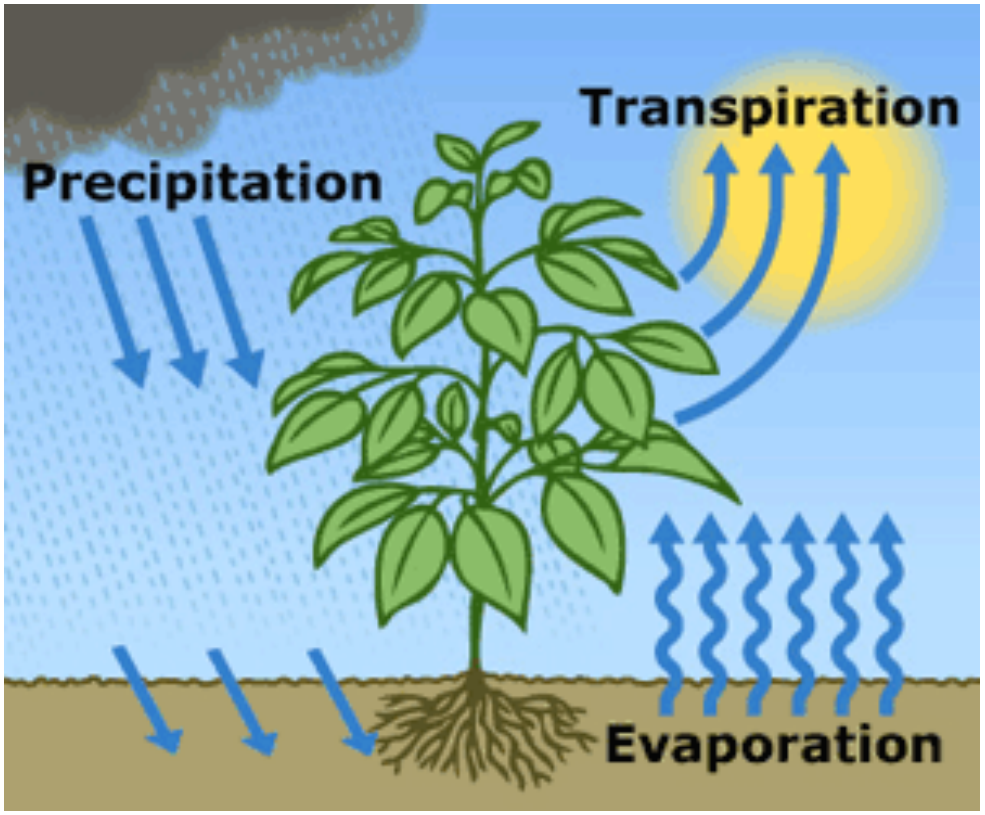
# Evapotranspiration

# What is Evapotranspiration?

The sum of evaporation from the land surface plus transpiration from plants




Source: USGS

# Overview

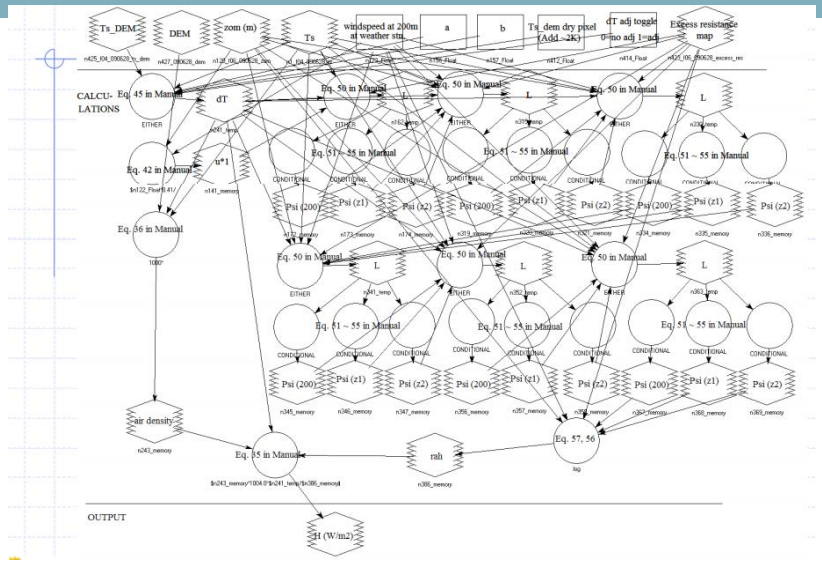

- Importance of ET
- Challenges of Measuring ET
- Benefits and opportunities of using remote sensing for ET
- Methods of deriving ET using remote sensing:
- Summary

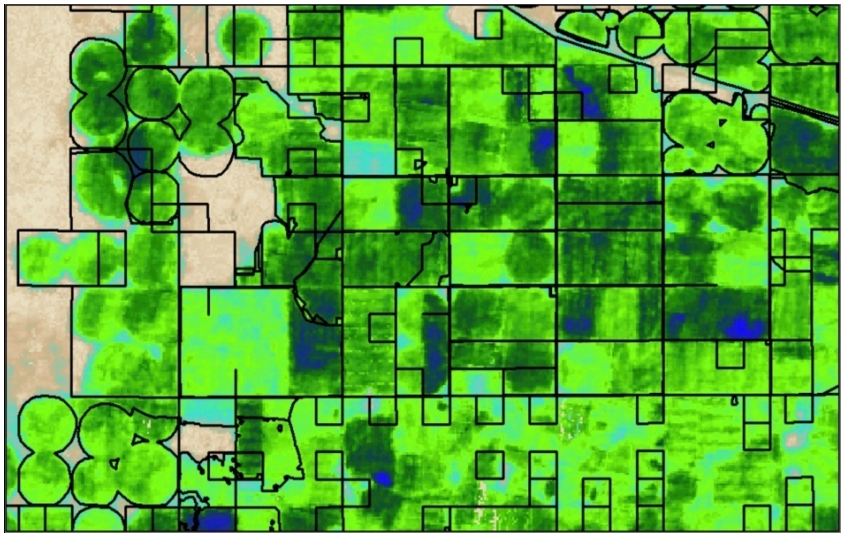
# Importance of ET

- Critical component of water and energy balance of climate-soil-vegetation interactions.
- Used for
  - Determining agricultural water consumption
  - Assessing drought conditions
  - Develop water budgets
  - Monitor aquifer depletion
  - Etc.…

# Challenges of Measuring ET

- ET is complex (many variables)
- ET varies across time and space (A LOT!)



