NASA APPLIED SCIENCES PROGRAM
DECISION SUPPORT THROUGH EARTH SCIENCE RESEARCH RESULTS

Integration of Remote Sensing into Mosquitoborne Encephalitis Virus Intervention Decision Support Systems

William K. Reisen, PI

2009 Progress Report
RM08-6044 for NNA06CN02A

April 2009

C Barker, UC Davis-CVEC, Co-I
F Melton, CSUMB / NASA Ames, Co-I
R Nemani, NASA Ames Research Center, Co-I
B Eldridge, UC Davis-CVEC, Co-I
B Lobitz, CSUMB / NASA Ames, Co-I
T Smith, Centers for Disease Control, Co-I
V Kramer, CA Department of Health Services, Co-I
S Mulligan, MVCAC, Co-I

Introduction.

The North American mosquitoborne encephalitides such as West Nile virus (WNV) are zoonoses maintained and amplified in transmission cycles involving *Culex* mosquitoes and a variety of birds, especially those in the order Passeriformes. Tangential equine and human infections typically follow amplification of virus within this primary cycle. Although equine vaccines are available and widely used, protection of the public health relies entirely on reducing infected mosquito-human contact either through reducing mosquito population size or providing public education to modify human behavior [staying indoors at night, using repellents, etc]. Failure to interrupt or dampen amplification has resulted in epidemics and emergency aerial adulticiding to halt transmission.

California Mosquito-borne Virus Surveillance and Response Plan (CMVSRP).

