittances (referred as PW) could reduce bias significantly for MSG SEVIRI 3.8 micron channel. Jonathan Mittaz found that there is a 2 K bias in this channel comparing observed radiance to predicted radiance with the CRTM. He suggested that we should use PW approach to convolve transmittances. In this report, the details of processing the PW approach in CRTM are documented.

2. Method. The line by line (LBL) model LBLRTM-v9.4 is run over spectrum from 500 to 3750 cm^{-1} with 0.1 cm^{-1} resolution and over the UMBC 48 atmospheric profiles for 7 secant angles and 101 AIRS pressure levels. The upwelling (from space to level) and downwelling (from surface to level) transmittances are computed. Different atmospheric gases combinations are considered in order to be able to compute CRTM predictor coefficients. The each interval line-by-line top of the atmosphere (TOA) radiance is calculated by using simple emission model and assuming blackbody surface. The radiance received by the satellite sensor is computed by convolving the interval radiances with the instrument SRF:

$$R = \frac{\int \phi(\nu) R(\nu) d\nu}{\int \phi(\nu) d\nu} . \quad (1)$$

In order to obtain the transmittance coefficients to predict the optical depth in fast models, CRTM using the transmittances which are convolved the line-by-line transmittances by the instrument SRF. The transmittances resulting from the basic convolution is referred to Ordinary transmittances (ORD) while Planck weighted transmittances take into account the variation of the Planck function for each spectral interval (ν). The level i ordinary transmittance is given by

$$\tau_i^{ORD} = \frac{\int \phi(\nu) \tau_i(\nu) d\nu}{\int \phi(\nu) d\nu} , \quad (2)$$

while the Planck weighted transmittance is given by

$$\tau_i^{PW} = \frac{\int \phi(\nu) B(\nu, T_i) \tau_i(\nu) d\nu}{\int \phi(\nu) B(\nu, T_i) d\nu} . \quad (3)$$

3. Results. Based on the convolved transmittances, two sets of CRTM transmittance coefficients are produced, one with the ordinary transmittances and the other with PW transmittances. We have compared the brightness temperatures produced with the two sets of coefficients to the LBL results for six satellite sensors: METEOSAT-08 SEVIRI, NOAA-17 AVHRR/3, NOAA-18 AVHRR/3, NOAA-17 HIRS/3, NOAA-18 HIRS/4, MetOp-a HIRS/4.The radiance-temperature conversions are the same for all three methods, with same central wave number and band correction. Figs. 1-6 show the biases and standard deviations for CRTM simulated brightness temperature with LBL results for these six sensors respectively. The biases and standard deviations for METEOSAT-08 SEVIRI and NOAA-17 HIRS/3 have similar results as Brunel and Turner (2003).

4. Reference.

Brunel, P. and S. Turner, 2003: On the use of Planck-weighted transmittances in RTTOV. Poster at 13th International TOVS Study Conference, Ste Adele, Canada, 29 October 2003 - 4 November 2003. http://cimss.ssec.wisc.edu/itwg/itsc/itsc13/thursday/brunel_poster.pdf

