Middle atmosphere temperature climatology at Mauna Loa from Rayleigh/Raman lidar measurements.

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INTRODUCTION

The JPL Lidar at Mauna Loa Observatory (MLO) continues to make regular measurements of ozone, temperature and aerosol profiles for the Network for the Detection of Stratospheric Change (NDSC) program. This report describes the development of a temperature climatology from one aspect of the lidar results.

The temperature structure of the middle atmosphere has been studied for several decades using a variety of techniques. Temperature profiles derived from lidar measurements currently provide improved vertical resolution and accuracy making lidar one of the most suitable instruments for looking at local variations of the middle atmosphere temperature. Lidars can also provide long-term data series relatively absent of instrumental drift, and integration of the measurements over several hours removes most of the gravity wave-like short scale disturbances.

Here we describe a seasonal climatology of the middle atmosphere temperature derived from lidar measurements obtained at MLO (19.5°N). The JPL Rayleigh/Raman lidar [*McDermid et al.*, 1995] has obtained temperature measurements between ~15 and ~90 km since 1993. Most of the routine measurements comprise a 1.5 hour integration experiment, usually at the beginning of the night 4-5 nights a week, insuring a good survey of stratospheric ozone and temperature as required by the NDSC program.

DATA ANALYSIS AND RESULTS

Lidar temperature record

Plate 1 shows a summary of all of the lidar temperature profiles recorded at MLO between January 1994 and July 1997.

Climatological temperatures

Each individual lidar temperature profile was interpolated to obtain data points every one kilometer. The tops of the profiles were truncated about 10 km lower than the initial tie-on altitudes so that the results containing a non negligible part of a priori information and/or noise were not used. High confidence levels are expected up to 75 km altitude. The profiles were then merged into a composite single year of data. A weighted running average with a triangular 33-day width filtering scheme was applied to each day of the composite year that a profile was available. The remaining days with no profile were filled with an interpolated profile obtained using a two-dimensional minimum curvature spline method. Although these interpolated profiles were plotted they were not retained in the numerical database in order to avoid inaccuracies in the different analyses described later. No removal of tidal structures was performed even though the role of the diurnal and semidiurnal tides may not be negligible above 80 km at MLO.

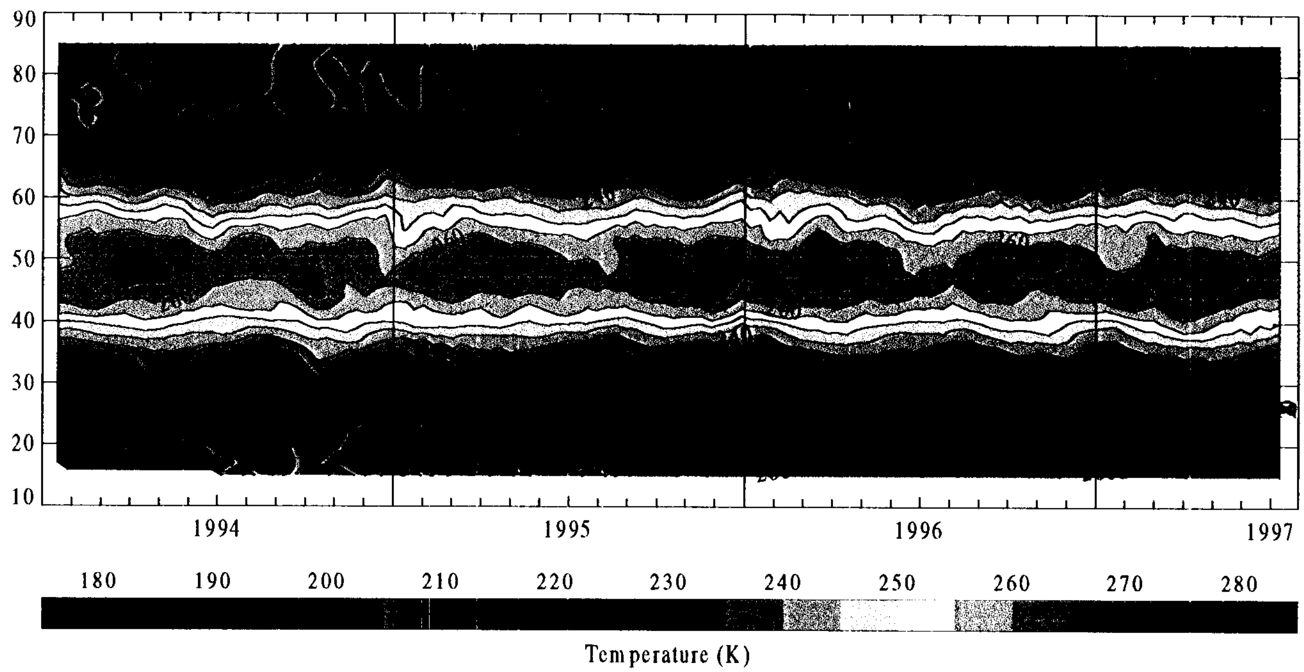

Plate 1. Lidar temperature record at MLO.

