National Aeronautics and Space Administration

APPLICATIONS OF EARTH OBSERVATIONS FOR SOCIETAL BENEFIT

Results of Project Grants Beginning in 2006

NASA Earth Science
Applied Sciences Program

Preface

"[NASA] shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

National Aeronautics and Space Act of 1958

Welcome to the NASA Applied Sciences Program's report on the results of a project solicitation entitled *Decision Support through Earth-Sun Science Research Results*.

The Applied Sciences Program promotes innovative and practical uses of Earth science data and models. The Program funds projects that advance the use of Earth-observing, environmental satellite measurements and scientific knowledge in the decisions, actions, and services of public- and private-sector organizations.

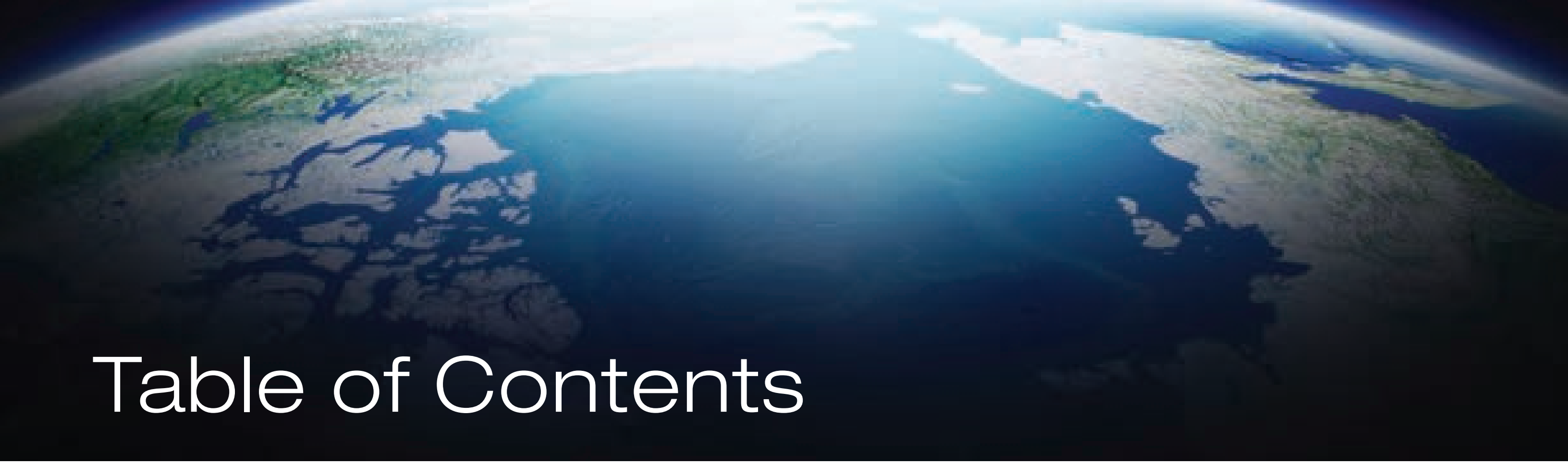
The Program selected the 21 projects described here through an open, competitive solicitation of applications proposals across many themes, such as agriculture, disasters, aviation safety, water management, air quality, ecological forecasting, and public health. The projects were partnerships involving industry, academia, and government working with scientists and applied researchers to apply and demonstrate the value of Earth observations and science.

Each project produced a final report documenting the improved performance of the decision-making activity it addressed. This document summarizes the results from all 21 projects.

Our partners in these projects made possible the outcomes and benefits derived from the work. On behalf of the Applied Sciences Program, I thank them and the principal investigators and the project teams for their dedication and commitment to apply Earth observations for societal benefit.

In the spirit of the 1958 Space Act, we will continue to promote and enable the use of Earth science to serve society. To learn more, visit *http://AppliedSciences.NASA.gov.*

Lawrence Friedl, Director
Applied Sciences Program
Earth Science Division
NASA Science Mission Directorate



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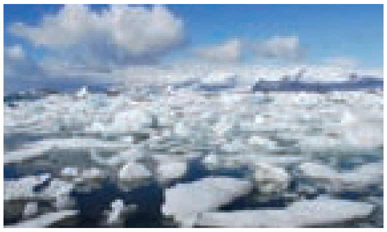


The Applied Sciences Program is part of the Earth Science Division of the NASA Science Mission Directorate. To learn more about the Applied Sciences Program, visit *http://AppliedSciences.NASA.gov.*

Introduction

The Applied Sciences Program promotes efforts to discover and demonstrate innovative and practical uses of Earth science data and knowledge. The Program funds applied research and applications projects to support public- and private-sector organizations' uses of Earth-observing satellite data and scientific knowledge in their decisions, actions, and services. The projects are carried out in partnership with end-users to enable sustained use and benefits. More information about the Program is available at *http://AppliedSciences.NASA.gov*.

In 2005, the Program issued a solicitation for proposals entitled Decision Support Through Earth-Sun Science Research Results. The solicitation requested projects supporting the Program's objective to integrate Earth science data in organizations' decision support tools and activities. The solicitation served NASA's goal "to expand and accelerate the societal and economic benefits of NASA research in Earth science, information, and technology."

> Earth observations and Earth science products broadly include measurements from Earth-observing satellites, data products, outputs and predictions from Earth science models, algorithms, visualizations, knowledge about the Earth system, and additional geospatial products. The Earth-observing satellites include NASA in-orbit and planned satellites as well as foreign, commercial, and other U.S. Government satellites. This solicitation encouraged proposal teams to use commercially-available data sets where possible.

The Program sought proposals for results-oriented projects that assessed an applications idea, validated methods, developed prototypes, and supported the adoption of the application by the end users. The solicitation requested projects in two arenas: 1) integrated system solution projects, which were targeted efforts to integrate Earth science products into decision-making activities, and 2) solutions network projects, which promoted the development of broad organizational collaborations to seek and support several applications.

Project teams and the benefiting organizations were to document the improved performance of the decision support tools achievable through the use of the Earth observations and data. Essentially, organizations could try out the Earth science products in their decision making processes to assess performance, and then adopt the products for sustained use.

The solicitation was open to all organizations – private, nonprofit, academic, and public. NASA strongly encouraged teams of organizations and collaborations across organizational sectors and across expertise. NASA recommended that the end-user organizations that owned and operated the decision support tools being improved be explicit and active members of the project teams.

The solicitation focused on 12 themes of national priority, and the projects had to address one or more of those themes:

- Agricultural Efficiency
- Air Quality
- Aviation
- Carbon Management
- Coastal Management
- Disaster Management
- Ecological Forecasting
- Energy Management
- Homeland Security
- Invasive Species
- Public Health
- Water Management

This solicitation was Appendix A.24 in a broader solicitation issued by the NASA Science Mission Directorate in January 2005. The broader solicitation, entitled Research Opportunities in Space and Earth Science 2005 (ROSES-2005), was issued with solicitation code NNH05ZDA001N.

The Program employed a two-step review and selection process. In Step 1, proposal teams submitted brief descriptions of the projects. The Program assessed the alignment of each Step 1 submission to the intended objective of the solicitation and responded with a nonbinding judgment that encouraged or discouraged submission of a full Step 2 proposal.

Step 1 proposals were due on July 20, 2005, and NASA received 105 submissions. The Program responded to the Step 1 proposal teams on October 3, 2005, encouraging 77 teams and discouraging 28 teams from submitting a Step 2 proposal. The Program held a community-wide telecon on October 7, 2005, to discuss and answer questions about Step 2 of the solicitation.

Step 2 proposals were due on November 22, 2005, and NASA received 94 Step 2 submissions. The total included some proposals from respondents who did not submit a Step 1 project description or were discouraged from submitting a full proposal. Some respondents encouraged to submit a full proposal declined to do so. Proposers included businesses, academia, research institutes, nonprofit organizations, and federal, state, and local government agencies.

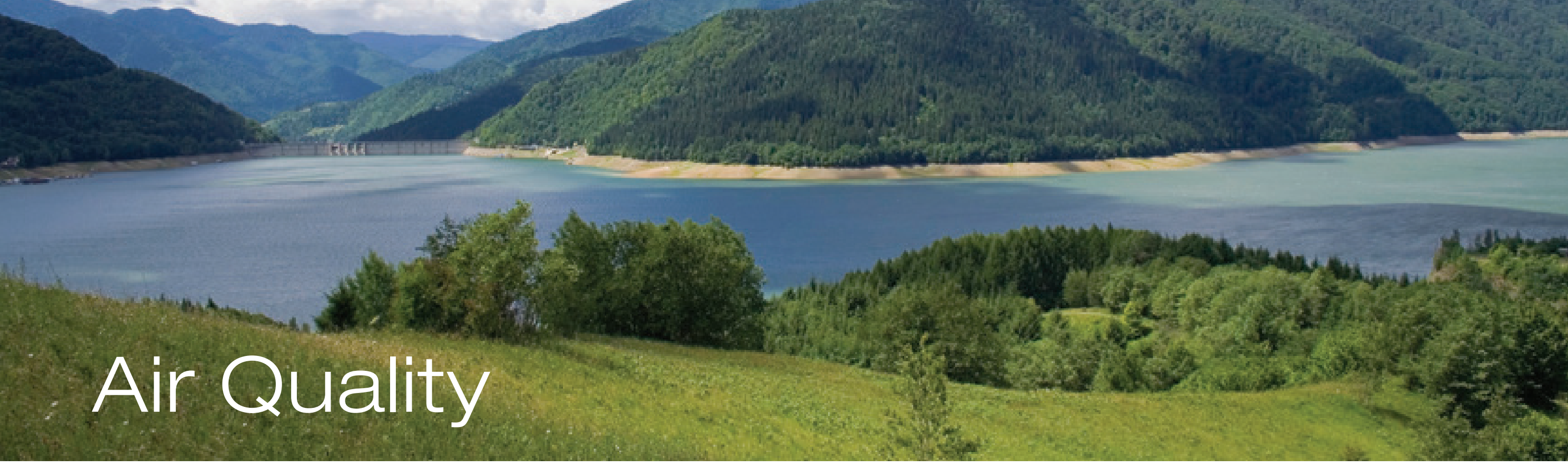
The Applied Sciences Program conducted a peer-review evaluation of the Step 2 proposals. Panels of experts in Earth science, technology, applications, and management assessed the proposals and provided information and ratings to NASA. The review criteria included the intrinsic merit of the proposed activity, relevance to NASA strategic goals and objectives, and cost realism.

On April 7, 2006, NASA announced the selection of 21 projects for awards, totaling approximately $20 million over the lifetimes of the projects. This set included 19 integrated system solutions projects and two solutions networks projects. Collectively, the awarded projects covered 11 of the 12 national priority themes identified in the solicitation.

The NASA Ames Research Center's Earth Science Division administered the grants for the projects. Some investigators requested no-cost extensions to the initial three-year duration, so the projects finished at different times.

This document presents information and results from the projects. Overall, the projects introduced a range of organizations to the availability and utility of Earth science data. These projects pioneered approaches to innovative and practical applications, and developed a host of transition pathways from research to applications for the Applied Sciences Program and NASA Earth science.

The following pages showcase decision support through Earth science and how the projects advanced the use of Earth science to benefit society.



Air Quality

Improving Air Quality Predictions With Satellite Data

Fine particles and ground level ozone are two air pollutants of significant concern in the United States. Both can harm the health of people and ecosystems. Ground level ozone is a pollutant formed when the exhaust and smoke from cars, trucks and industry react in the environment. Fine particles are small enough to penetrate deep into the lungs, and come from a large variety of sources. Understanding and modeling how these pollutants move and change in the atmosphere are critical for predicting air quality events that affect the health of people and ecosystems.

The United States regulates air pollutants via national ambient air quality standards set by the U.S. Environmental Protection Agency (EPA). To meet these standards, air quality managers reduce air pollutant concentrations by regulating air pollution emissions. They determine the long-term effectiveness of such regulations by running weather and air quality models. Air quality managers also run air quality models to forecast near-term smog episodes so they can alert the public when air quality is likely to be poor.

Satellite data help improve combined weather and air quality modeling systems by showing how air pollution moves, especially over long distances. They are also useful in determining how well air quality models capture that transport. The NASA Applied Sciences Program supported three projects aimed at air quality forecasting and planning, especially by improving the accuracy of air quality models by using satellite data. Two of these improved short-range forecasting tools, while the third improved long-range planning tools.

Air Quality Forecasts

Assimilating *Aura*-derived Trace Gas Retrievals and MODIS AOD into an Operational Multi-pollutant Ensemble Air Quality Forecast Decision Support System With a Focus on Ozone and Haze Prediction

Principal investigator:
John N. McHenry, Baron Advanced Meteorological Systems

Participating organizations:
Gangneung-Wonju National University, South Korea
Lantern Incorporated
NASA Goddard Space Flight Center
North Carolina Central University
North Carolina Office of Information Services
Risk Management Solutions
Science Systems and Applications, Inc.

Baron Advanced Meteorological Systems (BAMS) led a project that applied Earth science data and data analysis techniques to improve predictions of the effects of smoke, other particles, and ozone on human health and ecosystems. The project included evaluation of data from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) and Ozone Monitoring Instrument (OMI) instruments and NASA data processing systems to improve an air quality forecasting decision support system (Figure 1). The Visibility Improvement State and Tribal Association of the

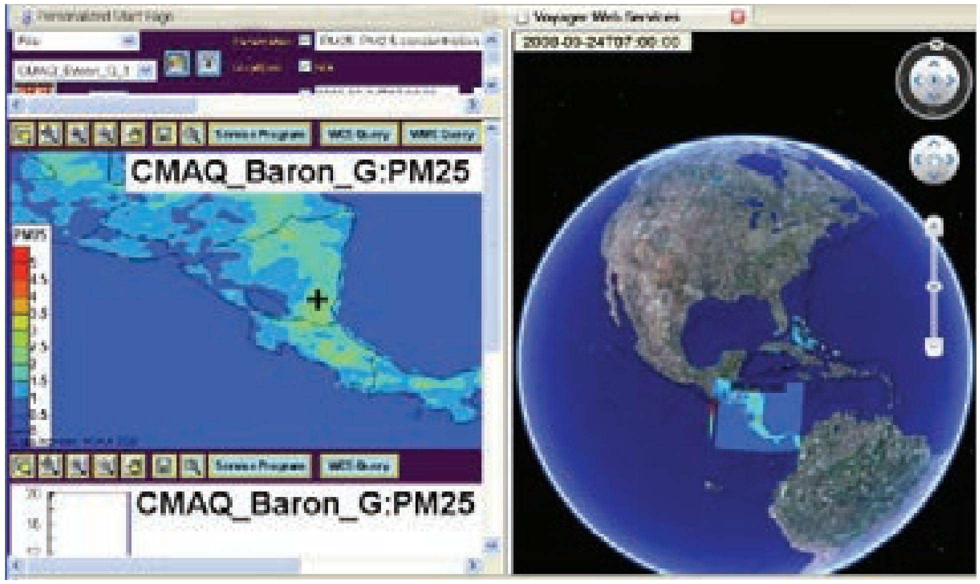


Fig. 1: BAMS prototype air quality forecast decision support system running at the Water Center for the Humid Tropics of Latin America and the Caribbean, visualized via Google Earth.

Southeast (VISTAS) supported the work with the intention of improving predictions of ground level fine particles and ozone, and in response to EPA recommendations to include those parameters in near-term air quality forecasts. BAMS operated the decision support tool at the request of VISTAS.

A primary tool for predicting air quality is the Community Multi-Scale Air Quality (CMAQ) model. CMAQ requires information on land surface features and constituents in the atmosphere. In this project, NASA's Land Information System generated an improved land surface model with a spatial resolution of 1 km. Inputs for that model included *Landsat-7* and Shuttle Radar Topography Mission (SRTM) data. For the atmospheric constituents of interest, MODIS data provided information on the concentration of particles in the atmosphere, the aerosol optical depth (AOD). The MODIS observations were validated by ground-based observations. The satellite imagery provides comprehensive coverage that ground-based instruments cannot match.

The other atmospheric constituent of interest was nitrogen dioxide (NO_2). NO_2 is a precursor of nitric acid, a major pollutant. The project evaluated the utility of NO_2 observations from OMI on the NASA *Aura* satellite in modeling and predicting local and regional NO_2 concentrations.

