

DROUGHT-ASSOCIATED CHIKUNGUNYA EMERGENCE ALONG COASTAL EAST AFRICA

JEAN-PAUL CHRETIEN,* ASSAF ANYAMBA, SHERYL A. BEDNO, ROBERT F. BREIMAN, ROSEMARY SANG, KIBET SERGON, ANN M. POWERS, CLAYTON O. ONYANGO, JENNIFER SMALL, COMPTON J. TUCKER, AND KENNETH J. LINTHICUM

Department of Defense Global Emerging Infections Surveillance & Response System (DoD-GEIS), Silver Spring, Maryland; NASA Goddard Space Flight Center, Greenbelt, Maryland; US Army Medical Research Unit-Kenya, Nairobi, Kenya; International Emerging Infections Program, CDC, Nairobi, Kenya; Kenya Medical Research Institute, Nairobi, Kenya; Field Epidemiology and Laboratory Training Program, CDC, Nairobi, Kenya; Division of Vector-Borne Infectious Diseases, CDC, Fort Collins, Colorado; USDA-ARS Center for Medical, Agricultural & Veterinary Entomology, Gainesville, Florida

Abstract. Epidemics of chikungunya fever, an *Aedes* spp.-borne viral disease, affected hundreds of thousands of people in western Indian Ocean islands and India during 2005–2006. The initial outbreaks occurred in coastal Kenya (Lamu, then Mombasa) in 2004. We investigated eco-climatic conditions associated with chikungunya fever emergence along coastal Kenya using epidemiologic investigations and satellite data. Unusually dry, warm conditions preceded the outbreaks, including the driest since 1998 for some of the coastal regions. Infrequent replenishment of domestic water stores and elevated temperatures may have facilitated Chikungunya virus transmission. These results suggest that drought-affected populations may be at heightened risk for chikungunya fever, and underscore the need for safe water storage during drought relief operations.

Transmitted by *Aedes* spp. mosquitoes, Chikungunya virus (CHIKV) causes febrile illness with joint pain. Illness is rarely fatal but can be severe and prolonged, and lead to other complications. Sylvan transmission cycles involving forest-dwelling *Aedes* spp. and wild primates maintain endemicity throughout tropical Africa. In tropical Asia, urban *Aedes aegypti* and *Aedes albopictus*-human cycles are thought to maintain CHIKV between epidemics.¹

During 2005–2006, large-scale chikungunya fever epidemics affected western Indian Ocean Islands and India (Figure 1A).^{2–7} The outbreak strain from the western Indian Ocean Islands was related to previous East-, Central-, and South-African isolates,⁸ and followed outbreaks along the Kenyan Coast in 2004, in Lamu (Bedno SA and others, unpublished data) then Mombasa (Breiman RF and others, unpublished data; Sang R and others, unpublished data). The total number of cases across the outbreaks during 2004–2006 is unknown, but they constitute, by far, the largest chikungunya fever epidemic on record. In La Reunion alone, the World Health Organization estimated that more than 200,000 people had been infected.² Estimated infections in Comoros and Lamu were 215,000 (63% of the population) and 13,500 (75% of the population), respectively, based on serological surveys (Breiman RF and others, unpublished data).

To explore eco-climatic contributions to epidemic chikungunya fever emergence in Kenya, we obtained satellite data through an early warning system developed for Rift Valley fever.⁹ This is part of the US Department of Defense Global Emerging Infections Surveillance and Response System (DoD-GEIS),¹⁰ which participated in the Lamu field investigations with the Kenya Ministry of Health and the US Centers for Disease Control and Prevention.

Normalized Difference Vegetation Index (NDVI), a measure of green vegetation density, was derived from measure-

ments made by the VEGETATION optical instrument on board the SPOT-4 earth observation satellite at nominal spatial resolution of 1 km.¹¹ The data were processed into monthly composites, and expressed as anomalies, or percent departure from reference monthly means over 1998–2005.^{12,13}

