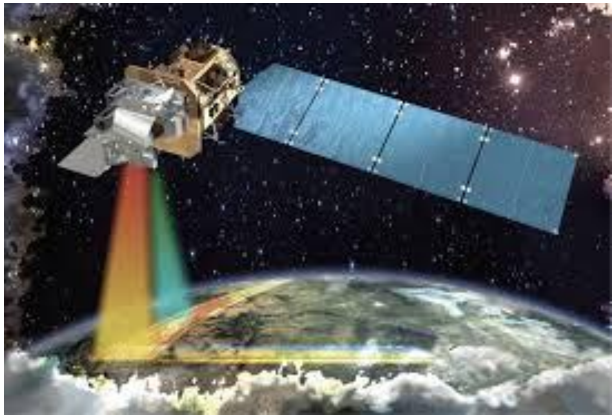
ANALYSES TO DETERMINE NEEDED SPECIFICATIONS FOR THERMAL IMAGING ON LANDSAT 9 AND BEYOND



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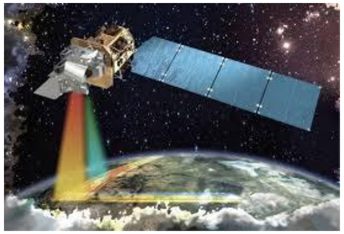
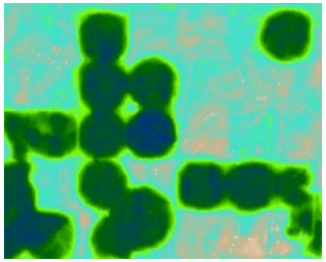
*Results provided to the **NASA Sustainable Land Imaging Architecture Study Team** March 30, 2014*

Background



- A series of analyses were made to provide information to the NASA Sustainable Land Imaging architecture study team regarding impacts of the accuracies and requirements of future 30 m – 100 m scale Earth Imaging missions on accuracy of thermally-based Evapotranspiration (ET) retrievals.

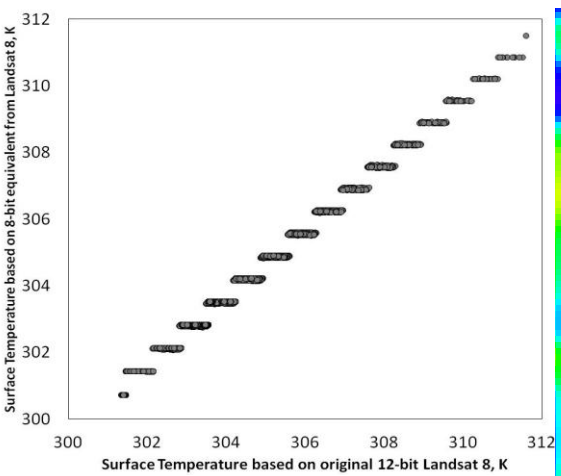


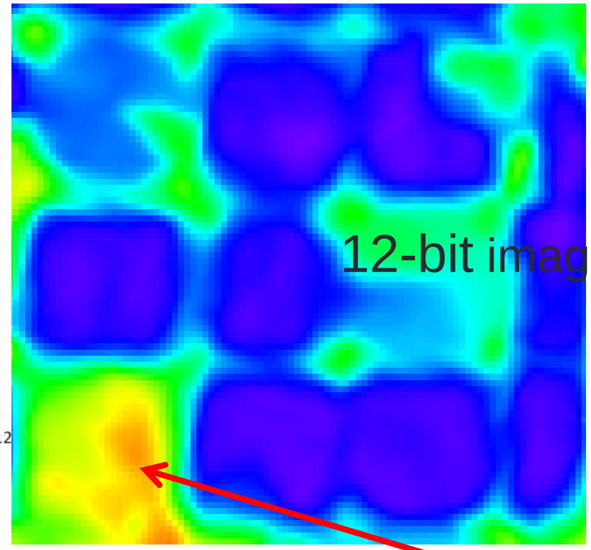
Approach

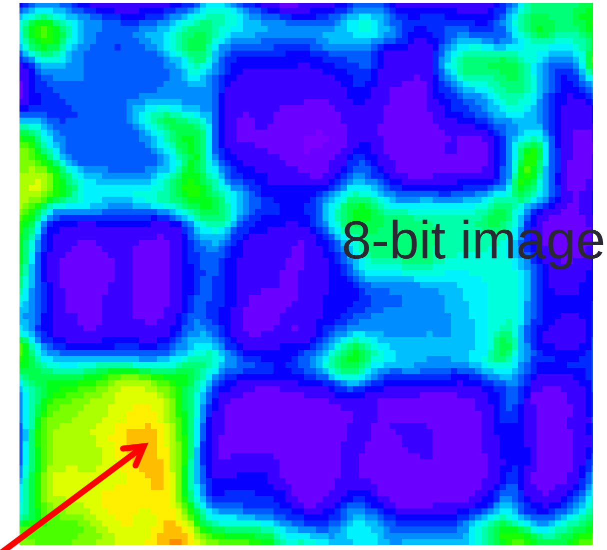
- We utilized the METRIC (Mapping Evapotranspiration at high Resolution using Internalized Calibration) to assess impacts on ET
  - METRIC is an operational surface energy balance-based model used in the midwest and western US to produce 30-m resolution ET maps for water resources management, water rights litigation, and water transfers
  - METRIC uses a CIMEC approach for calibration (Calibration using Inverse Modeling at Extreme Conditions) that removes impacts of systematic biases in remote sensing inputs including radiometric inputs and their calibrations
  - As a result, METRIC-produced ET is relatively resilient to many biases, provided they are systematic.

Thermal Sensor Accuracy for Evapotranspiration (ET) Retrievals

- **Q1:** What minimum signal to noise ratio (SNR) or dTNE is acceptable for ET retrievals?
- ***Approach***: We degraded L8 thermal images by ganging sequential digital numbers (DN's) to reduce the apparent numerical resolution and then recomputed ET and compared to nondegraded ET products
- **We compared ET retrieved from images processed during the L8 and L7 March 2013 underfly to assess differences caused by SNR and scaling of the two systems.**







Surface Temperature

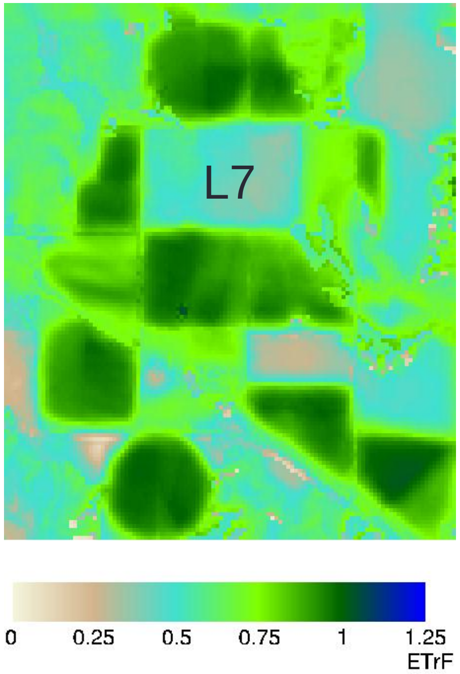
12-bit images have smoother transitions from pixel to pixel

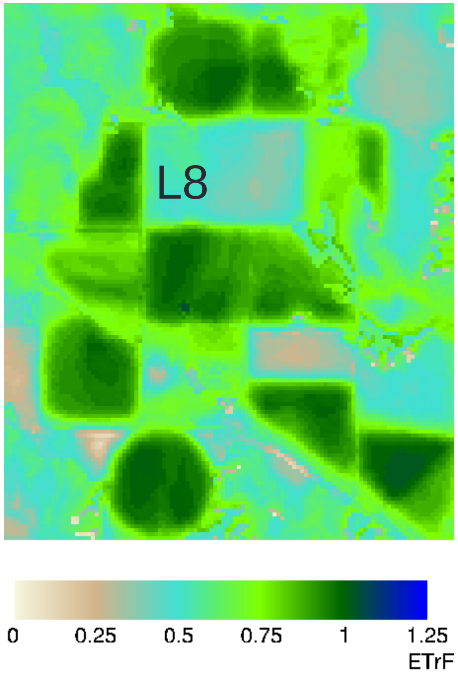
Analysis 1

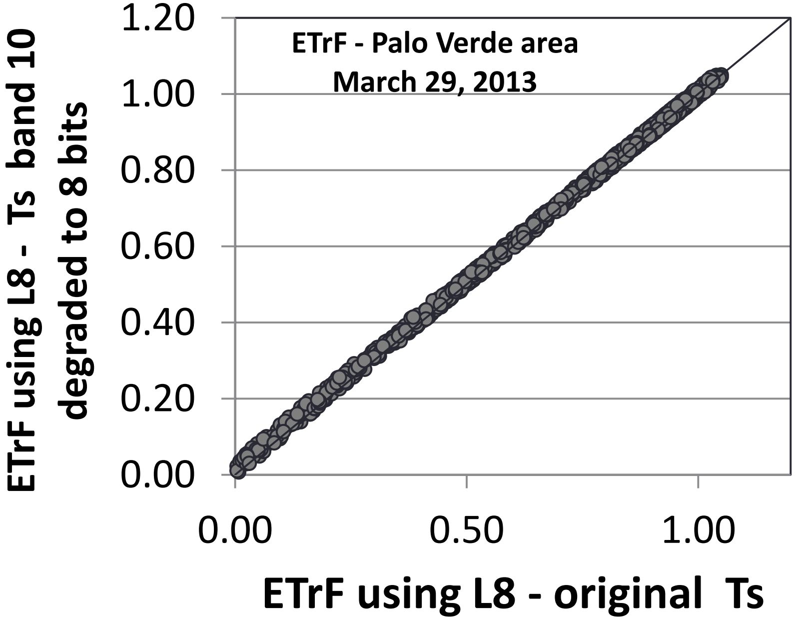
Thermal Sensor Accuracy for Evapotranspiration (ET) Retrievals

- **Q1:** What minimum signal to noise ratio (SNR) or dTNE is acceptable for ET retrievals?

Results:*The degradation had little effect on LST and ET, and created a maximum RMSE of about* ***1.5% error*** *in overall ET estimates.*







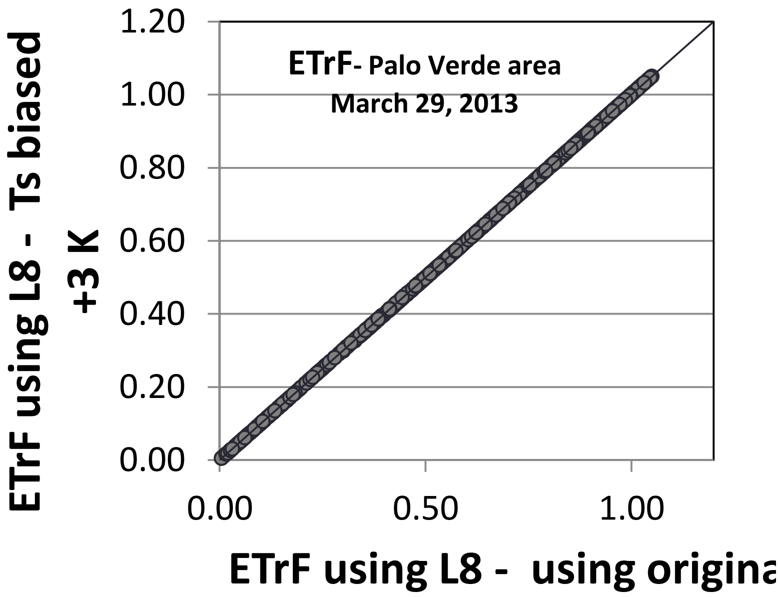
We have made this analysis, initially, for the L7/L8 underfly period near Blythe, California (Palo Verde)

Thermal Sensor Accuracy for Evapotranspiration (ET) Retrievals

- **Q2**: **What type of bias in land surface temperature (LST) retrievals can be tolerated for ET** determination using a CIMEC **(calibration using inversion)** type of calibration approach used in common ET models such as METRIC?

