https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

Uncovering the veil of night light changes in times of catastrophe

Vincent Schippers[1] and Wouter Botzen[1,2]

[1]Utrecht University School of Economics; Kriekenpitplein 21-22, 3584EC Utrecht, Netherlands
[2]Institute for Environmental Studies (IVM), VU Amsterdam; De Boelelaan 1111, 1081 HV Amsterdam, Netherlands

Correspondence: Vincent Schippers (v.g.schippers@uu.nl)

Abstract. Natural disasters have large social and economic consequences. However, adequate economic and social data to study subnational economic effects of these negative shocks are typically hard to come by especially in low-income countries. For this reason, the use of night light data is becoming increasing popular in studies that aim to estimate the impacts of natural disasters on local economic activity. However, it is often unclear what observed changes in night lights represent exactly. In this paper, we examine how changes in night light emissions following a severe hurricane relate with local population, employment, and income statistics. We do so for the case of Hurricane Katrina, which struck the coastline of Lousiana and Mississippi in August 2005. Hurricane Katrina is an excellent case for this purpose since it is one of the biggest hurricanes in recent history in terms of human and economic impacts, made landfall in a country with high-quality sub-national socioeconomic data collection, and is covered extensively in the academic literature. We find that overall night light changes reflect the general pattern of direct impacts of Katrina as well as indirect impacts and subsequent population and economic recovery. Our results suggest that change in light intensity is mostly reflective of changes in resident population and the total number of employed people within the affected area, and less so but positively related to aggregate income and real GDP.

1 Introduction

Natural disasters have large social and economic consequences around the world. Impacts of natural disasters are projected to rise as a result of a combination of climate change increasing the frequency and/or severity of extreme weather events and continued urbanization in disaster-prone areas (IPCC, 2014). Studying these impacts, however, is not trivial. For many areas where natural disasters have large impacts, adequate data on local population and economic activity are not available. For this reason, there is a growing literature that studies the local effects of natural disasters by making use of changes in local night light intensity (see e.g. Bertinelli and Strobl, 2013; Gillespie et al., 2014; Elliott et al., 2015; Zhao et al., 2018; Kocornik-Mina et al., 2020). The idea is attractive as night light data is available at high levels of spatial detail, is available consistently over time for the whole globe, and does not suffer from inadequate data collection and measurement error relating to the capacity of (national) statistical offices to measure the state of the economy. Night light intensity is used in a wide range of applications, such as a proxy for economic activity (e.g. Hodler and Raschky, 2014; Michalopoulos and Papaioannou, 2013), or as a proxy for population and GDP (Elvidge et al., 1997; Sutton and Costanza, 2002; Ebener et al., 2005; Sutton et al., 2007; Ghosh et al., 2010) or GDP growth (Chen and Nordhaus, 2011; Henderson et al., 2012). In other studies night lights are used to study urbanization (Henderson et al., 2003; Zhang and Seto, 2011; Ma et al., 2012), migration in response to flood risk (Mård et al.,

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

2018), and population displacement due to violent conflict (Li and Li, 2014; Li et al., 2015). However, few studies examine how night lights and economic activity relate to each other in shock times, and there is relatively poor understanding of what changes in night light intensity reflect exactly especially when downturns in lights are considered (Bennett and Smith, 2017).

In this paper, we aim to advance our understanding on this issue by studying in detail the effects of Hurricane Katrina on county-level population, employment, and income for the most heavily affected counties in Mississippi and Louisiana, and then relating these to changes in night light intensity. Hurricane Katrina is one of the biggest hurricanes in recent history in terms of human and economic impacts, located in a country with high-quality sub-national data collection. We exploit this high-quality data by relating local changes in economic activity to changes in night light. Our key goal is to assess to what extent it is possible to capture the regional economic dynamics following damages from a big natural disaster by making use of the annual nighttime lights. We show that immediate damages are captured well by reduction in night light; there is a strong and negative correlation between the degree of housing damage and reduction in light intensity at the county-level. Furthermore, we show that recovery of population, employment and income after Katrina takes years for some of the most heavily affected countries. While not related one-to-one, this dynamic is reflected in a relatively quick recovery of night light intensity in these counties. Our results show that the use of night light data for studying the immediate economic impact of a big natural disaster such as Hurricane Katrina is warranted. Using these data in areas where alternative economic statistics at the desired level of geographical aggregation are absent may therefore allow for studying the effects of shocks on regional economies.

