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Upper atmosphere research at the Instituto Nacional de Pesquisas Espaciais of Brazil

R. Clemesha, P. P. Batista, H. Takahashi, D. Gobbi, A. F. de Medeiros and D. M. Simonich
Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brazil

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RESUMEN

La investigación sobre la atmósfera alta en el Instituto de Investigaciones Espaciales de Brasil se concentra en las áreas de fotoquímica y dinámica de la mesopausa y la termosfera baja, climatología de la atmósfera media y aerosol estratosférico. Por el momento el principal énfasis está en la dinámica de la mesopausa. Los estudios experimentales se llevan a cabo con lidar, resplandor atmosférico y radar de meteoros y con técnicas espaciales. El lidar operando en San José de los Campos (23°S, 46°W) mide la distribución vertical del sodio atmosférico entre 80 y 110 km, el perfil de densidad atmosférica, de 35 a 70 km, y el aerosol estratosférico alrededor de los 20 km. El fotómetro de resplandor atmosférico instalado en Cachoeira Paulista (23°S, 45°W) y en San José de Cariri (7°S, 37°W) mide la emisión del oxígeno atómico y molecular del OH y del sodio. La temperatura entre 75 y 95 km se determina a partir de los espectros rotacionales del OH y O_2. Con un sistema de imágenes se mide la estructura horizontal de las mismas emisiones en San José de Cariri. Estas observaciones tienen por objeto el estudio de la propagación de ondas internas de gravedad y sus efectos en la mesopausa. Un radar de meteoros instalado en Cahoeira Paulista se usa para determinar la estructura del viento entre 80 y 110 km durante las 24 horas, con el propósito principal de estudiar las mareas atmosféricas y las ondas planetarias. Ocasionalmente se hacen experimentos a bordo de satélites, que se lanzan desde Natal (6°S, 35°W) o Alcántara (“°S, 44.5°W) y se usan para estudiar la distribución vertical de la emisión del resplandor atmosférico y su relación con otros parámetros atmosféricos.

PALABRAS CLAVE: Atmósfera alta, aeronomía, dinámica de la atmósfera, química de la atmósfera, resplandor atmosférico.

ABSTRACT

Upper atmosphere research at the Instituto Nacional de Pesquisas Espaciais of Brazil is concentrated in the areas of photochemistry and dynamics of the mesopause and lower thermosphere, middle atmosphere climatology, and stratospheric aerosols. The main emphasis is on mesopause region dynamics. Experimental studies are carried out by lidar, airglow, meteor radar and rocket-borne techniques. A lidar at São José dos Campos (23° S, 46° W) measures the vertical distribution of atmospheric sodium between 80 and 110 km, the atmospheric density profile, from 35 to 70 km, and stratospheric aerosols around 20 km. Airglow photometers at Cachoeira Paulista (23° S, 45°W) and São João do Cariri (7° S, 37° W) measure emissions from atomic and molecular oxygen, hydroxyl and sodium. Temperature in the 75-95 km region is determined from the rotational spectrum of OH and O_2. An imaging system measures the horizontal structure of the same emissions in São João do Cariri. These observations are aimed mainly at studying the propagation of internal gravity waves and their effects on the atmosphere in the mesopause region. A meteor radar at Cachoeira Paulista is used to determine wind structure between 80 and 110 km on a 24-hour basis, with the main purpose of studying atmospheric tides and planetary waves. Occasional rocket experiments launched from Natal (6° S, 35° W) or Alcântara (2° S, 44.5° W) are used to study the vertical distribution of airglow emissions and their relationship with other atmospheric parameters.

KEY WORDS: Upper atmosphere, aeronomy, atmospheric dynamics, atmospheric chemistry, airglow.

INTRODUCTION

Research into the upper atmosphere is carried out by three groups from the Aeronomy Division at the Brazilian Instituto Nacional de Pesquisas Espaciais (INPE). The work of two of these, the Upper Atmospheric Physics and Atmospheric Airglow groups, is mainly concerned with the neutral upper atmosphere. Ionosphere research carried out by the third group will not be described here.

