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 Keibel 2004, Reason 2007, Brown 2009, Matyas and Silva 2013, Silva et al. 2015, Arivelo and Lin 2016). Research has been conducted on the genesis and tracks of TCs in this region (e.g., Jury et al. 1999, Vitart 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 product 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 longitudes 33° - 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 (Lonfat et al. 2004).

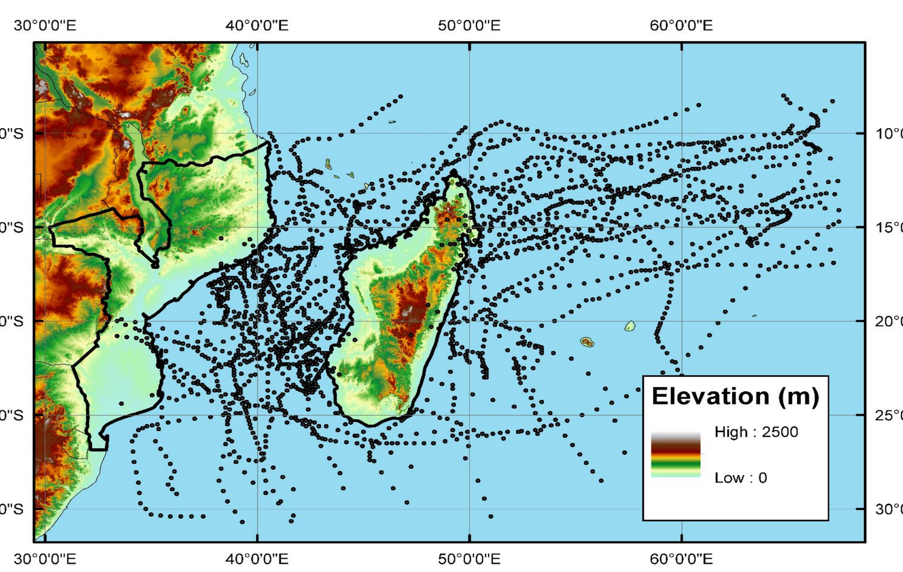


Fig. 1. Study region, elevation, and 3-hourly TC positions. Mozambique and Madagascar are outlined in black.

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 1.0 mm/hr rain rate (Fig. 2a) (Lonfat 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 outwards 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 landfall
- 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 Mann-Whitney U tests to examine differences in quadrant extent for rain fields over water vs. land and over the SWIO vs. MC

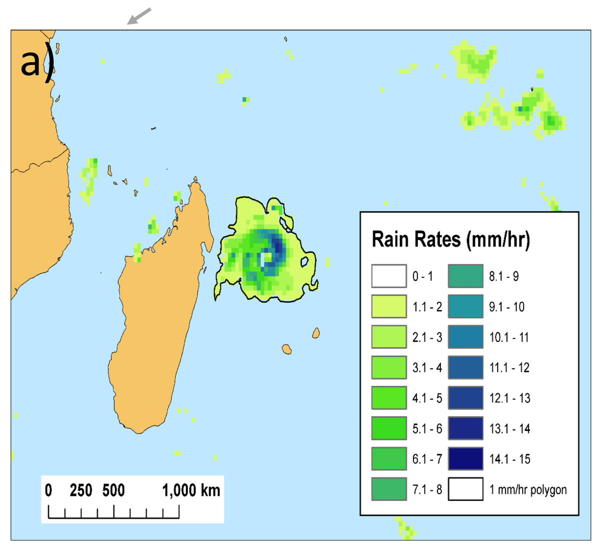
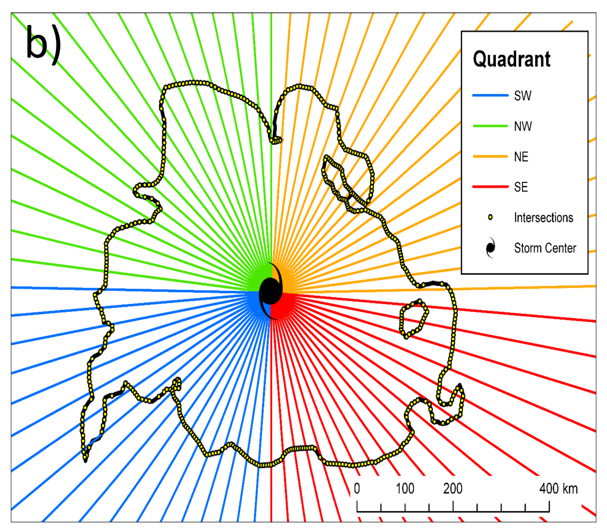


