LOW FREQUENCY OSCILLATIONS IN TOTAL OZONE MEASUREMENTS

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ABSTRACT

Low frequency oscillations with periods of approximately one to two months are found in eight years of global grids of total ozone data from the Total Ozone Mapping Spectrometer (TOMS) satellite instrument. The low frequency oscillations corroborate earlier analyses based on four years of data. In addition, both annual and seasonal one-point correlation maps based on the eight-year TOMS data are presented. The results clearly show a standing "dipole" in ozone perturbations, oscillating with 35-50 day periods over the equatorial Indian Ocean-west Pacific region. This contrasts with the eastward moving dipole reported in other data sets. The standing ozone dipole appears to be a dynamical feature associated with vertical atmospheric motions. Consistent with prior analyses based on lower stratospheric temperature fields, large-scale standing patterns are also found in the extratropics of both hemispheres, correlated with ozone fluctuations over the equatorial west Pacific. In the Northern Hemisphere, a standing pattern is observed extending from the tropical Indian Ocean to the north Pacific, across North America, and down to the equatorial Atlantic Ocean region. This feature is most pronounced in the NH summer.

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1. Introduction

In recent years, considerable attention has been focused on atmospheric ozone. In the first place, ozone protects living organisms by absorbing solar ultraviolet radiation shorter than about 290 nanometers. Secondly, this absorption of ultraviolet radiation constitutes an important heat source in the middle and upper atmosphere, so knowledge of the distribution of ozone and its spatial and temporal variation is crucial for accurate modeling of the atmosphere. Moreover, in the lower stratosphere, transport dominates the ozone distribution; therefore ozone may be used as a quasi-conserved tracer to provide useful information about dynamical transport in the lower stratosphere.

The Total Ozone Mapping Spectrometer (TOMS) carried by the Nimbus 7 satellite measures total ozone with high spatial resolution and the measurements have been performed since late 1978. The availability of this relatively long time series, with near global coverage, makes the TOMS data set suitable for the study of low frequency oscillations (periods in the range of one to two months) and their spatial correlations. It is just these oscillations which have recently been the focus of a considerable number of observational and modeling investigations. (See, for example, *Gao and Stanford* [1987, 1988a] and the references therein.)

TOMS data have been used recently in an increasing number of observational studies, especially those related to the depletion of ozone in the Antarctic. (See the special Antarctic Ozone Depletion issue of the *Geophysical Research Letters* [1986]).

Tung [1986] provided a theoretical basis for suggesting that changes in lower stratospheric temperature can lead to changes in column ozone concentration. He also pointed out that the column density of ozone should be fairly well correlated with the latitudinal as well as the longitudinal distribution of the large-scale temperature pattern at the altitude of maximum ozone partial pressure.

In the lower stratospheric temperature field, large-scale low frequency oscillations with periods around 40-50 days have been observed [*Gao and Stanford*, 1987, 1988a]. Based on Tung's theoretical idea, low frequency oscillations observed in the temperature field can be expected to be reflected in total ozone measurements. A natural question then arises, viz., is there a related low frequency oscillation in total ozone? *Sabutis et al.* [1987] reported evidence for 35-50 day oscillations in TOMS data over the southeast Pacific and southern Indian Oceans.

The motivation of the present paper is to examine the characteristics of the low frequency oscillations in the TOMS data in greater detail, using the recalibrated TOMS data set and with time series twice the length of those used in *Sabutis et al.* Moreover, in the present paper we present annually averaged and seasonal maps of spatial correlations of total ozone.

2. Data and Analysis

Eight years of TOMS data covering Jan. 1, 1980 through Dec. 31, 1987 are used for this study. The data were obtained in the form of daily 5 deg x 5 deg maps constructed from area averages of high spatial resolution global measurements. Due to the absence of sunlight, TOMS measurements are absent at the high latitudes of the winter hemisphere. We have therefore restricted our study to the regions equatorward of 60 degrees latitude in both hemispheres. In these regions total ozone measurements are available year around, so that the ozone time series data do not exhibit winter gaps.

