Correlation between stratosphere and upper mesosphere: A comparison of Collm mesopause winds and Berlin stratospheric analyses

Christoph Jacobi and Peter Braesicke

Summary:

Collm mesopause winds are analysed with respect to their correlation with 30 hPa northern hemispheric stratospheric winds and pressure level heights. Correlation maps, based on the period of December 1978 through November 1997, are presented for each month of the year, showing possible connections between the lower and upper middle atmosphere, partly owing to the 10-12-year oscillation (TTO). Although in winter due to the propagation of planetary waves into the mesosphere direct coupling between the different layers of the atmosphere especially during stratospheric warmings is possible, the strongest correlation between stratosphere and mesopause region is found in summer, which is for the most part connected with the solar cycle dependence of the middle atmosphere.

Zusammenfassung:

Die Mesopausenwinddaten vom Collm werden in Bezug auf ihre Verbindung mit stratosphärischen Winden und Druckhöhen in 30 hPa untersucht. Abbildungen der Korrelationskoeffizienten, basierend auf dem Zeitraum von Dezember 1978 bis November 1997 zeigen mögliche Verbindungen zwischen Stratosphäre und Mesopausenregion, zum Teil über die 10-12-jährige Schwingung (TTO) der Stratosphäre. Obwohl im Winter wegen der Ausbreitung planetarer Wellen in die Mesosphäre speziell während rascher Stratosphärenerwärmungen eine direkte Verbindung zwischen den Schichten der Atmosphäre auftritt, werden die stärksten Korrelationen im Sommer gefunden, größtenteils durch den Einfluß der TTO.

1. Introduction

There have been numerous investigations on the coupling between the middle and upper atmosphere since a long time (Faust, 1967; Lauter, 1967; Heard, 1968; Manson, 1968; Ebel, 1975; Bencze, 1988; Abraham, 1997; Adler, 1997). A principle advantage of using upper atmosphere data e.g. for climate monitoring is the large scale size of wind systems there (Azcárraga et al., 1972; Muller and Kingsley, 1974; Muller et al., 1995), which to an important part excludes the influence of local effects on point measurements, so that the results from single time series can to a certain degree be interpreted in terms of a quasi-hemispheric signal. However, interpreting upper atmosphere data in terms of atmospheric processes requires the knowledge of the coupling processes between the different layers of the atmosphere. The mesosphere/lower thermosphere region is coupled to the middle and lower atmosphere due to gravity wave propagation and -breaking, and in winter through planetary waves that propagate upwards from the troposphere to the stratosphere and mesosphere. Thus different waves provide a direct dynamical link between the different layers of the atmosphere. However, there are many processes involved in this coupling. Therefore long-term studies are required that may cover the time scales of all concerned processes.

We are interested in dynamical links between the lower and upper middle atmosphere. Therefore stratospheric heights and winds have to be investigated together with upper middle atmospheric winds. Since the time scales of the relevant oscillations are long - at least the 10-12 year oscillation (TTO, Labitzke and van Loon, 1988; 1997) has to be taken into account, since the TTO influences planetary wave propagation and thus also the coupling between stratosphere and upper mesosphere - only long-term wind measurements in the mesopause region are useful for such a comparison. These time series are relatively rare, one of them is the Collm LF D1 wind time series. We will use monthly means of these data. When doing so, one has to be aware that many of the coupling processes are due to short term phenomena as gravity waves, tides, and planetary waves, especially during stratospheric warmings (Schminder and Kürschner, 1981; Jacobi et al., 1997a). However, most of these processes are very variable, so that it appears useful to use a more integrated measure of the dynamical processes, that is the prevailing wind.

Well-known oscillations that influence the stratosphere and mesosphere as well are the equatorial quasi-biennial oscillation QBO (Holton and Tan, 1980; 1982; Labitzke and van Loon, 1988, 1992; Jacobi et al., 1996) and the solar influence which represents itself in the 10-12 year oscillation (van Loon and Labitzke, 1994, 1997; Labitzke and van Loon, 1995) which is also found in upper atmospheric winds in summer (Jacobi et al., 1997b,c; Jacobi, 1998a,b). There is also an influence of the southern oscillation on the stratosphere (van Loon and Labitzke, 1987) which could lead to a possible correlation between stratosphere and upper mesosphere.

In the following we present correlation maps of the zonal prevailing wind v_{oz} at Collm and stratospheric parameters at 30 hPa. The analysis will mainly restrict to the presentation of the correlation patterns, but we will refer to current investigations on processes that are affected by stratosphere-mesosphere coupling, so that the presented figures will give additional insight into the dominant coupling processes involved.

2. Description of the datasets and analysis

The upper atmosphere zonal prevailing wind data measured at Collm are used. The measurements and data analysis have been extensively described by Kürschner (1975, 1991), Kürschner et al. (1987), Schminder (1995), Schminder and Kürschner (1988, 1994), and Jacobi et al. (1998). Monthly mean winds from three measuring paths are available since December 1978. They refer to a mean reflection point at 52°N, 15°E at a height of approximately 95 km.

