BUSHLAND EVAPOTRANSPIRATION AND AGRICULURAL REMOTE SENSING EXPERIMENT – 2007 (BEAREX07)

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ABSTRACT

In Texas High Plains, high-resolution daily ET maps would help planning irrigation scheduling. ET maps derived from satellite data with daily coverage such as Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR), and Geostationary Operational Environmental Satellite (GOES) sensors are not adequate since their thermal pixel size is larger than individual fields in the region. Therefore, an opportunity exists to utilize simultaneously acquired high resolution visible, near infrared (NIR) and shortwave infrared (SWIR) images from MODIS and thermal infrared (TIR) images from other high resolution sensors such as Landsat TM or Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to improve spatial resolution of ET maps. This paper presents a multi-institutional research effort "Bushland Evapotranspiration and Agricultural Remote Sensing Experiment 2007 (BEAREX07)" conducted during the 2007 cropping season. The main objectives of this research effort are to: evaluate land surface energy balance and crop coefficient-based ET models for their ability to estimate ET at point, plot, field, landscape and regional scales; evaluate the effects of remote sensing pixel resolution (thermal band) on modeled energy balance components of irrigated and dryland cropping systems and rangeland systems; evaluate existing and new algorithms to improve spatial resolution of surface temperature data derived from Aircraft/Landsat/ASTER/MODIS thermal images using high resolution visible, NIR and SWIR images; evaluate Large Aperture Scintillometer (LAS) systems for their ability to estimate path weighted sensible heat fluxes over heterogeneous landscapes; and evaluate Bowen Ratio and Eddy Covariance systems for their ability to estimate sensible and latent heat fluxes in the semi-arid, highly advective Texas High Plains. As part of BEAREX07, six field campaigns were scheduled to coincide with Landsat 5 and ASTER overpasses and were successfully completed. The field campaign was concentrated in and around the Conservation and Production Research Laboratory (CPRL), USDA-ARS, home of four large monolithic weighing lysimeters, at Bushland, Texas. Data collection included reflectance and thermal data from aircraft, Landsat TM, and MODIS sensors, soil water content, crop parameters, surface reflectance, surface temperature and near-surface red and infrared images using hand-held instruments in addition to net radiation and soil heat flux measurements. Surface energy fluxes measured using lysimeters, three Bowen ratio, and three Large Aperture Scintillometers at the CPRL. At present, efforts are being made to process remote sensing images for evaluating various energy balance based ET models such as Mapping Evapotranspiration with Internalized Calibration (METRIC), Surface Energy Balance Algorithm for Land (SEBAL), Two Source Model (TSM) and Simplified Surface Energy Balance (SSEB). BEAREX07 was the most comprehensive ET modeling study at point, field, landscape, and regional scales in the Texas High Plains. This data-rich multi-scale experiment will allow the estimation of ET from remote sensing and its evaluation at different scales.

INTRODUCTION

Irrigation in the Texas High Plains was developed solely from the Ogallala (High Plains) Aquifer, as precipitation and surface water resources in the region are generally inadequate for this purpose. The Ogallala Aquifer is one of the largest freshwater aquifers in the world; however it is a closed system. Consequently, withdrawals have greatly exceeded recharge, resulting in severe declines in ground water levels since irrigation development began. Declining well yields, changing water quality and increasing pumping energy costs continue to affect withdrawal rates, and therefore, crop productivity. If the present trend continues, the long-term economic viability of irrigated agriculture in the Texas High Plains will be adversely affected. One impediment to better ground water management is that the overall water balance of the region is still not fully understood, particularly evapotranspiration (ET), recharge and precipitation as they vary spatially in the region. In agriculture, ET is a major consumptive use of irrigation water and precipitation on agricultural land. Any attempt to improve water use efficiency must be based on reliable estimates of ET, which includes water evaporation from land, vegetative and water surfaces and transpiration by vegetation.

Remote sensing based land surface energy balance models are better suited for estimating crop water use at a regional scale (Allen et al., 2007a). Numerous remote sensing algorithms are available for estimating the magnitude and trends in regional evapotranspiration. Three models: Surface Energy Balance Algorithm for Land (SEBAL; Bastiaanssen et al., 2005), Mapping Evapotranspiration with Internalized Calibration (METRIC™; Allen et al., 2007), and Two Source Energy Balance (TSEB; Kustas and Norman, 1999) are most commonly used. These models convert satellite sensed radiances into land surface characteristics such as albedo, leaf area index, vegetation indices, surface thermal emissivity and surface radiometric temperature to estimate LE (latent heat flux, W m^{-2}) or ET (e.g., mm d-1) as a "residual" of the land surface energy balance equation [$ET = (R_n - G - H)/\lambda v$], where R_n is net radiation, G is soil heat flux, H is sensible heat flux (all in W m^{-2} units), and λv is latent heat of vaporization (~2.45 MJ kg^{-1}). To validate such remote sensing based estimates of regional ET, ground-truth can be obtained from lysimetric measurements and other relatively small areal LE determinations (with Scintillometer, Eddy Covariance or Bowen Ratio systems).

