Estimating Ground-Level Solar Radiation and Evapotranspiration In Puerto Rico Using Satellite Remote Sensing

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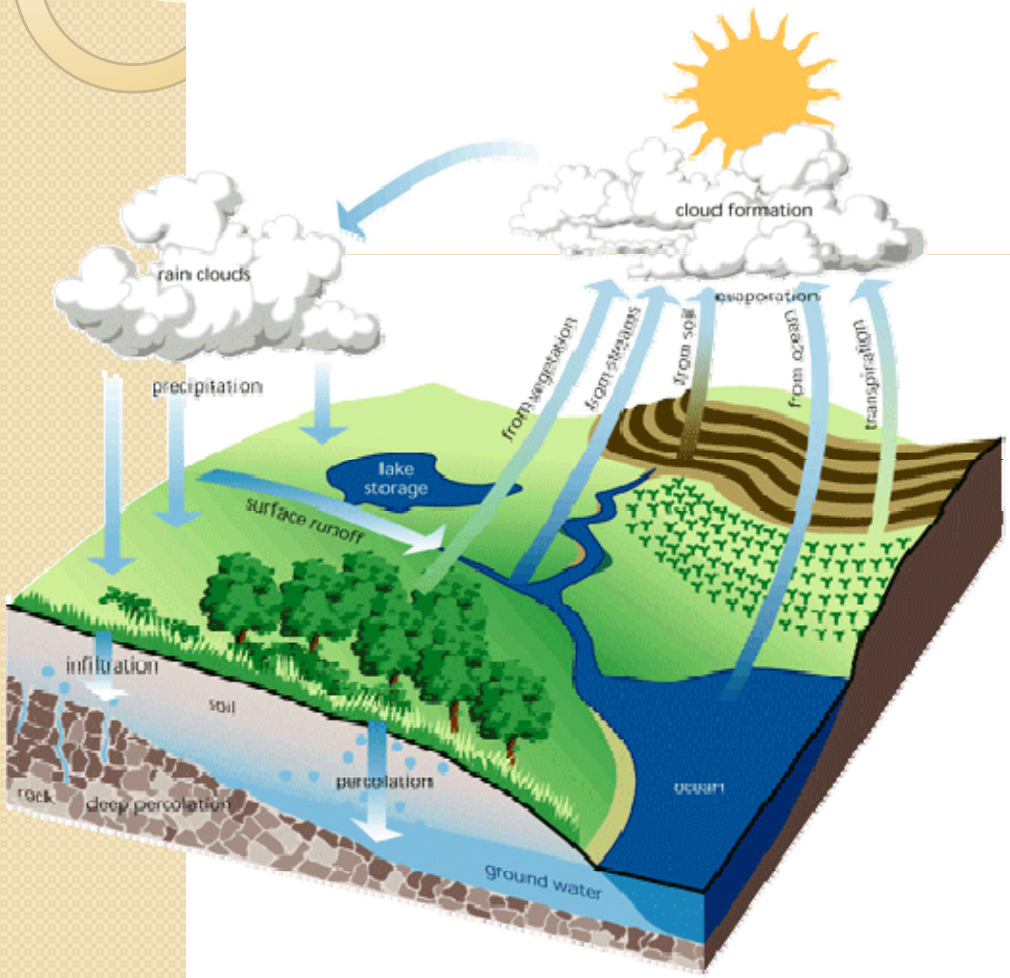
USDA Hatch

Evapotranspiration (ET)



http://www.sylvansource.com/images/hydrologic-cycle.gif

- In Agriculture
  - •Optimal crop yield depends on providing the plants potential ET via rainfall or irrigation.

- In Water Resources Planning
  - •ET strongly influences aquifer recharge, surface runoff and stream flow

- In Puerto Rico, if ET = 5 mm/day, this is equivalent to **45 million m^3 or 12 billion gallons of water per day.**

Conversion of 5 mm of liquid water into vapor, over the area of PR requires approximately **1.3 billion KW of energy per day**.

- ET is highly correlated with solar radiation, therefore, solar radiation measurements throughout the island are essential.

Currently situation in Puerto Rico

•Estimation of ET requires weather data, including solar radiation

•In PR, solar radiation is only available at selected locations.

- The majority of the UPR Experiment Stations are currently not measuring solar radiation

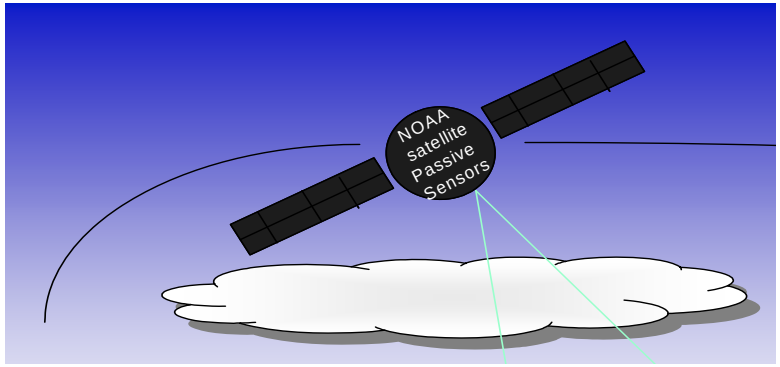
•A number of the radiation sensors are sensors and are not appropriate for use in ET equations.

•At this time there are approximately twenty functional solar radiation sensors (pyranometers) in Puerto Rico.

