Results of a comparison of radiative transfer models for simulating AIRS radiances

by

R. Saunders, P. Rayer Met Office, A. von Engeln, Bremen Univ.,
N. Bormann ECMWF, S. Hannon UMBC, S. Heilliette CNRS/LMD, Xu Liu,
F. Miskolczi, NASA LRC, Y. Han NOAA,G. Masiello IMAA-CNR, J-L Moncet,
V. Sherlock NIWA, D.S. Turner MSC, Gennady Uymin AER

Abstract

At the workshop for Soundings from High Spectral Resolution Observations in May 2003, an AIRS radiative transfer model comparison was proposed under the auspices of the ITWG. Results from 14 models have been submitted. The aim of the intercomparison was (i) to compare the forward model calculations for all AIRS channels from all models for 52 diverse profiles and one tropical Pacific profile coincident with AIRS data; (ii) to estimate forward model error covariances; (iii) to assess the jacobians from each model using a measure of fit for a limited selection of channels; and (iv) to document the time taken to run each model. Preliminary results of this inter-comparison are presented in this paper. For the forward model calculations most models agree to within 0.02K when compared to a reference model RFM. When compared with observations however the mean differences increase to 1K. For the jacobians all models have some profiles/channels that do not fit the RFM reference well.

1. Introduction

Several years ago comparisons of radiative transfer (RT) models for ATOVS infrared and microwave channels have been made (Soden *et. al.,* 2000; Garand *et. al.,* 2001) which helped to better define the radiative transfer modeling errors for ATOVS. More recently with the advent of high spectral resolution infrared sounders (e.g. AIRS and IASI), enhanced versions of the ATOVS radiative transfer models have evolved. The success of the AIRS spectrometer in providing stable high resolution spectral infrared radiances has provided an impetus to improve our RT modeling for these sounders.

As a result an effort was initiated at the first workshop for Soundings from High Spectral Resolution Observations at Madison, Wisconsin in May 2003, for an AIRS radiative transfer model comparison under the auspices of the International TOVS Working Group. The aim of the inter-comparison was (i) to compare the forward model calculations for all AIRS channels from all models for 52 diverse profiles and one tropical Pacific profile coincident with AIRS data; (ii) to estimate forward model error covariances; (iii) to assess the jacobians from each model using a measure of fit for a limited selection of channels; and (iv) to document the time taken to run each model. This study will allow the error characteristics of AIRS fast RT models to be better estimated for retrieval and data assimilation applications. Preliminary results of this

inter-comparison are presented here and will be more comprehensively documented in a journal paper.

2. Models submitted

The 14 radiative transfer models that participated in this study are listed below in Table 1. Computed brightness temperatures for all 2378 AIRS channels and for 52 diverse atmospheres sampled from ECMWF model analyses were submitted. In addition, one profile from the Western Tropical Pacific ARM site coincident with AIRS observations was also modelled (see Section 4). Results were submitted for three zenith angles, nadir, 45 deg and 60 deg, but only the nadir results are presented here. A subset of the models also computed layer to space transmittances, temperature, water vapour and ozone jacobians for 20 of the AIRS channels listed in Table 2. The fit of the jacobians to a reference is important to assess the performance of the RT model in a data assimilation and retrieval application. In addition, model run times were also documented. RFM, a line-by-line model, based on GENLN2 was used as a reference for the results presented below.

Model	Reference	Contact	Transmittance	Jacobian
RTTOV-7	GENLN2	R. Saunders, METO	Yes	Yes
RTTOV-8	GENLN2	R. Saunders, METO	Yes	Yes
Optran	LBLRTM	Y. Han, NESDIS	Yes	Yes
OSS	LBLRTM	J-L. Moncet, AER	No	Yes
LBLRTM		J-L. Moncet, AER	No	Yes
RFM	GENLN2	N. Bormann, ECMWF	Yes	Yes
Gastropod	kCarta(1)	V. Sherlock, NIWA	Yes	Yes
ARTS		A. von Engeln,Bremen	No	No
SARTA	kCarta(2)	S. Hannon, UMBC	No	No
PCRTM	LBLRTM	Xu Liu, NASA, LRC	Yes	Yes
4A	STRANSAC	S. Heilliette, LMD	Yes	Yes
FLBL		D.S. Turner, MSC	Yes	Yes

Table 1. Models which participated in comparison.