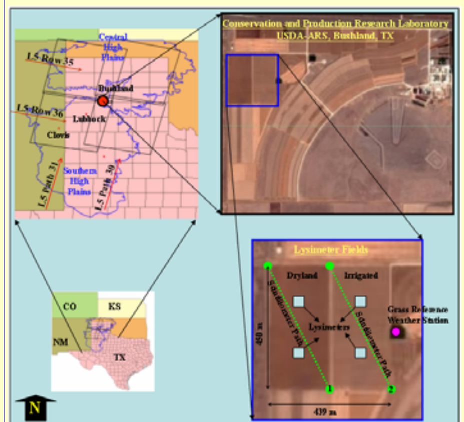
Surface temperature is one of the key boundary conditions in most energy balance models for estimating spatially distributed ET. Numerous remote sensing satellites provide thermal images that can be used to derive radiometric surface temperature. However, the spatial resolution of these thermal images is coarser than that acquired in other wavelengths such as visible, NIR (Near Infrared) and SWIR (Shortwave-Infrared). For example, the MODIS sensor provides thermal images at 1000-m resolution compared to 250-m resolution for images acquired in other bandwidths on the same satellite platform. Further, time intervals between successive satellite overpasses (repeat cycle) over the same geographic area vary from satellite to satellite. The more frequent the repeat coverage, the coarser the spatial resolution of the images acquired. For example, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor has a repeat cycle of 8 days with 15-90 m spatial resolution compared to daily coverage of MODIS with 250-1000 m resolution. ET maps derived from satellites with daily coverage such as MODIS and Advanced Very High Resolution Radiometer (AVHRR) would not satisfy producer needs because their pixel size is larger than individual fields in the region, causing significant errors in distributed ET estimation (Tasumi et al., 2006). The errors in estimated ET will be partly due to the presence of contaminated pixels, i.e., pixels with multiple land uses/vegetation types with significant differences in cover, surface roughness and/or moisture content. This condition is more common in arid and semi-arid regions where fully irrigated fields are usually surrounded by extremely dry landscape. Limited research has been done to evaluate the scale influences on the estimation of ET using multiple aircraft and satellite sensors (McCabe and Wood, 2006). However, no such study has been implemented in semi-arid or arid regions of the U.S. to evaluate scale influences on estimating ET using land surface energy balance models. Detailed discussion on the present status and challenges in ET mapping for agricultural management can be found in Gowda et al. (2007).

OBJECTIVES

The main objectives of this research effort are to evaluate:

- Land surface energy balance and crop coefficient-based ET models for their ability to estimate ET at point, plot, field, landscape and regional scales;
- Effects of remote sensing pixel resolution (thermal band) on modeled energy balance components of irrigated and dryland cropping systems and rangeland systems;
- Existing and new algorithms to improve spatial resolution of surface temperature data derived from Aircraft/Landsat/ASTER/MODIS thermal images using high resolution visible, NIR and SWIR images;
- Large Aperture Scintillometer (LAS) systems for their ability to estimate path-weighted sensible heat fluxes over heterogeneous landscapes; and
- BR and EC systems for their ability to estimate sensible and latent heat fluxes in the semi-arid, highly advective Texas High Plains.

STUDY AREA



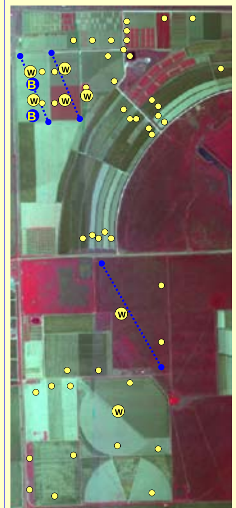
BEAREX07 was conducted during the 2007 cropping season in and around the CPRL-USDA-ARS site, Bushland, TX.

- CPRL is the home of four large monolithic weighing lysimeters (3 m length x 3 m width x 2.5 m depth) located in the middle of 4.7-ha (210 x 225 m) fields that are larger than Landsat TM's thermal pixel size (120 x 120 m).
- In 2007, two of the lysimeters (SW and NW) were planted to dryland grain sorghum in clumps as part of another study. The SE and NE lysimeter fields were planted to forage corn and sorghum, respectively, and were irrigated.
- Each lysimeter field is equipped with one net radiometer [Q*7.1, Radiation and Energy Balance Systems (REBS), Seattle, WA] and one infrared thermometer (IRT) (2G-T-80F/27C, Exergen, Watertown, MA) and three soil heat flux plates (Campbell Scientific Inc., Logan, UT) for measuring net radiation, surface temperature, and soil heat fluxes, respectively.

