NOAA CREST

# Estimating Evapotranspiration using Satellite Remote Sensing in Puerto Rico, Haiti and the Dominican Republic

Eric. W. Harmsen[1], John Mecikalski[2], Pedro Tosado Cruz[1] Ariel Mercado Vargas[1]

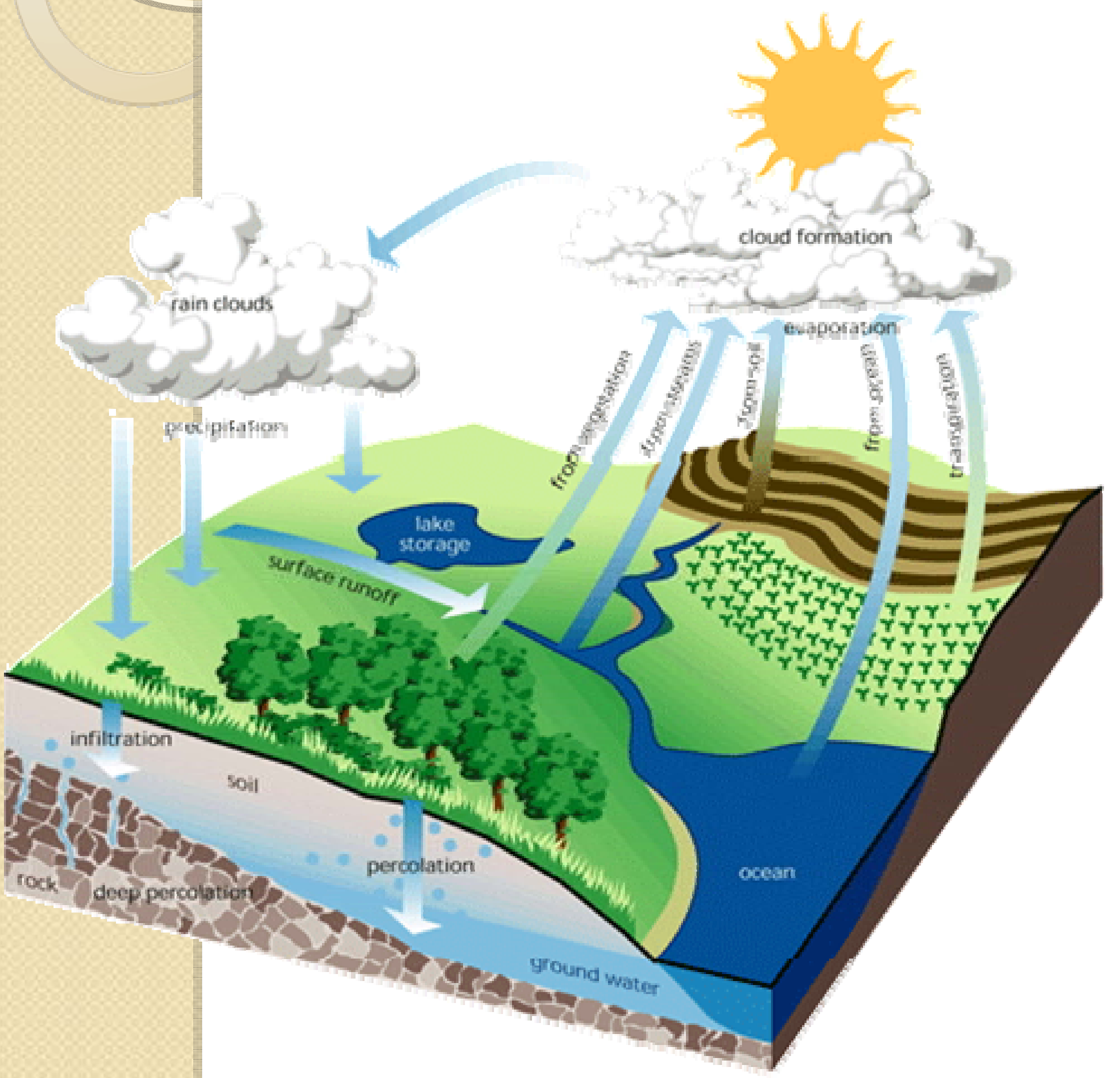
1. University of Puerto Rico – Mayaguez
2. University of Alabama - Huntsville

**The 46th Annual Meeting of the Caribbean Food Crops Society, July 12, 2010**

http://academic.uprm.edu/abe/PRAGWATER/

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

# Currently situation in Puerto Rico

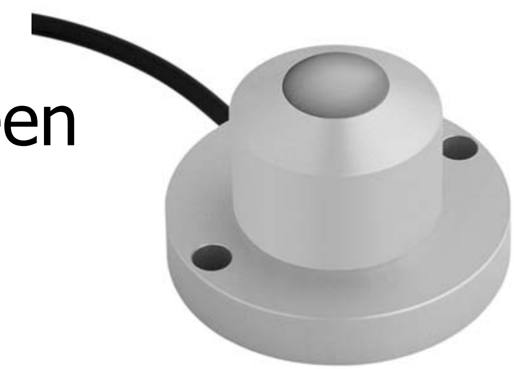
- Estimation of ET requires weather data, including solar radiation

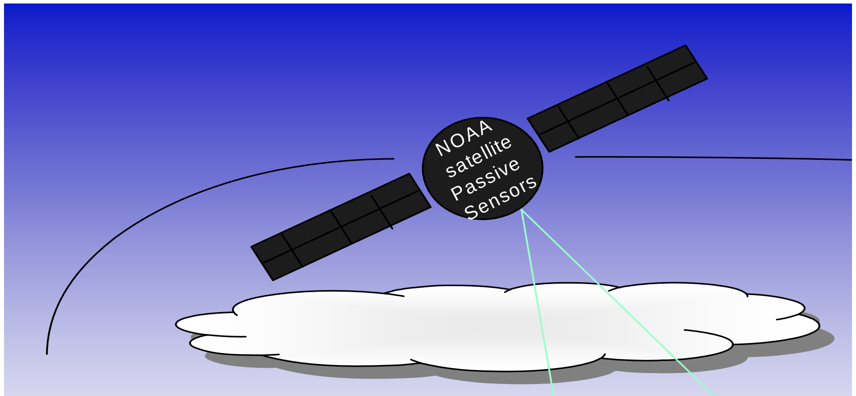
- In PR, solar radiation is only available at selected locations.

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

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

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






# 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 km$^2$, estimating solar radiation using remote sensing (assuming a 1 km$^2$ satellite resolution) is like having 9,000 pyranometers in Puerto Rico!!**

# OBJECTIVE

- To introduce several new water resource-related remote sensing products for Puerto Rico, Haiti and the Dominican Republic.

- The development of the methodology has advanced more quickly in Puerto Rico, therefore, the information presented here can be considered a prototype of what is being developed for the other two countries (i.e., Haiti and the Dominican Republic).

