METRIC: High Resolution Satellite Quantification of Evapotranspiration

University of Idaho, Kimberly, Idaho

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Co-developers and Collaborators:
R. Allen, M. Tasumi, R. Trezza, W. Bastiaanssen, T. Morse, W. Kramber, J. Wright
Evapotranspiration “mapping” with SEBAL and METRIC™

- **Surface Energy Balance Algorithm for Land**
  - Dr. Wim Bastiaanssen, WaterWatch, *The Netherlands*
    - beginning in 1990
    - SEBAL is commercially applied in the U.S.A. by SEBAL-North America

- **Mapping EvapoTranspiration with high Resolution and Internalized Calibration**
  - Allen and Tasumi, University of Idaho, *Kimberly*
    - beginning in 2000
    - rooted in SEBAL2000
  - METRIC™ is energy-balance-based ET mapping tied down and partly calibrated using ground-based reference ET (from weather data)
  - METRIC™ is designed to work well in advective conditions of the western U.S.
Energy balance gives us “actual” ET

Surface Energy Balance:

ET is calculated as a “residual” of the energy balance

\[ R_n - G - H \]

- \( R_n \) (radiation from sun and sky)
- \( G \) (heat to ground)
- \( H \) (heat to air)

Basic Truth:
Evaporation consumes Energy

The energy balance includes all major sources (\( R_n \)) and consumers (ET, G, H) of energy
Energy balance gives us “actual” ET

Therefore, we can account for impacts on ET caused by:

- water shortage
- disease
- crop variety
- planting density
- cropping dates
- salinity
- management

(These effects can be converted directly into a crop coefficient)
Net Radiation – southcentral Idaho – August 14, 2000

Thousand Springs
Wood River Valley
Craters of the Moon
Lake Walcott
Twin Falls
Burley

Net Radiation (W/m²)

0
200
400
600
800+

Rn
H
ET
G
Surface Temperature – southcentral Idaho – August 14, 2000

Thousand Springs
Twin Falls
Burley
Lake Walcott
Wood River Valley
Craters of the Moon
North
Major Irrigated areas in Idaho and areas of METRIC application

Seasonal ET for SE Idaho

Idaho from Landsat
Why use High Resolution Imagery?

ET from individual Fields is Critical for Water Rights, Water Transfers, Farm Water Management

Minidoka County, Idaho
Why use High Resolution Imagery?

Riparian vegetation and small fields along the Middle Rio Grande, New Mexico
Why use High Resolution Imagery?

Landsat vs MODIS

Landsat False Color (MRG)  
8/26/2002 10:33am

MODIS False Color (MRG)  
8/26/2002 11:02am
Need for ET Maps in Idaho

- Quantify Net Depletion from Groundwater Pumping *(unmeasured)*
- Compare actual ET with Water Right
- Calculate Natural and Irrigation-Induced Recharge to Aquifers *(via water balance to calibrate MODFLOW)*
- Determine “Actual” ET for Developing better Crop Coefficient Curves
What Landsat sees

Transmissivity of atmosphere

Visible \hspace{1cm} Near Infrared

Wavelength in Microns: 0 \hspace{0.2cm} 0.4 \hspace{0.2cm} 0.6 \hspace{0.2cm} 0.8 \hspace{0.2cm} 1.2 \hspace{0.2cm} 1.6 \hspace{0.2cm} 2.0 \hspace{0.2cm} 2.4

Various amounts of reflection

(Band 6 is the surface temperature band (not shown))
SEBAL/METRIC Style of Satellite Energy Balance

- Use of a “floating” temperature difference (dT) vs. surface temperature function in SEBAL and METRIC (Bastiaanssen 1995, 1998) that is customized for each image provides internal and relatively automatic calibration.

- Design of SEBAL and METRIC make process relatively insensitive to the parameterization of aerodynamics.

