Earth Remote Sensing to Improve Public Health

How USRA Earth scientists have responded to global human needs.

A part of the Great Rift Valley in eastern Africa, where the viral disease of Rift Valley fever was first identified. This disease affects domestic animals and humans throughout sub-Saharan Africa and results in widespread livestock losses and frequent human mortality.

USRA began its involvement in the Earth sciences in 1976 when officials at NASA's Marshall Space Flight Center (MSFC) asked the Association to assist in defining the experimental program for the Low-Gravity Atmospheric Cloud Physics Laboratory (ACPL). USRA's second president, Dr. Alexander J. Dessler, turned to Dr. Milford H. "Bill" Davis (1925-2010) to manage the work. Davis was a highly-regarded cloud physicist who had recently retired from the National Center for Atmospheric Research.

M.H. "Bill" Davis

The ACPL was designed to investigate the physics of cloud formation, as Davis explained to the USRA Council of Institutions in the spring of 1976:

> *The Low-Gravity Atmospheric Cloud Physics Laboratory, if it is approved, will be flown on the first Spacelab missions in 1980. Spacelab is a part of the Space Shuttle Program which will provide a "shirt-sleeve" environment in which scientist-astronauts can perform experiments while in orbit, then return to earth after a few days or weeks.*
>
> *An orbiting platform provides many unique opportunities for observing the earth and other bodies from outside the atmosphere, and for performing experiments concerning the space environment itself. The idea behind the ACPL, however, is to make use of the very low gravity that is experienced in orbit (of the order of 10^{-6} surface gravity) to perform critical laboratory experiments on the behavior of the tiny water droplets and ice particles that are the subject matter of cloud microphysics and that govern much of what we call "weather."*[1]

Davis explained that USRA's task was to assist

Essay by W. David Cummings. Design by Erin Senoz.

MSFC in specifying the functional requirements of the ACPL and to provide science-based advice to the two companies, General Electric (GE) and TRW, bidding to build the laboratory:

> *More broadly, I see our function as making sure that good scientific research is done in the orbiting laboratory, and that the program is broadly based in the scientific community. We have come into the program quite late in its development, but I have a strong sense of the need for the sort of focus that we are providing.*[2]

After three years of further study and analysis, and the selection of GE as the contractor to build the orbital laboratory, the ACPL was approved for three flights on the Space Shuttle. However, the project was canceled when it became apparent that the thermal design requirements were so stringent that the laboratory couldn't be built within budget.

At the time, it seemed an inauspicious beginning for a USRA program in the Earth sciences. But it led to an ongoing collaboration with NASA in the Earth sciences, perhaps for the reason noted in Dessler's report to the USRA Board of Trustees following the cancellation of the ACPL:

> *Davis held a conference in Boulder that examined NASA's future role in the general field of cloud microphysics. Davis' report was characteristically candid, and he was congratulated for this by John Carruthers and others at NASA Headquarters.*[3]

Davis continued to manage USRA's support of MSFC in the Earth sciences, building a USRA visiting scientist program there in atmospheric science. It marked the beginning of a very successful area of research for USRA, with support from MSFC, NASA Headquarters, and NASA's Goddard Space Flight Center (GSFC).

Much of USRA's work in the Earth sciences at MSFC has been focused on enabling technologies for acquiring and analyzing remotely-sensed data, particularly as it relates to the Earth's hydrological cycle. The work of Drs. William L. Crosson and Charles A. "Chip" Laymon, for example, advanced the ability to use remote sensing to measure soil moisture in the top ten centimeters of the Earth's surface. Their work indirectly affected public health because it contributed to a better understanding of Earth-atmosphere interactions and improved weather forecasting.

Some of USRA's work at MSFC has been focused more directly on the use of remote sensing to examine issues related to public health. For example, the work of Maurice Estes Jr. and his colleagues, Drs. Crosson, Laymon and Mohammad Al-Hamdan, focused on the urban heat island phenomena, its relation to air and water quality and other threats to public health, such as the impact of air pollution on hypertension and cognitive health.[4 5]

Urban Heat Islands (UHI)

The UHI results from the replacement of "natural" land covers (e.g., trees and grass) with urban land surface types, such as pavement and buildings. Heat stored in these surfaces is released into the air and results in a "dome" of elevated air temperature that presides over cities. The effect of this dome of elevated air temperature is known as the UHI, which is most prevalent about 2-3 hours after sunset on days with intense solar radiation and calm winds.[6]

Maurice Estes was trained as an urban planner, and his work on the applications of Earth remote sensing to questions of public health was funded in part by the U.S. Environmental Protection Agency and was confined to US cities such as Atlanta and Salt Lake City. USRA's work in Earth science applications related to public health on a more global scale began in earnest in 1992 with the establishment of a USRA Universities Earth Sciences Program (UESP), which was directed by another Estes, Professor John E. "Jack" Estes (1939-2001) of the

