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Evolution and Prediction of Two Extremely Strong Atlantic Niños in 2019–2021: Impact of Benguela Warming

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Key Points:

- The two extremely strong Atlantic Niños in 2019–2021 are associated with a basin-wide atmosphere-ocean coupling
- The two Atlantic Niños are triggered by Benguela warming and predicted in the near term by models
- The events are amplified by the in-phase variations of the intraseasonal-interseasonal and interdecadal-trend variations

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract

As El Niño's little brother in the equatorial Atlantic Ocean, Atlantic Niño affects the climate variability in the tropical Atlantic Ocean and the vicinity. In 2019–2021, two extremely strong Atlantic Niños occurred with peaks in January 2020 and July 2021, respectively. The coupling between the ocean and atmosphere associated with the Atlantic Niños is similar to that associated with El Niño-Southern Oscillation. Both the Atlantic Niños were triggered and modulated by a Benguela Niño-like warming, through inducing wind stress anomalies in the South and equatorial Atlantic Ocean. In addition to the atmosphere-ocean coupling at intraseasonal-interseasonal time scales, interdecadal and longer time scale variation amplified the Atlantic Niños. Model predictions only capture the evolution of the Atlantic Niños at a 1-month lead, consistent with the low prediction skill for sea surface temperature anomalies in the tropical Atlantic Ocean.

Plain Language Summary

Two extremely strong Atlantic Niños, characterized by anomalous warming in the equatorial Atlantic Ocean surface, occurred in January 2020 and July 2021. The development of these two events resulted from the coupling between the atmosphere and ocean in a way that is analogous to the El Niño-Southern Oscillation in the equatorial Pacific. A unique feature of these two Atlantic events is the prominent role of anomalous warming in the vicinity of the Benguela coast that preceded the equatorial Atlantic warming. Both intraseasonal-interseasonal and interdecadal and longer time scale variations contribute to the strength of the Atlantic Niños. In prediction, the evolution of the Atlantic Niños is captured only in the near-term and failed beyond 1 month. That may partially be due to the low predictability of the Benguela Niño-like warming, an indication of prediction challenge.

1. Introduction

Extratropical climate predictability at seasonal-interannual time scales mostly comes from various teleconnections induced by anomalous heating or cooling in the central and eastern tropical Pacific Ocean associated with an atmosphere and ocean coupled phenomenon: El Niño-Southern Oscillation (ENSO) (National Research Council, 2010; Yeh et al., 2018). In the tropical Atlantic Ocean, similar seasonal-interannual atmosphere-ocean coupled variation, called Atlantic Niño (Foltz & McPhaden, 2010; Lübbecke et al., 2018; Zebiak, 1993), also occurs at irregular intervals, and has been routinely monitored by the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC; Hu et al., 2022). Statistically, Atlantic Niño usually develops in boreal spring, peaks in the summer, and dissipates in the fall with a typical duration of several months (e.g., Vallès-Casanova et al., 2020), which contrasts ENSO that initials in spring and summer, peaks in autumn and winter, and usually lasts about one year or sometimes up to two or three years (Gao et al., 2023; Okumura et al., 2011). Atlantic Niño has an impact on ENSO and the climate in the tropical Atlantic and its vicinity (e.g., Chikamoto et al., 2020; Vallès-Casanova et al., 2020; Hasan et al., 2022; Li et al., 2016).

Similar to ENSO, the Bjerknes feedback (Bjerknes, 1969) is also the key mechanism resulting in the development of Atlantic Niño (e.g., Hu & Huang, 2007; Lee, 2020; Lübbecke et al., 2010; Vallès-Casanova et al., 2020; Zebiak, 1993). A relaxation of near-surface westward trade winds may lead to eastward propagation of a downwelling equatorial Kelvin wave along the thermocline, which deepens the thermocline in the central and eastern basin and suppresses the upwelling, leading to ocean surface warming in the central and eastern equatorial Atlantic Ocean. Furthermore, the warming reduces the zonal sea surface temperature (SST) gradient across the basin which amplifies the warming via a further weakening of the zonal wind stress, a positive feedback between the atmosphere and ocean (Zebiak, 1993).

On the other hand, Atlantic Niño may be affected by ENSO. Statistically, the largest positive correlation is present when the Niño3.4 index (average SST anomalies from 5°S to 5°N, 170°W to 120°W), a typical index for monitoring ENSO, leads the ATL3 index (average SST anomalies from 3°S to 3°N, 20°W to 0°; see Section 2), a typical index for monitoring Atlantic Niño, by 18 months (see Figure S1 in Supporting Information S1). Nevertheless, Chang et al. (2006) argued that there is a competition between cooling that results from increased wind stress and warming that results from increased air temperature, both of which are remote impacts of El Niño on the Atlantic. When one of these processes dominates over the other, an Atlantic Niño (warm or cool) event could ensue. In addition, Atlantic Niño may also be triggered by warming along the southern African coast, or a Benguela Niño (Hu & Huang, 2007). The warming associated with Benguela Niño induces westerly wind anomalies in the South and equatorial Atlantic Ocean via weakened South Atlantic anticyclone (Lübbecke et al., 2010). That initiates the Bjerknes feedback-like processes and leads to growth of an Atlantic Niño.

