Program and Abstracts Book

NASA/USDAS Workshop on

Evapotranspiration

April 5 to 7, 2011
Silver Spring, MD

NASA/USDA Workshop on Evapotranspiration

April 5 to 7, 2011

Hilton Washington DC/Silver Spring, MD
8727 Colesville Road,
Silver Spring, Maryland, USA, 20910.

Workshop Objectives:

1) To define the needs and requirements for evapotranspiration data in weather and climate studies, in natural and agro-ecoystem monitoring, and in water resource management
2) To review the methods used to measure and model evapotranspiration.
3) To assess surface and satellite observation systems required to support ET measurement, modeling and evaluation.
4) To assess the feasibility of developing a proposal for a task on evapotranspiration for the 2012-2015 GEO Work Plan.
5) To 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

April 5, 2011

08:30 – 09:30: Registration

Location: Capitol Ballroom
Opening Remarks (Chair: *Dave Toll)*
09:30 – 09:40 Greetings and overall workshop objectives (Bill Kustas, Brad Doorn)
09:40 – 09:50 ET incorporation into GEO workplan and ECV for GCOS (Rick Lawford)
09:50 – 10:00 ET white paper, ECV and need for cohesive ET community (Rick Allen)

Need and Requirements for ET Information (Chair: *Bill Kustas)*
10:00 – 10:15 Climate Change Implications: What do we need to know about ET? (Joe Barsugli)
10:15 – 10:30 ET information for water management in the Western US (Tony Willardson)
10:30 – 10:40 ET information for irrigation, water rights negotiations, and species protection (Dave Tuthill)
10:40 – 10:50 Practical Applications of the METRIC Evapotranspiration Model (Tony Morse)
10:50 – 11:05 ET information for water management in the Middle East (Ben Zaitchik)

11:05 – 11:35: *Coffee Break and Posters*

11:35 – 11:50 Remote Sensing Requirements for Scheduling Irrigations (Tom Trout)
11:50 – 12:05 ET information for the Water Census (Jerad Bales)
12:05 – 12:20 ET information for managing river basins (Alan Harrison)
12:20 – 12:35 Forecasting Evaporative Demand across the Conterminous US (Mike Hobbins)

12:35 – 13:50 *Lunch*

ET Processes and Modeling (Chair: *Brad Doorn)*
13:50 – 14:05 Overview (John Norman)

Land-surface models

14:05 – 14:20 Surface evaporation in Noah land model in NCEP operational weather and climate models (Mike Ek)

Remote sensing approaches and intercomparisons

14:20 – 14:35 Multi-model Multi-Platform Analysis of Global-scale Evapotranspiration for Climate Studies (Remi Meynadier)
14:35 – 14:45 METRIC/SEBAL (Rick Allen)
14:45 – 14:55 Two-Source Energy Balance (Bill Kustas)
14:55 – 15:05 Introduction to a MODIS Global Terrestrial Evapotranspiration Algorithm (Qiaozhen Mu)

15:05 – 15:35 *Coffee Break and Posters*

Data fusion and assimilation in mapping ET

15:35 – 15:45 Data Assimilation (Wade Crow)
15:45 – 15:55 Integration of Multi-Scale Thermal Satellite Imagery for Evaluation of Daily Evapotranspiration at Continental to Sub-Field Scales (Martha Anderson)
15:55 – 16:00 Introduction to the breakout groups (Rick Lawford)
16:00 – 17:00 Breakout groups - ET applications, modeling, and knowledge gaps

Breakout Rooms: Capitol Ballroom, and the Council and Assembly rooms

Applications (Tom, Trout, Ted Engman)

This Working Group will review application areas where ET information could be used to enhance operational decisions and improved policies. The Group will also assess the degree to which ET is currently being used in these various applications as well as identifying new areas of applications that are expected to emerge in the near future. In addition, they will review the obstacles and limitations currently inhibiting the use of ET information and provide a list of criteria defining ET data requirements (e.g., spatial and temporal resolution, latency) for various applications.

Modeling (Bill Kustas, Mike Ek)

Users require ET information on different time and space scales depending on the application. It is recognized that different models satisfy different requirements and have different levels of complexity and requirements for input data. This working group will answer questions such as:

What types of models work best for annual, monthly, daily and hourly (or instantaneous) requirements, and for predictions? What are the limitations of various modeling approaches in terms of scale, input data needs, implicit assumptions, and context for the application (e.g., regional extent, terrain and landcover characteristics, climatic conditions)? Can the group define generic and specific improvements needed in current models and/or suggest new or hybrid approaches that can meet user requirements, and what steps should be taken over the next few years to ensure these needs are met?

Gaps in knowledge of ET processes (John Norman, Christa Peters-Lidard)

In addressing ET monitoring and prediction issues, it is important to have an understanding of the important processes on all scales. At the plant scale we do not know the precise rates of movement of water through different plants from the roots to the leaves, nor do we know how these fluxes respond to external forcings such as wind or water stress. At the larger scale we do not fully understand how to scale up these processes and combine their cumulative inputs with evaporation from wetlands and shrublands to get estimates that would be relevant over scales of kilometers. Moving to the scale of a model grid square there is also a need to understand how to average over larger areas such as a city or a watershed with small wetland, and to move from surface fluxes to fluxes in the boundary layer. This group is expected to review the knowledge gaps and to identify those which are most critical in terms of deriving better ET monitoring and prediction products.

17:00 – 17:30 Breakout group reports
17:30 PM Adjourn

Location: Potomac room
April 6, 2011
08:30 – 08:45 Recap of Day 1 and goals for Day 2 Charlie Walthall

ET Measurement techniques (Chair: *Martha Anderson)*
08:45 – 09:00 Micrometeorological techniques (John Prueger)
09:00 – 09:15 Scintillometry (Massimo Menenti)
09:15 – 09:30 Measurement uncertainties (Joe Alfieri)

09:30 – 10:15 *Poster viewing with presenters, coffee*

Current and Planned ET Observation Systems (Part 1) (Chair: *Ted Engman)*
Ground-based networks
10:15 – 10:30 NEON (Brian Wee)
10:30 – 10:45 Fluxnet (Tilden Meyers)
10:45 – 10:50 Introduction to breakout groups (Rick Lawford)
10:50 – 10:55 Breakout groups - Future needs in research, observations

Breakout Groups: Potomac, Annapolis and Severn Room
Ground-based ET Measurement Techniques and Networks (Tilden Meyers, Joe Alfieri)

Observations of ET, obtained over a range in vegetation and climate conditions, are required to evaluate modeling approaches, and to incorporate into models through assimilation systems. However, reliable ET measurements of ET are difficult to obtain, especially in real time, due to many factors. This group should formulate a statement that characterizes our ability to measure ET, describing both the capabilities and limitations of current observational techniques and monitoring networks. What refinements are required, and what new instrumentation is on the horizon? What is the standard set of measurements that should be collected at an ET monitoring station? What are the gaps in the global observing network, and which are most crucial to fill? How can we ensure long term continuity in measurements, and better interoperability and integration between ET data systems?

Satellite systems and ET Measurements (Rick Allen, Martha Anderson)

The users of ET information have a range of requirements in terms of space and time resolution, data latency and data accuracy. In addressing these needs scientists have developed a number of approaches for using satellite data from different spectral bands to produce ET products. However, these products are limited by the nature of the ET algorithms, the availability of accurate information in the most appropriate spectral bands, overpass times, the extent and nature of calibration/validation activities, and product development and testing activities. This breakout group will address questions related to issues affecting satellite mission and science programs such as: Are we making the best measurements from space for ET products and, if not, what is needed? How can the cal/val activities be improved in terms of geographical representation and methodologies? Do we need more missions for ET measurements? Do we need new sensors for assessing ET? Are there new algorithms needed for ET monitoring and, if so, what needs to be done? What are the best avenues for developing new ET products with the current suite of satellites and measurements? What would be needed to generalize the current suite of ET products available over the USA to all parts of the world?

Research Needs (Brad Doorn, John Norman)

There is a range of research needs that must be addressed to produce better products for users. Better products depend on better assimilation models and algorithms that make use of all of the information available. Better models and algorithms require a better understanding of the fundamental processes that drive ET processes. This breakout group is expected to review the gaps in our knowledge about ET (see the April 5th breakout group on this topic) and to develop some priorities for general directions on future research to address these gaps. This could include the targeted analysis of existing data bases, field campaigns and process studies, model development and testing exercises, applications research on methodologies and research on new ways to disseminate information to users.

