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# Horizontal winds in the mesosphere at high latitudes

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**Abstract**

A total of 146 meteorological rocket flights applying the 'falling sphere' technique are used to obtain horizontal winds in the mesosphere at polar latitudes, namely at the Andøya Rocket Range (69°N, 125 flights), at Spitsbergen (78°N, 10 flights), and at Rothera (68°S, 11 January flights only). Nearly all flights took place around noon or midnight, i.e., in the same phase of the semi-diurnal tide. Meridional winds at 69°N show a clear diurnal tidal variation which is not observed in the zonal winds. The zonal wind climatology shows a transition from summer to winter conditions with the zero wind line propagating upward from 40 km (end of August) to 80 km (end of September). Zonal winds are smaller at Spitsbergen compared to Andøya which is in line with a common angular velocity at both stations. Meridional winds at noon are of similar magnitude at all three stations and are directed towards the north and south pole, respectively. Horizontal and meridional winds generally agree with empirical models, except for the zonal winds at Antarctica which are similar to the NH, whereas there is a significant SH/NH difference in CIRA-1986.

*Keywords:* Mesosphere; Horizontal winds; Polar latitudes; Tides; Antarctica

## 1. Introduction

Little is known about the dynamical and thermal structure of the mesosphere at polar latitudes, in particular during summer conditions when daylight hampers optical measurements from the ground or from satellites. Radar techniques cover only the ionospheric part of the mesosphere (say above 75 km). The most direct way to measure winds is to detect the horizontal and vertical deflection of a target carried by the wind. The target is transported into the upper atmosphere by means of a small rocket and is tracked from the ground by a radar. The most common techniques applying this principle are the 'falling spheres' (FS) and the 'foil clouds' (Meyer, 1985; Widdel, 1990). Foil clouds achieve the best vertical resolution but cover only a rather limited altitude range in the upper mesosphere and lower thermosphere. Here, we report on wind measurements from a total of 146 falling spheres launched around the summer season at polar latitudes, namely at the Andøya Rocket Range (69°N, 'ARR'), at Longyearbyen on the island Spitsbergen (78°N, 'LYB'), and at Rothera in Antarctica (68°S, 'ROTH'). These flights give horizontal winds from approximately 80 to 35 km. Vertical winds are generally too small to be detected. Falling spheres also give densities and temperatures which have been summarized elsewhere (Lübken, 1999; Lübken and Müllemann, 2003; Lübken et al., 2004).

## 2. Instrumental technique and launches

The limited and height-dependent sphere reaction time-constant causes a smoothing of wind profiles. The smallest scales in horizontal winds detectable by FS are typically 3 and 2 km at 70 and 50 km, respectively

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(Meyer, 1985). The uncertainty of winds is typically 3 and 1 m/s at 70 and 50 km, respectively. A total of 146 FS flights have been used in this study: 125 at 69°N (April–October), 10 at 78°N (mid July–mid August), and 11 at 68°S (January flights only). Most of the flights from Andøya and the flights from Spitsbergen and Rothera are specified in more detail in the publications mentioned above (and references therein). For ARR we have also used results from 34 unpublished flights performed in the following three campaigns: TRAMP/TRANSITION in August/September 1999 (13 flights), MIDAS/SOLSTICE in June 2001 (7 flights), and ROMA/AUTUMN in August–October 2002 (14 flights).

