An algorithm for projecting radar rainfall rate

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Objectives

- To develop an algorithm for predicting one to three hours in advance the spatial distribution of rainfall rate.
- The proposed algorithm can be used to couple with a hydrological numerical model to predict flooding events
- The algorithm will use satellite or radar rainfall data to predict the rainfall field, and may be implemented to operate with GOES-R, which will be shuttled in 2015

The algorithm

- The introduced algorithm in this work includes two major components:
  - Cloud motion vector to advect the pixels of cloud cells
  - Empirical model to project the spatial distribution of the rainfall rate

Identification of convective core

- An image of radar reflectivity is converted into a sequences of pixels
- Discontinuous sequences in a reflectivity vector will indicate the presence of different rainfall cells
- Identifies the cloud convective core based in a sequence of radar images

Principle of displacement

$W_{t-1} =$

	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									

$W_{t=}$

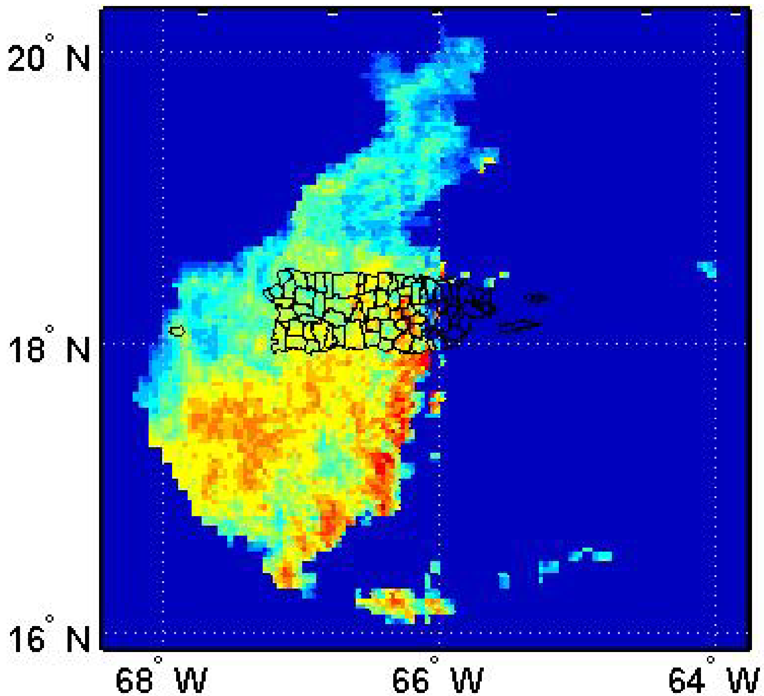
	1	2	3	4	5	6	7	8	9
1									
2			1	1	1	1			
3					1	1			
4					1	1	1		
5					1	1	1	1	
6					1	1	1	1	
7					1		1	1	
8							1		
9									

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

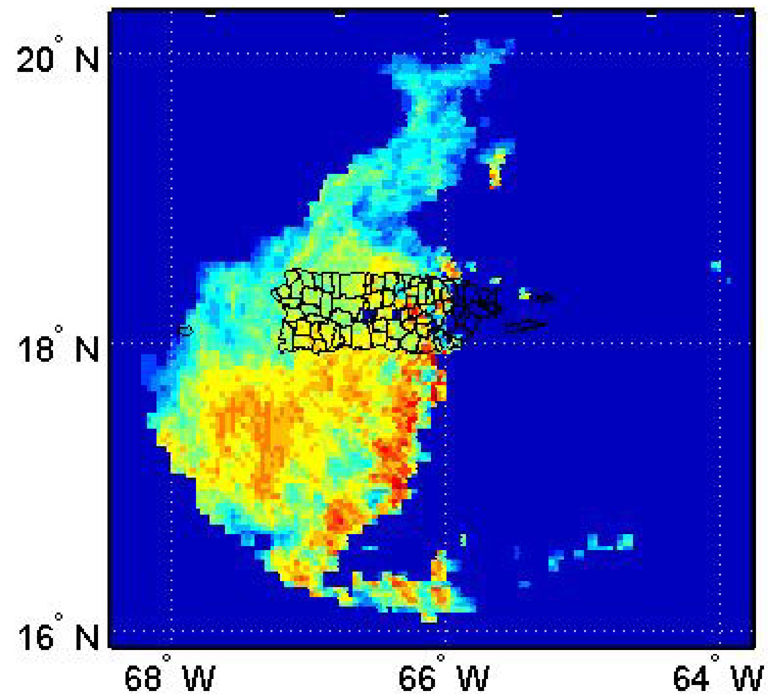
	1	2	3	4	5	6	7	8	9
1									
2		−1	0	0	0	1			
3				−1	0	1			
4				−1	0	0	1		
5				−1	0	0	0	1	
6				−1	0	0	0	1	
7				−1	1	−1	0	1	
8						−1	1		
9									

