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The impact of climate change on the epidemiology and control of Rift Valley fever

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Summary

Climate change is likely to change the frequency of extreme weather events, such as tropical cyclones, floods, droughts and hurricanes, and may destabilise and weaken the ecosystem services upon which human society depends. Climate change is also expected to affect animal, human and plant health via indirect pathways: it is likely that the geography of infectious diseases and pests will be altered, including the distribution of vector-borne diseases, such as Rift Valley fever, yellow fever, malaria and dengue, which are highly sensitive to climatic conditions. Extreme weather events might then create the necessary conditions for Rift Valley fever to expand its geographical range northwards and cross the Mediterranean and Arabian seas, with an unexpected impact on the animal and human health of newly affected countries. Strengthening global, regional and national early warning systems is crucial, as are co-ordinated research programmes and subsequent prevention and intervention measures.

Keywords

Climate change – Early warning system – Rift Valley fever – Vector-borne disease.

Global warming and emerging vector-borne diseases

Certain diseases are associated with particular environmental conditions, seasons and climates (14). Some of these diseases are transmitted by vectors, such as arthropods (mosquitoes, lice, ticks) or rodents, which are sensitive to changes in climatic conditions, especially temperature and humidity. Local climatic parameters therefore play a central role in determining the distribution and abundance of these vector organisms, either directly or indirectly, through the effects of such parameters on the host animals. The distribution of vector-borne diseases is restricted by, among other things, the climate tolerance limits of their vectors. Abiotic factors have a direct impact on the bionomics of arthropods and, thus, on the dynamics of their populations. There is also a minimum temperature for arthropods to complete their extrinsic incubation period and this is a limiting factor for infection transmission in many temperate areas. In addition, biological restrictions that limit the survival of the infective agent in the vector population also determine the limits for disease transmission.

At present, the world climate is in a warming phase. The Intergovernmental Panel on Climate Change (IPCC) concluded that, 'the balance of evidence suggests a discernible human influence on global climate' (15). Indeed, evidence suggests that human activities contribute to warming the planet and climate models predict an increase in global mean temperatures of between 1ºC and 3.5ºC during the 21st Century, with large differences in trends between locations. Temperature changes are one of the most obvious and easily measured changes in climate, but atmospheric moisture, precipitation and atmospheric circulation also change as the whole system is affected. These effects alter the hydrological cycle, especially the characteristics of precipitation/rainfall (amount, frequency, intensity, duration, type) (37). Finally, it is anticipated that global climate change will induce changes in the magnitude and frequency of extreme events (10) and have significant effects on the geographical range and seasonal activity of many vector species (25). It is therefore expected that global climate change will alter the distribution and increase the risk of some vector-borne zoonoses, including Rift Valley fever (RVF), leading to significant changes in the geographical distribution and frequency of RVF epidemics.

Rift Valley fever and climate change

Rift Valley fever: ecological features

Rift Valley fever is an acute, mosquito-borne viral disease, mainly affecting ruminants and humans. It causes abortions in pregnant animals and high mortality in young animals, characterised by massive hepatic necrosis and pantropic haemorrhage. In humans, RVF causes a severe influenza-like disease, occasionally with more serious effects, such as haemorrhagic complications, hepatitis, encephalitis, blindness and sometimes death.

The virus is a member of the family Bunyaviridae, in the genus *Phlebovirus*. It is a ribonucleic acid virus, which is related to some other members of the group by haemagglutination or indirect fluorescent antibody tests at low titres and from which it may be readily distinguished by virus-serum neutralisation tests. The virus is transmitted by mosquitoes of at least six genera with over 30 different species shown to be competent vectors. It is transmitted transovarially by some of the *Aedes neomelaniconium* species of mosquitoes (24). In particular, it can be transferred transovarially from females to eggs in some mosquito species of the *Aedes* genus. These insects are floodwater-breeding species. They emerge in huge numbers in flooded depressions and other habitats where oviposition has occurred. Between flooding periods, the eggs can survive desiccation for many years, and cause major epidemics at irregular intervals of 5 to 35 years. The disease was first recognised and characterised after heavy rainfall in the Great Rift Valley in Kenya in 1931, hence its name (8).

The occurrence of RVF can be endemic and/or epidemic, depending on the climatic and ecological characteristics of different geographic regions. In the high rainfall forest zones of coastal and Central Africa, RVF is reported to occur in endemic cycles, which are poorly understood. Virus activity is often detected either by serological studies in susceptible animals or by the appearance of sporadic human disease cases or fortuitous virus isolations. Currently available evidence suggests that this may happen annually if there is heavy rainfall, but at least every two or three years, otherwise. The disease was shown to be endemic in some semi-arid zones, such as northern Senegal (5, 39). Epidemic areas are characterised by:

– plateau grasslands with relatively high rainfall (East Africa)

– semi-arid zones (Saudi Arabia, West Africa)

– irrigated zones (Egypt, Yemen).

In these areas, RVF epidemics appear at 5-to-15-year cycles (27) and the generation of epidemics seems to be associated with the simultaneous intensification of virus activities over vast livestock areas, where it is already present as cryptic endemic foci (35).

Historical information has shown that pronounced periods of RVF virus activity in East Africa occur during periods of heavy, widespread and persistent rainfall, now associated with El Niño events, triggered by large-scale changes in sea surface temperature in the Pacific Ocean and the western Equatorial Indian Ocean, leading to climate anomalies at the regional level (21).

The historical records of Rift Valley fever

In the Horn of Africa, RVF epidemics have occurred only a few times in the past 40 years, in 1961-1962, 1982-1983, 1989, 1997-1998 and in 2006-2007. In southern Africa, the disease was first recorded in 1950, when a major epizootic in South Africa caused an estimated 100,000 deaths and 500,000 abortions in sheep (9). A second extensive epizootic occurred in South Africa and Namibia from 1974 to 1975. Periodic severe outbreaks have also been experienced in Zimbabwe, Zambia and Mozambique.

