SATELLITE IRRIGATION MANAGEMENT SUPPORT WITH THE TERRESTRIAL OBSERVATION AND PREDICTION SYSTEM

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ABSTRACT

In California and other regions vulnerable to water shortages, new technologies are needed to support agricultural producers and water managers in maximizing the benefits of available water supplies. The Satellite Irrigation Management Support (SIMS) project combines NASA's Terrestrial Observation and Prediction System (TOPS) with Landsat and MODIS imagery to map crop evapotranspiration (ET) and develop information products to support irrigation management and other water use decisions. The primary focus of the effort is to develop the computing and data processing systems required to support the use of satellite and weather data for rapid assessment of current crop conditions over large areas, and generate product formats that are convenient for agricultural producers and other end users. Supporting datasets include reference ET grids from the California Irrigation Management Information System (CIMIS), and USDA's Cropland Data Layer. SIMS map products are generated at 30 meter resolution on a daily basis over appx. 60,000 sq. km. of California farmland. Wireless sensor networks and surface renewal instrumentation have been deployed on several commercial farms to monitor ET and soil moisture parameters to facilitate evaluation of SIMS products. To support retrospective analyses, the project is utilizing the NASA Earth Exchange to process the complete Landsat archive for California from 2003 to present.

Keywords: Landsat, crop evapotranspiration, water management

INTRODUCTION

In California and much of the western U.S., municipal, agricultural, and environmental demands increasingly compete for limited water supplies. Continued environmental and regulatory constraints on water supplies in California are anticipated as the effects of population growth, climate change, and declining water conveyance infrastructure continue to evolve. To address these challenges, there is a need to provide new sources of information on crop water use to growers, to enhance their ability to efficiently manage available irrigation water supplies.

Estimates of crop evapotranspiration (ETc) can support efficient irrigation management. ETc represents the combined processes of crop transpiration (productive water use) and evaporation from the soil surface (generally considered non-productive). A common approach to irrigation scheduling is to calculate ETc through a crop coefficient, a dimensionless value representing typical ETc for an unstressed canopy relative to a reference ET (ETo) value that captures the effect of weather on evaporative demand. The crop coefficient (Kc) integrates the effects of crop transpiration and soil evaporation. The *basal* crop coefficient (Kcb) primarily represents transpiration, plus a minor diffuse evaporation component (evaporation from a dry soil surface). Kcb can be used to calculate *basal* ETc (ETcb) as a measure of productive water use, or biological demand of well-watered crops. Growers seeking to avoid water stress may choose to fully replace water consumption, while those practicing deficit irrigation may elect to apply a lesser amount. To facilitate the use of crop coefficients, weather networks throughout much of the western U.S. measure and archive ETo. One such network is the California Irrigation Management Information System (CIMIS), which is operated by the California Department of Water Resources and records hourly and daily ETo values from a well-watered grass surface at numerous locations statewide (Temesgen et al., 2005).

Guideline Kc(b) values are available for several crops and growth stages (initial, development, mid-season, late-season), as from the FAO-56 procedures of Allen et al. (1998). The initial stage is associated with crop establishment, generally running from planting date to about 10% ground cover. During the ensuing development stage, the crop grows to its maximum cover and Kc. The mid-season stage is a sustained period at maximum Kc, followed by a late-season stage that, depending on crop type, may continue at maximum Kc or may decline due to crop senescence. It should be noted that FAO-56 and other tabulations, however valuable, are intended as a general guide. Actual crop development and water use in a field depends on planting configuration and cultivation practices as well as climatic conditions, thus local observations of plant stage development are recommended where possible.

Canopy light interception is a main driver of ETc(b) and hence Kc(b). Fractional green canopy cover (Fc) is a readily measured property that is a good indicator of light interception. As such, accurate and efficient estimation of actual Fc might allow improved scheduling and allocation of irrigation water (Baush, 1995; Hunsaker et al., 2005). Several studies have used weighing lysimeters or Bowen ratio instrumentation to relate Fc (or the closely related metric, fractional ground shaded area) to crop water use in California (e.g., Grattan et al., 1998; Ayars et al., 2003; Williams and Ayars, 2005; Bryla et al., 2010). Previous studies have shown that various spectral vegetation indices, calculated from visible and near-infrared (NIR) reflectance data, are linearly related to canopy light interception (e.g., Asrar et al., 1984; Goward and Huemmrich, 1992; Johnson and Scholasch, 2005). Research in California's San Joaquin Valley shows a strong relationship between Landsat normalized difference vegetation index (NDVI) and Fc for multiple horticultural crops (Trout et al., 2008). As such, it appears that indices such as NDVI can potentially track canopy development and light interception for particular crops in near-real-time.