- **Approach:**
  - We Introduced globally systematic biases **(+/- 3 K)** into LST retrievals from L7 and L8, recomputed ET, and compared to ET from non-biased retrievals

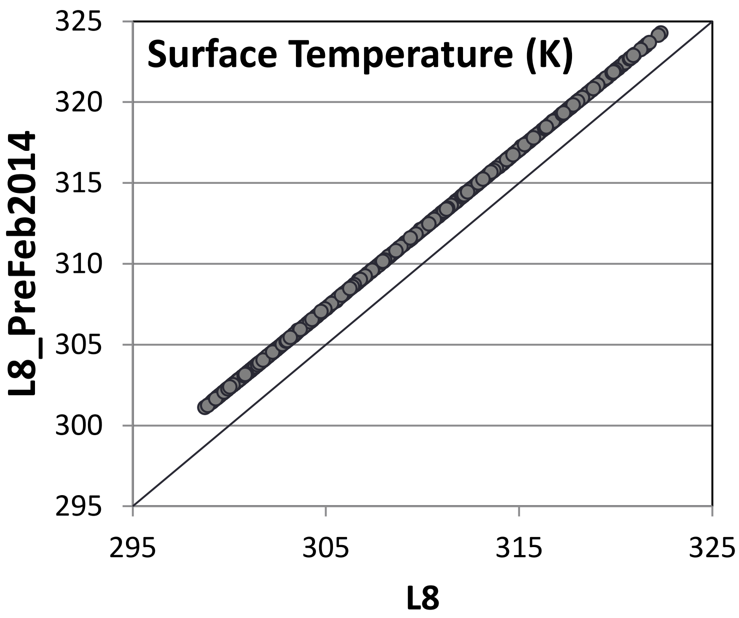
Results: *The **systematic** bias in temperature calibration of up to 3 K or 1% of LST does not substantially impair the accuracy of ET retrievals produced by the METRIC – **CIMEC** approach.*
RMSE in ET with a +/- 3 K bias is less than 0.1%.

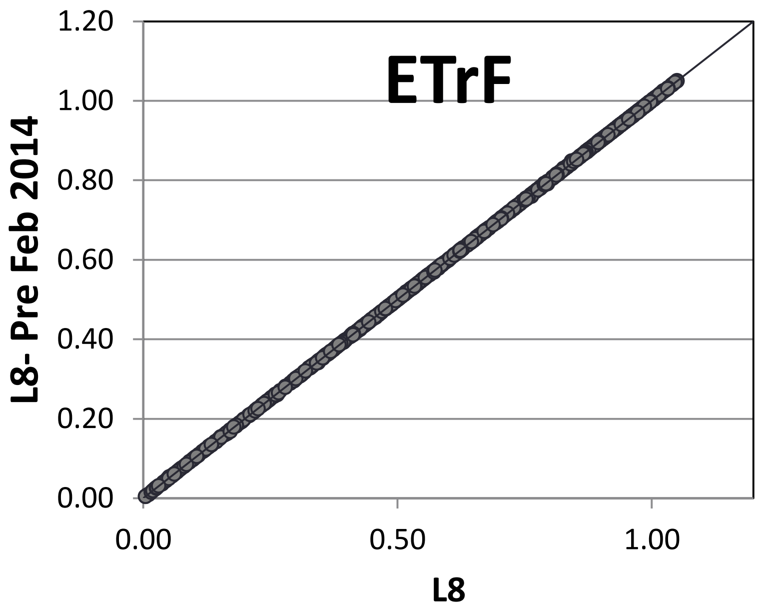


We have made this analysis, initially, for the L7/L8 underfly period near Blythe, California (Palo Verde)

Thermal Sensor Accuracy for Evapotranspiration (ET) Retrievals

- A related analysis was done by comparing ETrF during the March 29 underfly before and after the recalibration of the L8 shortwave and thermal images (in Feb. 2014): Palo Verde, CA





Conclusion: *The recalibration of band 10 (left) caused about a 3 K reduction in LST. However, the use of recalibrated LST and shortwave data did not substantially impair the accuracy of ET retrievals produced by the METRIC – CIMEC approach. RMSE in ETrF was less than 0.1%.*

Analysis 2

What if we have a thermal free-flyer?

What is the impact of using land surface temperature (LST) data acquired at a different time from acquisition of short-wave reflectances?

- **Questions and Approach (2 Questions):**
- A. **Cloud detection:** What is the best current L8 reflectance band or bands to specify on a 'thermal satellite' platform to assist with cloud and cloud shadow identification?
  - a. Evaluate how successful cloud and cloud-shadow identification is when using a thermal band, only
  - b. Analyze the advantage of providing red and NIR for identifying areas of high and low vegetation amounts that are associated with cool and warm surface temperature when discriminating clouds
  - c. Determine maximum spatial resolution required for the reflected band (bands) relative to the thermal band.

- B. **Time separation:** What is the impact of time separation between thermal and reflected imagery
- --- Reprocess ET retrievals from L7 and L8 thermal images where
  - a) reflectance data are taken from an L8 or L7 image that is 1 to 32 days earlier or later than the thermal imagery.

We have made A and B evaluations in both Nebraska (cloud-prone region) and Idaho (more clear region)

Can we detect clouds with only thermal band or do we need one or more shortwave bands?

- **Results– Manual masking with all bands was the basis**

Path 30 Row 32 (central Nebraska) 3-Jul-13	% clouded pixels missed relative to Manual Masking using All bands	% clouded pixels that are the same as Manual Masking using All bands	% erroneous masked pixels relative to Manual Masking using All bands	% clouded pixels missed relative to FMask using All bands	% clouded pixels that are the same as FMask using All bands	% erroneous masked pixels relative to FMask using All bands
Manual masking using:						
Thermal	0.9	98.3	0.8	8.5	91.2	0.2
Thermal and Red	1.1	98.1	0.8	8.7	91.2	0.1
Thermal and NIR	1.7	97.8	0.6	9.5	90.4	0.1
Thermal, Red, NIR, NDVI	1.6	97.9	0.5	9.5	90.4	0.1

Comment: 98% of clouded pixels were discernible (manually) using the thermal band alone for this particular date. Manual percentages were about 8% less than **FMask**. Thermal along can probably get the job done, depending on cloud elevation and density.

Analysis 2

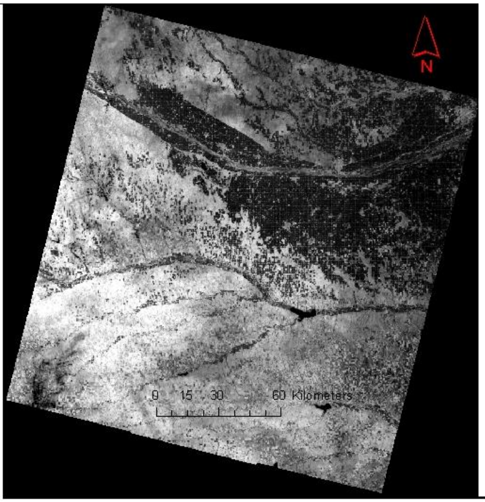
What is the impact of using land surface temperature (LST) data acquired at a different time from acquisition of short-wave reflectances: Impact on Cloud Identification – **thin Cirrus**

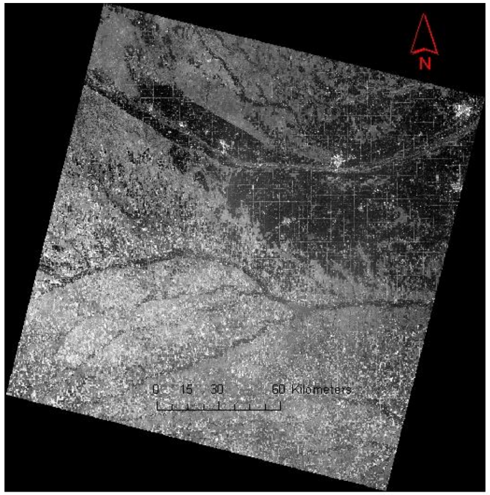
Path 30 Row 32 (central Nebraska) **8/20/2013**	% clouded pixels missed relative to Manual Masking using All bands	% clouded pixels that are the same as Manual Masking using All bands	% erroneous masked pixels relative to Manual Masking using All bands	% clouded pixels missed relative to FMask using All bands	% clouded pixels that are the same as FMask using All bands	% erro mask pixels relative to FMask using All bands
Manual masking using:						
Thermal	70.3	25.1	4.6	0.1	94.0	5.9
Thermal and Red	72.2	27.8	0.0	0.7	99.3	0.0
Thermal and NIR	72.2	27.8	0.0	0.7	99.3	0.0
Thermal, Red, NIR, NDVI	72.2	27.8	0.0	0.7	99.3	0.0

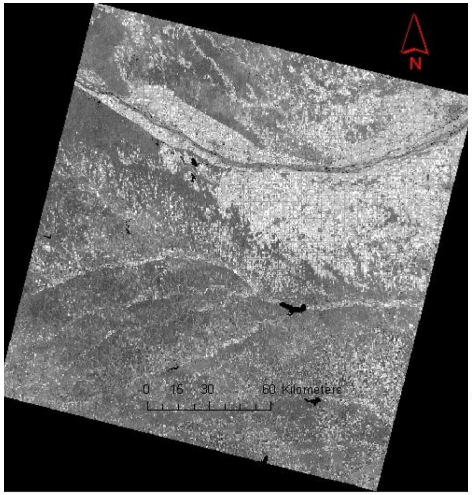
Comment: 70% of clouded pixels were missed by the manual masking using only thermal or thermal plus NIR or red, and were missed by Fmask compared to manual masking where all bands were available, especially the blue band. (see next slide).

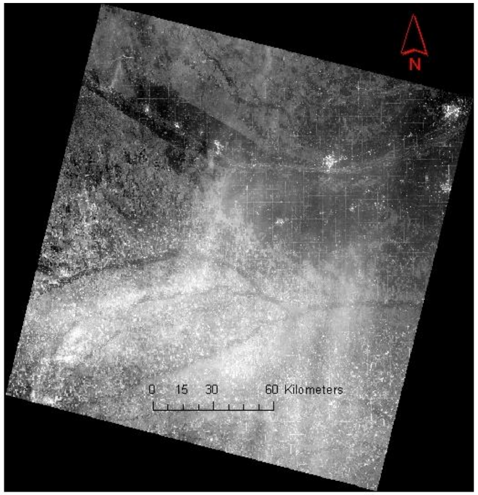
What is the impact of using land surface temperature (LST) data acquired at a different time from acquisition of short-wave reflectances: Impact on Cloud Identification—thin Cirrus

Landsat 8 Path 30 Row 32, August 20, 2013, Nebraska.