## 3. Wind climatology at 69°N

In Fig. 1 we show zonal and meridional winds from 22 individual FS flights performed in a period of ±2 weeks around summer solstice. The launches took place from the ARR during the MAC/SINE (1987) and MIDAS/SOLSTICE (2001) campaigns. The flights around noon time (12–16 LT = 11–15 UT) are shown in blue, whereas the flights around midnight (22–03 LT = 21–02 UT) are shown in red. Mean zonal winds are negative (=towards the west) and increase in magnitude with height. There is no significant day/night variation. Meridional winds are much smaller and show a clear diurnal tidal signature: they are directed towards the north pole (positive) and the equator (negative) during day and night, respectively. We have compared the mean meridional wind and its tidal variation with various empirical and theoretical models, e.g., with the Global Scale Wave Model (GSWM) of Hagan and Forbes (2002), with the empirical model HWM93 of Hedin et al. (1996), with the COMMA/IAP model of Berger and von Zahn (2002), and (at the lowest FS heights) with ECMWF. There is general agreement between the FS results and these models, including the variation with the diurnal tide. We note that below approximately 70 km the diurnal tide is expected to be stronger than the semi-diurnal tide. Studying model results in more detail shows that at our sampling periods (noon/midnight) we can expect maximum positive/negative deviation from the mean in the meridional winds.

Regarding zonal winds, we again expect from models that the diurnal variation prevails below ~70 km. Furthermore, we expect the zero nodes of the modulation around noon and midnight. This explains why we do not observe a substantial diurnal variation in our zonal winds and why our mean zonal winds agree nicely with daily mean winds from the models mentioned above. In particular, our mean winds agree with CIRA-1986 (Fleming et al., 1990).

In Fig. 2 we show a total of 65 zonal wind profiles from 69°N in the period from July 28 until October 15. The flights took place in various campaigns from

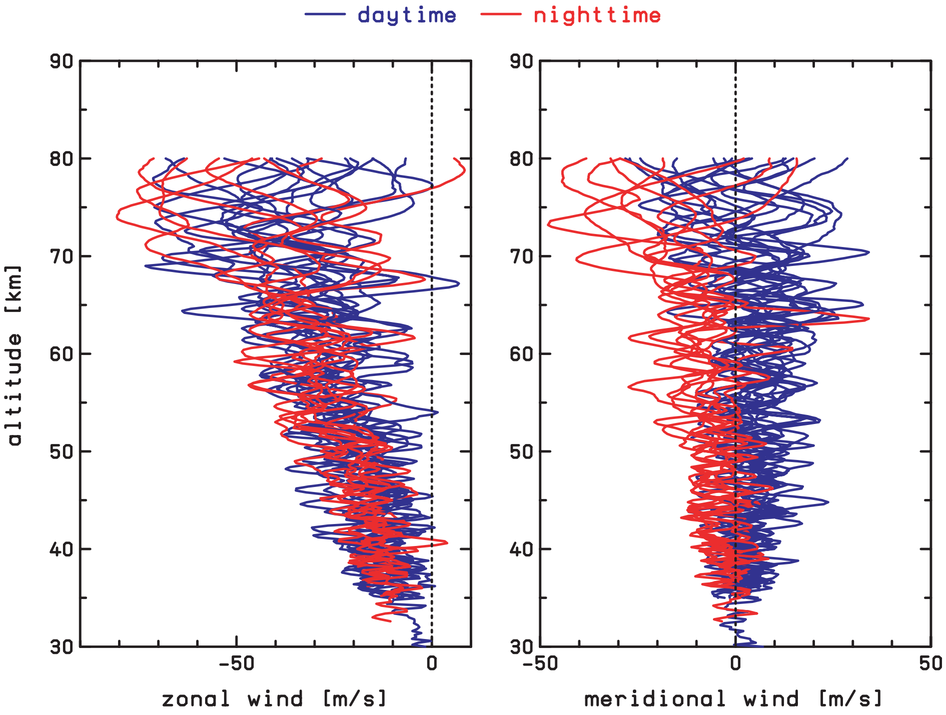

Fig. 1. Zonal and meridional winds from 14 FS flights around local noon (12–16 LT, blue) and 8 flights around local midnight (22–03 LT, red) at 69°N. Only flights in the period of ±2 weeks around summer solstice are considered in this plot.