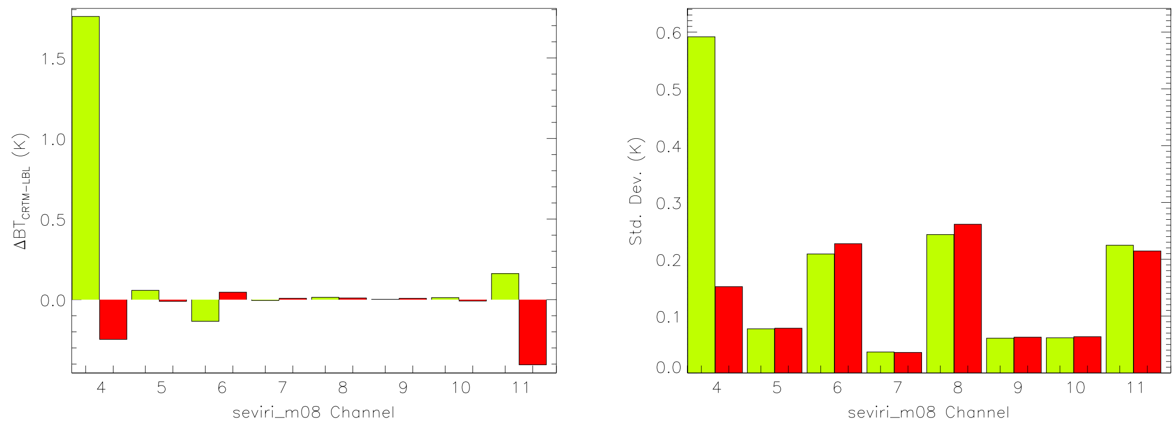

Figure 1: Biases (CRTM minus LBL) and standard deviations for METEOSAT-8 SEVIRI channels 4-11. Green bar for ORD, red for PW. The PW transmittances reduce the bias and standard deviation for channel 4 significantly to an acceptable value.

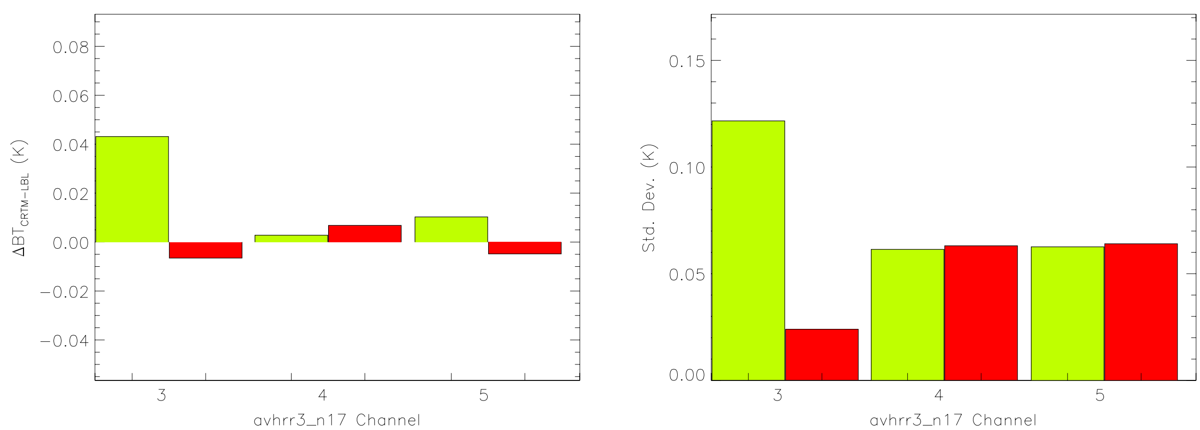

Figure 2: Same as Figure 1, except for NOAA-17 AVHRR/3 channels 3, 4, 5.

