

TIDAL ACTIVITY IN THE METEOR ZONE OVER BUDRIO, ITALY

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Abstract: A brief survey is presented here of the variations with time and height of atmospheric tides observed at Budrio (45° N, 12° E) in the wind field between 80 and 110 km altitude during the 1978-82 year period. Variations of amplitude maxima mainly of the semidiurnal tide in the winter data of 1979 and 1980 show periodicities of a few days throughout the observing period. Upward propagation of tidal energy during a stratospheric warming in January 1982 is proposed to be inhibited because of instabilities in atmospheric conditions.

The CNR radar station at Budrio, near Bologna, first carried out observations in 1976, keeping records throughout these last years for time intervals varying between 2 days and 3 months. Records for 2-6 days were kept for every month in 1976; 4-7 days for every month in 1978; 2-3 weeks during the "special" periods (11-25 January, 14-18 March, 11-23 September) of the CTOP (Cooperative Tidal Observational Project) in 1979, and in the course of three observational campaigns jointly with the University of Sheffield in 1979 (26 July - 4 August) and in 1980 (16 July - 2 August and 7 November - 1 December) the latter within the EBC (Energy Budget Campaign) program; and for up to 2-3 months (Winters 1981-82, '82-'83 and '83-'84) in the course of the SWAMP (Stratospheric Warming Mesospheric Project) a sub-program of MAP (the Middle Atmosphere Program). In table 1 the time intervals of wind observations are presented: numbers represent the number of days of observation.

VERNIAVI et al., (1980) have presented the first results obtained in the February 1976 - January 1977 year period from wind observations in the lower thermosphere. These results indicate the necessity of furthering the study of monthly and seasonal variations in amplitudes and phases of tides and the possible correlation between the long-period waves in the meteor zone and variations with the same periods in tropospheric parameters. Unfortunately, the recording method did not allow measurements of the height of the radio echoes, so that the wind data were referred to an average height of 96 km.

A new observational campaign was conducted at Budrio throughout all of 1978 aiming at studying the vertical propagation of gravity, tidal and planetary waves by using an interferometric system pointed eastwards and able to associate with every echo its real height. At the end of 1980, a second interferometer pointed northwards was constructed so as to allow the measurement of the southerly wind component. Consideration of the two systems for interferometric measurements indicate an accuracy in the height of the echo and the radial velocity measured with the Doppler effect is $\pm 2-3$ km and 3 m/s, respectively. For the results presented here, it has been assumed that the wind values depend only on time and height, and represent the components of the horizontal wind along the main axis of the antennae.

Table 1

Number of observational days at Budrio in the 1976-83 year period.

| | 31 | 7 | 7 | 12 | 10 | 10 | 8 | 12 | 1983 |
|--|-----------|----------|-----------|-----------|----------|-----------|-----------|-----------|--|
| | <u>30</u> | | | <u>10</u> | <u>8</u> | | <u>24</u> | <u>13</u> | <u>24</u> 1982 |
| | | | | | | <u>10</u> | | <u>15</u> | <u>10</u> 1981 |
| | | | | <u>55</u> | | <u>14</u> | <u>15</u> | <u>9</u> | <u>14</u> <u>24</u> 1980 |
| | <u>15</u> | | <u>15</u> | <u>3</u> | <u>4</u> | <u>10</u> | <u>10</u> | <u>15</u> | <u>13</u> <u>4</u> <u>10</u> 1979 |
| | <u>5</u> | <u>4</u> | <u>3</u> | <u>3</u> | <u>3</u> | <u>3</u> | <u>4</u> | <u>3</u> | <u>12</u> <u>3</u> <u>5</u> 1978 |
| | <u>6</u> | <u>2</u> | <u>2</u> | <u>2</u> | <u>2</u> | <u>2</u> | <u>3</u> | <u>2</u> | <u>4</u> <u>2</u> <u>2</u> <u>4</u> 1976 |
| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP OCT NOV DEC |

The data from 1976 and 1978 have been analyzed using the autocovariance function method; from 1979, use has been made of the Fourier transform and "maximum entropy" methods, the latter being employed for studying vertical profiles of the fine structure of the wind field (CEVOLANI and FORMIGGINI, 1981). For the data from 1979 onwards, the Fourier transform method has proven to be the best for studying the phenomena in question, and the inverse Fourier transform, centered on a suitable band of frequencies of the transform spectrum has been used to describe time variations of the amplitudes and phases of the most important oscillations.

Results of the 1978 observations - Average values of tidal parameters were obtained from observations of zonal winds carried out regularly at Budrio for a few consecutive days in each month of 1978. The normalized spectra of wind amplitudes, corresponding to each month and referred to an average height of 95 km are presented in Figure 1. The amplitudes and average phases of the diurnal, semidiurnal and terdiurnal tides have been obtained with a weighted least-squares method, while the frequencies have been deduced from the autocovariance function. Figure 2 presents the seasonal variations of a) the prevailing wind, b) the semidiurnal, c) the diurnal, and d) the terdiurnal tide in 1978 over Budrio. Comparison is made with results of 1976, and for prevailing winds only, with the values interpolated from the CIRA (1972) model for 45°N lat. From Figures 1 and 2, it appears obvious that the energy associated with the semidiurnal tide is the most important compared to that of other components. A salient aspect of the wind observations performed at Budrio in 1978 and previous years is that these exhibit not only systematic variations in the amplitude and phase of the tides throughout the year; but also that sometimes little coherence exists between results of the same month of different years and even in observations carried out in consecutive days of the same month. This observed variability of the tides is suggested to be linked with different contributions from their distinct modes which can interfere with each other with effects that vary with season, latitude and even with longitude.

