A Time Lag Model to Estimate Rainfall Rate Based on GOES Data

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Outline

- Motivation
- Description of data
- Projection algorithm
- Relation between radar and satellite variables
- Lag time model
- Results
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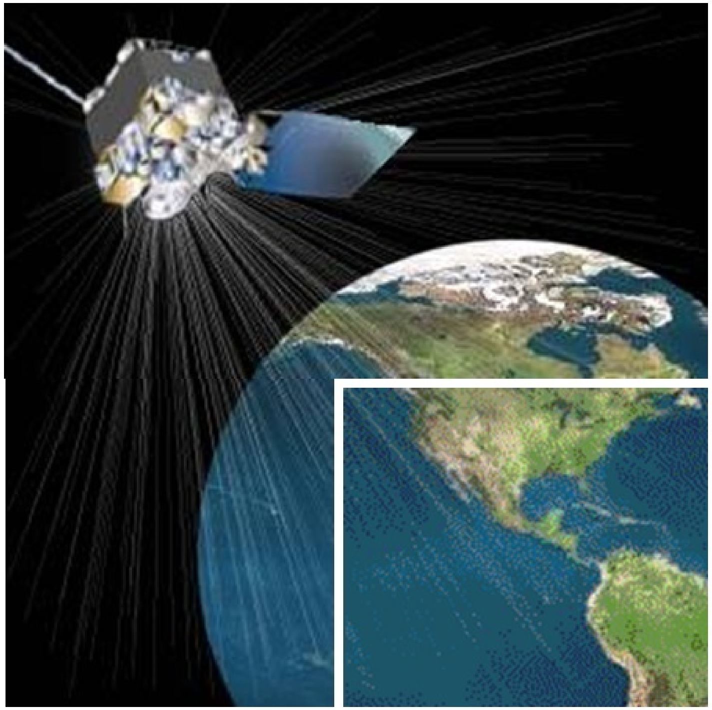
Motivation

- NEXRAD
  - Operates in S-band with 10 cm wavelength.
  - Observations at every 6 minutes.
  - The maximum horizontal range is 462
- Polar satellite
  - Altitude: 870 km
  - Advanced Microwave Sounding Unit-A
  - Microwave Humidity Sounder (MHS)
  - Observations every 12 hours
- Geostationary satellite
  - 35,800 km
  - GOES-12 75 W longitude and the equator
  - Visible and infrared channels
  - Observations every 15 min



Motivation

- The challenge of this work is to infer the presence of rainfall pixels and estimate the rainfall rate by looking the visible reflectance and the brightness temperatures from GOES channels.
- Infrared channels provide indirect measurements of rainfall.
- It is known that the presence of heavy rainfall is associated with cold clouds.
  - However, there are cold clouds with no rain,
  - and also there are heavy rains from warm clouds.

Radar Data

- NEXRAD data over Puerto Rico come from a WSR-88D unit located in Cayey (18.12°N, 66.08°W, 886.63 m elevation).
- The radar frequency is 2.7 GHz and the maximum horizontal range is 462 km, and the radar scans the entire island every 6 minutes.
- The study area covers 121x121 radar pixels with a grid size of 2.6x2.8km.
- Reflectivity is used to identify rain/no rain pixel
- Reflectivity is also used for calibrating rainfall rate

Satellite data for rainfall detection

- Four bands of the GOES imager are used:
  - Channel 1: visible (0.65 μm),
  - Channel 2: near infrared (3.9 μm),
  - Channel 3: water vapor (6.7 μm), and
  - Channel 4: thermal IR (10.7 μm).
- Albedo of Channel 2
- Two band differences were also calculated:
  - Difference for Ch 2 – Ch 4
  - Difference for Ch 3 – Ch 4.

Satellite data for rainfall estimation

Variable Name	Variable	Source	Time lags
Z	Reflectivity (dBz)	radar	0, 1, 2, 3
T_4	Brightness Temperature Channel 4	satellite	0, 1, 2, 3
T_3	Brightness Temperature Channel 3	satellite	0, 1, 2, 3
T_{43}	Difference of $T_4 - T_3$	satellite	0, 1, 2, 3
α	Albedo Channel 2	satellite	0, 1, 2, 3
λ	Visible Reflectance Channel 1	satellite	0, 1, 2, 3

The evolution of the cloud microphysical process start by drop condensation, continues with drop grow, and finished with drop precipitation.

