Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 47 (2011) 1165–1171
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Sodium lidar measurements of mesopause region temperatures at 23° S

Barclay Clemesha *, Dale Simonich, Paulo Batista

Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brazil

Received 17 August 2010; received in revised form 23 November 2010; accepted 24 November 2010
Available online 30 November 2010

Abstract

A sodium lidar, capable of measuring temperature in the 80–100 km region, has been in operation at São José dos Campos (23° S, 46 W) since March 2007. Good quality data have been obtained for late autumn, winter and spring, but weather conditions make it extremely difficult to make measurements from mid-November to mid- February. We find the temperature structure to be strongly modulated by tides and gravity waves, but average profiles typically show a primary mesopause height close to 100 km with temperatures around 180 K, and a tendency for a secondary minimum of about 185 K to occur close to 90 km. Vertical temperature gradients greater than 50 K/km are sometimes seen even on profiles averaged over several hours. The strongest gradients are always positive and are frequently associated with strong gradients in sodium concentration. On the other hand, we frequently see rapid changes in the temperature profile, suggesting that models and non-local temperature measurements, as made by satellite radiometers, for example, are of little use in applications such as the analysis of gravity wave propagation seen in airglow images.

Keywords: MLT; Upper atmosphere; Temperature; Lidar; Sodium

1. Introduction

Lidar measurements of atmospheric sodium were pioneered by a number of workers at the Radio Research Station, Slough (now the Rutherford Appleton Laboratory) in UK (Bowman et al., 1969; Gibson and Sandford, 1972). The same workers were also the first to measure temperature via determination of the Doppler broadening of the sodium D2 line (Gibson et al., 1979). The first accurate measurements of the mesopause region temperature profile appear to have been made by Fricke and von Zahn (1985) at Andoya, followed by She et al. (1990) at Colorado State University. Since that time temperature measurements have also been made using potassium instead of sodium (von Zahn and Hoffner, 1996) and the alternative technique of the iron-Boltzmann lidar has been implemented at polar latitudes by Gardner et al. (2001) and at Arecibo by Raizada and Tepley (2002).

2. Instrumentation

At INPE, São José dos Campos (23° S, 46° W), we have been making measurements of atmospheric sodium since 1972 and temperature in the 80–100 km region since early 2007. Our lidar transmitter generates the required 589 nm emission by mixing the 1064 and 1319 nm outputs from two pulsed NdYag lasers, seeded by diode-pumped CW NdYag oscillators, as shown in Fig. 1, a technique first used by Kawahara et al. (2002) in their Syowa lidar. Wavelength control is achieved by thermally tuning the seeders, the temperatures of which are controlled by thermoelectric heater/coolers, each of which is in a feedback loop with a temperature sensor. To measure atmospheric temperature we alternate the laser wavelength between the D2a peak and the crossover minimum between the D2a and D2b peaks by tuning the 1064 seeder, the 1319 laser being left at a fixed wavelength. Long-term drift in the laser frequencies is taken care of by making multiple scans through the D2 lines at the start of every data run and using the signal returned from the Na layer as a reference. We normally find the drift in wavelength to be negligible except when

* Corresponding author.
E-mail address: brc@laser.inpe.br (B. Clemesha).

0273-1177/$36.00 © 2010 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2010.11.030

