Journal of Atmospheric and Terrestrial Physics, Vol. 47, No. 1-3, pp. 183-193, 1985.
Printed in Great Britain.

0021-9169/85 $3.00 + .00
Pergamon Press Ltd.

Wind structure and variability in the middle atmosphere during the November 1980 Energy Budget Campaign

F. J. SCHMIDLIN
NASA Goddard Space Flight Center, Wallops Flight Facility, Wallops Island, VA 23337, U.S.A.

M. CARLSON, D. REES
University College London, U.K.

D. OFFERMANN
University of Wuppertal, F.R.G.

C. R. PHILBRICK
AFGL, Hanscom AFB, MA 01731, U.S.A.

and

HANS ULRICH WIDDEL
Max-Planck-Institute for Aeronomie, Katlenburg-Lindau, F.R.G.

(*Received for publication* 29 *August* 1984)

Abstract—Between 6 November and 1 December 1980 a series of rocket observations were obtained from two sites in northern Scandinavia (~68°N) as part of the Energy Budget Campaign, revealing the presence of significant vertical and temporal changes in the wind structure. These changes coincided with different geomagnetic conditions, i.e. quiet and enhanced. This represents the largest amount of rocket data ever gathered from high latitudes over such a short interval of time. Prior to 16 November the meridional wind component above 60 km was found to be positive (southerly), while the magnitude of the zonal wind component increased with altitude. After 16 November the meridional component became negative (northerly) and the magnitude of the zonal wind component was noted to decrease with altitude. Time-sections of the perturbations of the zonal wind show the presence of vertically propagating waves, which suggest gravity wave activity. These waves increase in length from 1 km near 30 km to over 12 km near 80 km. The observational techniques employed at Andøya (~69°N), Norway, and Esrange (67.9°N), Sweden, consisted of chaff foil, instrumented rigid spheres, chemical trails, inflatable spheres and parachutes.

INTRODUCTION

Measurements of wind in the stratosphere, mesosphere and lower thermosphere were obtained over northern Scandinavia during November 1980 in conjunction with the Energy Budget Campaign (OFFERMANN, 1985). Multiple observations were obtained within a few minutes of each other during four uniquely defined experimental periods keyed to geomagnetic conditions. These observations permitted an analysis of high latitude wind structure and a determination of its variability between 20 and 90 km. Five *in situ* wind sensing techniques were employed: inflatable passive spheres, instrumented accelerometer spheres, Starutes, metalized foil chaff and chemical trails. Although this combination of sensors permitted wind data to be obtained to 160 km, this paper emphasizes the measurements obtained below 90 km. Although data from each sensor were limited to the sensor's designed altitude-measurement range, sufficient overlap of the profiles exists to permit us to assess the compatibility of the different techniques. Table 1 lists the dates and times of the observations, the technique and general comments.

An earlier report (OFFERMANN and THRANE, 1981) provides details of the campaign and its objectives, the experimental criteria and information about the instrumentation employed. Briefly, the Energy Budget Campaign was conducted to examine the atmospheric heat budget during the occurrence of auroral or geomagnetic events and to identify those mechanisms instrumental in depositing, storing or removing energy from the middle atmosphere. One mechanism under consideration is the influence of the horizontal winds on the energy distribution (RICHMOND, 1979). Thus, wind observations and observations of other para-

Table 1. Dates and times of wind observations relative to geomagnetic conditions are given and the types of wind measurement techniques used

Geomagnetic condition	Date	Time (UT)	Observation techniques	Comments
	7/11/80	2200	Starute	20–80 km
		2250	Inflatable sphere	26–56 km
	10/11/80	0010	Starute	23–73 km
		0218	Inflatable sphere	30–87 km
Quiet	11/11/80	2200	Starute	20–80 km
		2346	Inflatable sphere	30–87 km
		0027	Chemical trail	90–155 km
		0032	Foil chaff	Launched from Andøya, Norway; 74–93 km
		0155	Inflatable sphere	32–90 km
		0226	Starute	21–70 km
	12/11/80	0020	Starute	21–82 km
		0107	Inflatable sphere	28–90 km
Slightly enhanced	16/11/80	0346	Foil chaff	Launched from Andøya, Norway; 73–86 km
		0447	Instrumented rigid sphere	52–140 km
		0447	Chemical trail	90–145 km
		0512	Inflatable sphere	30–73 km
		0537	Foil chaff	86–97 km
		0633	Starute	20–82 km
		0752	Inflatable sphere	28–90 km
		0823	Starute	22–80 km
Active	27/11/80	2245	Starute	20–80 km
	28/11/80	0047	Inflatable sphere	30–88 km
		0329	Inflatable sphere	26–90 km
		0419	Starute	21–60 km
Active	1/12/80	0024	Inflatable sphere	25–61 km
		0124	Chemical trail	85–130 km
		0124	Instrumented rigid sphere	55–140 km
		0139	Inflatable sphere	30–87 km
		0233	Starute	24–79 km
		0324	Starute	20–66 km

meters (e.g. temperature, density, electron density, etc.) were scheduled when the geomagnetic activity reached predefined limits. These limits were no increase in geomagnetic activity, slightly enhanced conditions and very active or enhanced conditions. The background or control state was determined to be when there was a lack of activity. Additionally, the very active condition required that two measurement periods be considered on account of poor surface weather launch conditions at Esrange (OFFERMANN and THRANE, 1981).

