Seasonal Variation in Equatorial Mesospheric Temperatures Observed by SME

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(Manuscript received 26 May 1989, in final form 10 January 1990)

ABSTRACT

Observations made by the Solar Mesosphere Explorer (SME) satellite from 1982 through 1986 are used to examine the seasonal variation of temperature in the equatorial mesosphere between 58.5 and 90 km. Near the equator, seasonal variability is dominated by a strong semiannual oscillation (SAO) whose amplitude increases from about 3 K in the lower mesosphere to 7.3 K near 80 km. Above 80 km, the amplitude of the oscillation decreases to a minimum at 83 km, but increases again sharply above that level, reaching 16.6 K at 90 km, the highest level observed. The structure of the temperature SAO is consistent with previous observations of the SAOs in temperature and zonal wind, although the very large amplitude at 90 km may be due in part to contamination by the diurnal tide. Just below 80 km, temperatures are warm (cold) near the solstices (equinoxes), implying westerly (easterly) accelerations above; the behavior at 85.5 km lags that at 80 km by about 2 months.

There is evidence in the data for a seasonal asymmetry in the temperature oscillation, the cycle encompassing Northern Hemisphere winter and spring being strongest. The asymmetry is particularly large in the development of the warm anomaly in the lower mesosphere, which at 60–70 km is over 5 K larger in February than in August. The behavior parallels that documented by Delisi and Dunkerton for the stratospheric SAO, and is consistent with their suggestion that planetary wave driving plays an important role in the development of the oscillation.

1. Introduction

Seasonal variability of the mean zonal wind and temperature fields in the equatorial upper stratosphere and mesosphere is dominated by the semiannual oscillation (SAO). The SAO was identified by Reed (1962) in radiosonde observations of stratospheric temperature, and its existence has been confirmed by numerous other observational studies of the stratosphere and mesosphere (e.g., Reed 1965, 1966; Quiroz and Miller 1967; van Loon et al. 1972; Belmont et al. 1974, 1975; Cole and Kantor 1975, 1978; Hopkins 1975). Hirot a (1978, 1980) and Hamilton (1982) have shown that the zonal wind SAO extends throughout the mesosphere, where a second maximum in amplitude, comparable to that at the stratopause, is found near 80 km. For the mesospheric temperature SAO, the data compiled by Cole and Kantor indicate a large amplitude oscillation, with separate peaks of 6 and 8 K at 75 and 90 km, respectively.

Recent work has employed satellite measurements to document the existence of the SAO in the stratosphere and lower mesosphere. An advantage of satellite observations is their much denser coverage in both space and time. Crane (1979) used one and one-half years of data from the pressure modulator radiometer (PMR) on Nimbus-6 to demonstrate the existence of the temperature SAO in the stratosphere and mesosphere. He identified amplitude maxima of only 2 K near the stratopause and mesopause. Gao et al. (1987) found a semiannual amplitude maximum of 2.4 K in the upper stratosphere in their analysis of satellite microwave and infrared radiance data from NOAA satellites. Because of the coarse vertical resolution (10–15 km) of PMR and the NOAA radiometers, the values obtained by Crane and Gao et al. (which are considerably smaller than obtained from rocketsonde observations) must be considered underestimates of the true SAO amplitude.

Hitchman and Leovy (1986) presented a thorough study of the SAO using data derived from the Limb Infrared Monitor of the Stratosphere (LIMS) on Nimbus-7. For the relatively short period in 1978 and 1979 covered by these data, they showed the presence of a strong oscillation in the upper stratosphere and lower mesosphere, with maximum amplitude near the stratopause. Although Hitchman and Leovy did not com-
pute the amplitude of the semiannual harmonic, a peak-to-peak variation of some 10 K between December and March at 45 km is apparent in their Fig. 3. This is considerably larger than the estimates obtained from nadir-sounding instruments, as expected from the much better vertical resolution of LIMS. Hitchman and Leovy also derived zonal mean winds from the temperature data under the assumption of thermal wind balance and remarked on the asymmetry between the strong easterly phase at the stratopause in northern winter and the weaker easterlies in southern winter. Such asymmetry in the SAO has also been noted by Belmont et al. (1975) and Hopkins (1975), and has been studied in detail recently by Delisi and Dunkerton (1988a,b) using temperature data from the Stratospheric and Mesospheric Sounder (SAMS) aboard Nimbus-7.

