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

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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
- Anomolies 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

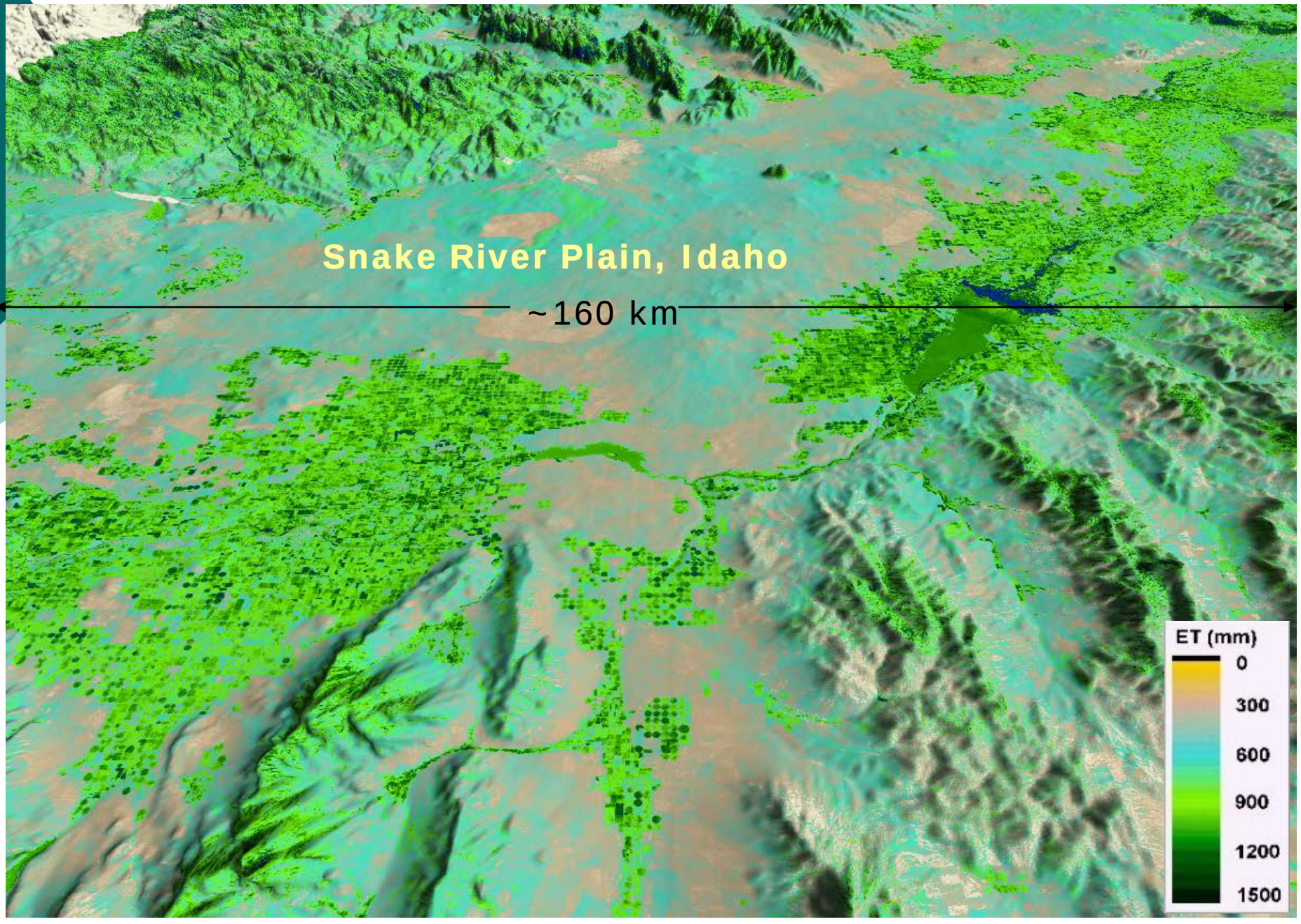
- Gapfilling LS7 SLC-off with natural neighbor
- Statistics Landsat Science Team to support 4-day return time
- Ash Institute Award
- METRIC training courses
- METRIC used in
  - 11 states for water transfers, endangered species management, hydrologic studies
  - two court hearings/decisions
  - eight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

