Assessment of Adequate Quality and Co–location of Sondes with Space Borne Hyperspectral Infrared Instruments to Validate Retrievals of Temperature and Water Vapor

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Abstract

A method is presented to assess whether a given reference ground based point observation, typically a radiosonde measurement, is adequately co–located with and sufficiently representative of hyperspectral infrared instrument measurements. Once this assessment is made, the ground based data can be used to validate and calibrate, with a high degree of accuracy and precision, the hyperspectral retrievals of temperature and water vapor.

Problem

Space-borne infrared hyperspectral instruments typically measure Earth views in a spectral range from 600 to 3000cm^{-1} wavenumbers with a spectral sampling of about 0.25cm^{-1}. From these measurements it is possible to retrieve atmospheric profiles of temperature and water vapor with a high degree of accuracy. These, so called, retrievals can have a temperature accuracy of about 1 K in layers 1 km thick and humidity accuracy from 10 to 20% in layers 2 km thick within the troposphere.

It is not simple to validate these retrievals against independent reference measurements, like for example sondes. The comparison of retrievals and reference measurements is not only important for validation, but also for the calibration of the retrievals themselves since there are usually many unknowns in the complex retrieval methodology that need to be fine tuned. In these comparison exercises, it is sometimes the case that the temperature and humidity retrievals do match up very well with the sondes, but in other cases they do not agree significantly. It is therefore critical that any validation and calibration performed comparing the retrievals with independent measurements are indeed done using adequate reference measurements. A method to assess the adequacy of an individual reference measurement to a particular retrieval methodology is presented.

Data

Infrared hyperspectral data is obtained from the IASI instrument on board the polar orbiting satellite Metop-A. IASI is measuring within the whole spectral range from 645 to 2760cm^{-1} with a spectral sampling of 0.25cm^{-1} with a spatial resolution of about 12 km at nadir. One single IASI field of view is analyzed in this study over the Sodankylä observatory, northern Finland (location: 67.368N, 26.633E, 179 m a.s.l.) on July, 17th, 2007 at 08:18Z.This particular field of view is selected because it is cloud free, making the radiative transfer model calculations simpler, and it has a significant set of accompanying ground based measurements from the EPS/Metop Sodankylä campaign.

Radiosonde data are from the EPS/Metop Sodankylä campaign, which took place during the time period 4th June to 5th September 2007 (for more details see [1]). Also, ECMWF analyses have been used either on its own or to complement the radiosonde data. The particular reference temperature and water vapor profiles, which are plotted in Fig. 1, are obtained from:

- Nearest geo–located ECMWF analysis at 06Z, which is about 2:30 hours before satellite overpass time. This profile will be referred to as "ECMWF".

- Interpolated sonde data from a Cryogenic Frost point Hygrometer sonde (CFH) launched one hour before satellite overpass time and an "in situ" bias corrected RS92 sonde launched five minutes before satellite overpass time. See [1] for more details. This profile will be referred to as "Interpolated".

- RS92 sonde launched five minutes before overpass time with the humidity bias corrected using Vömel et al. [6]. This data will be referred to as "PTU -5 min Vomel".