Results of the 1979 observations - In order to study in detail the variability of the tides with height and time in the lower thermosphere, observations were conducted at Budrio in 1979 for zonal winds during three "special" periods (11-25 January, 14-28 March and 11-23 September) of the CTOP and between 26 July and 4 August within the joint project with the University of Sheffield. This series of observations had the dual aim of analysing tidal parameter variations on short and large time scales, showing up deviations from average structures even in long periods and studying more closely the seasonal variations of different tidal modes in the lower thermosphere (CEVOLANI and BONELLI, 1985). The Fourier transform and inverse transform method has been applied to time series of these data after sorting them into uniformly spaced height intervals with sampling at 5 km between 80 and 110 km. Figures 3 and 4 present the daily vertical profiles of zonal tidal amplitudes limited to 11-20 January and 27 July - 3 August 1979, together with profiles of phases obtained for three distinct days (11, 15 and 20) in January and (27, 30 and 3) in July - August 1979. For the semidiurnal tide only the average profiles of amplitudes and phases for altitudes between 80 and

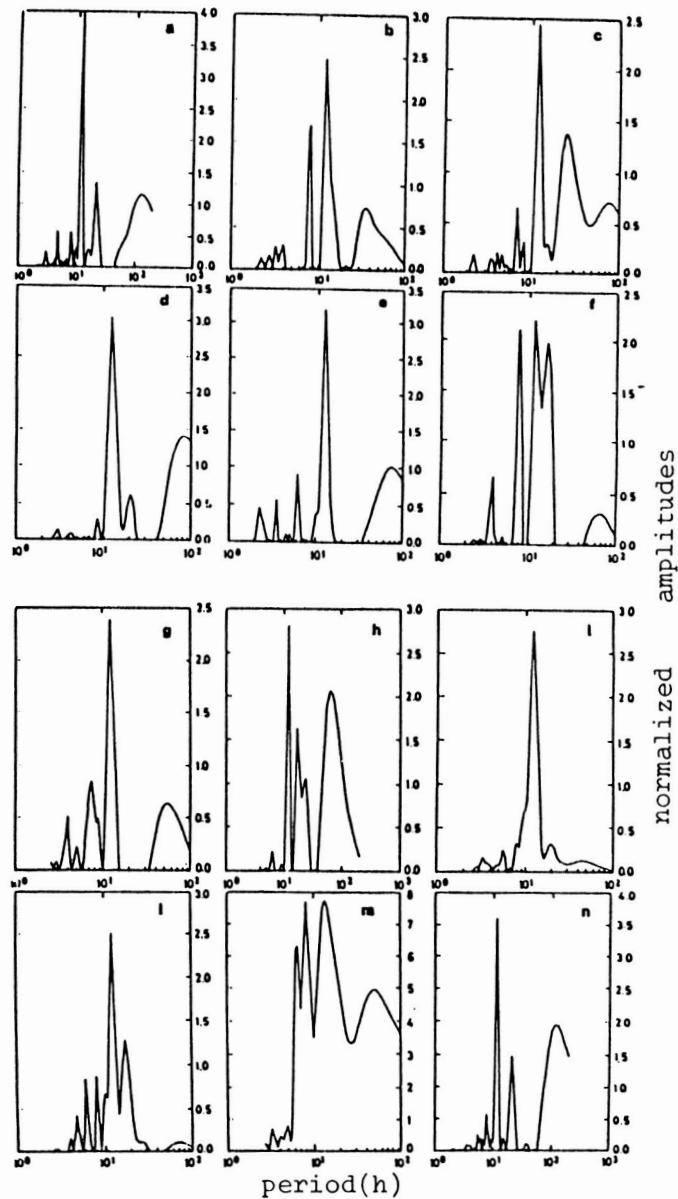


Fig. 1 Normalized amplitude spectra of the zonal wind observed at Budrio in the following periods: a) January 16-21; b) February 13-17; c) March 14-17; d) April 20-23; e) May 8-12; f) June 19-22; g) July 11-14; h) August 20-24; i) September 9-12; l) October 18-22; m) November 1-4; and n) December 14-19, 1978.

