A Satellite Algorithm to Retrieve Rainfall Rate for the Caribbean Basin

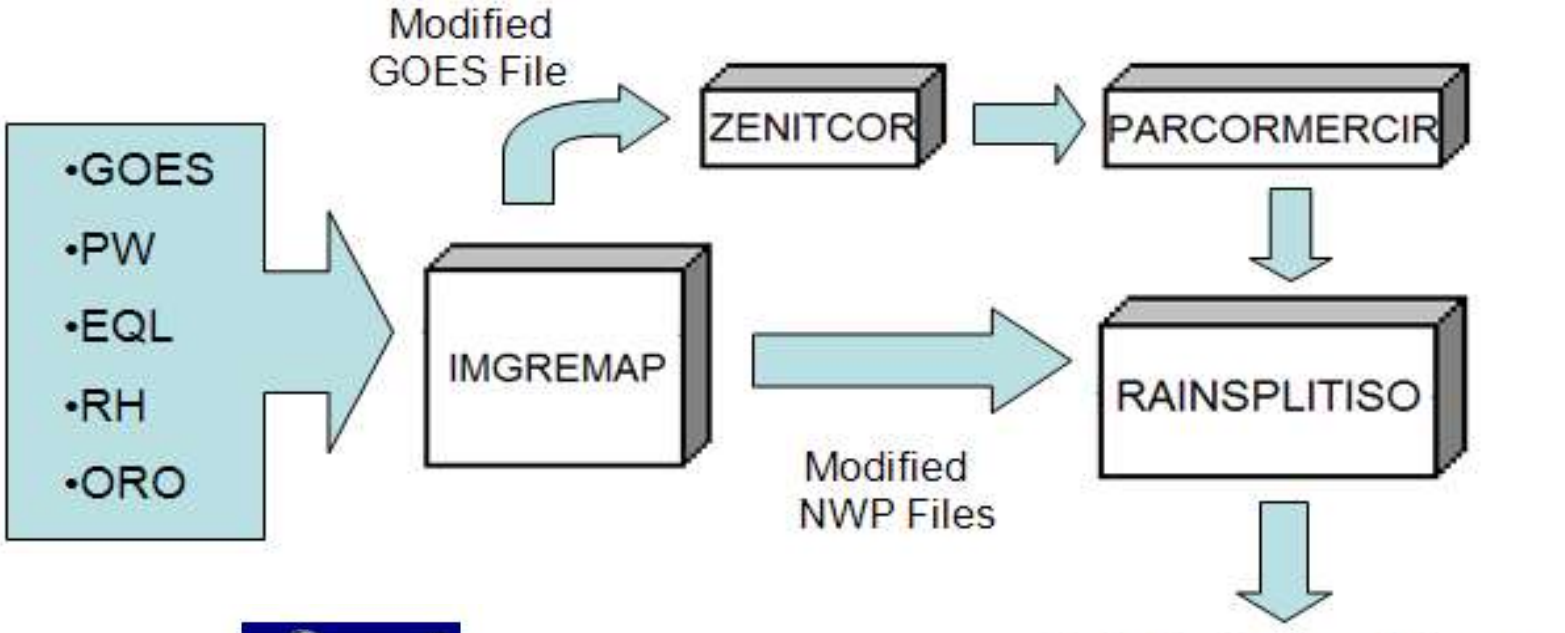
Nazario D. Ramirez, Robert J. Kuligowski, and Joan M. Castro

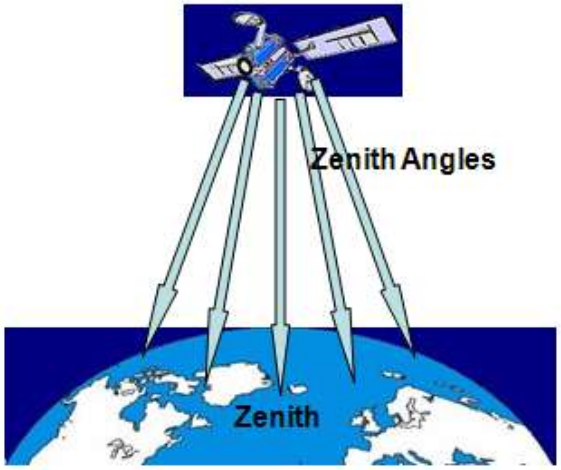
Novena Reunión Nacional de Percepción Remota y Sistemas Geográficos de Información (PRYSIG).
Mayaguez, PR, Dec 2 2011

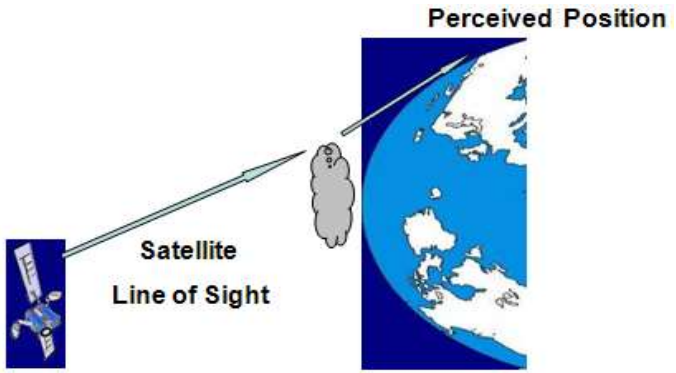
Motivation

- Estimation of rainfall amounts is critical for protecting human lives and infrastructure, particularly in the case of heavy rainfall that triggers flash floods or landslides.
- The physical principle to estimate rainfall
  - Cold clouds are typically associated with large rainfall rate
  - Warm clouds with small rainfall or no rainfall
- Satellite rainfall retrieval algorithms have been developed to retrieve rainfall rate from cold clouds.
  - GMSRA (4 GOES channels)
  - SCaMPR (microwave and thermal channel from GOES)
  - PERSIANN (rain gauge, radar, and satellite data, and ANN)
  - Hydro-Estimator
    - http://www.star.nesdis.noaa.gov/smcd/emb/ff/HydroNowcaster.php
- Problem: Those algorithms have been calibrated with could clouds..