11:50 – 12:20 Breakout group reports

12:20 – 13:50: *Lunch*

ET topics (Chair: *Tony Morse)*

13:50 – 14:05 The Soil Moisture Active Passive Mission (SMAP) for soil moisture observations (Molly Brown)
14:05 – 14:20 ET for NIDIS, Water Census and FEWSNET (Jim Verdin)
14:20 – 14:35 Determine ET white paper writing groups (Dave Toll)
14:35 – 15:35 Breakout groups - ET White paper writing groups

(White paper writing groups)
Need and requirements for ET information (Tom Trout, Dave Toll)
Applications

ET processes (John Norman, Massimo Menenti)
Drivers, modeling techniques, gaps in knowledge

ET modeling (Bill Kustas, Mike Ek)
Summary of current modeling approaches, including strengths and limitations

ET measurement (Joe Alfieri, John Prueger)
Ground-based flux measurement techniques

Current and planned ET observation systems (Tilden Meyers, Rick Allen)
Includes both surface and satellite systems

Pathway to Attaining ECV Capabilities (Jared Entin, Rick Lawford)
What remains to be done before we can routinely generate an ET ECV?

15:35 – 16:05 *Coffee Break and Posters*

16:05 – 16:35 Breakout group reports
16:35 – 17:00 Open Discussion
17:00 Adjourn

April 7, 2011

Location: Potomac room
08:30 – 08:45 Recap of Day 2 and goals for Day 3 (Brad Doorn)

Current and Planned ET Observation Systems (Part 2) (Chair: *Rick Allen)*

Spaceborne sensors
08:45 – 09:00 Landsat - TIRS (Betsy Forsbacka)
09:00 – 09:15 "Introduction of NOAA GOES and GOES-R Observations for ET Monitoring (Xiwu Zhan)
09:15 – 09:30 MODIS/VIIRS/Microwave sensors/GRACE (Jared Entin)

09:30 – 09:45 European satellites (Massimo Menenti)
09:45 – 09:50 Introduce breakout groups (Rick Lawford)
09:50 – 10:50 Breakout groups - ET White paper writing groups
10:50 – 11:20 Breakout group reports
11:20 – 12:00 Synthesis and final remarks (Rick Lawford/Brad Doorn/Bill Kustas)
12:00 Adjourn

Poster Presentations:

1) Molly Brown: The Soil Moisture Active Passive Mission (SMAP) for soil moisture observations
2) M. Tugrul, Yilmaz: Using Thermal Infrared Remote Sensing based ALEXI Evapotranspiration to obtain skillful Water Budget Estimations
3) Andrew Jarvis and Kaniska Mallick: A numerical scheme for partitioning terrestrial latent heat observation into evaporation and transpiration
4) Forrest, Melton: Satellite Irrigation Management Support with the Terrestrial Observation and Prediction System
5) Ayse Irmak: Evapotranspiration of Semi-Arid Sand Hills of Nebraska through Micrometeorological and Satellite-based Energy Balance Modeling (METRIC) techniques
6) Alan Lipton: Analyzing Evapotranspiration with Complementary Satellite Products
7) Hatim Geli, Christopher Neale, and John Osterberg: The Application of the Two-source Model Using High/Low Spatial Resolution Imagery and LiDAR Data to Estimate the Evapotranspiration of Tamarisk
8) Ray Anderson: The Regional Evaporative Fraction Energy Balance (REFEB) platform; a new technique to observe regional Evapotranspiration
9) Peyman Daneshkar Arasteh: Comparison of Remotely Sensed LAI and PAR with Ground Measurements in Qazvin Plain, Iran
10) Saleh Taghvaeian: Studying Water Balance Components Using Remotely Sensed Estimates of Evapotranspiration
11) Sumantra, Chatterjee: A modified crop coefficient approach for estimating regional evapotranspiration
12) Mike Hobbins: Examining the spatio-temporal variability of potential evaporation across the conterminous US
13) Suat Irmak: Nebraska Water and Energy Flux Measurement, modeling and Research Network (NEBFLUX)
14) Ayse Irmak, Ian Ratcliffe, Pariskit Ranade: Title: Monthly and Seasonal Evapotranspiration Mapping Using Land Surface Energy Balance with METRICtm and Daily Gridded Weather
15) Marzieh Azarderakhsh: Assessing remote sensing based ET estimates over the Amazon basin

16) Andrew French, Doug Hunsaker, Kelly Thorp: Combining Remote Sensing and Crop Growth Models to Estimate Evapotranspiration over Irrigated Lands at Daily Time Steps
17) Richard Allen: Fusion of Moderate Resolution Landsat-based Energy Balance with Daily Weather Grids to Produce High Definition Evapotranspiration over Hydrologic Time Periods
18) Rick Mueller: The Cropland Data Layer (CDL) Program
19) Gabriel Senay; Stefanie Bohms; James Verdin: Large Scale Evapotranspiration Estimation using Remote Sensing and Global Weather Datasets
20) Joshua Fisher: On uncertainty in global evapotranspiration estimates from choice of input forcing datasets
21) Tony Morse: Practical Applications of the METRIC Evapotranspiration Model
22) Xiwun Zhan: Intercomparison of an ET-based Drought Index Derived from Geostationary Satellite Data with Standard Drought Indicators
23) Qiaozhen Mu, Maosheng Zhao, Steven W. Running: Applications of Global MODIS Evapotranspiration Algorithm at AmeriFlux Tower Site and Global Scale
24) Timothy Martin: Satellite-Based Evapotranspiration Mapping and Water Use in Irrigation Systems of Morocco
25) Timothy Martin: Web-based Dissemination of Surface Energy Balance Evapotranspiration Estimates

ABSTRACTS

Name: Joseph Barsugli

Email: joseph.barsugli@colorado.edu

Title: Climate Change Implications: What do we need to know about ET?

Abstract:

This talk is not about what will happen to ET under climate change. Rather it is brief look at the conceptual and practical problems that arise when trying to project what a region's water balance will look like decades into the future. Modern climate models include sophisticated land surface models -- at the spatial scales of the model grid. Even then, climate models have biases in temperature, precipitation and other drivers of climatological ET, so the model's surface water balance may not even be in the same hydrologic regime as the real-world water balance. One common practice is to use uncoupled hydrologic models forced by bias-corrected climate model output. The question I will raise is: Given the state of the practice, what can be gained from better monitoring of ET?

Name: Thomas Trout

Email: thomas.trout@ars.usda.gov

Title: Remote Sensing Requirements for Scheduling Irrigations

Abstract:
The critical information for improving irrigation water management is accurate scheduling of irrigations. Irrigation scheduling is done with ground-based reference ET weather station networks and crop-specific coefficients. Crop coefficients, Kc, are estimated from tables based on conditions for a standard crop. Basal crop coefficients can also be estimated from canopy ground cover, which can be estimated from satellite-based NDVI. Irrigation scheduling DSS based on satellite imagery and reference ET are being deployed in California, southern Europe, and Australia. These systems operate adequately with current Landsat 5 images because canopy ground cover can be interpolated and extrapolated based on crop growth and 30 m resolution is adequate for most farm fields. Preferred frequency and resolution is at least weekly with 10 m resolution. Imagery for real-time irrigation scheduling should be available rapidly and efficiently processed.

Name: Anthony Morse

Email: tmorselll@yahoo.com

Title: Practical Applications of the METRIC Evapotranspiration Model

Abstract:
Nineteenth-century observers from John Wesley Powell to Mark Twain warned that water in the west is a limited and tenuous resource. Those observations are even more compelling at the beginning of the 21st century. The pressures on western water are increasing with a changing climate, an increasing population, and a growing body of environmental regulation. Water-resource agencies in western states are attempting to meet these pressures with new tools, one of which is an energy-balance evapotranspiration model, METRIC. The METRIC model uses data from weather stations and Landsat to compute and map evapotranspiration in great detail over large spatial extents. Eleven western states have developed applications based on evapotranspiration data put out by METRIC. In Idaho, these applications include 1) developing water budgets for hydrologic modeling, 2) assessment of injury in administering agricultural water-rights, 3) irrigation needs assessment for endangered species protection, 4) analysis of ET by land-use/land-cover type for planning, 5) water-rights negotiations, and 6) monitoring agricultural pumpage. METRIC results have been used in legal proceedings and are now part of adjudicated decisions. Perhaps the most important feature of using METRIC with Landsat data is that evapotranspiration is computed for each of Landsat's 900 square-meter pixels, which enables evapotranspiration to be aggregated up to the level of individual fields where western water and water rights are actually managed.