INPE’s interests in upper atmospheric research include climatology of the upper stratosphere, mesosphere and lower thermosphere, upper atmospheric dynamics, including winds, tides, planetary waves and internal gravity waves, mainly in the upper mesosphere and lower thermosphere, atmospheric chemistry, including minor constituents of the mesopause and lower thermosphere regions, excitation and emission processes, stratospheric aerosols, and global change in the upper atmosphere.

Experimental techniques include measurement of atmospheric airglow emissions in the visible and near infrared, optical imaging of airglow emissions, laser radar, meteor radar and rocket payloads. Work is also starting on a scientific satellite - EQUARS, which will carry several experiments aimed at upper atmospheric studies. It is hoped that the satellite will be launched in late 2005. Airglow photometers are operated in Cachoeira Paulista (23°S, 45°W), Santa Maria (29°S, 54°W) and São João do Cariri (7°S, 37°W), airglow imaging measurements at the time of writing are made only in São João do Cariri although, in the past they have also been made at Cachoeira Paulista, lidar measurements are made at São José dos Campos (23°S, 46°W), meteor radar winds measurements are made at Cachoeira Paulista, and rocket experiments are launched from Natal (6°S, 35°W) and Alcântara (2°S, 44°W). The types of measurement being made are shown in Table 1, and the locations of the various installations used are shown in Figure 1.

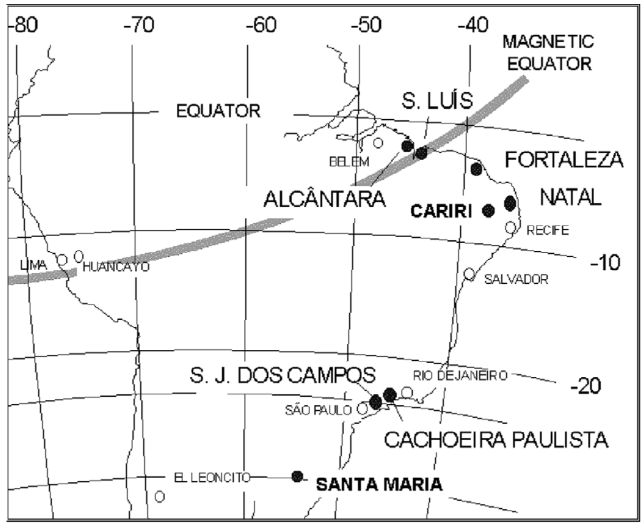

Fig. 1. Location of INPE's experimental installations for upper atmosphere studies.

Lidar measurements are used to study stratospheric aerosols, the temperature profile from 30 to 70 km (via the Rayleigh scattering profile), the atmospheric sodium layer between 80 and 110 km and the temperature profile in the same region via measurements of the Doppler spreading of the lidar return from sodium. Airglow measurements, both ground-based and rocket-borne have been used to study excitation process, photochemistry and atmospheric dynamics, including gravity waves, tides and planetary waves. Airglow imaging has been used mainly to study internal gravity waves, although imaging has also been used to study long-lived meteor trails. The meteor radar is mainly being used to study atmospheric tides and planetary waves. Rocket experiments have been used to measure emission profiles in the upper mesosphere and thermosphere, leading to studies of mesospheric ozone, atomic oxygen and hydroxyl excitation, "quenching processes" and atmospheric sodium chemistry (in conjunction with simultaneous lidar measurements). Most of the rocket experiments have also carried plasma probes developed by INPE´s ionosphere group. The rocket experiments have all been made in cooperation with the Brazilian Air Force Space and Aeronautics Institute (Instituto de

