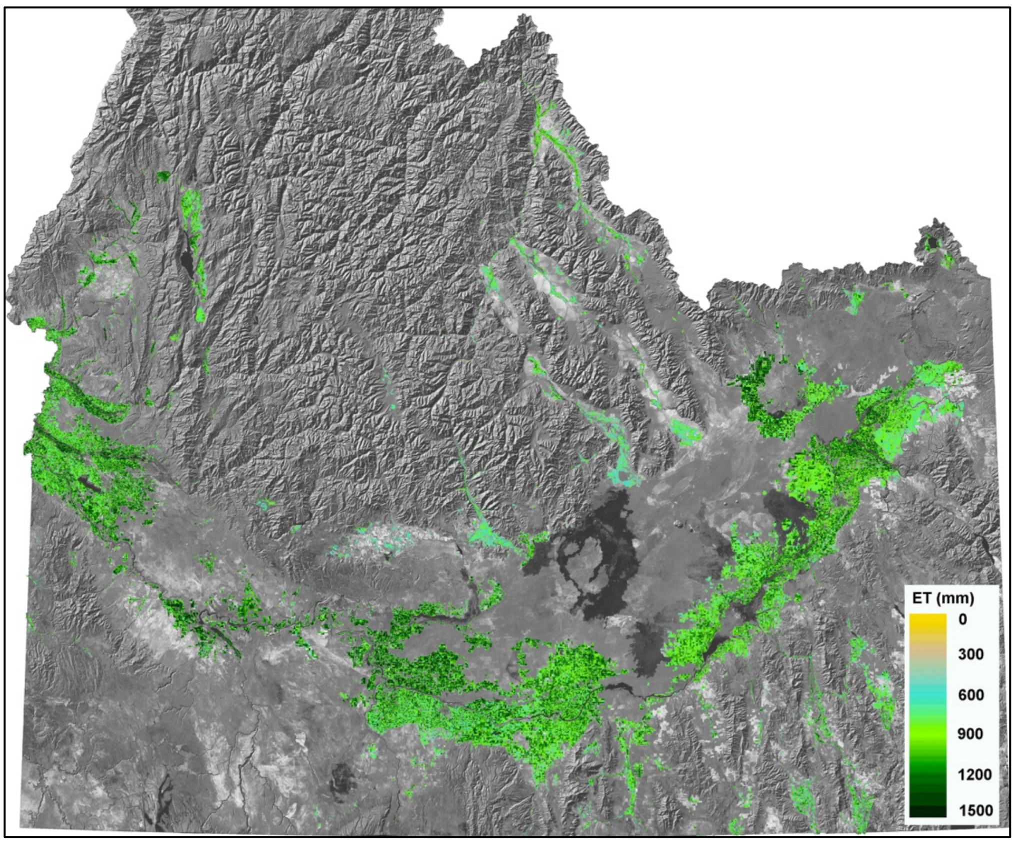
Final Report

2011 Western States Workshop on Remote Sensing of Evapotranspiration

October 12 and 13, 2011
Boise, Idaho



Southern Idaho Evapotranspiration from Irrigated Agriculture April-October, 2000

Compiled by

Anthony Morse
Spatial Analysis Group, LLC.

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I. Introduction

This is a summary of presentations made at the 2011 Western States' Evapotranspiration workshop held in Boise, Idaho on October 12th and 13th. The conference was sponsored by the following organizations:

The National Aeronautics and Space Administration (NASA)
The U.S. Geological Survey (USGS)
Idaho Water Engineering, Inc. (IWI)
The University of Idaho (UI)
The Desert Research Institute (DRI)
The Group on Earth Observation (GEO)
The Idaho Department of Water Resources (IDWR)
The Idaho National Laboratory (INL)
The Idaho Water Resources Research Institute (IWRRI)
The National Oceanographic and Atmospheric Administration (NOAA)
The University of Nevada Reno (UNR)
The U.S. Department of Agriculture (USDA)

NASA generously provided financial support in the form of a grant issued under the ROSES program.

This report is structured in a way to describe the presentations as a function of the stated workshop objectives, without reference to specific authors. The workshop agenda is listed in Appendix A. The PowerPoint presentations used by each presenter can be accessed on the Web at http://www.westernstatesetworkshop.com/past-events/boise-2011. Those PowerPoint presentations were the basis of this report and. In some cases it was necessary to add text not included by the authors.

II. Workshop Purpose

Water managers and users have a tremendous need for more and better information about consumptive water use.. Remote sensing of evapotranspiration (ET) is a powerful, emerging tool that enables water-resource managers to quantify and map ET with unprecedented detail.

III. Workshop Genesis

The 2011 Western States' Workshop on Remote Sensing of Evapotranspiration was a follow-on to the NASA/USDA Conference on remote sensing of ET held in

Silver Spring, MD in April, 2011. That workshop was focused on research and climate-related issues for ET.

The specific workshop goals were as follows: 1) Define the needs and requirements for evapotranspiration data in weather and climate studies, in natural and agro-ecosystem monitoring, and in water resource management. 2) Review the methods used to measure and model evapotranspiration. 3) Assess surface and satellite observation systems required to support ET measurement, modeling and evaluation. 4) Assess the feasibility of developing a proposal for a task on evapotranspiration for the 2012-2015 GEO Work Plan. 5) Explore the level of support and consensus for developing a strategy for establishing evapotranspiration as an Essential Climate Variable (ECV) within the Global Climate Observing System (GCOS) framework. 6) Develop an applied research community of ET, and the Thermal Band in general. 7) Better understand the applied research requirements (near-term to long-term). 8) Continue to build a strong argument for ET-related observations, research, and technology to support water resource applications.

Water Resource professionals now have at their disposal a new set of computer modeling tools that are supported by nearly 30 years of archived data that can be used to map ET. Within the last few years, a small group of people has developed applications using those models and data. This workshop is was designed to: 1) compliment the NASA/USDA workshop by addressing the operational use of ET for water resource issues in the arid western United States, 2) bring together those people who have developed applications with those who have a need and a desire to learn more the remote sensing of ET; and 3) expand the use and development of ET models and data in order to address real-world water resources issues. The workshop objectives reflected that design.

IV. Workshop Objectives

1.To provide basic information regarding existing, proven technology used for remote sensing to measure and model evapotranspiration.

2.To identify user needs for the development of applications to use this technology.

3. To provide an opportunity for developers and users of this technology to identify potential applications in the Western States.

4. To create a list of actions for participants to pursue for implementation of applications throughout the Western States.

V. Workshop Results

1. Perspectives

The results of the workshop are grouped according to the workshop objectives. The results are presented as an integrated body of work without attributing specific ideas to specific authors.

> Objective 1: To provide basic information regarding existing, proven technology used for remote sensing to measure and model evapotranspiration.

<u>General Perspective and Overview of Techniques</u> – Rick Allen, UI

The basic challenge is that ET is variable with space and time. Landsat is the best available platform to capture that spatial and temporal variability because Landsat's large scene size (10,000 square miles) coupled with a small pixel size that enables pixel-by pixel ET to be aggregated to compute ET for agricultural fields. It is at the field level that water rights and best management practices are administered and that irrigators manage water.

There are several methods by which to map ET using satellite images 1) full energy balance models, 2) vegetation index models, and 3) simplified energy balance models. Full energy balance models, in turn can be subdivided into research models such as those used by the U.S. Department of Agriculture, and operational models such as SEBAL (the Surface Energy Balance Algorithm for Land) and METRIC (Measuring Evapotranspiration with High Resolution and Internalized Calibration).

Energy balance models are more desirable than traditional methods of ET estimation for operational applications. Energy balance models yield actual ET and can detect impacts on ET caused by such factors as: 1) water shortage, 2) disease,3) crop variety, 4) planting density, 5) cropping dates, 6) salinity, and 7) agricultural management practices. Traditional methods, which yield potential ET, are less reliable as they usually estimate ET on a countywide basis unless a complete agricultural census is available for a county. These estimates are impacted by uncertainty in planting and harvesting dates of individual fields, and by uncertainty in agronomic and water management effects.

Energy balance models are superior to vegetation index models such as NDVI. Energy balance models measure the evaporation from wet soil that is not detected by vegetation index models, as illustrated by Figure 1.