Two consecutive images of reflectivity

(15 minutes)

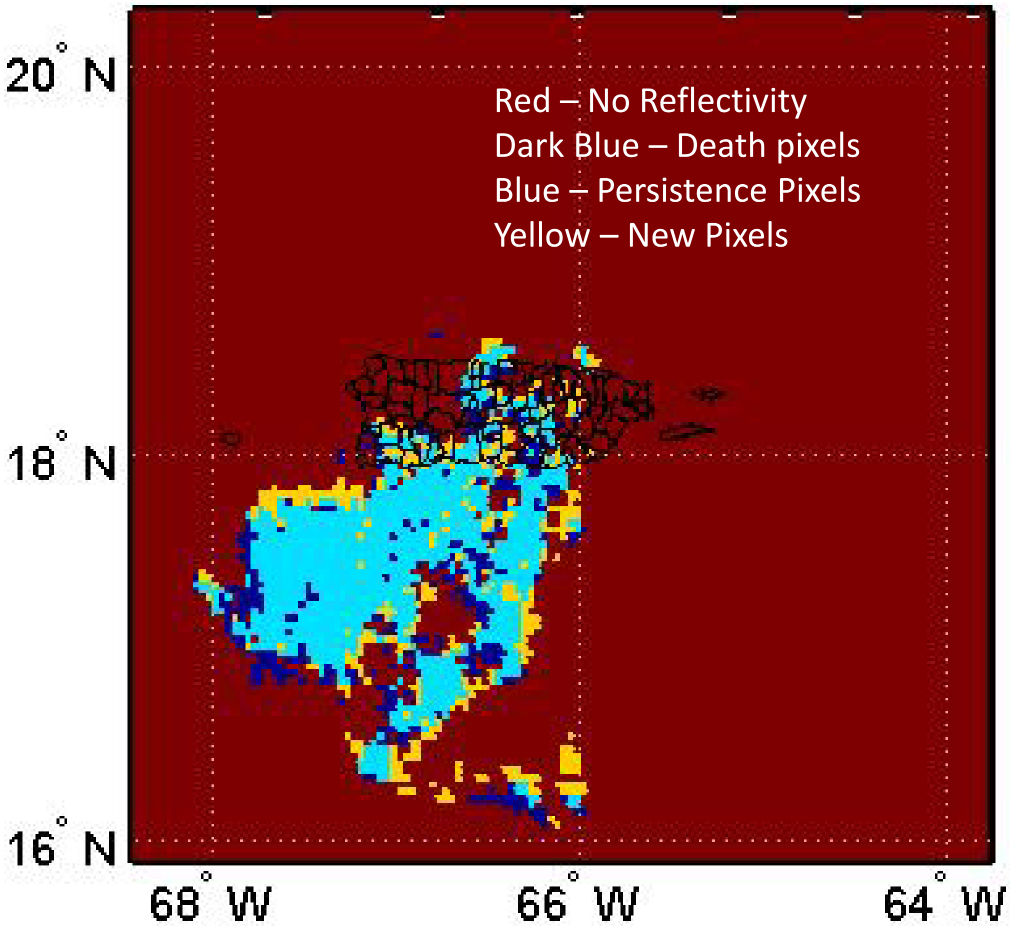


Reflectivity (dBZ) April 18, 2003 @ 1845 UTC



