Coupling 6S Correction for SEBAL Evapotranspiration Estimation in Lower Colorado River Basin

Dr. Xiaofang Wei
Dr. Subramania I. Sritharan
André Morton, Keith Farrow, Central State University
Andrew French, USDA Agricultural Research Services
David Ekhardt, John Osterberg, US Bureau of Reclamation
Dr. Doyle Watts, Wright State University

2011 Annual Conference

Remote Sensing of Evapotranspiration

- US Bureau of Reclamation
  - Hydroelectric project
  - Dam and aqueduct construction
  - Water allocation and supply

2011 Annual Conference

Remote Sensing of Evapotranspiration

- Central State University

- International Center of Water Resources Management

Remote Sensing of Evapotranspiration

- Alliance Universities and Institutes
  - Central State University
  - Wright State University
  - Utah State University
  - Colorado State University
  - Bowling Green State University
  - Cleveland State University
  - University of Arizona
  - University of Toledo
  - Ohio Aerospace Institute
  - Agricultural Research Service

Remote Sensing of Evapotranspiration

- Objectives of the Project
  - Employ advanced remote sensing techniques to predict evapotranspiration and water use under a set of complicated conditions

asprs

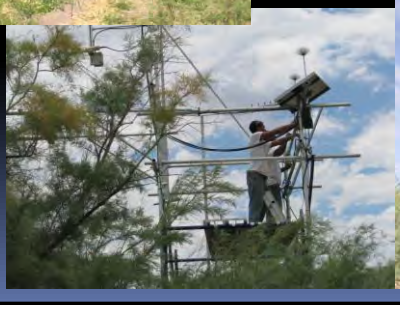
Remote Sensing of Evapotranspiration

- Study Area (Blythe, California)
  - Palo Verde Irrigation District
  - Cibola National Wildlife Refuge

asprs

Remote Sensing of Evapotranspiration






Summer Intense Field Campaigns

- Multi-level Synoptic Data Collection (In the years of 2007, 2008, and 2009)

Landsat 5, ASTER, Landsat 7

USU Aircraft Airphoto

USBR Helicopter ASD

CSU Ground Crew

Summer Intense Field Campaign




Summer Intense Field Campaign





2011 Annual Conference

asprs

Data

- Landsat TM imagery
  - 22 scenes data were ordered
- CIMIS Weather data
- Aerial photo
- Land cover and land use
- DEM

CIMIS

- California Irrigation Management Information System (CIMIS)
  - Station 135
  - Station 151
  - Station 175

CIMIS

- Meteorological Data (CIMIS)
  - Solar Radiation (SR)
  - Net Radiation (Rn)
  - Average Daily Air Temperature (Tavg)
  - Relative Humidity (RH)
  - Wind Speed (WS)
  - Wind Run (WR)
  - Dew Point Temperature (DP)
  - Precipitation (Ppt)
  - Potential ET by CIMIS (CIMIS ETo)

CIMIS

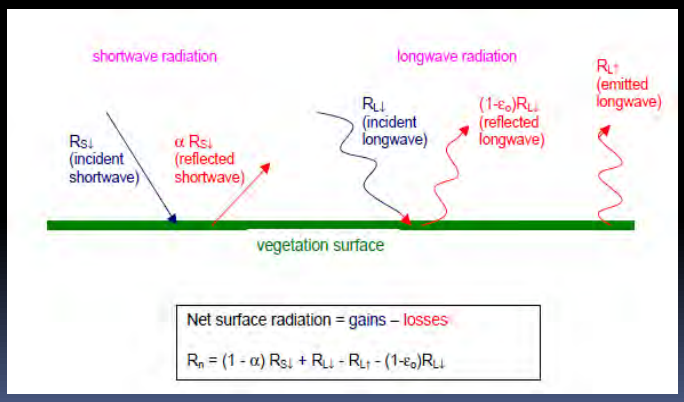
- CIMIS Weather data
  - Wind speed –at 2.0 meters above the ground(MPH)
  - Air temperature – at a height of 1.5 meters above the ground (ºF)
  - Soil temperature – at (6 inches) below the soil surface (ºF)
  - ET – reference daily ET (inch)

