Estimation of Effective Radius at Cloud Tops Using Satellite Data

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Agenda

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- Effective Radius Algorithm
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- Evolution of Rainy Cells
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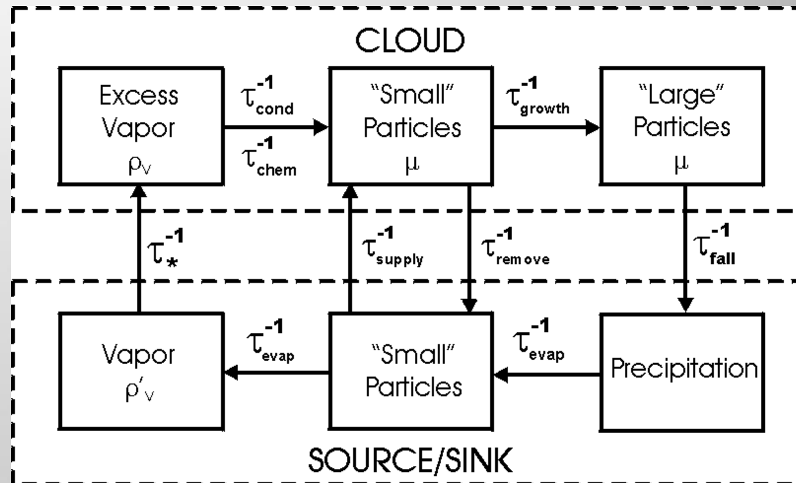
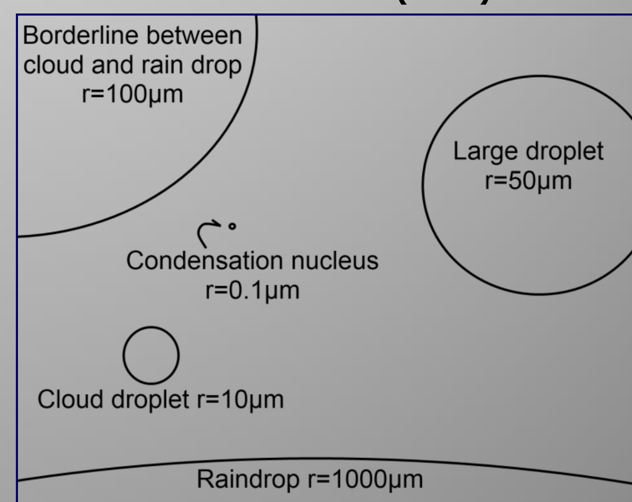
Drop Size Distribution

- A cloud rainfall event is the result of a complex thermodynamic process that starts with nucleation of cloud drops, continues with drop growth, and finishes with water drop precipitation.
- Usually, the atmosphere is filled with small aerosol particles, and molecules of vapor may collect onto the surface of aerosol particles.
- Cloud drops also grow by collision among the drops. However, collision between two drops does not guarantee coalescence; it depends on whether the droplets are electrically charged or if an electrical field is present.
- Houze [1993] shows that for a drop to start the descending trajectory requires having a radius of at least of 15μm.
- Thus, the time period from the drop nucleation to drop precipitation may last from 30 minutes to few hours depending on the inherent conditions of the troposphere.



The Hydrologic Cycle: Thermodynamic processes which govern cloud microphysics. Source: National Weather Service (2010)



The radius of cloud droplets vary by several orders of magnitude

Drop Size Distribution

NOAA-CREST

The water droplet size is assumed to be represented by the modified Gamma probability density function:

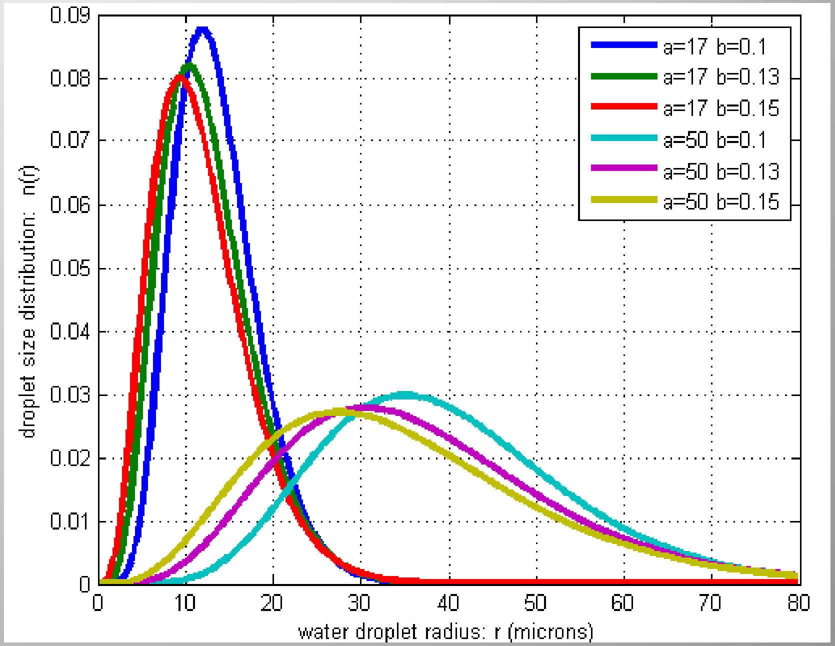
$$n(r) = Lr^{\left(\frac{3-b}{b}\right)} e^{-\left(\frac{r}{ab}\right)}$$

where **r** is the water droplet radius
a is effective radius of water droplet ($a>0$)
b is effective variance of the droplet size ($0<b<0.5$)
L is a scaling constant