MEASUREMENT TECHNIQUE COMPARABILITY

Before discussing comparability, however, a brief description of the different techniques is in order. As described in more detail in SCHMIDLIN *et al.* (1981), the Starute is a ram-air inflated balloon shaped like a parachute. It is metalized to facilitate radar tracking and because of its unique design is a very stable decelerator, i.e. it performs with no (or extremely small) oscillations, in contrast to a typical parachute. The inflatable sphere is also metalized and is inflated after ejection from the rocket payload by an inert gas. First and second time derivatives of the radar position data are necessary to correct for external influences on target motion, i.e. fall speed and changes in vertical and horizontal accelerations over the altitude range of the sensor. It is important that the inflatable sphere be tracked with a precision tracking radar. During the Energy Budget Campaign the German Space Organization Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR) made a precision C-band radar available at Esrange. This radar's angular precision is stated as being ~0.023° in azimuth and elevation and 2.7 m in range (TODD, 1980). For technical reasons the low weight-to-area ratio essential for a slow descent speed and a fast response to horizontal winds and vertical gusts cannot be achieved by the sphere nor Starute techniques. This, therefore, puts a demand upon the quality and precision of the radar and requires smoothing of the positional data.

The foil chaff experiment of WIDDEL (1978, 1981) provides the radar with a reflective surface so that the radar position data may also be used to obtain wind information. The evaluation procedure for obtaining winds from chaff is the same as for the Starute or falling sphere. The chaff foils are 2.5 μm thick and are cut to a resonant length of the tracking radar frequency to enhance the received signal. Because the weight-to-area ratio of chaff is very low (3.4×10^{-3} kg m^{-2}), the speed of descent of the foil cloud is of the order of 40–60 m s^{-1} at 92 km and decreases with decreasing height. At 75 km the speed of descent decreases to approximately 5–8 m s^{-1}. The low speed of descent permits the cloud to respond to small, short-lived fluctuations of wind speed. The detection and measurement of transient vertical movements of air parcels is therefore possible (ROSE and WIDDEL, 1969). On its descent the foils tend to spread out. This tendency can be satisfactorily compensated for by using proper methods for the deployment of the foil cloud (WIDDEL, 1978), but strong windshears with their associated turbulence overcome the confinement of the foil cloud and often terminate the measurement. A good check for the quality of the tracking data is to plot the trajectory with the time scale removed, e.g. height vs meridional direction, height vs zonal direction, etc. Such plots allow an estimate of the size of the cloud and separation of genuine movements of the cloud caused by wind changes from those caused by turbulence (Fig. 1).

The instrumented rigid sphere uses a three-axis piezoelectric accelerometer and was developed to provide higher resolution measurements over a deeper altitude layer than was available from previous instrumented spheres (PHILBRICK *et al.*, 1978). The wind velocity is determined by comparing accelerometer component ratios between upleg and downleg trajectories. The accelerometer determination of the winds relies upon three different methods of reduction, depending on whether the analysis is performed on upleg and downleg motion of the cross-track trajectory or in-track trajectory. Each method of analysis has different errors, with errors from the cross-track analysis of upleg and downleg trajectories the smallest. Any differences observed between upleg and downleg

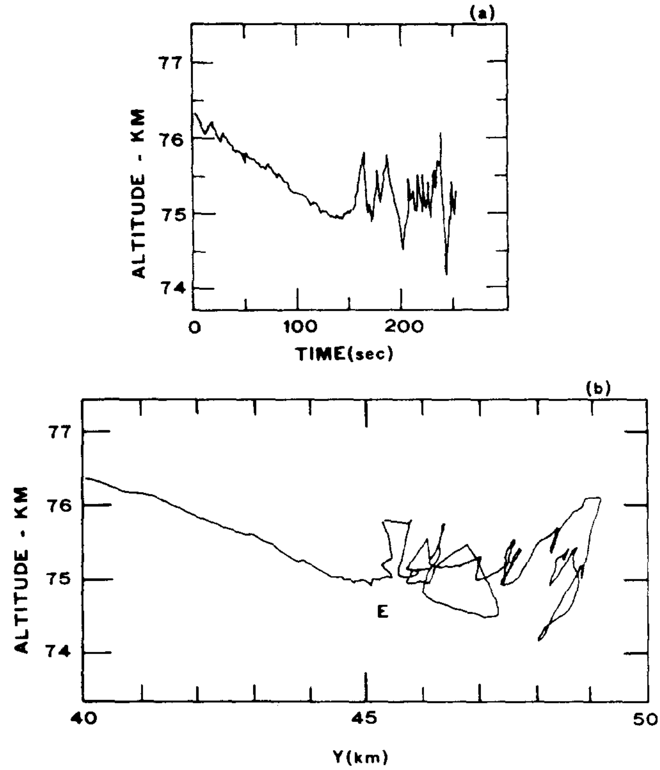

Fig. 1. Graphical representation of unsmoothed radar position track of foil chaff showing break-up in turbulence: (a) height vs. time; (b) time scale removed, height vs meridional direction (towards north). Origin: radar location. E indicates point of encounter with turbulence.

wind analysis is assumed to come from temporal and/or spatial changes in the wind field. In-track winds can be determined by assuming spatial uniformity and can only be determined by a closed solution when both upleg and downleg data are available. Generally, winds above 84 km are determined using the upleg and downleg trajectories. Below 85 km, wind analysis can be extended using only downleg data when the wind field is uniform. Wind errors are largest in the latter case, especially along the in-track component.

Chemical trail data of REES *et al.* (1981) were obtained by releasing trimethyl-aluminum (TMA) above 80 km, where photochemical reactions cause chemiluminous emissions. The wind data were obtained by synchronously photographing the trail from multiple sites (usually three sites are the minimum desired) over a period of 10–60 min. Distortion of the trail with time may then be interpreted into ambient wind structure.