# Main Limitation of ET Ground Measurements

They are point measurements and cannot capture spatial variability

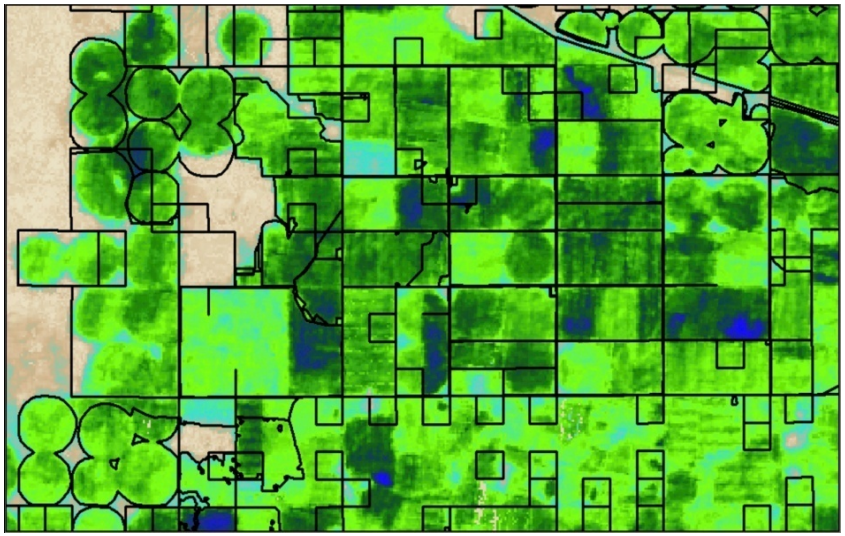
Eddy Flux Towers

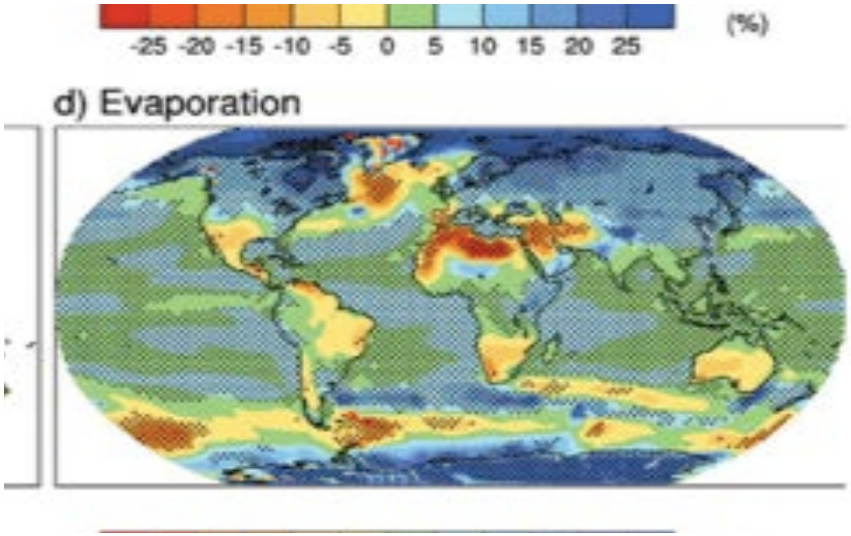
Lysimeters

*Source: Rick Allen, University of Idaho*

# Benefits of Using Remotely Sensed Satellite Data

- Provides relatively frequent and spatially continuous measurement of biophysical variables at different spatial scales:
  - Radiation
  - Vegetation coverage and density





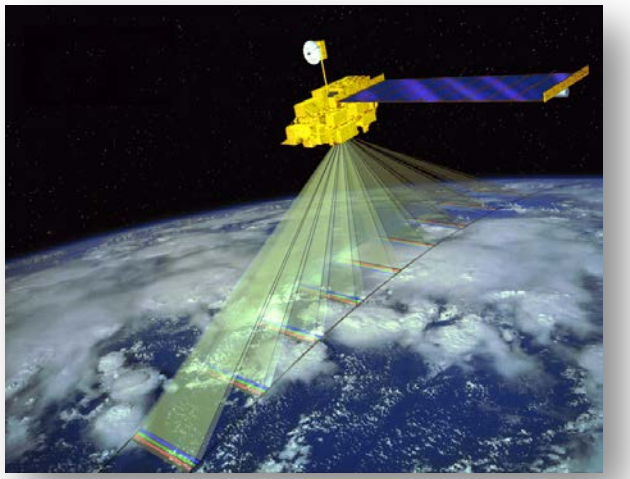

*Source: David Toll, NASA Goddard Space Flight Center*

# Methods for Deriving ET

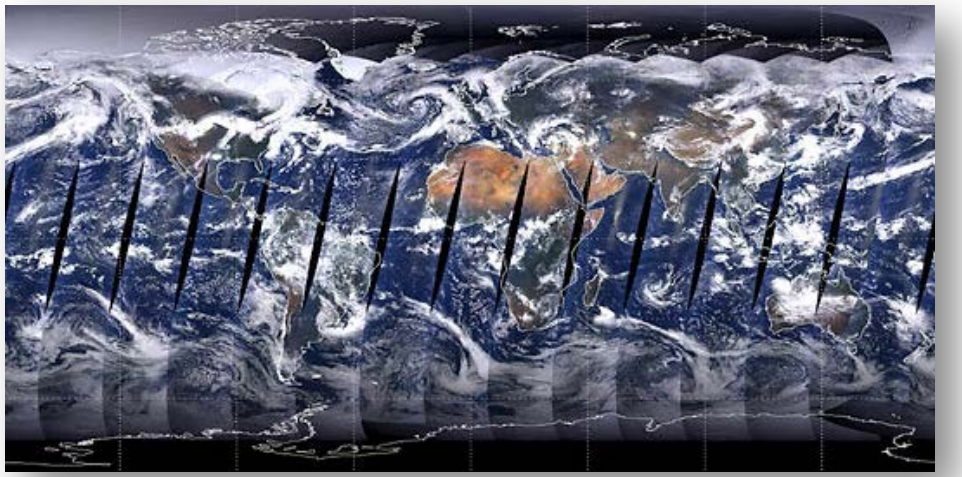
| Method | Spatial Resolution | Source | Availability |
|---|---|---|---|
| Land Surface Models: NLDAS/ GLDAS | 1 - 1/8 degree (Global) | NASA/NOAA | Free/download |
| Other Physical Models: MODIS | 1km (Global) | University of Montana | Free/download |
| Energy Balance: METRIC/SEBAL | 30 m (Local, Regional) | Various | Not Free/contract |
| Vegetation/ET Relationships | 30 m (Local, Regional) | Various | Free/Not Free |
| ALEXI | 10 km – 30 m | USDA | Free/download |

# Methods for Deriving ET: MODIS

# MODIS (Moderate Resolution Imaging Spectroradiometer)



- Spatial Resolution
  - 250m, 500m, 1km
- Temporal Resolution
  - Daily, 8-day, 16-day, monthly, quarterly, yearly
  - 2000-present
- Data Format
  - Hierarchal data format – Earth Observing System Format (HDF-EOS)

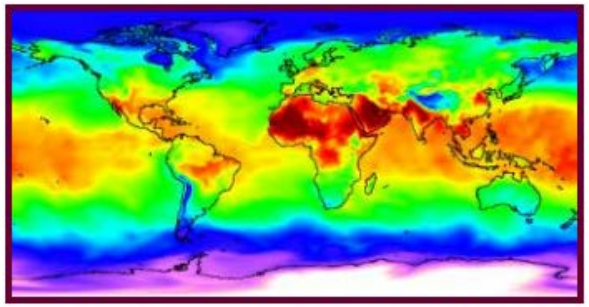


- Spectral Coverage
  - 36 bands (major bands include Red, Blue, IR, NIR, MIR)
    - Bands 1-2: 250m
    - Bands 3-7: 500m
    - Bands 8-36: 1000m

# MODIS Global ET Products

**Numerical Terradynamic Simulation Group (NTSG), University of Montana**

**Input MODIS data (RS)**
**(Albedo, FPAR/LAI, Land cover)**

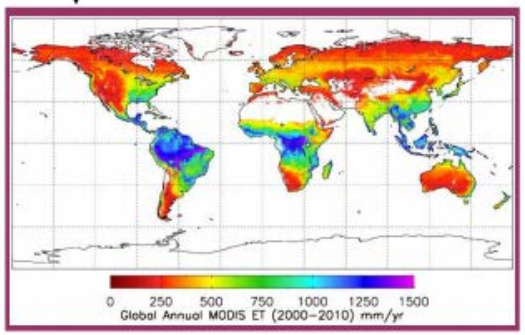


**Daily Meteorological data (MET)**
**(S↓ , VPD, Temperature. No Prcp!)**

**Penman-Monteith equation**

$$\lambda E = \frac{\Delta \bullet R_a \bullet (R_n - G) + \rho \bullet C_p \bullet VPD}{R_a \bullet (\gamma + \Delta) + \gamma \bullet R_S}$$

**ET = f (RS, MET)**




MODIS ET: soil evaporation, evaporation from intercepted water by canopy and plant transpiration.