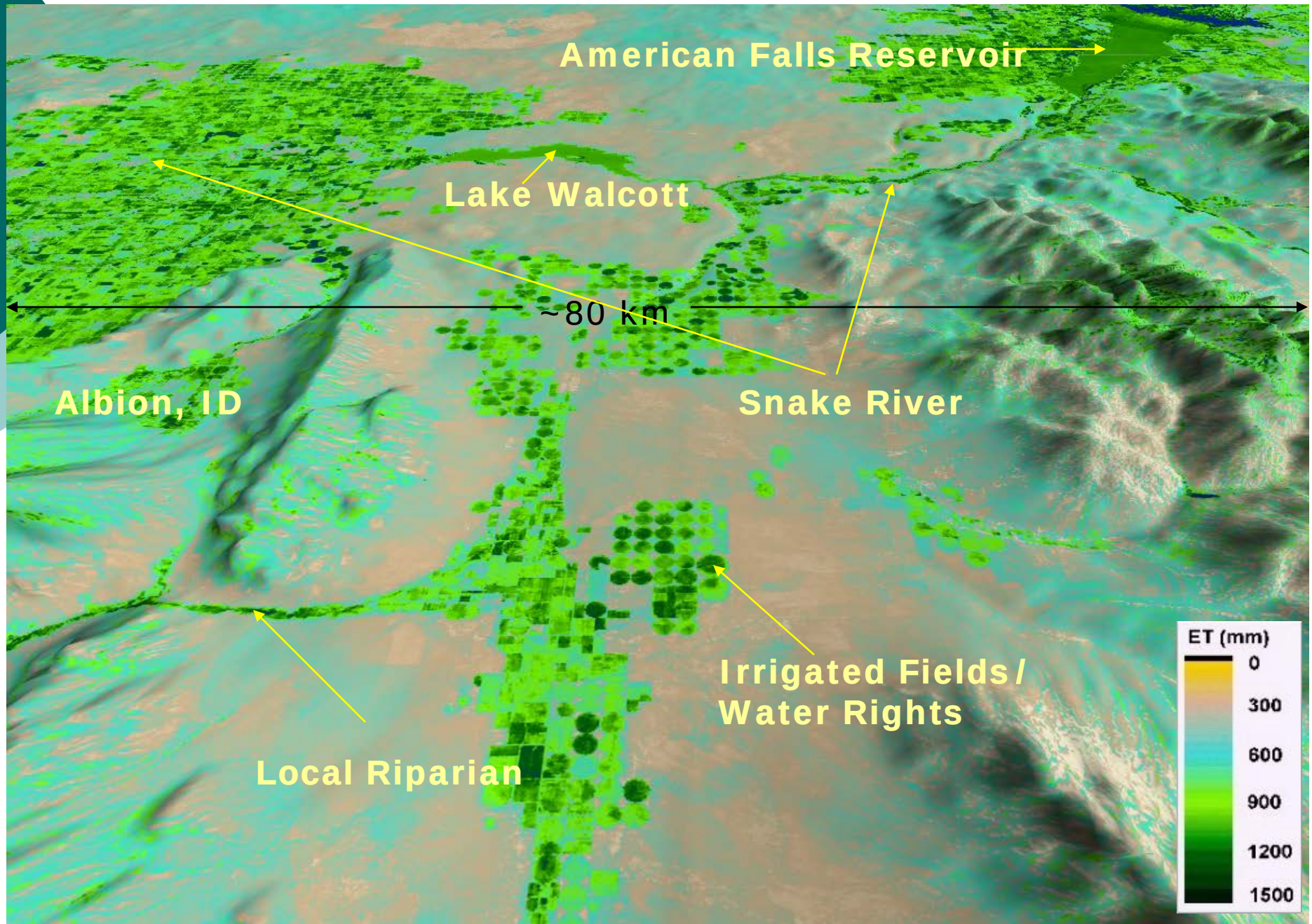
ET at 30 m resolution

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



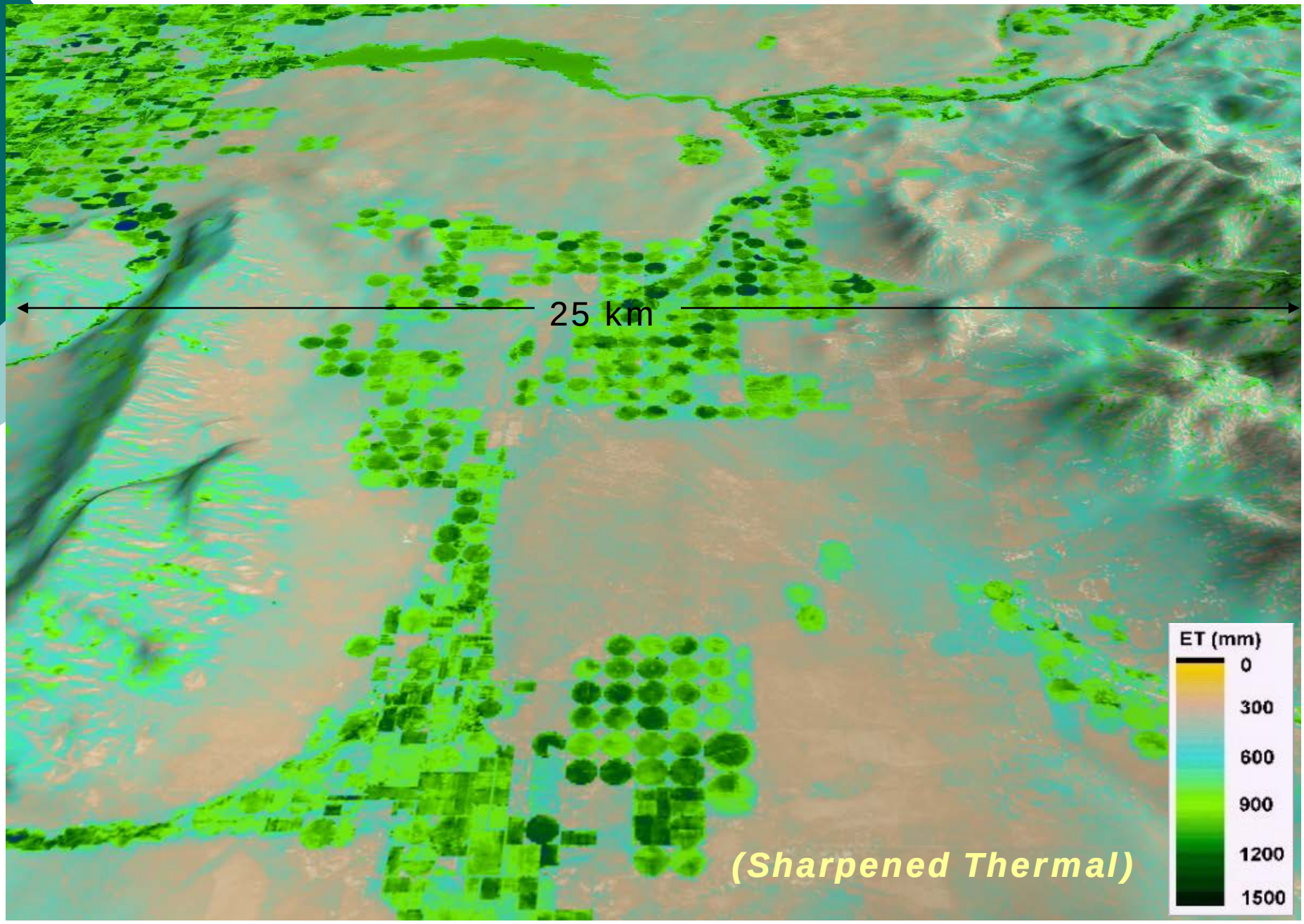
ET at 30 m resolution

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



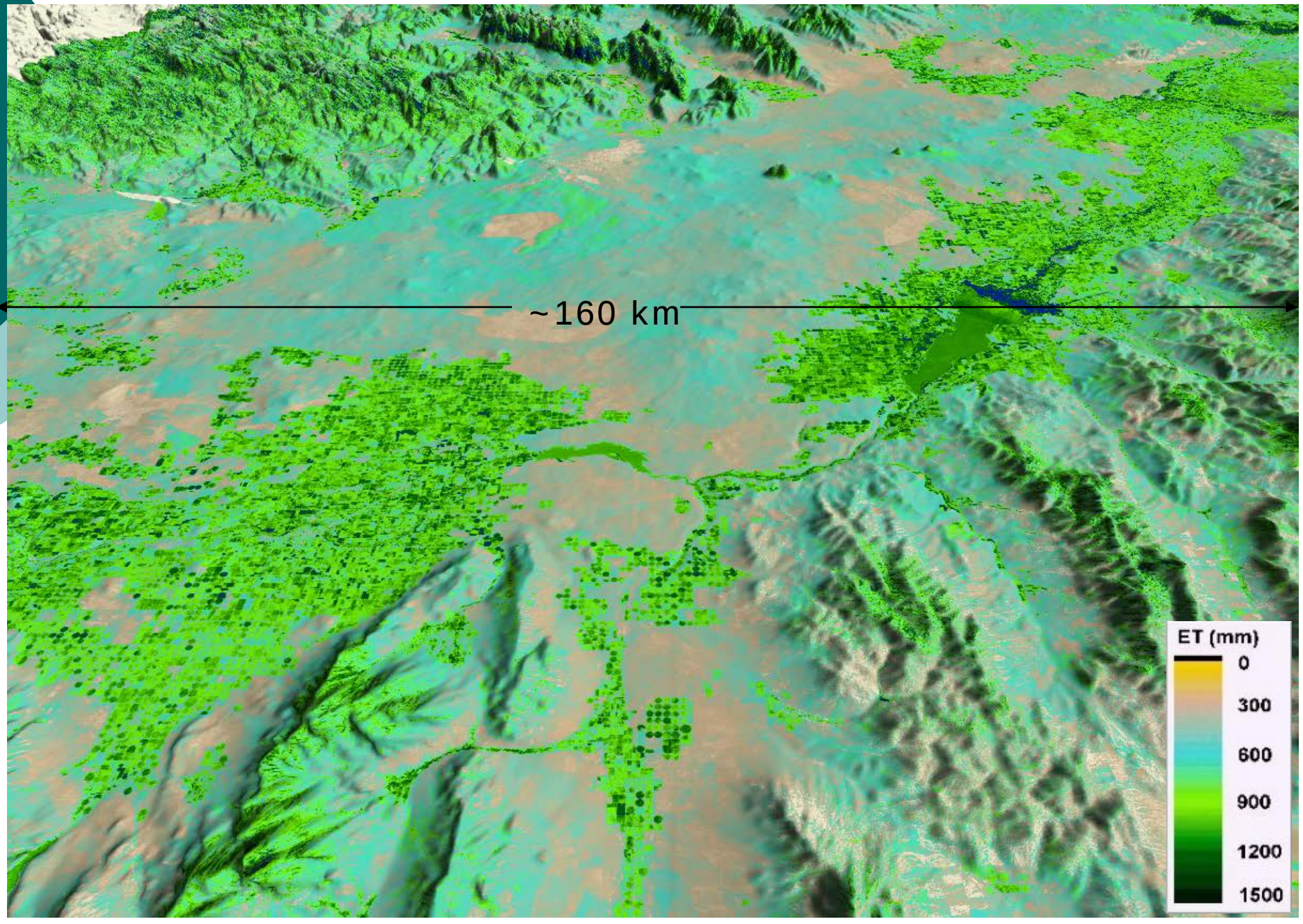
ET at 30 m resolution

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



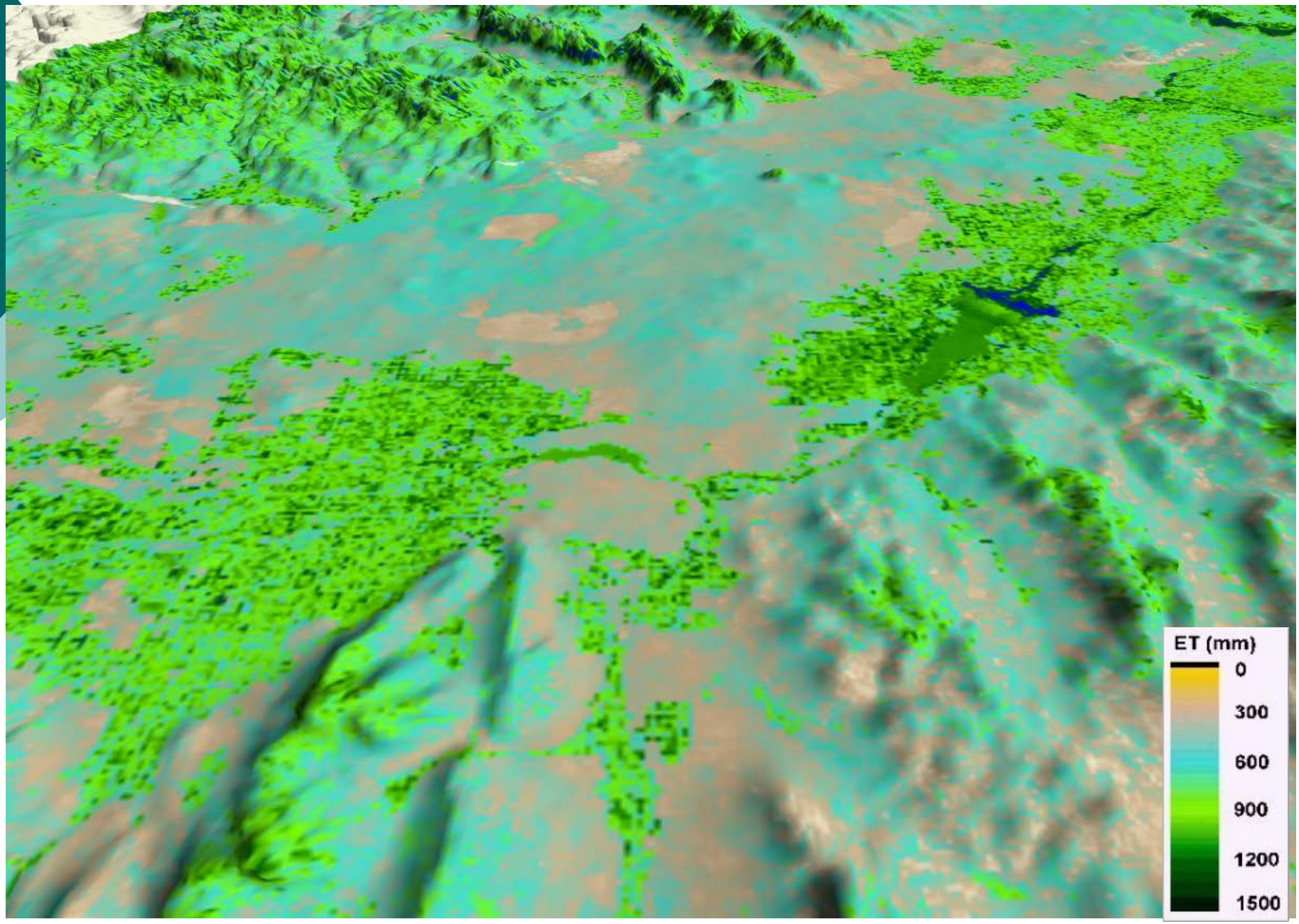
ET at 30 m resolution

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



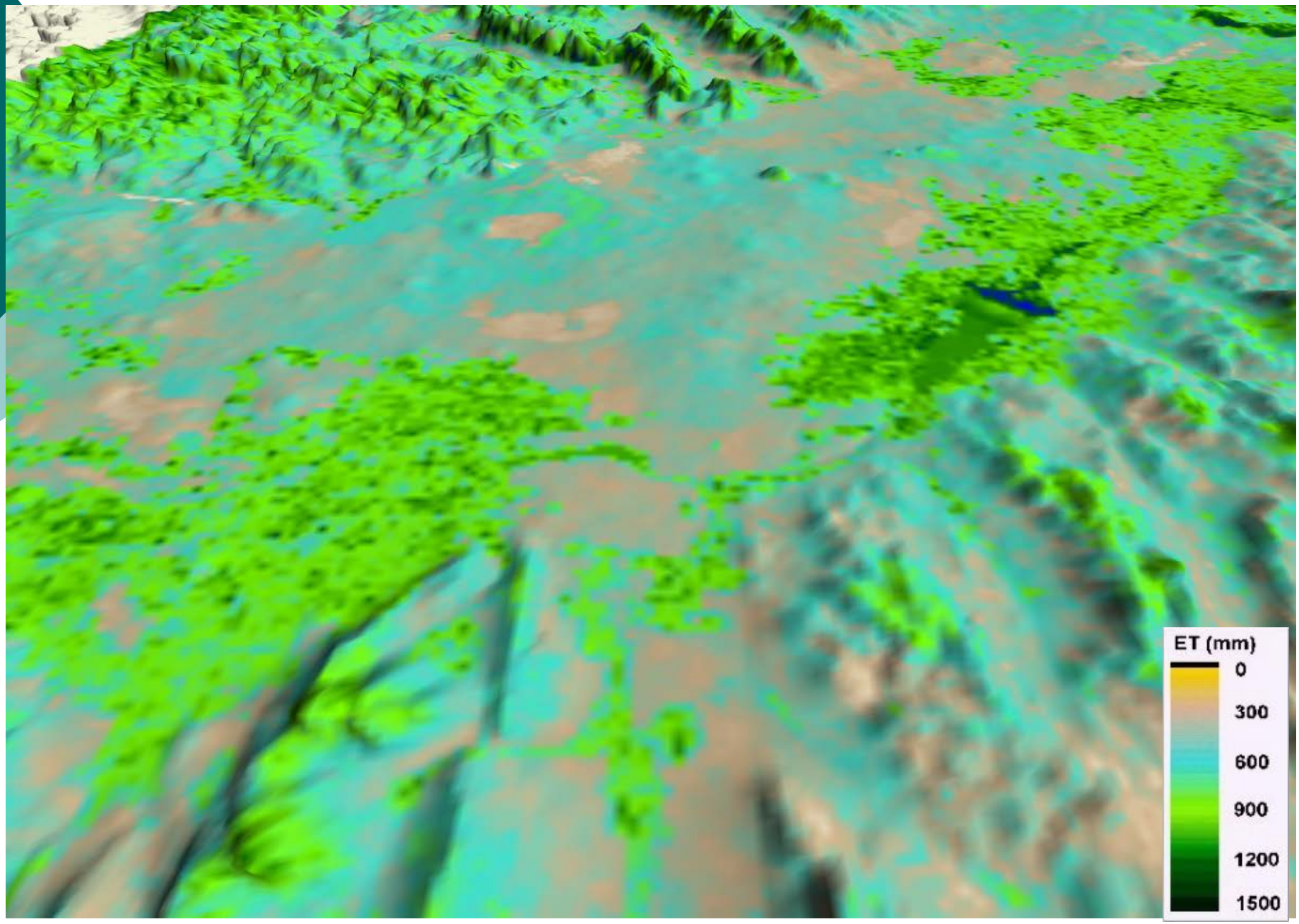
ET/DEM at 250 m resolution

April – October, 2006 ET from METRIC-Landsat



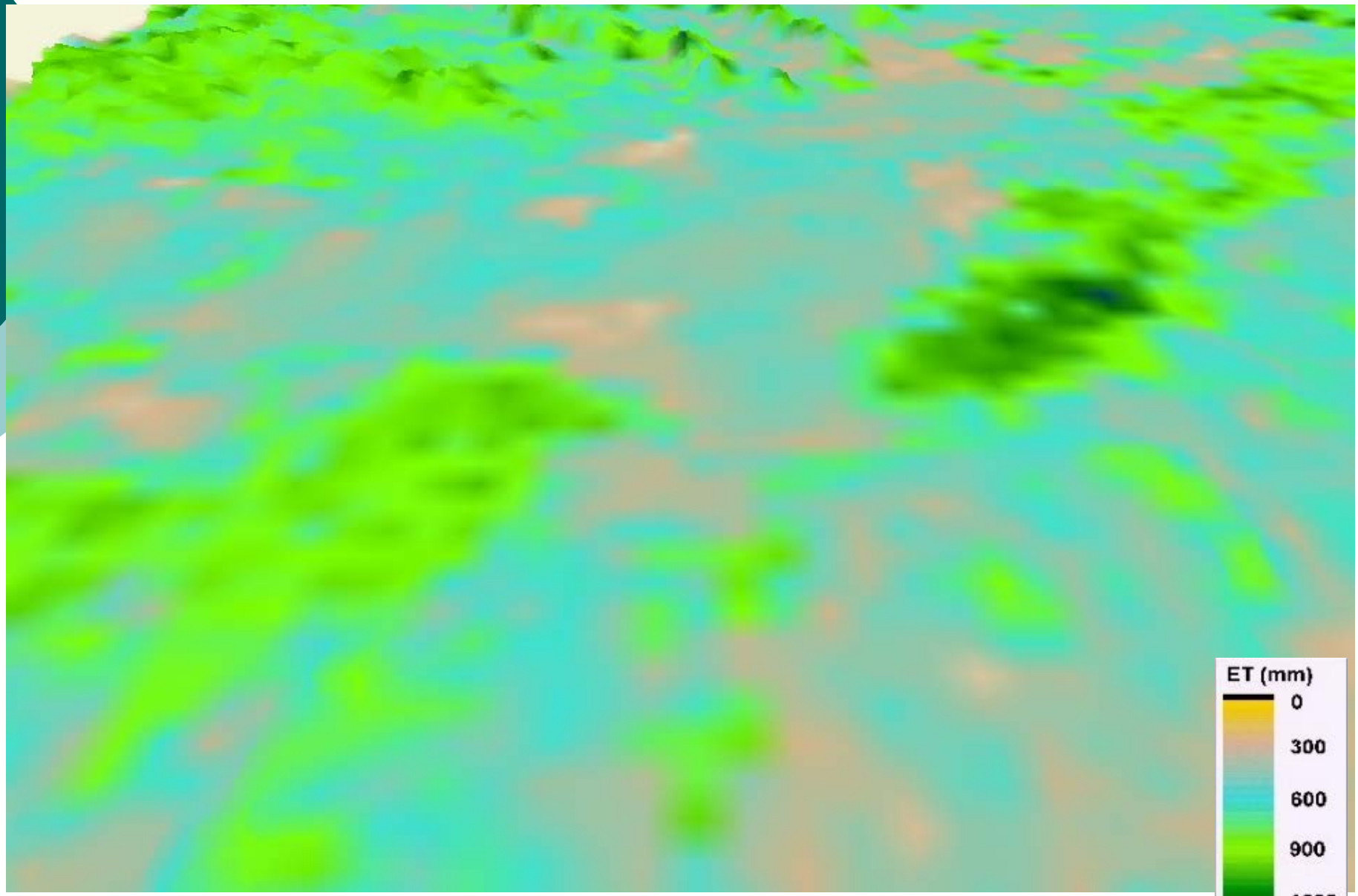
ET/DEM at 1 km resolution

April – October, 2006 ET from METRIC-Landsat



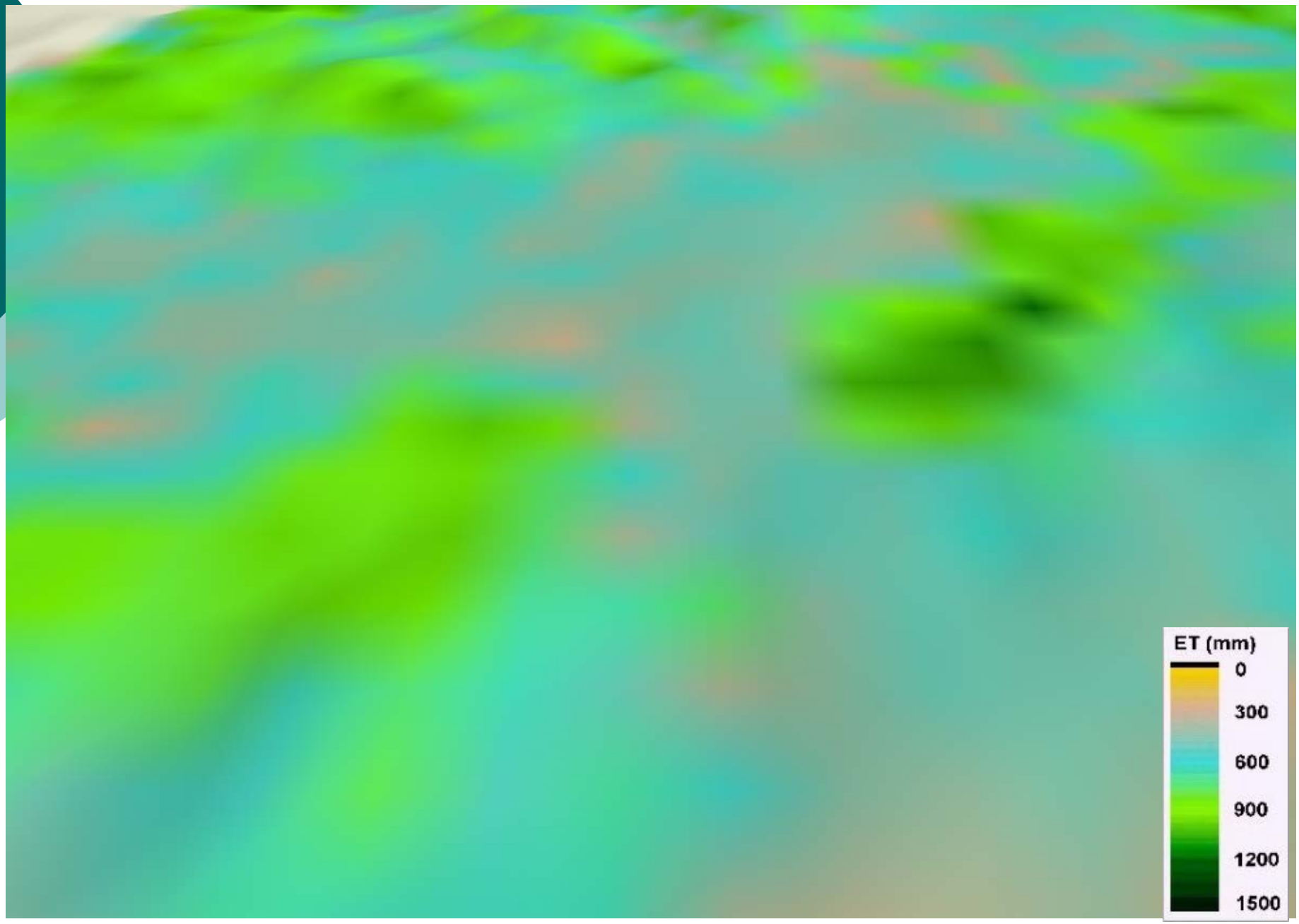
ET/DEM at 4 km resolution

April – October, 2006 ET from METRIC-Landsat



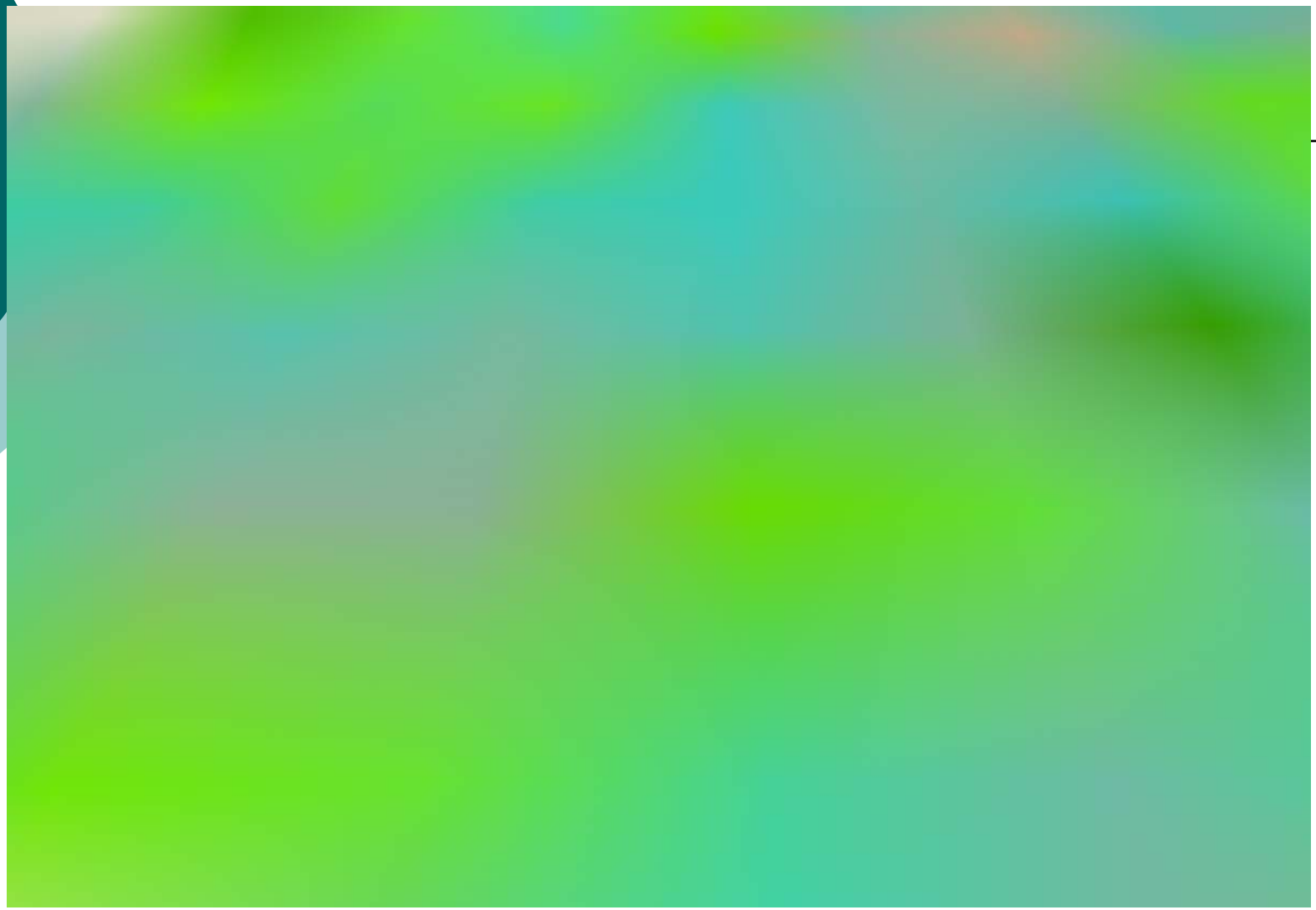