Reflectivity (dBZ) April 18, 2003 @ 1900 UTC

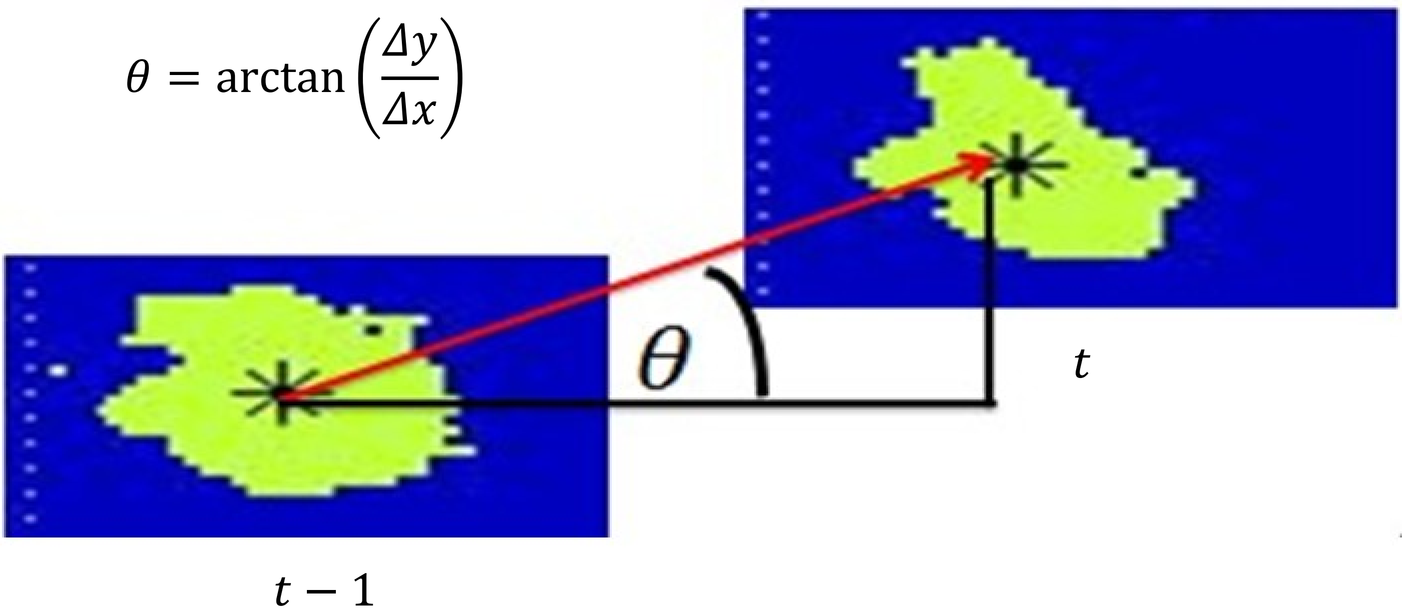
Reflectivity change (15 min)