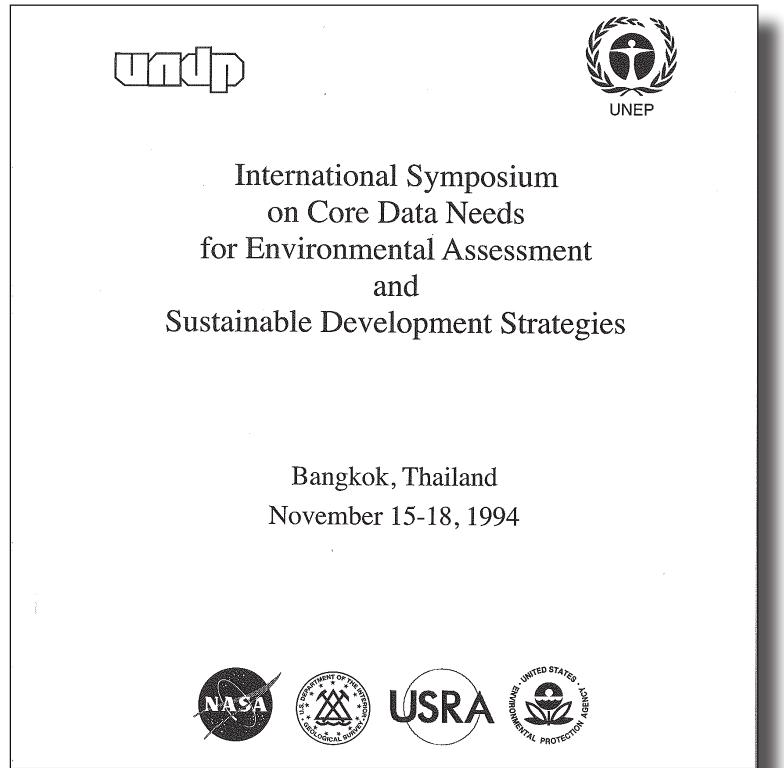
University of California, Santa Barbara (UCSB), and funded by NASA Headquarters. Professor Estes worked on a part-time consulting basis to direct the UESP, so USRA assigned a senior administrator, Elizabeth Pentecost, to be the Deputy Program Manager for him.

Jack Estes had recently spent a year at NASA Headquarters on leave from UCSB, and he saw the need for a program that would provide an opportunity for junior and senior scientists from disciplines related to the Earth sciences to work for one- to two-year periods with managers at NASA Headquarters. Their assignment would be to bring outside technical expertise covering a broad spectrum of disciplines to help NASA managers better understand the state of Earth science, including the programmatic issues and requirements related to scientific uncertainties and information needs. These experts would assist in the definition of new NASA missions and formulate recommendations and alternatives as a basis for national and international policy.

Among the scientists whom Estes brought to NASA Headquarters was D. Wayne Mooneyhan, who had served as the director of NASA's Earth Resources Laboratory in Mississippi from 1970 to 1985. He also served as director of the United Nations Environmental Programme Global Resources Information Database before joining USRA through the UESP.[7]

Mooneyhan remained with USRA as a Visiting Senior Scientist following his two-year appointment with the UESP, and with funding from the United Nations, Mooneyhan and Pentecost assisted the United Nations Development Programme and the United Nations Environment Programme in organizing an International Symposium on Core Data Needs for Environmental Assessment and Sustainable Development Strategies, which was held in Bangkok, Thailand, on 15-18 November 1994.

The symposium had 65 participants from nations across the globe, including Argentina, Australia, Bangladesh, Brazil, China, Costa Rica, Denmark, Djibouti, Ghana, India, Italy, Japan, Jordan, Kenya,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UNEP

International Symposium
on Core Data Needs
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and
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Bangkok, Thailand
November 15-18, 1994

NASA USRA

Lesotho, Malaysia, Mexico, the Netherlands, the Philippines, Russia, Senegal, South Africa, Thailand, the United Kingdom, Uganda, the United States, and Zimbabwe. The motivation for the symposium was to investigate the possible use of satellite remote sensing to aid countries, particularly in environmental management and development. The first step, and the main goal of the symposium, was to seek consensus on the priority issues for environmental assessment and sustainable development and the core data sets needed to respond to these issues.

One of the panels at the symposium dealt with human health data needs, and particularly the problem of diseases propagated by mosquitoes as "vectors." Dr. Mario Rodriguez of the Ministry of Health in Mexico, made the point that:

> *The prevention of vector-borne infectious diseases requires fresh and freshly-processed data. Environmental conditions determine the co-existence of the disease agent, animal reservoirs and humans and therefore, the presence of disease. Remote sensing can help detect these vectors and their interactions. Since health is connected to the environment, it is possible to use remote sensing ... to study health.*[8]

Image courtesy: Assaf Anyamba

Assaf Anyamba

The nexus of remote sensing, the environment, and health would be the focus of the research of Dr. Assaf Anyamba, a USRA Earth scientist who grew up in the Nandi Hills area of western Kenya and received his undergraduate degree in Geography and Economics from Kenyatta University in Nairobi in 1989. He then obtained a Master's degree in Geography from Ohio University in 1992. Anyamba had to finish his thesis work early so that he could accept a summer internship in USRA's Graduate Student Summer Program in Earth System Science at GSFC. The program was open to students who had been accepted at an accredited graduate school, and Anyamba had been accepted into the PhD program at Clark University for the fall of 1992. Only ten students per year were invited to participate in the ten-week USRA Summer Program.

Anyamba had been interested initially in the application of satellite remote sensing to mapping. During his summer internship, he was introduced to the connections between changes in vegetation as observed by satellite remote sensing and the El Niño Southern Oscillation (ENSO).[9] Anyamba now knew what he wanted to study for his PhD at Clark University. Following his summer internship with USRA, he worked under Professor J. Ronald Eastman at Clark, and in 1997 he received his PhD in Geography with a focus on remote sensing of land surface patterns of the ENSO. Anyamba returned to USRA in 1999, when he joined the Visiting Scientist Program at GSFC.[11] That year, he and his colleagues published a paper in *Science* magazine that explained how satellite remote sensing might be used to predict the outbreak of Rift Valley fever in Kenya:

> *Rift Valley fever (RVF), a viral disease first described in Kenya in 1931, affects domestic animals and humans throughout sub-Saharan*

