

Title	CLIMATE ANOMALIES AND EXTREME EVENTS IN AFRICA IN 2003, INCLUDING HEAVY RAINS AND FLOODS THAT OCCURRED DURING NORTHERN HEMISPHERE SUMMER
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Citation	African study monographs. Supplementary issue (2005), 30: 165-181
Issue Date	2005-03-31
URL	http://dx.doi.org/10.14989/68453
Right	
Type	Departmental Bulletin Paper
Textversion	publisher

CLIMATE ANOMALIES AND EXTREME EVENTS IN AFRICA IN 2003, INCLUDING HEAVY RAINS AND FLOODS THAT OCCURRED DURING NORTHERN HEMISPHERE SUMMER

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ABSTRACT The climate of 2003, particularly during Northern Hemisphere summer, was marked by exceptionally abnormal events throughout the world, and Africa was no exception. As record heat waves prevailed over Europe, heavy rains and floods occurred over the west-central Sahara, across the Sudano-Sahelian region and western Kenya, while drought conditions gripped the Guinea Coast and southeastern Southern Africa, and cold waves hit southern South Africa. Among the most remarkable events were record rainfall in the western portion of the Sahara-Sahel and drought conditions over the Guinea Coast that were both caused by an extreme northward penetration of the ITCZ relative to normal years. In addition, record-breaking cold weather occurred in southern South Africa in mid-August by a strong extratropical cyclone accompanied by a cold front. During Southern Hemisphere summer, Madagascar, Mozambique, Zimbabwe, and Malawi frequently experienced heavy rains and floods associated with tropical cyclones and their remnants. More than 550 people died and over 2.5 million were displaced because of floods in Africa in 2003. Africa's vulnerability to climate hazards could be reduced through enhancements of both short- and long-term coping strategies, climate monitoring and early warning systems, flood control infrastructures, and other disaster preparedness measures at all levels, including sub-regional, national, and local levels. Mechanisms that caused various events in Africa in 2003, events which can be viewed as regional responses in Africa to anthropogenic global warming, must be explored from the perspective of global change.

Key Words: Climate anomalies; Extreme events; Heavy rains; Floods; Northern Hemisphere summer 2003.

INTRODUCTION

Ample evidence suggests that ongoing anthropogenic global warming has recently increased the frequency and magnitude of many extreme climate events, including floods, droughts, tropical and other storms, anomalous temperatures, and fires (IPCC, 2001b). The African continent is particularly vulnerable to climate change because of widespread poverty, recurrent droughts, inequitable land distribution, and overdependence on rain-fed agriculture (IPCC, 2001a). In many African countries, adverse effects from climate anomalies and events such as severe droughts or floods have increasingly threatened food security and human lives. Arid, semi-arid, and dry subhumid areas, which are collectively defined as "drylands," are particularly vulnerable to climate anomalies and events. This is best exemplified by the effects of persistent, severe droughts in

the Sudano-Sahelian region south of the Sahara from the late 1960s to the early 1990s, and of ENSO (El Nino Southern Oscillation)-related significant droughts and/or floods that occurred over the Horn of Africa, equatorial East Africa, and southeastern Southern Africa in the 1980s and 1990s.

Onset of El Nino conditions from November 1997 to January 1998 in the equatorial Pacific Ocean was associated with abnormally wet conditions over the drylands of the Horn of Africa and equatorial East Africa (Fig. 1a), with outbreaks of rift valley fever in flood-stricken areas. During the same period, most of southeastern Africa experienced severe drought and food shortages. In contrast, during the 1999-2000 La Nina event subsequent to the 1997-98 El Nino, climatic conditions reversed. Conditions were drier than normal over the Horn of Africa and equatorial East Africa, and wetter over Southern Africa with powerful tropical cyclones accompanied by unusually heavy rains and extreme floods (Fig. 1b).

Persistent rains in February 2000 coupled with extremely heavy rains (250-500 mm) associated with Tropical Cyclone Eline pushed monthly rainfall to 350-1,000 mm, or 500-1,000% of normal, in southern Mozambique, northeastern Botswana, and South Africa. Record flooding ensued downstream of the Limpopo and Zambezi rivers (South African Weather Bureau, 2000; Fig 1b). Remnants of Eline traversed the sub-continent, reaching central Namibia where torrential rains caused flash floods in ephemeral desert rivers. These climate anomalies that have repeated almost every year have caused severe crop shortages in most countries from the Horn of Africa to Southern Africa. The total population at risk for food shortages was 20 million or more in some years.

