Nitrous oxide observations from GOSAT-2/TANSO-FTS-2: Evaluation and potential

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Nitrous oxide (N_2O), with a lifetime of approximately 120 years, is the third most significant greenhouse gas after carbon dioxide (CO_2) and methane (CH_4), contributing to global warming. It has a global warming potential 300 times greater than CO_2 over a 100-year horizon. N_2O emissions are not regulated by the Montreal Protocol and, although they are subject to the Kyoto Protocol, the observed annual increase of ~0.25% in N_2O over the past decade is expected to continue until 2100. N_2O emissions arise from both biotic (living organisms) and abiotic (environmental factors such as water, soil, and air) processes, with sources being 1) 60% natural and 2) 40% anthropogenic. In 2019, the annual average concentration of N_2O in the atmosphere was approximately 332 parts per billion per volume (ppbv).

Despite its importance, tropospheric N_2O measurements and surface emission sources remain globally understudied, with limited surface observations. However, sparse FTIR/NDACC instruments monitor N_2O profiles, and satellite observations in the thermal infrared (TIR) from IASI (Ricaud et al., 2009; Chalinel et al., 2022), AIRS, and GOSAT (Kangah et al., 2017) provide valuable global data. GOSAT-2/TANSO-FTS-2, which has some sensitivity to lower tropospheric N_2O, offers potential for studying surface emissions using inversion methods.

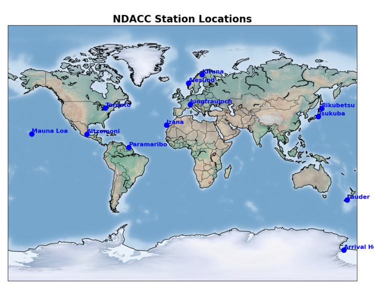
This study evaluates the quality of GOSAT-2/TANSO-FTS-2 N_2O observations for 2019 (version 1.06). Comparisons with NDACC N_2O profiles, IASI from TN2OR (Chalinel et al., 2022), and chemical transport models will assess the reliability of GOSAT-2 measurements at different atmospheric levels. The study includes discussions on measurement sensitivities, evaluation results, and the potential for inverting N_2O surface fluxes.

Instrument characteristics

Since 2008, thermal infrared (TIR) measurements from satellite instruments such as MetOp/IASI, and GOSAT-2/TANSO-2 are available and allow access to total columns and vertical profiles of tropospheric N_2O. Initial studies have shown that it is possible to reveal long-range transport via temporal and spatial variability of N_2O in the tropics (Ricaud et al., 2009) with IASI and over the Mediterranean (Kangah et al., 2017) with TANSO. In this table, we present the instrument characteristics of TANSO-2 and IASI for which the observations are compared in this poster.

