Space-based Validation of Methane Products from AIRS/AMSU in China

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Abstract. The CH_4 profiles derived from AIRS/AMSU (Atmospheric Infrared Sounder/ Advanced Microwave Sounding Unit, hereinafter referred to as AIRS) and GOSAT (Greenhouse Gases Observing Satellite) at China's five major WMO/GAW atmospheric background stations are comprised in this paper. The five background sites are Waliguan, Lin'an, Longfengshan, Shangdianzi and Shangri-La station. The data was selected from April 2009 to December 2013. The results show that AIRS and GOSAT CH_4 profiles have the similar vertical distribution. The GOSAT CH_4 concentrations are slightly higher than the AIRS ones at the near surface level. They are in highest coincidence from 500 to 600 hPa with the differences all within 17.9 ppbv. The AIRS retrievals are obviously higher than GOSAT retrievals with larger difference (maximum 254.5 ppbv) from 10 to 70 hPa. The difference of the two inversions is smaller in spring than in other seasons. The CH_4 inversion accuracy of AIRS is greatly affected by cloud within the field of view, and also comes from retrieval algorithms, seasonal changes and so on.

1. Introduction

Earth's atmospheric temperature and ocean temperature are rising, and the sea level has gradually increased since 1950s according to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [1]. Global warming is an indisputable fact. CH_4 as the second most important greenhouse gas next to carbon dioxide (CO_2), increasing of its emissions can exacerbate global warming. The concentration of methane has risen from 700 ppbv in the preindustrial era to 1800-1900 ppbv today, which is largely due to human activities [2]. CH_4 is not only a greenhouse gas, but also a chemically active gas that is easily oxidized in the atmosphere and produces a range of hydroxides and hydrocarbons [3]. Therefore, it deserves attention.

Currently, the concentration of atmospheric CH_4 is obtained primarily by ground-based observations and space-borne measurements. The World Meteorological Organization (WMO) started implementing the Global Atmosphere Watch (GAW) program in 1989. In 1994, China established an online observing system of greenhouse gases such as CO_2 and CH_4 at the Waliguan Atmospheric Background Station in Qinghai Province. At the end of 2008, four main atmospheric background stations (Waliguan in Qinghai, Lin'an in Zhejiang, Longfengshan in Heilongjiang and

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Shangdianzi in Beijing) set up Wavelength-Scanned Cavity Ring Down Spectroscopy system(WS-CRDS), and started a continuous high-precision observation from January 2009[4]. Since July 2010, the Shangri-La Atmospheric Background Station in Yunnan Province has set up an online observation system for CH_4 greenhouse gases and conducted continuous high-precision observations to fill gaps in greenhouse gas observations in southwestern China [5]. Higher accuracy of observation can be obtained by ground-based observations; however, there are only about 300 global greenhouse gas-observation stations in the world at present. Ground stations are unevenly distributed and the cost of observation is too high to obtain the wide range data, which has become a major factor constraining the research of carbon cycle [6]. So the space-borne measurements are crucial.

