Land Remote Sensing Models Quantify Ecosystem Carbon Dynamics: Land Cover Change, Management, and Climate Impacts

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Introduction

This LRS project accurately estimates the net ecosystem exchange (NEE) of carbon for monitoring and assessment of land use, land management, and climate change at 1-km resolution. This Model Tree approach incorporates collaborators' point-based flux tower measurements with NDVI and environmental drivers to develop *predictive models* of gross primary productivity (GPP), respiration (Re), and net ecosystem exchange (NEE). We capitalize on our extensive archival and near real time satellite data, land cover database, and diverse data sources to quantify spatially explicit carbon fluxes to complement the top-down approach of climate modelers. Collaboration with Ameriflux, Agriflux, and USDA ARS flux tower networks provides a rich collection of land surface-atmospheric exchanges to yield a robust modeling capability which appears to provide the best quantitative estimates of flux and to have global applications. Our regional application in the Northern Great Plains presents our first example of these capabilities.

The successful proof of concept and robust capability have significant science impact and now allow us to
(1) incorporate quantitative estimates of water fluxes,
(2) extend to other ecoregions and other vegetation types (agriculture and wetlands),
(3) achieve net regional carbon budgets in support of the North American Carbon Program,
(4) provide estimates in other areas of the world without flux towers, and
(5) provide a valuable and quantitative tool for ecosystem services to managers and policy makers.

This unique and highly quantitative capability has resulted in extensive collaboration with other national agencies and global flux tower projects. It contributes directly to the requirements of the major climate change and monitoring programs: US Climate Change Science Program, Orbiting Carbon Observatory (OCO) mission, Global Earth Observation System of Systems (GEOSS), Global Terrestrial Observing System (GTOS), Integrated Global Observation of the Land (IGOL), Global Carbon Project (GCP), Terrestrial Carbon Observations (TCO) activity, and North American Carbon Program (NACP).

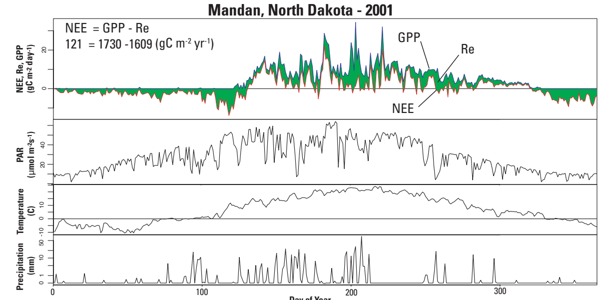
Flux Tower Measurements

Measured at flux towers
- Net Ecosystem Exchange (NEE)
- Photosynthetically Active Radiation (PAR)
- Temperature
- Precipitation
- Vegetation and soil

Ecosystem Respiration (Re) is derived from NEE, PAR, Temperature, and Precipitation using a light curve equation

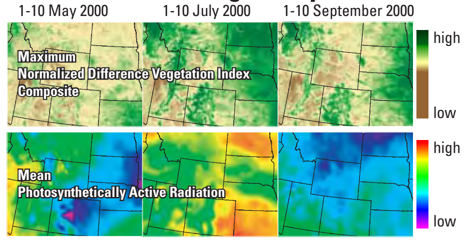
Gross Primary Production (GPP) is equal to NEE + Re

