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Synergistic retrieval and complete data fusion methods applied to simulated FORUM and IASI-NG measurements

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Abstract. This document includes the results of two simulation experiments that should be regarded as *complementary* to the results presented in the paper of Ridolfi et al. 2022, the reader should, therefore, refer to that paper to find a detailed description of the experiments themselves. The aim is to assess the differences between the synergistic retrieval (SR) and the complete data fusion (CDF) techniques when used to exploit the synergy between the measurements of the planned FORUM (Far Infrared Outgoing Radiation Understanding and Monitoring) and IASI-NG (Infrared Atmospheric Sounding Interferometer-New Generation) satellite missions. The main simulation experiment reported in Ridolfi et al. 2022 is carried out at Antarctic latitudes, where the atmosphere is sufficiently dry, allowing to measure surface emissivity also in the Far-InfraRed (FIR) spectral region that, starting from 2027, for the first time will be systematically measured from space by FORUM. At lower latitudes, due to water vapour absorption, the FIR region becomes more and more opaque, making it hard or impossible to measure surface emissivity from space. As soon as the atmospheric transparency decreases, the sensitivity of the measurements to surface spectral emissivity decreases and the retrieval error increases, thus undermining the usefulness of the retrieval itself. Since, to date, a global sensitivity study is still missing, we do not know whether it will be useful trying to retrieve surface spectral emissivity from FORUM measurements at latitudes different from the polar ones. Despite of that, it is still interesting to assess the relative behaviour of the SR and the CDF techniques also in critical atmospheric scenarios where the sensitivity of the measurements to surface spectral emissivity is quite poor. In the following two Sections, we illustrate the results of two simulation experiments, carried out at middle- and tropical latitudes.

S1 Mid–latitude experiment

In this experiment, the reference atmosphere $\mathbf{x}_0$ (Ridolfi et al., 2022) is built starting from the Diverse Profile Dataset (DPD) scenario no. 27, available from the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) NWP Satellite Application Facilities (for data and related documentation, see: `www.nwpsaf.eu/site/software/atmospheric-profile-data/`). This is a clear-sky atmospheric scenario corresponding to mid- latitude spring conditions over land (45.309°N, -103.125°E, 975 m a.m.s.l., 1 April 2007). The true surface spectral emissivity is assumed from the Huang et al. 2016 models as follows:

a) Case of perfectly matching FORUM and IASI-NG measurements: grass model for both measurements.

b) Case of a mismatch between the measurements: grass model for FORUM, deciduous model for IASI-NG.

The covariance matrices $\mathbf{S}_\mathrm{S}$ and $\mathbf{S}_\mathrm{M}$ representing, respectively, the seasonal and the mismatch profiles variability, used to build the true atmospheres sounded by the two instruments, are obtained from profiles extracted from the ERA5 dataset (see Ridolfi et al. 2022). The statistics obtained from 900 test runs based on the mid-latitude scenario described above are presented in Fig.s from S1 to S5. Specifically, Fig.s S1, S2 and S3 are analogous to Fig.s 2, 3 and 4 of Ridolfi et al. 2022 and refer to the case of exactly matching measurements, while Fig.s S4 and S5 are analogous to Fig.s 5 and 6 of Ridolfi et al. 2022 and refer to the case of not perfectly matching measurements.

S2 Tropical latitudes experiment

In this experiment, the reference atmosphere $\mathbf{x}_0$ is built from the DPD scenario no. 42. This is a clear-sky atmospheric scenario corresponding to tropical summer conditions over sea (4.61°N, 52.65°E, 1 July 2006). The true surface spectral emissivity is assumed from the Huang et al. 2016 models as follows:

- Case of perfectly matching FORUM and IASI-NG measurements: sea model for both measurements.
- Case of a mismatch between the measurements: sea model for FORUM, grass model for IASI-NG.

