

Comparison of Simulated Radiances, Jacobians and Information Content for the Microwave Humidity Sounder and the Advanced Microwave Sounding Unit–B.

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Abstract

The Microwave Humidity Sounder (MHS) has similar scan characteristics to the Advanced Microwave Sounding Unit-B (AMSU-B). However, the radiometric characteristics are somewhat different, particularly for two channels. Both of these channels will sense somewhat deeper into the atmosphere for the MHS than the AMSU-B. The MHS also has higher information content than the AMSU-B due to its improved noise characteristics.

1. Introduction

The Advanced Microwave Sounding Unit – B (AMSU-B) is a five channel microwave sounder which has been flown on NOAA-15, 16 and 17. It is used to retrieve water vapour profiles by NOAA/NESDIS, and its radiances are assimilated into the analyses of major numerical weather prediction centres in the U.S. and elsewhere. With the launch of NOAA-N, this instrument will be replaced by the Microwave Humidity Sounder (MHS). The MHS will also fly on the METOP series of satellites. Although the scanning characteristics of the two instruments are the same, there are significant differences in their radiometric characteristics. This may be noted by comparing the frequencies and bandpasses of the MHS for NOAA-N and the AMSU-B for NOAA-K/15, which are given in Table 1. The major differences are the change of channel 2 from 150 GHz to 157 GHz, and the change of channel 5 from a double sideband symmetric about the 183.31 GHz water vapour line to a single bandpass at 191.31 GHz. The other channels are very similar for the two sensors. Figure 1 gives a visual representation of the bandpasses for these two instruments. Based on these differences it is expected that channels 2 and 5 will produce somewhat different brightness temperatures for the MHS, but that channels 1, 3 and 4 should be essentially the same as the AMSU-B. This paper is in two sections: The first presents the differences in the brightness temperatures and Jacobians that are to be expected with the change to the MHS and the second gives an estimate of the information content difference between the two instruments.

2. Radiance and Jacobian Comparison

2a. Radiative Transfer

The radiative transfer model used in this study is the NESDIS/NCEP Community Radiative Transfer Model (Kleespies et al., 2004). This model is based upon the Optical Path Transmittance (OPTRAN) model (McMillin et al., 1995). OPTRAN was chosen for this work because it performs very well for the water vapour channels. The atmospheres used for the simulation are the University of Maryland, Baltimore County (UMBC) Atmospheric InfraRed Sounder (AIRS) 48 profile set (Strow et al., 2003). This set has 100 layers for temperature, water vapour and ozone mixing ratio. Ozone was neglected for this study, as it is known that the strength of the ozone lines near 183 GHz is many orders of magnitude less than that of the water vapour line. These profiles were also used as the training set for OPTRAN. Calculations were made for a nadir-viewing angle with a surface emissivity of 0.6. Cloud liquid water scattering and absorption were not included in the simulation.

The methods described in Garand et al. (2001) were applied to verify the results from the Jacobian code. The 'brute force' Jacobians were computed from the forward model by centred finite differencing. The input temperature profile was perturbed layer by layer first by +0.5K then by -0.5K, and the results differenced. Similarly the water vapour profile was perturbed each layer in turn first by +5% then -5% mixing ratio and the results differenced. The results were tabulated and examined, and found to be exactly the same as that from the Jacobian model to within the last one or two significant digits.

2b. Radiance and Jacobian Results

Figure 2 presents the brightness temperatures computed for the MHS versus those for the AMSU-B. As might be expected from Table 1, channels 1, 3 and 4 are essentially identical in these plots. The major differences are in channel 2, where the change from 150 to 157 GHz is quite evident in the MHS measuring consistently warmer brightness temperatures than the AMSU-B. The differences in brightness temperatures for channel 5 are less apparent, but again, the MHS brightness temperatures are warmer than the AMSU-B. Table 2 gives the mean and the standard deviation of the differences. The most significant differences are for channel 2, where the MHS is on the average 6.6K warmer than the AMSU-B. The large standard deviation of 4.8K for this channel is the result of it sensing deeper into the atmosphere, where the water vapour has greater variance.

Figure 3 shows the jacobians for the US Standard Atmosphere, a hot and moist atmosphere, and a cold and dry atmosphere. The temperature jacobians are almost identical, except for channel 2 in the hot and moist atmosphere. Similarly, the water vapour jacobians are also very much alike except for channel 2.

The mean and standard deviation of the difference of the AMSU-B and MHS jacobians are given in Fig. 4. Again it is seen that the greatest standard difference is in channel 2, with channel 5 displaying the second greatest standard difference. In both cases the maximum standard difference occurs near the surface, where the water vapour is most variable (Fig. 5).

3. Information Content

The one dimensional variational retrieval (Eyre, 1989) utilizes a cost function defined as

$$\mathbf{J}(\mathbf{x}) = (\mathbf{x} - \mathbf{x}^b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}^b) + (\mathbf{y}^o - \mathbf{y}(\mathbf{x}))^T (\mathbf{O} + \mathbf{F})^{-1} (\mathbf{y}^o - \mathbf{y}(\mathbf{x})) \quad (1)$$

where \mathbf{x}^b is a background estimate of the model state vector usually given by a short term forecast, \mathbf{x} is the desired solution, \mathbf{y}^o is the vector of observations, $\mathbf{y}(\mathbf{x})$ is an operator which transforms the model state vector into the same form as the observations, and \mathbf{B} , \mathbf{O} and \mathbf{F} are the background, observational and forward modelling error covariance matrices respectively. For this purpose, $\mathbf{y}(\mathbf{x})$ is the radiative transfer operator. Neglecting the possibility of multiple minima, the most probable solution is where the gradient of $\mathbf{J}(\mathbf{x})$ is zero:

$$\nabla \mathbf{J}(\mathbf{x}) = \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}^b) - \mathbf{K}(\mathbf{x})^T (\mathbf{O} + \mathbf{F})^{-1} (\mathbf{y}^o - \mathbf{y}(\mathbf{x})) = 0 \quad (2)$$

where $\mathbf{K}(\mathbf{x})$ is the matrix of partial derivatives of $\mathbf{y}(\mathbf{x})$ with respect to the elements of \mathbf{x} , or the jacobian. The information content can be estimated from the covariance matrix which is the Hessian of (1) (Rodgers, 1976)

$$\mathbf{S} = \left\{ \mathbf{B}^{-1} - \mathbf{K}(\mathbf{x})^T (\mathbf{O} + \mathbf{F})^{-1} \mathbf{K}(\mathbf{x}) \right\}^{1/2} \quad (3)$$