For the stratospheric data we use gridded 30 hPa pressure level heights h_{30} from Berlin analyses (e.g. Pawson et al., 1993). Estimates of zonal geostrophic wind v_{30} at that height were calculated from the monthly mean geopotential heights by assuming geostrophic equilibrium (Pawson et al., 1993):

$$v_{30} = \frac{g}{2\Omega a \sin\varphi}\left(\frac{\Delta z}{\Delta\varphi}\right), \qquad (1)$$

with z as the height of the 30 hPa level, φ as the latitude, g as the acceleration due to gravity, and Ω as the rotation rate of the earth, and a as the radius of the earth.

The wind field of the mesopause region, as reflected in Collm wind data, and the stratospheric heights and winds are compared by simply using a linear regression analysis:

$$v_{oz} = x_1 + \Delta_1 \cdot v_{30}, \qquad \text{and} \qquad v_{oz} = x_2 + \Delta_2 \cdot h_{30}, \qquad (2)$$

with Δ_1 and Δ_2 showing the dependence of v_{oz} on the respective parameter. For the analysis, however, we use the correlation coefficients between v_{oz} and v_{30}, or v_{oz} and h_{30}, respectively, which will give insight into possible connection between the two height regions.

3. Results

Maps of the correlation coefficient between v_{oz} and h_{30} in the northern hemisphere are shown in the Figures 1 - 4 for each month of the year. The respective correlation coefficients between v_{oz} and the geostrophic zonal wind v_{30} derived from the h_{30} values are shown in Figures 5 - 8. Since the stratospheric winds are derived from the height gradients, these figures do not contain much more information, but are partly useful for visualising possible connections. Regions of correlation coefficients above 0.5 or below -0.5, respectively, are emphasized.

Considering the correlation between v_{oz} and h_{30}, the patterns appear variable from month to month, and additionally in most of the months a longitudinal variability is visible. As an exception from this rule, in spring and early summer in part large negative values are found at latitudes below 50°N, but positive values at higher latitudes (Figure 2). This means, however, that the mesopause region winds are negatively correlated with the stratospheric winds in midlatitudes. This can be seen in Figure 6. One of the dominating periods influencing the interannual variability of spring and summer monthly mean winds at the mesopause region is the 11-year solar cycle (Jacobi et al., 1998a,b). Negative correlation coefficients mean, however, that the influence of the solar cycle is different in the stratosphere and upper mesosphere. This is in correspondence with results of Hauchecorne et al. (1991), who reported a very complex height structure of the solar cycle influence on mesospheric temperatures, which possibly is connected with planetary wave propagation changes within the TTO (Keckhut et al., 1995).

The correlation patterns between stratospheric height and mesopause region wind in winter are more variable. For instance, the patterns in December (lower panel of Figure 4) and January (upper panel of Figure 1) are very different, so that in December positive correlations are found in the northernmost latitudes, but in January the correlation is negative there.

Considering the correlation with stratospheric winds, this means that in early and late winter (i.e. November, December, and March, Figures 5 and 8) the mesopause region winds are positively correlated with stratospheric winds at lower latitudes, and in part negatively correlated with high-latitude winds, while in January and February the opposite pattern is found. This may be due to the reaction of the upper mesosphere on stratospheric warmings that in part lead to a direct coupling between stratosphere and upper mesosphere through planetary wave propagation and the breakdown of the stratospheric polar vortex. The undisturbed conditions, however, are reflected in the early winter patterns and show a negative correlation between stratospheric vortex and upper mesosphere. This means, as it is the case in summer, the mesosphere reacts to external influences just in the opposite way as the stratosphere does.

In the autumn months (especially in September, and October, lower panels of Figures 3 and 7, upper panels of Figures 4 and 8) the patterns exhibit rather weak correlation between stratosphere and mesopause region. This is mostly due to enhanced uncertainty of the mesopause region winds in connection with the autumn transition of the wind field (e.g. Schminder and Kürschner, 1992, 1994; Schminder et al., 1997a,b). Usually shorter periods than one month are necessary to investigate correlations between the different layers of the atmosphere.

4. Conclusions

There are some months when the coupling between stratosphere and upper mesosphere appears to be enhanced, although it is not very strong on an annual mean. Usually, stratospheric and mesospheric wind fields are negatively correlated, that is, a stronger stratospheric polar vortex in winter is connected with weaker mesospheric winds, and in summer the mesopause region winds are negatively correlated with stratospheric zonal geostrophic winds at nearly the entire northern hemisphere. In summer, an influence of the 11-year solar cycle is found both in stratosphere and upper mesosphere. This leads to enhanced correlation coefficients then.

However, stratospheric warmings in the northern winter are leading to a reversed correlation, which means that in January and February stratospheric winds at higher latitudes are positively correlated to mesopause region winds.

