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Classification of warm and cold water events in the eastern tropical Atlantic Ocean

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Abstract

For the tropical Atlantic Ocean two phenomena showing anomalous sea surface temperature (SST) warming have been described: the Atlantic Niño in the equatorial Atlantic and the Benguela Niño off the Angolan coast. In this study, both Niño types are integrated into a new set of SST regions and the definition of a robust standardized index for the long-term period 1870–2011. Comparisons of these regions and indices show a close connection between anomalous warming and cooling in the equatorial Atlantic and the Benguela region. Therefore, instead of considering equatorial Atlantic and Benguela warm and cold events separately, we propose to classify them into three subtypes of one comprehensive Atlantic Niño. Copyright © 2013 Royal Meteorological Society

Keywords: **tropical Atlantic; Atlantic Niño; Africa; warm water event; classification**

1. Introduction

While Pacific El Niños have been studied extensively, only few investigations focus on warm water events in the Atlantic Ocean. So far, two phenomena akin to the Pacific El Niño with high-interannual sea surface temperature (SST) anomalies have been described for the eastern tropical Atlantic, one of them centered in the equatorial region as part of the Atlantic zonal mode (Philander, 1986, Zebiak, 1993) and another one close to the coast of northern Namibia and Angola referred to as Benguela Niño (Shannon *et al*., 1986). Additionally Okumura and Xie (2006) specify November/December SST anomalies in the tropical Atlantic in terms of an Atlantic Niño II to distinguish it from the actual Atlantic Niño which peaks in summer. These tropical Atlantic SST anomalies are less frequent and less intense compared with the Pacific ones. However, warm water anomalies in the south-east Atlantic, like their Pacific counterparts, have striking effects on regional rainfall and on the local ecosystem, hence on the fisheries, as marine life off the coast heavily relies on the nutrient-rich upwellings. Benguela Niños can therefore reduce marine productivity and temporarily devastate the anchovy and sardine fisheries (Heymans *et al*., 2004).

Benguela Niños have been described for the years 1934, 1949, 1963, 1984 (Shannon *et al*., 1986), 1995 (Gammelsrød *et al*., 1998) and 2001 (Rouault *et al*., 2003). Wang (2002) describes 11 Atlantic Niños during the 50-year period 1950–1999 with SST anomalies (3°N–3°S and 20–0°W) exceeding 0.7 °C and lasting more than 1 month. Generally, Atlantic and Benguela Niños have long been analyzed in separate studies and regarded as distinct events. But some recent studies suggest that both Niños should be perceived as one event as they are highly correlated, e.g. Lübbecke *et al*. (2010). However, these studies are only based on data for the recent years, long-term studies are still lacking (Rathmann and Jacobeit, 2009). Thus, the main objective of this paper is to develop a robust and suitable index to describe warm water anomalies in the tropical south-east Atlantic Ocean for the extended period back to 1870. Furthermore, a classification of warm and cold water events based on this index will be derived.

2. Definition of Atlantic Niño regions and corresponding indices

In contrast to the index regions (quadrants) for the Pacific Niño there is no general agreement on similar regions for the Atlantic. Several index regions have been used to study SST variability in the equatorial Atlantic and in the Benguela system so far, most frequently the ATL3 region (3°N–3°S and 20–0°W (Zebiak, 1993)) and the Angola Benguela area (ABA, 19.5–10.5°S and 8.5–15.5°E (Florenchie *et al*., 2003)). To study both Atlantic and Benguela Niños, the definition of index regions needs to be reviewed.

For the present study the monthly SST dataset HadISST1.1 (Rayner *et al*., 2003) is used. It is available with a 1° × 1° resolution for the period 1870–2011. For the earlier period the dataset is based on *in situ* data (e.g. ship observations, buoys and buckets), from 1982 onward it also includes satellite-based data. When compared with the 2° × 2° ERSST Version 3 (Smith *et al*., 2008), the tropical Atlantic data differs before 1950 owing to different data sampling techniques, but is highly correlated after 1950