- RS92 sonde launched five minutes before overpass time without any kind of bias corrections. This data will be referred to as "PTU -5 min".
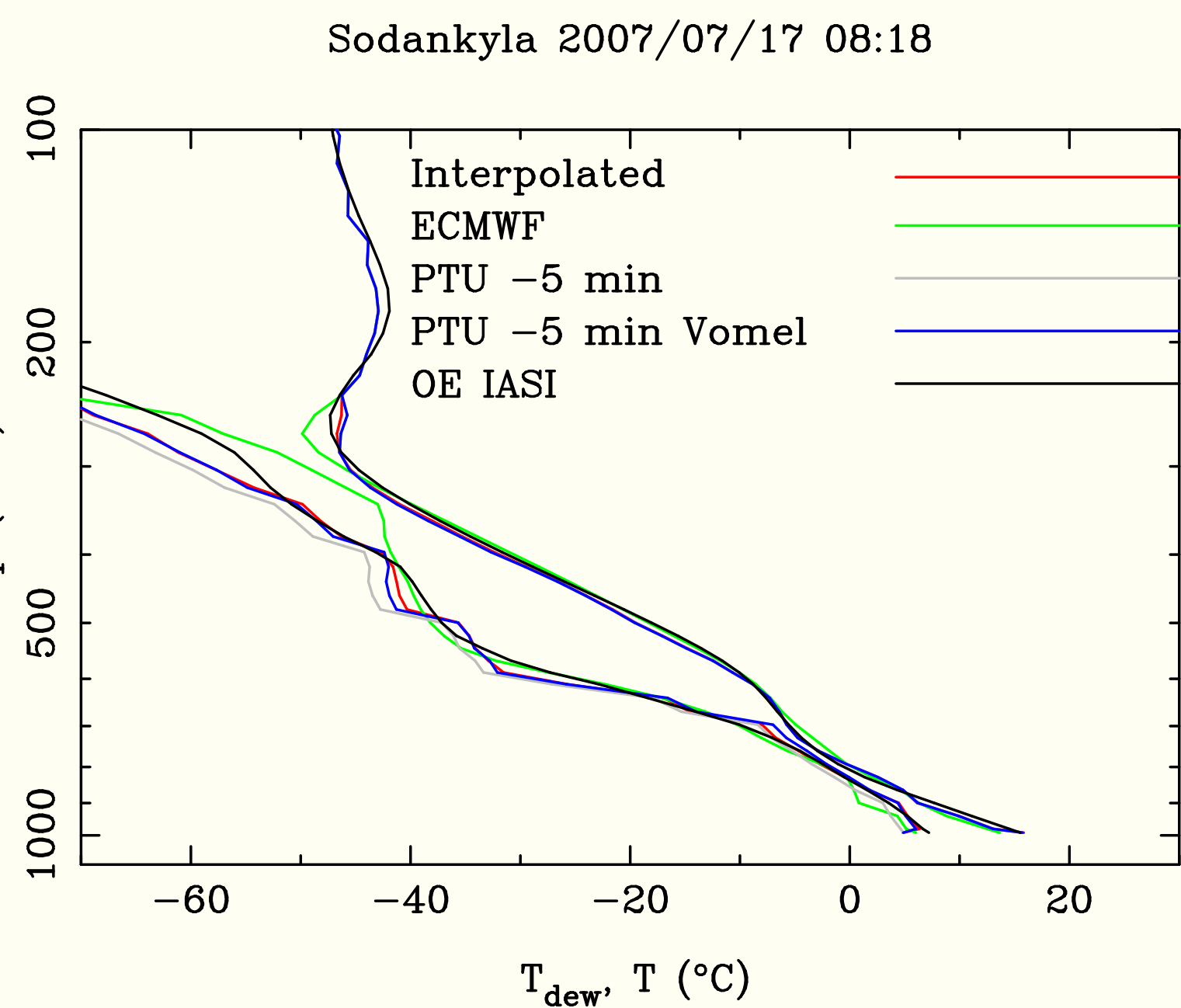

Fig. 1. Temperature and dew point temperature of the different profiles used in this poster.

References

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[4] Moncet, J. and G. Uymin and A.E. Lipton and H.E. Snell: Infrared radiance modeling by optimal spectral sampling, J. Atmos. Sci., 65, 3917 – 3934, (2008).

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[6] Vömel, H., H. Selkirk, L. Miloshevich, J. Valverde-Canossa, J. Valdés, E. Kyrö, R. Kivi, W. Stolz, G. Peng, and J.A. Diaz, (2007b) Radiation Dry Bias of the Vaisala RS92 Humidity Sensor, J. Atmos. Oceanic Technol., 24, 953–963, 2007b.

IASI Retrievals

IASI retrievals have been calculated using:

- Optimal Estimation (OE) [5] with physical constraints (prohibit supersaturation and superadiabaticity).

- Use all IASI channels from band 1 and 2 excluding the ozone band.

- Background state and matrix obtained from the Chevallier dataset [2].

- OE has been fine tuned with co–located ECMWF analyses, both with respect to bias corrections and measurement error covariance matrix. Due to the significant inaccuracy of ECMWF water vapor analyses (also shown in this poster, see Fig. 1), the resulting measurement error covariance matrix used in OE is clearly overestimated in the water vapor band. This leads to a big expected error in the water vapor retrievals (Fig. 5).

- First guess fed into the OE is the "Interpolated" profile.

