Examining ACE-FTS and PEARL-FTIR Data in the Arctic

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Motivation

During the winter, conditions in the Arctic atmosphere become extremely cold due to the formation of the polar vortex, a stable circulation cell that isolates the Arctic from the rest of the atmosphere. This in turn allows reactions that impact the ozone layer to favorably occur. Much can be learned by observing, analyzing, and comparing data from some of the trace gases that react due to the conditions brought on by the polar vortex. As a result, this research seeks to demonstrate these observations to compare measurements from two different instruments to see how they agree during the Arctic springtime.

Background

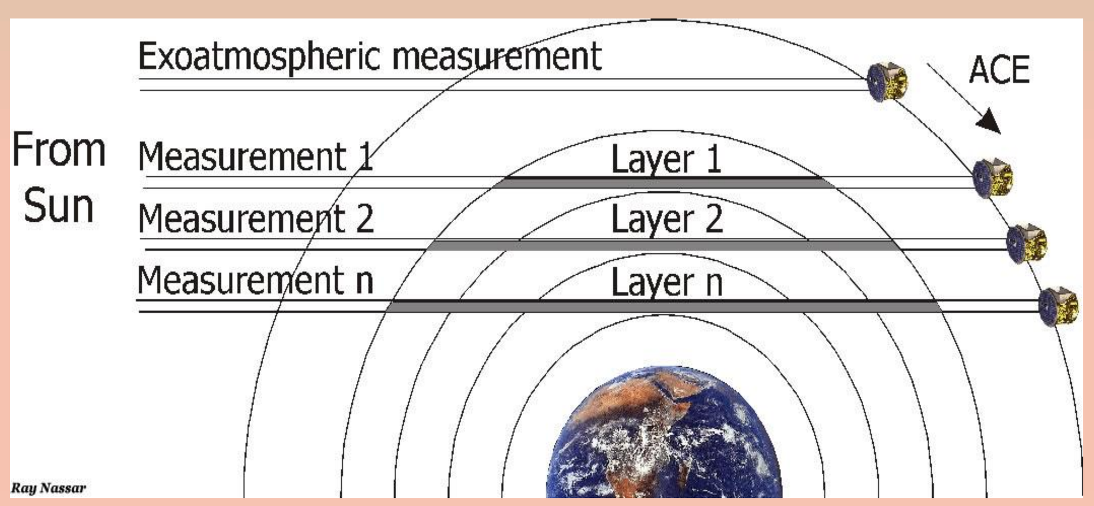
Hydrogen chloride or HCl, can be found throughout the stratosphere and the upper troposphere, but the gas is most important in the middle stratosphere due to the ozone layer and the polar stratospheric clouds (PSCs) that form in the region. PSCs are ice-like clouds that form at very low temperatures in the polar vortex during wintertime. These clouds are important because they enable a reaction between the reservoir gases of HCl and chlorine nitrate ($ClNO_3$) that releases chlorine and begins the catalytic cycle that depletes the ozone layer. This reaction can be seen here:

$$ClNO_3 + HCl \xrightarrow{PSC} Cl_2 + HNO_3$$

The measurements of this trace gas by a ground-based instrument and a space-based instrument will be compared by calculating total column and partial columns. The measurements made by the two instruments will then be compared as both an absolute and a percentage difference in order to evaluate the agreement between the two.

ACE-FTS

Name: Atmospheric Chemistry Experiment Fourier-Transform Spectrometer (ACE-FTS).
Launch: Launched onboard the SCISAT satellite on 12 August 2003.
Objective: To help scientists understand the depletion of the ozone layer better, especially in the Arctic region. This was done by measuring the atmosphere focusing on high latitudes.
Measurements: The ACE-FTS instrument is a Fourier-transform infrared spectrometer that measures the atmosphere by solar occultation. These occultations occur during the sunrise or sunset as the satellite travelling in its orbit. Figure 1 shows the limb-viewing (occultation) method used by the instrument so that it can measure different layers of the atmosphere. The measurements retrieved from the spectra include profiles of temperature, pressure and volume mixing ratio from 70 different trace gases.
Coverage: The latitude region covered can be seen in figure 2. This region varies through the year as the sunrises and sunsets change. This coverage goes from 85° N to 85° S.



