RESULTS FROM THE THREE CANADIAN ARCTIC VALIDATION OF ACE CAMPAIGNS CONDUCTED AT EUREKA FROM 2004 TO 2006

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ABSTRACT

The Atmospheric Chemistry Experiment (ACE) is a Canadian scientific satellite mission performing remote sensing measurements of the Earth's atmosphere. Three ACE Arctic validation campaigns have been conducted at Eureka (Canada) between February and April in 2004, 2005 and 2006. This period coincides with the most chemically active time of year in the Arctic and also, at this time, there are a significant number of ACE satellite measurements near Eureka. The polar vortex regularly passes over the campaign site so measurements both inside and outside the vortex region can usually be made from this location. A suite of ten ground-based and balloon-borne instruments made observations during the measurement campaigns. This paper discusses the ozone total column and profile comparisons from the 2004 and 2005 campaigns and presents preliminary results from the recently completed 2006 campaign.

1 INTRODUCTION

Three Arctic measurement campaigns have been conducted in Eureka (Canada) in spring 2004, 2005 and 2006 to validate measurements from the Atmospheric Chemistry Experiment (ACE) satellite mission [1]. The ACE satellite (SCISAT-1) was launched on 12 August 2003 and science operations began in February 2004. Two instruments on board the satellite provide measurements of chemical species: an infrared Fourier Transform Spectrometer (ACE-FTS) and a dual UV-visible-NIR spectrophotometer called ACE-MAESTRO (Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation). The main goal of the ACE mission is to provide measurements to enhance our understanding of the ozone distribution in the upper troposphere and the stratosphere, especially over the Arctic.

The validation campaigns were conducted between February and April in 2004, 2005 and 2006 at Environment Canada's Arctic Stratospheric Ozone (AStrO) Observatory, which, in 2005, became the Polar Environment Atmospheric Research Laboratory (PEARL) run by the Canadian Network for the Detection of Atmospheric Change (CANDAC). This facility is located in Eureka, Nunavut (80.05°N, 86.42°W, 610 m). The February to April period coincides with the most chemically active time of year in the Arctic and with a significant number of satellite overpasses. Seven ground-based instruments were operated during the 2004 campaign: a ground-based version of the ACE-FTS (PARIS-IR - Portable Atmospheric Research Interferometric Spectrometer for the Infrared), a clone of the ACE-MAESTRO, a SunPhotoSpectrometer (SPS), a zenith-viewing UV-visible grating spectrometer, a Bomem DA8 Fourier transform spectrometer, a Differential Absorption Lidar (DIAL) and a Brewer spectrophotometer. For the 2005 and 2006 campaigns, a Système d'Analyse par Observation Zénithale (SAOZ) and a second Brewer spectrophotometer were added to the set of instruments. In addition to the ground-based instruments, balloon-borne ozonesonde and radiosonde sensors were flown frequently during all campaigns.

We focus here on comparisons of ozone measurements made by the ground-based, balloon-borne and satellite-borne instruments during the three ACE Arctic Validation campaigns. Comparisons of both retrieved ozone columns and profiles will be presented. Also, the ozonesonde profiles from the three campaigns will be compared to highlight the differences between the years.

2 SATELLITE MEASUREMENTS

SCISAT-1 satellite is in an orbit at 650 km altitude and an inclination of 74°. ACE-FTS is the primary instrument and is a high-resolution (0.02 cm^{-1}) infrared FTS operating from 750-4400 cm^{-1}, with a two-channel visible/near IR imager (0.525 and 1.02 μm) [1]. ACE-MAESTRO is the secondary instrument and measures from 285 to 1030 nm with 1-2 nm resolution. The instruments have been making routine solar occultation observations of the Earth's atmosphere since February 2004. These sunrise and sunset measurements are used to determine atmospheric profiles of ozone and other trace gas species and temperature, pressure and atmospheric extinction [2]. The ACE-FTS and ACE-MAESTRO measurements are made with a vertical resolution of ~4 km and ~1 km, respectively. The ACE-FTS data product consists of these results interpolated onto a 1-km grid. ACE-FTS version 2.2 "updated" ozone profiles and ACE-MAESTRO version 1.1 ozone profiles are used in the comparisons described below.

