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Extreme weather and economic well-being in rural Mozambique

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Abstract Societies dependent on rain-fed agriculture are highly vulnerable to weather extremes; thus, linkages between rainfall variability and economic well-being merit close attention. The hypothesis of this paper is that rainfall patterns impact changes in income within our study region of central and northern Mozambique. Utilizing satellite-based estimates of rainfall analyzed within a GIS, we establish a 12-year rainfall climatology and calculate monthly rainfall anomalies for 419 villages during three growing seasons. We also approximate storm-total rainfall from tropical cyclones entering the Mozambique Channel. Hierarchical cluster analysis groups the villages according to the monthly rainfall anomalies and rainfall received from Cyclones Delfina and Japhet. Then, using data from the National Agricultural Survey of Mozambique conducted in 2002 and 2005, we relate rainfall and change in income through the calculation of Pearson's correlation coefficients and independent-samples *t* tests using village-groups produced by the cluster analysis. We find that no season closely approximates the 12-year climatology and that rainfall varied among the three seasons. Although most villages experience income declines, those affected by Delfina exhibit the worst economic performance, indicating that heavy rainfall from some tropical cyclones can have long-lasting negative effects on income. Additionally, receiving above-normal rainfall may hinder economic well-being more than below-normal rainfall. Our study identifies patterns in sub-national rainfall variability and economic well-being that enable a more detailed understanding of weather-related effects on socio-economic outcomes.

Keywords Climate variability · Rainfall · Rural development · Africa · Mozambique · Tropical cyclones

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1 Introduction

The development literature has increasingly emphasized the role of climate variability in shaping vulnerability in rural communities, particularly in southern Africa (O'Brien and Vogel 2003; Leichencko and O'Brien 2002). Growing interest in the interactions of economic and climate risk illustrates the need for better understandings of how extreme weather impacts people in the developing world (Mirza 2003; Schipper and Pelling 2006). Previous researchers have established that southern Africa experiences high variability in rainfall on an interannual basis (Cook et al. 2004; Reason et al. 2005; Rouault and Richard 2005; Usman and Reason 2004). Climate-change scenarios predict a 10–20% decrease in rainfall over southern Africa by 2030 (Lobell et al. 2008; Sithole and Murewi 2009), thus increasing the vulnerability of farmers relying on rain-fed agriculture (Brown and Funk 2008). Countries in southern Africa also confront many critical obstacles to economic development, including high poverty rates, corruption, weak infrastructure, and high rates of disease (World Bank 2010).

Several elements make Mozambique an appropriate case study for investigating linkages between weather and economic well-being in rural areas. The majority of rural Mozambicans are poor, with 54% living below the poverty line in 2005 and 80% of the people relying on rain-fed agriculture for subsistence. Evidence also suggests that poverty has increased in the recent decades due to frequent natural hazards, low agricultural productivity, lack of basic infrastructure, poor health, and market failures (Hall and Young 1997; Mittleman 2000; Pitcher 2002; Sheldon 2002; Hanlon and Smart 2008; Cunguara and Hanlon 2010). Poverty limits the ability of smallholder farmers to mitigate the negative effects of extreme weather events (Mirza 2003; Hahn et al. 2009; Eriksen and Silva 2009). Eight major floods and seven major droughts have affected the country during the past 30 years (Klinman and Reason 2008), and such events have been linked to significant negative impacts on crop production (Usman and Reason 2004). In addition, Mozambique has experienced damaging tropical cyclones that have had long-lasting impacts on society, including the breakdown of informal social support networks (Brouwer and Nhassengo 2006; Christie and Hanlon 2001). As researchers predict that southern Africa will experience an increase in climate variability, extreme events in the region are likely to continue (IPCC 2007).

Our hypothesis is that rainfall patterns impact changes in household income in our study region. As a first step toward linking rainfall variability to economic well-being in Mozambique, this study examines rainfall patterns during the three growing seasons that occurred between two national socio-economic surveys of rural households conducted in 2002 and 2005. We focus on villages in the central and northern regions of Mozambique as they share a common growing season. As most climate-scale studies of precipitation have been for the larger region of southern Africa (e.g., Jury et al. 2004; Shongwe et al. 2009; Usman and Reason 2004), we develop a satellite-based rainfall climatology and explore monthly rainfall patterns at the sub-national level. Extreme drought occurred in southern Africa from 2002 to 2005 (Mather et al. 2008; Rouault and Richard 2005), having major impacts on agriculture in Mozambique as reported by the Food and Agriculture Organization of the United Nations (FAO 2003, 2004, 2005). Additionally, two tropical cyclones caused different rainfall patterns in our study region during this period (Kadomura 2005). As such, our study seeks to determine whether receiving below-normal or above-normal rainfall exhibits a higher correlation with the changes in rural household income over the study period.

Our study region contained 419 villages for which the socio-economic data are available. Satellite-based rainfall estimates are analyzed within a GIS to establish a rainfall climatology, determine the percent of normal rainfall occurring within each of the study months, and calculate rainfall totals that resulted from the passage of tropical cyclones for each village. Correlation coefficients are calculated to demonstrate the extent to which rainfall patterns deviated from normal, and to relate monthly rainfall and tropical cyclone rainfall totals to changes in income. To further explore linkages between income and rainfall, we perform a hierarchical cluster analysis to group villages according to the rainfall they received across the study period. The mean changes in income within these groups are compared using independent samples *t* tests to determine whether any of these groups experienced changes in income that are significantly different from the other groups. Our findings identify patterns in sub-national rainfall variability and economic well-being that enable a more detailed analysis of weather-related effects on socio-economic outcomes.