Estimation of Evapotranspiration(ET)

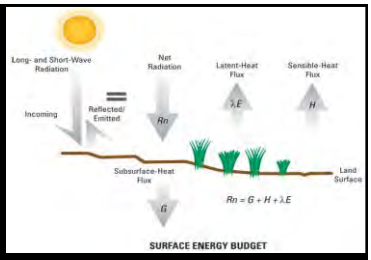
- Surface Energy Balance Algorithm for Land (SEBAL)
  - An image-processing mode for the calculation of evapotranspiration rates and other energy exchanges between land and atmosphere
  - Surface radiation balance
  - Surface energy balance

Methodology

- Surface radiation balance



Estimation of ET



- **Surface Energy Balance**

$$\lambda ET = R_n - G - H$$

http://nevada.usgs.gov/water/et/measured.htm

  - **where**

    λET - the latent energy of evaporation (W/m2),

    Rn -the net radiation flux at the soil surface (W/m2),

    G - the soil heat flux (W/m2), and

    H - the sensible heat flux to the air (W/m2)

Estimation of ET

- Solar incidence angle
  - The angle between the solar bean and a vertical line perpendicular to the land surface

$$\begin{aligned}\cos\theta = {} & \sin\delta\sin\varphi\cos\beta - \sin\delta\cos\varphi\sin\beta\cos A \\ & + \cos\delta\cos\varphi\cos\beta\cos\omega \\ & + \cos\delta\sin\varphi\sin\beta\cos A\cos\omega \\ & + \cos\delta\sin\beta\sin A\sin\omega\end{aligned}$$

  - Where:

    δ – Solar declination,

    Φ – Latitude,

    β – Slope,

    ω – Latitude,

    A – Aspect .

Estimation of ET

- Reflectance radiance

$$L_\lambda = \frac{L_{max} - L_{min}}{QCAL_{max} - QCAL_{min}} \times (DN - QCAL_{min}) + L_{min}$$

$$L_\lambda = (Gain \times DN) + Bias$$

- Spectral reflectance
  - The ratio of the reflected radiation to the incident shortwave radiation

$$\rho_\lambda = \frac{\pi \cdot L_\lambda}{ESUN_\lambda \cdot \cos\theta \cdot d_r}$$

Estimation of ET

- Reflectance albedo
  - Corrected by atmospheric transmissivity and path radiance

$$\alpha = \frac{\alpha_{toa} - \alpha_{path-radiance}}{{\tau_{sw}}^2}$$

$$\tau_{sw} = 0.75 + 2 \times 10^{-5} \times Z$$

Estimation of ET

- Surface temperature
  - NDVI, thermal emissivity

$$T_0 = \frac{T}{\varepsilon_0^{0.25}}$$

$$\varepsilon_0 = 1.009 + 0.047 \ln(NDVI)$$

$$T = \frac{K_2}{\ln\left[\frac{K_1}{L_6} + 1\right]}$$

$$T_{0\_DEM} = T_0 + 0.0065\Delta Z$$

Estimation of ET

- Soil heat flux
  - The rate of heat storage into the soil and vegetation by conduction.

$$\frac{G}{R_N} = T_s/\alpha(0.0038\alpha + 0.0074\alpha^2)(1 - 0.98NDVI^4)$$

Estimation of ET

- Surface Roughness
  - The height above the "zero-plane displacement" that the zero-origin for the wind profile just begins within the surface or vegetation cover

