A9. Long-term climate change and impacts

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The tropical Atlantic climate has undergone long-term changes that are projected to accelerate under future global warming. The impact of these changes extends from the marine ecosystem to continental climate. The Tropical Atlantic Observing System (TAOS) is key to monitoring and understanding these changes and reducing uncertainties in climate projections for the region. Here a brief summary is provided of long-term changes and their impacts. We cover the oceanic and climatic variables and highlight some ecosystem changes in eastern boundary upwelling systems. Relevant discussion of bio-geochemistry and dissolved oxygen in the tropical Atlantic is covered by sections A3.4 and A3.5.

A9.1 Historical changes

Historical reconstructions of *in-situ* measurements of sea surface temperature (SST) indicate that over the last century the tropical Atlantic Ocean has warmed by almost 1°C, with the strongest warming along the African coast and South Atlantic (Figure A9.1) (*Nnamchi et al.*, 2016). This warming rate is close to the global average increase in SST. The observed trends in SST over the historical period (Figure A9.1) are largely consistent with climate model simulations (*Keenlyside and Ba*, 2010) and have been attributed to anthropogenic emissions of greenhouse gases (Ch 10, *IPCC*, 2013).

The warming of the tropical Atlantic has not been uniformed in time: there were two warming periods from around 1900 to 1940 and from 1970's to present, and a period from 1940 to 1970 of rather little warming (Figure A9.1). These changes coincided with similar trends in global mean temperature, but also with large-scale basin-wide fluctuations in North Atlantic SST – referred to as Atlantic Multi-decadal variability (AMV) (*Keenlyside and Ba*, 2010). The most recent warming occurred over both the tropical South and North Atlantic, and was greatest on the eastern and equatorial upwelling regions and during boreal summer (*Tokinaga and Xie*, 2011).

The cause of the multi-decadal trends is still under debate. As discussed in section 3.8, AMV could result for internal climate dynamics or from external forcing (*Ting et al.*, 2009). In particular, climate models are able to capture the most recent tropical Atlantic warming pattern when external forces are prescribed (*Terray*, 2012). These experiments suggest that the warming pattern is associated with both increases in greenhouse gases warming offset by greater aerosol cooling in the northern hemisphere than in the southern hemisphere (*Tokinaga and Xie*, 2011). As discussed in section 3.7, observations suggest that the warming in the tropical Atlantic was associated with an increase in upper ocean heat content and connected with a strengthening of surface wind speeds, which would tend to cool the ocean; thus this suggests that the observed warming was instead driven by changes in ocean circulation (*Servain et al.*, 2014; *Lübbecke et al.*, 2015).

Sea surface salinity (SSS) is a key indicator of climate change, as it is largely controlled by changes in the hydrological cycle (*Yu*, 2011). Furthermore, SSS changes impact upper ocean stratification and can have implications for the basin wide circulation. Historical observations since 1950 show SSS in the tropical Atlantic has increased faster than in other tropical basins (*Durack and Wijffels*, 2010; *IPCC*, 2013). The SSS changes in tropical Atlantic over the period 1970-2002, while consistent with that expected from climate change but are not sufficiently large to be distinguished from internal climate variability (*Terray et al.*, 2012). Long-term changes in SSS have also been linked to continental precipitation (Sec. 3.2) (*Li et al.*, 2016a).

Changes in ocean circulation and their relation to the Atlantic Meridional Overturning Circulation (AMOC) are discussed in detail in section 3.3. Models and theory indicate that changes in the AMOC could explain some of the long-term trends and multi-decadal changes in the tropical Atlantic (*Kawase*, 1987; *Johnson and Marshall*, 2002; *Zhang*, 2007; 2010). Direct observations of AMOC are insufficient to identify such relations, and there are large-uncertainties in ocean reanalysis and long-term ocean model hindcasts on these timescales (*Keenlyside and Ba*, 2010; *Danabasoglu et al.*, 2016; *Karspeck et al.*, 2017). Fingerprints of the AMOC based on model and historical observations provide indirect evidence that historical AMOC variability was dominated by multi-decadal variations (*Latif et al.*, 2006; *Zhang*, 2008). Long-term hydrographic data indicate water masses at depth in the tropical Atlantic are undergoing long-term changes that could be related to the AMOC (Sec. 3.3).