Non-overlapping, three-day means were obtained from the daily grids. The three-day mean time series were then used for investigations of power spectra at various locations and were further used for spatial correlations of the low frequency oscillations. To simplify the computation, the total ozone $\Omega(\phi,\lambda,t)$ is Fourier analyzed by Fast Fourier Transformation:

$$\Omega(\phi,\lambda,t) = \sum_{n=0}^{487}[C_n(\phi,\lambda)\cos\omega_n t + S_n(\phi,\lambda)\sin\omega_n t] \quad (1)$$

where $\omega_n = 2\pi n/(2922 \text{ day})$, and ϕ and λ are latitude and longitude. C_n and S_n are Fourier coefficients of the time series.

Then the power spectrum $P_n(\phi, \lambda)$ for a grid with latitude ϕ and longitude λ can be obtained:

$$P_n(\phi,\lambda) = [C_n^2(\phi,\lambda) + S_n^2(\phi,\lambda)]/(2\Delta F) \quad (2)$$

where $\Delta F = (2922 \text{ day})^{-1}$.

The calculation of correlation is also performed in the spectral domain by using these same Fourier coefficients:

$$R(\phi,\lambda) = \sum_{\Delta\omega}[C_n(r)C_n(\phi,\lambda) + S_n(r)S_n(\phi,\lambda)]/[\sigma(r)S(\phi,\lambda)] \quad (3)$$

where $\sigma^2(\phi,\lambda) = \sum_{\Delta\omega}C_n^2(\phi,\lambda) + S_n^2(\phi,\lambda)]$.

The reference point for the correlation is denoted by (r). The correlations are made for a band of frequencies $\Delta\omega$. Further details about the method can be found in *Gao and Stanford* [1988b].

3. Results

3.1 *Power Spectral Densities*

The power spectrum of total ozone at latitude ϕ and longitude λ, $P_n(\phi,\lambda)$, is obtained from the Fourier coefficients by using formula (2).

To eliminate the effect of strong annual and semi-annual cycles, the annual oscillation and up to its seventh harmonic were removed, and their power replaced by the average values of their two neighboring spectral points.

The raw periodogram was smoothed with a 15-point running mean and the resulting bandwidths are indicated on the figures to follow. The power spectral density for total ozone in the southeast Pacific and southern Indian Oceans are shown in Figure 1.

The 35-50 day oscillations were observed at these two locations by *Sabutis et al.* [1987], based on analysis of four years of TOMS data covering 1 April 1979 through 3 April 1983. Subsequent to their analysis, the TOMS data have been carefully recalibrated [*Fleig et al.*, 1986]; furthermore, a significantly longer data set is now available. The present investigation utilizes this new global data set, starting with 1 January 1980 to avoid serious data gaps prior to that date.

The power spectral density results based on eight years of TOMS data show clear evidence for existence of the low frequency oscillation at both locations mentioned above. The spectra shown in Figure 1, from a significantly longer data set, corroborate the enhanced power near 35-50 day periods reported by *Sabutis et al.* [1987].

The power spectra for other regions were also investigated. In general, the results may be summarized by saying that the spectra of total ozone over tropical regions lack clear peaks in the low frequency range of 35 to 50 day periods. The power spectra of middle and higher latitudes show some low frequency peaks, and in many cases also show a strong peak at higher frequency, with periods of about 22 to 28 days. Some examples of these spectra are shown in Figure 2. Further study of these 22 to 28 day features is beyond the scope of present paper.

3.2 *Spatial Correlations*

In the lower stratospheric temperature field, *Gao and Stanford* [1988a] showed that the low frequency oscillations in extratropical regions were statistically correlated with the oscillations in the tropics; in addition, a possible midlatitude feedback path was observed in the correlation maps.

We have calculated similar correlation maps using eight years of TOMS data. For comparison with the Gao and Stanford results, we have also taken the reference point for the correlations to be located at Equator, 175 W. As in the earlier work, the zonal mean is removed. To emphasize the low frequency features, a bell-shaped bandpass filter is used. The filter covers 41 frequency points and has half-amplitudes at periods near 40 and 50 days. Figure 3 shows these correlation maps with various lags. Contour level intervals of 0.15 are used in these maps.

