GOES DATA AND A TRANSFER FUNCTION TO ESTIMATE HOURLY AIR TEMPERATURE FOR PUERTO RICO.

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Introduction

- An air temperature model will be developed to estimate the heat index and the heat waves over the Caribbean.
- The heat index is the combination of air temperature and relative humidity in an attempt to estimate the human perception equivalent temperature.
- Relative humidity reduces the capability of evaporation rate producing lower rate of heat removal from the body and hence the sensation of being overheated.
- The heat wave is the presence of extreme hot events that persists for at least three consecutives days over the same area and causes severe health impacts over the society.

Introduction (cont.)

- In tropical areas the hourly surface air temperature is affected by the interaction with atmospheric and surfaces processes such as solar radiation, elevation, wind, relative humidity, vegetation, soil texture, soil moisture, and cloud and rainfall intervention.
- Moderate-resolution Imaging Spectroradiometer (MODIS) has 36 bands ranging in wavelength from 0.4 μm-14.4 μm, with spatial resolutions.
  - 1-2 bands - 250m
  - 3-7 bands - 500m
  - 8-36 bands - 1000m
- Geostationary Operational Environmental Satellite (GOES) senses electromagnetic energy at five different wavelengths. (0.65 μm to 12 μm)

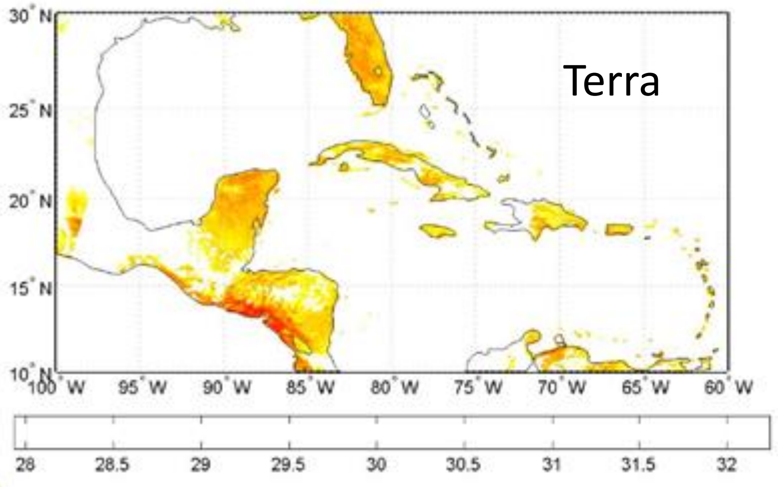
Satellite data

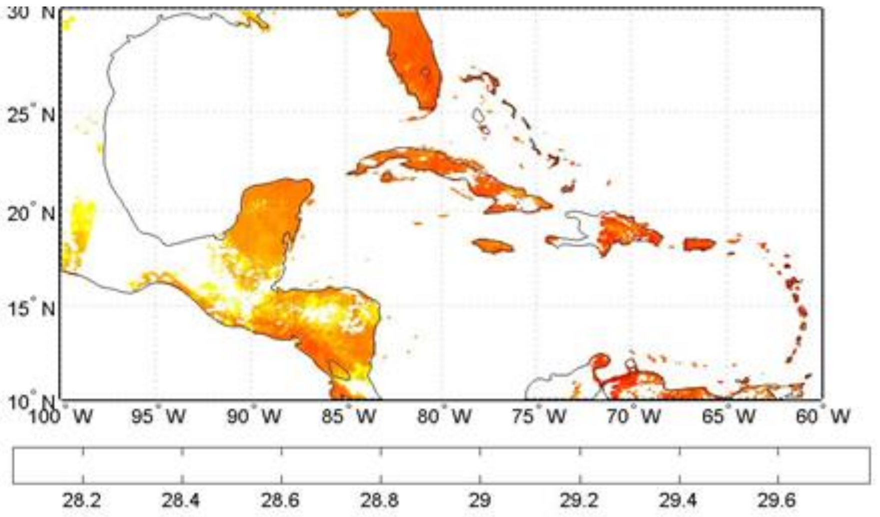
- MODIS provide high spatial resolution of parameters related to air temperature. However, there are only tow observations a day.
- On the other hand, GOES provides information in the visible and infrared channels at every 15 min.
- MODIS products were used to identify which GOES channels are related to air temperature.
  - **<u>MODIS products</u>**:
    - ➢ LST= land surface temperature
    - ➢ Pw= precipitable water
    - ➢ NDVI= Normalized Difference Vegetation Index
  - **<u>GOES channels</u>**
    - ➢ visible (0.65 µm):
      - ▪ Solar radiation, and visible reflectance
    - ➢ near infrared (IR; 3.9 µm)
      - ▪ Albedo
    - ➢ water vapor (WV; 6.7 µm)
    - ➢ thermal IR (10.7 µm)
    - ➢ thermal IR (12 µm)

Land surface temperature

The most relevant parameters from GOES are:

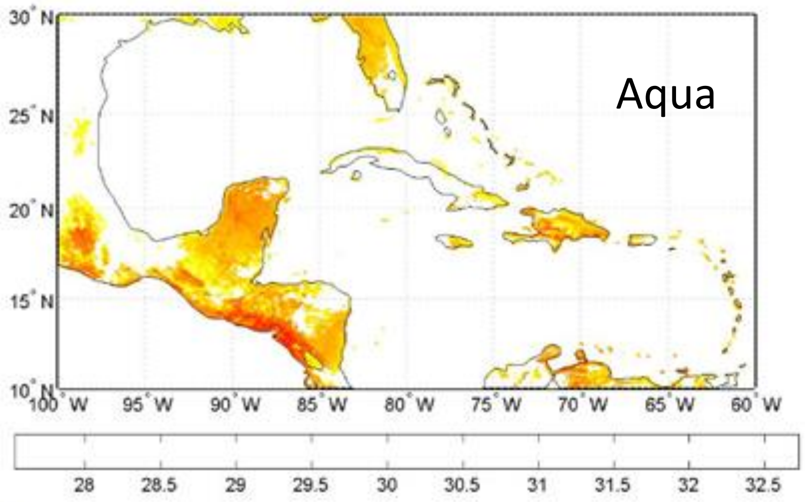
- Solar radiation,
- Visible reflectance
- Albedo 3.9 µm
- Band differences

