The Global Range of the Stratospheric Decadal Wave. Part I: Its Association with the Sunspot Cycle in Summer and in the Annual Mean, and with the Troposphere

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ABSTRACT

The authors correlate the 23-yr series of reanalyzed 30-hPa heights and temperatures and 10-hPa heights with the 11-yr solar cycle for the summers of both hemispheres and for the annual mean. The size and spatial pattern of the correlations in the Northern Hemisphere are the same as those of the correlations computed with a nearly twice as long series from the Freie Universität Berlin: a belt of correlations that encircles the hemisphere in the outer Tropics–subtropics. The correlation pattern is similar in the Southern Hemisphere.

The spatial distribution of correlations between 30-hPa temperatures and the solar cycle has the same configuration as the height correlations with the cycle. The largest temperature correlations move with the sun from one summer hemisphere to the other.

The first eigenvector in a principal component analysis of the 30-hPa heights in summer and in the annual mean has the same shape as the above-mentioned pattern in the correlations between the stratospheric data and the 11-yr solar cycle. The EOF 1 explains 77% of the variance in summer on the Northern Hemisphere and 72% on the Southern Hemisphere, and the time series of its amplitude is dominated by a decadal wave in phase with the 11-yr sunspot cycle.

1. Introduction

A decadal oscillation with a period of 10–12 yr exists in the lower and middle stratosphere of the Northern Hemisphere, which during the observed period of four decades has been in phase with the 11-yr sunspot cycle (SSC). The oscillation is described in, for instance, van Loon and Labitzke (1994, referred to below as vLL) and Labitzke and van Loon (1995, hereafter LvL) by means of analyses that have been made since 1958 in the Stratospheric Research Group at the Freie Universität Berlin (FUB). A corresponding series for the Southern Hemisphere was lacking until the first 23 yr of global reanalyses became available from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) [see Kalnay et al. (1996)].

In the following, we shall describe correlations of the 30- and 10-hPa heights and the 30-hPa temperatures with the SSC, using the NCEP–NCAR data. The description deals only with the summer of either hemisphere and with the annual mean, and uses the 10.7-cm solar flux as a measure of the SSC. The winters and the association with total ozone will be discussed in a forthcoming paper.

The first empirical orthogonal function (EOF 1) outlines the dominant mode of interannual variability in the stratosphere. We use correlations of the time series of its amplitude with temperatures and geopotential heights in the troposphere to show the degree of association between tropospheric interannual variability and the major component of the stratospheric variability.

2. Correlations between the NCEP–NCAR data and the solar cycle

a. Heights

The highest correlations between the SSC and the annual mean heights of the 100-, 50-, and 30-hPa levels on the Northern Hemisphere are concentrated in a belt around the hemisphere between 10° and 45°N in the 40-yr dataset from FUB. This belt widens from winter to

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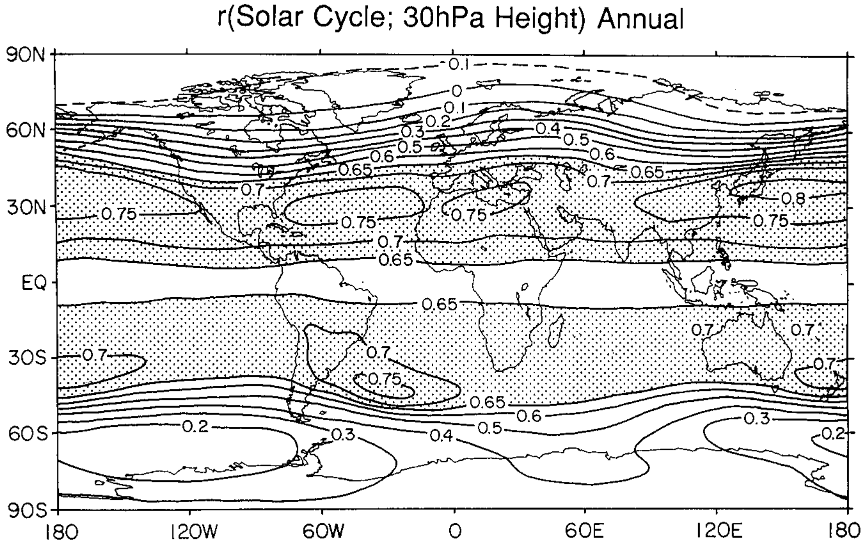

FIG. 1. Correlations between the NCEP–NCAR 30-hPa annual mean heights and the 10.7-cm solar flux (11-yr sunspot cycle), 1973–95. Shading has been applied to enhance features on this and the following maps.

summer. The high correlations with the SSC are associated with temperature variations in the middle and upper troposphere of the same latitudes (vLL, LvL). The 40-yr sample of the Northern Hemisphere has the same spatial distribution and size of the correlations as the NCEP–NCAR correlations in Fig. 1. The correlation pattern and the size of the correlations on the Southern Hemisphere in Fig. 1 look like those on the Northern Hemisphere. It is thus likely that the Southern Hemisphere would present a pattern similar to that in Fig. 1 in a longer series.

The highest solar correlations in the annual mean NCEP–NCAR data (0.65–0.8 in Fig. 1) are in the latitudes 10°–45°. In terms of the actual range in a solar cycle at 30°N in the North Pacific Ocean it amounts to 140–150 m in a strong cycle, such as the one that peaked in 1980–81, and to about 60 m in a weak cycle like the one in 1969–70, using annual mean FUB values.