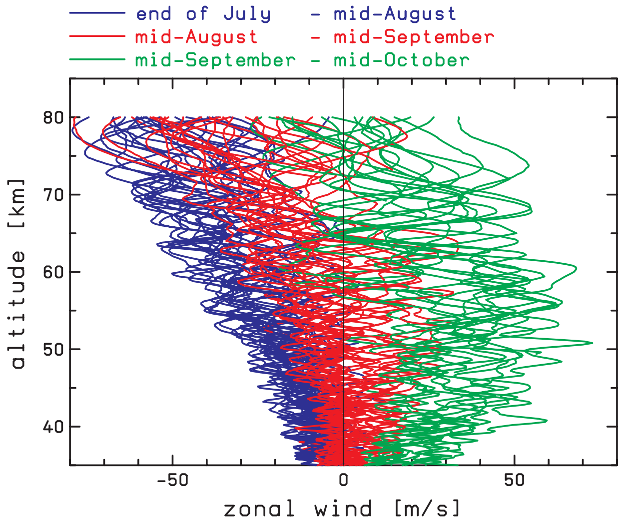

Fig. 2. Seasonal transition of zonal winds at 69°N. Different time periods are indicated by different colors (see insert). A total of 65 FS flights from July 28 to October 15 are shown in this plot.

1991 to 2002. Different colors are used for different time periods to demonstrate the seasonal variation. At the end of July winds in the mesosphere are still in the summer phase, i.e., westward. In mid October the transition is completed and the winter phase with eastward winds is prevailing. Similar to the temperature climatologies published in the references given above we have determined a zonal wind climatology for the period from May to October. As is demonstrated in Fig. 3 the wind data at a certain altitude are averaged over approximately 11 days and a spline fit through the mean values is calculated. The resulting time/altitude matrix of wind data is further smoothed by a spline fit on the height profiles. This procedure finally results in mean wind profiles from end of April (=4.75) until beginning of October (=10.25) with a time step of approximately 1 week (0.25). The final zonal wind climatology is shown in Fig. 4. This plot shows the main features of the dynamical structure of the mesopause in summer and in the transition regions. For example, zonal winds are negative (towards the west) in summer and increase in magnitude from −10 to −40 m/s at 40 and 70 km. The transition from summer to winter occurs first in the upper stratosphere and later in the mesosphere. The winter/summer transition occurs at the end of April and appears roughly at the same time at all altitudes.

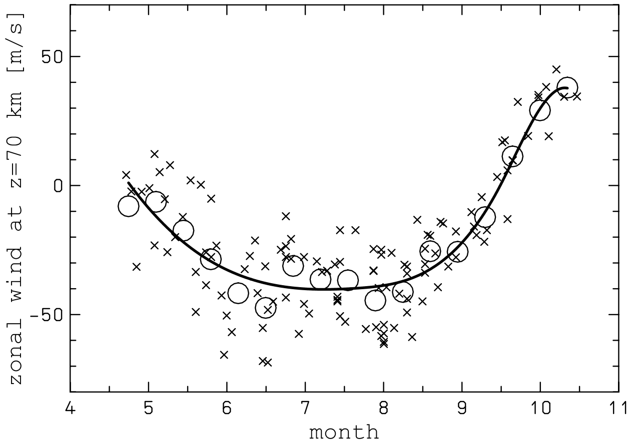

Fig. 3. Zonal winds as a function of season at 70 km and 69°N. A total of 125 FS flights are shown in this plot. Individual data are pre-averaged over ~11 days (large circles) and a spline was fitted to these mean values (solid line).

