Recent Data Show no Weakening of the Walker Circulation

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1 Abstract

Various authors have examined the strength of the equatorial Pacific overturning known as the Walker Circulation in both climate models and observations, attributing a generalized weakening to anthropogenic global warming. Here we review the analysis in Power and Smith [2007] using updated Southern Oscillation Index (SOI) and NINO sea surface temperature indices. We find no significant long-term changes in the indices, although the SOI appears to have recovered from an anomalously low period from 1976 to 1998. The increasing sea surface temperature in the NINO4 region is not significant, nor representative of other NINO regions. The findings of a weakening Walker circulation appear to be premature, and the corresponding climate model projections cannot be substantiated at this time. The reports of weakening of horizontal atmospheric circulation in climate models should be regarded as an inconsistency and not as an indicator of anthropogenic climate change.

2 Introduction

The best test of a theory tests the fundamental assumptions, as the results indicate not only if, but also why there is divergence from observations. The

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explanation given for decreasing strength of atmospheric circulation is as follows [Held and Soden, 2006, Vecchi et al., 2006]: As the surface warms, water vapor concentration in the lower troposphere increases by roughly 7% per 1K of surface warming consistent with the Clausius-Clapeyron equation and fixed relative humidity. However, the rate of precipitation, limited by the radiative cooling of the troposphere, increases more slowly by approximately 2% per K of warming [Houghton et al., 2001]. Because precipitation must match evaporation, atmospheric transport of the moister air must therefore decrease. This is contrary to the intuition that the atmosphere will become more energetic as it warms.

Tanaka et al. [2005] showed a weaker Walker and monsoon circulations for JJA climate in the IPCC 20th Century simulation models, projecting a 9, 8, and 14%, weakening in the Hadley, Walker, and monsoon circulations, respectively. Vecchi et al. [2006] found the decline in sea level pressure (SLP) in the Geophysical FluidDynamics Laboratory CM2.1 model agreed with observations over the same period. Examining a larger suite of IPCC models, Vecchi and Soden [2007] found the weakening occurs preferentially in the east-west (i.e., Walker) rather than north-south (i.e., Hadley) component of the tropical circulation, and was due to a relative decrease in the frequency of strong updrafts.

Power and Smith [2007] confirmed the weakening of the Walker circulation (WC) on a range of observational data, finding an increase in sea surface temperature (NINO4), and a step decrease in the SOI. The structural form of the change suggested to them a permanent change in atmospheric circulation due to global warming: "We also document what appears to be a concurrent period of unprecedented El Niño dominance. However, our results, together with results from climate models forced with increasing greenhouse gas levels, suggest that the recent apparent dominance might instead reflect a shift to a lower mean SOI value." The 'consensus' is summed up by Vecchi et al. [2006], who stated: "The size of this trend is consistent with theoretical predictions, is accurately reproduced by climate model simulations and, within the climate models, is largely due to anthropogenic forcing."

In an apparent contradiction to this consensus, Chen et al. [2002] found evidence for strengthening of the tropical general circulation in the 1990s. Despite the precedence of Chen et al. [2002] in the literature, and prominent publication, Chen et al. [2002] was not reconciled or cited in any of Tanaka et al. [2005], Vecchi et al. [2006], Vecchi and Soden [2007], Power and Smith

[2007], nor in the most recent IPCC review [Meehl, 2007].

The difference in findings may be because Chen et al. [2002] eliminated the effects of strong El Niño events during that period, which may confound the detection of small generalized trends. The WC is affected by the El Niño southern oscillation (ENSO), which over the last half-century has been said to have experienced unusually extreme and frequent El Ninõ events [Trenberth and Hoar, 1997] although others indicate it is within the bounds of natural variation [Harrison and Larkin, 1997]. It has also been suggested that the tendency for El Niño's has increased due the weakening of the WC [Fedorov and Philander, 2000], but statistical studies do not find significant non-stationarity [Solow and Huppert, 2003]. Unlike the WC, the models show no consensus in the response of ENSO to global warming [Power and Smith, 2007]. Patterns of proxy records show a large decadal variability related to another oceanic regime, the Pacific Decadal Oscillation (PDO) [Ault et al., 2009]. The influence of the PDO and the presence of natural climate-shifts in the ENSO series [Boucharel et al., 2008] pose a risk of false positives if significance tests are based on contemporary observations.

