Nova Acta Leopoldina NF *112*, Nr. 384, 165–172 (2010)

Solar Signals in African Climate since 1901

Joachim RATHMANN and Jucundus JACOBEIT (Augsburg)

With 5 Figures

Abstract

The present paper may contribute to an improved assessment of sun-climate relationships with a regional focus on Africa. Some statistical relationships between solar activity and the climate of southern Africa have been identified since the beginning of the 20th century based mainly on different time series analyses (autocorrelation, spectral and wavelet analyses) in addition to simple correlation and composite analyses. Solar cycle signals can be shown for South African winter temperatures, East African precipitation and northern Namibia / southern Angola precipitation during winter and spring. Furthermore, significant solar signals can be revealed in SSTs (Sea Surface Temperatures) of the southern equatorial Atlantic and SLP data of the subtropical anticyclones above the Atlantic and Indian oceans.

Zusammenfassung

Eine veränderliche Solaraktivität nimmt auf allen Zeitskalen Einfluss auf das Klima der Erde. Am regionalen Beispiel Afrikas werden solar-klimatische Kopplungen seit Beginn des 20. Jahrhunderts mit Hilfe statistischer Methoden aufgedeckt. Dazu wurden Zeitreihenanalysen (Autokorrelationsanalysen, spektrale Varianzanalysen und Waveletanalysen) ergänzt um Korrelations- und Kompositenanalysen berechnet. Aus den Ergebnissen lassen sich signifikante solare Signale im Untersuchungsgebiet aufdecken. Ein solarer Einfluss auf die winterliche Lufttemperatur in Südafrika ist wahrscheinlich, der Niederschlag weist in der Region nördliches Namibia, südliches Angola und in Ostafrika ein markantes quasidekadisches Signal auf, ebenso die Meeresoberflächentemperatur im südäquatorialen Atlantik. Eine weitere Region mit einer möglichen solar-induzierten Klimavariabilität liegt in den subtropisch-randtropischen Hochdruckgebieten über dem südlichen Atlantik und südlichen Indik.

1. Introduction

Since the year 1900 the global climate has warmed by approximately 0.8 °C. Most of this warming is due to the rising concentration of carbon dioxide and other anthropogenic greenhouse gases (SOLOMON et al. 2007). A noteworthy contribution of solar variability to recent warming is generally dismissed, because the responses to the solar 11-year cycle are too small to be detected unambiguously in observations. But – although there have been hundreds of studies during the last decades concerning climate response to the 11-year sunspot cycle (cf. BENESTAD 2002) – the influence of solar activity changes on the climate of the Earth is still characterized by a "low level of scientific understanding" (SOLOMON et al. 2007).

The sun influences the Earth's climate by its whole radiation spectrum, the so called solar wind and its influence on cosmic rays. The most highly variable parts of the sun's radiation spectrum can be found at short wavelengths, e.g. the ultraviolet (UV) ones. Both model and observational studies show some tropospheric circulation changes due to the 11-year sunspot cycle (e.g. HAIGH 2003, GLEISNER and THEJLL 2003, LABITZKE 2005, LEAN and RIND 2008, ROY and HAIGH 2009, LEAN 2010). STAGER et al. (2007) identify relations between the sunspot number and lake level data of Lake Victoria and other great lakes in East Africa during the 20th century. ROY and HAIGH (2009) identify solar cycle signals in global SST data, covering more than 150 years. CAMP and TUNG (2007) apply composite analyses to detect the influence of the solar cycle on surface temperatures during the last decades. They obtain a significant signal and conclude that a globally averaged warming of almost 0.2 K between sunspot minimum and maximum is much larger than previously reported. But this value might be too large because of volcanic cooling (LEAN and RIND 2008). The present paper summarizes some results which have been obtained by regional climate studies focussing on Africa (RATHMANN 2009).

2. Data

This study uses the global HadSLP2 data set, a monthly gridded SLP reconstruction (UK Met Office Hadley Centre) with a 5° latitude by 5° longitude resolution. The recent version HadSLP2 spans the years 1850 to 2004 allowing to obtain a long-term perspective on SLP variability and secular changes. HadSLP is a reconstruction based on EOFs derived from recent periods with high data coverage. The data set is based on both marine and terrestrial surface observations. These observational data have been quality-checked and afterwards interpolated on a regular grid by using Reduced-Space Optimal Interpolation (RSOI) (ALLAN and ANSELL 2006).