Our paper connects to a number of different literatures about natural disasters, climate change, and their economic impact, as well as strands of literature that are concerned with economic development. First, our study connects with the literature on the economic consequences of floods and other natural disasters that uses night lights or economic indicators to proxy these consequences. Specifically for floods, most closely related is the work by Kocornik-Mina et al. (2020), who study the urban impact of large-scale floods in a global sample, using nighttime light intensity as a proxy for local economic activity. The authors find a short-lived negative effect of flooding in the year of the flood, suggesting that economic activity recovers to the pre-flood equilibrium rather quickly. In effect, our case study of Katrina is a part of their broader analysis, which we study in more detail and for which we examine the relationship between decline and recovery of night light and economic activity in detail. Moreover, we show that observable reductions in light intensity are possible for multiple years after the disaster. Related to Kocornik-Mina et al. (2020) is the work by Elliott et al. (2015) who similarly find a significant but short-run effect of typhoons on economic activity in cities in coastal China, also proxied by nighttime lights, and Gillespie et al. (2014) who study the impact of the 2004 tsunami in the Indian Ocean on affected communities in Sumatra, Indonesia.[1] Second, most economic studies use more traditional indicators of economic activity to study disaster impacts instead of night lights. Strobl (2011) assesses the economic growth impact of hurricanes for US counties and reports a decline in GDP growth in the year of impact

[1]This work is part of a growing literature that studies the local economic impacts of hurricanes and other natural disasters, often making use of nighttime lights as a proxy for local economic activity. Related papers on hurricanes are Bertinelli and Strobl (2013) on the local economic impact of hurricanes in the Caribbean, Mohan and Strobl (2017) on the short-term impact of cyclone Pam in the South Pacific, Del Valle et al. (2018) on cyclone impacts in Guangdong, China, Ishizawa et al. (2019) on hurricane impacts in the Dominican Republic, and Miranda et al. (2020) on windstorm impacts in Central America more generally. Night lights have also been used to study earthquake impacts (Kohiyama et al., 2004; Fan et al., 2019; Nguyen and Noy, 2020), and a combination of disaster types globally (Felbermayr et al., 2022) and for Indonesia and Southeast Asia respectively (Skoufias et al., 2020, 2021).