We test the hypothesis of the weakening of the WC with a simple linear regression on updated data for SOI and the NINO sea surface temperature (SST) indices 2 to 5, taking into account autocorrelation. We then quantify the liklehood of the period of low SOI based on historic data to determine whether the period was 'unprecedented', and use structural break tests to detemine the overall form of changes in SOI, sea temperature, and global temperature.

We find that although the SOI was low during the 90's it has since recovered to normal levels, concluding that the decline in the WC cannot be confirmed at this time, and that observational of decline in the pressure of Vecchi et al. [2006], Power and Smith [2007] was confounded by the influence of strong El Niño's.

3 Analysis

We downloaded the monthly data series (1876 to 2009) for SOI from the Australian Bureau of Meteorology website (http://www.bom.gov.au), and the (Kaplan and Reynolds) NINO indices from the The Royal Netherlands Meteorological Institute (http://www.knmi.nl). We calculated the error bounds of the coefficients of linear regressions fit to these data both with and without modification for autocorrelation. The adjustment for autocorrelation conforms to Santer et al. [2008] but dates back to at least Quenouille [1952]. Here, the number of degrees of freedom n_t are adjusted to an effective degrees of freedom n_e, assuming a strictly first order autoregression coefficient r, by the relation:

$n_e = n_t \frac{1-r}{1+r}$ (1)

The standard deviation is then adjusted with the ratio of the square root of the unadjusted and effective degrees of freedom.

$sd_{AR} = sd_{OLS} \sqrt{\frac{N-2}{n_e-2}}$

Figure 1 shows the SOI and ocean SST in the NINO3.4 (or NINO5) region over the period. The number of SOI data points is $N = 1602$ and the degrees of freedom $n_t = 1600$. An adjustment (1) of 0.228 gives an effective degrees of freedom of 365, increasing the standard error of the slope by a factor of 2.1. The SOI has a slightly negative slope – almost significant (95% CL) when not adjusted ($p_{OLS} = 0.058$) but non-significant when adjusted for autocorrelation ($p_{AR} = 0.177$) (Table 1).

Table 1 lists for all indices the coefficients of slope, their significance both independent and adjusted for autocorrelation, and the autocorrelation coefficient AR. The slopes of the indices NINO2-5 covering different areas of ocean surface from west to east, are variable and mostly not significant. The NINO4 index quoted in Power and Smith [2007], appears to be significantly increasing ($p_{OLS} = 0.05$) but is not significant when autocorrelation is taken into account ($p_A R = 0.83$). The decrease in the NINO2 index, positioned in the deep ocean upwelling zone off the coast of Chile, is significant ($p_a = 0.03$) when autocorrelation is taken into account.

	Slope	p_OLS	AR	p_AR
SOI	-0.0128	0.06	0.63	0.18
NINO2	-0.0044	0.00	0.92	0.03
NINO3	-0.0008	0.05	0.94	0.36
NINO4	0.0017	0.00	0.94	0.84
NINO3.5	0.0004	0.32	0.94	0.57

Table 1: The coefficients of slope, their significance for ordinary least squares and autocorrelated assumptions (p), and the autocorrelation coefficient (AR) for SOI and all NINO indices.