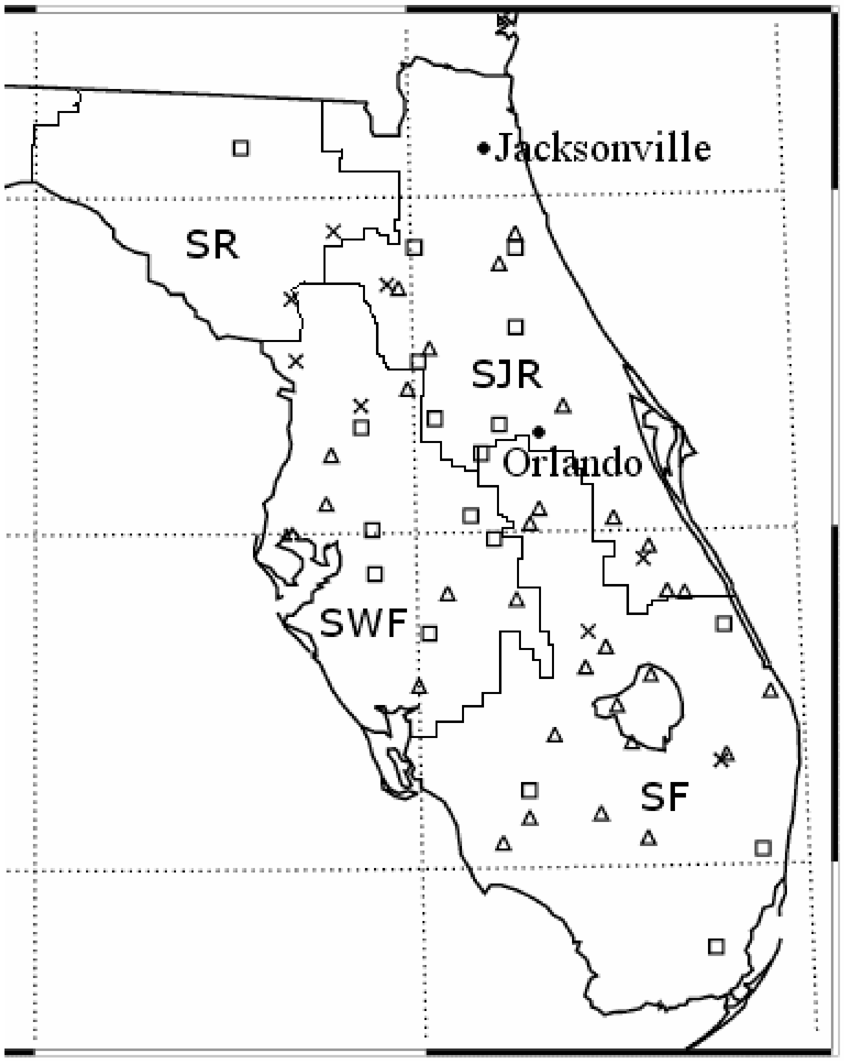
# Technical Approach

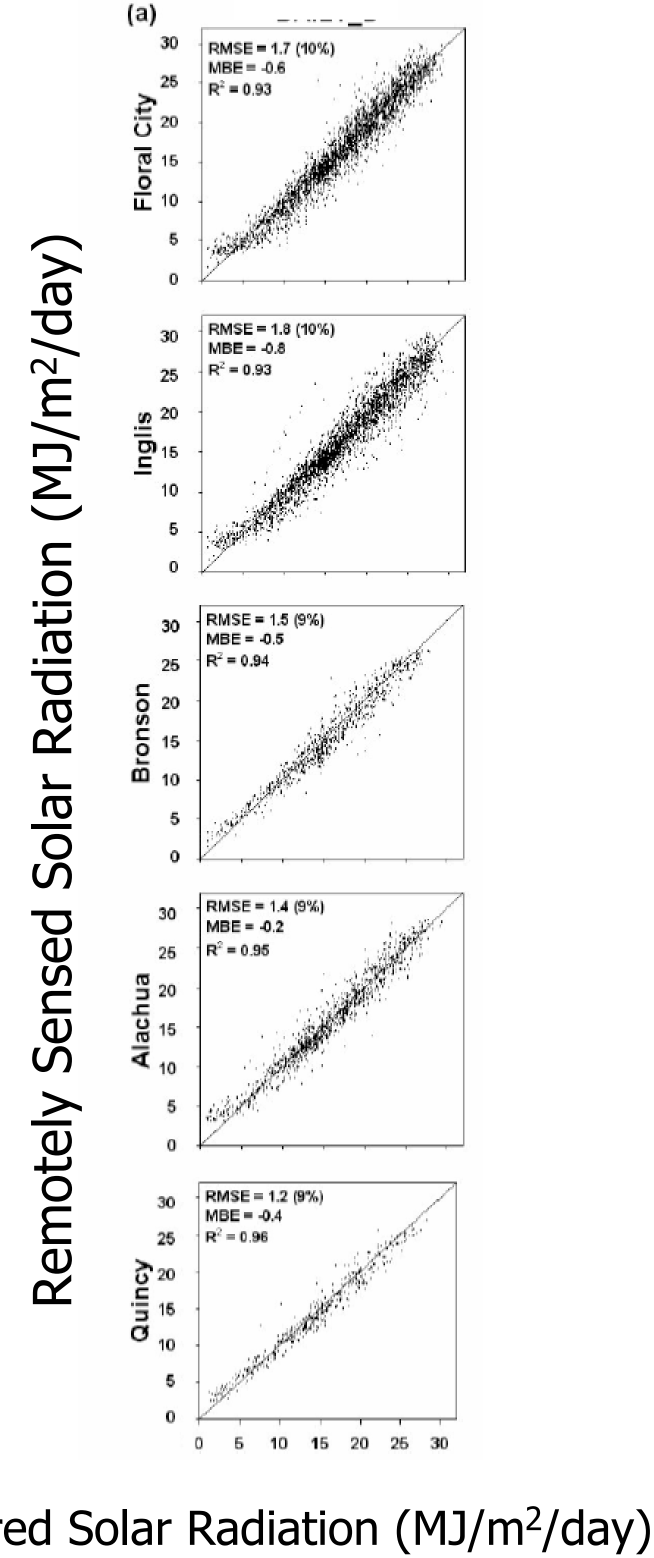
# Remotely Sensed Solar Radiation

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

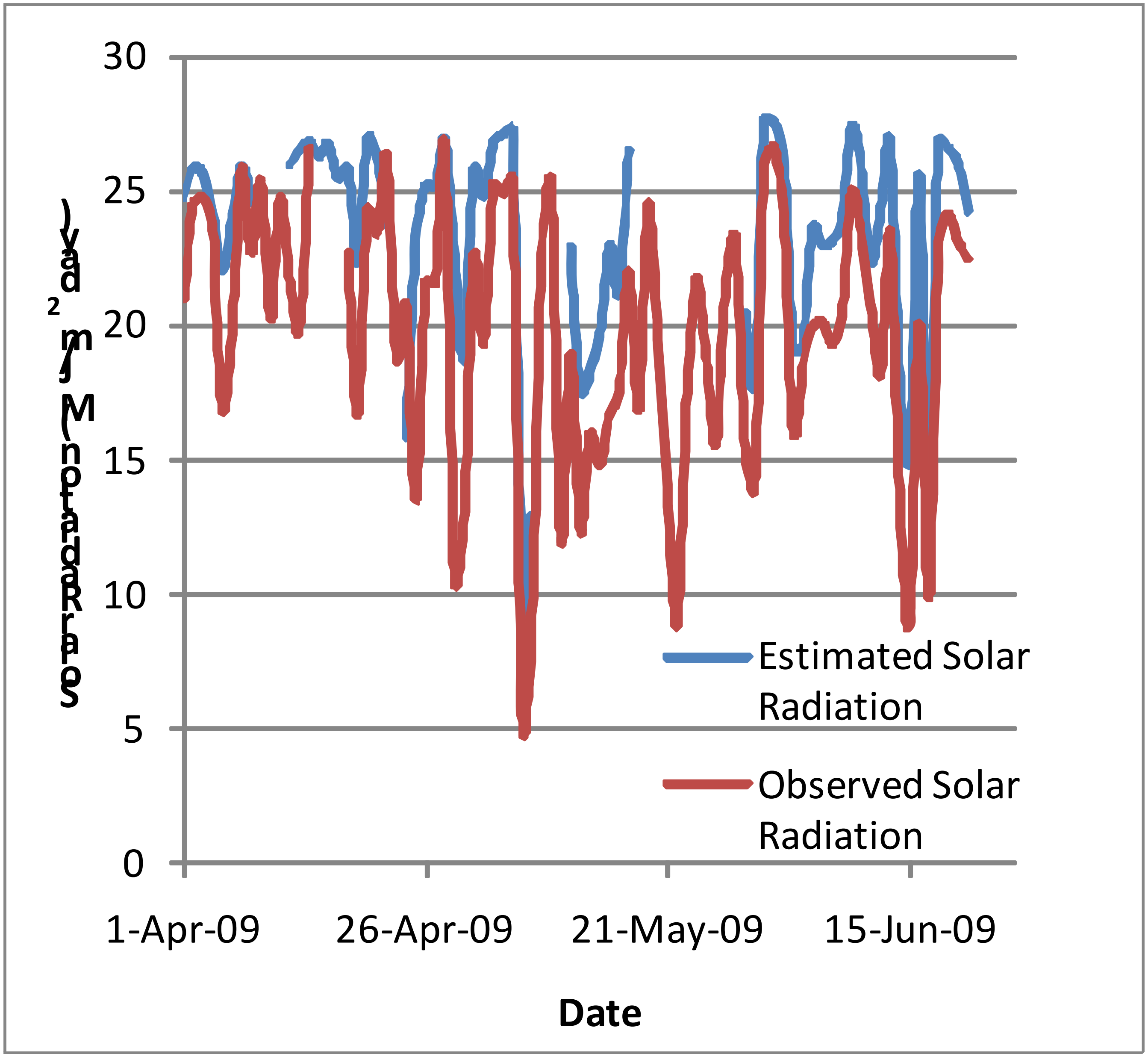
Data were obtained from the GOES-East satellite.
Geostationary platform
1 km resolution visible channel
2 km Haiti and the Dominican Republic
High time resolution (30 minutes)

