

TUNABLE DIODE LASER SPECTROMETERS (TDLS'S) AS AIRBORNE IN-SITU SENSORS FOR STRATOSPHERIC TRACE GASES

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In this paper two spectrometers will be described, based on tunable diode lasers, suitable for operation on board of a stratospheric aircraft. These instruments are used to carry out measurements about production, transformation and transportation of atmospheric constituents. The principles of operation, the environmental constraints, the technological solutions and some results will be shown.

1. Introduction

The knowledge of our atmosphere is a fundamental issue for both understanding some important phenomena, like greenhouse effect, ozone depletion, climate changes, and adopting the necessary countermeasures. While most of the antropogenic emissions occur close to the ground, some natural important productions of gaseous species are distributed all along the height of the troposphere: volcanic emissions of HCl and HF, nitrogen oxides from lightning, etc. A major role in the distribution of the gaseous species in the atmosphere is played by the tropopause, the thermal inversion layer which divides the troposphere from the stratosphere. There is presently one aircraft only, which can carry a payload of 1500 kg up to a height of 21000 m. It's the Myasishev M55 "Geophysica", a Russian plane built for military purposes, and then transferred to a private company and equipped to host several instruments, based on different principles, which can measure different atmospheric parameters (dust, water content, ozone, NO_x, CFC's, etc.). There are many constraints for devices to be mounted on board of such an aircraft:

1. The power supply on board is either 28 VDC or 110 VAC, 400 Hz. There are limitations on the available power, whose stability is not the same as in one's laboratory.
2. Pressure ranges from 1000 to 50 mBar, temperature from -70 to +50 °C.
3. All instruments must pass the EMI test suitable for this kind of platform.

4. Mechanical design must keep into account vibrations, and instruments must pass severe vibration tests.

2. The instruments

Both instruments are based on the Beer-Lambert law:

$$I_{out} = I_{in} \cdot e^{-\alpha L}, \quad (1)$$

where I_{out} , I_{in} are the powers of the light beam respectively at the exit and at the entrance of the sample, L is the length of the sample and:

$$\alpha = S \cdot g(\nu) \cdot n. \quad (2)$$

In (2) S is the strength of the absorption, g is the absorption profile vs frequency and n is the density of the absorbing molecules. Once ν and L are fixed, the density n can be retrieved from the absorption measurements, provided that temperature and pressure are known. The optical pathlength should be maximized, but a compromise must be found with the transmission and the dimensions of the multipass cell. When the absorption is of the order of 1%, the detection technique of direct absorption can be easily employed, when the absorbance is lower than this value it is usual to adopt more effective detection techniques, in order to enhance the S/N ratio. Now we enter into the details of the two instruments, for which two quite different layouts have been selected.

2.1. Measurement of CO

The starting point for the measurement of CO is the analysis of its infrared absorption spectrum. This species has its fundamental absorption band around 2140 cm^{-1} ($4.67 \text{ }\mu\text{m}$). In this region lead salts diode lasers are available, and the main interferences come from water, carbon dioxide and nitrogen oxide (N_2O). The use of lead salts lasers results in a serious constraint to the experimental apparatus. This sources require cryogenic temperatures for operation, and the same holds for the detectors in the middle infrared. The simplest solution is a Dewar, filled with liquid nitrogen, containing both laser and detector. In order to ensure the stability of the boiling point of nitrogen, the Dewar must be pressurized. The optics layout of this instrument is shown in Figure 1 [1]. The white disk in the center of Fig. 1 is the cover of the Dewar. The laser beam exits from the upper left side. Part of the beam is reflected by a beam splitter.

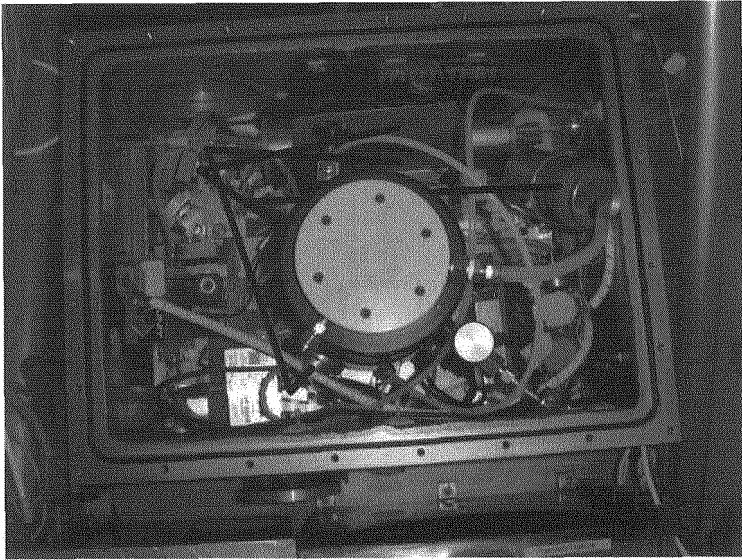


Figure 1. Photo of the optical layout of the CO analyzer.

