Operational Evapotranspiration from Landsat-based Energy Balance – Evolution, Successes and Future Challenges

Rick Allen
University of Idaho

Collaborators: Tony Morse (SAG), Jan Hendrickx (NMT), Justin Huntington (DRI), Ayse Irmak (UNL), Wim Basitaanssen (WaterWatch), Martha Anderson (USDA-ARS), Ricardo Trezza (UI), Jeppe Kjaersgaard SDSU), Tim Martin (RTI).
primary accomplishments

- Advances and Refinements in Components of METRIC
  - An “Engineering and Operational” Energy Balance Model for Establishing ‘maps’ of Evapotranspiration
  - Useful in State and Federal Operations
  - Better understanding of local ET behavior and model needs
- Improved Handling of EROS Landsat Imagery
- Support of TIRS on future Landsat Missions
specific accomplishments

- Mountain aerodynamics
  - terrain roughness
  - wind speed vs. elevation
  - wind shielding by mountains
    - impact of wind direction
  - improved radiation model (Allen and Trezza) with diffuse including terrain reflectance
- Background evaporation modeling (daily timestep) between Landsat overpass dates
- Cloud filling strategies with background evaporation matching
- Gridded weather data
  - conditioning
- automated pixel selection
specific accomplishments

- Three source Temperature estimation
- Anomalies with LST
  - registration of NN in NLAPS L1T
  - NN vs. CC
- Adjustment of nadir reflectance to hemispherical
- Aerodynamic estimation of evaporation
- Evaporative fraction vs. ETrF for rainfed vegetation
- Soil heat flux = f(sensible heat flux)
- Sharpening Landsat 120 m thermal to 30 m
- Sharpening MODIS 1000 m thermal to 30 m
- Automated calibration
specific accomplishments

- Gapfilling LS7 SLC-off with natural neighbor
- Statistics Landsat Science Team to support 4-day return time
- Ash Institute Award
- METRIC training courses
- METRIC used in
  - 11 states for water transfers, endangered species management, hydrologic studies
  - two court hearings/decisions
  - eight consulting studies
challenges

- Dealing with clouded periods
- Dealing with irrigation/precipitation events between images – explore data fusion w/MODIS, etc.
- Getting more frequent return time
- Fusion of Energy Balance with Gridded weather data for Periods between Images
ET at 30 m resolution

Growing Season ET -- April – October, 2006 from METRIC-Landsat

Snake River Plain, Idaho

~160 km
ET at 30 m resolution

Growing Season ET -- April – October, 2006 from METRIC-Landsat

American Falls Reservoir
Lake Walcott
Albion, ID
Snake River
Irrigated Fields/
Water Rights
Local Riparian

~80 km
Growing Season ET -- April – October, 2006 from METRIC-Landsat (Sharpened Thermal)
ET at 30 m resolution

Growing Season ET -- April – October, 2006 from METRIC-Landsat

~160 km
ET/DEM at 250 m resolution

April – October, 2006 ET from METRIC-Landsat
ET/DEM at 1 km resolution

April – October, 2006 ET from METRIC-Landsat
ET/DEM at 4 km resolution

April – October, 2006 ET from METRIC-Landsat

ET (mm)

0
300
600
900
1200
1500
ET/DEM at 10 km resolution

April – October, 2006 ET from METRIC-Landsat
ET/DEM at 32 km resolution

April – October, 2006 ET from METRIC-Landsat
Progression of ET in time
At Moderate (-ly high) Resolution

**May**

**July**

**Sept.**
Improving Mountain Aerodynamics

Increasing $z_{om}$ for Terrain Roughness

Increased Wind Speed in Mountains
07/18/2007 L5 – Smith River Basin

3 km diameter circle

DEM
Increasing $z_{om}$ for Terrain Roughness

$07/18/2007 \text{ L5}$

Std. Dev. of elevation, m

$z_{om} = z_{om}^{\text{flat}} + f(\text{Std. Dev. DEM, } z_{om}^{\text{flat}})$
Increased Wind Speed in Mountains

07/18/2007 L5

Relative elev. within 3km circle, m

Wind Speed increase = \( f(\text{Rel.Elev., Std.Dev.DEM}) \)
Reducing Wind Speed on **Leeward Slopes**

Wind Speed decrease = \( f(\sin(\text{slope}), \cos(\text{aspect, wind direction})) \)
Impact of Terrain Roughness
-- (07/18/2007) L5

\[ ET_{r,F} = \text{fraction of potential ET} \]
\[ (= \text{Relative ET index}) \]

No Adjustment \hspace{1cm} w/Substantial Terrain Roughness
ET_{r,F} map before and after **doubling Wind Speed in Mountains (Max.)** (07/18/2007)
Impact of Leeward shielding
-- (07/18/2007)  L5

$ET_{r,F} =$ fraction of potential ET
($=$ Relative ET index)

