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Numerical Weather Prediction

Notes on AGIRS performance

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Notes on AGIRS Performance.

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1. Introduction.

This document investigates the performance of the proposed AGIRS (Advanced Geostationary Infrared Sounder) instrument — a high spectral resolution sounder which would be an extension of the SEVIRI instrument on future Meteosat Second Generation satellites.

EUMETSAT document EUM/STG/SWG/5/98/DOC/8 describes the proposed AGIRS characteristics. It would measure the infrared spectrum between 4.33μm and 5.49μm (with the possibility of a gap in the coverage between 4.71μm and 5.0μm) at a resolution of about 2cm^{-1}. The instrument's radiometric noise would be 0.25K at a scene brightness temperature of 280K.

This study follows that in Collard (1998) for the IASI instrument. The instrument performance is evaluated through inspection of the analysis error covariances expected from a 1DVAR retrieval. The equivalent results for HIRS and IASI are also shown as a comparison.

The notation herein generally follows that recommended by Ide *et al.* (1997).

2. Method of Investigating Retrieval Accuracy and Vertical Resolution.

Rodgers (1976) shows that for linear problems, (or approximately for weakly non-linear problems), the best estimate of the atmospheric state, $\mathbf{x}$, and associated error covariance, $\mathbf{A}$, is given by the optimal estimation method of retrieval (Rodgers, 1976) where

$$\hat{\mathbf{x}} = (\mathbf{B}^{-1} + \mathbf{H}^T(\mathbf{O}+\mathbf{F})^{-1}\mathbf{H})^{-1}(\mathbf{B}^{-1}\mathbf{x_0} + \mathbf{H}^T(\mathbf{O}+\mathbf{F})^{-1}\mathbf{y}) \qquad (1a)$$

and

$$\mathbf{A} = (\mathbf{B}^{-1} + \mathbf{H}^T(\mathbf{O}+\mathbf{F})^{-1}\mathbf{H})^{-1}. \qquad (1b)$$

Here, $\mathbf{H} = \nabla_x \mathbf{y}(\mathbf{x})$ is the matrix of instrument weighting functions, $\mathbf{B}$ is the error covariance matrix for the *a priori* data, $\mathbf{x_0}$, and $\mathbf{y}$ is the vector of observations which have error covariances $\mathbf{O}$. $\mathbf{F}$ is the matrix of forward model error covariances.

If the true atmospheric state is represented by the vector $\mathbf{x_T}$, one finds that in the linear case (e.g., Eyre (1987))

$$\begin{aligned}(\hat{\mathbf{x}} - \mathbf{x_0}) &= (\mathbf{HB})^T(\mathbf{HBH}^T + (\mathbf{O}+\mathbf{F}))^{-1}\mathbf{H}(\mathbf{x_T} - \mathbf{x_0}) \\ &= \mathbf{R}(\mathbf{x_T} - \mathbf{x_0}) \qquad (2a)\end{aligned}$$

or, alternatively

$$\hat{\mathbf{x}} = \mathbf{R}\mathbf{x_T} + (\mathbf{I} - \mathbf{R})\mathbf{x_0} \qquad (2b)$$

It follows that

$$\mathbf{R} = \mathbf{I} - \mathbf{A}\mathbf{B}^{-1} \qquad (3)$$

where $\mathbf{I}$ is the identity matrix.

$\mathbf{R}$ is the *Model Resolution Matrix* (Menke, 1984) which can be used in a variety of ways to define the vertical resolution of a retrieval. The preferred definition here follows Purser and Huang (1993) where the vertical resolution for level i with height interval $dz(i)$ is $dz(i)/\mathbf{R}(i,i)$.

In addition to the vertical resolution and variance of the retrieval at each altitude, the quality of the retrieval as a whole may be characterised by the number of degrees of freedom for signal (DFS), which is given by the trace of the resolution matrix, and the information content, given by $-0.5 \ln |\mathbf{AB}^{-1}|$.

