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Unusual conditions in the tropical Atlantic Ocean in 1984

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During the first half of 1984, oceanic and atmospheric conditions in the tropical Atlantic were, in many respects, similar to conditions in the Pacific Ocean during El Niño: the upper ocean was unusually warm in the eastern part of the basin, rainfall was heavy over the normally arid regions to the south of the Equator, and coastal upwelling was inhibited in regions (southwestern Africa) where this is a seasonal phenomenon. The change in sea-surface temperatures, which resulted when unusual eastward currents to the south of the Equator transported warm surface waters towards Africa, contributed to the change in atmospheric conditions. The altered atmospheric conditions, in turn, contributed to the change in the oceanic circulation and the change in the sea-surface temperature.

Figure 1 contrasts the sea-surface temperatures (SSTs) in the tropical Atlantic in June 1983 and June 1984. The higher SSTs in 1984 were associated with exceptionally heavy rainfall over northeastern Brazil and the coastal zone of southwestern Africa but were also associated with a persistence of the drought in the Sahel, the region to the south of the Sahara desert. This happened because the Intertropical Convergence Zone[1] (ITCZ), the narrow east–west band of rising air, cloudiness, and heavy rainfall onto which the south-east and north-east trades converge, was displaced unusually far southward during 1984. Such a displacement of the ITCZ is also a feature of El Niño in the Pacific Ocean. However, the other important feature of El Niño, eastward movement of the atmospheric convective zone that is normally over the western equatorial Pacific, had no counterpart in the Atlantic during 1984. In the Pacific the eastward movement of the region of heavy rainfall and low sea-level pressure, towards the arid eastern equatorial Pacific where sea-level pressure is normally high, results in negatively correlated variations in the eastern and western sides of the ocean basin. During the warm event in the Atlantic, by contrast, the increase in rainfall and decrease in sea-level pressure was fairly uniform in the east–west direction.

The dominant change in the Atlantic was not a zonal one—the low-pressure convective zone over the Amazon Basin was not dislodged from the continent—but was a meridional one associated with the equatorward movement of the ITCZ. The ITCZ is the principal region of rainfall over the tropical Atlantic Ocean and the adjacent land. Seasonally it moves between the Equator and 15 °N, approximately, so that northeastern Brazil has a rainy season in March and April when the ITCZ is furthest south, whereas the Sahel (10 °N to 15 °N in west Africa) has a rainy season centred on August when the ITCZ is furthest north. Because of this dependence on the ITCZ for rainfall, latitudinal precipitation gradients are enormous: annual mean rainfall along the west African coast is 1,939 mm at Bissau (12 °N), 542 mm at Dakar (15 °N) and 123 mm at Nouakchott (18 °N). These statistics make it clear that slight variations in the position of the ITCZ, which has a very small north–south extent, have a major effect on rainfall variations in west Africa. The unusual southerly position of the ITCZ in 1984 contributed significantly to the persistence into 1984 of the drought in the Sahel, and to the heavy rainfall and floods in northeastern Brazil and the coastal zone of equatorial and southwestern Africa, including Angola.

Atmospheric convective zones over the ocean are usually over the warmest surface waters. The ITCZ, for example, is in the neighbourhood of the Equator when SSTs in that region are at

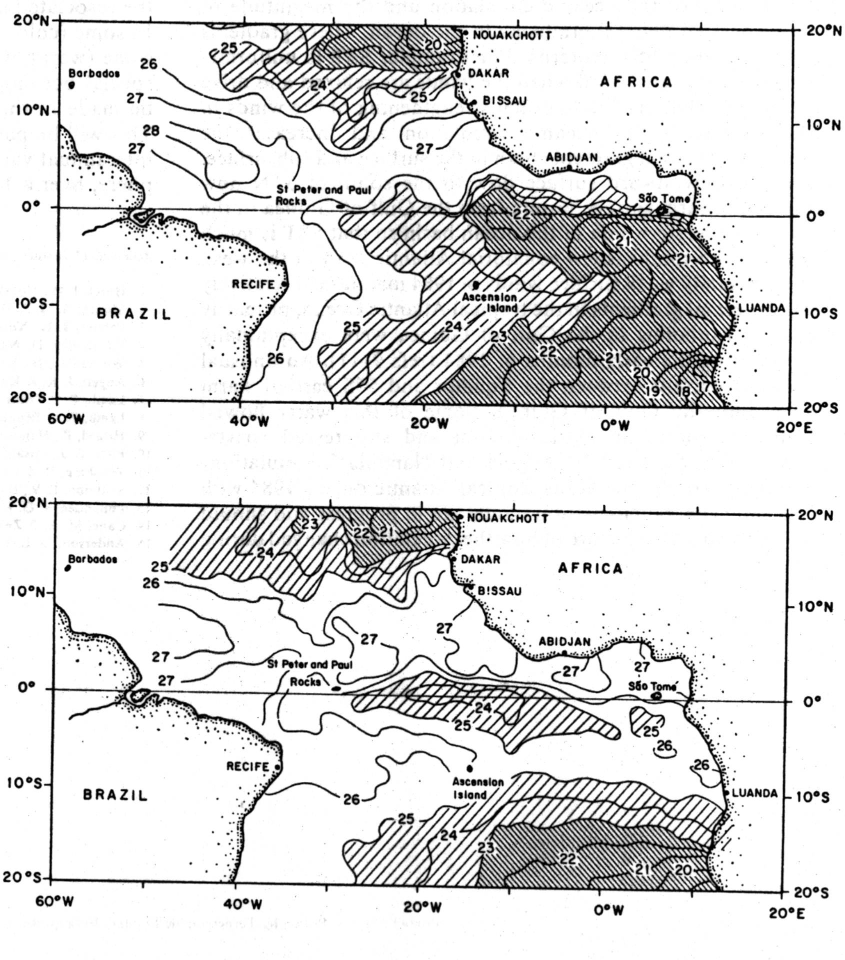

Fig. 1 Sea-surface temperatures (°C) in the tropical Atlantic Ocean in June 1983 (top) and June 1984 (bottom).

