A simulation study of the impact of AIRS fast model errors on the accuracy of 1D-Var retrievals from AIRS radiances

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Abstract

In this poster we characterise the forward model differences between two AIRS fast models participating in the ITWG AIRS fast model intercomparison, Gastropod v0.3.0 [Sherlock et al., 2003] and RTTOV7.1 [Saunders et al., 2002]. We then examine the impact of these model differences (and their spectral correlation) on the accuracy of full nonlinear iterative 1D-Var retrievals from synthetic AIRS radiances with and without bias correction using the NESDIS channel selection. Retrieval error covariance matrices and degrees of freedom for signal are estimated for ensembles of 1D-Var retrievals and are compared with predictions from linear theory.

cross retrievals: radiance simulation and retrieval performed using different models. **direct retrievals**: radiance simulation and retrieval performed using the same model.

Method

Simulate radiances with Gastropod and RTTOV for a set of 69 tropical, mid and high latitude profiles drawn from the ECMWF 50-level diverse profile set [Chevallier, 1999].

Use these simulations to estimate bias correction and forward model error covariance for cross-retrievals and combine with realisations of AIRS intrumental noise [Sherlock et al., 2003] (and forward model error in direct retrievals) to generate synthetic AIRS spectra.

Perturb each of the 69 profiles (twice) in accordance with the 1D-Var background error covariance **B** [Collard and Healy, 2003] to generate background state vectors for retrievals (138 retrievals in total).

Retrieve temperature (on 44 levels between 0.1 and 1013.25 hPa + Tskin) and humidity (on 27 levels between 122 and 1013.25 hPa) using the Met Office 1D-Var v3.1 retrieval software [Collard, 2004] distributed by the Eumetsat NWP SAF.

Standard statistical estimates of ensemble background and retrieval error covariance matrices $\mathbf{B_e}$ and $\mathbf{A_e}$.

Estimate DFS using projection onto the eigenvectors of **B**:

$$\mathrm{DFS} = \sum 1 - \frac{\mathbf{e}_i^T \mathbf{A}_e \mathbf{e}_i}{\mathbf{e}_i^T \mathbf{B}_e \mathbf{e}_i}$$

to account for modified ensemble background error covariance (1D-Var profile checks).

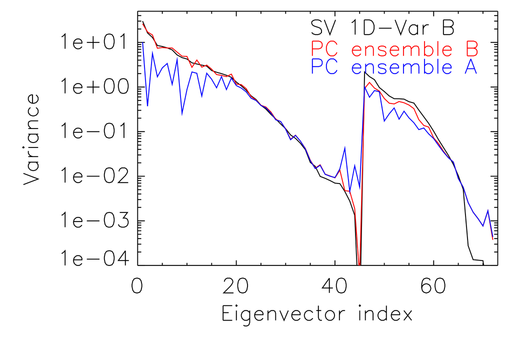

FIGURE 1: Example of projection of the ensemble background and retrieval error covariance matrices onto the eigenvectors of **B**.

Compare with optimal linear theory for full specification of the observation error covariance **R** [Rodgers, 1990], and suboptimal linear theory for a diagonal approximation to **R** matrix [Watts and McNally, 1988]. Ensemble linear error covariance estimate $\mathbf{A}_\mathrm{L} = \frac{1}{\mathrm{N}} \sum \mathbf{A}_{\mathrm{L},k}$ for the k=1 to N=69 atmospheric states.

Characterisation of forward model differences

RTTOV–Gastropod forward model differences estimated from radiance simulations for the 69 atmospheres show:

- Significant biases (0.5–2.0 K) in the CO_2 ν_2 and ν_3 bands, isolated water vapour lines in the longwave window region and some channels in the H_2O ν_2 band.
- Standard deviations comparable or greater than instrumental noise levels in the O_3 ν_1 and ν_3 bands, the CO_2 ν_3 band, the shortwave window region, the H_2O ν_2 band and water vapour line centres in longwave window region.
- Significant off-diagonal contributions to **R** across most of the spectrum because fast model differences are comparable with or greater than instrumental noise levels in many spectral intervals.