ET/DEM at 10 km resolution

April – October, 2006 ET from METRIC-Landsat



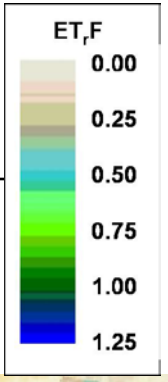
ET/DEM at 32 km resolution

April – October, 2006 ET from METRIC-Landsat

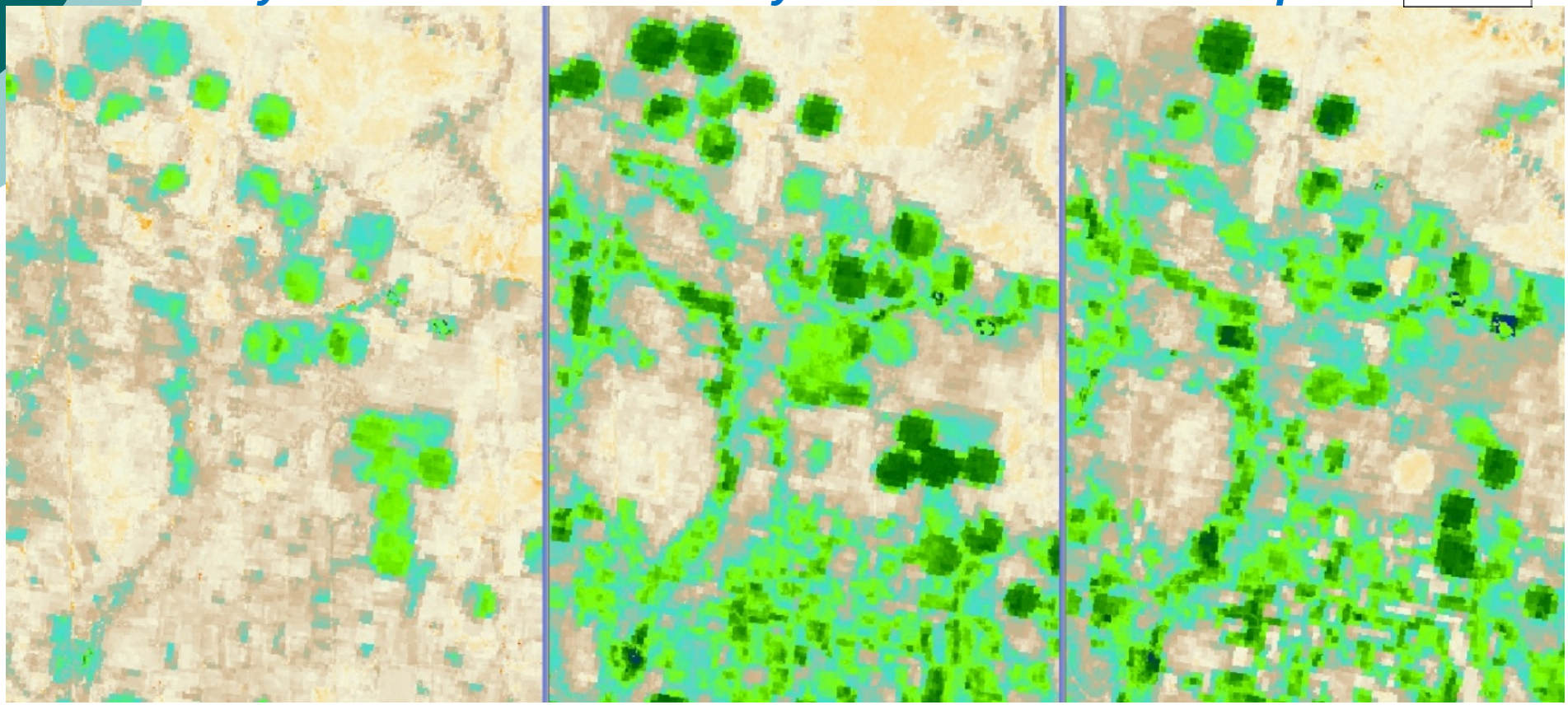


Near Scottsbluff, Nebraska, 1997, Landsat 5

Progression of ET in time At Moderate (-ly high) Resolution

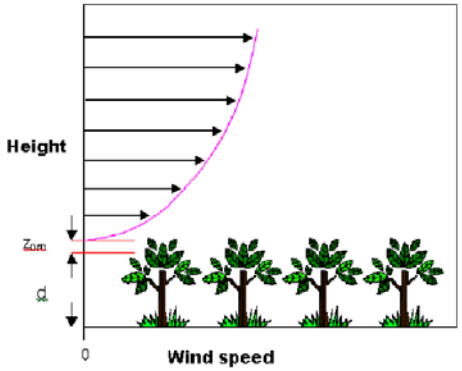


May ***July*** ***Sept.***



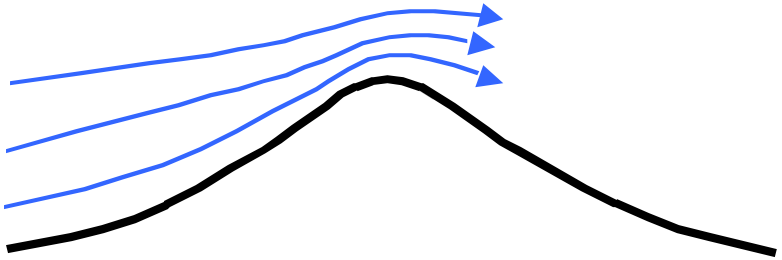
Improving Mountain Aerodynamics

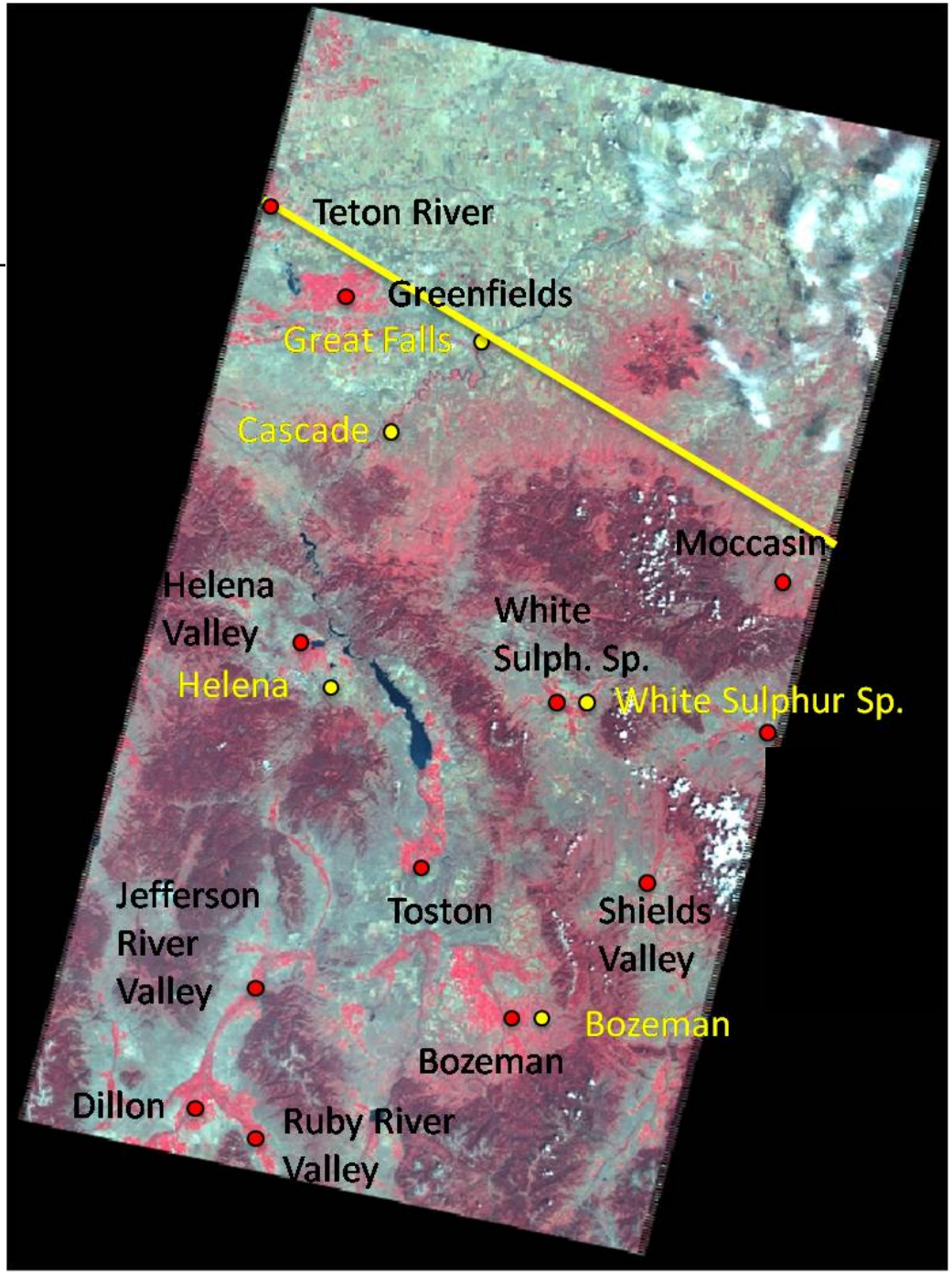
Increasing z_{om} for Terrain Roughness



+

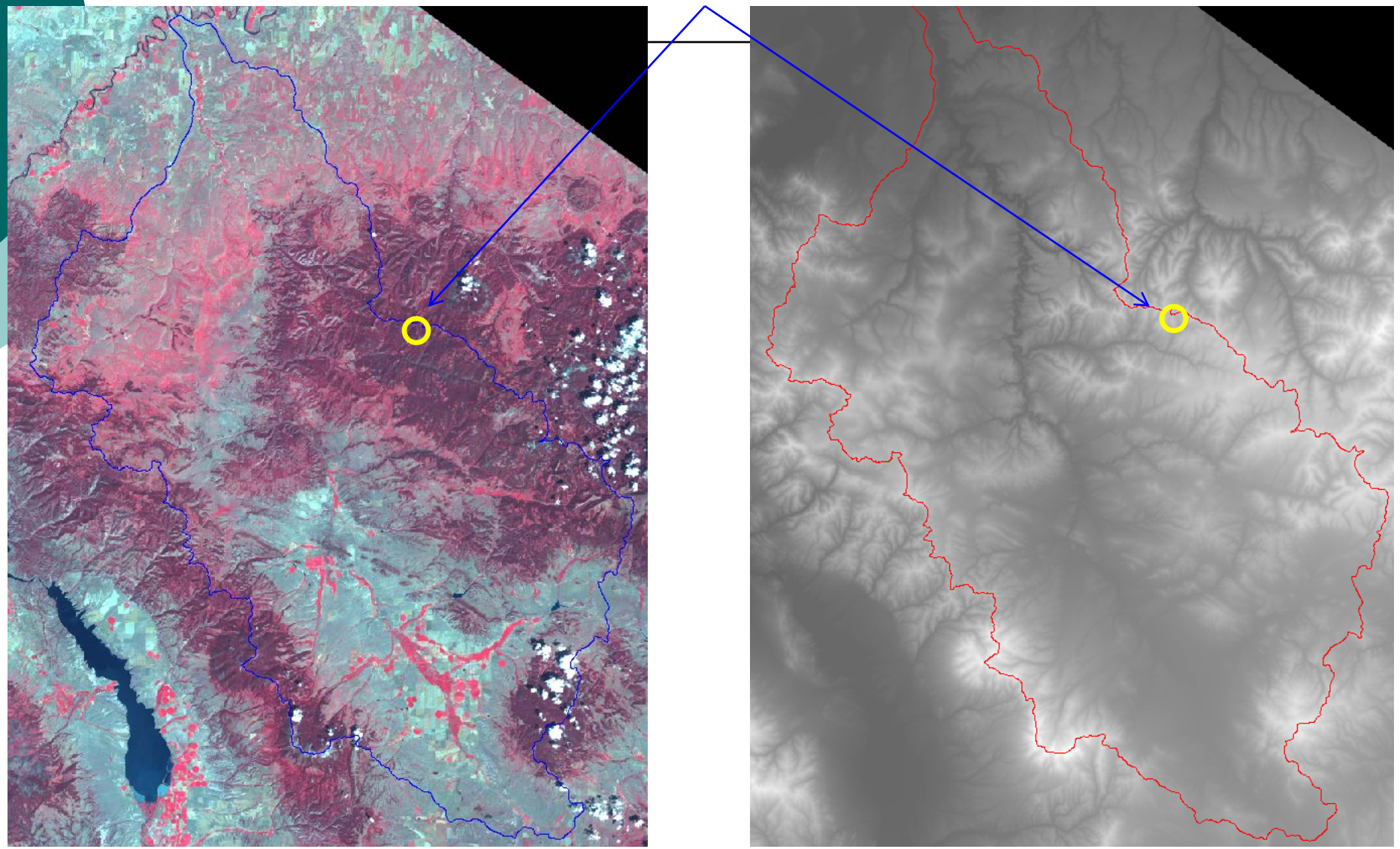
Increased Wind Speed in Mountains




Teton River
Greenfields
Great Falls
Cascade
Moccasin
Helena Valley
Helena
White Sulph. Sp.
White Sulphur Sp.
Toston
Shields Valley
Jefferson River Valley
Bozeman
Bozeman
Dillon
Ruby River Valley

