National Aeronautics and Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

NASA Evapotranspiration Data Products and Applications

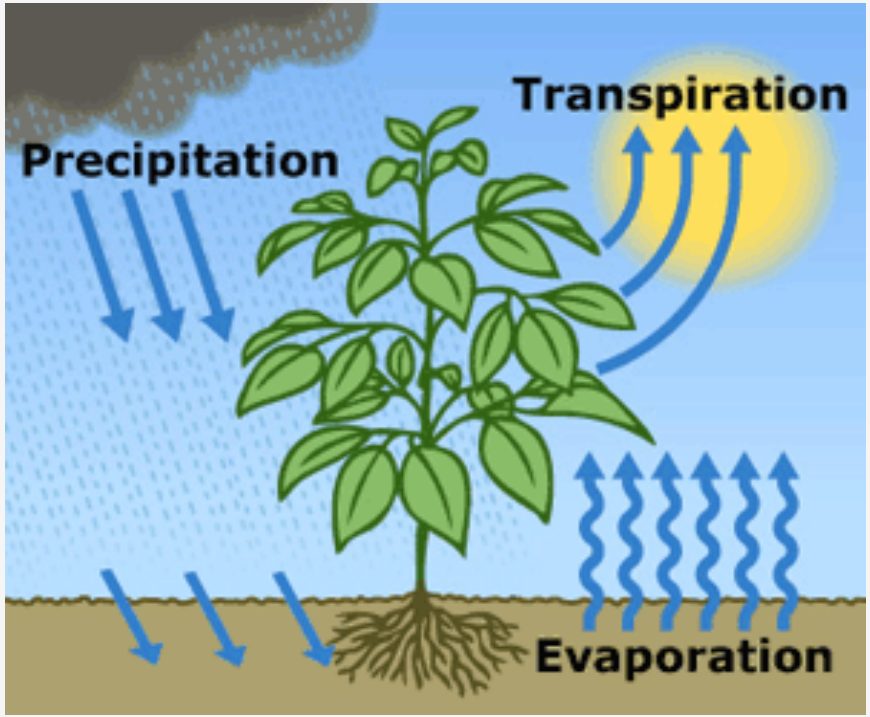
Outline

- About Evapotranspiration (ET)
- Methods of Estimating ET Based on Remote Sensing
- ET Data Products Based on Remote Sensing
- Applications of ET data
- Demonstration of a Web Tool to Access Landsat-Based ET

About Evapotranspiration

What is evapotranspiration (ET)?

- The sum of evaporation from the land surface plus transpiration from plants
- ET transfers water from land surface to the atmosphere in vapor form
- Energy is required for ET to take place (for changing liquid water into vapor)



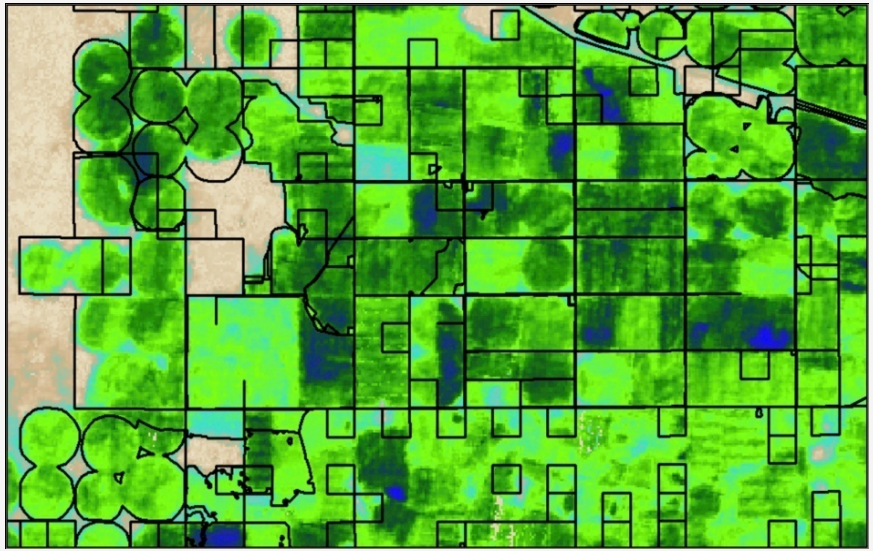
Source: USGS

Importance of ET

- Critical component of the water and energy balance of climate-soil-vegetation interactions
- Useful for:
  - determining agricultural water consumption
  - assessing drought conditions
  - developing water budgets
  - monitoring aquifer depletion
  - monitoring crops and carbon budgets

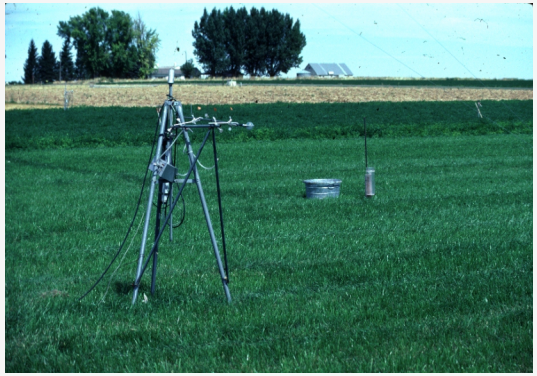
Challenges in Measuring ET

- ET depends on many variables:
  - solar radiation at the surface
  - land and air temperatures
  - humidity
  - surface winds
  - soil conditions
  - vegetation cover and types
- Highly variable in space and time



ET Ground Measurements

- Limitation
  - They are point measurements and cannot capture spatial variability



Eddy Flux Towers

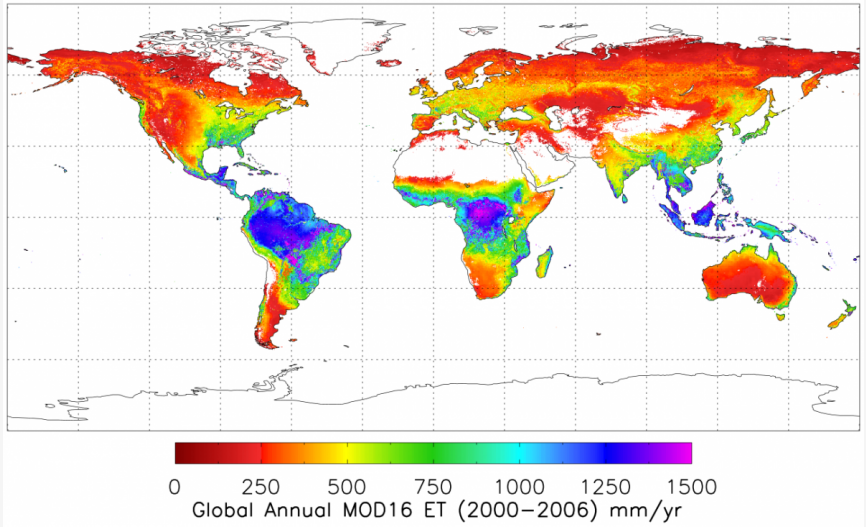
Lysimeters

Image Credit: Rick Allen, University of Idaho

Benefits of Estimating ET from Remote Sensing Data

- Provide relatively frequent and spatially continuous measurement of biophysical variables used in estimating ET at different spatial scales including:
  - radiation
  - land surface temperatures
  - vegetation coverage and density
  - precipitation
  - soil moisture
  - weather and climate variables