Combining the wind profiles from those measurements made close in time in order to derive a single, continuous profile would be highly desirable and have advantages over individual profiles. This, however, is not simply accomplished. The time difference between the measurements, the types of sensors used and the spatial separation between the observations all are important considerations. Wind differences observed between two measurement techniques separated by a few minutes and a few kilometers may be reconciled with, perhaps, little difficulty. Differences observed between measurements made 100 or more kilometers apart, however, would be much more difficult to reconcile. During a previous campaign it was noted that under undisturbed conditions the wind field did not change in structure over a horizontal distance of 50 km (AZCARRAGA *et al.*, 1972). This may not be the case when conditions are disturbed.

As an example of these problems, Fig. 2a shows a comparison of the zonal wind component of the foil chaff measurement made from Andøya (69°N, 16°E), Norway, on the night of 10/11 November 1980 with the TMA chemical trail measurement made 5 min earlier from Esrange (67.9°N, 21°E), Sweden. In spite of the approximately 250 km distance between the two launch ranges and the time difference between the observations the agreement is quite good. Similar agreement is found for the meridional component, as seen in Fig. 2b. It should be noted that 10/11 November was a night during which no enhanced geomagnetic activity was observed. Comparison between the chaff measurement, an inflatable sphere and a Starute measurement separated by as much as 2.5 h also reveals reasonably good agreement. In spite of the large separation between Andøya and Esrange and the time difference between these measurements the agreement observed suggests that the atmosphere may have been well behaved on the night/morning of 10/11 November 1980. The inflatable spheres, separated in time by almost 2 h, show rather large wind differences above 83 km, which may be due to measurement inconsistency, gravity waves or, possibly, tidal motion. Another obvious feature of Figs. 2a and 2b is the smoother profiles presented by the faster falling sphere, with the attendant reduction in wind resolving capability (HYSON, 1968).

Comparison of the profiles obtained during the evening of 16 November 1980 from Esrange indicates a somewhat different result. The zonal component is shown in Fig. 2c. A large disagreement can be noted between the chemical trail and chaff and between the chemical trail and the instrumented rigid sphere. The 1 h time difference between the chaff and chemical trail may be an explanation for the difference, however, the instrumented sphere and chemical trail measurements were made simultaneously. Furthermore, below 90 km altitude the inflatable sphere and Starute are in good agreement, but deviate considerably from the rigid sphere profile. Figure 2d shows the comparison between these same sensors for the meridional component. The outstanding differences are seen to be between the chemical trail and chaff and between the inflatable sphere and the rigid sphere. The difference noted between the inflatable sphere and Starute above about 78 km is mainly due to the different fall speeds of the two techniques. The Starute is falling at nearly one-half the fall speed of the sphere and is responding better to the wind flow. Below 75 km they begin to agree in almost all respects and both are noted to differ from the rigid sphere data.

The measurements obtained on 1 December 1980 show quite good agreement between the inflatable sphere and Starute (see Figs. 2e and 2f). However, when these profiles are compared to the instrumented sphere profile disagreement is noted, especially below 80 km. The rigid sphere meridional wind data were found to be inaccurate below 80 km and, consequently, the meridional wind profile is not included in Fig. 2f. The differences between the chemical trail profiles and the instrumented sphere profiles are not explained at this point, since both measurements were made from payloads launched on the same rocket vehicle. However, the chemical trail measurements are obtained as the payload is ascending, while the instrumented sphere measurements are obtained during the upward and downward payload trajectory. The differences in time and in position could cause the observed wind differences. Although separated in time, the inflatable sphere and chemical trail agree quite well over the small altitude increment where they overlap.