An optical remote sensing approach, implemented in regions with an available ETo network, potentially enables timely estimation of crop water use for irrigation scheduling and resource monitoring (Calera-Belmonte, 2003; Hornbuckle et al., 2009; Johnson et al., 2010). The prototype capability described here combines satellite imagery with CIMIS ETo data to track crop development and productive water use across ~60,000 km^2 of California agricultural lands.

SIMS OVERVIEW

The Satellite Irrigation Management Support (SIMS) system uses Landsat and MODIS data as a basis for mapping crop coefficients and crop evapotranspiration, and is developing information products and tools to support resource managers and growers with water management decisions. The prototype utilizes the Terrestrial Observation and Prediction System (TOPS), a NASA modeling framework developed to monitor and forecast environmental conditions (Nemani et al., 2009), to integrate satellite and meteorological observations. The primary focus of the effort is to extend TOPS to provide the computing and data processing systems required to support the use of satellite data for timely assessment of crop conditions, and to provide data and information in formats compatible with end-users.

SIMS ingests Landsat-5 TM, Landsat-7 ETM+, and MODIS satellite imagery for California's Central Valley and other agricultural regions. Each Landsat scene is atmospherically corrected using software developed under the Landsat Ecosystem Disturbance Adaptive Processing System (Masek et al., 2006), which incorporates the 6S atmospheric radiative transfer modeling approach of Vermote et al. (2002) as included in the standard MODIS data processing chain. The scenes are then converted to NDVI and mosaicked, and transformed to Fc via prior empirical relationships (Trout and Johnson, 2008). Landsat provides the spatial resolution required to produce information at individual field scale, while the daily temporal resolution of MODIS provides gap-filling capability to ensure data availability. Fc is then converted to Kcb using relationships developed through past weighing lysimeter experiments and following

FAO methods. Finally, ETcb is retrieved by combining the Kcb grids with ETo retrieved from the standard Spatial CIMIS product, which maps the entire state at 2 km resolution on a daily basis (Hart et al., 2009).

SIMS utilizes the OpenLayers JavaScript library to display map data in web browsers (Figures 1,2). To enhance spatial context and facilitate searches by users, the interface utilizes the Google™Maps API to combine SIMS overlays with Google-maps, Google-terrain, Google-satellite base layers. NDVI, Fc, and Kc overlays are updated on nominal 8-day intervals, and ETcb is updated daily. Data are also accessible via an OPeNDAP web service, and in addition to viewing maps at native 30 m resolution, users can display time-series plots and download time-series data for any variable from specified points or polygons (Figure 2). The project is utilizing the NASA Earth Exchange (Nemani et al., 2011) on compute resources in the NASA Advanced Supercomputing facility to process the complete Landsat archive for California from 2003 to present.

Integration of data from the NOAA NWS Forecasted Reference ET (FRET) system will allow forecasting of irrigation demand with lead times of up to 1 week, supporting applications for both irrigation scheduling and water delivery planning.

MODEL COMPARISON

Model comparison was performed using Landsat-5 imagery of the San Joaquin Valley (path 42, row 35) collected monthly during the main growing season (Apr-Nov) of 2009. Reflectance-based Kcb estimates, obtained via SIMS transformation equations, were compared to Kc calculated as with the ratio of potential ET (ETp) to CIMIS-derived ETo. The ETp estimates were in-turn derived from spatially distributed meteorological data using the ASCE standardized Penman-Monteith grass reference equation, constrained by satellite-estimated leaf area index and minimal stomatal resistance. Kcb and Kc should, in theory, be equivalent except in cases where evaporation from soil is occurring, in which case Kc will exceed Kcb. The occurrence of such evaporation is unknown to this analysis, hence this phenomenon is here considered a noise source. Observed r^2 ranged from 0.87-0.94 across all fields analyzed, with mean average error between datasets ≤ 0.1 for most crops (Table 1).

Reflectance-based ETcb results were compared to "actual" evapotranspiration (ETa) data generated by the Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen et al., 1998). SEBAL combined spectral radiances in Landsat optical and thermal bands with CIMIS meteorological data to derive ETa as a surface energy budget residual by applying radiative, aerodynamic and energy balance physics in 25 computational steps. As above, ETa would be expected to exceed ETcb when soil evaporation is occurring. Conversely, ETa should be less than ETcb for water-stressed vegetation due to stomatal regulation. Reasonable agreement was observed for the full dataset, with mean absolute error (MAE) between the two approaches <1 mm/d and r^2 0.78-0.90 for most of the crop types examined. As per expectation, stronger correspondence was found for fields deemed by SEBAL to contain unstressed plants (observed ET at-or-near potential) during satellite overpass, with MAE reductions averaging about 30 percent to ~0.5 mm/d and r^2 >0.90 for most crops (Table 1).