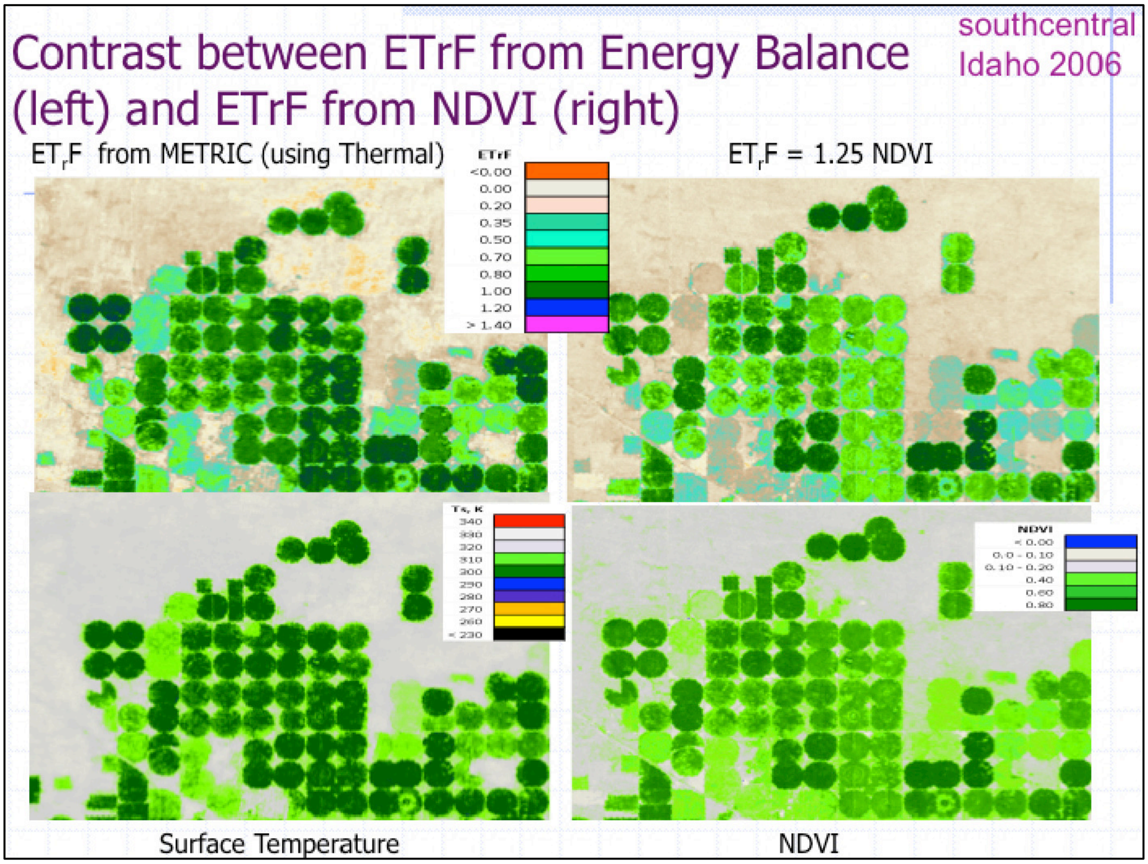


Figure 1. The contrast between ETrF from Energy Balance (left) and from NDVI (right).

Landsat is superior to other satellites as a data-source for computing and mapping ET.
Figure 2 illustrates the advantage Landsat has over MODIS in pixel size. Although MODIS has a shorter return time than Landsat, the smaller Landsat pixel size more than compensates for the shorter MODIS return time.

Energy balance models are not without their own challenges. These challenges include variations in surface temperature, air temperature, albedo, net radiation, soil heat flux, aerodynamic resistance, wind speed, and extrapolation of instantaneous ET to 24-hour ET. Nevertheless, these challenges have solutions. When models calibrate against ET at the extremes and the input biases are incorporated, then the biases fall out during the final estimation process. The model results compare well with ET as measured by weighing lysimeters, as illustrated by Figure 3. Landsat scenes that have portions obscured by clouds can be masked. Using a gridded daily evaporation process model can minimize the effect of rain events.

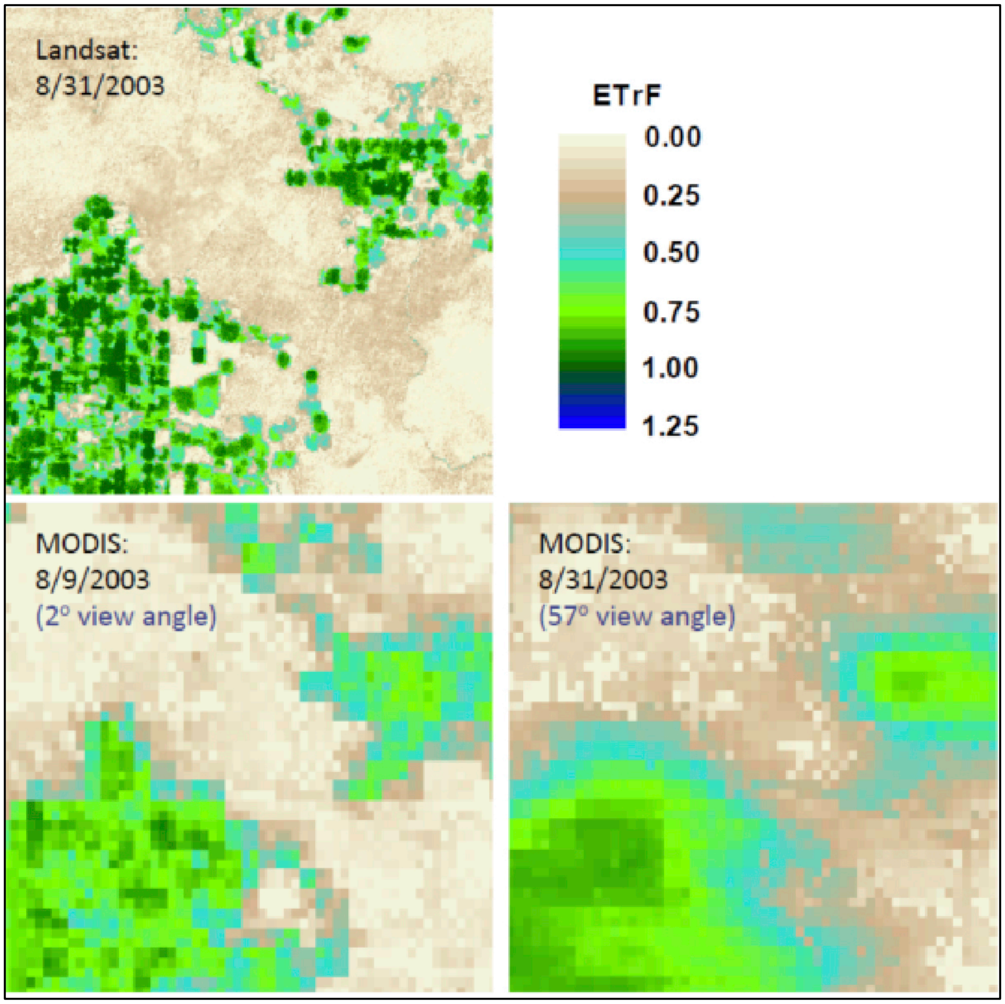


Figure 2. Comparison of the Landsat pixel size and the MODIS size.

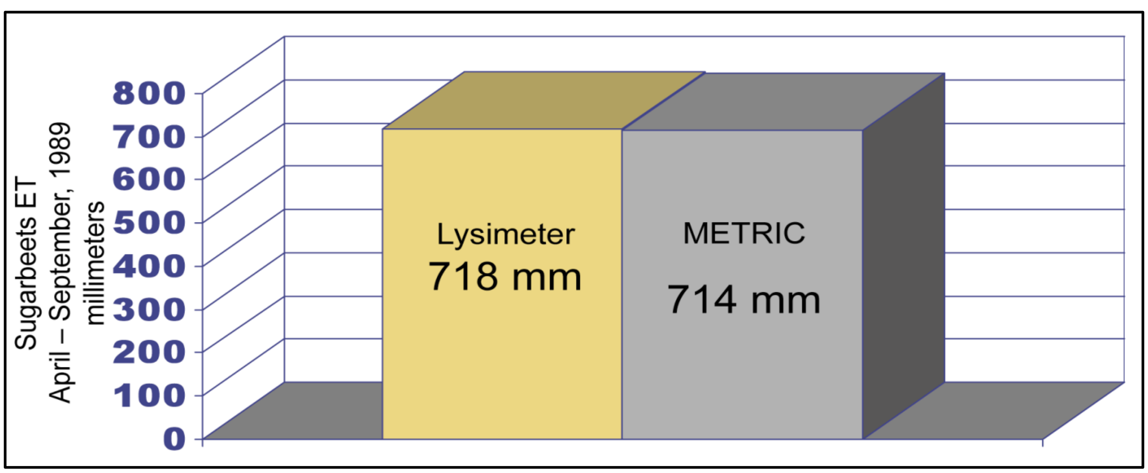


Figure 3. Comparison of seasonal ET of a sugar beet field from METRIC with ET measured by a weighing lysimeter.

NASA Perspectives - Ed Scheffner

Other satellites besides Landsat have the potential to be for ET mapping using the energy balance approach. NASA has several satellites in orbit now and in the planning stages that will have thermal sensors. The satellites in orbit now that have thermal capability, are Aqua and Terra, both of which carry MODIS. Of the satellites that are planned in support of the Decadal Survey, HyspIRI will have thermal capability. HyspIRI will have seven bands in the far infrared and thermal parts of the spectrum.

Landsat will continue to play an integral role in ET mapping. Landsat 5 remains operational and Landsat 7 is operational with limitations. The Landsat Data Continuity Mission, scheduled for launch in December 2012, will become Landsat 8 on launch, and will have two thermal bands. There is no funded plan for a 9^{th} Landsat satellite.

HyspIRI (Hyperspectral Infrared Imager) is a "tier2" Decadal Survey satellite. It has 10 nm spectral resolution between 380 and 2500 nm, with a 19-day repeat cycle. As yet, there is no launch date scheduled.

USDA Perspectives - Bill Kustas

The U.S. Department of Agriculture, Agriculture Research Service (UDSA/ARS) has an active program that has contributed remote sensing tools for ET estimation. These tools have been applied in the three areas as follows:

1) Improved Prediction of Irrigation Water Use for California Crops from Remote Sensing

The goal was to develop a relationship between ground cover and the basal crop coefficient (K_{cb}) for horticultural crops. Kc is related to light interception by ground cover. Regressing NDVI against fractional ground cover for a data set of 12 crops results in an r^2 of .97. Combining NDVI from Landsat with weather data, reference ET and crop class results in a map of basal crop ET that can be delivered to mobile devices via text message or other means.