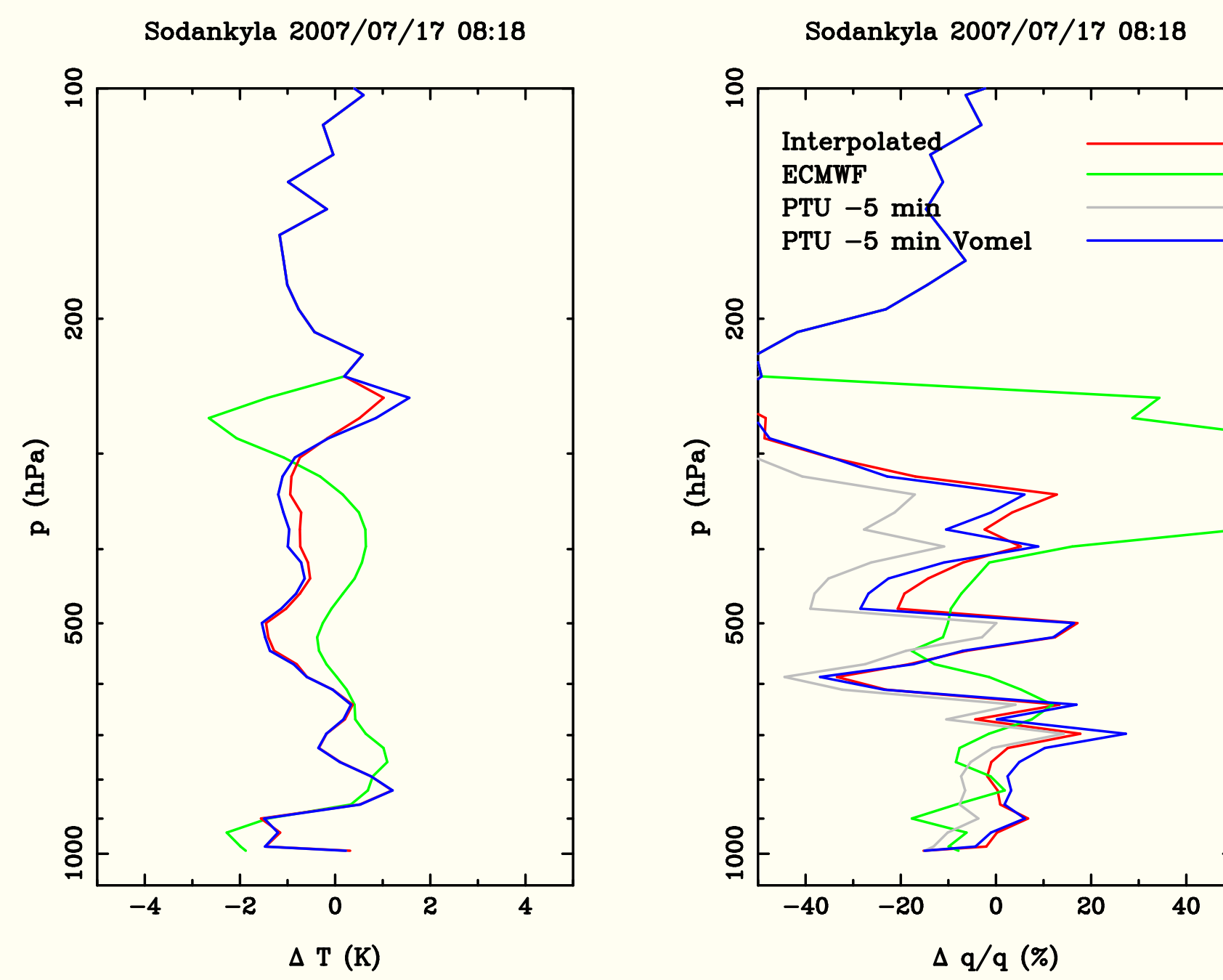- Radiative transfer model is OSS [4] trained with LBLRTM 11.3.

Fig. 2. Difference of the reference profiles minus the OE retrieval.

