MINI SAOZ : A LIGHT UV-VISIBLE SPECTROMETER SONDE FOR STUDYING CONVECTIVE TRANSPORT IN THE STRATOSPHERE

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1. INTRODUCTION

Since 1988, the SA (Service d'Aéronomie) has developed a UV-Visible spectrometer, the SAOZ (Système d'Analyse par Observations Zénithales), for monitoring ozone and NO_2 columns from the ground, deployed later in a network of more than 22 stations operating all over the world [1]. Based on the same technique, a balloon version of the SAOZ was developed, flown since its maiden flight in 1991 more than 125 times on short duration balloons and 15 times for long duration Infra-Red Montgolfier flights around the world for studying ozone, NO_2, OClO, BrO, H_2O, aerosols at all latitudes [2]. However, since these early developments, new technologies have been made available allowing to reducing the size and increase the performances of the instrument. A new sonde, the mini-SAOZ was thus developed for studying the impact of fast vertical convective transport on the composition of the lower stratosphere in the tropics.

2. THE MINI SAOZ SPECTROMETER

The mini-SAOZ is a UV-Visible spectrometer, developed at LATMOS since 2009 on more advanced technology, better adapted to current demand. The instrument is a spectrometer from Avaspec with an optical fibre and a CCD detector (active surface with 2048 x 14 pixels). It is made of an optical bench Czerny Turner spectrometer of 75 mm focal length, two mirrors, one to collimate the sunlight and one to focus it on the detector (Fig. 1). A switch connected to the fibre allows acquisition of dark current associated to the spectrum. Of lightweight (716 g) and small size (175 x 110 x 44 mm), it is well adapted for use on a balloon sonde.

The spectral resolution and range of the instrument depends on the grating and the slit size. For the first mini SAOZ flight, the resolution was of about 0.7 nm with a 10 µm slit and a grating of 300 lines/nm providing a spectral range of 270 nm - 1400 nm for the measurement of ozone, NO_2, O_4, O_2, H_2O and aerosols. For the second flight on the following year, two different instruments have been used, the first of 25 µm slit and 600 lines/nm for the near infrared with a theoretical resolution of 0.7 nm within 500-1000 nm, and the second of 200 µm slit and 1800 lines/nm for the UV-Visible with a theoretical resolution of 1.1 nm within 310-460 nm.

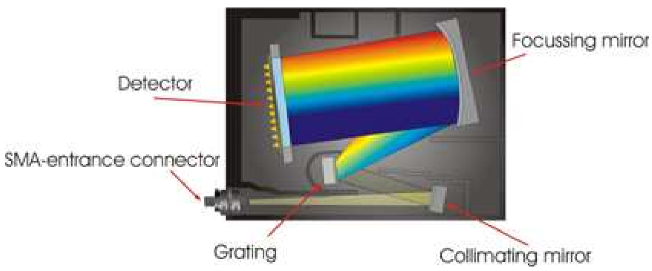

Figure 1: Optical bench design

The first was designed for the measurement of water vapour, O_4, O_2 that is density and temperature, whilst the second was adapted to that of BrO, UV ozone, CH_2O and OClO (if present),

The SAOZ spectral retrieval is making use of the DOAS (Differential Optical Absorption Spectroscopy) method. It requires a reference spectrum, which is measured immediately after reaching float altitude at the smallest possible sun zenith angle and thus the minimum slant column of absorbing species. This reference spectrum is then aligned in wavelength to the well-known high resolution Kurucz spectrum using the Fraunhofer lines. The slant columns amount of each species is then retrieved by least squares correlation with laboratory cross-sections of each. Finally, vertical profiles are derived from slant columns using the onion peeling inversion scheme.

The technique used for those measurements is direct sun observations, known as solar occultation, in two

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configurations (Fig. 2). First at relatively high sun during the ascent of the balloon from launch altitude across the troposphere and the stratosphere, followed by the observation of sunset or sunrise from float altitude.

