The Wetting Front

Soil And Water Management Research Unit News

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WIRELESS MAKES SENSE IN AGRICULTURE

By Susan O'Shaughnessy

Wireless sensor networks (WSNs) are sets of sensors and/or routers that are self-organized and self-configured to automatically establish and maintain connectivity among each other (mesh networking). These networks are prevalent in industrial settings such as manufacturing and wastewater treatment for purposes of automatic data acquisition, control and monitoring of processes, and system maintenance (Akyildiz et al., 2005). Wireless technology is being progressively integrated into agricultural applications as well. Examples include farm machinery, where GPS receivers collect satellite data for automated guidance, the acquisition of local ET data via the internet for irrigation scheduling, and the operation and monitoring of pumps and irrigation systems using cell phone communication. Wireless technology has also become a critical component to precision agricultural applications in research such as the monitoring, control, and automatic irrigation scheduling of continuous-move sprinklers in response to sensor measurements, data collection for spatial field mapping and the implementation of variable rate irrigation systems (Pierce et al., 2006). The benefit of wireless sensor networks in agriculture will help facilitate data acquisition from direct field measurements. The majority of sensors used in agriculture today function independently of one another and are embedded in farm machinery operated for planting, fertigation, and harvesting. Mesh networking among field sensors will allow continuous point sampling to assess within-season variations of crops. Amassing data temporally as well as spatially will aid farmers in monitoring the variability in crop quality and crop productivity (Camilli et al., 2007) throughout the growing season.

Wireless sensors networks operate primarily in the 900 MHz and 2.45 GHz frequency bands (Andrade-Sanchez et al., 2007). Both frequency bands have been established for public use and neither choice requires a license to operate (Dowla, 2003). These RF modules are offered in a variety of communication standards developed by the Institute of Electrical and Electronic Engineers (IEEE), the most familiar being the IEEE 802.xxx series which includes wireless Wi-Fi (IEEE 802.11), Bluetooth (IEEE 802.15.1), Zigbee (IEE802.15.4), and IEEE 802.16 (broadband standard for wireless metropolitan networks, (Akyildiz et al., 2005). The Bluetooth and Wi-Fi protocols operate in the 2.45 GHz range and have relatively fast data transmission rates but limited communication range and higher power consumption. The Zigbee standard, which can now be integrated into both the 900 MHz and 2.45 GHz frequency bands, allows users to take advantage of low power requirements and mesh networking capabilities.

At the Bushland Conservation and Production Research Laboratory, we designed a prototype wireless infrared thermometer (IRT) sensor module using readily available off-the-shelf components and installed two separate wireless sensor networks onto a center pivot and in a cotton field from July 2, 2007- October 1, 2007. The communication

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News Flash

Due to rising cost of printing and postage this will be the last issue of the Wetting Front Newsletter sent by mail.
All future issues will be sent by email or available on the website www.cprl.ars.usda.gov.
If you like to receive each issue by email send your email address in an email with Subject Line: Wetting Front to Carole Perryman at carole.perryman@ars.usda.gov
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CPRL Email addresses have been changed to firstname.lastname@ars.usda.gov

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protocol for both networks was established with the 802.15.4 standard, but the firmware for the Pivot network contained the Zigbee protocol that allowed for mesh networking, while the Field network did not. The hypothesis was that the mesh networking system was best suited for installation on the pivot spans and its "self-healing" or mesh capabilities would overcome the majority of interference problems associated with metal trusses, towers and reduced line-of-sight due to the drop hoses.

A photograph of the wireless sensor module is shown in Fig. 1. Among other components, the interface circuit contained an 8-bit microprocessor that enabled collection of the IRT reading, sensor body temperature, and battery voltage. The microprocessor also enabled the RF modules in the Field WSN to be placed into a "sleep" mode in between readings and during non-daylight hours. The sensors in both of the WSNs were calibrated against a black body calibrator at three different temperatures to incorporate the sensor body temperature into the individual calibration equation and adjust for drift. Each wireless sensor module was powered with a 6 V sealed lead acid battery which was trickle recharged by a 5 watt solar panel through a voltage regulating and isolation recharge circuit. The antenna was a wire antenna directly attached to the RF module and all components were encapsulated inside of the white plastic housing.

Figure 1. Agricultural Science Technician, Chad Ford, performing maintenance on a wireless sensor module. The battery and solar panel are to the left of the sensor.

The sensor modules on the Pivot-WSN were located on masts along the spans at lengths of 70, 82, 138, 150, 166, 178, 207, and 219 m from the pivot center point and pointed "into" the plots receiving irrigation treatments that replenished soil water content to100% of field capacity. The sensor modules for the Field-WSN were located at distances of 75, 144, 172, and 223 m from the pivot (Figure 2).

