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OBSERVATIONS AND STATISTICAL SIMULATIONS OF A PROPOSED SOLAR CYCLE/QBO/WEATHER RELATIONSHIP

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Abstract. The 10.7 cm solar flux is observed to be highly correlated with north pole stratospheric temperatures when partitioned according to the phase of the equatorial stratospheric winds (the quasi-biennial oscillation, or QBO) (Labitzke and van Loon, 1988a). We supplement their observations with calculations showing that temperatures over most of the northern hemisphere are highly correlated or anticorrelated with north pole temperatures. The observed spatial pattern of solar cycle correlations at high latitudes is shown to be not unique to the solar cycle. We present results similar to the observed solar cycle correlations, with simulated harmonics of various periods replacing the solar cycle. These calculations demonstrate that correlations at least as high as those for the solar cycle results may be obtained using simulated harmonics.

Introduction

Recently, a connection was proposed involving the modulation of solar cycle effects by equatorial stratospheric wind regimes. Labitzke (1987) discovered an apparent relationship between the 11-year solar cycle and the north pole stratospheric temperatures. The correlation was very strong but occurred only when the equatorial stratospheric winds were westerly. This preliminary study showed that the 30 mb winter and north pole temperatures were highly correlated with the sunspot number, but only when the 50 mb equatorial winds were westerly. This partitioning of the data according to the phase of the quasi-biennial oscillation (QBO) produced a correlation of 0.78, which was stated to be significant at the 99.9% confidence level. The study was later expanded (Labitzke and van Loon, 1988; van Loon and Labitzke, 1988; Labitzke and Chanin, 1988; Labitzke and van Loon, 1989) to include levels from the surface to 80 km in the northern hemisphere as well as stratospheric data in the southern hemisphere.

Labitzke and van Loon (1988) used a level of about 45 mb to define the QBO and found a positive correlation between 30 mb north pole temperatures during the west phase of the QBO and a negative correlation in the east phase. They presented an intriguing northern hemisphere map of the correlation (during the QBO west phase) between the solar flux and 50 mb temperatures. This diagram showed that a broad region covering the polar cap is positively correlated with the solar flux, with large negative correlations found in most of the low latitudes.

The purpose of this paper is to supplement Labitzke and van Loon's (1988) work by 1) examining more closely the nature of the spatial correlations found using stratospheric temperature data; 2) comparing their results (which used Berlin temperature data) to a map produced using National Meteorological Center (NMC) temperature data; and 3) determining whether similar correlations could be obtained by substituting harmonics of various periods in place of the solar cycle.

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Results

Labitzke and van Loon (1988) showed that the solar flux, during the west phase of the QBO, is positively correlated with 50 mb temperatures over a broad region surrounding the pole and anticorrelated at lower latitudes. This pattern is similar to geopotential height differences (QBO east phase minus west phase) during winter at 10 mb (Holton and Tan, 1982) or 10 mb geopotential height differences (partitioned according to pressure/precipitation in the equatorial Pacific) found by van Loon *et al* (1981). Labitzke and van Loon noted that this is also the stratosphere's response pattern to the southern oscillation and the QBO. The same geographic pattern, however, may also be seen in a one-point correlation map of north pole NMC temperatures with other temperatures on the same grid (Figure 1). This spatial correlation of temperature is apparently the reason for the observed shape of the correlation pattern with the solar cycle, etc., as well as with the simulated harmonics we discuss below. This pattern indicates that January - February average stratospheric temperature fields have very few degrees of freedom. Time series of temperatures at any grid point in this region would tend to look very similar. Such a pattern could be generated using any time series that is well correlated with north pole temperatures.

