

Application of radiative transfer to slanted line-of-sight geometry and evaluation with AIRS data

Paul Poli¹, Joanna Joiner², and Delphine Lacroix³

¹ Centre National de Recherches Météorologiques (GMAP), Meteo France, previously at the Global Modeling and Assimilation Office, NASA Goddard Space Flight Center

² Atmospheric Dynamics and Chemistry Branch, NASA Goddard Space Flight Center

³ Centre National de Recherches Météorologiques (CNRM/GMAP), Meteo France

Abstract

The passive infrared and microwave nadir sounders such as (A)TOVS observe the atmosphere from a polar orbit by directing their scan pointed at the ground up to about 49 degrees from nadir. Except for the pixels located right on the satellite ground track, the radiance measurements collected by these instruments characterize atmospheric emission paths which are slanted with respect to the zenith direction at the ground. At the outer swath edges, the deviations from nadir reach about 60 degrees in terms of Satellite Zenith Angle (SZA). The radiative transfer codes used to assimilate these data for operational Numerical Weather Prediction applications make the appropriate corrections to account for the extra path induced by the non-zero SZA. However, no corrections are made to account for the fact that the atmospheric profiles along the slanted line-of-sight (LOS) are different from the vertical because of horizontal gradients in the atmosphere. Using actual AIRS satellite orbits, zenith and azimuth angles, as well as three-dimensional fields of temperature, water vapour, and ozone produced by the European Centre for Medium-Range Weather Forecasts, we extracted both vertical and slanted atmospheric profiles. We present here the results of our study comparing the brightness temperatures calculated along slanted and vertical LOS with AIRS observations. We provide a discussion of our results in the light of results obtained earlier using three-dimensional fields from the NASA Global Modeling and Assimilation Office.

Introduction

Although it is common to consider passive sounders measurement's as vertical soundings, the (A)TOVS soundings sense the atmosphere along non-vertical but slanted line-of-sights (LOS), except for those footprints right on the satellite ground track. Radiative transfer codes in use in the Numerical Weather Prediction (NWP) centers account for the longer path travelled in the atmosphere when the Satellite Zenith Angle (SZA) is non-zero. However, the atmospheric profiles of temperature and constituent information used in input of those radiative transfer codes are usually extracted at the vertical of the footprint. In this work, we simulate AIRS radiances from three-dimensional (3D) fields provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) six-hour forecasts, accounting for the slanted LOS. The methodology is presented first, followed by a discussion of the results obtained by comparison with vertical calculations. We then discuss our results in light of those obtained earlier using 3D fields from the NASA Global Modeling and Assimilation Office (GMAO) and present our conclusions and perspectives for future work.

Methodology

We used as 3D (background) fields the ECMWF 6-hour forecast products, available on 60 levels and with a regular grid with fixed latitude and longitude spacing ($0.5^\circ \times 0.5^\circ$). For the AIRS observations, we used the same AIRS observations as those selected by the Meteo France screening procedure between 20050125 21 UTC and 20050126 03 UTC. As shown later in this document, the channels selected by the Meteo France AIRS screening procedure do not include middle- or upper-stratospheric channels. Only 133 channels with a weighting function peaking in the troposphere or the lower stratosphere were selected. The screening procedure also aims at screening out those observations that could be contaminated by clouds.

The satellite zenith angles are of common use in NWP and do not need further introduction. The satellite azimuth angles indicate the bearing (from the North, positive toward the East), between the footprints and the satellite. The Fig. 1 shows that these angles remain about the same for all the pixels located on the same side of the satellite, for a given ascending (or descending) orbit. The inclination of the EOS Aqua platform is 98° , so that one could expect satellite azimuth angles of either 270° or 90° for an ascending orbit, depending whether the footprint is located on the eastern or the western side of the swath. However, because the instrument scans three footprints along the orbit at a time, the scan of the AIRS instrument is not exactly perpendicular to the orbit, so that the azimuth angles are neither exactly identical to those values, nor do they remain constant for the same field-of-view number.

