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PETER W. BLUM

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DIURNAL VARIATION OF THE THERMOSPHERE FROM SATELLITE

DRAG DATA

Peter W. Blum*
Laboratory for Planetary Atmospheres
Goddard Space Flight Center
Greenbelt, Maryland 20771

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*NRC/NAS Research Associate

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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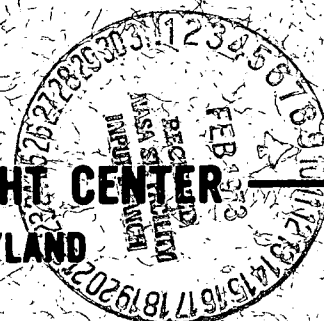Laboratory for Planetary Atmospheres
Goddard Space Flight Center

Three main observational methods for the determination of the diurnal variation of the thermosphere exist at present: satellite drag analysis, radar back scatter observations and satellite borne mass-spectrometry. The third method is very promising, but most data that have become available until now are from drag analysis and radar observations. Radar observations have a high time resolution and therefore yield on analysis detailed information on the various harmonic components of thermospheric temperatures. Drag analysis has on the other hand a low time resolution and therefore much less information on the higher harmonic components of the diurnal density variation may be derived from it. The phase discrepancy that is observed between thermospheric densities and temperatures, which is most pronounced in summer, is probably an effect due to the higher harmonics of the diurnal variation. This may be deduced from recent radar observations (Salah and Evans, 1972) which show that the fundamental components of temperature and density show no such discrepancy. For this reason the accuracy of the determination of the various harmonics of the diurnal density variation from drag data is of interest.

The results of satellite drag analysis are generally considered to be represented accurately by Jacchia empirical atmospheric models (Jacchia, 1972). The dependence of the density on the various physical parameters as for instance local time, latitude, solar activity and season is included in these models. Thermospheric densities are described in terms of model temperatures which are not necessarily identical with the true kinetic temperatures. Jacchia's expression for the latitudinal and local time dependence of the model temperatures yields on harmonic analysis diurnal and higher components. In the isothermal region an indication for the phases and relative amplitudes of the higher harmonics (i.e. the amplitude ratio of the harmonic component to the amplitude of the fundamental) of thermopheric densities may be obtained by considering the relevant values for the model temperatures. This affords only a very rough approximation as in the isothermal region these values are constant for the temperatures, but height dependent for the densities with an increase of the higher harmonic content with increasing altitude. Also the phase discrepancy

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between temperature and density is neglected but for the considerations presented here the approximation is sufficient. The presence of at least one higher order Fourier component of thermospheric densities is certain, as the time difference between the extrema of density is not exactly 12 hours, but closer to 11 hours and the minimum is definitely flatter than the maximum. In the Jacchia model the diurnal component has the largest magnitude, the semi-diurnal and third order component have an amplitude of 0.159 and 0.02 respectively of the fundamental amplitude with a rapid decrease of the higher components. The phase, i.e. the time of the maximum of the first harmonic is at 14.3 hours L. T., the semi-diurnal component peaks at 13.8 hours L. T. (Blum and Harris, 1972). It will be examined how far this harmonic analysis yields data that are supported by observations.

The density data derived from drag analysis have undergone considerable smoothing due to the inherent low time resolution of the method (Jacchia, 1972). The physical parameters that are observed are actually the times of the extremes of density and the density ratio at these times. For the determination of the first and second harmonic of the diurnal variation four parameters are required: the amplitudes and phases. As only three observables are available it is clear that there exists some degree of freedom in the particular choice of the four parameters. The times of the extrema are only dependent on the phases of the harmonic components and the ratio of their amplitudes. Once these are fixed, then the density ratio at the times of the extrema depends only on the amplitude ratio of the diurnal component and the zero-order component. In the Jacchia model the density ratio at the times of the extrema is latitude-dependent, while the times themselves are independent of latitude. We have investigated what variation of the phases and amplitude ratio of the first two harmonics is possible without causing a marked deviation of the model from observations. The times of the extrema in the Jacchia model are 14.2 and 3.2 L. T. For a given amplitude ratio of the first two harmonics, the phases of these harmonics are completely determined by the times of the extrema. A lower limit for this amplitude ratio is given by the 11 hour difference between the extrema which implies that the ratio of the amplitude of the semi-diurnal component to the diurnal component is not negligible and cannot be less than 0.06. An upper limit for the amplitude ratio arises from the condition that only one minimum is observed. This latter condition limits the ratio to 0.28. In the Jacchia model this ratio is actually 0.159 (Blum and Harris, 1972).