The motion vector

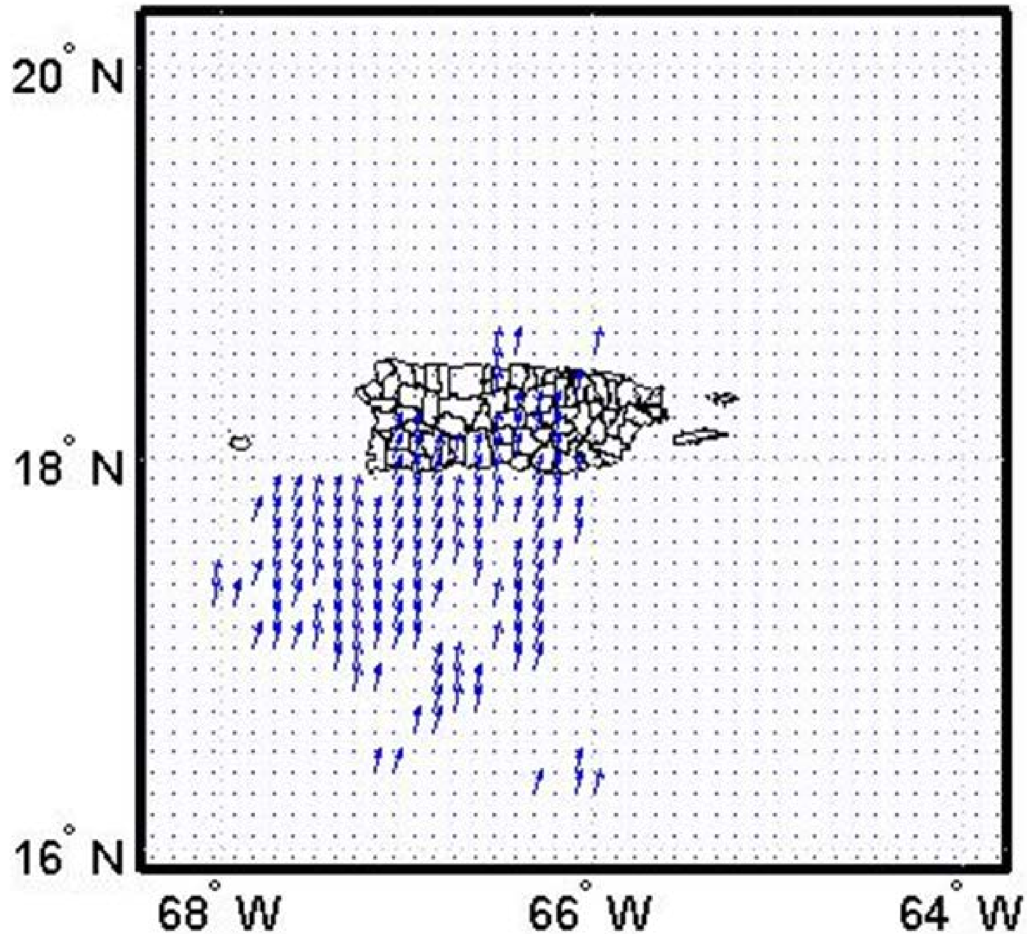
$$m = \sqrt{(\Delta x)^2 + (\Delta y)^2}$$

$$\theta = \arctan\left(\frac{\Delta y}{\Delta x}\right)$$



The motion vector for a rainfall event that occurred on October 27, 2007 (at 19:15 and 19:30 UTC)

The motion vector



The location of the motion vector for a rainfall event that occurred on April 18, 2003 @ 1900 UTC

Prediction of rainy pixels

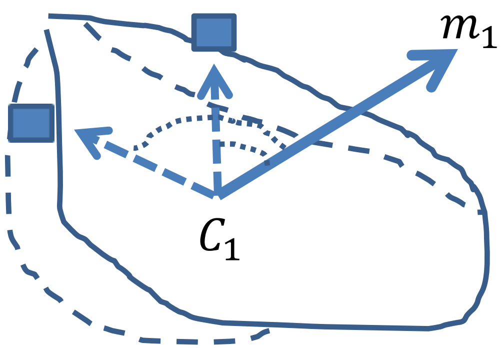
$$y = \frac{e^{\sum a_i x_i}}{1 + e^{\sum a_i x_i}} + \varepsilon$$

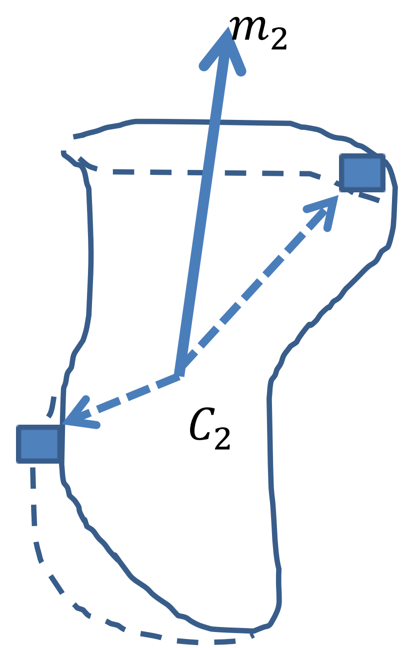
$$y = \begin{cases} 1, & \text{new rainy pixel} \\ 0, & \text{death pixel} \end{cases}$$

