U.S. Global Change Research Program

PREDICTING CLIMATE-SENSITIVE INFECTIOUS DISEASES TO PROTECT PUBLIC HEALTH AND STRENGTHEN NATIONAL SECURITY

A workshop report and framework for future action

June 2019

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The 2017 National Security Strategy states that "biological threats to the U.S. homeland—whether as the result of deliberate attack, accident, or a natural outbreak—are growing and require actions to address them at their source."[1]

The foundation for these threats exists in the natural world: three-quarters[2] of emerging infectious diseases (EIDs) come to humans from other animals; some of these emerging diseases (and many others that are already established) are waterborne or carried by insect vectors. These risks are partially shaped by climate-related variables such as rainfall, temperature, and humidity[3] and consequent changes in the environment, which was the focus of this workshop and report.

The purpose of this document is to outline the challenges and a possible path forward for increasing the U.S. government's ability to predict, prevent, and prepare for climate-sensitive infectious diseases that threaten U.S. interests at home and abroad.

Addressing these threats at their source requires a sustained intersectoral approach – combining the knowledge of earth systems and observations, ecology, public health, social science, and more. In July and August 2017, participants from departments and agencies from across the U.S. government met to identify ways to address climate-sensitive diseases of national security and public health concern. Motivated by recent outbreaks of vector-borne and zoonotic diseases in the Americas and other regions of the world, an interagency steering committee chose to focus on these diseases among the range of climate-sensitive human diseases. The purpose of the two webinars and one workshop was to assess the scientific and operational systems in place for addressing these climate-sensitive diseases and identify scientific and institutional gaps and opportunities to improve knowledge, preparedness, or both. This report summarizes the key discussion points and findings of the group's work.

The participants agreed that changes in climate patterns will affect a variety of infectious disease risks – both directly and through impacts to water and ecosystems, nutrition, and health care delivery systems. Significant progress towards understanding how climate impacts disease and health systems has been made in the scientific arena, and participants noted several common goals, including enhancing the effectiveness of interventions to limit the spread of diseases. While climate information and prediction tools could inform planning and decision making with months of lead time, much of the work on climate prediction is not fully coordinated with public health preparedness and response operations in at-risk areas, nor is it integrated with longer term planning and prevention efforts. Health decision-making needs have not been fully identified, key research and knowledge gaps remain, and obstacles to taking early action have not been resolved. For example, Early Warning Systems for climate sensitive diseases

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1 The White House. National Security Strategy of the United States. December 2017. https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905-2.pdf
2 Belay ED, Kile JC, Hall AJ, Barton-Behravesh C, Parsons MB, Salyer SJ, et al. Zoonotic Disease Programs for Enhancing Global Health Security. Emerg Infect Dis. 2017;23(13). https://dx.doi.org/10.3201/eid2313.170544
3 McIntyre, K. Marie, Setzkorn C, Hepworth P, Morand S, Morse A, and Baylis M. Systemic Assessment of the Climate Sensitivity of Important Human and Domestic Animals Pathogens in Europe. Scientific Reports. 2017: 7 (7134) doi:10.1038/s41598-017-06948-9

are proliferating and have proven valuable in some circumstances, yet they remain highly under-utilized. When implemented with sustained decision maker engagement, through a robust Integrated Information System or other institutional construct that integrates climate, social and environmental experts and information, these systems can generate meaningful information for the health sector and offer both scientific and institutional examples from which to learn.

The group identified a framework for approaching these challenges (Figure 1). This framework builds on the lessons of the Integrated Information and Early Warning systems which demonstrate the value of engaging decision makers to help identify the science and operational needs. The framework is centered on an operational cycle of observation, analytics and modeling, and risk communication. Research, policy engagement, and outreach are critical buttressing measures that provide the knowledge, resources, and partnerships necessary for the operational cycle to function. The group also identified a series of steps that could strengthen each aspect of the framework.

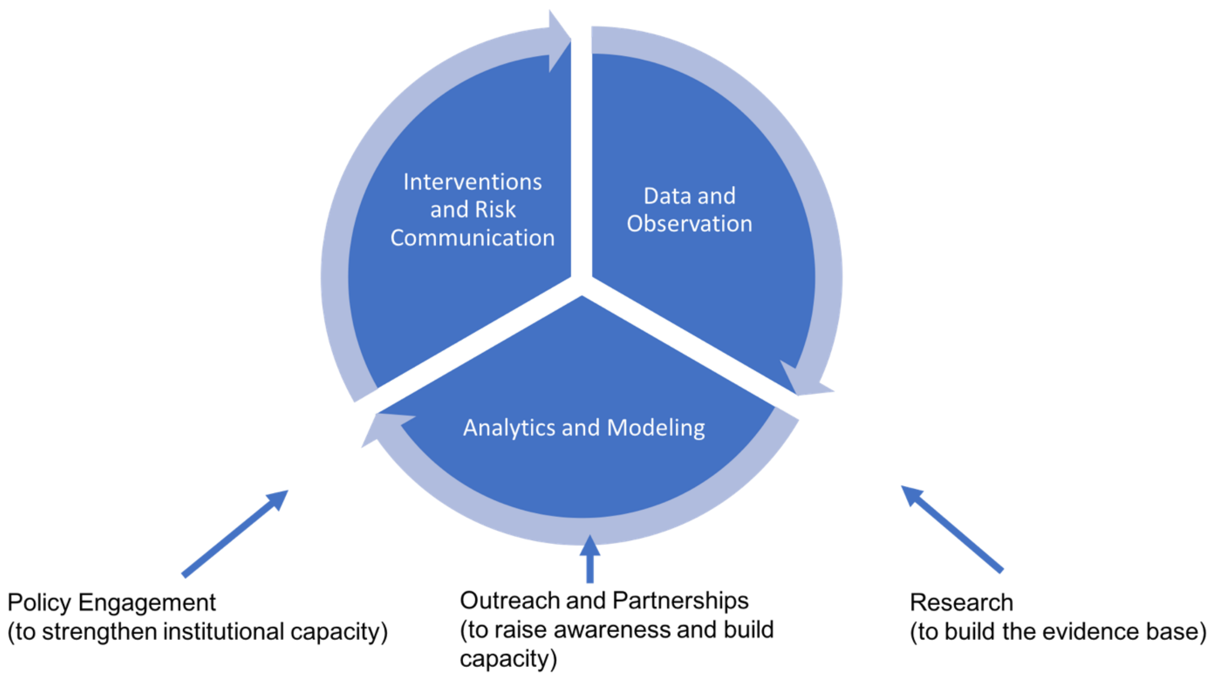

Figure 1. A framework for advancing climate-sensitive disease work.