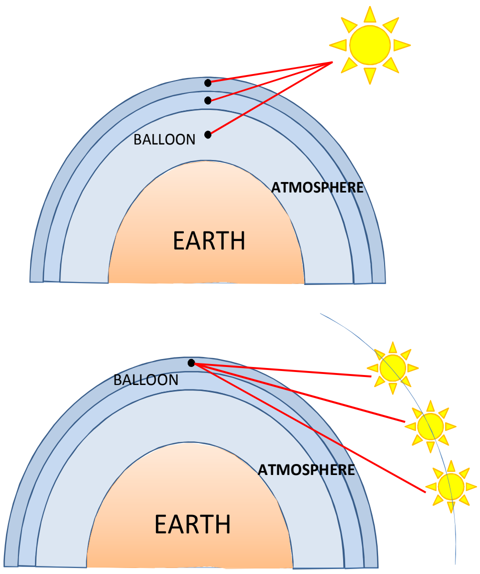

Figure 2: Solar occultation measurements during the ascent at SZA<90° (top), and during sunset from float altitude at SZA>90° (bottom)

3. TEST FLIGHTS AND RESULTS

The objective of the first flights described here, carried out from Esrange in Kiruna in Northern Sweden, was the testing and the characterisation of the mini-SAOZ payload in preparation of future flights on small balloons planned in Brazil for studying convective transport in the lower stratosphere. The first flight took place on April 29, 2010 with a single broadband mini-SAOZ and the second on March 11, 2011 with two instruments, the UV-Vis and near IR versions, on the same balloon.

3.1. First test flight on April 29, 2010

This flight made use of an old SAOZ polystyrene box, where the mini-SAOZ components were housed into the two upper compartments, while the third was used by CNES for hosting the telemetry/telecommand. Because of its energy dissipation, the on-board electronics and the PC were placed in the upper compartment in which a cooling channel was added. The spectrometer was placed beneath, linked by an optical fibre to the sunlight collecting conical mirror (Fig. 3). A GPS was added on the top. Although the instrument performed quite well, two problems were encountered:

i) the malfunction of the GPS, replaced in the data analysis by the use of CNES GPS information;

ii) the excessive heating of the payload by the PC heat release, although limited by the thermal conductor, which resulted in a dark current increase and thus in a limitation of the time of exposure and larger noise.

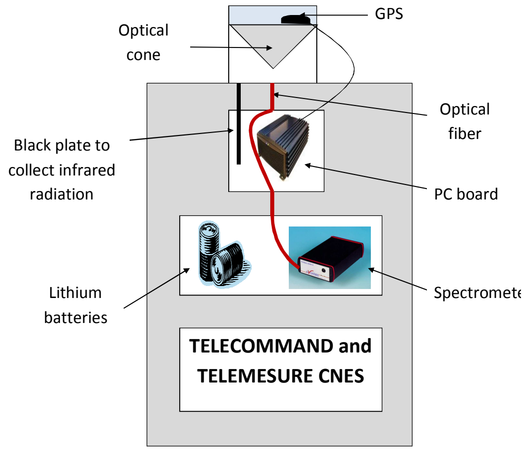

Figure 3: Configuration of the mini SAOZ payload for the first flight

Four periods of measurements were available from this flight: the ascent, the solar occultation from float altitude at sunset, that of sunrise still from float but at lower altitude, and the daytime descent (Fig. 4). Most precise measurements are those of sunset at the highest altitude as shown in Fig. 4. Measured species were nitrogen dioxide, ozone, water vapour, oxygen and oxygen dimer.

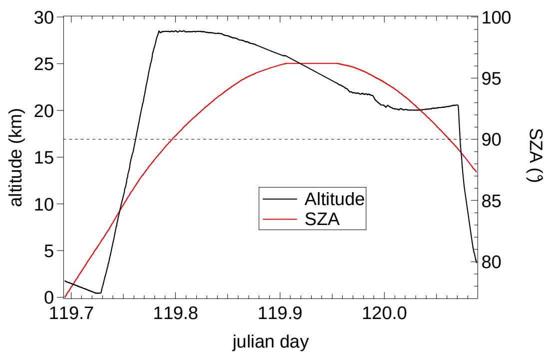

Figure 4: Altitude and SZA during the first flight

The results of this first flight are shown in Fig. 5.

a) Ozone and nitrogen dioxide on top panels are showing unusual low mixing ratios above 18 km. This comes from the unexpected presence of a late vortex over Kiruna as shown by Potential Vorticity (PV) maps at 550 K (about 22 km) on 29 and 30 April at 12 UT (Fig. 6), where the ozone and NOx concentration was slightly reduced.

