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NO LONG TERM CHANGE OF THE THERMAL STRUCTURE IN THE MESOSPHERE AT HIGH LATITUDES DURING SUMMER

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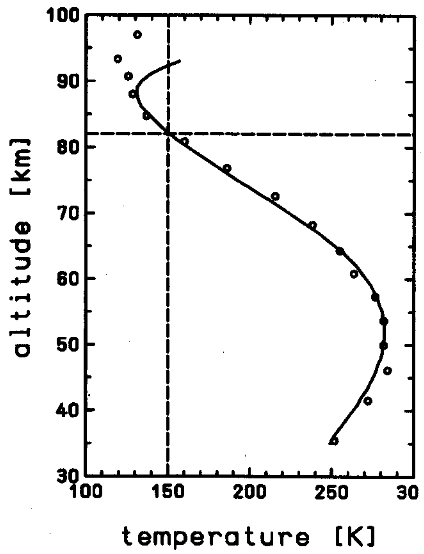
ABSTRACT

In the 1960s a total of 21 rocket-grenade (RG) temperature soundings have been performed in the mesosphere at high latitudes (~70°N) in summer, 6 flights at Kronogård (66°N) and 15 at Point Barrow (71°N). These 'historical' data are compared with a compilation of falling sphere measurements performed in the last ~10 years from the Andøya Rocket Range (69°N). The difference between 'old' and 'new' temperatures is very small and is compatible with zero. This suggests that there is no significant change of the thermal structure in the polar summer mesosphere during the last ~35 years. A detailed analysis shows that a solar cycle influence on the temperature differences is very unlikely since most measurements were performed during the same phase of the solar cycle (i. e., at small activity). Considering natural variability and instrumental uncertainties we find no significant temperature trend in the altitude of interest here (50–85 km). This result is true for both RG stations located at rather different longitudes. In the lower (upper) mesosphere at 50–60 km (75–85 km) we find a small but not significant positive (negative) temperature trend of +0.06±0.02 K/y (–0.09±0.03 K/y). These numbers are much smaller in absolute magnitude compared to temperature trends observed at middle latitudes by lidars and rocket-borne techniques. Our numbers are also much smaller compared to the very large (negative) values of up to –1.2 K/y recently reported from the middle mesosphere at very high latitudes of 81°N (Golitsyn et al., 1996). We note, however, that the instrumental uncertainty of the technique involved there (rocket-borne thermistors) increases to unacceptably large values in the middle and upper mesosphere.

INTRODUCTION

Long term changes in mesospheric layered phenomena have been reported regarding the appearance of 'noctilucent clouds' (Gadsden, 1998a) at high latitudes and the sinking of radio wave reflection heights at mid latitudes (Bremer, 1992; Taubenheim, 1997). Long term trends of the thermal structure in the mesosphere at mid latitudes detected by lidar and rocket-borne measurements showed large (negative) values of up to –0.4 K/y (Hauchecorne et al., 1991; Keckhut et al., 1995; She et al., 1998; Dunkerton et al., 1998; Keckhut et al., 1999) which is much larger (in absolute magnitude) compared to model calculations (Rind et al., 1990; Berger and Dameris, 1993; Portmann et al., 1995; Akmaev and Fomichev, 2000). Even larger temperature trends were reported from rocket-borne thermistor measurements at very high latitudes by Golitsyn et al. (1996). We will come back to these results later in this paper.

The mesosphere at high latitudes in summer is presumably the region with smallest natural variability in the entire terrestrial atmosphere since most waves are absorbed in the mean background wind field at lower altitudes. This is definitely an advantage when studying long term trends. However, the data base is rather sparse since remote sensing optical techniques from the ground or from satellites are very limited in producing reliable data due to permanent day light conditions present north of the polar circle during summer. Therefore the data base in this region is basically given by in-situ measurements based on rocket-borne techniques (Lübken and von Zahn, 1991; Golitsyn et al., 1996; Lübken, 1999).



