Evapotranspiration Workshop: New Technologies and Methods for estimating ET

Use of Remote Sensing to estimate ET

José L. Chávez

Assistant Professor and Irrigation Extension Specialist
Civil and Environmental Engineering Department
Colorado State University

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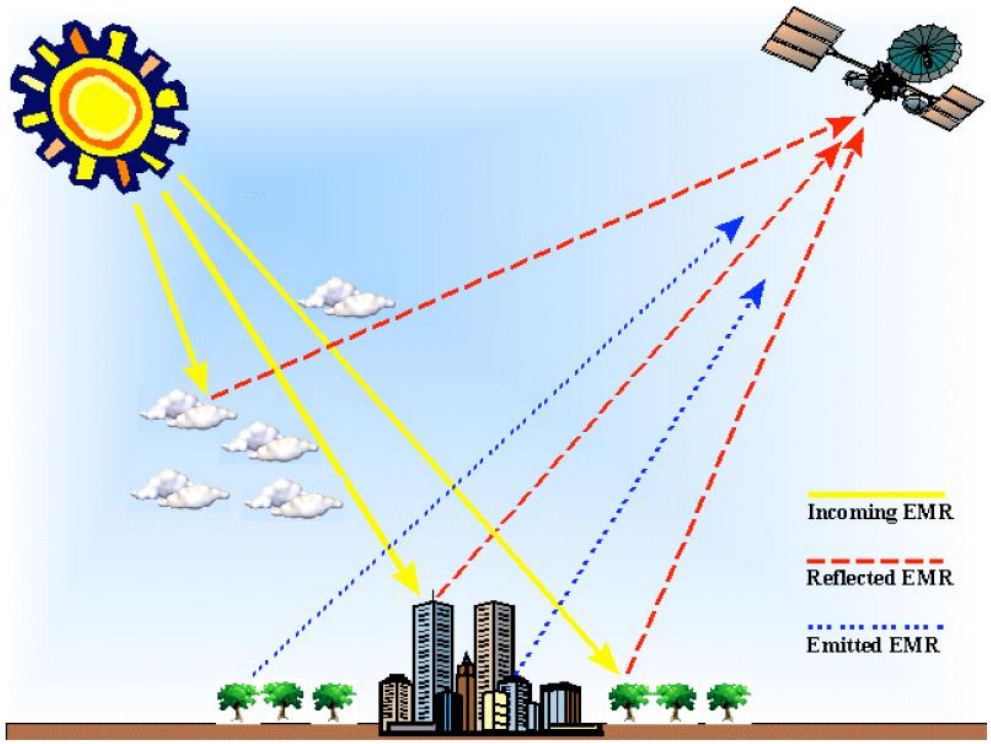
Presentation Outline

- Energy balance based methods:
  - One source models
    - function of surface radiometric temperature (T_s),
    - function of surface aerodynamic temperature (T_o),
    - function of a linear relationship between dT and T_s,
  - Two source model

- Reflectance-based crop coefficient method
- Fractional vegetation ground cover-based method
- Crop water stress index & Water deficit index based
- Dimensionless temperature method

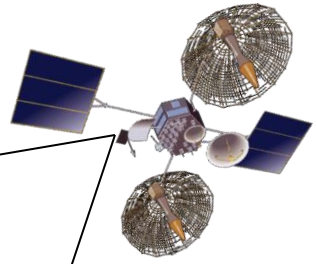
Remote Sensing

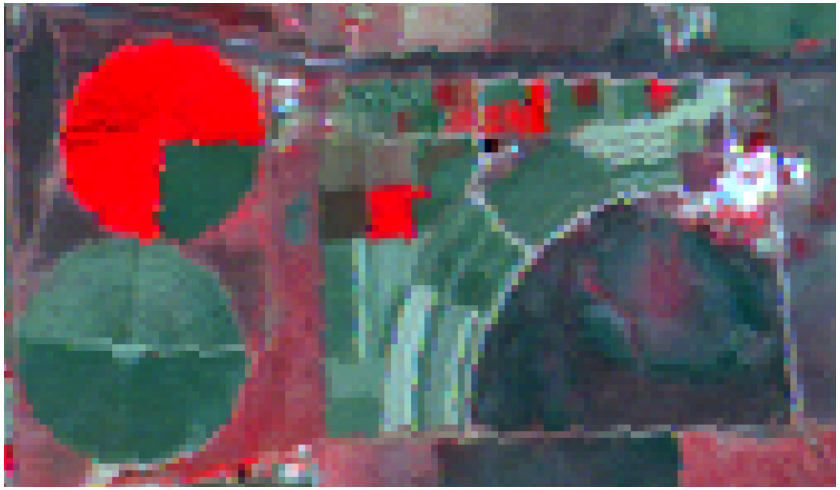
Remote sensing is the acquisition of information about an object or phenomenon, without making physical contact with the object.

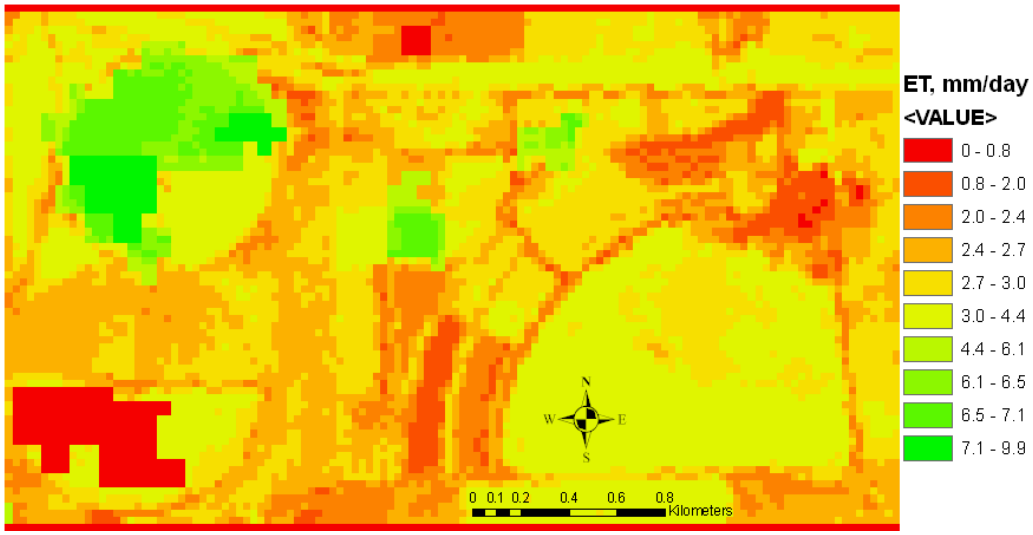


Remote Sensing of ET

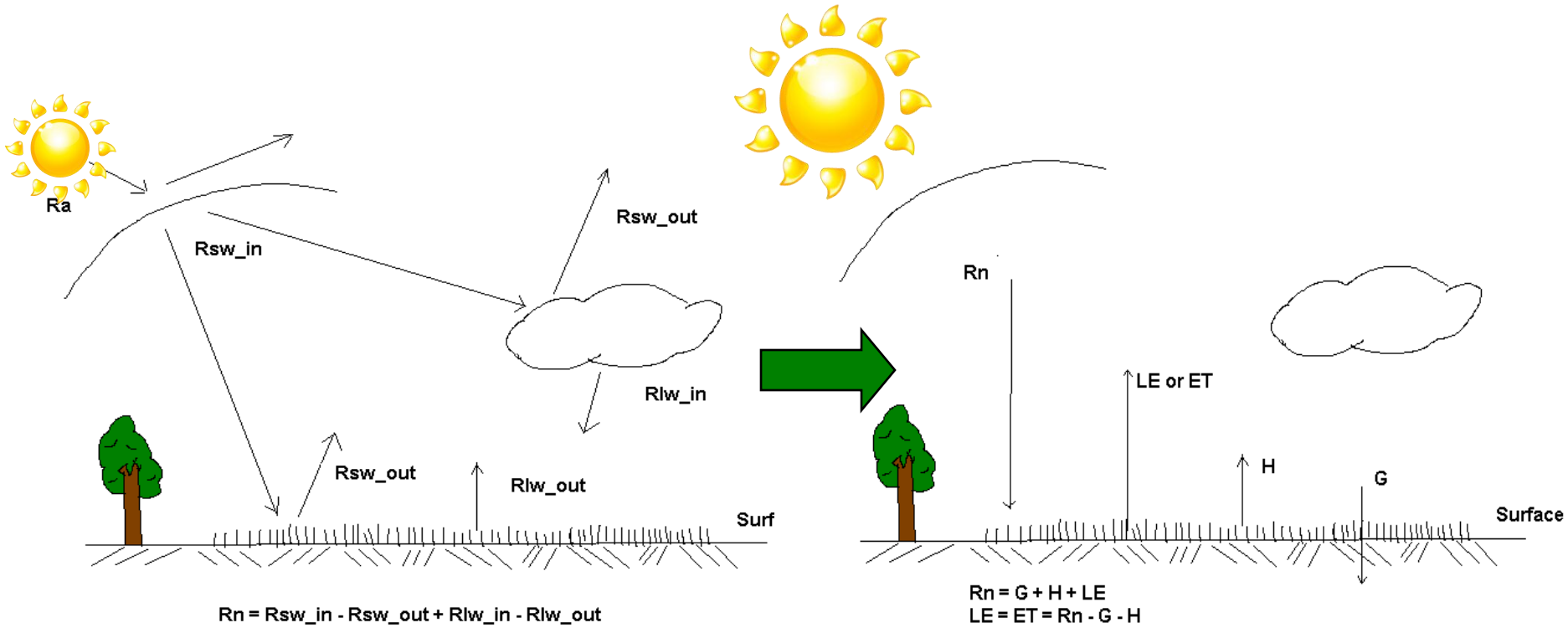
Remote sensing of ET is the estimation of vegetation/crop actual evapotranspiration rates using remotely sensed surface characteristics (reflectance, temperature), a processing algorithm, and weather data.