The covariance matrices $\mathbf{S}_\mathrm{S}$ and $\mathbf{S}_\mathrm{M}$ representing, respectively, the seasonal and the mismatch profiles variability, used to build the true atmospheres sounded by the two instruments, are obtained from profiles extracted from the ERA5 dataset (see Ridolfi et al. 2022). The statistics obtained from 900 test runs based on the tropical scenario described above are presented in Fig.s

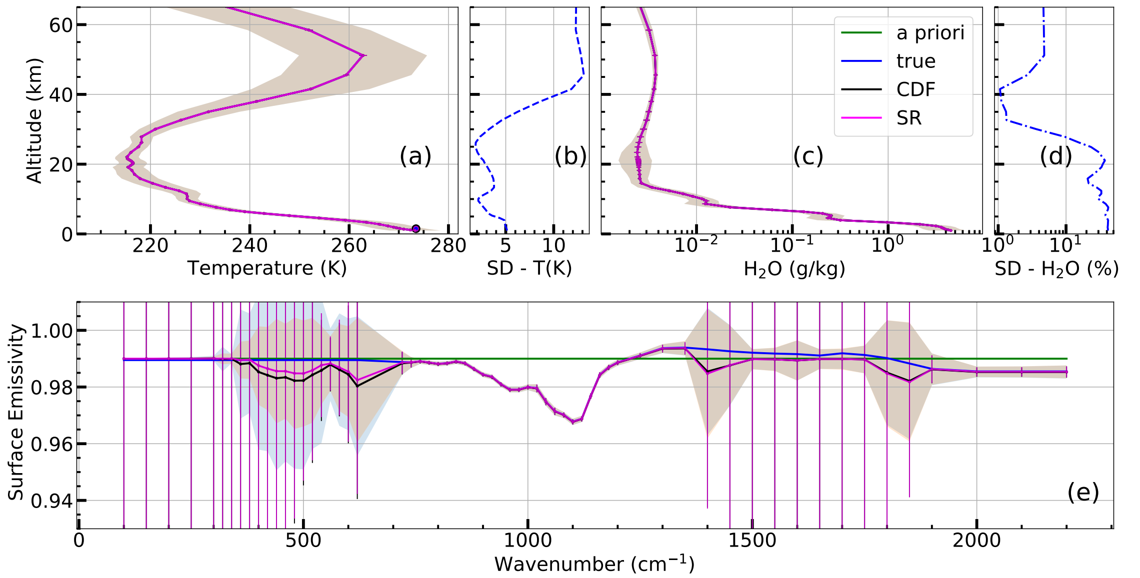

Figure S1. Case of perfectly matching measurements at mid-latitudes. Average on the 900 trials, of a priori (green), true (blue), CDF (black) and SR (magenta) profiles. Panel (a) refers to the temperature profile and to surface temperature (bottom symbol in the plot). Panels (c) and (e) refer to the H_2O VMR and to the surface spectral emissivity profiles, respectively. Error bars represent the average profile errors as evaluated from the error propagation covariance matrices (CMs). Shadowed areas represent the SR and CDF profiles standard deviation. The standard deviations of the true profiles of temperature and of the H_2O VMR profiles are plotted in panels (b) and (d), respectively.

from S6 to S10. Specifically, Fig.s S6, S7 and S8 are analogous to Fig.s 2, 3 and 4 of Ridolfi et al. 2022 and refer to the case of perfectly matching measurements, while Fig.s S9 and S10 are analogous to Fig.s 5 and 6 of Ridolfi et al. 2022 and refer to the case of not perfectly matching measurements.

S3 Discussion and conclusion

The test retrieval experiments based at middle- and tropical latitudes presented in this document confirm the conclusions of Ridolfi et al. 2022, regarding the agreement between SR and CDF. Specifically:

- In case of perfect matching of the measurements, the SR and CDF approaches provide results that differ by much less than the error due to measurement noise, both on average and also when processing individual pairs of measurements.
- In the presence of a realistic mismatch between the measurements, the differences between SR and CDF solutions of the individual processed pairs of measurements may approach the value of the error due to measurement noise, specifically in the cases of surface emissivity and of the H_2O profile below 10 km. Average differences are still much smaller than the error due to measurement noise.