The background covariance matrix was provided by Tony McNally of ECMWF (personal communication). This matrix was computed from an ensemble of data assimilation experiments where the members differed because of random perturbations to the observations. The use of the ECMWF background covariance was purely a matter of convenience as it was readily available at the time this work was performed. The instrument errors are the Noise Equivalent Delta Temperatures (NEDT) provided by Tsan Mo of NOAA/NESDIS (personal communication). The NEDT used were those which were measured on-orbit for the AMSU-B on NOAA-15, and the measured pre-launch values for the MHS on NOAA-N (Table 3). The forward radiative transfer errors were set to 0.2 K as in Fourrié and Thépaut (2003) and were assumed to be constant with channel. The observational and forward modelling error covariance matrices are considered diagonal for lack of better information.

3a. Information Content Results

The upper panels in Fig. 6 shows the improvement of the AMSU-B and MHS temperature and moisture information over the ECMWF covariances for the US standard atmosphere and the same hot and moist atmosphere and cold and dry atmosphere used above. The MHS demonstrates a small improvement of about 0.1K in temperature information in the mid-troposphere, and about a 0.1g/Kg improvement in moisture information below about 700 hPa for the US standard atmosphere. The MHS also showed a small improvement over the AMSU-B of about 0.1 K from about 700 hPa to 200 hPa for the hot and moist atmosphere, but no improvement in the moisture information. The MHS shows no improvement over the AMSU-B for the temperature information, and a small improvement of about 0.1 g/Kg in the moisture information between about 800 to 700 hPa for the cold and dry atmosphere.

The question remains as to whether the small improvement in information content of the MHS over the AMSU-B is due to the changes in the jacobians, or in the improved noise performance of the MHS. The lower panels in Fig. 6 show the information improvement over the ECMWF covariances with the NEDT of both instruments set to the same pre-launch MHS values. In this case the improvement in information content is essentially the same for both instruments, demonstrating that the additional information is due to the better NEDT performance of the MHS.

4. Summary

It can be expected that the MHS will demonstrate a slight improvement in information content as compared to the AMSU-B due to the better NEDT performance of the MHS. This improvement will be airmass dependent. Experience has shown that on-orbit measured NEDT is somewhat better than that measured pre-launch, so the information content estimates presented here may be an underestimate.

5. Acknowledgments

This work was performed while the first author was a visiting scientist at EUMETSAT under the auspice of Johannes Schmetz during the period 28 June – 23 July 2004. The views expressed in this publication are those of the authors and do not necessarily represent those of NOAA.

6. References

- Eyre, J. R., 1989: Inversion of cloudy satellite sounding radiances by nonlinear optimal estimation. I: Theory and simulation for TOVS, *Q. J. R. Meteorol. Soc.*, **115**, 1001-1026.
- Fourrié, N. and J-N. Thépaut, 2003, Evaluation of AIRS near-real-time channel selection to numerical weather prediction. *Q. J. R. Meteorol. Soc.*, **129**, 2425-2439.
- Garand, L., D. S. Turner, M. Larocque, J. Bates, S. Boukabara, P. Brunel, F. Chevallier, G. Deblonde, R. Engelen, M. Hollingshead, D. Jackson, G. Jedlovec, J. Joiner, T. Kleespies, D. S. McKague, L. McMillin, J.-L. Moncet, J. R. Pardo, P. J. Rayer, E. Salathe, R. Saunders, N. A. Scott, P. Van Delst, and H. Woolf, 2001: Radiance and Jacobian intercomparison of radiative transfer models applied to HIRS and AMSU channels, *JGR*, **106**, 24,017–24,031
- Kleespies, T. J., P. van Delst, L. M. McMillin, J. Derber, 2004: Atmospheric Transmittance of an Absorbing Gas. 6. OPTRAN Status Report and Introduction to the NESDIS/NCEP Community Radiative Transfer Model, *Appl. Opt.*, **43**, 3103-3109.
- McMillin, L. M., L. J. Crone, and T. J. Kleespies, 1995: Atmospheric transmittance of an absorbing gas. 5. Improvements to the OPTRAN approach, *Appl. Opt.* **34**, 8396-8399.
- Rodgers, C. D, 1976: Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation, *Rev. Geophys. and Space Physics.*, **14**, 609-624.
- Strow, L.L., S.E. Hannon, S. De Souza-Machado, H.E. Motteler and D. Tobin, 2003. An overview of the AIRS radiative transfer model. *IEEE Trans. Geosci. Remote Sens.* **41**, 303-313.

Table 1: MEASURED RADIOMETRIC CHARACTERISTICS OF THE NOAA-17 AMSU-B AND THE NOAA-N MHS.

Note however that the MHS central frequencies are the nominal values.

Central Frequency (GHz)			Lower IF -3 dB Frequency (GHz)		Upper IF -3 dB Frequency (GHz)		# Bandpasses	
Chan	AMSU-B	MHS	AMSU-B	MHS	AMSU-B	MHS	AMSU-B	MHS
1	89.002	89	0.399	0.111	1.406	1.207	1	1
2	149.984	157	0.398	0.111	1.402	1.207	1	1
3	183.299	183.311	0.751	0.752	1.248	1.210	2	2
4	183.299	183.311	2.511	2.524	3.267	3.434	2	2
5	183.299	190.311	6.016	0.113	7.971	1.079	2	1

Table 2. MHS - AMSU-B BRIGHTNESS TEMPERATURE DIFFERENCE FOR THE UMBC AIRS 48 PROFILES

Channel	Mean difference (K)	Standard Deviation of the difference (K)
1	-0.0123	0.0035
2	6.6553	4.7687
3	-0.0992	0.1091
4	0.0903	0.4982
5	0.7148	1.3365

Table 3. MHS AND AMSU-B NOISE EQUIVALENT DELTA TEMPERATURES (K).