SURFACE ENERGY BALANCE



Net Radiation, R_n

$$R_n = (1 - \alpha)\, R_{sw\downarrow} + R_{L\downarrow} - R_{L\uparrow}$$

albedo , α

$R_{sw\downarrow}$

$R_{L\uparrow}$

reflectance, ρ_λ

ε_o

T_{sfc}

radiance, L_λ

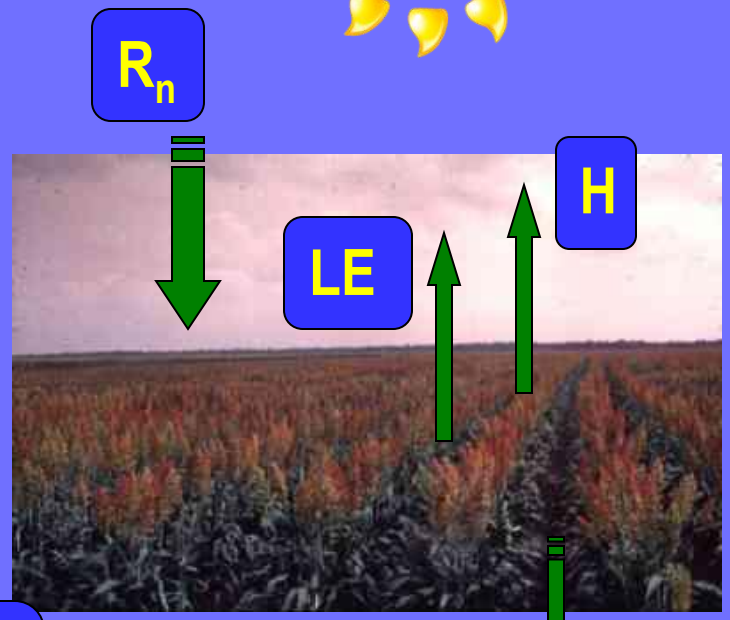
fc

T_{bb}

RED, NIR, VIS bands images

NDVI, OSAVI, LAI

Thermal image



Soil Heat Flux, G

$G = 0.35\ \mathbf{R_{n,SOIL}}$ (Choudhury et al., 1987)

$G = ((\mathbf{T_s} - 273.15)\ (0.0038+0.0074\ \boldsymbol{\alpha})\ (1-0.98\ \mathbf{NDVI}^4))\ \mathbf{R_n}$

(Bastiaanssen, 2000)

$G = [(0.3324 - 0.024\ \mathbf{LAI})\ (0.8155 - 0.3032\ \mathrm{Ln}(\mathbf{LAI})]\ \mathbf{R_n}$

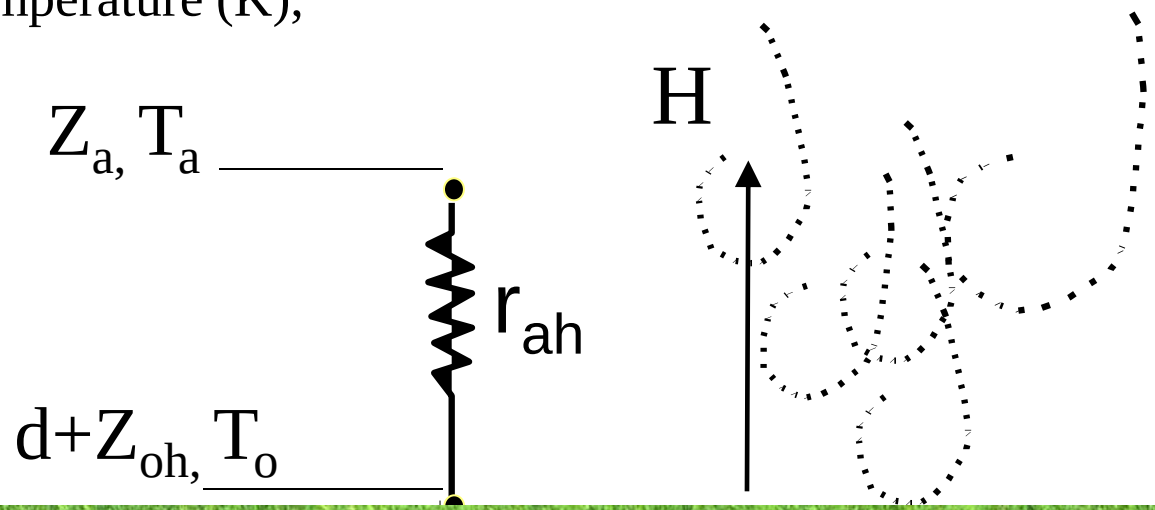
(Chávez et al., 2005)

One Source: Sensible Heat Flux (H)

$$H = \rho \times c_p \times (T_o - T_a) / r_{ah}$$

r_{ah} = the aerodynamic resistance to heat transport (s/m),
c_p is the specific heat capacity of the air (1004 J/kg/K),
ρ is air density (kg/m^3),
T_o = surface aerodynamic temperature (K),
T_a = air temperature (K)

$$r_{ah} = \frac{\ln\left(\frac{z_a - d}{z_{om}}\right)\ln\left(\frac{z_a - d}{z_{oh}}\right)}{u \times k^2}$$

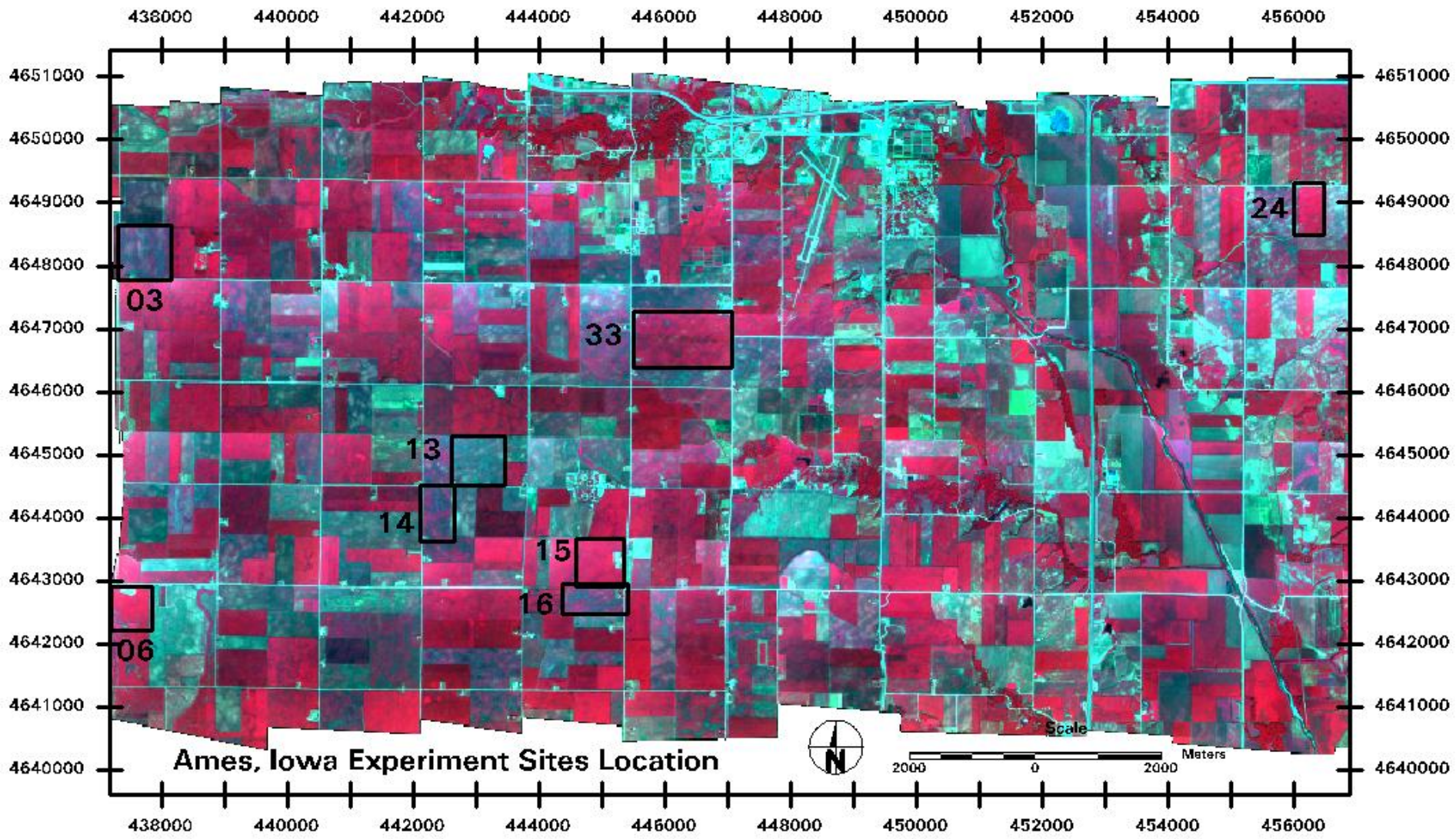


$$H = \rho \times c_p \times (T_s - T_a) / r_{ah}$$

T_s = surface radiometric temperature (K)

ET estimation over Corn and Soybean Fields (Iowa)