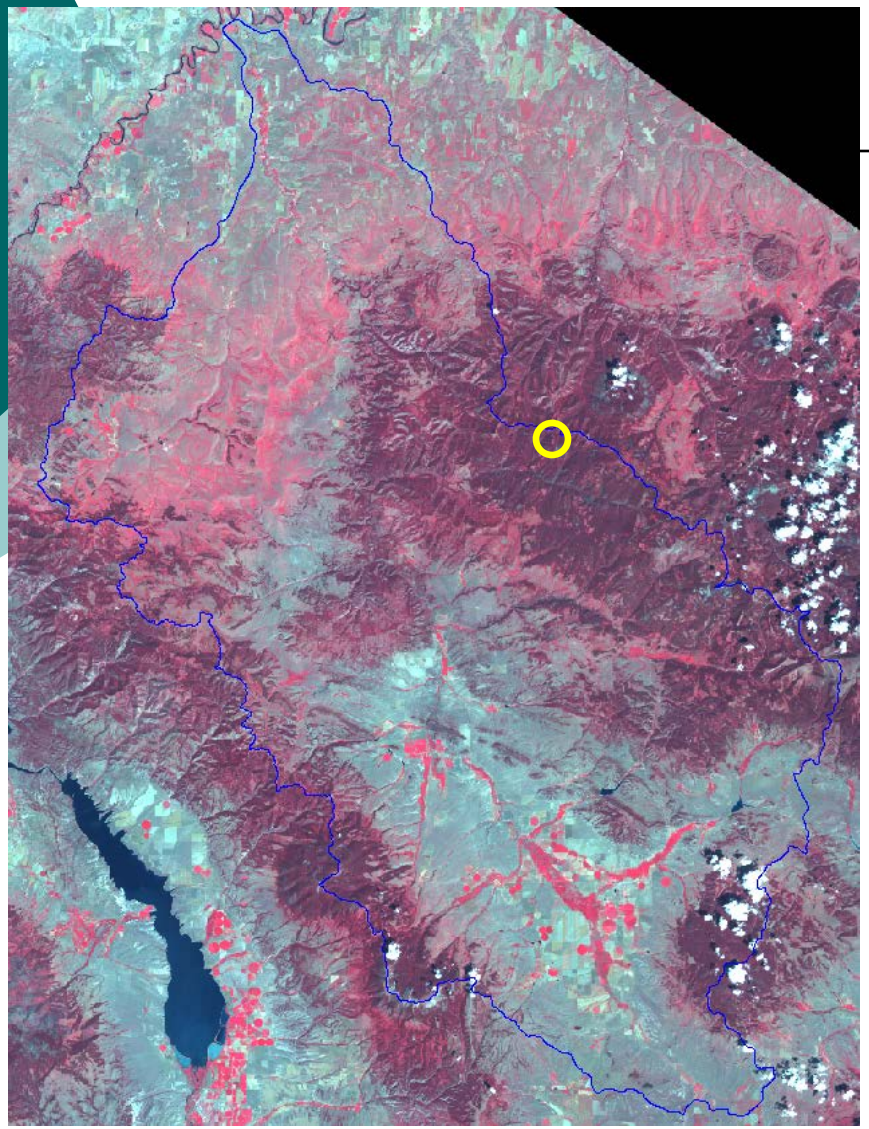
07/18/2007 L5 – Smith River Basin DEM

3 km diameter circle

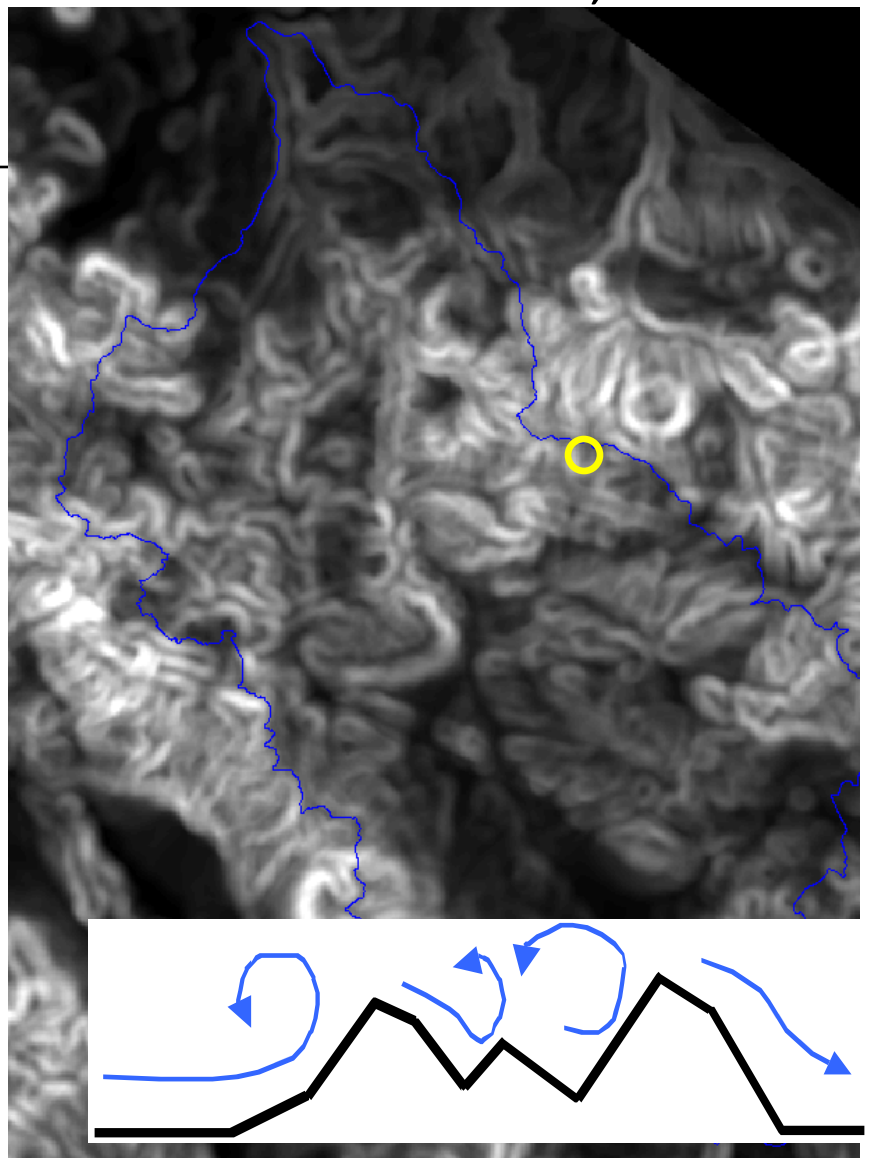


Increasing z_{om} for Terrain Roughness

07/18/2007 L5



Std. Dev. of elevation, m

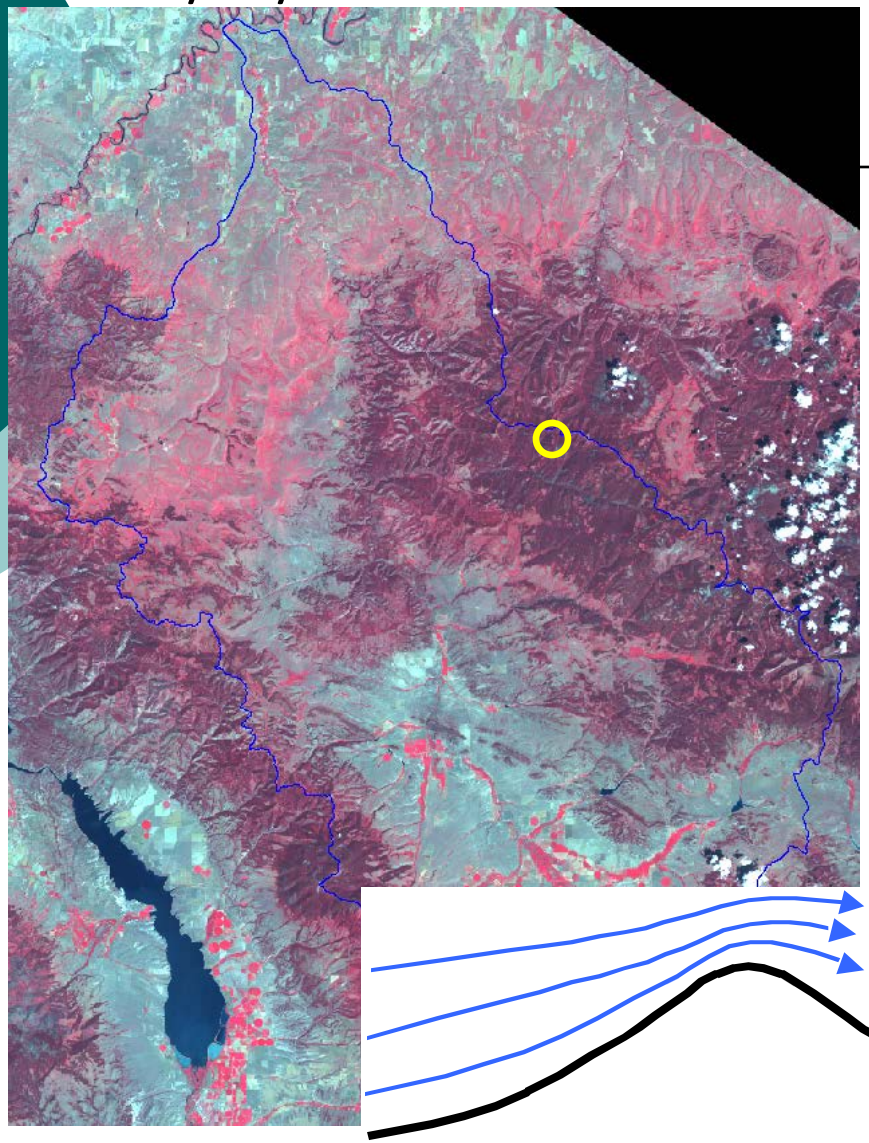


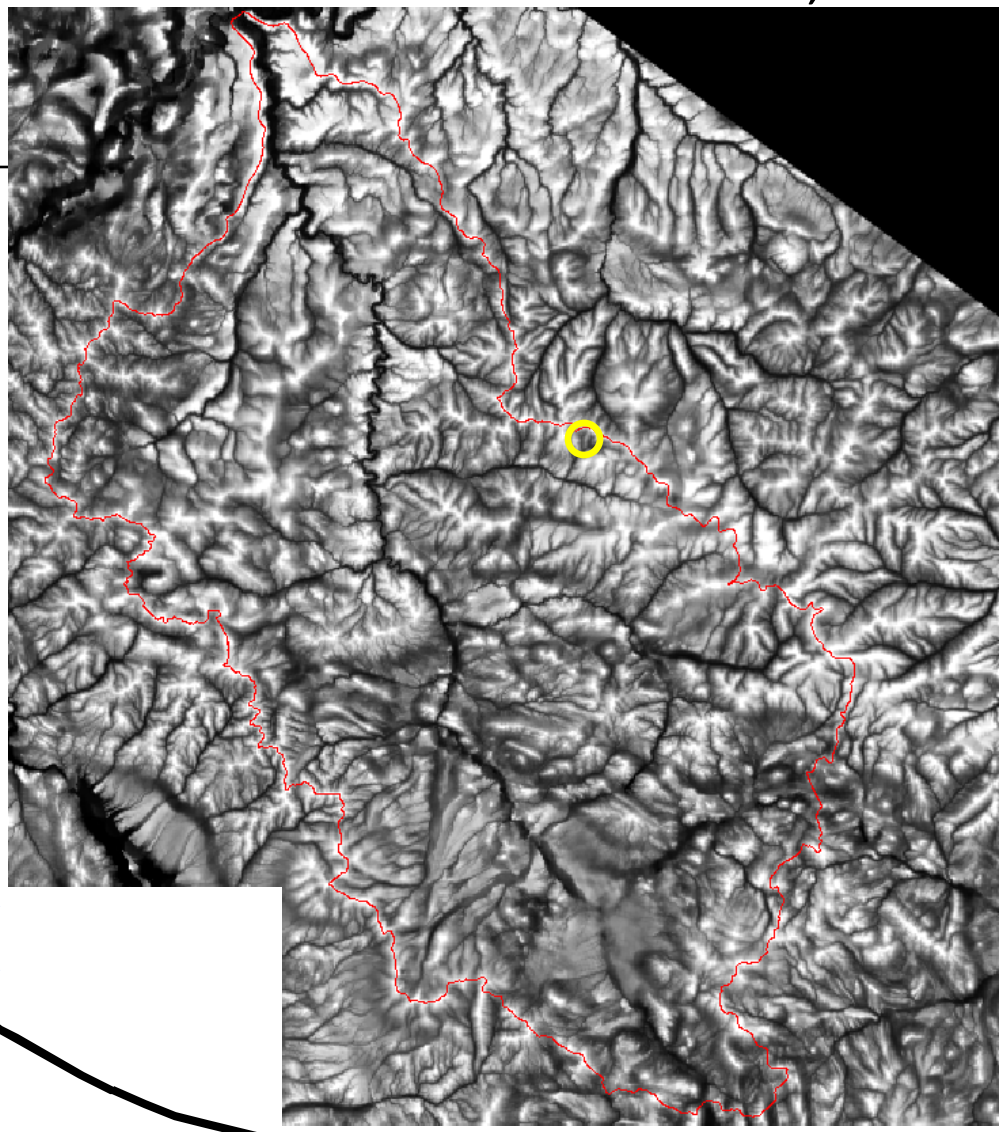
$$z_{om} = z_{om\text{"flat"}} + f(\text{Std.Dev.DEM}, z_{om\text{"flat"}})$$

Increased Wind Speed in Mountains

07/18/2007 L5

Relative elev. within 3km circle, m

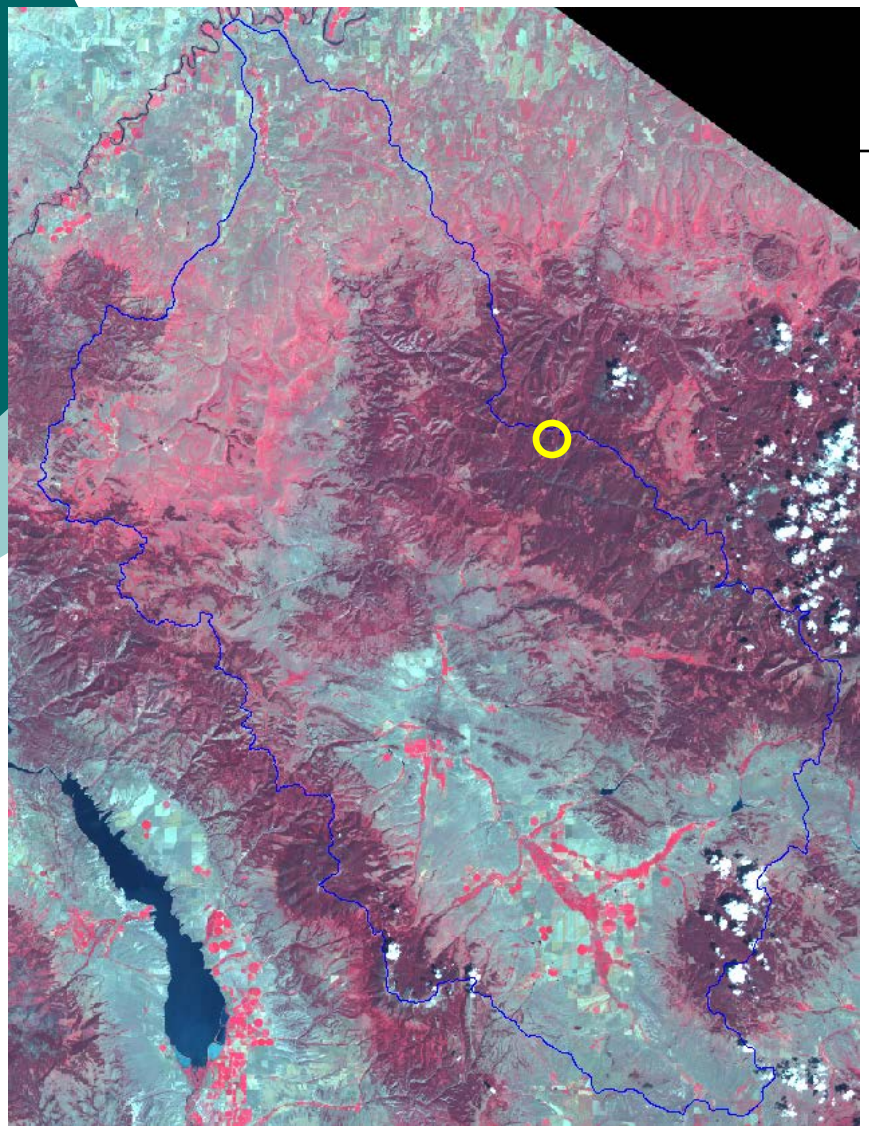




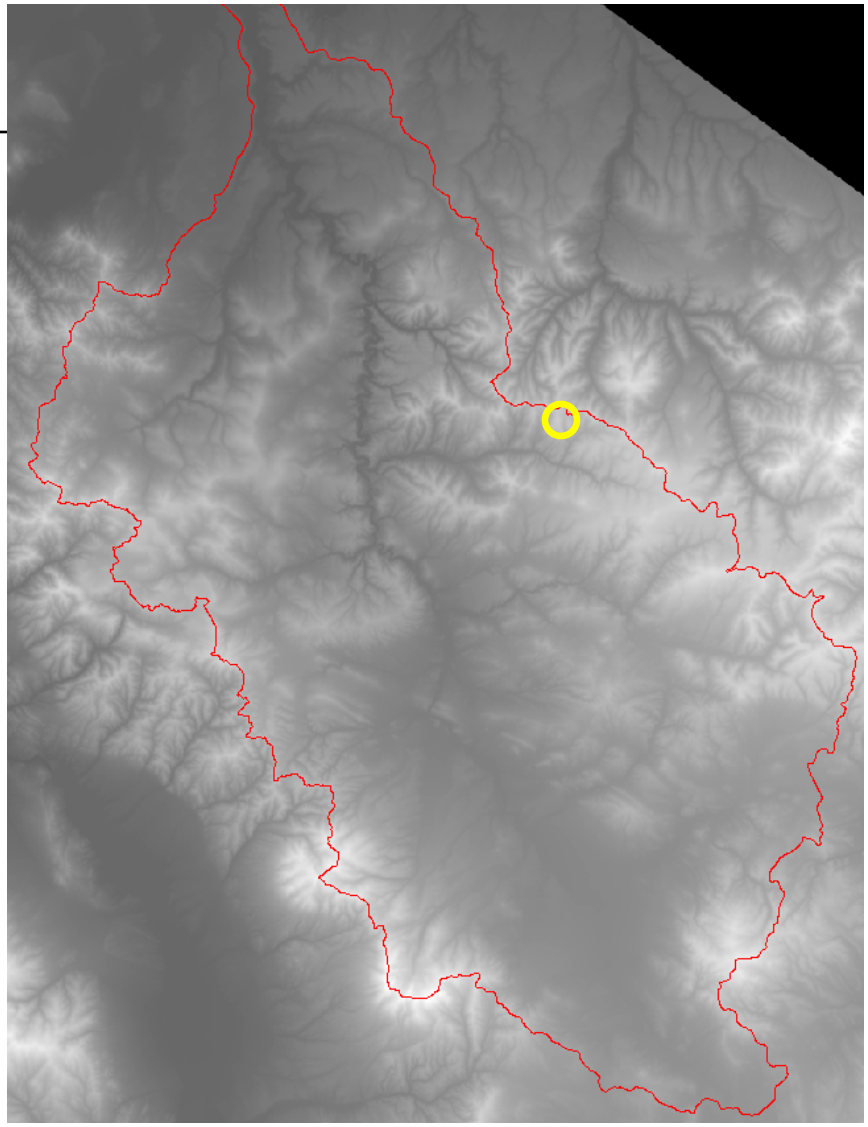
Wind Speed increase = *f*(Rel.Elev., Std.Dev.DEM)

Reducing Wind Speed on Leeward Slopes

07/18/2007 L5



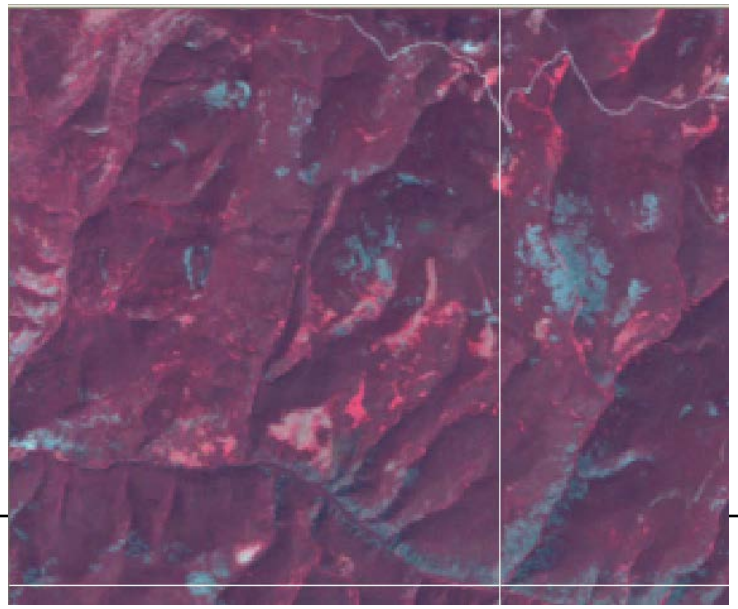
DEM, m

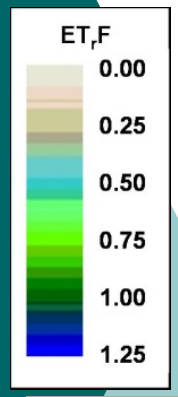


Wind Speed decrease = *f*(sin(slope), cos(aspect, wind direction))

Impact of Terrain Roughness

-- (07/18/2007) L5

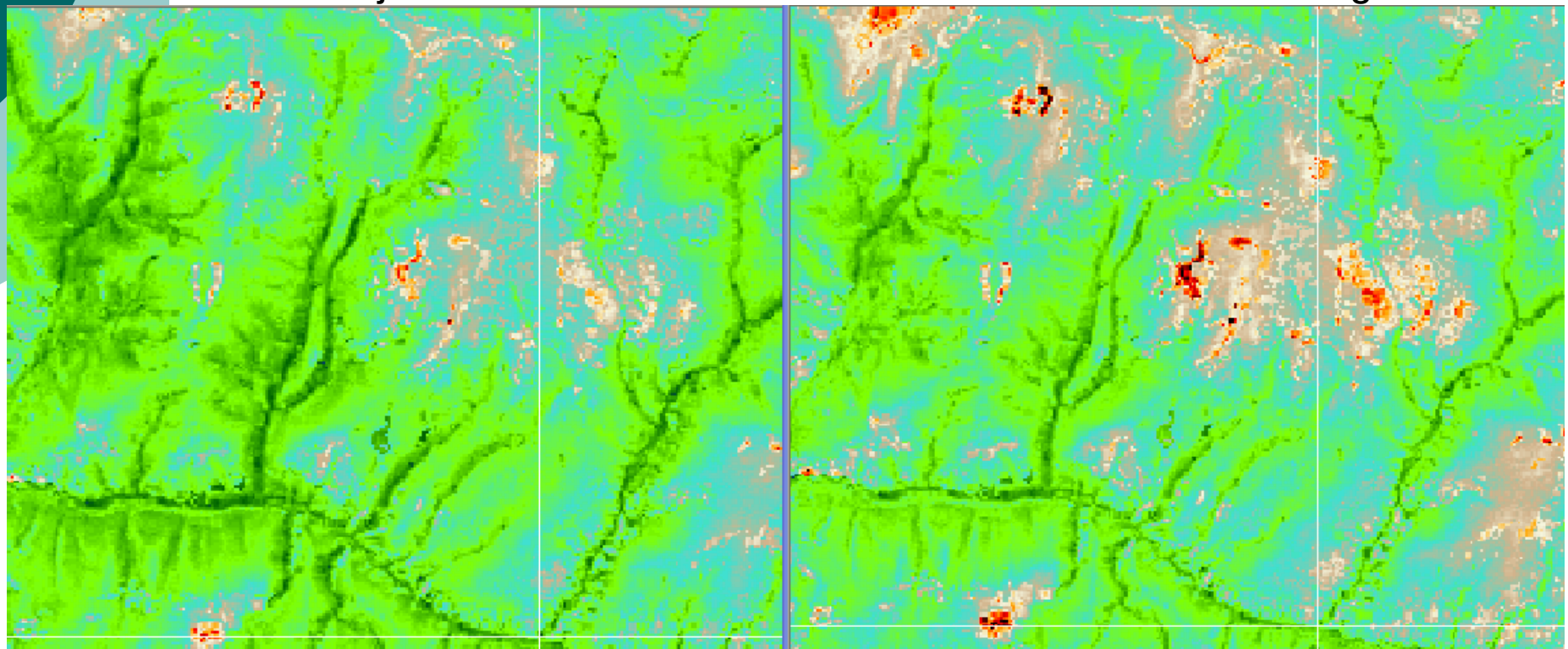




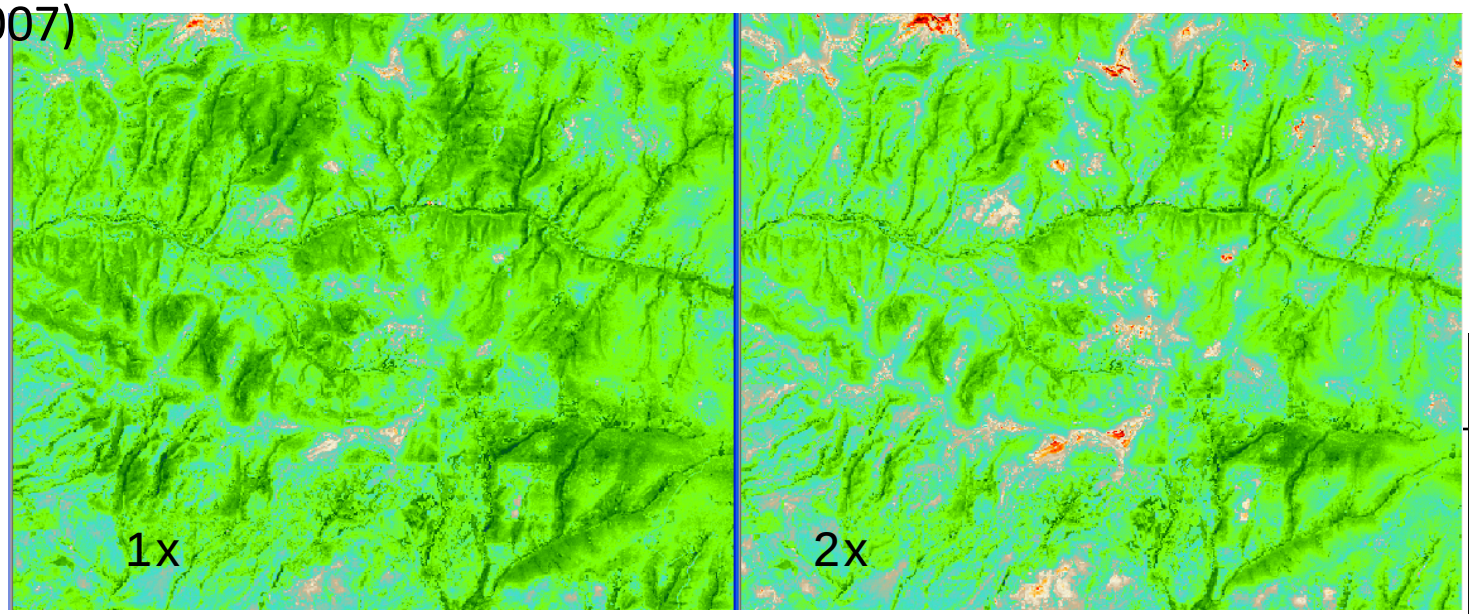
ET_rF = fraction of potential ET
(= Relative ET index)

