ET Investigations surrounding Landsat

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University of Idaho

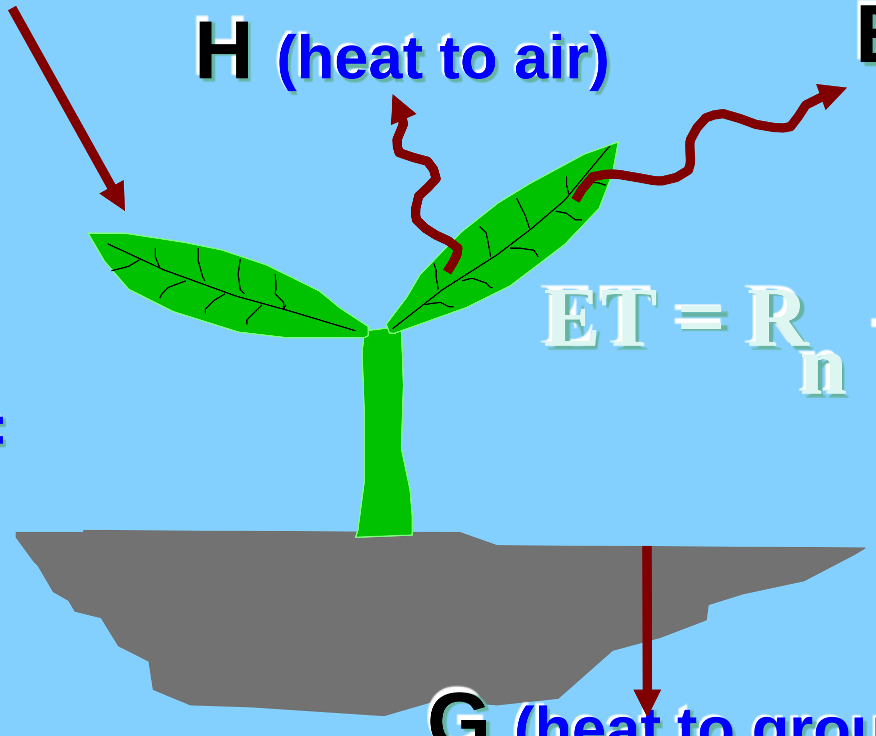
Topics

- ET Processing developments (to METRIC)
  - Evaporation from open water
  - Adjusting for Evaporation from soil from Rain events between Landsat images
- Growth in Applications and Areas of Application

Why use an "Energy balance"?

ET is calculated as a "residual" of the energy balance

R_n •(radiation from sun and sky)

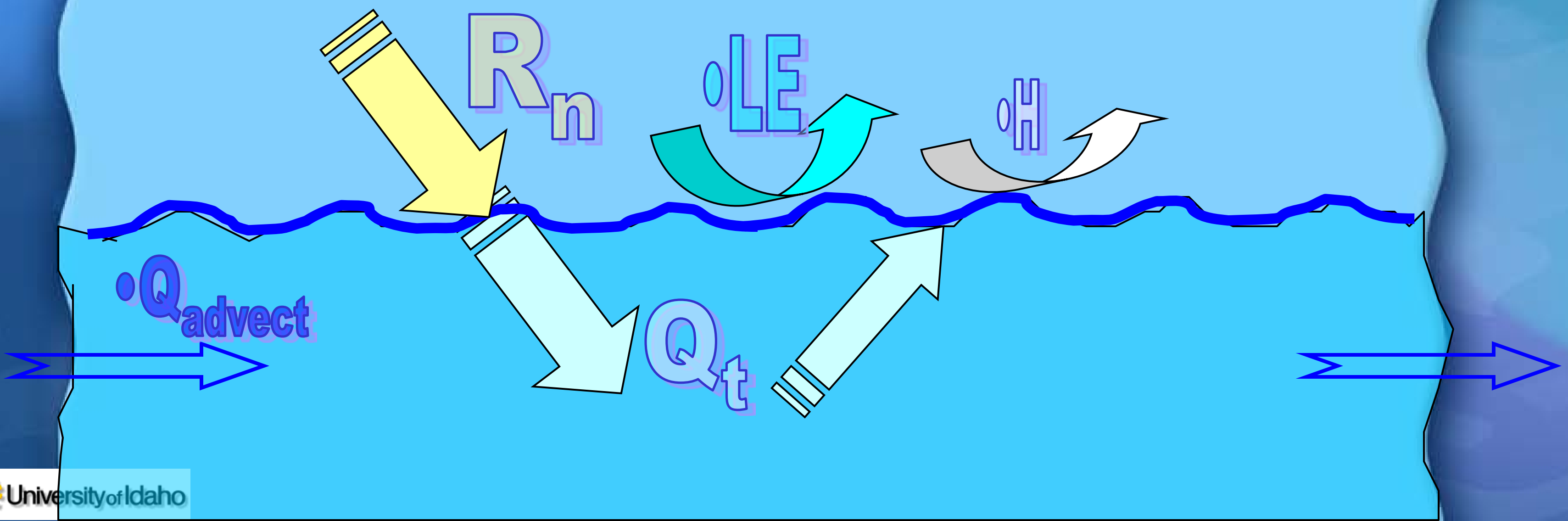


$$ET = R_n - G - H$$

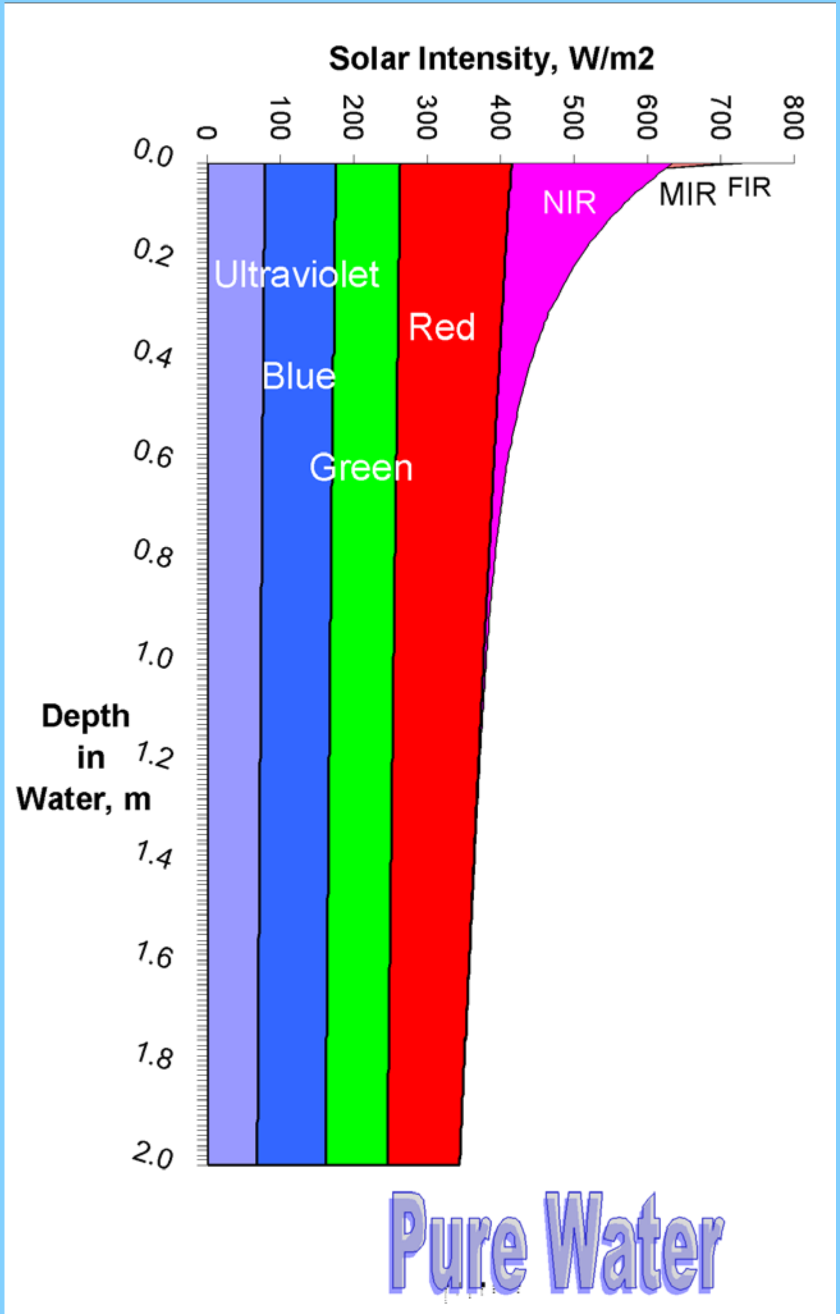
•***Basic Truth***: Evaporation consumes Energy

Evaporation by Energy Balance

- $LE = R_n - Q_t - H + Q_{advect}$
  - Problem: Instantaneous Q_t can be more than one-half as large as R_n
  - Q_t varies with
    - turbidity
    - water depth
    - advection into and from water body