In the FUB data the largest area with high correlation coefficients on the Northern Hemisphere is on the maps for July–August. This is also true for the reanalyzed period (Fig. 2a). No statistical testing has been done on the correlations in this paper since the samples are too short, 23 yr, to yield meaningful statistical significance levels. It should be noted, however, that in the previous papers on this subject the maps of summer and annual correlations for the Northern Hemisphere were tested for field significance by the Monte Carlo method described by Livezey and Chen (1983), and they turned out to be field significant at the 1% level (Labitzke and van Loon 1993). The sample was then 31 yr, and in the intervening years the correlations have remained stable or improved. There is not yet an explanation of how the SSC could affect the atmospheric levels dealt with in this paper, but it should be remembered that the lack of evidence is not evidence of lack of a mechanism.

The first full year with FUB analyses of the Northern Hemisphere extending to the equator is 1974. For comparison, the correlations between these analyses and the SSC are shown in Fig. 2b; the map is similar to Fig. 2a and considering that the FUB series is one year shorter than the NCEP–NCAR analyses and that it is based on once-a-day radiosonde observations, whereas the reanalyses were made four times daily and incorporate satellite observations, the small differences between Figs. 2a and 2b are not important. Near the equator, however, the NCEP–NCAR correlations are markedly higher than the FUB correlations. A check of the time series showed that the reason for this difference is that the FUB analyses resolve the quasi-biennial oscillation better and therefore have higher interannual variability.

The highest correlations with the solar cycle on the Southern Hemisphere in summer (Fig. 3) are slightly lower than the corresponding ones on the Northern Hemisphere but are also arranged in a belt around the hemisphere. The axis of their highest values lies 10° closer to the pole than that on the Northern Hemisphere. The reason for this difference in position may be related to the fact that the earth is in perihelion during the southern summer and in aphelion during the northern summer.

Correlations between the SSC and the zonally averaged, annual mean 30-hPa heights in Fig. 4 emphasize the symmetry of the correlation maxima about the equator. Correlations that use the 1-yr-shorter FUB series are plotted in the same diagram; their peak is in the same position and of the same size as that of the NCEP–NCAR data, but the correlations elsewhere are smaller

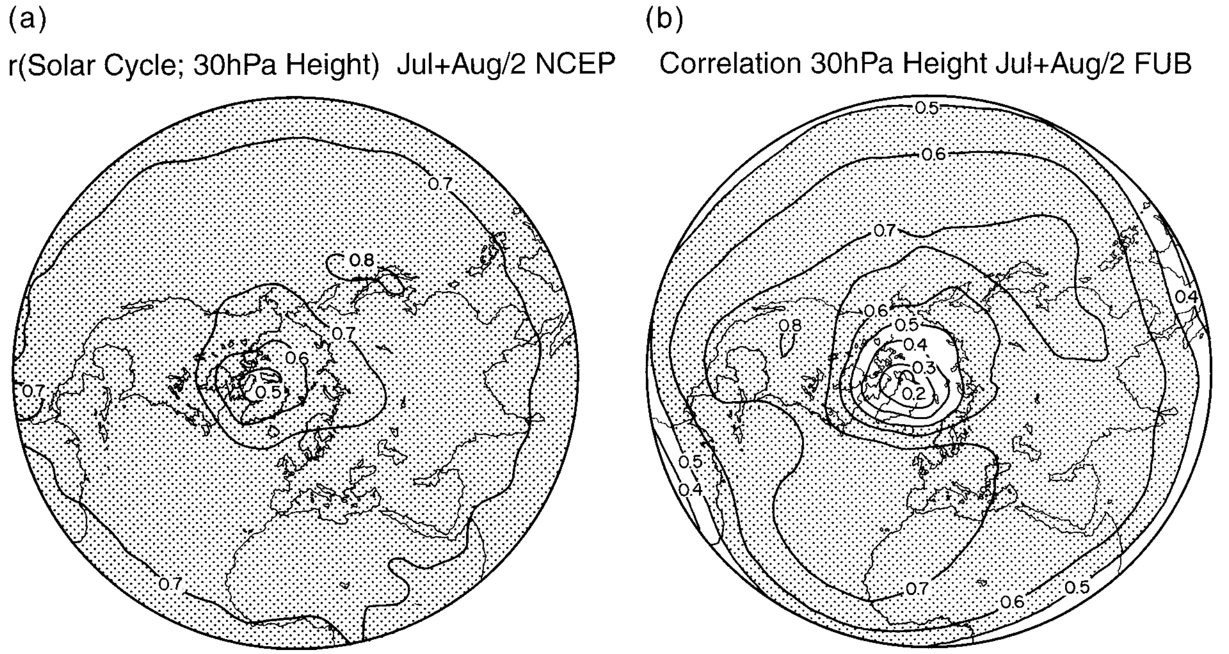

FIG. 2. (a) Correlations between the NCEP–NCAR 30-hPa heights in the Northern Hemisphere in July–August and the 10.7-cm solar flux. (b) The same as (a) but with the data from the Freie Universität, 1974–95.

with the FUB data, especially on the equator. The difference is due to more interannual variability in the FUB data.