METHODS AND MATERIALS

- Six remote sensing campaigns were conducted for acquiring high resolution aircraft images which were scheduled to coincide with ASTER and Landsat TM overpasses.
- Utah State University (USU) airborne multispectral digital system was used to acquire high-resolution short wave (green, red and near-infrared) and thermal infrared imagery.
  1. Spatial resolution - 0.5 m in the shortwave bands and 1.8 m in the thermal infrared band
  2. Flight lines were planned to ensure 30% overlap between parallel flight lines
- A research plan was submitted to the ASTER Science Team, National Aeronautical and Space Administration in collaboration with Dr. Andrew French, ALARC-USDA-ARS and it was approved for acquisition of ASTER images during the BEAREX07.
- Three LAS were deployed at the CPRL in collaboration with Dr. Bridget Scanlon, University of Texas – Austin.
- A weather station was installed on the rangeland to complement the LAS system and to augment the existing weather station data in the study area.
- Field data collected during the remote sensing campaigns included leaf area index, wet/dry biomass, crop height, leaf width, crop yield in addition to row direction and width and plant density in 40 locations, thus capturing the crop variability/management practices within the CPRL.
- Soil moisture content was determined using soil water reflectometers (model CS616, Logan, UT) and Time Domain Reflectometry (TDR).
- Surface reflectance and surface temperature measurements at the time of aircraft/satellite overpasses were made using a hand-held multispectral radiometer/scanner (MSR5; CROPSCAN, Inc., Rochester, MN) and a variable zoom IRT Agri-Therm II (Everest Interscience Inc.), respectively.

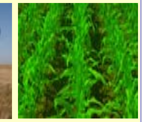
RESULTS AND DISCUSSION



Bowen Ratio

Scintillometer

Weather Station



R/IR Image

Lysimeter

CROPSCAN (MSR5)

Digital Image

Agricultural Digital Camera

Handheld IR Thermometer

Net Radiometer

W Weather Station and Infrared thermometer
B Bowen Ratio
Scintillometer
Crop observation locations

- A comprehensive groundtruth database was developed for evaluating remote sensing based ET models.
- Twenty-five high resolution aircraft images were acquired through the cropping season.
- Seven Landsat TM images that were acquired during BEAREX07 were purchased from the U.S. Geological Survey and were cloud free for most part of the scenes including the CPRL.
- NASA did not acquire the requested ASTER images for unknown reasons.
- MODIS data acquired during the BEAREX07 were downloaded from the MODIS website.
- Continuous measurements were made with the LAS systems throughout the 2007 cropping season.
- Efforts are also being made to process Landsat 5 TM images for evaluating ET models such as METRIC, SEBAL, TSEB, Surface Aerodynamic Temperature (SAT; Chávez et al., 2005) and Simplified Surface Energy Balance (SSEB; Senay et al., 2007).

CONCLUSIONS

BEAREX07 was successfully completed. We are now planning the BEAREX08 campaign with cotton on our irrigated and dryland lysimeter fields during the 2008 cropping season. We are expecting Dr. Michael Salvage, a visiting scientist from South Africa, to join us to work on the energy balance closure problem with EC systems. Also, efforts are being made to broaden the scope of the BEAREX08 in collaboration with two other USDA-ARS laboratories: the Hydrology and Remote Sensing Laboratory, Beltsville, MD and the National Soil Tilth Research Laboratory, Ames, IA. This research is the most comprehensive remote sensing ET modeling study at point, plot, field, landscape and regional scales in the Texas High Plains. It provides quality assured datasets for evaluating/improving existing remote sensing based ET models and developing new models if required. It is also expected to provide an operational ET remote sensing methodology for high resolution regional ET mapping for the Texas High Plains.

REFERENCES

- Allen, R. G., M. Tasumi, and R. Trezza. 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC): Model. ASCE J. Irrig. Drain. Eng. 133(4): 380-394.
- Bastiaanssen, W.G.M., E.J.M. Noordman, H. Pelgrum, G. Davids, B.P. Thoreson, and R.G. Allen. 2005. SEBAL model with remotely sensed data to improve water-resources management under actual field conditions. ASCE Journal of Irrigation and Drainage Engineering, 131(1):85-93.
- Chávez, J.L., C.M.U. Neale, L.E. Hipps, J.H. Pruger, and W.P. Kustas. 2005. Comparing aircraft-based remotely sensed energy balance fluxes with eddy covariance tower data using heat flux area functions. Journal of Hydrometeorology AMS, 6(6):923-940.
- Gowda, P.H., J.L. Chavez, P.D. Colaizzi, S.R. Evett, T. A. Howell, and J. A. Tolk. 2007. ET mapping for agricultural water management: Present status and Challenges. Irrigation Science, DOI 10.1007/s00271-0088-6.
- Kustas, W. P., and J. M. Norman. 1999. Evaluation of soil and vegetation heat flux predictions using a simple two-source model with radiometric temperatures for partial canopy cover. *Agric. For. Meteorol.* 94: 13-29.
- Senay, G.B., M. Budde, J.P. Verdin, and A.M. Melesse. 2007. A coupled remote sensing and simplified surface energy balance approach to estimate actual evapotranspiration from irrigated fields.
- Tasumi, M., R.G. Allen, and R. Trezza. 2006. Calibrating satellite-based vegetation indices to estimate evapotranspiration and crop coefficients. In Proceedings of the 2006 USCID Water Management Conference. Ground Water and Surface Water under Stress: Competition, Interaction, Solutions. Eds. D. Wichelns and S. S. Anderson. Publisher USCID, Denver, CO.