ET studies in Puerto Rico

- 1950-1970: few drainage lysimeter studies
- 1970-1990: application of meteorological methods
- 1990-2000: Pan evaporation methods
- 2000-present:
  - field studies
  - use of GIS and
  - remote sensing

Methods provide point values of ET



Satellite Remote Sensing

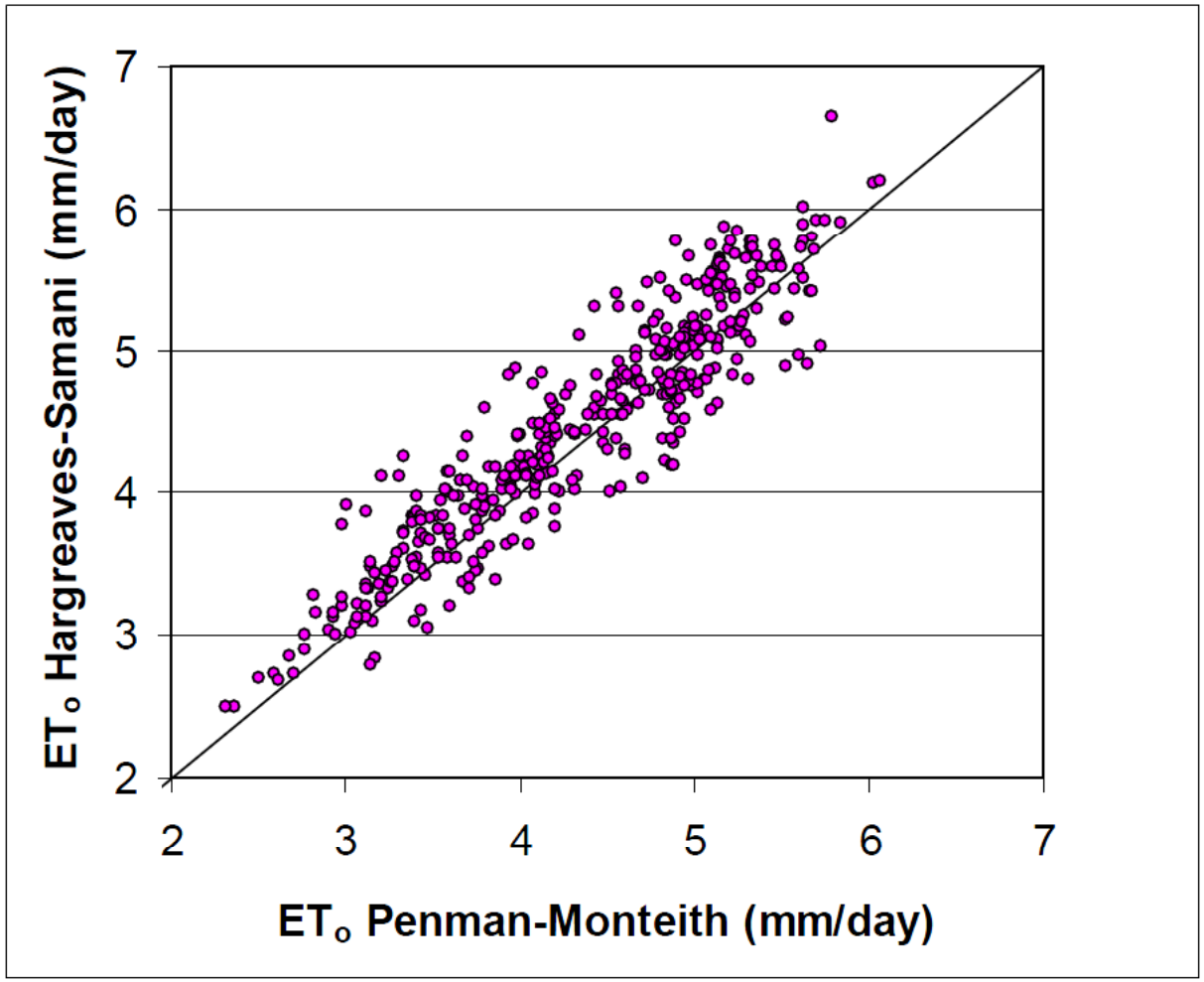
•Estimate solar radiation ⟶ Estimate ET

•Remote sensing of solar radiation has several advantages over the use of pyranometer networks

- Large spatial coverage
- Relatively high spatial resolution
- Availability of data in remote areas
- Data (or maps) can be made easily accessible to the public via the Internet

- **Since Puerto Rico's land area is approximately 9,000 km², estimating solar radiation using remote sensing (assuming a 1 km² satellite resolution) is like having 9,000 pyranometers in Puerto Rico!!**

Comparison of a Radiation Method and Penman-Monteith reference evapotranspiration method at thirty-four locations in Puerto Rico



OBJECTIVE

- **To develop an algorithm for estimating daily, high resolution (1-km), crop reference evapotranspiration (ET_o) over Puerto Rico.**

- This research represents a preliminary step in the development of an ET_o product for PR.

- This product is a potentially valuable tool for conducting water resource studies and for supporting irrigation scheduling efforts.

- The solar radiation product is also potentially valuable for
  - Solar energy studies
  - Photosynthesis and respiration studies
  - Health-related studies (e.g., skin cancer)
  - Etc.

