SSEBop FANO Overview

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USGS EROS

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U.S. Department of the Interior
U.S. Geological Survey

ET Estimation in Agriculture…

- It is a **RESPONSE** variable as opposed to precipitation (driver)
- It reflects the integrated effects of Energy/Aerodynamics, Soil Moisture, Vegetation and Environmental Stress

Potential

Energy | Wind/RH

Limitations

Moisture | Vegetation | Env. Stress





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ET = Crop Water Use

Evapotranspiration = transpiration + evaporation

Photo: Suat Irmak, UNL-Department of Biological Systems Engineering

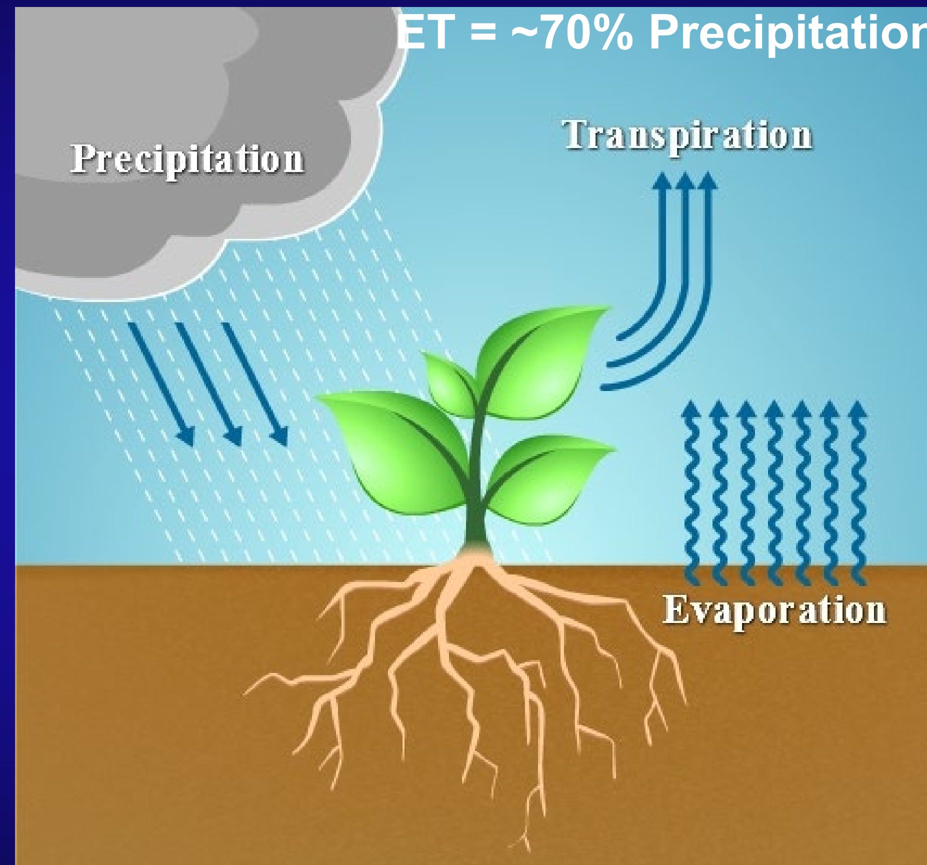

Image: http://blogs.oregonstate.edu/inspire/2011/07/21/evapotranspiration/

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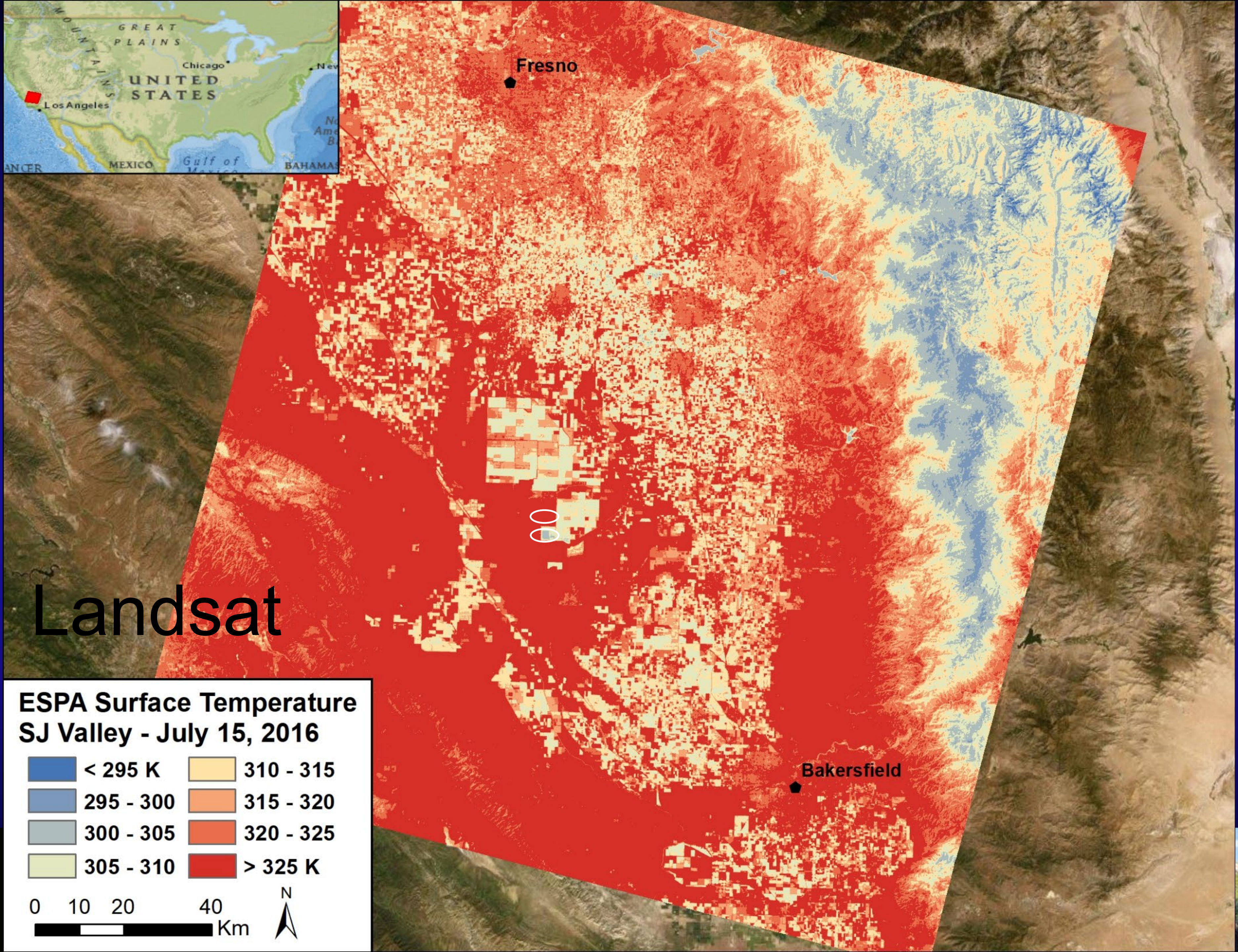
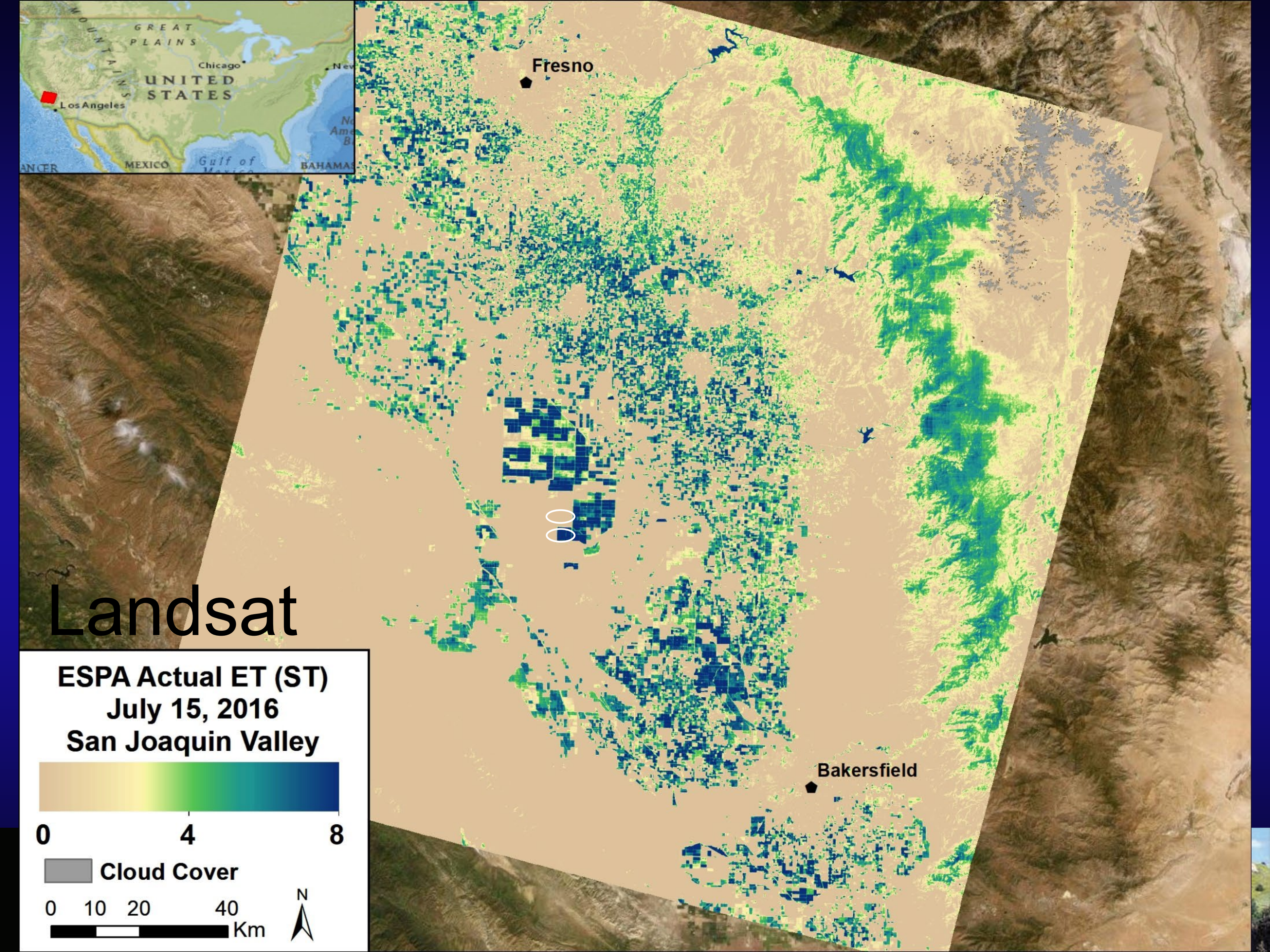


