Some Aspects of the Diurnal and Semidiurnal Tidal Wind Field in Meteor Zone

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ABSTRACT

The diurnal and semidiurnal tidal wind field variations in the altitudes between 80 and 100 km of the earth's atmosphere over a mid-latitude station are studied by means of the phases of the zonal and meridional wind measurements made at Atlanta (34° N, 84° W). The rotation of diurnal tidal wind vector is seen to be clockwise at lower heights (80–86 km), swinging between clockwise and anti-clockwise at intermediate heights (88–96 km) and anti-clockwise at higher heights (96–100 km). The senses of rotation of diurnal and semidiurnal tidal wind vectors are compared between the stations located in the same and opposite hemispheres. The results are consistent with the tidal theory in the case of Atlanta and Adelaide (35° S, 139° E) whereas in the case of other stations considered in the present study, they showed marked variations.

I. INTRODUCTION

Extensive meteor radar measurements have been made for many years at mid– and high–latitude stations by several investigators to study in detail the various periodic components of neutral wind and associated tidal phenomena at 80–100 km height region of the upper atmosphere, where thermotidal oscillations are major components of the total meteorological variation (Roper and Salah, 1978; Aso et al., 1980; Vincent and Ball, 1981; Bernard, 1981; Carter and Balsley, 1982; Ahmed and Roper, 1983; Dartt et al., 1983; Tsuda et al., 1983; Manson et al. 1985a). Of all the oscillations, diurnal (24h) and semidiurnal (12h) tides contribute maximum to the upper atmosphere dynamics. By analyzing the meteor wind data recorded over Adelaide (35° S, 139° E), Elford (1959) found diurnal tide's contribution with an amplitude of about 20 m s^{-1} and semidiurnal tide's contribution with an amplitude of about 10 m s^{-1}. Greenhow and Neufeld (1961) analyzed similar data recorded over Jodrell Bank (53° N, 2° W) and found diurnal tide's contribution with an amplitude of about 13 m s^{-1}. Thus, the radio meteor wind data suggest latitudinal dependence of diurnal and semidiurnal tidal contributions to the mean wind field at meteoric altitudes which is in agreement with the theory developed by Chapman and Lindzen (1970). Also, according to the theory, tidal wind vector should represent a constant amplitude with clockwise rotation in the Northern Hemisphere and anti–clockwise rotation in the Southern Hemisphere and should differ in phase by 180° between the two hemispheres.

Several comparisons / compaigns have been conducted to achieve the global tidal picture for complete understanding of the upper atmosphere circulation features. The results of one such campaign, namely, Co–operative Tidal Observations Programme (CTOP) of URSI / IAGA have been reported by Roper and Salah (1978). In order to update the information by adding input from other ground–based radar techniques such as M.F. (partial

reflection) and V.H.F. (Mesosphere–Stratosphere–Troposphere), recently Atmospheric Tides in the Middle Atmosphere Programme (ATMAP) of MAP and a working group on Tides in Mesosphere and Lower Thermosphere of ICMUA have begun global studies of tides. As a part of ATMAP Campaign, several inter–comparisons between stations delineating symmetric–antisymmetric, migrating–nonmigrating and seasonal–latitudinal behaviour of atmospheric tides have been initiated and concentrated on the results already available on these aspects (e.g., Glass et al., 1975; Bernard et al., 1981; Manson et al., 1985 a,b; Forbes, 1985). Station pairs which are already started providing information on the above aspects include Kyoto–Adelaide, Poker Flat–Mawson, Saskatoon–Christchurch, Durham–Urbana and the USSR network. Results of some of the above comparitive studies have been reported (Aso and Vincent, 1982; Manson et al., 1983; Massebeuf et al., 1979; Manson et al., 1985a).