During 2019–2021, two extremely strong Atlantic Niños occurred (Figure 1a). The peak value of the ATL3 index is 1.42°C in January 2020 for the first Atlantic Niño and 1.43°C in July 2021 for the second one, which are the two largest peak values at least since January 1982. Richter et al. (2022) argued that the warming in late 2019 was the strongest Atlantic Niño event in the satellite era. Given the uniqueness and extremity of the two Atlantic Niños in 2019–2021, it is meaningful to examine how these events occur, whether they were predictable, and how different time-scale phenomena involve their occurrence. In this work, we focus on the anomalous evolution of SST, subsurface ocean temperature, atmospheric deep convection, low-level wind, and their connection with Benguela Niño-like warming, as well as multi-time scale contributions and model predictions. The rest of the paper is organized as follows. The observational and model forecast data, and methods are introduced in Section 2. Section 3 shows the results, including the evolution of the atmospheric and oceanic coupling, the role of Benguela Niño-like warming, the contribution of multi-time scale variations, and the prediction of the extremely strong Atlantic Niños in 2019–2021. A summary and discussion are given in Section 4.

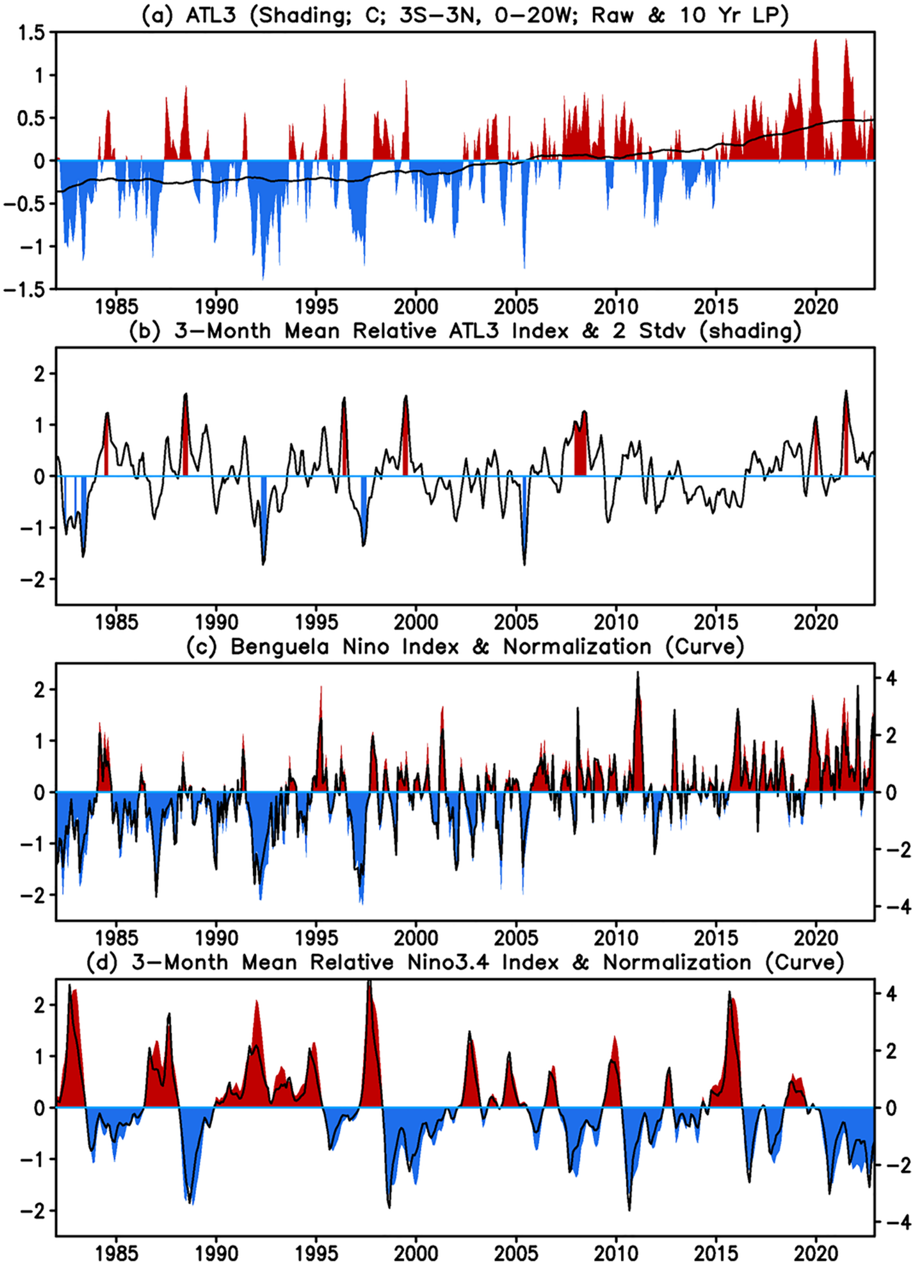
2. Data and Methods

Monthly mean SSTs are from the upgraded version of Optimum Interpolation SSTs with improved bias corrections (OIv2.1; Huang et al., 2021). OIv2.1 data are available from September 1981 onward and on a 1° by 1° resolution. The Niño3.4, ATL3, and Benguela Niño indices are defined as the averaged SST anomalies (SSTAs) in (5°S–5°N, 170°W–120°W; Barnston et al., 1997), (3°S–3°N, 20°W–0°; Zebiak, 1993), and (10°–20°S, 7°–11°E; see the green rectangle in Figures 3b and 3h) to represent ENSO, Atlantic Niño, and Benguela Niño, respectively. To eliminate the warming trend of the global tropical ocean between 20°S–20°N and to focus on the seasonal and interannual variations, following van Oldenborgh et al. (2021), 3-month means of the relative ATL3 (Figure 1b) and relative Niño3.4 (shading in Figure 1d) indices, defined as the original indices with the tropical mean (20°S–20°N) SST anomalies subtracted, are computed.