$$\mathbf{L} = \frac{ab^{\left(\frac{2b-1}{b}\right)}}{\Gamma\left(\frac{1-2b}{b}\right)}$$

where,

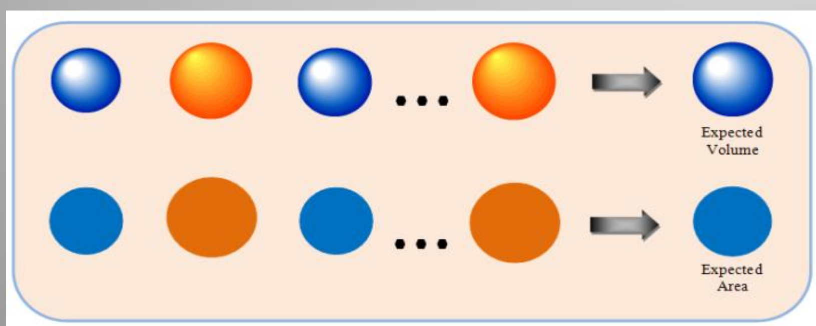
$$\Gamma(m) = \int_0^\infty x^{m-1} e^{-x} dx$$

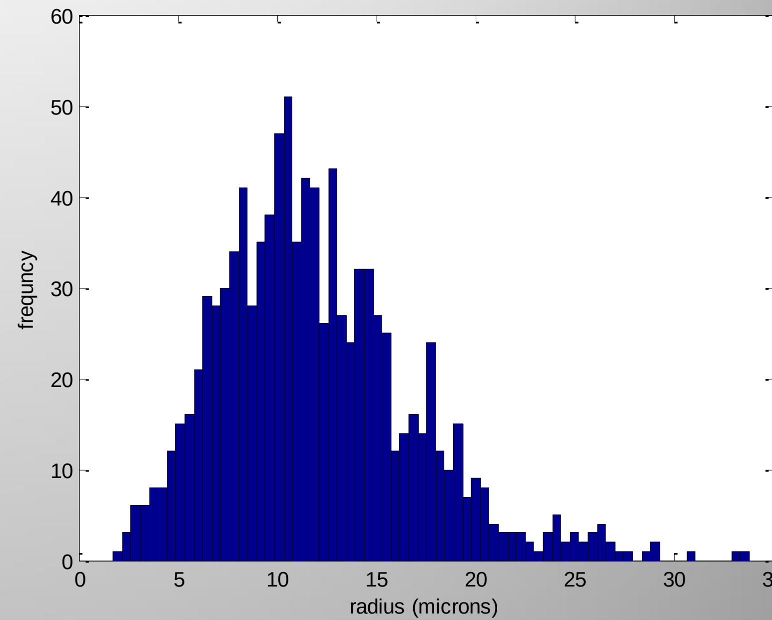


Differences in effective radius have a large effect on the shape of the drop size distribution (DSD); whereas the effective variance has a smaller effect on DSD. The two distinct clusters of distributions in this example demonstrate how dramatically effective radius influences the distribution (Ramirez et al. 2009).

Drop Size Distribution

- **Effective radius is defined as the ratio of expected volume of water of a sphere with radius *r* to the expected area of a circle of radius *r*.**



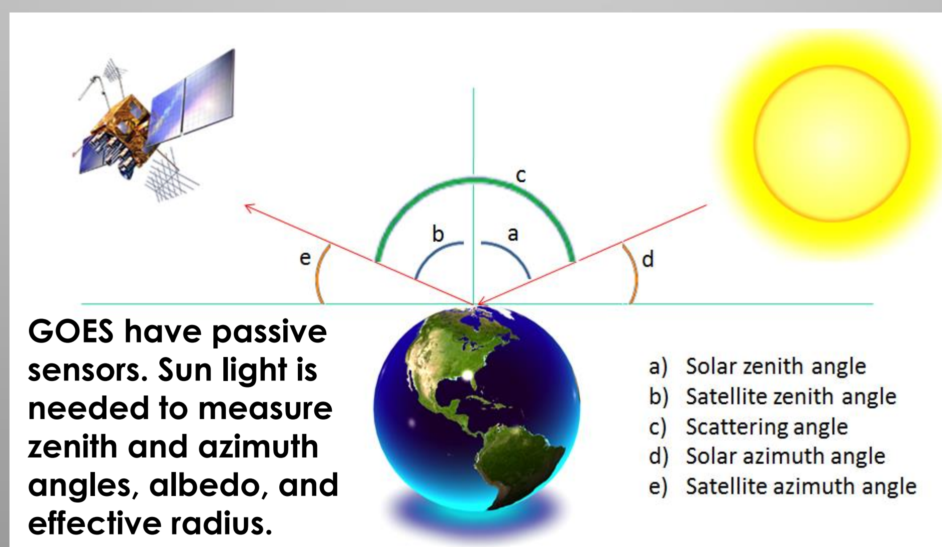


Simulation of a water DSD for which a=16 μm and b=0.13 μm.

$$\frac{Expected\ volume\ of\ rainfall}{That\ fall\ into\ an\ expected\ area} = \frac{E(r^3)}{E(r^2)} = ab\,\frac{\frac{1}{b}\Gamma\left(\frac{1}{b}\right)}{\Gamma\left(\frac{1}{b}\right)} = a$$

