Satellite Indicators of Vegetation Condition, Crop Canopy Development, and Agricultural Water Use in California

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California Department of Water Resources, USDA Agricultural Research Service, Western Growers, Del Monte Produce, Constellation Wines, CSU Fresno, Davids Engineering, NOAA NWS, USGS

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Overview

Satellite indicators for sustainability monitoring / reporting:

- **Plant growth index**: Identifying trends in vegetation condition from long-term satellite data records

- **Indicators of crop water use**: Applications of satellite data and the NASA Terrestrial Observation and Prediction System to map NDVI, fractional cover, crop coefficients, and basal crop evapotranspiration
Some definitions

- **NDVI**: normalized difference vegetation index
- **Fc**: fractional cover (% of ground area covered by vegetation)
- **ET₀**: reference crop ET; grass, collected by CIMIS
- **Kcb**: crop coefficient; “fraction of reference ET”
- **ETcb**: basal ET, unstressed crop on dry soil surface
Satellite Imagery

- Landsat 5/7 satellites pass over California every 8 days; daily overpass by MODIS
- Collect data at 30m/250m resolution
- Landsat 8 scheduled for launch in 2012
- AVHRR 1-8km, 1982-2010
Plant Growth Index: Tracking Trends in Ecosystem Conditions

- Included in the 2008 Heinz Center State of the Nation’s Ecosystems Report
- Based on NDVI calculated from AVHRR GIMMS data (1982-2010) and MODIS (2000-present)
- Changes in the amount of energy captured by plants over large areas, as reported in this indicator, may signal significant changes in ecosystem functioning.
- Indicator can provide information about influence of climate, nitrogen deposition, disturbance, etc.

Significant trends in NDVI. Green values represent an increase in index values over the period for a particular 5-mile square pixel, and red values represent a relative decrease. White represents areas with no significant trend up or down.
Plant Growth Index: Summarizing Patterns by Ecosystem Type

**Ecosystem Area with Increasing or Decreasing Plant Growth Index**

**Forests**
- Index Relative to Average for 1982–2003
  - 0 to 0.02
  - 0.02 to 0.05
  - more than 0.5


Technical details: The Index value for a given year is the 1982–2003 average minus that year’s value. This was done for each ~5-mile-square pixel across the country.
Separating Response to Anthropogenic and Natural Disturbance Events

Predicted Change in ISA, 2010 to 2050

Burned Area in California, 1982-2010

Increase in ISA (%)

Value

High: 33.4673
Low: 0

Cause of Ignition

Prescribed
Natural

SERGoM, Bierwagen et al., 2010
California Agriculture

- Leads nation in cash farm receipts ($38B)
- Major domestic/int’l supplier of specialty crops
- Includes 9 of the top 10 national counties
- Half of US-grown fruits, nuts, vegetables
- >400 commodities produced

Source: Calif. Dept. Food & Agriculture
Water Resource Management Challenges

- Competing demands
- Drought impacts
- Ecosystem decline
- Impaired water bodies
- Aging water conveyance infrastructure
- Groundwater overdraft
- Climate change and population growth

Source: Calif. Water Plan 2009
Signs of the times…
Roadmap for Next Decade

- Use & re-use water more efficiently
- Reduce water-related energy consumption
- Invest in new water technology
- Improve data & analysis for decision-making

Source: DWR California Water Plan 2009
Motivation: Optimizing Irrigation Scheduling

- California Department of Water Resources and UC Berkeley surveyed growers in 1990s and found that those who utilized weather and ETo data reported an increase in yields of 8% and a decrease in applied irrigation of 13% (DWR, 1997; Parker & Zilberman, 1996)

- Use of ET data in irrigation scheduling increasing but still not widespread

Table 5. Method Used by California Farmers to Decide When to Irrigate, 2003

<table>
<thead>
<tr>
<th>Method</th>
<th>Percent of Farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition of crop</td>
<td>71%</td>
</tr>
<tr>
<td>Feel of soil</td>
<td>56%</td>
</tr>
<tr>
<td>Personal calendar schedule</td>
<td>27%</td>
</tr>
<tr>
<td>Scheduled by water delivery organization</td>
<td>11%</td>
</tr>
<tr>
<td>Soil moisture sensing device</td>
<td>10%</td>
</tr>
<tr>
<td>Daily ET reports</td>
<td>8%</td>
</tr>
<tr>
<td>Other</td>
<td>6%</td>
</tr>
<tr>
<td>Commercial or government scheduling service</td>
<td>5%</td>
</tr>
<tr>
<td>When neighbors irrigate</td>
<td>4%</td>
</tr>
<tr>
<td>Plant moisture sensing device</td>
<td>3%</td>
</tr>
<tr>
<td>Computer simulation model</td>
<td>1%</td>
</tr>
</tbody>
</table>

Note: Many farmers use more than one method when deciding when to irrigate, thus the total of all methods exceeds 100%.
Source: USDA 2003
California Irrigation Management Information System (CIMIS)

Welcome

CIMIS Overview

The California Irrigation Management Information System (CIMIS) is a program in the Office of Water Use Efficiency (OOWUE), California Department of Water Resources (DWR), that manages a network of over 120 automated weather stations in the state of California. CIMIS was developed in 1982 by the California Department of Water Resources and the University of California at Davis to assist California's irrigators manage their water resources efficiently. Efficient use of water resources benefits California by saving water, energy, and money (more...)