2002 NASA SMACEX – SMEX02

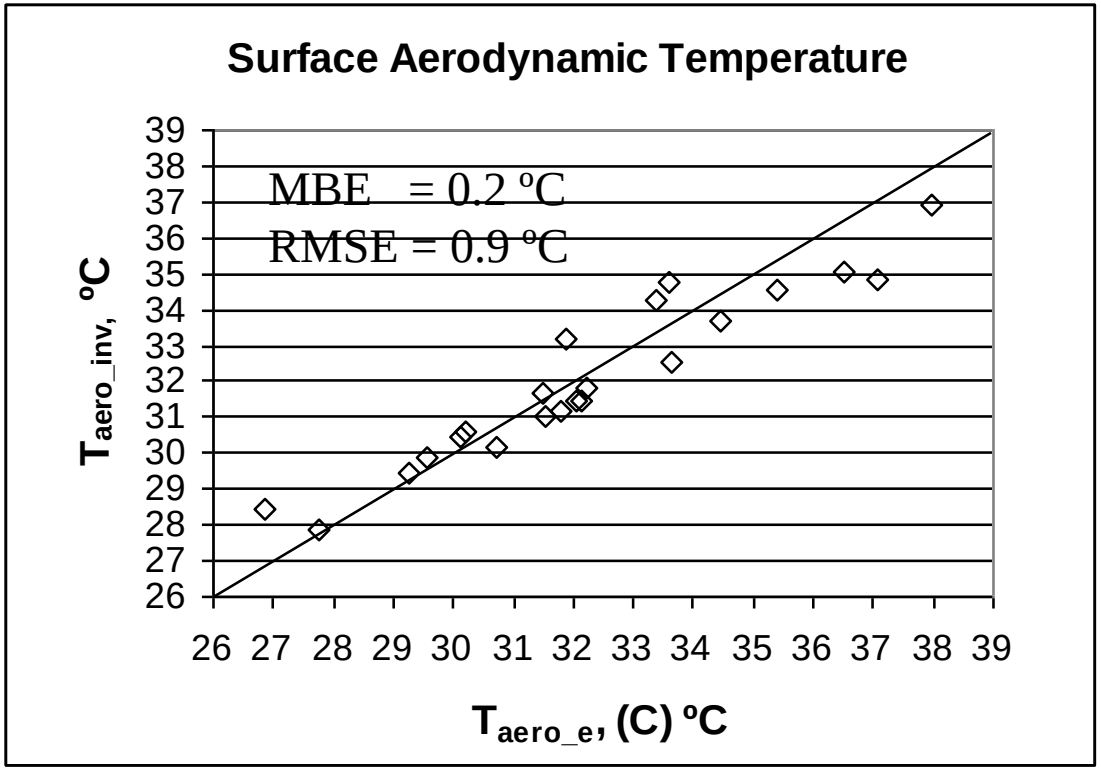


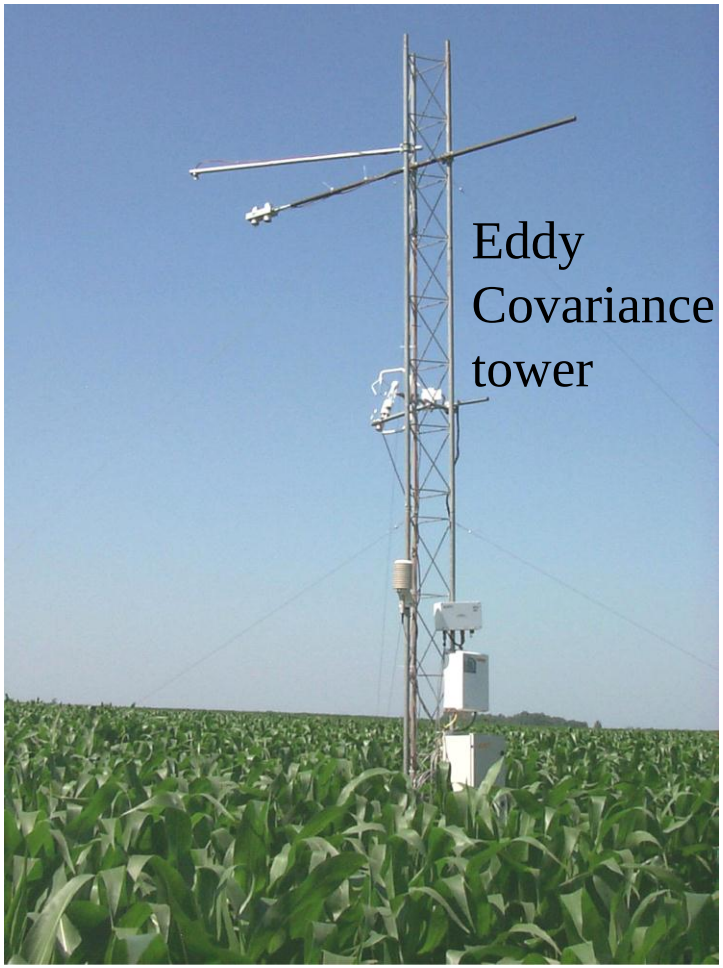
Iowa T_{aero} or T_o (SAT) modeling for Corn and Soybeans

$$T_{aero} \text{ or } T_o = 0.534\ T_s + 0.39\ T_a + 0.224\ LAI - 0.192\ U + 1.68$$

Chávez et al. (2005)

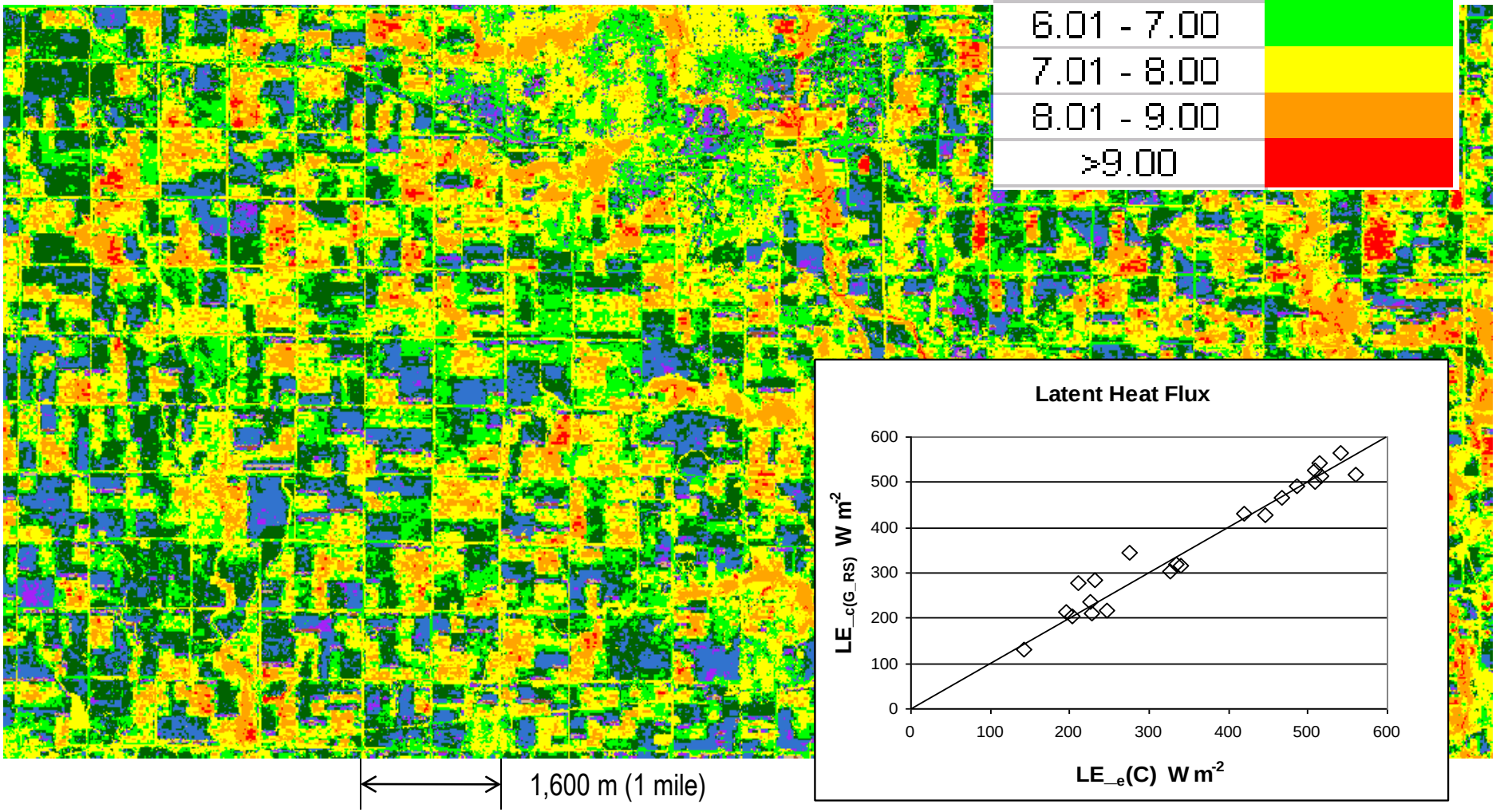
where temperature units are in °C, LAI in $m^2\ m^{-2}$, and U in $m\ s^{-1}$.





24 Hour ET (ET_d, mm/d) Map DOY 182

< 0.15	
0.15 - 2.00	
2.01 - 3.00	
3.01 - 4.00	
4.01 - 5.00	
5.01 - 6.00	
6.01 - 7.00	
7.01 - 8.00	
8.01 - 9.00	
>9.00	

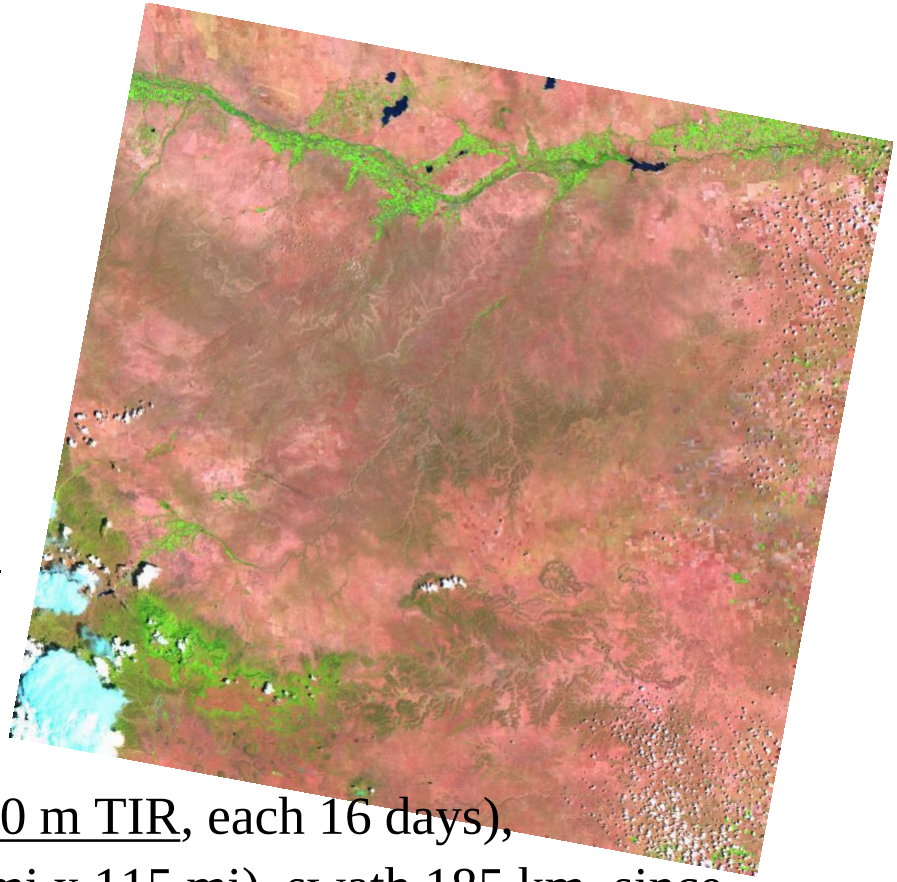


One Source: SEBAL

- Surface Energy Balance Algorithm for Land
- Developed by
  - Dr. Wim Bastiaanssen, *The Netherlands*
- Applied to Satellite imagery:
  - **energy balance** is applied at *each "pixel"* to map spatial variation

• reflectance of light energy (VIS, NIR),
• vegetation indices (combination of VIS bands),
• surface temperature (thermal band),
• relative variation in surface temperature (dT) to estimate H,
• horizontal wind speed *(from a weather station)*

Satellite Images used in SEBAL



- SEBAL needs both short wave (VIS) and thermal (TIR) bands

- SEBAL can used images from:

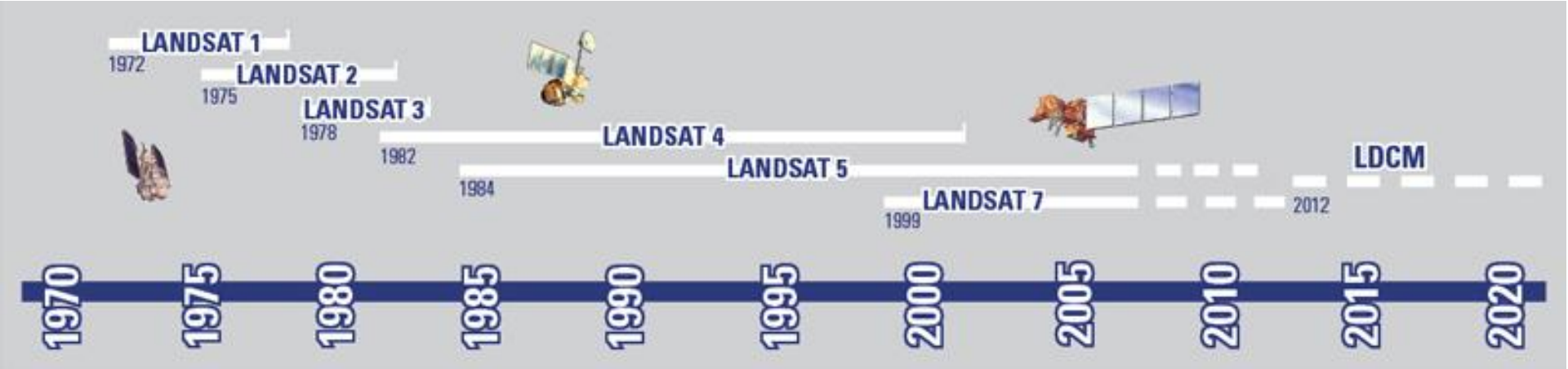
  NASA-Landsat 5 (30 m VIS and 120 m TIR, each 16 days),

  Scene size: 170 km x 185 km (106 mi x 115 mi), swath 185 km, since 1984. Altitude of 705.3 km (438.3 mi)

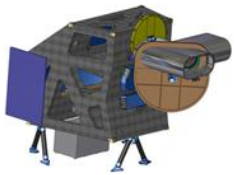
- On November 18, 2011, image acquisitions were suspended for a period of 90 days, due to fluctuations in the performance of a critical amplifier that is part of the satellite's transmission system. Suspension period extended 90 more days.