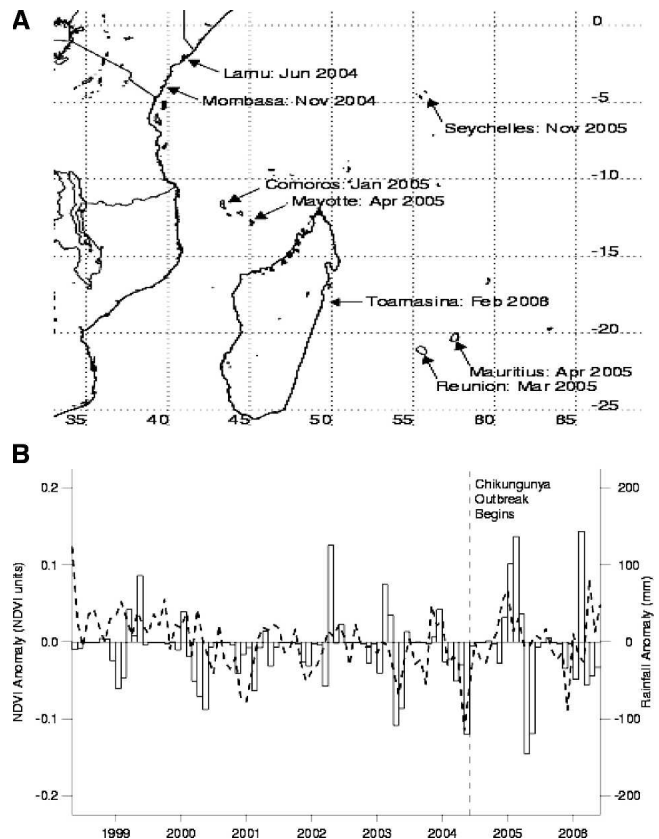


FIGURE 1. (A) Location of chikungunya fever epidemics in Kenya and West Indian Ocean islands during 2004–2006, by month and year of outbreak start. (B) Normalized Difference Vegetation Index (NDVI) anomalies (dashed line) and rainfall anomalies (bars) for Lamu. Negative NDVI and rainfall anomalies indicate unusually dry conditions.

* Address correspondence to Jean-Paul Chretien, Department of Defense Global Emerging Infections Surveillance & Response System, Division of Preventive Medicine, Walter Reed Army Institute of Research, 503 Robert Grant Avenue, Silver Spring, MD 20910-7500. E-mail: Jean-Paul.Chretien@na.amedd.army.mil.

