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Research Articles

Climate indices, rainfall onset and retreat, and malaria in Nigeria

A.J. Thomson

Adaptive Knowledge Management, Victoria, BC, Canada

Abstract

Background & objectives: Rainfall in western sub-Saharan Africa is related to seasonal shifts of the Inter-tropical Convergence Zone, which moves northward early in the year, retreating in the second half of the year. The objective of the present study was to determine significant relationships between onset and retreat timing and climate indices. The relationship between timing and malaria case reporting was then evaluated.

Methods: Relationships between published rainfall onset and retreat dates for Nigeria from 1971–2000 were evaluated in relation to pairs of climate indices using response surface analysis. Graphical representation of the response surface in relation to the underlying data was used to identify instances of overfitting. Association of onset and retreat timing with published case reporting records was evaluated using graphical and correlation analysis.

Results: Onset timing and rate of advance were related to ENSO (El Niño-Southern Oscillation), in combination with the Northern Annular Mode (NAM), while retreat timing was related to NAO (North Atlantic Oscillation), in combination with the East Pacific (EP) or West Pacific (WP) index, depending on location. Later onset was associated with faster northward progression of onset. Retreat date at Kano, the most northerly of the study locations, increased over the period 1990–2000, with higher case reporting for Nigeria as a whole being associated with the last three years of that period.

Interpretation & conclusion: Rainfall retreat occurs much faster than onset, with onset and retreat timing and rate of onset advance being related to combinations of climate indices rather than to a single index. Threshold for determining a "rainy" day would influence results. The increase in national case reporting with delayed retreat at Kano may be related to the extension of the short transmission period in the north.

Key words El Niño-Southern Oscillation; mosquito; North Atlantic Oscillation; *Plasmodium falciparum*; response surface analysis

Introduction

Malaria transmission dynamics encompasses a very broad spectrum of biotic and abiotic factors with the climate factor including four major components, namely temperature, rainfall, relative humidity and wind. Rainfall itself has several sub-components, namely onset and retreat timing, total precipitation, number of rainy days and related floods and drought. Effects of temperature and precipitation variations on insects affecting human health and agriculture have long been a focus of research, and recent studies have addressed the manner in which patterns are shifting under the influence of climate change. However, in east Africa, the role of climate variability in driving changes in malaria patterns, reflecting changes in mosquito vector dynamics, remains controversial[1,2].

The El Niño-Southern Oscillation (ENSO) cycle is a key factor affecting the emergence and prevalence of vector-borne infections[3]. Rainfall in particular is important, not only through its quantity and timing, but also through its effects on relative humidity[4] and on human activity patterns, as well as its relevance to control activities. For example, the rainy season is the period of active farming in most rural communities of Nigeria[5], while mosquito net use compliance is usually much lower during the dry season than the rainy season in Burkino Faso[6]. Larviciding of breeding sites a month before onset of rainfall is recommended for vector control in Nigeria[7].

While El Niño events have been suggested as a potential predictor for malaria epidemics in Sri Lanka, over the long-term association breaks down[8]. ENSO is one of the numbers of climate indices, each reflecting temperature or pressure changes at different locations on the earth's surface, and it has been demonstrated[9] that for the continental United States, seasonal (3-month) temperature and precipitation anomalies are related to climate index combinations, ENSO and Arctic Oscillation (AO), part of the larger Northern Annular Mode (NAM), rather than to a single index. These combinations reflect interaction of conditions at different locations.

Combinations of climate indices at a monthly scale are associated with weather events of significance to outbreak and collapse of insect populations. Lethal winter temperatures for mountain pine beetle (*Dendroctonus ponderosae* Hopkins) across western Canada are related to the combination of the NAM with the Pacific/North American Pattern (PNA)[10]. In eastern Canada, the timing of spruce budworm (*Choristoneura fumiferana* (Clemens)) emergence and the bud burst of its principal host, balsam fir (*Abies balsamea* (L.) Mill.) are also related to combinations of climate indices[11], including the East Pacific (EP) index which is associated with changes in the jet stream pattern.

In western sub-Saharan Africa, rainfall is related to seasonal shifts of the Inter-tropical Convergence Zone (ITCZ), which moves northward early in the year, retreating in the second half of the year. Onset and retreat dates for four locations in Nigeria—Ibadan, Ilorin, Kaduna and Kano have been reported in the literature[12]. The present study explores the relationship of onset and retreat dates at these locations to climate index interactions using response surface analysis, and the relationship of the dates to malaria case reporting.