*Mu et al., 2007, RSE; Mu et al., 2011. RSE. Mu et al., 2009, WRR*

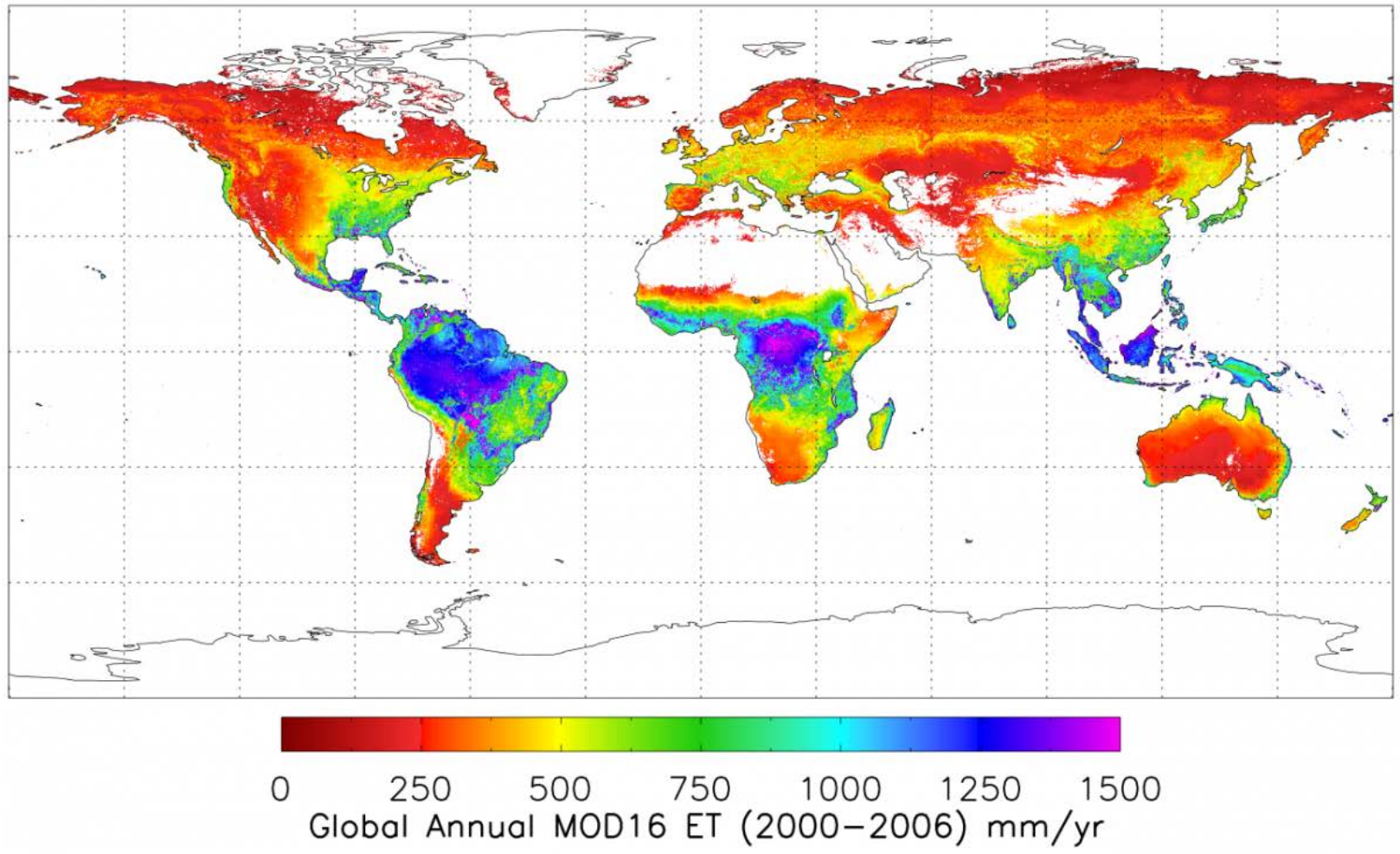
*Source: Qiaozhen Mu, University of Montana*

# Characteristics of MODIS ET Products

- Spatial Resolution 1 km
- Spatial Coverage: Global
- Time frame: 8-day, monthly, annual
- Time period: 2000-2014
- Data download:

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

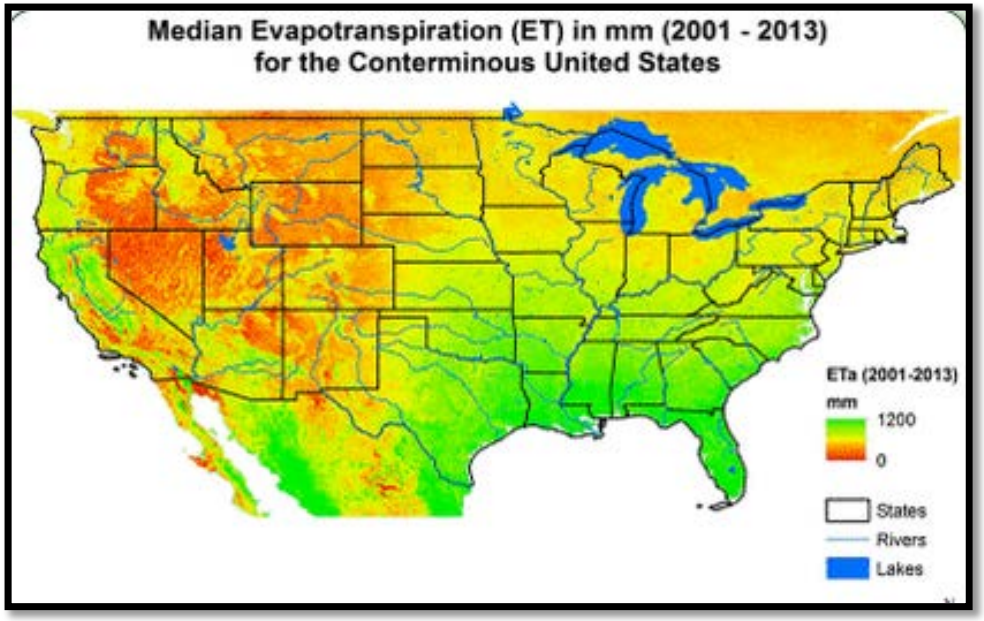
# MOD16 Global Terrestrial ET Data Set




*Source: Qiaozhen Mu, University of Montana*

# USGS WaterSMART ET

http://www.usgs.gov/climate_landuse/lcs/projects/wsmartet.asp




Annual total ET (median of 2001-2013) derived from the 1km MODIS-based thermal dataset. The product is produced from 8-day accumulation of ET from January to December.

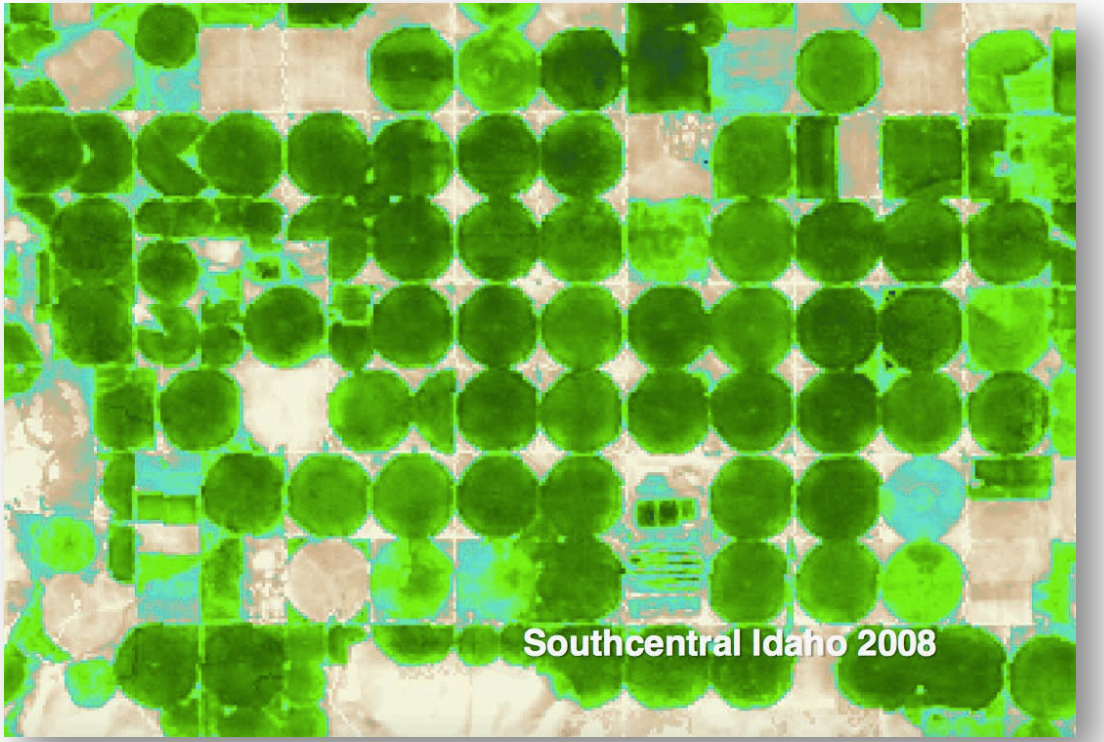
Monthly and yearly summaries are available at the USGS Geoportal http://cida.usgs.gov/gdp/

