METRIC: High Resolution Satellite Quantification of Evapotranspiration

Rick Allen
University of Idaho, Kimberly, Idaho

Overview

Co-developers and Collaborators:
M. Tasumi, R. Trezza, W. Bastiaanssen, T. Morse, W. Kramber, J. Wright
ET “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 SEBAL™

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.
Why Energy balance?

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

\[ ET = R_n - G - H \]

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

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)
Major Irrigated areas in Idaho and areas of METRIC application.
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
True Color – southcentral Idaho – August 14, 2000

- Thousand Springs
- Twin Falls
- Burley
- Lake Walcott
- Wood River Valley
- Craters of the Moon
- Dairy area (lots of corn, alfalfa)
- Recent burn
- Basalt
- 100 miles
“False” Color – southcentral Idaho – August 14, 2000

Red indicates active vegetation

- Thousand Springs
- Twin Falls
- Burley
- Wood River Valley
- Craters of the Moon
- Lake Walcott
- Dairy area (lots of corn, alfalfa)
- Recent burn
- Basalt
- North

100 miles
Ground Heat Flux – southcentral Idaho – August 14, 2000

Soil Heat Flux (W/m²)

North

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

recent burn
basalt
Instantaneous ET – southcentral Idaho – August 14, 2000
24-hour ET – southcentral Idaho – August 14, 2000

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

Evapotranspiration (mm/day)
0.0
1.5
3.0
4.5
6.0
7.5
8.2

ETr Fraction
0.0
0.2
0.4
0.6
0.8
1.0
1.1

recent burn
basalt
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 → Near Infrared

Wavelength in Microns:

0 0.4 0.6 0.8 1.2 1.6 2.0 2.4

Visible

Near Infrared

(Band 6 is the surface temperature band (not shown))

Various amounts of reflection

Land Surface

Various amounts of reflection
Disposition of Solar Radiation in the Atmosphere

- Extraterrestrial Radiation
- Absorption by 
  - H₂O, O₂, O₃, N₂O
- Scattered to Space
- Reflected from Clouds
- Reflected
- Scattered
- Indirect
- Direct Solar
Longwave (Infrared) Radiation in the Atmosphere

Emission = f \( T^4 \)

Emission lost to Space

Absorption
H_2O, CO_2, CH_4, CFC's

Emission from Clouds
Absorption by Clouds

Emission from Surface
Reflection from Surface

Emission from Clouds
Broadband Surface Albedo

EBT-BBT = ‘old’ method used in METRIC until 2004
(based on broad-band transmissivity)

Updated method:
Transmissivity of individual bands

\[
\tau_{in,b} = C_1 \exp \left[ \frac{C_2 \cdot P_{air}}{K_t \cos \theta_h} - \frac{C_3 W + C_4}{\cos \theta_h} \right] + C_5
\]
ERDAS Imagine Image Processing and Modeling System
METRIC Energy Balance

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

In METRIC, Weather Data are used for:

• Wind speed for **sensible heat flux** calculation

• **Reference ET** for Calibrating the Cold Pixel

• **Reference ET** to **Extrapolate ET** over:
  • 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.
Sensible Heat Flux ($H$)

\[ H = \left( \rho \times c_p \times \Delta T \right) / r_{ah} \]

$\Delta T$ = “floating” near surface temperature difference (K).

$r_{ah} = \text{the aerodynamic resistance to heat transport (s/m).}$

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

\[ u_* = \text{friction velocity} \]

\[ k = \text{von karmon constant (0.41)} \]
Aerodynamic Equations used in METRIC™

\[ H = \left( \rho \, c_p \right) \left( T_{a1} - T_{a1} \right) / r_{ah} \]

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

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

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

Correction for atmospheric instability

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

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

\[ L = -\rho_{air} \, C_{p_{air}} \, u_\ast^3 \, T_0 \]

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

\[ \Psi_{m(200m)} = -5 \left( \frac{Z_2}{L} \right) \quad \text{and} \quad \Psi_{h(z_2)} = -5 \left( \frac{Z_2}{L} \right) \quad \text{for stable} \]
Near Surface Temperature Difference (dT)

