

TerrSet

Geospatial Monitoring and Modeling System

- Land Change Modeler
- GeOSIRIS
- Habitat and Biodiversity Modeler
- Ecosystem Services Modeler
- Earth Trends Modeler
- Climate Change Adaptation Modeler
- IDRISI GIS Analysis
- IDRISI Image Processing

TerrSet is an integrated feature-rich software system for monitoring and modeling the Earth system for sustainable development. Based on three decades of development within the Graduate School of Geography at Clark University, TerrSet offers a constellation of integrated vertical and horizontal applications.

TerrSet Geospatial Monitoring and Modeling System

The Land Change Modeler (LCM) for analyzing land cover change, empirically modeling its relationship to explanatory variables and projecting future changes. LCM also includes special tools for the assessment of REDD (Reducing Emissions from Deforestation and forest Degradation) climate change mitigation strategies.

GeOSIRIS – a unique tool for national level REDD (Reducing Emissions from Deforestation and forest Degradation) planning, developed in close cooperation with Conservation International. With GeOSIRIS, one can model the impact of various economic strategies on deforestation and carbon emissions reductions.

The Habitat and Biodiversity Modeler (HBM) for habitat assessment, landscape pattern analysis and biodiversity modeling. HBM also contains special tools for species distribution modeling.

The Ecosystem Services Modeler (ESM) for assessing the value of various ecosystem services such as water purification, crop pollination, wind and wave energy, and so on. ESM is based closely on the InVEST toolset developed by the Natural Capital Project.

The Earth Trends Modeler (ETM) – a tool for the analysis of time series of earth observation imagery. With ETM, one can discover trends and recurrent patterns in fundamental earth system variables such as sea surface temperature, atmospheric

temperature, precipitation, vegetation productivity and the like. ETM is an exceptional tool for the assessment of climate change in the recent past (e.g., the past 30 years).

The Climate Change Adaptation Modeler (CCAM, pronounced “see cam”) – a tool for modeling future climate and assessing its impacts on sea level rise, crop suitability and species distributions.

The IDRISI GIS Analysis Tools – a broad spectrum of fundamental tools for GIS analysis, primarily oriented to raster data. Special features of the IDRISI tool set include a suite of multi-criteria and multi-objective decision procedures and a wide range of tools for statistical, change and surface analysis. Special graphical modeling environments are also provided for dynamic modeling and decision support. IDRISI also provides a scripting environment and an extremely flexible application programming interface (API) that allows the ability to control TerrSet using languages such as C++, Delphi and Python.

The IDRISI Image Processing System – an extensive set of procedures for the restoration, enhancement, transformation and classification of remotely sensed images. IDRISI has the broadest set of classification procedures in the industry including both hard and soft classification procedures based on machine learning (such as neural networks) and statistical characterization.

Land Change Modeler

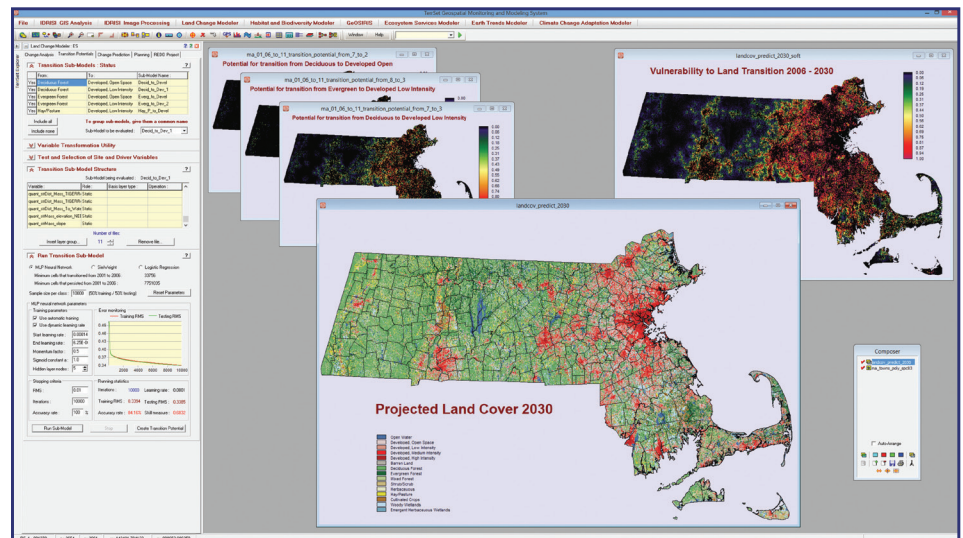
Land cover change is one of the largest imprints of humans on the Earth system. Understanding and projecting transitions into the future is critical for smart development, biodiversity conservation and managing climate mitigation strategies such as REDD (Reducing Emissions from Deforestation and forest Degradation). The Land Change Modeler (LCM) analyzes historical land cover data to assess, model and predict land cover change using powerful machine learning procedures. Major components of LCM include:

Land Change Analysis

Given two historical land cover layers, quickly generate graphs and maps of land change, including gains and losses, net change, persistence and a breakdown of contributors to each transition. LCM includes the ability to generalize complex transitions using trend surface analysis.