No Adjustment

w/Substantial Terrain Roughness

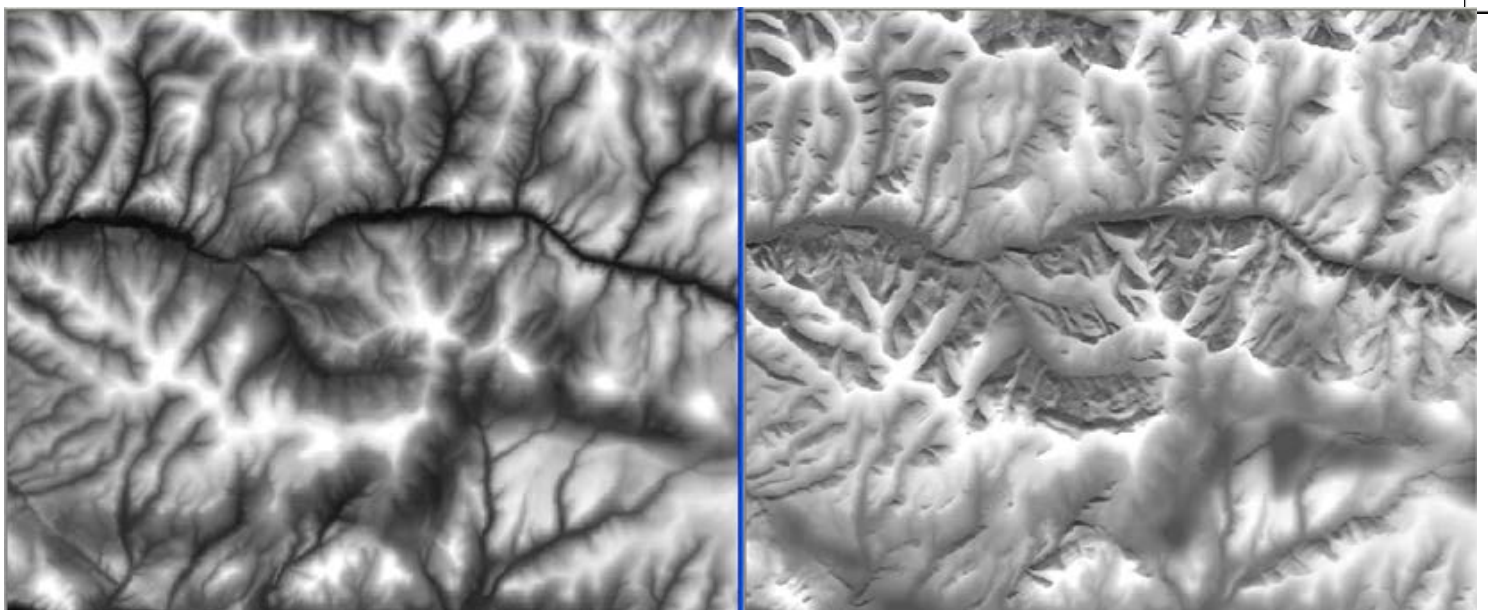


ET_rF map before and after **doubling Wind Speed in Mountains (Max.)** (07/18/2007)



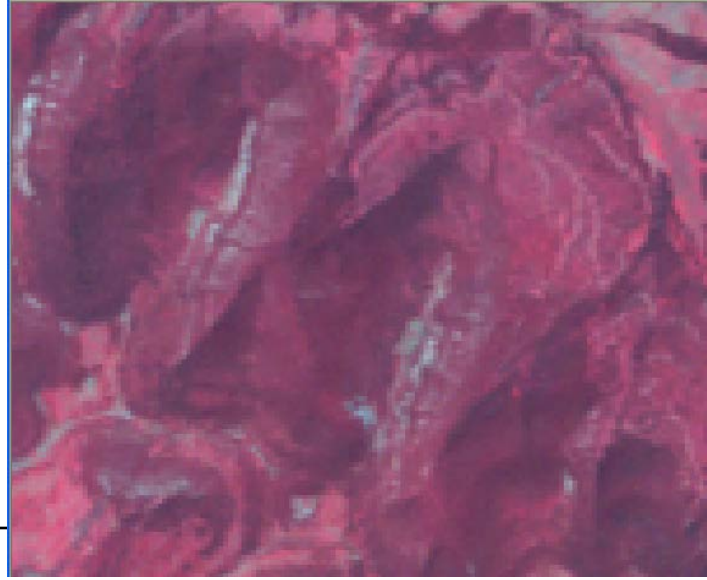
Relative elevation

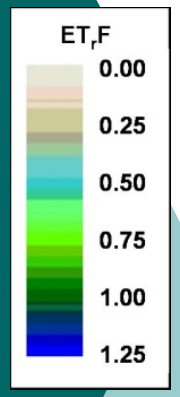
adjusted Wind Speed



Impact of Leeward shielding

-- (07/18/2007) L5

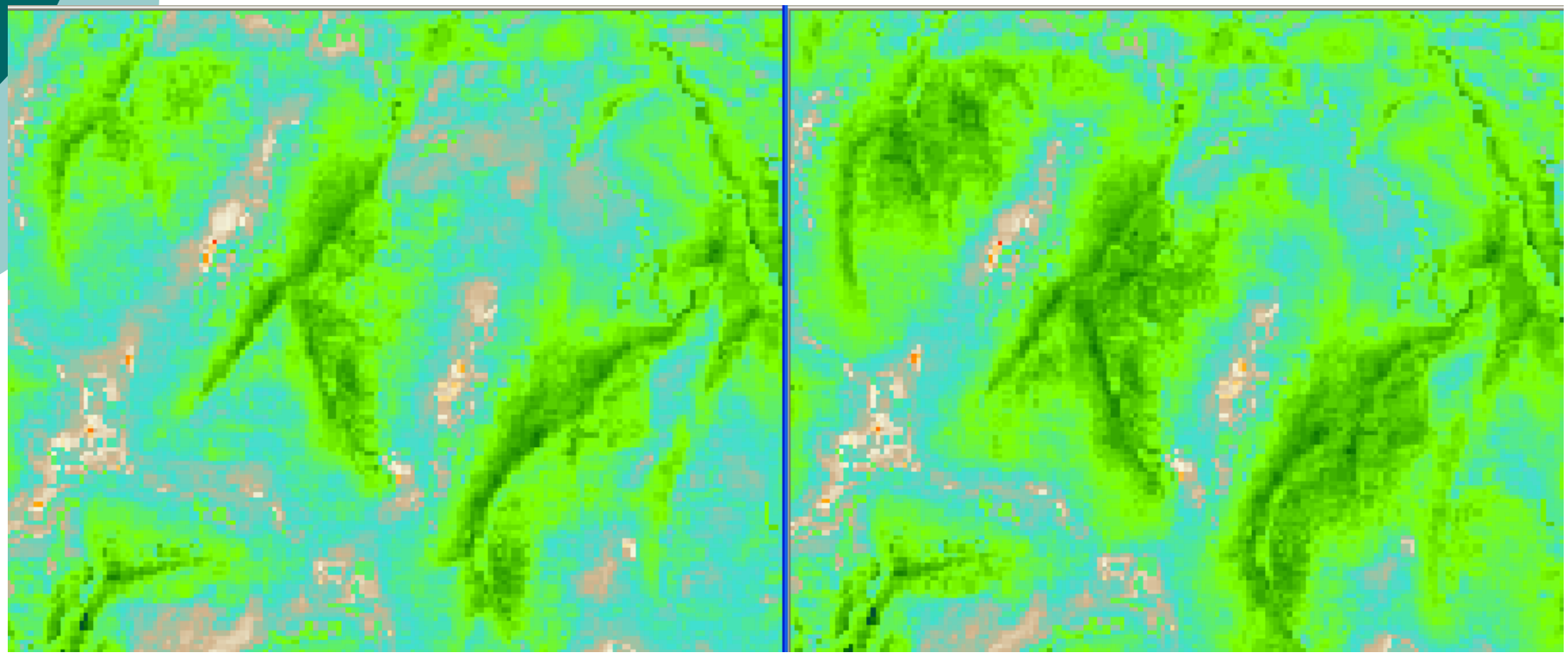




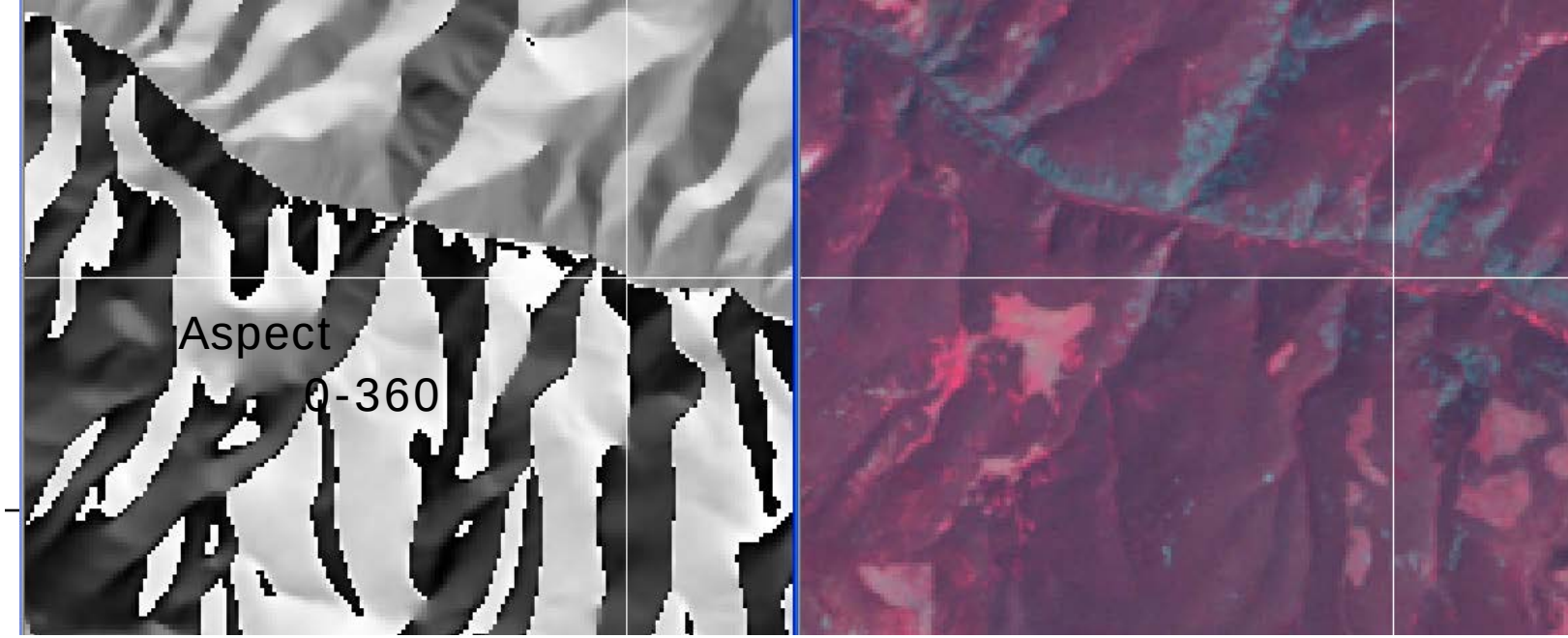
ET_rF = fraction of potential ET
(= Relative ET index)

No Adjustment

Adjustment with Wind from North

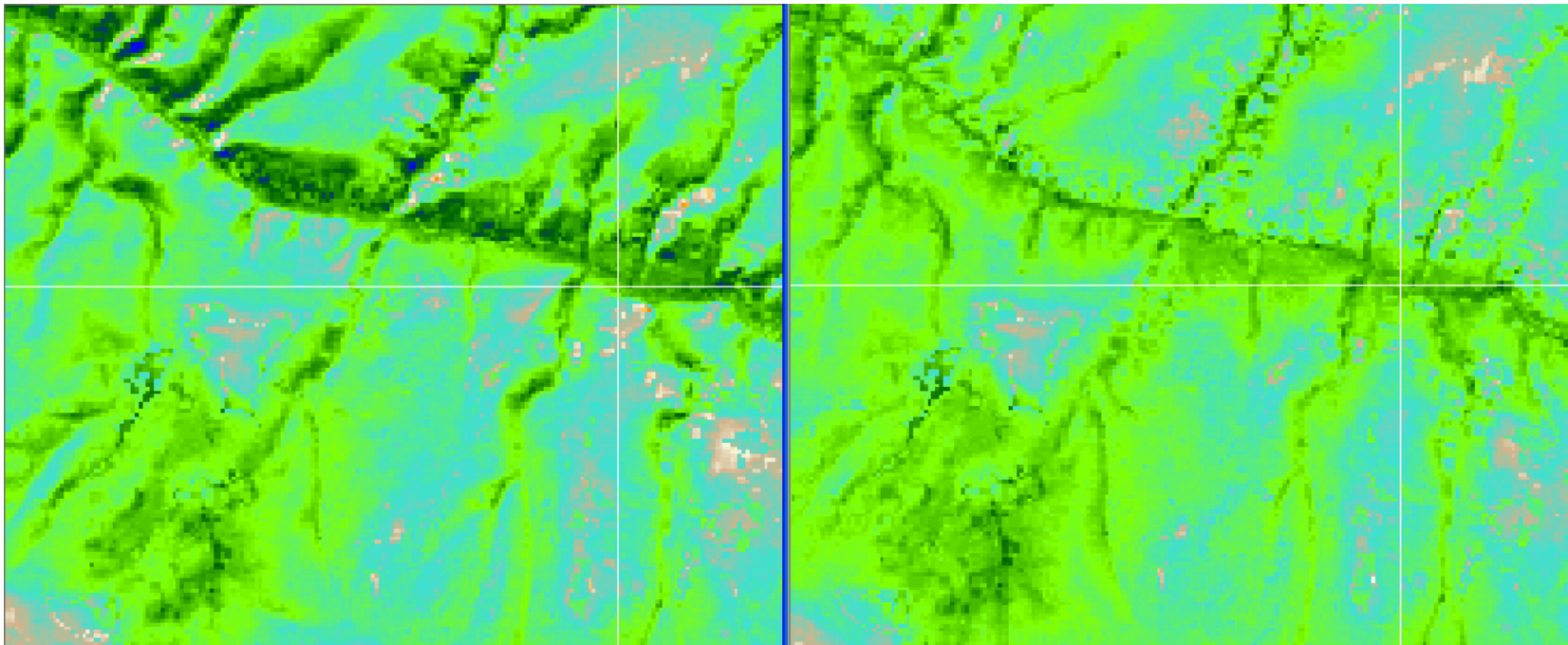


07/18/2007
L5



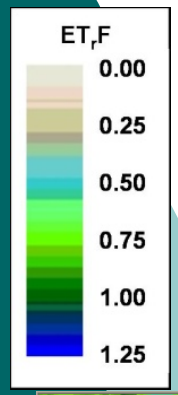
ETrF using **Wind aspect = 0**

ETrF using **Wind aspect = 180**

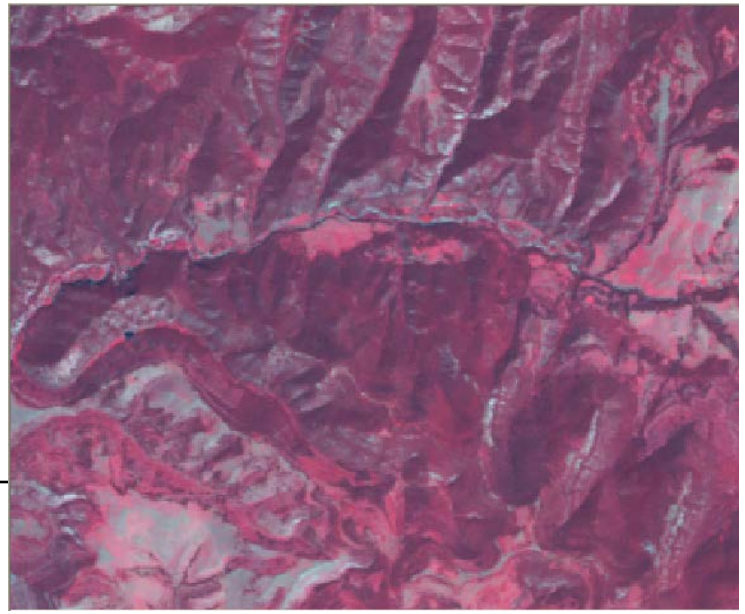


Total Impact of new aerodynamic enhancements

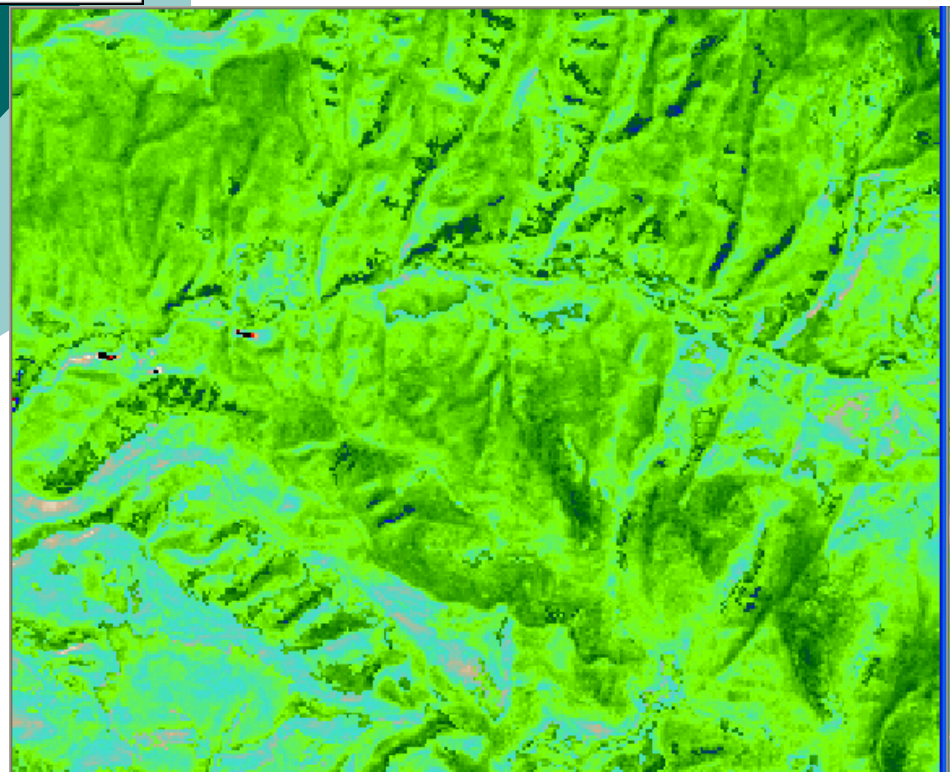
-- (07/18/2007) L5



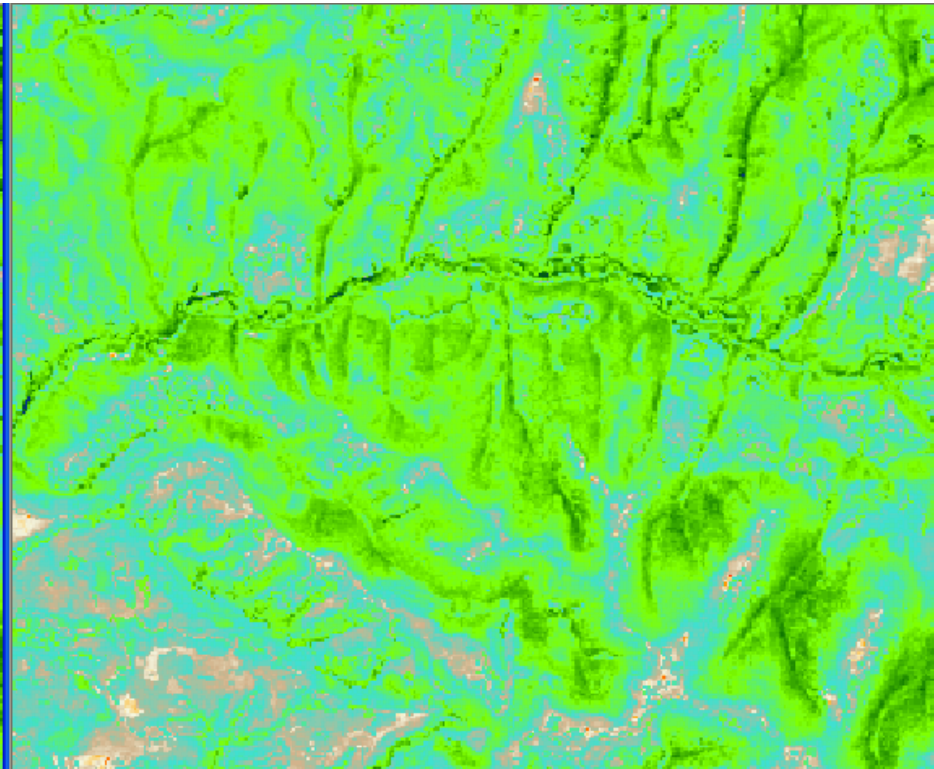
ET_rF = fraction of potential ET
(= Relative ET index)