Name: Mike Hobbins

Email: mike.hobbins@noaa.gov

Title: Forecasting Evaporative Demand across the Conterminous US

Michael Hobbins(1), David Streubel(2), and Kevin Werner(1)

(1) Colorado Basin River Forecast Center/NWS/NOAA, Salt Lake City, UT
(2) Hydrology and Climate Services Division, Western Region Headquarters/NWS/NOAA, Salt Lake City, UT

Abstract:
Agriculturalists and operational hydrologists often seek to predict actual evapotranspiration (ET) fluxes to provide guidance in decision-making. However, they are, in general, unable to estimate or forecast ET directly as they can seldom characterize actual moisture conditions in the soil and vegetation regimes at operationally useful time or space scales. Instead, they first estimate evaporative demand (E0) (sometimes known as "potential ET") as an upper limit to

actual ET and then apply E0 to drive hydrologic models or empirical relations that account for soil moisture conditions and vegetative constraints on moisture transfer, and thereby derive actual ET. A common, scientifically sound measure of E0 is the reference crop ET (ETrc) measure provided by the Penman-Monteith equation.

Here we summarize the development of NWS's new near-term forecast system for ETrc. The forecast system has two components:
(i) a daily to weekly ETrc forecast based on the following National Digital Forecast database forcings: temperature, dewpoint, wind speed, and cloud cover. All of these forcings are already currently forecast and are available at an hourly time-step and a 2.5- to 5-km spatial resolution.
(ii) an ETrc climatology derived from the following North American Land Data Assimilation System (NLDAS) forcings: temperature, specific humidity, wind speed, and shortwave and longwave downwelling radiation. The NLDAS-derived ETrc time-series is 30 years long (1980-2009), daily, and CONUS-wide at a 1/8th-degree spatial resolution. This component provides a climatological context to users who might otherwise be unfamiliar with the concept of ETrc.

The ETrc forecast system, which provides the first large-scale operational forecasts of evaporative demand, is an early result of ongoing work within an E0-forecast/climatology framework at the Colorado Basin River Forecast Center (CBRFC). The primary goal of the work is to improve streamflow forecasts across the Colorado River basin and eastern half of the Great Basin by updating the Sacramento Soil Moisture Accounting (Sac-SMA) model underpinning the NWS River Forecast System. We are currently testing the streamflow simulation skill of replacing the Sac-SMA model's current static E0 driver with a new dynamic forecast E0 in test-basins across the CBRFC domain. Other significant potential uses for forecast and near-term observed E0 are in the monitoring and prediction of ongoing droughts (e.g., as an input to the US Drought Monitor) and in assisting local and regional agencies (e.g., Denver Water and the U.S. Bureau of Reclamation) in forecasting water demand.

Name: Michael Ek, Youlong Xia, and Helin Wei

Email: michael.ek@noaa.gov

Title: Surface evaporation in Noah land model in NCEP operational weather and climate models

Abstract:
In weather and climate models, land-surface models provide the surface boundary conditions, i.e. for heat, moisture, and momentum, where the surface moisture flux affects both the surface water and heat budgets. As such, accurate estimates of surface evaporation by the Noah land model are crucial for the weather and climate models used in NCEP operations. We examine the formulation for surface evaporation used in the Noah model, its continued enhancement and validation using data from various surface observations (i.e. surface flux sites, soil moisture networks, etc), and in this regard the role of the Noah model in NCEP

models. We also review the North American Land Data Assimilation System (NLDAS) where evaporation estimates and climatological anomalies are determined by land-surface models (Noah included) run in an uncoupled mode driven by atmospheric forcing.

Name: Remi Meynadier

Email: c/o efwood@princeton.edu

Title: Multi-model Multi-Platform Analysis of Global-scale Evapotranspiration for Climate Studies

Eric F. Wood, Raghuveer K. Vinukollu, Remi Meynadier, Justin Sheffield, Matthew McCabe

Abstract:
With anthropogenic climate change, the surface heat fluxes may change, which could have significant impacts on the climate system in terms of land-atmospheric coupling, partitioning of the water and energy budgets and water and energy cycle variability. Although the current state-of-the-art climate and weather models can reliably simulate the climate system dynamics, recent papers have documented the uncertainty in their estimated evapotranspiration (ET) fluxes. The recent studies have shown differences or spread in the range of 15-40% among the observational driven remote sensing retrievals, land surface models, climate and weather models, with differences between individual models and a multi-model consensus mean estimate of up to 100 mm/year, as compared to the lowest reported estimate (Jimenez, et al., 2011; Vinukollu et al., 2011). Notable differences have also been reported among different remote sensing retrievals of ET using process models. However, it is difficult to determine if these differences are due to differences in model parameterizations/structures or input drivers and protocols. As part of the senior author's NASA funding, six remote sensing ET data sets have been developed, and consist of ET estimates from three process models using a combination of three net radiation estimates (ISCCP, SRB, SRB-QC) and two sources of surface meteorological inputs (ISCCP, MERRA reanalysis). The process models are a modified Penman-Monteith (PM-Mu) (Mu et al., 2007), Priestley-Taylor (PT-Fi) (Fisher et al.,2008), and the Surface Energy Balance System (SEBS) Su et al., 2005). The three models adjust the surface resistances using aerodynamic principles or provide ecophysiological constraints to account for changing environmental factors thus scaling ET from its potential value to an actual estimate. The objectives of the current study are: (1) To evaluate the importance of the input forcings on the ET estimates; checking for uncertainties and consistencies among the input forcings; (2) To understand the sensitivity of the three process models to the various input forcings; (3) To understand the dynamics in ET in a multi-model and multi-platform analyses framework. In the presentation, the impact of input uncertainty on the estimated ET fluxes will be provided as well as the results of a sensitivity analysis for the three models. Such research contributes the NASA's Energy and Watercycle Study (NEWS) and the (WCRP Global Energy and Water Experiment (GEWEX) Landflux initiatve. Both NEWS and Landflux have as goals the

documentation of terrestrial turbulent heat fluxes, including the seasonal and inter-annual variability.

References:

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C. Jimnez, C. Prigent, B. Mueller, and 16 others 2010 Global intercomparison of 12 land surface heat flux estimates. J Geophys. Res. Atmosph. 116, D02102, doi:10.1029/2010JD014545, 2011

Fisher, J. B., K. P. Tu, and D. D. Baldocchi, 2008: Global estimates of the land-atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at 16 FLUXNET sites. Remote Sensing of Environment, 112, 901-919

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Raghuveer K. Vinukollu, Eric F. Wood, Craig R. Ferguson, Joshua B. Fisher 2011: Global estimates of evapotranspiration for climate studies using multi-sensor remote sensing data: Evaluation of three process-based approaches, Remote Sensing of Environment, 115(3): 801-823, 15 March 2011.

Name: Qiaozhen Mu

Email: qiaozhen@ntsg.umt.edu

Title: Introduction to a MODIS Global Terrestrial Evapotranspiration Algorithm

Abstract:

MODIS global ET products by Mu et al. (2007, 2010) are the first regular 1-km2 land surface ET datasets available for the 109.03 Million km2 global vegetated land areas at 8-day intervals. Mu et al. (2010) describes improvements made on the ET algorithm of Mu et al. (2007) (hereafter called old algorithm). The old algorithm calculates ET as the sum of the evaporation from moist soils and the transpiration from vegetation during daytime. The improved algorithm adds the evaporation from wet soils and intercepted canopy precipitation, as well as nighttime ET, to the calculation of the ET estimate. Additional improvements are outlined in Mu et al. (2010), and include: the addition of modelled soil heat flux; improved modelling of stomatal, aerodynamic and boundary layer resistances; and the separation of dry and wet canopy and soil surfaces. The input MODIS data to the improved algorithm include 1) MOD12Q1 land cover type 2 (Friedl et al., 2002); 2) MOD15A2 LAI/FPAR (Myneni et al., 2002); 3) MCD43B2 and MCD43B3 albedo (Lucht et al., 2000; Jin et al., 2003). The input non-satellite data are MERRA GMAO (NASA's Global Modeling and Assimilation Office) daily meteorological reanalysis data over 2000-2009. We compared the improved algorithm with the old one both globally and locally at 46 eddy flux towers. The global annual total ET over the vegetated land surface is 62.8 X 10^3 km^3, agrees very well with other reported estimates of 65.5 X 10^3 km^3 over

the terrestrial land surface (Oki and Kanae, 2006), which is much higher than 45.8 X 10^3 km3 we estimated with the old algorithm. For ET evaluation at eddy flux towers, the improved algorithm reduces mean absolute bias (MAE) of daily ET from 0.39 mm day-1 to 0.33 mm day-1 driven by tower meteorological data, and from 0.40 mm day-1 to 0.31 mm day-1 driven by GMAO data, a global meteorological reanalysis dataset. MAE values by the improved ET algorithm are 24.6% and 24.1% of the ET measured from towers, within the range (10-30%) of the reported accuracy of ET measurements, implying less uncertainty of the improved algorithm. Compared to the old algorithm, the improved algorithm increases the correlation coefficients of the measured ET with tower-driven ET estimates from 0.83 to 0.86, and from 0.81 to 0.86 with GMAO-driven ET. At the global scale, averaged over 2000-2006, MOD16 annual ET can explain 84% of variations of pseudo ET observed at 234 watersheds. The global annual ET/PET ratio can capture the major droughts happened over 2000-2009. Based on these results, the improved ET algorithm has a better performance in generating global ET data products, providing critical information on global terrestrial water and energy cycles and environmental changes.