In 1956, King et al. [7] proposed a technology of satellite infrared atmospheric detection, which started the space-borne observation of atmospheric composition. Halogen Occultation Experiment (HALOE) is mounted on the Upper Atmosphere Research Satellite (UARS), and its observations are limited to the tropopause. The height of observations based on the Michelson interferometer and Atmospheric Chemistry Experiments (ACE) on ENVISAT are similar to HALOE's. Atmospheric Infrared Sounder(AIRS) on board the EOS/Aqua platform was launched in May 2002, has 6 space-borne sensors with 2378 channels covering the wavelength range of 649-1136, 1217-1613 and 2169-2674 cm^{-1}, providing vertical profiles of CH_4[8]. The Greenhouse Gases Observing Satellite (GOSAT), world's first spacecraft to measure the concentrations of carbon dioxide and methane, was launched on January 23, 2009 in Japan. Methane profiles can be obtained by the thermal infrared band of Fourier Transform Spectrometer (FTS). Zhang et al. [9] analyzed the temporal and spatial distribution of methane in the middle and upper troposphere in China from 2003 to 2008 using AIRS CH_4. The results show that AIRS CH_4 is consistent with ground-based CH_4, with an error of less than 1.5%. Wang et al. [10] validated the near-surface CH_4 concentration of the AIRS V6.0 level 2 support product using the ground-based data at Waliguan in Qinghai, Lulinshan in Taiwan and Ulaan Uul in Mongolia, and found that the error was less than 2% , the trend of change is consistent. Using the vertical profiles of CH_4 provided by AIRS V6.0 product, Xiong et al. [11] compared the AIRS retrieval results with simulation results of global tracer model version 3 (TM3) in South Asia from 2003 to 2007, and found that AIRS and TM3 have a consistent trend. Feng et al.[12] used the ground-based CH_4 of Waliguan Atmospheric Background Station to validate the AIRS retrieval CH_4,and the results show that the AIRS retrieval CH_4 is consistent with ground-based CH_4 and there is a significant positive correlation between them.

China's space-borne observations of greenhouse gas are in their infancy. At present, there are few studies on the accuracy of methane profiles retrieved by space-borne instruments in China. Comparison of the AIRS and GOSAT retrieval methane profiles has not been done yet. Therefore, in this paper, AIRS Level 2 standard CH_4 products are validated by GOSAT inversions at China's five major WMO/GAW atmospheric background stations, LAN, LFS, SDZ, WLG and XGLL site, and the possible causes of AIRS retrieval error are also discussed.

2. Study area and data

2.1. Environment of atmospheric background stations

The five stations selected in this paper are located in the area with typical climate and ecological environment in China and have regional characteristics. Waliguan station is located on the northeast slope of the Qinghai-Tibet Plateau, slightly affected by human activities. The vegetation is dominated by plateau meadows (Asakusa, arid and semi-arid desert, grasslands) and sandbanks, with grazing mainly around the atmospheric background station. The dominant wind direction in winter is the southwest, the northeast and the southeast in summer, with obvious plateau continental climate [13]. Waliguan station is the world's highest and the first atmospheric background station in the hinterland of the mainland. Lin'an Atmospheric Background Station is located in China's subtropical monsoon region, on behalf of background characteristics of atmospheric composition in the eastern industrial zone [14]. The CH_4 emission sources such as paddy fields and wetlands at LAN are numerous. Large population, human factors, dense cities and landfills will also affect the background methane concentration. The Longfengshan Atmospheric Background Station is located in Wuchang, Heilongjiang Province, China. It belongs to the temperate monsoon climate and represents the climate characteristics of the Northeast Plain. The main types of crops are rice and corn. Shangdianzi Atmospheric Background Station is located in Beijing-Tianjin-Hebei economic zone in China, belonging to warm temperate semi-humid monsoon climate zone. The main vegetation at SDZ is forest land and farmland [15]. There is no intensive industrial area and population 30 km around it, but it will be affected by air mass transport of Beijing-Tianjin-Hebei Economic Circle. Located at the junction of Yunnan, Tibet and Sichuan provinces, Shangri-La station represents the mixed atmosphere conditions in the southwest region of China. It is located in the monsoon climate zone and is the intersection of the East Asian monsoon and the South Asian monsoon. Its underlying surfaces are mainly coniferous forest, primitive forest and meadow [16].

2.2. Data

2.2.1. AIRS Instrument and Its Retrieval CH_4.

Atmospheric Infrared Sounder (AIRS) on board the Aqua/EOS platform was launched by the NASA in May 2002. The spectral resolution of AIRS is 1200 ($\lambda\backslash\Delta\lambda$) [17], with a swath of 1650 km and a spatial resolution of 13.5 km. The detector is mainly for vertical detection of atmospheric moisture and temperature from the surface to 40 km altitude [18]. The main retrieval band of methane is infrared 7.6 μm. 7.6 μm absorption band of CH_4 has approximately 200 channels in it, the main interference components are H_2O, N_2O and so on. Retrieval algorithm eventually selected 71 channels that are relatively insensitive to water vapor and HNO_3. For the specific retrieval principle, see Xiong[8]. In the retrieval system, AMSU is combined to retrieve atmospheric temperature and humidity profiles, and the retrieval spatial resolution is about 45 km. The data used in this paper is from the AIRS/AMSU Level 2 Standard product (https://airs.jpl.nasa.gov/). The data from April 2009 to December 2013 are selected.