Transition Potential Modeling

Modeling the potential of land to experience specific transitions (such as deforestation for agricultural development) lies at the very heart of LCM. Using



The Land Change Modeler (LCM) in TerrSet uses map layers of historical change in combination with layers of potential explanatory variables (such as slope, proximity to roads, and so on) to develop empirical models of change. From these, projections can be made of the expected land cover at a future date. The LCM dialog to the left shows the process of specifying explanatory variables associated with a specific transition and the use of the Multi-Layer Perceptron (MLP) neural network to learn their association with the transition. The result is a series of transition potential maps (upper left). These are then used in combination with Markov Chain analysis to generate a projected land cover map for a future date (lower-center). In addition, LCM can generate a soft projection—a map of the vulnerability to land transition (upper-right).

historical land cover layers along with a set of potential explanatory variables (such as proximity to roads, soil type and slopes), LCM uses empirical modeling tools to establish the relationship between them. LCM currently supports logistic regression, a modified KNN (K-nearest neighbor) and an exceptionally powerful Multi-layer Perceptron (MLP) neural network for model development. In the latter case, a very detailed accounting is provided of model skill and the degree of contribution of each explanatory variable.

Change Prediction

Using transition potential models as a foundation, LCM uses Markov Chain analysis to project the expected quantity of change and a competitive land allocation model to determine scenarios for a specified future date. Options exist to incorporate planning interventions such as incentives and constraints, proposed reserve areas and infrastructural changes.

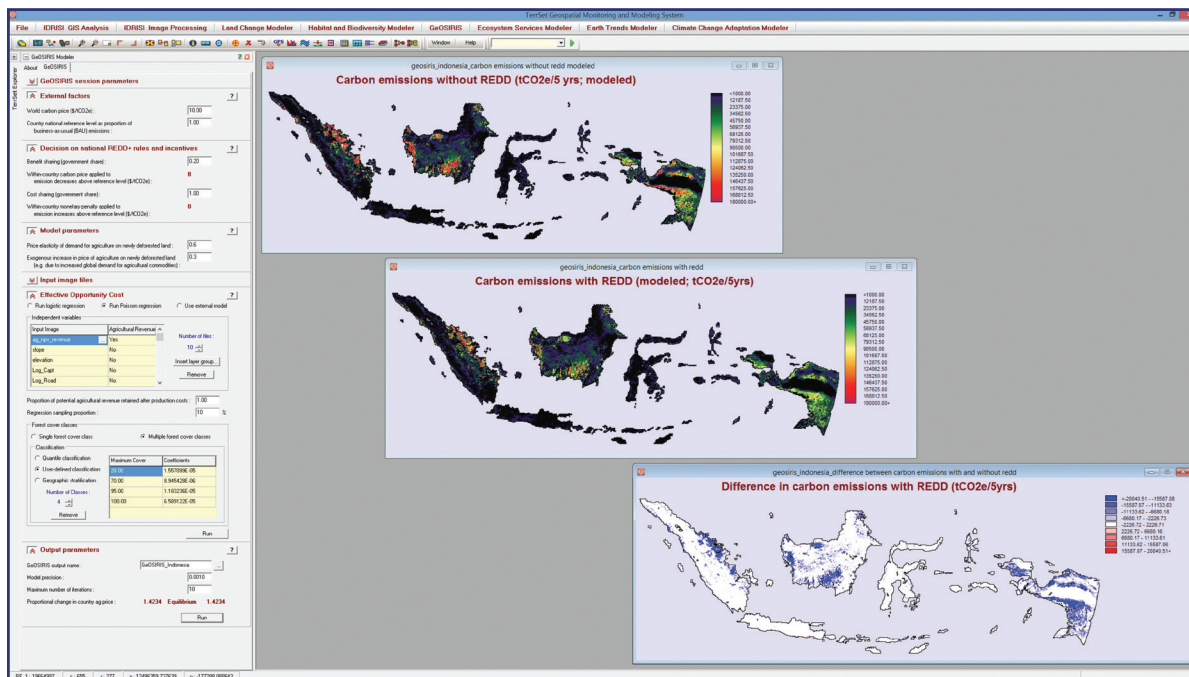
GeOSIRIS

GeOSIRIS is a national-level REDD (Reducing Emissions from Deforestation and forest Degradation) planning tool that quantifies and maps the impacts of REDD policies on deforestation, carbon emissions, agricultural revenue, and carbon payments. Whereas LCM's tools are appropriate for the development and assessment of individual projects, GeOSIRIS is oriented to the evaluation of alternative economic policy decisions for reducing greenhouse gas emissions and distributing REDD revenues. This application is a spatial implementation of the OSIRIS economic model created by Conservation International, the World Resources Institute and the Environmental Defense Fund. The model requires map layers of forest cover, forest cover change (which can be output from LCM), biomass,