POTENTIAL PATHWAYS TO PROGRESS

Potential actions identified at the workshop include both near and longer-term tasks, and generally align with the cross-cutting challenges outlined below of scientific knowledge; gaps between data and observations to forecasts and action; policy engagement, partnerships and institutional design. Possible future actions include:

- Develop and sustain integrated institutional engagements that support ongoing interpersonal and interdisciplinary interactions, build trust, foster legitimacy, and create the context for taking early actions (including forecasts, predictive tools and information). This includes both researchers and decision makers across levels of government and across sectors that affect health outcomes.
- Enhance the scientific basis for early action and response through research, integrated modeling, monitoring and evaluation—encouraging collaboration across agencies and with academia.
- Raise broader awareness and focus on specific technical problems through innovation challenges and other crowdsourcing opportunities.
- Develop seasonal health forecasts and risk maps of climate-sensitive disease risks that are used to inform policy and decision makers about risks to US interests at home and abroad
- Identify best practices and synthesize lessons learned from existing early warning and integrated information systems.
- Understand and articulate the economic and social value of predicting climate-sensitive diseases and taking early action.
- Build awareness and understanding about climate-sensitive diseases and the suite of proactive responses by developing, or more fully utilize existing, educational and outreach material.

The workshop participants did not prescribe specific actions to be taken by each agency but noted that the participants involved would work within their agencies to consider ways to work together following the workshop in order to implement identified possible actions. Toward that end, it is envisioned that agencies will consider actions related to the main topics above to further this effort and foster greater protection for Americans at home and abroad.

THE PROCESS

To address these challenges, the U.S. Global Change Research Program's Interagency Crosscutting Group on Climate Change and Human Health established an interagency steering committee to design and conduct a series of meetings (two web conferences and a workshop held in July and August 2017). The goal of these meetings was to share information across the agencies on predictive modeling of climate-sensitive infectious diseases for public health and national security in order to more clearly understand the science needs of the federal government, impediments to action, and assure appropriate engagement. In addition, the outcomes of this workshop will inform the U.S. Global Change Research Program's Interagency Crosscutting Group on Climate Change and Human Health's ongoing efforts to develop decision support tools for climate sensitive health issues, as well as group members' other domestic and international efforts.

Two web conferences provided workshop participants with important background information in advance of the full day meeting, as well as an engagement opportunity for collaboration with non-federal, academic and public health practitioners. These communities are essential to engage because they have firsthand experience and knowledge of major research and user-needs to better understand, predict, and respond to climate-sensitive disease outbreaks across different timescales.

A "State of the Science" web conference provided an opportunity for both federal and academic scientists to discuss the latest research on predictive modeling and its application to predicting risks of climate-sensitive emerging infectious diseases. The "Predictions in Practice" web conference provided an opportunity for public health practitioners that work with or benefit from EID predictive models to share information on public health preparedness at multiple time scales, operational capacity, and the needs to improve responses to climate-sensitive EIDs.

A one-day workshop brought together federal program leads to map current processes, identify needs and gaps, and clarify which processes to prioritize for enhanced cooperation. This activity helped to address operational capacity challenges and illuminate areas where greater agency leadership, coordination and support can make a difference. The workshop leveraged the existing OH-SMARTTM (One Health Systems Mapping Analysis and Resource Toolkit) framework to map the process and identify gaps and roadblocks to enhance the science. The framework allows participants to walk through the process, from the information needed for decision makers to take earlier actions, to the use of short-term and long-term climate information, predictions, and models.

MOTIVATION AND NEED

PURPOSE AND STAKEHOLDERS

The purpose of this document is to outline the challenges and a possible path forward for increasing the U.S. government's ability to predict, prevent, and prepare for climate-sensitive infectious diseases that threaten U.S. interests at home and abroad.

A wide variety of departments/agencies, offices, and action officers may be stakeholders in implementing the framework (see Figure 1). Moreover, some stakeholders sit at junction points between steps in the operational cycle (e.g., analytics and risk communication) or between operations and buttressing measures such as policy engagement or research. These "bridging" stakeholders play a particularly key role for facilitating and coordinating actions moving forward.

WHAT ARE THE RISKS?

Weather conditions, such as temperature, rainfall, and humidity, and climate patterns, such as El Niño, have long been understood as drivers of infectious disease burden (see Figure 2). A range of threats - from water-borne diseases such as cholera; to vector-borne diseases such as Zika and Lyme disease; to directly transmitted diseases such as meningitis - have all demonstrated sensitivity to one or more meteorological variables or seasonal patterns. These threats are known as climate-sensitive diseases. Climate change is expected to cause an additional 250,000 deaths annually worldwide between 2030 and 2050 due to malnutrition, malaria, diarrhea, and heat stress[4] and the effects of climate change on health will cost between $2-4 billion per year by 2030[5,6]. Steps to build resilience and adapt to these risks are likely to alter the eventual impact on both lives and dollars.

Figure 2 illustrates the potential health benefits of taking actions before an outbreak is underway.