Each wireless sensor module transmitted a total of 14 bytes of data to include the sensor identity, the temperature reading of the IRT, the body temperature of the IRT sensor and the battery voltage. Using notation similar to Andrade-Sanchez et al. (2007), we defined this total 'byte package' as a data packet and the packet reception rate as:

$$PRR_x = \left[\frac{RR_x}{TR_x}\right]*100$$

where PRR is the packet reception rate, RR is the number of records received during the time interval x, and TR_x is the total number of records transmitted during the interval time 'x'.

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On May 3-4, 2007, Steve Evett participated in the USDA-ARS Internet Technology Steering Committee semi-annual meeting at Tucson, AZ.

Robert Schwartz was interviewed by KGNC Ag Radio, CREET Beat, on "Reduced tillage and soil water conservation" on May 22, 2007.

On May 22, 2007, Steve Evett gave a seminar on the Middle Eastern Regional Irrigation Management Information System project in Jordan, Israel and Palestine to the USDA-ARS Cropping Systems Research Laboratory, Lubbock, TX.

Jose Chavez presented a seminar on "MODTRAN4 Procedures to Calibrate Thermal Imagery." at the USDA-ARS-CPRL, Conservation and Production Research Lab, Bushland, TX on June 7, 2007.

From June 16 to September 17, 2007, Steve Evett hosted Partson Mubvumba as a scientific fellow sponsored by the International Atomic Energy Agency. Partson worked with Steve and several technicians and scientists in ongoing field studies where he learned techniques of accurate soil water content determination and water balance calculations for estimation of crop water use and water use efficiency. Partson has since returned to Zimbabwe where he is a soil scientist working with small farmers.

Steve Evett conducted a workshop presentation on weighing lysimeter for crop water use determination in Nazareth, Israel, July 2007.

Steve Evett presented "The role of a weighing lysimeter in crop water use determination for irrigation scheduling – case in the Jordan Valley" at a workshop, titled "Information and Technology Transfer to the Farmer", that took place in Nazareth, Israel, for the period of July 8-11, 2007. The workshop was sponsored by the Middle Eastern Regional Irrigation Management Information System (MERIMIS) project and the Ahali Centre, Nazareth. Steve then visited Victor Alchanatis and Yafit Cohen at the Agricultural Research Organization of Israel in Tel Aviv where they discussed ongoing research in their joint BARD project. Later, Steve visited Naftali Lazarovitch at the Ben Gurion University of the Negev before traveling to Jordan to work on the weighing lysimeter installation at the Dayr Alla Research Station in

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Wireless Network Structures

An embedded base computer was mounted in a weatherproof enclosure on the pivot and serially connected to the CAMS panel. Two separate coordinators for each WSN were connected to the base computer located near the pivot. The Pivot coordinator was plugged into the serial port and located inside of the weather enclosure. The Field coordinator was connected to a USB port and sited anterior to the center pivot using an extension cable, (Figure 2)

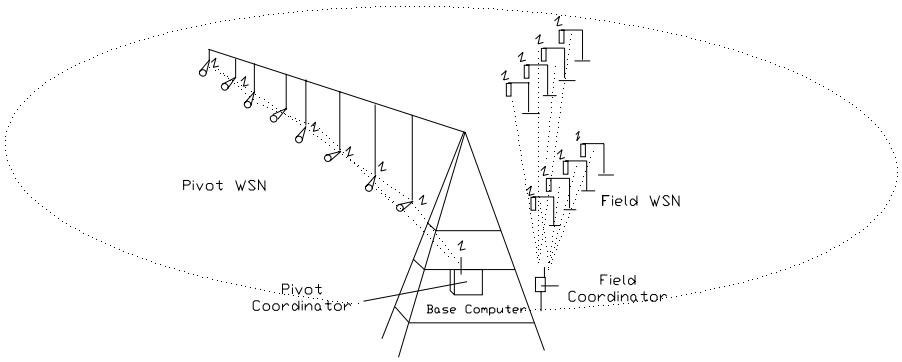

Figure 2. Center pivot diagram depicting the two different WSNs; the Pivot WSN was capable of the broadcast and unicast communication mode with mesh networking; the Field WSN used a point-to-point topology with no mesh networking abilities.

Because this network system was mounted on the center pivot spans, we configured the RF modules using the Zigbee protocol, enabling mesh networking to help abate interference issues. Each of the sensor nodes functioned as a router ,as well as, a sensing device, with the exception of the most distal sensor module (the GPS end device).