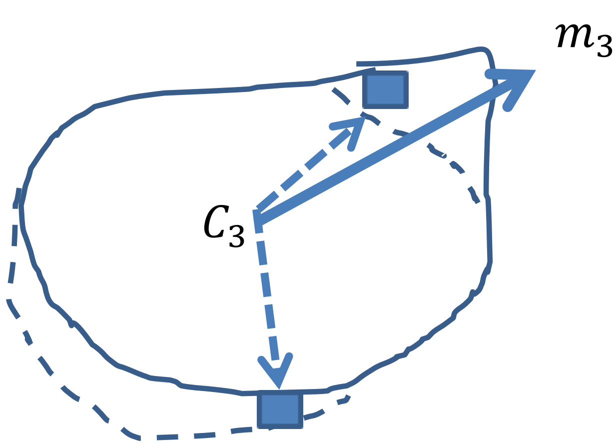
x_1= angle between pixel and motion vector

x_2 = distance between pixel and motion vector

x_3 =cloud cell velocity







Basis of rainfall prediction

- To estimate the potential rain rate at a given point in time requires considering the status of the clouds at the current time and also at consecutive previous points in time

- Reflectivity can be predicted by measuring the evolution of the cloud microphysical process and by using the wind vectors that advect the clouds

Rainfall prediction model

- The proposed model is a dynamical model that may be expressed as a linear function of reflectivity as follows:

$$Z_t(i,j) = a_0 + \sum_{K\in A} \sum_{L\in A} a_{KL} Z_{t-1}(i+K, j+L) + \sum_{M\in B} \sum_{N\in B} a_{MN} Z_{t-2}(i+M, j+N) + \varepsilon_t$$

$$A = \{0, \pm 1, \pm 2\}, \qquad B = \{0, \pm 1, \pm 2, \pm 3, \pm 4\}$$

- To reduce computational effort three consecutive images will be used to predict reflectivity.

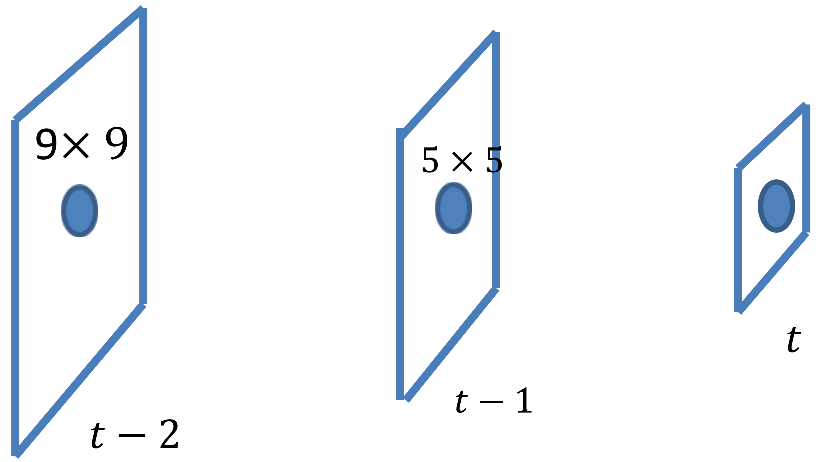
- The temporal variability is expressed by a subscript in the model, and the spatial variability is modeled by exploring the neighborhood of the underlying pixels and is represented by the variables in parentheses.