Penetration of Solar Radiation



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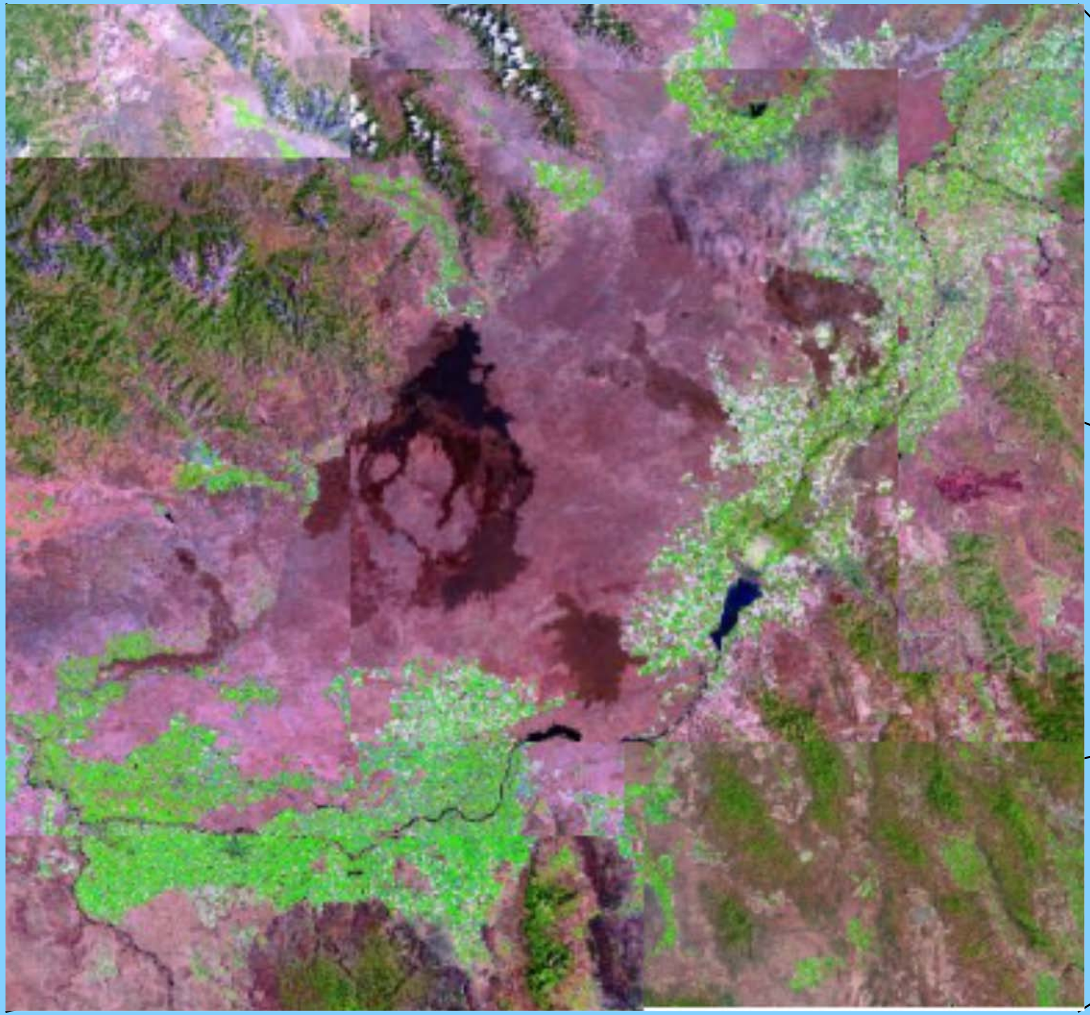
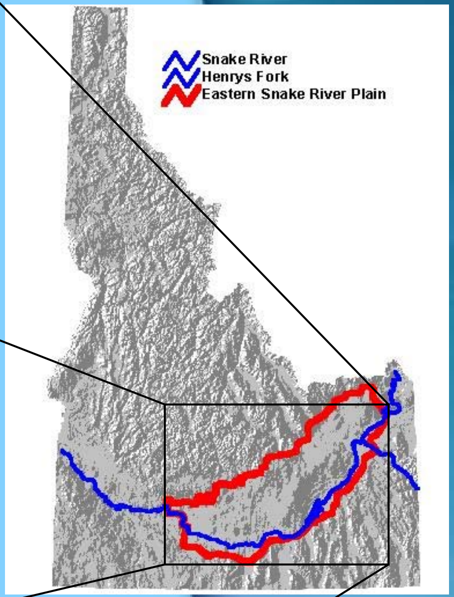
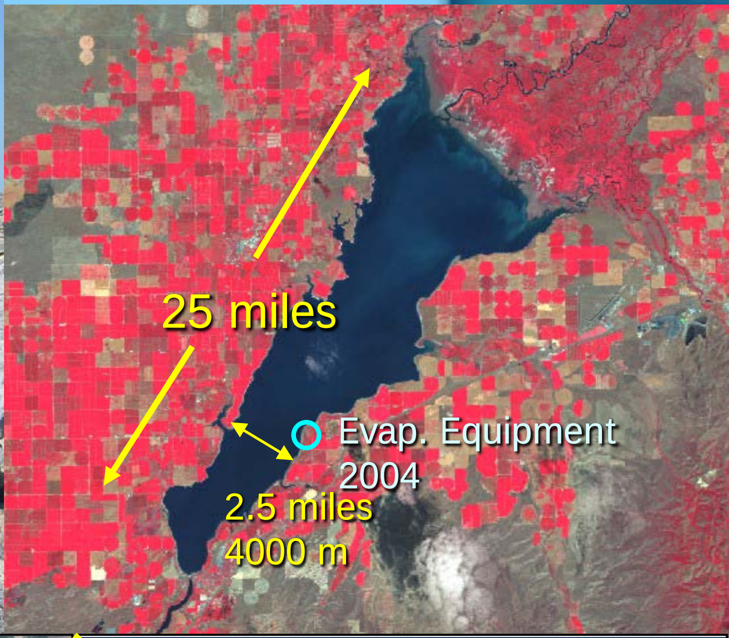
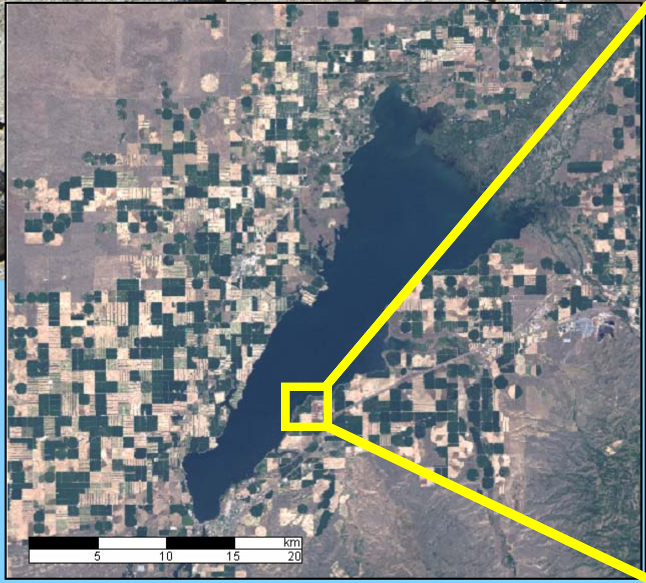
American Falls Reservoir

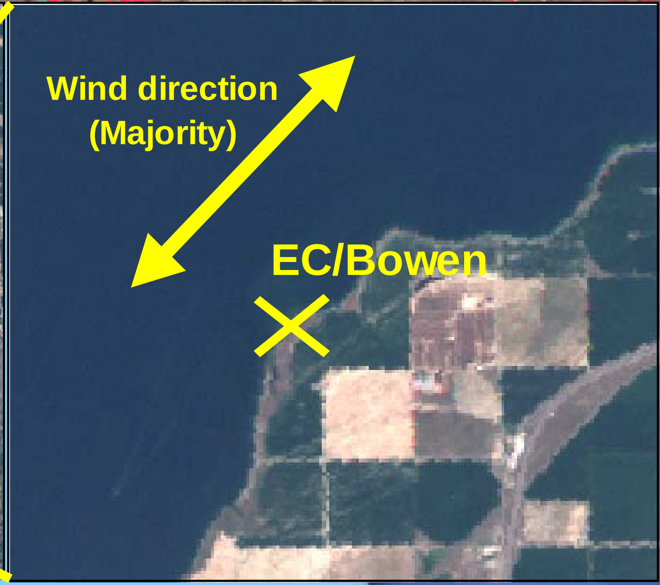




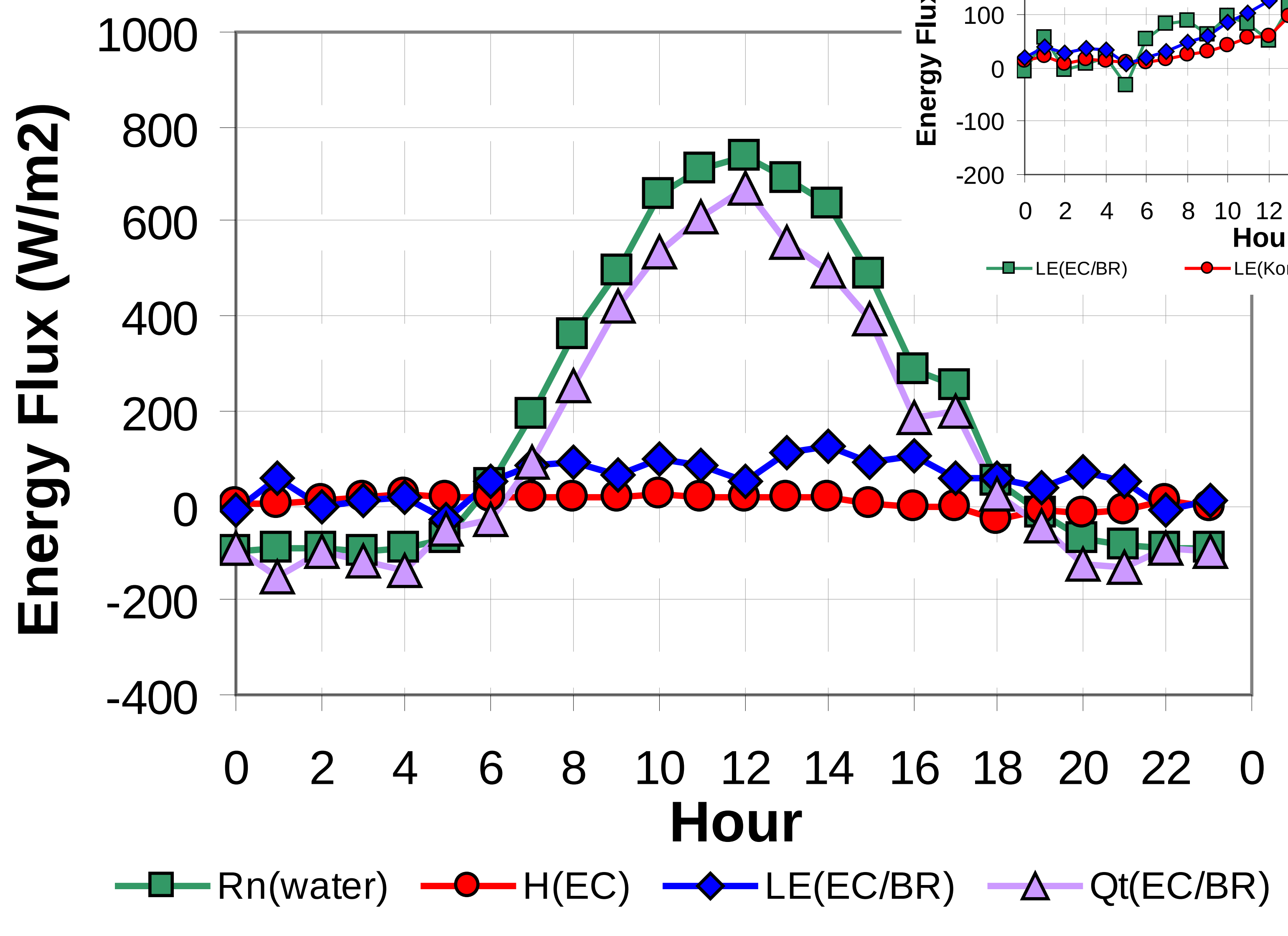
Set up at American Falls Res.