- Focus is on a ‘small’ region of interest (100 miles x 100 miles) (i.e., not the world, not 17 western states).
METRIC Energy Balance

- **METRIC** is a sort of “hybrid” between pure remotely-sensed energy balance and weather-based ET method

- **Combines** the strengths of energy balance from satellite and accuracy of ground-based reference ET calculation:
  - **Satellite-based energy balance** provides the spatial information and distribution of available energy and sensible heat fluxes over a large area (and does most of the “heavy lifting”)
  - **Reference ET calculation** “anchors” the energy balance surface and provides “reality” to the product.
METRIC is anchored by *everything* we *know* about ET that is *consistent* and *straightforward* (i.e., $E_{Tr}$)

$E_{Tr}$ contains information on:

- Direct impact of wind speed on ET process
  - at image time
  - during the day *(for extrapolation)*
- Impact of vapor pressure deficit and other *advective* factors
  - at image time
  - over the course of the day *(for extrapolation)*
- Impact of afternoon clouding on daily ET *(for extrapolation)*

*Plus, the approach is congruent with the alternative* ($K_c \cdot E_{Tr}$)
Weather Data

In METRIC, Weather Data are used for:

- **Wind speed** for **sensible heat flux** calculation
- **Vapor pressure** for incoming solar **transmissivity** (minor)
- Calculate **Reference ET** for **Calibrating the Cold Pixel**
- **Extrapolate ET** using **Reference ET** for:
  - 24-hour period
  - Days between Images
Weather Data from USBR AgriMet

In METRIC™ applications, Alfalfa Reference ET$_r$ is computed using the hourly ASCE Standardized Penman-Monteith Equation.

In Idaho, USBR AgriMet data are used:
- high quality and consistent
- frequent sensor calibration and QC
- available via web
- generally good agricultural locations
- relatively long history
Kimberly Lysimeters - September 4, 1990

Data from Dr. J.L Wright

ASCE Standardized Penman-Monteith (tall reference) at Kimberly, Idaho

- hourly time step
Sensible Heat Flux (H)

\[ H = \frac{\rho \times c_p \times dT}{r_{ah}} \]

- \( dT \) = the near surface temperature difference (K).
- \( r_{ah} \) = the aerodynamic resistance to heat transport (s/m).

\[ r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right)}{u_* \times k} \]

- \( u_* \) = friction velocity
- \( k \) = von karmon constant (0.41)
Near Surface Temperature Difference (dT)

To compute the sensible heat flux (H), define near surface temperature difference (dT) for each pixel

\[ dT = T_{\text{near surface}} - T_{\text{air}} \]

\[ dT = T_{z1} - T_{z2} \]

- \( T_{\text{air}} \) is unknown and unneeded

SEBAL and METRIC™ assume a linear relationship between \( T_s \) and dT:

\[ dT = b + aT_s \]

- \( T_s \) is used only as an index and can have large bias and does not need to represent aerodynamic surface temperature
Calculations for the Weather Station

\[ u_{200} = u^* \frac{\ln \left( \frac{200}{Z_{om}} \right)}{k} \]

\[ u_{200} = 3.49 \text{ m/s} \]
Aerodynamic Equations used in METRIC™

\[ H = \frac{(\rho c_p)(T_{a1} - T_{a1})}{r_{ah}} \]

\[ T_{a1} - T_{a2} = f(T_s) \]

\[ r_{ah} = \frac{\ln\left(\frac{Z_2}{Z_{ns}}\right) - \Psi_{h(z_2)} + \Psi_{h(z_1)}}{u_* \times k} \]

\[ u_* = \frac{u_{200}k}{\ln\left(\frac{200}{Z_{0m}}\right) - \Psi_{m(200m)}} \]