During 2003, although no distinct El Nino conditions were present in the

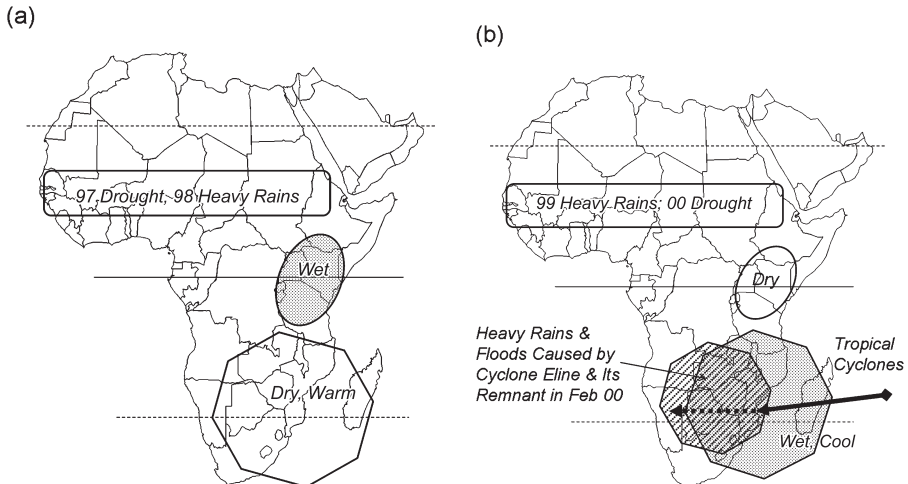


Fig.1. Significant climate anomalies and extreme events in Africa during the most recent ENSO years.

(a) 1997/98 El Nino (warm) years (Data from IPCC, 2001a; NOAA/CPC, 2002a; UNEP, 2002).

(b) 1999/2000 La Nina (cold) years (Data from IPCC, 2001a; NOAA/CPC, 1999, 2000, 2002b; UNEP, 2002).

equatorial Pacific Ocean, severe climate anomalies occurred throughout the world with heat waves and droughts in Europe and Canada, and a cool summer and heavy rains in Japan (NOAA/NCDC, 2004). In particular, during Northern Hemisphere summer from June through August 2003, Europe experienced heat unprecedented since 1500 (Luterbacher *et al.*, 2004) under the influence of a hot, dry ridge, which was associated with the subtropical Azores Anticyclone that stalled over Southern Europe. The death toll due to heat exceeded 35,000. Water shortages, forest fires, food crop failures, permafrost melting in the Alps, and other disastrous events occurred over Western Europe. The human toll of the heat wave was most severe in France, where 14,802 died (Earth Policy Institute, 2003). Weather in Africa was also unusual during this period. Heavy rains and floods occurred over the Sudano-Sahelian region and over equatorial East Africa, droughts plagued the Guinea Coast, and droughts and cold waves affected South Africa. (NOAA/NCDC, 2004).

This paper investigates climate anomalies and extreme events that occurred in 2003 across Africa, with an emphasis on rainfall anomalies and significant flood events during Northern Hemisphere summer, to serve as a basis for Africa-wide climate/environmental change studies. Data used in this study originated mostly from web pages published by the Dartmouth Flood Observatory, FEWS NET/USAID (Famine Early Warning System Network/U.S. Agency for International Development), NOAA/CPC (National Oceanic and Atmospheric Administration/Climate Prediction Center), NOAA/NCDC (NOAA/National Climatic Data Center), ReliefWeb, South African Weather Service, and vf-tropi.com.

CLIMATE ANOMALIES AND EXTREME EVENTS DURING NORTHERN HEMISPHERE SUMMER (JUNE-SEPTEMBER) 2003

I. Northern Hemisphere Africa

1. Western Parts of the Sudano-Sahelian Region and the Sahara

Beginning in early June 2003, the Intertropical Convergence Zone (ITCZ) in northern hemispheric Africa and the attendant rainbelt of heavy showers moved markedly northward (Fig. 2) into the Sudano-Sahelian region. The mean position of the ITCZ reached its normal northernmost extreme in mid-July, almost one month early (FEWS NET, 2003a). The ITCZ continued moving northward, reaching 20.5°N in mid-August, about 1.4° north of the normal extreme climatological position (FEWS NET, 2003d; French, 2003a, b). Because the ITCZ was unusually far north, there was enhanced rainfall in regions between 10°N and the Sahara Desert, and reduced rainfall with locally severe drought over coastal regions of the Gulf of Guinea (Figs. 2, 3a).