AMSU-B is measured on-orbit for NOAA-17 and MHS is pre-launch for NOAA-N

Channel	AMSU-B	MHS
1	0.33	0.22
2	0.54	0.35
3	0.92	0.45
4	0.63	0.35
5	0.77	0.40

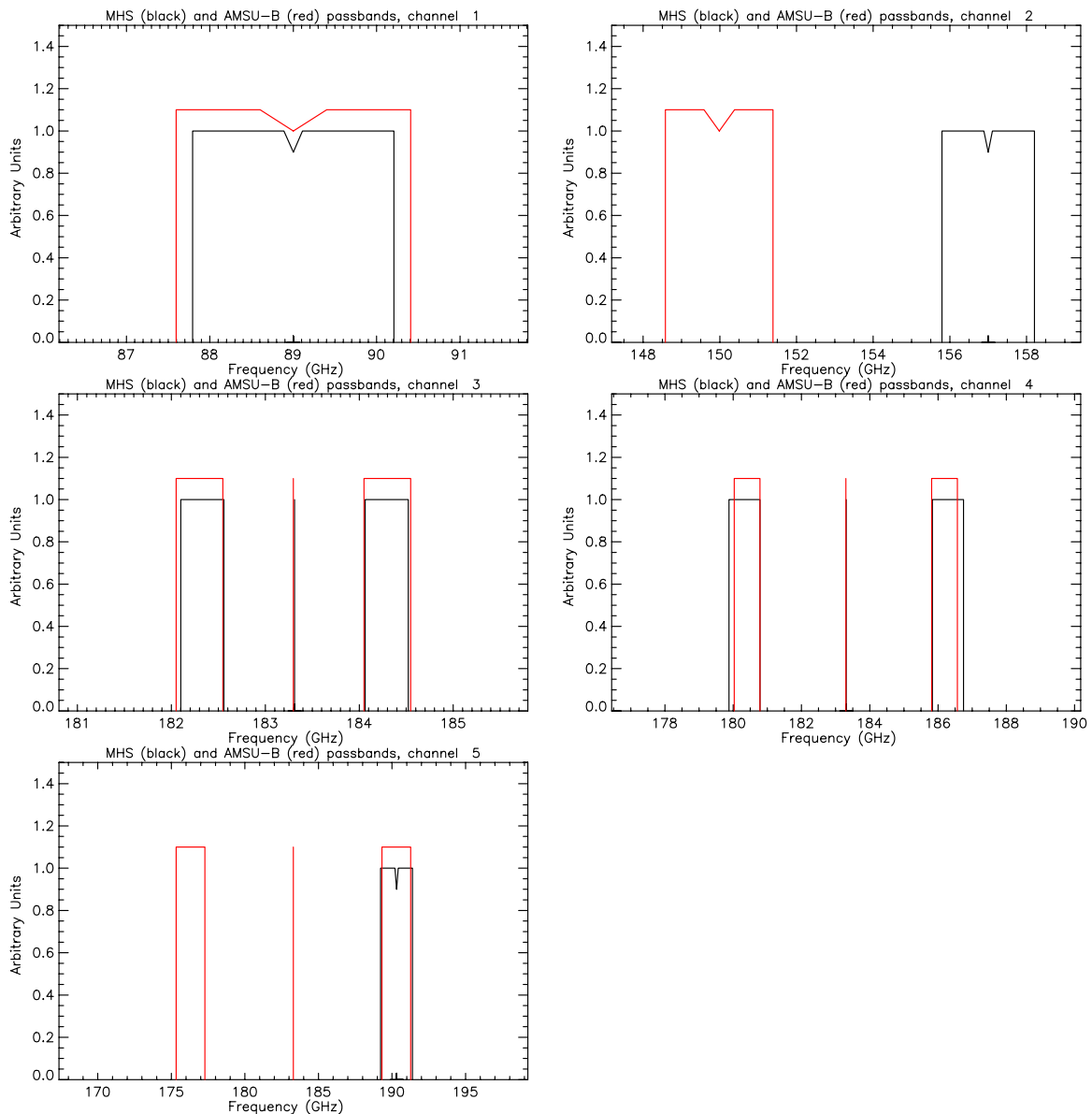


Figure 1: Bandpasses for the MHS for NOAA-N (black) and the AMSU-B for NOAA-M (red). The angular notch at the central frequency of the single band channels represents the stopband. The height of the bandpasses in this figure has no meaning. The height is set greater for the MHS to distinguish it from the AMSU-B where the bandpasses are similar. The vertical line for channels 3, 4 and 5 represents the central frequency.