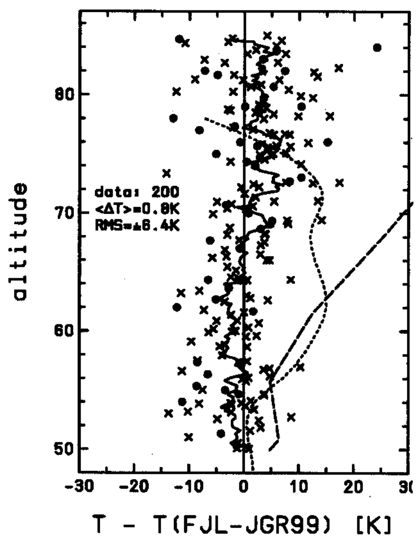


Fig. 1. Rocket-grenade temperatures (circles) measured on 16 June 1966 at Point Barrow (71°N) compared with the mean profile for June 15 from a recent compilation of measurements performed at Andøya (69°N) and published by Lübken (1999).

Fig. 2. Difference of RG temperatures measured in Kronogård (66°N, dots) and Point Barrow (71°N, crosses) relative to the FS mean closest in season. The dotted (dashed) line shows where one would expect the differences if there were a trend similar to that observed at mid and very high latitudes, respectively. See text for more details.

In this paper we compare temperature measurements from the mid 1960s performed by the rocket-grenade technique with more recent soundings by so called 'falling spheres' (FS). More details on the experimental technique and the data base is available in the literature (Stroud et al, 1960; Theon et al., 1967; Witt, 1968; Schmidlin, 1991). We concentrate on the mesosphere at high latitudes during the summer season, which in the scope of this paper is from mid May until mid August. A summary of these results has recently been published by Lübken (2000); here we present more details on the data evaluation, on systematic variations due to solar variability, and on height dependent trends.

DATA BASE

A total of 21 rocket-grenade (RG) temperature profiles have been measured in the summer season at high latitudes, 6 profiles at Kronogård (66°N) and 15 at Point Barrow (71°N). These 'historical' measurements are compared with approximately 80 soundings by 'falling spheres' which were performed in the last years and which are summarized in Lübken (1999), hereafter refered to as FJL-JGR99. Typical experimental uncertainties of the RG and FS techniques are less than ±3K below approximately 80 km. The height resolution is a few kilometers for both techniques. Various studies and intercomparison campaigns have been conducted in the past to demonstrate the reliability and the restrictions of these techniques (Stroud et al., 1960; Quiroz and Gelman, 1976; Lübken et al., 1994). The main conclusion from these studies is that temperatures in the stratosphere and mesosphere derived by these techniques are indeed reliable within the altitude resolution and error bars given.

In Figure 1 a single profile measured by the rocket-grenade technique on 16 June 1966 is shown together with the FJL-JGR99 mean for mid June. It is obvious from this Figure that there is no apparent difference between the 'old' and 'new' profile between 35 and ~90 km, in particular if we consider natural variability (typically ±5–6K in the middle and lower mesosphere) and the combined experimental uncertainties. In fact, the RG data and the FS mean are practically identical in the mesosphere up to an altitude of ~90 km.

We attribute the larger differences above ~90 km mainly to natural variability. We have marked the 150 K temperature value at 82 km in Figure 1 since this is the altitude where NLCs are most frequently observed and where the temperature turns out to be very persistent in the last 35 years (see later).

TEMPERATURE DIFFERENCE BETWEEN 'OLD' and 'NEW' DATA

We have taken all 21 RG profiles available in the summer season and calculated the differences between the RG data points (total of 200 in the altitude range from 50 to 85 km) and the corresponding FJL-JGR99 mean closest in season (see Figure 2). Note that the mean profiles in FJL-JGR99 are calculated and listed with a time difference of 0.25 months. As can be seen from Figure 2 there is obviously no significant difference between the 'old' RG data and the means of FJL-JGR99 which implies that temperatures in the mesosphere cannot have changed much in the last 35 years. The mean difference taken over the entire altitude range is 0.8 K with a RMS deviation from the mean of ±6.4 K. We have plotted the data points from Kronogård and Point Barrow differently in Figure 2 to demonstrate that the main result, i. e., no significant temperature difference, is the same for both stations located at rather different longitudes (20°E and 157°W for Kronogård and Point Barrow, respectively).