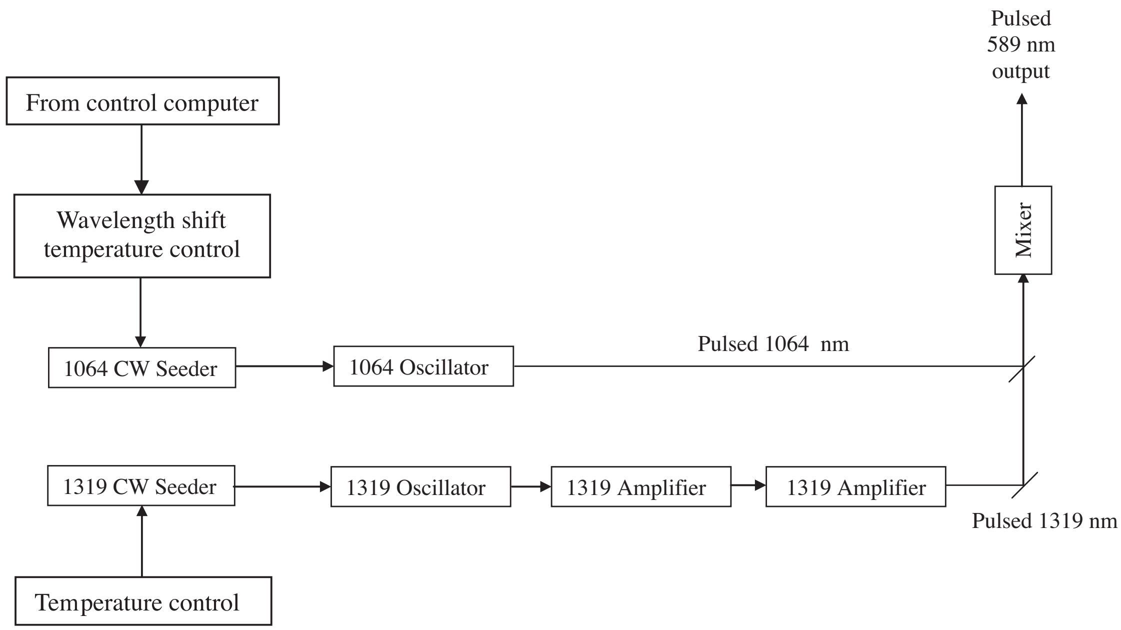

Fig. 1. Narrow-band tunable pulsed laser for 589 nm.

the laser has been recently re-aligned. It is estimated that we can set the 589 nm output wavelength of the system to an accuracy of ±50 MHz. The thermal time constant of the seeders is such that it takes 40 s to switch wavelengths. We normally take 250 shots at the D2 peak followed by 750 at the crossover wavelength at 10 pps, so that a complete measurement cycle can be made in 3 min. Using high quantum efficiency Hamamatsu photomultipliers we typically count around 1000 pulses per 300 m height interval from the peak of the Na layer. We normally sum the signal over 5 height intervals in order to minimize the statistical fluctuations in the photon counts. The temperature is derived from the ratio of the relative Na scattering cross-sections at the two wavelengths, due allowance being made for the difference in the lidar beam extinctions. Variations in the transmission of the lower atmosphere and the laser pulse energy are taken into account by normalizing the lidar return to the Rayleigh scattering from 40 km. Variations in the sodium layer occurring between the on-line and off-line measurements are largely eliminated by interpolating the data at fixed times using a 3-point interpolation routine. This means that independent data points are 9 min apart and that only third order and above variations will affect the derived temperatures. In practice such variations are rare, even in the presence of sporadic layers. We estimate the absolute error in our temperature measurement in regions of high sodium concentration to be ±5 K. The absolute sodium concentration is determined by comparing the resonant scattering from the sodium layer with the Rayleigh scattering from around 40 km. We estimate the absolute accuracy of the measured sodium concentration to be about ±10%, and the relative error of the time/height – averaged profiles is about 2% at the peak of the layer. The ~100 MHz bandwidth of the laser emission, measured using a high finesse 2 GHz free spectral range Fabry Perot interferometer, is taken into account when computing temperatures. Our lidar configuration is somewhat unusual in that the basic lidar is aligned horizontally, aimed at a 120 cm flat mirror, making it possible to steer the beam over part of the sky. A simplified diagram of the laser optics is shown in Fig. 2 and relevant lidar parameters are given in Table 1.

3. Results

3.1. Mean temperature profile and seasonal variations

Local cloud cover makes it extremely difficult for us to operate the lidar in summer. As can be seen from Fig. 3, which shows the number of nights of data obtained per month since the start of operations in 2007, we have no data for January, three nights of data in December and 2 in November. We have reasonably good data coverage for the rest of the year. Note that all our measurements have been made at night. Nightly data runs are typically 8 h in duration so multiplying the ordinate scale of Fig. 3 by 8 gives the total data time in hours. The total amount of data analyzed in this paper amounts to about 1600 h, involving a total of about 9600 independent temperature profiles. The annual mean temperature profile is shown in Fig. 4. The profile shown in this figure is the mean of 11 monthly profiles, equal weight being given to each month. The error bars in Fig. 4, representing the standard deviations of the daily averages, give an idea of the geophysical noise in the data. The mean mesopause temperature is 180 K, just below 100 km, and there is a secondary mesopause at 89 km with a temperature of 185 K. The temperature rises rapidly above 100 km, reaching 200 K at