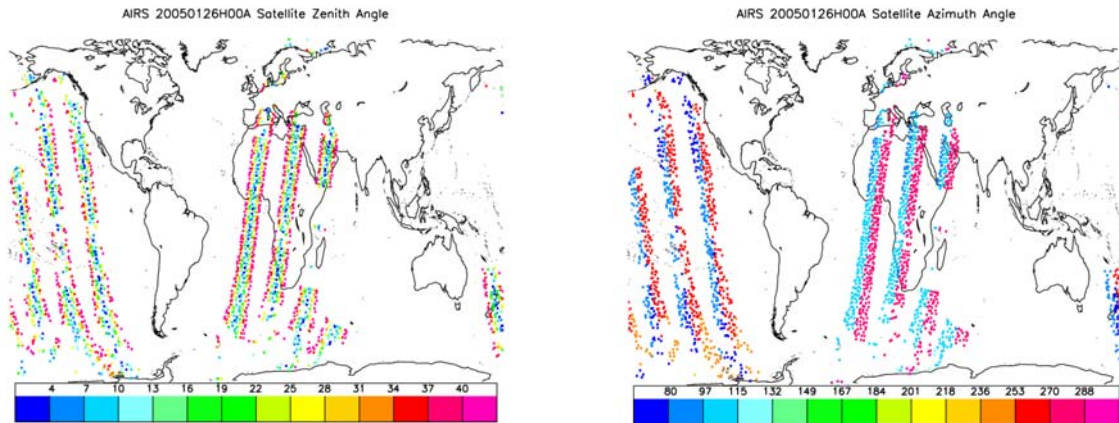


Fig. 1: *Left*: Map of satellite zenith angles. *Right*: Map of satellite azimuth angles.

For each AIRS footprint of the dataset, we extracted from the 3D fields the vertical profile of temperature (specific humidity, ozone). We then applied the RTTOV-8_5 radiative transfer code (Eyre 1991; Matricardi et al. 2001) and obtained the brightness temperatures T_b^{vertical} for those channels whose data were selected by the screening procedure. We then extracted the slanted profile of temperature (specific humidity, ozone constituent) along a LOS whose orientation was given by the AIRS zenith and azimuth angles and applied RTTOV-8_5 to obtain a second set of brightness temperatures T_b^{slanted} .

Results and Discussion

The Fig. 2 (left) shows the standard deviation of the differences ($T_b^{\text{slanted}} - T_b^{\text{vertical}}$). The figure also shows (overlaid with stars) the AIRS noise detector in terms of noise equivalent at the average temperature (NEDT) of all the scenes (calculated from NEDT250, AIRS Instrument Team 2002). Differences much smaller than the detector noise indicate that there is very little benefit (on average) in trying to account for the slanted LOS, since the improvement in the fit to the observations would remain well below the total error budget of the data. However, differences on the order of (or exceeding) the detector noise suggest that the fit to the observations might be improved in proportions that would affect the information content of the data when used in data assimilation. Indeed, assuming non-biased and Gaussian background and measurement errors, reducing the observation minus background differences reduces the error in the subsequent analysis. Given the geometry of the problem at stake, and regardless of the NEDT of the AIRS instrument, one expects larger differences in ($T_b^{\text{slanted}} - T_b^{\text{vertical}}$) for (a) the very high peaking channels (since the offset in distance between the slanted and vertical LOS is larger at higher altitude), and (b) observing phenomena which present higher horizontal variability, such as tropospheric water vapour or, for the stratospheric temperatures, the mid-latitude regions rather than the tropics.