Initially the communication mode for the Pivot WSN was configured to broadcast (point-to-multipoint) the outgoing message from the coordinator to each of the sensor nodes. This communication mode simplified timing and synchronization issues associated with serial data acquisition. After a short trial period, the communication mode was changed to a unicast mode (point-to-point) to reduce the latency. The broadcast mode of communication entailed the coordinator sending outgoing messages to all of the sensor nodes in the network; each message was encoded with the address of the target sensor. Only the target sensor responded by sending its data back to the coordinator, utilizing the other nodes as routers.

In the unicast mesh-networking mode, the coordinator sent a message to a specific sensor node and the other nodes were used as routers to transmit the data. Again, only the targeted sensor node acted on the message and returned its data to the coordinator through the network pathway. Towards the end of the experiment, we briefly investigated the operation of this WSN using the unicast non-mesh networking communication mode. Figure 3 illustrates the differences between the unicast mesh networking and unicast non-mesh networking modes. Pathways in the mesh networking system were established by the network.

Field-WSN

The Field-WSN coordinator individually polled each of the remote sensor devices using a unicast communication mode and sending a message directly to a specific sensor node. The returning data packet traveled from the sensor node to the Field coordinator.

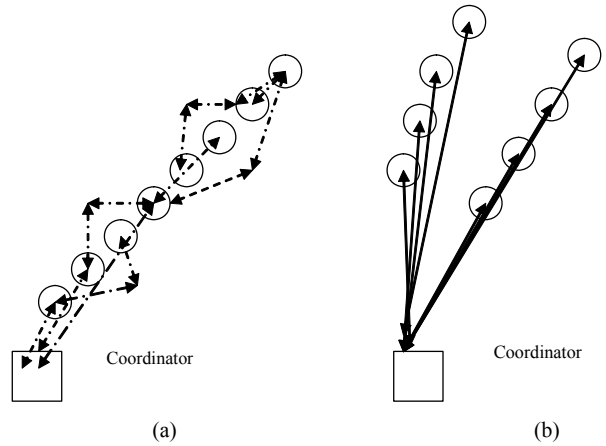

Figure 3. Network topologies showing: (a) Pivot WSN- unicast, mesh networking; (b) Field-WSN- unicast, non-mesh architecture.

RESULTS

Overall, the Field-WSN (unicast, non-mesh network) performed superior to the mesh networking system on the pivot spans. The Field-WSN required 8 seconds to collect data reliably from all eight sensors. However, it is important to note, that using a non-mesh networking protocol on the Pivot-WSN resulted in a less than ideal level of reliability for data transmission, <80% reliability for 100% of the trial period. The information below breaks down the results for the different network configurations.

The time required to collect data from the set of 9 sensors on the Pivot WSN, using the broadcast communication mode with mesh networking, increased the latency of transmission of the entire network by 400% as compared to the Field-WSN. After reconfiguring the communication mode to a unicast method, while maintaining mesh networking capabilities, the latency was reduced by 63%. Table 1 summarizes the performance results.

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Challenges of WSNs

Agricultural settings can impose unique barriers to wireless technology. Wave propagation can vary in fallow fields compared with cropped fields, and severe weather can cause a dramatic loss in signal strength (Hebel et al., 2007). Reflection from farm machinery and interference from other networks also have the potential to attenuate signals. Goense and Thelen (2005) reported that after deploying a wireless sensor network consisting of humidity and temperature sensors among a potato crop, radio propagation was influenced by canopy development and distance from the base modem.

Logistical issues that we experienced with the WSNs included powering down all the sensor nodes when (1) deploying them to the field for the first time; (2) when adding new sensor modules to the network; and (3) when trouble shooting the network for connectivity issues. In addition, we were limited to the number of nodes that we could deploy in a single network and still maintain a high level of reliability. These problems were due to the limitations of the RF module firmware and resulted not only in reduced scalability but also diminished the reliability of the Pivot-WSN.

Wireless sensor networks will become easier to establish in the agricultural industry as RF technology advances. In the near future, wireless sensor networks are expected to provide new economic opportunities for U.S. agriculture through their application for remote, real-time monitoring and control of important aspects of high quality food production and processing systems (Sanchez-Andrade et al., 2007).

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the Jordan Valley with Mohammed Jitan, Naem Mazahrih and Mahmoud Sawahla.

Prasanna Gowda was invited to attend the "NRC Colloquium on the water implications of biofuels production in the United States" on July 12, 2007 in Washington D.C.

Terry Howell presented a lecture and training on "Irrigation Scheduling and Crop Water Requirements" to the USDA-FAS, US Dept. of State sponsored International Workshop to Improve Agricultural Water Management in Iraq August 5-9, 2007 at Amman, Jordan. The workshop was part of USDA's overall goal of assisting Iraq in revitalizing its agriculture sector. There were 50 Iraqi scientists and engineers in attendance plus speakers from the U.S. involved in this workshop, August 5-9, 2007.