During each of the three Arctic validation campaigns, there were up to ten ACE occultation measurements within 200 km of Eureka. The ground track locations for these occultations are shown in Fig. 1. In addition, from mid-February to mid-March in each year, there were approximately 20 more occultations within 500 km of the PEARL/AStrO site.

3 GROUND-BASED AND BALLOON-BORNE MEASUREMENTS

This section describes the instrument suite developed for the first ACE Arctic Validation Campaign in 2004 and additions and changes made for the 2005 and 2006 campaigns.

In 2004, seven ground-based instruments were operated during the intensive phase of the campaign (21 February to 9 March). There were two FTSs: PARIS-IR [3] and the high-resolution Bomem DA8 MSC-FTS [4] run by the Meteorological Service of Canada (MSC). PARIS-IR has the same resolution (0.02 cm^{-1}) and spectral range (750 – 4400 cm^{-1}) as the ACE-FTS and the MSC-FTS has an apodized resolution of 0.004 cm^{-1} and measures using a series of wide-band interference filters over the range from 700 to 5000 cm^{-1}. In 2004 and 2005, one suntracker was shared by the two FTSs, so simultaneous measurements were not possible. In 2006, a mirror system was constructed to split the incoming solar beam so that spectra could be recorded simultaneously.

The MSC-FTS has been installed at PEARL/AStrO since 1993 and is a component of the primary Arctic station of the international Network for the Detection of Stratospheric Change (NDSC, now Network of the Detection of Atmospheric Composition Change or NDACC) [5]. Over the last decade, it has recorded