Monthly mean outgoing long-wave radiation (OLR) data on a 2.5° × 2.5° grid are from Liebmann and Smith (1996). Monthly mean surface wind stress and 20°C isotherm depth (D20) are on a 1° × 1° grid from the Global Ocean Data Assimilation System (GODAS; Behringer, 2007). GODAS is a real-time ocean reanalysis, which is used for monitoring global ocean and ENSO evolution at CPC (Hu et al., 2022).

To assess the skill of the equatorial Atlantic and Benguela Niño predictions, we evaluate forecasts from the NOAA coupled forecast system model version 2 (CFSv2) and five other models participating in the North American Multimodel Ensemble (NMME; Kirtman et al., 2014). In addition to CFSv2, the other five models are the National Aeronautics and Space Administration NASA_GEOS5v2, the National Center for Atmospheric Research NCAR_CCSM4, the Geophysical Fluid Dynamics Laboratory GFDL_SPEAR, the Environment and Climate Change Canada CanCM4i and GEM5_NEMO. The predictions (hindcasts and real-time forecasts) start from January 1982 to the present with lead times extending to 9 months. The number of ensemble members ranges from 4 to 24 and the spatial resolution of the NMME reprocessed data is 1° × 1°. Details about the models and data can be found in Kirtman et al. (2014) and https://www.cpc.ncep.noaa.gov/products/NMME/. To calculate the anomalies, lead time and target month-dependent climatologies were applied for each model.

To identify the contributions of time scale-dependent variations to the Atlantic Niños in 2019–2021, Ensemble Empirical Mode Decomposition (EEMD) of the ATL3 index is conducted (Wu & Huang, 2009). EEMD is


(a) ATL3 (Shading; C; 3S–3N, 0–20W; Raw & 10 Yr LP)

(b) 3–Month Mean Relative ATL3 Index & 2 Stdv (shading)

(c) Benguela Nino Index & Normalization (Curve)

(d) 3–Month Mean Relative Nino3.4 Index & Normalization (Curve)

Figure 1. (a) ATL3 (shading; °C) index and its low-frequency component based on a 10-year low-pass filter (curve), (b) 3-month mean relative ATL3 index (°C; shading for the values larger than two standard deviations), (c) Benguela Niño index (shading; °C) and its normalization (curve), and (d) 3-month mean relative Niño3.4 index (shading; °C) and its normalization (curve) during January 1982–December 2022. Anomalies in units of °C are represented by the left-hand *y*-axis, and normalized anomalies by the right-hand *y*-axis.

adaptive and derives optimal frequencies for decomposing data from the data itself which is a natural filter to separate data into components of different timescales (Huang et al., 1998; Wu & Huang, 2009).

Except for the OIv2.1 SST starting from September 1981 and NMME from January 1982, all other data used in this work are from January 1979 to December 2022. The anomalies are computed as the departures from climatologies during January 1991–December 2020.