ENSO

Over much of the middle to lower latitudes of the globe, El Niño-Southern Oscillation events are a most important source of year to year variability in climate. These episodes involve large-scale ocean-atmosphere interactions. The Southern Oscillation component represents a tendency for atmospheric surface pressure to stay below normal throughout the central and south Pacific while it stays above normal across Australia, South-East Asia and the Indian Ocean, and vice versa. During the phase where the pressure is low in the Pacific, warm water replaces the usually cool surface waters of the central and eastern equatorial Pacific–an event known as 'El Niño' (although originally 'El Niño' referred to only the warming off Peru). Together, the anomalies in the atmosphere and ocean are known as El Niño-Southern Oscillation (ENSO) events. During the opposite phase, an 'anti-ENSO event', surface waters in the eastern Pacific are colder than normal. ENSO events are aperiodic, but occur with a frequency of between 2 and 10 years. A commonly used ENSO indicator is the Southern Oscillation Index (SOI) which is based on the atmospheric pressure difference between Tahiti and Darwin.[10]

> *Africa and results in widespread livestock losses and frequent human mortality. Its occurrence is known to follow periods of widespread and heavy rainfall associated with the development of a strong intertropical convergence zone, the region in the equatorial tropics where air currents from the north and south converge and produce precipitation. Such heavy rainfall floods mosquito breeding habitats in East Africa, known as "dambos," which contain transovarially infected Aedes mosquito eggs and subsequently serve as good habitats for other Culex species mosquito vectors. …*
>
> *Vegetation responds to increased rainfall and can be easily measured by satellite. Normalized difference vegetation index (NDVI) data from the advanced very high resolution radiometer (AVHRR) on National Oceanic and Atmospheric Administration (NOAA) satellites have been used to detect conditions suitable for the earliest stages of an RVF epizootic.*[12]*… Here we show that several climatic indices can be used to predict outbreaks up to 5 months in advance.*[13]

The authors further explained the link between ENSO and NDVI:

> *The El Niño-Southern Oscillation (ENSO) phenomenon is a principal cause of global interannual climate variability. Warm ENSO events are known to increase precipitation in some regions of East Africa. The Southern Oscillation Index (SOI) is the most commonly used index for the ENSO phenomena and extends back to the late 19th century. This index compares atmospheric pressure in Tahiti with that of Darwin, Australia, and is expressed as a standard deviation from the norm. Strong negative anomalies are associated with an El Niño event. Anomalous climatic conditions caused by ENSO are now recognized to be linked with outbreaks of various human and livestock diseases in various countries. Above normal East African rainfall is associated with negative SOI anomalies resulting in more green vegetation, which then is detected by the satellite-derived NDVI.*[16]

Having grown up in Kenya, Anyamba knew firsthand the societal impacts of Rift Valley fever. In an article on climate-disease connections in Kenya, Anyamba and his colleagues wrote:

> *Rift Valley fever is a good example of a disease that is well coupled with climatic anomalies. The ability to forecast these ENSO events almost a year in advance means that we can in principle anticipate with some level of confidence the areas that are likely to be*

NDVI

The Normalized Difference Vegetation Index (NDVI) is a measure derived by dividing the difference in infrared and red reflectance measurements by their sum

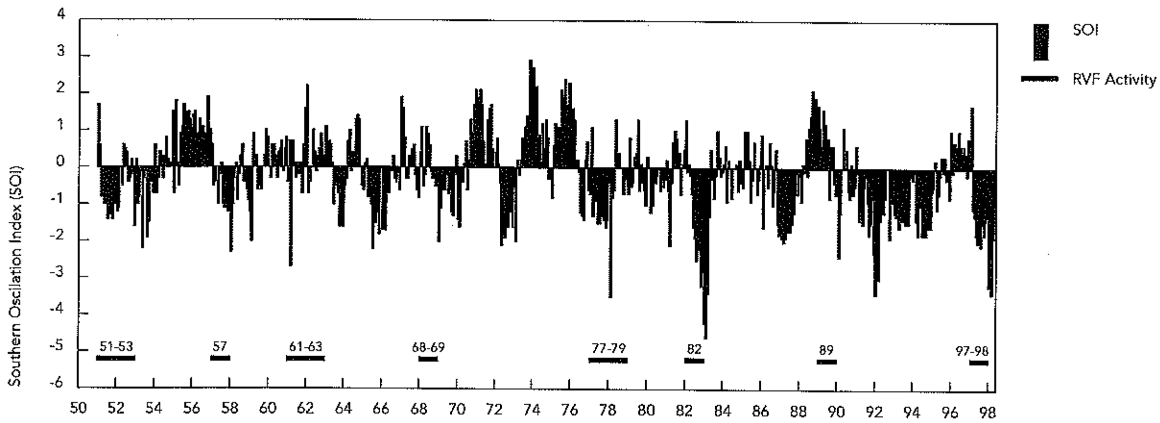
$$NDVI = (\rho_2 - \rho_1)/(\rho_2 + \rho_1)$$

where ρ_1 and ρ_2 are the upwelling land surface reflectance in the red and infrared portions of the electromagnetic spectrum. A green vegetation canopy strongly absorbs incident solar radiation in the visible red band (0.55-0.70 µm)[14] due to high chlorophyll density and the presence of carotene pigments, and high scattering and thus reflectance in the infrared band (0.73-1.1 µm) resulting from leaf structural characteristics and phenological canopy effects. This index has been found to provide a strong vegetation signal and good spectral contrast from most background materials.[15]

impacted. This provides a valuable lead-time to take measures to reduce negative societal impacts of ENSO on health and economic well-being. Livestock is the main source and in some cases the only source of livelihood and cash economy in the semi-arid and arid parts of Kenya. The death of large herds of livestock from RVF and other livestock-related diseases and flooding destroys the local economy. During the 1997-1998 ENSO event, the Gulf Arab countries banned the importation of livestock products from East Africa due to the fear of spreading RVF to humans in these countries. This ban, enforced for almost a year, resulted in a loss of foreign exchange earnings to Kenya, Somalia, and Ethiopia, and in effect jeopardized the domestic economy and the livelihoods of pastoral farmers. In addition, it takes many years to restock and build productive livestock herds to generate market value. The occurrence of RVF may and does perpetuate poverty conditions for several years in these areas. Pastoral farmers are forced to take loans from the respective governments to buy livestock. It often takes a long time to pay back these loans.[17]