REDD Analysis

REDD—Reducing Emissions from Deforestation and forest Degradation—is a climate change mitigation strategy that offers developing countries incentives to reduce their forest carbon emissions. Critical to the development of a REDD project is the ability to model expected land cover change in the absence of intervention. LCM is the ideal tool for this purpose and provides additional tools to quantify baseline carbon stock changes, including both CO₂ and non-CO₂ greenhouse gas emissions, and the possible associated leakage from displaced baseline activities. LCM's REDD tools follow the World Bank's BioCarbon Fund methodology and have been successfully employed in establishing approval for projects submitted to the Verified Carbon Standard program.

soil carbon, peat, potential agricultural revenue, site accessibility and administrative divisions (at multiple levels). Parameters include the global price of carbon, the national reference level for emissions as a proportion of business-as-usual, national/sub-national proportional cost/benefit sharing, price elasticity of demand for agriculture on newly deforested land and exogenous increases in price due to changes in demand. With these inputs, users can calculate the effective opportunity cost to establish the relationship between deforestation and potential agricultural revenue. Following this, a wide variety of map outputs can be produced including expected carbon emissions with and without the REDD policy in place, agricultural revenue, expected deforestation, cost efficiency of emissions reductions, and so on.



GeOSIRIS is a national-level planning tool for REDD (Reducing Emissions from Deforestation and forest Degradation). Developed in partnership with Conservation International, GeOSIRIS allows the user to specify the price of carbon, national level objectives for carbon emissions, the distribution of offset income between national and local levels, and a variety of economic parameters such as price elasticity of demand for agriculture on newly deforested land. GeOSIRIS empirically determines the effective opportunity cost based on a set of environmental variables and a provided map of potential agricultural revenue. Outputs include maps of expected carbon emissions with and without the proposed REDD policy as in the example for Indonesia above.

Habitat and Biodiversity Modeler

The Habitat and Biodiversity Modeler (HBM) is a toolset designed for Conservation GIS professionals. It provides tools for the modeling of species distributions, habitat assessment, habitat change and gap analysis, biodiversity analysis, and the planning of reserves and biological corridors.

Species

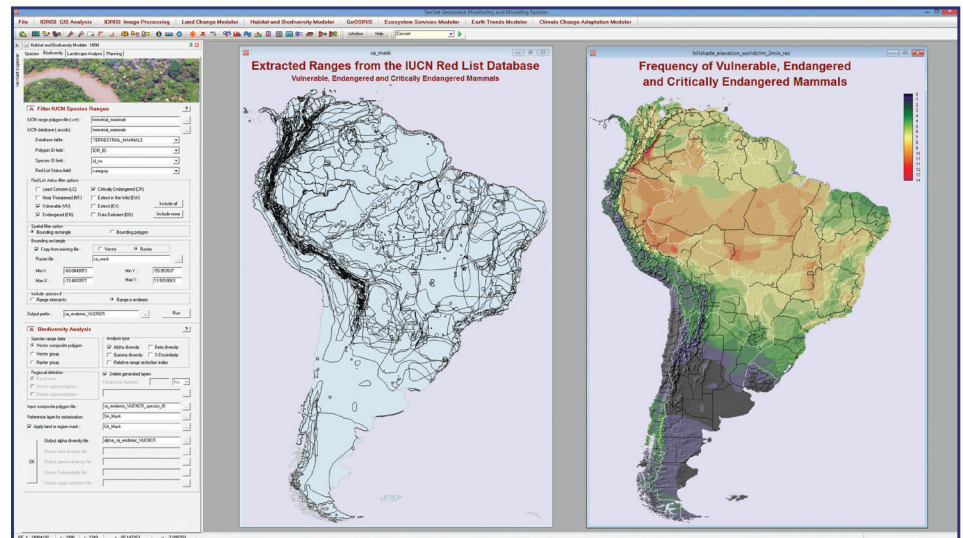
At the species level, HBM provides a wide variety of options for the modeling of species distributions based on observed locations and bioclimatic variables. Options are provided for presence only data (Mahalanobis Typicality and MaxEnt), presence/absence (Logistic Regression and a Multi-Layer Perceptron neural network) and abundance data (Multiple Regression). For individual species, the Habitat Assessment tool allows the mapping of primary and secondary habitat as well as potential corridor areas. Facilities are also provided for the assessment of habitat change and gaps in the protection system.

Biodiversity Analysis

HBM's Biodiversity tab provides a special utility for working with the IUCN (International Union for Conservation of Nature and Natural Resources) Red List of Threatened Species database. Subsets of species ranges can be extracted based on the Red List threat level, location and endemism. Given a set of extracted ranges (typically hundreds to thousands of ranges), maps of alpha diversity, gamma diversity, beta diversity, Sorensen's dissimilarity, and range restriction can be generated.