At the start of the project, BAMS predicted that including MODIS and OMI products in the CMAQ model would provide a 10 to 15 percent improvement in fine particle and ozone forecasts from the decision support system. Such improvement could lead to "real-time mitigation of poor air quality impacts on public health and with respect to federal air quality standards." To evaluate the contribution of the NASA data, BAMS tested the enhanced modeling capability against air quality forecasting systems at the National Weather Service (NWS), the Naval Research laboratory (NRL), and the NASA SERVIR system at the Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC) in Panama. The results on all systems indicated that an increase of 10 to 15 percent in the standard model performance metrics was achievable.

At the conclusion of the project, CATHALAC implemented the procedures established by the project team. The impact on the VISTAS was not fully determined.

For more information, visit *www.baronams.com.*

Meeting Standards for Regional Air Quality

Industrial societies emit airborne chemical compounds and particles that can harm human health and the natural and agricultural systems that people rely on to maintain life. The chemical and physical nature of these pollutants is for the most part understood. Federal guidelines in the United States prescribe the maximum allowable concentrations of gases and aerosols in order to maintain high standards of air quality. Before federal or state agencies can take action to meet air quality standards, the agencies must have suitable information on the sources of air pollution and the manner in which air pollutants spread regionally. Typically, such information comes from measurements at the sites of large emissions and from air quality observations obtained from a network of instruments on the ground, on towers, and on aircraft.

The NASA Earth Science Division supports observations of atmospheric constituents from space. The observations are used to understand the physical and chemical dynamics of the atmosphere, elements that are essential to understand how the atmosphere works globally, and to gain insight and predictive capabilities for weather and climate forecasts. Some of the atmospheric observations obtained by NASA have the potential to improve our understanding of the sources and distribution of the pollutants that must be controlled to meet air quality standards.

As part of the solicitation, the NASA Applied Sciences Program sponsored two projects to evaluate the use of NASA satellite-based atmospheric observations in existing tools used by agencies responsible for air quality monitoring. One project addressed the flow of information to air quality managers in the northwestern United States. The other project examined the impact of satellite observations on the development of state plans to meet national air quality standards. Both projects had positive results. The products and processes that emerged are now part of the regular procedures used by air quality managers in the United States.

Air Quality Decision Support

Using NASA Earth-Sun Satellite Products to Enhance a Comprehensive Air Quality Decision Support System in the Pacific Northwest

Principal investigator:
Brian Lamb, Washington State University

Participating organizations:
National Center for Atmospheric Research
U.S. Forest Service

The project team used data from NASA Earth-observing satellites to improve three existing environmental decision support systems used by resource managers in the Pacific Northwest and southern Canada. These systems are employed to monitor regional air quality for burning in agricultural areas. Data from NASA enhanced the weather prediction and air chemistry results, and improved the use of other Earth observations in the weather forecast system. The project also provided users with improved visualizations of the forecast system products. Key results included quicker and more accurate information on major air pollutants such as nitrogen dioxide NO_2 and carbon monoxide (CO) obtained by using observations from OMI on the NASA *Aura* satellite, and the Measurements of Pollution in the Troposphere (MOPITT) and Atmospheric Infrared Sounder (AIRS) instruments on the NASA *Terra* and *Aqua* satellites, respectively. Ensemble meteorological modeling that gathers observations from a wide range of resources, including satellite products, was enhanced through this project, and the results are being used to investigate how ensemble meteorological forecasts enhance the air quality prediction system in the Pacific Northwest. A number of new Web products, including enhanced mapping, interactive gaming, and routine display of NO_2 data from OMI were developed through this project.

For more information, visit *http://lar.wsu.edu/airpact/index.html* and *www.cleardarksky.com/csk.*

Improving State Implementation Plans

Use of Satellite Data to Improve the Physical Atmosphere in State Implementation Plan Decision Making Models

Principal investigator:
Richard McNider, University of Alabama in Huntsville

Participating organizations:
EPA
Universities Space Research Association
University of North Carolina

The project team integrated satellite data into the State Implementation Plan (SIP) modeling process, in which emission reduction strategies are developed to reduce air pollution levels and meet National Ambient Air Quality Standards. Across the country, tens of billions of dollars in emission controls depend on this modeling process. The project employed satellite data to improve the simulation of the physical atmosphere in which emission reduction scenarios are modeled. Errors in specification of atmospheric physical variables such as temperature, winds, photochemical production rates, and mixing heights can alter the calculated efficacy of emission control strategies. The project team performed a series of benchmark experiments to determine the impact of satellite data, including MODIS land surface temperature and emissivity products, in the modeling system. Techniques using NOAA *Geostationary Operational Environmental Satellite* (*GOES)* cloud data improved photolysis rates in a model used by state governments in the SIP process, EPA's CMAQ model. EPA's December 2008 official release of CMAQ version 4.7 incorporated these techniques for the air quality community.

Benchmark studies included testing techniques that used satellite data to improve temperature (Figure 2) and mixing height calculations (Figure 3) in the modeling system. The results showed that adjustment of surface moisture and heat capacity improved the prediction of temperature compared with both high-resolution satellite data and NWS data. Comparisons of special aircraft observations to mixed layer height predictions with and without satellite data showed improved performance when satellite data were included.

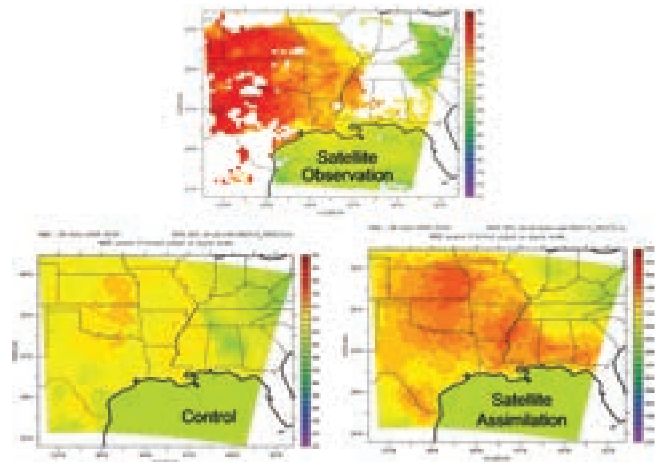


Fig. 2: Comparison of satellite skin temperatures and the corresponding ground radiating temperatures from the Fifth-Generation Penn State/National Center for Atmospheric Research Mesoscale Model (MM5) used as input to run CMAQ. The upper panel gives the observed GOES skin temperature, while the lower left panel shows ground radiating temperature for the control MM5 run without satellite data, and the lower right panel shows the case where satellite measurements were incorporated into the model run.

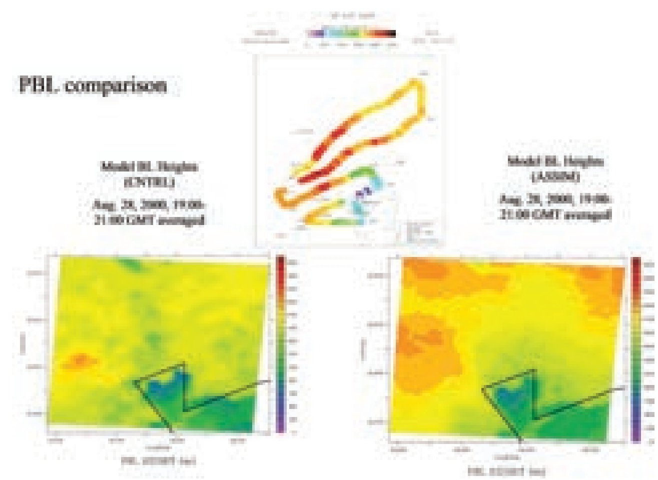


Fig. 3: Top panel shows aircraft observations of boundary layer height or mixed layer height. The lower left panel shows model-predicted boundary layer heights without satellite data. The lower right panel shows model-predicted boundary layer heights using the added satellite data.

Water Resources

Enhancing Regional Water Usage Decision Making

Water resources is an applications theme in the Applied Sciences Program of NASA's Earth Science Division. For decades, NASA has collected space-based observations and supported research and applications that provide essential information for water management and policy decisions. The data available for water resources projects are far more extensive now, and projects can address key questions in more depth: 1) how much freshwater is available and how is the supply changing? 2) what are the current and future demands for water,

near term and long term, especially in agriculture? 3) how is water consumed in agriculture, and how can that information be used to improve water use efficiency? 4) how is groundwater supply changing and how do such changes affect the physical and economic landscapes? 5) how is soil moisture changing and what are the effects of those changes on agriculture and flood control? 6) how can Earth observations improve forecasts of the magnitude and extent of floods? NASA Earth observations and the scientific research they support are relevant to these questions and their associated management actions. Evaluating the utility of the data involves focusing NASA capabilities on the specific needs of resource managers and policy makers with the goal of incorporating NASA data and data processing capabilities into the operational procedures of the users. Reaching that goal requires a robust understanding of the users' decision processes and information needs.

Four projects awarded through this solicitation addressed water resources issues. Three projects focused on evapotranspiration and soil moisture, and two projects examined water supply issues and the general issue of integrating NASA data into the procedures of operational users.

Evapotranspiration and Soil Moisture

Evapotranspiration (ET) is the process by which water is removed from the soil by direct evaporation into the atmosphere and by transpiration through plants as part of photosynthesis. Measurement of ET sheds light on the amount of water in the soil and the potential for that water to be consumed by plants. Soil moisture inferred from measurements of ET can also contribute to stream hydrology models. Farmers use soil moisture data to determine the timing and intensity of irrigation. Hydrologists use the data to calculate the timing and intensity of runoff and the potential for groundwater recharge. The accuracy and timing of soil moisture data are critical in agriculture and flood monitoring.

Benchmarking ET Remote Sensing Algorithms Used for Operational Hydrologic Decision Support Tools

Principal investigator:
Jan M.H. Hendrickx, New Mexico Institute of Mining and Technology

Participating organizations:
Daniel B. Stephens and Associates
Murray State University
U.S. Army Corps of Engineers
U.S. Bureau of Reclamation
University of Idaho
University of Wyoming

The project team evaluated data products from *Landsat* and MODIS in three decision support tools used to forecast ET, determine the hydrograph (a plot showing volume of stream discharge over time following a precipitation event) of stormwater discharge, and gauge groundwater recharge rates. The U.S. Bureau of Reclamation, Army Corps of Engineers, and U.S. Geological Survey regularly use these decision support tools. The impact of using *Landsat* and MODIS data was evaluated by comparing the model results in the decision support tools before and after *Landsat* and MODIS data products were incorporated into the process. The results were largely positive. Of those tested, the model that used initial soil moisture concentrations based on *Landsat* image products outperformed all others (Figure 4). The Army Corps of Engineers now uses *Landsat*-derived soil moisture whenever possible. The annual groundwater recharge rates predicted in mountain blocks in the southwestern United States using *Landsat* imagery were different from those predicted without using *Landsat* imagery. A qualitative validation found *Landsat*-based groundwater recharge rates more realistic, and the user, Daniel B. Stephens and Associates, began using *Landsat*-derived soil moisture maps in its modeling whenever possible. In contrast, *Landsat* and MODIS data products marginally improved the ET forecasts, but the effort and cost involved precluded incorporating those data products into operational procedures.

Enhancing Water Management Decision Support Systems with High Spatio-temporal Resolution Mapping of Evapotranspiration

Principal investigator:
Timothy C. Martin, Riverside Technology, Inc.

Participating organizations:
Colorado Division of Water Resources
Colorado Water Conservation Board

The project sought to augment the capabilities in two water management decision support tools—the South Platte Decision Support System (SPDSS) in Colorado and RiverWare™, a tool applied to the upper Rio Grande River in New Mexico—by using reflectance and thermal data from the Advanced Spaceborne Thermal and Emission Reflection Radiometer (ASTER), MODIS, and *Landsat* to calculate evapotranspiration (Figure 5). Prior to this project, ET was calculated in both sites indirectly by using an ET measurement from a standard crop and adjusting it by using a derived coefficient for the crop type and growth stage in each field of interest. The ET aggregated over a large area approximated the water use. It was understood that improving the accuracy of the ET measurements would significantly benefit water managers' efforts to understand the relationship between water demand and availability over time and over the entire study area.

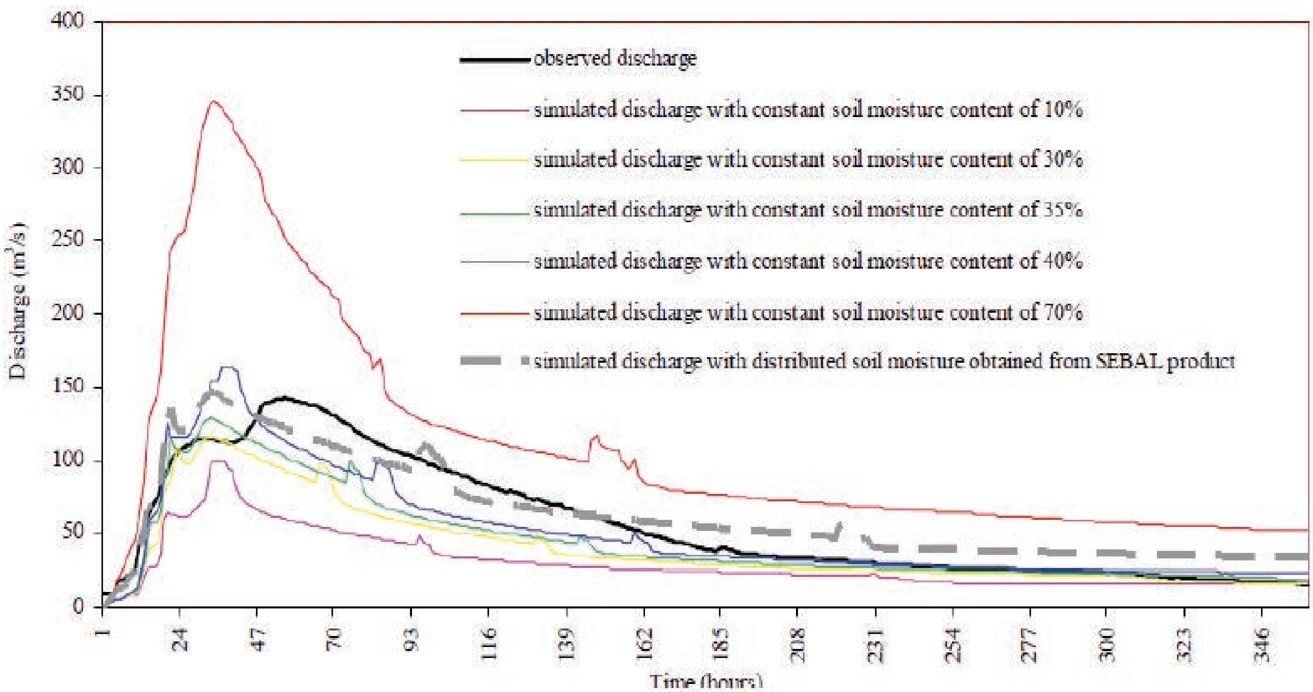


Fig. 4: Effect of initial soil moisture distribution on the difference between simulated and observed hydrograph. Dashed line is the *Landsat*-derived discharge using the Surface Energy Balance Algorithm for Land (SEBAL) product.