2) Cotton Evapotranspiration and Yield Variations with Canopy temperature and Irrigation Deficit

Cotton ET and yield vary greatly with irrigation deficit, but indirectly due to cotton's indeterminate phenology. This project investigated the relationships between crop water stress and irrigation deficit, leaf water potential, and yield.

Cotton yield and water use efficiency were modeled using AquaCrop and the results were compared with field measurements under four irrigation levels ranging from 0% to 100% replenishment of soil water depletion below field capacity.

3) Multiple-Scale ET – Merging Multiple Satellite Observations

Drought monitoring needs multi-scale data. Landsat-based ET models validate evaporative stress indices derived from large-area coverage of GOES and MODIS platforms.

<u>USGS Perspectives</u> - Jim Verdin

The U.S. Geological Survey provides estimates of evapotranspiration for WaterSMART. WaterSMART is a Department of the Interior program that focuses on improving water conservation and helping water-resource managers make sound decisions about water use. The work done by the USGS includes water availability studies in support of regional aquifer studies, especially in the Colorado River Basin, and evaluation of existing ET remote sensing activities. The existing activities involve providing guidelines and specifications for remote sensing of ET, monitoring of fallowed land, and evaluating crop-water productivity.

USGS uses MODIS data to compute ET using a Simplified Surface Energy Balance (SSEB) model. The SSEB ET data are used in the Columbia Plateau Regional Aquifer Study and for estimating ET by HUC-8 basins of the Colorado River Basin. In a comparison of SSEB ET with ET measured by four lysimeters at Bushland, Texas, the R^2 was .84.

<u>Western States Water Council</u> - Tony Willardson, Executive Director

“Needs and Strategies for a Sustainable Future”

The Western States Water Council was founded at the Western Governors' Conference in 1965. The conference based the WSWC on two resolutions: 1) The future growth of the western states depends upon the availability of adequate quantities of water at suitable quality; and 2) The need for accurate and unbiased appraisal of present and future requirements of each area of the West and for the most equitable means of providing for the meeting of such requirements demands a regional effort.

The WSWC works in six general areas of interest: 1) Growth and Water Policy, 2) Meeting Future Water Demands, 3) Water Infrastructure Needs and

Strategies, 4) Resolution of Indian Water Rights Claims, 5) Climate Change Impacts, and 6) ESA & Protecting Aquatic Species. Basic to all six areas of interest are three questions: 1) How much water do we have? 2) How much water do we need? 3) Do we have enough? In all these matters, there is a general lack of data on regional water needs and on past, present, and future uses.

There is a truism that applies to many things, but certainly to water: “We cannot manage what we cannot measure.” To that we should add the need to monitor our water resources in order to understand trends as quickly as possible.

The WSWC has identified priority needs for water information. These needs are 1) available surface and ground water supplies, 2) present water uses, 3) snowpack (being done by NRCS), 4) streamflow (being done by USGS), 5) evapotranspiration, and 6) climate change impacts. The Council’s interest in working with NASA on Landsat 8 issues stemmed from the importance of being able to monitor evapotranspiration.

The importance of using Landsat as a data source is in the combination of its pixel size and the area covered by one of its images. Landsat’s pixels are well-suited for analyzing individual agricultural fields, and it is at the field level that water is managed in the western states. That importance was recognized and well described in a letter dated May 5, 2008 from 12 western-state members of the U.S. Senate to the Senate Appropriations Subcommittee on Commerce, Justice, and Science.

The WSWC continues to believe that Landsat and evapotranspiration data derived from Landsat are critical to good water management in the west because good decision making and risk management require sound science and adequate data. The states have a primary and critical role in western water management. Sustainable water use in the West will depend in large part on state initiative and innovation, and the application of evapotranspiration data derived from Landsat thermal infrared sensor represents an important innovation.

That innovation is a critical tool for measuring water use and facilitating transfers between uses. Continuing Federal financial support is essential to support the present use of Landsat data for ET measurements, and to enable future, innovative applications.

2. Successful Applications for Water Management and Decision-Making

Idaho –Bill Kramber

Between 2000 and the present, the Idaho Department of Water Resources has aggressively developed applications based on output from the METRIC ET model. By the end of 2011, IDWR has used ET maps and data for eleven separate applications. These applications are:
ET by land use/land cover type for water planning, 2) monitoring aquifer depletion, 3) computing water balances for hydrologic models, 4) balancing irrigation with the needs of anadromous fish, 5) legal findings of fact, 6) monitoring agricultural water use, 7) evaluating water use for water-rights buy-back programs, 8) assessing water rights compliance, 9) administering water rights, 10) analyzing the basis for water right curtailment orders, and 11) as the basis of water negotiations with Tribes. In monitoring aquifer depletion, IDWR discovered that using Landsat and METRIC, monitoring costs could be reduced from $119 per well to $32 per well.

Colorado and Wyoming - Tim Martin, Riverside Technology, Inc.
Riverside Technology, Inc. (RTI) has used METRIC-computed ET in several areas. RTI has monitored consumptive use by irrigated agriculture in support of an interstate water compact over the last five years in the North Platte River Basin of Wyoming and Nebraska. RTI compared METRIC ET to a State-of-Colorado consumptive use model in the South Platte River Basin under provisions of a NASA ROSES grant. Also as part of a ROSES grant, RTI applied METRIC ET as an input to the Upper Rio Grande Water Operations Model for the State of New Mexico. RTI worked for The World Bank to monitor and evaluate irrigation systems in Morocco. In an ongoing project, RTI is working for the Wyoming State Engineer to assess consumptive use in Wyoming.

In all the RTI projects, the METRIC-derived ET proved to be valuable for several reasons: 1) Analysts were able to assess actual ET when irrigation was both spatially and temporally complex. 2) The ET estimates were unbiased. 3) The projects were able to accomplish pre- and post-rehabilitation assessment. 4) River compacts and treaties can be monitored. 5) Conflicts over water rights can be resolved. 6) ET can be used as input to surface and ground water models. 7) The ET data can be input to water management decision support systems.

In particular, the reliable, spatially-distributed ET data used with GIS data and analysis allow very detailed analysis and understanding of ET at the parcel level.

<u>Montana, Oregon, Wyoming, New Mexico, Idaho, Nebraska, and California</u> – Rick Allen, UI

The University of Idaho, and it’s partners and collaborators have completed 17 projects applying METRIC ET data in seven western states.

Idaho – METRIC ET data were used for two applications. First, the data were used to assess the performance of irrigation canal companies in order to understand the relationship between the amount of surface water withdrawn from the Snake River to the amount of water consumptively used. Second, the data were used to understand the difference in ET between fields irrigated by gravity spreading versus center-pivot sprinkling.

New Mexico – UI used METRIC ET data to assess the impact of salt cedar on the flow of the Rio Grande, and to quantify the change in the ET of irrigated agriculture due to increased pecan production.

California – UI assessed the impact of Imperial Valley agriculture and on the Salton Sea from a water transfer of 15% of the Imperial Valley water supply to municipal uses out of the basin.

Montana – ET data were used to estimate ground water recharge and compute water balances in four basins for the USGS and the Montana Bureau of Mining and Geology. UI also worked on the Flathead Indian Reservation to improve stream flows for endangered fish by better managing irrigation impacts.

Wyoming – UI worked with Riverside Technology, Inc. on the North Platte Water Decree.

Oregon – UI worked in the Klamath Basin with the US Forest Service to assess the impact of stock water use on wetland areas, and with USGS to assess consumptive use by irrigated agriculture.

Nebraska – UI worked with the University of Nebraska and the Central Platte Natural Resource District using METRIC ET data to estimate aquifer recharge in the Nebraska panhandle for the period April 1 to October 31, 1997.

Nevada – UI worked with the Desert Research Institute using METRIC ET data in assessing water transfers from irrigated agriculture to municipal use.

Nevada - Justin Huntington, Desert Research Institute
Water is a very expensive commodity in Nevada. The going price for a municipality to purchase 1 acre-foot of water is approximately $20,000. At that rate, a single 125-acre field that is irrigated with 4 acre-feet per year by center pivot will yield about $10,000,000. Nevada law limits new-use transfers to the mean annual net irrigation water requirement (NWIR). Until recently, there was no consistent method to estimate that NWIR, and the best estimates were based on Blaney-Criddle potential ET.

DRI has developed new tools to improve the NWIR. These tools are a basin-by-basin estimate of NWIR based on American Society of Civil Engineers Standardized Penman-Monteith ET equation, and METRIC ET for specific basins. The use of remote sensing and METRIC is the best way, and likely the only way, to estimate the actual consumptive use over large areas. The METRIC data are used specifically for several reasons. 1) To analyze ET for water right transfers in order that the water that is purchased is “wet” water. 2) To confirm crop coefficients. 3) USGS is using DRI METRIC ET data to improve the calibration of ground water flow models in the Carson Valley. In the future, DRI envisions using METRIC ET data to 1) compute actual seasonal ET by county, and 2) update the water balance for each county.

DRI has made ET data available without cost on their web portal. There is some concern that remote sensing of ET may yield too much information for some people’s comfort. Nevertheless, water managers cannot afford to ignore reality.

California – Forrest Melton, California State University, Monterrey Bay
The NASA Applied Sciences Program supports research in California to 1) integrate surface and satellite data to map crop cover, crop coefficients and ET; 2) develop new information to manage irrigation water; and 3) to evaluate the relationships among ET, soil moisture, and irrigation practices.