2.2.2. GOSAT retrieval CH_4.

The Greenhouse Gases Observing Satellite (GOSAT) was launched on January 23, 2009 in Japan. The spatial resolution of 10.5km. The instrument on board the satellite is the Thermal and Near-infrared Sensor for carbon Observation (TANSO). TANSO is composed of two subunits: the Fourier Transform Spectrometer (FTS) and the Cloud and Aerosol Imager (CAI). FTS is used for greenhouse gas detection and CAI is for collecting cloud and aerosol information. The FTS has four spectral bands: band 1 (0.75-0.78μm), band 2 (1.56-1.72μm), band 3 (1.92-2.08μm) and band 4 (5.5-14.4μm). The spectral resolution of band 4 is 0.2 cm^{-1}. In the methane retrieval algorithm, all channels of 7.3-8.8μm are used to retrieve methane, meanwhile, H_2O, N_2O, O_3, temperature profiles are also retrieved and surface temperature, surface emissivity are derived. In this paper, the L2 methane profile products retrieved by FTS thermal infrared band were used (http://www.gosat.nies.go.jp/en/) and the data closest to the atmospheric background stations matches AIRS. Because GOSAT satellite was launched 2009, the data of common time period between AIRS and GOSAT FTS, April 2009 - 2013 December, are compared.

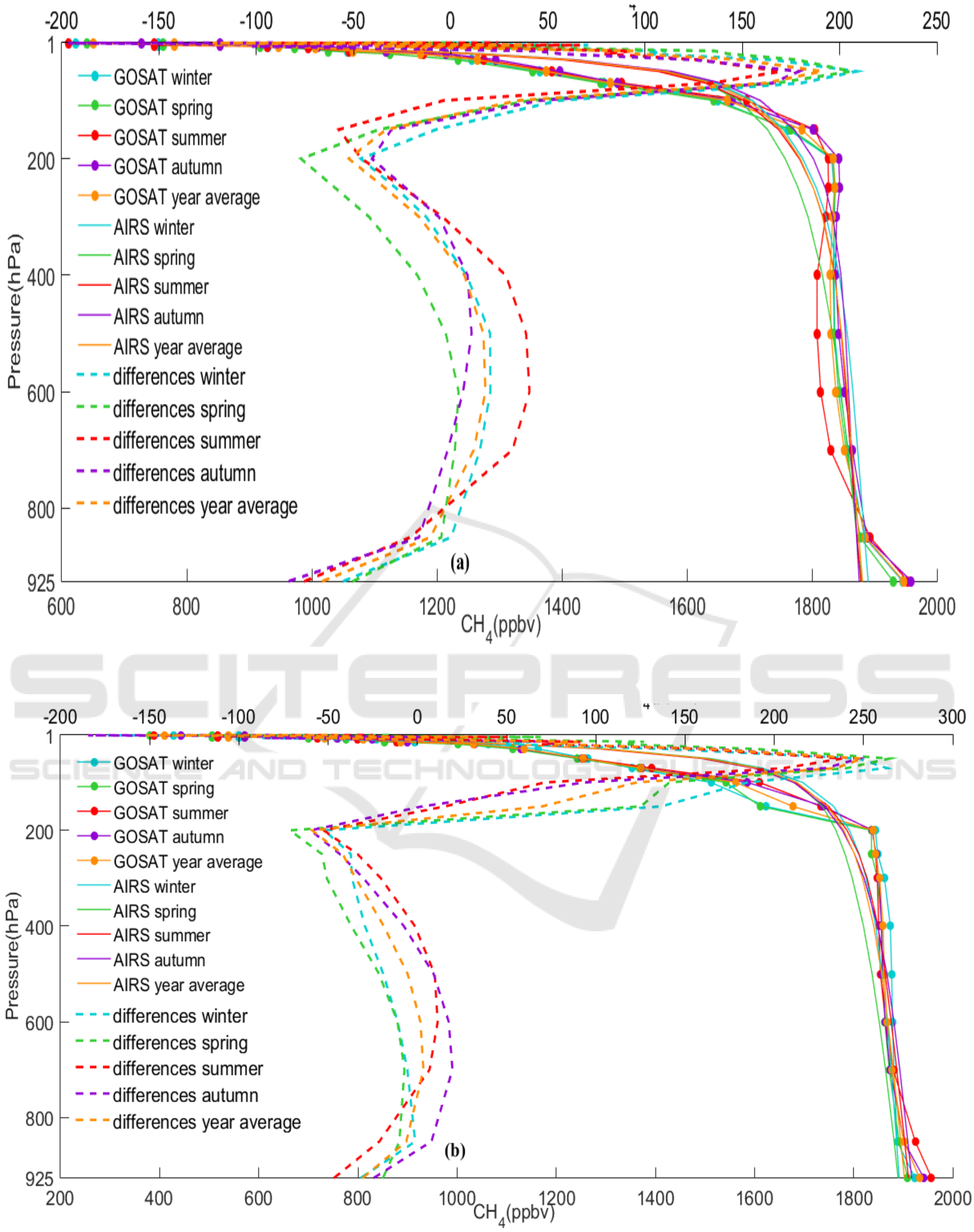
3. Comparison between AIRS and GOSAT CH4 profiles

