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Zonal Meteor Wind Observations at Budrio, Italy

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Abstract. Intensive meteor radar wind observations were made at Budrio (45°N, 12°E) near Bologna, during the Energy Budget Campaign, November 1980, in the altitude region between 75 and 115 km. After describing briefly the CNR meteor radar station, zonal wind results are presented in terms of prevailing components and oscillations of different time scales: tidal (24,12 and 8 h), gravity and planetary waves. The monthly prevailing winds differ from those established during the November 1976 and 1978 wind observations and from the CIRA 1972 model for 45°N seasonal variations. Quasi 2-day wind oscillations exhibit amplitudes lower than those obtained at the same station during the summer 1980 observations.

Key words: Meteor winds – Energy Budget Campaign – Tides – Gravity waves

Introduction

The meteor radar station at Budrio (45°N, 12°E) near Bologna, performed initial observations in 1976. Throughout the whole year February 1976–January 1977, recording runs lasting two or more days were made every month with the aim of studying the prevailing and tidal components in the lower thermospheric wind structure (Verniani et al. 1980). By that time, the interferometric system was not completely operational and we preferred to refer all wind data to the height of 95 km, instead of associating each value of the wind with the corresponding diffusive height. We thus obtained information on the seasonal variations of the prevailing wind, of the diurnal, semidiurnal and terdiurnal tides and also of long period oscillations with periods of about 2 days, all referred to this average height.

A new observational campaign was carried out at Budrio throughout the year 1978 with the aim of studying the vertical propagation of gravity, tidal and planetary waves and also of identifying other long period oscillations by means of recording runs lasting many consecutive days per month. Internal gravity waves with periods 2–8 h were observed at Budrio in the region 80–100 km during the spring and summer of 1978 and the results indicate the possible importance of these waves in propagating upwards and transporting momentum from one region to another (even a modest momentum transfer from a coherent wave system can lead to substantial change in the prevailing winds) (Cevolani and Formiggini 1981). Determination of the vertical structure of wind components is made possible by the use of an interferometric system which yields accurate values for the height of each echo. The following objectives were achieved during the 1978 wind observations at Budrio: (a) a great number of usable meteor echoes per day (≧ 1,000) and (b) reliable altitude definition (±2 km).

Current work at Bologna is focussed on the zonal propagation of planetary waves and their seasonal variations. Of particular interest is the latitudinal structure of the quasi 2-day oscillations which we are investigating this year in the form of simultaneous observations together with Sheffield University, in England. The 1978, 1979 and 1980 summer data have being examined by the two different groups to gain further information on the nature of these free atmospheric modes.

Other arguments of present interest in Bologna involve the study of the atmospheric effects on the parameters of echoes. A recent paper dealing with the effects of the lower-thermospheric winds on the echo duration has been published (Cevolani and Hajduk 1979). Moreover, systematic flux measurements of individual meteor streams and a comparison of the results at different stations – Budrio (Italy), Ondřejov (CSSR) and Dushanbe (USSR) are being performed jointly. The first results of this cooperative exercise are included in another recent paper (Hajduk and Cevolani 1981).

Equipment and Data Processing

Equipment

In this section a brief description of the Bologna meteor radar is given.

Verniani et al. (1974) described the Bologna CNR meteor radar in detail and subsequently Verniani et al. (1980) presented the early results obtained during the 1976 wind observations carried out at the Budrio station. In this last paper the status of the meteor radar station before April 1978 was described. The system was then improved to measure height directly. The original meteor recording system was based on a photographic device, and meteor heights were estimated from the decay time of the echo amplitudes. However, with the pressing need for good height resolution when investigating propagating wave structure, a seven aerial interferometer system was set up.

The equipment situated at Budrio is a coherent pulse Doppler radar and essentially consists of a transmitter with a directional antenna, a receiving system with an interferometric antenna and a real-time echo processor. The radar transmitter operates at 42.7 MHz, with a peak power of about 200 kW. The pulse duration is 10 μs and repetition frequency 140 Hz. The transmitting antenna consists of a linear array of five aerials, each made up of three half-wave dipoles; it is directed eastwards and its

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direction of maximum radiation has an elevation of 45° The beam width is 30° × 30° at 3 dB points. The receiving system is composed of seven directional antennas, seven receivers and a phase-sensitive product detector. The interferometric system has been built up for determining the height of the reflection point on each meteor trail. The height is determined by the range of the reflection point (deduced from the echo decay) and by the zenith angle which, in turn, can be calculated by the phase differences between the signals received by the various antennas. The real-time processor (Schaffner 1966) first discriminates the meteor echoes from among all the received signals, then extracts the desired information from the selected echoes and records it on magnetic tape.

At the beginning of 1979, a second, alternative three-aerial interferometer directed eastwards was constructed and, at the end of 1980, another analogous interferometric system directed northwards was built up, so that in the immediate future the total wind vector may be derived. Consideration of calibration of the two interferometric systems performed in all observing directions, and meteor echo results, suggest that the uncertainties in echo height and radial velocity are approximately ± 2 km and $\sim 3\ \mathrm{ms}^{-1}$ for individual echoes. For the following results, it is first assumed that the wind values depend only on time and altitude, and represent the component of the horizontal wind along the main axis of the aerials. It is further assumed that echoes exceeding $\pm 15°$ from the mean axis are eliminated, minimizing the error introduced by the quadrature component.