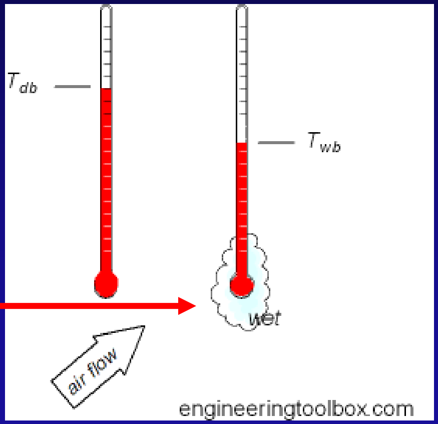
GREAT PLAINS
MOUNTAINS
Chicago
New
UNITED STATES
Los Angeles
MEXICO
Gulf of Mexico
BAHAMAS
Fresno
Bakersfield
Landsat
ESPA Surface Temperature
SJ Valley - July 15, 2016
< 295 K
295 - 300
300 - 305
305 - 310
310 - 315
315 - 320
320 - 325
> 325 K
0 10 20 40
Km
N


Fresno
Bakersfield
GREAT PLAINS
Chicago
UNITED STATES
Los Angeles
MEXICO
Gulf of Mexico
BAHAMAS
Landsat
ESPA Actual ET (ST)
July 15, 2016
San Joaquin Valley
0
4
8
Cloud Cover
0 10 20 40
Km
N

SSEBop Explained with "Psychrometry"

$$ea = es - \gamma \; (Td - Tw)$$

$$\gamma = \frac{CpP}{\varepsilon\lambda} = 0.665 * 10^{-3} P$$



ea = actual vapor pressure (kPa)
es = saturated V.P. (kPa) at Tw

γ psychrometric constant [kPa °C^{-1}]
P atmospheric pressure [kPa],
λ latent heat of vaporization, 2.45 [MJ kg^{-1}]
c_p specific heat of air at constant pressure, 1.013 10^{-3} [MJ kg^{-1} °C^{-1}]
ε ratio molecular weight of water vapor/dry air = 0.622.

Ferrel, W.M. (1886); Allen et al. (1998)

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Air vs “Surface” Psychrometry

(Thermometer vs Satellite Psychrometry)

Vapor pressure/relative humidity (standard psychrometry)

$$ea = es - \gamma \ (Td - Tw)$$

(Ferrel, W.M. (1886); Allen et al. (1998))

=>Large temp difference is a result of dry air (low RH) and hence low vapor pressure

Actual ET: Satellite “Psychrometry” Approach (SPA): SSEBop

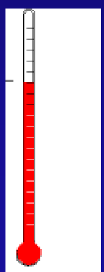
$$ETa = ETo - \gamma^{s} (Ts - Tc) ETo$$

(Senay, 2018. App Eng. in Ag.)

=>Large temperature difference is a result of dry soil/vegetation complex (low moisture, high stress) and hence low actual ET

Energy Balance Model: SSEBop

Land surface temperature differences are used to measure landscape water use rates through the effect of evaporative cooling



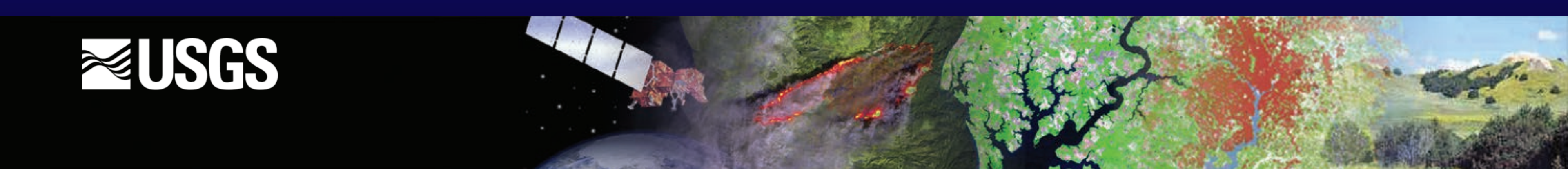
ET = Max

ET = moderate

ET = small

http://www.croplife.com/equipment/
irrigation-control-gets-ever-more-precise/

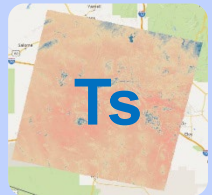
https://www.irrigationaustralia.com.au/
about-us/types-of-irrigation/drip-irrigation



Operational Simplified Surface Energy Balance (SSEBop)

SSEBop
Evapotranspiration

Surface Temp (Ts)

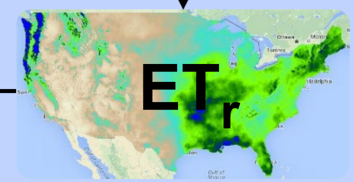


parameters

NDVI, Air Temp, γ^s

Weather Data

Radiation, Temp, Wind, RH, Pressure

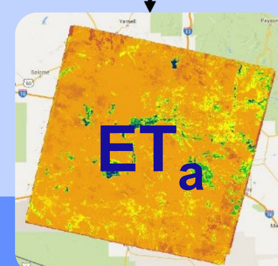


Reference ET

$ET_{fraction}$

Principle: Satellite Psychrometry

Two–Parameter Model

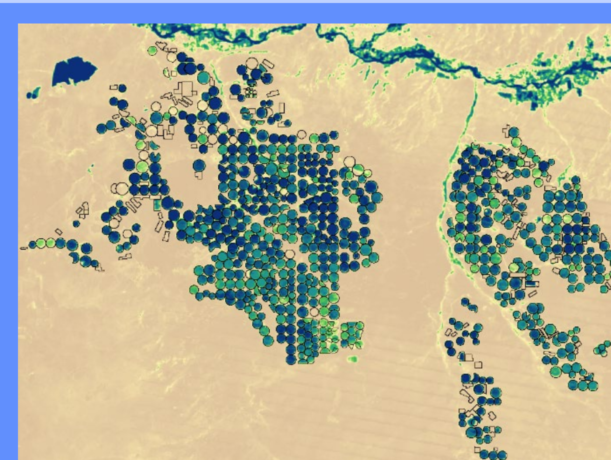


ETa = ETf * ETr

$$ETf = 1 - \gamma^s(Ts - Tc)$$

$$\gamma^s = \frac{\rho . C_p}{R_n . r_{ah}}$$

$Tc = Ts - f.dT(0.9 - NDVI)$: FANO Equation (v6)



SSEBop: Senay et al., 2013 JAWRA; 2018 App. Eng. in Ag; 2023 RS

Determining the Tc parameter

$$ETf = 1 - \gamma^{s}(Ts - Tc)$$

- Satellite Pyschrometry: the determination of the wet-bulb.
- Satellite acquires the ambient surface temperature (dry-bulb).
- We use the FANO Equation to determine Tc.

SSEBop: FANO

- A model parameterization approach using the **F**orcing **A**nd **N**ormalizing **O**peration.
- **Forcing:** it forces the landscape to have a wet-bulb value for the boundary condition. This represents the land surface temperature at maximum ET.
- **Normalizing:** parameters are normalized to formulate the linear FANO equation.

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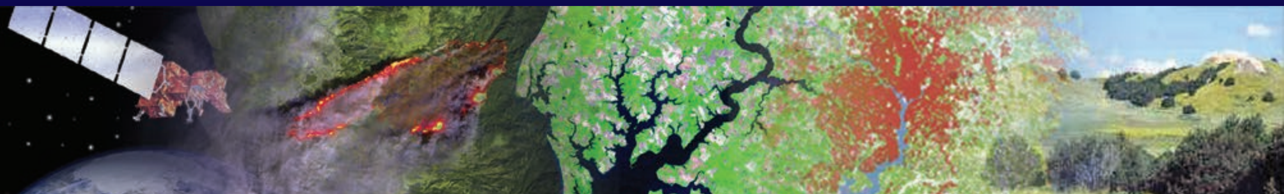
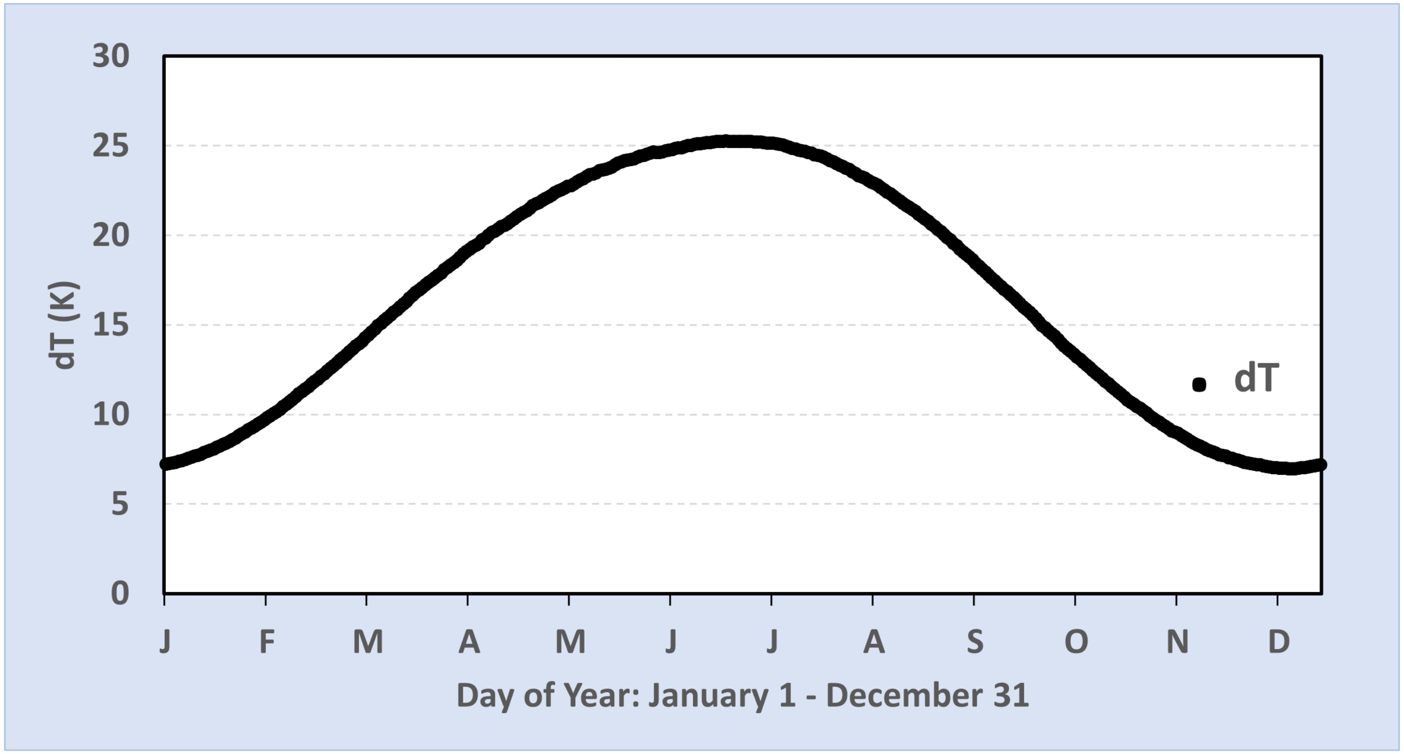


