SST Variability and External Forcing of Recent Climate Changes in Southern Africa

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Abstract

This study focuses on selected internal and external forcing factors for climate change in southern Africa. The former are discussed in terms of SST variability, the latter in terms of changing solar activity. Solar irradiation correlates significantly with changes in surface air temperature, implying possible solar contributions to the 20^{th} century warming.

SST trends, the Indian Ocean dipole pattern as well as South Atlantic warm events (Benguela El Niños) are presented with their particular influence on southern African climate.

Introduction

This paper intents to contribute to the understanding of inter-decadal and multidecadal variations in the climate of southern Africa since 1871. Emphasis is given to influences of SSTs and changing solar activity on atmospheric circulation. Thus, the main features of SST variability and changes in solar activity applying correlation, regression, composite, PC and CC analyses.

Data

The monthly Global Sea-Ice and Sea-Surface Temperature (GISST2.3b) data (1° x 1°, 1871 - 1998) and the recently released HadISST data are used in this study, as well as the Global Mean Sea Level Pressure (GMSLP2.1f) data with 5° x 5° latitude by longitude grid resolution. These data have just been superseded by the revised HadSLP dataset (1871 - 1998).

Highly resolved (0.5° x 0.5°) gridded temperature and precipitation data, starting in 1901, have been obtained from the Climatic Research Unit (Norwich). These data have been improved and corrected within the PIK (Potsdam Institute for Climate Impact Research).

Solar irradiance reconstructions by Lean (1998) are primarily used to determine solar influences on climate. Further sun-related factors as the number of sunspots, the solar cycle length and the geophysical aa-index are used as secondary indicators.

Methods and results

SST Variability

At least since Folland et al. (1986) showed the influence of SSTs on Sahel rainfall variability, many studies were carried out to identify modes and trends of SST variability (e.g. Cai & Whetton, 2001) and their impacts on African rainfall (Mason, 1995, Landman & Mason, 1999, Rouault et al., 2002, Nicholson, 2003). This paper addresses variations of the Indian Ocean dipole (Saji et al., 1999, Behera & Yamagata, 2001) and South-Atlantic warm events, so called Benguela El Niños (Shannon et al., 1986), and points to their importance for the climate of southern Africa.

The SST data have been subjected to s-mode principal component analyses (PCA) in order to identify main centres of SST variability. All analyses have been carried out on monthly and annual time scales to avoid the difficulties in determining adequate seasons and season lengths.

The dominant SST pattern refers to El Niño. Other features, such as dipole patterns in the Atlantic and Indian Oceans, are rather secondary implying patterns of more regional than global influence. The resulting PC time coefficients have been further analysed by canonical correlation analyses (CCA) in order to investigate the influence of the Atlantic and Indian Oceans on the climate of southern Africa.

CCA patterns for October, as an example, show the strong coupling of the Indian Ocean tropical dipole with heavy precipitation in eastern Africa. The time coefficients of Saji et al. (1999) may well be reproduced by this analysis and traced back to 1901 (Rathmann & Jacobeit, 2003).

In order to detect South Atlantic warm events, a regional SST index (10° S - 20° S, 5° E - 15° E) has been calculated. 20 months exceeding deviations from the mean of more than one standard deviation have been taken for calculating February composites, referring to the month when SST warming is at its maximum.

The time series of this regional index has a correlation of 0.74 with the time series of the first s-mode PC which explains 19.32 % of the total variance (Fig. 1). The maximum values of the first and second PCs are located at the southern and the northern tropical Atlantic, respectively, implying the existence of a tropical Atlantic dipole pattern. Considering the intense discussion on the physical nature of such climatic dipoles in the Atlantic and Indian Oceans (Enfield et al., 1999, Dommenget & Latif, 2002, Hastenrath, 2002) these results have to be carefully checked by further analyses. The composites show a strong temperature increase in the Benguela current during the warm events but no significant change in the Pacific Ocean. A weakening of the trades is obvious on the corresponding SLP composites for

