Fire, Land Cover and Climate Change: Impacts on River Flows in Semiarid Shrubland Watersheds

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ABSTRACT

This project is designed to address the following question in Mediterranean-type ecosystems (MTEs): **What is the combined effect of potential climate change and modified fire regimes on river flow characteristics that are important for water resources, ecosystem processes and functioning, and property damage?** Increased ignition sources associated with growing human populations and expected changes in climatic conditions are likely to increase fire frequencies in shrubland watersheds, typical of MTEs, over the next century. The following general hypothesis is tested for chaparral watersheds in California: **Changes in fire regime and climate will alter aggregate ecosystem conditions giving rise to modified long-term river flow characteristics.** The research hypothesis will be tested using an existing, physically based ecohydrological model (RHESSys) applied to two chaparral watersheds near Santa Barbara, California. The research project includes the following related components: 1) Time-space variations of shrub LAI during fire recovery are estimated from Landsat TM data and AVHRR data, 2) RHESSys is calibrated and evaluated using a bi-variate approach based on satellite-based estimates of LAI patterns and observed streamflow and 3) RHESSys is used to evaluate the impact of future fire and climate regimes on vegetation recovery and associated hydrologic response.

Results from this study will further our understanding of how indirect anthropogenic modifications to landcover (different fire and climate regimes) are likely to affect water resources and related ecosystems in the heavily populated semiarid MTE regions of the world. In addition, the modeling approach will contribute to our understanding of the carbon cycle in these ecosystems and ultimately will become part of an integrated modeling system for decision support. The remote sensing products (LAI) will provide a valuable time-series data set of this critical variable for other hydrologic or biogeochemical studies and MODIS validation efforts.

Research Fields:	Fire Ecology; Runoff, Streamflow
Geographic Area/Biome:	Semi-arid
Remote Sensing:	AVHRR; LANDSAT
Methods/scales:	Integrated Assessment; Local Scale

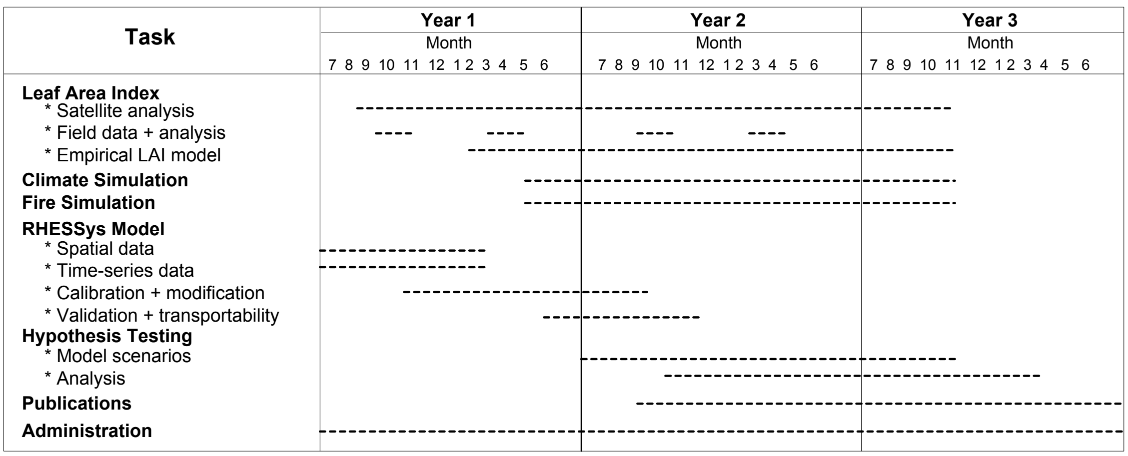
NASA ESE Scientific Questions and Themes

• What are the changes in land cover?
• What are the consequences of LCLUC?

Social Science:	0%
Carbon:	25%
Water:	75%

Goals

PROJECT TIME-LINE



The principal research goals of the project are to:
1) Develop empirical relationships between leaf area index (LAI) and stand age using Thematic Mapper (TM) and Advanced Very High Resolution Radiometer (AVHRR) data for two study watersheds near Santa Barbara, CA.
2) Parameterize and calibrate an ecohydrological model (RHESSys) to simulate LAI spatial patterns and river flows. Use the satellite time-space LAI patterns and observed river flows for this calibration and validation.
3) Use downscaled GCM outputs in the RHESSys model to assess the impact of climate change and altered fire frequencies on river flows.

Year one activities have focused on goals 1) and 2) with the following specific objectives:
1) Process time-series of TM and AVHRR, including precise geometric and radiometric registration of the TM imagery. Develop models to predict LAI as a function of stand age and antecedent precipitation.
2) Conduct limited field surveys to verify satellite-based estimates of LAI and to determine the controls over LAI.
3) Assemble spatial data and time series data for the two study watersheds for use in the RHESSys model and complete initial calibration run. Compare RHESSys hydrologic performance to a contrasting distributed hydrologic model, MIKE-SHE.
4) Initiate the climate and fire simulation components of the project.