dT (1/ γ^s) parameter for SE Nevada

$$dT = \frac{R_n . r_{ah}}{\rho . C_p}$$

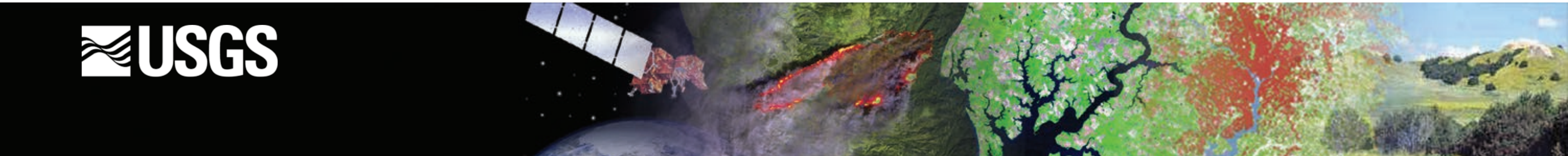
Input to the FANO Eqn.



dT: temperature difference [K, °C]
Rn: Net radiation [$MJ.kg^{-1}.d^{-1}$]
rah: aerodynamic resistance for heat [$s.m^{-1}$]
c_p: specific heat of air at constant pressure, 1.013 10^{-3} [$MJ.kg^{-1}°.C^{-1}$]

Kagone and Senay (2022)

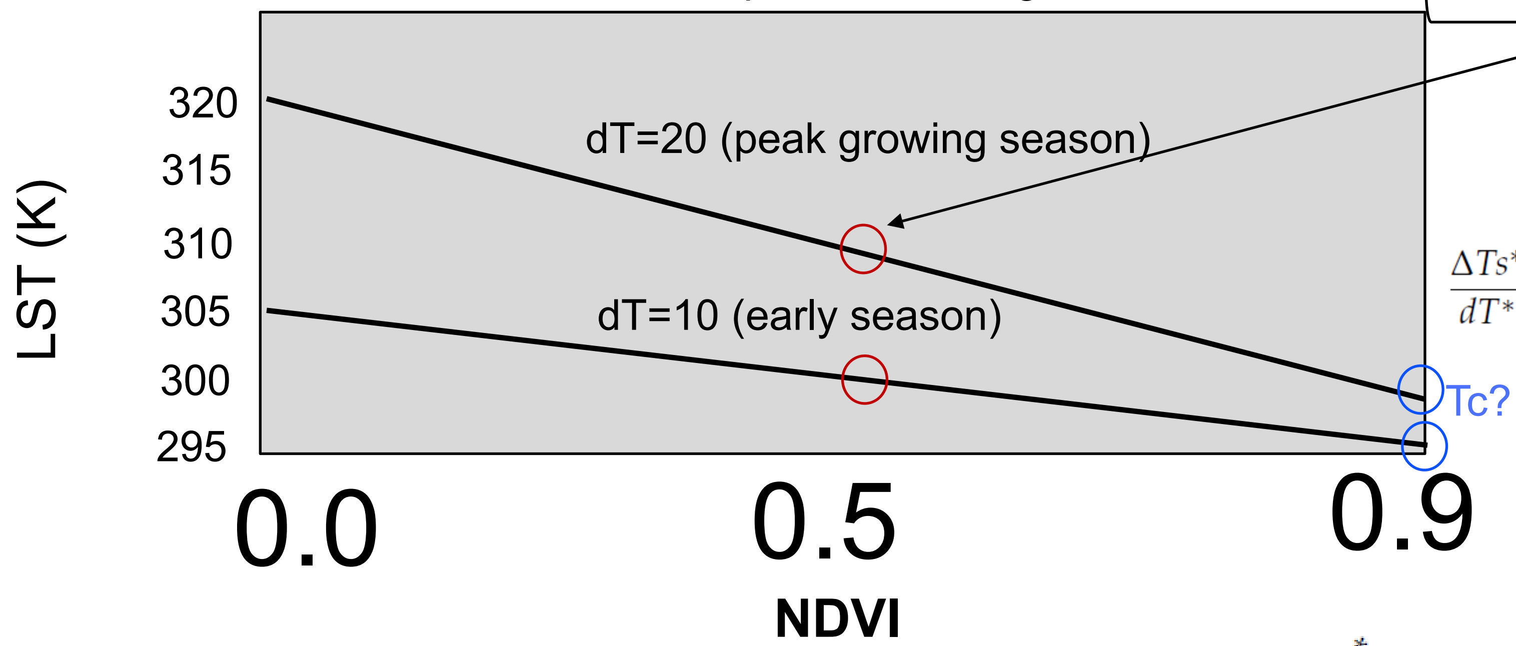
Global dT is available at: Global gray-sky dT: the inverse of the surface psychrometric constant parameter in the SSEBop evapotranspiration model | U.S. Geological Survey (usgs.gov)



Determining Tc using FANO Equation

Senay et al. (2023), RS.

- LST is inversely related to NDVI (“non-wet “ landscapes)
- But degree (slope) of relation varies by season
- Normalizing by dT accounts for seasonal variation
- Maximum NDVI with maximum ET =~ 0.9 (assumed)
- Unknown Tc: we want to predict Tc using observed NDVI, dT, Ts



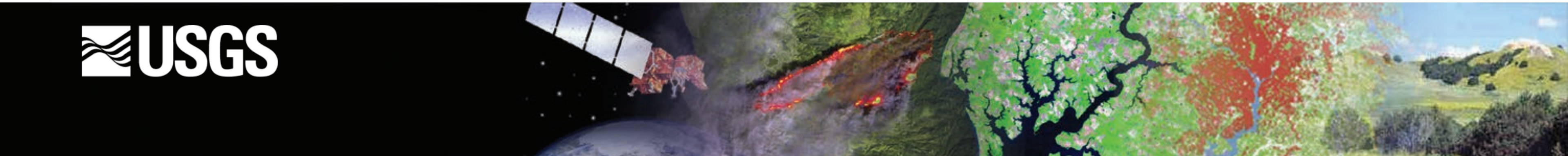
$$\frac{\Delta Ts^*}{dT^*} = -f \cdot \Delta NDVI^*$$