As expected, at middle- and tropical latitudes, the atmosphere is significantly more humid and opaque as compared to the Antarctic case explored in Ridolfi et al. 2022. This implies significantly larger errors in the retrieved surface spectral emissivity, especially in the FIR region.

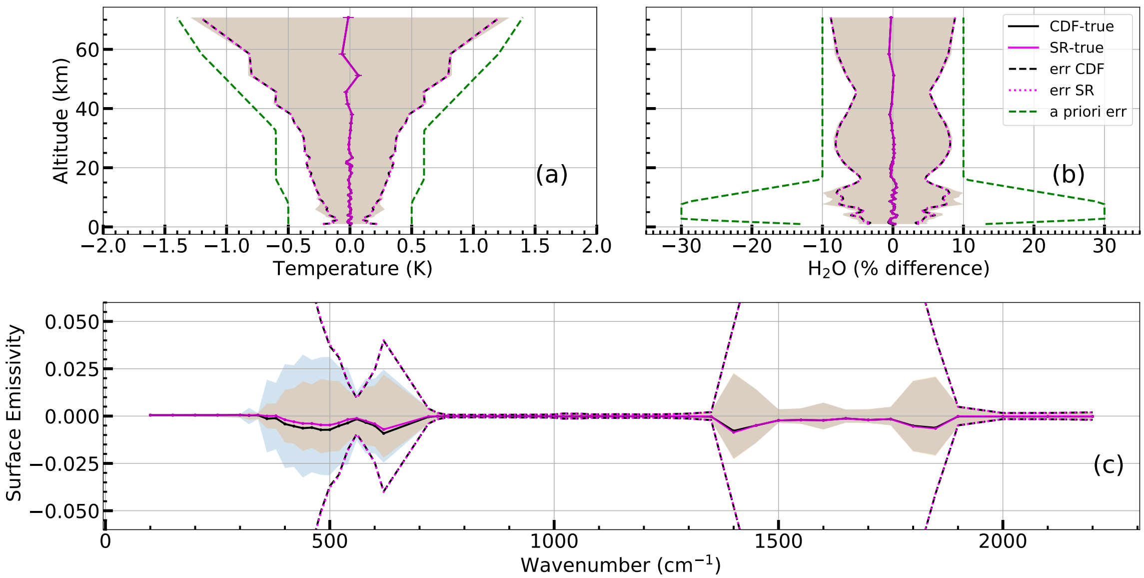

Figure S2. Case of perfectly matching measurements at mid-latitudes. Average differences between CDF and true profiles (black), and between SR and true (magenta) profiles. Dashed lines represent the average a priori error (green) and the errors of CDF (black) and of SR (magenta) as evaluated from the error CMs. Shadowed areas represent the standard deviations of the differences, error bars are the standard errors of the average differences. Panel (a) refers to the temperature profile. Panels (b) and (c) refer to the H_2O VMR and surface spectral emissivity profiles, respectively.

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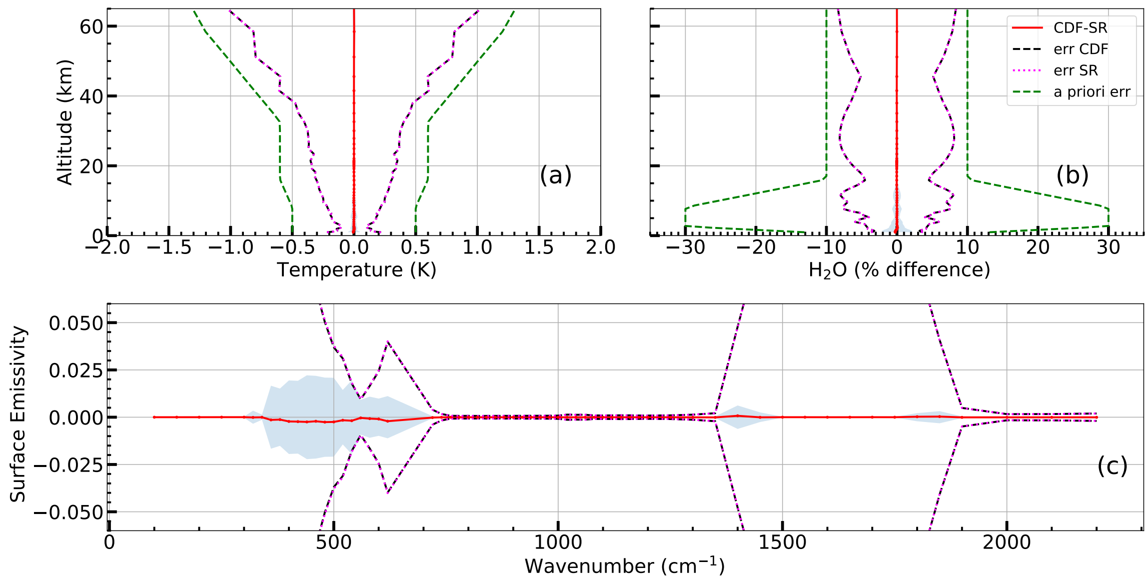