In 1973, RVF outbreaks occurred in irrigated areas in the Sudan. In 1977, the disease was recognised in Egypt after the flooding of the Aswan dam and subsequent irrigation of vast areas, causing an estimated 600 human deaths, as well as heavy losses in sheep, goats, cattle, buffaloes and camels along the Nile Valley and Delta (28). Rift Valley fever outbreaks again occurred in Egypt in 1993 (3).

In West Africa, a large RVF outbreak occurred in the human population between 1987 and 1988 (19, 20, 34), and was similarly thought to be causally linked with the newly constructed dam on the Senegal River at the Mauritania-Senegal border (16). During this outbreak, a higher frequency of neurological signs in humans was reported than had been in other epidemics. The increase in the level of the water table, upstream of the lake established by the dam, created extensive new breeding habitats for mosquitoes. Abortions were reported in small ruminants and camels, with some mortality in young animals. A further episode of virus activity in the region – again, first identified through evidence of human disease – occurred in 1998, in the province of Hodh El Gharbi, south east of Mauritania (32). Two years later, in September 2000, RVF was detected outside the African continent for the first time, in Saudi Arabia and Yemen, resulting in a high number of human fatalities and major losses in the livestock population (1, 17). This was considered the first documented RVF outbreak outside Africa, although the virus could have been endemic in the *wadi* (a dry riverbed located in a valley) environments for some years, in cryptic foci, and recent serological investigations suggest that the virus persists in these areas (11).

The 1997-1998 epidemic, which is considered one of the most devastating epidemics of RVF in East Africa, was associated with torrential rains (60 to 100 times the seasonal average) that occurred across most of East Africa from late October 1997 to January 1998, and resulted in the worst flooding in the Horn of Africa since 1961.

In December 1997, unexplained human deaths were reported in the north-eastern province of Kenya and southern Somalia. Surveys confirmed the presence of a haemorrhagic syndrome in humans that included fever with mucosal or gastro-intestinal bleeding. Some patients with this syndrome were shown to have acute infection with RVF virus. Human RVF cases were confirmed in people in the north-eastern, central, eastern and Rift Valley provinces of Kenya, and in the Gedo, Hiran and Lower Shabelle provinces of Somalia. Livestock losses of up to 70% in sheep and goats, and 20% to 30% of cattle and camels, were also reported and surveys confirmed that RVF was present in livestock.

By the end of 2006, the disease re-emerged in its epidemic form in the Garissa district of Kenya, requiring the government to take stringent control measures in an attempt to mitigate the impact on both humans and animals. The disease further spread to, or emerged in, Somalia and Tanzania. Although some lessons were learned from the 1997-1998 epidemic, it is clear that control activities were hampered by a lack of preparedness and the absence of a clear strategy that should have been prepared during the inter-epidemic period of almost ten years. Although the disease has been known for decades, national authorities are still caught unprepared to handle large epidemics, partly due to the irregular nature of the epidemic cycles that occur after long periods of no visible RVF activity.

Inter-epidemic periods are characterised by a sharp decrease in awareness and a decline in the collective memory of the disease that was once known by elders, or veterinary staff who no longer practise by the time of a new epidemic. In these inter-epidemic periods, scarce resources dedicated to animal health problems are re-allocated towards other disease problems or more pressing issues.

Rift Valley fever and climate change: impact on geographical distribution

Climate changes may affect the three fundamental components of the epidemiological cycle of RVF, namely: vectors, hosts and virus. The consequences of global warming on vectors, in particular, may be many.

The hatching dynamic of *Aedes* mosquitoes, the main reservoir of RVF in Africa, strongly depends on the rainfall pattern (27). *Aedes* females lay eggs in pond mud. Although these eggs become desiccated when ponds dry up, they remain viable for several years or even decades in the dry mud. The ovaries and ovarian ducts in a mosquito infected with RVF can transmit the virus to the nascent eggs. When infected via transovarial transmission, eggs allow the virus to persist in the field during dry and/or inter-epizootic periods. Eggs need to be flooded to hatch. Heavy rainfall results in a massive hatching episode and, consequently, the development of a large vector population. Then, once infection has been amplified in livestock, secondary vectors such as *Culex* and *Anopheles* spp., which breed in semi-permanent pools of water, become involved in the transmission of the virus.

In East Africa, outbreaks were clearly correlated with the unusual heavy rainfall associated with El Niño (21), which consequently flooded many *Aedes* breeding habitats. El Niño-Southern Oscillation events are a combined ocean-atmosphere phenomenon, involving changes in the temperatures of surface waters in the tropical Pacific and in its closely linked atmospheric counterpart, the Southern Oscillation. El Niño-Southern Oscillation events involve a large exchange of heat between the ocean and the atmosphere, and affect:

- global mean temperature
- trade winds

– tropical circulation

– precipitation.

Such events occur about once every three to seven years. As mentioned in the IPCC report, heavy rainfall events are likely to become much more frequent in years to come and: 'extremes of the hydrological cycle, such as floods and drought… are apt to be enhanced with global warming' (37). In fact, the increase in rainfall in East Africa, extending into the Horn of Africa, is robust across the entirety of the models surveyed in the IPCC report (6). Thus, it may be assumed that the frequency and severity of RVF outbreaks on this part of the continent will increase. This could also affect other countries that import animals from Africa, such as some islands in the Indian Ocean. One example is Comoros, which is dependent on the importation of livestock from Kenya and Tanzania – countries where RVF is endemic.

The correlation between outbreaks of RVF and periods of heavy rainfall observed in East Africa does not apply to West Africa (4). However, RVF is also endemic in some sub-Saharan countries. Recent studies conducted in the Ferlo region of Senegal, which included daily mosquito catches and rainfall records (30), demonstrated that several generations of *Aedes vexans* can emerge during the same rainy season, depending on:

– the succession of rains and dry periods

– consecutive changes in the water levels of temporary ponds

– the flooding of quiescent eggs laid on the shores.