Correction for atmospheric instability

\[ \Psi_{h(z_2)} = 2\ln\left(1 + \frac{x(z_2)^2}{2}\right) \]

\[ x_{(height)} = \left(1 - 16\frac{(height)}{L}\right)^{0.25} \]

\[ L = -\frac{\rho_{air}C_{p_{air}} u_*^3 T_0}{k g H} \]

\[ \Psi_{m(200m)} = 2\ln\left(\frac{1 + x(200m)}{2}\right) + \ln\left(\frac{1 + x(200m)^2}{2}\right) - 2\arctan(x(200m)) + 0.5\pi \]

\[ \Psi_{m(200m)} = -5\left(\frac{Z_2}{L}\right) \quad \text{and} \quad \Psi_{h(z_2)} = -5\left(\frac{Z_2}{L}\right) \quad \text{for stable} \]
How METRIC™ is "Trained"

METRIC™ is "trained" for each image by defining dT at the 2 "anchor" pixels:

- **At the "cold" pixel:**
  \[ H_{\text{cold}} = R_n - G - L E_{\text{cold}} \]
  - where \( L E_{\text{cold}} = 1.05 \times \lambda \times ET_r \)
  - \( dT_{\text{cold}} = H_{\text{cold}} \times r_{\text{ah}} / (\rho \times c_p) \)

  *(in classical SEBAL, \( H_{\text{cold}} \approx 0 \) and \( T_{\text{cold}} \approx T_s \) is for water)*

- **At the "hot" pixel:**
  \[ H_{\text{hot}} = R_n - G - L E_{\text{hot}} \]
  - where \( L E_{\text{hot}} \approx 0 \) *(if indicated by water balance)*
  - \( dT_{\text{hot}} = H_{\text{hot}} \times r_{\text{ah}} / (\rho \times c_p) \)

  *("1.05" is reduced and estimated as \( f(NDVI) \) during winter, etc.)*
Samples from an Agricultural Area

Hot Pixel

Dry Bare Field

Wet Bare Field

Water Stressed

Dense Green Field

Wet and Dense Green Field

Cold Pixel

$T_s - DEM (K)$

LAI
Cold Pixel:
The coldest green Ag. Fields consume as much as 5% more than $ET_r$ (Corn, Beans, Sugar Beets, Alfalfa)

$$ET(cold - pixel) = 1.05ET_r$$

$ET_rF=1.05$

Daily $ET_rF$, Corn on Lysimeter, Kimberly
ET_{r,F} at the Hot pixel: (is it really zero?):
The operator must direct METRIC concerning any residual ET at the hot pixel. ET_{r,F} can be estimated using the FAO-56 surface evaporation estimation procedure.
Soil Heat Flux (G)

via Bastiaanssen (1995):

\[ \frac{G}{R_n} = T_s (0.0038 + 0.0074\alpha)(1 - 0.98NDVI^4) \]

via Tasumi et al., (2003) from USDA-ARS data at Kimberly:

\[ \frac{G}{R_n} = 0.05 + 0.18 \exp(-0.521 \text{ LAI}) \text{ for LAI > 0.5} \]

\[ \frac{G}{R_n} = 1.80 \frac{(T_s - 273)}{R_n} + 0.084 \text{ for LAI < 0.5 (~bare soil)} \]

and \[ G = \frac{G}{R_n} \times R_n \]
For clear, deep water

Monthly average $G$ vs. $R_n$ measured in a deep Japanese lake (mean depth of 21m) (data from Yamamoto and Kondo, 1968).

Monthly evaporation from three Great Lakes (Derecki, 1981)
Comparison with Lysimeter Measurements:

Lysimeter at Kimberly (Wright)
Measured vs METRIC Instantaneous ET
-- Sugar Beets, 1989, Kimberly, ID

[Graph showing the comparison of measured ET (mm/hour) and SEBAL ET (mm/hour) with dates marked on the graph.]
Interpolation to the rest of the day (and month) (and year)
\[ \text{ET}_r F = \text{Fraction of } \text{ET}_r = K_c \]

\[ \text{ET}_r F \text{ is consistent through the day} \]