b) O_2 and O_4 are measured in several spectral bands: O2V1 at 620-635 nm, O2V2 at 680-700 nm and O2V3 at 750-775 nm, O4V4 at 420-490 nm and O4V5 at 500-670 nm. The concentrations of the different spectral bands are consistent, although significant differences could be seen for example because of line saturation on the most sensitive channel (i.e. O3V3 at low altitude). Except at top altitude, the O_4 measurements are consistent with their error bars, although O4V5 shows larger uncertainty.

c) Water vapour (bottom panel) is measured within four spectral bands:

i) H2O1 between 400 nm and 550 nm
ii) H2O2 between 555 nm and 670 nm
iii) H2O3 between 675 nm and 870 nm
iv) H2O4 between 870 nm and 1060 nm

The two first are not shown because of their low sensitivity in the stratosphere. Only low altitude ascent measurements are available at these wavelengths. At the opposite, many lines are saturated at the lowest altitude in the fourth spectral band. Most useful measurements in this configuration are thus those of the third shown in Fig. 5 (bottom pane) of ± 0.5 ppmv precision in the lower stratosphere. They are compared in Fig. 5 to a water vapour profile of the Russian FLASH-B Lyman alpha hygrometer [3] flown in Sodankyla, but on March 17th, that is one month earlier, also in the polar vortex, but at lower tropopause level around 10 km instead of 12-13 km on April 29. Thus only stratospheric measurements can be compared, showing minimum mixing ratio of about 4 ppmv between the tropopause and 20 km, increasing to 5-6 ppmv at higher altitude in the stratosphere. Although there is still improvement required in the water vapour spectral retrieval at all wavelengths, the consistency of the mini-SAOZ and FLASH-B is encouraging.

In summary, although showing some need for improvements, the first flight of the mini-SAOZ demonstrates the ability of the new-instrument to carry reliable measurements by solar occultation at sunset.

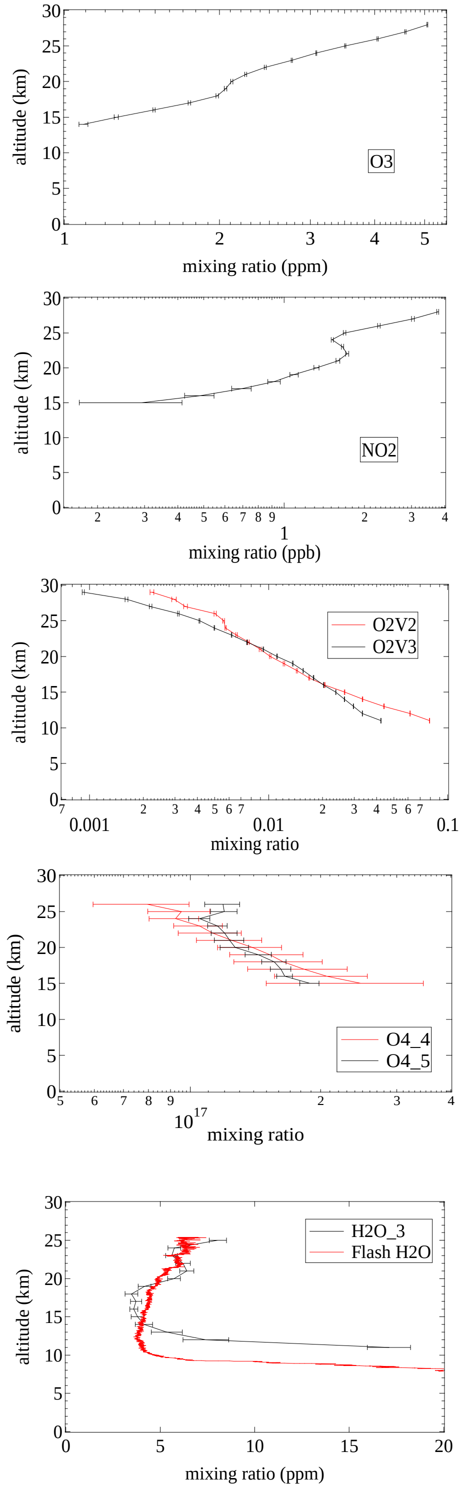

Figure 5: Vertical profiles of species mixing ratio at sunset derived from the first mini-SAOZ flight. From top to bottom:O_3, NO_2, O_2, O_4 and H_2O.