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

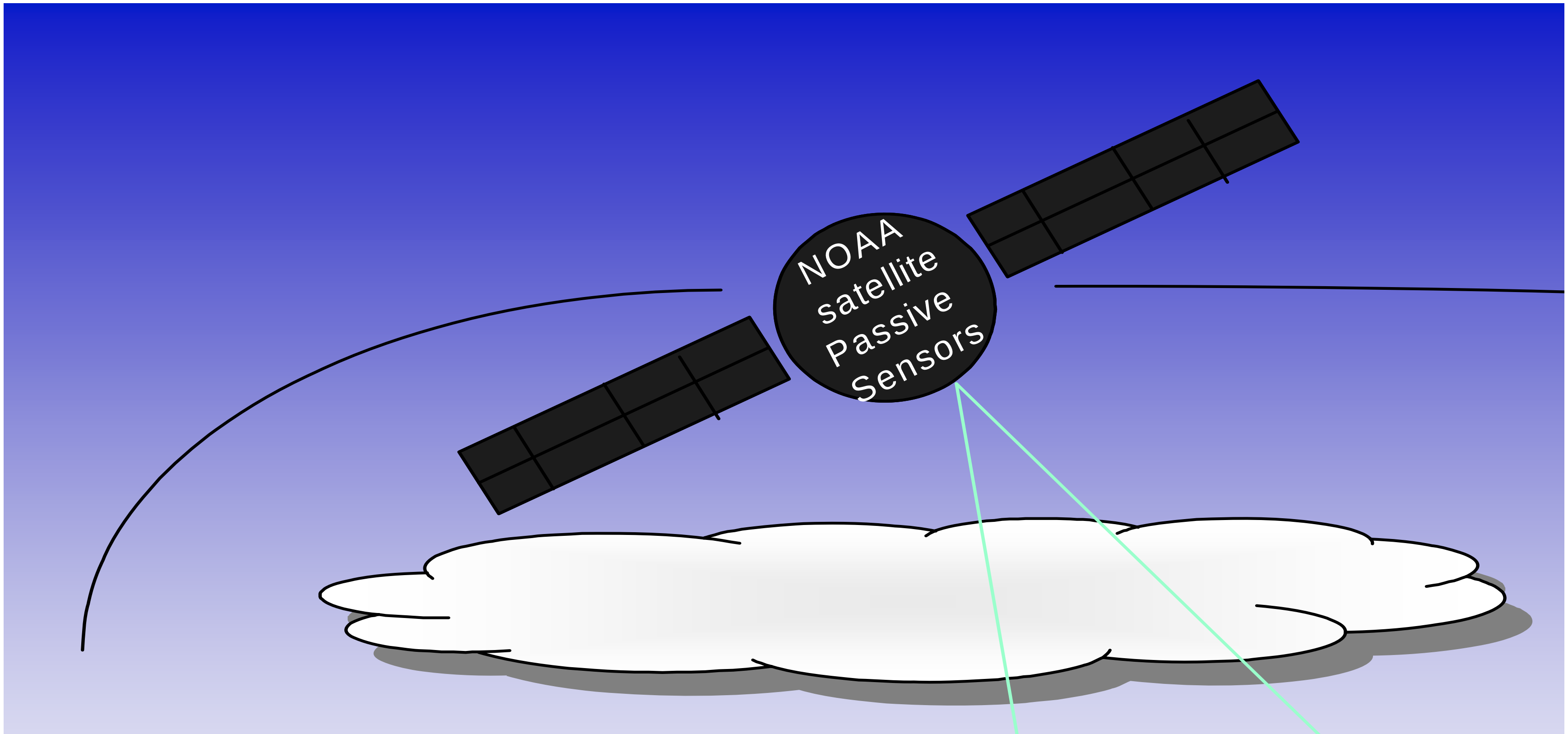


# Comparison of remotely sensed and measured solar radiation at Fortuna, PR, during the period April 1 through June 21, 2009



# How do we solve remote sensing problems?



# Hargreaves Equation for Reference Evapotranspiration

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

$ET_o$ is reference evapotranspiration
$R_s$ is daily integrated solar radiation (insolation)
$T$ is mean temperature

# Actual Evapotranspiration

$$ET_a = \lambda\ LE$$

λ is the Latent Heat of Vaporization (2.45 MJ/kg)
LE is the Latent Heat Flux

# Surface Energy Balance

$$R_n - LE - H - G = 0$$

$R_n$ is net radiation
LE is the latent heat flux
H is the sensible heat flux
G is soil heat flux, assumed to be zero for 24 hour analysis.

The only unknown variable in the above equation is the effective surface temperature $T_s$.

We solve for $T_s$ using the **fzero** function in MatLab

# Latent Heat Flux

$$LE = \frac{\rho \cdot C_p \cdot \left(e_o\left(T_s\right) - e\left(T_a\right)\right)}{\gamma \cdot \left(r_a + r_s\right)}$$

LE is the latent heat flux
$\rho$ is density of dry air
$C_p$ is specifc heat of air
$\gamma$ is the psychrometric constant
e is vapor pressure
$T_s$ is effective surface temperature
$T_a$ is the air temperature
$r_a$ is aerodynamic resistance
$r_s$ is surface resistance

# Sensible Heat Flux

$$H = \frac{\rho \cdot C_p \cdot \left(T_s - T_a\right)}{r_a}$$

HE is the Sensible Heat Flux
ρ is density of dry air
$C_p$ is specifc heat of air
$T_s$ is effective surface temperature
$T_a$ is the air temperature
$r_a$ is aerodynamic resistance

# Aerodynamic Resistance ($r_a$)

$$r_a = r_{ao} \cdot \phi + r_{bh}$$

$r_a$ is aerodynamic resistance
$r_{ao}$ is aerodynamic resistance under conditions of neutral atmospheric stability
$\varphi$ is stability coefficient
$r_{bh}$ is excess resistance

# Aerodynamic Resistance ($r_a$)

$$r_{ao} = \frac{\ln\left[\frac{(z - z_{disp})}{z_o}\right] \cdot \ln\left[\frac{(z - z_{disp})}{(0.1) \cdot z_o}\right]}{k^2 \cdot u}$$

$r_{ao}$ is aerodynamic resistance under conditions of neutral atmospheric stability

z is height at which meteorologic measurements are taken

$Z_{disp}$ is zero plane displacement

$Z_o$ is roughness length

K is Van Karman constant (0.41)

u is wind velocity

# Stability Coefficient (φ)

$$\phi = \left[ 1 - \frac{\left[\eta \cdot \left(z - z_{disp}\right) \cdot g \cdot \left(T_s - T_a\right)\right]}{T_o \cdot u^2} \right]$$

φ is stability constant
η is a constant commonly taken as 5
z height at which meteorological measurements are taken
g gravitational constant
$Z_{disp}$ is zero plane displacement
$T_s$ is effective surface temperature
$T_a$ is air temperature
$T_o$ is average of $T_s$ and $T_a$
u is wind velocity

# Water Balance

$$SMD2 = PRECIP - ET_a - RO - DP + SMD1$$

SMD1 and SMD2 are the soil moisture content at beginning and end of the 24 hour period

PRECIP is the rainfall during the day
ETa is daily actual evapotranspiration
RO is surface runoff
DP is deep percolation

# Surface Runoff (RO)

$$RO = (PRECIP - 0.2S)^2 / (PRECIP + 0.8S)$$

$$S = [(25400 / CN) - 254]$$

RO is surface runoff
PRECIP is rainfall
S is the maximum potential difference between rainfall and runoff at the moment of rainfall initiation
CN is the curve number which is a proportion of rainfall converted to runoff

# Soil Moisture and Deep Perclation

An initial value of SMD2 is calculated with a modification of water balance equation:

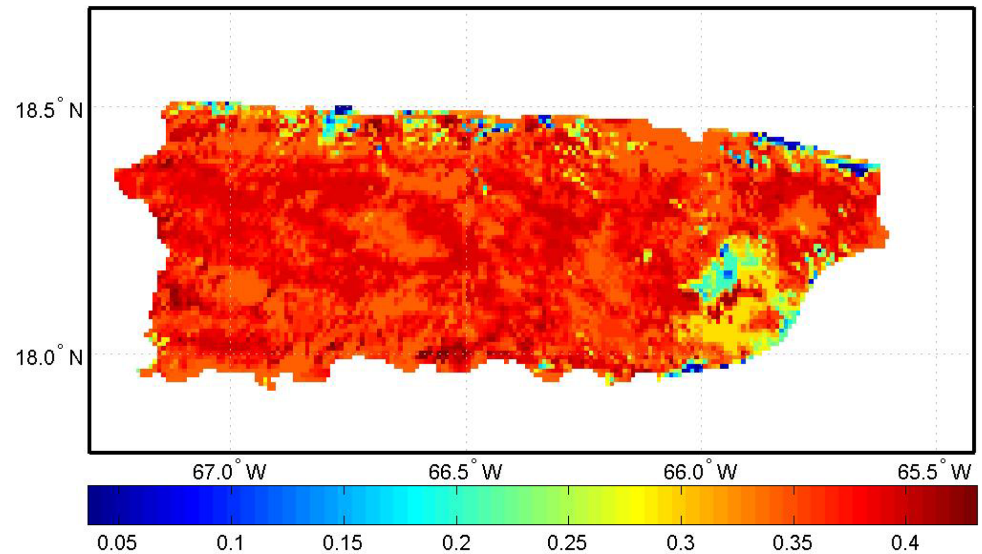
$SMD2_i$ = PRECIP – $ET_a$ – RO + SMD1.

If the Value of $SMD2_i$ is larger than the depth of water in the profile at field capacity (FCD), then DP = $SMD2_i$ - FCD and the value of SMD2 is equal to FCD. If however, $SMD2_i$ < FCD, then DP = 0, and SMD2 = $SMD2_i$.

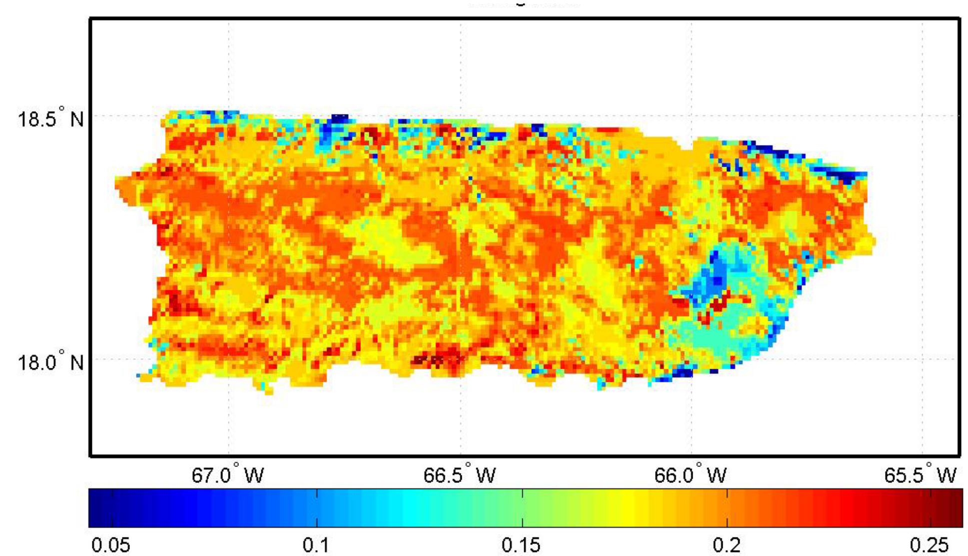
# RESULTS

- An analysis was performed for a10 day period between June 20 and June 29, 2010.
- The soil moisture was adjusted daily based on the surface water balance
- Images are shown for June 29, 2010