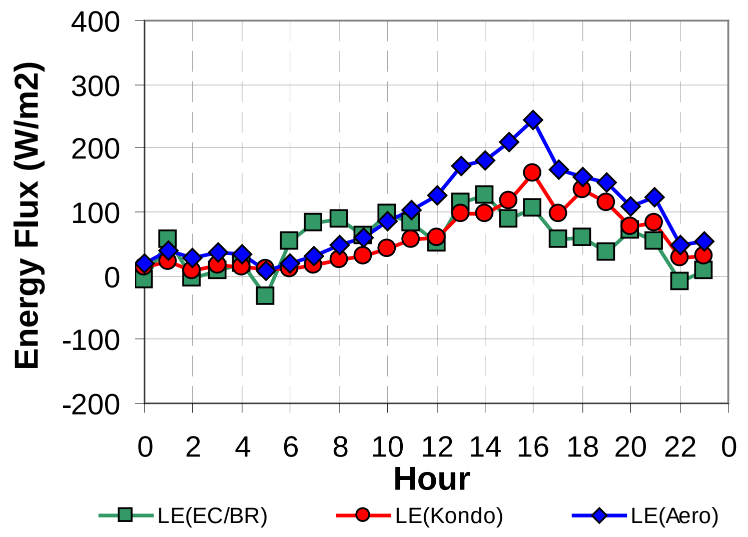






Typical Day in June





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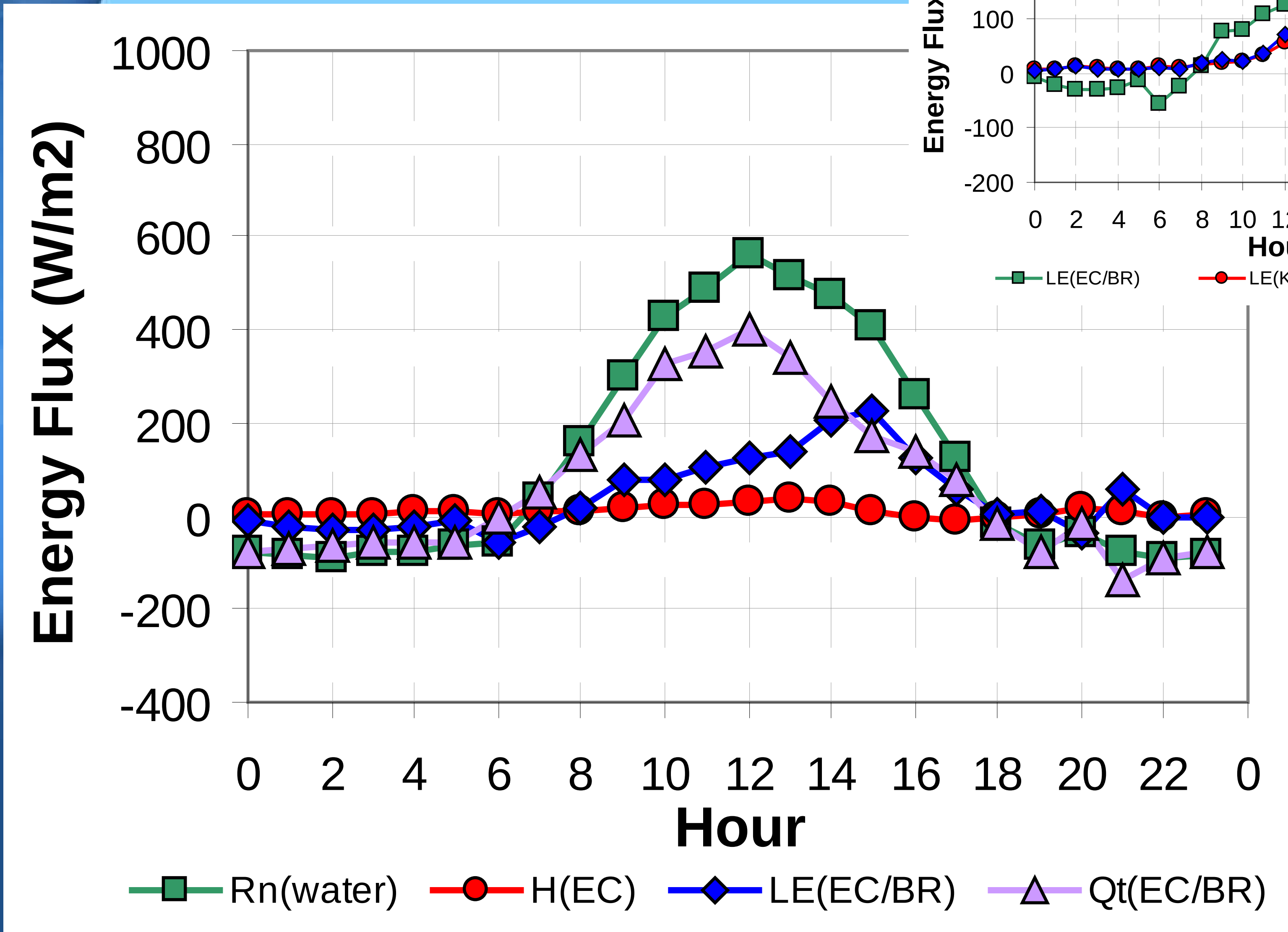
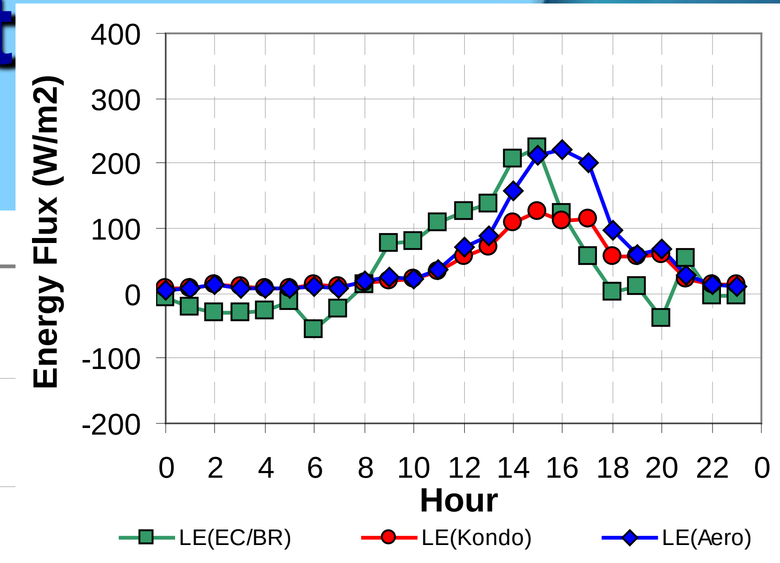
Typical Day in Sept





Aerodynamic Estimation of Evaporation from Water

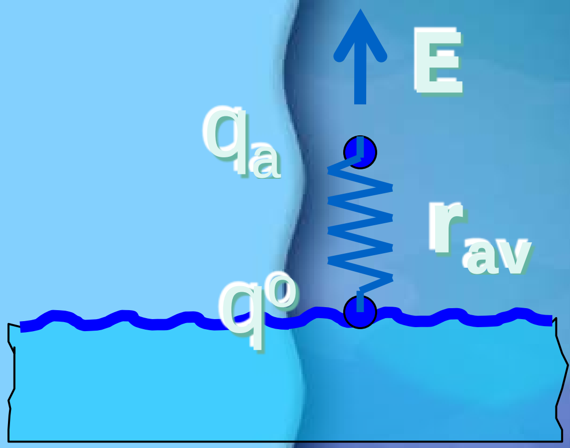
- **Using standard aerodynamics:**

$$E = 3{,}600{,}000 \;\rho_a \; \frac{\left(q^o(T_s) - q_a\right)}{\rho_w \, r_{av}}$$

  - **T_s is surface temperature**
  - **q^o is saturated specific humidity at surface temperature**
  - **q_a is specific humidity of air:**

$$q_a = q^o(T_s)\; \frac{q_{a\,weather\;station}}{q^o(T_{s\;\;veg\;\;(cold)})} \;\; \sim \text{constant}\;\; RH$$

$$r_{av} = \frac{\left[\ln\left(\frac{z_{bl}}{z_{om}}\right) - \psi_{mbl}\right]\left[\ln\left(\frac{z_2}{z_{oh}}\right) - \psi_{h2}\right]}{0.41^2\, u_{bl}}$$



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3-D Sonic Anemometer for EC (H)
American Falls Reservoir - 2004

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REBS Bowen Ratio Sys. (for H/LE)

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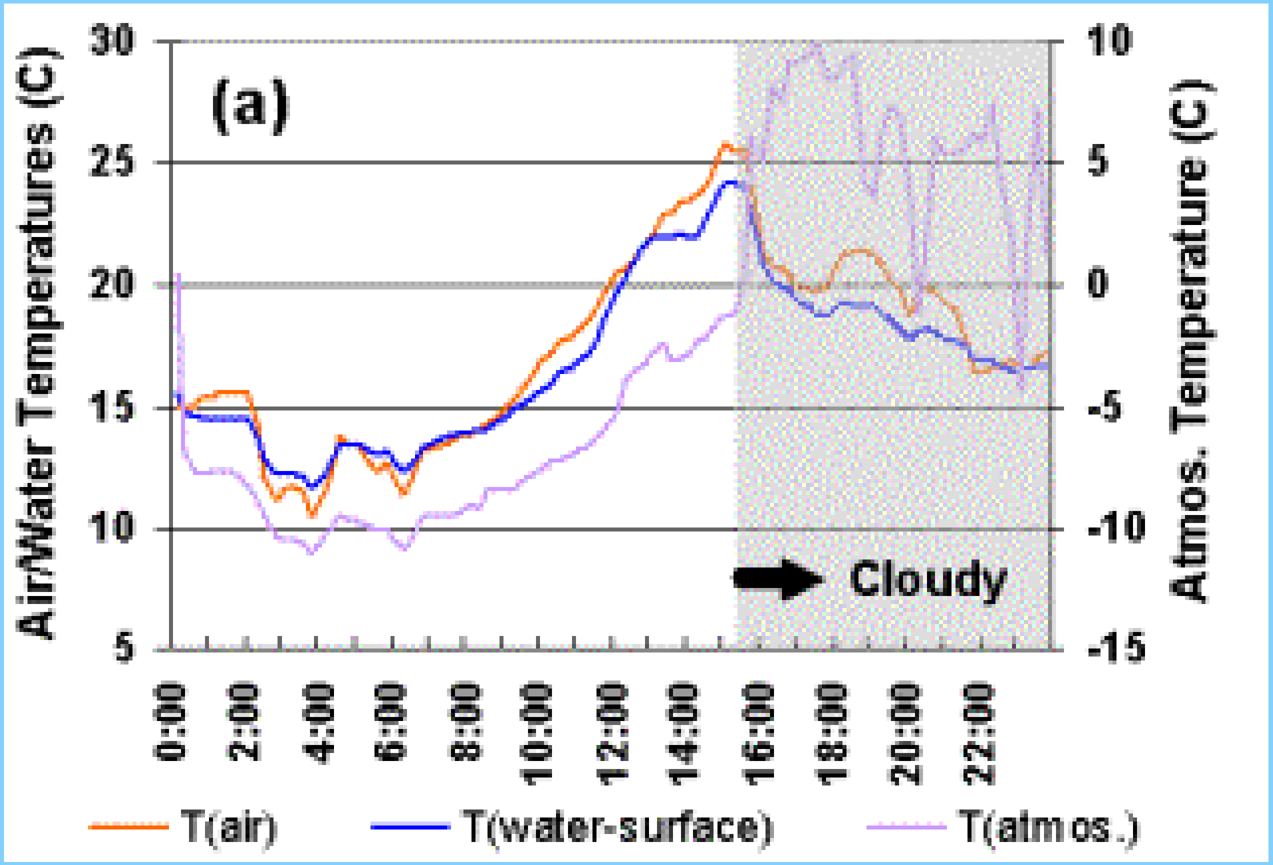
Typical temperatures in aerodynamic equations



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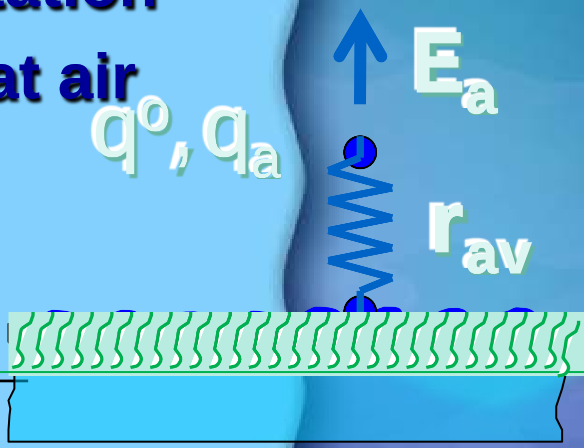
Translation of Instantaneous Evaporation to the day:

- **Using the "E_a" expression of Penman(1948) derived from weather station data, only:**

$$E_a = 3{,}600{,}000\ \rho_a\ \frac{\left(q^o(T_a) - q_a\right)}{\rho_w\, r_{av}}$$

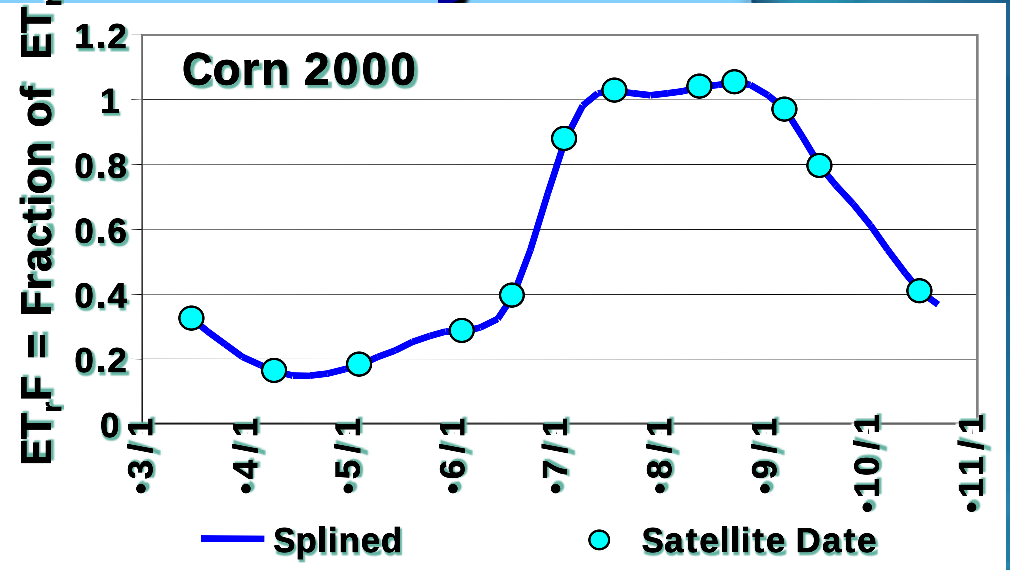
  - T_a is air temperature at weather station
  - q^o is saturated specific humidity at air temperature
  - q_a is specific humidity of air:

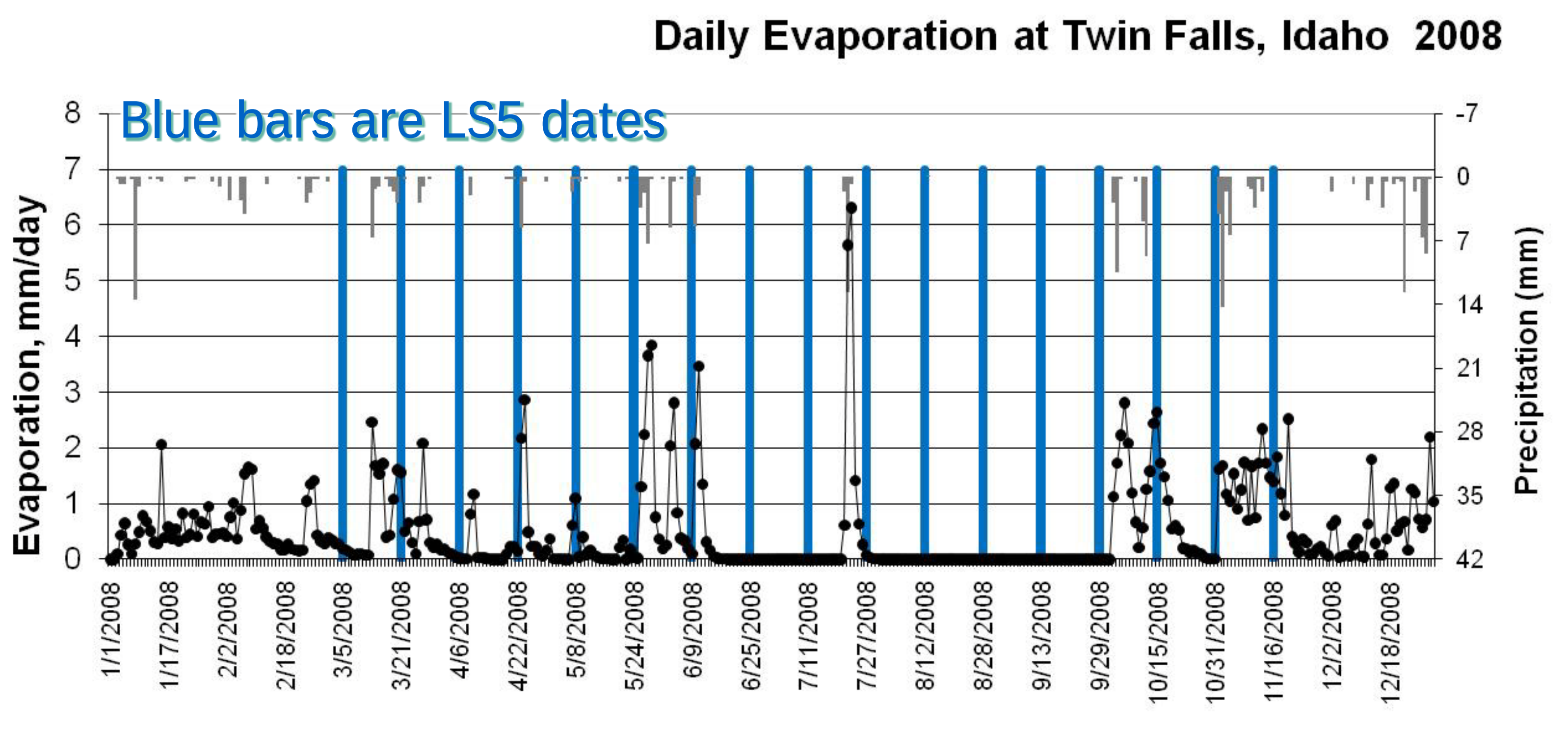


$$E_{24\ for\ each\ pixel} = E_{at\ satellite\ time\ for\ each\ pixel}\ \frac{E_{a24}}{E_{a\ at\ satellite\ time}}$$

Adjusting for Background Soil Evaporation when Interpolating Evapotranspiration between Satellite Overpass Dates

Interpolation for Monthly or Seasonal ET

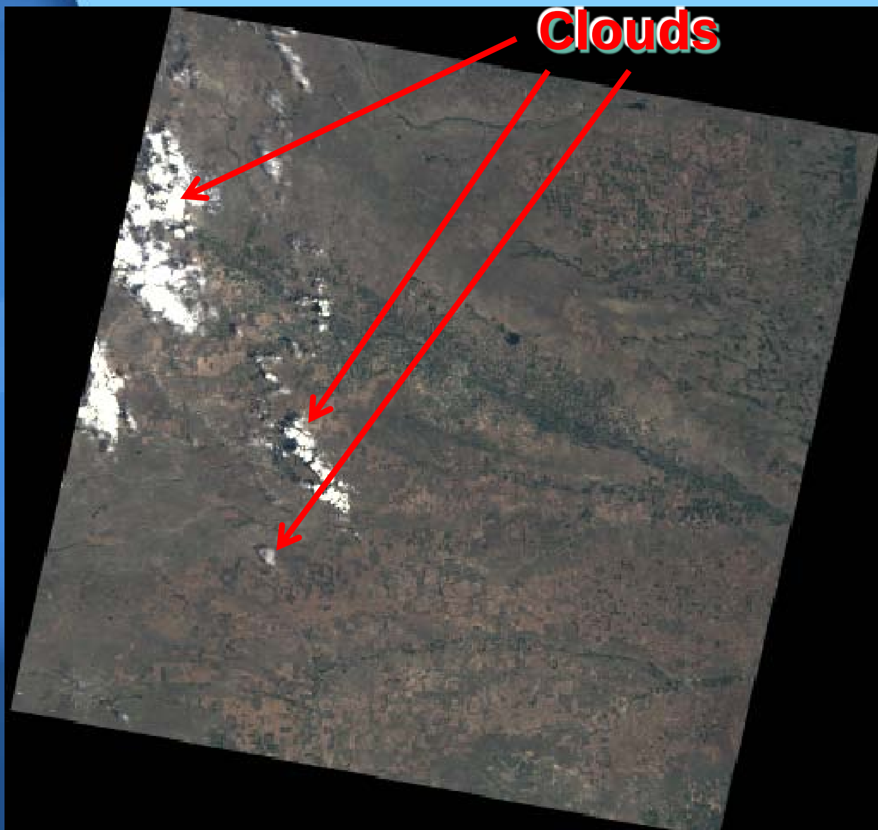




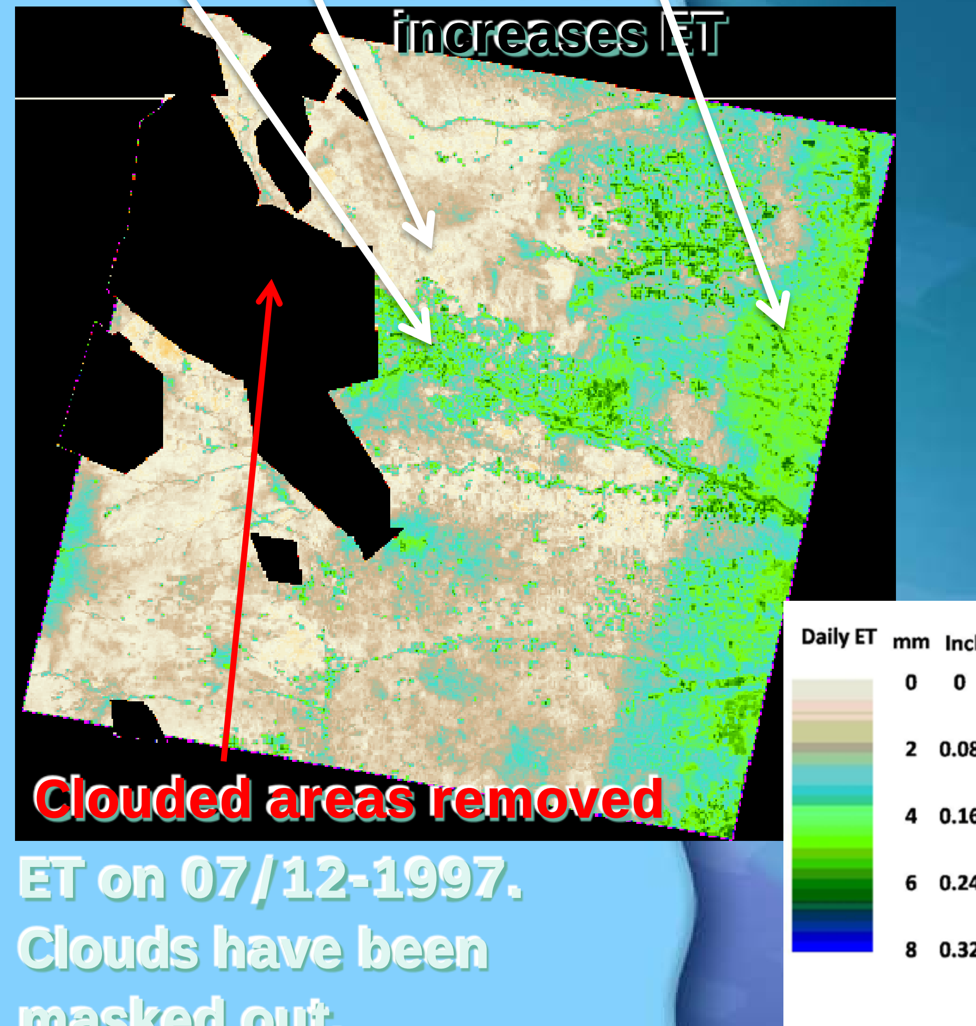
Cloud Mitigation

ET can not be estimated for areas covered by clouds.

Areas with cloud cover must be 'masked' out



Landsat image 07/12-1997



ET on 07/12-1997. Clouds have been masked out.