## 4. Winds at 78°N and at 68°S

In Fig. 5, we show mean zonal and meridional winds derived from the FS flights performed at Longyearbyen (Spitsbergen, 78°N) in the period from mid July until

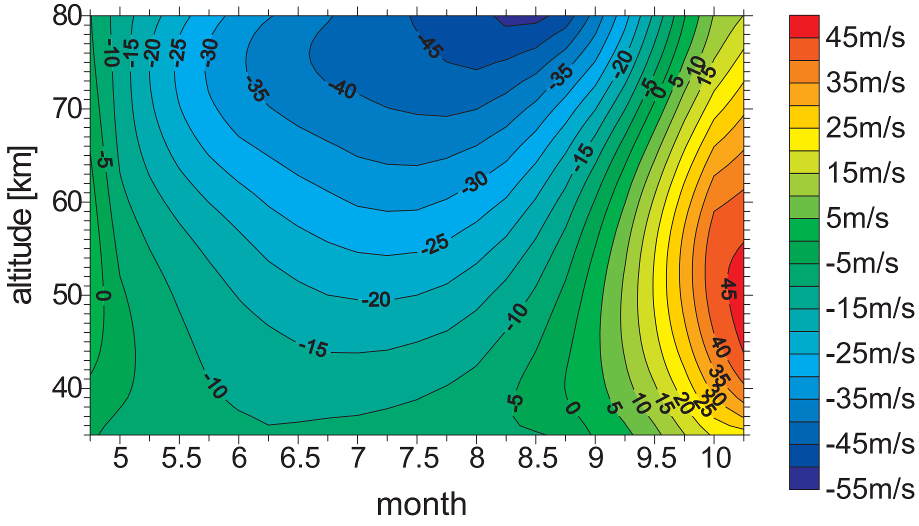

Fig. 4. Zonal wind climatology at 69°N derived from falling spheres.

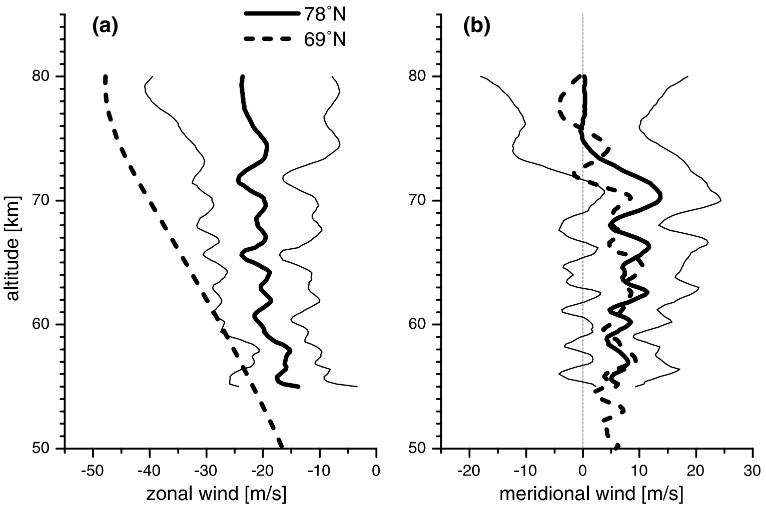

Fig. 5. Left: mean and variability of zonal winds at Spitsbergen (78°N) during summer conditions, i.e., from mid July to mid August (solid lines). For comparison, the mean winds at 69°N are shown for beginning of August (dotted line). Right: mean meridional winds and variability (solid lines) for flights around noon. The dotted line shows the mean from 69°N, again for noon time, but from a slightly earlier period (around solstice) since there have been only very few flights around noon in the period mid July–mid August.

