Proceedings of the 26th Annual Central Plains Irrigation Conference, Burlington, CO., Feb 25-26, 2014
Available from CPIA, 760 N. Thompson, Colby, KS

A WEB-BASED TOOL THAT COMBINES SATELLITE AND WEATHER STATION OBSERVATIONS TO SUPPORT IRRIGATION SCHEDULING[1]

TOM TROUT[1], FORREST MELTON[2], LEE JOHNSON[2]
[1]USDA AGRICULTURAL RESEARCH SERVICE, FT.COLLINS, CO
[2]CALIFORNIA STATE UNIVERSITY, MONTEREY BAY, CA & NASA AMES RESEARCH CENTER

ABSTRACT

The Satellite Irrigation Management Support (SIMS) project combines NASA's Terrestrial Observation and Prediction System (TOPS), Landsat and MODIS satellite imagery, and reference evapotranspiration from surface weather station networks to map daily crop irrigation demand in California in near real time. TOPS-SIMS currently maps crop fractional cover, basal crop coefficients, and basal crop evapotranspiration. Map products are generated at 30 meter resolution on a daily basis over approximately 15 million acres of California farmland. TOPS-SIMS is a fully operational prototype, and a publicly available beta-version of the web interface is being pilot tested by farmers, irrigation consultants, and water managers in California. Data products are distributed via dynamic web services, which support both visual mapping and time-series queries, to allow users to obtain information on spatial and temporal patterns in crop canopy development and water requirements. This system can be extended to other areas that have adequate ET weather networks.

INTRODUCTION

Proper scheduling of irrigation applications is critical to efficient water use. The most common method to estimate crop water use and schedule irrigation application is to use weather data to estimate the water use or evapotranspiration of a reference crop, and then apply a crop coefficient to convert the reference evapotranspiration (ET_O) to the evapotranspiration of a crop in a field (ET_c). This method is often referred to as the FAO-56 method (Allen et al., 1998).

Satellite imagery can be used to help estimate crop water use. One approach is to use imagery to estimate vegetation indices and surface temperatures and estimate ET_c using energy balance techniques (e.g., Bastiaanssen et al., 1998; Anderson et al., 2004; Allen et al., 2007). Because this method estimates ET only at the time of the image, which is infrequent, it must be combined with more frequent weather station data to estimate daily or weekly ET. Thermal image resolution tends to be low, making it difficult to apply to small fields (<40 ac). Image analysis is complex such that the process is difficult to automate and the time lag between image collection and results is currently too long for irrigation scheduling decisions.

---

[1] Adapted from Melton etal. 2012. Satellite Irrigation Management Support with the Terrestrial Observation and Prediction System: A Framework for Integration of Satellite and Surface Observations to Support Improvements in Agricultural Water Resource Management. IEEE J. of Selected Topics in Applied Earth Observations and Remote Sensing. 5(6):

An alternative approach is to use only vegetation indices from satellite images to estimate crop ground cover. Vegetation indices are related to sunlight interception and thus potential crop water transpiration, and can be used to estimate crop coefficients (e.g., Neale et al., 1989; Neale et al., 2003; Hunsaker et al., 2005; Rafn et al., 2008). When combined with reference ET values from ground-based weather stations, they enable estimates of crop water use. Satellite data needed to calculate vegetation indices are available frequently and at relatively high resolution, and vegetation indices are easy to calculate (and thus automate) and fairly easy to interpolate between measurements. This method estimates the transpiration water use of a non-stressed crop, referred to as basal ET (ET_{cb}), and thus must be adjusted upward for soil evaporation and downward for crops that are deficit irrigated.

In the western U.S., agricultural weather networks such as the Colorado Agricultural Meteorological Network (CoAgMet), the High Plains Regional Climate Center Automated Weather Data Network (HPRCC-AWDN), the Kansas Mesonet, and California Irrigation Management Information System (CIMIS), provide WEB-based hourly information on weather conditions and ET_O. Within California, CIMIS currently operates 140 stations across the state and provides data to growers and irrigation consultants on ET_O and weather conditions. CIMIS currently has about 40,000 users. However, the most recent farm and ranch irrigation survey conducted by the USDA indicated that only 12% of growers in California utilize reports on daily crop-water evapotranspiration in scheduling irrigation (USDA, 2008). One constraint to practical use of reference ET scheduling is the difficulty to determine appropriate crop coefficients. Development of an automated system for mapping crop coefficients and delivery of data to users would enhance the use of ET data in irrigation management.

