STRATOSPHERIC COMPOSITION MEASUREMENTS USING THE MAESTRO INSTRUMENT ON A BALLOON PLATFORM LAUNCHED FROM KIRUNA DURING SPRINGTIME, 2011

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ABSTRACT

The Canadian Space Agency (CSA) is in the process of developing a high altitude balloon program aimed at enhancing and sustaining Canadian expertise in addressing scientific, technical and operational questions in the context of the needs of the space industry, academia and government institutions. In order to assure the success of the program, the CSA intends to enter into national and international collaborations to bring together the capacity to ensure needed support in making future Canadian balloon flights. To initiate a collaboration with the Centre National d'Études Spatiales (CNES), the CSA has joined efforts with Environment Canada and the Universities of Toronto and Saskatoon to provide a scientific instrument as part one of the scientific payloads composing the CNES 2011 Kiruna balloon Campaign. The Canadian MAESTRO-B (Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation from Balloon) is a replica of the MAESTRO instrument. It was developed by Environment Canada in partnership with COMDEV and University of Toronto to fly as part of the Canadian Atmospheric Chemistry Experiment on the Canadian SCISAT satellite. The instrument measures atmospheric composition, specifically O_3, NO_2, BrO, water vapor and aerosol extinction. The scientific objectives for the MAESTRO-B flight during the Kiruna 2011 campaign are the provision of satellite validation information and support further development of the retrieval algorithm to extract stratospheric aerosol particle information and water vapor concentrations from data collected by the MAESTRO instrument on board SCISAT. The Cnes balloon campaign toke place in Esrange (67.9 N, 21.1 E) during spring of 2011. This paper describes the experiment, the necessary changes to adapt this instrument to fit in the Cnes gondola, and shows an example of the measurements taking during the flight.

1. INTRODUCTION

The Atmospheric Chemistry Experiment (ACE) mission on Canada's SciSat satellite is designed to examine the composition of the Earth's atmosphere from space, with special emphasis on the middle atmosphere distribution of ozone and related trace gases in the Arctic [1]. SciSat was launched on 12 August 2003 and is still functioning well on orbit. The ACE payload is comprised of two instruments: the Fourier transform spectrometer (ACE_FTS) which operates in the infrared from 750 to 4400 cm^{1} (2.3–13.3 nm) with an unapodized spectral resolution of 0.02 cm^{1}, and the Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation (MAESTRO) instrument, which is a dual, diode_array spectrometer measuring in the UV_visible_near_infrared (UV_VIS_NIR) spectral regions with a nominal wavelength range between 285 and 1015 nm (400 and 1010 nm for its primary measurement mode of solar occultation). Both the FTS and MAESTRO make measurements in the solar occultation mode and share a common suntracker and optical boresight. Therefore, they examine almost the same slant column of air, albeit with different fields of view (FOVs), and with only a slight difference resulting from differential refractive effects and a relatively small 0.02° FOV (1 km tangent altitude).

MAESTRO-B is a duplicate of the space instrument suitably packaged for use on the ground and on balloon payloads (see Fig. 1 for instrument diagram). The instrument measures atmospheric composition, specifically O_3, NO_2, BrO, water vapour and aerosol extinction. The scientific objectives of the balloon experiment are the provision of satellite validation information and the further development of the algorithms extracting of stratospheric aerosol size information and water vapour concentrations from data collected by the MAESTRO instrument on board SCISAT. While MAESTRO on the SCISAT satellite was unable to produce data for the retrieval of BrO concentration profiles because of an unexplained loss of sensitivity at short wavelengths [2], the

Proc. '20th ESA Symposium on European Rocket and Balloon Programmes and Related Research'
Hyère, France, 22–26 May 2011 (ESA SP-700, October 2011)

MAESTRO-B heritage instrument, the Environment Canada SunPhoto_Spectrometer, demonstrated the capacity for making such measurements during flights on board the NASA ER_2 aircraft. MAESTRO-B is expected to provide BrO data.
The balloon campaign took place at Esrange (67.9 N, 21.1 E) during springtime of 2011.

