Estimation of Effective Radius at Cloud Tops Using Satellite Data

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Agenda

• Introduction
• Drop Size Distribution
• Effective Radius Algorithm
• Rainy Cells Tracking Method
• Evolution of Rainy Cells
• Comparison Rain Rate and Effective Radius
• Preliminary Results
• Future Work
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 15 µm.

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

\[ n(r) = L r^{(3-b)} e^{-\left(\frac{r}{ab}\right)} \]

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

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

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 $r$.

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

GOES have passive sensors. Sun light is needed to measure zenith and azimuth angles, albedo, and effective radius.
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.
A useful parameter that helps us to determine the presence of 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 $\mu$m. For instance, when $T_4$ is lower than 200 K, there 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 ($T_4 \leq 200 \, ^\circ K$) 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 persist cold condition and several pixels left convective potential.
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)

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th>New</th>
<th>Persistence</th>
<th>Dissipating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.1251</td>
<td>0.2039</td>
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<td>Standard Deviation</td>
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<td>Mode</td>
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<td>0.0852</td>
<td>0.0222</td>
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<tr>
<td>Min</td>
<td>0.0222</td>
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<td>0.0222</td>
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<td>Max</td>
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<tr>
<td>Q1</td>
<td>0.0326</td>
<td>0.0588</td>
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<td>Q3</td>
<td>0.125</td>
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<tr>
<td>IQR</td>
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<td>Kurtosis</td>
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<tr>
<td>Coefficient of Variation</td>
<td>0.3648</td>
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<td>0.301</td>
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### Effective Radius (µm)

<table>
<thead>
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<th>Descriptive Statistics</th>
<th>New</th>
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<th>Dissipating</th>
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<tr>
<td>Min</td>
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<td>14.9172</td>
<td>17.8429</td>
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<tr>
<td>Max</td>
<td>51.66</td>
<td>51.66</td>
<td>51.66</td>
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<tr>
<td>Q1</td>
<td>36.3938</td>
<td>37.0698</td>
<td>35.0016</td>
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<td>Q3</td>
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<td>IQR</td>
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<tr>
<td>Skewness</td>
<td>-0.0826</td>
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<tr>
<td>Kurtosis</td>
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<td>2.092</td>
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<tr>
<td>Coefficient of Variation</td>
<td>1.1586</td>
<td>1.2283</td>
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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 $\mu m$ 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.
ACKNOWLEDGEMENTS

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