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Addresses of authors

Christoph Jacobi
Institute for Meteorology, University of Leipzig, Stephanstr. 3, 04103 Leipzig

Peter Braesicke
Meteorological Institute of the FU Berlin, Carl-Heinrich-Becker-Weg 6 - 10, 12165 Berlin

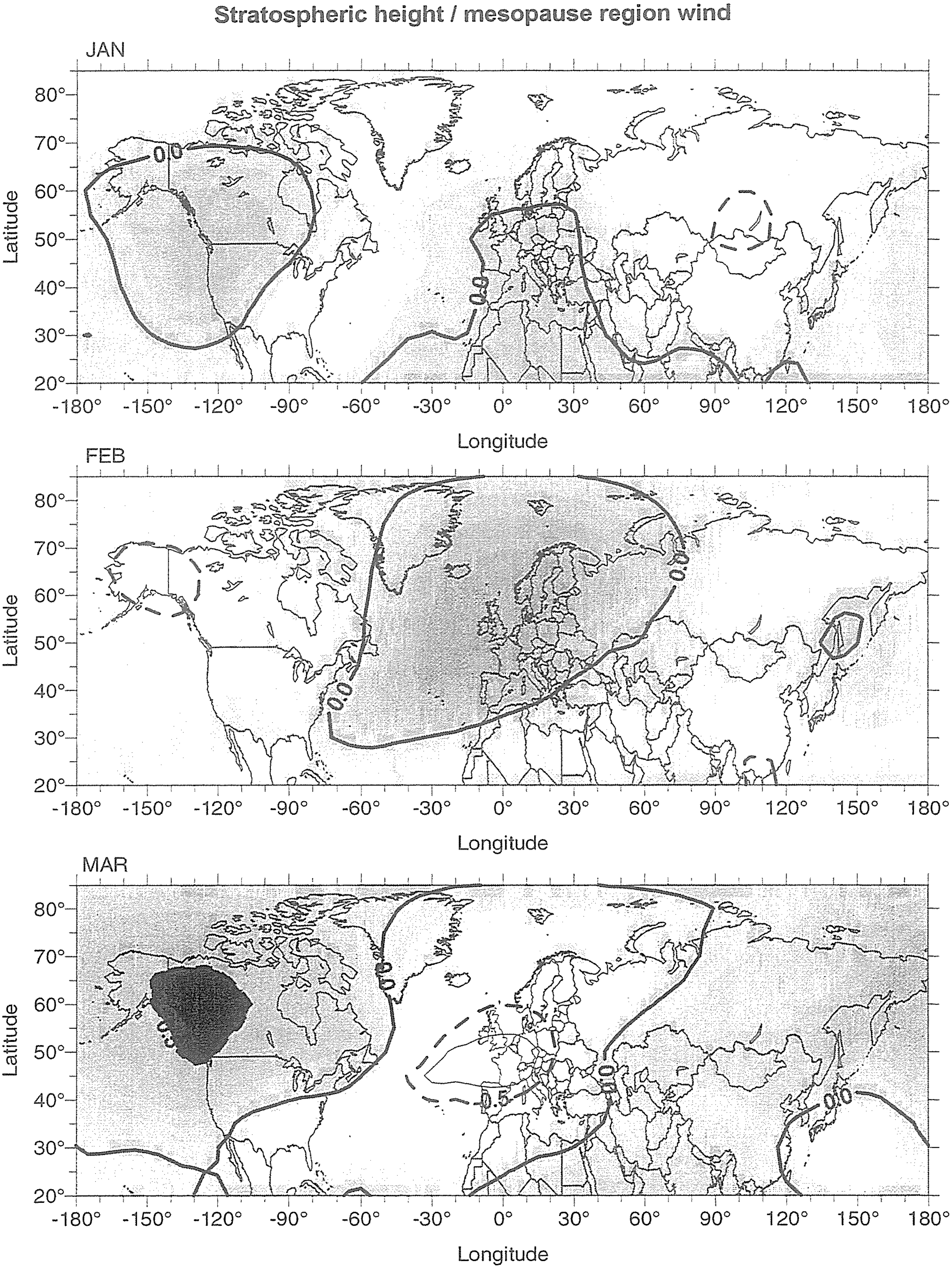

Fig. 1: *Correlation coefficients between Collm mesopause region zonal prevailing winds and heights of the 30 hPa level for January, February, and March.*