The more recent observational results relating to the structure and variability of tides in the 80–120 km height region have been reviewed by Forbes (1985) with a particular emphasis on seasonal–latitudinal variations in the vertical structure of diurnal and semidiurnal tidal winds. By using several years of meteor wind data, Muller (1986), Elford (1973) and Ahmed and Roper (1983) studied the seasonal variability of atmospheric tides. The results of these studies relating to mid–latitudes suggest that semidiurnal tide exhibits a consistent characteristics seasonal–latitudinal behaviour whereas for diurnal tide it is difficult to define a specific behaviour because of a variety of vertical structures that occur depending on phase interference between the evanescent and propagating components. Many numerical models have been developed (Lindzen and Hong, 1974; Hong and Lidzen, 1976; Walterscheid, 1981; Bernard, 1981; Aso et al., 1982; Forbes, 1982 a,b) to simulate atmospheric tides by including a number of physical processes taking place at upper levels (> 70 km). Since the tidal structure at these levels is very sensitive to thermal excitation, background mean wind distribution and other atmospheric properties, the modelling studies made so far have been found to give average picture rather than specific. To study some of the above aspects, the meteor wind data collected over Atlanta (34° N, 84° W) during the period August 1974–March 1978 are analyzed. This paper describes the results of this analysis and compares with those of some of the mid– and high–latitude stations located in both Northern and Southern Hemispheres.

II DATA AND ANALYSIS

Monthly mean data of diurnal and semidiurnal tidal components of zonal (EW) and meridional (NS) winds measured with the Georgia Tech Meteor Wind Facility at Atlanta in the altitude region 80–100 km (at 2 km height interval) during August 1974 – March 1978 (44 months) are used in the present analysis. The details of the radar facility and accuracies involved in the wind and height measurements are available in the literature (Roper, 1975; 1978). The difference between the phases of diurnal tidal components of zonal (φ_{1EW}) and meridional (φ_{1NS}) winds, $\Delta\varphi_1$ ($\varphi_{1EW}-\varphi_{1NS}$) and of semidiurnal tidal components of zonal (φ_{2EW}) and meridional (φ_{2NS}) winds, $\Delta\varphi_2$ ($\varphi_{2EW}-\varphi_{2NS}$) at each height are computed and averaged for respective months over the 44–month period to obtain monthly mean values at each 2 km between 80 and 100 km height. These monthly mean phase differences are utilized for studying the seasonal and height variations of rotation of tidal wind vectors.

III. RESULTS

According to the tidal theory, positive $\Delta\varphi$ indicates clockwise and negative $\Delta\varphi$ indicates anti–clockwise rotation of wind vector on harmonic dial. The results relating to the

monthly, seasonal and latitudinal variation of diurnal and semidiurnal tidal wind field are described below.

1. *Variation of Tidal Wind Field over Different Months*

Figure 1 shows the monthly mean variations of the difference in phase (in hours) for diurnal ($\Delta\varphi_1$), and semidiurnal ($\Delta\varphi_2$) components at eleven successive height intervals of each 2 km of the height region 80–100 km. The phase differences for both the components are found to vary considerably from month at all heights. At lower heights between 80 and 88 km the rotation of diurnal wind vector is clockwise almost for half of the year (April–September). From 90 km onwards, the rotation of this vector fluctuated between clockwise and anti–clockwise at 100 km level.

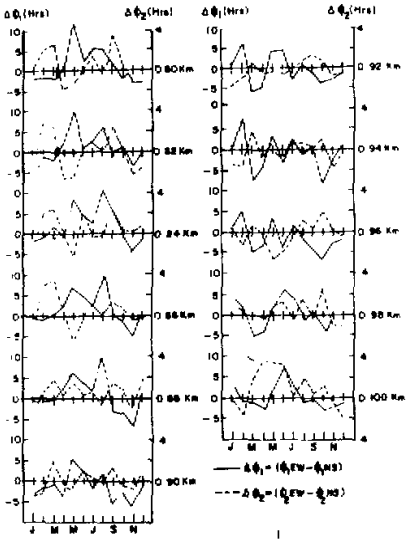

Fig. 1. Monthly mean variations fo the difference in phase (in hours) for diurnal ($\Delta\varphi_1$), and semidiurnal ($\Delta\varphi_2$) components at eleven successive height intervals of each 2 km of the height region 80–100 km.