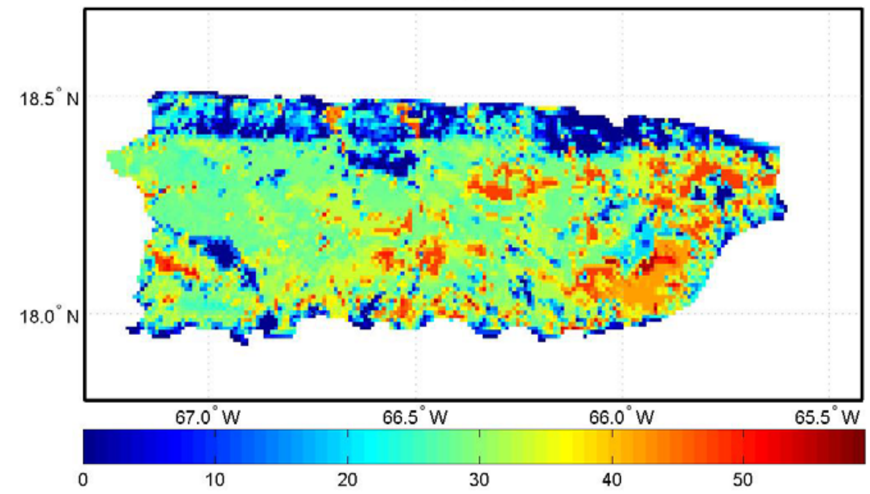
# Field Capacity



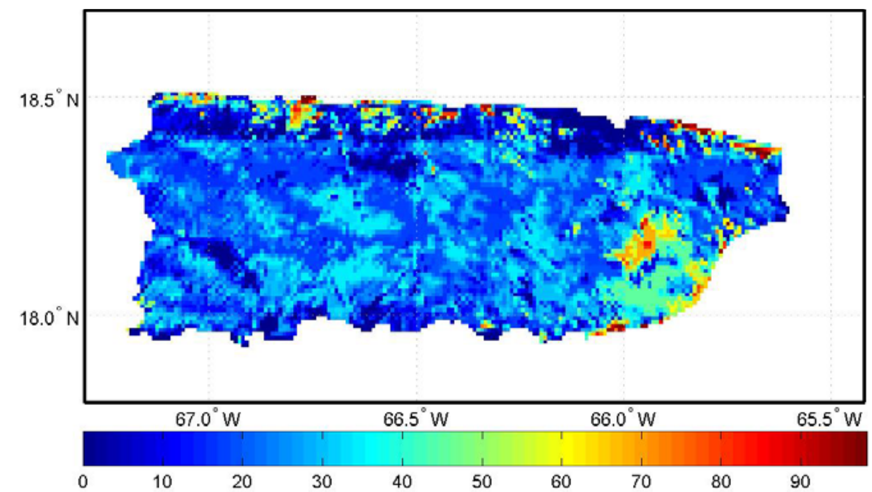

# Wilting Point



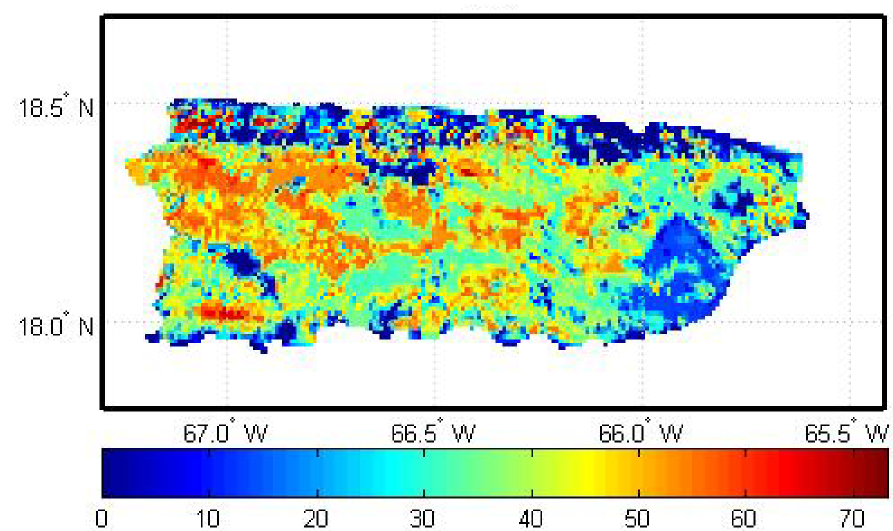
# Percent Sand,



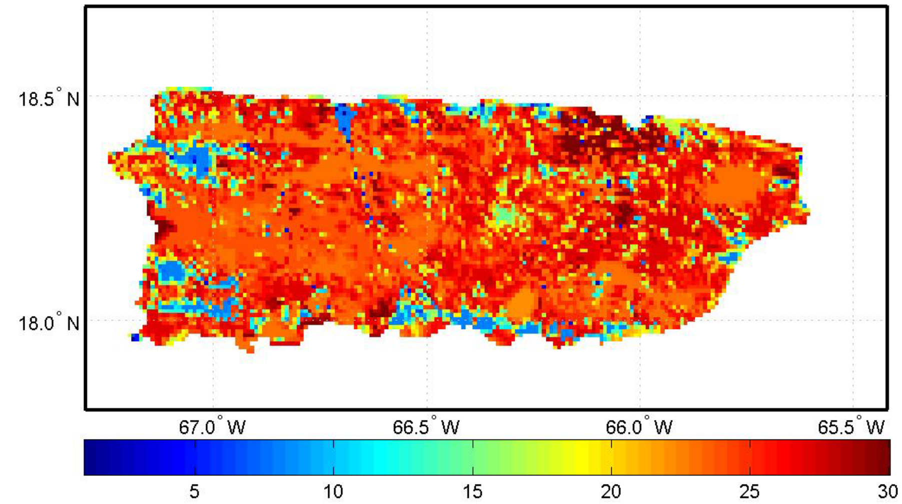

# Percent Silt



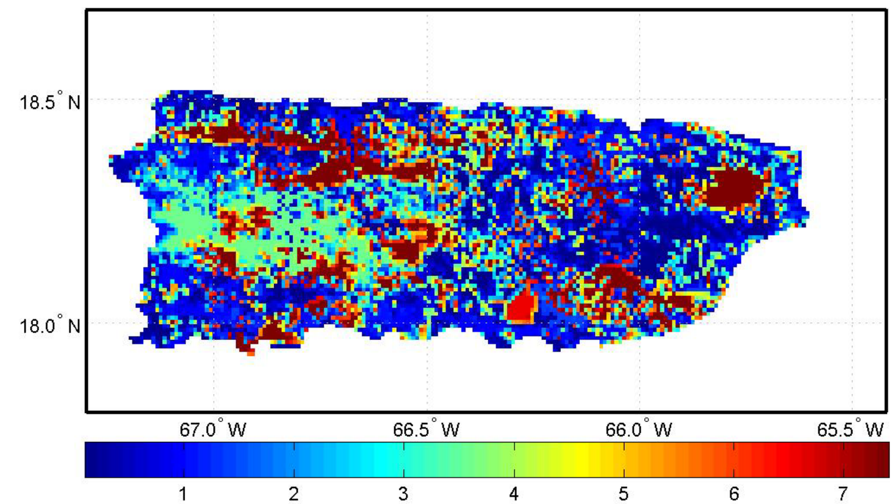