California – Bryan Thoreson, SEBAL North America

Remote sensing of ET has enjoyed commercial success in California. SEBAL North America, Inc. (SNA) has applied the SEBAL ET model to commercial projects in the Imperial Valley, the Central Delta, and the San Joaquin Valley.

For the Imperial Irrigation District, SNA processed Twelve Landsat 5 images between October, 1997 and November, 1998. The objective of the analysis was to quantify the actual ET at scales ranging from individual fields to the entire Imperial Irrigation District. The actual ET would allow water resource planners to evaluate actual ET in relation to estimated potential ET, which would provide information on potential impacts of implementing water conservation measures. on crop ET and yields.

SNA processed eight Landsat images between March and September 2008 for the California Department of Water Resources (CDWR). The objective of the analysis was to use actual ET to improve CDWR’s estimate of water demand and consumptive use in the Central Delta.

In the San Joaquin Valley, SNA processed nine Landsat scenes in the 2008 growing season. The analysis used the shadow value of water and the change in actual ET to improve the understanding of the economic value of agricultural production.

3. Specific Challenges in Remote Sensing of Evapotranspiration

Rick Allen, UI
Justin Huntington, DRI
Jan Hendrickx, NMT
Tony Morse, SAG
Christopher Neale, USU

The use of energy-balance models to compute ET has no shortage of challenges. These challenges include 1) terrain roughness and wind-speed calculations in non-agricultural areas with rough terrain; 2) processing areas that are particularly susceptible to cloud cover; 3) compensating for precipitation events that have the potential to bias ET calculations; 4) compensating for the data gaps in Landsat 7 caused by the scan-line corrector error; 5) developing a sharpening algorithm to compensate for the difference between 120-meter thermal pixels and 30-meter visible and short wave pixels in Landsat 5 data; and 6) developing an algorithm for computing ET from open water.

All these challenges have solutions, although all the solutions can be improved.

Forests, Mountains, Grasslands, Riparian – Rick Allen, University of Idaho

Energy balance models include equations to account for the effects of wind speed and turbulence. Those equations are reasonably straight-forward for uniform vegetation canopies on flat ground, but become complex problems for variable canopies on variable terrain. Similarly, thermal emission and reflectance presents some complex modeling problems for variable terrain.

Cloud Compensation – Jan Hendrickx, New Mexico Tech

"So many things I would have done
But clouds got in my way" – Joni Mitchell

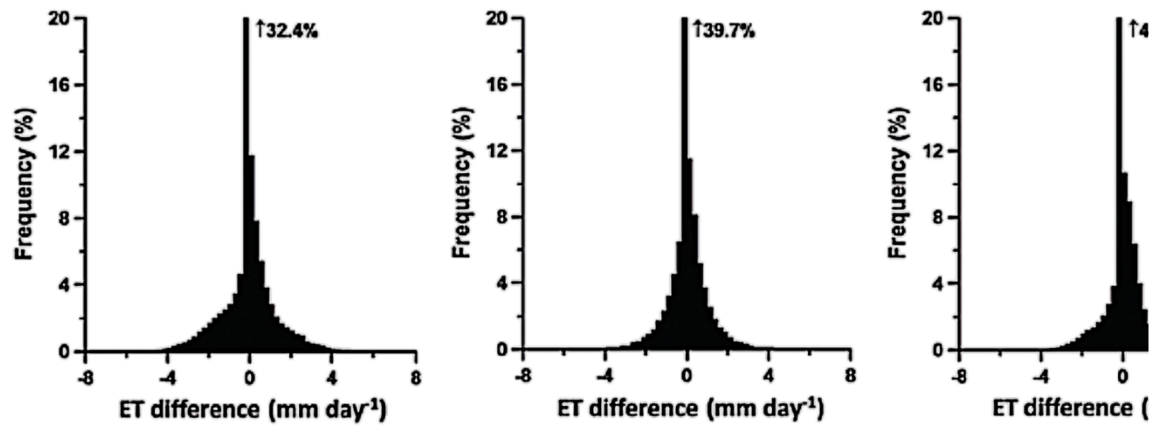
There are two ways to compensate for clouds: 1) if there are few clouds, interpolate in time; 2) if there are many clouds, down-scale a MODIS ET map to Landsat scale. In the second case, the interesting issues are 1) whether or not a MODIS ET map can be down-scaled to Landsat scale, and 2) what the accuracy would be.

In scaling Landsat up to MODIS, the results are good. For two dates on a 9 km by 6 km area along the Rio Grande in New Mexico, Landsat ET data were up-scaled to the MODIS pixel size of 250 meters square. Comparing the result to MODIS ET data, the differences were minimal, as summarized by Table 1.

June 16, 2002		September 14, 2000	
mean difference	standard deviation	mean difference	standard deviation
mm/day	mm/day	mm/day	mm/day
0.41	0.39	0.31	0.37

Table 1. The mean difference and standard deviation for 2 dates of imagery between Landsat ET data up-
scaled to 250-meter pixels and MODIS 250-meter pixels.

Down-scaling is more complex. Nevertheless, in evaluating three down-sizing algorithms, the results proved reasonable, as illustrated by Figure 4.



s=1.20	s=0.88	s=0.89
Pixel by pixel difference	Subtraction	Regression

Figure 4. Comparison of three methods of downsizing MODIS ET maps to Landsat-scale ET maps.

<u>Evaporation From Open Water – Rick Allen, University of Idaho</u>

Using an energy balance model to compute evaporation from open water is problematic. The G term in the general energy balance equation (ET=Rn-H-G) is distorted by the transparency of water. There is a potential solution from using a full aerodynamic estimate based on water near constant water temperature and RH across the image.

Conversion of Agricultural Land to Urban Use – Tony Morse, Spatial Analysis Group

Water Planners at the Idaho Department of Water Resources needed to understand how water use would change in the future as agricultural land is subdivided for housing. At one time, there was some controversy about how much water would be needed by a subdivision: whether it was less or more than agriculture. IDWR had available polygons of land use/land cover that were generated from large-scale aerial photographs flown in 2000. IDWR also had seasonal ET output from METRIC for the period 3/31/2000 thru 10/31/2000. A simple overlay of the polygons on the ET data resulted in the results summarized in Table 2.

Seasonal ET in MM	Standard Deviation in MM	Area in Hectares	Land-Use/Land-Cover Type
1,025	285	5,862	Wetland
924	165	5,344	Water
826	252	2,057	Recreation
820	212	2,711	Perennial
812	189	141,075	Irrigated Crops
731	203	2,745	Canal
684	157	4,126	Urban Residential
657	192	10,164	Rural Residential
609	188	2,243	Farmstead
606	146	11,516	New Subdivision
552	256	232	Sewage Treatment
548	263	2,120	Public Areas
536	243	2,853	Other Agriculture
524	182	604	Dairy
479	205	1,691	Feedlot
467	193	129	Junk Yard
459	211	1,837	Abandoned Agriculture
436	215	3,042	Idle Agriculture
420	222	2,313	Transportation
380	196	5,762	Commercial/Industrial
335	258	1,912	Barren
298	239	12,742	Unclassified
242	160	90,647	Rangeland
237	112	18	Petroleum Tank Farm

Table 2. Seasonal ET by land use/land cover class for 2000 in the lower Boise River Valley, Idaho.

Intercomparison of Remote Sensing Methods for Agriculture and Riparian Systems in Palo Verde, Ca -Christopher Neale, Utah State University

This was a blind comparison of the ability of 6 ET models to map ET on both irrigated land and riparian land. Landsat scenes from 2007 and 2008 and corresponding weather data were distributed to the teams. The 6 models were 1) Remote Sensing Model (Bowling Green State University), 2) Remotely Sensed Dual Coefficient Method (HydroBio), 3) METRIC (University of Idaho), 4) ReSET (Colorado State University), 5) ALEXI-DisALEXI (U.S. Department of Agriculture), 6) Regional ET Estimation Model (New Mexico State University). The results from each model were compared to a single set of data recorded by flux towers on the ground.

All models tended to over-predict ET in the riparian forest. In the irrigated areas, the models based on a vegetation index under-predicted ET, while METRIC did well.

4. Dealing with Challenges

a. Time Integration and Spatial Resolution

Jan Hendrickx

The central question with time integration is this: How can Landsat scenes taken once every 17 days be used for hydrologic modeling over time periods of several weeks to 30 years? ET, which is a capricious flux variable, can be stabilized by incorporating soil moisture in a hydrologic model.

Rick Allen

METRIC adjusts for between-overpass ET and for precipitation events. METRIC can compute continuous ET on a per-pixel basis even though Landsat scenes are acquired every 17 days. METRIC has features that enable continuous calculation. METRIC computes reference ET using weather data from the U.S. Bureau of Reclamation's AgriMet sites, and then computes a reference ET fraction. A spline function interpolates reference ET fraction between Landsat overpass dates as illustrated by Figure 5.