This mechanism could be the way the disease persists at low incidence (4, 30). This situation would worsen with longer durations of dry days between periods of more intense precipitation during the rainy season (allowing the draining of the ponds and the embryogenesis of eggs), a scenario clearly predicted for some regions of Africa (Fig. 1).

It can also be speculated that, as seen under experimental conditions, global warming could affect the biology of vectors, by increasing feeding frequency and egg production, and decreasing the length of the development cycle and the extrinsic incubation period. This may result in a higher vector density, an increased vector capacity to transmit the virus and a higher transmission rate. The real impact in natural conditions remains to be evaluated.

Since 1998, six strains of bluetongue (BT) virus have spread across 12 Mediterranean countries, and travelled 800 km further north into Europe than previously (being observed in Belgium, France, Germany, Luxembourg and the Netherlands). This significant emergence in the Mediterranean basin has been fuelled largely by the main Afro-tropical BT virus (BTV) vector, *Culicoides imicola* Kieffer 1913 (33). The strain BTV8, which is responsible for the latest outbreaks in Europe, originated in sub-Saharan Africa. The unexpected appearance of BTV at such high northern latitudes, in the absence of *C. imicola*, demonstrates that the *Culicoides* species endemic to the Palaearctic region can transmit BTV (29).

The foremost hypothesis is that the spread of BTV in Europe has been driven by:

– recent changes in the European climate which have allowed increased virus persistence during winter

– the northward expansion of *C. imicola*

– beyond the range of *C. imicola*, transmission by the indigenous European *Culicoides* species.

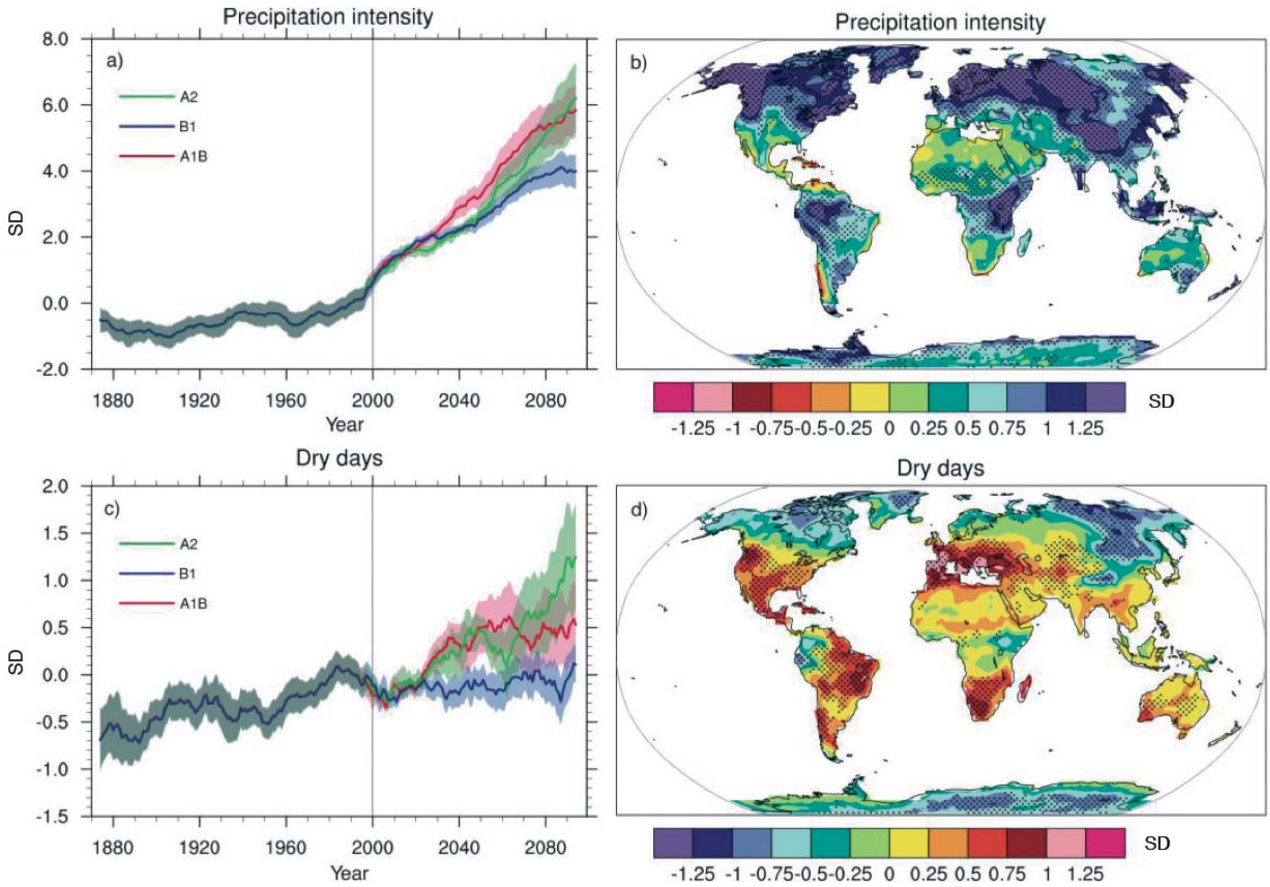
All of these factors have thereby expanded the risk of BTV transmission over larger geographical regions (33).

The same phenomenon may occur with RVF and its vectors, *Aedes* and *Culex*, which are also present in Europe. There is thus an increased probability of the northern extension of RVF from West Africa and the Middle East into Europe.

Suitable habitats for mosquitoes that breed in floodwaters exist throughout the Middle East and Europe. Many of the species associated with RVF in other countries are found in the European Union (EU). Increased temperature may have an impact on vector capacity (7, 18, 38). It is thus considered possible that arthropod species within EU countries could also become competent vectors for RVF, if initial infection occurs (12).

Since numerous susceptible livestock species are widespread in the EU, and vaccination is not practised, early signs of infection and disease might be missed. Intra-community movement of livestock occurs routinely. Thus, if infection is present in the EU, the probability of RVF establishment within vector and livestock populations has been assessed as at least higher than negligible and possibly much higher, if the climate changes significantly (12), with warmer temperatures and greater humidity.