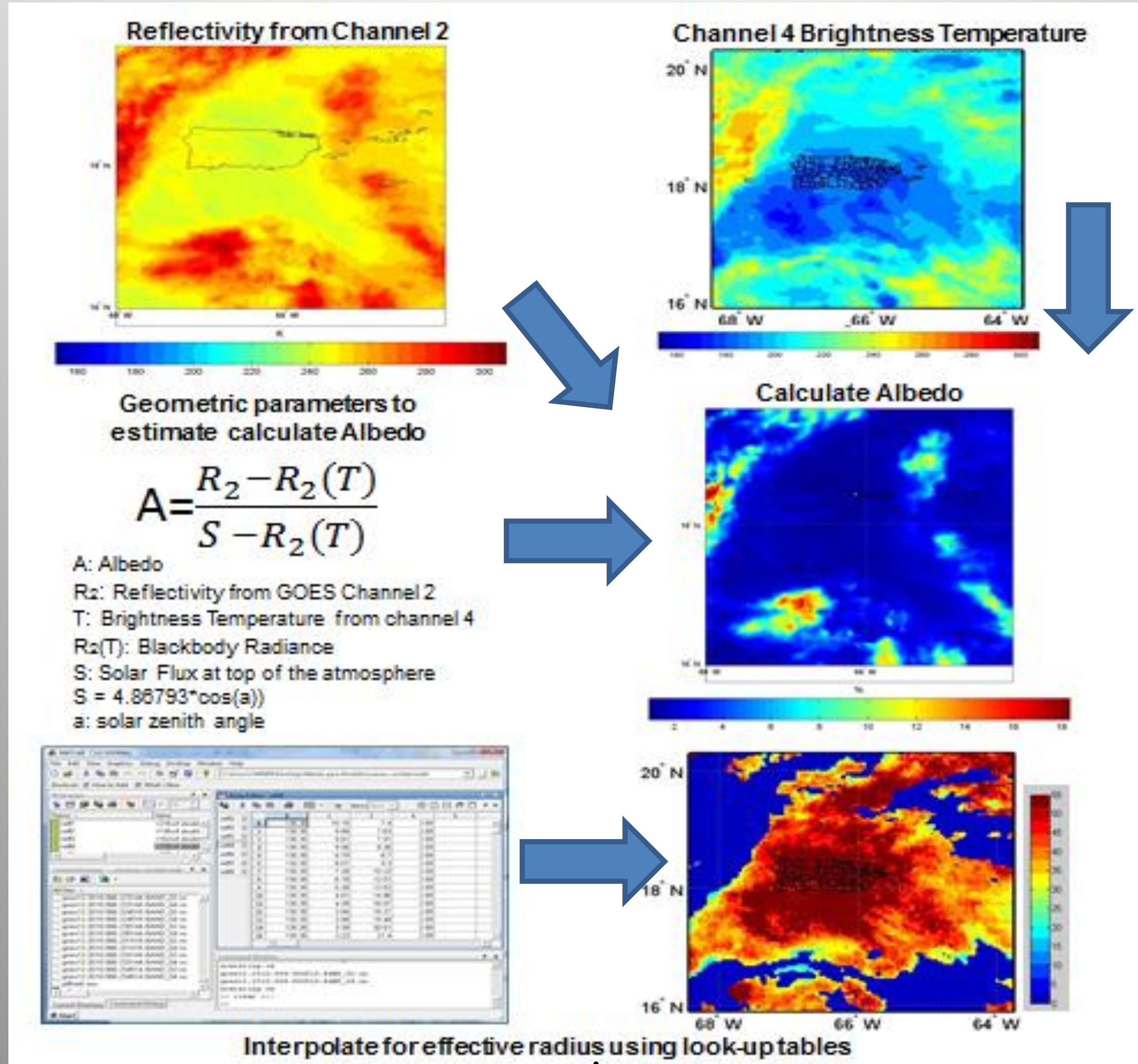
Algorithm to retrieve the effective radius of clouds

- Reflectivity of GOES channel 2 (T2 - 3.9 µm) and brightness temperature from GOES channel 4 (T4 - 10.7 µm) are computed.
- Geometric parameters of the satellite and sun positions are computed (zenith and scattering angle).
- Calculate the blackbody radiance at 3.9 µm with temperature T (which is estimated using the 10.7 µm brightness temperature), and calculate solar flux at the top of the atmosphere.
- Using the previous information the albedo of channel 2 is estimated.
- Finally, the radiative transfer theory is used to estimate the effective radius using albedo, solar zenith and scattering angles.



Geometric Parameters (angles)

Algorithm to retrieve the effective radius of clouds



Rainfall event in Puerto Rico, during October 27, 2007 at 19:30 UTC.