Table 1

Experimental installations for upper atmosphere research

Instrument	Location(s)	Measurements
Lidar	São José dos Campos; Alcântara (in conjunction with rocket measurements	Stratospheric Aerosols Temperature profile: 30-70 km Atmospheric sodium: 80 - 110 km Doppler temperature: 80 - 105 km
Airglow photometers	Cachoeira Paulista São João do Cariri Santa Maria	OI, O_2, OH and Na emissions, including OH and O_2 rotational temperature
Airglow imager	São João do Cariri	Imaging of the OI 577.7 and 630 nm, OH NIR, and O_2 (0,1) emissions
Meteor radar	Cachoeira Paulista	Winds: 75 - 110 km
Rocket measurements	Natal and Alcântara	Vertical profiles of OI, O_2, OH and Na emissions

Aeronáutica e Espaço - IAE), using their Sonda II and Sonda III rockets. In the following paragraphs we present some extracts from recent research and highlights from earlier work.

ATMOSPHERIC TIDES AND PLANETARY WAVES

INPE's upper atmosphere and airglow groups have published numerous studies of at mospheric tides (see, for example, Clemesha *et al*., 2001; Batista *et al*., 1990, Batista *et al*., 1985; Takahashi *et al*., 1984). More recently we have started to study planetary waves at low latitudes (Takahashi *et al*., 2001). In March 1999 a meteor radar started to operate at Cachoeira Paulista, making continuous measurements of the wind field between 80 and 110 km. Results from these measurements are just beginning to appear in the literature. An interesting example of the power spectrum of the wave field determined by the meteor radar is given in Figure 2. In the upper panel of this figure is shown how the spectrum of the meridional wind at 88 km varies from April 1999 to October 2001. As expected, the diurnal tide dominates for most of the time, but the fact that this wind almost vanishes in November/December, is not predicted by models such as the Global Scale Wave Model (Hagan *et al*., 1999). At about the same time of the year, or a little later, a strong quasi-2-day wave is observed. The zonal wind, shown in the lower panel, shows a weaker diurnal oscillation but strong episodes of planetary wave activity, with periods as long as 15 days.

TWO-DIMENSIONAL WAVE NUMBER SPECTRUM OF GRAVITY WAVES

The airglow imager is an excellent instrument for studying the horizontal structure of gravity waves propagating near to the mesopause. Waves are visible in all the emissions from this region. In Figure 3 we show an example seen in the near infrared emissions from hydroxyl on January 19, 1999 at 0139 LT. Figure 3(a) shows the original CCD image, taken through a wide-angle fish-eye lens. (b) shows a linearized version of the image, where the geometrical distortion introduced by the fish-eye lens has been corrected to make the x and y coordinates directly proportional to horizontal distance in the emitting layer. (c) shows a 3-D representation of a small section of the image, with strong gravity wave activity. (d) shows a 2-dimensional Fourier analysis of this section of the image. This last panel shows the wave energy as a function of wave number in radians/km. The horizontal scales in this figure go from -1 to +1 radians/km. The presence of two symmetrical peaks is an artifact introduced by the Fourier transform of a real function. The ambiguity in propagation direction is resolved by examination of a sequence of images, showing the true direction of propagation of the observed wave. In this case the wave was propagating at an azimuth of 94 degrees and had a horizontal wavelength of 13.5 km.

IMAGING OBSERVATIONS OF F-REGION PLASMA BUBBLES - EFFECT OF RADIATIVE LIFETIME

Equatorial ionospheric plasma bubbles have been observed at Cachoeira Paulista using OI 630 nm and OI 557.7 nm all-sky images (Takahashi *et al*., 2001). It is frequently observed that the plasma bubble structure, generated at the equatorial plane and projected in the emission layer at around 250 km altitude, shows multi-bifurcation features indicating the complexity of interaction between the electric field and plasma in the magnetic flux tube. It was noted that the 557.7 nm image shows more detail of the plasma bubble structure than 630 nm. This is evident in the 3-D representations of corresponding images in 557.7 and 630 nm shown in Figure 4. We believe that this effect results from the difference in life time of the upper levels O(1S) (about 1 second) and O(1D)