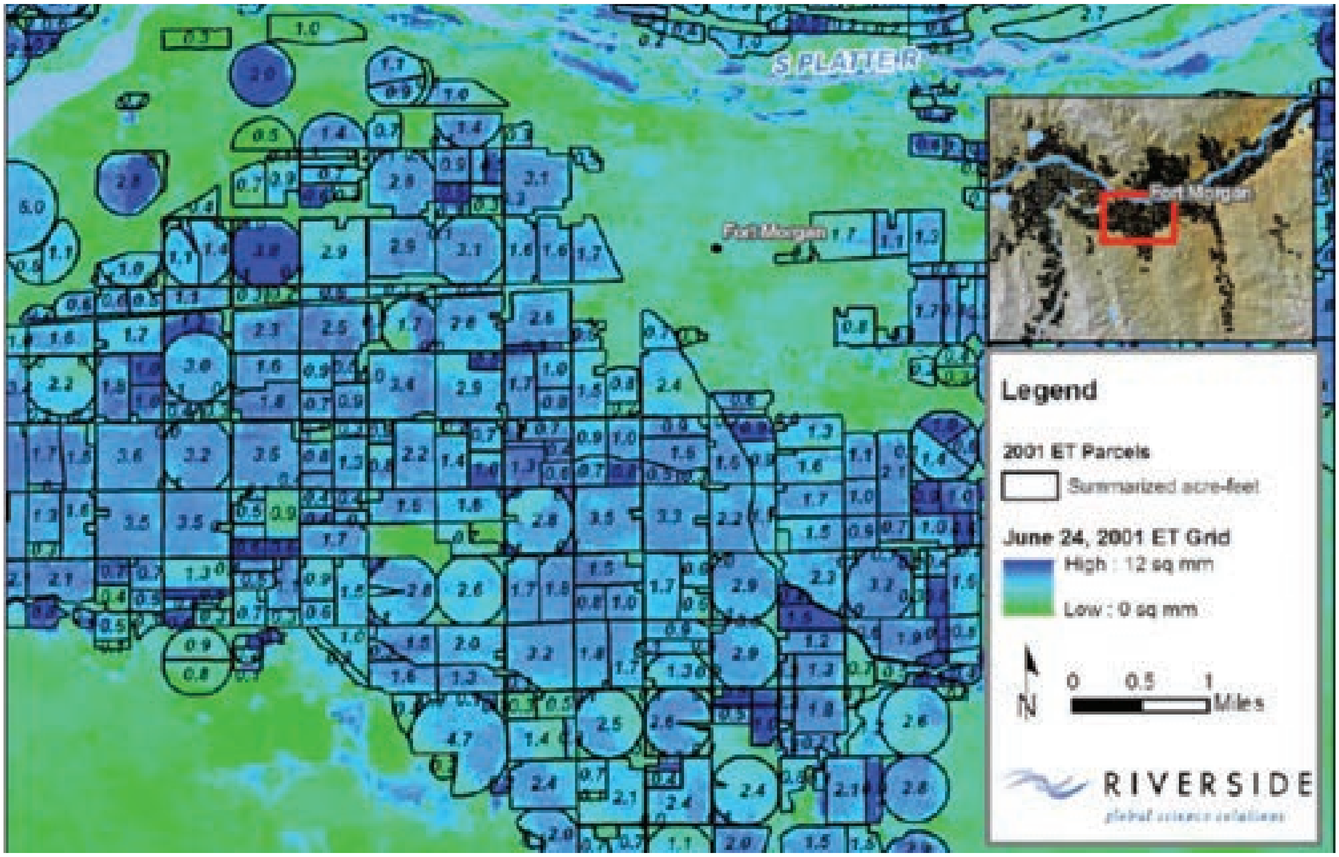


Fig. 5: Example of daily METRIC ET (in acre-ft.) summarized by parcel for an area near Fort Morgan, Colorado, for June 24, 2001.

A critical parameter to determine ET is soil temperature. ASTER, MODIS, and *Landsat* data provided soil temperature observations. Data from three systems were necessary because no one system met all the requirements. ASTER data were adequate but not available routinely; MODIS data were available daily, but the resolution was too coarse to observe single fields; and *Landsat* data were excellent for resolving individual fields but available only every 16 days, at best. Thermal data from *Landsat* were used in the METRIC (Mapping Evapotranspiration at High Resolution With Internalized Calibration) model to derive ET. In the South Platte watershed, seven data sets from *Landsat-5* and *Landsat-7* were processed for the 2001 irrigation season. ET calculations from those images were the basis for daily ET estimates, and the daily estimates were aggregated to monthly and seasonal totals. In the Rio Grande Basin in New Mexico, MODIS data from 2002, 2005, and 2007 were processed through METRIC in a similar manner.

Compared with the standard method for ET calculation, results using the METRIC model demonstrated that the addition of satellite-based methods for ET calculation can improve irrigation water management, support water planning at the watershed scale, and provide new information for estimating aquifer depletion and groundwater modeling.

At the conclusion of the project, a prototype Web-based tool was in place to demonstrate the utility of METRIC-derived estimates of ET. However, there was no commitment from either of the user agencies to continue supporting this work.

A Soil Temperature and Moisture Decision Support System for Agriculture

Principal investigator:
William Myers, National Center for Atmospheric Research

Participating organization:
Telvent DTN Meteorlogix

Crop and pest growth alike are driven by temperature and moisture, especially in the soil. If soil temperature can be forecast accurately, then pesticides can be applied as pests emerge and when wind and rain will not blow and wash the pesticides away. An accurate forecast of soil temperature and moisture therefore becomes valuable in knowing when to look and spray for pests.

Researchers at the National Center for Atmospheric Research (NCAR) teamed up with the largest supplier of agricultural weather forecasts in the United States to enhance a decision support system (DSS) for timing pesticide applications. To this end, they improved their land surface model of soil temperature and moisture by changing the way it represents heat transport and temperature in the soil, and incorporating NASA satellite data into the modeled soil surface.

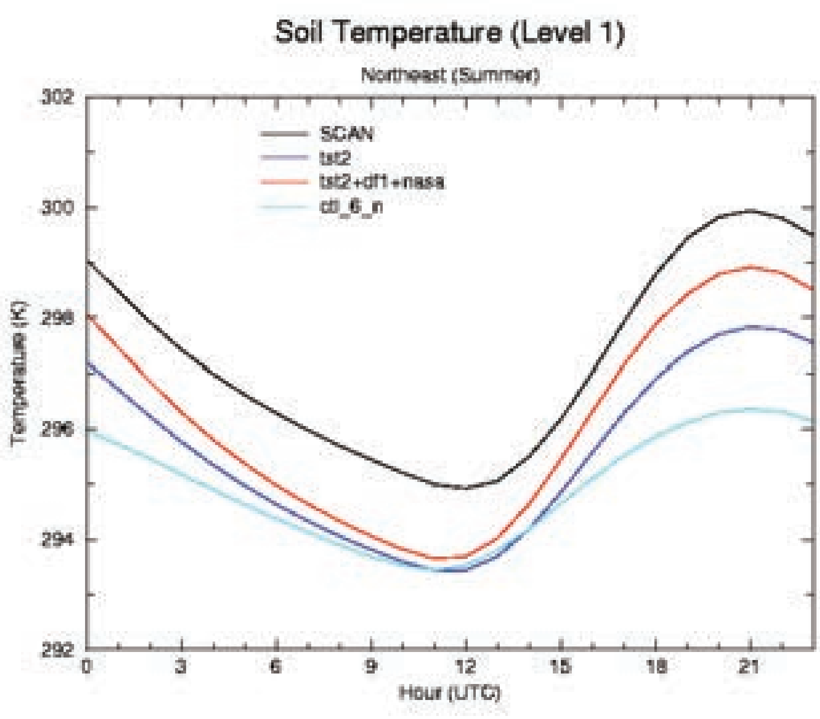
Every model contains approximations, and land surface models are no different. NCAR's High-Resolution Land Data Assimilation System (HRLDAS) model uses several parameters to describe the soil's physical properties, among them the ability to conduct heat. The project team found that it could improve heat transfer in the model's soil by using six layers instead of four. The team further refined HRLDAS by allowing each piece of land to have different physical characteristics. Previous uses of HRLDAS covered a very small area, so one soil type was enough, but the project team expanded the model to cover most of the continental United States, requiring additional flexibility.

The project team also used data from NASA's MODIS instrument to replace climatological land cover and land use data in the model. The team found that using the MODIS data improved the simulation in heavily vegetated areas (Figure 6), while performance in areas of desert or dormant vegetation did not improve and sometimes got worse. Further investigation revealed a mix of causes. Some areas had been misclassified in the climatological land cover database and MODIS observations, while others featured a mix of land cover types that was more complex than could be represented by a single land cover classification. By looking at photographs of several ground observing sites, the project team found that this issue was most pronounced in areas where vegetation and land use varied dramatically over short distances. In such areas, the team concluded that the 1 km resolution of the usual MODIS data was too coarse, and that finer resolution data would help. Finer resolution helps when multiple land uses exist in a single coarse cell of the model, such as when a small field lies between a pond and a forest. The project team suggested that such differences would be better resolved by finer, 100 m data.

Most of these changes made it into the Telvent DTN DSS, improving soil moisture forecasts from the largest distributor of agricultural forecasts in the United States. However, late in the project Telvent DTN Meteorlogix's participation waned as the market for agricultural forecasts changed. According to the principal investigator, introductions of new pest-resistant crops made forecasts for timing pesticide sprays less valuable, and the company lost interest in refining soil temperature and moisture forecasts further.

For more information, visit *www.ral.ucar.edu/research/land/technology/lsm.php*.

Fig. 6: Incremental improvement in soil temperature forecast as compared to the observations (black line) from three sets of progressive changes to the model, plotted for the northeastern part of the modeled area in summer. Each change includes the previous changes: adding two layers to the soil model (light blue, ctl_6_n), allowing the model surface to vary by soil type plus adding two layers (dark blue, tst2), and the previous two plus using MODIS surface data (red, tst2+df1+nasa).



Streamflow Forecasting

Evolving a Solutions Network of Resource Conservation and Development Councils, Watershed Management Teams, and NASA Research Institutions Across the Nation

Principal investigator:
J. A. Ward, Battelle Memorial Institute

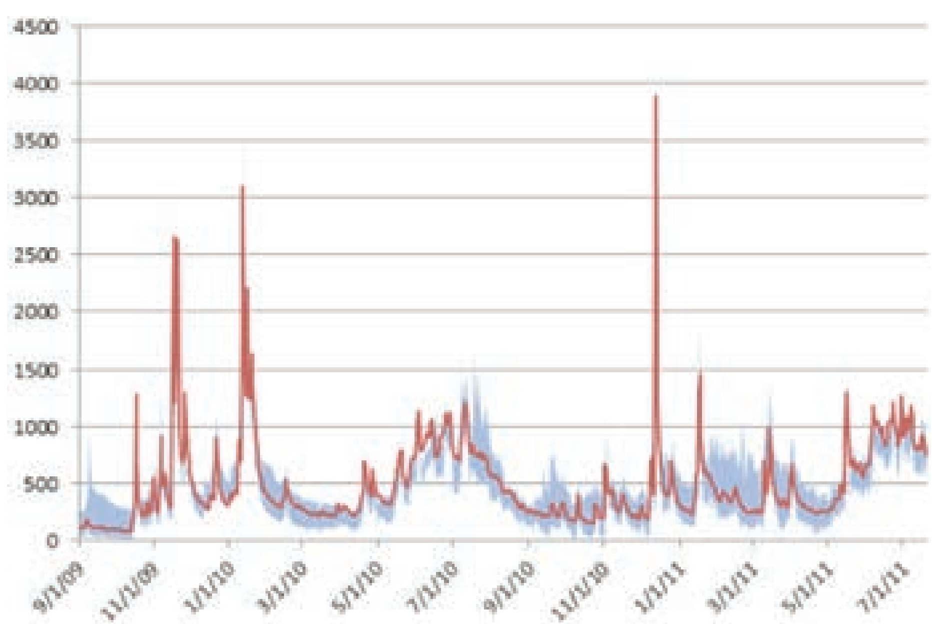
Participating organizations:
Clallam County, Washington
Dungeness River Management Team
Elwha–Morse Creek Management Team
Idaho National Laboratory
North Olympic Peninsula Resource Conservation and Development Council
Olympic National Park
Peninsula College, Port Angeles, Washington

The project team received an award to work with the North Olympic Peninsula Resource Conservation and Development Council to enhance decision support tools for local watershed management. The primary task in support of the council was to use MODIS data to improve streamflow forecasts for the Dungeness River. A second task examined the ability of *Landsat* data to provide information on stream sedimentation following removal of two dams on the Elwha River.

MODIS snow cover products were added to a hybrid model of the Dungeness River watershed to determine the amount of water stored in the snow and available for runoff through the watershed. Such information is used by resource managers to forecast daily, monthly, and seasonal flows through the system and to predict the amount of water available for use, the likelihood of flooding, and the recharge of local groundwater. Performance of the model with the MODIS data was benchmarked and the data processing was transferred to Peninsula College. Since October 2008, the model has generated daily streamflow forecasts available to resource managers and the public. Although model performance closely tracks with observed streamflow (Figure 7), the model outputs have been used more for teaching and outreach than in resource management and planning because the model output was not able to track specific weather events or generate reliable monthly or seasonal forecasts.

A second area of interest for the North Olympic Peninsula Resource Conservation and Development Council was removal of dams along the Elwha River and the impact that the removal would have on near-shore environments and the availability of water. Removal of the dams would result in the transport of several million cubic meters of sediment downstream. The council wanted to monitor the movement of the sediment before, during, and after removal of the dams. Project members considered using *Landsat* data to assist in monitoring the location and concentration of sediment. The council sponsored collection of data from a local stream on factors associated with movement of sediment including salinity, turbidity, water temperature, total dissolved solids, and dissolved oxygen. The ground-based observations were compared with data collected from

Fig. 7: Dungeness River discharge: observed and forecast flow in cubic feet per second from a hybrid model using MODIS snow cover data.



Landsat-5 and *Landsat-7* between January and April 2011. No significant correlations emerged between the *Landsat* observations and the stream data.

Beyond the two specific stream-based tasks, the project focused on public outreach and technology transfer. The council and related organizations on the Olympic Peninsula remain interested in the use of NASA data, but no examples of integration of such data in operational procedures have, as yet, been achieved.

WaterNet: The NASA Water Cycle Solutions Network

Principal investigator:
Paul Houser, Center for Research on Environment and Water

Participating organizations:
City University of New York
Hydromet DSS
International GEWEX Project Office
Massachusetts Institute of Technology
University of Arizona
University of California, Irvine
University of Maryland, Baltimore County

WaterNet, as described by the project team, is a "solutions network devoted to the identification and recommendation of candidate solutions that propose ways in which water cycle-related NASA research results can be skillfully applied by partner agencies, international organizations, and state and local governments." The project worked with academia and representatives from state and national organizations concerned with water resources management and policy to describe common information needs and to propose ways in which those needs could be met through the use of NASA Earth science data and models. The products of the project were solutions reports that addressed specific water resources information needs, and scientific contributions that focused on research topics related to water supply and usage.

Six candidate solutions emerged from the project. The reports varied from general topics, such as the state of the global water system (which resulted in a list of fundamental questions that must be answered to understand the status of the global water system and how it will be affected by climate change), to specific topics such as integration of snow cover in Arizona as an indicator of water supply for utility companies in the Southwest, to enhancements to the information available to the California Nevada River Forecast Center. Some solution reports include reference to NASA data from the *Gravity Recovery and Climate Experiment* (*GRACE*), MODIS, and the *Tropical Rainfall Mapping Mission* (*TRMM*), but all reports were demonstration projects. Although WaterNet made an impact on data sharing in the water resources community, there are no examples of the demonstration projects resulting in a transition to operational use.

Ecological Forecasting

Observing, Forecasting, and Responding to Ecological Change

Earth observations from space contribute to our understanding of the effects of human activities, physical processes (e.g., weather and volcanic eruptions), and biological processes (e.g., spread of plant and animal species) on the landscape and seascape. Data from spaceborne instruments built and launched by NASA provide insights on both the human and natural elements of environmental change. The Ecological Forecasting Applications area of NASA's Applied Sciences Program sponsors projects that use NASA Earth science data and models to provide better information to those responsible for managing natural systems and the interplay between natural systems and human activities.

Five projects selected through the solicitation addressed issues in ecological forecasting. Three projects dealt with terrestrial processes: tracking and predicting the spread of invasive plant species in Yellowstone National Park, implementing better tools for observing and tracking ecological changes in U.S. national parks, and predicting the impact of the introduction of a biological control agent on an invasive plant. Ocean ecosystems were the subject of two projects: predicting the location and condition of a significant fishery off the coast of northwestern South America, and predicting the day-to-day location of right whales during their migration to mitigate the potential danger to the whales from fishing and ship traffic.

Ecological Forecasting: Land

Integration of a Large-area Invasive Spread Network with Climate Models for Decision Support

Principal investigator:
Robert Crabtree, Yellowstone Ecological Research Center

Participating organizations:
Bonneville County, Idaho
Greater Yellowstone Coordinating Committee
Harvard University
Idaho State University
Montana State University
NASA Ames Research Center
NASA Goddard Space Flight Center
North Dakota State University
U.S. Forest Service
University of California, Berkeley
University of Montana
Yellowstone National Park

The introduction and spread of plants, animals, and pathogens not native to an area can completely transform an ecosystem, often in ways that are not beneficial to the services provided by that ecosystem to its traditional components or for people who rely on those services for essential resources. Managers responsible for maintaining natural systems such as national parks need the best available information on the location and potential spread of harmful invasive species so that mitigation and adaptation efforts can be implemented.