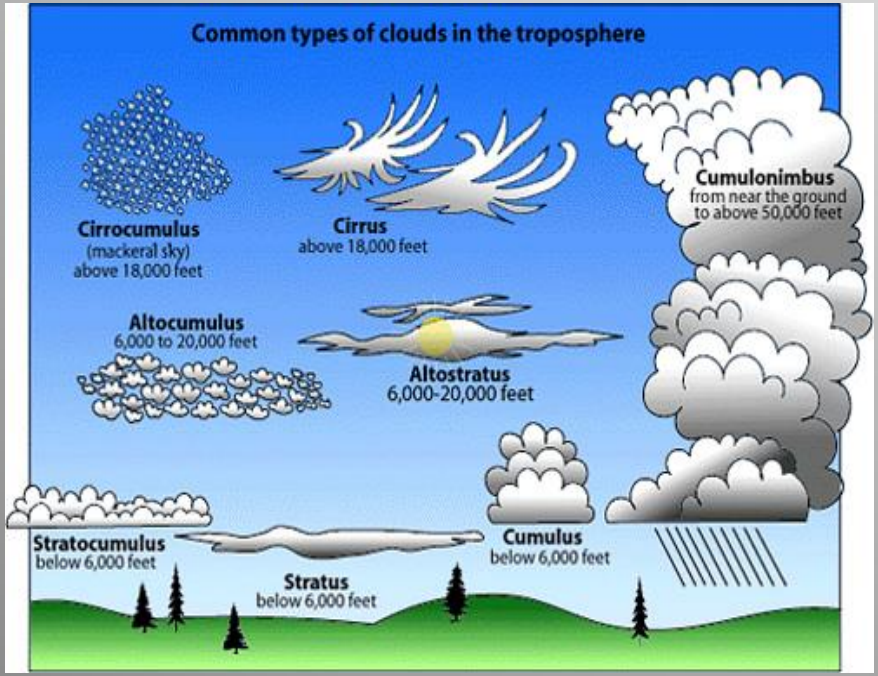
Objectives

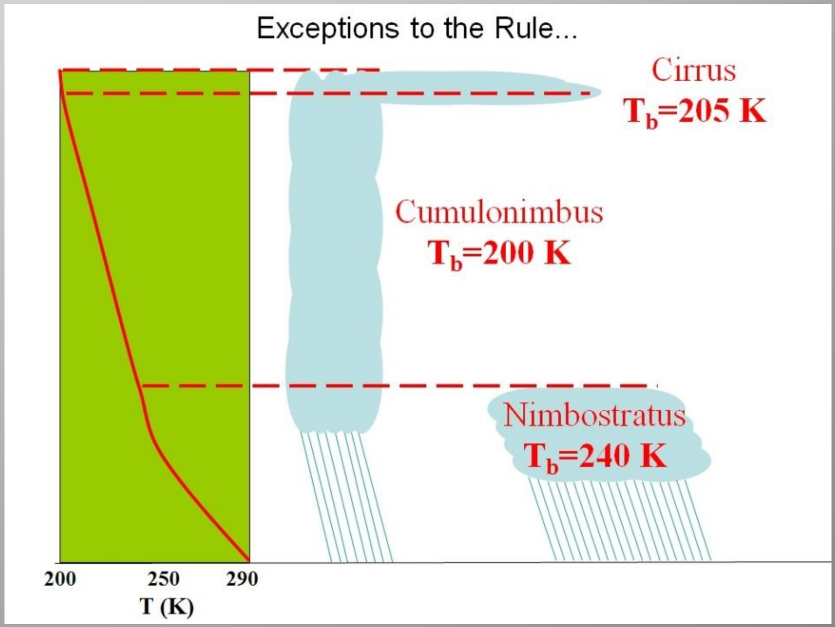
- This research focus on the evolution of effective radius by studying the sequence of radiative properties of convective cloud cells. The main objectives of this work are:

  1. To implement the Lindsey-Grasso's algorithm is used to study the evolution of the effective radius on the top of rainy clouds.
  2. Study the lifecycle of rainy clouds in Puerto Rico.
  3. The evolution of effective radius may be correlated with variations of rainfall intensity.

Tracking rainfall cells

- A useful parameter that helps us to determine the presence a possible rainy cloud is the brightness temperature, which is measured at the top of the cloud. The indicator is provided by GOES far infrared channel 4 (thermal band or T_4) at 10.7 μm. For instance when T_4 is lower than 200 K, exists a great possibility to identify a convective cloud cell.





Tracking rainfall cells

Detecting rainy cloud cells

- **Unsupervised cluster approach (Otsu Method) is considered to identify potential raining cells for each image.**
- **Two images are selected to obtain potential matching cells. *Temporal scale: 15 minutes* .**
- **Potential raining cells have 25 pixels/cell. *Spatial resolution: 4 km*.**