Thermal NIR Red Blue

See summary table on previous slide. 70% of clouded pixels were missed by the manual masking using only thermal or thermal plus NIR or Red, and by Fmask compared to manual masking where all bands were available, especially the blue band. **The blue band provided the means to identify the thin cirrus cloud.**

Analysis 2

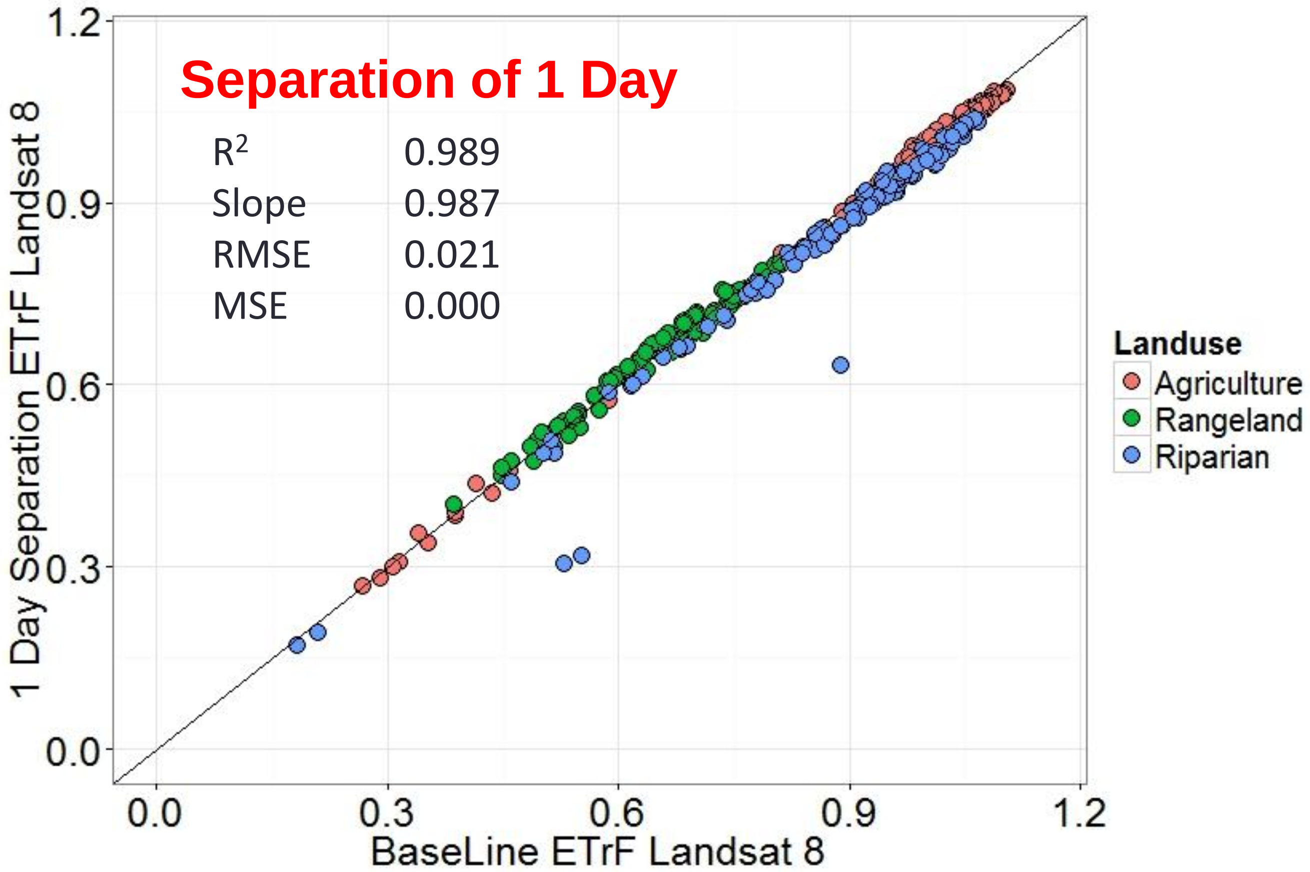
How does time separation between thermal and shortwave reduce accuracy of ET retrievals?

- **Approach: (Using overlap area gave us opportunity to evaluate the difference between 1day, 8 day, 16 day, 32 day separation time)**
- B. **Evaluate the impact of time separation between thermal and reflected imagery**
- --- Reprocess ET retrievals from L7 and L8 thermal images where
  - a) reflectance data are taken from an L8 or L7 image that is 1 to 32 days earlier and later than the thermal imagery.
  - **Comment:**
  - Separation of thermal and reflected data reduces accuracy of the ET estimate if clouded images cause the two inputs to be separated by more than about 10 days (see following slides that evaluate different lengths of time between inputs)

Analysis 2

What is the impact of using land surface temperature (LST) data acquired at a different time from acquisition of short-wave reflectances on ETrF?

Path 30 Row 32 (**Central Nebraska**) – L8 – **8/20/2013 for thermal, 8/21 short wave**

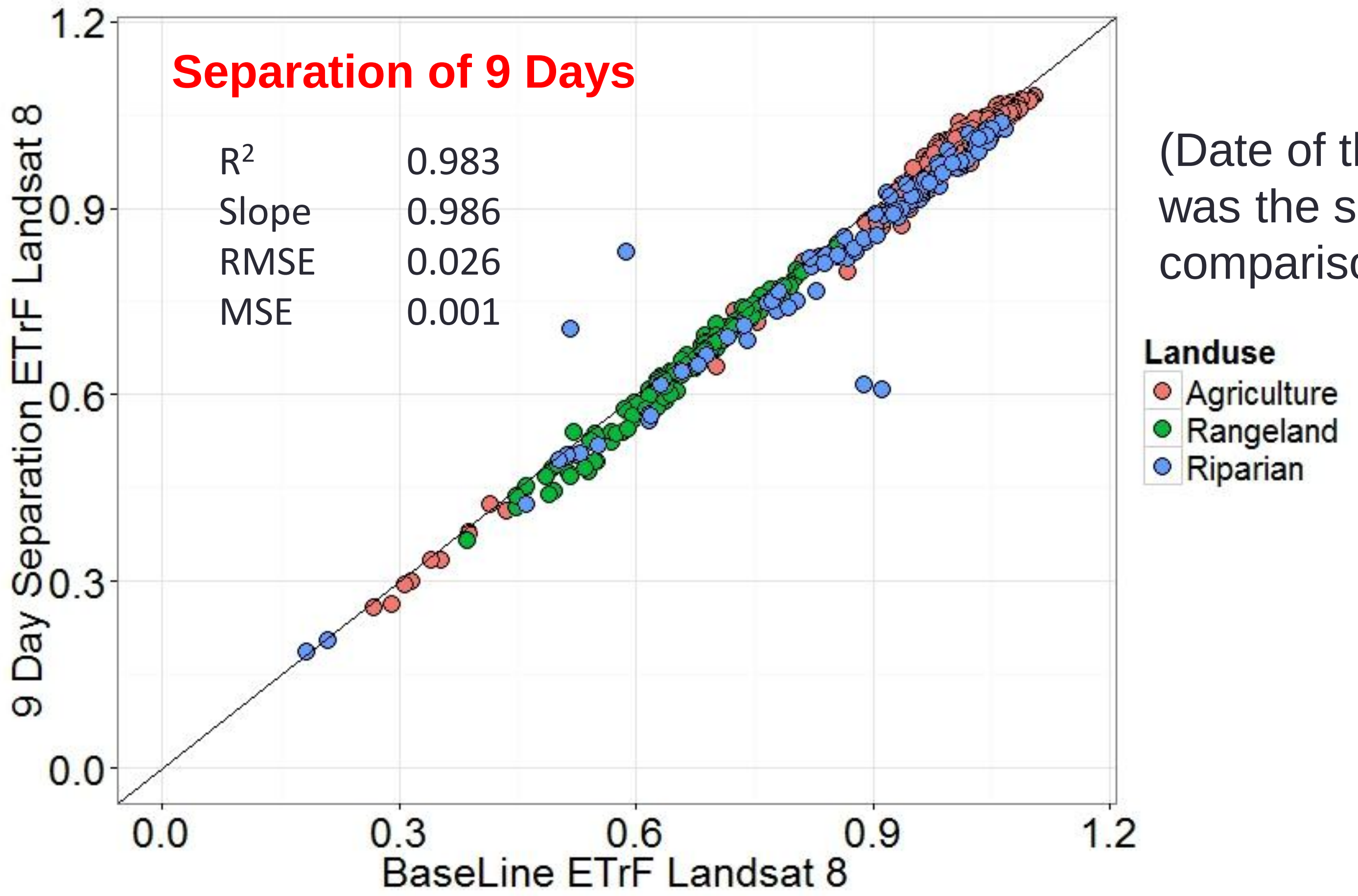


ETrF is the "fraction of reference ET" where reference ET represents a maximum rate of ET from full vegetation cover not short of water. ETrF is a 'relative ET' term produced by METRIC (dimensionless)

Analysis 2

What is the impact of using land surface temperature (LST) data acquired at a <u>different time</u> from acquisition of short-wave reflectances on ETrF?

Path 30 Row 32 (**Central Nebraska**) – L8 **– 8/20/2013 for thermal, 8/29 short wave**

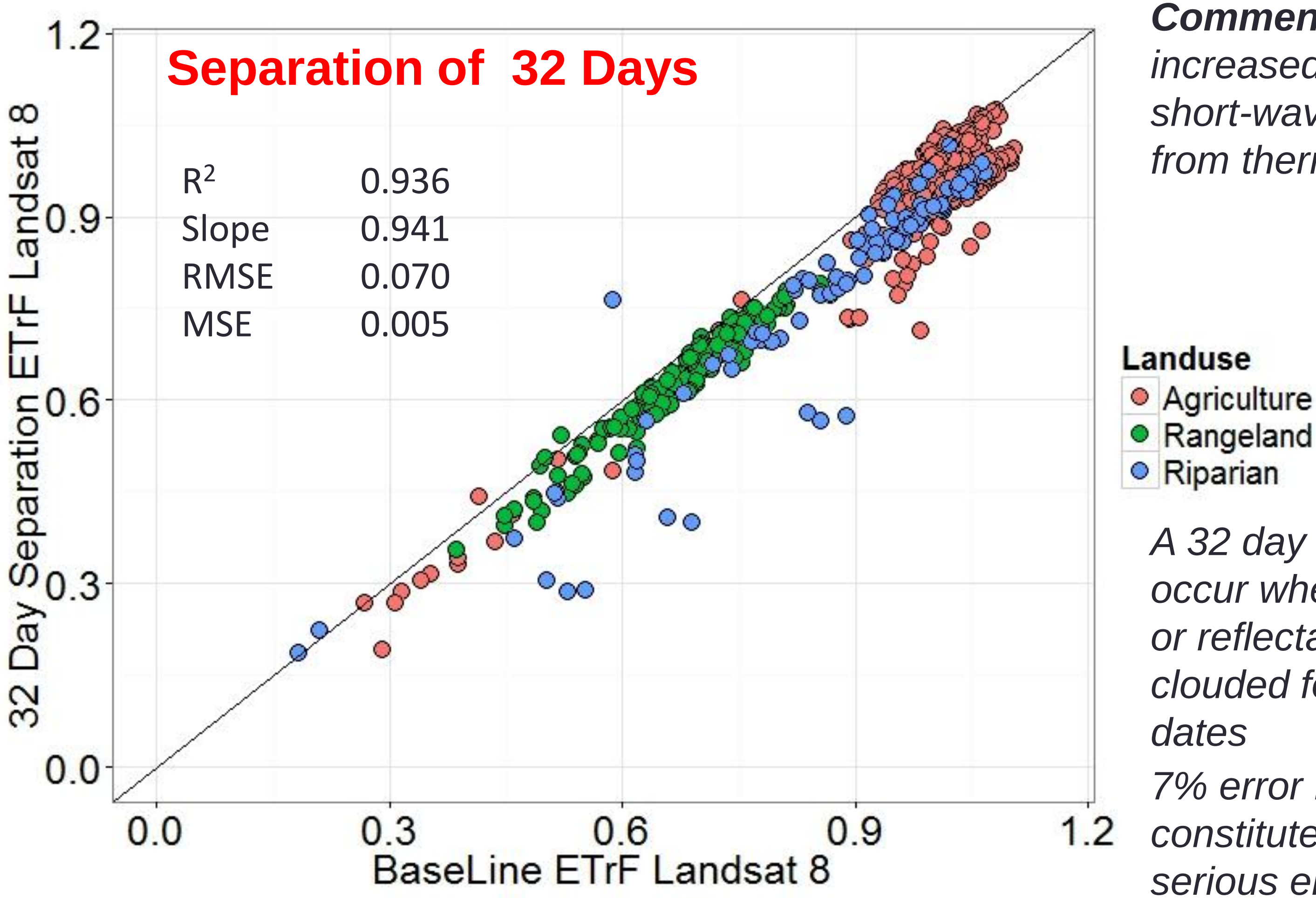


(Date of thermal image was the same for comparison)

Analysis 2

What is the impact of using land surface temperature (LST) data acquired at a different time from acquisition of short-wave reflectances on ETrF?