Sea Surface Temperature (SST) data are taken from the HadISST1.1 data set developed by the UK Met. Office. The data start in 1870 having a spatial resolution of 1° latitude by 1° longitude. The SST grid is based on observational data which have been interpolated by a two-stage reduced-space optimal interpolation procedure (RAYNER et al. 2003).

High-resolution temperature and precipitation data, covering the global land areas, are taken from the CRU05 dataset provided by the Climate Research Unit (CRU, Norwich) (NEW et al. 1999, 2000). The dataset has a spatial resolution of 0.5° latitude by 0.5° longitude, covering initially the 1901–1998 period. Recently, there are updates of this dataset available (MITCHELL and JONES 2005), and the present study is based on an improved and updated version of the original CRU05 data (ÖSTERLE et al. 2003).

As an indicator of solar activity changes over the past century, the sunspot number (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/YEARLY.PLT) and reconstructed total solar irradiance (TSI) data have been used (LEAN et al. 1995).

3. Methods

In a first step, simple correlation analyses between TSI and climate data have been calculated to receive a first indication of possible solar-climate relationships. The resulting correlation maps have to be interpreted very carefully even if the correlation coefficients are highly significant. There has always to be a reasonable physical mechanism that explains why the correlation reflects a linkage between cause and effect. But the scientific concept of causality is more complex, and even cause-effect linkages without correlation are possible (RATHMANN 2008).

Furthermore, various composite analyses have been performed: at first calculating differences between composites of temperature, precipitation, SLP and SST for months above and below the long-term mean annual sunspot number, respectively. Additionally, these calculations have been done for months above (below) the 90th (10th) and 75th (25th) percentiles (Fig. 1) in order to check whether some results might only be a matter of chance.

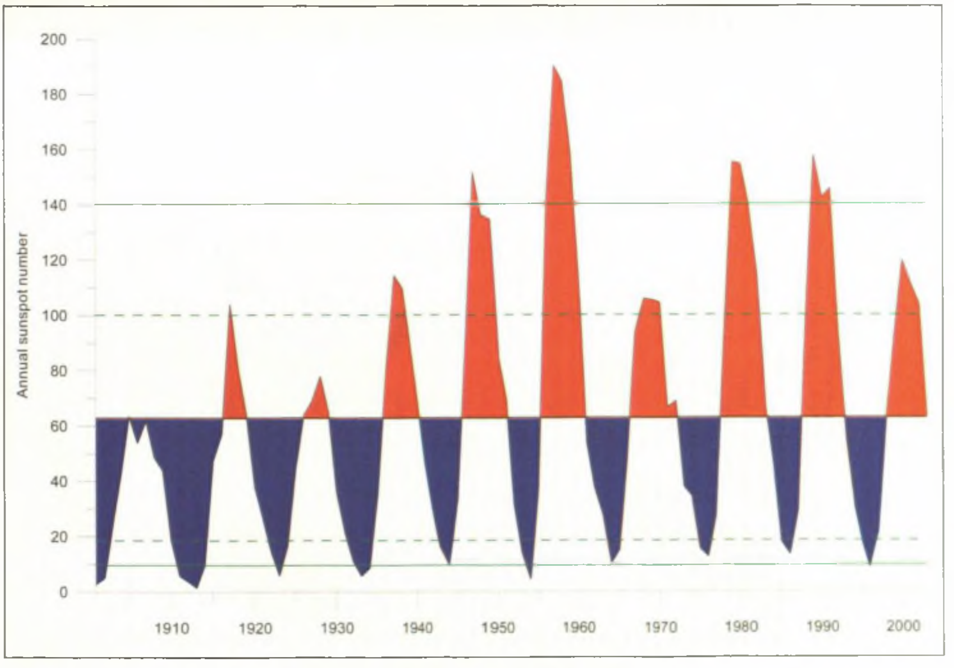

Fig. 1 Annual sunspot numbers (SSN) above (red) and below (blue) the long-term mean (62.55 for 1901–2003), respectively; green dashed lines: SSN corresponding to the 75th and 25th percentiles, respectively); green lines: SSN corresponding to the 90th and 10th percentiles, respectively.