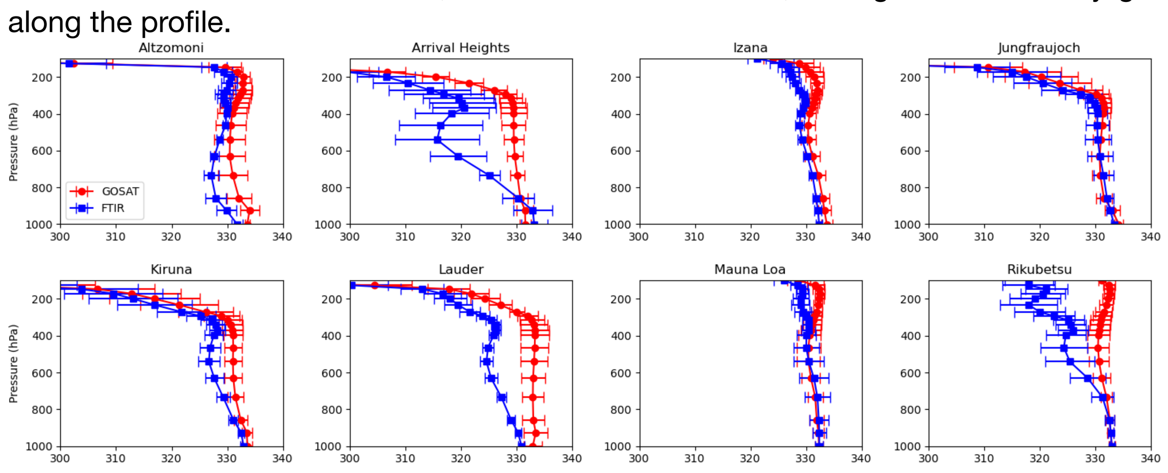
	GOSAT-2/TANSO-2	MetOp/IASI
L2 Version	GOSAT-2 provided on 01/04/2022	2.0; 2.1 from TN_2OR
Period	MAM 2019	2011, MAM 2019
Spectral band	1,188-1,800 cm^{-1}	1,210-2,000 cm^{-1}
Spectral sampling	< 0.2 cm^{-1}	0.25 cm^{-1}
Footprint	10 km	12 km
Simultaneous retrievals	N_2O, CH_4, H_2O, T	N_2O, CH_4, H_2O, T, Ts, emissivity
A priori	Dynamical = model	Fix over the globe
Pixels used	Nadir-viewing & Sunglint data	All

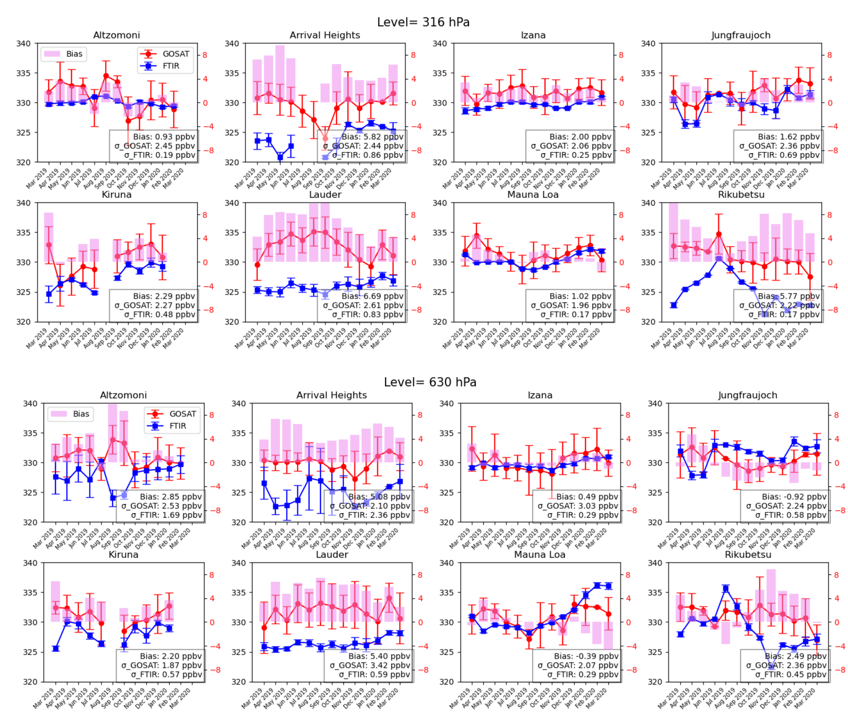
Comparison GOSAT-2/TANSO-FTS-2 vs NDACC



We compared the TANSO-2 satellite data with the NDACC data between March 2019 and March 2020. The NDACC sites are distributed globally. Below, we present the yearly profiles of the different observations. We selected NDACC sites where the data were available and scientifically acceptable (N_2O greater than 300 ppbv). We applied the TANSO-2 averaging kernel to the NDACC data, considering them as the reference. For Kiruna, Arrival Heights, and Lauder, TANSO-2 is systematically biased high, likely due to the extreme northern or southern positions of these sites. For Rikubetsu, we observed similar behavior above 600 hPa, while for the other sites, the agreement is fairly good along the profile.