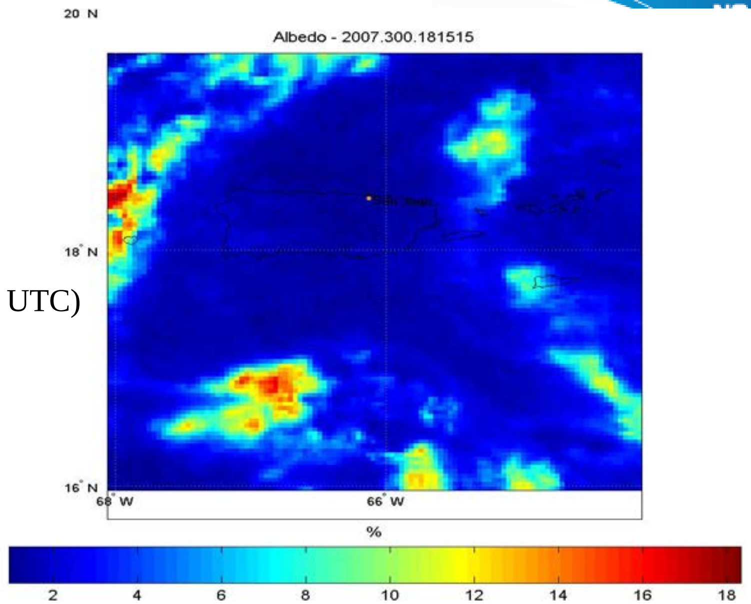
Albedo (3.9μm)

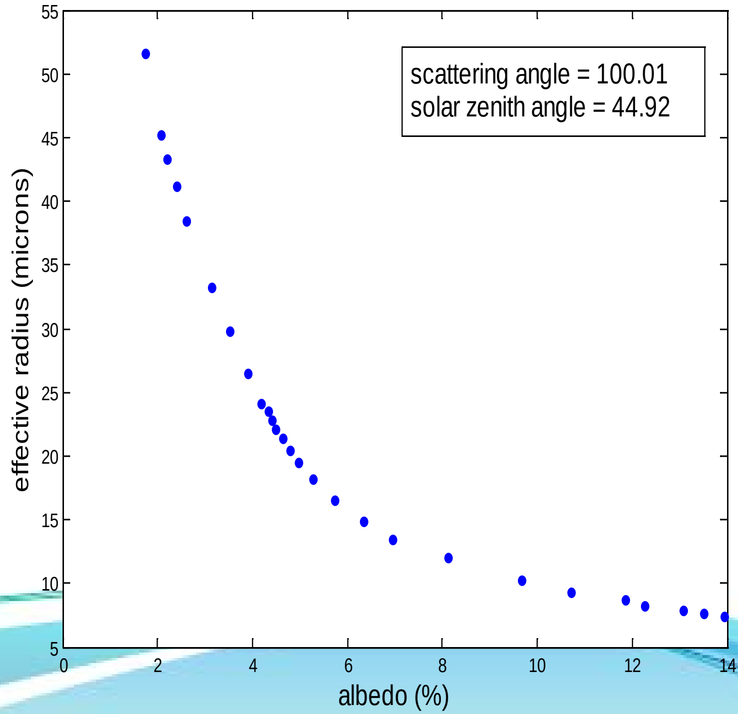
- Albedo is defined by:

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

  - 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

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

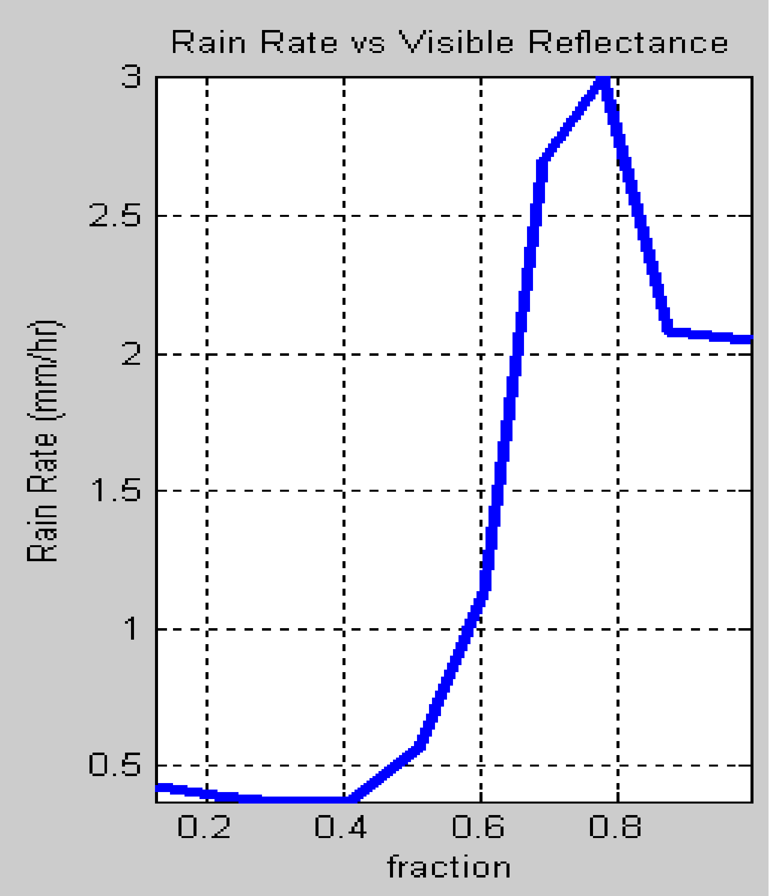


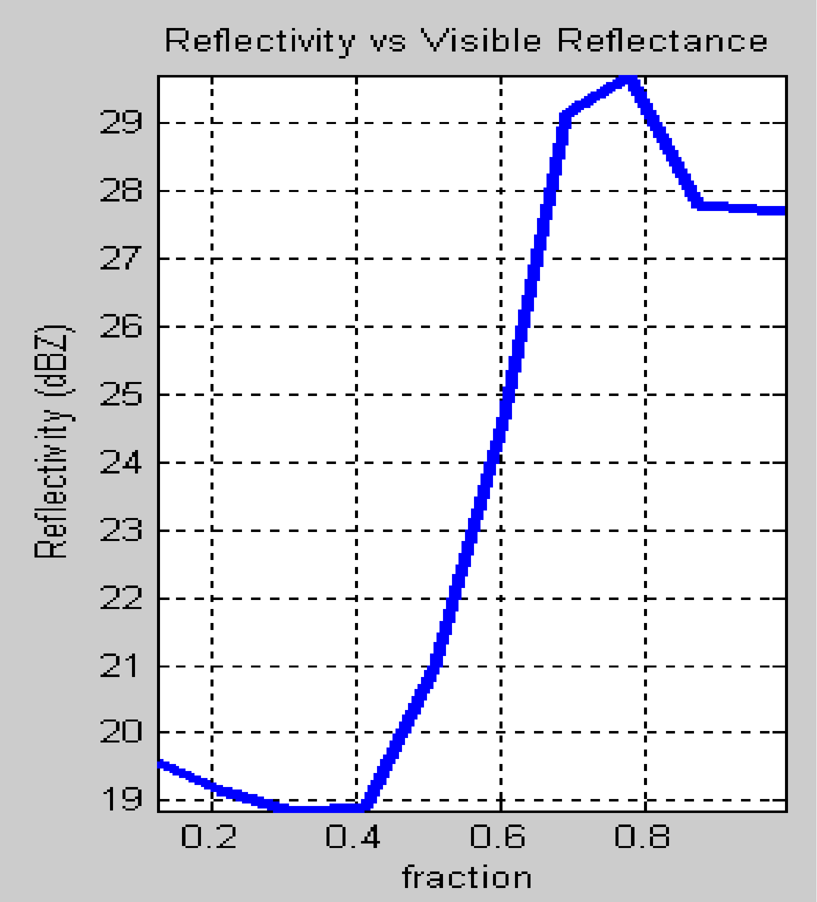


Projection algorithm

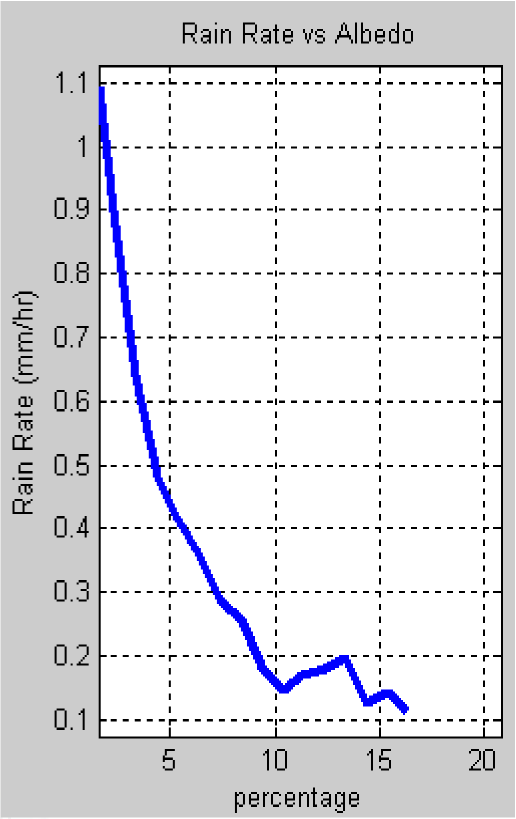
- Based on the angle formed by two vectors in the n-dimensional space.
- Projection principle: when two vectors are collinear the radiative variables of clouds may exhibit similar properties, and when the vectors are orthogonal the radiative variables may have no elements in common.
- Radar data are used to identify rain/no rain pixels.
- The central tendency 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 and classify the third vector into a rain or no rain population.