Figure S3. Case of perfectly matching measurements at mid-latitudes. Average differences between CDF and SR profiles (red). Dashed lines represent the average a priori error (green) and the errors of CDF (black) and of SR (magenta) as evaluated from the error CMs. Shadowed areas represent the standard deviations of the CDF minus SR differences. Panel (a) refers to the temperature profile. Panels (b) and (c) refer to the H_2O VMR and surface spectral emissivity profiles, respectively.

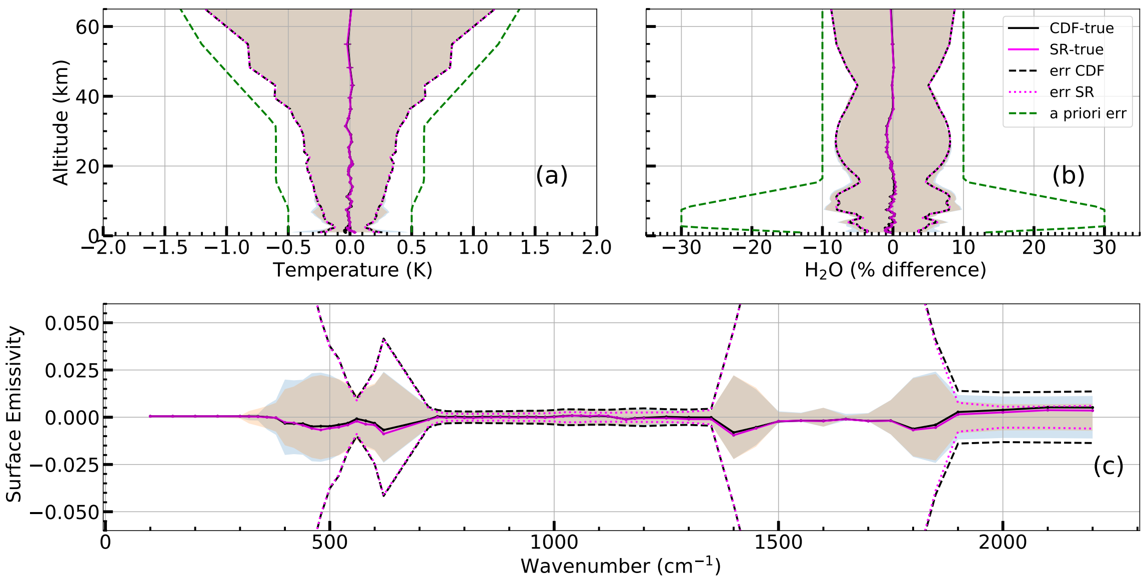

Figure S4. Case of not perfectly matching measurements at mid-latitudes. Average differences between CDF and true profiles (black), and between SR and true profiles (magenta). Dashed lines represent the average a priori error (green) and the errors of CDF (black) and of SR (magenta) as evaluated from the error CMs. Shadowed areas represent the standard deviations of the differences, error bars are the standard errors of the average differences. Panel (a) refers to the temperature profile. Panels (b) and (c) refer to the H_2O VMR and surface spectral emissivity profiles, respectively.

