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THERMOSPHERIC TIDES DURING THERMOSPHERE MAPPING STUDY PERIODS

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ABSTRACT

Neutral exospheric temperatures at 53°, 43° and 33° latitude from Millstone Hill steerable-antenna Thomson scatter measurements, and at 19° latitude from the Arecibo Observatory, obtained during three Thermosphere Mapping Study (TMS) coordinated campaign intervals during 1984 and 1985, are analyzed for diurnal and semidiurnal tidal components. The resulting amplitude and phase latitudinal structures are compared with numerical simulations. The observed semidiurnal tidal components are thought to be significantly affected by tidal waves propagating upwards from below the thermosphere during these solar minimum periods. We speculate that current inadequacies in specifying F-region plasma densities and mean zonal winds at lower altitudes within the simulation model may account for certain discrepancies between observations and theory.

INTRODUCTION

Neutral exospheric temperatures derived from Thomson scatter measurements of Te, Ti, Ne and solution of the ion thermal balance equation are analyzed for solar tidal components. The measurements were obtained during three "Thermosphere Mapping Study" intervals covering equinox, winter and summer conditions: 17-24 September 1984, 15-18 January 1985, and 25-28 June 1984. Using the steerable capability of the Millstone Hill (43°N) antenna, data were gathered along a meridian spanning roughly 30-55° latitude. In this paper the temporal variations in temperature at 33°, 43°, and 53° latitude are quantitatively analyzed, complemented by similar measurements and analyses at the Arecibo Observatory (18°N). Thus, the seasonal-latitudinal structures of the individual Fourier-component amplitudes and phases are investigated. These results are interpreted through comparison with the numerical simulations of Forbes /1,2/.

THE DATA AND METHODS OF ANALYSIS

The data were analyzed in several ways to ensure removal of geomagnetic effects. Each time series was fit with a sum of local-time Fourier components and a K_p-term as follows:

$$T = T_o + \sum_{n=1}^{4} T_n cos n\Omega(t - P_n) + \alpha K_p e^{.03 K_p} \quad (1)$$

where

T = total temperature

T_o = diurnal-mean temperature

T_n = amplitude of n^{th} harmonic of temperature

P_n = local time of maximum of n^{th} harmonic of temperature

$\Omega = 2\pi/24$ hours^{-1}

This formula, and the Millstone Hill results presented here for the 17-24 September 1984 "Equinox Transition Study" are based upon work by J.M. Forbes and W.L. Oliver, which will be published elsewhere. The K_p used in equation (1) lags the temperatures by 6 hours, as this yields the best correlation. The procedure followed was, first, to least-squares fit the above formula without the K_p term to the data, and then to examine the residuals from this "quiet-day" curve for variations related to K_p. The K_p term was then included in the fitting procedure, and any correlations between K_p and local time were looked for. A superposed epoch analysis was also performed whereby a single equivalent day was formed for each time series by separating the data into one-hour local time bins and averaging, and then fitting this "quiet-day" curve with a sum of Fourier components. The K_p's corresponding to each temperature measurement were similarly averaged and binned, to check for K_p-biased local time periods. The above techniques were applied to the individual measurements and to hourly average values, and the results checked for consistency.

During periods when sufficient data were available, all of the above methods yielded nearly identical results. A summary of the tidal components is provided in Table 1. During the 17-24 September 1984 campaign, there existed a sufficient mixture of quiet and active conditions over all local time intervals that the tidal and geomagnetic variations in the Millstone Hill measurements could be separated using linear regression analysis. Although the interval was shorter at Arecibo (19-21 September), penetration of the storm effect to this latitude was sufficiently weak that the normal quiet-day variation remained relatively undisturbed. This is clearly evident from the excellent fit to these data shown in Figure 1 wherein a small K_p effect is included, and by the superposed epoch analysis (Figure 2a) which yielded almost identical Fourier coefficients. At 53 degrees latitude there appeared to be significant contamination from joule and particle precipitation heating so that reliable neutral temperatures could not be derived.

