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Overview of the West African monsoon 2011

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Overview of the West African Monsoon 2011[1]

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The West African Monsoon (WAM) is characterized by summer rainfall and winter drought; most of the annual rainfall in western Africa comes between June and September. Unlike the Indian monsoon, the WAM is a very variable feature in terms of rainfall; throughout the twentieth century India never experienced more than two consecutive years of drought, whilst the Sahelian region has suffered from a long-lasting drought for the last twenty years.

Typically, the onset of the WAM coincides with the development of a cold tongue of water in the Gulf of Guinea in late June. As the sun moves polewards during the west African summer, the land warms faster than the ocean and the thermal contrast drives the surface pressure pattern of a Saharan 'heat low' and high pressure over the equatorial Atlantic ocean. This results in the seasonal migration of the Intertropical Convergence Zone (ITCZ) northwards, reaching west Africa around 22 June, before moving back to equatorial Africa by October. The dry, northeasterly trade winds crossing the African continent, known locally as the Harmattan (Figure 1), are pushed back by the northern shift in the ITCZ and low-level moist southerly monsoon winds are diverted inland for the summer, bringing the life-giving rain with them. The role of the Sahara heat low is particularly important as its centre reinforces the ITCZ depression, hence increasing the surface pressure gradient. In the lower troposphere, the cyclonic circulation associated with the heat low tends to result in an increase in both the southwesterly monsoon flow along its eastern flank and the northeasterly Harmattan flow along its western flank (Parker *et al*., 2005b). An animation of the evolution of the African monsoon can be found following this link: www.cpc.ncep.noaa.gov/products/Global_Monsoons/African_Monsoons/African_Monsoons.shtml

[1]This article is based on a presentation to the RMetS's National Meeting on 'Understanding the weather of 2011' on 4 February 2012.

Background to the 2011 monsoon season

Many crops in the region are grown close to their limits of thermal tolerance with little irrigation in place. The consequent vulnerability of crops to natural variability in the climate jeopardizes food security – particularly during times of political upheaval. In 2011, the political situation was particularly volatile. Political and social unrest, especially resulting from the 'Arab Spring' and most pronounced in Libya, Egypt and Côte d'Ivoire, therefore had a serious and protracted economic and humanitarian impact with huge displacements of people and pressures on food availability and prices. As of 30 March, for example, nearly 400 000 people had fled Libya to neighbouring Egypt and Tunisia, and thousands of Nigerians living in Libya had returned home. The protracted violence in Côte d'Ivoire had similarly displaced over one million people internally, and over 120 000 fled to neighbouring Liberia. There were reports of fuel shortages in Abidjan due to the embargo and conflict. As Liberia is strategically important for the food economies of several Sahelian countries, such as Mauritania, Mali, Burkina Faso and Niger, the weeks before the onset of the 2011 WAM saw sharply-rising prices for key staples compared to the 2010 levels. Social unrest was also reported in Mauritania and Senegal with protests and riots in Aioun (Mauritania) at the beginning of March arising from the high price of bread (WFP, 2011). So communities throughout sub-Saharan Africa were already living 'on the edge' before the arrival of the monsoon, and were clearly going to be highly vulnerable to even small changes in rainfall patterns.

Forecasts for the season

Given this background, reliable seasonal forecasts were essential for the JAS rainfall, the growing period for most crops in sub-Saharan Africa. These forecasts were prepared in May and June for the Sahel and other climatologically-defined regions in north Africa, using dynamical model forecasts, which have been shown to do at least as well as combined statistical and dynamical forecasts.

Long range forecasts such as these often yield conflicting information. This was the case in 2011, especially given the weak sea-surface temperature (SST) signals in April since SST anomalies are the basis of predictability for rainfall in the region. In the tropical north Atlantic and eastern tropical south Atlantic, the forecasts were for a return to normal SSTs following a period of warmer

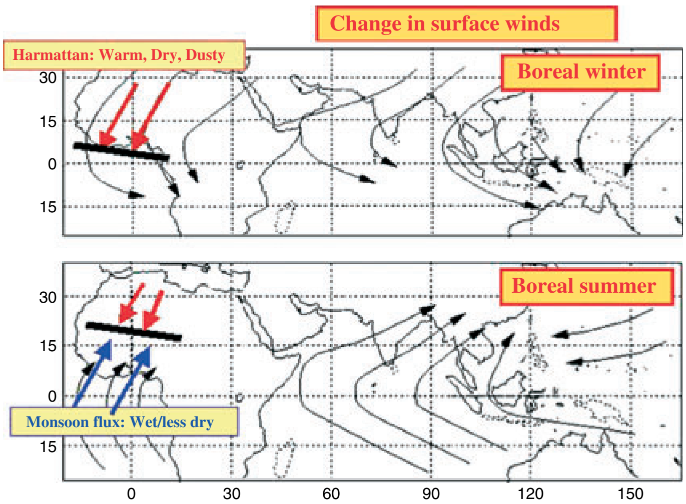

Figure 1. Schematic representation of the West African Monsoon. (Courtesy of AMMA International.)