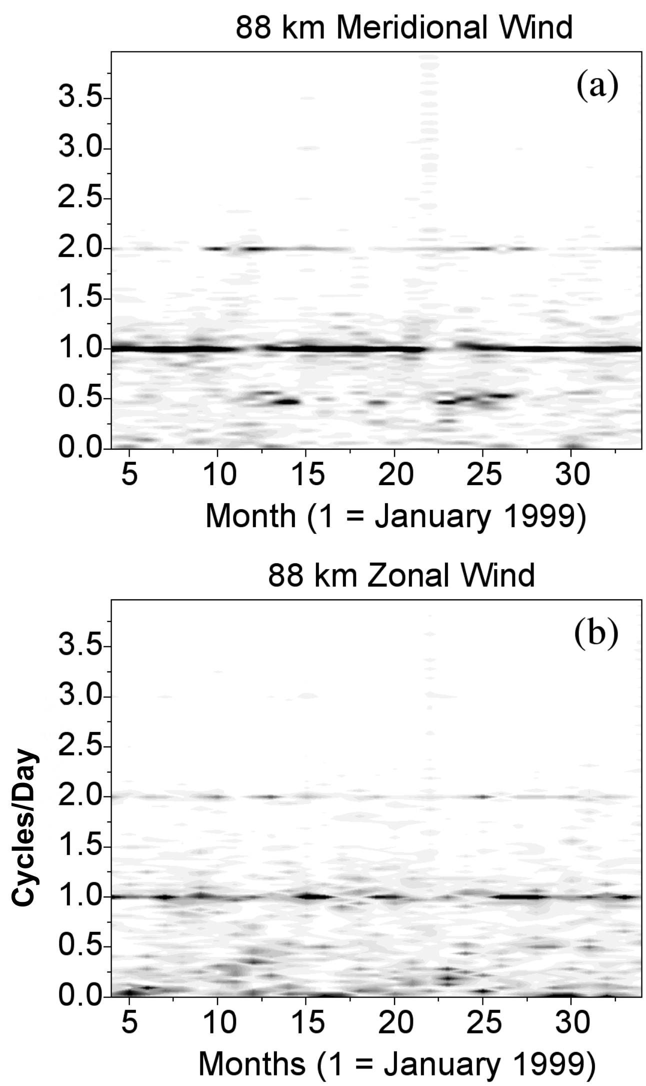

Fig. 2. Gray scale plots against time of the normalized power spectrum of (a) Meridional and (b) Zonal wind for a height of 88 km, observed at Cachoeira Paulista.

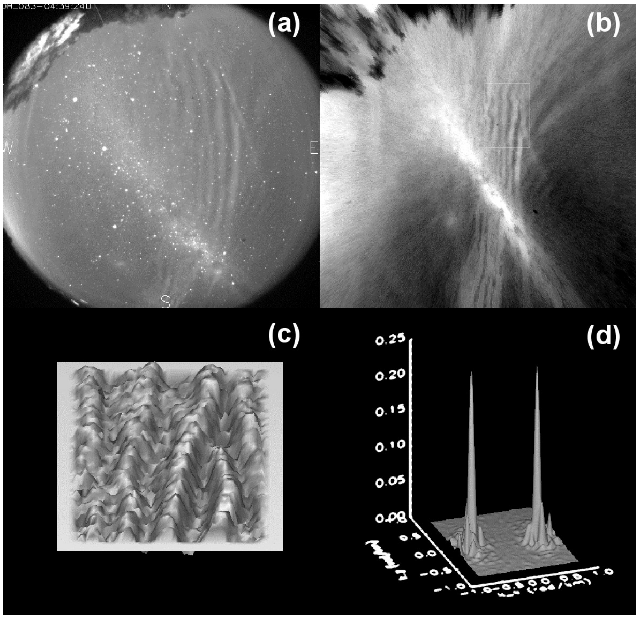

Fig. 3. Gravity waves observed by an all-sky imager: (a) all-sky image; (b) linearized image; (c) x, y, z plot of wave structure; (d) wave number spectrum.