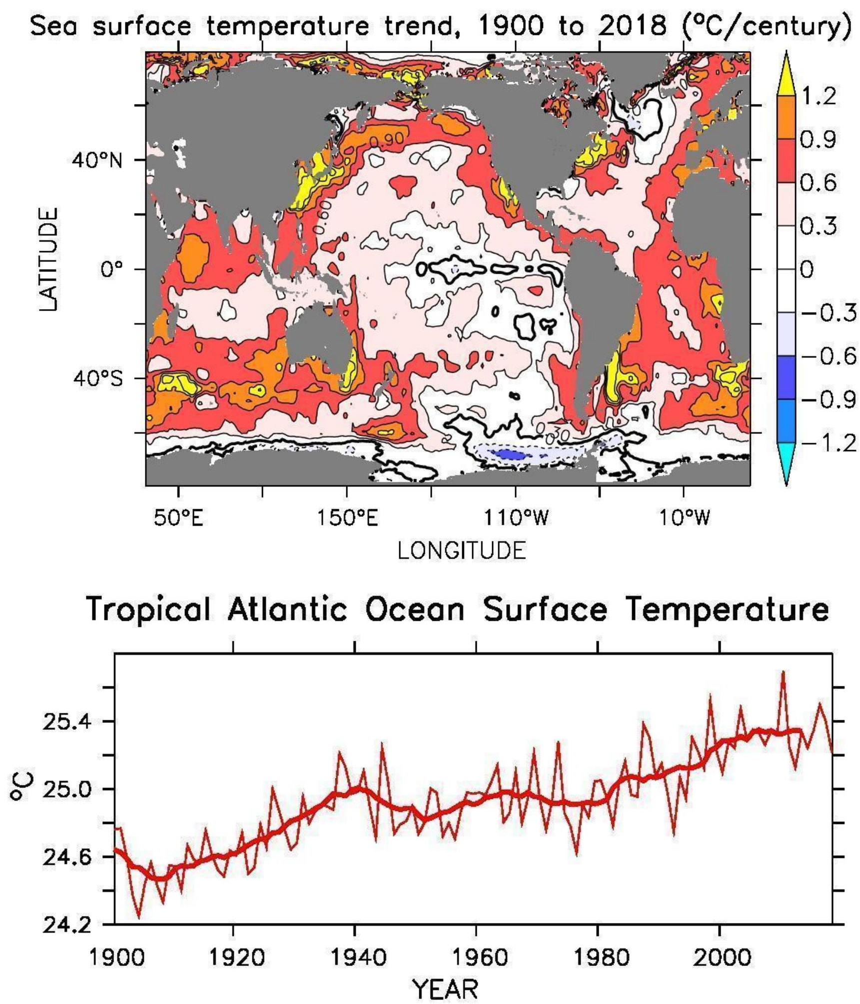


Figure A9.1: Historical change in global and tropical Atlantic sea surface temperature (SST): (Upper) Linear trend in SST calculated over the period 1900 to 2018 in degrees per century; (Lower) Annual mean SST averaged over the tropical Atlantic (30S-30N) from 1900-2018. The eleven-year running mean is indicated by the solid lines in the lower panel. SST data are from HadISST (*Rayner et al.*, 2003).

Sea level in the tropical Atlantic has undergone long-term rise superposed with multi-decadal shifts. However, our understanding of sea level rise over the tropical Atlantic over the last century is hampered by severely limited tide gauge records, especially along the African and South American coasts; for example, the tide gauges in Dakar (Senegal) and in Takoradi (Ghana), are the only ones in West Africa with temporal series longer than 40 years (*Thoreux et al.*, 2018). The available records suggest that sea level has risen at around 2.1 mm yr^{-1} since 1927 along the north west African coast and this rate is greater than the estimated 1.7 mm yr^{-1} in sea level rise globally (*Church and White*, 2011; *IPCC*, 2013; *Marcos et al.*, 2013), with even higher rates during the most recent 20 years (*Thoreux et al.*, 2018). A long-record from South American coast at 34°S indicates that sea level rose at around 1.6 mm yr^{-1} between 1905 and 1987 (*Raicich*, 2008). Satellite altimeter measurements since 1993 provide an estimate of sea level globally. These data indicate that sea level has been rising at a nearly spatially uniform rate of approximately 2 mm yr^{-1} over the tropical Atlantic between 1993 and 2018, and this is close to the global sea level rise during this period (*Cazenave et al.*, 2018). As described in section 3.7, the storage of heat in the ocean can account for roughly one third to one half of the observed global sea level rise over the past few decades.