The mean annual temperature climatology is presented in Plate 2 which clearly shows a semiannual cycle at the stratopause, maximum temperature 266 K at 47 km, and an annual cycle in the lower stratosphere with a very cold minimum of 190 K at 17 km identified as the tropical tropopause. As expected at these latitudes, the amplitude of the seasonal variations is weak. At the top (80-85 km), where the effect of the mesospheric tides is the largest, the measured cold temperatures are more representative of early night temperatures than nightly (or even a 24-hour) mean temperatures.

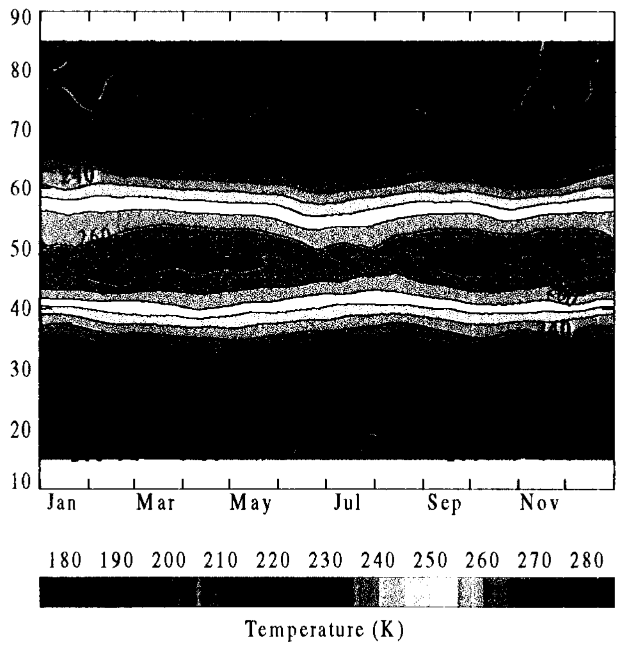

Plate 2. Mean annual temperature climatology at MLO.

Temperature deviations from the annual mean

The annual mean temperature profile was then subtracted from each available daily composite profile to obtain the daily deviation from the annual mean. Plate 3 shows this deviation. MLO exhibits a dominant semi-annual cycle between 25 and 80 km altitude. This is not surprising since MLO is located at 19.5°N and is influenced by the equatorial dynamical pattern which in turn is affected by both northern and southern hemispheres. The semi-annual cycle observed here is almost a continuous downward propagating oscillation with an approximate vertical speed of 12 km/month and can be identified as the thermal semi-annual oscillation (SAO). The so-called mesopause and stratopause SAOs appear here as a combined single SAO propagating downward from the mesopause to 30 km with minimum amplitude at 45 km. A phase inversion is observed near 82 km similar to that observed by SME at 83 km [*Garcia and Clancy*, 1990]. The oscillation is strongly modulated with the first cycle being stronger than the second. The seasonal asymmetry of the wind and temperature SAO has been widely reported (see for example, *Garcia et al.* [1997]). One explanation of this [*Delisi and Dunkerton*, 1988] is that it is a consequence of a stronger dynamical forcing in the northern hemisphere. However, due to the relatively northward location of MLO, the late winter maxima and early summer minima of the mid-latitude annual cycle and the equatorial SAO are in phase and may also cause the first oscillation of the semi-annual cycle to be of larger magnitude than the second. Finally, in Plate 3 an annual cycle is observed below 25 km and a cold spot can be noted in November at 64 km.

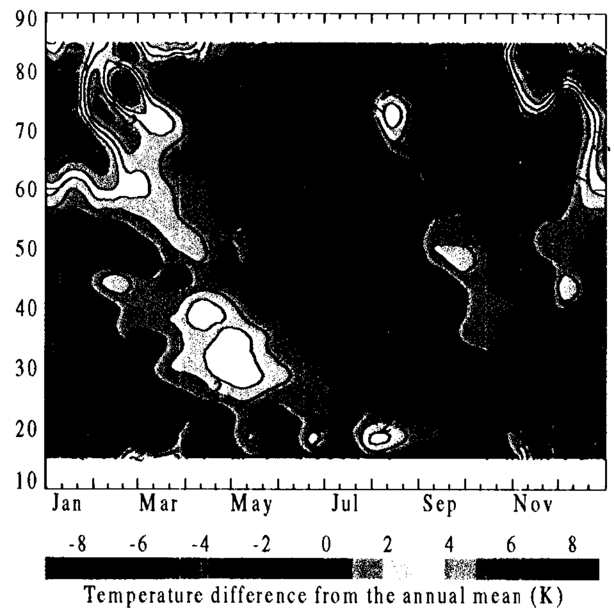

Plate 3. Mean temperature seasonal variations at MLO.