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

of 0.5% on average. Notably, this impact is netted out at the state level within a year, implying that effects are local in nature. Closely related to this is work on the economic growth impacts of hurricanes in Central America and the Caribbean (Strobl, 2012), and in a global sample (Hsiang and Jina, 2014; Berlemann and Wenzel, 2018). Heger and Neumayer (2019) study the long-term economic growth impact of the Indian Ocean tsunami of 2004 for Aceh, using both GDP and annual night lights, and find a positive effect that can be explained by the large aid inflow and coordinated reconstruction efforts. Again, no effect on economic growth is observable at the national level. We also relate to a broad literature that studies the impacts of other natural disasters on economic growth (Noy, 2009; Cavallo et al., 2013; Fomby et al., 2013; Felbermayr and Gröschl, 2014).[2] A critique is that many of these studies have used aggregate national GDP indicators to study the impacts of disasters which often are local events (Felbermayr et al., 2022; Botzen et al., 2019). We contribute to this literature by combining insights of impacts on economic activity in the affected region through conventional economic statistics with an analysis of changes in night light activity to assess the value of the latter in studying impacts of natural disasters on local economic activity. Third, our work relates closely to studies that have examined the social and economic impacts of Hurricane Katrina, which we will discuss in detail in the next section. These studies analyze the effects of Katrina on neighborhoods in New Orleans (Logan, 2006), on the economic welfare of displaced individuals (Paxson and Rouse, 2008; Groen and Polivka, 2008; Deryugina et al., 2018; Groen et al., 2020), business survival and recovery (Jarmin and Miranda, 2009; Basker and Miranda, 2018), and its substantial wider effects on the affected regional economies (Vigdor, 2008; Hallegatte, 2008; Xiao and Nilawar, 2013). We incorporate and synthesize the existing empirical evidence in the next section, before turning to the analysis on the effects ~~the effects~~ of Hurricane Katrina on night light intensity of the affected region. Fourth, we relate to a growing literature on the use of nighttime light for empirical analysis of economic growth and development, starting with the seminal contributions by Henderson et al. (2012) and Chen and Nordhaus (2011). Most relevant to our work are the studies with a focus on sub-national development patterns by e.g. Michalopoulos and Papaioannou (2013, 2014), Hodler and Raschky (2014), and Henderson et al. (2017). Ghosh et al. (2013) and Donaldson and Storeygard (2016) provide excellent overviews of the various applications of night lights in this literature. Recent tests of the relation between night lights and GDP at the local level using regional, city-level, and prefecture-level data (e.g. Hodler and Raschky, 2014; Storeygard, 2016; Kocornik-Mina et al., 2020) show a promising correspondence with the lights-to-GDP elasticity established by Henderson et al. (2012).[3] However, for our purposes we are interested in the relationship between night lights and economic activity in the context of a natural shock. We contribute to this discussion by presenting new findings about the relationship between night lights and economic activity in shock times for the detailed case study of hurricane Katrina. Finally, and more broadly, our study connects with the literature on estimating the costs of climate change, sea level rise, and the increasing risk from hurricanes and flooding that coastal cities face in the near future (Hallegatte et al., 2013; Aerts et al., 2014; de Ruig et al., 2019). We study in this paper one case of a heavily urbanized coastal region that is exposed to the risks of hurricane landfalls. Global warming and sea level rise are expected to aggravate these risks in many parts of the world (IPCC, 2014). Understanding the consequences of hurricanes on coastal economies is

[2] For reviews of this literature, see Cavallo et al. (2011); Klomp and Valckx (2014); Botzen et al. (2019).

[3] Note that this literature also has critical contributions that show that the lights-to-GDP elasticity is not necessarily equal across the globe and between different regions within countries. See Bickenbach et al. (2016) and Gibson et al. (2020, 2021) for a discussion. We contribute to this discussion by studying one region in detail and explicitly assessing the relation between light intensity and economic indicators in the context of a large natural disaster.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

therefore important for risk management and planning. Since adequate data to study local economic impacts are not available in large parts of the (developing) world, we aim to contribute to this discussion by assessing the extent to which remotely sensed night light can be of use in this context.

2 Direct and economic consequences Hurricane Katrina

We first summarize the immediate impact of Hurricane Katrina, and asses its economic impact on the affected region. We then make the link with visible effects of Katrina on the affected counties from space, by assessing the changes in night light intensity of the affected areas. We then assess the recovery in light intensity over the subsequent years, before turning to a comparison between economic impacts and effects on night light intensity.