The Greater Yellowstone Coordinating Committee coordinates the actions of multiple agencies—local, state, and federal—that share responsibility for resource management, including response to invasive species, in the greater Yellowstone area. The committee uses a decision support tool to provide information on the present locations of invasive species. The tool is part of the large-area Invasive Species Network, a capability available nationwide.

Four invasive species were examined for this project: white pine blister rust, cheatgrass, Canada thistle, and leafy spurge. All four pose major threats to native Yellowstone ecosystems. Successful control of these species requires information on their location and a predictive capability to know where they are likely to occur so that available resources can be focused on areas of greatest concern and control measures initiated before a species is well established in a new location.

The predictive capability was a new element in this project. Project staff employed a NASA-developed tool, the Invasive Species Forecasting System (ISFS), now operated by the U.S. Geological Survey at the National Institute of Invasive Species Science, and data from NASA spaceborne and airborne systems (MODIS, *Landsat*, and the Airborne Visible/Infrared Imaging Spectrometer), and the NASA Carnegie-Ames-Stanford Approach (CASA) model to identify sites within the greater Yellowstone area most likely to support one or more of the invasive species of interest. CASA predictions are based on output from the ISFS. Inputs include ground-based information on where the species are located and have been found in the past, combined with various ecological parameters, including vegetation indicators, slope and aspect, rainfall, and burned area condition, obtained from remotely sensed data for the entire study region. The principal investigator states that the predictive maps that emerge from this process are now, "essential to almost all invasive species research and management decision making." And further, this decision support capability "addresses a crucial, unmet technology need within the invasive species community and significantly advances the nation's ability to manage biological invasions."

For more information, visit *www.yellowstoneresearch.org.*

Ecological Condition of U.S. National Parks: Enhancing Decision Support through Monitoring, Analysis, and Forecasting

Principal investigator:
Andrew Hansen, Montana State University

Participating organizations:
California State University, Monterey Bay
Colorado State University
NASA Ames Research Center
National Park Service
Woods Hole Research Center

The National Park Service has an ongoing need to monitor the condition and change of national park lands in order to meet its responsibilities to maintain the parks for public benefit and ecological stability. The importance of establishing benchmark conditions for the parks is crucial now, because climate change will impact the parks in ways that are not well understood. If the drivers for ecological change in the parks can be identified and the likely future condition of the park understood, park managers can take effective action now to mitigate and adapt to climate change and ensure that the parks will continue to meet public needs.

The Park Service initiated an inventory and monitoring program to identify indicators of ecological health that could be applied to all parks in the system. Initially this program did not make use of remotely sensed data, but it was soon apparent to the Park Service that the use of such data was essential for an inventory and monitoring program across all parklands and to adopt a reasonable approach to forecasting ecological conditions. With those requirements in mind, this project had three objectives: 1) identify NASA data and other products useful as indicators for National Park Service inventory and monitoring work, as well as delineating the boundaries of the surrounding park-centered ecosystems appropriate for monitoring; 2) add value to these data sets for understanding change through analysis and forecasting; and 3) deliver these products and a means to integrate them into the National Park Service inventory and monitoring decision support framework. The Park Service initiated a new project called Park Analysis of Landscapes and Monitoring Support (PALMS) to make certain that the outputs from the project were integrated to the maximum extent in Park Service procedures.

The first part of the project involved identification of critical ecosystem indicators. This objective was accomplished through a series of meetings and workshops that included Park Service and NASA personnel. National parks were identified across the United States to be part of the project to make sure that the defined indicators were applicable in different ecosystems. Among the ecosystem indicators defined were phenology of the vegetation (when the vegetation reaches different stages of development in the growing season), ecosystem productivity, runoff, and biodiversity.

NASA Earth science inputs in the project were substantial and included MODIS products for Normalized Difference Vegetation Index (NDVI), land surface temperature, snow cover, leaf area index, i.e., the amount of green vegetation, and land cover. Advanced Very High Resolution Radiometer (AVHRR) data were also employed for vegetation condition at a coarser resolution, and *Landsat* data at 30 m resolution were used for land cover. The Terrestrial Observation and Prediction System (TOPS) from NASA Ames was the primary tool for generating products from NASA data and for forecasting future ecological conditions (Figure 8).

The NASA data products were fed through the PALMS project into the Park Service's decision support tool to determine the status and trends in selected indicators of park ecosystem conditions to provide early warnings of anomalous conditions, to provide data to better understand the dynamic nature of park ecosystems and baseline conditions, and to increase use of scientific data in the decision making process in the parks. These outputs from the Park Service decision support tool affected policy and management decisions, such as 1) policies related to resource and funding allocations; 2) collaborative agreements on resource issues with owners of land adjacent to the parks; 3) public education and outreach on greater park ecosystems; 4) management decisions regarding prioritizing restoration, protection and remediation of ecosystems; 5) reduction and mitigation of habitat loss and land use impacts; and 6) improvement of cross-boundary monitoring and management.

At the conclusion of the project, the first two objectives were met. Integration of the results into Park Service procedures was under way but not complete. The primary impediment was lack of time. The three-year term of the project was not sufficient to meet the inventory and monitoring enhancements desired by the Park Service and to embed the new approach into operational use. One factor limiting adoption of the new approach was the lack of time to train park managers in the meaning and use of the NASA geospatial products.

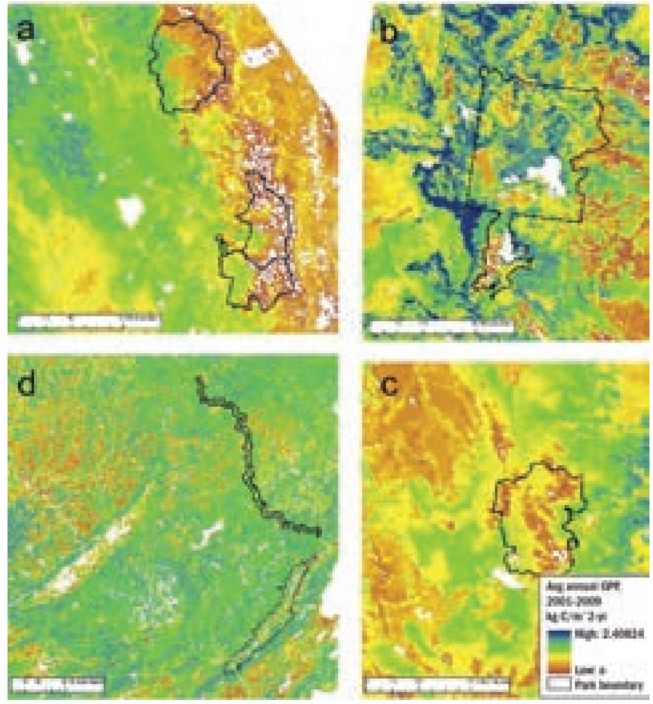


Fig. 8: Daily estimated GPP (gross primary production) was analyzed and assimilated into a model to convey patterns in space and time of productivity in the parks and surrounding ecosystems. Shown here are maps of average annual total GPP for 2001-2009 for these national parks: (a) Yosemite and Sequoia-Kings Canyon, (b) Yellowstone and Grand Teton, (c) Rocky Mountain, (d) Delaware Water Gap and Upper Delaware.

Explicit Biological Control Agent Modeling of Invasive Species Using NASA Remote Sensing and Micro Climate Models

Principal investigator:
Marc Kramer, University of California, Santa Cruz

Participating organization:
U.S. Department of Agriculture

The U.S. Department of Agriculture (USDA) is one of the federal agencies responsible for implementing controls on invasive plant species. Responding to noxious plants can take several forms, including physically removing the plants, poisoning the plants with chemical control agents, or biological control, i.e., the introduction of a plant-specific animal, insect, or pathogen that will infect or feed on the invasive plant and kill it, reduce its spread rate, or both. Biological controls are favored because they are cost-effective and have, if developed and administered properly, limited or no negative side effects on local ecosystems.

Yellow star thistle (Figure 9) is an invasive plant on the grasslands of California and a major threat to the productivity of those lands. To control yellow star thistle, USDA uses the Hierarchical Environment for Research Modeling of Ecological Systems (HERMES) modeling tool, a site-specific tool that models biological systems. HERMES simulates plant growth, and can help predict the time in season when a plant may be especially susceptible to biological control.

The tephritid fly is a potential biological control for yellow star thistle. To be effective, the fly must be ready to lay eggs when the thistle is starting to flower. The fly larvae establish themselves in the flower and destroy the seed of the thistle. Establishing and maintaining the required synchrony between the phenology of the plant and the biological stage of the fly requires current information about local and regional weather conditions, especially temperature and winds.

Prior to this project, USDA obtained site-specific weather information only. As a consequence, the agency lacked the ability to monitor, both spatially and temporally, the effectiveness of the biological control. This project enhanced the HERMES tool to be spatially explicit by linking the model with the state-of-the-art Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) weather model, operated by the NRL Marine Meteorology Division. Input to COAMPS from NASA included wind data from MODIS and SeaWinds sensors. MERCURY is the enhanced HERMES decision support tool. At the conclusion of the project, MERCURY was tested over a 30,000 km^2 area in California to compare the predicted versus observed weather data over select gauges in the study site, to run the decision support tool with the tephritid fly, and to compare predicted versus observed insect emergence timing across the study domain. In the words of the project leaders, "The critical benchmark used to compare the existing USDA DSS with the NASA enhanced DSS is that the MERCURY modeling approach performs as well as a weather station-driven USDA insect model output, which corresponds to existing capabilities." The results of the project indicated that the modeling approach with NASA data outperformed the weather station data-only approach for predicting emergence of the tephritid fly (Figure 10) and calibrating that emergence with the period of susceptibility of yellow star thistle. At the conclusion of the project, USDA was continuing to evaluate the model results as a prerequisite for adopting the MERCURY model results into its biological control processes.

In the realm of ecological forecasting, this project is an illustration of how ecosystems that have undergone unintended, damaging change through the spread of an invasive plant species can be returned to a more sustainable state through processes that mimic natural ecosystem dynamics, and how NASA Earth science data can play a positive role in reaching that outcome.

Ecological Forecasting: Oceans

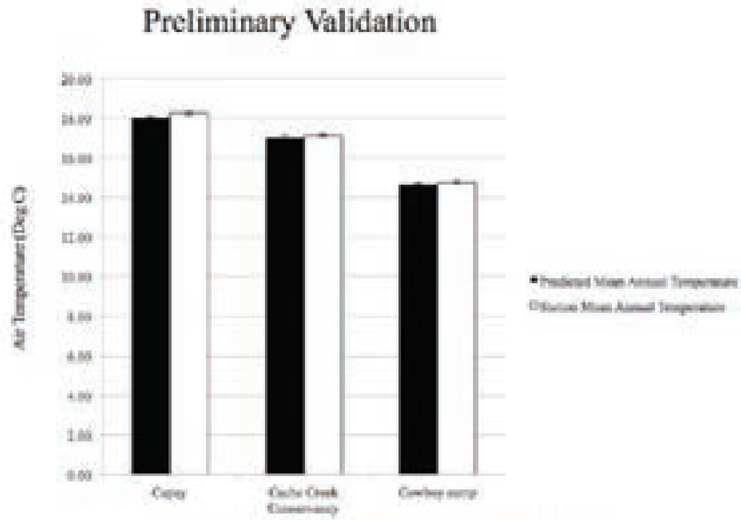
Two ocean ecosystem projects focused on maintaining an essential fishery and an endangered species. In both instances, the actions taken by resources managers were based on an understanding of the role of the species within the ocean ecosystem and the assurance that the actions taken will be in accordance with the role of the species within that system.

Utilizing Remote Sensing, Modeling, and Data Assimilation to Sustain and Protect Fisheries: Ecological Forecasting at Work

Principal investigator:
Francisco Chavez, Monterey Bay Aquarium Research Institute

Participating organizations:
Duke University
Instituto del Mar del Peru
University of Maine

Yellow Star Thistle



Comparison between observed and 2007 COAMPS modeled daily mean air temperature for three validation sites in Cache creek.

Fig. 9: Yellow star thistle and validation data for COAMPS-generated daily mean air temperature, a critical parameter for effective biological control of yellow star thistle.

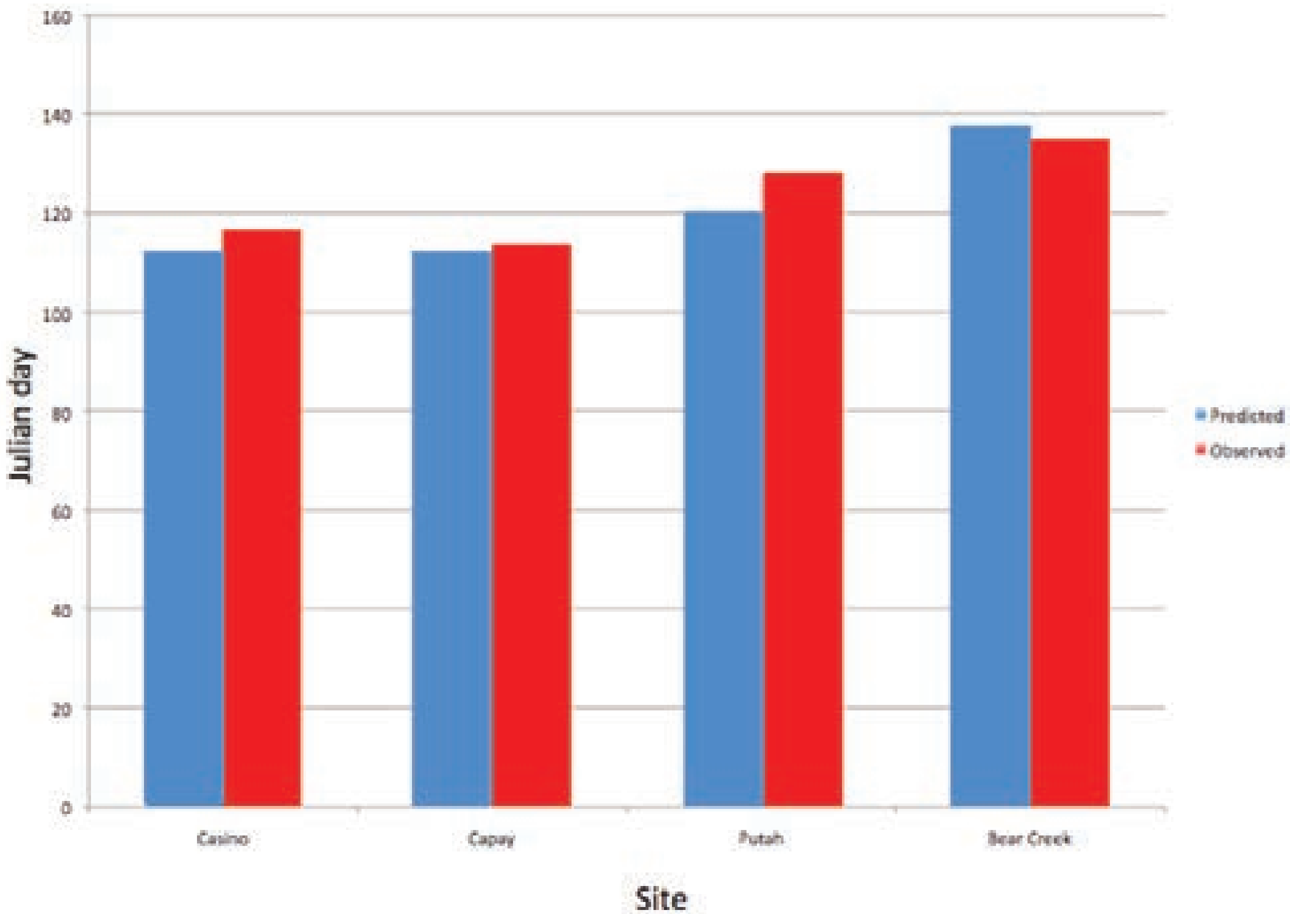


Fig. 10: Predicted versus observed peak spring female adult emergence of the tephritid fly across the study area.