Observed minus Calculated Radiances

To get a sense of how well the reference atmospheric profiles are representative of the atmosphere at the IASI field of view, the IASI measured radiances can be compared to the calculated ones using a radiative transfer model. The calculated radiances are obtained using:

- In the profiles obtained from radiosonde measurements ("Interpolated", "PTU -5 min" and "PTU -5 min Vomel"), these are used up to an atmospheric level where they do measure appropriately. Above this level, the "ECMWF" profile is used. See [1] for more details.

- The OSS radiative transfer model, trained with LBLRTM 11.3, is used [4].

- Surface emissivity is the one corresponding to old pine leaf from the MODIS UCSB emissivity library [3].

- Surface skin temperature has been retrieved from the spectra to give the closest calculated radiances to the observed ones.
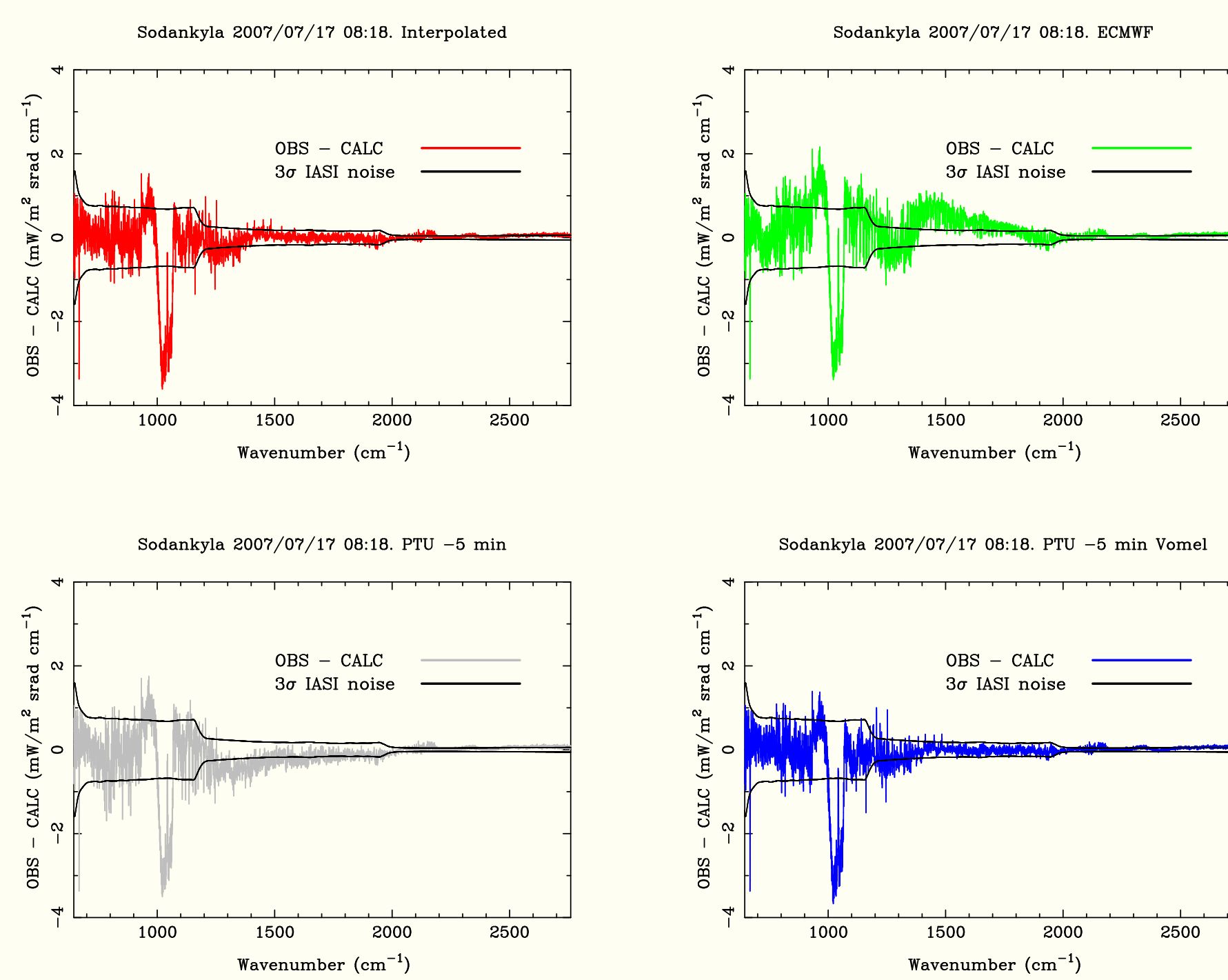

Fig. 3. IASI observed minus calculated radiances (OBS-CALC) for the "Interpolated" (upper left), "ECMWF" (upper right), "PTU -5 min" (lower left) and "PTU -5 min Vomel" (lower right) profiles.