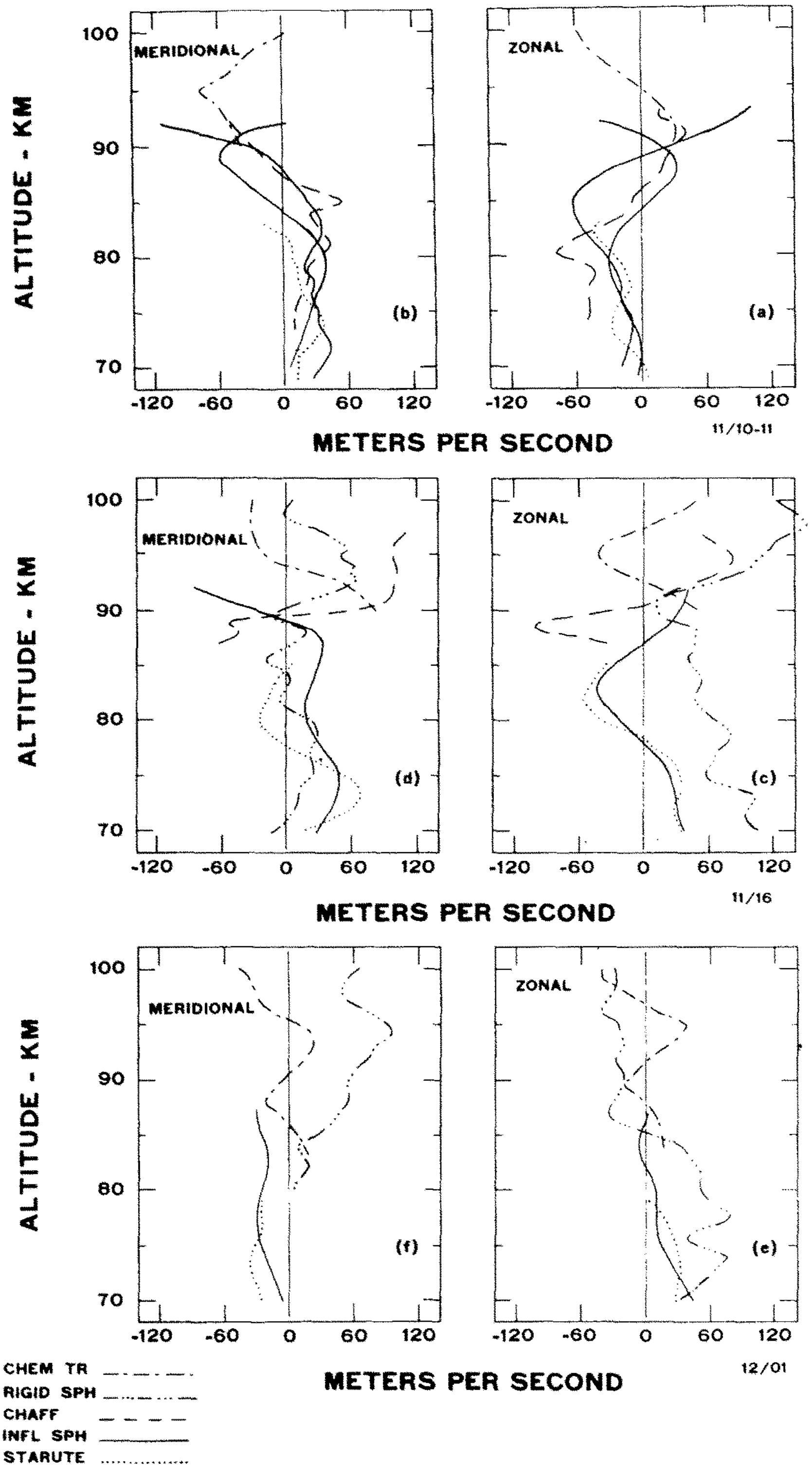

Fig. 2. Comparison of wind profiles obtained with different wind sensing techniques. (a) Zonal wind profiles on 10/11 November 1980 from chemical trail, foil chaff, inflatable spheres and Starute. The times of observations are not given since the figure only intends to show the relative difference observed between the techniques (see Fig. 4). (b) As (a) except for meridional wind component. (c) Zonal wind profiles on 16 November 1980 from chemical trail, foil chaff, instrumented rigid sphere, inflatable sphere and Starute. (d) As (c) except for meridional wind component. (e) Zonal wind profiles on 1 December 1980 from chemical trail, instrumented rigid sphere, inflatable sphere and Starute. (f) As (e) except for meridional wind component.

It seems clear from analysis of Figs. 2a–f that differences exist between the various profiles. This points out that time differences, spatial differences and sensor differences are important and must be considered when carrying out any interpretation of wind measurements. Near the top of the inflatable sphere profiles large differences can be noted between the wind data measured with the inflatable sphere and wind data measured using other measurement techniques. Differences between two inflatable sphere measurements made within 1–2 h should also be noted in Figs. 2a–b. Whether this is because of true atmospheric variability or measurement error is being examined in more detail using inflatable sphere measurements from other launch sites with multiple radar tracking capability. One important point to be made from Figs. 2a–f, however, is that the Starutes and inflatable spheres show the most similar measurements.

DISCUSSION

The wind measurements made available as a result of the Energy Budget Campaign permitted a detailed look at the wind structure during the four special observational periods. This information, and the associated temperature data, when used in concert with high altitude meteorological analysis, such as is possible from satellite temperature retrievals, helped to explain (anomalous) circulation features noted by LABITZKE and BARNETT (1985). Although more difficult to measure, turbulence may also act as an effective method for removing or redistributing heat. Direct measurements of turbulence at these high altitudes are scarce, but selective analysis procedures make it possible to infer turbulence intensity. The role of turbulence is discussed by THRANE *et al.* (1985) and will not be considered here.

In the discussion that follows, a brief description is given of mean wind conditions, wind variability over short time periods, vertical oscillations and wave propagation. In the present context, the mean wind is defined as the average of the wind measurements which were obtained during each of the 4–6 h long observational periods. Generally, the mean wind situation was different during each of the four observational periods. These differences in the mean winds could be the result of averaging over less than a 24 h period. Whether the differences are related to other geophysical events (i.e. geomagnetic activity) still needs to be established using all experimental data.

Figure 3a shows that during the night of 10 November 1980 the mean meridional wind direction between 40 and 85 km was predominantly from the south with a magnitude of less than 30 m s^{-1}. Below 37 km a slight northerly component is apparent. Furthermore, during this night the zonal wind direction was from the west and reached a 45 m s^{-1} peak speed near 58 km. Above 58 km the speed of the westerly wind decreased and finally became easterly above 68 km.

During the morning of 16 November 1980 the mean meridional wind was from the south, as shown in Fig. 3b, and above 55 km altitude reached speeds of twice those observed during the night of 10 November. The zonal wind was from the west and gradually increased in magnitude with increasing altitude. At 65 km the

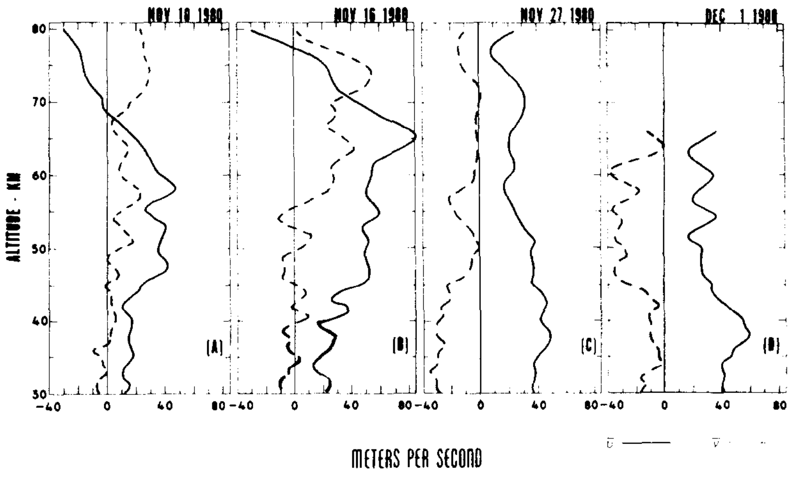

Fig. 3. Mean wind shown for each of the geomagnetic periods: (a) 10/11 November 1980; (b) 16 November 1980; (c) 27/28 November 1980; (d) 1 December 1980. U indicates mean zonal wind, V indicates mean meridional wind.