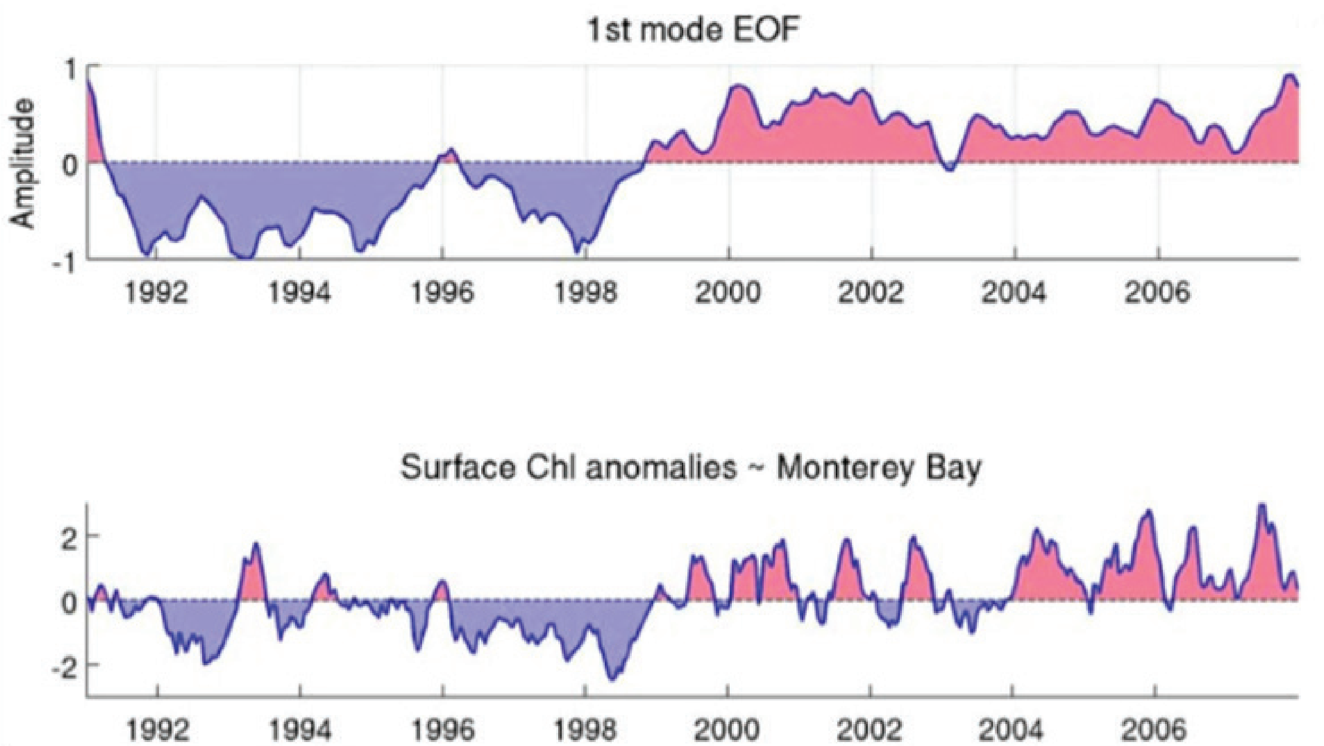


Fig. 11: Model predictions (in mg/m^3) of chlorophyll concentrations (top) and observed chlorophyll in Monterey Bay (bottom). Location of chlorophyll concentrations is an indicator for location of anchovies.

This project enhanced an existing decision support system employed by fishery managers in Peru to manage the anchovy fishery off the northwest coast of South America. Satellite-based data products and an extensive record of *in situ* data collected regularly in the fishery were inputs in a model that considers the interaction between physical ocean processes, such as upwelling of cold water along the coast, and biological factors. No other ocean region has this combination of environmental observations, fish resources, fisheries monitoring, and well-validated climate forecast models for forcing high-resolution operational ecosystem models. The project was able to predict the location and magnitude of the fishery nine months in advance (Figure 11). These predictions provide better data to the fishery managers and allow them to control the exploitation of the fishery in a manner that maximizes economic investment while maintaining the sustainability of the fishery and the role of the anchovy in ocean ecosystems.

The decision support system benefited from three enhancements: 1) satellite remote sensing products that describe the trends in sea surface temperature, sea level, and chlorophyll; 2) an improved model of physical (sea surface temperature, sea level, sea level pressure, winds, irradiance, and currents) and biological (chlorophyll and primary production) variability and their impacts on fish abundance; and 3) short- (months) to long- (year) term forecasts (or trends) of environmental conditions that impact fish abundance. NASA data employed included MODIS, from *Aqua*, and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) for chlorophyll-a, and ocean winds from *Quick Scatterometer* (*QuikSCAT*). Satellite data were used with *in situ* observations of fish catches and related conditions to develop nine-month predictions of environmental variability and fishery location. These predictions continued to be generated and made available online at *www.mbari.org/bog/fast/forecast.html*. At the request of the Peruvian managers responsible for the fishery, monthly summaries of satellite products were made available online at *http://coastwatch.pfel.noaa.gov/FAST*.

Predicting Right Whale Distributions from Space: An Operational System for Marine Ecosystem Modeling

Principal investigator:
Andrew J. Pershing, University of Maine

Participating organizations:
Cornell University
University of Massachusetts

The right whale is a critically endangered species. Approximately 450 remain. NOAA is responsible for assuring the safety of right whales when they traverse active fishing grounds and sea lanes in and around the United States.

Copepods are small crustaceans that serve as the primary nutritional source for right whales. The intention of this project was to predict the times when right whales would likely be found in active fishing zones by monitoring and predicting the changes in the concentration of copepods (Figure 12). With that information, NOAA could order a cessation of fishing practices of potential harm to the whales until the whales had passed.

Predicting copepod concentrations was accomplished using the Satellite-based Estimates and Analysis of Stage-resolved Copepod Abundance in Pelagic Ecosystems (SEASCAPE) model. Copepods begin life as eggs and transition through 11 life stages before reaching adulthood. The rate at which copepods pass through these stages is strongly linked to water temperature. SEASCAPE uses satellite-derived sea surface temperature (SST) measurements from AVHRR or MODIS to determine the copepods' development rate. The rate at which a female copepod produces eggs is strongly linked to phytoplankton abundance, which can be derived from chlorophyll measurements. SEASCAPE uses chlorophyll measurements from SeaWiFS or MODIS to predict egg production rates. As the population develops, it is transported by ocean currents. Ocean current predictions were obtained using the Finite Volume Community Ocean Model (FVCOM). FVCOM assimilates a range of satellite products, including SST from MODIS and AVHRR and sea surface height from *TOPEX/Poseidon*. The population of copepods is kept in check by temperature and density-dependent mortality.

After the right whale project began, NOAA changed its rules for fisheries and required whale-safe fishing techniques at all times. Consequently, the enhancement to the decision-making process envisioned by the project was no longer necessary. However, the issue of predicting when right whales were likely to be in shipping lanes remained. The SEASCAPE approach was again applied, but at finer spatial (about 1 km^2) and temporal (approximately daily) resolutions. An additional modeling approach, called the Maximum Entropy approach or MaxEnt, was applied to the SEASCAPE output to relate spatial environmental data to animal and plant distributions in a variety of contexts. As the project team states, MaxEnt "takes in a data set of sightings, each associated with a vector of environmental data, and estimates a probability distribution function that determines habitat suitability as a function of the environmental variables."

The approach proved reasonably successful, but neither NOAA nor any other operational user concerned with preventing incidents between right whales and ships has made it operational. The primary outcome of this work is ongoing interest by NASA in using the habitat modeling approach to study the impact of climate change on whale habitat.

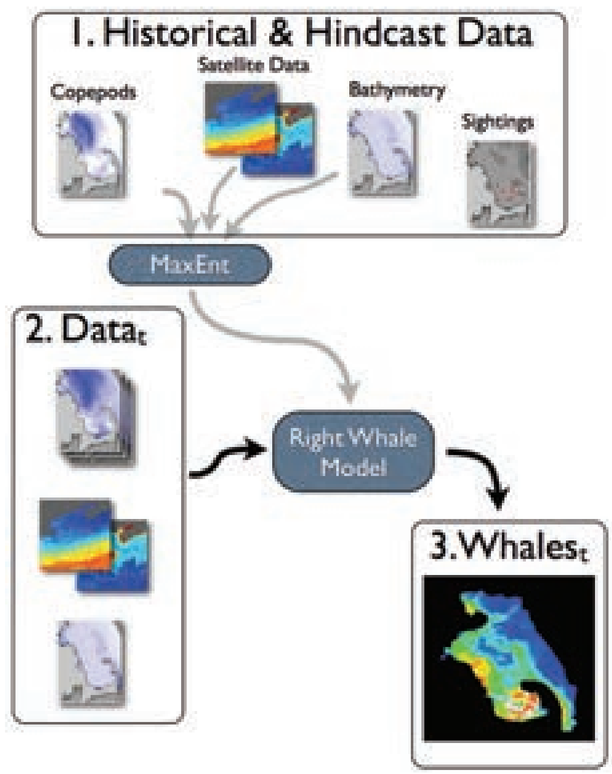


Fig. 12: A conceptual diagram of the right whale modeling component of this project. SEASCAPE calculates historical copepod abundances first. The project team then pairs historical right whale sightings with copepod abundances calculated by SEASCAPE at the time and place of the sighting, along with the sea surface temperature, chlorophyll and depth in box 1. This information goes into the MaxEnt algorithm, which produces a right whale habitat model. SEASCAPE copepods and satellite data along with the bathymetry, shown in box 2, go into the habitat model, producing an estimate of right whale habitat suitability for that day, as shown in box 3.

Assessing Power Generation and Transmission

Two projects from the solicitation address aspects of power generation and manipulation. The first addresses solar, wind, and to some extent, hydro power in developing countries and the United States. The second project explored the effect of space weather on electrical power transmission in North America.

Solar and Wind Energy Resources

Improving Decision Support Tools and Decision-making Processes for Renewable Energy Planning and Assessment Using NASA Earth-Sun Systems Data and Modeling Results

Principal investigator:
Eugene A. Fosnight, U.S. Geological Survey

Participating organizations:
Dakota State University
NASA Langley Research Center
U.S. National Renewable Energy Laboratory

The Solar and Wind Energy Resource Assessment (SWERA) began in 2001 with contributions from several national agencies through the Global Environment Facility within the United Nations Environment Programme (UNEP). SWERA was initially a country-centric project focused on the production of national solar and wind assessments supporting renewable energy decision makers in 13 countries within a global framework that included several continental data sets (Figure 13).

Subsequently, in 2005 with support from NASA, SWERA began the transition into a global DSS with integrated tools including prototype small hydropower assessments to complement the solar and wind assessments. NASA global renewable energy assessments and climate data were integrated into SWERA to provide global coverage and a more complete portfolio of information needed to assess the global renewable energy potential.

The SWERA DSS provides access to renewable energy information to anyone (Figure 14). This is accomplished by working with national producers of renewable energy assessments and by providing a common mapping and database interface for consumers of the information.

The close partnership among the U.S. National Renewable Energy Laboratory (NREL), the German Aerospace Center (DLR), Denmark's National Laboratory for Sustainable Energy (Risoe/DTU), and the National Institute for Space Research (INPE) in Brazil, working with national partners to produce the assessments is critical to the success of a sustainable DSS to serve the end user community. The SWERA DSS provides tools for partners to upload and create metadata for renewable energy data, maps and documents, to support editing of the website content, and tools for end users to query, view, and download the data. The original DSS had content in English, Spanish, and Portuguese.

The NASA SWERA project funded evolution of the underlying system architecture to support improved analysis tools within the SWERA DSS and to support standard-compliant map and data Web services throughout the renewable energy user community. The incorporation of NASA's global database of renewable energy and climate data made SWERA truly global in scope. The depth of the time series of the NASA science data provided needed information describing the variability of the resource data. The small hydropower prototype built on NASA SRTM elevation data and TRMM rainfall estimates to estimate small hydropower potential.

The SWERA project had three broad goals: 1) improve the underlying structure of the DSS, incorporating standards compliant metadata and Web services

Fig. 13: The 13 original SWERA members. NREL contributed renewable energy expertise and 27 national data sets. The U.S. Geological Survey (USGS) developed prototype hydropower data sets for two countries. The UNEP office at the USGS Earth Resources Observation and Science (EROS) Center partnered with Dakota State University (DSU) to improve the SWERA DSS and to develop the Renewable energy Resource EXplorer (RREX) for query and visualization of the renewable energy data, including a prototype small hydropower mapping tool. Standards-compliant map and data Web services were integrated into a GIS and energy analysis system. DSU developed the user survey to assess the usability of the SWERA DSS.

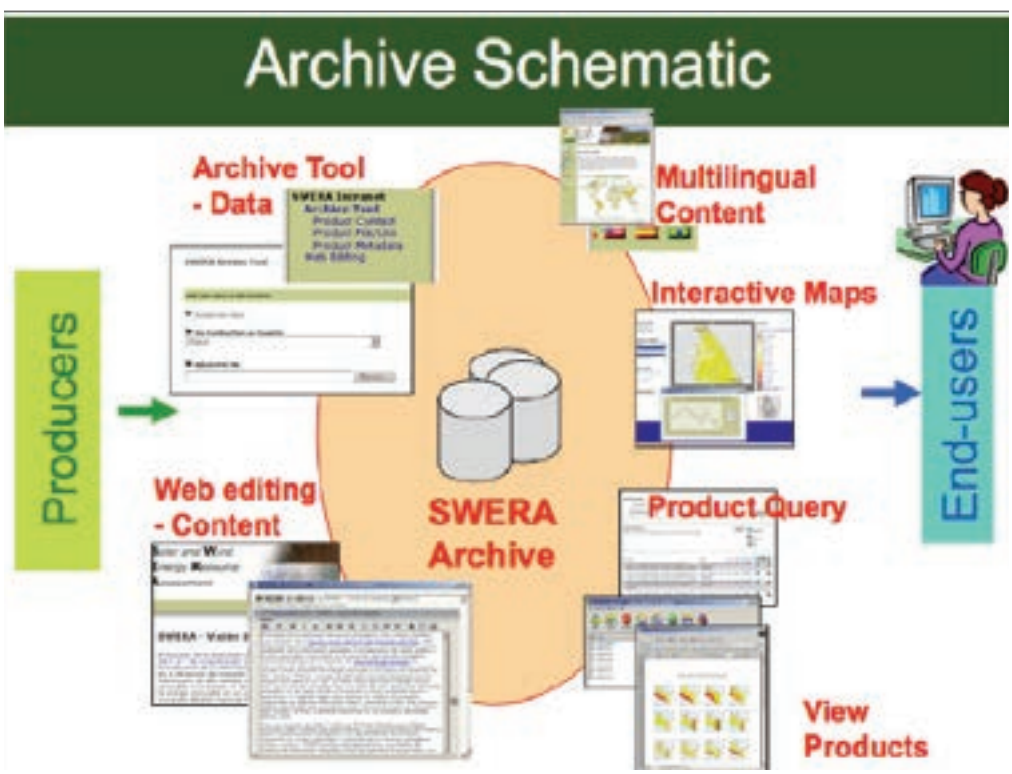


Fig. 14: SWERA schematic.

to better serve a diverse renewable energy user community—from consumers through energy analysts and developers to investors and policy makers; 2) use NASA Earth science results to move from a country-specific DSS to a global one through the incorporation of renewable energy and climate data sets; and 3) incorporate NASA Earth science results into a small hydropower prototype.

In 2010, SWERA changed its focus to serve as a global user-centric DSS. The SWERA DSS was redesigned to serve a very broad multi-resource user community including consumers, investors, developers, policy makers, and researchers. This was accomplished through the development of an easy-to-use mapping and graphing application, the Renewable energy Resource EXplorer (RREX), a flexible search tool for exploration of the source data, interfaces to energy analysis tools, standards-based Web services that permit the data to be widely used, and the investigation of small hydropower to expand the portfolio of energy assessment types. A user manual is available to provide guidance on the use of SWERA (*http://en.openei.org/wiki/SWERA/Getting_Started*).

RREX provides an easy-to-use system to explore, query, compare, and visualize renewable energy data. The map and data services used by RREX to generate the maps and graphs are also available for use by the energy analysis community to utilize and ingest the renewable energy and climate data from the SWERA database into mapping and analysis tools.

The SWERA user community is served by a range of product types. Among the simplest are maps and documents that can be downloaded and read. The second-tier products are RREX and geospatial toolkits. Finally, the source spatial data sets can be downloaded for use in energy analysis tools and geographic information systems.