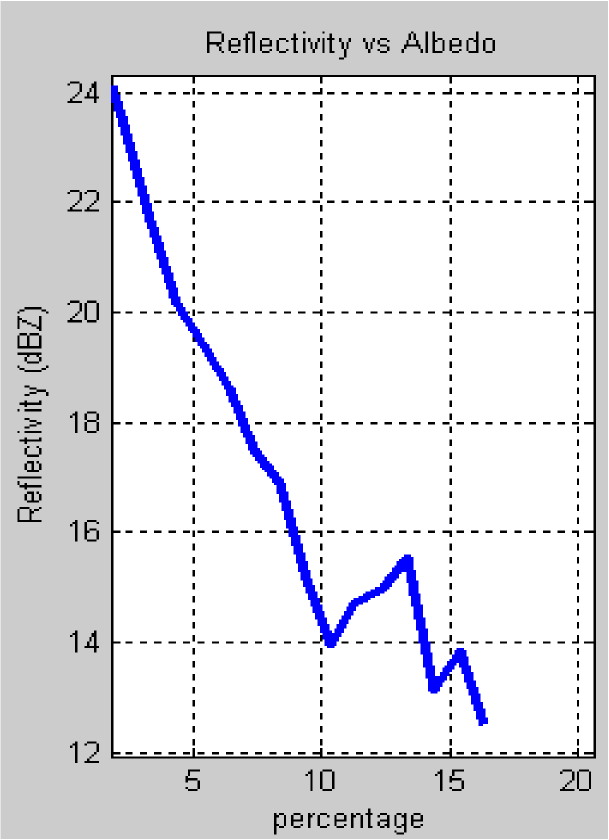
The first observation on radar and satellite data (Visible Reflectance)

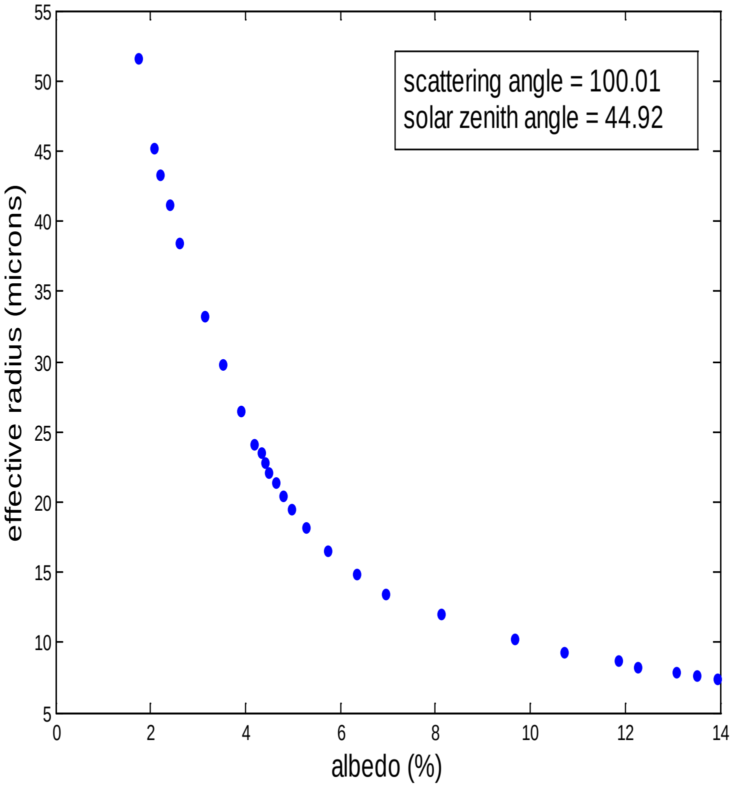




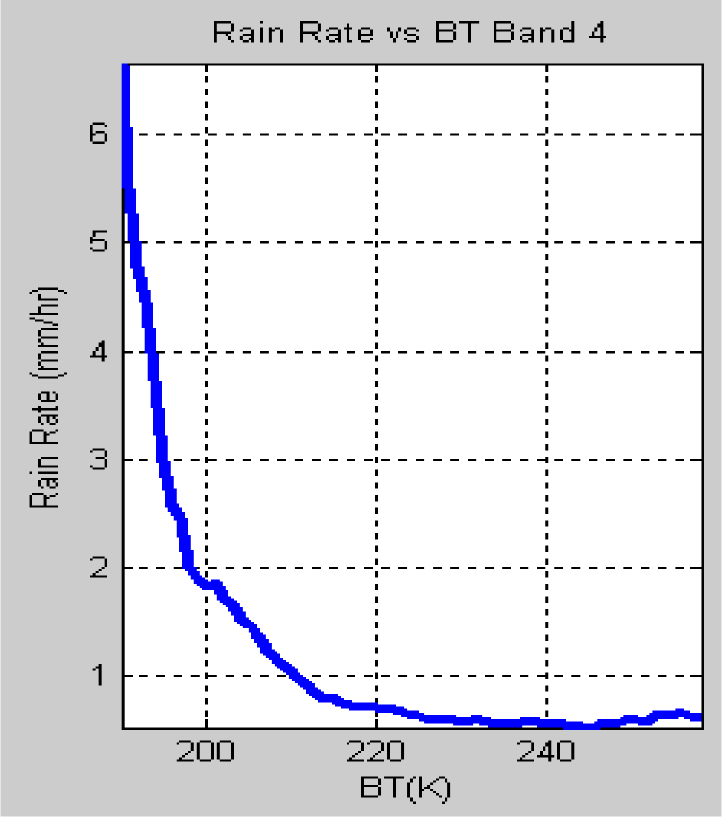
The second observation on radar and satellite data (Albedo)