# Methods for Deriving ET: Landsat

## Energy Balance And Vegetation Indices

# Why Landsat?

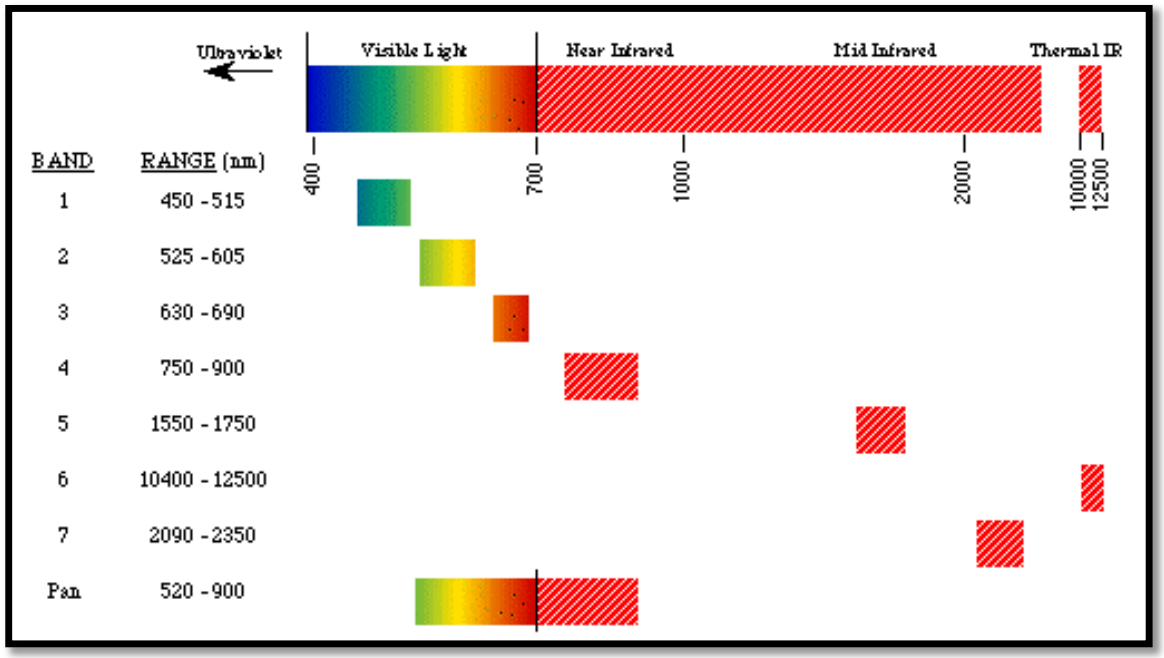
- Landsat allows field-level ET
- Landsat has a thermal band which is important for some ET approaches




Source: Richard Allen, University of Idaho

# Characteristics of Landsat: Spectral

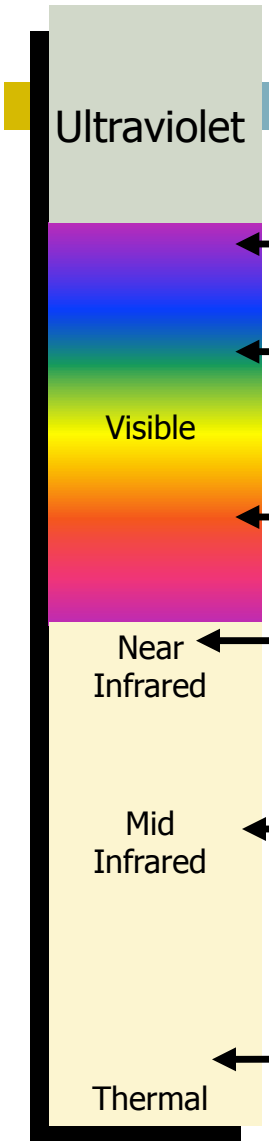
- Landsat instruments measure primarily light that is reflected from Earth's surface (with one exception)
- Landsat instruments are designed to detect visible and infrared (near and mid) wavelengths.




Source: NASA Goddard Space Flight Center

Landsat bands of ETM+ (Landsat 7)

# Landsat Bands: What is Important for ET?




BAND 1: Blue
Scattered by the Atmosphere
Illuminates material in shadows not seen in longer wave lengths
Best water penetration for clear water

BAND 2: Green
Contrast between clear and turbid water
Reflectance peak of vegetation in Visible region

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)
Fire Fuels Modeling
Differentiation between evergreen and deciduous vegetation

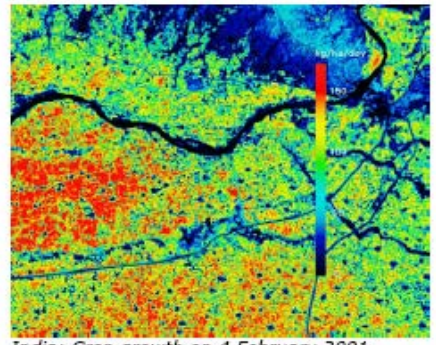
-BANDS 5 and 7: Mid-Infrared
Discrimination of oil on water
Moisture content of soil and vegetation
Limited cloud penetration
Contrast between vegetation types

BAND 6: Thermal
Solar reflectance from metal buildings
Heat emissions from fires and smoke stacks
Smoke Penetration
Emitted and latent heat

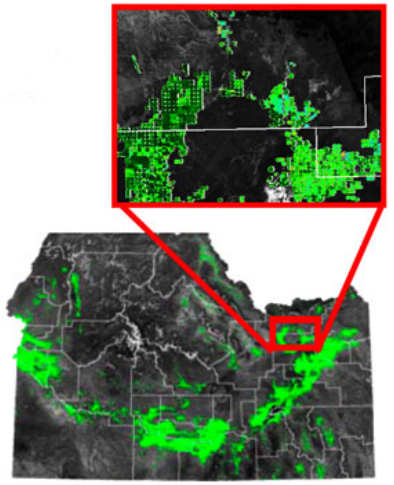
# Methods for Deriving ET: Energy Balance

# Evolution of Energy Balance Approach

- SEBAL –
  - Surface-Energy Balance Algorithm for Land
  - Developed by Dr. Wim Bastiaanssen (Netherlands) in late 1990s
  - Applications: ET and crop productivity
- METRIC
  - Mapping Evapotranspiration with High Resolution and Internalized Calibration
  - Developed by Dr. Rick Allen, University of Idaho in the mid-2000s



*India: Crop growth on 4 February 2001*



**Agricultural evapotranspiration for southern Idaho. Image courtesy of IDWR.**

*Source: Rick Allen, University of Idaho*

# How METRIC Works

Requires satellites with Red, Near IR and Thermal IR

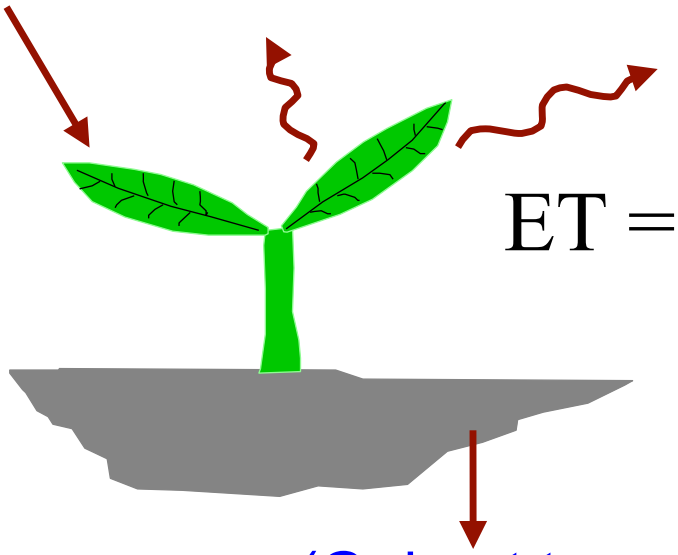
Rn: Landsat reflectances and surface temperature

G estimated from Rn, surface temp. and vegetation indices

H estimated from surface temp. ranges, surface roughness, and wind speed

(Rn -radiation from sun and sky)

(H - heat to air)



$$ET = R_n - G - H$$

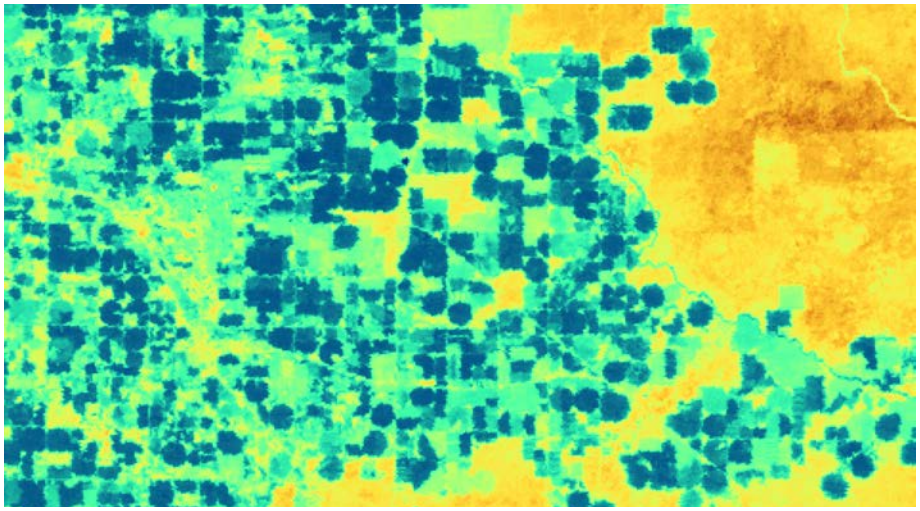
***Basic Truth***:
Evaporation consumes Energy