The reanalyses also allow correlations at levels higher than 30 hPa (24 km), which until now was our upper limit. Figure 5 shows the global picture of correlations between the geopotential heights at 10 hPa (30 km) and the solar cycle. The correlations remain high at this level, and again somewhat higher in summer on the Northern Hemisphere (Fig. 5a) than in summer on the Southern Hemisphere (Fig 5b); but in the southern winter (Fig. 5a) the correlations are higher than in the northern winter (Fig. 5b). The correlation maxima on both hemispheres move widely from winter to summer; on the Southern Hemisphere the maximum lies at 15°S in winter (Fig. 5a) and moves to 55°S in summer. The corresponding movement on the Northern Hemisphere is from 25°N in winter (Fig. 5b) to 55°N in summer.

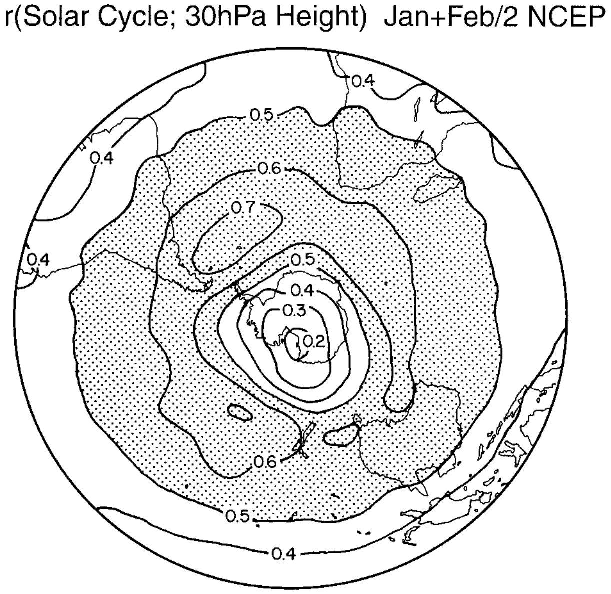

FIG. 3. The same as Fig. 2a but for the Southern Hemisphere in January–February.

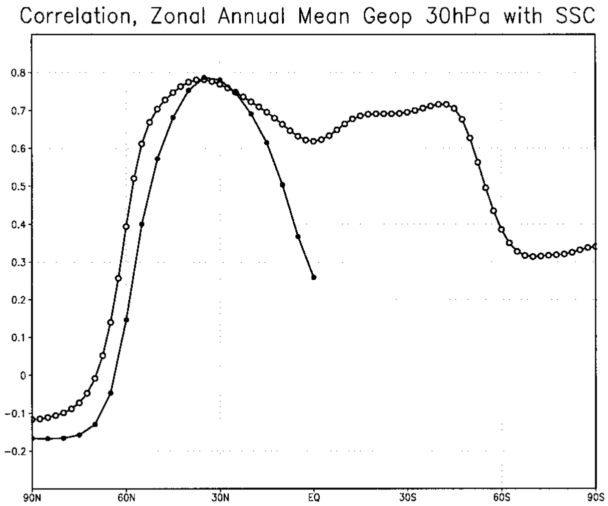

FIG. 4. Correlations between the zonally averaged 30-hPa heights and the 10.7-cm solar flux. The global curve shows correlations with the NCEP–NCAR data, the other with the FUB data.