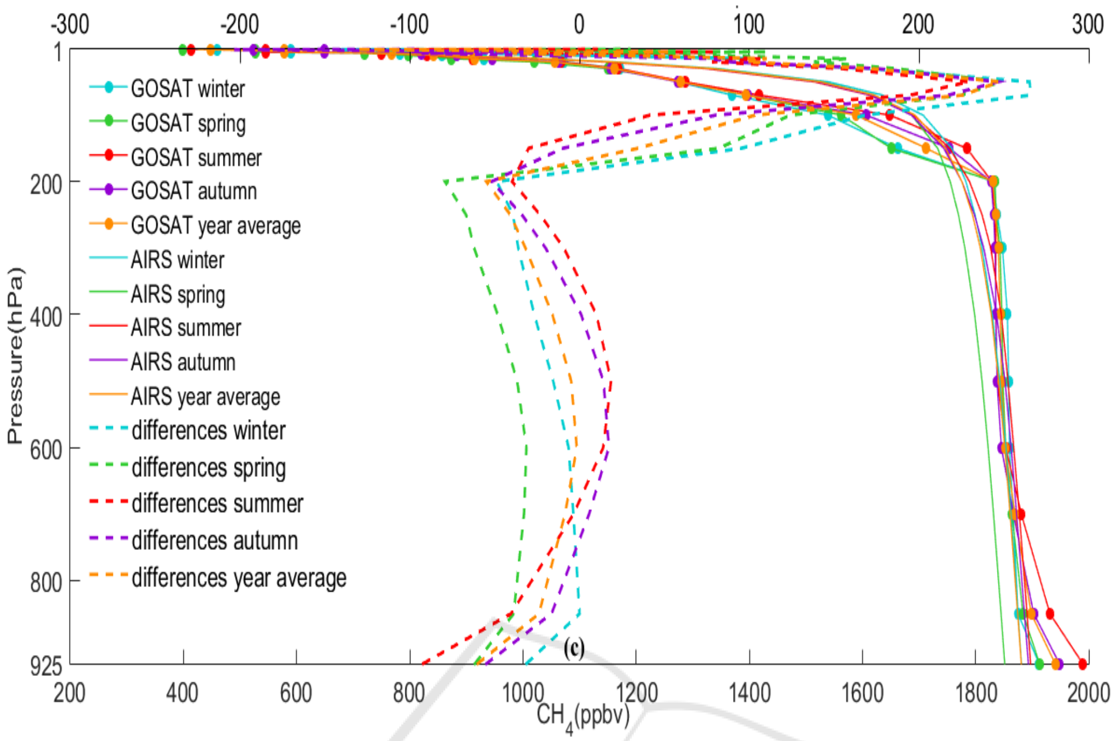
The CH_4 vertical profiles retrieved from AIRS and GOSAT for the pixels closest to each background station (maximum distance less than 100 km) were compared. The GOSAT has a nadir spatial resolution of about 10.5 km and no retrieval value in some places because of the lager scanning gap, so the colocation maximum distance is selected as 100 km. The AIRS profiles and the GOSAT profiles were all averaged seasonally. March to May represents spring, June to August represents summer, September to November represents autumn, December, next January and February represents the winter. AIRS and GOSAT products were matched in time and space.