Integration of these data sources into current management practices and operational models presents a number of challenges, especially for applications such as irrigation scheduling that require information in near real-time. In addition to typical issues associated with processing large volumes of data from heterogeneous sources, satellite data must be atmospherically corrected to minimize artificial scene-to-scene variability and data gaps due to cloud cover or instrument failure must be filled.

The NASA Terrestrial Observation and Prediction System (TOPS, Nemani et al., 2009) provides a modeling and computing framework for integrating satellite and surface observations in near real-time to address many of these challenges. In the following sections, we describe an application of the TOPS framework to develop a system for near real-time mapping of crop canopy conditions and associated crop irrigation requirements at the resolution of individual fields. To support continued improvements in management of agricultural water supplies, the data processing system is designed to provide growers and water managers with frequent, accurate, and easily available information that includes key indicators of crop canopy development and crop water use requirements.

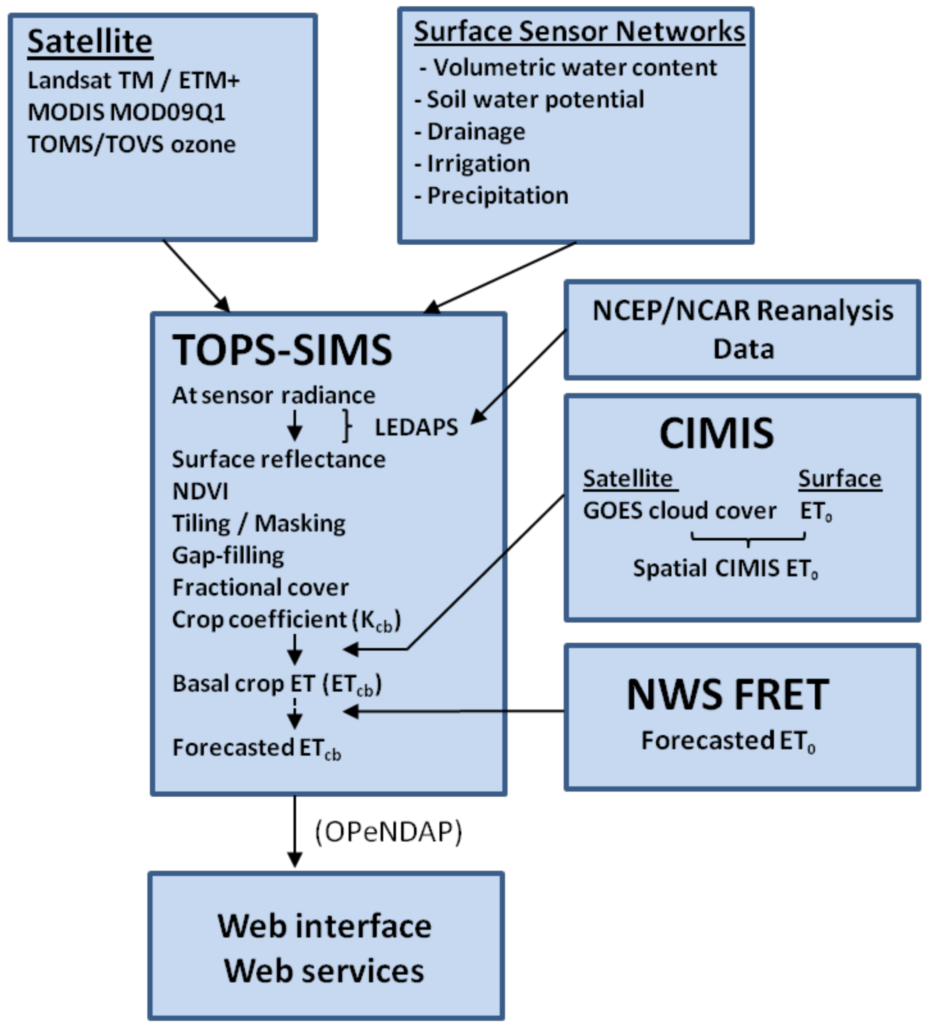


Figure 1: Overview of the TOPS-SIMS architecture with primary data inputs and outputs