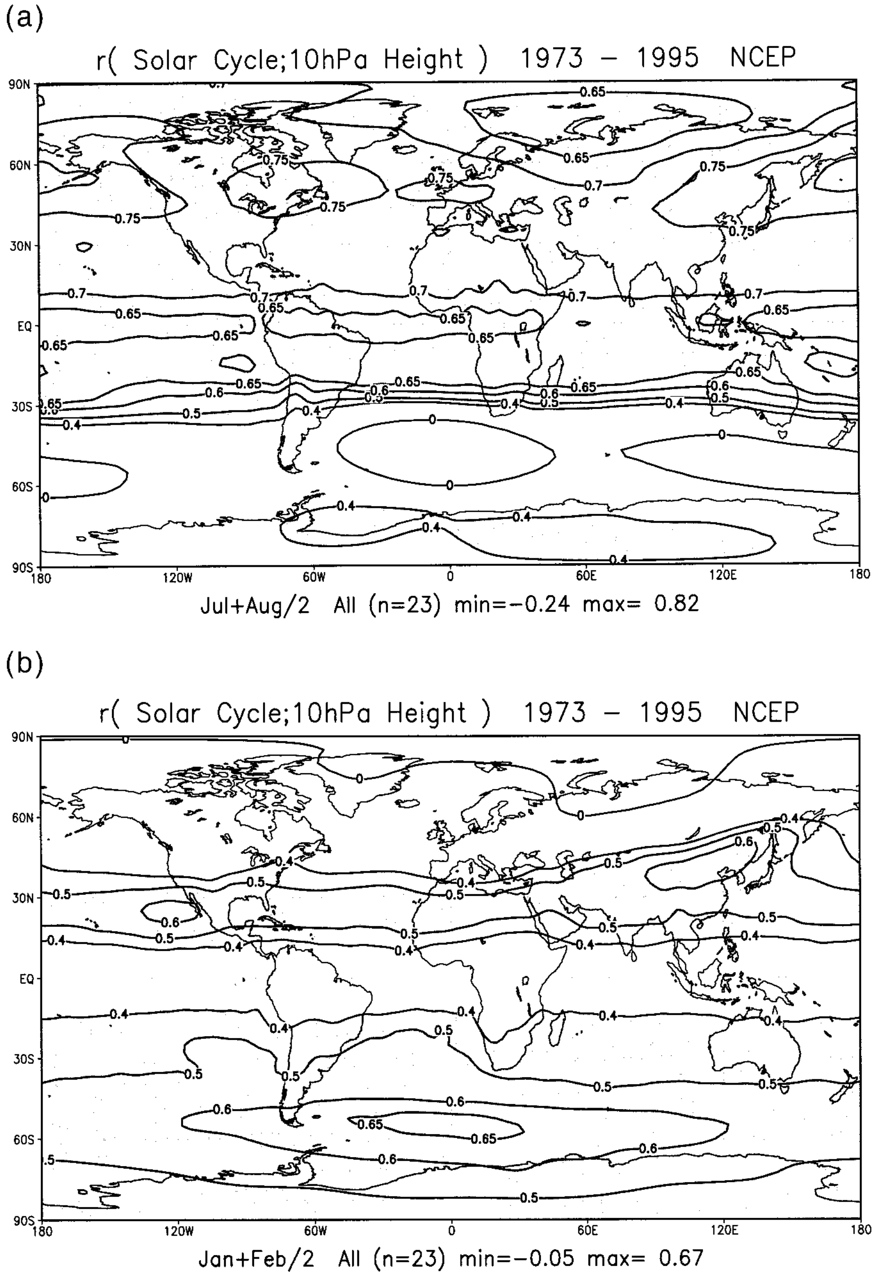

FIG. 5. (a) Correlations between the 10.7-cm solar flux and the NCEP–NCAR 10-hPa heights in July–August. (b) The same as (a) but for January–February.

The association with the movement of the sun is obvious at this level, as one could expect from the 30-hPa temperature correlations in the next section.

b. Temperatures

The highest correlations between the 30-hPa temperature and the SSC in June–July (Fig. 6a) form a belt around the Northern Hemisphere in temperate latitudes. In the same months there are few noteworthy correlations in the Southern Hemisphere. At the southern solstice (Fig. 6b), there is a continuous zone of high correlations on the Southern Hemisphere, whereas the Northern Hemisphere has only patches of moderately high correlations. *The highest correlations between the 30-hPa temperatures and the sunspot cycle thus move with the sun from one summer hemisphere to the other, and there is little association with the sun at this level on the winter hemisphere.*

In summer 35%–50% of the interannual variance of the temperature in the areas of high correlations can be ascribed to the SSC. The correlations are small above