(G -heat to ground)

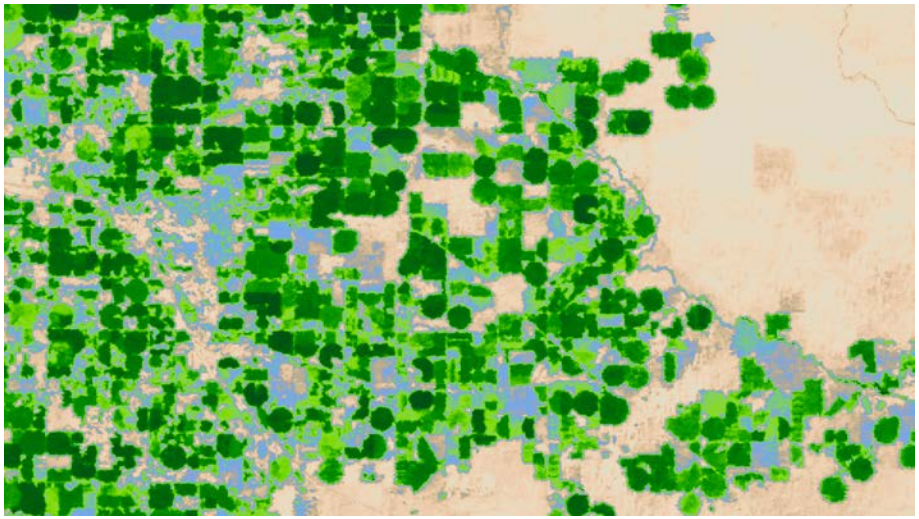
*Source: Rick Allen, University of Idaho*

# ET from METRIC

This is an image of agricultural fields in Idaho from the Landsat thermal band. Irrigated fields are cooler (blue), while surrounding areas are warmer (yellow and red)



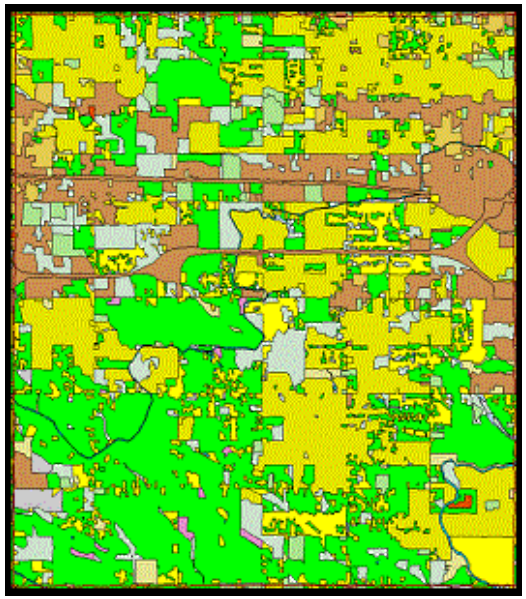
This image is a map of evapotranspiration created using METRIC. Areas with higher ET are shown in darker green



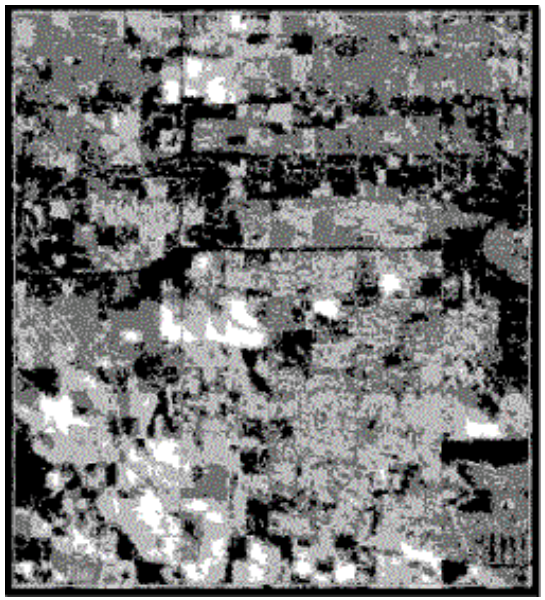
Credit: NASA/Goddard Scientific Visualization Studio

# ET By Land Use Class

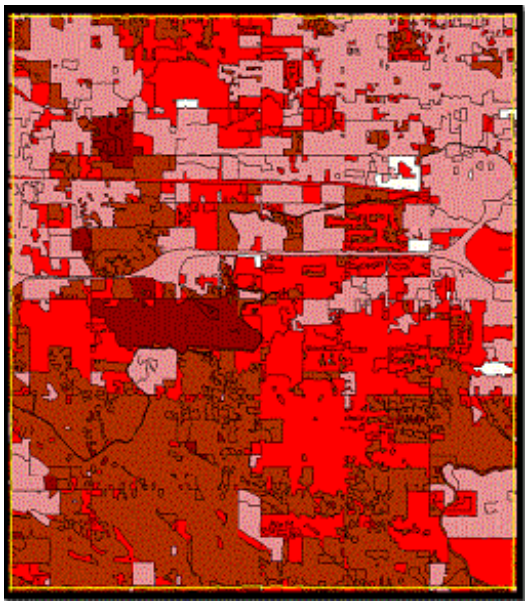
## How Does Water Use Change as Land Use Changes?