The 26-28 June 1984 zenith measurements at Millstone Hill were the most difficult to analyze due to noisiness in the data connected with use of a short pulse (corresponding to roughly 30 km vertical resolution) during this experiment. (We analyzed 100 km-resolution data for the September 1984 experiment and 50 and 100 km-resolution pulse data for the January 1985 campaign). Hourly averages of the vertical antenna data at Millstone Hill are illustrated in Figure 3. The superposed epoch analyses of these data as illustrated in Figure 4b at 33° and 43° latitude give results quite consistent with the linear regression analyses, and

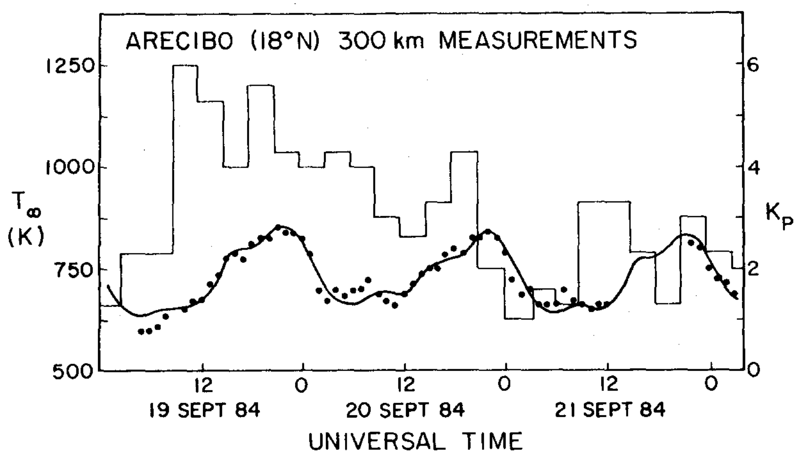

Fig. 1. Hourly-average temperatures at Arecibo (18°N) during 19-21 September 1984, with fitted curve defined by equation (1) and coefficients in Table 1, and the three-hourly K_p index.

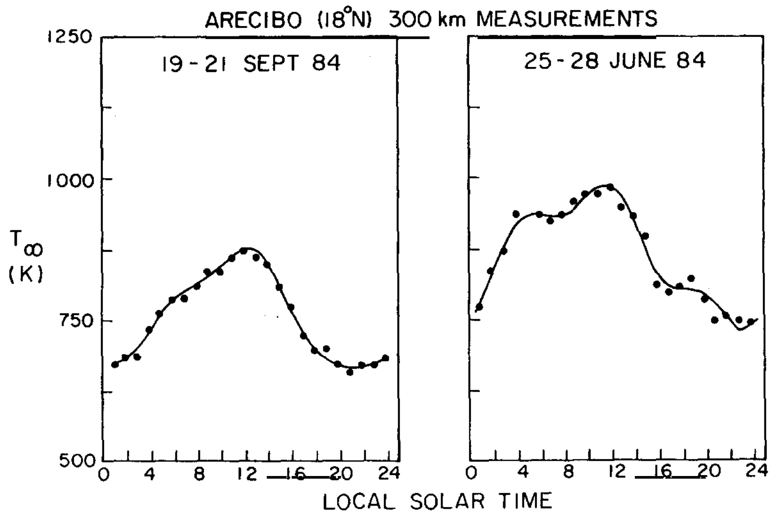

Fig. 2. Hourly average temperature measurements at Arecibo (18°N) for single "equivalent day" covering the 19-21 September 1984 (left) and 25-28 June 1984 (right) time periods.

