ECOSTRESS METRIC EVAPOTRANSPIRATION ALGORITHM

Rick Allen, University of Idaho-Kimberly

Member of the Landsat Science Team

HyspIRI TQ3 Science Support

Collaborators:

Ayse Kilic, Univ. Nebraska-Lincoln
Ricardo Trezza, Univ. Idaho
Jan Hendrickx, New Mexico Tech.
Justin Huntington, Desert Research Institute
Baburao Kamble, Univ. Nebraska-Lincoln

2014 HyspIRI Science and Applications Workshop

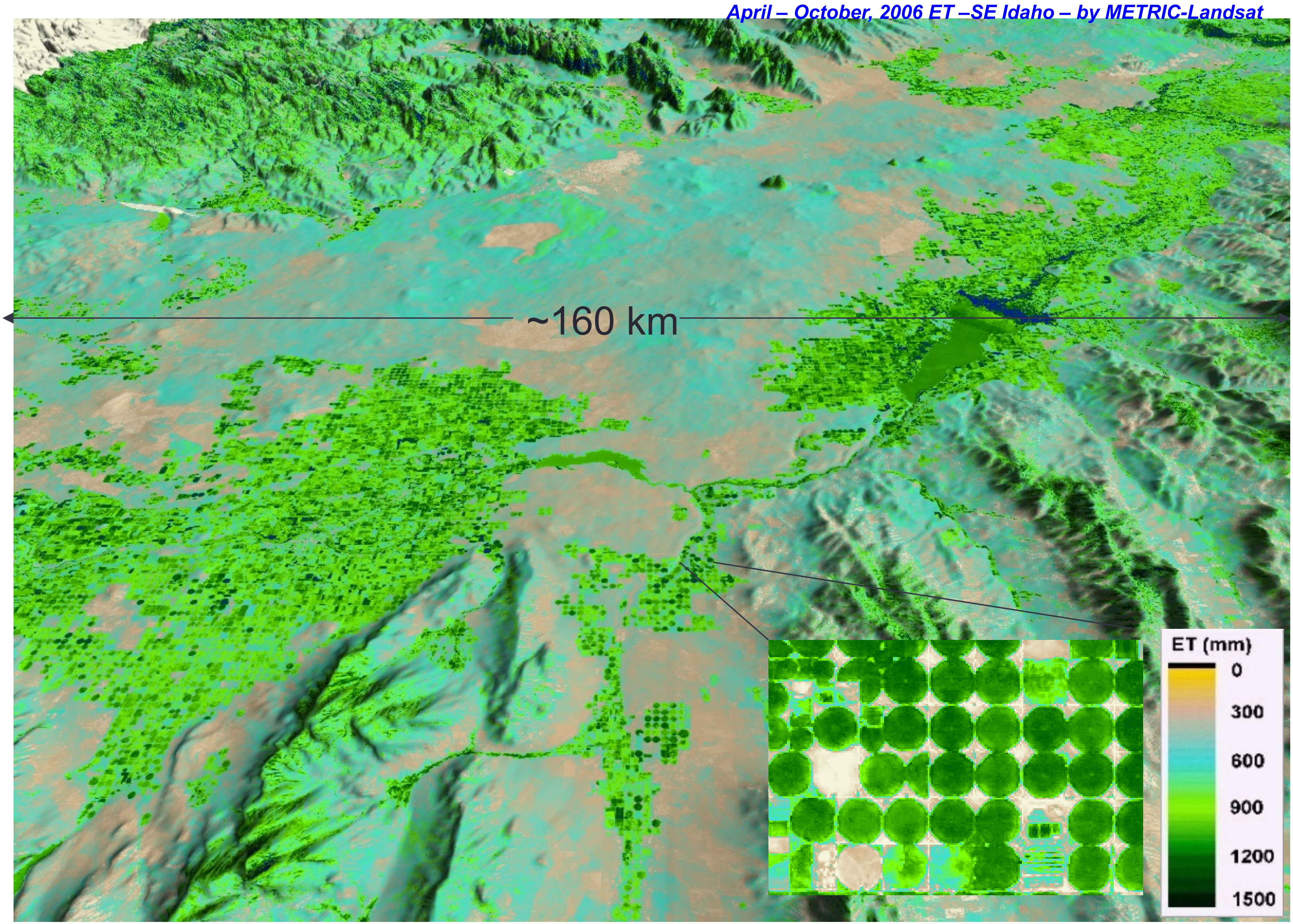
Definitions

- ECOSTRESS - ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
- METRIC – Mapping EvapoTranspiration at high Resolution using Internalized Calibration

Applications

- METRIC is used for ***water resources management*** and planning and ***water rights management*** by the States of:
  - Idaho, Montana, Oregon, Nevada, New Mexico, Wyoming, Nebraska, North Dakota and Washington
- by entities including
  - Metropolitan Water District of Southern California
  - Gallo Wines
- in litigation including
  - Montana vs. Wyoming (US Supreme Court)
  - Texas vs. New Mexico (US Supreme Court)
  - Antelope Valley vs. City of Los Angeles (impacts of ground-water pumping)
  - Upper Klamath River basin of Oregon and California (endangered species v. irrigation)

ET is needed at the field scale and for historical and present



Science Questions on ECOSTRESS relative to ET and METRIC

- How should thermal/energy balance-driven/end-member calibration algorithms such as METRIC be evolved to work accurately and consistently in the precessing west-to-east orbit of the International Space Station (ISS)?

- What sizes of automated moving-windows best provide the statistical description for end member-based calibration given:
  - continually varying sun angle and radiation energy balance
  - continually varying impacts of wind speed on convective fluxes of sensible heat
  - continually varying residual evaporation rates from precipitation wetting events
  - high seasonal variation in vegetation dynamics ranging from heat and drought to partial snow cover
  - complex terrain

- What are best time-integration strategies to produce ET maps showing total fluxes over periods of weeks and months that are meaningful and useful to water managers and studies of water behavior of ecosystems?

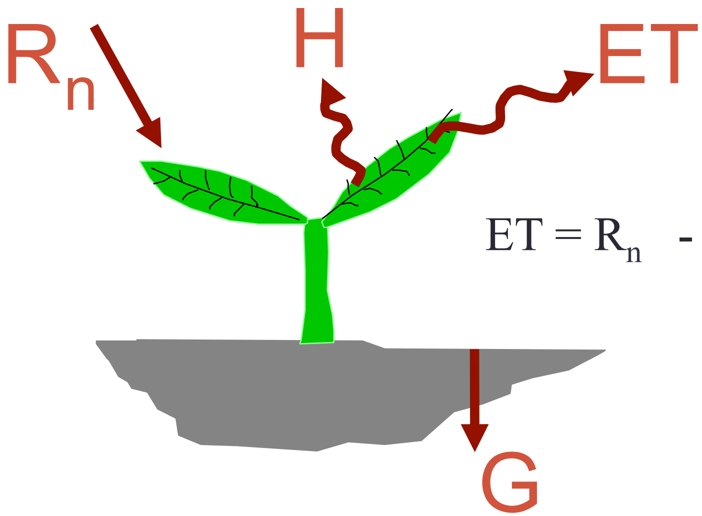
Two Primary Families of **Energy Balance:**

- Forcing / boundary layer growth models
  - Federal GDAS / LDAS / LIS systems
  - NOAH – NOAA
  - MOSAIC – NASA
  - VIC – Letenmeier
  - HIRLAM (KNMI, The Netherlands, Europe)
  - Alexi two source – Norman, Anderson, Kustus

-Continuous in time
-Driven by gridded weather data
-Informed by Remote Sensing
-Large grid sizes (1 km – 32 km)

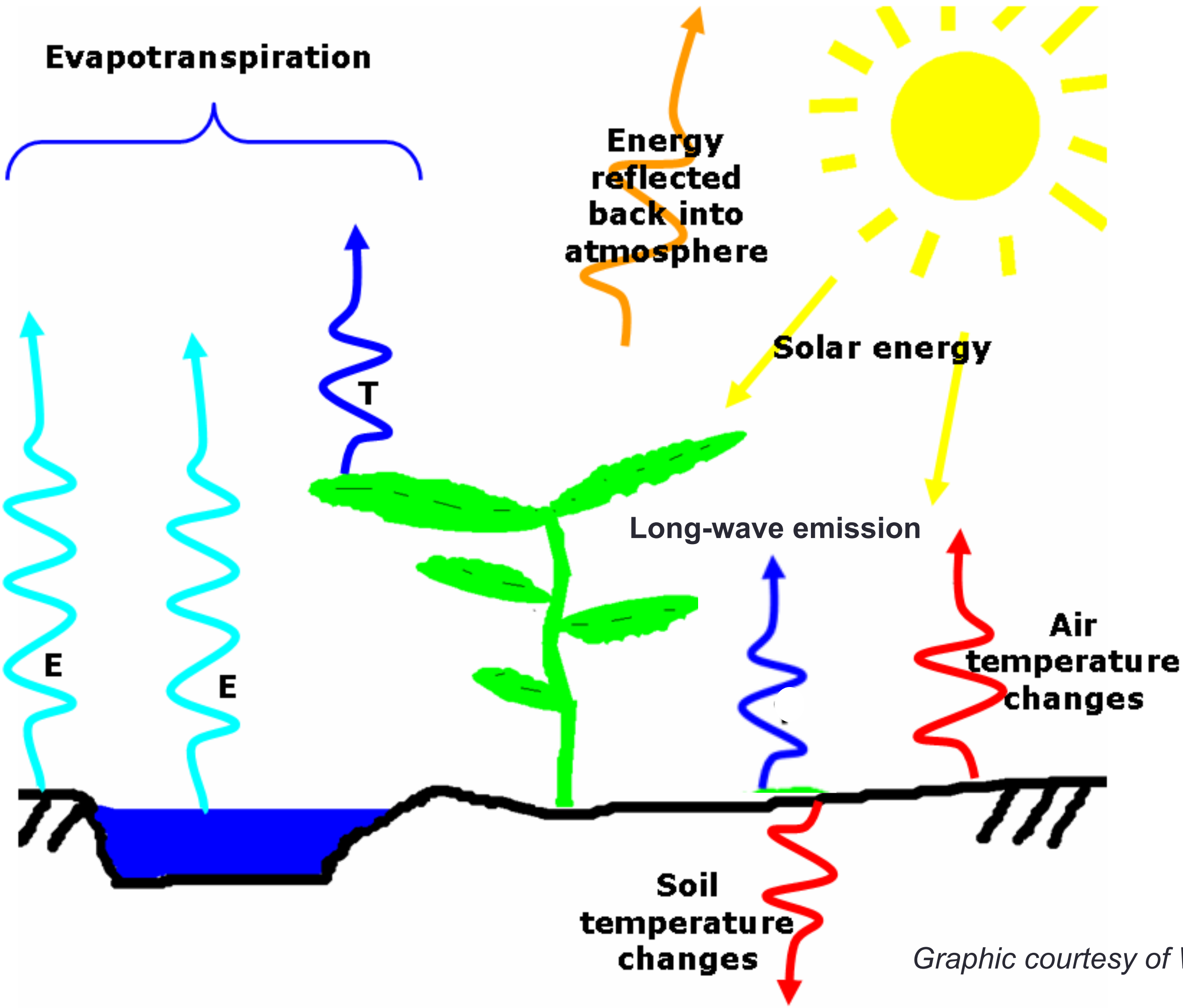
- Snapshot models
  - SEBAL
  - SEBI
  - SEBS
  - REEM
  - disAlexi
  - METRIC
  - etc (derivatives)