Gastropod transmittance prediction error estimates [Sherlock et al., 2003] are illustrated for comparison.

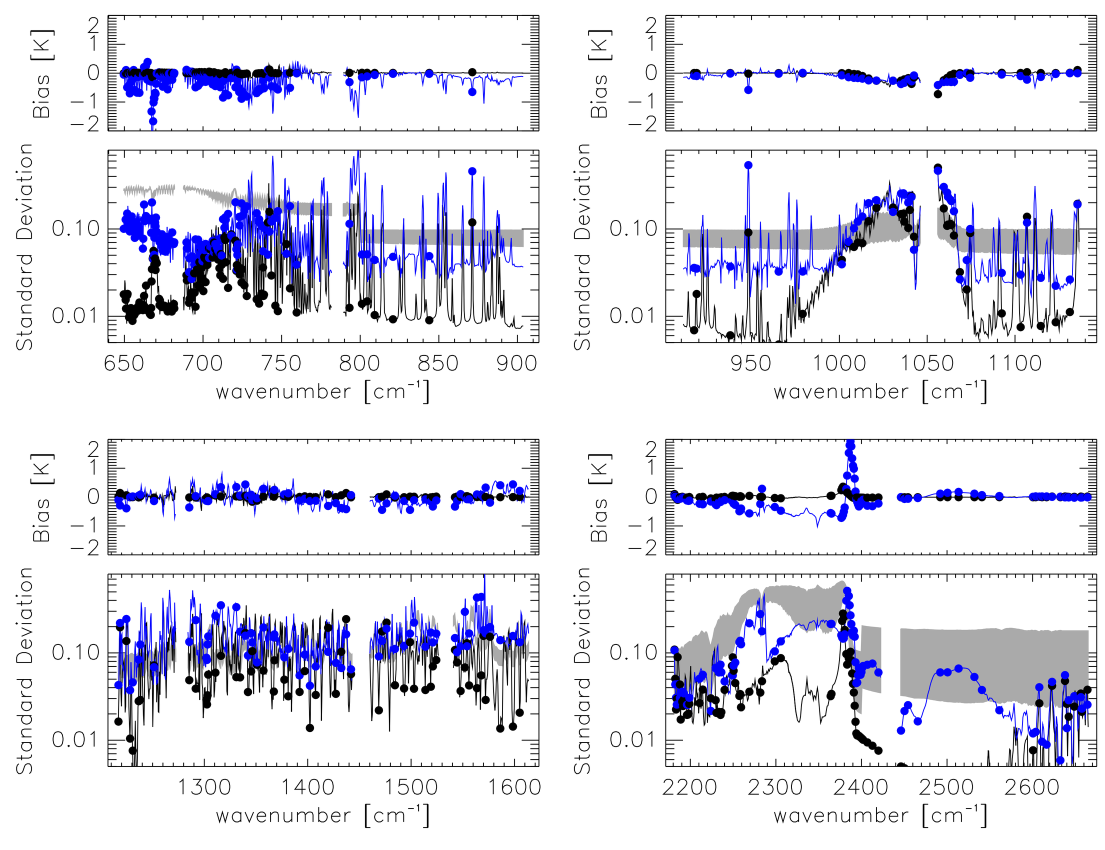

FIGURE 2: Bias and standard deviation of Gastropod forward model errors (black) and Gastropod–RTTOV differences (blue) for the AIRS instrument. Lower bound estimates of AIRS instrumental noise levels for a representative range of scene temperatures are illustrated with grey shading. The NESDIS channel set is indicated with filled circles.