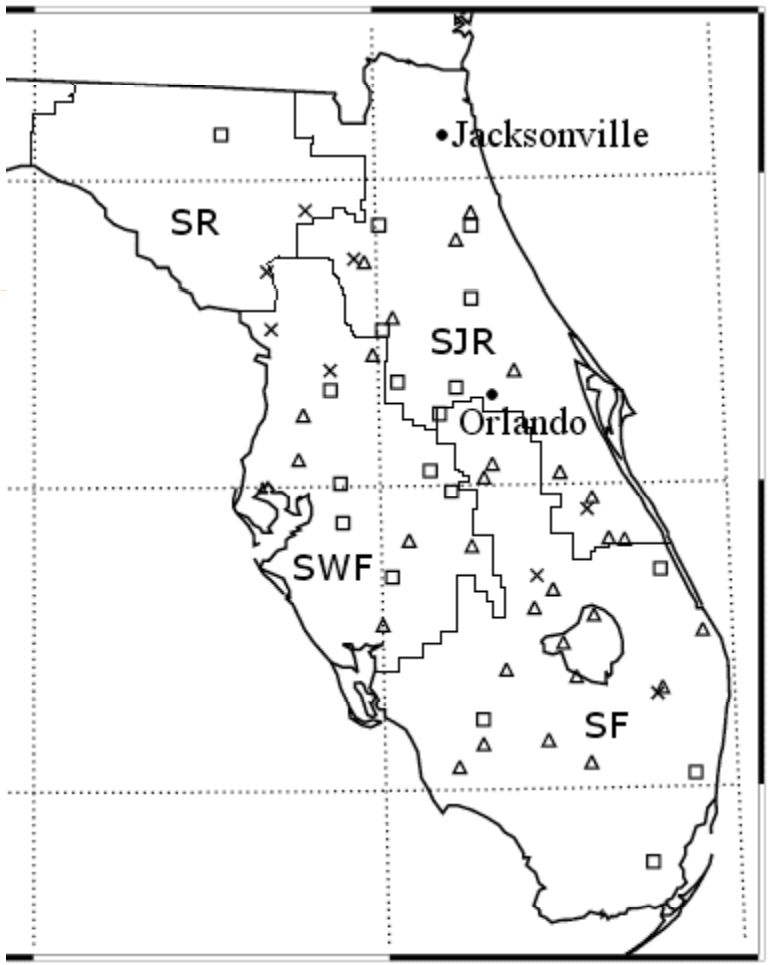
METHODOLGY

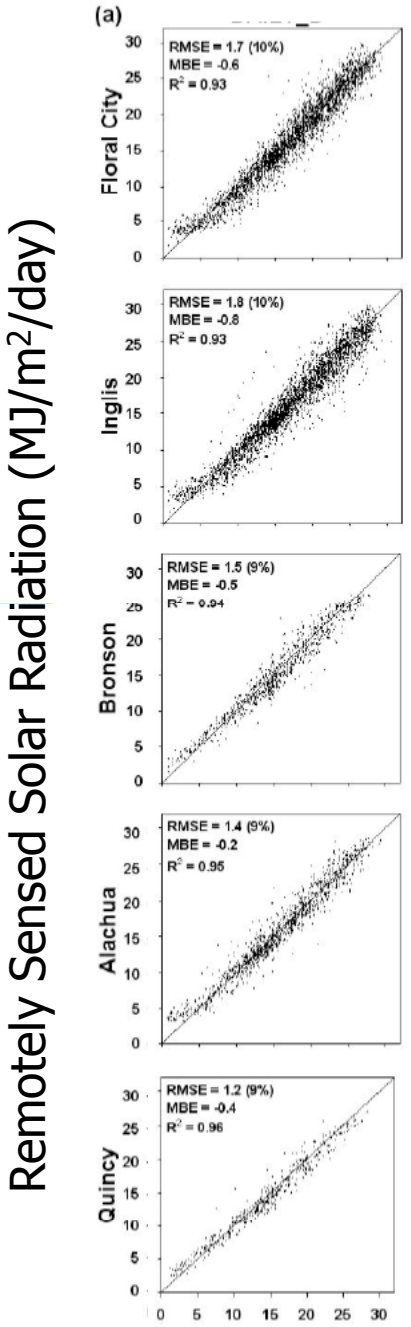
Remotely Sensed Solar Radiation

Solar radiation was obtained using the Modified Gautier and Diak method (Gautier et al., 1980; Diak and Gautier, 1983).

Data were obtained from the GOES-East satellite.
Geostationary platform
1 km resolution visible channel
4 km resolution thermal channel
High time resolution (e.g., 15 minutes)

A calibrated, high-resolution GOES satellite solar insolation product for a climatology of Florida Evapotranspiration
(Paech et al., 2009)