Hydro- Estimator algorithm

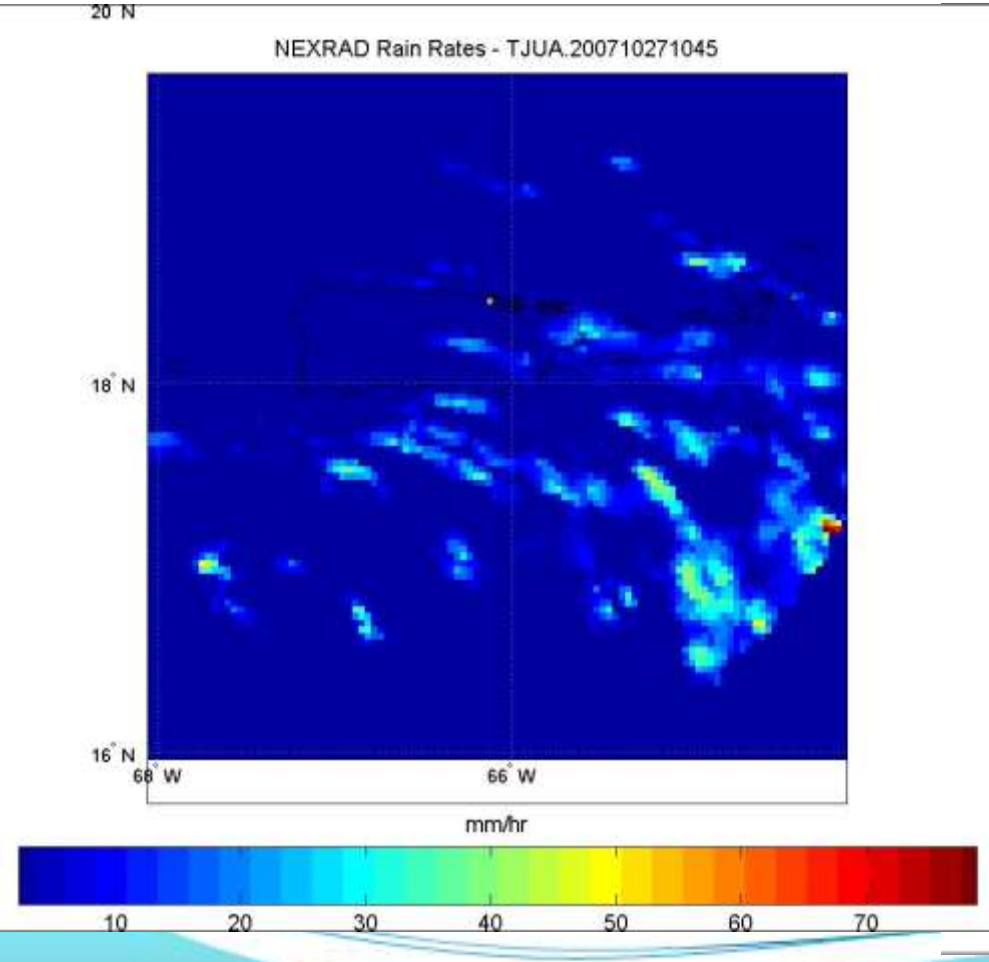


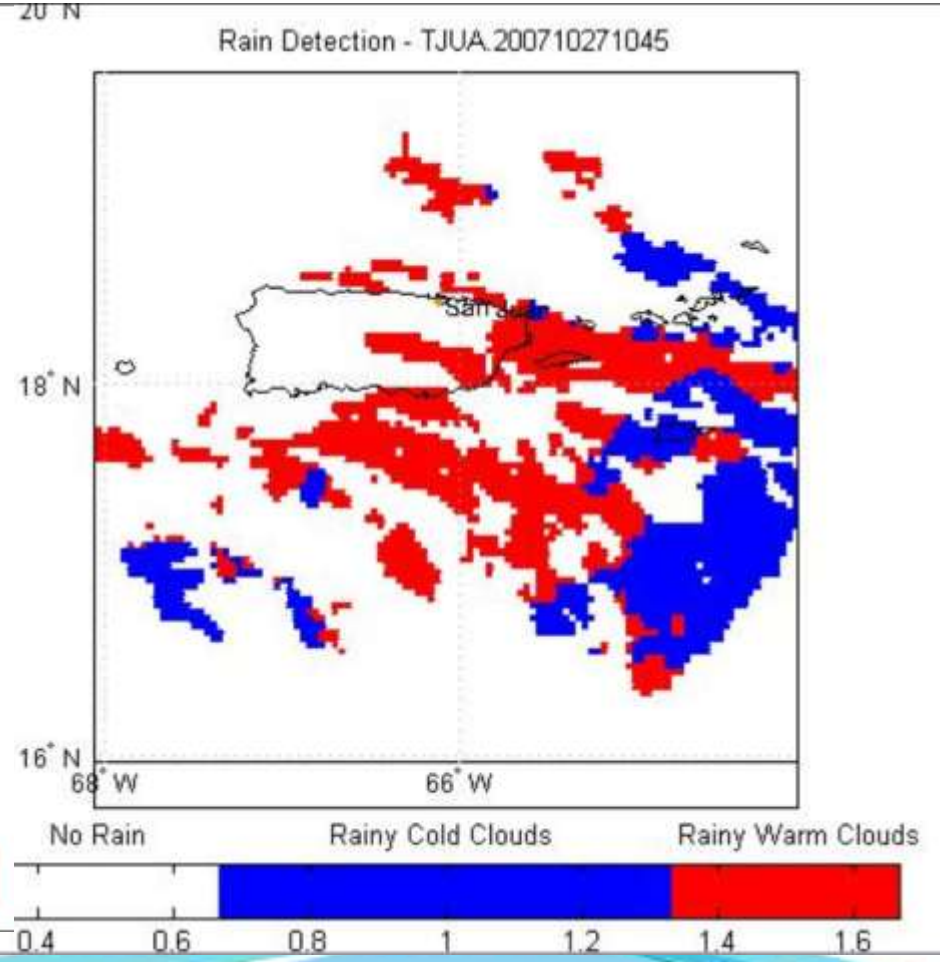




The Hydro-Estimator was implemented in Puerto Rico.

Problem: In Puerto Rico there are a considerable warm rainy clouds that are not detected by the Hydro Estimator.





General Description

- We proposed a new rainfall rate retrieval algorithm that takes into account the estimation of rainfall rate over warm and cold clouds.

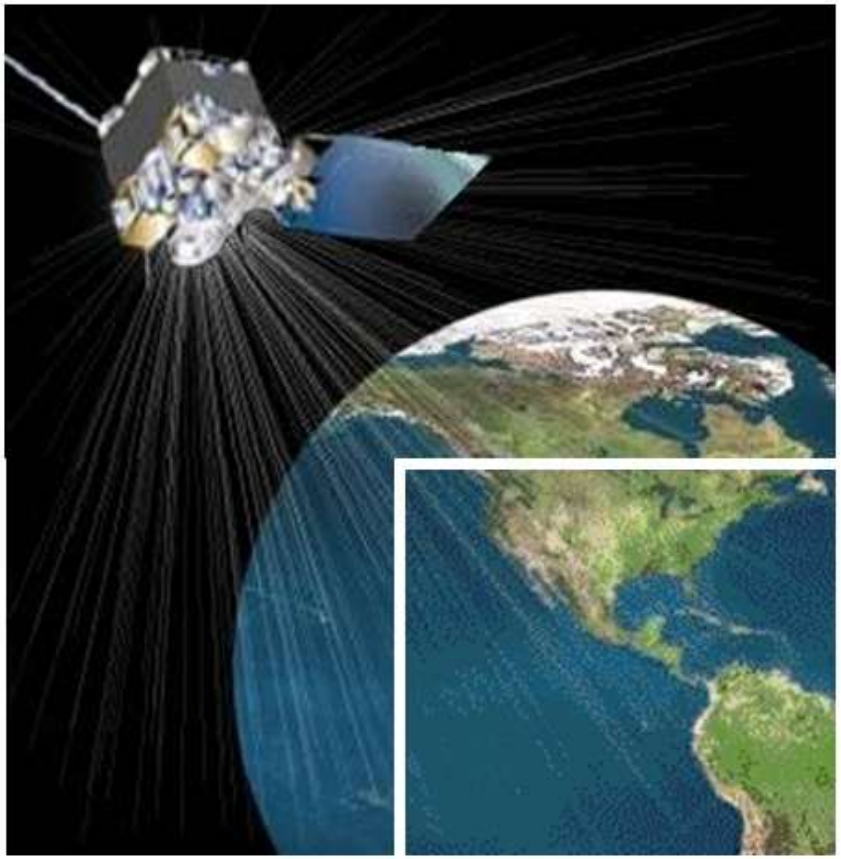
- The developed algorithm has two major components:

  – A rainy cloud pixels detection

  – Estimation the amount of rainfall rate.