2 Rainfall climatology of central and northern Mozambique

In order to understand rainfall patterns at the subnational level in Mozambique, we place them in the wider context of the physical mechanisms driving precipitation in the region. In northern and central Mozambique (Fig. 1), the growing season spans November–April

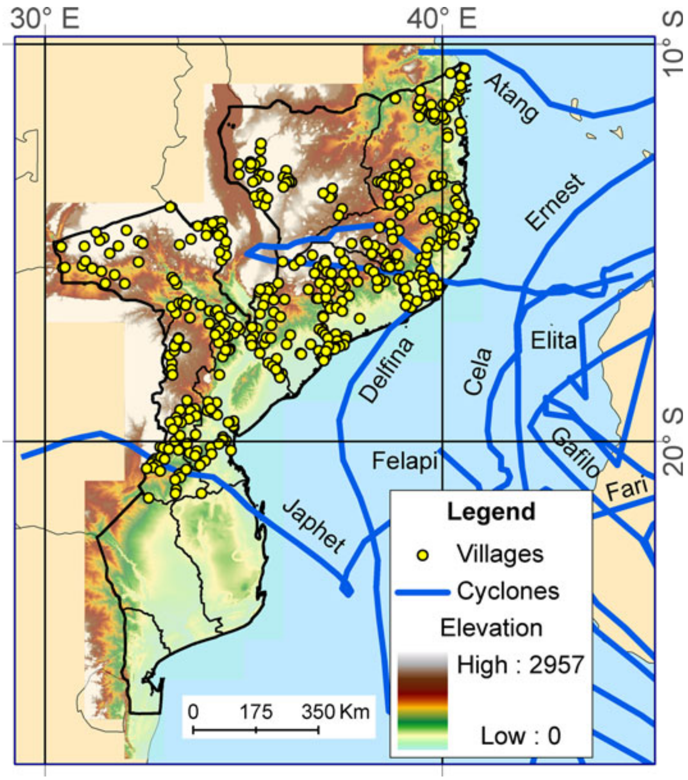

Fig. 1 Map of Mozambique showing the locations of the study villages, elevation, and tracks of all tropical cyclones during the study period

(Tadross et al. 2009), and interannual variations in rainfall totals are high (Cook et al. 2004; Fauchereau et al. 2003). Rainfall occurs in association with the migration of the intertropical convergence zone (ITCZ) to a latitude of approximately 20° S (Washington and Preston 2006), with moisture advection primarily from the southwestern Indian Ocean (Reason 2007; Thomas et al. 2007). Tropical temperature troughs (TTTs) and their associated northwest-southeast oriented cloud bands link the Angola low with westerly disturbances in the middle latitudes of the southern hemisphere (Reason 2007; Shongwe et al. 2009; Usman and Reason 2004). Although TTTs occur infrequently and can develop in different locations over the continent on both intra- and inter-annual time scales, they are responsible for the majority of the rainfall during the austral summer (Cook et al. 2004; Usman and Reason 2004; Washington and Todd 1999). Topographic ascent can also enhance rainfall over the northwestern portion of Mozambique (Thomas et al. 2007; Wisner 1979) (Fig. 1). During drier seasons, anticyclonic conditions prevail as the ITCZ remains north of 20°S (Cook et al. 2004; Jury and Pathack 1993).

Multiple atmospheric teleconnections contribute to the interannual variability of rainfall over Mozambique, including the El Nino-Southern Oscillation (ENSO), the Indian Ocean dipole (IOD), and the subtropical Indian Ocean dipole (SIOD). Researchers agree that ENSO events strongly influence rainfall over southern Africa (Jury et al. 2004; Reason and Jagadheesha 2005; Rouault and Richard 2005; Usman and Reason 2004; Watterson 2009). When La Nina conditions prevail, TTTs anchor over the continent near 25°E to produce rainfall over Mozambique (Jury et al. 2004). During El Nino events, TTTs shift to approximately 55°E so that subsidence associated with anomalous high pressure and a lack of rainfall dominates southeastern Africa (Jury et al. 2004; Reason 2007). Anomalous sea surface temperatures (SSTs) in the tropical Indian Ocean have also been linked to rainfall variations in southern Africa. When the IOD is positive, SSTs are anomalously high in the equatorial western Indian Ocean, leading to enhanced convection in this region, which includes coastal northern Mozambique. During positive IOD months, subsidence is enhanced elsewhere over southern Africa (Manatsa et al. 2008; Richard et al. 2001). The positive phase of the SIOD indicates that anomalously warm SSTs are present south of Madagascar. Evaporation from the ocean and moisture advection into Mozambique from the southeast are enhanced (Behera and Yamagata 2001; Hansingo and Reason 2009) so that positive values of the SIOD are associated with increased rainfall over most of Mozambique, while negative values of this index are associated with dryness. Both the IOD and the SIOD have been shown to operate independently of ENSO.

Tropical cyclones provide another source of rainfall for Mozambique. Rainfall from these systems can alleviate drought conditions (Angel 2006; Sugg 1968) or can produce severe flooding (Reason 2007; Reason and Keibel 2004; Vitart et al. 2003). A tropical cyclone can cause extensive flooding in a region even though its circulation center does not pass directly overhead, as its rain shields can extend hundreds of kilometers outward from the center of circulation (Lonfat et al. 2007; Matyas 2010). According to cyclone track data obtained from the Joint Typhoon Warning Center (JTWC) (http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/best_tracks/shindex.html) and plotted within a GIS, 87 cyclones have tracked within 100 km of Mozambique during the 60-year period 1949–2008. Of these, 45 have made landfall. Thus, on average the country could experience rainfall from a cyclone 1–2 times per year. Like the positioning of TTTs, the tracks of tropical cyclones are associated with atmospheric teleconnections. During La Nina events, and/or when the SIOD is in a positive phase, cyclones tend to move in zonal (east-to-west) patterns across the SWIO, increasing the probability of affecting Mozambique. During El Nino years and/or when the SIOD is negative, cyclones recurve toward the southeast before entering the

Mozambique Channel (Ash and Matyas 2012; Vitart et al. 2003), so landfalls in Mozambique are less frequent when either of these conditions prevail.