On August 6-8, 2007, Steve Evett and visiting scientist Partson Mubvumba visited the USGS Southwest Biological Science Center to work with Ed Grote to improve time domain reflectometry determinations of soil water content in desert biological crusts.

Prasanna Gowda was interviewed by KGNC Ag Radio, CREET Beat, on Remote sensing ET research at the Conservation and Production Research Laboratory, USDA-ARS, Bushland, TX on August 9, 2007.

Prasanna Gowda taught a US-India Forum sponsored 10-day SWAT/ADAPT modeling workshop at the Indian Institute of Technology, New Delhi, India in collaboration with the Texas A&M University, August 20-30, 2007.

Jose Chavez attended Texas certified Crop Advisors (CCA) approved continuing education course. Precision Ag EXPO, Plainview, TX on September 6, 2007.

On August 30, 2007, Steve Evett visited the Desert Research Institute, Las Vegas, NV, to participate in the external science panel meeting for the NSF research project titled "Scaling Environmental Processes in Heterogeneous Arid Soils (SEPHAS)." The panel inspected the recently constructed weighing lysimeters and discussed science plans for the research program.

Jose Chavez attended the Campbell Scientific Inc. CR1000 datalogger and Loggernet software training course in Logan, UT on September 10-13, 2007.

Susan O'Shaughnessy was interview by KGNC Ag Radio, CREET Beat, on September 26, 2007 on the subject on "Automation of the center pivot system using wireless networks."

From September 27 through October 8, 2007, Steve Evett traveled to Vienna, Austria to meet with officials of the Soil and Water Management & Crop Nutrition Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and to lecture in the FAO/IAEA Interregional Training Course on Use of Nuclear and Related Techniques to Measure Storage, Flows and Balance of Water in Cropping Systems. Dr. Evett met with Mr. Minh-Long Nguyen, Head of Section and with Ms. Lee K. Heng, Soil Scientist in the section to consult and advise on issues of soil water content determination and appropriate equipment for experiments in soil water balance and crop water use. In the training course, Dr. Evett delivered 15 lectures and led two field exercises and two computer laboratory exercises on

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the topics of soil water determination using direct and indirect (capacitance, TDR, neutron probe) methods, principles of crop water use determination using soil water balance, soil water flux calculations, crop water use estimation using reference evapotranspiration calculations and crop coefficients, and weighing lysimeter methods.

On October 11-12, 2007, Steve Evett traveled to Rocky Ford, CO to advise Colorado State University staff on installation of neutron probe access tubes in the new weighing lysimeter there.

Prasanna Gowda attended a 2-day workshop "Constraints for combining modeling and management for groundwater" in Austin, TX on October 15-16, 2007 sponsored by the Texas Water Development Board and University of Texas, Austin.

Paul Colaizzi was interviewed by KGNC Ag Radio, CREET Beat, on October 24, 2007 on "Remote Sensing research at USDA-ARS, Bushland, TX."

Judy Tolk provided a tour of field projects here at the Conservation & Production Research Laboratory for the Cattlemen's Association of Anderson Co, KY on October 30, 2007.

Karen Copeland, Chad Ford, Brice Ruthardt and Susan O'Shaughnessy attended training October 30 through Nov 1, 2007 titled "PIC-microprocessor Workshop" held at the Amarillo TAES Center, Amarillo, TX. The course was be taught by RCG Consultants.

Prasanna Gowda was interviewed by journalist Larry Reichenberger, FURROW Magazine on Cotton and ET remote sensing.

Steve Evett taught a fourth grade class at Bushland Elementary how to make adobe bricks (miniature) on Friday, November 16, 2007. Steve visited the class again on Tuesday, November 20, 2007 and taught the students how to construct buildings from the bricks.

Robert Schwartz discussed/presented "Seasonal and Long Term Changes in Manure Phosphorus Availability" as part of the Nutrient Management Training workshop at the Texas A&M Research Extension Center, Amarillo, TX on November, 20, 2007. The workshop was hosted by Texas Cooperative Extension Service to train nutrient management specialists in the region.

Bushland Evapotranspiration and Agricultural Remote Sensing EXperiment 2007 (BEAREX07)

By Prasanna H. Gowda, Terry A. Howell, Bridget R. Scanlon, Christopher C.M.U. Neale, Paul D. Colaizzi, Steven R. Evett, Jose L. Chavez

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 in terms of evapotranspiration (ET), recharge and precipitation as they vary spatially in the region.

ET has long been recognized as the process that plays the most important role in determining exchanges of energy and water mass between the hydrosphere, atmosphere and biosphere (Sellers et al., 1996). In agriculture, it 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. ET varies regionally and seasonally according to weather and wind conditions (Hanson, 1991). Understanding these variations in ET is essential for managers responsible for planning and management of water resources especially in arid and semi-arid regions of the world where crop water demand generally exceeds precipitation and requires irrigation from surface and/or groundwater resources to meet the deficit.

