

**AN IMPROVED GENERAL FAST
RADIATIVE TRANSFER MODEL
FOR THE ASSIMILATION OF
RADIANCE OBSERVATIONS**

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READING

UK

An improved general fast radiative transfer model for the assimilation of radiance observations

- i) Fast radiative transfer model for AIRS
- ii) Improved version of RTTOV-6

Both models were developed for use at ECMWF and later on merged into RTTOV-7.

An improved general fast radiative transfer model for the assimilation of radiance observations

A prerequisite for exploiting satellite radiance data in the NWP model using the variational analysis scheme is the prediction of radiances given first guess model fields of temperature, water vapour, ozone, surface emissivity and perhaps clouds.

Line-by-line (and pseudo line-by-line) models are too slow to be used operationally in NWP.

To cope with the processing of observations in near real-time, fast radiative transfer models have been developed.

A fast radiative transfer model has to be accurate and computationally efficient.

An improved general fast radiative transfer model for the assimilation of radiance observations

The fast radiative transfer model (RTTOV, Eyre 1991, Saunders et al. 1999) that is used operationally at ECMWF is a regression based (on pressure levels) fast model.

In a regression based fast radiative transfer model the convolved optical depth at wave number ν from level j to space can be written as

$$\hat{\sigma}_{j,\nu}^{model} = \hat{\sigma}_{j-1,\nu}^{model} + \sum_{k=1}^M a_{j,\nu,k} X_{k,j}$$

where M is the number of predictors and the functions $X_{k,j}$ constitute the profile-dependent predictors of the fast transmittance model.

An improved general fast radiative transfer model for the assimilation of radiance observations

To compute the expansion coefficients $a_{j, <k}$ (sometimes referred to as fast transmittance coefficients) one uses a set of diverse atmospheric profiles to compute, for each profile and for several viewing angles, accurate line-by-line level-to-space transmittances for each level defined in a fixed pressure atmospheric layer grid.

The training set of atmospheric profiles must be selected to represent the range of variations in temperature and absorber amount found in the real atmosphere.

The line-by-line level-to-space transmittances are convolved and then used to compute the $a_{j, <k}$ coefficients by linear regression of $\hat{\sigma}_{j,v}^{lbl} - \sigma_{j-1,v}^{lbl}$ [or $-\ln(\hat{\tau}_{j,v}^{lbl} / \hat{\tau}_{j-1,v}^{lbl})$] versus the predictor values $X_{k,j}$ calculated from the profile variables for each profile at each viewing angle.

An improved general fast radiative transfer model for the assimilation of radiance observations

A fast radiative transfer model (RTAIRS) for the Advanced Infrared Sounder (AIRS) has been developed at ECMWF that is based on RTIASI (Matricardi and Saunders, 2000), the ECMWF fast radiative transfer model for the Infrared Atmospheric Sounding Interferometer (IASI).

An improved general fast radiative transfer model for the assimilation of radiance observations

RTAIRS is an extension of RTIASI that features:

- i) A revised set of predictors to improve prediction of ozone transmittances
- ii) Introduction of predictors to model the water vapour continuum type absorption (self continuum).
- iii) Weighting of the input data prior to perform the regression.

An improved general fast radiative transfer model for the assimilation of radiance observations

IN RTAIRS the atmosphere is divided into 43 layers defined by pressure levels from 0.005 hPa to 1013.25 hPa.

The database of line-by-line transmittances was generated using GENLN2 (Edwards, 1992).

The line parameters were obtained from the HITRAN96 (Rothman et. Al, 1998) molecular database.

Continua for water vapour, CO₂, O₂ and N₂ and line mixing for CO₂ were fully accounted for in the computations.

H₂O and O₃ are allowed to vary. Other gas species are treated as fixed.

An improved general fast radiative transfer model for the assimilation of radiance observations

The most basic predictors are defined from the layer temperature and from the layer absorber amount of the variable gases.

Simple functions involving combinations of the basic predictors and of the viewing angle can account for the behaviour of the layer optical depth of a gas treated as having the transmittance properties of a gas in a homogeneous layer at pressure P , temperature T and absorber amount n .

This can be accurate for monochromatic transmittances but in practice we have to predict polychromatic (convolved) transmittances and predictors that account for the dependence of the layer transmittance on the properties of the atmosphere above the layer must be added.

An improved general fast radiative transfer model for the assimilation of radiance observations

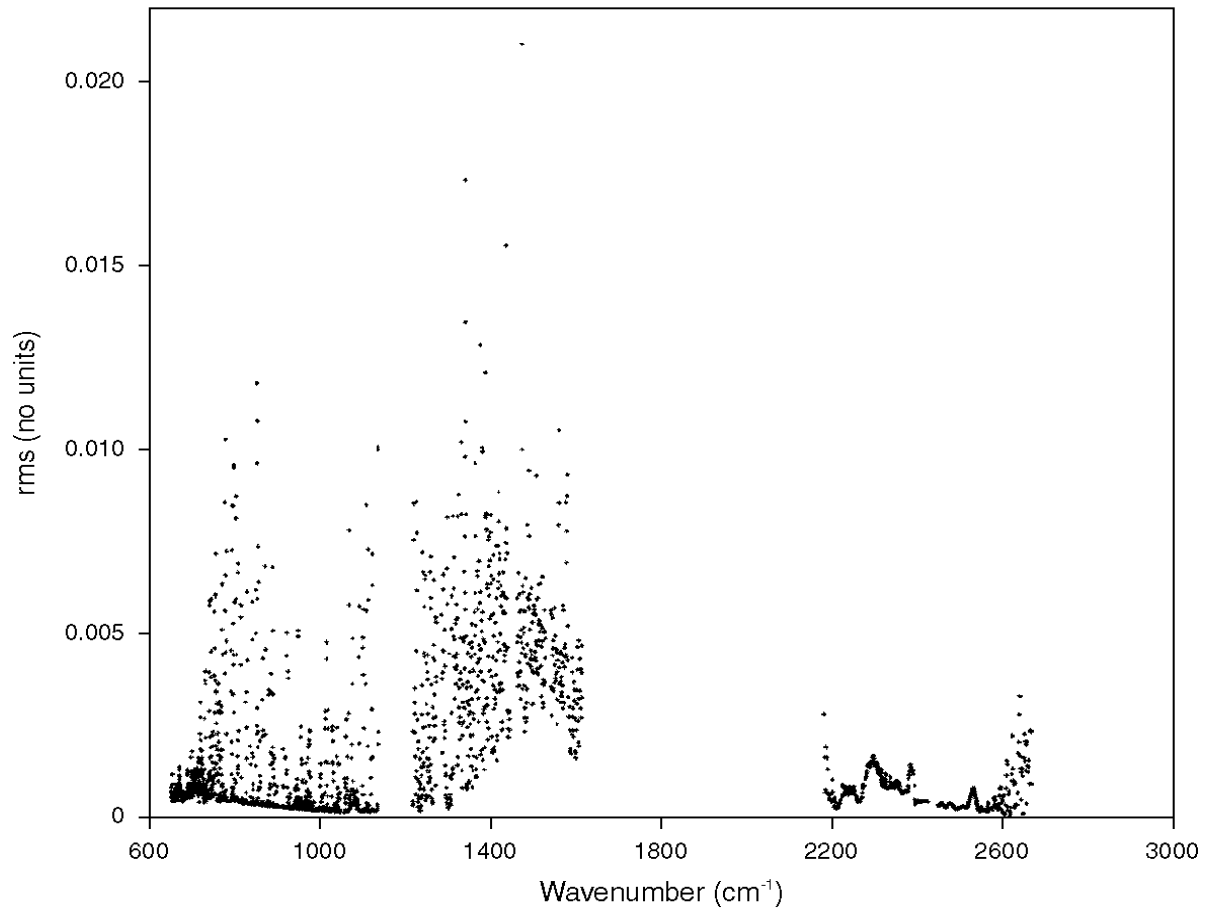
The accuracy of the fast model can be assessed by comparison of the transmittances and radiances computed by the fast model with the corresponding values from line-by-line models in different ways.

i) Fast model transmittance profiles and TOA radiances for the dependent set of profiles used to train the fast model can be compared with the Line-by-line equivalents.

ii) A set of profiles independent of the regression coefficients can be used to allow uncertainties from different type of profiles to be included.