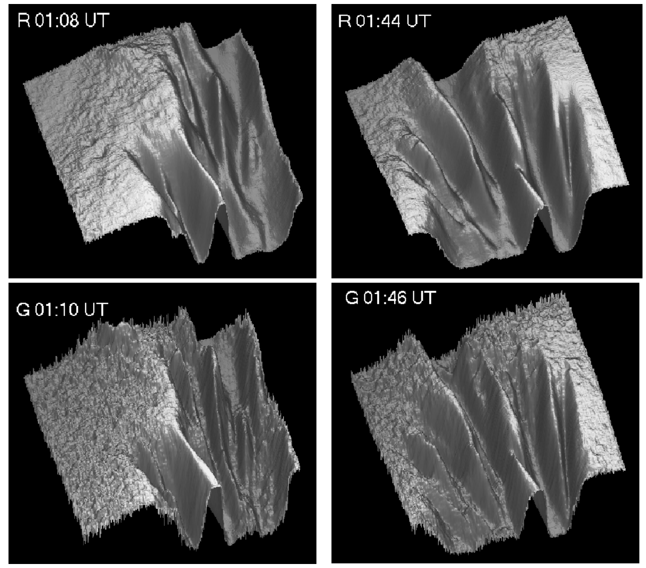

Fig. 4. Three-dimensional graphic representations of the O16300 (R) and OI 5577 (G) intensity maps. Horizontal extension is about 800 km and the equator side is at the lower part of the picture.

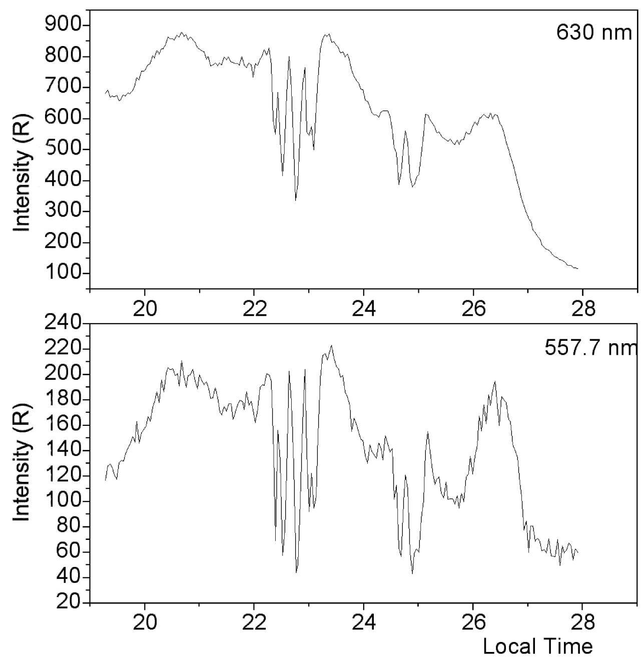

Fig. 5. Zenith intensities for OI 630 nm and F-region component of the OI 557.7 nm emissions. Cachoeira Paulista, March 18, 1999.

(about 3 minutes), responsible for the 557.7 nm and 630 nm emissions, respectively. Zenith-pointing photometer observations (Figure 5) reveal that the amplitude of the depletion in 557.7 nm is larger than that in 630 nm. These facts indicate that thermal relaxation is significant in 630 nm. We conclude that the thermospheric 557.7 nm emission is better suited to observing equatorial ionosphere plasma bubble dynamics than is the 630 nm emission. For further study of plasma bubbles, it would be desirable to reduce the integration time for producing an image from 90 seconds (as used at present) to at least a half that value in order to observe higher frequency bubble structure.