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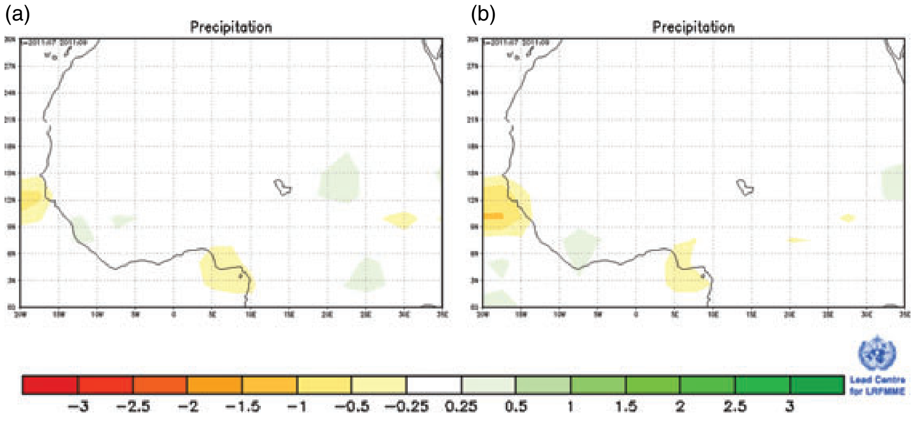

Figure 2. Forecast for July-August-September 2011 rainfall based on ensemble means from (a) 12 system multi-model forecast, (b) 7 coupled systems. (Source: WMO.)

waters from April to June; south of the equator, in the Gulf of Guinea, SSTs were now below average. Such a pattern of SST anomalies usually leads to drier-than-average weather near the Guinea coast and above-average rainfall further north. In the Pacific, the cold phase of ENSO (La Niña), which had been observed since August 2010, weakened between March and May 2011; a near-neutral ENSO was not likely to be influential during the WAM rainy season. In the Indian Ocean, close to normal SSTs were expected to persist from July to September.

Forecast from WMO Global Producing Centres (GPC)

The weak SST signal meant that there was little overall signal from most of the 12 GPC models (at least in terms of the ensemble mean), though there was some weak indication for dry conditions in the extreme west and the eastern Guinea coast (Figure 2). In terms of probabilities, the Met Office dynamical forecast model, GloSea4, had a dry signal (relative to the 1996–2009 climatology) for much of the region. The ECMWF model indicated below-normal rainfall along the Guinea coast and had a weak signal for wet conditions in parts of the Sahel (Figure 3(a)). When this was combined with the Meteo-France ensemble (to make EUROSIP, Figure 3(b)), the dry signal along the Guinea coast weakened, though it was still present, and the wet signal in the Sahel also weakened but was still present in the far east, whilst there was also a weak dry signal for the far west. Using a methodology to 'correct' for systematic pattern-errors in the models, an experimental multi-model