No Adjustment  Adjustment with Wind from North
Total Impact of new aerodynamic enhancements

-- (07/18/2007) L5

\[ \text{ET}_F = \text{fraction of potential ET} \]
(= Relative ET index)

Before | After
ET during the growing season

1997 image date ET_r F estimates

July 12, 1997 image date ET_r F estimates

April 23
May 9
June 26

July 12
August 13
September 30
October 16
We work on the basis of ‘relative’ ET (i.e., $ET_r F$) and compute ET for each day between images as $ET_i = ET_r F_i \times ET_{r_i}$ where $ET_r$ is the ‘reference’ or ‘potential’ ET on day $i$ and $F = f(\text{weather})$. 
ET ‘index’ (fraction of full-cover ‘reference’ ET) during the 1997 growing season in Western Nebraska.

Extents of evaporation from recent Rain Events.

Landsat scenes: 160 x 160 km

April 23
May 9
June 26

July 12
August 13
September 30
October 16

from METRIC/Landsat
Adjusting for background evaporation from soil in proportion to NDVI

ET from August 13 1997 not adjusted for background soil evaporation

ET from August 13 1997 adjusted for background soil evaporation to represent the month
Central Platte region, Nebraska

ETrF from 8/4/2007 before adjustment

ETrF from 8/4/2007 after adjustment

Final ETrF representing a one month time period

Dr. Ayse Irmak, UNL
North Platte region, Nebraska – final Monthly ET

April

May

June

July

August

Sept.

Oct.

(More frequent images would reduce this complication and increase accuracy)
“Conditioning” Weather Data to reflect a well-watered (Irrigated) Environment
NARR vs. Irrigated Agriculture: Near Surface Air Temperature

Twin Falls, Idaho

Date

Temperature (K)

3-hour Agrimet (Instantaneous)
3-hour NARR

August 16-18, 2011 Landsat Science Team Meeting
NARR vs. Irrigated Agriculture: Near Surface Vapor Pressure

Actual Vapor Pressure (ea)

Date

Dry vs. Irrigated Agriculture:
Near Surface Vapor Pressure –
Conditioned using Profile/Flux Theory

Twin Falls, Idaho
Dry vs. Irrigated:
“Reference Evapotranspiration” – Dry (meas.) vs. Conditioned vs. Irrigated (meas.)

24 h Reference ET, mm

- Irrigated Site
- Ambient Desert
- Conditioned Desert

DoY 2009

Twin Falls, Idaho
Landsat Nadir View Simulator

Pipe fitting - $1.30
Ring clamp - $2.10

Nadir View: Priceless
Landsat Nadir View Simulator

Wim Bastiaanssen, WaterWatch, the Netherlands, one of the fathers of ET retrievals from satellite (SEBAL)
Landsat Nadir View Simulator

Ratio of albedo estimated from Nadir View To measured hemispherical albedo

2 m corn – Kimberly, Idaho

Ratio

0 0.4 0.8 1.2 1.6 2


Time
Landsat Nadir View Simulator

Ratio of albedo estimated from Nadir View
To measured hemispherical albedo

(8:00am - 5:50pm)

0.6 m oats – Kimberly, Idaho
Comparison of Energy Balance Components with Ground-based Flux Measurements
Hollister Sage Brush site – Installed Feb. 2010

- 3 3-D sonic anemometers
- 1 LiCor 7500 H2O/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
Island Park (nr. Yellowstone) Site: Alpine forest (south tower)  
Installed October 2010
Island Park Lodgepole Pine site – Installed Oct. 2010

- 2 3-D sonic anemometers
- 2 LiCor 7500 H2O/CO2 Infrared A.
- 7 Net radiometers
- 1 Scintec BLS900 Scintillometer
- 24 Soil Heat Flux Sensors
- 48 Soil Temperature Sensors
- 32 Soil Water Content Sensors
- 2 Rain Gages
- 2 Sonic Snow Depth Sensors
- 2 Infrared Temperature Sensors
Large Aperture Scintillometer (Sensible Heat Flux)
“Mapping Evapotranspiration from Satellites”

*Idaho Department of Water Resources and University of Idaho*

2009 Award for Harvard’s Ash Institute’s Innovations in American Government Award
PBS “Visionaries” film w/ Sam Waterston
“Remarkably, METRIC enables Idaho DWR analysts and administrators to measure ET across large expanses of both space and time.”

“METRIC....is measurably more accurate, fast, and cost-effective than the traditional, cumbersome, slow and expensive methods that were commonly used in the last century.”

“...it would be practically impossible to adjudicate water rights disputes in the future without [TIRS].”

“It is measurably effective in that it has distinctive capacities to monitor evapotranspiration and consumptive water use across both space...and time (..with the help of historic Landsat thermal band images).”
Typical Idaho December Morning
Typical Idaho December Morning
Grandaughter’s are the best!