A FRAMEWORK FOR SATELLITE IRRIGATION MANAGEMENT SUPPORT

The TOPS Satellite Irrigation Management Support (TOPS-SIMS) framework integrates satellite observations from Landsat and MODIS with meteorological data from ground-based reference ET information and ancillary data on crop type and site specific conditions (Figure 1). The system employs a modular architecture to facilitate support for a wide range of models and data. The initial implementation provides a capability for mapping of fractional cover (F_c), associated basal crop coefficients (K_{cb}), and basal evapotranspiration (ET_{cb}) over 15 million acres of farmland in California's Central Valley. F_c and K_{cb} are mapped every eight days, and ET_{cb} maps are produced on a daily basis at spatial resolutions that are useful for irrigation management at the field level (100 ft. or ¼ acre). Automated atmospheric correction and gap-filling algorithms are optimized for agricultural areas to provide a robust and reliable data stream. Information from TOPS-SIMS is distributed to water managers and agricultural producers via a browser-based irrigation management decision support system. Users can combine the supplied K_{cb} or ET_{cb} with formal or intuitive estimates of soil evaporation and crop water stress levels to derive total water consumption over the recent period at the field level. By accounting for the irrigation application rate, distribution uniformity, and any corrections for water replacement targets (e.g., intentional deficit irrigation or leaching requirement), users can translate TOPS-SIMS output into an irrigation management strategy.

TOP-SIMS Information Collection and Analysis

TOPS-SIMS ingests Landsat-7 , Landsat-8, and MODIS satellite imagery for California's Central Valley and other agricultural regions. It also uses Landsat 5 or other previous satellite imagery to generate historical maps of vegetation indices, K_{cb}, and ET_{cb}. Landsat provides the spatial resolution necessary to produce information at the scale of individual fields. The daily temporal resolution of MODIS provides a gap-filling capability to ensure data availability. At present, strategies for full automation have only been developed for mapping of basal crop coefficients (K_{cb}) from surface reflectance, and thus the initial suite of algorithms implemented in the TOPS-SIMS framework rely on this approach. In the future, it may be possible to implement additional models, including energy balance models and models for downscaling of soil moisture estimates from satellite missions such as the Soil Moisture Active Passive (SMAP) mission.

Each Landsat scene is atmospherically corrected using software developed under the LEDAPS project (Masek et al., 2006). Landsat 7 and 8 data are tiled onto a common grid to form an 8-day composite to facilitate use of overlapping portions of each scene to increase the frequency of observations and reduce data gaps due to cloud cover. This compositing approach also reduces the effects of the Landsat 7 scan line correction error, as only the central portion of the Landsat 7 scenes are used, where the gaps are narrower.

The next step is to calculate the normalized difference vegetation index (NDVI; Tucker, 1979) from the composited scenes. NDVI is an index calculated from the red and near infrared wavelengths and provides a measure of photosynthetically active vegetation. At this stage, a suite of gap-filling algorithms are employed to ensure spatially continuous data over agricultural regions.

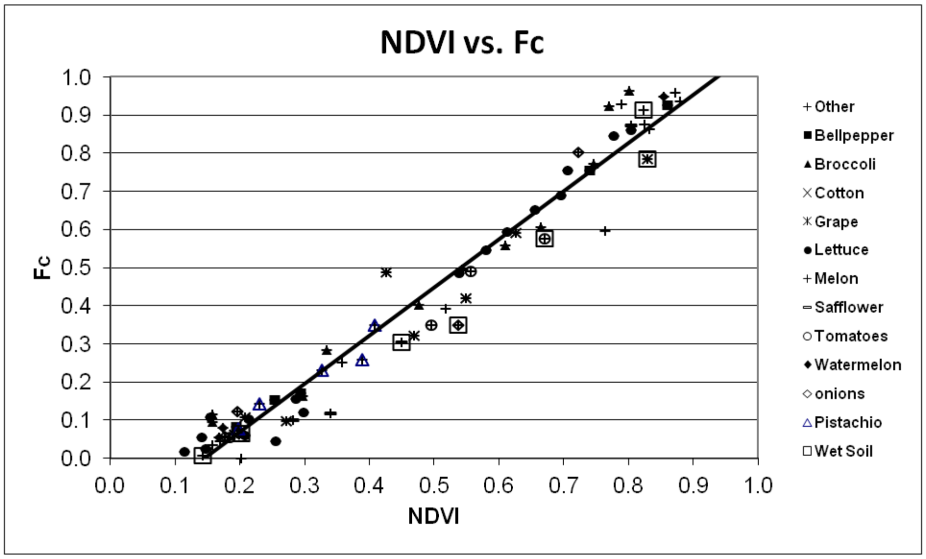
NDVI data is transformed to canopy ground cover, $F_{c,}$ via empirical relationships developed by USDA and NASA. Johnson and Trout (2012) and Trout et al. (2008) collected field measurements of F_c across multiple crop types in the California Central Valley. These data were compared with satellite observations collected on the same day, and revealed a robust relationship between NDVI and F_c (Figure 2a). This approach is also consistent with other previous studies showing 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).