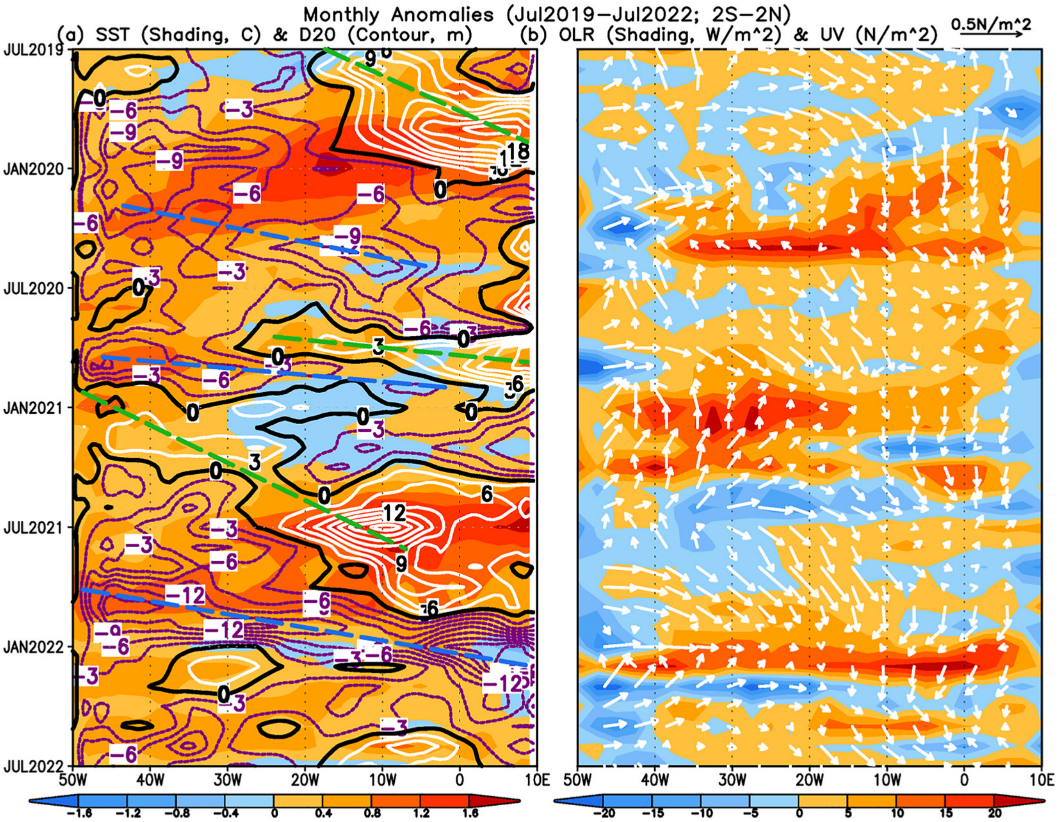


Figure 2. Hovmöller diagrams of the monthly mean anomalies of (a) SST (shading) and D20 (contours), and (b) OLR (shading) and surface wind stress (vector) averaged from 2°S–2°N during July 2019–July 2022. The dashed green (blue) lines in (a) represent the downwelling (upwelling) Kelvin wave-like anomalies. The units are °C for SST, m for D20, W/m^2 for OLR, and N/m^2 for wind stress.

3. Results

3.1. The Atmospheric and Oceanic Coupling During 2019–2021 Atlantic Niños

For the Atlantic Niño in 2019–2020, positive SSTAs along the equatorial Atlantic Ocean emerge in the late summer of 2019 and peak in the winter of 2019–2020 with westward propagation (shading in Figure 2a). Uniquely, the peak of the Atlantic Niño in 2019–2020 appears in winter, instead of in summer as with most Atlantic Niños, such as 1984 (August), 1988 (July), 1996 (June), 1999 (July), 2008 (June), and 2021 (July) (Figures 1a and 1b), reflecting the temporal diversity of Atlantic Niños (Valles-Casanova et al., 2020). Here, an Atlantic Niño is defined as the 3-month mean relative ATL3 larger than two standard deviations (shading in Figure 1b). The peak timing in January 2020 is probably associated with the timing of the Benguela Niño-like warming (Figures 3a–3f), which will be discussed in the next subsection. The positive SSTAs gradually decline and return to neutral during June 2020–April 2021. Positive SSTAs along the equatorial Atlantic Ocean re-emerge in the spring of 2021, propagate westward, and peak in the summer of 2021, forming the second strong Atlantic Niño (Figure 3g–3l). Then, the positive SSTAs weaken and mostly remain above normal during January 2022–July 2022.

The SSTA evolution is linked to the fluctuation of the thermocline along the equatorial Atlantic Ocean (contours in Figure 2a). Before the positive SSTA growth during July 2019–February 2020, positive (negative) D20 anomalies develop in the eastern (western) equatorial Atlantic Ocean. With the presence of the negative D20 anomalies since January 2020, positive SSTAs weaken and return to near normal during June 2020–April 2021. Positive D20 anomalies in the western equatorial Atlantic Ocean re-emerge in January–March 2021 and propagate eastward, then amplify in the eastern equatorial Atlantic Ocean during June–August 2021, corresponding to the growth of positive SSTAs and the peak of the second Atlantic Niño in July 2021. Meanwhile, negative D20 anomalies are observed in the western Atlantic Ocean. The positive D20 anomalies decline due to the invasion of