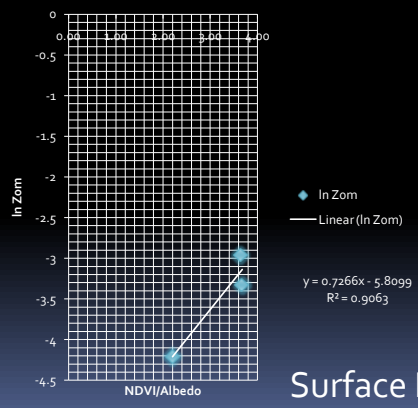
$$Z_{0M} = 0.018 \times LAI$$

$$Z_{0M} = \exp\left[(a \times NDVI) + b\right]$$

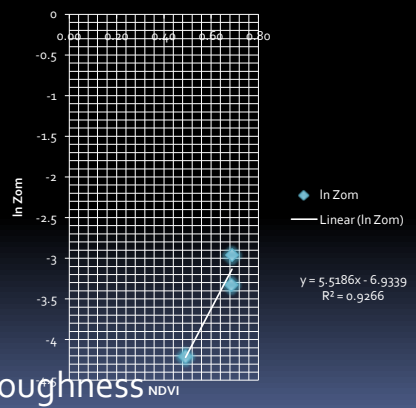
$$Z_{0M} = \exp\left[\left(a \times \frac{NDVI}{\alpha}\right) + b\right]$$

Estimation of ET

NDVI/albedo V.S. ln Zom



NDVI V.S. ln Zom



Surface Roughness

Estimation of ET

- Sensible heat flux H

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

Where:

ρ - air density (kg/m3),

cp - air specific heat (1004 J/kg/K),

dT - the temperature (K) difference (T1-T2) between two heights (z1and z2), and

r_{ah} - the aerodynamic resistance to heat transport (s/m)

Estimation of ET

- Estimation of sensible heat flux

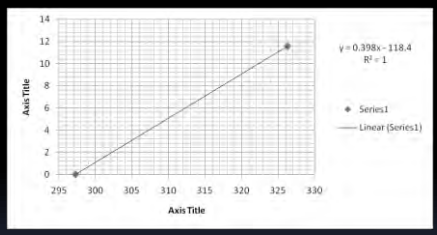
$$\mu^* = \frac{k \times u_x}{\ln\left[\frac{Z_x}{Z_{0m}}\right]}$$

$$\mu_{200} = \mu^* \frac{\ln\left[\frac{Z_x}{Z_{om}}\right]}{k}$$

$$r_{ah} = \frac{\ln\left[\frac{Z_2}{Z_1}\right]}{u_* \times k}$$

Estimation of ET

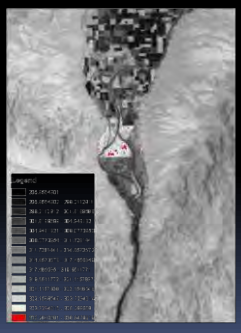
- Cold pixel
  - Well irrigated vegetation pixel
  - $H_{cold} = 0$
- Hot pixel:
  - A "hot" (dry) pixel
  - $ET_{hot} = 0$



Estimation of ET

Coldest Points

Hottest Points



Estimation of ET

- Latent heat flux – evapotranspirtation

$$\lambda ET = R_n - G - H$$

- Instantaneous ET $ET_{inst} = 3600 \frac{\lambda ET}{\lambda}$

- ET fraction ETrF

$$ETrF = \frac{ET_{inst}}{ET_r}$$

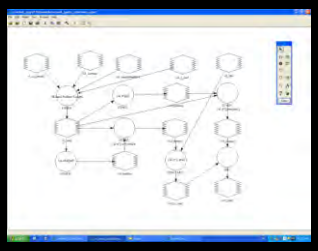
Estimation of ET

- 24-hour actual evaporatranspiration (ET_{24})

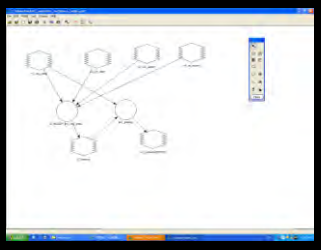
$$ET_{24} = \frac{86400 \lambda_{ET} R_{n24}}{\lambda}$$

  - Where:
    - Rn24 - net radiation,
    - 86,400 - the number of seconds in a 24-hour period,
    - λ - the latent heat of vaporization (J/kg), and can be expressed in mm/day

