Lidar Study of Stratospheric Thermal Structure and Long Term Trends over a Sub-tropical Station Mount Abu (24.5° N, 72.7° E)

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Abstract: Stratosphere plays a vital role in deciphering various geophysical phenomena taking place in the Earth's atmosphere. It is also a well known reservoir of ozone which protects us from the hazard of the UV radiation emanating from the Sun. For more than two decades, Rayleigh Lidar has become a dynamic atmospheric probe for providing height profile of temperature in the middle atmospheric region. A Nd: YAG laser based Rayleigh Lidar was set up at a high altitude observatory near Mt. Abu (24.5°N, 72.7°E, msl ~1.7 km) in the Indian sub-tropical region to study the Earth's neutral atmospheric temperature structure. The system transmits pulses of 7 ns duration at a frequency of 10 Hz with an average power of about 350 mJ at 532 nm. For the study of temperature climatology in the stratosphere, we have used the Rayleigh Lidar data collected for 5 years from 1997 to 2001. The temperature profiles are derived from photon count profiles following the method of *Hauchecorne and Chanin* (1980). The systematic and statistical errors in deriving temperature are found to be less than ~1 K below 50 km. The monthly mean temperature profiles obtained are compared with three different model atmospheres (CIRA-86, MSISE-90 and Indian low latitude model). To study the inter-annual variability, mean monthly temperature profiles have been estimated for different years. The mean stratopause height and its temperature are found to be 48 km and 270 K, respectively. For the study of long term changes in the thermal structure of the stratosphere, consistently good data series for 11 years from 1997 to 2007 has been investigated. Monthly mean temperature profiles for each month have been used to remove seasonal variability. Linear regression analysis is performed to calculate temperature trends in different altitude regions. Considering the imprints of seasonal and solar cycle variability, a linearly decreasing temperature trend in stratospheric temperature has been found using the data from 1997-2007. Temperatures observed by HALOE onboard UARS also shows similar trends, over Indian sub-tropical region.

Introduction

Lidar is a powerful technique for active remote sensing of the middle atmosphere. Lidar probing of the atmosphere utilises both scattering and absorption by the medium. Rayleigh scattering by air molecules has been used extensively to determine the density of the atmosphere in the region from 30 to 90 km. Temperature profiles are derived from relative density data assuming that the atmosphere obeys the barometric equation. From the perturbations in the density or temperature profiles one can also determine gravity wave features.

Lidar probing of the atmosphere was initiated at the Physical Research Laboratory (PRL) in the early nineties. A powerful Nd-YAG laser based lidar (operating at 532 nm) is situated at Mt. Abu and regular measurements of density and temperature are being made since November 1997. During the monsoon period from mid-June to mid-September over the site, regular measurements are not possible due to poor weather condition. A total of 600 nights of observations were made in the Rayleigh mode of operation during the period from November 1997 to November 2007, out of which 450 nights have provided data of sufficient quality to yield temperature profiles. Monthly mean temperature profiles have been obtained in the altitude range from 30 to 75 km from September to June.

SPECIFICATIONS OF THE PRL's LIDAR

LASER (Nd:YAG 581C-10, Quantel, France)

Average output power	10W
Output energy per pulse	400 mJ at 532 nm
Repetition rate	10 Hz
Pulse duration	7 ns
Beam divergence	0.3 mrad

RECEIVING OPTICS

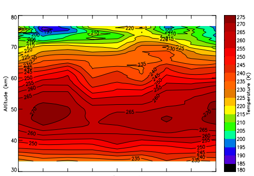
Telescope type	Cassegrain
Diameter	0.90 m
Field of view	1 mrad
Filter bandwidth	1 nm
Maximum λ	532 nm
Photomultiplier	9813A (Thorn EMI, UK) (photon counting mode)

SIGNAL PROCESSOR

(SR430, Stanford Research Systems, USA)

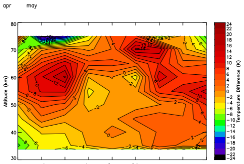
Bin width	640 ns (96 m alt. resolution)
Integration	600 s

Temperature Climatology over Mt. Abu

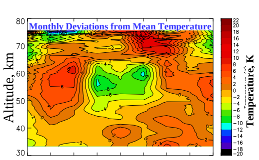


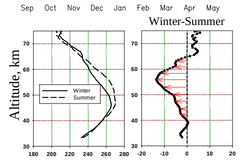
Study of neutral atmospheric temperature over Mt. Abu (1997-2001)

There are significant differences in observed and model Temperature (Observed – CIRA86)



Seasonal Temperature Variation over Mt. Abu

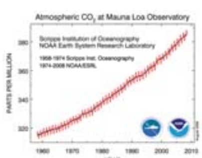


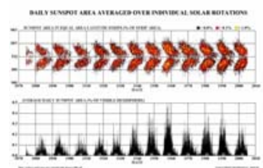


Climatologically, a strong **cold winter pool** is observed at Mt. Abu, and downward cooling trend during vernal equinox and upward during autumnal equinox, which is in contrast to the low latitude behavior.

What are the Causes for possible trends in Earth's atmosphere ?