Before

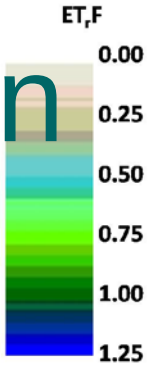


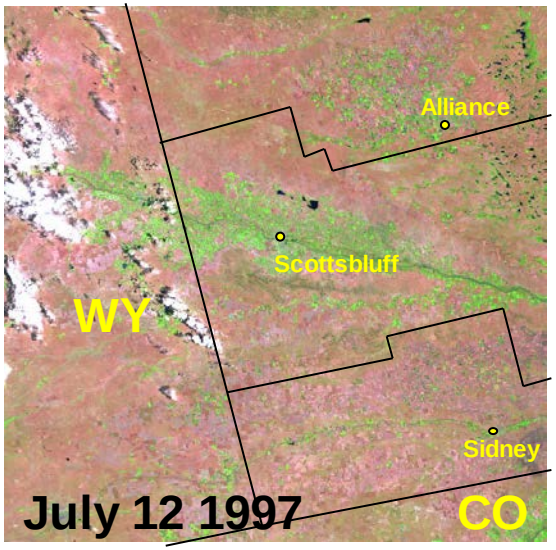
After



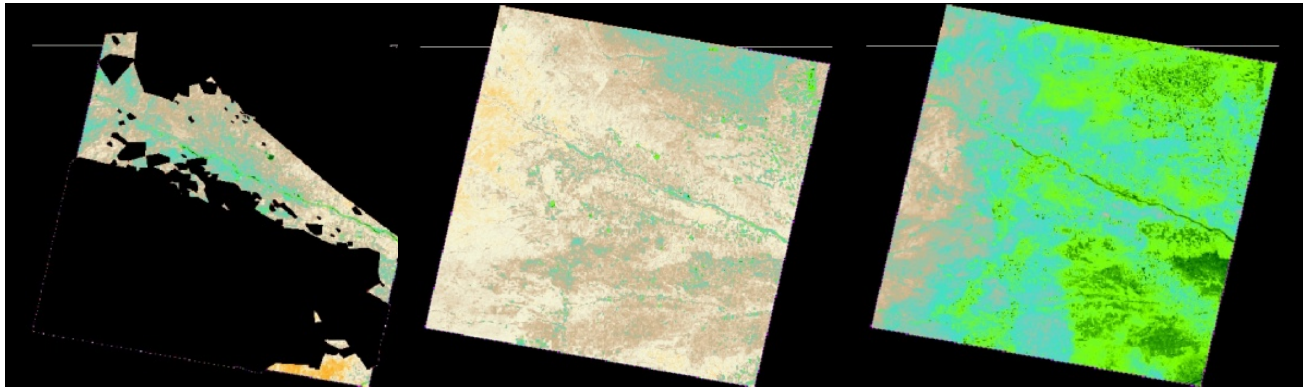

ET

ET during the growing season

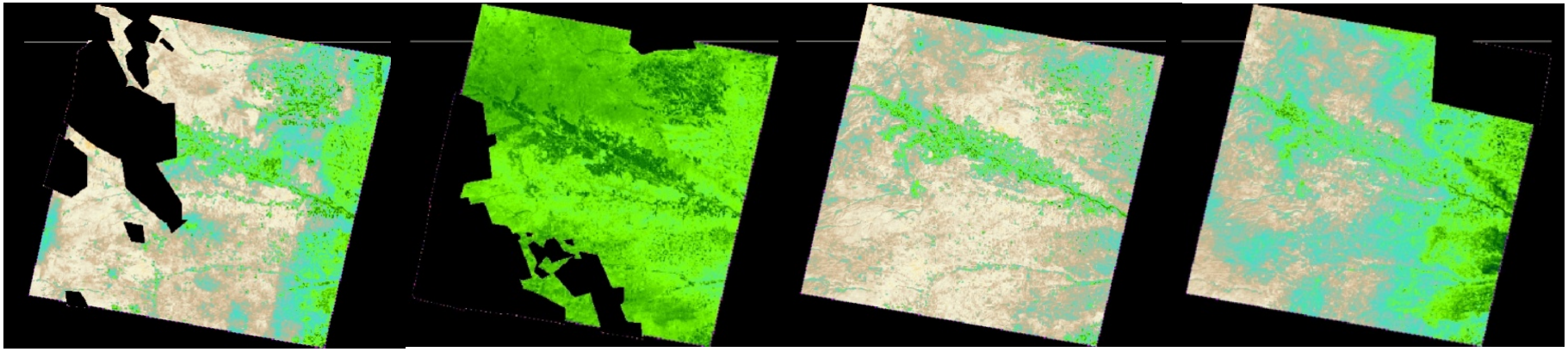




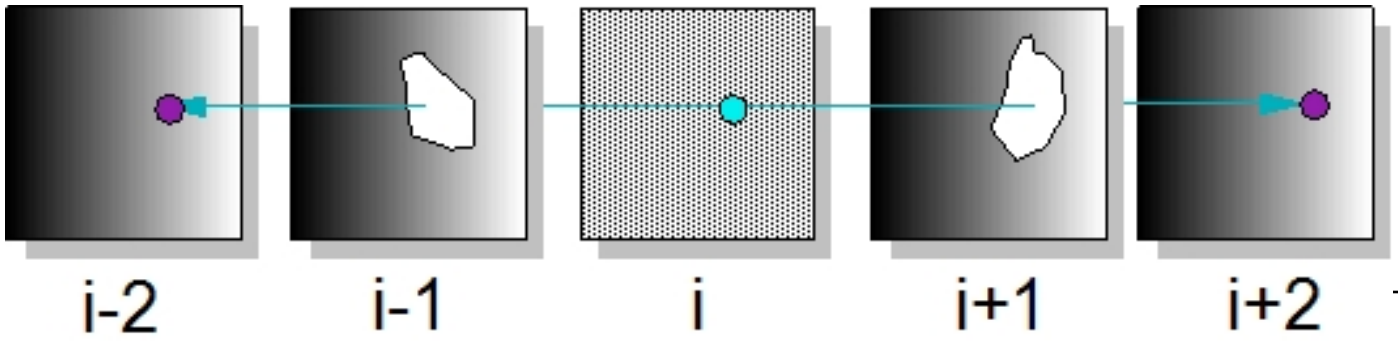
1997 image date ETrF estimates



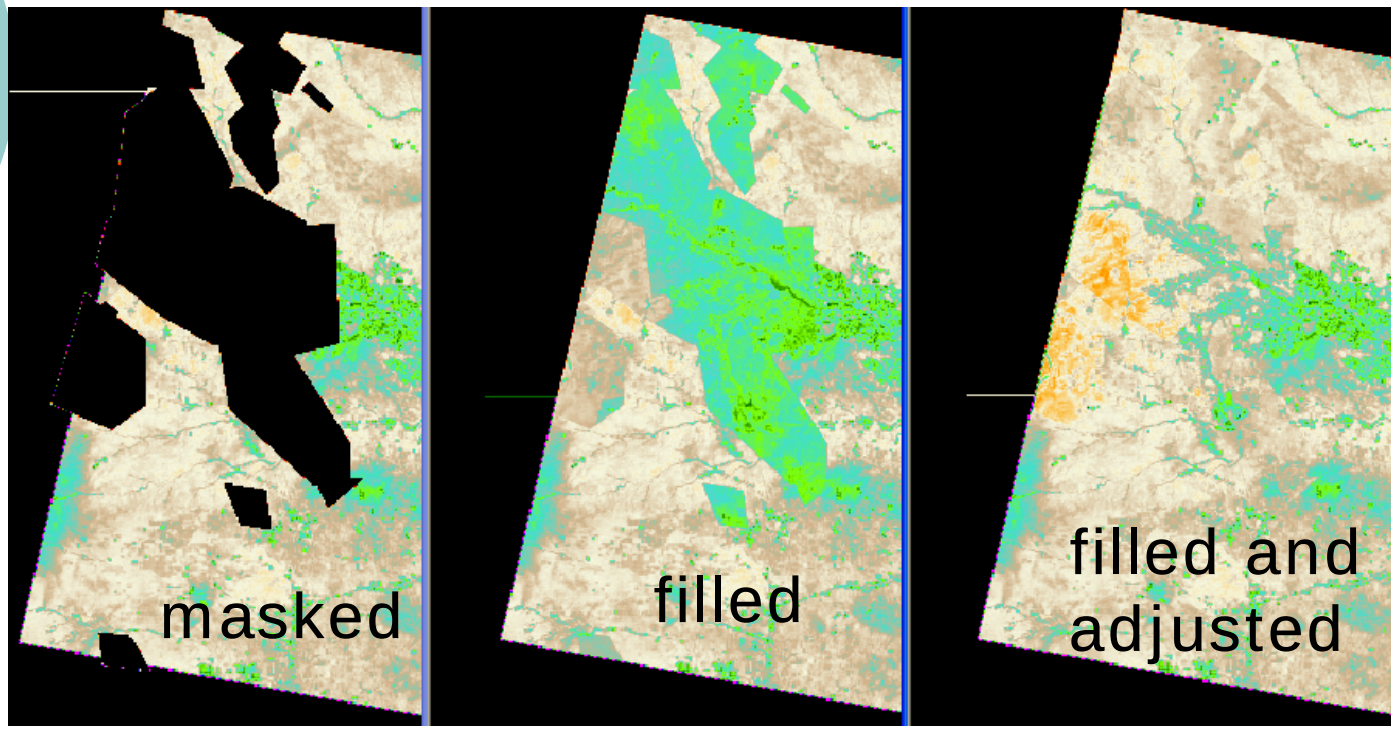
April 23 May 9 June 26



July 12 August 13 September 30 October 16



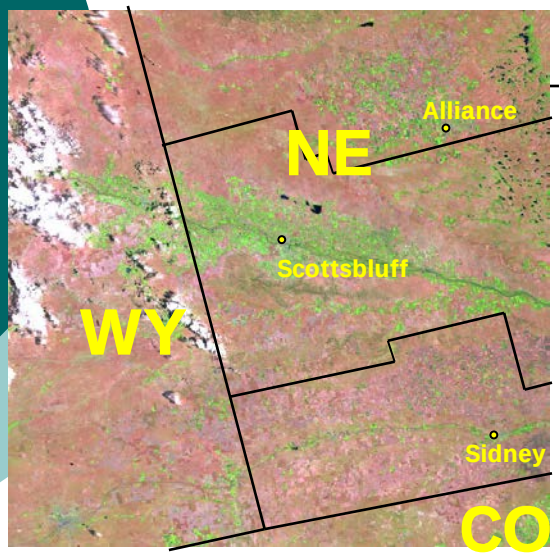
Filling From Adjacent In time



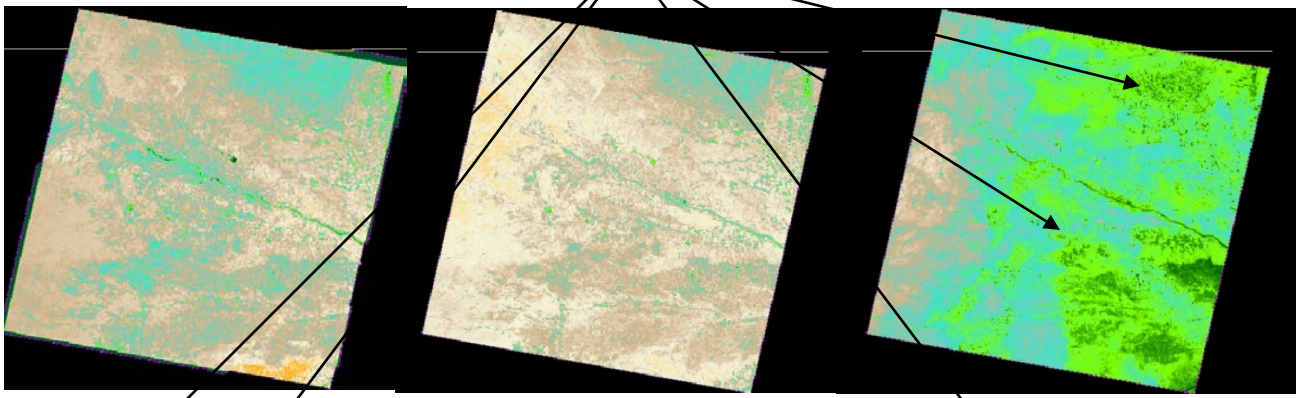
Adjusted using a daily evaporation process model

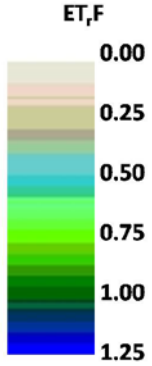
We work on the basis of 'relative' ET (i.e., ET_rF) and compute ET for each day between images as $ET_i = ET_rF_i \times ET_{r\,i}$ where ET_r is the 'reference' or 'potential' ET on day i and = *f(weather)*.

ET ‘index’ (fraction of full-cover ‘reference’ ET) during the 1997 growing season in Western Nebraska



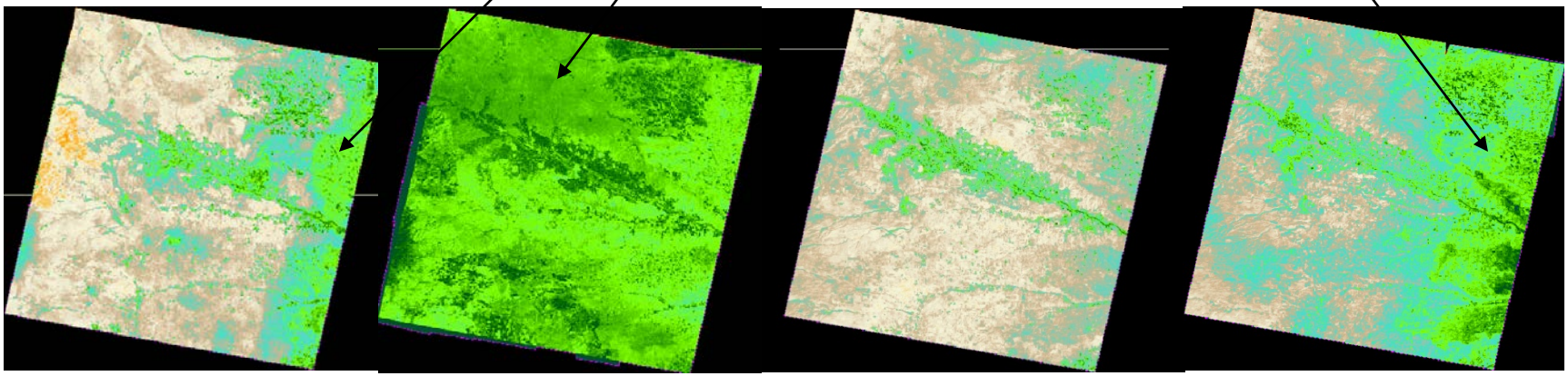
Extents of evaporation from recent Rain Events





Landsat scenes: 160 x 160 km)

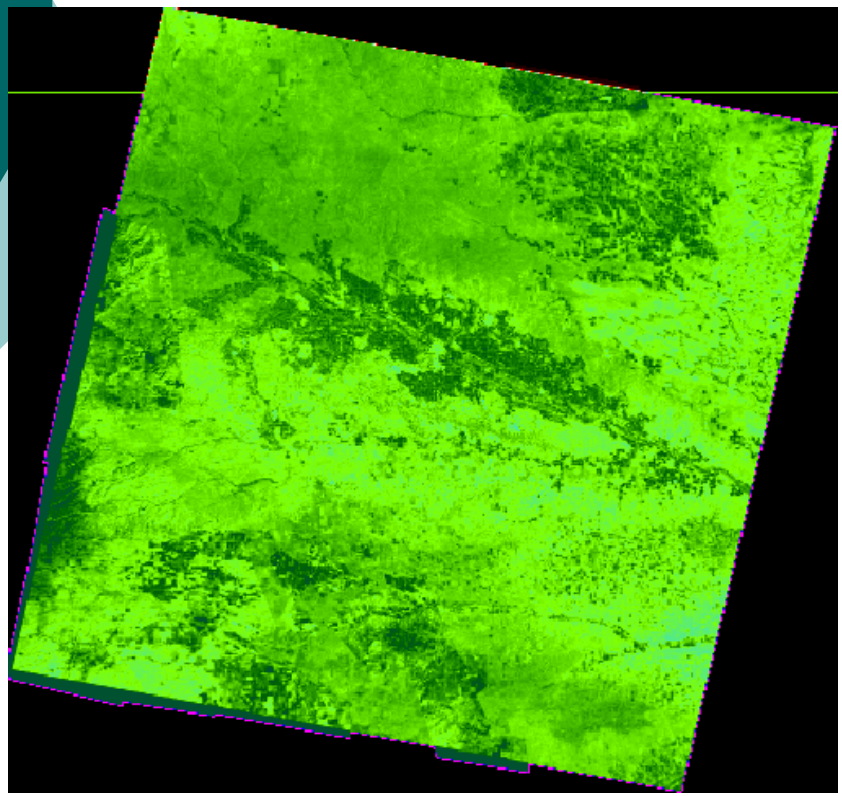
April 23 May 9 June 26



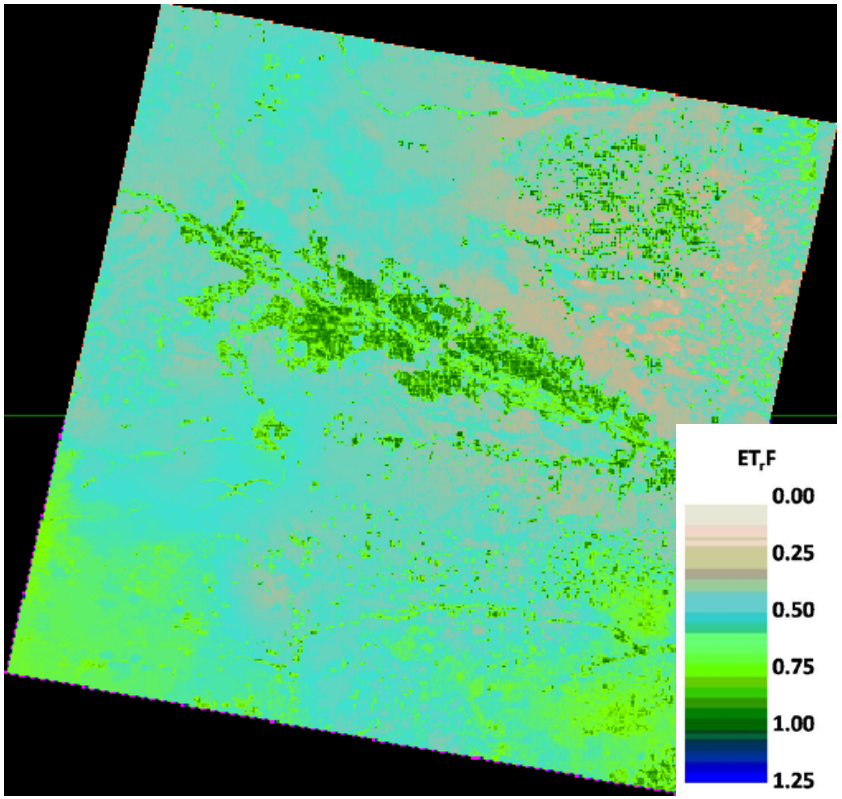
July 12 August 13 September 30 October 16