The calculations are done for mid-latitude winter and summer scenarios taken from the TIGR dataset (Fig. 1). The Jacobians are calculated using the IASI fastmodel developed by Marco Matricardi at ECMWF which is then re-apodised to a 2cm^{-1} FWHM Gaussian instrument spectral response function to approximate that of AGIRS (although AGIRS would be a grating spectrometer with a triangular ISRF).

The background error covariance matrix used is the ECMWF 1DVAR 40-level forecast error covariance matrix which is interpolated to the 43 levels used by the fastmodel. As stated above, the instrument's radiometric noise is assumed to be 0.25K at 280K to which an additional 0.2K forward model noise is added in quadrature.

A typical observation by AGIRS is shown in Figure 2 with the same spectral interval at IASI resolution and the filter functions for the four HIRS channels in that region. The lower resolution of AGIRS compared to IASI is evident in the shorter wavelength side of the region where AGIRS is unable to pick out the detailed line-to-line variation in the CO_2 band. At the longwave end of the region (dominated by H_2O), AGIRS is somewhat more successful at observing the individual lines. Based on this and given that AGIRS has significantly fewer channels than IASI (245 versus 8461) but far more than HIRS (19) one would expect the AGIRS performance to be intermediate between the two other instruments.

It should be noted that the actual instrument noise depends (through the non-linearity of the Planck function) on the brightness temperture of the observed scene and is thus much higher than 0.25K in the cold CO_2 band around 4.4μm(Fig. 3). The performance of both the AGIRS and IASI retrievals are affected by this, while HIRS measurements have much lower instrument noise and are limited by forward model error which can be assumed to not vary with scene temperature. For this reason one would expect the difference in retrieval performance between summer and winter to be much greater for IASI and AGIRS than for HIRS.

3. **Results and Discussion.**

Figures 4 and 5 show the expected performances of AGIRS, IASI and HIRS for the winter and summer cases respectively*. In the former case, the performance of a hypothetical AGIRS variant with instrumental noise reduced by a factor of ten is also shown. The purpose of showing this is to illustrate the sensitivity of the retreivals to this noise source which we have seen is particularly dominant in the 4.4μm region in the specified IASI configuration.

For temperature retrievals using AGIRS the analysis errors are seen to be similar to or slightly better than HIRS with better vertical resolution but still much worse than IASI. Reducing AGIRS's instrument noise tenfold results in temperature retrieval performance midway between IASI and HIRS.

* Note that all IASI and HIRS channels 1–8 and 10–19 are used in these calculations, not just those in the spectral interval observed by AGIRS.