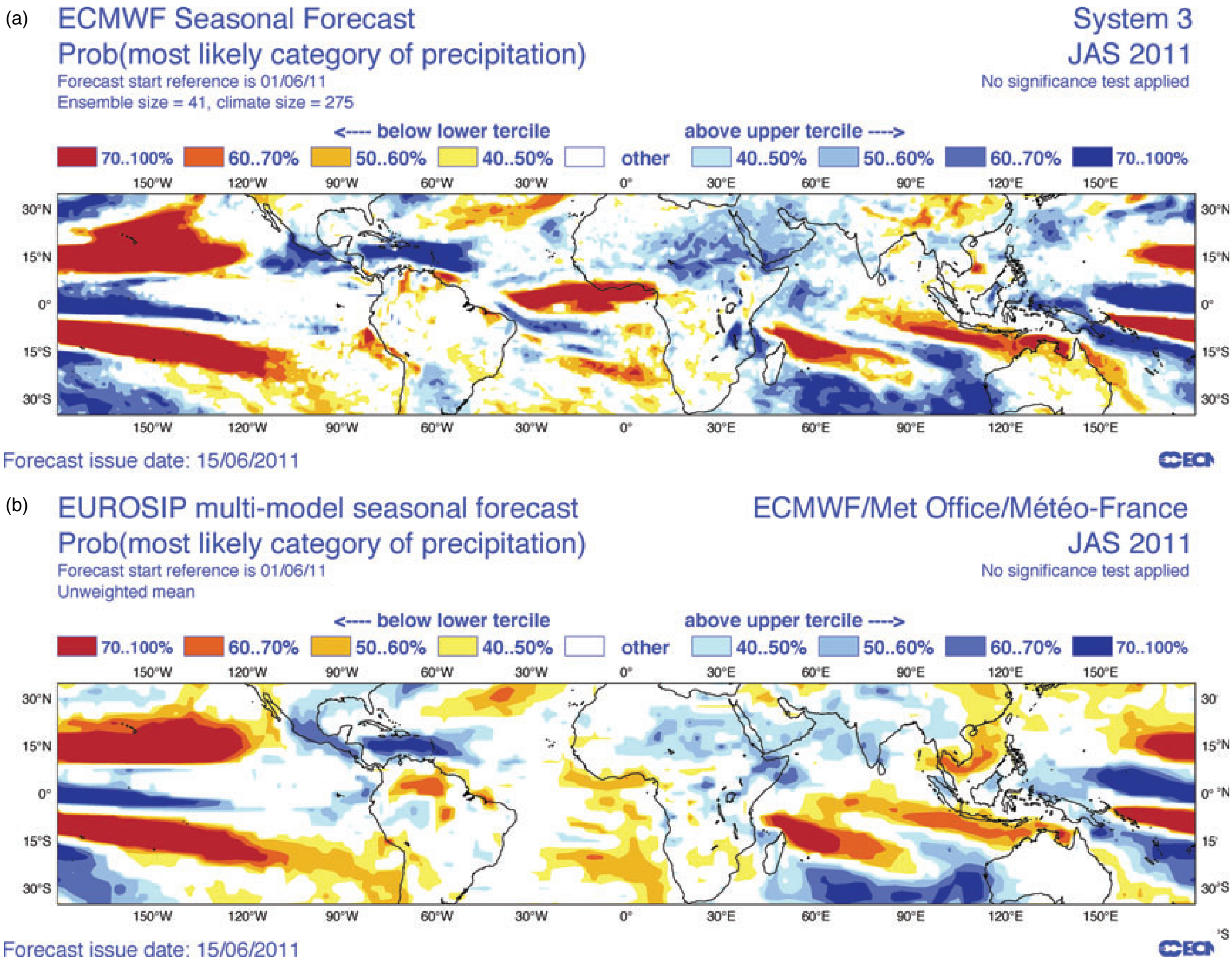

Figure 3. Forecast for July-August-September (JAS) 2011 rainfall for Africa. (a) from ECMWF and (b) combined ECMWF/Met Office/Meteo-France (EUROSIP), showing the probability of exceeding median rainfall. Yellow to red indicates a forecast of below-normal rainfall, greens and blues above-normal rainfall. (Source: ECMWF.)

product suggested dry conditions in the northwest, with above-average rainfall more likely in the southeast.

PRESAO consensus forecast

In early June, the overall PRESAO (regional) consensus forecast was generated and distributed by the African Centre for Meteorological Applications for Development (ACMAD). This included statistical forecasts from the member countries and is shown as forecast probabilities in Figure 4. It indicated average rainfall over most of the region, though a dry signal for the Guinea coast was the second most-likely occurrence, reflecting at least the Met Office and EUROSIP model forecasts. Over the Sahel, the wet category was the second most likely over a wide area.

Consensus forecasts have limited applicability for African national weather centres; forecast probabilities for the average category are systematically too high and information relevant to farmers, such as the timing and distribution of rainfall amounts through the season, is not included in them. Most national weather centres will use these forecasts only as either a placebo or a warning to their end-user communities.

The 2011 monsoon onset and evolution

Expectation was for the onset around 20 June. In fact, there was an early onset of the rains in central Sahel in May, a delayed onset in west Africa and then a rapid recovery in August. As already described, the development of the Atlantic equatorial cold tongue in the Gulf of Guinea plays a significant role on the timing of the onset. Although in 2011 there was a distinguishable cold tongue, the minima was only around 23°C (Figure 5(b)); this was similar to the 2006 WAM (Janicot *et al*., 2008) which also developed later and is in contrast to the 2005 WAM early-onset which featured a strong Atlantic dipole with a cold tongue minima of around 20°C, a pattern favouring a more northward location of the ITCZ (e.g. Fontaine and Janicot, 1996). The delay involves complex ocean-atmosphere interactions (Brandt *et al.,* 2011) but, fundamentally, an increased meridional SST gradient would accelerate the monsoon onset with the associated stronger monsoon winds contributing to accelerate the cooling in the Gulf.

The rainfall across the region mostly results from the northward movement of the low-level monsoon flux from March to August and the southward retreat from September to November. At their northernmost reach, the humid air masses meet drier and warmer air to form the Inter Tropical Front (ITF) (Figure 6). Since the rains appear to the south of the ITF, tracking this through the season enables a quick evaluation of the progress and quality of the rainy season. In the west (Figure 6(a)), the ITF was generally south of its mean position from mid-June to early August, and the dry conditions delayed the start of the crop-growing season. It was a similar story in the east (Figure 6(b)), apart from the brief early onset in the central Sahel when some northward progress of the rainfall facilitated improved planting conditions, particularly in parts of southern Sudan, south Kordufan and south Darfur.

During mid-August, the ITF advanced rapidly across its central portion and tracked ahead of the climatological mean position; its western portion was around 20°N, 0.8° ahead of the mean, whilst its eastern portion neared 17.5°N, just 0.1° ahead of the mean. This movement was linked to anomalous westerlies from the Atlantic Ocean, which enhanced moisture influx, and there was also an increase in the number of coherent African Easterly waves, key synoptic features of the WAM and important for distributing rainfall geographically and temporally through it (Cornforth *et al*., 2009).

Rainfall patterns and atmospheric circulation

Coastal west Africa, Mauritania, many parts of Nigeria, local areas of Cameroon, eastern Sudan and portions of Ethiopia, in particular, received below-average rainfall (Figure 7) with anomalous lower tropospheric diver-

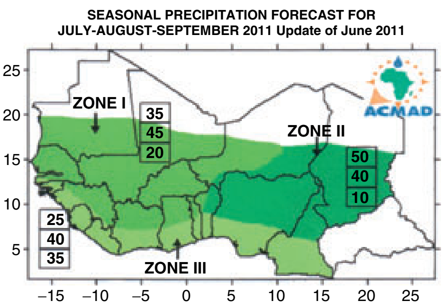

Figure 4. Consensus forecast for July-August-September rainfall in 2011. Boxes indicate likelihood of above-normal (top), normal (middle) and below-normal (bottom) rainfall. Zones represent homogeneous climatic rainfall.