Convective activity was excited by the combined effects of the African easterly wave located near 15°N and deep, moist maritime air flow that characterized the Guinea Monsoon. As a result, localized heavy rains and floods were common in the Sudano-Sahelian region from Senegal in the west to Sudan and

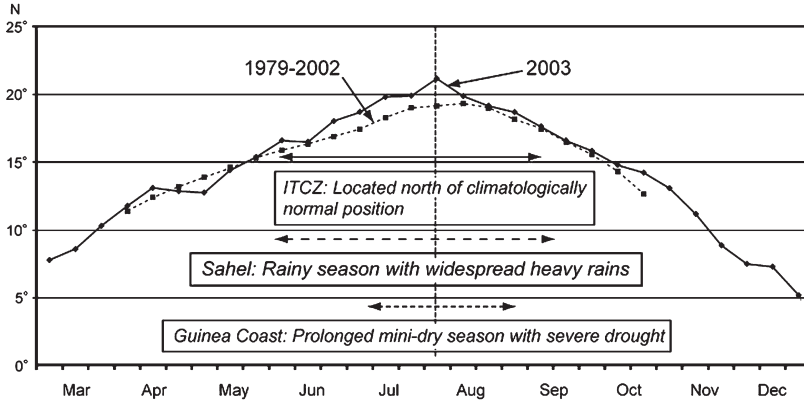


Fig. 2. Mean position of the ITCZ in West Africa 10°W-10°E from May-December 2003 in comparison of the long-term mean, with comments on rainfall anomalies in the Sahel and the Guinea Coast regions during the Northern Hemisphere summer season highlighted (Modified from NOAA/CPC, 2003).

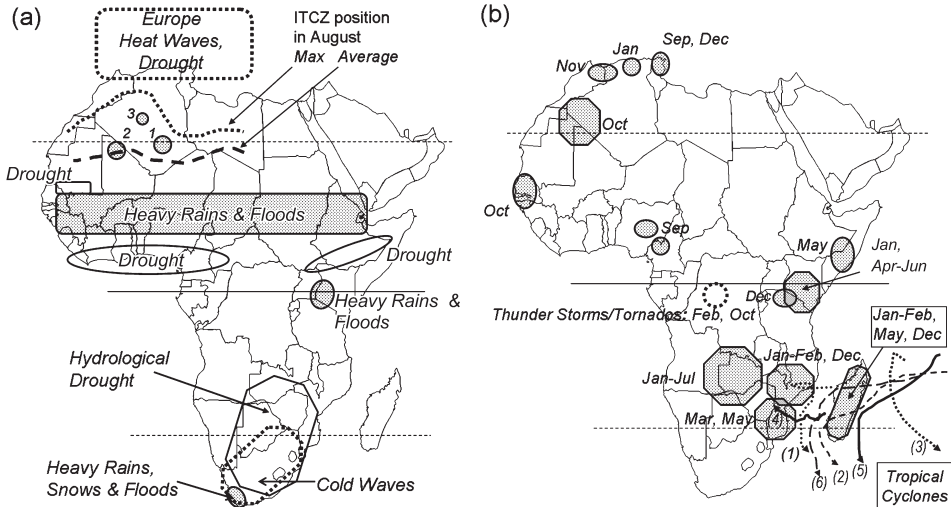


Fig. 3. Significant climate anomalies and extreme events in Africa in 2003.
 (a) Significant climate events in August 2003 (Data from DFO, 2003; FEWS NET, 2003a, 2003b, 2003c, 2003d, 2003e, 2003f; NOAA/NCDC, 2004; ReliefWeb, 2003c, 2003d; South African Weather Service, 2003a, 2003b). 1: Tamanrasset; 2: Taoudenni; 3: Reggane.
 (b) Heavy rains and floods in other months in 2003 with tracks of tropical cyclones (Data from DFO, 2003; FEWS NET, 2003g, 2003h; JAXA/EORC, 2003; NOAA/CPC, 2004; ReliefWeb, 2003a, 2003b, 2003c, 2003d, 2003e, 2003f, 2003g). Tracks of tropical cyclones—(1) Delfina: 30 December 2002 - 9 January 2003; (2) Fari: 23-30 January, 2003; (3) Gerry: 8-15 February, 2003; (4) Japhet: 26 February - 3 March, 2003; (5) Manou: 3-10 May, 2003; (6) Cela: 5-21 December, 2003.

Eritrea/Ethiopia in the east (Fig. 3a). On 10-11 August, when the ITCZ reached its extreme northward extent, near 30°N (AGRHYMET, 2003; Fig. 4b), localized torrential rains fell and floods occurred over the western central Sahara,