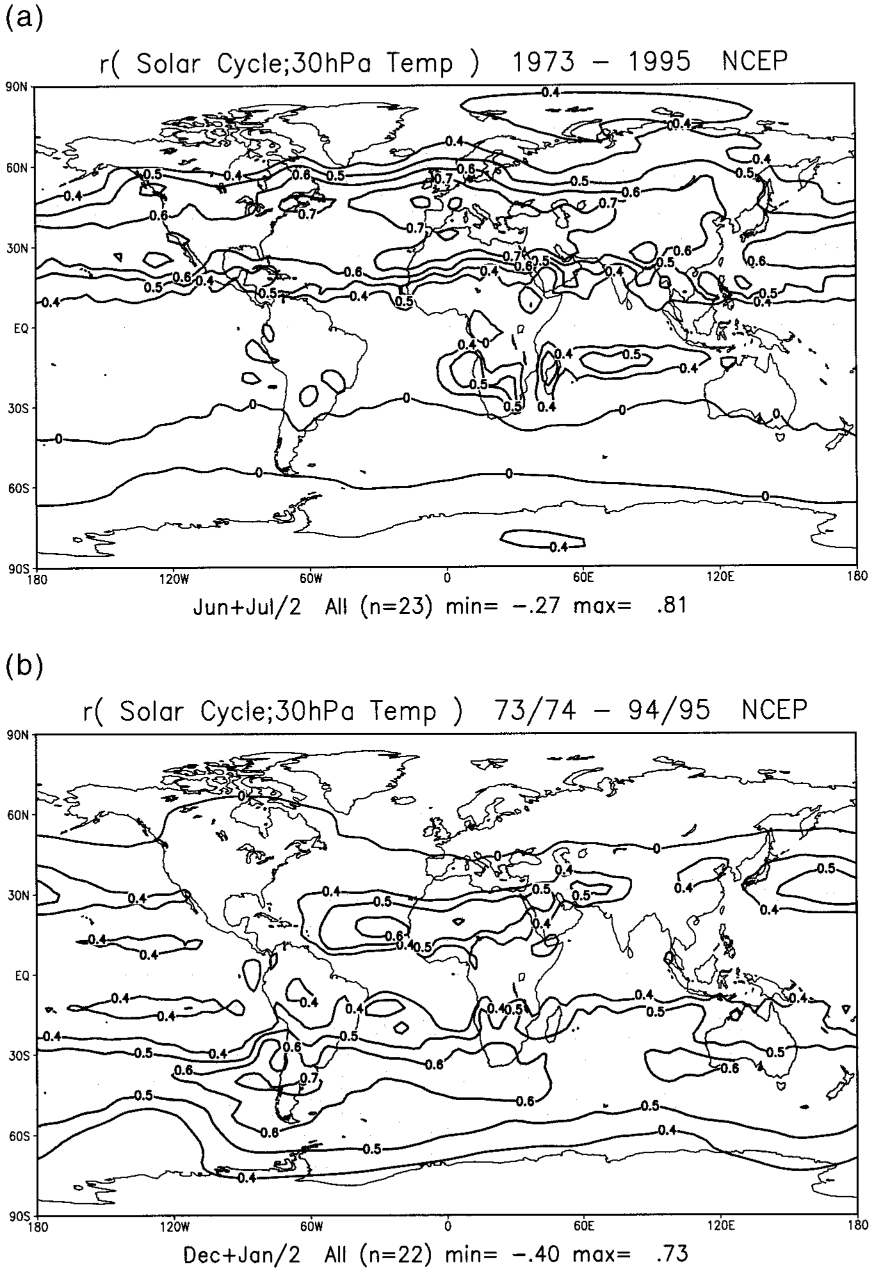

FIG. 6. (a) Correlations between the 30-hPa temperatures in June–July and 10.7-cm solar flux. The same as (a) but for December–January.

the equator at both solstices, which is also the case in the equinoctial months (not shown). The fact that the highest correlations lie well removed from the equator at all times of the year suggests a dynamical control on the radiative influence of the sunspot cycle.

3. A principal component analysis

a. The first eigenvector

The EOF 1 in the 30-hPa heights in the summers of both hemispheres, computed with correlation matrices, is shown in Fig. 7; it explains 77% of the variance in the northern summer and 72% in the southern summer and thus describes the dominant pattern in the interannual variation of the 30-hPa heights. The units are arbitrary but refer to the size of the amplitude. In both Figs. 7a and 7b the sign is the same over the whole hemisphere with the highest values in temperate latitudes. The 30-hPa heights in this mode therefore rise and fall at the same time at all latitudes, with the largest range in the zone of highest values. The axis of this zone lies closer to the pole in the Northern Hemisphere

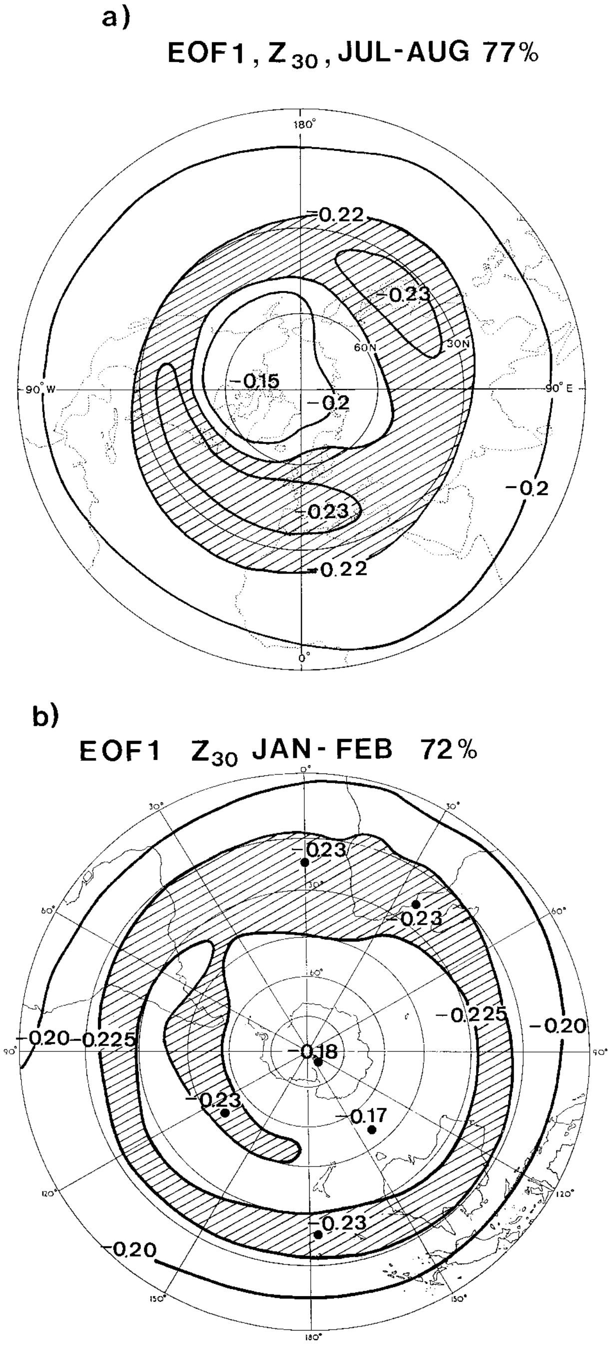

FIG. 7. (a) The EOF 1 in the 30-hPa heights on the Northern Hemisphere in summer. (b) The same as (a) but for the Southern Hemisphere. EOF 1 explains 77% of the variance in the Northern Hemisphere and 72% in the Southern Hemisphere. The values are multiplied by 10.