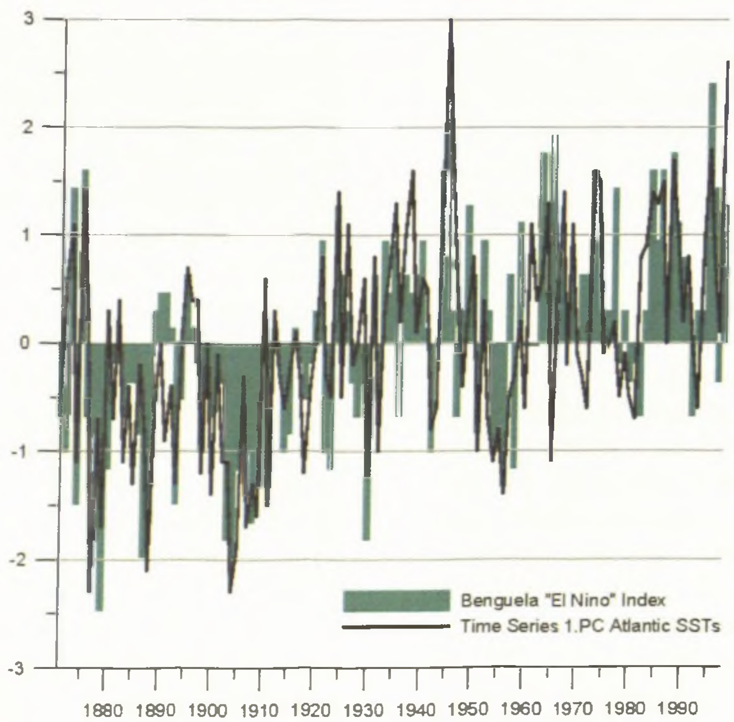

Fig. 1: Time series of the first s-mode PC for February SSTs (1871 – 1998) and time series of South Atlantic warm events (Benguela El Nino Index).

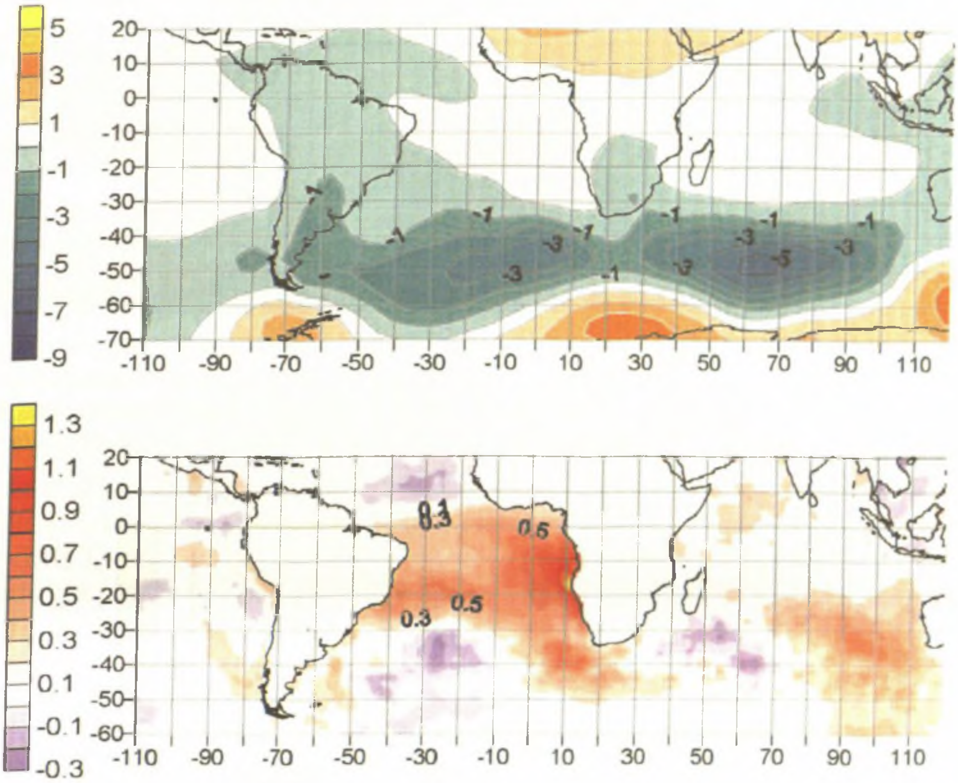

Fig. 2: SLP (upper panel) and SST (lower panel) composites for 20 February South Atlantic warm events 1871 – 1998. Deviations from the long-term mean are shown in hPa and K, respectively.

Benguela El Niños (Fig. 2). SLP decrease leads to a suppression of cold water upwelling and in turn to a SST increase. Consistent influences on African rainfall, however (e.g. heavy precipitation at the coast, dryer conditions in the continental interior), could not be detected in terms of composite patterns implying that each event has its own particular precipitation pattern, whereas air temperature of the same areas always significantly exceed the long-term mean during South Atlantic warm events.
Furthermore, SST trend detection by means of linear regressions, referring to each gridbox, have been performed for distinct 30-year intervals as well as for the whole 128-year period from 1871 to 1998 (Fig. 3). Results show a marked SST increase, especially in the southern oceans and during the last decades in the tropical Pacific and Indian Oceans. But due to the large variance of the SST data, most of the trends are not statistically significant, most gridboxes even fail to reach an unit trend-to-noise ratio.