DISCUSSION AND CONCLUSION

As has been observed in all previous middle atmospheric temperature climatologies [*Clancy and Rusch*, 1989; *Garcia and Clancy*, 1990, *Hauchecorne et al.*, 1991; *Bills and Gardner*, 1993; *Clancy et al.*, 1994; *Yu and She*, 1995, *Garcia et al.*, 1997] a semiannual cycle is dominant at lower latitudes. Below 60 km the annual cycle is in phase with the solar flux leading to a warm summer and cold winter stratosphere and lower mesosphere, as expected. Above 65 km, the annual cycle is in opposite phase to the solar flux, as a consequence of a dynamically driven mesosphere, and is characterized by a warm winter and cold summer mesosphere. The observed downward propagating temperature behavior in the mesosphere points out the dominant wave driven pattern, in contrast with the vertically stationary behavior observed below 50-55 km. At MLO the dominant semi-annual cycle is modulated by the northern mid-latitude annual cycle thus contributing, together with the well known seasonally asymmetric equatorial SAO, to the first warm-cold cycle (winter and spring) being stronger than the second (summer and fall).

Systematic departures from the CIRA-86 model were observed, Plate 4, which confirms the similar results of previous comparisons [*Hauchecorne et al.*, 1991; *Clancy et al.*, 1994]. In particular, too cold temperatures in the CIRA-

86 model lead to a large differences (> 15 K) around 90-95 km compared to lidar results, possibly due to an overestimation of non-LTE effects in the computation of the CIRA-86 temperatures [*Lawrence and Randel*, 1996]. On an annual basis CIRA-86 seems to be too warm around 55-60 km, too cold between 60 and 75 km, too warm between 75 and 85 km, and much too cold around 90-95 km. Using too cold CIRA-86 temperatures at 90-95 km for initialization can lead to some dramatic temperature errors at the very top of the Rayleigh lidar profiles. For this reason the JPL lidar group is currently investigating the use of a different a priori temperature information to avoid such uncertainty.

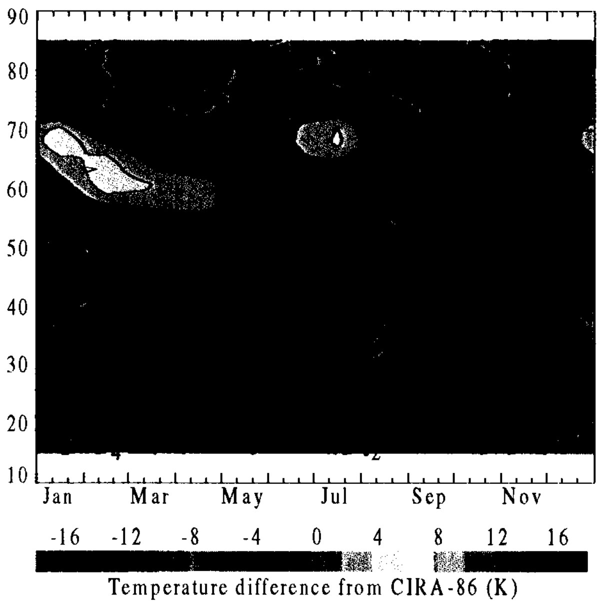

Plate 4. Differences between the lidar and CIRA climatologies

The chaotic nature of the seasonal variations of the middle atmospheric temperature allows most of the discrepancies observed between the lidar and CIRA-86 climatologies, to be explained. Above MLO, it is likely that most of the observed departure in the middle and upper mesosphere is related to tidal effects and/or the mesopause thermal SAO. The amplitudes of 1-5 K predicted by tidal models [*Hagan et al.*, 1995; *Hagan*, 1996] may be underestimated [*Keckhut et al.*, 1996] and this will be investigated in more detail in the future.

The climatology presented in this paper was obtained using composite temperature profiles from several years of measurements. Of course, a non-negligible interannual variability may disturb the temperature field from year to year. However, the trends already observed in previous climatologies [*Hauchecorne et al.*, 1991; *Hood et al.*, 1993] remain small compared to the seasonal variations. Also, the effect of volcanic eruptions, such Pinatubo in 1991 [*Keckhut et al.*, 1995], may have non-negligible disturbing effects. All trends, 11-year solar cycle, Quasi Biennial Oscillation (QBO), and volcanic eruption effects are currently being investigated. The use of such a complete climatology is crucial for many purposes such as providing a reference atmosphere for models and instruments, a background atmosphere for smaller scales studies, an overall comprehension of the strongly coupled lower-middle-upper atmosphere, and more. To this date, only a few instruments can provide such long-term data series. With the recent and future development of many ground based lidars within the NDSC at many latitudes, a more complete climatology of the middle atmospheric temperature should be available within few years.

ACKNOWLEDGEMENTS

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under an agreement with the National Aeronautics and Space Administration.

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