Maximum value of the rms error

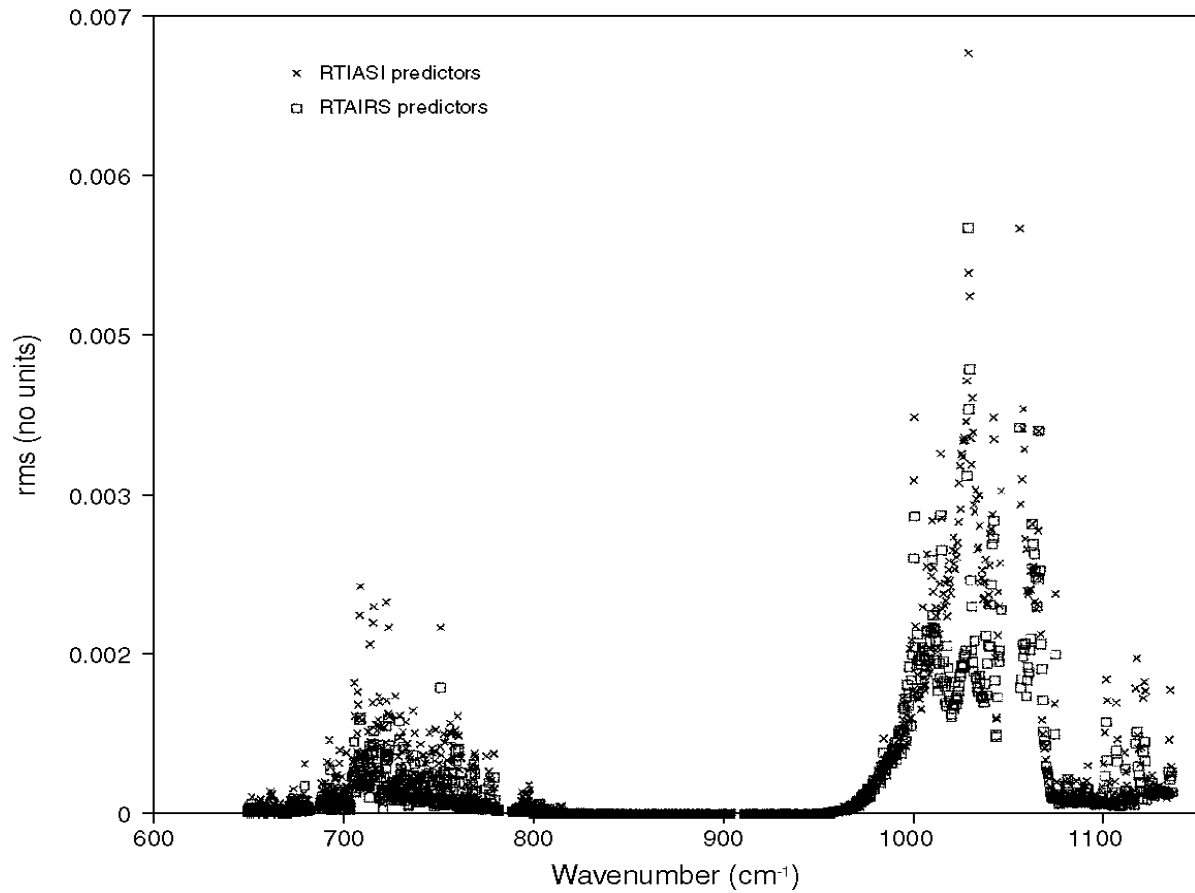
Dependent set – Temperature and water vapour sounding channels



Maximum value of root mean square difference between fast model and GENLN2 layer to top of atmosphere transmittances for AIRS for 43 diverse water vapour profiles and 6 viewing angles