from METRIC/Landsat

Adjusting for background evaporation from soil in proportion to NDVI

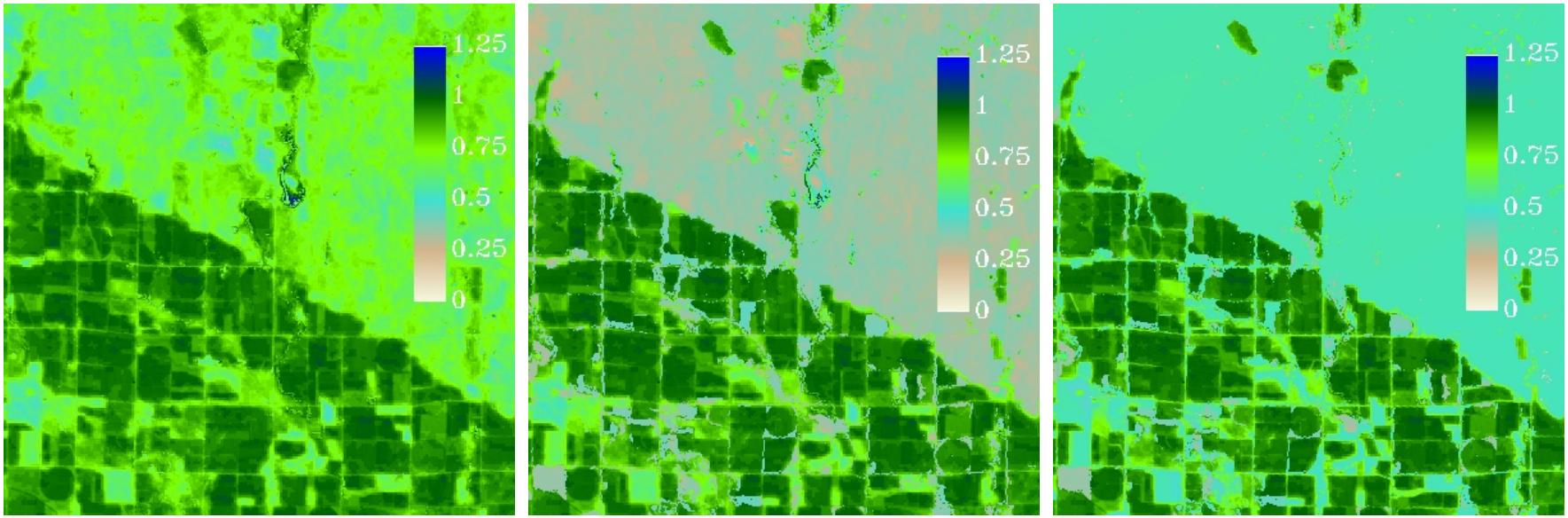


ET from August 13 1997 not adjusted for background soil evaporation



ET from August 13 1997 adjusted for background soil evaporation to represent the month

Central Platte region, Nebraska



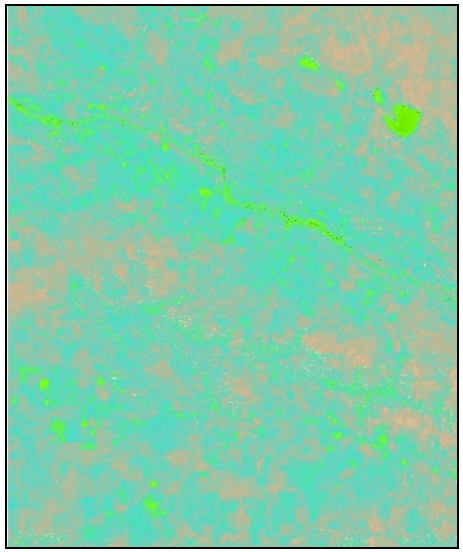
ETrF from 8/4/2007 before adjustment

ETrF from 8/4/2007 after adjustment

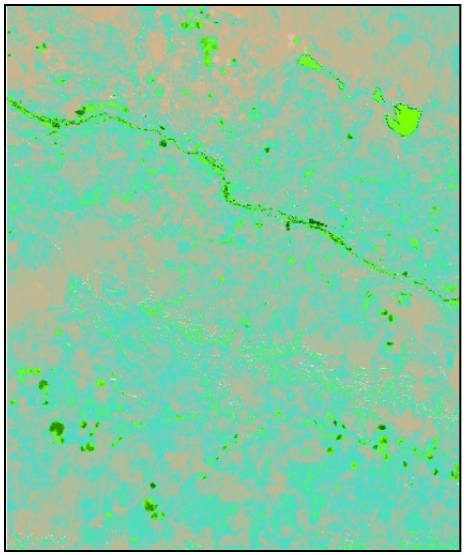
Final ETrF representing a one month time period

Dr. Ayse Irmak, UNL

North Platte region, Nebraska – final Monthly ET



April



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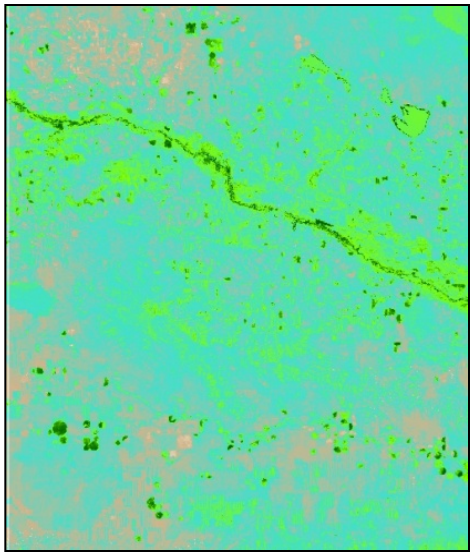

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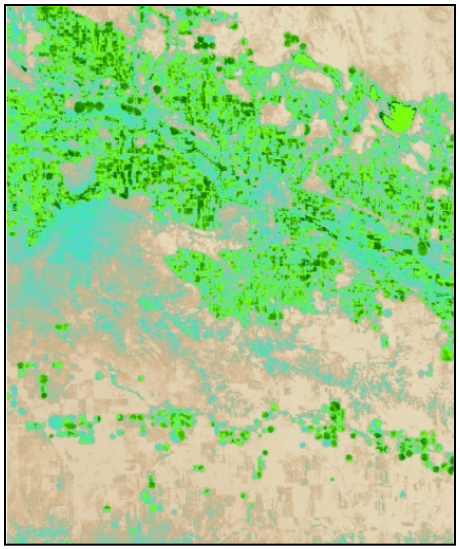

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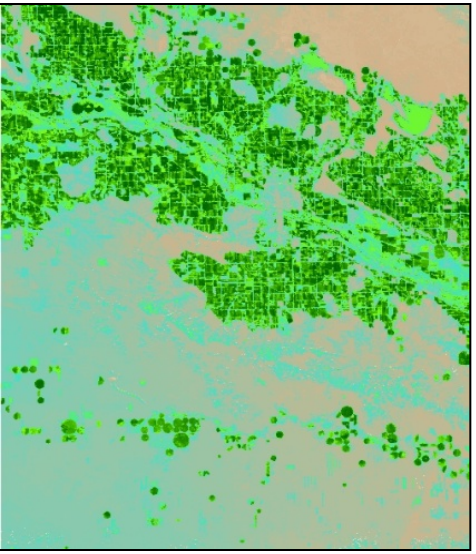
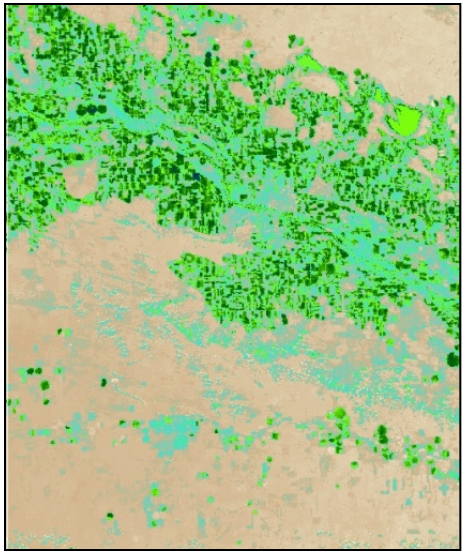


August



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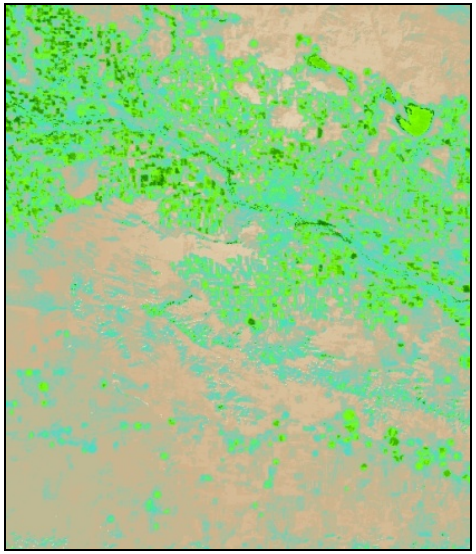

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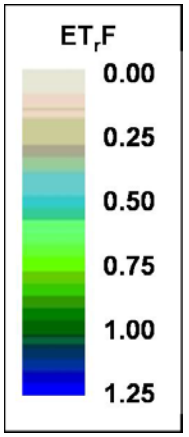
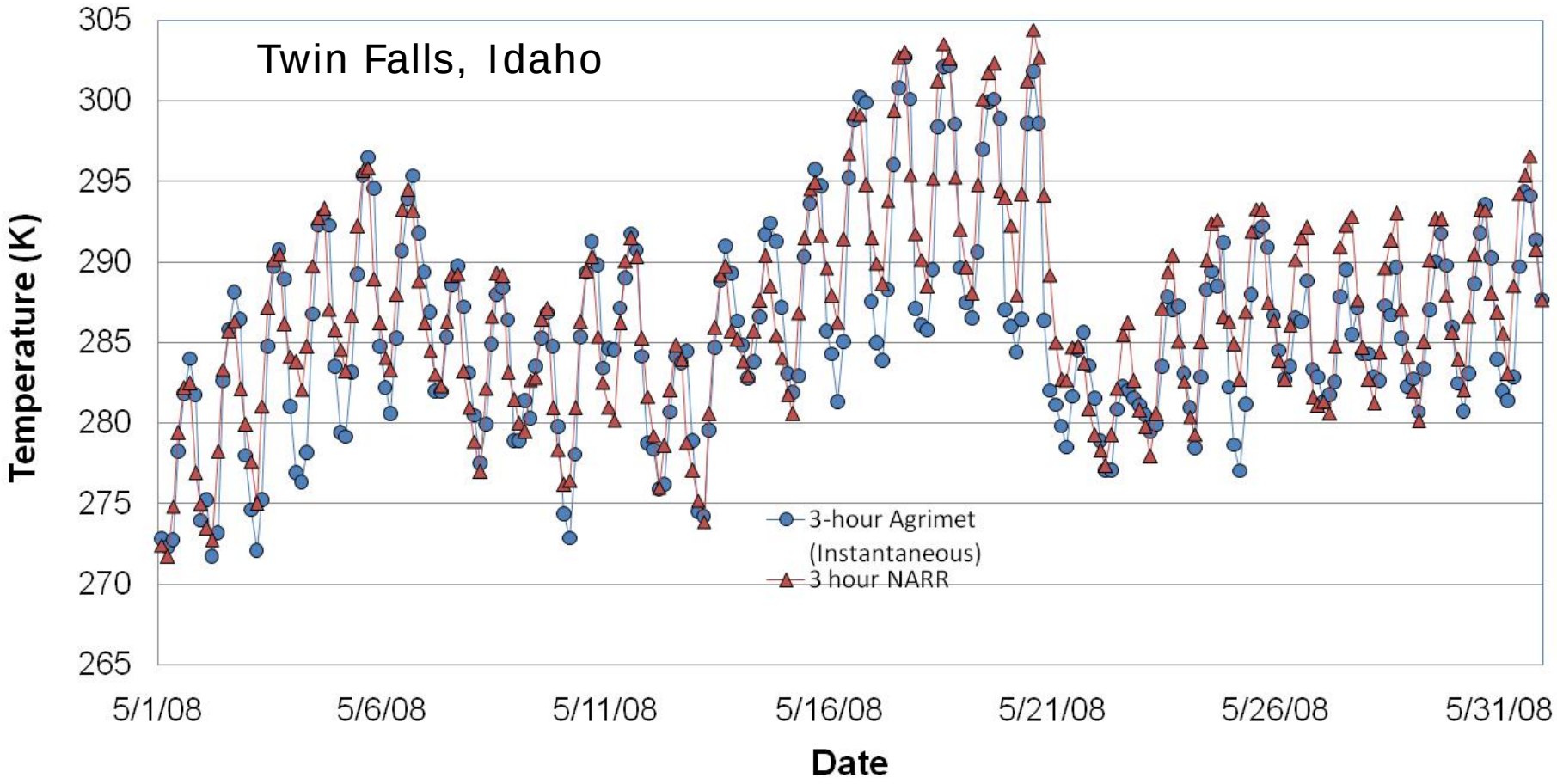


Univ. Idaho

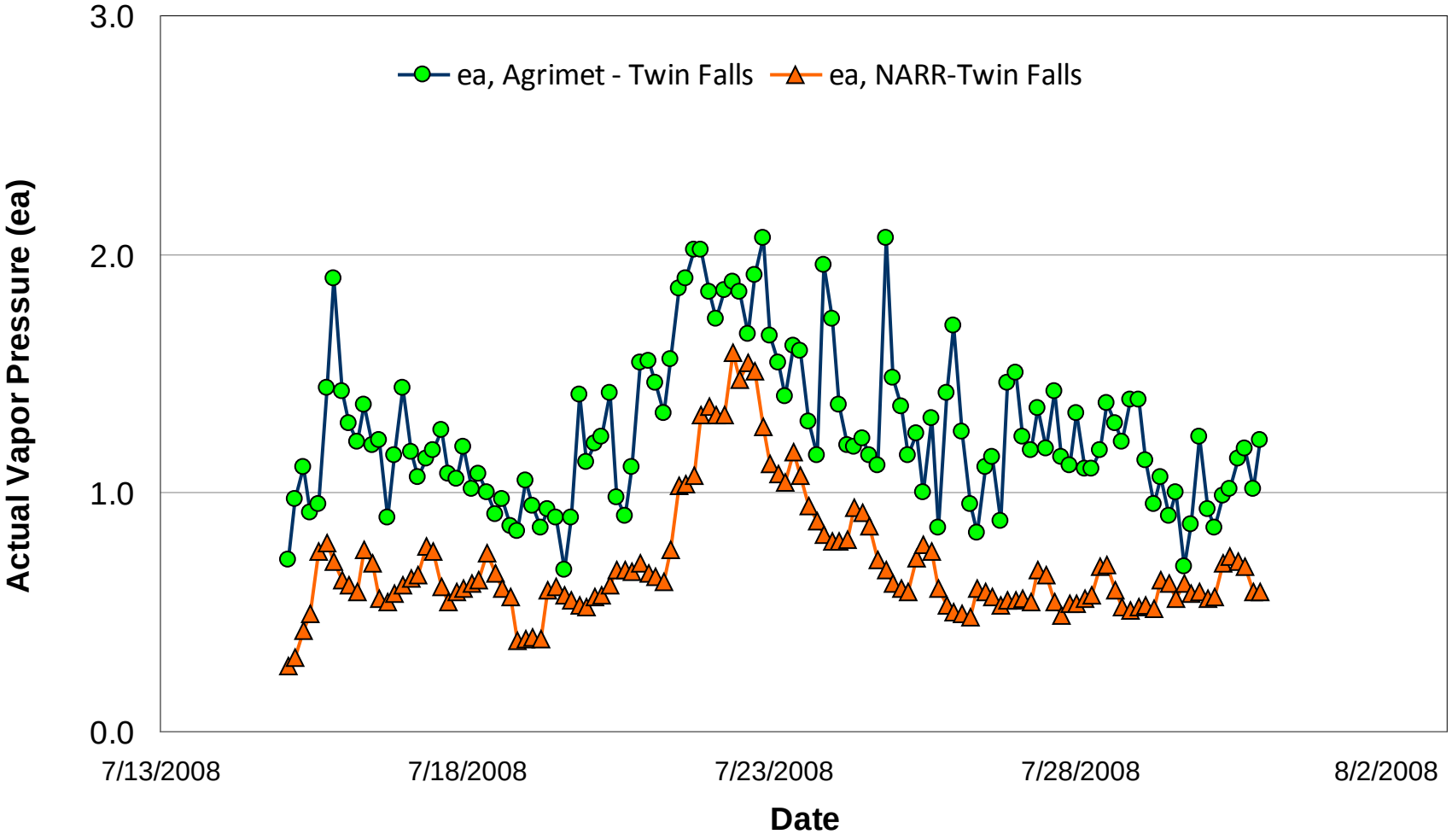
(More frequent images would reduce this complication and increase accuracy)

“Conditioning” Weather Data to reflect a well-watered (Irrigated) Environment

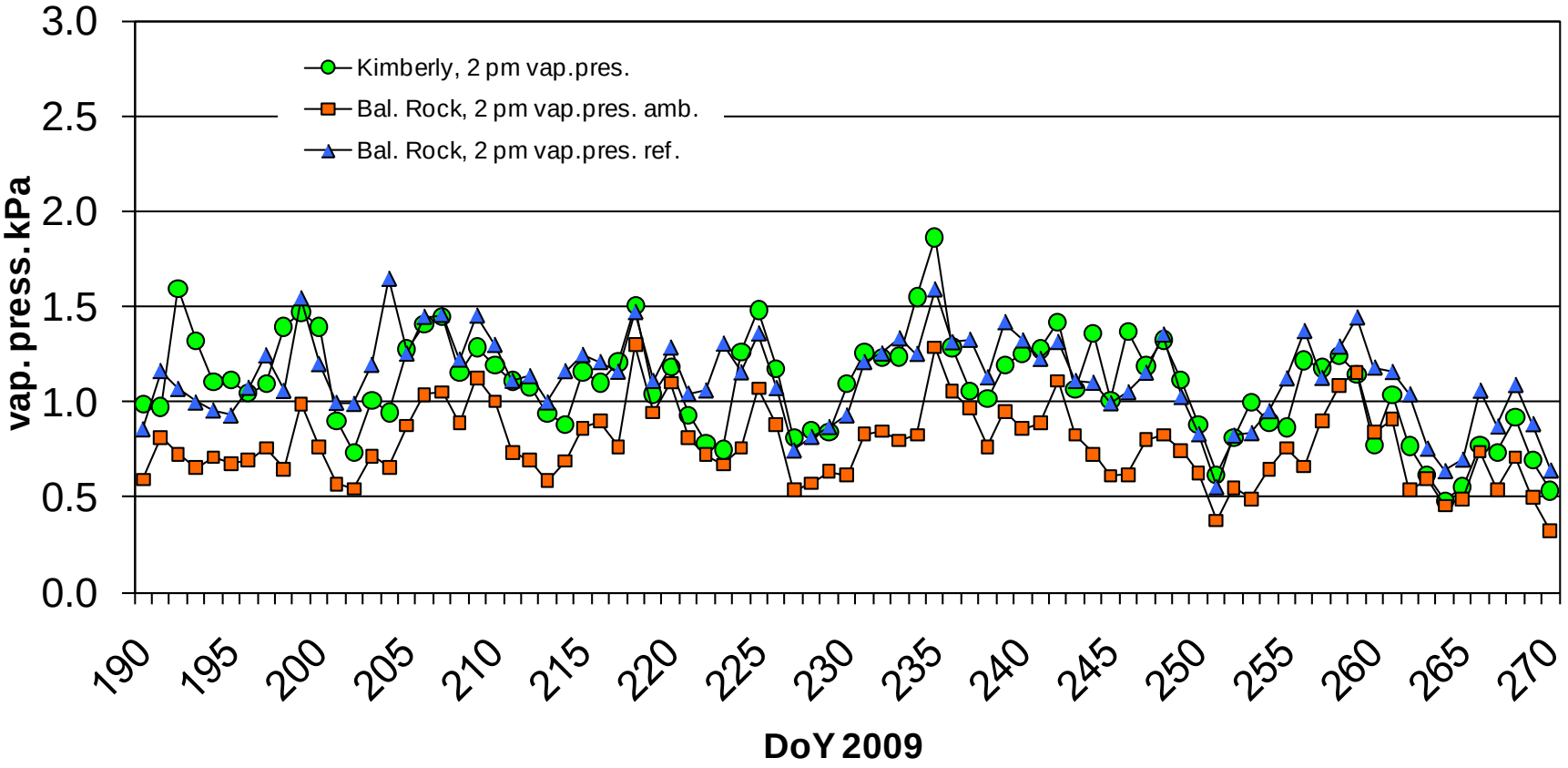
NARR vs. Irrigated Agriculture: Near Surface Air Temperature



