Validation of satellite ozone profile retrievals using Beijing ozonesonde data

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Ozonesondes launched from Beijing, China, over a 3 year time period (September 2002 to July 2005) are used to evaluate the performance of ozone profile retrievals in the upper troposphere and lower stratosphere (UTLS) from two new spaceborne instruments, the Atmospheric Infrared Sounder (AIRS) on the NASA Aqua satellite and the Microwave Limb Sounder (MLS) on the NASA Aura satellite. Since the Global Positioning System ozone sensors (GPSO3) used in Beijing ozonesondes are new, comparisons with simultaneously launched Vaisala ECC sensors, and comparisons with an ozonesonde climatology from Sapporo, Japan, are presented. The results show that although the new GPSO3 sensor has a positive bias (about 20–30%) below 200 hPa and a negative bias (about 5–10%) above 60 hPa relative to known sensors, the measured ozone variability is consistent with Vaisala ECC ozonesondes, particularly in the UTLS region. The GPSO3 ozonesonde profiles over Beijing are then used to evaluate coincident ozone profiles from AIRS version 4 retrieval and MLS version 1.5 retrieval. Qualitatively, both satellite data sets can reproduce the gradients and variability of ozone in the UTLS region. Quantitatively, the agreement between the AIRS and ozonesonde ozone profiles is largely within 10% in the UTLS region (from 400 to 70 hPa). The statistical difference between the retrieval and ozonesonde data is minimum in the vicinity of the tropopause. The MLS ozone profiles also show good quality in the UTLS region with the best performance between 147 and 46 hPa.


1. Introduction

Ozone is a critical atmospheric trace species in the stratosphere and troposphere. Stratospheric ozone forms a protective layer that absorbs enough solar ultraviolet light to make life possible on the surface of the earth. Ozone is also a radiatively active trace gas that plays a significant role in atmospheric heating rates. Tropospheric ozone is highly reactive and central to many chemical transformations. The reactivity of ozone also makes it a pollutant, which can adversely impact human health and plant growth. Since ozone in both the stratosphere and the troposphere is strongly affected by human activity, understanding the distribution and transport of ozone in both regions is critical for understanding the future evolution of the earth’s atmosphere and anthropogenic impacts on it.

In particular, the upper troposphere and lower stratosphere (UTLS) is a region with a large ozone gradient. Transport in the region has large effect on ozone values on either side of the tropopause. The UTLS is a critical region for understanding the radiative balance of the climate system [Gettelman et al., 2004], and ozone is a key component of this radiative balance, as well as an important reactive species in the atmosphere. In the past, the coverage of global satellite data for this region has been limited in space and time. New satellite data from the Atmospheric Infrared Sounder (AIRS) on the NASA Aqua satellite [Aumann et al., 2003] and the Microwave Limb Sounder (MLS) on the NASA Aura satellite [Waters et al., 2006] present new opportunities for investigating complex processes such as stratosphere-troposphere exchange, but the validity of these new data has yet to be established.

In this paper, we present a validation study of recently available satellite data using ozonesonde profiles over Beijing, China (116°28’E, 39°48’N). Situated in Northern Hemisphere midlatitudes in a region of the strong winter-time jet, Beijing is an excellent location for observing the dynamical variability of UTLS ozone. In winter and spring, there are strong upper tropospheric gradients associated with the jet. Significant stratosphere-troposphere exchange also occurs in this region [Wernli and Bourqui, 2002]. Eastern China is also a heavily industrialized region, and there is significant tropospheric ozone production [e.g., Naja and Akimoto, 2004].

