Long-term temperature trends in the 35-65 km range by Rayleigh Lidar measurements at 23° S from 1993 to 2016 and comparison with SABER from 2004 to 2016

Paulo Prado Batista[1], Barclay Robert Clemesha[1*], Ana Roberta Silva Paulino[2] and Dale Martin Simonich[1*]
[1] Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brazil, * retired - paulo.batista@inpe.br
[2] Universidade Estadual da Paraíba, Campina Grande, PB, Brazil

COLAGE XI

Introduction A Lidar tuned to sodium resonance line at 589 nm has been operated at São José dos Campos, Brazil (23°S, 46° W) since 1993 processing the Rayleigh signal from which the temperatures from ~35 to ~65 km are retrieved in a nightly mean basis. In order to remove tidal effects only profiles obtained from 18:30 LT to 23:30 LT were considered in this analysis. We used these nightly profiles to determine the monthly temperature profiles from April 1993 to April 2016. The mean temperature characteristics for every year and for the whole period are obtained and do not differ too much from the previous climatology using shorter data series. A model including solar cycle, southern oscillation index, QBO, Annual and Semiannual oscillations and Linear trends has been fitted to the monthly temperatures every 3 km from 36 to 63 km. Variable linear trends with altitudes are determined with a maximum negative trends at 54-55 km attaining 2.8 K/decade.

Introduction

Lidar measurements of aerosols at INPE (São José dos Campos, SP, Brazil) started in 1969 and sodium measurements in 1971

After 1993 more powerful laser introduced in the system permitted the measurements of Rayleigh signal up to 75 km.

Average nocturnal profiles are obained on a near regular basis.

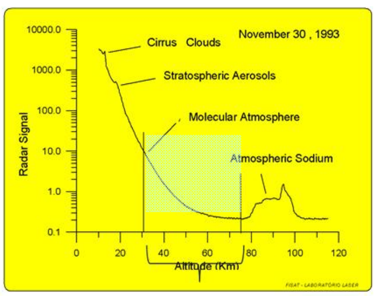
Monthly average profiles are used to study the temperature and density climatology from 30 to 65 km altitude.

24 years of temperature data from 35 to 65 km of altitude are used to study the long-term variability during that period.

INPE Lidar specification	
TRANSMITTER	RECEIVER
Wavelength: 589 nm	Área: 0.39 m2
Bandwidth: 10 pm 6 pm [a] <100MHz [b]	Bandwidth: 800 pm 1100 pm[a]
Pulse Energy: 300 mJ	Efficiency: 24% q. e ~ 40% [c]
Pulse rate: 5-10 pps 10 s^{-1} [a]	Height resolution: 250 m 300 m[a]
	Beamwidth: 0.4 mR 0.32 mR[a]

Lidar specification for the period 1993 to 2009
[a] After March 2006, [b] After March 2007, [c] Afer March 2009

Lidar specification



The figure shows an example of INPE's Lidar signal. The signal is blocked from 0 to 12 km. Cirrus clouds and stratospheric aerosols overlap the atmospheric molecular signal from 15 to 30 km. Resonant scattering of sodium are obtained from 78 to 105 km. From 30 to 75 km clean molecular Rayleigh signal is used to measure the atmospheric density and temperature.

Data processing

- The Lidar equation establishes that without the presence of aerosols (for h > 30 km) the backscattered signal is proportional to the atmospheric number density:

$$N(z_i) = \frac{N_0\, AK\, T^2(z_0, z_i)}{4\pi (z_i - z_0)^2} n_r(z_i)\beta_r$$

- Using the Perfect Gas Law and the Hydrostatic Equation P(z) or T(z) can be evaluated:

$$P(z) = \frac{R\,\rho(z)T(z)}{M} \quad ; \quad dP(z) = -\rho(z)g(z)dz$$

- The error in the density can also be determined being equal to the statistical error in the counting rate:

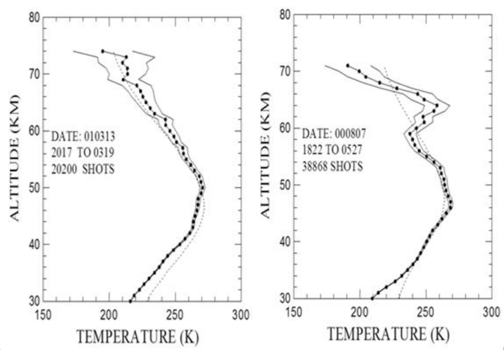
$$\frac{\delta\rho(z_i)}{\rho(z_i)} = \frac{(N(z_i)+N_m)^{1/2}}{N(z_i)}$$

- The temperature is then given by:

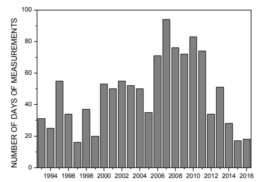
$$T(z_i) = \frac{M\, g(z_i)\, \Delta z}{R\, \mathrm{Log}[P(z_i - \Delta z/2)/P(z_i + \Delta z/2)]}$$

The standard method is used to retrieve the pressure from density assuming top level value from model. Downward integration is used to infer the pressure, and them the absolute temperature.