Prediction rainfall model

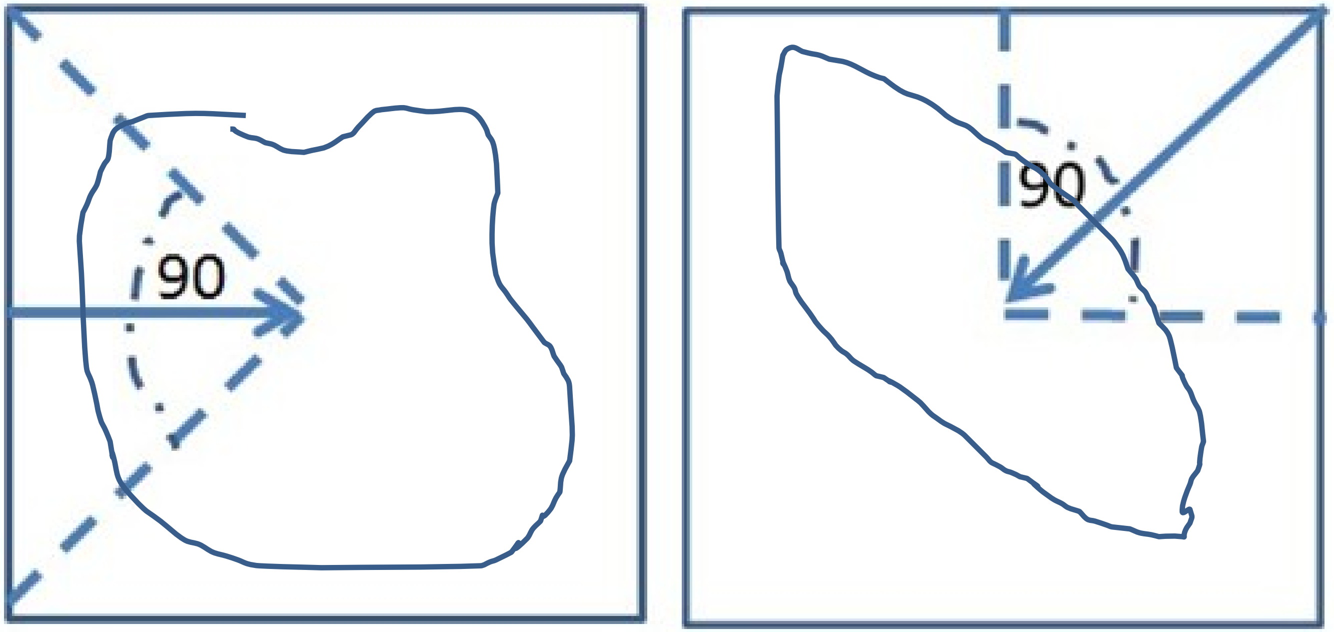
$$Z_t(i,j) = a_0 + \sum_{K\in A}\sum_{L\in A} a_{KL} Z_{t-1}(i+K, j+L) + \sum_{M\in B}\sum_{N\in B} a_{MN} Z_{t-2}(i+M, j+N) + \varepsilon_t$$

$$A = \{0, \pm 1, \pm 2\}, \qquad B = \{0, \pm 1, \pm 2, \pm 3, \pm 4\}$$

$(i+2, j-2)$	$(i+2, j-1)$	$(i+2, j)$	$(i+2, j+1)$	$(i+2, j+2)$
$(i+1, j-2)$	$(i+1, j-1)$	$(i+1, j)$	$(i+1, j+1)$	$(i+1, j+2)$
$(i, j-2)$	$(i, j-1)$	(i, j)	$(i, j+1)$	$(i, j+2)$
$(i-1, j-2)$	$(i-1, j-1)$	$(i-1, j)$	$(i-1, j+1)$	$(i-1, j+2)$
$(i-2, j-2)$	$(i-2, j-1)$	$(i-2, j)$	$(i-2, j+1)$	$(i-2, j+2)$