The new ozonesonde data set used in this study was measured with a Global Positioning System (GPS) Ozonesonde sensor (GPSO3), developed by the Institute of.
Atmospheric Physics (IAP) of the Chinese Academy of Sciences (CAS). A full characterization of this new sensor is yet to be published in English language journals (J. Bian et al., Ozone profile measurements by using Global Positioning System Ozonesonde (GPSO3) over Beijing, manuscript in preparation, 2007, hereinafter referred to as Bian et al., manuscript in preparation, 2007). To facilitate the validation study, we provide two intercomparison results in this paper to show the consistency of this new sensor with known sensors: (1) comparisons with simultaneously launched Vaisala ECC ozonesonde sensors and (2) comparisons with an ozonesonde climatology from a nearby station. We then proceed to compare profiles from the sondes with the satellite data to evaluate the performance of ozone profile retrievals from AIRS and MLS. In this study we use ozone profile data measured by the GPSO3 over Beijing (116°28′E, 39°48′N) from September 2002 through July 2005. Extensive comparisons with established sensors have been performed. Descriptions of the sensor and the performance of the new system have been given in Wang et al. [2003] and Xuan et al. [2004], both published in Chinese language journals. A detailed description of the system, the performance characteristics, and the ozone profile measurements over Beijing for English language journals will be presented in a separate paper (Bian et al., manuscript in preparation, 2007). In this section, we only provide some summary information to facilitate the use of this data set in satellite data validation.

GPSO3 is an ozonesonde system, developed by IAP, CAS, which measures the ozone concentration by an electrochemical sensor, the same principle of operation as the widely used ECC ozonesonde [Komhyr et al., 1995]. Since September 2002, regular ozonesonde launches have been conducted once a week, at about 1400 Beijing time (0600 UTC). During three intensive observation periods (24 March to 10 April 2003, 23 March to 9 April 2004, and 15 March to 1 April 2005), GPSO3 ozonesondes were launched every day. All the ozone concentration measurements are corrected by a factor of the total column ozone measured by Dobson (75#) ozone spectrometer at Xianghe (117°00′E, 39°46′N) (55 km to the east of Beijing) [Bian et al., 2002] over the integrated column ozone from an ozonesonde, and only sondes with the correction factor between 0.80 ~ 1.20 are used in this paper [Logan et al., 1999].

To characterize the performance of this new sensor, extensive intercomparisons have been conducted both in laboratory and in field between GPSO3 and Vaisala ECC ozonesondes [Komhyr et al., 1995], and the key results are described in section 2.2. Additional support information for the sensor is given by a comparison with the climatology of ozonesonde data from Sapporo, Japan (43°6′N, 141°18′E). Sapporo data is chosen because the station is at a similar latitude and longitude as Beijing and has an established reputation for research quality data [Logan et al., 1999; Naja and Akimoto, 2004] (section 2.3).

2.2. GPSO3-Vaisala ECC Ozonesonde Comparisons

Extensive comparisons have been made between GPSO3 and Vaisala ECC sensors to characterize the performance of the new ozonesonde system. These studies include comparisons (1) in a laboratory (calibration using standard ozone measurement: Model 49C O3 Analyzer, Thermo Environmental Instruments Inc.), (2) on the ground, (3) launched on the same balloon and (4) simultaneous parallel launches. Using these results, the sensitivity, accuracy, time response and performance at different pressure levels of the GPSO3 sensor in comparisons with the Vaisala ECC sensors have been documented [Xuan et al., 2004; Wang et al., 2003]. The results show that the GPSO3 sensors report variability consistent with the Vaisala ECC sensors but tend to have a 20–30% high bias in the troposphere. To illustrate the consistency and differences of GPSO3 with Vaisala ECC, Figure 1 shows comparison results between GPSO3 and Vaisala ECC ozonesondes (manufactured by ENSCI Corporation) obtained from 13 pairs of parallel launches over Beijing in spring 2005. In Figure 1a, the mean and standard deviation of both ozonesondes across all 13 launches are consistent, especially from 300 hPa to 70 hPa. However, GPSO3 appear to have a positive (10 nb or 30%) bias in the troposphere, and a slight (15 nb or less, or 10% or less) negative bias above 60 hPa (Figures 1b and 1c).