Landscape Analysis

At the landscape level, a facility is provided for landscape pattern analysis that maps normalized entropy, relative richness, edge density, patch area and patch compactness. In cases where land cover



The Habitat and Biodiversity Modeler (HBM) includes a wide range of tools for habitat assessment and species distribution/biodiversity modeling. In this illustration, the IUCN Red List species database for terrestrial mammals (freely available on line) was scanned to extract the range polygons of species endemic to South America. Once extracted, the polygons were then used to create a map of frequency using the alpha diversity mapping option.

maps from two dates are available, the process of change can be mapped. For example, a landscape may not be particularly fragmented, but may be actively fragmenting. Other processes that can be detected include deformation, perforation, shift, shrinkage, enlargement, attrition, aggregation, creation and dissection.

Planning

For planning, tools are provided for biological corridor analysis and reserve planning. The corridor tool allows you to specify the target width and number of branches as well as produce maps of development suitability and conservation value. It then maps corridors of least biological risk. For reserve planning, we have provided an integrated interface to the well-known Marxan reserve planning tool.

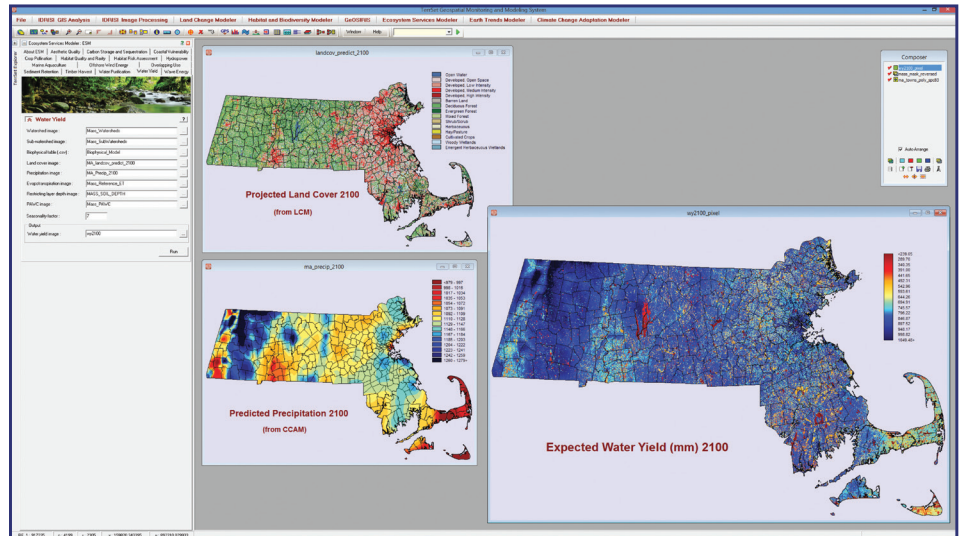
Ecosystem Services Modeler

The Ecosystem Services Modeler is a spatial decision support system for assessing the value of natural capital for sustainable development. The Ecosystem Services Modeler provides 15 ecosystem service models that are based closely on the InVEST toolset developed by the Natural Capital Project. Fully integrated into the TerrSet system, users can access a powerful platform for deriving the data for use in the 15 models, such as deriving future land use scenarios using the Land Change Modeler and predicted future precipitation using the Climate Change Adaptation Modeler to assess the impacts on water yield or sedimentation.

- Water Yield: measures the average annual yield based on inputs such as precipitation, land cover, evapotranspiration.
- Hydropower: estimates the potential energy production from a reservoir and its value.

- Water Purification: calculates nutrient retention and the avoided cost of water treatment.
- Sediment Retention: estimates sediment retention in a watershed and the avoided cost of sediment removal.
- Carbon Storage and Sequestration: estimates the amount of carbon currently stored or sequestered in the landscape and its value.
- Timber Harvest: models total biomass and net present value of harvested timber at the parcel level.
- Habitat Quality and Rarity: assesses the impacts of anthropogenic threats on the quality and rarity of habitats.
- Crop Pollination: evaluates the abundance and economic value of pollinators for agriculture.

- **Habitat Risk Assessment:** an alternative to the Habitat Quality and Rarity approach, the Habitat Risk Assessment (HRA) model focuses on management strategies and exposure/consequences.
- **Offshore Wind Energy:** evaluates potential wind energy sites and their economic value.
- **Aesthetic Quality:** models the visibility/visual impact of developments. The TerrSet approach includes a full consideration of atmospheric conditions on visibility.
- **Overlapping Use:** calculates the frequency and importance of human activities within a management zone.
- **Coastal Vulnerability:** evaluates the exposure of coastal communities to storm-induced erosion and inundation.
- **Marine Aquaculture:** estimates the productivity and economic value of existing aquaculture systems or identifies the best potential sites for new aquaculture projects.
- **Wave Energy:** evaluates wave-generated energy provision potential including consideration of the siting of wave energy conversion facilities.