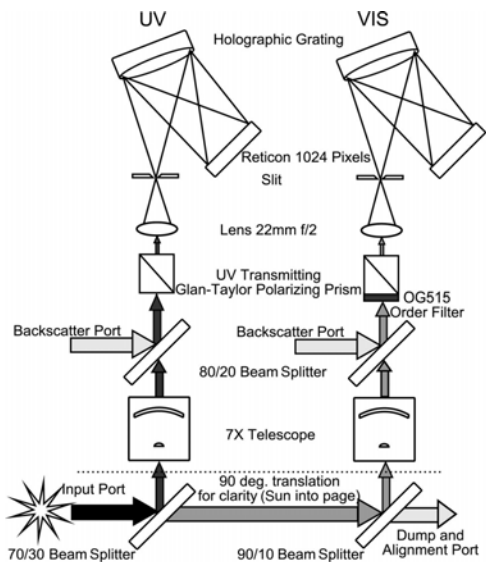

Figure 1. MAESTRO diagram.

2. PREPARATION

In order to support the development of a collaboration agreement between the CSA and the CNES on stratospheric ballooning and to put in practice the understanding of technical and scientific interfaces used by both Agencies, we envisioned to take under a pilot project. The CNES offered to the CSA the opportunity to fly a Canadian instrument in a CNES payload during the Kiruna 2011 Balloon Campaign. As time was constrain, the CSA partner with Environment Canada to fly an existent instrument with balloon flight heritage and with which scientists from both institutions would be familiar. MAESTRO_B was chosen for this aspect and also because the data collected could support further improve the SCISAT MAESTRO instrument data processing algorithms.

The possibility to fly MAESTRO_B became firm by August 2010 when preparation of the instrument for the flight was started. A letter of intent with instrument technical description and flight requirements was sent to the CNES. MAESTRO_B being an occultation instrument requires pointing. However, for many reasons the best configuration for the CNES was to integrate MAESTRO_B on the Duster payload with no solar pointing. This decision was communicated to the scientific and technical team by early October. Therefore, the team had two challenges not previously envisioned. (1) to put together a battery pack control circuit and (2) to implement a suitable omidirectional collector or opto-mechanical pointing system. Such system did not exist readily in our laboratory and had to be designed, build and tested in fly conditions.

The choice of an omni-directional pointing system was problematic. The MAESTRO spectrometers are very small and are based on an asymmetrical design incorporating an off-axis, concave holographic diffraction grating. This design works well if the field of view (FOV) of the instrument is always uniformly filled, but is subject to wavelength and sensitivity shifts if the FOV is not uniformly illuminated.

In order to address this problem a novel collector system was designed. The design is intended to collect light from all azimuth directions between zenith angles 85 and 96 degrees. The field of view of the instrument is filled with light scattered in transmission through the centre of a quartz hemispheric dome which as been frosted on the inside by sandblasting. Light can entre the dome directly by scattering at the inner surface but may also enter after scatting from a 5 degree, conical Spectralon (R) diffuser plate placed over the open end of the hemispherical dome. The 5 degree cone allows light from 5 degrees above the horizontal to still directly impinge on the dome, while the scatterplate increases the collection efficiency at larger zenith angles. Light from all azimuth angles, therefore, approximately fills the FOV of the instrument.

MAESTRO has two spectrometers - one for the UV (270 to 525 nm) and one for the visible (500 to 1000 nm). Each of these has a separate field lens and foreoptics tube under normal circumstances.. However, if the instrument were to view the sun through an omnidirectional collector, they had to have their beams combined. If separate collectors were used, one might obscure the other depending on the azimuth angle of the sun relative to the gondola. For this reason, a new set of foreoptics was designed and constructed which allowed the use of a beam splitter to provide both instruments with an on-axis view of the illuminated patch of light from the frosted dome.

The mirror and beamsplitter were designed and constructed before the end of December, 2011, but the frosted dome was only delivered late in January. Mechanical parts for the foreoptics were completed around the end of February. This tight schedule allowed only for a short functional test of the system in the laboratory using a quartz iodine lamp. Solar testing had to wait until the instrument was deployed in Kiruna. Figure 2 provides a view of the new developed light collector mounted in the MAESTRO_ instrument.