Satellite data

- Four bands of the GOES imager were used:
  - Channel 1: visible (0.65 μm),
  - Channel 2: near infrared (3.9 μm),
  - Channel 3: water vapor (6.7 μm),
  - Channel 4: thermal IR (10.7 μm).
- Brightness temperature
- Visible reflectance
- Albedo of Channel 2



Albedo (3.9μm)

- It has been shown that the reflection function at a water (or ice) absorbing channel in the near-infrared is primarily a function of cloud particle size
- Albedo is defined by:

$$\alpha = \frac{R_{3.9} - R_{e3.9}}{S - R_{e3.9}},$$

  - where:
    - α is the albedo at 3.9 microns
    - $R_{3.9}$ is the observed radiance from band 2
    - $R_{e3.9}$ is the equivalent black body emitted thermal radiation at 3.9 microns for cloud at temperature T
    - S is the solar irradiance of GOES 12

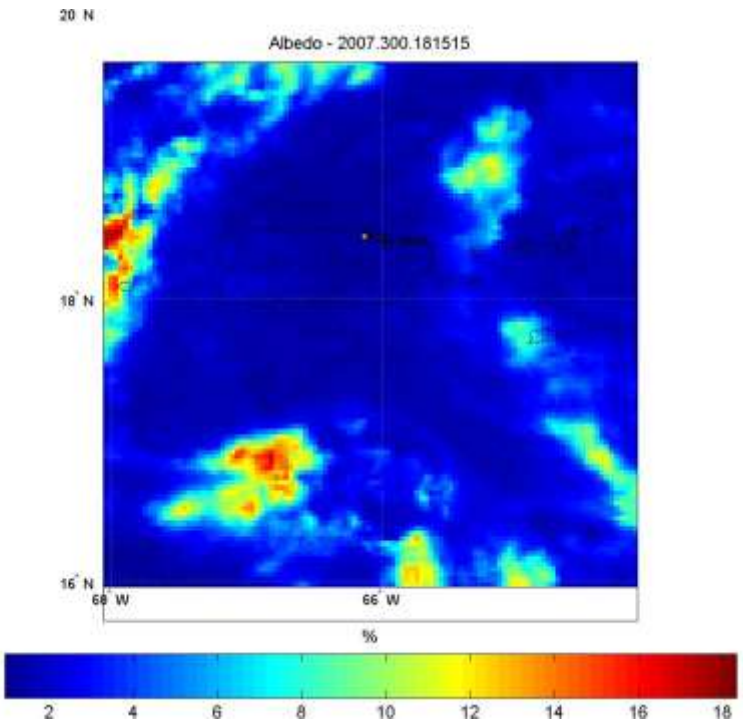


Figure 7. Albedo from October 27, 2008 (18:35 UTC)

Projection algorithm

- The algorithm is based on the angle formed by two vectors in the n-dimensional space.
  - If two vectors are collinear the cloud radiative variables will exhibit similar properties
  - If two vectors are orthogonal the radiative variables will have no elements in common.
- Satellite data are used to create rain and no rain pixel populations.
- The centroid of each population is used to generate rain and no rain calibration vectors.
- A pixel from an independent data set is used to create a third vector, which is projected into the previously calibrated vectors, with the purpose of classifying the third vector into a rain or no rain population.

Example

- Assuming that two variables are available
  - Albedo from channel 2
  - Brightness temperature from channel 4.
- Assuming that two populations are characterized by:

$$\textbf{Rain 1}: \quad \vec{x} = [2 \quad 190]$$
$$\textbf{No rain 2}: \quad \vec{y} = [20 \quad 240]$$

A sample from an independent data set will be classified:

$$\textbf{Unknown}: \quad \vec{a} = [5 \quad 235]$$

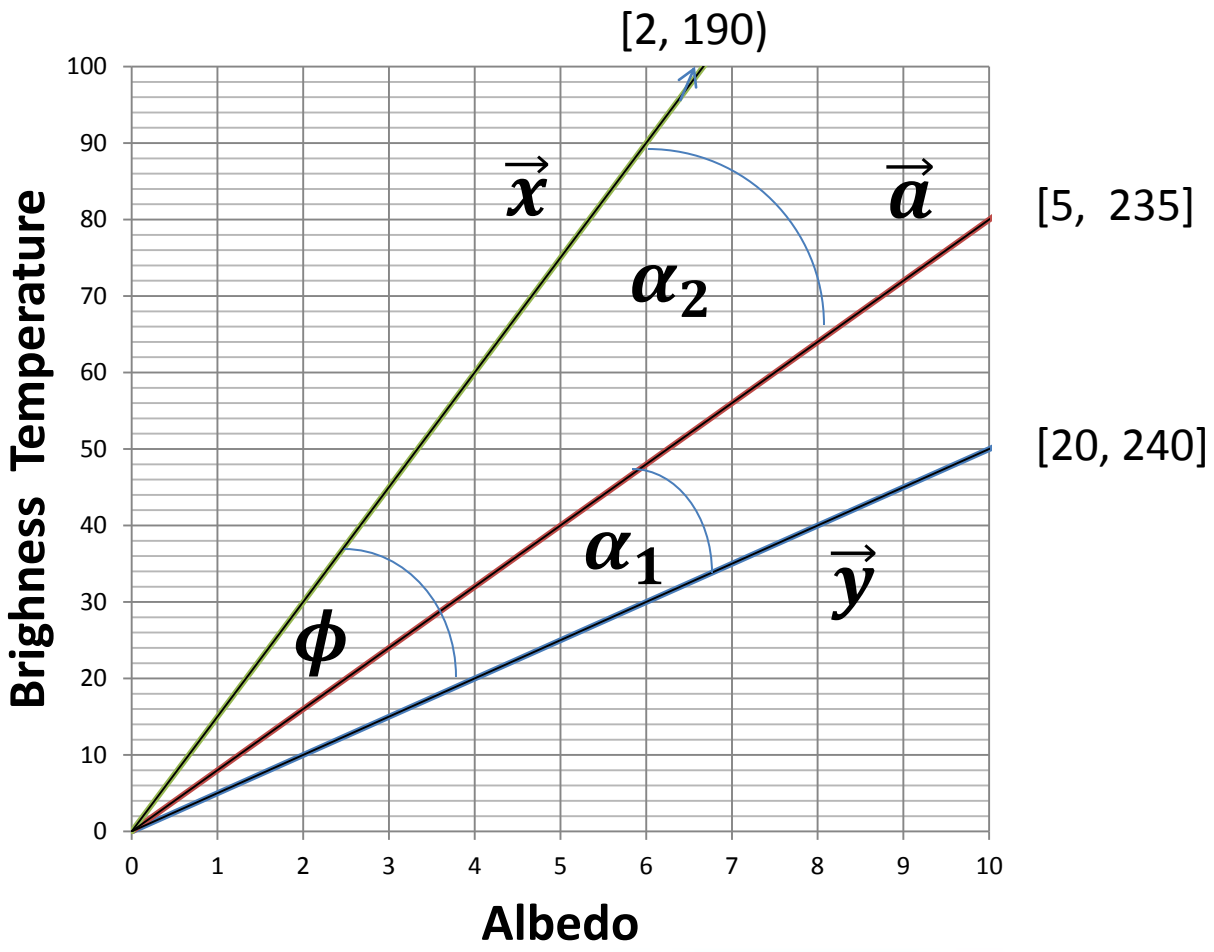
Projection in two dimensions

$\phi = 7.5^o$

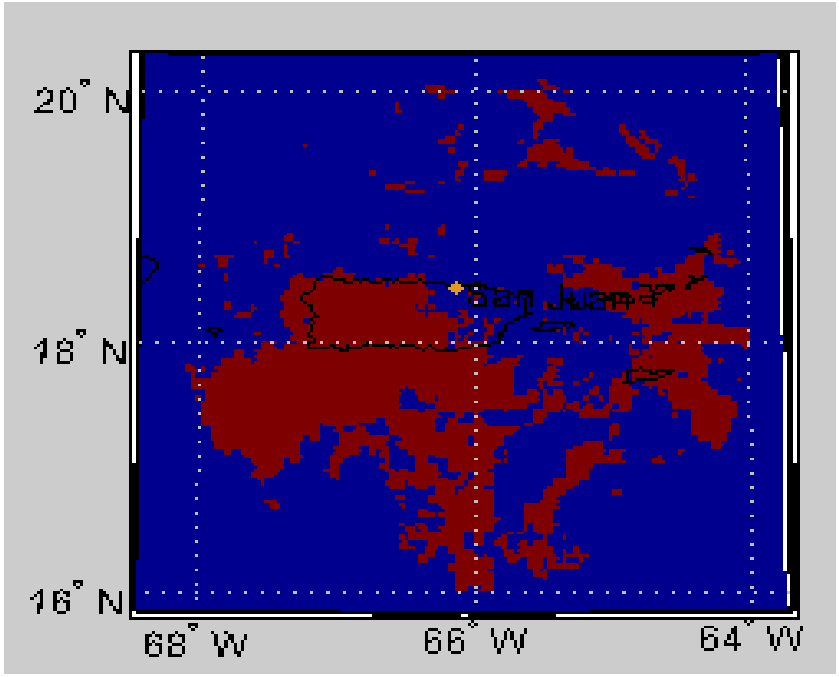
$\alpha_1 = 3.3^o$

$\alpha_2 = 4.2^o$

$\alpha_1 + \alpha_2 = \phi$

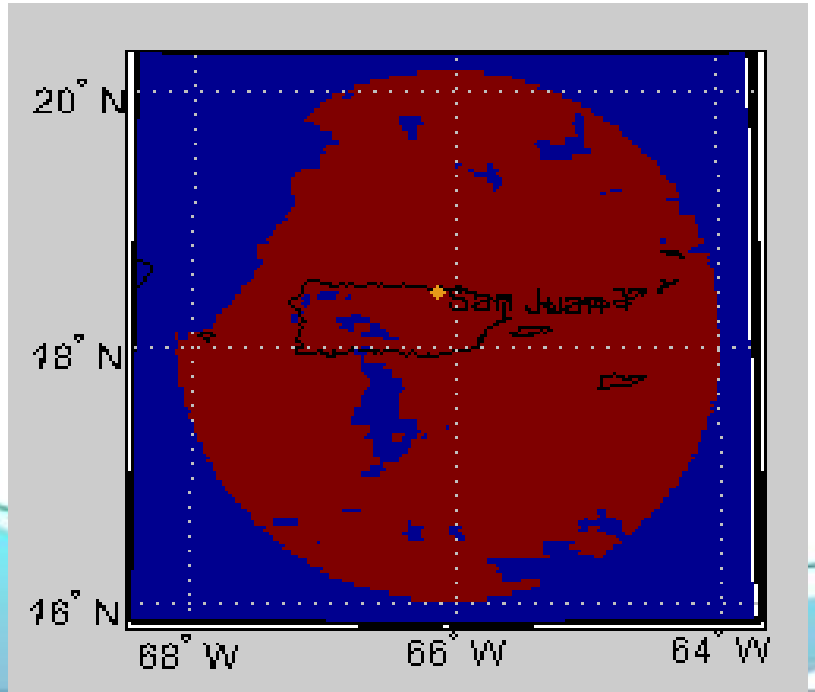


NEXRAD Radar

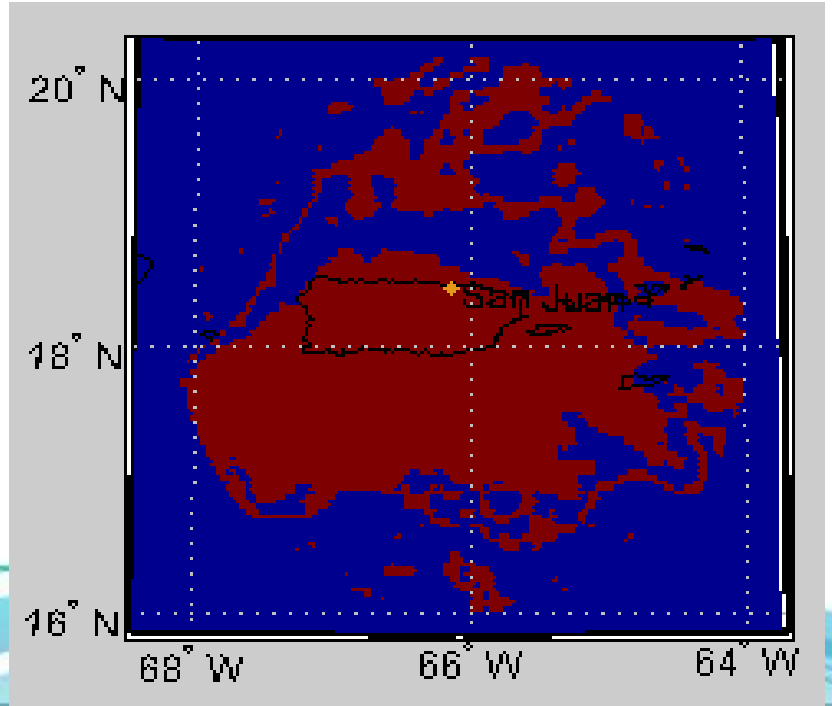


(17:45 UTC,
October 27, 2007)