For comparison the lidar trends from Keckhut et al. (1995) observed at mid latitudes (44°N) are also shown in Figure 2. If there were a trend at high latitudes similar to that observed at mid latitudes (i. e., cooling by up to −0.4K/y) the mesosphere in the mid 1960s should have been warmer by up to 14 K compared to today. The temperature differences shown in Figure 2 should than be positive and should be grouped around the dotted line representing the lidar trend. Obviously, the differences are much smaller which demonstrates that the trend (if there is any at all) is much smaller compared to that observed at mid latitudes.

In Figure 2 we also compare our results with the rocket-borne thermistor measurements published by Golitsyn et al. (1996) which were performed at Heiss Island (81°N), i. e., approximately 10 degrees north of the FS and RG measurements. Again, if there were a trend at ~70°N similar to that reported at Heiss Island the differences shown in Figure 2 should be positive and should be grouped around the dashed line. This is obviously not the case: Above ~55 km there is a significant difference between the dashed line and the data points which increases with altitude to very large values of up to ~40 K at 75 km (which is the upper most altitude published in Golitsyn et al., 1996). We will come back to this large discrepancy in the discussion section.

SOLAR CYCLE INFLUENCE

The most important natural long term variation of temperatures in the upper atmosphere is presumably caused by the 11-year solar cycle. We have studied in detail a potential solar cycle influence on the RG and FS temperatures. We have taken all rocket-grenade data in a given altitude bin (here 65±3 km) and plotted the difference to the FJL-JGR99 mean as a function of the monthly mean 10.7 cm solar flux measured in the month of the rocket flight (crosses in Figure 3). The same procedure was performed for the FS temperatures, except that the temperature in the center of the altitude bin (here 65 km) was taken (squares in Figure 3). The monthly mean solar flux data were taken from the data base published by the Dominion Radio Astrophysical Observatory in Penticton, Canada (www.drao.nrc.ca). The fact that some data appear in a vertical column in Figure 3 is due to the fact that some measurements were performed during the same month in the same or in consecutive years, i. e., at the same or at very similar solar flux values.

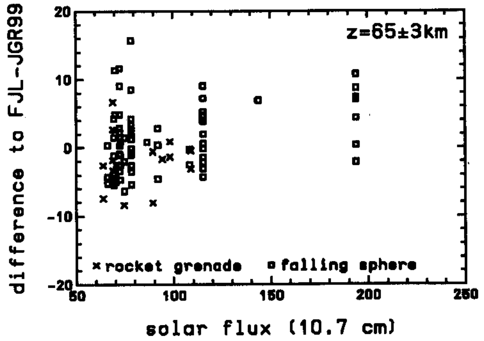


Fig. 3: Temperature differences (RG and FS minus FJL-JGR99, respectively) as a function of monthly mean solar 10.7 cm flux for an altitude bin of 65±3 km (see text for more details). RG data are shown as crosses and falling sphere data are shown as squares.