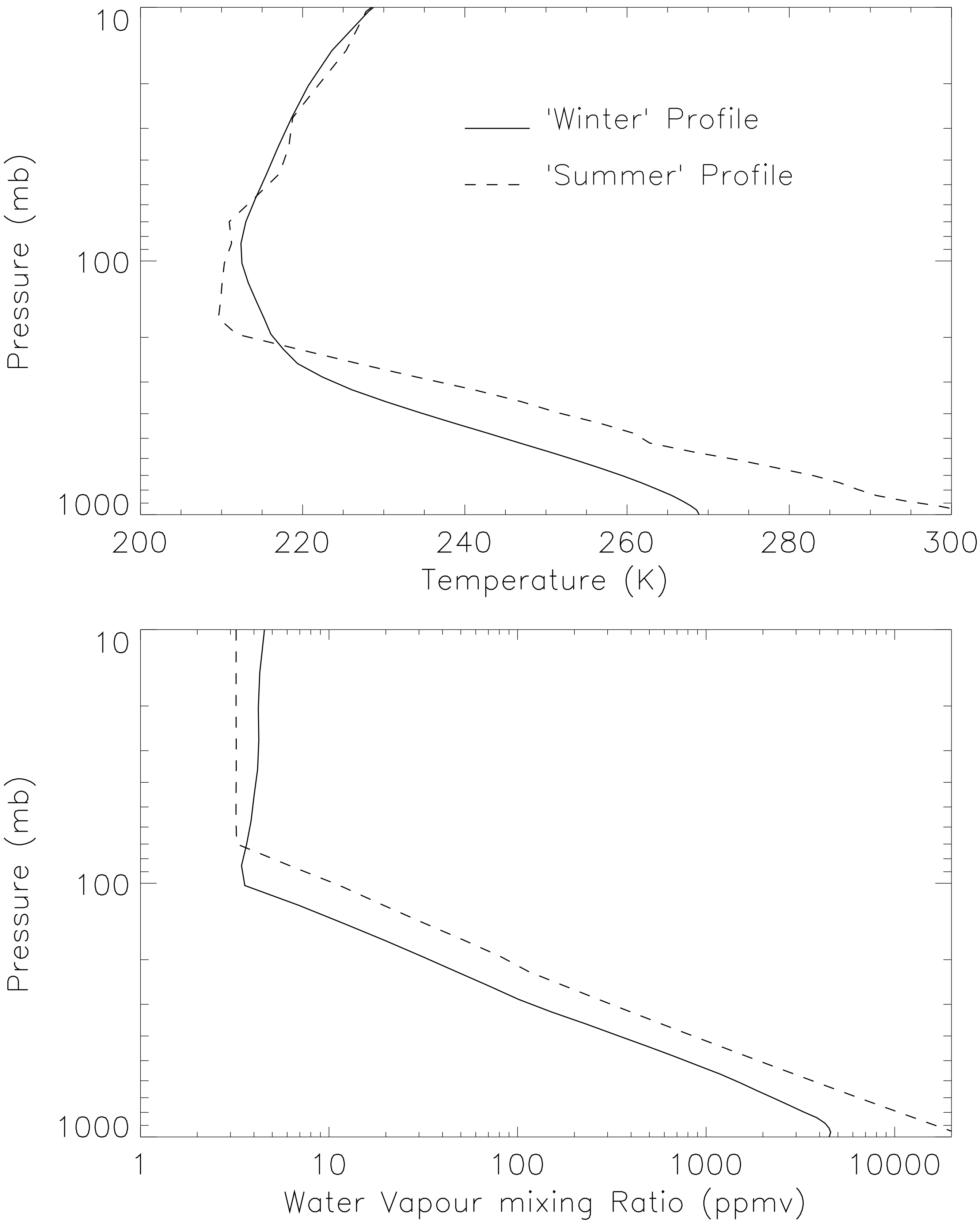

Fig. 1. The "summer" and "winter" atmospheric profiles used in these investigations. Both come from the TIGR dataset.

