Trace Gas Retrievals Using the Polar Atmospheric Emitted Radiance Interferometer (P-AERI)

Alessio C. Spassiani[1]*, P. M. Rowe[2] and V. P. Walden[2]
[1]York University, Toronto, ON, Canada [2]University of Idaho, Moscow, ID, USA
*borgo89@yorku.ca

Abstract

The Arctic and Antarctic are expected to experience the most drastic change in their environment due to climate change. The main increase in the global temperature is attributed to carbon dioxide, however some research has shown that the combined effect of traces gases will be equal to that of CO_2.[1] It is therefore important to develop a greater understanding of the effects that trace gases have on climate change and to have a well-developed data record of trace gas column amounts to observe these patterns of change. The objective of this research project is to retrieve the amount of trace gases over a three-year period (March 2006 – April 2009) where the Polar Atmospheric Emitted Radiance Interferometer (P-AERI) was at the 0PAL facility at Eureka, Nunavut, for clear sky times only. The P-AERI has a spectral coverage from 500-3,000cm^{-1}. The retrievals focused on the trace gases; CO_2, CH_4, H_2O, O_3, N_2O, HNO_3, and CO. The findings of this project may allow for a better understanding of the pattern changes in the trace gas column amounts over the time period.

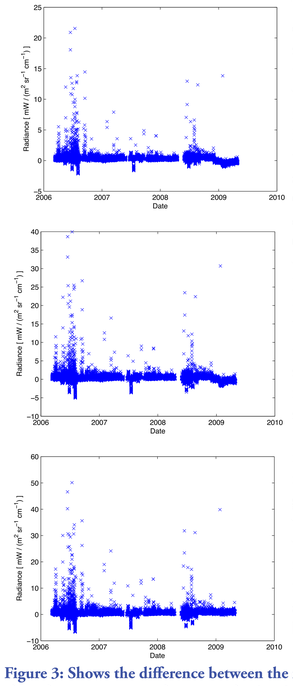
Figure 1: The P-AERI instrument installed at the OPAL Facility.

Figure 2: The OPAL Facility located at the North West Quadrant of the Eureka Weather station.

Instrument

The Polar Atmospheric Emitted Radiance Interferometer (P-AERI), shown in figure 1, is an atmospheric emitted radiance interferometer (AERI) that is modified for use in the polar regions. The AERI is a ground-based Fourier-transform infrared (FTIR) spectrometer that passively measures atmospheric emission and was developed by the Space Science and Engineering Center (SSEC) at the University of Wisconsin.[2,3] The P-AERI is modified such that it is able to view the atmosphere and surface at any angle from 0 to 180 degrees. The interferometer, Model MR-100, is manufactured by ABB Bomem Corporation. It has two spectral channels: channel 1 measures frequencies from 500-1800cm^{-1} and channel 2 measures frequencies from 1750-3000cm^{-1}. The work presented focuses on data from channel 1. The instrument was stationed at the Zero-altitude PEARL Auxiliary Laboratory (0PAL), as seen in figure 2, in Eureka, Nunavut, Canada (80°N 86°W) from March 2006 to June 2009. Measurements were taken every seven minutes with a resolution of 0.5cm^{-1} year round, even during the polar night.[2,3]

Method: filtering data



The main focus of this work is the retrieval of trace gas column amounts during clear sky times. The presence of clouds makes the retrieval of trace gases difficult since water results in strong absorption of radiation throughout the spectrum of interest. Clear sky times were determined using the mixed-phase cloud retrieval algorithm (MIXCRA)[4] output created by Chris Cox which, retrieves cloud optical depth and uses a optical depth threshold of 0.25 to determine if the instrument was viewing clouds at the time of the spectrum. From the clear sky time data, simulated radiances were calculated using the line-by-line radiative transfer model (LBLRTM). Time series were created showing the measured and simulated radiances in microwindows between strong lines, 900cm^{-1}, 961 cm^{-1} and 1,201.5 cm^{-1}. Times where the measured radiance was larger than the simulated radiance by 0.8mW/(m^{2}srcm^{-1}) or greater, were removed when this criteria was not meet at all three atmospheric windows analyzed. Measured radiance much larger than the simulated radiance is the result of large amounts of water in the atmosphere, probably clouds, which should be avoided when possible.

Figure 3: Shows the difference between the measured and simulated spectrum for all the clear sky spectrums at the atmospheric windows 900 cm^{-1} (top), 961 cm^{-1}(middle) and 1201.5cm^{-1} (right).

There are several spectra where the simulated radiance was much larger than the measured radiance. This is visible in figure 3 where the difference values are negative. By comparing the difference between the measured and simulated radiance to atmospheric variables such as, temperature, relative humidity and precipitable water vapour(PWV), one was able to see that the difference was dependent on the temperature and PWV. Above a temperature of 255K there are more spectra where the simulated radiances are larger than the measured radiance as shown in figure 4. Similarly, when the PWV was above 0.8cm there was more spectra with a negative difference. The temperature and PWV are related in that the higher the atmospheric temperature, the more water vapor will be in the air for the same relative humidity. Therefore, above a PWV threshold of 0.8cm the simulated radiance becomes larger than the measured. This is probably a result of poor calibration for those times.

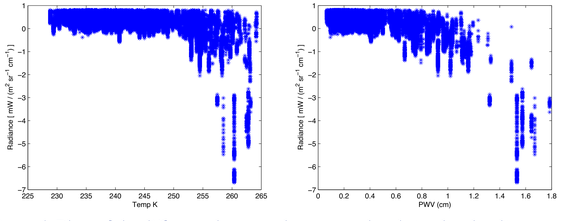


Figure 4: Plots of the difference between the measured and simulated radiances versus the temperature (left) and radiances versus the PWV (right).