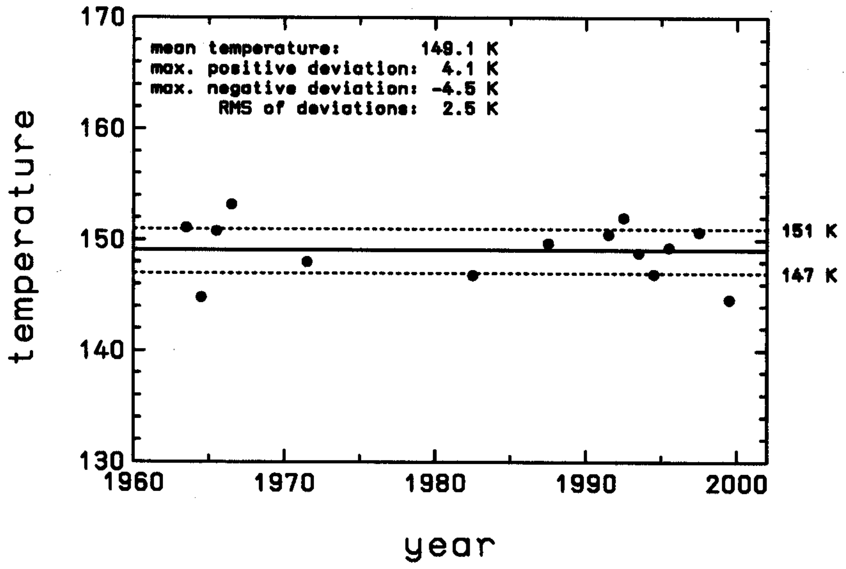


Fig. 4. Mean temperatures at 82 km for summer seasons (here mid May until mid August) from the early 1960s until 1999. Only measurements at latitudes close to 70°N are considered. Three entirely different experimental techniques have been used to measure the data shown in this plot.

As can be seen from Figure 3 most of the RG and FS measurements were performed at the same phase of the solar cycle, namely at low activities. Furthermore, no significant dependence of the temperature differences on solar activity is observed, at least not exceeding natural variability. We conclude that our comparison is most likely not influenced by solar cycle variations.

TRENDS AT VARIOUS ALTITUDES

The obvious way to analyze trends is to study temperatures as a function of time on decadal time scales. This procedure is somewhat problematic in our case, however, since the data base is very limited. In Figure 4 we show temperatures at 82 km averaged in each summer season since 1964. We chose 82 km since NLCs are most frequently observed close to this altitude, not only by lidar techniques available today (e. g., von Cossart et al., 1999) but also by visible observations performed more than 100 years ago (Jesse, 1896). Only measurements close to 70°N have been taken into account. Apart from the RG and FS temperatures introduced above we show measurements performed by so called 'active falling spheres' in 1982 which gave a temperature of 147.8 at 82 km (Philbrick et al., 1984). As can be seen from Figure 4 the mean temperature at 82 km shows a remarkable repeatability within the last 35 years and is again and again observed to be close to 150 K. The RMS deviation from this value is less than ±3 Kelvin. This persistency lead us to introduce the terminology 'equithermal submesopause' (Lübken et al., 1996). It is interesting to note that data from three entirely different experimental techniques contribute to the means shown in Figure 4. In the scope of this paper the most important result from this analysis is that there is obviously no apparent trend at 82 km in the upper mesosphere at ~70°N.

We have analyzed the statistical characteristics of the temperature differences in more detail by choosing data within a certain altitude bin and shifting this bin through the entire mesosphere. Figure 5 shows the result for a height range of 5 km centered at 70 km where (only) 27 RG temperatures are available. The statistical analysis of the temperature differences shown in Figure 5 is based on the following idea: We assume a certain temperature trend, project the mean profiles from FJL-JGR99 backward in time to the grenade measurements and count how many data points are above and below the projection. For example, if

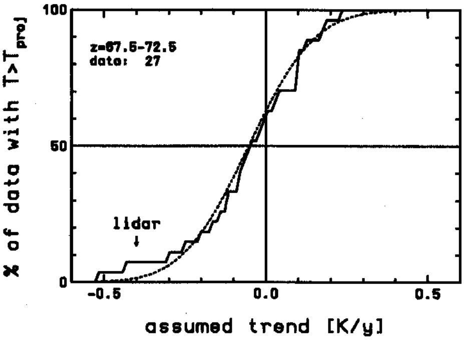


Fig. 5. Number of rocket-grenade temperatures (in per cent of total number of data) in the altitude range 70±2.5 km for which the temperature is larger than the FS mean temperatures from FJL-JGR99 projected backward in time assuming a trend given on the abscissa (see text for more detail). The dotted line shows the expected curve for a Gaussian distribution of temperature differences. The mean trend is -0.053 K/y with an uncertainty of ±0.031 K/y, i.e., practically zero.