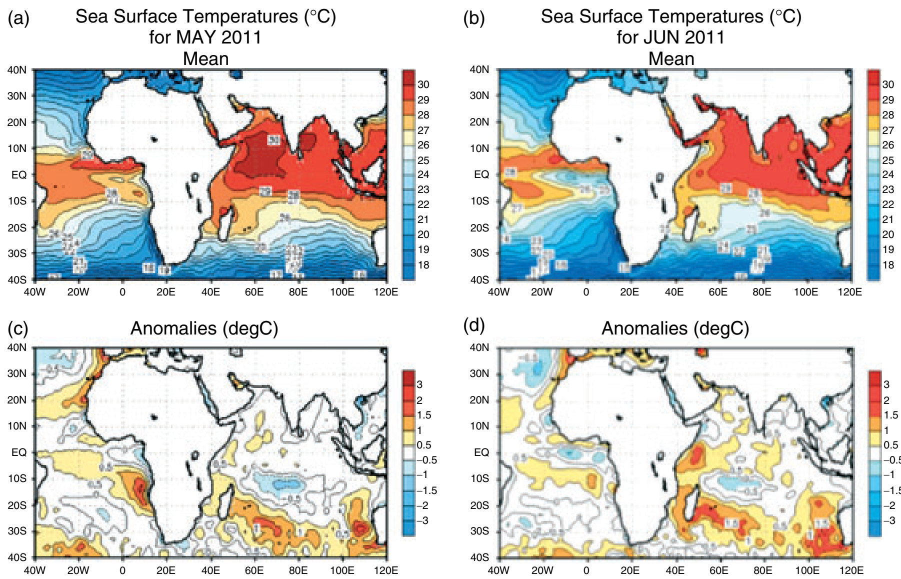

Figure 5. Monthly mean ((a), (b)) SSTs (source: NOAA) and anomalies ((c), (d)) for May and June 2011.

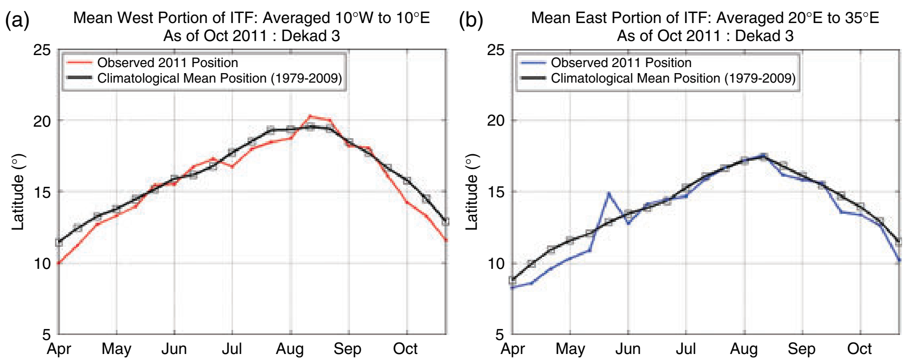

Figure 6. Time series of the evolution of the latitudinal means of the western (a) and eastern (b) portions of the Inter Tropical Front (ITF). (Source: NOAA.)

gence tending to suppress rainfall to the east, whilst strong Harmattan winds in the central and West Sahel raised temperatures in, for example, Mauritania. The late arrival of the rain did not bode well for the total rainy season quality in the important agricultural regions and especially for food production, since the persistence of generally dry conditions during June, early and mid July had led to significant delays in early- and re-planting processes. Coupled with the ongoing political instability in the region, adaptive and mitigating actions were needed in many areas. Fortunately, Rainwatch, a monitoring tool based at ACMAD for Niger (developed by Aondover Tarhule and Peter Lamb, CIMSS, University of Oklahoma) provided the ongoing feedback to the Niger government necessary for the seasonal climate management. Rainwatch continued to report very low totals throughout the season despite some improvement in the rainfall received in mid-August in the extreme south and east of Niger as discussed above (Figure 8: compare with Figure 6). During August the drought was exacerbated across Niger and was especially severe around the capital, Niamey, where the accumulated seasonal total by September was below the 10th percentile. At the beginning of September, the government went into early warning mode and the Prime Minister and his Minister of Agriculture briefed the diplomatic corps and international organization representatives accredited to Niger on the evolution of the 2011 agricultural season. They indicated that (a) the 2011 crop season was already jeopardized, (b) there would be an inevitable deficit in crop and pastoral production and (c) Niger would need help to deal with the situation. The announcement meant the government was able to provide early notification of its need to its partners. The usefulness of such tools as Rainwatch is that they can contribute in timely fashion to the basis for subsequent national and regional adaptation and mitigation.

Rainfall was above average across the Senegal-Mali-Guinea border, southwestern and central Mali, eastern Burkina Faso, eastern Ghana, parts of Chad and CAR, northern Congo Brazzaville, Uganda and western Kenya, arising from strong westerly wind anomalies across the Gulf of Guinea and the adjoining areas of the Atlantic Ocean (Figure 9). Anomalous wind convergence between these westerlies and easterlies from the Congo Air Boundary area may have contributed to some of the heavy rainfall events, such as those over southwestern Cameroon. The 200mbar wind anomaly (not shown) featured anomalous easterlies across northern Africa and anticyclonic anomalies over the southern Atlantic Ocean and southwest Indian Ocean.

Verification

Given the spatial and temporal variability of the 2011 WAM, it is not surprising that the JAS seasonal rainfall forecasts have not verified very well (Figure 7). The anomalies were patchy and there are some areas of disagreement between the two datasets, not least in the climatological base period used. There seems to be little in the way of coherent large-scale anomalies, though the forecast perhaps would have benefited by following EUROSIP and the calibrated multi-model and raising the risk of dry conditions, particularly in the west; the consensus over northern Nigeria and Cameroon and southern Chad was quite strong for this to be over 50%. There were some above-normal totals observed here (see for example, the above normal tercile in the CPC-FEWS observations,