Global ET Based on MODIS Averaged over 2000-2006



http://ntsg.umt.edu/project/mod16

Methods of Estimating ET Based on Remote Sensing

Remote Sensors and Observations for ET

Satellite	Sensor	Parameter
Terra and Aqua	MODIS	Normalize vegetation Index (NDVI) Leaf Area Index (LAI) Albedo (fraction of surface solar radiation reflected back)
Landsat	OLI, ETM+	Spectral Reflectance

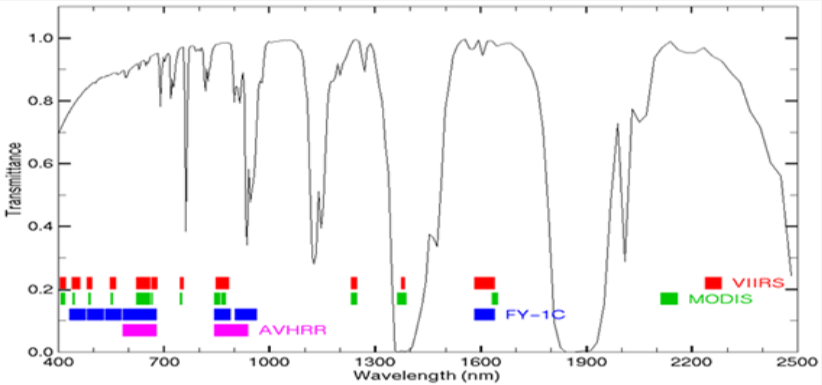
MODerate Resolution Imaging Spectroradiometer (MODIS)

http://modis.gsfc.nasa.gov

- On-board Terra and Aqua
- Designed for land, atmosphere, ocean, and cryosphere observations
- Spatial Coverage and Resolution:
  - Global, Swath: 2,330km
  - Spatial Resolution Varies: 250m, 500m, 1km
- Temporal Coverage and Resolution:
  - 2000-present, 2 times per day

Spectral Bands

- 36 bands (red, blue, IR, NIR, MIR)
  - Bands 1-2: 250m
  - Bands 3-7: 500m
  - Bands 8-16: 1000m

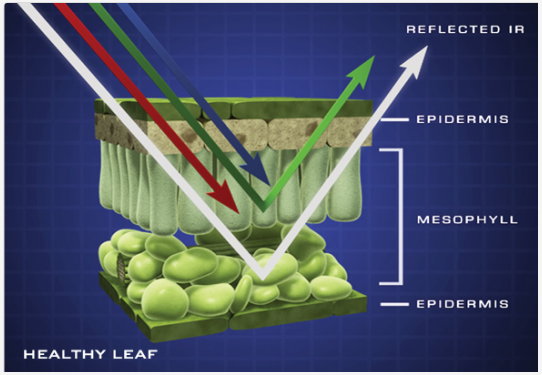


cimss.ssec.wisc.edu

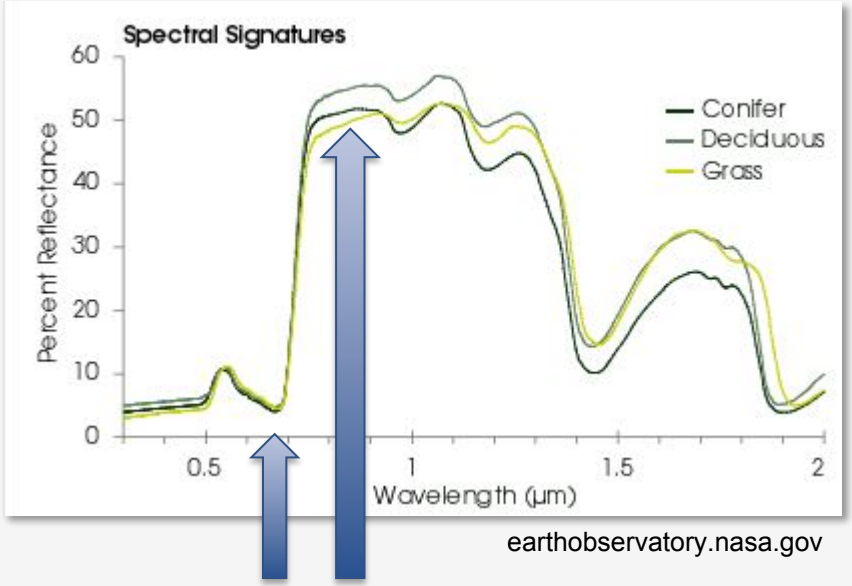
MODIS Normalized Vegetation Index

http://arset.gsfc.nasa.gov/land/webinars/advancedNDVI

- Based on the relationship between red and near-infrared wavelengths
  - chlorophyll strongly absorbs visible (red)
  - plant structure strongly reflects near-infrared



missionscience.hq.nasa.gov; Credit: Jeff Carns



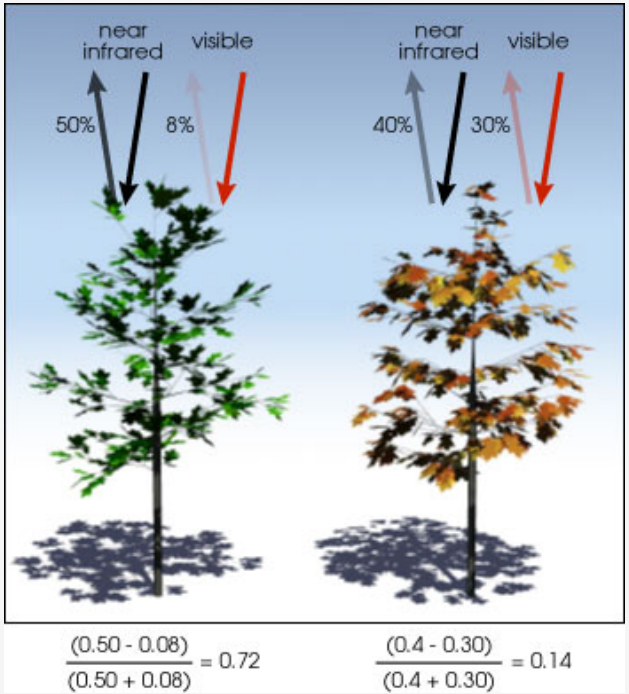
earthobservatory.nasa.gov

Red Near-Infrared

NDVI Formula

http://earthobservatory.nasa.gov/Features/MeasuringVegetation

- NDVI = $\frac{\text{Near-Infrared - Red}}{\text{Near-Infrared + Red}}$
- Values range from -1.0 – 1.0
  - Negative values - 0 mean no green leaves
  - Values close to 1 indicate the highest possible density of green leaves
- Other relevant MODIS products:
  - Leaf Area Index
  - Land Cover
  - Albedo
  - More info: http://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table