Principal Component Analysis (PCA) is widely used in climate research in order to identify major patterns of atmospheric circulation, to pick out centers of atmospheric (or oceanic) variation or, generally, to reduce dimensions of original data and to remove linear dependencies between basic variables. In the present study, s-mode orthogonally (Varimax) rotated PCAs were carried out for monthly SLP, SST, precipitation and temperature data. All resulting PC time coefficients have further been submitted to different time-series analyses: autocorrelation, spectral variance and wavelet analyses. This has been done to identify cyclic components within the data. Spectral analysis is able to determine periodicities more precisely than simple autocorrelation analyses. But spectral analysis is only able to identify the spectral (frequency) components that exist in the signal, whereas wavelet analysis provides a time scale presentation of the signal. Wavelet analysis of time series is a powerful tool for describing processes that are non-stationary and occur over finite spatial and temporal domains. It allows to show a time-series signal simultaneously in time and frequency (Beecham and Chowdhury 2010).

In the present study, a complex Morlet wavelet has been used as a so called mother wavelet. The software applied for these calculations is based on original routines from TORRENCE and COMPO (1998).

4. Results

Differences of temperature-composites for months with sunspot maxima and minima are reaching up to 1 K in July (Fig. 2). This might be due to the influence of changes in the direct solar radiation on the high pressure system which establishes in winter above the South African highlands. Differences of precipitation-composites (not shown), calculated in the same way, depict increased precipitation during months of strengthened solar activity in East Africa for the long-rains period (RATHMANN and JACOBEIT 2009).

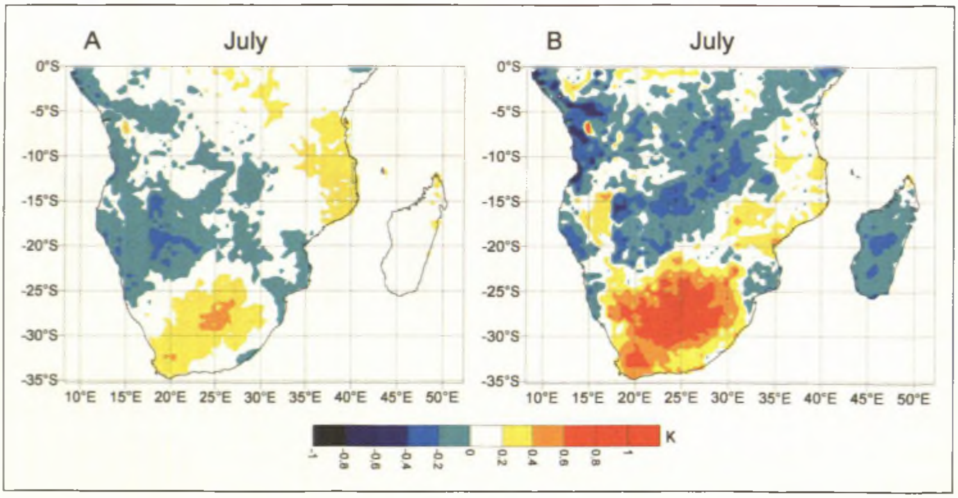

Fig. 2 (*A*) Differences of July temperature composites for sunspot numbers above and below the long-term mean value (62.55 for 1901–2003), respectively; (*B*) as (*A*) but for sunspot numbers above and below the 90th and 10th percentiles, respectively.

Differences of SST-composites include only very small values in the lower latitudes (not shown); this might be due to two opposing effects: Higher solar activity raises tropical SSTs, but due to an enhanced evaporation at the same time, energy is removed from the surface, leading to lower SSTs. Further relationships can also be shown by correlation analyses, for example between the TSI and SST data (with time coefficients for the latter from a s-mode PCA): there are highly significant values ($r = 0.7$ at the 99 % confidence level) for particular centers of SST variation in the midlatitudes between 50° S and 60° S (RATHMANN 2009).

Further results are based on time series analyses. For instance, spectral analyses applied to the time coefficients of SST PCs, representing the centre of SST variation in the southern equatorial Atlantic Ocean, confirm a highly significant (99 %) quasi-decadal signal for August

(Fig. 3). Figure 4 shows the wavelet power spectrum of this PC time coefficient, emphasizing a quasi-decadal SST variability.