3. Forward model comparisons

For the forward model comparisons, Figure 1 shows a portion of the spectrum from 810 to 880 cm^{-1} for the mean profile (number 52). Some differences between the different RT models are clear in this part of the spectrum. The obvious differences at channel 590 (845 cm^{-1}) are due to the different way each model treats the absorption due to CFCs. There are also significant differences in the 'window' regions between the lines due to differences in the water vapour continuum formulation. Those fast models which are based on a line-by-line model included in the study generally follow the model on which they were trained on. For example, OSS follows LBLRTM closely. RTTOV-7, based on GENLN-2, which is similar to RFM, does follow RFM below 850 cm^{-1} but there

are significant differences in the window regions at higher frequencies due to water vapour continuum differences.

Figure 2 shows the mean channel differences for all the models. Significant differences are seen for the ARTS model, which predicts lower radiances than the others in the higher absorption bands. σ-IASI is slightly warmer than the other models in the atmospheric window and cooler at shorter wavelengths. Hartcode has a warm bias from 1350 to 2300 cm^{-1}. The differences for each model are summarised in Figures 3 and 4 where the values are binned as histograms and integrated over all the channels. *It is important to bear in mind that these differences are with respect to RFM and this may not be the best reference, so the biases are only relative to RFM.* With a few exceptions, the differences of the models from RFM are similar.

Channel Number	AIRS channel	Frequency cm^{-1}	Jacobian computed
1	71	666.7	T
2	77	668.2	T
3	305	737.1	T
4	453	793.1	T, Q
5	672	871.2	T, Q
6	787	917.2	T
7	1021	1009.2	T, O_3
8	1090	1040.1	O_3
9	1142	1074.3	Q
10	1437	1323.8	Q
11	1449	1330.8	Q
12	1627	1427.1	Q
13	1766	1544.3	Q
14	1794	1563.5	Q
15	1812	1576.1	Q
16	1917	2229.3	T
17	1958	2268.7	T
18	1995	2305.5	T
19	2107	2385.9	T
20	2197	2500.3	T

Table 2.   List of AIRS channels used for transmittance and jacobian comparisons.

4.   Comparisons with AIRS measurements

Comparisons with observed AIRS radiances were made for one profile over the tropical western Pacific ARM site as shown in Figure 5 and summarised in Figure 6. The profile characteristics were measured by in situ balloons and supplemented by ECMWF model profiles which provided the ozone, water vapour above 200hPa and

temperature above 60hPa. SARTA shows best agreement with the AIRS observations and this is clear around AIRS channel 2150 (circled) which is due to the improved CO_2 R-branch line mixing formulation in kCARTA and also a new water vapour continuum (Hannon pers comm.). The good fit of SARTA is not surprising as the spectroscopic parameters were tuned on a dataset that included this profile. Hartcode, OSS and LBLRTM models are further from the observations (generally warmer at shorter wavelengths). The latter 2 models may have been run with an incorrect nadir view angle and so this is being checked.

5. Comparison of layer to space transmittances and jacobians

Profiles of surface to space transmittance and temperature, water vapour and ozone jacobians were computed by some of the RT models for the 52 profiles and a selection of 20 AIRS channels defined in Table 2. The channels were chosen with different peaks in their weighting functions for mixed gases, water vapour and ozone. An example of the jacobians computed is shown in Figure 7. For this profile, in general the models are in good agreement except between 0.1 and 5 hPa. In order to determine how closely the transmittances and jacobians fit to a reference profile, a 'goodness of fit' parameter M is used defined as:

$$M = 100 \times \sqrt{\frac{\sum \left(X_i - X_{ref} \right)^2}{\sum \left(X_{ref} \right)^2}}$$

where X_i is the profile variable at level i and X_{ref} is the reference profile which was taken to be the RFM model profile for this study. Figures 8A–C summarise the fit for transmittance profiles, temperature and water vapour jacobians for some of the models. For transmittances RTTOV-8 and 4A differ most from RFM but only for some channels. For temperature jacobians the models have a similar performance for most channels, although for a few channels some models have a poorer fit. AIRS channel 787 seems particularly difficult to model. For the water vapour jacobians RTTOV-8 and to a lesser extent Gastropod and PCRTM have the worst fits to the RFM profiles. The poor fits are only from a few profiles however.

6. Summary and future work

Results of the comparisons of the AIRS RT models for nadir views are presented here. For the forward model comparisons all the models agree within 0.06K and most models are within 0.02K of the RFM model used as a reference. Exceptions to this are in regions affected by CFCs or CO_2 line mixing where larger differences can be found.