As far as hosts are concerned, climate changes may induce modifications in their distribution and density, as well as their migratory pathways. Historically, the dissemination of RVF has been attributed in part to nomadic herds: the modification of migratory pathways could introduce the virus into previously virus-free areas. Climate modification may also result in the selection of a strain that is either more or less virulent.



(a) Globally averaged changes in precipitation intensity (defined as the annual total precipitation divided by the number of wet days) for a low (Special Report on Emissions Scenario [SRES] B1), middle (SRES A1B) and high (SRES A2) scenario
(b) Changes in spatial patterns of simulated precipitation intensity between two 20-year means (2080-2099 minus 1980-1999) for the A1B scenario
(c) Globally averaged changes in dry days (defined as the annual maximum number of consecutive dry days)
(d) Changes in spatial patterns of simulated dry days between two 20-year means (2080-2099 minus 1980-1999) for the A1B scenario
Solid lines in (a) and (c) are the 10-year smoothed multi-model ensemble means; the envelope indicates the ensemble mean standard deviation (SD)

Fig. 1
Changes in extremes based on multi-model simulations from nine global coupled climate models, adapted from Tebaldi *et al.* (36)

Obstacles to detecting Rift Valley fever in newly affected areas

If a new disease outbreak, particularly in an area or country which has previously been disease-free, can be recognised early and dealt with effectively while it is still localised, the prospects of its eradication with a minimum of production losses are excellent. Conversely, if there are substantial delays in either of these elements, recognition or control, the disease may become widespread and very difficult and costly to control and eliminate. Unfortunately, the latter has often occurred. It is a fact that early detection, epidemiological analysis and reporting of outbreaks of epidemic diseases is often one of the weakest links in the chain of actions necessary to prevent, detect, control and eliminate the disease. This has been the experience in many countries, particularly when dealing with the first occurrence of a newly introduced, emerging disease, such as Rift Valley fever. If the disease does not come rapidly to the attention of central veterinary authorities, and remains undetected for a while, it could cause important production losses and risks to human health. It is therefore of paramount importance to develop and strengthen early warning systems and tools that allow the prompt detection of such diseases, since these will inevitably move outside their distribution ranges and colonise previously disease-free areas.

Existing early warning systems and risk assessment tools: prospects for better forecasting of Rift Valley fever

In parts of East Africa known to experience RVF epidemics, remote-sensing technologies which measure rainfall and vegetation have been used to predict RVF before it reaches epidemic proportions. Data sets used in these predictions include satellite vegetation indices and Cold Cloud Duration and Inter-tropical Convergence Zones, which correlate with climatic changes (7). Measurements from the advanced very high resolution radiometer sensor (AVHRR), on board the polar-orbiting satellite series operated by the National Oceanographic and Atmospheric Administration (NOAA), are used to generate the Normalized Difference Vegetation Index (NDVI) and monitor ecological conditions and dynamics during the vegetation growing season (2). The NDVI is calculated from surface reflectance measurements in the red (Channel 1, 0.58 µm to 0.68 µm) and infra-red (Channel 2, 0.725 to 1.1 µm) portions of the electromagnetic spectrum to describe the relative amount of green biomass as follows: NDVI = (Channel 2 – Channel 1)/(Channel 2 + Channel 1).

In East Africa, vegetation index maps have been used, together with ground data, to monitor vector populations and RVF viral activity, thus establishing a correlation between these two parameters. Indeed, a detailed analysis was conducted with virus isolation data over a 25-year period and the NDVI for the study areas (21, 22). As the water table rose to the point where flooding may have occurred, the NDVI ratio approached 0.43 to 0.45 (22). This point was reached during each of the epizootic episodes in the study period. The main advantage of using remote-sensing data to predict RVF occurrence is the relatively low operational cost of the monitoring and forecasting system. It is readily available on a country and regional basis, and its use may allow preventive or intervention measures to be taken, such as the vaccination of susceptible stock, and use of repellents and mosquito larvae control methods (21, 23). Predictive models have been greatly improved by the addition of Pacific and Indian Ocean sea surface temperature anomaly measurements, together with rainfall and NDVI data. An accuracy rate of 95% to 100% was estimated for the prediction of RVF epizootics in Kenya, with a lead time of two to five months (21). These studies illustrate the enormous potential of remote-sensing data in monitoring and predicting periods of RVF virus activity and epidemics (2, 22). However, these associations have not been adequately validated beyond East Africa, largely because of inadequate ground data on viral activity. Even in East Africa, further area studies are required.

The Emergency Prevention System for Transboundary Animal Diseases programme (EMPRES) co-ordinates the RVF early warning system initiative at the international level. Data integration and analysis are performed at EMPRES before being disseminated to recipient countries, international organisations and key stakeholders, in the form of the RVF bulletin and risk assessments. At the headquarters of the Food and Agriculture Organization of the United Nations (FAO), near real-time climatic data, such as rainfall estimates and NDVI values, are obtained from the Africa Real Time Environmental Monitoring System (ARTEMIS). The FAO established ARTEMIS in 1988, to assist these programmes by providing a routine flow of satellite imagery, in nearly real time, indicating the status of the growing season and development of vegetation over Africa.

These data are collected and processed using the FAO-developed Windisp 3.0 software. Risk maps are produced by calculating a vegetation index and rainfall anomalies, comparing current conditions with long-term mean conditions. The resulting maps show areas experiencing above-normal rainfall, a predominant factor known to be associated with the emergence of RVF epizootics in East Africa. Other partner institutions, such as the National Air and Space Administration (NASA) Goddard Space Flight Center, produce monthly RVF risk maps, based on the persistence of vegetation index anomalies in RVF-epidemic-prone regions. These maps are then used by the EMPRES group in their qualitative risk assessment studies (Fig. 2).

Eventually, RVF risk assessments are produced, based on the combined results of national surveillance programmes (i.e. serological monitoring of sentinel herds or flocks located in high-RVF-risk areas), seasonal climate forecasts and NDVI anomalies. Alerts are delivered to countries when the prevailing climatic conditions in the region are conducive to an RVF epidemic.