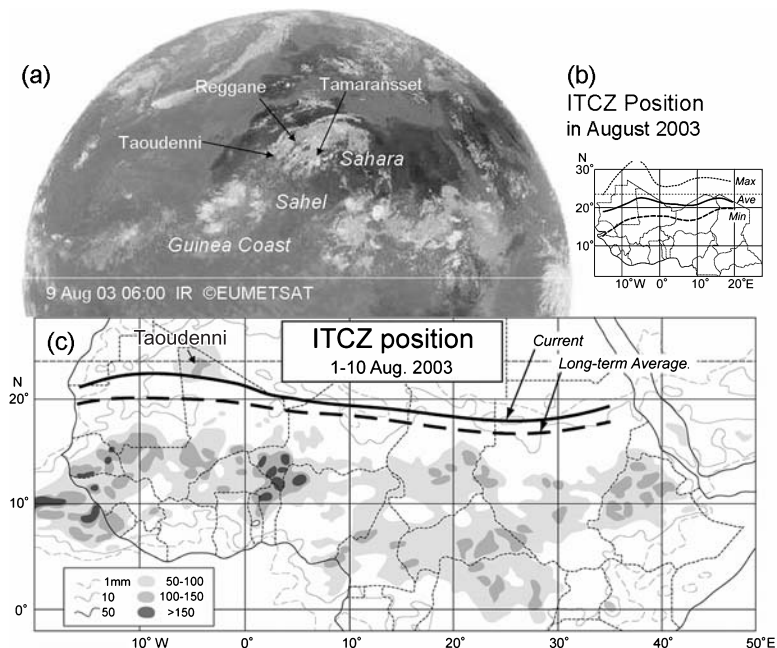


Fig. 4. ITCZ positions and heavy rains during the first decade of August 2003 in Northern Hemisphere Africa.

- (a) METEOSAT infrared image on 9 August 2003 at 6:00 UTC showing spotty heavy rains over the Central Sahara and across the Sahel region (Copyright ©2003 EUMETSAT; EUMETSAT, 2003a).
- (b) The maximum, average, and minimum positions of the ITCZ in August 2003 in West Africa (Modified from AGRHYMET, 2003).
- (c) The 1-10 August 2003 and the long-term average 1-10 August ITCZ positions, and NOAA/CPC Africa decadal rainfall estimates for 1-10 August 2003 (Modified from NOAA/CPC, 2003). Note that widely scattered heavy rains of more than 100 mm across the Sahel region and spotty heavy rains over the west-central part of the Sahara around Taoudenni, northern Mali. In contrast, the Guinea Coast region from Liberia to Ghana was under the condition of severe dryness.

especially over areas around Tamanrasset ($22^{\circ}42'N$) in the Hoggar Mountains and Reggane Basin ($26^{\circ}43'N$) in central Algeria (DFO, 2003; Figs. 3a, 4a, 4c). The Tomonian district 480 km east of Bamako, Mali, saw unusually heavy rains on 10 August, with 117 mm in a single day. That rain destroyed more than 700 grain storehouses and flooded 1,800 houses (ReliefWeb, 2003d).

As the ITCZ moved to the south after mid-August, the belt of heavy rains shifted to the Sudanian zone. Heavy rains fell from late August to early September around Kaduna in central Nigeria (Fig. 3b), leading to large-scale over-the-bank flooding on the Kaduna River, a tributary of the Niger River on 7 September (ReliefWeb, 2003e, f). More than 2,000 properties were destroyed and about 2,500 families were made homeless (Table 1). During September and October, 200,000 people in Nigeria were displaced because of flooding on the Niger River and its major tributaries, and the Hadejia and Jamaare Rivers, which are tributaries of the Komadougou Yobe River flowing into Lake Chad

Table 1. Main damages from heavy rains and floods in the Sudano-Sahelian countries during July–September 2003.

Country	Reported major damages.
Mauritania	3,600 houses destroyed and 21,000 homeless. ⁽¹⁾
Senegal	8 dead and 5,300 homeless. ⁽¹⁾
Mali	10,000 lost their homes in Bamako. ⁽¹⁾ At least 180 ancient mud buildings on the World Heritage List destroyed in Timbuktu. ⁽²⁾
Burkina Faso	10 major towns flooded, 900 homes destroyed, and 3,000 families affected. ⁽¹⁾
Niger	7 dead, 1,000 homes destroyed, and 5,400 families affected. ⁽¹⁾
Nigeria	Over 2,000 properties destroyed, 3,600 homeless, and 10,600 displaced in Kaduna area. ⁽³⁾
Sudan and Eritrea	79% of city area flooded and 80% of population homeless in Kassala, eastern Sudan. 20 dead and 325,000 displaced during 28 July–21 August in Sudan and Eritrea. ⁽⁴⁾

Data from: (1) ReliefWeb, 2003c; (2) BBC, 2003; (3) ReliefWeb, 2003d, 2003e; (4) DFO, 2003.

in Jigawa State (DFO, 2003). Damage along the Kaduna, the Hadejia, and the Jamaare Rivers was aggravated by dam-released floodwaters. Similar events occurred along the upper stretches of the Benue River, a major tributary of the Niger River; 300 houses were washed away in a flash flood caused by discharge from Lagdo Dam in northern Cameroon.

Flood levels peaked in mid-September along the middle reaches of the Niger River: 10,000 people lost their homes in Bamako, the capital of Mali that is on the banks of the Niger River (Table 1). In Timbuktu, Mali, which is also on the Niger River, historic mud-built buildings on UNESCO's World Cultural Heritage List were threatened by flooding, and at least 180 mud buildings were destroyed directly by the impact of heavy rains (BBC, 2003). As the floodwaters moved downstream, record floods occurred along the mid- to lower reaches of other major rivers such as the Senegal, the Volta, and the Chari-Logone between September and November.