Despite individual differences, a consistent picture of the equatorial SAO emerges from these studies. Its salient features are distinct amplitude maxima near the stratopause and mesopause, downward phase progression of the wind and temperature anomalies, out-of-phase behavior between the mesopause and stratopause maxima, and a pronounced asymmetry between successive cycles such that the cycle encompassing northern winter and spring is significantly stronger than its counterpart in southern winter and spring. The wind and temperature SAOs represent two facets of a single, dynamically driven phenomenon (e.g., see Hitchman and Leovy 1986). Although behavior in the stratosphere is well established from a wealth of observational studies, the evolution of the SAO in the mesosphere is much less thoroughly documented. In particular, there are few data describing the seasonal variation of temperature in the mesosphere. The detailed satellite analyses of Hitchman and Leovy (1986) and Delisi and Dunkerton (1988a,b) extend only into the lower mesosphere, and do not capture the second amplitude maxima in temperature near the mesopause. Aside from the study of Crane (1979) using PMR data and rocketsonde analyses from a few tropical stations, such as those reported by Koshel’kov and Butko (1980) and Cole and Kantor (1975, 1978), the behavior of the temperature SAO at altitudes above 65 km is largely undocumented.

The purpose of the present study is to examine the seasonal variability of mesospheric equatorial temperatures derived from radiance observations made by the Solar Mesosphere Explorer (SME) satellite during 1982–86. Although some of these data have been discussed briefly in the recent paper by Clancy and Rusch (1989), they have not been compared with other measurements of the mesospheric SAO, nor have their implications been examined in detail. The SME observations provide nearly five years of continuous coverage at altitudes between 58.5 and 90 km with relatively high vertically resolution (≈4 km). The principal limitations of the data are their limited longitudinal coverage and the fact that the measurements must be averaged over one month to enhance their reliability. Thus, computation of true zonal means averaged over short periods, as was done by Hitchman and Leovy and by Delisi and Dunkerton, is not possible with the SME dataset. In addition, it is well known that significant zonal asymmetries (planetary waves, inertial instabilities) may be found in the vicinity of the equator (Hitchman and Leovy 1986). However, it may be anticipated that contamination by such zonally asymmetric motions (with the possible exception of the diurnal tide; see section 3) will be much reduced in the monthly mean values studied here.

Section 2 of the paper discusses briefly the SME temperature retrievals, resolution, and spatial and temporal coverage. The seasonal variation of mesospheric temperatures is presented in section 3, where it is shown that a marked seasonal asymmetry, paralleling that found in the stratosphere by Delisi and Dunkerton, is also present at mesospheric levels in each of the years examined. Conclusions and implications of the analysis are summarized in the last section.

2. SME mesospheric temperature retrievals

The mesospheric temperatures analyzed in this paper were derived from global observations made by the ultraviolet spectrometer (UVS) on board the SME spacecraft. The UVS measured limb profiles of Rayleigh scattered solar irradiance within two 1-nm passbands, typically 265 and 296 nm. Clancy and Rusch (1989) derived atmospheric densities from these limb radiances to obtain mesospheric temperature profiles with ≈4 km vertical resolution. A detailed error analysis of SME temperatures is provided in the paper by Clancy and Rusch. Here we mention only the most important features and limitations of the data.

The small signal-to-noise ratio of the UVS radiances constrain the temporal resolution of the temperature profiles to monthly averages. Thus, mesospheric temperatures are available as monthly mean profiles from January 1982 through September 1986 and as composite annual profiles, constructed by averaging over the 1982–86 data for each month of the year. The near-polar orbit of SME provided daily coverage over sunlit latitudes at intervals of 5° and at a fixed local time of approximately 3:00 pm. Vertical coverage extends between 58.5 and 90 km at 3.5 km altitude intervals. At 90 km, one-sigma temperature errors for the 5-year climatology are ≈9 K, but they decrease to 1–2 K below 80 km. Trends in SME temperatures due to calibration drifts are less than 0.3 K yr⁻¹; observed trends over the 1982–86 period range from −1.5 to +1.0 K yr⁻¹.

The SME temperature profiles do not represent true zonal averages, since on a given day only 3 to 5 longitudes are sampled. In Fig. 1 the equatorial longitudes observed by SME are indicated as a function of time.
The pattern of longitudinal coverage changed several times during the 1982–86 period. Nevertheless, comparisons of longitudinal differences among SME observations (Clancy and Rusch 1989) indicate only modest biases in the monthly mean values due to the nonzonal coverage.