The comparison against AIRS observations shows bigger differences with mean brightness temperature differences at the 1K level. The SARTA model fits the AIRS

observations best especially in the 2100-2200 cm^{-1} region but has been tuned using this profile. Hartcode is consistently warmer than the AIRS observations at all frequencies.

In terms of transmittances RTTOV-8 and 4A are consistently different from RFM but this may just reflect the fact that these models have recently been updated and include more up to date spectroscopy than RFM.

The performance of the models in terms of jacobians is not consistent with most models having problems for some profiles. For temperature the AIRS 917 cm^{-1} channel appears to be the most problematic channel for modeling jacobians with 4 out of the 8 models diverging significantly from RFM. For water vapour RTTOV-8 is consistently different from the RFM response for most water vapour channels but this may be due to the new spectroscopy in the kCARTA dataset on which this version of RTTOV-8 was trained.

For future work the results for off-nadir simulations need to be incorporated in both the forward model and Jacobian comparisons. There are more models to add to the transmittance and jacobian comparison (i.e. RTTOV-7, σ-IASI). The water vapour jacobians for some of the channels with weak water vapour absorption should also be studied as bad jacobians here can still cause problems for the retrieval or assimilation. Finally the results for the ozone jacobians will also be analysed.

7. References

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Soden B, Tjemkes S, Schmetz J, Saunders R, Bates J, Ellingson B, Engelen R, Garand L, Jackson D, Jedlovec G, Kleespies T, Randel D, Rayer P, Salathe E, Schwarzkopf D, Scott N, Sohn B, de Souza-Machado S, Strow L, Tobin D, Turner D, van Delst P, Wehr T. 2000. An intercomparison of radiation codes for retrieving upper-tropospheric humidity in the 6.3-mu m band: A report from the first GVaP workshop. *Bulletin of The American Meteorological Society* **81** *(4): 797-808.*
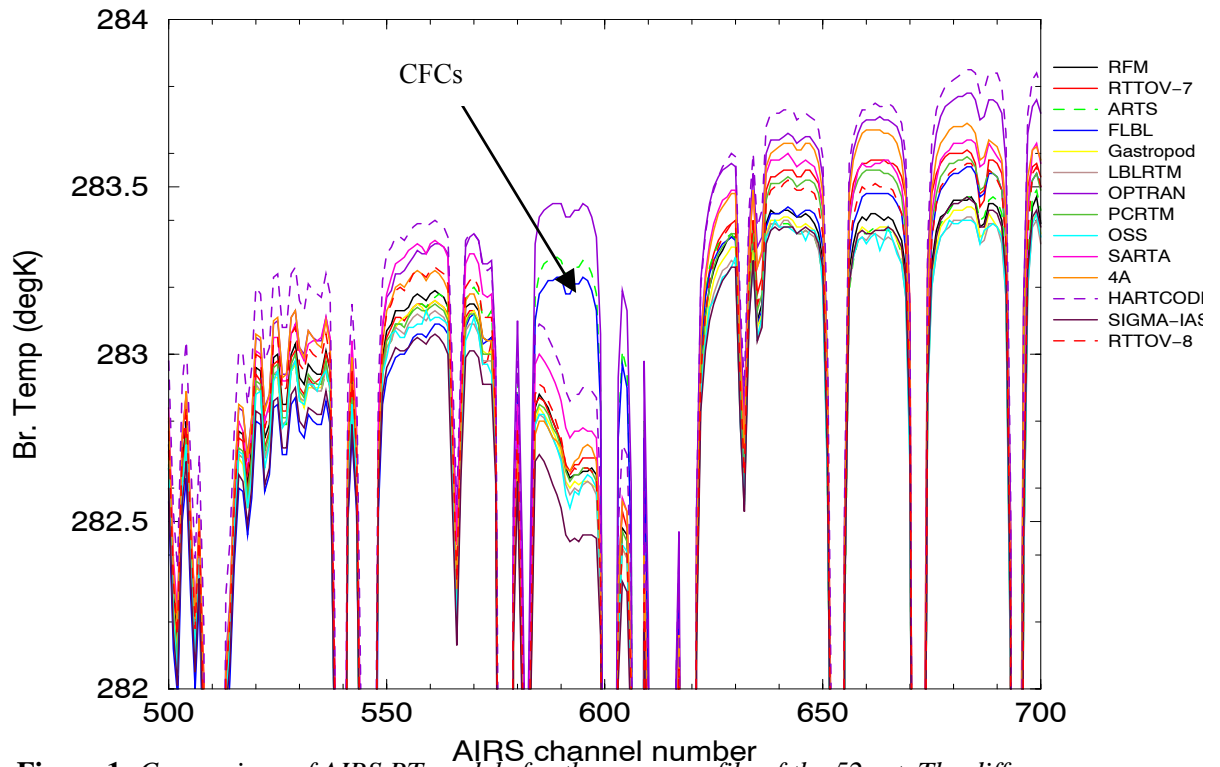
Figure 1: *Comparison of AIRS RT models for the mean profile of the 52 set. The differences around channel 590 are due to the different treatment of CFCs in the models*
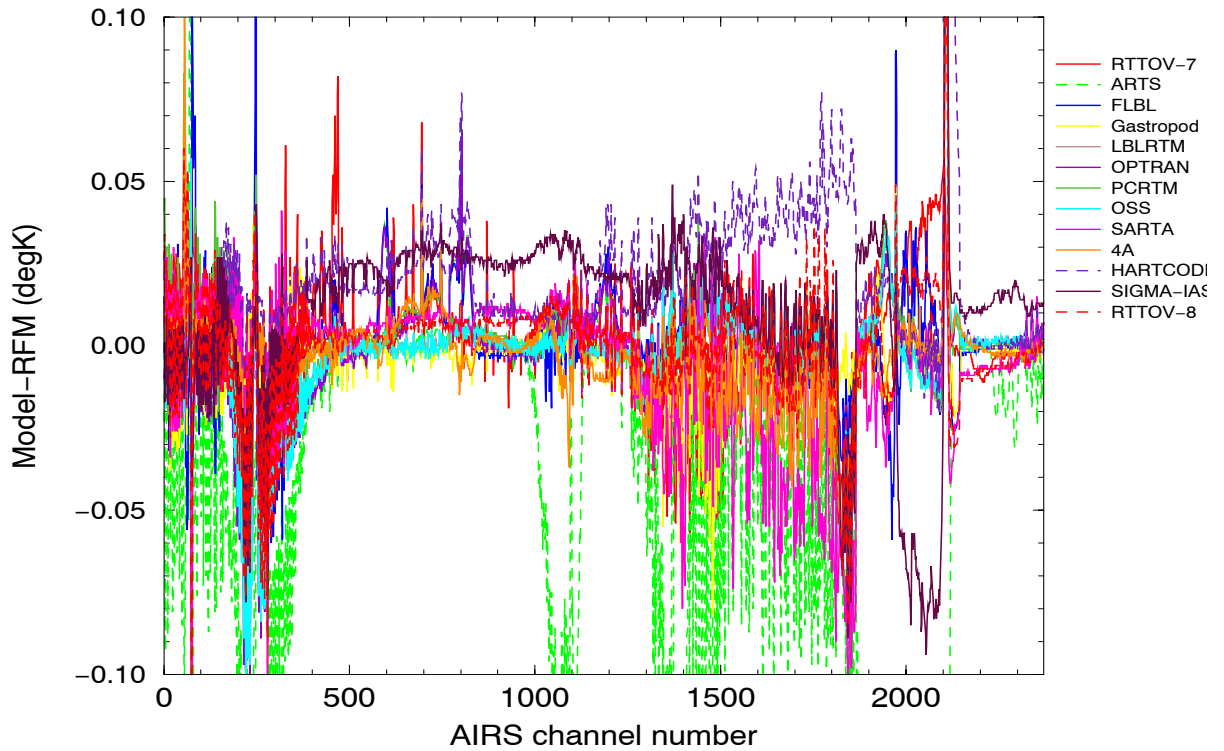