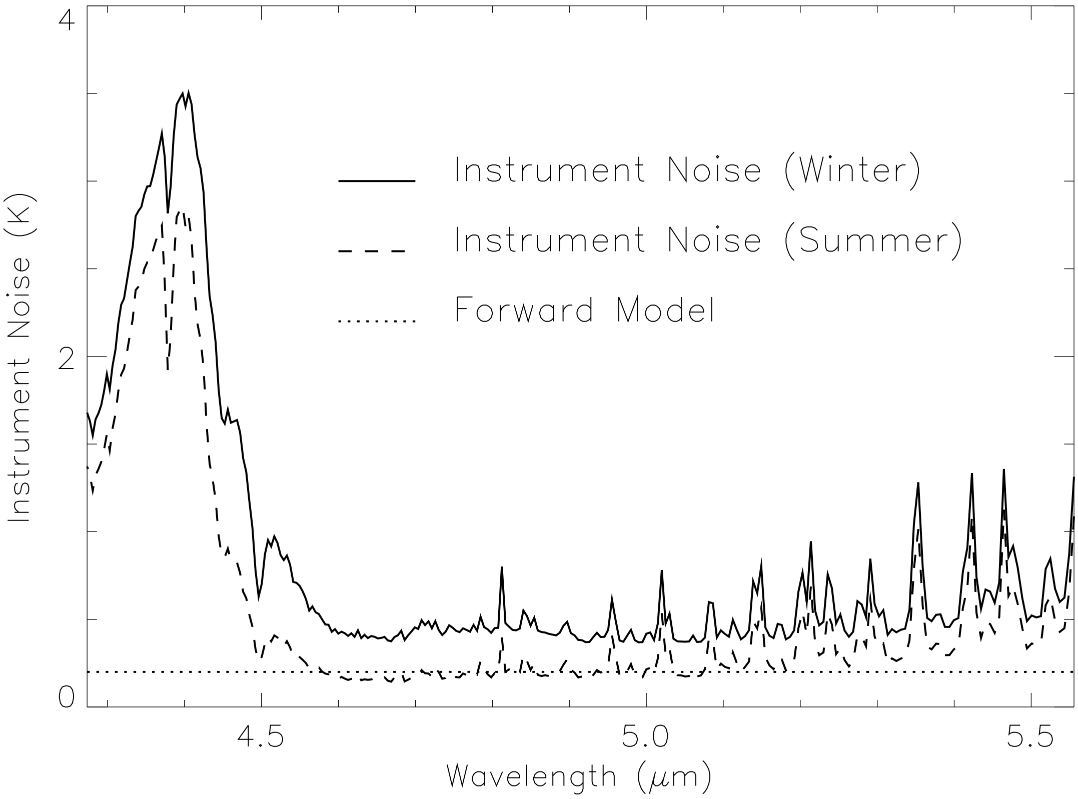

Fig. 3. The true AGIRS instrument noise (based on 0.25K at a 280K scene temperature) for the "winter" and "summer" scenarios and the assumed forward model noise used in this investigation. Note the very large noise values in the 4.4μm region.

For humidity retrievals, AGIRS consistently performs around midway between HIRS and IASI at all tropospheric altitudes.

As expected, AGIRS retrievals are better in the summer rather than winter case due to the increased scene brightness temperature.

In all cases removing the AGIRS channels between 4.71μm and 5.0μm is seen to be negligible.

These results are summarised in terms of degrees of freedom for signal and information content in Table 1 which shows that AGIRS's performance is generally a modest improvement on that of HIRS but is well short of IASI's.