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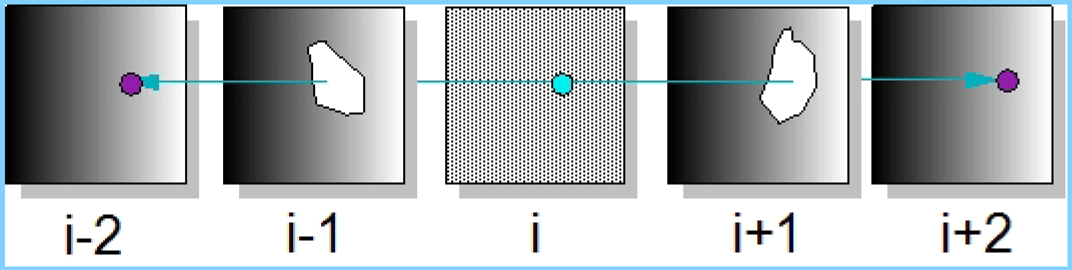
Procedure for cloud gap filling



‘i’ is the image to be cloud filled,

‘i-2’ and ‘i-1’ are two images earlier than image i

‘i+1’ and ‘i+2’ are two images later than image i

In this example, information of the gap filling is ‘borrowed’ from image ‘i-2’ and ‘i+2’

ETrF vs NDVI relation is developed for each image

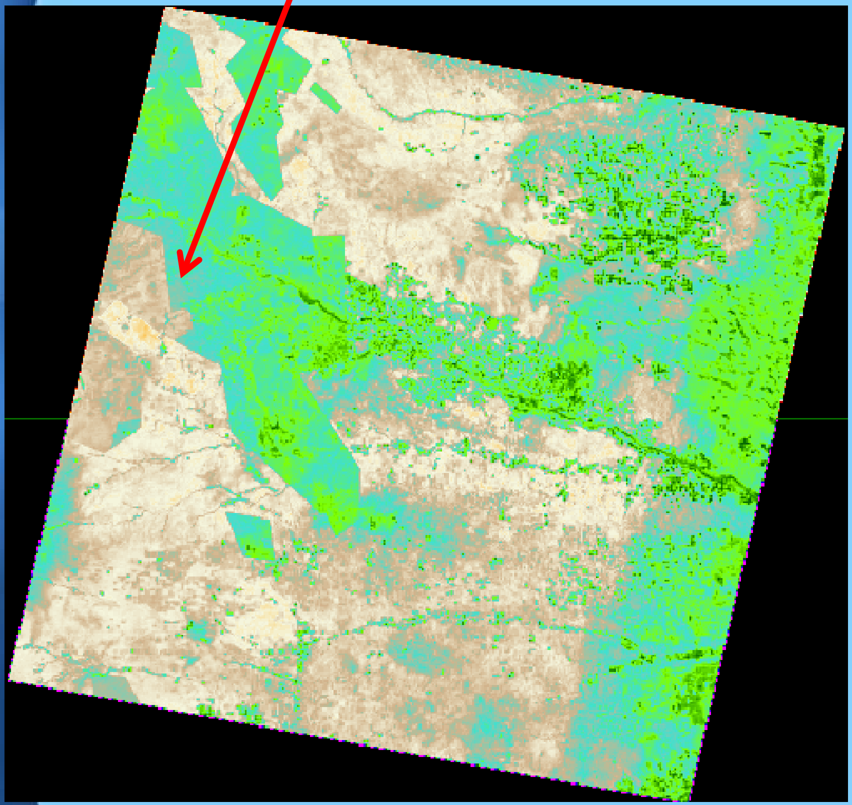
--Provides general adjustment for change in Vegetation over time (ETrF is ‘relative’ ET)

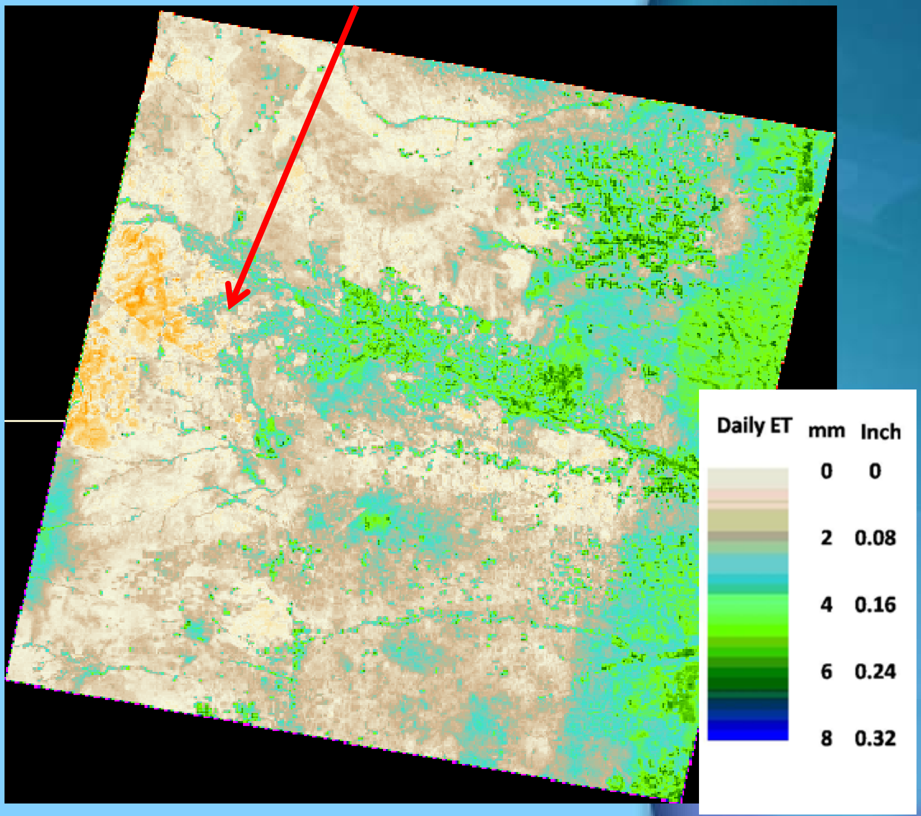
$$ET_rF_2 = \frac{\Delta t_2\left(ET_rF_1 + a_2 - a_1 + [b_2 - b_1]NDVI_1\right) + \Delta t_1\left(ET_rF_3 + a_2 - a_3 + [b_2 - b_3]NDVI_3\right)}{\Delta t_1 + \Delta t_2}$$

Step 2: Adjusting for changes in Evaporation due to Rainfall

Filled areas are too high for bare soil

Better matching





Filled with no adj. Filled with adj. for Evap.

07/12-1997

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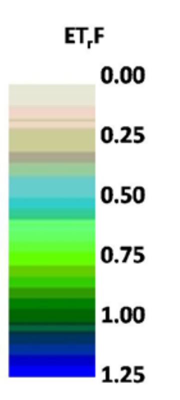
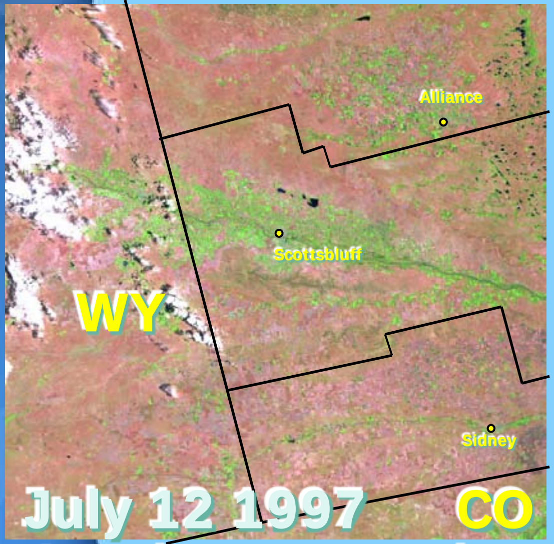
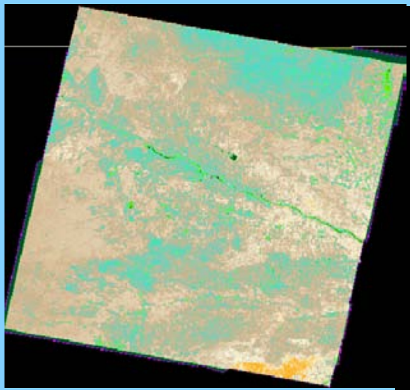
ET_rF during the growing season showing impacts of wetting events