Maximum value of the rms error

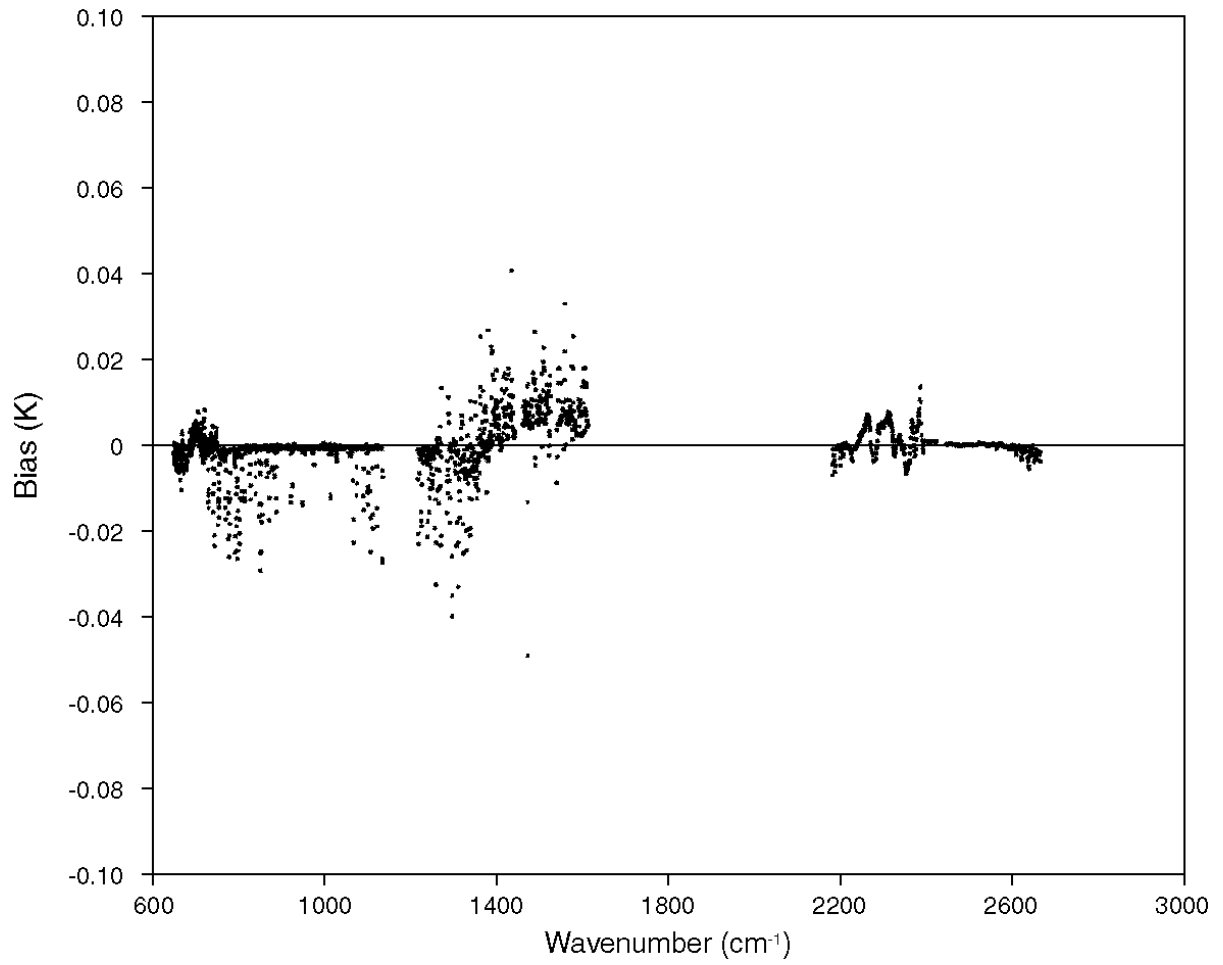
Dependent set – Ozone channels



Maximum value of root mean square of difference between fast model and GENLN2 layer to top of atmosphere transmittances for AIRS for 34 diverse ozone profiles and 6 viewing angles. Results are shown for the transmittance model used in RTIASI and for the improved model used in RTAIRS.

Fitting errors of the fast radiative transfer model for AIRS

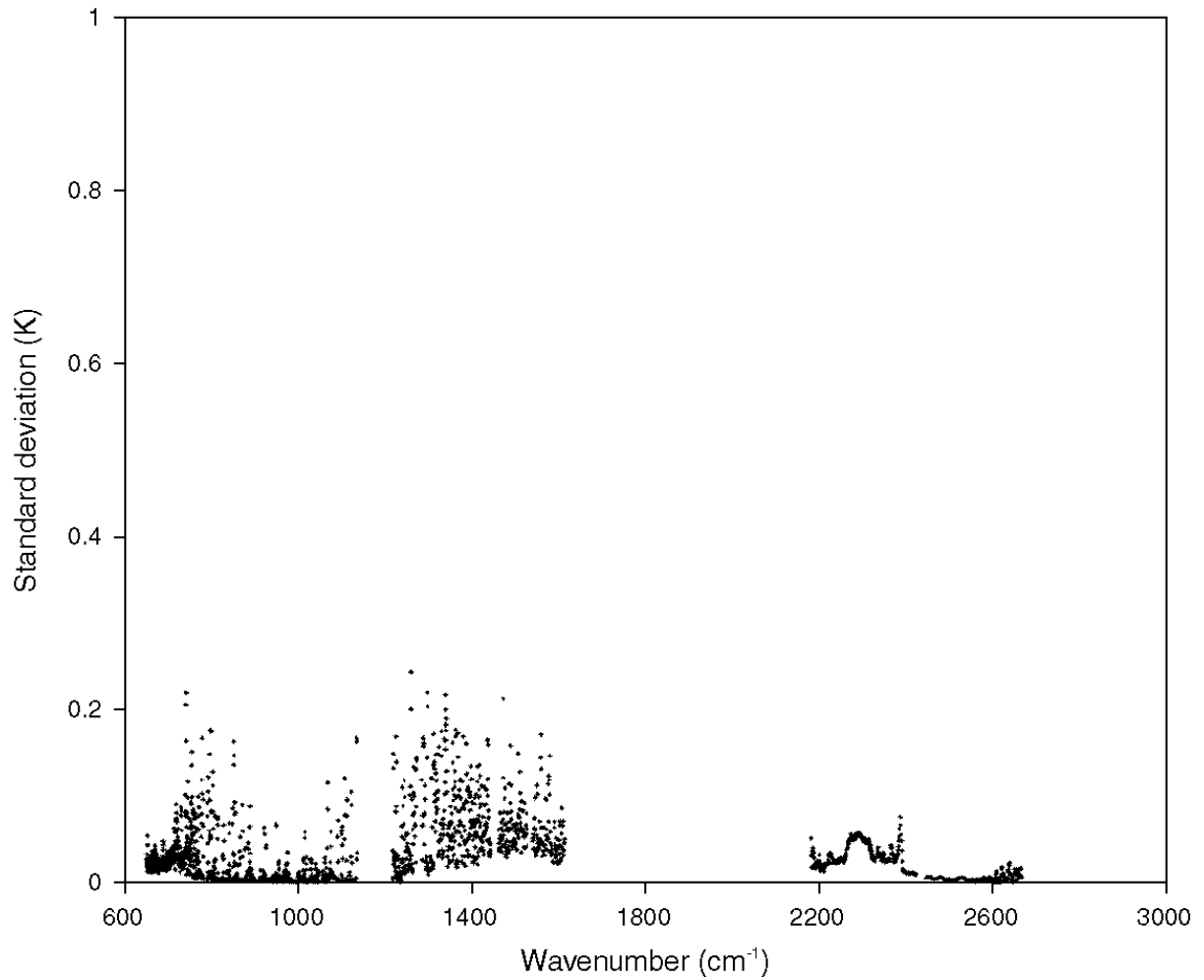
Dependent set – Temperature and water vapour sounding channels



Mean value of the difference (bias) between fast model and GENLN2 computed brightness temperatures for AIRS for 43 diverse water vapour profiles and 6 viewing angles.