SWERA acts as a sharing center for countries and organizations. Through the project, government agencies may share information with interested parties. Industry personnel, investors, and other researchers are able to find this information and incorporate the shared information within their research and decision making. SWERA makes data for developing countries more accessible, and the use of such energy resources appealing to private as well as public investors. In effect, SWERA assists full realization of renewable energy resource potential within the different locations. Through SWERA, consistent, reliable, and verifiable data are shared with investors, lawmakers, government agencies, and any other concerned parties. Not only are the data shared through SWERA, but geospatial toolkits are available to analyze and visualize the data. SWERA provides an interface for finding and accessing information to make it easily accessible to the public.

Integrated Forecasting System for Mitigating Adverse Space Weather Effects on the North American High-voltage Power Transmission System

Principal investigator:
Michael Hesse, NASA Goddard Space Flight Center

Participating organizations:
Dakota State University
Electrical Power Research Institute
National Renewable Energy Laboratory

The Sun is a dynamic body. The energy and particles it radiates toward Earth are not constant. During storms on the Sun's surface, known as coronal mass ejections, the amount and intensity of the Sun's emissions may increase greatly. This surge in solar activity, known as space weather, can generate large variations in the Earth's magnetosphere and ionosphere, and induce currents in electrical systems on the Earth's surface that disrupt radio communications, navigation systems, and power transmission. Extreme space weather events are not common, but they occur with some regularity and the impact of geomagnetically induced current (GIC), the manifestation of extreme space weather on the electric grid, has the potential to disrupt electrical power and cause substantial economic and social damage. Those effects of GIC on power transmission and utilization of electric devices can be mitigated if electrical utilities are warned of the coming events in time to shut down or otherwise protect systems before the GIC strikes.

The Electric Power Research Institute (EPRI) developed a system to forecast the effects of solar-generated GIC on the North American power grid. EPRI used SUNBURST, a research support tool employed by the electric power industry in the United States. The forecasting system consists of a chain of models describing the Sun-Earth system. A key element of SUNBURST is its use of data from two NASA satellites, the *Solar and Heliospheric Observatory* (*SOHO*) and the *Advanced Composition Explorer* (*ACE*) to drive the models.

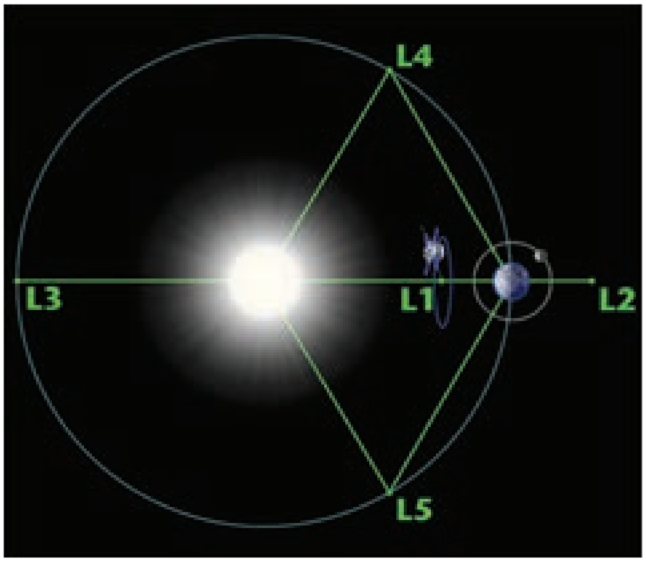


Fig. 15: The NASA *ACE* satellite resides well outside the Earth's magnetosphere and between the Earth and the Sun at the Lagrange point L1. *ACE* observes material streaming off the Sun before it enters near-Earth space (Image: NASA/H. Zell).

SUNBURST was developed and in place before the solicitation. The purpose of this project was to enhance SUNBURST, verify and validate its predictions, and prepare the system to provide warning of impending GIC during the period of maximum solar activity around 2013.

The established GIC forecasting system is composed of two partially separate components providing long lead-time Level 1 (one to two days, from *SOHO* observations) and short lead-time Level 2 (30 to 60 minutes, from *ACE* observations) estimates. Two different approaches for verifying and validating the two levels of the system were devised and executed as part of the project.

The Level 2 GIC forecasts are driven by observations of solar activity taken by *ACE* at the L1 Lagrange point, about 1.5 million km from the Earth (Figure 15). Ideally, depending on the structure and speed of the solar activity, GIC forecasts can give 30 to 60 minutes lead-time for end users to react. Although the lead time is relatively short, it is sufficient to allow operators to shut down transmission systems and take other actions to mitigate the impact of GIC.

This project included a comprehensive economic analysis of the impact of GIC on high-voltage power transmission systems from several different perspectives. Table 1 lists the anticipated dollar costs to utilities and society from GIC events of increasing intensity. As the intensity of the event doubles, the dollar impact increases exponentially. Societal losses include loss of wages to utility workers and shutdown of their support systems.

This study concluded that despite the difficulties associated with analyzing rare extreme events, both Level 1 and Level 2 forecast accuracies were good enough to generate potential economic benefit for users of the forecasting system. Final validation of the forecast systems awaits the next major GIC event.

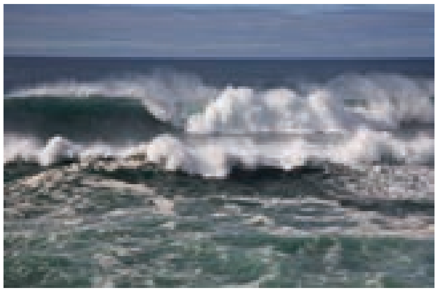
GIC Level	Utility Loss*	Societal Loss*
100 amp	0.5	0.5
200 amp	115	115
400 amp	794	22,400
*Million dollars		

Table 1: Anticipated losses to utilities and society from GIC events of different intensity.

Disaster Management

Responding to Unusual Events in Natural Systems

NASA is often called upon to make its Earth observations and related data available to those with a mandate to respond to natural and manmade disasters. During the last decade, NASA responded to hurricanes, flooding, oil spills, droughts, wildfires, and other disasters with imagery obtained by NASA spaceborne and airborne instruments. Such data help personnel in other agencies respond effectively to mitigate disasters and help the communities involved recover after the events.



The Disasters Applications area in NASA's Applied Sciences Program enables first responders and other disaster-response agencies to use NASA observations, derived data products, modeling and data analysis to improve predictions and respond to disasters better. The goals of the work sponsored by NASA in this program element are to aid in disaster early warning and response and recovery efforts. As with other elements within the Applied Sciences Program, the beneficiaries of this research are the decision support systems sponsored by those agencies with established roles and responsibilities to plan for, respond to, and help recover from, disasters.

Three projects funded under this solicitation illustrate NASA's approach to disaster management. One project involved an operational agency at the state level, the other at the federal level. Both projects enhanced the performance of existing decision support systems, and both projects used existing tools to distribute data products online to those who benefit from the information developed.

Droughts and Flood

A Gulf Coast Monitoring and Hazards Decision Support Tool—Enhancements Using NASA Earth Science Products, Data, and Models

Principal investigator:
Enrico J. D'Sa, Louisiana State University

Participating organization:
Louisiana Department of Natural Resources

Louisiana State University operates the Wave-Current-Surge Information System (WAVCIS) to inform the Louisiana Department of Natural Resources (DNR) about conditions in the Gulf of Mexico and to monitor storm surge, water quality, effects of sand mining, and oil spill impacts on coastal environments. WAVCIS was enhanced with NASA satellite products for sea surface height, sea surface temperature, and ocean color to improve the accuracy and timeliness of forecasts for coastal environments. The data sources included MODIS, SeaWiFS, *QuikSCAT*, and *Jason-1*. MODIS 250 m data were also evaluated for the rendition of vegetation cover before and after a hurricane to identify the location and extent of damage to coastal and near coastal forests (Figure 16).

Products derived from the NASA systems were generated daily and made available through the WAVCIS and the Gulf Coast Information System (GCIS) websites. Several of the products, such as sea surface height and sea surface temperature, have been validated successfully against buoy measurements that are part of WAVCIS. The data products are also used to update forecasts of coastal water parameters, such as sea surface height, wind direction, and wind strength, which can be used to predict the extent and magnitude of coastal flooding. The Navy Coastal Ocean Model is one of the models used by the project for such predictions.

The data products developed during this project are still generated and made available through the WAVCIS and GCIS websites. The investigators continue to work with the Louisiana DNR and similar agencies along the Gulf Coast to supply information suitable for tracking and predicting disasters in the coastal zone.

For more information, visit *www.wavcis.lsu.edu.*

Enhancing NOAA AWIPS DSS by Infusing NASA Research Results for Drought and Other Disaster Management

Principal investigator:
Yao Liang, Indiana University

Participating organizations:
NASA Goddard Space Flight Center
NOAA National Weather Service
University of Pittsburgh

NWS is responsible for issuing weather forecasts and warnings about potential disasters directly or indirectly attributable to weather events. AWIPS, the Advanced Weather Interactive Processing System, is an interactive information processing display and telecommunications system employed by the NWS for its predictions and warnings. AWIPS combines meteorological, hydrological, satellite, and radar data to aid decision making.

This project developed software for NWS that allows precipitation data to be assimilated first by NOAA's Noah land surface model and then used to improve predictions of streamflow, soil moisture, and evapotranspiration. The improved accuracy of Noah land surface results in turn allows the NWS to provide more accurate forecasts of riverflow using its River Forecast System and aid decision support systems dependent upon NWS forecasts of riverflow.

Key to the success of this project is the Multiscale Kalman Smoother (MKS) software developed by the project specifically to allow map-based overlay of precipitation data collected at multiple scales and spatial resolutions. At its core, the MKS software uses a Kalman filter to determine first the statistical properties of the precipitation data from each source, then, based upon those properties, to smooth and interpolate data from each source, and, finally, to overlay data from all sources onto a map of each watershed. The overlaid, registered data are input to NWS's Noah land surface model.

Estimates of soil moisture obtained from NASA's Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) satellite sensor proved important to the success of the project, particularly during the validation phase. But the NASA North American Land Data Assimilation System (NLDAS) precipitation data at 1/8° resolution proved critically

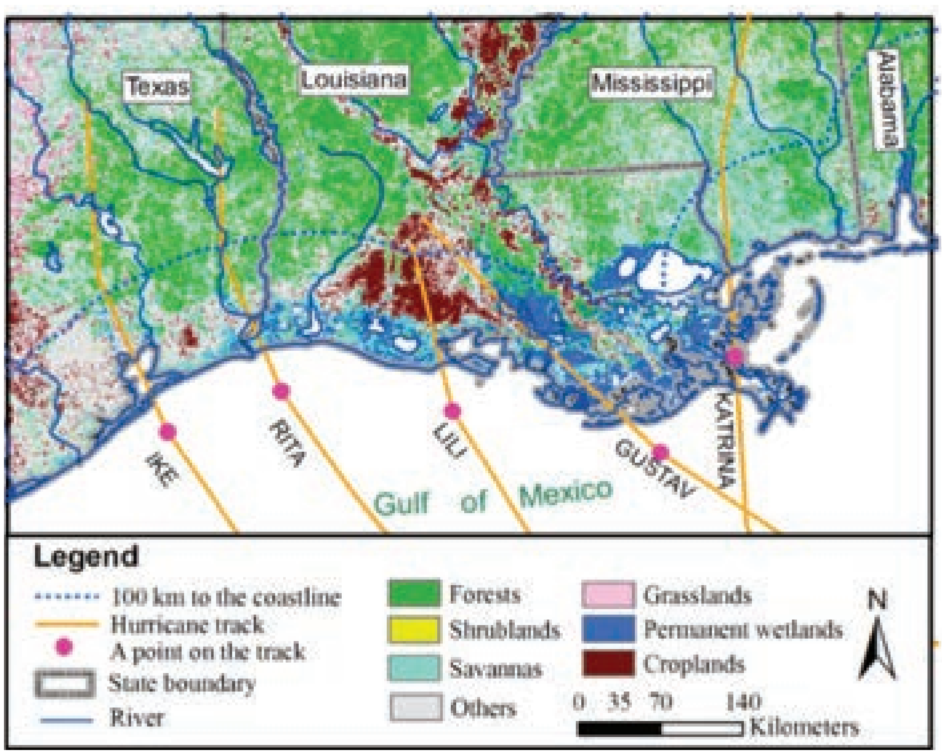


Fig. 16: Change in MODIS-derived land cover resulting from the 2005 hurricane season.

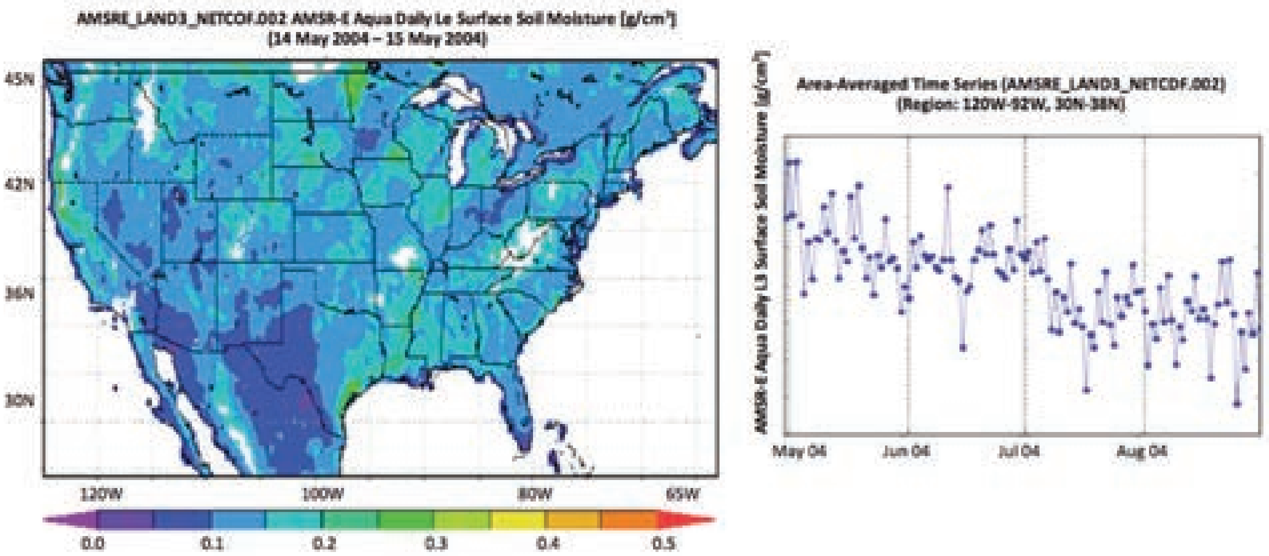


Fig. 17: AMSR-E daily surface soil moisture product as incorporated into the NWS Noah land surface model.

important to improving estimates of streamflow. When making the streamflow predictions, the project software overlaid the 1/8° resolution NASA NLDAS precipitation data onto 4 km resolution NOAA Next Generation Radar precipitation data (Figure 17).

Efforts to validate the estimates of streamflow, soil moisture, and evapotranspiration—all provided by project software—were extensive. Comparisons with high quality ground truth measurements of streamflow in a number of watersheds allowed time series analysis of model predictions over long periods. These analyses demonstrated that model accuracy increased when project-developed software was employed and input included both NOAA and NASA precipitation data.

This project created high quality software and a user-friendly interface that produced measurably improved forecasts of streamflow. The primary contact at NOAA noted after completion of the project that the enhancements to NOAA's existing streamflow estimation process were "extraordinary" and the NASA-based tools were "very powerful." However, before the software could be incorporated into the NWS River Forecast System, it had to be vetted by the NWS computer security group; this vetting process was not completed at the end of the project. The project researchers realized too late in the project the magnitude of the vetting process and the project resources that would be needed to support it. As a consequence, the long-term impact of this project on the decision support tool has not, to date, been realized.

For more information, visit *www.nws.noaa.gov/ops2/ops24/awips.htm.*

Integrating NASA Earth Science Capabilities into the Interagency Modeling and Atmospheric Assessment Center for Improvements in Atmospheric Transport and Dispersion Modeling

Principal investigator:
Matthew Simpson, Lawrence Livermore National Laboratory

Participating organizations:
NASA Goddard Space Flight Center
NASA Stennis Space Center
National Center for Atmospheric Research

The project team developed a method that uses data from MODIS, *Landsat*, and SRTM to improve the Earth surface characteristics in the Lagrangian Operational Dispersion Integrator (LODI) dispersion model. The National Atmospheric Release Advisory Center (NARAC) at Lawrence Livermore National Laboratory uses LODI to model the dispersion of toxic, radioactive, and other hazardous plumes for the U.S. Department of Homeland Security.