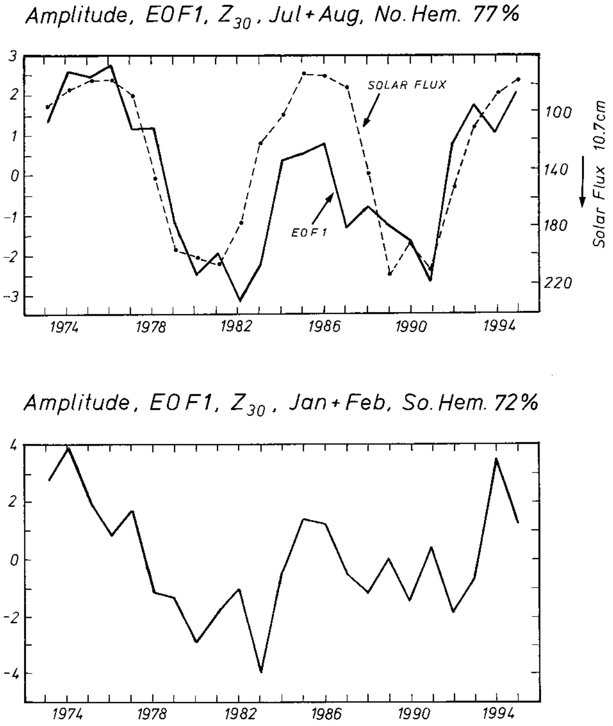

FIG. 8. Time series of the amplitude of EOF 1 in the 30-hPa heights in summer in the Northern (top) and Southern Hemispheres with the 11-yr sunspot cycle (thin curve, values reversed) added on top.

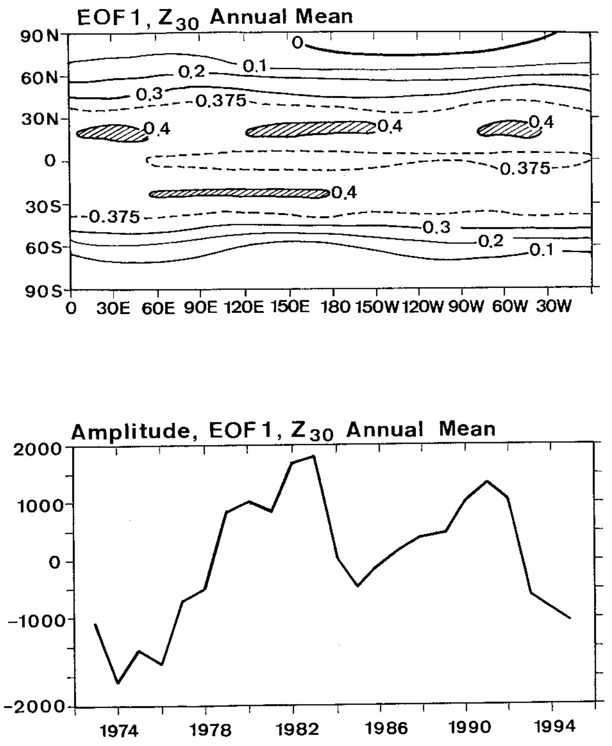

FIG. 9. The EOF 1 in the global annual mean 30-hPa heights and the time series of its amplitude. The EOF 1 explains 53% of the variance.

(40°N) than in the Southern Hemisphere (25°S), but there is an additional peak at 45°S in the South Pacific Ocean.

Both time series of the EOF amplitudes (Fig. 8) contain a decadal oscillation that is close to the 11-yr