-Discrete in time
-Driven by Remote Sensing
-Smaller grid sizes (30 m – 1 km)



$$ET = R_n - G - H$$

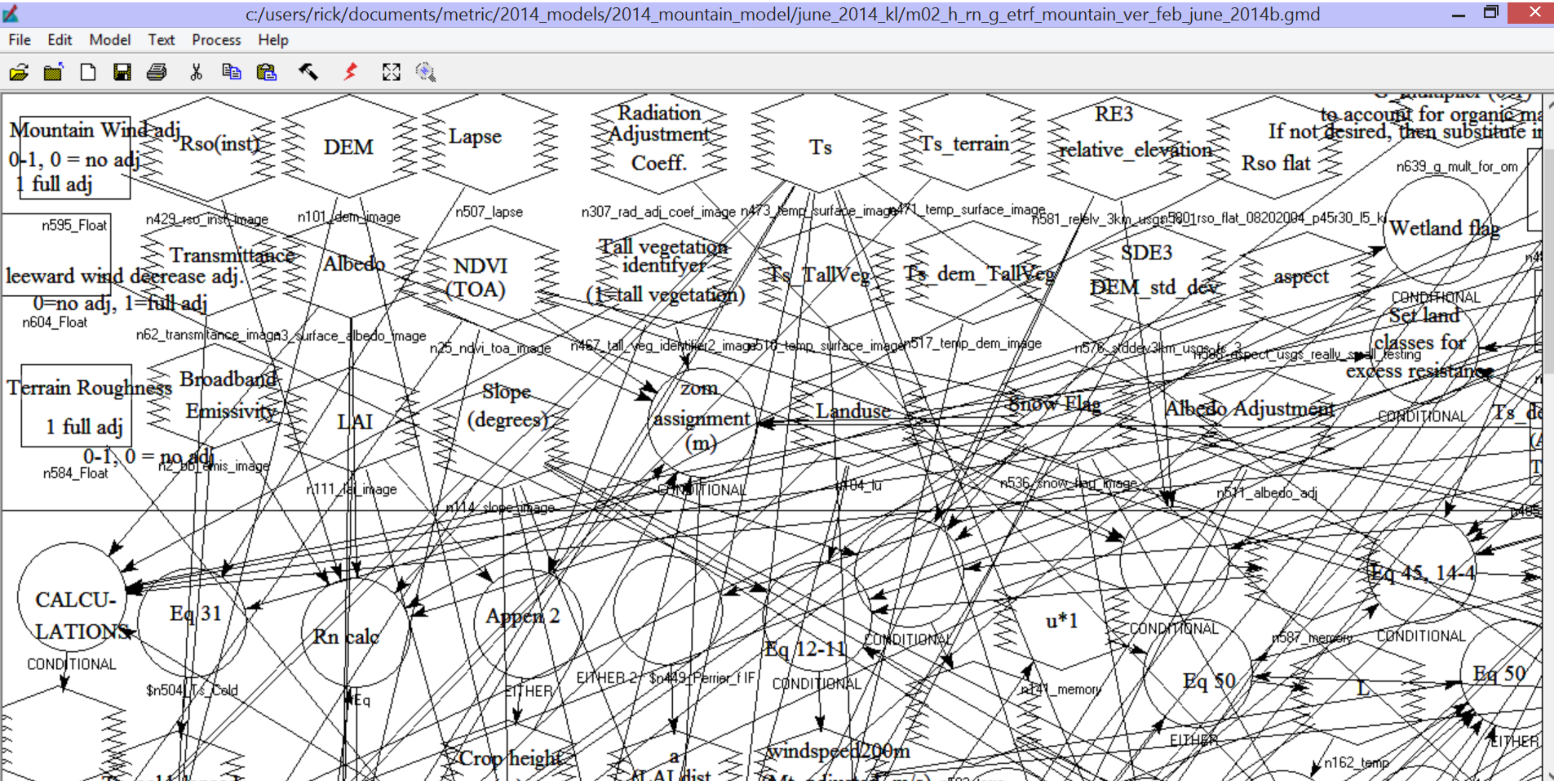
-- "Snapshots" will, in effect, become 'movies' with ECOSTRESS



Graphic courtesy of WaterWatch

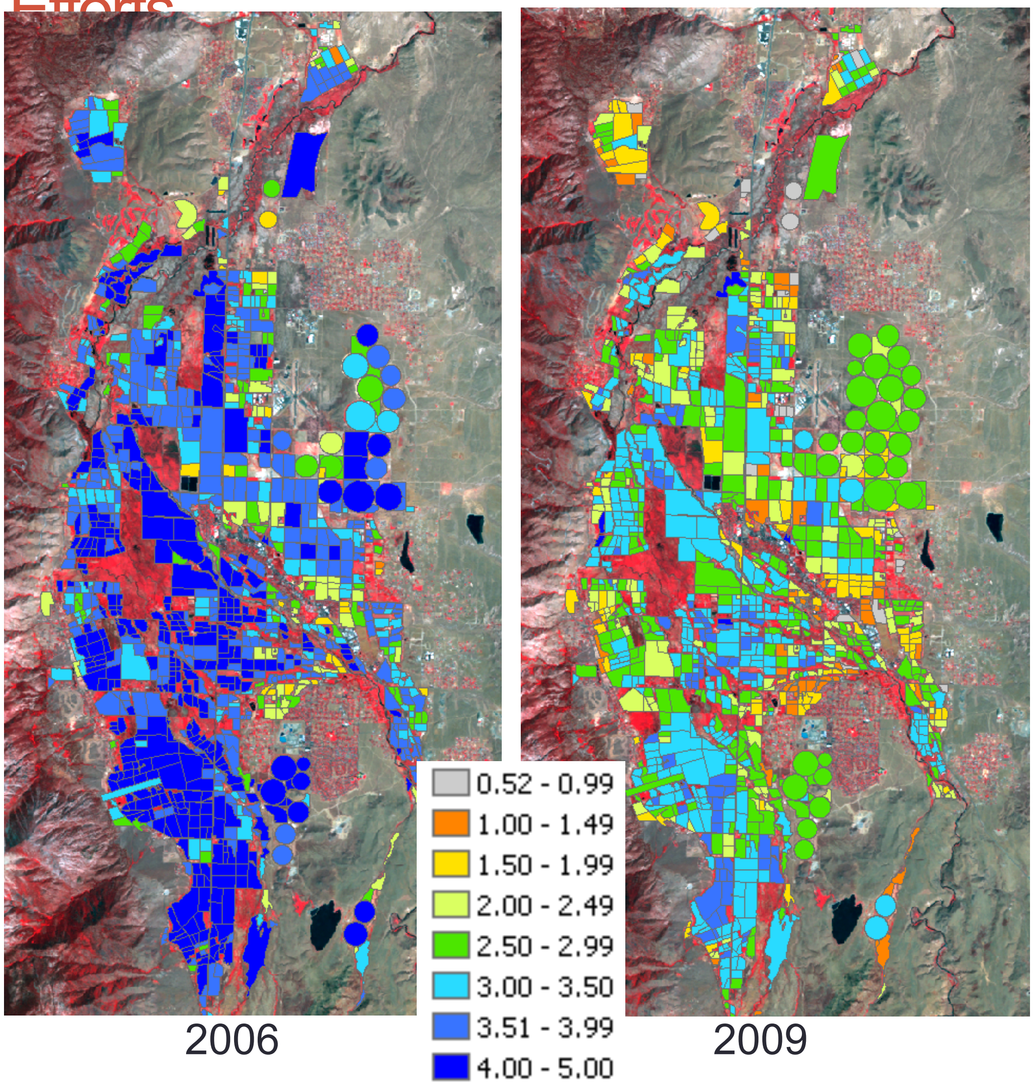
Three major components of the Surface Energy balance are driven by LST (sensible heat flux, net long-wave radiation, ground heat flux)

Example Portion of METRIC "Mountain" model coded in ERDAS ModelMaker



METRIC model is coded in ERDAS ModelMaker, Python, and Google Earth Engine JavaScript

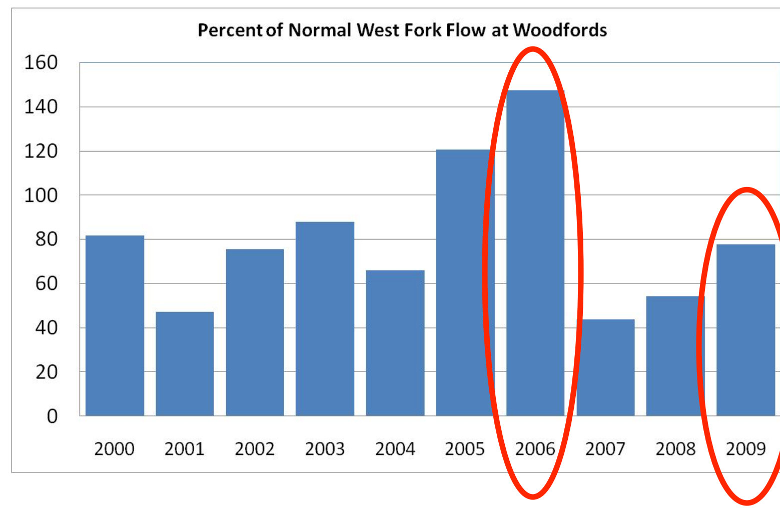
Carson Valley NV - Comparison of METRIC ET in Wet and Dry Years 2006 and 2009 to Support USGS Groundwater Modeling Efforts