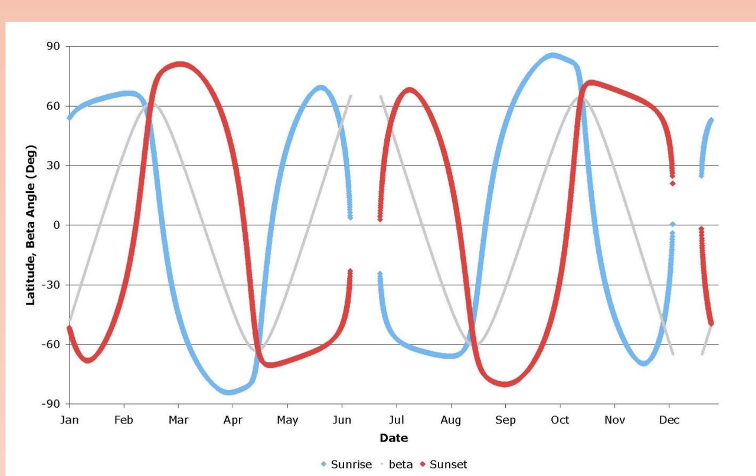


Figure 1 on the top is the limb-viewing occultation method used. Figure 2 on the bottom is the coverage during the year. Both were retrieved from the ACE instrument website at: http://www.ace.uwaterloo.ca/gallery.php

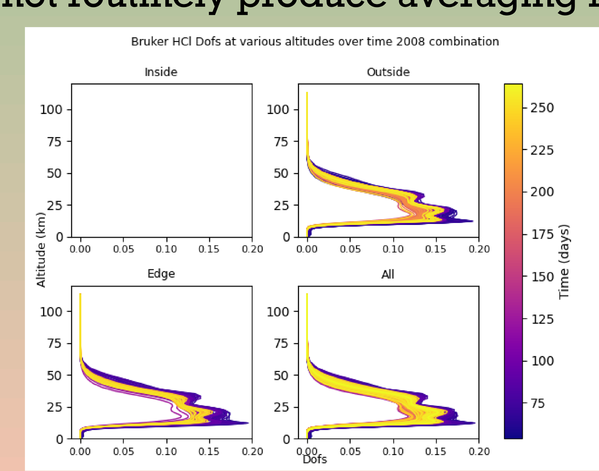
PEARL-FTIR

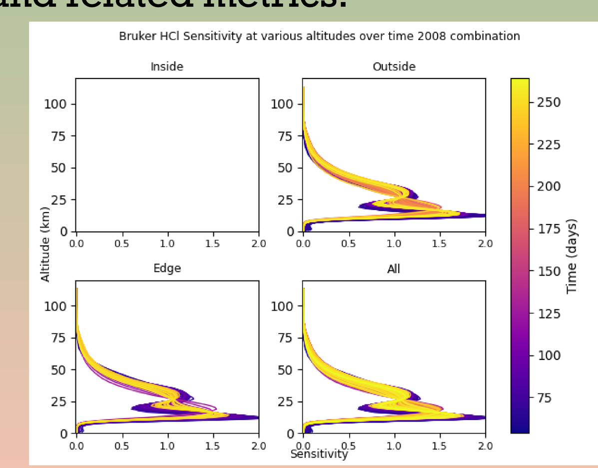
Name: Polar Environment Atmospheric Research Laboratory Fourier-Transform Infra-Red Spectrometer. Also called the Bruker 125HR.
Installed: Installed at the Polar Environment Atmospheric Research Laboratory (PEARL) in Eureka, Nunavut, Canada in July 2006.
Objective: Installed in northern Canada, the instrument is used to take profile and column measurements of the atmosphere of the high Arctic. Its positioning also allows it to take measurements inside and outside of the polar vortex depending on the year.
Measurements: The PEARL-FTIR instrument is a ground based high-resolution Michelson interferometer. The PEARL-FTIR records solar absorption spectra (as does the ACE-FTS), which are used with the SFIT4 retrieval algorithm to obtain estimates of trace gas profiles and total column quantities.
Coverage: The covered region is around the PEARL Ridge Lab located in Eureka, Nunavut (80.05N, 86.42W), depending on where the solar occultation is occurring and the weather at the time.