Data Processing

The measured parameters include range, Doppler frequency, radial velocity, zonal velocity at 95 km, "real" zonal velocity, interferometric height of echo, decay time of echo, diffusive height of echo, and corresponding errors. Zonal velocities at 95 km are calculated by considering the mean height of 95 km in the relation $u = u_r \operatorname{cosec}[\arccos(h/r)]$ (Verniani et al. 1980) where u is the zonal wind velocity, u_r the radial velocity, h the height and r the range. "Real" zonal velocities are calculated by using the corresponding interferometric height of echo. Many of the methods used to process meteor wind data assume periodic models and fit the models to the data in some minimum error sense. In order to ensure a reasonable fit, the raw wind samples for each meteor trail are used to produce a uniform time series. Hourly averages of the wind are computed for every hour from the values of the zonal wind and are assigned a weight. This series is frequency analysed to determine which components are appropriate to be included in the model.

In the data processing, we use four main programs. The first program calculates the echo heights and zonal wind velocities after determining the distance of the echo and the radial wind velocity. A second program sorts the echoes into height intervals and places this information into several files, then reads from these files and calculates hourly wind weighted values for each height interval. Data are generally sorted into both seven and four height intervals: the first solution gives better height resolution but the number of echoes contributing to each hourly point is lower and therefore the reliability is reduced. The third program calculates the amplitudes and phases of the different wind components by using a weighted least-squares method and the frequencies of these waves by using the conventional spectral analysis (autocovariance function or discrete Fourier transform). The same program, although referred to as a spectral analysis method, produces an amplitude periodogram. The resolution of the discrete Fourier transform is essentially equal to the reciprocal of the length of the total time sample. Thus, a fairly long time sample is needed to determine the shape of a given spectral component. The fourth program also performs a spectral analysis by using the "maximum entropy" method (MEM) which is mainly employed when short time series are encountered. The MEM spectra have a much higher resolution and are capable of following a spectral tidal component with a shorter total time sample. Also, long period components can be studied with shorter and less costly observing runs. The main shortcoming of the MEM spectral estimate is the lack of quantitative method of determining the length of the prediction error filter. It is known from experience that a too short length results in a smoothed estimate, whereas an excessive length introduces spurious detail into spectrum.

The results thus obtained indicate that the zonal wind can be split up into the prevailing wind, three oscillations which can be interpreted as a diurnal, a semidiurnal and a terdiurnal tide and into other perturbations that include both short period waves (gravity waves) and long period oscillations (planetary waves) (Verniani et al. 1980).

Results

The present data refer to the 7–30 November 1980 observing period. The data of November's first week were not too successful with interference and several breakdowns, mainly late in the morning (08–13 h LT), and are not included here. Interference during October and November 1980 represented serious problems for our observations at Budrio, but nevertheless, about 19,000 usable echoes have been collected during the whole November period. Data were also recorded during several periods in 1980, 12–26 March, 4–18 June, 16 July–4 August, 3–16 September, 16–31 October, but since the data reduction for these periods is not fully completed, only occasional reference is made to some relevant results mainly in connection with long period wind oscillations. Because of the prominence of periodic fluctuations in the data, all data time series were subjected to harmonic analysis in which the steady component represents the prevailing wind, probably including unresolved amplitudes of wind fluctuations whose periods are longer than the time series. Data on atmospheric oscillations are presented in the form of the amplitude and phase of a particular periodic component. Following the usual convention, zonal wind amplitudes are positive towards the east and phases refer to the local time at which the zonal wind amplitude is maximum (in our case, this occurs in the east direction). Since most methods of spectral estimation require uniformly spaced data, a long data time series (7–30 November) of horizontal velocities averaged over the 75–115 km height interval (average 95 km) has been used for a monthly comprehensive study. Remaining gaps (comprising 16 non-consecutive points in the time series) have been filled by linear interpolation. These gaps did not cause any significant uncertainty in the spectral estimates. In order to deduce wind profiles of main zonal wind components for periods with a consistent daily meteor flux, particular attention was drawn to some days with high meteor rate by considering also the incidence of large wind amplitudes. In fact, the daytime metor echo rate at Budrio was generally below the monthly mean for the November month on account of multiple ionospheric-ground scatter due to intense solar activity during the Energy Budget Campaign 1980. The potential superiority of the MEM method over other spectral estimators, in particular for short data lengths is recognised by other authors (Ulrich and Bishop 1975). This method has been used successfully in the analysis of individual days' data in order to study in closer