Methods

Study area: Nigeria's climate is more varied than that of any other country in West Africa due to the large distance from the south to the north of the country, covering virtually all of the climatic belts of West Africa[12]. The four cities on which the study is based form a transect from Ibadan in the south (lat 7.4°N, long 3.9°E) to Kano in the north (lat 12.0°N, long 8.5°E). Ilorin (lat 8.5°N, long 4.5°E) is closer to Ibadan than to Kaduna (lat 10.5°N, long 7.4°E), and Kaduna is closer to Kano than to Ilorin.

Precipitation data: Rainfall frequency-based onset and retreat dates for the years 1971–2000 are from Odekunle's study Tables 7 and 8 respectively[12]. Dates were given in days of the year, and were converted to month to facilitate choice of climate index data (Fig. 1). Fundamental to this approach is the amount of precipitation required for a day to be considered "rainy": a threshold value of 0.85 mm was employed in Odekunle's study, having been found appropriate for agricultural purposes in West Africa[13]. Rates of advance of onset (*i.e*. difference in date of onset) from Ibadan to Ilorin, Ilorin to Kaduna, and Kaduna to Kano were calculated by subtraction. Similarly, retreat rates from Kano to Kaduna, Kaduna to Ilorin, and from Ilorin to Ibadan were calculated.

Climate indices: Climate index data were down-

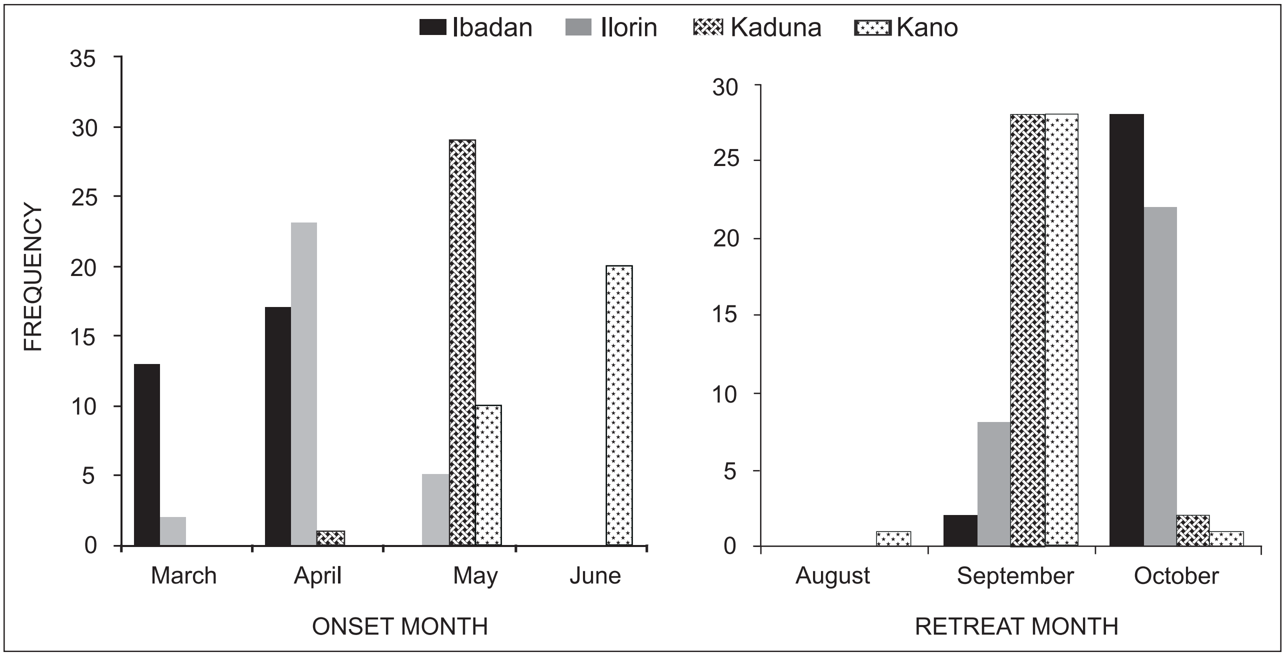

Fig. 1: Frequency of occurrence of rainfall onset and retreat months at Ibadan, Ilorin, Kaduna and Kano for the years 1971–2000.

loaded from Internet sites (Table 1). Some indices, such as ENSO, are based on sea surface temperatures, while others such as PNA are based on atmospheric pressure[14,15].

