Evaluation of TanSat Carbon Dioxide total column measurements

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Abstract

We have evaluated TanSat Carbon Dioxide total column measurements against the ground-based measurements from Total Carbon Column Observing Network instruments. In the evaluation we determined station specific biases and precisions. Also the trends and seasonal cycle amplitudes were compared to see how well the long term changes can be followed by the TanSat measurements.

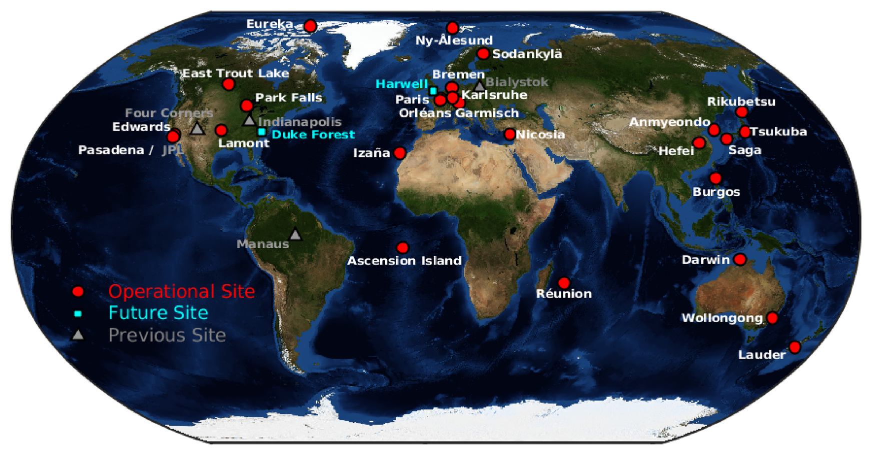
We found the TanSat Carbon dioxide total columns agreeing well with the TCCON measurements. The biases were between -1.6 – 1.4 ppm with precision (1-sigma) varying from 0.5 to 2.5 ppm depending on the station. There were vast amount of measurements made over snow surfaces but the average retrieval uncertainty over the snow cover was 3.11 ppm when it was only 1.37 ppm over snow free land. In general, the prior profiles agreed well with AirCore measurements with some deviations in the upper atmosphere during spring.

TanSat data description

TanSat satellite orbits the earth on a sun-synchronous orbit. The primary instrument onboard is the hyperspectral grating spectrometer (Atmospheric Carbon dioxide Grating Spectrometer, ACGS), that measures NIR/SWIR backscattered sunlight in the molecular oxygen (O2) A-band (0.76 mm) and two CO2 bands (1.61 and 2.06 mm) [Liu et al., 2018]. From the spectra column-average dry-air mole fractions of atmospheric carbon dioxide (XCO_2) is retrieved. The instrument can be operated in three observation modes: nadir, sun-glint, and target mode. The most common operation mode is the nadir mode. The footprint is 2 km x 2 km in the nadir mode with nine footprints in each swath, while the total width of the field of view (FOV) is 18 km. In this study we used the UoL-FP (University of Leicester Full-Physics retrieval algorithm for retrieval of CO2 from TANSAT data) version 1.0 dataset [Yang and Bosch, 2020].