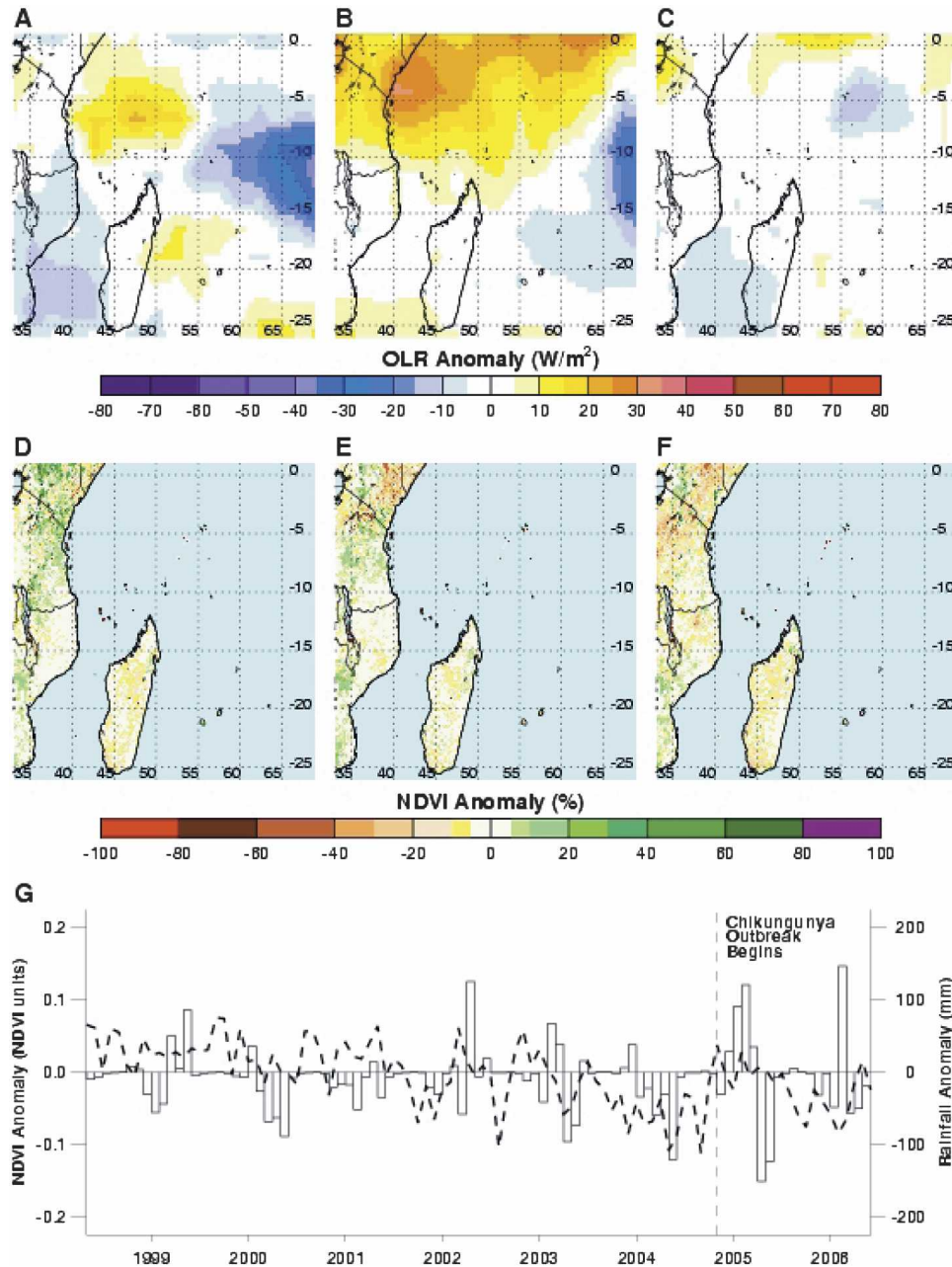


FIGURE 2. Outgoing Longwave Radiation (OLR) anomalies for (A) April, (B) May, and (C) June, 2004 (positive OLR anomalies indicate unusually warm and dry conditions). Normalized Difference Vegetation Index (NDVI) anomalies for (D) April, (E) May, and (F) June, 2004. G, NDVI (dashed line) and rainfall (bars) anomalies for Mombasa, Kenya. Negative NDVI and rainfall anomalies indicate unusually dry conditions. This figure appears in color at www.ajtmh.org.

Rainfall data is based on a satellite rainfall estimation algorithm using an area-averaged 10×10 km window centered on outbreak location.¹⁴ Daily rainfall estimates were summed to compute monthly totals. Data are expressed as monthly anomalies with respect to reference monthly means over 1995–2005. Outgoing longwave radiation (OLR) data were derived from measurements made by the NOAA polar-orbiting satellites series, and expressed as monthly anomalies with respect to reference means over 1979–2005. Negative OLR anomalies in the tropics represent regions of precipitating clouds, whereas positive OLR anomalies are associated with dry conditions.¹⁵

Cases of non-malarial febrile illness at Lamu District Hos-

pital increased sharply in June 2004; of 88 patients who presented with symptoms consistent with chikungunya fever in August, 56 (63%) tested positive for acute CHIKV infection by PCR or IgM capture enzyme-linked immunosorbent assay (ELISA; Bedno SA and others, unpublished data). Longitudinal NDVI measurements for Lamu showed that the drought conditions preceding the chikungunya fever outbreak were the most severe since 1998 (Figure 1B). Rainfall estimates were among the lowest for this time of year, usually the main rainy season (Figure 1B).

OLR measurements indicated unusually dry and warm conditions throughout East Africa, but especially along coastal Kenya, in May 2004 (Figure 2A–2C). NDVI measurements

also indicated severe drought conditions along the northern Kenya coast during April–June 2004 (Figure 2D–2F). As in Lamu, longitudinal NDVI and rainfall measurements were well below expected levels before the chikungunya fever outbreak in Mombasa, which occurred in November 2004 (Figure 2G).

