UPPER ATMOSPHERE RESEARCH AT INPE

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ABSTRACT

Upper atmosphere research at INPE is mainly concerned with the chemistry and dynamics of the stratosphere, upper mesosphere and lower thermosphere, and the middle thermosphere. Experimental work includes lidar observations of the stratospheric aerosol, measurements of stratospheric ozone by Dobson spectrophotometers and by balloon and rocket-borne sondes, lidar measurements of atmospheric sodium, and photometric observations of O, O_2, OH and Na emissions, including interferometric measurements of the OI6300 emission for the purpose of determining thermospheric winds and temperature. The airglow observations also include measurements of a number of emissions produced by the precipitation of energetic neutral particles generated by charge exchange in the ring current. Some recent results of INPE's upper atmosphere program are presented. ~~in this paper~~.

1- INTRODUCTION INPE maintains an active program of research into a number of aspects of upper atmosphere science, including both experimental and theoretical studies of the dynamics and chemistry of the stratosphere, mesosphere and lower thermosphere. Experimental work involves mainly ground-based optical techniques, although balloon and rocket-borne sondes are used for studies of stratospheric ozone, and a rocket-borne photometer payload is under development for measurements of a number of emissions from the thermosphere. Theoretical studies include numerical modelling with special reference to a number of minor constituents related to the experimental measurements. In the following sections we present a brief description of INPE's experimental facilities in the area of upper atmosphere science, and outline some recent results.

2- EXPERIMENTAL FACILITIES INPE's facilities for atmospheric research are distributed between four campuses: São José dos Campos (23°S, 46°W), Cachoeira Paulista (23°S, 45°W), Natal (6°S, 35°W) and Fortaleza (4°S, 38°W).

2.1- Lidar The INPE lidar, installed at São José dos Campos, uses a flash-lamp pumped dye laser tuned to the sodium D2 (5890Å) line, and provides data on Rayleigh and Mie scattering from the stratosphere and resonant scattering from the atmospheric sodium layer situated between about 80 and 105km. The stratospheric return provides information on the vertical distribution of stratospheric aerosols, and the high altitude data give the atmospheric sodium profile. By means of a narrow angular beamwidth (0.2 mR) and a narrow band receiver (0.2 Å) it is possible to operate the lidar during the day, a capability shared with very few other lidars.

2.2- Airglow Photometers INPE operates a number of airglow photometers at its airglow observatory in Cachoeira Paulista, and has one instrument operating at Natal. In the near future it is intended to instal a second instrument in Natal or Fortaleza, and transfer one instrument from Cachoeira Paulista to the same location. Most of the photometers are multichannel instruments of the tilting filter type, and some of these are designed for scanning in elevation and/or azimuth.

Airglow emissions being measured at Cachoeira Paulista include OI 7774Å, 6300Å and 5577Å, the OH (9-4) and (8-3) bands, the 8645Å molecular oxygen band, NaD 5890Å, N_2^+ 4278Å and 3914Å and Hβ 4861Å. The sodium emission is also measured at Natal.

Most of the photometers have been developed by INPE, and the more recent instruments have microprocessor based control and data acquisition systems. A Fabry-Perot interferometer for measuring F region temperature and winds is being tested at São José dos Campos, and has already provided useful data. This instrument will be transfered to the Airglow Observatory at Cachoeira Paulista when it becomes fully operational.

2.3- Ozone Measurements INPE operates 2 Dobson spectrophotometers which make daily total ozone measurements at Cachoeira Paulista and at Natal. The Cachoeira Paulista instrument has been in operation since 1974 and the Natal measurements started in 1978. Twice monthly balloon-borne ECC sondes have been launched from Natal since 1978 (4 times per month since 1982) in a cooperative program with NASA. Rocket measurements of ozone up to 70km were made between 1978 and 1982. These measurements were discontinued because of problems with the calibration of the optical ozone measuring instrument, but should be recommenced at the end of this year.

3- RESEARCH RESULTS Details of the results of INPE's work in the field of upper atmosphere research are, of course, to be found in the relevant journal publications. In this paper we present a brief synopsis of some of the results published during the last 12 months. A complete list of papers published by INPE's upper atmosphere group during the past 3 years is to be found in section 4.