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., 2007b), 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 λ_v is latent heat of vaporization (~2.45 M J 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

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images is coarser than that acquired in other wavelengths such as visible, NIR (Near Infrared) and SWIR (Shortwave-Infrared). For example, the Moderate Resolution Imaging Spectroradiometer (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.

In the Texas High Plains, high resolution daily ET maps would help in scheduling irrigation. ET maps derived from satellites with daily coverage such as MODIS, Advanced Very High Resolution Radiometer (AVHRR), and Geostationary Environmental Satellite (GOES) 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 (Kustas et al., 2004). 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 and Kustas et al., 2004 in humid Iowa region; Jacob et al., 2002 for Mediterranean climate). However, no such study has been implemented with both aircraft and satellite sensor platforms in semi-arid or arid regions of the U.S. to evaluate scale influences on estimating ET using land surface energy balance models. Moreover, previous studies assessed scale effects by comparing ET estimates against surface fluxes derived from eddy covariance systems. It is known that the eddy covariance method has an energy balance closure problem i.e., $R_n \neq H + LE + G$ (Oncley et al., 2000). Therefore, calibration of the EB models against lysimetric and/or well-calibrated scintillometer measurements over irrigated and dryland conditions may enhance their ability to estimate regional ET accurately. Detailed discussion on the present status and challenges in ET mapping for agricultural management can be found in Gowda et al. (2007).

Given these knowledge gaps in ET remote sensing research, there is a need for thorough evaluation of existing and new remote sensing based ET models as well as flux measurement systems such as scintillometers, Bowen Ratio (BR) and Eddy Covariance (EC) systems for the semi-arid Texas High Plains using lysimeter data. In addition, opportunity exists to utilize simultaneously acquired high resolution visible, NIR and SWIR images from MODIS and thermal images from other high resolution sensors such as Landsat TM to improve the frequency and resolution of ET maps, making them useful for crop irrigation scheduling and general landscape hydrologic water balance.

BEAREX07

BEAREX07 is a multi-agency/university collaborative research effort between the Conservation and Production Research Laboratory (CPRL), USDA-ARS; University of Texas – Austin, TX; Utah State University, Logan, UT; and Arid-Land Agricultural Research Center (ALARC)-USDA-ARS, Maricopa, AZ. The main objectives of this research effort are to evaluate: (1) land surface energy balance and crop coefficient-based ET models for their ability to estimate ET at point, plot, field, landscape and regional scales; (2) the effects of remote sensing pixel resolution (thermal band) on modeled energy balance components of irrigated and dryland cropping systems and rangeland systems; (3) 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; (4) Large Aperture Scintillometer (LAS) systems for their ability to estimate path-weighted sensible heat fluxes over heterogeneous landscapes; and (5) BR and EC systems for their ability to estimate sensible and latent heat fluxes in the semi-arid, highly advective Texas High Plains.

BEAREX07 was conducted during the 2007 cropping season in and around the CPRL- USDA-ARS site, Bushland, TX (Fig. 1). The CPRL is the home of four large monolithic weighing lysimeters (3 m length x 3 m width x 2.4 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 (Fig. 1). The SE and NE lysimeter fields were planted to forage corn and sorghum, respectively, and were irrigated. One small lysimeter (1.5 m by 1.5 m by 2.4 m deep) is located in the grass reference ET weather station field (0.31 ha) which is a part of the Texas High Plains ET Network (TXHPET, 2006). Each lysimeter field is equipped with one net radiometer [Q*7.1, Radiation and Energy Balance Systems (REBS)[1], 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.

(See Figure 1 on following page for Location of study area)

BEAREX07 consisted of six remote sensing campaigns for acquiring high resolution aircraft imagery, which were scheduled to coincide with ASTER and Landsat TM overpasses. The 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. More information on this sensor can be found in Neale and Crowther

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[1] *See Disclaimer on page 12*

