APPENDIX H. NASA SATELLITE IRRIGATION MANAGEMENT SUPPORT SYSTEM

FORREST MELTON[1,2], LEE JOHNSON[1,2], KIRK POST[1,2]
[1]NASA AMES RESEARCH CENTER, COOPERATIVE FOR RESEARCH IN EARTH SCIENCE AND TECHNOLOGY
[2]CALIFORNIA STATE UNIVERSITY, MONTEREY BAY

SUMMARY

The NASA Satellite Irrigation Management Support (SIMS) framework (Melton et al., 2012) was originally developed to enhance the utility and accessibility of satellite data for irrigation management and scheduling. Since the utility of satellite data for irrigation management is maximized when data is available in near real-time, SIMS relies on algorithms for estimation of evapotranspiration (ET) that are compatible with full automation. The current implementation of SIMS relies on remote sensing data in the red and near-infrared wavelengths and reference evapotranspiration (ET_O) data from the California Irrigation Management Information System (CIMIS) for calculation of basal crop evapotranspiration (ET_{cb}). ET_{cb} is the evapotranspiration from a well-watered crop with minimal soil evaporation from exposed soil. This approach adjusts the reference evapotranspiration to account for crop growth stage and condition, and is sensitive to sustained crop water stress once it impacts the crop canopy, but is not sensitive to temporary ET effects due to moderate or intermittent deficit irrigation. In many irrigation management situations, ET_{cb} is preferable for irrigation scheduling since it represents the crop's biological water demand. It also provides a consistent reference against which growers of certain crops (e.g., winegrapes) may elect to adjust irrigation to achieve target levels of crop water stress to meet their desired production goals.

Ongoing field trials to quantify the accuracy of SIMS ET_{cb} relative to measured actual crop evapotranspiration (ET_a) in commercial fields conducted over six years for 15 major California crops have shown that the mean absolute error (relative to field measurements) for seasonal total ET_{cb} is within +/-10% for well-watered crops, and within +/-15% for all crops studied to date. Due to its relatively low operational costs, low required operator expertise, and reasonable accuracy, SIMS has been included in this study as a complement to ET models that rely on more complex energy balance approaches.

SIMS currently relies on data from Landsat 7 and Landsat 8, with use of data from Landsat 5 for studies prior to November, 2011, and limited use of data from the MODIS instrument onboard NASA's Terra and Aqua satellites to fill gaps during periods of extended cloud cover. Ongoing work is incorporating data from Sentinel-2A to further increase the satellite observation frequency at the 20-30m spatial resolution. SIMS can directly ingest top-of-atmosphere (TOA) reflectance data or top-of-canopy (TOC) surface reflectance data products from USGS, or can apply fully automated atmospheric corrections using the LEDAPS (Masek et al., 2006) and L8SR (Roy et al., 2014) software packages to calculate TOC surface reflectances and screen out clouds within the satellite scene.

SIMS uses TOC or TOA reflectances to calculate the normalized difference vegetation index (NDVI), a well-established remote sensing index of vegetation condition. Joint research with USDA-ARS in California's San Joaquin Valley has demonstrated a strong relationship between NDVI and crop fractional cover (F_c), and SIMS uses resulting equations from Trout et al. (2008)

and Johnson et al. (2012) to calculate F_c from NDVI. SIMS then combines F_c with estimates of crop height and stomatal control to calculate the actual basal crop coefficient (K_{cb_actual}) for each 30m x 30m pixel (after Allen et al., 2007; Allen and Pereira, 2009). SIMS incorporates data on crop type when available to apply crop-specific coefficients for calculation of K_{cb_actual} values. K_{cb_actual} in SIMS corresponds to the fraction of reference ET (ET_{rf}) used in many energy balance models to interpolate between satellite overpass dates. SIMS calculates the actual ET_{cb} (ET_{cb_actual}) following the FAO-56 approach (Allen et al., 1998) and multiplies K_{cb_actual} for each 30m x 30m pixel by the California Department of Water Resources Spatial CIMIS daily ET_O (Hart et al., 2009). The SIMS archive currently contains F_c, K_{cb_actual}, and daily ET_{cb_actual} data for irrigated fields for California at 30m (0.25 acre) spatial resolution, from 2010-present.

Limitations of SIMS are that it is less sensitive to transitory ET decreases from intermittent deficit irrigation, and ET increases from bare-soil surfaces following irrigation or precipitation events. Also, K_{cb_actual} and ET_{cb_actual} data coverage is currently limited to agricultural land cover types, but could be extended to other land cover types fairly readily in the future. Strengths of SIMS are that it can be fully automated, which greatly reduces data production costs, can be driven with data from multiple satellite instruments to increase observation frequency and operational reliability, and has been shown to accurately estimate ET_a for the well-watered crops that characterize much of the agricultural acreage in the Delta. As such, SIMS provides a complement to energy-balance based remote sensing approaches for estimating ET_a and enhances the operational reliability and data continuity of satellite-derived ET data as part of an ensemble of models.

REFERENCES

Allen, R. G., & Pereira, L. S. (2009). Estimating crop coefficients from fraction of ground cover and height. *Irrigation Science, 28*(1), 17-34.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO, Rome, 300*(9).

Allen, R. G., Wright, J. L., Pruitt, W. O., Pereira, L. S., & Jensen, M. E. (2007). Water Requirements *Design and Operation of Farm Irrigation Systems* (2nd Edition ed., pp. 208-288): American Society of Agricultural and Biological Engineers.

Hart, Q. J., Brugnach, d. M. F., Temesgen, B., Rueda, C., Ustin, S. L., & Frame, K. (2009). Daily reference evapotranspiration for California using satellite imagery and weather station measurement interpolation. *Civil engineering and environmental systems, 26*(1), 19-33.

Masek, J. G., Vermote, E. F., Saleous, N. E., Wolfe, R., Hall, F. G., Huemmrich, K. F., Feng, G., Kutler, J., & Teng-Kui, L. (2006). A Landsat surface reflectance dataset for North America, 1990-2000. *IEEE Geoscience and Remote Sensing Letters, 3*(1), 68-72.

Melton, F. S., Johnson, L. F., Lund, C. P., Pierce, L. L., Michaelis, A. R., Hiatt, S. H., Guzman, A., Adhikari, D. D., Purdy, A. J., Rosevelt, C., Votava, P., Trout, T. J., Temesgen, B., Frame, K., Sheffner, E. J., & Nemani, R. R. (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 Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 5*(6), 1709-1721.

Roy, D. P., Wulder, M. A., Loveland, T. R., C.E, W., Allen, R. G., Anderson, M. C., Helder, D., Irons, J. R., Johnson, D. M., Kennedy, R., Scambos, T. A., Schaaf, C. B., Schott, J. R., Sheng, Y., Vermote, E. F., Belward, A. S., Bindschadler, R., Cohen, W. B., Gao, F., Hipple, J. D., Hostert, P., Huntington, J., Justice, C. O., Kilic, A., Kovalskyy, V., Lee, Z. P., Lymburner, L., Masek, J. G., McCorkel, J., Shuai, Y., Trezza, R., Vogelmann, J., Wynne, R. H., & Zhu, Z. (2014). Landsat-8: Science and product vision for terrestrial global change research. *Remote Sensing of Environment, 145*, 154-172.