Following two field campaigns, we recognized the need to modify our LAI verification strategy. Collecting field LAI data according to our original experimental design proved to be impractical. Many of the sites could not be accessed due to impenetrable chaparral shrubs and extremely steep terrain. Furthermore, it became apparent that the LAI within areas designated as "uniform" in the imagery, were often highly heterogeneous at the stand and sub-pixel level, necessitating an extremely large sample size to characterize the mean LAI of a stand. Field observations also revealed that major differences in TM-derived LAI are primarily a function of percent cover and vegetation type. While we will continue a limited random sampling strategy to measure LAI with a light-bar, we intend to:

• Focus on comparing the *spatial* patterns of LAI derived from TM data and the RHESSys model rather than absolute LAI values at individual points.

• Identify areas of discrepancy between RHESSys model and TM-derived predictions of LAI spatial patterns and conduct field surveys and high resolution photographic surveys (light aircraft) in these areas to quantify LAI, cover fractions, and vegetation type.

<u>Progress</u>

• AVHRR analyses indicate that intra-annual variations in the LAI of chaparral shrublands are greater than reported in the literature.

• Field surveys have revealed that the mix of different vegetation types (grasses, shrubs, trees) is the primary control over LAI spatial patterns.

• The RHESSys model appears to be well suited to making river flow predictions in chaparral watersheds and predicts watershed mean LAI values close to those estimated using a Thematic Mapper-5 NDVI-based model.

• A coherent landscape organization of predicted soil moisture pattern can be seen at 30 m resolution, but not at coarser resolutions.

Twelve TM-5 images, covering the period 1985 – 2001, have been purchased and registered to a base image (1995) using DIME software (Positive Systems Inc.). Radiometric registration is a key step in the image processing sequence. We have extended existing pseudo-invariant feature (PIF) approaches to: 1) ensure statistical rigor in the regression models, 2) obtain a range of brightness in the selected targets and 3) exclude mixed pixels or pixels with anomalous digital counts within our PIFs.

A detailed analysis of vegetation recovery after fire has been conducted using AVHRR imagery collected over the Santa Cruz watershed between 1990 and 1999. Using a portion of the watershed that burnt in 1993, we characterized the intra-annual and inter-annual variability in LAI (derived from NDVI) before and after this fire. A similar post-fire analysis was conducted for the Jameson watershed, which was burnt in 1985. Jameson is a small sub-watershed within one of the larger study watersheds. The post-fire recovery trajectories conform to the pattern expected from previous field studies and our analyses based on TM data.

Two field campaigns have been executed to measure LAI in stands representing different vegetation densities. Field LAI values were in the range of values calculated using the TM NDVI model. Besides the previously stated challenges to field observations of LAI, we also found from measurements of shrubs without leaves that stems and branches in contributed approximately 0.75 - 1.0 LAI to the measured total.

Based on a review of current literature, a set of community-specific vegetation parameters were derived for chaparral, coastal sage scrub and live oak and added to the RHESSys model vegetation database. One of the key challenges in this project is providing accurate estimates of spatially variable precipitation inputs to RHESSys from base climate stations for the project watersheds. Initial precipitation scaling was based on a digital map of mean annual precipitation (MAP) for Santa Barbara County. Other scaling procedures are being investigated.

RHESSys permits both spatially variable and grid based landscape topologies. For a small test watershed (Jameson), we explored the sensitivity of model response to landscape representation by comparing calibrated results for a range of topologies. For MIKE-SHE and a range of RHESSys landscape representations, manual, Monte-Carlo based calibration was done to maximize Nash-Sutcliffe efficiency between observed and estimated monthly streamflow for water years 1974 to 1980. Nash-Sutcliffe efficiencies for RHESSys ranged between 0.88 (270 m resolution) and 0.95 (patch mode), similar to values for the more hydrologically sophisticated MIKE-SHE model.

Figure 1 illustrates soil moisture patterns predicted by different RHESSys landscape representations and the MIKE-SHE model (using optimal calibration parameters). These results suggest that a coherent landscape organization of soil moisture pattern can be seen at the 30m spatial resolution but is not evident at coarser resolutions.

Following a spin-up period of approximately 30 years of simulation to stabilize soil and litter stores, RHESSys predicted a mean watershed LAI of 2.1. Mean LAI using a TM-based NDVI model was 2.2 for the Jameson watershed. This close correspondence between model and remote sensing mean basin LAI is encouraging and a significant result since this study represents the first time RHESSys has been applied to a chaparral dominated system. However, comparison of the two spatial patterns of LAI reveals significant areas of discrepancy, particularly in the riparian zones (Figure 2).