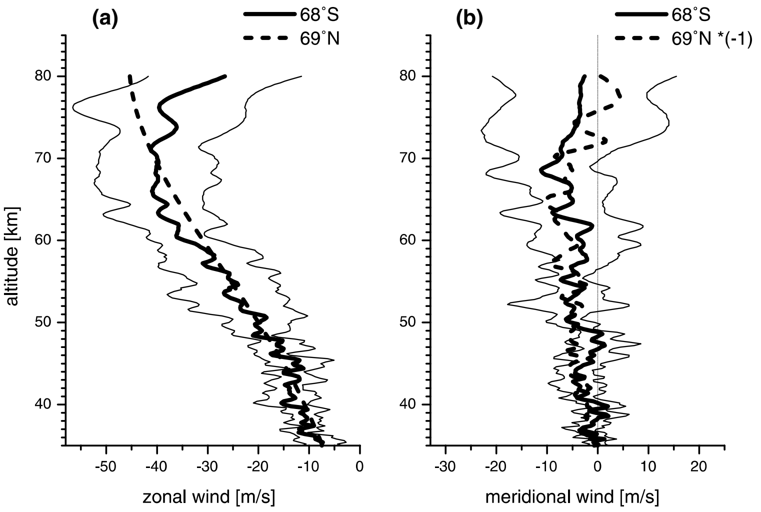

Fig. 6. Left: mean and variability of zonal winds at Rothera, Antarctica (68°S) during January (solid lines). For comparison, the mean winds at 69°N are shown for mid July (dotted line). Right: mean meridional winds and variability (solid lines) for flights around noon. The dotted line shows the mean from 69°N, again for noon time, but from a slightly earlier period (around solstice) since there have been only very few flights around noon in July in the NH. The NH meridional winds have been multiplied by a factor of −1 to facilitate intercomparison.

mid August 2001. We also show the mean winds for the beginning of August (=8.00) from 69°N. Mean zonal winds at LYB are significantly smaller compared to ARR. The difference is compatible with a constant angular velocity which leads to a zonal wind difference by a factor of cos(69°)/cos(78°) ≈ 1.7. The zonal winds at LYB agree with the models mentioned above, in particular with CIRA-1986 and with COMMA/IAP. The meridional winds for noon time in Fig. 5 are smaller in magnitude than the zonal winds and are positive, i.e., directed towards the north pole. Since we do not have measurements at ARR in exactly the same time period (mid July–mid August and noon time) we chose to compare with meridional winds from a slightly earlier period, namely from solstice ±2 weeks. Again, flights from noon time only are considered. As can be seen from Fig. 5 meridional winds at both stations are very similar. The meridional winds are in good agreement with the COMMA/IAP model. We have not performed a detailed comparison with other models.

In Fig. 6 mean zonal and meridional winds from Rothera (68°S) are shown. As has been shown by Lübken et al. (2004) the thermal and dynamical structure changes rapidly in February. We have therefore used the January data only as representative for the summer season. For comparison we also show the zonal winds from 69°N for mid July (=7.50). As can be seen from Fig. 6 the height profiles of zonal winds are very similar in both hemispheres. This result is contrary to CIRA-1986 where zonal winds in the SH are significantly smaller compared to the NH. Of course, our conclusion comes from observation at one pair of latitudes only (69°N/68°S) and cannot be extrapolated to other latitudes. We note that the early summer/winter transition of zonal winds in the SH (see Fig. 7 Lübken et al., 2004) is in agreement with the SH/NH difference in seasonal symmetry asymmetry reported from upper mesospheric winds by Dowdy et al. (2001).

In Fig. 6 we also show the noon time meridional winds which are negative, i.e., directed towards the south pole. Again, we compare with noon time meridional winds from the NH, but for a slightly different period (solstice). The meridional winds from the NH in Fig. 6 have been multiplied by a factor of $-1$ to facilitate intercomparison. As can be seen the mean meridional winds are of similar magnitude at these stations and are directed poleward (north pole and south pole, respectively). This corroborates the conclusions drawn from the comparison of temperatures and zonal winds at both hemispheres, namely that the thermal and dynamical structure in the SH/NH is very similar in January/July. Systematic differences as deduced in some models are not found in our data (Siskind et al., 2003).

In summary, the FS wind data give important information on the dynamical structure of the mesosphere at polar latitudes, including variations by tides and systematic changes with season. Most of our experimental results are in agreement with models, but we have also identified important differences, for example in the SH/NH symmetry.

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