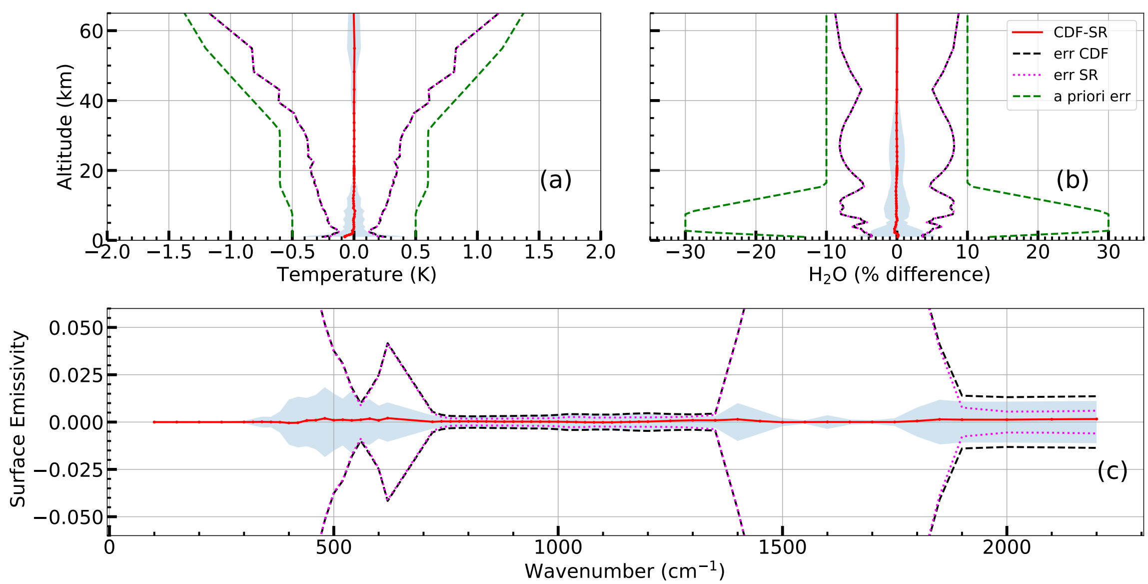

Figure S5. Case of not perfectly matching measurements at mid-latitudes. Average differences between CDF and SR profiles (solid red lines). Dashed lines represent the average a priori error (green) and the errors of CDF (black) and of SR (magenta) as evaluated from the error CMs. Shadowed areas represent the standard deviations of the CDF minus SR differences. Panel (a) refers to the temperature profile. Panels (b) and (c) refer to the H_2O VMR and surface spectral emissivity profiles, respectively.