A9.2 Climatic Impacts

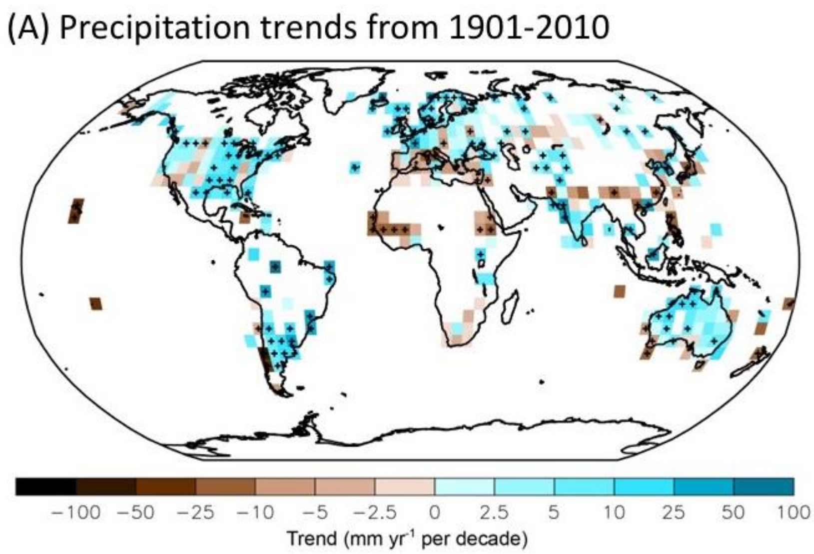
The long-term changes in the tropical Atlantic Ocean have been associated with changes in marine ecosystems, coastline and in continental climates on both sides of the basin. It has also been argued that tropical Atlantic changes influenced the tropical Pacific Ocean. Long-term observations of African and South American tropical climates are sparse and have been declining further recently (e.g., *Nicholson et al.*, 2018). This makes proper assessment and attribution of changes over the historical period difficult. Over the period 1901 to 2010, land surface temperatures over West Africa and Brazil have warmed on average by more than 1°C which is larger than the global mean increase of around 0.9°C (Ch. 2, *IPCC*, 2013). Station based rainfall data from 1901 to 2010 indicate a trend towards dryer conditions in parts of West Africa and the Caribbean and wetter conditions in parts of North East Brazil and the Gulf of Guinea (Figure A9.2). These trends appear more pronounced during the period 1950 to 2010, and they are consistent with southward shift in the Atlantic Intertropical Convergence Zone (ITCZ) and the SST warming patterns discussed above (*Bader and Latif*, 2003; *Giannini et al.*, 2003; *Pomposi et al.*, 2015). There is however a large uncertainty in these trends as they are not present in some reconstructed data sets (Ch. 2, *IPCC*, 2013).

Multi-decadal variations are a prominent feature of Tropical African and Caribbean/Brazilian continental climate. Increased land surface temperature warming trends over Africa and South America coincided with the warming periods described above, and the period 1940 to 1970's coincided with weaker warming of global mean surface temperature (Ch. 2, *IPCC*, 2013). There are also pronounced multi-decadal variations in rainfall over West Africa, North East Brazil, and the Caribbean region (Sec. A3.2). In particular, superimposed on the long-term drying trend, Sahel rainfall exhibited a wet period in the 1940's, a severe dry period in the 1980's, and weak recovery thereafter (Figure A9.3b) (*Folland et al.*, 1986; *Nicholson et al.*, 2000; *Dong and Sutton*, 2015). Rainfall over the North East of Brazil (*Lacerda et al.*, 2015), the Caribbean (*Hetzinger et al.*, 2008), and over Central and West North America (*Enfield et al.*, 2001) also exhibited decadal to multi-decadal variations that modulate the impact of El Niño Southern Oscillation (ENSO) on the continent (*Kushnir et al.*, 2010). As described in section 3.2 these variations were all related to tropical Atlantic SST, as well SST in the tropical Pacific Ocean.

Long-term observations of the marine ecosystem are sparse, and this makes the detection and attribution of trends difficult. Along the African coast the R/V Dr Fridtjof Nansen (FAO, Nansen Project, http://www.fao.org/in-action/eaf-nansen/en/) has carried out particularly useful stock assessment along the Africa coast for almost three decades using fisheries acoustics sea surveys.

These data have been used to show that the warming of SST along North West Africa appears to have driven a northward shift in *Sardinella aurita*, and other key small pelagic fish stocks for the region (*Sarré et al.*, 2019). These data also reveal similar shifts in Sardinella along the Angolan coast (Marek Ostrowski (IMR) *pers. comm*.). The last 35 years have seen an increase in marine heatwaves in the tropical North Atlantic that is expected to increase further in response to global warming (*Oliver et al.*, 2018). Marine heatwaves are major stressor on marine organisms, including coral bleaching, disease outbreaks, and forced migration (*Comte and Olden*, 2017; *Hughes et al.*, 2018). The responses of marine organisms and biogeochemical cycles to climate change remains largely unknown (*Auger et al.*, 2016; *Brochier et al.*, 2018; *Foltz et al.*, 2019).