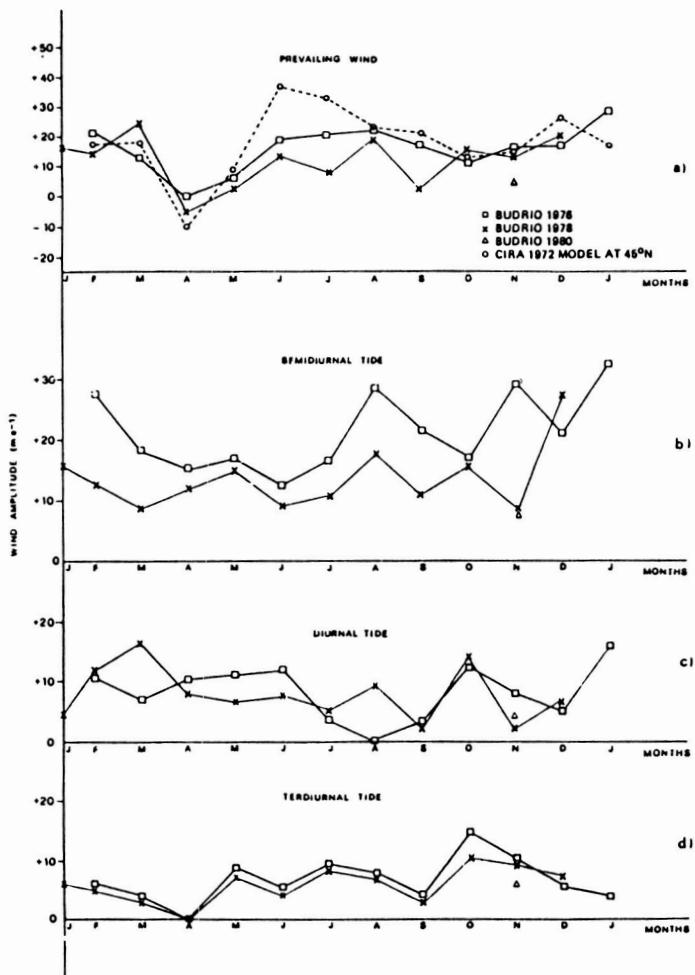


Fig. 2a-d Seasonal variations of: a) the prevailing wind; b) the semidiurnal tide; c) the diurnal tide; d) the terdiurnal tide in different years at Budrio.

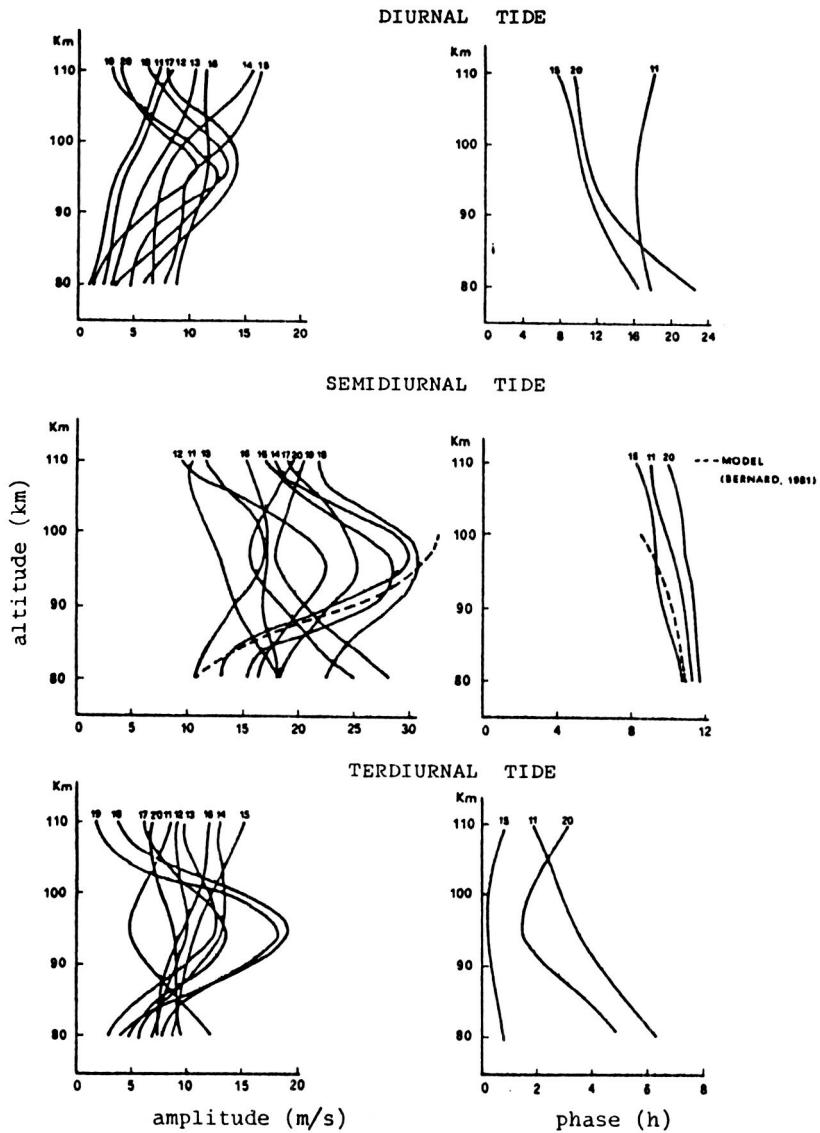


Fig. 3 Vertical profiles of: a) amplitudes and b) phases of the diurnal (D), semidiurnal (S) and terdiurnal (T) tide observed at Budrio between 80 and 110 km in the 11-20 January 1979 period.