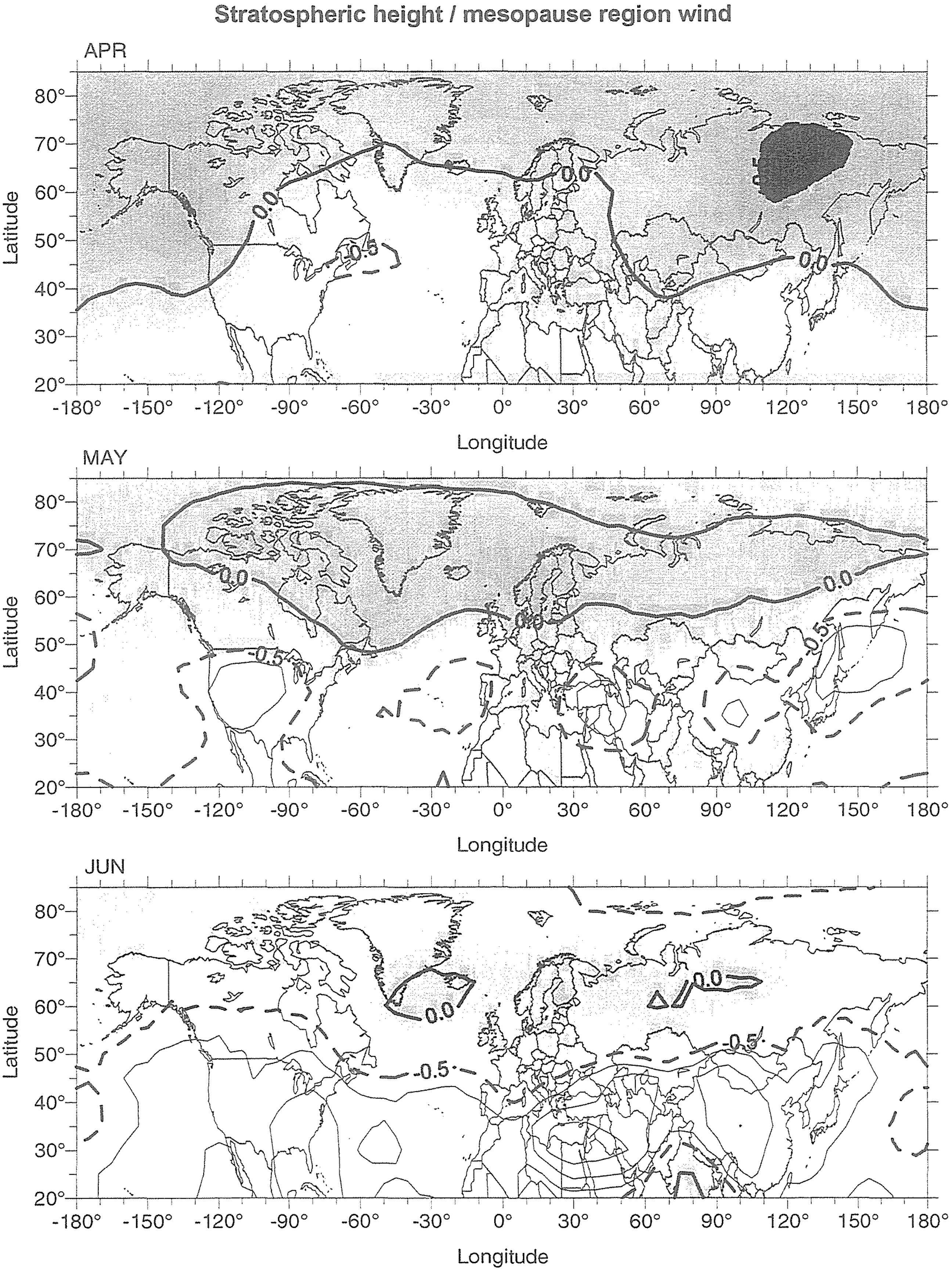

Fig 2: *As Figure 1, but for April, May, and June.*

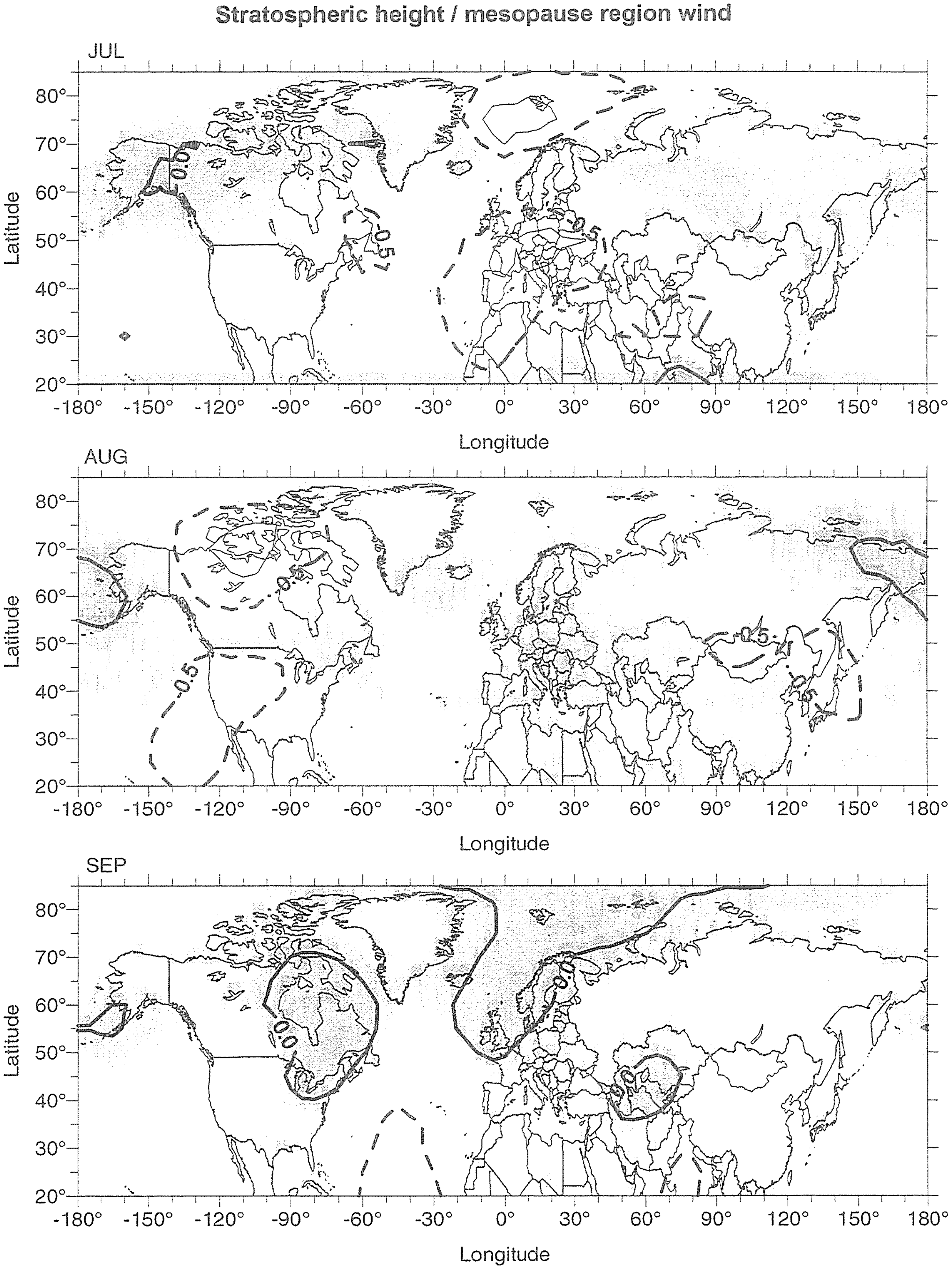

Fig. 3: *As Figure 1, but for