ET (ft/yr)

- GW Model average annual ET = **3.0 ft** and is being used for all years no matter if Carson River flow is high or low
- Assisting USGS to refine this assumption in ongoing transient modeling efforts

- METRIC Average ET 2006 = **3.5 ft**
- METRIC Average ET 2009 = **2.6 ft**

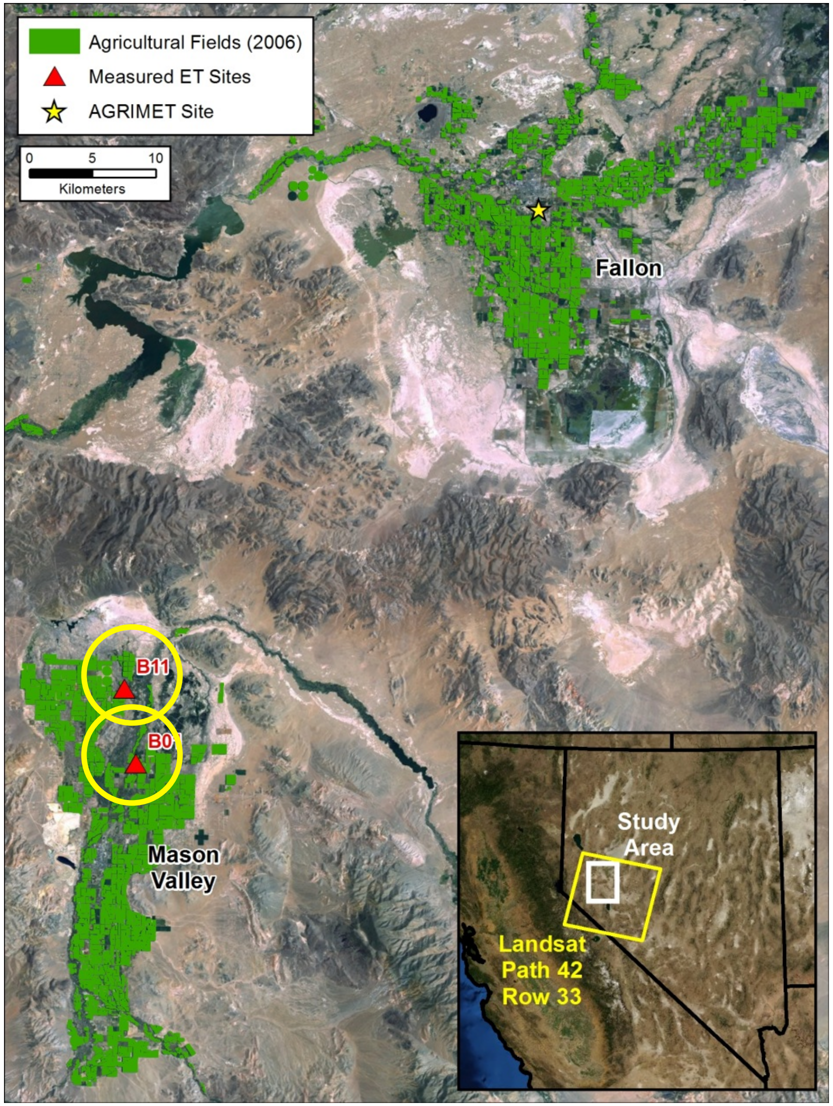


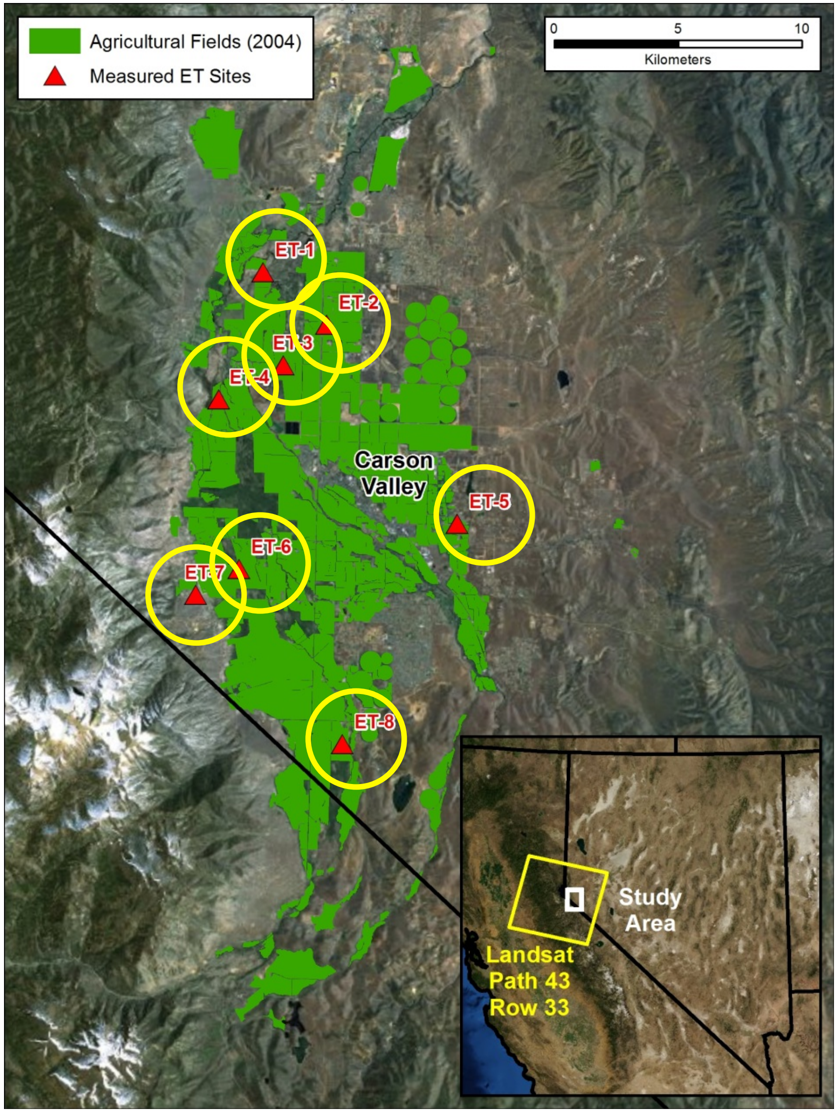
- 2006 = 150% of normal flow
- 2009 = 80% of normal flow
- Yearly ET a function of supply **AND** Demand – 2009 was a cool spring…

Analyses by Dr. Justin Huntington Res. Group, DRI

2011 Blind Comparison of Automated Daily ET to Measured Daily ET in Carson and Mason Valley, NV / CA

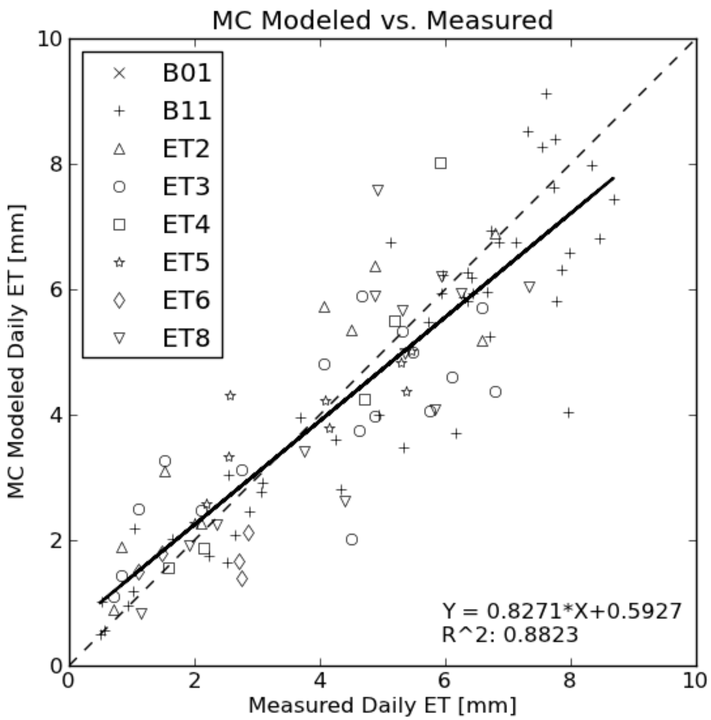
Analyses by Dr. Justin Huntington Res. Group, DRI

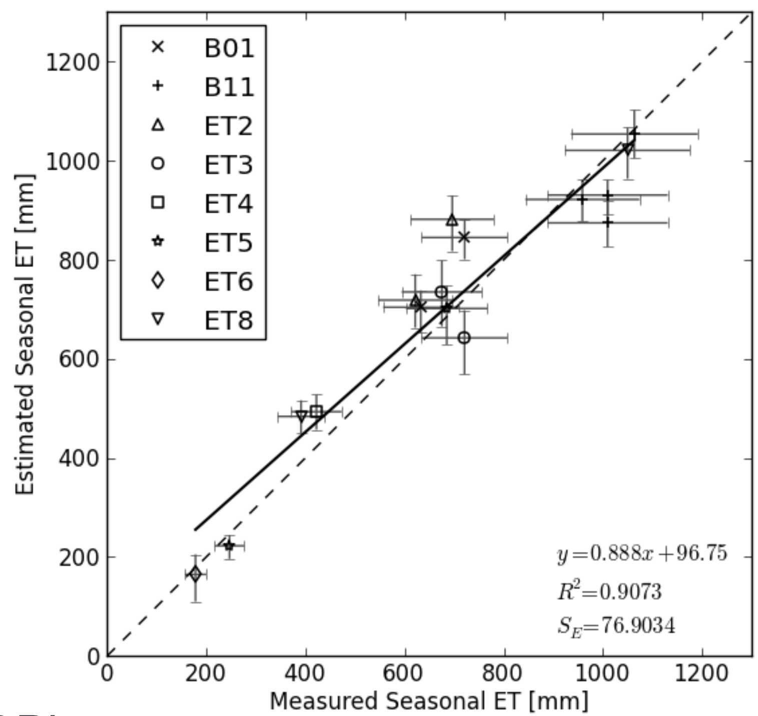




2011 Blind Comparison of METRIC ET to Measured ET – Nevada

- Daily error is not bad when considering the error in measured daily ET is ~ +/- 20%
- Whiskers on X = +/- 12% USGS estimated uncertainty in measured ET, Y = +/- 95% confidence interval of 100 automated estimates of ET using different input parameters
- Over a season the error in daily estimates largely cancels out