3 Rainfall analyses and results

3.1 Method of analysis

We conduct our rainfall analyses at monthly and seasonal scales to enhance comparability with the FAO's reported rainfall impacts on agriculture in Mozambique. As rain gauge data with high spatial and temporal resolution are sparse over most of Africa (Adeyewa and Nakamura 2003) and particularly within Mozambique, we estimate rainfall totals through an analysis of the Tropical Rainfall Measuring Mission (TRMM)'s 3B43 product. Our use of these data to estimate rainfall is justified as Adeyewa and Nakamura (2003) and Dinku et al. (2007) found that the TRMM 3B43 product exhibited a high correlation with rain gauge measurements over several regions within Africa. The algorithm that creates this product combines passive microwave and infrared satellite-based data with measurements from rain gauges to produce rainfall totals. Data are available at a spatial resolution of 0.25° × 0.25° for latitudes 50°N–50°S, and are available monthly beginning in January, 1998 (Huffman et al. 2007). The 3B43 data spanning 1998–2009 are acquired using the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC). Monthly rainfall totals for November–April are obtained for a region spanning 9°–30°S and 26°–46°E. However, we eliminate April from the analysis as we cannot match the satellite-derived rainfall during April 2004 to rain gauge data published by the FAO (2004) and Godfrey et al. (2005).

First, we construct a 12-year rainfall climatology by importing the monthly TRMM-estimated rainfall data into a GIS and interpolating the data using ordinary spherical kriging. We assign values to each of the 419 villages, then add the values for each year and divide by twelve to obtain the climatological average. Next, we examine the actual rainfall occurring during the study period. We divide the rainfall occurring each month by its climatological value to obtain the percentage of normal rainfall at each village to facilitate comparisons across areas that normally receive different rainfall amounts. We also sum these percentages and divide by five to obtain the average percentage of normal rainfall received November to March for each season. Season 1 spans 2002–2003, while Seasons 2 and 3 cover 2003–2004 and 2004–2005, respectively.

To assess the rainfall contributed by tropical cyclones during our study period, we import the cyclone track data obtained from the JTWC into the GIS. All cyclones within the Mozambique Channel (Fig. 1) are extracted for further analysis. Rainfall data are obtained from the TRMM 3B42 V6 derived dataset (http://disc2.nascom.nasa.gov/Giovanni/tovas/TRMM_V6.3B42_daily.shtml), which is similar to the aforementioned 3B43 product but contains daily rainfall values. We import the TRMM data into the GIS and perform ordinary spherical kriging, then add the daily rainfall values to determine the storm-total rainfall produced by each tropical cyclone. Our analysis reveals that only two cyclones produced more than 150 mm of rainfall affecting at least 30 villages within our study region and study period. Cyclone Delfina and its remnant circulation produced rainfall over the region from 31 December 2002–6 January 2003, while rainfall from Cyclone Japhet produced rainfall over the study region 1–5 March 2003. As we select 150 mm as a threshold for villages receiving very high rainfall totals from cyclones, we do not discuss Cyclone Atang, which made landfall in Tanzania but produced 50–140 mm of rainfall in seven Mozambican villages near the Tanzanian border in November 2002.

We utilize two statistical techniques to explore the spatial and temporal patterns of rainfall. After confirming that all variables are distributed normally, Pearson's correlation coefficients are calculated between the climatological and actual rainfall values for each month as well as latitude and longitude to characterize the extent to which rainfall differed from normal. To explore the spatial patterns of the normal and actual rainfall, we perform two separate hierarchical cluster analyses. The first employs climatological rainfall values in each study month, while the second utilizes the percentage of normal rainfall for all 15 study months. Both analyses are performed emphasizing between-groups linkage with intervals determined by squared Euclidean distance. Optimal clustering solutions are selected based upon the spatial patterns they present when plotted in the GIS with a stipulation that a cluster contain 30 villages minimum.

3.2 Climatological and actual rainfall patterns

Our 12-year rainfall climatology agrees well with longer-term rainfall patterns and previous research in the region described earlier. All correlation coefficients calculated between latitude and longitude and the five growing season months are significant at $\alpha = 0.05$. Normally, early season rainfall is greatest in the southern and western portions of the study region (Table 1), while rainfall is typically highest in the north and east in January and in the south and east in February and March. Plots of the 12-year average rainfall within the four groups produced by the hierarchical cluster analysis confirm this spatial pattern (Fig. 2). Rainfall over the growing season typically assumes an inverted "U" shape, with lowest totals in November (50–100 mm) and March (100–200 mm) and highest in January (200–300 mm) for most villages (Fig. 2), although some villages receive less rainfall in February than in March. As discussed previously, the migration of the ITCZ into and out of the region along with the northwest–southeast orientation of TTTs that contribute to moisture advection and rainfall produce these spatial patterns of rainfall.

Pearson's correlation coefficients calculated between all study months, monthly climatology, and latitude and longitude demonstrate that generally, the normal seasonal pattern of rainfall did not occur during our study period (Table 1). For example, the south and west should receive more rainfall than the north and east during the first 2 months of the growing season. However, the lack of rainfall early in Seasons 1 and 3 in the south and west was detrimental to the first crops planted (FAO 2003, 2005). Correlations between latitude and the seasonal rainfall anomalies (not shown) illustrate that the north generally received more rainfall during the study period than the south, particularly in Seasons 1

Table 1 Pearson's correlation coefficients for monthly rainfall at each village ($n = 419$) and latitude; longitude

	November	December	January	February	March
Season 1	0.564; 0.365	0.479; 0.679	0.196; 0.516	0.698; 0.246	−0.742; −0.718
Season 2	X; −0.408	0.626; 0.396	−0.435; −0.610	0.176; 0.146	−0.358; −0.703
Season 3	0.745; 0.755	0.539; 0.457	−0.173; −0.235	0.161; 0.253	−0.199; X
Climatology	−0.684; −0.793	−0.441; −0.477	0.099; 0.344	−0.253; 0.331	−0.138; 0.334

All correlations shown are significant at $\alpha = 0.05$

Positive correlations indicate north and east; negative correlations indicate south and west