July, August, and September.*

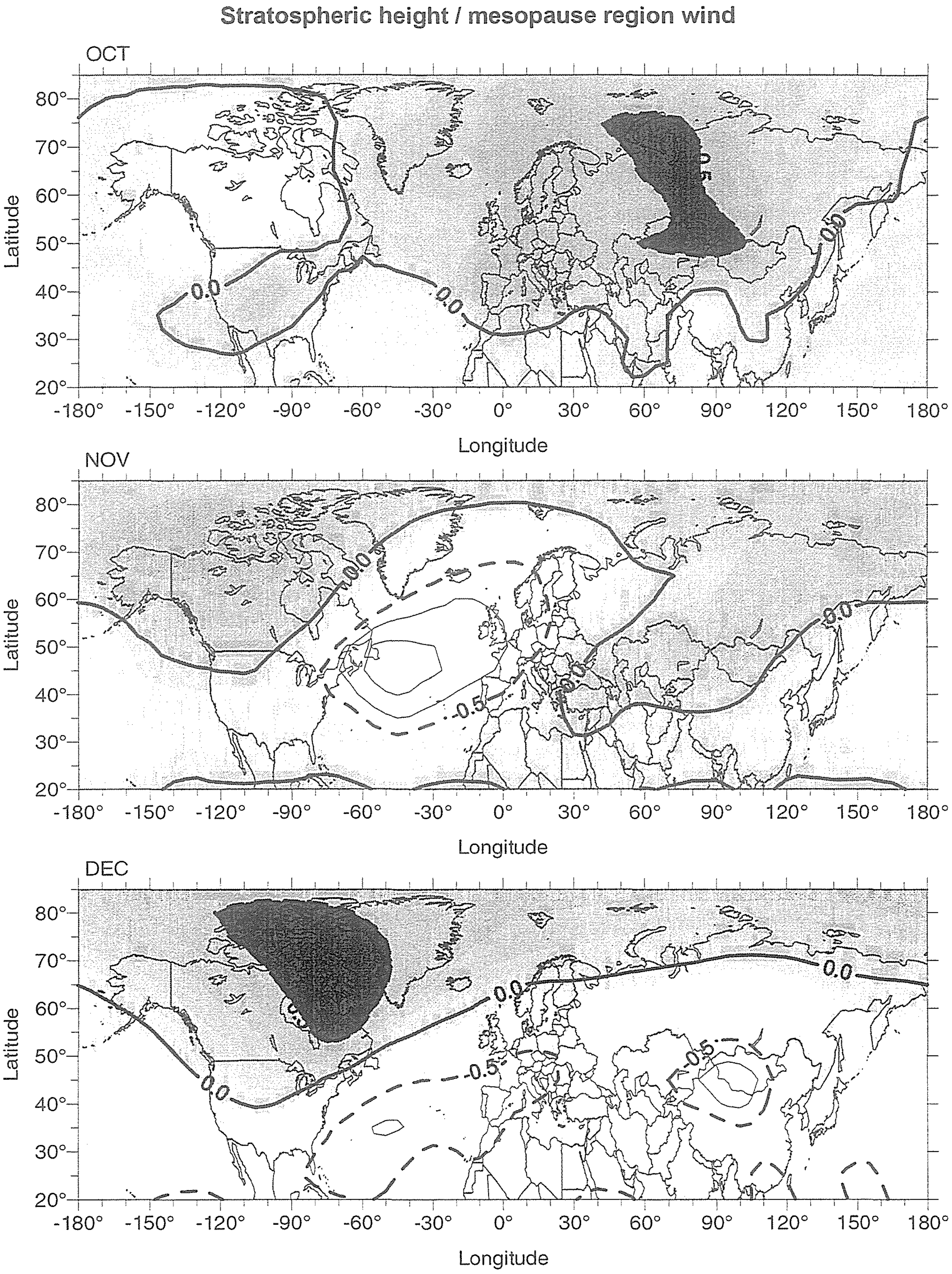

Fig. 4: *As Figure 1, but for October, November, and December.*

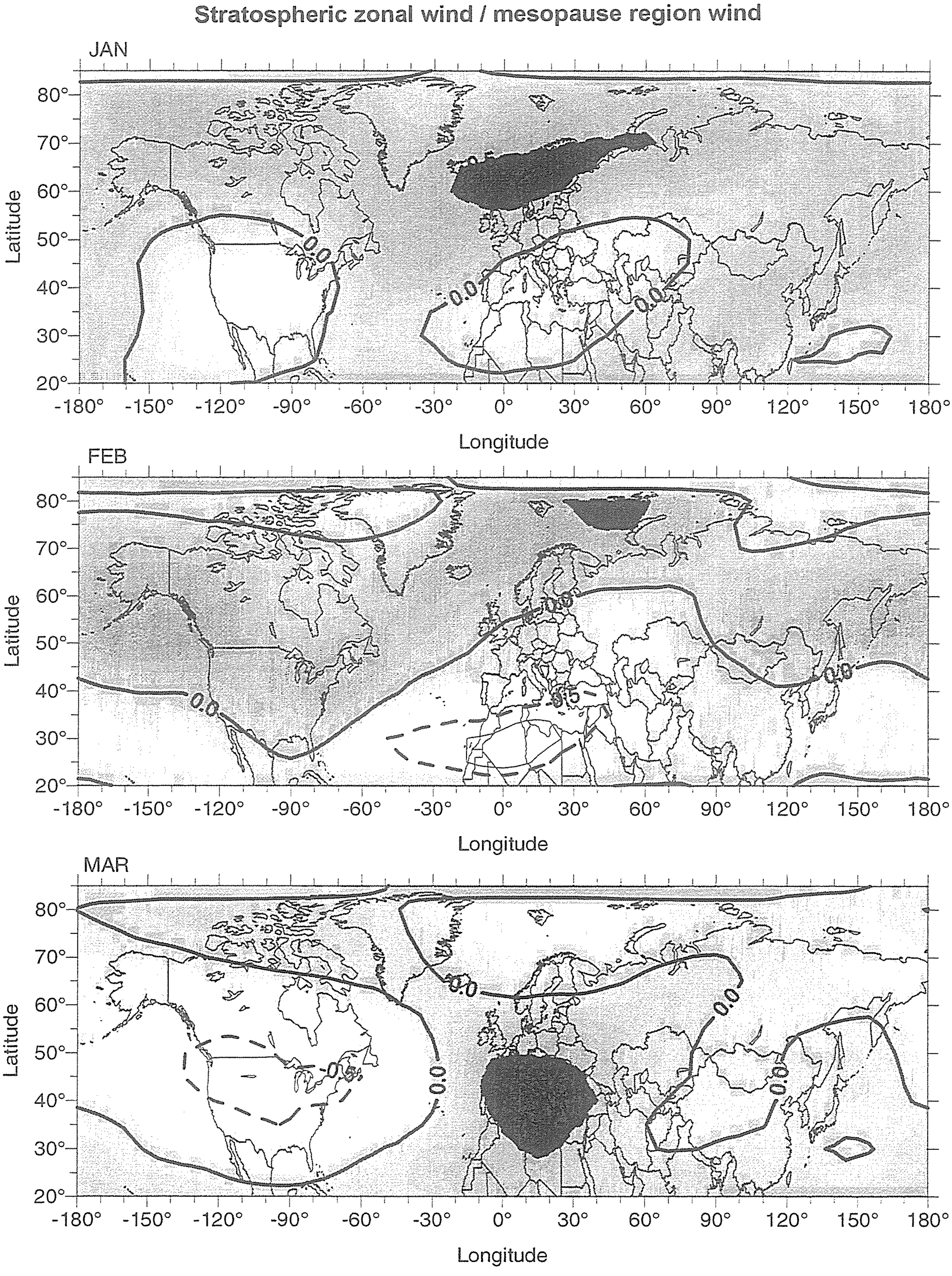

Fig. 5: *Correlation coefficients between Collm mesopause region zonal prevailing winds and 30 hPa zonal geostrophic wind for January, February, and March.*