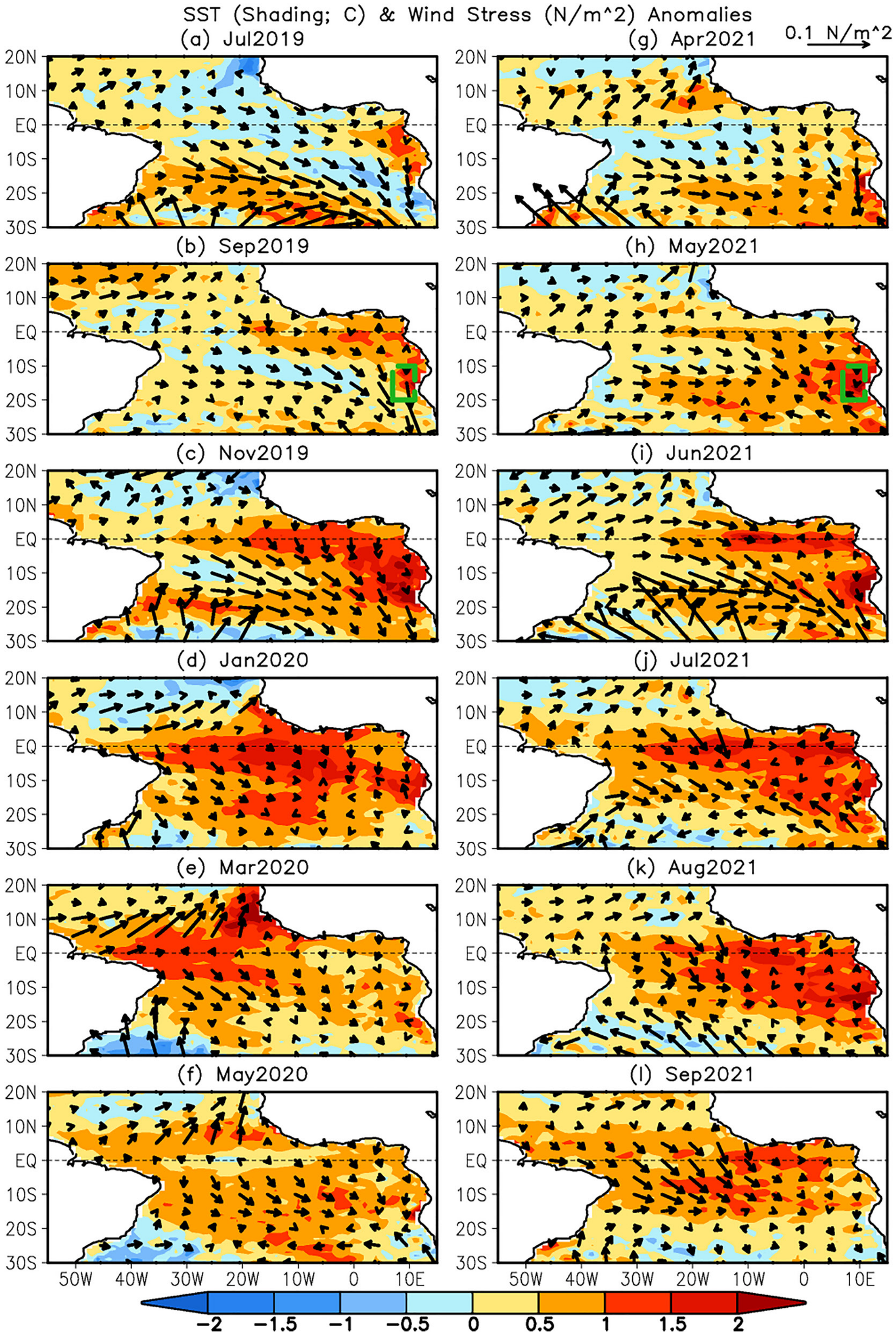


Figure 3. SST and surface wind stress anomalies in (a) July 2019, (b) September 2019, (c) November 2019, (d) January 2020, (e) March 2020, (f) May 2020, (g) April 2021, (h) May 2021, (i) June 2021, (j) July 2021, (k) August 2021, and (l) September 2021. The units are °C for SST and N/m^2 for wind stress. The green rectangles in (b, h) represent the area (10°–20°S, 7°–11°E) to define the Benguela Niño index.

the negative D20 anomalies which are initiated in October 2021, propagate eastward, and reach the eastern coast in December 2021–January 2022. Such fluctuation of the thermocline and Kelvin wave-like eastward propagation of the positive and negative D20 anomalies (see the green/blue dashed lines in Figure 2a) are similar to that associated with ENSO.

The SST and D20 anomalous evolutions (Figure 2a) are coherent with the fluctuations of the surface wind stress (vectors in Figure 2b) and deep convection anomalies (shading in Figure 2b). For instance, with the growth of the positive SST and D20 anomalies during the second half of 2019 and early 2020 (Figure 2a), westerly wind stress anomalies and enhanced convection are observed. With the diminishing of the positive SST and D20 anomalies from the spring and early summer of 2020 (Figure 2a), the westerly wind stress anomalies disappear, and the deep convection is suppressed. Similarly, for the Atlantic Niño in 2021, with the growth of the positive SST and D20 anomalies during the spring and summer of 2021 (Figure 2a), westerly wind stress anomalies and enhanced convection are observed. With the reduction of the positive SST and D20 anomalies from the late autumn of 2021 to early 2022 (Figure 2a), the westerly wind stress anomalies weaken or turn to easterly wind stress anomalies, and the deep convection is suppressed. Therefore, collectively, the coupling of the atmospheric and oceanic anomalies during the Atlantic Niños in 2019–2021 is similar to that in the tropical Pacific associated with ENSO (Bjerknes, 1969; Zebiak, 1993; Hu, Kumar, Huang, & Zhu, 2013).

3.2. Role of Benguela Niño-Like Warming

The Atlantic Niño in 2019–2020 co-occurred with a borderline El Niño in the tropical Pacific, while the Atlantic Niño in 2021 emerged in the background of a triple-dip La Niña during 2020–2023 (Figure 1d; Li et al., 2022; Hasan et al., 2022). Statistically, the maximum positive correlation with a value of 0.25 is found when the Niño3.4 index leads the ATL3 index by 18 months (bars in Figure S1 in Supporting Information S1). Thus, only about 6% of the ATL3 index can be explained by the Niño3.4 index based on a linear perspective, and the ENSO condition seems not a crucial factor in the evolution of the Atlantic Niños in 2019–2021. That is consistent with Richter et al. (2022) who argued that neither the tropical Pacific ENSO nor the Indian Ocean contributed substantially to the Atlantic warming in late 2019. Interestingly, both the Atlantic Niños in 2019–2021 seem triggered by warming along the west coast of southern Africa, Benguela Niño (Figure 1c; Koungue et al., 2021). Specifically, the peak values of the Benguela Niño index are larger than two standard deviations in November 2019–January 2020 and in May and June 2022 (Figure 1c).