$$\Delta Ts^* = -f \cdot dT^* \cdot \Delta NDVI^*$$

$$\Delta NDVI^* = \mathrm{NDVI}^* - \mathrm{NDVImax}$$

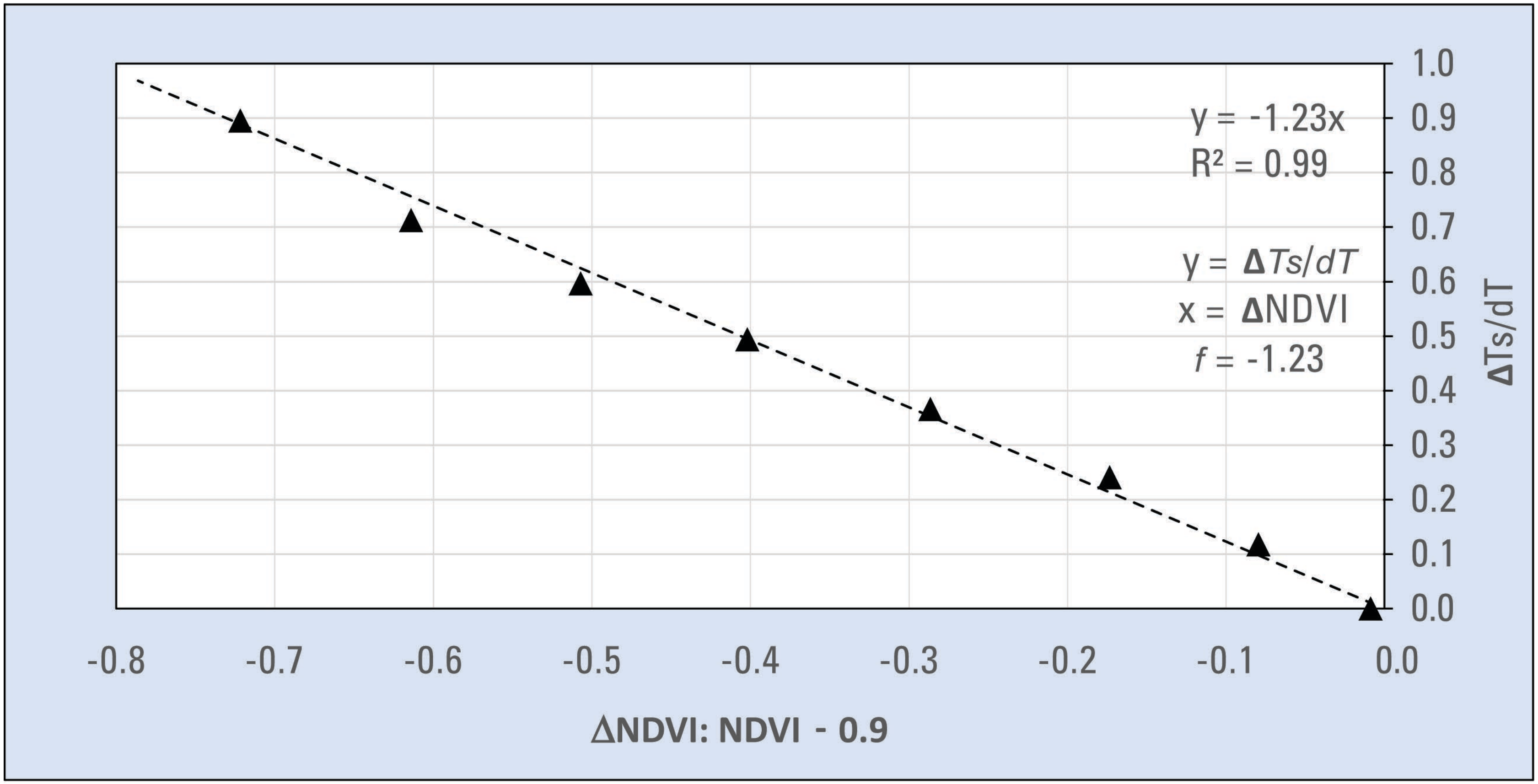
$$\Delta Ts^* = Ts^* - Tc^*.$$

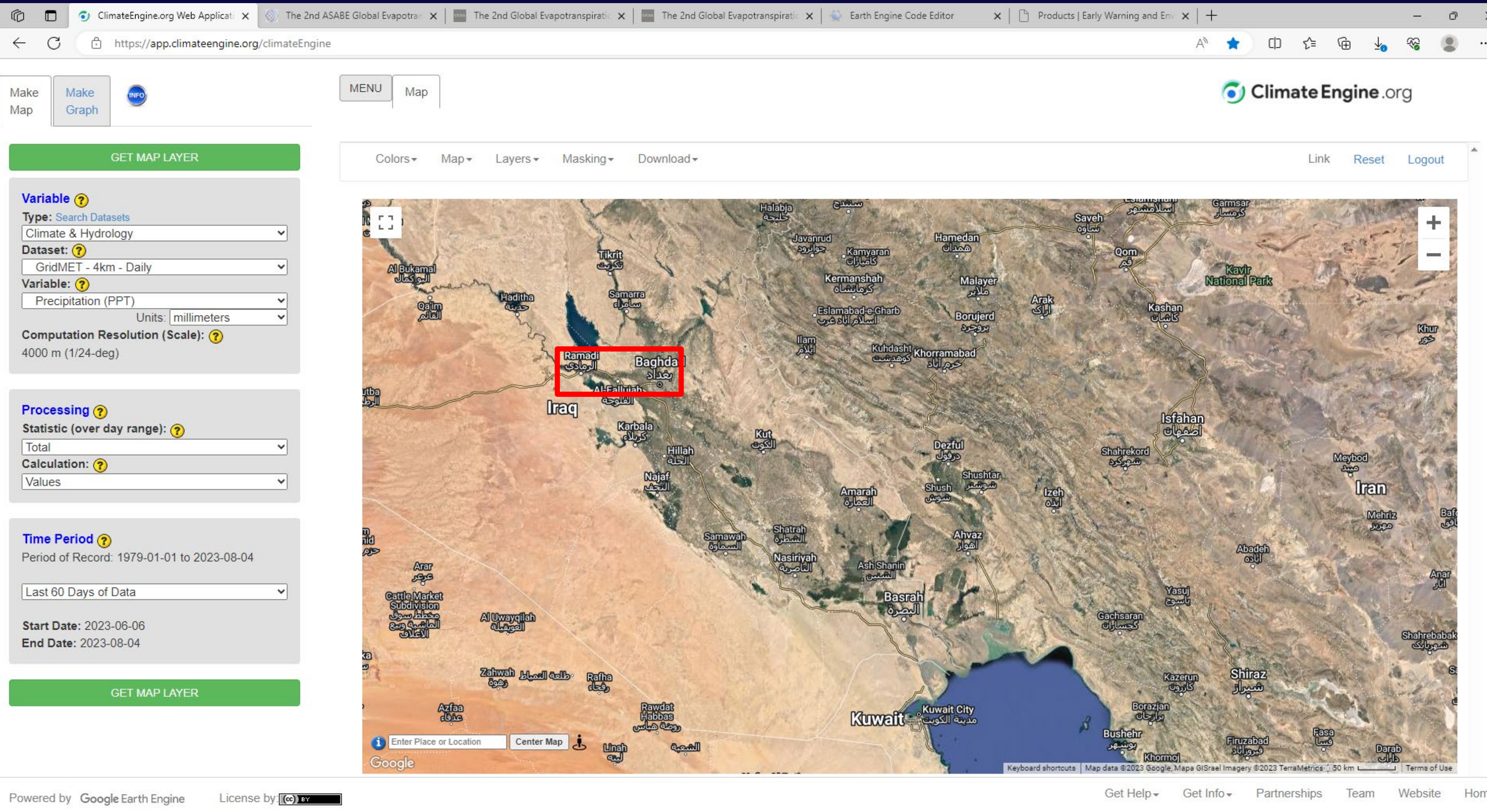
Same NDVI yields different Tc on different seasons.
Soln: Normalizing by dT



FANO Equation Formulation

$$\frac{\Delta Ts^*}{dT^*} = -f \cdot \Delta NDVI^* \quad \Rightarrow \quad Tc = Ts - f.dT(0.9 - \mathrm{NDVI})$$




https://app.climateengine.org/climateEngine
Make Map
Make Graph
MENU
Map
Climate Engine.org
GET MAP LAYER
Variable
Type: Search Datasets
Climate & Hydrology
Dataset:
GridMET - 4km - Daily
Variable:
Precipitation (PPT)
Units: millimeters
Computation Resolution (Scale):
4000 m (1/24-deg)
Processing
Statistic (over day range):
Total
Calculation:
Values
Time Period
Period of Record: 1979-01-01 to 2023-08-04
Last 60 Days of Data
Start Date: 2023-06-06
End Date: 2023-08-04
GET MAP LAYER
Colors
Map
Layers
Masking
Download
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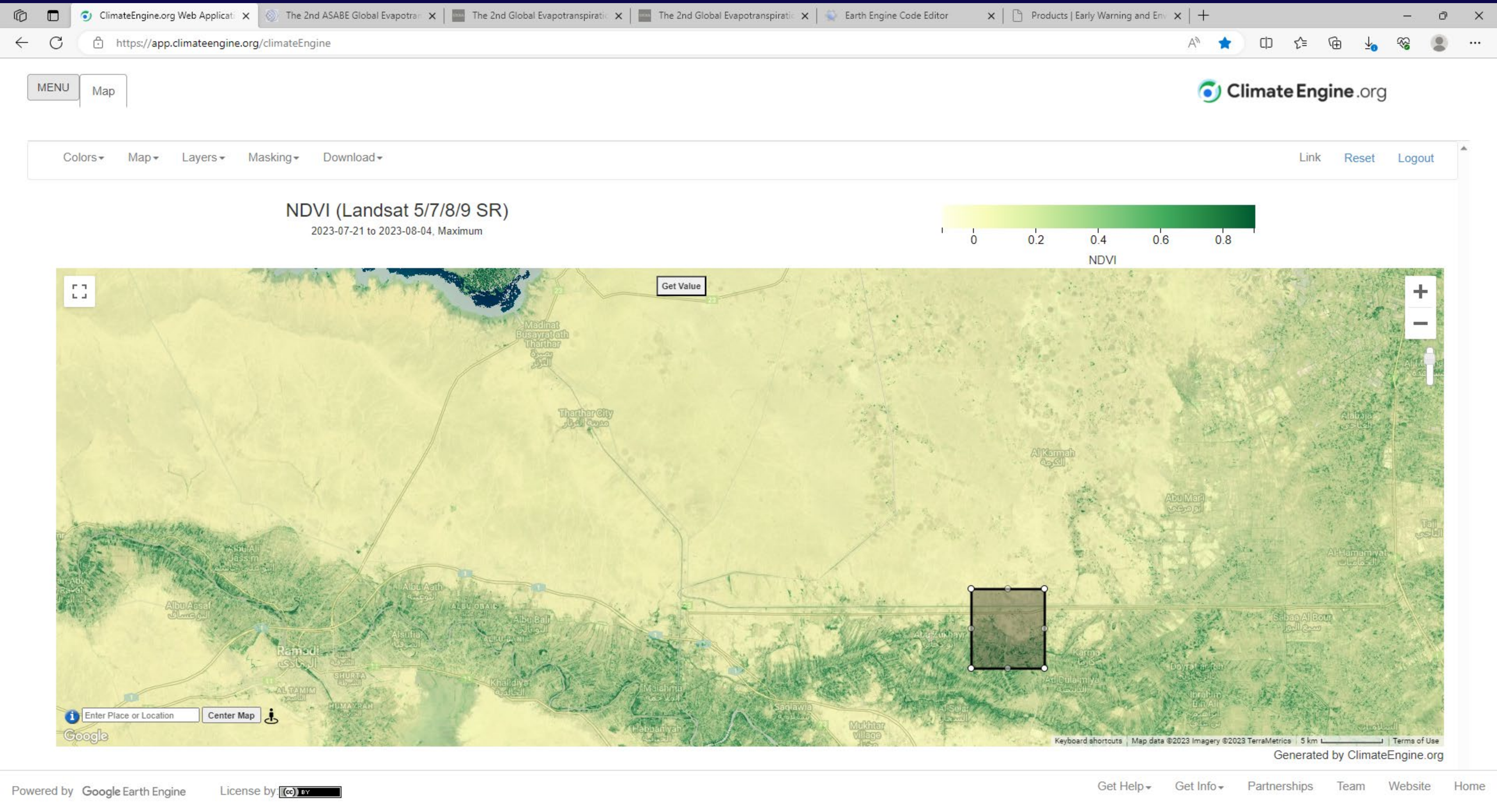
NDVI 5-km = ~0.3