Mandan, North Dakota - 2001

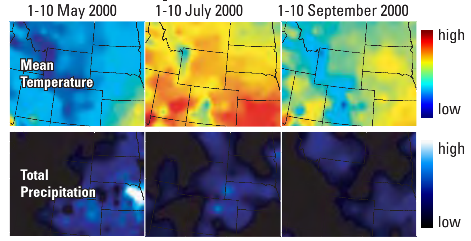


Regional Driving Variables

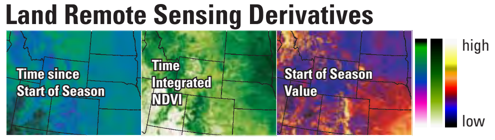
Land Remote Sensing 10-day Summaries



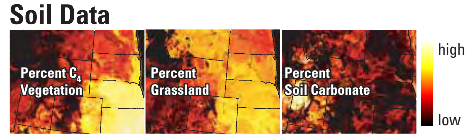
Climate 10-day Summaries



Land Remote Sensing Derivatives



Soil Data



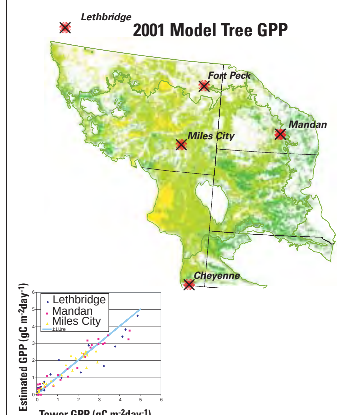
This project would not have been possible without the strong collaboration and support of the following:
USGS Earth Surface Dynamics, Land Remote Sensing, and Geographic Analysis and Monitoring Programs, NOAA Atmospheric Turbulence and Diffusion Division, the collaborative CO_2 flux scaling project (University California, Davis) funded through the US Agency for International Development Global Livestock Collaborative Research Programs (USAID GL-CRSP) and USDA Agricultural Research Service, USDA Agriflux, and USGS National Center, EROS Commercial Remote Sensing (CRS) Characterization, Calibration, Verification, and Validation. Tagir Gilmanov's, coordinator of the FLUXNET WORLDGRASSFLUX network, will continue to contribute his expertise in flux towers, light use efficiency, carbon dynamics and ecology. Without the vital contributions of data and science by the flux tower operators, A.B. Frank, Larry B. Flanagan, J.A. Morgan, M.R. Haferkamp, and Tilden P. Meyers, the project would not be possible.

Please visit http://edc.usgs.gov/carbon_cycle/FluxesResearchActivities.html or http://edc.usgs.gov/calval/, or contact Bruce Wylie at wylie@usgs.gov for more information.

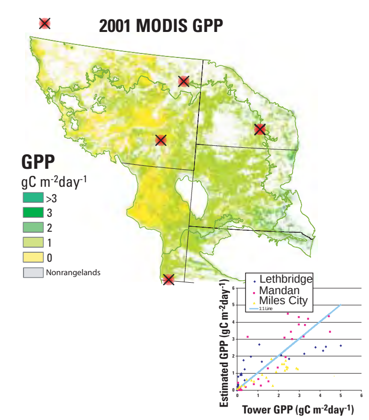
Model Tree Estimates of Gross Primary Production

We compared our Model Tree GPP estimates with the independently derived MODIS GPP product. Although the two methods are in general agreement, initial comparisons show that the MODIS GPP estimates are higher on average and have greater extreme values. The scatter plots show the distribution of the two products against measurements at three flux towers. Please note that since the flux towers were used to calibrate the Model Tree, these towers cannot be used to directly compare the two regional estimates at the towers. The model tree estimates will be integrated with the GEMS biogeochemical model. GEMS estimates for the trends blocks will be compared to the Model Tree estimates.

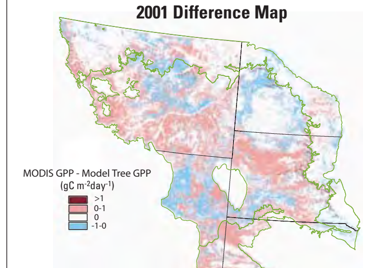
2001 Model Tree GPP



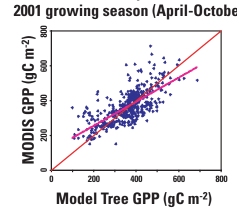
2001 MODIS GPP



2001 Difference Map



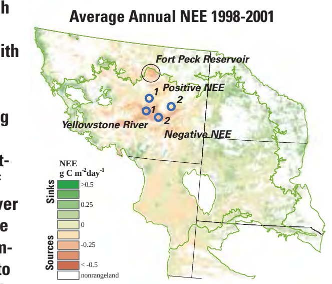
GPP comparison
2001 growing season (April-October)