Fig. 2. a) Rain rates with 1 mm/hr polygon for Hudah (2000) and b) zoomed in view at same time showing extent lines (every 5° for display purposes) and polygon intersections every 1° divided into quadrants. The farthest intersecting point along each 1° line is used to calculate extent.



Characteristics When Rain Fields First Intersect Land

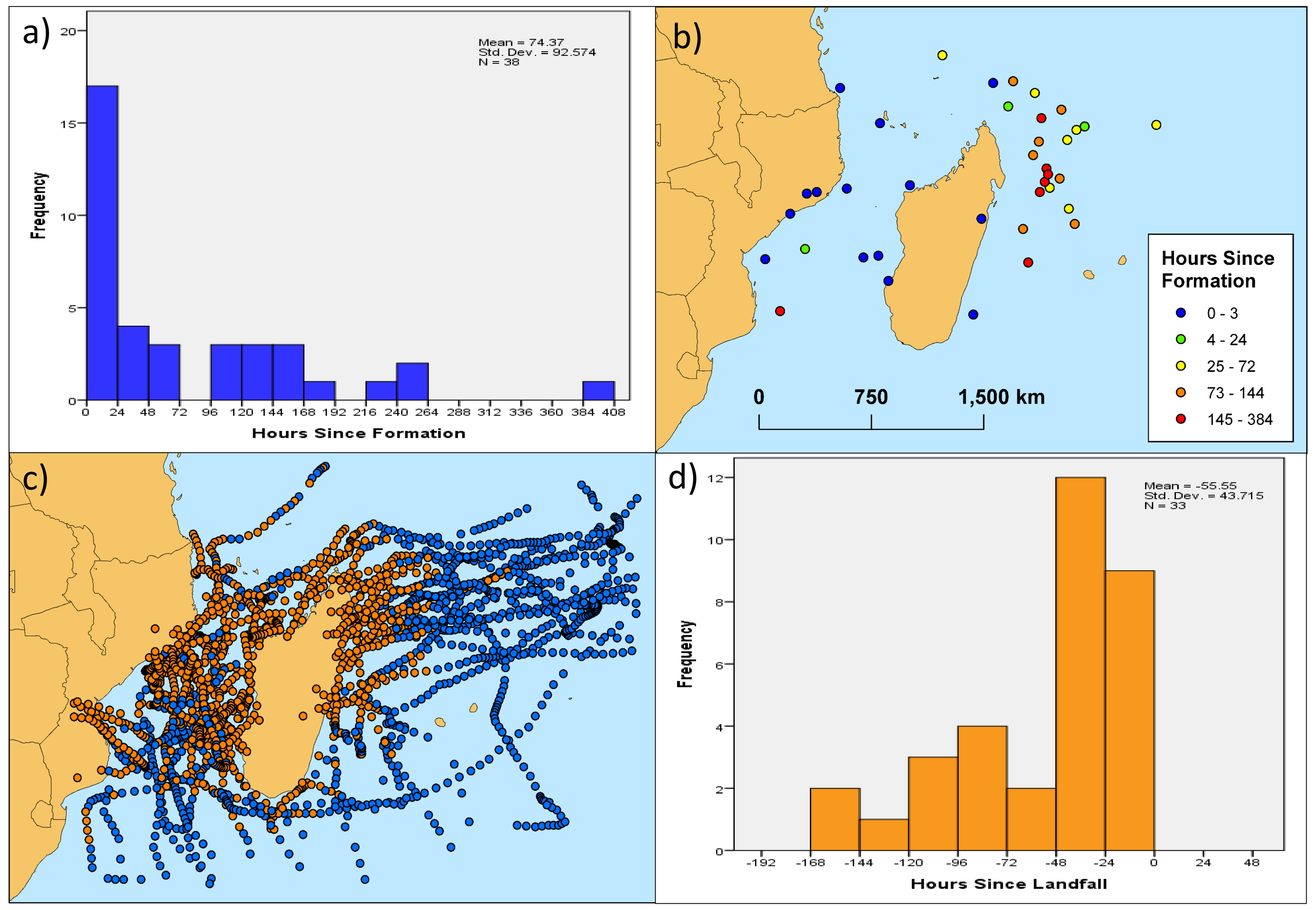


Fig. 3. a) Hours since formation and b) location of center when TC first produces rainfall over land. c) TC positions where rainfall occurs over land (orange) or not over land (blue), and d) time since landfall when rainfall first occurs over land (negative indicates time before landfall).

37% of the 38 TCs produce rainfall over land when they first form (Fig. 3a). Many are located over the MC or over land (Fig. 3b). Also, 70% of observations within the MC produce rainfall over land (Fig. 3c). The shortest span of the MC is 420 km, and average quadrant extents are 200 km, yielding a diameter of 400 km. Thus, chances are high that when a TC moves over the Channel, it will produce rainfall either over Madagascar or Mozambique. TCs approaching Madagascar from the northeast (Fig. 3c) are more typical examples of long-track storms where a TC intensifies while moving westward and makes landfall several days later. Most TCs produce their first rainfall over land when within 48 hours of landfall (Fig. 3d), but some large and/or slow-movers with looping tracks produce rainfall over land more than 4 days prior to landfall.

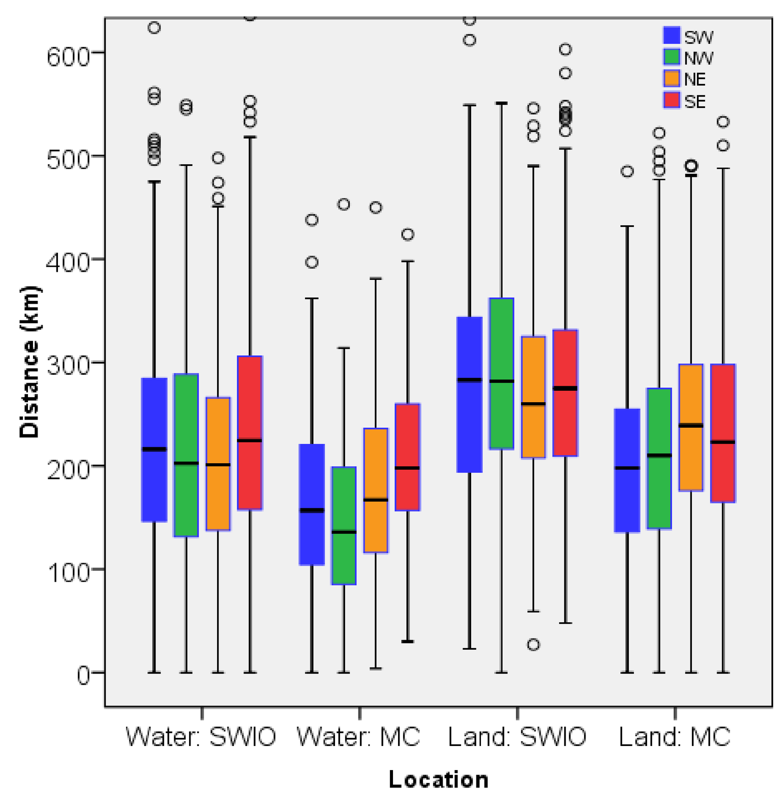


Fig. 4. Boxplot showing 25, 50, and 75th percentiles of rain field extent in each quadrant when the TC center is over different water bodies and whether or not rainfall is occurring over land.