3. The seasonal variation of temperature in the equatorial mesosphere

Figure 2 shows monthly mean temperature departures from the time mean for the series as a function of height for the period January 1982 through September 1986. The behavior, which is substantially the same at all latitudes within 15° of the equator (not shown), is dominated by a semiannual oscillation at essentially all levels. It is also apparent that the principal features of the seasonal cycle are repeatable from year to year. Peaks in the amplitude of this oscillation are found near 80 and 90 km, separated by a region of small amplitude centered around 83 km. Maximum peak-to-peak amplitudes are approximately 30 K at 90 km and 15 K at 80 km. The amplitude of the oscillation decreases steadily below 80 km until, near 60 km, peak-to-peak amplitudes are less than 5 K.

Below 85 km there is a noticeable asymmetry in the strength of successive semiannual cycles, such that the cycle that encompasses the December solstice and March equinox is considerably stronger than the cycle covering the remainder of the year. Delisi and Dunkerton (1988a,b) have referred to these cycles as the
"first" and "second" cycle of the SAO, a terminology that is adopted in the remainder of this paper. The warm anomaly that descends from the upper mesosphere throughout the first cycle is much larger in the lower mesosphere than its counterpart during the second cycle. In fact, the warm anomaly is so weak in the second cycle that positive deviations from the time mean are not seen in all years. For example, the temperature between 60 and 70 km in July of 1982 is warmer than in April or October, but still colder than the long-term time mean. By contrast, temperatures throughout the entire mesosphere are always warmer than the time mean during December and January, and much warmer in some cases (1982–83, 1984–85).

The strong warm anomaly that develops during the first cycle is usually followed by a strong cold anomaly, especially in the upper mesosphere. Thus, at 75–85 km, negative departures from the time mean are larger in most years during February and March than in August and September. Interestingly, in the lower mesosphere the behavior of the cold anomalies is much more uniform between the first and second cycles (compare, for example, May and October at 60–70 km). The behavior of the SAO in the mesosphere parallels closely that documented for the stratosphere by Delisi and Dunkerton using SAMS data, except that in the stratosphere the first cycle is characterized by large cold anomalies followed by large warm anomalies. The aforementioned features can be seen more clearly in Fig. 3, which shows an annual composite of the SME data for 1982–86. Note, in particular, the similarity between the seasonal asymmetry of the oscillations seen in Fig. 3 and in Fig. 6 of Delisi and Dunkerton (1988b).

Comparison of our results with those of Delisi and Dunkerton also reveals reasonably good agreement between the amplitude and phase of the SAO at the lowest level observed by SME (58.5 km) and the highest level observed by SAMS (8 scale heights, or approximately 56 km). Possible connections between the seasonal asymmetry of the SAO in the stratosphere and mesosphere are explored in section 4.

The very strong semiannual oscillation peaking at 90 km has not been discussed in detail previously. However, similar behavior can be seen clearly in the rocketsonde temperature data compiled by Cole and Kantor (1975, 1978). For example, the equatorial monthly mean temperatures at 90 km tabulated by Cole and Kantor (1978) are plotted in Fig. 4 as deviations from their annual mean. These data represent composites derived from observations made at several tropical stations (Ascension Island, Natal, Kourou, and Guam) at various times between 1964 and 1971; the longest temperature record, that for Natal, is less than three years long. For comparison, composite SME temperature anomalies at 90 km are also shown in the figure. Both sets of observations show a strong semiannual oscillation with maximum warm anomalies near the equinoxes and maximum cold anomalies near the solstices. However, the rocketsonde data show smaller peak-to-peak amplitudes than the SME composite. (Interestingly, they also indicate an asymmetry between the first and second cycles, something that is not apparent in the SME data at this level.) It is possible that the oscillation seen by SME at 90 km reflects the influence of tidal motions, particularly because SME observations are made over restricted longitude sectors at the same local time each day. Under these circumstances, seasonal variations in the amplitude or phase of the diurnal temperature tide can be expected to alias onto the monthly mean values. The seasonal variation of tidal motions in the lower thermosphere is rather poorly known. However, numerical modeling (e.g., Lindzen 1967; Forbes 1982) predicts large amplitudes for the diurnal thermal tide in the tropical lower ther-

![Figure 3](image1.png)

**Fig. 3.** Annual composite of temperature deviations (K) from the series mean for 1982–86 at the equator.

![Figure 4](image2.png)