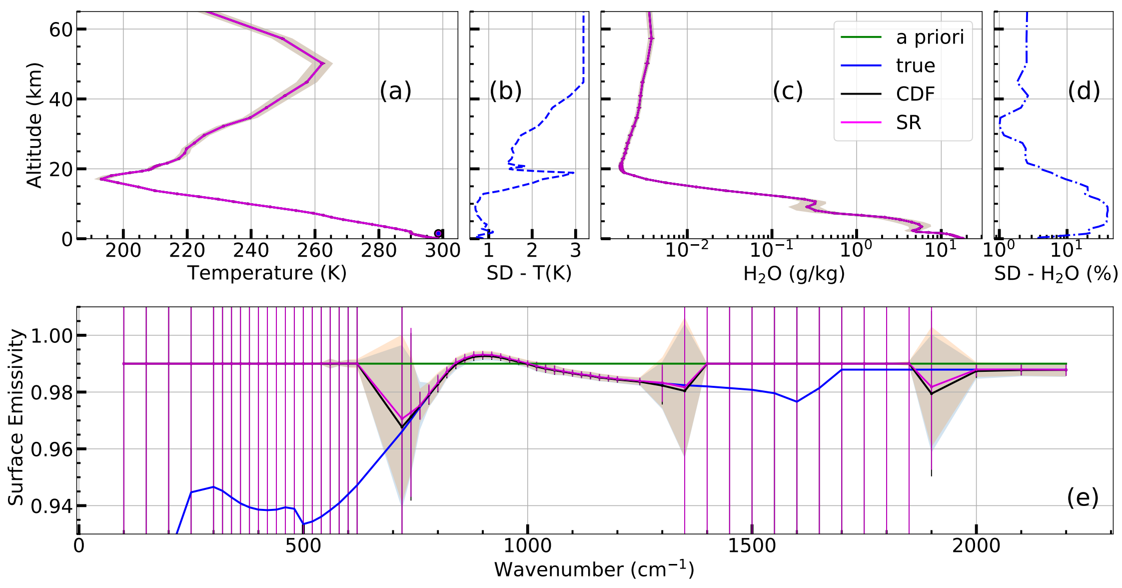

Figure S6. Case of perfectly matching measurements at tropical latitudes. Average on the 900 trials, of a priori (green), true (blue), CDF (black) and SR (magenta) profiles. Panel (a) refers to the temperature profile and to surface temperature (bottom symbol in the plot). Panels (c) and (e) refer to the H_2O VMR and to the surface spectral emissivity profiles, respectively. Error bars represent the average profile errors as evaluated from the error CMs. Shadowed areas represent the SR and CDF profiles standard deviation. The standard deviations of the true profiles of temperature and of the H_2O VMR profiles are plotted in panels (b) and (d), respectively.

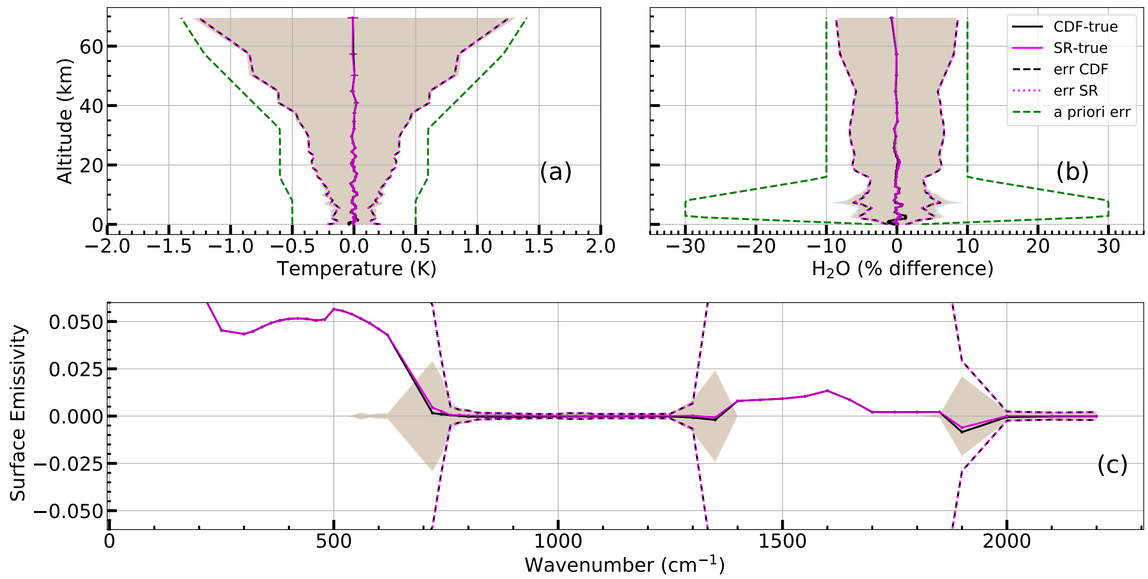

Figure S7. Case of perfectly matching measurements at tropical latitudes. Average differences between CDF and true profiles (black), and between SR and true (magenta) profiles. Dashed lines represent the average a priori error (green) and the errors of CDF (black) and of SR (magenta) as evaluated from the error CMs. Shadowed areas represent the standard deviations of the differences, error bars are the standard errors of the average differences. Panel (a) refers to the temperature profile. Panels (b) and (c) refer to the H_2O VMR and surface spectral emissivity profiles, respectively.