Malaria data: As indicated above, onset and retreat data were available for the years 1971–2000. Of these years, malaria case reporting data for Nigeria were available for 1990–2000[16], being 11,16,992; 9,09,656; 12,19,348; 9,81,943; 11,75,004; 11,33,926; 11,49,435; 11,48,542; 21,22,663; 19,65,486; and 24,76,608 cases respectively.

Statistical analyses: Response surface analysis of the data was performed using Minitab® Release 15 (Minitab Inc.). Onset and retreat dates were analyzed for each of the four locations using all 45 pair-wise combinations of the indices in Table 1. The analysis

Table 1. Sources of climate index data used in analyses

Index	Source
ENSO	http://www.iphc.washington.edu/staff/hare/html/decadal/post1977/nino34.txt
EP	ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh
NAM	http://159.226.113.17/staff/ljp/data-NAM-SAM-NAO/NAM-AO.htm
NAO	http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html
NOI	http://www.cdc.noaa.gov/Correlation/noi.data
PDO	ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest
PNA	ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh
TNA	http://www.cdc.noaa.gov/correlation/tna.data
TSA	http://www.cdc.noaa.gov/correlation/tsa.data
WP	http://www.cdc.noaa.gov/correlation/wp.data

ENSO: El Niño-Southern Oscillation; EP: East Pacific; NAM: Northern Annular Mode; NAO: North Atlantic Oscillation; NOI: Northern Oscillation Index; TNA: Tropical Northern Atlantic Index; TSA: Tropical Southern Atlantic Index; PDO: Pacific Decadal Oscillation; PNA: Pacific/North American Pattern; and WP: West Pacific.

was repeated for each location using the indices for each month of onset, based on Fig. 1, and separately using indices for the preceding month. Thus, for example, both Ibadan and Ilorin onsets, which began in March, were evaluated in relation to February and March indices, while Kano with the earliest onset in May, was evaluated in relation to indices from April and May. In each case, the response surface was based on a linear function of each index and including an interaction term. While previous studies[17] included measures from multiple months within a single equation in the step-wise regression approach, in the present study, only single month-specific index values were included in any model.

With only 30 yr of onset and retreat data, but with the incorporation of 45 pairs of indices, multiple months of index data and four locations, as well as the utilization of two linear terms and an interaction term in the response surface, there is considerable opportunity for overfitting, resulting in spurious relationships. Graphical representation of the response surface in relation to the underlying data facilitated determination of such cases, which can exhibit anomalous patterns such as a saddle point in the response compared with the regularly-changing patterns of Figs. 2 and 3. Figures 2 and 3 are similar in regularity to those illustrated in other index interaction studies. Saddle points can also result from the presence of outliers, identified by the statistical programme as having high leverage (Fig. 4a), and the analyses can be repeated omitting these outliers (Fig. 4b).

In Figs. 2, 3 and 4, the data point distributions, in which symbol size was scaled relative to the onset,