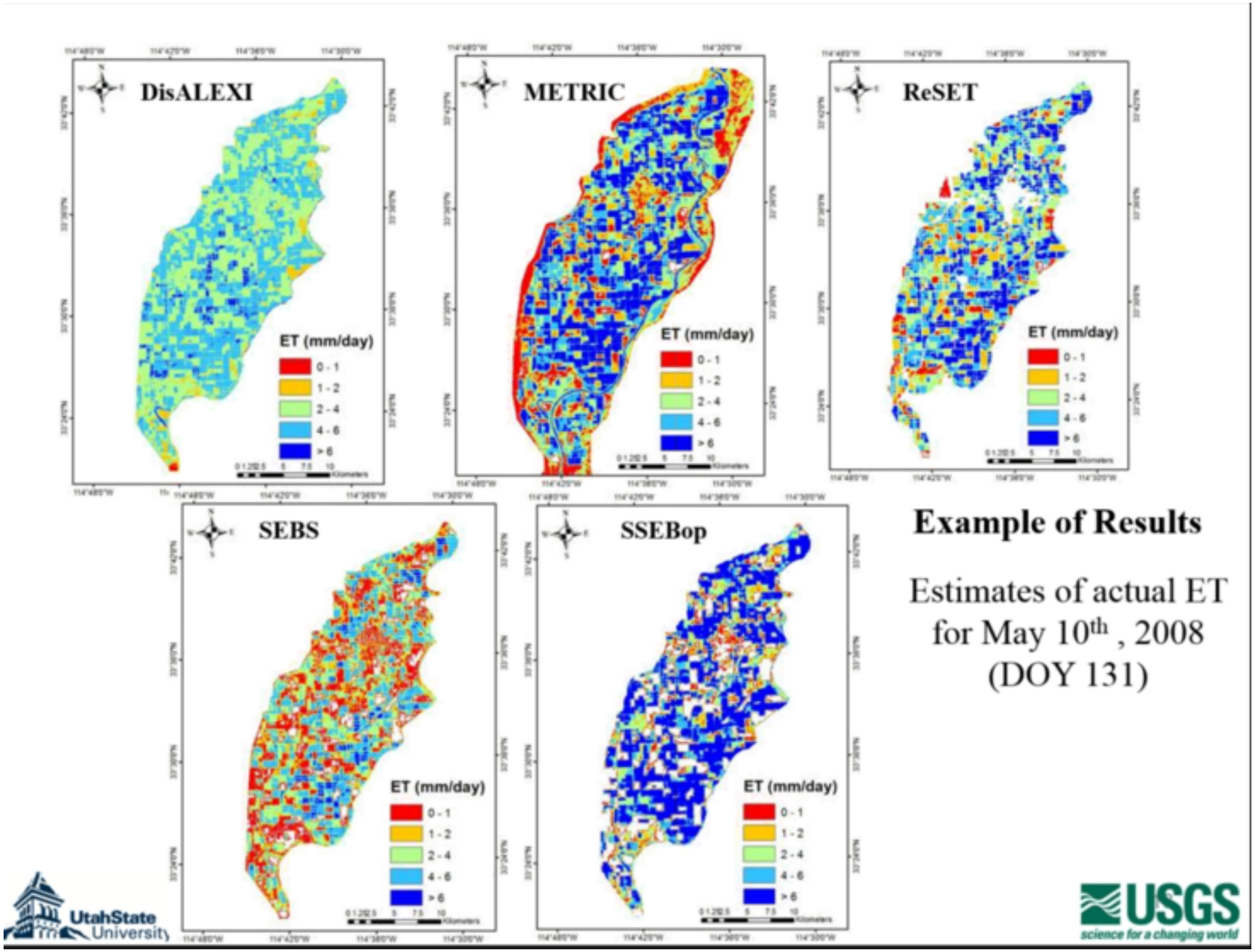


Analyses by Dr. Justin Huntington Res. Group, DRI

2014 Blind Intercomparison of RS of ET Models and Measurements – Palo Verde,CA

Five Remote Sensing of ET models

Five different results



Comparison Analyses by Dr. Christopher Neale and Hatim Geli, Utah State University

2014 Blind Intercomparison of RS of ET Models and Measurements – Palo Verde,CA

Summary of Intercomparison

Comparison against Ground-Flux Measurements over Alfalfa

	RMSE	BIAS	BIAS (%)	MAE	Sample	Mean	Std. Dev.
Measured					16	6.55	2.4
SSEBop	1.5	-0.2	-7.2%	1.3	16	6.35	2.8
SEBS	2.7	-2.5	-42.0%	2.5	16	4.09	2.1
METRIC	0.9	-0.1	1.6%	0.6	16	6.45	1.9
ReSET	1.3	-0.8	-9.8%	1.1	16	5.70	1.7
PT-JPL					16		
DisALEXI	2.1	-1.7	-22.9%	1.7	16	4.87	1.4

Comparison Analyses by Dr. Christopher Neale and Hatim Geli, Utah State University

2014 Blind Intercomparison of RS of ET Models and Measurements – Palo Verde,CA

Comparison against Annual ET for the 93,000 acre Palo Verde Irrigation District -- as derived from Infow-Outflow water balance

Seasonal Water Balance

Water balance Component	Depth (mm/year)	DisALEXI	ReSET	METRIC	SSEBop	SEBS	P-T
Precipitation	71	71	71	71	71	71	71
Inflow Main Canal	2479	2479	2479	2479	2479	2479	2479
Total Inflow	2550	2550	2550	2550	2550	2550	2550
Canal Spills	284	284	284	284	284	284	284
Drainage	998	998	998	998	998	998	998
ET	**(1000)**		**956**	**1223**	**952**	**X**	
Total Outflow	(2282)		2238	2505	2234	X	
Inflow- Outflow	(268)		312 (-12.2%)	34 (-1.8%)	316 (-12.4%)	X	

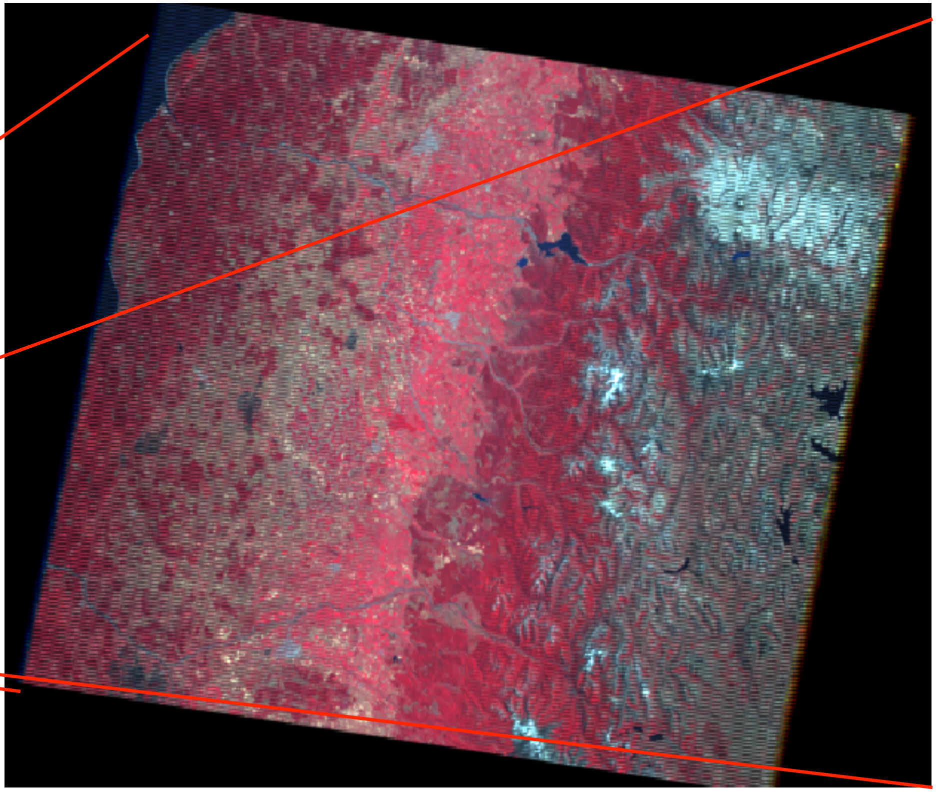
Conclusion – The specific endmember calibration approach of METRIC tends to function well and consistently

UtahState University

USGS science for a changing world

Comparison Analyses by Dr. Christopher Neale and Hatim Geli, Utah State University

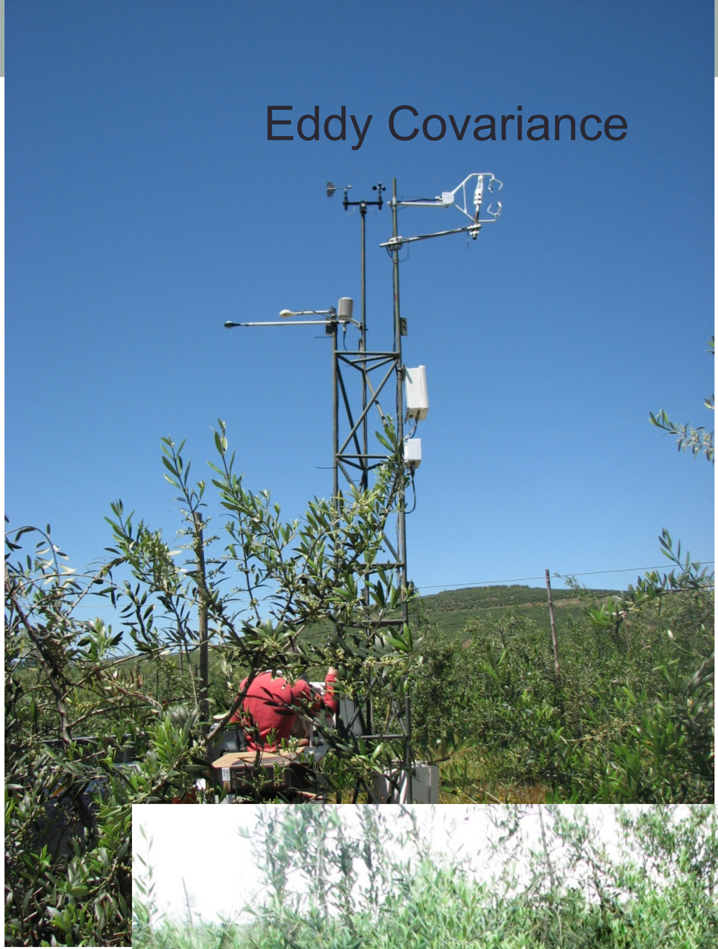
Olives in Chile



Study area is in the center of Chile

Path 233, Row 85, Landsat 7 processing (2011 & 2012)