It is interesting to note that from Salah and Evans (1972) radar observations the ratio of the semi-diurnal to the diurnal component of the kinetic temperature can be shown to vary between 0.13 and 0.28 according to season, so that at least as far as temperatures are concerned a good part of the possible range of the variation seems to be actually existing. In figure 1 the phases of the two

components for all permissible amplitude ratios are shown. On each curve the amplitude ratio is the parameter that changes with its value shown. As the times of the extrema themselves is not very accurately determined from observations, we have also calculated the phases when the time of the maximum is shifted by 0.2 and 0.4 hours from Jacchia's model and the minimum is shifted double these times, as it is flatter and less well determined. The resulting phases of the diurnal and semi-diurnal components are shown in figure 1 for deviations of the extrema in both directions. Figure 2 shows the shape of the diurnal variation that results from various values of semi-diurnal content. The times of the extrema of the three curves of the figure are exactly in accordance with Jacchia's model. It is seen that the phase of the diurnal component is rather well-determined, its uncertainty is less than one hour or 4%. On the other hand the uncertainty of the phase of the semi-diurnal component is more than two hours or about 20%. The amplitude ratio of the semi-diurnal component to the diurnal component is determined least well, its uncertainty factor is about 4. Evidently no physical significance should be attached to the third and higher component of the diurnal density variation as deduced from Jacchia's model, as their amplitudes and phases are due to Jacchia's choice of a particular mathematical expression to represent the density variation.

The existence of higher harmonic components than the semi-diurnal in the exospheric temperature variation is well established by back scatter radar observations. These components must cause components of comparable order of magnitude in the density variation. Salah and Evans have deduced from their observations a third harmonic component that is only slightly less than the semi-diurnal component. Our estimate on the uncertainty of the semi-diurnal density component was based on the assumption that the third and higher components are negligible compared to the semi-diurnal component, as expressed in Jacchia's formula. If this estimate is not quite correct, and the radar observations point to this, then the situation is changed drastically and no deduction regarding the relative amplitude and phases of the semi-diurnal and higher components may be deduced from drag data at all.

It may be advisable to take the uncertainties described here into account when a comparison is made between theoretical results derived with a use of Fourier analysis and the drag determined densities of the thermosphere.

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Jacchia, L., S.A.O. Special Report 332, 1972.