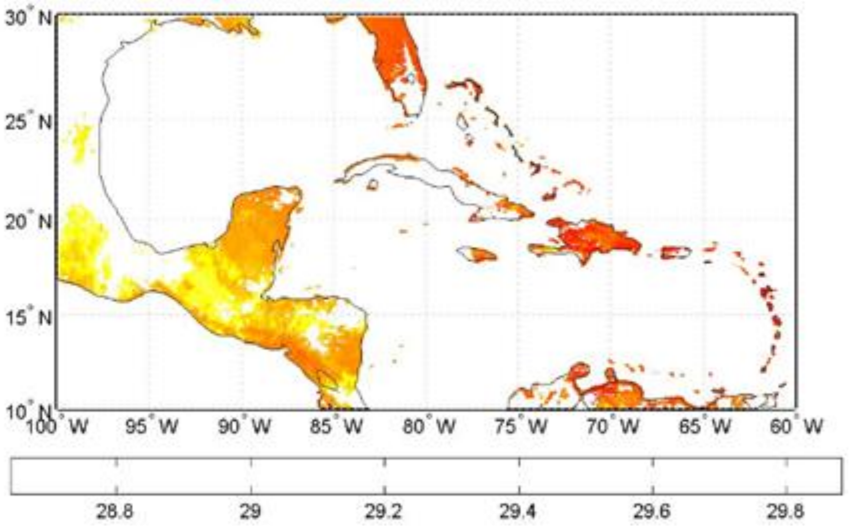




Observed (MODIS)

Estimated (GOES)

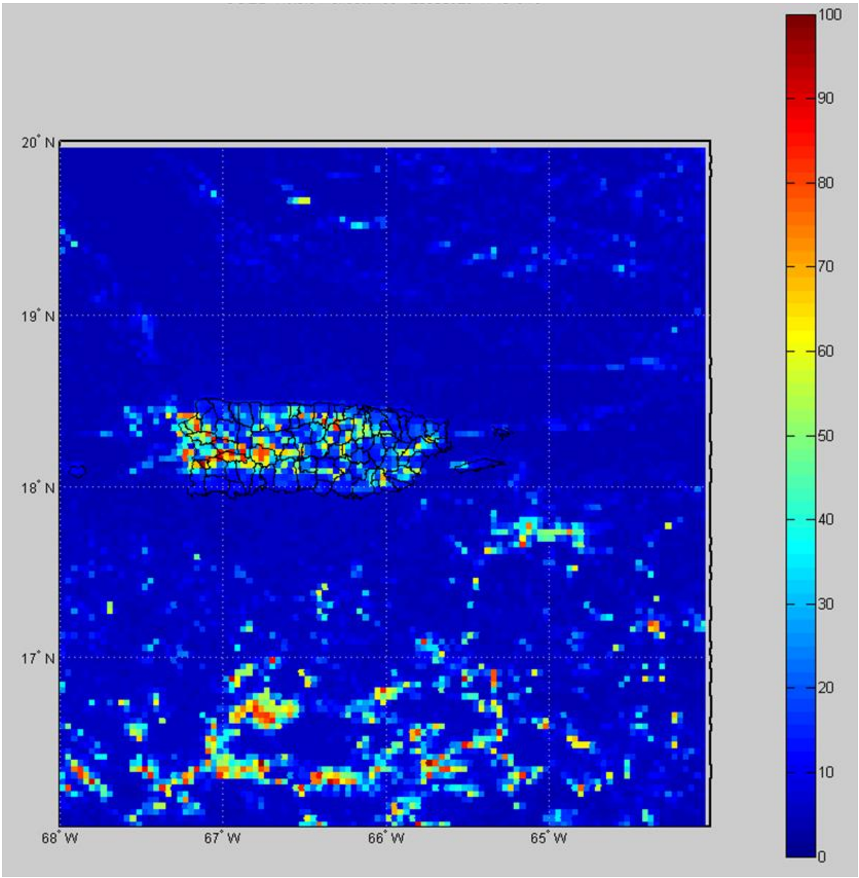




GOES products: Visible reflectance (0.65 µm)

$$V = ak(x - x_s)e^{bt}$$

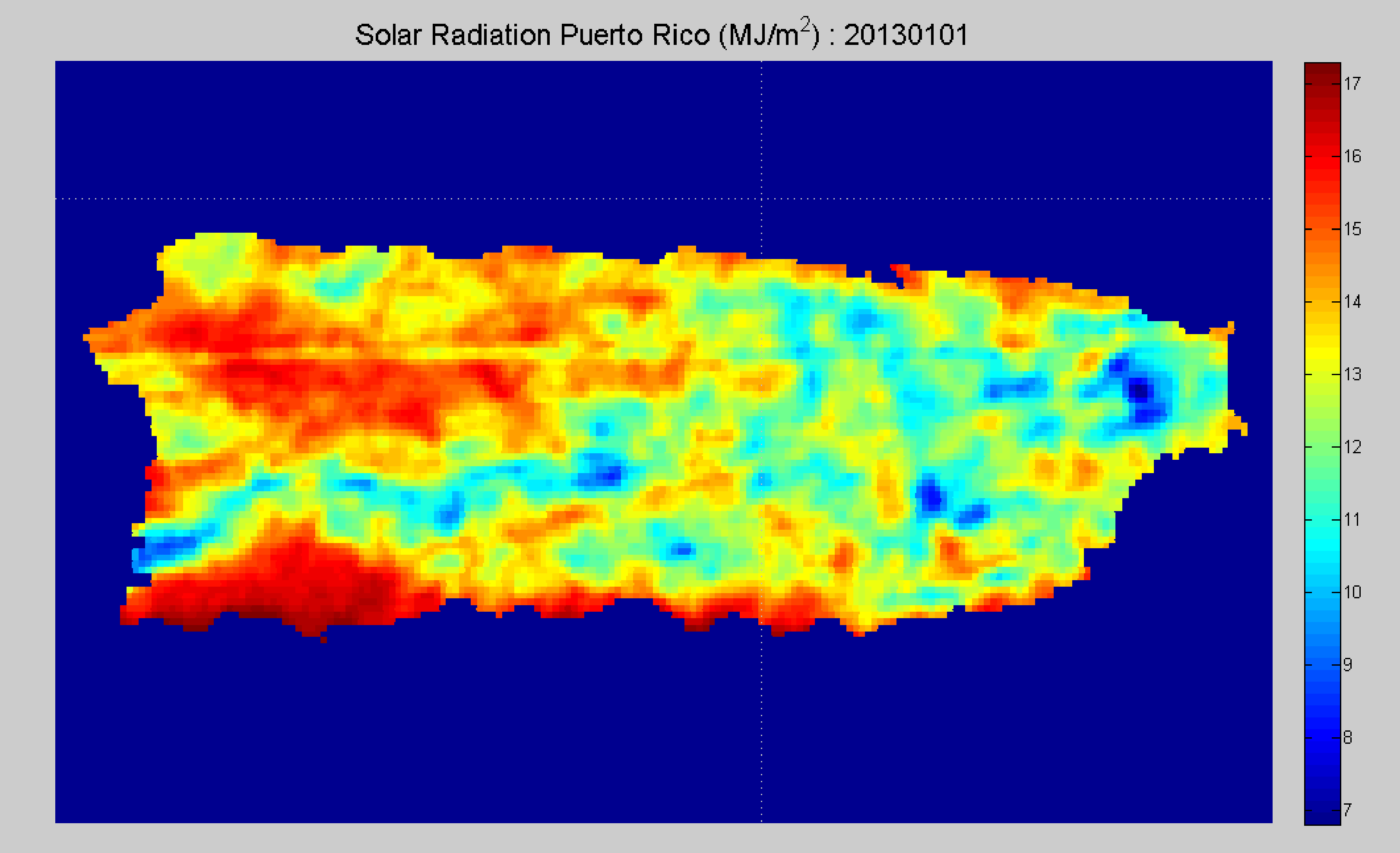
- V is the visible reflectance
- t is the time in years from the date when the satellite was launched, to the date of the image
- a, b, and k are calibration coefficients
- x is the 10-bit count
- x_s is the instrument response to space scene where signal is expected to be zero



