Spatiotemporal Disruption of Mobile Communication Patterns in the New York Metro Area by Hurricane Irene

Christopher Small[1], Richard Becker[2], Ramon Caceres[3], Simon Urbanek[2]

[1]Lamont Doherty Earth Observatory, Columbia University, New York, NY, USA.
[2]AT&T Labs, 1 AT&T Way, Bedminster, NJ, USA.
[3]AT&T Labs, 33 Thomas Street, New York, NY, USA.

The anticipated impact of Hurricane Irene on the New York Metro area prompted widespread preparations in the days preceding the arrival of the storm. Evacuation orders were issued for over 370, 000 people in New York City (NYC) alone. The mass transit system connecting NYC to northern New Jersey, Long Island and southern Connecticut suspended operation the day before the storm arrived. Throughout the metro area, numerous bridges, tunnels and parkways were closed in anticipation of flooding. Although the impacts of the storm were less than expected in the NY Metro area, the preparations and closures severely disrupted regular patterns of activity. We attempt to quantify some of these spatial and temporal disruptions from spatiotemporal analysis of mobile communication patterns before, during and after the storm passed through the NY Metro area on the morning of 28 August 2011.

We conduct a spatiotemporal analysis of 10, 871 time series of voice-call and text-message volumes transmitted through a spatial network of cellular antennas in the NY Metro area at hourly intervals between 1 February 2011 and 31 January 2012. We grouped into a *sector* the set of antennas that reside on the same cellular tower and point in the same compass direction, yielding 10,871 sectors in the area within a 50-mile radius of Times Square. For each sector and each hour of each day, we gathered counts of how many new voice calls (call volume) and how many text messages (SMS volume) were handled by the antennas in that sector. This study used only the anonymous and aggregate data just described. We did not have access to any Personally Identifying Information (PII) for users of the network.

Combined Empirical Orthogonal Function (EOF) analysis of the call and SMS volume data characterizes the spatial and temporal patterns in the both data sets. A Principal Component (PC) transformation of the combined call start and SMS daily volumes indicates that ~86% of combined variance is associated with the temporal mean spatial distribution of volumes within the NY metro area (Fig. 1). Five low order dimensions of the transformed data account for 95% of total variance. The temporal EOFs of these low order dimensions reflect both weekly and seasonal cycles as well as changes in network configuration (addition and removal of antennas).

Beyond the geographic distribution of high and low call volumes, the most conspicuous feature in the data is the weekly cycle. The correlation matrices in Fig.

2 clearly show both the strong weekly periodicity and the seasonal cycle associated with movement through the NY Metro area. The weekly pattern is so strong (correlation > 0.95) that anomalous spatial patterns on holidays clearly stand out in the correlation matrices. However, the largest disruption to the spatiotemporal correlation is clearly the arrival of Hurricane Irene (by then downgraded to Tropical Storm) on 28 August (Julian day 240). The strength of the weekly correlation, and the magnitude of disruption of storm preparations, are both apparent in the actual correlations shown in Fig. 3. The normally high (> 0.95) correlation of each day to the same day one week prior begins to break down on Friday 26 August as call and SMS volumes begin to increase to anomalous levels throughout the NY Metro area. The increased slope with high linear correlation indicates that the spatial pattern is initially retained as volumes begin increasing in proportion to prior week volumes. However, on Saturday, 27 August the spatial correlation begins to break down as volumes move spatially within the network. By the time Irene makes its NYC landfall at Coney Island around 9am on Sunday 28 August the spatial structure of the network reaches maximal disruption with an overall spatial correlation of ~0.7 (compared to the prior Sunday). This disruption persists somewhat the following Monday as the correlation has not yet returned to its typical 0.97.