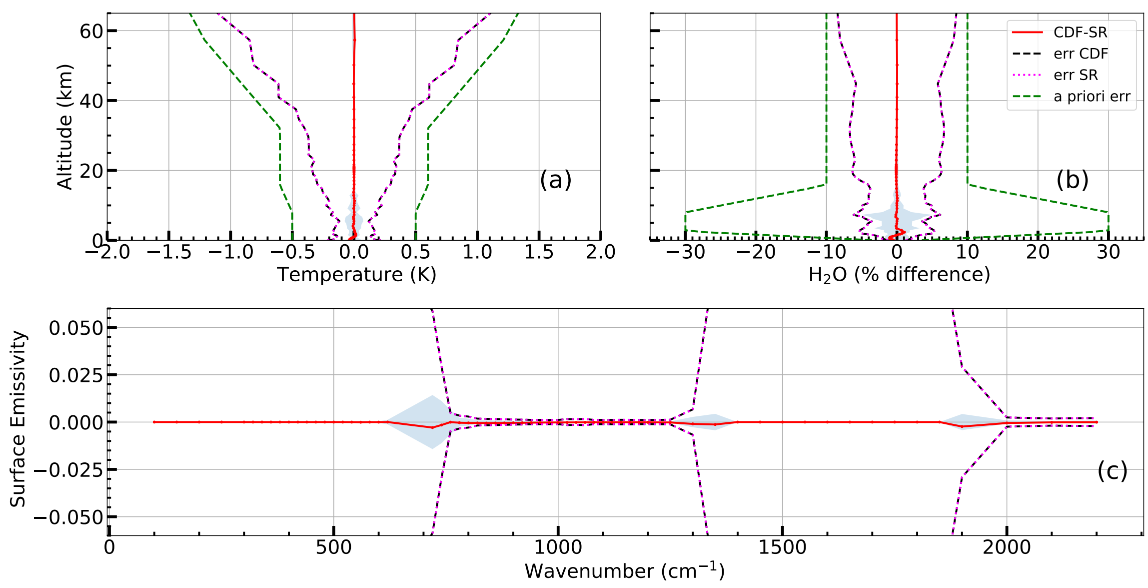

Figure S8. Case of perfectly matching measurements at tropical latitudes. Average differences between CDF and SR profiles (red). Dashed lines represent the average a priori error (green) and the errors of CDF (black) and of SR (magenta) as evaluated from the error CMs. Shadowed areas represent the standard deviations of the CDF minus SR differences. Panel (a) refers to the temperature profile. Panels (b) and (c) refer to the H_2O VMR and surface spectral emissivity profiles, respectively.