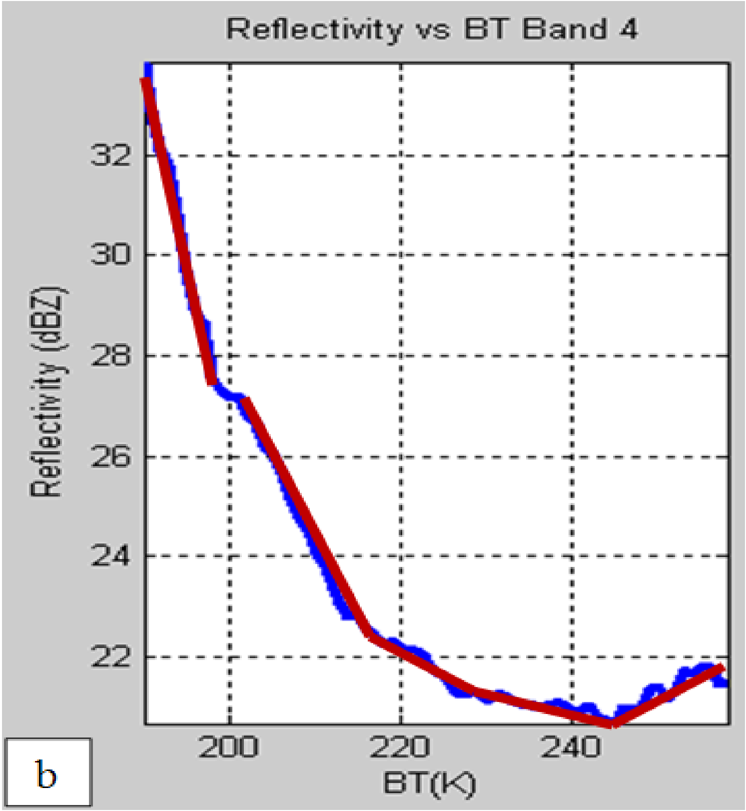




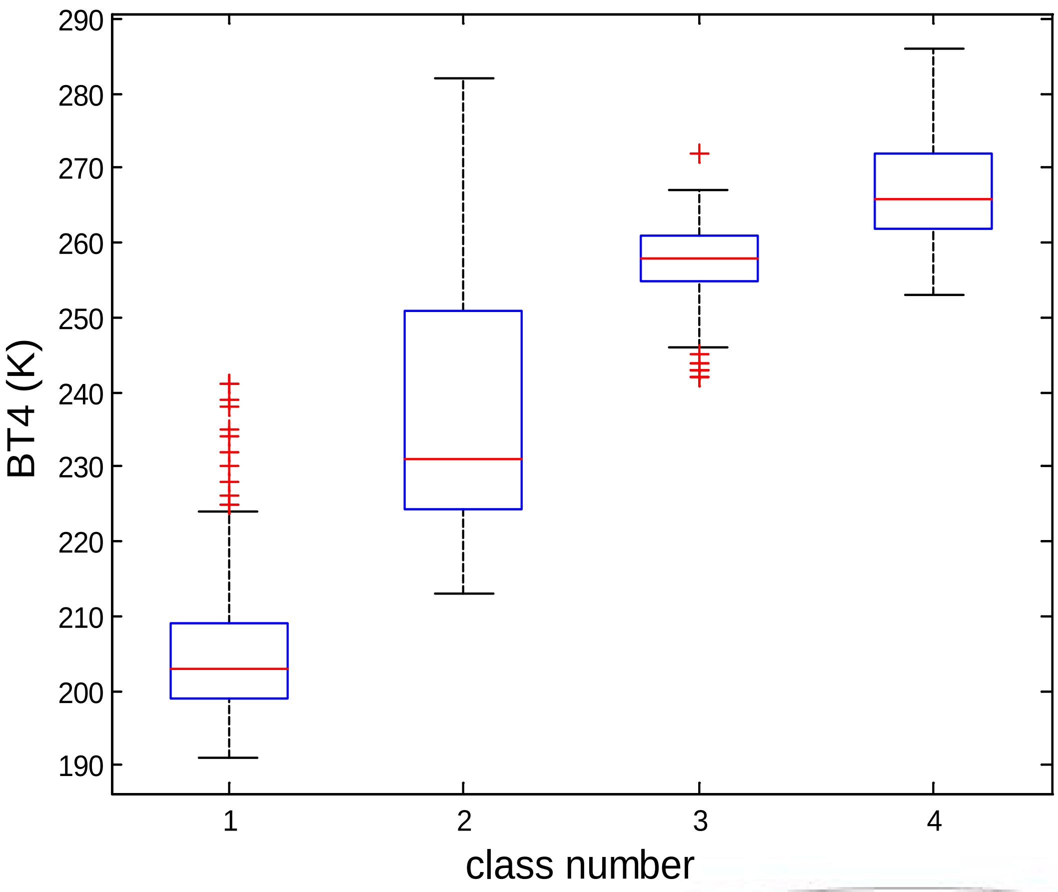


The third observation on radar and satellite data





Four groups of data



Time Lag Model

- The sequence of consecutive images of cloud radiative variables will provide the opportunity of deriving proxy variables for estimating both the evolution of the cloud microphysics and the wind components with visible and IR GOES channels.
- The rain rate can be estimated by measuring the evolution of the cloud microphysical processes and by using a sequence of images.
- It is assumed that variations of the cloud radiative properties will be associated to variations of rain rate

Time Lag Model

$$Z_t = m_0 + m_1 X_{1,t-d_1} + m_2 X_{2,t-d_2} + \cdots + m_k X_{k,t-d_k} + \varepsilon_t,$$

$$d_i = 0, 1, 2, 3$$

$$Z_t = \upsilon_1(B) B^{d_1} X_{1,t} + \upsilon_2(B) B^{d_2} X_{2,t} + \cdots + \upsilon_J(B) B^{d_J} X_{J,t} + \varepsilon_t$$

- where

$$\upsilon_j(B) = \frac{\omega_j(B)}{\delta_j(B)} = \frac{\omega_{j,0} + \omega_{j,1}B + \omega_{j,2}B^2 + \cdots + \omega_{j,s}B^s}{1 - \delta_{j,1}B - \delta_{j,2}B^2 - \cdots - \delta_{j,r}B^r} \quad j = 1,2,\ldots,J$$