Given the significant systematic differences between GPSO3 and Vaisala ECC, the correlations between them are analyzed and given in Figure 2. In Figure 2a, except in the layers from 510 hPa to 390 hPa and from 20 hPa to 16 hPa, the correlation coefficients are larger than 0.50, and particularly over 0.80 from 370 hPa to 50 hPa and below 700 hPa. Figures 2b and 2c give the scatterplots and derived correlation coefficients for GPSO3 versus Vaisala ECC at 250 hPa and 80 hPa, respectively. These results show that the GPSO3 has biases relative to Vaisala ECC, but new sensor also reproduces the ozone variations measured by Vaisala ECC, particularly in the UTLS region.

The diagnosis of the difference between the two types of sensors is an ongoing research at IAP. The initial results suggest that the differences may be due to the different sensitivity at different pressure range and the time response function of the two sensors. A fuller description of the sensor evaluation will be given by Bian et al. (manuscript in preparation, 2007).

2.3. Beijing-Sapporo Ozonesonde Comparisons

In addition to comparisons of GPSO3 to Vaisala ECC ozone sensor, we have compared the vertical distribution of ozone at Beijing with the ozonesonde data at Sapporo, Japan (43°6′N, 141°18′E). Ozonesonde data from January 2002 through August 2005 (sonde type is KC-96) [Naja and Akimoto, 2004] are used to compare with Beijing GPSO3 measurements for a similar period.

Figure 3 shows the vertical ozone distribution of at Beijing and Sapporo in three different seasons, i.e., spring (MAM), summer/fall (JJASO), and winter (NDJF). In all the seasons, the ozone profiles at both sites generally agree well with each other. Particularly, between 400 and 30 hPa...
in MAM, 150 and 30 hPa in JJASO, and 400 and 30 hPa in NDJF, both sites not only have same structure, but also have very similar mean and standard deviation. In the lower troposphere, however, the measured ozone concentration is higher at Beijing than at Sapporo in all the three seasons, and the largest difference occurs in summer/fall (JJASO), when the mean value at Sapporo is outside the standard deviation of Beijing at the lower levels.

This significant difference is likely partially caused by the different sensors used by two stations, but there are geophysical reasons for the tropospheric ozone concentration to be higher at Beijing than at Sapporo. By using coincident observations of total ozone from the Total Ozone Mapping Spectrometer (TOMS) and stratospheric ozone profiles from the Solar Ultraviolet (SBUV) irradiance (SBUV) profiler (SBUV).
instruments on a daily basis over a time period spanning more than two decades (1979–2001), Fishman et al. [2003] show the resultant climatological seasonal depictions of the tropospheric ozone residual (TOR). The residual tropospheric ozone during 1998–2000 over Beijing is 40 DU in MAM, 54 DU in JJA, 39 DU in SON and 29 DU in DJF. This is higher than the TOR over Sapporo in all seasons, by 20–30% (Sapporo TOR values are 34 DU in MAM, 45 DU in JJA, 32 DU in SON and 22 DU in DJF). Higher TOR at Beijing may be caused by higher amounts of troposphere NO$_2$ [Chandra et al., 2004], which are observed by satellite from space [Richter et al., 2005].

3. Descriptions of Satellite Data

3.1. AIRS Data

AIRS on Aqua is in a sun-synchronous polar orbit, with equatorial crossing 1330 and ~0130 local time. The AIRS instrument suite is a nadir scanning sounder with combined infrared and microwave retrievals [Aumann et al., 2003]. The 2378 independent channels on AIRS permit retrieval of an entire profile in the presence of up to 90% cloud fraction. AIRS cloud fraction is defined as the product of cloud coverage and infrared emissivity. Some of these retrieved profiles are flagged as poor quality using internal quality control procedures. We use AIRS level 2 data retrievals (version 4.0), described by Fetzer et al. [2003] and available at http://www-airs.jpl.nasa.gov/. Details of the general theory used to derive geophysical parameters using AIRS/AMSU observations is given by Susskind et al. [2003] and specific details of the AIRS version 4.0 retrieval algorithm and quality control are given by Susskind et al. [2006]. AIRS version 4 retrievals use a subset of the 2378 AIRS channels to derive an initial guess profile on the basis of a statistical relationship between AIRS cloud-cleared