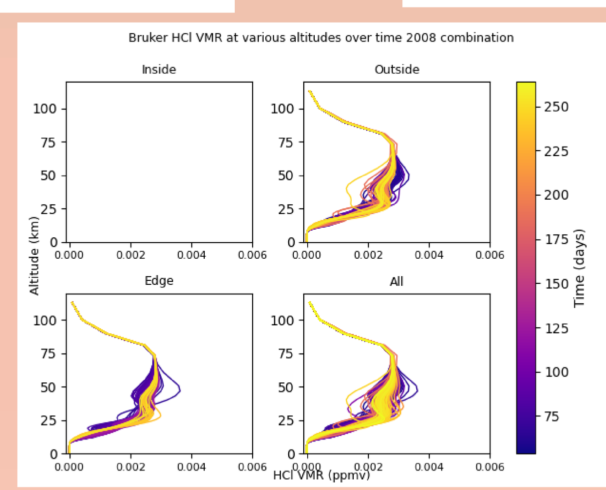
PEARL-FTIR Retrieval Properties

The information content of the retrievals performed using the PEARL-FTIR observations is contained within the averaging kernel (avk) of the retrievals. This avk is a matrix used to characterize the data and is the result of the retrieval algorithm. x'=A(x)-(A-I)(x_a). x' is the best estimate profile estimated by the SFIT4 algorithm, x_a is the a priori profile measured by the instrument, x is the true unknown profile representing the real gas measurements of the atmosphere, I is the identity matrix and A is the averaging kernel. The a priori is the initial guess taken by the instrument using other sources, this is then used by the retrieval algorithm to better treat the measured data. The avk contains information about the sensitivity of the retrieval to the measurement, and the amount of information contained in the retrieved trace gas profiles and columns.

These plots are split into 4 different sections depending on measurement location with respect to the polar vortex (e.g., inside the vortex, outside the vortex, on the edge, all measurements). The degrees of freedom for signal on the left represent the amount of information available at different altitudes. The sensitivity in the middle represents the fraction of the data that is derived from the measurement versus the a priori information (value of 1 is best). On the bottom is the volume mixing ratio (VMR) plots that these first two plots apply to. The VMR plot is more uniform as the sensitivity decreases because the retrieval profiles converge to the a priori estimate used.
The ACE-FTS instrument does not use this retrieval method which means that its dataset does not routinely produce averaging kernels and related metrics.