**Fig. 4.** Annual cycle of temperature (K) at 90 km from tropical rocketsonde data (Cole and Kantor 1978; solid line) plotted as deviations from the annual mean. For comparison, SME composite temperature deviations from the annual mean at the equator are indicated by the dashed line.
mosphere. In addition, there are several sets of observations which suggest that the tide is subject to large seasonal variability in the tropics. For example, Vincent and Ball’s (1981) radar measurements indicate that the amplitude of the diurnal wind oscillation between 80 and 90 km at Townsville (19°S) is roughly a factor of 2 larger in November than in June, although its phase is relatively constant. Similarly, Aso and Vincent (1982) show diurnal wind amplitudes in March and September about twice as large as the amplitude in January. Because these tidal data cover periods of only a few days or weeks during certain months in different years, no definitive conclusion can be reached regarding seasonal variability. However, the data are consistent with a seasonal cycle having largest amplitudes near the equinoxes.

The amplitude and phase of the semiannual harmonic of temperature are shown as functions of altitude in Fig. 5a. For comparison, the semiannual harmonic extracted by Cole and Kantor (1975) from data obtained at Ascension Island and Natal between 1964 and 1968 is plotted in Fig. 5b. There is good qualitative agreement between SME and rocketsonde observations. In both cases the amplitude of the semiannual harmonic increases throughout the mesosphere to a maximum at 75–80 km, which is separated from an even larger amplitude peak at 90 km by a minimum near 82 km. The SME harmonic has amplitude of 7.3 K at 79 km and 16.6 K at 90 km. The 79 km value agrees fairly well with the magnitude (6 K) of the corresponding feature (at 75 km) in Cole and Kantor’s analysis, but the peak at 90 km is considerably larger. Rapid downward phase progression is evident in the SME data between 90 and 70 km, but below 70 cm the phase is nearly constant. Temperatures at 60–70 km lag those at 80 km by about 2 months; warmest temperatures occur in early December (and June) at 80 km and in mid-February (and August) at 60 km. Cole and Kantor’s semiannual harmonic exhibits somewhat faster phase progression in the mesosphere so that temperatures at 60 km lag those at 80 km by almost three months.

A further check on SME observations can be made by examining the semiannual wind harmonic computed by Hirota (1978) from rocketsonde data taken at Ascension Island in 1970 and 1971 (World Data Center A, 1975). Assuming that tropical zonal mean winds and temperatures are in approximate geostrophic balance, and taking the latitudinal derivative of the thermal wind equation at the equator, we have

$$
\bar{u}_x = -\frac{aR}{20H} \frac{\partial^2 \bar{T}}{\partial \psi^2}
$$

(1)

where $\psi = a \theta$, and $a$, $R$, $\Omega$, $H$ and $\theta$ are the radius of

Fig. 5. (a) Amplitude (solid line) and phase (dashed line) of the semiannual temperature harmonic at the equator extracted from the SME annual composite for 1982–86. A phase of 0 months corresponds to 1 January. (b) As in panel (a), except for the tropical rocketsonde data analyzed by Cole and Kantor (1975).
the earth, the gas constant for dry air, the earth’s angular frequency, the atmospheric scale height, and the latitude in radians, respectively. Overbars in (1) denote zonally averaged quantities.

According to (1), $\tilde{u}_z$ is proportional to the meridional curvature of $\tilde{T}$; i.e., to $-\tilde{T}/L^2$ where $L$ is a characteristic horizontal scale. Examination of SME data reveals no obvious differences in the meridional scale of temperature anomalies in the tropics (not shown), so $\tilde{T}$ may be estimated from $\tilde{u}_z$ to within a constant factor $L^2$. Specifically, if we express the semiannual wind harmonic as

$$\tilde{u}_{z,\text{SAO}} = A(z) \cos(\phi(z))$$

where $A(z)$ and $\phi(z)$ are the amplitude and phase of the semiannual Fourier component of $\tilde{u}_z$, then

$$\tilde{u}_{z,\text{SAO}} = (A_2^2 + A_2^{2\phi_2^2}) \cos(\gamma(z)),$$

where $\gamma(z) = \tan^{-1}(A\phi_2/A_2) + \phi(z)$.