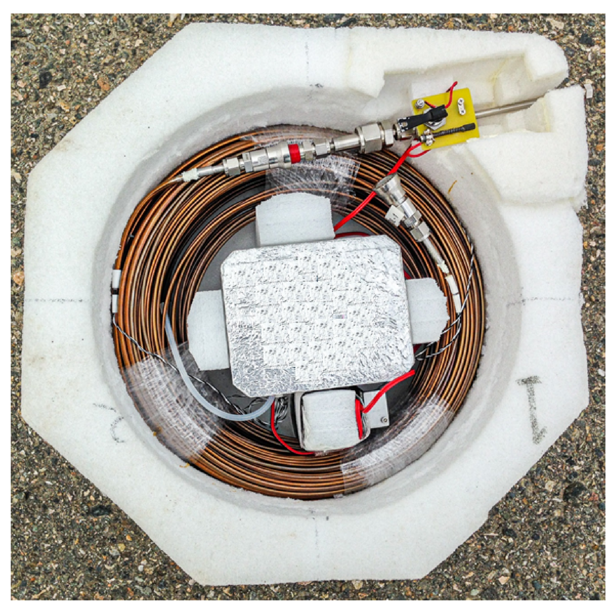
Ground-based and in-situ reference data

TCCON



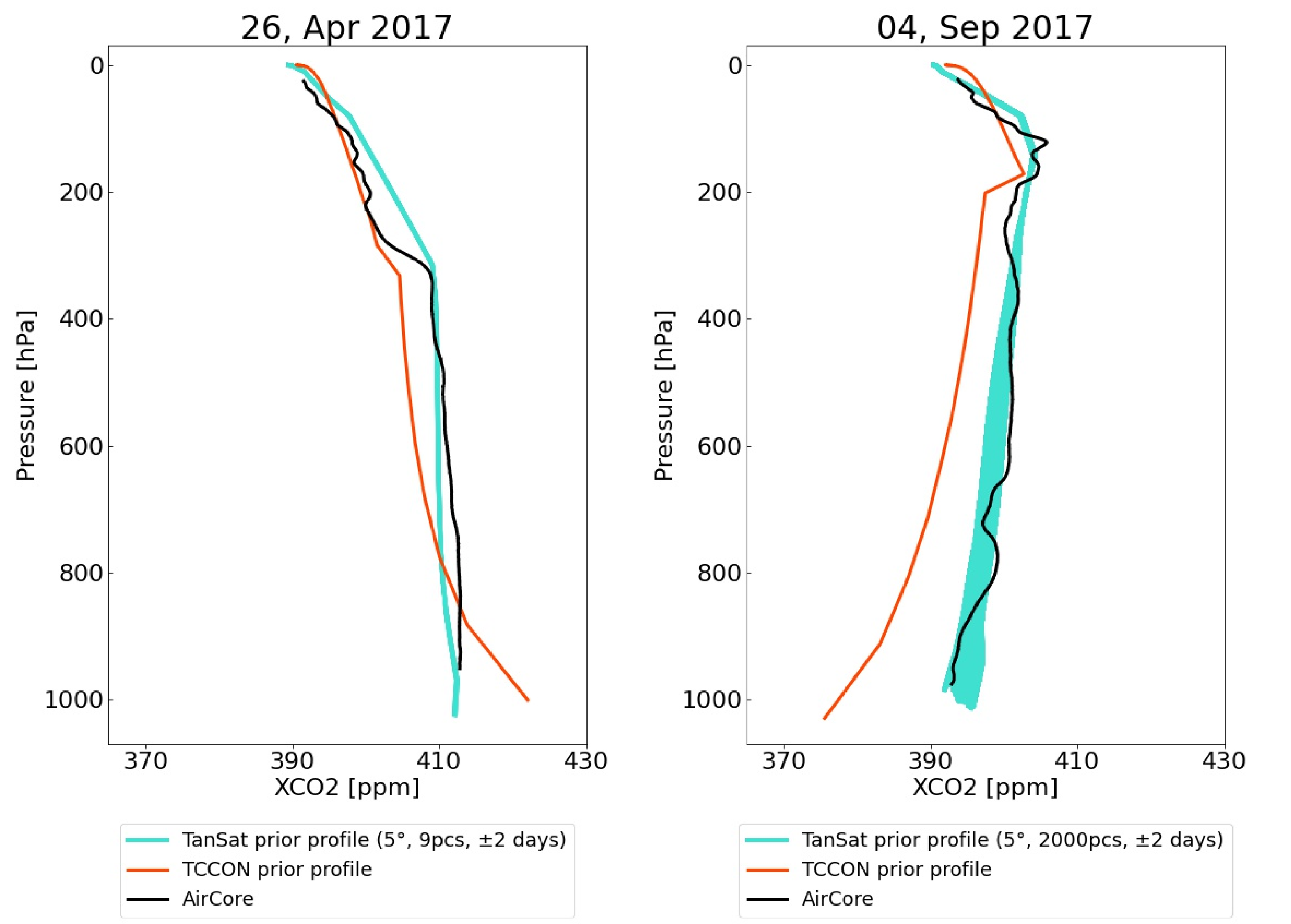
Total Carbon Column Observing Network (TCCON) is a network of ground-based high-resolution Fourier Transform Spectrometers. The standard measurement is made from direct solar light with resolution of 0.02 1/cm at near and short-wave infrared range. From the spectra the column-averaged dry-air mole fractions of several gases are retrieved including the most important greenhouse gases - Carbon dioxide(CO_2) and methane(CH_4). The error in CO_2 measurements is below 0.25% [Wunch et al., 2017]. While a new retrieval algorithm is on its way, in this work we have used the GGG2014 version of the TCCON data.