To convert F_c to the basal crop coefficient, K_{cb}, TOPS-SIMS uses different approaches for retrospective versus near real-time mapping of K_{cb}. For retrospective mapping of annual crops or for fields where information on the current crop type is available, F_c is converted to K_{cb} based on a physical description of the crop canopy (Allen and Pereira, 2009). For real-time mapping, while crop type for perennial fields (vineyards, orchards) can be reasonably determined from prior-year maps, the spatial distribution of annual crops is generally unknown within-season. A generalized F_c-K_{cb} relationship representing a best-fit to crop specific relationships (Figure 2b) is thus applied for near real-time mapping of fields deemed to contain annual crops. Use of this approach introduces K_{cb} mean estimation uncertainty ranging from 3-14% across the major crop categories (vegetables, roots/tubers, legumes, fibers, oils, cereals). For perennial crops, results from multi-year studies recently performed on large weighing lysimeters at the University of California Kearney Agricultural Center are used for F_c-K_{cb} conversion (Ayars et al., 2003; Williams and Ayars, 2005). Both studies reported a strong relationship between mid-day canopy light interception, which is closely related to F_c, and the crop coefficient.

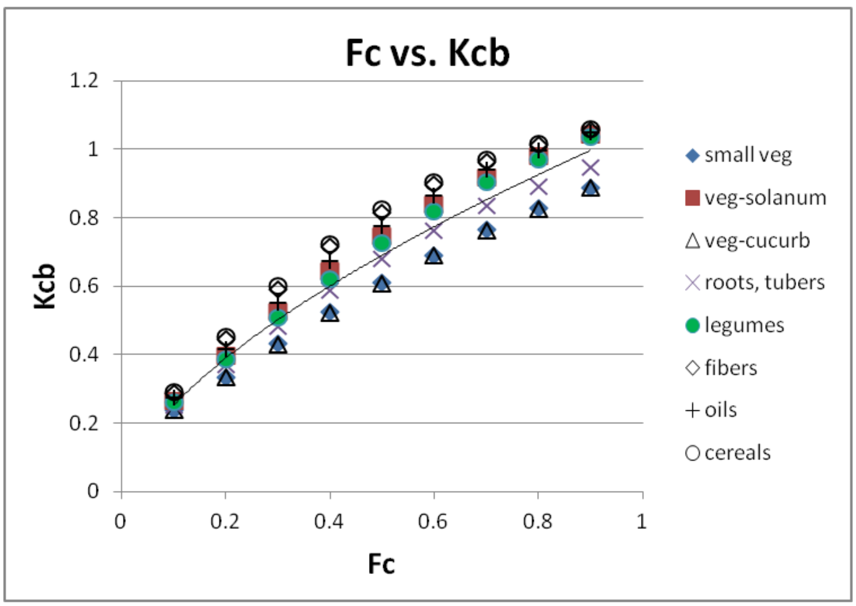
Finally, the basal crop evapotranspiration, ET_{cb}, for both annuals and perennials is calculated as the product of K_{cb} and ET_O. For California, ET_O is retrieved by TOPS-SIMS via FTP (file transfer protocol) from the standard Spatial CIMIS 2 km daily statewide ET_O grids (CIMIS, 2014).

Data Distribution via Web Interface and Web Services

While TOPS-SIMS simplifies the process of integrating satellite and surface observations to map K_{cb} and ET_{cb} values, distribution of data and information via intuitive, easy to use interfaces is critical to facilitating use of the information by water managers and agricultural producers. A web-based user interface providing access to visualizations of TOPS-SIMS information eliminates the barriers to data access, as only a web browser is needed to view and query the information, and no knowledge of specialized data formats is necessary. TOPS-SIMS overlays a selection of open-source and commercial base map layers, including maps of streets, land use, and aerial imagery. NDVI, F_c, and K_{cb} overlays are updated on nominal 8-day intervals, and ET_{cb} is updated daily. These overlays can be requested for any date, and annual traces for the parameters for any location (100 ft pixel) can be viewed graphically or downloaded to compare current to past conditions. In addition to providing views of TOPS-SIMS data at the native 100 ft resolution, the web interface also allows users to retrieve quantitative information from any variable by specifying a point or polygon and requesting the most current values or a time-series summary (Figure 3).