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

  - Classical: \( dT = T_{\text{surface}} - T_{\text{air}} \)
  - SEBAL/METRIC: \( dT = T_{z1} - T_{z2} \)

- \( T_{\text{air}} \) 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.
METRICtm-ERDAS submodel for sensible heat and ETfTrF

M02. Main energy balance model for SEBAL-ID: Sensible heat flux, Net radiation, Ground heat flux, Reference ET fraction and ET

Copyright (C) 2003 R.G. Allen, M.T. Tsanis, R. Trezza and University of Idaho. All rights reserved.
How METRIC™ is “Trained”

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

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

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

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

("1.05" is reduced and estimated as \( f(NDVI) \) during winter, etc.)
Hot Pixel

Samples from an Agricultural Area

Dry Bare Field

Wet Bare Field

Water Stressed

Dense Green Field

Wet and Dense Green Field

Cold Pixel

\[ T_{s, DEM} (K) \]

\[ \text{LAI} \]
ET\textsubscript{r}F at the Hot pixel: (is it really zero?):
The operator must direct METRIC concerning any residual ET at the hot pixel. ET\textsubscript{r}F can be estimated using the FAO-56 surface evaporation estimation procedure.
Soil Heat Flux (G)

via Bastiaanssen (1995):

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

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

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

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

and \[ G = \frac{G}{R_n} \times R_n \]
Water Heat Flux (G) (Appendix 10)

For clear, deep water


Monthly evaporation from three Great Lakes (Derecki, 1981)

FIG. 6. Seasonal distribution of average monthly evaporation.
Water Heat Flux (G)

American Falls, Reservoir, Idaho
2004 – midday readings

<table>
<thead>
<tr>
<th>Month</th>
<th>Rn</th>
<th>H</th>
<th>LE</th>
<th>G</th>
<th>G/Rn</th>
<th>Kc</th>
<th>WS</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>066</td>
<td>23</td>
<td>54</td>
<td>529</td>
<td>0.87</td>
<td>0.15</td>
<td>5.91</td>
</tr>
<tr>
<td>6</td>
<td>743</td>
<td>16</td>
<td>52</td>
<td>675</td>
<td>0.91</td>
<td>0.11</td>
<td>2.43</td>
</tr>
<tr>
<td>7</td>
<td>696</td>
<td>26</td>
<td>111</td>
<td>560</td>
<td>0.80</td>
<td>0.25</td>
<td>2.79</td>
</tr>
<tr>
<td>8</td>
<td>696</td>
<td>46</td>
<td>71</td>
<td>579</td>
<td>0.83</td>
<td>0.15</td>
<td>2.76</td>
</tr>
<tr>
<td>9</td>
<td>500</td>
<td>27</td>
<td>81</td>
<td>391</td>
<td>0.78</td>
<td>0.27</td>
<td>1.95</td>
</tr>
<tr>
<td>10</td>
<td>421</td>
<td>30</td>
<td>64</td>
<td>327</td>
<td>0.78</td>
<td>0.30</td>
<td>2.19</td>
</tr>
<tr>
<td>11</td>
<td>267</td>
<td>21</td>
<td>25</td>
<td>220</td>
<td>0.83</td>
<td>0.22</td>
<td>2.67</td>
</tr>
</tbody>
</table>

Based on combination of eddy covariance and REBS Bowen ratio measurements. Tasumi and Allen, 2004, preliminary data, University of Idaho

Units for $R_n$, $H$, LE, $G$ are W/m$^2$. Wind speed, WS, is in m/s. $K_c = \text{Evap} / \text{ET}_r$
Water Heat Flux (G)