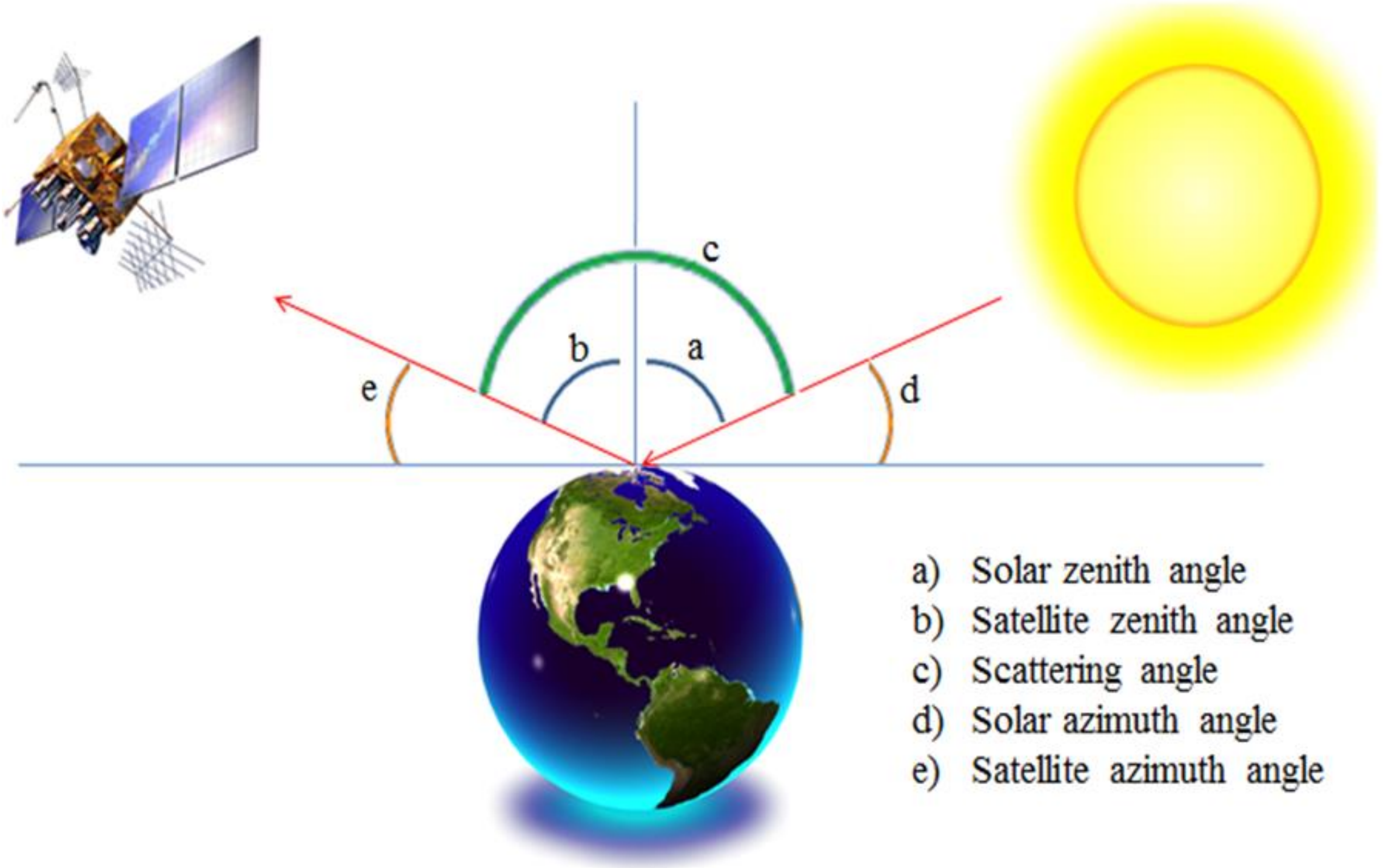
Visible Reflectance
September 29, 2008 – 1745 UTC

Solar Radiation (Insolation) (MJ/m^2)

Date: January 1, 2013



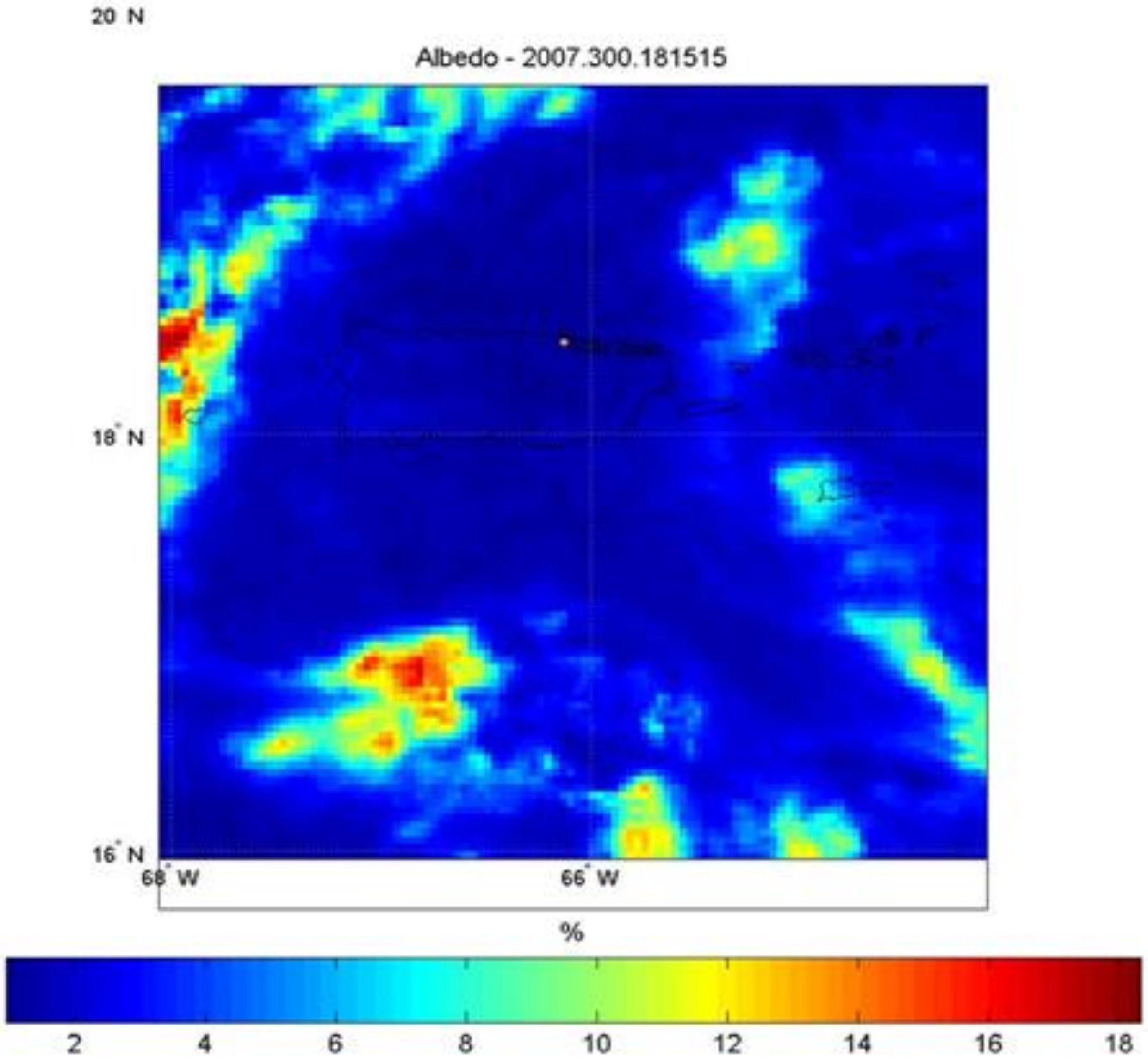
Geometric parameters to retrieve albedo (3.9μm)