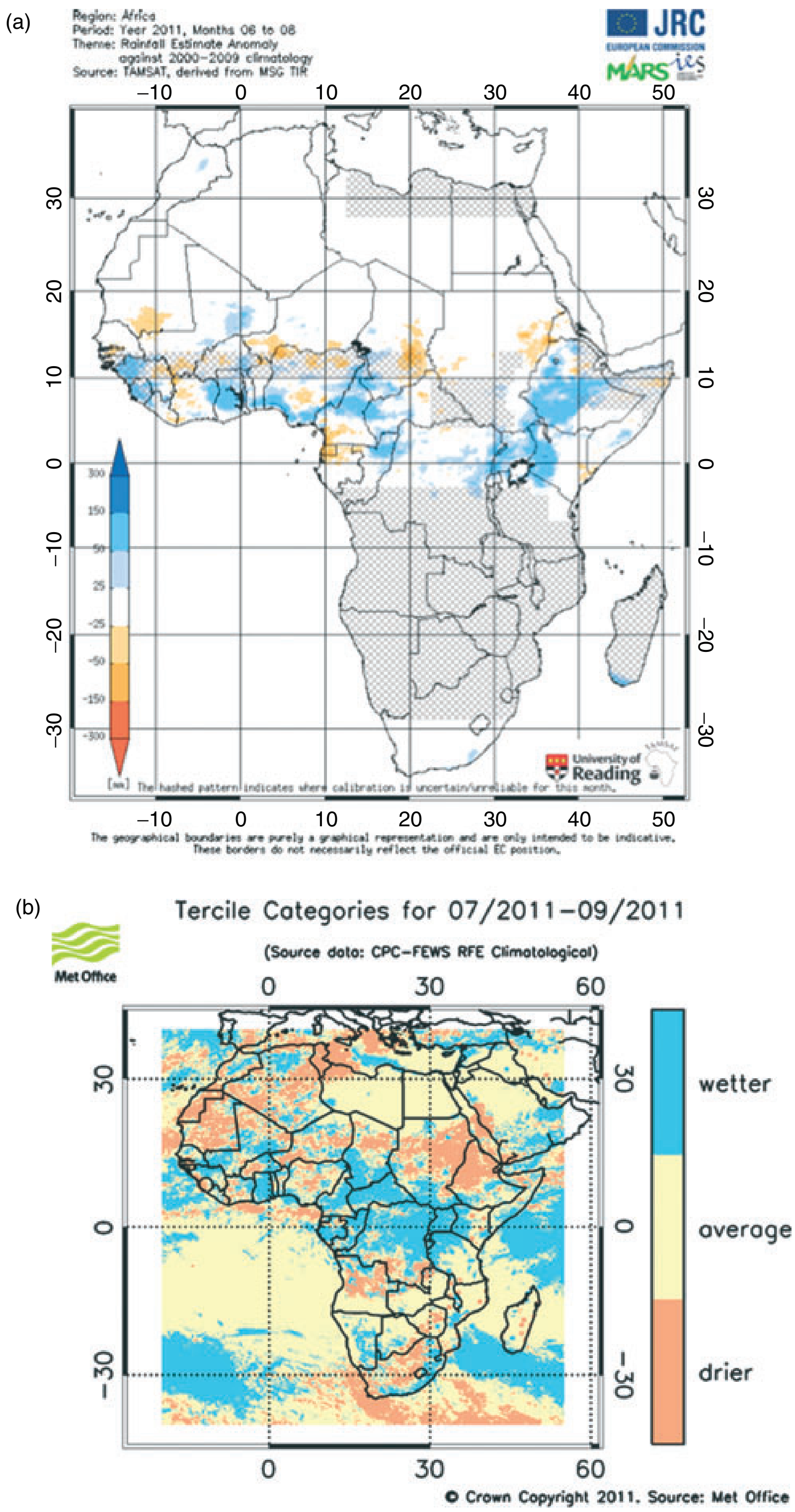

Figure 7. Verification of forecasts (a) Observed JAS anomalies relative to 1971–2000. (Source: TAMSAT.) (b) Observed tercile category (relative to 1995–2010) from CAMS_OPI (Climate Anomaly Monitoring System and OLR Precipitation Index). (Source: Met Office.)