Long-term changes in tropical Atlantic climate can potentially affect the patterns of interannual variability and associated teleconnections (Sec. 3.2 and 3.3). Lack of comprehensive long-term observations and large biases in climate models (Sec. 3.7) mean that only a few studies have addressed this. Atlantic Niño variability appears to have weakened during the period 1950 to 2009, as the eastern tropical Atlantic Ocean warmed (*Tokinaga and Xie*, 2011). The AMV modulates not only the characteristics of the Atlantic Niños, but also its inter-basin teleconnections (Indian and Pacific). In particular the Atlantic Niño-ENSO relationship has been found strongest during negative AMV phases (*Martín-Rey et al.*, 2014; *Losada and Rodríguez-Fonseca*, 2016), when equatorial Atlantic SST variability is enhanced (*Martín-Rey et al.*, 2017; *Lübbecke et al.*, 2018a).



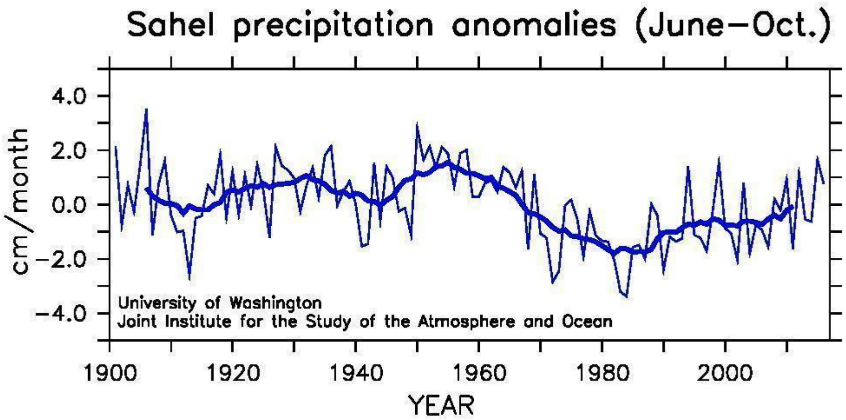


Figure A9.2: Historical change in rainfall over West African: (a) Trend in precipitation for the period 1901 to 2010 from the Global Historical Climatology Network (*Vose et al.*, 1992). White areas indicate incomplete or missing data. Black + indicate grid boxes where trends are significant (i.e., a trend of zero lies outside the 90% confidence interval). Figure is adapted from figure 2.29 IPCC AR5 (*IPCC*, 2013). (b) Sahel precipitation anomalies averaged from June-October and over the domain 20-10°N, 20°W-10. The eleven-year running mean is indicated by the solid lines. Data are from University of Washington (*Mitchell*, 1997).

Recent studies have also indicated a growing importance of the tropical Atlantic Ocean in the global climate system, particularly in the tropical areas (*Cai et al.*, 2019). In particular, observations and model experiments suggest that the warming of the tropical Atlantic during the last three decades drove SST changes over the Pacific and Indian Oceans (*Li et al.*, 2016b). It was argued that these changes drove the slowing in the rate of global warming between the late 20th and the early 21st century (*Kosaka and Xie*, 2013; *Medhaug et al.*, 2017). These changes may also have driven a stronger coupling between interannual variability in both basins and thereby enhanced seasonal predictability (*Cai et al.*, 2019). Model experiments show that when it comes to the global impact of the AMV, it is the North tropical Atlantic expression of the phenomenon that is responsible for teleconnections to the North Pacific, the surrounding continents and the Indian summer monsoon (*Ruprich-Robert et al.*, 2017).