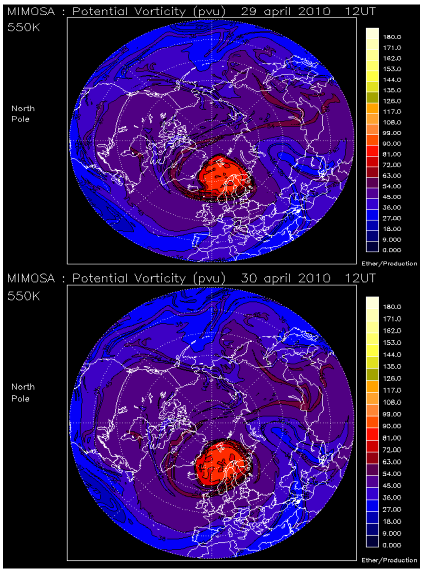

Figure 6: Maps of potential vorticity at 550 hPa on April 29-30, 2010 at 22 UT) from the MIMOSA model available at http://ether.ipsl.jussieu.fr/

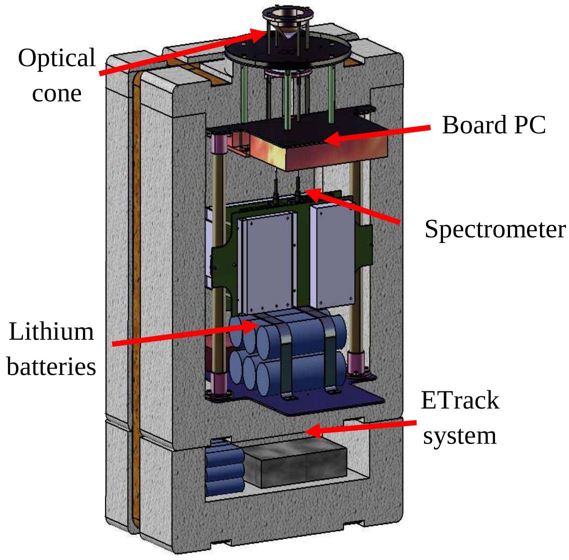

Figure 7: Design of the mini SAOZ payload

3.2. Second test flight on March 11, 2011

Following these encouraging results, the development of the mini-SAOZ sonde was continued in the laboratory with the objective of creating an operational autonomous payload. The whole system was redesigned (Fig. 7) for a smaller 12 kg, 440x420x590 mm payload. The PC board was changed for a lesser heating model. The optical conical entrance and the full mechanical design were revised. Finally, the GPS was changed and an E-Track GPS /Iridium satellite transmission system added to follow the flight. A further test flight of the complete new payload was then decided.

The flight took place again in Kiruna, on March 11, 2011, the balloon carrying both the UV and NIR mini-SAOZ versions. Because of strong stratospheric wind forcing an early cut-down, the flight lasted 2h15 only (Fig. 8). Moreover because of a wrong indication of the GPS system, the balloon was launched earlier than expected, at 79° SZA instead of 83°. As a consequence, payload was cut before 90° SZA and no sunset solar occultation observations could be performed during this flight limited to ascent measurements and few spectra during the fast descent at sunset.

Overall, this test of the new designed mini-SAOZ payload was rather disappointing. Although the

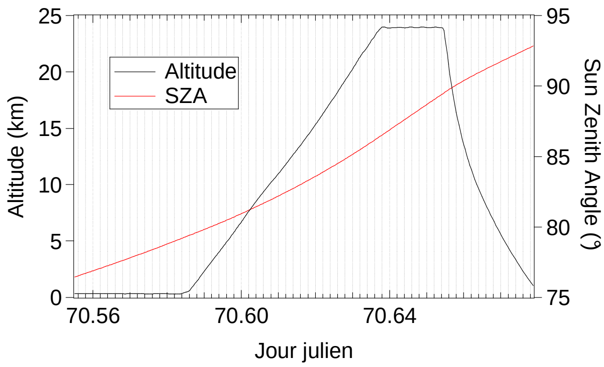

Figure 8: flight profile 2011

instrument itself was working satisfactorily and the inner payload temperature cooler than previously, the GPS system did not synchronised properly with the consequences already seen. The GPS information was replaced in the analysis by that of the E-Track, but ascent data only are available, far less sensitive than solar occultation. And it is recently only that the GPS failure was identified caused by a software default now corrected and tested at length at ground. It can be thus anticipated that the mini-SAOZ payloads are now available for successful measurements in the tropics during the TROPICO campaign planned in Brazil in January-February 2012.