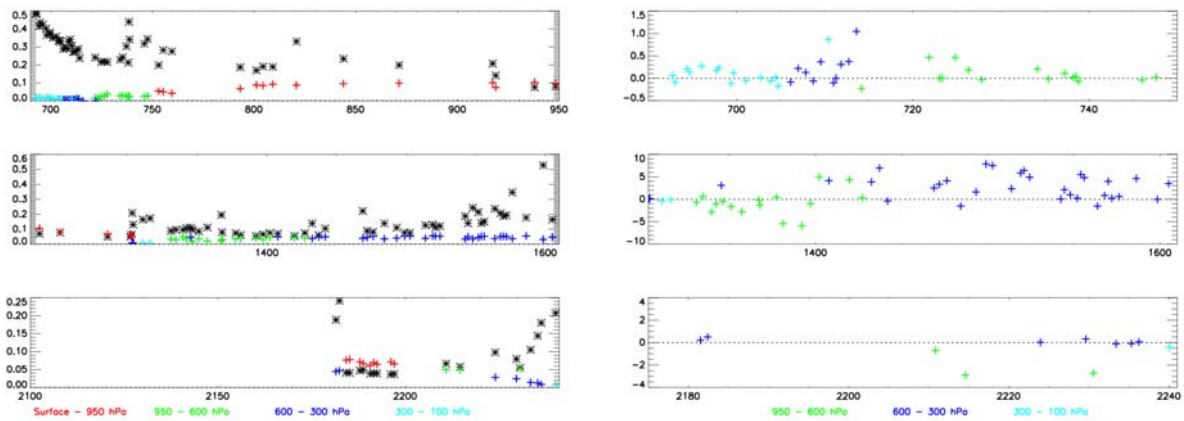


Fig. 2: *Left*: Crosses show standard deviation of the differences ($T_b^{\text{slanted}} - T_b^{\text{vertical}}$). The colour of the cross indicates peaking pressure level. Stars show NEDT@ average scene temperature. *Right*: $100 \cdot [\text{stdev}(T_o - T_b^{\text{vertical}}) - \text{stdev}(T_o - T_b^{\text{slanted}})] / \text{NEDT}$. Positive values indicate improvement by using slanted LOS radiative transfer.

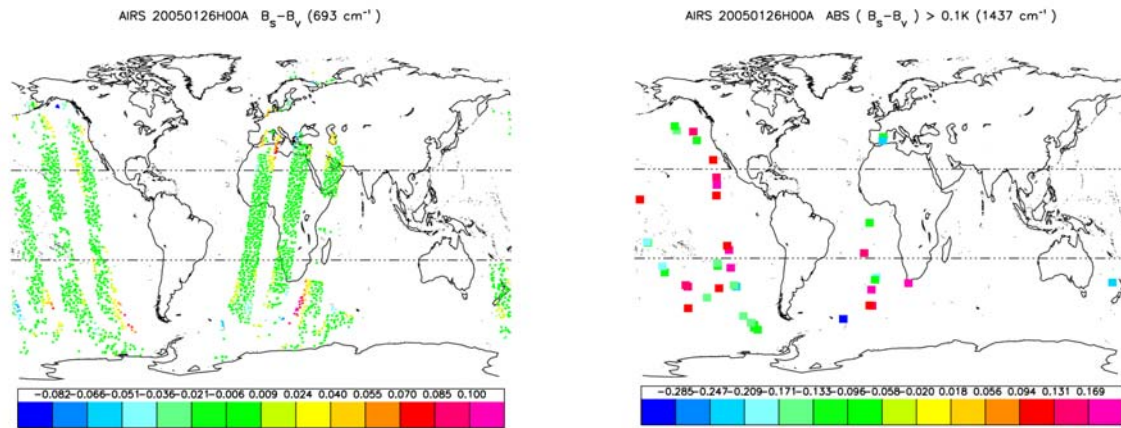


Fig. 3: Maps of the differences ($T_b^{\text{slanted}} - T_b^{\text{vertical}}$) for two selected channels: *Left*: 693 cm^{-1} , temperature channel peaking around the 122 hPa pressure level. *Right*: 1437 cm^{-1} , water vapour channel peaking around the 560 hPa pressure level (shows only the pixels where the differences exceed $\pm 0.1\text{K}$).

The Fig. 2 (left) shows that the differences between slanted and vertical calculations remain inferior to the detector noise in the $15\mu\text{m}$ band and for the window channels between $800 - 950 \text{ cm}^{-1}$. However, the differences ($T_b^{\text{slanted}} - T_b^{\text{vertical}}$) are close to the detector noise for the tropospheric water vapour channels around 1400 cm^{-1} . This suggests that there might be some benefit in trying to account for the slanted LOS in the radiative transfer calculations for those channels.