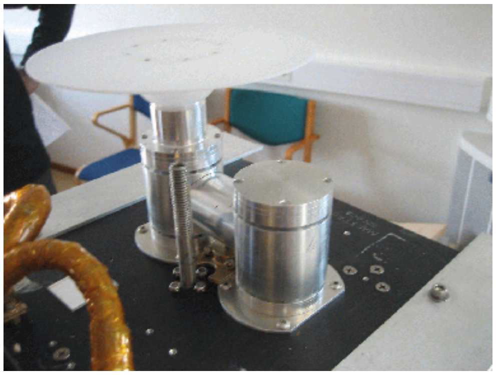

Figure 2 The MAESTRO omnidirectional light collector. The horizontal tube carries light from the beamsplitter under the collector to the UV spectrometer. (Photo courtesy CNES.)

3. TESTING

The MAESTRO software and hardware were tested in the laboratory at EC in October. A vacuum test of the instrument and its power systems was conducted in the Instrument Calibration Facility at the University of Toronto. This facility has been used to test a number of space instruments including MOPITT and MAESTRO. The instrument performed satisfactorily.

A power control module was required to allow the instrument power to be commanded on and off by the CNES AETNA command and telemetry system. A simple magnetic latching relay was selected as the simplest and most reliable method for commanding the power, and the power supply and switching system was repackaged for the Duster gondola' In the process of repackaging the power supply, the power regulator semiconductors were de-mounted and re-mounted. The decision was taken to re-test the system in vacuum to ensure that nothing had been altered in the performance of the system. This test was completed successfully at the end of January, before the new foreoptics were installed.

The performance of the omnidirectional collector was tested in Kiruna using the sun as a source. Some spectral shift was seen in the tests made 90 degrees in azimuth apart. The results of these tests may be useful in the data analysis.

4. STRUCTURE DESIGN

Since the gondola was to be unpointed and an omnidirectional light collecting system was to be used to collect solar light for the occultation measurements, the instrument had to be either mounted on the top of the gondola high enough for the collector to see the sun over 360 degrees of azimuth angle, or hung out the bottom of the gondola. Otherwise, there would be particular directions that would have the structure shadow the input light collector and result in a loss of data. If it happened that the gondola rotated very slowly during sunset or stopped with an obstruction in the way at the critical 90 to 95 degree solar zenith angle range, vertical profile data would be compromised.

Mounting the instrument under the gondola was not an option because the payload would land on it after the flight was terminated. Hanging the instrument on a line below the gondola is not very desirable either, for the same reason. A structure to support the instrument high enough above the gondola in the region of the suspension cables was designed to make it possible for the instrument to receive light from the sun from 360 degrees in azimuth, with minor narrow gasps corresponding to the azimuthal positions of the suspension straps. The straps themselves were taped to make them as narrow as possible before the flight. The angle structure was bolted to the deck of the gondola and CNES added safety straps to reduce torque loads on the mounting and provide a secondary attachment mechanism. Fig. 3 show MAESTRO_B mounted in the metallic structure and Fig. 4 shows the instrument being integrated into the gondola.

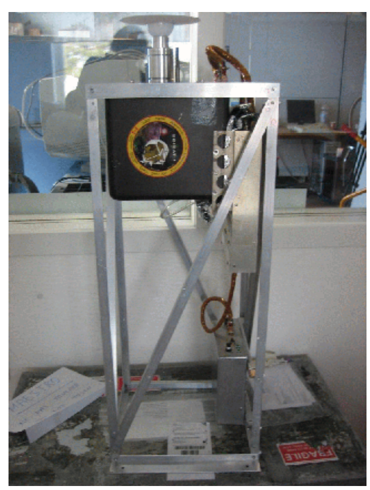

Figure 3 MAESTRO (in the black enclosure) mounted on the structure used to support it on the gondola. (Post-flight photo courtesy of CNES).