2.1 Hurricane Katrina: landfall and economic impacts

On 29 August 2005 Hurricane Katrina made landfall close by New Orleans. Although it was downgraded from a Category 5 to a strong Category 3 hurricane, it was as an exceptionally large storm when it approached the shoreline with wind speeds up to approximately 200km per hour (Knabb et al., 2005). The storm killed almost 2,000 people and caused substantial damage of $125 billion in total due to winds, extreme precipitation, and major storm surge flooding (National Hurricane Center, 2018). A large part of these damages occurred in New Orleans that experienced massive flooding of about 80% of its land (Pistrika and Jonkman, 2010). Several levees that were meant to protect the city of New Orleans – which is situated largely below sea level – were overtopped or breached due to the storm surge (see Figure 1). Major unanticipated flooding occurred especially in Orleans Parish and St. Bernard Parish. These areas were inundated for a long time as it took 43 days until all flood waters were removed from the city (Knabb et al., 2005). The distributional impact across the City of New Orleans resembles a clear pattern of segregation that was present long before Katrina struck. The parts of the city that proved most vulnerable (see 1) were those that were majority black and low income neighborhoods, and recovery was also slowest in these areas (Logan, 2006). Other Parishes were mainly affected by wind and less severe flooding of a shorter duration for which warnings were issued. As a consequence, more housing units were destroyed in the inner city compared with these outside Parishes (Vigdor, 2008). Some areas were never rebuilt. Wider devastating effects were recorded in the south coast of Louisiana and Mississippi, where in some counties well over half of the residential housing stock was severely or completely damaged.

Hurricane Katrina had large impacts on the population and economic activity in New Orleans that differ between its Parishes and vary over time. Especially the Orleans and Bernard Parishes experienced severe population declines in about 2 years after Katrina, which were also the Parishes that experienced most severe flooding. The short-term population decline was even more severe. Within a week the population reduced from more than 400,000 to almost zero because people evacuated the city, of which about half had returned 2 years later after which the population more or less stabilized until mid-2008 (Vigdor, 2008). Deryugina et al. (2018) estimated that a third of the evacuees from New Orleans still had not returned by 2013. Katrina reinforced a trend of an already shrinking population, which may explain why the population has not fully recovered.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