Data from GOES Albedo (3.9μ

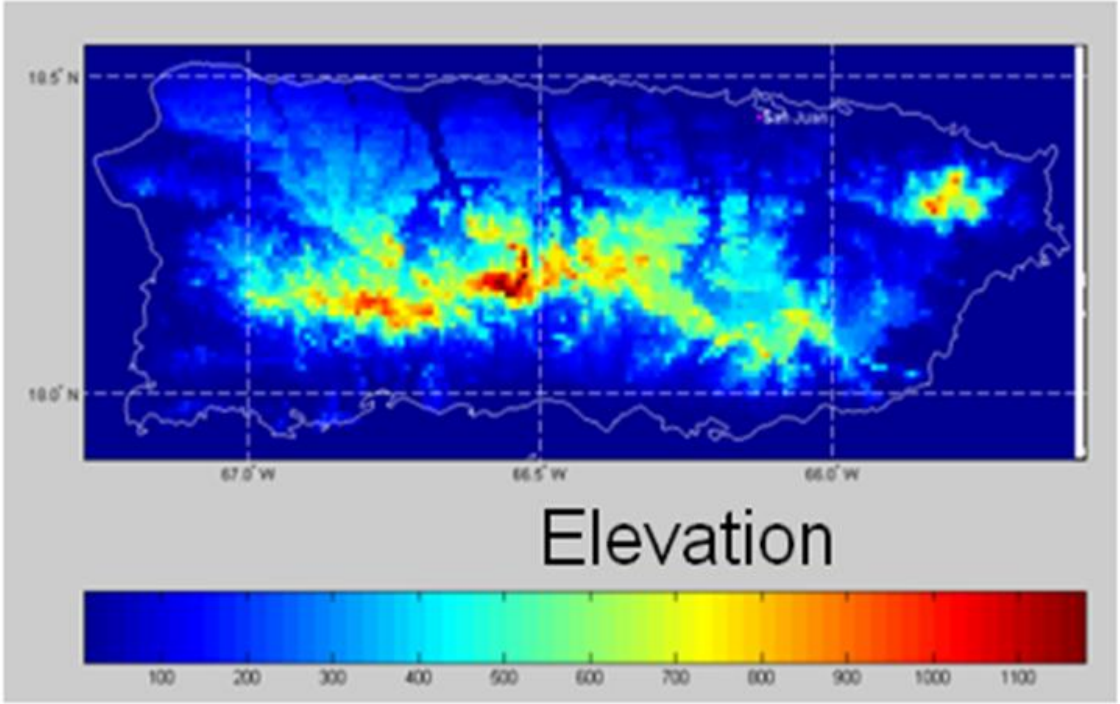
$$A = \frac{R_{3.9} - R_{e,3.9}}{S - R_{e,3.9}}$$

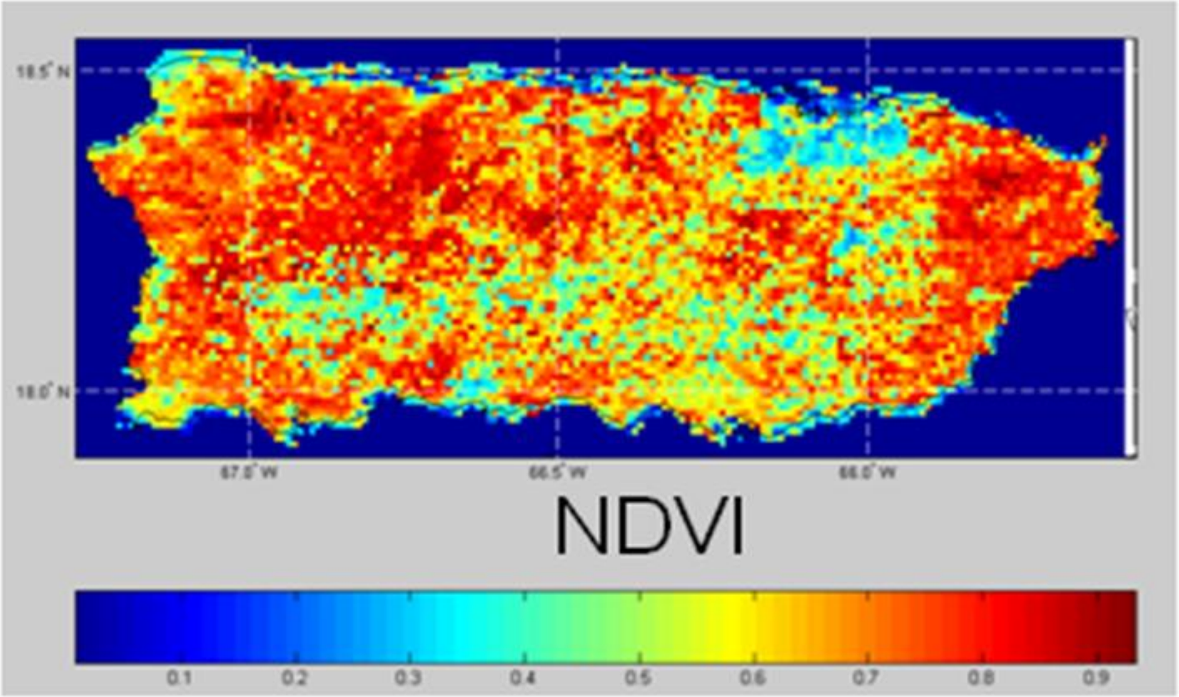
- A is the albedo at 3.9 microns
- $R_{3.9}$ is the observed radiance from band 2
- S is the solar irradiance of GOES band 2
- $R_{e,3.9}$ is the equivalent black body emitted thermal radiation at 3.9 microns for cloud at temperature T



