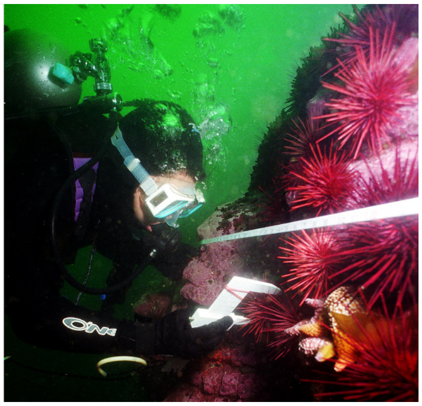

Meetings

Meeting Review

Ecological Models and Satellite Imagery

"Ecological Models and Satellite Imagery: from Observations to Forecasts," an Ecological Modeling for NASA Applied Sciences Workshop held at the Asilomar Conference Center, Pacific Grove, California, 29 March–1 April 2005.

An unprecedented number of satellites currently orbit the Earth, measuring terrestrial, atmospheric, and marine variables ranging from land cover, to precipitation, to sea surface temperature and chlorophyll concentrations. As a result, we are awash in environmental data to a degree unique in history. How to make sense of this potential Babel? If these rich data sets are to foster progress in ecology (indeed, in any of the Earth sciences), we must improve our ability to integrate data from diverse sources, whether satellite based or in situ. To address this challenge, many researchers and resource managers are turning to ecological models as integration tools. These models are a key component of our developing capability to generate ecological forecasts (Clark et al. 2001). To explore how investigators use models to bring together satellite and in situ data sets for improved understanding and decision support, the U.S. National Aeronautics and Space Administration (NASA) hosted a workshop focusing on modeling developments within three areas of its Applied Sciences Program—public health, invasive species, and ecological forecasting.

The workshop format consisted of plenary presentations by researchers, with evening sessions and the morning of 1 April reserved for synthesis discussions. Habitat suitability and niche modeling constituted a common thread across the three program areas, while research and applied talks each took up roughly half of the program.

Geoffrey Henebry (University of Nebraska–Lincoln, Nebraska) started things off with a call for a synoptic ecology built upon the remote sensing of ecological change. To determine the "plots" of ecological systems, one needs to identify spatiotemporal baselines concerning phenomena such as land surface phenology, outbreaks and spread of invasive species, succession in ecological communities, and the growth of urban areas—topics that lend themselves to recurrent observations. Over time, these observations allow for the detection of anomalies and unique events. It is in the detection, quantification, assessment, and attribution of the unusual that we build the understanding necessary for making ecological predictions as well as estimates of the uncertainties associated with them.

Andrew Hansen (Montana State University, Bozeman, Montana) presented results from two case studies. The first modeled the distribution of bird species richness in the Pacific Northwest of the United States, using statistical regression and geographic models to relate energy, as proxied by net primary productivity and climate data of vapor pressure deficit, and bird species richness from Breeding Bird Survey data. His team found higher levels of species richness associated with intermediate levels of energy. Another study by Hansen and collaborators ran models to simulate different scenarios of exurban development in the Greater Yellowstone Ecosystem to the year 2020 and assess the concomitant impacts on lands important to biodiversity. The means of assessing these impacts was a biodiversity index generated from measures of irreplacability, migration corridors, and bird hot spots, among others. This work found that a growth management scenario could significantly limit the impacts of new homes on places important to biodiversity in the Greater Yellowstone Ecosystem.

Inside out and outside in

In research characterized as going from the "inside out," or from the organism to the broader ecosystem, David Spencer (U.S. Department of Agriculture Agricultural Research Service, Davis, California) used individual-based models to simulate virtual invasive plants in the United States (the giant reed *Arundo donax*), their increase in biomass over time, and the degree of light reduction under *A. donax* canopies. In addition to canopy shading characteristics, the model provided estimates of the timing of greatest shoot and biomass production, as well as the morphological patterns for rhizome and shoot growth. These are vital parameters for ascertaining what types of biocontrol might be effective, and the invasive plant's impact on native vegetation. Combining individually modeled plants into stands should allow this work to be scaled to levels detectable via remote sensing. Edward Wiley (University of Kansas, Lawrence, Kansas) approached the challenge of invasive marine fishes from the "outside in," going from the environment to the organism. His team employed the genetic algorithm GARP to model ecological niches for invasive fishes using environmental coverages derived from both satellite sources (e.g., sea surface temperature, chlorophyll *a*, and suspended solid concentrations from the NASA Moderate-Resolution Imaging Spectroradiometer (MODIS) sensor) and in situ sources (e.g., bathymetry and silicate, phosphate, and nitrate concentrations). In a companion freshwater example, Wiley demonstrated the ability of GARP to generate statistically significant "postdictions" of the spread of the invasive largemouth bass (*Micropterus salmoides*) in Japan.