Fitting errors of the fast radiative transfer model for AIRS

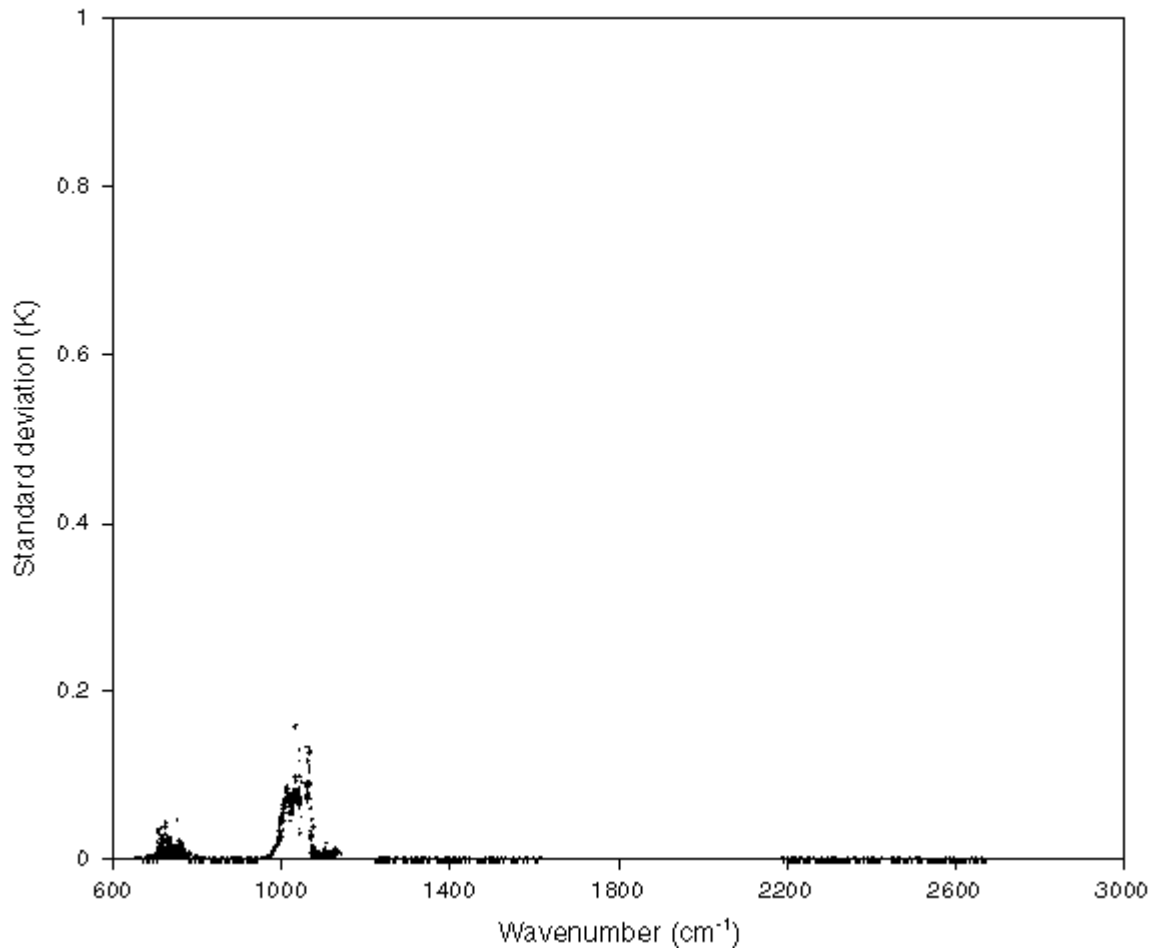
Dependent set – Temperature and water vapour sounding channels



Standard deviation of the difference between fast model and GENLN2 computed brightness temperatures for AIRS for 43 diverse water vapour profiles and 6 viewing angles.

Fitting errors of the fast radiative transfer model for AIRS

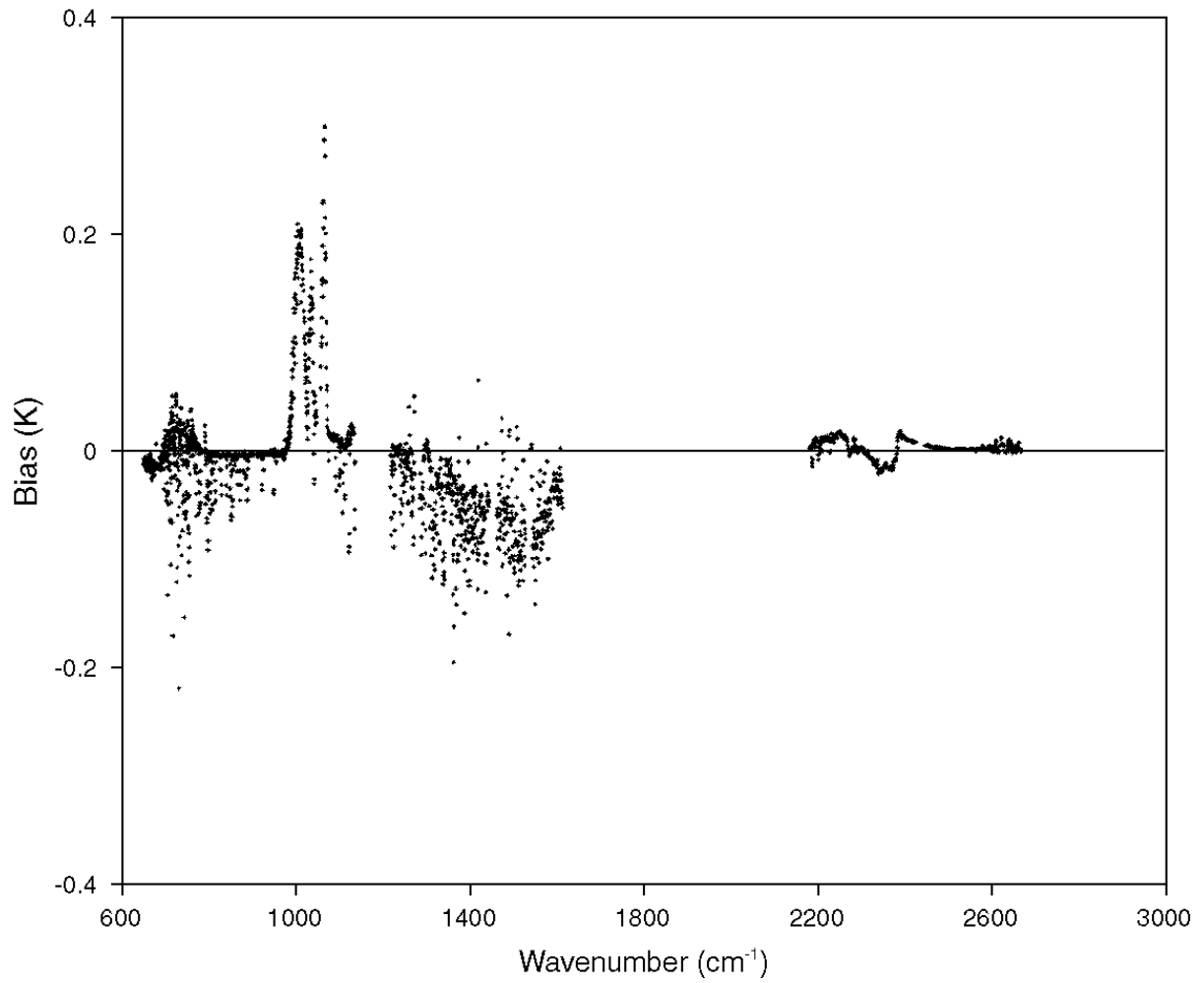
Ozone channels – dependent set



Standard deviation of the difference between fast model and GENLN2 computed brightness temperatures for AIRS for 34 diverse ozone profiles and 6 viewing angles.