For instance, appreciable warming emerges along the Southern and Central African coast in July 2019 (Figure 3a), which induces westerly wind stress anomalies in the South Atlantic Ocean and the weakening of the South Atlantic anticyclone. With the growth of warming along the coast during August–November 2019 (Figures 3b and 3c), the westerly wind stress anomalies strengthen and migrate to the equator. That triggers the coupling between the atmosphere and ocean along the equatorial Atlantic Ocean. With the diminishing of the warming along the African coast, the westerly wind stress anomalies weaken, or the wind stress anomaly direction reverses in the southeastern Atlantic Ocean during January–May 2020 (Figures 3d–3f), leading to the decline of the equatorial Atlantic Ocean warming and decay of the Atlantic Niño in 2019–2020.

The situation for the Atlantic Niño in 2021 is similar. With a warming present along the coast in April 2021 (Figure 3g), westerly wind stress anomalies prevail and the anticyclone weakens in the South Atlantic Ocean. The warming growth along the coast during May and June 2021 (Figures 3h and 3i) is associated with the strengthening of the westerly wind stress anomalies and their migration to the equator, triggering the coupling between the atmosphere and ocean along the equatorial Atlantic Ocean and generating the Atlantic Niño. With the diminishing of the warming along the coast, the westerly wind stress anomalies weaken, or the wind stress anomaly direction reverses in the southeastern Atlantic Ocean during July–September 2021 (Figures 3j–3l). That leads to the decline of the equatorial Atlantic Ocean warming and the decay of the Atlantic Niño in 2021.

This cause-effect relation between the Atlantic Niños in 2019–2021 and Benguela Niño-like warming is consistent with the lead-lag correlation between the ATL3 index and the Benguela Niño index (see the green rectangle in Figures 3b and 3h). The maximum positive correlation of about 0.50 is present when the Benguela Niño index leads the ATL3 index by 0–2 months (curve in Figure S1 in Supporting Information S1; Illig et al., 2020). That is consistent with the linkage between Benguela and Atlantic Niños proposed by Hu and Huang (2007). Later, Lübbecke et al. (2010) emphasized the role of a weakened South Atlantic anticyclone in the connection.

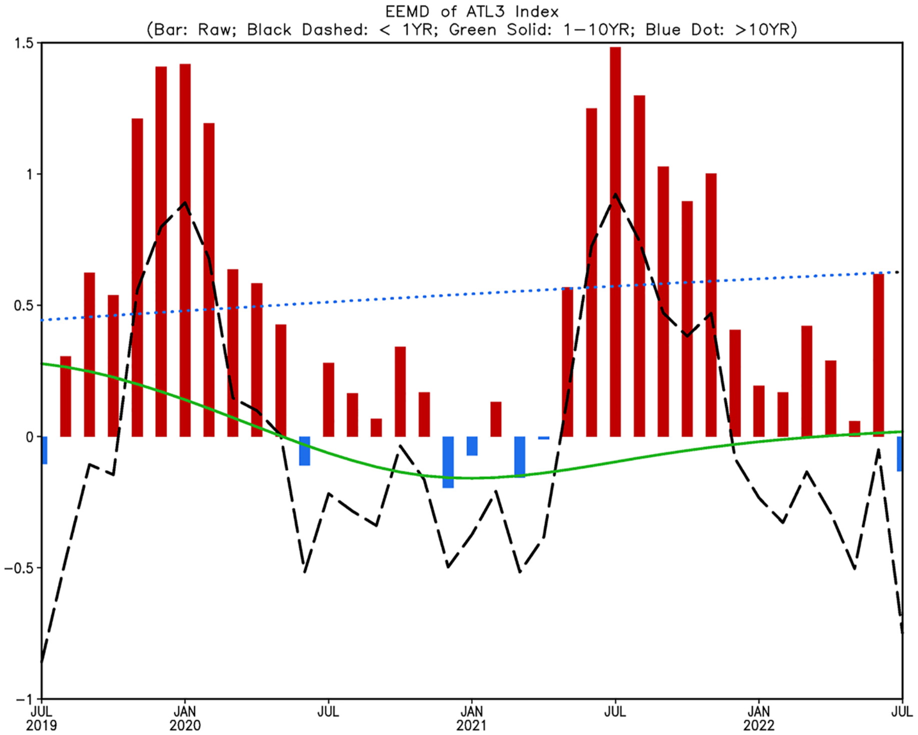


Figure 4. Monthly ATL3 index (bar, °C), and its intraseasonal-interseasonal (black dashed line), interannual (green solid line), and interdecadal-trend (blue dotted line) components during July 2019–July 2022.

3.3. Contribution of Multi-Time Scale Variations

Variability across a range of time scales is a basic feature of the North Atlantic SST variability (e.g., Li et al., 2020). We speculate that a multi-time scale amplification leads to the extremely strong Atlantic Niños in 2019–2021. To identify the contributions of different time scale variations to the Atlantic Niños in 2019–2021, EEMD is applied to the ATL3 index. From Figure 4, we notice that the intraseasonal-interseasonal (dashed black line) component is the major contributor to the Atlantic Niños in 2019–2021, while the interannual component (solid green line) has a relatively smaller contribution. That implies that the 2019–2021 Atlantic Niños are mainly an intraseasonal-interseasonal phenomenon. Interestingly, the interdecadal-trend time scale component (dotted blue line) has a considerable contribution. Specifically, at the peak of the Atlantic Niño in 2019–2020, the ATL3 index in January 2020 is 1.42°C with contributions of 0.86°C, 0.11°C, and 0.45ºC from the intraseasonal-interseasonal, interannual, and interdecadal-trend time scale components, respectively. While, at the peak of the Atlantic Niño in 2021, the ATL3 index in July 2021 is 1.43°C with contributions of 0.93°C, −0.08°C, and 0.58°C from the intraseasonal-interseasonal, interannual, and interdecadal-trend time scale components, respectively. Therefore, in addition to the atmosphere-ocean coupling at intraseasonal-interseasonal time scales, interdecadal and longer time scale variation amplifies the Atlantic Niños in 2019–2021, implying a potential impact of low-frequency variation due to natural forcings and/or human activities on Atlantic Niños.