The spatial structure of the disruption can be seen in volume anomaly maps comparing of daily volume sums with sums from the same day, one week prior. Regional maps clearly show conspicuous drops in call volumes in near-coastal zones with corresponding increases in specific inland locations throughout the region. These changes are superimposed on a background of anomalously high volumes throughout most of the region reflecting increased activity associated with the storm event itself. In addition to the expected volume drops in coastal zones, some interesting patterns emerge. Volume deficits are most apparent on the barrier islands on the Atlantic shores of Long Island and New Jersey. No consistent changes are seen on the Connecticut or New York shores of Long Island Sound. Surprisingly little change is observed on the Atlantic coast of Staten Island – despite its proximity to the path of the storm. Several conspicuous volume deficits are also seen in some coastal areas of NYC – but not in strong correspondence with areas for which evacuation orders were issued. One conspicuous anomaly is seen in volume increases in the vicinity of Long Beach on the barrier island east of JFK airport on and even before 28 August. Volumes at Long Beach increased abruptly 5 days prior to Irene's arrival and persisted during the storm and for at least a week afterwards.

Comparisons of hourly volume time series for different locations provide additional detail on disruptions preceding and recovery following the storm. Almost all time series in Fig. 4 show anomalously large volume increases on the Friday preceding the storm, followed by precipitous decreases in volume throughout the Saturday leading up to the storm's arrival. Differences in absolute and relative volumes on 28 August following Irene's landfall give some indication of the extent to which coastal areas may have been evacuated – at least by users of the cellular network under study. Some areas maintain significant volume through the storm while many show almost no activity on the day of the storm and for days after.