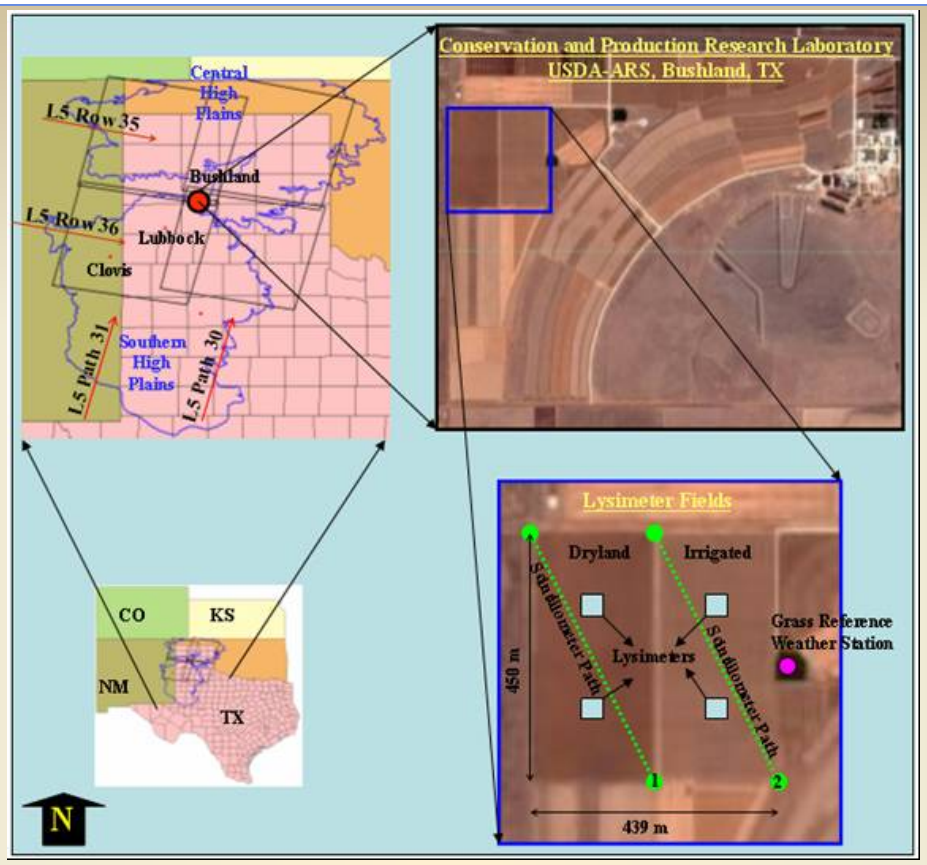

Figure 1

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(1994). The spatial resolution of acquired images was 0.5 m in the shortwave bands and 1.8 m in the thermal infrared band. The flight lines were planned to ensure 30% overlap between parallel flight lines and to guarantee complete coverage over the study area. In addition to aircraft images, 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.

During the 2007 planting season, three LAS were deployed at the CPRL in collaboration with Dr. Bridget Scanlon, University of Texas - Austin: one across two dryland lysimeter fields on the west side, one across two irrigated lysimeter fields on the east side, and one over rangeland (Fig. 1). The orientation of each LAS was selected to have the scintillometer's path perpendicular to the predominant wind direction and to avoid direct sun light on the lenses. Refractive index of air measurements was made on a continuous time scale at 1 Hz and averaged at 15-min intervals, synchronized with the weather station and lysimeter measurement averaging period. In addition, infra-red thermometers, net radiometers and soil heat flux plates were installed near both transmitter and receiver to measure surface temperature, net radiation and soil heat flux over 15-min intervals. The height of each LAS was adjusted to maintain its height above the crop surface throughout the BEAREX07 campaign. For estimating sensible heat flux (H) from the refractive index of air, air temperature and wind speed data are required. 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. In addition, soil water moisture content and continuous surface temperature data were available at several different locations as part of numerous ongoing experiments at the CPRL. Ground truth data for regional land use mapping were collected in a six-county area around the CPRL.

CURRENT STATUS

A comprehensive ground truth database was developed for evaluating remote sensing based ET models. During the BEAREX07 campaign, 25 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. Unfortunately, NASA did not acquire the requested ASTER images for unknown reasons. MODIS data acquired during the BEAREX07 were downloaded

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from the MODIS website. Continuous measurements were made with the LAS systems throughout the 2007 cropping season.

At present, we are geometrically/radiometrically correcting the high resolution aircraft imagery for lens radial distortions and geo-rectifying using common control points to an orthophotoquad base map. The rectified images will be stitched along the flight lines forming image strips. The short wave imagery will be calibrated in terms of reflectance using the system calibration and measurements of incoming solar irradiance measured with an Exotech radiometer placed over a standard reflectance panel with known bi-directional properties, set out at the CPRL at the time of aircraft overpasses. The image strips will be corrected for atmospheric effects using the MODTRAN radiative transfer model. The strips will then be stitched together forming a mosaic covering the entire study area with pixels representing at-surface reflectance. The thermal imagery will be processed in a similar way. The individual thermal images corrected for lens radial distortions will be rectified to the 3-band multispectral mosaic and stitched together into larger image strips along portions of the flight lines. These strips will be combined in a mosaic together to cover image blocks. These rectified image blocks will eventually be combined to form a large thermal mosaic covering the entire study area. The image mosaic will be calibrated first to obtain at-sensor apparent temperatures using the sensor calibration bar at the bottom of each image and then calibrated for atmospheric interference and surface thermal emissivity using MODTRAN (radiative transfer software). 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).