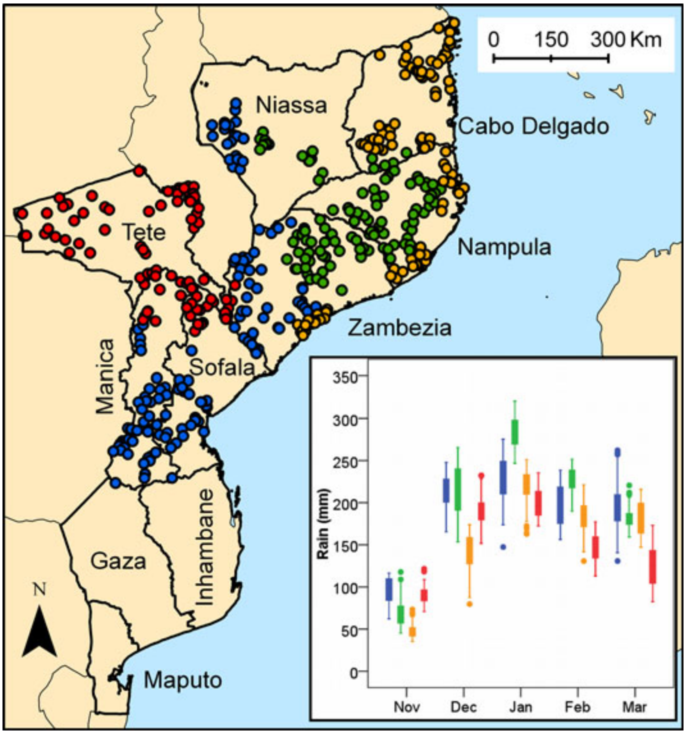

Fig. 2 November–March rainfall climatology for villages in the study region stratified into the four groups resulting from the climatological hierarchical cluster analysis

and 3. A strong negative correlation with longitude for Season 2 (not shown) indicates that the west, rather than north or south, received more rainfall during this season.

Although the spatial patterns of rainfall varied from year to year, generally, less rainfall than normal occurred within the study region, a finding that agrees with previous research describing the extended drought in southern Africa during this time (Rouault and Richard 2005; Mather et al. 2008). There were 365 instances where less than 65% of normal rainfall occurred in consecutive months for a village, and these dry periods occurred within the first 2 months of Seasons 1 and 2, and January–March of Season 3. Adding the 5-month rainfall total for each season and subtracting from the 12-year average (Fig. 3a–c) demonstrates that a deficit of more than 150 mm of rainfall occurred in all three seasons for 12 villages in Manica Province, while 98 experienced this deficit in two of the three seasons. The combined effects of El Nino (Seasons 1 and 3), a negative SIOD (Season 1) and positive IOD (Seasons 1 and 2) (Table 2) could help to account for the generalized pattern of dryness experienced across the three growing seasons.

Yet even during this dry period, many villages also received more rainfall than normal, especially during Season 1 as 39% of villages received more than 150 mm of rainfall above the seasonal average (Fig. 3a). These findings comport with those of Kadomura (2005) who described abnormally high rainfall events in the southern African region during 2003. Generally, TTTs tend to develop east of Madagascar and fail to bring moisture into Mozambique during El Nino years. However, our analysis of satellite data shows that TTTs stretched across the northern portion of the country during Season 1 to provide several

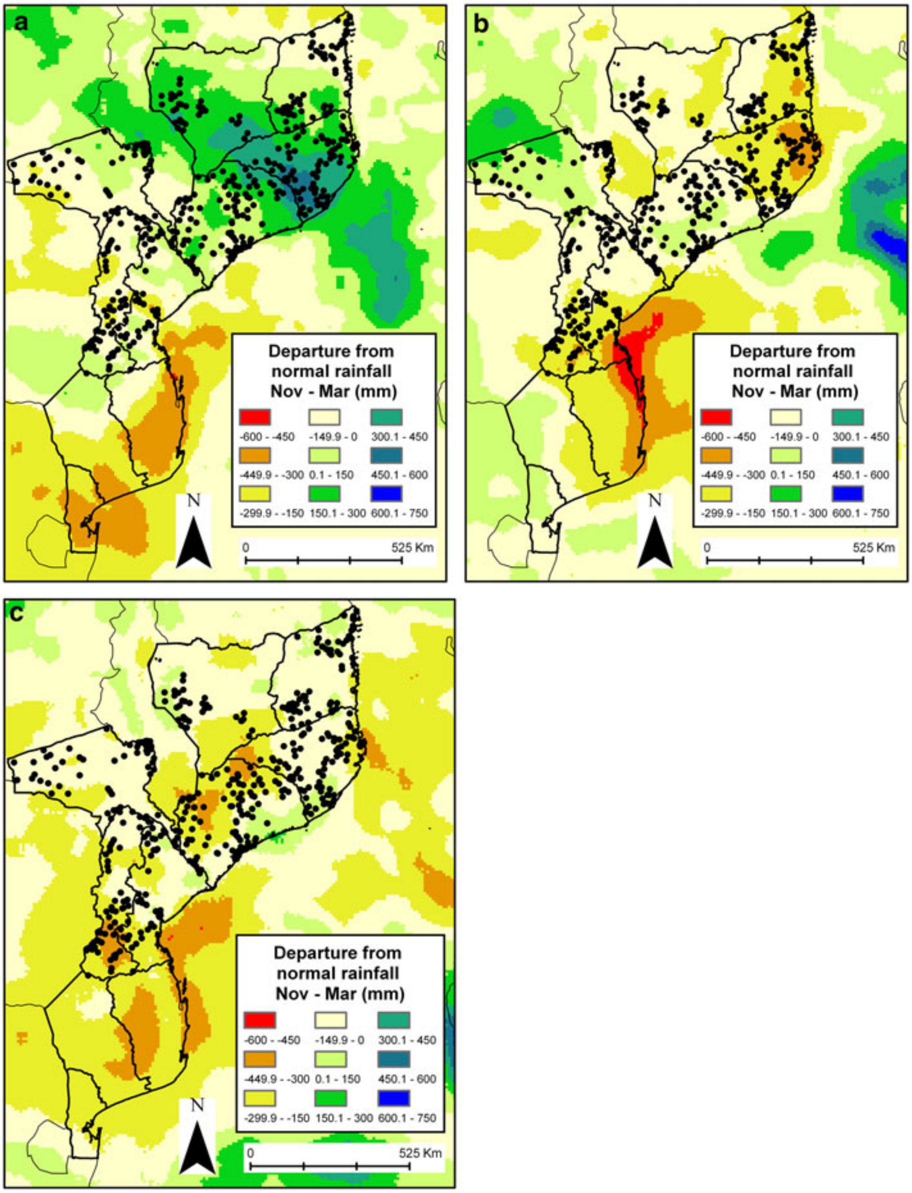

Fig. 3 Cumulative rainfall anomalies November–March for **a** season 1, **b** season 2, and **c** season 3

multi-day rainfall events, particularly in late January and March 2003. Above normal rainfall totals in early January and March were also caused by the passage of Cyclones Delfina and Japhet, which are discussed in more detail later in the paper. A general north-to-south gradient in rainfall occurred (Fig. 3a), and it is not surprising that the FAO (2003) reported successful harvests in the north, but major crop failures resulted from drought conditions in the southern portion of our study area so that food aid was required.