Collaboration between Samuel Ortega, Univ. Talca and Ayse Kilic, UNL and UI Remote Sensing Research groups

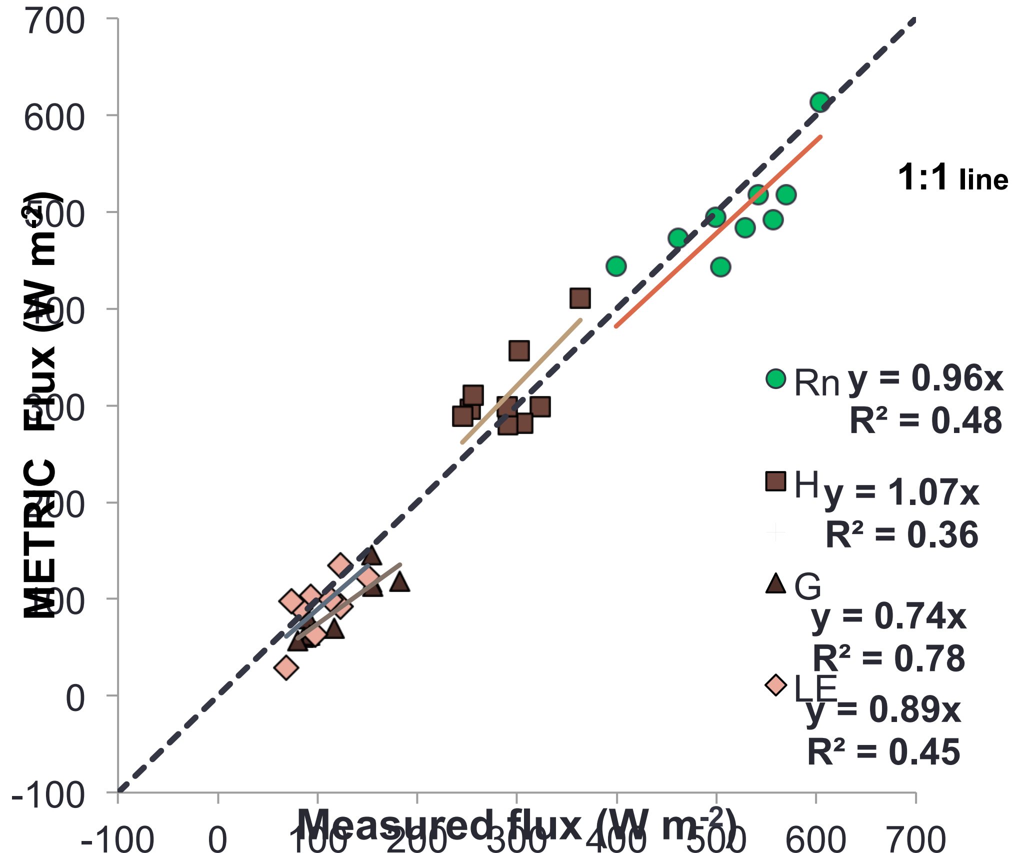


New olive production in central Chile with relatively dense tree spacing.

ET fluxes were measured using an eddy covariance system mounted above the crop.

Photos by Dr. Samuel Ortega, Univ. Talca, Chile, collaboration with A. Kilic.

METRIC vs. Ground Measurements – Olive Orchard near Talca, Chile



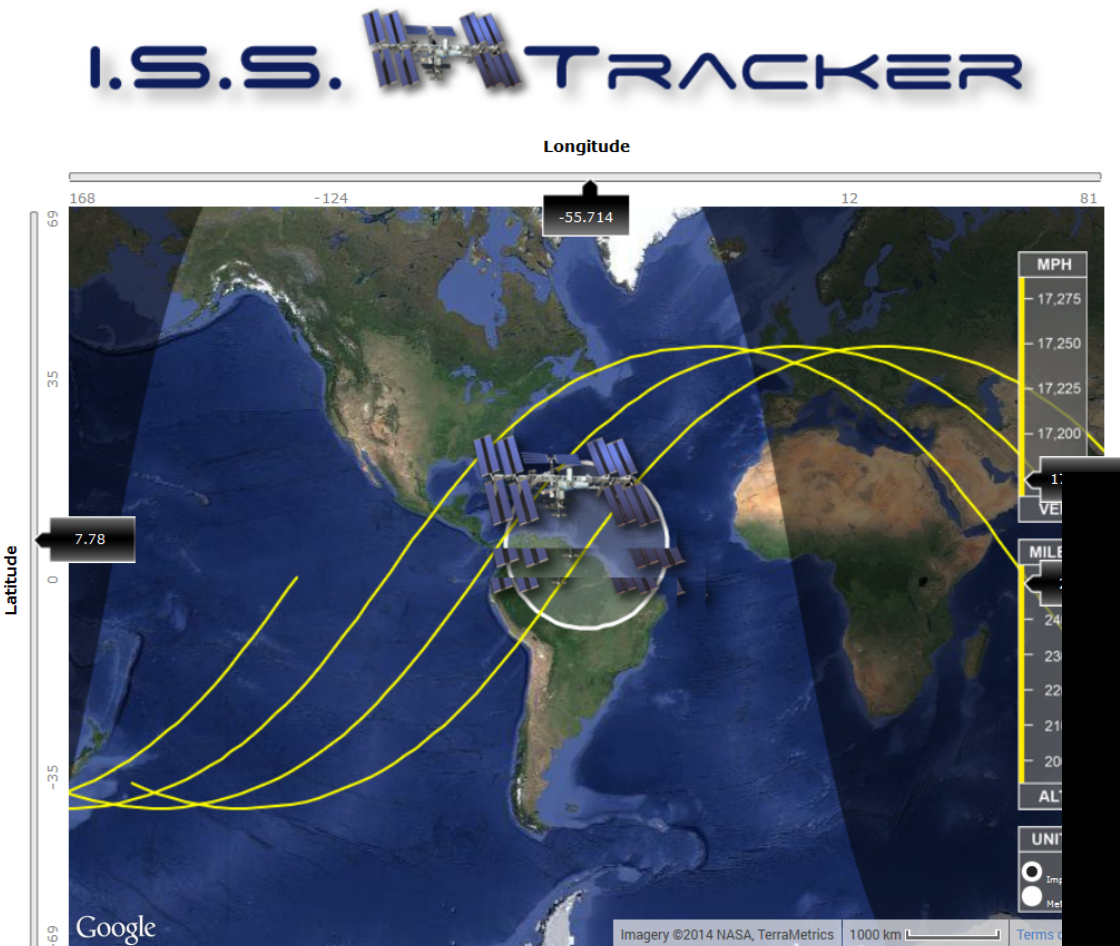
Olives have low ground-cover and leaf area, making ET estimation challenging. 1000 m blockiness in ET (right) is caused by land use classification error in the Global Land Cover product.

- We have made some enhancements to the model (Perrier function for surface roughness, Leaf Area Index)
- Correction to the global land cover map