Implementation in ERDAS IMAGINE

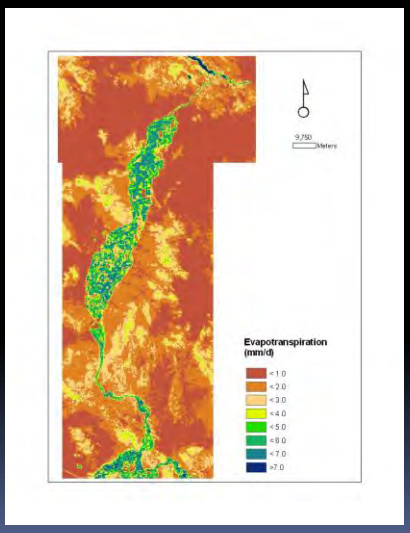


Correction for Heat Transport and Momentum

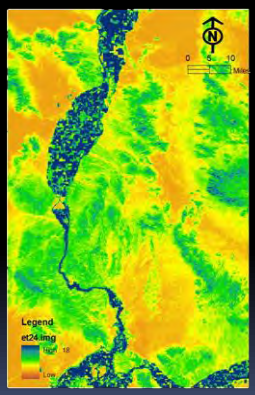


Cosine of Solar Incident Angle

SEBAL Evapotranspiration (ET)