BEAREX08

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 Arid Lands Agricultural Research Center, Maricopa, Arizona.

EXPECTED RESULTS

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.

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MEETINGS & PRESENTATIONS

Bill Rice presented "Use of geographic information systems to influence the selection of sampling site locations for the evaluation of microbial diversity" with Prasanna Gowda at the 107th American Society of Microbiology General Meeting, May 21-25, Toronto, ON, Canada, Abstract 07-GM-A-3995-ASM.

The paper titled "METRIC estimated ET evaluation on the semi-arid Southern High Plains," was presented by Jose Chavez at the AGU Jointly Assembly. Acapulco, Mexico on May 22-26, 2007.

Susan O'Shaughnessy attended the North Plains Research Field/Wheat Field Day on May 24, 2007 at Etter, TX.

Susan O'Shaughnessy attended the International Conference on Biological Senorics in Minneapolis, MN, June 15-17, 2007. Lectured presentation on "IRT Wireless Interface for Automatic Irrigation Scheduling of a Center Pivot System"

Jose Chavez presented the paper titled "Evapotranspiration mapping using METRIC for a region with highly advective conditions." at the 2007 Annual International ASABE Meeting, Centennial Celebration, June 17-20, 2007 in Minneapolis, MN.

The paper titled "A simple empirical stream flow prediction model for ungauged watersheds," was presented by Jose Chavez, at the 2007 Annual International ASABE Meeting, Centennial Celebration, June 17-20, 2007. Minneapolis, MN.

Terry Howell participated in the 100th ASABE Meeting in Minneapolis, Minnesota on June 17-20, 2007 attending the 2010 ASABE/IA Fifth Decennial Irrigation Organizing Committee Meeting and SW-245 and SW-241 Technical Committee meetings.

Susan O'Shaughnessy attended the 2007 Annul International Society of Agricultural and Biological Engineers in Minneapolis, MN on June 18-20, 2007, also presented a poster on "Spectral Imagery Feedback as a Joint Trigger to the TTT Method of Automated Irrigation."

Terry Howell and SWMRU scientists met with the USDA-ARS-SPA leadership team at Bushland, Texas on June 26-27, 2007 to review the Conservation & Production and Research Laboratory research programs

Susan O'Shaughnessy attended the High Plains Livestock 2027, September 5-6, 2007 in Amarillo, TX.

Terry Howell presented "Evapotranspiration and Cotton ET" to the Bridging the Headgate Workshop at Altus, Oklahoma on September 18, 2007 sponsored by the USDA-NRCS.

Terry Howell participated in the 58th ICID Executive Committee Meeting and the Fourth USCID International Conference on Irrigation and Drainage in Sacramento, CA on September 29 to October 6, 2007 and presented the paper "Evapotranspiration of Deficit Irrigated Sorghum and Winter Wheat".

Jose Chavez and Susan O'Shaughnessy attended Texas Section American Society of Agricultural and Biological Engineers 43rd Annual Meeting, Kerrville, TX on October 10-11, 2007

Terry Howell was a team member on the review team for the USDA-ARS Northern Plains Agricultural Research Laboratory at Sidney, Montana on October 23-25, 2007.

Louis Baumhardt, Jose Chavez, Paul Colaizzi, Steve Evett, Chad Ford, Prasanna Gowda, Terry Howell, Robert Schwartz, Judy Tolk and Paul Unger attended the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA. Louis Baumhardt, Jose Chavez, Paul Colaizzi, Steve Evett, Prasanna Gowda, Robert Schwartz presented posters. Steve Evett, Terry Howell and Judy Tolk gave oral presentations.

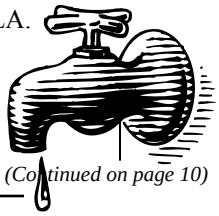
Louis Baumhardt presented a poster on "Evaluating irrigation management strategies to maximize cotton yield and water use efficiency: A simulation analysis." while attending the ASA International Annual Meeting New Orleans, LA, November 4-10, 2007

A poster was presented on Evaluation of Radiation Partitioning Models at Bushland, TX, by Paul Colaizzi on November 5-7 at the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA.

A poster was presented by Jose Chavez on "An Aerodynamic Temperature-based Regional ET Model Evaluation for Texas High Plains' Agricultural Conditions," at the ASA-CSSA-SSSA 2007 International Annual Meetings in November 4-8, 2007, New Orleans, LA.

Judy Tolk presented a talk on "Managing field water supply to enhance water use efficiency" and chaired a session on "Advances in Water Use and Water Use Efficiency" while attending the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA.