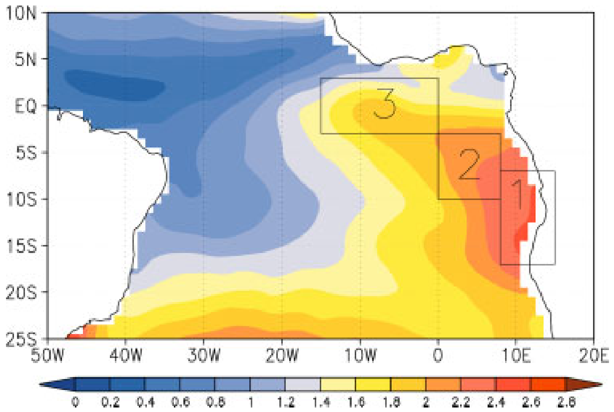

Figure 1. Standard deviation of HadISST1.1 anomalies for the period 1870–2011 (°C) and Atlantic Niño regions ATLN1, ATLN2 and ATLN3.

(correlation coefficients >0.7). Major differences in the South Atlantic are limited to data sparse areas south of 25°S which are not included in the index region definition. Owing to the fact that the ERSSTs show an unrealistic high variability in the Benguela current before 1950, the smoother HadISSTs were used for this study. The HadISST dataset is also in good agreement with the satellite- and observation-based data of the 1° × 1° NOAA OI-Analysis Version 2 (Reynolds *et al*., 2002, referred to as OISST). The latter dataset is only available for the period 1982–2011 and was mainly used for validation purposes.

For the period 1870–2011, HadISST anomalies are calculated by subtracting the mean seasonal cycle. The standard deviation of these SST anomalies (Figure 1) is used to identify regions of similar SST variability in the tropical Atlantic between 10°N and 25°S. Figure 1 shows a large area of high variability reaching from the south-west African coast into the equatorial Atlantic. The area with highest variability is located off the coast of Angola and northern Namibia (ATLN1, corresponding to a northward moved ABA region). Equatorial Atlantic variability is represented by a resized ATL3 region (now called ATLN3), and a third transition region is fit in between (ATLN2) to finally cover the whole cold tongue area. This leads to the following three Atlantic Niño regions (Figure 1):

- ATLN1: 17–7°S and 8–15°E
- ATLN2: 10–3°S and 0°W-–8°E
- ATLN3: 3°S–3°N and 15–0°W

Furthermore, there is no universal index with thresholds for warm and cold events so far. Zebiak (1993) calculates a simple ATL3 index from area-averaged SST anomalies, Florenchie *et al*. (2004) identify warm and cold episodes on the basis of ABA SST anomalies exceeding 1 °C, Lübbecke *et al*. (2010) define Niño (Niña) events as periods with ABA (or ATL3) SST anomalies exceeding a threshold of +0.7 (−0.7) standard deviations (stddev) for at least 3 months. To remove the significant positive SST trends in the South Atlantic and to achieve comparable indices for all regions despite their different seasonal cycles, we propose the following steps to calculate all three ATLN indices:

1. Average 1° × 1° SST anomalies for ATLN regions 1–3.
2. Calculate monthly SST anomalies with respect to 30-year reference periods updated every 5 years.
3. Standardize these anomalies using the standard deviation from the period 1971–2000.

Instead of one single reference period, multiple moving 30-year periods are used to calculate anomalies for successive 5-year periods in order to remove trends and define warm and cold events by their contemporary climatology (e.g. for index values during 1961–1965, the 1946–1975 reference period is used), similar to the Oceanic Niño Index defined by National Oceanic and Atmospheric Administration–Climate Prediction Center (NOAA CPC). The most recent 30-year reference period (1981–2010) is used for the years from 1996 until now and may be updated when the next reference period 1986–2015 can be calculated. As 1996–2000 is the last period which does not need to be recalculated, the reference period 1971–2000 is used to calculate the standard deviation for step 3 (standardization).

All three indices, ATLN1, 2 and 3 (Figure 2), show a great resemblance in their time series for the whole study period. Well-studied warm events such as 1963, 1984 and 1995 (e.g. Shannon *et al*., 1986, Gammelsrød *et al*., 1998) are seen in all three indices. This striking similarity is confirmed by their correlation coefficients: for lag zero ATLN1 and 3 indices are correlated at 0.74, ATLN1 and 2 at 0.84, and ATLN2 and 3 at 0.91 (Figure 3). Cross-correlation coefficients reach their peak at lag zero although the ATLN3 region has a tendency to lag ATLN1. Calculating monthly correlations indicates that ATLN3 lags ATLN1 in February and March (not shown).