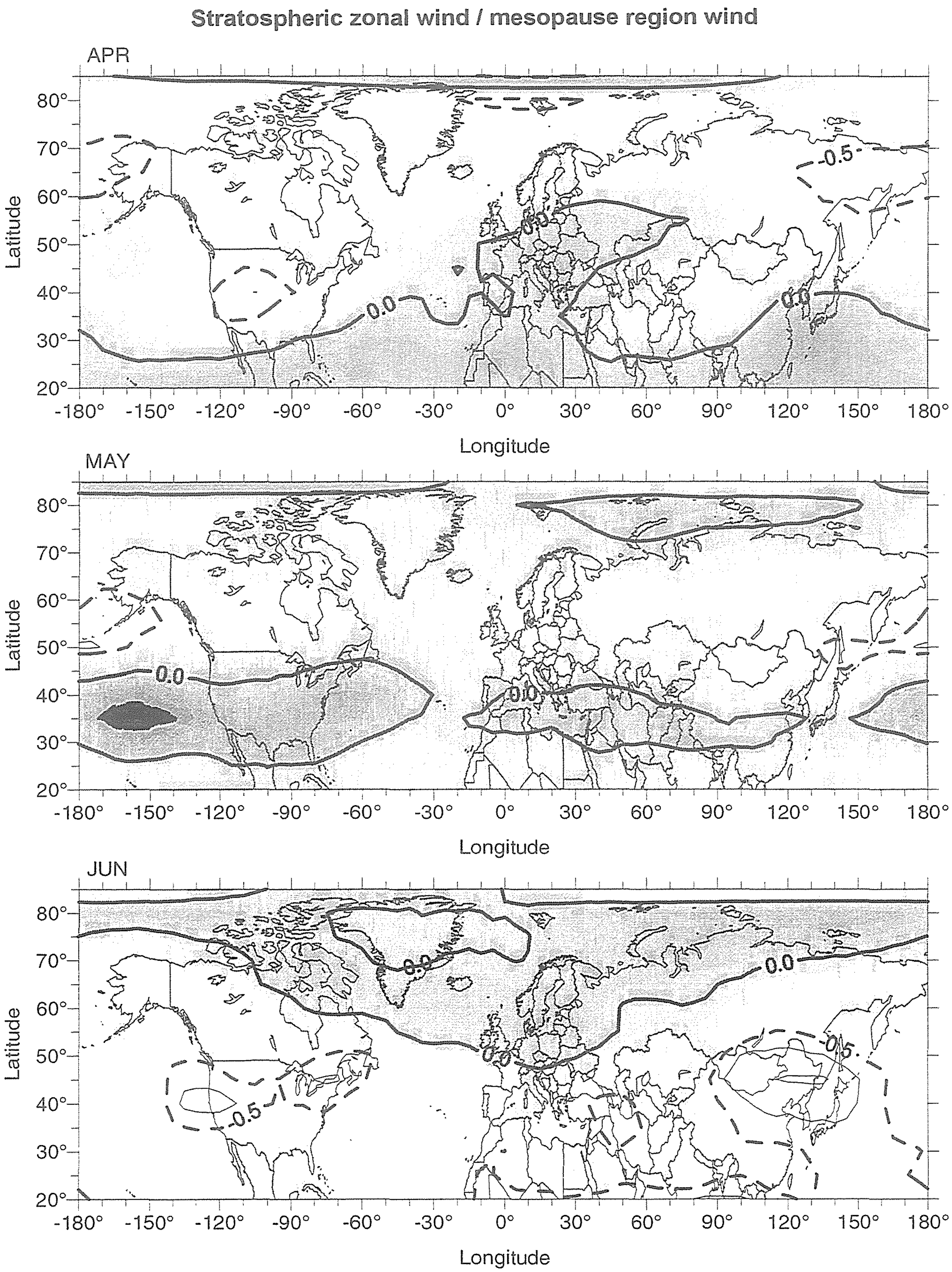

Fig. 6: *As Figure 5, but for April, May, and June.*

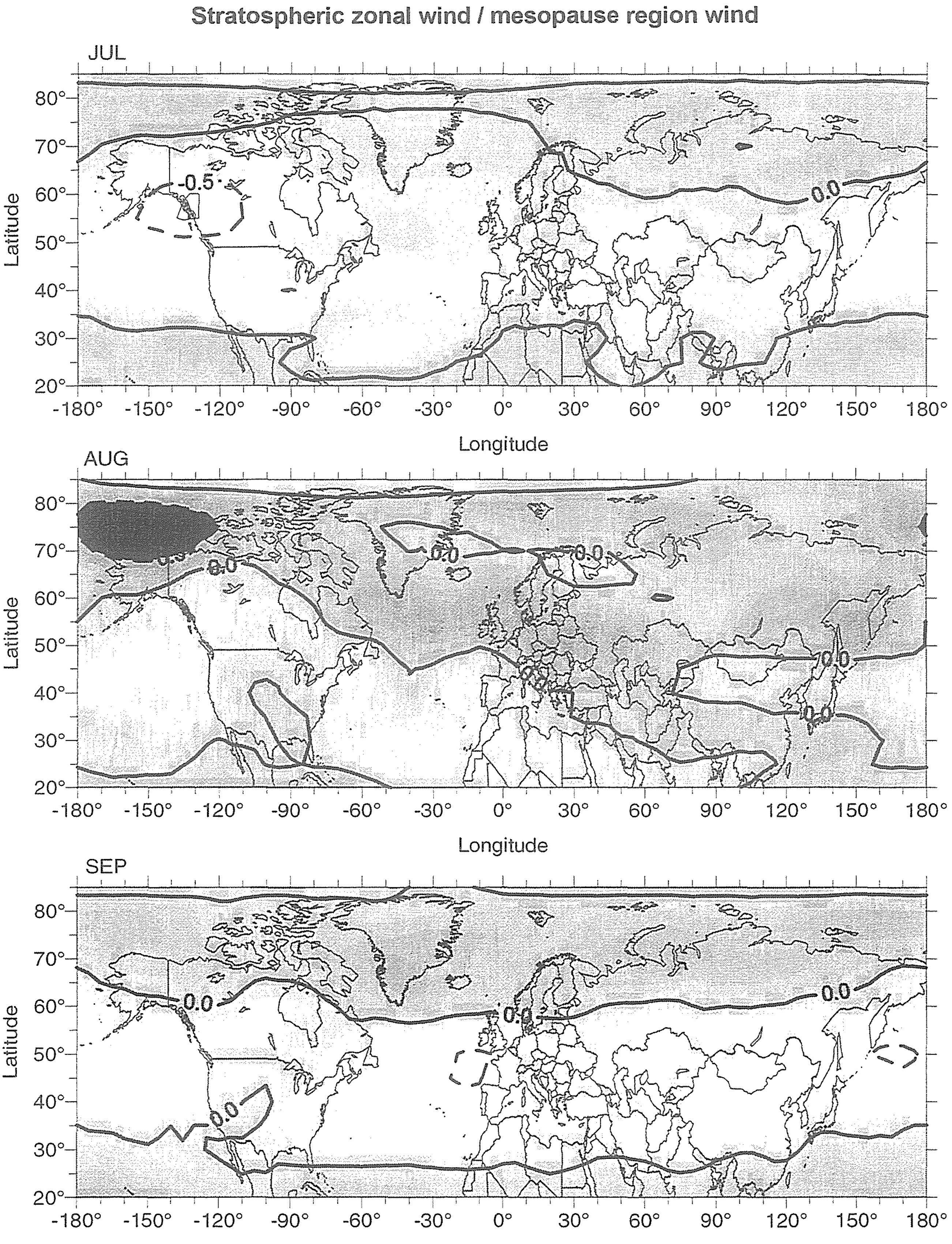