Path 30 Row 32 (**Central Nebraska**) – L8 **– 8/20/2013 for thermal, 9/22 short wave**



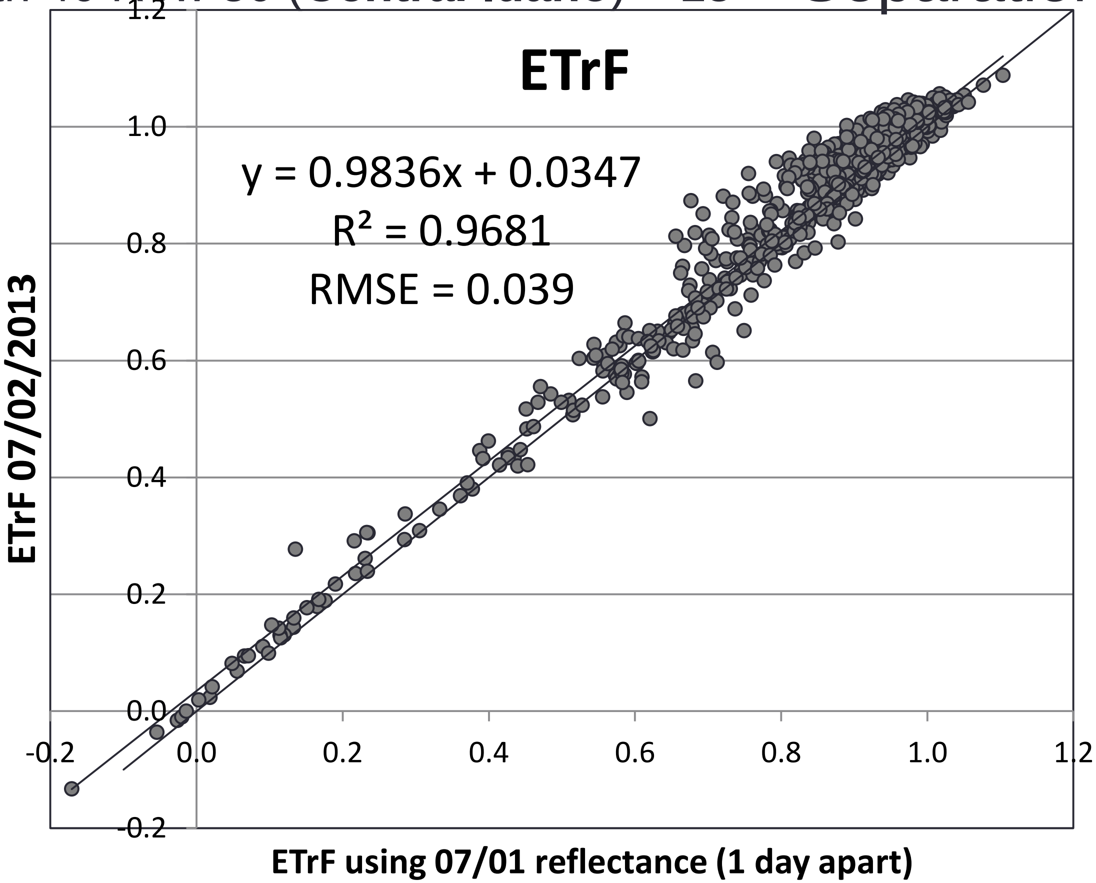
***Comment**: Error (RMSE) increased to **7%** when short-wave was separated from thermal by 32 days.*

A 32 day separation may occur when either thermal or reflectance images are clouded for intervening dates

7% error in ET may constitute substantial and serious error for use in water resources management and in litigation.

What is the impact of using land surface temperature (LST) data acquired at a different time from acquisition of short-wave reflectances on ETrF?

Path 40 Row 30 (**Central Idaho**) – L8 – Separation of 1 Day

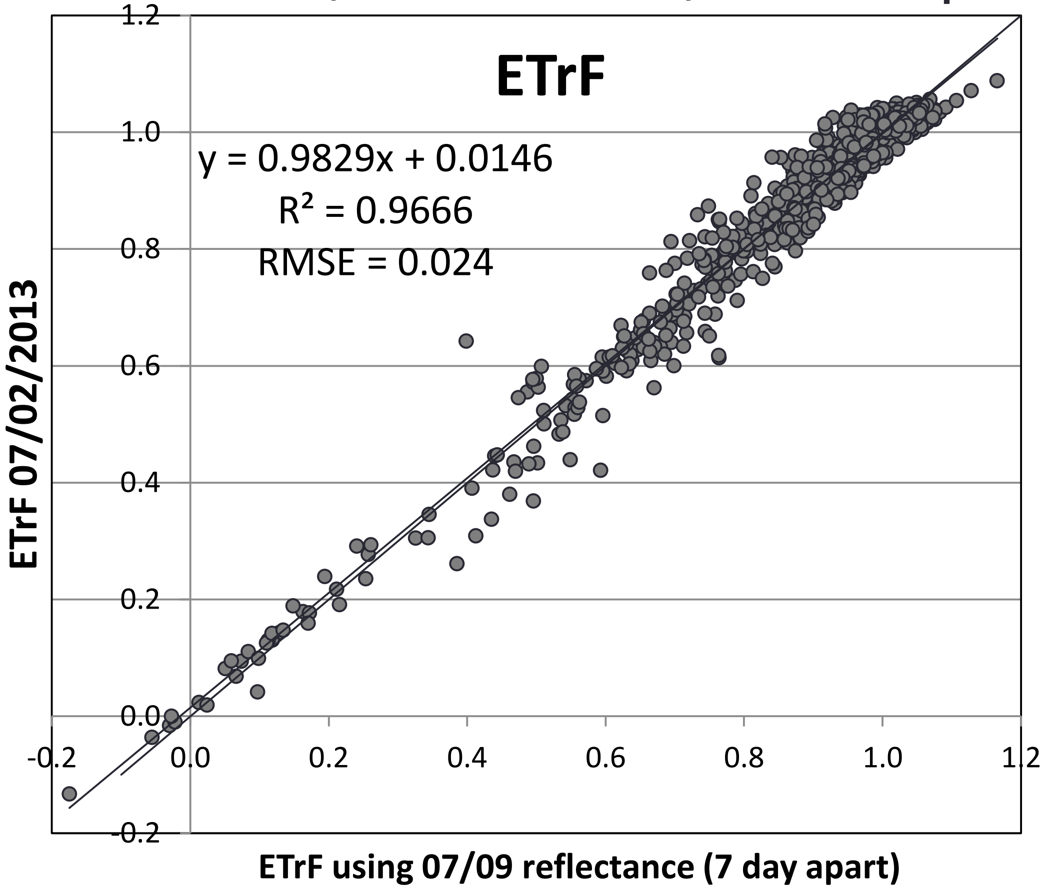


ETrF is the "fraction of reference ET" where reference ET represents a maximum rate of ET from full vegetation cover not short of water. ETrF is a 'relative ET' term produced by METRIC (dimensionless)

Analysis 2

What is the impact of using land surface temperature (LST) data acquired at a different time from acquisition of short-wave reflectances on ETrF?

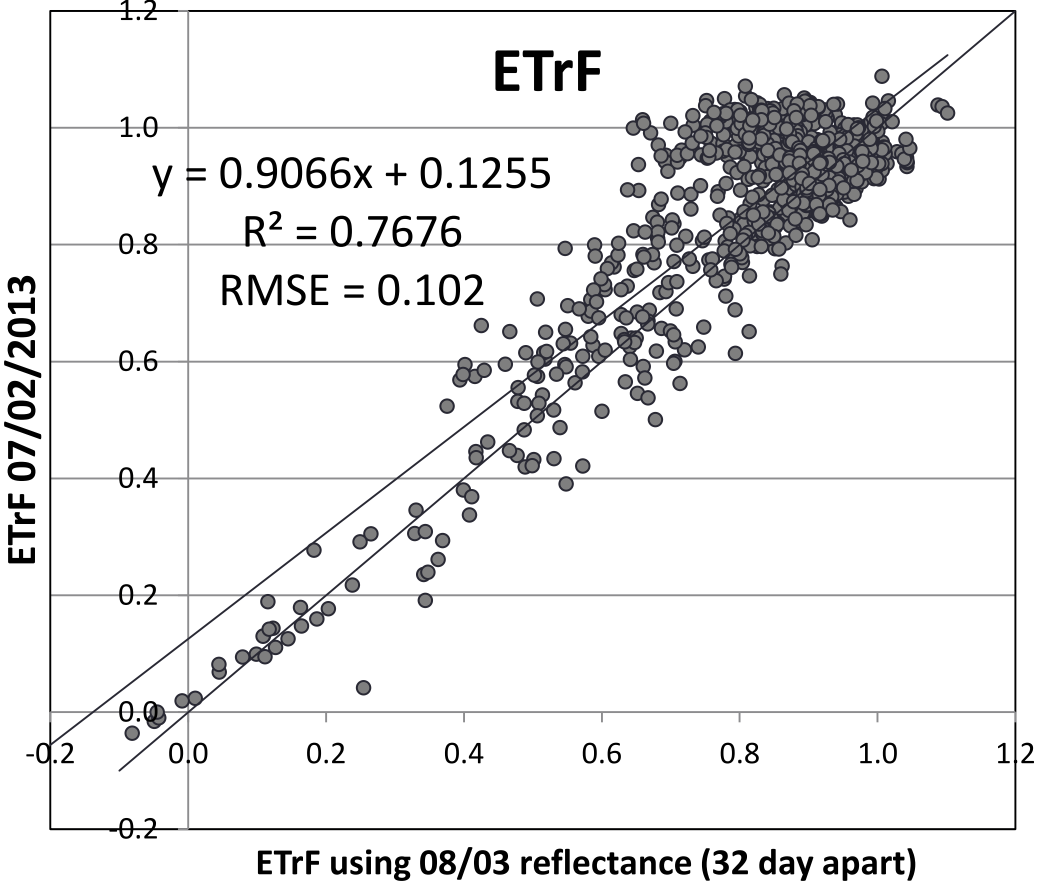
Path 40 Row 30 (**Central Idaho**) – L8 – Separation of 7 Days



Analysis 2

What is the impact of using land surface temperature (LST) data acquired at a <u>different time</u> from acquisition of short-wave reflectances on ETrF?

Path 40 Row 30 (**Central Idaho**) – L8 – Separation of 32 Days



***Comment**: Error (RMSE) increased to **5%** when short-wave was separated from thermal by 16 days and to **10%** when short-wave was separated from thermal by 32 days.*

A 32 day separation may occur when either thermal or reflectance images are clouded for intervening dates

10% error in ET may constitute substantial and serious error for use in water resources management and in litigation.

