Spatial analysis of rain rates for tropical cyclones affecting Madagascar and Mozambique

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Introduction

When tropical cyclones (TCs) affect Madagascar and Mozambique, they can cause floods that impact livelihoods in these economically disadvantaged countries (e.g., Reason and Kelbí 2004, Reason 2007, Brown 2009, Matyas and Silva 2013, Silva et al. 2015, Arvelo and Lin 2016). Research has been conducted on the genesis and tracks of TCs in this region (e.g., Jury et al. 1999, Vittat et al. 2003, Hoskins and Hodges 2005, Chang-Seng and Jury 2010, Ash and Matyas 2012, Matyas 2015), and rainfall variability in general (e.g., Williams et al. 2007, Reason 2007). To better understand the evolution of rainfall events, it is important to calculate the distance that the rain field of a TC extends away from its circulation center to determine where and when rainfall will be received. We employ a Geographic Information System (GIS) to analyze rain rates every 3 hours from the TRMM 3B42 data for 38 TCs 1998-2015. Observations are limited to those when the system is a tropical entity of at least tropical depression intensity located between 33° S-68° E. After determining the extent of rainfall in each direction-relative quadrant, we investigate relationships with 1) storm location as a) interaction with topographical boundaries may lead to spatial clustering of high or low rainfall extents, and b) rain rates for TCs in the Mozambique Channel are lower than for other TCs (Chang et al. 2014), which could lead to a smaller extent, and 2) storm intensity as more intense TCs should have a larger extent of rainfall (Confort et al. 2004).

Data and Methods

- Linearly interpolate IBTrACS 6-hr TC positions and intensity to every 3 hours
- Obtain TRMM 3B42 data for 38 TCs producing rainfall over study region 1998-2015
- Using a GIS, contour 1.0mm/hr rain rate (Fig. 2a) (Confort et al. 2004, Chang et al. 2014)
- Convert smoothed contours to polygons and determine centroid
- Include polygons with centroids <500 km from TC center (Jiang et al. 2011)
- Calculate extent of rainfall outward from center each 1° (Fig. 2b)
- Average measurements in each quadrant (NW, SW, SE, NE) (Guo and Matyas 2016)
- Determine if any part of a polygon is over land by intersecting rainfall polygons with land
- Note if TC center is over Southwest Indian Ocean (SWIO) or Mozambique Channel (MC)
- Calculate time since formation and since rainfall
- Check for spatial clustering of extent using Optimized Hot Spot Analysis in ArcMap
- Explore relationships with intensity using Jonckheere-Terpstra Test for Ordered Alternatives and Spearman’s Rank Correlation Analysis; test for spatial patterns using Optimized Hot Spot Analysis
- Use Man-Witney U tests to examine differences in quadrant extent for rain fields over water vs. land and over the SWIO vs. MC

Whether the storm center is over the SWIO or MC and whether or not the rain fields intersect land make a difference in terms of rain field extent (Fig. 4). Rain fields are bigger over land and over the SWIO. Seven of 8 Mann-Whitney U tests confirm the differences are statistically significant (p<0.02) for all quadrants, with the exception being the NE quadrant for over-water locations. The western quadrants are the largest as TCs over the SWIO produce rain over Madagascar, and smallest for TCs not producing rain over land when located over the MC, thus orography may aid rainfall development on the windward side and hinder it on the leeward side of Madagascar. The hot spot analysis examines this further.

Optimized Hot Spot Analysis; Relationship w/ Intensity

The hot spot analysis shows that TC rain fields have large extents in all quadrants (Fig. 5a-d) as they approach Madagascar, especially on the leading western side. While orography may play a role, this region also features higher maximum sustained winds (Fig. 5e). However, higher wind speeds occur in the southern MC and the western side is smaller west of Madagascar, suggesting that winds off of the leeward side of the tropical region may limit rainfall extent. The NE quadrant is large for TCs over parts of the MC where intensity is also lower. The SE quadrant has the weakest spatial clustering of TC extent (Table 1). This might be attributed to storm motion as it is the left rear quadrant for many TCs, but the left front quadrant for others where winds speed are highest. The proximity to a deep tropical moisture source may explain why extents are larger in the northern (equatorward) part of the study region. Results of the Jonckheere-Terpstra test confirm that extent increases with each class of intensity. Correlations of $\rho_{Max}$, with rain field extent are significant with 99% confidence. Future work will explore relationships between orography, intensity, and moisture as well as incorporate vertical wind shear and storm motion.

References