Hydro-Estimator



Projection Algorithm



Rainfall rate estimation

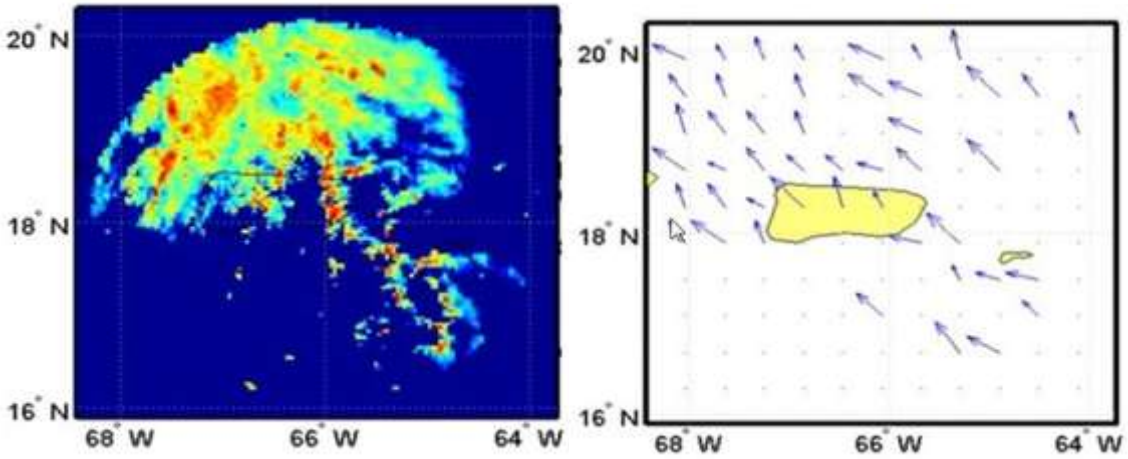
- The evolution of the cloud microphysical process start by nucleation, condensation, continues with drop grow (collision and coalescence), and finished with drop precipitation.
- The growth or decay of clouds may be captured by computing the differences of two consecutive brightness temperature measurements from the thermal IR channel and two consecutive brightness temperature measurements from the water vapor channel.

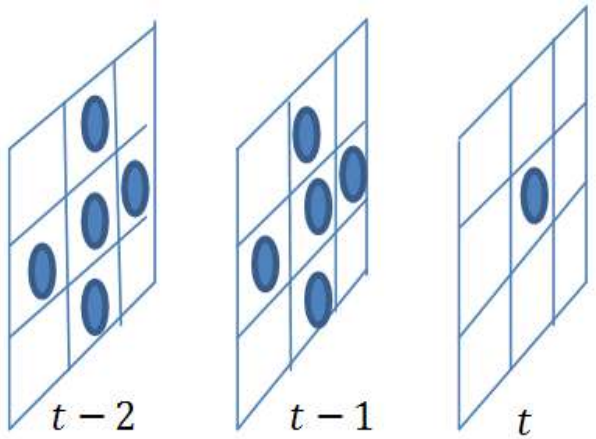
No	Variable Name	Variable	Time lags	Spatial lags
1	T_2	Brightness Temperature Channel 2	0, 1, 2	$i \pm 1, j \pm 1$
2	T_3	Brightness Temperature Channel 3	0, 1, 2	$i \pm 1, j \pm 1$
3	T_4	Brightness Temperature Channel 4	0, 1, 2	$i \pm 1, j \pm 1$
4	T_{42}	Difference of $T_4 - T_2$	0, 1, 2	$i \pm 1, j \pm 1$
5	T_{43}	Difference of $T_4 - T_3$	0, 1, 2	$i \pm 1, j \pm 1$
6	A	Albedo Channel 2	0, 1, 2	$i \pm 1, j \pm 1$
7	V	Visible Reflectance Channel 1	0, 1, 2	$i \pm 1, j \pm 1$