To our knowledge, these were the first confirmed chikungunya fever outbreaks in coastal Kenya. Epidemic chikungunya fever emergence there after unusually warm, dry conditions contrasts with previous African and Asian epidemics, which followed heavy rain.¹ Although the original source and vector of CHIKV in the Lamu outbreak are unknown, widespread domestic water storage could have facilitated vector breeding and human contact. Infrequent water replenishment (expected because of drought) has been shown to increase domestic *Aedes aegypti* populations in coastal Kenya.¹⁶ Climatic effects, particularly elevated temperature, on virus development in vector mosquitoes also could have enhanced transmission efficiency.¹⁷ Interestingly, epidemic dengue-3 emergence in East Africa has also coincided with severe drought.¹⁸

Though preliminary, these results suggest that drought-affected populations may be at heightened risk for chikungunya fever, and underscore the need for safe water storage (especially ensuring tight lids on reservoirs to prevent mosquito breeding and egress) during drought relief operations. Vector precautions and control measures should be maintained after chikungunya fever outbreaks because as in Asia, large epidemics may recur as population immunity declines.¹ Integrated satellite-based drought monitoring and epidemiologic surveillance could identify areas at risk for chikungunya fever epidemics, and allow countries to institute timely prevention or control programs.

Received November 2, 2006. Accepted for publication November 21, 2006.

Acknowledgments: The authors thank the Kenya Ministry of Health and the staff of Lamu District Hospital for collaborating on this study.

Financial support: This study was supported by the Department of Defense Global Emerging Infections Surveillance & Response System.

Disclaimer: The opinions expressed here belong to the authors and are not necessarily the official views of the U.S. Army, the U.S. Navy, or the U.S. Department of Defense.

Authors' addresses: Jean-Paul Chretien, Department of Defense Global Emerging Infections Surveillance & Response System, Division of Preventive Medicine, Walter Reed Army Institute of Research, 503 Robert Grant Avenue, Silver Spring, MD 20910-7500, Telephone: 301-319-9418, Fax: 301-319-9213, E-mail: Jean-Paul.Chretien@na.amedd.army.mil. Assaf Anyamba and Jennifer Small, Goddard Earth Sciences & Technology Center, Goddard Space Flight Center, Bldg. 33, Rm. G109 (MC 923.0), Greenbelt, MD 20771, Telephone: 301-614-6601, Fax: 301-614-6699, E-mails: Assaf@ltpmail.gsfc.nasa.gov, and jsmall@pop900.gsfc.nasa.gov. Sheryl A. Bedno, Unit 64109 Box 401, APO AE 09831-4109, Telephone: +254-20-272-9303, Fax: +254-20-272-4592, E-mail: sbedno@wrp-nbo.org. Robert F. Breiman, CDC-KEMRI, Unit 64112, APO AE 09831-4112, Nairobi, Kenya, Telephone: +254-20-271-3008 x166, Fax: +254-20-271-4745, E-mail: RBreiman@ke.cdc.gov. Rosemary Sang, KEMRI, P.O. Box 54840,00200, Nairobi, Kenya, Telephone: +254-20-722541, Fax: +254-20-720030, E-mail: Rsang@kemri.org. Kibet Sergon, CDC-KEMRI, Unit 64112, APO AE 09831-4112, Nairobi, Kenya, Telephone: +254-20-271-3008, Fax: +254-20-271-4745, E-mail: kibetsergon@yahoo.com. Ann M. Powers, Division of Vector-Borne Infectious Diseases, Centers for Disease Control and Prevention, Foothills Campus / Rampart Road, Telephone: 970-266-3535, Fax: 970-266-3599, E-mail: akp7@cdc.gov. Clayton O. Onyango, MRC-Fajara Laboratories, P.O. Box 273 Banjul,

The Gambia, West Africa, Telephone: +220-449-5442/6 Ext 345, Fax: +220-449-5919, E-mail: conyango@mrc.gm. Compton J. Tucker, Code 614.0, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, Telephone: 301-614-6644, Fax: 301-614-6695/9, E-mail: compton@ltpmailx.gsfc.nasa.gov. Kenneth J. Linthicum, USDA-Center for Medical, Agricultural & Veterinary Entomology, 1600/1700 S.W. 23rd Drive, Gainesville, Florida 32608, Telephone: 352-374-5700, Fax: 352-374-5850, E-mail: klinthicum@gainesville.usda.ufl.edu.