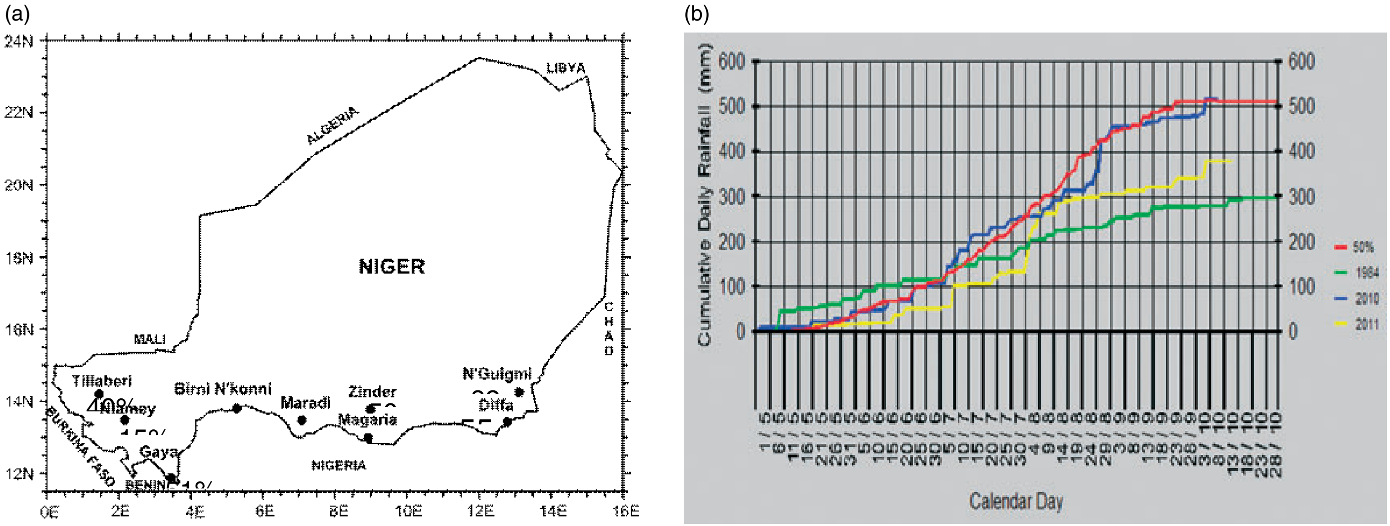

Figure 8. 1 May to 15 October 2011 monsoon rainfall evolution over selected stations in Niger as shown by Rainwatch. (a) Percentages for each station give the approximate cumulative percentile through October 2011; (b) Cumulative daily rainfall and percentiles for Niamey Airport station 13.483°N, 2.167°E. (Source: Peter Lamb, Rainwatch.)

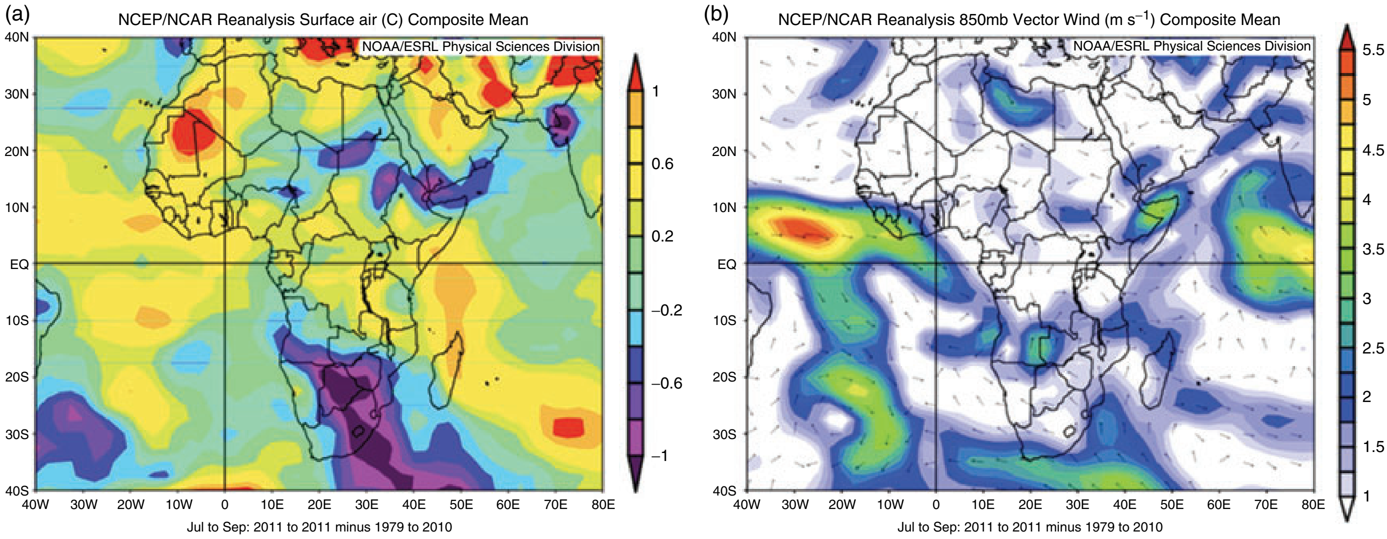

Figure 9. July to September 2011 seasonal anomalies from the NCEP Reanalysis for (a) surface air temperature; (b) 850mbar wind anomalies derived from the reference period 1979–2010. (Source: NOAA.)

Figure 7(b)), though not over northern Nigeria as predicted. Consistent with the forecast, TAMSAT observations (Figure 7(a)) and CPC-FEWS show some hint of a dry band through the Sahel and over Mauritania, as suggested in the multi-model forecast). There are also some strong dry anomalies centred over Sierra Leone in the TAMSAT though this is not matched by a widespread below tercile value in the CPC-FEWS dataset.

Table 1 compares forecasts from the Met Office with outcomes over recent years. Overall, the correlations between the predicted and observed categories are 0.21 for the Sahel, 0.20 for the Sudan and 0.25 for the Guinea Coast. These do not represent a statistically significant level of skill but there is hope that the new dynamically-only based forecast (GloSea4) will offer some improvement. The years marked in bold performed particularly poorly. We know, though, that prediction of the rainfall for the WAM was a challenge, based on the April initial conditions and the weak SST signals, and this was reflected in the mixed performance of the forecasts, depending on the region you focus on, and the degree of uncertainty in verification according to reference periods selected. Underlying the skill remains our considerable uncertainty of, and continuing struggle to understand, the fundamental processes governing the WAM dynamics and its variability, and the uncertainty in the initial conditions linked to the lack of observations in this region of the world.

Concluding remarks

Although the 2011 West African monsoon season was, overall, near normal, rainfall was patchy. The irregularity of the rainfall during the crucial July–August–September season proved difficult to predict, highlighting the significant challenges we continue to face for this region. This high spatio-temporal variability of the rainfall in 2011 accentuated the contrast between the Sahel and the Gulf of Guinea region, particularly in August. The dipole pattern we observed may well be part of a decadal variability signal; Figure 10(a) shows that the 2011 JAS rainfall anomaly pattern compared with the base period 1979–2010 shows a marked decrease in the Sahel and increase along the Guinea Coast. There is also a decrease over the Horn of Africa, reflecting the failure of the long rains again this year for that region. This is a reversal of the rainfall anomaly pattern of the last ten years (Figure 10(b)) compared with the same base period. This may be a consequence of the above normal SSTs in the west Pacific and the Indian Ocean, which are likely to impact on the Walker Circulation,

Table 1

A comparison of Met Office forecasts and outcomes, 1992–2011.