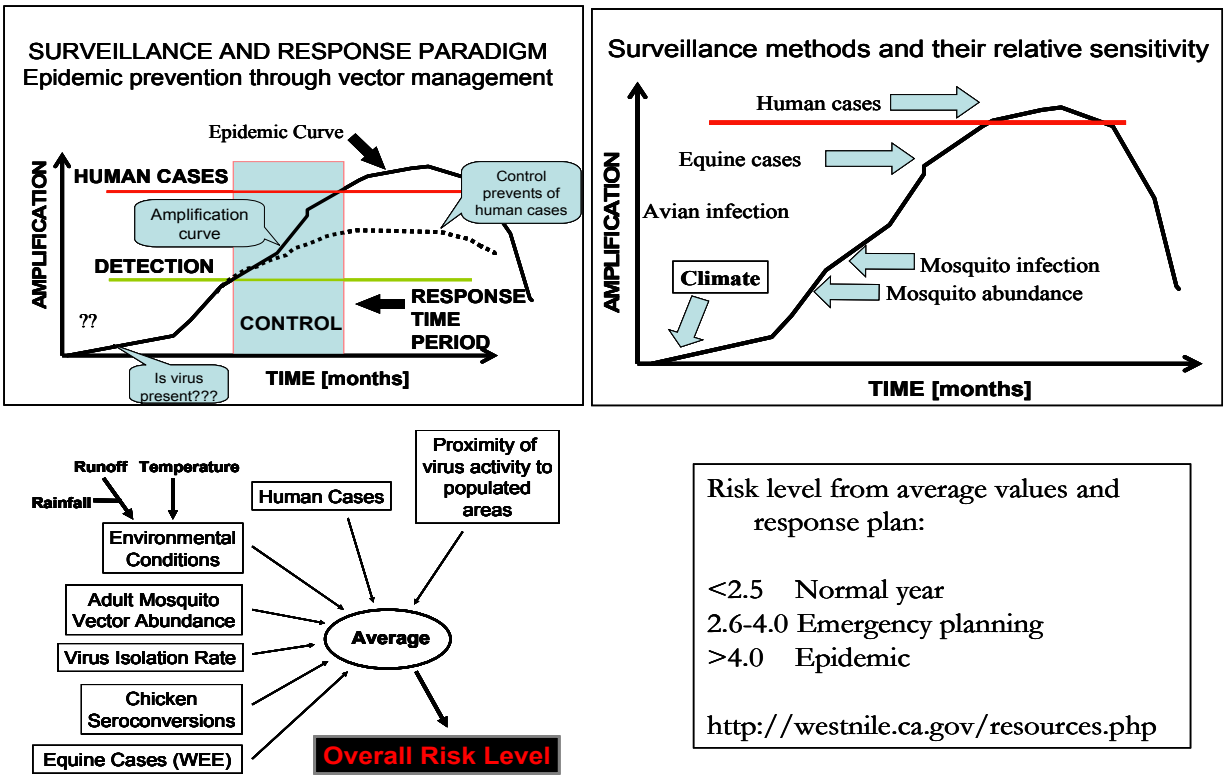


Fig. The CMVSRP surveillance and response paradigm depicting how effective early season control can dampen virus amplification and prevent human infection. Surveillance assets are shown along the amplification curve based on their relative sensitivity and time of detection. Data currently are coalesced into an overall risk estimate which is related to control recommendations within the Plan. Climate is the only variable with forecasting capability.

Detailed surveillance of viral amplification within the mosquito-bird cycle provides information critical to risk assessment models used in directing control decisions. The CMVSRP [Fig.] was developed jointly by the California Department of Public Health, the University of California, Davis and the Mosquito and Vector Control Association of California to provide state-wide guidelines for the collection of surveillance information to monitor the distribution and amplification of mosquitoborne encephalitis viruses in California, focusing on West Nile (WNV), St Louis encephalitis (SLEV) and western equine encephalomyelitis (WEEV) viruses. Weekly or biweekly measures of mosquito abundance and infection, sentinel chicken infection, numbers of dead birds reported by the public and tested for WNV, horse cases and human cases are captured in real time within the Surveillance Gateway, a data management system written by B. Park, UC Davis (<http://gateway.calsurv.org/>), and submitted weekly to ArboNET maintained by the Centers for Disease Control and Prevention in Ft Collins, CO. Originally, climate

measures were gathered from ground stations operated by CIMIS (California Irrigation Management Information System) or NOAA and related to long term averages to determine trends. Forecasting skill has been investigated and has shown promise, but has not been incorporated into the statewide system. ArboNet is a national surveillance data system managed by the Division of Vectorborne Infectious Diseases at the CDC in Ft Collins. Currently, positive surveillance data on mosquito infection, sentinel chickens, dead birds, equine cases and human cases are recorded and visualized at the county level using maps provided by the USGS.

At the start of our project neither the CMVSRP nor ArboNet utilized information from NASA satellites or ecosystem models. A survey of vector control agencies in California conducted at the start of our project found that only 1 in 29 responding agencies previously used satellite data of any kind, yet over 75% of respondents indicated that they would use risk maps and other relevant environmental measures derived from NASA satellites and ecosystem models if it was easily accessible. In addition, both the CMVSRP and ArboNet lacked a predictive capability, because operation of predictive models required acquisition and processing of environmental measures in near real-time.

NASA's Terrestrial Observation and Prediction System (TOPS) provides a suite of environmental measurements derived from NASA satellites and ecosystem models that are well suited to the development of models for mosquito abundance and virus transmission risk. In addition, TOPS provides a capability for delivery of these datasets in near real-time. The CMVSRP system now incorporates temperature data from TOPS to enhance surveillance and vector control efforts and to extend the existing decision support system. Starting in 2009 the CMVSRP will be enhanced to include early season predictive capability and evaluate the use of additional ecosystem measures.

NASA Terrestrial Observation and Prediction System (TOPS).

The Terrestrial Observation and Prediction System (TOPS) is a modeling framework that synthesizes NASA ESS data sets, including those from the AQUA, TERRA, and Landsat platform sensors. At minimum, this project will utilize data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard TERRA and AQUA, the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) onboard AQUA, as well as historical Landsat and AVHRR data. TOPS also provides capabilities for rapid integration of data from new sensors as they become available, and this project will evaluate demonstration products provided from new sensors currently available or planned for launch prior to 2009, such as the Visible/Infrared Imager/Radiometer Suite (VIIRS) onboard the National Polar-orbiting Operational Environmental Satellite System Preparatory Project (NPP) planned for launch in 2009.