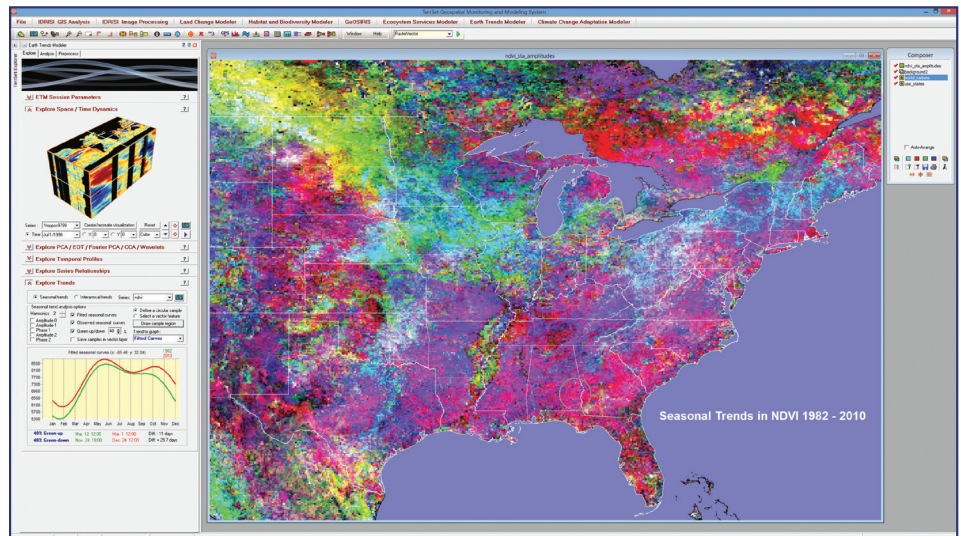


The Ecosystem Services Modeler (ESM) is closely based on the InVEST tools developed by the Natural Capital Project. Fifteen ecosystem service models have been implemented. In this illustration, ESM is used to evaluate water yield in the year 2100. The predicted land cover input was generated by LCM and the predicted precipitation was generated by CCAM.

Earth Trends Modeler

Over the past 30 years there has been a veritable explosion of earth observation image time series such as monthly global sea surface temperature and vegetation index imagery. The Earth Trends Modeler (ETM) is a ground-breaking tool for the analysis of such data. With ETM, one can map long term trends, trends in seasonality (such as vegetation phenology) and search for recurrent patterns over time, over space or over space-time. Additionally, ETM's pattern seeking tools are particularly adept at looking for coupled patterns across multiple image series. For example, the patterns associated with ENSO (the El Nino Southern Oscillation) in oceanic, tropospheric and stratospheric temperatures are related, but different in space and lagged in time. ETM has the tools to discover such patterns and much more, including:

- Interactive tools for the exploration of image time series, including animation of space time cubes, temporal profiling and the graphing of seasonal trends for user-defined regions of interest. Profiles can be generalized by superimposing a linear trend, a Theil-Sen median trend, a polynomial trend (up to 9th order), a moving average, a Gaussian moving average or a moving maximum.



The Earth Trends Modeler (ETM) is specially designed for the analysis of earth observation image time series. In this illustration, a series of 348 global images of monthly NDVI vegetation index data were analyzed for the presence of trends in seasonality. Pixels colored gray (which are almost absent) indicate a stable seasonality. All other colors represent trends. ETM provides an interactive legend (lower left) to interpret the trend for any area chosen either by a vector boundary or a circular area of interest (the area in eastern Alabama and western Georgia in this case). The green curve represents the beginning of the series (1982) while the red one represents the end (2010). The X axis is time and the Y axis is NDVI. As can be seen, NDVI has generally increased with a growing bimodality. Spring is coming a bit earlier (11 days) and the autumn is extending longer (almost 30 days).