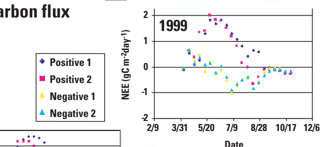


Investigating Causes of Sinks and Sources

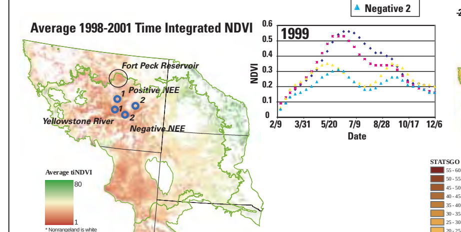
The Model Tree estimate of NEE can directly contribute to a better understanding of the relationships among the driving variables at local scales. An area north of the Yellowstone River and near the Fort Peck Reservoir, for example, were carbon sources in the 1988-2001 period. Growing season temperatures were high in the Yellowstone River source area, however early summer precipitation is not associated with these carbon source areas. The carbon source near the Fort Peck reservoir is associated with high clay content, whereas this is not true along the Yellowstone River. The patterns of carbon sources and sinks are closely related to the patterns of Time Integrated NDVI. An inspection of four sample locations near the Yellowstone River exhibit strong drops in NEE and NDVI during the growing season for the source areas when compared to neighboring sink areas. We continue to investigate the driving forces causing carbon flux patterns.

Average Annual NEE 1998-2001

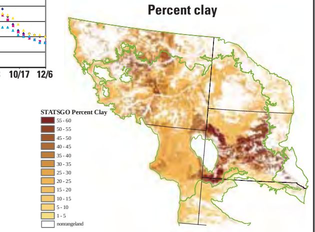




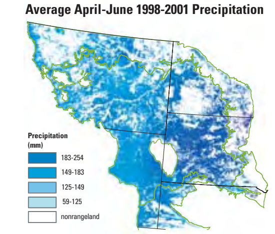
Average 1998-2001 Time Integrated NDVI



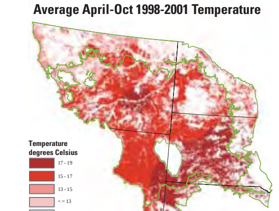
Percent clay



Average April-June 1998-2001 Precipitation



Average April-Oct 1998-2001 Temperature

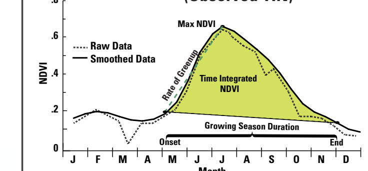


Rangeland Condition Relative to Climatic Potential

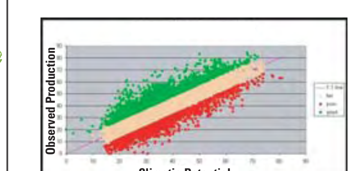
The spatial modeling approach allows us to monitor rangeland conditions. Time Integrated NDVI (TIN), the NDVI summed over the growing season for each pixel, is a surrogate for vegetation productivity. For a sample of 7,000 pixels across 4 seasons, we train a model to predict TIN as a function of monthly precipitation, monthly temperature, percentage clay, and STATSGO rangeland productivity for a normal year. We apply the model to all pixels to create a map of "climatic potential" for rangeland production. The scatter plot shows the estimated potential production (climatic potential) on the horizontal axis, and the TIN (observed production) on the vertical axis, and then we classify the pixels into three groups: good, fair and poor rangeland production. Interpreting the index as the "climatic potential" for range productivity, we can map areas that are more productive than expected (green) or likely to have been degraded or overgrazed (red). Where the methods are in close agreement (near the 1:1 line), we label the range condition as "fair" (buff color). A summary map indicates where the various conditions dominate over a series of years.