Table 1. Comparison of reflectance-based Kcb and ETcb with Penman-Monteith Kc and surface energy balance ETa estimates for several major San Joaquin Valley crops. The ET comparison applies to fields that were unstressed at time of satellite overpass.

	Kcb			**ETcb**		
crop	r^2	**MAE (unitless)**	**n**	r^2	**MAE (mm/d)**	**n**
almond	0.87	0.09	119	0.91	0.57	94
oranges	0.85	0.08	126	0.91	0.34	62
grape	0.87	0.16	120	0.94	0.85	53
cotton	0.90	0.10	81	0.91	0.52	51
corn	0.92	0.20	44	0.59	1.56	32
alfalfa	0.88	0.08	87	0.93	0.45	60
tomato	0.94	0.07	51	0.93	0.40	38

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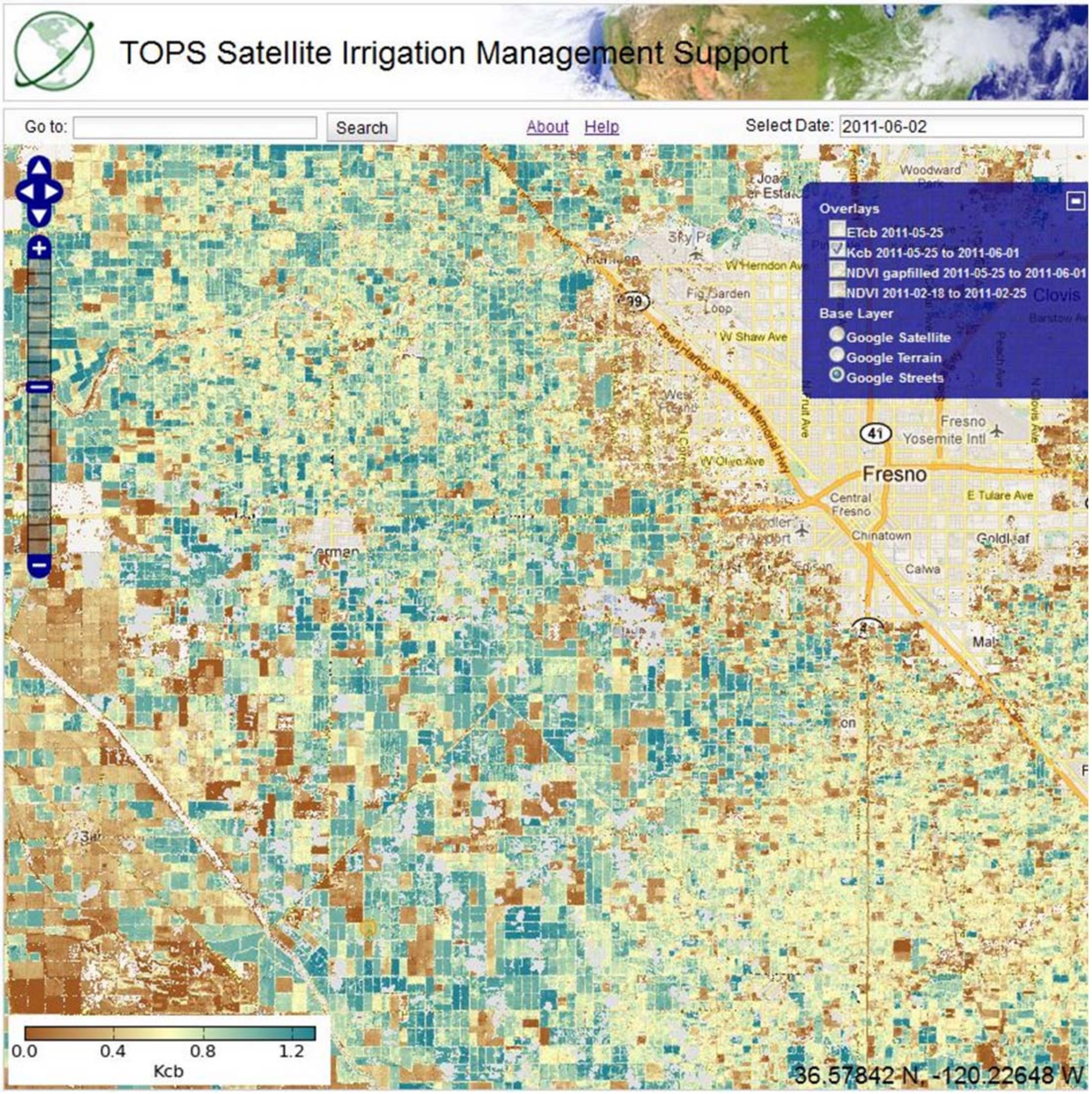

Figure 1. SIMS screenshot showing crop coefficient overlay near Fresno, Calif. on 2-Jun-2011. Base layer is Google-streets.