The International Research Institute for Climate and Society (IRI) has also developed operational tools to monitor rainfall and vegetation for its work on malaria. Such tools could also prove useful for arboviruses.

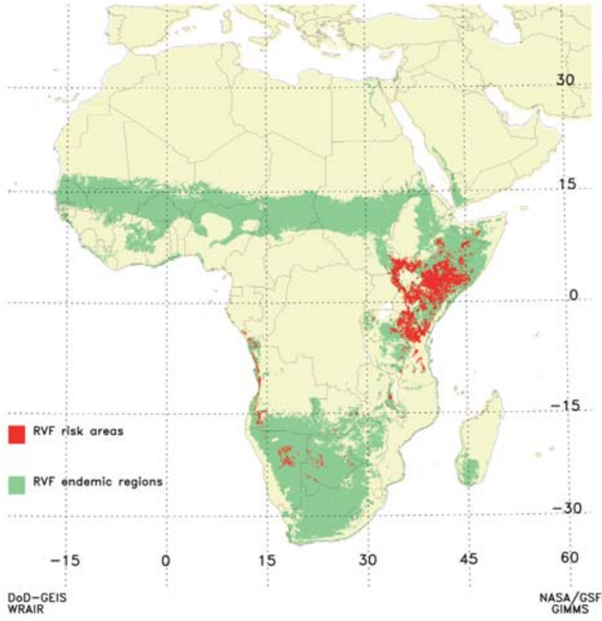


Fig. 2
Potential risk for Rift Valley fever (RVF) in February 2007

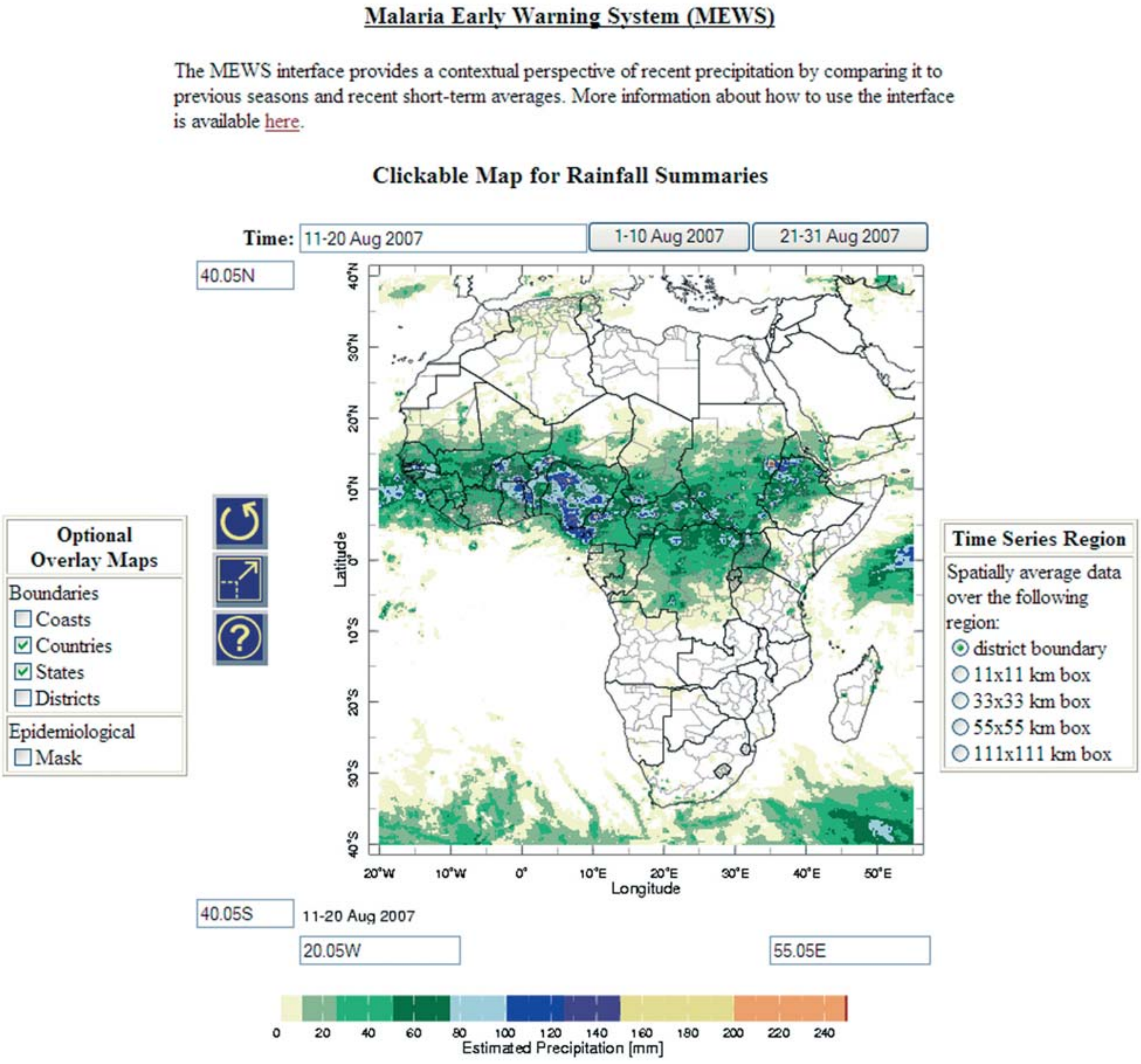
Monitoring rainfall

Using satellite rainfall estimates, updated every ten days, IRI has developed a web-based interface, which enables the user to gain a contextual perspective of the current rainfall season by comparing it to previous seasons (13).

The interface takes the form of an online 'clickable map': http://iridl.ldeo.columbia.edu/maproom/.Health/.Regional/.Africa/.Malaria/.MEWS/. The map displays the most recent (at the time of writing) ten-day (dekadal) rainfall map (Fig. 3).