Albedo from
October 27, 2008 (18:35 UTC)

Surface information





From MODIS

Air temperature

- The air temperature has three major components
  - Trend (time, and surface characteristics)
  - Seasonal component (solar radiation effect)
  - Stochastic component (cloud intervention)

Periodic Identification
Using Discrete Fast Fourier Transform

$$w(k) = \sum_{t=1}^{n} T_t e^{2\pi i(t-1)(k-1)/n}$$

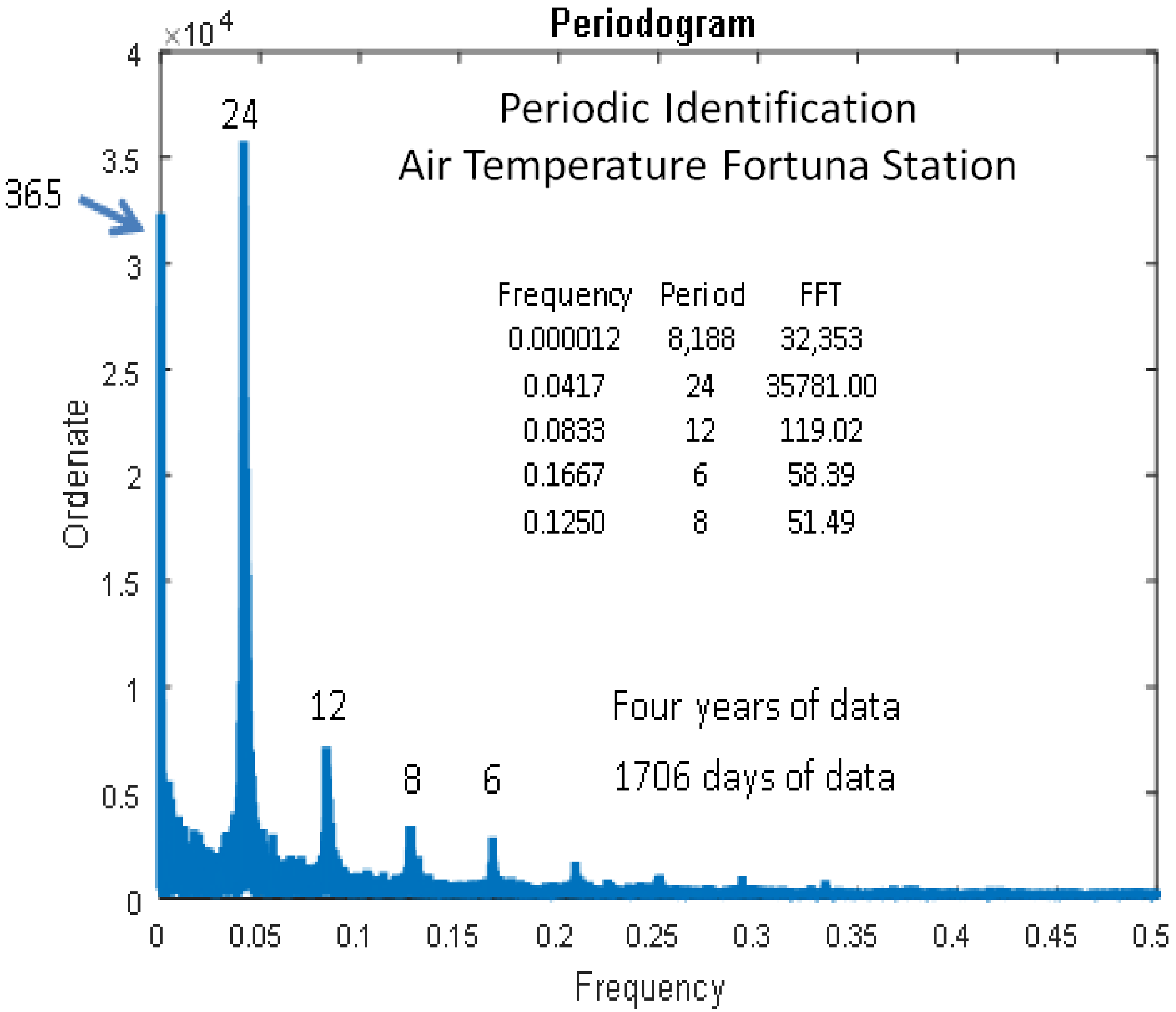
$$k = 1, \ldots, n$$

T_t= observed air temperature at time t

$w(k)$ = ordinate = FFT

$$\frac{k-1}{n} = frequency$$

$$Period = \frac{1}{frequency}$$



Cloud intervention will be modeled with A Stochastic Transfer Function Model

$$Z_t = v_1(B)B^{d_1}X_{1,t} + v_2(B)B^{d_2}X_{2,t} + \cdots + v_J(B)B^{d_J}X_{J,t} + \varepsilon_t$$

Noise
ARMA Model

Response

$$v_j(B) = \frac{\omega_j(B)}{\delta_j(B)}B^{d_1} = \left(\frac{\omega_{j,0} + \omega_{j,1}B + \omega_{j,2}B^2 + \cdots + \omega_{j,s}B^s}{1 - \delta_{j,1}B - \delta_{j,2}B^2 - \cdots - \delta_{j,r}B^r}\right)B^{d_1}, \qquad j = 1,2,\ldots,J$$

Impulse response function

Memory

delay

$$v_t = \left(\frac{\omega_0 + \omega_1 B}{1 - \delta B}\right)B^d X_t = (\omega_0 + \omega B)(1 + \delta B + \delta^2 B^2 + \delta^3 B^3 \cdots)B^d X_t$$

Air temperature model

GOES

Trend and surface characteristics

Seasonal component from solar irradiance

$$T_{k,t}(i,j) = b_{0,k} + b_{1,k}t + b_{2,k}z(i,j) + b_{3,k}La(i,j) + b_{4,k}Lo(i,j)$$

$$+ \sum_{l=1}^{4} \bar{A}_d \left[\alpha_{l,k} sin\left(\frac{2\pi t}{\rho_l} + \phi_d\right) + \beta_{l,k} cos\left(\frac{2\pi t}{\rho_l} + \phi_d\right)\right]$$

GOES

$$+ \bar{A}_y \left[\alpha_{5,k} sin\left(\frac{2\pi t}{\rho_5} + \phi_y\right) + \beta_{5,k} cos\left(\frac{2\pi t}{\rho_5} + \phi_y\right)\right] + b_{5,k}T_{2,t}(i,j) + b_{6,k}T_{3,t}(i,j) +$$