Acknowledgements

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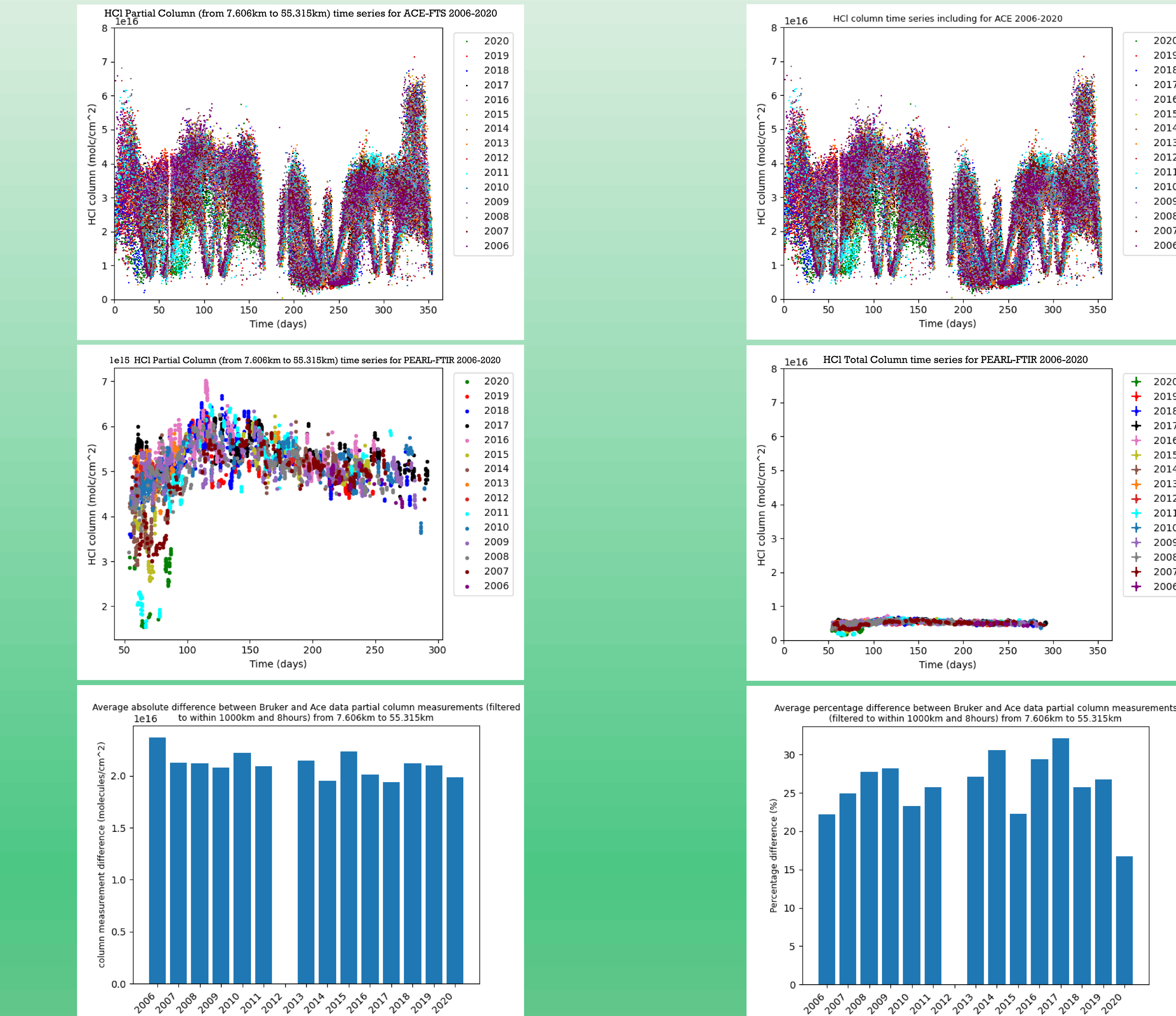
Analysis of Retrieved Trace Gas Columns



The top two plots represent the ACE-FTS total and partial column time series where we can see the changes in the measurements over the year. The partial column is a column measurement taken between two specific altitude bounds, it is represented on the top left plot and takes data points within 1000km of the location of the PEARL-FTIR measurements and has altitude bounds of 7.606km to 55.315km. However, the partial column time series on the left is almost identical to the total column on the right since most of the ACE-FTS data is located within those bounds. When we compare these time series to the PEARL-FTIR ones below, we see that they are very different. The two middle plots are of the PEARL-FTIR partial column time series using the same altitude bounds as the ACE-FTS, the one on the right uses the same plot limits as the ACE-FTS data as well. Using this middle right plot we can get an idea of the difference between the ACE-FTS data and the PEARL-FTIR data. On the bottom left we see the absolute difference of the mean of the partial column measurements. The difference between the ACE-FTS and the PEARL-FTIR data in this bar plot seems to be constant, but when we look at the percentage difference on the bottom right, we see that the difference changes by ~5% from year to year and the average percentage difference is ~25%. The equation used to calculate the percentage difference between the ACE-FTS data and the PEARL-FTIR was: $100 - \left(\frac{ACEData[i] - BrukerData[i]}{ACEData}\right) * 100$

Discussion

Looking at these 15 years of data from the ACE-FTS instrument dataset as well as the PEARL-FTIR instrument dataset, we can observe that the two do not seem to be too far off. The mean percentage difference for the partial column and the total column measurement shows that the difference between these two datasets is ~25%. This demonstrates that there is a difference between the data measured by each instrument, but when looking at the orders of magnitude, that being of 10^{15} to 10^{16} molecules/cm^2, this difference ends up not being that great. Juxtaposing this comparison technique and percentage difference to the ones found in the Griffin et al. 2017 paper, we can get an idea of what could be done in the future to compare these two datasets better. Future work in this research could be done to account for the difference in measurement sensitivity between the two instruments and smooth the ACE-FTS measurements by the avk from the PEARL-FTIR.

References

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