Annual index correlation analyses are repeated with the more recent OISST data. Results are consistent with the above findings. All three indices are significantly (99% level) correlated at comparable magnitudes: for lag zero ATLN1 and 3 indices at 0.69, ATLN1 and 2 at 0.75, and ATLN2 and 3 at 0.83.

Subsequently, different threshold values and event durations are analyzed in order to find definite ones which include all well-known historical events in the Atlantic and Benguela Niño regions. On the basis of the examination of event time series and SST composites, a warm (cold) water event is defined as a period with SST anomalies exceeding one positive (negative) standard deviation for at least three consecutive months. Expressed in degree Celsius, one standard deviation is 0.74 °C (ATLN1), 0.50 °C (ATLN2) and 0.48 °C (ATLN3). To prevent splitting of longer events, the index is allowed to drop below the threshold by 0.2 stddev units for 1 month if at least three consecutive months exceeding the threshold were already found.

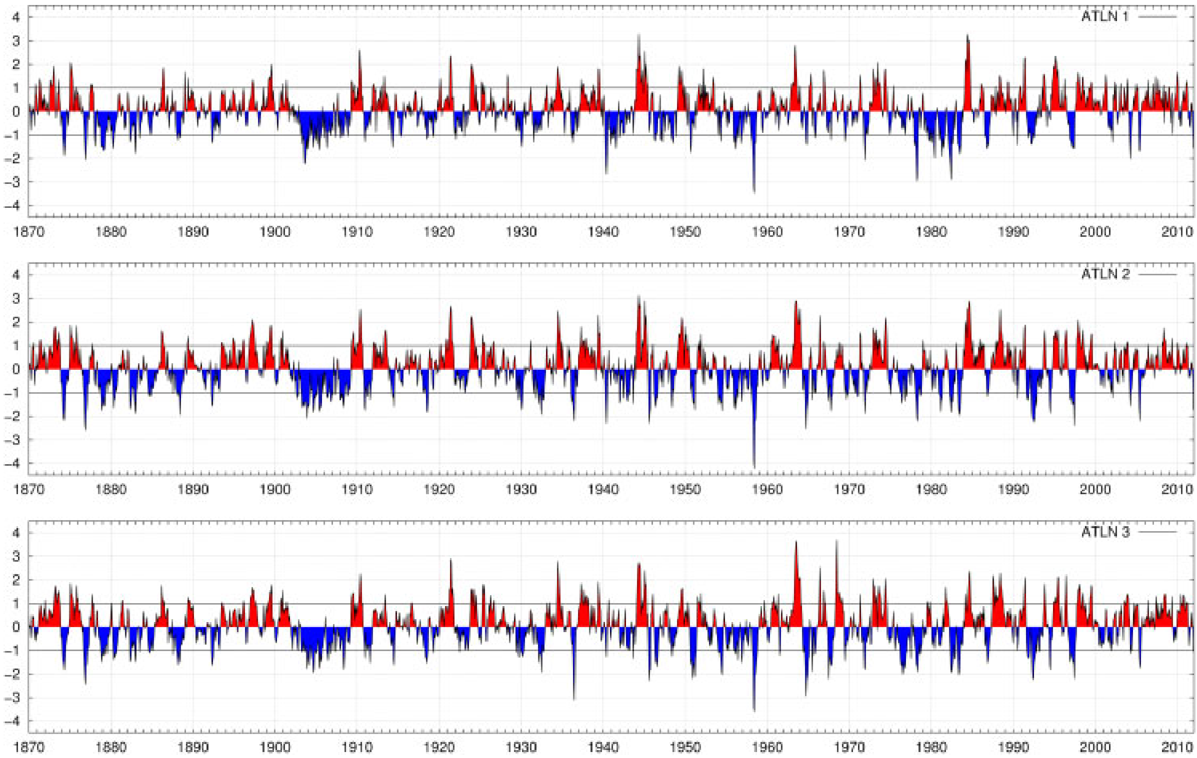

Figure 2. Atlantic Niño indices 1, 2 and 3 (top to bottom) calculated from HadISST1.1 for the period 1870–2011.

