COMPARISON OF ATMOSPHERIC METHANE OBSERVATIONS FROM AIRS AND IASI

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ABSTRACT

This paper presents a comparison of methane (CH\textsubscript{4}), one important greenhouse gas in terrestrial atmosphere, observed from two hyperspectral infrared sensors on satellites, one is the Atmospheric Infrared Sounder (AIRS) onboard NASA/AQUA and the other is the Infrared Atmospheric Sounding Interferometer (IASI) onboard METEOP-A and -B. Comparison using about 500 cases shows the mean DOFs from AIRS is slightly smaller than IASI, with the difference of -0.049±0.152. Overall the retrieved CH\textsubscript{4} from AIRS is larger than IASI, and their difference is 10.2±23.8 ppb below 650 hpa and 27.4±26.9 ppb above 350 hPa. In the most sensitive layer of infrared sounder between 350 and 650 hPa, their difference is as small as 2.8±17.2 ppb. Compared to aircraft measurements, AIRS retrievals tend to be overestimated while IASI retrievals tend to be underestimated in most cases, suggesting the necessity to further improve the algorithms and call for more dedicated aircraft measurements for validation.

Index Terms- Hyperspectral Infrared Sensors, Satellite, Greenhouse Gases, Terrestrial Atmosphere

1. INTRODUCTION

As the third most important long life greenhouse gas, atmospheric methane (CH\textsubscript{4}) plays an important role in atmospheric chemistry and absorbing long-wave radiation that warms the atmosphere. Mainly attributed to the impact of human activities, the concentration of CH\textsubscript{4} in the atmosphere has increased from the pre-industrial levels of about 700 parts per billion (ppb) to about 1800-1900 ppb. Accurate measurements of CH\textsubscript{4} in the boundary layer of troposphere have been made from ground-based network for ~30 years, however due to the limit of those stations, the quantification of different emission sources in different regions of CH\textsubscript{4} still remains large uncertainties. Thus, recent space-borne measurements from satellites from hyperspectral Atmospheric Infrared Sounder (AIRS) on NASA/AQUA and the Infrared Atmospheric Sounding Interferometer (IASI) on METEOP-A and -B provide complementary observations of atmospheric CH\textsubscript{4} and one advantage is their large spatial and temporal coverage. This paper intends to compare the AIRS CH\textsubscript{4} standard products in AIRS-V6 and the IASI standard products from National Oceanic and Atmospheric Administration (NOAA), so as to understand the capability and/or problem of TIR.
measurements in observing the global spatial and temporal of CH$_4$, particularly in the mid to upper troposphere.

2. DATA AND METHOD

AIRS was launched in polar orbit (13:30 LST, ascending node) on the EOS/Aqua satellite in May 2002. It has 2378 channels covering 649-1136, 1217-1613 and 2169-2674 cm$^{-1}$ at high spectral resolution ($\lambda/\Delta\lambda = 1200$). The spatial resolution of AIRS is 13.5 km at nadir, and in a 24-hour period AIRS nominally observes the complete globe twice per day. The IASI is a cross-track scanning Michelson interferometer that measures 8461 channels at 0.25 cm$^{-1}$ spacing in three bands between 645 to 2760 cm$^{-1}$ in a 2 X 2 array of circular footprints with a nadir spatial resolution of roughly 50 km X 50 km (with a corresponding single footprint spatial resolution at nadir of roughly 12 km). IASI on the Metop-A platform of the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) was launched into a 817-km-altitude polar orbit on 19 October 2006, and Metop-B was launched on Sept. 17, 2012. The satellite crosses the equator at approximately 9:30 am and 9:30 pm local time. Like AIRS, IASI has a wide swath with a scan angle of ±48.3°. Its nominal scan line covers 30 scan positions towards the Earth with four instantaneous IFOV. The Advanced Microwave Sounding Unit (AMSU) is flying on the same platform as AIRS and IASI, so a combination of AIRS (or IASI) with AMSU enables us to derive the retrieval products under partial cloudy conditions, thus greatly improve the yield of the products to more than 60-70%.