# Percent Clay



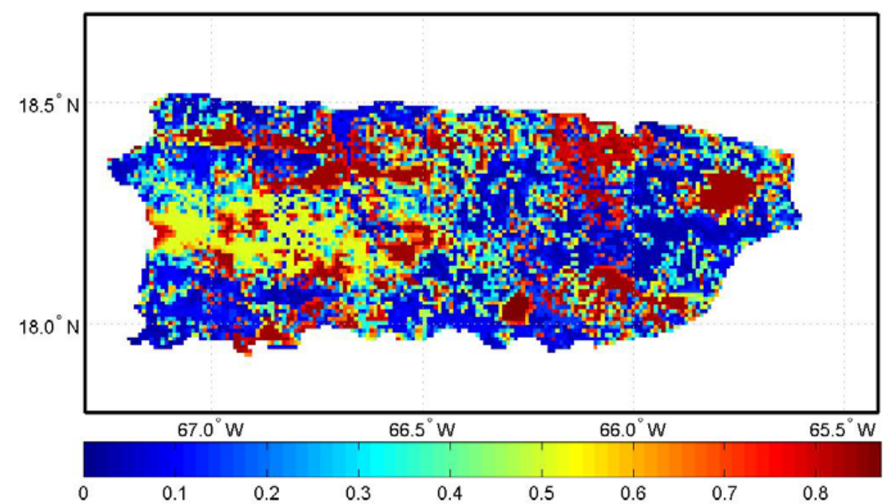
# Land Cover



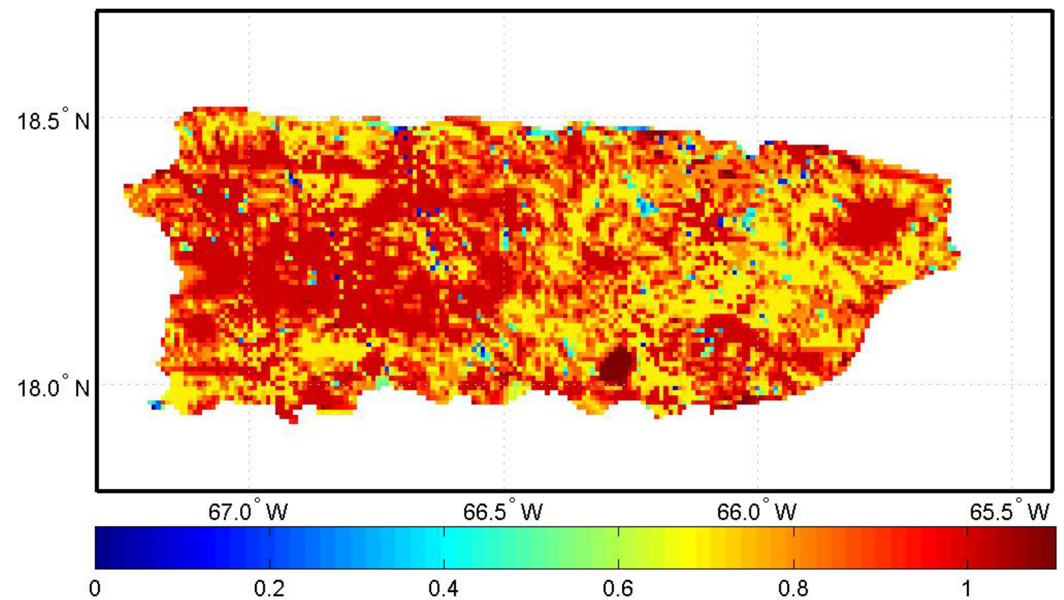

# Zero Plane Displacement



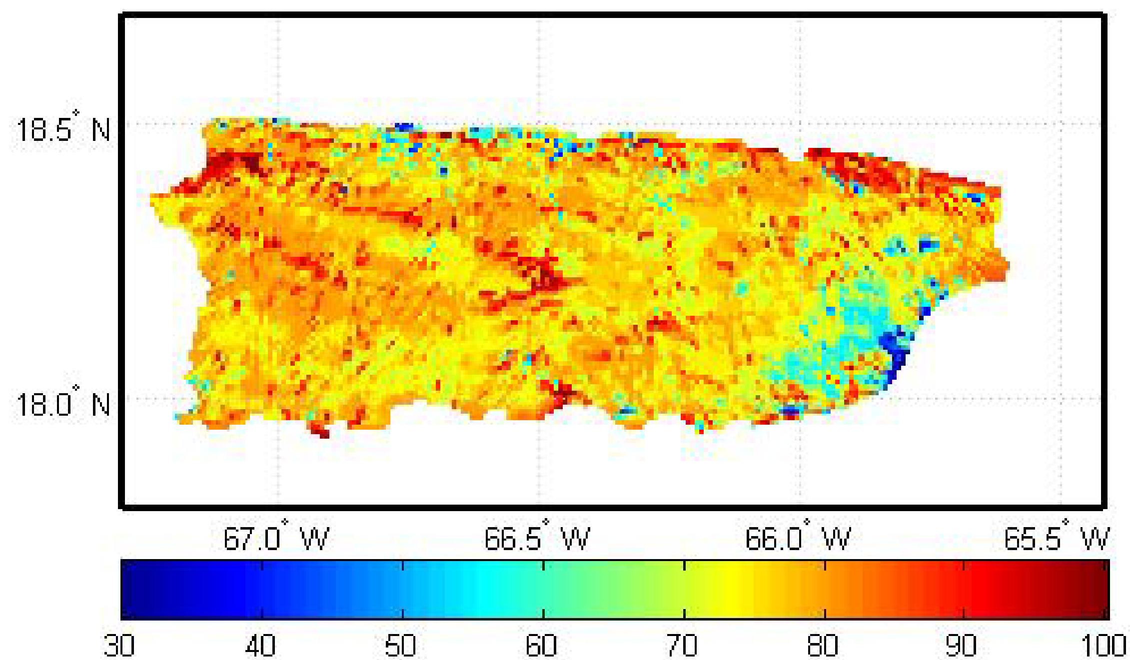

# Surface Roughness



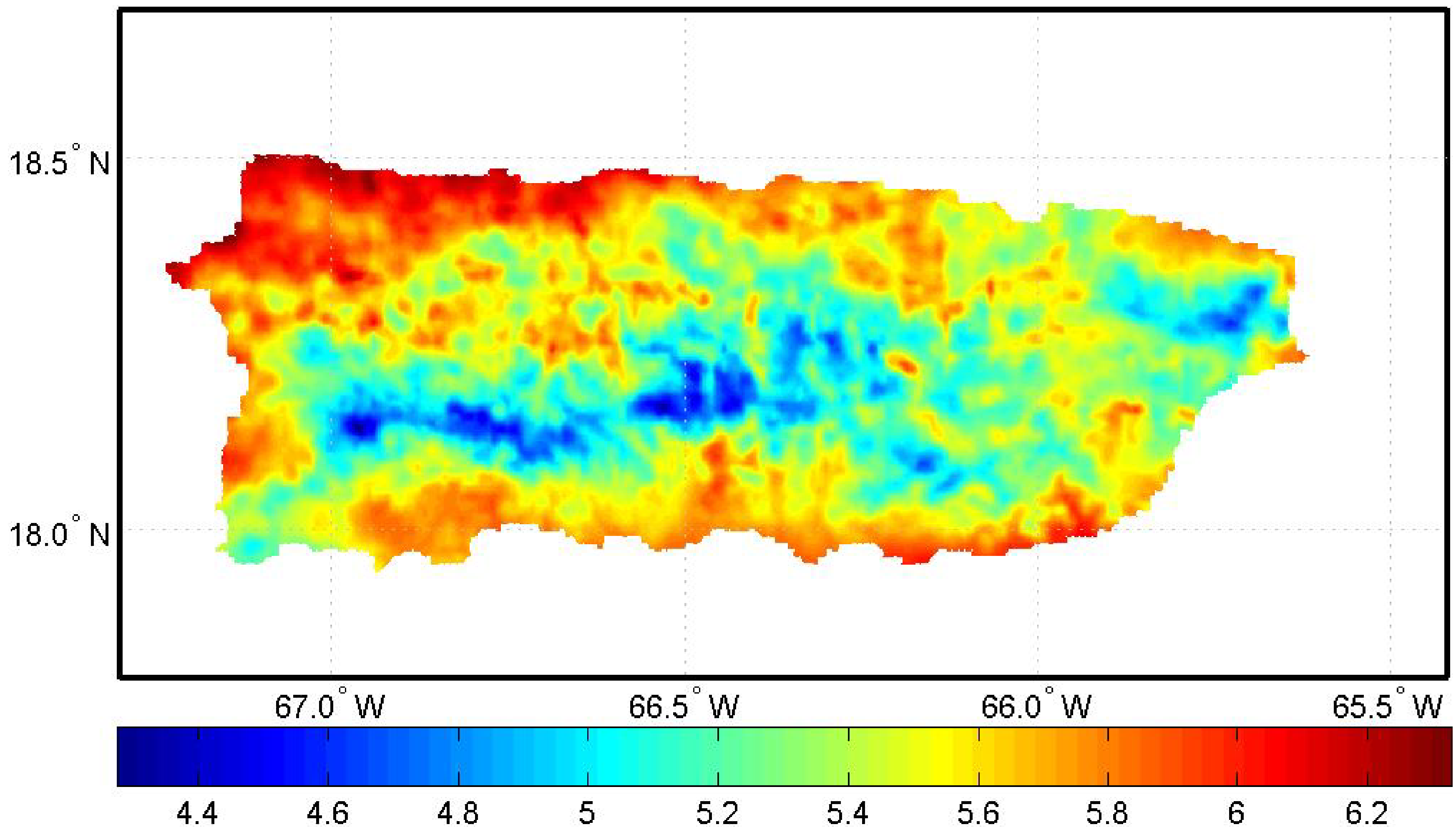
## Root depth



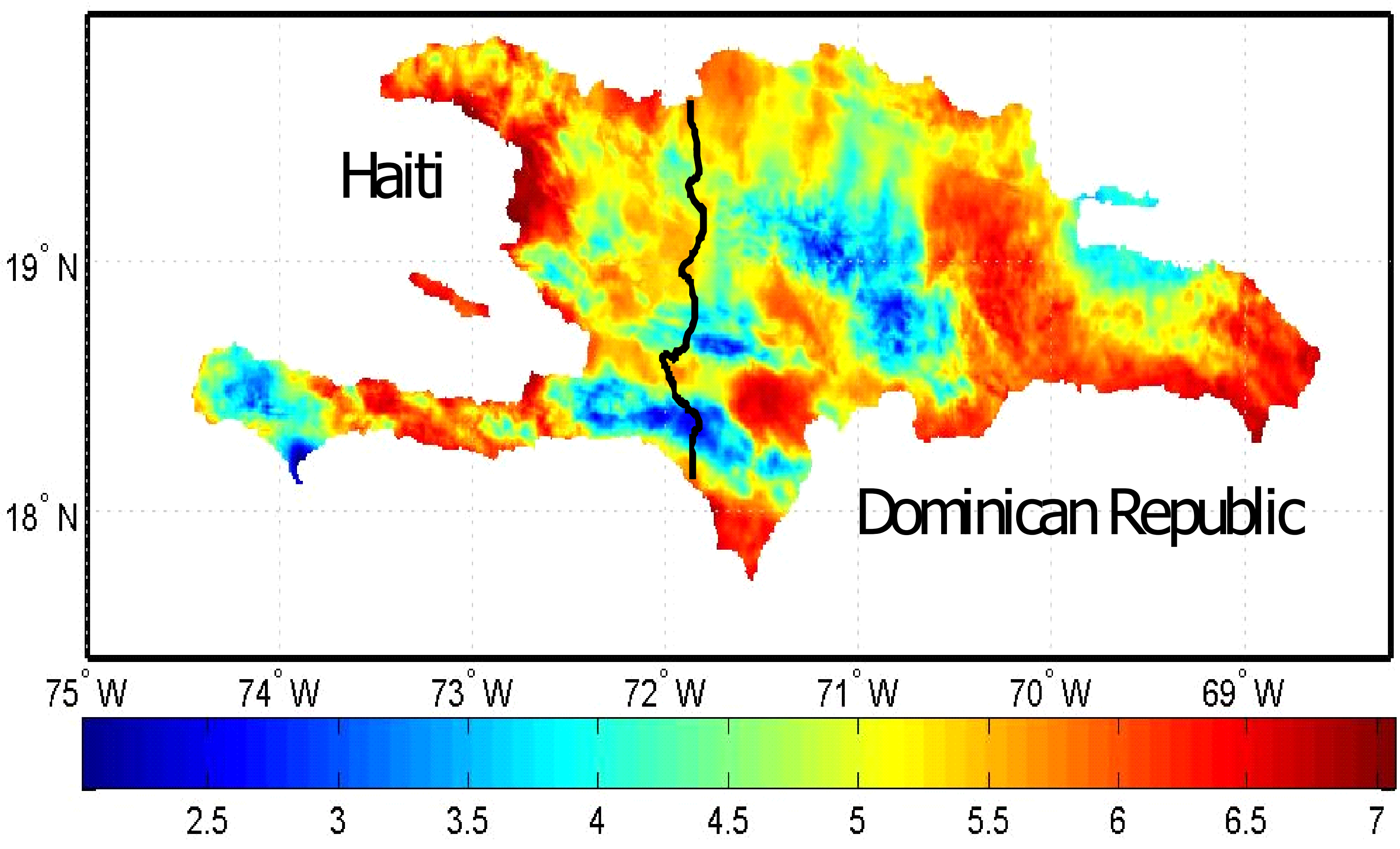

