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Nearly zero temperature trend in the polar summer mesosphere

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Abstract. A series of in-situ temperature measurements performed by falling spheres at high latitudes in the last ~10 years is compared with historical temperature data collected by the rocket grenade technique in the mid 1960s. Concentrating on summer (here from mid May to mid August) and on altitudes between 50 and 85 km, where natural variability and instrumental uncertainties are small, the observed trend is very small, if present at all. Taking into account all data from 50 to 85 km the mean trend is -0.024 K/y with a statistical error of ±0.014 K/y, i. e., practically zero. The mean deviation of the grenade temperatures from the falling sphere data is 0.8±6.4 K and the differences are randomly distributed. We have also analyzed various subsets of the entire data set, e. g., in a restricted altitude range where lidars have shown large trends at mid latitudes, namely from 55 to 75 km. The main result remains unchanged: The deviation between 'old' and 'new' data is practically zero and the temperature trend in the high latitude summer mesosphere is certainly much smaller (if any at all) compared to that observed at mid latitudes.

Introduction

There seems to be increasing evidence for a long term cooling and sinking of the mesosphere. The main indirect indications for such a trend are the increased occurrence frequency of noctilucent clouds (NLC) [*Gadsden*, 1990] and the sinking of the constant pressure level in the upper mesosphere determined from radio wave reflection height measurements performed since more than 40 years [*Taubenheim et al.*, 1997]. Long term changes in the thermal structure have been reported from lidar temperature measurements performed since the late 1970s [*Hauchecorne et al.*, 1991; *Keckhut et al.*, 1995; *She et al.*, 1998] and from rocketsonde data [*Golitsyn et al.*, 1996; *Dunkerton et al.*, 1998]. We note that the majority of these measurements have been made at middle and low latitudes. Though difficult to perform, temperature measurements in the high latitude summer mesosphere are rather attractive for long term studies since the natural variability is very small here.

In this paper we compare historical temperature measurements in the high latitude summer mesosphere performed by in-situ technique in the mid 1960s with a climatological mean deduced from meteorological rocket flights from recent years. Some part of this data set has previously been used to study the temperature and altitude of the polar mesopause in summer [*von Zahn*, 1990]. We will first introduce the experimental techniques and the data base and will than compare 'old' and 'new' measurements.

The Data Base

We concentrate on measurements in the mesosphere during summer (which in the context of this paper is from mid May until mid August) since the natural variability is rather small here: The RMS deviation of individual measurements from the weekly mean is typically ±4–6 K [*Lübken*, 1999]. Furthermore, the instrumental uncertainties of the techniques introduced below are small in the mesosphere but increase significantly above ~85 km.

In the late 1950s the so called 'rocket grenade' (RG) technique was invented to determine temperatures from the troposphere up to the mesosphere by measuring the speed of sound. Explosives were ejected from a small rocket and the arrival times of the sound waves at the ground were measured [*Stroud et al.*, 1960]. Here we will consider only those flights which took place at Kronogård (66°N) in Sweden and at Point Barrow (71°N) in Alaska since only these stations are close in latitude to the falling sphere flights introduced below. The temperature uncertainties are less than ±3 K below 75 km and the altitude resolution is 5–7 km, given by the distance between two consecutive puffs [*Stroud et al.,* 1960]. A complete list of rocket grenade flights in the high latitude summer mesosphere is shown in Table 1. Only some of the results from these flights have been published in the literature [*Theon et al.*, 1967; *Witt*, 1968]; several flights have been presented in NASA internal reports only.

Since the mid 1980s temperatures at high latitudes are deduced from in-situ measurements of densities by the 'falling sphere' (FS) technique [*Schmidlin*, 1991]. A small rocket transports a folded up sphere, made of metalized mylar, to an altitude of typically 110 km. After it is released the sphere inflates to 1-m diameter and passively falls through the atmosphere whereby it decelerates. A high-precision radar tracks the descent trajectory which is then used in the equations of motion to determine atmospheric density and horizontal winds. Temperatures are obtained by integrating the density profile assuming hydrostatic equilibrium. The height-dependent sphere reaction time-constant causes a smoothing of the density, temperature, and wind profiles. The smallest scales detectable are typically 8, 3, and 0.8 km at 85, 60, and 40 km, respectively. The uncertainty of the temperature data is typically 7, 3, and 1.5 K at 90, 80, and 70 km altitude, respectively [*Schmidlin*, 1991]. Various intercomparison campaigns have demonstrated that the FS technique gives reliable temperatures with the restrictions stated above (see e. g., *Lübken et al.*, 1994). Considering summer season, only 89 falling spheres have been launched at high latitudes since 1987, mainly from the Andøya Rocket