Table 2 Teleconnection indices for each study month

	SOI[a]	IOD[b]	SIOD[c]
Nov 2002	**−6.0**	**1.010**	**−0.07**
Dec 2002	**−10.6**	**0.695**	**−1.06**
Jan 2003	**−2.0**	**0.235**	**−1.21**
Feb 2003	**−7.4**	0.045	**−0.68**
Mar 2003	**−6.8**	0.093	**−0.11**
Nov 2003	**−3.4**	**0.486**	0.08
Dec 2003	9.8	**0.493**	1.01
Jan 2004	**−11.6**	**0.612**	0.29
Feb 2004	8.6	**0.616**	0.02
Mar 2004	0.2	0.071	0.55
Nov 2004	**−9.3**	−0.005	0.77
Dec 2004	**−8.0**	−0.496	0.10
Jan 2005	1.8	−0.975	0.57
Feb 2005	**−29.1**	−0.856	0.47
Mar 2005	0.2	−0.755	**−0.36**

Bold values indicate that dryness should prevail in the study region according to prior studies

[a] Southern Oscillation Index data obtained from http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

[b] Indian Ocean Dipole data obtained from http://www.jamstec.go.jp/frsgc/research/d1/iod/

[c] Subtropical Indian Ocean Dipole data obtained from http://www.jamstec.go.jp/res/ress/behera/iosdindex.html

The rainfall patterns of Season 2 differ greatly from Season 1 as evidenced by an insignificant correlation coefficient between these two seasons (−0.051). Season 2 is the driest of the three seasons according to the season-averaged rainfall anomalies for each village as 41% of villages had a deficit of more than 150 mm (Fig. 3b), and nearly one quarter of the villages received less than 75% of normal rainfall across the season. Villages in Nampula and Cabo Delgado Provinces experienced the lowest percentage of normal rainfall across the season. Despite the relatively dry season, the central portion of the country received more rainfall than normal in the beginning and/or end of the season. In November, 116 villages in Tete, Zambezia, and Niassa Provinces received more than 150% of normal rainfall, while this excess occurred in 37 villages within Tete and Manica during March (Fig. 4). Crop harvests were mixed in this region, particularly across Zambezia, and farmers replanted two and three times due to the irregular rain (FAO 2004).

Rainfall anomalies averaged over Season 3 exhibit statistically significant correlations with Season 1 (0.443) and Season 2 (-0.380). Early season rainfall was well above normal in the north, and rainfall decreased as Season 3 progressed for most villages. February and March 2005 are two of the three driest months in the study. Soils in the north retained the early-season moisture throughout the drier months, so crop harvests were good (FAO 2005). However, very dry conditions occurred in Tete, Manica and Zambezia Provinces, where rainfall totals in consecutive months were less than 50% of normal. Rainfall shortages of more than 150 mm occurred in 31% of villages in the study region (Fig. 3c). Once again, poor harvests due to the drought made food aid necessary for villages in the southern portion of the study region (FAO 2005).

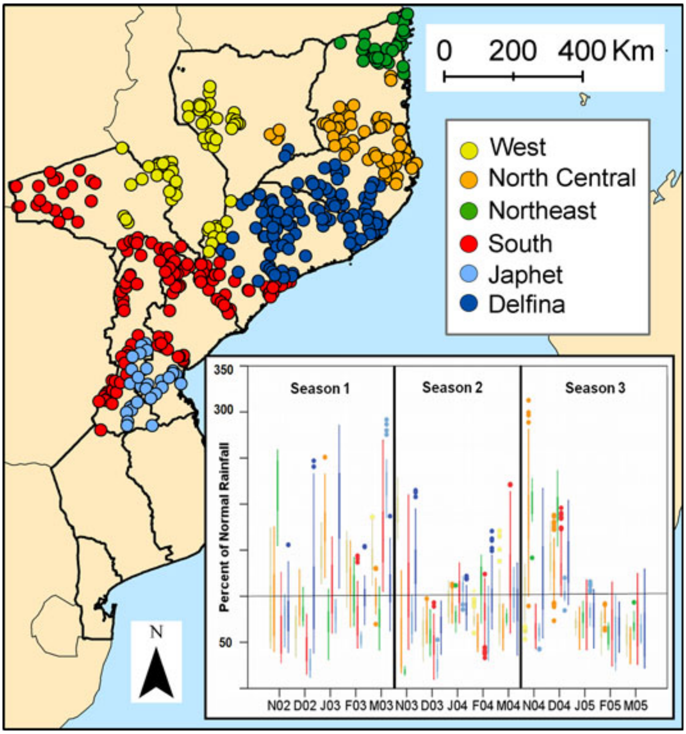

Fig. 4 Average rainfall received each study month for the four groups produced by the hierarchical cluster analysis utilizing rainfall anomalies and two groups receiving 150 mm or more rainfall from a tropical cyclone

The hierarchical cluster analysis based on the percentage of normal rainfall received by villages during the 15 study months produces four clusters, in addition to the regions identified as receiving more than 150 mm of rainfall from the two cyclones discussed in the next section. The general spatial patterns of the four non-cyclone clusters demonstrate that across the study period, rainfall patterns are distinct in the far northeast within Cabo Delgado Province, the north central portion of the country in Cabo Delgado and Nampula Provinces, the western portion of the country in the higher elevations near the border with Malawi, and the southern reaches of the study area including portions of Zambezia, Tete, Manica, and Sofala Provinces (Fig. 4). Graphs of the average percentage of normal rainfall for each group support our finding that villages in the north received more rainfall during the study period than those in central Mozambique, and that more rain occurred within Season 1 than the other two seasons.