GOES

Cloud intervention

$$\left(\frac{\omega_{0,k} - \omega_{1,k}B}{1 - \delta_{1,k}B}\right) T_{4,,k,t}(i,j) e^{-g_t(i,j)} + b_{9,k}T_{4-3,k,t}(i,j) + b_{10,k}T_{2-6,k,t}(i,j) + \left(\frac{1 + \theta B}{1 - \phi B}\right) a_t(i,j)$$

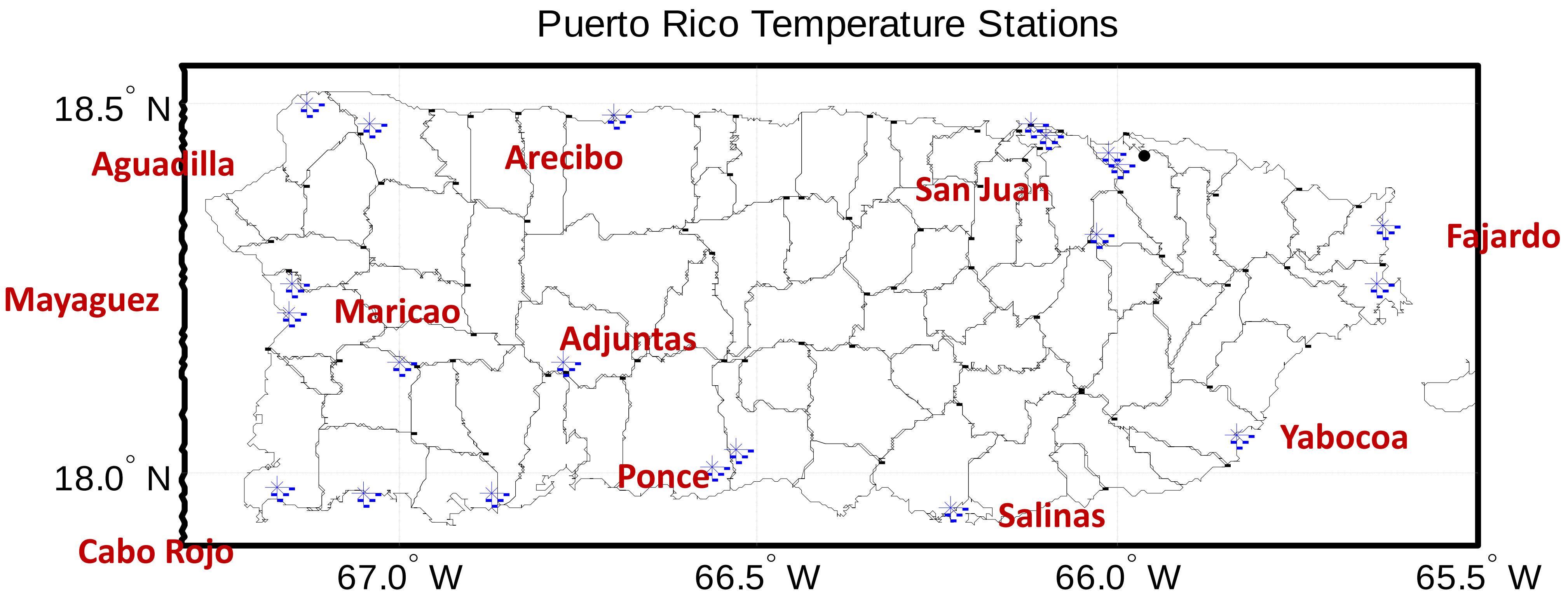
where

$$g_t(i,j) = \begin{cases} 0, & \text{if } s_t \leq 660\ °\text{K} \\ \tau_t, & \text{if } s_t > 660\ °\text{K} \end{cases} \qquad \tau_t = -10 + \frac{1}{60} \sum_{s=t-2}^{t} T_{4,s}(i,j)\, e^{-g_s(i,j)} \qquad s_t = \sum_{i=t-2}^{t} T_{4,i}$$

$$\rho_l = 6, 8, 12, 24 \qquad \rho_5 = 365 \times 24$$

Puerto Rico Stations Location

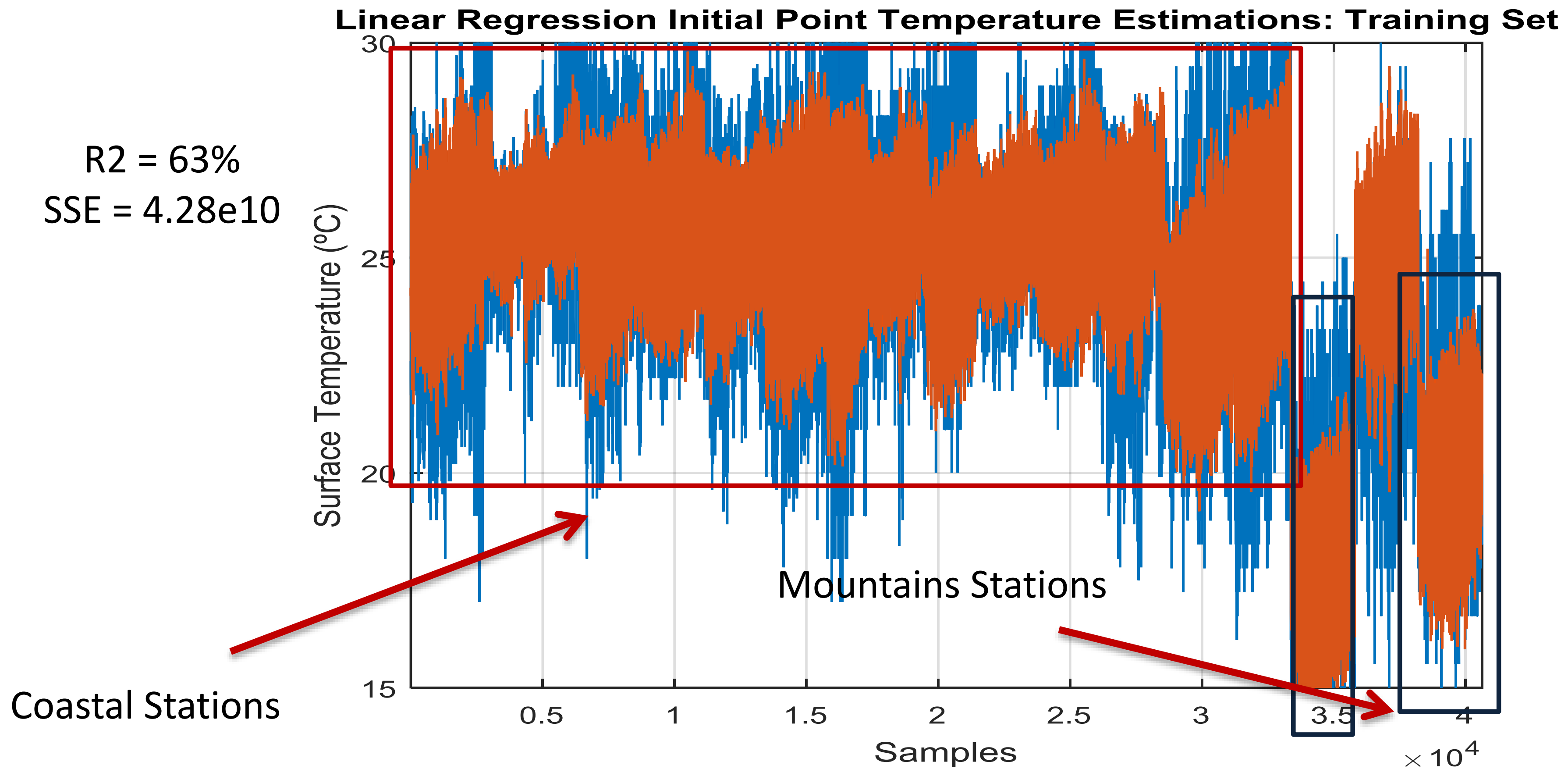
- 21 stations were selected to train and validate the Time Series Model.