## CN number



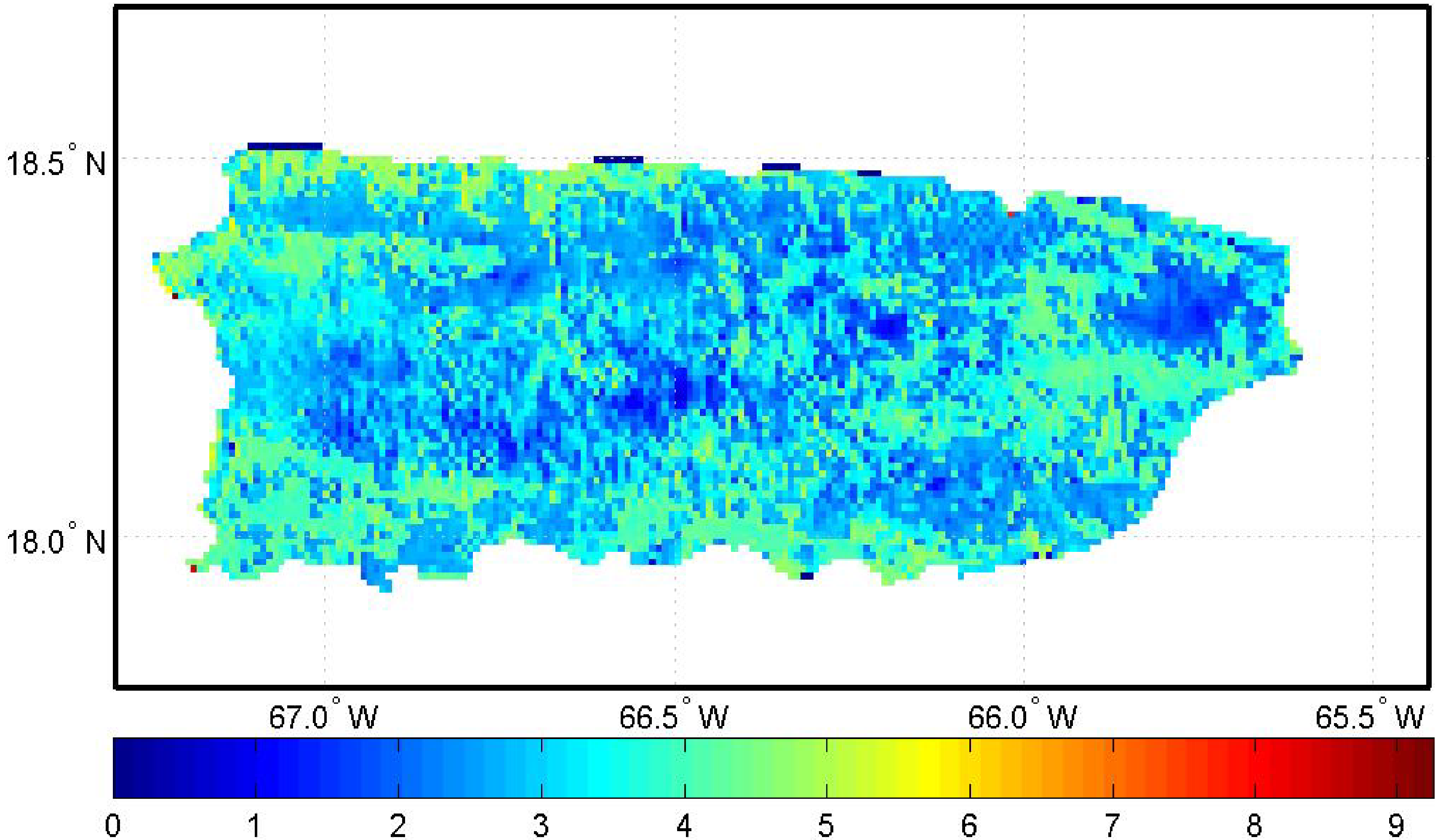
# Estimated reference evapotranspiration ($ET_o$) for Puerto Rico on June 29th, 2010.



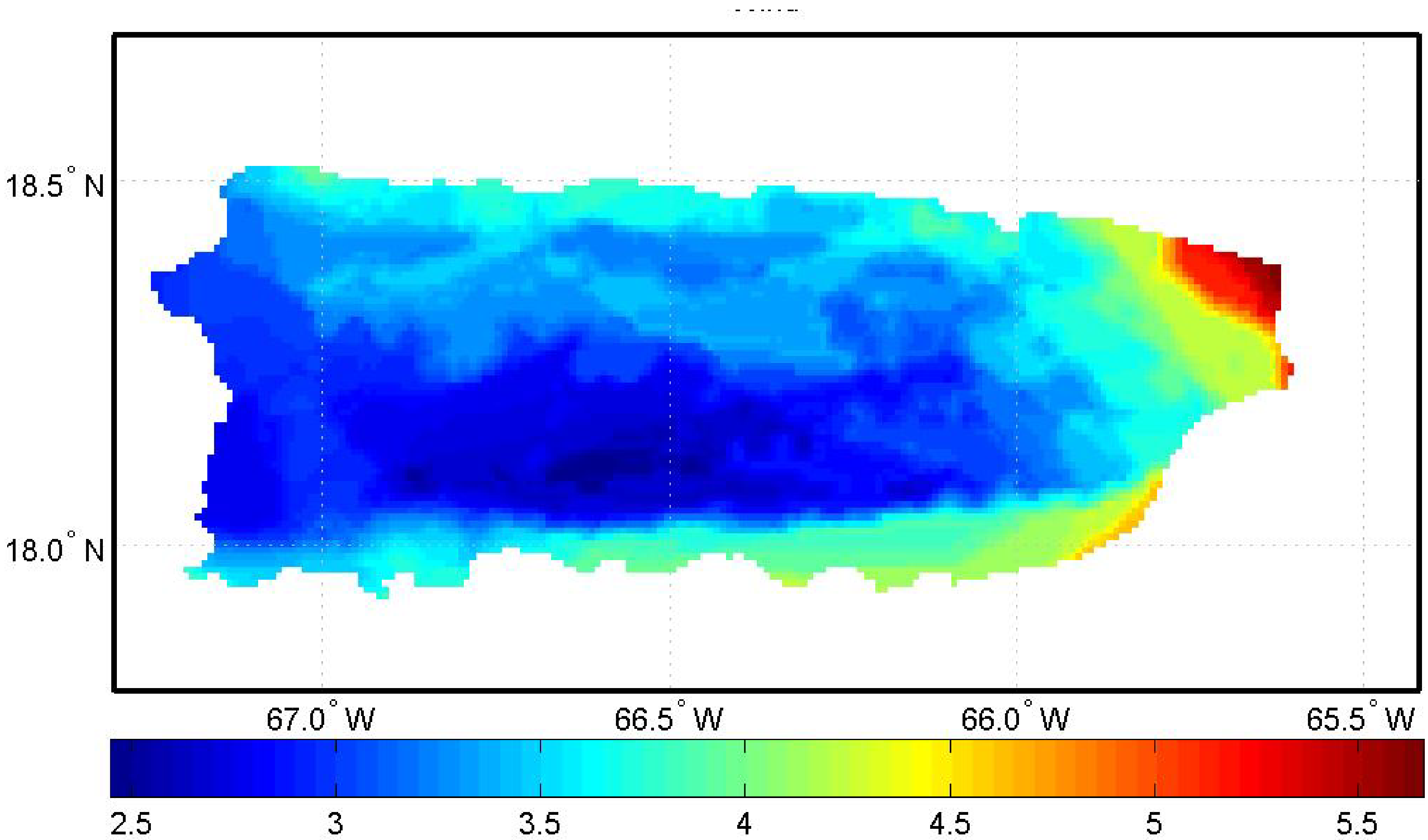
# Estimated reference evapotranspiration ($ET_o$) for Haiti and the Dominican Republic on June 29th, 2010.