peak westerly wind speed of about 90 m s^{-1} was reached. Above this altitude the zonal speed decreased and became easterly above 77 km.

On the night of 27 November 1980 and again during the early morning of 1 December 1980 the meridional component was found to be considerably different than observed during the first two launch periods. The southerly wind which was noted during these earlier events was now northerly. The meridional wind speed, previously observed to be practically nil, was now found to be about 40 m s^{-1} (below 55 km), while the meridional wind speed of near 40 m s^{-1} (above 60 km) was now observed to be nearer to zero speed, as seen in Fig. 3c. The zonal component, though still westerly, was considerly reduced in magnitude, except below 45 km altitude where the wind speed generally showed an increase. Figure 3d shows that on 1 December the meridional wind speed below 45 km altitude was at least 30 m s^{-1} less than previously observed, while above 45 km the meridional speed, once again, was elevated. The meridional component was still northerly, while the zonal component was very similar to that observed on 27 November.

As discussed earlier, the launch periods were selected based on the level of enhancement of the geomagnetic conditions and, as shown in Figs. 3a–b, there is little doubt that the averaged wind conditions changed when geomagnetic conditions changed. It is not clear from the small sample of data available, however, whether real correlation exists. If correlation does exist, can a determination of the control or cause of these changes be identified? The discrete nature of the available observations makes it difficult to relate the wind changes to the onset of the changing geomagnetic conditions or other changes in atmospheric energy.

What appears to be more logical is that the changes in the mean wind conditions are related to changes in the large-scale circulation patterns. LABITZKE and BARNETT (1985) in a companion paper in this issue show the various northern hemisphere circulation patterns near the dates of the launchings. Examination of these patterns suggests that the wind changes were caused by a migration of the polar low pressure region, which results in the eastward movement of a planetary wave 1.

While the above discussion of the changes noted in the prevailing mean winds is interesting, care must be exercised. The mean winds referred to are composed of observations available within a 4–6 h period. Thus, the changes noted in Figs. 3a–d may simply be due to the variability that exists in the phase of the 24 h tide, and to a lesser extent to the 12 h tidal phase. Although the profiles were averaged for similar times on four different nights, variability of the tidal activity could account for the large changes. Amplitudes of the tides of 10–20 m s^{-1} at 60–90 km must be assumed to be present and were not removed. Neither were the 5–20 m s^{-1} amplitudes known to exist with planetary waves at high latitudes (CARTER and BALSLEY, 1982; MANSON *et al.*, 1981, 1982). Furthermore, measurements from the MST radar located at Poker Flat (65.1°N, 147.5°W), Alaska, suggest that tidal and planetary wave activity exists above 60 km, but little relationship with other measurement techniques has been shown (BALSLEY *et al.*, 1982).

Although the profiles shown in Figs. 3a–d reveal information about the wind structure, they do not show the changes which occur over much shorter time periods. The averaging of the profiles tends to remove details which show more convincingly the nature of the short-period winds. The figures that follow identify much more vividly the magnitudes and wavelengths of vertical oscillations. Cursory examination of these profiles suggest that both in-phase and out-of-phase changes exist.

In the discussion that follows, two different wind sensors are used to describe the wind behavior. It is important to confirm that each technique is virtually observing the same wind condition. This is important since we took care to compare different techniques earlier in this paper. Figure 4 contains zonal wind measurements from a Starute and an inflatable sphere obtained within 31 min of each other. The extremely

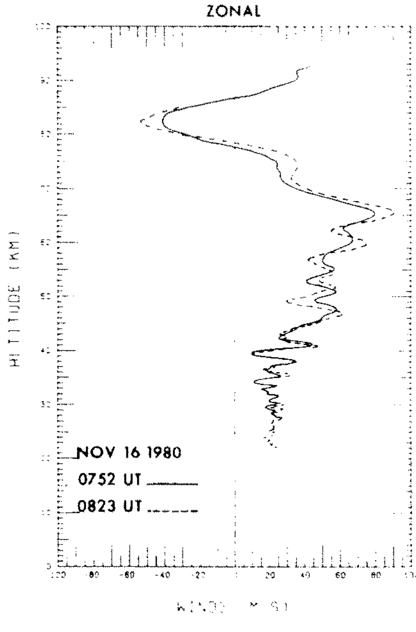

Fig. 4. Inflatable sphere and Starute wind profiles obtained 31 min apart at Esrange. The profile agreement shows the quality of the techniques used to represent the wind structure.

close similarity of the two profiles suggests, first of all, that the Starute and sphere techniques are measuring the same wind, second, that the large-scale vertical wavelengths may be fixed in position and, third, the difference in the position of the smaller scale wavelength peaks might be related to propagating waves. These two profiles are also useful in delineating the vertical scale of the oscillations with altitude. Direct measurements starting near 30 km give a vertical wavelength of about 1 km, near 40 km about 3 km, near 50 km about 4 km, near 62 km about 5 km, near 75 km about 9 km, and at 82 km about 15 km. Comparing the change of magnitude of the wind at 50 km, 65 km and 75 km it appears that the rate of change of amplitude ranges from 0.3 to 0.5 m s^{-1} per min.