3.1- Lidar Observations of the El Chichón Aerosol Lidar measurements at São José dos Campos show that the El Chichón dust cloud had reached this latitude by mid-July, 1982. The first measurement made after the eruption showed two layers with scattering ratios of 1.8 and 2.7 at 18 and 24km respectively, as compared with pre-injection values of about 1.2. These values refer to a wavelength of 5890Å, and are for a profile obtained on July 9th. Measurements made in subsequent months showed large fluctuations, particularly in the upper layer, where the scattering ratio varied between 1.2 and 5. The lower layer varied much less than the upper, with the result that the integrated backscatter, a measure of the total stratospheric aerosol burden, remained roughly constant until late August, when it increased from about $3x10^{-4}$ SR^{-1} to about $1x10^{-3}$ SR^{-1}. Subsequent to this date the integrated aerosol oscillated around a value of about $8x10^{-4}$ SR^{-1} until mid-March 1983, since when it has decreased to about $5x10^{-4}$ SR^{-1}. The height of the upper layer decreased fairly uniformly with time until late November, when it reached 20km, by which time it had merged with the lower layer. In 1983 the layer has again shown a bifurcated structure with a lower peak close to 18km and an upper one 2 to 4km higher.

3.2- Tidal Oscillations in the Atmospheric Sodium Layer The vertical distribution of atmospheric sodium has been measured at São José dos Campos over a total of about 20 complete diurnal cycles between April and August, 1981. Average time variations of the sodium density show strong oscillations with 12 and 24 hour periods. Both the diurnal and semidiurnal components of the oscillations display large amplitudes and a 180^{o} phase inversion near the layer peak. These features are interpreted in terms of the propagation of tides in the layer, taking into account the interaction between the tide and the minor constituent layer. It has been shown that the vertical wind is the most important factor determining the amplitude of the oscillation in sodium density at a fixed height, thus making it possible to estimate the phase and amplitude of the wind oscillations over a limited height range. Diurnal and semidiurnal vertical wind amplitudes of 2-6cm s^{-1} and 5-20cm s^{-1}, respectively, have been inferred. The 12-hour component shows vertical phase propagation with a wavelength of ~50km, in agreement with recent theories. The 24-hour component, however, shows characteristics of an evanescent mode instead of the expected $S_{1,1}$ mode. Maximum upward vertical velocity occurs at about 2100 LT at all heights for the diurnal component, and at 0600 and 1800 LT at 85km for the semidiurnal component. These results appear to be the first reported measurements of the vertical displacements produced by the diurnal and semidiurnal tides.

3.3- Theoretical Modelling of the Atmospheric Sodium Layer Recent results for sodium reaction rates have led to a reassessment of the relative importances of a number of sodium compounds thought to exist in the upper mesosphere and lower thermosphere. In order to evaluate the effect of these reactions, a dynamic time dependent atmospheric photochemistry-vertical diffusion model has been developed to calculate the diurnal variation of sodium and compare it with recent measurements. A much larger reaction rate coefficient for the three body production of NaO_2 makes this constituent the main sodium compound at heights below about 85km, and the inclusion of photolysis results in a large diurnal variation in NaOH concentration. The diurnal variation in the abundance of free sodium is small, but the concentration at 80km varies by about one order of magnitude. Both of these results are in agreement with the measured diurnal variation of free sodium.

3.4- Tidal and Solar Cycle Effects on the OI5577Å, NaD and OH(8,3) Airglow Emissions The OI5577Å, NaD and OH(8,3) airglow emission intensities measured at Cachoeira Paulista from 1977 to 1982 have been analysed from the point of view of their nocturnal and seasonal variations. The nocturnal variations of the atomic oxygen emission and the OH rotational temperature (derived from the relative intensities of the P, Q and R branches of the 8,3 emission) show a significant semidiurnal oscillation, with the phase of maximum moving from midnight in January to early morning in June. Semiannual variations of the OI5577Å and NaD emissions were observed, with maximum intensities in April-May and October-November. The rotational temperature, however, showed an annual variation with maximum in summer and minimum in winter, while no significant seasonal variation was found in the OH emission intensity.

3.5- The $O_2(^1\Sigma)$ Atmospheric Band at 8645Å and the Rotational Temperature Ground based measurements of the $O_2(^1\Sigma)(0,1)$ Atmospheric band at 8645Å and the rotational temperature, together with OI5577Å NaD and OH(9,4) band emissions have been carried out at Cachoeira Paulista. It was found that the O_2 band intensities occasionally vary from 200 Rayleighs to 1000 Rayleighs during a night and covariations with OI5577Å emissions were observed. The rotational temperatures determined from the P branch of the $O_2(^1\Sigma)$ vary between 180°K and 230°K. The amplitude of the nocturnal temperature variations is frequently larger than that derived from the OH emission, and the phase of the variations normally leads that of the OH. On some nights it was observed that the temperature variations of both the emissions were out of phase, suggesting a vertical phase propagation of the atmospheric wavelike perturbations.