In order to retrieve CH$_4$ in both clear and partial cloudy scenes, 9 AIRS fields-of-view (FOVs) within the footprint of AMSU are used. The retrievals algorithm for both AIRS and IASI is a sequential retrieval using AIRS (or IASI) and AMSU observations, which includes the steps of microwave only retrieval, cloud clearing, initial IR retrieval, and a final physical retrieval. The CH$_4$ retrieval is performed on the basis of successful retrievals of the water vapor profile, the temperature profile and surface characteristics. In this study the AIRS data used was downloaded at NASA Goddard Earth Sciences Data and Information Services Center (NASA/GES/DISC), and the IASI data was downloaded from NOAA's Comprehensive Large Array-data Stewardship System (CLASS) (http://www.nsof.class.noaa.gov/saa/products/search?datatype_family=IASI). More detail about the algorithm and the products can be referred to Xiong et al. [2008, 2013].

The CH$_4$ vertical profiles from aircraft measurements by the HIAPER Pole-to-Pole Observations (HIPPO) program over the Pacific Ocean [Wofsy et al., 2011] provide a unique dataset for validation of satellite retrievals over a wide latitude and altitude range (67°S – 85°N; 500-12000 m). There were five HIPPO missions, i.e. January, 2009 (HIPPO 1), October–November 2009 (HIPPO 2), May-April, 2010 (HIPPO 3), June-July 2011 (HIPPO-4) and August-September 2011 (HIPPO-5). In this study we analyzed the AIRS and IASI observations collocated with the HIPPO aircraft measurements. In order to take into account the skill of the CH$_4$ retrievals, the averaging kernels is usually applied to the in situ aircraft data based on the following equation [Rogers, 2004]:

$$\hat{x} = Ax + (I - A)x_a$$

where $I$ is the identity matrix, $A$ is the averaging kernel matrix, $x_a$ is the first guess profile (unit: part per billion, ppb), $x$ is the “truth” or the aircraft measurement, and the computed value of $\hat{x}$ is referred to as the convolved data later in this paper and compared with AIRS and IASI retrievals. In this paper, a direct comparison between AIRS
and IASI is made without considering the difference in the averaging kernels between AIRS and IASI retrievals.

3. RESULTS

We used the AIRS or IASI retrievals within 250 km from HIPPO aircraft measurements in the same day. The average of these match-up AIRS and IASI data was compared to aircraft measurements and compared to each other. The total number of collocated cases used in this study is N = 463. Figure 1 shows the comparison of AIRS and IASI corresponding to 463 HIPPO aircraft measurements. The mean DOFs from AIRS is slightly smaller than IASI, and the difference is $-0.049 \pm 0.152$. This is partly due to the higher spectral resolution of IASI than AIRS. On average, the retrieved CH$_4$ from AIRS is slightly larger than IASI, and the differences are 10.2$\pm$23.8 ppb below 650 hpa and 27.4$\pm$26.9 ppb above 350 hPa, respectively. In the most sensitive layer between 350 and 650 hPa, their difference is as small as 2.8$\pm$17.2 ppb.

To check the error of AIRS and IASI retrievals against the aircraft measurements, Figure 2 shows the comparison of AIRS and IASI retrieved CH$_4$ at around 500 hPa against the aircraft measurements from HIPPO. Overall, both AIRS and IASI retrievals capture the latitudinal gradients. However, it is evident that in many cases AIRS retrievals have a positive bias, particularly in the summer (June-August) and Fall (September-November) and in latitude zones between 30°S to 50°N. IASI retrievals have a negative bias in most cases, especially in the Fall and winter (Dec, Jan, Feb). In the spring (March-May), both AIRS and IASI agree well with aircraft measurements but the number of samples is relatively less than in other seasons.

These differences between AIRS, IASI and aircraft measurements indicates that more works need to be done to further improve the retrieval algorithms, including the improvement to the upstream temperature and water vapor retrievals, and the tuning of CH$_4$ spectroscopy. It is hard to say which retrieval is conclusively better than the other one. In the above comparison the time difference between AIRS and IASI observations and aircraft measurements has not taken into account. This time difference could be one reason leading to the positive bias of AIRS and the negative bias of IASI, as most data used for AIRS is at 1:30pm local time and IASI is at 9:30am local time, and a deeper convection developed at 1:30 pm than at 9:30 am makes the CH$_4$ with high concentration in the boundary layer transported to the upper layer of atmosphere. To investigate this impact from time difference calls for some dedicated aircraft measurements that are well collocated with the overpass of satellites in the future validation.

Fig.1 Comparison of AIRS and IASI retrieval DOFs and the mean difference in different altitude using 463 cases corresponding to HIPPO aircraft measurements. Correlation coefficients of DOFs R=0.80.
Fig. 2 Comparison of AIRS and IASI retrieved CH4 at ~500 hPa with HIPPO aircraft measurements for different seasons and different latitudes

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