Analysis 3

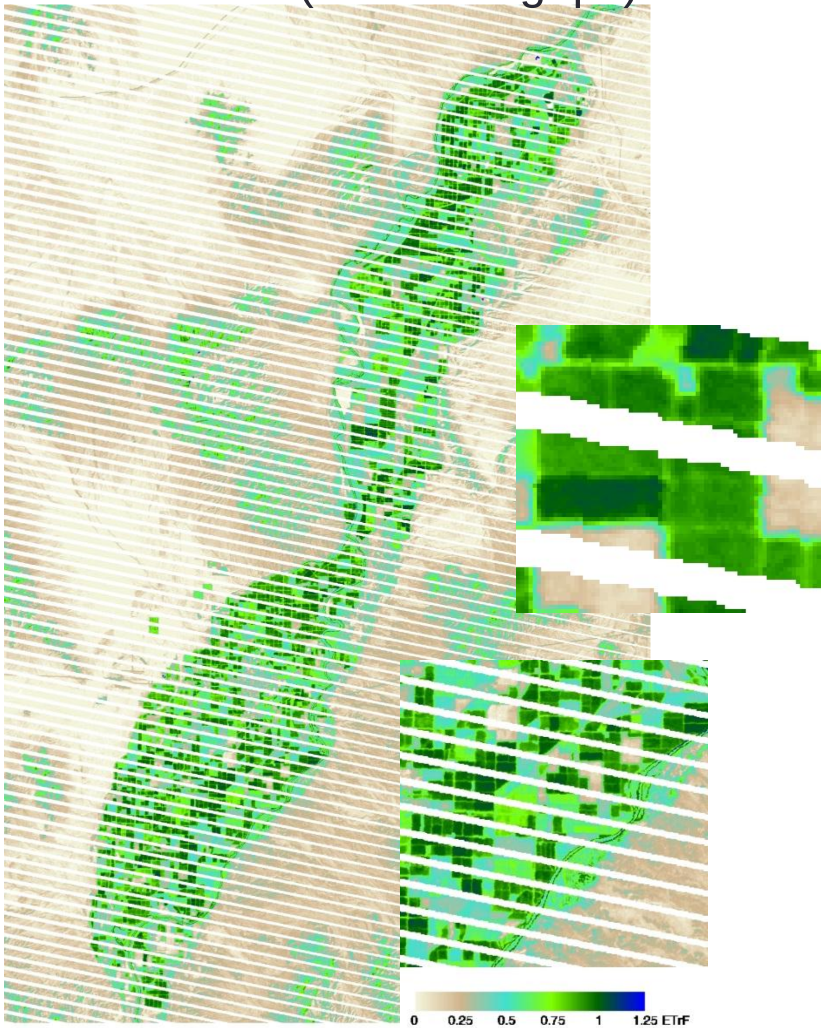
What is the impact of thermal pixel size on accuracy of ET within agricultural fields?
How much accuracy in ET do we loose along field edges when using 100 meter L8 thermal rather than 60m L7?

- **Approach:**
- Use the March 29 underfly of Landsat 8 and 7 for the Palo Verde (Blythe, California) area to evaluate degradation of ETrF with proximity to the edge of an agricultural field

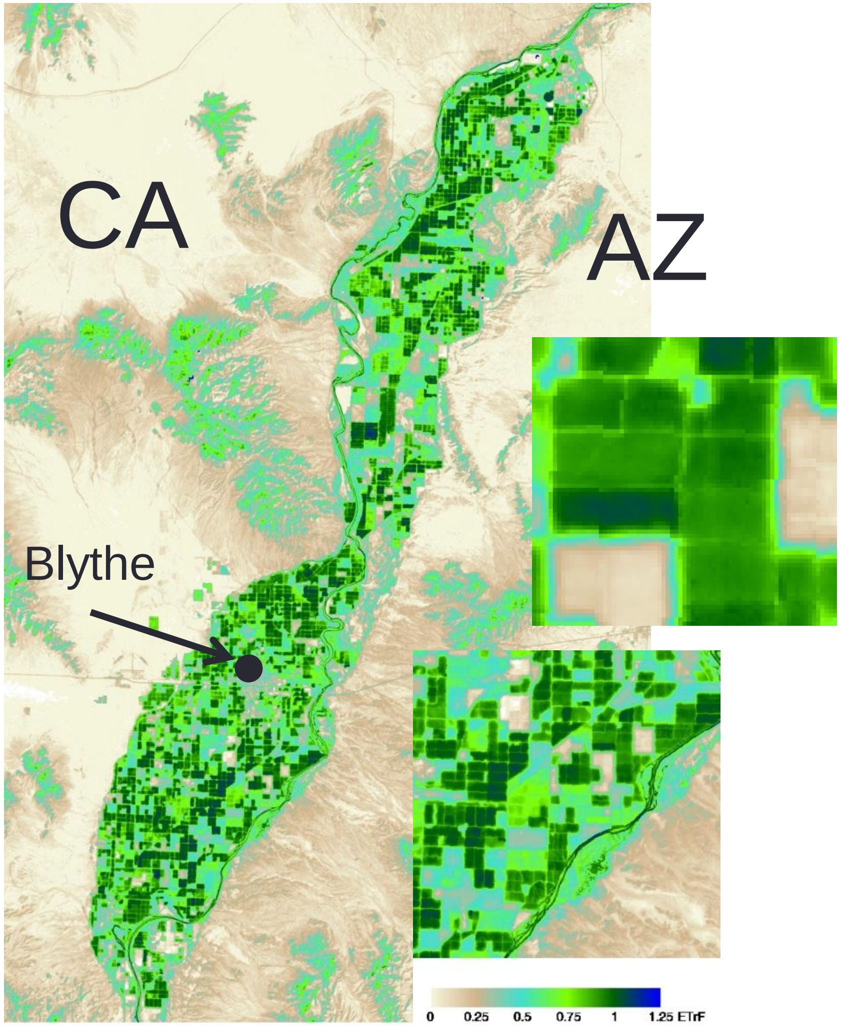
- Compare differences in ETrF between L8 and L7 where the larger 100 m thermal pixel of L8 should create larger degradation of ETrF near field boundaries

Landsat 7 Underfly with Landsat 8

Landsat 7 (with SLC gaps)

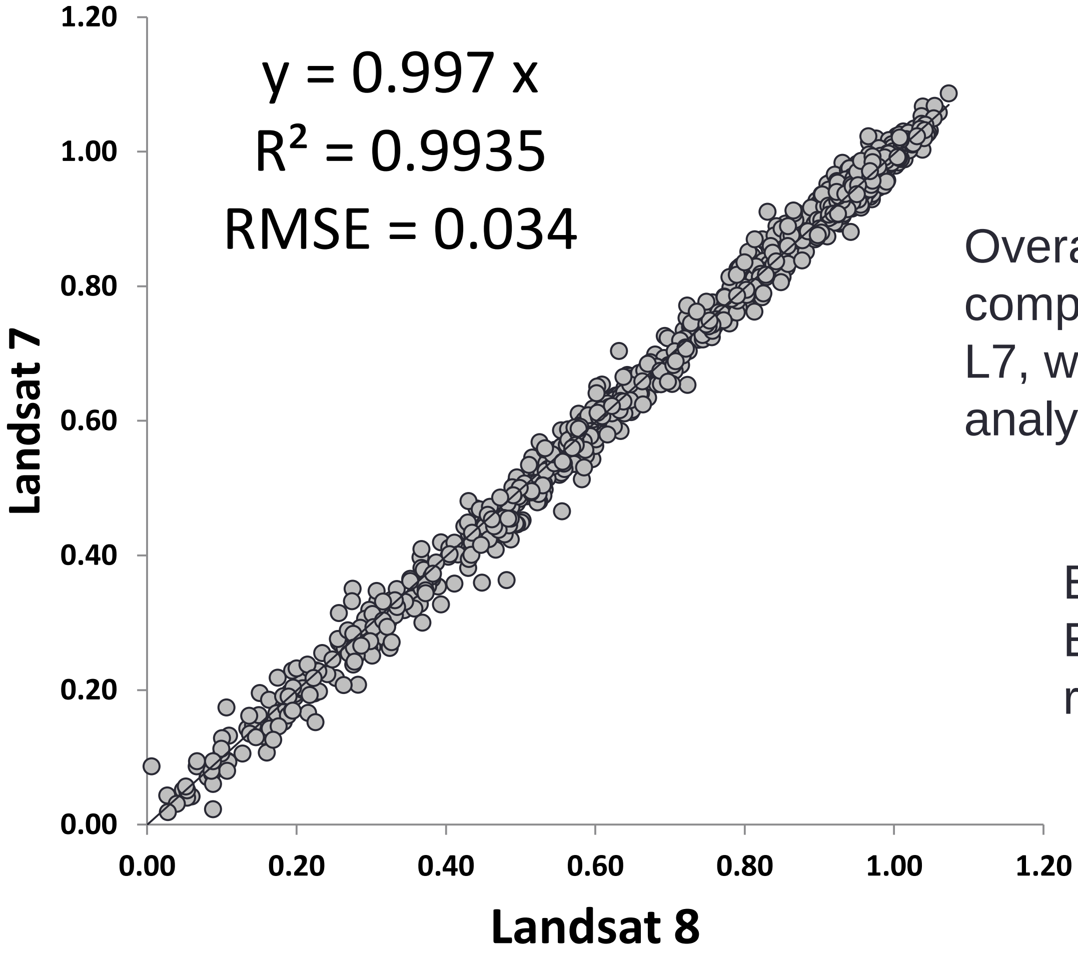


Landsat 8



ETrF images for Palo Verde (Blythe) area of SE California, March 29, 2013

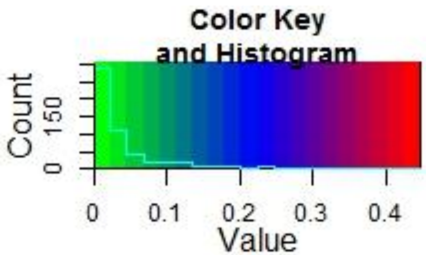
ETrF Comparison Between Landsat 8 and Landsat 7



Overall, ETrF from L8 compared well with ETrF from L7, which permitted this analysis.

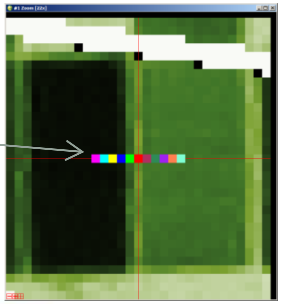
ETrF is the ‘relative’ ET rate (fraction of reference ET)

Departure of ETrF from that for the field center for 50 transects for **Landsat 7** (60 m thermal pixel), March 29, 2013, Palo Verde, CA