Reprint requests: Jean-Paul Chretien, Department of Defense Global Emerging Infections Surveillance & Response System, Division of Preventive Medicine, Walter Reed Army Institute of Research, 503 Robert Grant Avenue, Silver Spring, MD 20910-7500, E-mail: Jean-Paul.Chretien@na.amedd.army.mil.

REFERENCES

- Jupp PG, McIntosh BM, 1988. Chikungunya virus disease. Monath TP, ed. *The Arboviruses: Epidemiology and Ecology*. Boca Raton, FL: CRC, 137-157.
- World Health Organization, 2006. Disease outbreak news: chikungunya and dengue in the south west Indian Ocean. http://www.who.int/csr/don/2006_03_17/en/index.html. Accessed 26 October 2006.
- World Health Organization African Region, 2006. Update on current outbreaks. http://www.afro.who.int/csr/epr/current_epidemics/april_2005.pdf. Accessed 26 October 2006.
- United Nations Office for the Coordination of Humanitarian Affairs—Integrated Regional Information Networks, 2006. Madagascar: Chikungunya virus confirmed. <http://www.reliefweb.int/rw/RWB.NSF/db900SID/DPAS-6MNCQW?OpenDocument>. Accessed 26 October 2006.
- ProMED-mail, 2006. Chikungunya—Mayotte, Reunion, Comoros. <http://www.promedmail.org/>. Accessed 26 October 2006.
- ProMED-mail, 2006. Chikungunya—Mauritius and Reunion Island. <http://www.promedmail.org/>. Accessed 26 October 2006.
- ProMED-mail, 2006. Chikungunya—Seychelles. <http://www.promedmail.org/>. Accessed 26 October 2006.
- Schuffenecker I, Itean I, Michault A, Murri S, Frangeul L, Vaney M, Lavenir R, Pardigon N, Reynes J, Pettinelli F, Biscornet L, Diancourt L, Michel S, Duquesnoy S, Guigon G, Frenkel M, Bréhin A, Cubito N, Desprès P, Kunst F, Rey FA, Zeller H, Brisse S, 2006. Genome microevolution of Chikungunya viruses causing the Indian Ocean outbreak. *PLoS Med* 3: 1058–1070.
- Linthicum KJ, Anyamba A, Tucker CJ, Kelley PW, Myers MF, Peters CJ, 1999. Climate and satellite indicators to forecast Rift Valley fever epidemics in Kenya. *Science* 285: 397–400.
- Chretien JP, Blazes DL, Gaydos JC, Bedno SA, Coldren RL, Culpepper RC, Fryauff DJ, Earhart KC, Mansour MM, Glass JS, Lewis MD, Smoak BL, Malone JL, 2006. Experience of a global laboratory network in responding to infectious disease epidemics. *Lancet Infect Dis* 6: 538–540.
- Tucker CJ, 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment* 8: 127–150.
- Holben BN, 1986. Characteristics of maximum-value composite images from temporal AVHRR data. *Int J Remote Sens* 7: 1417–1434.
- Anyamba A, Tucker CJ, Mahoney R, 2002. From El Niño to La Niña: vegetation response patterns over East and Southern Africa during 1997–2000 period. *J Clim* 15: 3096–3103.
- Xie P, Arkin PA, 1996. Analyses of global monthly precipitation using gauge observations, satellite summaries, and numerical model predictions. *J Clim* 9: 840–858.
- Chelliah M, Arkin PA, 1992. Large-scale interannual variability of outgoing radiation anomalies over the global tropics. *J Clim* 5: 371–389.
- Subra R, 1983. The regulation of preimaginal populations of *Aedes aegypti* L. (Diptera: Culicidae) on the Kenya coast. I. Preimaginal population dynamics and the role of human behaviour. *Ann Trop Med Parasitol* 77: 195–201.
- Watts DM, Burke DS, Harrison BA, Whitmire RE, Nisalak A, 1987. Effect of temperature on the vector efficiency of *Aedes aegypti* for dengue 2 virus. *Am J Trop Med Hyg* 36: 143–152.
- Gubler DJ, Sather GE, Kuno G, Cabral JR. Dengue 3 virus transmission in Africa. *Am J Trop Med Hyg* 35: 1280–1284.