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#### Partners or Cooperative Project: Partners

**Project Title:** Improving the Meso-gamma Scale Prediction in Puerto Rico Region: Observation Analyses and Numerical Experiments of Streamers

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# **SECTION 1: Summary of Project Objectives**

The aim of this project is to investigate a typical mesoscale feature that develops around the Puerto Rico area during the afternoon. This typical mesoscale feature is named a streamer. The name streamer is used locally. This phenomenon is better known across the Caribbean islands as line of clouds or wakes. A streamer is described as a cloud band that develops on the leeside of most of the Caribbean islands (Fig. 1). Riehl (1954) described the Puerto Rican streamer as a cloud roll of 20-40 miles long and ~1 mile width that could reach 2,000-10,000 ft. altitude. Notice that adjacent islands such as Vieques, Culebra and Mona Island are all part of the big island of Puerto Rico. A southeasterly or a general easterly flow (i.e., trade wind) must be present in association with streamers development. The objective of our research is to advance our understanding of the formation and development of streamers over Puerto Rico as well as the Caribbean islands. One particular area under consideration for this research is the northeast sector of Puerto Rico. A typical streamer event (i.e., observed roll cloud) could develop rapidly into a convective system in the northeast sector of Puerto Rico in the afternoon, which may last up to 4 hours. Subsequently, heavy precipitation can reach 4-5 inches in some cases. Most of the studies related to island's weather were based on the Hawaiian Islands, where the highest mountain peak is about 4.21 km. The highest peak in Puerto Rico is Cerro Punta in Jayuya, measuring 1,338 meters (4,390 ft) above sea level. This location is over the western interior center of the island (Fig. 2).

However, the main convective initiation in Puerto Rico is located at El Yunque rainforest which is surrounded by the second and third highest peaks in the island named Punta del Este and Punta del Oeste in the Municipality of Rio Grande, located towards the Northeast of the island (1051M). It seems that topography plays an important role in the

evolution of the streamers. High-resolution (i.e., meso-gamma scale) WRF simulations are conducted to investigate the life cycle of streamers as well as to investigate the role they play in the precipitation activity on the islands.

The calculations of the Froude number, nondimensional mountain height, and the critical mountain height are conducted to investigate the topography effect. By calculating these fields, the values will give further insight as to whether streamers or island wakes are occurring from the islands of Vieques and Culebra, as well as from mountains in Puerto Rico. The model simulations have been evaluated by comparing with the collected observed analyses including soundings, WSR-88D radar and satellite images for the selected case study. These comparisons will eventually aid in the overall goal of the understanding the formation of streamers and smaller convective systems on the island of Puerto Rico and to how the WRF model can help NWS forecasters in San Juan, Puerto Rico.

# **SECTION 2: Project Accomplishments and Findings**

A database was created with observation data for a 3-month period including June, July and August of 2006. Some streamers are capable of generating large amounts of precipitation, while others do not generate any precipitation at all. This characteristic makes the streamer's intensity forecast over Puerto Rico more challenging. This study focuses on 18 streamer cases found over the 3-month period. Atmospheric soundings, visible satellite and Doppler radar imagery were used to study these cloud rolls. The daily satellite imagery was compared with the Doppler radar imagery to estimate the days with streamer formation. These data were analyzed to find the atmospheric variables that clearly contribute (or lack thereof) in the formation of the streamers. Rain gauges and Doppler radar precipitation estimates also were taken into consideration with each streamer day to investigate their similarities and differences. Soundings were used to characterize the air mass present over the island before the formation of streamers. The low levels (i.e., 925, 850 and 700 hPa) mixing ratio was used to depict the moisture distribution in terms of the development of streamers (Fig. 3). The inversion height was calculated from soundings to better characterize the trade wind flow regimes (Fig. 4). For each streamer day found, a statistical analysis and a comparison between the mixing ratio and the inversion height level was computed.

Table 1 demonstrates the analysis of each streamer case from June to August of 2006. From the eighteen streamer cases detected over the 3-month period (19% of the period considered), six of these streamer cases (33% of the cases) were found to generate 1-5 inches of rain over northeast Puerto Rico. There were 55.6% of these streamers developed during August 2006. It is noteworthy that the mixing ratio at 925 hPa during August was about 1-2g kg<sup>-1</sup> higher than for the June and July cases. Figure 3 shows the time evolution of mixing ratio distribution. Comparing the mixing ratio values with the inversion height level and precipitation estimates, it was found that 66% of the streamer cases showed an inversion height level below or near 700 hPa. The streamers with the higher amounts of precipitation (approximately 1-5 inches) had moisture concentrated below the inversion. The mixing ratio values at 700 hPa for these "wet streamers" were around 4-6 g kg<sup>-1</sup>. The height of the inversion layer was found to have no relation with the formation of the streamers and their capacity of generate significant precipitation. For example: consider the streamer that developed during 9 June. This streamer was able to generate around 0.1-2.0 inches of rain over the northeast section of Puerto Rico and its small temperature difference at the inversion (comparing with the environmental temperature) at 1200 UTC was around 0.05°C. One possible drawback of this database is the lack of precipitation data for the area under consideration. However, a larger database (i.e., 3 months) could decrease the error by the analysis of more streamer cases.