Image courtesy: Assaf Anyamba

Scientists taking samples from a flooded dambo in Kenya before the 2006 outbreak of Rift Valley fever.



Time series of SOI anomalies from 1950 to May 1998. Periods of RVF activity in Kenya are depicted as thick black bars. Note that in most cases, outbreaks occurred during periods of the negative phase of the SOI. (From figure 3 of Anyamba et al., 2001, p. S137.)

With this as background, Anyamba and a colleague from the U.S. Department of Defense (DoD), Dr. Kenneth J. Linthicum,[18] designed an operational system by which lives and livelihoods might be saved, as opposed to analyzing data to show what might have been done to prevent the loss of lives and livelihoods. This operational system began to form in 1999, when NASA and the DoD initiated the development of a program to systematically monitor and map areas at potential risk for outbreaks of diseases such as RVF. As the joint program evolved, it increasingly used the NDVI data generated by the Global Inventory Mapping and Monitoring System that Anyamba and his colleagues had been developing at GSFC.

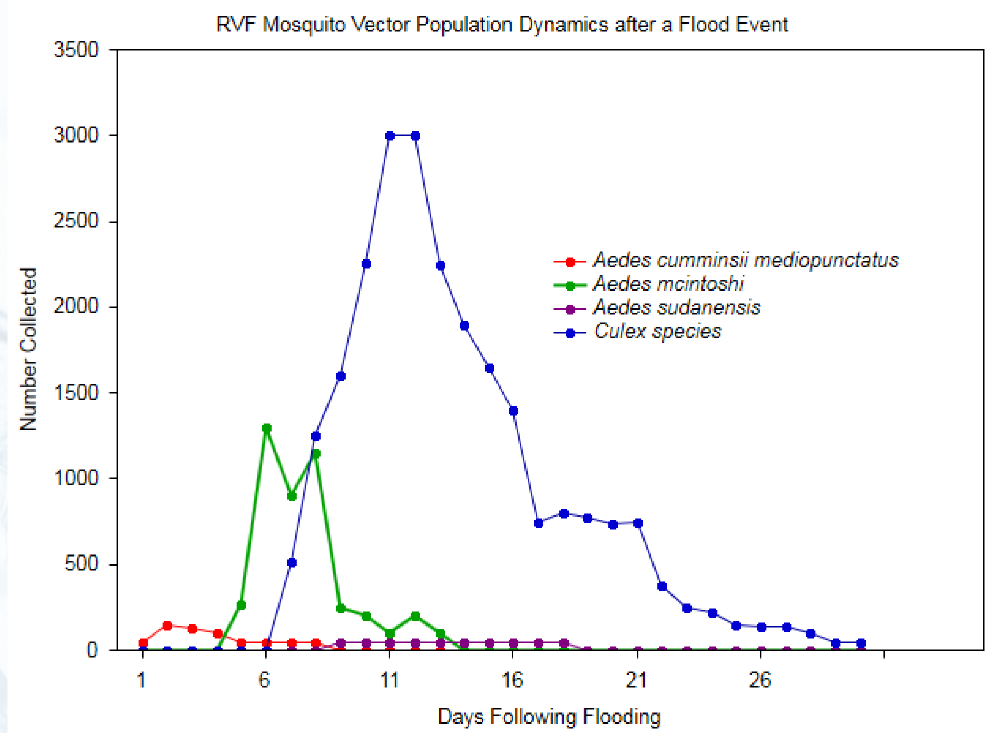
Credit: good-pix galleries (pixgood.com)

Map of East Africa, showing the Great Rift Valley. Rift Valley fever takes its name from the region in Kenya where it was first discovered, namely the Great Rift Valley, which is part of the Rift Valley geological structure of East Africa. The structure is caused by a developing rupture of the African tectonic plate, forming two plates that are slowly moving apart.

As Anyamba and others have noted, the challenge of implementing an effective operational program that uses remotely sensed data to provide advanced warnings of disease outbreaks is extremely complicated:

[T]he resolution of satellite-borne remotely sensed imagery is such that picture elements (pixels) commonly represent multiple land covers. In addition, remote sensing instruments sense electromagnetic energy that has travelled through the atmosphere. Thus, the seasonal character of vegetation index measurements over time may exhibit trends that represent changes in land cover and viewing conditions (such as changes in the presence of water vapor and aerosols) as well as true phenological responses.[19]

A single indicator, such as anomalies in the SOI, isn't sufficient to accurately predict elevated rainfall in at-risk regions. Concurrent anomalies in sea-surface temperatures in the eastern-central Pacific Ocean and the western equatorial Indian Ocean are much better leading indicators for elevated rainfall in the RVF endemic region of the Horn of Africa than anomalies in the SOI.[20]



Mosquito population dynamics after a flood event.