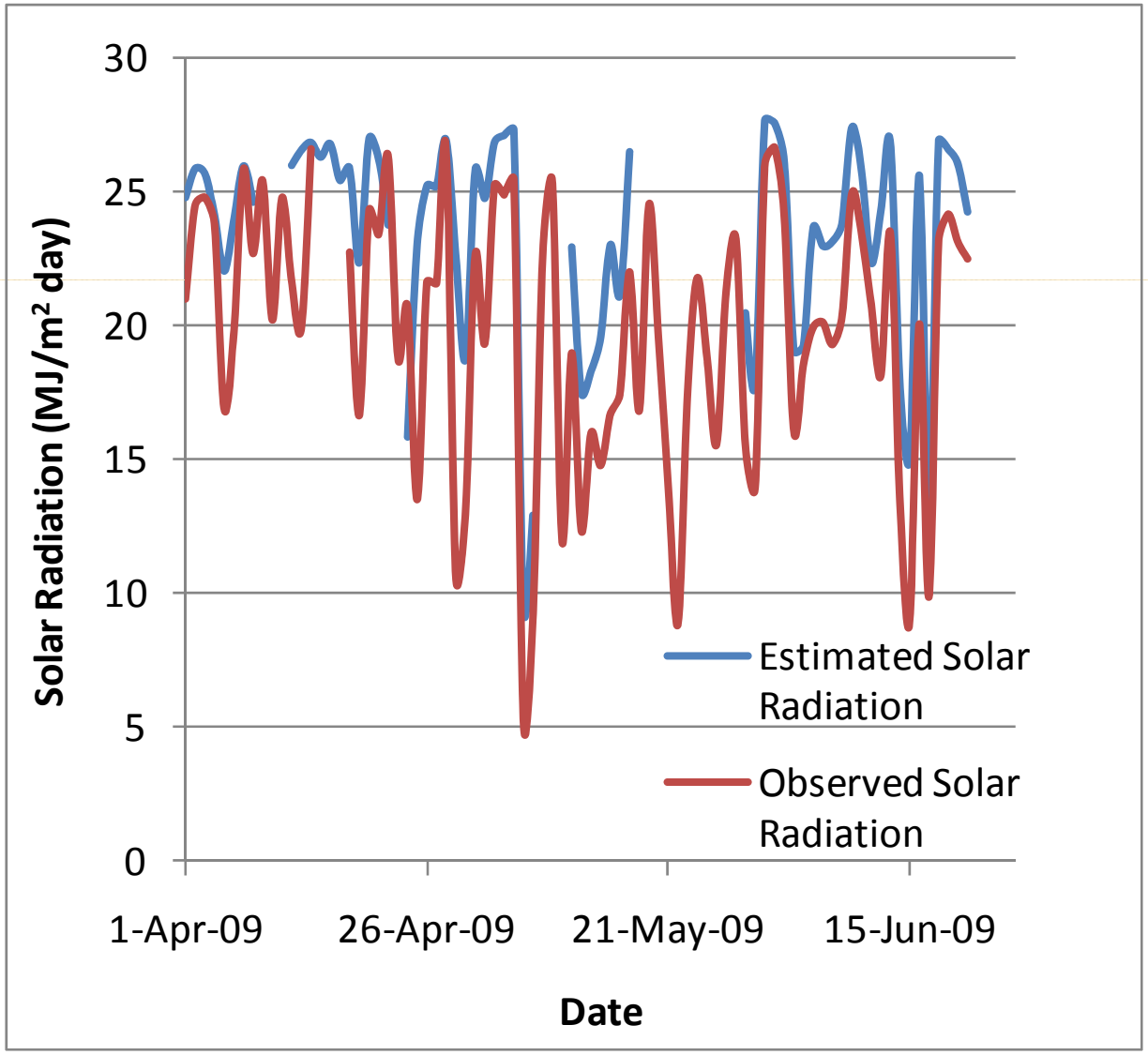




Remotely Sensed Solar Radiation ($MJ/m^2/day$)

Measured Solar Radiation ($MJ/m^2/day$)

Comparison of remotely sensed and measured solar radiation at Fortuna, PR, during the period April 1 through June 21, 2009



Example Application 1. Reference Evapotranspiration (ET_o)

- ET_o was estimated over Puerto Rico for March 5, 2009 using three ET_o methods:
  - Hargreaves-Samini (HS)
  - Preistly-Taylor (PT)
  - Penman-Monteith (PM)
- Weather parameters were estimated using the methods presented in Harmsen et al. (2002)

Hargreaves-Samani (HS) equation

$$ET_o = 0.0135\ R_s\ (T+17.8)$$

ET_o and solar radiation (insolation), R_s, are in the same equivalent units of water evaporation [$L\ T^{-1}$], and T is mean temperature in degrees C.

Priestly-Taylor (PT) equation

$$ET_o = \alpha \cdot \frac{\Delta \cdot (R_n - G)}{(\Delta + \gamma)}$$

where α is the Priestly-Taylor constant

Penman-Monteith (PM) reference evapotranspiration equation

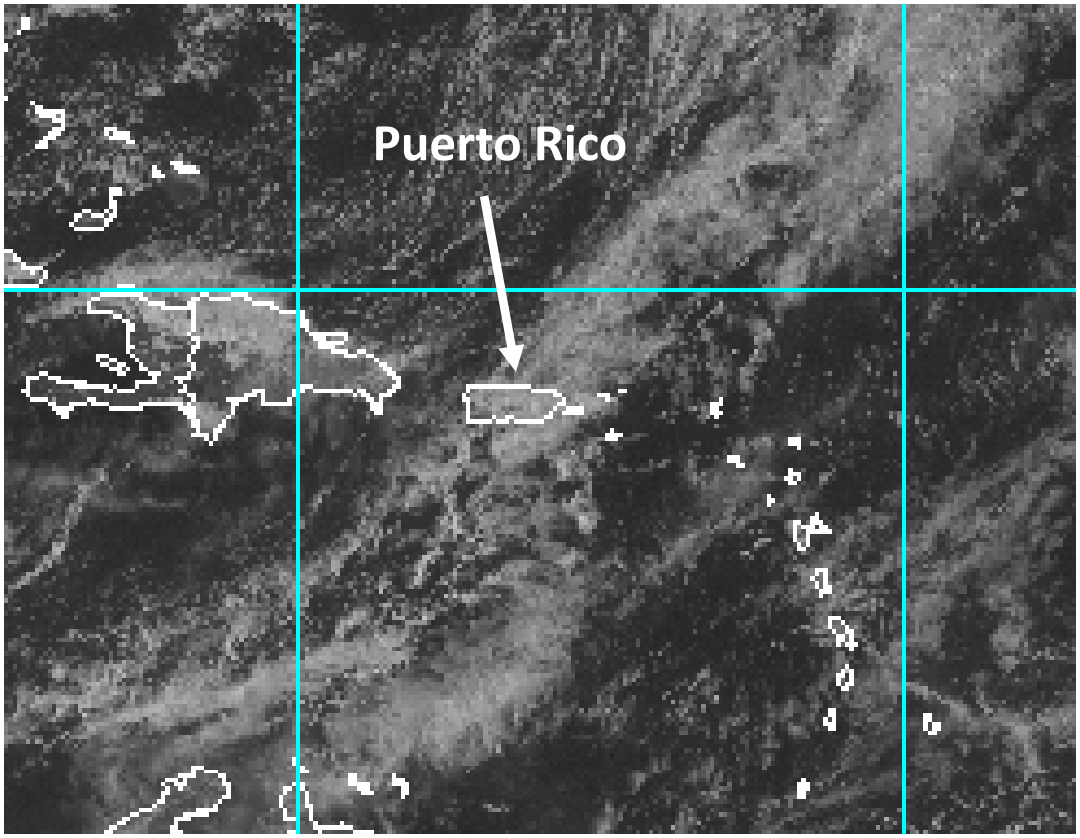
$$ET_o = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \left(\frac{900}{T + 273}\right) \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)}$$

where
Δ is slope of the vapor pressure curve [kPa °C^{-1}]
R_n is net radiation [MJ m^{-2} day^{-1}]
G is soil heat flux density [MJ m^{-2} day^{-1}]
λ is psychrometric constant [kPa °C^{-1}]
T is mean daily air temperature at 2 m height [°C]
u_2 is wind speed at 2 m height [m s^{-1}]
e_s is the saturated vapor pressure and e_a is the actual vapor pressure [kPa]