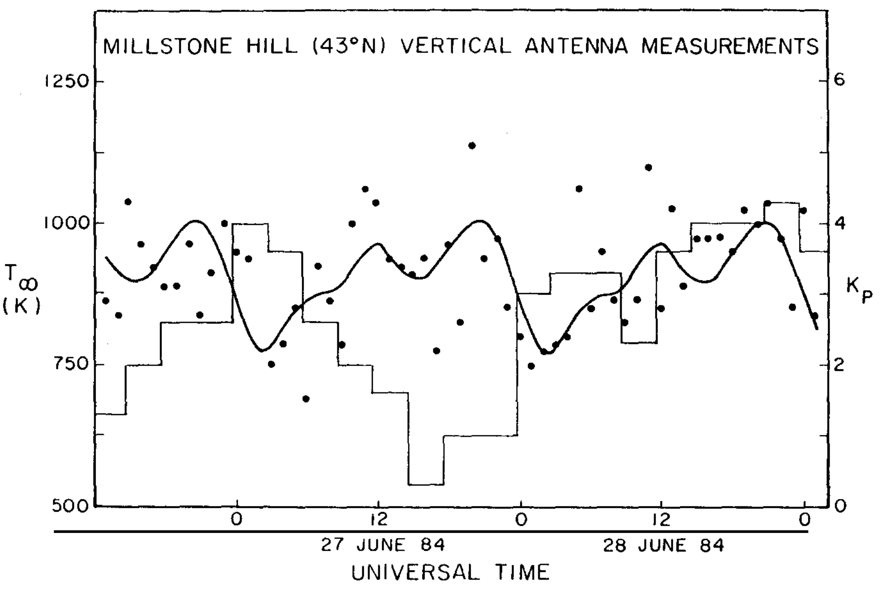

Fig. 3. Same as Fig. 1, except for Millstone Hill (43°N) vertical antenna measurements during 26-28 June 1984.

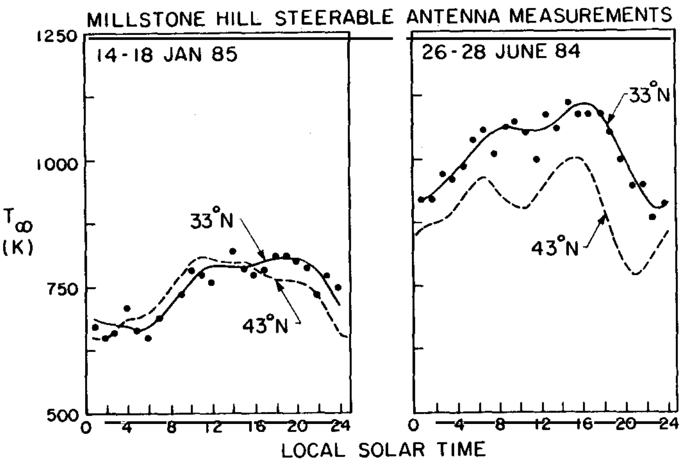

Fig. 4. Hourly-average temperatures at 33°N from Millstone Hill steerable-antenna measurements for single "equivalent day" covering 14-18 January 1985 (left) and 26-28 June 1984 (right). Also shown are fit curves corresponding to zenith antenna (43° N) measurements (dashed line).

exhibit a conspicuous double-peaked structure which remains detectable down to Arecibo (see Figure 2b). At 53° latitude a section of missing data caused a correlation to exist between K_p and local time precluding separation of local-time and K_p variations in this data set (note the quasi-periodicity of K_p in Figure 3). In addition, the Millstone data at high latitudes also showed evidence of contamination from joule heating.

The 15-18 January 1985 campaign measurements from Millstone Hill were much smoother (Figure 5 and 4a) and did not exhibit the degree of local time or latitude structure characteristic of the June measurements. Due to lack to data and local time coverage, the 53 degree latitude data were also discarded for this time period.