Figure 3. Comparison of vertical ozone distributions and relative differences between Beijing (black) and Sapporo (gray) in (a and b) MAM, (c and d) JJASO, and (e and f) NDJF. In Figures 3a, 3c, and 3e, thick line is the mean profile, and error bars are ±1σ from the mean. In Figures 3b, 3d, and 3f, percent difference is shown for March-May (MAM) (Figure 3b), June-October (JJASO) (Figure 3d) and November-February (NDJF) (Figure 3f). Ob stands for the ozone concentration in Beijing, and Os stands for Sapporo.
radiant temperature-moisture-ozone profiles [Goldberg et al., 2003]. The statistical relationship is built prelaunch using simulated AIRS radiances and temperature-moisture-ozone profiles from global ECMWF analyses for selected days. The initial guess profiles are derived and given at 100 levels. These initial guess profiles are then used in the physical retrieval algorithm, which finds geophysical parameters that best match cloud cleared regression in a subset of the AIRS channels (147 for temperature, 66 for H2O and 23 for O3). The physical retrieval algorithm uses overlapping trapezoidal perturbation functions with widths in the UTLS of ~2 km for temperatures 1–3 km for H2O and 3–5 km for ozone [Susskind et al., 2003]. The full characterization of the information content of this data is in progress (C. D. Barnet, personal communication, 2006). Because AIRS is an IR (thermal) instrument, AIRS is most sensitive to the ozone distribution in the coldest portion of the atmosphere, in the vicinity of the tropopause. The true vertical resolution of the data depends on the cloud coverage and the thermal structure of the profile, which varies from profile to profile. Horizontal resolution is approximately ~45 km, and there are on the order of 300,000 AIRS profiles per day. AIRS standard retrieved products are archived on 28 levels from the surface to the mesosphere. We use standard version 4 level 2 retrieved profiles obtained from the NASA Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC).

[17] In contrast to AIRS temperature and water vapor products, only limited validation of the AIRS ozone products has been performed. Gettelman et al. [2004] compared AIRS ozone data to in situ aircraft data in the tropical upper troposphere and found a consistent positive bias in AIRS version 3 retrievals in the upper troposphere and lower stratosphere of 30%. The same analysis with version 4 data ozone data indicates the bias has been reduced to ~20%.

3.2. MLS Data

[18] The Microwave Limb Sounder (MLS) on the NASA Aura satellite is in a similar sun-synchronous orbit to the Aura satellite, with a local equatorial crossing time 15 min later. The Earth Observation System MLS (EOS-MLS) instrument on Aura is described by Waters et al. [2006]. Ozone is retrieved using several radiometers at 2500, 640, 240 and 190 GHz (mostly from 240 GHz) at six levels per decade of pressure, starting at 316 hPa (316, 215, 147, 100, 68.1, 46.4, 31.6, etc). Profiles are retrieved every 165 km along the line of sight, with a field of view of approximately 6 km across track (horizontal) and 3–4 km in the vertical. There are approximately 3500 MLS profiles per day. MLS EOS ozone data products and early validation is discussed by Froidevaux et al. [2006]. Single profile precision for ozone in the UTLS is estimated at 30%. Few existing comparisons in the UTLS region exist, though Froidevaux et al. [2006] show that MLS ozone data in the UTLS is biased 10–20% high relative to other satellites or limited in situ data. We use version 1.5 level 2 retrieved profiles from the NASA GSFC DAAC.

4. Methodology

[19] In this study we compare GPSO3 ozonesonde profiles with AIRS and MLS retrievals. We use slightly different criteria for each set of comparisons. AIRS data are binned to the locations of the soundings using colocation criteria of ±50 km in space, ±3 hours in time. Consistent with AIRS quality control, we require that the retrieval process successfully complete an infrared retrieval algorithm (denoted by the retrieval type = 0). We have also performed quality filtering using the ozone quality flag, and the results are essentially the same (statistics are the same, conclusions are the same). In general two to five AIRS profiles meet this criteria for each ozonesonde launch. All profiles meeting these location, time and quality criteria are averaged together. For direct comparisons, ozonesonde data are binned to be consistent with AIRS levels. For example, the binned value at the standard AIRS pressure level of 200 hPa is the mean layer mixing ratio from 200 to 150 hPa.