Four of 18 streamer cases were chosen for further investigation using the high resolution Weather Research and Forecasting (WRF) model. The case study presented in this report was a convective system that formed on the western side of Puerto Rico on 27 June 2006. Figures 5 and 6 show the composite satellite and radar images used for this study. A noteworthy feature was the convective activity developed within 3 hours. It can be seen that the entire western half of the island was affected by the development of the convective cells from 1745 UTC to 1825 UTC (Fig. 5). Another noteworthy feature was the thin cloud line that formed over the northeastern part of the island, which was a footprint of a streamer. The observed sounding valid at 1200 UTC 27 June from San Juan is shown in Fig. 7. The precipitable water as indicated from the sounding was about 6.2 cm. The easterly flow extended from the surface up to 600 hPa in this case. Figures 8a and 8b show the simulated radar reflectivity at 1800 UTC from domain 1 (i.e., 4 km grid spacing) and domain 2 (i.e., 1 km grid spacing), respectively. The simulated results demonstrate that the model was able to recapture the observed radar reflectivity (cf. Fig. 6), especially the 1 km grid spacing domain showed multiple convective cells on the west coast of Puerto Rico. Nevertheless, the model simulation also recaptured the streamer developed in the northeastern part of the island. Figures 9a and 9b show the simulated 10m wind field over the northeastern part of the island at 1500 UTC and 1800 UTC 27 June 2006, respectively. The low mountain (i.e., El Toro) demonstrated the blocking effect. Subsequently, a line of convergence formed on the leeside of the mountain, which was consistent with the satellite imagery analyses (cf. Fig.5). Another streamer case demonstrated in this report occurred in August 20, 2006. Figure 10 shows the 10-m wind evolution within 3 hours that depicted the transition of the land-sea breeze as well as the convergence over the leeside of the mountain in northeast part of the island.

Overall, the streamer formation is caused by wind convergence at the leeside of the mountains where the Rain Forest is located. The topography plays an important role in the evolution of the streamers. In addition, wind channeling, daytime heating and sea breeze convergence along the northeast part of the island; also plays an important role in the formation of streamers. In general, the simulation results suggest that high-resolution modeling is necessary to better resolve the development of streamers as well as the smaller scale convective activity.

## **SECTION 3: Benefits and Lessons Learned: Operational Partner Perspective**

Partnerships between university researchers and the NWS operational forecasters are of paramount importance. It is with these relationships that develop new operational techniques to better forecast and model our daily weather. Specifically, the relationship between the FIT and the NWS San Juan, Puerto Rico have fostered a study to investigate the effects topography has on tropical island weather. Namely, "streamers" that develop downwind along the higher peaks of Puerto Rico and the USVI during specific flow regimes may locally affect the weather across the islands and surrounding coastal waters. This study has identified a few cases where these "streamers" may have initiated further weather across the forecast area of the NWS San Juan. That said, further investigation and better, high resolution modeling could be employed to identify the effect of El Yunque and the surrounding high peaks of adjacent islands have on the formation of "streamers." Further studies may help to identify the causative effects specific wind flow patterns may initiate, assisting operational forecasters with advancing lead time on tropical rainfall.

## SECTION 4: Benefits and Lessons Learned: University Partner Perspective

The collaboration between the Florida Tech and the NWS Puerto Rico office provides an important benefit to advance our understanding of the processes of fine scale circulations as well as the lower boundary forcing (i.e., topography) over Puerto Rico region. Three graduate students (Melissa Sheffer, Evelyn Rivera, Jackie Shafer and Hector Dr Lima) had been partially supported by this project. Evelyn Rivera is currently working in NWS/Miami. Melissa Sheffer is working on the modeling study of convective initiation in Puerto Rico. She is planning to graduate by the spring semester of 2008. The partnership indeed provides my institution the opportunity to contribute to our discipline in a significant way.

# **SECTION 5: Publications and Presentations**

Chiao, S. and coauthors, 2007: Numerical studies of the Streamers in Puerto Rico region. In preparation.