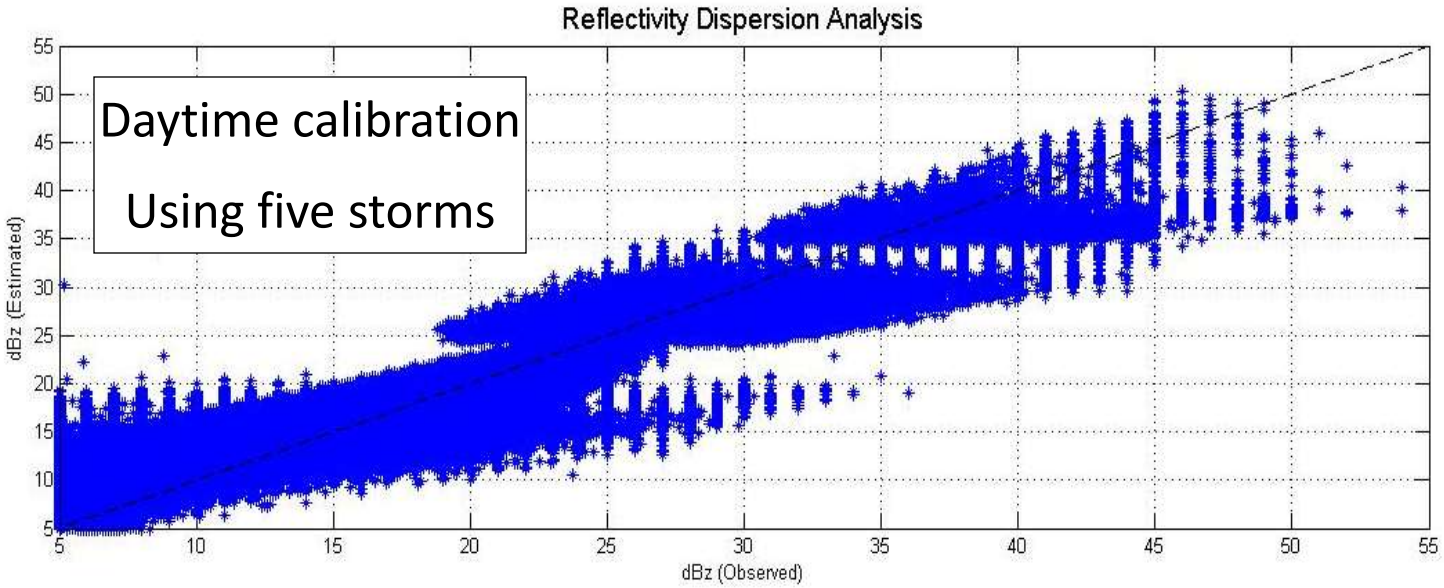
A new rainfall retrieval algorithm

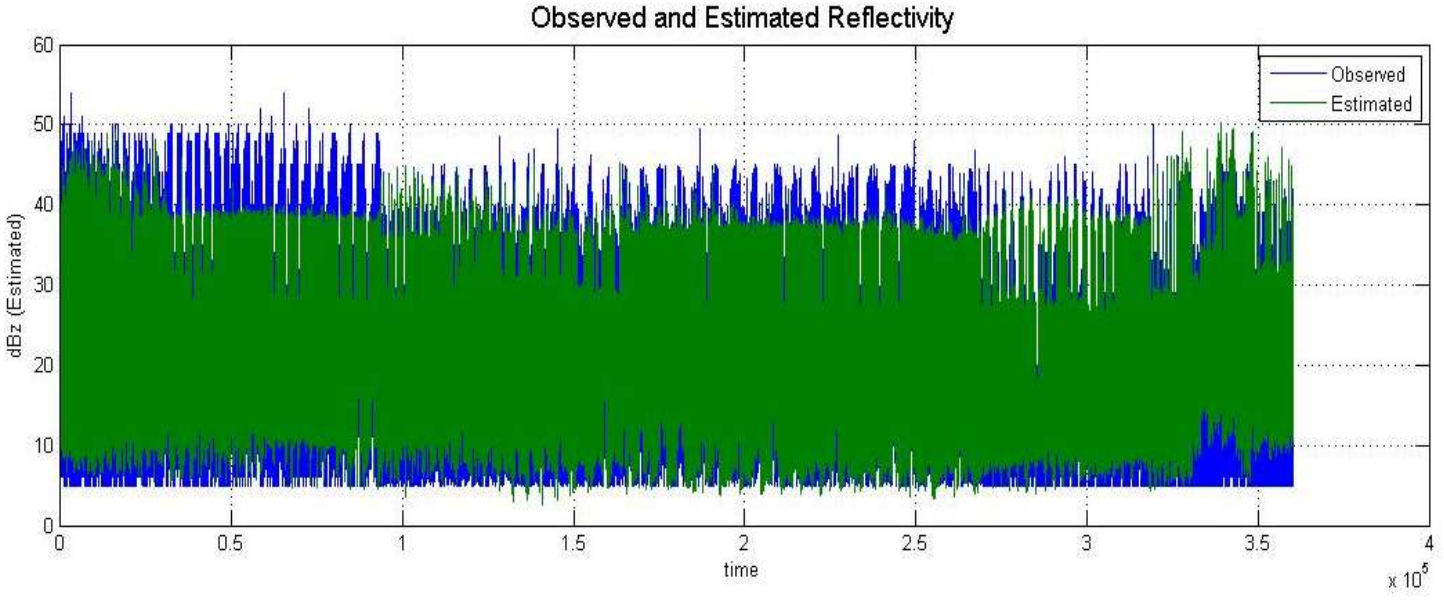
$$Z_t(i,j) = a_0 + a_1 X_t(i,j) + a_2 X_{t-1}(i,j) + a_3 X_{t-1}(i,j-1) + a_4 X_{t-1}(i-1,j) + a_5 X_{t-1}(i+1,j) + a_6 X_{t-1}(i,j+1) + a_7 X_{t-2}(i,j) + a_8 X_{t-2}(i,j-1) + a_9 X_{t-2}(i-1,j) + a_{10} X_{t-2}(i+1,j) + a_{11} X_{t-2}(i,j+1) + \varepsilon_t$$

Motion vector of band 4 is computed to determine which variables will participate in the model.