A common feature that can be seen in all the plots is that the rotation of diurnal wind vector is always anti–clockwise during November and December throughout the height range 80–100 km. Also, the trend of variation of diurnal and semi–diurnal wind vectors is noticed to be same almost at all heights during February and March. At levels from 92 to 100 km, the phase difference between the diurnal tidal components of zonal and meridional winds is found to be nearly 6 hours representing a clockwise rotation of 90° which is in accordance with the tidal theory (Chapman and Lindzen, 1970).

2. *Seasonal and Annual Mean Variation of Tidal Wind Field*

The seasonal and annual means of differences in phase of both diurnal and semidiurnal tidal wind components in the height band of 80–100 km are presented in Table 1. This table summarizes the height variation of the sense of rotation of tidal wind vector in different seasons. With regard to the diurnal wind vector, the rotation is clockwise during summer

throughout the height region 80–100 km and it is anti–clockwise in winter except at heights between 96 and 98 km. The rotation of this vector is found to be clockwise from 80 to 90 km and anti–clockwise from 90 to 100 km height regions during autumn and spring. Similar situation is observed during winter for semidiurnal component but unlike the diurnal wind vector, semidiurnal wind vector exhibited clockwise rotation during autumn.

The height variation of the annual mean differences in phase of diurnal and semidiurnal wind components between 80 and 100 km is also presented in Table 1. It is found that both diurnal and semidiurnal wind vectors rotate clockwise almost at lower levels from 80 to 90 km and at higher levels from 90 to 100 km. At heights between 90 and 96 km, the rotation of both the wind vectors is noticed to be anti–clockwise.

Table 1. Height Variation of Diurnal and Semidiurnal Tidal Wind Field during Different Seasons

Height (km)	Winter	Spring	Summer	Autumn	Annual
Diurnal Component			$(\varphi_{1EW}-\varphi_{1NS})$		
80	−0.40	−0.78	6.31	1.15	1.57
82	−2.76	−0.08	4.37	2.32	1.46
84	−2.75	0.32	4.94	3.35	1.46
86	−1.64	0.46	4.84	2.72	1.60
88	−2.38	0.31	3.49	1.03	0.61
90	−3.56	−2.12	1.97	−1.78	−1.15
92	−1.53	−1.45	1.80	−2.55	−0.93
94	−0.55	−1.45	0.89	−2.99	−1.03
96	0.38	−1.26	0.50	−2.62	−0.75
98	1.05	−2.57	4.38	−1.66	0.30
100	−0.06	−1.78	4.08	−1.41	0.20
Semidiurnal Component			$(\varphi_{2EW}-\varphi_{2NS})$		
80	−0.83	0.26	0.05	1.26	0.19
82	−1.53	1.10	−1.38	0.87	−0.24
84	−0.08	1.54	−0.06	0.86	0.57
86	−0.63	2.07	−0.15	0.77	0.51
88	−0.38	0.84	0.90	0.62	0.50
90	−0.42	0.20	0.08	0.18	−0.01
92	−1.09	0.02	−0.30	1.08	−0.07
94	−1.13	−0.35	0.22	0.46	−0.20
96	−0.26	−0.46	−1.67	1.23	−0.29
98	−0.22	−0.12	0.46	0.22	0.07
100	−0.46	1.33	2.22	1.18	1.06

3. *Latitudinal Variation of Tidal Wind Field*

In order to study the latitudinal dependence of the sense of rotation of semidiurnal wind vector, with this component dominating over the diurnal component at mid– and high–latitudes, monthly variations of the difference in phase of semidiurnal components of zonal and meridional wind data for Atlanta (34° N, 84° W) are compared with the available data for

Adelaide (35 ° S, 139 ° E) at 90 km and those for Kharkov (50 ° N, 36 ° E), Sheffield (53 ° N, 1 ° W), Jodrell Bank (53 ° N, 2 ° W), Obninsk (55 ° N, 36 ° E), Heiss Island (80 ° N, 58 ° E) and Molodezhnaya (67 ° S, 46 ° E) at 95 km in Figure 2. These comparisons between the stations located in the same and opposite hemispheres revealed marked differences.