earthobservatory.nasa.gov

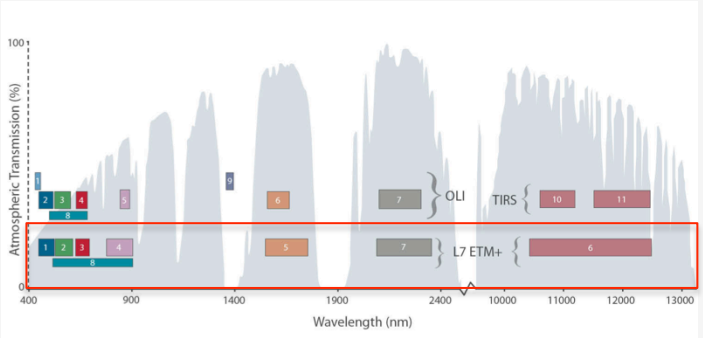
Enhanced Thematic Mapper (ETM+)

http://geo.arc.nasa.gov/sge/landsat/l7.html

- Onboard Landsat-7
- Polar orbiting satellite
- Spatial Coverage and Resolution:
  - Global, Swath: 185km
  - Spatial Resolution: 15m, **30m**, 60m
- Temporal Coverage and Resolution:
  - April 15, 1999-present
  - 16-day revisit time

Spectral Bands

- 8 bands (blue-green, green, red, reflected & thermal IR, panchromatic)
  - Bands 1-5, 7: 30m
  - Band 6: 60m
  - Band 8:15m



NASA

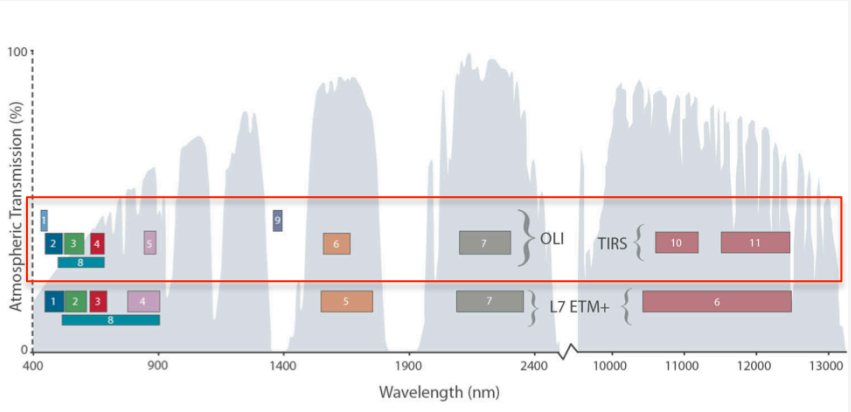
Operational Land Imager (OLI)

http://landsat.usgs.gov/landsat8.php ; http://landsat.gsfc.nasa.gov/?p=5779

- Onboard Landsat-8
- Polar orbiting satellite
- Spatial Coverage and Resolution:
  - Global, Swath: 185km
  - Spatial resolution: 15m, **30m**
- Temporal Coverage and Resolution:
  - Feb 11, 2013 – present
  - 16-day revisit time

Spectral Bands

- 9 bands (blue-green, green, red, near IR, shortwave and thermal IR)
  - Bands 1-7, 9: 30m
  - Band 8:15m



Importance of Landsat for ET

- Landsat allows field-level ET (30m resolution), much higher resolution than MODIS-based ET (1 km)
- Landsat has a thermal band that is important for some ET approaches

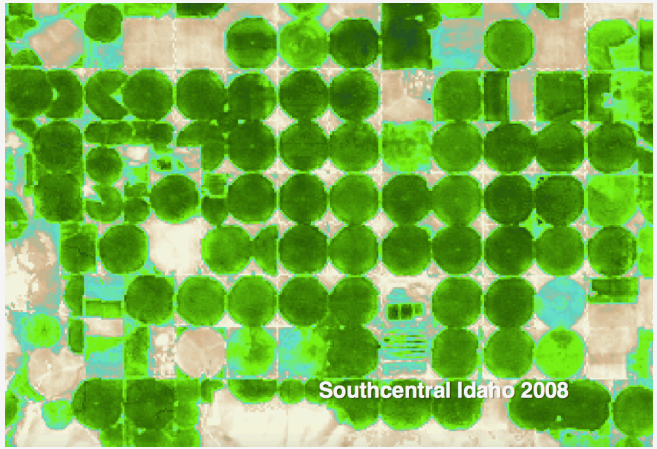


Image Credit: Richard Allen, University of Idaho

Landsat Bands

What is important for ET?

- Band 3: Red
  - Chlorophyll absorption band for vegetation discrimination
  - Carotene and xanthophylls reflectance (dead foliage)
- Band 4: Near-Infrared
  - Internal leaf tissue strongly reflective (decreases as stress increases)
  - Differentiation between evergreen & deciduous vegetation
- Bands 5 & 7: Mid-Infrared
  - Moisture content of soil and vegetation
  - Contrast between vegetation types
- Band 8: Thermal
  - Solar reflectance
  - Emitted heat

Estimation of ET – not easy!

- ET can be derived primarily from:
  - Surface Water Balance
    ET=Precipitation + Irrigation – Runoff – Ground Water + Vertical Water Transport ± Subsurface Flow ± Soil Water Content
  - Surface Energy Balance
    ET (Latent Heat Flux) = Net Surface Radiation – Ground Heat Flux – Sensible Heating Flux
  - Meteorological and Vegetation/Crop Data (Penman-Monteith Equation)

*Reference: http://www.fao.org/docrep/X0490E/x0490e04.htm#determining%20evapotranspiration

ET Estimation by Land Surface Models

Global Land Data Assimilation System (GLDAS): http://ldas.gsfc.nasa.gov

- Integrate satellite and ground observations within sophisticated numerical models based on water and energy balance methods

Remote Sensing Inputs

- Surface Solar Radiation
  - from atmospheric models with satellite data assimilation
- Precipitation (TRMM and Multi-Satellites)
- Vegetation Classification & Leaf Area Index (MODIS & AVHRR)
- Topography (Landsat)

Integrate Outputs

- Soil Moisture
- Evapotranspiration
  - Surface/Sub-surface Runoff
  - Snow Water Equivalent