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[4] World Health Organization. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. World Health Organization, 2014

[5] World Health Organization. Climate Change and Health. 1 February 2018. http://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

[6] Arent, D.J., Tol, R.S., Faust, E., Hella, J.P., Kumar, S., Strzepek, K.M., Tóth, F.L., Yan, D., Abdulla, A., Kheshgi, H. and Xu, H., 2015. Key economic sectors and services. *Climate Change 2014 Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects*, pp.659-708.

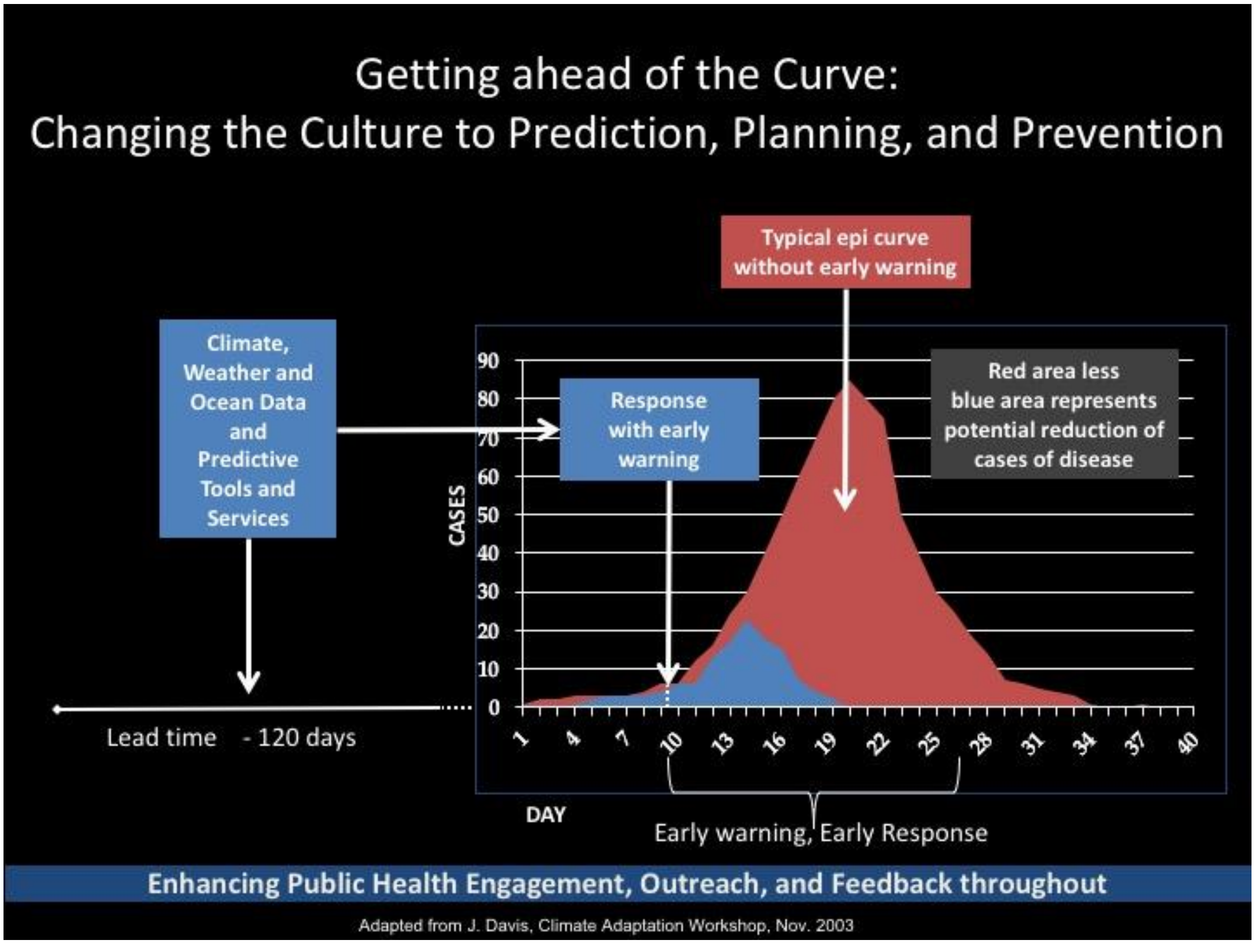

Figure 2. A typical epidemic curve, showing the number of cases of disease over time, is depicted in red, with the first case of a vector-borne disease occurring on day 1, the number of cases peaking on day 20, and declining thereafter. A hypothetical curve factoring in early warning driven by integrated environmental and health models is shown in blue. This curve begins later because early warning should result in early action, delaying the first case of the disease, and the curve also peaks much sooner and at a lower number of cases because of interventions enabled by early warning. The difference between the blue and red curves suggests the number of cases that can be prevented by early warning and action.

Climatic conditions are projected to increase infectious disease incidence and pose threats to both global communities and the health and economy of the United States. For example, due to rising temperatures, there is a projected increase in the risk of malaria for eastern, central and southern Africa. In eastern Africa, estimates of additional people at risk range from 40–80 million with 2°C warming and around 70–170 million with 4°C warming[7]. Malaria is already spreading to the highlands of Ethiopia, Kenya, Rwanda and Burundi, where it previously was not present[8]. The 2015-2016 Zika

[7] Caminade C, Kovats S, Rocklov J, Tompkins AM, Morse AP, Colón González FJ, Stenlund H, Martens P, Lloyd SJ (2014) Impact of climate change on global malaria distribution. Proc Natl Acad Sci USA 111(9):3286–3291. doi:10.1073/pnas.1302089111
[8] Caminade, C., Ndione, J. A., Kebe, C. M. F., Jones, A. E., Danuor, S., Tay, S., . . . Morse, A. P. (2011). Mapping Rift Valley fever and malaria risk over West Africa using climatic indicators. Atmospheric Science Letters, 12(1), 96-103. 10.1002/asl.296

outbreak in the Americas was likely partially due to favorable climate conditions caused by El Niño that allowed the disease, which was likely introduced to Brazil in 2013, to spread[9].

