Modeling Soil Moisture in California at Multiple Scales

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Project Objectives

The project aims to model root-zone soil moisture using vegetation phenological information derived from remotely sensed data, combined with ground-based meteorological data, soil properties, and vegetation types. In the first phase of research, we have analyzed relationships between volumetric soil water content in the rooting-zone of annual grassland, oak savanna and chaparral stands, and six vegetation indices (VIs) derived from Moderate Resolution Spectrometer Sensor (MODIS) data. We have also tested the performance of DayCENTURY in simulating soil moisture and primary production. In addition, we finished installation of soil moisture probes in Sedgwick Ranch, Santa Barbara. Continuous measurements of soil water content at different landscapes will be used to evaluate the impact of scale on the relationship between soil moisture and VI. Laboratory work including analysis of bulk density and particle size distribution of each site from Sedgwick is in progress.

Approach and Procedures

To develop a physically meaningful relationship between soil moisture and vegetation responses, gross primary production (GPP) of vegetation is used to bridge the available water in soil and vegetation indices. Soil water content then can be retrieved from the model of VI (\textit{see fig. 1} for the outline of procedures). Data of four sites (Tonzi Ranch, Vaira Ranch, Sky Oaks old stand, and Sky Oaks young stand) from AmeriFlux network in California have been used to evaluate relationships between soil moisture, GPP, and VIs derived from MODIS data. Based on the relationship, soil moisture is expected to be modeled as a function of VI. To extend the model to areas in which required data are not available, DayCENTURY were tested with data from Tonzi Ranch and Varia Ranch, simulating volumetric soil water content in the rooting-zone and primary production.

To analyze the scale affects on the relationship and to evaluate the sensitivity of models to various scales, we deployed soil moisture probes at two depths in 14 sites in Sedgwick Ranch (in Santa Barbara), covering three landscapes (grassland, oak savanna, and shrubland) and a range of topographically variety (\textit{fig. 2}). Soil moisture measurements will then be analyzed in a similar fashion to see if our findings at the coarse MODIS resolution (500m), particularly the relationships between soil moisture and GPP/VI, will change at SPOT’s (Satellite Pour l'Observation de la Terre) finer resolution (20m).

Results

Results showed that in grassland GPP is controlled by soil moisture from the beginning of March to the end of October when water is limited while insolation is sufficient. The relationship

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between soil moisture and GPP is non-linear and can be modeled using quadratic function (table 1 and fig. 3). However, at the beginning of the growing season in grassland (generally from November to February in the next year), GPP is more affected by insolation than soil moisture, probably because during this period insolation is a limited resources while water is sufficient. We also found a significant linear relationship between GPP and Visible Atmosphere Resistant Index (VARI) in grassland (fig. 4). In oak savanna, the analysis suggested that overstory GPP (GPP of trees and grasses in savanna) is not well correlated with soil moisture. The relationship between overstory GPP and VARI is less significant than the relationship between understory GPP (GPP of grass in oak savanna) and VARI. The test of DayCENTURY suggested that it can simulate soil moisture dynamics fairly well in grassland and oak savanna, and it can produce reasonable results of weekly NPP.

**Discussion**

The analysis we have done so far provides evidence that vegetation indices derived from remotely sensed data can reflect plant available soil water status. The relationship is significant for grassland, which can be used to model soil moisture as a function of VI at large scale, though at the beginning of the growing season dynamics of grassland are primarily controlled by insolation. The relationship between soil moisture and VI is less significant for oak savanna, and thus in the following research we will focus on modeling soil moisture in grassland. DayCENTURY and ISOLSM are ecosystem modeling tools to help examine the relationship in areas in which soil moisture and GPP data are not available. The test of ISOLSM will be finished by March. After that, we will enter the second phase of our research, focusing on the application of DayCENTURY and ISOLSM to extending our analysis to areas absent of required data. We will also analyze spatial and temporal variations of modeled soil water content in California.

**Figure 1:** Outline of procedures
**Figure 2:** The map of soil moisture probes in Sedgwick Ranch, Santa Barbara. Eight sights are in grassland covering north facing slope, south facing slope, valley, and ridge. Seven of them are active, one stopped working due to the damage by animals. Two sites are in chaparral stand, located in the valley near the foothills. Four sites are in oak savanna, on the north-facing slope, south-facing slope, valley, and ridge.
**Table 1. The relationship between GPP and soil moisture at 20cm in open grassland (Vaira Ranch) from year 2001 to 2006.**

<table>
<thead>
<tr>
<th>Year (Day of the year)</th>
<th>Correlation Coefficient</th>
<th>Regression Model</th>
<th>R square</th>
<th>P-value</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 (D50-315)</td>
<td>0.7831</td>
<td>GPP= -297.6<em>x^2 + 151.5</em>x - 10.34</td>
<td>0.7403</td>
<td>0</td>
<td>206.4967</td>
</tr>
<tr>
<td>2002 (D50-310)</td>
<td>0.6912</td>
<td>GPP= -161.9<em>x^2 + 93.78</em>x - 0.6942</td>
<td>0.5279</td>
<td>0</td>
<td>209.1609</td>
</tr>
<tr>
<td>2002-2003 (D40-320)</td>
<td>0.9088</td>
<td>GPP= -74.35<em>x^2 + 74.89</em>x - 7.333</td>
<td>0.8262</td>
<td>0</td>
<td>233.1257</td>
</tr>
<tr>
<td>2004 (D50-310)</td>
<td>0.6719</td>
<td>GPP= -153.3<em>x^2 + 88.06</em>x - 13.41</td>
<td>0.5266</td>
<td>0</td>
<td>259.8232</td>
</tr>
<tr>
<td>2005 (D40-320)</td>
<td>0.8868</td>
<td>GPP= -114.3<em>x^2 + 79.13</em>x - 4.124</td>
<td>0.8590</td>
<td>0</td>
<td>172.0592</td>
</tr>
<tr>
<td>2006 (D40-320)</td>
<td>0.8199</td>
<td>GPP= -124.1<em>x^2 + 88.27</em>x - 8.941</td>
<td>0.7352</td>
<td>0</td>
<td>186.6348</td>
</tr>
</tbody>
</table>
Figure 3: The relationship between GPP and soil moisture at 20cm in open grassland.

Figure 4: The relationship between GPP and VARI in open grassland.
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