[20] For MLS data, we use a similar comparison methodology. Because the MLS data coverage is sparse, and each observation represents a view along the satellite line of sight of nearly 200 km, we use broader colocation criteria of ±900 km (8° in space, and ±12 hours in time). We have also tried tighter colocation criteria (5° in space) and get far fewer correspondences, but similar mean and difference statistics. Because of coarse sampling and limited vertical coverage, MLS data have more difficulties capturing small-scale events in the UTLS region, but should provide good results in the middle stratosphere.

[21] Approximately 50 pairs of GPSO3 and satellite samples are available and about 50% of the coincidences are between March and May, because of a spring intensive observation period. Hence we have divided the data into three seasons for seasonal comparisons: spring (March–May or MAM), summer/fall (June–October or JJASO) and winter (November–February or NDJF).

5. Results

5.1. AIRS-GPSO3 Comparisons

[22] Figure 4 shows the comparison between AIRS and GPSO3. Figure 4a shows the mean and ±1σ from the mean of all the 49-pair samples at different levels. AIRS and GPSO3 correspond well from 400–70 hPa, i.e., the vertical distribution of the mean is similar with small bias, and the mean difference is less than 1 standard deviation of the data. Outside of this region, however, there is significant distinction between AIRS and GPSO3, particularly between 50 and 15 hPa, where the mean AIRS–GPSO3 difference exceeds the standard deviation of the GPSO3 data. This is more clearly seen in Figure 4b. In Figure 4b, individual differences for a particular sounding at a particular level are shown as asterisks, while thick lines in Figure 4b are the mean difference, and thin lines are ±1 standard deviation (σ) of the difference AIRS generally indicates less ozone than the GPSO3 soundings. Between 400 and 50 hPa, i.e., the UTLS region, the standard deviation is very large in comparison with other levels, which means that there are significant synoptic variations in ozone in this region. We focus on the UTLS region in more detail below.

[23] Figures 4c–4h show AIRS-GPSO3 comparison in three seasons, i.e., spring (MAM), summer/fall (JJASO), and winter (NDJF). There are 23-pair samples for MAM (Figures 4c and 4d), which account for nearly 50% of all samples, so the structures of the mean and ±1σ from the
mean between 400 and 50 hPa are similar to those for all the samples (Figures 4a and 4b). Between 400 and 50 hPa, the mean difference at each level is less than 20%. AIRS is 15% lower than GPSO3 at 200–150 hPa, while AIRS is 14–19% higher than GPSO3 between 250 and 400 hPa and 7% higher at 100–70 hPa. The standard deviation of the difference is between 29 and 43%.

[24] In summer and fall (JJASO), we have 15-pair samples (Figures 4e and 4f). The AIRS–GPSO3 mean difference is larger than in spring. For the mean value between

Figure 4. Comparison between GPSO3 ozonesonde (black) and AIRS (gray). (a and b) All data, (c and d) spring (March-May), (e and f) summer/fall (June-September), and (g and h) winter (October-February). In Figures 4a, 4c, 4e, and 4g the thick line is the mean profile, error bars mark $\pm 1\sigma$ from the mean. In Figures 4b, 4d, 4f, and 4h, individual % differences are in gray, and the mean (thick line) and $\pm 1\sigma$ from the mean (error bars) are shown.
400 and 50 hPa, AIRS is within the standard deviation of GPSO3 at each level. Between 400 and 150 hPa in Figure 4f, the mean difference between AIRS and GPSO3 is negative (AIRS observes less ozone than the ozonesondes), by −2 to −30%, and is significant between 250 and 150 hPa. Between 150 and 50 hPa, however, the mean difference between AIRS and GPSO3 is positive, with largest bias (19%) at 100–70 hPa layer, and the standard deviation is comparatively large, with 38% and 47% at 70–50 hPa and 100–70 hPa layer, respectively.