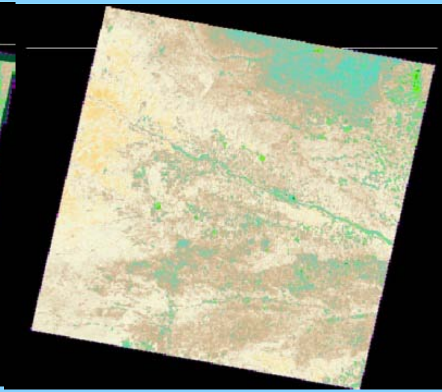


Landsat true color

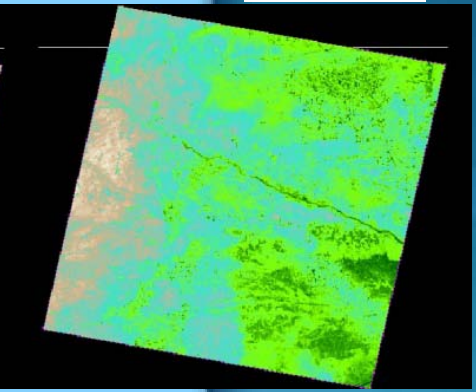
1997 image date ETrF estimates



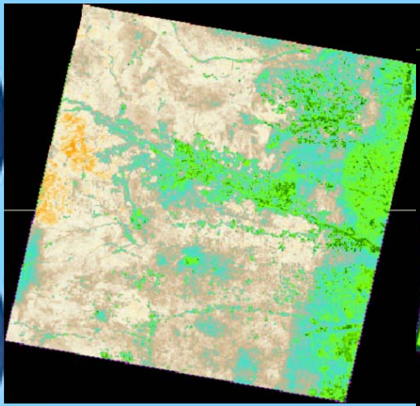
April 23



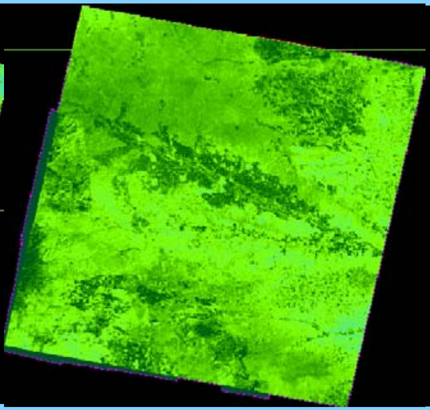
May 9



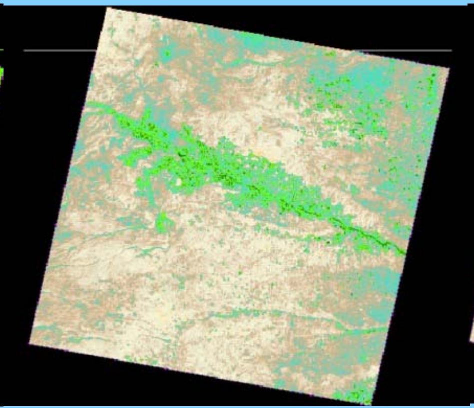
June 26



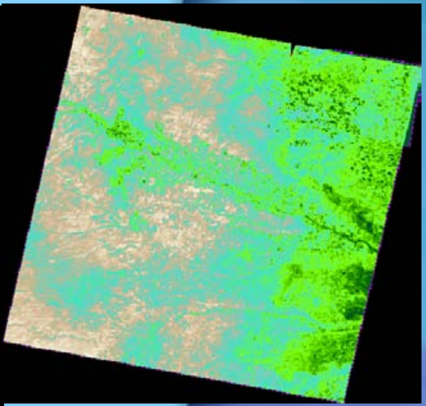
July 12



August 13



September 30



October 16

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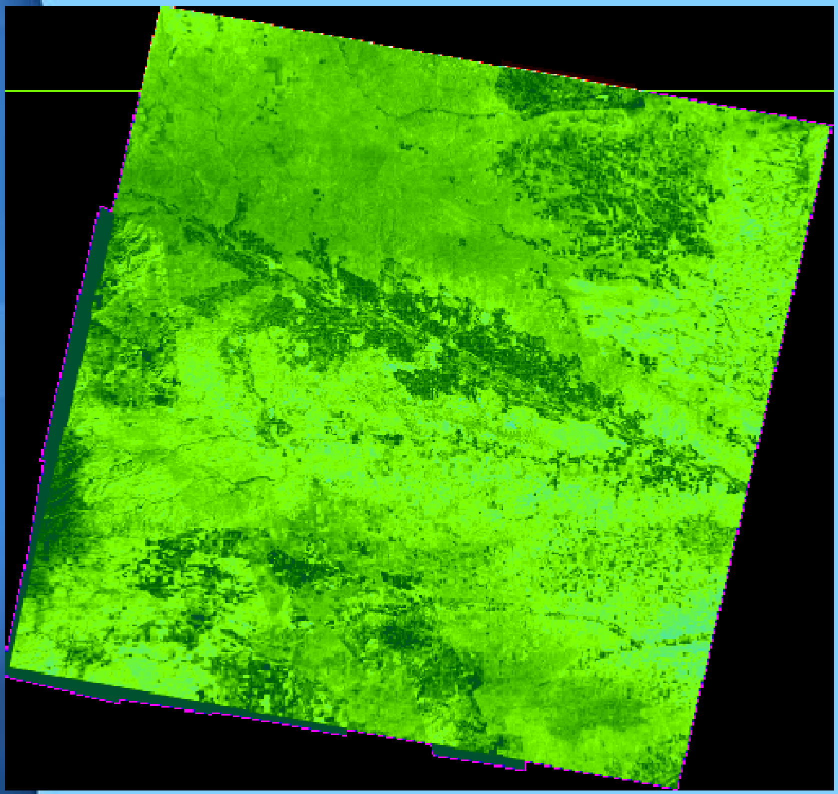
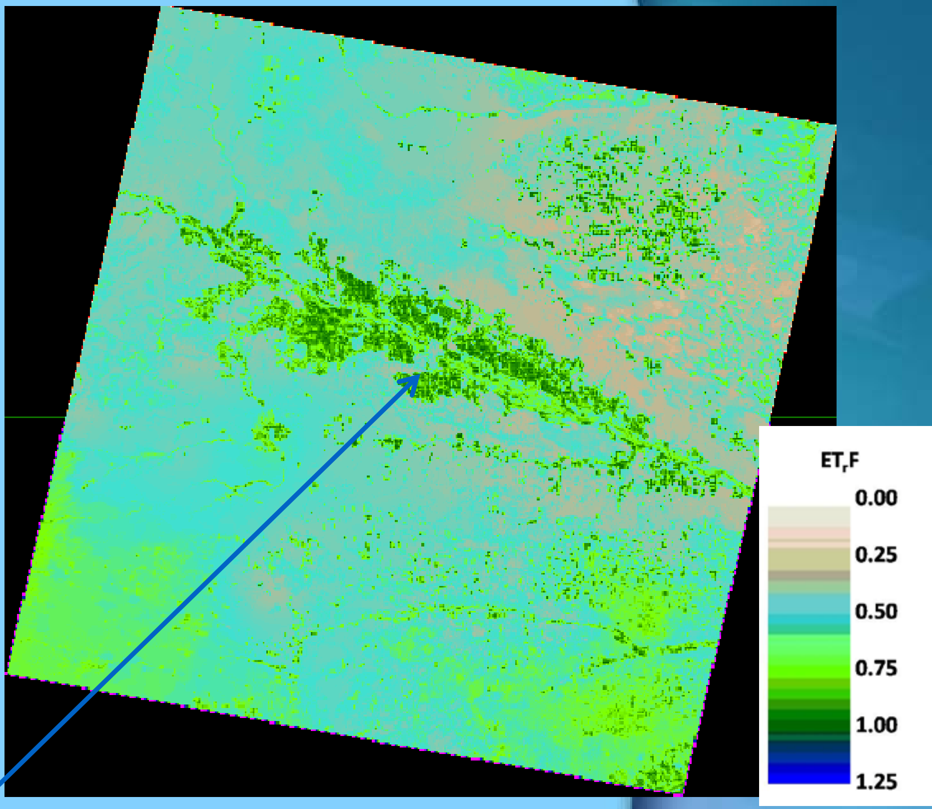
Adjusting for background evaporation from day of image to monthly period *(using a gridded daily evaporation process model)*



ET from August 13 1997 before adjustment



ET from August 13 1997 adjusted to represent August

Irrigated Agriculture

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Refining Components of the Surface Energy Balance for Forests and Steep Terrain

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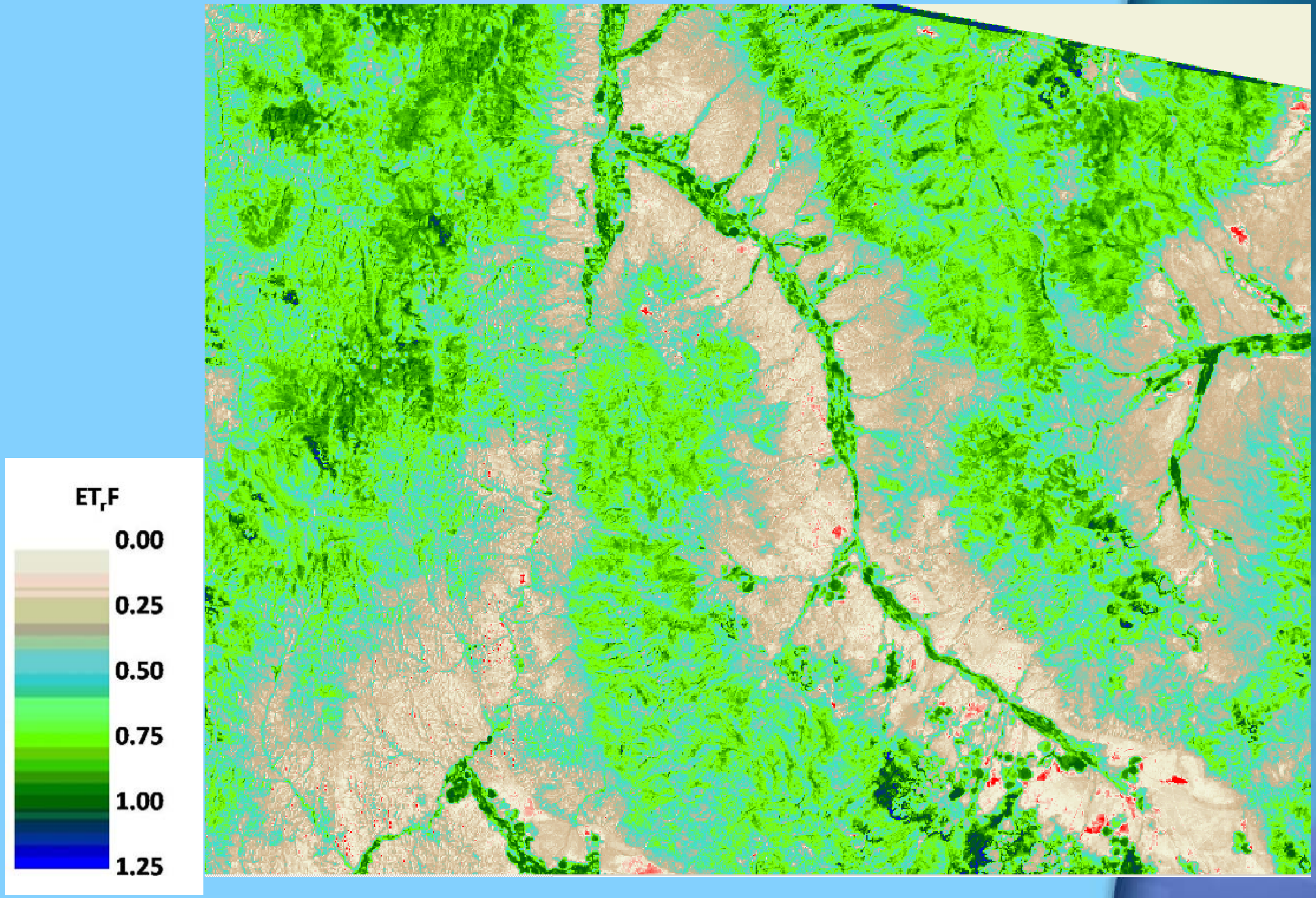
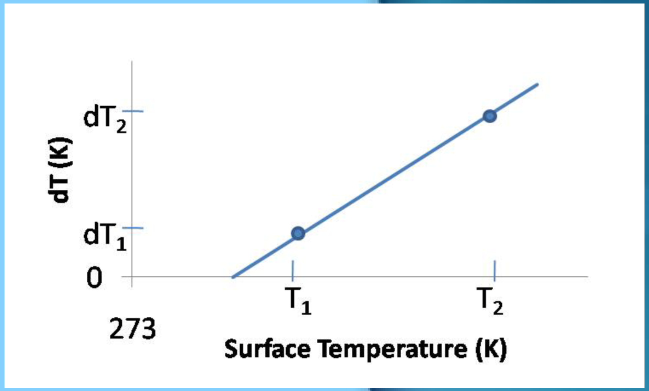
Salmon, Idaho area -- July 2006



Surface Temperature 'Delapsing' for spatial distribution of near surface air temperature gradient

- **Two lapse rates:**
  - A **customized** rate on flat ground (Lapse~6-10 K)
  - A **dry adiabatic** lapse rate in mountains (Lapse~10 K)



$$T_{s\_delapsed} = T_{s\_radiometric} + Lapse$$

Cross valley thermal emission

- North vs. South facing slopes can vary in LST by 10 – 20 K
- Causes thermal emission to vary by up to 150 W/m2 (30%)

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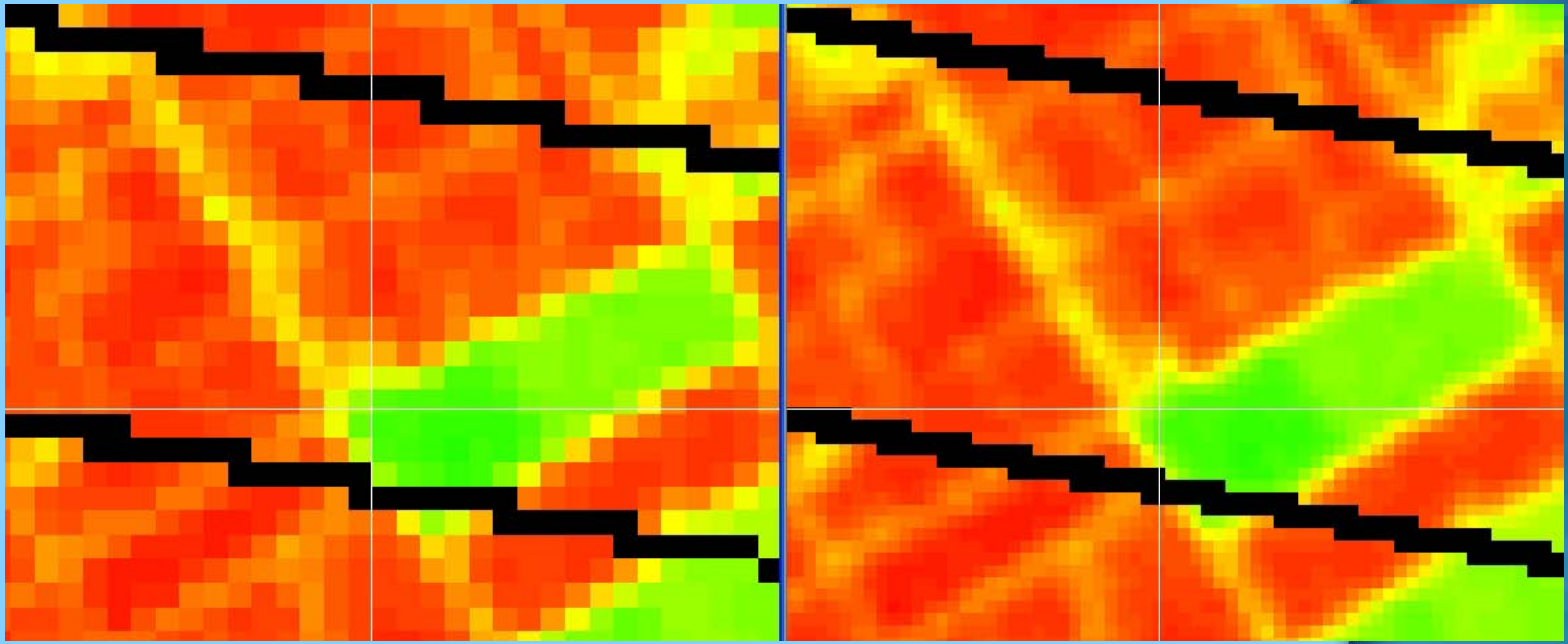
Analysis of Landsat thermal band prototype data resampled by USGS-EROS to 30 m

J. Kjaersgaard and R. Allen, University of Idaho. October 2009



- Close-up of Band 6 resampled to 60 m (left) and 30 m (right) by EROS as an L1T product for Pecan orchards in NM.
- DN=0 is black; DN 130-150 red through yellow; DN 150-170 yellow through green.