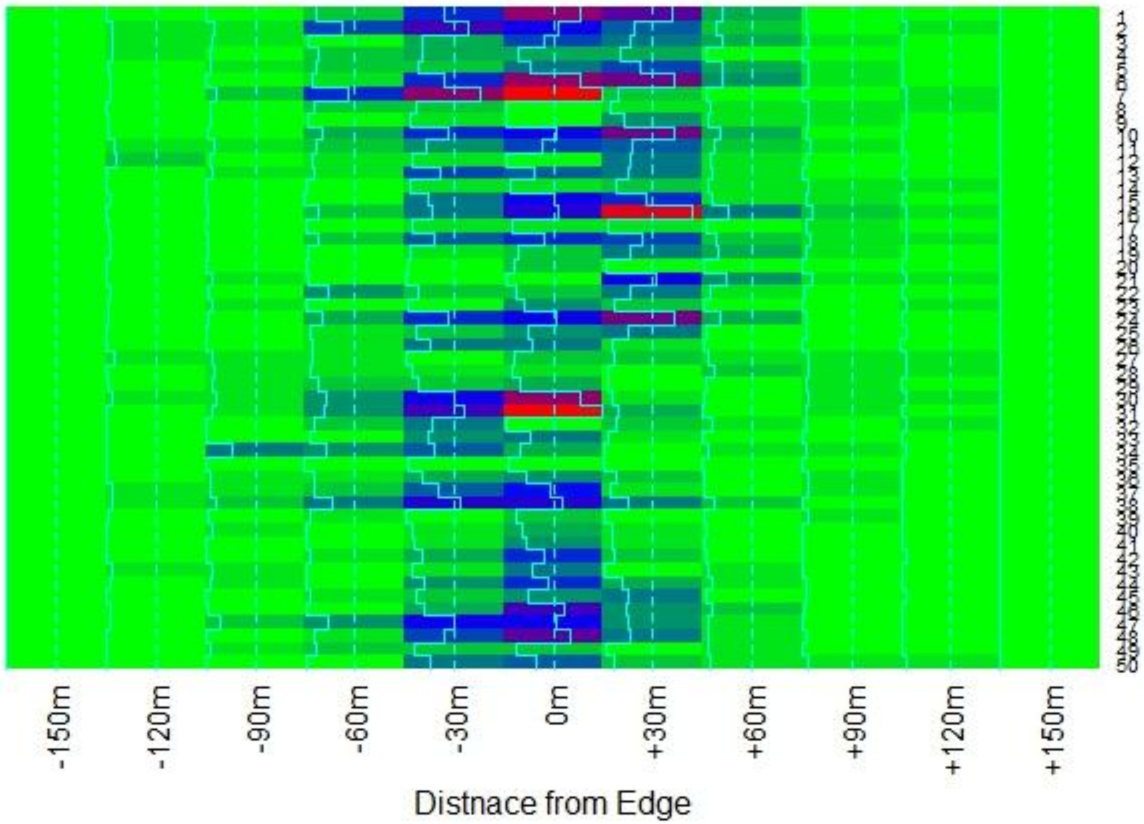


Landsat 7

Transect analysis

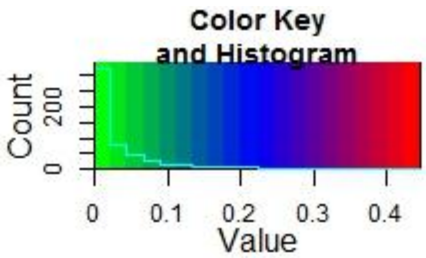


Error in ET between field edge and center



- Transects extended in both directions from field edges
- The greater the value, the greater the error introduced to ET due to proximity of the thermal pixel to the field edge.

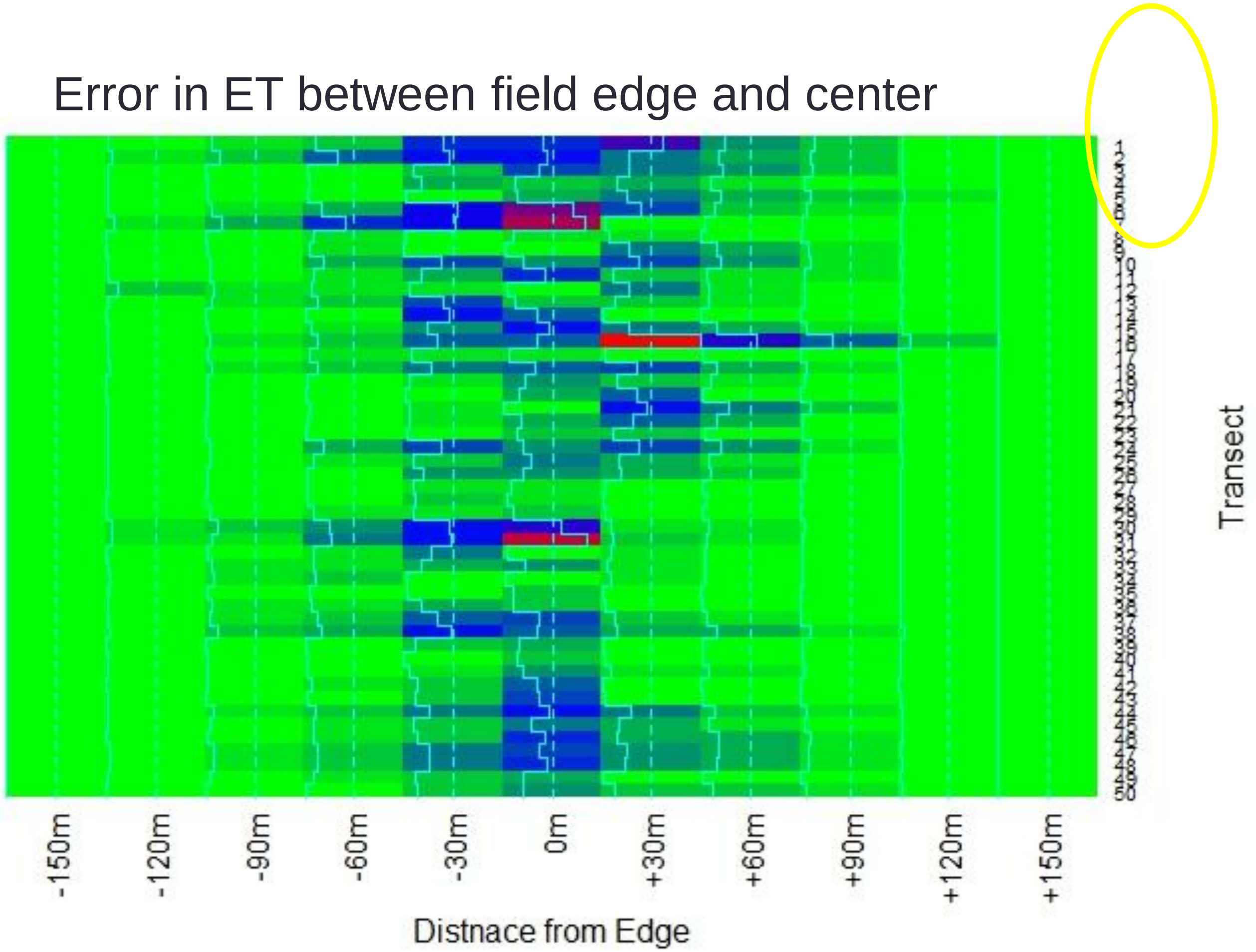
Departure of ETrF from that for the field center for 50 transects for **Landsat 8** (100 m thermal pixel), March 29, 2013, Palo Verde, CA



Landsat 8

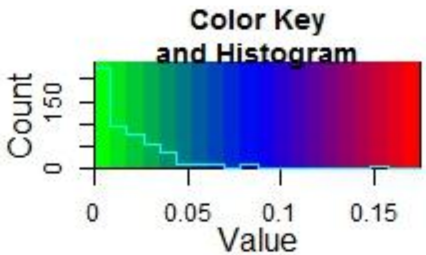
Transect analysis

Error in ET between field edge and center



- The greater the value, the greater the error introduced to ET due to proximity of the thermal pixel to the field edge.

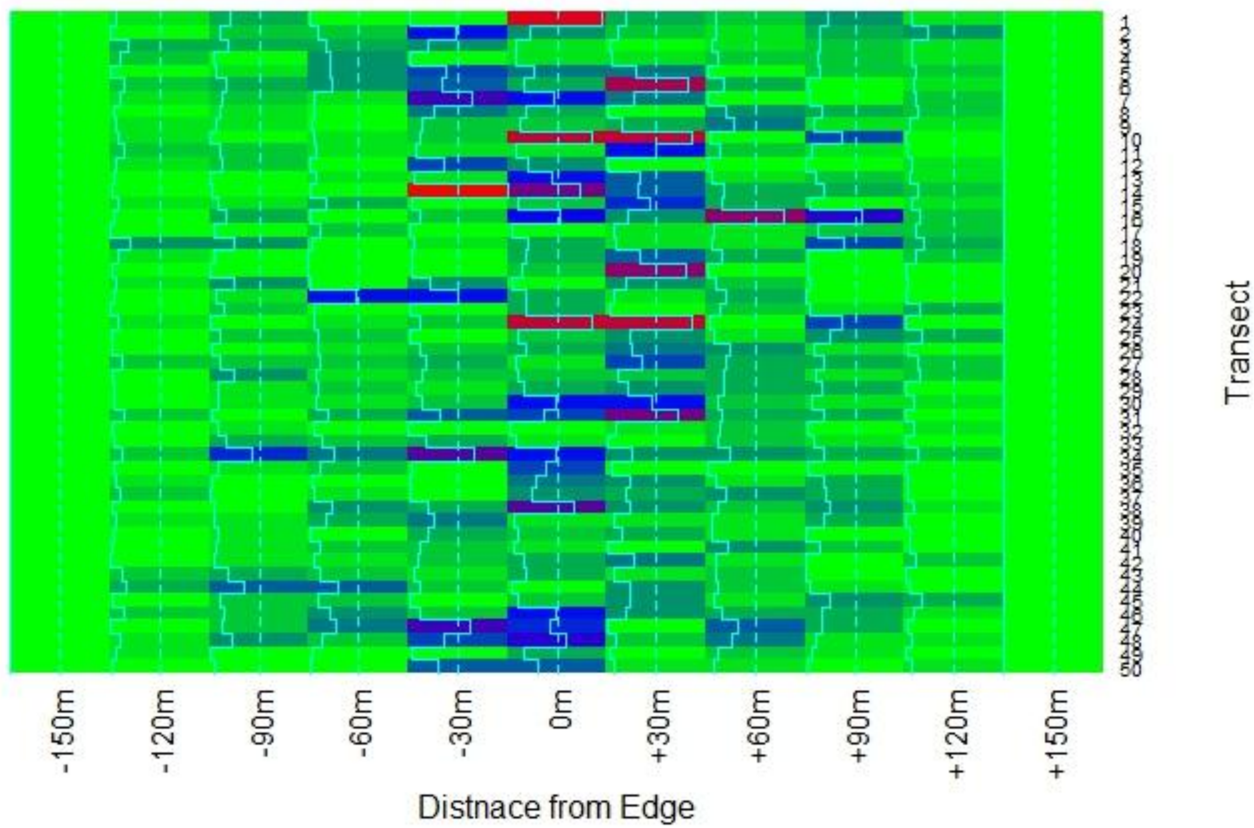
Difference in ETrF **between L7 and L8,** normalized to ETrF from the field center for 50 transects, March 29, 2013, Palo Verde, CA



Landsat 7 – Landsat 8

Transect analysis

Error in ET between field edge and center



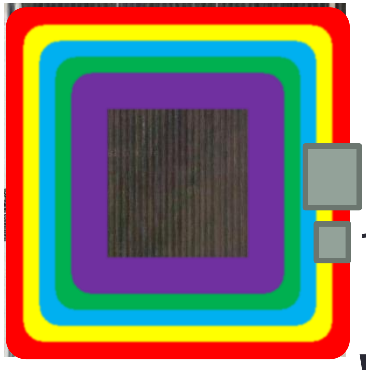
Conclusion: The departure of ETrF by Landsat 8 from that of Landsat 7 increased toward the field edge (center of plot) as the L8 thermal pixel was impacted by areas outside the field sooner than was L7.

Impact is as much as 15% within 30 m of field edge.