The comparison between the present results and those for Adelaide points out that the semidiurnal wind vectors rotate at both the stations in opposite direction during April, May, June and July and they follow each other during the rest of the year. Comparison of the results of Atlanta (present study) with those reported earlier (Devara and Ahmed, 1982) for Obninsk, Heiss Island and Molodezhnaya and those of Muller (1966) for Sheffield, Kharkov and Jodrell Bank reveals that the sense of rotation of semidiurnal wind vector is opposite during local summer and winter and the wind vector rotates in clockwise direction throughout the year at all stations except Atlanta and Heiss Island. Recent results of the 5–year averages of meteor wind data at 95 km over Kuhlungsborn (54 ° N, 11 ° E) also showed that the sense of rotation of semidiurnal tidal wind vector is clockwise throughout the year (Devara, 1986).

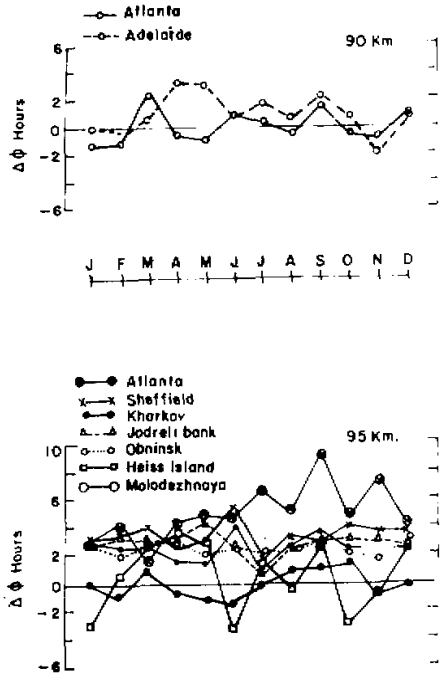

Fig. 2. Latitudinal variation of tidal wind field.

IV. DISCUSSION

The observed variation in the wind field due to diurnal and semidiurnal tidal components in the present study could be either due to the interaction between fundamental and higher order modes or due to reflection of propagating modes. The latter appears to be more important for explaining the observation at all latitudes that show amplitude nodes and associated 180 ° phase shifts. The 90 ° phase difference observed between the diurnal tidal component of zonal and meridional winds in the present study is in agreement with the theory (Chapman

and Lindzen, 1970) and with the results reported by Manson et al. (1981) for Saskatoon. Aso et al (1979) also noticed similar feature in the meteor wind observations at Adelaide.

The seasonal and annual mean variations in the rotation of diurnal and semidiurnal wind vectors noticed in the present study can not be explained by the resonance hypothesis. But as suggested by Greenhow and Neufeld (1956) these could be explained up to certain extent. in terms of standing pressure waves that generate in the pressure systems on ground and cause certain modifications in the wind field pattern at meteoric altitudes. Recently. the seasonal structure of tides in the lower thermosphere has been examined by Manson et al. (1981) at Saskatoon. These results suggest that seasonal tidal characteristics strongly be associated with variations in the thermotidal forcing rather than coupling effects due to asymmetric mean meridional temperature gradients and zonal winds.