Analyses by Samuel Orlando Ortega Salazar, with UNL group

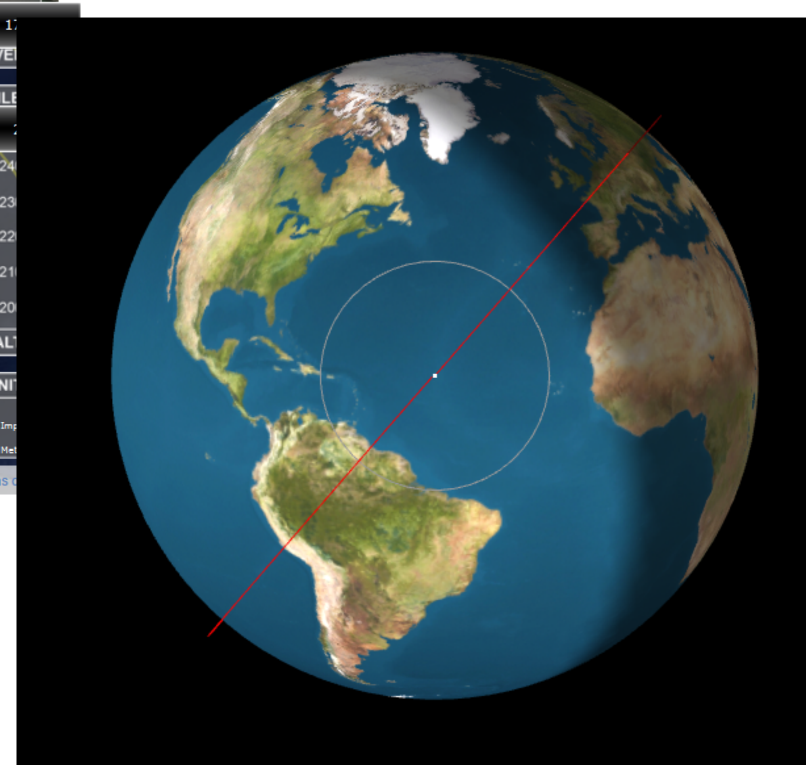
METRIC-ECOSTRESS

Porting Algorithms



Orbital speed
17000 mph
7660 meters/second

Altitude: 420 km

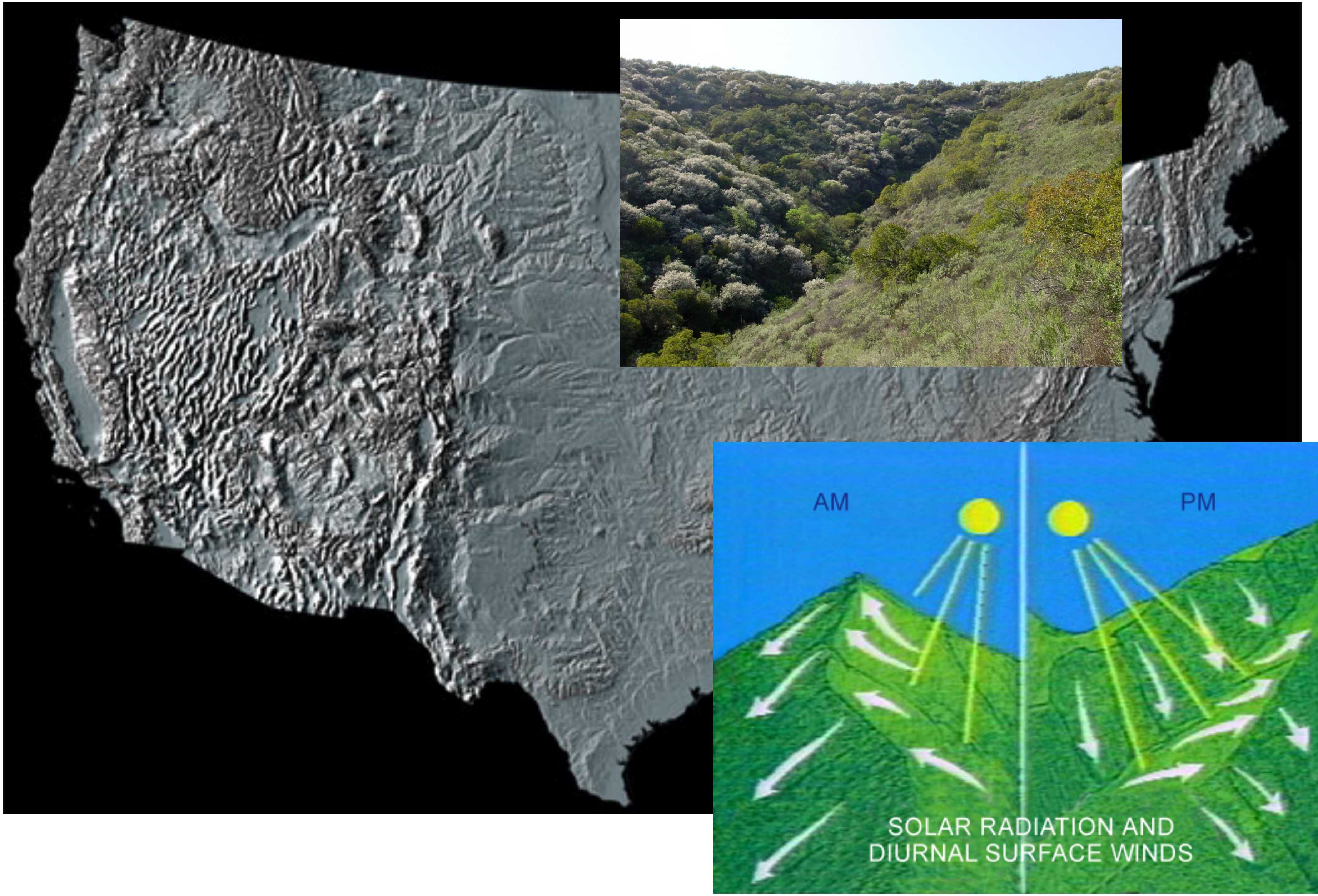


Sun angle continually changing
Land / precipitation conditions continually changing

Close up Orbit -- 420 km

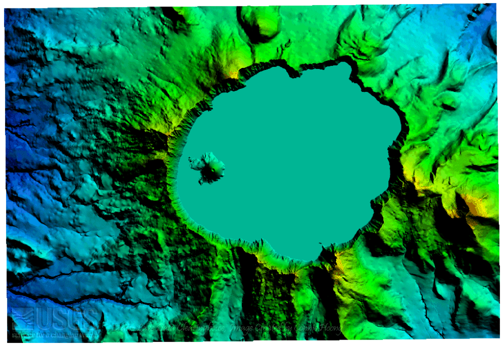
International Space Station

Topography of the United States and World is Complex – impacting solar radiation balance



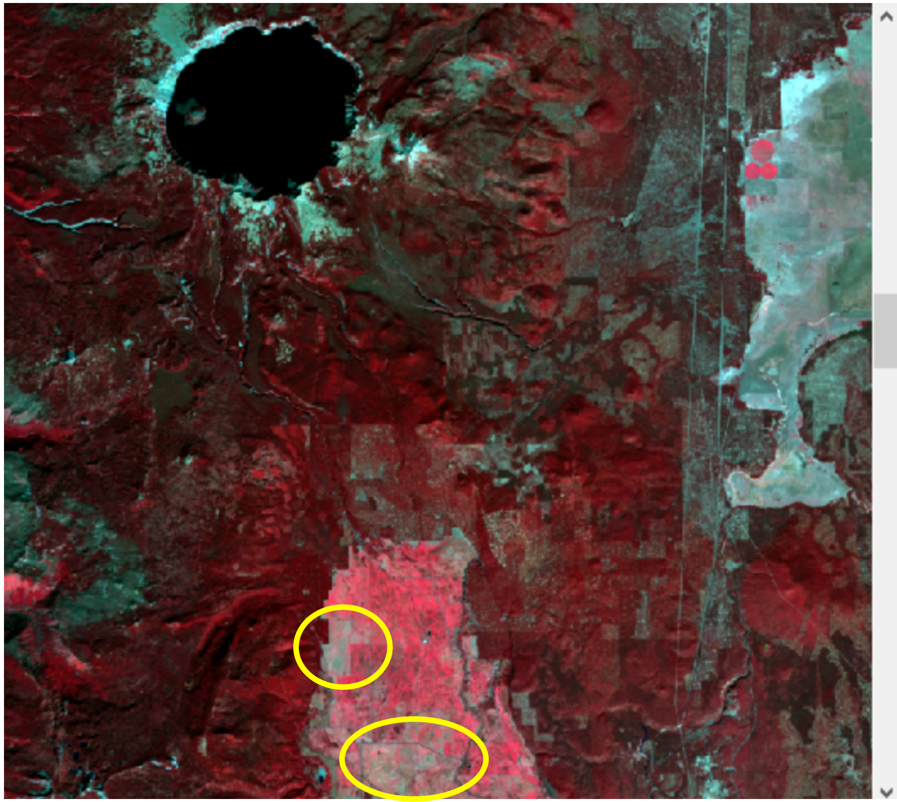
METRIC includes radiation algorithms for slopes and terrain roughness algorithms

Crater Lake

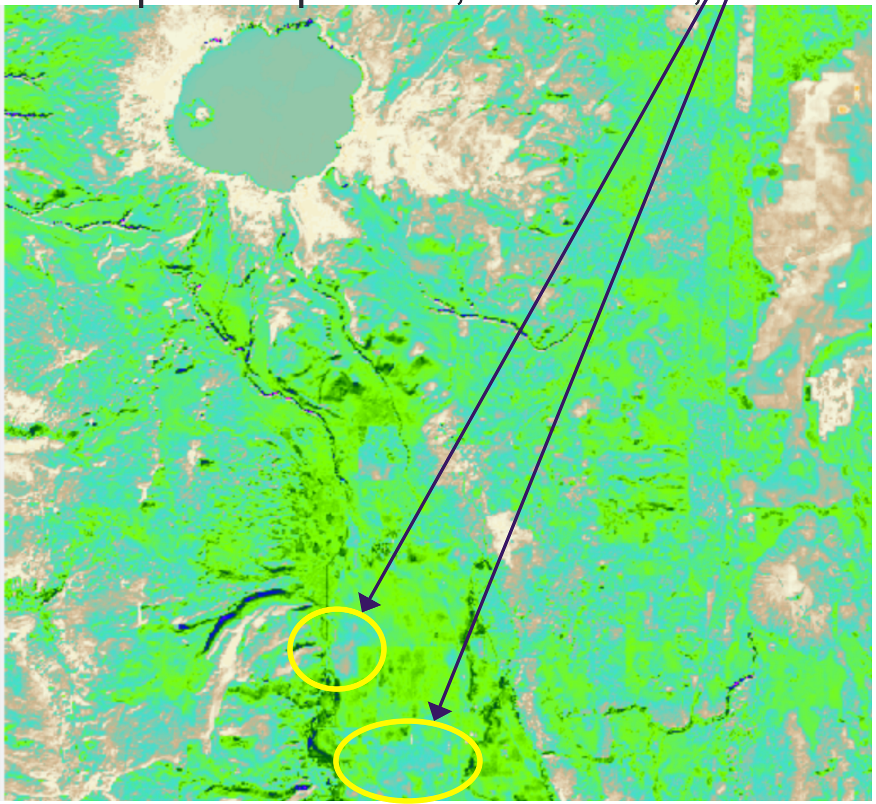


Upper Klamath River Basin of Oregon, California

- 2013 Settlement on water rights
- used ET maps from METRIC as basis for negotiation
- using METRIC for near-real time monitoring of **retired irrigated parcels**



Evapotranspiration, October 3, 2014



Satellite Energy Balance is ‘Challenged’ by Uncertainty and Bias in components – These are reduced by use of Endmember Calibration Based on Maximum and Minimum ET:

- Surface temperature
  - Aerodynamic vs. Radiative Temperature
  - Bias in Satellite Sensor Calibration
  - Atmospheric Correction
- Air temperature *(varies with H)*
- Albedo calculation
- Net radiation calculation *(incoming long-wave)*
- Soil heat flux
- Aerodynamic resistance calculation
  - Aerodynamic roughness for momentum
  - Aerodynamic roughness for sensible heat flux
  - Buoyancy effects
- Wind speed field
- Extrapolation of instantaneous ET to 24-hour periods

METRIC-ECOSTRESS

Student Collaboration

Student Collaboration

- Participation in development of strategies and coding and testing of algorithms for applying a moving window-based calibration scheme to develop endmember based calibration points for the surface energy balance employed in the METRIC ET process.
- Students will conduct algorithm development and testing pre-launch using an extensive archive of METRIC-based ET imagery retrieved from Landsat-based processing since 2000.
- Three NSF-supported energy and CO_2 flux systems in Idaho will provide ground data to students for testing the moving window-based calibration against challenging targets of energy balance and ET retrieval from sagebrush and lodgepole pine.
- Post launch testing of algorithms and calibration strategies will be shared with students, as will extension of early ET results with real-time water resources processes in Idaho, California and Nevada, where state Departments of Water Resources will be invited to explore ingestion of ET data into their water operations.