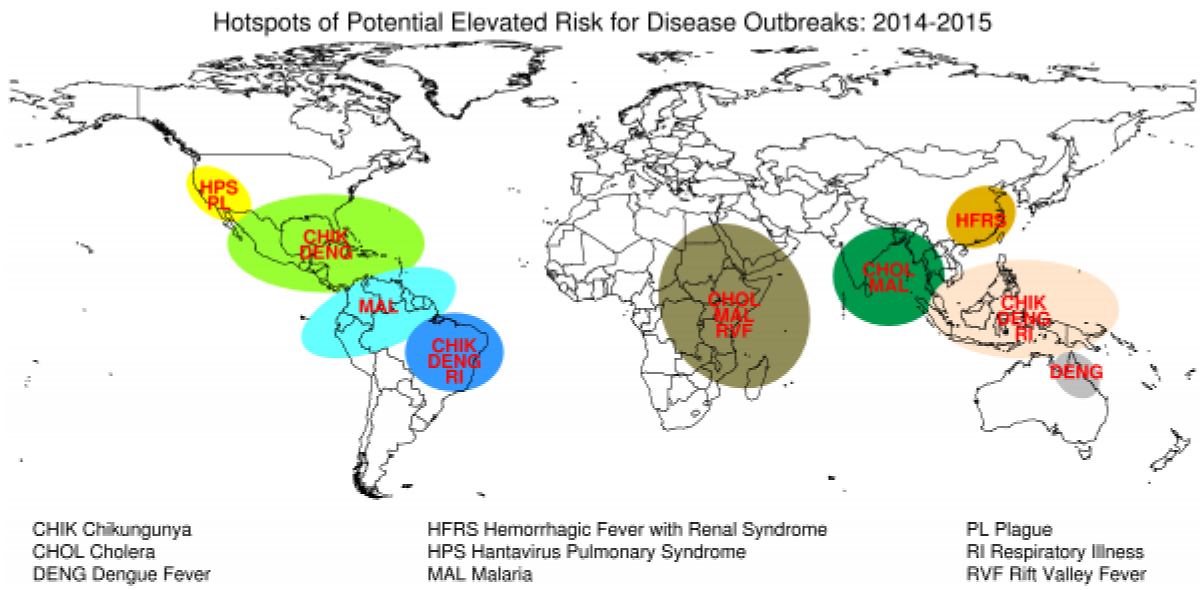

Figure 3. The El Niño Southern Oscillation affects climate and weather patterns globally, thereby altering the range, abundance, and behavior of pathogens - and the animals that carry them. These climate and weather parameters are predictable several months in advance, thereby providing decision makers extended lead time to take preventive measures and preparatory actions.

[9] Caminade, C., Turner, J., Metelmann, S., Hesson, J. C., Blagrove, M. S. C., Solomon, T., Morse, A., Baylis, M. (2017). Global risk model for vector-borne transmission of zika virus reveals the role of El Niño 2015. Proceedings of the National Academy of Sciences, 114(1), 119-124. 10.1073/pnas.1614303114

WHAT ARE THE OPPORTUNITIES FOR EARLY ACTION?

The burgeoning capacity to predict climate and weather driven factors, in combination with social and behavioral data that can affect risk of disease outbreak or occurrence, holds great promise to allow a range of appropriate preventive actions with weeks, months or even longer lead times. It is at the intersection of the scientific capacity and institutional ability to act that the potential exists to shift the operational context of managing climate sensitive disease risks.

HOW CAN SCIENCE MITIGATE THE EFFECTS OF CLIMATE CHANGE ON PUBLIC HEALTH?

Science can help in at least two distinct ways. First, stronger scientific understanding and analytic capacity, combined with more temporally and spatially compatible data streams and clear user demand could help strengthen public health practice by providing timely and geographically-specific disease forecasts. Second, improved forecasts with lead times of weeks to months or longer enable earlier warning, foster more cohesive efforts to engage decision makers to expand and further shift the paradigm of prediction and prevention of climate-sensitive disease outbreaks (see Figure 3). Such activities are important to both national security (e.g., safeguarding U.S. citizens and interests at home and abroad), as well as global health security (e.g., maintaining the capacity to prevent, detect, and respond to infectious disease threats). Better data and robust science also offer the opportunity for the creation of marketable, user-friendly tools (such as apps or dashboards) that may have economic potential in the private sector.

Our improved capacity to understand and predict weather, climate and other earth system changes that affect health, holds great potential to usher in a new era of using that information to provide health decision makers more advance warning (weeks to months and years) to predict, plan for, prepare for, and prevent the extent of impact of a climate-sensitive disease or disease outbreak. Below is an illustrative example of how early action motivated by climate and environmental information can help save lives and reduce disease burden.

Infectious Disease Early Warning in Practice: Rift Valley Fever

The Rift Valley Fever (RVF) Monitor and related Emerging Risk Notification provide a model for what could be done regularly to manage other emerging climate-sensitive disease risks in the future. RVF is a deadly mosquito-borne disease that affects both humans and valuable livestock in Africa. RVF outbreaks occur during specific environmental conditions: heavy rains and vegetation overgrowth in areas with low grassland depressions. Rainfall that drives these conditions is strongly correlated with El Niño, which is predictable, which then allows for the monitoring and prediction of RVF risk with up to three months lead time (see for example Figure 5). DOD, NASA and USDA run and produce the Rift Valley Fever Monitor (https://www.ars.usda.gov/southeast-area/gainesville-fl/center-for-medical-agricultural-and-veterinary-entomology/docs/rvf_monthlyupdates/). But in 2015, the El Niño was expected to be strong, and the RVF risk high, so several agencies joined forces to put together an "Emerging Risk Notification" that combined not only the monitoring and risk prediction, but also actions that could be taken in advance to reduce or eliminate the outbreak (Figure 4).