[25] There are 11-pair samples in winter (NDJF). The AIRS-GPSO3 comparison is still good between 400 and 50 hPa (Figure 4g). The bias between AIRS and GPSO3 shows the opposite distribution to summer and fall (JJASO). AIRS has a positive bias in the lower atmosphere, with maximum (14%) bias at 400–300 hPa layer and larger standard deviation (about 38% at 400–300 hPa layer), and a negative bias in the lower and middle stratosphere, with an extreme of −21% at 100–70 hPa layer and smaller standard deviation (less than 20
degree 4h).

[26] The individual difference of all samples with altitude is shown in Figure 4b. The bias between AIRS and GPSO3 between 400 and 50 hPa is generally less than 10% with the exception of 200–150 hPa layer (AIRS is 15% lower than the sounding mean). The small size of bias is partly caused by compensation between different seasons. Between 400 and 250 hPa, AIRS sees more ozone in spring, but less in summer-fall; between 100 and 50 hPa, AIRS sees more stratospheric ozone than the sounding in summer-fall, but much less in other seasons. The relatively large negative bias between 250 and 100 hPa in summer-fall is reduced by much less negative or positive bias in spring and winter. The bias is smaller than those given by Fetzer et al. [2005], which shows the difference in the free troposphere on the order of 20 to 70%. The standard deviation of differences between 400 and 50 hPa is between 25 and 40%. Outside the UTLS, the bias between AIRS and GPSO3 is within −4 to −16% (−16% at 30–20 hPa layer) between 50 and 10 hPa, and 6% at 10–7 hPa layer. In the lower troposphere, however, the bias is much larger, particularly between 700
and 400 hPa, where the bias is within 24% to 34%, and the standard deviation is also very large, over 50%; these results are very close to those given by Fetzer et al. [2005].

[27] To further understand the implication of the biases in the satellite data, we examine the correlation between the satellite data and ozonesonde data at a given altitude for a range of altitude. A good linear relationship is found between AIRS and GPSO3 between 400 and 70 hPa. Figure 5 gives the scatterplots and derived correlation coefficients for AIRS versus GPSO3 at four different layers: 250–200 hPa (Figure 5a), 200–150 hPa (Figure 5b), 150–100 hPa (Figure 5c), and 100–70 hPa (Figure 5d), using data from all 49 samples. The correlations show that there is a consistency between AIRS and GPSO3 ozone variability in the UTLS region. Although the satellite data may be biased in ozone values, the data provide correct ozone variation statistically. Table 1 lists the correlation coefficients between 400 and 70 hPa ranges. Outside this range, the correlation coefficients are below 0.50.

[25] To shed more light on the instrument sensitivity and retrieval performance, we performed a comparison between AIRS and GPSO3 using a tropopause referenced coordinates system. Figure 6 gives the individual percentage differences between AIRS and GPSO3 as a function of altitude (and pressure) relative to the tropopause height (and tropopause pressure) for all 49 samples (pink crosses), and the mean difference at different layers (red lines). The median and upper/lower quartiles are also given in Figure 6 (blue lines) to provide information on frequency distributions. As indicated by Figure 6, the AIRS ozone retrieval accuracy varies with the distance relative to the tropopause level. The mean difference is close to zero in the layer containing the tropopause, but the bias increases away from the tropopause (negative and positive above and below the tropopause, respectively). This is consistent with the AIRS instrument’s sensitivity to the region of strong thermal contrast. Particularly in the lower stratosphere, the lack of temperature gradient may hamper accurate AIRS retrievals. Figure 6 also shows that the relatively large percentage differences below the tropopause are contributed by few outliers with high biases. The medians for these layers generally show smaller biases than the means.

5.2. MLS-GPSO3 Comparisons

[29] Figure 7 illustrates comparisons between GPSO3 ozonesondes over Beijing and colocated MLS profiles meeting the correspondence criteria discussed in section 3. Figure 7 is similar to Figure 4, with all soundings plotted in Figures 7a and 7b, and each of the three seasons plotted in subsequent panels. MLS data is only available on six levels per decade of atmospheric pressure, with the lowest four levels in the UTLS below 215 hPa.