Island Park Lodgepole Pine

- Installed 2010

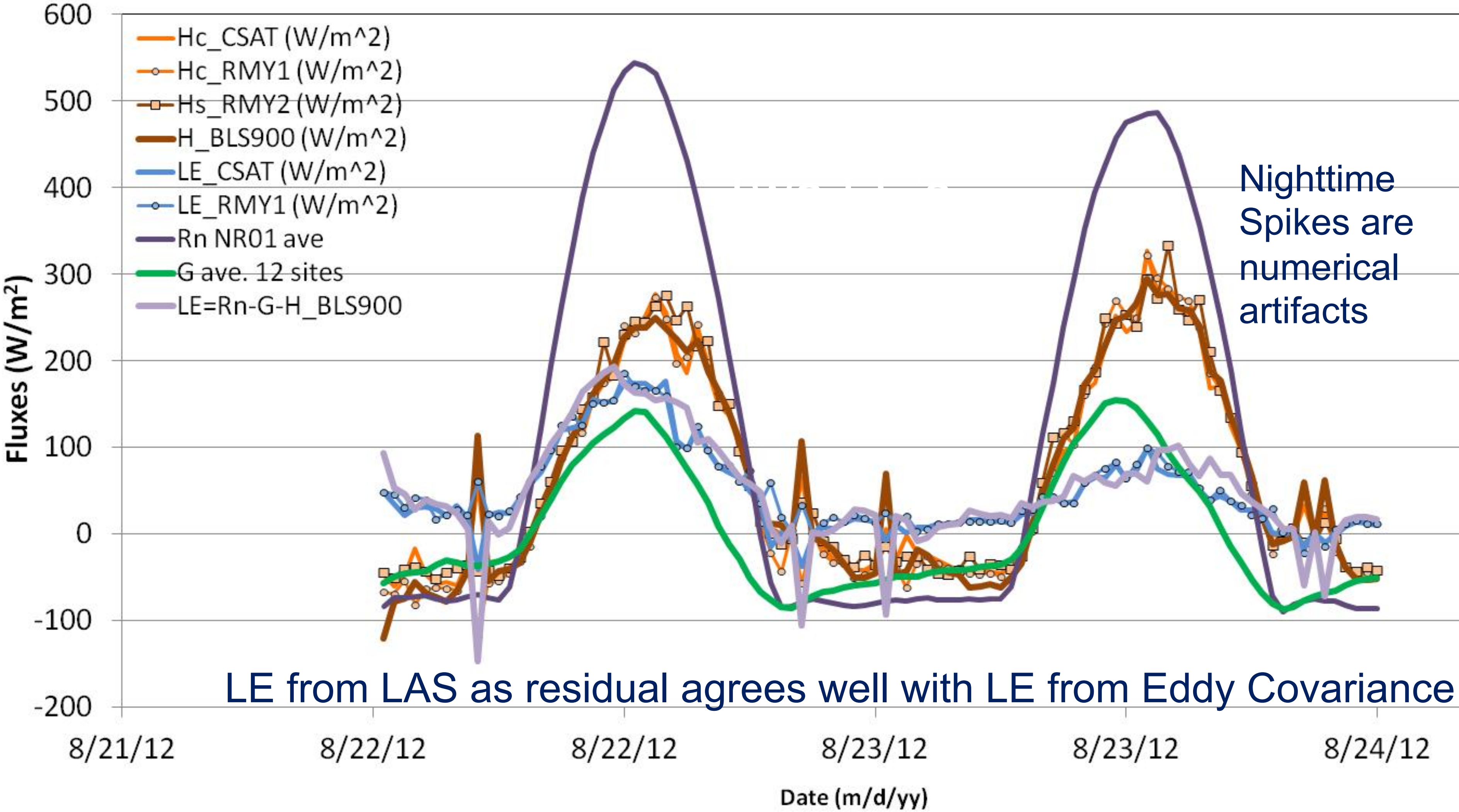
Hollister Sage Brush site
– Installed Feb. 2010

Equipment List:

"Sensor Redundancy "

3	3-D sonic anenometers
1	LiCor 7500 H20/CO2 Infrared A.
3	Net radiometers
1	Scintec BLS900 Scintillometer
16	Soil Heat Flux Sensors
32	Soil Temperature Sensors
20	Soil Water Content Sensors
7	Soil Water Potential Sensors
2	Rain Gages
2	Infrared Temperature Sensors

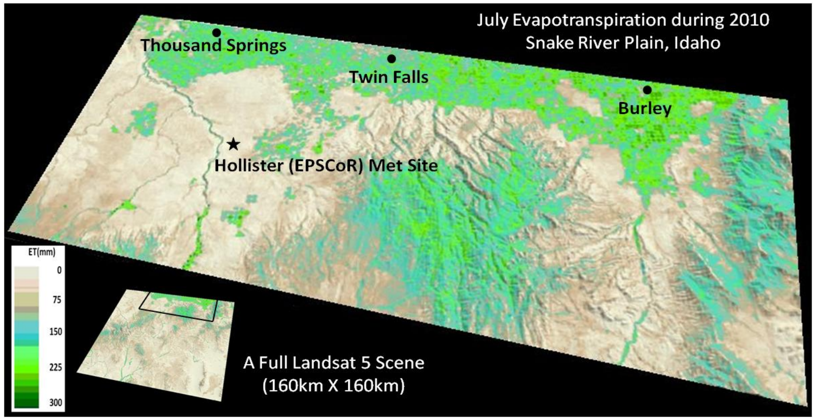
EB Components - Hollister Sage Brush Flux Site

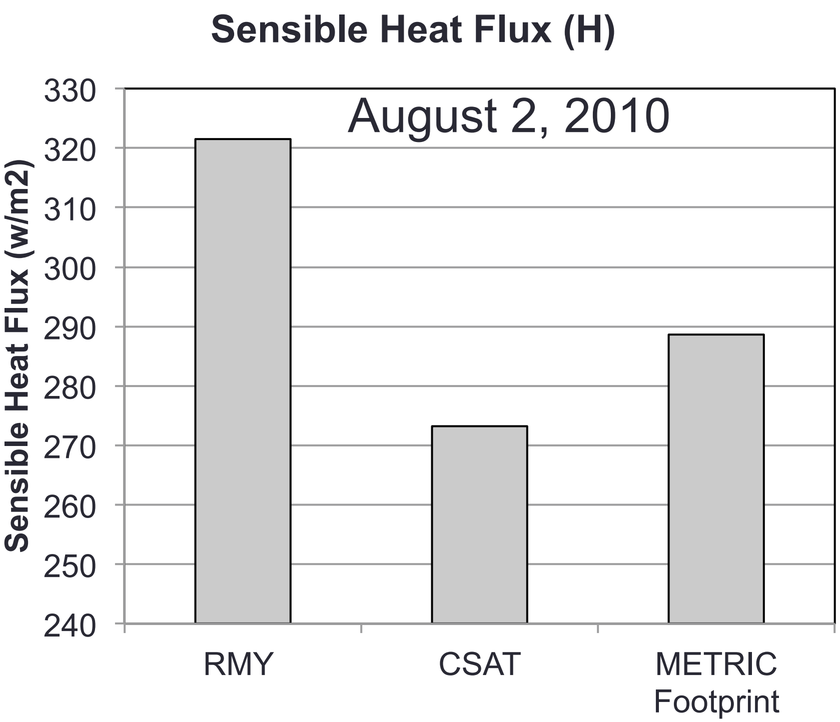


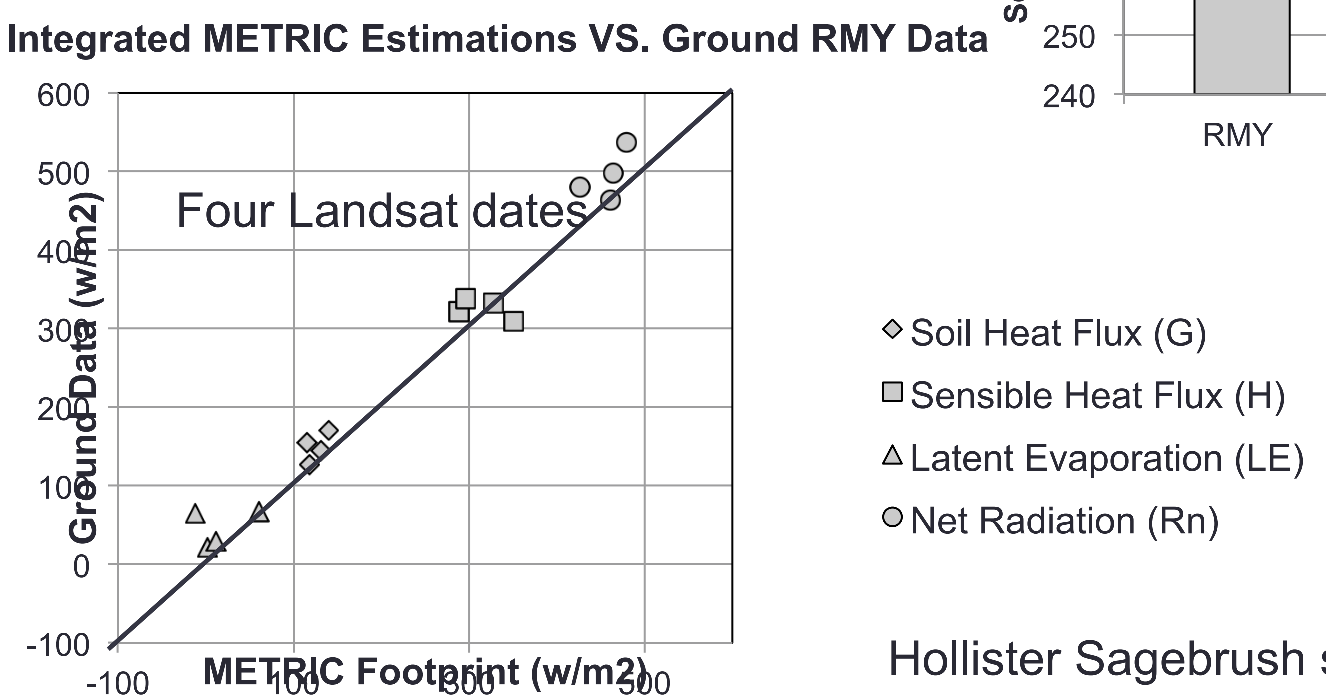
Nighttime Spikes are numerical artifacts

LE from LAS as residual agrees well with LE from Eddy Covariance

Student-based accuracy assessments







Hollister Sagebrush site, 2010

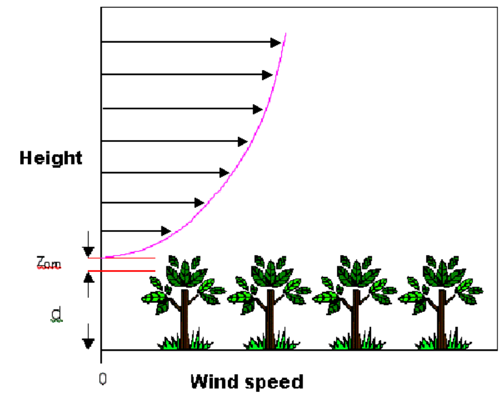
Thank you

Extra Slides

Why use Inverse Modeling?