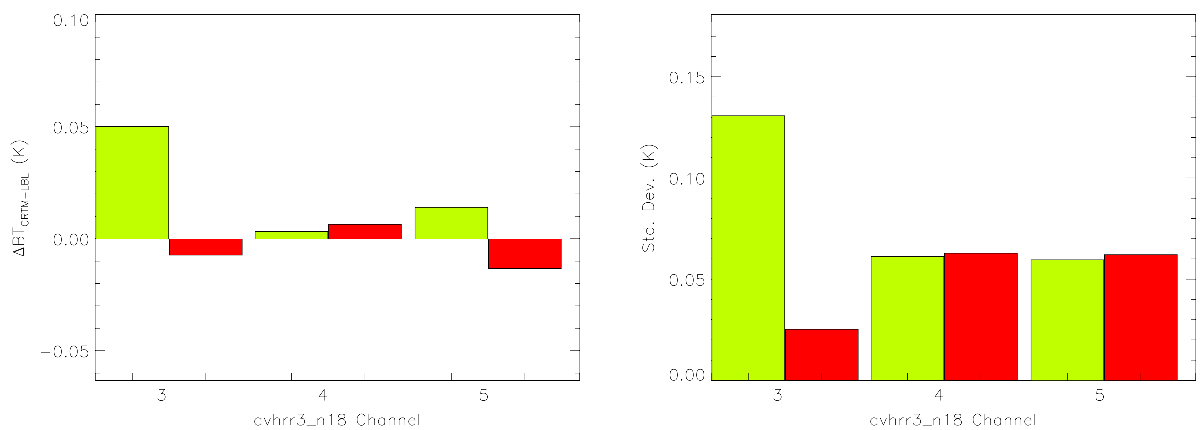

Figure 3: Same as Figure 1, except for NOAA-18 AVHRR/3 channels 3, 4, 5.

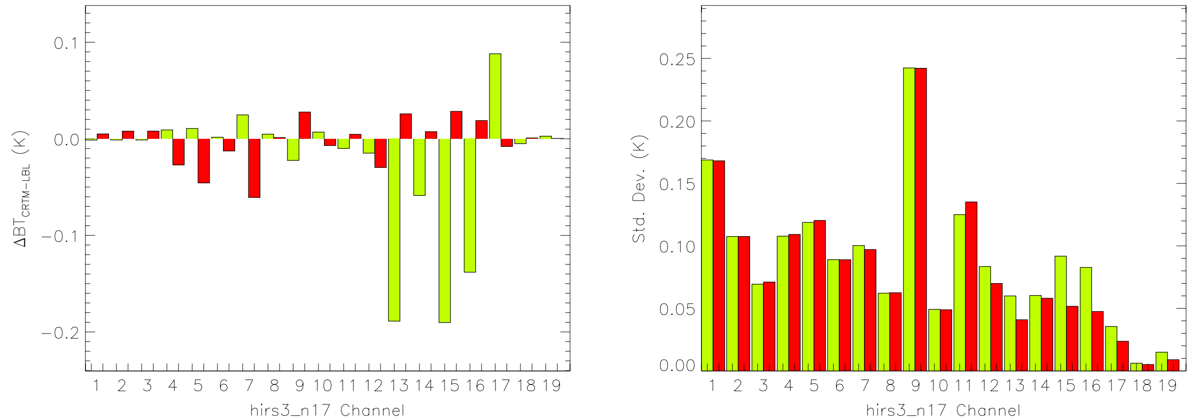

Figure 4: Same as Figure 1, except for NOAA-17 HIRS/3 channels 1-19.

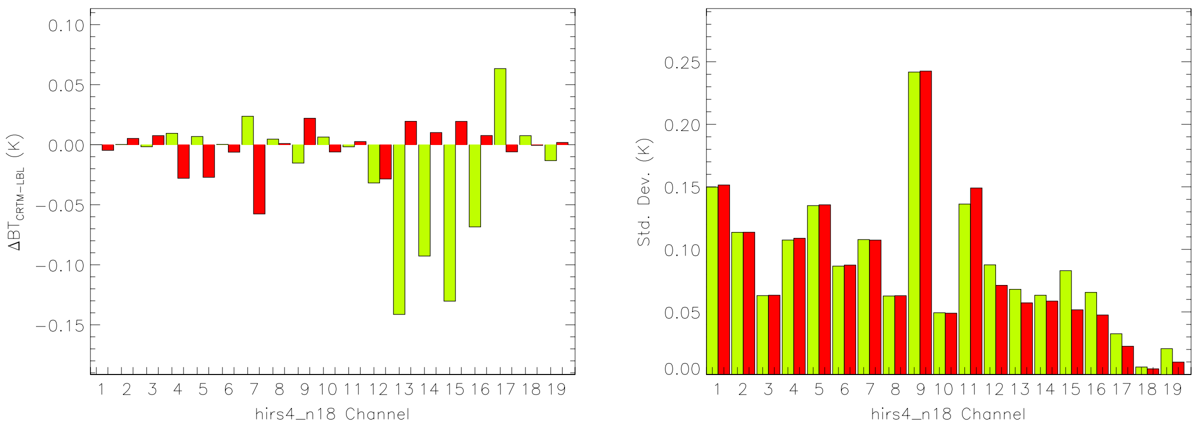

Figure 5: Same as Figure 1, except for NOAA-18 HIRS/4 channels 1-19.