Kimberly Lysimeters - July 07, 1989

Sugar Beets

\( \text{ET}_r F = \text{ET}_c / \text{ET}_r \)
Use of EF vs. ET$_r$F to Estimate 24-hr ET

ET$_r$F is less sensitive to regional advection effects

- ET$_r$ "captures" most regional advection effects
  (advection: low afternoon RH, high afternoon T and wind)

EF at Kimberly (Grass, 5/20/89)

ET$_r$F at Kimberly (Grass, 5/20/89)

These graphs illustrate the comparison between ET$_r$F and EF for estimating 24-hour ET, with a focus on the stability and advection effects during the day.
\[ ET_r F = \text{Fraction of } ET_r = K_c \]

**Assumption:** \( ET_r F \) is consistent through the day
Extrapolation of Inst. to 24-hour ET : ET$_{rF}$ method - METRIC

Sugar Beets and Potatoes ET$_{rF}$ for 1988 and 199 satellite dates

$y = 0.9812x + 0.0406$

$R^2 = 0.9888$

ET$_{rF}$ for Sugar Beets

May to September, 1989, Data from Dr. J.L. Wright

ET$_{rF}$ based on Lysimeter Data by Dr. J.L. Wright, USDA-ARS
24-Hour Evapotranspiration (ET$_{24}$)

\[ ET_{24} = ET_r F \times ET_{r-24} \]

Path 39: Am. Falls - 24-hour ET

(in EF method, \( ET_{24} = EF \times R_{n24} \))
Where EF may have advantage

- Hourly ground weather data are sparse or of poor quality (use EF and base ET on $R_n$ computed from trig)
- A large, shallow water body is present (T for cold pixel)
- Regional advection is relatively small (to use EF)
- Large images are processed (i.e., MODIS)
Where $\text{ET}_r F$ may have advantage

- Hourly ground weather data are available and are of good quality

- Tall, well watered vegetation is available for the cold pixel ($\text{ET}_{\text{cold}} \sim 1.05 \, \text{ET}_r$)

  (otherwise, $\text{ET}_{\text{cold}} = f(\text{NDVI})$)

- Regional advection is relatively large

- Congruency with the $K_c$ $\text{ET}_r$ procedure is useful

- Landsat or ASTER are used (high resolution, smaller coverage than MODIS)
Seasonal Evapotranspiration (ET$_{seasonal}$)

- Interpolate ET$_r$F between images (after cloud masking) (same principle as in constructing a crop coefficient curve).

- Assume ET for entire area of interest changes in proportion to change in ET$_r$ at weather station.
Seasonal Evapotranspiration ($ET_{seasonal}$)

1. Compute the cumulative ET for period of interest:

$$ET_{period} = \sum_{i=1}^{n} (ET_r F_i \times ET_{r24i})$$

($n$ = length of period in days)

2. Compute the seasonal ET

$$ET_{seasonal} = \sum ET_{period}$$
Kimberly, Idaho – Periods between Satellites

Impact of using Kc from a single day to represent a period: Kimberly 1989

ET during period, mm

0 50 100 150 200 250 300

04-May 20-May 21-Jun 07-Jul 23-Jul 25-Sep

Lys. Kc on Sat. date x sum ETr

Sum. all lysimeter meas. (Truth)

METRIC ET for period
Seasonal ET - 1989

Cumulative ET in 1989 for Sugar Beets

Error = 2.5%

Cumulative ET (mm) from 4/1/89

- SEBAL-ID Estimation
- Lysimeter Measurement
Comparison of Seasonal ET by METRIC™ with Lysimeter

ET (mm) - April-Sept., Kimberly, 1989

Sugar Beets

- Lysimeter: 718 mm
- METRIC: 714 mm
Comparison of Seasonal ET by SEBAL\textsubscript{2000} with Lysimeter