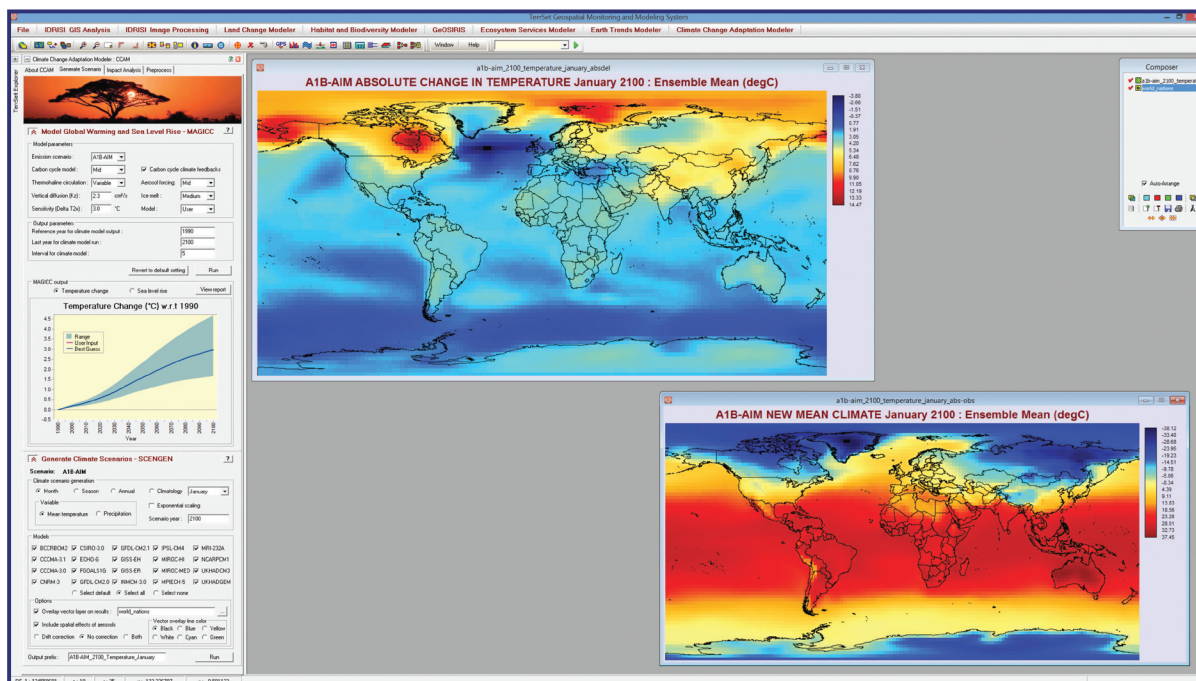
- Mapping of long-term trends including degree of linearity, degree of non-linear monotonicity, rate of change (both parametric OLS and non-parametric Theil-Sen median trend), trends in seasonality, and trend significance for both linear and seasonal trends.
- Space-time pattern analysis. Techniques include Principal Components (Empirical Orthogonal Function analysis), Extended PCA, Empirical Orthogonal Teleconnection (EOT) analysis, Extended EOT, Multichannel Singular Spectrum analysis (MSSA) and Canonical Correlation analysis (CCA). CCA and the extended modes allow the analysis of multiple series. Further, in most cases, the user can select either S-mode to focus on patterns over time, or T-mode to extract patterns over space.

- Spectral analysis, including Fourier-PCA and Wavelet Analysis (Maximum Overlap DWT).
- Linear modeling with image series dependent variables and multiple image or index series dependent variables. Dependent variables can also be lagged forwards or backwards in time. Outputs are in the form of images of correlation, partial correlation, R2 and adjusted R2. Residual series can also be output.
- Preprocessing tools include gap filling (missing data interpolation), deseasoning and denoising. Tools are also provided for detrending and pre-whitening (trend-preserving removal of serial correlation).

Climate Change Adaptation Modeler

The Climate Change Adaptation Modeler (CCAM – pronounced “see-cam”) addresses the growing challenge of adapting to a rapidly changing climate. The Climate Change Adaptation Modeler is a suite of tools for modeling future climate and assessing its impacts on sea level rise, crop suitability and species distributions. It includes tools for climate scenario generation using the National Center for Atmospheric Research’s MAGICC and SCENGEN models (based on CMIP3/AR4), crop suitability modeling using the Food and Agriculture’s EcoCrop database, modeling sea level rise impact, downscaling climate projections, and the derivation of bioclimatic variables. With CCAM, you can, for example:

- Generate global temperature and precipitation climate scenarios using any one, or an ensemble, of 20 atmosphere/ocean general circulation models (AOGCMs) based on user-selectable greenhouse gas and sulfur dioxide emission scenarios.
- Derive up to 19 bioclimatic variables (such as maximum temperature of the warmest month, minimum precipitation of the driest month, etc.) for use in species distribution models (using HBM).
- Model the impact of future projections of temperature and precipitation on crop suitability. Crop parameters can be added for any crop, but the included database provides the parameters for almost 2000 crops.
- Model the effect of projected sea level rise incorporating both the uncertainty of the projection and the uncertainty in the elevation model.



The Climate Change Adaptation Modeler includes an interface to the National Center for Atmospheric Research’s MAGICC and SCENGEN models for generating climate scenarios (based on CMIP3/AR4). In this illustration, the MAGICC suite of coupled gas-cycle, climate and ice-melt models was used to determine changes in greenhouse-gas concentrations and global-mean surface air temperature (the graph) using the A1B-AIM scenario. SCENGEN was then used to generate an ensemble forecast for January 2100 based on 20 atmosphere/ocean general circulation models.

IDRISI GIS Analysis

The foundation of TerrSet is the IDRISI GIS Analysis and Image Processing system. All components use the IDRISI API and the IDRISI data file structures. While IDRISI was once a standalone product, it is now incorporated within the TerrSet System.

Like all GIS software systems, IDRISI handles both vector and raster data. However, its orientation is primarily raster. While vector systems are focused on the management of objects in space, raster systems focus on space itself. Using a fine grid data structure, raster systems have exceptional analytical power. With their powerful implicit topology, raster systems are excellent for modeling geographic processes, particularly those that involve flows over space.