Land Use / Land Cover



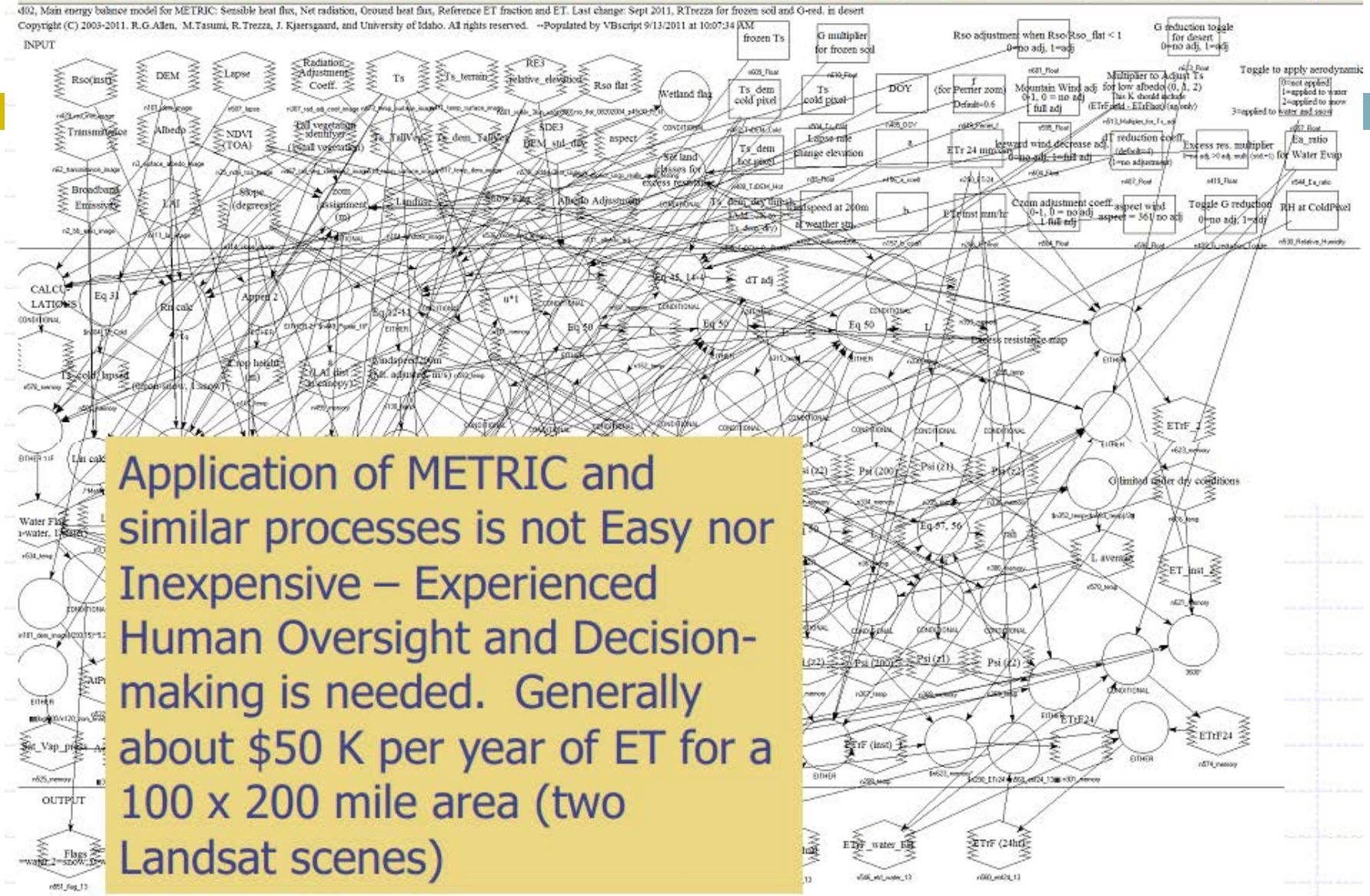
ET From METRIC



ET By Land Use / Land Cover

Source: Anthony Morse, Idaho Department of Water Resources

# 'full' METRIC$^{tm}$-ERDAS submodel for sensible heat and ETrF

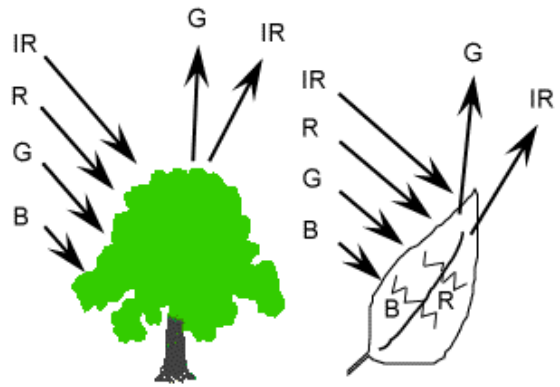


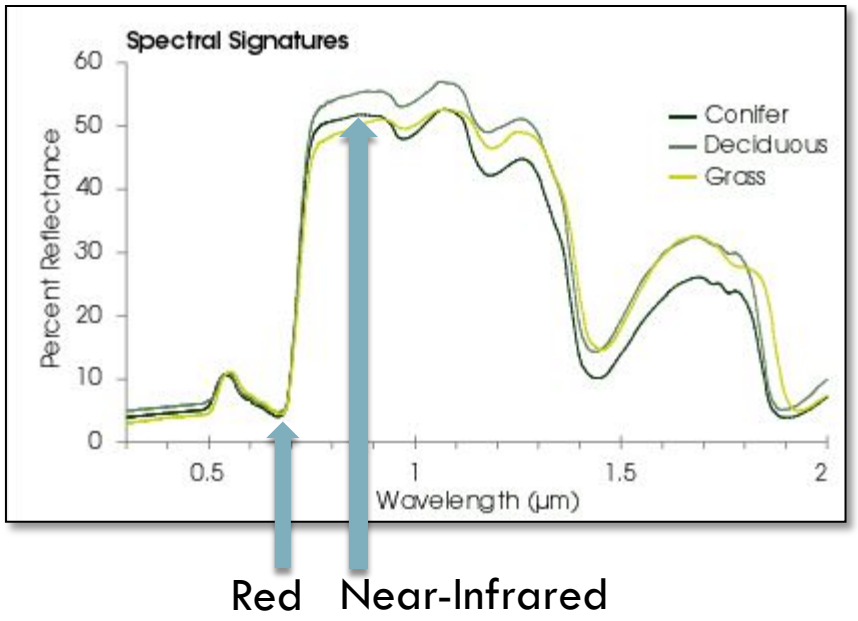

*Source: Rick Allen, University of Idaho*

# Methods for Deriving ET: Vegetation Indices

# What is a Vegetation Index?

- Based on the relationship between red and near-infrared wavelengths.
  - Chlorophyll strongly absorbs visible (red)
  - Plant structure strongly reflects near-infrared



# What is NDVI?

- Normalized Difference Vegetation Index
- NDVI formula:

$$\frac{\text{Near-Infrared} - \text{Red}}{\text{Near-Infrared} + \text{Red}}$$

- Values range from -1.0 to 1.0
  - Negative values to 0 mean no green leaves
  - Values close to 1 indicates the highest possible density of green leaves.