Figure 2 shows a hemispheric grid of correlation coefficients between the solar cycle and northern hemisphere temperatures at 50 mb. Labitzke and van Loon used Berlin temperature data, while Figure 2 is the same field produced with NMC temperatures. The only difference between the plots is the source of the temperature fields. Since the NMC analyses are a routine product, with analysis

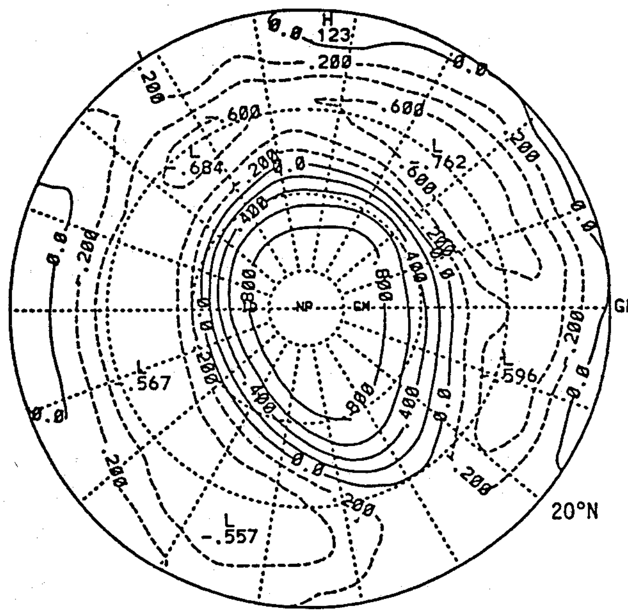

Fig. 1. One-point correlation map of 1964-88 north pole 50 mb January - February average temperatures correlated with all other points on the grid.

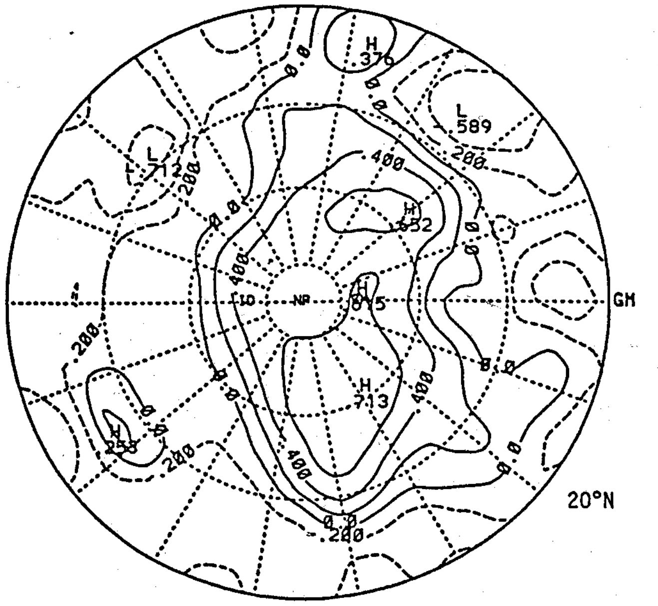

Fig. 2. Lines of equal correlation of coefficient between January - February average 50 mb north pole temperatures and the 10.7 cm solar flux, 45 mb west phase QBO only, 1965-87.

techniques that often changed, they might be expected to be less reliable than the Berlin analyses, which are a research product. The general pattern at high latitudes is similar; however, there are large differences south of 50° N. At low latitudes the interannual variability in the NMC data is approximately 1.5° C. The average north pole (absolute) temperature difference between the two data sets is 2° C. If, at low latitudes, the difference between the two data sets is on the order of the interannual variability, then correlations with these temperatures have little meaning. However, the major feature (high correlations in the polar region) is very similar between the two plots.

An experiment was designed to see how often high correlation coefficients, as observed by Labitzke and van Loon (1988), could be obtained using simulated harmonics of various periods. Their Figure 1b shows the correlation between north pole (January - February average) temperatures at 30 mb and the solar cycle when the data are partitioned according to the QBO phase at about 45 mb. There are three time series involved in this study: the solar cycle, the QBO, and the north pole temperatures. Any one of these time series could be simulated in order to test a given hypothesis. In fact, tests have been performed using each of these series (Labitzke and van Loon, 1988; Barnston and Livezey, 1989; G.W. Brier, personal communication, 1989). Due to the apparent relationship between northern stratosphere temperatures and the QBO (Holton and Tan, 1980), we prefer to leave the atmospheric data intact and simulate the solar cycle. We asked the question: Could similar results be obtained using simulated solar cycles with periods other than 11 years?