Fitting errors of the fast radiative transfer model for AIRS

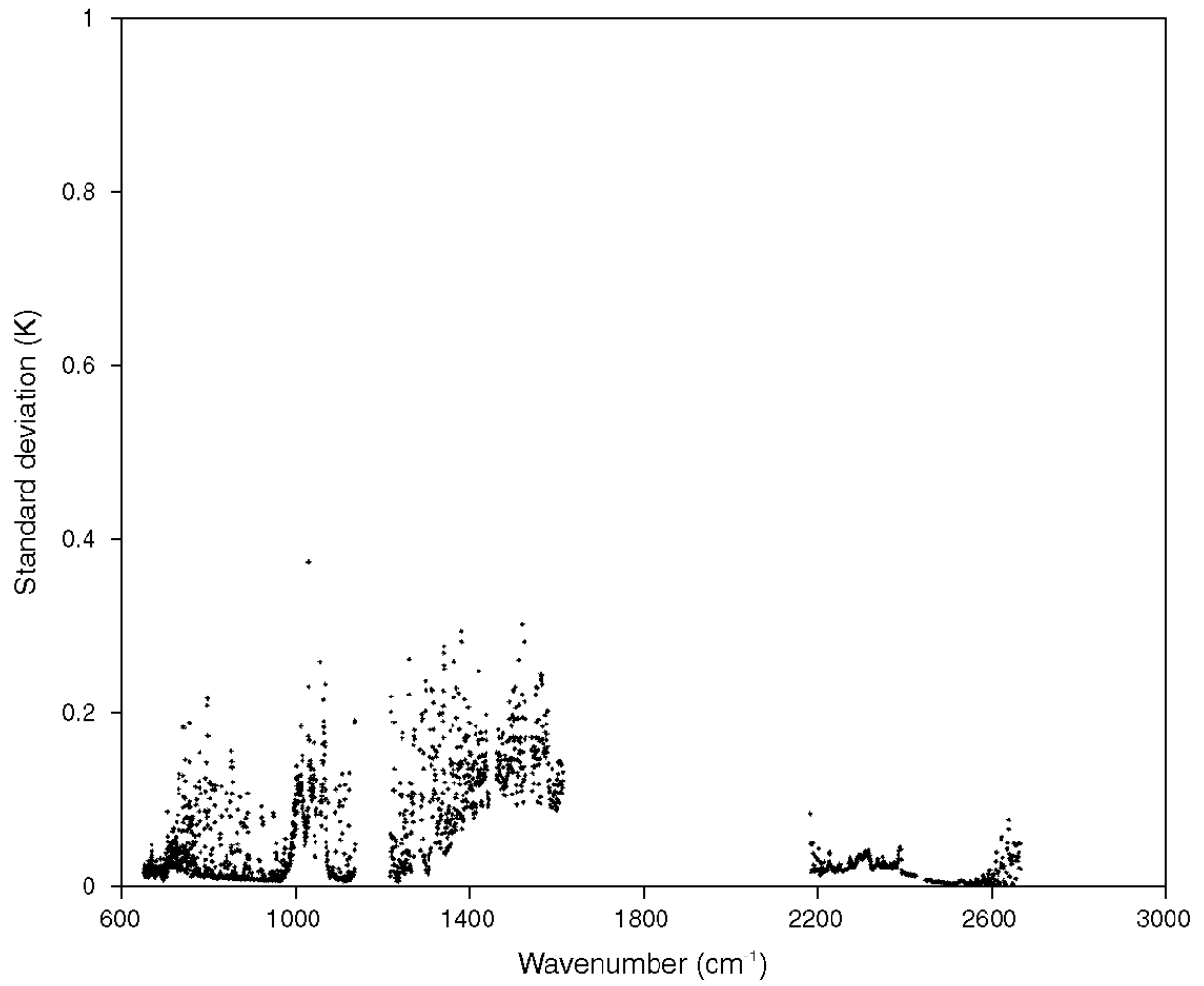
Independent set



Mean value of the difference (bias) between fast model and GENLN2 computed brightness temperatures for AIRS for 117 independent profiles and 6 viewing angles.

Fitting errors of the fast radiative transfer model for AIRS

Independent set



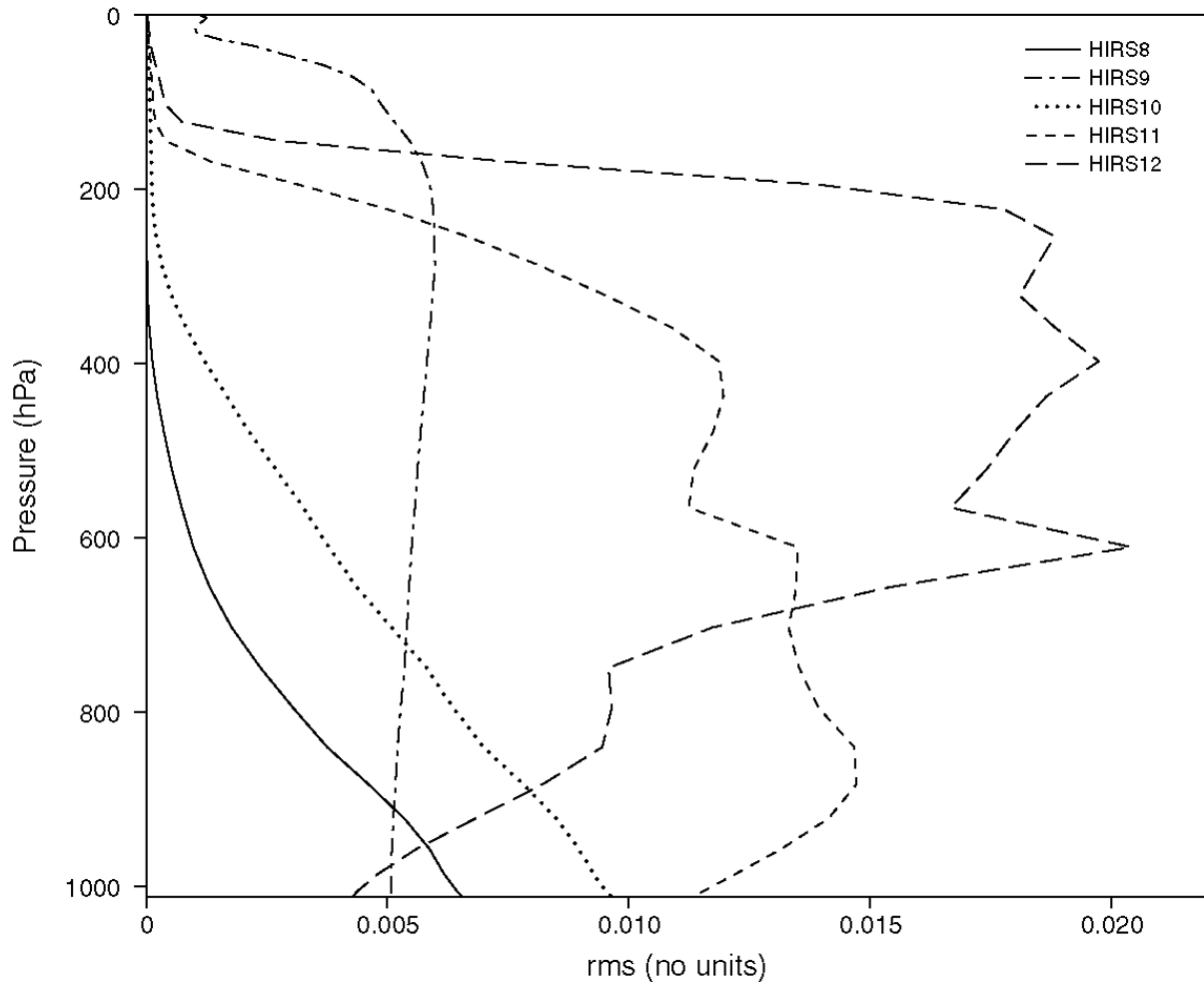
Standard deviation of the difference between fast model and GENLN2 computed brightness temperatures for AIRS for 117 independent profiles and 6 viewing angles.

An improved general fast radiative transfer model for the assimilation of radiance observations

An improved version of RTTOV (RTTOV-M) has been developed at ECMWF that features the predictors used in RTAIRS.