ET Estimation by Surface Energy Balance

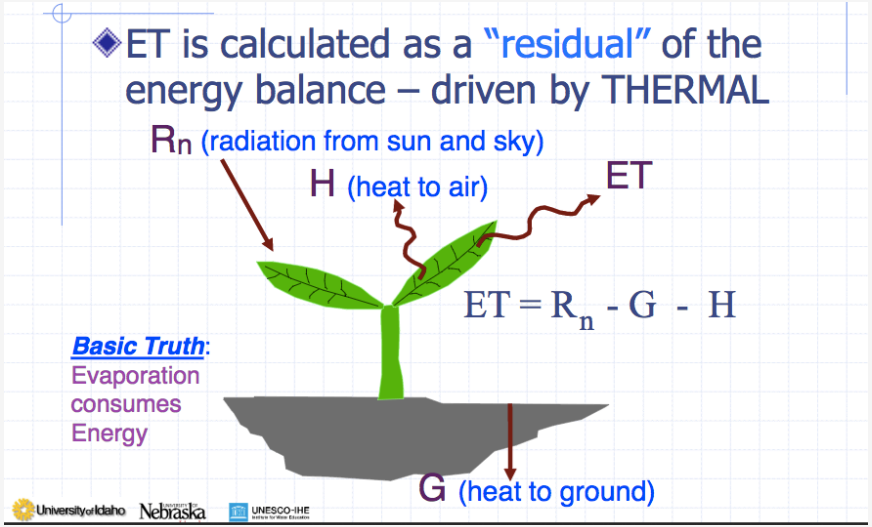
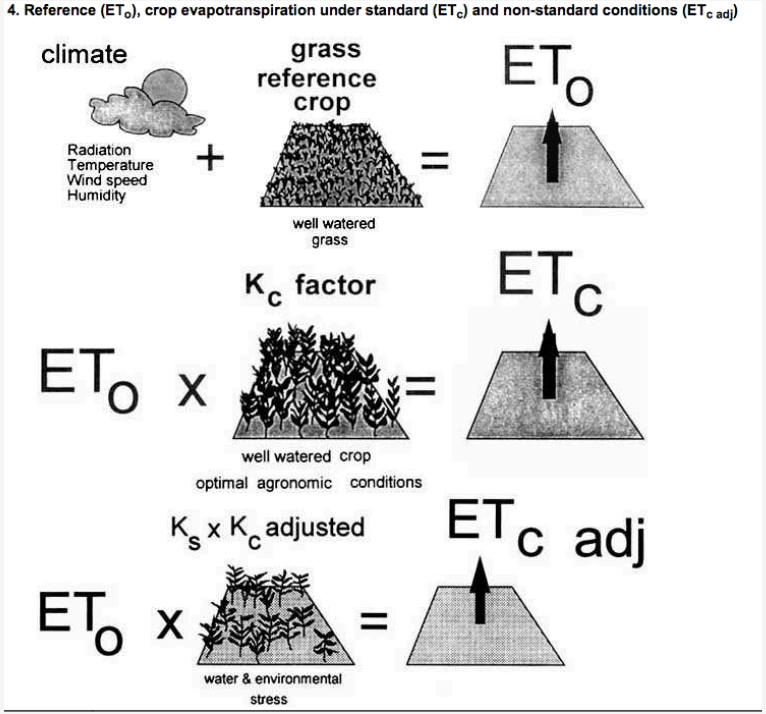


Image Credit:
https://c3.nasa.gov/water/static/media/other/Day1_S3-3_Allen.pdf

- Used by multiple groups to develop ET products
- Uses MODIS & Landsat
  - land surface temperatures
  - land cover

ET Estimation from Vegetation and Crop Information



- ET_o: reference ET for well-watered grass reference (Penman-Moneith Equation)
- ET_c: crop ET for standard crop conditions:
  - disease free, well fertilized, grown in large fields, optimum soil water conditions, achieving full production under given climatic conditions
- $ET_{c\ adj}$: adjusted for non-standard crop conditions
- K_c: crop coefficient

*Reference: http://www.fao.org/docrep/X0490E/x0490e04.htm#determining%20evapotranspiration

Penman-Monteith Equation for ET_o

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

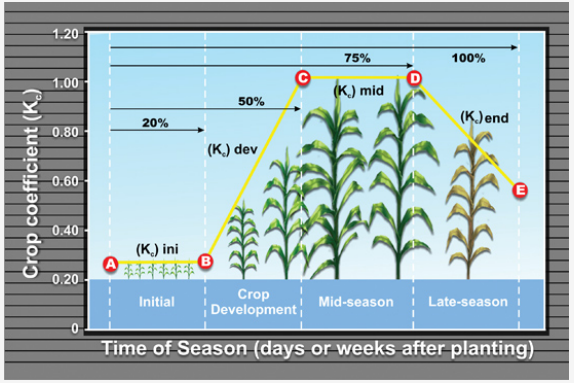
- R_n: net surface radiation
- G: ground heat flux
- $(e_s - e_a)$: vapor pressure deficit
- r_a & r_s: aerodynamic & surface resistance
- γ: psychrometric constant
- λ: latent heat constant
- c_p: specific heat constant

- Requires climate and crop information
- r_a & r_s depend on Vegetation Height, Leaf Area Index (LAI)
- R_n depends on the fractional solar radiation reflected back from the surface (albedo)
- LAI and albedo are both available from MODIS

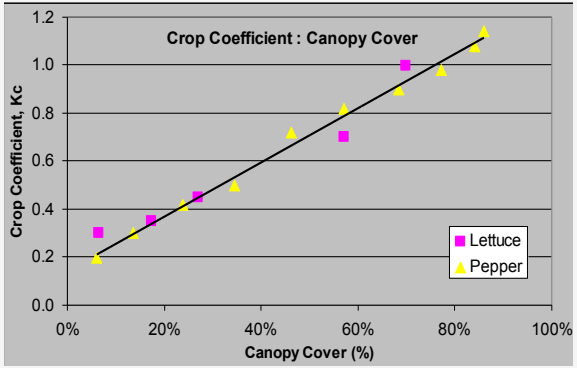
*Reference: http://www.fao.org/docrep/X0490E/x0490e06.htm#penman%20monteith%20equation

Crop Coefficient (K_c) and Normalized Vegetation Index (NDVI)

- K_c is related to light interception (ground cover)
- There is a direct relationship between K_c and NDVI
  – available from MODIS



Credit: Tom Trout, USDA



ET Data Products Based on Remote Sensing

ET Data Products Based on Remote Sensing Observations

Global Products

- MOD16: MODIS Global Evapotranspiration Project
  - http://ntsg.umt.edu/project/mod16
- METRIC: Mapping EvapoTranspiration with high-Resolution and Internalized Calibration
  - https://c3.nasa.gov/water/static/media/other/Day1_S1-3_Anderson.pdf
  - http://eeflux-level1.appspot.com
- ALEXI: Atmosphere-Land Exchange Inverse Model
  - https://c3.nasa.gov/water/static/media/other/Day1_S1-4_Anderson.pdf
  - http://www.ospo.noaa.gov/Products/land/getd/index.html
- GLDAS: Global Land Data Assimilation System
  - http://ldas.gsfc.nasa.gov/gldas/

ET Data Products Based on Remote Sensing Observations

Regional Products: can be adapted for other regions

- SIMS: Satellite Irrigation Management Support (California)
  - https://c3.nasa.gov/water/static/media/other/Day1_S2-2_Melton.pdf
- NLDAS: North American Land Data Assimilation System (North America)
  - http://ldas.gsfc.nasa.gov/nldas
- SSEBop: Operational Simplified Surface Energy Balance (US & Africa)
  - http://www2.usgs.gov/climate_landuse/lcs/projects/wsmartet.asp
- ETWatch: Multi-Satellite Based Energy Balance Model (China)
  - https://c3.nasa.gov/water/static/media/other/Day2_S1-4_Wu_2.pdf