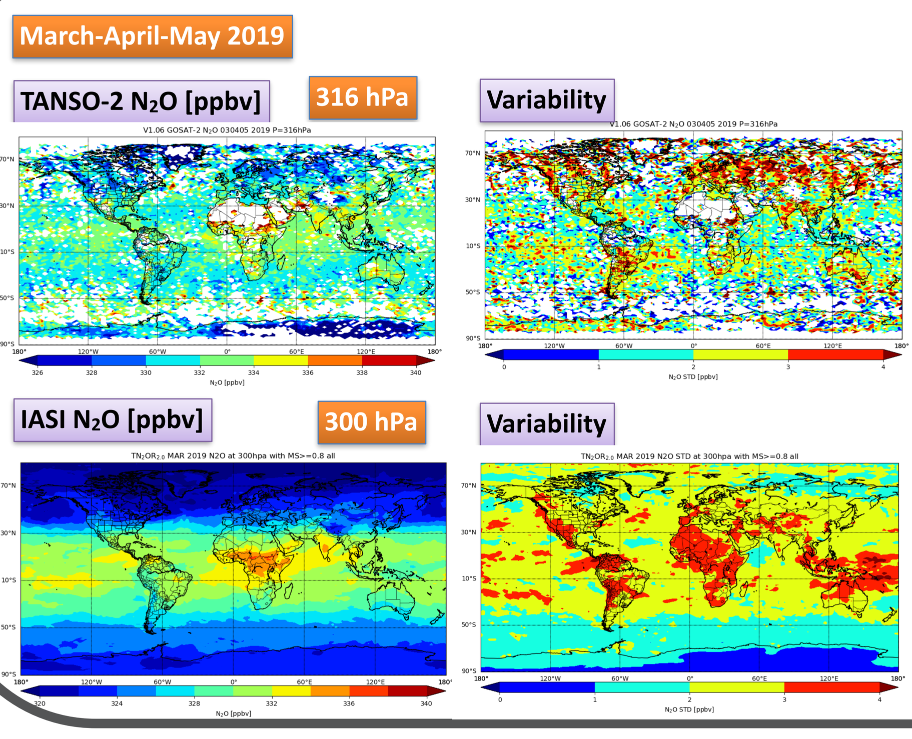
N2O Profiles from March 2019-March 2020





Moreover, we compared the data month to month at two GOSAT-2 levels, 630 hPa and 316 hPa. For Kiruna and Arrival Heights, the bias is 2.3 and 5.8 ppbv respectively, and remains constant throughout the year at both levels. Interestingly, despite the different locations, the behavior of the data is similar at these two sites. However, for Rikubetsu, the behavior is distinct. Here, the bias is significantly higher at 316 hPa with a mean bias of 5.77 ppbv, compared to 2.49 ppbv at 630 hPa. Notably, both datasets show a small decrease in N_2O levels, which is a surprising finding. Additionally, it is important to highlight that the variability of the GOSAT-2 data is higher than that of the NDACC data, indicating a greater range of fluctuations in the satellite measurements. Overall, these observations suggest that while there are consistent patterns at some sites, variability at others like Rikubetsu indicates the need for further investigation to understand the underlying causes.