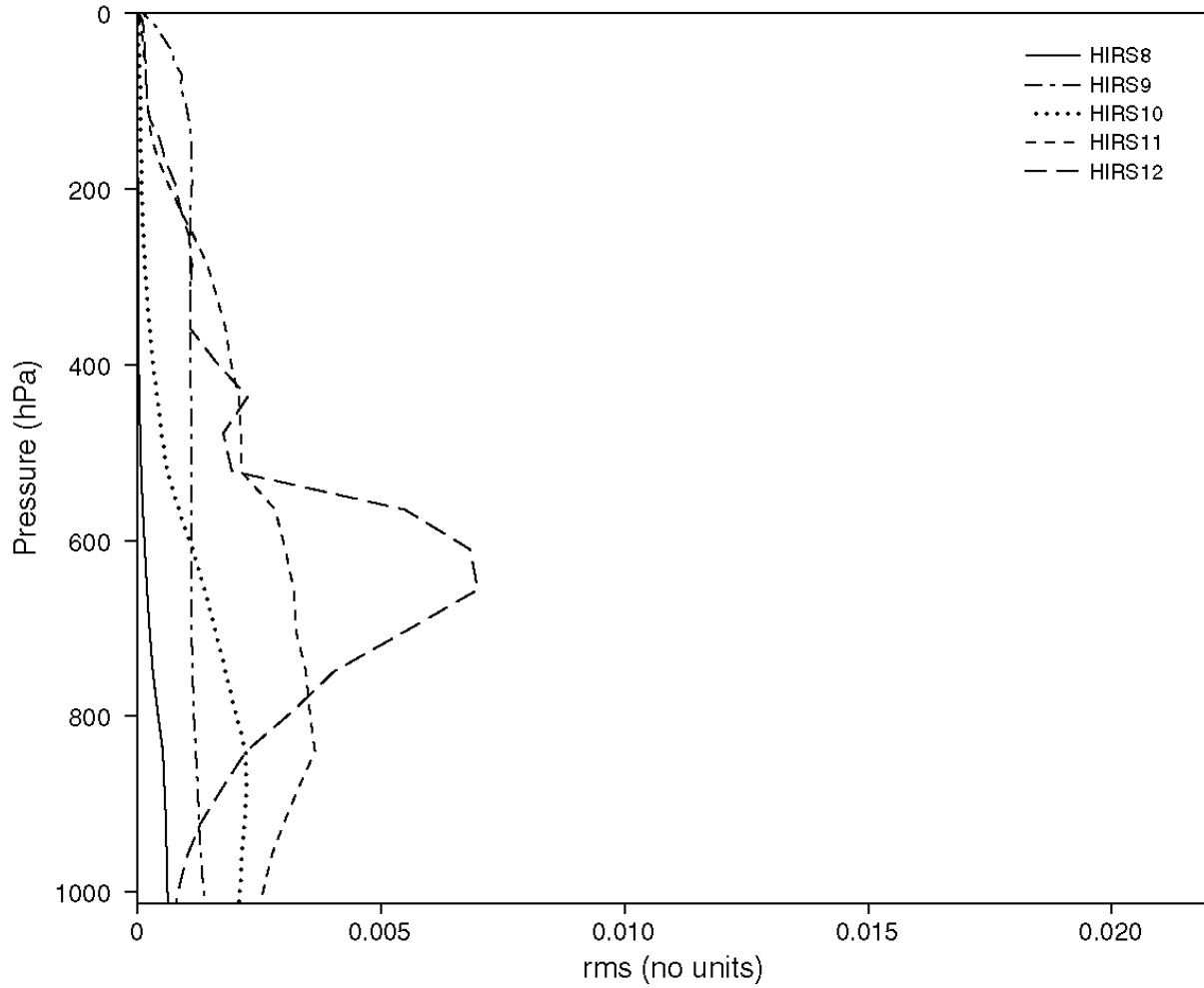
This new model can reproduce line-by-line radiances and Jacobians for the surface sensing, water vapour and ozone channels of the advanced TIROS operational vertical sounder (TOVS) with significantly improved accuracy.

Root mean square error of the difference between
fast model and line-by-line transmittances
Dependent set – Operational model



Root mean square of the difference between RTTOV-6 and GENLN2 HIRS channels 8,9,10,11 and 12 layer to top of the atmosphere transmittances for NOAA-14 for the profiles used to train the fast model and 6 viewing angles.

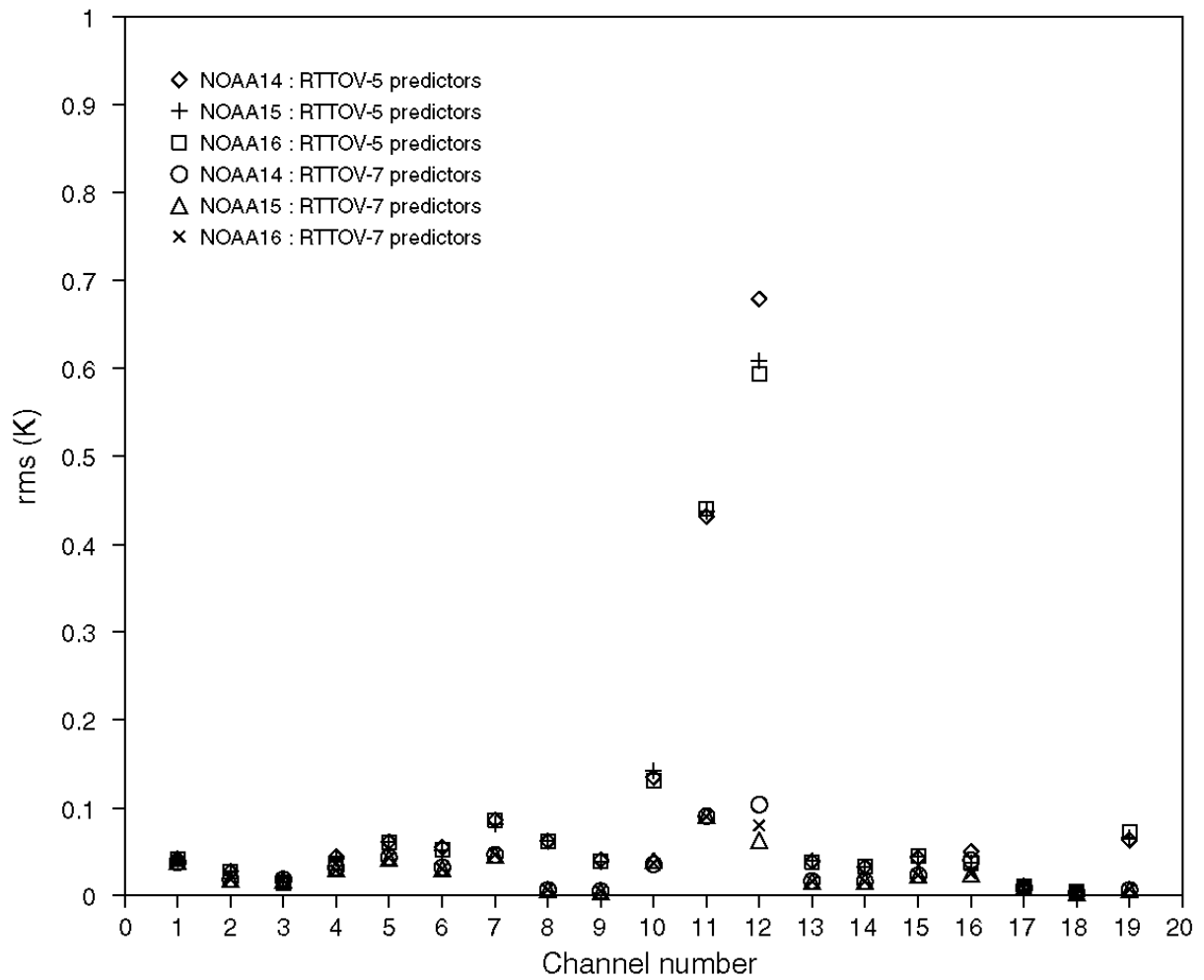
Root mean square error of the difference between
fast model and line-by-line transmittances
Dependent set – Improved model



Root mean square of the difference between RTTOV-7 and GENLN2 HIRS channels 8,9,10,11 and 12 layer to top of the atmosphere transmittances for NOAA-14 for the profiles used to train the fast model and 6 viewing angles.