In addition to utilization of NASA ESS satellite data, this project is using multiple data products from NASA Earth science models. To convert NASA products to relevant input variables, we will establish procedures to incorporate products derived from TOPS (http://ecocast.arc.nasa.gov). Currently, TOPS integrates data from satellite and ground-based observation networks to produce a comprehensive suite of over 30 variables describing land surface and ecosystem conditions. The products include information derived from satellites (land cover, snow cover, surface temperature, vegetation density, vegetation productivity), surface weather stations (max/min temperatures, humidity, solar radiation and rainfall), and modeled fluxes (soil moisture, vegetation stress). Long-lead forecasts of ecosystem conditions from TOPS will be used to drive models of mosquito abundance and produce seasonal forecasts.

TOPS Data Products to be Incorporated:

<u>MODIS/VIIRS/AVHRR (from TOPS)</u>
- LAI (Leaf Area Index)
- FPAR (Fraction of absorbed Photosynth. Active Radiation)
- LST (Land Surface Temperature)
- NDVI (Normalized Difference Veg. Index)
- Landcover (Annual)
- Snow
- SST (Sea Surface Temperature)

<u>Meteorology</u>
- Maximum Temperature
- Minimum Temperature
- Rainfall
- Solar Radiation

- Dew Point / VPD (Vapor Pressure Deficit)

TOPS Ecosystem
- Snow
- Soil Moisture (TOPS/AMSR-E)
- Phenology

TOPS-BGC Forecasts
- LAI
- Soil Moisture
- ET (Evapotranspiration)
- Phenology
- Snow

Plans for integration.

The overall goal of our **Integrated System Solutions** project is to improve the CMVSRP DSS through the integration of data from TOPS, developed jointly by NASA Ames Research Center and the University of Montana. After initial validation of this model system in California, we will extrapolate our findings to the western U.S. through collaboration with the CDC and TOPS data products for the western U.S. We will accomplish this overall goal by addressing the following proposed specific objectives:

1. Link remote sensing (RS) and meteorological data compiled as a comprehensive 1-km resolution dataset for the State of California (MODIS leaf area indices [LAI] and MODIS/AVHRR normalized difference vegetation indices [NDVI], MODIS and Landsat landcover, AMSR-E and TOPS soil moisture, and TOPS snow cover, maximum temperatures, minimum temperatures, land surface temperatures [LSTs], precipitation, and vapor pressure deficits) to mosquito and encephalitis virus data compiled by the Center for Vectorborne Diseases at UC Davis (UCD-CVEC).
2. Integrate the best-performing models into TOPS using the Ecocast applications programming interface (API) to produce spatially continuous 1-km weekly forecast maps of mosquito abundance and potential virus activity. Drive models using the National Oceanic and Atmospheric Administration (NOAA) Long-Lead 90-day climate outlooks to produce seasonal forecasts of mosquito abundance and virus risk.
3. Distribute risk estimates, maps, and data statewide via the existing California Vectorborne Disease Surveillance web-based interface to local vector control agencies (VCAs) and California public health and veterinary officials. Conduct workshops at regional meetings to expand DSS use in VCA operations.
4. Following integration into the California system, extrapolate mosquito abundance and virus transmission risk forecasts to the western U.S. and evaluate forecasting skill using data gathered by the CDC ArboNET system. Incorporate estimates of mosquito abundance and encephalitis risk into forecasts distributed via the CDC ArboNET DSS.

Progress.

This third **status** report summarizes progress on Grant No. 05-DEC05-S2-0016 entitled “Integration of Remote Sensing into Mosquitoborne Encephalitis Virus Intervention Decision Support Systems” during the Q3 – Q4 2008 and Q1 2009.

Computing enhancement. With distribution of automated risk assessments on a weekly basis and to take advantage of spatial databases, the previous database (MS SQL Server 2000) is being migrated to a new server (PostgreSQL). The new database environment will allow end users to establish their own spatial criteria for custom, ‘on-the-fly’ risk assessments. To facilitate utilization, transportability and enhanced mapping features, the Surveillance Gateway program is being rewritten. Gateway ver2 will be available by the April start of the 2009 California surveillance season and seamlessly integrated into our data acquisition and reporting system.