Analysis 3

Variation in from L8 for 30 m rings around fields, March 29, 2013, Palo Verde, CA

Ring analysis (30 m rings around field edges compared)



100 m Thermal Pixel (L8)

60 m Thermal Pixel (L7)

Variation in ET with distance from field edges

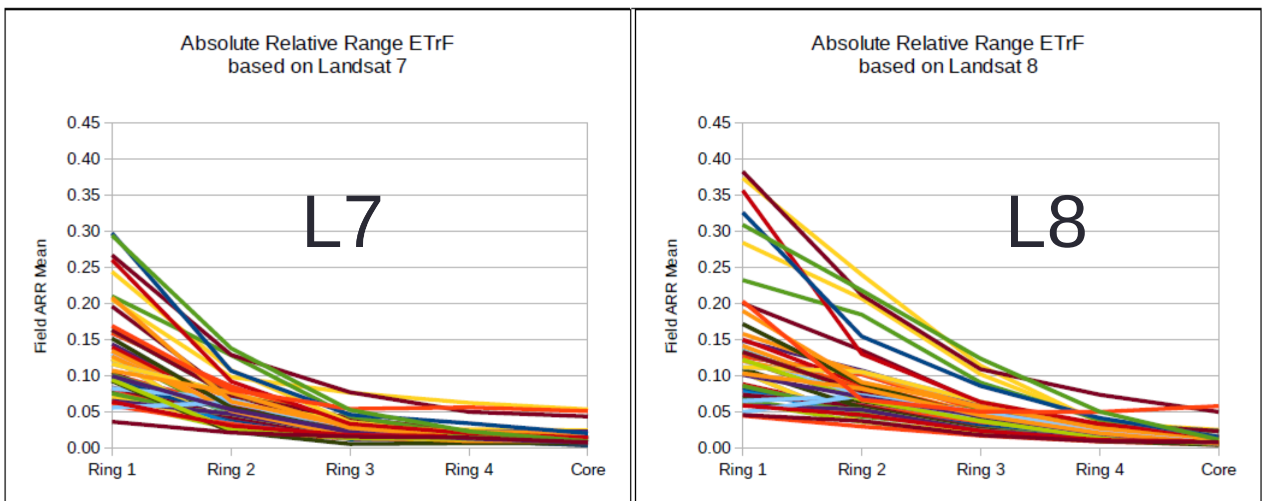


Figure 8: ETF absolute relative range for rings from the field edge (1) to the interior. (Landsat 7 on the left and Landsat 8 on the right.

Landsat 7 has less variation in Ring **1&2** because it has 60 m thermal pixel

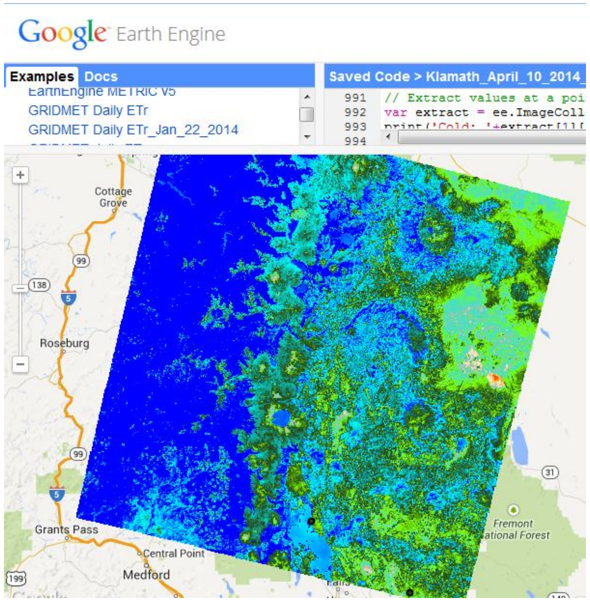
Distance from field edge (Ring 1, Ring 2, Ring 3, etc.)

(1 “Ring” = one 30 m Pixel

EEFlux (ET) on Google Earth Engine

Desert Research Institute; Univ. Nebraska-Lincoln; Univ. Idaho

- Status:
  - EEFlux version 0.5 is up and running and is being tested
  - NLDAS (hourly weather data) at 12 km is available for > 30 year period for CONUS
  - GridMET (daily, bias corrected weather data) at 4 km is available for > 30 year period for CONUS
  - Statsgo soils data is available for CONUS for top 0.15 m of soil
  - A time series daily soil water balance is functioning.
- Future Work:
  - Time integration of ET between Landsat images
  - Complete automation of application



Klamath, 2014

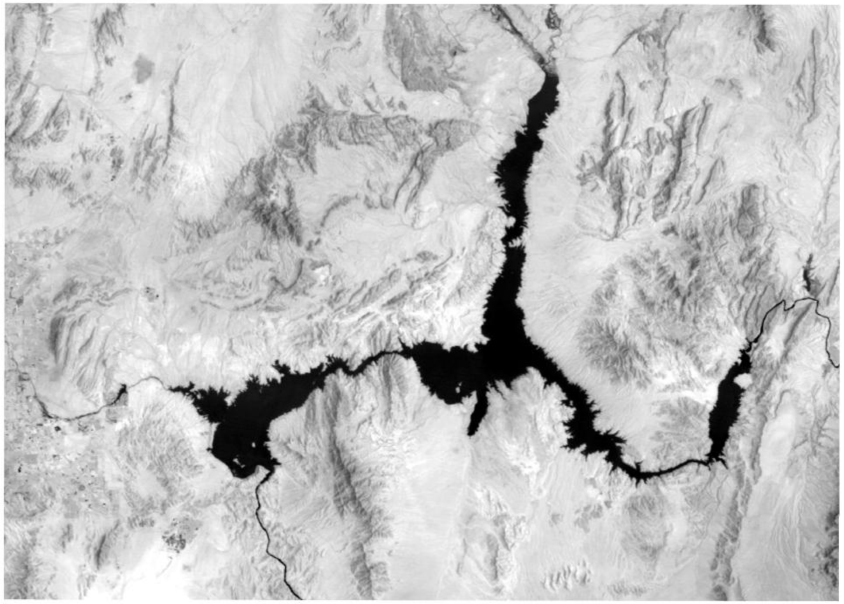
Landsat TIRS-Based Open Water Evaporation

Justin Huntington and group. DRI

- Land surface energy balance estimates of open water evaporation are complicated by heat storage of the water body, causing a delay, and often times a reduction, in monthly evaporation compared to a Class A Pan or grass surface that have less storage

- Landsat TIRS can be used to retrieve water "skin temperature" that is used to estimate saturated specific humidity

- When combined with local or gridded weather data of actual specific humidity and wind speed, evaporation is estimated using an aerodynamic – bulk mass transfer approach



Lake Mead, NV/AZ

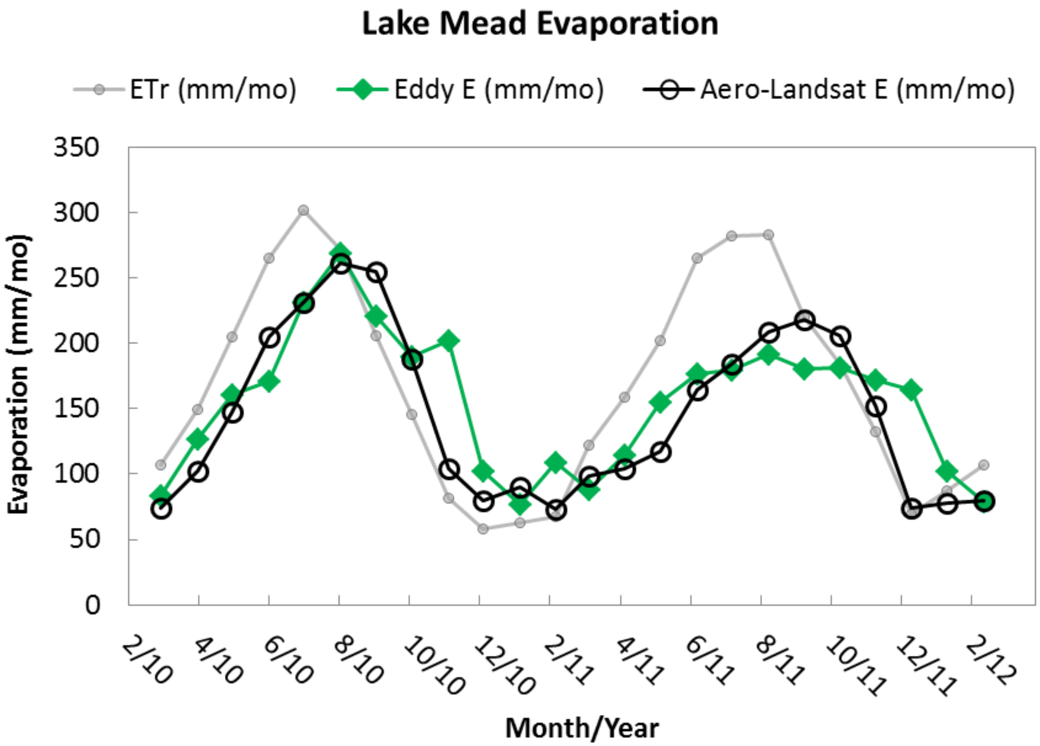
Landsat TIRS-Based Open Water Evaporation

- Initial tests of Landsat TIRS aerodynamic evaporation from Lake Mead compared to USGS eddy flux measurements

Photo by M. Moreo - USGS

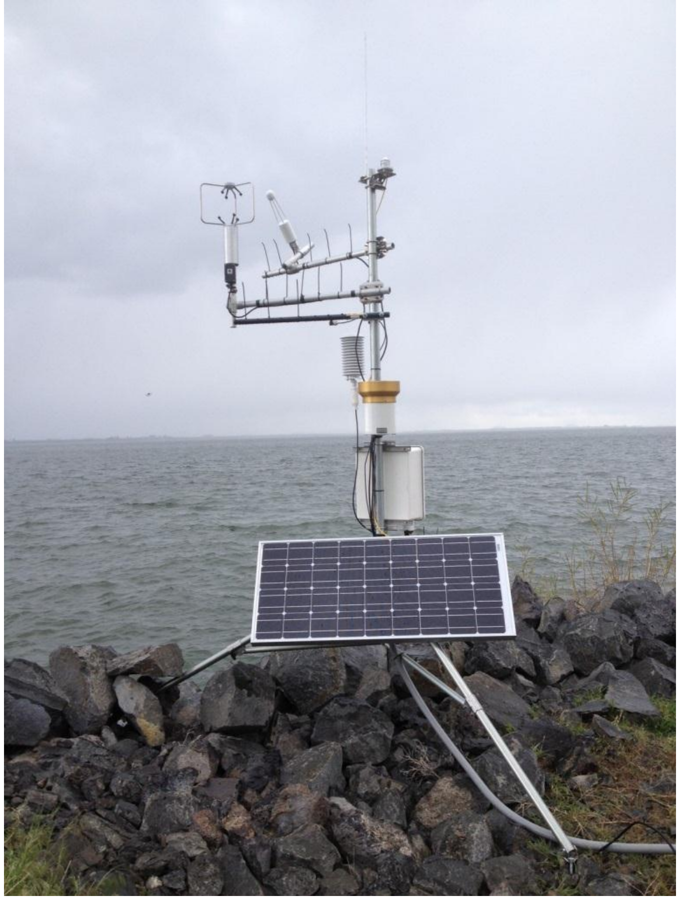
Initial results suggest that a TIRS based aerodynamic approach can simulate open water evaporation relatively well, and captures the lag in evaporation due to the heat storage effect…

Looking into Nov, 2010 and Dec, 2011… More frequent TIRS would be useful.



Landsat-TIRS Based Open Water Evaporation

- More tests are being performed for different water bodies using DRI's and USBR's Open Water Evaporation Network



American Falls, ID

American Falls, ID

Lahontan Reservoir, NV

Stampede Reservoir, CA

- **Extra Materials**

What is the role of Revisit Time in producing accurate time-integrated ET retrievals (i.e., monthly ET, growing-season ET)?