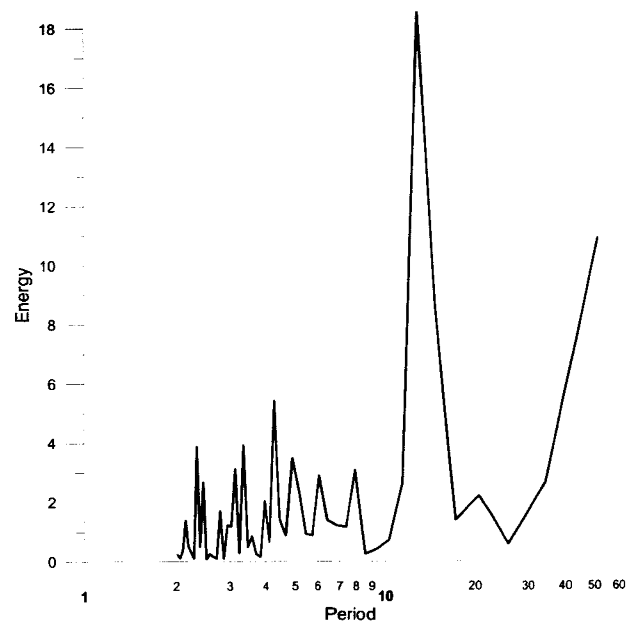

Fig. 3 Power spectrum of the PC time coefficients 1901–2003 for the SST center of variation in the southern equatorial Atlantic for August. Periods (in years) on a logarithmical scale.

The analysis of SLP data gives spectral maxima on a decadal time scale for the southern edge of the St. Helena high pressure system above the central South Atlantic Ocean during all seasons, but most pronounced in southern winter (not shown), when the high pressure cells are intensified. This result indicates an expansion of the Hadley cell during periods of higher solar activity (see also Roy and Haigh 2009).

A spectral peak on a decadal time scale can also be identified in the wavelet power spectrum (not shown) for the time coefficients of a temperature-PC representing the region of South Africa (Rathmann and Jacobeit 2009). This possible solar signal is controlled by the anticyclone above the southern Atlantic Ocean which itself shows a spectral peak at the same period (Fig. 5).

Quasi-decadal and therefore possible solar signals in precipitation time series can be revealed for Namibia and Angola by correlation analyses with TSI data. Just the same regions indicate a significant (95 %) quasi-decadal variability resulting from autocorrelation and spectral analyses (Rathmann 2009). Additional wavelet analyses, based on the monthly time coefficients of the s-mode precipitation-PC representing this region, also show spectral maxima on this time scale. A solar-cycle signal for East African precipitation in March is very

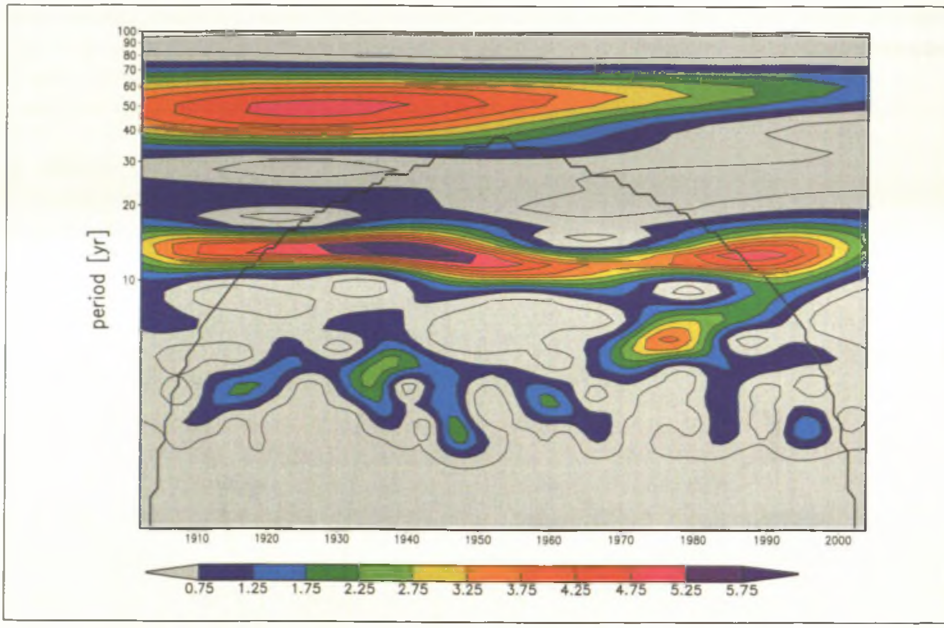

Fig. 4 Wavelet power spectrum of the PC time coefficients 1901–2003 for the SST center of variation in the southern equatorial Atlantic for August. The periods are shown on the y-axis with a logarithmic scale, the years 1901–2003 on the x-axis. The colour scale gives the wavelet power of a particular period during a definite section of time. Black lines outline the "cone of influence", i.e. the area that suffers from edge effects and therefore cannot be interpreted.