CIMIS Data Uses

Since the beginning of the CIMIS weather station network in 1982, the primary purpose of CIMIS was to make available to the public, free of charge, information useful in estimating crop water use for irrigation scheduling. Although irrigation scheduling continues to be the main use of CIMIS, the uses have been constantly expanding over the years. At present, there are approximately 8,000 registered CIMIS users from diverse backgrounds accessing the CIMIS computer directly. It is estimated requests for CIMIS information on the WWW average about 70,000 per year. There are also many secondary suppliers of CIMIS weather data, such as other web sites, radio, newspapers, consultants, and local water agencies. (more...)

ET Overview

Evapotranspiration (ET) is the loss of water to the atmosphere by the combined processes of evaporation (from soil and plant surfaces) and

http://www.cimis.water.ca.gov/
Mapping Crop Coefficients and Indicators of Crop Water Use from Satellite Data

**USDA studies provide basis for linking NDVI to fractional cover.**

Trout et al., 2008; Johnson & Trout, in review

Recent studies by Allen & Pereira (2009) and others provide basis for linking fractional cover to $K_{cb}$ for a range of crops. Additional studies ongoing in collaboration with CSU Fresno and UC West Side Research & Extension Center

Also see Bryla et al., 2010; Grattan et al., 1998; Hanson & May, 2006; Lopez-Urrea et al., 2009
Approach

- Builds on the California Irrigation Management Information System (CIMIS)
  - Operating since 1982
  - Currently 139 stations
  - Recent addition of 2km statewide ET$_0$ grids

- Standard approach for incorporating weather information into irrigation management practices

$$\text{ET}_{cb} = \text{ET}_0 \times K_{cb}$$

Integration of satellite and surface observation networks

Spatial CIMIS ET$_0$
March 31, 2011
Coverage includes ~15 million acres of farmland in the Central Valley and coastal agricultural valleys.
Normalized Difference Vegetation Index (NDVI); measure of vegetation density
TOPS Satellite Irrigation Management Support

Go to: huron, ca

Select Date: 2011-08-13

Overlays:
- ETcb 2011-08-05
- Rcb 2011-08-05 to 2011-08-12
- NDVI gapped 2011-08-05 to 2011-08-12
- NDVI 2010-06-10 to 2010-06-17

Base Layer:
- Google Satellite
- Google Terrain
- Google Streets

Disclaimer: This data is for research and evaluation purposes only.

NASA Official: Ramakrishna R. Nemani Curator: Forrest Melton

Waiting for ecocast.arc.nasa.gov...
Users can query maps for current values.
Users can also view and download data for the current year-to-date or past years.
Integration of data from CIMIS also allows automated calculation of ETcb on a daily basis.
ETcb maps can also be queried, and data can be downloaded directly into Excel or other software tools.
Summarizing Patterns at Regional Scales

Central Valley Total Daily ETcb, 2011

- 2011, Central Valley, Total ETcb (AF)
- 2011, Tulare Total ETcb (AF)
- 2011, SJ Valley, Total ETcb (AF)
- 2011, Sacramento, Total ETcb (AF)
Summarizing Patterns at Regional Scales

Central Valley Total Daily ETcb, 2011

- 2010, Central Valley, Total ETcb (AF)
- 2011, Central Valley, Total ETcb (AF)
TOPS SIMS Applications

Field scale:
- Reference for irrigation management support
- Optimization of irrigation, especially during fertilizer applications
- Calculation of seasonal ETcb for reporting of sustainability metrics for on-farm water use (applied irrigation as a % of ETcb)?