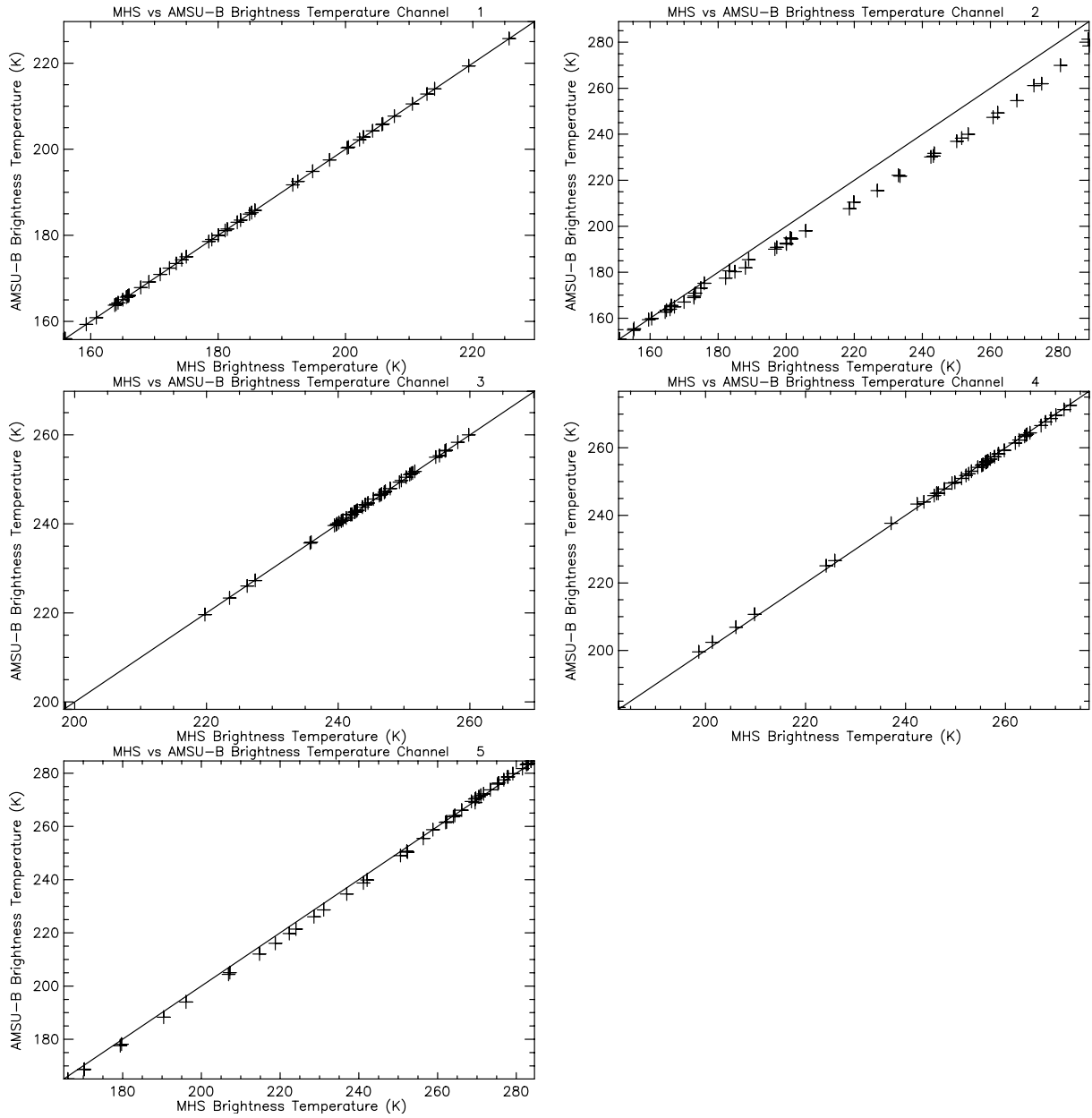


Figure 2. Brightness temperatures computed by the NESDIS/NCEP community model for the MHS and AMSU-B using the UMBC AIRS 48 profile set. These are for nadir view with emissivity set to 0.6 .

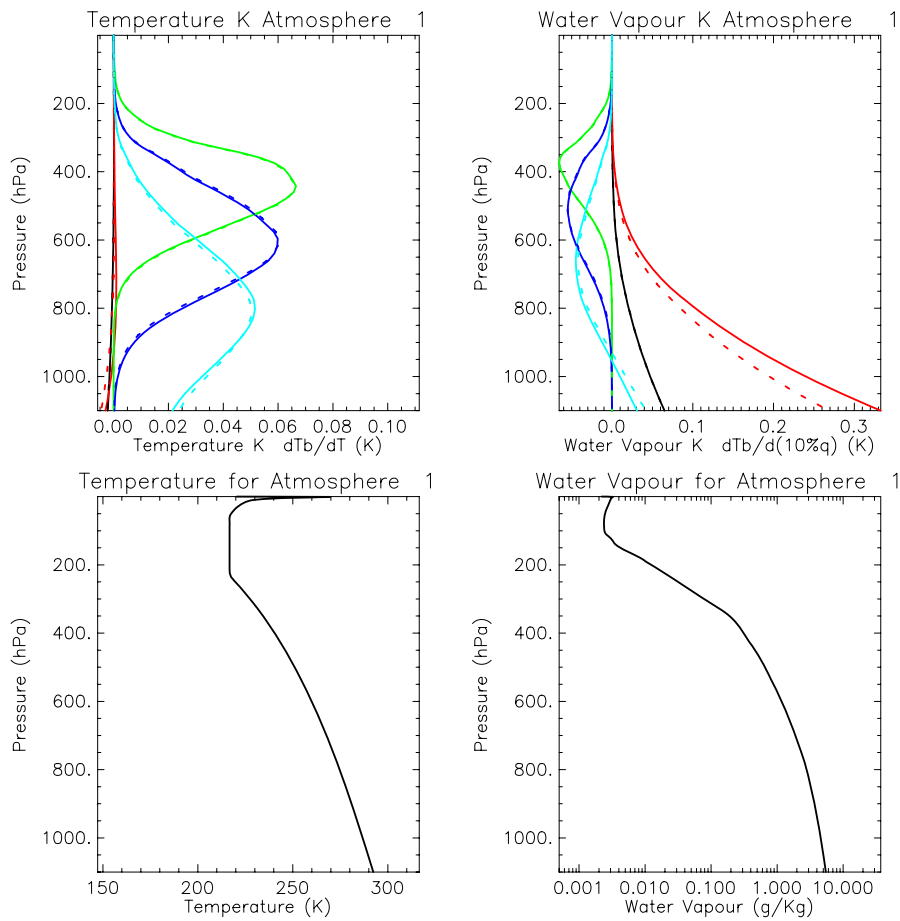


Figure 3a: Temperature and water vapour jacobians (top) for the US Standard Atmosphere. Temperature and water vapour profile (bottom). The atmosphere number refers to the number in the UMBC profile set. The figures are colour coded such that black = channel 1, red = channel 2, green = channel 3, blue = channel 4 and cyan (light blue) = channel 5. AMSU-B is solid line and the MHS is the dotted line.