Figure 1 shows the comparison of the CH_4 profiles between AIRS and GOSAT in four seasons (April 2009 - December 2013). The lower horizontal axis represents the methane concentrations; the upper horizontal axis represents the differences between the AIRS and GOSAT methane concentrations. The solid lines represent the AIRS and GOSAT CH_4 profiles in four seasons, while the dotted lines represent the differences between AIRS and GOSAT CH_4 profiles. As shown in figure 1, the methane vertical profiles of AIRS and GOSAT are relatively close. The methane concentrations in troposphere are hardly varying with height with slightly higher in the near-surface layer, and decrease significantly with height above the troposphere. The annual mean differences of near-surface methane between the AIRS and GOSAT are -65.69 ppbv, -30.21 ppbv, -59.87 ppbv, -14.74 ppbv and 0.45 ppbv, respectively at Lin'an, Longfengshan, Shangdianzi, Waliguan and Shangri-La sites.

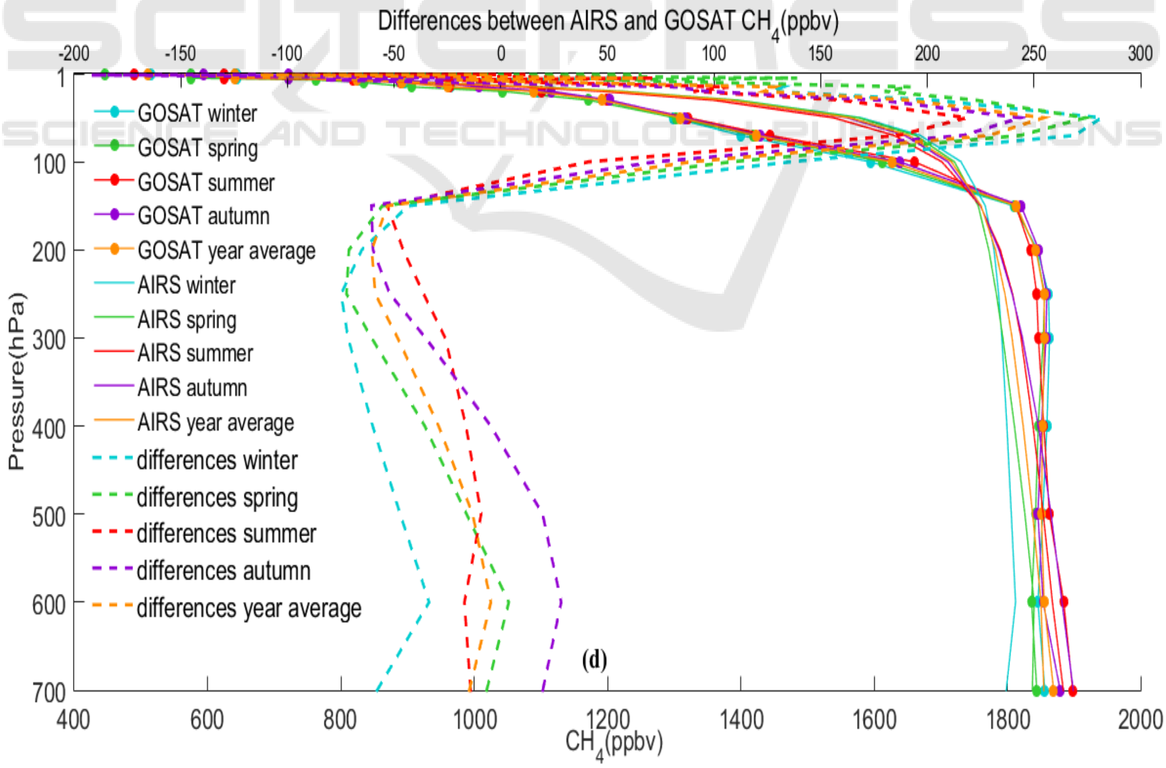
It can be seen from Figure 1 that the AIRS CH_4 below 200 hPa is generally smaller than the GOSAT's. The differences between 10-70 hPa are larger. Especially around 50hPa, AIRS CH_4 is over 200 ppbv higher than the GOSAT's with the largest difference. The coincidence in 500–600 hPa between AIRS and GOSAT is higher with deviation less than 17.9 ppbv. Therefore, both data sets can be applied when studying the changes of tropospheric CH_4 in China. However, GOSAT provides fewer CH_4 products in near-surface layers; only less than 400 samples are available over the selected time.