Summary: Publically Available Global ET Products

ET Source	Method	Remote Sensing Observations
GLDAS	Land Surface Model Water and Energy Balance	TRMM and multi-satellite Precipitation MODIS and AVHRR Land Cover Landsat Topography
MOD16	Normalized Vegetation Index (NDVI) –based Model	MODIS
METRIC	Energy Balance	Landsat
ALEXI	Energy Balance	MODIS, Landsat, GOES

Summary: Publicly Available Global ET Products

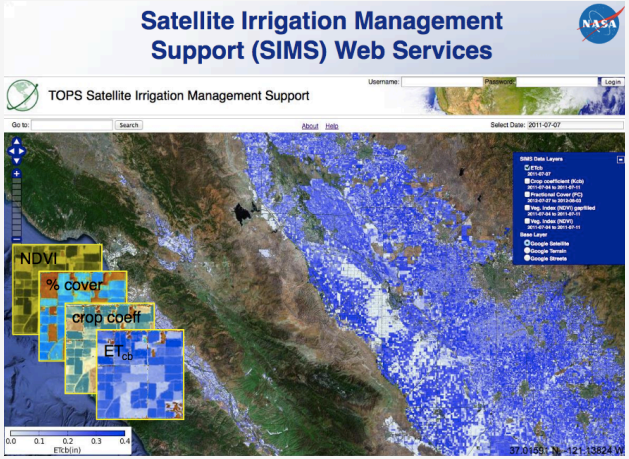
ET Sources	Spatial/Temporal Resolutions	Data Source	Availability
GLDAS	• 1/8th-1 degree (Global) • 3-hour, monthly • 1979 – May 2016 • 1979 – 2010	• NASA/NOAA • Mirador • Giovanni	• http://mirador.gsfc.nasa.gov • http://giovanni.gsfc.nasa.gov/giovanni
MOD16	• 1km (Global) • 8-day, Monthly • 2000 – 2014 (will be extended to present)	• University of Montana	• http://ntsg.umt.edu/project/mod16
METRIC	• 30m (Global) • 2011 – March 2016	• Google Earth Engine Evapotranspiration Flux (EEFlux)	• http://eeflux-level1.appspot.com
ALEXI (GOES)	• 8km (will be available globally from MODIS) • Daily, 2-12 week composites	• NOAA	• http://www.ospo.noaa.gov/Products/land/getd/index.html

Applications of ET

ET for Irrigation Management

http://ecocast.arc.nasa.gov/simsi/

- Beta web interface complete
- Webtool publicly accessible
- Being tested by multiple growers
- Integrated with UCCE CropManage irrigation management tool
- Prototype calculator for on-farm water use efficient metrics completed



*Reference: https://c3.nasa.gov/water/static/media/other/Day1_S2-2_Melton.pdf

ET for Irrigation Management

http://ecocast.arc.nasa.gov/simsi/

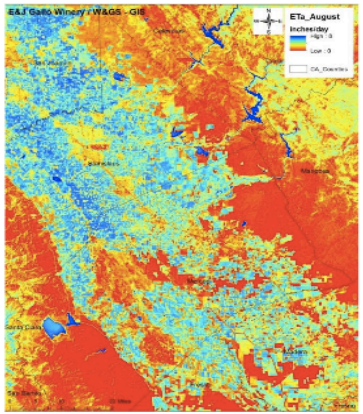
- Landsat-based ET helps wine producers and grape growers in CA plan timing and amount of irrigation

wine&grapesupply

Mapping Evapo-Transpiration at high Resolution with Internalized Calibration (Rick Allen et al.)

Science – Actual ET

- Gallo's analysts were trained by Dr Rick Allen to allow for on premise runs of METRIC



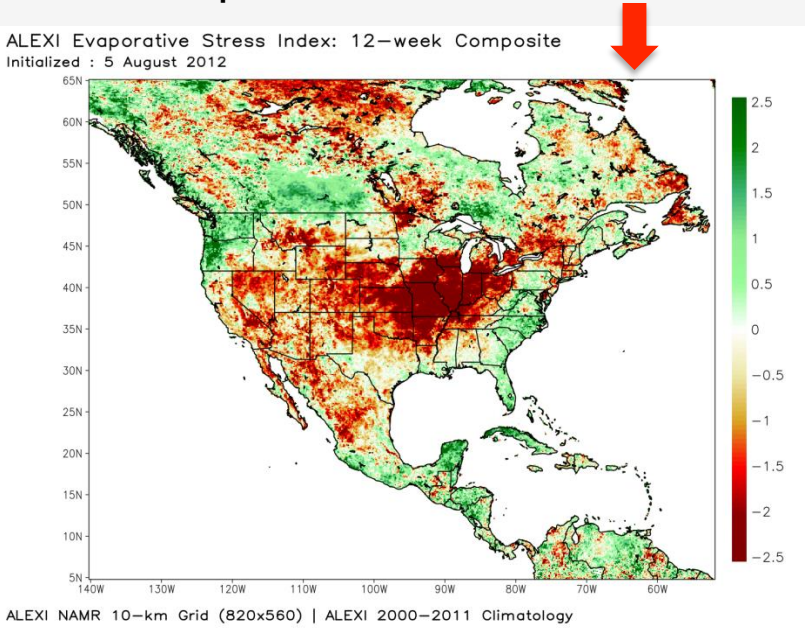
Business

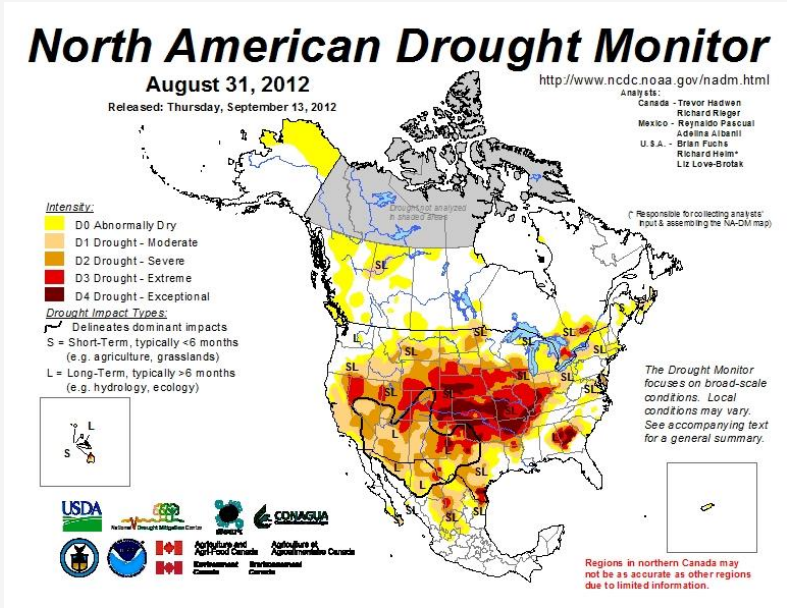
- Some of the benefits that Gallo observed in the last years of using Landsat imagery & METRIC include:
  - Decrease in the amount of water applied by 20–30 percent, subject to region,
  - Improved water management with the ability to run a seasonal water balance,
  - Development of more efficient seasonal irrigation schedules,
  - Improvement in grape quality which leads to improved wine quality,
  - Upward movement in the wine program, due to higher grape quality, leading to an increase in bottle price and an increase in revenue,
  - Reduced trimming of excess leaf canopies from over-irrigation,
  - Decrease in the cost of irrigation from reduction of water and energy used,
  - Using current year's data of water allocation to determine and plan next year's allocation.