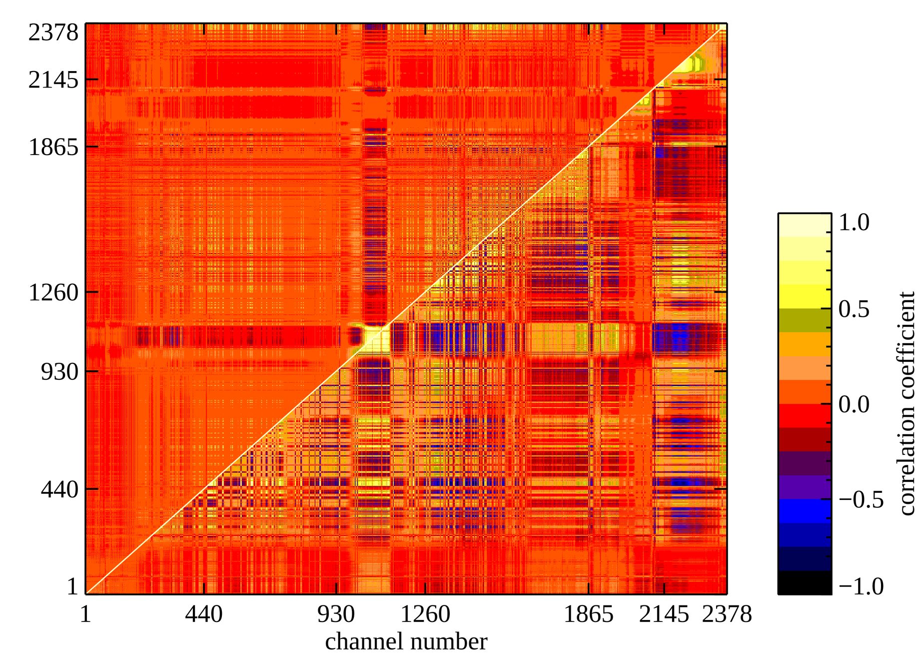

FIGURE 3: Correlation coefficients for the observation error covariance matrix **R = E + F**. Upper triangle, correlations for the case where **F** is the Gastropod forward model error covariance matrix. Lower triangle, correlations for the case where **F** is the forward model error covariance matrix derived for the RTTOV–Gastropod differences.

Characterisation of retrieval accuracy

Cross retrieval error characteristics are similar for the two sets of cross retrieval (only one illustrated):

- Flat bias correction: Loss of accuracy in stratospheric temperature and tropospheric humidity retrievals compared with direct retrievals. Corresponding loss of 2.5–3.5 DFS for 1D-Var retrievals. Loss of 2 DFS associated with diagonal approximation to **R**.
- No bias correction: Substantial loss of accuracy. No benefit to assimilation with a diagonal approximation to **R**.
- Reasonable qualitative agreement with the predictions of linear theory. Note modified background error covariance for retrieval ensemble; linear theory neglects Jacobian errors.

Direct retrievals were performed using the Gastropod model and its associated transmittance prediction error covariance estimate.