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

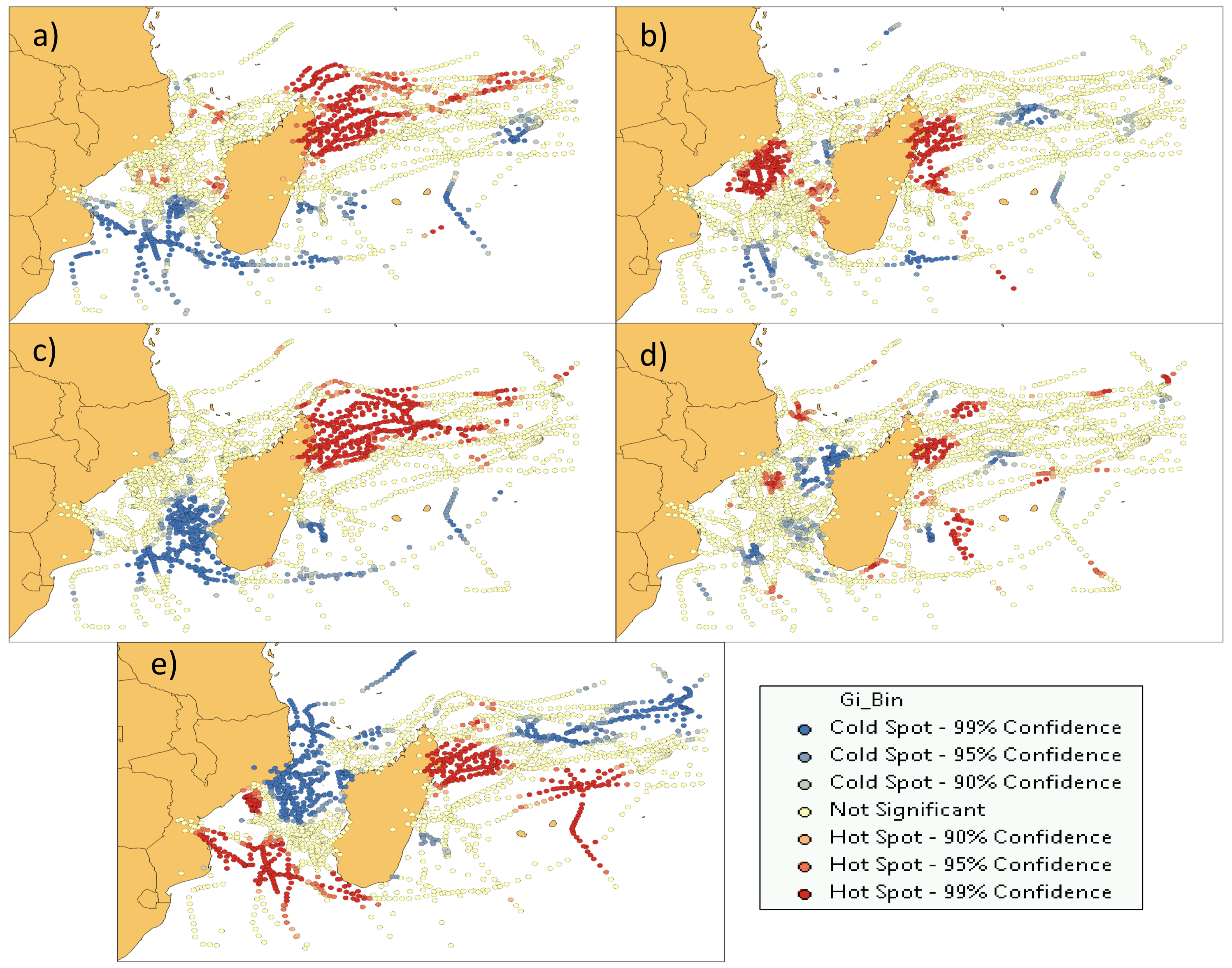


Fig. 5. Results of hot spot analysis for rainfall extent in a) NW, b) NE, c) SW, and d) SE quadrants, and e) maximum sustained wind speed. Clusters of higher (lower) values are hot (cold) spots.