Training Set: Initial estimates

R2 = 63%

SSE = 4.28e10



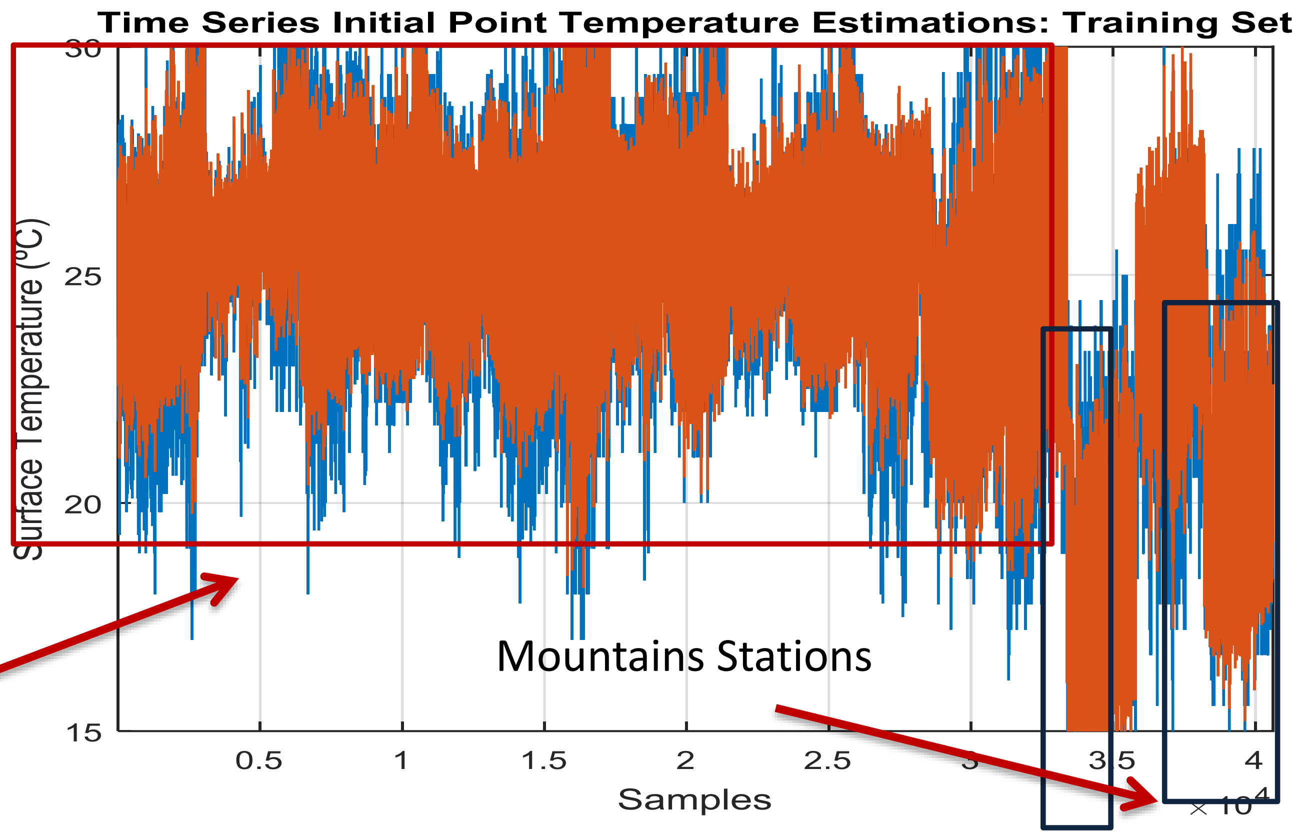
Blue: Observed

Orange: Estimated

Training Sample 121 days per station

Training Set: Optimal Solution

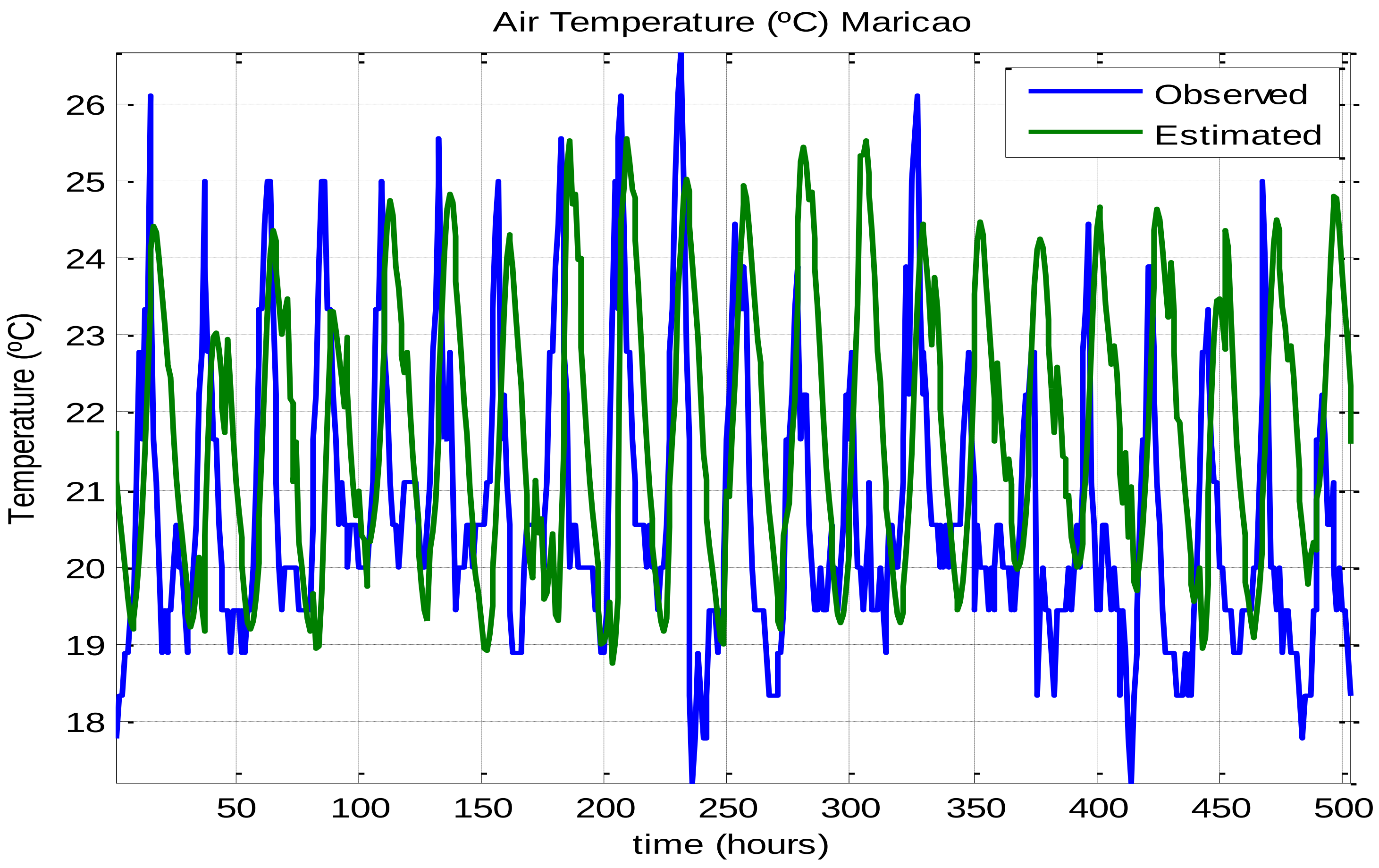
R2 = 93%
SSE = 2.40e4

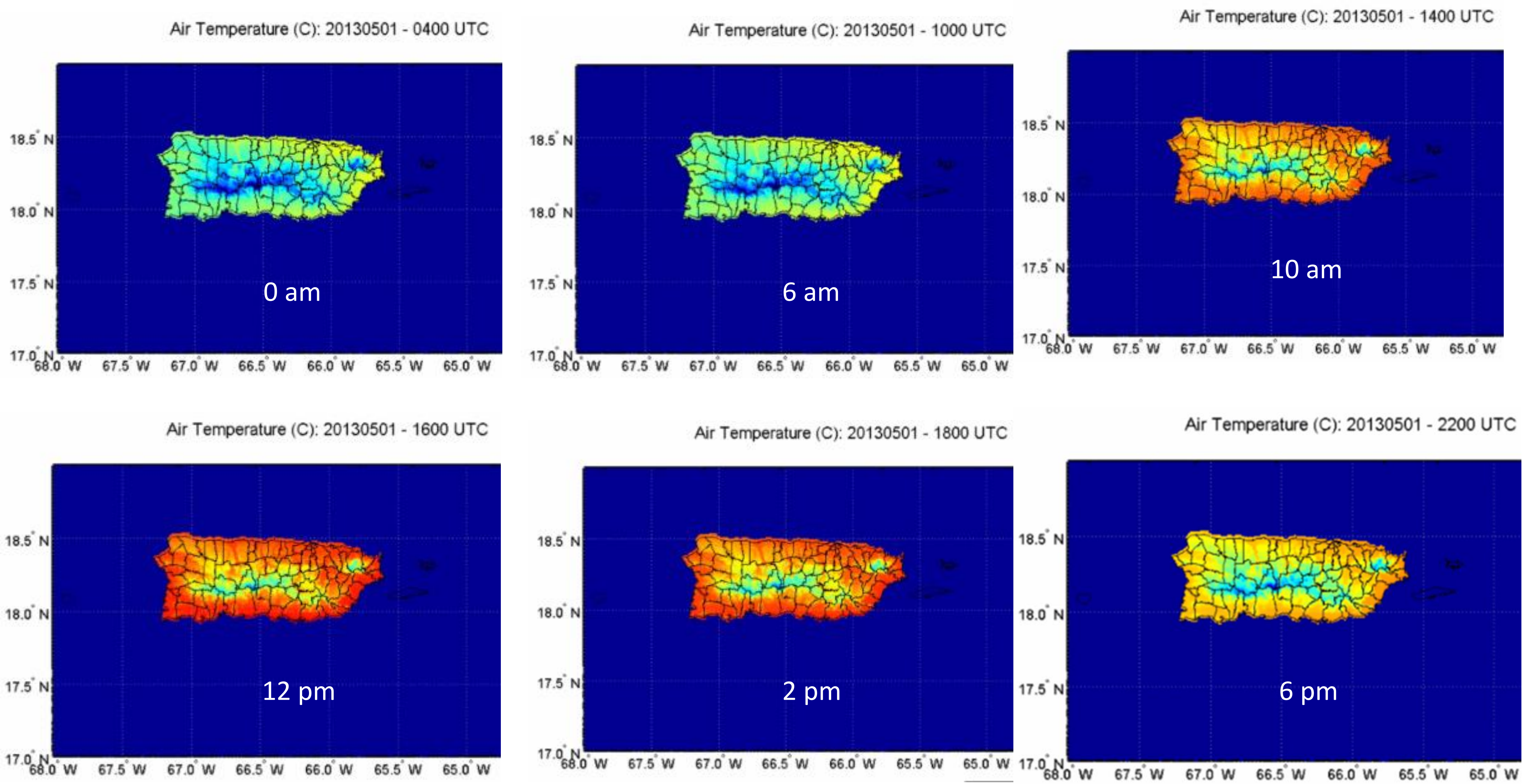


Coastal Stations

- Optimal Solution during 121 days for 21 weather stations: Improve estimation of maximum and minimum temperatures. Errors are less than initialization model.

Validation Set: Maricao, Puerto Rico (Mountain Station)




Air Temperature (C): 20130501 - 0400 UTC
0 am
Air Temperature (C): 20130501 - 1000 UTC
6 am
Air Temperature (C): 20130501 - 1400 UTC
10 am
Air Temperature (C): 20130501 - 1600 UTC
12 pm
Air Temperature (C): 20130501 - 1800 UTC
2 pm
Air Temperature (C): 20130501 - 2200 UTC
6 pm
18.5° N
18.0° N
17.5° N
17.0° N
68.0° W
67.5° W
67.0° W
66.5° W
66.0° W
65.5° W
65.0° W

Conclusion

- We have shown that the proposed algorithm is feasibility.
- The model has been trained with the minimum input variables and the minimum of time series length.
  - Training set: from January to April 2013
  - Tested set: the first week of May 2013
- Some variables are not included yet, such as: NDVI, solar radiation, visible reflectance, soil texture, soil moisture.
- It is expected to train the model with 3 to five years of data
- The model will be implemented for the Caribbean basin.

Acknowledges

- This work has been supported by the NSF with grant CBET-148324 and the UPRM.