This beam reaches a reference detector at room temperature, after passing across a cell filled with pure CO and a ZnSe etalon, for relative frequency reference. The main part of the beam enters a multipass cell (36 m pathlength), and then is focused onto a detector, placed in the same Dewar. The air flow through the multipass cell is driven by a small pump, which operates only at altitudes greater than 5000 m, in order to avoid blowing dust or raindrops into the cell.

The detection technique is direct absorption. The laser frequency is scanned across an absorption line at 1 kHz repetition frequency. The signals from the two detectors are digitized with 12 bit vertical resolution, and averaged over 2000 scans. The data processing is carried out off-line, after landing.

A typical result, obtained during a measurement campaign in Brazil in January/February 2005, is shown in Fig. 2. Such results are related to those coming from other instruments, detecting ozone, NO_x, etc.

3. Measurement of methane

The instrument for methane detection has been designed [2] by keeping into account some specific constraints: the volume and the shape of the available space, the maximum weight and power consumption.

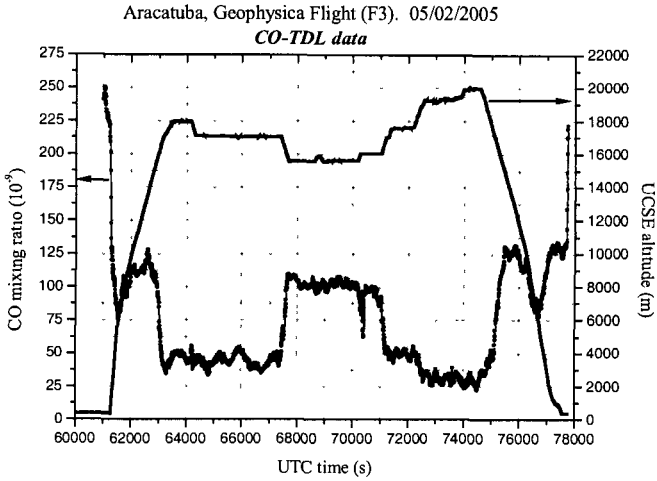


Figure 2a. CO mixing ratio vs time during a flight in Aracatuba (BR) in February 2005.

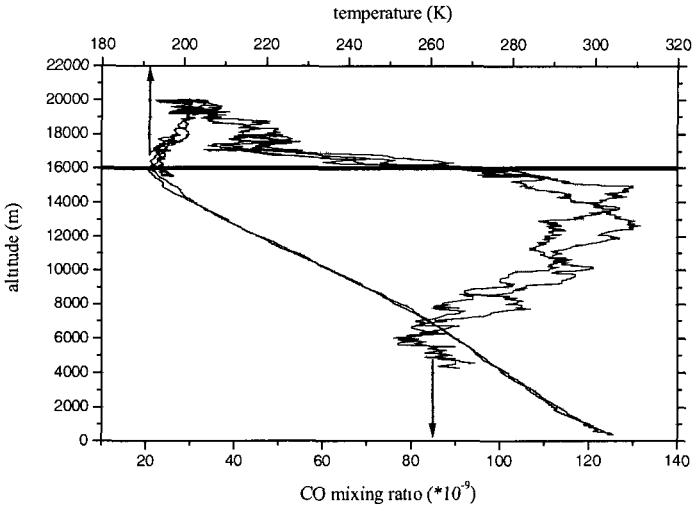


Figure 2b. Profiles of CO mixing ratio and temperature with height. The horizontal line corresponds to the tropopause.

For the limitations above it was not possible to have a pressurized vessel and to use liquid nitrogen, so that a room temperature diode laser had to be employed. The optical setup is very similar to that of the CO analyzer but, due to the low strength of the absorption lines in the near infrared, a more effective

detection technique, the so called two-tone frequency modulation [3], had to be adopted. A typical result is shown in Fig. 3.

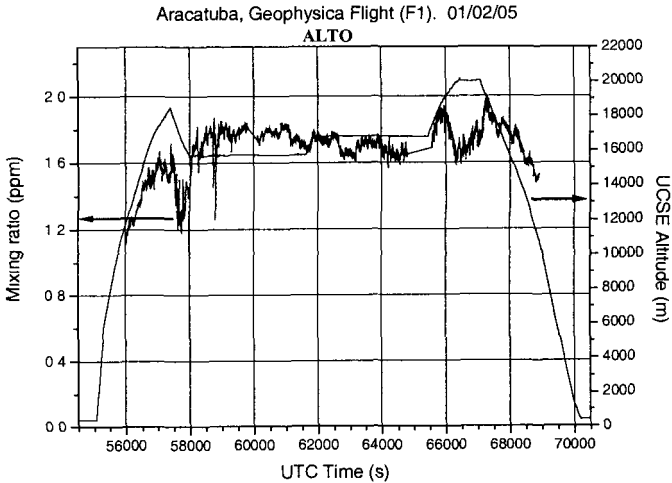


Figure 3 CH₄ mixing ratio vs time during a flight in Araçatuba (BR) in February 2005.

4. Conclusions

Diode laser based analyzer have proved to be useful for fast and sensitive detection of trace gases in the lower stratosphere. The data obtained during the measurement campaigns are being used for environmental analysis.

5. Acknowledgments

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6. References

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