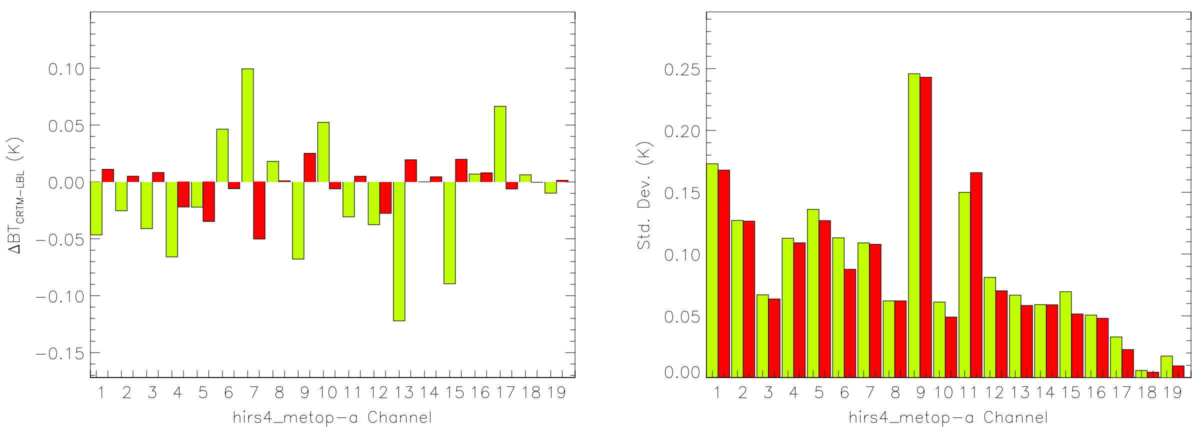

Figure 6: Same as Figure 1, except for MetOp-a HIRS/4 channels 1-19.