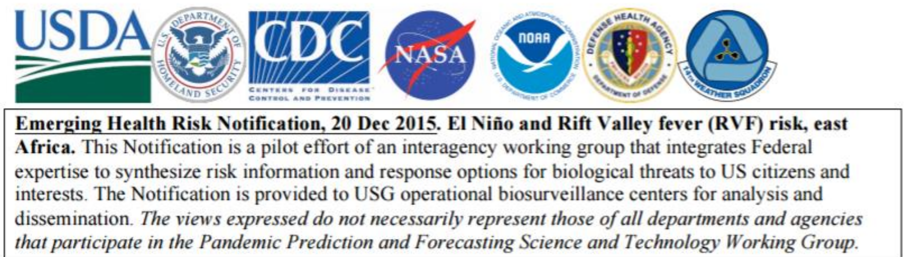
Emerging Health Risk Notification, 20 Dec 2015. El Niño and Rift Valley fever (RVF) risk, east Africa. This Notification is a pilot effort of an interagency working group that integrates Federal expertise to synthesize risk information and response options for biological threats to US citizens and interests. The Notification is provided to USG operational biosurveillance centers for analysis and dissemination. *The views expressed do not necessarily represent those of all departments and agencies that participate in the Pandemic Prediction and Forecasting Science and Technology Working Group.*

Figure 4. Example of an Interagency "Emerging Risk Notification." The full Emerging Health Risk Notification can be found at: https://cpo.noaa.gov/sites/cpo/NOAA%20OneHealth/East%20Africa%20Rift%20Valley%20fever%20risk%20notification%2020%20Dec%202015.pdf

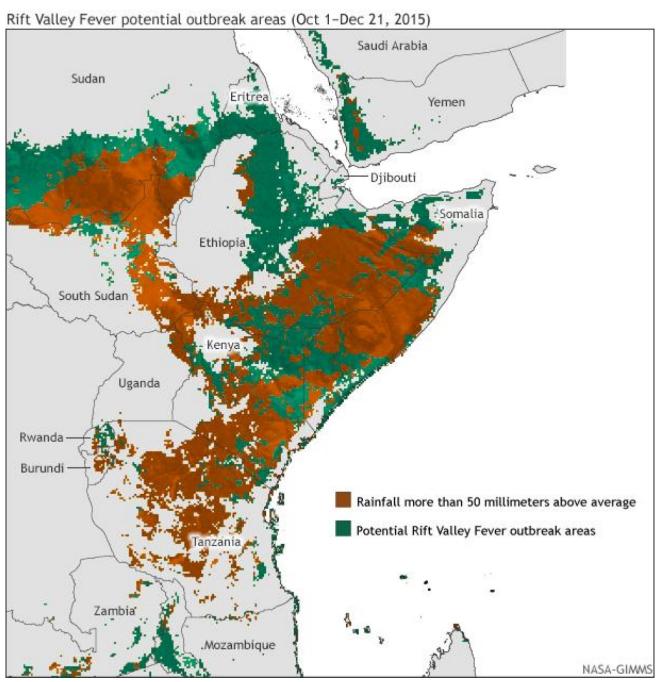

Figure 5. An example of a map depicting Rift Valley Fever Risk potential 1-3 months in advance. (www.ars.usda.gov/southeast-area/gainesville-fl/center-for-medical-agricultural-and-veterinary-entomology/docs/rvf_monthlyupdates/).

WHAT HAVE BEEN SOME KEY ROADBLOCKS TO DATE?

While each aspect of the framework (Fig 1) has unique challenges, some cross-cutting issues are common across multiple domains. Identifying these challenges can inform the immediate action steps laid out below. The three main cross-cutting challenges identified were:

Scientific Knowledge: Predicting climate-sensitive infectious diseases is highly complex. These predictions require data and knowledge derived from a range of disciplines and improve with enhanced interdisciplinary collaboration. While collaborative mechanisms are increasing, climate science and health science have generally evolved through distinct academic pathways with limited overlap. Research is geographically diffuse and few models provide the sub-seasonal or seasonal lead times needed for most public health planning. In the absence of improved science, prediction will likely be of limited applicability to public health.

Taking Action: Gaps between Data Collection, Forecast and Action: Synthesizing relevant data is a massive operational task – scientific experts in the relevant agencies must generate timely data streams, analyze them for meaning, and communicate actionable and accurate information to decision-makers. Practical challenges - such as mismatched geographic scales or time frames, effective messaging of probabilistic uncertainty, and timely delivery of information abound. The field of disease forecasting is improving, but there is reluctance to incorporate forecasts into definitive actions. Decision makers and scientists must sustain engagement to understand and agree upon the information and confidence that is needed so that modelers can provide actionable information to decision makers.

Agency Leadership Engagement, Partnerships and Institutional Design: Despite the vast array of health problems and interventions that may benefit from climate information, many potential stakeholders have not been engaged through awareness raising and partnership formation. And the ability to take action is often hindered by scientific gaps, legitimacy to act and manage risks, and institutional impediments. Establishing or enhancing institutional arrangements, such as integrated information systems, that sustain engagement among the multiple decision makers and scientists in order to build trust and confidence is necessary to move from science to action.