(From figure 2 in Anyamba et al., Remote sensing contributions to prediction . . . 2012) Background image:Tischenko Irina/Shutterstock.com

The mosquito vectoring is also complex, involving different species of mosquitos:

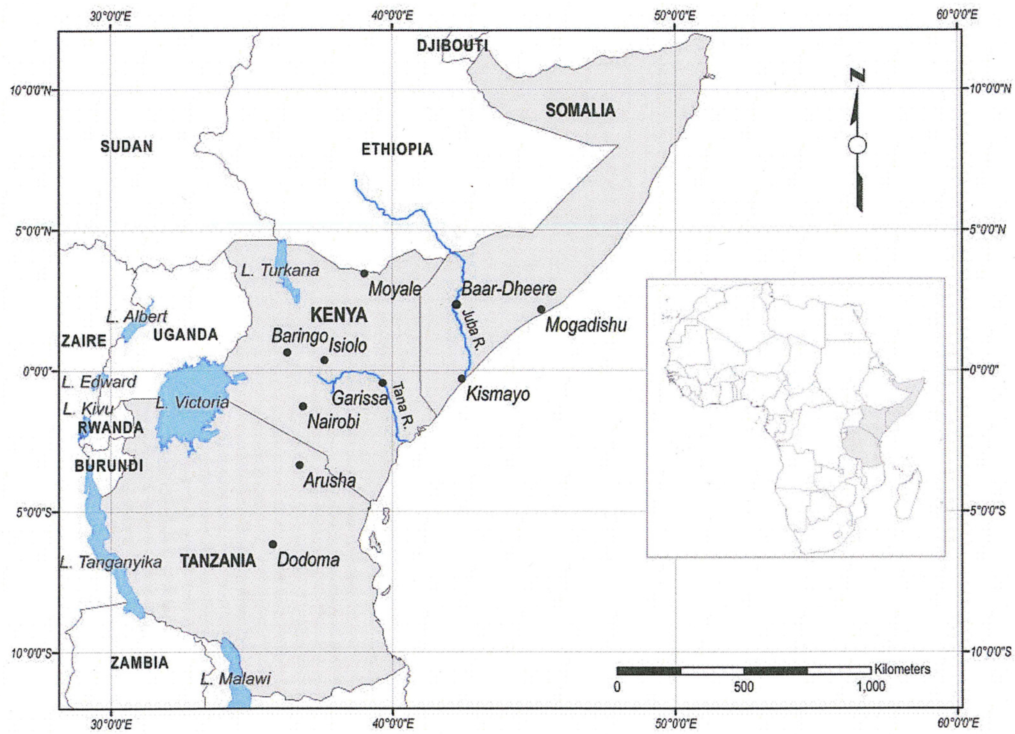
> *The flooding of dambos induces the hatching of transovarially infected Aedes mcintoshi mosquito eggs that are dormant in the soil, producing infected adult females in 7–10 days that can transmit RVF virus to domestic animals.... After a blood meal, the Aedes mosquitoes will lay infected eggs on moist soil at the edge of mosquito habitats, but appear to not be an efficient secondary vector of the virus between infected and noninfected domestic animals and humans.... However, Culex species mosquito vectors subsequently colonize these flooded dambos and, with a delay of several weeks, large populations of these mosquitoes emerge and efficiently transmit the virus from domestic animals, which amplify the virus, to noninfected domestic animals and humans ...*[21]

And, while increased rainfall results in an increase in mosquito vector populations, decreased rainfall can be a problem as well:

> *Decreased rain can severely reduce or eliminate food resources forcing vectors and vertebrate hosts into human settlements, increasing vector-human contact ...*[22]

Anyamba and his colleagues persevered despite these challenges, and by the early 2000s, the risk monitoring and mapping system they were developing used the analysis and interpretation of observations from several satellites, including data on sea surface temperatures, cloudiness, rainfall, and vegetation dynamics.

By the fall of 2006, their models were refined to the point of being able to predict outbreaks of RVF in various parts of the Horn of Africa. In an article for the *Proceedings of the National Academy of Sciences*, Anyamba and his team of colleagues–from the DoD's Division of Preventive Medicine, the World Health Organization's (WHO) Department of Epidemic and Pandemic Alert and Response, the U.S. Army Medical Research Unit-Kenya, and the U.S. Department of Agriculture's Research Service Center for Medical, Agricultural, and Veterinary Entomology–reported on the first prospective prediction of an RVF outbreak.[23]



RVF outbreak region (shaded) in the Horn of Africa. From figure S1 in Anyamba et al., 2009.

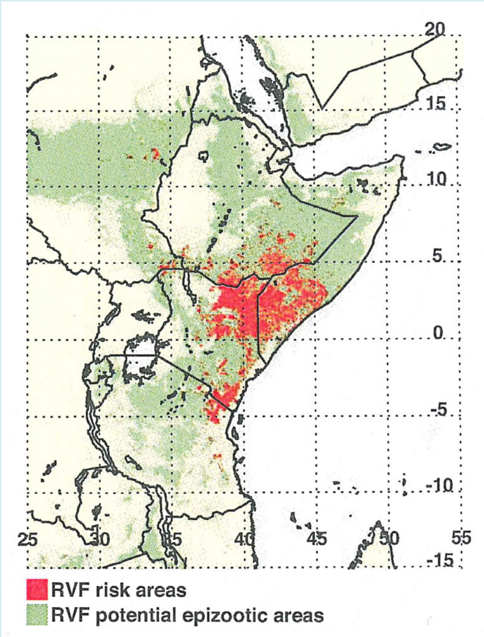
The team used information from previous RVF outbreaks and the analysis of satellite data to map areas in Africa at elevated risk of RVF. They began to issue monthly early-warning advisories for the Horn of Africa in September 2006. Based on NDVI data that showed anomalously high levels of green vegetation during the month of October, the team could see that most of the central Rift Valley, eastern and north-eastern regions of Kenya, southern Ethiopia, most of central Somalia, and northern Tanzania were at an elevated risk for RVF outbreaks, and they issued an early-warning advisory for these regions in early November 2006. The U.S. DoD–Global Emerging Infections Surveillance and Response System and the Department of Entomology and Vector-borne Disease, U.S. Army Medical Research Unit-Kenya initiated entomological surveillance in Garissa, Kenya, in late November 2006. The first human cases of RVF in Kenya were reported from Garissa in mid-December 2006.[24] The impact of the outbreak of RVF was mitigated because the early warning enabled the government of Kenya, in collaboration with the WHO, the U.S. Centers for Disease Control and Prevention, and the Food and Agricultural Organization of the United Nations to mobilize resources to implement disease mitigation and control activities in the affected areas, and prevent its spread to unaffected areas.[25]