*Reference: https://c3.nasa.gov/water/static/media/other/Day1_S2-3_Mendez.pdf

ET for Drought Monitoring Over North America

- ALEXI Evaporative Stress Index showing drought condition

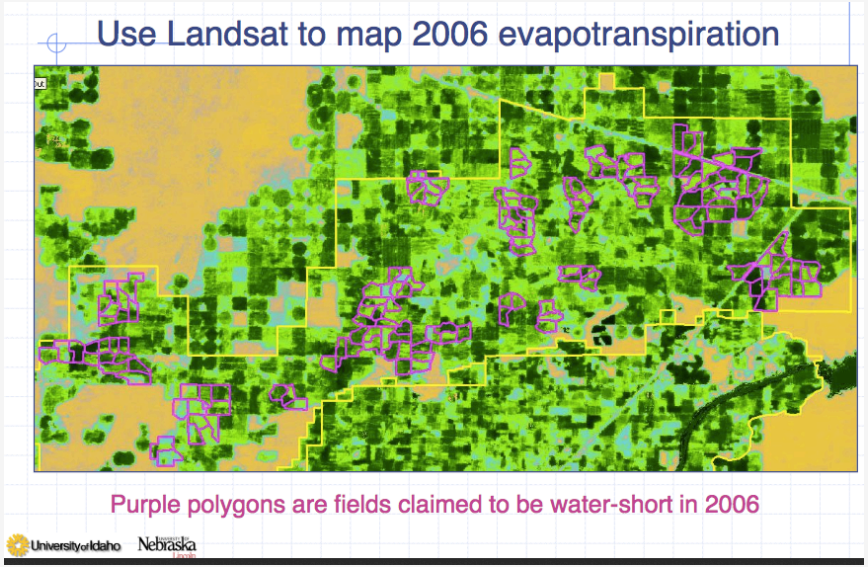




*Reference: https://c3.nasa.gov/water/static/media/other/Day2_S1-7_Hain.pdf

ET for Water Allocation

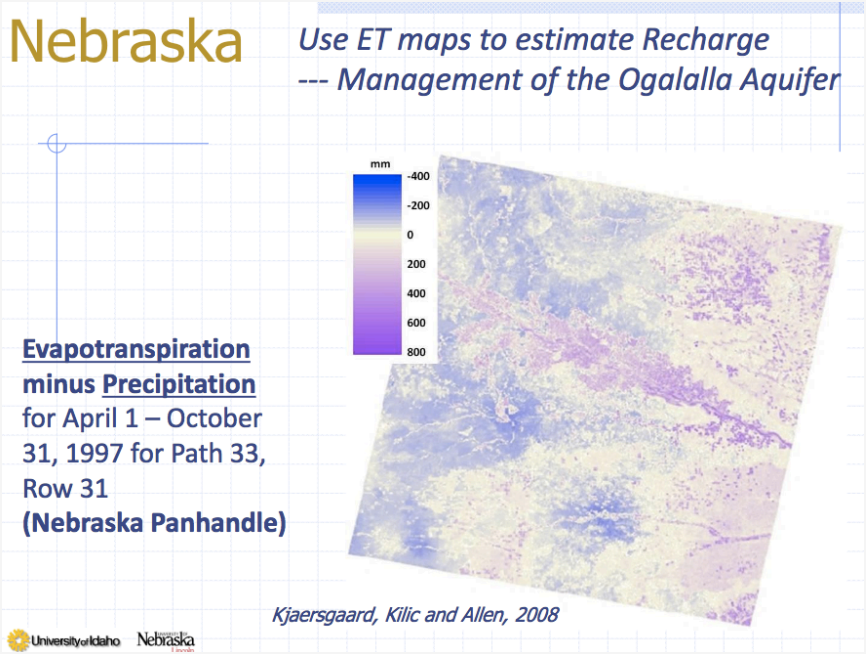
- METRIC ET used for deciding water deficit
- Example
  - based on the ET and NDVI analysis, Idaho Department of Water Resources verified that certain fields claimed to be water deficient were not



*Reference: https://c3.nasa.gov/water/static/media/other/Day1_S1-3_Allen.pdf

ET Used in Planning for Aquifer Management

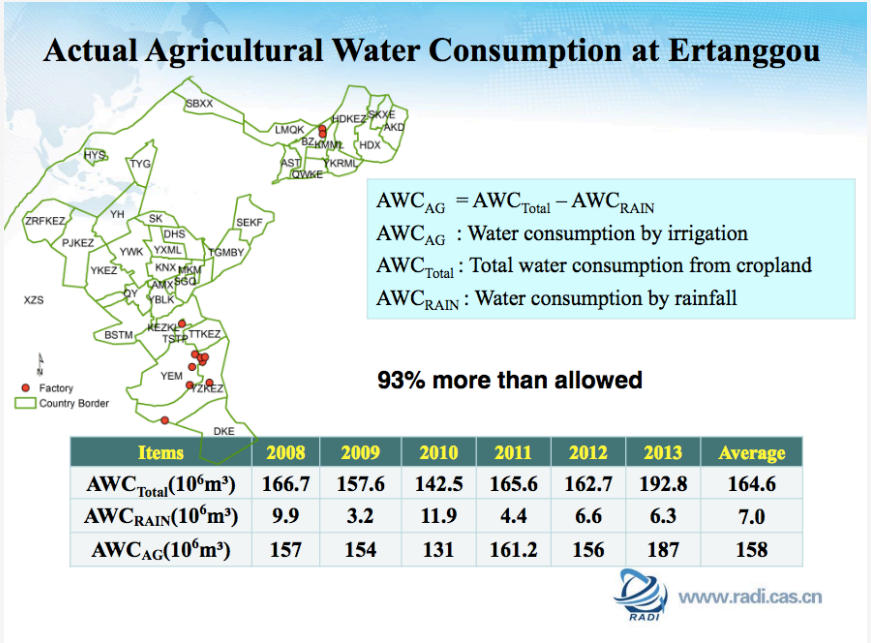
- METRIC ET, together with precipitation, helped estimate Ogalalla Aquifer recharging



*Reference: https://c3.nasa.gov/water/static/media/other/Day1_S1-3_Allen.pdf

ET Used in Agricultural Water Use in China

- Based on ET from ETWATCH and rainfall data excessive use of water for agriculture was noted 2008-2013
- Very useful for planning water resource allocation



Items	2008	2009	2010	2011	2012	2013	Average
$AWC_{Total}(10^6m^3)$	166.7	157.6	142.5	165.6	162.7	192.8	164.6
$AWC_{RAIN}(10^6m^3)$	9.9	3.2	11.9	4.4	6.6	6.3	7.0
$AWC_{AG}(10^6m^3)$	157	154	131	161.2	156	187	158