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Table 1. Rocket grenade flights at high latitudes during summer.

date	time (UT)	altitude
Kronogård (66°N)		
July 29 1963	23:28	38.3-88.6
Aug. 01 1963	23:27	36.0-87.9
Aug. 07 1963	22:29	36.0-94.9
Aug. 07 1964	00:16	39.3-87.9
Aug. 16 1964	01:13	46.7-97.3
Aug. 17 1964	00:49	41.0-90.0
Point Barrow (71°N)		
Aug. 07 1965	01:13	46.4-95.7
Aug. 07 1965	09:39	45.0-92.6
Aug. 07 1965	18:15	44.1-90.9
Aug. 09 1965	00:10	45.7-93.4
June 16 1966	17:18	35.4-96.9
June 22 1966	21:52	36.0-78.8
Aug. 14 1966	10:35	35.4-89.9
Aug. 14 1966	22:08	35.6-92.9
May 15 1967	01:40	35.8-94.6
May 08 1967	21:20	34.5-92.3
June 24 1971	05:00	34.2-91.5
July 02 1971	09:59	32.5-84.0
July 12 1971	05:18	32.8-88.6
May 16 1972	21:40	33.7-92.0
May 17 1972	06:45	33.1-90.9

Range (ARR) at 69°N. The results from these flights have recently been published as a climatology of the thermal structure in the polar mesosphere [*Lübken*, 1999], hereafter referred to as FJL-JGR99. This paper and references therein also contain the original data sources and the dates and times of the launches.

Results

Since the data base described above is rather limited we cannot perform a comprehensive statistical analysis but have to rely on a fairly simple comparison between 'old' and 'new' data. In Figure 1 we show individual grenade temperatures in the mesosphere from the flights listed in Table 1 together with the FJL-JGR99 weekly mean centered on June 1, July 1 and August 15 (in this Figure we have ignored the May flights since they are rather early in season, and also the flight from August 1, 1963, since the profile exhibits a strange and unexplained temperature inversion in the upper mesosphere). As can be seen from Figure 1 there is no apparent difference between the data from the 1960s and the mean profiles from the 1990s, at least not below ~85 km where the natural variability and the instrumental uncertainties are small.

In Figure 2 the differences between all individual grenade temperatures and the mean profile from FJL-JGR99 closest in season are shown (the mean profiles in FJL-JGR99 are listed with a time difference of 0.25 months from end of April until end of September). It is obvious from Figure 2 that there is no significant trend at these altitudes, in fact the differences are compatible with zero trend: The mean of the deviations is 0.8 K and the RMS deviation from the mean is ±6.4 K. We note that this variability in the RG data is very similar to the natural variability of the FS temperatures [*Lübken*, 1999]. The solid line in Figure 2 represents a running mean over 5 data points and the dotted line shows the expected differences if there were a trend similar to that observed by lidars (see discussion section). We note that there is a weak but consistent positive vertical gradient in the differences shown in Figure 2.

To arrive at more quantitative results we have analyzed the differences shown in Figure 2 in more detail. To this end we assume a certain temperature trend, project the mean profiles from FJL-JGR99 backward in time to the grenade measurements and count how many RG data points are above and below the projection. All data in the altitude bin 50–85 km are taken into account. For example, if we assume a trend of -0.4 K/year (typically observed in the mid-latitude mesosphere), nearly all grenade temperatures are smaller than the backward projection, only 7% of the temperatures are larger. We have performed this study for various assumed trends. The result of this analysis is shown in Figure 3. As can be seen from this Figure the temperature differences are nicely described by an integrated Gaussian distribution which demonstrates that the differences are randomly distributed. The trend is compatible with zero: The mean trend is -0.024 K/y with an error of ±0.014 K/y.