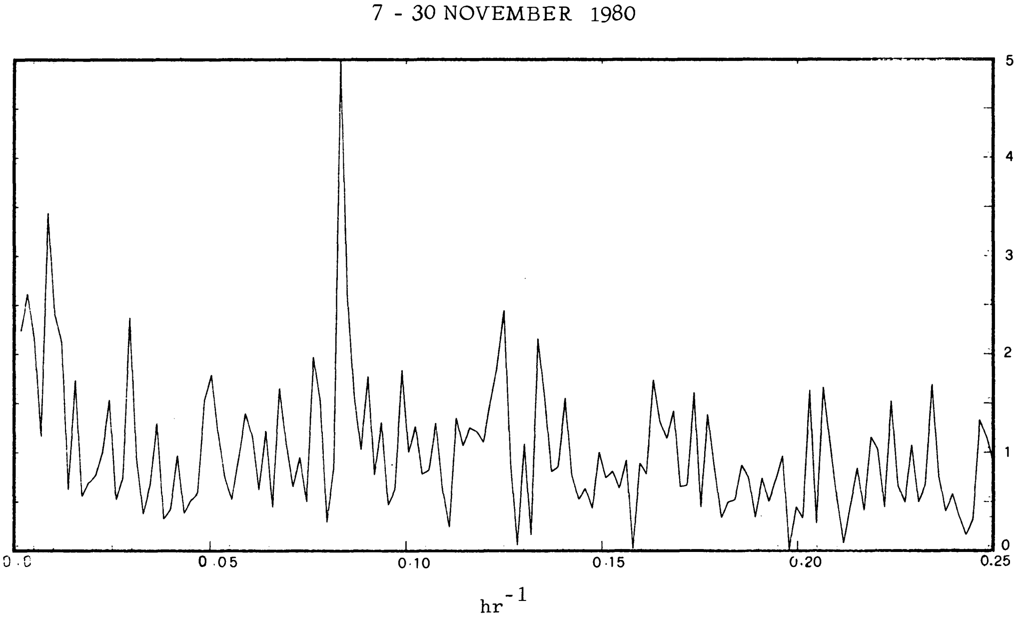


Fig. 1. Amplitude spectrum of the zonal wind at Budrio for the 7–30 November 1980 period for the 75–115 km height interval (average 95 km)

detail short-period wind components in connection with gravity wave propagation (Stening et al. 1978). Significant variations, even in brief periods, have been pointed out in the structure of the zonal winds observed at Budrio in the November 1980 period and have been attributed to the presence in the meteor zone of gravity waves, possibly with a period of a few hours, superimposed on the diurnal trend of the wind. The nature of gravity waves suggested to us that we should select days during which the amplitudes of the irregular wind component were consistent and this, taking into account also the requirement for periods with an adequate hourly meteor flux at different levels between 80 and 110 km, took place on only a few days. MEM, used for these short periods, thus allowed us to study gravity wave propagation associated with velocity-altitude profiles. MEM spectra have been obtained for data sorted into seven uniformly spaced height intervals with sampling at 5 km intervals between 80 and 110 km, whereas longer data series could not be extracted from the total November data length, in order to use the Fourier transform method reliably.

The long time series over the quoted height interval (average 95 km) has been subjected to spectral analysis by using the discrete Fourier transform: the corresponding amplitude spectrum is presented in Figure 1.

Figures 2a–d show the 1976 and 1978 monthly wind results obtained at Budrio. These results are compared with the present ones and thus allow us to study the variability of the prevailing wind and of the diurnal, semidiurnal and terdiurnal wind harmonics in different years.

Two short unsmoothed time series (23–24, 28–29 November 1980) have been subjected to the MEM method. The spectra obtained with a filter length of $\frac{2}{3}n$, where n is the data length, allow us to obtain profiles of the prevailing wind, gravity waves ($T=3.5$, 4.5, 6 h) and tides ($T=8$, 12, 24 h) (Figs. 3 and 4). A filter length of $\frac{1}{3}n$ results in a smoothed estimation obviating the resolution advantages of MEM, while a filter length of n introduces spurious detail into the spectrum. Since the number of data points (crosses in Figs. 3 and 4) is limited, a linear interpolation has been preferred to any other fitted polynomial curve. The amplitudes and phases of the zonal velocity components for the seven height intervals between 80 and 110 km and for the two-day periods were subjected to harmonic analysis, a least squares fit being made to the data with a prevailing or mean component, 24, 12 and 8 h periodic components, plus velocity fluctuations at 3.5 and 6 h periods. Sufficient data were available to allow this analysis to be undertaken for all heights and for the two short time series.

The Fourier transform results indicate a slightly dominant 12-h oscillation, but the amplitudes of all the main components were unusually low with respect to the theoretical predictions and the previous results obtained at Budrio in different years. Several of the amplitudes are of a similar magnitude to the r.m.s. velocity uncertainty (3 ms^{-1}). MEM has also been applied to the long velocity time series and the resulting spectra confirm the periods and magnitudes revealed by the Fourier transform method.

Prevailing Wind

The amplitudes of the mean zonal flow at 95 km of altitude, as provided by using the discrete Fourier transform are low (of the order of a few ms^{-1}). The average prevailing components from the sample, including all altitudes (average 95 km), are compared with the corresponding ones for November 1976 and 1978, together with the monthly variations of the prevailing wind in the two different years and the values interpolated from the CIRA (1972) model at 95 km for 45°N latitude. As is shown in Fig. 2a, our 1976 and 1978 measurements and the CIRA model exhibit similar trends with a minimum in April, when the model lists a negative zonal wind. Though the CIRA model exhibits two minima corresponding to equinoctial months, the low amplitudes recorded in the November 1980 appear to be atypical of this month.

The average prevailing component variation with altitude for two short time series (23–24, 28–29 November 1980), has been obtained by using the MEM method and is shown in Figures 3a and 4a. The direction of the zonal flow in the two closely-spaced periods changes slightly with altitude and very small amplitudes are generally observed. At 90 km altitude, the amplitudes are negative; in the 95–100 km region, the magnitudes have the same values in the two different periods and are in close agreement with the amplitudes extracted from the spectrum of Figure 1 relative to the 75–115 km height interval obtained for the 7–30 November 1980 period.

Tides

Regular wind observations carried out at Budrio in the 1976–1980 year period, have revealed not only systematic variations of the amplitude and phase of the semidiurnal, diurnal and terdiurnal tides throughout the year but also often show little consistency between sets of data obtained during the same month in different years or even between observations in one month. Information on the structure of tidal modes present in the wind patterns of November 1980 are derived from the profiles of Figure 3d, e, f and 4d, e, f, which relate to the 23–24 and 28–29 November 1980 periods, using the MEM method. It has become customary to try to identify which tidal mode is present in any profile by measuring the vertical wavelength of the tide, and this is possible by plotting the phase of the tide as a function of altitude. A downward phase propagation is consistent with an upward propagation of energy.