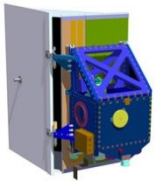
LANDSAT SATELLITES

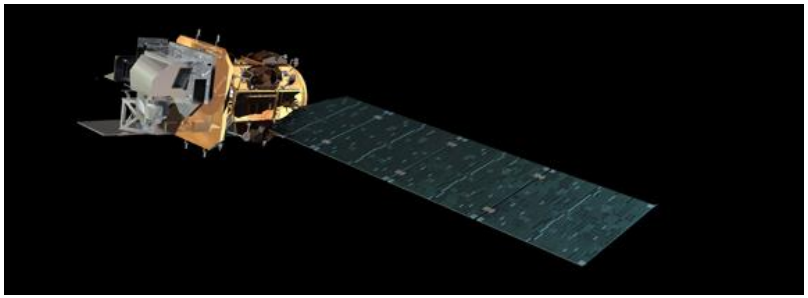
Landsat Data Continuity Mission (LDCM)



The Landsat Data Continuity Mission (LDCM) is the next-generation Landsat satellite and is expected to be launched Jan. 2013. This mission will ensure the continued acquisition and availability of Landsat-like data.





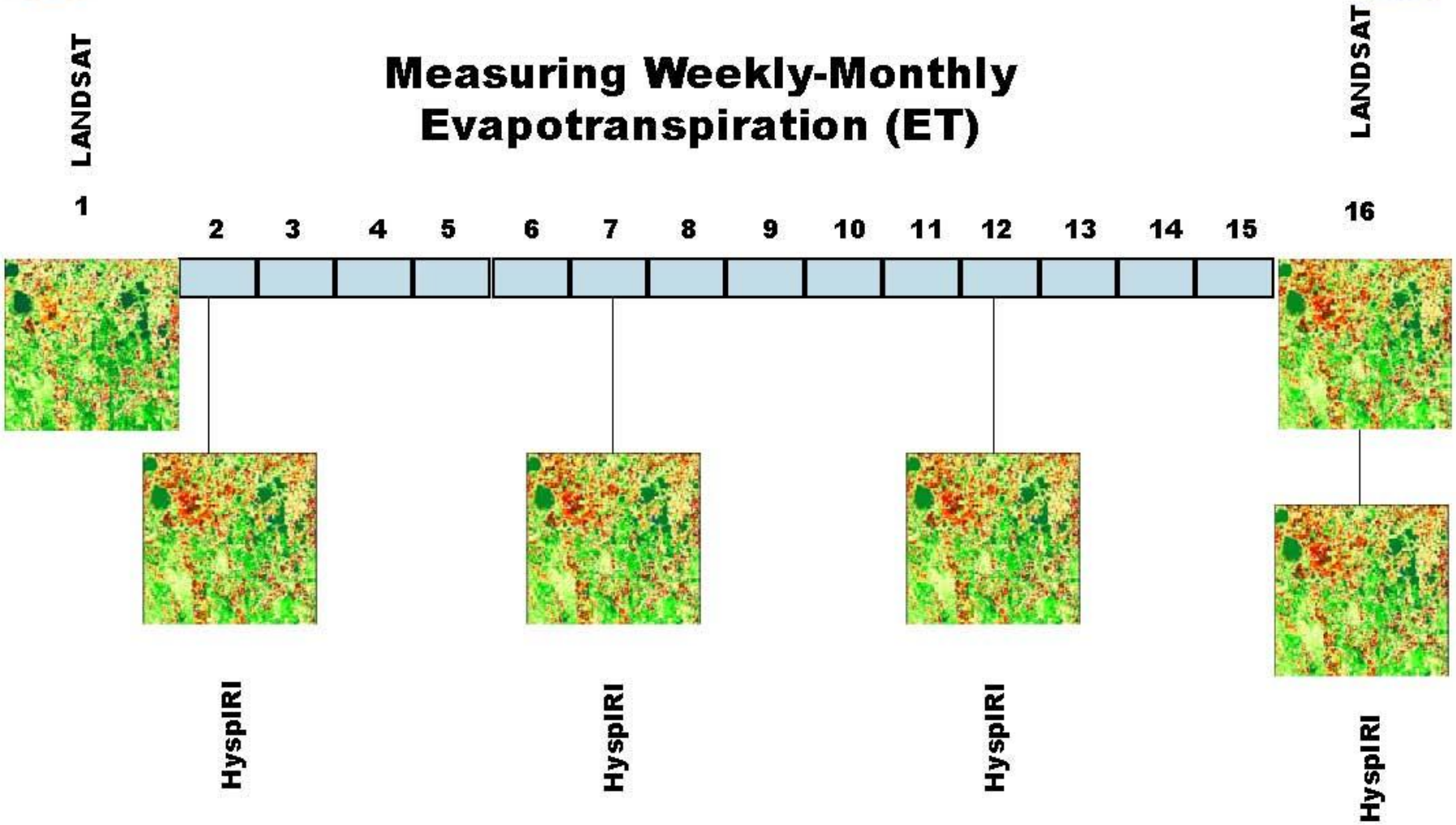


Hyperspectral Infrared Image (HyspIRI) Satellite

- The HyspIRI mission includes:
- an imaging spectrometer (VSWIR: 380 nm - 2500 nm) in 10 nm contiguous bands
- and a multispectral imager measuring from 3 to 12 μm in the mid and thermal infrared (TIR).
- spatial resolution of 60 m.
- The VSWIR will have a revisit of 19 days and the TIR will have a revisit of 5 days.

- 30 km swath
- Launch scheduled for mid 2014

Evapotranspiration and Water Use and Availability



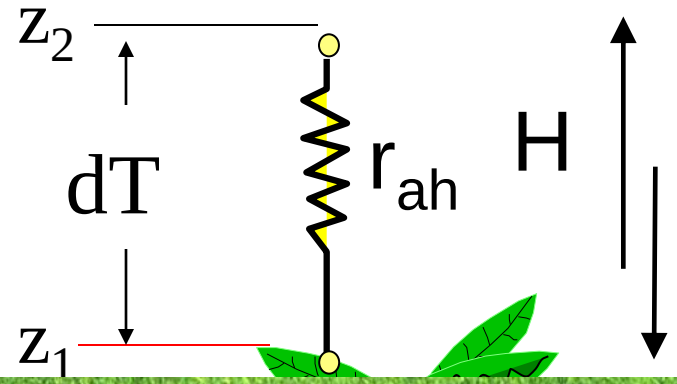
HyspIRI-TIR provides ET data every 5 days, allows weekly-monthly measurement
And expectation for a cloud-free scene (typically 1 in every 3 data takes)

SEBAL: Sensible Heat Flux (H)

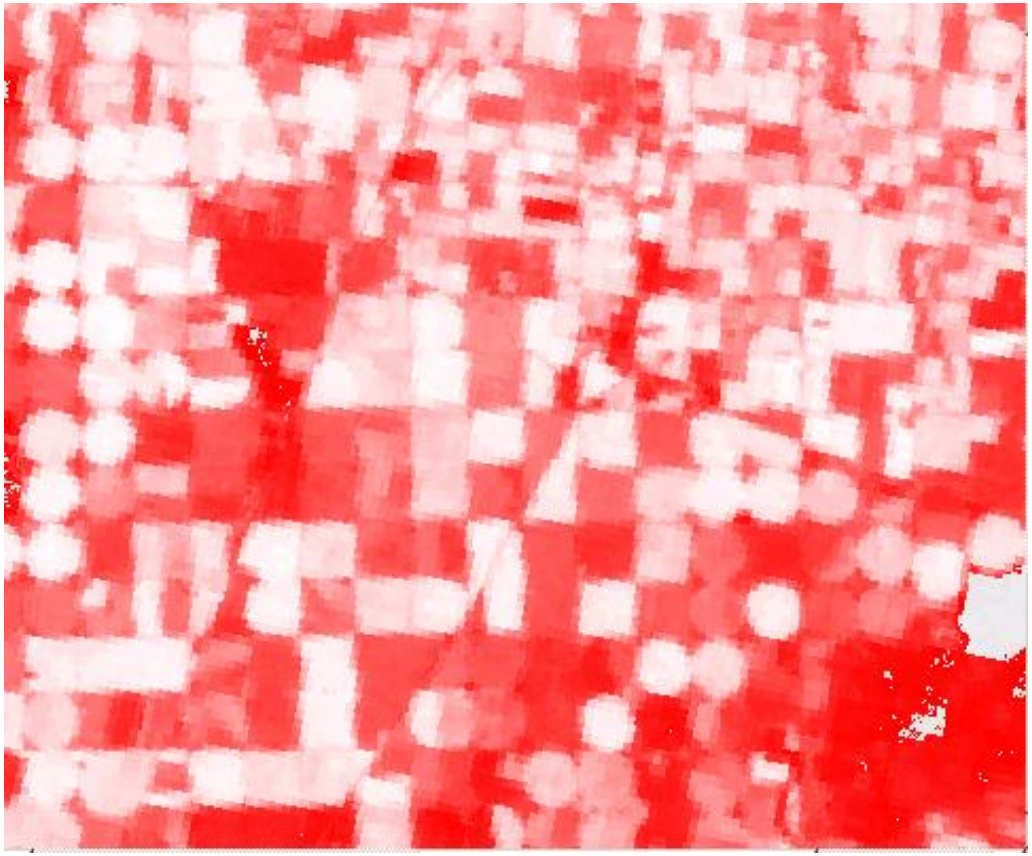
$$\mathbf{H = (\rho \times c_p \times dT) / r_{ah}}$$

dT = the near surface temperature difference (K)

$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right)}{u_* \times k}$$



Surface Temperature Image



White – cold
(18-22 ºC)