Accumulated rainfall in the three months from July to September at most observation stations in the drylands of West Africa exceeded long-term averages and record amounts from the past 50-70 years (up to 200-300% of the normal) (French, 2002/03a, 2003b). Some areas in the western parts of the southern to central Sahara had 500% or more of normal rainfall. Although there was widespread damage to human lives, houses, and other structures throughout the drylands of West Africa south of the Sahara, the wet conditions also supported the best cereal and cotton harvest in the Sahel in the past 50 years. Grain production for countries in the Sahel for 2003-04 was estimated as of March 2004 to be 32% above the mean total production for the last 5 years. In Senegal, grain production was 66 % above the 5-year mean. Per capita production also increased, 22 % above the mean for the last 5 years, which was a new record in the past 15 years (FEWS NET/CILSS, 2004).

2. Eastern Parts of the Sudano-Sahelian Region

Excessive and unusually heavy rains fell from late July to mid-August in eastern Sudan, northern Ethiopia, and Eritrea. In eastern Sudan, very heavy rains (500 mm) from 26-30 July caused widespread flooding east of Khartoum on the Blue Nile River and near Kassala on the Awash River (FEWS NET, 2003e). The flood event of the Awash River, which originates in the northern Ethiopia-Eritrea highlands, was the most severe in the last 70 years, flooding 79% of the houses and making 70,000 homeless in Kassala from mid-July to August. Localized record flooding and landslides occurred (DFO, 2003). Total numbers of those displaced from 28 July to 21 August 2003 reached 325,000 (DFO, 2003; Table 1).

3. Guinea Coast Region

Coastal regions along the Gulf of Guinea from Liberia to southern Nigeria are typically dry from July through early September because the ITCZ and its accompanying rainbelt usually move north into the Sahel during those months. In 2003, this dry season started about a month early across the coastal zone and also ended later. Thus, there were dryer conditions in the coastal zone during July-early September, reflecting the more northerly final position of the ITCZ compared to normal years (French, 2002/03a, 2003a) (Figs. 2, 3a). Drought conditions caused water shortages for rain-fed crops and resulted in the lowering of water levels in reservoirs, which led to a drop in hydroelectric power generation.

II. Equatorial East Africa and Southern Africa

1. Equatorial East Africa

June through August is generally dry over equatorial East Africa, including most of Kenya, Tanzania, and eastern Uganda, because the ITCZ is displaced north far from the Equator. However, in 2003, the western part of Kenya, which sits within the basin of Lake Victoria, experienced normal or above normal rainfall with frequent locally heavy rains (French, 2003/04b). Maximum total recorded rainfall during June-August was 861.9 mm at Kakamega in the Western Kenya Highlands. This three-month total, the greatest since 1958, was 161.3% of the long-term mean (Kenya Met. Dept., 2003). Between 26 August and 12 September, flooding occurred along the lower floodplains of the Nzoia and Yala Rivers. Dikes along the Nzoia River in the Budalangi Division of Siaya District collapsed for the second time that year leaving 2,500 homeless, most of whom were victims of the previous flooding in April (DFO, 2003; ReliefWeb, 2003d). Floodwaters of the Nzoia River originated mainly from downpours over headwaters in the Cherengany Hills and on Mt. Elgon (East African Standard, 2003).

2. Southern Africa

During winter 2003 in the Southern Hemisphere (June-September), most of

the drylands, or regions that see summer rainfall in Southern Africa, experienced seasonal dryness. Parts of southern Mozambique, southern Zambia, eastern Botswana, and northeastern South Africa were in persistent hydrological drought conditions due to a long-lasting dryness since early 2003, particularly poor rainfall during the last rainy season (40-65% of normal) (FEWS NET, 2003b, 2003c, 2003d, 2000e; Fig. 3a). Unusually cold weather with temperatures 2-6°C below normal were common over much of southern Africa from June-August (French, 2003/04c).

In areas where winter rainfall is expected, particularly the Western Cape Province of South Africa, a dry July was followed by an abnormally wet August. The latter month was marked by the frequent passage of extratropical storms. On 18-20 August, a powerful storm over the South Atlantic Ocean swept a cold front into South Africa (Fig. 5). Heavy rains and floods, snows in higher elevations, and strong winds accompanied the storm. Winds over southeastern Cape Province exceeded 90 km/hr (with gusts to 130 km/hr), causing wind damage over parts of greater Cape Town. During the night of 20 August, record-cold August temperatures occurred across South Africa and Lesotho. Some stations reached -10°C, and black frost covered wide areas (South African