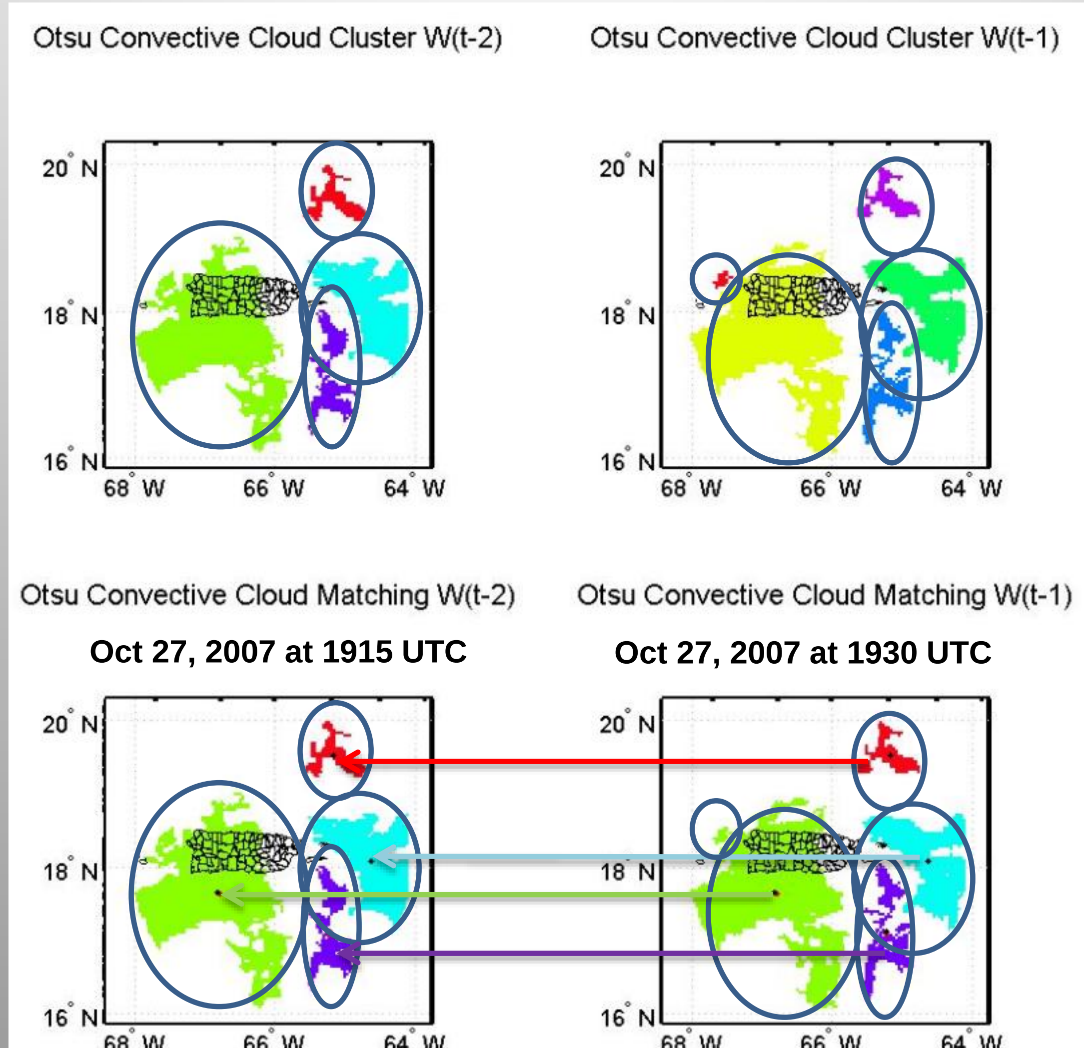
Estimating the cloud motion vector

- **Based on a convective brightness temperature threshold, shape and cell size, a cell centroid is determined.**

Prediction of rainy pixels

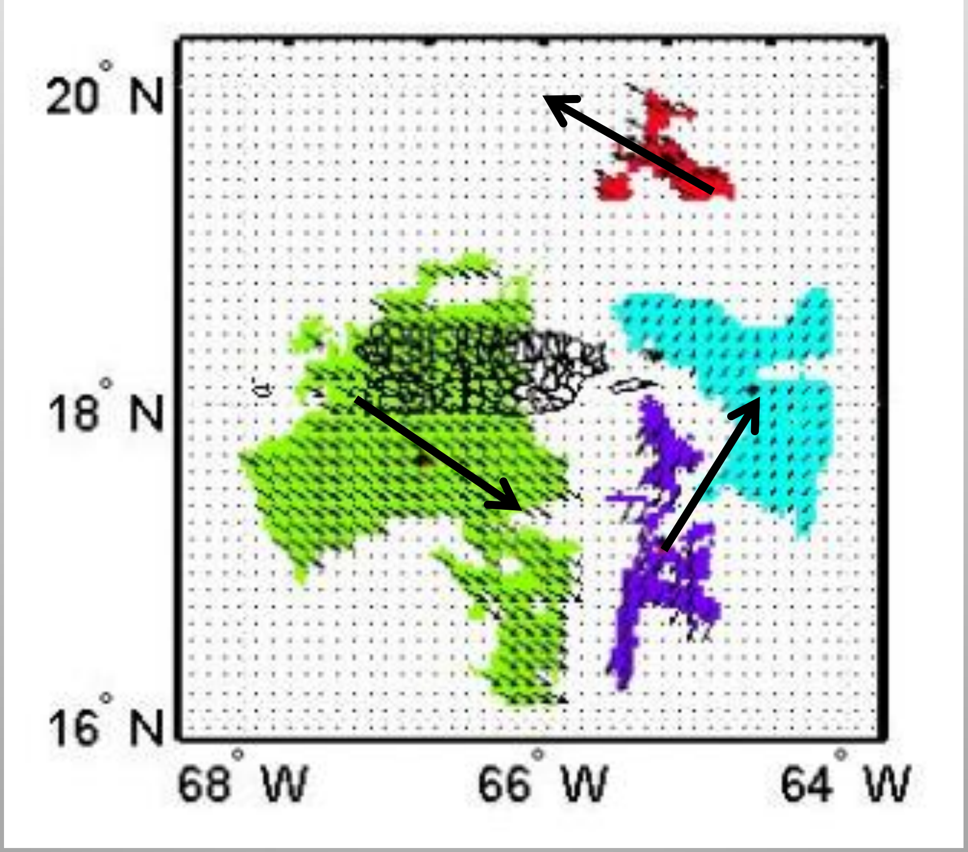
- **Using the equation of the line for two point, temporal tracking cell is estimated.**

Tracking rainfall cells:



Ostu's Cluster Match for all raining cells

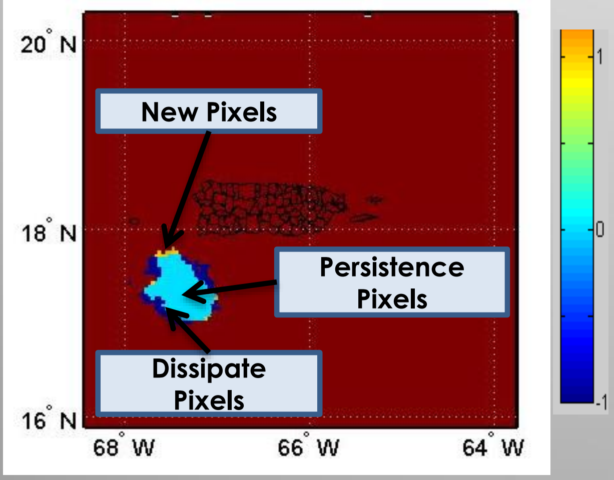
Cloud motion vector: Tracking



The motion vector for a rainfall event that occurred on October 27, 2007 (at 1930 UTC)