STRATOSPHERIC AEROSOLS

The INPE lidar has been operating since 1972. Although the main interest in this work is in the atmospheric sodium layer, the lidar also provides information on stratospheric aerosols in the form of scattering ratio profiles. The scattering ratio is the ratio of the observed lidar return to that expected from a purely molecular atmosphere at a wavelength of 589 nm. Stratospheric aerosols are mainly formed by the oxidation of sulfur-bearing gases emitted in explosive volcanic eruptions. Over the past 30 years two massive injections have occurred, in addition to a number of smaller events. The injections in question were the result of the eruptions of the El Chichón volcano in Mexico, in 1982, and the Pinatubo volcano in the Philippines, in 1991. As can be seen from Figure 6, both these injections caused major increases in the aerosol loading. Interesting aspects of stratospheric aerosols relate to their effect on radiative transfer in the atmosphere, their lifetime, and their global transport by atmospheric circulation.

GLOBAL CHANGE IN THE UPPER ATMOSPHERE

The lidar measurements of atmospheric sodium have been mainly aimed at studying atmospheric dynamics and chemistry. However, an intriguing aspect of these meas-

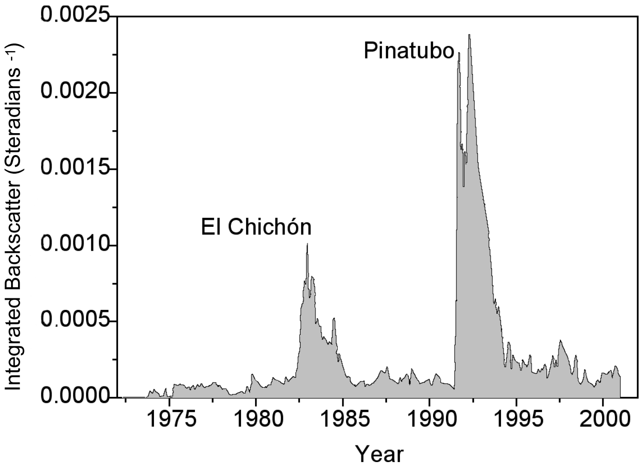

Fig. 6. Long-term variation of stratospheric aerosol loading measured at São José dos Campos.

urements is the observation of a long-term trend in the centroid height of the sodium layer. The centroid height can be measured with great precision, since it depends only on the determination of the time delay in the lidar return from the layer. Although the height of the layer suffers large day-to-day variations, believed to result from both dynamical and chemical sources, a statistical study of many years of data has shown a clear long-term trend. Figure 7 shows the results of a regression analysis including a linear trend and a sunspot cycle component. This analysis (Clemesha *et al.*, 1997) indicates that the centroid height of the sodium layer decreased at a rate of 46±9 m, yr-1 between 1972 and 1994. A possible explanation of this trend is that it is the result of a cooling of the upper atmosphere caused by the increase in the global concentration of the so-called greenhouse gases, as predicted by atmospheric models (see for example, Roble and Dickinson, 1989). If we make the admittedly simplified assumption that the observed height decrease is simply the result of the cooling-induced subsidence of the atmospheric constant density surfaces, then it could correspond, for example, to a cooling of 1.5 K from a height 20 km up.

THE BRANCHING RATIO OF THE CHAPMAN REACTION

The sodium emission in the night airglow is believed to be the result of the oxidation of sodium atoms by ozone followed by the reduction of the oxide by atomic oxygen in the reaction NaO + O → Na(^{2}P, ^{2}S) + O_2. Over the years there has been considerable controversy over the correct value of the branching ratio between the production of Na(^{2}P) and Na(^{2}S). This mainly resulted from the fact that laboratory studies gave values for Na(^{2}P) production much too low to explain the observed airglow. In 1992 we carried out a rocket experiment in which the vertical profile of the sodium emission was measured simultaneously with those for various oxygen emissions. At the same time and location (Alcântara)