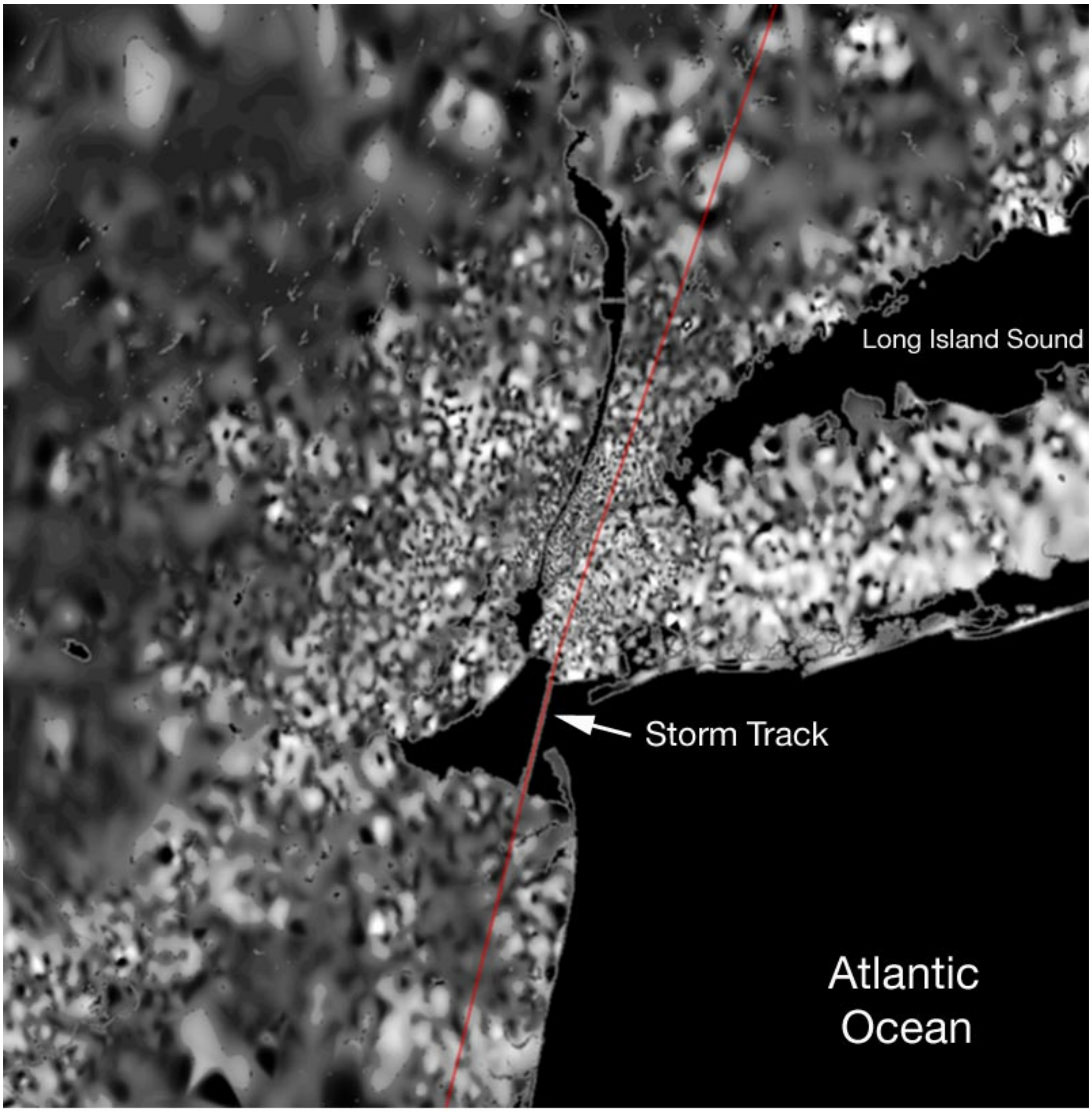

Figure 1 Temporal mean call start + SMS text volume map of the New York Metro area. Lighter shading corresponds to higher volumes. Gray coastline vector distinguishes barrier islands with low volumes.

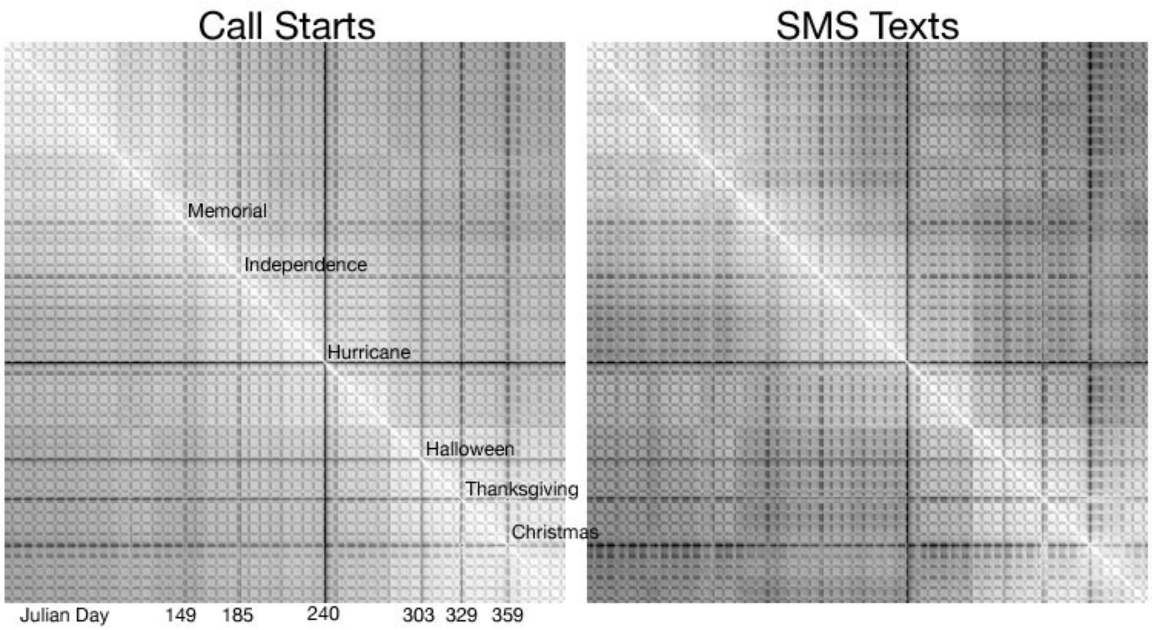

Figure 2 Correlation matrices for call starts and SMS messages in the NY metro area in 2011. Each matrix shows the spatial correlation of 10871 daily volume sums from 2/1/2011 to 1/31/2012. Correlations range from 0.7 (black) to 1.0. Lower correlations result from greater deviations from the spatial distribution of volumes that characterizes the typical weekly pattern.