Fig. 7: *As Figure 5, but for July, August, and September.*

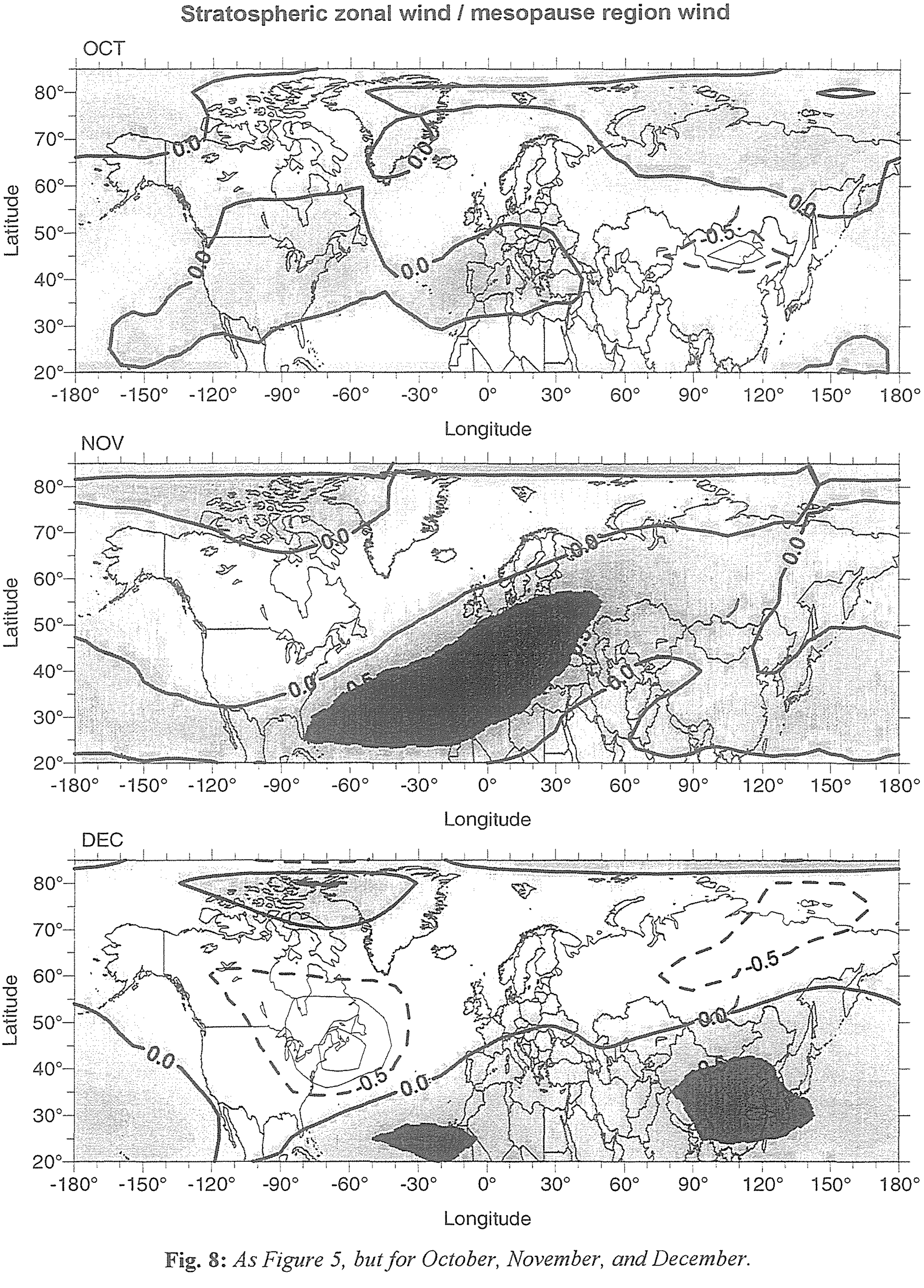

Fig. 8: *As Figure 5, but for October, November, and December.*