NEXT STEPS AND WAYS FORWARD

Based on the outcomes of the workshop and webinars, several potential actions have been identified. These have been organized below in line with their place in the framework (Fig. 1), with the acknowledgment that some avenues require progress in several different steps. Each step is followed by a series of guiding questions for follow up. The actions include near and longer-term tasks, and generally align with the cross-cutting challenges of scientific knowledge; gaps between data and observations to forecasts and action; and policy engagement, partnerships and institutional design. Specific potential actions include:

- Develop and sustain integrated institutional structures that support interpersonal engagement and create the context for taking early actions (including forecasts, predictive tools and information). This includes decision makers across levels of government and across sectors that affect health outcomes. (Step 1)
- Enhance the scientific basis for early action and response through research, integrated modeling, monitoring and evaluation—encouraging collaboration across agencies and with academia. (Steps 2,4)
- Raise broader awareness and also focus on solutions to specific technical problems through innovation challenges and other crowdsourcing opportunities. (Step 2)
- Develop seasonal health forecasts and maps of climate-sensitive disease risks that are used to inform policy and decision makers about potential threats to US interests at home and abroad. (Steps 3,5)
- Identify best practices and synthesize lessons learned from existing early warning and integrated information systems. (Steps 3,6)
- Understand and articulate the economic and social value of predicting climate-sensitive diseases and taking early action. (Steps 4,5)
- Build awareness and understanding about climate sensitive diseases and the suite of proactive responses by developing, or more fully utilizing, existing educational and outreach material. (Steps 2,4,6)

Step 1: Coordinating policy context, institutional collaboration and decision needs by designing or re-designing institutions to support sustained engagement of decision makers so that needs are well defined, to facilitate uptake and appropriate use of science, and support early actions to reduce risk.

a. **Effective Institutional Design:** Create or enhance institutional arrangements to develop integrated information systems, which sustain engagement among scientific disciplines and decision makers. Define and prioritize the problems to be addressed. Develop useful information on risks with estimates of confidence in those forecasts to inform decisions and actions. Evaluate actions taken and processes used to inform future efforts. Examples of such integrated information systems include the National Integrated Drought Information System (NIDIS) and the National Integrated Heat-Health Information System (NIHHIS), and systems like the Famine Early Warning System (FEWSNet).

i. What existing networks and activities can be brought together to create functional institutional structures to support the US in understanding, predicting and taking action to reduce the health and economic burden of climate-sensitive diseases that threaten US interests at home and abroad?
ii. How can leadership level dialogue be initiated to address the benefits and liabilities of forecasting risk and taking action?
iii. What are the best pathways to establishing a network of agency partners who work together to address the science, policy and action gaps, and ensure close connection with academia and the private sector?

b. **Data Management – Stock Taking and Gap Analysis:** It is clear that while much earth observation data are collected, often more temporally and spatially resolved data are needed to inform decisions, forecasts and warnings. Similarly, health, disease, and other socially relevant data are often missing for the geographic and temporal scales needed. And finally, accessing and integrating the appropriate and useful data remains an enormous challenge for emerging climate-sensitive health risks. Taking into account current experience such as through the National Integrated Drought Information System and the National Integrated Heat-Health Information System:
   i. What can we learn about data curation and management? About stakeholder and private sector engagement? About practical issues such as user access? About technical issues such as timeliness, geographic specificity, and usefulness? About standardization?
   ii. Which issues need to be de-conflicted for climate-sensitive infectious diseases (e.g., privacy, national security classification, political/social sensitivity, publication of results in open-access publications)?
   iii. What data sources currently exist which could support integrated EID research, modeling, and operational prediction, and ideally what data sources would exist in the future to support these systems? In particular, what data sources are available for biological data related to pathogens or vectors?

Step 2: Improving capacities for data analytics and forecasting/modeling

a. **Engaging the Public Through "Challenges":** U.S. government agencies have used a variety of mechanisms for encouraging students and other citizen scientists to participate in global scientific affairs. Among these are 'hackathons', 'challenges', 'Diplomacy Labs', and volunteer intern programs. Such mechanisms are particularly useful for sparking innovative ideas and encouraging experimentation. They also provide less formal avenues for interdisciplinary and international cooperation.
   i. Which of these mechanisms could support work on climate-sensitive diseases? What is an appropriate scale for such a challenge? How should prompts be coordinated and results be memorialized to reduce duplication?

b. **Integrated Modeling:** Though the weather and climate modeling communities and public health modeling communities have improved model skill, they have done so within their disciplines. Integrated modeling, which includes other physical and social drivers of infectious diseases in addition to climate and weather drivers, can build on enhanced disciplinary model skill to provide more accurate forecasts. Stakeholders create integrated models by fusing model research and development efforts with social, economic, demographic, health, and other disciplines.

i. Integrated Earth System & Health Modeling – How can the modeling communities from several disciplines work more closely together on shared problems (model initialization, process studies, verification) to produce integrated environmental health models for infectious diseases?
ii. Integrating across Timescales – How can modeling approaches that have been tuned for specific timescales (weather versus seasonal versus decadal models for example) be integrated to produce a continuum of useful and useable information, and how can the proper interpretation and use of this information by decision makers be supported?
iii. Multi-model Ensembles (MMEs) – How can MME approaches be more thoroughly studied and cultivated? MMEs of both weather & climate model predictions as well as ecological habitat & public health have been shown to have better skill and reliability[10], but MME approaches are still relatively under-deployed across the modeling communities.

c. **Engage the Monitoring & Evaluation Community:** How can new areas of knowledge or potentially game-changing discoveries be incorporated into existing interagency processes? What tools do researchers have for detecting the impact of Early Warning Systems or Integrated Information Systems?

Step 3: Communicating the results of analysis to those that need to know, and building partnerships for action

a. **Identify Best Practices and Lessons Learned for Early Warning:** Multiple U.S. government departments and agencies are charged with issuing a wide range of public notices, from severe weather warnings to public health risk communications to international travel advisories. Partners may hold particularly relevant knowledge or insights. Drawing from the experience and wisdom of interagency partners, what is known about good practices and lessons learned for similar advisory/warning activities? How would it apply in the context of climate-sensitive disease?
b. **Identify Avenues and Create Pathways for Practical Application:** A stronger evidence base and improved forecasting capabilities need to be linked with public health decision making and infectious disease prevention and response. Which U.S. government pathways are available for creating those links? Do existing pathways suffice, or are new pathways needed? How is the risk of failure to act managed? What is the risk of issuing or taking action based on a forecast, and how is that handled?