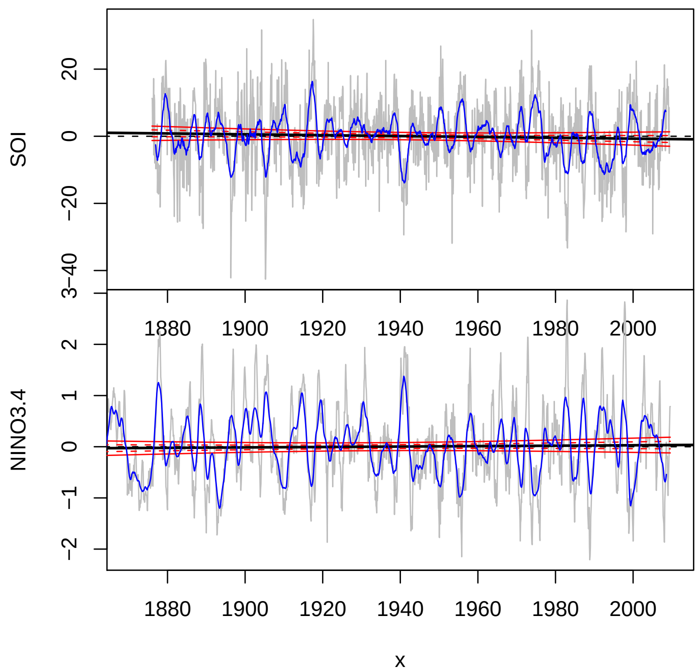

Figure 1: The trend in the SOI (upper) and NINO3.4 (lower), 95% confidence intervals without autocorrelation (red dashed) and with autocorrelation (red solid) and the 24 month moving average (blue).

Table 2: Expected results for three possible hypotheses on three statistical tests of the SOI time series.

	Hypothesis	Slope	Consistency	Break
H1	WC declining	Sig -ve	NS	step down
H2	WC unchanged	NS	NS	no change
H3	Anomalous 1976-98 period	NS	Sig	step up and down

Figure 2 compares the consistency of the trend in the SOI for a given year up to 2009, against the distribution of all trends of the same length over the whole period from 1876. The 95% and 99% significance levels are shown (red dashed, and solid lines respectively). The trend in SOI to 2008 starting at successively earlier years (2003, 2002, 2001, etc) increases strongly since 1998. While the trends from 1990 to 1993 exceed the unadjusted 95% significance level, they do not exceed 99%, suggesting that the low in SOI between 1990 and 1993 was less than a one in one hundred year event.

Figure 3 depicts three time series: the global mean temperature (upper HadCRUT3 after Jones et al. [1999]), the SOI (middle) from 1960, and the NINO3.4 index of SST. The fit and position of three segment structural change models are shown in red. The position of the breaks was chosen by exhaustive search for the minimum of the sum of squares, known as a Chow test (i.e. a test which takes year-to-year variability and the magnitude of the change into account, but not the autocorrelation, after Chow [1960]). Models with a single break in July 1976 and with two breaks in February 1979 and February 1997 are highly significant ($F(32, 1, 356) < 0.001$). The 95% confidence intervals of the breaks are indicated with red bars.

The position of segments between the two breaks suggests the SOI changed from the long-term mean of $SOI = 0.0 \pm 1.1$ to a new, lower, mean of $SOI = -4.1 \pm 2.8$ between 1979 to 1998 (with a $p_{OLS} < 0.001$ and $p_{AR} < 0.01$). The largest and most reliable indicator of ENSO based on ocean sea temperature, NINO3.4, has large and overlapping confidence intervals indicating unclear break points. However, the segmentation indicates ocean temperatures in the NINO3.4 region increased to a higher level between 1979 and 1998 and decreased thereafter.

4 Discussion

The expected results for each of the hypotheses are summarized in Table 2. The non-significant decline in the slope of the SOI supports hypothesis H2 and H3 but not H1 (Figure 1). The trends from 1990 to 1993 are significant at the 95% confidence level but not the 99% level, supporting H3. The generally positive trends since then suggest a strong, but not unusual rate of recovery in the SOI from a temporary low, supporting H2 and H3 but not H1(Figure 2). The break test indicates a significant step down and then up in SOI, excluding H1 and supporting H2 (Figure 3).

These results provide strong support for H3: a temporary anomalous period of low SOI values between 1978 and 1998, and particularly between 1990 and 1993, that has since recovered to pre-1978 levels. There is some support for H2, a constant SOI, as estimates using contemporary data may well be underestimate decadal variability [Ault et al., 2009]. There is no support in any of the statistics for H1 – a declining SOI. Examination of the methodology in Vecchi et al. [2006] and Power and Smith [2007] indicates an undue influence of conditions during the period between 1976 and 1998.

Power and Smith [2007] analysed the slope of the NINO4 index finding increasing ocean temperatures. However, the indices indicate both increasing and decreasing ocean temperatures in the NINO regions, with only NINO2 significantly decreasing at the 95% confidence level. It is not clear why Power and Smith [2007] chose to highlight the NINO4 index as no explanation was given. NINO4 is the only SST index with a significant upward slope (when autocorrelation is not accounted for), and is not representative of the range and significance of NINO indicators. The SST's in the largest of the regions, NINO3.4 (or NINO5) increased up to 1998, and slightly decreased thereafter (Figure 3 lower).