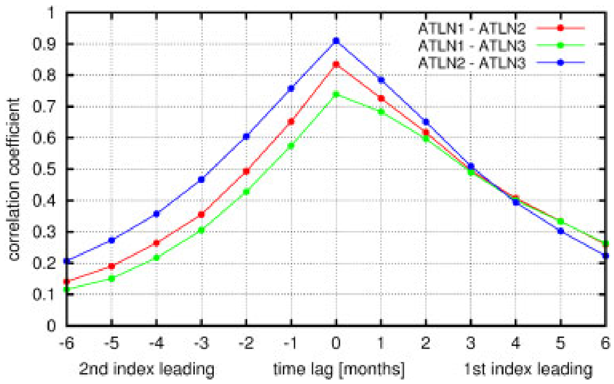

Figure 3. Cross-correlation coefficients for ATLN 1 and 2 (red), ATLN 1 and 3 (green), ATLN 2 and 3 (blue) for the period 1870–2011. All values are significant at the 99% level.

3. Classification of Atlantic warm and cold events

Besides the index time series, composites of high-pass filtered SST anomalies are calculated for each warm and cold event in each region. Both time series and composites show an evident connection between warming and cooling of all three indices: for strong events, including the well-known historical events, all three indices exceed the thresholds. For events with only one or two indices exceeding the threshold, the other index or indices at least show(s) less pronounced anomalies of the same sign.

These observations lead to the following classification of warm and cold anomalies into three Atlantic Niño and Niña subtypes:

- Major event: all ATLN indices exceed one positive (negative) standard deviation for at least three consecutive months [warm (cold) event criterion].
- Minor event: at least one index meets the warm (cold) event criterion; the other indices exceed an average of 0.5 stddev for at least one 3-month period.
- Warm (cold) episode: period consisting of multiple connected events, including at least one major event. SST anomalies between two events do not change the sign and the event-break does not last for more than 6 months.

As for single events, splitting of warm (cold) episodes is prevented by tolerating a small (0.2 stddev) sign change for only 1 month of one index. This classification is based on all three index regions and does not treat them separately anymore. Thus, Atlantic and Benguela Niños are now combined into one comprehensive Atlantic Niño with different regional characters. Based on this classification, 13 major warm events, 20 minor warm events, 6 warm episodes as well as 12 major cold events, 22 minor cold events and 2 cold episodes are found in the study period 1870–2011. Only three individual cold events and two individual warm events cannot be classified as one of these types, as Niña/Niño conditions are found in only one ATLN region but no significant warming or cooling in the other two regions. All these five regional events are short and SST anomalies in the corresponding region are less pronounced.

Figure 4 shows distinct examples of the different Atlantic Niño and Niña subtypes: the major warm