Standard Deviation of OBS-CALC

To proceed further, an estimation of the standard deviation of the observed minus calculated radiances differences obtained using just one set of measurements for one particular IASI field of view is needed. To accomplish this, the square root of the moving average over a spectrum of the square of the observed minus calculated radiances is obtained. The length of the window of the moving average is 500 channels.
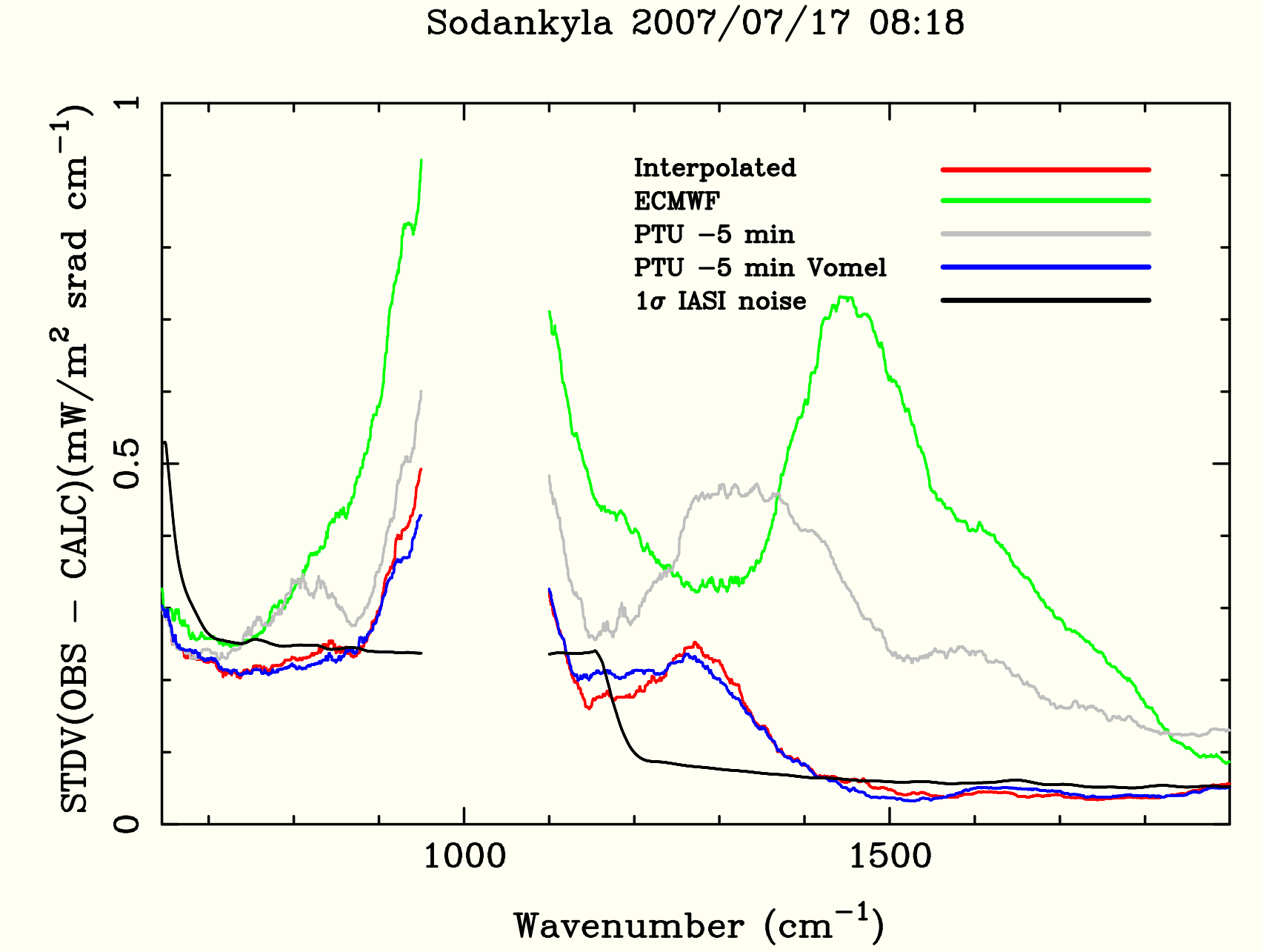
Standard Deviation of OBS-CALC (cont.)