The locus of rainfall in East Africa began to shift southward during December 2006. By using their risk mapping models, the team then issued another alert on the potential of RVF in northern Tanzania, and from mid-January 2007 RVF cases began to be reported there.[26]

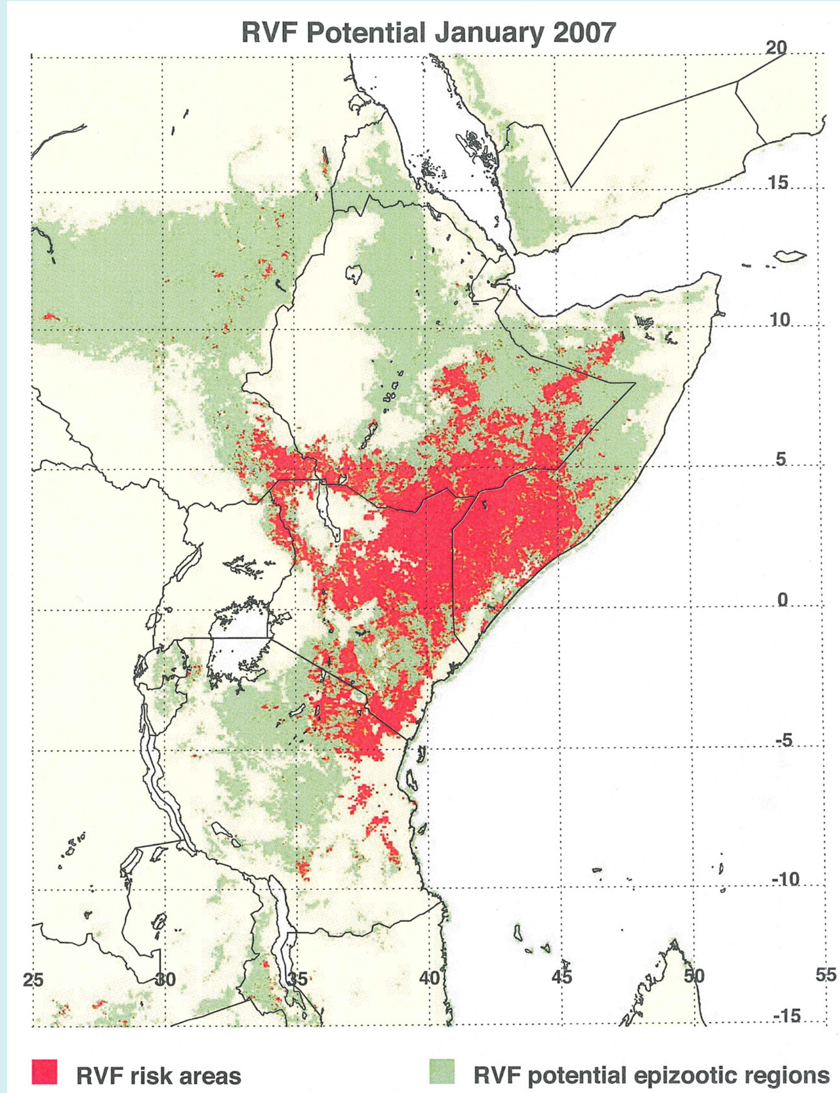
Continued monitoring in 2007 resulted in a warning alert for Sudan in early June, and the first human case of RVF was identified there in early October.[27]

The team reported its results in a journal article in 2010:

> *In contrast to the 1997–1998 outbreak ..., the early warning described here for late 2006 and early 2007 enabled vector and disease surveillance activities to be initiated in Kenya and Tanzania 2 to 6 weeks before the human disease cases were identified. After the early identification of RVF transmission between the end of November and early December 2006 in Kenya, enabled by the early warning, subsequent enhanced surveillance activities and additional mitigation activities were implemented, including animal movement restrictions/quarantines, distribution of mosquito nets, social mobilization and dissemination of public information related to reducing human contact with infected animal products and mosquito vectors, and specific domestic animal vaccination and mosquito control programs in at-risk areas...*



Top: RVF calculated risk map for December 2006 for the Horn of Africa. Right: RVF calculated risk map for January 2007 for the Horn of Africa. Top from Figure 6 of Anyamba et al., 2009, p. 957. Right from figure S6 of Anyamba et al., 2009, Supporting Information, p. 9.