3.6- <u>Vertical and Horizontal Phase Propagation in the Mesopause Region Observed by the OI5577Å, O_2 Atmospheric Band, NaD and OH(8,3) Band Nightglow Emissions</u> Meridional scanning observations of the NaD and OH(8,3) emissions show that on most of the nights of the observations the intensities varied uniformly along the meridional zone scanned, suggesting that the normal nocturnal variations are controlled by some regular atmospheric variation such as tides. However, on a few nights, horizontal intensity gradients and wavelike propagation of the NaD emission were observed. The observed apparent wavelength, phase velocity and period suggest the passage of internal gravity waves in the emission layer. On the night of 13-14 June 1983, both the NaD and OH(8,3) emissions showed a horizontally propagating wave structure, and simultaneously a vertical phase propagation was observed from nocturnal variations of several mesospheric emissions.

3.7- <u>Observations of Large Scale F-Region Irregularities Using Airglow Emissions at 7774Å and 6300Å</u> Simultaneous scanning mearements of the atomic oxygen 7774Å and 6300Å emissions, to study the dynamics of low-latitude large scale F-region irregularities, were carried out at Cachoeira Paulista during the period October-November, 1980. The measurements were made with a two-channel photometer which permitted scanning observations both along and across the magnetic meridian. Onservations at 7774Å can detect large scale irregularities near the F-region peak height, whereas observations at 6300Å detect such irregularities at an altitude about 50km to 100km lower, depending on the F-region height. On many nights, during spread-F conditions, as indicated by an ionosonde operating at the same location, the presence of large intensity depletions of short duration were detected in both emissions. These depletions were observed to move towards the east in the east-west scans, and apparently towards the south in the north--south scans.

3.8- <u>Observations of Optical Emissions from Precipitation of Energetic Neutral Atoms and Ions from the Ring Current</u> Observations of N_2^+ 1N, H Balmer β(BHaβ) and other emissions due to particle precipitation have been observed at two low-latitude sites (Mt. Haleakala, Hawaii and Cachoeira Paulista, Brazil) and one mid-latitude site (McDonald Observatory, Southwest Texas). Results are compared for magnetic storms of April 12, 1981 and July 14, 1982. The emission have the characteristics appropriate to the precipitation into the thermosphere of energetic neutral atoms and/or ions originating in the ring current. These characteristics include high rotational/vibrational excitation of the N_2^+ 1N bands and at time the occurrence of HBaβ emission with the same onset time as the N_2^+ 1N emission and partial correlation with it afterward. The latitude variation shows a strong increase from low to mid latitudes. The strongest emissions occur in the evening to midnight local time period, and the storm time variations shows strongest emissions during main phases. The time variations of HBaβ and N_2^+ 1N emissions indicate that there is more O/O^+ precipitation than H/H^+ precipitation in the latter part, and sometimes the whole duration of the precipitation events and the variations are consistente with H^+ being lost from the inner ring current faster than other species, such as O^+ and He^+. Lower limits for the energy deposition rates for the strongest emissions at 40-45^{o} dip latitude are 1-2mWm^{-2} and for the strongest emissions at 12^{o}S dip latitude, 0.5mWm^{-2}. Ionization production at its peak altitude somewhere above 110km would be in the range from $10^2cm^{-3}\ s^{-1}$ to a few times $10^3cm^{-3}s^{-1}$ for the events in Texas, and from 10^0 to $10^2cm^{-3}\ s^{-1}$ for the stronges events in Hawaii and Brazil.

3.9- Atmospheric Ozone Atmospheric ozone has been measured using ECC ozonesondes at Natal since 1978. Points of interest that have come out of the data are as follows: 1) Tropospheric ozone densities at Natal are higher by about 30% than previously published results in the equatorial region. 2) Natal total ozone measurements are about 15% higher than equatorial zone averaged satellite data. 3) In the stratosphere the ozone correlation with temperature is positive below the ozone peak and negative above it. 4) The average total ozone content over Natal measured by ECC sondes and a Dobson spectrophotometer differs by less than 4%. 5) From the correlation between O_3 and T it can be inferred that ozone undergoes a QBO type oscillation which at 30 mb has an amplitude of about 10% with a period of about 30 months.