Milestones

Project milestones are listed below; those related to the current report are highlighted in grey. (Milestone dates have been adjusted from the original proposal to reflect the project start date of 1 October 2006). The current version of the Surveillance Gateway now includes an automated reporting feature that allows submission of .xtml files directly to the CDC’s ArboNet surveillance system for arboviruses. This

automated data exchange has set the stage for future expansion of the current Gateway to other areas. As a first step in this expansion beyond California, CVEC now tests mosquito pools for the Washington State Department of Health and has made initial steps towards enhancing their data management.

		2007				2008				2009		
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Project Milestone Schedule												
1. Survey CMVSRP and ArboNET users to establish DSS baseline usage												
2. Compile 23-yr dataset of ecosystem and met. conditions for CA and western U.S. using TOPS												
3. Transfer dataset to UC Davis-CVEC												
4. Validate prelim. models linking RS params to mosq. abundance/virus activity												
5. Selection of optimal model and integration into TOPS												
6. Demonstration 1: Prototype data product distributed via CMVP for review by end users												
7. Integrate Ecocast modules for NASA data management into CMVSRP												
8. Initiate production of abundance/virus risk forecasts & anomaly tracking												
9. Integrate products with CMVSRP for distribution and analysis												
10. Transfer models / Ecocast components to CVEC												
11. Re-survey CMVSRP users to evaluate new products												
12. Tabulate survey results; adjust products as needed based on feedback												
13. Distribute updated products via CMVSRP												
14. Demonstration 2: Initiate test production of integrated system during the 2007 virus season												
15. Evaluate test production through user surveys												
16. Final product revision and validation												
17. Complete final integration and product handoff												
Project Reporting Schedule												
Presentation of results at MVCAC annual meeting												
NASA Year 1 Review Meeting / Project Report												
First round of publications on integrated system submitted												
Presentation of results at MVCAC annual meeting												
Paper presented at Annual WNV Conference												
NASA Year 2 Review Meeting / Project Report												
Presentation of results at SOVE Conference												
Presentation of paper / talk at Fall AGU												
Second round of publications on use of integrated system												
Presentation of results at MVCAC annual meeting												
Third round of publications on evaluation of integrated system												
NASA Year 3 Review Meeting / Project Report												

Work has been initiated on all project milestones scheduled for completion through Q3 of 2008 and has made significant progress on milestones scheduled for Q4 of 2008. Current project status is summarized in the Quad Chart below.

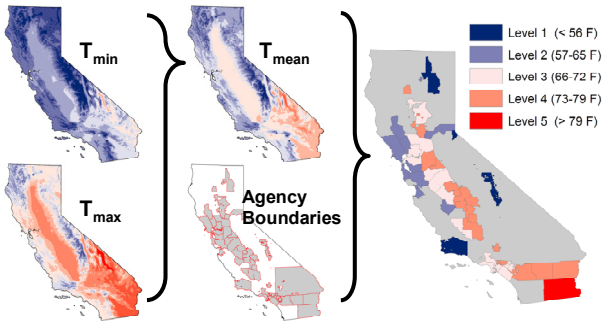
NASA Applied Sciences Program, Public Health

Integration of Remote Sensing into Mosquitoborne Encephalitis Virus Intervention Decision Support Systems

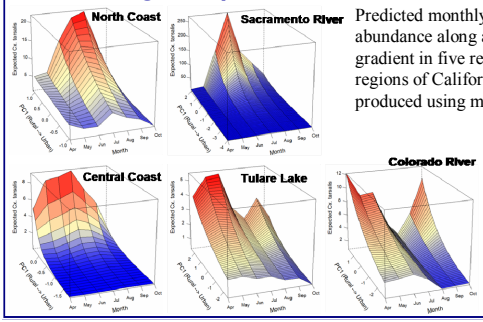
Project Objectives

- Improve the ability of decision support systems (DSSs) used in California and the U.S. to forecast mosquito abundance and virus transmission risk for West Nile virus and other encephalitis viruses.
- Improve the California Mosquito-borne Virus Surveillance and Response Plan (CMVSRP) used by state and local public health officials in California and the Arbovirus Surveillance Network (ArboNET) managed by the CDC Division of Vector-Borne Infectious Diseases through incorporation of data from the NASA Terrestrial Observation and Prediction System (TOPS).
- Use a modeling approach to integrate estimates of environmental conditions from TOPS with observations of mosquito abundance to generate forecasts of mosquito abundance and virus transmission risks. TOPS provides satellite observations of vegetation condition, land surface temperature, snow extent, gridded meteorological surfaces, and regional forecasts of surface conditions.