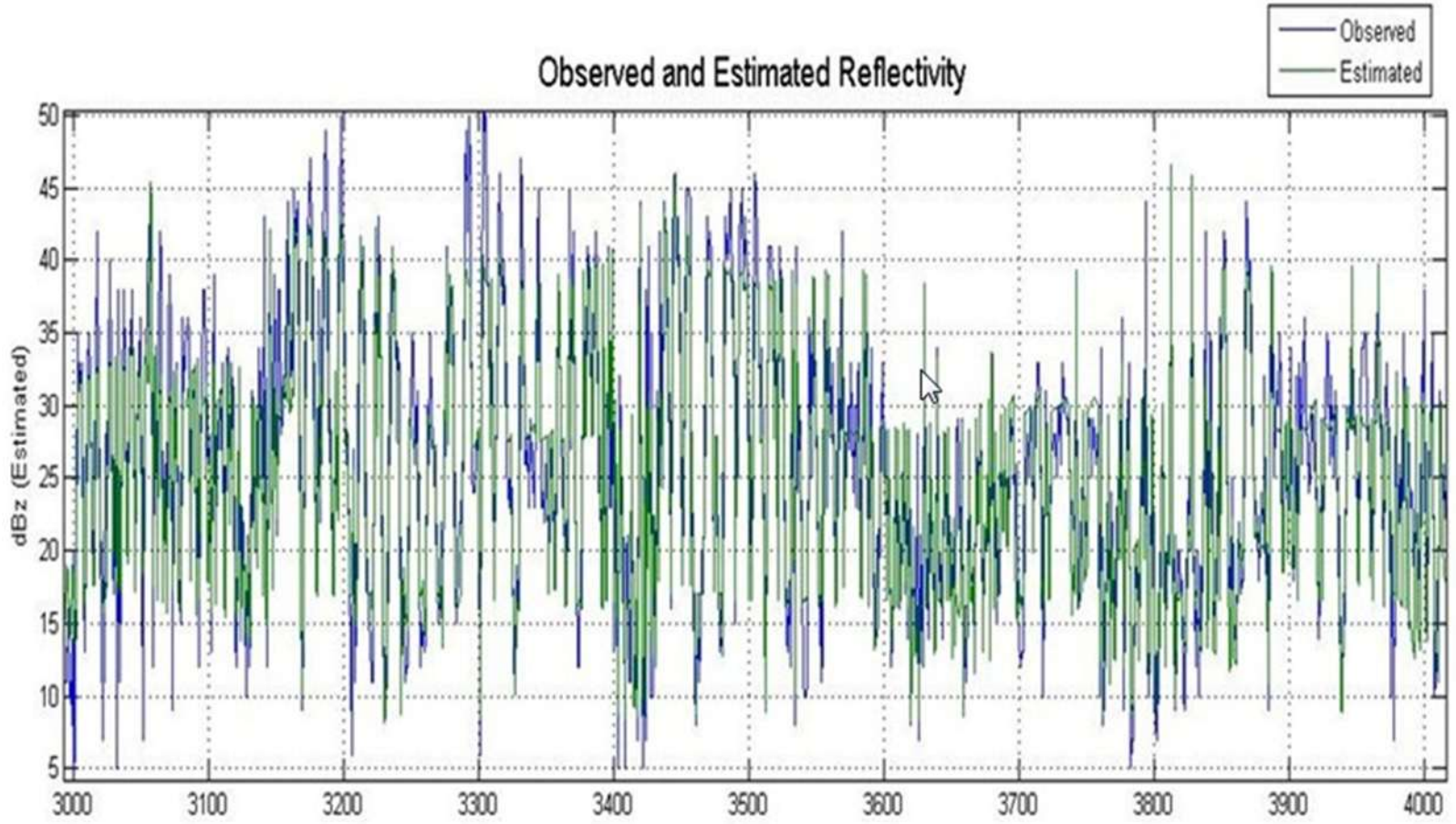




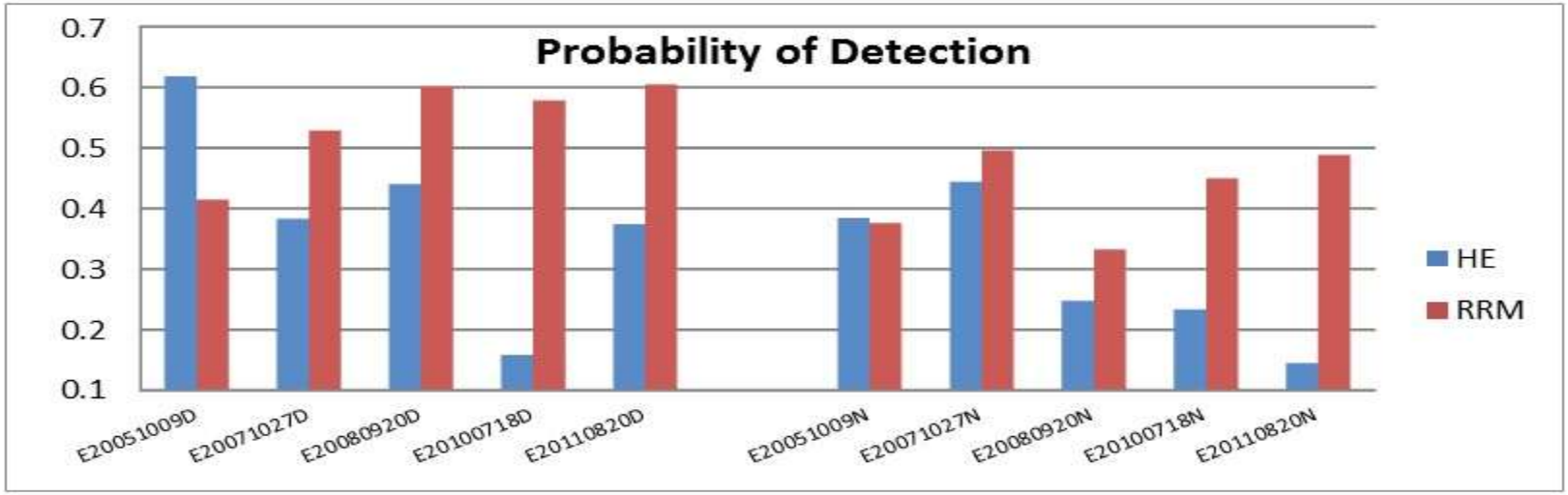

Reflectivity Dispersion Analysis
Daytime calibration
Using five storms
dBz (Estimated)
dBz (Observed)


Observed and Estimated Reflectivity
Observed
Estimated
dBz (Estimated)
time
x 10^5