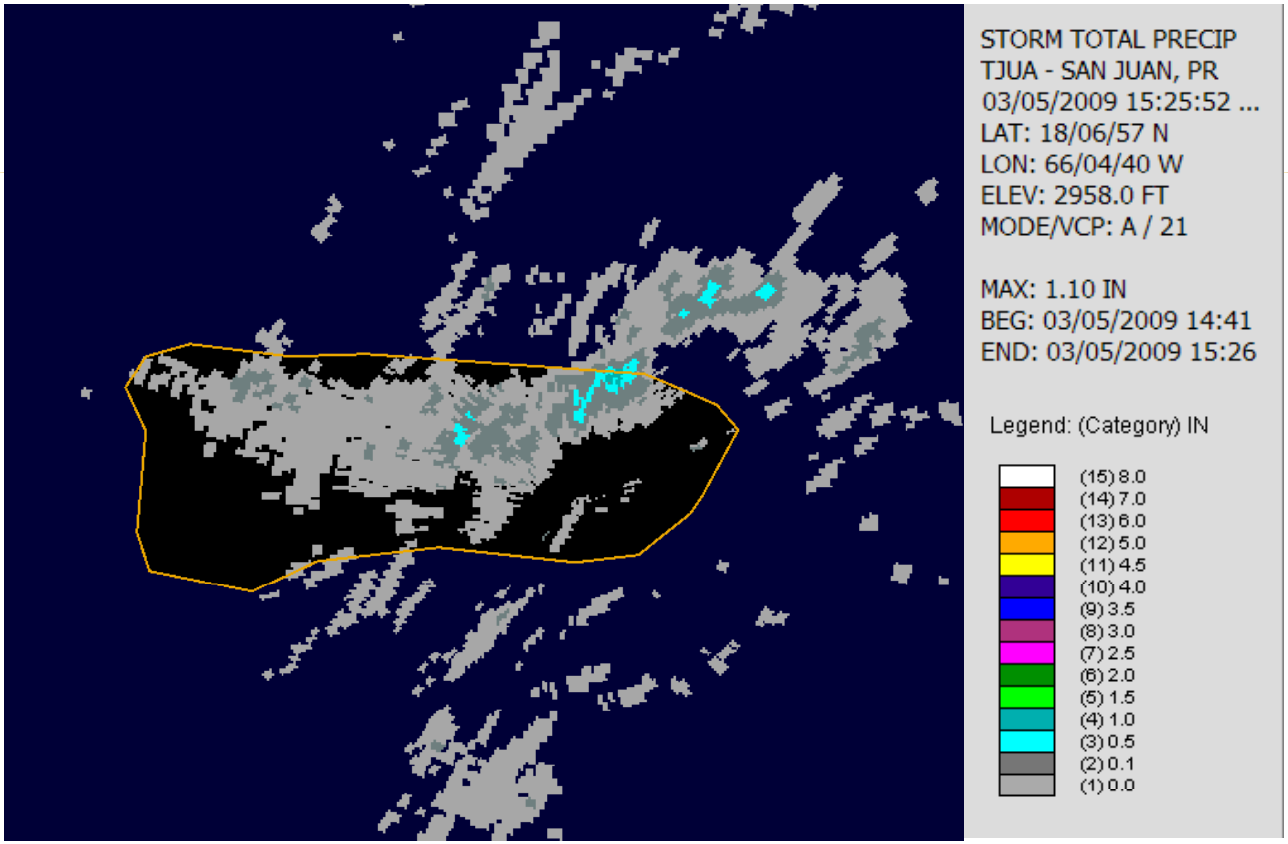
The equation applies specifically to a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec m^{-1} and an albedo of 0.23.