NARR vs. Irrigated Agriculture: Near Surface Vapor Pressure

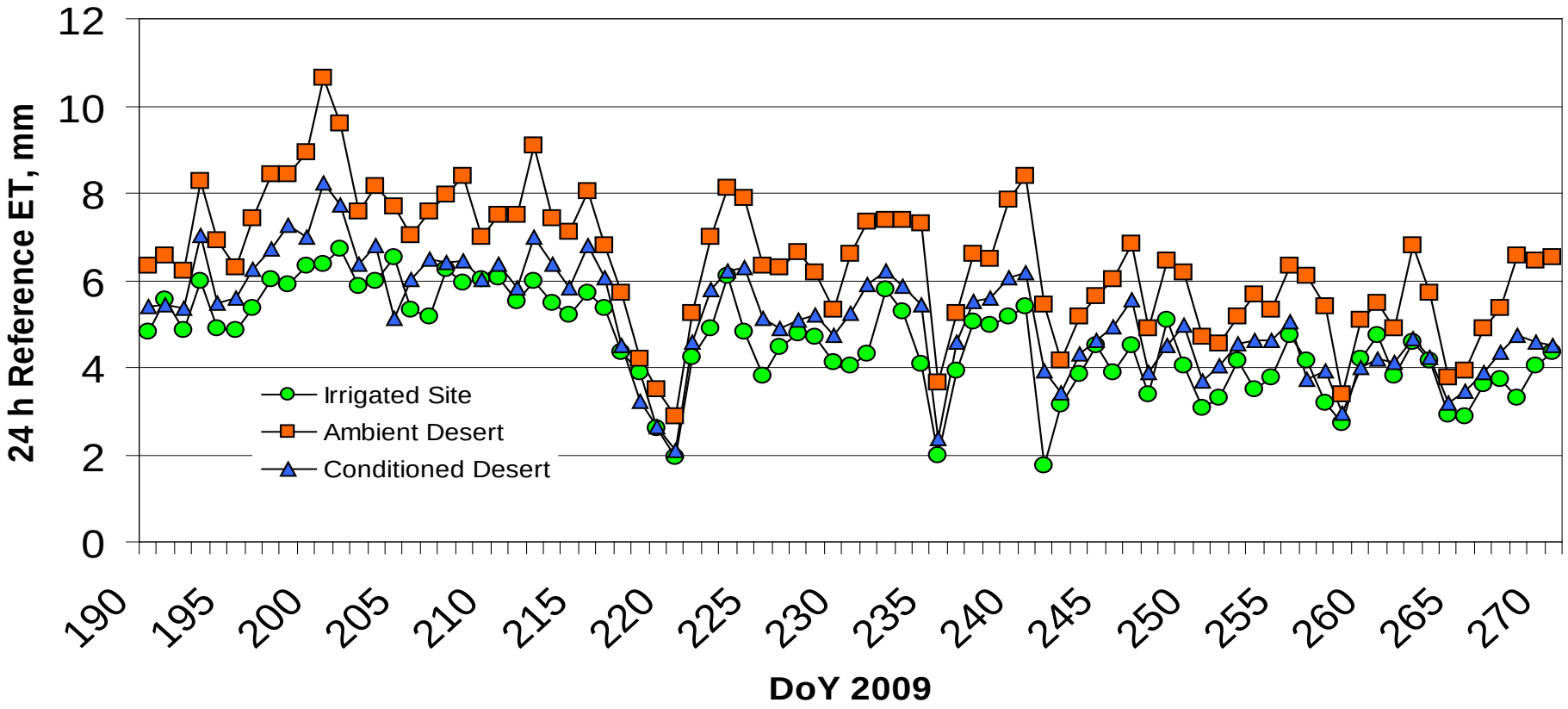


Dry vs. Irrigated Agriculture: Near Surface Vapor Pressure – Conditioned using Profile/Flux Theory



Twin Falls, Idaho

Dry vs. Irrigated: "Reference Evapotranspiration" – Dry (meas.) vs. Conditioned vs. Irrigated (meas.)



Twin Falls, Idaho

Landsat Nadir View Simulator

Pipe fitting - $1.30
Ring clamp - $2.10

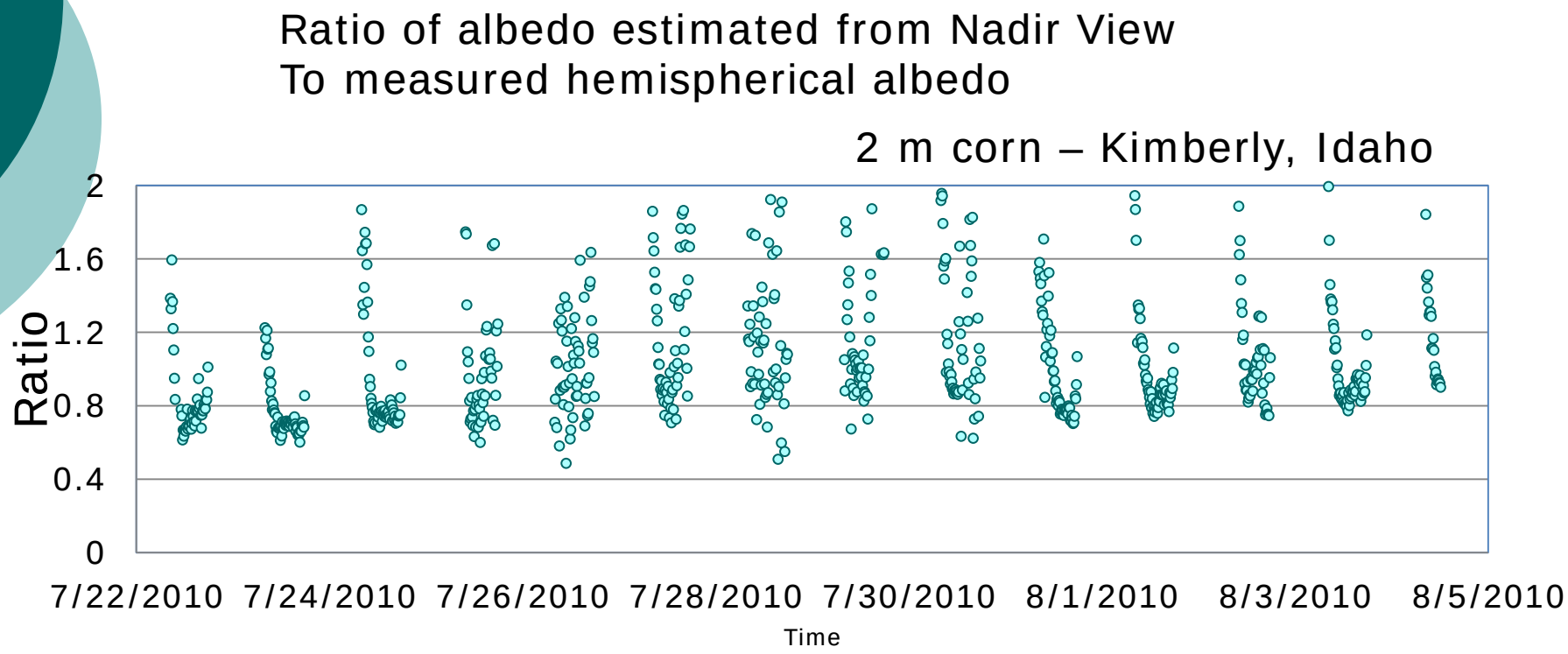
Nadir View: Priceless

Landsat Nadir View Simulator

Landsat Nadir View Simulator

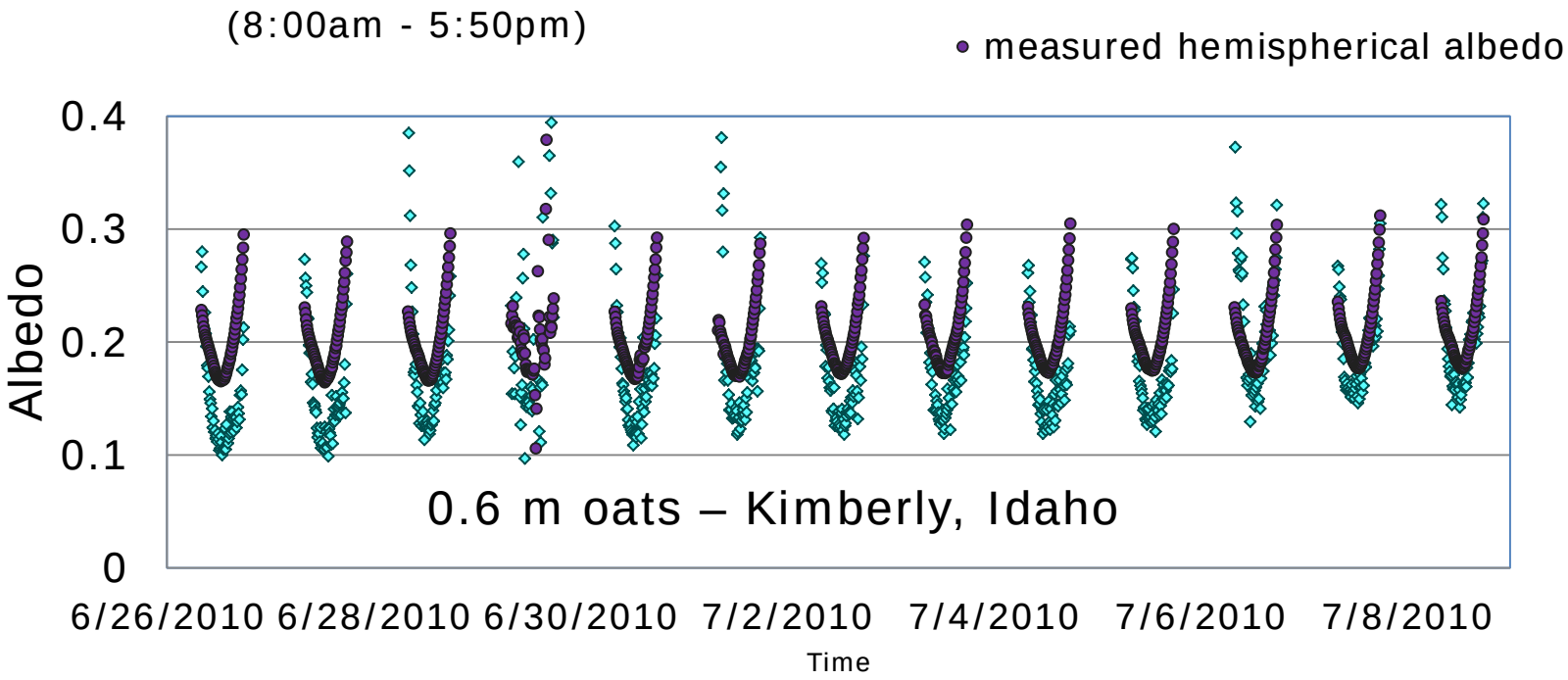
Wim Bastiaanssen, WaterWatch, the Netherlands, one of the fathers of ET retrievals from satellite (SEBAL)

Landsat Nadir View Simulator



Landsat Nadir View Simulator

Ratio of albedo estimated from Nadir View
To measured hemispherical albedo



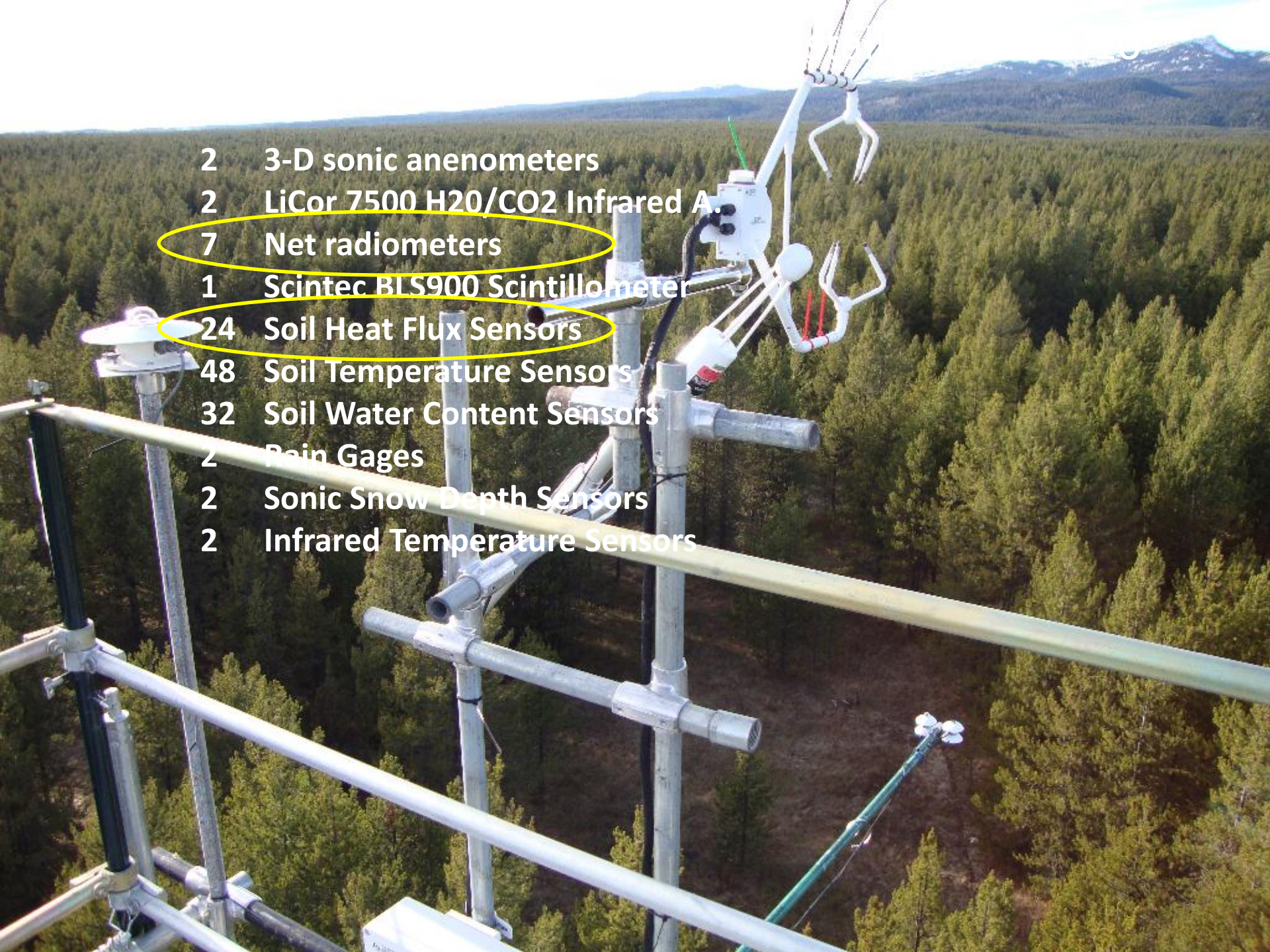
Comparison of Energy Balance Components with Ground-based Flux Measurements

Hollister Sage Brush site – Installed Feb. 2010

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

Island Park (nr. Yellowstone) Site: Alpine forest (south tower)
Installed October 2010

north tower


2 3-D sonic anenometers
2 LiCor 7500 H20/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

HARVARD Kennedy School
ASH INSTITUTE
for Democratic Governance and Innovation

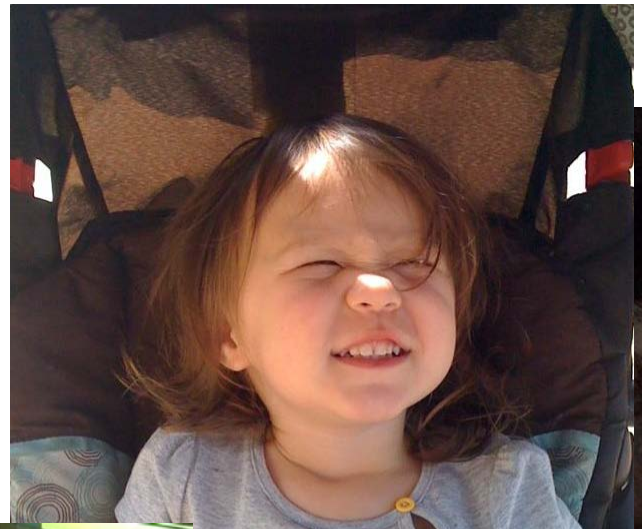
PBS “Visionaries” film w/ Sam Waterston

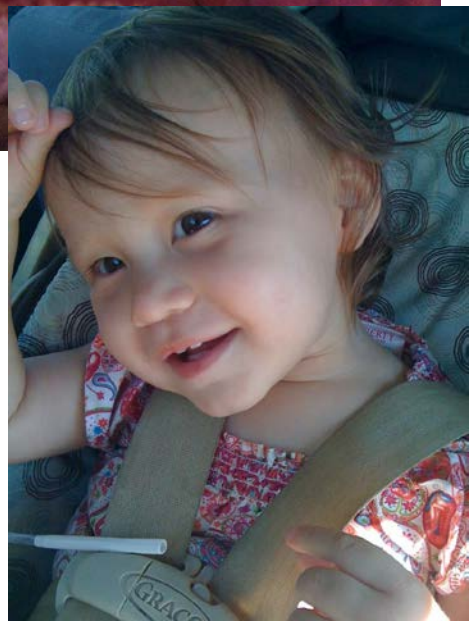
Quotes from Harvard's Site Visit Report

- "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 (..<u>with the help of historic Landsat thermal band images</u>)**."

Typical Idaho December Morning

Typical Idaho December Morning





Grandaughter’s are the best!