An important consequence of the long-term and multidecadal changes in tropical Atlantic SST is their impact on climate extremes. Some of these impacts, such as the increases in the frequency of droughts and floods in parts of the basin, were reviewed in chapter A3.2. Here we briefly review the impact of warming on tropical cyclones (TCs), referred to as hurricanes in the Atlantic. Multidecadal variability in Atlantic intense hurricane (i.e., hurricanes which reach surface winds ≥ 50 ms^{-1}) was described by Goldenberg et al. (2001). They suggested that the SST changes associated with AMV caused the rapid transition from the relatively inactive 1971-1994 period to the highly active seasons thereafter. Kossin and Vimont (2007) pointed more directly at the cross equatorial SST gradient in the tropical Atlantic as a governor of TC activity (measured by seasonal mean storm frequency, storm duration, and storm intensity) and that this measure is well related to interannual variations in storm activity. Emanuel (2005) argued that the seasonally integrated total power dissipation of TCs has increased in step with the rapid rise of SST in the tropical North Atlantic since the mid-1970s. These observations seemed consistent with the growing understanding that SST warming with climate change is expected to lead to the rise in the number of intense hurricanes (*Emanuel*, 1987; *Bengtsson et al.*, 2007; *Knutson et al.*, 2010). Model simulations under CMIP5 (Coupled Model Intercomparison Project Phase 5 from IPCC) show that the changes in TC activity during the 20th century, as measured by the theoretical TC Potential Intensity metric (*Emanuel*, 1988), has been influenced primarily by AMV related SST and atmospheric conditions and not by anthropogenic warming (*Ting et al.*, 2015). The impact of anthropogenic warming on TC activity appears masked by wind shear changes that are controlled by the relative warming of the tropical Atlantic compared to other basins (*Latif et al.*, 2007). Sobel et al. (2016) argued in addition, that the competition between the warming impact of greenhouse gas increase and the cooling induced by aerosols in the tropical North Atlantic relative to the tropical South Atlantic Ocean (see Figure A9.1) caused a negligible change in TC Potential Intensity and thus uncertain impact on the intensity distribution of observed storms.

A9.3 Future changes

Model based projections indicate that continued anthropogenic emission of greenhouse gases will drive major changes in tropical Atlantic climate in the coming century and that these will have major environmental and socio-economic consequences. Overall, multiple generations of models robustly predict a continuation of the long-term warming in the mean state of the tropical Atlantic basin. According to the last IPCC report, the tropical Atlantic will warm at a rate close to the global mean and more or less uniform across the basin (Figure A9.3a) (Ch 12, *IPCC*, 2013). Oceanic rainfall is projected to increase over the equatorial Atlantic at rate of 3 to 6 % per degree of global warming, and to decrease in the subtropics (Figure A9.3b). Continental rainfall is projected to decrease over most of South and Central America and parts of West Africa, and to increase over parts of the Sahel and eastern equatorial Africa. However, large uncertainties exist in the patterns of climate change over the tropical Atlantic and surrounding continents (*Hawkins and Sutton*, 2009). In addition, although there is some model agreement on the projected changes in SST and precipitation, these models exhibit even larger biases in the tropical Atlantic (*Richter*, 2015) (see Sec. A3.7). Recent studies indicate that these biases introduce large regional uncertainties in climate change projections for the tropical Atlantic (Mojib Latif *pers. comm*.; Teferi Demissie *pers. comm*.).

Climate change projections indicate that SSS in the tropical Atlantic will continue to increase, as a result of the enhancement of the hydrological cycle (*Terray*, 2012; *IPCC*, 2013). This is associated with an increased moisture transport from the tropical Atlantic to the Pacific (*Richter and Xie*, 2010) that will enhance the climatological difference in SSS between the basins and may counteract the project weakening of the AMOC under global warming (*Latif et al.*, 2000).

There are few studies on future changes in ocean circulation in the tropical Atlantic. At a basin scale, global warming is expected to lead a reduction of the strength of the AMOC (*Schmittner et al.*, 2005; *Schneider et al.*, 2007; *IPCC*, 2013; *Reintges et al.*, 2017). The reduced poleward heat transport could lead to warming of the tropical and South Atlantic, with associated large-scale shifts in atmospheric circulation (*Stouffer et al.*, 2006). Ocean-atmosphere interaction in the tropical Atlantic and salinity biases can impact AMOC changes and recovery (*Mecking et al.*, 2016; *Mecking et al.*, 2017). The weakening of the AMOC can also interact with the wind driven subtropical cells that can lead to rapid changes in continental rainfall (*Chang et al.*, 2008).

Global warming will continue to drive sea level rise over the tropical Atlantic and for CMIP5 RCP4.5 scenario (Representative Concentration Pathway at +4.5 W m^{-2}) we expect a further near uniform increase of 20 cm by the end of the century (*IPCC*, 2013). We are not aware of studies focusing on future sea level rise over the tropical Atlantic Ocean. However, studies of global sea level rise indicate that uncertainties exist in the pattern of sea level change over the tropical Atlantic that are similar to those of the other tropical oceans (*Bordbar et al.*, 2015).