Spatial & temporal aggregation:
- What was the potential crop transpiration for the San Joaquin Valley last week / month / year?
- How did crop water use for the Central Valley last year compare with historical norm?
- What is the anticipated irrigation demand for an irrigation district next week?
Strategies for Verifying Satellite Estimates of ETcb

**Objective:** Understand limitations and improve utility for irrigation management

1) Compare TOPS SIMS ETcb against other satellite-driven ET models and Kc values against FAO guidelines

2) Compare TOPS SIMS ETcb against surface measurements of ET (surface renewal stations, eddy covariance)

3) Use of sensor networks to monitor soil moisture and quantify irrigation application rates
Satellite ET Mapping Comparison:
TOPS SIMS (ETcb) vs SEBAL (ETa)

Almond

Grape

Alfalfa

Tomato

Equations for each crop:

- **Almond**:
  \[ y = 0.9709x - 0.0462 \]
  \[ R^2 = 0.9051 \]
  \[ MAE = 0.566 \]
  \[ MBE = -0.190 \]

- **Grape**:
  \[ y = 1.3043x - 0.3319 \]
  \[ R^2 = 0.9386 \]
  \[ MAE = 0.845 \]
  \[ MBE = 0.782 \]

- **Alfalfa**:
  \[ y = 0.8014x + 0.8106 \]
  \[ R^2 = 0.9343 \]
  \[ MAE = 0.448 \]
  \[ MBE = -0.132 \]

- **Tomato**:
  \[ y = 1.0036x - 0.2776 \]
  \[ R^2 = 0.9268 \]
  \[ MAE = 0.398 \]
  \[ MBE = -0.255 \]
Crop coefficients: SIMS vs. FAO guidelines

Cotton

Processing Tomato

Wheat

Lettuce
# Sensor Network Installations

<table>
<thead>
<tr>
<th>Crop Type</th>
<th>Crop</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain</td>
<td>Corn*</td>
<td>CSU Fresno</td>
</tr>
<tr>
<td>Grain</td>
<td>Wheat</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Garlic</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Lettuce*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Broccoli</td>
<td>Salinas Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Cauliflower</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Tomato(2)*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Cotton (drip)*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Vine</td>
<td>Melon</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Vine</td>
<td>Wine grapes</td>
<td>Salinas Valley</td>
</tr>
<tr>
<td>Vine</td>
<td>Raisins*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Tree</td>
<td>Peach*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Tree</td>
<td>Almond*</td>
<td>San Joaquin Valley</td>
</tr>
</tbody>
</table>

*Surface renewal instrumentation.
Field Instrumentation

**Volumetric Soil Water Content**
Decagon 10HS / EC-5 Probe
3-4 per mote, 28 per field

**Soil Water Potential**
Irrometer Watermark 200SS-V or Decagon MPS-1
1-2 per mote, 8-16 per field

Also tested
Delta-T ML2 ADR Probe

**Deep Drainage**
Decagon Passive Capillary Lysimeter
1-2 per field

**Surface Renewal**
instrumentation also installed at 7 sites

**Irrigation Volume**
Badger Flow Meters + RTR
2 per field

Objective: Tracking of irrigation and relative changes in soil water balance over the growing season to support evaluation of ETcb estimates
Summary

- Satellite observations offer promise for supporting development of sustainability indicators with spatially continuous, consistent observations.

- Applications for tracking indicators of ecosystem change and crop water use among many others.

- Value of satellite data increased when integrated with observations from surface networks.
Use of a crop stress coefficient of 0.85 after July 1 reduces MAE to 0.38 mm / day
Indicators of Soil Water Balance and Deficit Irrigation from the Soil Moisture Sensor Network

Cotton: Cumulative ETcb vs Precip + Irrigation

- Cumulative ETcb (mm)
- Cumulative Precip + Irrigation from flow meters (mm)
- Soil Water Potential (kPa)
- Soil Water Content (mm)
- Water Bal. (P + I - D - ETcb)
Future Work

• Integration of data from the International Space Station Agricultural Camera (ISSAC) as alternate to Landsat 5 for 2012

• Outreach and education activities in partnership with Western Growers, UCCE, USDA, and local water districts

• Proposal pending with NASA for continued work on TOPS-SIMS focused on transfer to CDWR as the long-term operational partner

• Proposal pending with NASA for work on fallowed area mapping with USDA, USGS, and CDWR to provide early assessments for drought impact monitoring

• CDFA funding received to conduct side-by-side irrigation trials to quantify benefits of use of Kcb / ETcb data in terms of reduced inputs (water, fertilizer, energy) and / or increased yield; integrate TOPS-SIMS with UCCE irrigation calculator

• CSU ARI funding received to: 1) continue work on integration of TOPS-SIMS and the CSU Fresno Wateright irrigation scheduling tool; and 2) continue weighing lysimeter experiments
SIMS vs. Surface Renewal

- Measures components of surface energy balance to estimate ET (Snyder et al., 1997)
- Deployed in almonds, peaches, corn, raisin grapes, cotton, tomatoes, and lettuce in 2011

Evapotranspiration, Cotton, Five Points, CA

- **FAO**
- **TOPS-SIMS**
- **Surface Renewal**