Comparison with IASI TN_2OR

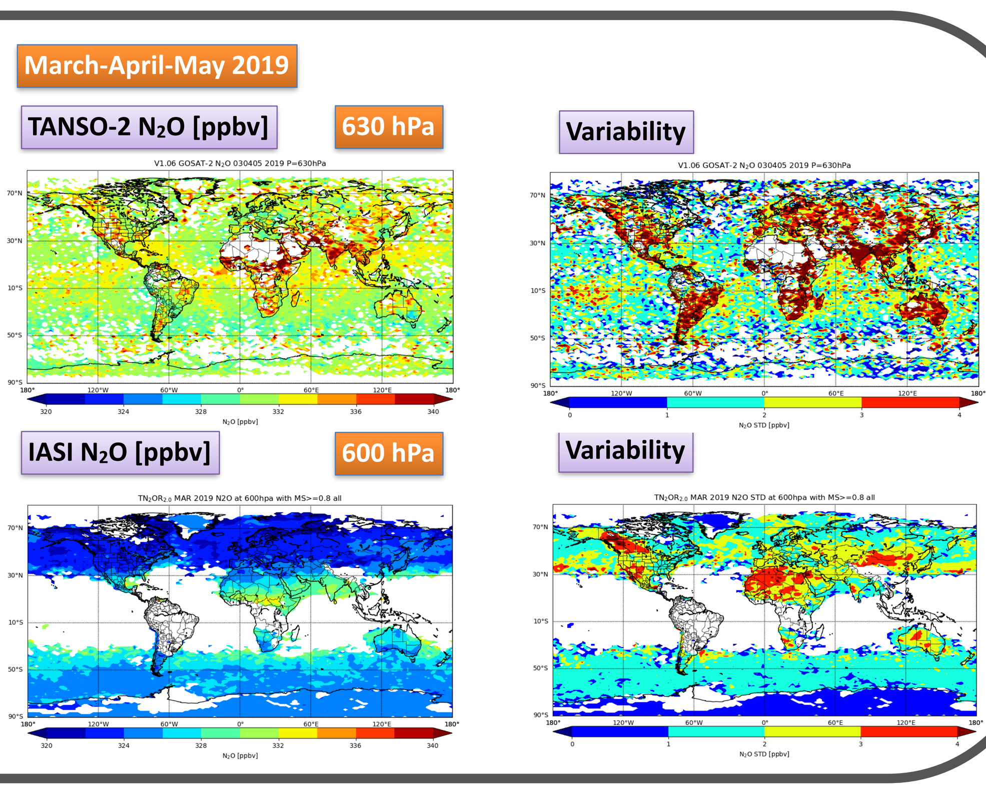


In the figure (left), the N2O observations for March, April, and May 2019 from both instruments at approximately 300 hPa reveal local maxima over Africa, and to some extent over India and the oceans in the tropical band. However, the contrast between tropical latitudes and higher latitudes is not well captured in the TANSO-2 data. Noisy pixels persist in the southern hemisphere due to regions with very low Degrees of Freedom. The satellite pixels are averaged into 1.26° x 2.5° boxes, compatible with the LMDz model, and the resulting standard deviation, which represents the variability, shows similar values. The variability is higher over the continents for both datasets, but the N2O concentration from TANSO-2 is slightly lower than that from IASI.

In the figure (right), the N_2O at 630 hPa from TANSO-2 still shows high local maxima over Africa and over India that are not present in the IASI data. This is likely due to the lack of sensitivity of IASI at this vertical level. In addition, lots of pixels (white areas) do not reach the criteria of measurement sensitivity (MS) defined below, which is higher than 0.8. One can see that the variability is still larger over the continents and TANSO-2 shows a larger variability compared to IASI. Moreover, the TANSO-2 N_2O distribution at 630 hPa presents some areas that are not correlated to the distribution at 316 hPa highlighting a better vertical sensitivity.

$$MS(P_i) = \frac{AK(P_i, P_i)}{max[AK(P, P_i)]} \; for \; i = 1 \; to \; n$$

where n is the total number of vertical layers and P the pressure level.