Transmission Risk Forecasts Incorporated into CMVSRP DSS



Forecasting Mosquito Abundance



Predicted monthly *Cx. tarsalis* abundance along an urban—rural gradient in five representative regions of California. Forecasts produced using model developed using TOPS data and historical data on mosquito abundance compiled by UC Davis CVEC.

Project Accomplishments & Status

- Developed models for mosquito abundance and virus transmission risk that incorporate information on climate / weather from TOPS.
- Presented initial model results and risk forecasts to vector control personnel in CA and officials from the CA Dept. of Public Health (DPH) for review.
- Integrated TOPS data and risk models into the CMVSRP DSS for distribution via a web-based data gateway.
- Currently working with vector control personnel and officials from DPH on verification and validation of integrated data products and models.
- Currently working to extend models of mosquito abundance to incorporate additional measures of environmental conditions from TOPS and implement use of seasonal climate forecasts.

Project reporting

Milestone 10. Selection of optimal model and integration into TOPS. As described in the previous report, the intermediate stage of integrating virus transmission risk models into TOPS was bypassed, and models are currently running at CVEC. TOPS products used as inputs to these models continue to be generated and distributed daily to CVEC for use in the CMVSRP. To provide increased flexibility, NASA Ames has also implemented WMS, WCS, and OPeNDAP servers to provide multiple data access interfaces for TOPS data products. These interfaces will be tested and deployed for use in supporting CMVSRP in Q2 2009. In addition, a version of the TOPS data gateway has been implemented for the TOPS datasets for the CMVSRP to facilitate exploration, subsetting, and download of the data by CMVSRP users.

Milestone 11 & 12. Resurvey CMVSRP users and Tabulate survey results. The California Department of Public Health conducted a survey during November 2008 that, in part, determined usage of the Surveillance Gateway system. Seventeen of 18 responding reported routine use for data management. Spatial and temporal manipulation of risk assessment calculation using Gateway software was indicated as a useful addition – this will be enhanced by improved mapping software in Gateway ver2.

Milestone 13. Distribute update products via CMVSRP. All MVCAC clients and the CDPH have internet access to the Surveillance Gateway and with this risk assessment tools that include TOPS model outputs for California. We have been meeting with the CDPH and are planning to revise the current CMVSRP to include forecast and nowcast modules. Forecast components will apply Dr. CM Barker's dissertation research to produce seasons in advance forecasts of mosquito and perhaps virus activity levels. Nowcast components will monitor and report risk in real time and thereby continuously truth forecasts.

Miltestone 14. Demonstration 2. Initiate test production of integrated system. The integrated system has been on line through the Gateway since last year. Risk forecasts were distributed to vector control districts and public health personnel via the CMVSRP CalSurv data gateway throughout the 2008 virus season.

NASA Year 2 Review Meeting/Project Report.
Status: completed

CM Barker and WK Reisen attended NASA review meeting in Biloxi and presented a status report describing our project in September 2008.

Publications:

Status: On going

Our preliminary findings on the use of climate variation to forecast mosquito abundance have been published (Reisen et al. 2008). A review of our incorporation of TOPS data into the CMVSRP program appeared in an important Institute of Medicine Report (Reisen and Barker 2008). Much of our novel modeling studies appear in the PhD Dissertation of CM Barker that is now completed and being prepared for publication.

Presentation of results at the MVCAC annual meeting.

Symposium was presented at the 2009 MVCAC meeting in Burlingame, California entitled: "UC Davis-MVCAC collaborative research on West Nile virus epidemiology and control in California". Two papers addressed climate research.