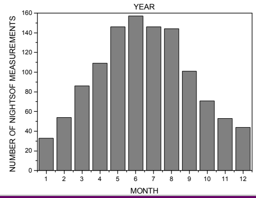
Examples of a regular profile (left) and a disturbed profile with a mesospheric inversion layer (right)



Statistics of measurements from 1993 to 2016

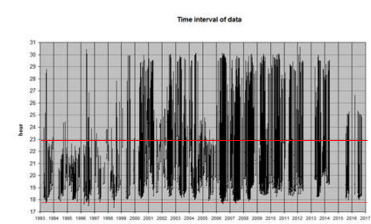


Number of days with measurements for each year from 1993 to 2016.

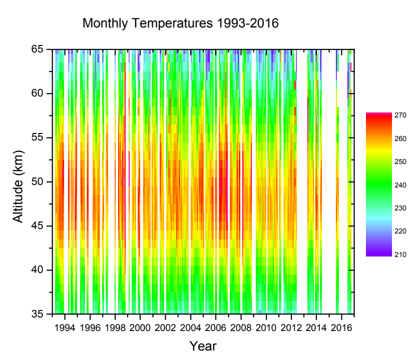


Number of nights with measurements at each month for the entire period 1993 to 2016.

Days and hours when Lidar data were obtained



Data were used between 18:30 to 23:30 when most of them were obtained.



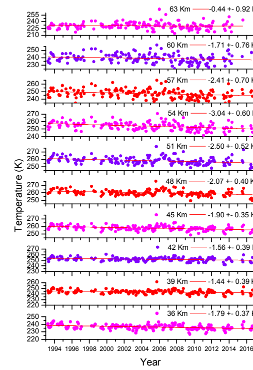
Height-Time plot of the Monthly averaged Temperatures from April 1993 to April 2016.

Fitting Model

As the temperature variation contains natural periodic signs, QBO, ENSO, 11-year solar cycle, besides the Annual, Smiannual and Terannual a regression model is used in each altitude:

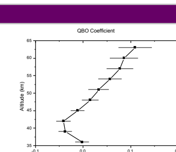
$$T_{hi}(t) = A_0 + \sum_{j=1}^{3}\left[A_j \cos\left(2\pi j/12(t-\phi_j)\right)\right] + \alpha_{hi} t + \beta_{hi} QBO(t)$$
$$+ \gamma_{hi} Solar(t) + \delta_{hi} ENSO(t) + residue(t)$$

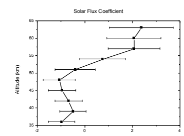
t is in month and A_0, A_j, α, β, γ, and δ are the coeficients of the mean, annual, semiannual, terannual, trend, QBO, Solar and ENSO contributions to the temperature variation determined by least mean square fit.



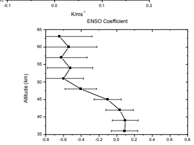
Plot of the monthly averaged temperatures from 1993 to 2016 in each 3 km from 36 to 63 km . Also represented are the simple linear trends. Negative trends are observed in all the altitudes, being maxima at 54 km.

QBO Coefficient with height



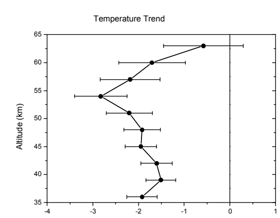


Solar flux dependence with height



Enso Coefficient with height

Temperature trend and corresponding error with height. Note averaged value around -2 and maximum cooling rate at 54 km.



Summary and conclusions

- Monthly temperature profiles were measured at São José dos Campos, Brazil (23 S, 44 W)with a Rayleigh Lidar from 1993 to the 2016 (24 years)
- Annual and Seasonal climatologies for the temperature from 36 to 63 km are obtained
- Natural periodic signals, QBO, ENSO, 11-year solar cycle are obtained
- Systematic temperature decrease are identified from 36 to 63 km, attaining a maximum rate of ~ -2.8 K/decade at 54 km