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[10] Tebaldi C, Knutti R. The use of the multi-model ensemble in probabilistic climate projections. Philos Trans R Soc A Math Phys Eng Sci [Internet]. 2007;365(1857):2053–75. Available from: http://rsta.royalsocietypublishing.org/cgi/doi/10.1098/rsta.2007.2076

Step 4: Enhancing research efforts to improve the state of the science regarding causal mechanisms, and monitor/evaluate programmatic impact

a. **Engage the Research Community:** What is the state of the science on climate-sensitive disease? What are some key scientific questions that remain unanswered and how can these questions be answered?
b. **Engage Policymakers and the Public:** How can findings from academia be communicated most effectively to policymakers and the (U.S. and international) public? How can information be communicated in a manner that supports decision making and reduces health risks?

Step 5: Enhancing Policy Engagement

a. **Review Existing Interagency Efforts:** Which efforts are already in place? How are they designed and how do they operate? What are best practices and lessons learned from these examples?
b. **Explore Interagency Arrangements for Joint Product Development:** Where gaps exist, are there willing partners to fill them? How would the arrangement be scoped and shaped? What are the SMART (specific, measurable, achievable, realistic, and time-bound) objectives?
c. **Develop Capacity for Global Risk Mapping of climate-sensitive diseases:** What products can deliver a global view of climate-sensitive disease risk? Who will create and manage product development, delivery, and dissemination? What observational infrastructure must be in place to predict and verify global risk predictions? How will uncertainty at building-block levels (e.g., specific disease forecasts) be managed?
d. **Develop Seasonal Forecasts for Health:** How do we build on or enhance existing seasonal climate forecast products to make health-relevant information? Which areas are ripe for pilots? For sustained forecast products or forecasts of opportunity? Who are the local, national, regional, and international partners?

Step 6: Increasing stakeholder outreach and public awareness; building partnerships and capacity

a. **Stock-Taking:** What efforts are already underway to build capacity and strengthen awareness of climate-sensitive disease? To what extent are these programs targeted at programs (e.g., USAID Climate Risk Screening) versus students (e.g., NIH STEM education?) versus the general public (e.g., NASA GLOBE Mosquito Habitat Mapper)? What lessons learned and best practices can be gleaned from these activities? Conversely, where (e.g. in which geography, among which stakeholders) are the still significant gaps? How might those gaps be filled?

ANNEXES

AGENDAS AND KEY POINTS FROM WEB CONFERENCES ON "STATE OF THE SCIENCE" AND "PREDICTIONS IN PRACTICE"

A. State of the Science Web Conference Agenda

August 10, 2017, 10:00-12:00pm ET

10:00 – 10:10	**Introduction**
10:10 – 10:25	"Climate sensitive infectious diseases: data needs for science and public health practice" Dr. Jan Semenza (European Centre for Disease Prevention and Control)
10:25 – 10:40	"Climate Variability and Recent Disease Outbreaks" Dr. Assaf Anyamba (Universities Space Research Association & NASA Goddard Space Flight Center)
10:40 – 10:55	"Weather- and climate-informed modeling of vectors and vector-borne diseases" Dr. Andy Monaghan (University Corporation of Atmospheric Research)
10:55 – 11:10	"Predicting outbreaks of arboviral diseases: successes, challenges, and future outlook" Dr. Chris Barker (University of California, Davis)
11:10 – 11:35	Expert Panel Discussion Initiated by Dr. Dylan George (In-Q-Tel)
11:35 – 11:55	Plenary Discussion
11:55 – 12:00	Closing Remarks

B. Predictions in Practice Web Conference Agenda

August 17, 2017, 10:00 AM -12:00 PM ET

10:00 – 10:10	Introduction
10:10 – 10:40	"DOD climate forecasting and use of predictions to protect the health of DOD military personnel" Lt Col Robert Branham, U.S. Air Force Weather Dr. Lisa Patrican, National Center for Medical Intelligence Mr. Juan Ubiera, Defense Health Agency, Armed Forces Health Surveillance Branch Dr. Jody Wireman, NORAD and U.S. Northern Command
10:40 – 10:55	"Predicting and Responding to Emerging Vector-borne Disease Threats" Dr. Ben Beard, CDC National Center for Emerging and Zoonotic Infectious Diseases
10:55 – 11:10	"Integration of Climate and Health Data: The role of the Climate and Health Observatory in Mozambique" Dr. Eduardo Samo Gudo, National Institute of Health, Ministry of Health, Mozambique
11:10 – 11:25	"Applying Vector-Borne Disease Projections for Climate and Health Strategic Planning in Arizona", Arizona Public Health Department Matt Roach, Arizona Department of Health Services, Climate and Health Program Dr. Heidi Brown, University of Arizona
11:25 – 11:45	Discussion Initiated by Madeleine Thomson (International Research Institute for Climate and Society, and Columbia University Mailman School of Public Health)
11:45 – 11:55	Weather Decadal: Bringing together the geoscience and health communities Mr. Scott Rayder, Senior Advisor to the UCAR President
11:55 – 12:00	Closing Remarks

Key takeaways from the webinars

The below section represents points made by speakers at the webinars. Statements by participants reflected in this record, including U.S. government employees, do not necessarily reflect any final decision or action of any U.S. federal agency or the USGCRP.