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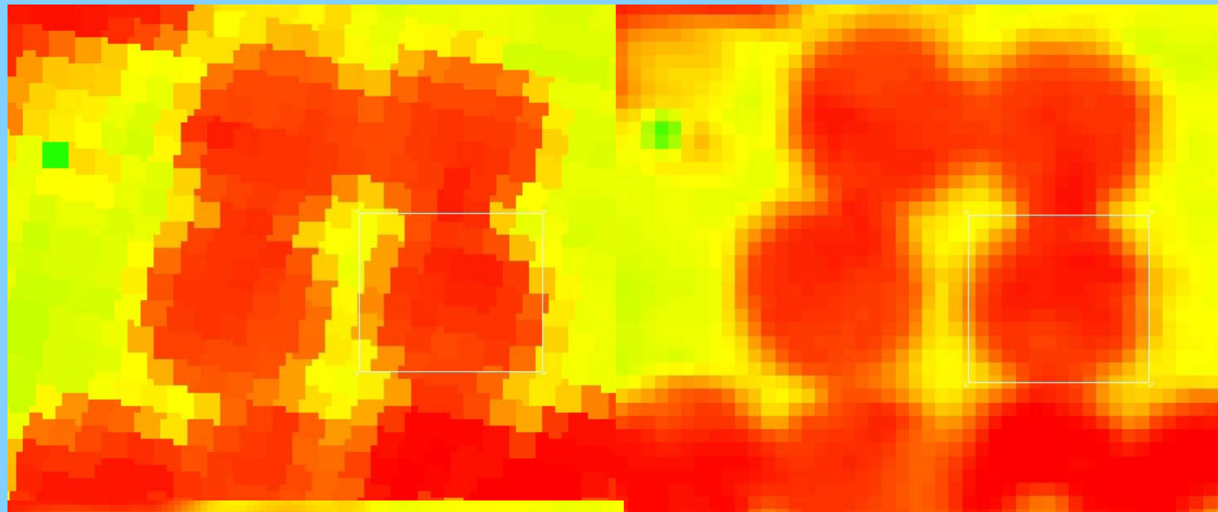
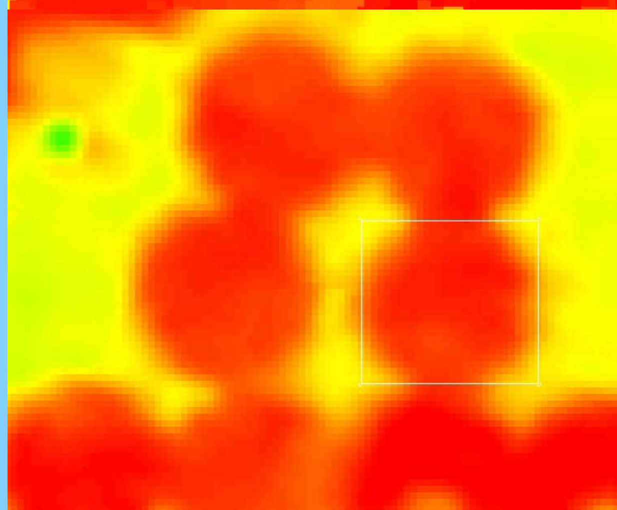
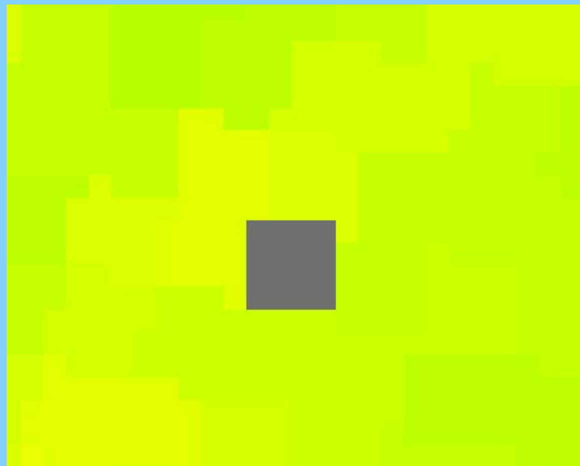


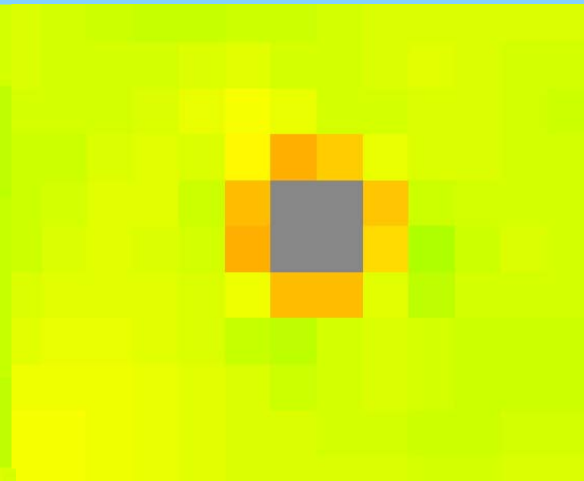


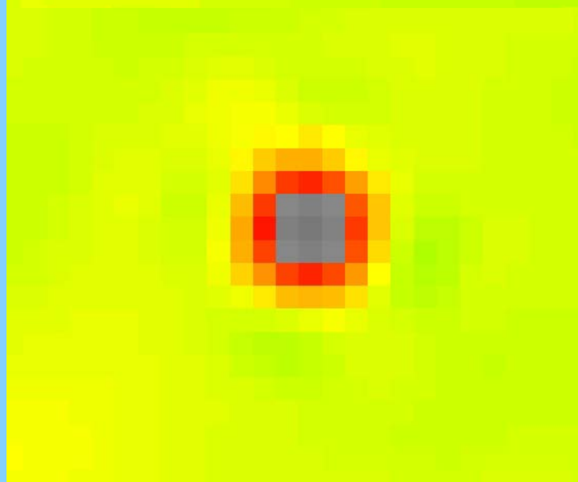
DN 130-165 is red through yellow; DN 165-200 is yellow through green.

Thermal band from LS5 from July 10 1996 resampled to 30 m using NN (upper left) via NLAPS and to 60 m (upper right) and 30 m (bottom left) using CC via LPGS.

(Center Pivots in Idaho)







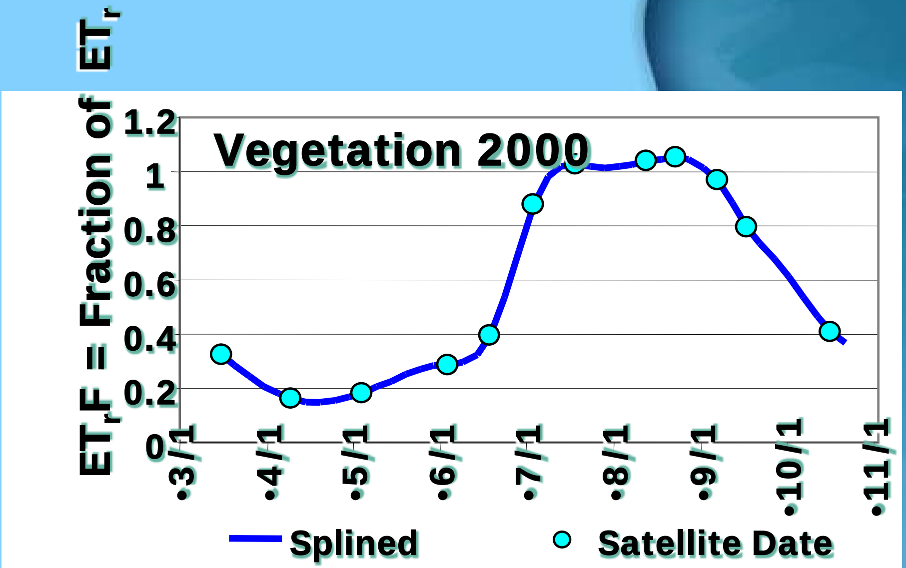
Single Rogue 120 m Thermal Pixel

DN 130-165 is red through yellow; DN 165-200 is yellow through green.

Thermal band from LS5 from July 10 1996 resampled to 30 m using NN (upper left) via NLAPS and to 60 m (upper right) and 30 m (bottom left) using CC via LPGS.

Impact of OverPass Return Frequency on Success of Producing Growing Season Evapotranspiration

- **Requirement for Seasonal ET:**
  - <u>0.8 clearness</u> tolerance each 32 day maximum time-between sighting of the ground
    - for specific areas of interest that comprise ~ 20% of a Landsat scene
    - ~ April – October growing season in Idaho



Example of building seasonal ET

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For a 16 day overpass (one satellite) *(> 0.8 clearness each 32 days)*

- For path 39 row 30 (eastern Idaho),
  - over the 26 year *Landsat 5* record, only ONE of 26 years (4%) qualified.
  - over the 10 year *Landsat 7* record, NONE of 10 years (0%) qualified.

- For path 40 row 30 (southcentral Idaho),
  - over the 26 year *Landsat 5* record, only two of 26 years (8%) qualified.
  - over the 10 year *Landsat 7* record, only one of 10 years (10%) qualified.

For an 8 day overpass (two satellites) *(> 0.8 clearness each 32 days)*

- **For path 39 row 30 (eastern Idaho),**
  - **over the 10 year record (2000-2009), <u>four of 10 years (40%) qualified</u>.**

- **For path 40 row 30 (southcentral Idaho),**
  - **over the 10 year record (2000-2009), <u>five of 10 years (50%) qualified</u>.**

- **Conclusion: Halving the return time (16 → 8 days) increased probability of successful years by 5x to 9x**

A four day overpass return is expected to increase the probability of successful growing season ET for any year to 80% (vs. 40 – 50% for 8 day return and vs. ~5% for 16 day return)

(> 0.8 clearness criterion per image on a 32 day maximum interval in southern Idaho (a relatively low cloud region))

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For a 16 day overpass (one satellite) *(> 0.7 clearness each 48 days)*

- **For path 39 row 30 (eastern Idaho),**
  - **over the 26 year *Landsat 5* record, <u>ten of 26 years (38%) qualified</u>.**
  - **over the 10 year *Landsat 7* record, <u>five of 10 years (50%) qualified.</u>**
- **For path 40 row 30 (southcentral Idaho),**
  - **over the 26 year *Landsat 5* record, <u>ten of 26 years (38%) qualified.</u>**
  - **over the 10 year *Landsat 7* record, <u>only three of 10 years (30%) qualified.</u>**

Note that 0.7 clearness each 48 days is less than satisfactory

For an 8 day overpass (two satellites) *(> 0.7 clearness each 48 days)*

- **For path 39 row 30 (eastern Idaho),**
  - **over the 10 year record (2000-2009), <u>nine of 10 years (90%) qualified</u>.**
- **For path 40 row 30 (southcentral Idaho),**
  - **over the 10 year record (2000-2009), <u>nine of 10 years (90%) qualified</u>.**
- **Conclusion: Halving the return time (16 → 8 days) increased probability of successful years 3x, but 0.7 clearness each 48 days is not satisfactory**