Name: Martha Anderson

Email: martha.anderson@ars.usda.gov

Title: Integration of Multi-Scale Thermal Satellite Imagery for Evaluation of Daily Evapotranspiration at Continental to Sub-Field Scales

Abstract:
Development of robust algorithms for routine monitoring of evapotranspiration (ET) over large areas at spatial resolutions that discriminate individual agricultural fields (<100 m resolution) and small hydrologic features will benefit an array of water resource management applications. Land-surface temperature (LST) derived from thermal infrared (TIR) remote sensing has proven to be a valuable input to surface energy balance algorithms for estimating ET and serves as an effective proxy for spatially distributed surface moisture and precipitation measurements. Routine monitoring with the current suite of TIR sensors provides broad coverage of a range of spatiotemporal sampling scales. Geostationary satellites such as GOES provide 15 minute LST fields at 5-10 km spatial resolution, polar orbiting systems such as MODIS generate TIR data at 1km resolution every one-two days, while the Landsat TIR systems can produce relatively high resolution (60-120 m) maps every 8-16 days depending on the number of satellites in orbit at a given time. The MODIS and Landsat sensors sample shortwave bands that allow for vegetation cover and amount to be mapped at 250 m and 30 m resolution, respectively. This paper will discuss a strategy for integrating GOES, MODIS and Landsat TIR and shortwave imagery to map daily ET at 30 m resolution. The methodology is based on the continental-scale Atmosphere-Land Exchange Inverse (ALEXI) surface energy balance algorithm, which maps hourly ET using GOES data. Associated flux disaggregation techniques (DisALEXI) downscales ALEXI fluxes using

MODIS and Landsat TIR imagery, which can be improved to the patial resolution of the shortwave bands using thermal sharpening. Finally, a new spatial data fusion algorithm, STARFM, is used to merge the MODIS and Landsat-scale ET evaluations, generating daily predicted fields at the Landsat scale. In this way, we make full use of all available TIR data in interpolating surface moisture conditions between infrequent Landsat overpasses. The methodology has been tested over sites in southern Florida, which represents an area where high-resolution time-continuous ET data are urgently needed for decision making by water management agencies.

Name: Molly Brown

Email: molly.brown@nasa.gov

Title: The Soil Moisture Active Passive Mission (SMAP) for soil moisture observations

Abstract:
The Soil Moisture Active Passive (SMAP) mission is one of the first-tier projects recommended by the U.S. National Research Council Committee on Earth Science and Applications from Space. The SMAP mission is under development and it is scheduled for launch in 2014. The SMAP mission is designed to produce high-resolution and accurate global mapping of soil moisture and its freeze/thaw state using an instrument architecture that incorporates an L-band (1.26 GHz) radar and an L-band (1.41 GHz) radiometer. The project science goals address several topics in water, energy and carbon cycle science as well as provide improved capabilities in several hydrometeorological and hydroclimatological (natural hazards) applications. The preliminary baseline algorithms are undergoing tests and evaluations using airborne field experiment observations. Additional tests are made using the end-to-end SMAP Algorithm Testbed simulation environment. Data characteristics and access for use in applications such as those calculating evapotranspiration will be the focus on this talk.

Name: Xiwu Zhan

Email: xiwu.zhan@noaa.gov

Title: Intercomparison of an ET-based Drought Index Derived from Geostationary Satellite Data with Standard Drought Indicators

Authors: Christopher Hain (1), Martha Anderson (2), Xiwu Zhan (3), and John Mecikalski (4)
(1) I.M. Systems Group at NOAA / NESDIS, Camp Springs, MD, USA,
(2) Hydrology and Remote Sensing Laboratory,

USDA Agricultural Research Service, Beltsville, MD, USA,
(3) NOAA / NESDIS, Camp Springs, MD, USA,
(4) Atmospheric Science Department, University of Alabama in Huntsville, Huntsville, AL, USA

Abstract:
The utility and reliability of standard meteorological drought indices based on measurements of precipitation is limited by the spatial distribution and quality of currently available rainfall data. Furthermore, precipitation-based indices only reflect one component of the surface hydrologic cycle, and cannot readily capture non-precipitation based moisture inputs (e.g., irrigation, shallow groundwater tables, lateral flows) that may temper drought impacts, or affect the rate of water consumption across a landscape. The ESI conveys information about actual stress rather than potential for stress and reflects a different component of the hydrologic cycle that has typically not been considered in drought monitoring, focusing on water use (ET) rather than water supply (precipitation). The Evaporative Stress Index (ESI) quantifies anomalies in the ratio of actual to potential ET (PET) mapped using signals of diurnal land-surface temperature change obtained from geostationary satellites (e.g., GOES, MSG, MT-SAT, FY2) and the Atmosphere Land Exchange Inverse (ALEXI) model (Anderson et al. 1997). This study investigates the behavior and response timescales of the ESI through a retrospective comparison with standard precipitation based drought indices, and with operational drought classifications recorded in the United States Drought Monitor (USDM). Drought indices based on anomalies in both ET and ET/PET are compared over the continental U.S. for the 2000-2010 growing seasons (April to October) to standard drought indicators including the Standardized Precipitation Indices and the Palmer drought indices. Quantitative analysis of spatial and temporal correlation suggests that the performance of the ESI is similar to that of precipitation-based indices of comparable timescale, but with higher spatial resolution and without requiring any precipitation data.

This study suggests that the ESI is a useful complement to the current suite of drought indicators, with particular added value in parts of the world where rainfall data are sparse or unreliable. Finally, future work is being focused on the expansion and application of ALEXI and ESI to additional domains (currently Europe and Africa using MSG thermal data) with the ultimate goal of global application of ALEXI and ESI.

POSTER ABSTRACTS

Name: M. Tugrul, Yilmaz

Email: tugrul.yilmaz@ars.usda.gov

Title: Using Thermal Infrared Remote Sensing based ALEXI Evapotranspiration to obtain skillful Water Budget Estimations

Abstract:
Skillful water budget cycling is essential to many hydrological, agricultural, and meteorological applications. Models conserve the water (input water is equal to output water), however, they are heavily dependent on the parameterization of the specific model that is used. Observations obtained from local meteorological and hydrological stations are very accurate; however, they suffer from the sparsely located nature of the stations, which is pertinent especially for the developing countries.

Among the water budget closure elements, water storage change over long periods of time vanishes where the total amount of water left in the system as runoff is small relative to the other elements of the water budget. Hence, magnitude wise, precipitation and evapotranspiration are the two most important components of long term water budget calculations. Many hydrological models estimate evapotranspiration using precipitation observations; however obtained evapotranspiration information, and the total water budget skill, becomes heavily dependent on the skill of the observed precipitation. Hence, it is viable to seek for an alternative approach, where evapotranspiration and precipitation information are estimated independently.

There are many remotely estimated precipitation products (TRMM, CMORPH, PERSIANN, etc). However, there are fewer options for obtaining a skillful remotely sensed evapotranspiration product. Among them Atmosphere-Land Exchange Inverse (ALEXI) is a thermal-based remotely sensed daily evapotranspiration product with high spatial resolution (5km). Using geostationary satellite that provides frequent estimates of land surface temperature, ALEXI relates the clear sky morning temperature gradient to the sensible heat flux estimates where evapotranspiration is obtained as a residual from the energy balance closure. Water storage change and the streamflow data are the least available components through remote sensing. Although there are applications currently remotely estimate the water storage information, in this application we are going to rely on Land Surface Models to provide consistent storage change information, where runoff will be estimated as a residual from the water budget. This study would be useful to obtain improved water balance elements particularly over developing countries where there are limited ground observations. Value added hydrological fields may be used to improve the hydrological, agricultural, and meteorological applications.