	Sahel		*Sudan*		*Guinea Coast*	
Year	*Predicted*	*Observed*	*Predicted*	*Observed*	*Predicted*	*Observed*
1992	Dry	**Dry**	Very dry	**Average**	Very dry	**Dry**
1993	Very dry or dry	Dry	Very dry	Very dry	Dry or average	Average
1994	Very dry or dry	**Wet**	Dry or very dry	**Average**	Dry or average	**Average**
1995	Average	Average	Dry	Dry	Very wet	Wet
1996	Dry or average	**Very dry**	Average	**Very dry**	Very wet	**Average**
1997	Dry or average	Very dry	Dry or average	Very dry	Dry	Very dry
1998	Very dry	Average	Very dry	Average	Wet or very wet	Dry
1999	Wet	Very wet	Wet	Wet	Very wet	Wet
2000	Wet	**Dry**	Wet	**Dry**	Wet	**Dry**
2001	Wet	**Dry**	Wet	**Dry**	Average	**Average**
2002	Average	Average	Average	Dry	Average	Dry
2003	Very wet	**Wet**	Wet	**Wet**	Very dry	**Average**
2004	Very wet	**Average**	Average	**Dry**	Very dry	**Dry**
2005	Very wet	**Average**	Average	**Dry**	Very dry	**Dry**
2006	Average or wet	Average	Dry or average	Average	Dry or average	Dry
2007	Dry or average	**Wet**	Dry or average	**Average**	Dry or average	**Wet**
2008	Wet	Wet	Wet	Wet	Wet	Wet
2009	Dry or average	**Wet**	Dry or average	**Average**	Average or wet	**Dry**
2010	Average	**Wet**	Dry	**Wet**	Dry or very dry	**Wet**
2011	Wet	Average	Dry	Average	Dry or very dry	Dry

suppressing rainfall in east Africa and enhancing the zonal pressure gradient. There were certainly significant low-level westerly wind anomalies that brought surplus moisture to areas of the Guinea Coast and Cameroon; further in-depth analysis is required.

As the WAM 2011 rainy season drew to its close, the humanitarian impact continued to be significant as the delayed onset and relatively quick retreat left many areas with water and food shortages. In 2011, droughts also occurred in the Horn of Africa, parts of China and the United States of America and other parts of the world, and in November 2011 the IPCC indicated that there is growing evidence that the frequency and extent of drought has increased as a result of human induced climate change (http://www.ipcc.ch/news_and_events/docs/srex/SREX_press_release.pdf). WMO Secretary-General, Michel Jarraud, has said: *Despite the repeated occurrences of droughts throughout human history and the large impacts on different socio-economic sectors, no concerted efforts have ever been made to initiate a dialogue on the formulation and adoption of national drought policies. The time is ripe for nations to move forward with the development of a pro-active, risk-based national drought policy,* whilst Luc Gnacadja, Executive Secretary of the UN Convention to Combat Desertification has remarked that *Drought is predictable and does not happen overnight. Therefore, it should not claim lives nor lead to famine,*