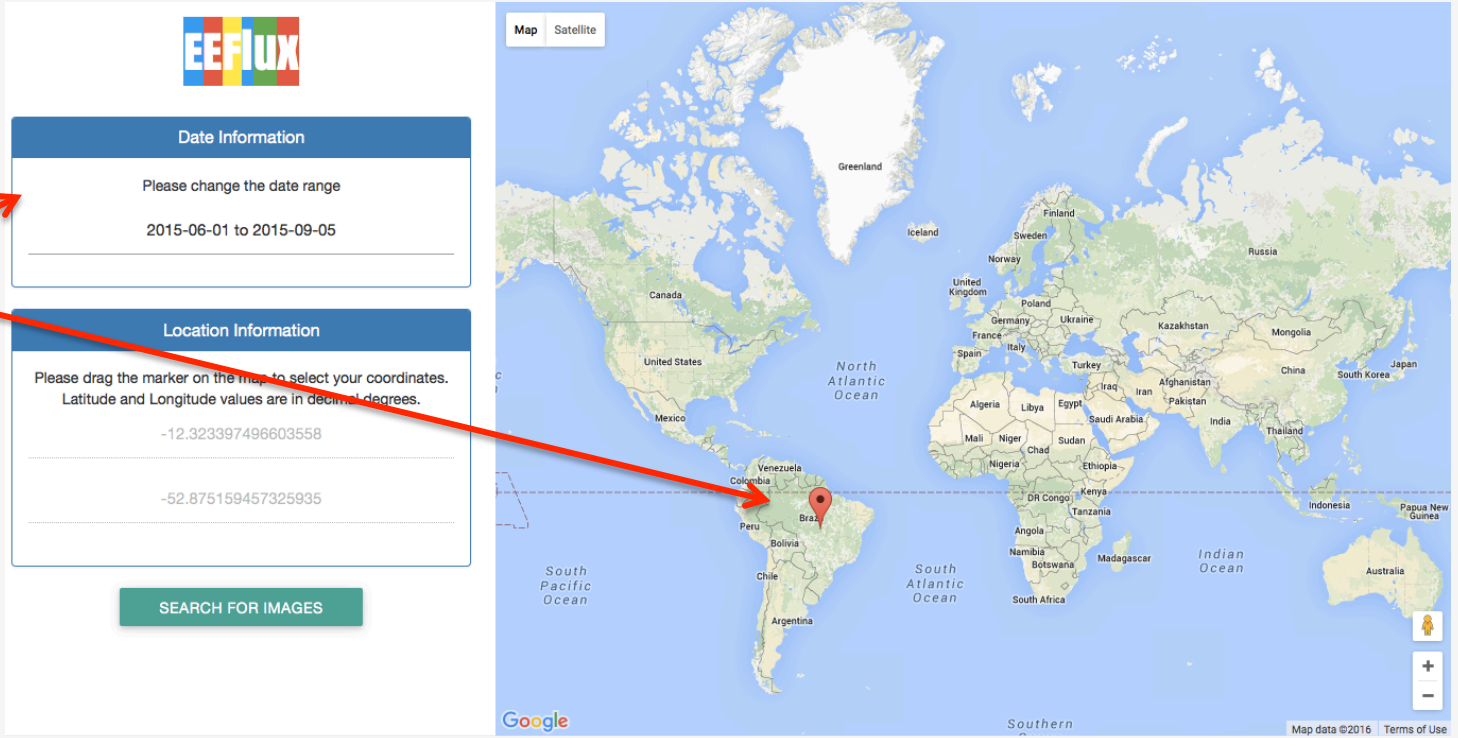
*Reference: https://c3.nasa.gov/water/static/media/other/Day1_S1-3_Allen.pdf