New Findings:	-
New Potential:	A more rigorous and statistically sound radiometric registration procedure. RHESSys model adapted for chaparral watersheds.
New Products	TM-5 time series (1985 -2000) for the Santa Barbara region (radiometrically and geometrically registered).

<u>Next Steps</u>

1. Complete radiometric registration of all TM images and finalize LAI-stand age relationships for both TM and AVHRR data. Generate a complete time-space series of LAI for the period 1985-2000.
2. Develop a RHESSys modeling strategy to account for regions with high within patch spatial variability in both LAI and species type. Controls exerted by local small-scale geomorphic events (soil erosion) and unrecorded small fires on both vegetation type and biomass must be accounted for if RHESSys patterns are to be compared with those derived from remote sensing. A strategy to account for these controls in RHESSys will likely involve initialization based on external information, potentially derived from high-resolution aerial photography or additional analysis of TM data to access sub-pixel characteristics (i.e. spectral mixture analysis).

3. Extend RHESSys modeling to the two larger watersheds and continue hydrologic and LAI comparisons.
4. Explore the impact of different spatial soil moisture patterns on predictions of ecological processes such as evapotranspiration and net productivity. A detailed discussion of the above analysis including differences between MIKE-SHE and RHESSys and sensitivity to landscape representation will be summarized in a manuscript).
5. Conduct climate downscaling and fire frequency simulation studies and initiate model scenario tests using these outputs.

Conclusions

• The planned year-1 activities have been accomplished or will be completed by the end of this summer.
• Field campaigns during this first year have revealed the need to modify our surveys to include high spatial resolution aircraft imagery in selected areas. Areas where satellite and RHESSys model predictions of LAI disagree will be surveyed in detail.
• Extending the hydrologic component of the study to include a model with contrasting structure to RHESSys has proved very valuable for assessing RHESSys performance in the study watersheds and the model predicted spatial patterns of soil moisture and evapotranspiration.

Publications

• McMichael, C., Hope, A. and Roberts, D. (submitted), Post-fire recovery of leaf area index in California chaparral: a remote sensing-chronosequence approach, International Journal of Remote Sensing.