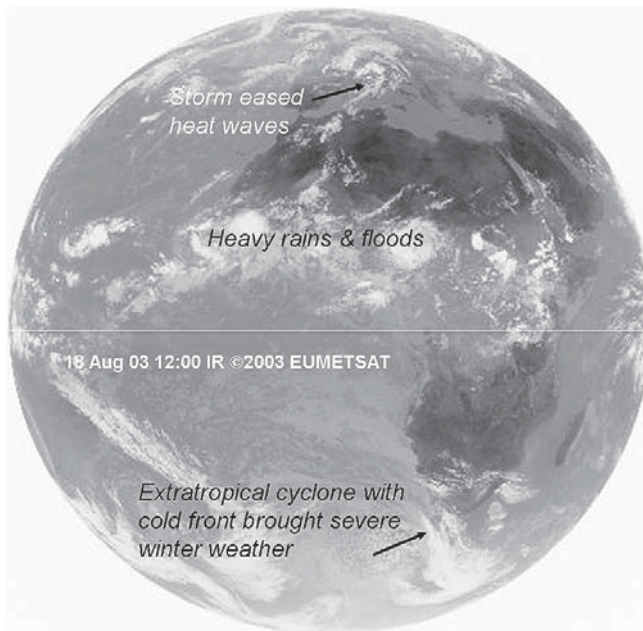


Fig. 5. METEOSAT infrared image on 18 August, 2003 at 12:00 UTC (Copyright ©2003 EUMETSAT; EUMETSAT, 2003b).

As Europe saw relief from persistent, record summer heat waves by the passage of a storm, southern parts of South Africa suffered under the influence of a strong extratropical cyclone accompanied by severe winter frontal weather (South African Weather Service, 2003a, 2003b). The Sahel region was at the height of the rainy season which was characterized by widely scattered heavy rains.

Weather Service, 2003a, 2003b).

CLIMATE ANOMALIES AND EXTREME EVENTS IN OTHER SEASONS OF 2003

A number of unusual events, such as heavy rains and floods, occurred in various parts of Africa, as shown in Fig. 3b and summarized below, during 2003 in months other than Northern Hemisphere summer (June-September):

I. January-March 2003

1. North Africa

Heavy rains associated with a temperate cyclone from 14-16 January caused flooding of ephemeral rivers in northern and central Tunisia, killing eight and displacing 27,000. Heavy rains continued in northern Tunisia until mid-January. Floods recurred there on 25-26 January, killing two people (DFO, 2003).

2. East Africa

Floodwaters on the Auji River that originated from heavy rains that fell in the Nandi Hills of western Kenya were clogged with water hyacinth (*Eichhornia crassipes*), one of the world's 100 worst invasive alien species. Flooding occurred over low-lying areas of the Kisumu estates along Lake Victoria from 4-6 January (DOF, 2003).

3. Congo Basin

A violent tornado struck six villages in the central Congo Basin in the District of Yumbi, Province of Bandundu, DR Congo (Fig. 3b), at 11 PM on 2 February. The tornado destroyed 1,664 houses, killed 164, and injured 1,702, and 1,970 families were made homeless (ReliefWeb, 2003b).

4. Southern Africa

Over Southern Africa, drought conditions prevailed during the Southern Hemisphere rainy season from December 2002-March 2003. Total rainfall across western Zimbabwe, extreme eastern Botswana, and northeastern South Africa was only 40 to 70% of normal (FEWS NET, 2003e; French, 2002/03b). During the same period, northeastern Southern Africa, including Madagascar, received normal to above normal rainfalls. Tropical cyclones, or the remnants of tropical cyclones, were frequent (Fig. 3b).

During January, extremely wet conditions prevailed over Madagascar. Monthly rainfall totaled 400 to 900 mm (170-360% of normal). Similarly, very wet weather was common across northern Mozambique, Malawi, and parts of eastern Zambia, where monthly totals were 300-400 mm, or 120-150% of normal (French, 2002/03b). Ex-Tropical Cyclone Delfina, which made landfall over northern Mozambique on 31 December 2002 (Fig. 6a), produced heavy

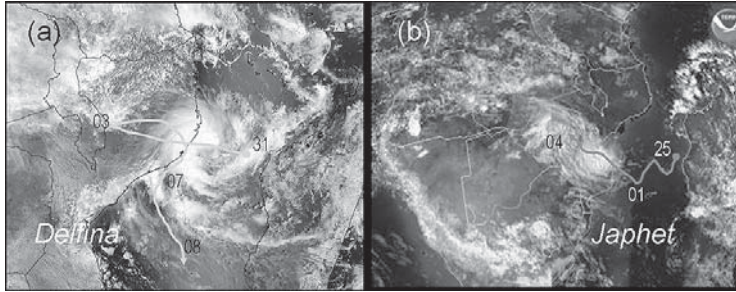


Fig. 6. Two tropical cyclones that made landfall on the east coast of Mozambique during January-March 2003 (Tracks from JAXA/EORC, 2003).

(a) Tropical Cyclone Delfina just before made landfall on the east coast of northern Mozambique with heavy rains over parts of northern Mozambique and Malawi (MODES image on 31 December, 2002 from NASA/EONH, 2002; Track from 31 December, 2002-4 January, 2003 from JAXA/EORC, 2003).