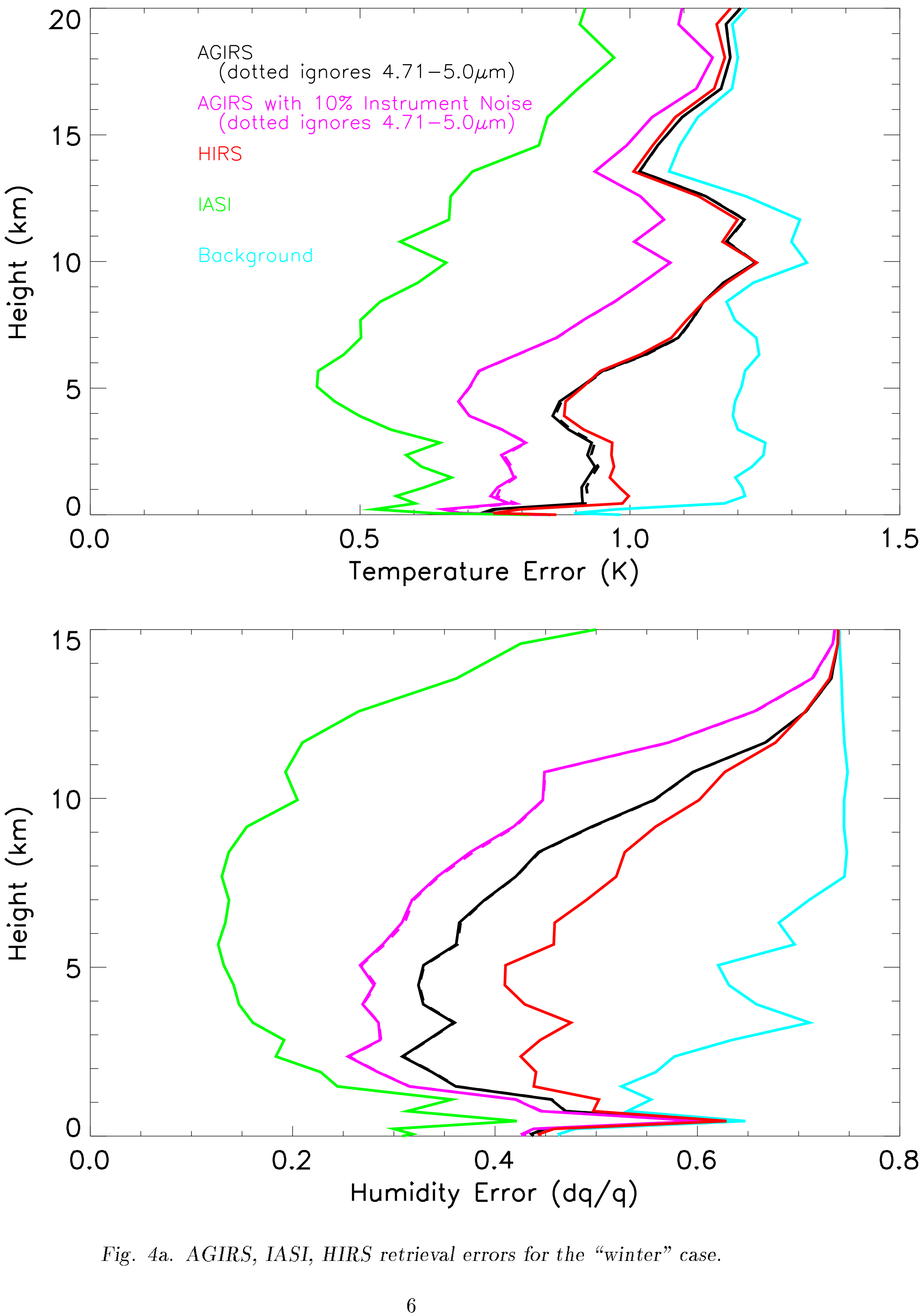

Fig. 4a. AGIRS, IASI, HIRS retrieval errors for the "winter" case.