Figure 2: *Mean brightness temperature difference for each AIRS channel of the RT model simulations differenced with the RFM model for 52 diverse profiles and nadir view simulations*
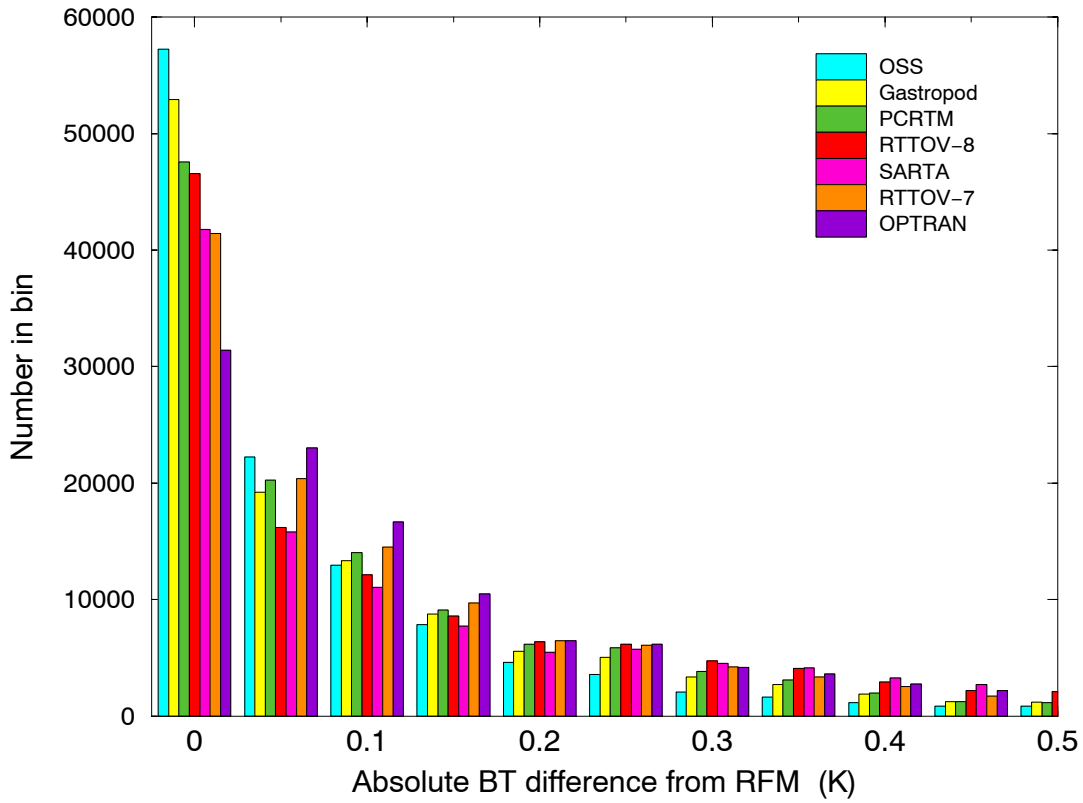
Figure 3: *Brightness temperature difference histogram for all AIRS channels for the fast RT model simulations differenced with