Dark red – hot
(35-49 ºC)

$$dT = T_o - T_a$$

$$dT = b + a\,T_s$$

$$H = (\rho \times c_p \times dT) / r_{ah}$$

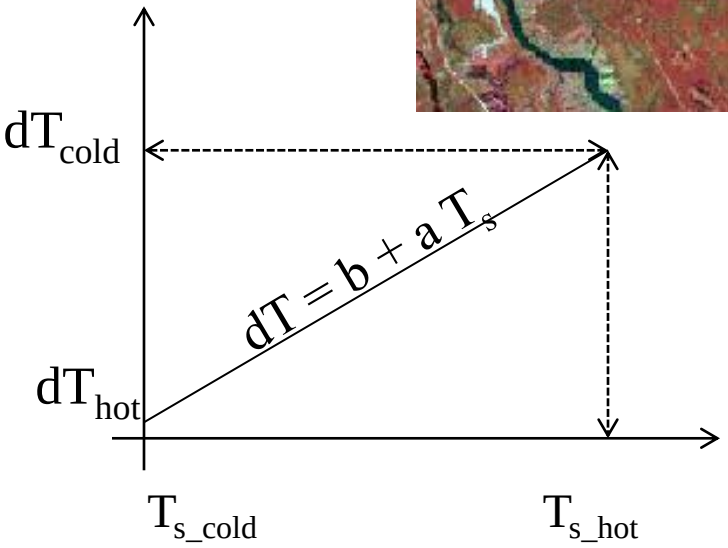
SEBAL: dT function definition

$$dT = b + a\,T_s$$

SEBAL fixes dT at 2 "anchor" pixels:

- At the "cold/wet" pixel (water body):

- At the "hot" pixel (bare soil):



$$\mathbf{H = (\rho \times c_p \times dT) / r_{ah} \longrightarrow LE = R_n - G - H}$$

METRIC

- Mapping Evapotranspiration at High Resolution using Internalized Calibration

- Main developers: Dr. Richard Allen, Dr. Mashiro Tasumi, and Dr. Ricardo Trezza.

- METRIC is an extension of SEBAL.

METRIC: Concepts

- METRIC does not assume H = 0 at the wet/cold pixel,
- METRIC does not assume LE = R_n – G at the dry/hot pixel,
- METRIC selects extreme pixels in only agricultural areas,
- METRIC uses ET_rF (not EF) to extrapolate instantaneous to daily ET values,
- METRIC needs high quality weather data on an hourly or shorter time step and relies on the accuracy of ET_r estimates.

Where: ET_r = alfalfa reference ET (**ASCE EWRI, 2005**)

ET_rF = alfalfa reference ET fraction

METRIC Soil Heat Flux

Soil Heat Flux (G)

Tasumi (2003):

$G/R_n = 0.05 + 0.15\ e^{-0.52\ LAI}$, for LAI >= 0.5

$G/R_n = 1.8\ (T_s - 273.15)/R_n + 0.084$, for LAI < 0.5

Instantaneous LE (ET_i) and daily ET

$$LE\ (W/m^2) = R_n - G - H$$

$$ET_i\,(mm/hr) = 3,600\,\frac{LE}{\lambda_v\,\rho_w}$$

$$ET_rF = \frac{ET_i}{ET_{r\_i}}$$

$$ET_d = ET_rF \times ET_{r\_d}$$

One Source: ReSET (Remote Sensing of ET)

Elhaddad & Garcia (2008)

- ReSET expands upon SEBAL and takes into consideration the spatial variability in weather parameters over a region by using data from multiple weather stations.

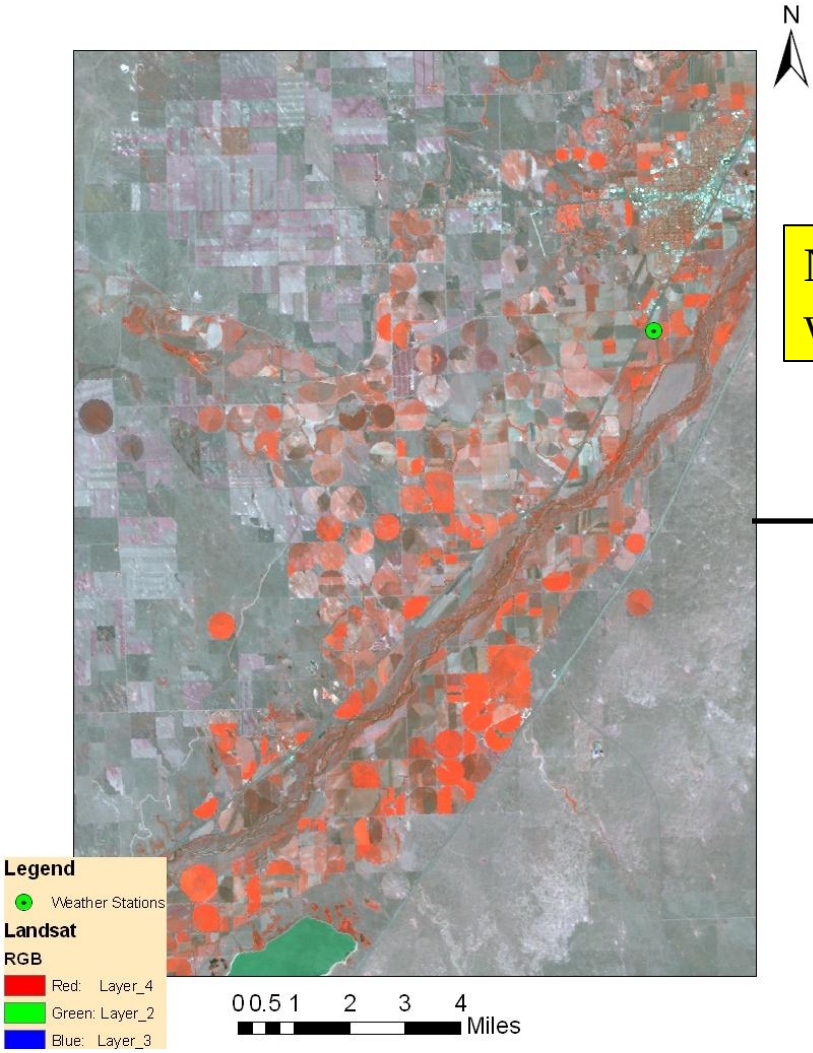
- ReSET interpolates between the available weather stations in time and space taking into consideration the spatiotemporal variability of the available weather data by generating surfaces of wind run and ET_r between weather stations.

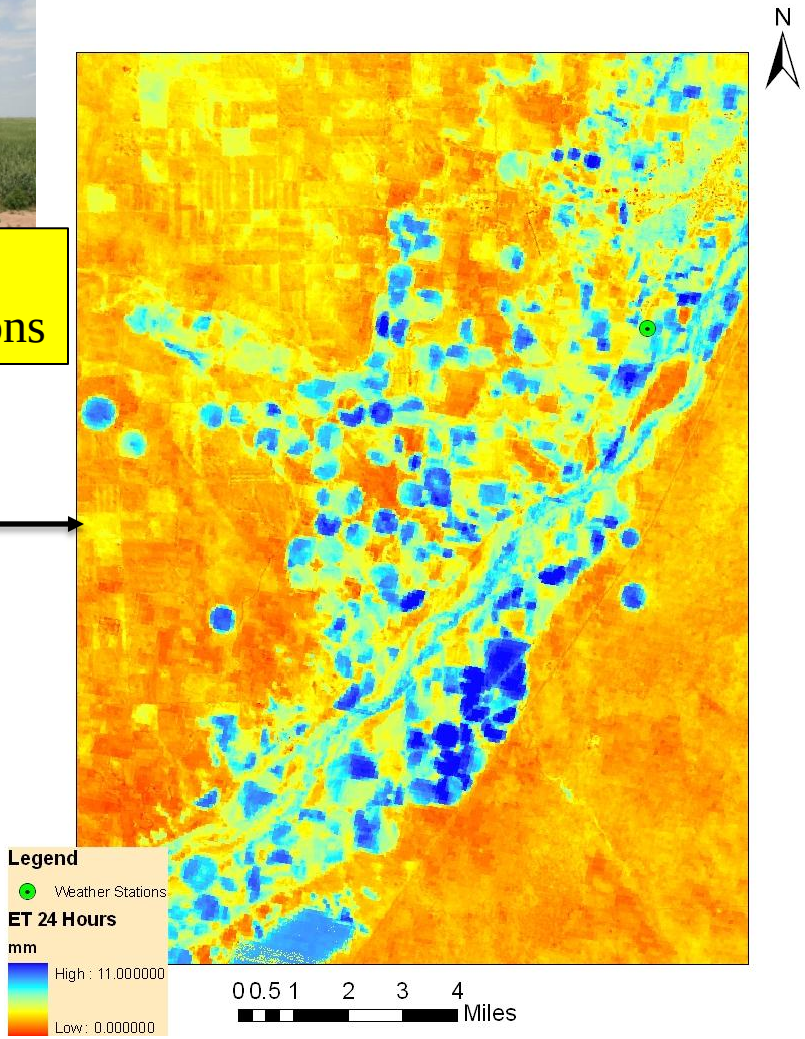
- ReSET model second enhancement is the ability to calculate the cumulative ET over time between the dates of the available Landsat scenes.