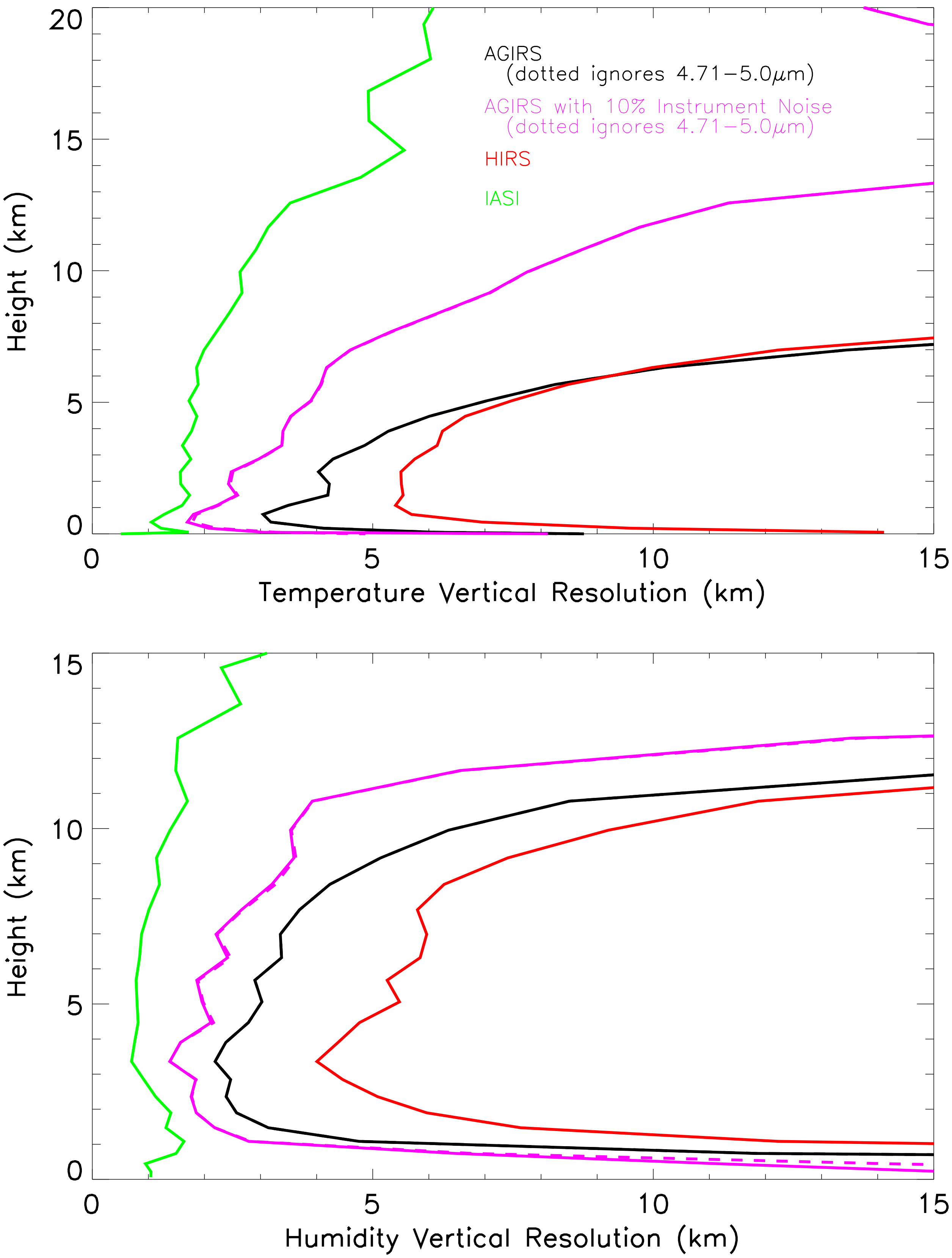

Fig. 4b. AGIRS, IASI, HIRS retrieval vertical resolution for the "winter"case.