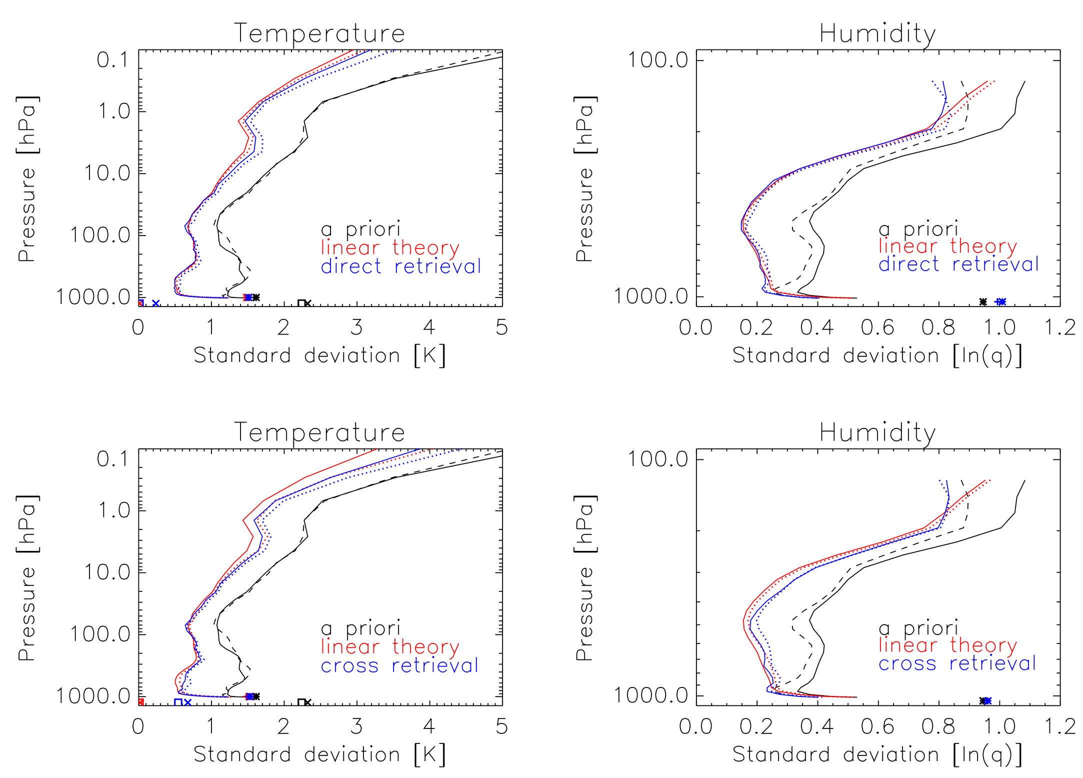

FIGURE 4: Retrieval standard deviations derived from linear theory (red) and 1D-Var retrievals (blue) for full (solid) and diagonal (dotted) approximations to the forward model error covariance matrix. Cross retrievals are bias corrected. The diagonal elements of the a priori error covariance matrix (solid black) and the retrieval background ensemble (dashed black) are illustrated for reference.

Direct retrieval	ret	ref	bias	N_{ret} full **R**	N_{ret} diag **R**	DFS full **R**	DFS diag **R**
1D-Var	G	G	-	138	134	16.1	14.3
Linear	G	-	-	-	-	17.6	16.7
Cross retrieval	**ret**	**ref**	**bias**	**N_{ret} full R**	**N_{ret} diag R**	**DFS full R**	**DFS diag R**
1D-Var	R	G	F	131	123	7.3	0
	G	R	F	130	106	8.9	2.2
	R	G	T	133	133	13.5	11.6
	G	R	T	130	131	12.4	10.8
Linear	G	-	-	-	-	17.3	15.1

TABLE 1: Summary of degrees of freedom for signal (DFS) derived from linear theory and 1D-Var retrievals. ret identifes the model used in retrievals. ref identifies the model used to simulate the spectra (G=Gastropod, R=RTTOV). The T/F bias logical indicates whether bias correction has been applied or not. N_{ret} is the number of converged 1D-Var retrievals (from 138 member ensembles).

Conclusions

Fast model differences, where significant, are principally due to differences in spectroscopy. Additional error sources may also play a role e.g. differences in stratospheric extrapolation assumptions; fast model transmittance prediction errors in the H_2O ν_2 band.

The results of the experiments undertaken for a representative ensemble of atmospheric states with bias correction suggest that if these fast model differences are representative of real fast model errors, and if bias correction can be performed accurately, the accuracy of temperature and humidity retrievals using the NESDIS channel selection should not significantly compromised by radiative transfer model errors.

The accuracy of retrievals with a given channel selection depends critically on other aspects of the assimilation system (bias correction, specification of the observation error covariance matrix). For this reason 1D-Var simulation studies of the type undertaken here have a role to play in estimating and minimizing the impact of suboptimal retrieval choices in operational data assimilation systems.

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