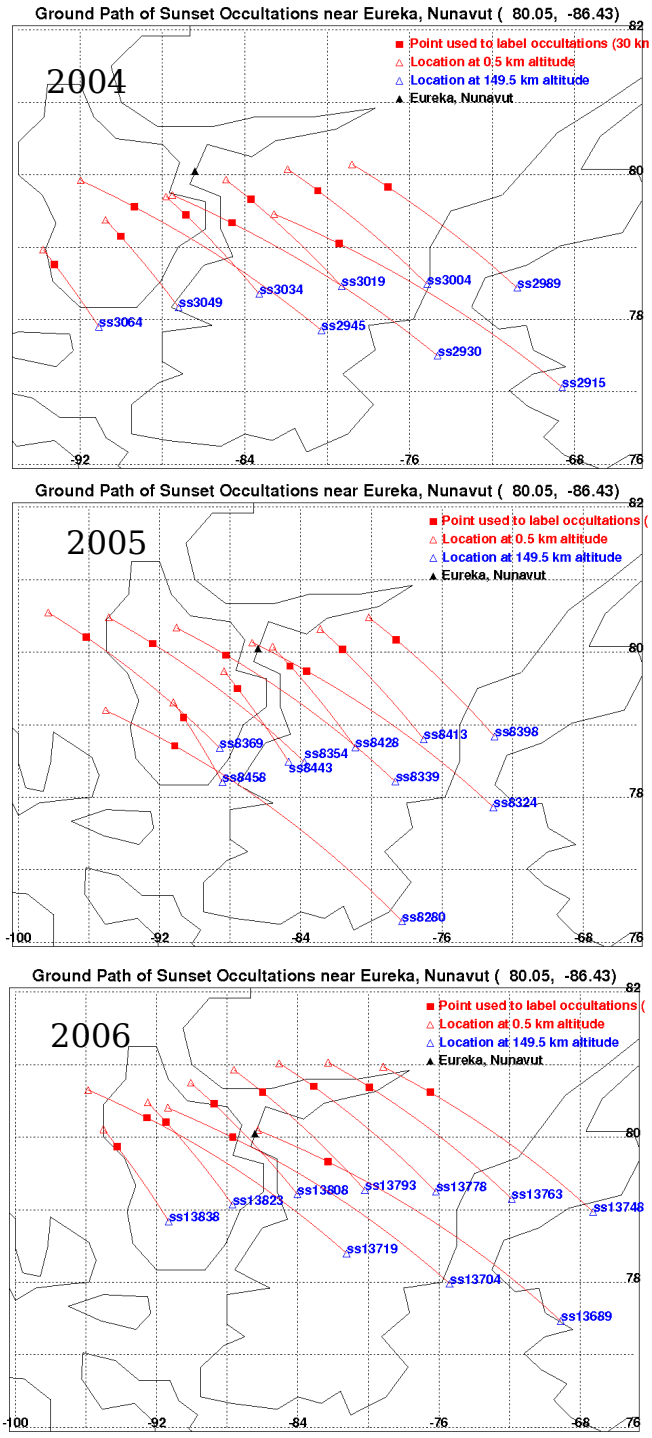

Fig. 1. The ground paths of the ACE occultations within 200 km of the PEARL/AStrO site during the 2004, 2005 and 2006 validation campaigns. The black triangle in each plot shows the location of PEARL/AStrO. Top: in 2004, there were 9 occultations between 26 February and 7 March. Middle: in 2005, there were 10 occultations in the 24 February to 8 March period. Bottom: in 2006 there were 10 occultations from 21 February to 8 March.

atmospheric solar absorption spectra during each spring (and some autumns).

Similar spectral fitting techniques are used to retrieve atmospheric information from the spectra measured by the two FTSs. However, the MSC-FTS uses SFIT1 [6] whereas PARIS-IR uses SFIT2 [7]. For ozone retrievals, both used similar microwindows at 782, 2776, and 3040 cm^{-1} and PARIS-IR used an additional microwindow at 982 cm^{-1}.

Four UV-visible grating spectrometers were used for the 2004 campaign: a ground-based version of the ACE-MAESTRO, the SPS (forerunner of the MAESTRO) [8] measuring between 295 and 785 nm with a resolution of 1.2–4.0 nm, a zenith-viewing UV-visible grating spectrometer [9,10] with a spectral range of 325 to 680 nm and a resolution of approximately 1.5 nm in 2004 and from 340 to 560 nm at a resolution of 0.9 nm in the NO_2 region and 1.6 nm in the ozone region in the later campaigns, and a Brewer spectrophotometer [11]. Ozone vertical column amounts were produced from the grating spectrometer measurements using the Differential Optical Absorption Spectroscopy (DOAS) technique and the MAESTRO and SPS ozone analyses were done using a spectral fitting method. For the 2005 and 2006 campaigns, two more UV-visible spectrometers, a SAOZ [12] and a second Brewer, were added to the measurement suite.

Profile measurements of ozone were obtained from a DIAL, a 5-channel lidar which uses a XeCl laser with hydrogen Raman shifter providing outputs at 308 and 353 nm [13], and from balloon-borne ozonesondes [14] which were flown frequently (almost every day) during all of the campaigns. The resolution of the DIAL profiles is 1.3 km below 30 km, quadratically increasing to 5 km at 50 km and 5 km thereafter whereas the sonde profiles have a vertical resolution of less than 50 m.

4 OZONE RESULTS FROM 2004 AND 2005

Fig. 2 shows the daily average total ozone columns measured by the ground-based UV-visible spectrometers and the FTSs, compared with a total column value derived from the ACE-FTS results. For 2004 and 2005, the derived ACE-FTS total ozone columns generally agree with those measured by the campaign instruments to within their combined uncertainties. The one exception to this are the MSC-FTS results. The total column retrievals from PARIS-IR and the MSC-FTS have been compared more closely to investigate the observed discrepancies. It appears that the retrieval method (SFIT1 vs. SFIT2), molecular line list used and spectral resolution of the instrument affect the total column results differently depending on the microwindow used. Investigation of these effects is continuing in order to determine a consistent set of parameters to use in the retrieval processes. In the 2005 comparisons, some discrepancies were observed between the UV-visible grating spectrometer (DOAS) and the SAOZ results. A detailed analysis of the spectra from the two instruments is being performed, including a comparison of different retrieval algorithms.