Solar influences
Solar variability is a controversial factor of climate change across all time scales (Benestad, 2002; Rind, 2002). This study tries to establish statistical associations between various solar parameters (see section 2) and southern African climate. Significant correlations (95 % confidence level) were found between solar irradiance and surface air temperature with highest

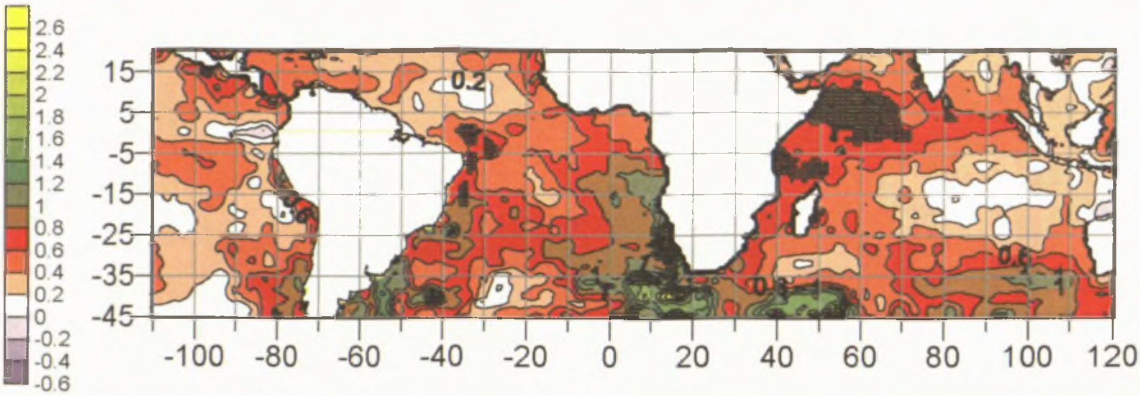

Fig. 3: Linear trends of Febrary SSTs for the period 1871 – 1998. Grid boxes with trends exceeding the standard deviations, respectively, are marked by dots, enlarged circles indicate the 95 % significance level.

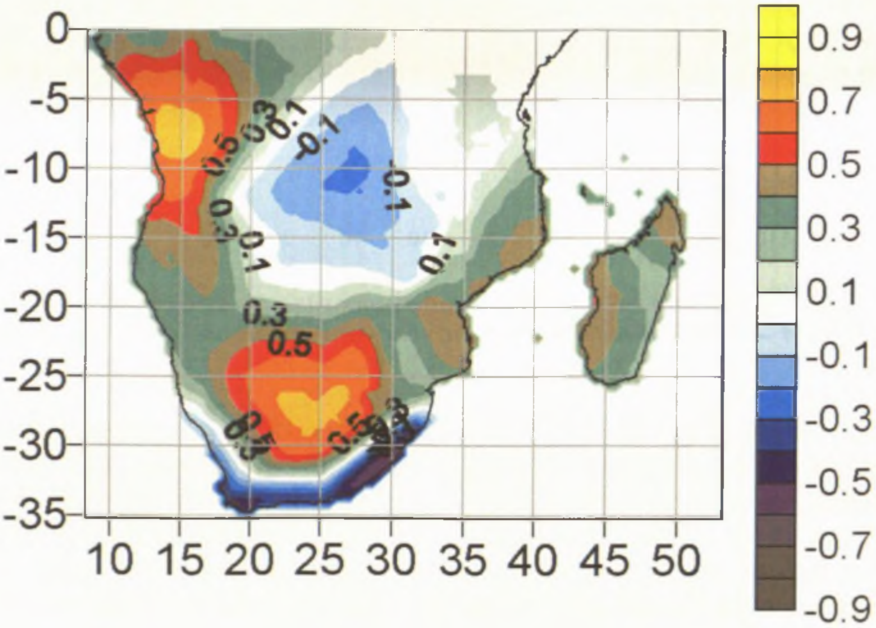

Fig. 4: Correlations of solar irradiance and annual mean air temperature (1901 – 1998) in southern Africa.

values in the region of Angola and the central interior of southern Africa (Fig. 4). This region simultaneously reveals the strongest increasing temperature trend in the 20th century. Correlations with precipitation and SLP show very uneven patterns, whereas those with SSTs become significant in high southern latitudes. However, restricted data reliability in this region does not allow any further conclusions.

30-year running correlations with temperature show high values in the first half of the 20th century. Thus, increasing surface air temperatures during this period may partly be due to increasing solar activity. More detailed time series analyses will further be performed by using wavelet techniques.

Final remarks

Atlantic and Indian Ocean SSTs include both widespread variability and a long-term warming trend with corresponding influences on southern African climate.

External forcings of regional climates on decadal to secular time scales are difficult to prove. Statistical relationships are not able to establish physical explanations. But they are important indicators for possible links which may further be substantiated by different data and time series analyses.

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