The Fig. 3 (left) shows a map of the differences ($T_b^{\text{slanted}} - T_b^{\text{vertical}}$) for a lower-stratospheric temperature channel peaking around 122 hPa. As expected, the largest differences occur in the mid-latitudes, owing to the fact that the lower stratospheric temperature gradients are coarser in the tropics. The Fig. 3 (right) shows a map of the differences but for a mid-tropospheric water vapour channel. Only those pixels with differences larger than 0.1K are shown. The plot indicates that the largest differences are observed in the more moist regions, as expected: i.e. tropics and southern (summer) hemisphere.

The Fig. 2 (right) shows $100 \cdot [\text{stdev}(T_o - T_b^{\text{vertical}}) - \text{stdev}(T_o - T_b^{\text{slanted}})] / \text{NEDT}$, where T_o refers to the observed AIRS brightness temperature. Positive values indicate that slanted LOS radiative transfer calculations yield a better fit to the AIRS observations than assuming a vertical LOS. On the contrary, negative values indicate that the slanted LOS does not help fit the AIRS observations. The magnitude of the improvements and degradations is expressed in percents of the NEDT. The figure indicates overall larger improvements than degradations. Improvements of about 1% are observed for the mid-tropospheric temperature channels around 710 cm^{-1} . The largest improvements are obtained for the mid- to upper-tropospheric water vapour channels, and reach about 8% of the NEDT. These results are consistent with expectations, i.e. the largest impacts are obtained for channels where we expect to see the highest horizontal variabilities: namely, rather high-peaking channels observing fields subject to substantial horizontal variations.

When compared to results obtained earlier (Joiner and Poli 2005) conducting the same calculations but using a different background (GMAO analyses instead of ECMWF 6-hour forecasts) and a different radiative transfer code (SARTA (Strow et al. 2003) instead of RTTOV-8_5), three main features are

obvious. First, we find in both studies that the effects of neglecting slanted LOS versus vertical LOS are comparable to the detector noise for some channels in the 6.7 μm water vapour band. Second, the results presented here are consistent with the previous results showing that taking into account the slanted LOS improves the fit to the observations for the upper-tropospheric temperature channels. Third, the results shown here suggest that the ECMWF background contains horizontal gradients in mid- and upper-tropospheric humidity which enable to improve the fit to the AIRS observations when the slanted LOS is taken into account. We cannot conclude however on the quality of the horizontal gradients in the ozone field since we did not retain any AIRS ozone channel in the present study.

Conclusions and Future Work

This paper is a follow-up to a study conducted earlier attempting to identify the importance of accounting for horizontal gradients as regards nadir-viewing infrared instruments. The present results confirm the results obtained earlier with a different background. The major findings of this study indicate that accounting for the slanted LOS when carrying out radiative transfer calculations helps improve the fit to the AIRS observations up to about 8% of the AIRS detector noise for mid- and upper-tropospheric water vapour channels. However, those channels with the largest differences induced by slanted versus vertical calculations are usually upper-tropospheric channels for which the direct impact on NWP may be small.

The problem of accounting for horizontal gradients will become more acute with future sounders which will feature a finer horizontal resolution, both from polar and from geostationary orbit. We also note that this problem will require an answer in data assimilation terms as the horizontal resolution of NWP models increases.

References

- AIRS Instrument Team, 2002. AIRS channel properties.
http://airs.jpl.nasa.gov/data/level2/DOCS/chan_prop.2002.08.30.v6.6.2.pdf
- Eyre, J. 1991. A fast radiative transfer model for satellite sounding systems. ECMWF Research Dept. *Tech. Memo.* **176**.
- Joiner, J. and Poli, P. 2005. Note on the effects of horizontal gradients for nadir-viewing microwave and infrared sounders. *Quart. J. Roy. Meteorol. Soc.*, **131**, 1783—1792.
- Matricardi, M., Chevallier, F. and Tjemkes, S. 2001. An improved general fast radiative transfer model for the assimilation of radiance observations. ECMWF Research Dept. *Tech. Memo.* **345**.
- Strow, L. L., Hannon, S. E., De Souza-Machado, S., Motteler, H. E., and Tobin, D. 2003. An overview of the AIRS radiative transfer model. *IEEE Trans. Geosci. Remote Sensing*, **41**, 303—313.