The lower correlation values in Figure 3 (compared with that in temperature field of our earlier study) is mainly due to the longer time coverage of this data set. However, longer time series lengths increase the temporal degrees of freedom and reduce the significance level needed for statistical correlation. The estimated temporal degrees of freedom for the bandpass filtered TOMS data used for the present correlation calculations is not less than 40, and the estimated 95 percent significance level at a given location is about 0.25. The same methods were used here for the estimations as those discussed in previous papers [*Gao and Stanford* 1988a, 1988b].

The previously known "dipole" structure over the equatorial Indian and Pacific Oceans is clearly visible in Figure 3. These two anti-correlated regions are about 90 degrees apart longitudinally, consistent with earlier observations (for example, *Lau and Chan* [1985]; *Weickmann et al.* [1985]; *Gao and Stanford* [1988a]). However, the "dipole" structure observed here does not show much eastward movement, in contrast with the eastward propagating dipole feature observed in lower stratospheric temperature and out-going longwave radiation analyses.

According to Tung [1986], the basic mechanism behind the good correlation between column ozone and lower stratospheric temperature is the vertical motion resulting from the temperature deviations from their radiative equilibrium value. The colder air has less radiative cooling, leading to more net heating and results in upward motion. In the time mean, this vertical motion, which is almost parallel to the gradient of ozone concentration, creates changes in ozone mixing ratio which has its maximum located in the stratosphere. To understand the dipole behavior observed in total ozone, perhaps one should associate the standing component in the temperature disturbance with the vertical motion and the traveling component with longitudinal advection. Since the longitudinal motion has no effect on a zonally symmetric ozone distribution (approximately true of the observed tropical total ozone field, *Bowman and Krueger* [1985], the associated longitudinal propagation feature does not cause a significant traveling dipole feature in total ozone.

In Figure 3, on the correlation maps with 0-, 5-, and 25-day lags, a response pattern is observed in the Southern Hemisphere (SH) extratropical region, consistent with the possible feedback path for low-frequency atmospheric oscillations observed previously in lower stratosphere temperature correlation maps [*Gao and Stanford*, 1988a].

In the Northern Hemisphere (NH), a relatively strong standing wave pattern is observed, extending approximately from the tropical Indian Ocean, to eastern China-Korea, to the North Pacific south of Alaska, over North America, and returning to the tropical Atlantic Ocean.

Figures 4 and 5 show the seasonal correlation maps for eight years of NH summers (1 April - 30 September) and NH winters (1 October - 30 May), respectively. The tropical Indian Ocean-west Pacific dipole is clearly seen in both seasons. The extratropical NH Pacific-North America-Atlantic standing wave pattern is most apparent in the NH summer (Fig. 4). The seasonal effects may reflect different source strengths, but also seasonally varying wind curvature effects which selectively allow or prevent propagation of the low frequency signals to higher latitudes.

4. Summary

Low frequency oscillations with period near 35-50 days over the southeast Pacific and southern Indian Oceans are observed in eight years of TOMS data. The power spectral densities of total ozone over these two regions corroborate the results reported by *Sabutis et al.* [1987] based on shorter time series.

One-point correlation maps are calculated and show a dipole feature over the tropical Indian Ocean-west central Pacific Ocean. The dipole feature observed in the TOMS data is located in the same region with the same period as that observed in lower stratospheric temperature analyses. In contrast, however, the dipole feature in the TOMS data does not show eastward propagation and is more indicative of a standing wave phenomenon, in the seasonal and annual means. An argument is given why ozone perturbations should show primarily a standing dipole, whereas traveling features are found in tropical temperature and cloud data sets.

Extratropical response patterns are visible in one-point correlation maps and are consistent with similar features observed in lower stratospheric temperature field analyses.

The standing component of the tropical dipole source region observed here, in contrast with the eastward traveling dipole seen in other studies, may offer at least a partial answer to the puzzling question of why there exist extratropical standing waves at all, given the previously observed eastward moving tropical source.

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REFERENCES

Antarctic Ozone Depletion (1986). *Geophys. Res. Letts., 13*, No.12, November Supplement.

Bowman, K. P., and A. J. Krueger, A global climatology of total ozone from the Nimbus 7 Total Ozone Mapping Spectrometer, *J. Geophys. Res., 90*, 7967-7976, 1985.