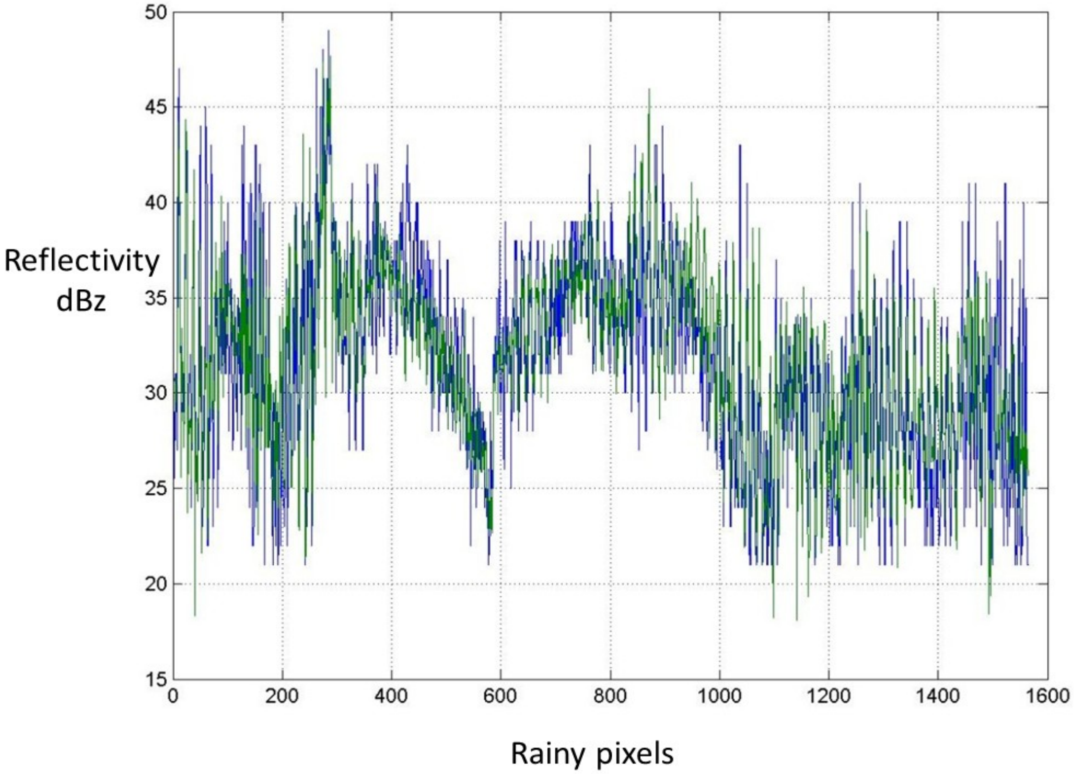
The model includes a large number of variables; however, the direction of cloud motion vector is used to activate the most relevant parameters



$$Z_t(i,j) = a_0 + \sum_{K\in A}\sum_{L\in A} a_{KL} Z_{t-1}(i+K, j+L) + \sum_{M\in B}\sum_{N\in B} a_{MN} Z_{t-2}(i+M, j+N) + \varepsilon_t$$

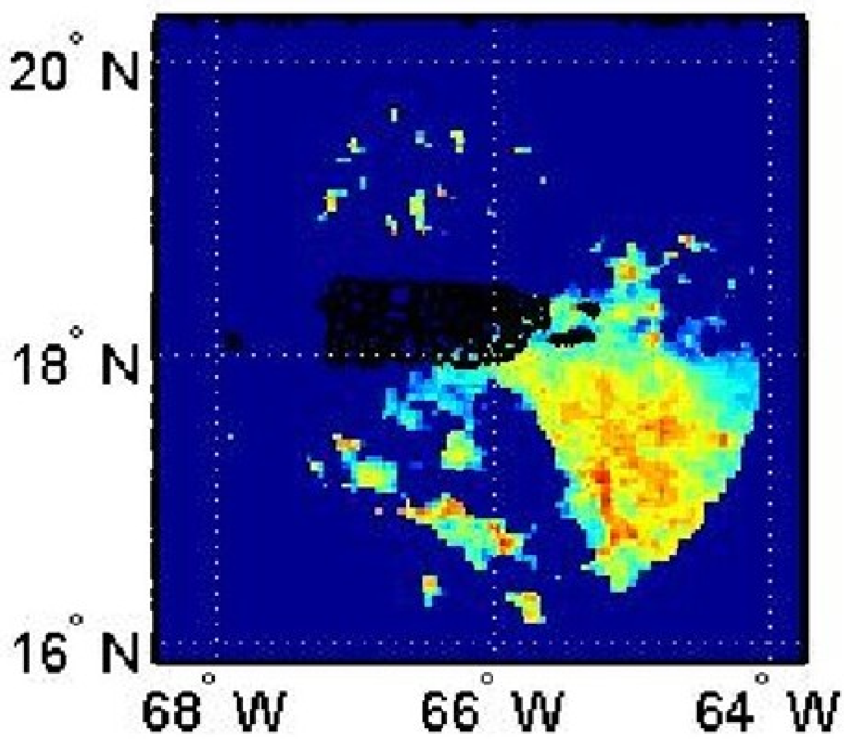
$$A = \{0, \pm 1, \pm 2\}, \qquad B = \{0, \pm 1, \pm 2, \pm 3, \pm 4\}$$