Quadrant	n	Mean Extent (km)	Avg. Dist. 30 Nearest Neighbors (km)	n Sig. Features	Jonckheere-Terpstra *p*-value	Vmax *ρ*
Northwest	2074	224	152	852	<0.01	0.45
Southwest	2174	213	152	852	<0.01	0.38
Southeast	2227	233	223	293	<0.01	0.25
Northeast	2176	226	173	657	<0.01	0.32

Table 1. Statistics produced during hot spot analysis, Jonckheere-Terpstra test results (tropical depression, moderate tropical storm, severe tropical storm, tropical cyclone, intense tropical cyclone) and Spearman's Rank correlation coefficients with maximum sustained wind speed each quadrant.

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 terrain 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 wind speeds 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 V_{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

Arivelo, T., and Y. Lin. 2016. Climatology of heavy orographic rainfall induced by tropical cyclones over Madagascar: From synoptic to mesoscale perspectives. *Earth Science Research* 5 (2):146.
Ash, K., and C. Matyas. 2012. The influences of ENSO and the Subtropical Indian Ocean Dipole on tropical cyclone trajectories in the South Indian Ocean. *Internat. Journal of Climatology* 32 (1):41-56.
Brown, M. ed. 2009. *Madagascar's cyclone vulnerability and the global vanilla economy*. New York: Altamira Press.
Chang, I., M. Bentley, and J. Shepherd. 2014. A global climatology of extreme rainfall rates in the inner core of intense tropical cyclones. *Physical Geography* 35:478-496.
Chang-Seng, D., and M. Jury. 2010. Tropical cyclones in the SW Indian Ocean. Part 2: structure and impacts at the event scale. *Meteorology and Atmospheric Physics* 106 (3-4):163-178.
Guo, Q., and C. Matyas. 2016. Comparing the spatial extent of Atlantic basin tropical cyclone wind and rain fields prior to land interaction. *Physical Geography* 37:5-25.
Hoskins, B., and K. Hodges. 2005. A new perspective on Southern Hemisphere storm tracks. *Journal of Climate* 18 (20):4108-4129.
Jiang, H., C. Liu, and E. Zipser. 2011. A TRMM-based tropical cyclone cloud and precipitation feature database. *Journal of Applied Meteorology and Climatology* 50 (6):1255-1274.
Jury, M., B. Pathack, and B. Parker. 1999. Climatic determinants and statistical prediction of tropical cyclone days in the southwest Indian ocean. *Journal of Climate* 12 (6):1738-1746.
Lonfat, M., F. Marks, and S. Chen. 2004. Precipitation distribution in tropical cyclones using the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager: A global perspective. *Monthly Weather Review* 132 (7):1645-1660.
Matyas, C. 2015. Tropical cyclone formation and motion in the Mozambique Channel. *International Journal of Climate* 35 (3):375–390.
Matyas, C., and J. Silva. 2013. Extreme weather and economic well-being in rural Mozambique. *Natural Hazards* 66:31-49.
Reason, C. 2007. Tropical cyclone Dera, the unusual 2000/01 tropical cyclone season in the South West Indian Ocean and associated rainfall anomalies over Southern Africa. *Meteorology and Atmospheric Physics* 97 (1-4):181-188.
Reason, C., and A. Keibel. 2004. Tropical Cyclone Eline and its unusual penetration and impacts over the southern African mainland. *Weather and Forecasting* 19 (5):789-805.
Silva, J., C. Matyas, and B. Cunguara. 2015. Regional inequality and polarization in the context of concurrent extreme weather and economic shocks. *Applied Geography* 61:105-116.
Vitart, F., D. Anderson, and T. Stockdale. 2003. Seasonal forecasting of tropical cyclone landfall over Mozambique. *Journal of Climate* 16 (23):3932-3945.
Williams, C., D. Kniveton, and R. Layberry. 2007. Climatic and oceanic associations with daily rainfall extremes over southern Africa. *International Journal of Climatology* 27 (1):93-108.