(b) Tropical Cyclone Japhet made landfall on the east coast of central Mozambique and heavy rains spread over central Mozambique and most of Zimbabwe (DMSP F-14 2.7 km visible imagery on 4 March, 2003 at 13:00 UTC from NOAA/EVP, 2003; Track from 25 February-4 March, 2003 from JAXA/EORC, 2003).

rains (up to 600% of normal) over northern Mozambique, parts of Malawi, and northern Madagascar (French, 2002/03c) on 4-5 January. Resultant floods damaged crops, roads, bridges, and urban water supply systems. Furthermore, 18,000 to 20,000 houses were destroyed, and 350 schools were damaged. The number of affected people was 100,000 as of 10 January (ReliefWeb, 2003a). Flooding continued from 1 January to 17 February, killing 23 people and displacing 400,000 (DFO, 2003).

Cyclone Fari made landfall on 28 January along the east-central coast of Madagascar, with 24-hour rainfalls of up to 230 mm on the west coast. From 18-31 January, 16 people died and 25,000 people were displaced because of flooding on the Ikopa River in and around Madagascar's capital Antananarivo (DFO, 2003).

During the first ten days of February, very heavy rains up to 339 mm fell over northeast Madagascar as Cyclone Gerry developed. A tropical disturbance in late February produced very heavy rains (170-344 mm) across west-central Madagascar. This disturbance developed into Tropical Cyclone Japhet on 26 February, bringing heavy rains over northern Zimbabwe, southern Zambia, and central Mozambique (French, 2002/03b; Fig. 6b). Between 4 and 8 March, remnants of Tropical Cyclone Japhet dropped very heavy rains (up to 373 mm /603% normal) (French, 2002/03b) across much of central Mozambique and eastern Zimbabwe. These rains caused flooding of the lower Limpopo, the Save, and other rivers in coastal Mozambique (SAFDN, 2003), killing eight and displacing 8,300 (DFO, 2003).

In the floodplains of the upper to middle reaches of the Zambezi River and its tributaries, including areas across Angola, southwestern Zambia, northeastern Namibia, and the Caprivi Strip, seasonal flooding began earlier and became more serious than usual in early April because of heavy rains over the headwa-

ters on the Angola Highlands that had persisted since December 2002. Mongu, which is located in the Barotse Plain of western Zambia, experienced the worst floods in 50 years; twenty-five villages washed away (DFO, 2003). Flood waters around Mongu receded by mid-May, but floods continued downstream, especially in eastern Caprivi, through June and early July with 22 villages submerged or surrounded by water and 12,000 people displaced. This was the worst flood in about 20 years, and the Government of Namibia declared a flood crisis over Caprivi on 3 June. Floods in the Zambezi Basin during the 6 months starting 1 January killed seven and displaced 20,000 (DFO, 2003).

II. April-June 2003

1. East Africa

The year's first flood in western Kenya occurred in late April, forcing the evacuation of 18,000 (ReliefWeb, 2003c). In the last ten days of April, Kenya recorded abnormally heavy rains (77-260 mm, 126-624% of normal) across its inland areas (French, 2002/03b). Weekly rainfall during 29 April-5 May exceeded 150 mm in some areas. Heavy rains aggravated flooding through May over much of Kenya and eastern Uganda, where 77 died and one million were displaced between 21 April and 3 June (DFO, 2003). The areas most affected were the flood-prone lowlands of Nyanza and Western provinces, as well as some districts in the Eastern and Northeastern provinces. As of 16 May, more than 35 had died and about 60,000 were displaced in floods in Kenya (MOFA, 2003) that affected alluvial lowlands along the lower reaches of the Nyando and Nzoia Rivers in the Lake Victoria Basin. Rivers in the Rift Valley such as the Kerio River and the lower Tana River also flooded (DFO, 2003).

In southern Ethiopia and adjacent areas of Somalia, the worst flooding in memory killed 106 and displaced 111,000 between 6-20 May (DFO, 2003)

2. Southern Africa

In May, in the middle of the normal dry season, late-developing tropical cyclone Manou (Fig. 3b) in the Indian Ocean dropped heavy rains (up to 570 mm, or 258% of normal) over the east coast of Madagascar (French, 2002/03b). From June 21-30, unseasonably heavy showers (more than 1000% of normal) hit the coast of southern Mozambique; above-normal rains (more than 600% of normal) also fell in eastern Zimbabwe (French, 2002/03b).