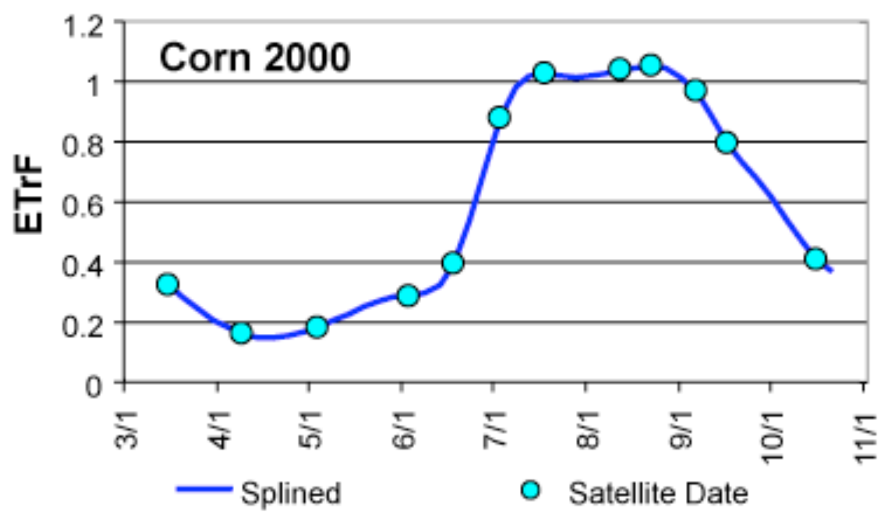


Figure 5. The spline of Reference ET fraction with Landsat overpass dates for corn through a growing season.

Using a daily water-balance model with gridded precipitation data adjusts for rain events that can bias METRIC, as illustrated by Figure 6.

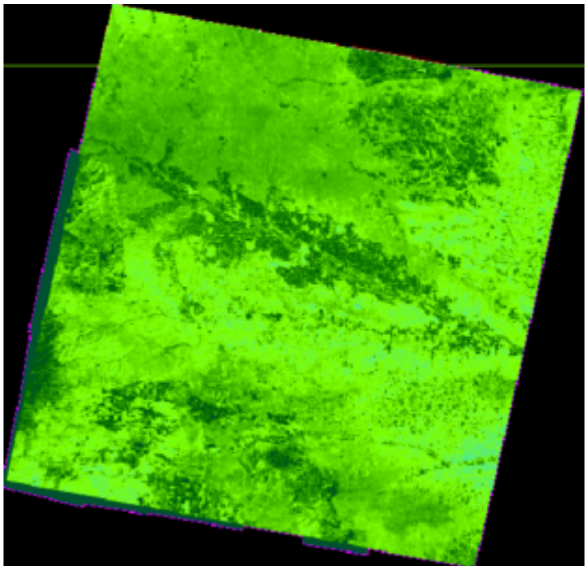


Figure 6-a. ET image from 8/13/1997 not adjusted for soil background evaporation.

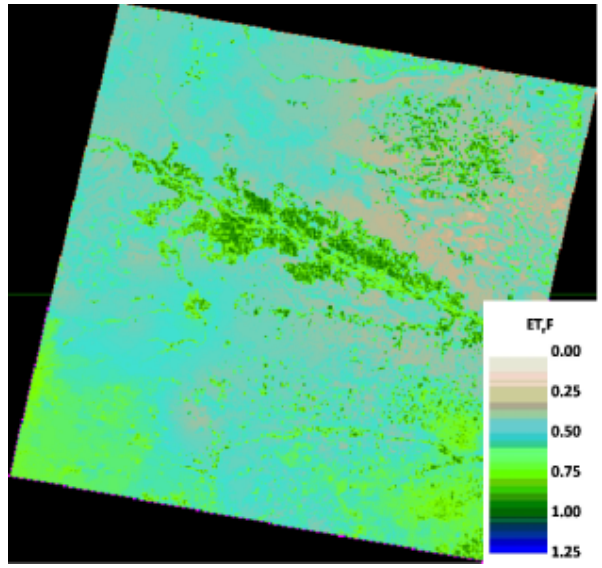


Figure 6-b. ET image from 8/13/1997 adjusted for soil background evaporation.

Justin Huntington

For the state of Nevada, scale has 3 components: 1) accuracy, 2) spatial, and 3) temporal. Accuracy should be approximately ± 10%. The spatial scale is in the range of 30 to 120 meters, square, which works well for agricultural fields. And the temporal scale for agricultural applications is annual, but is quasi semi-state for phreatophytes.

In Nevada, the maximum annual appropriation for groundwater is based on the steady-state aquifer recharge, or natural groundwater discharge. It is easier to estimate groundwater ET than it is to estimate recharge. Therefore, phreatophyte ET is important.

However, remote sensing of ET can be problematic. The standard energy balance ET equation, ET=Rn-H-G, can have errors in the H and Rn terms that are larger than the ET. Precipitation events can also increase uncertainty. The impact of uncertainty in ET computations can correspond to tens of millions of dollars.

b. Resource Requirements

Idaho Experiences – Hal N. Anderson
Having a senior executive champion is key to making the risky and potentially expensive investment in new technology however The “Bleeding Edge” is not a comfortable place for most Government Executives. There is a need to focus on a business process that is important but that can continue while development effort is on-going. How to use contractors and or University researchers needs to be well thought out. It is very important to have the agency staff involved in actually doing the work. Beware of mission creep with contractors. Federal grant support provided Idaho the necessary resources and incentive to “jump in”. One thing that Idaho never did was to deliberately strategize a transition from a grant-funded program to a state funded business process.

Entities that are engaged in ET application programs should consider a long term strategy early in the technology development process, however flexibility is a premium element. Finding the right agency staff to lead the effort is vital to success. Hire the technical expert or train the business process expert, this is one of the more difficult issues to resolve.

One of Idaho’s greatest challenges was expanding the technology use beyond the initial planning applications to include the regulatory business processes primarily due to institutional compartmentalization. Operational questions that were challenging in Idaho related to having the Remote Sensing and GIS programs separate organizational units or integrated within business processes they were supporting. There was also significant debate about assigning ET/Remote Sensing program to the Information Technology group and not to the programs their products were supporting.

Nevada Experiences – Adam Sullivan Nevada Dept. of Water Resources

The Nevada Department of Water Resources (NDWR) needs groundwater discharge by basin to calibrate basin yield, and needs field-scale ET to assess interbasin transfer requests and requests for change in manner of use. NDWR wants to use the best science available and wants to be able to do the assessments in-house. To address these needs, the Nevada State Engineer has found a source of external funding, committed staff for 5 years, and established a relationship with research cooperators.

Commercial Perspectives – Bryan Thoreson, SEBAL North America, Inc.

From the commercial perspective, the resource requirements are primarily human and fiscal. As to human resources, specialized skills are needed to successfully implement energy-balance models using remote sensing data. The people running the models need to understand atmospheric physics, need to be proficient in the use of geographic information systems, and need a practical understanding of crop water needs, growth characteristics, and on-farm irrigation practices. These skills are not ones that can be learned once and used without updating through continuing education.

The costs to run energy-balance models can be significant. Because the technology needed to implement an energy-balance model is complex, extensive communication is needed with potential and existing clients. The costs to design applications and process data can be large.

Intermountain West Experiences – Rick Allen, University of Idaho

The University of Idaho has worked with three states processing METRIC data: Idaho, Montana, and Wyoming. The working relationships generally have been designed to get the states processing Landsat data through METRIC with minimal supervision by UI personnel.

UI and the Idaho Department of Water Resources have the longest-standing relationship, which began in 2000 and continues. UI has provided training to IDWR personnel and provides code updates. IDWR personnel run the METRIC model in-house. UI personnel review the results for IDWR. UI also processes some Landsat data under contract with IDWR.

In Montana, UI has been working with the Montana Department of Natural Resources and Conservation to process some data and to train MDNRC personnel in running METRIC. The Montana Bureau of Mines and Geology contracted with UI to deliver ET products.

UI is working with a private contractor under contract to the Wyoming State Engineer to process ET data in the Colorado River Basin.

c. What Worked and What Did Not Work

<u>U.S. Bureau of Reclamation</u> – Dave Ekhardt, USBOR

The USBOR uses an energy balance ET model in California's Sacramento Valley, and in the Colorado River Basin. The energy-balance model is called ReSET, which was developed at Colorado State University from an early version of SEBAL, and has since been modified by USBOR personnel.

USBOR produces an annual report on the consumptive use of water in the Colorado River Basin. In these reports, consumptive use is computed as potential ET using the Blaney-Criddle equation. In a typical year, at least 30% of the irrigated land in the basin does not receive a full allocation of water. The Blaney-Criddle equation is unable to account for that shortage, and the consumptive use statistics include that error.

In the Sacramento Valley, USBOR estimates the ET of pasture land for use in water transfer negotiations. The Valley is excellent for ET estimation because of large fields, hot and dry summers, very little cloud cover, good weather data, and because the Valley in the center of a Landsat path.

In general, ReSET worked well. However, ReSET overestimated ET in the spring when the temperature, the vapor pressure deficit, and the wind speed were low, and overestimated ET in the autumn when the reverse was true. USBOR found that using ReSET resulted in: 1) ET for cold pixels that was about 30% low; 2) applying an empirically-derived correction to the 24-hour dswrf data was about 15% low; 3) modifying the Rn/24 estimates by using a new T defined as modified surface irradiance divided by top-of-atmosphere irradiance was about 10% low; 4) a good match results from scaling the resulting Rn/24 to the Rn/24 from weather stations using the standardized ASCE equation developed by Brunt (1932).

Idaho – Sean Vincent, Idaho Department of Water Resources

The Hydrology Section at IDWR has been a user of METRIC ET data for more than 5 years. During that time, METRIC ET data have been used in a variety of ways, some more successful than others.

There are several examples of successful applications. These include: 1) determining net recharge for input to two separate ground water models; 2) establishing ET rates for different land use types that were used to assess the adequacy of water supply under different land use scenarios; 3) assessing actual ET for water rights being bought-out 4) the evaluation of claims of water shortage for specific agricultural fields.