ET (mm) - July-Oct., Montpelier, ID 1985

- Lysimeter: 388 mm
- SEBAL: 405 mm

Total
Annual ET for all of California

Created by SEBAL-North America for 2002 using MODIS satellite imagery (resolution = 1 km)

http://www.sebal.us
Imperial Valley, CA via Landsat 7

ET during January – March, 2003
Imperial Irrigation District
Jan.-March 2002 - ET - all areas

Million cu. meters/year

UI (METRIC) 423
(SNA (SEBAL) 443

(Landsat) (MODIS)
Imperial Valley, CA

via Landsat 7

ET (mm)

0
100
200
300
400

Imperial Valley ET during January – March, 2003

Imperial Irrigation District
Total Annual ET - all areas

Acre-Feet / year

2500000
2000000
1500000
1000000
500000
0

1,959,000
1,950,000
2,046,000
2,085,000

2002, SNA
1987 (low year)-approx.
1987-1996 ave via WB
1996 (high year)-approx.

1987-1996 ave via WB

1996 (high year)-approx.
Sensitivity (or lack of) for METRIC to:

- Atmospheric correction of reflectances using radiative transfer model (MODTRAN)
- Atmospheric correction of surface temperature using radiative transfer model (MODTRAN)
- Estimated aerodynamic roughness
To Correction of Surface Temperature for Atmosphere

Estimated 24 hour ET (mm/day), 7/21/2000, path 40/30, Agr. Area Only

\[ y = 1.0042x \]

\[ R^2 = 0.9996 \]

(Predictions are not sensitive due to calibration at hot and cold pixels)
to Aerodynamic Roughness, zom, (of all areas) --- Agricultural Areas

Estimated 24 hour ET (mm/day), 7/21/2000, Agricultural Area

\[ y = 1.0062x \]
\[ R^2 = 0.9991 \]

Estimated 24 hour ET (mm/day), 7/21/2000, Agricultural Area

\[ y = 0.9948x \]
\[ R^2 = 0.9992 \]

(Predictions are not sensitive due to calibration at hot and cold pixels)
Comparison to $K_c$ Curves
Use to Refine Local $K_c$ Curves

Potato

717 fields in the Twin Falls area

Average “curve”

Vegetation Index
K_c near 1.0 indicating high production agriculture
Alfalfa

325 fields

Day of Year

Kc

(University of Idaho)
Comparison with Local $K_c$ Curves
-- south-central Idaho

Agrimet $K_c$’s are based on Wright (1981) (lysimeter)

Little need to adjust $K_c$ for:
- Potato
- Sugar Beet
- Corn
- Bean

EB model
Allen&Brockway
Agri Met
Crop Coefficient (ETrF)

717 Potato Fields,
2000

NDVI

3 June 19 June
Crop Coefficient (ETrF) vs. NDVI for 717 Potato Fields, 2000

Data points are differentiated by date:
- 3 June
- 19 June
- 21 July

Legend:
- • 3 June
- ○ 19 June
- ▲ 21 July
0.0

Crop Coefficient (ETrF)

NDVI

717 Potato Fields,
2000

“basal” Kc

3 June
19 June
21 July
“mean” $K_c$ vs. NDVI

May to September 2000
Magic Valley, Idaho
Averages of 100's of fields each satellite date

Well-watered fields

$K_c (ETrF) = 1.25 \text{ NDVI}$
Small Hysteresis on increasing and decreasing NDVI

Magic Valley, 2000, METRIC

Averaged over 100’s of fields

NDVI

Kc (ET,F)