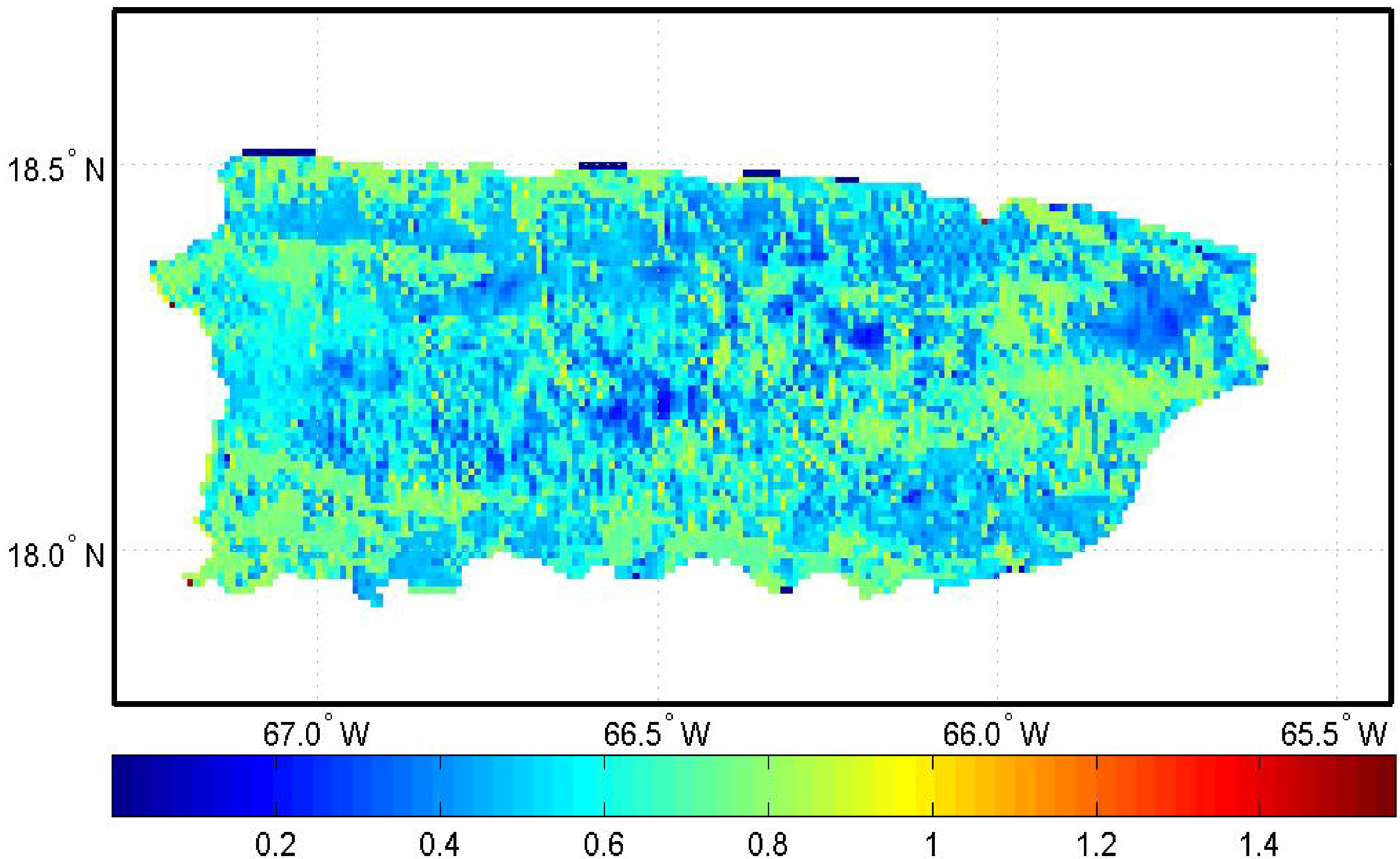
# Estimated actual evapotranspiration ($ET_a$) for Puerto Rico on June 29th, 2010.



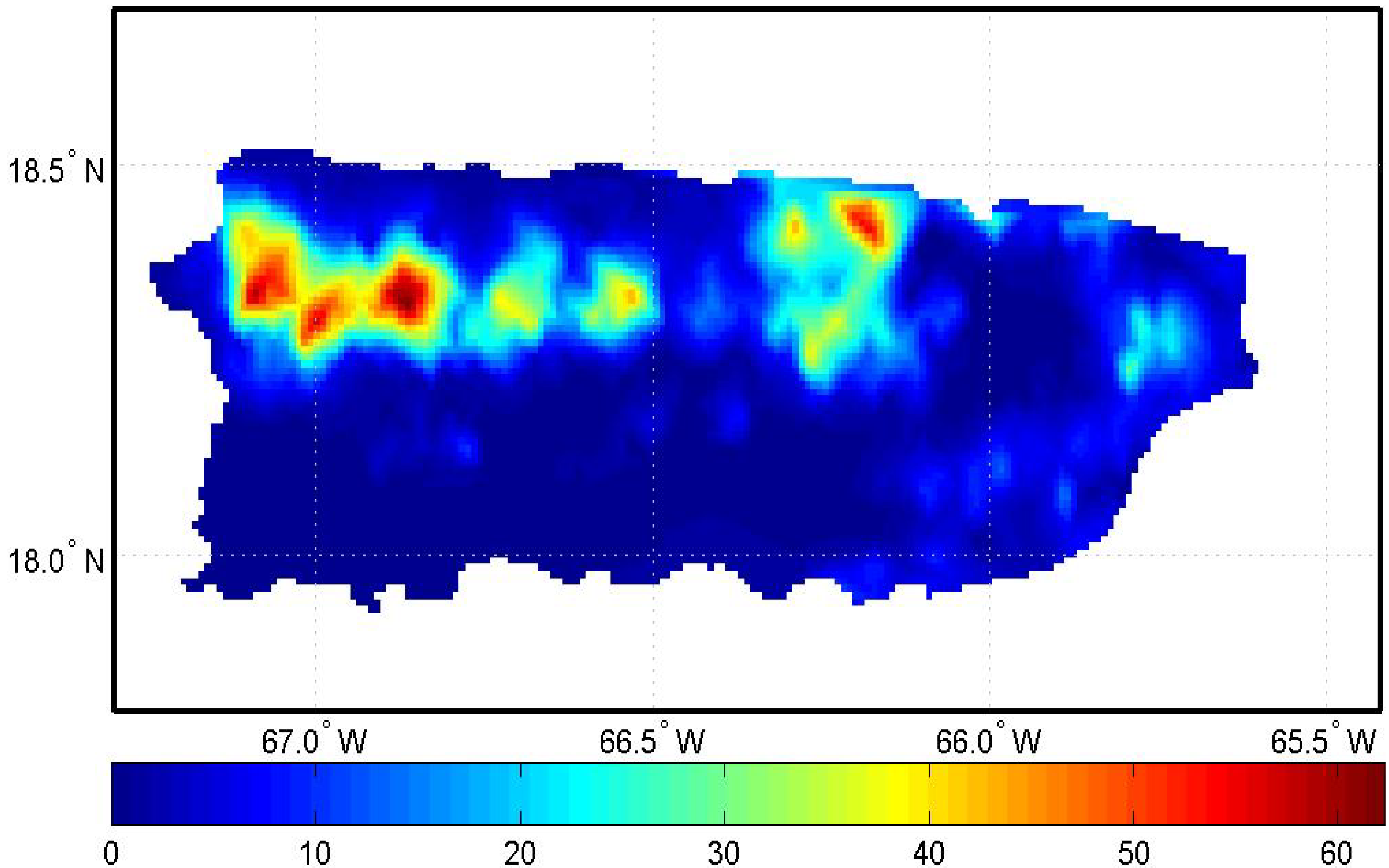
# Wind Speed (m/s)
(National Weather Service's National Digital Forecast Database ).



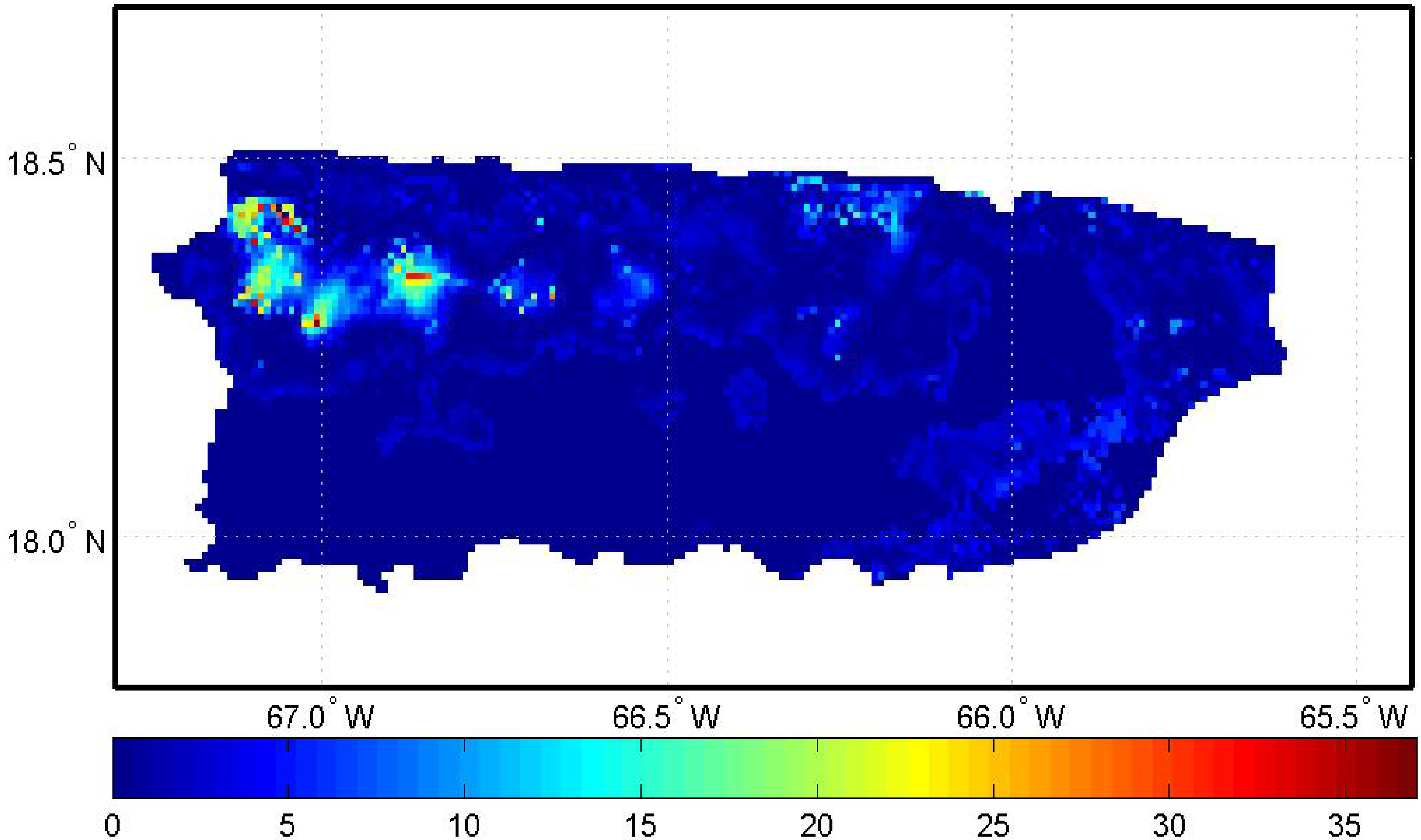
# Estimate "crop" coefficient ($K_c$) over Puerto Rico on June 29, 2010.