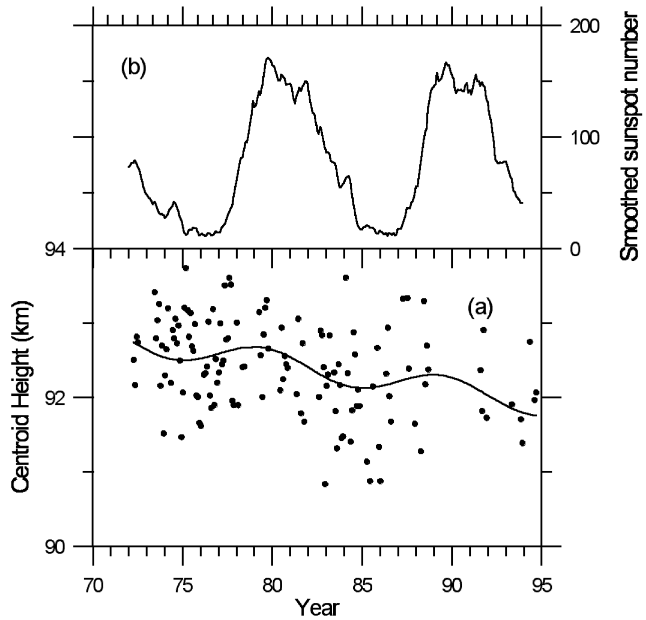

Fig. 7. (a) Monthly means of the sodium layer centroid height for 1900-2200 LT. The continuous line represents the fitted linear and 10-yr trends. (b) 6-month running means of the sunspot number.

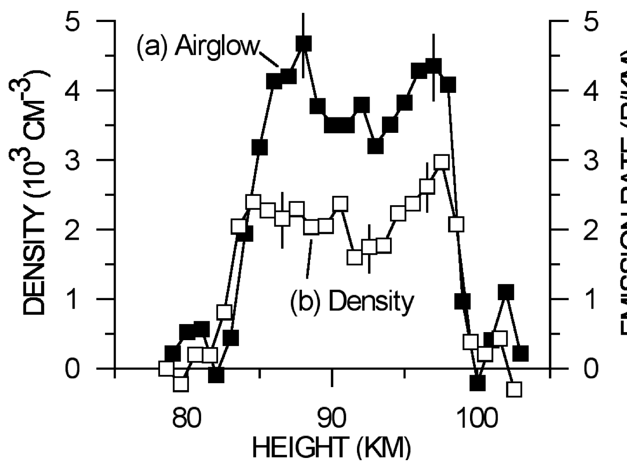

Fig. 8. Simultaneous height profiles of (a) the NaD airglow, measured by a rocket-borne photometer and, (b) atomic sodium concentration, measured by lidar. Measurements made at Alcântara on May 31, 1992.

a sodium lidar measured the vertical profile of free sodium atoms. The emission and atomic profiles are shown in Figure 8. On the basis of these measurements it was possible to determine a range of 0.05 to 0.20 for the branching ratio consistent with model computations for the sodium distribution. This work is described in detail in Clemesha *et al.* (1995).

CONCLUSION

Over the past three decades INPE researchers have made a strong contribution to studies of the upper atmosphere at equatorial and low-latitudes. During this period over 250 papers have been published in the areas of the photochemistry and dynamics of the mesopause and lower thermosphere, middle atmosphere climatology, and stratospheric aerosols. This work has made important contributions to our understanding of the upper atmosphere in areas such as the photochemistry of the sodium layer, excitation mechanisms for the atmospheric airglow, atmospheric tides and gravity waves and long-term change in the upper atmosphere. In this paper the authors have attempted to present a few highlights from recent work. Details of INPE's research in this area can be found in the extensive publication lists available by following the links at http://www.laser.inpe.br/.

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R. Clemesha, P. P. Batista, H. Takahashi, D. Gobbi, A. F. de Medeiros and D. M. Simonich
Instituto Nacional de Pesquisas Espaciais,
CP 515, São José dos Campos, 122201 SP, Brazil
Email: clem@laser.inpe.br