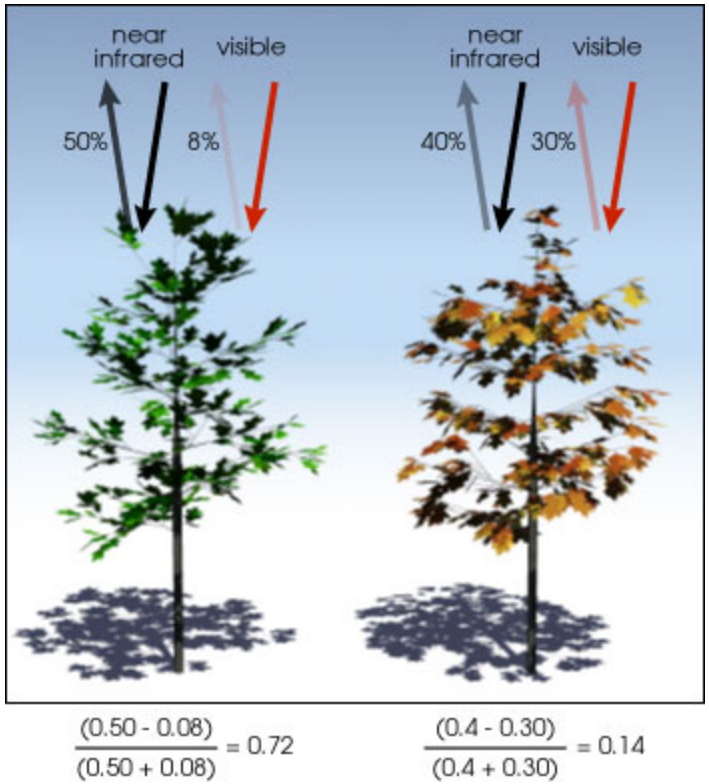



Image Credit: Robert Simmon

# Examples of NDVI

$$\frac{\text{Near Infrared} - \text{Red}}{\text{Near Infrared} + \text{Red}}$$

Values represent varying levels of vegetation density

North America, July 2000

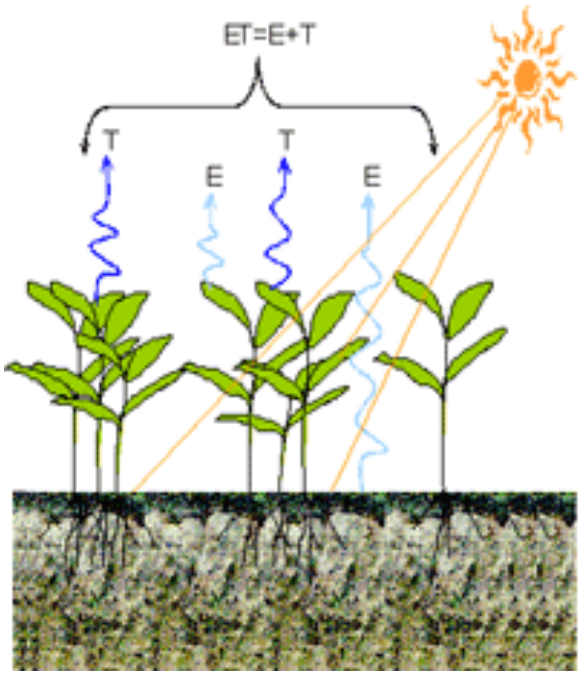
Africa, March 2000

Source: NASA Goddard Scientific Visualization Studio

*Other terms you need to know….*

# Crop Evapotranspiration (ETc)

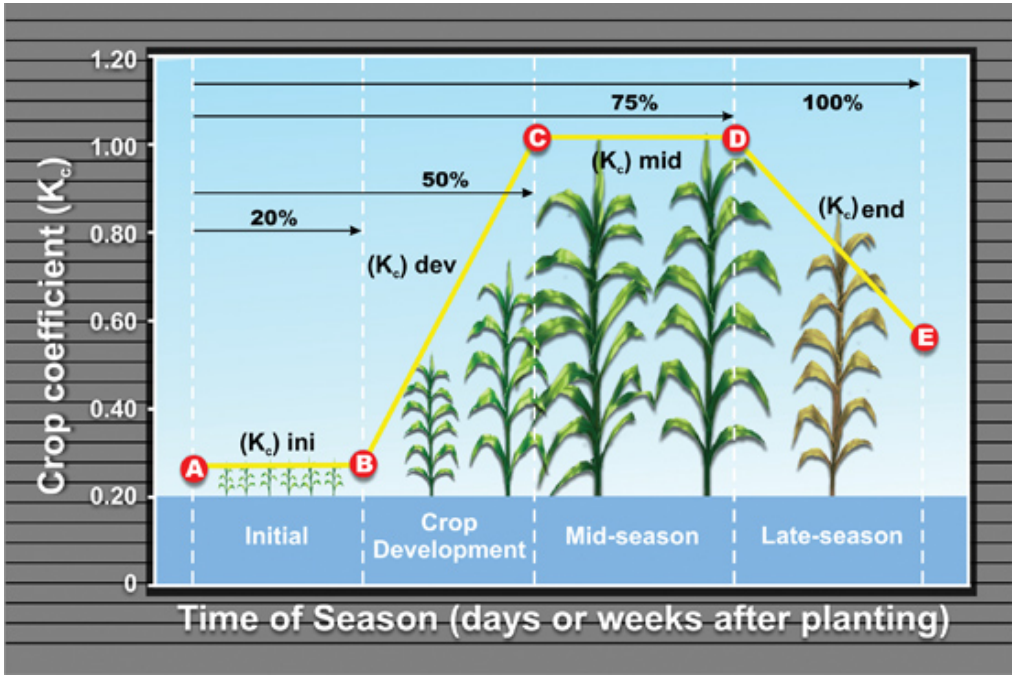
- ETc = the combined processes of crop transpiration (T) and evaporation from the soil surface (E) for a well-watered (non-stressed) crop
- ETo = reference ET (measure on the ground). Typically a well-watered grass surface.




Source: California Department of Water Resources

# Crop Coefficient (Kc)

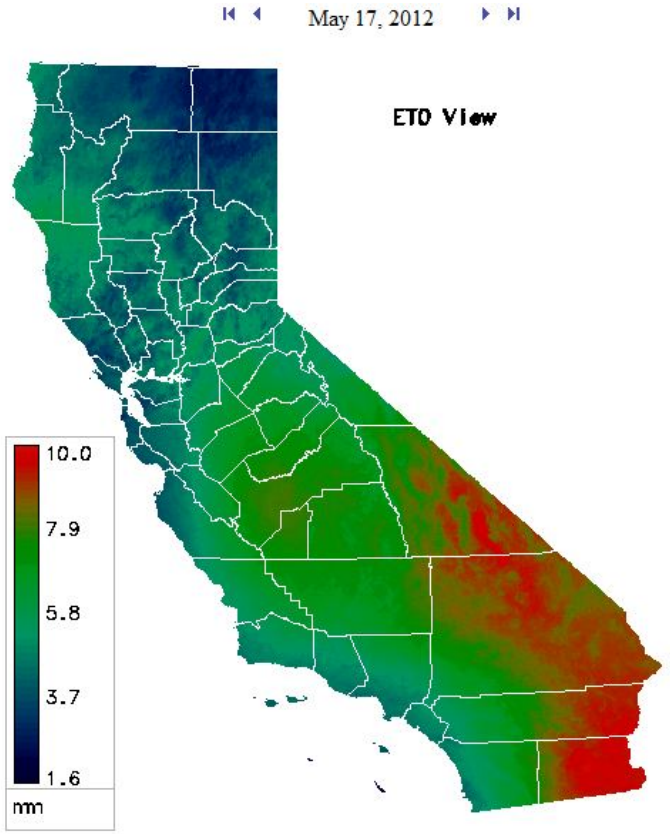
- Vary by type of crop, stage of growth of the crop, and some cultural practices.




Source: University of Nebraska-Lincoln Extension

# Calculating ETc

- Apply crop coefficient (Kc) to reference ET (ETo) : Etc = Eto * Kc
- In California, the California Irrigation Management Information System (CIMIS) provides daily ETo values, gridded across the entire state at 2km resolution.

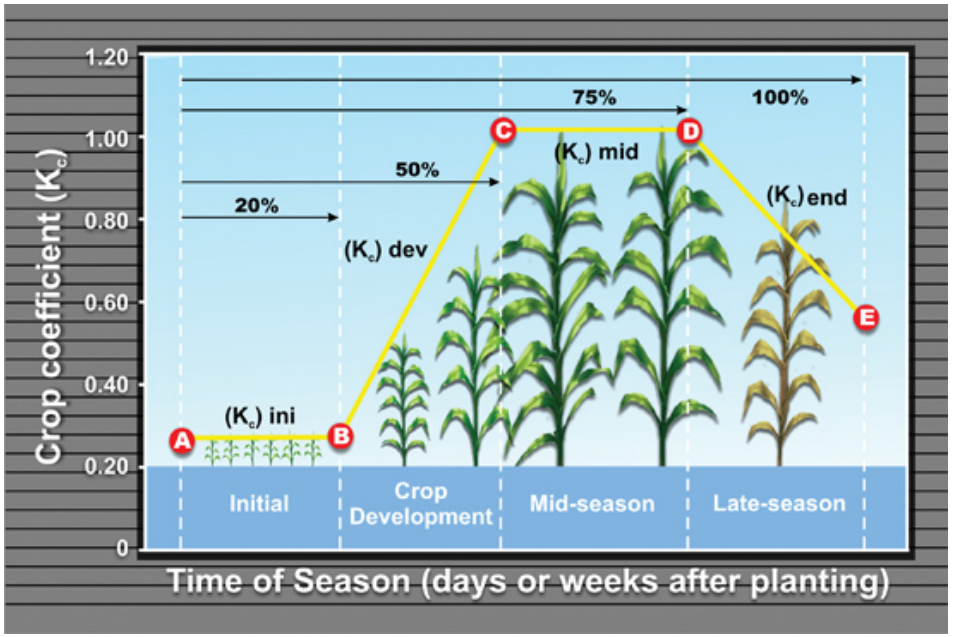


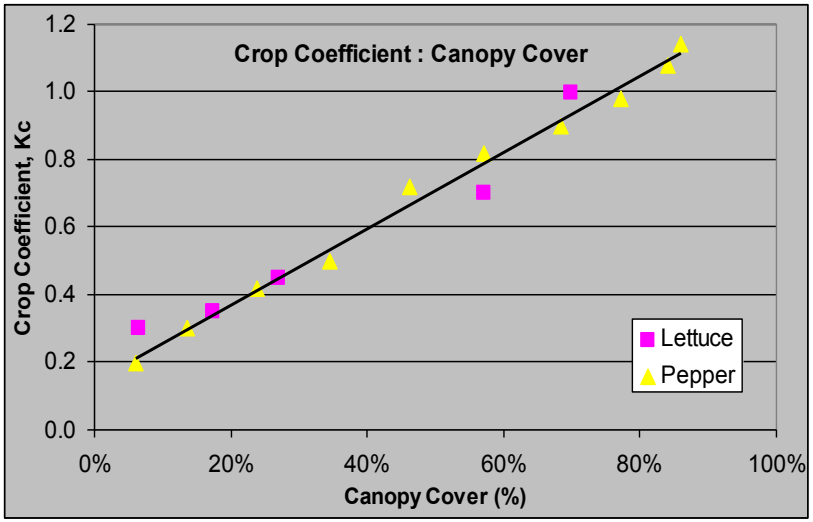

Daily Eto values from CIMIS

# Crop Coefficients (Kc) vs. Vegetation Indices

Kc is related to light interception (ground cover)