The warming tendency in the ATL3 region is almost monotonic since at least 1982 (Figure 1a). To assess the extremity of the two Atlantic Niños in 2019–2021 without global warming influence, 3-month mean of the relative ATL3 index (Figure 1b) is computed. It is suggested that although the amplitudes decrease when the low-frequency impact is eliminated by using the 3-month mean relative ATL3 index (Figure 1b), the amplitude for Atlantic Niños is still the largest in June–August 2021 with a value of 1.66°C, and the peak in December 2019–February 2020 with a value of 1.16°C ranks the seventh strongest during 1982–2022, all exceeding two standard deviations (Figure 1b).

3.4. CFSv2 and NMME Predictions

The warming during July 2019–July 2020 is mostly captured at a 1-month lead and partially at a 2-month lead by CFSv2 (Figure 5a) and other NMME models (Figures S2a and S2b in Supporting Information S1). Beyond a 2-month lead, almost all models predict a small ATL3 index in the winter of 2019–2020. The prediction for the

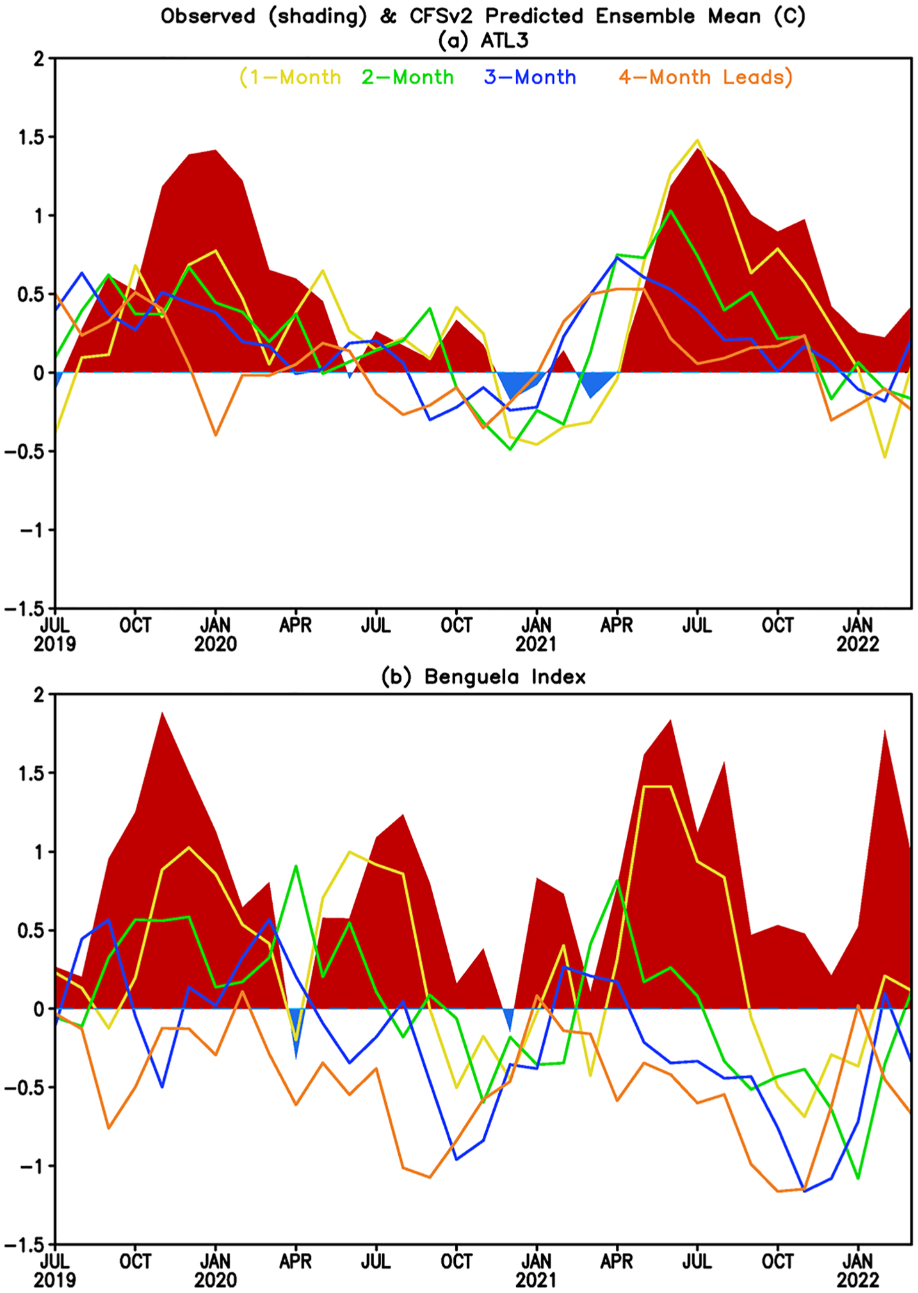


Figure 5. Observed (shading) and CFSv2 predicted (curves) monthly mean (a) ATL3 and (b) Benguela Niño indices during July 2019–March 2022 of 1–4 month leads. The unit is °C.