ReSET: Satellite Based ET Modeling

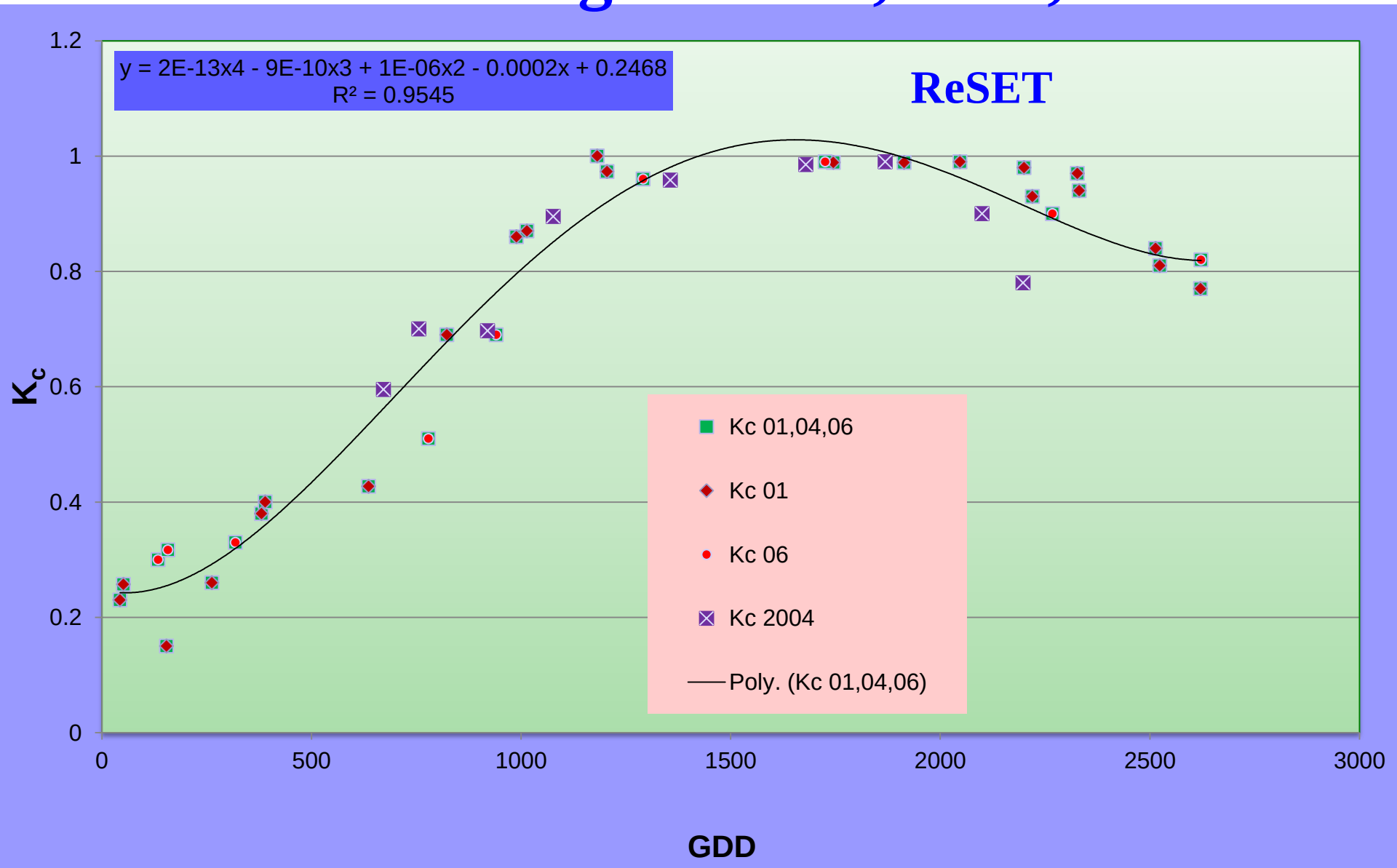
Network of weather stations

ET Model



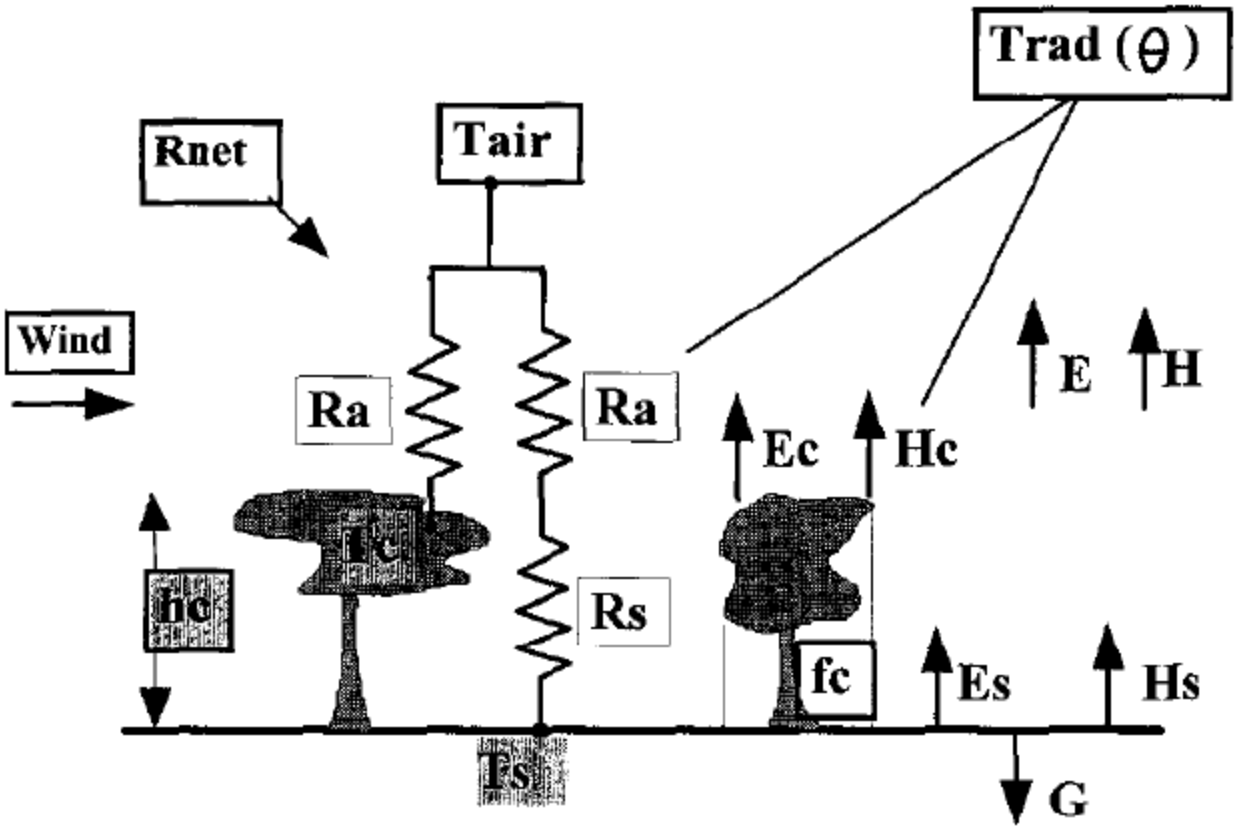


ReSET: Crop coefficient (K_c) generation for Corn using LS 2001, 2004, 2006



Two Source Model (TSM)

J.M. Norman et al. / Agricultural and Forest Meteorology 77 (1995) 263–293



$$T_{RAD}(\theta) = \left[f(\theta) T_C^n + (1 - f(\theta)) T_S^n \right]^{1/n}$$