Those applications worked for several reasons: 1) because METRIC could map the actual amount of water used, as opposed to the amount diverted; 2) Landsat pixels allowed the aggregating of data up to the level of the farm field; 3) the costs and time requirements were reasonable; 4) no crop classification was needed; and 5) METRIC ET data were accepted by the scientific community, water managers, and by Idaho courts.

The Hydrology Section used METRIC ET data in one application that was less successful. That application involved assessing the recharge component of a ground water model for non-agricultural land. The problem was that ET for rangeland was small compared to the errors in the computations, which made ET unreliable.

5. Implementation of Technology

The Benefits of Archived Data – Bill Kramber, IDWR

The Idaho Department of Water Resources has developed more than a dozen water-resource applications that use Landsat data and the METRIC ET model. Several of these applications depend on data from the Landsat archive.

The Eastern Snake Plain Aquifer Model is an integral part of administering the water rights on approximately 2 million acres of irrigated agriculture. IDWR and UI are processing all available years of Landsat data through METRIC ET model as part of the procedure of calibrating the ground water model. The full set of ET data will also show long-term trends in ET on the Snake River Plain.

The administration of water rights often involves the need to determine water use during some specific, past time-frame. In responding to a water call, IDWR is able to use archived Landsat data to compute the actual ET for specific agricultural fields in order to base administrative decisions on quantitative data that are independent of specific parties to a dispute.

Future Improvements to Remote Sensing of ET with LiDAR and RADAR – Randy Lee, INL

LiDAR can provide refinements in several components of energy-balance ET models. These components include the height and shape of vegetation canopies, plant spacing, biomass, leaf area index, soil roughness, and frontal area index. Both airborne and satellite platforms can provide these data.

MODIS-based Global ET and Drought Severity Index Products – Qiaozhen Mu, Univ. of Montana

MODIS data are combined with daily meteorological data for input to the Penman-Monteith equation on a global scale. The output from the equation is validated at 46 Ameriflux towers and with data from 232 watersheds, world-wide. Three ET data products are available at ftp://ftp.ntsg.umt.edu/pub/MODIS/MOD16/. Those data products are 8-day, monthly, and annual 1-km MOD 16 ET.

Strategies for Rapid Production of ET – Eric Rafin, Bill Kramber, IDWR

The Idaho Department of Water Resources uses ET data for more than a dozen applications. Most of those applications use ET computed by the METRIC ET model. However, IDWR also used the normalized difference vegetation index (NDVI) for some ET applications. IDWR is interested in the relationship between NDVI and METRIC-computed ET in order that NDVI can be used when time is of the essence in providing a solution. The NDVI is an index that is frequently used at IDWR for other-than-ET applications as well, and IDWR personnel have written scripts to compute NDVI within ArcGIS software.

The Pros and Cons of Simplified Methods for Computing ET – Jan Hendrickx, New Mexico Tech

Using a vegetation index such as the Normalized Difference Vegetation Index (NDVI) is a simpler way to compute ET than is using a full energy balance model. However, the simpler way does not come without cost. Table 3 summarizes the amount of ETrF explained by using NDVI.

Image Date	Rangeland	Dryland	Irrigated	All Land Cover
3/18/2009	0.10	0.10	0.57	0.38
4/16/2008	0.09	0.03	0.45	0.37
4/19/2009	0.02	0.01	0.44	0.31
5/18/2008	0.15	0.23	0.29	0.23
6/22/2009	0.14	0.16	0.18	0.12
8/22/2008	0.47	0.53	0.81	0.76
8/25/2009	0.32	0.39	0.75	0.74
9/23/2008	0.34	0.48	0.79	0.71
9/26/2009	0.34	0.36	0.78	0.64
All Dates	0.32	0.35	0.71	0.58

Table 3. Amount of ETrF explained by NDVI vegetation index. Data from Highplains, Texas

How Much Ground Data Are Needed – Justin Huntington, DRI and Rick Allen, UI

In this context, ground data are weather data, which are needed to compute reference ET. In the arid west, temperature can vary significantly over a relatively small distance, as illustrated by Figure 7, which shows data from two stations of the U.S. Bureau of Reclamation's AgriMet system. Given these variations, it is clear that good, long-term weather networks are needed in order to have representative Reference ET to support the computing of ET.

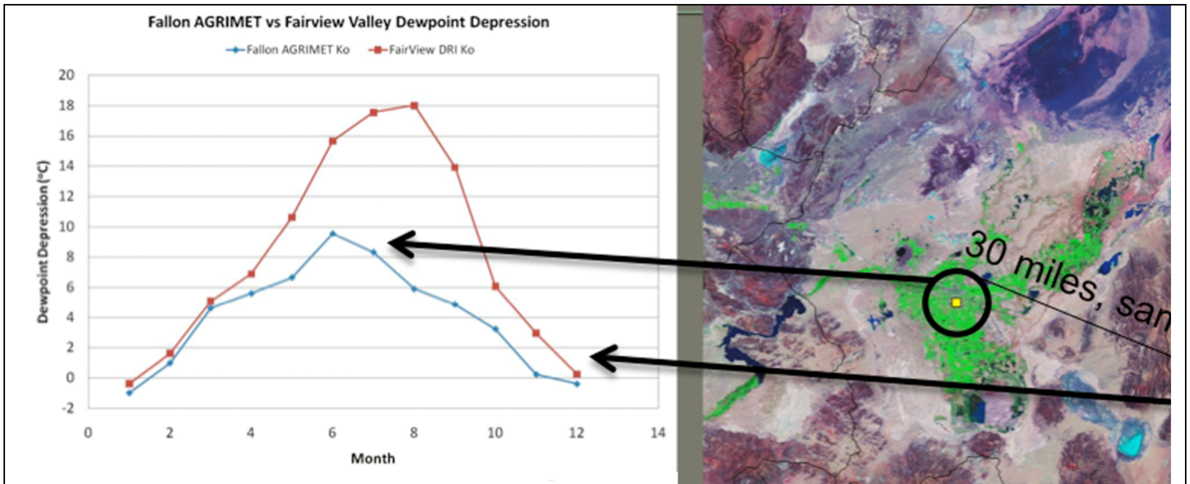


Figure 7. Comparison of dewpoint depression (°C) for two Nevada weather stations separated by 30 miles and at equal elevation (modified from Huntington).

Who Should 'Turn the Crank'? - Justin Huntington, DRI and Rick Allen, UI

Using an energy-balance ET model is not yet a turn-key experience. Although relatively inexperienced users can run the models, the results will reflect that inexperience. Even among experienced users, results can vary. UI found that differences in scene calibration among experienced users could result in differences of up to 10% in daily ET.

The DRI compared the differences in daily ET among trained users and an automated algorithm. DRI concluded that: 1) It is important to be trained by experts in the use of the model 2) It is important to partner with experts 3) It is important to compare results 4) It is important scrutinize the ET mapping to make sure the results are reasonable 5) The errors in daily ET from METRIC largely cancel out over a season, and 6) METRIC is well-constrained given that users have some training and critical thinking.

VI. SUMMARY

What We Have Learned – Dave Tuthill, Idaho Water Engineering, Inc.

What we have learned from listening to the workshop presentations can be summarized very concisely as follows:

1. There is broad-based interest in remote sensing of ET on the part of states, federal agencies, academic community, and private entities.
2. Many projects involving remote sensing of ET are now underway throughout the western United States.
3. There is a vast need for additional applications at every user level.

APPENDIX 1

Workshop Agenda

Day One -- October 12, 2011

07:00 – 08:30: Registration and Speakers Breakfast
Place Posters in the Ivory Room
Opening Remarks (Ballroom)
08:30 – 08:40 Welcome – *Layne Bangerter, State Director of Natural Resources and Environment, Staff of Idaho Senator Mike Crapo*
08:40 – 08:50 Greetings and Overall Workshop Objectives -- *Dave Tuthill, IWE*
Perspectives (Ballroom)
08:50 – 09:30 General Perspective and Overview of Techniques -- *Rick Allen, U of I*
09:30 – 09:50 NASA Perspectives -- *Ed Sheffner, NASA*
09:50 – 10:10 USDA Perspectives – *Bill Kustas, USDA*
10:10 – 10:30 USGS Perspectives – *Jim Verdin, USGS*
10:30 – 11:00 Coffee Break and Posters (Ivory Room)
11:00 – 12:30
Successful Applications for Water Management and Decision-Making (Ballroom Panel)
Chair: *Hal Anderson, IWE*

ID – water transfers, mitigation and litigation of competing uses, hydrologic studies, endangered species -- *Tony Morse, SGA and Bill Kramber, IDWR*

CO, WY – confirmation of traditional ET estimation in basin management and accounting, interstate agreements -- *Tim Martin, RTI*

MT, OR, WY, NM, ID, NE, CA – Management for native-American rights, water purchases, ground-water recharge, invasive species, ground water/surface water management, irrigation project performance – *Rick Allen, U of I*

NV – water transfers from agriculture to cities and basin management -- *Justin Huntington, DRI, and Adam Sullivan, NDWR*

CA –Integrating Satellite and Surface Observations for Crop Evapotranspiration Mapping and Irrigation Management Support in California -- *Forrest Melton, CSU, Monterrey Bay*

CA –Applications by a commercial enterprise – *Bryan Thoreson, SNA*

12:30 – 13:30 **Luncheon** (Buffet in the Ballroom)
Speaker: *Tony Willardson*, *Executive Director, Western States Water Council*
"Use of Remote Sensing in the Western United States"

13:30 – 14:30 **Specific Challenges in Remote Sensing of ET** (Ballroom Panel)
Chair: *Molly Maupin, USGS*
Rick Allen, U of I, Justin Huntington, DRI, Jan Hendrickx, NMT, Tony Morse, SGA, Christopher Neale, USU

- Forests, Mountains, Grasslands, Riparian
- Rainfed and Irrigated Agriculture
- Cloud compensation
- Evaporation from Open Water
- Conversion from Ag to Urban

- Intercomparison of Remote Sensing methods for agriculture and riparian systems in Palo Verde, CA

14:30 – 15:00 **Break and Poster Session** (Ivory Room)

15:00 – 16:15 **Participant Input – Part 1**

Breakout Groups Session 1 (6 groups in Ballroom and Ivory Room)
Chair: *Dave Toll, NASA*

- What are your ET expectations?
- What are your ET needs?
- What are the limitations?
- How do we overcome these limitations?