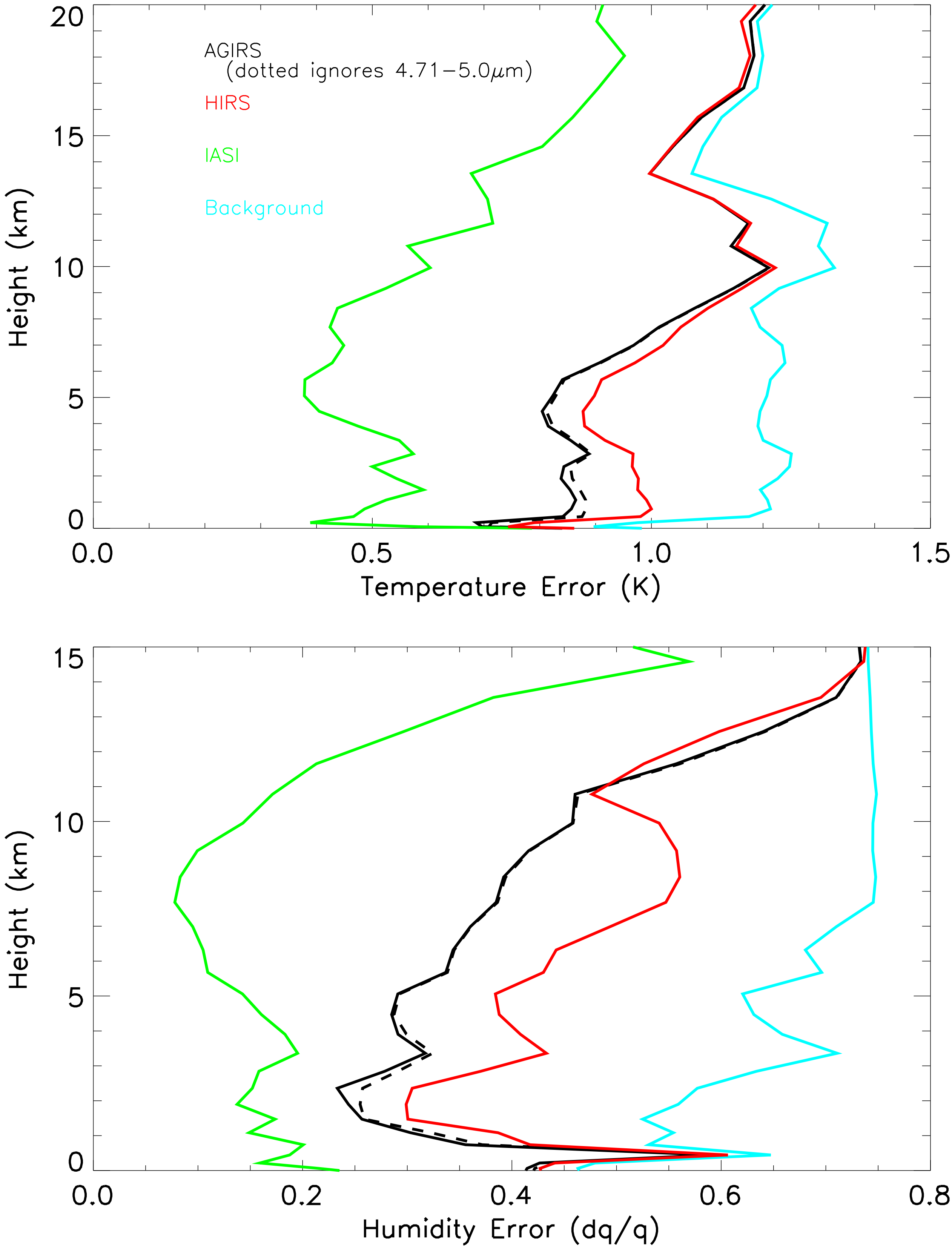

Fig. 5a. AGIRS, IASI, HIRS retrieval errors for the "summer" case.