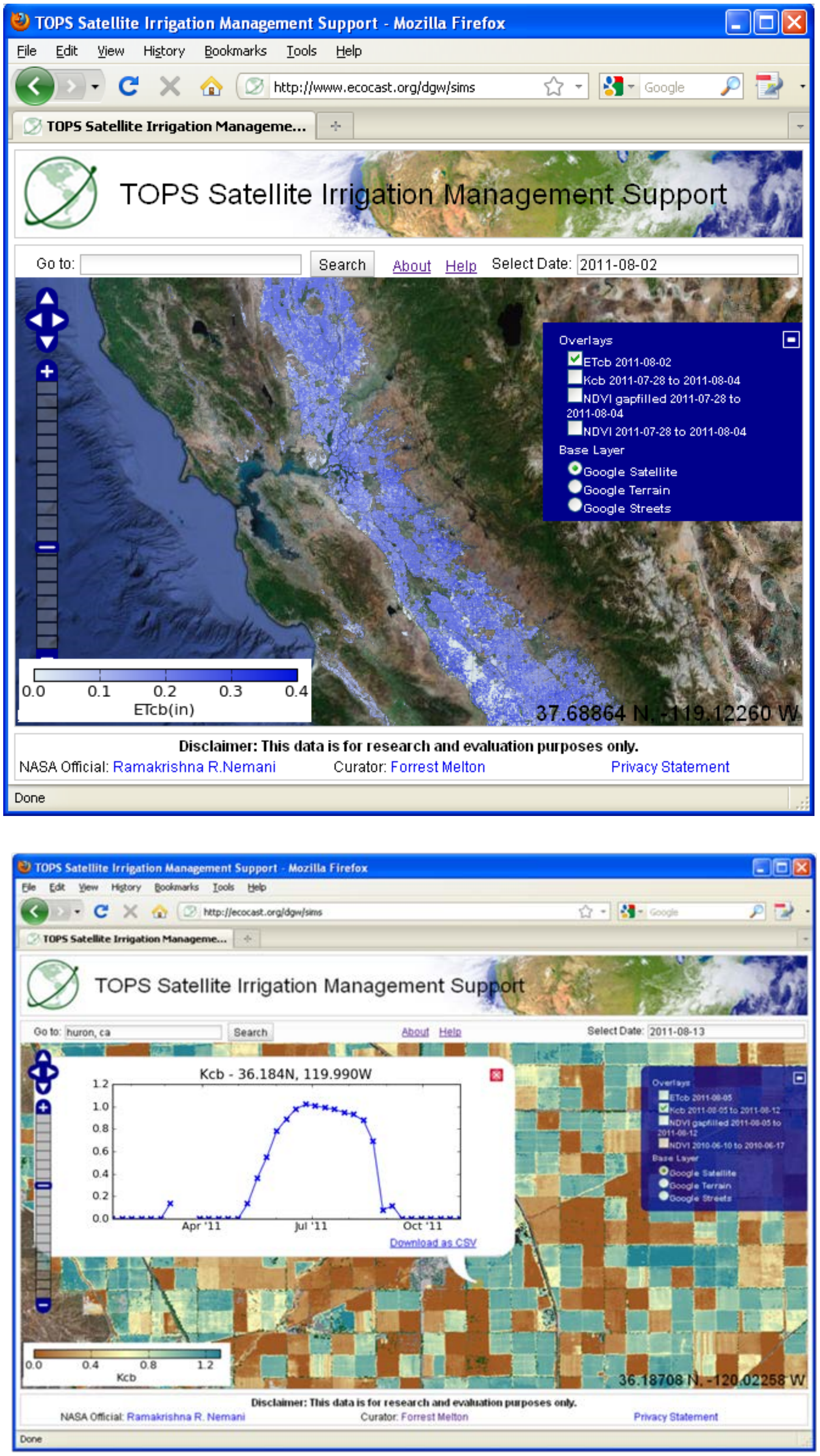


(a)



(b)

Figure 2: Past studies conducted by USDA in collaboration with NASA (Trout et al., 2008; Johnson and Trout, 2012) provide the basis for linking NDVI to fractional cover using relationships that are robust across different crop types and canopy architectures (a). Use of a generalized equation (after methods of Allen and Pereira, 2009) for converting fractional cover to FAO crop coefficients provides a robust approach for mapping K_{cb} values (b). When the crop type at a particular location is specified or can be identified with confidence, crop specific equations may also be applied.