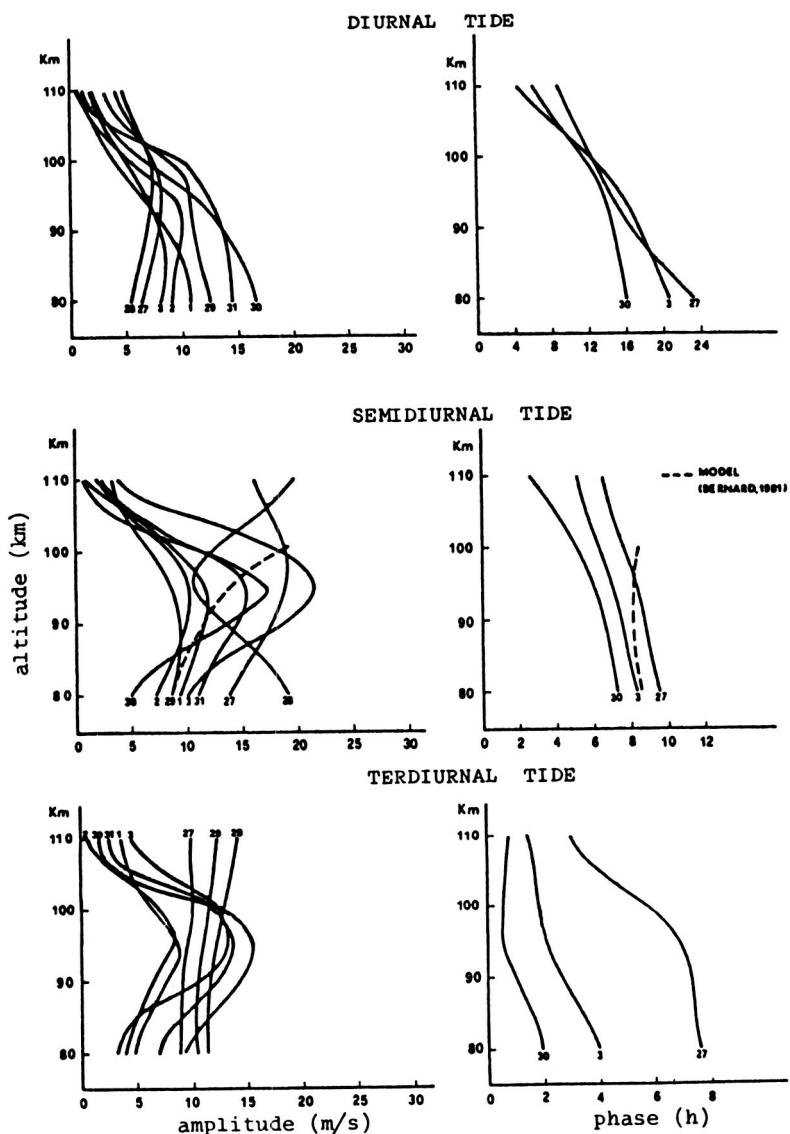


Fig. 4 Vertical profiles of: a) amplitudes and b) phases of the diurnal (D), semidiurnal (S) and terdiurnal (T) tide observed at Budrio between 80 and 110 km in the 27 July-3 August 1979 period.

100 km, deduced from a realistic tidal excitation model by ozone at the solstices (BERNARD, 1981), are presented for comparison. The inverse transform centered on peaks of the three tidal oscillations, whose frequencies are deduced by Fourier transform, give the time amplitude and phase variation for the whole observing period. In Figures 5 and 6 are presented the variations of amplitude maxima of the three tides in the periods 11-25 January and 26 July - 4 August respectively, for the altitude intervals: a) 75-90, b) 90-100, and c) 100-115 km.

The diurnal tide - The data from the 1979 observation periods show that the diurnal tide carries only a small part of the total energy of the wind in the lower thermosphere. Generally amplitudes have a tendency to increase with height in winter and decrease in summer. The maximum amplitudes are never above values of 15 m/s and are obtained in the two quoted periods at different heights. The trend with height of the observed phases is generally typical of the main mode (1,1) with vertical wavelengths $\lambda = 25-30$ km for altitudes below 95 km. Above this altitude, phase in winter diminishes less rapidly (on the 11th of January a slow progression is recorded) as one might expect in the presence of evanescent modes, that is of modes whose energy is exposed to reflection processes. In contrast, in summer phases diminish more rapidly above the height in question, indicating the possible importance of modes which propagate upwards with short wavelengths. The seasonal variations found in the average phases are not consistent and the amplitude maxima of the zonal wind are generally recorded eastwards at 95 km where phases vary from 1200 hrs local time in winter to 1400-1500 hrs local time in summer. This progression can be linked with variations of the average wind and temperature profiles which can influence modes of the diurnal tide. It can be interesting to examine the variability of amplitudes of the diurnal tide on short time scale, that is in the course of a few consecutive days. Figure 5 shows periodicities of a few days in variations of amplitude maxima observed in winter at high altitudes, whereas it appears more problematic to isolate such periodicities in summer (see Figure 6).

The semidiurnal tide - The data of the 1979 observing periods have emphasized the variability of this oscillation not only with height but also on large time scales (seasonal variations) and short ones (variations in a period of a few consecutive days). The amplitudes of this tide appear clearly higher in winter with respect to the ones recorded in summer (Figures 3 and 4). The phase profiles for the months of January and July-August indicate the presence of vertical wavelengths with $\lambda \geq 100$ km (typical of the main mode (2,2)) relative to oscillations which propagate upwards and eastwards. Average phases at 95 km vary from 1000 to 1100 hrs local time in winter, and from 0700 to 0800 hrs local time in summer. The deviations of the observed phase in summer from the theoretical (FORBES, 1982) can result from: a) reflection of the (2,2) mode in the thermosphere due to damping phenomena; b) interaction of the semidiurnal modes with average winds which can modify the propagation conditions. The data of the two quoted periods have revealed variability of this wave even on short time scales. The inverse transform method indicates that the tide is modulated in amplitude throughout the observing period. Figures 5 and 6 show the amplitude variations of maxima with time scales possibly of 3-5 days in winter and summer, at the three quoted height intervals. It is important to stress that in winter in the intermediate layer (90-100 km)