Semidiurnal Tide. In our November 1980 velocity spectrum for an average height of 95 km (Fig. 1) the semidiurnal tide exhibits a well defined peak. However, the observed amplitudes are low and differ markedly from those observed in November 1976 ($\sim 30\ \mathrm{ms}^{-1}$) though they are closer to the November 1978 values ($\sim 7\ \mathrm{ms}^{-1}$). In addition, the semidiurnal tide profiles obtained for the above mentioned short periods show small amplitudes in the overall 75–115 km region (Figs. 3e and 4e). Our results appear to be consistent with modes of short vertical wavelength ($\lambda \cong 30$ km) corresponding to the S_2^6 mode (Fellous et al. 1975). However, an irregular behaviour is often found in the 7–30 November period. These irregularities can be seen over several adjacent (in space and time) estimates of amplitude and phase, so that the effect is only partly due to data unreliability. Many causes may be responsible for this irregular behaviour: (a) changes in the source (Bernard 1981); (b) the presence of more than one tidal mode leading to interference, or reflections leading to standing waves (Fellous et al. 1975); (c) coupling of energy from one mode into another or into the background flow (Spizzichino 1970). In the presence of background winds, shorter wavelength propagating modes are expected to be enhanced in the meteor region by mode coupling. The presence of superposed modes, possibly propagating in both directions can alter the apparent phase gradients (Poulter 1980). Variations in time of the semidiurnal tide over scales greater than 5–6 days as observed at Budrio and described hereafter, suggest that the most probable cause of these irregularities may be changes in the source (ozone and water vapour distribution) or propagation conditions. In order to study in closer detail the amplitude variations of the semidiurnal tide during the November 1980 period, an inverse Fourier transform has been calculated using a window centred on 12 h of proper bandwidth (Kaiser et al. 1979). The inverse transform thus indicated how the amplitude varied throughout the recording period. An inverse Fourier transform centred on the 12 h peak has been calculated for the 75–115 km height interval (time is relative to 13 hours LT, 7 November 1980) and indicates that this tide is modulated in amplitude throughout the recording period, varying over time scales of about 5 days (Fig. 5).

Diurnal Tide. The diurnal tide represents a small part of the total wind energy: the amplitudes derived from the velocity spectrum of Figure 1 are very small. A mode at 20 h period has been extracted in the spectrum, with a very low amplitude. It is likely that these amplitudes are much reduced by the averaging over the whole 7–30 November period, due to the strong phase changes which occur in this month (Fellous et al. 1975). Moreover, the non linear vertical phase variation of this tide can mean that different modes are present simultaneously during the quoted transitional period (Fellous et al. 1975). However, individual days' data presented in Figures 3f and 4f, exhibit larger amplitudes than those extracted from the spectrum of Figure 1: the consistent amplitudes observed at 100 km ($13\ \mathrm{ms}^{-1}$ on 23–24 November and $18\ \mathrm{ms}^{-1}$ on 28–29 November 1980) indicate the possible importance of significant short vertical wavelength propagating modes. The individual phase profiles for the two quoted periods demonstrate rapid changes near 90–100 km which are consistent with a vertical wavelength, $\lambda = 20$ km (S_1^1 mode). Above these heights the phase progression is generally less, as would be expected of evanescent modes. Similar irregularities in phase progression emphasize the possible importance of non-linear interactions between the diurnal modes and other wind components (Spizzichino 1970).

Terdiurnal Tide. The amplitude spectrum of Figure 1 exhibits a peak with a period near 8 h. As for the other two tides, the amplitudes derived for the whole observing period are smaller than those recorded in the individual examples quoted (Figs. 3d and 4d) and this is probably due to the lack of coherence of this oscillation. The two profiles of Figure 3d and 4d show very similar trends below 100 km and the relative amplitudes do not exceed $10\ \mathrm{ms}^{-1}$ Phase gradients seem to be consistent with wavelengths of 30–40 km. These values do not agree with the theoretical vertical wavelength of a directly excited terdiurnal mode which must be very large, but they are in close agreement with previous observational results (Glass and Spizzichino 1974). On the other hand, the amplitudes of this mode are quite similar in the years 1976 and 1978 (Fig. 2d) and exhibit the theoretical annual variation, with a reversal around the equinoxes (Glass and Fellous 1975). The recurrence of this harmonic in the amplitude spectra of 4-year observations at Budrio and the existence of a 8 h oscillation in ground level data, support the suggestion that it is a tidal harmonic.

Gravity Waves

Gravity waves with periods between 2 and 8 h were previously observed in 1978 by the meteor radar at Budrio (Cevolani and Formiggini 1981). The summer 1978 amplitude spectra of the zonal wind exhibited significant peaks with periods of 3, 4, 5 and 6 h and the phase of the corresponding oscillations generally increased with altitude. These oscillations then propagated vertically with a downward phase speed as expected theoretically for gravity waves. Examples of gravity wave phase propagation observed at Budrio in the summer of 1978, are presented in Figure 6. Typical vertical wavelengths of gravity waves are also represented. In the 1978 results, the gravity wave energy per unit volume increased with height. As a possible explanation of this behaviour, Spizzichino (1970) proposed the existence of non linear interactions between gravity waves and tides. Moreover, the summer 1978 data emphasized the importance of wave motions as sources of momentum in the upper atmosphere and even a modest momentum transfer from a coherent wave system was shown to lead to substantial changes in the prevailing winds.