Fitting errors of the improved RTTOV for HIRS

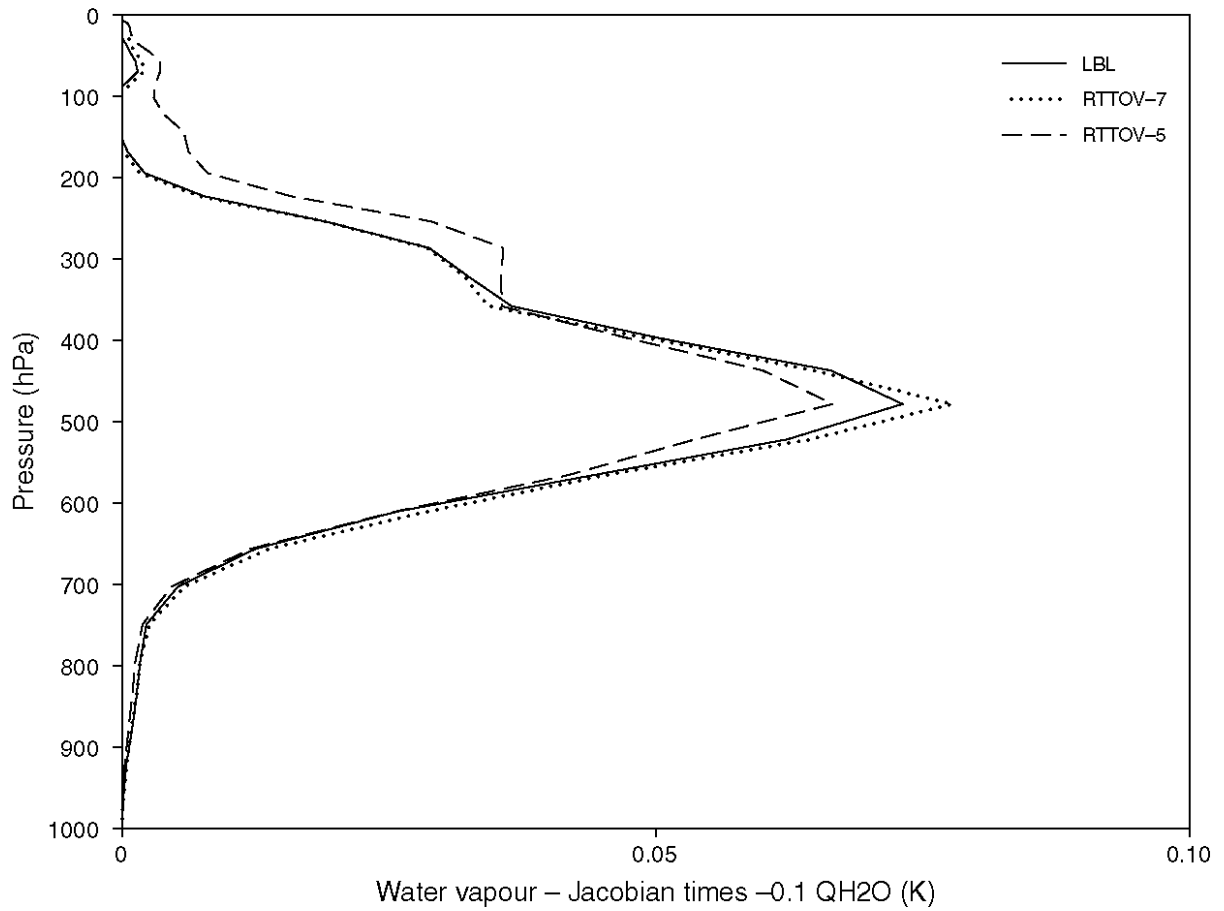
Dependent set



Root mean square of the difference between fast model and GENLN2 computed brightness temperatures for 43 diverse water vapour profiles and six viewing angles. Results are shown for RTTOV-6 and RTTOV-7. The HIRS channels of NOAA-14, NOAA-15 and NOAA-16 are plotted.

HIRS Channel 12

Profile=19



Water vapour Jacobian for channel HIRS-12 computed using GENLN2, RTTOV-7 and RTTOV-5.

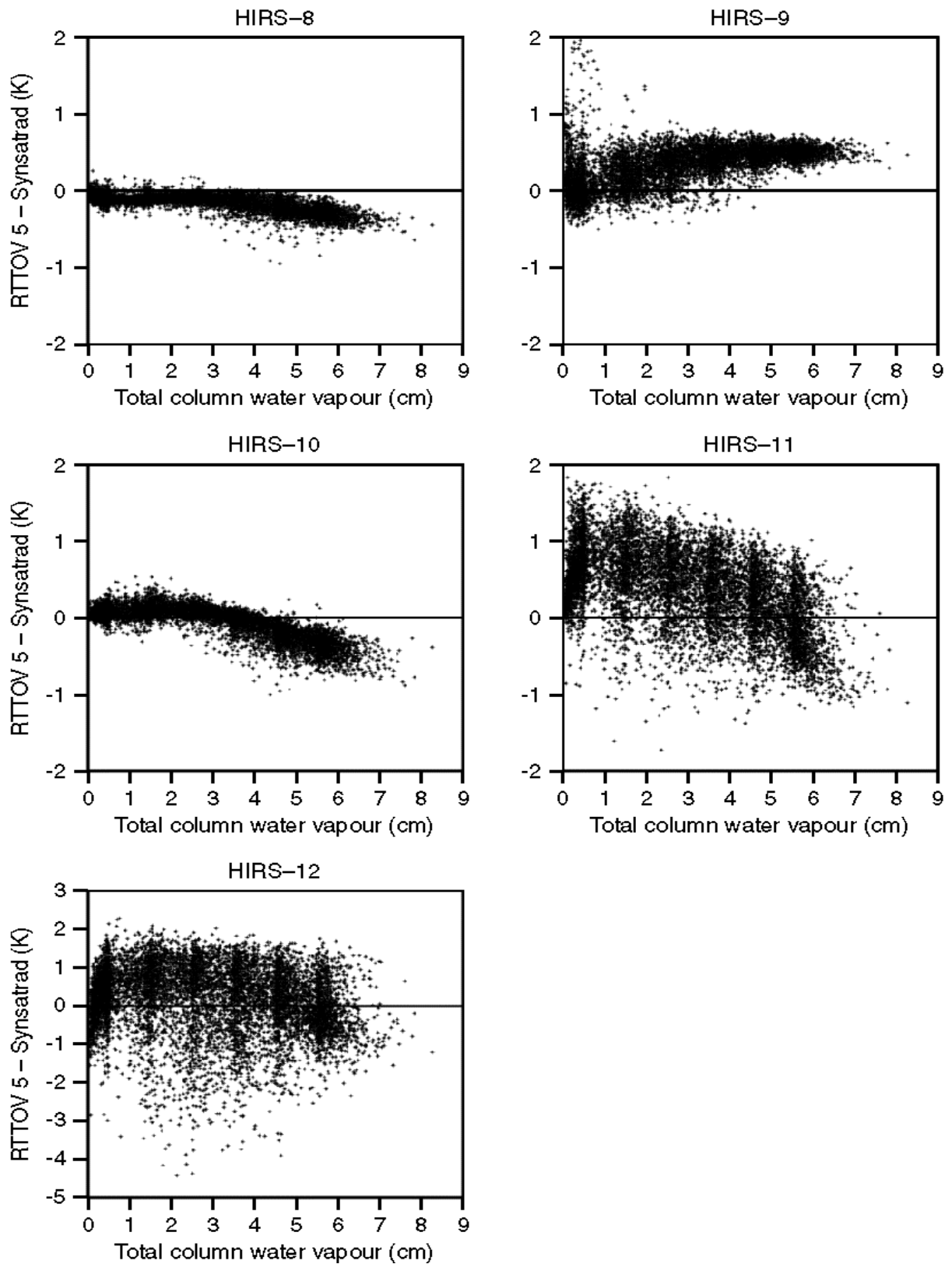
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Results similar to those for HIRS channels were achieved for the infrared and water vapour channels of the MVIRI instrument on board the METEOSAT satellites.