Comparison with Chemistry Transport Models

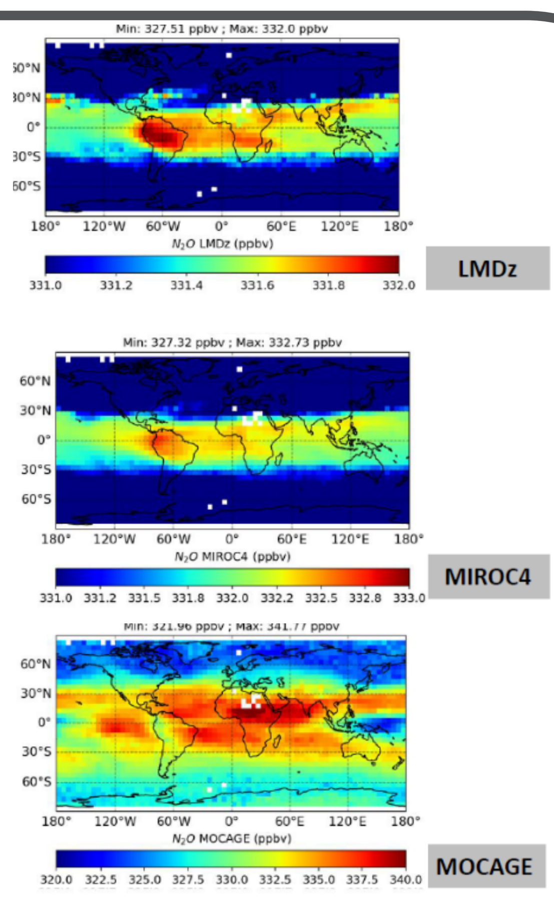
Three chemistry transport models were used to evaluate the TANSO-2 N2O horizontal distributions at 300 hPa for MAM 2019. The maximum over Africa, as calculated by MOCAGE, aligns well with the observations, whereas LMDz and MIROC-4 indicate a N2O maximum over South America. The global scale variability in MOCAGE (approximately 10 ppbv) better reflects the measurements by TANSO-2, while the variability in LMDz and MIROC-4 is significantly lower, at less than 2 ppbv. These differences can likely be attributed to the varying convection schemes and emission inventories employed by the models. Additionally, the model data were convolved with the TANSO-2 averaging kernels (AKs) for a more accurate comparison.

March-April-May 2019

300 hPa

Note that the values on the colour bar are different

	MOCAGE	LMDz	MIROC-4
lat x lon	1°x1°	1.27°x2.5°	2.77°x2.8°
Number of vertical levels	60	39	67
Convection scheme	Bechtold et al	Tiedke et al.	Arakawa-Schubert



Conclusions

The GOSAT-2/TANSO-2 (v01.06) N_2O observations are available from March 2019 to March 2020. Two independent pieces of information are present: one in the upper troposphere at about 300 hPa, consistent with IASI data, and another one in the middle troposphere around 600 hPa, providing an added value compared to IASI. When compared to NDACC observations, TANSO-2 data exhibit systematic biases at certain sites. For example, at Kiruna and Arrival Heights, TANSO-2 consistently shows higher N_2O levels, likely due to the extreme northern and southern positions of these sites. At Rikubetsu, the bias is more pronounced at 316 hPa than at 630 hPa, but a notable decrease in N_2O which is unexpected, is observed in both datasets. This indicates that while there is a general agreement in the negative slope of N_2O levels, the extent of variability is greater in the TANSO-2 data compared to NDACC. A higher variability in TANSO-2 measurements compared to NDACC is highlighted.

Three chemistry transport models (MOCAGE, LMDz, MIROC4) were used to evaluate the horizontal distributions of N_2O observed by TANSO-2 at 300 hPa from March to May 2019. MOCAGE shows a maximum N_2O concentration over Africa, consistent with the observations, while LMDz and MIROC-4 indicate a maximum over South America. The global scale variability in MOCAGE, approximately 10 ppbv, better reflects the TANSO-2 measurements, whereas the variability in LMDz and MIROC-4 is significantly lower, at less than 2 ppbv. These differences are likely due to the varying convection schemes and emission inventories used by the models.

In conclusion, these new results demonstrate the great potential of TANSO-2 for probing the middle to lower troposphere, which is promising for estimating N_2O surface fluxes.

References:

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