Salah, J.E. and J.V. Evans, Measurements of thermospheric temperatures by incoherent scatter radar, 1972, COSPAR Conference, Madrid, Spain.
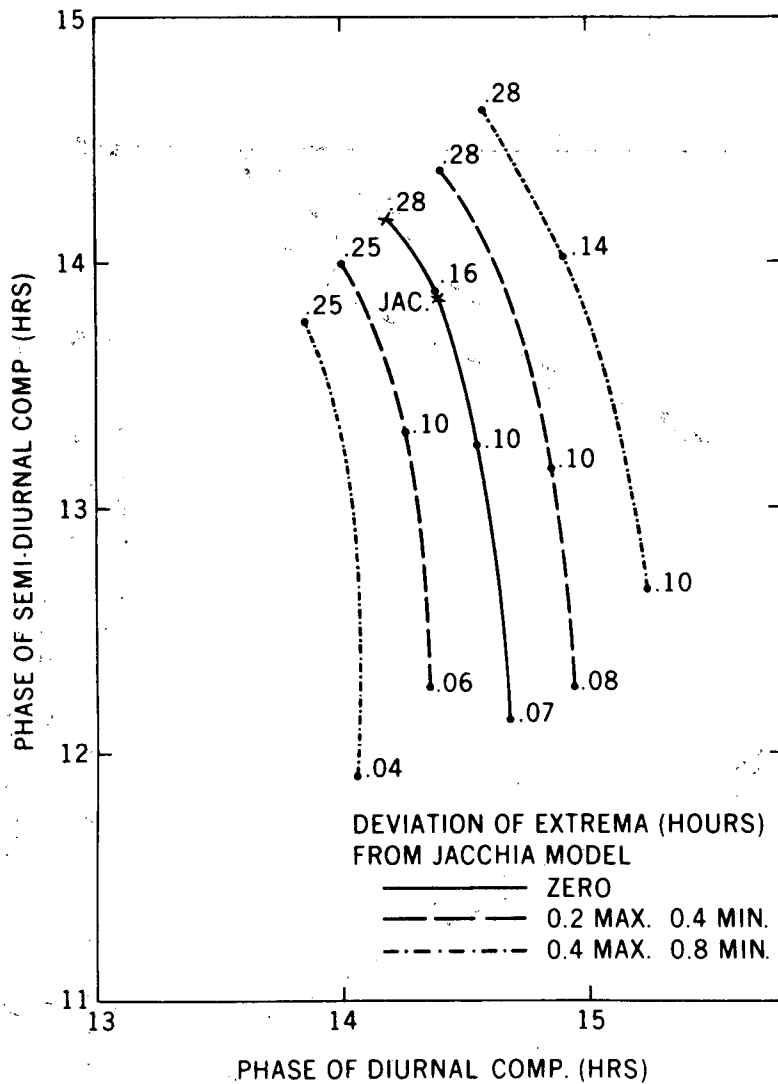
Figure 1. Possible combinations of the diurnal and semi-diurnal
components of the diurnal variation of the thermosphere
that are all in accordance with satellite drag data. Each
curve represents a diurnal variation that has exactly the
same times of the extrema. The solid curve corresponds
to Jacchia's model, the other curves have deviations of
the time of the maximum of 0.2 and 0.4 hours and of the
time of the minimum of 0.4 and 0.8 hours from the
Jacchia model. The parameter that changes along each
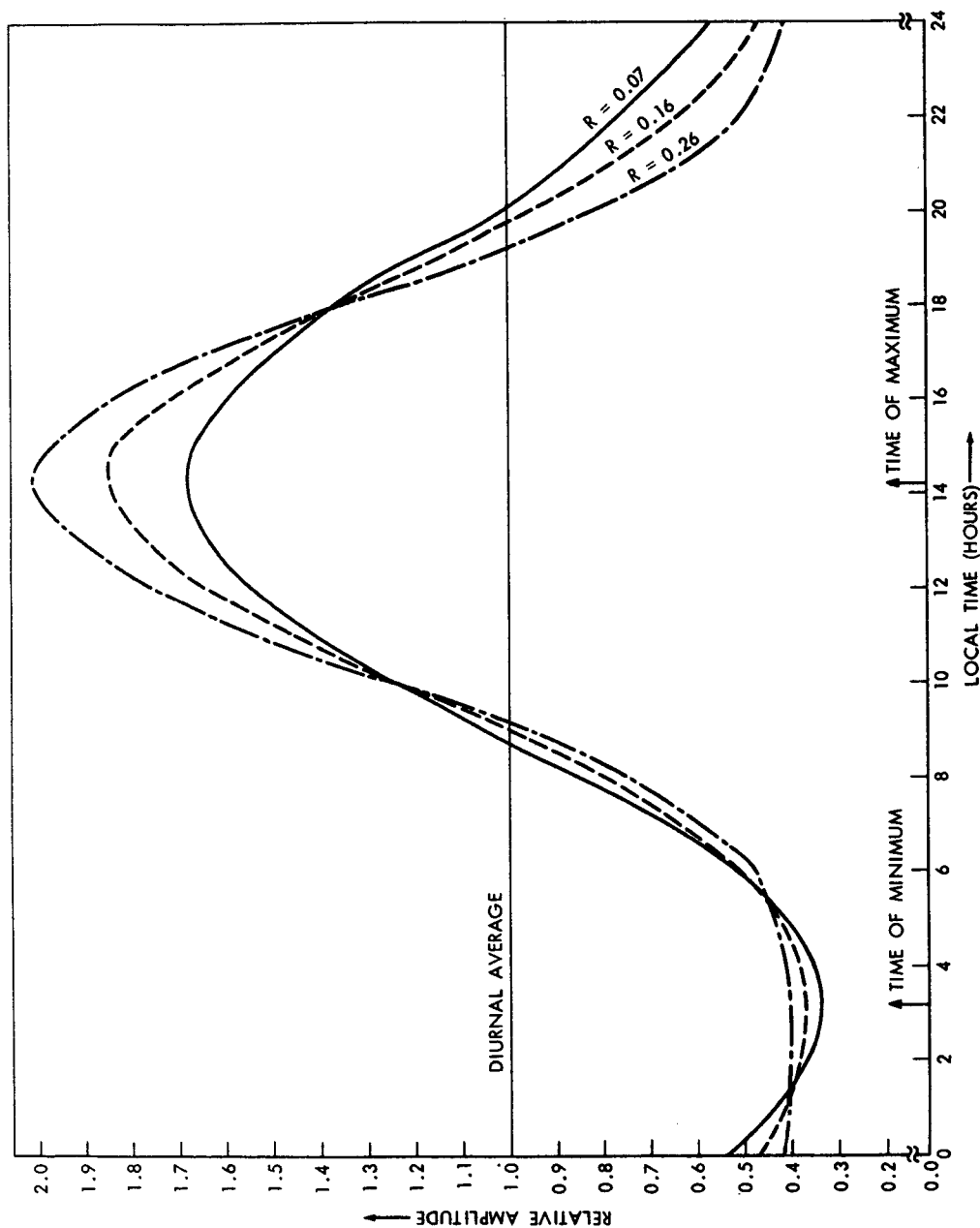curve is the ratio of the amplitudes of the semi-diurnal
to the diurnal component.

Figure 2. Shape of the diurnal variation for three values (0.07, 0.16 and 0.26) of the ratio R of the amplitudes of the semi-diurnal to the diurnal component of the thermospheric diurnal variation. All curves have exactly the same times of the extrema as the Jacchia model (i.e. they correspond to three points of the solid curve of figure 1). Furthermore their diurnal average is equal and the ratio of the maximum to the minimum was adjusted to 5 for all curves. The curve with the amplitude ratio 0.16 is in accordance with Jacchia's model.

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