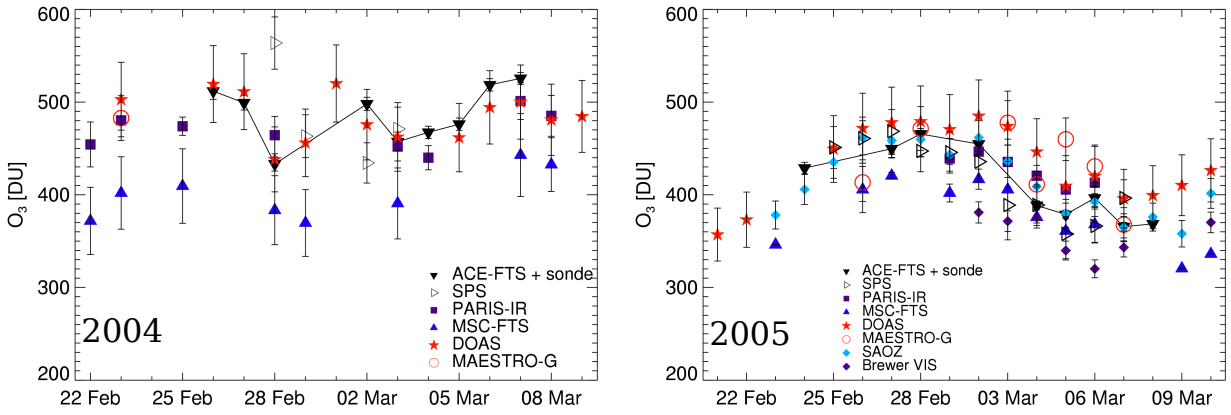

Fig. 2. Daily average total ozone columns measured by the ground-based UV-visible spectrometers and the FTSs, and the derived ACE-FTS total column (using ozonesonde measurements for the troposphere below 10 km). The intensive phase (22 February to 8 March) results for the 2004 (left) and 2005 (right) campaigns are shown. The ACE-FTS occultations used for these comparisons are within 200 km of PEARL/AStrO. The black line shows the ACE-FTS results. The SPS and MAESTRO analyses are still preliminary. The Brewer spectrophotometer results are also preliminary since this instrument is not usually used at such low sun angles. An analysis technique is currently being refined in order to obtain measurements at lower sun angles.

Comparisons of the ozone profiles obtained from the ACE-FTS, ACE-MAESTRO visible spectrometer, and DIAL in 2004 show reasonable agreement, to within 10% over the altitude range ~15-40 km (Fig. 3, left). These results are consistent with recent comparisons with other satellite instruments (SAGE III [15], POAM III [15], and HALOE [16]). The ACE-FTS and ozonesonde results from 2004 agree to within ±5% between 10 and 25 km. However, in 2005, the ozone profile measured by the ozonesondes was up to 5% higher than that from the ACE-FTS (Fig. 3, right). The difference between these two results is being examined. The slope in the percent difference curves for the ACE-FTS and ACE-MAESTRO comparisons suggest that there may be a residual offset in timing or co-registration between the two instruments. There are plans to account for this in the next version of the ACE-MAESTRO retrieval code.