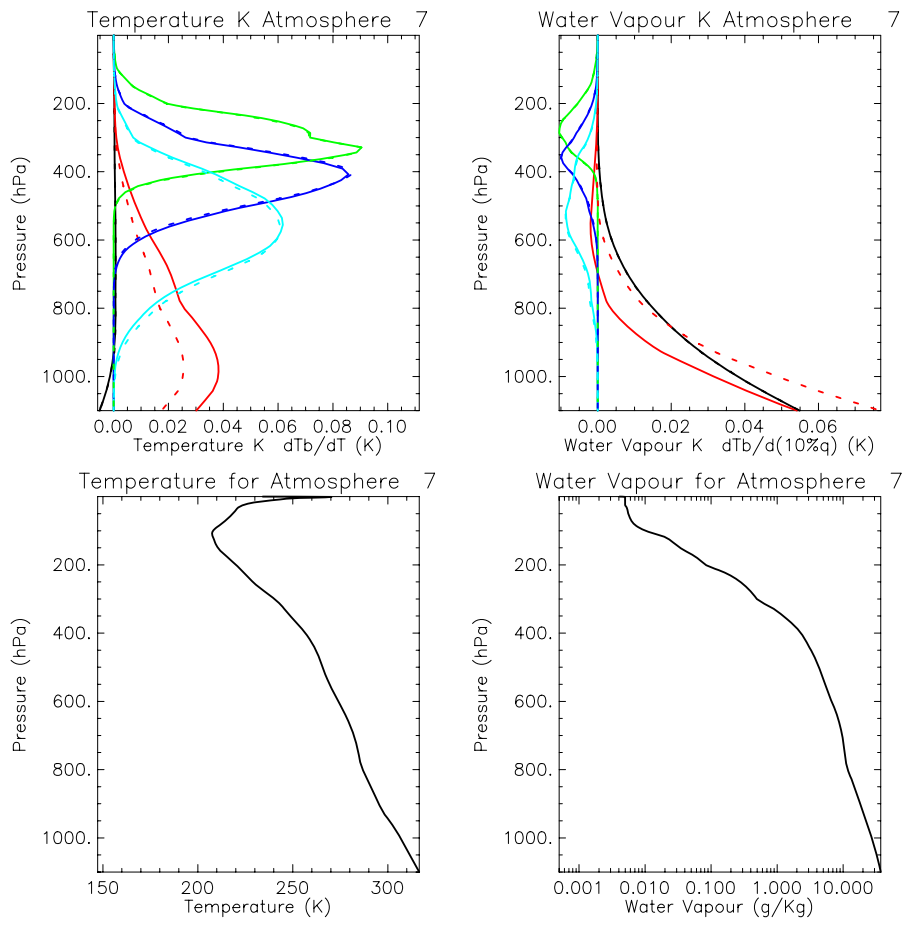


Figure 3b: Temperature and water vapour jacobians for a hot and moist atmosphere.

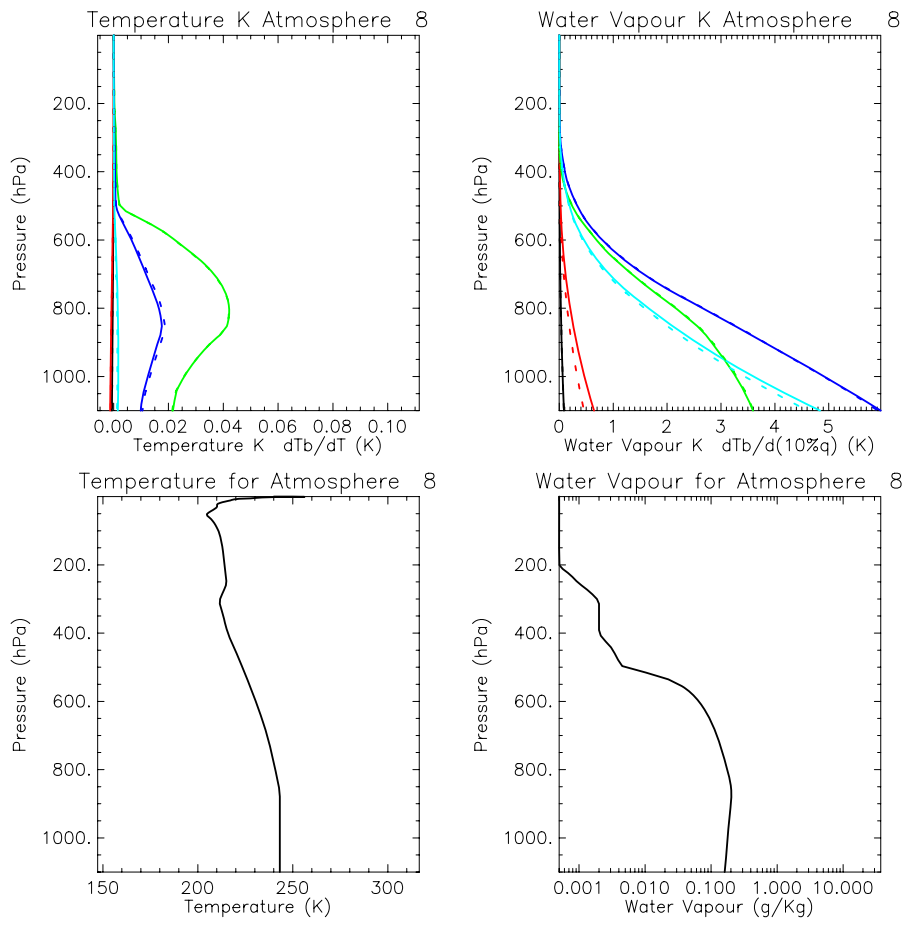


Figure 3c: Temperature and water vapour jacobians for a cold and dry atmosphere.