Fleig, A. J., P. K. Bhartia, C. G. Wellemeyer, and D. S. Silberstein, Seven years of total ozone from the TOMS instrument- A report on data quality, *Geophys. Rev. Letts., 13*, 1355-1358, 1986.

Gao, X. H., and J. L. Stanford, Low-frequency oscillations of the large-scale stratospheric temperature field, *J. Atmos. Sci., 44*, 1991-2000, 1987.

---, Possible feedback path for low-frequency atmospheric oscillations, *J. Atmos. Sci., 45*, 1425-1432, 1988.

---, An efficient approach for statistical calculations with globally gridded filtered time series, *J. Climate, 1*, 429-434, 1988.

Lau, K. M., and P. H. Chan, Aspects of the 40-50 day oscillation during the northern winter as inferred from outgoing longwave radiation, *Mon. Wea. Rev.*, 113, 1889-1909, 1985.

Sabutis, J. L., J. L. Stanford, and K. P. Bowman, Evidence for 35-50 day low frequency oscillations in total ozone mapping spectrometer, *Geophys. Res. Lett., 9*, 945-947, 1987.

Tung, K. K., On the relationship between the thermal structure of the stratosphere and the seasonal distribution of ozone, *Geophys. Res. Lett.*, *13*, 1308-1311, 1986.

Weickmann, K. M., G. R. Lussky, and J. E. Kutzbach, Intraseasonal (30-60 day) fluctuations of outgoing longwave radiation and 250 mb stream function during northern winter, *Mon. Wea. Rev.*, *113*, 941-961, 1985.

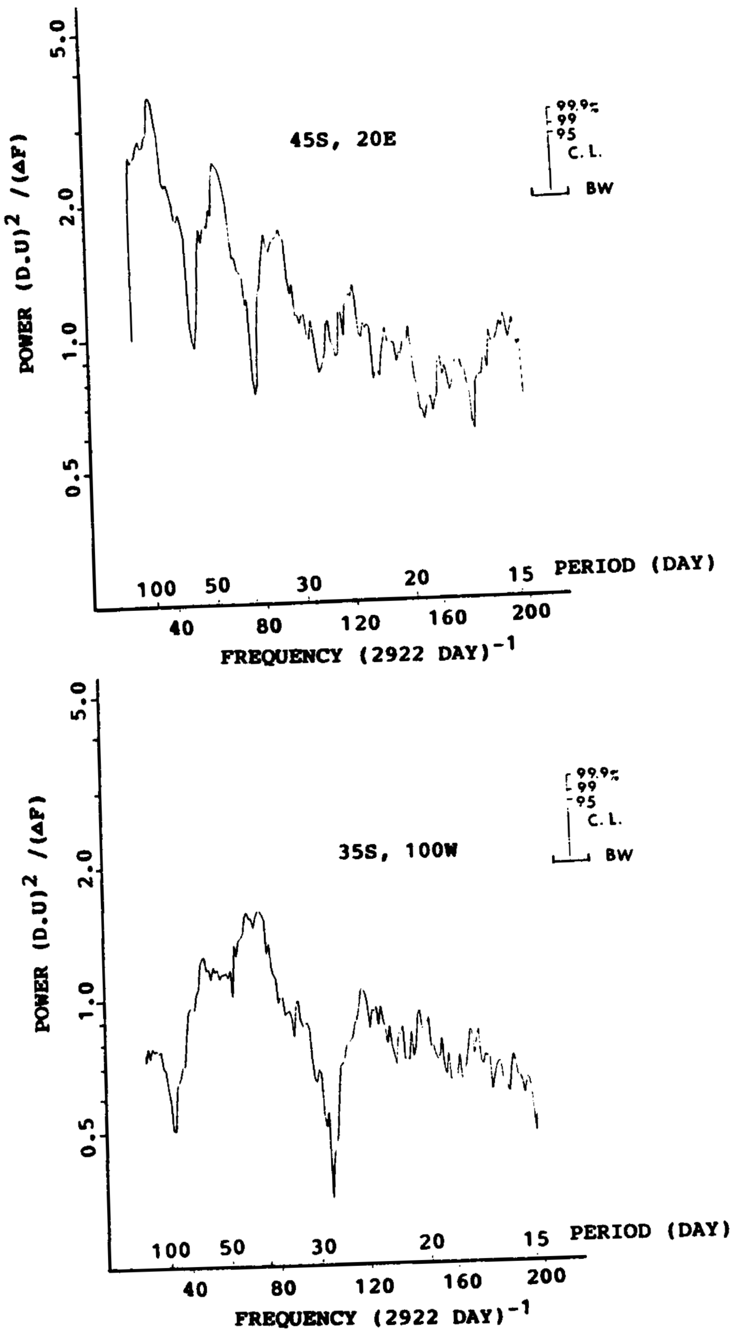
Fig. 1. Power spectral density vs. frequency of column total ozone at 35 S, 100 W and 45 S, 20 E. The spectra have been smoothed with 15-point running means and the resulting bandwidths (BW) are indicated. The C.L. (confidence level) scale is based on the chi-square distribution. D.U. stands for Dobson units and ΔF is defined in the text.