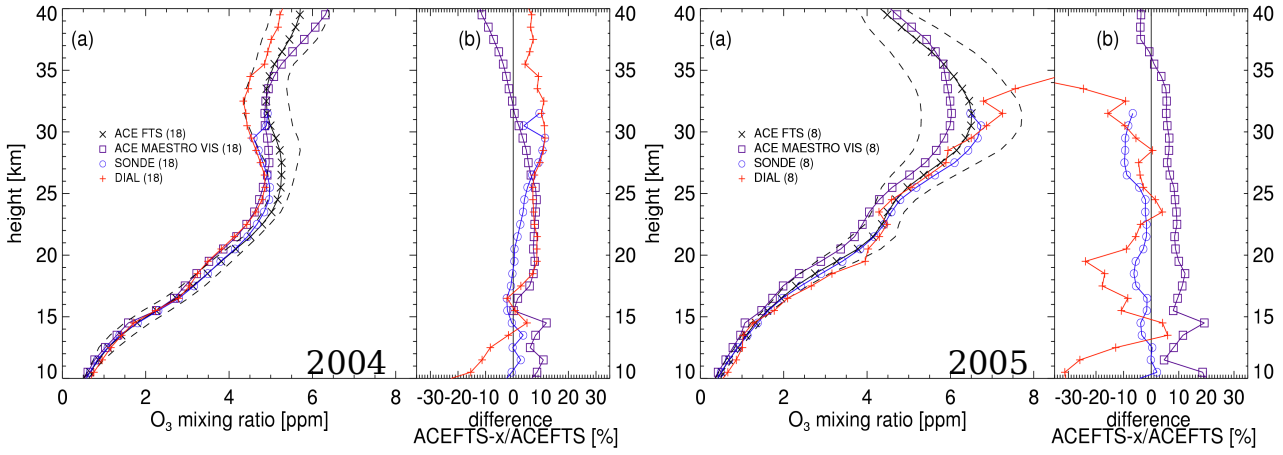

Fig. 3. Mean ozone profile comparisons for the 2004 and 2005 campaigns. In each panel, (a) shows the mean profiles measured by ACE-FTS, the ACE-MAESTRO visible spectrophotometer, ozonesondes and the DIAL and (b) shows the mean of the differences relative to the ACE-FTS profile: (ACE-FTS−x)/ACE-FTS. The ozonesonde profiles used were within 500 km and 12 hours of the ACE occultation measurements. The time criterion was extended to 18 hours for the DIAL profiles. Note: the 2005 DIAL profiles are still preliminary results. Dashed lines indicate the one standard deviation from the ACE-FTS.

5 PRELIMINARY OZONE RESULTS FROM 2006 CAMPAIGN

In comparing the observations from the first two campaigns, there is evidence of the different atmospheric conditions above Eureka in these two years. In Fig. 2, the 2004 column amounts show no decrease in ozone during the intensive phase of the campaign whereas the 2005 results do show a decrease during March. This is consistent with the position of the polar vortex. In 2004, PEARL/AStrO was outside the vortex until 9 March. In 2005, however, PEARL/AStrO was inside the vortex until 25 February and on the edge until 7 March.

Fig. 4 shows the ozone profiles over Eureka for the first week in March for all three campaigns. It can be seen that the measurements in 2004 took place during a period of high ozone where peak ozone values were as large as 10^{13} molecules cm^{-3} compared to the measurements in 2005 when ozone peak values stayed below $8 \cdot 10^{12}$ molecules cm^{-3} and showed a decline over this period. In 2006, ozone concentrations were variable with a minimum of about $2 \cdot 10^{12}$ molecules cm^{-3} observed on two days at a height of about 15 km, where usually the ozone peak occurs.

In 2006 FTS measurements were conducted differently from the previous years, in that both instruments were able to measure simultaneously rather than in series. This was done to reduce the uncertainty introduced by measurements looking at different directions (due to the moving sun) and therefore measuring slightly different air masses . These measurements have been useful in investigating the discrepancies observed between the MSC-FTS and PARIS-IR results.