- Global warming in the lower atmosphere accompanied by cooling in the middle atmosphere
- Chemical contamination due to man-made and natural causes
- Long- term changes in the solar activity
- Changes in tidal forces in the middle atmosphere
- Long term changes in gravity and planetary wave activity
- Effects of volcanic activity (mostly confined to the stratosphere) etc.





Certain Facts about Anthropogenic & Natural forcing of the Atmosphere

- Atmospheric abundances of greenhouse gases are increasing because of human activities.
- Greenhouse gases absorb and re-radiate infrared radiation efficiently. This property acts directly to heat/cool the planet.
- Altered amounts of greenhouse gases affect the climate for many centuries and remain in the atmosphere for a decade to centuries.
- Climate itself has considerable inertia, mainly because of the high heat capacity of the world ocean.
- Human-caused CO_2 increases and ozone decreases in the stratosphere have already produced more than 1°C global average cooling there.
- This stratospheric cooling is generally consistent with model predictions.
- Natural variability of climate adds confusion to diagnose human-induced climate changes.
- Apparent long-term trends can be artificially amplified or damped by the contaminating effects of undiagnosed natural variations.

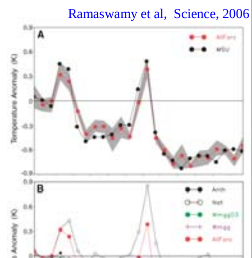
Mahlman, Science, 1997

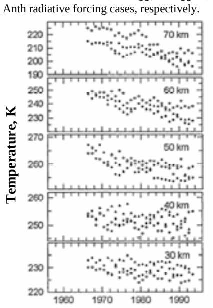
Observations and Model Studies from Literature

- Observations reveal substantial cooling of the global lower stratosphere over 1979–2003
- Climate model simulations indicate that the space-time structure of the observed cooling is largely attributable to the combined effect of changes in both
- Anthropogenic factors , ozone depletion and increases in well-mixed greenhouse gases.
- Natural factors, solar irradiance variation and volcanic aerosols.
- The anthropogenic factors drove the overall cooling during the period, and the natural ones modulated the evolution of the cooling.

Ramaswamy et al, Science, 2006

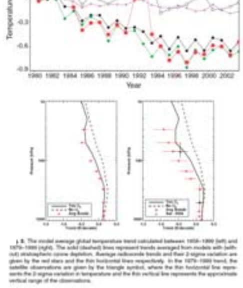
Model simulated ensemble-mean (AllForc, red curve) and Microwave Sounding Unit (MSU, black curve) satellite observations of the globally and annually averaged temperature (T4) anomalies over 1979–2003 (relative to their respective 1979–1981 averages). The gray shading denotes the range of the five-member ensemble simulations and is a measure of the simulated internally generated variability of the climate system. (B) Model-simulated ensemble mean of the globally and annually averaged temperature (T4) anomalies (relative to the respective 1979–1981 averages) for the AllForc, Nat, Wmgg, WmggO3, and Anth radiative forcing cases, respectively.





Time dependence of annual mean atmospheric temperatures averaged over 10 km layers centered at the given altitudes, based on rocket (30-70 km, separately for flight (hollow circles), middle (black circles) and low (triangles) latitudes).

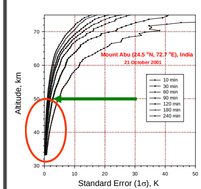
Golitsyn et al GRL, 1996



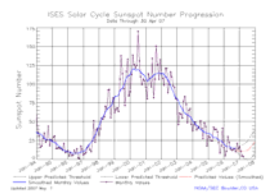
Cordero and Forster , ACPD, 2006

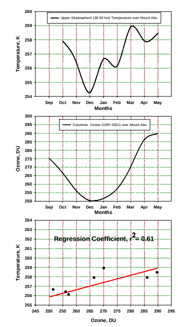
Results

Statistical Errors in the Observed Temperature over Mt. Abu

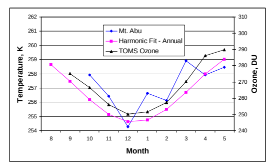


Sunspot variation during the study period

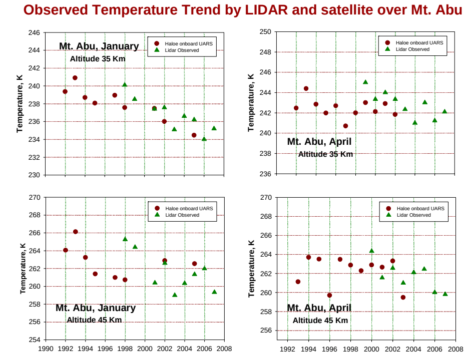




Stratospheric Temperature and Ozone at Mt. Abu



Observed Temperature Trend by LIDAR and satellite over Mt. Abu



Summary

- Stratospheric Cooling trend is found at Mt. Abu (a sub-tropical station) during 1997- 2007.
- Temperature models (CIRA86, MSISE90, Indian low latitude model) are not exhibiting the feature observed.
- There is a need for further refinement of the models with more observational input.
- HALOE onboard UARS also shows similar temperature trends over Mt. Abu.
- Observed Cooling trends are possibly associated with the reducing stratospheric ozone over Mt. Abu.

Concluding remark: It is demanding to have more observational inputs from different regions and platforms to quantify the role of natural and anthropogenic forcing in the observed trends and their association with other processes.

Acknowledgements

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