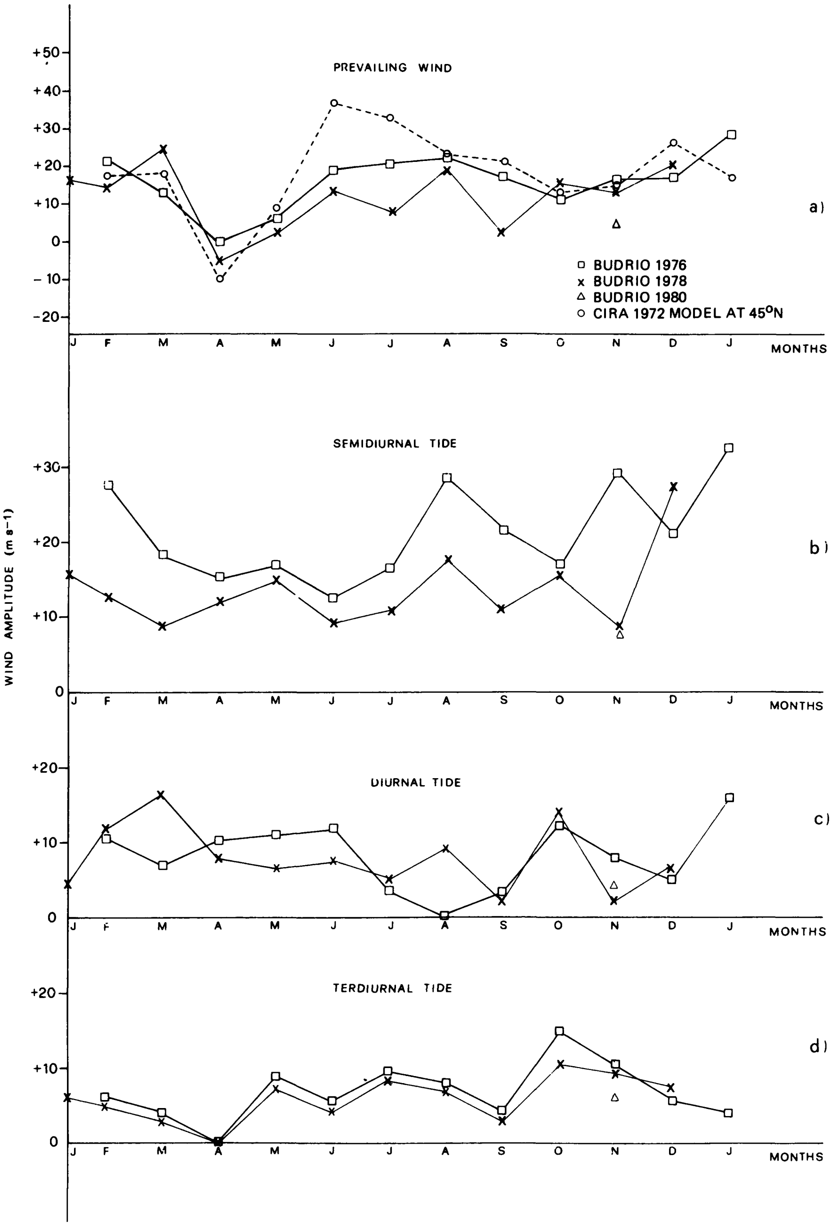


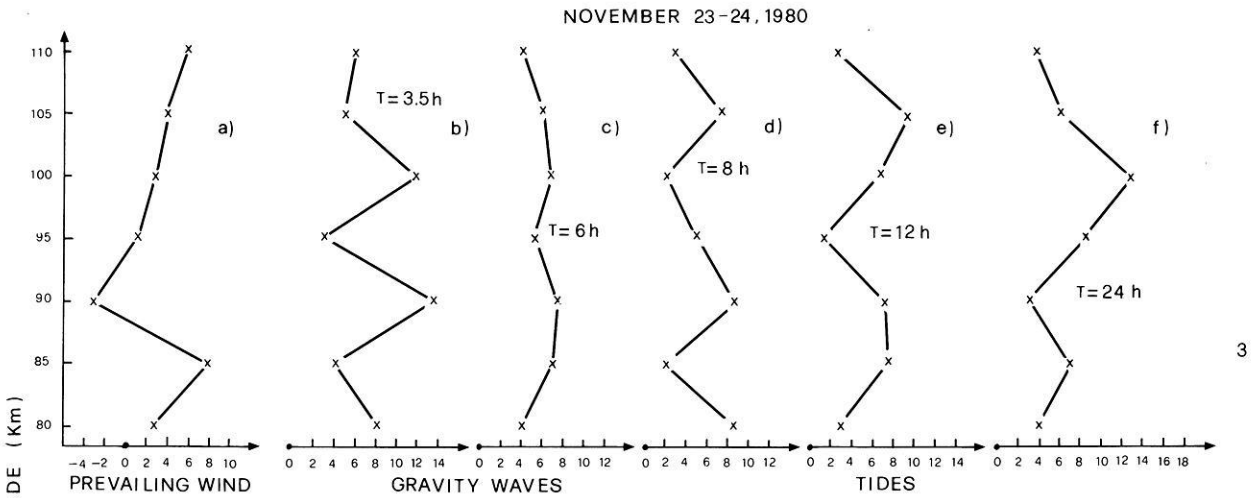
Fig. 2a–d. Seasonal variations of **a** the prevailing wind; **b** the semidiurnal tide; **c** the diurnal tide; **d** the terdiurnal tide in different years at Budrio