Based on these results, the weakening of the WC found by Vecchi et al. [2006] and Power and Smith [2007] cannot be substantiated at this time. Some suggestion for future work follow.

5 Implications

The implications of a constant, versus a weakening WC, are interrelated to a number of other unsettled controversies concerning the upper troposphere. The conventional explanation for decreasing strength of atmospheric circulation hinges strongly on the concentration and role of water vapor concentration in the upper troposphere. While not increasing quite as fast as the Clausius-Clapeyron equation would indicate, a number of authors claim that atmospheric humidity is changing in ways consistent with those predicted by global climate models [Soden et al., 2002, Minschwaner et al., 2006, Held and Soden, 2006, Dessler and Sherwood, 2009]: a positive trend in absolute (specific) humidity and a slight decrease in relative humidity, which would be consistent with declining horizonal atmospheric transfer.

However, studies based on other data sources find a drying in the upper troposphere [Paltridge et al., 2009] along with a decrease in cloudiness [Hatzidimitriou et al., 2004]. The 35-year trend in radiosonde-derived specific humidity is significantly negative at all altitudes above 850 hPa (roughly the top of the convective boundary layer) in the tropics and southern midlatitudes and at altitudes above 600 hPa in the northern midlatitudes [Paltridge et al., 2009]. Even though these data are very universally regarded as uncertain, it illustrates the current uncertainties and inconsistencies with climate-model simulations in the upper troposphere.

Other sources of inconsistencies between models and observations in the upper troposphere tropical region may well be relevant [Karl et al., 2006]. The strength of feedback compared with observations in NINO regions during El Niño events, show climate models overestimate by up to 50% the positive water vapor feedback, and underestimate negative feedbacks from horizontal transport and clouds [Sun et al., 2006, 2008]. At least for the NCAR models, the middle and upper tropospheric water vapor shows the most excessive response to surface warming (700-300 mbar) with the maximum discrepancy to ERBE observations at 500 mbar reaching 18%/K in CAM3 [Zhang and Sun, 2008]. Key disagreement also exists between simulations of the decadal variability in the tropical-mean radiation budget [Clement and Soden, 2005] and in low-level cloud feedback [Clement et al., 2009].

If we assume that atmospheric circulation is constant as our results suggest, the simple mass balance arguments under decreasing WC and increasing troposphere temperature would imply a decline in humidity in the regions of horizontal transfer in the upper troposphere. Moreover, results from both model sensitivity experiments and an empirical analysis of ERBE observations suggest that the strength of horizontal circulation should be relatively insensitive to changes in the tropical-mean radiation budget relative to the vertical convection [Clement and Soden, 2005]. A declining WC was regarded as a confirmation of anthropogenic climate change by Vecchi et al. [2006] and Power and Smith [2007]. Generalized changes in WC are unsupported given our results and findings: no evidence for weakening of the Walker circulation, disagreements over upper troposphere humidity levels, inconsistency of various feedbacks in the ENSO region, and low sensitivity of horizontal transport to the radiation budget changes.

Inconsistencies between models and observations should be of concern to modellers, particularly as strong and positive water vapor feedback, over and above non-feedback radiative increases, is necessary for models to explain the magnitude of past natural climate variation via increases in GHG's [Dessler and Sherwood, 2009]. As noted by Zhu et al. [2007] in the changes in the cloud amount in response to ENSO and to global warming, different mechanisms may produce similar results [Sun et al., 2006]. Clouds produce large decadal variability in the global energy budget and cloud albedo steadily decreased during the post-1960 period [Wielicki et al., 2002, Cess and Udelhofen, 2003, Pallé et al., 2005, Hatzidimitriou et al., 2004]. These findings suggest alternative explantions for enhancing radiative forcing, such as increased absorption of solar radiation during intense El Niños.

A potential explanation for homeostasis in the strength of atmospheric circulation, driven by a constant pressure differential, may be found in theories based on a Maximum Entropy Production (MEP) principle [Miskolczi, 2007, Paltridge et al., 2007]. A general weakening in atmospheric circulation would violate the principal of non-declining work. The tendency of the local optimization principle of MEP to produce quasi-stable self-organizing states [Niven, 2009] also helps to justify models based on ocean-regimes, as seen empirically (Figure 3), statistically [Boucharel et al., 2008] and justified theoretically by Tsonis et al. [2007]. The Great Pacific Climate Shift (GPCS) around 1976, occurred at the start of the recent increase in global mean temperature. Temperature continued to increase while the SOI remained largely negative. Another shift occurred in 1998 where both reverted to the previous state with temperature remaining at a higher level, suggesting El Niños may have a greater role in warming than generally thought [Stockwell and Cox, submitted].