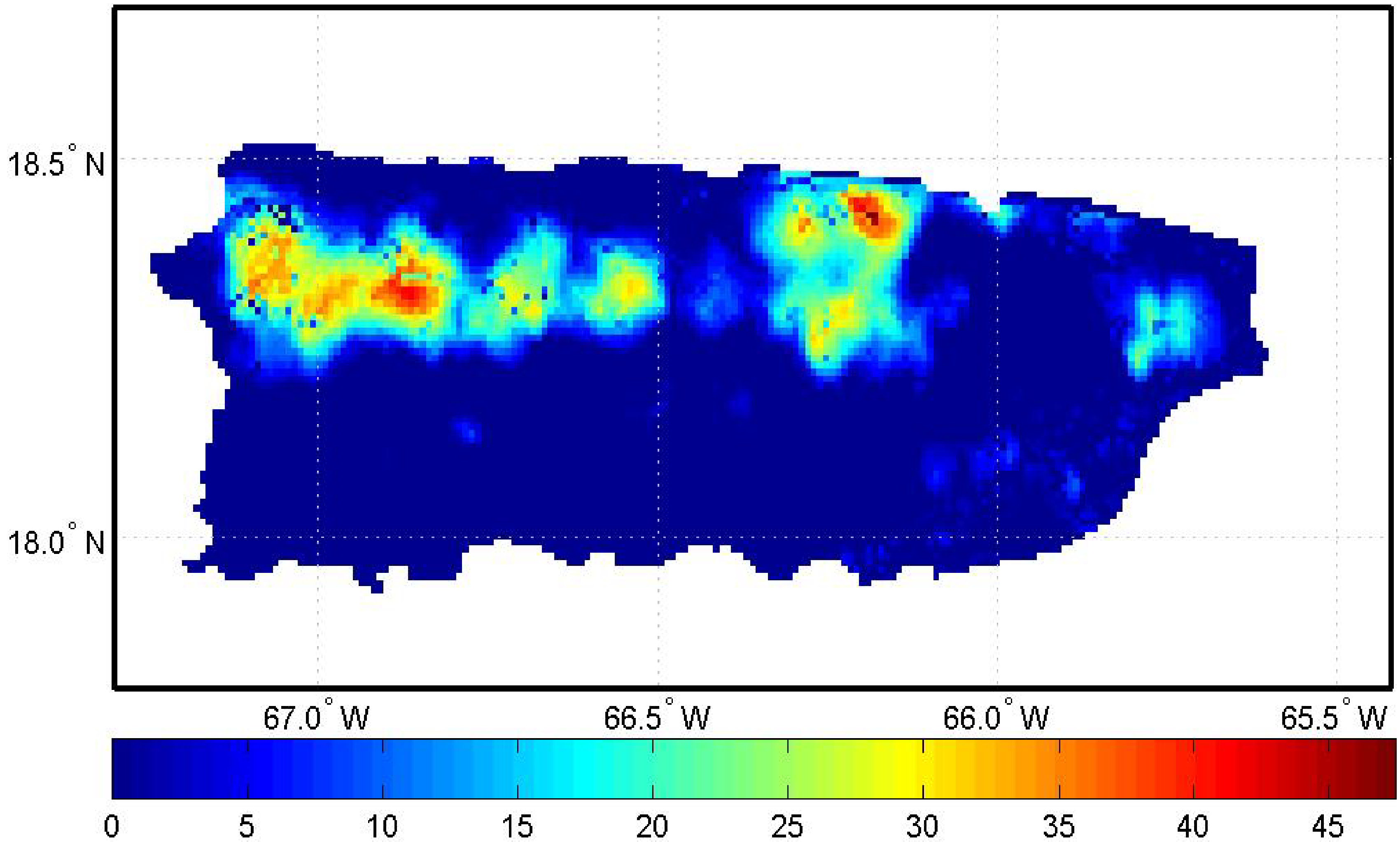
# Rainfall over Puerto Rico on June 29, 2010 (NOAA's Advance Hydrologic Prediction Services).



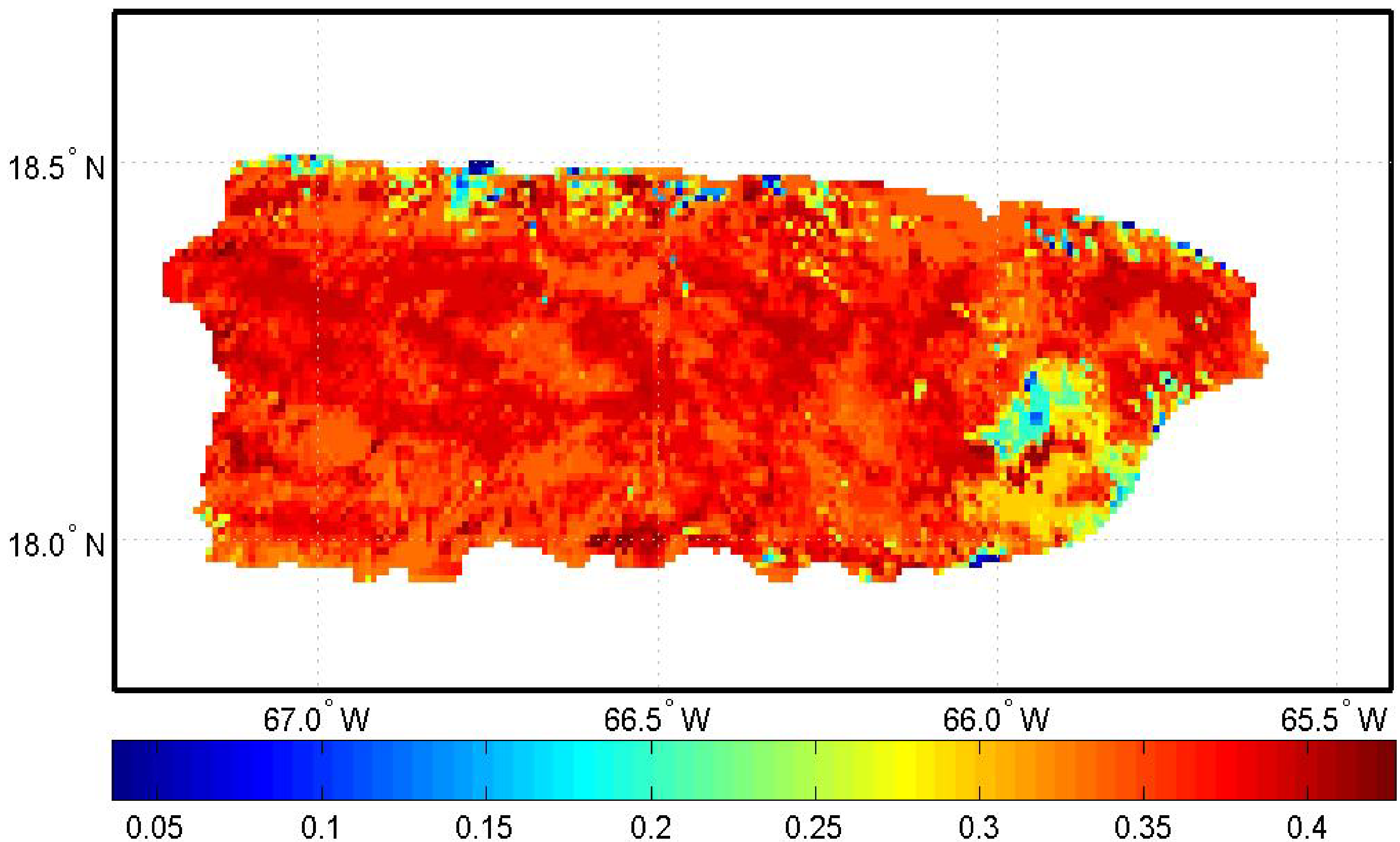
# Estimated surface runoff in Puerto Rico on June 29, 2010.



# Estimated deep percolation on June 29, 2010.



# Estimated soil moisture in Puerto Rico on June 29, 2010.



# Summary and Conclusions

- We describe a method for estimating reference evapotranspiration in Puerto Rico, Haiti and the Dominican Republic.
- Methods for estimating the actual evapotranspiration and the hydrologic water balance over Puerto Rico were also described.
- Estimates of reference evapotranspiration for June 29, 2010, were provided for Puerto Rico, Haiti and the Dominican Republic,
- Estimated actual evapotranspiration, surface runoff, deep percolation and soil moisture content for Puerto Rico for the same day were presented.

# Acknowledgements


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