The present hourly rate (10–150 echoes) of the meteor radar of Budrio does not allow us to identify gravity waves with periods smaller than about 1–2 h. Individual days' data (23–24, 28–29 November 1980) have been subjected to spectral analysis using the MEM method for seven different uniformly spaced height intervals in the 75–115 km region. The profiles of Figure 3b, c and 4b, c indicate the possible importance of gravity waves propagating upwards with amplitudes larger than those of the other main wind components. At 80–85 km, amplitudes of 14–16 ms^{-1} are present in different profiles, associated with gravity waves with periods of 3.5 and 4.5 h. These examples show that the energy densities of gravity waves can become dominant in the lower thermosphere. The phase gradients derived by performing a least squares fit to the individual days' data, allow us to obtain vertical gravity wavelengths of 20–45 km with periods between 3.5 and 6 h. Amplitudes are of the order of 10 ms^{-1} The derived wavelengths are typical of gravity waves and indicate that these waves propagate upwards with a phase velocity of the order of 1–2 ms^{-1}. These results appear to be in close agreement with those obtained for the 1978 wind campaign.

Long Period Oscillations

By using the discrete Fourier transform we have found several long period oscillations in the zonal wind measured at Budrio in the 7–30 November 1980 period for the 75–115 km height interval (average, 95 km, Fig. 1). As shown in this spectrum, the periods of such oscillations are usually of 2–3, 5–6 and about 10 days.

The presence of long period oscillations in the meteor zone with quasi 2-day periods, has been noticed in the Budrio recording runs since long term observations began in 1976. Quasi 2-day oscillations were detected in the quoted height interval in our November 1980 observations, with an amplitude of about 2–3 ms^{-1}. Some indication of the presence of such modes has been found in our data time series for summers of previous



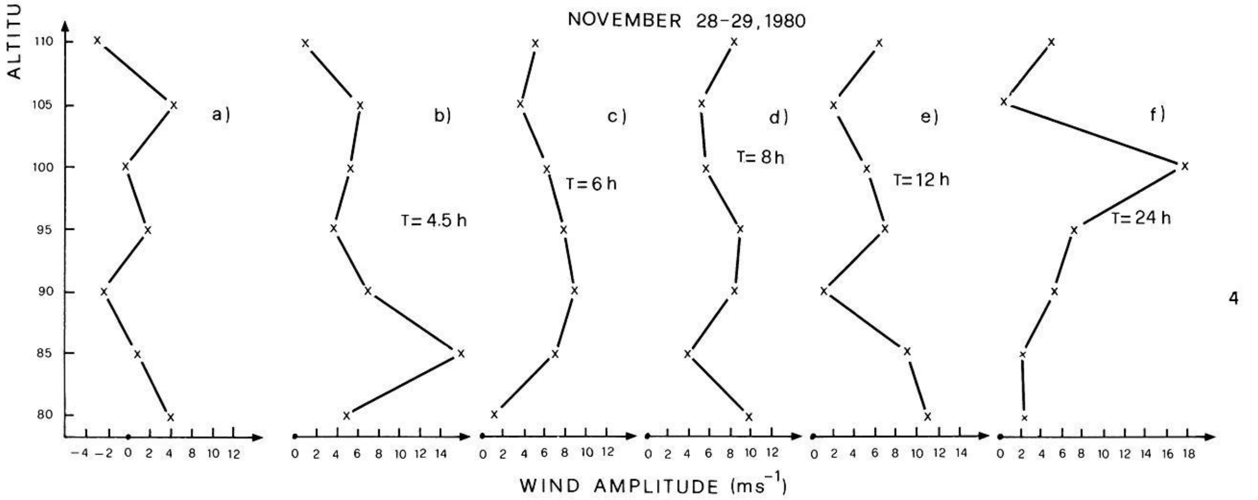


Fig. 3a–f. Altitude profiles of the prevailing wind, gravity waves and tides for the 23–24 November 1980 period, at Budrio

Fig. 4a–f. Altitude profiles of the prevailing wind, gravity waves and tides for the 28–29 November 1980 period, at Budrio

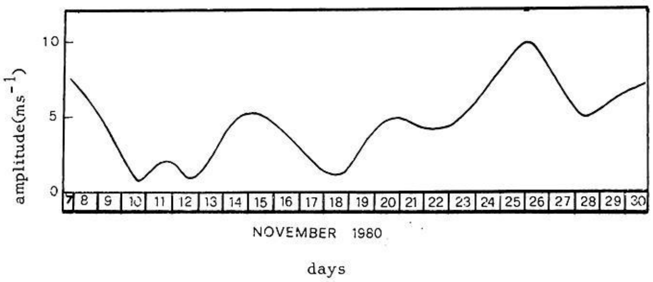


Fig. 5. Inverse Fourier transform of the 12 h peak in the Fourier transform with a bandwidth of 11.8–12.4 h for the 75–115 km height interval. Time is relative to 13.00 hours LT, 7 November 1980