Eighty different harmonics between 2.2 years and 18 years were tested. Labitzke and van Loon found that QBO phase partitioning at about 45 mb resulted in the highest correlation. In our test, any level from 70 mb to 10 mb could be selected (70, 50, 30, and 10 mb, with three interpolated levels between each, or 13 levels total).

In order to test all possible phases of the simulated harmonics, ten different phases (successive adjustments by $\pi/10$) were tested in each case. The test involved 80 different periods at ten different phases each, or 800 different harmonics. The 80 harmonic periods were spaced evenly in log (frequency) obviating any bias in favor of long or short periods.

Our simulation attempts to address the question of data selectivity. We assume that the phase of the QBO has not been determined *a priori*. High correlations (or anticorrelations) in either the east or west phase are accepted as "positive" results. We further assume that the level at which the QBO is defined is selected *a posteriori* in the following way: for each of the 800 test cases, the phase and level of the QBO is chosen in order to maximize the correlation with north pole temperatures.

For the period 1964 - 1988 we used NMC January -

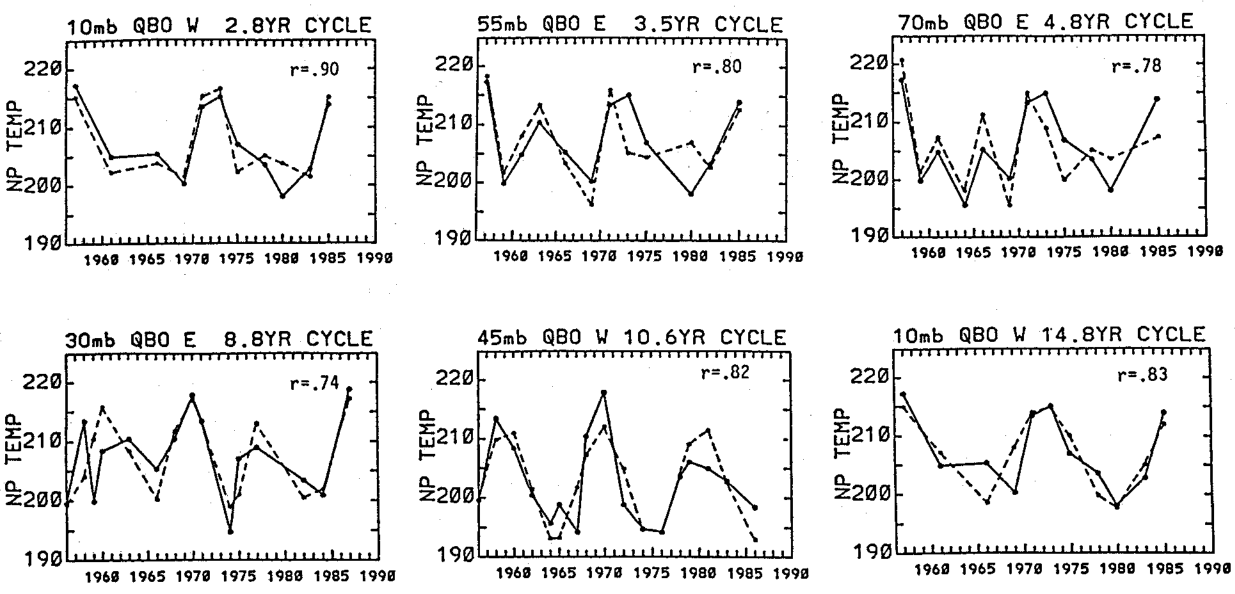

Fig. 3. Representative time series of January - February average 30 mb north pole temperatures (solid) and various simulated harmonics (dashed), when the data are partitioned according to the phases and levels of the QBO as indicated. The time series of north pole temperatures is split into east and west categories according to the phase of the QBO at the pressure level indicated in each panel.