4- JOURNAL PUBLICATIONS 1981-1984

BATISTA, P.P.; CLEMESHA, B.R.; KIRCHHOFF, V.W.J.H.; SIMONICH, D. M. "Tidal Oscillations in the Atmospheric Sodium Layer", J. Geophys. Res., Submitted for publications, 1984.

BITTENCOURT, J.A.; TEIXEIRA, N.R.; SAHAI, Y. and TAKAHASHI, H. "Mapping of Ionospheric F-Region Parameters from Atomic Oxygen Airglow Emissions". J. Atmos. Terr. Phys., 45,697-705, 1983.

CHRISTOPHE, J.; THULLIER, G.; FAHRENBACH, M.; SAHAI, Y.; WEILL,G. "Tropical Nightglow and Ionospheric Models Predictions". J. Atmos. Terr. Phys., 45, 137-148, 1983.

CLEMESHA, B.R.; BATISTA, P.P.; KIRCHHOFF, V.W.J.H.; SIMONICH,D.M. "Mesospheric Winds from Lidar Observations of Atmospheric Sodium". J.G.R., 86,868-870, 1981.

CLEMESHA, B.R.; KIRCHHOFF, V.W.J.H.; SIMONICH, D.M. "Remote Measurements of Tropospheric and Stratospheric Winds by Ground Based Lidar". Applied Optics, 20, 2907-2910, 1981.

CLEMESHA, B.R.; KIRCHHOFF, V.W.J.H.; SIMONICH, D.M. "Comments on "A Meteor Ablation Model of the Sodium and Potassium Layer" by D.J. Hunten. Geophys. Res. Lett.,8, 1023-1025, 1981.

CLEMESHA, B.R.; SIMONICH, D.M.; BATISTA, P.P.; KIRCHHOFF, V.W.J. H. "The Diurnal Variation of Atmospheric Sodium". J. Geophys. Res., 87, 181-186, 1982.

CLEMESHA, B.R.; SIMONICH, D.M. "Lidar Observations of the El Chichón Dust Cloud at 23°S". Geophys. Res. Lett., 10, 321-324, 1983.

CLEMESHA, B.R.; SIMONICH, D.M. "Lidar Observations of the El Chichón Aerosol at a Southern Latitude Station". Geofísica Internacional, in press, 1984.

CLEMESHA, B.R. "Lidar Studies of the Alkali Metals". to be published in the Middle Atmosphere Handbook, Vol. 13, 1984.

KANE, R.P.; SAHAI, Y.; TEIXEIRA, N.R. "Maximum Entropy Spectral Analysis of Total Ozone". Submitted to Pure Applied Geophysics, 1983.

KIRCHHOFF, V.W.J.H.; CLEMESHA, B.R.; SIMONICH, D.M. "Seasonal Variation of Ozone in the Mesosphere". J. Geophys. Res., 86, 1463-1466, 1981.

KIRCHHOFF, V.W.J.H.; CLEMESHA, B.R.; SIMONICH, D.M. "Average Nocturnal and Seasonal Variations of Sodium Nightglow at 23°S, 46°W". Planet. Space Sci., 29, 765-766, 1981.

KIRCHHOFF, V.W.J.H. "Campos Elétricos na Região Ionizada da Atmosfera". Rev. Bras. Física, 11, 711-725, 1981.

KIRCHHOFF, V.W.J.H.; CLEMESHA, B.R.; SIMONICH, D.M. "The Atmospheric Neutral Sodium Layer, 1, Recent Modeling Compared to Measurements". J. Geophys. Res., 66, 6892-6898, 1981.

KIRCHHOFF, V.W.J.H.; SAHAI, Y.; MOTTA, A.G. "First Ozone Profiles Measured with ECC Sondes at Natal (5.9°S, 35.2°W). Geophys. Res., Lett., 8, 1171-1172, 1981.

KIRCHHOFF, V.W.J.H.; CLEMESHA, B.R. "The Dissipation of a Sodium Cloud". Planet. Space Sci., 31, 369-372, 1983.

KIRCHHOFF, V.W.J.H.; CLEMESHA, B.R. "The Atmospheric Neutral Sodium Layer, II, Diurnal Variations". J. Geophys. Res., 88, 442-450, 1983.

KIRCHHOFF, V.W.J.H.; CLEMESHA, B.R. "Eddy Diffusion Coefficients in the Lower Thermosphere". Geophys. Res. Lett., 88, 5765-5768, 1983.

