The average influence of decadal solar forcing on the atmosphere in the South Pacific region

Harry van Loon\textsuperscript{1,2} and Gerald A. Meehl\textsuperscript{2}

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\textsuperscript{1}Colorado Research Associates, Northwest Research Associates, Boulder, Colorado, USA.
\textsuperscript{2}National Center for Atmospheric Research, Boulder, Colorado, USA.

\[1\] Composite mean difference analyses are applied to historical sea level pressure (SLP) and sea surface temperature (SST) data to investigate the spatial dependence of the Pacific climate system response to 11-year solar forcing. Previous work has found that the SST and SLP responses are most clearly detected near the times of sunspot maxima, which occur as much as two years prior to the centers of the broad decadal solar cycle maxima. In January–February, the SLP response at sunspot maximum is nearly the same on either side of the equator, although the amplitude is larger in the winter hemisphere. The solar influence is seen as above normal SLP in the sub-Arctic Pacific, as found previously, and as corresponding positive SST anomalies in the sub-Antarctic Pacific, as shown here for the first time. These SST anomalies are associated with previously documented signals at sunspot maxima of greater ocean upwelling and cooling along the Pacific equator, and a poleward extension of the tropical convergence zones in both hemispheres. Previous studies using multiple linear regression methods show the broad decadal solar maxima being associated with the lagged warm response in equatorial Pacific SSTs seen in the composites, which is not inconsistent with the present results. In the South Pacific Ocean, the solar effect is visible in the southern summer in the year before the sunspot number peak. The SST and SLP anomalies in the South Pacific in the solar peaks differ markedly from those in Cold Events (La Niña events) of the Southern Oscillation. Citation: van Loon, H., and G. A. Meehl (2011), The average influence of solar forcing on the atmosphere in the South Pacific region, Geophys. Res. Lett., 38, L12804, doi:10.1029/2011GL047794.

1. Introduction

\[2\] This paper continues two previous diagnostic studies of the average influence in the North Pacific Ocean of the sun at 14 of its decadal peaks [van Loon et al., 2007; van Loon and Meehl, 2008, hereafter referred to as vL7,8]. Based on composite mean analyses for years of peak sunspot number, it was found that, on average in the northern winter, the equatorial eastern Pacific sea surface temperature (SST) tended to be below normal, the sea level pressure (SLP) in the Gulf of Alaska was above normal, and the tropical convergence zones on both hemispheres were displaced poleward. Furthermore, the Hadley and Walker circulations and the stratospheric Quasi-Biennial Oscillation (QBO) were affected by the solar irradiance cycle, as was the tropical rainfall over the Pacific. Some aspects of the SLP signals in the Pacific have appeared in other associations [e.g., Wexler, 1956; Favorite and Ingraham, 1976; Christoforou and Hameed, 1997].

\[3\] The SLP anomalies in the northern winter (January–February or JF average) are shown in Figure 1a for the composite average of ten sunspot peak years, also referred to as peak solar years, when extremes were reached in the monthly mean number of spots: 1907, 1917, 1928, 1937, 1947, 1957, 1968, 1979, 1989, and 2000. We have used the climate–mean 1968–1996 to arrive at the anomalies. This is the default mean in the NCEP/NCAR analyses [Kalnay et al., 1996] in which the last five solar peaks are available, and thus can be used to compute anomalies of various quantities.

\[4\] The peaks of sunspot numbers tend to occur early in the more broad decadal maxima in the 11 year solar cycle [Roy and Haigh, 2010, Figure 4] and are coincident with the anomalously cool SSTs in the equatorial eastern Pacific that are seen using composites [vL7,8; Zhou and Tung, 2010]. Thus, the warm SLP response in that region, which lags the cool response by a couple of years in the composites and in some models [Meehl and Arblaster, 2009; Meehl et al., 2009], occurs more in line with the broad decadal TSI decadal maximum [Roy and Haigh, 2010]. This is the signal that is more often seen in analyses using multiple linear regression or filtered data. This is illustrated in a schematic diagram with idealized sunspot cycles and equatorial Pacific SST time series (Figure S1 of the auxiliary material). Thus an apparent discrepancy between solar maximum being associated with either anomalously cool or warm equatorial Pacific SSTs [e.g., Tung and Zhou, 2010; White et al., 1997; Roy and Haigh, 2010] is a matter of the timing that involves the initial climate system response to the rapid increase in TSI from solar min to solar max (L. L. Hood and R. E. Soukharev, The lower stratospheric response to 11-year solar forcing: Evidence for coupling to the troposphere–ocean response, submitted to Journal of the Atmospheric Sciences, 2011), and that transition often is associated with a peak in sunspots (and associated TSI [see Gray et al., 2010]) early in the broad decadal solar maximum. When this timing is taken into account, these studies are all consistent.

\[5\] Earlier studies have described at least two possible mechanisms that could produce these effects [e.g., Meehl et al., 2008, 2009]. The first is a top-down mechanism where greater UV in peak solar years warms stratospheric...
ozone, resulting in a chain of processes that ends up strengthening convection in the deep tropics. The second is a bottom-up mechanism that involves coupled air-sea-radiative processes in the tropical and subtropical Pacific that also end up strengthening convection in the deep tropics. These two mechanisms likely add together to reinforce each other \cite{Meehl2009} and produce the signals shown in this paper.