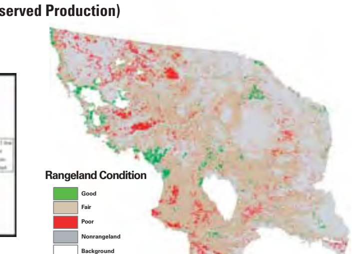
Observed Production
(Observed TIN)

Climatic Potential
Estimated TIN = f(ppt, temp, soil)



Rangeland Condition
(Climatic Potential - Observed Production)



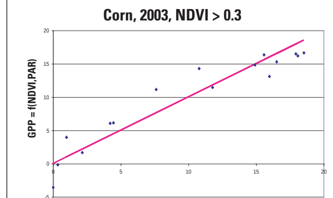


The "climatic potential" method may be enhanced by 1) identifying areas of similar ecosystem functionality where relationships between climate and NDVI are consistent and 2) monitoring over long periods to identify changes in ecosystem functionality. South Dakota is interested in historic and near-real-time range condition for water erosion and water quality assessments.

Future Work: Ecosystem Management, Human Impacts

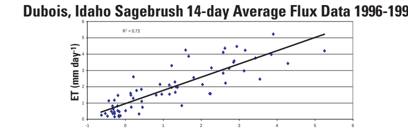
We will extend the methods for extrapolating flux tower data to include agricultural lands and wetlands, working toward the goal of understanding total *ecoregion* carbon dynamics. Croplands are managed ecosystems, and economic and policy influences as well as biophysical processes influence land managers' choices and determine which areas will be sources and sinks. We have corn and soybean flux data from the USDA Agricultural Research Service towers in Iowa, and Ameriflux towers near Lincoln, NE. We expect our remote sensing and modeling approach to perform well for yield and GPP, as indicated for corn. NEE will be more challenging because tillage methods directly affect soil respiration and organic matter levels. These are not directly observed by satellite sensors, but are embodied in GEMS. Wetlands are very dynamic and can rapidly shift from a sink to a source depending on their developmental stage. We will implement a spectral unmixing approach to quantify the proportions of water and vegetation as one step toward wetland ecosystem carbon dynamics.

Corn, 2003, NDVI > 0.3



As human populations expand and climates change, water will become an increasingly valuable asset. Flux towers not only quantify fluxes of CO_2 but water fluxes as well. We will implement similar Model Tree methods for extrapolating evapotranspiration for large areas. Exploratory investigations in Sagebrush ecosystems show strong relationships between the driving variables and evapotranspiration (ET). High resolution estimates of water flux are important for monitoring drought.

Dubois, Idaho Sagebrush 14-day Average Flux Data 1996-1999



This integration of remote sensing and models at high resolution provides the quantitative extrapolation of fluxes needed to support ground-based estimates and understanding of ecosystem services that support the Integrated Global Observation of the Land.

Future Work: Sensitivity, Operational Processing, New Sensors

We will quantify the sensitivity of the Carbon Flux estimates to establish confidence intervals and uncertainty estimates. As the procedure is extended to new ecoregions, new vegetation types (agriculture and wetlands) and new flux towers, we will establish operational data and analysis flows to improve processing efficiencies. Additional flux towers measurements will be incorporated to improve model calibration and robustness. Operational procedures will include the online visualization, interactive modeling and dissemination of the Carbon flux estimates and derivative products.

We will plan beyond the existing suite of land remote sensing sensors to NPP VIIRS and NPOESS. Of particular importance is preparation for the Orbiting Carbon Observatory (OCO) mission. Our cooperative arrangements with flux tower operators and our per pixel estimates of NEE will provide an important opportunity to validate NEE estimates, to reduce uncertainty estimates, and to provide a testbed for OCO. In addition to new sensors, new dirivative products, such as improved growing degree days, available water, snow cover, soil organic matter, soil moisture, precipitation and plant residue, are becoming available.

Flux Tower Collaborations shown with Omernik Level III Ecoregions