Figure 1 also shows the differences in different seasons. In general, the methane concentrations retrieved by GOSAT and AIRS at the near surface layer in summer and autumn are higher than those in winter and spring, mainly because of the larger CH_4 source emissions in the summer and autumn. At the XGLL site, the near-surface CH_4 in autumn and winter is greater than spring and summer, which is the same as the seasonal change of CH_4 obtained by ground-based observation [14]. The differences below 200 hPa in summer are larger than the other three seasons. AIRS CH_4 is higher than the GOSAT CH_4 in summer, autumn and winter in 400-700 hPa layer at LAN site. The difference is over 200 ppbv at 50 hPa in winter, with larger difference than the other seasons. At the Longfengshan station, the AIRS retrieved CH_4 concentration is less than that of GOSAT below 200 hPa with smallest difference happening in winter, and much higher than GOSAT near the 50 hPa with larger difference in spring. The change of Shangdianzi is similar to Longfengshan. The biases below 200 hPa in winter are larger in Waliguan.


GOSAT winter
GOSAT spring
GOSAT summer
GOSAT autumn
GOSAT year average
AIRS winter
AIRS spring
AIRS summer
AIRS autumn
AIRS year average
differences winter
differences spring
differences summer
differences autumn
differences year average
Pressure(hPa)
CH_4(ppbv)
(a)
(b)



-300
-200
-100
0
100
200
300
GOSAT winter
GOSAT spring
GOSAT summer
GOSAT autumn
GOSAT year average
AIRS winter
AIRS spring
AIRS summer
AIRS autumn
AIRS year average
differences winter
differences spring
differences summer
differences autumn
differences year average
Pressure(hPa)
1
200
400
600
800
925
(c)
200
400
600
800
1000
1200
1400
1600
1800
2000
CH4(ppbv)



Differences between AIRS and GOSAT CH4(ppbv)
-200
-150
-100
-50
0
50
100
150
200
250
300
GOSAT winter
GOSAT spring
GOSAT summer
GOSAT autumn
GOSAT year average
AIRS winter
AIRS spring
AIRS summer
AIRS autumn
AIRS year average
differences winter
differences spring
differences summer
differences autumn
differences year average
Pressure(hPa)
1
100
200
300
400
500
600
700
(d)
400
600
800
1000
1200
1400
1600
1800
2000
CH4(ppbv)