Name: Andrew Jarvis and Kaniska Mallick

Email: k.mallick@lancaster.ac.uk

Title: A numerical scheme for partitioning terrestrial latent heat observation into evaporation and transpiration

Abstract:
Here we present a new method for partitioning the eddy covariance terrestrial latent heat flux (E) observations into wet evaporation (E) and plant sourced water loss (transpiration) (T) in the Penman-Monteith framework. This method uses unobserved component models to estimate key unmeasured variables embedded within various micrometeorological expressions. In doing so we have also specified the potential evaporation (EP) and transpiration (TP) and the transition between these two end member conditions based on the surface wetness (w) dynamics following rainfall and dew formation. The methods were first tested on synthetic data sets, revealing very good agreement between the "observed" and partitioned flux components, canopy conductance and aggregate surface wetness. For real world (eddy covariance) data the method shows good convergence performance and appears to produce very plausible results both for the flux components, aggregate surface wetness dynamics and surface conductance retrievals. Corroboration of these results with satellite and ancillary tower data will be presented.

Name: Mike Hobbins

Email: Mike.Hobbins@noaa.gov

Title: Examining the spatio-temporal variability of potential evaporation across the conterminous US

Abstract:
Due to the essentially unknowable nature of the distribution of soil and vegetative moisture at the temporal and spatial scales useful to water managers and agriculturalists, hydrologists have long used the concept of potential evaporation (Ep) to describe the upper limit to actual evapotranspiration (ET). Ep is then used to drive hydrologic models or empirical relations that account for soil moisture conditions and vegetative constraints on moisture transfer to yield estimates of actual ET. Formulations of Ep vary greatly as to their data requirements and, consequently, their scientific validity and temporal dynamics.

The NWS Colorado Basin River Forecast Center (CBRFC) seeks to improve streamflow forecasts across the Colorado River basin and eastern half of the Great Basin by updating the Sacramento Soil Moisture Accounting (Sac-SMA) model and its atmospheric forcing datasets such as Ep

underpinning the NWS River Forecast System. To this end, this streamflow reanalysis study has replaced the evaporation driver of the Sacramento Soil Moisture Accounting model (which currently consists of climatological monthly pan evaporation values) with daily Ep from a synthetic pan evaporation model (the PenPan model) that modifies the Penman equation to accurately characterize the radiative and advective dynamics of evaporation pans. The new Ep is temporally and spatially dynamic, scientifically sound, and unbiased with respect to pan evaporation observations; it is driven by hourly North American Land Data Assimilation System (NLDAS) data for temperature, specific humidity, wind speed, and shortwave and longwave downwelling radiation, estimated across CONUS at a 1/8th-degree spatial resolution from 1979 to the present.

Given the hydroclimatologic heterogeneity and varied temporal scales across which the CBRFC forecasts streamflow, it is essential to characterize the temporal and spatial variability of Ep, both in its magnitude and in its sources. Here we examine the temporal and spatial variability in Ep using a first-order, second-moment uncertainty analysis applied to the gridded Ep reanalysis time-series across various time-scales and CONUS-wide. Our results have broad implications, particularly in identifying which drivers require the most pre-processing in such formulations, and which, perhaps, may even be ignored in moving to a forecast context that has fewer data inputs available. We also summarize the effects on streamflow simulation skill of the new Ep driver in an ongoing streamflow reanalysis across the period 1980-2010.

Other significant potential uses for forecast and near-term observed Ep are in the analyses of ongoing droughts (e.g., as an input to the US Drought Monitor) and in assisting local and regional agencies (e.g., Denver Water and the U.S. Bureau of Reclamation) in forecasting water demand, and to forecast daily and weekly forecast reference crop ET, a project underway across the NWS Western Region (roughly the western one-third of CONUS). Each of these applications require a climatological context for the analyses / forecasts to be meaningful. This context is provided based on our work with the NLDAS forcings.

Name: Andrew French, Doug Hunsaker, Kelly Thorp

Email: andrew.french@ars.usda.gov

Title: Combining Remote Sensing and Crop Growth Models to Estimate Evapotranspiration over Irrigated Lands at Daily Time Steps

Abstract:
Accurate spatially distributed evapotranspiration (ET) estimates over irrigated lands in the U.S. Southwest could be especially valuable for growers and water district managers while monitoring and forecasting crop water needs. Currently ET can be estimated frequently at coarse spatial scales (1+km), or infrequently (>2 weeks) at fine to moderate spatial scales (10-30m), neither of which are adequate for routine crop water management. At critical growth stages, timing and depths of anticipated irrigations need to be assessed daily. To solve this

problem, two approaches are needed. The first is to increase the frequency of higher resolution remote sensing imagery, implementation of which is a long term endeavor that will require more earth resource satellites than currently available. The second approach is to refine, validate, and spatially extend crop growth models over irrigated lands. This task is a more tractable one, where improvements in decision making can potentially be achieved in shorter time frames. To illustrate how this integration approach could be implemented, research conducted over farm scale crops at US ALARC, Maricopa, Arizona will be presented. Tests show that ET estimates derived from higher resolution remote sensing data in visible, near infrared and thermal infrared wavelengths can be reasonably extended up to ten days using simple crop growth models and estimates of cover fraction/surface temperature relationships. Research underway will pursue integration approaches with greater emphasis upon plant physiological and soil moisture status.

Name: Forrest, Melton

Email: forrest.s.melton@nasa.gov

Title: Satellite Irrigation Management Support with the Terrestrial Observation and Prediction System

Abstract:
In California and other regions vulnerable to water shortages, new technologies are needed to support agricultural producers and water managers in maximizing the benefit of available water supplies. The Satellite Irrigation Management Support project is a NASA supported effort to apply the NASA Terrestrial Observation and Prediction System (TOPS) and data from NASA satellites to map basal crop coefficients (Kcb) and basal crop evapotranspiration (ETcb), and develop information products and tools to support agricultural producers in making irrigation decisions. The primary focus of the effort is to develop the computing and data processing systems required to support the use of satellite and weather data to provide rapid assessments of current crop conditions over large areas, and translate the data into formats that are useful to agricultural producers in irrigation scheduling and water management practices. The project is also building prototypes of web and mobile phone based reporting and data access systems to allow evaluation of data products by agricultural producers. To facilitate quantitative evaluation of the crop coefficient and ETcb maps produced, the project is deploying wireless sensor networks at sites throughout the San Joaquin Valley in California to collect information on soil moisture conditions and irrigation applications. We present the TOPS-SIMS architecture, results to date from the Kcb mapping efforts, and lessons learned from the use of wireless soil moisture monitoring networks to evaluate soil water balance estimates.

Name: Ayse Irmak

Email: airmak2@unl.edu

Title: Evapotranspiration of Semi-Arid Sand Hills of Nebraska through Micrometeorological and Satellite-based Energy Balance Modeling (METRIC) techniques

Abstract:
The Sand Hills region of Nebraska is one of the largest grass-stabilized sand dune formations in the world. The region covers an area of roughly 50,000 - 60,000 km2 that supports a system of five major ecosystems: (1) lakes, (2) wetlands (with lakes, ~5%), (3) sub-irrigated meadows (water table is within ~1 m of surface; ~10%), (4) dry valleys (water table is 1-10 m below surface; ~20%), and (5) upland dunes (water table is more than 10 m below surface; ~65%). The main objective of this research was to improve our understanding of the water use for three ecosystems of Nebraska Sand Hills using ground-based micrometeorological observations, and a land surface energy balance modeling. Flux measurements were obtained from an ongoing study at the University of Nebraska-Lincoln's Gudmundsen Sand Hills Laboratory that utilizes the Bowen ratio method to estimate evapotranspiration (ET) at three locations: (1) a subirrigated meadow, (2) a dry valley, and (3) an upland dune. We have employed satellite remote sensing technology in concert with a surface energy balance model that Measures Evapotranspiration at high Resolution using Internal Calibration (METRIC) to provide daily estimates of ET. Our results showed that the subirrigated meadow's primary consumer of energy was LE, in the dry valley sensible and latent heat fluxes almost balance, and in the upland dune sensible heat flux dominated the use of available energy. Measurement of the energy budget by Bowen ratio stations, in concert with remote sensing, revealed strong spatial gradients in LE and H that are associated with undulating topographic relief. Daily estimates of ET based on Bowen ratio measurements and METRIC model had an uncertainty of roughly 1 mm, which is encouraging when applying remote sensing results across such a broad spatial scale. We also present results showing the daily, monthly, and annual variations in the surface energy balance and associated meteorological variables, which reveals how the three major ecosystems in this complex terrain interact with the underlying groundwater and atmospheric boundary layer throughout the year.