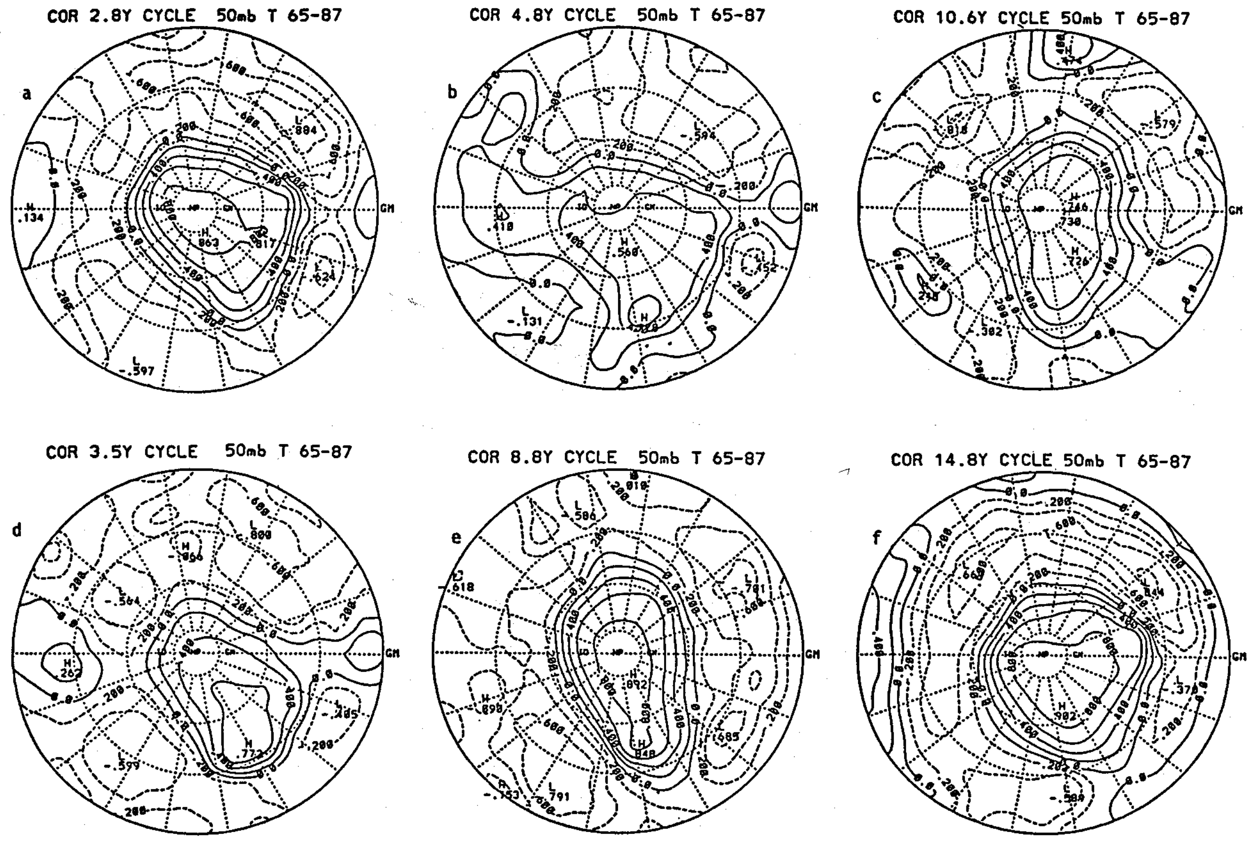

Fig. 4. Lines of equal correlation coefficient between January - February average 50 mb north pole temperatures and various harmonics when the data are partitioned according to the QBO levels shown in the corresponding panel of Fig. 3.

February average temperatures, while for 1956 - 63 we used Labitzke and van Loon's (1988) Berlin temperatures. This averaging period was used by Labitzke and van Loon (1988) because the largest contribution to the correlation coefficient comes from the months of January and February. This selection tends to bias the results in favor of the solar cycle. We have made no attempt to account for this selectivity.

Out of these 800 cases, 4.75% had correlation coefficients equal to or greater than Labitzke's result of 0.76. Twelve percent had correlations greater than or equal to 0.7. When the east and west phases were combined (by taking the square root of the sum of the squares of the two coefficients), 2.25% of the harmonics resulted in correlations exceeding Labitzke and van Loon's results.