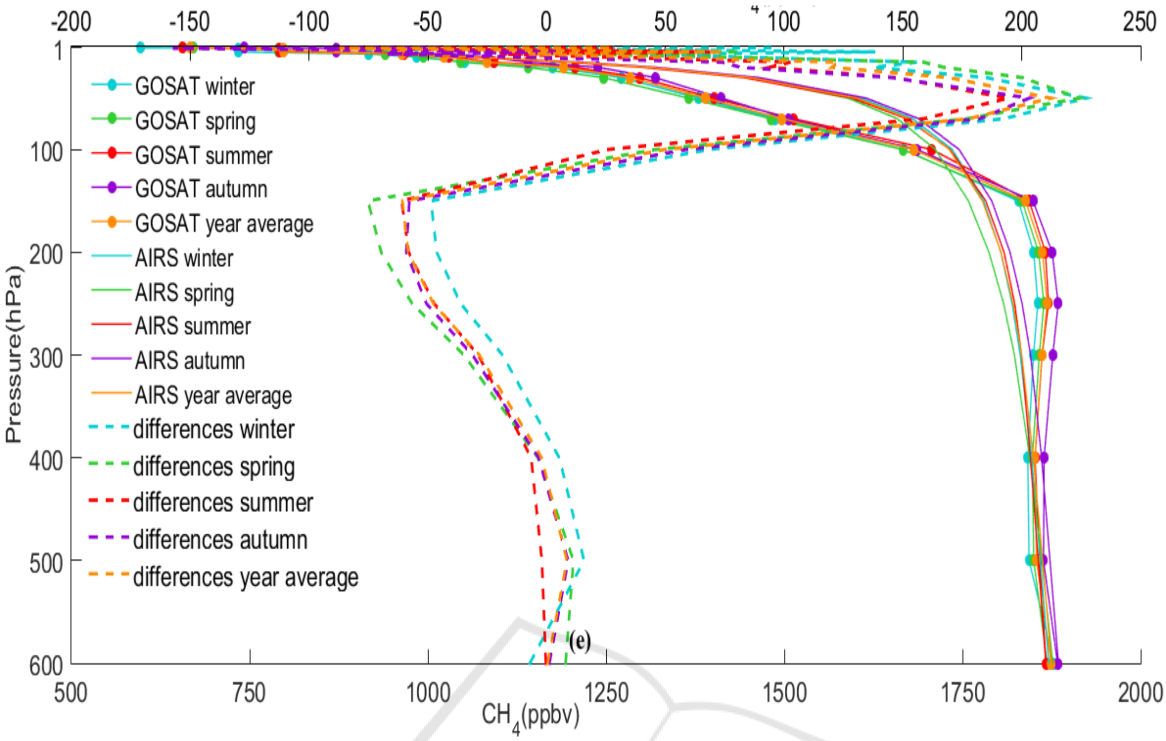


Figure 1. The CH_4 profiles and differences between the AIRS and GOSAT in five atmospheric background stations ((a), (b), (c), (d), (e) represent LAN, LFS, SDZ, WLG and XGLL sites, respectively. The lower horizontal axis represent the methane concentrations, the upper horizontal axis represent the differences).

4. Conclusions

The vertical profiles of methane concentration retrieved by AIRS and GOSAT in the period from April 2009 to December 2013 was compared in detail in this paper. The main conclusions are as follows:

1) The vertical distribution of methane concentrations retrieved by AIRS and GOSAT are consistent with the height. The higher coincidence of the two data sets appears at 500 hPa-600 hPa layer with differences less than 17.9 ppbv. The AIRS CH_4 at 50 hPa is much higher than the GOSAT CH_4.
2) The GOSAT CH_4 concentrations of Lin'an, Longfengshan, Shangdianzi and Waliguan sites are higher than those of AIRS with the concentrations in summer and autumn higher than winter and spring at near surface layers. While in Shangri-La site, CH_4 in autumn and winter are higher than that of spring and summer near surface.
3) The CH_4 inversion accuracy of AIRS is greatly affected by cloud within the field of view, and also comes from retrieval algorithms, seasonal changes and so on.

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