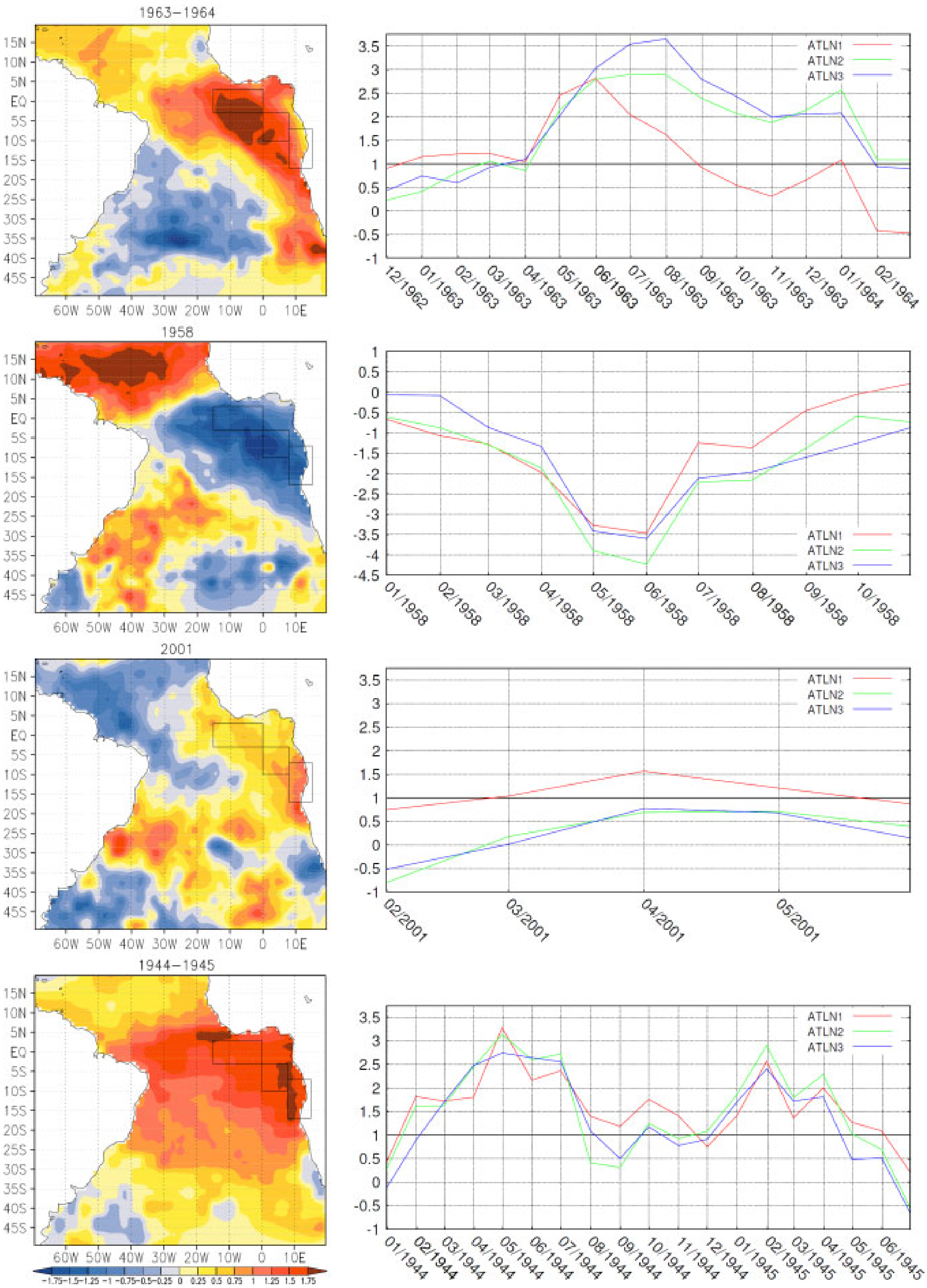

Figure 4. Examples of the Atlantic Niño and Niña subtypes (from top to bottom): major warm event 1963–1964, cold event 1958, minor warm event 2001, warm episode 1944–1945. For each example composites of high-pass filtered SST anomalies and index time series are shown. Index regions are highlighted as black rectangles.

event 1963–1964, the major cold event 1958, the minor warm event 2001 with the main warming centre in the ATLN1 region, and the warm episode 1944–1945 which consists of two major events. All four examples clearly show that warming or cooling affects the whole eastern tropical Atlantic reaching from the Angolan coast to the equatorial Atlantic. The different event subtypes are characterized by different event durations: minor warm (cold) events last for 5 (4) months on average, major events for 9 (6) months and episodes for 14 (23) months. Considering the events' onset – notwithstanding the type – most of them start in late austral spring/early summer or austral autumn months.

To confirm our results a classification was also run on the OISST dataset. All major warm and cold events and the majority of the minor events found in the HadISST classification are also found in the OISSTs. Minor differences in event onset and event lengths lie within the expected range of random deviations between different datasets.

4. Conclusion

In this study warm and cold events in the eastern tropical Atlantic have been examined by means of long-term observational SST data for the period 1870–2011. By defining three regions covering most of the Benguela cold tongue area and by calculating SST anomaly indices for each region, a strong connection between SST variability in all three regions was found. This confirms the link between equatorial Atlantic and Benguela SST variability and also the highly similar variability shared within the whole eastern tropical Atlantic area indicated in some earlier studies. But for the first time these important connections could be confirmed on a long-term basis. Studying all warm and cold events between 1870 and 2011 in the different regions in more detail clearly reveals that in most cases anomalous warming and cooling affect all three regions. Instead of considering Atlantic and Benguela Niños as separate phenomena, warm and cold events in the three ATLN regions have been classified into three subtypes of one comprehensive Atlantic Niño. Depending on the SST anomalies in the different ATLN regions, warm and cold events are classified into major events, minor events or episodes. This classification now serves as a solid base for further research on the dynamics of anomalous warming and cooling in the eastern tropical Atlantic.

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