As per the tidal theory, the zonal wind components in the Northern Hemisphere and Southern Hemisphere should be in phase and anti–phase respectively for symmetric and anti–symmetric modes and vice versa in the case of meridional wind components between the two hemispheres. A close inspection of the sense of rotation of semidiurnal wind vector between Atlanta and Adelaide at 90 km (Figure 2) reveals that a mixture of symmetric and anti–symmetric modes occurs during spring. with dominance of symmetric modes from June to October and anti–symmetric modes during November, January and February. These features are partly in accordance with the findings of Aso and Vincent (1982). Comparison of the month to month differences in phases of semidiurnal component of zonal and meridional winds between Atlanta and Adelaide at 90 km height revealed an opposite trend of variations from March to June. This shows an opposite nature of seasonal variation in the rotation of semidiurnal component in opposite hemisphere which is consistent with the results of Ahmed (1976). Also, comparison of the present results of smaller diurnal and semidiurnal tidal wind vectors during summer and relatively larger during winter at Atlanta with the model predictions by Walterscheid et al. (1980) for seasonal phase variations at 90 km in the Northern Hemisphere suggests an agreement between the observations and model.

Due to 180° phase difference of different modes occurring between the two hemispheres, mixing of all modes may produce significant hemispheric difference in the resultant tidal wind field. Muller (1966) suggested that the variations in the sense of rotation of diurnal tidal wind vector at high–latitude Northern Hemisphere stations do not offer much support to a persistent diurnal tidal pattern throughout the year. Manson et al. (1985a) concluded that the behaviour of diurnal tide can be interpreted more easily at low–latitudes than at mid– and high–latitudes. Inter–comparison of observations made at the same latitude but different longitudes showed that the tidal phase could differ by several hours (Glass et al., 1975). Also, comparison of data at stations in the same and opposite hemispheres shows significant differences in the tidal structure, especially for the diurnal tide. Briggs and Spencer (1954) compared the wind measurements made at Cambridge and Jodrell Bank, both stations located almost at the same latitude and longitude. noticed a considerable change in wind pattern with height. By comparing the wind observations at Jodrell Bank with other stations in the Northern Hemisphere, Greenhow and Neufeld (1955) concluded that there was no much agreement. Devara and Ahmed (1982) also noticed a small agreement between the wind fields over the stations located in the same and opposite hemisphere.

V. CONCLUSIONS

Results of the analysis of meteor wind data for Atlanta for the period August

1974–March 1978 suggest the following:

i) There are marked variations in the monthly mean rotation of diurnal and semidiurnal wind vectors in the altitudes between 80 and 100 km,

ii) The rotation of diurnal wind vector is clockwise at lower heights (80–88 km), changing either clockwise or anti–clockwise at intermediate heights (88–96 km) and anti–clockwise at higher heights (96–100 km),

iii) The diurnal tidal components of zonal and meridional winds are in quadrature as expected in the tidal theory,

iv) The rotation of wind vector is anti–clockwise for diurnal and semidiurnal tides during winter whereas it is clockwise for diurnal tide during summer and for semidiurnal tide during autumn.

v) A typical comparison of the results for semidiurnal wind vector of Atlanta with those of other stations located in the same and opposite hemispheres has revealed that the sense of rotation of the vector is opposite during local summer and winter.

vi) Simultaneous and considerably long series of meteor wind observations over a network of stations over the globe may lead to better understanding of specific nature of variation of wind structure over different latitudes. Also, such observations would be much useful for the verification of the results of various wind models established for different stations over the globe.

The meteor wind data for Atlanta are taken from the technical report entitled "Radio Meteor Winds Measured Over Atlanta" by R.G. Roper of Georgia Institute of Technology, Atlanta. Some of the work reported in this paper was carried out by the first author when he was with the Andhra University, Waltair. One of the authors (GC) is thankful to the University Grants Commission, New Delhi, for providing the research fellowship.

REFERENCES

Ahmed, M.I. (1976), Seasonal variation of the phases of semidiurnal neutral wind components, *Indian J. Radio & Space Phys.*, **5**: 322–323.