The general coherence of the wind profiles of Fig. 4 gives the impression that propagating gravity waves are most likely present. The observed wavelengths are similar to those found with internal gravity waves, however, because discrete measurements limit time and spatial information about the true turbulent condition we must preclude conclusive judgment concerning wave continuity in time and space. Nevertheless, oscillations with periods in the range of 10–200 min are usually manifest in gravity waves. The observations obtained in the Energy Budget Campaign were obtained within this range of time. It is not clear from the profiles shown in which direction these waves might be propagating.

The general character of the profiles illustrated in Figs. 5a–d indicates that the oscillations, in some cases, may reach peak-to-peak changes in speed of 35–40 m s^{-1} within a few hours. The vertical wavelengths of these oscillations are small near 30–40 km altitude, being approximately 1–2 km, and largest above about 70 km, reaching 12 km or more. It is possible that short-wavelength oscillations are also present at the higher altitudes, but were not observed because of the dissipation of gravity waves or may be suppressed simply because of the high fall speed of the sensors. The fall velocities of the Starute and sphere at 70 km, 220 and 400 m s^{-1}, respectively, limit the radar and data reduction capabilities from resolving small oscillations.

Examining the profiles of Figs. 5a–d further, a number of interesting characteristics immediately become apparent. For example, in Fig. 5a the four profiles obtained within a 4.5 h interval tend to lack coherence, except between approximately 50 and 60 km. The two profiles above 80 km, obtained from spheres, are typical of the variation previously observed in the wind at these high levels over a few hours. Figure 5b suggests that the individual profiles were more coherent during slightly enhanced geomagnetic conditions and even reveal an orderly change with time

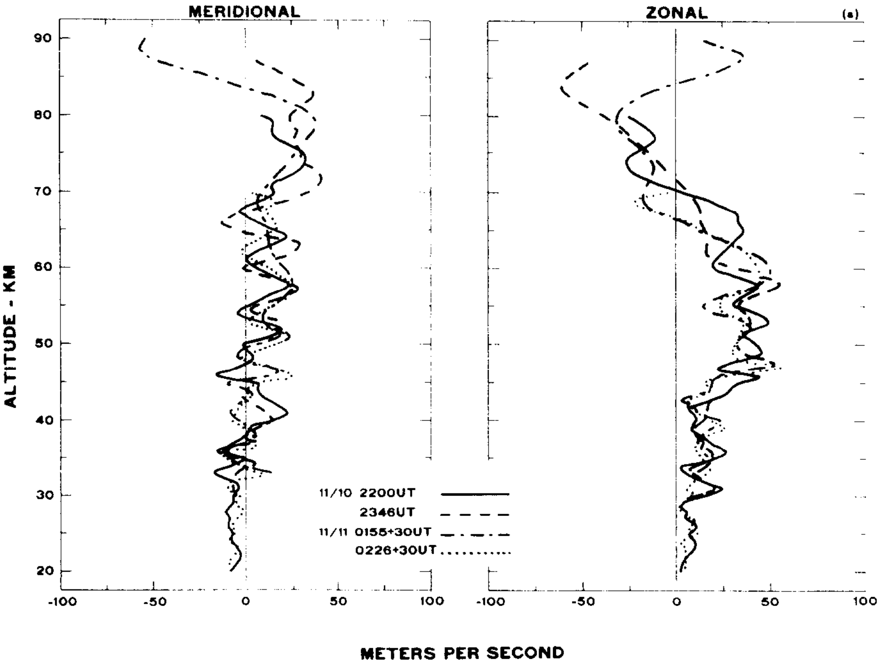

Fig. 5. Detailed wind profiles from only the inflatable spheres and Starutes: (a) 10/11 November 1980; (b) 16 November 1980; (c) 27/28 November 1980; (d) 1 December 1980.

of the meridional wind component between 50 and 62 km. The observation at 0512 UT indicated that a peak northerly wind of 30 m s^{-1} occurred near 55 km, but the last observation within the group at 0823 UT indicated that the wind at this level became southerly with a speed of about 10 m s^{-1}, a 40 m s^{-1} change within 3 h. The meridional and zonal wind profiles suggest that the vertical wavelengths may have a rather long persistence. The oscillations that appear in all of the profiles are not always in phase and might be the

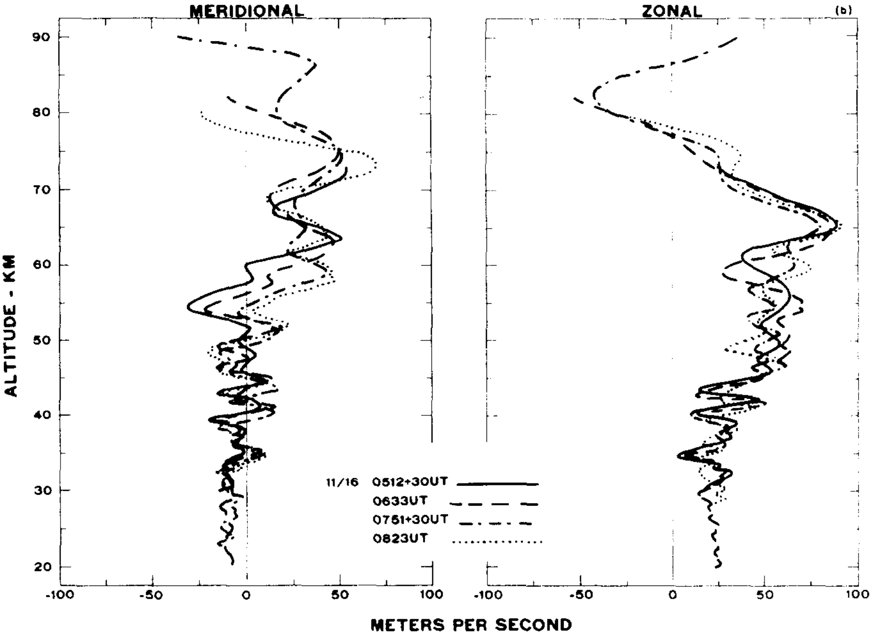

Fig. 5(b).