SOME PRELIMINARY RESULTS

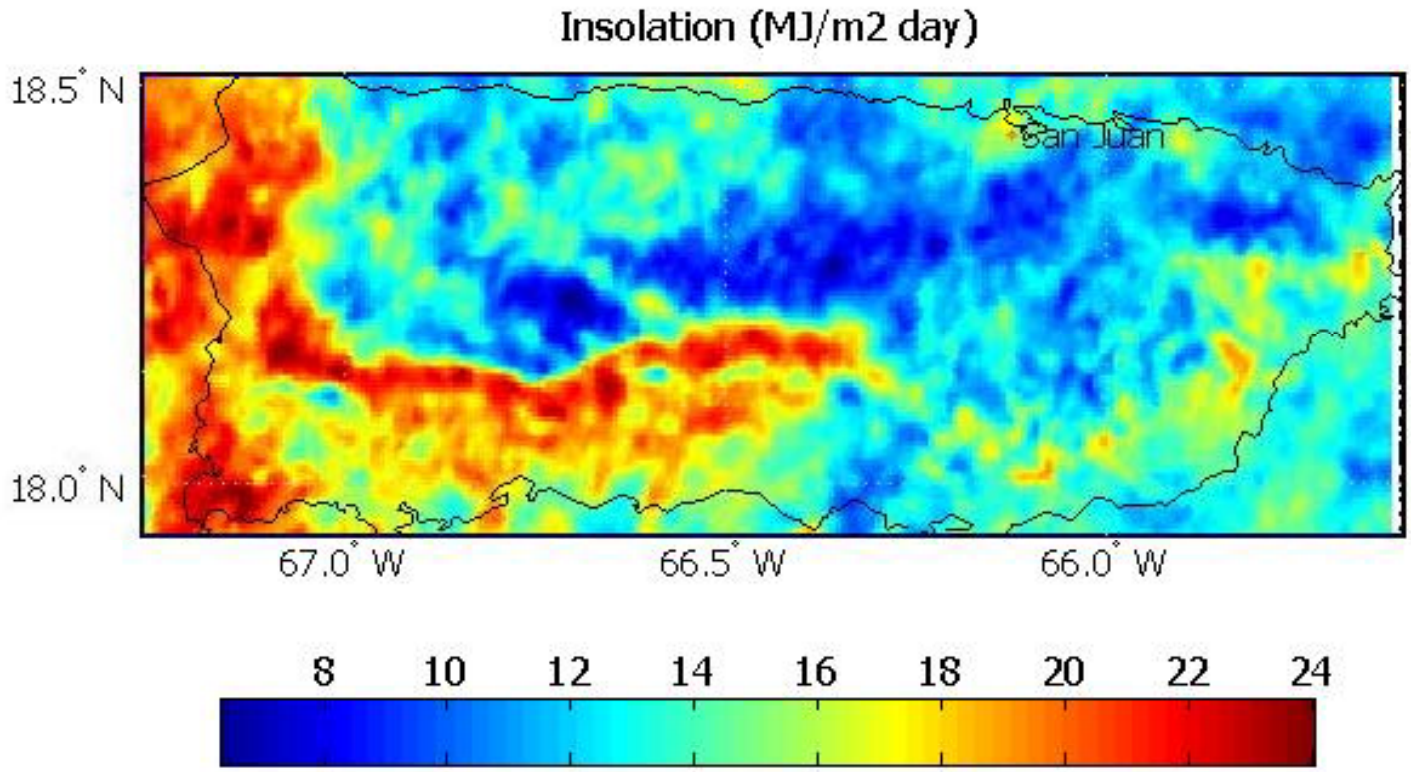
Visible satellite image of Caribbean region at 15:15 local time (19:15 UTC), March 5th, 2009



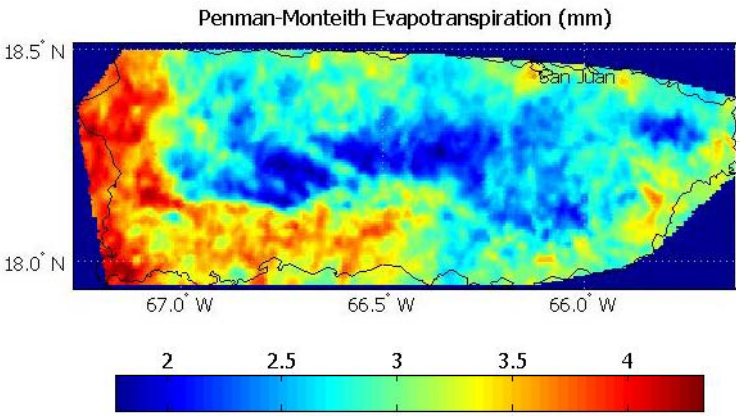
NEXRAD radar storm total precipitation in inches over Puerto Rico at 15:26 local time (19:26 UTC), March 5th, 2009

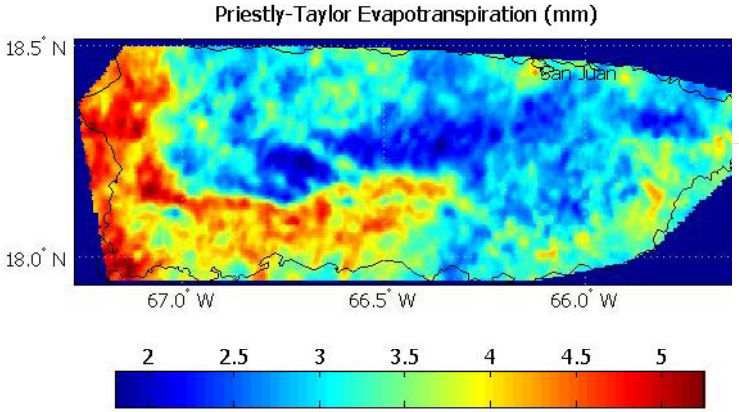


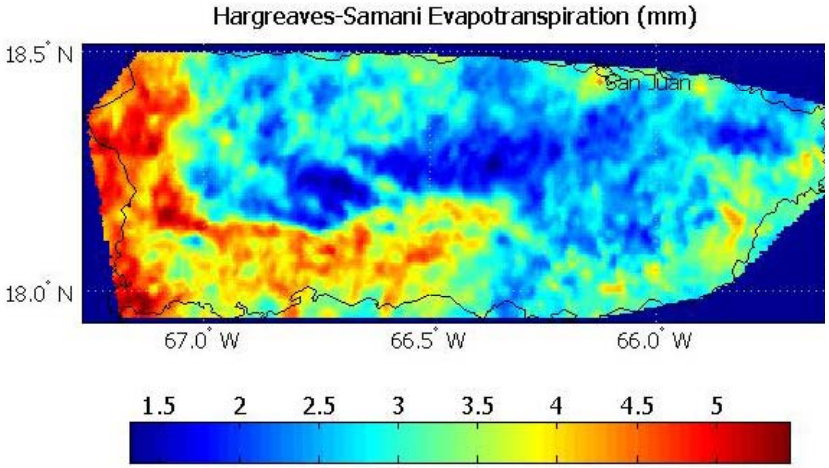
Integrated daily solar insolation for Puerto Rico on March 5th, 2009



Comparison of reference ET from PM, PT and HS methods







Example Application 2. Evapotranspiration (ET)

• Cumulative seasonal (75-day) water consumptive use was determined for five different crops and seven locations in PR.

• Vegetable crops evaluated: tomato, sweet, corn, squash, lettuce and sweet pepper.
•April 1 – June 21, 2009.