The oscillation described by (3) should then be proportional to the semiannual temperature harmonic; i.e.,

$$\tilde{T}_{\text{SAO}} = \frac{2\Omega H L^2}{a R} \tilde{u}_z.$$

Figure 6 shows the amplitude and phase of $\tilde{u}_z$ obtained as in (3) from Hirota’s data. This can be compared with the semiannual harmonics of the SME and rocketsonde temperature data (Fig. 5). Incidentally, if one assumes a meridional scale $L = 15^\circ$, then (4) gives $\tilde{T} = 1.55 \tilde{u}_z$, which from Fig. 6 yields values of approximately 6 K at 80 km and 7.7 K at 90 km. Thus, both the structure and amplitude of $\tilde{u}_z$ are quite consistent with the rocketsonde temperature data, a result that is gratifying since Hirota’s winds and Cole and Kantor’s temperatures are derived from different sets of rocketsonde observations. Further, the exercise demonstrates that large amplitudes for the temperature SAO at 90 km are implied under geostrophic balance by the rapid decay of the wind oscillation above 80 km.

The semiannual harmonic of $\tilde{u}_z$ is also consistent with SME data, but there are important differences. Like the SME temperature observations, the amplitude of $\tilde{u}_z$ shows a peak in the upper mesosphere and an even larger maximum at 90 km. However, the mesospheric peak in $\tilde{u}_z$ is located at 75 km, and the maximum at 90 km is only 20% larger than the peak at 75 km. By contrast, the semiannual amplitude peak in SME data at 90 km is more than twice as large as the maximum at 80 km.

In spite of these differences between SME observations and rocketsonde analyses, the same principal features are present in both sets of data. There is, in particular, strong agreement on the presence of a large mesospheric temperature SAO that grows with altitude to a peak in the vicinity of 80 km. There is also evidence for an even larger semiannual peak at 90 km, which is consistent with the behavior of the wind SAO.

4. Summary and discussion

Perhaps the most striking feature of the mesospheric temperature oscillation observed by SME is the strong seasonal asymmetry between 60 and 85 km, which parallels that documented for the stratosphere by Delisi and Dunkerton (1988a,b). In both stratosphere and mesosphere the first cycle of the semiannual oscillation, encompassing Northern Hemisphere winter and spring, is considerably stronger than the second cycle. Delisi and Dunkerton have suggested that the seasonal asymmetry of the stratospheric SAO is the result of stronger planetary wave activity in northern winter. Body forces exerted by planetary waves propagating into the tropics and advection of zonal mean momentum by the wave-driven meridional circulation lead to stronger easterlies at the stratopause and colder stratospheric temperatures in northern winter. Stronger equatorial westerlies (and warmer temperatures) during northern spring are then produced by enhanced transmissivity of eastward-propagating gravity and Kelvin waves through the winter easterlies leading subsequently to stronger wave-induced westerly accelerations. Nonlinear advection in the upper, equatorward branch of the circulation cell
induced by extratropical wave forcing could also contribute to the westerly phase. (See Fig. 13 of Delisi and Dunkerton, 1988b, for a schematic representation of the process.)

The seasonal asymmetry of the mesospheric SAO can also be ascribed to interhemispheric differences in planetary wave activity. Specifically, the mechanism proposed by Delisi and Dunkerton to account for the strong westerly phase of the stratopause SAO in northern spring may be envisaged to operate at mesospheric altitudes throughout northern winter. Thus, the strong stratospheric easterlies of Northern Hemisphere winter would facilitate transmission into the mesosphere of eastward-propagating gravity waves and lead, upon wave breaking, to strong westerly forcing and large warm anomalies during this season. Insofar as strong stratospheric easterlies are the result of nonlinear advection by the meridional circulation cell forced by planetary waves in Northern winter, one might also expect the upper branch of this wave-driven circulation to contribute to westerly accelerations and positive temperature tendencies in the mesosphere.

The strong mesospheric westerly phase would propagate downward during the course of winter, reaching the stratopause by northern spring. The large cold anomaly that develops in the upper mesosphere at this time could be attributed, by analogy to Delisi and Dunkerton’s (1988b) mechanism, to enhanced transmissivity of westward-propagating gravity waves that produce easterly accelerations underlaid by cold temperatures. In this conception of the SAO, the solstitial behavior is strongly influenced by the effects of planetary wave driving on the mean meridional circulation, while the behavior about the equinoxes is driven primarily by breaking gravity waves (whose propagation is influenced by the wind system of the preceding solstice). In any case, some sort of semiannual forcing is required to produce the SAO, since in the absence of such forcing there is no reason to expect a semiannual period. An obvious source of semiannual forcing is planetary wave driving, whose effects maximize during the solstices. The well-known asymmetry in wave activity between northern and southern winter would then be a natural candidate for explaining the asymmetry of the SAO. Without further observational evidence and numerical modeling this view must be regarded as speculative, but it is an attractive working hypothesis when the striking similarities between the stratospheric and mesospheric SAOs are considered.