Dekadal rainfall can be spatially averaged over a variety of user-selected geographic areas. By selecting a specific location of interest (by clicking on the map at the area being studied), four time-series graphs can be generated (Fig. 4). These graphs provide an analysis of recent rainfall, in comparison with that of previous seasons, and a long-time series.

The graphs allow the users to see automatically whether the area of interest is wetter (blue) or drier (red) than normal and decide whether risks are associated with vector developments.



Malaria Early Warning System (MEWS)

The MEWS interface provides a contextual perspective of recent precipitation by comparing it to previous seasons and recent short-term averages. More information about how to use the interface is available here.

Clickable Map for Rainfall Summaries

Time: 11-20 Aug 2007

40.05N

40.05S

20.05W

55.05E

11-20 Aug 2007

Optional Overlay Maps

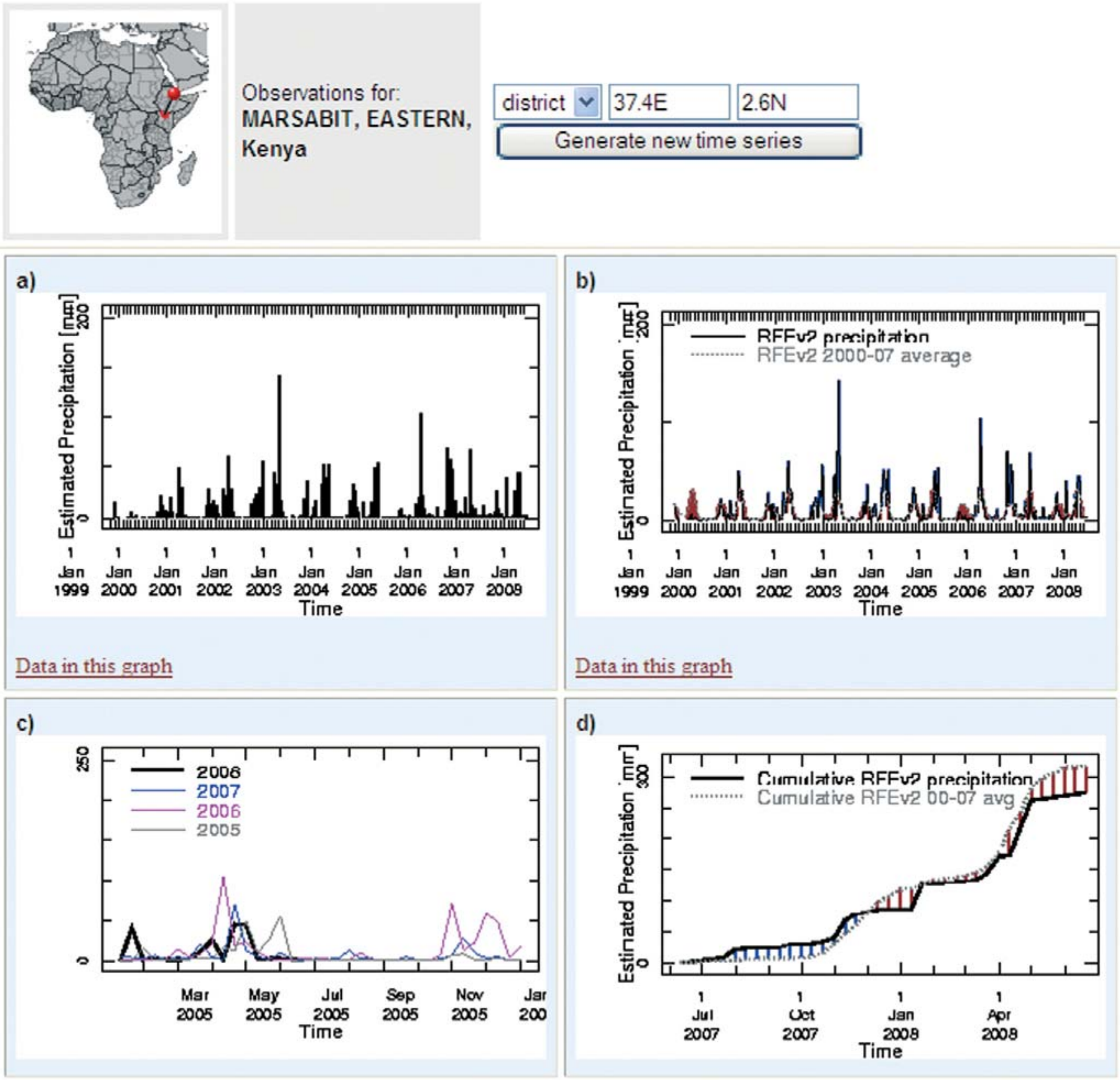
Boundaries
☐ Coasts
☑ Countries
☑ States
☐ Districts

Epidemiological
☐ Mask

Time Series Region

Spatially average data over the following region:
● district boundary
○ 11x11 km box
○ 33x33 km box
○ 55x55 km box
○ 111x111 km box

Fig. 3
The malaria early warning system 'clickable map' for monitoring rainfall, developed by the International Research Institute for Climate and Society



Observations for:
MARSABIT, EASTERN, Kenya

district 37.4E 2.6N

Fig. 4
By selecting an area on the 'clickable map' created by the International Research Institute for Climate and Society four time-series graphs are generated, providing an analysis of recent rainfall in comparison with the rainfall of previous seasons

Monitoring vegetation and bodies of water

To monitor vegetation and bodies of water, images from the moderate resolution imaging spectroradiometer (MODIS) on board the Terra satellite (TERRA-MODIS), provided by NASA, are used. Frequent images at high spatial resolution (250-metre spatial resolution) are made available free of charge.