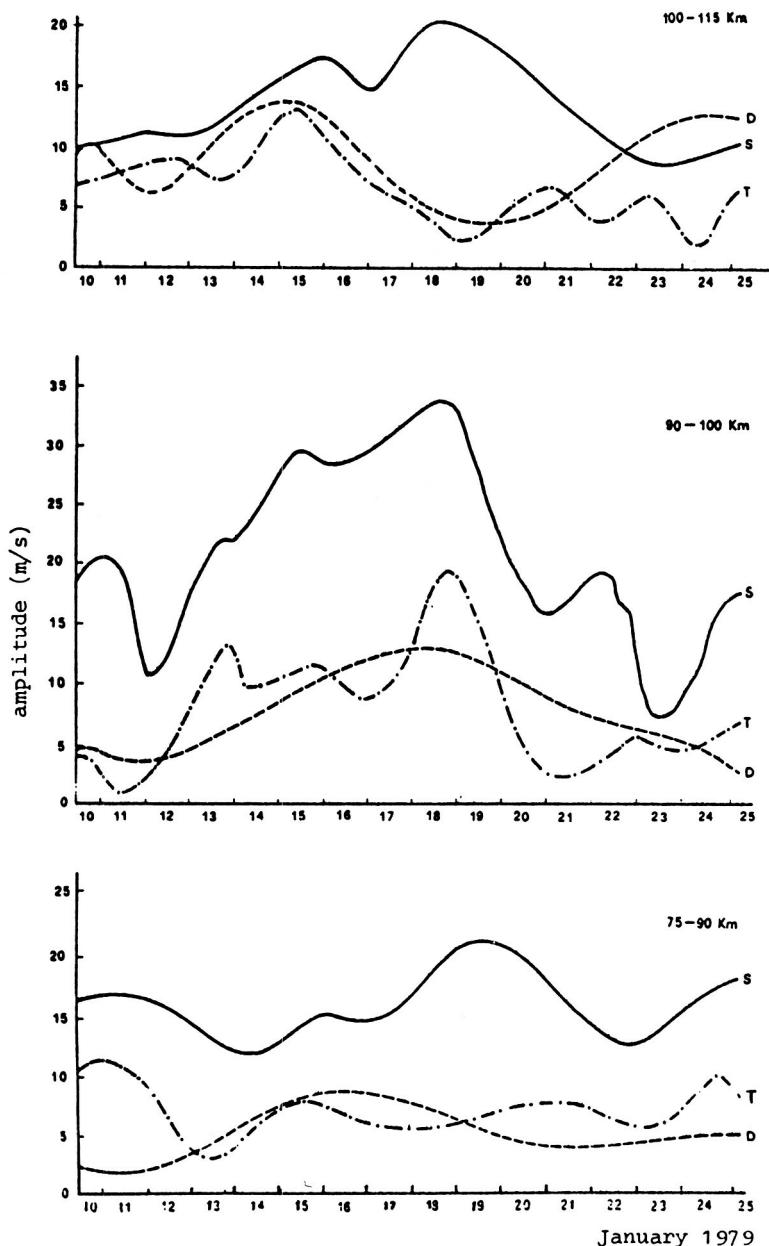


Fig. 5 Variations of amplitude maxima of the diurnal (D), semidiurnal (S) and terdiurnal (T) tide observed at Budrio in the 11-25 January 1979 period, for the height intervals: a) 75-90; b) 90-100; and c) 100-115 km.