Map Algebra / Modeling

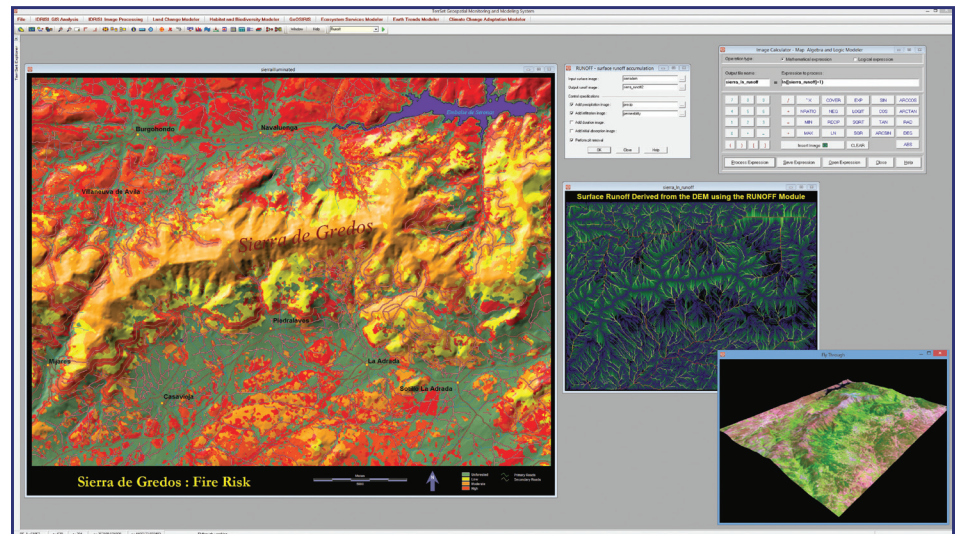
Perhaps the most fundamental property of raster systems is their ability to treat map layers as variables in an equation. TerrSet's IDRISI GIS provides an extremely rich set of logical and mathematical operators such as one would find on a scientific calculator. In this manner, mathematical models such as the Universal Soil Loss equation can be solved. The basic tools such as arithmetic operators, exponentiation, trigonometric functions and logarithmic operators can be performed either through the use of simple dialogs, or written as equations using the Image Calculator. In addition, TerrSet provides a very powerful graphical modeling tool complete with feedback loops and iterations.

Distance and Context Operators

The IDRISI GIS component in TerrSet provides a very rich set of tools for the assessment of distance across space including Euclidian distance, non-Euclidian cost distance where the effect of frictions to movement are accommodated, to anisotropic cost distance where the frictions are different in various directions. Tools are also provided for optimal path analysis and spatial allocation based on distance. Context operators (also known as neighborhood or focal operators) derive values based on individual cells and their neighbors. The IDRISI GIS includes a wide selection for filtering, pattern analysis and determining rates and directionality of change (such as slope and aspect). The latter can be used to describe force vectors and tools are provided for their combination to derive resultant forces.

Surface Analysis

Surface interpolation procedures in TerrSet's IDRISI GIS include inverse distance weighting, triangulated irregular network (TIN) modeling, Thiessen polygons, trend surface mapping and Kriging. Tools are provided to derive topographic features such as slope gradients, aspect, illumination (hillshading), and curvature and facilities to delineate watersheds and viewsheds, determine surface runoff and flow patterns, evaluate sedimentation and model soil erosion.



The foundation for TerrSet is the IDRISI GIS suite of analytical tools. This figure illustrates some of the many GIS analysis tools provided. These include a risk mapping based on a multi-criteria evaluation, a modeling of surface runoff incorporating information on precipitation and soil infiltration and the use of the Image Calculator for basic map algebra tasks. The bottom right shows a view of the FlyThrough interactive 3-D flight viewer.

Spatial Statistics

IDRISI provides a wide range of tools for statistical analysis of map layers including descriptive statistics, point distribution measures, autocorrelation analysis, pattern and texture measures, polynomial trend surface analysis, linear and multiple linear regression, logistic regression and multinomial logistic regression.

Decision Support and Uncertainty Management

A hallmark of TerrSet's IDRISI GIS has been the development of tools for multi-criteria/multi-objective decision support and uncertainty management. This development continues, and now TerrSet incorporates a major graphical modeling tool for multi-criteria and multi-objective decision support – the Spatial Decision Modeler (SDM). SDM incorporates tools for use of fuzzy sets to convert variables into comparable factors, the Analytical Hierarchy process for the derivation of factor weights, Ordered Weighted Averaging for multi-criteria evaluation and a newly designed procedure for multi-objective land allocation (MOLA). The new MOLA allows one to set targets for allocations based on either area or accumulated cost of land acquisition. In addition, it allows one to control contiguity, the number of contiguous allocations and the relative degree of compactness (specified as the minimum spanning distance). This is a first-of-its-kind implementation in the GIS industry and a major breakthrough in decision support.