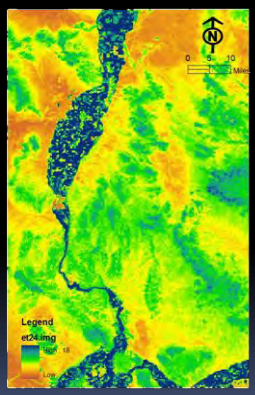
SEBAL Evapotranspiration



Daily ET

5/8/2007

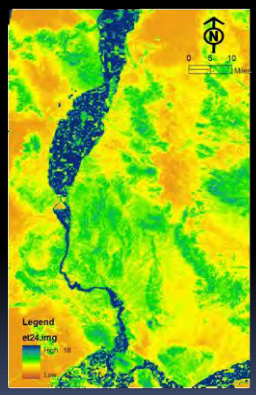
SEBAL Evapotranspiration



Daily ET

6/9/2007

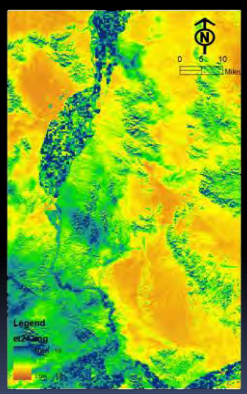
SEBAL Evapotranspiration



Daily ET

9/13/2007

SEBAL Evapotranspiration

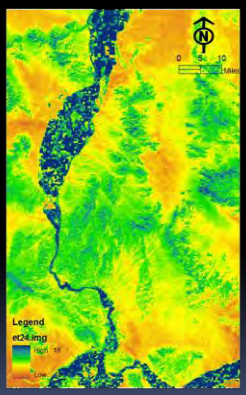


Daily ET

3/7/2008

2011 Annual Conference

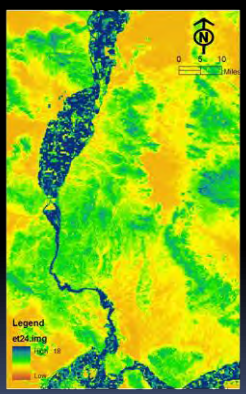
SEBAL Evapotranspiration



Daily ET

4/24/2008

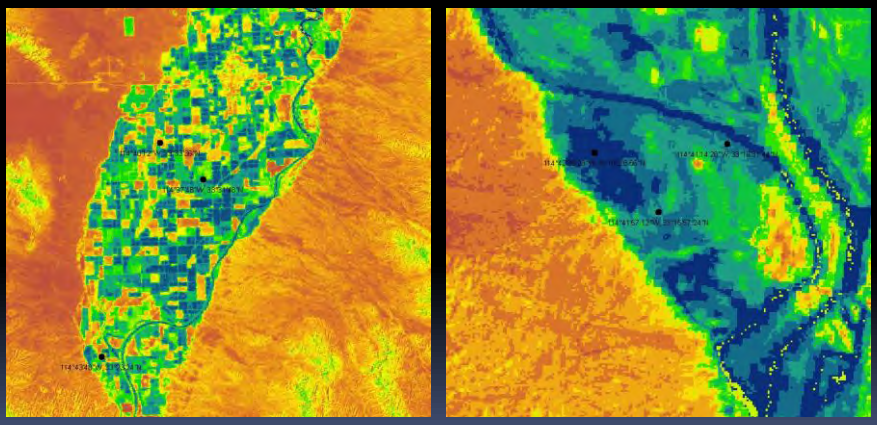
SEBAL Evapotranspiration



Daily ET

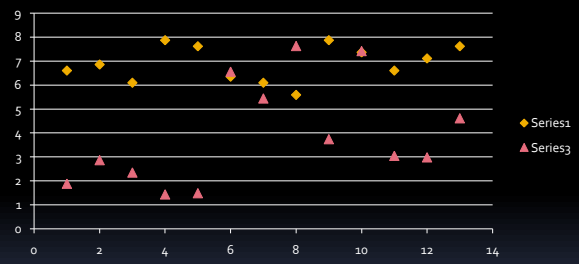
6/11/2008

SEBAL Evapotranspiration (ET)



Validation of SEBAL

- Comparison with CIMIS weather data



Atmospheric Correction

- The conversions will provide a better basis for comparison data between images taken from different acquisition dates and by different sensors (Vermote, 2006).
- In this research, atmospheric correction were conducted by using:
  - Second Simulation of the Satellite Signal in the Solar Spectrum (6S)
  - FLAASH

6S Radiative Transfer Code

- 6S - Second Simulation of a Satellite Signal in the Solar Spectrum
  - Vermote E., et al. from le Laboratoire d'Optique Atmosphérique
  - July 1992 – 5S (Simulation of a Satellite Signal in the Solar Spectrum)
  - July 1997 – 6S (Second Simulation of a Satellite Signal in the Solar Spectrum)
  - May 2005 – vector version of 6S

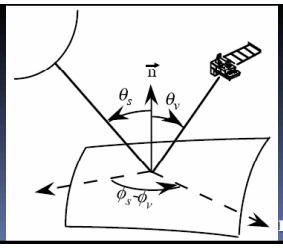
6S Radiative Transfer Code

- An accurate analytical expression of the reflectance measured by a satellite-sensor or a sensor aboard an aircraft (Vermote, 2006)
- An accurate simulation of satellite and plane observations
  - A realistic molecular/aerosol/ mixed atmosphere
  - Lambertian/anisotropic ground surfaces
  - Gaseous absorption
  - Elevated targets

6S Radiative Transfer Code

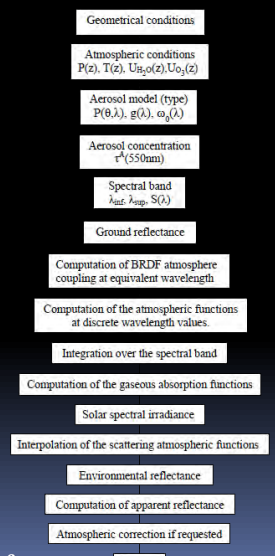
- 6S code predicts a satellite signal between 0.25 and 4.0 µm assuming cloudless atmosphere (Vermote, 2006).
  - The apparent reflectance at the satellite level for Lambertian surface:

$$\rho'(\theta_s,\theta_v,\phi_v) = t_g(\theta_s,\theta_v)\left\{\rho_a(\theta_s,\theta_v,\phi_v) + \frac{T(\theta_s)}{1-<\rho(M)>S}\left[\rho_c(M)e^{-\tau/\mu_v} + <\rho(M)>t_d(\theta_v)\right]\right\}$$



6S Radiative Transfer Code

- General Flow Chart of 6SV Computation
  - Geometrical conditions
  - Atmospheric model for gaseous components
  - Aerosol model
  - Spectral condition
  - Ground reflectance