Sugar Beet

Potato
Application of ET “maps”
Actual ET from wetlands and riparian systems

Boise Valley Seasonal ET 2000
Boise River Valley, Idaho

ET BY LAND USE CLASS

<table>
<thead>
<tr>
<th>Class Name</th>
<th>ET in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Tank Yards</td>
<td>237</td>
</tr>
<tr>
<td>Rangeland</td>
<td>242</td>
</tr>
<tr>
<td>Unclassified</td>
<td>298</td>
</tr>
<tr>
<td>Barren</td>
<td>335</td>
</tr>
<tr>
<td>Commercial / Industrial</td>
<td>380</td>
</tr>
<tr>
<td>Transportation</td>
<td>420</td>
</tr>
<tr>
<td>Idle Agriculture</td>
<td>436</td>
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<tr>
<td>Abandoned Agriculture</td>
<td>459</td>
</tr>
<tr>
<td>Junk Yard</td>
<td>467</td>
</tr>
<tr>
<td>Feedlot</td>
<td>479</td>
</tr>
<tr>
<td>Dairy</td>
<td>524</td>
</tr>
<tr>
<td>Other Agriculture</td>
<td>536</td>
</tr>
<tr>
<td>Public</td>
<td>548</td>
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<tr>
<td>Sewage</td>
<td>552</td>
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<tr>
<td>New Subdivision</td>
<td>606</td>
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<tr>
<td>Farmstead</td>
<td>609</td>
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<tr>
<td>Rural Residential</td>
<td>657</td>
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<tr>
<td>Urban Residential</td>
<td>684</td>
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<tr>
<td>Canal</td>
<td>731</td>
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<tr>
<td>Irrigated Crops</td>
<td>812</td>
</tr>
<tr>
<td>Perennial</td>
<td>820</td>
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<tr>
<td>Recreation</td>
<td>826</td>
</tr>
<tr>
<td>Water</td>
<td>924</td>
</tr>
<tr>
<td>Wetland</td>
<td>1,025</td>
</tr>
</tbody>
</table>

- **Benefit:**
  New Information

- **Cost:**
  ±$70,000
Middle Rio Grande Region of New Mexico

- Interest in consumptive use of irrigated agriculture
  - Small holdings
  - Less than full water supply in areas
  - Some areas of water logging
- Interest in nonbeneficial consumptive use
- Interest in ET by riparian systems
False color, Daily, Monthly and Annual ET$_r$F
path 34, San Acacia, New Mexico to Colorado

Daily 8/26/2002
Monthly August 2002
Annual 2002
False color, Daily, Monthly and Annual ET$_{rF}$ for an area along the MRG south of Albuquerque
Landsat true-color image (left) and landuse map (right) showing distribution of cottonwood and salt cedar land-use types along the MRG river near Isleta. The bottom set is a close-up of the top.
Evaporation during 2002 from continuously bare areas along the MRG and precipitation received at Angostura and Boys Ranch (averaged).
Frequency Distribution of ET

15,000 acres of cottonwood and salt cedar

June ET (mm/m.o.) vs. Relative area

Annual ET (mm) vs. Relative area

Cottonwoods
Saltcedar
Estimated water consumption by class of riparian vegetation within the riparian area between San Acacia and Cochiti during 2002*

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Total area (acres)</th>
<th>Annual ET$_{rF}$ ($K_c$)</th>
<th>Annual ET (mm)</th>
<th>Annual Water Consumption (AF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cottonwood</td>
<td>10,800</td>
<td>0.67</td>
<td>1380</td>
<td>49,000</td>
</tr>
<tr>
<td>Salt Cedar</td>
<td>4,550</td>
<td>0.54</td>
<td>1110</td>
<td>17,000</td>
</tr>
<tr>
<td>Willow</td>
<td>630</td>
<td>0.71</td>
<td>1440</td>
<td>3000</td>
</tr>
<tr>
<td>R. Olive</td>
<td>90</td>
<td>0.63</td>
<td>1280</td>
<td>400</td>
</tr>
</tbody>
</table>

*Assumes constant ET$_{rF}$ (i.e., ET/ETr) during the day

From report by University of Idaho (Allen et al., 2004) to Keller-Bliesner Engineering, Logan, UT for U.S. Department of Justice

High Resolution Classification courtesy of Dr. Christopher Neale Utah State University
Middle Rio Grande Region of New Mexico