years obtained at an average height of 95 km: in the spectra of 13–16 July and 24–26 August 1976 two wind oscillations of 51 and 40 h periods and of 7 and 10 ms^{-1} amplitude respectively were isolated (Verniani et al. 1980); in those of 11–14 July and 20–24 August 1978, two significant peaks of 51 and 60 h periods and of 5 and 13 ms^{-1} amplitude have been identified; moreover, in the 26 July–5 August 1979 spectrum, a very significant peak of 43 h period and of 17 ms^{-1} amplitude has recently been pointed out (well defined peaks appeared having about the same phase in three different height intervals, 75–90 km, 91–104 km and 105–120 km) (Cevolani, in press 1982). Recently, in a cooperative exercise with the University of Sheffield, two peaks with periods of about 43 h and 60 h have been detected in the wind amplitude spectrum for the 16 July–2 August 1980 period at an average height of 95 km (Fig. 7). As can be seen, an important feature associated with these quasi 2-day oscillations is the variability from year to year of the precise period. The existence of such oscillations in the meteor wind has now been confirmed by observations at various locations across the globe and it is also known that considerable amplification of these waves takes place about a month after the summer solstices (Muller and Nelson 1978). The latitudinal structure of these is scarcely known and there is not yet significant evidence for the existence of global waves of such period at meteor altitudes. A series of observations from satellites have clearly pointed out wave patterns in the temperature fields at stratospheric and mesospheric heights in summer (Muller et al. 1979). A westward travelling wave, zonal number 3, whose period is close to 2 days has, by that time, become firmly established. The fact that planetary wave energy may propagate vertically through the stratosphere and mesosphere in the presence of strong westward winds during the summer and that the amplification of quasi 2-day modes is observed only during a comparati-

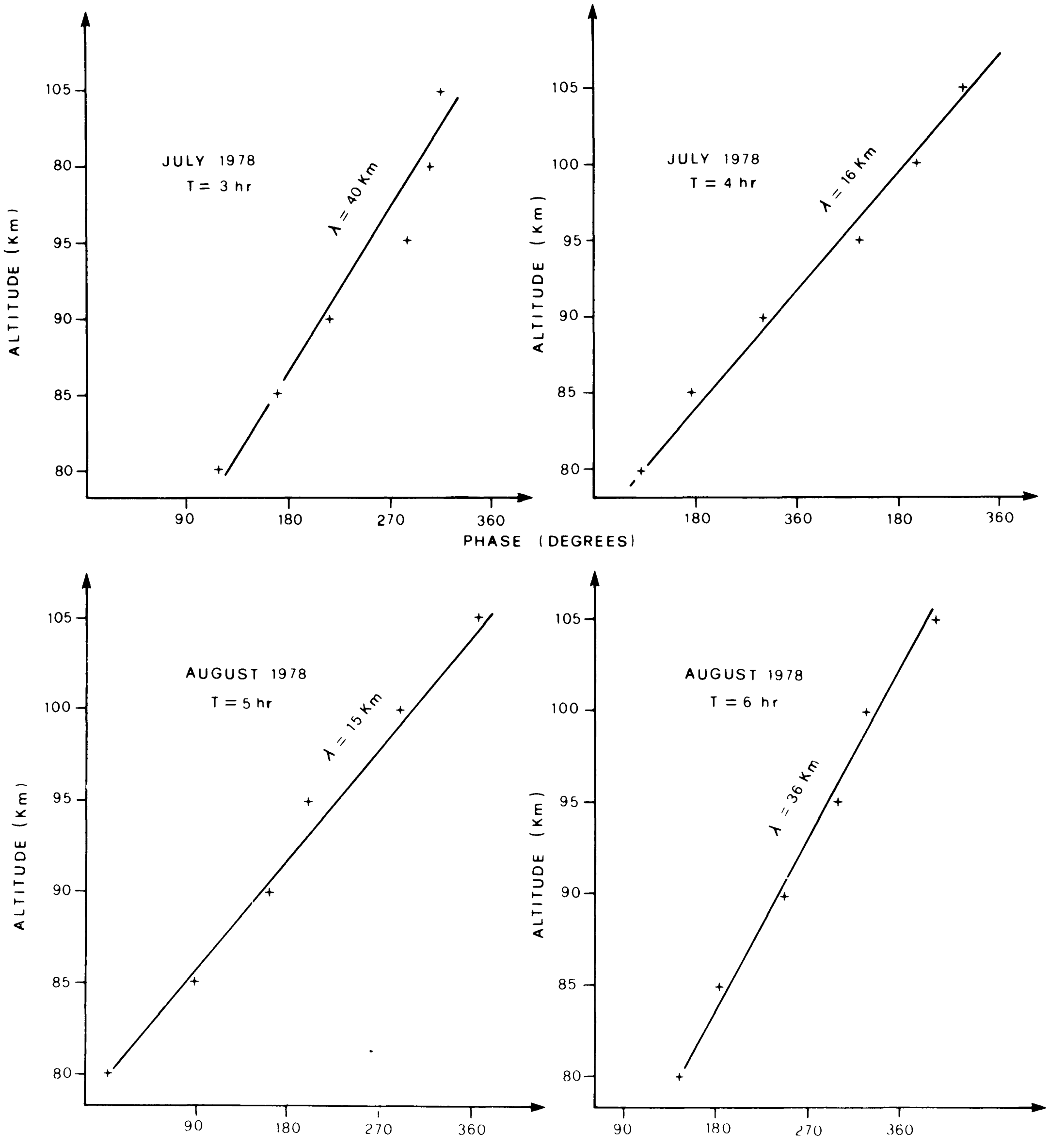


Fig. 6. Examples of phase variation versus height for some particular peaks of the small-scale wind amplitude spectra for July and August 1978

vely short period, suggests that we are dealing with atmospheric free oscillations (Muller et al. 1979). The theoretical problem of the vertical propagation of planetary waves was considered by Salby (1978) for the case of travelling waves. The author found that for free modes in a realistic atmosphere there are only two discrete vertical modes of propagation possible. The first mode is evanescent except for a thin region in the upper stratosphere. The lowest order wavenumber 3 mode of Salby's first type has a period of 2.08 days. Geisler and Dickinson (1976) showed that the response of the quoted mode is greatest at solstices and the summer mesosphere appears resonant to this free mode. The amplification of the quasi 2-day oscillations observed at Budrio about a month after the summer solstices of 1979 and 1980 confirms these theoretical predictions.