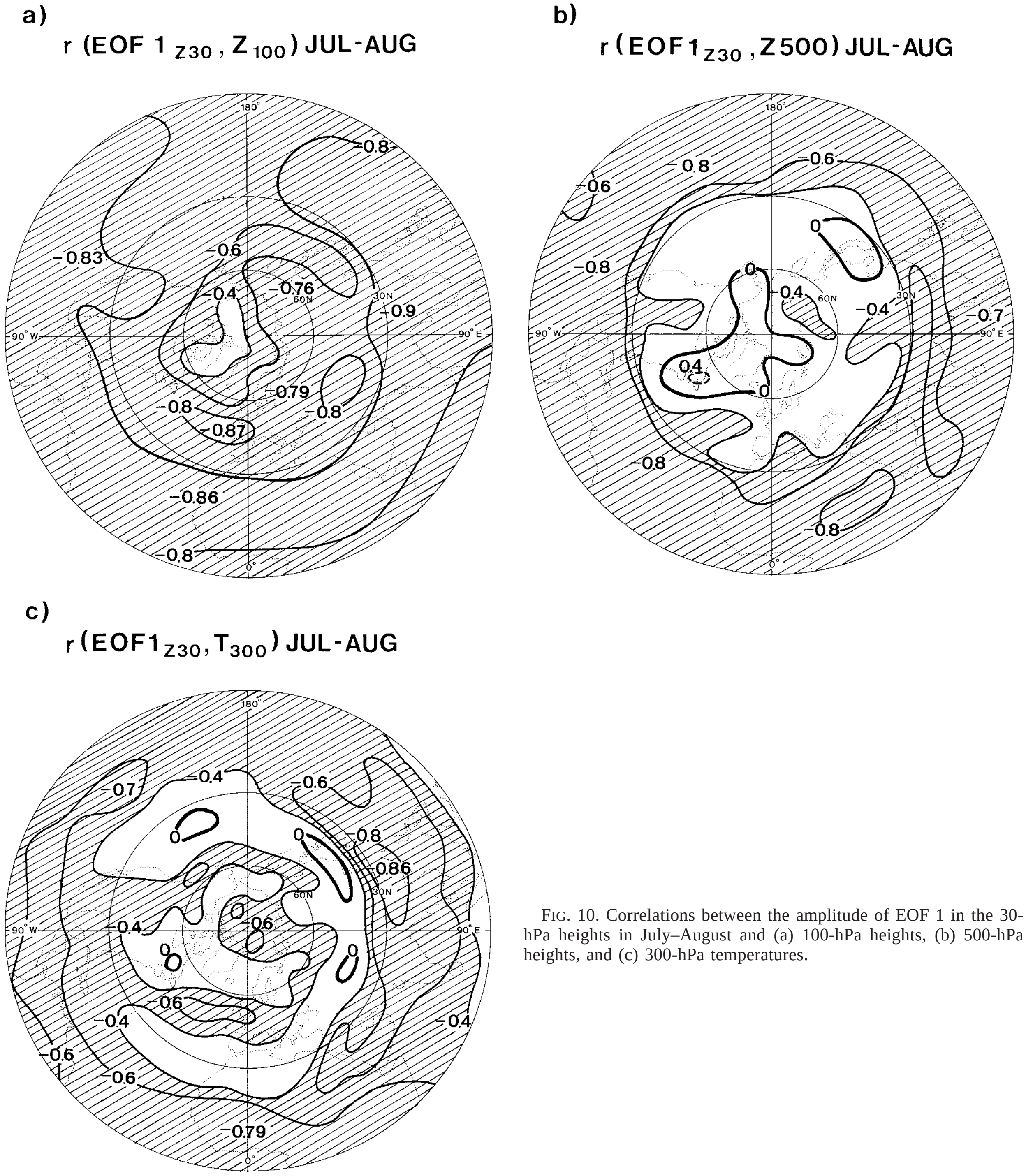

FIG. 10. Correlations between the amplitude of EOF 1 in the 30-hPa heights in July–August and (a) 100-hPa heights, (b) 500-hPa heights, and (c) 300-hPa temperatures.

sunspot cycle, the SSC had minima in the mid-1970s, 1980s, and 1990s and maxima in 1980–81 and 1990–91 (the SSC is reversed in the figure). We know from Figs. 1 and 2a, and from vLL and LvL, that the 30-hPa heights in July–August are positively correlated with the SSC over the entire Northern Hemisphere. This is so also in the Southern Hemisphere in summer (Fig. 3). Considering the pattern of the solar correlations in Figs. 2 and 3, the similar pattern of the first EOFs in Fig. 7, and the phase of the decadal oscillation in the EOF 1 amplitudes in Fig. 8, we conclude that *the first EOF in summer to a large extent describes the pattern of the solar influence on the stratospheric heights.*