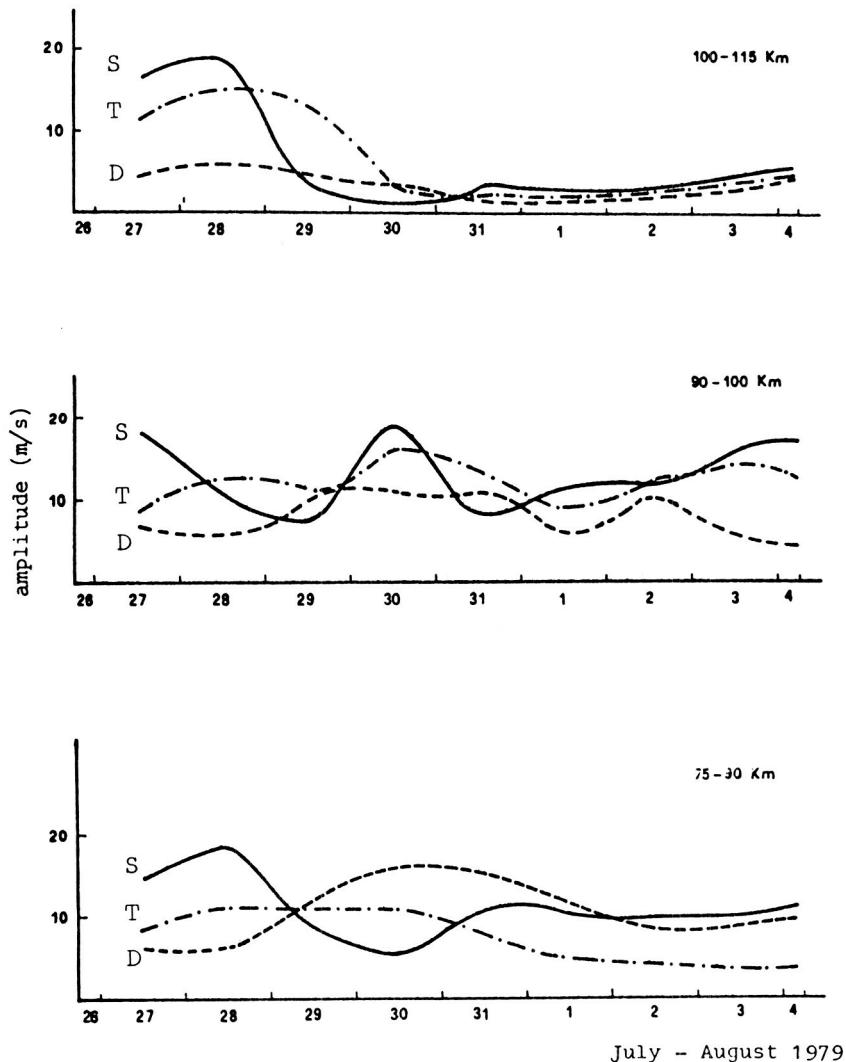


Fig. 6 Variations of amplitude maxima of the diurnal (D), semidiurnal (S) and terdiurnal (T) tide observed at Budrio in the 26 July-4 August 1979 period, for the height intervals: a) 75-90; b) 90-100; and c) 100-115 km.

the amplitude of the tide varies by a factor of 3 in the course of a week (12-18 January).

The terdiurnal tide - The results of the 1979 observations emphasize the lack of coherence of this oscillation, which nevertheless shows a normally pronounced peak around 8 hrs. The amplitudes are generally consistent (maximum values are about 15 m/s at 95 km) and more significant than the diurnal ones. These amplitudes do not perceptibly vary in winter and summer months in contrast to what was seen in the semidiurnal tide. Phase variations in the diurnal vertical profiles are quite large and do not allow any comparison with those of the two other tides. There appears to be a correlation between the temporal variability of this tide and the semidiurnal tide as observed in the two periods of 1979. Figures 5 and 6 show that short time scale variations (3-5 days) of the terdiurnal tide generally correlate closely with the corresponding ones of the semidiurnal tide. This correlation is more consistent in winter data and underlines the possible importance of the common excitation of both of the tides, mainly due to the absorption of solar radiation by ozone. The seasonal and short time scale variations of this tide suggest a possible link with variations in the thermal excitation of its source rather than with the effects induced by the presence of average zonal winds.

Results of the 1980-'82 year observations - A further observational wind campaign was carried out at Budrio in summer (July-August) 1980 jointly with the University of Sheffield, utilizing data from both Sheffield and Stornoway, in order to allow hour by hour comparison of tides and planetary waves in the meteor region at different latitudes (CEVOLANI et al., 1983). These three-station observations of the semidiurnal tide showed the mean tidal pattern to agree with the predicted main solar tide (Figure 7). Systematic differences existed, however in the amplitudes and phases recorded at different latitudes which may reflect local variations in the stratospheric wind and temperature fields. Variations in the amplitude and phase of the tides did not correlate with longer period planetary wave activity and the results suggest that in the upper mesosphere and lower thermosphere such interaction was not present and that the two kinds of waves existed independently. The possibility remains that the variations were caused by non-solar tidal modes (generated at lower altitudes by the interaction between the primary solar tide and travelling or quasi-steady atmospheric structures) which would account for the systematic variations between the stations.

Zonal wind observations were carried out at Budrio in the 7 November - 1 December period during an integrated ground based, balloon and rocket campaign - the Energy Budget Campaign (EBC) 1980 - planned for the study of energy inputs and outputs in the upper atmosphere (60-180 km) during geomagnetic disturbances. The meteor radar observations carried out at Budrio and different stations in middle latitudes during the EBC provide a comprehensive picture of upper atmosphere dynamics for that period (Fellous et al., 1985). The main wind component at all stations is outstandingly the semidiurnal tide. This oscillation is strongly modulated in amplitude and an important result is in evidence of the large horizontal extent of this phenomenon, as shown in Figure 8. The variations of semidiurnal amplitude over 8° in the latitude and 15° in longitude appear reasonably well correlated