Evolution of Rainy Pixels

- Select convective cloud cells that occur every 15 minutes interval: GOES Images (I(t) and I(t-1))
- Identify the new, persistent, and dissipating rain pixels
- Assigned 1's for each low brightness temperature threshold pixel (T4 ≤ 200 ˚K) per cloud cell.
- Calculate the matrix difference D(t) = I(t) – I(t-1)



This figure shows convective cloud cell evolution, when new pixels satisfy low temperature threshold, other pixels persists cold condition and several pixels left convective potential.

$$h_t = \begin{cases} 1, & \text{new pixel} \\ 0, & \text{persistance pixel} \\ -1, & \text{dissipating pixel} \end{cases}$$

	1	2	3	4	5	6	7	8	9
1									
2			1	1	1	1			
3					1	1			
4					1	1	1		
5					1	1	1	1	
6					1	1	1	1	
7					1		1	1	
8							1		
9									

$W_{t=}$

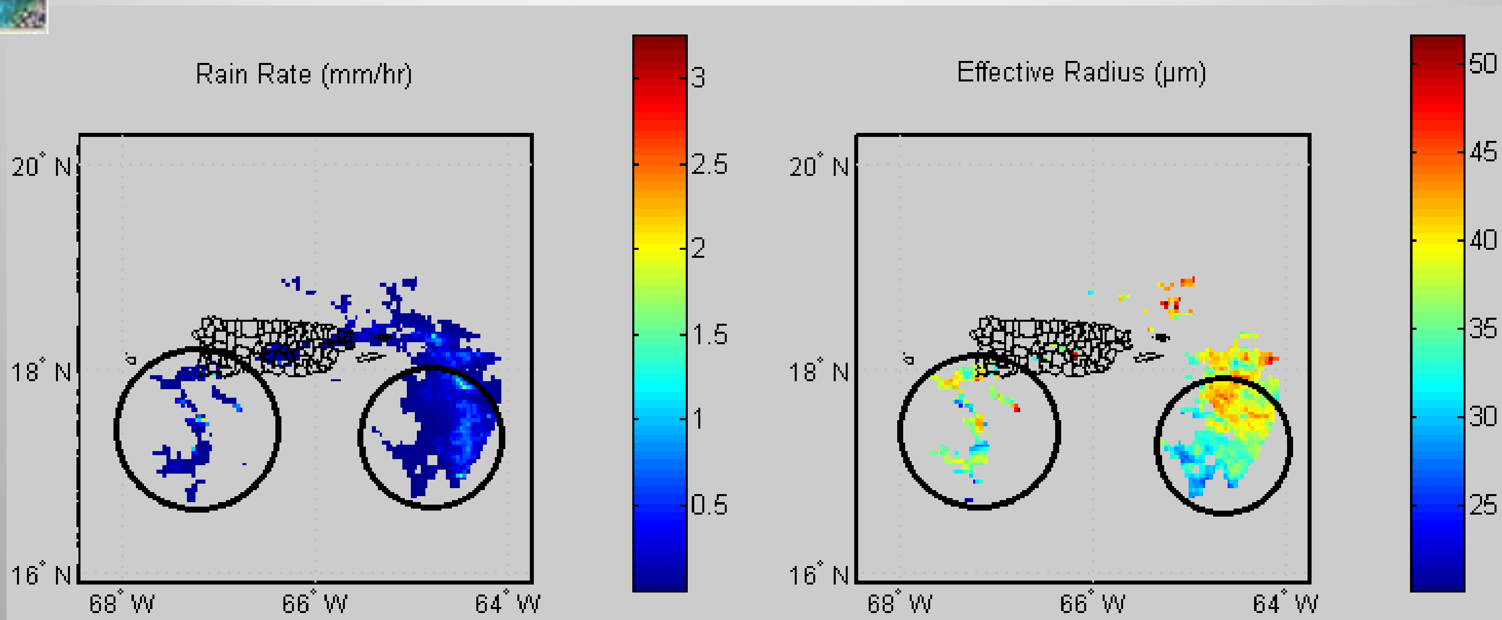
	1	2	3	4	5	6	7	8	9
1									
2		1	1	1	1				
3				1	1				
4				1	1	1			
5				1	1	1	1		
6				1	1	1	1		
7				1		1	1		
8						1			
9									