Fig. 4. Estimation of the standard deviation of the observed minus calculated radiance differences for each reference atmospheric profile. Note the very low standard deviation, below 1σ IASI instrument noise, for some regions of the spectrum for the "Interpolated" and "PTU -5 min Vomel" profiles, as already acknowledged in [1]. Note also that there is only one parameter retrieved when obtaining the calculated radiances, which is the surface skin temperature.

Atmospheric Profile Errors

In order for the estimation of the standard deviation of the radiances difference (Fig. 4) to be meaningful, they need to be translated from radiance space into atmospheric profile space. To do that, the OE theory [5] needs to be recalled by expressing the cost function, J, as

$$J = (y - F(x))^{\mathrm{T}} S_\epsilon^{-1}(y - F(x)) + (x - x_a)^{\mathrm{T}} S_a^{-1}(x - x_a), \quad (1)$$

where y is the hyperspectral measurements, F is the radiative transfer model, S_ϵ is the measurement error covariance matrix, x is the atmospheric profile state, x_a is the background state and S_a is the background covariance matrix. This cost function is usually linearized around an atmospheric state close to the final solution, x_x,

$$J \approx (\delta y - K\delta x)^{\mathrm{T}} S_\epsilon^{-1}(\delta y - K\delta x) + (\delta x - \delta x_a)^{\mathrm{T}} S_a^{-1}(\delta x - \delta x_a), \quad (2)$$

where K is the Jacobian of F at the linearizion point x_x, $\delta x = x - x_x$ and $\delta y = y - F(x_x)$. To find the most likely atmospheric state, x_O, corresponding to a IASI observation, y_O, the derivative of J with respect to δx is set to zero, giving as a final retrieval solution

$$\delta x_O = (K^{\mathrm{T}} S_\epsilon^{-1} K + S_a^{-1})^{-1} K^{\mathrm{T}} S_\epsilon^{-1} \delta y_O. \quad (3)$$

It is known that the error or covariance of this retrieval solution [5] is

$$S_x = (K^{\mathrm{T}} S_\epsilon^{-1} K + S_a^{-1})^{-1}, \quad (4)$$

which is a quantity that will be needed later. A similar technique can be applied to obtain the most likely state vector, x_C, corresponding to the calculated radiances, y_C, obtained from applying a radiative transfer model to any of the reference atmospheric profiles,

$$\delta x_C = (K^{\mathrm{T}} S_\epsilon^{-1} K + S_a^{-1})^{-1} K^{\mathrm{T}} S_\epsilon^{-1} \delta y_C. \quad (5)$$

The difference between the two state vectors, $\Delta x = x_O - x_C$, gives a quantity that measures the error in the state vector when using the calculated radiances, y_C, instead of the observed ones, y_O. In other words, Δx provides a measure of the reference state co–location error plus any errors we might have done in the radiative transfer model assumptions. This will be referred to as co–location and adequacy errors of the reference profiles. Solving for Δx gives