TIDAL RESULTS AND INTERPRETATION

Diurnal and semidiurnal amplitudes and phases (see Table 1) are plotted versus latitude for the three TMS periods and compared with the numerical simulations of Forbes /1,2/ in Figures 6 and 7. The Forbes /1,2/ background atmospheric and heating specifications correspond to a global mean exospheric temperature of 1000K, which is in excess of values appropriate to the near solar minimum conditions applicable here. In addition, Forbes calibrated his EUV heating rates to force agreement with measured exosheric temperatures over Millstone Hill during the downside of solar cycle 20 (1970-1975), whereas it is now known that empirical relationships between heating and solar indices can change from one part of the solar cycle to another /3/. So, it is not too disturbing that the Forbes diurnal amplitudes overestimate those measured during the three TMS periods. However, it is interesting to note the relative lack of latitude structure reflected in the observed amplitudes as compared with the simulations, while on the other hand the model phases do not reflect the 3-4 hour shift to later local times of the diurnal temperature phase from 43° to 38° latitude. As the Forbes model assumes coincidence of geographic and geomagnetic coordinates and utilizes the Chiu /4/ ionospheric model which is known to be deficient at low latitiudes, we tentatively speculate that a more realistic specification of ion drag, consistent with the simulated neutral winds and observed electric fields, may serve to account for these discrepancies.

The measured semidiurnal amplitudes (Figure 7), while of the same order (15- 40K) as the simulations, generally decrease towards lower latitudes contrary to model behavior. Note that for the June 1984 period especially,the decrease in semidiurnal amplitude and increase in diurnal amplitude towards the equator

TABLE 1

LOCAL-TIME FOURIER COMPONENTS (TIDES) AND K_p-TERM COEFFICIENT α (SEE TEXT) DERIVED FROM NEUTRAL EXOSPHERIC TEMPERATURES DURING THREE THERMOSPHERE MAPPING STUDY CAMPAIGNS

CAMPAIGN	LATITUDE		TIDAL COMPONENTS T_o	T_1	P_1	T_2	P_2	α
17-24 September, 1984 ETS	53°	*	—	–	—	–	—	–
	43°		683	91	11.9	35	6.2	42
	33°		707	90	14.3	20	9.1	31
(19-21 September only)	18°		706	82	15.0	18	4.5	10
25-28 June, 1984 GTMS	53°	**	—	–	—	–	—	–
	43°		908	64	11.5	52	4.0	05
	33°		976	73	12.5	34	5.0	00
	18°		845	100	14.0	10	8.2	00
15-18 January, 1985 GTMS	53°	***	—	–	—	–	—	–
	43°		748	68	13.9	20	9.4	00
	33°		731	63	15.8	18	9.4	00
	18°		691	67	15.6	17	4.1	00

* Contaminated by Joule/Particle Heating

** Limited data; K_p correlated with local time

*** Insufficient Data

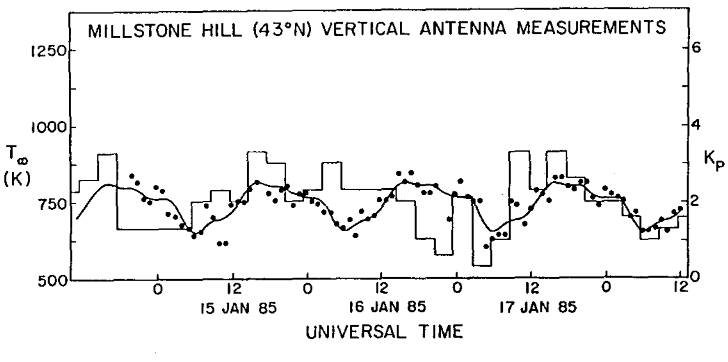

Fig. 5. Same as Fig. 1, except for Millstone Hill (43°N) vertical antenna measurements during 15-17 January 1985.