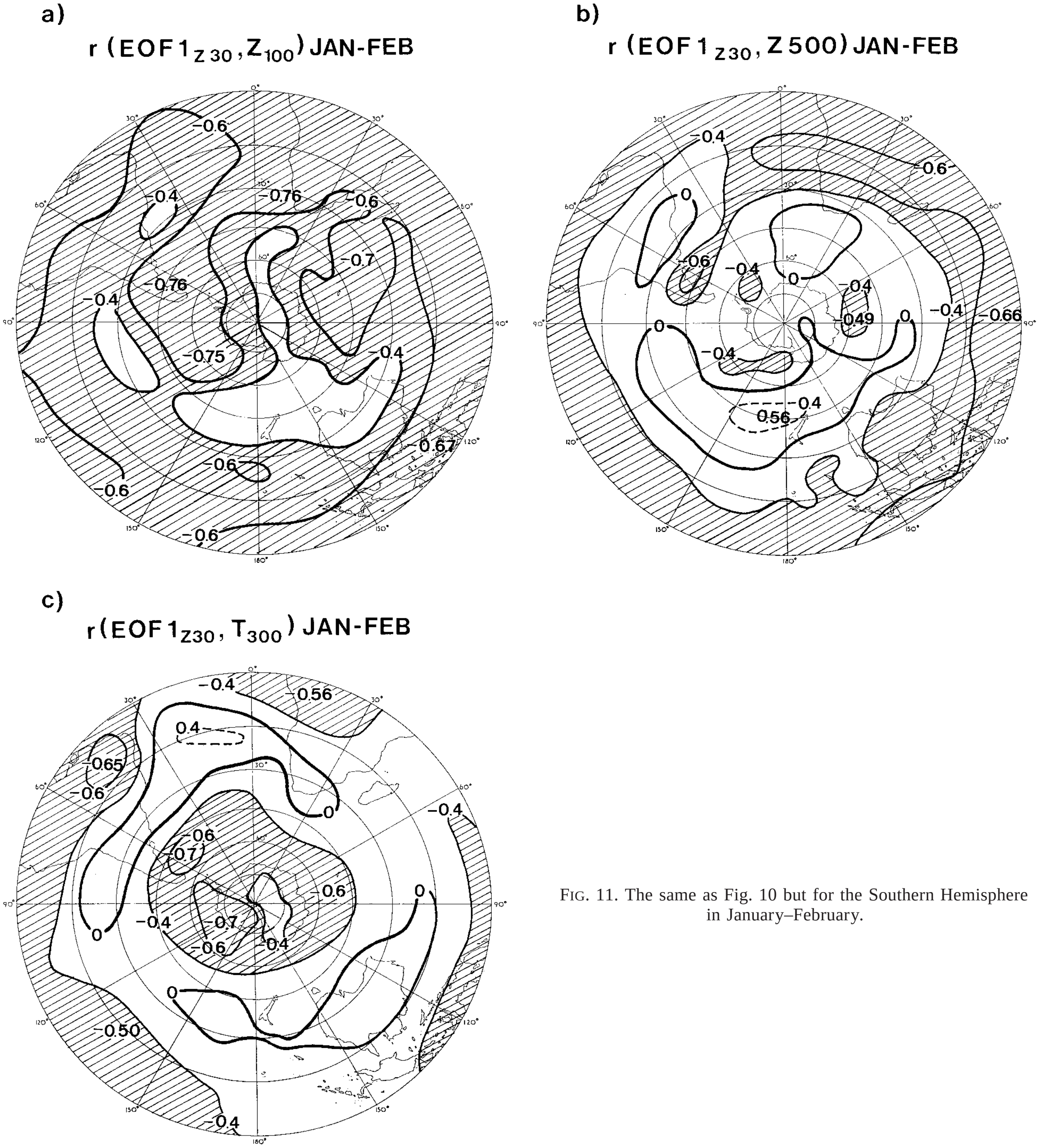

FIG. 11. The same as Fig. 10 but for the Southern Hemisphere in January–February.

The first eigenvector in the annual mean, global 30-hPa heights, Fig. 9, accounts for 53% of the variance and has the same sign over nearly all of the globe; the highest values are in two zones centered near 25°N and S. The amplitude series in Fig. 9 oscillates in phase with the SSC, and in this mode the global stratospheric heights therefore rise and fall largely with the period of the SSC, and most so between 35°N and S.

b. Correlations with the troposphere

In the following, we correlate the time series of the amplitude of EOF 1 (Fig. 8) in the 30-hPa heights with tropospheric temperatures and geopotential heights. The correlations for July–August are in Fig. 10. As noted above, the time series of the amplitude of EOF 1 is dominated by a wave in phase with the solar cycle. The sign of the amplitude (Fig. 8) is negative in solar maxima, and a large negative correlation in Fig. 10 therefore means that the heights and temperatures tend to be higher at maxima than in minima of the solar cycle.

Although the 100-hPa surface lies 8 km below 30-hPa, the 100-hPa heights are highly correlated with EOF 1 (Fig. 10a). A further 10 km below, at the 500-hPa level (Fig. 10b), the tropical heights are still well correlated with EOF 1 in the same sense as at 100 hPa: when EOF 1 is negative, the heights tend to be high. Considering the hydrostatic relationship, it is not surprising that the temperatures in the tropical troposphere are highly correlated with EOF 1 in the 30-hPa heights (Fig. 10c).

One finds the same relationships in summer in the Southern Hemisphere (Fig. 11), but the correlation coefficients are smaller. In addition to those in the southern Tropics, there are substantial correlation coefficients at higher latitudes in the 100-hPa heights and the 300-hPa temperatures.

When interpreting the correlations, one must remember that (a) EOF 1 does not explain all the interannual variance in the stratosphere, (b) its amplitude series is not an exact replica of the solar cycle, and (c) the correlations do not show a one-to-one relationship between EOF 1 and the tropospheric heights and temperatures. The decadal wave in the amplitude of EOF 1 is therefore not necessarily strongly reflected in the tropospheric data.

4. Conclusions

The NCEP–NCAR reanalyses for the period 1973–95 cover the globe in the troposphere and lower stratosphere. We have used this series to compute correlations between the 11-yr sunspot cycle and the 30-hPa heights and temperatures and the 10-hPa heights. Until the reanalysis appeared, such correlations could be made only for the Northern Hemisphere, with a series beginning in the International Geophysical Year and produced by the Stratospheric Research Group at the Freie Universität Berlin. We have earlier used this series for such correlations, and the global correlations with the NCEP–NCAR data confirm the pattern that we found in the Northern Hemisphere. The highest correlations follow the sun from one summer hemisphere to the other.

It has not yet been proven that the correlations show an effect of the solar cycle on the stratosphere, but it is encouraging to observe that the new correlations with the data from the Southern Hemisphere are almost as large and have the same spatial pattern as those for the Northern Hemisphere. Furthermore, the fact that the highest correlations move with the sun is, if not proof, a pointer to a probable association with the sun.

A principal component analysis of the 30-hPa heights in the summer of either hemisphere and in the annual global mean shows a pattern in the first EOF that is similar to the correlation pattern with the solar cycle. The first eigenvector explains 77% in the Northern Hemisphere, 72% in the Southern Hemisphere, and 53% in the global annual mean. The time series of the amplitude of EOF 1 varies in phase with the 11-yr sunspot cycle. Correlations between the amplitude of EOF 1 and heights and temperatures in the middle and upper tropospheres are high over wide areas.

To sum up the new results of this paper: in addition to the NCEP–NCAR reanalyses confirming our earlier findings for the Northern Hemisphere, they show that the correlations in the Southern Hemisphere are similar to those previously found for the Northern Hemisphere and also that for summer on either hemisphere and for the annual global mean, the first eigenvector in the stratospheric data to a large extent describes the solar influence on the stratosphere.

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