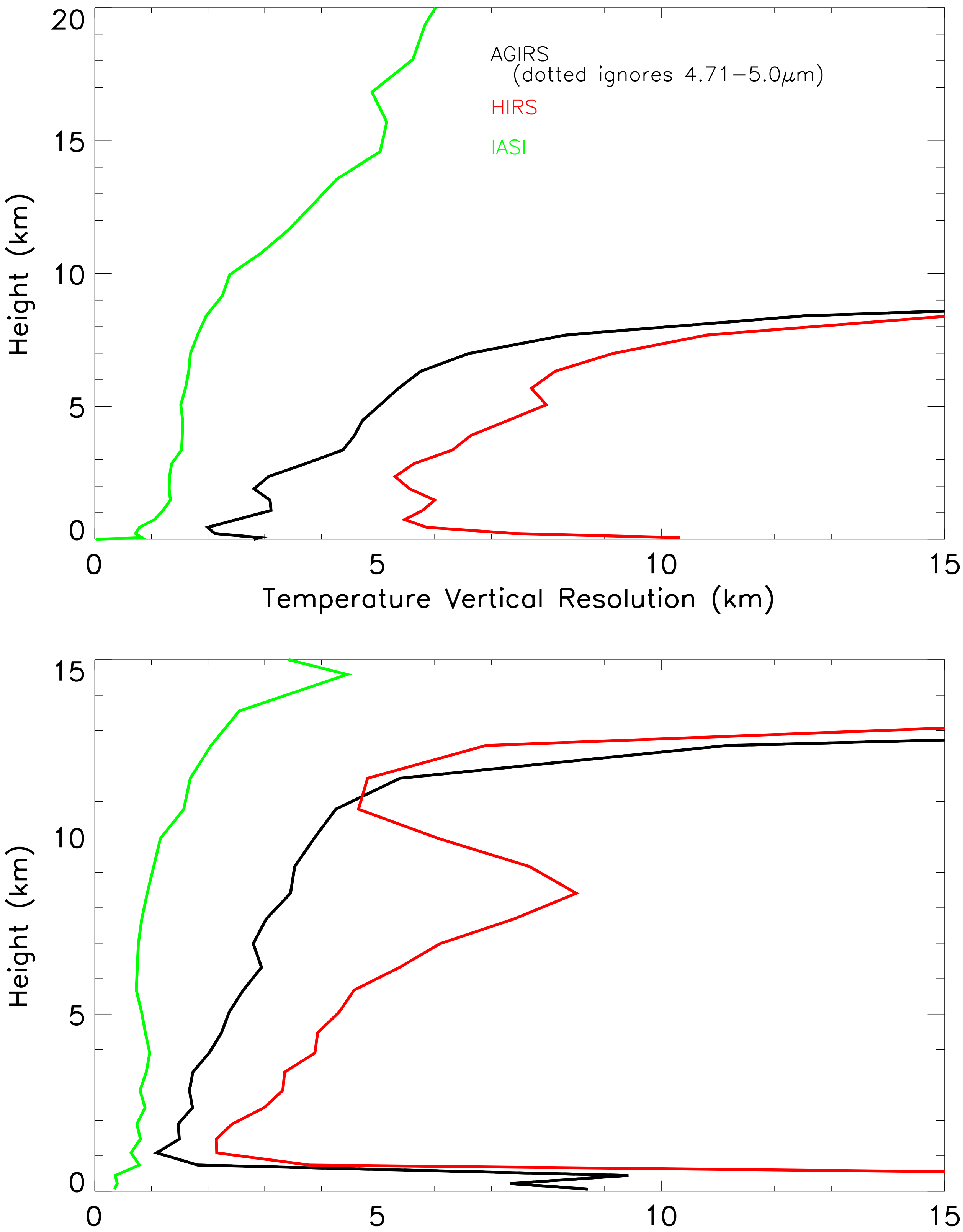

Fig. 5b. AGIRS, IASI, HIRS retrieval vertical resolution for the "summer"case.

Scenario	Winter Case		Summer Case	
	DFS	Inf. Cont.	DFS	Inf. Cont.
AGIRS	6.567	12.911	9.031	19.776
AGIRS (With Gap)	6.567	12.471	9.031	18.884
AGIRS (10% Noise)	11.253	24.584	13.587	30.240
AGIRS (10% Noise & Gap)	11.160	24.096	12.958	29.147
IASI	26.134	53.764	30.211	67.064
HIRS	4.705	6.766	5.808	9.511

Table 6.3.
Degrees of Freedom for Signal and Information
Content for retrievals using HIRS, AGIRS and IASI.

4. Conclusion.

The above preliminary studies show that retrievals using the proposed AGIRS instrument will in general be somewhat better than those using the current HIRS instrument. However, most of the improvement will come through better measurement of tropospheric humidity with little increase in temperature sounding ability unless the instrument noise is reduced substantially. AGIRS's performance will be significantly inferior (3–4 times in terms of degrees of freedom for signal) than IASI's, however.

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