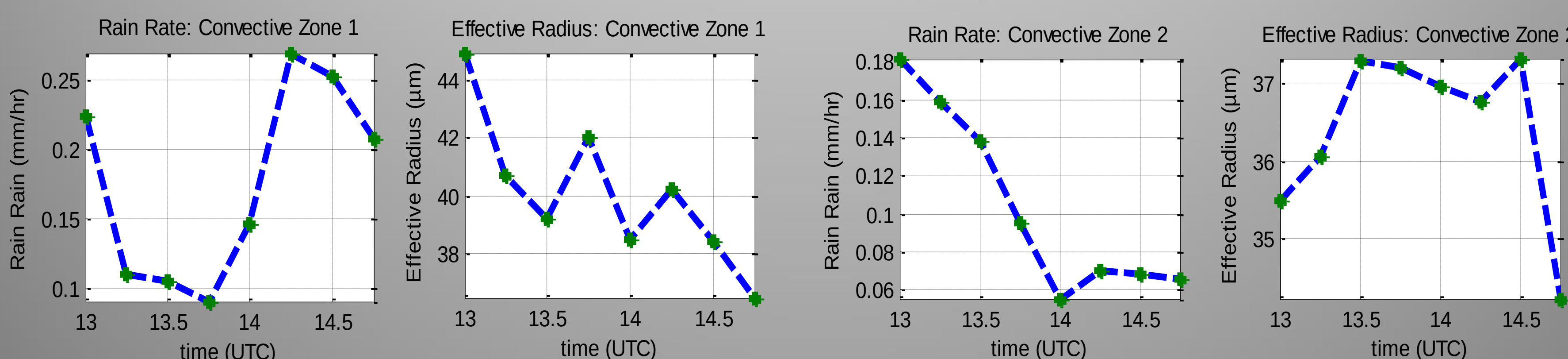
W_{t-1}

	1	2	3	4	5	6	7	8	9
1									
2		−1	0	0	0	1			
3				−1	0	1			
4				−1	0	0	1		
5				−1	0	0	0	1	
6				−1	0	0	0	1	
7				−1	1	−1	0	1	
8						−1	1		
9									