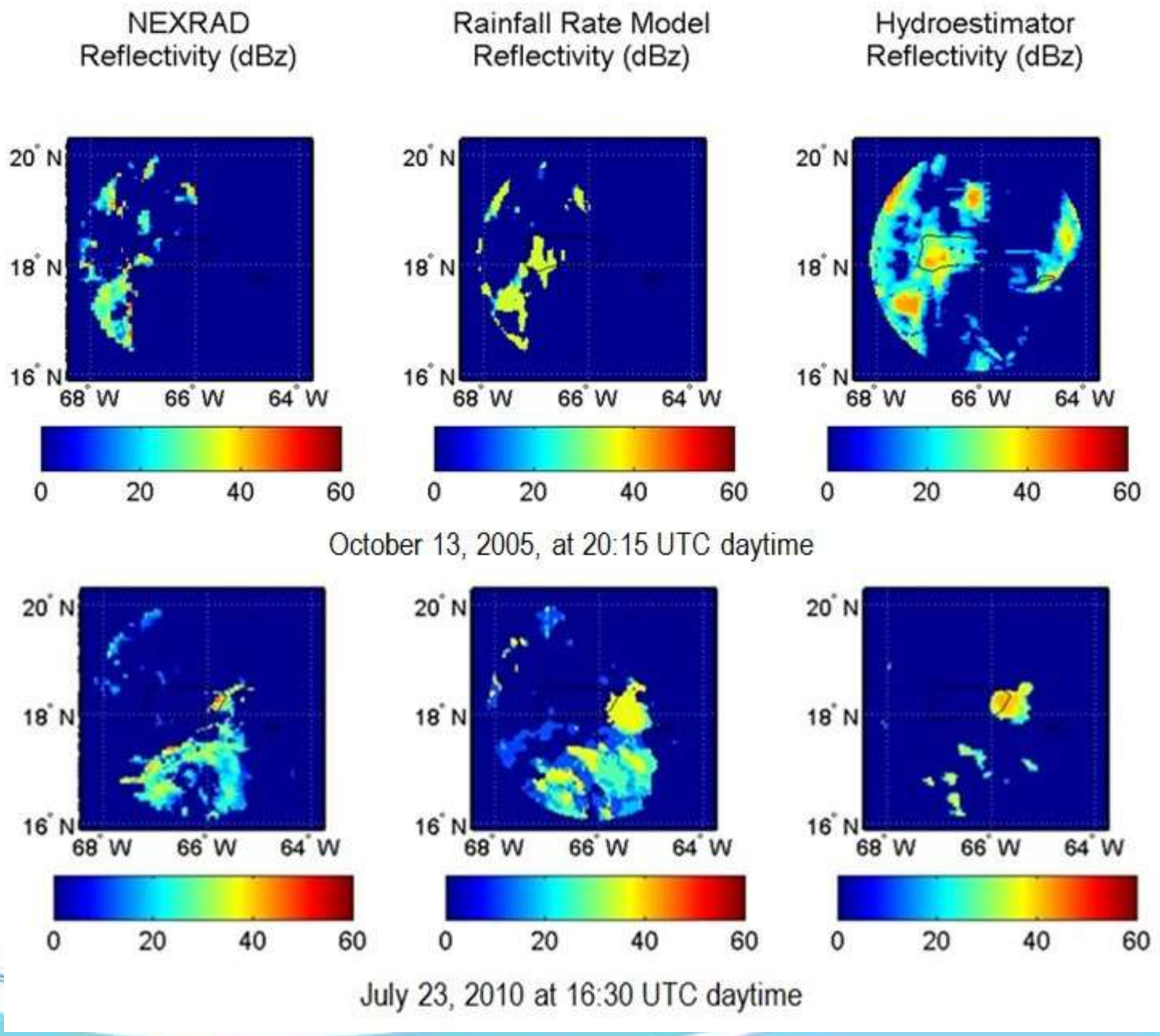
Calibration

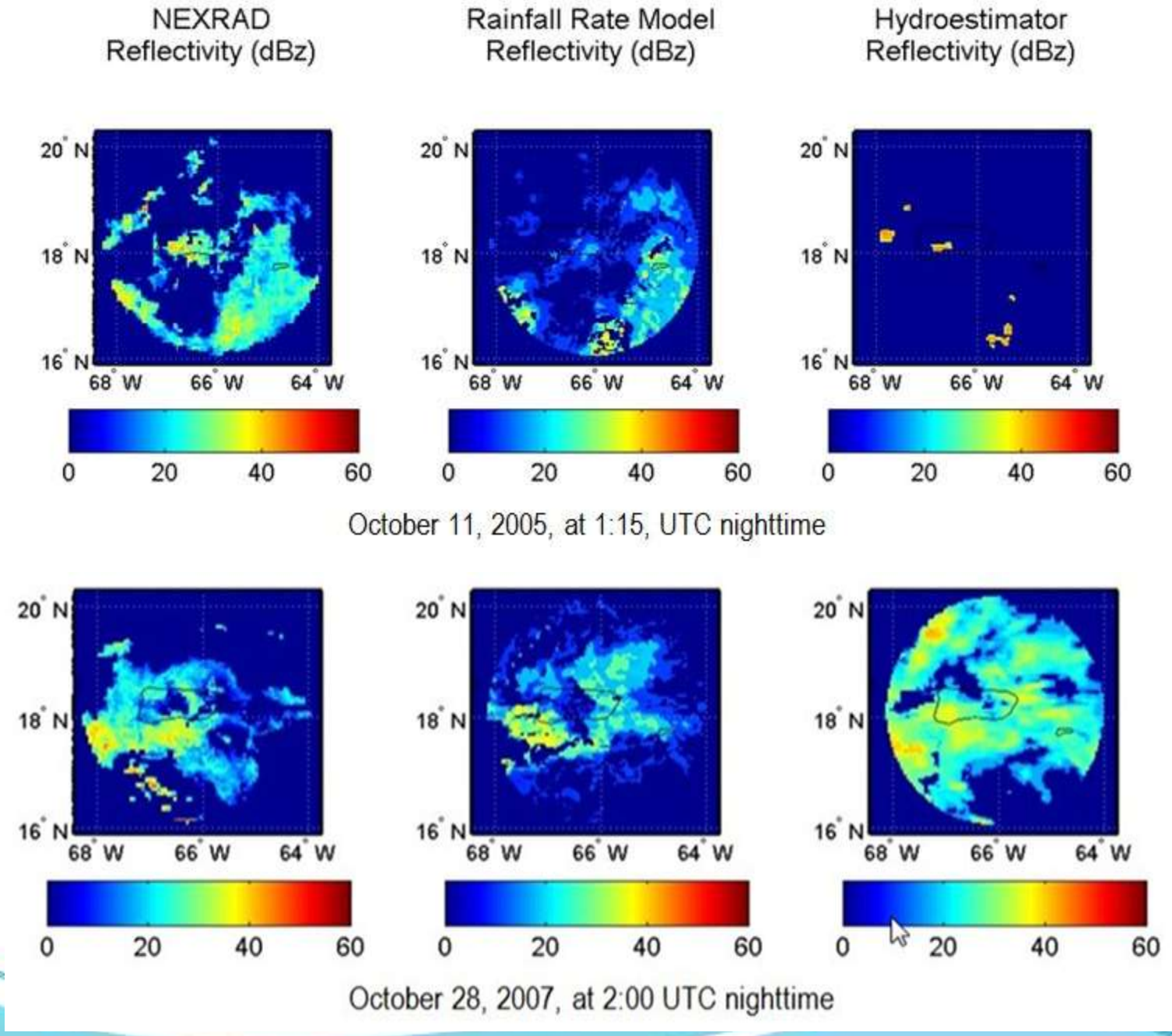


Validation

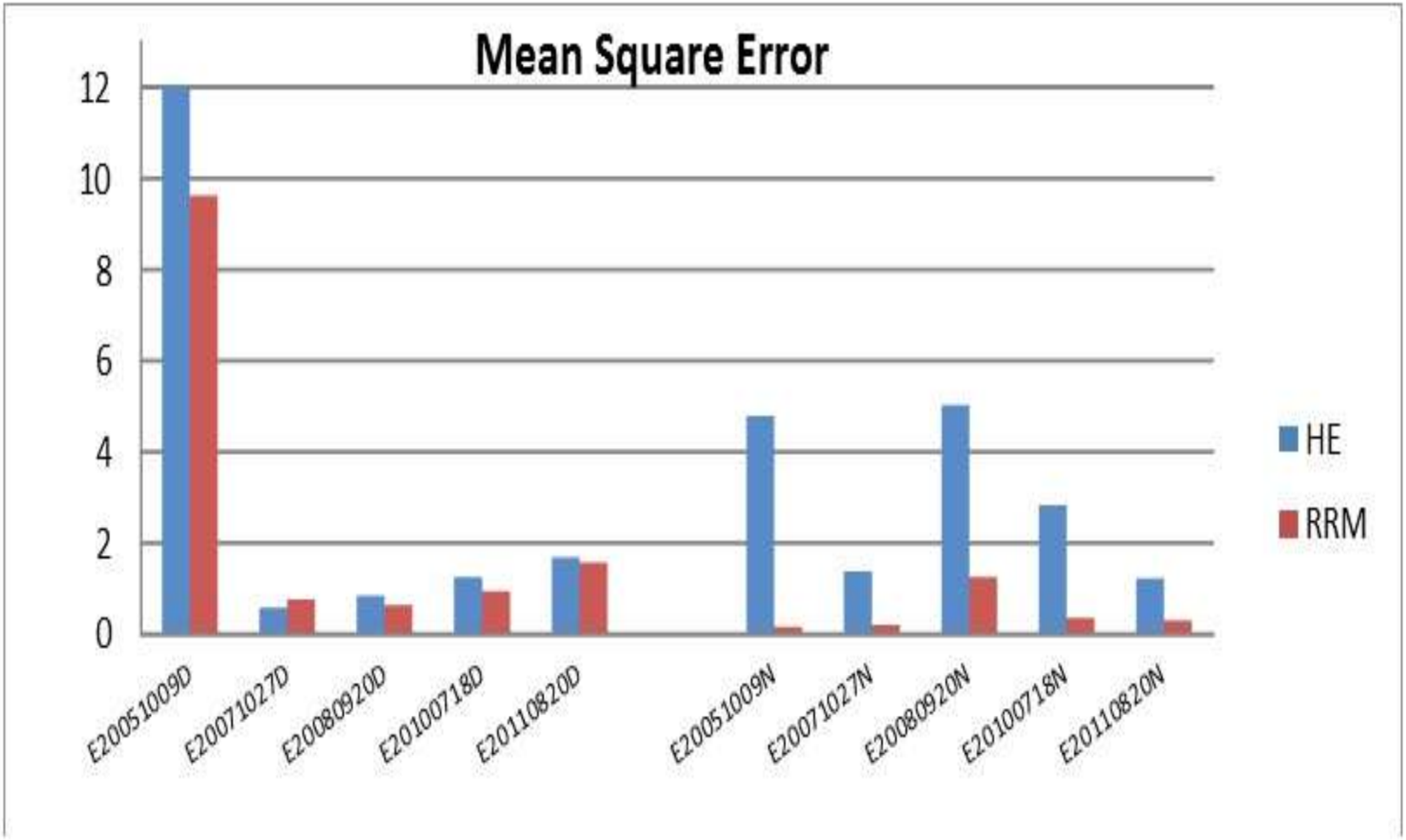

Probability of Detection
0.7
0.6
0.5
0.4
0.3
0.2
0.1
E20051009D
E20071027D
E20080920D
E20100718D
E20110820D
E20051009N
E20071027N
E20080920N
E20100718N
E20110820N
HE
RRM


False Alarm Rate
art Area
0.9
0.8
0.7
0.6
0.5
0.4
E20051009D
E20071027D
E20080920D
E20100718D
E20110820D
E20051009N
E20071027N
E20080920N
E20100718N
E20110820N
HE
RRM


NEXRAD
Reflectivity (dBz)
Rainfall Rate Model
Reflectivity (dBz)
Hydroestimator
Reflectivity (dBz)
20° N
18° N
16° N
68° W
66° W
64° W
0
20
40
60
October 13, 2005, at 20:15 UTC daytime
July 23, 2010 at 16:30 UTC daytime


NEXRAD
Reflectivity (dBz)
Rainfall Rate Model
Reflectivity (dBz)
Hydroestimator
Reflectivity (dBz)
20° N
18° N
16° N
68° W
66° W
64° W
0
20
40
60
October 11, 2005, at 1:15, UTC nighttime
October 28, 2007, at 2:00 UTC nighttime

Validation


Mean Square Error
12
10
8
6
4
2
0
E20051009D
E20071027D
E20080920D
E20100718D
E20110820D
E20051009N
E20071027N
E20080920N
E20100718N
E20110820N
HE
RRM

Conclusions

- A new algorithm has been developed to estimate the rainfall rate.
- The algorithm has been calibrated for Puerto Rico and can be used to estimate rainfall over the Caribbean basin.
- The algorithm is specially useful for areas that are not covered by the radar.