https://app.climateengine.org/climateEngine
MENU
Map
Climate Engine.org
Colors
Map
Layers
Masking
Download
Link
Reset
Logout
NDVI (Landsat 5/7/8/9 SR)
2023-07-21 to 2023-08-04, Maximum
0
0.2
0.4
0.6
0.8
NDVI
Get Value
Ramadi
Enter Place or Location
Center Map
Generated by ClimateEngine.org
Powered by Google Earth Engine
License by
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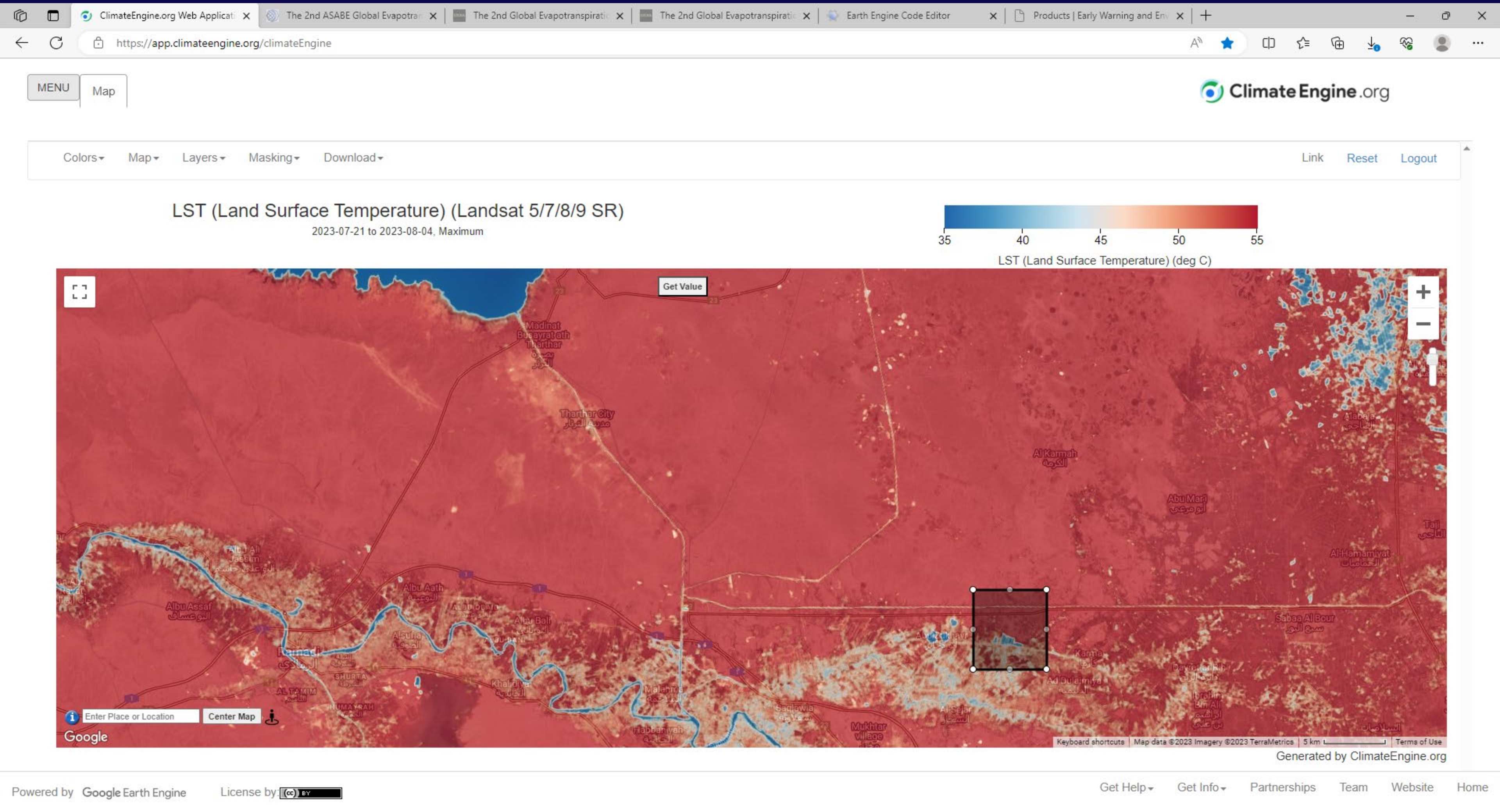
LST 5-km = ~50 = 323 K



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Sample Calculation:

Assuming

$dT^* = 20$ K

$Ts^* = 323$ K

$NDVI^* = 0.30$

$$Tc^* = Ts^* - 1.25 * dT\,(0.9 - NDVI^*)$$

$$Tc^* = 323 - 1.25 * 20(0.9 - 0.3)$$

$$Tc^* = 308\ K$$

$Tc^* = 35^{o}C$ (which is comparable to the water temp)

TC* is then disaggregated to 1 km to Tc using air temperature (Ta). But Ta does not vary much over flat areas and its effect is limited.

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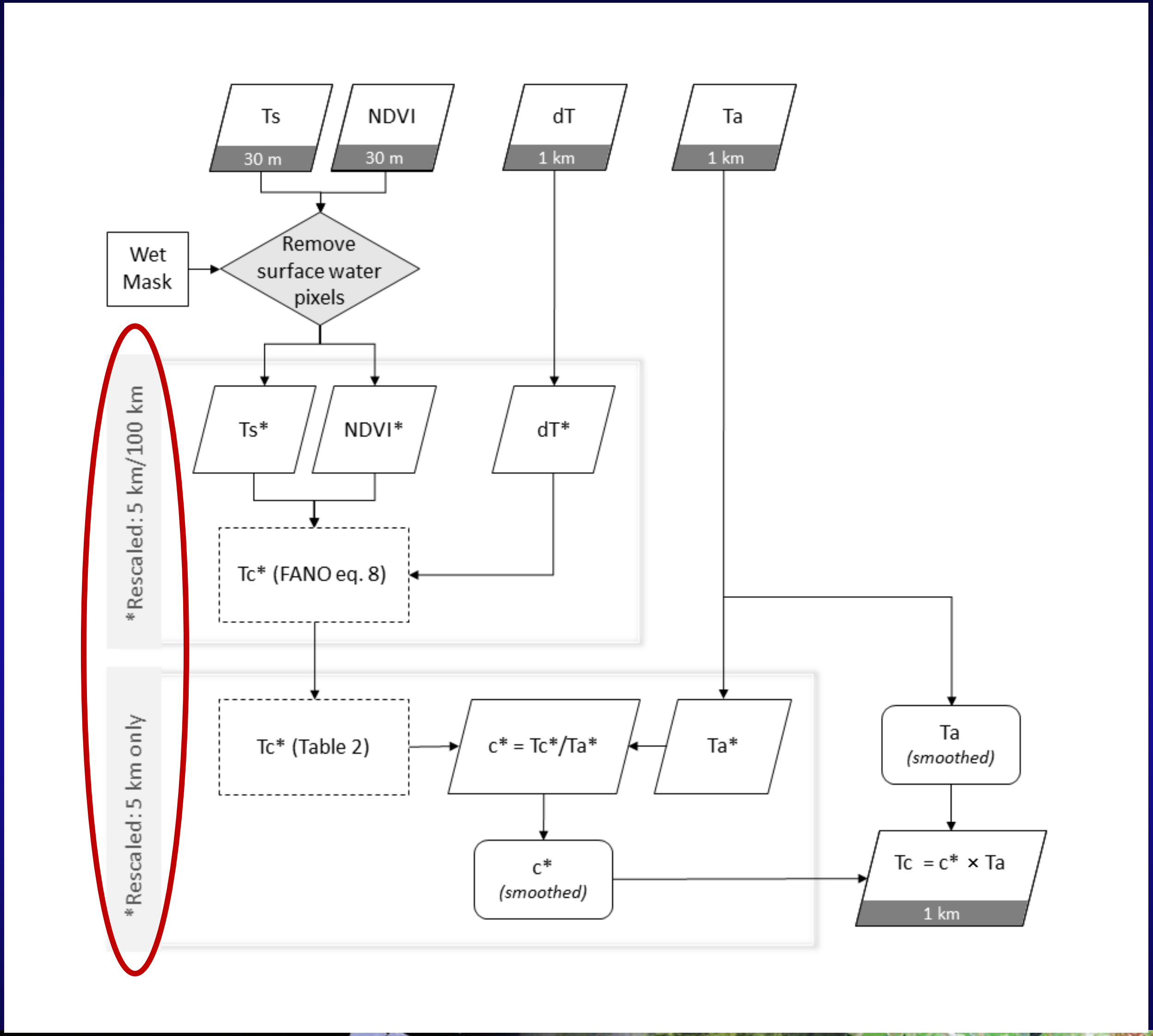
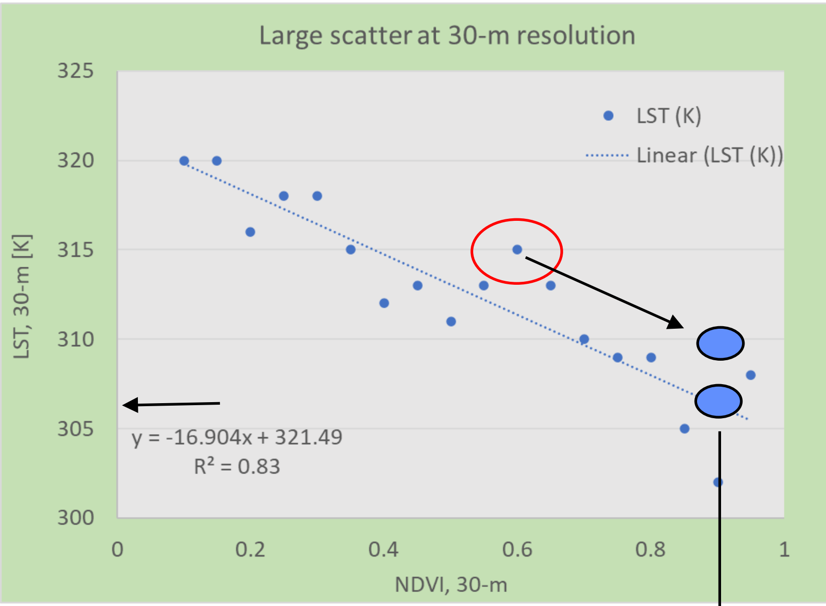
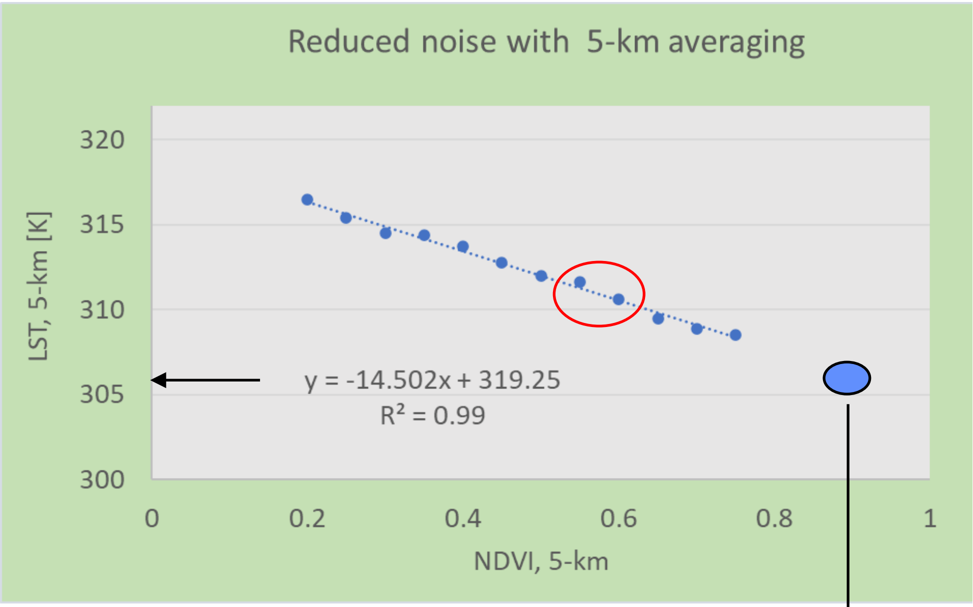
Tc Determination Steps