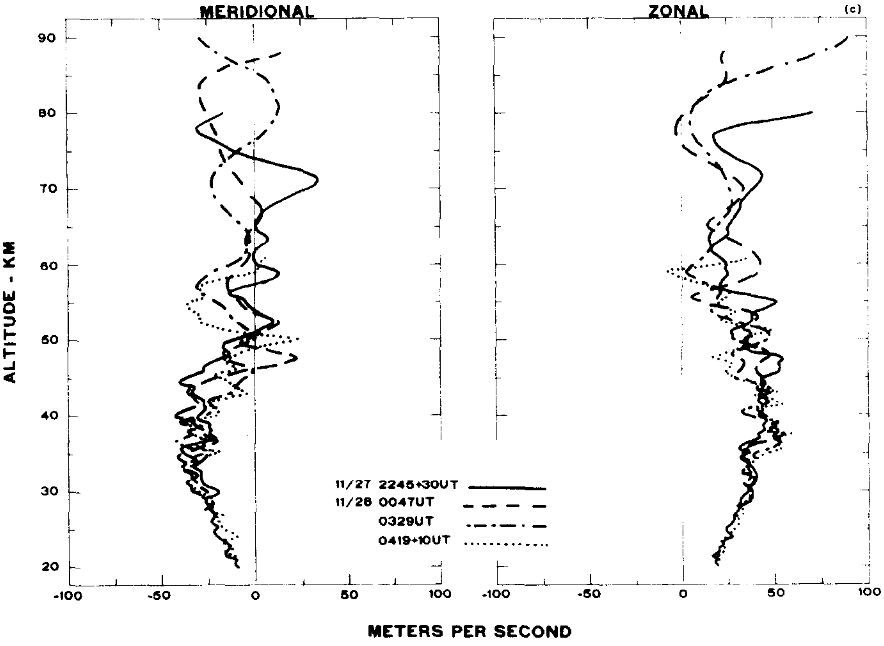

Fig. 5(c).

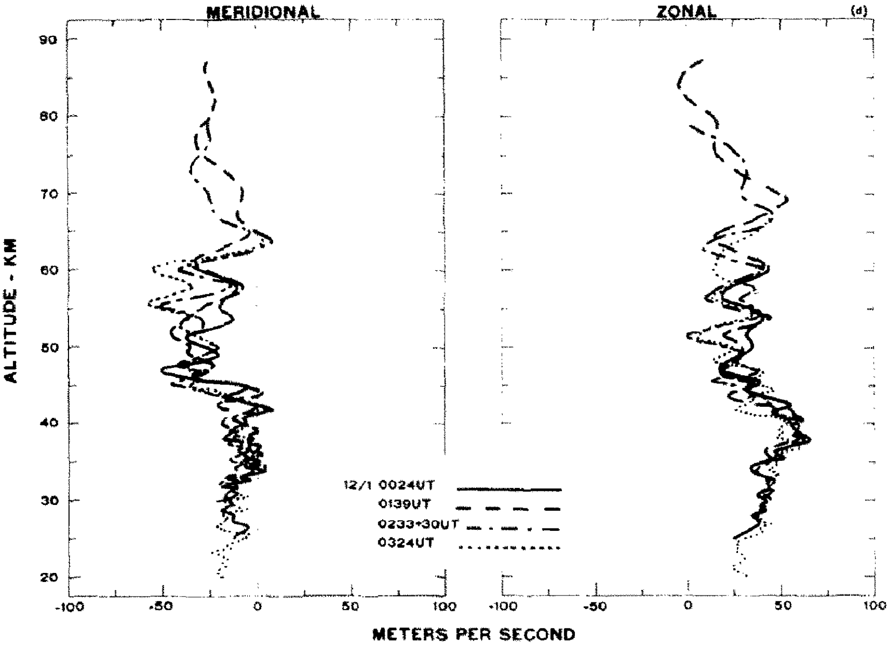

Fig. 5(d).

result of the presence of several gravity waves. The example shown by Fig. 5c is characteristic of the disorganized behavior encountered. Especially noteworthy is the meridional component above 60 km, where the two sphere profiles indicate the wind direction changed from northerly to southerly and back to northerly in less than 3 h.

It could be argued that the previous simple description of the wind behavior and its relationship to gravity waves is not very realistic. For one thing, with the exception of Fig. 5c, the vertical structure is quite organized, while a spectrum of waves would be more representative of gravity wave behavior. Occasional single waves, standing waves, reflected waves and the presence of critical layers would almost certainly be expected. However, any analysis attempt would have problems, mainly because the measurements are not instantaneous but in some instances (e.g. Starute) required 40 min to complete.

Examination of time–height sections of the perturbation velocities v' and u' (where $v' = \bar{v} - v$; $u' = \bar{u} - u$) revealed wavelengths consistent with the observations. On 16 November 1980 during slightly enhanced geomagnetic conditions the wave propagation direction was generally downward at between ~ 0.5 and ~ 0.6 m s^{-1}, as shown by Fig. 6. The varying time required to complete an observation (in some cases as long as 40 min) was considered in the construction of this cross-section.