1. Ying Fang: Surveillance diagnostics and the search for new viruses.
2. Veronica Armijos: Identification and distribution of new flaviviruses in California
3. Sarah Wheeler: Long term persistence of West Nile virus RNA in passeriform birds
4. Stan Wright: Interpreting early season seroconversions in House finches
5. Tara Thiemann: Novel approaches to the identification of mosquito blood meal sources
6. Susanne Kluh/Jennifer Wilson: Recrudescence of West Nile virus in Los Angeles
7. Chris Barker: *Culex tarsalis* abundance as a predictor of western equine encephalomyelitis virus transmission
8. Gene Abbott: Controlling neglected swimming pools and West Nile virus in Bakersfield
9. Hugh Lothrop: Novel adulticides suitable for *Culex* control
10. Bill Reisen: Emerging trends in West Nile virus epidemiology and risk assessment

Papers at annual CDC WNV Conference, 19-20 Feb 2009.
Reisen, WK: West Nile virus ecology in temperate areas. [included information on TOPS products]
Eisen, L. West Nile virus risk assessment models [included data on the California model and the Surveillance Gateway]
Kramer, V.L. Surveillance and Response – The California Model [more information on the Surveillance Gateway and risk assessment using TOPS]

Annual meeting of the American Society of Tropical Medicine and Hygiene, 7-11 Dec 2008.

Invited papers were given in the following symposia:
Symposium 111: Predicting and mitigating outbreaks of vector-borne disease utilizing satellite remote sensing technology and models
Paper: Reisen, W.K. Integration of remote sensing into encephalitis virus intervention decision support system.
Symposium 155: Heterogeneity in West Nile virus transmission

Paper: Reisen, W.K. Factors enabling the transmission of West Nile virus across the diverse landscapes of California [included some data on climate impact]

Publications

Barker CM, Park B, Melton F, Eldridge BF, Kramer VL, Reisen WK. 2008. 2007 year-in-review: Integration of NASA's meteorological data into the California response plan. Proc Mosq Vector Control Assoc Calif 76:7-12

Barker,CM. 2008. Spatial and temporal patterns in mosquito abundance and virus transmission in California. PhD Dissertation, University of California, Davis

Eldridge BF, Park B, Barker CM, Reisen WK. 2008. Future directions in data management. Proc Mosq Vector Control Assoc Calif [in press]:

Melton F, Nemani RR, Michaelis A, Barker CM, Park B, Reisen WK. 2008. Monitoring and modeling enviornmental conditions related to mosquito abundance and virus transmission risk with the NASA Terrestrial Observation and Prediction System. Proc Mosq Vector Control Assoc Calif 76:89-93

Park B, Eldridge BF, Barker CM, Reisen WK. 2008. Building upon California's Surveillance Gateway. Proc Mosq Vector Control Assoc Calif 76:27-28

Reisen WK, Cayan D, Tyree M, Barker CM, Eldridge BF, Dettinger M. 2008. Impact of climate variation on mosquito abundance in California. J Soc Vector Ecol 33:89-98

Reisen WK, Barker CM. 2008. Use of climate variation in vectorborne disease decision support systems. pp. 198-218 Global Climate Change and Extreme Weather Events: Understanding the Potential Contributions to the Emergence, Reemergence and Spread of Infectious Disease. Washington, DC.: Instute of Medicine.

Reisen WK. 2008. How climate affects mosquito biology and arbovirus transmission. Proc Mosq Vector Control Assoc Calif 76:57-63

Reisen WK. 2009. Impacts on biological systems: mosquito-borne diseases. Indicators of Climate Change in California. Sacramento, CA: Integrated Risk Assessment Branch, California Environmental Protection Agency.

Reisen WK, Carroll BD, Takahashi R, Fang Y, Garcia S, Martinez VM, Quiring R. 2009. Repeated West Nile virus epidemic transmission in Kern County, California, 2004-2007. J Med Entomol 46:139-157.PM:19198528.

Wheeler SS, Barker CM, Armijos MV, Carroll BD, Husted SR, Reisen WK. 2008. Differential impact of West Nile virus on California birds. The Condor 111:1-20

Wheeler SS, Barker CM, Carroll BD, Reisen WK. 2008. Impact of West Nile Virus on California Birds. Proc Mosq Vector Control Assoc Calif 76:77-79