Why 5-km Spatial Averaging? To Reduce Noise

Avoid over- or under-predication of Tc for neighboring pixels.





NDVI = 0.90
LST = 306.3 K

NDVI = 0.90
LST = 306.2

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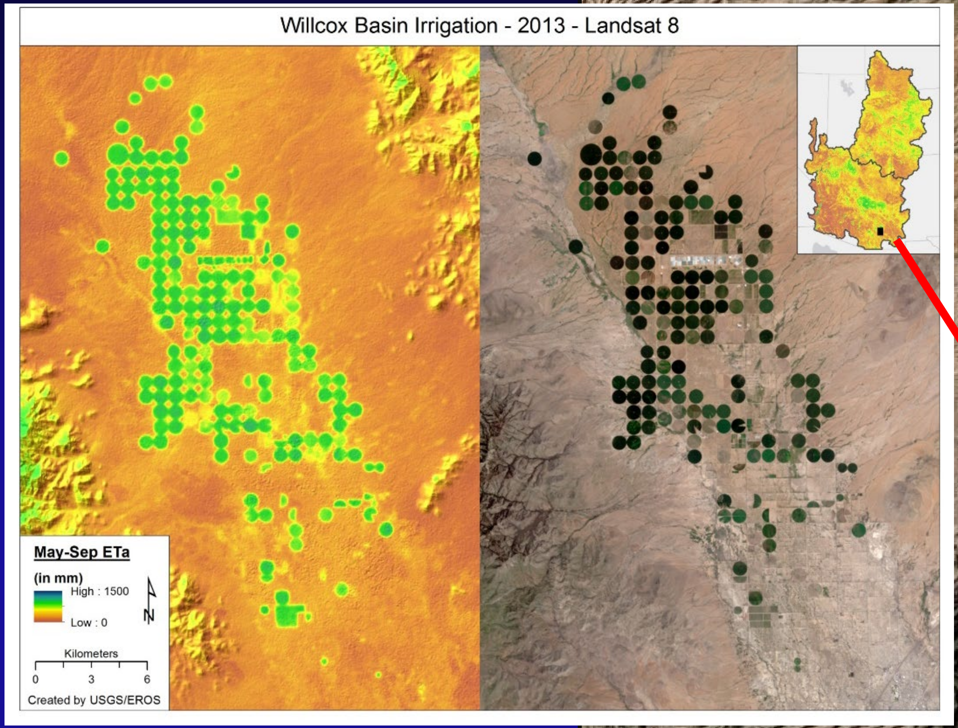
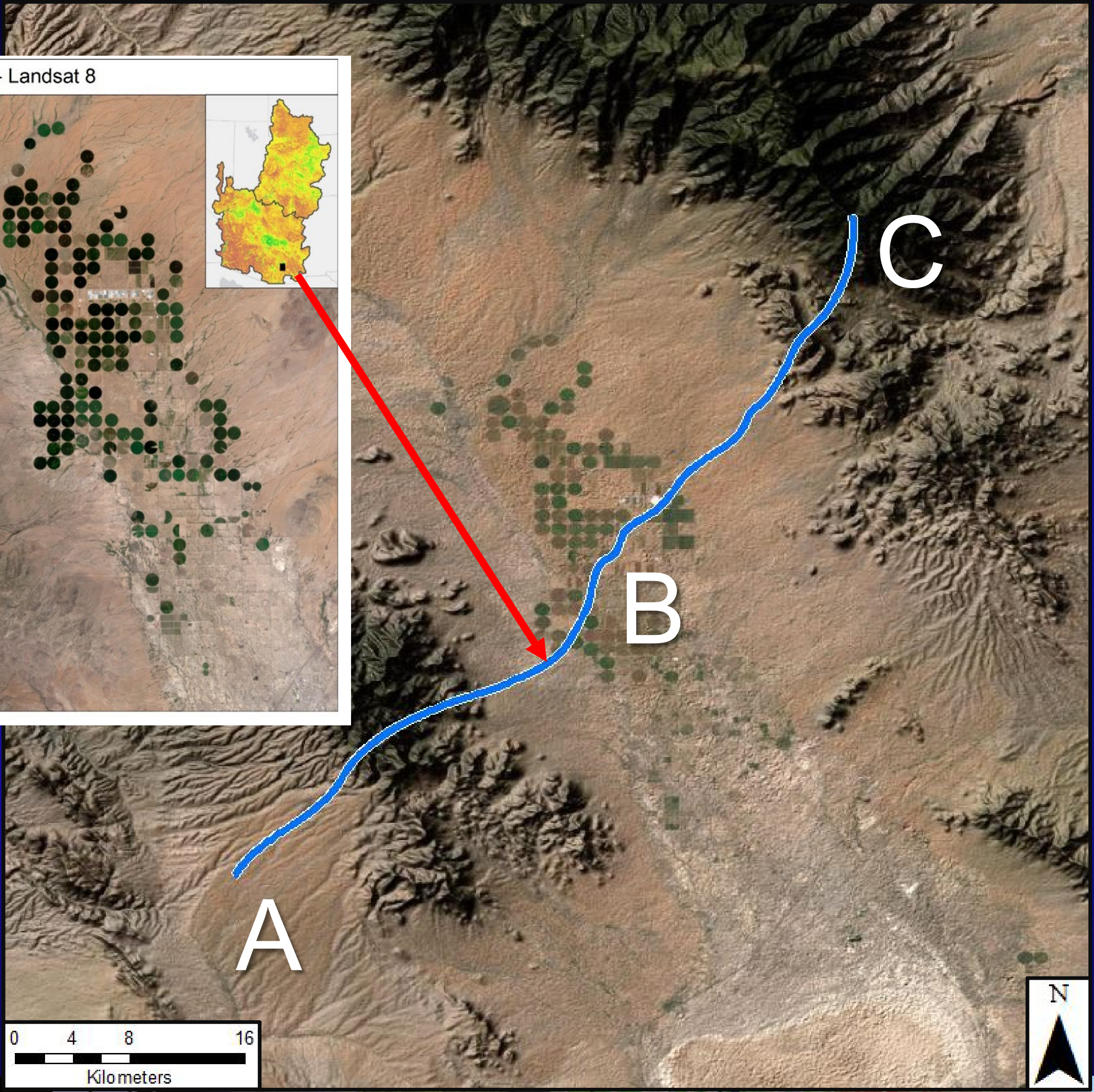
Transect in Willcox Irrigation Basin