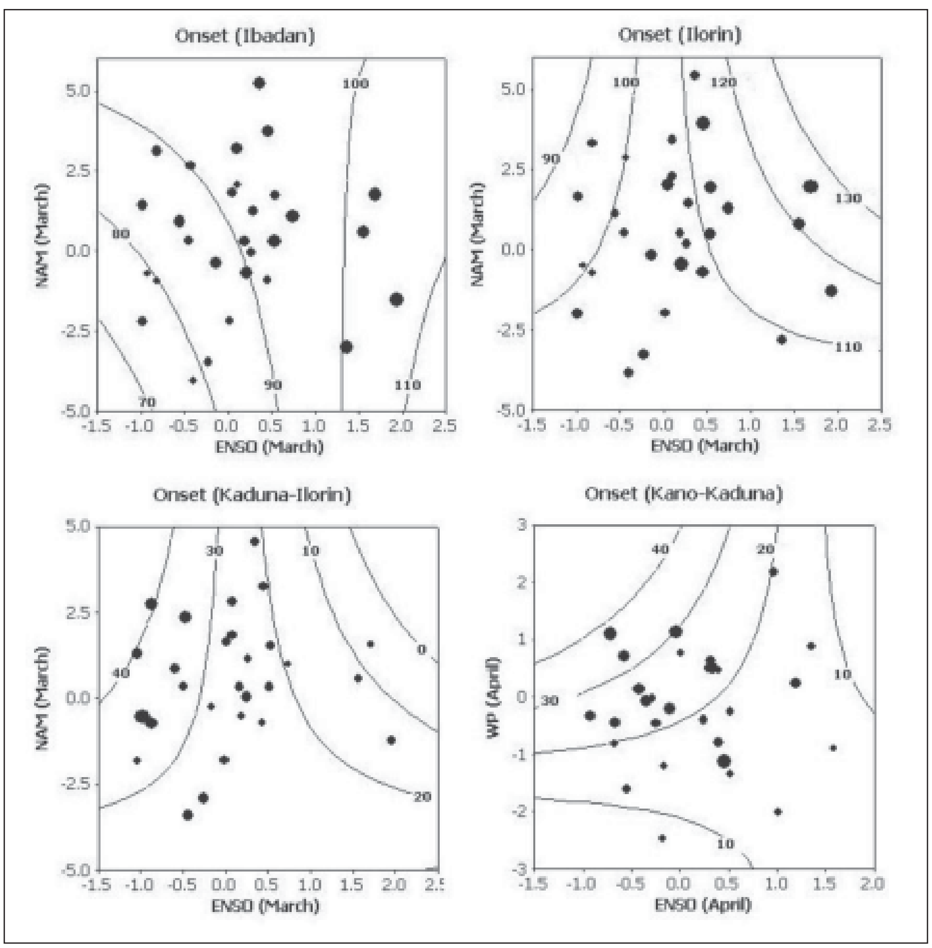

Fig. 2: Response surfaces on day of rainfall onset at Ibadan and Ilorin, and rate of onset advance from Kaduna to Ilorin and Kano to Kaduna.