T_s

T_a

U

LAI

f_c

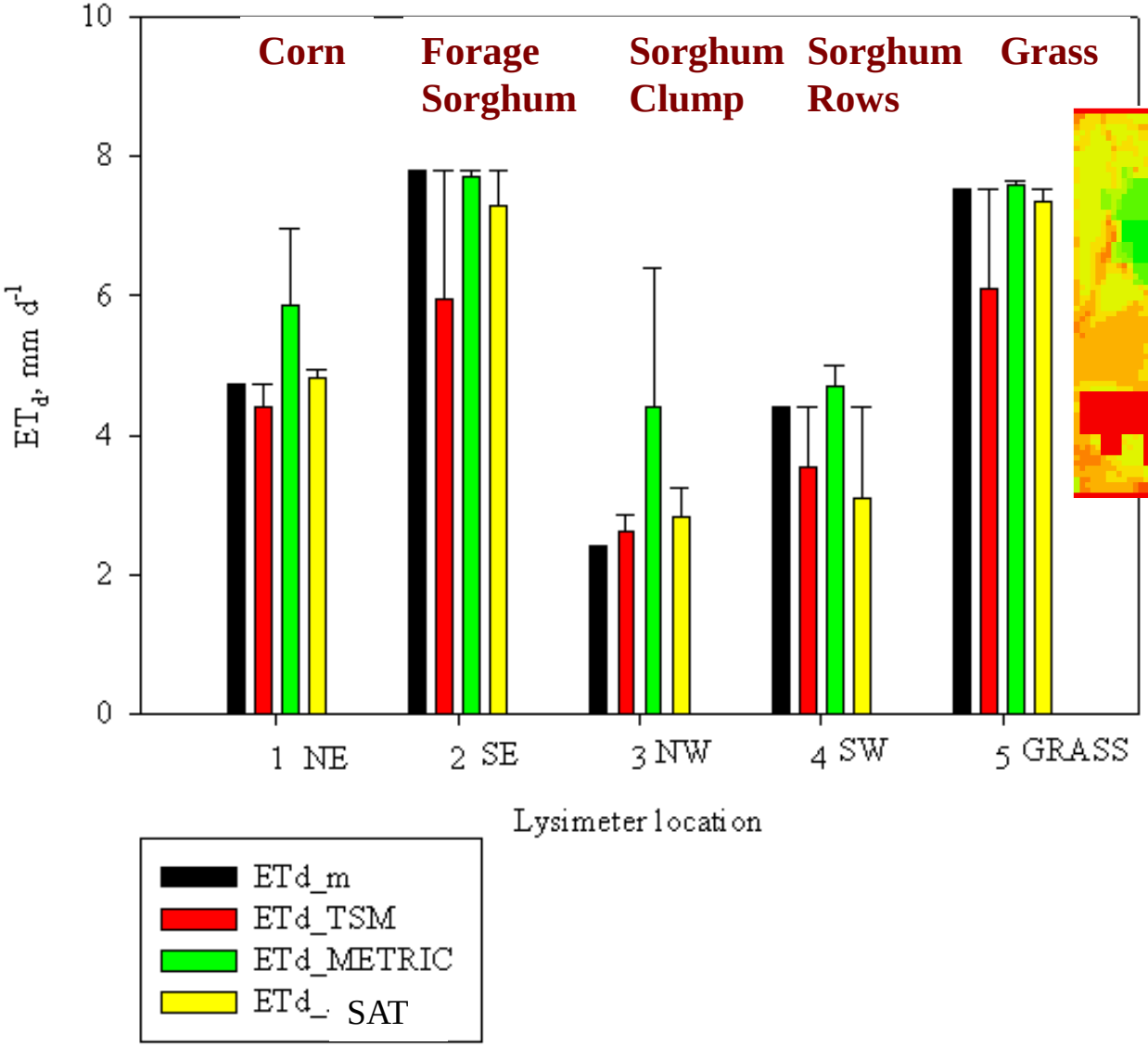
f_g

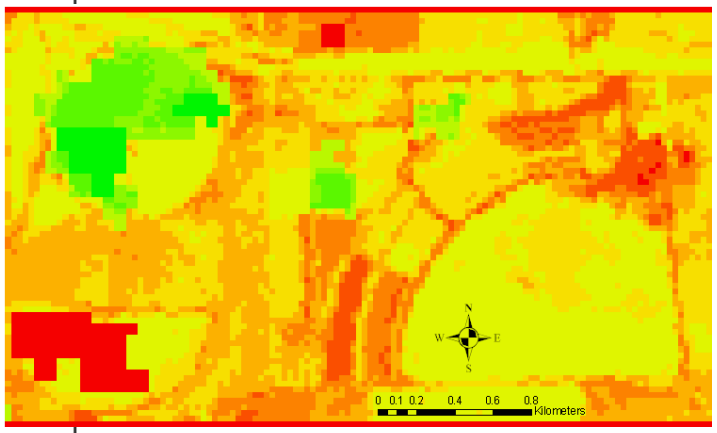
h_c

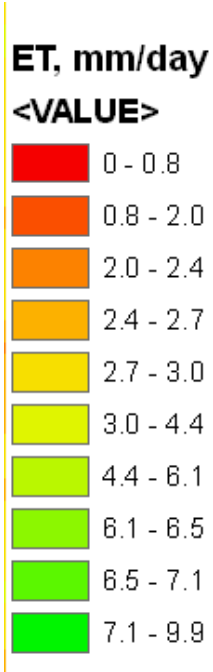
w

R_n

RS of ET_d evaluation with weighing Lysimeters





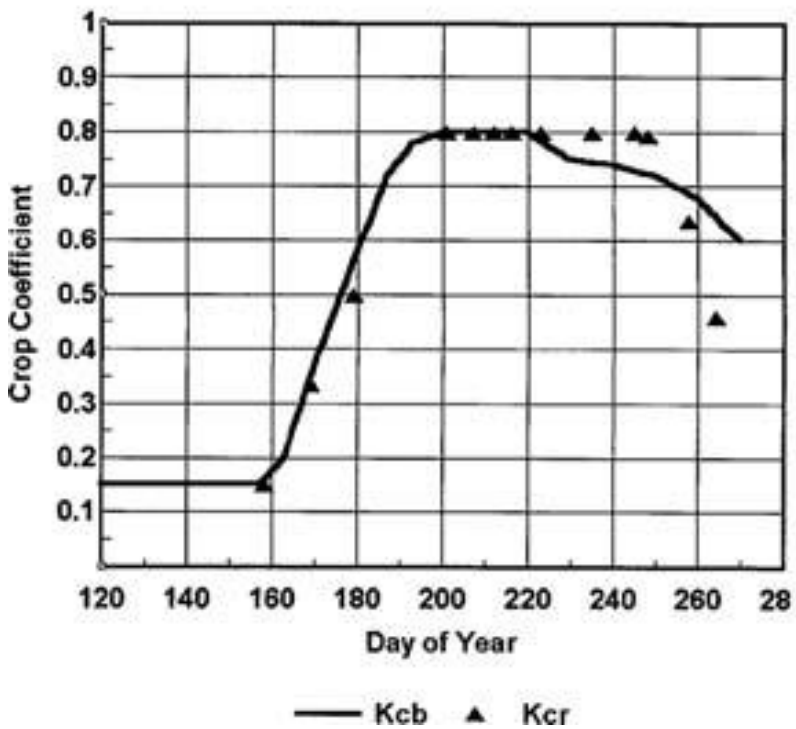


Reflectance-based Crop Coefficient ET

$$\mathbf{ET = K_{cr} \times ET_r}$$

For Potatoes:

$K_{cr} = 1.085 * SAVI + 0.051$



Neale, Jayanthi, and Wright (2005)

For Corn: Neale et al. (1989)

$K_{cr} = 1.092 \times NDVI - 0.053$, for Fruita, CO

$K_{cr} = 1.181 \times NDVI - 0.026$, for Greeley, CO

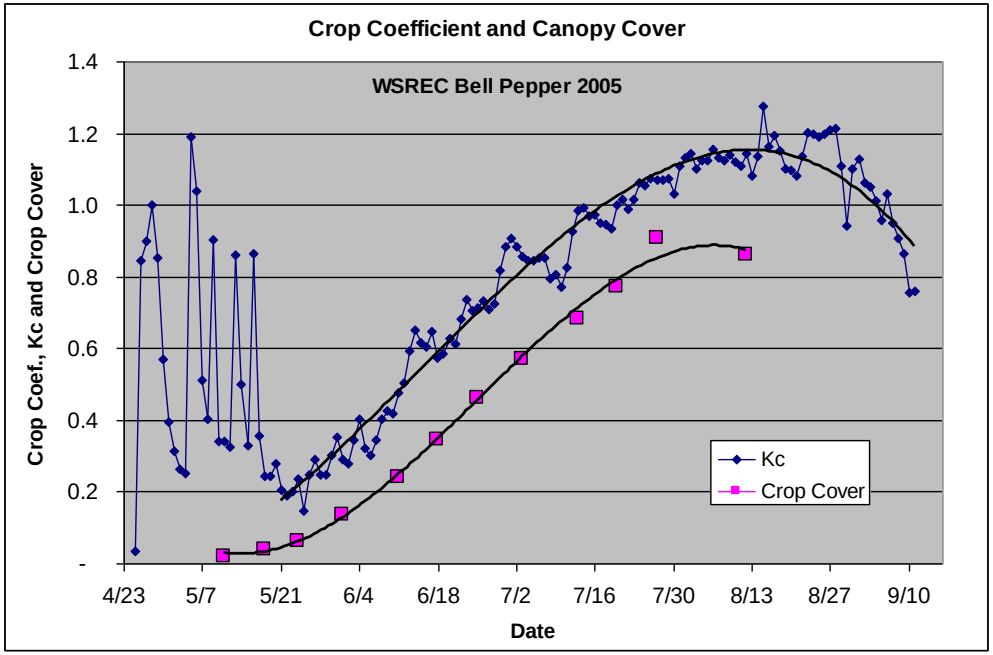
Bausch (1993)

$K_{cr} = 1.416 \times SAVI + 0.017$

$$NDVI = (R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED})$$

Vegetation fraction of ground cover based ET

$NDVI \rightarrow f_c \rightarrow K_{cb} \rightarrow ET_{cb}$ Approach

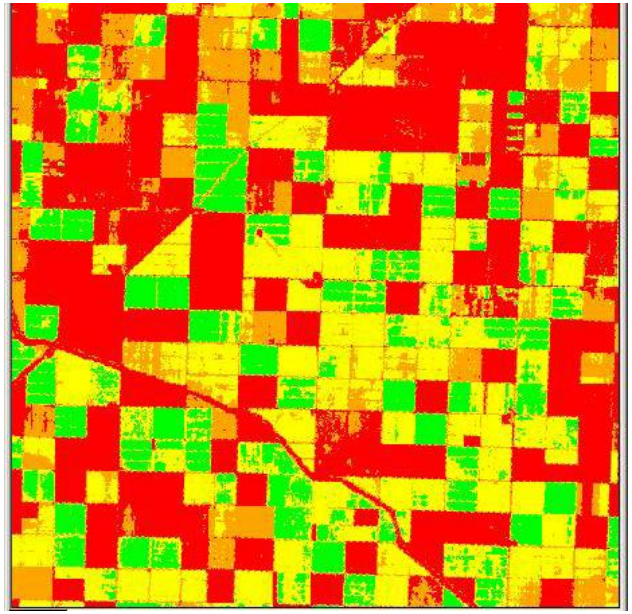


Trout &Johnson (2007)
Johnson & Trout (2012)

$$f_c = 1.22 \times NDVI - 0.21$$

$$K_{cb\_o} = 1.13 \times f_c + 0.14$$

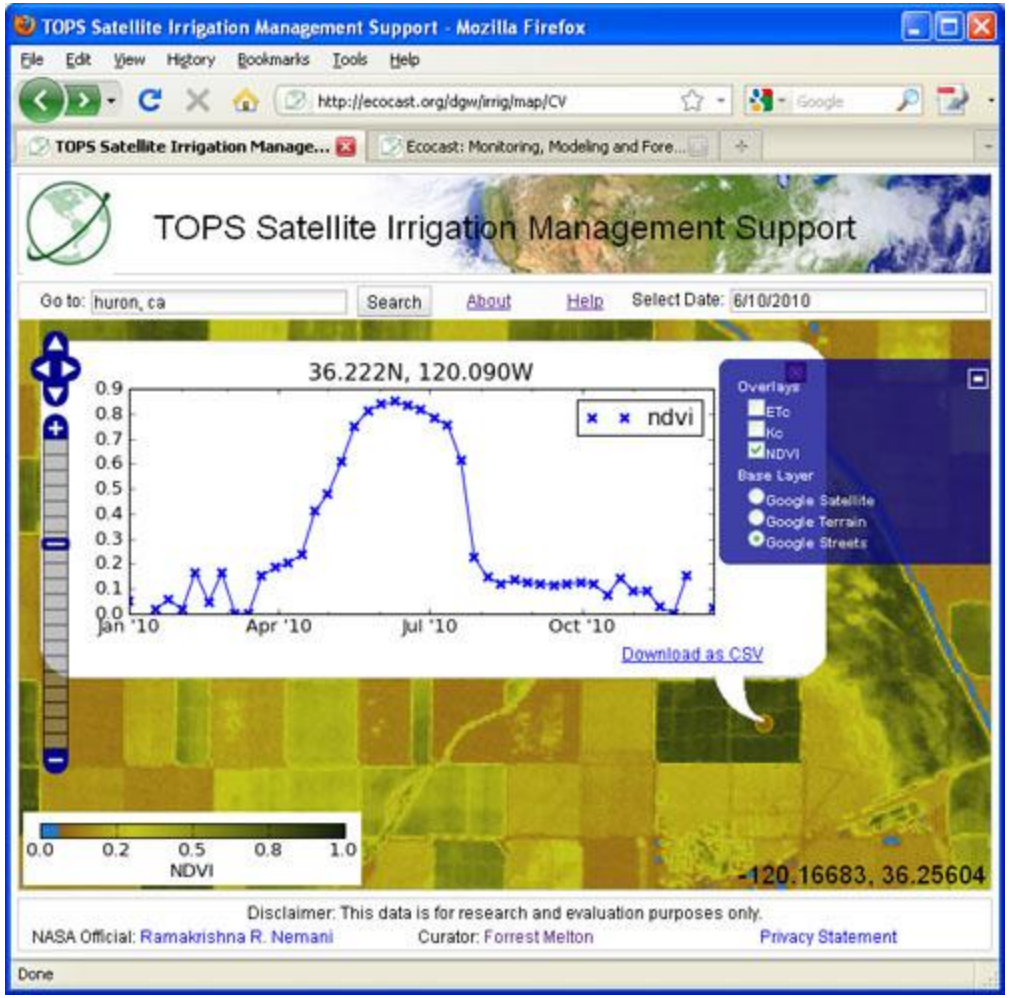
$$ET_{cb} = K_{cb\_o} \times ET_o$$



Satellite Irrigation Management Support (SIMS)

$NDVI \rightarrow f_c \rightarrow K_{cb} \rightarrow ET_{cb}$ approach implementation