$$\Delta x = (K^{\mathrm{T}} S_\epsilon^{-1} K + S_a^{-1})^{-1} (K^{\mathrm{T}} S_\epsilon^{-1} \Delta y), \quad (6)$$
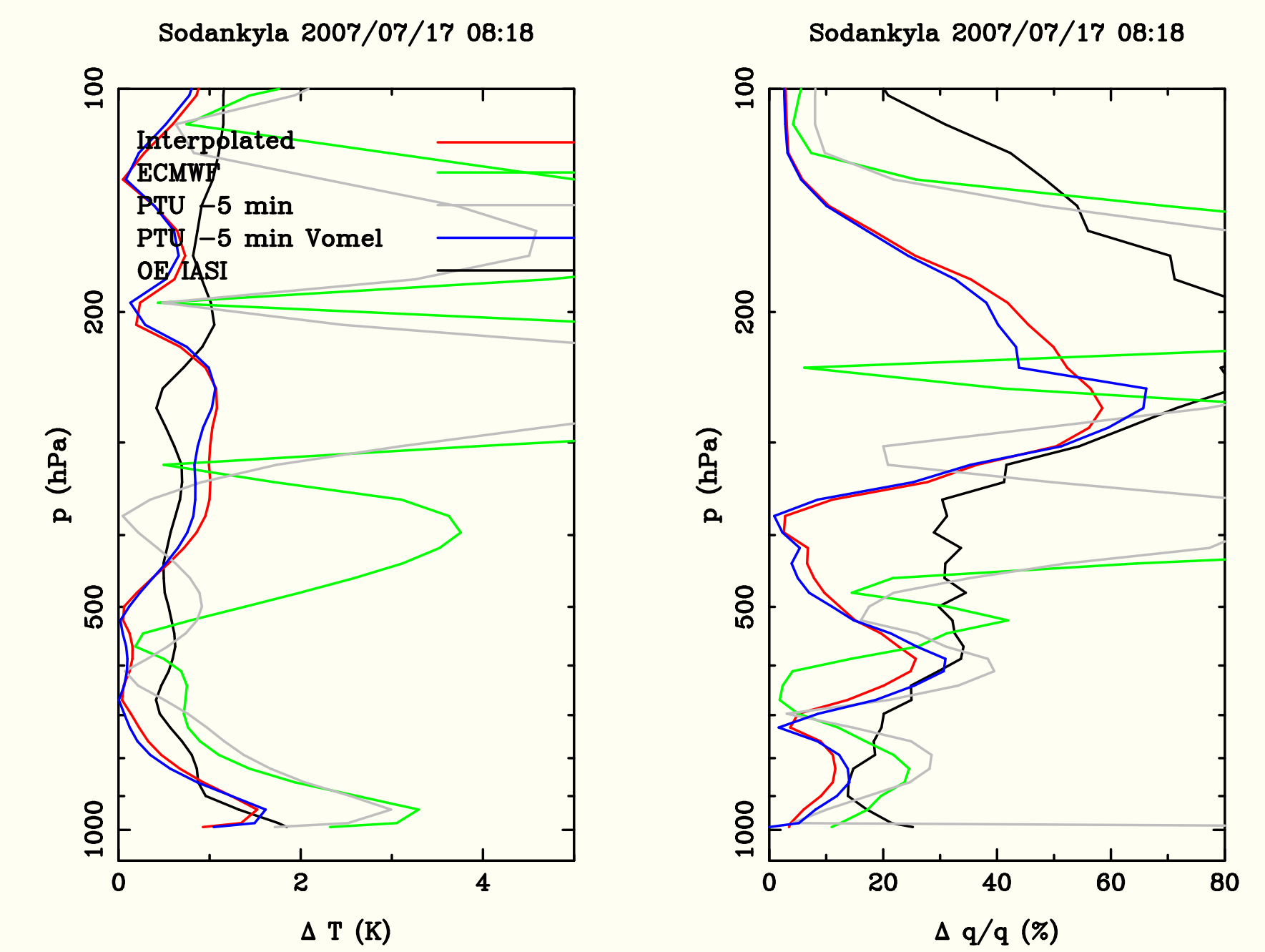
where $\Delta y = y_O - y_C$.

Fig. 5. Retrieval error (diagonal of Eq. 4 in black) and co–location and adequacy errors (Δx from Eq. 6) for the different reference profiles.

Discussion

The reference measurements will be useful if the co–location and adequacy errors in the atmospheric profiles, Δx from Eq. 6, is below or of the order of the retrieval error, S_x from Eq. 4. Fig. 5 shows that, with these particular observations, this is the case for the "Interpolated" (an interpolation of CFH launched 1 hour before satellite overpass time and "in situ" humidity bias corrected RS92 sonde launched 5 minutes before satellite overpass time) and "PTU -5 min Vomel" (Vömel [6] humidity bias corrected RS92 sonde launched 5 minutes before satellite overpass time). Clearly, in this case, the "ECMWF" (ECMWF analysis) and the "PTU -5 min" (uncorrected RS92 sonde launched 5 minutes before overpass time) do not qualify as proper reference calibration or validation profiles.