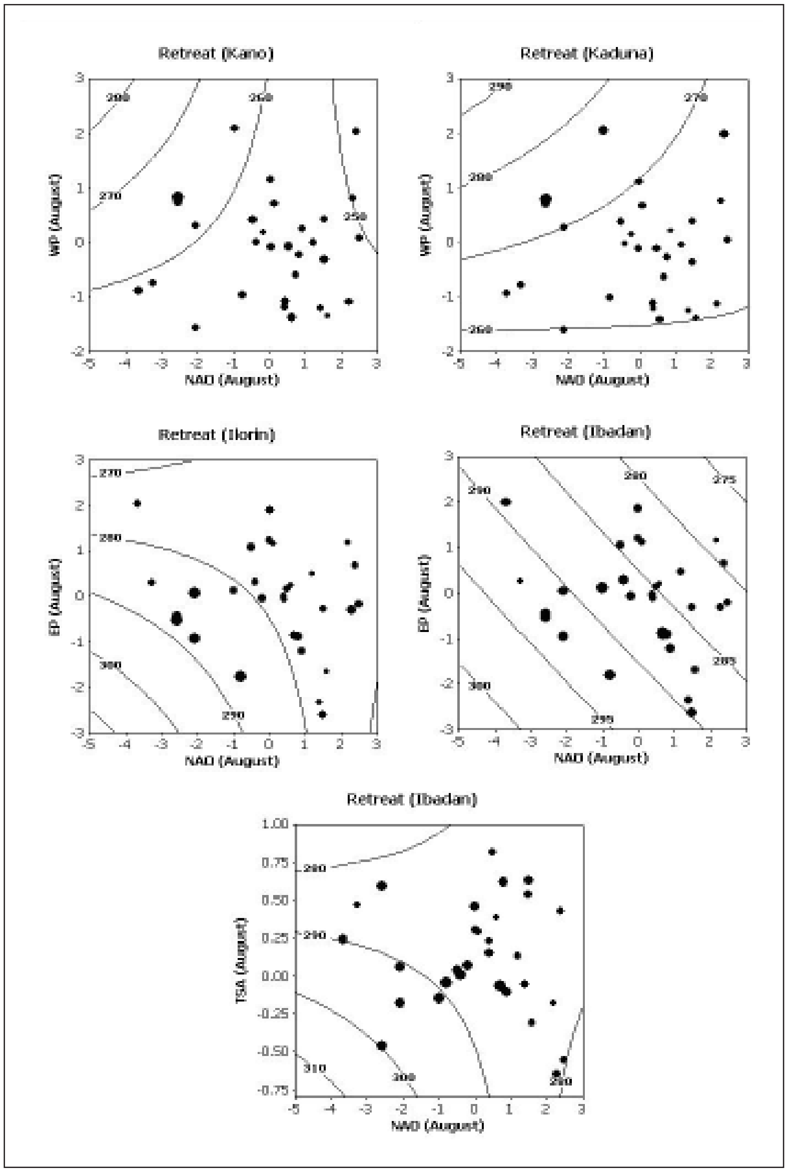

Fig. 3: Response surfaces on day of rainfall retreat at Kano, Kaduna, Ilorin and Ibadan. Two figures are shown for retreat date at Ibadan: (i) highest r^2 (NAO/TSA, r^2 = 0.34); (ii) second highest r^2 and consistency with other relationships (NAO/EP, r^2 = 0.33).

retreat or rate data, were created in SigmaPlot 9.0 (Systat Software Inc.), scaled to the Minitab graph and overlaid on the response surface. Initial response surface analyses consistently identified the year 1989 as anomalous, so this year was omitted from all analyses; 1989 was also identified as anomalous in previous studies[12].

In interpreting the patterns of the contour lines of the response surface, the closer that contour lines lie parallel to an axis, the less that climate index influences the response in that region of the graph. The degree of spacing between contour lines reflects the rate of change. In areas of the graph that contain data, but where contour lines are widely separated, this indicates relatively unchanging response. The more closely the contour lines lie perpendicular to an axis, the more that index influences the response. Contour lines at an angle close to 45^o to both axes indicate strong interaction.

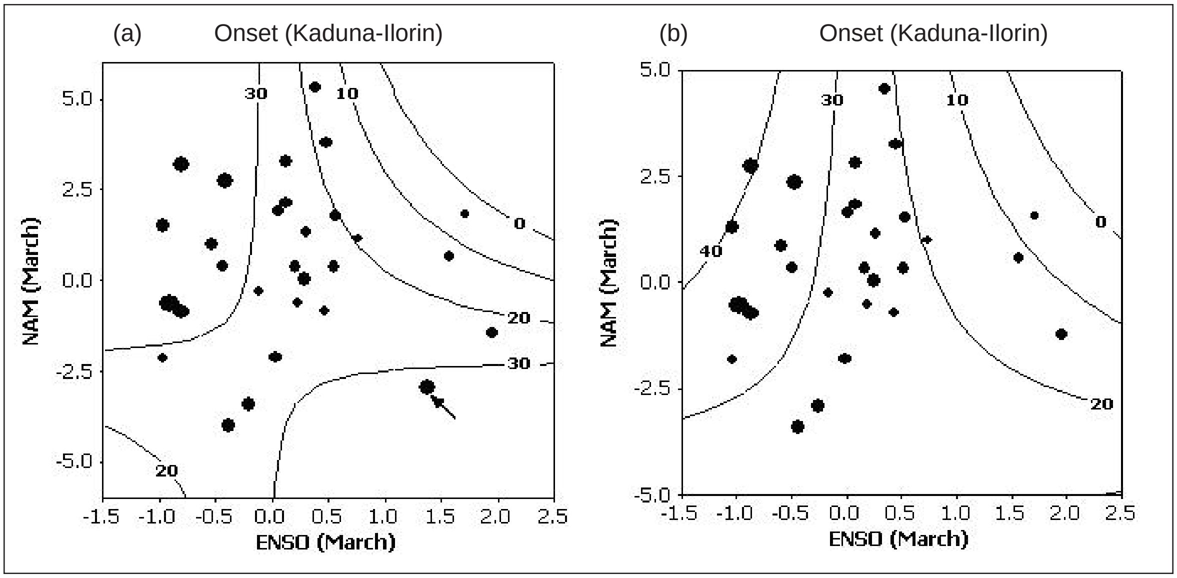

Fig. 4: Graphical evaluation of relationships, with point size scaled between the smallest at the minimum and maximum values (Table 2)—(a) Saddle point resulting from an outlier (the data point at 1987 indicated by an arrow) in the values for the difference in time of onset between Kaduna and Ilorin; and (b) Omitting that data point resulted in a surface consistent with other relationships for the month of March.