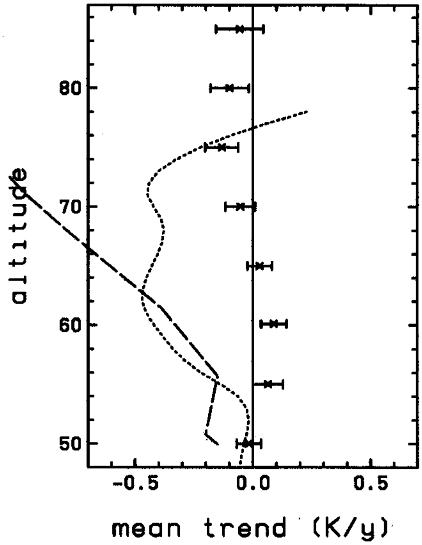


Fig. 6. Mean temperature trends determined from the differences shown in Figure 2. The error bars shown present two standard deviations. For comparison the lidar trend at mid latitudes (dotted line; Keckhut, 1995) and the data sonde trend at high latitudes (dashed line; Golitsyn, 1996) are shown.

we assume a trend of –0.4 K/year (typically observed in the mid-latitude mesosphere and indicated by 'lidar' in Figure 5), nearly all grenade temperatures are smaller than the backward projection, i. e., the percentage of data with temperatures larger than the projection is very small (~6% in our example). This study was performed for various assumed trends (abscissa in Figure 5). As can be seen from this Figure the temperature differences are nicely described by an integrated Gaussian distribution function which demonstrates that the differences are randomly distributed. The trend is compatible with zero: The mean trend is -0.053 K/y with an error of ±0.031 K/y.

We have applied the procedure demonstrated in Figure 5 to height bins of 5 km centered at altitudes of 50, 55, 60 km etc. The result is shown in Figure 6. The error bars shown in this plot present two standard deviations. The mean trends are slightly positive between 55 and 60 km, and slightly negative above 70 km. Considering the error bars, however, these trends are not significant and are compatible with zero in the entire mesosphere. As before, we show the lidar and rocket-borne thermistor trends at middle and very high latitudes, respectively, for comparison. It is obvious from Figure 6 that the RG/FS trends are much smaller (if there is any trend at all) compared to the lidar and thermistor trends.

DISCUSSION

Our results suggest that there is very little or no trend in the high latitude summer mesosphere. This is in contrast to the large (negative) trend observed at mid latitudes. We note that the influence of an increased abundance of green-house gases on the thermal structure of the mesosphere is not easy to predict since dynamical feedback mechanisms can play a substantial role in controlling the thermal structure in the upper atmosphere, on top of the enhanced radiative cooling and radiative coupling between the stratosphere and the mesosphere. It is well known that dynamical effects (e. g., gravity waves) drive the atmosphere away from radiative equilibrium in the summer mesosphere. However, long term changes in gravity wave generation (in the troposphere), propagation (mainly in the troposphere and stratosphere) and breaking (mainly in the mesosphere) are not known. In general, it is not surprising to observe different long term trends at different latitudes and altitudes.

Regarding the increase of NLC occurrence frequency observed at high latitudes, we note that current theories of NLC particle generation and growth suggest that the thermal structure close to the mesopause is presumably crucial for the detection of NLC layers further down, for example at 82 km (Gadsden, 1998b). Our data base does not allow to make any statement about trends at mesopause altitudes since natural variability and instrumental error bars are too large here. Furthermore, we need to consider that it takes several hours before NLC particles grow from there initial phase until they are detectable by the naked eye or by lidars. During this time the particles have been transported several hundred kilometers. Taking into account the mean wind direction as a function of altitude, the particles have started their growth presumably at higher latitudes where the long term trend is probably even smaller as suggested by models. Furthermore, we note that at least part of the NLC occurrence increase could be caused by water vapor increase (Thomas et al., 1989). We conclude that the observed NLC occurrence increase is not yet understood.

Regarding the very large difference between our results and the trends deduced from rocket-borne thermistor measurements (Golitsyn et al., 1996) we note that the thermistor data stem from different latitudes (81°N) and have been averaged over the entire season, not just only for summer. More important, we note that the uncertainty of the thermistor measurements increases to unacceptably large values above ~65 km since large corrections to the raw measurements have to be performed to account for systematic temperature deviations caused by e. g., radiative cooling and heating of the thermistor, in particular during daylight conditions. It is therefore considered likely that the thermistor results are erroneous in the middle and upper mesosphere. We note that model results on trends in the mesosphere suggest very small cooling and even heating at high latitudes, in agreement with our results but in contradiction with the thermistor results.

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