Fig. 2. As in Figure 1, except spectra of column total ozone at 55 S, 125 W and 35 S, 140 E, and Equator, 175 W.

Fig. 3. All-season data, one-point correlation maps of 40-50 day filtered TOMS ozone. Reference point: equator, 175 W. Contour level interval 0.15. Solid lines begin at R=0, dashed lines indicate anticorrelations. Lag time (days) as indicated. Data used: eight years (1 Jan. 1980 - 31 Dec. 1987) of TOMS.

Fig. 4. Same as Figure 3, but for NH summer (1 April - 30 September).

Fig. 5. Same as Figure 3, but NH winter (1 October - 31 March).



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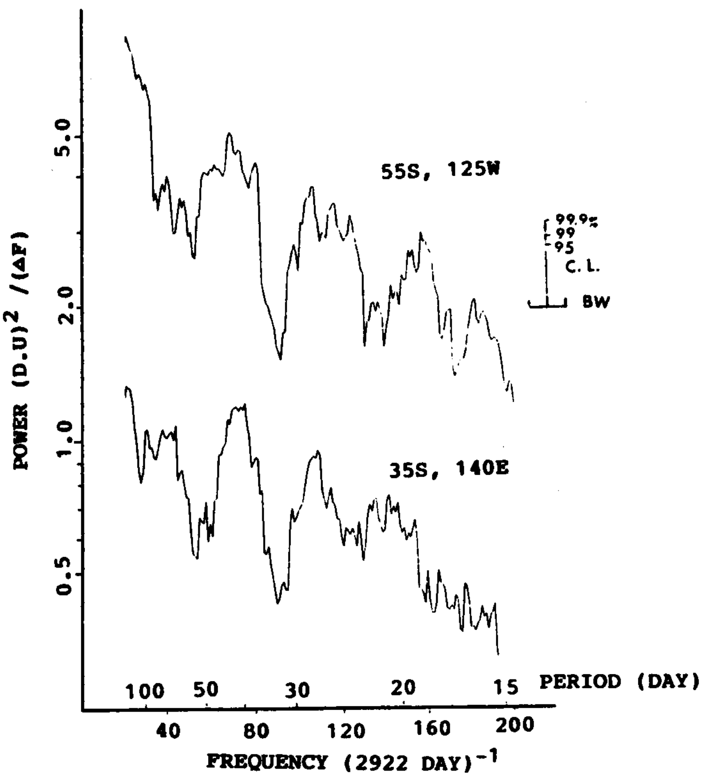