KIRCHHOFF, V.W.J.H.; HILSENRATH, E.; MOTTA, A.G.; SAHAI, Y.; MEDRANO-B., R.A. "Equatorial Ozone Characteristics as Measured at Natal (5.9°S, 35.2°W)". J. Geophys. Res., 88, C11, 6812-6818, 1983.

KIRCHHOFF, V.W.J.H.; BATISTA, P.P. "Calculation of the Vertical Drift of the Sodium Ion". Ann. Geophys., 1(6), 509-514,1983.

KIRCHHOFF, V.W.J.H. "Atmospheric Sodium Chemistry and Diurnal Variations: an up-date". Geophys. Res. Lett.,10,721-724, 1983.

KIRCHHOFF, V.W.J.H.; A.G. MOTTA. "Medidas de Ozônio na Troposfera e Estratosfera de Natal". Rev. Bras. Geofis., 2, 25-30, 1983.

KIRCHHOFF, V.W.J.H.; TAKAHASHI, H. "Sodium Clouds in the Lower Thermosphere". Planet. Space Sci., in press, 1984.

KIRCHHOFF, V.W.J.H. "Are Northern Hemisphere Tropospheric Ozone Densities Larger?" EOS, in press, 1984.

ROHRBAUGH, R.P.; TINSLEY, B.A.; RASSOUL, H.; SAHAI, Y.; TEIXEIRA, N.R.; TULL, R.W.; DOSS, D.R.; COCHRAN, A.L.; COCHRAN, W.D. and BARKER, E.B. "Observations of Optical Emissions from precipitation of Energetic Neutral Atoms and Ions from the Ring Current, J. Geophys. Res., 88, 6317-6330, 1983.

SAHAI, Y.; BITTENCOURT, J.A.; TEIXEIRA, N.R.; TAKAHASHI, H. "Plasma Irregularities in the Tropical F-Region detected by OI7775Å and 6300Å Nightglow Measurements". J.Geophys. Res., 86:3496-3500, 1981.

SAHAI, Y.; BITTENCOURT, J.A.; TEIXEIRA, N.R. "Comments or "Airglow Observations of the OI7774Å Multiplet at Arecibo During a Magnetic Storm", by Roer G. Burnside, John W. Meriwether and James C.G. Walter, J. Geophys. Res., 85, 767, 1980". J. Geophys. Res., 86;4839-4840, 1981.

SAHAI, Y.; BITTENCOURT, J.A.; TEIXEIRA, N.R.; TAKAHASHI, H. "Simultaneous Observations of OI Å and (OI) 6300Å Emissions and Correlative Study with Ionospheric Parameters". J.Geophys. Res., 86:3657-3660, 1981.

SAHAI, Y.; KANE, R.P.; TEIXEIRA, N.R. "Low-latitude Total Ozone Measurements in the Brazilian Sector". Pure and Applied Geophysics, 120, 616-625, 1982.

SAHAI, Y.; BITTENCOURT, J.A.; TEIXEIRA, N.R.; TAKAHASHI, H. "Observations of Large F-region Irregularities using Airglow Emissions at 7774Å and 6300Å". Annales Geophysicae, 1, 271-276, 1983.

SIMONICH, D.M.; CLEMESHA, B.R. "Resonant Extinction of Lidar Returns from the Alkali Metal Layers in the Upper Atmosphere". Applied Optics, 22, 1387-1389, 1983.

TAKAHASHI, H.; SAHAI, Y.; CLEMESHA, B.R.; SIMONICH, D.M.; BATISTA, P.P. e TEIXEIRA, N.R. "Simultaneous Measurements of the OH(8,3) Band and OI5577Å Airglow Emissions". Revista Brasileira de Física, 11, 727-741, 1981.

TAKAHASHI, H.; BATISTA, P.P. "Simultaneous measurements of OH (9,4), (8,3), (7,2), (6,2) and (5,1) bands in the airglow". Journal of Geophysical Research, 86, nº A7, P. 5632-5542,1981.

TAKAHASHI, H.; BATISTA, P.P.; SAHAI, Y. "Tidal and Solar Cycle Effects on the OI5577Å, NaD and OH(8,3) Airglow Emissions observed at 23°S". Planetary and Space Science, in press,1984.

TINSLEY, B.A.; ROHRBAUGH, R.P.; SAHAI, Y.; TEIXEIRA, N.R. "Energetic Oxygen Precipitation as a Source of Vibrationally Excited N_2^+ IN Emission observed at Low Latitudes". Geophys. Res. Lett., 9, 543-546, 1982.