AirCore



AirCore is a sampling system to gather vertically resolved gas sample from the atmosphere. The main part is long (>100 m) long, thin-walled and narrow steel tube that is coiled [Karion, 2010]. The original design was a one-piece structure but later also two-piece designs have been made to improve vertical resolution of the profile at higher altitudes [Membrive et al., 2017]. The coil is lifted to 30 km altitude with a balloon. When the coil descends, using a parachute to slow the speed, it is gradually filled by the surrounding air because of the rising ambient pressure. When the coil reaches ground the input valve is closed. As in the narrow tube the mixing is slow, the coil then contains a vertically resolved sample of the atmosphere that can be analyzed with a gas analyzer. At the Arctic Space Centre in Sodankylä about 10 soundings a year are made.

Verifying prior profiles using AirCore measurements

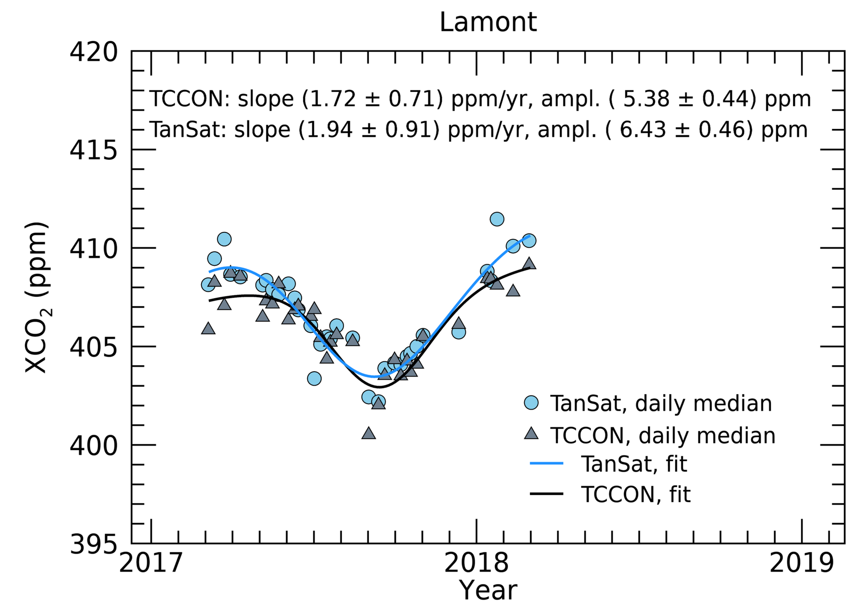


There were 8 AirCore soundings co-located (within 2 days, 5 degrees in latitude and longitude) with TanSat measurements at FMI Arctic Space Centre in Sodankylä. Here are shown two examples; one in spring and one in autumn. Typically the TanSat prior profiles agreed well with AirCore soundings following the same general shape but of course not every small detail. In spring the stratospheric part is hard to model and there are some small discrepancies.

Results from TCCON comparison

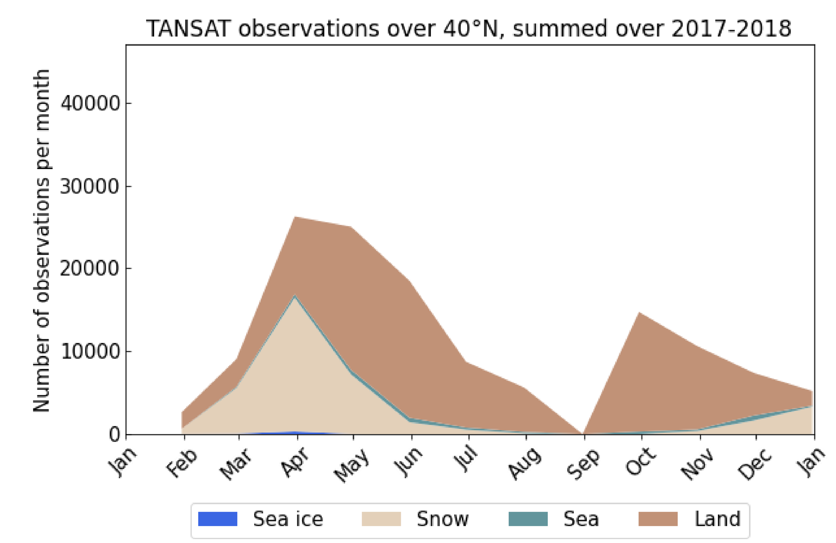
TCCON site	Bias (ppm)	Std. dev (ppm)	Rel. bias %
Bialystok	0.5	2.0	0.1
Bremen	0.4	1.0	0.1
Burgos	0.0	1.3	0.0
Caltech	-1.4	1.8	-0.3
Darwin	-0.2	1.7	-0.1
East Trout Lake	0.1	1.2	0.0
Edwards	1.1	0.5	0.3
Garmisch	-0.2	1.1	0.0
JPL	-1.0	2.1	-0.2
Karlsruhe	0.9	1.9	0.2
Lamont	0.6	1.3	0.2
Lauder	1.4	1.3	0.3
Orleans	1.2	1.1	0.3
Paris	-2.9	7.0	-0.7
Park Falls	0.0	1.5	0.0
Rikubetsu	-1.6	2.5	-0.4
Saga	-1.2	1.5	-0.3
Sodankylä	-0.2	2.5	-0.1
Tsukuba	-0.2	2.3	-0.1
Wollongong	-0.4	1.2	-0.1
Zugspitze	0.2	1.6	0.1