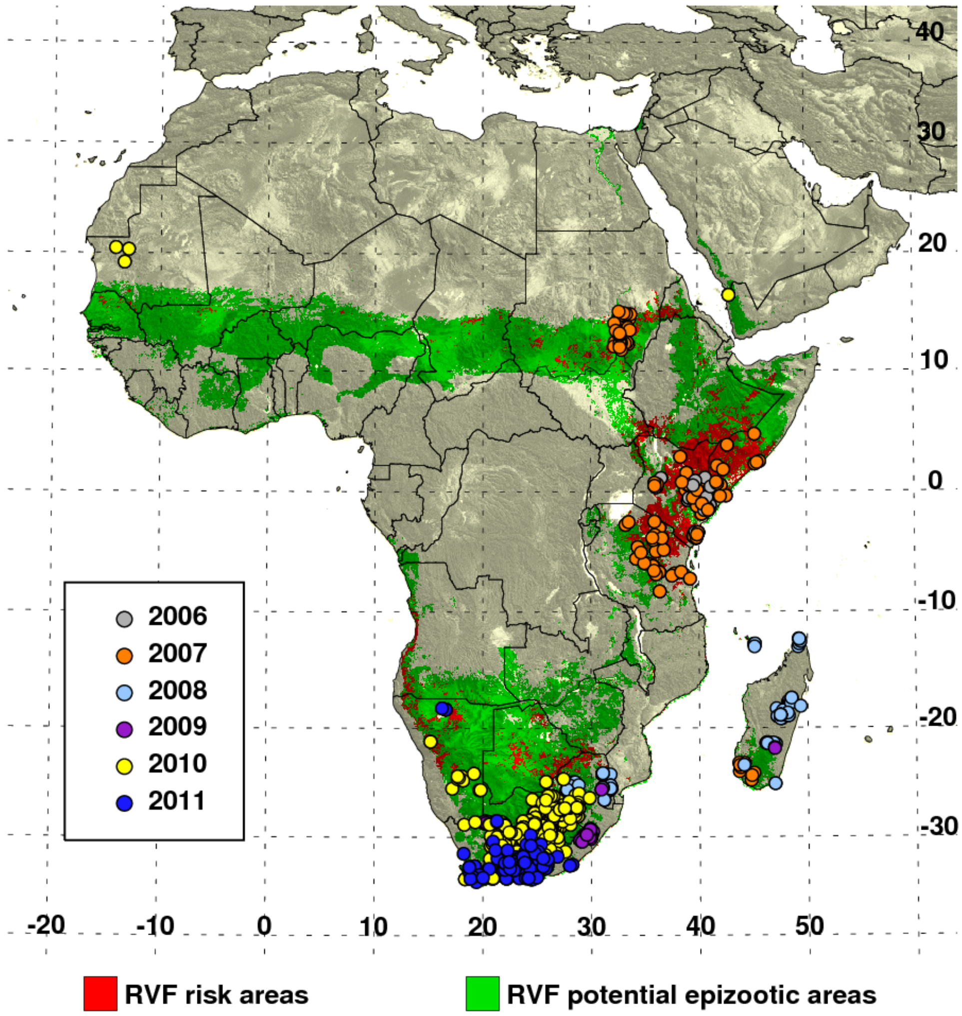


This analysis demonstrates that satellite monitoring and mapping of key climate conditions and land surface ecological dynamics ... are an important and integral part of public health surveillance and can help reduce the impact of outbreaks of vector-borne diseases such as RVF. This is one of many societal benefits that result from a robust earth observing system that monitors key climate variables in a systematic and sustained fashion.[28]

The human death toll from RVF in Kenya during the 2006-2007 outbreak was much less than it was during the 1997-1998 outbreak. Still, 158 Kenyans lost their lives to the disease. There were 51 deaths reported in Somalia, 109 in Tanzania, and 214 in Sudan.[29] The loss of livestock and forced closure of livestock markets, with the attendant negative societal effects, were substantial in these countries.

While others worked on additional approaches, such as the development of vaccines for use against the RVF virus in animals and humans, Anyamba and members of his multi-agency team continued to refine their risk model. During subsequent outbreaks of RVF, they have been able to lengthen the time gap between the early warning alert in each country and the first reported human case. Because of their advanced warning and the response of the government of Kenya, for example, in the vaccination of animals in areas where the outbreak was anticipated, there were no reported cases of RVF in Kenya during the strong ENSO event of 2015-2016.[30]

At this writing, the U.S. Department of Agriculture hosts a Rift Valley Fever Monitor on the web that is updated on a monthly basis.[31] This system has been used to predict RVF outbreaks in other parts of



Composite RVF risk map based upon extended heavy rainfall, ecological habitats associated with epizootics, and population density map of cattle, sheep, and goats, and outbreak locations based upon human case data. The composite RVF Risk Map shows data for (1) East Africa (September 2006-May 2007), (2) Sudan (June-November 2007), and (3) southern Africa including Madagascar (October-May composite aggregated for each year 2007-2011). RVF human case data are mapped for (1) East Africa (Kenya, Somalia, Tanzania) 2006-2007, (2) Sudan 2007, (3) Southern Africa (Madagascar, South Africa, Botswana, Namibia, South Africa) 2008-2001, and (4) West Africa/Middle East (Yemen/Saudi Arabia) 2010. (From figure 2 of Linthicum et al., 2016, p. 407)

Africa and in the Arabian peninsula as shown in the accompanying figure.