-

$$\varepsilon_t = \frac{\Theta(B)}{\Phi(B)} a_t$$

-

$$\Theta(B) = 1 + \theta_1 B + \theta_2 B^2 + \cdots + \theta_q B^q$$

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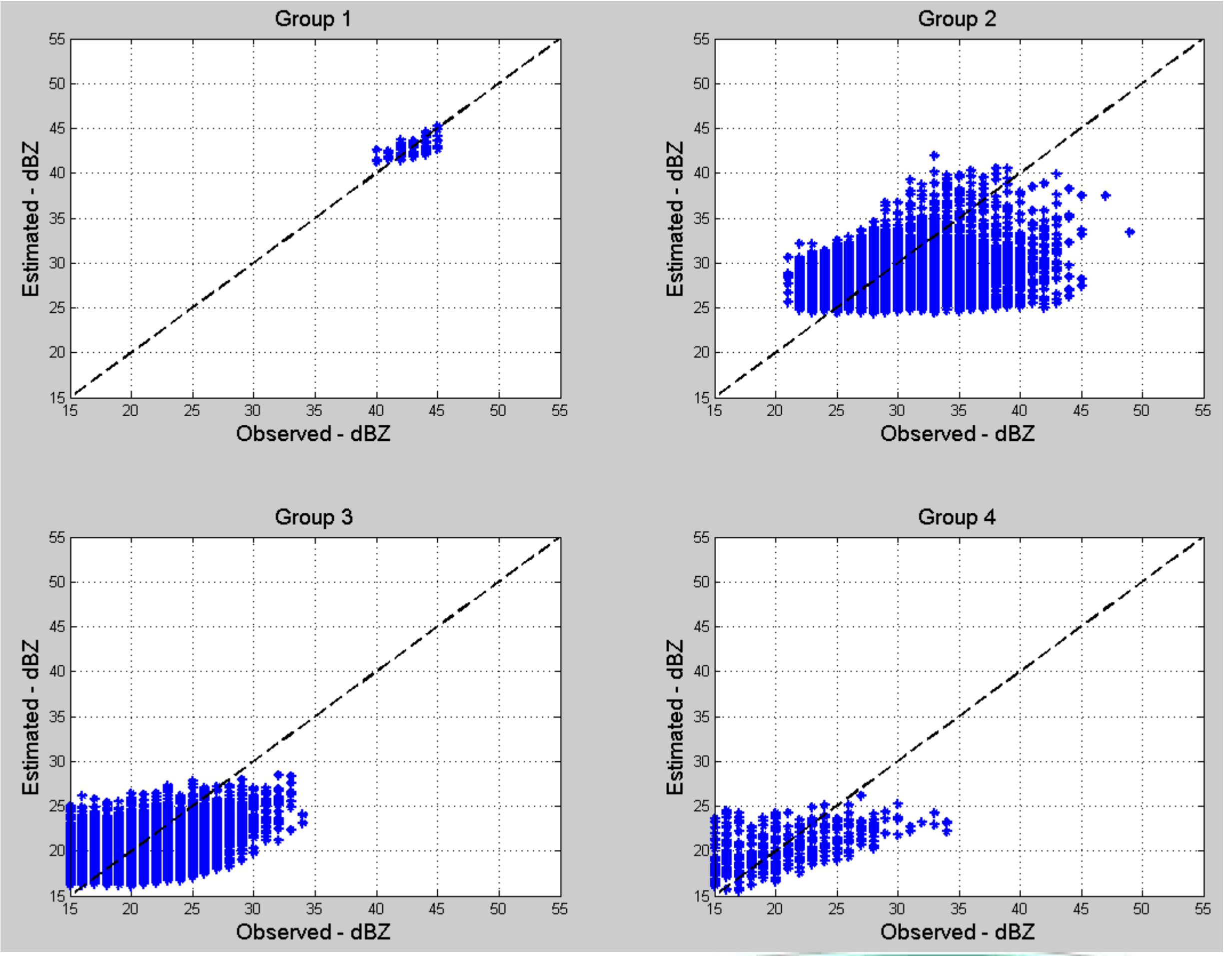
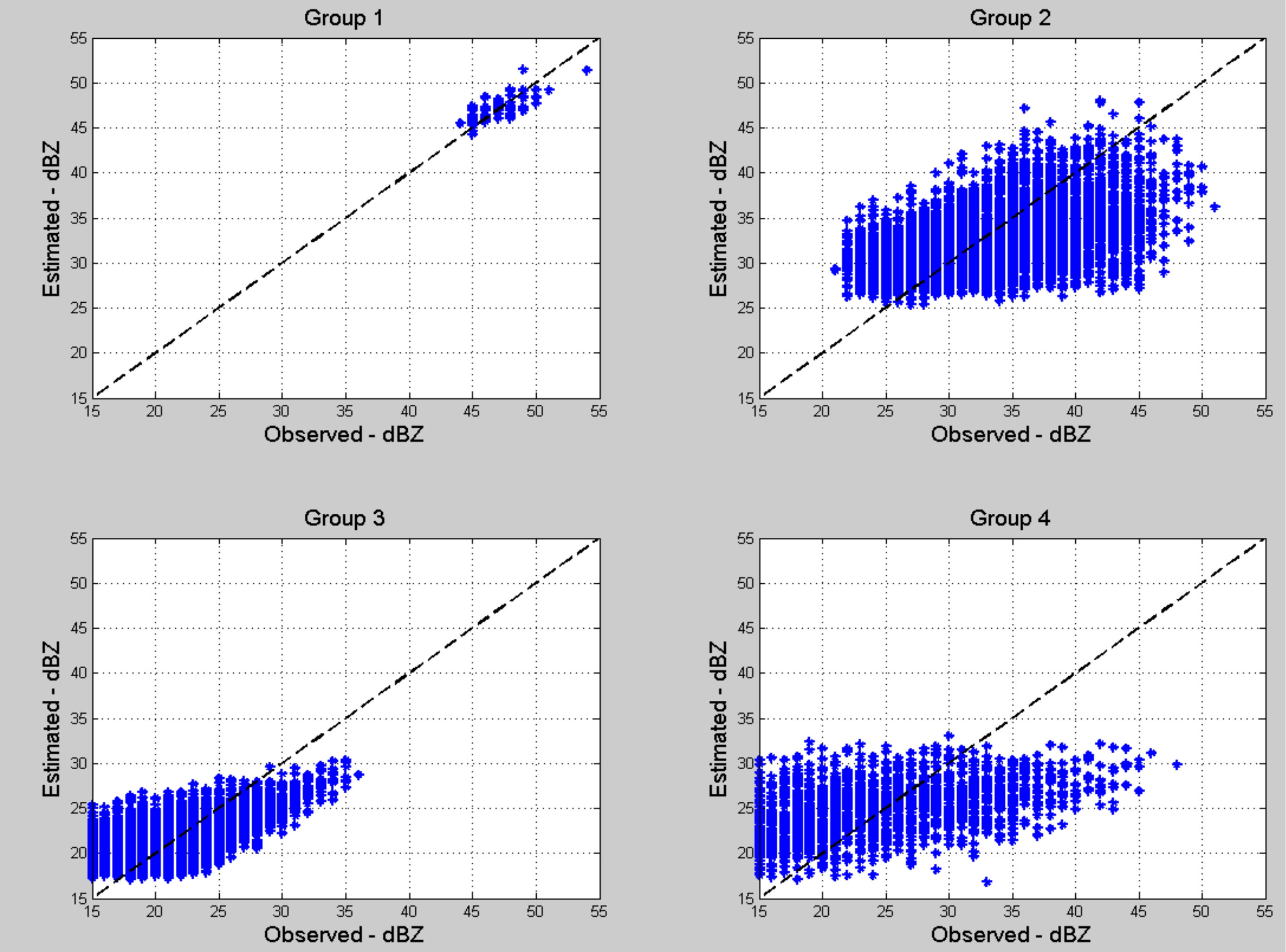
$$\Phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_q B^q$$