a maximum (March and April) and it moves northward when SSTs at, and to the south of the Equator in the central and eastern Atlantic start to fall. Interannually, southward displacement of the ITCZ is correlated with, and in models is effected by, an increase in SST to the south of the Equator and a simultaneous decrease in SST farther north[2,3]. SST variations in the tropical Atlantic, therefore, influence rainfall variations over Africa and Brazil. There are, however, other factors that influence the position of the ITCZ and the rainfall. Palmer[3] finds that, in a general circulation model of the atmosphere, SST variations in the tropical Pacific Ocean have a significant effect on the position of the ITCZ over the Atlantic Ocean. This result suggests that the atmospheric convergence onto the region of unusually high SST in the eastern tropical Pacific in 1983 was the cause of the intense trade winds over the Atlantic in 1983. Palmer's calculations indicate that the high SST in the Atlantic during 1984 should have weakened the trade winds over the Pacific. Such a weakening was not observed—the trade winds over the Pacific were stronger than usual in 1984—possibly because SST in the tropical Pacific during 1984 were much lower than normal. There are factors, other than SST, that influence the atmospheric circulation in the tropics. For example, it has been suggested that an expansion of the Northern Hemisphere circumpolar vortex and an equatorward displacement of the subtropical high-pressure belt affect the tropical circulation and the rainfall of the Sahel[4-7]. The degree to which SST variations in the tropical Atlantic affect rainfall in the Sahel appears to be modest[8] but there are indications that these SST variations have a more pronounced effect on rainfall over northeastern Brazil and southwestern Africa.

SST variations over large parts of the ocean are determined primarily by changes in the local flux of heat across the ocean surface. In the tropical oceans, however, SST variations are strongly influenced by changes in the large-scale oceanic circulation, in response to changes in the surface winds. On seasonal and interannual timescales the strength of the wind determines the intensity of the oceanic circulation and the magnitude of the associated thermal gradients in the ocean. These gradients are reflected in SST patterns. For example, SST is uniformly high in March and April when the winds are relaxed and drive a weak circulation. The seasonal strengthening of the winds in May intensifies the oceanic circulation and increases the horizontal thermal gradients both in the surface and subsurface. The strong westward surface flow to the south of 3 °N now transports warm surface waters from the Gulf of Guinea in the east to the western side of the ocean basin so that SST is much lower in the southeastern equatorial Atlantic than in the west. The unusually weak surface winds in 1984 maintained relatively small thermal gradients in the tropical Atlantic Ocean, primarily because isotherms in the Gulf of Guinea were exceptionally deep during the early months of 1984 (refs 9-11). An unusual eastward current between the Equator and 5 °S carried warm water into the Gulf of Guinea. Some of this water flowed southward along the African coast and suppressed coastal upwelling as far south as Angola and Namibia[12]. Simulations of oceanic conditions in the tropical Atlantic during 1984 with a realistic general circulation model are in progress and should provide a coherent picture of how the circulation changed during the warm event.

From an oceanographic point of view, the unusual conditions in the tropical Atlantic Ocean during 1984 were caused by changes in the surface winds. From a meteorological point of view, the unusual winds were in part attributable to changes in the SST. This circular argument suggests that interactions between the ocean and atmosphere were of central importance. These interactions are crucial both seasonally and interannually. (The large seasonal variations in SST near the Equator both influence the movements of the ITCZ and are influenced by the movements of the ITCZ which determine changes in the surface winds.) Interannual variations in the Atlantic Ocean can be viewed as perturbations to the seasonal cycle. In 1984, the seasonal migrations of the ITCZ took it further south than normal and it remained in a southerly position longer than normal. An unusual southward displacement of the ITCZ is also a feature of El Niño events in the Pacific Ocean. An additional feature of El Niño, but apparently not a feature of interannual variability in the Atlantic, is an eastward displacement of atmospheric convective zones at the western extreme of the ocean basin. Most studies[13-15] of interactions between the ocean and atmosphere in the tropics concern this zonal movement of convective zones. Studies of the air-sea interactions and the other factors that control the latitudinal movements of the ITCZ will shed light not only on phenomena such as droughts in western Africa and northeastern Brazil, but also on El Niño.

Finally, how often do warm events such as that of 1984 occur? The previous warm event with a comparable amplitude to the south of the Equator occurred in 1963 when the arid regions of southwestern Africa experienced severe floods, and a suppression of the coastal upwelling. However, the few available long time-series records show that there is considerable variability from year to year[8]. This variability is associated with the timing of the major feature of the seasonal cycle, the northward movement of the ITCZ. This movement starts abruptly so that the associated intensification of the south-east trades is sudden. In some (cold, dry) years, this happens as early as February, in some (warm, wet) years as late as June. Over the next decade, special oceanographic and meteorological measurements will be made in the tropical Atlantic to document this variability. This will be part of the international TOGA program, to study interannual variability of the tropical oceans and global atmosphere, over a 10-year period that started in 1985.

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