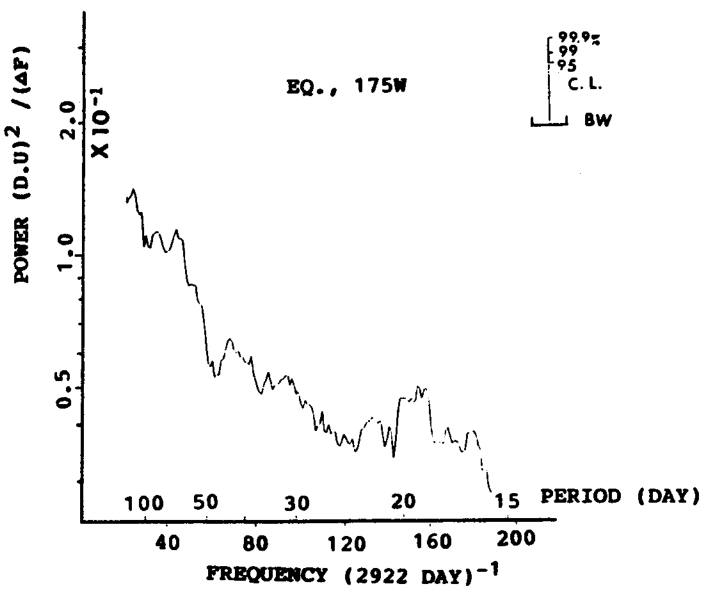

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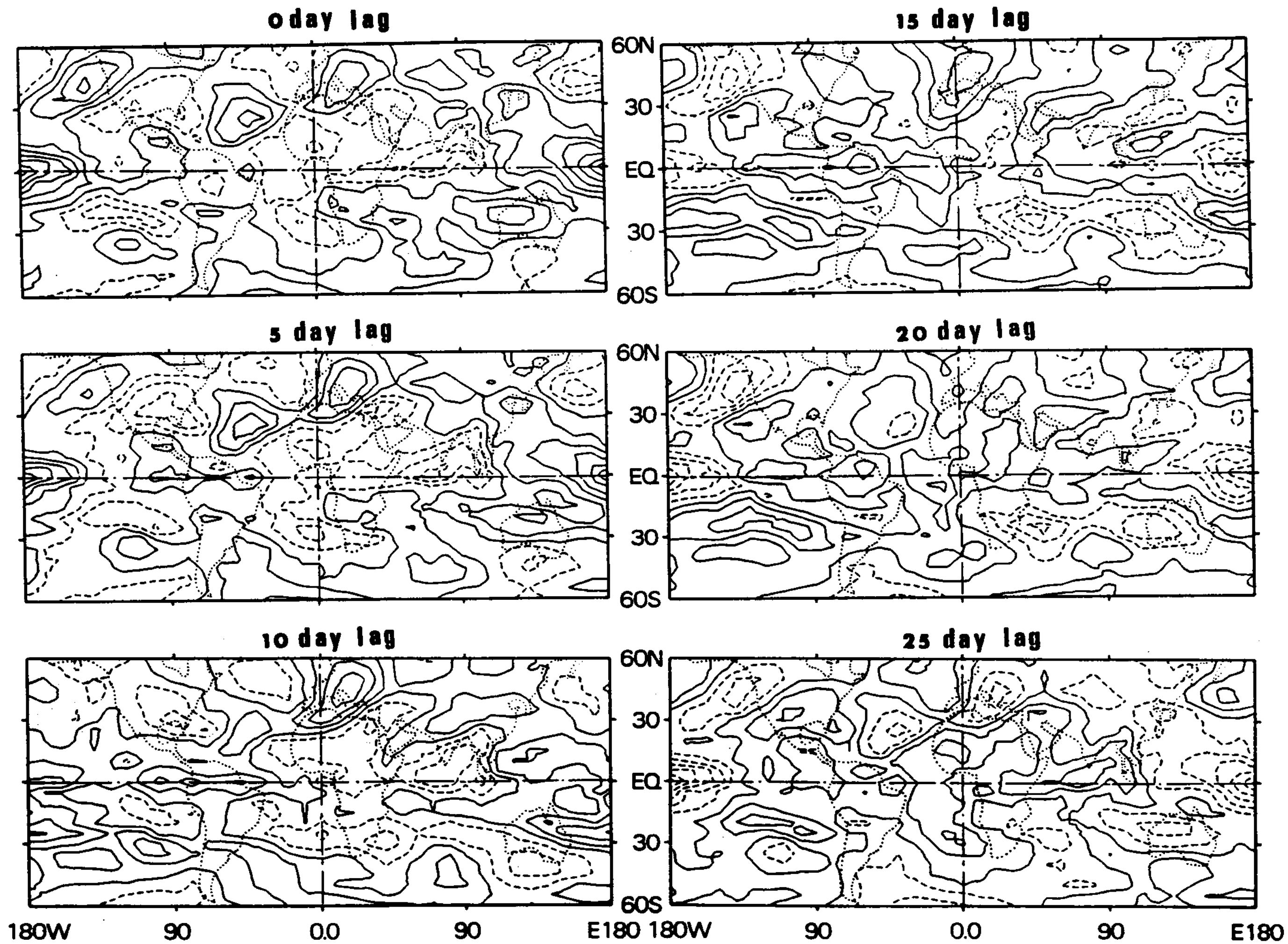