Selecting retrieval wavenumbers

Monthly mean profiles were created using the radiosonde profiles and ozonesondes over the entire period that the P-AERI was located at 0PAL. The radiosondes and ozonesondes were launched at least twice daily at 0Z and 12Z at Eureka and were updated with a priori data above 16km. The mean monthly precipitable water vapour (PWV) was also calculated and are displayed in table 1. Using the mean monthly profiles the total error in the measurements and simulations were calculated for the trace gases; H_2O, CO_2, HNO_3, N_2O, CH_4, O_3, CO, C_2H_2, HCN, CCl_4, F11 (CCL_3F), F12 (CCL_2F_2) and F113 (CCL_2FCCIF_2). This was used to determine the set of the most suitable wavenumbers to use in the retrieval of each gas for a specific PWV. The PWV associated with each spectrum can then be matched up with the predetermined set of wavenumbers found for a given PWV, providing the best results for the retrievals of the trace gases.

Table 1: Mean monthly PWV

PWV (cm)	Month
0.15	January
0.21	February
0.17	March
0.32	April
0.53	May
0.99	June
1.36	July
1.25	August
0.73	September
0.40	October
0.23	November
0.22	December

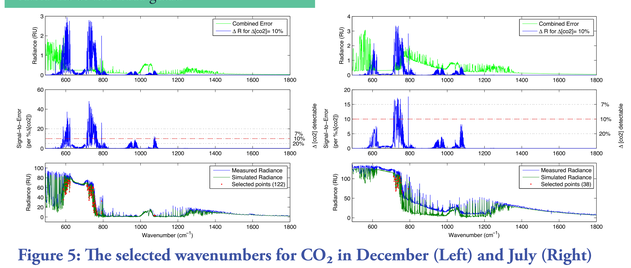


Figure 5: The selected wavenumbers for CO_2 in December (Left) and July (Right)

Figures 5 and 6 were created for each trace gas showing three different graphs. The top graph shows the change in the radiance of a given gas for a predetermined percent change in the gas amount along with, the combine radiance error. The middle graph shows the Signal-to-Error per percent change in the gas concentration. Retrievals for that particular gas can be done at the wavenumbers above a predetermined Signal-to-Error threshold. The bottom graph shows the selected points suitable for the retrieval. These figures are shown for CO_2 and H_2O for December and July in figure 5 and 6, respectively. The points selected for all the gases for these two months can be seen in figure 7. The number of suitable wavenumbers for the retrieval of each gas for each month is shown in table 2. It is important to note that for the summer months there is an increase in the amount of water present in the atmosphere resulting in more wavenumbers possible for retrievals of water but less wavenumbers appropriate for the retrieval of other gases.

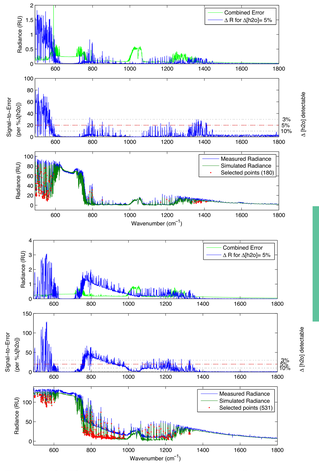


Figure 6: The selected wavenumbers for H_2O in December (top) and July (bottom).

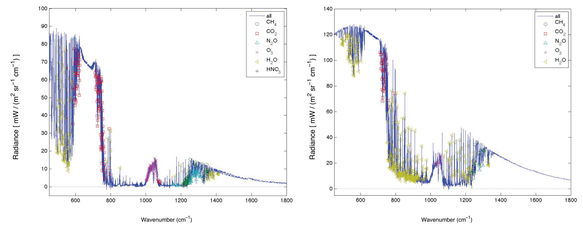


Figure 7: Shows the selected wavenumbers for the retrieval of each gas, H_2O, CO_2, HNO_3, N_2O, CH_4 and O_3, December (left) and July (right).

Table 2: Number of possible retrieval wavelengths

Month	H_2O	CO_2	HNO_3	N_2O	CH_4	O_3	HCN	C_2H_2
January	197	137	2	96	83	130	0	0
February	185	130	2	76	70	129	0	0
March	189	132	2	80	76	133	0	0
April	196	121	0	67	57	133	0	0
May	211	94	0	22	38	114	0	0
June	268	94	0	22	38	114	0	0
July	532	38	0	5	22	37	0	0
August	536	39	0	6	35	54	0	0
September	280	84	0	16	35	98	0	0
October	222	118	0	49	53	123	0	0
November	186	126	0	61	71	126	0	0
December	186	125	0	57	71	124	0	0

Future work

Future work includes the retrieval of the total column amounts of each of the trace gases listed using both channel one and channel two over the entire time period. Wavenumbers selected for each trace gas will be refined. Moreover, the results will be compared to those obtained by the E-AERI that was located at the PEARL facility in Eureka from October 2008 to April 2009.

Acknowledgements

Thank you to Dr. Von Walden of the University of Idaho and Dr. Kimberly Strong of the University of Toronto for providing the funding for my undergraduate summer internship. Thank you to Dr. Penny Rowe, Dr. Von Walden and Dr. Kimberly Strong for their help and mentoring.

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