III. October-December 2003

1. West and North Africa

Over the western Sudano-Sahelian region, rainy conditions (5-56 mm, 109-940 % normal) prevailed over western Mauritania, Senegal, and Gambia as late as the last ten days of October, a time of year that is normally dry (French, 2003/04a). Unusually heavy rains fell over desert areas of northern and western Mauritania, Western Sahara, western Algeria, and southern Morocco on 21-22

October. Flash floods resulted from rainfall (more than 50 mm on 21 October) over parts of the Morocco–Western Sahara–Algeria border area (FEWS NET, 2003f). A torrential storm dropped 100 mm rain in 12 hours on 19 November in the mountainous areas of Morocco, causing flash floods that killed 13 (DFO, 2003). On 12 December, the heaviest rains in 30 years, more than 60 mm, fell along the coast of Tunisia; causing valley flooding that killed seven people (DFO, 2003).

2. East Africa

Heavy rains caused rare flooding on 20-21 December in Kilimanjaro region of northern Tanzania, destroying 500 houses and displacing 2,000 people (DFO, 2003).

3. Congo Basin and Adjacent Regions

In the central DR Congo, severe thunderstorms struck the area around Bikoro, Equator Province (some 120 km from Mbandaka) on 9 October. A school was hit by lightning; 11 died and 73 were injured (ReliefWeb, 2003g). Heavy rains continued from late November through December over south-central Africa, from Gabon, Equatorial Guinea, and Angola in the west to the DR Congo and into Uganda in the east (FEWS NET, 2003g, 2003h).

4. Southern Africa

During mid-December, Tropical Cyclone Cela, which made landfall in northern Madagascar, brought heavy rains of up to 200-300 mm over west-central and northeastern Madagascar and northern Mozambique (FEWS NET, 2003h; French, 2003/04c).

SUMMARY AND CONCLUDING REMARKS

As described above, the climate of Africa in 2003 was exceptionally abnormal and eventful. During Northern Hemisphere summer, as record heat waves hit Europe, Africa experienced unusually heavy rains and floods in the west-central Sahara, across the Sudano-Sahelian region, and western Kenya. Simultaneously, drought conditions affected the Guinea Coast and southeastern Southern Africa, and severe cold waves hit southern South Africa (Fig. 3). Of these events, the two most remarkable events were the extreme northward penetration of the ITCZ into the Sahara that caused record summer rainfall over the western portion of the Sahara-Sahel and drought conditions over the Guinea Coast and record-breaking cold winter weather over southern South Africa in mid-August (Figs. 2, 3a, 4, 5). All these events suggest a temporally overall northward shift of the climate system across Europe-Africa. During Southern Hemisphere summer, heavy rains and floods that accompanied tropical cyclones and their remnants frequently affected Madagascar, parts of Mozambique, Zimbabwe, and Malawi (Figs. 3b, 6). Lowlands in the Lake Victoria Basin of

western Kenya repeatedly suffered from severe floods (Figs. 3a, 3b). In the seasonal floodplains of the Zambezi River and its tributaries, over-the-bank flooding set in earlier and ended later than in normal years. The flood victims throughout Africa in 2003, which are listed in the *Global Register of Major Flood Events 2003* (DFO, 2003), number in more than 550 died and more than 2.5 million displaced.

Many African countries are ill equipped to cope with flood hazards and therefore are highly susceptible to flood damage to croplands, settlements, roads, water supply systems and other infrastructures, and subsequent acute food shortages (Suda, 2000; IPCC, 2001b). To reduce Africa's vulnerability to climate hazards, particularly flood hazards, greater enhancement of both short- and long-term coping strategies, at all levels, including sub-regional, national, and local levels, is required. These enhancements include monitoring flood hazards, early warning systems, flood control infrastructures, and other disaster preparedness measures, in addition to existing drought preparedness and management systems. Enhancements should be extended to indirect effects of heavy rains and floods such as plagues of desert locusts (FAO, 2004) and outbreaks of water-borne ailments including malaria, rift valley fever, mumps, and eye infections.

Many of the climate anomalies and extreme events that occurred throughout Africa in 2003 may be manifestations of a regional response over Africa to anthropogenic global warming. In view of this, mechanisms and processes driving climate variations in current Africa must be explored in the context of global change. Special attention should be paid to coupled zonal and meridional atmospheric circulation variations and to the effects of sea surface temperature anomalies both in the Indian Ocean (*e.g.*, Shinoda & Kawamura, 1994; Saji *et al.*, 1999) and the Atlantic Ocean (*e.g.*, Vizy & Cook, 2001; Grannini *et al.*, 2003). Interannual and interdecadal variations in the appearance of anomalies and events also warrant careful inspection and analysis.

ACKNOWLEDGEMENT This study was financially supported in part by a Grant-in-Aid for Scientific Research (Project No. 13371013 headed by Dr. Kazuharu Mizuno, Kyoto University) from the Ministry of Education, Science, Sports, Culture and Technology of the Japanese Government. I thank Dr. Mizuno for providing me the opportunity to visit countries in Southern Africa in February 2002. That visit stimulated a study building a framework for Africa-wide comparative and synthetic studies of both recent and past climate/environmental changes. The present paper is a preliminary outcome of such studies. I also thank T. Ishida for drawing figures.

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