Impacts of Remotely-Sensed Vegetation Dynamics on Ecohydrological Response in a Small Mountainous Watershed

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Mountainous vegetation exhibits spatial and temporal patterns.

In the southwestern US, the North American monsoon leads to greening of forested ecosystems in the summer.

Monsoon greening affects:

- Bio-physical properties of multiple plant types (vegetation fraction).
- Interception and evapotranspiration processes.
- Mass and energy balance of the hydrologic system.
Motivation

To simulate these ecosystems, we need to detect vegetation dynamics from remote sensing.

Our overall objective is to incorporate vegetation dynamics into a distributed hydrologic model.

Our focus today will be on:

- Remote sensing methods to obtain vegetation parameters.
- Presenting new methodology for ingesting dynamic vegetation maps.
- Comparing results of static vs. dynamic vegetation maps on distributed soil moisture simulations.
Study Basin and Field Data Sets

Redondo Creek Basin in the Valles Caldera National Preserve, Jemez Mountains, New Mexico.

- Major topographic feature is Redondo Peak (3400 m). Complex terrain and structural geology.

- Distributed field observations of soil moisture carried out during summer monsoon 2005 at six (6) sites in basin.

- Long-term weather monitoring at high elevation site exhibits strong seasonal fluctuation in hydrologic conditions.

Distributed hydrological simulations in complex environments that exhibit strong seasonality (winter vs. summer) is at the forefront of our current capabilities.
Major vegetation types in Redondo Creek Basin.

- Spruce fir and mixed conifers at high elevation slopes.
- Mountain meadows and wetlands along valley bottoms.
- Well-established tree-line with recent invasions of ponderosa pine into historical grasslands.
- Aspect and elevation controls on vegetation distribution have been identified (Coop and Givnish, 2007), but open questions remain.

Aerial photography and ground-truthing observations used to derive vegetation and soil maps and classifications.
Remote Sensing Data Sets

Multi-platform remotely-sensed image processing using:

– Landsat 5 TM at 30-m resolution, 7 bands, 16-day period availability.

– MODIS Terra at 500-m resolution, 8 day composites.

– At present, derivation of albedo and vegetation fraction using:

Short-wave albedo (Landsat):

\[ \lambda_{\text{shortwave}} = 0.356\lambda_1 + 0.13\lambda_3 + 0.373\lambda_4 + 0.085\lambda_5 + 0.072\lambda_7 \]

Vegetation fraction (MODIS and Landsat):

\[ f = 1 - \left( \frac{\text{NDVI}_{\text{max}} - \text{NDVI}}{\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}}} \right)^{\frac{1}{c}} \]

- Topographic and geometric corrections

Remote sensing allows retrieval of vegetation parameters at discrete time periods which can be used to capture spatial and temporal changes.
Distributed Hydrologic Model

We are using the TIN-based Real-time Integrated Basin Simulator (tRIBS) (Ivanov et al. 2004) for distributed modeling of hydrologic processes (winter and summer time) in the Valles Caldera National Preserve.

Surface-subsurface hydrologic processes over complex terrain

Additional Details in Ivanov et al. (2004a,b), Water Resources Research, Journal of Hydrology

Distributed Hydrologic Modeling

- Coupled vadose and saturated zones with dynamic water table.
- Soil moisture infiltration waves.
- Lateral soil moisture redistribution.
- Radiation and energy balance.
- Interception and evapotranspiration.
- Hydrologic and hydraulic routing.

*Current model version used static vegetation cover, with impacts on the evapotranspiration, interception and radiation processes.*
Distributed Hydrologic Model

New model developments allow dynamic updating (in time) of the vegetation field and corresponding changes to vegetation-related parameters.

**Static vegetation fraction**

- 0-0.1
- 0.1-0.2
- 0.2-0.3
- Cloud

**Dynamic vegetation fraction**

- June 07
- July 09
- Aug 10
- Sep 27

Dynamic updating of land cover characteristics includes:

- Impact the Rutter Interception model and the modified Penman-Monteith equation, and the radiation components.

- Direct ingestion of vegetation parameter as spatial fields (square grids) for:
  - Albedo [ ]
  - Vegetation Fraction [ ]
  - Vegetation Height [m]
  - Free Throughfall Coefficient [ ]
  - Daily Minimum Stomatal Resistance [s/m]

- Updating occurs at time of remote sensing data availability and fields are resampled to the Voronoi polygon domain.
Distributed simulation conducted over the summer period 2005:

- Transition from snowmelt to monsoon season: June 7 to September 30, 2005.
- tRIBS model domain consists of ~62,000 computational nodes.
- Model forcing consisting of NEXRAD radar rainfall and weather station data.
- Temporal output associated with 6 field sampling stations and 1 weather station.
- To account for spatial uncertainties, we generate output for co-located and neighboring Voronoi polygons to each site.
Results at Weather Station

Static vegetation comparisons at the weather station:

- Good agreement between model and observed soil moisture.
- **Model captures the seasonal fluctuation in soil moisture.**
- Early period cannot be captured as it relates to snowmelt input prior to the simulation.
- Model simulations use literature values for soil and vegetation parameters. Minor calibrations performed on vegetation fraction and stomatal resistance.

**Soil Moisture Simulations at Weather Station**

*Model simulations cover the entire period (June 7 to September 30, 2005). NEXRAD rain gauge forcing shown for comparison.*
Results at Distributed Locations

Comparisons of soil moisture simulations at the distributed sampling sites show adequate model performance during the field campaign.

Site Locations

- Good comparison of soil moisture simulated at the co-located voronoi polygon and the uncertainty bounds generated by the results at the neighboring polygons.
Results in the Basin

Static vegetation simulations of the distributed moisture in the Redondo Creek basin showing the dynamics during the monsoon season.

- Low soil moisture in the early monsoon season with low spatial variations.
- Soil moisture increases between July and August and exhibits large spatial changes due to rainfall forcing and landscape parameters.
- Soil moisture begins to fall as the monsoon season terminates.
Results of Dynamic Vegetation

Results of incorporating dynamic albedo and vegetation fraction in the Redondo Creek model suggest sensitivity of simulated ET and soil moisture.

- Dynamic vegetation leads more realistic seasonal changes in ET and generally less ET
- Lower ET results in slightly higher soil moisture amounts in the weather station.
- Additional sensitivity expected for other vegetation parameters (height, stomatal resistance).
Results of Dynamic Vegetation

Dynamic vegetation also impacts the soil moisture spatial distribution and the streamflow generated in the basin during the summer monsoon.

Peak Soil Moisture Comparison

Outlet Hydrograph Comparison

Relative Soil Moisture, $S = \theta/n$ in top 10-cm
Conclusions

- Remote sensing techniques are useful for capturing the spatial and temporal dynamics of forested vegetation in mountains.

- Distributed model results are in good agreement with soil moisture observations at a set of distributed sites.

- Preliminary result of dynamic vegetation indicate model sensitivity and improved seasonal representation of ET.

- Future work will include dynamic updating of other vegetation parameters (stomatal resistance, throughfall coefficient).