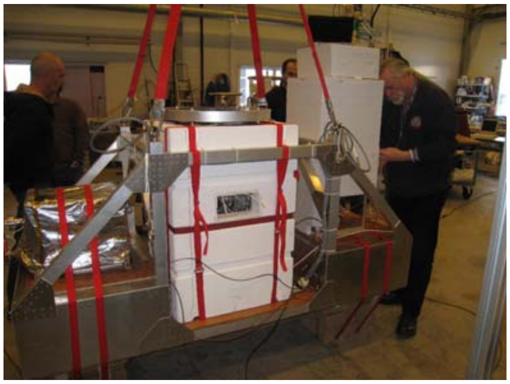

Figure 4. MAESTRO_B being integrated into the gondola in Kiruna, 2011.

5. THE FLIGHT

The 2011 winter and early spring meteorological conditions were challenging with very limited, if any, flight windows. Therefore, the campaign spanned over a larger time than envisioned. Finally, in April 7 the DUST payload was launched caring MAESTRO_B and the Italian DUSTER instrument. The Canadian team was not able to return to the field after a break in the campaign and the CNES team kindly took care of the operations for and during the flight. MAESTRO_B collected excellent data through both the UV and Visible spectrometers. The data were uploaded by CNES onto the Environment Canada server in Toronto. At this point we only have preliminary data and raw spectra acquired during the flight are show here as examples.

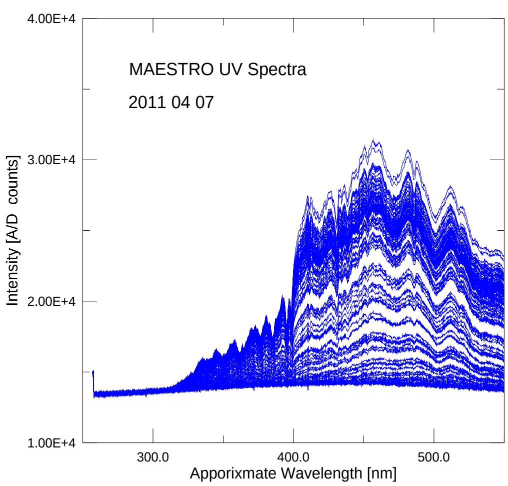

Figure 5. Raw spectra collected on the second-lowest gain buy the MAESTRO UV spectrometer during the Duster flight from ESRANGE.

Fig. 5 shows data from one of the 6 different gains used to collect spectra during the flight. Multiple spectra at different gains were collected throughout the flight so that good data could be obtained over the large dynamic range associated with occultation measurements.

Fig. 6 shows the intensity of one wavelength of light as a function of time during the flight. It reveals that the sun was being blocked for a considerable amount of time but that the intensity of light stayed high enough that good measurements appear to have been made.

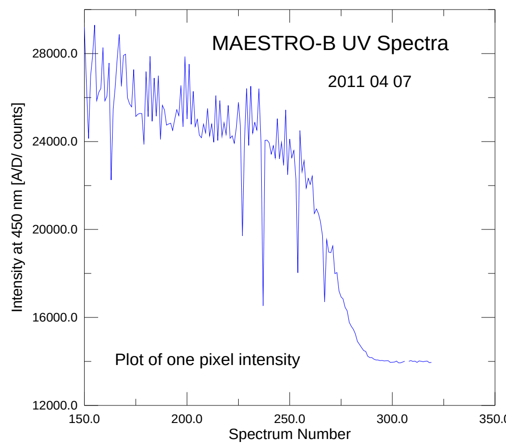

Figure 6. The intensity at one given wavelength, as a function of spectrum number acquired during the Kiruna 2011 flight.

6. SUMMARY

The participation of MAESTRO_B in the CNES kiruna 2011 balloon campaign was a pilot project. The opportunity was offered by the CNES and was very well received by the CSA that team up with Environment Canada to make this possible. The main objective was to provide a hands on example where the two Agencies would have to work together. The project was very successful. The several challenges faced illustrate the usefulness of such pilot project and the capability of adaptation and will of success from all the sides demonstrate the readiness of both teams in engage in a productive collaboration to provide the scientific community with a balloon launch site at mid-latitudes. The goal is to have our first join campaign in 2014.

ACKNOWLEDGEMENTS

The authors are greatly thankful to the CSA and the Environment Canada to support this activity and the CNES for the MAESTRO_B flight opportunity. Particular thanks are to the CNES field campaign team that provided outstanding support to this project.

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