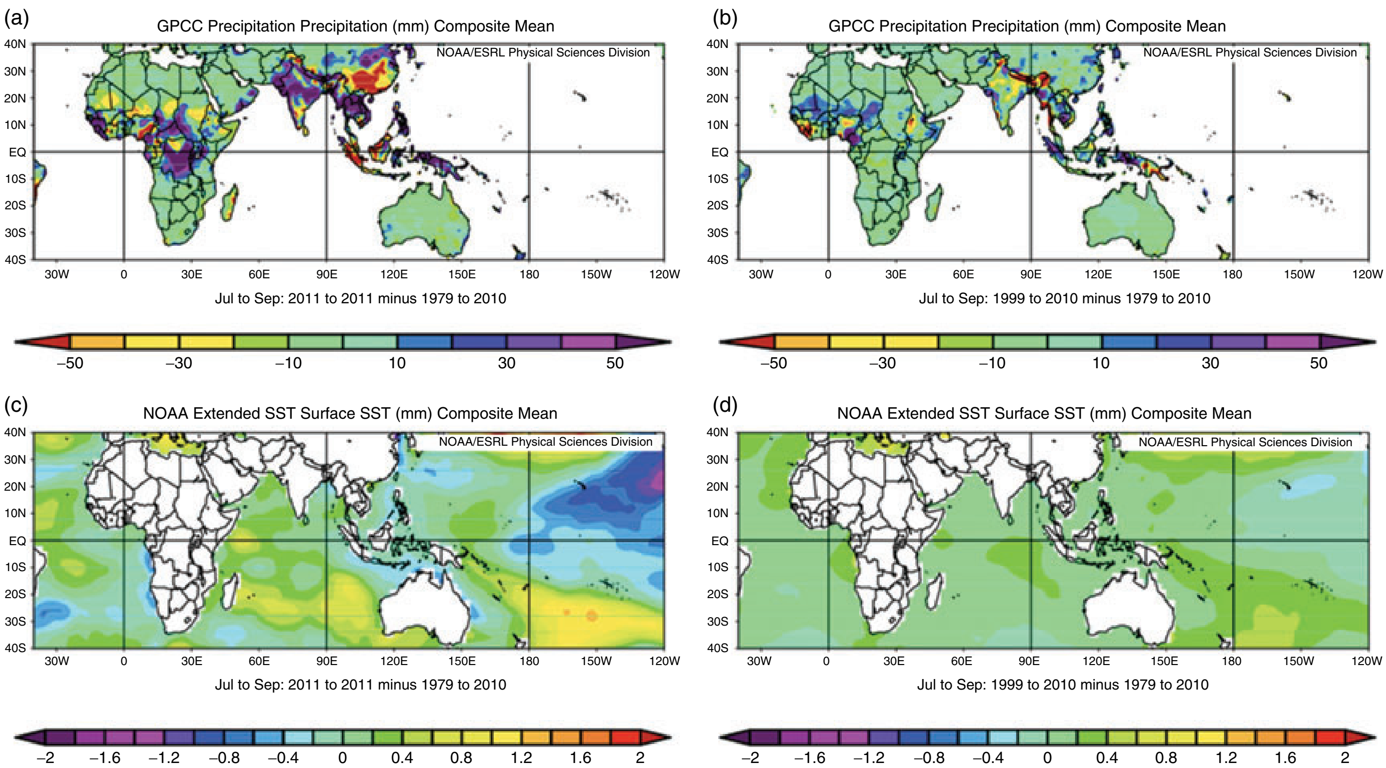

Figure 10. (a) Seasonal precipitation anomalies (mm) for July to September 2011 GPCC dataset derived from the reference period 1979–2010. (b) As in (a) but for anomalies averaged over 1999–2010. (c) and (d) As in (a) and (b) respectively but for SST.

which results when drought couples with policy failure or governance breakdown or both. However, as with desertification, drought is a silent and slow killer, and both have a way of creeping up on us, fooling us into underestimating their urgency (http://www.wmo.int/pages/mediacentre/news/nationaldroughtpolicies.html). National governments need help to increase their capacity to cope with extended periods of water shortages by adopting relevant climate-related policies. As climate scientists, we need to work together with the humanitarian sector and African policy-makers to share knowledge and help build resilience and in-country capacity for climate compatible development. This is particularly important for sub-Saharan Africa where the smallest vagaries of the monsoon can have dire impacts on the already vulnerable people. Sharing relevant weather and climate information effectively, the uncertainty in our science and a determination to drive our research questions by user need are fundamental in this communication process.

To improve the societal use of our science knowledge, the Africa Climate Exchange (Afclix) has recently been launched, funded through a NERC Knowledge Exchange Fellowship, the National Center for Atmospheric Science (NCAS-Climate), the Grantham Institute for Climate Change, the Walker Institute for Climate System Research and the University of Reading. Afclix will help to ensure that all climate-related policy decisions in sub-Saharan Africa relating to food security can be made with access to the best-available scientific information. With its emphasis on 'feet on the (African) ground' mechanisms of knowledge-sharing activities at the science-policy interface in Africa, Afclix will seek to channel the latest climate science into policy, initially for the identified strategic regions of Sudan and Senegal. The activities are underpinned by the Afclix interactive web portal (www.afclix.org) to ensure learning is shared effectively and different areas of expertise can continue to connect to form collaborative, cross-disciplinary research and teaching partnerships. The first exchange forum will take place in Khartoum in March 2012 together with the Sudan Meteorological Authority, government ministers and key NGOs. This follows on the heels of the successful Sudan Symposium held in December 2011 by the University of Reading and its five Sudanese partner higher education institutes, with considerable support from the UN Development Programme. The multidisciplinary collaborations fostered by Afclix are essential to enable Africa to help itself (Tarhule and Lamb, 2003).

Acknowledgements

My grateful thanks to Richard Graham and Andrew Coleman at the Met Office for providing the different forecasts, useful comment, and partial verification ahead of time. I would also like to thank Peter Lamb and Aondover Tarhule for their regular Rainwatch updates through this season and their agreement for the figures to be used in this article. My thanks also to Emily Black for reviewing the manuscript and to the Editor of *Weather* for his help in preparing the article. Data was provided by the ECMWF, NOAA/NCEP and the Met Office.

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Forecasting the wind at sunset

Alan Lapworth

Sharnbrook, Beds

In a previous article a forecasting rule was given for determining the wind strength during the evening when the main changes are due to diurnal variation. Recent studies have shown that the rule is site dependent so that some modification is necessary to ensure the rule is valid in all cases. In addition the original rule was unnecessarily complex and a simplified version which incorporates the dependence on location is described below.

Wind variation in the evening

During the evening, in the absence of major synoptic features, the daytime wind is usually found to decrease and on clear nights the wind will often almost completely die away. This decrease is well known but very few attempts have been made to quantify it. In a previous article in this magazine (Lapworth, 2008) a description was given of how observations made at the instrumented Met Office site at Cardington were used to enable a prediction of the evening wind changes to be made. A brief summary of this result follows.

The measurements at this site showed that the evening wind speed is strongly correlated with both the screen temperature and the upper (geostrophic) wind. A plot of 10m wind speed versus screen temperature on a typical night shows a fairly linear decrease in wind with falling temperature. However different nights with similar geostrophic wind speeds give different plots unless the temperature readings are first subtracted from the screen temperature at the time of evening transition – that is, the temperature when the vertical temperature flux changes from positive (i.e. convective) to negative. As tethered balloon profiles show that the vertical potential temperature profile in the boundary layer is constant (i.e. neutral) at transition, this shows that the critical parameter is the difference between the screen temperature and the temperature at the top of the boundary layer. If observations from a large number of nights with similar upper wind are plotted in this way, the data points are clustered around a well-defined line with a standard deviation of around 1ms^{-1}. However if plots are made from nights with a stronger geostrophic wind the data points lie on a different line, with an increased

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