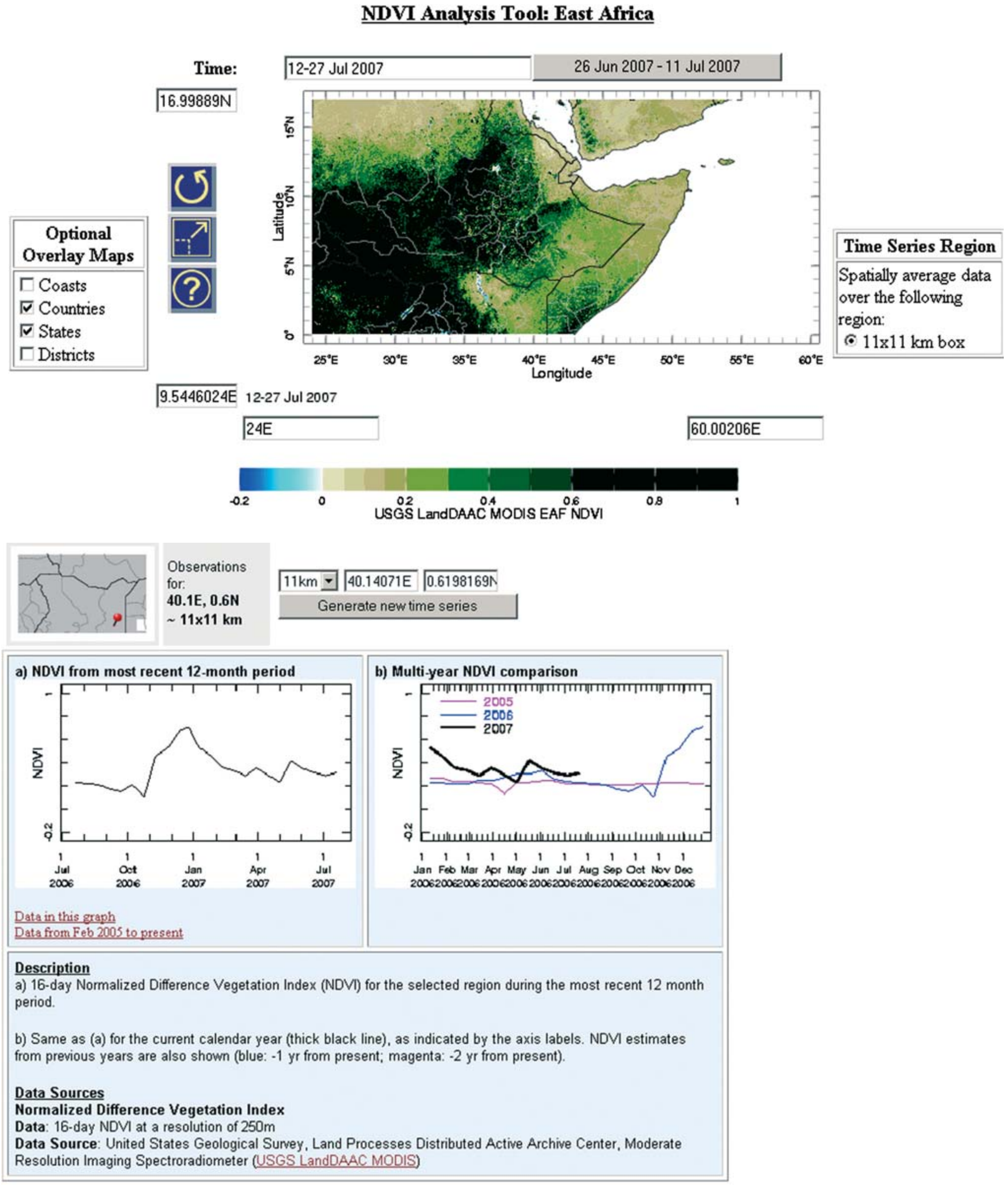
These are provided to the user community through the IRI Data Library website at: http://iridl.ldeo.columbia.edu/SOURCES/.USGS/.LandDAAC/.MODIS/.

The users can remotely:

– view a colour composite where the vegetation appears in green, the bare soils in brown and the water in blue

– compute long-term series of vegetation indices and compare them with historical data.

In Figure 5, the authors selected a location in North Kenya and displayed the evolution of the NDVI. The time-series for the years 2005, 2006 and 2007 indicates that the vegetation index values between November and December 2006 and in January 2007 were greater than the values



NDVI Analysis Tool: East Africa

Time: 12-27 Jul 2007

16.99889N

9.5446024E 12-27 Jul 2007

24E

60.00206E

Optional Overlay Maps
☐ Coasts
☑ Countries
☑ States
☐ Districts

Time Series Region
Spatially average data over the following region:
● 11x11 km box

Observations for:
40.1E, 0.6N
~ 11x11 km

11km 40.14071E 0.6198169N

a) NDVI from most recent 12-month period

b) Multi-year NDVI comparison

Data in this graph
Data from Feb 2005 to present

Description

a) 16-day Normalized Difference Vegetation Index (NDVI) for the selected region during the most recent 12 month period.

b) Same as (a) for the current calendar year (thick black line), as indicated by the axis labels. NDVI estimates from previous years are also shown (blue: -1 yr from present; magenta: -2 yr from present).

Data Sources
Normalized Difference Vegetation Index
Data: 16-day NDVI at a resolution of 250m
Data Source: United States Geological Survey, Land Processes Distributed Active Archive Center, Moderate Resolution Imaging Spectroradiometer (USGS LandDAAC MODIS)

Fig. 5
Normalized Difference Vegetation Index (NDVI) interfaces with time-series extractions for any particular location of interest can be seen on images from the moderate resolution imaging spectroradiometer (MODIS) on board the Terra satellite (TERRA-MODIS), provided by NASA

In this figure, a location in northern Kenya was selected. The time-series for the years 2005, 2006, 2007 (b) indicates that November-December 2006 and January 2007 had NDVI values greater than those in 2005. The development of vegetation in that region was correlated with an outbreak of Rift Valley fever during this period

Source: Images from TERRA-MODIS are accessible through the data library website of the International Research Institute for Climate and Society at: http://iridl.ldeo.columbia.edu/SOURCES/.USGS/.LandDAAC/.MODIS/.

in 2005. The development of above-normal vegetation in that region during November to December 2006 was associated with an epidemic of RVF.