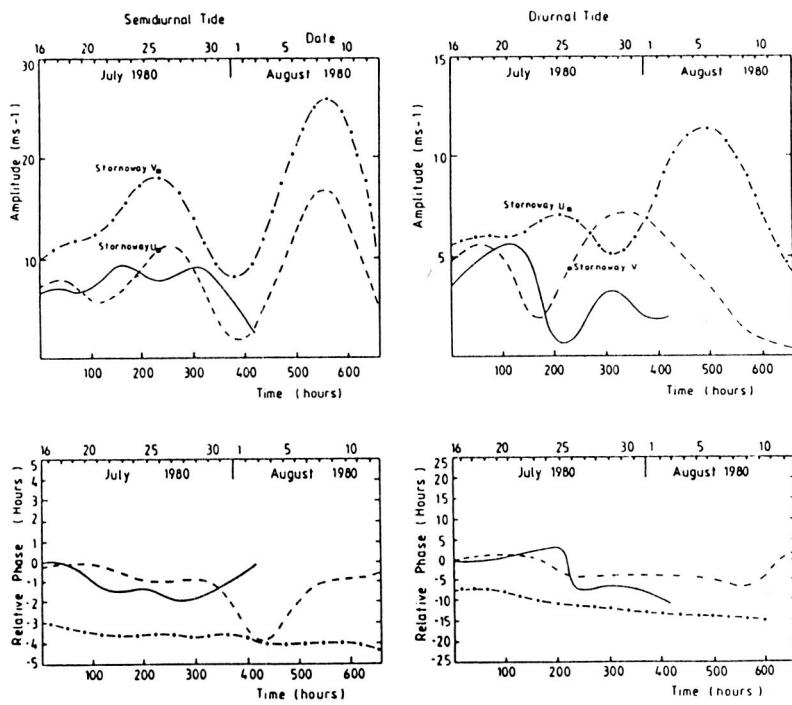


Fig. 7 Amplitude and phase variations of the semidiurnal and diurnal tide at 95 km during summer 1980 for Budrio zonal (—), Sheffield zonal (---), and Sheffield meridional (-●-) components. The average of six days of Stornoway zonal (U) and meridional (V) amplitudes are shown as square dots.

as measured by different instruments. It is recognized that the variation of the main tide over scales of several days and shorter time scale variations from place to place, relate to local effects. All tidal wind components as observed in late autumn at Budrio exhibit amplitudes generally lower than those measured in November of previous years. The daily variations in the amplitudes of the semidiurnal tide over scales larger than 5-6 days (Figure 8) 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 wavelengths. In the quoted period, the amplitudes of the diurnal and terdiurnal tides are not significant and the phases of these components exhibit non linear vertical variations. The complete description of these results awaits the formulation of a global model relating the energy input in the atmosphere and its distribution through dynamical processes.

Current meteor wind observations intended to monitor stratospheric warmings as part of the SWAMP campaigns, might well reveal the extent to which changes in stratospheric circulation influence the structure of tidal waves in the upper meso- and lower thermosphere. Information on the amplitude variation of tidal modes present in the meteor region at 95 km in the 11-22 December 1981 and 6 January- 2 February 1982 time periods, are shown in Figures 9 and 10 respectively, for zonal and meridional wind components. We can recognize the prominence of the amplitudes of the zonal tides with respect to those of the meridional ones. In December 1981 the tidal activity appears more intense and amplitudes up to 30 m/s for the semidiurnal tide and up to 15 m/s for the terdiurnal are recorded in the zonal wind structure. It is important to consider the persistence in the amplitude variation of the zonal tides of time scales of 5-6 days pointed out at Budrio in previous campaigns. A significant change in the pattern of the prevailing flow occurred between January 20 and 23, 1982: a reversal in the zonal flow was accompanied by a corresponding change in the meridional flow about the time of a temperature rise of 20-25 degrees in a few days observed at the 10 mb level by radiosondes in Central Europe. Figure 10 shows that at the time of the prevailing flow reversal, a strong weakening in the amplitudes of the tides was recorded in both wind component directions. On January 22-23, 1982, a minimum in the amplitude variation of the diurnal, semidiurnal and terdiurnal tides was generally observed, suggesting that the perturbation induced in the meteor region by the quoted temperature change during a minor stratospheric warming can also influence the tidal fields. It can be tentatively proposed that propagation of tidal energy at that time was seriously inhibited because of consequent irregularities and instabilities in atmospheric conditions, possibly accompanied by reflection and/or dispersion of energy through damping processes (CEVOLANI and DARDI, 1983).

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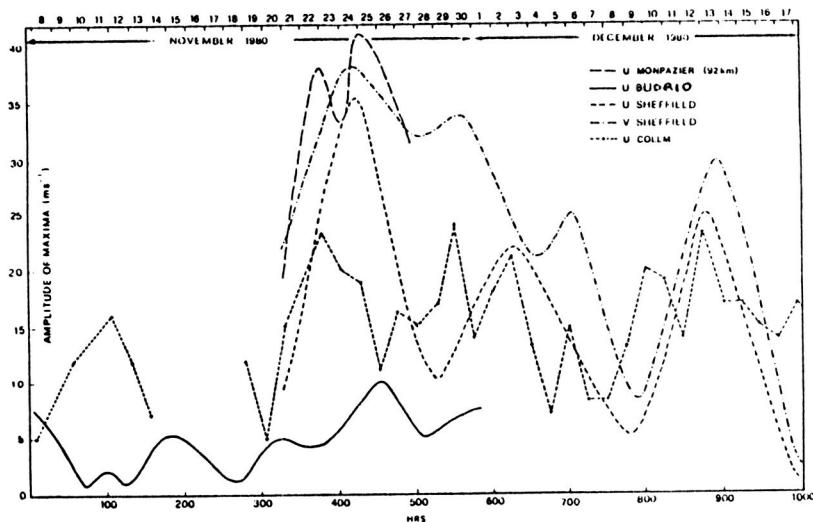


Fig. 8 Maximum amplitude variation with time of the 12 h tide at Budrio (zonal U), Sheffield (zonal U and meridional V), Monpazier (zonal U), and Collm (zonal U).