Rivera, E., S. Chiao, O. Bermudez, and I. Matos, 2008: Characterization of the Streamers over the Caribbean. The 88<sup>th</sup> AMS Annual Meeting, New Orleans, LA, January 20-24, 2008.

Sheffer, M., S. Chiao, and I. Matos, 2008: Modeling studies of lower topography induced convective activities in Puerto Rico. The 88<sup>th</sup> AMS annual meeting, New Orleans, LA, January 20-24, 2008.

Rivera, E., and S. Chiao, 2007: Streamers over the Caribbean. Florida Academy of Sciences Annual Meeting. St. Petersburg, FL, March 16-17, 2007.

## **SECTION 6: Summary of University/Operational Partner Interactions and Roles**

The Florida Institute of Technology and NWS Puerto Rico interacted on this project constantly. For the past year we had phone conferences as well as email exchanges. One student from FIT (Evelyn Rivera) had visited WFO at San Juan several times to discuss the strategy about data collecting and processing, which was the most important step for this project. We were able to present some preliminary result to the Florida Academy of Science annual meeting in March. In January 2008, two presentations will be delivered in the Tropical Meteorology Special Symposium of the AMS annual meeting in New Orleans. Both university and operational partner share the co-authorship of those 2 presentations. Currently, the PI is working on a manuscript to summarize our findings from this project. Over all, this project is a first step towards to advance our understanding of some local weather events in Puerto Rico. The partnership of FIT and WFO San Juan could lead to better understand the fundamental scientific as well as forecasts issues in simulating local severe weather events.



Figure 1: Example of streamers occurred in May 14, 2006.



Figure 2: Map of Puerto Rico and the islands of Vieques and Culebra.







**Figure 3:** The time evolution of mixing ratio calculated from soundings from San Juan, PR in June, July and August 2006 valid at (a) 925 hPa, (b) 800 hPa , and 700 hPa.











**Figure 5:** Composite imagery of GOES satellite images from June 27, 2006 for the time period between 1545 UTC and 2145 UTC.



**Figure 6:** Composite imagery of WSR-88D radar reflectivity from June 27, 2006 for the time period between 1545 UTC and 2145 UTC.



TJSJ 2006/06/27 1200Z

Figure 7: Observed sounding analysis from San Juan, PR valid at 1200 UTC 27 June 2006.



**Figure 8:** The WRF model simulated maximum radar reflective and 10 m wind field valid at 1800 UTC 27 June 2006 (a) 4 km grid resolution domain, and (b) 1 km grid resolution domain.



**Figure 9:** The simulated 10-m wind field from the 1km grid spacing domain valid at (a) 1500 UTC 27 June and (b) 1800 UTC 27 June 2006. Colored shadings represent the northeastern terrain feature in Puerto Rico.



**Figure 10:** The simulated 10-m wind field from the 1km grid spacing domain valid at (a) 1200 UTC 20 August and (b) 1500 UTC 20 August 2006. Colored shadings represent the northeastern terrain feature in Puerto Rico.

Date	Inversion	MIXR	MIXR	MIXR	Precipitation
(2006)	(hPa)*	(925 hPa)	(850 hPa)	(700 hPa)	(inches)
Jun 9	820, 650	13.97	9.4	2.82	0.1-2.0
Jun 19	700	14.34	12.52	6.73	0.1-1.5
Jun 25	770	12.68	8.43	4.34	0.1-0.75
Jun 26	790	13.35	9.92	4.81	0.1-0.75
Jul 16	1000, 790	13.35	9.15	4.67	0.5-1.0
Jul 20	1000, 750	14.9	11.19	4.27	0.1-0.5
Jul 21	1000, 600	12.76	10.95	7.08	0.5-2.0
Jul 22	1000, 500	15.29	11.27	8.33	0.25-0.75
Aug 6	730	16.09	13.29	9.38	1.5-4.5
Aug 8	780	15.68	12.69	4.08	1.25-6.0
Aug 9	790	16.19	12.04	4.67	0.10
Aug 12	1000, 820	14.8	7.44	4.21	Missing
Aug 16	1000, 640	16.71	14.18	6.18	0.1-2.25
Aug 21	1000, 650	15.48	10.61	8.93	0.1-0.75
Aug 23	800	16.4	11.34	5.5	No rain
Aug 27	1000, 750	15.68	9.02	4.74	0.1-0.3
Aug 28	760	13.53	11.72	4.54	0.1-0.5
Aug 29	730	15.78	12.94	3.51	0.1-2.5

 Table 1: Analysis of each streamer case during June, July and August 2006

\* Blue colored heights represent small inversions (change in temperature less than 0.10°C)