$H_t = W_t - W_{t-1}$

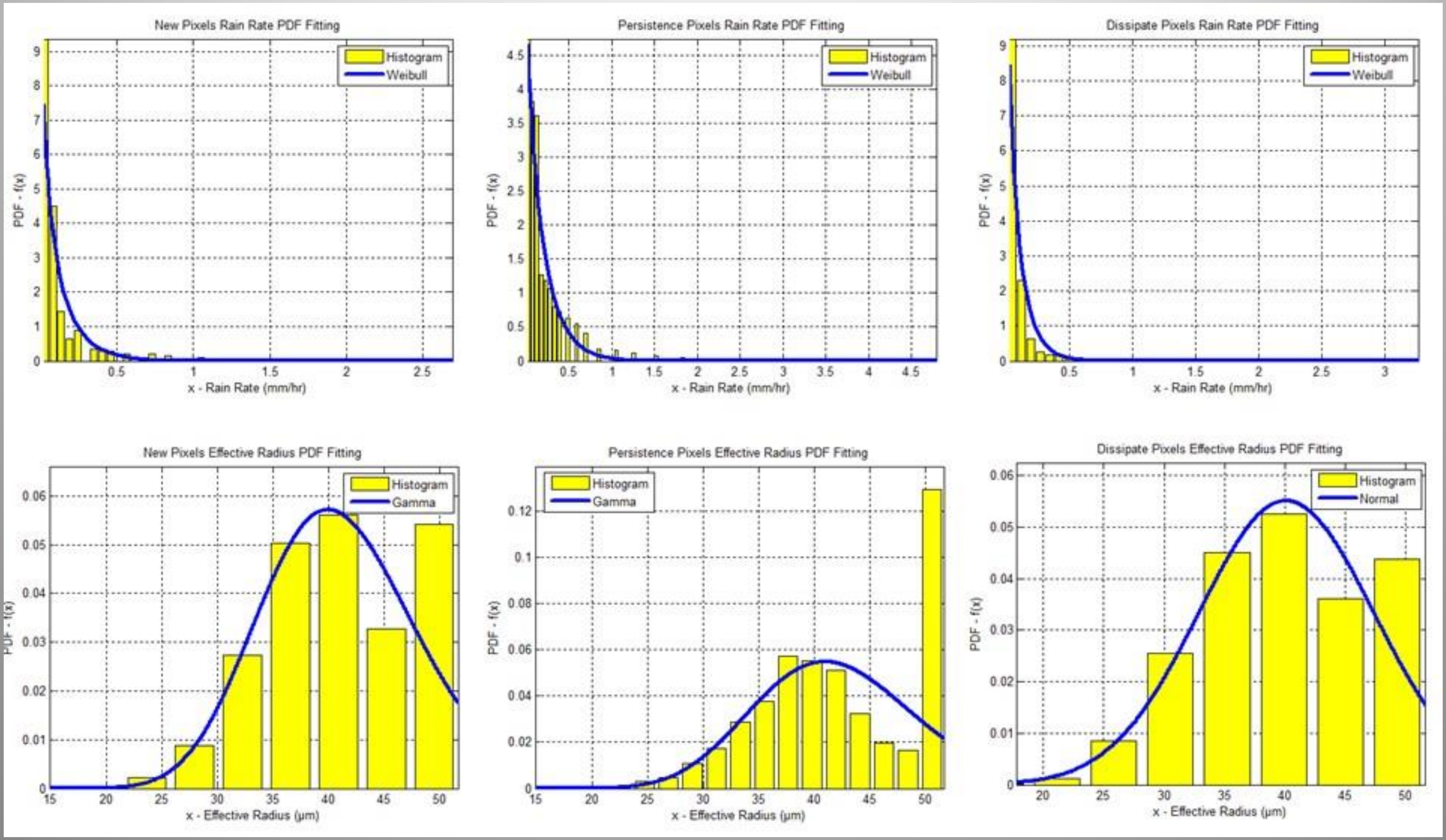
Effective Radius vs Rain Rate





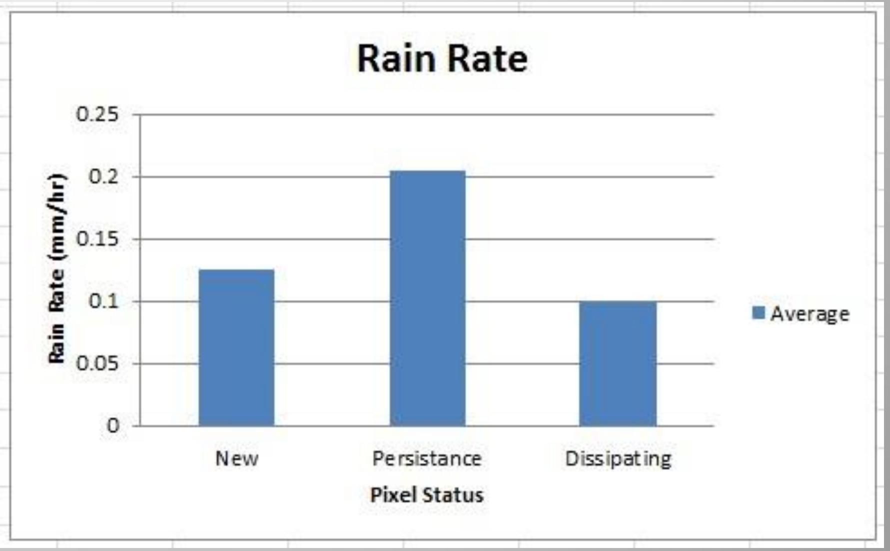
Rainfall event that occurred on October 27, 2007 (at 1300-1500 UTC)

Histogram of effective radius and rain rate

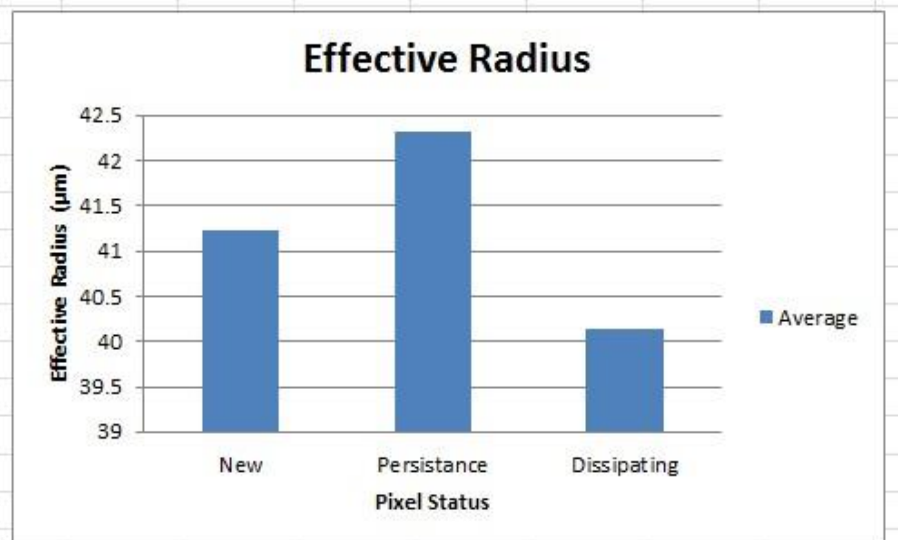


Characterization of effective radius and rain rate

Rain Rate (mm/hr)			
Descriptive Statistics	New	Persistance	Dissipating
Average	0.1251	0.2039	0.0989
Standard Deviation	0.2136	0.2745	0.1725
Median	0.0479	0.1032	0.0479
Mode	0.0222	0.0852	0.0222
Min	0.0222	0.0222	0.0222
Max	2.6929	4.7887	3.2625
Q1	0.0326	0.058	0.0269
Q3	0.125	0.2223	0.0852
IQR	0.0924	0.1643	0.0582
Skewness	4.7208	4.4852	6.3768
Kurtosis	33.7557	36.2334	65.7224
Coefficient of Variation	0.3648	0.3697	0.301



Effective Radius (μm)			
Descriptive Statistics	New	Persistance	Dissipating
Average	41.229	42.3116	40.1317
Standard Deviation	6.9114	7.2091	7.2372
Median	40.9158	41.596	39.9879
Mode	51.66	51.66	51.66
Min	14.9172	14.9172	17.8429
Max	51.66	51.66	51.66
Q1	36.3838	37.0698	35.0016
Q3	46.4919	50.8466	45.1316
IQR	10.1081	13.7768	10.13
Skewness	-0.0826	-0.1514	-0.0593
Kurtosis	2.369	2.092	2.3368
Coefficient of Variation	1.1586	1.2283	1.3051



Preliminary Results

- The Lindsey and Grasso algorithm was adopted to estimate effective radius at the top of rainy clouds.
- Rain Rate can be forecast using the motion vector and the evolution of the effective radius.
- The evolution of the rainy pixels were characterized by their probability distribution at three pixel stages.
- The effective radius for the new and persistent pixels follow the Gamma distribution, whereas the dissipating pixels follow the normal distribution. The mean value of the effective radius were: 40.1, 41.2, and 42.3 μm for dissipating, new, and persistence pixels, respectively.
- Effective radius can be used to develop the growth and decay function for rain cells.

Future Work

- The cloud motion vector algorithm will help to track the rain cells and be able to estimate the evolution of effective radius.
- The effective radius can be used to improve the estimation of the growth and decay of rainfall intensity and also to improve the short-term rainfall forecast.
- We plan to develop a real time algorithm to estimate the effective radius for tropical storms and hurricanes using GOES data.

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