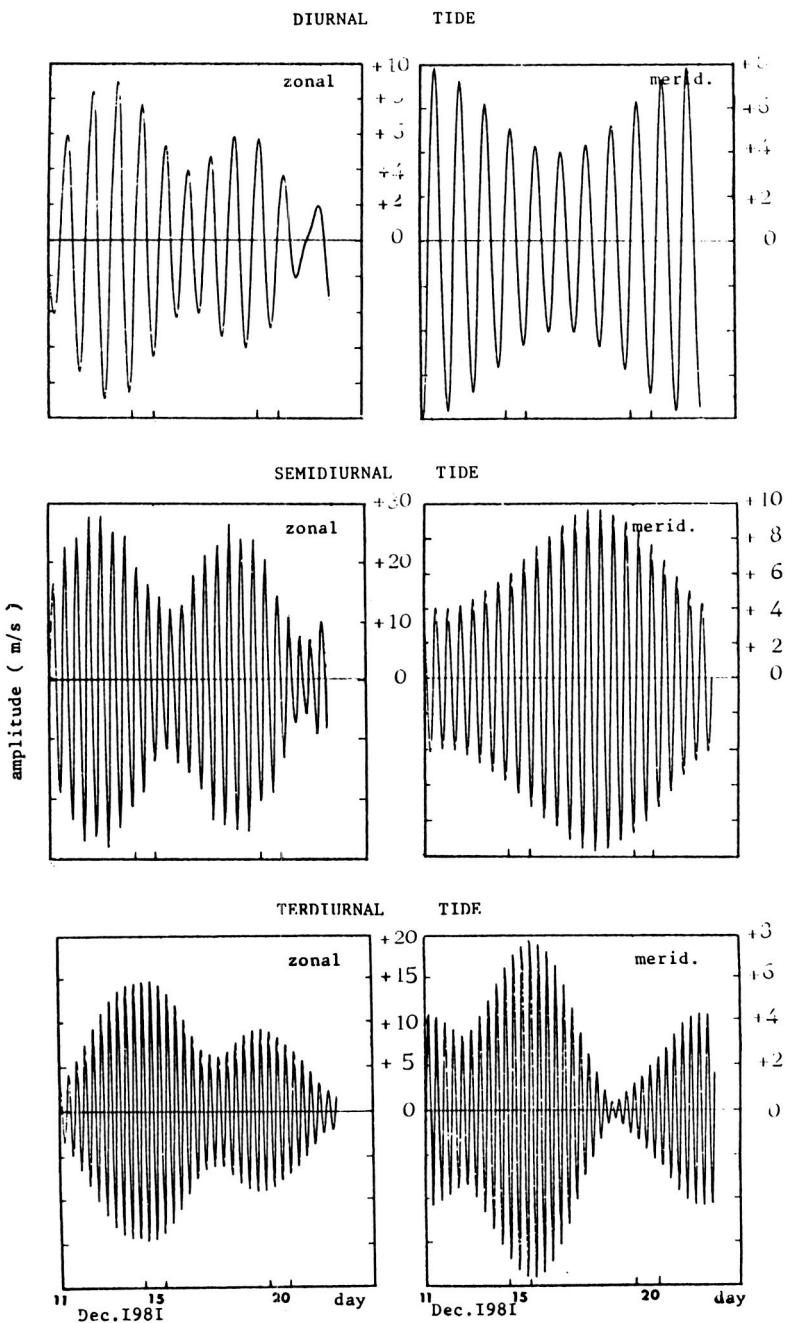


Fig. 9 Inverse Fourier transform of the 24, 12, and 8 h tidal peaks relative to zonal and meridional winds observed at Budrio at 95 km. Start time is 11.00 h LT, December 11, 1981.

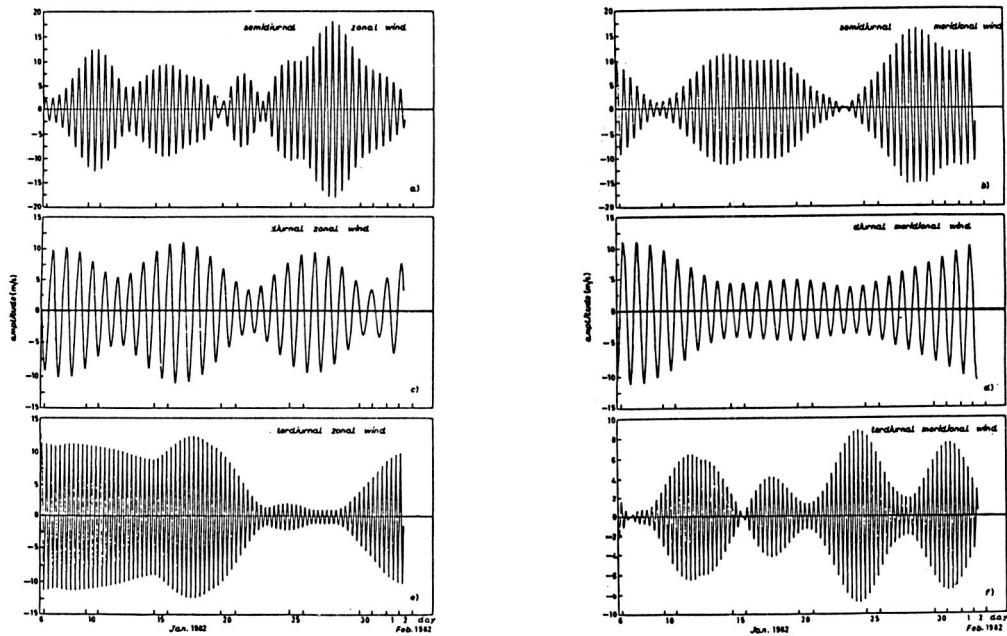


Fig. 10 Inverse Fourier transform of the 12, 24 and 8 h peaks in the Fourier transform relative to zonal (a, c, e) and meridional (b, d, f) winds observed over Budrio at 95 km.

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