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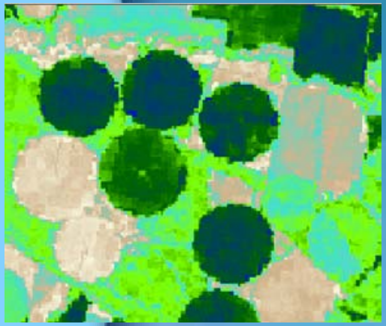
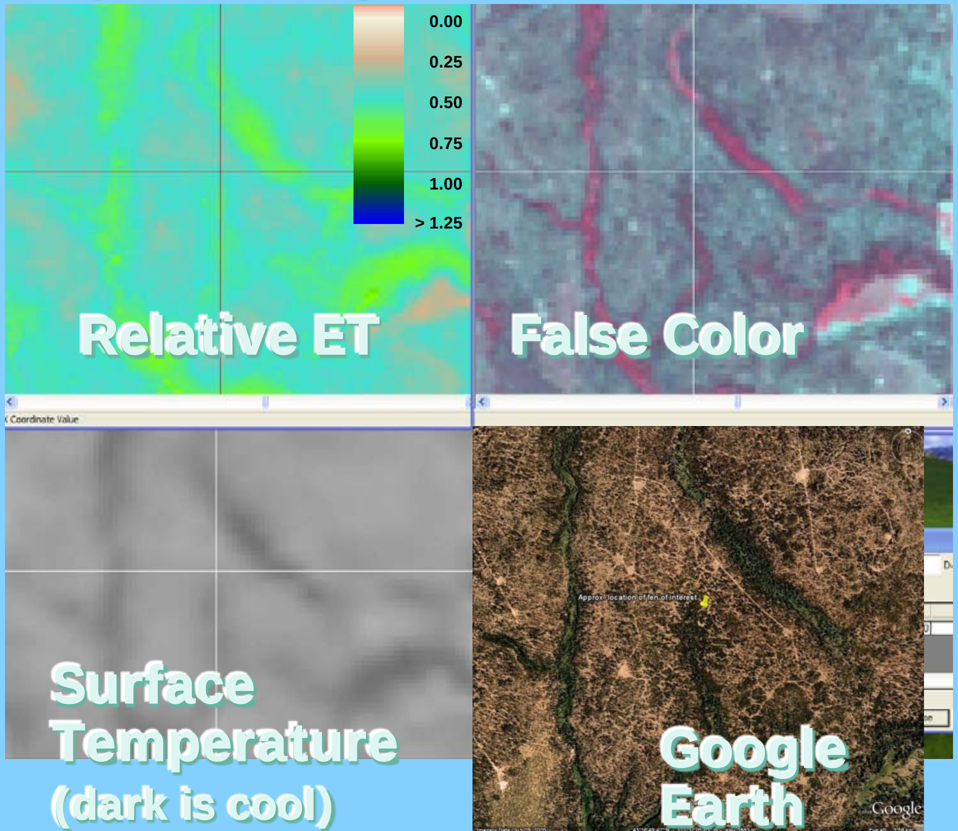
METRIC Applications in Western Water Management

- **Idaho**
  - currently processing 1996, 2008 (UI) and 1986 (IDWR) from archive for historical trends in ET *(field level)*
- **New Mexico**
  - Water consumption by invasive vegetation along the Rio Grande (UI) *(narrow systems require high res. LST)*
- **Colorado**
  - Conjunctive management of ground-water and surface water by State Engineer along the South Platte (Riverside Technology-UI *(NASA-ROSES)*
  - Assessment of water shortage and salinity impacts along the Arkansas River (an independent application by CSU)



METRIC Applications in Western Water Management

- **Oregon**
  - **"Fen" areas north of Klamath Basin where Stock Water Supplies for Grazing compete with local Ecosystems supplied by Springs *(US Forest Service)***
  - ***Very narrow systems require hi-res. thermal***



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METRIC Applications in Western Water Management

- **Nebraska**
  - Ground-water management and mitigation in the Ogallala Aquifer in western Nebraska (UI-UNL)
  - Testing against measured ET in central NE (w/SEBAL) (UNL)
- **Washington**
  - METRIC used as 'truth' for calibrating larger scale energy balance models to assess climate change (Climate Impacts Group-UW)
- **Federal**
  - improve performance of the US Bureau of Reclamation RiverWare and AWARDS programs for operating large river systems (UI)
  - Calibrate a more simple large scale EB model (USGS).

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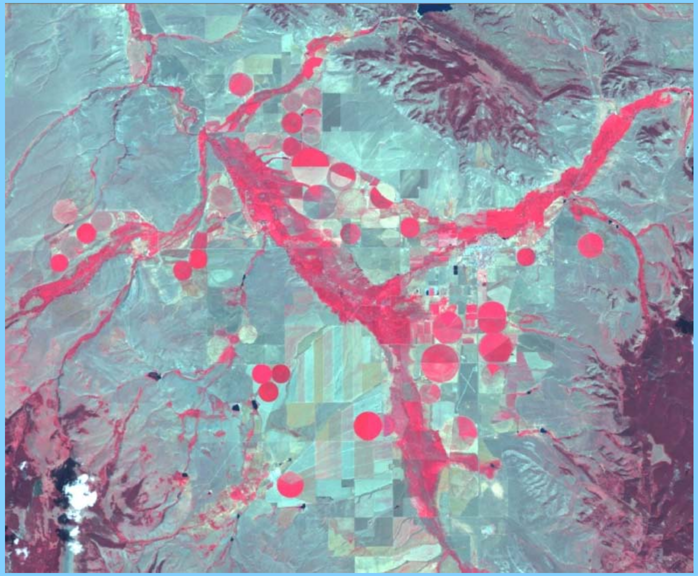
METRIC Applications in Western Water Management

- **Montana**
  - **Ground-water Recharge estimation in four different basins in a single path!**
  - **Customer: USGS and Montana Bureau of Mining and Geology**
  - **Recharge ≈ Precipitation – Evapotranspiration**
  - ***High resolution is needed due to narrow domains of irrigation***



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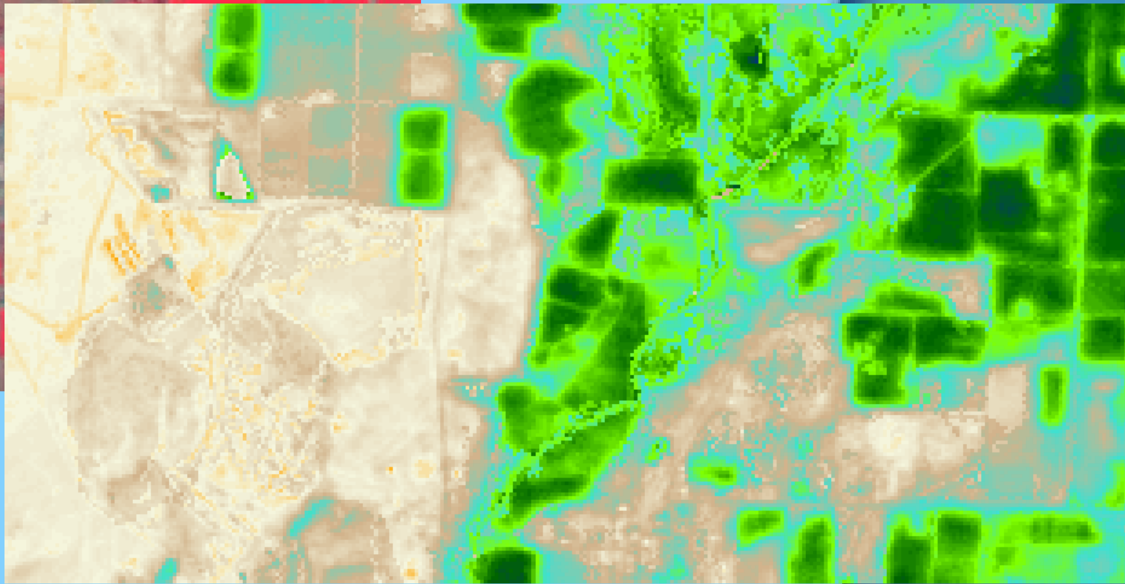
METRIC Applications in Western Water Management

- **Nevada – partnership with DRI**
  - **Water transfers from Irrigated Ag. to Reno/LV**
  - **Water transfers from phreatophytes and playa to Las Vegas**
  - ***Need High Resolution thermal for narrow irrigation corridors and sometimes narrow phreatophytic systems***



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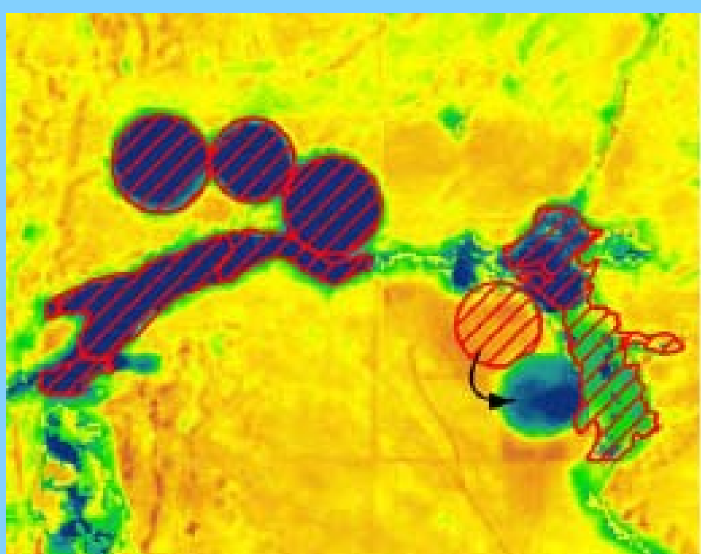
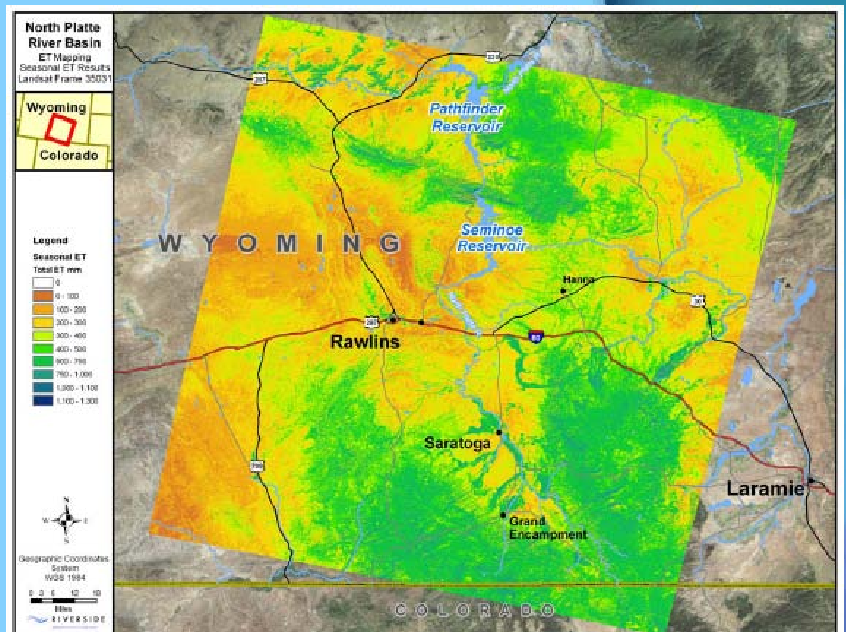
METRIC Applications in Western Water Management

- **North Platte Water Decree**
  - Nebraska / Wyoming / Colorado settlement in 2001
  - States proportion ET among themselves
  - High resolution monitoring is needed due to narrow irrigation corridors along streams





University of Idaho

METRIC Applications in Western Water Management

- State "X" vs. State "Y"
  - US Supreme Court case in preparation
  - Upstream vs. downstream water rights vs. Depletion by each state
  - High resolution ET needed to aggregate water use across irrigated fields surrounded by desert