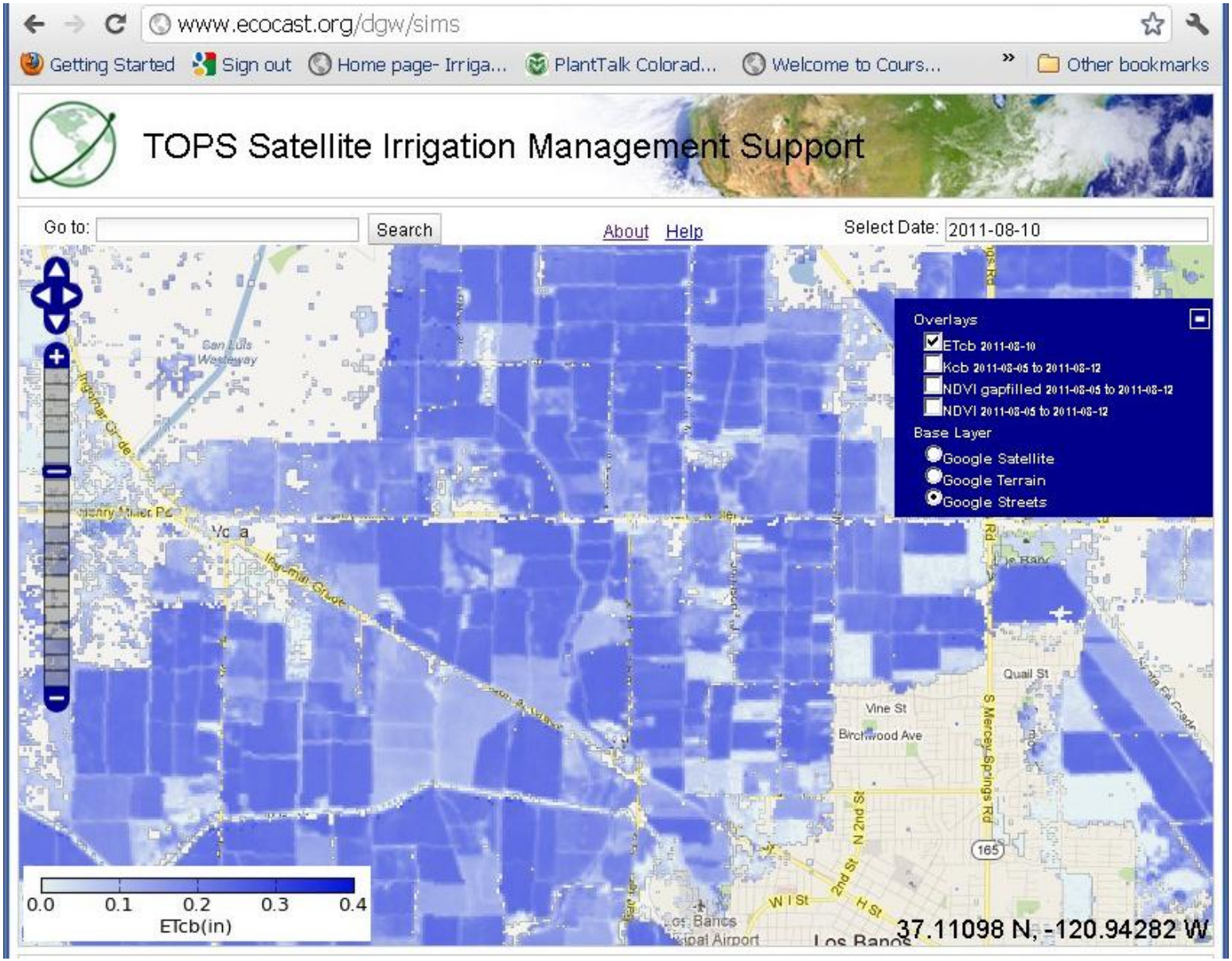
http://ecocast.arc.nasa.gov/sims/



California Irrigation Management Information System (CIMIS), operated by the California Dept. of Water Resources (CDWR), provides daily estimates of ET_o on a 2 km statewide grid.

The system being developed at NASA Ames builds on a prototype ET_c monitoring and irrigation forecasting system for wine grapes in California developed by NASA and California State University Monterey Bay (CSU Monterey Bay).

TOPS Satellite Irrigation Management Support: ET_{cb}



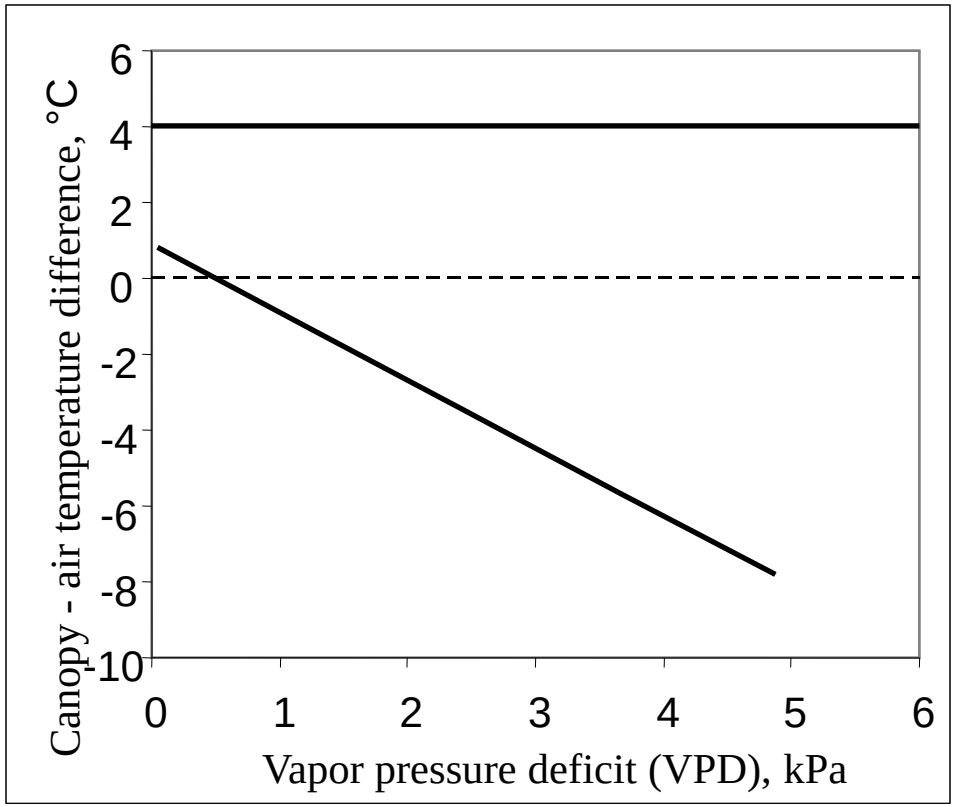
Crop Water Stress Index (CWSI)

Idso (1981)

Jackson et al. (1981)

$$CWSI = \frac{dT - dT_{min}}{dT_{max} - dT_{min}}$$

$$CWSI = 1 - \frac{ET_a}{ET_c}$$



where:

$dT = T_c - T_a$, canopy – air temperature

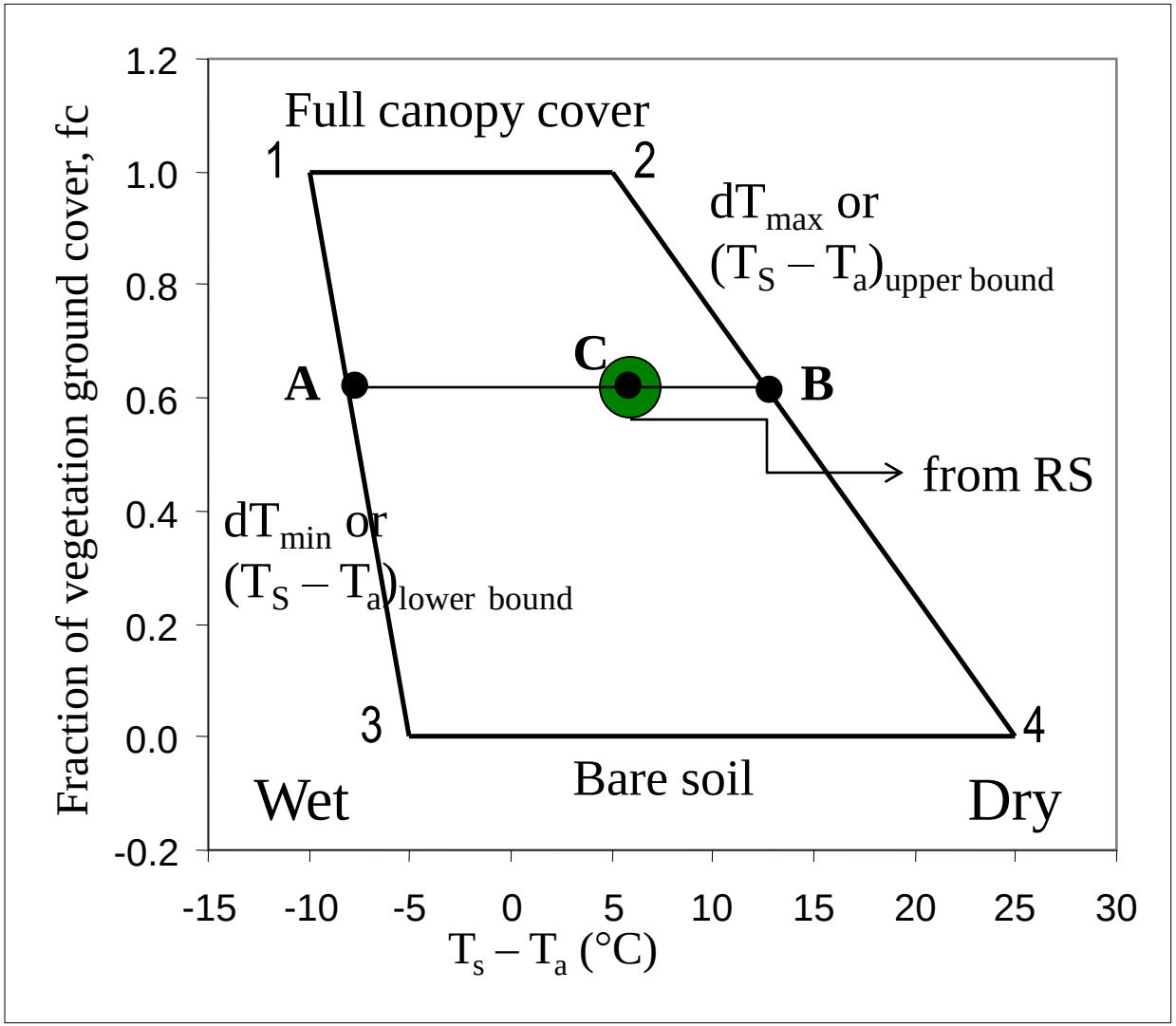
$dT_{min} = (T_c - T_a)_{min} = a + b\ VPD$

$dT_{min} = 3.11 - 1.97\ VPD$, (Idso, 1981), for corn

$dT_{min} = 2.67 - 2.06\ VPD$, (Nielsen & Garden, 1987), for corn

$dT_{max} = T_{c\ \text{dryland plot}} - T_a$

Water Deficit Index (WDI)
or the Vegetation Index/Temperature (VIT) trapezoid



Moran et al. (1994)

Account for partially vegetated fields

$$WDI = 1 - \frac{ET_a}{ET_c}$$

$$WDI = \frac{dT_{min} - dT_a}{dT_{min} - dT_{max}}$$

$$dT_a = (T_s - T_a)_{actual}, \text{ RS}$$

WDI = AC/AB

Concluding Remarks

- There are different remote sensing approaches to estimating actual crop water use or ET. However, some perform better under certain conditions,

- All approaches rely on accurate weather data from ground-based weather stations, and accurate calculations of **reference** (alfalfa or grass) evapotranspiration rates.