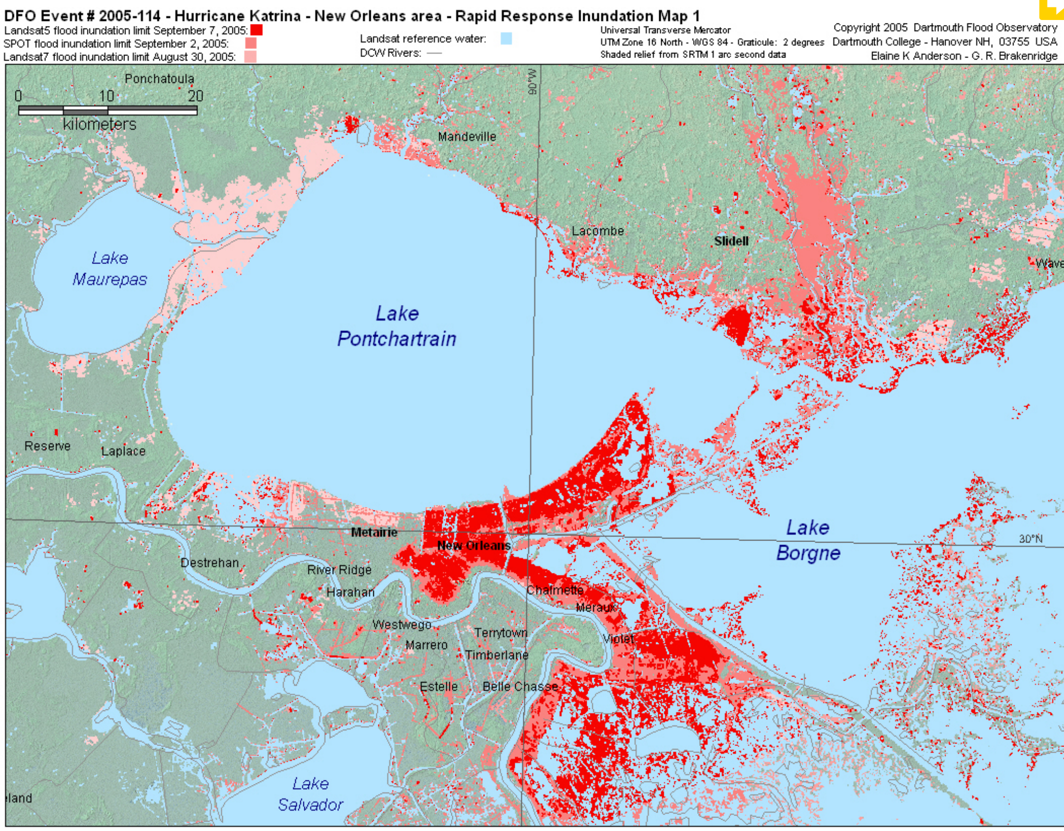

Figure 1. Flood map of New Orleans: image by Dartmouth Flood Observatory (2005). Color-coding indicates flooding by August 30, September 2, and September 7 respectively. Note how especially the eastern part of the city entire neighborhoods were still inundated a week after the hurricane. Knabb et al. (2005) report that the final waters were only cleared five weeks later.

Already pre-Katrina the city was experiencing continued out-migration due to lacking economic opportunities, which especially applied to the central city (Vigdor, 2008). Economic activity further deteriorated after Karina, which is reflected in lower employment. Private sector jobs declined by approximately 70,000 jobs in the New Orleans metropolitan area. The most severe decline in employment is observed in services-oriented sectors, which lost part of their customer base due to the population decline. Even though some positive employment growth occurred in the construction sector, this did not offset the declines of well over 10 to 20 percent in most other industries, ranging from business and trade to state and local government services (Vigdor, 2008). The overall loss in employment indicates that economic activity declined, but this does not necessarily mean that income declined as well. Perhaps surprisingly, the decline of income is only roughly half that of population and employment, mirroring the unequal effect that the hurricane had to different income groups. The low-lying and predominantly poorer and black neighborhoods of New Orleans were hit hardest (Logan, 2006).[4] It were the low-income and primarily African American

[4]The worst-affected neighborhoods had substantially higher numbers of renters, households below the poverty line, and unemployed compared to undamaged communities (Logan, 2006).

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Discussions

former residents who in large numbers were unable to return to the city after the disaster (see e.g. Paxson and Rouse, 2008).[5] Groen and Polivka (2008) describe that evacuees suffered substantially in terms of labor market outcomes in the year after Katrina, although on average these effects diminished over time. Moreover, evacuees who did not return to New Orleans had worse labor market outcomes than those who did return in the short run, part of which is explained by individual and family characteristics also discussed by Logan (2006) and Vigdor (2008). The long-run development of household income of those who lived in New Orleans during Katrina has been analyzed by Deryugina et al. (2018) using tax return data. They find labor income declined shortly after Katrina by \$2,000 and by \$2,300 in 2006 compared with similar households who lived outside of New Orleans when Katrina occurred, mirroring the findings by Groen and Polivka (2008). However, this income decline disappeared in 2008 when incomes of Katrina victims were \$1,300 higher (Deryugina et al., 2018). Explanations for this result are that wages in New Orleans increased in the years after Katrina to compensate for local price rises, especially for housing that was in short supply, and that evacuees moved to areas with improved job opportunities and higher wages. In addition, a strengthening local labor market with relatively scarce labor supply caused further upward pressure on relative wages (Groen et al., 2020). Focusing on business establishments rather than individuals, Basker and Miranda (2018) find very low survival rates for businesses that incurred physical damage from Katrina, especially for smaller and less productive establishments. Xiao and Nilawar (2013) focus on the regional impacts of the disaster and observe positive spillover effects on income and employment growth from heavily affected counties to their surrounding counties. This pattern suggests the presence of spatial demand shifts away from the core affected area into neighboring less affected counties. All in all, the social and economic impact of Katrina was enormous.