Simon Ferrier (Department of Environment and Conservation, Armidale, New South Wales, Australia) and his team modeled a community-level property of biodiversity (i.e., compositional turnover or beta diversity) by means of generalized dissimilarity modeling (GDM). GDM models dissimilarity in species composition between biological survey sites, or collection localities, as a function of environmental differences between these sites. Satellite data provide the source for several of the environmental variables used. GDM provides a powerful means of analyzing data from lesser known, yet highly diverse taxa, such as insects. Current applications of the approach include assessments of the representativeness of the world's protected area system (Ferrier et al. 2004).

Different types of data and models

In the public health arena, Uriel Kitron (University of Illinois, Urbana-Champaign, Illinois) presented work in which high spatial resolution remote sensing from the commercial IKONOS satellite system allowed the assembly of spatially explicit transmission models for schistosomiasis in coastal Kenya. Researchers studied changing human demographics via households, and performed spatial statistical analyses of snail distribution and human infection on the household level as it clustered around water contact sites (Clennon et al. 2004, Kariuki et al. 2004). In subsequent work, the IKONOS imagery are augmented by Landsat imagery and data from the Shuttle Radar Topography Mission and MODIS to document the connectivity of water bodies and demonstrate how local hydrological patterns sustain snails, and thus the disease, during times of drought. Other presentations demonstrated the application of remote sensing data within epidemiological models to derive public health tools for decision makers. Durland Fish (Yale School of Medicine, New Haven, Connecticut) and his colleagues have developed landscape-based epidemiologic models that incorporate Landsat data to forecast Lyme disease risk at spatial scales ranging from county to individual residential property. Disease risk maps enable public health agencies to improve the effectiveness of disease prevention methods by targeting high-risk populations. A similar approach was used to estimate West Nile virus risk in New York City during the 1999 outbreak (Brownstein et al. 2003). Human cases peaked in census tracts with intermediate levels of vegetation as determined by Landsat Thematic Mapper measures of NDVI (Normalized Difference Vegetation Index), which also had a higher frequency of mosquitoes infected with the virus. Ecological models using satellite-derived data for rapid assessment of disease risk have important applications with emerging diseases and threats from bioterrorism.

Coupling different types of models is a challenge. To improve fisheries management, Richard Barber (Duke University, Durham, North Carolina) and his team seek to improve our understanding of the relationship between changes in climate, at ocean basin and regional scales, and marine food webs. Seasonal to interannual changes in climate, such as El Niño Southern Oscillation (ENSO) or Pacific Decadal Oscillation (PDO) events, dramatically affect fisheries. Barber et al. have coupled a Pacific Ocean simulation model with regional ocean models of the California coastal waters. Satellites provide key environmental data sets such as sea surface temperature, ocean chlorophyll, sea surface height, and ocean winds, while supercomputers enable the simulation of the surface of the entire Pacific Ocean basin at 12.5-km spatial resolution. Coupling basin models with higher resolution, a three-dimensional physical-ecosystem regional ocean model brings the user to the scale of the upwelling zone. Fishery population models take the information from this point to project the impact of climate changes on populations of species of concern. Modeling the impacts of climate events on fisheries offers a common approach that could potentially lend itself to terrestrial modeling applications, such as the impacts of ENSO and/or PDO on disease outbreaks and the spread of invasive species.

Ecological models and observations for decision support

Several presentations highlighted decision support tools that combine Earth observation data and models for use by resource managers and public health officials. John Schnase and Jeff Morisette (NASA Goddard Space Flight Center, Greenbelt, Maryland) introduced the Invasive Species Forecasting System (ISFS), a joint initiative by the U.S. Geological Survey and NASA. ISFS uses geostatistical models that incorporate environmental coverages (both from satellite sensors, such as MODIS and Landsat ETM+, and in situ STATSGO soils data, etc.) and species location information from the U.S. National Biological Information Infrastructure (NBII) and other sources. These models generate maps, with associated estimates of uncertainty, of areas likely to support a given invasive species. The near-daily access to MODIS imagery allows detection of reflectance differences related to phenological changes, useful in the location of certain invasive plants. ISFS ‹http://invasivespecies.gsfc.nasa.gov/› currently focuses on several plant species in the western United States, but plans are for it to become a national system predicting the locations and possible spread of invasives of all taxa.