The other notable feature identified in our analysis of SME temperature data is a very large semiannual harmonic (16.6 K) at 90 km. The existence of a strong semiannual signal at very high altitudes is consistent with previous analyses (Cole and Kantor 1975, 1978), but the possibility that at least part of the variation seen by SME stems from contamination by the diurnal tide cannot be entirely dismissed. Nevertheless, assuming for the moment that a substantial fraction of the observed temperature oscillation represents a true oscillation in zonal mean temperature, it is interesting to speculate on its implications for the tropical meridional circulation in the lower thermosphere. Taking the thermal relaxation rate at these altitudes to be of the order of 0.1 days \(^{-1}\) (e.g., Wehrbein and Leovy 1982), the temperature oscillation observed by SME at 90 km implies an oscillation in mean vertical velocity of about 0.1 cm s \(^{-1}\). From Fig. 3 it appears that such vertical velocity perturbations can be sustained for periods of perhaps 1–2 months near the extremes of the oscillation. In the lower thermosphere, the chemical families O\(_3\) and HO\(_2\) undergo a very rapid transition from complete photochemical control at 80 km to dynamical control above 90 km (Brasseur and Solomon 1986) and, as a consequence, have very large vertical gradients in mixing ratio. It seems likely then that vertical velocities of the magnitude inferred from SME temperature data will produce large semiannual variability in such chemical constituents.

Sun and Leovy (1989) have recently presented an analysis of ozone variability in the middle atmosphere from SME observations. These authors report a large semiannual oscillation in ozone near 90 km; i.e., coincident with the large temperature oscillation at this altitude. They attribute the ozone oscillation to changes in vertical diffusion caused by semiannual variability in the amplitude of the diurnal tide, which is hypothesized to break in the lower thermosphere. However, a large SAO in mean vertical velocity suggests an alternative explanation in terms of downward advection of ozone. Vertical velocities of 0.1 cm s \(^{-1}\) sustained for 1–2 months could transport large amounts of O\(_3\) (and hence ozone) from the production region above 90 km. Near 90 km, the O\(_3\) vertical e-folding scale \(h\) is no more than 4 km, which gives a transport scale \(h/\dot{\nu}\) \(\approx\) 40 days. This is comparable to the photochemical lifetime for O\(_3\) at this altitude, which is of order 1 month (Brasseur and Solomon 1986). Thus, a substantial ozone anomaly could be maintained in this region during periods of downward advection.

Downward advection of ozone by the dynamical SAO raises two further, interesting possibilities: That the zonal mean temperature SAO at 90 km is enhanced by ozone heating, and that there may be significant semiannual in situ forcing of tidal motions at this altitude.\(^1\) The last of this could conceivably help account for observations (Vincent and Ball 1981; Aso and Vincent 1982) which suggest the presence of semiannual variability in the diurnal tide; unfortunately, it also

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\(^1\) The ozone mixing ratio profile has a secondary maximum of almost 1 ppmv near 90 km that arises from the extremely rapid increase in the abundance of O\(_3\) between 80 and 90 km. Absorption of ultraviolet radiation at the level of the secondary maximum produces heating rates of 3–4 K day \(^{-1}\), making ozone the principal contributor to short wave heating at 90 km. (See, for example, Brasseur and Solomon 1986).
increases the ambiguity of interpreting SME data as representative of zonal mean behavior. The interpretation of the SAO at 90 km is further confounded by the fact that, although the O$_x$ family is relatively long-lived at 90 km, the partitioning between ozone and atomic oxygen is still temperature dependent, with higher temperatures tending to reduce ozone, and vice versa.

It is not possible at present to evaluate the relative importance of these intriguing mechanisms and the possible feedbacks among them. Observations of true zonal mean fields, performed with sufficient time resolution to avoid the possibility of aliasing by tidal components, as well as detailed numerical modeling of the equatorial dynamics of the upper mesosphere are necessary to disentangle the various threads of argument that will ultimately lead to a complete description of the semiannual oscillation in the mesosphere.

Acknowledgments. We wish to thank Karen Rosenlof of L.A.S.P. for her help in processing the SME data and for preparing the figures that illustrate the mesospheric temperature climatology.

REFERENCES