Results

Best-fitting climate index combinations: The climate index combinations that provide the best-fit (highest r^2) for rainfall onset and retreat at each location are shown in Table 2. In the case of Kaduna and Kano, no good fit was found to the onset dates themselves, which would be dependent on dates of arrival at more southerly locations; rather, rate of advance of onset from Ilorin to Kaduna and Kaduna to Kano was found to have a good relationship to certain index combinations.

The response surfaces corresponding to the combinations listed in Table 2 are shown in Figs. 2 and 3. The density of the scaled data points in the figures

Table 2. Index combinations providing the best-fit (highest r^2) for rainfall onset and retreat at each location, with the month column indicating the month for which the index data are used

Event	Location	Min	Max	Month	Indices	r^2
Onset	Ibadan	71	109	March	ENSO-NAM	0.45
	Ilorin	88	124	March	ENSO-NAM	0.51
	Kaduna-Ilorin	8	58	March	ENSO-NAM	0.42
	Kano-Kaduna	4	46	April	ENSO-WP	0.31
Retreat	Kano	238	283	August	NAO-WP	0.23
	Kaduna	256	288	August	NAO-WP	0.43
	Ilorin	268	293	August	NAO-EP	0.40
	Ibadan (i)	272	298	August	NAO-TSA	0.34
	Ibadan (ii)	272	298	August	NAO-EP	0.33

For Kaduna and Kano, rate of advance of onset rather than day of onset is shown. Also included are the two results for retreat at Ibadan, discussed in relation to Figure 3. The minimum and maximum values used in scaling the data points in Figs. 2, 3 and 4 are shown.

Table 3. Equations for the response surfaces in Figures 2 and 3

Event	Location	Equation
Onset	Ibadan	88.90+8.36*‘ENSO’+1.35*‘NAM’-1.08*‘ENSO’*‘NAM’
	Ilorin	106.00+7.76*‘ENSO’+0.03*‘NAM’+1.93*‘ENSO’*‘NAM’
	Kaduna-Ilorin	27.25–8.84*‘ENSO’+0.18*‘NAM’-2.08*‘ENSO’*‘NAM’
	Kano-Kaduna	22.53–6.70*‘ENSO’+5.94*‘WP’-4.56*‘ENSO’ *‘WP’
Retreat	Kano	255.67–2.05*‘NAO’+1.24*‘WP’-1.12*‘NAO’*‘WP’
	Kaduna	265.63–1.34*‘NAO’+3.71*‘WP’-0.78*‘NAO’*‘WP’
	Ilorin	278.84–2.34*‘NAO’-2.27*‘EP’+1.09*‘NAO’*‘EP’
	Ibadan (i)	287.17–2.01*‘NAO’-5.94*‘TS’+3.79*‘NAO’*‘TSA’
	Ibadan (ii)	286.19–2.04*‘NAO’-2.45*‘EP’+0.03*‘NAO’*‘EP’

The equation predicts date of onset or retreat at the specified location, or rate of advance of onset. Also included are the two results for retreat at Ibadan, discussed in relation to Fig. 3. Table 2 shows the month for which the climate indices are used.

indicates the frequency with which particular combinations of index level occur, and the consequent likelihood of particular values of onset or retreat. The distribution of different-sized points helps illustrate the fit of the trend to the data in different regions of the graphs. The equations for each of the response surfaces are listed in Table 3.

Response surfaces—onset: As expected from the literature on rainfall in West Africa, ENSO plays a major role in determining onset and rate of advance of the ITCZ. Onset at both Ibadan and Ilorin was related to March ENSO-NAM interaction, as was advance of onset from Ilorin to Kaduna, all using March values of the indices. Spread from Kaduna to Kano was related to April values of ENSO and WP. The later the rainfall onset arrives at a location, the faster the rate of advance (Fig. 5).

Response surfaces—retreat: Rainfall retreat occurs much faster than onset (Fig. 1). For rainfall retreat, NAO is the predominant index, with August values being basic to all patterns (Fig. 3). Retreat at both Kano and Kaduna is related to NAO-WP interaction, while retreat at Ilorin and Ibadan is related to NAO-EP. In general, the relationship illustrated is that with the highest r^2, with no indication of a spurious relationship. However, if an additional criterion is used, i.e. high r^2 and conformity with more general relationships, different combinations of indices may be selected. Thus, for retreat date at Ibadan, the highest r^2 (0.34) is with NAO-TSA, whereas the second highest r^2 (0.33) is with NAO-EP, the same index combination as for Ilorin (Fig. 3). No relationship of retreat rate to retreat timing, or to onset rate or timing, was found.