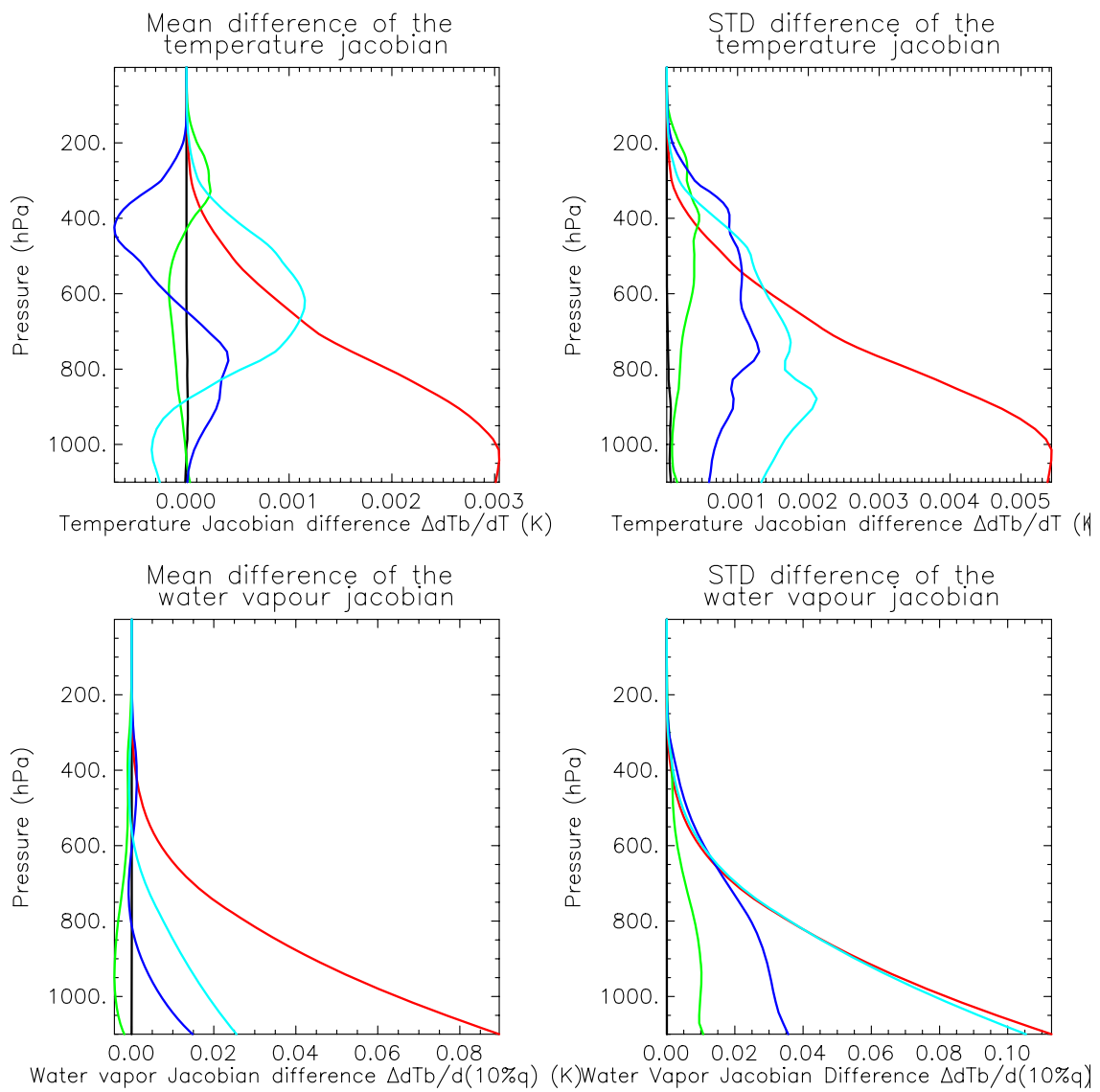


Figure 4. Mean and standard deviation of the difference between the MHS and AMSU-B jacobians for the 48 UMBC atmospheres. The figures are colour coded such that black = channel 1, red = channel 2, green = channel 3, blue = channel 4 and cyan (light blue) = channel 5.

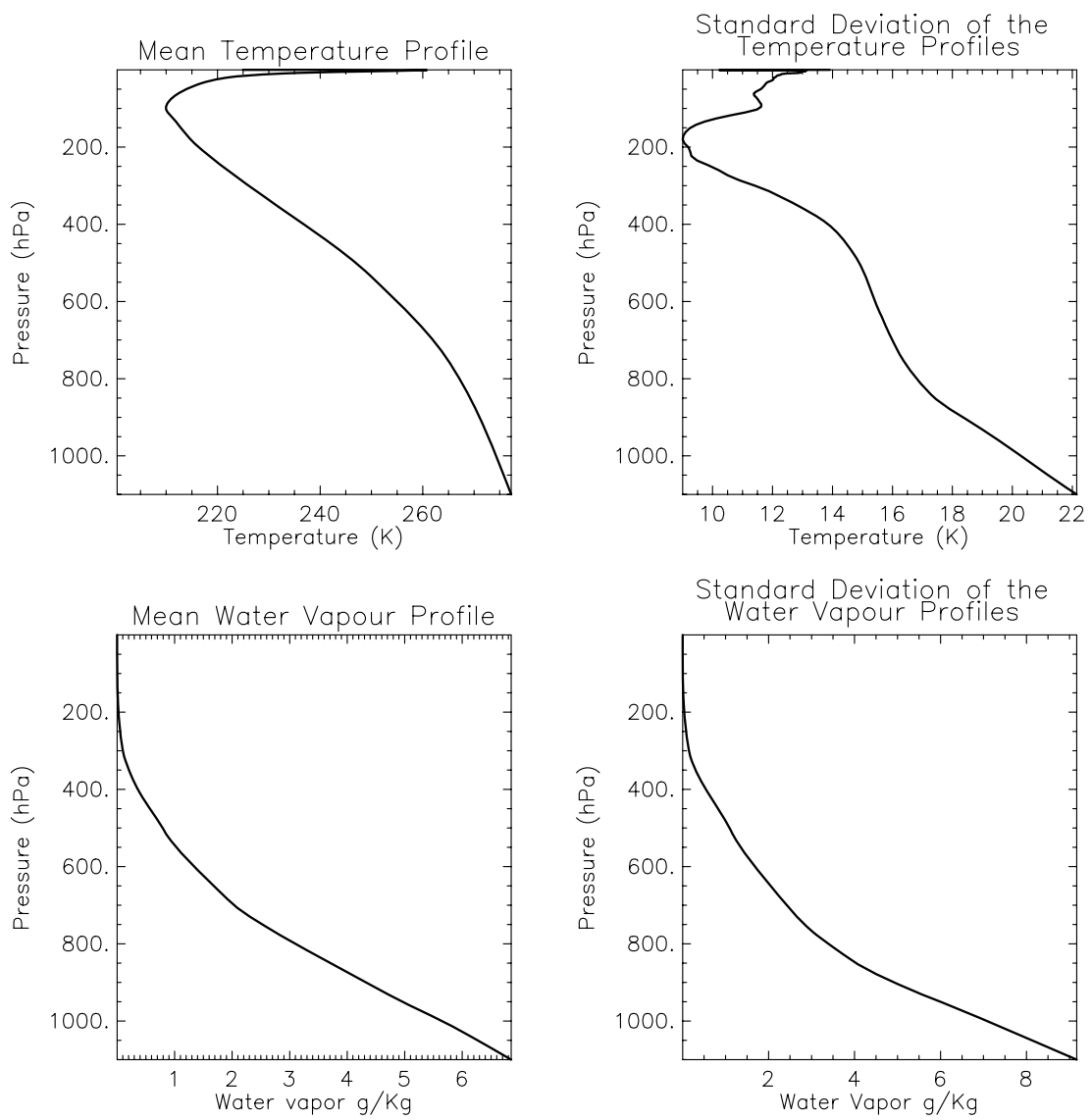


Figure 5. Mean and standard deviation of the 48 UMBC AIRS Profiles.