(a)

(b)

Figure 3: The TOPS-SIMS web interface provides visualization and data access, including support for geographic queries and selection of data for visualization by date and parameter. The map in (a) shows ET_{cb} (mm/day) for ~15 million acres of farmland in the Central and Salinas Valleys on

02-Aug-2011. Retrospective time-series for TOPS-SIMS output can be generated, as shown by the K_{cb} graph for 2011 for a location near Huron, CA (b). Time-series data can be downloaded from the interface in CSV format directly into a spreadsheet for further analysis.

<u>Extending the TOPS-SIMS Framework</u>

The current TOPS-SIMS K_{cb} and ET_{cb} mapping capabilities provide a demonstration of the potential utility of a modeling framework to integrate observations from satellite and surface sensor networks to provide new data and information services to the agricultural and water resource management user community. However, the TOPS-SIMS modular architecture also allows for a number of extensions that can be rapidly implemented to expand the data and information services available. Key short term objectives include: i) linking TOPS-SIMS to ET_O forecasts to provide forecasts of irrigation demand at various lead times; ii) use of web services and a model web approach (Geller and Melton, 2008) to integrate TOPS-SIMS outputs with operational and planning models utilized by water managers; iii) incorporation of site specific information provided by growers or uploaded automatically from flow meters or soil water sensors to allow generation of field-specific customized water balance reports; iv) expansion of inputs to include observations from a constellation of moderate resolution satellite sensors to increase observation frequency and improve the reliability and accuracy of data and information products from TOPS-SIMS; and v) incorporation of additional publicly available models for estimation of ET, including energy balance models for estimation of ET_c. The system can also be expanded geographically as interest and funding dictate.

SUMMARY

TOPS-SIMS employs a "system of systems" approach and applies the TOPS modeling framework to ingest observations from satellite and surface sensor networks to provide new data and information products to agricultural producers and water managers via easily accessible web interfaces and web services. The current framework provides capabilities for near real-time mapping of indicators of crop canopy development and crop water consumption at field scales over 15 million acres of California farmland. TOPS-SIMS is designed to integrate additional models and data services to support forecasting of crop irrigation requirements at weekly to seasonal lead times, and concurrent modeling of actual and potential evapotranspiration. Future integration of observations from a constellation of moderate resolution satellites would support further improvements in the frequency and long-term operational reliability of satellite-derived estimates of evapotranspiration and other hydrologic parameters.

REFERENCES

Allen, R., L. Pereira, D. Raes, and M. Smith, 1998. Crop evapotranspiration: guidelines for computing crop water requirements, FAO Irrigation and Drainage paper # 56, U.N. Food & Agriculture Organization, Rome.

Allen, R., M. Tasumi, and R. Trezza, 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC). J. Irrig. Drain. Eng., July/August.

Allen, R.G., Pereira, L.S., 2009. Estimating crop coefficients from fraction of ground cover and height. Irrig. Sci. 28, 17-34.

Anderson, M., J. Norman, J. Mecikalski, R. Torn, W. Kustas, J. Basara, 2004: A multiscale remote sensing model for disaggregating regional fluxes to micrometeorological scales. J. Hydrometeor, **5**, 343–363.

Asrar, G., M. Fuchs, E. Kanemasu, and J. Hatfield, 1984. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat, Agron. J**.,** 76:300-306

Ayars, J., R., Johnson, C. Phene, T. Trout, D. Clark, and R. Mead, 2003. Water use by drip-irrigated late-season peaches. Irrig. Sci., 22:187-194.

Bastiaanssen, W., M. Meneti, R. Feddes, and A. Holtslag, 1998. A remote sensing surface energy balance algorithm for land (SEBAL), J. Hydrol., 212-213:198-212.

California Irrigation Management Information System (CIMIS). 2014. Spatial CIMIS. http://wwwcimis.water.ca.gov/cimis/cimiSatSpatialCimis.jsp

Geller, G.N. and F.S. Melton. 2008. “Looking forward: Applying an ecological model web to assess impacts of climate change”, Biodiversity 9(3&4):79-83.