3.3 Tropical cyclone activity

Although several tropical cyclones passed through the Mozambique Channel during our study period, only Delfina and Japhet made landfall in Mozambique, which is fewer landfalls than would be expected climatologically over the 3-year study period. El Nino conditions typically lead to fewer landfalls in Mozambique (Vitart et al. 2003), and these conditions occurred during Seasons 1 and 3, so the two landfalls we analyze both occurred during an El Nino year. Both storms formed in the Mozambique Channel but took unusual tracks as neither moved directly southward and out of the channel as is the typical track of a cyclone forming within the channel (Reason 2007).

The TRMM data show that by 00 UTC on 31 December, rainfall from Delfina began to affect the study region. Landfall occurred later that day near Angoche in Nampula Province with maximum sustained winds of 28 ms^{-1} (55 kt). The JTWC (2003) reported and the TRMM data concur that the remnants of Delfina moved inland with a looping track (Fig. 5) so that the system remained over the study region for several days, bringing flooding rains to villages in Nampula and Zambezia Provinces. According to Bell et al. (2003), 100,000 people were left homeless and 34,000 ha of crops were destroyed in Mozambique. Our analysis reveals that 104 villages in our study region received more than 150 mm of rainfall over a 7-day period (Fig. 5). In some areas, more than 200 mm of rainfall occurred in 1 day, and 29 villages received more than 300 mm from this system.

In contrast, Japhet affected a smaller portion of our study region as it tracked straight through the region without recurving (Fig. 5). Landfall occurred on 2 March south of Vilanculos in Inhambane Province where winds were estimated to be 44 ms^{-1} (85 kt). The

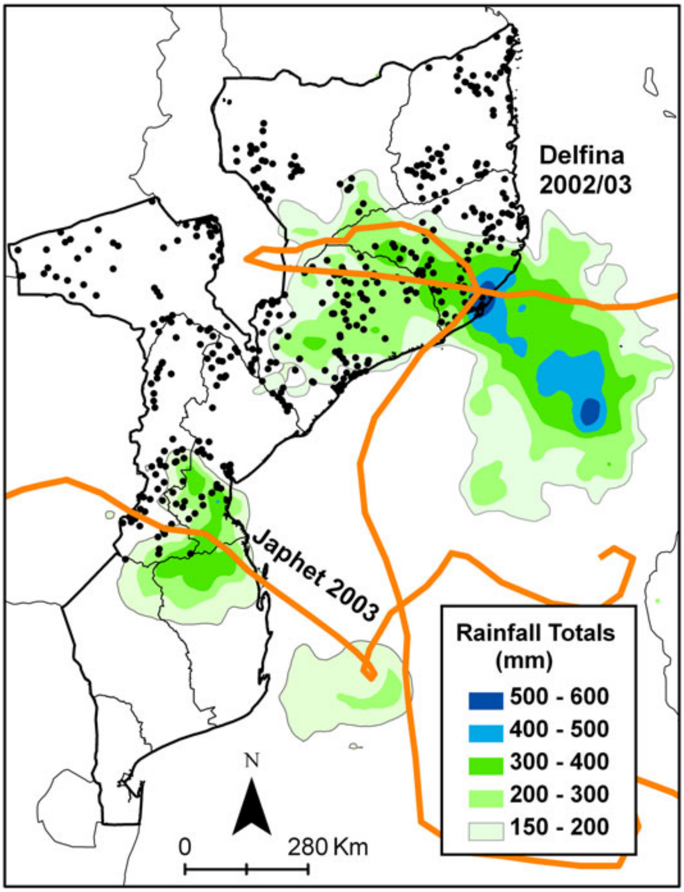

Fig. 5 Tracks of cyclones Delfina and Japhet and the storm-total rainfall produced by each cyclone

JTWC (2003) and Kadomura (2005) reported that structural damage and flooding occurred in areas outside of our study region, and in several locations in Sofala Province not sampled by the 2002 and 2005 surveys. Conversely, rainfall in areas of Sofala and Manica Provinces that are included in our study region helped to alleviate drought conditions (JTWC 2003). Although we find that 30 villages received more than 150 mm of rain, none received more than 200 mm on any 1 day. The FAO (2003) reported that, for some areas, rains from Japhet were favorable for crops and allowed for a good harvest.

4 Combined rainfall and socio-economic analyses

4.1 Socio-economic data

Mozambique provides a good opportunity to study socio-economic impacts of natural hazards in emerging economies. As described earlier, poverty and food insecurity affect the majority of rural Mozambicans and vulnerability to extreme weather events is high (Sheldon 2002; MADER 2005). Food shortages are common, and approximately 41% of rural children in Mozambique were stunted due to malnutrition in 2003 (UNICEF 2006). The central and northern areas of the country, which are the regions examined in this case study, experience some of the highest poverty rates in the country.

Economic globalization has arguably worsened the economic position of rural agriculturalists. In line with International Monetary Fund (IMF) recommendations, Mozambique began a series of structural adjustment programs in the 1980s and the country maintains a neoliberal economic agenda. Neoliberalism has had several impacts on the agricultural sector, including the lifting agricultural trade barriers and the elimination of government subsidies to rural producers. Mozambique has earned the praise of leading international financial institutions for its commitment to poverty reduction through market-based economic growth. However, evidence suggests economic insecurity and inequality in Mozambique deepened after structural adjustment due to increasing food prices, lack of agricultural subsidies, declining employment opportunities, and the dismantling of social protections for the poor (Pfeiffer et al. 2007; Silva 2007, 2008; Pitcher 2002; Wuyts 2003).

Mozambique is particularly vulnerable to droughts, cyclones, and floods, the frequency and severity of which are predicted to increase (IPCC 2007; Eriksen and Silva 2009). Recent natural disasters have destroyed numerous roads, homes and schools. For example, flooding in February and March of 2000, including the effects of Cyclone Eline, cost the Mozambican economy an estimated $700 million, including $428 million in reconstruction costs (World Bank 2000). Rural agriculturalists bore the brunt of the disaster, suffering crop and property losses that greatly limited their ability to cope in the disaster's aftermath (Christie and Hanlon 2001). In central Mozambique alone, 157 villages were flooded (Steinbruch et al. 2002). Humanitarian assistance is regularly required to feed communities devastated by such events (Sheldon 2002).