American Falls, Reservoir, Idaho
2004 – 24-hr averages

<table>
<thead>
<tr>
<th>Month</th>
<th>Rn (W/m²)</th>
<th>H (W/m²)</th>
<th>LE (W/m²)</th>
<th>G (W/m²)</th>
<th>G/Rn</th>
<th>Kc</th>
<th>WS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>170</td>
<td>25</td>
<td>64</td>
<td>81</td>
<td>0.47</td>
<td>0.41</td>
<td>5.53</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>208</td>
<td>6</td>
<td>34</td>
<td>168</td>
<td>0.81</td>
<td>0.17</td>
<td>3.69</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>199</td>
<td>21</td>
<td>73</td>
<td>104</td>
<td>0.52</td>
<td>0.36</td>
<td>3.67</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>208</td>
<td>22</td>
<td>23</td>
<td>162</td>
<td>0.78</td>
<td>0.11</td>
<td>2.65</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>118</td>
<td>11</td>
<td>16</td>
<td>91</td>
<td>0.77</td>
<td>0.12</td>
<td>3.13</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>64</td>
<td>16</td>
<td>32</td>
<td>15</td>
<td>0.24</td>
<td>0.45</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>18</td>
<td>17</td>
<td>22</td>
<td>-21</td>
<td>-1.20</td>
<td>0.65</td>
<td>3.35</td>
<td></td>
</tr>
</tbody>
</table>

based on combination of eddy covariance and REBS Bowen ratio measurements. 
Tasumi and Allen, 2004, preliminary data, University of Idaho

units for $R_n$, $H$, $LE$, $G$ are $W/m^2$. Wind speed, $WS$, is in m/s. $Kc = Evap / ET_r$
Interpolation to the rest of the day (and month) (and year)
ET_rF = Fraction of ET_r = K_c

Assumption: ET_rF is consistent through the day
Extrapolation of Inst. to 24-hour ET : ET,\textsubscript{F} method - METRIC

Sugar Beets and Potatoes ET\textsubscript{F} for 1988 and 199 satellite dates

\[ y = 0.9812x + 0.0406 \]
\[ R^2 = 0.9888 \]

ET\textsubscript{F} for Sugar Beets May to September, 1989, Data from Dr. J.L Wright

ET\textsubscript{F} based on Lysimeter Data by Dr. J.L. Wright, USDA-ARS
24-Hour Evapotranspiration (ET\textsubscript{24})

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

Path 39: Am. Falls - 24-hour ET

(in EF method, \( ET_{24} = EF \times R_{n24} \))
Seasonal ET

ET (mm)

0

250

500

750

1000

> 1000

meters

0

30000

30000

University of Idaho
Comparison with Lysimeter Measurements:

Lysimeter at Kimberly (Wright)
Kimberly, Idaho – Periods between Satellites

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

ET during period, mm

- 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%

- 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

Total
Comparison of Seasonal ET by SEBAL$_{2000}$ with Lysimeter

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

- Lysimeter: 388 mm
- SEBAL: 405 mm
Annual ET for all of California

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

http://www.sebal.us
Comparison to $K_c$ Curves

Seasonal Evapotranspiration during 2000
Eastern Snake River Plain, Idaho
Use to Refine Local $K_c$ Curves

Potato

717 fields in the Twin Falls area

Average “curve”

Vegetation Index

Day of Year

Day of Year

Potato

717 fields in the Twin Falls area
$K_c$ near 1.0 indicating high production agriculture
W. Grain

Day of Year

Kc

564 fields

60 100 140 180 220 260 300
Comparison with Local $K_c$ Curves
-- south-central Idaho

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

Little need to adjust $K_c$
Crop Coefficient (ETrF)

NDVI

717 Potato Fields,
2000

3 June
19 June
Crop Coefficient (ETrF)

NDVI

717 Potato Fields, 2000

3 June  19 June  21 July
Crop Coefficient (ETrF)

NDVI

717 Potato Fields, 2000

“basal” $K_c$

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

$K_c$ (ET$_{rF}$)

NDVI (toa)

- Alfalfa
- Potato
- Sugar Beet
- S.Grain
- Corn
- W.Grain

ET$_{rF}$ = 1.25 NDVI

University of Idaho
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

- Benefit: New Information
- Cost: $70,000

<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>
</tr>
<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>
</tr>
<tr>
<td>Sewage</td>
<td>552</td>
</tr>
<tr>
<td>New Subdivision</td>
<td>606</td>
</tr>
<tr>
<td>Farmstead</td>
<td>609</td>
</tr>
<tr>
<td>Rural Residential</td>
<td>657</td>
</tr>
<tr>
<td>Urban Residential</td>
<td>684</td>
</tr>
<tr>
<td>Canal</td>
<td>731</td>
</tr>
<tr>
<td>Irrigated Crops</td>
<td>812</td>
</tr>
<tr>
<td>Perennial</td>
<td>820</td>
</tr>
<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>