Capacity

Currently, there are various existing tools and resources that can be utilized and adapted to create sub-seasonal and seasonal disease predictions. Below are a few examples:

- Using Models to Predict Infectious Diseases
  - Advance-correlative ecological niche modeling measures disease transmission as if it were vector-based, incorporating both vector response to climate/weather and virus replication. This is a suitable model for longer climate change predictions.
    - Example 1: Using correlative niche models to anticipate Chikungunya suitability among global regions as a result of climate change
    - Example 2: Using models of Vibrio environmental suitability, which use remotely sensed data, to anticipate a 2014 spike in infections
  - Abundance models use weather data to estimate the number of mosquitoes on a given day. These predictions may then be utilized to predict and prepare for vector-borne disease outbreaks.
- Operational Applications
  - NORAD and USNORTHCOM have the ability to predict Rift Valley Fever outbreaks 2-4 months in advance
  - West Nile Virus predictive models based on seasonal forecasts and snow pack are used by the vector control communities in California
  - Arizona Public Health Departments utilizes local-scale predictions of risk that incorporate socio-economic information
  - DOD National Center for Medical Intelligence has an operational Dengue risk map
  - CDC National Center for Emerging and Zoonotic Infectious Diseases models Lyme Disease in endemic areas

Limitations

Various factors affect the viability of current disease prediction as a tool for public health action

- Data Availability
  - Lack of sufficient entomology monitoring and health surveillance data
  - Climatic data is large-scale and inaccurate at local levels
  - Local data sources often lack immediacy and reliability
- Translatable scales
  - Empirical models are good at local levels but difficult to scale up
  - Dynamic models are more portable and flexible because they factor changing environmental indicators, but are more expensive and less accurate at local levels

- Levels of Certainty in the models
    - Social vulnerabilities and future adaptive measures are often not factored into the models
    - Vector borne disease systems are often oversimplified and do not account for the various factors that affect vectors differently
- Development of Operational Systems
    - Operational systems take time to develop capacity and trust to deal with uncertainty
    - Communication fatigue, a result of over communication of warnings, can be a problem in endemic areas
- Public Health Utilization of Models
    - Public Health is limited in terms of capacity, competing demands, resources, and evidence-based interventions available. There is little apparent demand for predictive disease models among the public health community. These stakeholders need to be more convinced that information from predictive models are worth their resource investments.
- Timely Focus of Health Policy-Makers
    - Often times, local response is not initiated until surveillance data indicate an outbreak, by which time many outbreaks are already abating.

Needs

Different communities involved in developing and utilizing climate sensitive infectious disease models have varied needs. These communities interact and rely on one another, and need to coordinate activities to assure mutual success.

Research Communities

- Retrospective reconstruction of datasets
- Consistent estimates of variables and uncertainties, accurate representation of observed climate variability/change, continued update of input observations, reanalysis output on a timely basis
- Accurate, timely, and reliable disease surveillance data, including via rapid diagnostics for pathogens and vectors in the field; geo-tagged rather than aggregated (where feasible)
- High resolution weather forecast data
- Quality health data for validating human health outcomes

Public Health and National Security Communities

- US Public Health investment in predictive models requires clear link to public health action and impact
- Short-term and medium-term forecasts, effective spatial resolution of data products of < 10km, mosquito *activity* data
- Focus more on early warning and less on long-range forecasting
- Validation of models using high-quality disease surveillance data

Opportunity

In the current institutional and political environment, there are various opportunities for moving forward the needle on these issues, particularly in the realm of seasonal disease forecasts.

II. AGENDAS AND KEY POINTS FROM WORKSHOP ON PREDICTING CLIMATE-SENSITIVE INFECTIOUS DISEASE TO PROTECT PUBLIC HEALTH AND STRENGTHEN NATIONAL SECURITY

Workshop on Predicting Climate-sensitive Infectious Disease to Protect Public Health and Strengthen National Security Agenda

August 24, 2017, 8:30AM – 5:00 PM ET

8:30-9:00am	Registration	-----------
9:00-9:10am	Welcome	Dr. Jonathan Margolis Deputy Assistant Secretary for Science, Space, and Health, Bureau of Oceans and International Environmental and Scientific Affairs, U.S. Department of State
9:10-9:30am	Overview and Charge	Steering Committee
9:30-9:40am	Introduction to OH-SMART	Tracey Dutcher
9:40-10:20am	Gaining Perspective and Identifying Partners	Group activity
10:20-10:35am	Report Back	Plenary
10:35-10:45am	Break	-----------
10:45-12:45pm	Scenario Mapping and Analysis	Group activity
12:15-12:45pm	Report Back	Plenary
12:45-1:45pm	Lunch	Cafeteria
1:45-3:15pm	Research Process and Implementation	Group activity
3:15-3:45pm	Report Back	Plenary
3:45 -4:00pm	Break	-----------

4:00-4:35pm	Synthesizing Key Themes	Plenary
4:35-4:50m	Summary and Next Steps	Steering Committee
4:50-5:00pm	Closing	State Department

Key Points from Workshop

- **Scientific Knowledge**: Research not well-coordinated and with few models that provide sub-seasonal or seasonal lead times.
    - Predicting climate-sensitive infectious diseases is highly complex and requires sophisticated interdisciplinary collaboration
    - Climate science and health science are generally treated as academically distinct, though the number of collaborative mechanisms is increasing
    - Research on various aspects of this problem is happening but still diffuse and with very few models providing sub-seasonal or seasonal lead times.
    - In the absence of clear science, the discourse on these issues is likely to remain speculative or dismissive.
- **Operational Capacity**: Legitimate and accepted production of climate-sensitive infectious disease forecasts and observations and then communication mechanism needed
    - Ongoing, large gaps in understanding what is needed, when, and by whom for operational decision making
    - Massive operational task of producing of climate-sensitive infectious disease forecasts and observations, analyzing them for meaning, and communicating accurately to those that need them
    - Mismatches between information provided and information needed can lead to delays that are costly in human and financial terms
- **Demonstrating value**: It is important to generate evidence of effectiveness to promote acceptance from the public health system and sustained implementation.
    - Despite the vast array of health problems that may benefit from interventions informed by climate information, leadership to develop pilots and demonstration of effectiveness is needed to build support for both production and uptake of enhanced predictive information.

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