To calculate the change in income over the study period, our analysis uses household-level micro-data from the longitudinal National Agricultural Survey of Mozambique (*Trabalho de Inquérito Agrícola,* TIA). The survey was conducted in 2002 and 2005 by the Mozambican Ministry of Agriculture and Rural Development (MADER 2002, 2005) and USAID. The nationally representative household sample was drawn using a stratified, clustered sample design. The sample is stratified by the country's 10 major geographical regions and agro-ecological zones. The current study utilizes longitudinal data for 2,907 households located in 419 rural villages across central and northern Mozambique. The geographic coordinates of these villages are obtained from the TIA surveys and the locations are mapped within the GIS and cross-referenced using the geographic information from the 1997 Census. The three-year spacing of longitudinal household surveys generally provides an appropriate interval to study behavior changes and agronomic shifts in household activities (Carletto et al. 2010).

Using the TIA, each household's total income for each year is derived by calculating income from agricultural crop and livestock production, agricultural wage labor, non-agricultural wage labor, non-agricultural self-employment, sale of natural resources, and pensions and remittances. Since the bulk of food eaten in rural areas is produced by households for their own consumption, agricultural production income is calculated as the sum of crop and livestock sales and imputed income from own production consumed by the household. Agricultural wage labor consists of part-time and full-time off-own-farm agricultural employment. Non-agricultural wage labor consists of part-time and full-time off-farm employment in both the formal and informal sectors. Self-employment income consists of net business profits from both formal and informal activities. Natural resource income consists of net profits earned by harvesting and selling resource-based goods including forest products, charcoal, hunted game, and fish. Pension and remittance income consists of money or goods received from government assistance programs or from family members living and working away from home. The income totals are calculated following the procedures used by Mather et al. (2008) to make the results comparable with previous studies using the TIA surveys. All income figures for households are population weighted. Per capita income figures are then calculated by dividing a household's total income by the number of its members. Village mean per capita income is derived by averaging the per capita income for households within each village. The 2005 income figures are inflation adjusted to 2002 levels. The household change in per capita income is calculated as a ratio of 2005 adjusted income values to 2002 values. We remove all outliers with values more than three standard deviations from the mean (33 households and 5 villages). We use the natural log of the income change value in our statistical analyses to normalize the distribution.

We employ two techniques to test our hypothesis that an association exists between rainfall patterns and changes in income for our study region. First, we calculate Pearson's correlation coefficients between income and the percentage of normal rainfall for the 15 study months to identify which months have the strongest associations with change in income. Second, we explore spatial patterns in the change in income using the results of the second cluster analysis that grouped villages according to the percentage of normal rainfall received across all study months. We first place villages receiving at least 150 mm of rainfall from cyclones Delfina or Japhet into their own groups. The remaining villages are then entered into the cluster analysis. After verifying that the data within each group assume a normal distribution, we perform a series of independent samples *t* tests so that the average change in income for each of the six groups is evaluated against the other five.

4.2 Results of combined analysis

The majority (73%) of villages in our sample experience overall declines in income (Fig. 6). Median household income falls by 63% over the 2002–2005 study period. Various factors, including social, political, and historical elements, influence changes in household economic well-being. However, as previously noted, this time period was marked by numerous extreme weather events (both wet and dry) in our study area, making it likely that these events contribute to the poor economic performance. The northern coastal

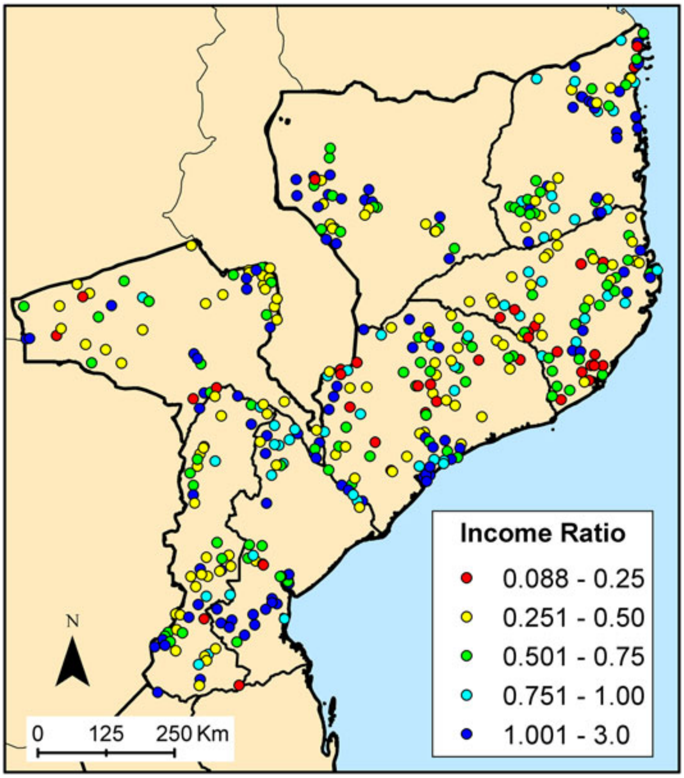

Fig. 6 The ratio of 2005 income to 2002 income for villages in the study region

province of Nampula fared the worst, with the median household income decreasing by 71%. The northern region of Mozambique is characterized by high poverty levels (Brück and Schindler 2009), so declining incomes in this region signify extreme hardship for households. The southern coastal province of Sofala experienced the lowest decreases in income, but the median household income still fell by 47%. In general, household income fell by substantial amounts in all seven central and northern provinces included in this study and rural poverty increased over the time period under investigation (Cunguara and Hanlon 2010).

Our results show that cyclones can have differing effects on changes in income. We find statistically significant correlations between change in income and rainfall in December 2002 (−0.197), January 2003 (−0.262), and from Delfina (−0.287). High rainfall totals in December 2002 and January 2003 are primarily associated with the passage of Delfina, though the TRMM data show that TTTs did contribute to multi-day rainfall events in northern Mozambique totaling more than 100 mm in late January 2003. The median income for the 104 villages in the Delfina region decreased by 46%, which is the highest economic loss of all six groups examined through *t* tests (Table 3). Furthermore, the results of the *t* tests indicate that this loss is statistically different from the other five groups (Table 4). Although we cannot say for certain that no other events in this region impacted income negatively prior to the 2005 survey, our findings suggest that damage caused by Delfina impacted the region more than 2 years after the storm's passage.