6 Conclusion

The claims by Tanaka et al. [2005], Vecchi et al. [2006], Vecchi and Soden [2007], Power and Smith [2007] for a weakening WC must be reconsidered, as additional data shows a strong recovery in SOI since 1998, and the SST trends in the NINO regions are inconclusive. One should be extremely cautious of studies using climate simulations to justify their claims, as natural variance may be greater than contemporary observations encompass, and projections of climate models often cannot be fully substantiated by their performance. Without greater understanding of the climate system, rapid changes such as a low SOI should not necessarily be interpreted as anthropogenic in origin, or as tipping points of global-warming-forced climate change (e.g. Zhang et al. [2008]).

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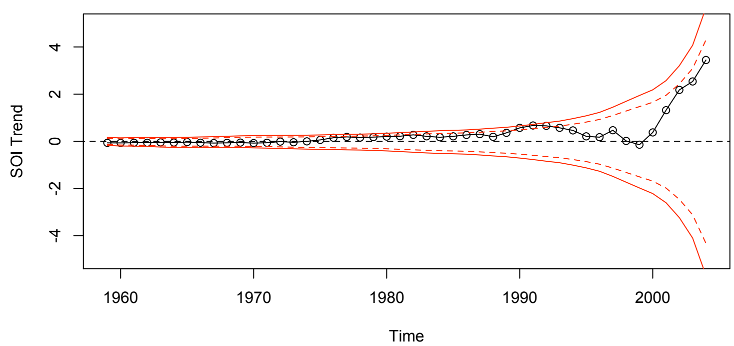

Figure 2: The trend in the SOI from 2009 (black line and circles), relative to the distribution of past trends at the 95% (dashed red) and 99% (solid red line) confidence levels.

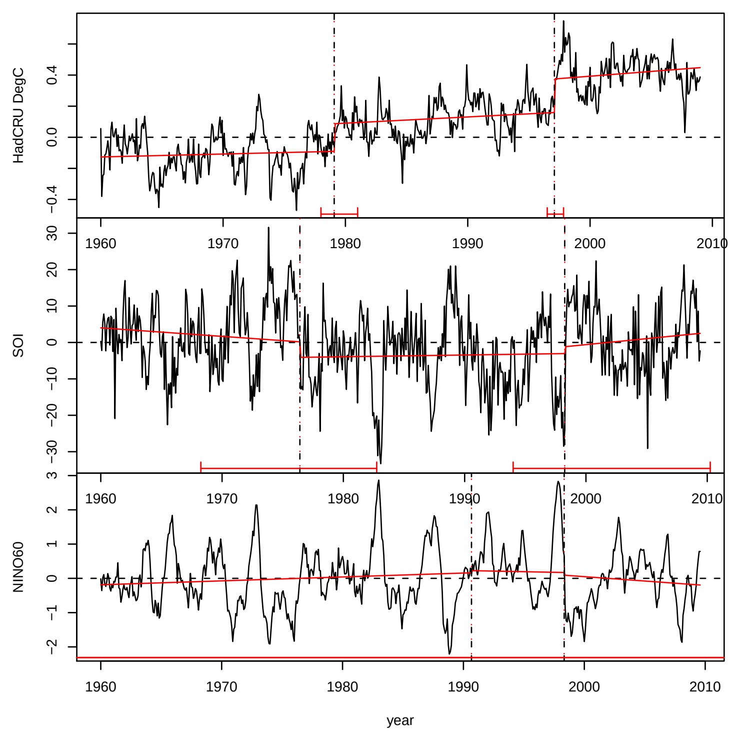

Figure 3: A Chow test on global mean temperature (HadCRUT3) and SOI indicates two related breaks in the mean values, with SOI at a lower mean from July 1976 to April 1998. The equatorial Pacific indicator of ocean sea temperature NINO3.4 does not show clear breaks, as indicated by the large and overlapping confidence intervals.