The Rift Valley Fever Project is now considered by the U.S. DoD to be the initial effort that spurred the extension of predictive surveillance capabilities to other priority vector- and water-borne diseases:

> *These include leishmaniasis, malaria, and Crimea-Congo and other viral hemorrhagic fevers in Central Asia and Africa, dengue fever in Asia and the Americas, Japanese encephalitis (JE) and chikungunya fever in Asia, and rickettsial and other tick-borne infections in the U.S., Africa and Asia.*[32]

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USRA's Dr. Assaf Anyamba has been a key leader in the interagency team that has brought about these important predictive services that depend on satellite remote sensing. Organizations and agencies around the world now depend upon and use these services, since all are aware of the potential for the globalization of viruses such as happened with the West Nile virus.[33] The U.S. DoD continues to support the surveillance work not only because of the protection it affords for U.S. military forces stationed abroad, but also for the needed ability to discriminate between naturally occurring outbreaks and those that might have been deliberately introduced as a tactic of bioterrorism.[34]

It has taken determination fueled by passion on the part of Anyamba to overcome not only technical difficulties but programmatic and bureaucratic obstacles, as well. An example of the latter was the withdrawal of funding from one of the key supporting agencies for about half a decade following the successful prediction of the outbreak of RVF in East Africa in 2006. This support has now been restored, but the lapse resulted in not only the loss of experienced staff but also the loss of years of archived data that were vital to the risk model that the team had developed.

When USRA was formed in 1969, it was focused on a partnership with NASA for the exploration of the Moon. As the Nation's interest in space research expanded to include the Earth sciences, USRA's partnership with NASA continued, perhaps in part because NASA valued the integrity of USRA managers like Bill Davis. This continued partnership allowed USRA's scientists to bring to bear their passion and ingenuity on challenging problems that require collaborations with many different agencies, as illustrated by the career of Dr. Assaf Anyamba. At this writing, his work within USRA's Goddard Earth Sciences Technology and Research program directly supports research and program services for several agencies, including

- The Production Estimates and Crop Assessment Division of the U.S. Department of Agriculture's Foreign Agriculture Service
- The U.S. Agency for International Development's Famine Early Warning Systems Network
- The U.S. DoD's Global Emerging Infections Surveillance System
- The U.S. Department of Agriculture's Center for Medical, Agricultural and Veterinary Entomology
- The U.S. Food and Drug Administration.

[1] Davis, M. H. (1976). The low-gravity atmospheric cloud physics laboratory (ACPL), Appendix F of the minutes of the USRA Council of Institutions Meeting, p. 28. USRA Archives.

[2] Ibid., pp. 28-29.

[3] Dessler, A. J. (1980). President's Report to the USRA Board of Trustees and Council of Institutions. USRA Archives.

[4] Estes Jr, M. G., Al-Hamdan, M. Z., Crosson, W., Estes, S. M., Quattrochi, D., Kent, S., and McClure, L. A. (2009). Use of remotely sensed data to evaluate the relationship between living environment and blood pressure. *Environmental Health Perspectives*, *Vol. 117*, No. 12, pp. 1832-1838.

[5] Loop, M. S., Kent, S. T., Al-Hamdan, M. Z., Crosson, W. L., Estes, S. M., Estes Jr, M. G., Quattrochi, D. A., Hemmings, S. N., Wadley, V. G., and McClure, L. A. (2013). Fine particulate matter and incident cognitive impairment in the REasons for Geographic And Racial Differences in Stroke (REGARDS) cohort. *PloS one, 8*(9), e75001.

[6] Quattrochi, D. A., Luvall, J. C., Rickman, D. L., Estes Jr, M. G., Laymon, C. A., Crosson, W., Howell, B. F., Gillani, N. V., and Arnold, J. E. (2002). High Spatial Resolution Thermal Remote Sensing of the Urban Heat Island Effect: Assessment of Risks to Human Health and Development of Mitigation Strategies for Sustainable Cities. Abstract. Retrieved from the NASA Technical Report Server.

[7] Mooneyhan, D. W. (1998). International applications of GIS. In T. W. Foresman (Ed.), *The History of Geographic Information Systems: Perspectives from the Pioneers*, p. 349. Prentice Hall Inc.

[8] Rodriguez, M. (1994). Human health data needs and availability in Mexico. In Appendix 6 of the report of the International Symposium on Core Data Needs for Environmental Assessment and Sustainable Development Strategies, Volume II, p. 111.

[9] "The 'El Niño' is an unusual warming of the normally cool near-surface waters off the west coast of South America. It was so named by the inhabitants of northern Peru in reference to the Christ-child, because it typically appears as an enhancement to the annual onset of a warm, southward setting current that occurs there around the Christmas season." (Enfield, D. B., 1993. Historical and prehistorical overview of El Niño/Southern Oscillation. In H. F. Diaz and V. Markgraf (Eds.), *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation*, p. 96. New York: Cambridge University Press.

[10] Whetton, P., and Rutherfurd, I. (1994). Historical ENSO teleconnections in the Eastern Hemisphere. *Climatic change, 28*(3), p. 221.

[11] Following his years at Clark University, where he obtained his PhD, Anyamba re-joined USRA as a post-doctoral student in USRA's Visiting Scientist Program at GSFC that was led by Dr. Michael Kalb. USRA lost the competition to continue the management of the visiting science program at GSFC, and Anyamba then worked for the University of Maryland, Baltimore County, until he rejoined USRA in 2011 as a staff scientist in the Goddard Earth Sciences Technology and Research (GESTAR) program, led by Dr. William Corso.

[12] The term "epizootic" refers to an outbreak of disease in animals, whereas "epidemic" refers to an outbreak of disease in humans.

[13] Linthicum, K. J., Anyamba, A., Tucker, C. J., Kelley, P. W., Myers, M. F., and Peters, C. J. (1999). Climate and satellite indicators to forecast Rift Valley fever epidemics in Kenya. *Science, 285*(5426), p. 397.

[14] 1 $\mu m = 10^{-6}$ meters is also called a "micron."

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