the RFM model for 52 diverse profiles and nadir view simulations*
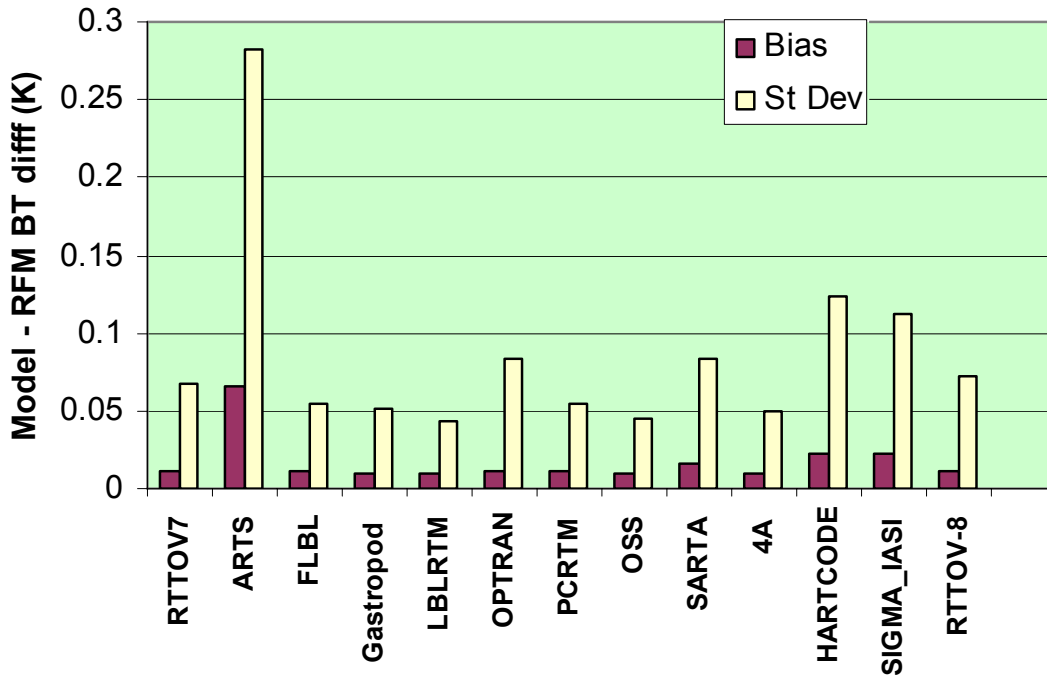
Figure 4: *Channel averaged brightness temperature mean difference and standard deviation of the difference for the RT model simulations differenced with the RFM model for 52 diverse profiles and nadir view simulations.*