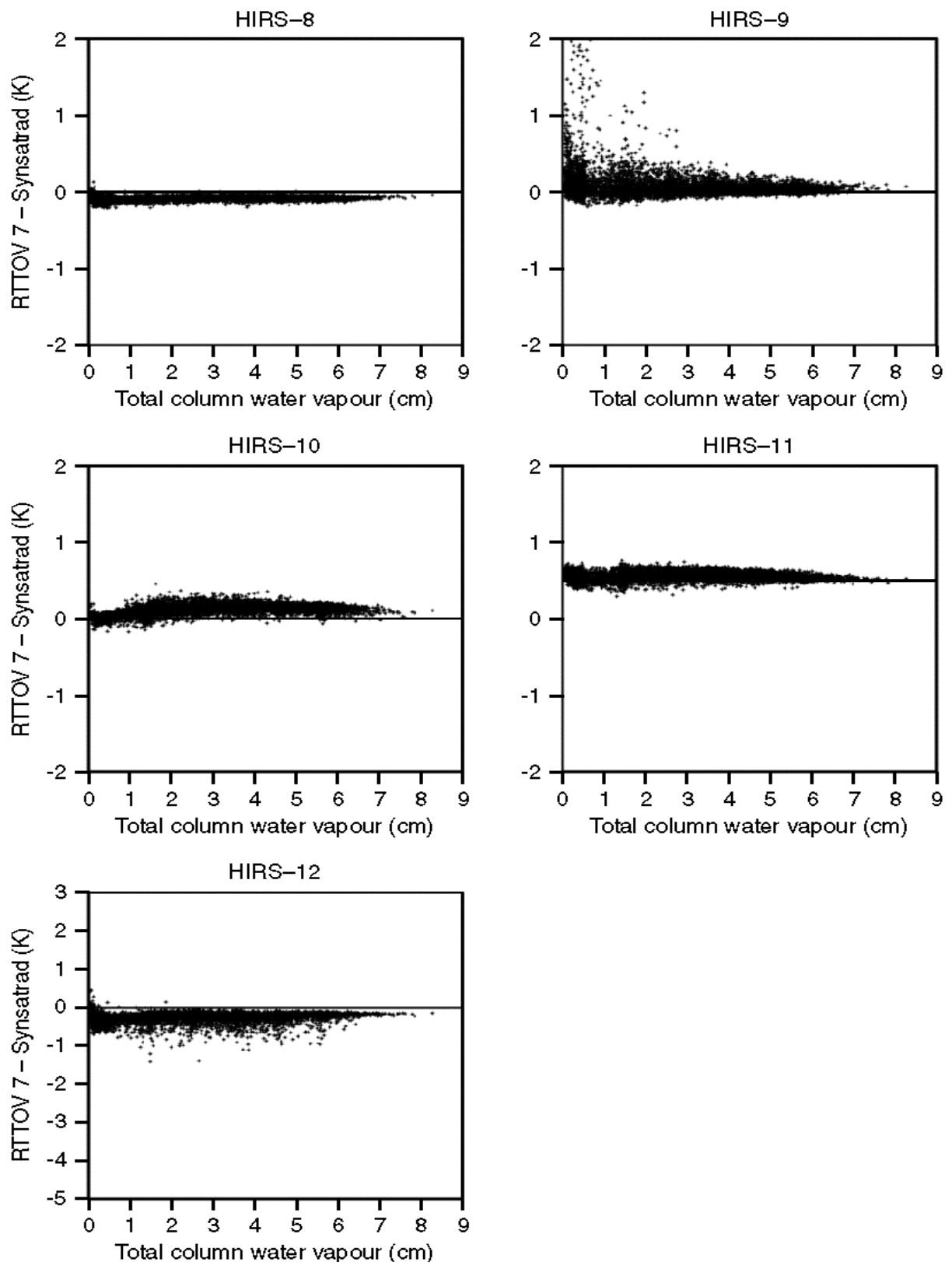
The RTTOV with new predictors was also found to be able to reproduce radiances for the AMSU channels to accuracy at or below the one achieved by RTTOV-6.

An improved general fast radiative transfer model for the assimilation of radiance observations

The comparison of RTTOV-M radiances with radiances computed using Synstrad, a radiative transfer model developed at EUMETSAT (Tjemkes and Schmetz, 1997), show that a major negative feature of RTTOV-6 (the strong dependence of the error on air mass type) has been corrected by the improved model.



Difference between RTTOV-5 and Synsatrad computed brightness temperatures for 8987 independent profiles for the channels HIRS-8, HIRS-9, HIRS-10, HIRS-11 and HIRS-12 of NOAA-14.



Difference between RTTOV-7 and Synsatrad computed brightness temperatures for 8987 independent profiles for the channels HIRS-8, HIRS-9, HIRS-10, HIRS-11 and HIRS-12 of NOAA-14.

An improved general fast radiative transfer model for the assimilation of radiance observations

Details can be found in the ECMWF Technical Memorandum 345.

Also, a paper is due to be submitted shortly to a journal.

CURRENT WORK

An interim version of RTAIRS and RTTOV-M has been developed that can handle variable CO₂.

FUTURE WORK

A much improved version of RTIASI/RTAIRS will be made available in March/May 2002.

It will feature:

- i) Four more fixed gas species (CCL_4 , F14, HNO_3 , OCS).
- ii) Spectroscopic parameters from the HITRAN2000 molecular database.
- iii) 90 vertical pressure levels from 0.005 hPa to 1050 hPa.
- iv) Variable CO_2 , N_2O , CH_4 and CO.
- v) Split water vapour continuum.

FUTURE WORK

- vi) Revised set of training profiles for water vapour in the stratosphere.
- vii) Slightly revised predictors for water vapour.
- viii) Revised scheme to weight the input data to the regression.