Name: Ray Anderson

Email: rganders@uci.edu

Title: The Regional Evaporative Fraction Energy Balance (REFEB) platform; a new technique to observe regional Evapotranspiration

Authors: Ray G. Anderson1,2,4, Michael L. Goulden1,3, James S. Famiglietti1,2

1Department of Earth System Science, University of California, Irvine, Irvine, CA

92697-3100
2UC Center for Hydrologic Modeling, Irvine, CA 92697-4690
3Department of Ecology and Evolutionary Biology, University of California, Irvine,
Irvine, CA 92697
4Email: rganders@uci.edu

Abstract:
Regional estimates of evapotranspiration (ET) are needed for environmental analysis and management purposes, however current methods for determining regional ET have significant limitations that reduce their usefulness. We developed a mobile surface measurement technique, the Regional Evaporative Fraction Energy Balance platform (REFEB), which measures Evaporative Fraction (EF) and Water Use Efficiency (WUE). In this presentation, we briefly examine the theory, instrumentation, validation, and uses of REFEB. We present results from a validation campaign in an irrigated agricultural region, the Imperial Valley, California against a tightly closed regional water balance. We also conducted an experimental campaign in a Mediterranean montane region, the San Jacinto/Santa Rosa Mountains; an extremely heterogeneous region that is challenging to existing regional ET approaches. The results show that REFEB is a viable approach for estimating regional ET in field campaigns and can be used to conduct large scale experiment measurements.

Name: Richard Allen

Email: rallen@kimberly.uidaho.edu

Title: Fusion of Moderate Resolution Landsat-based Energy Balance with Daily Weather Grids to Produce High Definition Evapotranspiration over Hydrologic Time Periods

Authors: Rick Allen, University of Idaho, Ayse Irmak, University of Nebraska, Jeppe Kjaersgaard, South Dakota State University

Abstract:
Satellite based surface energy balance models are now used routinely to produce evapotranspiration (ET) products on an operational basis for use in water resources management. Landsat satellite imagery is commonly used to produce estimates of ET with energy balance methods because of the relative high definition of thermal data that helps discern ET of individual agricultural fields. Cloud cover and relative infrequency of satellites makes the continuous integration of ET over time difficult, especially under conditions of evolving vegetation and varying soil surface wetness. With Landsat, it is common to find only one good image per month suitable for processing. As a result, monthly and ultimately seasonal ET depths are generally based on one or two “snapshots” of ET per month, with ET between satellite dates estimated using interpolated relative ET from the image dates coupled with a “potential” or “reference” that is weather based. In METRIC (Mapping Evapotranspiration at high Resolution using Internalized Calibration), daily ET are commonly expressed as the relative

ETr fraction, ETrF, calculated as ETrF = ET / ETr where ETr is tall reference ET computed from weather data (ASCE-EWRI, 2005) and ET is retrieved from the image snapshot using energy balance. Monthly ET depths are estimated by interpolating ETrF values to all days falling between image dates using a cubic spline function and multiplied by the corresponding daily reference ET (Allen et al., 2007a,b) A potential shortcoming to basing integrated ET averages on periodic snapshots from satellite images is that local or regional precipitation events antecedent to the satellite images may unduly dominate the ETrF image and may not represent evaporation from rainfall averaged over the monthly period. Also, rain events occurring between satellite images may not be "seen" in the images so that those evaporation amounts are not fully accounted for. This can impact accuracy of ET maps used for hydrologic water balances.

There is a valuable opportunity to utilize gridded weather products from NARR, NLDAS and similar land surface / weather modeling systems to produce a) reference ET grids needed between Landsat image dates and b) precipitation grids to be used in evaporation process models to adjust Landsat-based ETrF images to better represent the interpolated time periods. Precipitation grids in NARR and NLDAS need to be refined to improve local accuracy of evaporation estimates. The gridded weather data from NARR and NLDAS need to be "conditioned" in many situations, especially for irrigated areas in western US desert areas so that near surface air temperature, humidity and wind speed better represent well-watered conditions of irrigation, prior to being inserted into an ET estimation equation such as the Penman-Monteith.

Name: Peyman Daneshkar Arasteh

Email: pdaneshk@uci.edu

Title: Comparison of Remotely Sensed LAI and PAR with Ground Measurements in Qazvin Plain, Iran

Abstract:
Biophysical variables of leaf area index (LAI) and photo-synthesis active radiation (PAR) are the main canopy structure dependant variables that describe canopy physical-structural characteristics and energy-mass exchange rate. These variables are very important in remotely sensed evapotranspiration and productivity estimations.

In this study remotely sensed LAI and PAR using Landsat/ETM+ and TERRA/MODIS images were compared with ground measurements of LAI and PAR using ACCUPAR/LP80 device. Ground measurements were done in 5 different locations in Qazvin Plain, Iran; 29.86 to 40.03 degrees N latitude and 34.49 to 52.23 degrees E longitude simultaneous to satellite passes in 6 dates from June to August 2010. The results showed a R2=0.56 for LAI and R2=0.92 for PAR.

Name: Saleh Taghvaeian

Email: s.t@aggiemail.usu.edu

Title: Studying Water Balance Components Using Remotely Sensed Estimates of Evapotranspiration

Abstract:
Quantifying the water balance components of agro-riparian ecosystems in the Western US can significantly assist decision makers in managing the limited water resources of this semi-arid region in a more efficient way. Although traditional point measurements can be very accurate, they provide only one average value for the whole study area, which has limited application where significant heterogeneity in vegetation type and hydro-climatological conditions exist. Remote sensing techniques have proved to be reliable in mapping spatially distributed evapotranspiration (ET) at different temporal and spatial scales. In this study, 21 Landsat TM5 images acquired in 2008 are used as input data to the Surface Energy Balance Algorithm for Land (SEBAL) in order to estimate water consumption over an agro-riparian ecosystem along the Lower Colorado River. The results are then combined with the point measurements of precipitation, water diversion, groundwater elevation, and return flows in order to close water balance for an irrigation scheme, as well as a stretch of the river that contains both the irrigation scheme and associated riparian corridor. The results showed that SEBAL estimates can be effectively used to study water balance components. In addition, the spatially distributed nature of remotely sensed data provides water managers with a strong tool to simulate the effects of different management practices on water availability.

Name: Sumantra, Chatterjee

Email: schatterjee3@unl.edu

Title: A modified crop coefficient approach for estimating regional evapotranspiration

S. Chatterjee, S.I. Sritharan, D. Watts, R. Kandiah and X. Wei

Abstract:
In large scale water management, one primary challenge for the decision makers and operators is an accurate estimation of water lost by evapotranspiration (ET). The challenge becomes more complicated if the water use is by several different crop types and/or natural vegetation in the region. Though historically different ET estimating procedures have evolved to meet this challenge, these procedures have limitations with regard to accurate estimation of ET over a large region. Remote sensing techniques, taking different approaches, have been developed in the recent past to estimate ET from large areas with different vegetative cover. A common practice is to obtain crop coefficients using spectral imagery and couple them with ground based reference crop ET estimation to obtain regional ET, which may be termed as a hybrid

approach of using ground based data and remotely sensed images. Regional ET estimation is also possible using remote sensing if the imagery contained fields with reference crops for which ET values are available either through meteorological measurements or direct instrumentations such as Bowen Ratio Energy Balance (BREB) sensors. However, a practical complication is the existence of a field with reference crop that can be treated as an ideal reference crop by definition. The proposed research work describes the methodology for determining regional ET using measurements for any crop available in the region.

Although FAO56 guides of using a reference crop field and using Penman-Monteith ET (PM ET) estimation for that hypothetical field, often it becomes difficult to get micro-meteorological measurements (essential components of PM ET estimations) that are good representations of ideal reference crop field. To overcome this complexity we developed a procedure to bypass the need of obtaining reference crop ET values. Instead of using a reference crop ET, we showed that if crop coefficients can be accurately estimated using satellite images, then ET estimation made over any crop area can be projected over a large region.