Danny Hardin (University of Alabama at Huntsville, Alabama) discussed the implementation of the SERVIR decision support system in Central America. SERVIR brings together imagery from multiple satellites, regional climate models, and GIS layers with ecological and socioeconomic information, and visualization software to monitor and provide visualizations of environmental changes in the seven countries of Central America. This integrated regional system ‹http://servir.nsstc.nasa.gov/› has already demonstrated its effectiveness by producing data products on fire, red tide, and severe weather events for decision makers in Guatemala, El Salvador, Costa Rica, and Panama. A decision support tool briefed by Chris Potter (NASA Ames Research Center, Moffett Field, California) uses the CASA biosphere–atmosphere exchange model as the basis for an internet-based terrestrial carbon accounting tool known as CQUEST ‹http://geo.arc.nasa.gov/website/cquestwebsite/index.html›. Like ISFS and SERVIR, CQUEST integrates satellite and in situ data into models for decision support.

Common threads

Workshop participants emphasized the importance of maintaining the continuity of data sets for ecological research in order to detect anomalies that deepen our understanding of ecosystems under study and enhance our predictive abilities. Long-term data sets are also the only means to detect natural cycles that might be incorrectly attributed to other drivers.

A recurring issue was the degree of spatial resolution required for accurate modeling of phenomena of interest. David Stockwell (University of California at San Diego, California) noted that the accuracies of ecological niche forecasts from GARP models do not necessarily improve with the application of higher spatial resolution environmental data sets, e.g., 1-km imagery may yield accuracies equal to those derived from 30-m imagery (Stockwell, *in press*).

Seeking consensus among different model results is important in that it contributes to the robustness of these results. While the integration of many data sets was a constant theme for this workshop, there was also an appreciation of the need for parsimony in ecological modeling—the challenge of isolating those environmental inputs having the biggest impact on results. These inputs would presumably be the parameters around which we should focus future monitoring efforts, whether satellite or in situ.

A clear goal for ecological models is the generation of "if–then" scenarios that will allow resource managers and policy makers to discern the impacts of their decisions on the ecosystem goods and services upon which all depend. James Smith (NASA Goddard Space Flight Center, Greenbelt, Maryland) challenged participants to consider combining "inside out" approaches examining organismal energy balances with "outside in" efforts to detect ecological niche spaces of organisms from climate and other environmental data sets. The ultimate goal is to use this combined modeling approach to simulate migration events and other movements across the landscape. The relevance of such an approach to forecasting changes in the component parts of ecosystems during an era of potentially rapid climate change is obvious.

Finally, although NASA hosted the workshop, all participants would agree that satellite data alone are insufficient for significant progress in ecological prediction through modeling. Most, if not all, presentations made use of data collected in situ. A principal recommendation coming out of the workshop is the need to link satellite-based efforts with ground-based activities such as the U.S. National Science Foundation's Long Term Ecological Research (LTER) Network, as well as its proposed National Ecological Observatory Network (NEON). Collecting remote sensing and in situ data at common sites for collaborative work is essential. In fact, if there were one overriding challenge to come out of this workshop, it would be the challenge of integration: integration across data sets captured at different scales for different disciplines for use in different models. While difficult, examples of this type of integration are increasing. Ecological models are frequently the tool of choice for making this happen. The future of ecological forecasts and their ability to inform resource management practices rely upon the continued integration of often disparate information through ecological models, and the distillation of model outputs and their uncertainties into decision support frameworks.

Copies of some presentations as well as more information about this workshop are available at ‹http://

geo.arc.nasa.gov/sge/health/ecoworkshop/›

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Woody Turner
NASA Headquarters
Washington, D.C. 20546-0001
E-mail: Woody.Turner@nasa.gov

and

Forrest Melton
NASA Ames Research Center
Moffett Field, CA 94035-1000
E-mail: fmelton@arc.nasa.gov