Better predictions of future alteration and changes in the rainfall pattern, intensity, variability, and or frequency is particularly important for society and the overall economy, especially for West Africa that is highly vulnerable due to low adaptive capacity (*Sylla et al.*, 2016; *Akinsanola and Zhou*, 2018) and sometimes a strong part of global domestic product is related to maritime economies and/or coastal infrastructures. There is a general agreement that global warming will cause the intensification of the global hydrological cycle associated, with dry regions becoming drier, wet regions becoming wetter, and the intensity of extreme rainfall events increasing (*Neelin et al.*, 2003; *Held and Soden*, 2006; *Chou et al.*, 2009; *Chadwick et al.*, 2012). Since the Sahel (Guinea coast) sub-regions of West Africa are relatively dry (wet), it is logical to expect drying (more moisture) in the interior and at the coast (*Giannini*, 2010). This result is found in the multi-model ensemble mean (Figure A9.3b) and in high-resolution regional model experiments (*Akinsanola and Zhou*, 2018; 2019a; b). This robust positive response of West Africa rainfall to global warming was attributed to the enhancement of moisture convergence and surface evaporation (*Akinsanola and Zhou*, 2018; 2019b). Studies have suggested a changing wet season, with predominantly negative (positive) anomalies occurring at the beginning (end) of the rainy season (*Biasutti et al.*, 2009; *Akinsanola and Zhou*, 2019a). There is also a projected increase in consecutive dry days and extreme rainfall events (ibid). There is however great disagreement among models on even the sign of rainfall change over the Sahel (*Kamga et al.*, 2005; *Cook and Vizy*, 2006; *Monerie et al.*, 2017).

Fishery is increasingly crucial for the economy and the food security of Atlantic African coastal countries which benefit from e.g., the productive Canary Current upwelling system (from Morocco to Guinea Bissau). Indeed, because of the Sahelian food crisis, the demographic pressure on the coastal fringe increased the effort of artisanal fishing (*Binet et al.*, 2012; *Failler*, 2014; *Ba et al.*, 2017), which adds up to the industrial fishing and illegal fishing in some countries. Therefore, there is a strong interest in understanding the fisheries resources distribution and its modifications that will occur as a result of climate change during the 21st century. Indeed, recent studies at global scale have shown that Climate Change will profoundly affect global ecosystems, mainly through its effects on the ocean temperature (and stratification), acidity (pH) and dissolved oxygen level (*Gattuso et al.*, 2015). This will reflect on the distribution, abundance and catchability of exploited fish species with, for example, a respective decrease (increase) in fish populations at low (high) latitudes (*Cheung et al.*, 2010). Therefore, quantifying the potentially negative impact of Climate Change on the regional fisheries resources is essential for Atlantic African countries as well as but at a lower level for Brazil and Caribbean islands. Notably however, climate biogeochemical and fish population projections are known to be tarnished by a high level of uncertainties (*Bopp et al.*, 2013), especially if only one climate projection is considered or at regional scale (scale at which global climate models can display systematic biases), i.e., this last scale which fits with the wide majority of exploited fish stocks.

As theory suggests, the continuous warming of the tropics is expected to give rise to increase in the number of intense hurricanes, but the number of tropical storms is expected to decrease, as the atmosphere becomes more stable (*Bengtsson et al.*, 2007). However, climate models used in global climate change projections do not reliably resolve actual TCs and thus used only indirectly to assess future changes in TC activity (*Knutson et al.*, 2010). In the tropical Atlantic region, downscaling of CMIP3 model runs showed that future warming will lead to a reduction in the total number of TCs but an increase in the number of intense hurricanes (*Bender et al.*, 2010). This result was later confirmed, albeit with less confidence, when a new assessment of the subject was made based on CMIP5 models (*Knutson et al.*, 2013). *Sobel et al. (2016)* argues, based on the metric of Potential Intensity, that with the increase in greenhouse gas concentration in the tropical atmosphere, SST warming globally will overcome the cooling effect due to aerosols and this will potentially lead to the increase in the number of intense hurricanes.

Despite the model improvements made in CMIP5 with respect to CMIP3, most of the climate models are not able to correctly simulate the main aspects of tropical Atlantic variability (TAV) and associated impacts (see Sec. 3.8). This is likely the main reason why there are very few studies dealing with long-term changes in tropical Atlantic variability. The models that best represent the AMM show a weaker AMM variability for future climate conditions (*Breugem et al.*, 2006). Model biases are too strong to properly assess changes in the Atlantic Niño. Long term changes in the teleconnections associated with tropical Atlantic variability modes are expected as a result of global warming, but large uncertainties exist (*Lübbecke et al.*, 2018a; *Cai et al.*, 2019). The impact of Atlantic Niño variability on El Niño is however projected to weaken (*Jia et al.*, 2019). Single-model sensitivity experiments show that Atlantic Niño characteristics at the end of twenty- first century remain equal to those of the twentieth century, though changes in the climatological SSTs can lead to changes in the associated teleconnections (*Mohino and Losada*, 2015). It has been shown a weakening of the AMOC can change the mean background state of the tropical Atlantic surface conditions, enhancing equatorial Atlantic variability, and resulting in a stronger tropical Atlantic–ENSO teleconnection (*Svendsen et al.*, 2014), but large uncertainties still exist.