16:15 – 17:00 Breakout group reports for Session 1 (Ballroom)
Discussion
17:00 – 18:30 Hors D'oeuvres, No-Host Bar, and Posters (Ivory Room)

Day Two -- October 13, 2011

07:00 – 08:30: Registration and Speakers Breakfast
Dealing with Challenges (Ballroom Panels) Chair: *John Tracy, IWRRI*
0830 – 9:00 Time integration issues and Spatial Resolution requirements
Hydrological Modeling Approach – *Jan Hendrickx, NMT*
ETrF x ETref Approach and Evaporation Adjustment for Precipitation -- *Rick Allen, U of I*
What questions need to be addressed to support various study levels? *Justin Huntington, DRI*

09:00 – 09:40 Resource Requirements *(human resources, costs, levels of expertise and expert support)*
Idaho Experiences – *Tony Morse, SGA and Hal Anderson, IWE*
Nevada Experiences – *Adam Sullivan, NDWR*
Western State Experiences – *Jan Hendrickx, NMT*
Commercial Entity Perspectives – *Bryan Thoreson, SNA*
Intermountain West Experiences – *Rick Allen, U of I*

09:40 – 10:00 What Worked and What Did Not Work
New Mexico – *John Longworth, NM*
US Bureau of Reclamation – *Dave Ekhardt, BOR*
Idaho – *Sean Vincent, IDWR*

10:00 – 10:30 Coffee Break and Posters (Ivory Room)
Implementation of Technology (Ballroom Panel) Chair: *Ed Sheffner, NASA*
10:30 – 12:00
Benefits of Archived ET Data – *Bill Kramber, IDWR, Tony Morse, SGA*
Future Improvements to Remote Sensing of ET with LIDAR and RADAR – *Randy Lee, INL*
MODIS-based Global Evapotranspiration and Drought Severity Index products-- *Qiaozhen Mu, U of M*
Strategies for rapid production of ET – *Eric Rafn, IDWR*

Simplified methods vs. automation of the Energy Balance
Spatial resolution vs. Frequency of images
Pros and cons of simplified methods – *Rick Allen, U of I, Jan Hendrickx, UMT, Hal Anderson, IWE*
Some applications are fine for these uses
Other applications need more accuracy
How much ground data are needed? – *Justin Huntington, DRI and Rick Allen, U of I*
Gridded weather data for time interpolation
'Conditioning needs' for NLDAS and NARR data
Who should "turn the crank?" *Justin Huntington, DRI and Rick Allen, U of I*

Participant Input – Part 2
12:00 – 13:45 Lunch with Breakout Groups Session 2 (6 groups in Ballroom and Ivory Room) Chair: *Tony Morse, SAG*
Identify appropriate applications based on existing technology
What applications should be developed in your state or jurisdiction?
What types of pre-existing (off-the shelf) products would serve you best?
Who could you partner with?
What are advantages and disadvantages?
What are the funding mechanisms?
What are the timelines?
What are the next steps?

13:45 – 14:30 Breakout group reports for Session 2 (Ballroom)
Wrap-Up
14:30 – 14:45 Summary – *Hal Anderson, IWE and Rick Allen, U of I*
14:45 – 15:00 Closing Comments and Action Plan -- *Dave Tuthill, IWE*
Poster Presentations:
Include other technologies via poster sessions.

APPENDIX 2

ET Expectations and Needs

What are the Limitations and How Do We Overcome Limitations

What are you ET expectations and ET needs?

Group 1

- Needs for remote ET estimation in natural systems (riparian, mountain, rangeland, and desert).
- Needs for assessing groundwater ET.
- Needs for remote ET estimation in low ET environments.
- Needs for remote ET estimation for an entire basin water balance.
- Expectations for ET forecasting.
- Expectations for use of archived images to develop past ET for model calibration.
- Need/expect METRIC to utilize open source and open platforms for processing and analysis so low budget (or non US) organizations can process images.
- Need for "regular" or frequent training courses.
- Need for outreach/informational classes.
- Need for continued satellite with reflectance and thermal infrared.
- Some expectation remote of crop differentiation.
- Need to change paradigm of localized projects. Develop warehouse of processed images that can be purchased. Greater detail/precision if needed - with additional and funding

Group 2

- Validate water right uses on a seasonal basis
- Validate ET boundary conditions for GW models
- Can ET help with drought predictions and monitoring?
- Water availability
- Irrigation scheduling
- Fill spatial data gaps for ET
- Real time and forecasts (7 day) of ET
- Use of TE for water planning purposes
- Mountain ET

Group 3

  - Validate water right uses on a seasonal basis
  - Validate ET boundary conditions for GW models

- Can ET help with drought predictions and monitoring?
- Water availability
- Irrigation scheduling
- Fill spatial data gaps for ET
- Real time and forecasts (7 day) of ET
- Use of TE for water planning purposes
- Mountain ET

Group 4

- Variable scale range from regional/watershed scale down to field scale (30 m resolution)
- Accuracy greater then conventional methods of determining ET.
- Dependability of satellite(s) to continue to provide remote sensing imaging into foreseeable future.
- Image return interval of 4 days.

<u>ET Needs</u>

- Remote sensing imagery available within 2-4 weeks of capture.
- Remote sensing imagery available on 4-day interval (new imager taken every 4 days)
- Ability to predict ET into the future (weeks, months, ???)
- Ability to model/determine ET from open bodies of water (ponds, lakes, reservoirs).
- Methodology for determining and analyzing ET formalized and published/adopted as 'Standard Practice' (ASCE recognition or similar).
- Training provided to end users for determination of ET utilizing 'standard practice'.
- 'Standard practice' is cost effective and 'easily' implementable by end users.
- Methodology for determining ET must be defensible and beyond reproach, safe from discrediting during contested case proceedings.
- Fully developed suite of fall back tools in place for instances when remote sensing imagery is not available.
    - Field Sensors and Instrumentation
    - Alternative imagery (ideally free of charge)
- Field sensors and instrumentation for use in truthing remote sensing based methods for determining ET.

What are the limitations of remote ET estimation?

Group 1

- Validation of ET is a limitation. How can we know if we have gotten ET right in mountains?
- The lack of properly sited weather stations is a limitation.

- The current need for experts to process images is a limitation. The combination of trained in-house staff and expert assistance is an expensive solution.
- Funding is a limitation. Both funding for research and development (and satellites), as well as organizational funding to pay for expert training/processing.
    - Give data for free to develop "appreciation" for the ET product. Once compelling case for usefulness is developed, more support and funding might follow.
    - Package ET with the social/political needs and wants.
- The lack of conditioned, reliable, gridded weather data is a limitation.
- Limitations seem to be more technical in non-agricultural areas and organizational or monetary in agricultural areas.
- Lack of observations and ground truthing are limitations.
- Lack of correlation between ET products and the political/social benefits of the products.

Group 2

- Too few Landsat images need every 4 days to have cloud-free images
- Lack of automation
- Problems with cloudy and foggy and snowy conditions
- ET dynamics during the day
- Cost outside of US for Landsat images
- Education of potential users of the technology
- Cost of establishing remote sensing of ET programs
- Determination of costs/benefits of using ET
- Takes time to learn something new
- Resolution is too low

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Group 4

- Funding and support of remote sensing based ET determination into foreseeable future.
- Frequent unavailability of remote sensing imagery (clouds, fog, snow, etc)
- Current ET analysis methods too costly and too complex.
- Gains of remote sensing based ET determination not superior enough to existing methods to warrant displacing existing tried and true and simple methods.
- Societal values no longer emphasize/reward cutting edge science and technology.

How do we overcome these limitations?

Group 2

- Drones to fly under clouds
- More frequent overpasses at different times of the day

- Funding for outreach programs
    - State engineers
    - Irrigation Districts
    - Social media
- Show cost/benefit is low enough to merit change
- Funding for higher resolution data

Group 3

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Group 4

- Communication to Washington DC and ‘powers that be’ of the importance and indispensability of remote sensing based ET determination in water resource management.
- Strategic partnerships.
- Integration of ET tools into popular technology setting.
    - Social media
    - Mobile Devices
    - Internet

APPENDIX 3

Identify Appropriate Applications Based on Existing technology

What applications should be developed in your state or jurisdiction?

<u>Group 1</u>

Groundwater management
Irrigation scheduling
Water balance analysis
Modeling inputs

<u>Group 2</u>

Method to measure groundwater recharge, incidental/agricultural recharge, based on ET energy balance approach.
Flood flow predictions and forecasting and storm water management opportunities based on remote sensing (MODIS) and soil moisture.
Real time (2-3 week lag) data on crop distribution (NASS Crop Data Layer (CDL) product).
Daily/Weekly/Annual gridded weather data similar to CIMIS.
Groundwater monitoring using in-situ data, GRACE, ET/Water Balance ENSAR approaches.
Necessary method/data to support short term and long term forecasting of water demand (up to one season out).
Ability to develop remote sensing based water budgets in rural/sparsely populated areas where resources don't exist.