An exact representation of the Earth's surface in a dispersion model is impossible, so physical characteristics of that surface have to be represented simply. In LODI, surface characteristics are represented by maps of two quantities, roughness length and displacement height, that are fixed at each location in the model.

Using satellite data, the project team at NASA Goddard Space Flight Center developed a method to calculate rural surface roughness and displacement height, while the team at NASA Stennis Space Center developed a parallel method for urban areas. The project team calculated these characteristics using eight days of satellite data at a time, meaning that, unlike the fixed surface ordinarily used in the LODI model, the model surface could change with things like plant growth, leaf drop in fall, and storm damage. The satellite-derived surface proved to be smoother, allowing for stronger model winds near the ground. The stronger winds, in turn, made modeled plumes a little narrower and increased the maximum concentration near the plume source (Figure 18).

The team elected to test their new model in Oklahoma City, an excellent place to test a plume model because it is a large city surrounded by flat plains. LODI has a number of choices in how the Earth's surface is represented, and already included a carefully selected surface for Oklahoma City. This made for a high bar for the satellite method's new surface, since had to compete with a model surface that had been carefully developed to match conditions on the ground.

The project team compared model predictions with field measurements taken in and around Oklahoma City in the summer of 2003. The team's satellite-characterized surface achieved results that were the same, within experimental error, as those from a surface that had been developed with painstaking care over considerable time. This is a notable success, since the project team could quickly develop a new surface representation and do as well as a carefully tuned set of parameters that had taken considerable effort to develop. New model surfaces can now be developed from satellite data, and can take into account changes in season or changes in the surface due to severe storms, for example.

The new model capability is now a standard part of LODI, running at NARAC in support of the U.S. Department of Homeland Security.

For more information, *visit https://narac.llnl.gov/modeling.html.*

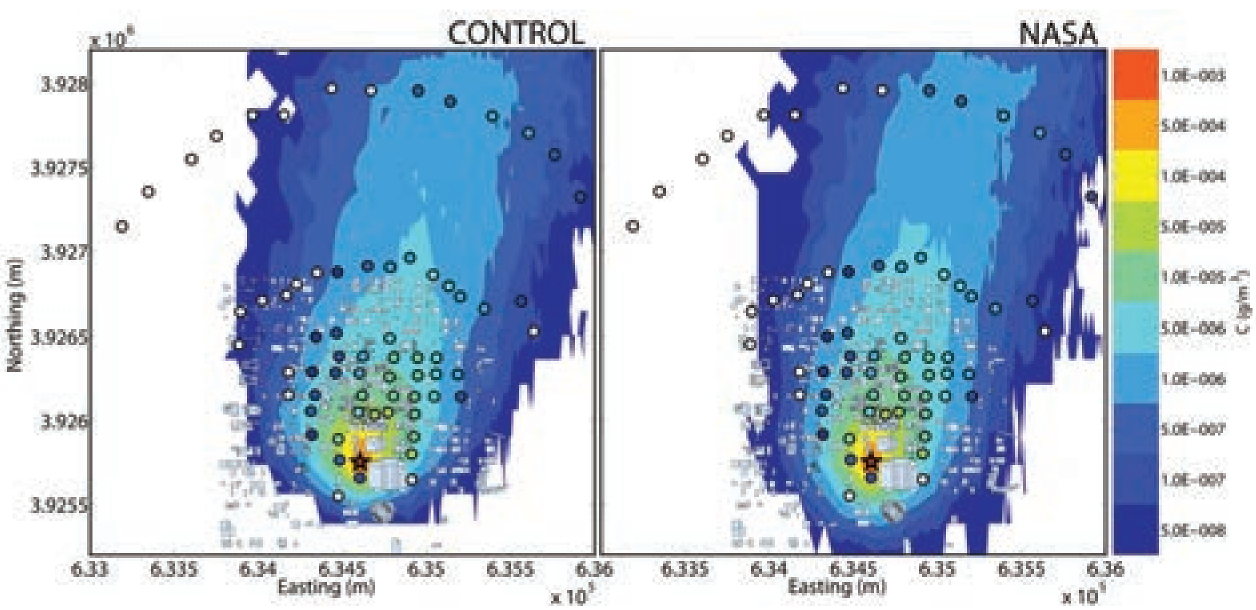


Fig. 18: Modeled plumes of a gas released in Oklahoma City using a) the default LODI model surface and b) the NASA model surface, reflecting a somewhat tighter plume in the model driven by NASA data. Winds are coming from the south, pushing the maximum concentration to the north of the release point (red star). Colored circles represent plume concentrations measured during a test release of inert gas in 2003.

Weather, Health, and Aviation

Managing Responses to Weather Events

Weather influences where we live, what we wear, the dwellings we live in, and the activities we do. Weather is the state of the atmosphere, to the degree that it is hot or cold, wet or dry, calm or stormy, clear or cloudy. Most weather phenomena occur in the troposphere, the layer of the atmosphere immediately above the ground and below the stratosphere. Weather is day-to-day temperature and precipitation activity, and weather forecasting is the application of science and technology to predict the state of the atmosphere at a future time.

Three projects funded by the NASA Applied Sciences Program addressed the application of weather and other Earth observations on livestock grazing lands, on air travel, and on public health.

Integration of Remote Sensing into Mosquito-borne Encephalitis Virus Intervention Decision Support Systems

Principal investigator:
William K. Reisen, University of California, Davis

Participating organizations:
California Department of Health Services
California State University, Monterey Bay
Centers for Disease Control and Prevention
Mosquito and Vector Control Association of California
NASA Ames Research Center
University of California, Davis

The North American mosquito-borne encephalitides, such as West Nile virus (WNV) are diseases communicable from animals to humans. They are maintained and amplified in transmission cycles involving *Culex* mosquitoes and a variety of birds. Detailed surveillance of viral amplification within the mosquito-bird cycle is information critical to risk assessment models used in directing decisions on mosquito control.

The overall goal of this integrated system solutions project was to improve a decision support system for mosquito-borne diseases in California through the integration of data from NASA and other sources with a system developed jointly by NASA Ames Research Center and the University of Montana.

The California Department of Public Health, in collaboration with the University of California, Davis, and the Mosquito and Vector Control Association of California, developed the California Mosquito-borne Virus Surveillance and Response Plan (CMVSRP) to provide statewide guidelines for the collection of surveillance information to monitor the distribution and amplification of mosquito-borne encephalitis viruses in California, especially WNV, St. Louis encephalitis, and western equine encephalitis viruses.

The CMVSRP did not originally incorporate information from NASA satellites or ecosystem models. A survey of vector control agencies in California conducted at the start of the project found only one of 29 responding agencies had previously used satellite data of any kind, yet over 75 percent of respondents indicated that they would use risk maps and other relevant environmental measures derived from NASA satellites and ecosystem models if such information was easily accessible. In addition, the CMVSRP lacked a predictive capability, because operation of predictive models required acquisition and processing of environmental measures in near real-time.

NASA's TOPS system includes a suite of environmental measurements derived from NASA satellites and ecosystem models well suited to the development of models for mosquito abundance and virus transmission risk. In addition, TOPS can deliver data sets in near real-time.

TOPS is a modeling framework that synthesizes NASA data sets, including those from *Aqua*, *Terra*, and *Landsat*. This project utilized data from the MODIS instruments onboard *Terra* and *Aqua*, AMSR-E onboard *Aqua*, as well as data from the *Landsat* and AVHRR archives.

TOPS integrates data from satellite- and ground-based observation networks to produce a comprehensive suite of more than 30 variables describing land surface and ecosystem conditions. The products include information derived from satellites (land cover, snow cover, surface temperature, vegetation density, and vegetation productivity), surface weather stations (maximum and minimum temperatures, humidity, solar radiation, and rainfall), and modeled fluxes (soil moisture and vegetation stress). Long-lead forecasts of ecosystem conditions from TOPS were used to develop models of mosquito abundance and produce seasonal forecasts.

Modeling and other studies have shown that winter and spring temperatures accurately forecast summer mosquito abundance. In addition, the rate of virus development within the mosquito, the length of the transmission season and, therefore, risk are linked directly to temperature conditions (Figure 19). The project focused initially on TOPS temperature products and communicated the model output generated (Figure 20) to user agencies showing risks for their agency. The data link between TOPS and the Center for Vectorborne Diseases at the University of California, Davis (CVEC) and the CMVSRP was configured to automate the incorporation of temperature layers from TOPS. In addition, significant improvements were made to the CMVSRP to include an interface for graphing trends and anomalies in mosquito abundance, other surveillance indicators such as the calculation of mosquito infection incidence, and related environmental conditions to support decision making for vector control efforts.

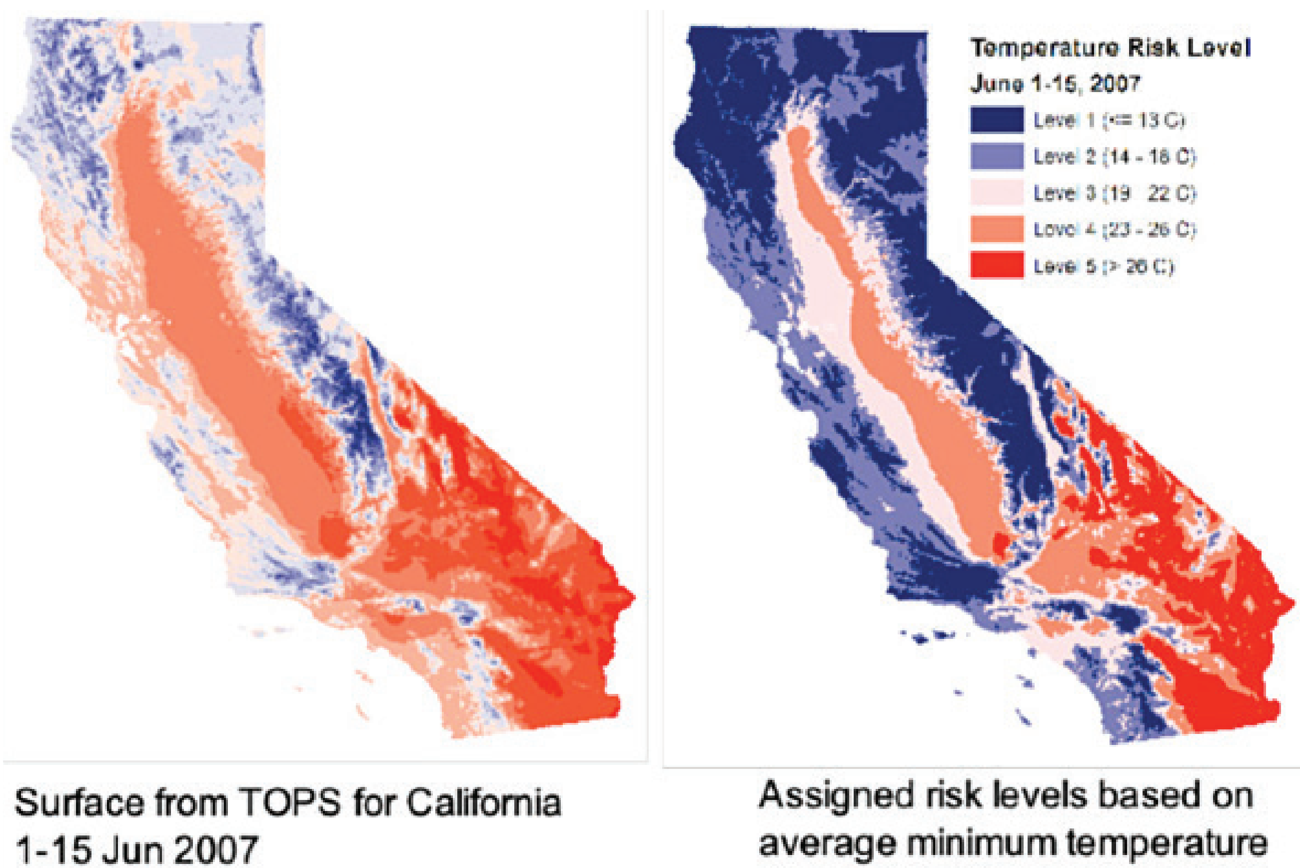


Fig. 19: Assigning WNV risk based on TOPS temperature surfaces.

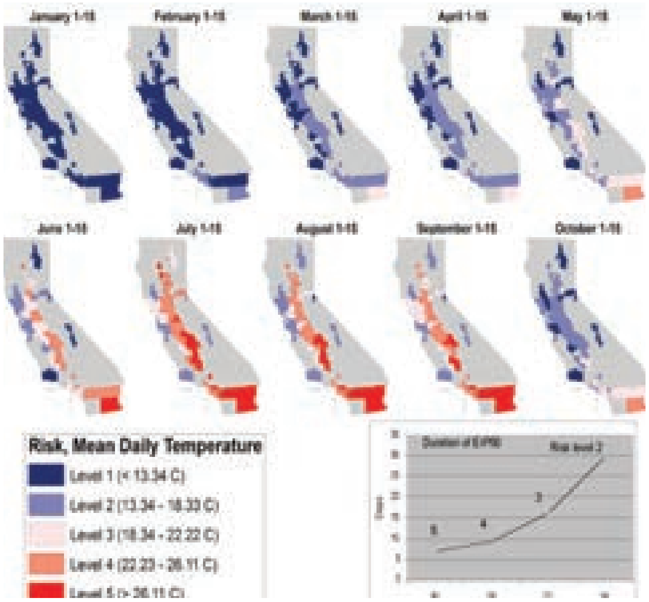


Fig. 20: Risk level in each mosquito district estimated using a degree-day model for WNV development in *Culex tarsalis*. Red indicates highest risk based on mean temperature data from TOPS.

After initial validation of this model system in California, the findings were extrapolated to the western United States through collaboration with the Centers for Disease Control and Prevention (CDC), using TOPS data products for the western United States. The project achieved its overall goals to:

1. Link remote sensing and meteorological data compiled as a comprehensive 1 km resolution data set for the state of California to mosquito and encephalitis virus data compiled by CVEC.
2. Integrate the best-performing models into TOPS using the NASA Ecocast applications programming interface to produce spatially continuous 1 km weekly forecast maps of mosquito abundance and potential virus activity.
3. Develop models using the NOAA long-lead 90 day climate outlooks to produce seasonal forecasts of mosquito abundance and virus risk.
4. 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.
5. Conduct workshops at regional meetings to expand DSS use in VCA operations.
6. Extrapolate mosquito abundance and virus transmission risk forecasts to the western United States following integration into the California system, and evaluate forecasting using data gathered by the CDC Arbovirus Surveillance Network (ArboNET) system.
7. Incorporate estimates of mosquito abundance and encephalitis risk into forecasts distributed via ArboNET.

The project also facilitated integration of NASA data sets into CMVSRP and ArboNET. The CVEC computing enhancements have provided sufficient computing and data storage capabilities to provide continuous support for model operation and generation of forecasts. As such, integration of the model into TOPS was not required. Instead, effort was focused on improving transfer mechanisms for NASA data to CVEC and improved data access mechanisms for decision makers using CMVSRP.

The TOPS data interface was extended to include a mapping interface that allows CMVSRP DSS users to query multiple data layers at a single point or region of interest and visualize graphs of current and recent environmental conditions in the context of historical baselines. The integrated system, consisting of TOPS temperature data translated into environmental risk levels and other surveillance data, was first delivered in 2008.

Enhancing the Livestock Early Warning System with NASA Earth-Sun Science Data, GPS, and RANET Technologies

Principal investigator:
Gabriel Senay, USGS

Participating organization:
Texas A&M University

Variations in rainfall from year to year tend to be most extreme in semi-arid regions. The Horn of Africa is such a region. The success of livestock herding, a significant form of livelihood in that region, depends on sufficient rain to support the rangeland for the livestock. Early warning of weather events and rangeland depletion can help save lives and reduce conflicts by informing expectations and providing direction to alternative sources of feed and water. Gabriel Senay and his associates pursued that objective by enhancing the Livestock Early Warning System (LEWS) with NASA Earth science data, GPS, and Radio and Internet for the Communication of Hydro-Meteorological and Climate Related Information (RANET) technologies.