NRCS SCAN Sites

- Solar Radiation
- Air Temperature
- Relative Humidity
- Wind Speed and Direction
- Barometric Pressure
- Soil Moisture at 4 Depths
- Data is Published on the Internet

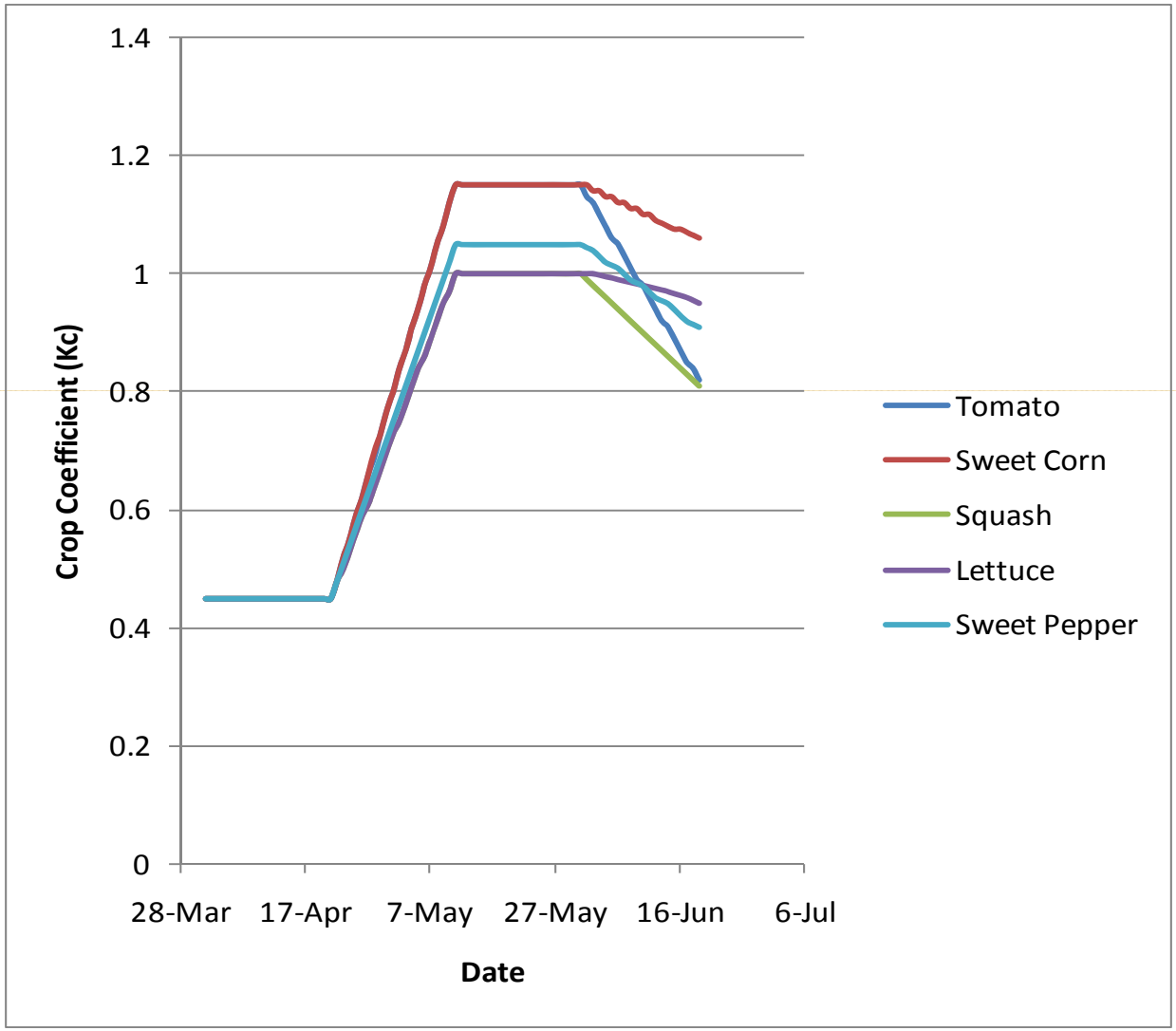
Crop Evapotranspiration

The actual crop evapotranspiration was estimated from the relation:

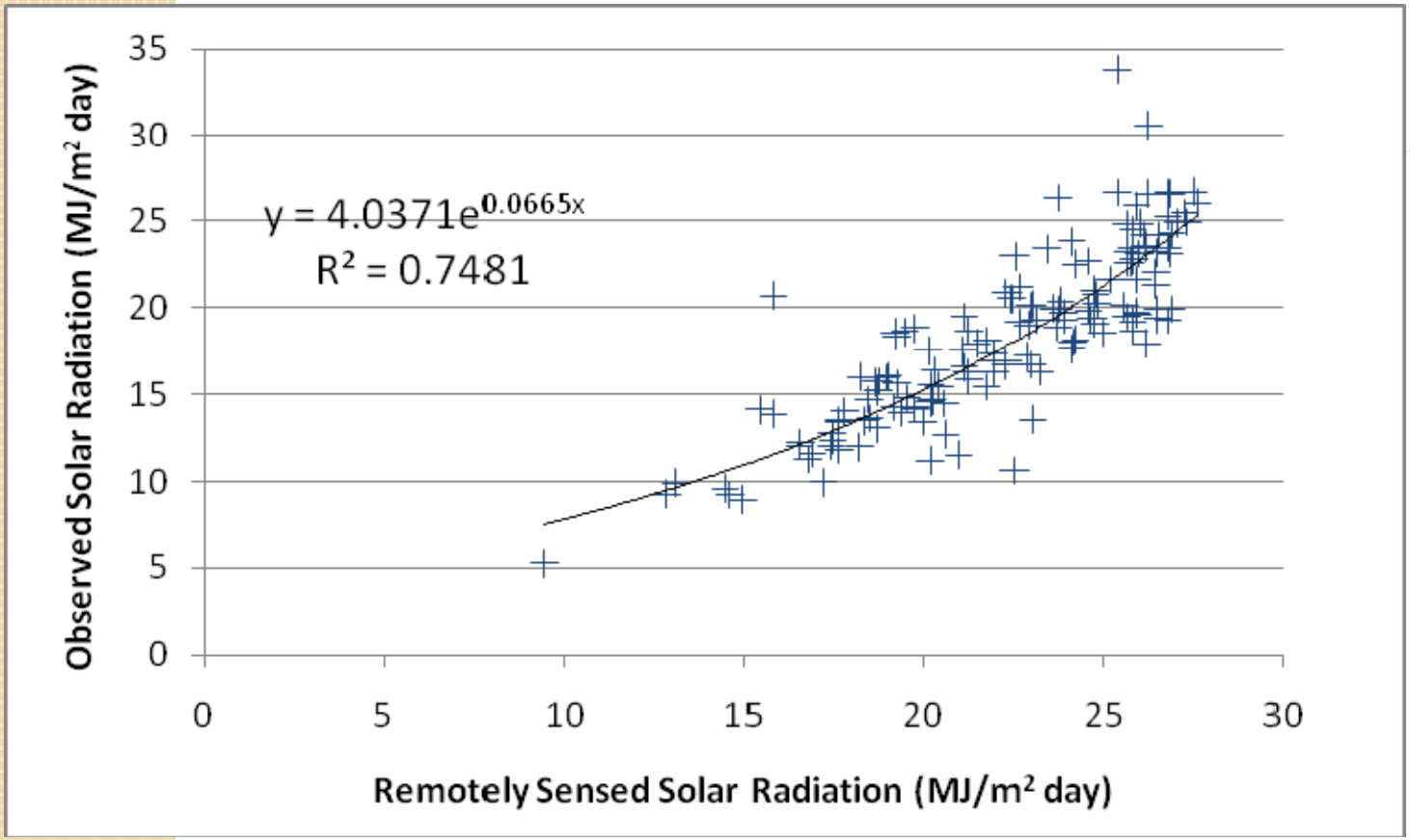
$$ET = K_c \, ET_o$$

where ET is crop evapotranspiration and K_c is the evapotranspiration crop coefficient.

Crop Coefficients (FAO Method)



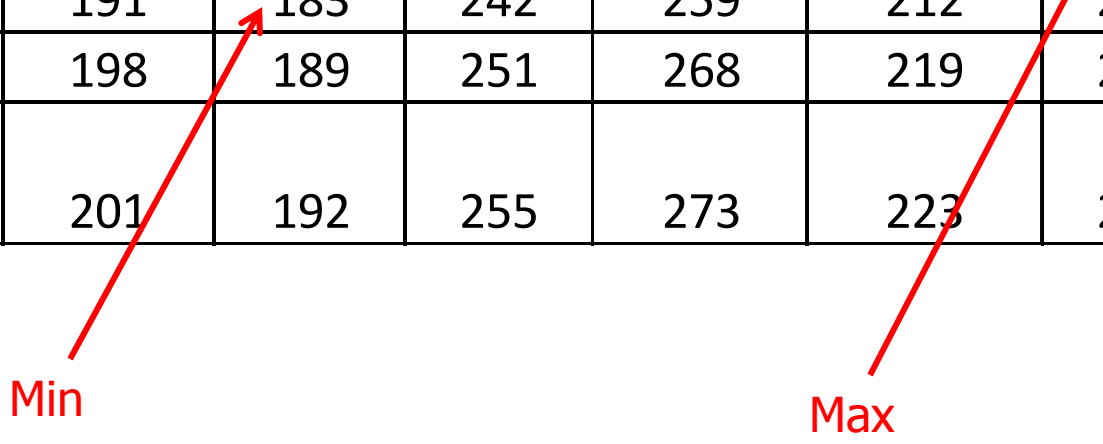
CALIBRATION OF SOLAR INSOLATION



Estimated and observed solar radiation from three of the SCAN weather station sites. A best-fit Exponential curve is include along with the data.

Cumulative seasonal (75-day) water consumptive use was determined for five different crops and seven locations in PR.

	Seasonal Evapotranspiration (mm)						
Crop	Isabela	Maricoa	Guilarte	Fortuna	Combate	Mayaguez	Bosque
Tomato	217	207	198	263	283	232	291
Sweet Corn	228	219	208	277	297	243	305
Squash	200	191	183	242	259	212	267
Lettuce	206	198	189	251	268	219	276
Sweet Pepper	210	201	192	255	273	223	280



Summary and Conclusions

- A remote sensing-based technique was presented for estimating reference evapotranspiration in Puerto Rico.
- The method relies on solar radiation derived from the GOES satellite.
- Reference evapotranspiration was estimated for Puerto Rico using three ET_o methods for March 5th, 2009, a day with scattered clouds and rainfall. The three methods were relatively close agreement.
- Seasonal (75-day) evapotranspiration was estimated for five vegetable crops at the seven NRCS SCAN sites (April 1 – June 21, 2009).
- The ability to estimate ET from remotely sensed data is an essential tool for managing the worlds future water supply.

Future work

- A rigorous validation/calibration of the solar insolation product will be conducted.
- A validation of the ET fluxes will be conducted using a Large Aperture Scintillometer (LAS)
- A publically accessible website will provide daily and half-hourly solar radiation, reference evapotranspiration and actual evapotranspiration.
- The system will be completely automated, and will require very little maintenance.
- The proposed system will serve as an expandable platform in which other agricultural and non-agricultural remote sensing products can be added.
- The proposed system can serve as a unified mapping platform for evaluating *climate change* in the future.

Acknowledgements

- Financial Support:
  - NOAA-CREST (NA17AE1625)
  - NSF-CASA (NSF 0313747)
  - USDA-Hatch (H-402)