SUMMARY

Three Arctic Validation Campaigns have been conducted at PEARL in Eureka to obtain validation measurements for the ACE mission using up to ten ground-based and balloon-borne instruments. The ozone measurements from the ACE-FTS, MSC-FTS, PARIS-IR, the grating spectrometer, the ground-based MAESTRO, the Brewers and the SAOZ have been compared as columns. For profile comparisons, the ACE-FTS, ACE-MAESTRO, the DIAL and the ozonesondes were used. In addition to the work discussed above, NO_2 column comparisons have been performed using data from the FTS and UV-visible spectrometers, and ACE-FTS, DIAL and radiosonde temperature profiles have been compared. Also, ground-based FTS column measurements are being compared to the satellite results for a range of other molecules including: CH_4, N_2O, H_2O, HCl, HF, HNO_3, NO, and CO.

These validation activities in the High Arctic show the difficulties associated with measurements in a continually changing environment. Comparisons of three years of data highlight the challenges inherent in using the measurements near the polar vortex and the care that has to be taken in performing comparisons.

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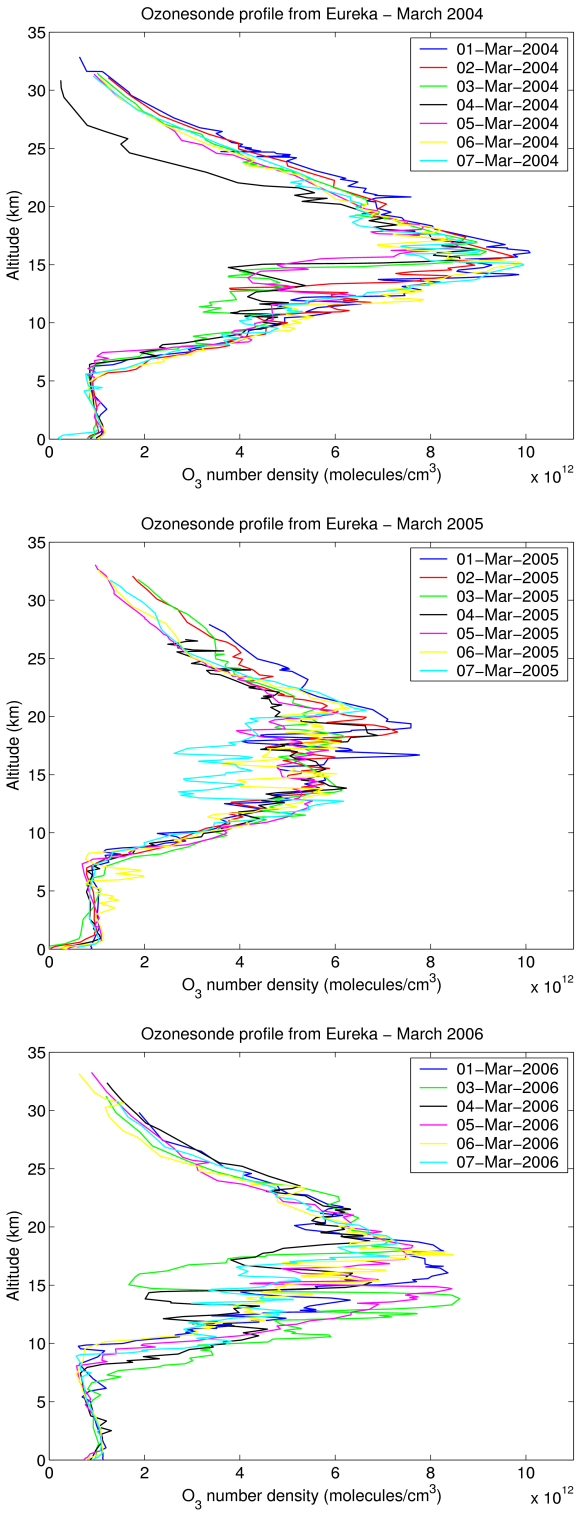

Fig. 4. Ozonesonde profiles for first week of March during the three different campaigns. During the 2006 campaign, an ozonesonde flight on 2 March was not possible due to bad weather.

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