We conducted our experiment in the Palo Verde Irrigation District (PVID) and Cibola National Wildlife Refuge (CNWR), in the Lower Colorado Region. We had one Bowen ratio tower installed inside an alfalfa field in PVID and three Bowen ratio towers installed inside the densely patched riparian vegetation containing salt cedar vegetation of different plant densities. Using this procedure we showed that we can successfully estimate ET at the location of one tower site by using only satellite images and ET estimation made from another tower site. Also we showed that ET from one tower site can be used to obtain ET over a large region. When compared with actual ET estimations using traditional crop coefficient method, our new procedure estimated ET within an accuracy range lying between 6% (except for one case, for which it was 11.8%). We believe this new procedure will simplify ET estimating procedures for large regions.

Name: Suat Irmak

Email: sirmak2@unl.edu

Title: Nebraska Water and Energy Flux Measurement, Modeling and Research Network (NEBFLUX)

Abstract:
Surface energy and water vapor fluxes play critical role in understanding the response of agro-ecosystems to changes in environmental and atmospheric parameters. These fluxes play crucial role in exploring the dynamics of water and energy use efficiencies of these systems. Quantification of the fluxes is also necessary for assessing the impact of land use and management changes on water balances. Accomplishing these goals requires measurement of water vapor and energy exchanges between various vegetation surfaces and microclimates for

long-enough periods to empathize the behavior and dynamics involved with the flux transfer so that robust models can be developed to predict these processes under different scenarios. Networks of flux towers such as AMERIFLUX, FLUXNET, FLUXNET-CANADA, EUROFLUX, ASIAFLUX, and CAR-BOEUROPE have been collecting data on exchange processes between biosphere and atmosphere for multiple years across the globe to better understand the functioning of terrestrial ecosystems and their role in regional and/or continental and global carbon, water, and energy cycles, providing unique service to the scientific community. Nonetheless, there is an imperative need for these kinds of networks to increase in number and intensity due to the great diversity among ecosystems and agro-ecosystems in species composition, physiological properties, physical structure, microclimatic and climatic conditions, and great diversity in management practices. The Nebraska Water and Energy Flux Measurement, Modeling, and Research Network (NEBFLUX) is a comprehensive network that is designed to measure surface energy and water vapor fluxes, microclimatic variables, plant physiological parameters, soil water content, surface characteristics, and their interactions for various vegetation surfaces. The NEBFLUX is a network of micrometeorological tower sites that uses mainly the Bowen ratio energy balance systems (BREBS) to measure surface water vapor and energy fluxes between terrestrial agro-ecosystems and microclimate. At present, ten BREBSs and one eddy covariance system are operating on a long-term and continuous basis for vegetation surfaces ranging from tilled and untilled irrigated and rainfed croplands, irrigated and rainfed grasslands, rainfed switchgrass to Phragmites (Phragmites australis)-dominated cottonwood (Populus deltiodes var. occidentalis) and willow stand (Willow salix) plant communities. The NEBFLUX project will provide good quality flux and other extensive supportive data on plant physiology [leaf area index, stomatal resistance, within-canopy radiation parameters, productivity (yield and/or biomass), and plant height], soil characteristics, soil water content, and surface characteristics to the micrometeorology, water resources engineering, and science community on broad spectrum of agro-ecosystems. The fundamental premise of the NEBFLUX project is to make continuous and long-term (at least ten complete annual cycles for each surface) exchange of water vapor and energy fluxes. In addition to the scientific and research objectives, information dissemination to educate the general public and youth is another important objective and output of the network. This presentation will describe basic principles and operational characteristics of the NEBFLUX.

Name: Ayse Irmak, Ian Ratcliffe, Pariskit Ranade

Email: airmak2@unl.edu

Title: Monthly and Seasonal Evapotranspiration Mapping Using Land Surface Energy Balance with METRICtm and Daily Gridded Weather

Abstract:
Water is the most important constraint facing agriculture in most of the Central High Plains of the U.S.A.. Local, state and federal water management regulatory agencies need good quality water use estimates for different land surfaces to assess short and long-term water

management, planning, and allocations on a watershed scale. The Bowen Ratio Energy Balance System (BREBS) and eddy correlation techniques offer alternatives for measuring evapotranspiration (ET) at a footprint scale. Despite the high accuracy of techniques, they may not be practical when quantifying ET at regional scales due to the number of measurement sites needed and the operational expense of such a dense network.

Satellite/remote sensing technology provides an opportunity for representing spatial and temporal variation of ET on a watershed scale. Land surface energy balance models are routinely used to produce ET maps using satellite data and weather measurements. Furthermore, high resolution thermal imagery from satellites such as Landsat made it possible to map within field ET variability. Typically, ET "snapshot" on each Landsat overpass day were created, allowing one or two "snapshots" of ET per month. However, Creating "maps" of ET that are useful in managing water resources requires the computation of ET over monthly and annual periods. Methods are needed to interpolate ET information between satellite image dates in producing accurate final ET product. This interpolation involves treatment of clouded areas of images, accounting for evaporation from wetting events occurring prior to or following overpass dates, and applying a grid of daily reference ET with the relative ET computed for an image, or a direct Penman-Monteith type of calculation, over the image domain for periods between images to account for day to day variation in weather. The particular methodology for estimating these spatial variables significantly impacts the accuracy of the final ET product. The overall objective of this paper is to describe the processes involved to produce daily, monthly, and seasonal ET maps from instantaneous Landsat imagery. A total of 45 Landsat images were acquired from the USGS Earth Explorer database for 2007 in Nebraska. METRIC was used to compute complete radiation and energy balances along with the resistances for momentum, heat, and water vapor transport for each pixel in the Landsat imagery. Extensive data quality analyses were conducted before the climate data were used. A distributed daily soil water balance model was developed and was employed to estimate residual moisture from the bare soil for 2007 for a given Landsat scene. The results from soil water balance were used to adjust the "background" evaporation of the processed image to better reflect that for the month or other period that it is to ultimately represent.

Name: Hatim Geli, Christopher Neale, and John Osterberg

Email: hatim.geli@aggiemail.usu.edu

Title: The Application of the Two-source Model Using High/Low Spatial Resolution Imagery and LiDAR Data to Estimate the Evapotranspiration of Tamarisk

Abstract:
The presence of Tamarisk in the southwest of the united state has become a concern to the water resource management community. This invasive species which becomes the dominant riparian vegetation, especially in arid to semi-arid environments, out-competes native species for moisture, lower the water table and increases soil salinity. We present this study as an

effort to provide reliable estimate of the amount of the water lost or consumed by tamarisk through evapotranspiration (ET) and to better understand the related land surface and near atmosphere interactions. The recent advances in remote sensing techniques and the related data quality made it possible to provide spatio-temporal estimates of ET at a considerably higher resolution and reliable accuracy over a wide range of surface heterogeneity. Here we tested one of the soil-vegetation atmosphere transfer models namely the Two Source Model (TSM) of Norman et al. (1995) with its recent modifications, to provide estimates of the different surface energy fluxes and ET. We investigated on the performance of the TSM using high spatial resolution airborne imagery at 1.0 m resolution for the shortwave reflectance and about 3.5 m for the longwave thermal infrared bands acquired by the research aircraft of the Remote Sensing Services Laboratory at Utah State University (USU). Also a comparison of the TSM estimates was made when using relatively low spatial resolution at 30.0 m of the Landsat imagery. Detailed LiDAR-derived vegetation height maps, acquired by the LASSI Lidar developed at USU, was used on both scenarios. Note that the airborne imagery was acquired during the same of the Landsat overpass dates. The study was conducted over the Cibola National Wildlife Refuge at the Lower Colorado River in southern California which is populated with dense stands of tamarisk, during the summer of 2007-2008 as part of a project funded by the US Bureau of Reclamation initiated for water resources management over the Palo Verde Irrigation District. The model results were compared to fluxes from eddy covariance and Bowen ratio towers deployed within the area.

Name: Andrew French, Doug Hunsaker, Kelly Thorp

Email: andrew.french@ars.usda.gov

Title: Combining Remote Sensing and Crop Growth Models to Estimate Evapotranspiration over Irrigated Lands at Daily Time Steps

Abstract:
Accurate spatially distributed evapotranspiration (ET) estimates over irrigated lands in the U.S. Southwest could be especially valuable for growers and water district managers while monitoring and forecasting crop water needs. Currently ET can be estimated frequently at coarse spatial scales (1+km), or infrequently (>2 weeks) at fine to moderate spatial scales (10-30m), neither of which are adequate for routine crop water management. At critical growth stages, timing and depths of anticipated irrigations need to be assessed daily. To solve this problem, two approaches are needed. The first is to increase the frequency of higher resolution remote sensing imagery, implementation of which is a long term endeavor that will require more earth resource satellites than currently available. The second approach is to refine, validate, and spatially extend crop growth models over irrigated lands. This task is a more tractable one, where improvements in decision making can potentially be achieved in shorter time frames. To illustrate how this integration approach could be implemented, research conducted over farm scale crops at US ALARC, Maricopa, Arizona will be presented. Tests show that ET estimates derived from higher resolution remote sensing data in visible, near infrared

and thermal infrared wavelengths can be reasonably extended up to ten days using simple crop growth models and estimates of cover fraction/surface temperature relationships. Research underway will pursue integration approaches with greater emphasis upon plant physiological and soil moisture status.