[30] In general, GPSO3 and MLS observations agree quite well throughout the range of the MLS data. Figure 7 illustrates that in all seasons there are slight statistical differences of 20% near the ozone maximum at 30–50 hPa. In general MLS data is higher than the GPSO3 sensors. This is in the same sense as the differences between the GPSO3 and Vaisala ECC sensors, indicating that near the peak of stratospheric ozone, MLS data is close to the Vaisala ECC soundings. MLS data also appear to be higher than GPSO3 soundings by 20% in the lower stratosphere (146 hPa and below). From the discussion in section 2.2, this would imply even larger differences with the Vaisala ECC ozonesondes, which have significantly (30%) less ozone in the UTLS region than the GPSO3. However, the wide spread of the sparse observations in the UTLS region and the difficulty of collocation mean that these differences are generally less than the standard deviation of the measurements at any level. We thus conclude that MLS ozone data in the UTLS is also reasonable, but may suffer from a positive bias at the lowest few levels (below 100 hPa) relative to the GPSO3 ozonesondes (and Vaisala ECC ozonesondes, by inference). Differences are similar in all seasons.

[31] A good correlation is found between MLS ozone and GPSO3 between 146 and 46 hPa. Figure 8 gives the scatterplots of MLS ozone versus GPSO3 ozone at 146, 100, 68, and 46 hPa for all 48 samples. The results show that the MLS data has better consistence with GPSO3 ozone in the lower stratosphere. The correlation coefficients are below 0.50 at other layers.

6. Discussions and Conclusions

[32] We have presented an intercomparison between a new ozonesonde data set, GPSO3, over Beijing, China, and two recently available satellite data sets, with a focus on the UTLS, to evaluate the performance of satellite retrieval. To facilitate the use of new ozonesonde data in validation, we have given some summary information showing the com-

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Figure 6. Differences between AIRS and GPSO3 at altitude relative to the tropopause height. Gray crosses are individual differences between sonde data binned to AIRS levels. Dashed lines are layer average differences. Solid lines and boxes mark the median, upper and lower quartiles for each layer.
Comparison of the new ozonesonde data with established sensors. GPSO3 sondes appear to be 20–30% high in the troposphere and biases 5–10% low in the middle stratosphere relative to Vaisala ECC ozonesondes, but variability is well reproduced, particularly in UTLS region. Comparisons with a nearby station, Sapporo, show similar agreement in the profiles.

Comparisons between ozonesondes and satellite data show that AIRS and MLS ozone retrievals in the UTLS region. In the vertical range of 400–70 hPa, the agreement is generally within 10%. Relative to the GPSO3 soundings, AIRS ozone appears to be biased high by 20–30% in the middle troposphere, and biased low near the ozone peak. The linear correlation coefficients between AIRS and GPSO3 are all above 0.50 between 400 and 70 hPa, which indicates the data provide significant information for analyzing ozone variability in this region. It is likely that the strong vertical temperature gradients around
the tropopause enhance the instrument sensitivity, as indicated by the comparisons in the relative altitude coordinates (Figure 6). Since ozone in the UTLS region is strongly correlated to the synoptic-scale variability of the tropopause, our results show that AIRS retrieval is capable for capturing the coherent structures of ozone gradient relative to the tropopause (albeit with a positive bias in the troposphere). MLS data also compare quite well to soundings, with a 20% positive bias relative to the soundings in the LS and 30% in the UT.

[34] This work shows the potential for the ozone data from MLS and AIRS to contribute to the knowledge of ozone transport and variability in the UTLS region. These results should also help understanding the strength and weakness of current retrieval. Further improvement of retrieval and characterization of the information content would be very valuable. In particular, similar measurements to AIRS will be possible from the future instruments, such as the Infrared Atmospheric Sounding Interferometer (IASI), to be launched on European meteorological polar-orbit satellites, and the Cross Track Infrared and Advanced Technology Microwave Sounder (CrIS) on National Polar-orbiting Operational Environmental Satellite System (NPOESS) platforms. Improved ozone retrievals for these high spectral resolution infrared instruments will help producing a continuous record of UTLS ozone measurements over the next 20 years.

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