Malaria case reporting: Retreat date at Kano, the most northerly location in the study, increased over

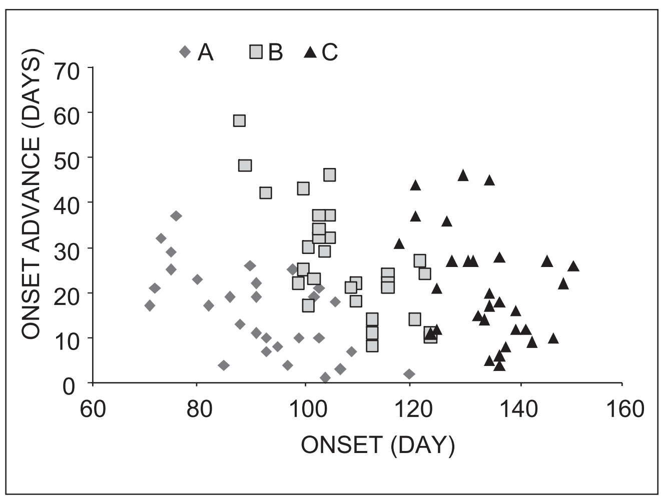

Fig. 5: Rate of onset advance in relation to day of onset at a location: (A) days for advance from Ibadan to Ilorin in relation to day of onset at Ibadan; (B) days for advance from Ilorin to Kaduna in relation to day of onset at Ilorin; and (C) days for advance from Kaduna to Kano in relation to day of onset at Kaduna.

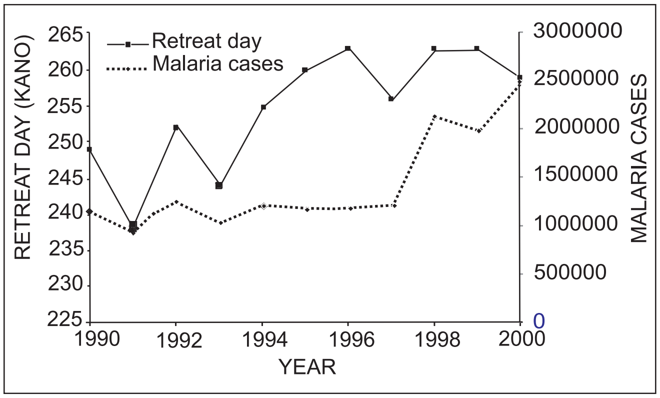

Fig. 6: Reported[18] malaria cases for Nigeria and day of retreat at Kano, the most northerly location in the study, for 1990–2000.

the period 1990–2000, and in the last three years of the period there was a sharp increase in reported malaria cases (correlation coefficient 0.6) (Fig. 6). The majority of cases in Nigeria are *Plasmodium falciparum* followed by *P. malariae*. *Plasmodium vivax* is rare[18].

Discussion

Numerous attempts have been made to estimate and forecast rainfall onset and retreat dates in western sub-Saharan Africa, but many of these approaches addressed only mean time of onset and retreat at a location and did not address year-to-year variability[17]. Failure of earlier approaches was ascribed to their utilization of only a single predictor variable, whereas step-wise multiple regression could be used to include multiple variables and demonstrate the importance of the Atlantic sea surface temperature (SST) and land/sea thermal contrast in predicting year-to-year variability in rainfall onset and retreat dates in Nigeria[17].

An alternative perspective on climate and West African rainfall comes from studies linking cyclical climatic variations to the ENSO, with increases in malaria cases in a number of regions in the world. However, forecasts are regarded as not very reliable, although they may be used to heighten awareness of possible problems in the coming year[19]. This low reliability may be associated with consideration of only a single climate index (ENSO), analogous to the observation described above[17].

In the present study, response surface analysis indicated that rainfall onset, rate of onset advance, and retreat dates at Ibadan, Ilorin, Kaduna and Kano in Nigeria were related to combinations of climate indices rather than to a single index. ENSO was the principal index correlated with onset, while NAO was the principal index correlated with retreat. Specific secondary indices may be related to different timings, different index weights between locations, covariance among the indices, or to variation in appropriateness of the rainfall threshold at different locations.