\cite{VAN LOON AND MEEHL: INFLUENCE OF SOLAR IN SOUTH PACIFIC} 2. Anomalies of Sea-Level Pressure

\cite{Figure 1} Figure 1 shows the SLP anomalies for 10 sunspot peak years of the decadal solar oscillation ("Year_0") since the beginning of the 20th century. North of about 30°S the pattern is the same as in the longer-term analyses in vL7,8.
Positive SLP anomalies in the Gulf of Alaska are separated from positive SLP anomalies in the tropics south of the equator by low amplitude negative anomalies which give rise to strengthened southeast trade winds (SE-trades). Weak negative SLP anomalies farther south lie between the positive anomalies south of the equator and positive SLP anomalies in the sub-Antarctic. The inter-hemispheric pattern is one of a mirror image in the Pacific about the positive anomalies in the southern tropics. Differences in Figure 1 (as well as Figures S2 and 2 discussed below) greater than about 1 mb are significant at the 5% level. This pattern is even stronger in the preceding southern winter (e.g., the July–August or JA season of the year before the peak solar, or “Year−1”), and is evident if the peak solar years are subdivided into two sets (Figure S2) as was done for the northern winter pattern in the North Pacific by vL7,8.

As an additional consistency check, the five solar peaks during the period in the NCEP/NCAR re-analyses (1957, 1968, 1979, 1989, and 2000) show the same essential elements of the positive SLP anomaly patterns in the North and South Pacific (Figure S3). The negative anomalies stretching from New Guinea to Cape Horn (Figures 1a and S3) with positive anomalies to the south suggest that the South Pacific Convergence Zone (SPCZ) and its extension are affected by the solar activity. Indeed Figure 1b (the anomalies of the precipitation rate in January–February of the five sunspot peaks in the NCEP/NCAR re-analysis) shows that the SPCZ is enhanced and poleward-shifted with an intensified low-latitude dry zone (negative precipitation anomalies in the tropical eastern Pacific). This confirms previously published results but highlights the extensive enhancement and southward shift of the SPCZ far into the southeast Pacific. Also of note are the large amplitude negative precipitation anomalies in the equatorial Pacific. Previous convective heating anomaly experiments [Meehl et al., 2008] showed that the anomalous high pressure in the North Pacific during peak solar years could be traced to forcing from the tropics. This is also the case for the anomalous high pressure in the South Pacific. Figure S4 shows that, for a negative convective heating anomaly placed at 150W, 5S (associated with the negative precipitation anomalies there in Figure 1b), the resulting SLP anomalies are similar to those in Figure 1a, with mirror-image anomalous high pressure centers in the North and South Pacific, with the northern center having larger amplitude.

In the southern summer in the year leading up to the peak (JF−1 in Figure 2a) the pattern in Figure 1a is discernible, with the positive SLP anomalies greater than 1 mb in the far South Pacific and just south of the equator. The amplitude is enhanced in the southern winter (JA−1 in Figure 2b) where there are areas of anomalies greater than 3 mb. In the southern spring (ON−1 in Figure 2c) the pattern has weakened somewhat, but is still similar to the previous seasons with anomalies greater than 1 mb. The increasing influence in Year−1 agrees with the findings of Mendoza et al. [1991]. In the southern summer of Year−1 (JF+1 in Figure 2d) there are still positive SLP anomalies in the far south though they are weak.

With regards to the SST anomalies in the equatorial belt, vL8 showed that the positive SLP anomalies just south of the equator in Figures 1a and 2, though relatively small in amplitude, are an important element in the solar signal
because of the above-normal SE-trades that are associated with them that produce negative SST anomalies between 20°N and 20°S, the northern winter prior to and following peak solar years. For seasons comparable to those in Figure 2, Figure S5 shows the evolution of the negative equatorial SST anomalies from the winter prior to the sunspot peak (JF\(_{-1}\) in Figure S5a; differences greater than about 0.5°C are significant at the 5% level) through the winter after the sunspot peak year (JF\(_{+1}\) in Figure S5d).

Finally, as previously noted by van Loon and Meehl [2008], the climate signal is different for peak solar years than for cold events (La Niña events) in the Southern Oscillation. Namely, SST anomalies in the equatorial Pacific for peak solar years are about half the amplitude as in La Niña events, and the sign of wind anomalies in the upper troposphere is different. This difference in peak solar years and La Niña years is further shown in Figure 3 that compares the anomalies in January in ten cold extremes in the Southern Oscillation to composite anomalies from nine sunspot peaks. As noted previously, the equatorial Pacific SST anomalies for peak solar years are about half that for La Niña events (Figures 3c and 3d). Additionally, there is a striking difference in South Pacific SLP anomalies such that the positive anomalies in the sub-Antarctic in the solar peaks (Figure 3a) have no counterpart in the La Niña cold extremes (Figure 3b). The latter shows the typical Southern Oscillation anomaly pattern in Cold Events: east of 140°W negative anomalies in the south and positive anomalies to the north; and west of 140°W positive anomalies to the south with negative anomalies to the north.

Acknowledgments. The years of the sunspot maxima were obtained from a list of solar maxima and minima in the NOAA website: ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/INTERNATIONAL/maxmin/new/MA. Average anomalies in composites of the decadal solar peaks in the South Pacific Ocean, using the data in the several websites with data from the NOAA, ESRL, Physical Science Division (http://www.esrl.noaa.gov/psd), and we acknowledge with gratitude their work in making these data available. The sites are maintained by Cathy Smith. The authors thank Lon Hood and one anonymous reviewer for constructive and helpful comments. Portions of this study were supported by the Office of Science (BER), U.S. Department of Energy, Cooperative Agreement DE-FC02-97ER62402, and the National Science Foundation. The National Center for Atmospheric Research is sponsored...
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References


G. A. Meehl and H. van Loon, National Center for Atmospheric Research, 3090 Center Green Dr., Boulder, CO 80301, USA. (meehl@ucar.edu; vanloon@ucar.edu)