Goward, S., and K. Huemmrich, 1992. Vegetation canopy PAR absorptance and NDVI: An assessment using the SAIL model, Rem. Sens. Environ., 39:119-140.

Gowda, P.H., Chavez, J.L., Colaizzi, P.D., Evett, S.R., Howell, T.A., and J.A. Tolk. 2008. ET mapping for agricultural water management: present status and challenges. Irrig Sci, 26:223-237.

Hart, Q., M. Brugnach, B. Temesgen, C. Rueda, S. Ustin, and K. Frame, 2009. Daily reference evapotranspiration for California using satellite imagery and weather station measurement interpolation, Civil Engrg. & Environ. Syst., 26:19-33.

Hunsaker, D.J., Barnes, E.M., Clarke T,R., Fitzgerald, G.J., Pinter, P.J. Jr, 2005. Cotton irrigation scheduling using remotely sensed and FAO-56 basal crop coefficients. Trans ASAE 48(4):1395–1407.

Johnson, L., and T. Scholasch, 2005. Remote sensing of shaded area in vineyards, HortTechnology, 15:859-863.

Johnson, L. and T. Trout, 2012. Satellite NDVI assisted monitoring of vegetable crop evapotranspiration in California’s San Joaquin Valley. Rem. Sens. 4(2):439-455, doi:10.3390/rs4020439.

Masek, J., E. Vermote, N. Saleous, R. Wolfe, F. Hall, K. Huemmrich, F. Gao, J. Kutler, and T. Lim, 2006. A Landsat surface reflectance dataset for North America, 1990-2000, IEEE Trans. Geosci. Rem. Sens. Letters, 3:68-72.

Munevar, A., and Chung, F. 1999. Modeling California's Water Resource Systems with CALSIM. Proceedings of 29th Annual Water Resources Planning and Management Conference. ASCE Conf. Proc. doi:10.1061/40430(1999)95

NASS, 2011. USDA National Agricultural Statistics Service Cropland Data Layer. Available at: http://www.nass.usda.gov/research/Cropland/SARS1a.htm. Last accessed 28 Oct 2011.

Neale, C.M.U, Jayanthi H., and J.L. Wright. 2003. Crop and irrigation water management using high resolution airborne remote sensing. In: Proceedings of 54th IEC meeting of the international commission on irrigation and drainage (ICID) workshop remote sensing of ET for large regions, 17 Sept (2003) Montpellier, France. CD-ROM. New Delhi, India.

Neale, C.M.U, Bausch, W.C., and D.F. Heeremann. 1989. Development of reflectance-based crop coefficients for corn. Trans ASAE 32(6):1891–1899.

Nemani, R., H. Hashimoto, P. Votava, F. Melton, W. Wang, A. Michaelis, L. Mutch, C. Milesi, S. Hiatt, and M. White, 2009. Monitoring and forecasting ecosystem dynamics using the Terrestrial Observation and Prediction System (TOPS), Rem. Sens. Environ., 113:1497-1509.

NWS, 2011. Experimental Forecast Reference Crop Evapotranspiration. Available at: http://www.wrh.noaa.gov/forecast/evap/FRET/FRET.php?wfo=sto. Last accessed 28 Oct 2011.

Rafn, E.B., Contor, B., and D.P. Ames, 2008. Evaluation of a method for estimating irrigated crop-evapotranspiration coefficients from remotely sensed data in Idaho, Journal of Irrigation and Drainage Engineering, Vol. 134(6):722-727.

Trout, T., L. Johnson, and J. Gartung, 2008. Remote sensing of canopy cover in horticultural crops, HortScience, 43:333-337.

Tucker, C.J. (1979) 'Red and Photographic Infrared Linear Combinations for Monitoring Vegetation', Remote Sensing of Environment, **8(2)**,127-150.

USDA-NASS, 2008. Farm and Ranch Irrigation Survey. Table 36 – Methods used in deciding when to irrigate. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/ Farm_and_Ranch_Irrigation_Survey/index.php, last accessed March 2, 2012.

Vermote, E., N. El Saleous, C. Justice, Y. Kaufman, J. Privette, L. Remer, J. Roger, and D. Tanre, 2002. Atmospheric correction of MODIS data in the visible to middle infrared: first results, Rem. Sens. Environ., 83:97-111.

Williams, L., and J. Ayars, 2005. Grapevine water use and crop coefficient are linear functions of shaded area beneath the canopy, Agric. For. Met., 132:201-211.