As onset at Ibadan and Ilorin is in both the cases in March (Fig. 1), relationship to March index values provides no opportunity for advance warning in the absence of predictions of climate index values, unless the index values themselves can be forecast. However, March index values in relation to spread rate from Ilorin to Kaduna, and April index values in relation to spread rate from Kaduna to Kano, both of which have a May onset, do allow some opportunities for advance warning. Conditions at Kano may be helpful in forecasting arrival in Niger to the north.

The graphical representation of the response surfaces along with a scaled representation of the underlying data points allows visualization of frequency with which particular combinations of index levels occur, and the consequent likelihood of particular values of onset or retreat. The distribution of different-sized points helps illustrate variation in goodness of fit in different regions of the graphs, and aids identification of spurious relationships. The graphical representation also provides a framework for exploring anticipated effects of climate change on index values, as one can get an indication of expected changes in onset and retreat timings, and duration of the rainy season, if climate change causes changes in frequency and magnitude of particular indices in different months.

Rainfall is one of the major factors influencing malaria transmission in Africa, and its forecasting is central to many malaria planning and decision processes. Rainfall monitoring and prediction constitute a key component of the World Health Organization's Malaria Early Warning Systems for sub-Saharan Africa, and of tools developed by the Roll Back Malaria (RBM) Technical Support Network on Prevention and Control of Epidemics[19,20]. Rainfall not only affects vector biology, but also regional economies, agriculture-based livelihoods and consequent ability of individuals, organizations and governments to respond to outbreaks of malaria and other diseases. Forecasting values of the indices related to rainfall onset and retreat is possible to varying degrees, with ocean–atmosphere linkages being particularly strong in tropical regions[21]. In Kenya, seasonal climate forecasts do not anticipate heavy rainfall[22], but onset and retreat timing may be more reliably predictable than amount of precipitation. Current early warning systems have low geographical resolution[23], but resolution may be increased by evaluation of index combinations in specific months as in the present study.

The present study explores only four locations within Nigeria, and is dependent on the threshold for defining a "rainy" day. As rate of advance of rainfall onset is related to index interactions, a broader study including locations reached by the ITCZ prior to its arrival in Nigeria would be of interest. In addition, the present study addresses only rainfall onset and retreat, not rainfall quantity, which is also known to be influenced by ENSO[24], and a similar approach could be used with this variable, as well as with temperature and humidity. Technical and practical hurdles will need to be overcome before new climate-related information based on the approach can be widely integrated into routine malaria-control strategies[25].

Determination of rainfall onset and retreat dates-based on rainy day frequency for individual years was more efficient than an approach-based on rainfall amount (cumulative percentage mean rainfall), and it was recommended that rainfall onset and retreat dates should be based on rainy days rather than rainfall amount[12] . Occasional large but isolated showers at the beginning or end of the year could adversely affect predictions based on percentage cumulative rainfall amount, whereas frequency was only high when the rainfall had truly commenced and low only when the rainfall had properly retreated. A different definition, or change in the threshold value of "rainy", would affect the results.

Retreat date at Kano increased during the years 1990–2000, while the years 1998–2000 were associated with an increase in malaria case reporting for Nigeria as a whole (Fig. 6). The case reporting records used in the present study are for the country as a whole, and interactions between meteorological, entomological and morbidity variables are complex[26], with interannual climate variability being an important contributor to both mosquito vector dynamics and parasite development rates[27]. More detailed, localized studies are therefore required to elucidate any underlying causality related case reporting to timing of rainfall retreat.

In that regard, the country profile for Nigeria, produced by the World Health Organization's Regional Office for Africa[28], indicates that transmission of malaria occurs all year round only in a small part of the south of the country, whereas in the remaining parts, the duration of transmission is 3–10 months between February and December. A 3 to 4 week delay in retreat timing would significantly prolong the 3-month transmission season in the north and, when occurring over several years, may also allow change in abundance and distribution of vectors.

There are 37 species of *Anopheles* in Nigeria, of which 13 species are malaria vectors[28]. In the present study, a precipitation threshold related to agriculture was used, whereas different species of mosquitoes might require different thresholds relating to their particular biology. Slight adjustments of values assigned to thresholds and rules in malaria-related models can strongly influence predictions[29].

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Corresponding author: Alan J. Thomson, 841 Victoria Ave, Victoria, BC, Canada V8S 4N4.
E-mail: ajthomson@AdaptiveKM.com

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