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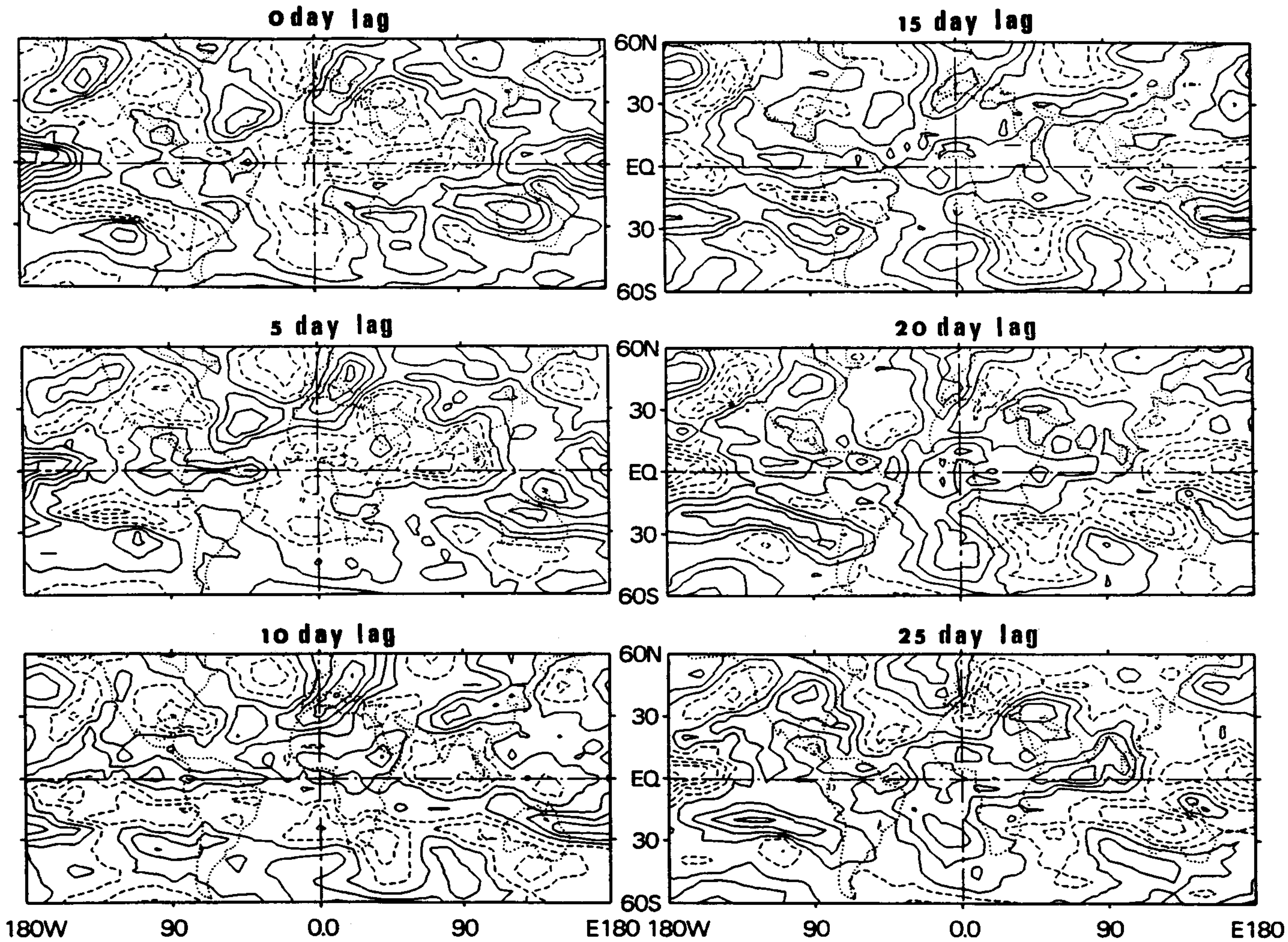