Name: Gabriel Senay; Stefanie Bohms; James Verdin

Email: senay@usgs.gov

Title: Large Scale Evapotranspiration Estimation using Remote Sensing and Global Weather Datasets

Abstract:
Landscape evapotranspiration (ET) is a key component of the hydrologic water balance of a watershed. The increasing availability of global datasets for weather variables and remotely sensed data for land surface temperature and other key variables allows us to make estimates of landscape ET at a global scale. Spatial distribution of landscape ET can be used as an indicator of vegetation performance and vegetation water use. While absolute magnitudes of ET are used for agro-hydrologic applications such as estimating missing water balance terms, anomalies of ET are used to detect drought for early warning applications. U.S. Geological Survey Earth Resources Observation Science Center has developed operational tools to estimate ET and its anomalies on a daily and 8-day time scales using water balance and energy balance principles for various parts of the world, including regions in Africa, Asia, Central America and the US. Operational ET estimates have shown promising results and applications. The near-real time water balance product for the conterminous US (CONUS) is posted daily at 7:00 pm at http://earlywarning.usgs.gov/usewem/swi.php from April 1 till October 31 since 2000. A procedure is being developed to stage historical (2000-2010) and operational ET products based on the Simplified Surface Energy Balance (SSEB) approach for Africa and the US by the summer of 2011. Drawing from experiences in the US and Africa, the paper will highlight the approaches, lessons learned, and opportunities and challenges for implementing the operational ET estimation in more regions of the world.

Name: Marzieh Azarderakhsh

Email: mazarderakhsh@gc.cuny.edu

Title: Assessing remote sensing based ET estimates over the Amazon basin

Abstract:
There are different data sets to estimate ET globally; in which the largest absolute disagreements occur over tropical rainforest regions. Three different global remote sensing based ET data sets are used in the study of water balance in Amazon basin by dividing it to

smaller sub-basins. Different data sets with lower uncertainties will be used for precipitation (P), runoff (R) and storage variation (dS/dt) terms of the water balance to estimate ET. The estimated values then are compared to the ET data sets. The evaluation of the data sets shows the accuracy of the estimates and their ability to capture the seasonal and spatial variability of the evapotranspiration over the Amazon. This study also, will detect some of their powerlessness and suggests including other important variables in estimating evapotranspiration such as open water areas and their time variability.

Name: Rick Mueller

Email:

Title: The Cropland Data Layer (CDL) Program

Abstract:
The Cropland Data Layer (CDL) Program produced by the National Agricultural Statistics Service released a continental 30 meter data product for crop year 2010. The CDL is an agricultural specific land cover classification derived from Landsat and Resourcesat-1 AWiFS imagery. Ground truth samples are drawn over the agricultural domain from the Farm Service Agency/Common Land Unit while non-agricultural data is drawn from the U.S. Geological Survey/National Land Cover Dataset. Additionally, National Elevation, Percent Imperviousness and Forest Canopy Datasets are used as ancillary data inputs. The CDL is a one of a kind data product, providing annual updates of the agricultural landscape, with crop year 2009 being the inaugural year for national coverage, albeit 56 meter resolution. The CDL data product is used by researchers, educators, and industry to analyze, monitor, and model changes in agricultural and natural resource activities as well as establish the basis for sustainability, yield, and carbon potential. The CDL data product is available at the following geo-visualization portal: http://nassgeodata.gmu.edu/CropScape/.

Name: Qiaozhen Mu, Maosheng Zhao, Steven W. Running

Email: qiaozhen@ntsg.umt.edu

Title: Applications of Global MODIS Evapotranspiration Algorithm at AmeriFlux Tower Site and Global Scale

Abstract:
Global ET algorithm developed by Mu et al. (2007) based on Cleugh et al. (2007) using the Penman-Monteith equation was improved. The improved MODIS ET algorithm runs at daily basis. Temporally, daily ET is the sum of ET from daytime and night. Vertically, ET is the sum of water vapor fluxes from soil evaporation, wet canopy evaporation and plant transpiration at

dry canopy surface. The MODIS ET has been validated from ET measured at eddy flux towers and ET estimated from 232 watershed by subtracting annual total precipitation with stream flow averaged over multiple years. Averaged over 2000-2010, the total global annual ET over the vegetated land surface is 61.65 X 10^3 km^3, with an average of 576 to 382 mm yr-1, comparable to the recent global estimates. MODIS ET data from 2000 to 2010 are ready and have been released to the public for users to freely download from our ftp site at ftp://ftp.ntsg.umt.edu/pub/MODIS/Mirror/MOD16/.

Name: Timothy Martin

Email: Tim.Martin@riverside.com

Title: Satellite-Based Evapotranspiration Mapping and Water Use in Irrigation Systems of Morocco

Abstract:
Increasing demands on the water resources of Morocco present serious challenges to irrigation districts and water managers. Through modernization of irrigation practices and delivery systems, water can be conserved by increasing efficiencies and improving water productivity. Satellite imagery and the METRIC surface energy balance method were used to derive reasonable and objective estimates of crop evapotranspiration (ET) in three Moroccan irrigation sectors. The METRIC analysis requires satellite imagery with thermal (surface temperature) information, as well as high quality weather data. Both Landsat and MODIS satellite images were used in this study. The spatially distributed ET estimates maps were combined with surface water supply records and weather data, and used as inputs to a water balance analysis to estimate the quantity of supplemental groundwater used for irrigation. The results are useful as a pre-project, baseline condition for investments in irrigation methods and system improvements. A similar approach can be used to monitor the irrigation system during and after the improvement project is completed.

Name: Timothy Martin

Email: Tim.Martin@riverside.com

Title: Web-based Dissemination of Surface Energy Balance Evapotranspiration Estimates

Abstract:
Quantification of water consumptive use is increasingly important as water resources are placed under growing tension by increased users and interests. Scarce water supplies can be managed more efficiently through the use of information and prediction tools accessible via the Internet. METRIC (Mapping ET at high Resolution with Internalized Calibration) represents a maturing technology for deriving a remote sensing-based surface energy balance for estimating

ET. This technology has the potential to become widely adopted and routinely used as input to operational and planning models for water demand forecasting, reservoir operations, ground-water management, irrigation water supply planning, water rights regulation, and for the improvement, validation, and use of hydrological models. Distribution of results via the Web provides a vehicle through which ET estimates can be made more accessible to hydrologic modelers and other end users. ET Server is a Web mapping application that allows end user to assess the results of the spatially distributed ET modeling. In addition, this application provides rapid and transparent access to the data, utilizing GIS-based analytical tools that facilitate ET assessments associated with a selected spatio-temporal scale of interest.

Name: Joshua Fisher

Email: jbfisher@jpl.nasa.gov

Title: On uncertainty in global evapotranspiration estimates from choice of input forcing datasets

Abstract:
There have been recent advancements in the global estimation of actual evapotranspiration in terms of model development and dataset production. These efforts have supported both water resources and climate research (e.g., GEWEX/LandFlux, iLEAPS). Three major global evapotranspiration intercomparison studies have been published this year [Jimnez et al., 2011; Mueller et al., 2011; Vinukollu et al., 2011]. However, two of the three studies compared evapotranspiration products from models run with completely different forcing data. The other study was able to drive three models with the same forcing data, but this was just one combination of the multitude of possible forcings available. Here, we add to these efforts by running a global evapotranspiration model [Fisher et al., 2008] with 19 different possible combinations of forcing data. These data include 3 net radiation products (SRB, CERES, ISCCP), 3 meteorological datasets (CRU, AIRS, MERRA), and 3 vegetation index products (MODIS, GIMMS, FASIR). The choice in forcing data creates a range in global monthly averaged evapotranspiration estimate of up to 1 W m^{-2}. Some of the forcing combinations include entirely remotely sensed data; we show that the difference between using all or partial remotely sensed inputs is minimal. The implication for this is that an extended time series can be pieced together from multiple combinations: we produce a global time series from 1984-2006. Future work will include running multiple models with the forcing matrix dataset.