Ahmed, M.I. and Roper, R.G. (1983), The diurnal and semidiurnal oscillations in meteor winds over Atlanta, *J. Atmos. Terr. Phys.*, **45**: 181–192.

Aso, T., Tsuda, Y. and Kato, Y. (1979), Meteor radar observations at Kyoto University, *J. Atmos. Terr. Phys.*, **41**: 515–525.

Aso, T., Tsuda, Y., Takashima, R., Ito, R. and Kato, S. (1980), Observations of lower ionospheric winds by the Kyoto meteor radar, *J. Geophys. Res.*, **85**: 177–184.

Aso, T. and Vincent, R.A. (1982), Some direct comparisons of mesospheric winds observed at Kyoto and Adelaide, *J. Atmos. Terr. Phys.*, **44**: 267–275

Aso, T., Naoyama, T. and Kato, S. (1982), Numerical simulation of semidiurnal atmospheric tides, *J. Geophys. Res.*, **86**: 388–395.

Bernard, R. (1981), Variability of semidiurnal tide in the upper atmosphere, *J. Atmos. Terr. Phys.* **43**: 663–674.

Bernard, R., Fellous, J.L., Massebeuf, M. and Glass, M. (1981) Simultaneous meteor radar observations at Monpazier (France, 44° N) and Punta Buringuen (Puerto Rico, 18° N) I–Latitudinal Variations of atmospheric tides, *J. Atmos. Terr. Phys.*, **43**: 525–533.

Briggs, B.H. and Spencer, M. (1954), Horizontal movements in the ionosphere, *Phys. Soc. Rep. Prog. Phys.*, **17**: 245–280.

Carter, D.A. and Balsley, B.B. (1982), The summer wind field between 80 and 93 km observed by the MST radar at Poker Flat, Alaska (65° N), *J. Atmos. Sci.*, **39**: 2905–2915.

Chapman, S. and Lindzen, R.S. (1970), Atmospheric Tides, Thermal and Gravitational, Reidal, Dordrecht, Netherlands.

Dartt, D., Nastram, G. and Belmont, A. (1983), Seasonal and solar cycle wind variations, 80–100 km, *J. Atmos. Terr. Phys.*, **45**: 707–718.

Devara, P.C.S. and Ahmed, M.I. (1982), On the atmospheric tidal wind variations at meteor heights, *Arch. Met. Geophys. Biokl. Ser. A.*, **31**: 35–47.

Devara, P.C.S. (1986), Wind variations in the lower thermosphere at a high– midlatitude station, *Curr. Sci.* **55**: 531–533.

Elford, W.G. (1959), Winds in the upper atmosphere, *J. Atmos. Terr. Phys.*, **15**: 132–136.

Elford, W.G. (1973). A 6-year synoptic study of winds between 80 and 100 km from meteor trail drifts. IAGA Rep: to Comm. VIII.

Forbes, J.M. (1982 a). Atmospheric Tides 1. Model description and results for the solar diurnal component. *J. Geophys. Res.*, **87**: 5222–5240.

Forbes, J.M. (1982 b). Atmospheric tides 2. The solar and lunar semidiurnal components. *J. Geophys. Res.*, **87**: 5241–5252.

Forbes, J.M. (1985). Atmospheric tides between 80 and 120 km. Handbood for Middle Atmosphere Program, **16**: 278–289.

Glass, M., Fellous, J.L., Massebeuf, M. Spizzichino, A., Lysenko, I.A. and Portnyagin, Yu. I. (1975). Comparison and interpretation of the results of simultaneous wind measurements in the lower thermosphere at Garchy (France) and Obninsk (USSR) by meteor radar technique. *J. Atmos. Terr. Phys.*, **37**: 1077–1085.

Greenhow, J.S. and Neufeld, E.L. (1955). Diurnal and seasonal wind variations in the upper atmosphere. *Phil. Mag.*, **46**: 549–562.