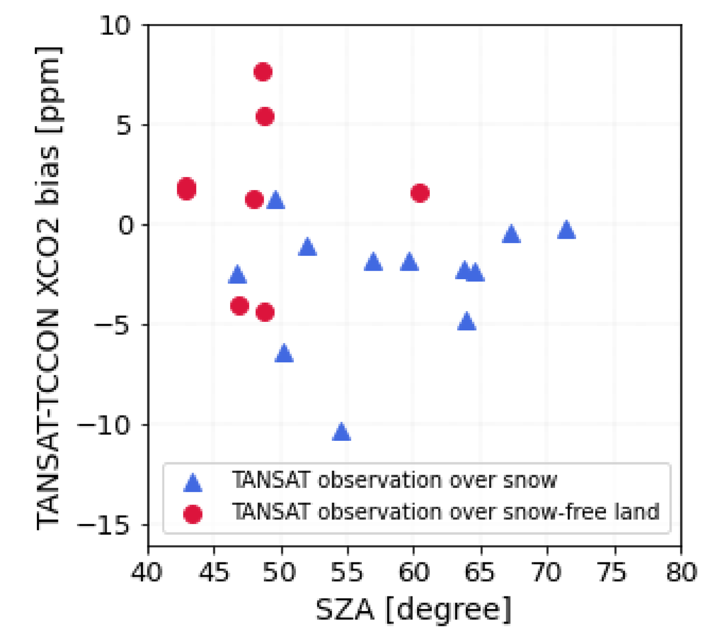
There were 21 TCCON stations with co-located measurements with TanSat (daily mean, 2.5 degrees in latitude, 5 degrees in longitude). The station specific biases in total CO_2 columns were between -1.6 to 1.4 ppm and the standard deviations varied from 0.5 to 2.5 ppm. The station specific results can be found from the table above. Paris was regarded as an outlier. The larger differences to TCCON in Paris are probably related to differences in the spatial coverage of the measurement close to an area with larger emissions from traffic and industry.



We also defined the seasonal cycle amplitude and trend from both TCCON and TanSat data. Here is an example using data from the Lamont TCCON instrument. The seasonal cycle seems to be well reproduced by the satellite data but with only one cycle it is hard to make strong conclusions.

Evaluation of retrievals over snow covered scenes





As the snow surface reflectance is low in near and short-wave infrared wavelength range, the coverage over high latitudes can suffer during winter and spring. The availability plot above shows that TanSat has a good coverage over snow covered surfaces; north of 40°N 28% of retrievals were over snow, when the corresponding number for GOSAT for example was 6%. However, the mean retrieval error over snow surfaces was 3.1 ppm when it was only 1.4 ppm over snow-free surfaces.

The comparison of TanSat data against the Sodankylä TCCON data [Kivi&Heikkinen, 2016] suggests there is no solar zenith angle dependent biases in the TanSat data. It seems TanSat measurements over snow have a small negative bias while measurements over snow-free surfaces have no bias or small positive bias. However, the amount of data is still quite limited to make strong conclusions yet.

Conclusions

- Bias in the TanSat OCFP product varies between -1.6 – 1.4 ppm against different TCCON FTS; corresponds to < 0.4%. Precision (1-sigma) varies between 0.5 to 2.5 ppm.
- TanSat yields a lot of retrievals over snow; 28% of all retrievals north of 40 °N, while for example the fraction for GOSAT was (6%).
  - However, the quality of the retrievals over snow is worse than over snow-free surface (average retrieval error 3.1 ppm over snow and 1.4 ppm over snow-free)
- TanSat CO_2 priors agree well with AirCore soundings over FMI Arctic Space Centre with discrepancies occurring mainly in the upper atmosphere during spring.

References

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