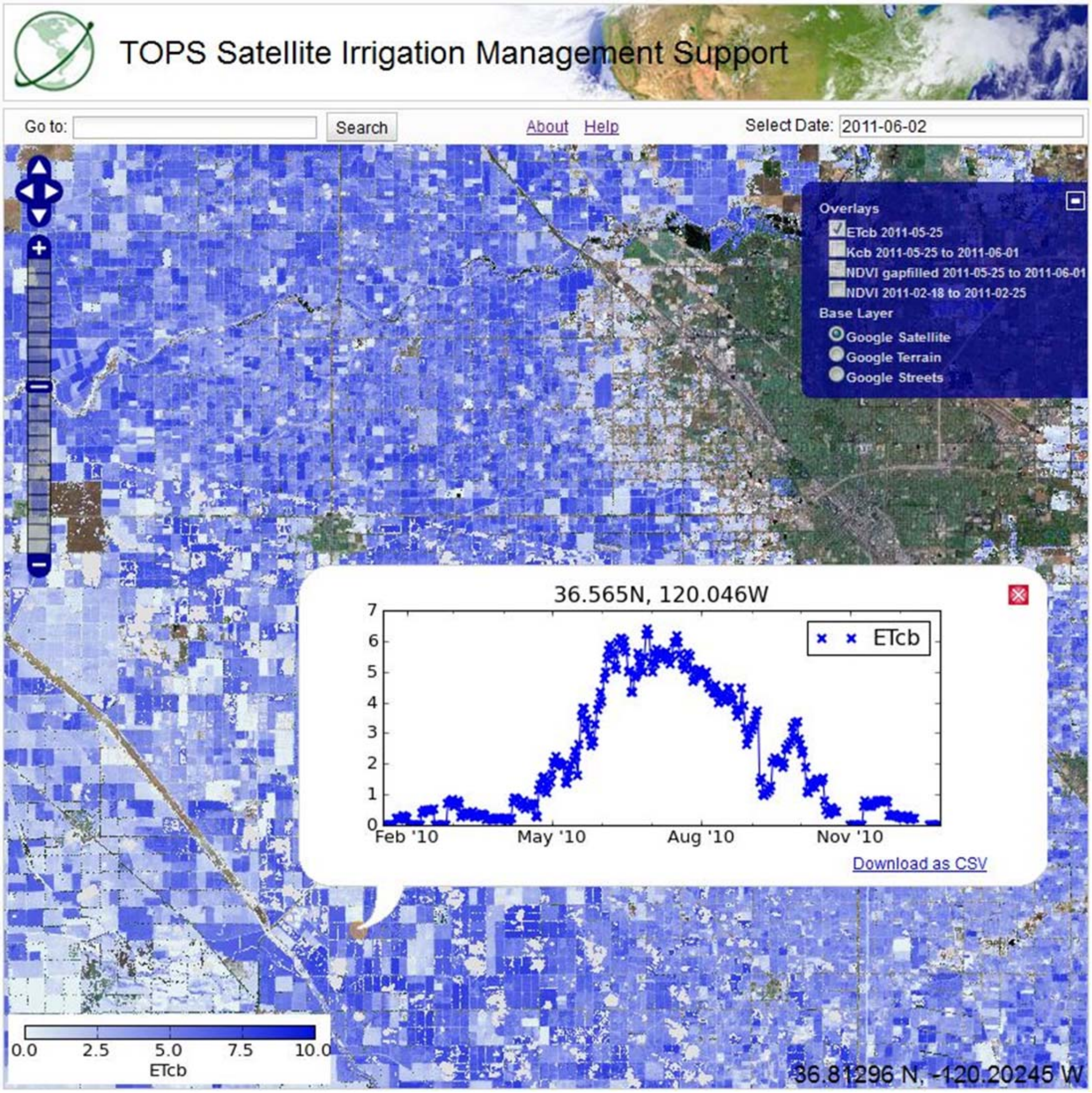

Figure 2. SIMS screenshot showing basal crop evapotranspiration (mm/d) overlay near Fresno, Calif. (same area as Fig. 1) on 2-Jun-2011, with downloadable 2010 time-series shown for selected active point. Base layer is Google-satellite.