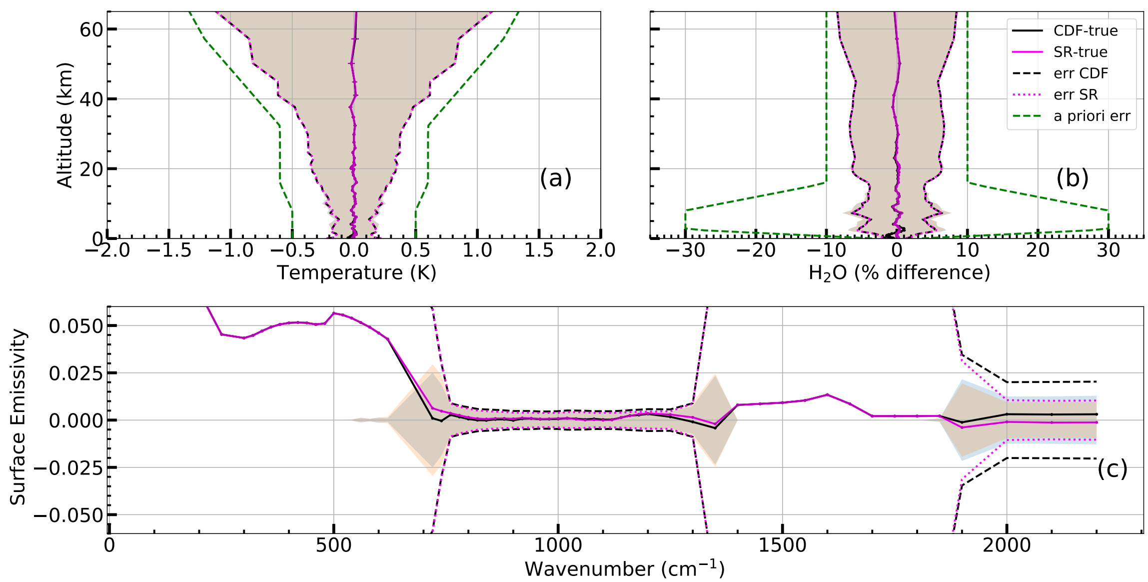

Figure S9. Case of not perfectly matching measurements at tropical latitudes. Average differences between CDF and true profiles (black), and between SR and true profiles (magenta). Dashed lines represent the average a priori error (green) and the errors of CDF (black) and of SR (magenta) as evaluated from the error CMs. Shadowed areas represent the standard deviations of the differences, error bars are the standard errors of the average differences. Panel (a) refers to the temperature profile. Panels (b) and (c) refer to the H_2O VMR and surface spectral emissivity profiles, respectively.

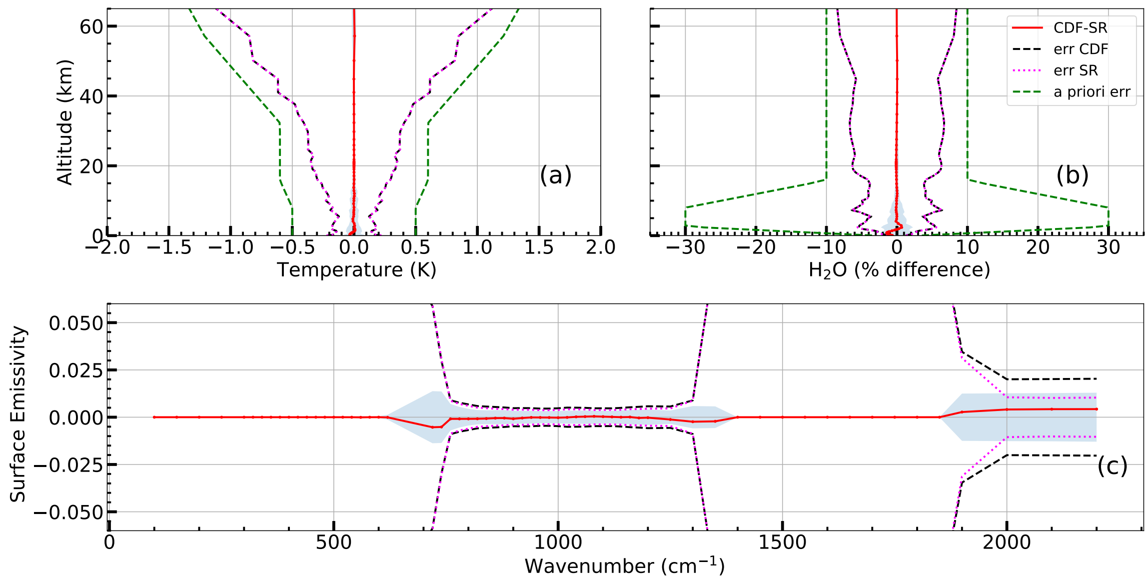

Figure S10. Case of not perfectly matching measurements at tropical latitudes. Average differences between CDF and SR profiles (solid red lines). Dashed lines represent the average a priori error (green) and the errors of CDF (black) and of SR (magenta) as evaluated from the error CMs. Shadowed areas represent the standard deviations of the CDF minus SR differences. Panel (a) refers to the temperature profile. Panels (b) and (c) refer to the H_2O VMR and surface spectral emissivity profiles, respectively.