Table 2 matches detailed technical requirements of the LEWS decision support tool with NASA capabilities. NASA inputs were used to monitor and characterize water resources, and map forage baseline and seasonal migration patterns to develop a sound and efficient decision support system for the region. The enhanced LEWS (Figure 21) was designed to solve problems in the region from drought to floods, conflicts, and land degradation, and also to play a key role in regional stability of an area known for frequent hostilities.

LEWS contains a forage characterization module and a water resources monitoring module. Both are built in such a way that the daily satellite data are processed, and the forage conditions and water resources data are produced every day with a one day lag. The goal of the project was to produce information on forage, water level conditions, and other drought forecast information daily (with a day lag), and disseminate the information to users through the Web and email. The project established a benchmark against which to measure future improvements in the scope and effectiveness of the LEWS decision support system when water resources monitoring and herd migration tools are added to existing forage monitoring products and assess the usefulness of the products to mitigate the effects of drought in the greater Horn of Africa.

For LEWS product dissemination, nongovernmental organizations (NGOs) and government agencies that have email and Internet capabilities in the study region were targeted to provide a new means of dissemination to pastoralist groups. In the case of NGOs, many are already working with pastoral groups in the region and currently use the LEWS products. Many of these NGOs also serve as community information centers for their target area, so making LEWS products available through this channel provided added services for the NGOs.

Prior to the existence of LEWS, pastoral communities used traditional knowledge to identify areas where forage and water were available. More recently, apart from the traditional approaches, most of the pastoral communities used scouts to locate forage and water. Even the NGOs and local government agencies working in the pastoral areas rely on historical knowledge and information gathered from regional surveys for planning and decision making. Such traditional methods of gathering information are mostly inaccurate, time consuming, and costly. There is also a great deal of risk in gathering such information because of intermittent hostilities. Further, sometimes information reported by scouts from competing pastoral groups is not reliable.

Now it is possible to access waterhole water level information in the pastoral regions of northern Kenya and southern Ethiopia in near real-time, irrespective of location and time. The satellite-based estimates used in this project are available for free on a daily basis over

DSS Required Observation & Predictions	NASA Inputs	Comments
Baseline forage characterization to make up-to-date pasture inventory and description	MODIS	Improve spatial characterization of baseline forage conditions and avoid field checks
Introduce new water resource monitoring tool	*TRMM*	Daily water level changes monitoring, daily rainfall estimates, catchment runoff modeling
Mapping and delineation of > 30 m diameter waterholes	ASTER	Mapping waterholes using 15 m ASTER data
Watershed delineation	SRTM	Watershed delineation tools using 90 m SRTM
Water level monitoring	NASA reservoir level tool (satellite altimeter)	Poor resolution for small ponds – Surrogate data from Lake Turkana measurements are evaluated to validate the general trends of a regional water balance model results
Monitoring flooding along migration routes	*TRMM*	Uses *TRMM* as input into the GeoSFM (Geospatial Stream Flow Model) of USGS/FEWS NET
Tracking migration in real time	GPS	GPS adequate for taking position fixes for tracking livestock migration patterns Perceived limitations are the skill required by the herder to operate the GPS, including maintenance requirements

Table 2: Description of NASA inputs and their requirements for LEWS.

the Internet. The operational cost to maintain the system to generate waterhole water levels is minimal. Because the data are generated using satellite-based estimates produced by NASA and hydrologic modeling techniques, they are consistent and reliable.

The project demonstrated the utility of combining NASA technologies and hydrologic modeling techniques to monitor water levels in small surface waterholes and forage in East Africa. It established that information on waterhole condition based on satellite data was more accurate than information from other, traditional sources. The models within the project were built in such a way that methodology can be applied to climatically similar regions elsewhere. LEWS beneficiaries expressed interest in seeing more historical data and increasing the coverage area of the system. In sum, the new LEWS DSS was viewed favorably in terms of its value to consumers, its usefulness for assisting with decision making, and content of the product.

For more information, visit *http://watermon.tamu.edu/index.html*.

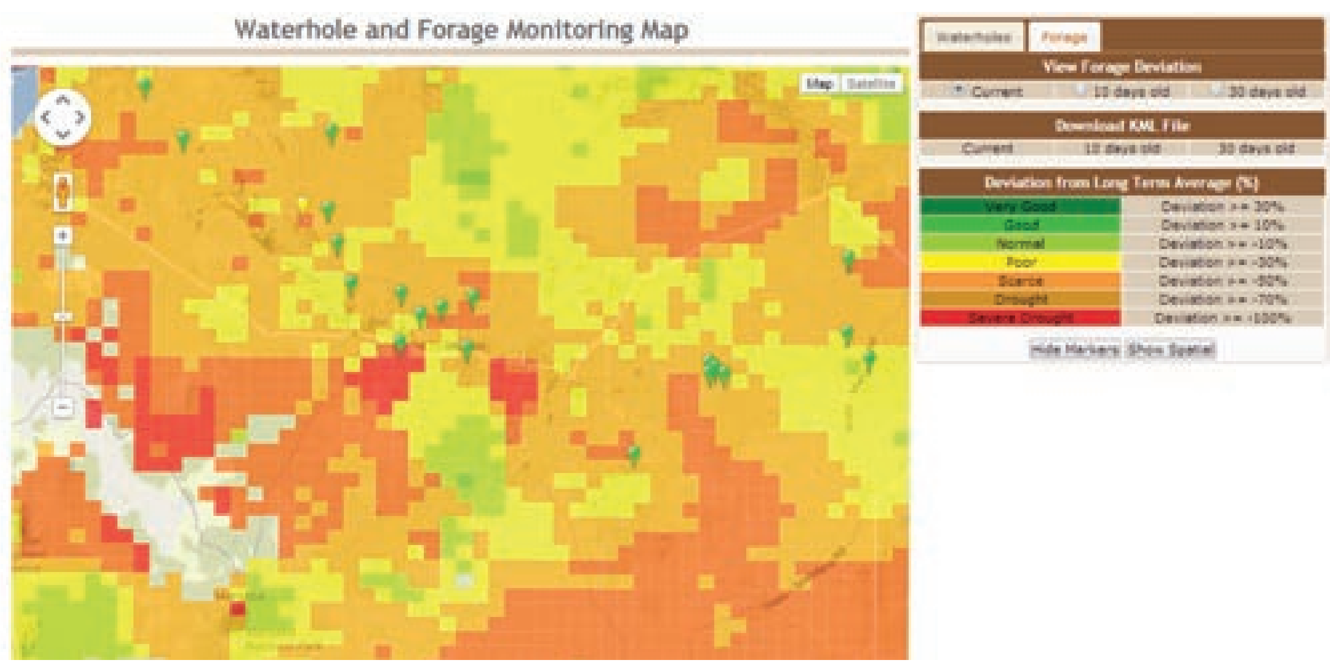


Fig. 21: Forage and water hole condition map for northern Kenya and southern Ethiopia. Waterholes are indicated by colored pins, while forage condition is indicated by the gridded background color, ranging from green for very good forage and full waterholes to red for poor forage and nearly empty waterholes.

Oceanic Convective Weather Diagnosis and Nowcasting

Principal investigator:
Cathy Kessinger, National Center for Atmospheric Research

Participating organization:
NRL

As the number of transoceanic flights increases, the need for better information on the location of weather phenomena hazardous to aircraft increases. The aviation community is now receiving current information on convection and associated hazards including turbulence, lightning, and icing, over the open ocean from nowcasting products, based on data from geostationary and polar-orbiting satellites and global numerical model results as available through Web-based displays. These products promise to improve the safety and reliability of transoceanic flight.

Three projects sponsored by NASA and led by researchers from NCAR and NRL led to the development and use of new weather products. The second of the three projects was supported through this solicitation. Data from NASA and NOAA satellites provide the basis for predicting the location of significant weather events over the ocean. The satellite observations are:

- *QuikSCAT* surface winds
- AMSR-E, *Aqua*
- Advanced Microwave Sounding Unit, *Aqua*, and NOAA *Polar Orbiting Environmental Satellites*
- AIRS, *Aqua*
- MODIS, *Aqua*, and *Terra*

The products derived from these observations include sea surface temperature, near surface winds, temperature and moisture soundings, cloud classification, and convective diagnosis. Together, these products and associated models predict the location of potentially hazardous flying weather one to two hours in advance (Figure 22).

This work was carried forward by a project awarded under the NASA solicitation Decision Support Through Earth Science Research Results 2007. The products continue to be generated and distributed at *www.ral.ucar.edu/projects/ocn*.

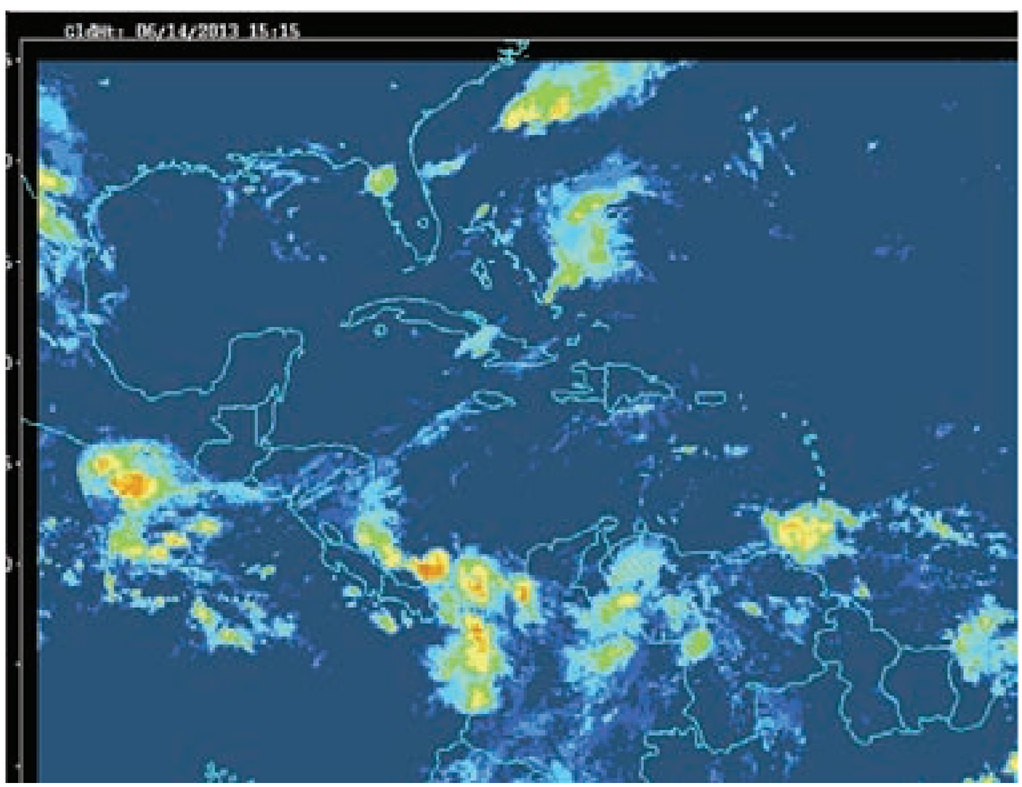


Fig. 22: Convection location product for June 14, 2013 over the Gulf of Mexico. Images are updated every 15 minutes.

Acronyms

ACE: Advanced Composition Explorer

AIRS: Atmospheric Infrared Sounder

AMSR-E: Advanced Microwave Scanning Radiometer-Earth Observing System

AOD: aerosol optical depth

ArboNET: Arbovirus Surveillance Network

ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer

AVHRR: Advanced Very High Resolution Radiometer

AWIPS: Advanced Weather Interactive Processing System

BAMS: Baron Advanced Meteorological Systems

CASA: Carnegie Ames Stanford Approach

CATHALAC: Water Center for the Humid Tropics of Latin America and the Caribbean

CDC: Centers for Disease Control and Prevention

CMAQ: Community Multi-Scale Air Quality

CMVSRP: California Mosquito-borne Virus Surveillance and Response Plan

COAMPS: Coupled Ocean/Atmosphere Mesoscale Prediction System

CVEC: Center for Vectorborne Diseases

DLR: German Aerospace Center

DNR: Department of Natural Resources

DSS: decision support system

DSU: Dakota State University

DTN: Data Transmission Network

EPA: United States Environmental Protection Agency

EPRI: Electric Power Research Institute

EROS: Earth Resources Observation and Science

ET: Evapotranspiration

FVCOM: Finite Volume Community Ocean Model

GCIS: Gulf Coast Information System

GeoSFM: Geospatial Stream Flow Model

GEWEX: Global Energy and Water Cycle Experiment

GIC: geomagnetically induced current

GOES: Geostationary Operational Environmental Satellite

GRACE: Gravity Recovery and Climate Experiment

HERMES: Hierarchical Environment for Research Modeling of Ecological Systems

HRLDAS: High-Resolution Land Data Assimilation System

INPE: Brazilian National Institute for Space Research

ISFS: Invasive Species Forecasting System

LEWS: Livestock Early Warning System

LODI: Lagrangian Operational Dispersion Integrator

MaxEnt: Maximum Entropy approach

METRIC: Mapping Evapotranspiration at High Resolution with Internalized Calibration

MKS: Multiscale Kalman Smoother

MM5: Fifth-Generation Penn State/National Center for Atmospheric Research Mesoscale Model

MODIS: Moderate Resolution Imaging Spectroradiometer

MOPITT: Measurements of Pollution in the Troposphere

NARAC: National Atmospheric Release Advisory Center

NCAR: National Center for Atmospheric Research

NDVI: Normalized Difference Vegetation Index

NGO: nongovernmental organization

NLDAS: North American Land Data Assimilation System

NOAA: National Oceanic and Atmospheric Administration

NREL: National Renewable Energy Laboratory

NRL: Naval Research Laboratory

NWS: United States National Weather Service

OMI: Ozone Monitoring Instrument

PALMS: Park Analysis of Landscapes and Monitoring Support

QuikSCAT: Quick Scatterometer

RANET: Radio and Internet for the Communication of Hydro-Meteorological and Climate Related Information

Risoe/DTU: Danish National Laboratory for Sustainable Energy

ROSES: Research Opportunities in Space and Earth Science

RREX: Renewable Energy Resource Explorer

SEASCAPE: Satellite-based Estimates and Analysis of Stage-resolved Copepod Abundance in Pelagic Ecosystems

SEBAL: Surface Energy Balance Algorithm for Land

SIP: State Implementation Plan

SOHO: Solar and Heliospheric Observatory

SPDSS: South Platte Decision Support System

SRTM: Shuttle Radar Topography Mission

SST: sea surface temperature

SWERA: Solar and Wind Energy Resource Assessment

TOPEX: Topography Experiment

TOPS: Terrestrial Observation and Prediction System

TRMM: Tropical Rainfall Measuring Mission

UNEP: United Nations Environment Programme

USDA: United States Department of Agriculture

USFS: United States Forest Service

USGS: United States Geological Survey

VCA: vector control agency

VISTAS: Visibility Improvement State and Tribal Association of the Southeast

WAVCIS: Wave-Current-Surge Information System

WNV: West Nile Virus

Acknowledgements

Numerous people deserve special recognition for their tremendous applications-development work, support of the projects, and development of this report.

First and foremost, the principal investigators, project teams, and the partners warrant significant praise. At the time of this solicitation, NASA was just expanding its emphasis on applying data from a broader set of Earth-observing satellites to support policy, business, and management decisions and actions. In many ways, these projects served as pathfinders to apply the Earth observations in organizations' decision-making activities, and they helped NASA and the Earth science community learn effective ways to pursue and accomplish applications.

Several people at NASA Ames Research Center administered the grants, handled the resources, and tracked the projects. In particular, we are deeply grateful and appreciative of Liane Guild, Jennifer Dungan, Vern Vanderbilt, Evelyn Perez, and Jay Skiles. A further, special thanks to Jay, who managed the team as well as handled numerous grants.

We appreciate the efforts of numerous people who developed and designed this report. In addition to the people above who provided information and materials, we especially thank Ed Sheffner, Jay Skiles, and Gailynne Bouret from NASA Ames who developed and wrote this report. We also appreciate the work of Lacey Olivares and Jeff Stehr from Booz Allen Hamilton for the design and production of this document.

Finally, we acknowledge and thank the many people who design the sensors, operate the Earth-observing satellites and platforms, process and deliver the data, and analyze and apply the measurements to benefit all humankind.

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NASA Earth Science

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