<u>Group 3</u>

All of them
Mountains and native vegetation
Training programs for the use of models
Pre-processed input data
Uncertainty and accuracy assessment of results vs. traditional methods

<u>Group 4</u>

ND: preliminary METRIC model operational at the ND Water Commission – for water use management and developing hydrologic modeling, with NDSU partnership. ND state has lots of oil $$$.

NWS-CBRFC: RFC's research is supposed to be at OHD in DC, but at CBRFC we are partnering with UCLA to generate MODIS/NLDAS-derived potential ET to import into existing hydrologic modeling. No off-the shelf product. Advantage is that it will be tailored to our own uses, as developed in-house, but disadvantages are personnel are limited and research is dependent on grants (1-3 year timelines) and there is no support.

NV: transfers of water rights from ag to M+I and from ag to environmental to monitor Walker Lake. 5 year program to develop in-house R/S expertise. Struggling with tremendous spatial variability across the state.

NE: Developing groundwater modeling: want to get hold of the ET component. Using NDVI to determine simpler questions: identifying irrigated vs. dryland. NE has irrigation metering requirements. Water use estimation – long-standing collaboration with UNL. No past use of R/S, and not completely switching – evaluation and comparison with existing techniques.

<u>Group 5</u>

Congruent ET maps of the State
Improve rangeland ET estimates
Predict consumptive use from Surface flow
Use irrigation scheduling
Planning

<u>Group6</u>

Groundwater discharge from native vegetation;
Field level crop ET
Water operations management (surface & groundwater)

<u>Group 7</u>

Grided ETref
Simple open water ET estimations, instead of evaporation pans.
Rangeland ET estimations (non-ag land, mountains, etc)
Inefficient end guns, consumptive use per unit bio-mass studies
Goat-proof evaporation pans.

<u>Group 8</u>

Domestic irrigation quantification
Determine consumptive use
Curtailment and compliance assessment, down to field level

Crop specific consumptive use
Validating model results
Interstate compacts and pump-back quantification
Proof of concept for decision makers
SWE and snow abstraction

What types of pre-existing (off-the-shelf) products would serve you best?

Group 1

Metric
Grass
Published reports
Archived Landsat
Weather data – CIMIS, AgriMet

Group 2

30 m resolution historical ET maps based off of existing LANDSAT imagery that will
support the analysis (west wide).
Remote sensing based land use patterns (crop distribution) near real time.
Improvements in gridded weather data on weekly/monthly/annual time steps.
Dissemination/broadcasting of information to mobile devices.

Group 3

What type of pre-existing products would serve you best:
Pret-a-porter weather data
Ready-to-use satellite data with standardized atmospheric correction
A check list of required data products and field equipment to run the remote sensing
based ET models

Group 4

Unidentified

Group 5

We need a rapid processing procedure.
Land-use classification.
Yearly land use classification,
Annual crop polygons, crop type.

Group 6

Currently use Landsat→atmos corr→ vegetation index; map phreatophyte zone;
Landsat to map irrigated lands (crop, non-crop; Want ET map
Model w/ static Kc

Group 7

Good surface reflectance and surface temperature data

Group 8

What products are available?
Automated processing tools

Who could you partner with?

Group 1

Universities (Cooperative Extensions)
State/Federal agencies
Local agencies
Conservation districts
Cooperative farmers
Water user associations

Group 2

Private sector
Data sharing (often a one-way street)
Cost/resource sharing
Feds (USGS, USDA, BoR, Army Corps, NOAA, NASA)
Increased communication amongst federal agencies
Increased cost/resource sharing on shared objectives
Increased coordination between Feds and States
Other Western states
Universities

Group 3

State water agencies, river commissions, water conservancy districts
State and private universities
Federal research and data gathering institutions (USDA-ARS, FSA, NRCS, USGS, BLM, Forest Service, USFWS. NASS)

Group 4

Unidentified

Group 5

Could partner with people outside of agriculture to expand use to river forecast, and energy balance in mountainous basins. Universities, agencies (local and federal), research institutes.

Group 6

county/state/fed agencies; Universities USBR, private irrig dists
State Depts of Water Resources, Bureau of Reclamation

Group 7

NOAA, NASA Earth Sciences, USGS, UofI Kimberly, USDA ARS.
Organizations with: Expertise and funding

Group 8

Unidentified

What are advantages and disadvantages?

Group 1

- Advantages
  - Reduced water consumption
  - Better understanding of water resources
  - Accuracy of consumption estimation
  - Tool for monitoring consumptive use
  - Credibility
- Disadvantages
  - Funding
  - Education level
  - Training issues
  - Reluctance/cost to adapt new technology
  - Data sharing issues

Group 2

- Advantages:
  - Shared resources
  - Leveraging expertise
  - Synergy
  - All partners are invested in the process/product
- Disadvantages
  - Inability lack of desire to share data between partners
  - Cross budget complications

Group 3

- Advantages:
  - Spatially distributed results
  - Free satellite imagery
  - Good seasonal ET totals of irrigated areas
- Disadvantages:
  - Initial Costs
  - Clouds and cloudy areas
  - No standardization of models or data inputs
  - Need improved estimates over native/non-irrigated vegetation (mountains, scrubland, grasslands, riparian, wetlands)

Group 4

Disadvantages:

Forecasting: no short-term forecasting; how does R/S help us with hydrologic non-stationarity and more strategic changes (land-use / land-cover / crop change (e.g., Brazil replacing crop with sugar cane for bio-fuels, depressed temperature)) that act on various time-scales. One danger is that states can become beholden to software companies (ND is using ERDAS)—need to look into open-source software; having good programmers is key.

Advantages:

Spatial scale (everybody loves 30-m resolution), but for groundwater and streamflow modeling larger scale is better (MODIS-scale).

Time-scale: whether temporal resolution (e.g., 16-day Landsat) is an advantage or a disadvantage is application-dependent: for streamflow simulation or water use by irrigation management, it's too long; for planning purposes, annual water balances, groundwater modeling it's fine.

Group 5

Advantages

Fee data

Improves our research capabilities and applications.

Improves modeling, water rights, and everything.

Disadvantages

It takes time and money and is potentially expensive.

It may be hard to get people to see the need.

It is difficult to integrate ET into the decision making process.

Group 6

Advantages-

decrease uncertainties, increase efficiency;

Disadvantages

cost/implementation

Group 7

Advantage:

Existing technology tested and proven.

Disadvantages:

Doesn't meet needs exactly.

Continuity of Landsat, (alternative maybe CBRS satellite)

Group 8

Resistance (legal) to change or new technologies
Need to build precedence to build support
ET difficult to explain to politicians/funding sources
Technology often consumer driven, need to develop broad acceptance to drive innovation

What are the funding mechanisms?

Group 1

State/Federal grants
State/Federal base funds
International organizations
Water user fees
Corporate funding
Private foundations

Group 2

Funded pilot programs USGS, NASA, NOAA, BoRec (feds)
Facilitating access to data to save costs
Demonstrating cost/benefits to get Congress or States on board with funding.
Cost of new methods will out weigh existing losses

Group 4

No funding is from below or above the state level. NE: also the state. NV: partially grant funding, water right applicants, user-fees fund most of the NV DWR. CBRFC: all research grants: NOAA and NASA. EROS: federally funded.

Group 5

Local counties, state, and federal. Could we have a taxation fund for agricultural users. An annual water right fee to apply metric and groundwater modeling. This funds CAMP. A water right fee could fund images.

Group 6

Cooperative agreements w/ state and county agencies
Power company (has interests in environmental water use); Prior unsuccessful effort to
fund via water-rights user fee

Group 7

USGS, NASA Roses
Sell data to end users

Group 8

Unidentified

What are the timelines?

Group 1

Past (we needed it yesterday)
Present (we need it now)
Future (we need it tomorrow)

Group 2

Unidentified

Group 3

Unidentified

Group 4

Variety of time-lines. ND: initiated with a pilot study on ET using SEBAL by SNA for Devils Lake, 2006 – 2009, then NDSU – to have a functioning, deliverable METRIC product within the year. CBRFC: two years into a project, but its continuance depends on whether or not we get further funding. NV: 5-year cooperative funding program provided to state and to DRI to generate 10 years of seasonal ET for 4 scenes. NE: no timeline.

Group 5

Next five years to implement water right fee for users to fund applications

Group 6

ASAP

Group 7

In-house capacity could be quick with good mentors and training.

Group 8

Yesterday

What are the next steps?

Group 1

Evaluate where we are
Define priorities/needs
Improve Product
Collaboration with involved parties
Lobbying decision makers
Educate public

Group 2

Capacity building
Education of users
Further understand and develop processes
Standardized/adopted/defensible methods
Automated processes to speed up ET determination.
Create off-the-shelf products

Group 3

Spread the word and publications, training
Look over the fence to see what neighboring states are doing and build partnerships
Show how these new technologies can provide richer information on ET and irrigation
water use

Group 6

Scoping of model interface requirements
Education & awareness for pgm mgmt
Imaging research continually ongoing to improve process
Comment: EROS atmospheric correction would help, assuming that it checks out

Group 7

Make a strong case to the right people.

Group 8

Coordination and Standardization