TerrSet's IDRISI GIS also contains a wealth of additional procedures for uncertainty management including error propagation tools through Monte Carlo Simulation, the evaluation of decision risk as a result of propagated error, calculation and aggregation of Fuzzy Sets, and the aggregation of indirect evidence to support a weight-of-evidence conclusion using both Bayesian and Dempster-Shafer approaches.

I DRISI Image Processing

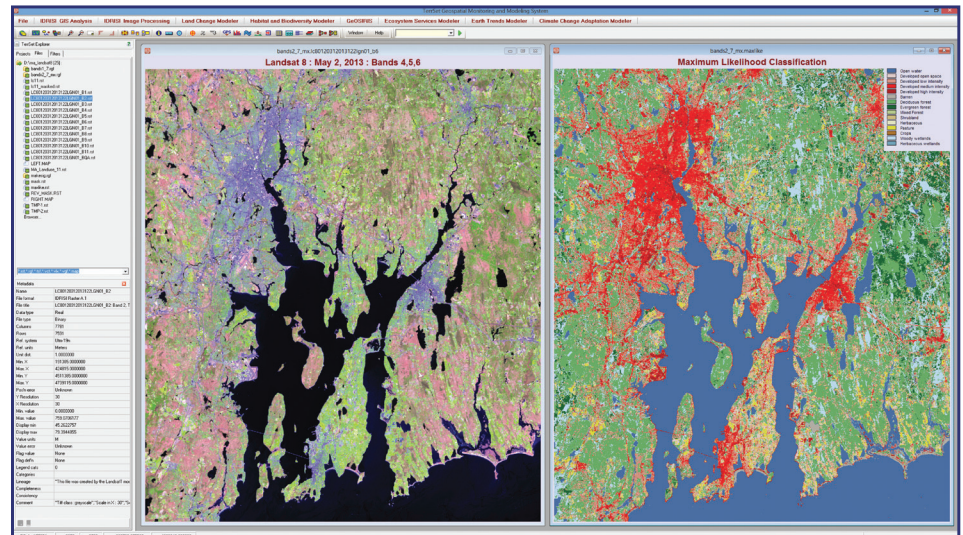
The final component of the TerrSet constellation is the IDRISI Image Processing toolset. The raster foundation of TerrSet provides an exceptional base for the analysis of remotely sensed imagery. Tools can be broadly classified into restoration, enhancement, transformation and classification. However, while the system provides a broad-spectrum approach to the analysis of remotely sensed images, the emphasis is unquestionably on the conversion of remotely sensed images to interpreted maps. The tools for classification are the broadest in the industry, including both hard and soft classification procedures based on machine learning (such as neural networks) and statistical characterization. Elements include:

Image Restoration

A complete set of geometric and radiometric correction tools including resampling, mosaicking, destriping and atmospheric correction. A special procedure is provided for Landsat import (including Landsat 8).

Image Enhancement

Image enhancement tools include stretching, compositing, filtering and sharpening images. For systems that include a higher-resolution panchromatic band, pan-sharpening procedures include a modified IHS (Intensity-Hue-Saturation) or Hyperspherical Color Sharpening (HCS) procedure. Spatial Fourier Analysis provides special opportunities for the removal of noise.



TerrSet includes the IDRISI Image Processing toolset with the most extensive set of classifiers for remotely sensed imagery in the industry. In this example, a Landsat 8 image of Rhode Island for May 2103 was classified using a Maximum Likelihood classifier and training data for classes consistent with the U.S. National Land Cover Database (NLCD).

Image Transformation

TerrSet's broad set of raster tools provides unlimited possibilities for transformation. However, special facilities exist for Principal Components and Canonical Correlation Analysis and vegetation index creation.

Image Classification

TerrSet contains the broadest set of classifiers (procedures for the computer-assisted interpretation) for remotely sensed imagery in the industry. Supervised classifiers include parallelepiped, minimum distance, maximum likelihood, Fisher Linear Discriminant Analysis, and K-nearest neighbor (KNN). Unsupervised classifiers include ISODATA, chain clustering, histogram peak and K-Means. Machine-learning classifiers include Classification Tree Analysis (CTA) and four neural network classifiers: Multi-Layer Perceptron (MLP), Self-Organizing Map (SOM), Fuzzy ARTMAP, and Radial Basis Function (RBF). Soft classifiers and mixture analysis tools include a Bayesian probability classifier, a Mahalanobis distance classifier, fuzzy set classifier, and linear spectral unmixing. Hyperspectral image analysis and classification is included. A special set of procedures are provided for segment-based classification. Tools for accuracy assessment are also provided.

System Requirements

- Windows 7 and above, or Windows Server 2003 and above.
- Microsoft ACE 2010 or Microsoft Office 2010 or later.
- 1.3 GB hard drive space for application.
- 7.4 GB for Tutorial data.
- 4 GB RAM, 8 GB or more recommended.
- HD display (1920 x 1080) or greater recommended.

For more information, visit www.clarklabs.org



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