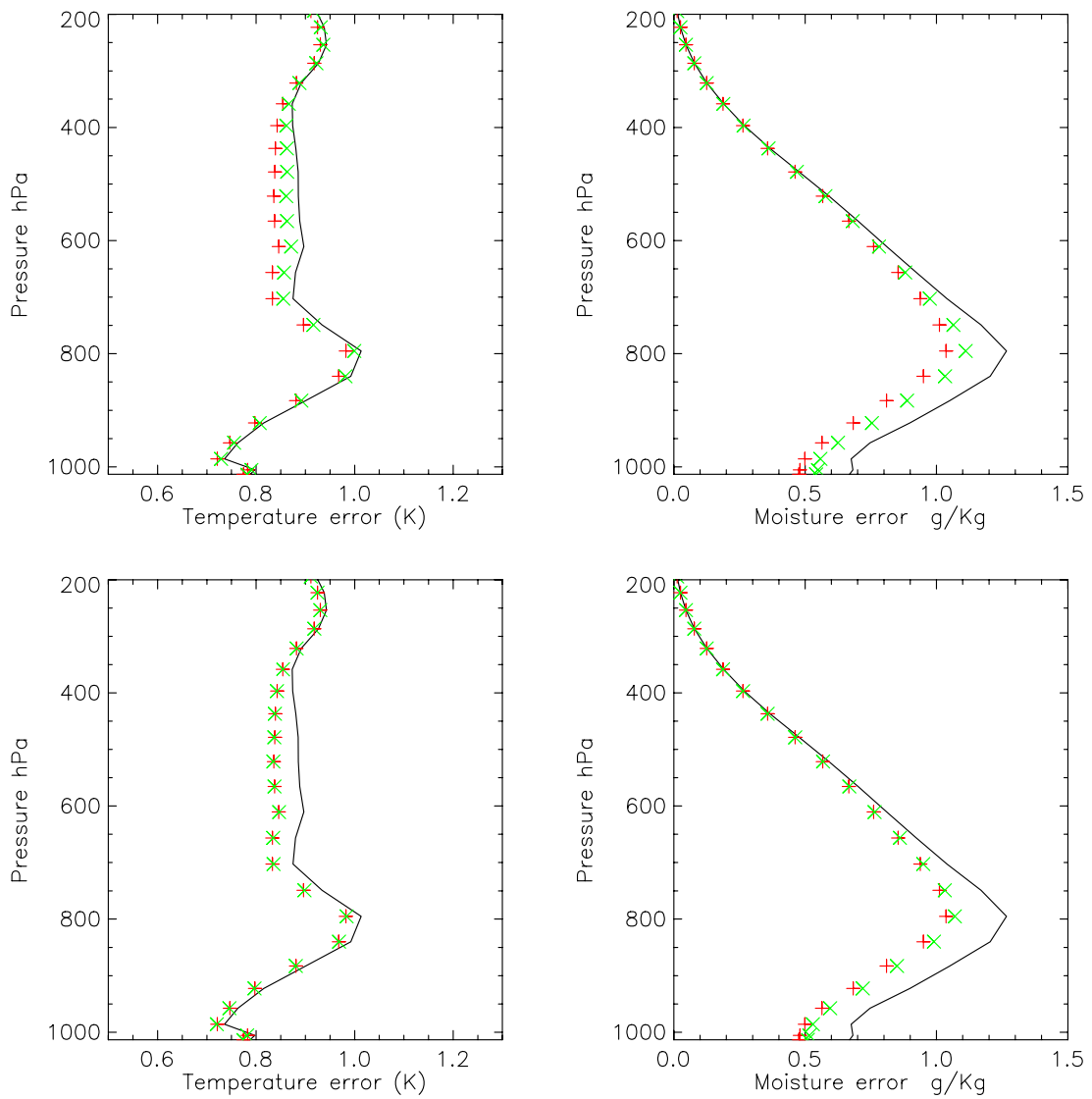


Figure 6a): Improvement of AMSU-B and MHS temperature and moisture information over ECMWF covariances for the US Standard Atmosphere. Solid line is ECMWF covariance. x is the AMSU-B, + is the MHS. Top panels are for instrument unique NEDT. Bottom panels are for both instruments using the MHS pre-launch NEDT. See text for details.