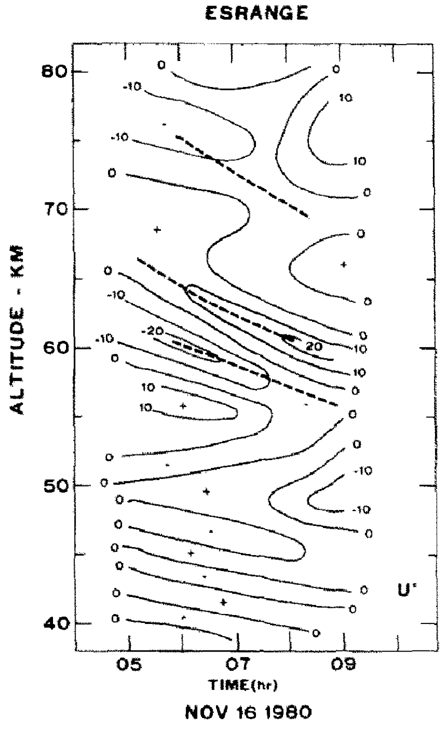

Fig. 6. Zonal wind perturbation u' constructed for 16 November 1980 showing downward propagating structure. It is important to mention that in the construction of this cross-section the varying time of data acquisition at each altitude was considered. In some cases the observation period may have been as long as 40 min.

CONCLUSIONS

Measurement data have shown the behavior of the middle atmosphere winds between 30 and 90 km to be variable in time and space, to contain considerable structure and to be complex in many ways. Because of the limited data sample, it is difficult to conclude whether the vertical wind structure is correlated with other geophysical events. However, the behavior of the component winds was found to be different on each of the four experimental nights. It seems that causal relationships between energy input and output in the atmosphere and geophysical events must remain elusive until larger geographic-scale experiments can be carried out.

The magnitude of vertical oscillations described in this paper were found to vary from small to large. The wavelengths of the oscillations were also observed to vary from 1 km near 30 km to as large as 10–15 km near 80 km. However, the capability of the techniques employed may restrict better resolution of the wind structure presented here. Time–height sections of the perturbation velocities showed downward propagating wave phases which varied in speed, but were usually of the order of 0.5 m s^{-1}.

Since present analysis depends on the interpretation of discrete observations which required as long as 40 min to complete, care must be exercised on how the data should be interpolated. Wave propagation direction, the rate of vertical propagation and the observed wavelengths are similar to those expected with internal gravity waves. The question of whether energy is being added to the atmosphere from the dissipation of gravity waves remains to be determined. High latitude gravity waves apparently are large in magnitude and contain a spectrum of waves which should be observed in greater detail, if possible. Continuous measurements, such as are available from radar techniques, are highly desirable, but these radars may not be located at the proper location to observe these waves. Alternatively, in future campaigns of the Energy Budget Campaign type a more intensive launch schedule would be useful. Observations made minutes apart are needed.

Acknowledgments—This research effort was supported by the Bundesministerium für Forschung und Technologie (BMFT), of the Federal Republic of Germany. We acknowledge the efforts of Ms Helen Shirk of NASA Goddard Space Flight Center/Wallops Flight Facility for preparation of the manuscript. Acknowledgment is also made for the encouragement and support of the various organizations within NASA and AFGL.

REFERENCES

Azcarraga A., Sanchez L., Rose G. and Widdel H. U. 1972 *Space Res.* **12**, 613.
Balsley B. B., Carter D. A. and Ecklund W. L. 1982 *Geophys. Res. Lett.* **9**, 219.
Carter D. A. and Balsley B. B. 1982 *J. atmos. Sci.* **39**, 2905.
Hyson P. 1968 *Q. Jl R. met. Soc.* **94**, 592.
Labitzke K. and Barnett J. J. 1985 *J. atmos. terr. Phys.* **47**, 173.
Manson A. H., Meek C. E. and Gregory J. B. 1981 *J. geophys. Res.* **86**, 9615.
Manson A. H., Meek C. E., Gregory J. B. and Chakrabarty D. K. 1982 *Planet. Space Sci.* **30**, 1283.
Offermann D. 1985 *J. atmos. terr. Phys.* **47**, 1.
Offermann D. and Thrane E. V. 1981 Bundesministerium für Forschung und Technologie Report FB-W81-052.
Philbrick C. R., Faire A. C. and Fryklund D. H. 1978 AFGL TR-78-0058.
Richmond A. D. 1979 *J. geophys. Res.* **84**, 5259.
Rees C., Carlson M., Maynard N. C. and Kaila U. 1981 Bundesministerium für Forschung und Technologie Report FB-W81-052, p. 362.
Rose G. and Widdel H. U. 1969 *J. Geophys.* **35**, 211.
Schmidlin F. J., Philbrick C. R. and Offermann D. 1981 Bundesministerium für Forschung und Technologie Report FB-W81-052, p. 382.
Thrane E. V., Andreassen Ø., Blix T., Grandal B., Brekke A., Philbrick C. R., Schmidlin F. J., Widdel H. U., von Zahn U. and Lübken F. J. 1985 *J. atmos. terr. Phys.* **47**, 243.
Widdel H. U. 1978 Bundesministerium für Forschung und Technologie Report FB-W78-23.
Widdel H. U. 1981 Bundesministerium für Forschung und Technologie Report FB-W81-052.

Reference is also made to the following unpublished material:

Todd G. E. 1980 Energy Budget Campaign Handbook, Part 2, Operations, Kiruna.