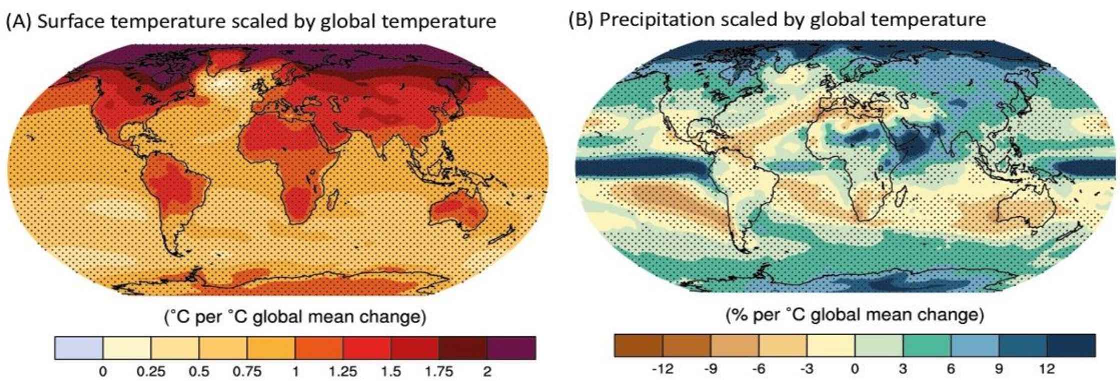


Figure A9.3: Projected changes in (a) surface temperature and (b) precipitation for 2081-2100 relative to 1986-2005. The patterns are scaled by the global mean change in temperature. The results show the multi-model mean from the IPCC coupled model intercomparison project version 5. Mean changes larger than the 95% percentile of the distribution of models are stippled. Figure is adapted from figure 12.10 IPCC AR5 (*IPCC*, 2013).

A9.4 Summary and Societal relevance

- Since the late 19th century, during the instrumental period, tropical Atlantic Ocean SST displayed gradual, long-term warming that was likely due to the increase in atmospheric greenhouse gas concentrations. This gradual warming was modulated by a multidecadal fluctuation that led to variations in the warming rate and, in particular, to a break in the warming in the mid-20th century.
- The warming of the basin was also not uniform in space. It was large in the tropical South Atlantic Ocean and smaller in the north.
- The time and space modulation of the basin warming was a combination of variability generated by processes internal to the climate system and the response to external forcing, primarily from temporally and spatially non-uniform aerosol distribution.
- Tropical Atlantic SST changes were associated with changes in precipitation over the ocean and the surrounding continents from North, Central and South America to West and Central Africa.
- Although less well observed than SST, there were also long-term changes in SSS (since 1950's) and sea level rise (since the 1920's) that are consistent with global warming, while the corresponding changes in ocean circulation are unknown.
- There is also indication from comparing model experiments with observations that these long-term changes in tropical Atlantic SST affected the climate of the tropical and extratropical Pacific Ocean and the Indian Ocean environment.

- The important societally-relevant expression of these long-term changes are in their impact on the frequency and intensity of extreme events. These range from hydrological extremes, such as short-term droughts and intervals of flooding, to oceanic “heat waves” and most pointedly, the change in the number and destructive potential of tropical cyclones.
- There is evidence that these long-term changes are also associated with changes in the marine environments and the coastline, which have adversely impacted marine life, their ecosystems and associated fisheries and thus sometimes the national GDP.
- In the future, the tropical Atlantic basin is expected to continue its warming, which will increasingly change the climate over the adjacent land areas, including on the one hand extended drying, particularly in the Caribbean and Central America and, on the other hand, increased flooding due to intensification of the hydrological cycle, associated with the increase moisture carrying capacity of the warming atmosphere. We also expect a decrease in the overall number of hurricanes but an increase in the number of intense hurricanes.
- We also expect a continued rise in sea level, increase in SSS, and a weakening of the AMOC, which is expected to contribute to changes in upper ocean heat content and American and African continental rainfall patterns.
- While the coupled climate models used in CMIPs have overall been able to simulate many of the observed changes in the region, they have been continually plagued by marked oceanic and atmospheric systematic errors and biases, which affect the confidence in their detailed regional predictions and projections.
- In order to monitor the changes in regional climate and the worldwide consequences and verify model long-range predictions and projections, sustained observations of the tropical Atlantic Ocean and surrounding land areas are needed. These need to provide basic information that will allow us to step back and support model outputs intended to verify, explain and attribute the expected and unexpected changes in the climate of the tropical Atlantic region.