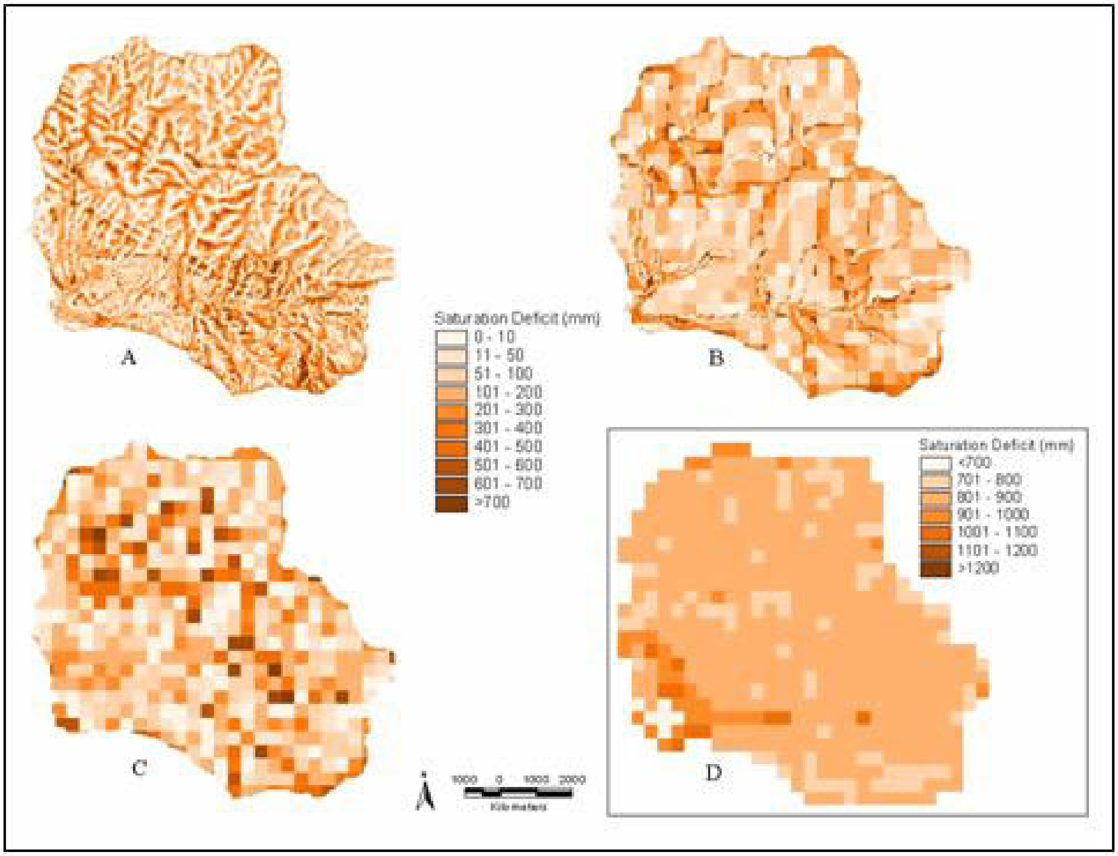


Figure 1: Spring 1980 saturation deficit for RHESSys (A. 30m grid; B. Spatially variable; C. 270m grid) and MIKE-SHE (D. 270m grid).

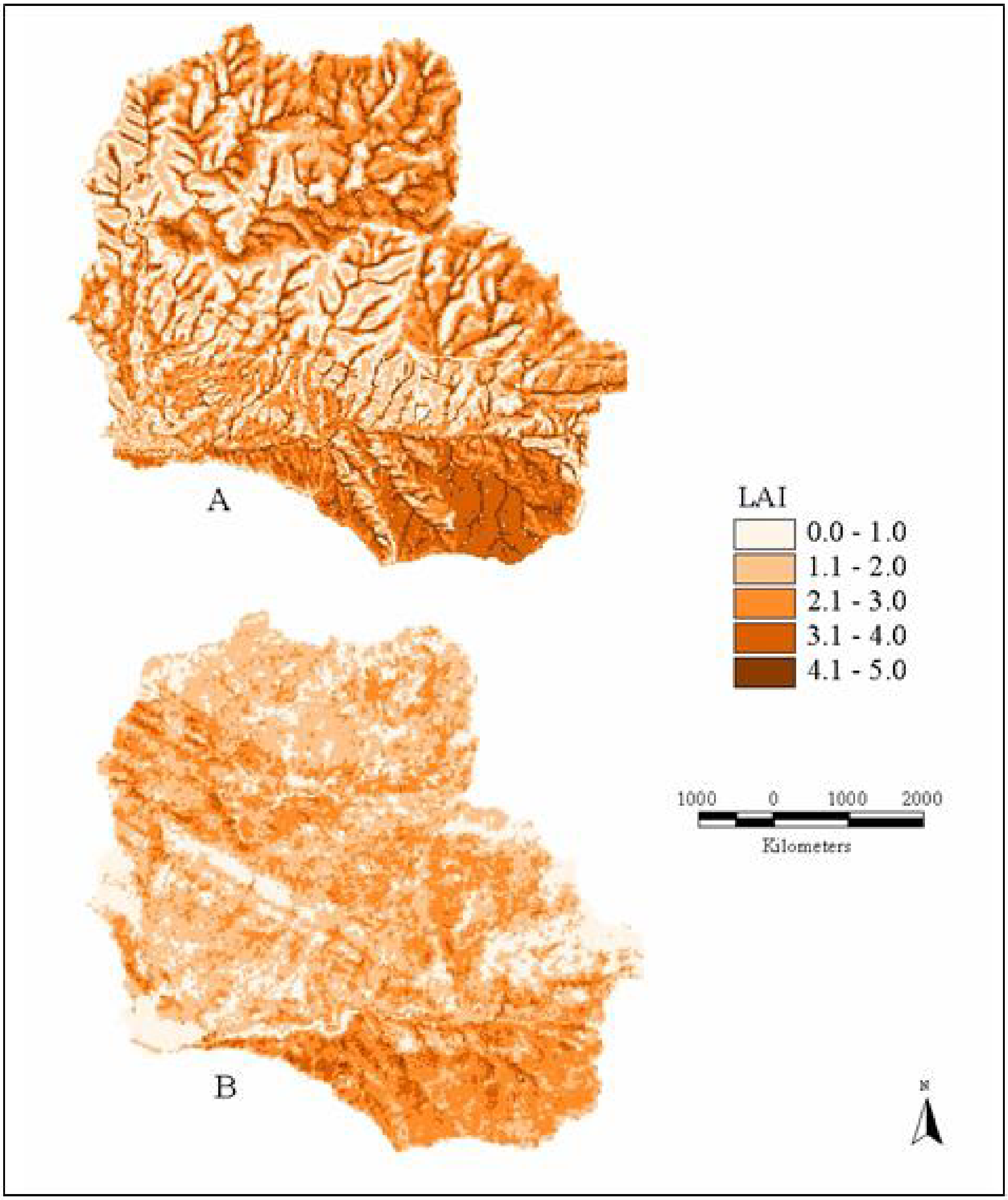


Figure 2: Spring LAI for the Jameson watershed (A. RHESSys modeled; B. TM-NDVI derived).