Greenhow, J.S. and Neufeld, E.L. (1956). The height variation of upper atmospheric winds. *Phil. Mag.*, **8**: 1157–1171.

Greenhow, J.S. and Neufeld, E.L. (1961). Winds in the upper atmosphere. *Quart. J. Roy. Meteorol. Soc.*, **87**: 472–487.

Hong, S.S and Lindzen, R.S. (1976). Solar semidiurnal tide in the thermosphere. *J. Atmos. Sci.*, **53**: 135–153.

Lindzen, R.S. and Hong, S.S. (1974). Effects of mean winds and meridional temperature gradients on solar and lunar semidiurnal tides in the atmosphere. *J. Atmos. Sci.*, **31**: 1421–1446.

Manson, A.H., Meek, C.E. and Gregory, J.B. (1983). Winds and waves (10 min–10 days) in the mesosphere and lower thermosphere at Saskatoon (52° N, 107° W, L = 4.4) during the year October 1979 to July 1980. *J. Geophys. Res.*, **86**: 9615–9625.

Manson, A.H., Meek, C.E. and Gregory, J.B. (1983). The semidiurnal tide at the equinoxes: MF radar observations for 1978–1982 at Saskatoon (52° N, 107° W). *J. Atmos. Sci.*, **40**: 969–976.

Manson, A.H., Meek, C.E., Smith, M.J. and Fraser, G.J. (1985a). Direct comparisons of prevailing winds and tidal fields (24h–12h) in the upper middle atmosphere (60–105 km) during 1978–1980 at Saskatoon (52° N, 107° W) and Christchurch (44° S, 173° E). *J. Atmos. Terr. Phys.*, **47**: 463–476.

Manson, A.H., Meek, C.E., Massebeuf, M., Fellous, J.L., Elford, W.G., Vincent, R.A., Craig, R.L., Roper, R.G., Avery, S., Balsley, B.B., Fraser, G.J., Smith, M.J., Clark, R.R., Kato, S., Tsuda, T. and Ebel, A. (1985b). Mean winds of the upper middle atmosphere (60–110 km): A global distribution from radar systems (M.F., Meteor, VHF). Handbook for Middle Atmosphere, **16**: 239–268.

Massebeuf, M., Bernard, R., Fellous, J.L. and Glass, M. (1979). The mean zonal circulation in the meteor zone above Garchey (France) and Kiruna (Sweden). *J. Atmos. Terr. Phys.*, **41**: 647–655.

Muller, H.G. (1966). Atmospheric tides in the meteor zone. *Planet. Space Sci.*, **14**: 1253–1272.

Roper, R.G. (1975). The measurement of meteor winds over Atlanta (34° N, 84° W). *Radio Sci.*, **10**: 363–369.

Roper, R.G. (1978). Winds from the Atlanta (34° N, 84° W) radio meteor wind facility. *J. Atmos. Terr. Phys.*, **40**: 891–894.

Roper, R.G. and Salah, J.E. (1978). Preliminary results from the URSI/IAGA cooperative tidal observations programme (CTOP). *J. Atmos. Terr. Phys.*, **40**: 879–885.

Tsuda, T., Aso, T. and Kato, S. (1983). Seasonal variation of solar atmospheric tides at meteor heights. *J. Geomag. Geoelectr.*, **35**: 65.

Vincent, R.A. and Ball, S. (1981). Mesospheric winds at low and middle latitudes in the Southern Hemisphere. *J. Geophys. Res.*, **86**: 9159–9169.

Waltershield, R.L., Deore, J.G. and Venkateswaran, S.V. (1980). Influence of mean zonal motion and meridional temperature gradient on the solar semidiurnal atmospheric tide: A revised spectral study with improved heating rates. *J. Atmos. Sci.*, **37**: 455–470.

Waltershield, R.L. (1981). Inertio-gravity wave induced acceleration of mean flows having an imposed periodic component: Implications for tidal observations in the meteor region. *J. Geophys. Res.*, **86**: 9698.