Figure 3 shows some of these results, analogous to Labitzke and van Loon's time series. There are five distinct frequency bands in addition to the solar cycle (which in this case turned out to be 10.6 years) that have correla-tions similar to (at least 0.74) or greater than Labitzke and van Loon's 0.76. These harmonics are 2.8, 3.5, 4.8, 8.8, and 14.8 years. Presumably, if the solar cycle had one of these periods (and had proper phase alignment), a study like that of Labitzke and van Loon would have discovered it in the atmospheric data.

As in Labitzke and van Loon's figure, there is a very close correspondence between the simulated cycles and the actual north pole temperatures when the years are sorted according to the phase of the QBO. Correlations with these harmonics range as high as 0.9 for the 2.8 year cycle. Thus, it is relatively easy to get correlations similar to those calculated using the solar cycle data by correlating with simulated harmonics.

As further comparison (following Labitzke and van Loon), northern hemisphere maps of temperatures at all grid points correlated with these harmonics were prepared, using NMC data (Labitzke and van Loon used Berlin data) for the same period (1965-87). Most of the maps in Figure 4 show a remarkable similarity to that obtained using the real solar cycle (Figure 2).

How likely is it that the solar cycle results occurred by chance? In our study, 4.75% had at least the 0.76 correlation coefficient calculated by van Loon and Labitzke. This result seems to cast doubt upon the high significance levels quoted in the recent papers. Listed below are several reasons that the significance levels shown here differ so greatly from those calculated by Labitzke and van Loon.

1. In the tests shown here, high correlations were the result of choosing among many QBO phase levels.
2. Plus or minus correlations are taken here to be "positive" results.
3. A high correlation with the east or the west phase of the QBO is also a "positive" result.
4. The solar cycle harmonic (10.6 years) is included in the test. If the solar cycle-atmosphere relation is real, then these results are slightly biased against showing high statistical significance.
5. The results shown here tended to included fewer data points than the time series studied by Labitzke and van Loon. Several of these results showing correlation with random harmonics were in the west phase at 10 mb and the east phase at 70 mb. The number of data points at these levels are 11 data points at 10 mb and 12 data points at 70 mb. This compares with 17 points in the Labitzke and van Loon study. With fewer data points it is easier to obtain a high correlation coefficient.

Conclusions

It has been demonstrated that stratospheric maps of temperature correlation coefficients tend to reflect the broad spatial one-point correlation of January - February average stratospheric temperatures. One may expect that if a time series is well correlated with temperatures at some point on the polar cap, then that series will also be well-correlated with temperatures in a broad surrounding area. The pattern is also similar to the stratosphere's response to the southern oscillation and QBO, as noted by Labitzke and van Loon (1988).

A further problem with correlation maps involving stratospheric temperatures is that the data are of questionable reliability at low and mid-latitudes. A comparison of correlations produced with NMC and Berlin analysis shows substantial differences outside the polar cap (south of about 50° N). Typical differences between the analyses at the pole are of the same order as interannual variability of January - February temperatures at low latitudes. This suggests that at mid and low latitudes the differences between the analyses are comparable to the interannual variability.

The determination of the statistical significance of a particular result is, in general, very difficult. As stated by Pittock (1978), "...unless the evidence is unambiguous and overwhelming, statistical tests of significance are surrounded by assumptions, qualifications, and uncertainties which make purely statistical conclusion suspect. One has only to consider the problems posed by data selection (whether conscious or unconscious or in space or time), auto correlations, smoothing, and *post hoc* hypotheses to realize that a real difficulty exists at this point." We attempt here to account for some of the data selection methods and determine how often Labitzke and van Loon's results can be obtained by substituting simulated harmonics for the solar cycle. Our calculations show that correlations such as they obtained occur fairly frequently using simulated harmonics.

We have not attempted to account for the selection of January - February data. This period of data was selected by Labitzke and van Loon (1988) because it showed the strongest relation with the solar cycle.

Further evaluation of statistical significance should better determine the probability that the observed results could have occurred by chance. This evaluation could include tests of field significance for many levels of data as well as data from other seasons or time periods.

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