To reduce the impacts of biases in the energy balance components: R_n and G

Sensible Heat Flux (H) – by "Classical" methods (non-CIMEC)



$$H = \rho \ c_p \ (T_{aero} - T_{air}) / r_{ah}$$

Challenge (BIAS):
Up to 2 K different from T_{rad} (satellite)

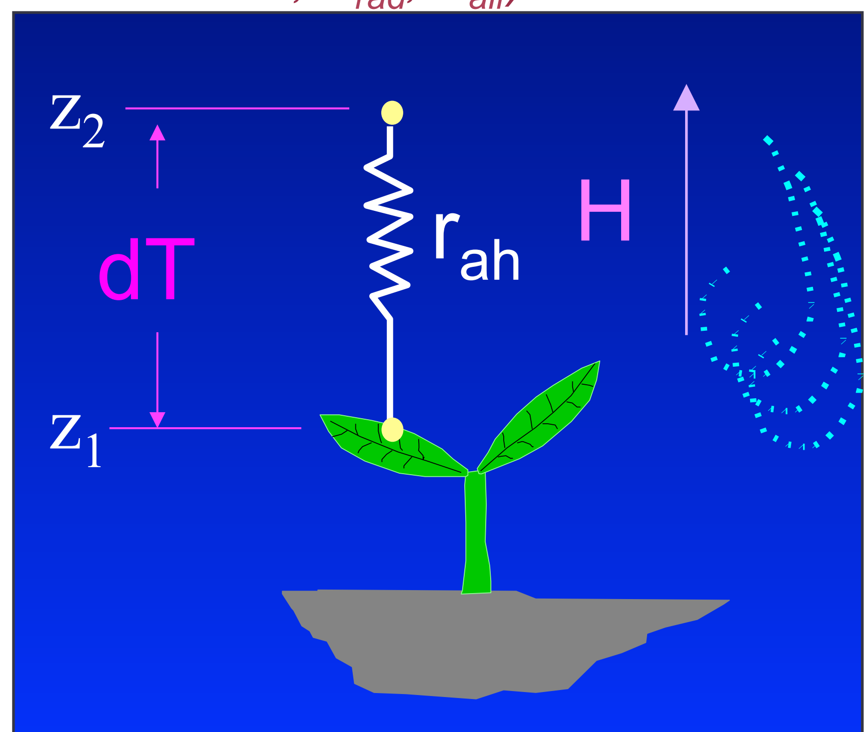
Challenge (BIAS):
Unknown Spatial Distribution of T_{air} (feedback between EB, T_{rad}, T_{air})

T_{aero} = aerodynamic temperature

r_{ah} = the aerodynamic resistance

$$r_{ah} = \frac{\ln\left(\frac{z_2 - d}{z_{oh}}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* \ k}$$

u_* = friction velocity
k = von karmon constant (0.41)



Sensible Heat Flux (H) – CIMEC models

$$H = (\rho \times c_p \times dT) / r_{ah}$$

Advantage:

r_{ah} 'floats' above the surface and is 'free' of z_{oh} and some limitations of a single source approach

Advantage:

dT is inverse calibrated (simulated) (free of T_{rad} vs. T_{aero} and free of T_{air})

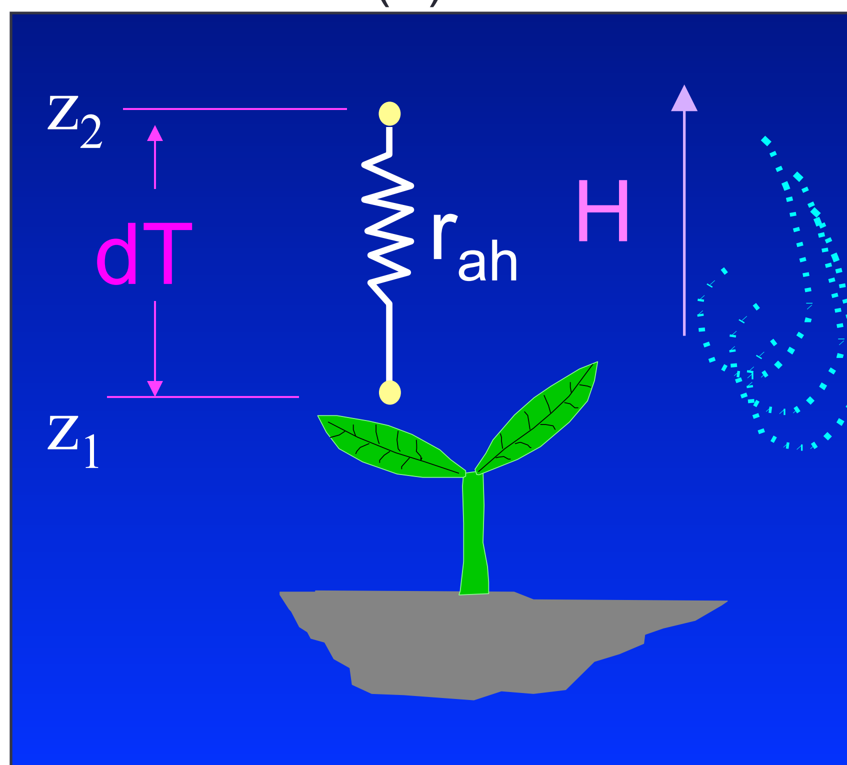
dT = "floating" near surface temperature difference (K)

r_{ah} = the aerodynamic resistance from z_1 to z_2

$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* \times k}$$

u_* = friction velocity

k = von karmon constant (0.41)

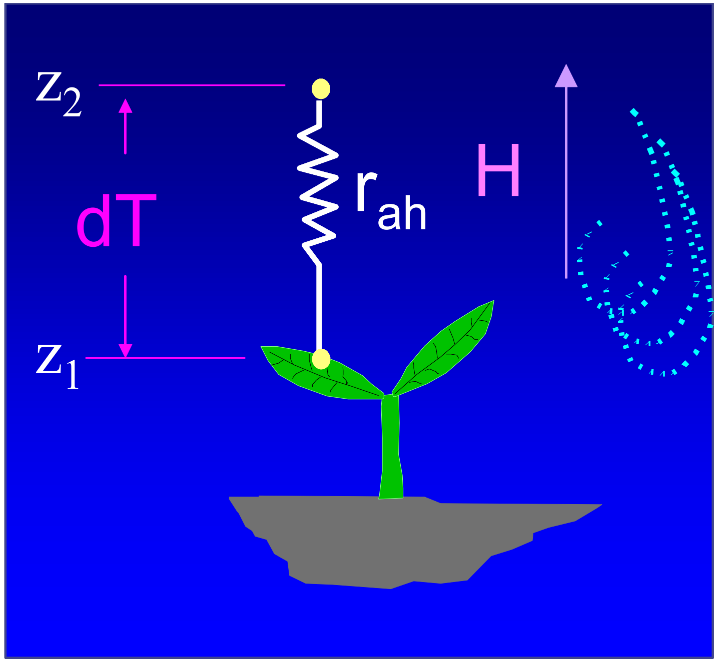


Calibration of *SEBAL* and *METRIC* CIMEC models:

Inversion of H eqn:

$$dT_{cold} = \frac{H_{cold} \; r_{ah\,cold}}{\rho_{air\,cold} \; c_p}$$

$$dT_{hot} = \frac{H_{hot} \; r_{ah\,hot}}{\rho_{air\,hot} \; c_p}$$



R_n – G - 1.05 $ET_{ref\ alfalfa}$ *(METRIC)*
or 0 *(SEBAL – classical)*

R_n – G - $ET_{residual}$

Calibration of *SEBAL* and *METRIC* CIMEC's:

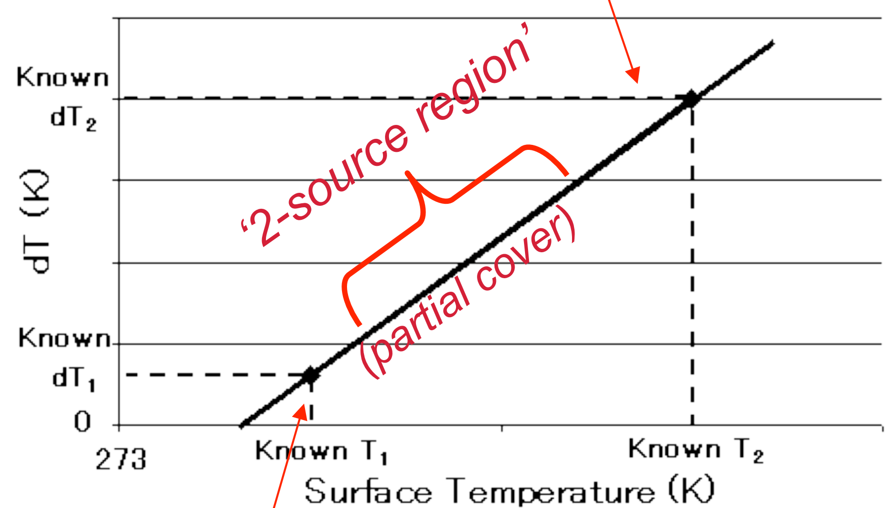
Derivation of linear dT vs. T_s function

$$a = \frac{dT_{hot} - dT_{cold}}{T_{s\ hot} - T_{s\ cold}}$$

$$b = dT_{hot} - a\,T_{s\ hot}$$

and $dT = a + b\,T_s$ at all pixels

Regardless of '1-source' or '2-source' model:
*'the dry condition' (<u>bare, dry field</u>) is a '<u>**1-source'**</u> condition.*



Regardless of '1-source' or '2-source' model:
*'the wet condition' (<u>fully veg. field</u>) is a '<u>**1-source'**</u> condition.*

Daily water balance using gridded weather and precipitation