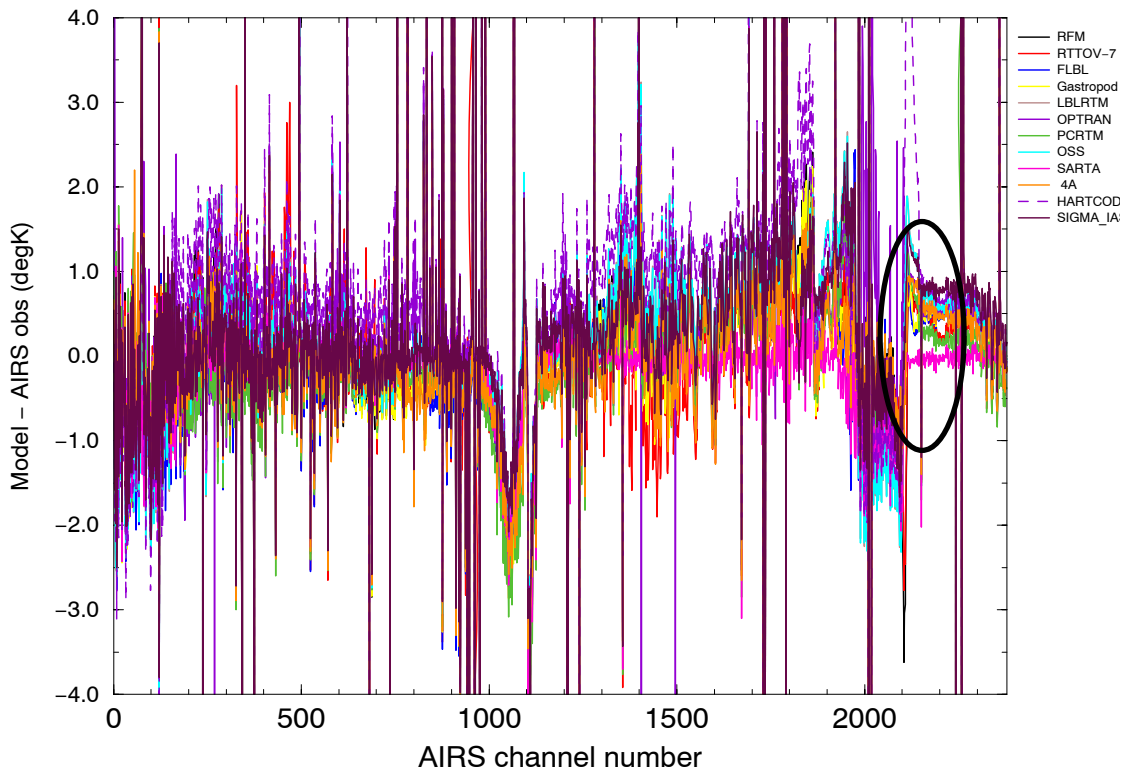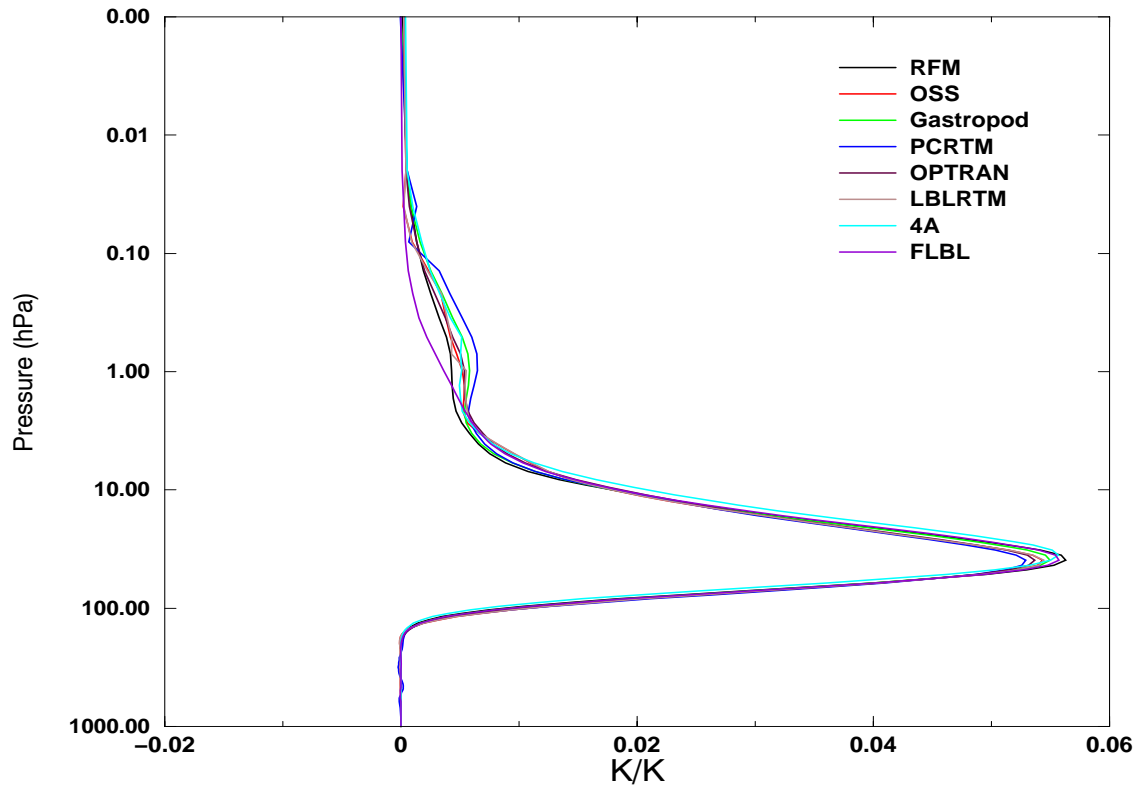
Figure 5: *Modelled – observed differences for AIRS channels over W. Pacific ARM site for a nadir angle of 11.55 deg*
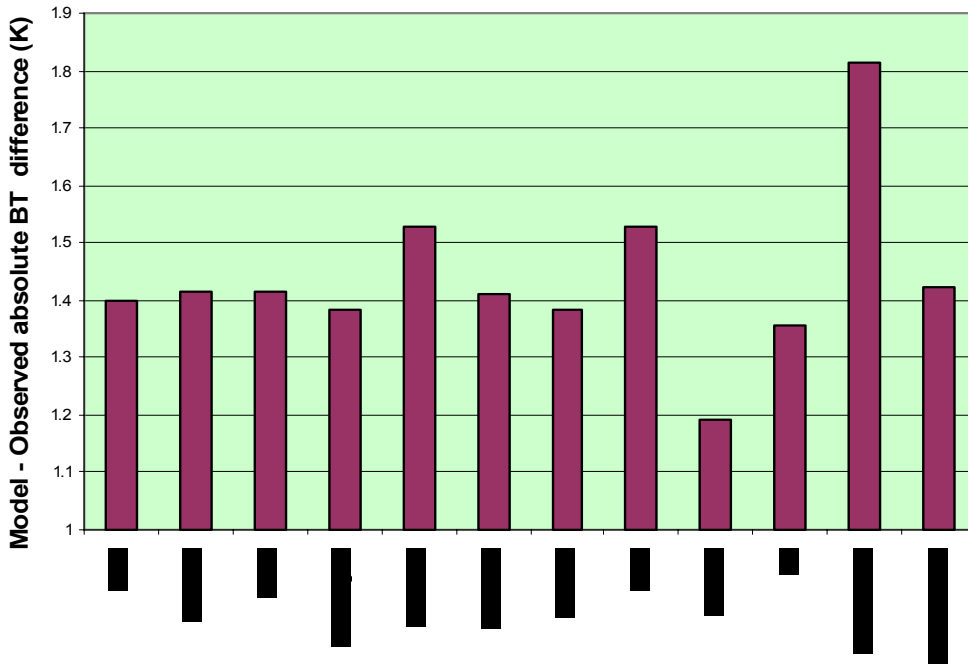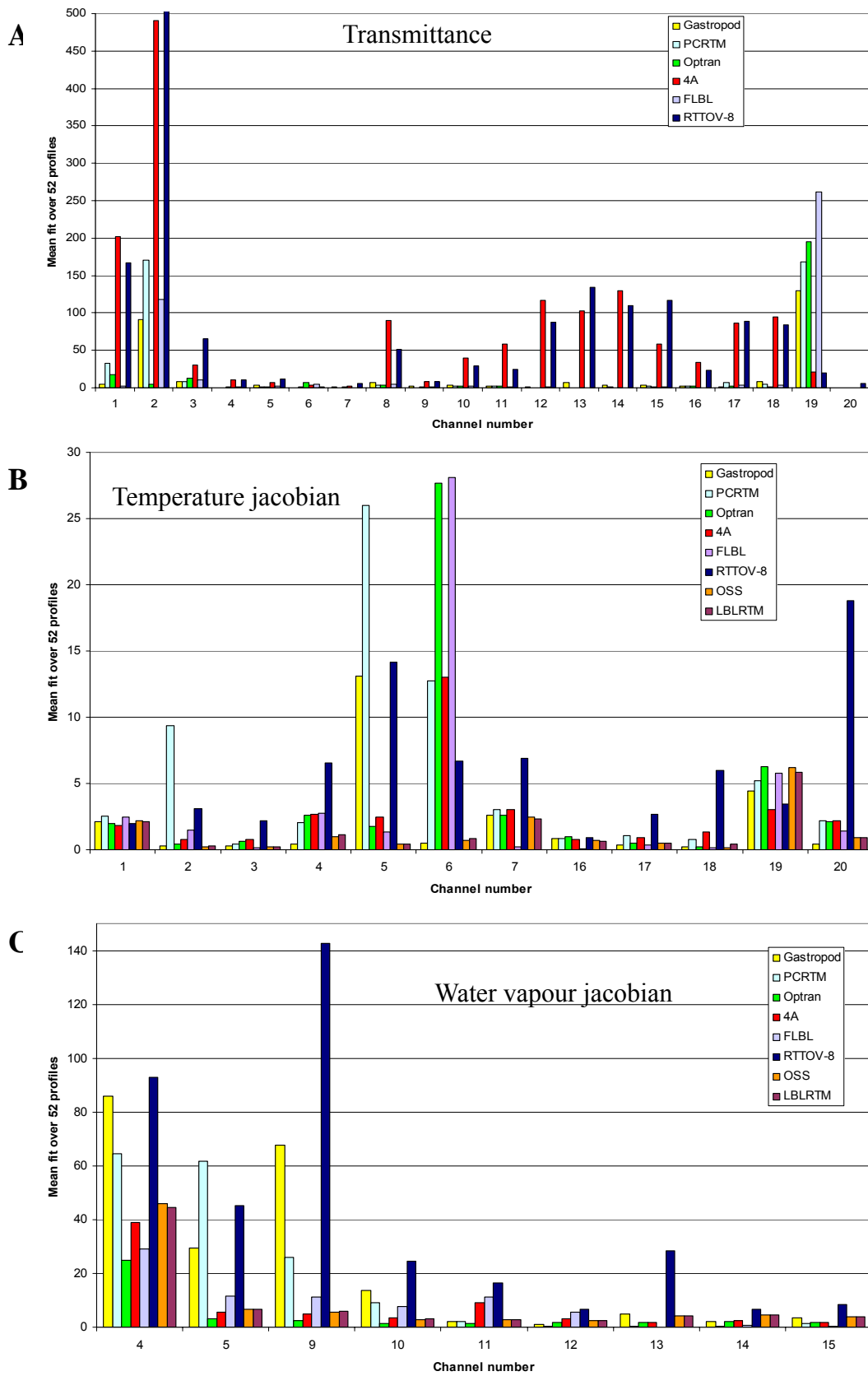

Figure 6: *Absolute mean difference between observed and simulated radiances averaged over all channels for each model for ARM site profile*

Figure 7: *Comparison of modelled temperature jacobians for profile 3 and AIRS channel 71*

Figure 8: *Plots of averaged goodness of fit for 20 AIRS channels (in Table 2) for level to space transmittance (A), temperature (B) and water vapour (C) jacobians.*

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