4. THE TROPICO PROJECT

Deep convective overshooting are phenomena known for long above the continents. They result in energetic updrafts from the equilibrium level at the outflow of thunderstorms at around 13-14 km up to 20 km altitude (Fig. 9). The vertical speed of the updraft can reach 50 to 100 $m.s^{-1}$. The expected impact of these is the injection of adiabatically cooled tropospheric air in the low stratosphere and, as shown by the many water vapour and ice crystals measurements performed during the HIBISCUS campaign in 2004 in Bauru [4] and those of the SCOUT-O3 project in 2005 in Northern Australia, and in 2006 and 2008 in Niamey in West Africa [5], the hydration of the lower stratosphere by geyser like frequent injection of ice crystals sublimating rapidly in the lower stratosphere.

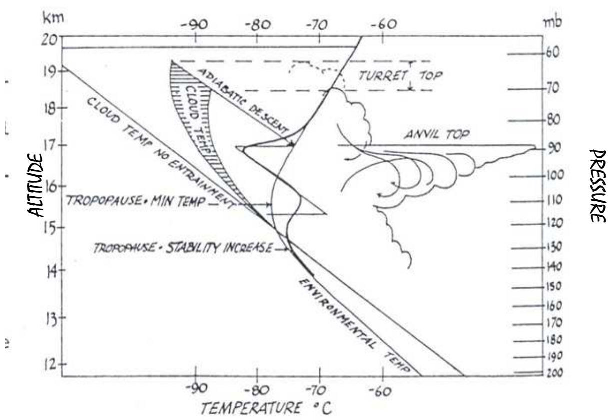

Figure 9: Scheme of energetic updraft of adiabatically cooled air by convective overshoot [6]

As shown by the overshooting features (OPFs) reported by the Precipitation Radar and the lightning flashes of the Lightning Imaging Sensor of Tropical Rainfall Measurement Mission (TRMM), overshoot mostly occur over tropical continental areas and particularly over South Eastern Brazil (Fig. 10), where the coming TROPICO project is planned to take place in January-February 2012. The objective of this project is to better understand the overshooting hydration mechanism, its frequency of occurrence, and finally estimate its impact of the stratosphere at the global scale by a combination of balloon and satellite measurements during the summer convective season.

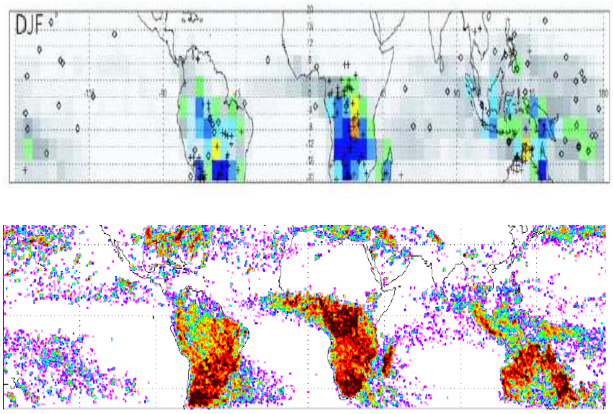

Figure 10 : Top: convective overshooting features reported by the TRMM (Tropical Rainfall Measuring Mission) satellite Precipitation Radar during the southern hemisphere summer [7]; Bottom: flashes reported by the lightning imaging sensor (LIS) on-board the same satellite. Bauru at 22°S, 50°W is located in one of the most convectively active region.

Within this frame, the objective of the newly developed mini-SAOZ instruments will be the measurement of water vapour profiles in the vicinity of convective systems, together with the signature of their impact on ozone, lightning NOx, bromine, and finally formaldehyde, that is on the chemistry of the lower stratosphere. It is hoped that the instruments flight tests described here will allow successful measurements of the above species and thus contribute significantly to the anticipated success of TROPICO.

5. CONCLUSION

Based on the heritage of the SAOZ balloon payload, a lighter, modern and hopefully higher performance UV-Vis spectrometer, the mini-SAOZ, has been developed, which was tested in flight in Kiruna on 2010 and 2011. Although the flights were not totally satisfactory on the technical side, the measurements performed demonstrate the capacity of the new instrument to provide the right expected information. The default in the on board software identified during these flights being now corrected, there is full confidence in the mini-SAOZ to provide successful measurements during the coming TROPICO field campaign and thus contribute to the improvement of the understanding of the impact of deep tropical land thunderstorms on the composition of the lower stratosphere.

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