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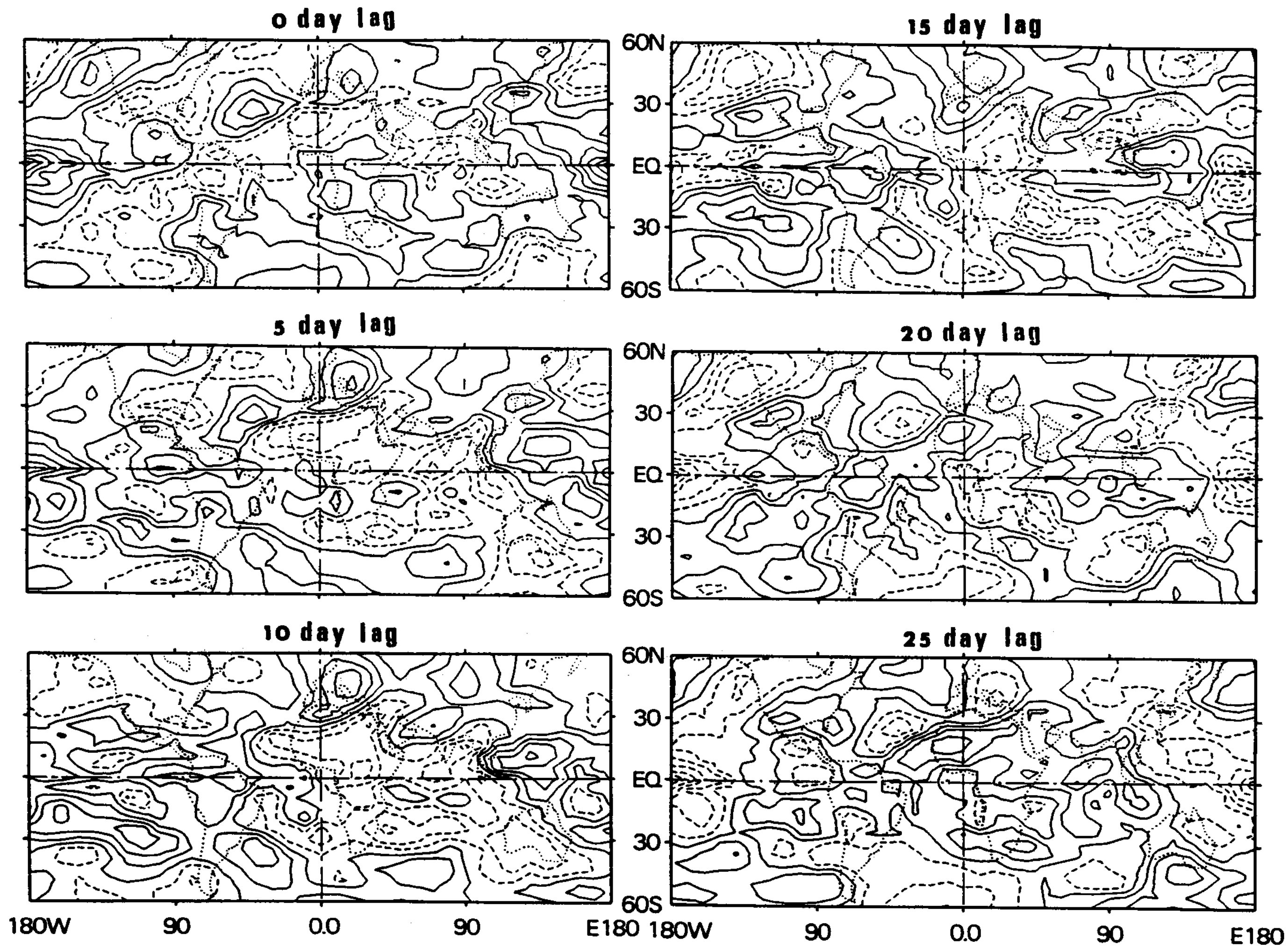

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