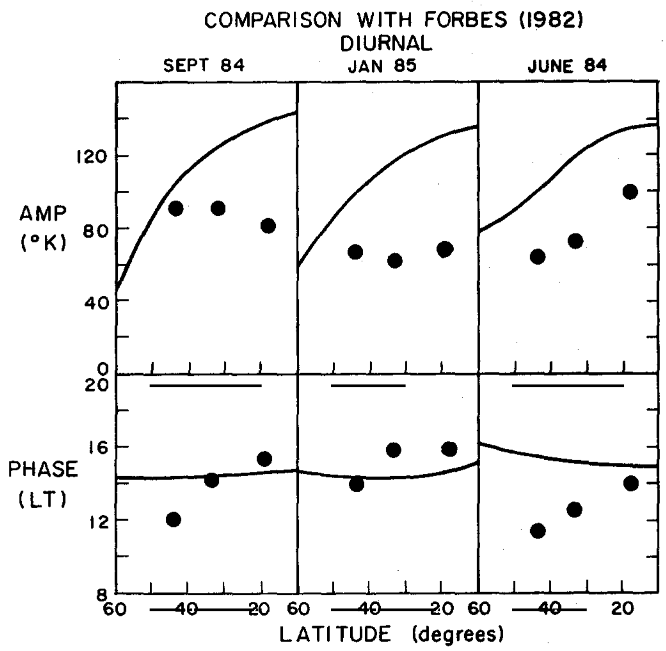

Fig. 6. Comparison of diurnal temperature amplitudes and phases (see Table 1) with simulations from the Forbes /1,2/ model.

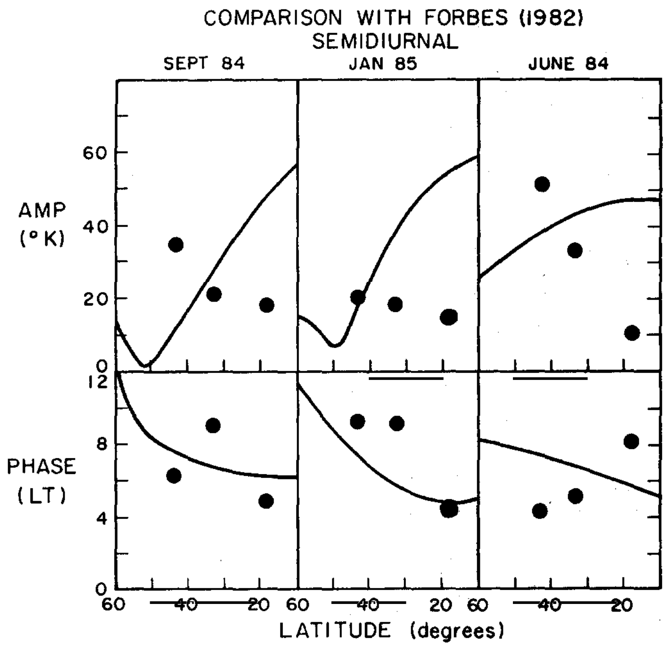

Fig. 7. Same as Fig. 6, except for semidiurnal component.

accounts for the double-peaked diurnal structure and its latitude dependence as noted previously. For the relatively low solar activity conditions corresponding to 1984 and 1985, one anticipates enhanced penetration of solar semidiurnal tides excited at lower levels /5,6,7/ and reduced in-situ excitation. The long-wavelength symmetric (2,2) and antisymmetric (2,3) modes penetrate above 150 km far more efficiently than the higher-order shorter-wavelength (2,4), (2,5), (2,6) modes, so one might anticipate that the (2,3) mode would be required to account for the amplitude and phase structure differences between the January and June observations in Figure 7. Within the Forbes /1,2/ model the (2,3) Hough mode extension plays a relatively minor role in determining F-region temperature sturctures. This occurs because the (2,3) fields directly excited by isolation absorption and indirectly excited through mean flow interactions tend to cancel within the 80- 100 km height region. This result, however, is sensitive to the assumed mean wind distribution, which in the case of the Forbes model is a generic one for solstice conditions originally used by Lindzen and Hong /8/. The in-situ component of the thermospheric semidiurnal variation may also benefit from more realistic parameterization of ion drag as discussed above for the dirunal component.

In conclusion, the exospheric temperature structures depicted here reflect amplitude and phase latitudinal structures of the diurnal and semidiurnal harmonics which are not particularly well reproduced by numerical simulations, and which suggest that improvements are necessary in the model F-region plasma density distributions and mean zonal winds at lower altitudes. Another means of arriving at more realistic model calculations would be to utilize lower thermosphere radar (meteor, partial reflection , Thomson scatter, MST) measurements of tidal winds to specify lower boundary conditions (ca. 95 km) of a thermospheric simulation model /9/.

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