Millimeters of ET
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>
</tr>
<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>
</tr>
<tr>
<td>Sewage</td>
<td>552</td>
</tr>
<tr>
<td>New Subdivision</td>
<td>606</td>
</tr>
<tr>
<td>Farmstead</td>
<td>609</td>
</tr>
<tr>
<td>Rural Residential</td>
<td>657</td>
</tr>
<tr>
<td>Urban Residential</td>
<td>684</td>
</tr>
<tr>
<td>Canal</td>
<td>731</td>
</tr>
<tr>
<td>Irrigated Crops</td>
<td>812</td>
</tr>
<tr>
<td>Perennial</td>
<td>820</td>
</tr>
<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

- 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
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.

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

Alfalfa* - MRG, 2002

Open Water - MRG, 2002

Cottonwood - MRG, 2002

Salt Cedar - MRG, 2002

* Sample fields were alfalfa in 2004, but might be other crops in 2002
Frequency Distribution of ET

15,000 acres of cottonwood and salt cedar

Graphs showing the frequency distribution of ET for June ET and Annual ET for cottonwoods and saltcedar.
Estimated water consumption by class of riparian vegetation within the riparian area between San Acacia and Cochiti during 2002*

<table>
<thead>
<tr>
<th>Total area (acres)</th>
<th>Annual ETᵢF ($K_c$)</th>
<th>Annual ET (mm)</th>
<th>Annual Water Consumption (AF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cottonwood</td>
<td>10,800</td>
<td>.67</td>
<td>1380</td>
</tr>
<tr>
<td>Salt Cedar</td>
<td>4,550</td>
<td>.54</td>
<td>1110</td>
</tr>
<tr>
<td>Willow</td>
<td>630</td>
<td>.71</td>
<td>1440</td>
</tr>
<tr>
<td>R. Olive</td>
<td>90</td>
<td>.63</td>
<td>1280</td>
</tr>
</tbody>
</table>

*Assumes constant ETᵢF (i.e., ET/ETᵢ) 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
ET_{\text{rF}} for Albuquerque

Albuquerque City Area Average

Month

ET_{\text{rF}}
“Performance” of Irrigation Projects

Seasonal Evapotranspiration during 2000
Eastern Snake River Plain, Idaho
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>Ratio</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Apr-Aug</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.35</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>0.2</td>
<td>0.35</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>0.4</td>
<td>0.35</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>0.6</td>
<td>0.35</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>0.8</td>
<td>0.35</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>1.0</td>
<td>0.35</td>
<td>0.2</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Legend:
- 2000
- 2003
Conclusions

ET maps are valuable for:

- Determining **Actual** ET
- Refining CropCoefficient 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/ (METRIC™)
- www.waterwatch.nl (SEBAL™)
- www.sebal.us
- http://maps.idwr.idaho.gov

More information at:

www.kimberly.uidaho.edu/water/ (METRIC™)
www.waterwatch.nl (SEBAL™)
www.sebal.us
http://maps.idwr.idaho.gov
METRIC with MODIS
Landsat5: 8/31/2003

\[ \overline{ET_r F} = 0.40 \]

\[ \text{std.dev.} = 0.36 \]

MODIS: 8/31/2003 (57°)

\[ \overline{ET_r F} = 0.46 \]

\[ \text{std.dev.} = 0.20 \]

MODIS: 8/9/2004 (2°)

\[ \overline{ET_r F} = 0.37 \]

\[ \text{std.dev.} = 0.25 \]

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

ET_rF by METRIC

\[ \text{ET}_r F \]

\[ \text{ET}_r F \]
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

MODIS: 8/29/2003~8day
MODIS: 8/9/2004 (2\textdegree)

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
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)
Model Sensitivity to Aerodynamic Roughness, $z_{om}$, (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)