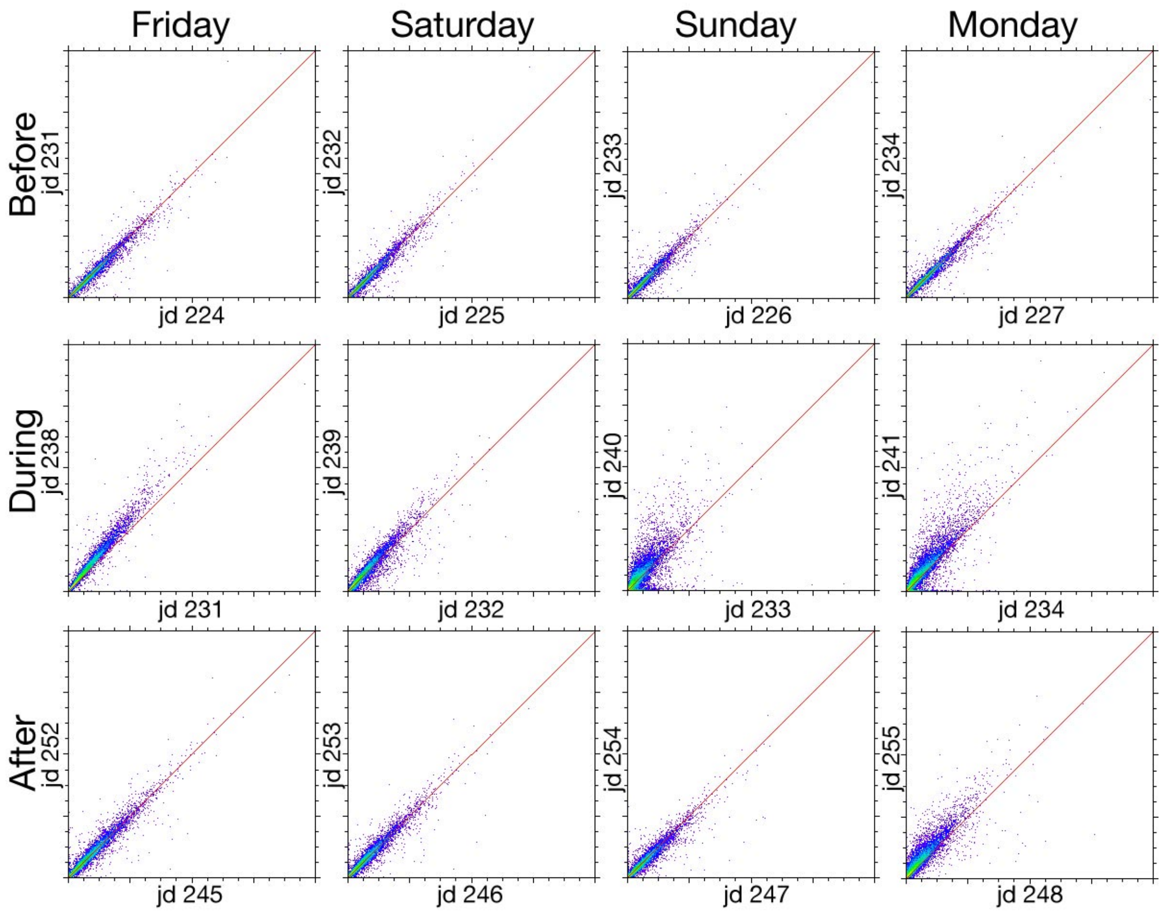

Figure 3 Spatial correlation disruption by Irene. Weekly correlations of combined call start and SMS volumes. Each density shaded scatterplot shows the week to week spatial correlation of normalized volumes on the same day of the week. Scales range from -3 to 60 standard deviations on each plot. Tropical Storm Irene made landfall on Coney Island around 9am on August 28th (jd 240).