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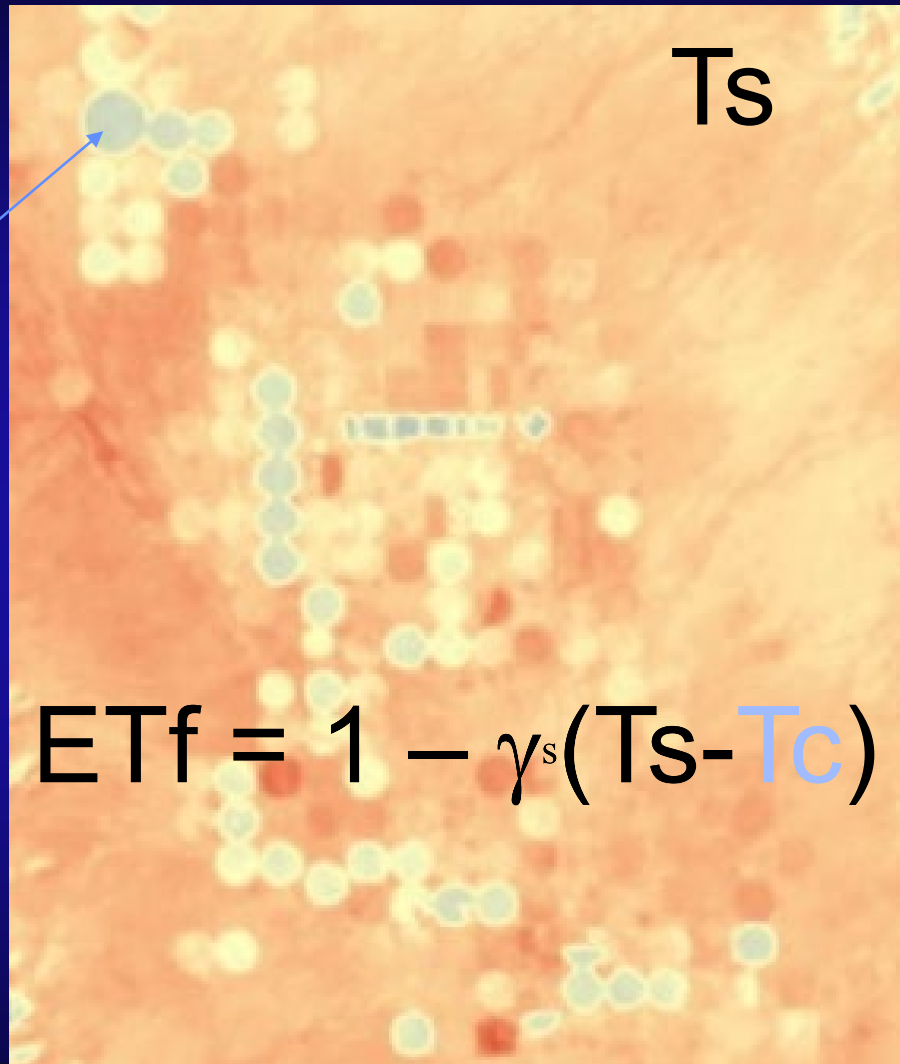
LST (Ts) distribution in an irrigated valley Willcox, AZ,: March 21, 2015)

Ts=Tc



lst2015081

degrees Kelvin

High : 320

Low : 280

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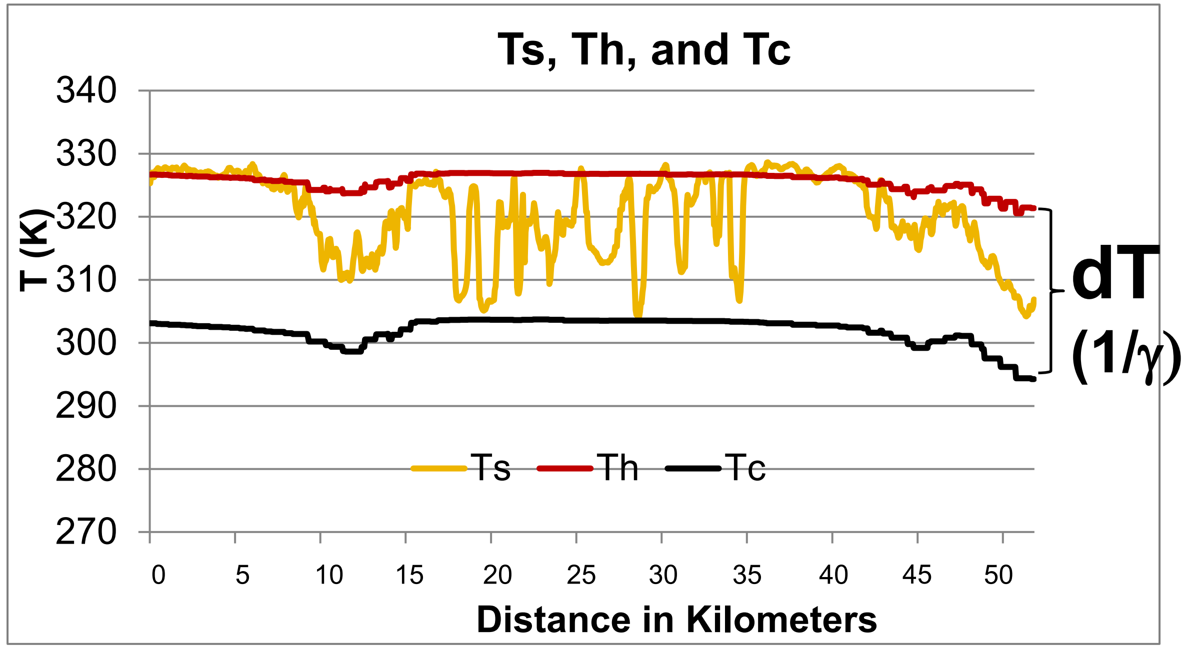
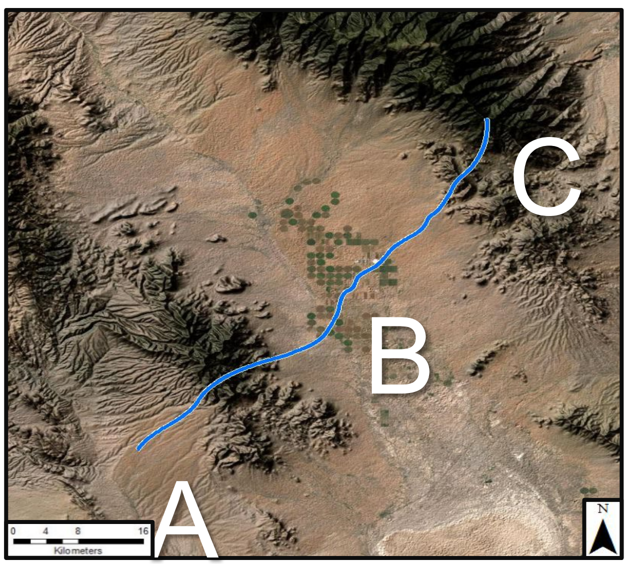
LST(Ts), Hot (Th)/Cold (Tc) Limits for Jun 23, 2014

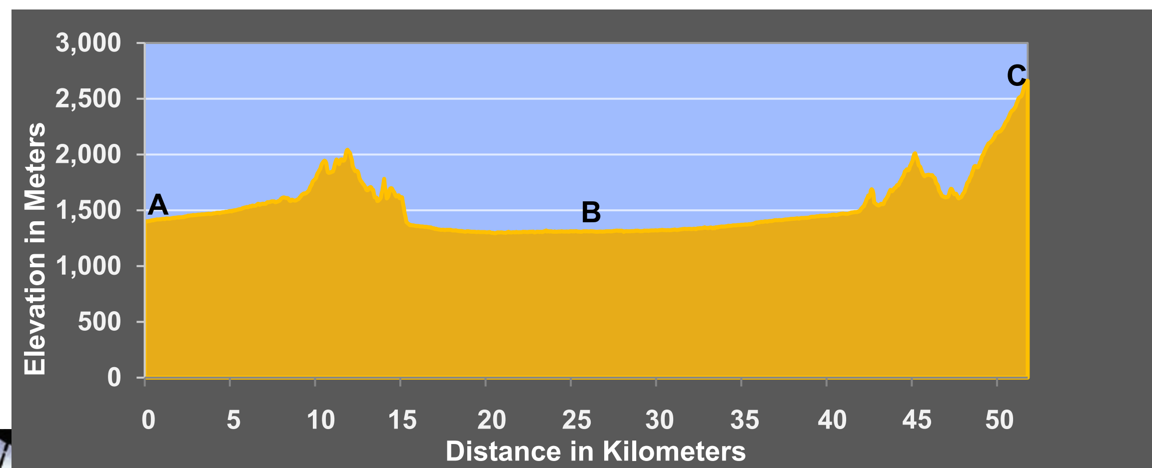
$$ETf = 1 - \gamma^{s}(Ts - Tc) \quad (0 - 1)$$