Applying space-based observations of Earth to improve human health and, in particular, forecast RVF is an emerging field. Although monitoring environmental conditions with remote-sensing data plays an important role in forecasting periodic epidemics, it is vital to stress that socio-economic, demographic and immunological factors are also crucial in determining the vulnerability of communities to such diseases. These factors should thus be taken into consideration when constructing early warning systems. Remote-sensing images are only part of a series of information that must be collected to monitor and forecast disease outbreaks. A comprehensive and integrated early warning system is required and the barriers to implementation – namely, cost and data management capability – must be overcome.

Conclusion

Climate change is emerging as one of the main challenges that humankind will have to face for many years to come. Human and animal health issues are only two of many concerns, albeit quite crucial. Climate change could also become a major threat to world food security, as it has a strong impact on food production, access and distribution.

Abnormal changes in air temperature and rainfall and the increasing frequency and intensity of drought and floods have long-term implications for the viability and productivity of world agro-ecosystems (31).

From a public health perspective, scientists anticipate that global climate change will have a range of impacts, mostly adverse, upon human health. While some impacts will result from direct changes in physical living conditions, many will reflect more complex changes in the biophysical and ecological systems that determine the prospects for population health (26).

While the implications of future climate change are complex and difficult to assess, it is certain that infectious zoonotic diseases will have an increased impact on global health issues and their control will be a major factor in social wellbeing. If vulnerable communities can be helped by significant investments in health services and improved management of climate-sensitive diseases in the immediate future, then humans will at least face the potential impacts of climate change with a lower baseline of infections.

Under global warming conditions, the climate tolerance limits of vectors are likely to expand northwards and southwards, creating favourable conditions for vectors to colonise new ecosystems and animal populations in temperate regions. These changes in the geographical distribution of vectors will also affect the distribution of vector-borne diseases, with a yet-unknown impact on animal and human health.

Forecasting such changes should be envisaged at the international level for diseases such as bluetongue, Rift Valley fever, West Nile fever and other vector-borne diseases, through co-ordinated research programmes.

Monitoring environmental predictors to forecast potential epidemics of RVF in time and space is still considered a growing field. However, establishing early warning systems based on this approach can and should be used to minimise the impact on livestock and human health. This is mostly possible because there is a reasonable understanding of disease epidemic cycles, which could change in a changing environment. In the context of climate change, it is even more important to develop such early warning systems and extend them to other diseases which also have major health impacts. Following the recent pattern of El Niño-Southern Oscillation effects, episodes of RVF may become more frequent, with shorter intervals between epizootics, justifying the need to invest in effective, national, regional and global early warning systems for vector-borne diseases.

Climatic seasonal forecasts and other predictors (NDVI, rainfall estimates) could further be used by National Veterinary Services to overcome some of the constraints on the maintenance of intensive ground surveillance and allow more sensitive predictions and comprehensive reviews of contingency plans. Such tools are also important in maintaining levels of awareness, not only for livestock-keepers and villagers, but also for the financial and political wings of governments so that they can more appropriately allocate the necessary resources.

■

Les conséquences du changement climatique sur l'épidémiologie et la prophylaxie de la fièvre de la Vallée du Rift

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Résumé

Le changement climatique modifiera probablement la fréquence des phénomènes climatiques extrêmes tels que les cyclones tropicaux, les inondations, les sécheresses et les ouragans, ce qui risque de déstabiliser et d'affaiblir certains aspects des écosystèmes indispensables aux sociétés humaines. Le changement climatique risque également d'affecter directement la santé des animaux, des hommes et des plantes : la distribution géographique des maladies infectieuses et des nuisibles se verra très probablement modifiée, y compris celle des maladies à transmission vectorielle comme la fièvre de la Vallée du Rift, la fièvre jaune, la malaria et la dengue, dont les vecteurs sont extrêmement sensibles aux conditions climatiques. Les évènements climatiques extrêmes pourraient ainsi créer des conditions favorables à l'expansion géographique de la fièvre de la Vallée du Rift vers le nord et au-delà de la Méditerranée et de la mer d'Arabie, avec des conséquences imprévisibles sur la santé animale et humaine des pays nouvellement atteints. Il est impératif de renforcer les systèmes d'alerte rapide au niveau mondial, régional et national, d'organiser des programmes de recherche et de mettre en œuvre les mesures de prévention et d'intervention qui s'imposent.

Mots-clés

Changement climatique – Fièvre de la Vallée du Rift – Maladie à transmission vectorielle – Système d'alerte rapide.

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Influencia del cambio climático en la epidemiología y el control de la fiebre del Valle del Rift

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Resumen

Es probable que el cambio climático altere la frecuencia de fenómenos meteorológicos extremos como ciclones tropicales, inundaciones, sequías o huracanes, y que ello debilite y desestabilice determinados servicios de los ecosistemas de los que dependen las sociedades humanas. También se piensa que el cambio climático afectará a la salud de animales, humanos y plantas por vías indirectas: seguramente cambiará la geografía de ciertas plagas y enfermedades infecciosas, lo que comprende la distribución de enfermedades transmitidas por vectores como la fiebre del Valle del Rift, la fiebre amarilla, la malaria o el dengue, vectores que son extremadamente sensibles a toda alteración de las condiciones climáticas. Los fenómenos meteorológicos extremos podrían incluso crear las condiciones necesarias para que el área de distribución geográfica de la fiebre del Valle del Rift se extendiera hacia el norte hasta cruzar los mares Mediterráneo y de Arabia, con imprevisibles consecuencias para la salud humana y animal en los nuevos países afectados. Es indispensable fortalecer los sistemas de alerta rápida a escala mundial, regional y nacional, contar con programas de investigación coordinados y aplicar las subsiguientes medidas de prevención e intervención.

Palabras clave

Cambio climático – Enfermedad transmitida por vectores – Fiebre del Valle del Rift – Sistema de alerta rápida.

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