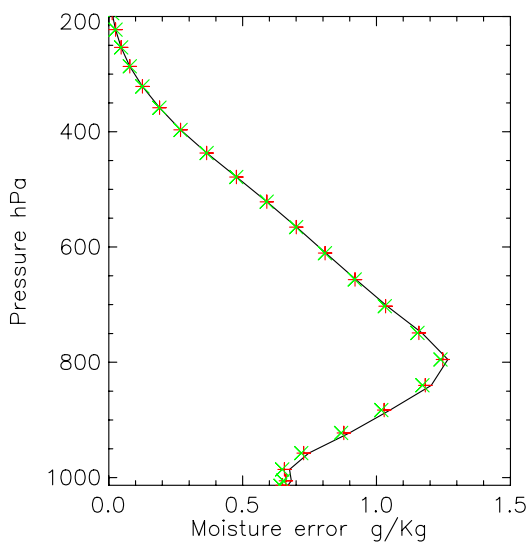
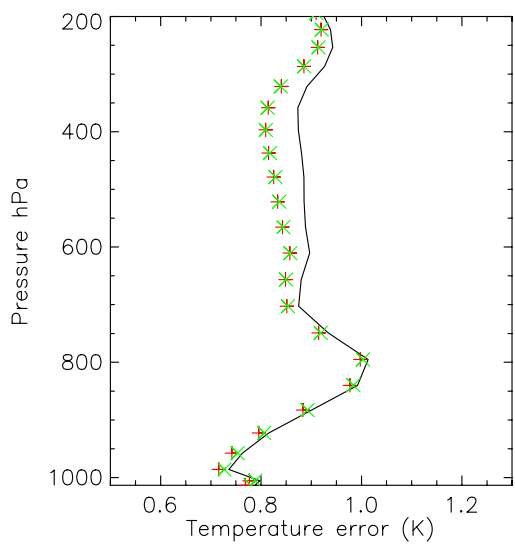
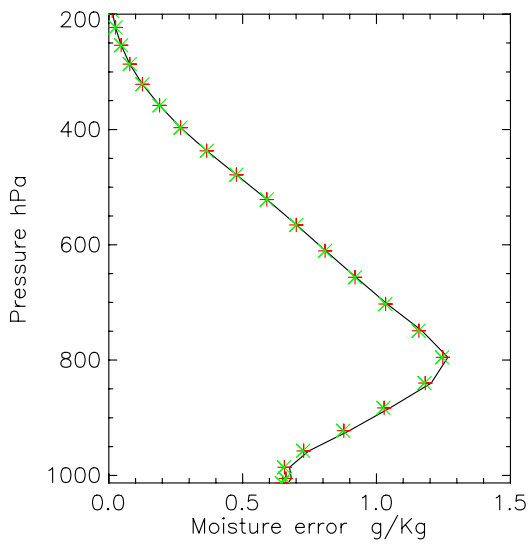
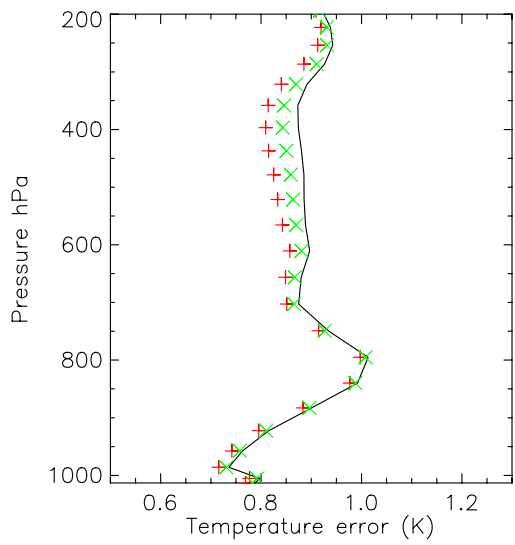


Figure 6b): Improvement of AMSU-B and MHS information over ECMWF covariances for a hot and moist atmosphere.

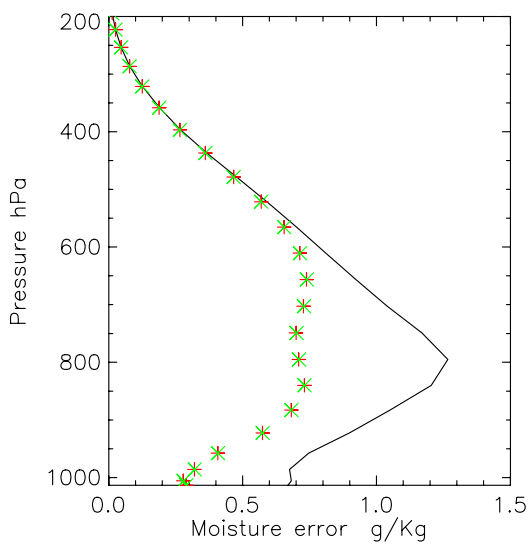
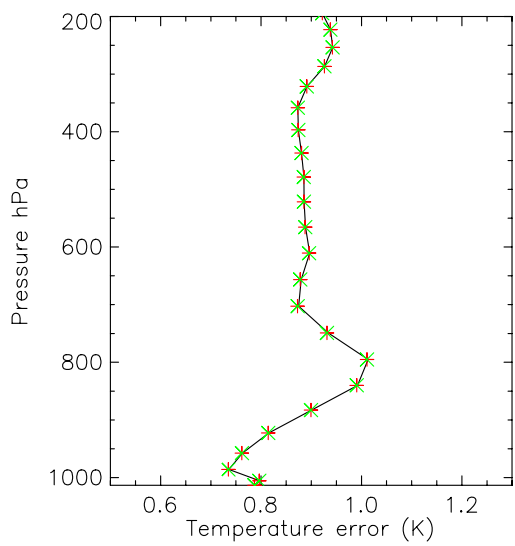
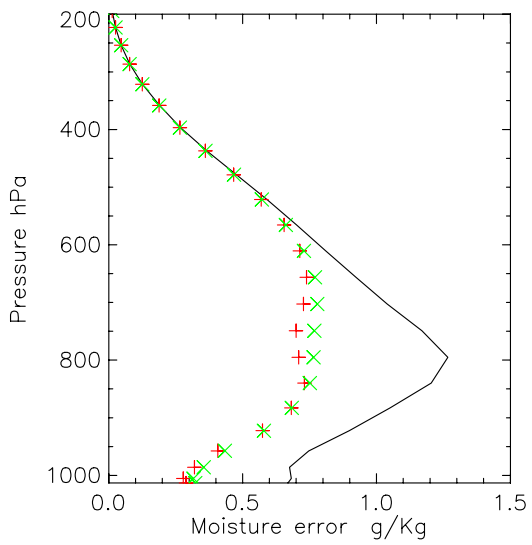
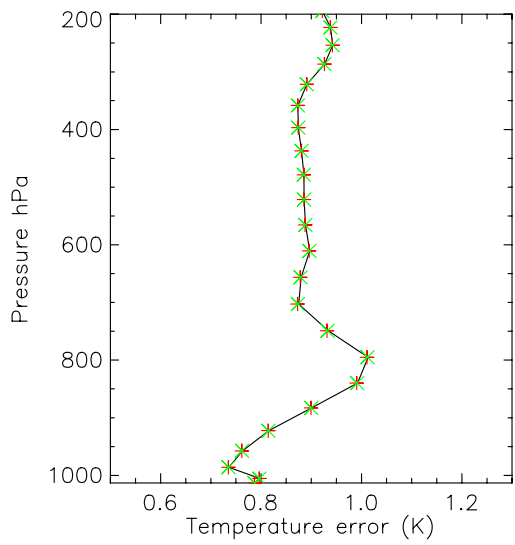


Figure 6c: Improvement of AMSU-B and MHS information over ECMWF covariances for a cold and dry atmosphere.