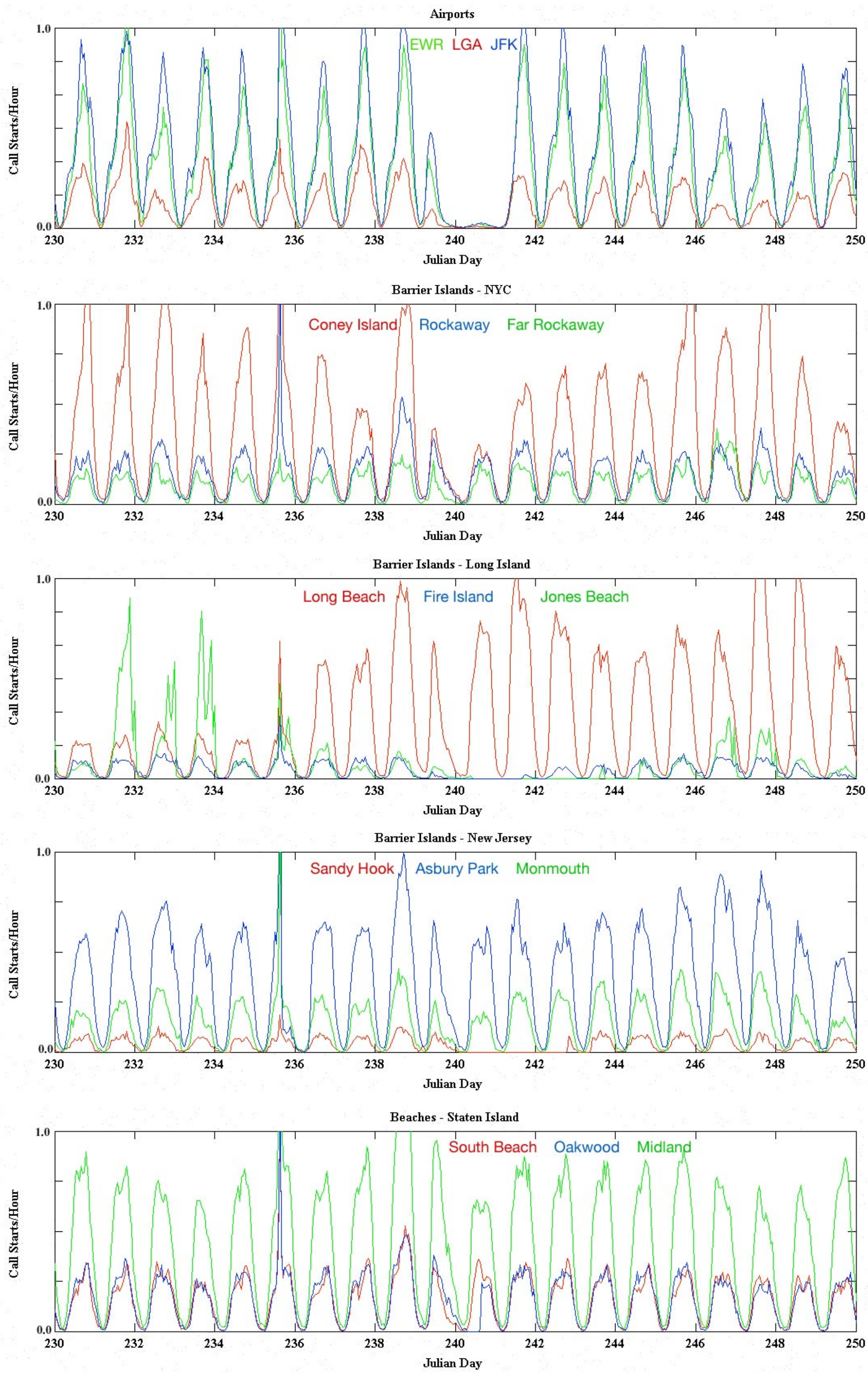

Figure 4 Hourly call start volumes (normalized) for representative antennas in coastal areas. Airport closures on 28 August (jd 240) show most pronounced drop and immediate recovery.