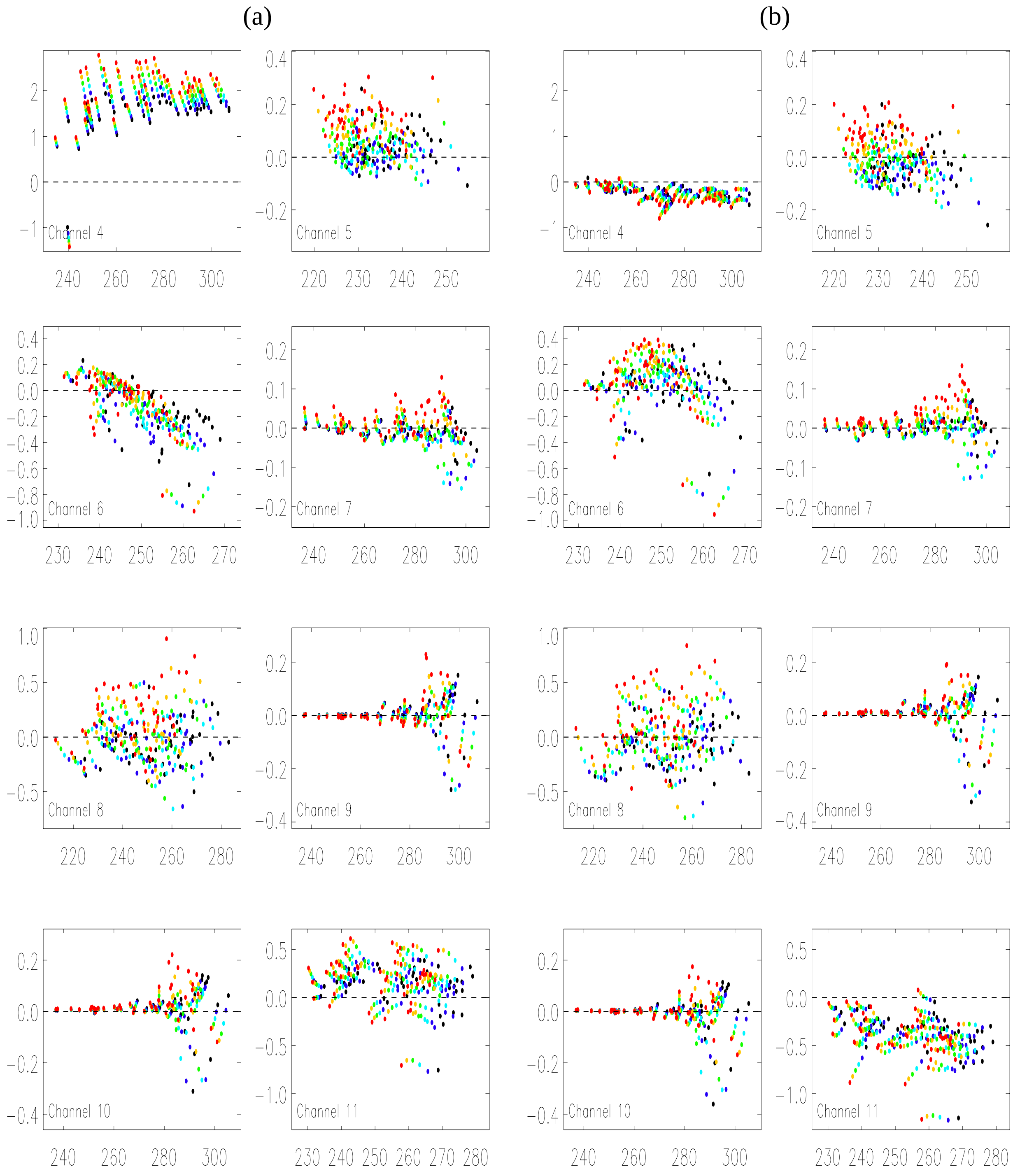

Figure 7: Brightness temperature difference for CRTM minus LBL for all profiles and all secant angles (colored) as a function of the BTs for METEOSAT-08 SEVIRI channels 4-11. Left plot (a) is for Ordinary transmittance while right plot (b) is for Planck Weighted transmittances. Few profiles (5, 37) may introduce large biases in both cases. Those profiles are representing extreme cases. Profile (5) tropical with higher surface temperature and very moist, and Profile (37) polar winter very dry.