Demonstration of a Web Tool for Landsat-Based ET Data Access

EEFlux : Google Earth Engine Based METRIC ET

http://eeflux-level1.appspot.com

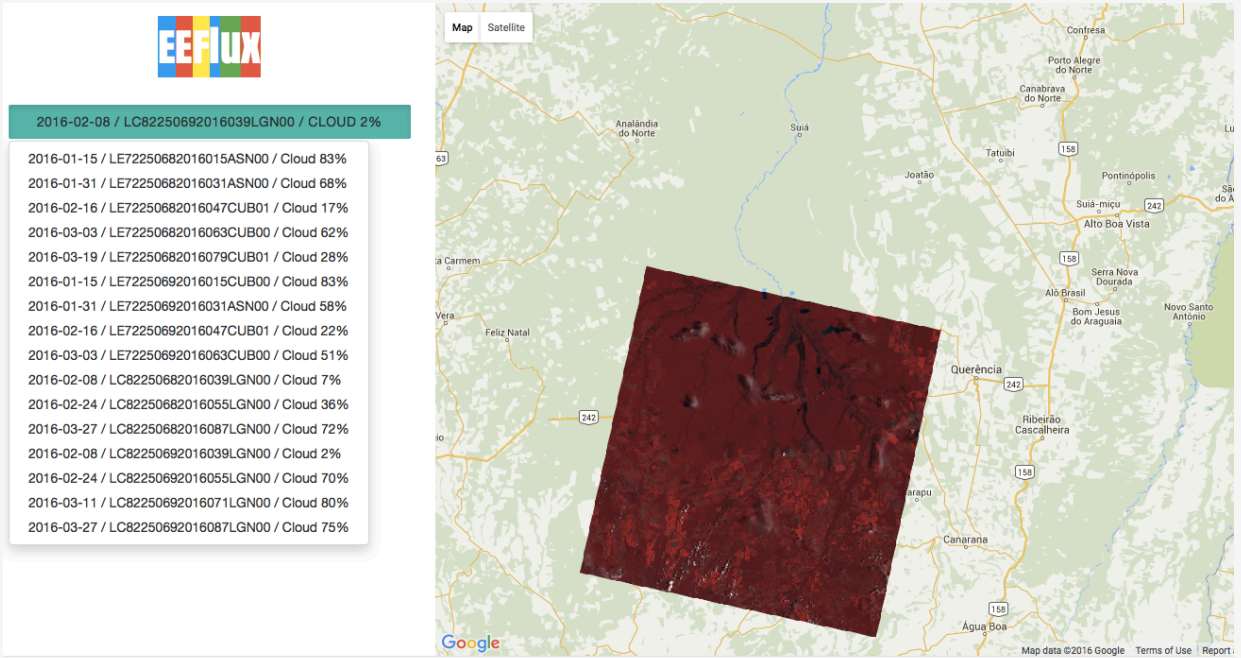
Interactive temporal and spatial search



EEFlux : Google Earth Engine Based METRIC ET

http://eeflux-level1.appspot.com

Landsat image selection from specified time range with % cloud cover selection



EEFlux : Google Earth Engine Based METRIC ET

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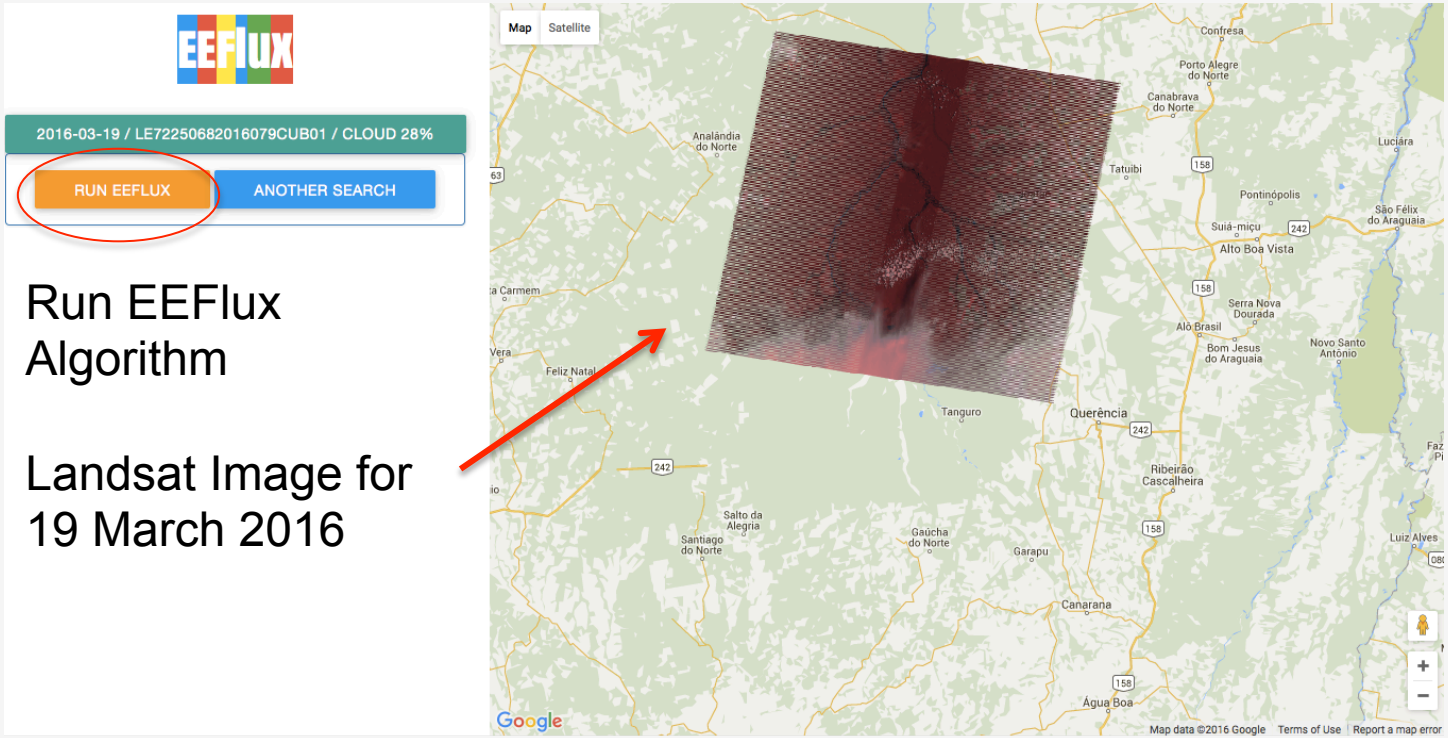
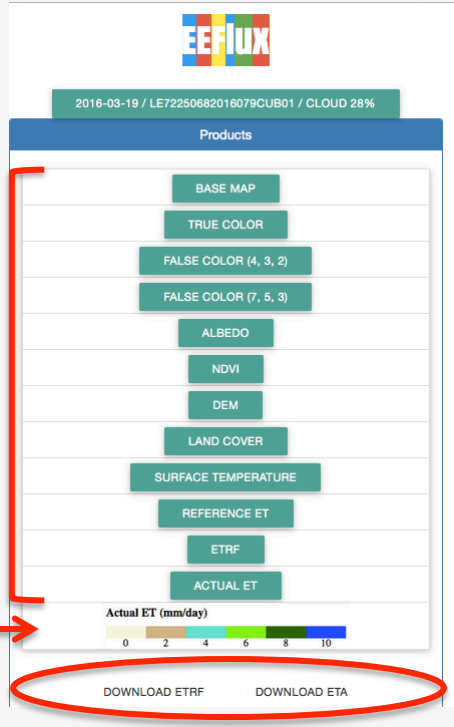
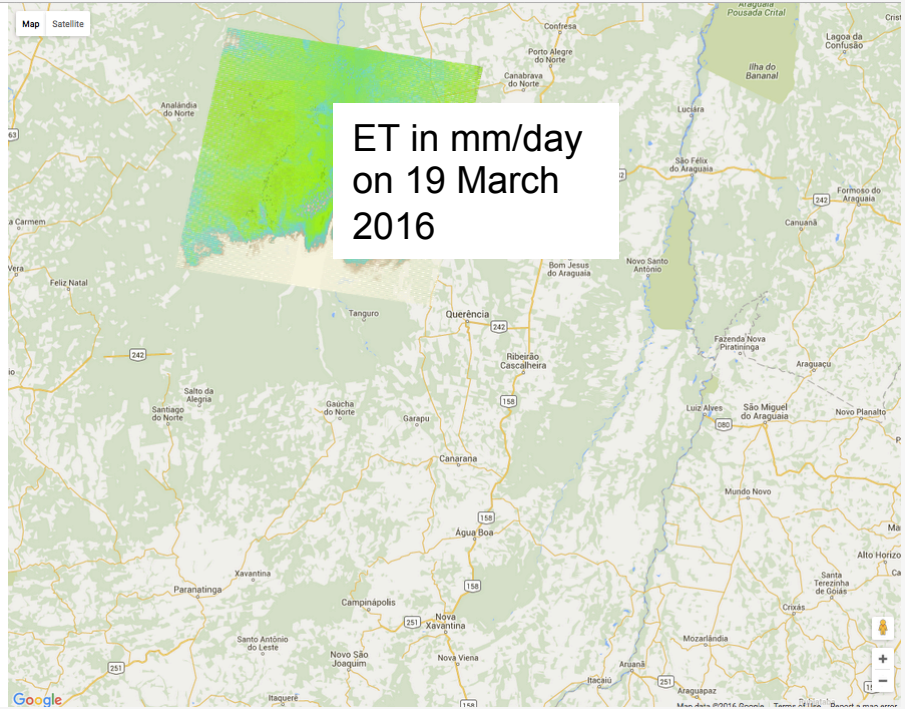


EEFlux : Google Earth Engine Based METRIC ET

http://eeflux-level1.appspot.com

Select parameter to plot and download





Questions

1. Name two methods for ET estimation

2. Name two ET data products based on Landsat and MODIS

3. Both Landsat and MODIS data are used for estimation of ET – is one better than another? Why?

4. Why is the amount of radiation at the surface important for ET processes ?

Summary

- Evapotranspiration is not measured, but calculated by water and/or energy balance methods
- Requires complex algorithm and a variety of climate land surface data
- Multiple algorithms for estimating ET are available – validation and inter-comparison for regional use are recommended
- Remote sensing data from Landsat and MODIS (land surface temperature, land cover, vegetation index, leaf area index, albedo) are very useful in estimating ET
- For more information, see resources on remote sensing based ET methodologies and applications from a 2013 International Workshop organized by NASA and the World Bank: https://c3.nasa.gov/water/resources/10/