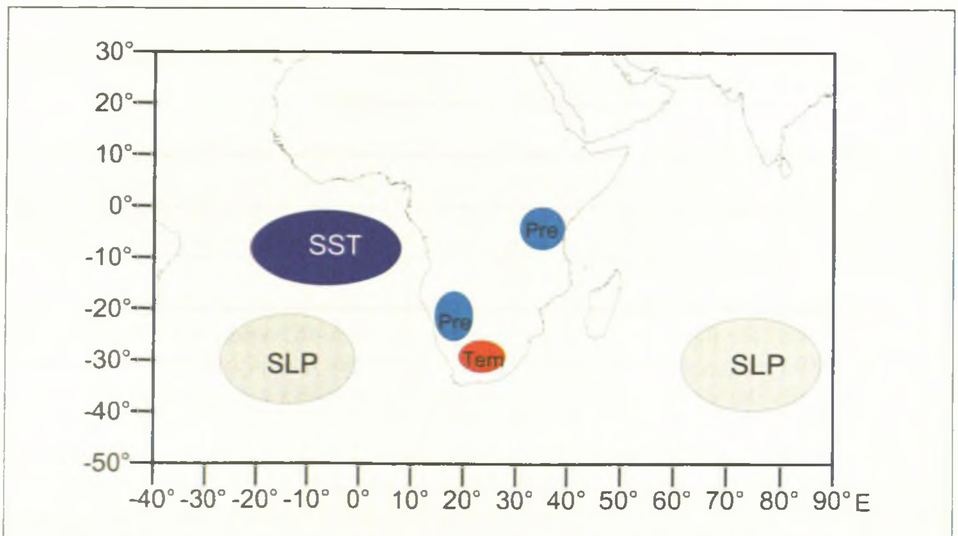

Fig. 5 Synopsis of regions for which solar signals in SST, SLP, Precipitation (Pre) or Temperature (Tem) data have been identified during the 1901–2003 period.

dominant during the first third of the 20th century (RATHMANN and JACOBEIT 2009), when solar forcing was still stronger compared to greenhouse gas forcing.

5. Summary and Conclusions

It is still unclear how the Sun's variable energy output exactly influences the Earth's climate. The present study contributes some statistical relationships between solar activity and the climate of southern Africa since the beginning of the 20th century mainly based on different time series analyses (autocorrelation, spectral and wavelet analyses) in addition to simple correlation and composite analyses. It could be shown that significant solar signals concentrate on particular regions (Fig. 5).

The present results indicate a strengthening of the subtropical high pressure systems above the southern Atlantic and southern Indian Oceans at solar maxima. A solar signal in South African winter temperatures reaches up to 1 K. Both composite and time-series analyses have shown robust relationships which might be explained by a direct radiation influence on the nearly cloud-free winterly high pressure system above central South Africa.

Precipitation in northern Namibia/southern Angola exhibits a striking quasi-decadal signal, and correlation analyses suggest a relationship with changing solar activity. Positive precipitation anomalies during the 'long rains' could be identified in East Africa during periods of increased solar activity. The increased precipitation might be caused by solar impacts on the Indian Ocean Dipole (IOD) which strongly influences the East African precipitation. Accordingly, NUGROHO (2007) has shown by means of wavelet analysis a strong solar signal on the IOD. Furthermore, a stronger Hadley circulation during periods of higher solar activity might lead to changes in the precipitation pattern (ROY and HAIGH 2009). Finally, this precipitation pattern during solar maxima is remarkably similar to an El-Niño-induced pattern. Increased solar activity leads to higher evaporation over the nearly cloud-free regions in the subtropics, and this might also lead to lower SSTs. Stronger regional Hadley and Walker cells due to the increased atmospheric moisture content include a stronger upward motion in tropical latitudes and a corresponding intensified subsidence in subtropical regions leading to a reduction of the cloud cover and therefore to an increasing solar irradiance input. These surface feedbacks might explain how a small solar signal is amplified in local climate (MEEHL et al. 2003).

Further studies should determine whether the increased solar activity of the recent decades – compared to earlier periods and superimposed on the 11-year solar cycle (SOLANKI et al. 2004) – has changed the solar fingerprints in the African climate system.

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Dr. Joachim RATHMANN
Prof. Dr. Jucundus JACOBEIT
Institute of Geography
University of Augsburg
Universitätsstraße 10
86135 Augsburg
Germany
Phone: +49 8215982131
Fax: +49 8215982264
E-Mail: joachim.rathmann@geo.uni-augsburg.de