We have performed this kind of analysis for various subsets of the entire data set, i. e., in restricted altitude ranges. At 55 to 75 km (where lidars at mid latitudes find large trends) the mean trend is +0.0015±0.02 K/y, i. e., practically zero. In the lower (upper) mesosphere at 50–60 km (75–85 km) we find a small but not significant

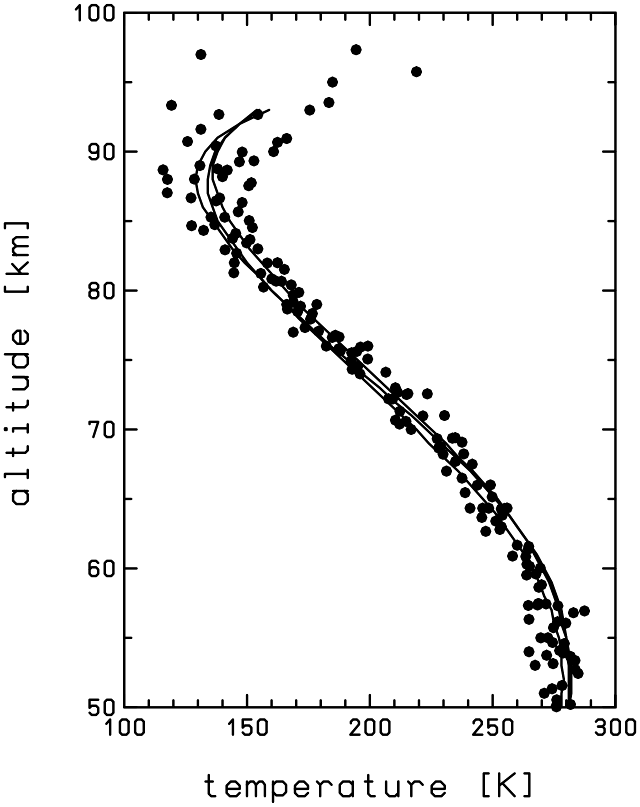

Figure 1. Individual rocket grenade temperatures (dots) and weekly mean of falling sphere temperatures (solid lines) centered on June 1, July 1, and August 1, respectively.

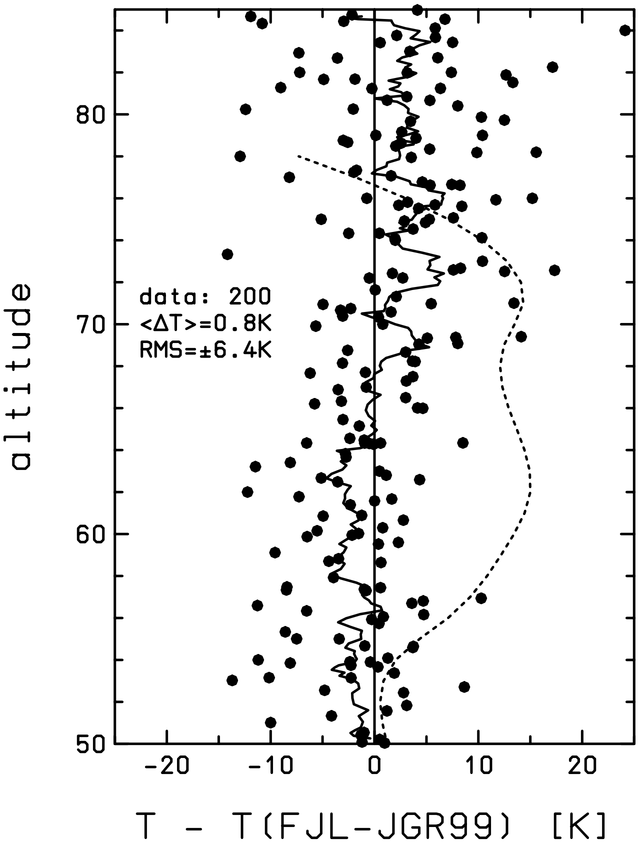

Figure 2. Difference of individual rocket grenade temperatures (dots) to the FS weekly mean closest in season. The solid line is a running mean over 5 data points. The dotted line shows where we would expect the grenade temperatures if there were temperature trends at high latitudes similar to those observed by lidar at mid latitudes [*Keckhut et al.,* 1995].