$$\gamma^{s} = \frac{\rho Cp}{Rn\, r_a}$$

$$ETa = ETo - \gamma^{s}(Ts - Tc)ETo$$

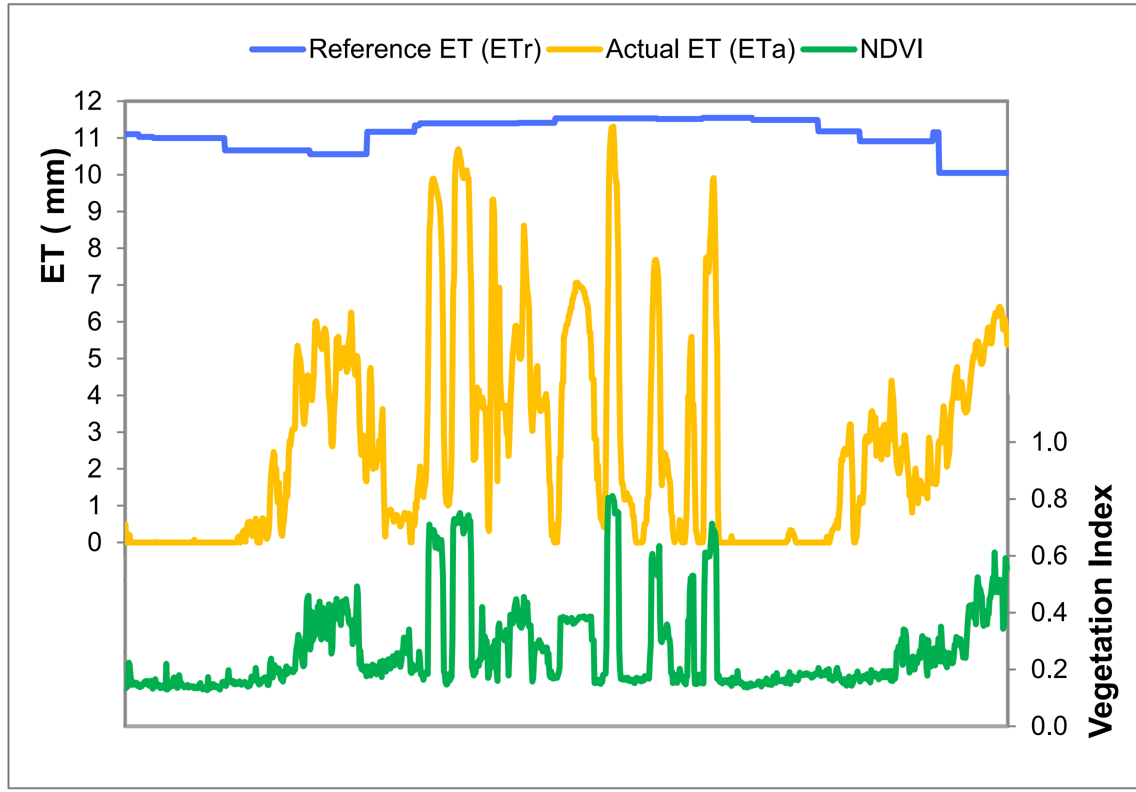


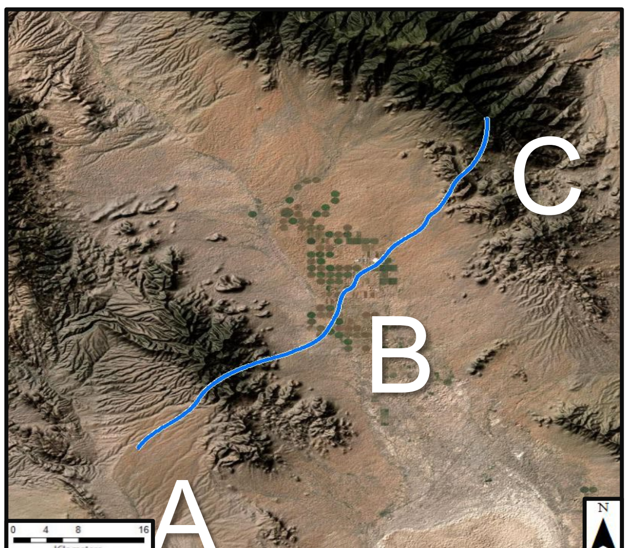


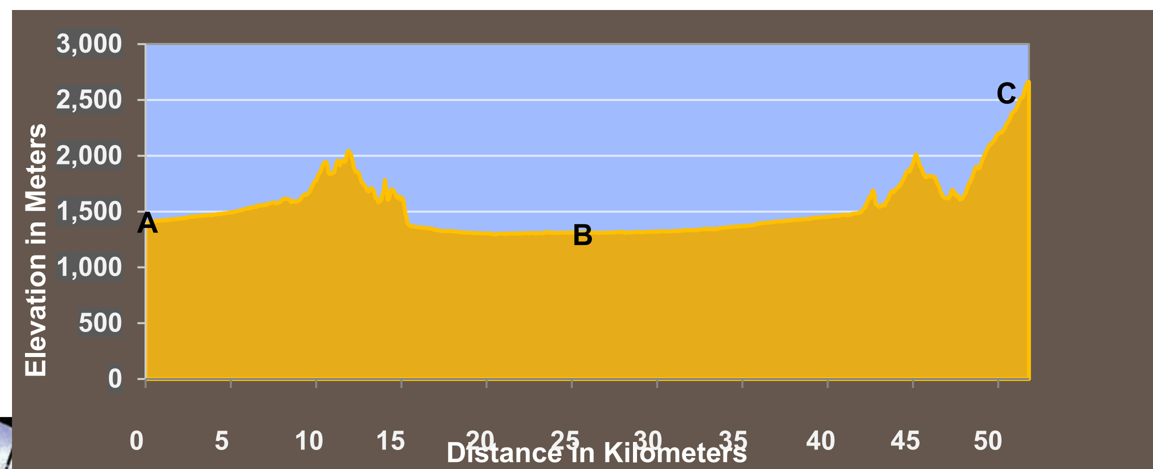


ETa, PET (ETr), NDVI

$$ETa = ETo - \gamma^{s}(Ts - Tc)ETo$$







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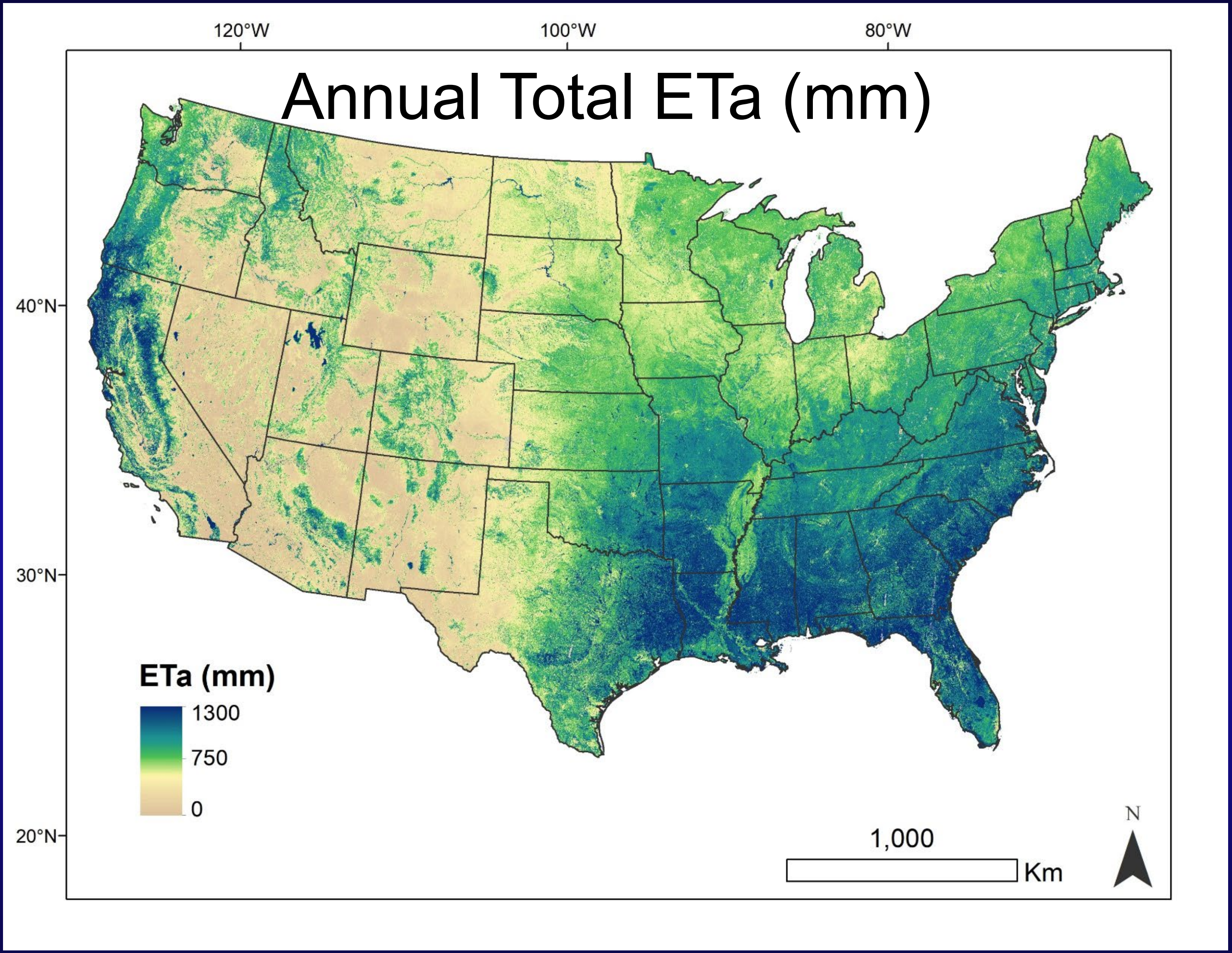
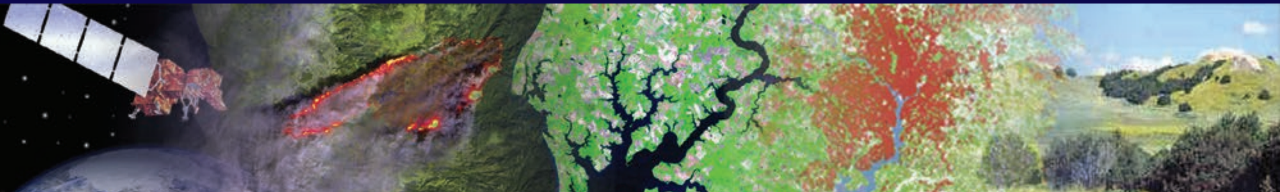
1st Ever Landsat Scale CONUS ETa



Questions?



Challenge: ET under potential vs water limiting conditions

- Landscape is at different levels of stress; thus, **actual ET is <= potential.**

- Allen et al (1998)
  - **ET = Ks * Kc * ETo**
    - Kc = **type and stage** of crop (~0.15 – 1.0)
    - Ks = **soil moisture** stress factor (0 to 1)

(This requires knowledge of crop types, stage and moisture distribution)

USGS

More direct estimation of stress using remote sensing approaches…

Land surface temperature (LST) derived from remotely sensed imagery can be used to estimate the combined effects of soil moisture and environmental stress factors on vegetation.

$$ET = ETf * ETo$$

$$Ks * Kc$$

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Energy Balance Approach for ET:

Accounts for water, agronomic and environmental stresses

USGS WaterSMART and FEWS NET use the SSEBop (Operational Simplified Surface Energy Balance) approach for:

1) Water Use and Availability Assessment

2) Drought Monitoring & Early Warning