Area is between Cochiti and San Acacia
ET$_{rF}$ for Albuquerque City Area Average

Month

ET$_{rF}$

0 0.2 0.4 0.6 0.8 1 1.2

1 2 3 4 5 6 7 8 9 10 11 12
Irrigation Project Performance -- Idaho

**Project wide Crop Coefficient -- METRIC**

*Twin Falls Tract -- 220,000 acres -- Alfalfa Reference Basis*

March, Sept., and Oct. unavailable for 2003
Irrigation Project Performance -- Idaho

Twin Falls Canal Company, Idaho

Evapotranspiration as a Ratio of Diversion plus Precipitation

Ratio

<table>
<thead>
<tr>
<th>Month</th>
<th>2000</th>
<th>2003</th>
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<tr>
<td>Apr</td>
<td>0.37</td>
<td>0.56</td>
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<tr>
<td>May</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>Jun</td>
<td>0.36</td>
<td>0.45</td>
</tr>
<tr>
<td>Jul</td>
<td>0.45</td>
<td>0.54</td>
</tr>
<tr>
<td>Aug</td>
<td>0.45</td>
<td>0.54</td>
</tr>
<tr>
<td>Apr-Aug</td>
<td>0.45</td>
<td>0.54</td>
</tr>
</tbody>
</table>
METRIC with MODIS
\[ \overline{ET_r F} = 0.37 \]
\[ \text{std.dev.} = 0.25 \]

\[ \overline{ET_r F} = 0.40 \]
\[ \text{std.dev.} = 0.36 \]

\[ \overline{ET_r F} = 0.46 \]
\[ \text{std.dev.} = 0.20 \]

\[ ET_r F = \frac{ET}{ET_r} \]

**ET_r F by METRIC**
Level 2 5min LST represents a daily instantaneous LST image. White locations are ‘missing’ LST due to missing thermal emissivity due to mis-categorization of pixel as a cloud near irrigated/desert boundaries.

Daily LST products have these fall-outs also, but the number of the holes is less, primarily because of the smearing effect of resampling.

Currently, METRIC uses Level 1 radiance (using calibration of LST vs. radiance by regression of ‘good’ pixels in LST image). Level 3 8-day LST may also be useable.
Another problem with MODIS Sensors:
Band 5 (2\textsuperscript{nd} NIR) has been having striped output.
Stripes are present in all Level 1 – 3 products.
This problem has been reported for many bands as “known issues”.
http://modland.nascom.nasa.gov/cgi-bin/QA_WWW/getSummary.cgi?esdt=MOD09

These two images false color using Bands 5-1-4.
Solution: Omit band 5 from albedo computations.
Scan Angle (from Zenith), Twin Falls, Idaho

August 1-16, 2004 ---MODIS

Sensor Scan Angle, Deg from Zenith

Day of Year

- Aqua
- Terra
Scan Angle Effect on Reflectance, S. Idaho

MODIS Surface Reflectance -- Crop Uniform

Aqua

Terra
Conclusions

ET maps are valuable for:

- Determining **Actual** ET
- Refining Crop Coefficient Curves (f.e. for a new ET reference)
- Water Rights Conflicts
- Ground-water Management
- Consumption by Riparian Vegetation

ET maps by METRIC℠ have good accuracy and consistency with the Reference ET approach
Requirements for SEBAL or METRIC™

- Satellite images with **Thermal Band**
  - Higher resolution (Landsat) is needed for field scale maps

- Good quality weather data if local calibration is desirable

- Experienced, thinking human at the controls
More information at:

- [www.kimberly.uidaho.edu/water/](http://www.kimberly.uidaho.edu/water/) (METRIC™)
- [www.waterwatch.nl](http://www.waterwatch.nl) (SEBAL™)
- [www.sebal.us](http://www.sebal.us)
- [http://maps.idwr.idaho.gov](http://maps.idwr.idaho.gov)