A9.5 Recommendations for the observing system

Observations are key to monitoring climate change in the tropical Atlantic and to improve climate models and thereby reduce uncertainties in future projections of climate change. Maintaining existing observational records is of paramount importance to ensure the continuous monitoring of long-term changes. The follow variables are of particular importance:

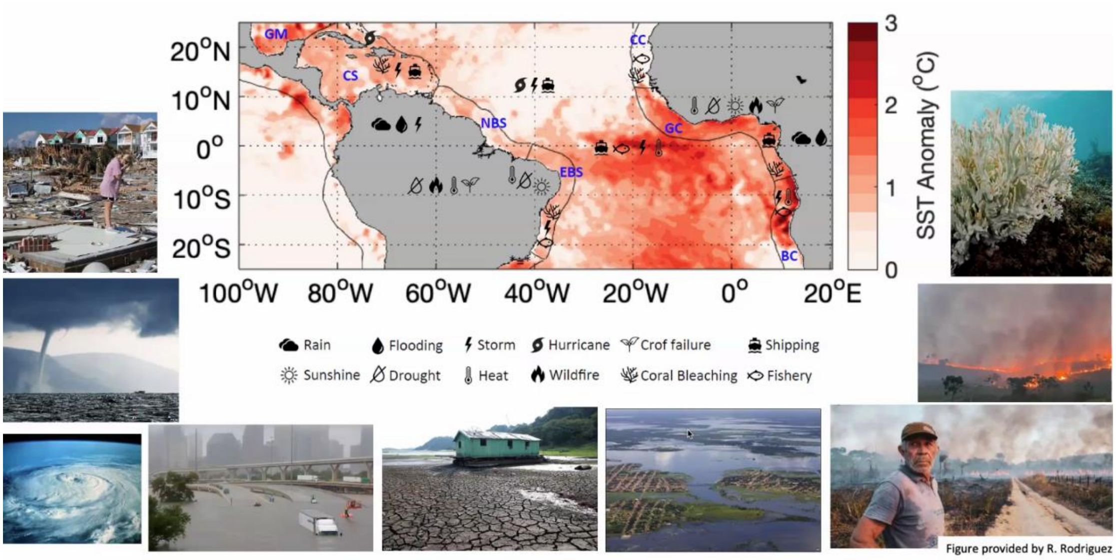
- Surface and subsurface ocean temperature to understand the mechanisms behind long-term changes, and to distinguish between internal and external driven climate variability.
- Ocean salinity as an indicator of long-term changes in the hydrological cycle and because of its importance for the ocean circulation.
- Sea Surface Height and to maintain long-term tide gauge records, so as to monitor sea level rise.
- Surface flux measurements are important for understanding changes in ocean heat and salt content, and associated climatic changes.
- *In-situ* arrays to monitor basin scale changes in the overturning circulation.
- Enhance continental climate observations, which have been declining. Lack of these data has limited understanding of the impacts of climate change.

In addition, we recommend the recovery of unused historical data and increasing the paleo-proxy archives in order to better understand changes over the historical period. Obviously, bio-ecological times series on biomass assessment and spatial distribution of key marine exploited (or not) species must be maintained when it exists, using standardized procedure (*Brehmer et al.*, 2019a) and related to essential environmental variables listed above, to better understand and evaluate the impact of long-term climate change on the marine ecosystem, their marine resources and services. Lastly, we encourage the recovery of historical coastline dynamics as well as historical event of littoral submersion and cyclone/hurricanes intensity.

Tropical Atlantic Observing System (TAOS)

REVIEW REPORT

Full Report



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May 2021

Sponsored by

This report was led by the CLIVAR Atlantic Region Panel (ARP) in collaboration with the PIRATA (Prediction and Research Moored Array in the Tropical Atlantic).

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Please use the following citation for the report:

Johns, William, S. Speich, M. Araujo and lead authors, 2021: Tropical Atlantic Observing System (TAOS) Review Report. CLIVAR-01/2021, 218 pp