Table 3 Statistics for groups entered into the independent samples t tests

	Number of villages	Mean ratio of 2005–2002 income (%)	Natural log of income ratio[a]	SD	SE of the mean
Japhet	30	96.4	−0.037	0.980	0.179
Northeast	33	87.4	−0.135	0.682	0.124
South	124	70.8	−0.346	0.719	0.065
West	63	66.1	−0.414	0.809	0.103
North Central	65	63.4	−0.455	0.523	0.066
Delfina	104	46.2	−0.771	0.642	0.063

[a] Natural logs of the mean income ratio values for villages are utilized in the analysis so that the data assume a normal distribution

Table 4 Significance values of the independent samples t tests

	Japhet	Northeast	South	West	North Central
Northeast	0.655				
South	*0.054*	0.140			
West	*0.052*	*0.089*	0.576		
North Central	**0.009**	**0.028**	0.238	0.737	
Delfina	**0.000**	**0.000**	**0.000**	**0.001**	**0.002**

Bold values indicate that the difference in the means of the two groups is statistically significant at $\alpha = 0.05$, italics indicate significance at $\alpha = 0.10$

Previous research has documented that rainfall produced by cyclones can have long-lasting negative impacts in Mozambique, as in 2000 when an estimated two million people were affected by the floods to which cyclone Eline contributed (Vitart et al. 2003). In terms of the maximum sustained wind speed at landfall, Delfina was a weaker cyclone than Eline, whose maximum sustained winds at landfall were nearly twice that of Delfina at 51 ms^{-1} (100 kt). Thus, the majority of damage suffered by villages in the Delfina region was likely due to the heavy rainfall and not fast winds. The JTWC reports confirm that Delfina caused flooding in Nampula and Zambezia Provinces. Our results suggest that heavy rainfall from the remnants of a relatively weak cyclone can have long-lasting detrimental effects on economic well-being in this region of Mozambique.

On the other hand, the passage of Japhet may have benefitted villages in our study region. The correlation coefficients show that villages faring better economically received more rain from Japhet (0.144) and overall in March 2003 (0.193). Most of the 30 villages in the Japhet region had a decrease in income. Yet, this loss on average is the smallest of the six regional groups (Table 3), and the results of the t tests indicate that this mean is significantly different from the villages in the Delfina region as well as in the north central, south, and west (Table 4). We note that beneficial rainfall may not be the only explanation for the relative economic success of villages in the Japhet region, particularly compared with those in the adjacent southern region that experienced similar dry conditions in Seasons 2 and 3 (Fig. 4). A Chi-square test for independence indicated that households in the Japhet region were more likely to have a household member gain salaried employment between 2002 and 2005 than those located outside the region, X^2 (1, $N = 2907$) = 7.7,

$p = 0.001$. This could possibly be due to employment generated by reconstruction projects in the aftermath of the cyclone, similar to that which occurred after Cyclone Eline in 2000 (Christie and Hanlon 2001). Interestingly, a similar test showed no statistical relationship between household location in the Delfina-impacted area and a household member acquiring salaried employment, X^2 $(1, N = 2907) = 2.3$, $p = 0.13$. The differences in salaried employment gains after these two cyclones suggest that future research should explore the combined effects of weather and socio-economic factors on income in the study region.

Cyclones are not the only mechanism by which abnormally high rainfall totals can occur in Mozambique. In November 2003, 40 villages in Tete and Zambezia Provinces received more than 200% of their normal rainfall. This is the highest percent of rainfall received during the study period that was not due to the passage of a tropical cyclone, and the negative correlation coefficient between November 2003 rainfall and change in income (−0.128) indicates that villages affected by this rainfall fared poorly as compared to other villages in the study region. Given that Tete and Zambezia Provinces have the highest elevations in the study region, a plausible explanation for the strong negative association between change in income and November 2003 rainfall is that flooding occurred that damaged crops. In support of our findings, FAO (2004) reported that Tete and Zambezia had low agricultural production overall during Season 2. Additionally, more months exhibit statistically significant negative rather than positive correlations with income ratios, and the correlation coefficients for the negative values are higher than those for the positive values. Thus, we find that even during this drought period, receiving above-normal rainfall, whether from tropical cyclones or other convective systems, tends to be associated with higher income losses than receiving below-normal rainfall.

5 Conclusions

This study compares a 12-year rainfall climatology with actual rainfall patterns during three agricultural growing seasons and relates these patterns to income change within rural Mozambican villages. We find that rainfall varies regionally over the three seasons. During Season 1, a north-to-south gradient in rainfall is observed and two tropical cyclones affect the study region differently with Delfina causing flooding in the north and Japhet bringing beneficial rains to the south. Seasons 2 and 3 are drier overall, with above-normal rainfall totals at the beginning and end of Season 2 in the west, and rainfall well above normal and decreasing to below normal in the northeast and north central during Season 3. Our findings about the relationship between rainfall anomalies and socio-economic well-being go against some generally held assumptions in the literature on climate mitigation and adaptation. First, cyclones are not always detrimental: Japhet may have had some positive effects on the economic position of households, either through beneficial rain or employment created by reconstruction efforts. Second, getting rain during a drought period is not always associated with improved economic well-being, especially when rainfall is well above normal. However, receiving more rainfall at the end of the growing season rather than in the beginning or middle when drought conditions exist may have positive effects on harvests and, thus, the economic performance of households.

Establishing the relationship between rainfall anomalies and socio-economic change in Mozambique has important implications for understanding vulnerability to natural hazards in rural areas characterized by extreme poverty and a heavy reliance on rain-fed agriculture. However, other factors in addition to rainfall patterns and extreme weather events, such as the acquisition of salaried employment, impact income changes for rural households. In order to better inform anti-poverty programs and enhance the sustainability of rural livelihoods, future analysis should consider the dynamic relationships between other drivers of socio-economic change as well as climate variability. As such, this study takes an important first step toward evaluating the extent to which weather impacts economic well-being by demonstrating the value of combining weather and socio-economic data in order to better understand patterns of vulnerability.

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