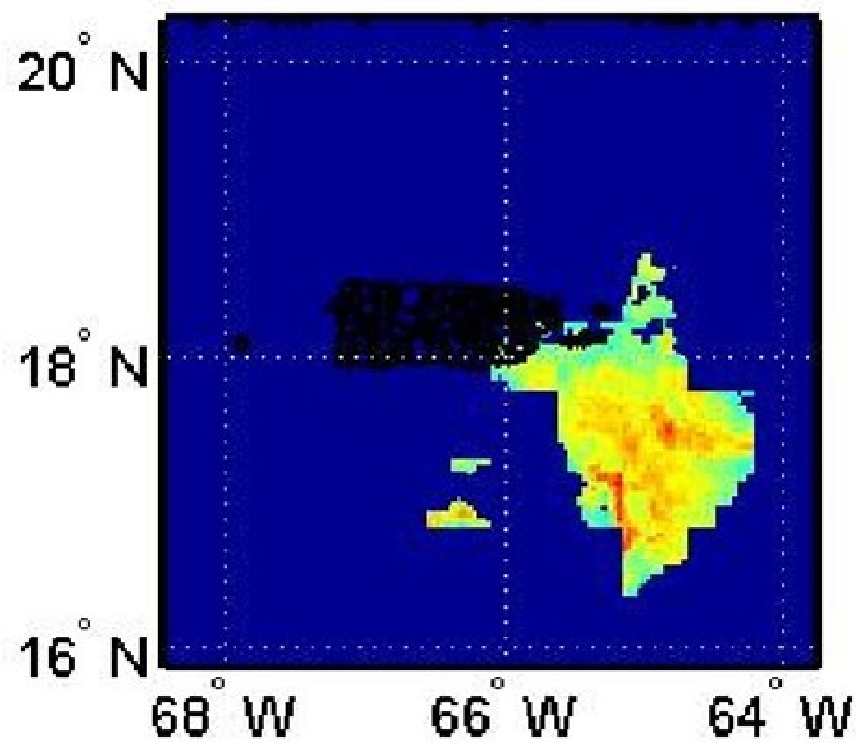
Observed vs predicted



Observed reflectivity in blue and predicted reflectivity in green (15 min lead time) on October 27, 2007 at 2:30 UTC (Hurricane Noel)

Preliminary results





Left panel shows observed reflectivity and right panel shows the predicted reflectivity

Summary

- The algorithm includes a convective cloud cell detection and cloud motion vector determination.
- The cloud motion vector is used to determine the advected pixels and the potential predictors that help to predict the rainfall distribution.
- To properly represent the spatial variability the radar covered area was divided into smaller regions and each region is used to develop a single regression model.
- The predictors are collected from the previous two rainfall images and forward selection algorithm is used to determine the best predictors in each region.
- The implemented lead time is 15 minutes and it is expected to predict up to 3 hours in advance. The entertained prediction algorithm is repeated the 15 minutes intervals up to accomplish the desired lead time.