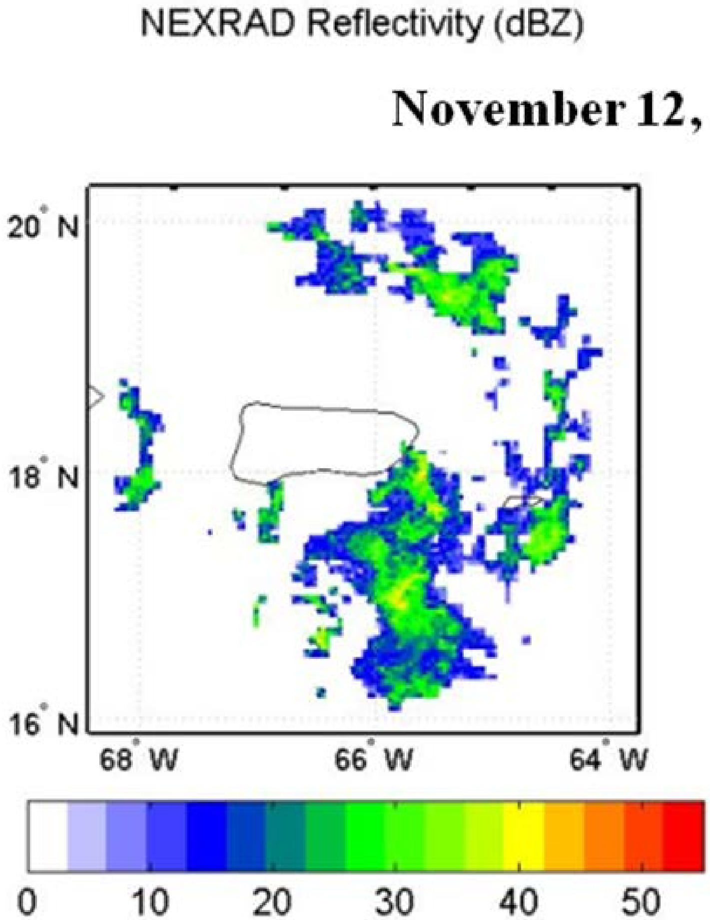
Nighttime scatterplot

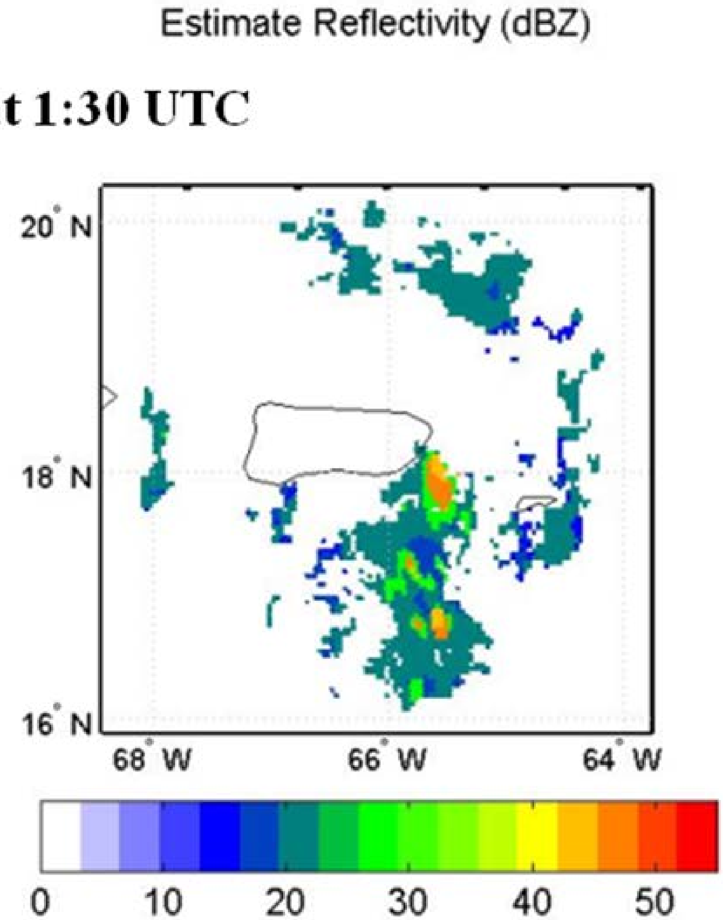


Daytime scatterplot



November 12, 2003, at 1:30 UTC





Conclusions and future work

- The Projection Algorithm is a potential tool to identify raining pixels.
- The time lag model shows some capabilities to estimate rainfall rate.
- The next task consists on integrating the PA and the TL model to develop a new rainfall rate algorithm.