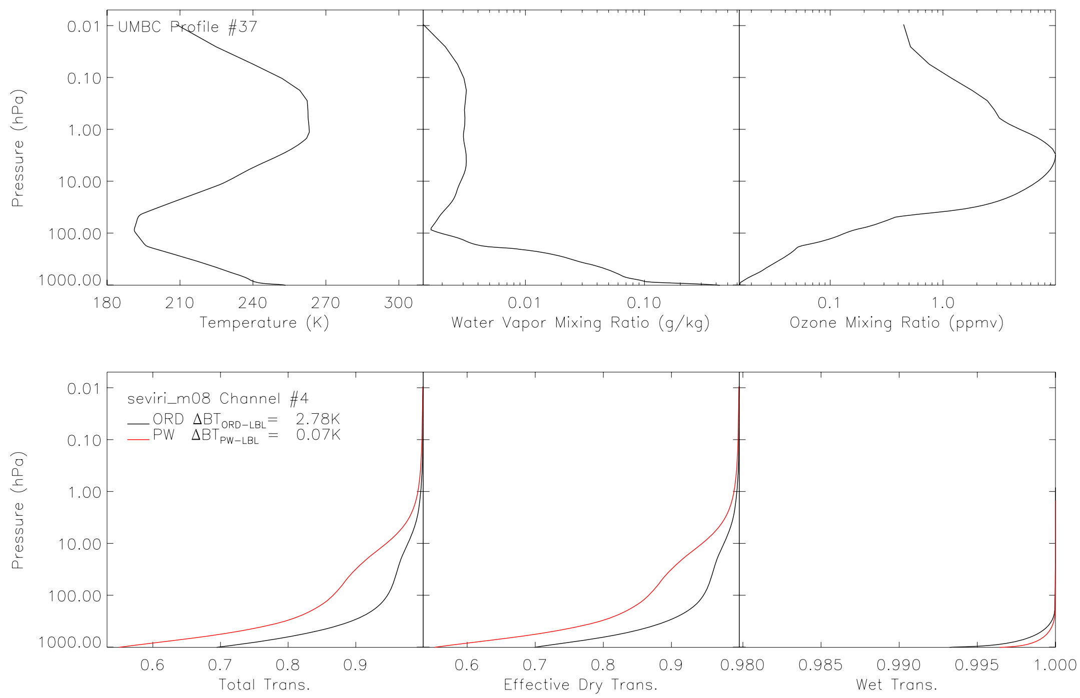

Figure 8: UMBC profile 37, which show the largest channel 4 ORD bias in Fig. 7, temperature, water vapor and ozone profile (upper panel), and total transmittance, dry effectively transmittance, and wet transmittance (lower panel) for ORD (black) and PW (red).

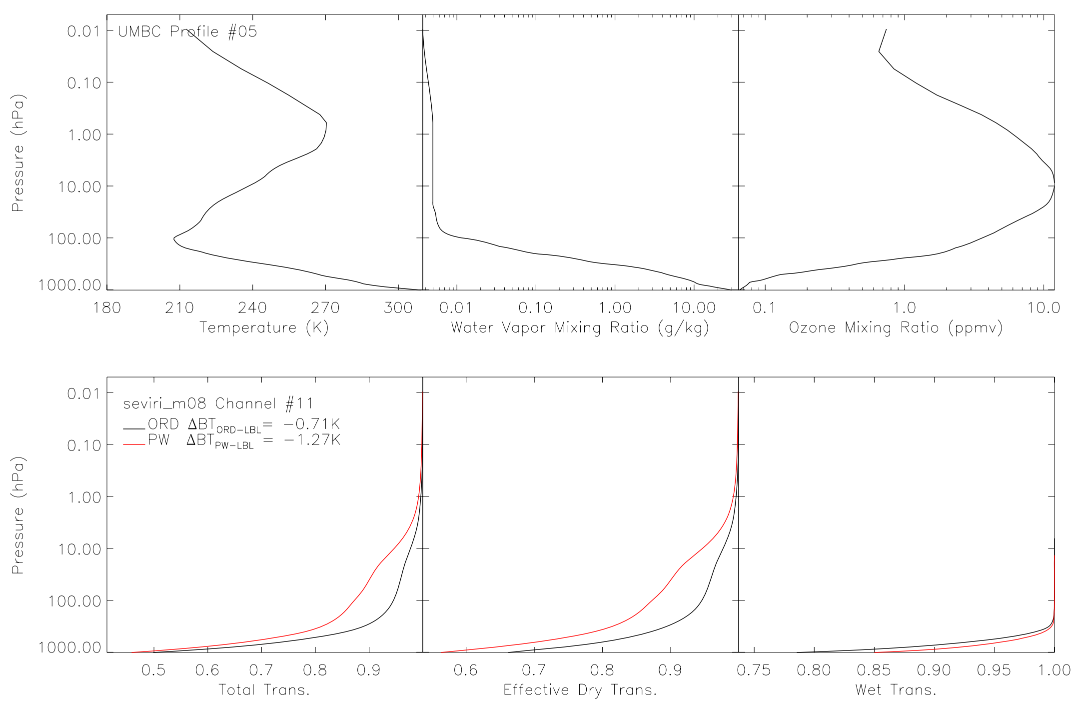

Figure 8: UMBC profile 5, which show the negative largest channel 11 PW bias in Fig. 7, temperature, water vapor and ozone profile (upper panel), and total transmittance, dry effectively transmittance, and wet transmittance (lower panel) for ORD (black) and PW (red).