There is a direct relationship between Kc and NDVI

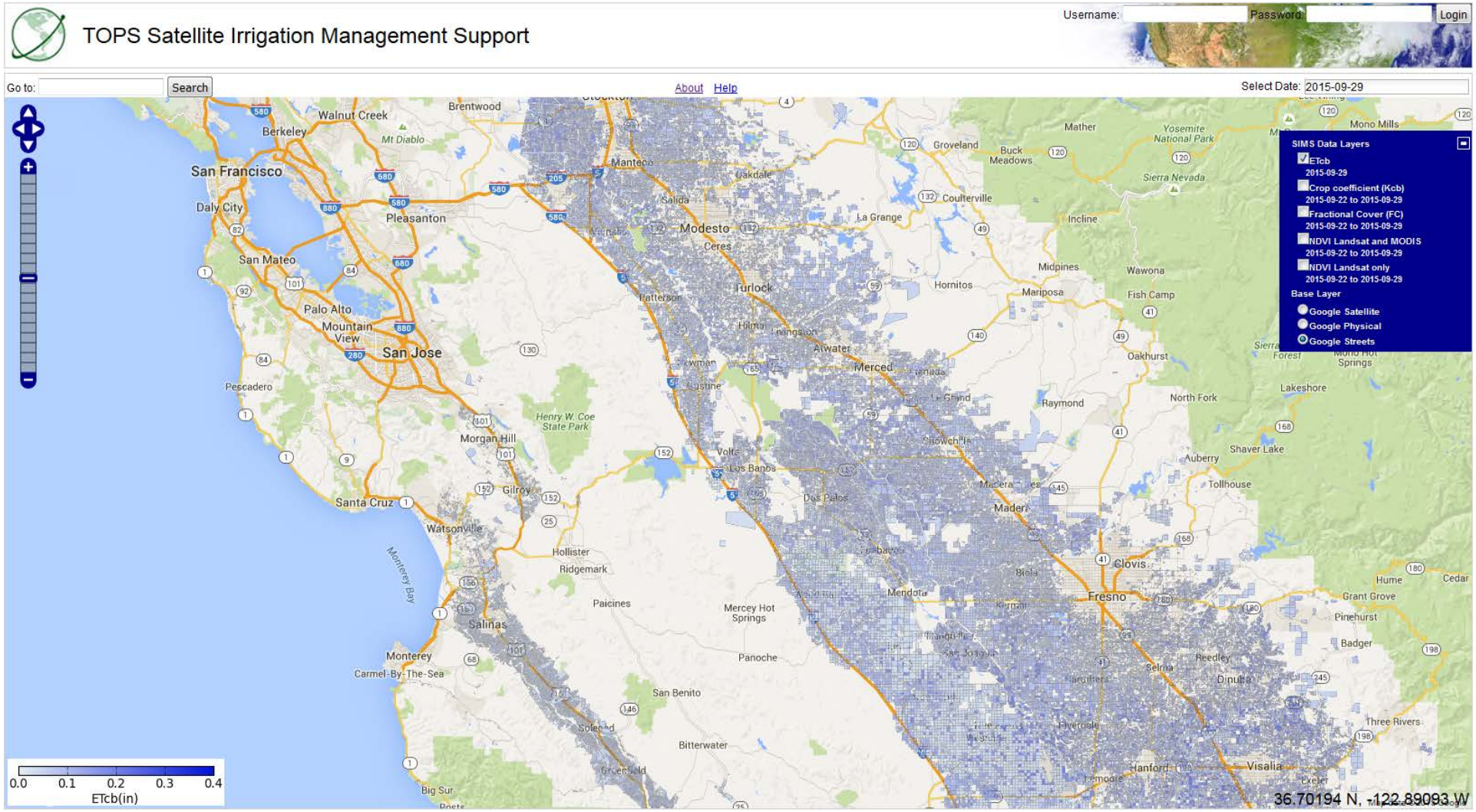


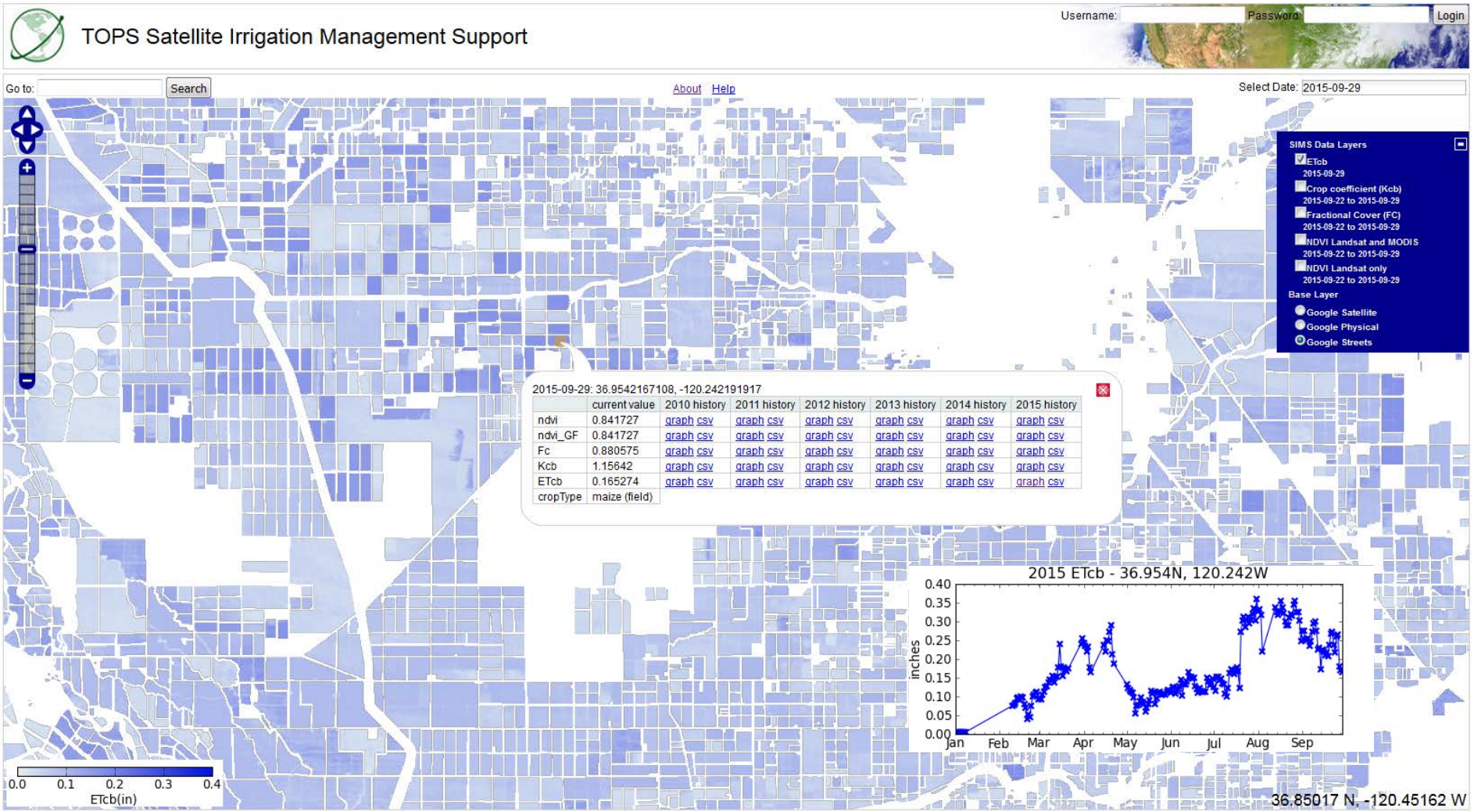




Source: Tom Trout, USDA

# TOPS Satellite Irrigation Management Support

http://ecocast.arc.nasa.gov/dgw/sims/




TOPS Satellite Irrigation Management Support
Username:
Password:
Login
Go to:
Search
About
Help
Select Date: 2015-09-29
SIMS Data Layers
ETcb
2015-09-29
Crop coefficient (Kcb)
2015-09-22 to 2015-09-29
Fractional Cover (FC)
2015-09-22 to 2015-09-29
NDVI Landsat and MODIS
2015-09-22 to 2015-09-29
NDVI Landsat only
2015-09-22 to 2015-09-29
Base Layer
Google Satellite
Google Physical
Google Streets
2015-09-29: 36.9542167108, -120.242191917
current value
2010 history
2011 history
2012 history
2013 history
2014 history
2015 history
ndvi 0.841727
ndvi_GF 0.841727
Fc 0.880575
Kcb 1.15642
ETcb 0.165274
cropType maize (field)
graph csv
2015 ETcb - 36.954N, 120.242W
inches
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
0.0
0.1
0.2
0.3
0.4
ETcb(in)
36.85017 N, -120.45162 W

# Advantages/Disadvantages for ET Derived from Vegetation Indices

- Primarily useful for estimating ET of a well-watered crop on a dry soil surface
- This method is simple and quick, and inexpensive.
- Can be used on other types of imagery – not just Landsat

# Summary

- ET is not directly measured from satellites.
- Deriving ET is a complex process (some methods are more complex than others).
- There are multiple ET products available that utilize different approaches and remote sensing instruments at different temporal and spatial resolutions.
- Any of the ET data derived from Landsat require special processing capabilities

# Thank You!