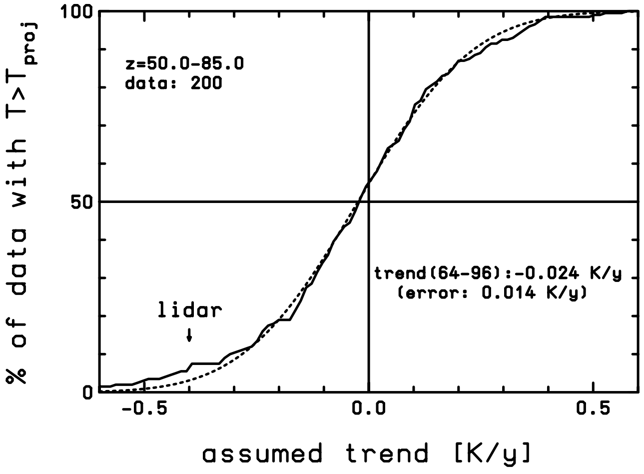

Figure 3. Number of rocket grenade temperatures (in per cent of total number of data) for which the temperature is larger than the FS temperatures projected backward in time assuming a trend given on the abscissa. The dotted line shows the expected curve for a Gaussian distribution of temperature differences. The mean trend is -0.024 K/y with an uncertainty of ±0.014 K/y, i.e., practically zero. The arrow labeled 'lidar' indicates the maximum trend observed by lidar at mid latitudes [*Keckhut et al.,* 1995]

positive (negative) temperature trend of +0.06±0,02 K/y (-0.09±0.03 K/y).

Discussion and Conclusion

We have analyzed the data set described above in terms of systematic short and long term variations, namely those caused by tides and solar cycle. Regarding tides we did not find any significant modulation of the mean temperatures. We note that most of the FS and RG flights took place around noon or around midnight, i. e., in the same phase of the prevailing semidiurnal tide. Therefore, we would not expect a significant modulation since model calculations suggest that the amplitude of the semidiurnal tide is only 2–3 K in the high latitude summer mesosphere and that the diurnal tide is even smaller [*Forbes*, 1982].

Regarding solar cycle variations we did not find any significant modulation in our data set. We note that the majority of the RG and FS temperatures were observed during solar minimum in the mid 1960s, mid 1980s, and 1990s. We conclude that it is very unlikely that our data base is biased due to systematic variations caused by tides or solar cycle.

In Figure 1 and 2 we have also indicated where we would expect the grenade temperatures if there were trends similar to those observed by lidar at middle latitudes (44°N) [*Keckhut et al.*, 1995]. If there were a negative trend the grenade temperatures should be larger compared to the FS mean. It is obvious from these Figures that there is no significant trend in our data set anywhere close to that observed at mid latitudes.

Regarding the datasonde measurements at 81°N there is definitely no trend in our data comparable to the large (negative) values of up to -1.2 K/y at 75 km reported by *Golitsyn et al.* [1996]. We note that the experimental uncertainties of the datasondes increase to more than ±10K above 70 km which is significantly larger than the error bars of the RG and FS techniques.

The observed NLC frequency increase reported by *Gadsden* [1998] is not necessarily in contradiction to our observation of a small or zero trend: Studies suggest that a very small trend in temperature and/or in temperature variability around the summer mesopause is sufficient to explain such a NLC increase [*Gadsden*, 1990]. Around the mesopause such small changes are below the detection limit of the RG and FS techniques considering natural variability and experimental uncertainties. Furthermore, an increase of water vapor could at least explain part of the NLC increase [*Thomas et al.*, 1989].

We conclude that there is no apparent temperature trend in the polar mesosphere and that the trend (if any) is much smaller compared to those observed at mid latitudes. It is interesting to note that this small trend is compatible with model calculations taking into account the increase of greenhouse gases [*Rind et al.*, 1990]. Some of these models even predict a warming (not cooling) for the summer mesosphere.

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