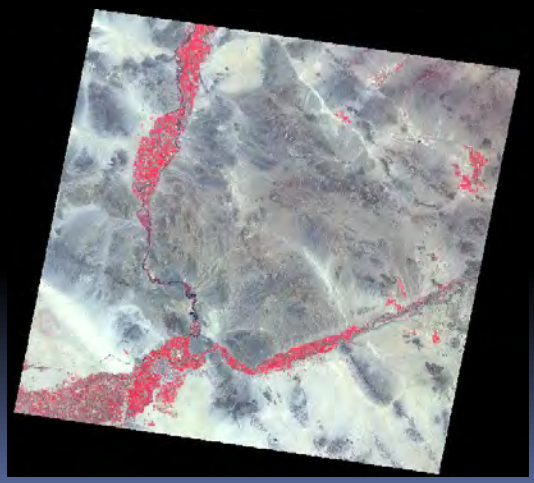


6S Radiative Transfer Code

- Geometrical conditions
  - Sensor position and solar position
- Atmospheric model for gaseous components
  - Predefined atmospheric model
  - User profile
    - atmospheric condiction on 34 levels
    - Integration of radiasonde data and standard atmospheric profile

6S Radiative Transfer Code

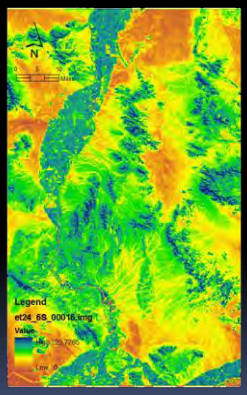
- 6S Code Corrected Reflectance Image



Cygwin

Image Composite of R: B_4, G: B_3, B: B_2

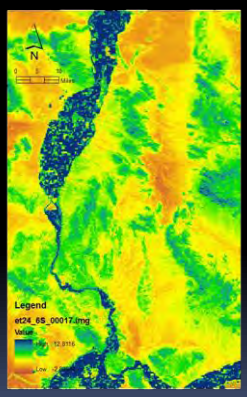
6S_SEBAL Evapotranspiration



Daily ET

4/24/2008

6S_SEBAL Evapotranspiration

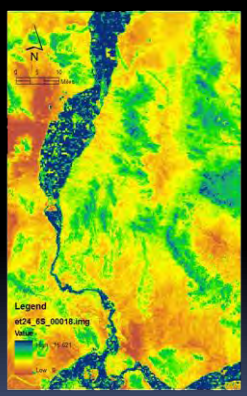


Daily ET

5/10/2008

asprs

6S_SEBAL Evapotranspiration



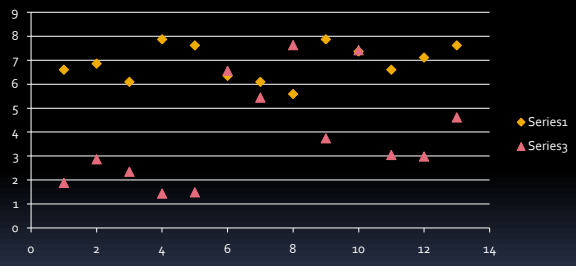
Daily ET

5/26/2008

asprs

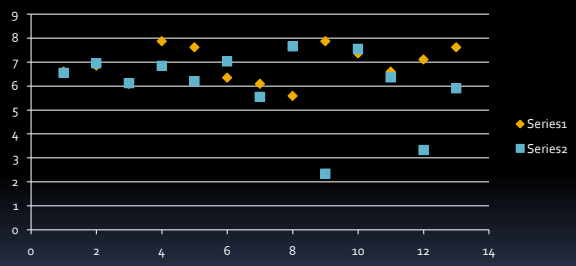
Validation of ET

- Comparison of SEBAL with CIMIS weather data



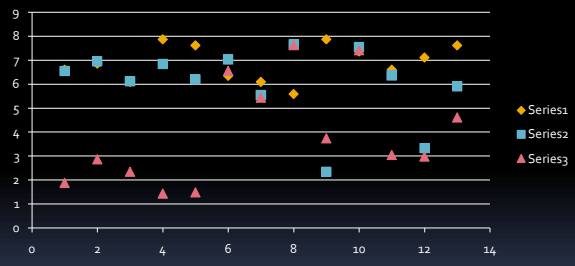
Validation of ET

- Comparison of 6S_SEBAL with CIMIS weather data



Validation of ET

- Comparison of SEBAL, 6S_SEBAL, and CIMIS weather data



Preliminary Conclusion

- SEBAL – a robust tool for ET calculation
- Limitation: empirical equations for surface temperature, surface roughness, soil heat flux
- Integration of 6S corrected reflectance should improve the ET estimation