- **Approach:**
- Evaluate impacts of nominal 4 day, 8 day and 16 day revisit times:

i. Evaluate and construct a time series from a WRS path overlap area for a combined LS7 /LS8 time series (or LS5/7) having nominal 4 day repeat (WRS overlap areas have 1 and 7 day separation between alternate satellite overpasses).

ii. Process METRIC for as many images as are available for:

a. A cloud-prone region (Nebraska), where long times between clear images can occur)

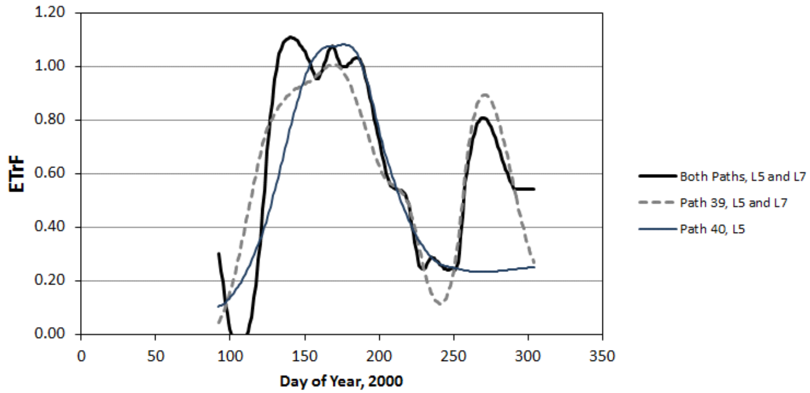
b. A less cloud-prone region (S.Idaho and SE California), where more Landsat image retrievals have low cloud occurrences

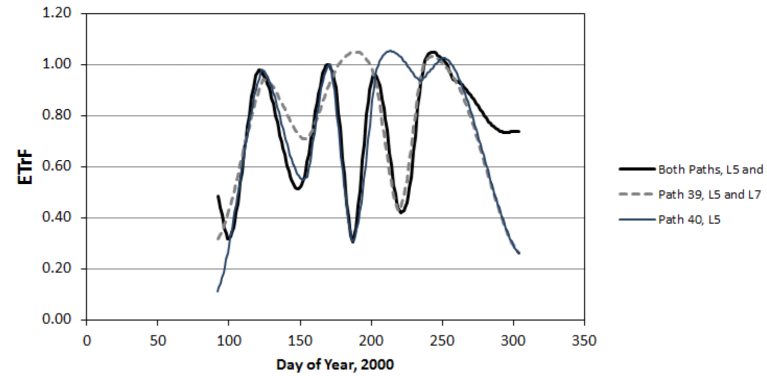
iii. Evaluate the positive impact of nominal 4 day revisit by processing and integrating, over time, ET from all images in the time series of overlap areas and two satellites

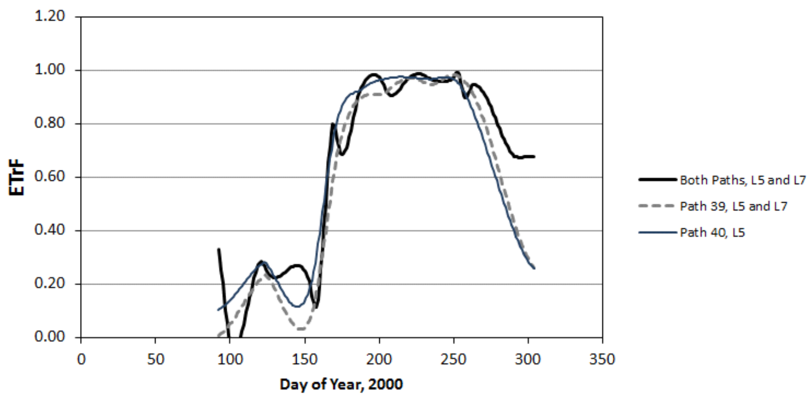
iv. Evaluate the impact of 8 day revisit by repeating (iii), but using only one path vs. using only the other path (producing two independent estimates of time integrated ET for intercomparison of growing season estimates for ET)

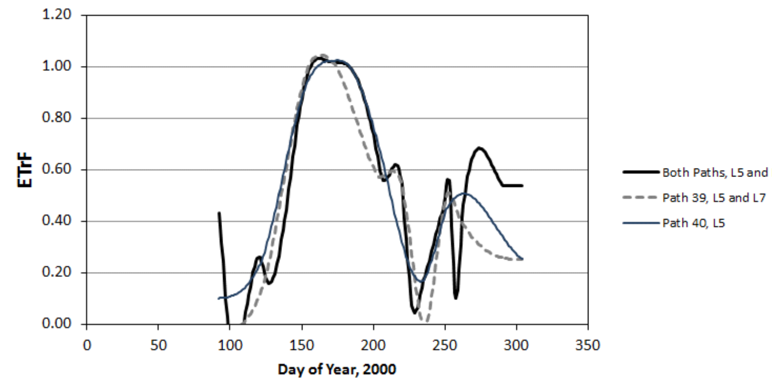
v. Evaluate the impact of 16 revisit by using only one path vs. the other path and using only one satellite vs. using the other satellite (producing four independent estimates of time integrated ET for intercomparison of growing season estimates for ET)

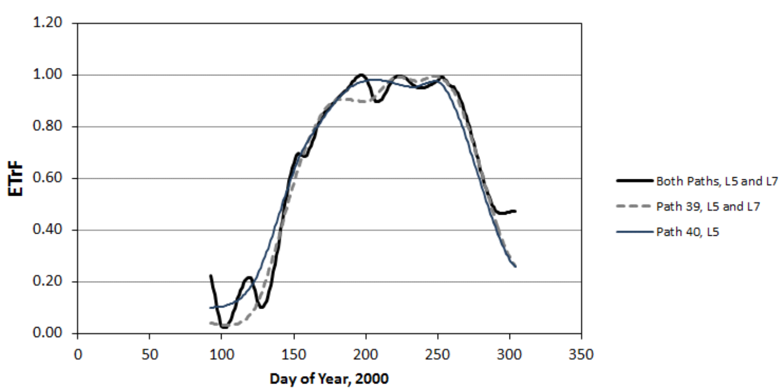
Analysis 4 --- Examples of Relative ET vs. Time as a function of Revisit frequency

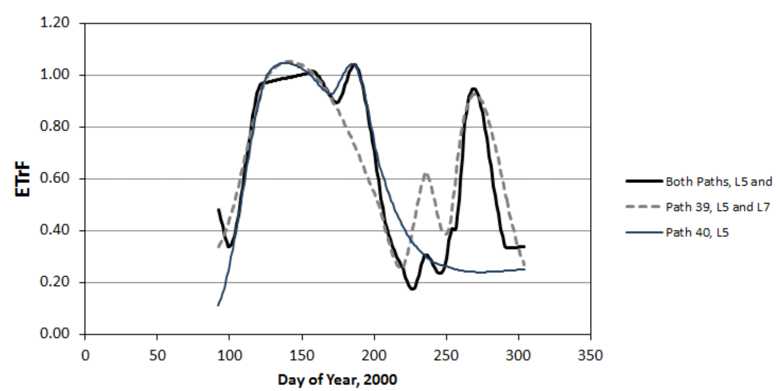




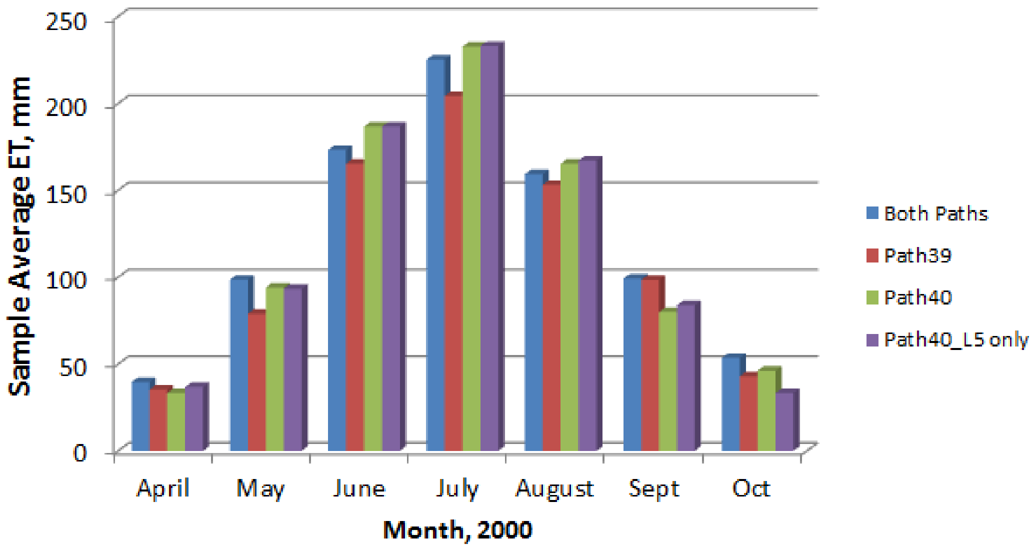








Analysis 4 --- Monthly ET vs. Image Availability (from Path Overlap)



Idaho

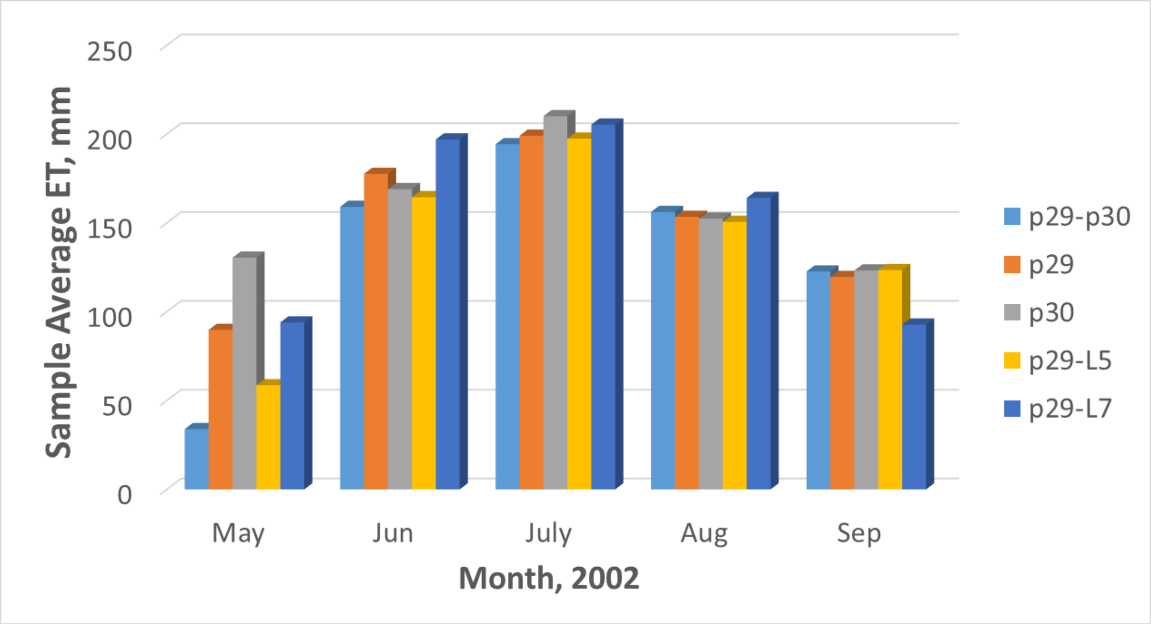
Seasonal (Average of the 1546 pixels)
April to October

	ET(mm)	% diff	ETrF
Both Paths	849	0.00	0.60
Path39	778	8.30	0.50
Path40	838	1.25	0.53
Path40_L5	834	1.74	0.53
ETr	1422		

Nebraska

Seasonal (Average of the 1500 pixels)
May to September

	ET(mm)	% diff	ETrF
Both Paths	666	0.00	0.66
Path30	784	17.72	0.78
Path29	740	11.11	0.74
Path29_L5	694	4.20	0.69
Path29_L7	753	13.06	0.75
ETr	1006		



Conclusion: Having 4 day revisit can increase Growing Season ET estimate by 8 to 15%