Steve Evett chaired a symposium on "Yield Response to Water: Examination of the Role of Crop Models in Predicting Water Use Efficiency" and chaired the



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business meeting of Division A-3 Agroclimatology and Agronomic Modeling while attending the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA. He also was one of the organizers of the symposium "Evaluating Water Flux in the Vadose Zone: Computational Methods and Geostatistical Approaches" in honor of the career of Dr. Art Warrick.

Steve Evett presented a talk on "A Weighing Lysimeter for Crop Water Use Determination in Jordan" at the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA.

Steve Evett presented "Spatial Variability of near-Surface and Profile Water Content: Sensors Impact the Result" at the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA.

Lee Heng presented "Calibration and Testing of FAO AquaCrop Model for Rainfed and Irrigated Maize" with Steve Evett at the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA.

Terry Howell presented "Hourly and Daily Evapotranspiration of Alfalfa under Regional Advection" at the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA.

Robert Schwartz presented "Temperature and Frequency Dependent Time-Domain Reflectometry Water Content Calibrations in Fine-Textured Soils" at the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA.

Prasanna Gowda presented "Bushland Evapotranspiration and Agricultural Remote Sensing Experiment 2007 (BEAREX07)" at the ASA-CSSA-SSSA 2007 International Annual Meetings in Nov. 4-8, 2007, New Orleans, LA.

David Mulla presented "Complexity in watershed scale nitrogen export: Effects of changing climate and management" with Prasanna Gowda at the ASA-CSSA-SSSA 2007 International Annual Meetings, New Orleans, LA, November 4-8, 2007.

Prasanna Gowda served as a chairperson for the session "Assessing soil management and properties" at the ASA-CSSA-SSSA 2007 International Annual Meetings, New Orleans, LA, November 4-8, 2007.

Terry Howell presented the paper "Hourly and Daily Evapotranspiration of Alfalfa under Regional Advection" at the 100th ASA-CSSA-SSSA Meeting on November 4-8, 2007 at New Orleans, LA. He was a co-author on seven other presentations and posters.

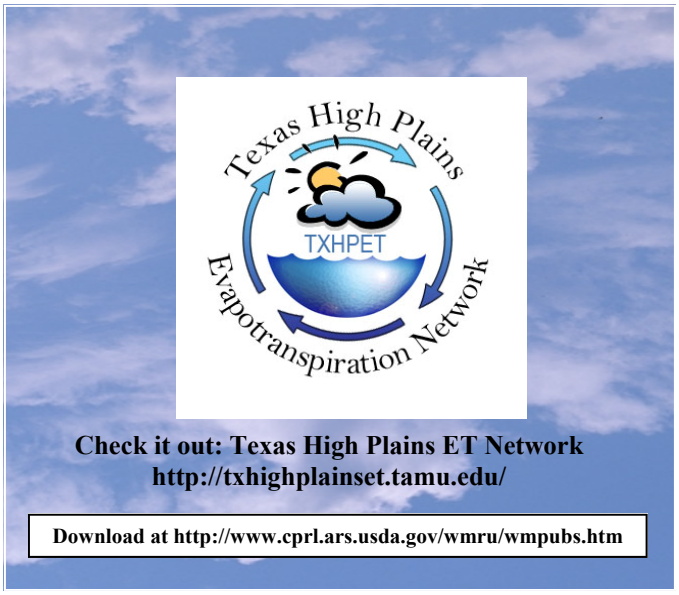
Robert Schwartz presented the paper "Seasonal and long term changes in manure phosphorus availability" at the Nutrient Management Training, Texas A&M Research & Extension Center, Amarillo, TX. November 20, 2007.

Terry Howell and Steve Evett hosted Carole Abourached from Oregon State University to acquire validation data on alfalfa for the FAO AquaCrop model on November 27, 2007.

Prasanna Gowda served as a chairperson for the session "Scintillometry and Applications in Hydrology and Meteorology" at the AGU Fall Meeting, December 10-14 in San Francisco, CA.

Jose Chavez, Terry Howell and Susan O'Shaughnessy attended the annual Irrigation Association Meeting & Exposition in San Diego, CA, December 9-11, 2007. Terry Howell presented the paper "Is Irrigation Real or Am I Imagining It?" and chaired the Technical Program Committee meeting. Susan O'Shaughnessy presented the paper "Wireless Infrared Thermometers for Automated Irrigation Scheduling of a Center Pivot." Jose Chavez presented the paper "Evaluating Three Evapotranspiration Mapping Algorithms with Lysimetric Data in the Semi-arid Texas High Plains."

Prasanna Gowda presented the paper "Preliminary Evaluation of sensible heat flux measurements from a Large Aperture Scintillometer using lysimetric data" at the AGU Fall Meeting, December 10-14, 2007 in San Francisco, CA.



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