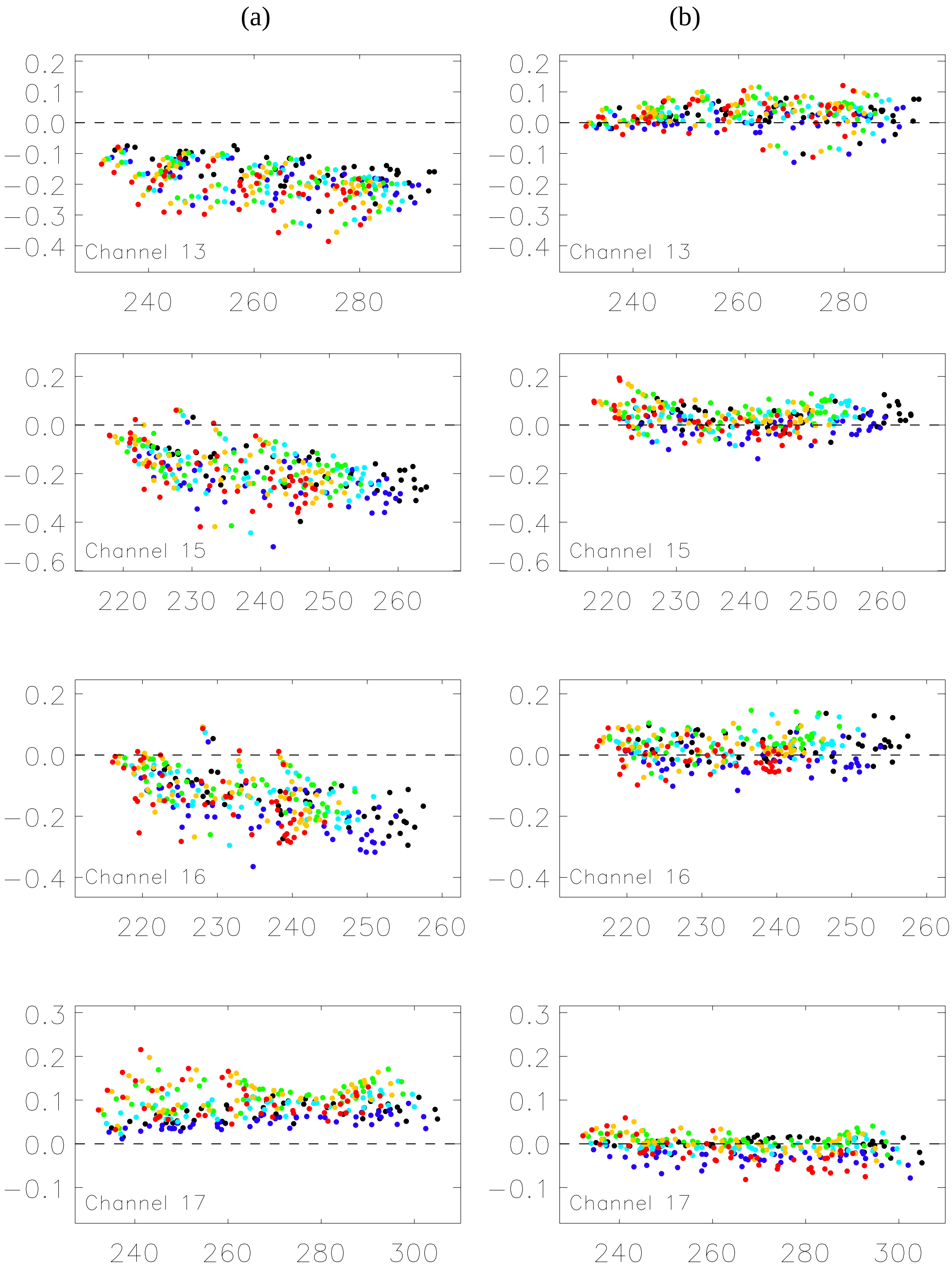

Figure 9: Brightness temperature difference for CRTM minus LBL for all profiles and all secant angles as a function of the BTs for NOAA-17 HIRS/3 most improved channels 13, 15, 16 and 17. Left plot (a) is for Ordinary transmittance while right plot (b) is for Planck Weighted transmittances.