evolution of the ATL3 index during March 2021–March 2022 is similar to that during July 2019–July 2020. The evolution of the ATL3 index during March 2021–March 2022 is captured by CFSv2 and other individual models and their ensemble averages at a 1-month lead (Figure 5a, Figure S2e in Supporting Information S1). For 2- and 3-month leads (Figure 5a, Figures S2f and S2g in Supporting Information S1), all models underestimate the strength of the warming, and NCAR_CCSM4 predicts a neutral or below-normal condition. At a 4-month lead (Figure 5a, Figure S2h in Supporting Information S1), all models fail to predict the evolution of the ATL3 index, and NCAR_CCSM4 predicts a strong cooling.

Thus, the extremely strong Atlantic Niños in 2019–2021 are only predicted by CFSv2 and NMME at a 1-month lead and partially captured at a 2-month lead. That may partially be due to the low predictability of the Benguela Niño-like warming (Figure 5b; see Figure S3 in Supporting Information S1), since it is the trigger of the two extremely strong Atlantic Niños in 2019–2021. That is also consistent with the fact that compared with the central and eastern tropical Pacific associated with ENSO, the prediction skills for both the ATL3 and Benguela Niño indices (see Figure S4 in Supporting Information S1) as well as for the Atlantic Ocean are much lower (Counillon et al., 2021; Hu, Kumar, Huang, Wang, et al., 2013).

4. Summary and Discussion

As El Niño's little brother in the equatorial Atlantic Ocean, Atlantic Niño affects the climate variability in the tropical Atlantic Ocean and the vicinity. During 2019–2021, two extremely strong Atlantic Niños occurred with a peak value of 1.42ºC in January 2020 for the first one, and 1.43ºC in July 2021 for the second one, and both are larger than two standard deviations and the strongest events since 1982. The physical processes associated with the two Atlantic Niños are similar. The SSTA evolution along the equatorial Atlantic Ocean is linked to the thermocline fluctuation and Kelvin wave-like activities, as well as the surface wind stress and deep convection anomalies, similar to the ENSO in the central and eastern tropical Pacific (e.g., Bjerknes, 1969; Zebiak, 1993). The Atlantic Niños in 2019–2021 are triggered and modulated by Benguela Niño-like warmings along the southern African coast (Koungue et al., 2021), by inducing wind stress anomalies in the South and equatorial Atlantic Ocean (Hu & Huang, 2007; Lübbecke et al., 2010). Nevertheless, wind stress curl anomalies north of the equatorial Atlantic may also affect the evolution of the Atlantic Niño in 2019–2020 (Richter et al., 2022). The extremely strong Atlantic Niños in 2019–2021 are a result of multi-time scale amplification. In addition to the atmosphere-ocean coupling at intraseasonal-interseasonal time scales, interdecadal and longer time scale variation largely contributes to the Atlantic Niños in 2019–2021, implying a potential impact of a warming climate on Atlantic Niño.

In dynamical seasonal climate prediction systems, the CFSv2 model and the NMME average only capture the evolution of the Atlantic Niños in 2019–2021 at a 1-month lead. That indicates a challenge to predict Atlantic Niño, even for the extremely strong ones like those in 2019–2021 beyond the 1-month lead, consisting with overall low prediction skill for the ATL3 index and for the Benguela Niño-like warming, as well as the overall low prediction skill for SSTA in the equatorial Atlantic Ocean (Counillon et al., 2021; Hu, Kumar, Huang, Wang, et al., 2013). The low prediction skill of Benguela Niño may be associated with complicated oceanic and atmospheric processes. For example, Koungue et al. (2021) noticed that the extreme Benguela Niño in 2019 was generated by a combination of local and remote forcing, including positive anomalies of near coastal wind-stress curl leading to downwelling anomalies through Ekman dynamics off Southern Angola and by anomalously weak winds reducing the latent heat loss, as well as by downwelling coastally trapped waves. Also, in addition to model biases (e.g., Huang et al., 2007), the low prediction skill in the tropical Atlantic may be because compared with ENSO, the signal-to-noise ratio (SNR) is smaller for Atlantic Niño. The low SNR/predictability is linked to the fact that there is no dominant time scale variation (Li et al., 2020) like ENSO in the tropical Pacific.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

[Dataset] OIv2.1 monthly mean SST (Huang et al., 2021) is available at https://www.ncei.noaa.gov/products/optimum-interpolation-sst. [Dataset] GODAS monthly mean D20 and surface wind stress (Behringer, 2007) are available at https://www.esrl.noaa.gov/psd/data/gridded/data.godas.html. [Dataset] NOAA monthly mean OLR data (Liebmann & Smith, 1996) is available at https://psl.noaa.gov/data/gridded/data.olrcdr.interp.html. [Dataset] NMME predicted monthly mean SSTs (Kirtman et al., 2014) are available at https://www.cpc.ncep.noaa.gov/products/NMME/data.html. [Code] EEMD code is available at https://github.com/mathnathan/EEMD. For assistance in getting these data and the codes, please contact us via the corresponding author.

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