In addition to quasi 2-day oscillations, a 5-day zonal wave has been extracted in our November 1980 spectra (Fig. 1). The amplitudes of this oscillation at different heights are of the order of 3–4 ms^{-1}. It has been suggested that this wave corresponds to the greatest symmetric low-frequency external normal mode of the atmosphere (Geisler and Dickinson 1976). A significant peak of period near 5 days, observed at lower levels by Madden and Stokes (1975) was identified in both summer and winter in ionosonde measurements and in stratospheric temperatures by Fraser (1977). A similar disturbance has also been noticed in tropical pressure data (Burpee 1976) and in partial reflection observations (Manson et al. 1978).

As mentioned above, a wind fluctuation of period near 10 days, has been identified in the quoted spectra of Figure 1. A 10–15 days oscillation has been observed in E region ionosonde measurements and was found to be correlated with the wavenumber 1 component of stratospheric radiance during autumn and winter (Cavalieri 1976). Oscillations of comparable period were also noticed during autumn and winter in a 10-mb. analysis constructed from rocket and rawinsonde data (Finger et al. 1966) and in the coherence spectra between ionosonde and stratosphere measurements (Fraser and Thorpe 1976).

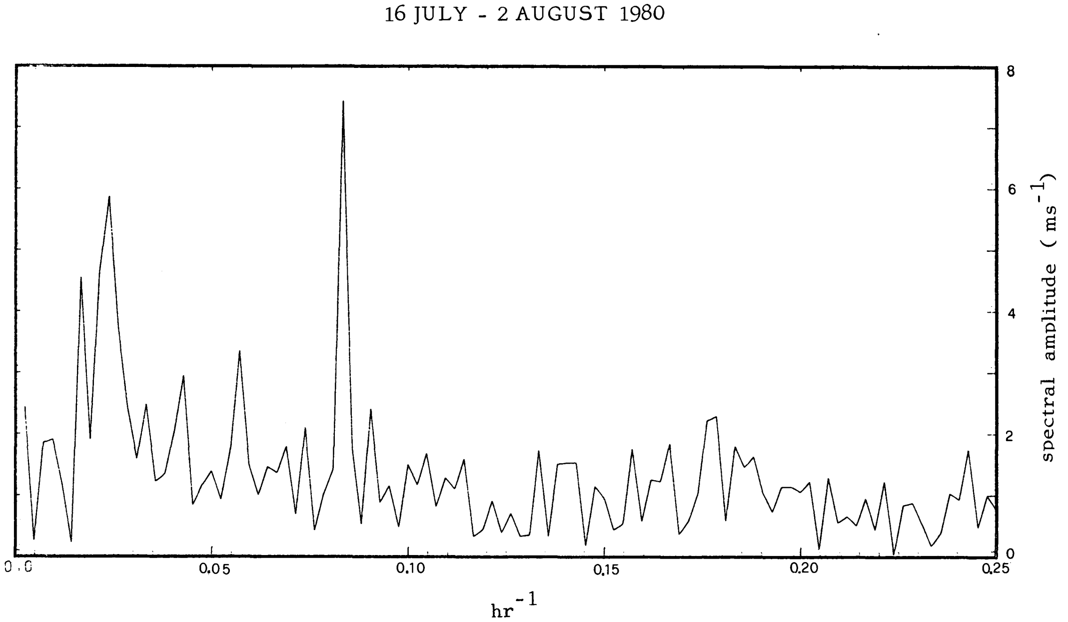


Fig. 7. Amplitude spectrum of the zonal wind at Budrio for the 16 July–2 August 1980 period for the 75–115 km height interval (average 95 km)

Conclusions

In this paper we have described the results of the November 1980 zonal wind oscillation observations carried out at Budrio during an integrated ground based, balloon and rocket campaign – the "Energy Budget Campaign 1980" – planned for the study of energy inputs and outputs in the upper atmosphere (60–180 km) during geomagnetic disturbances.

One of the main aims of this work has been to emphasize the variability of the winds in the upper mesosphere and lower thermosphere as observed in late autumn at Budrio. It has been shown that all the major wind components (prevailing winds, tides and gravity waves) exhibit amplitudes generally lower than those measured in November of previous years at Budrio. The daily variations in the amplitudes of the semidiurnal tide over time scales larger than 5–6 days suggest changes in the source whereas the daily drift in the phase of this tide could indicate that its vertical structure is consistent with short vertical wavelength propagating modes. The amplitudes of the diurnal and terdiurnal tides appear not relevant and the phases of these components exhibit non linear vertical variations. As for the summer 1978 results, the November 1980 wind observations indicate the possible importance of gravity waves in the energy budget of the quoted regions. Moreover, the wind time series examined here support the contention of earlier studies, that oscillations of periods near 2–3, 5–6 and 10–15 days occur frequently at lower ionospheric heights.

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