2.1.1 Visible impacts from space

A first analysis shows that the devastating impacts of Katrina are visible even from space. We collect the DMSP annual average stable night light composites provided by the National Oceanic and Atmospheric Association, and plot average annual night light intensity for the city of New Orleans below in Figure 2. The data comes at a resolution of 30 arc seconds (roughly 1km^2 at the equator), and intensity is given in digital numbers ranging from DN0 to DN63 reflecting dark to very bright respectively.[6] Even though New Orleans is a densely urbanized location where brightness of lights is as high as the satellite can record, city lights fell drastically in many parts of the city as a result of the flooding and wind damage caused by Katrina. In the eastern part of the city, as well as in its eastern suburbs (Chalmette) night light intensity almost halved, reflecting the severity of flooding in that part of the city. While some recovery is appartent in 2006, visible impacts especially in the eastern part of the city remain visible even in the raw light data. Next, we zoom out and assess direct impacts along the coastline of Louisiana and Mississippi. We collect the damage figures from the U.S. Department of Housing and Urban Development (2006), which reports damage assessments to occupied housing units based on FEMA's data on Individual Assistance Registrants and Small

[5] This is reminiscent of the out-migration of black population after the Great Mississippi Flood in 1927 reported by Hornbeck and Naidu (2014).

[6] Note that while the night light data are provided in a resolution of 30 arc seconds, the sensor resolution is much coarser and represents a ground footprint at nadar of roughly 25 square kilometers (Elvidge et al., 2013). For this reason, we do not focus on pixel-level outcomes in this study, but rather use the total sum of light per year at the county level.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

Business Administration Disaster Loan Applications. Damage to housing units is divided into three categories: minor damage (<\$5200), major damage (\$5200-\$30,000), and severe damage (\$>30,000). Housing damage of category major and severe as a percentage of total occupied housing units by county is reported below in Figure 3.[7] Damages were extremely high at over 50% in Plaquemines Parish (LA) and Orleans Parish (LA), 70% in Hancock County (MS) and close to 80% in St. Bernard Parish (LA). Four other counties have damages close to or over 20% of their housing stock: Jackson County (MS), Harrison County (MS), and St. Tammany Parish (LA) and Jefferson Parish (LA). In our main analysis, we focus on these eight most severely affected counties. Our main interest is the extent to which we can capture the regional economic dynamics following these damages by making use of the annual nighttime lights. To do so, we start with a simple descriptive analysis of the association between housing damage and light intensity between 2004 and 2005. We first plot changes in the total sum of light by county on the same map (see Figure 3 below), and find a pattern that is strikingly similar to that of the housing damage map in Figure 3. Indeed, an (unconditional) correlation plot reveals the same pattern, with a correlation of -0.60 that is significant at 1% (see Figure 4 below). The immediate impact of Hurricane Katrina is thus evidently captured quite well in the changes in night light intensity.

2.2 Regional impacts and recovery in night lights

We can further illustrate the reductions in light intensity by taking a closer look at the night light images for the affected region at large. However, two features of the night light data make comparison over space and across time challenging. The first issue is that the DMSP annual composite data is known for its problematic intertemporal and between-satellite measurement differences, due to varying gain settings of the sensor over time and ageing of the satellites (for a detailed discussion see Elvidge et al., 2009b, 2014). This makes it difficult to compare night light intensity within an area over time. In order to facilitate cross-time comparison, we calibrate the light composites by making use of the Elvidge et al. (2014) invariant area calibration method. The calibration exercise is based on a reference image for an area where true light intensity remains approximately unchanged throughout the study period, which then allows separating true changes in light intensity from pure satellite measurement error. In Appendix B, we discuss this calibration in detail and also propose alternative methods of adjusting the data: notably an alternative calibration by Zhang et al. (2016) and an econometric fixed effects approach more customary in economics (Henderson et al., 2012). Out of these options, the calibration by Elvidge et al. (2014) performs best for our purposes. In all main results that follow, we therefore use calibrated night light images following the methodology of Elvidge et al. (2014). We test our results for robustness with the alternative calibration proposed by Zhang et al. (2016) and by making use of an econometric panel fixed-effects correction proposed by Henderson et al. (2012) in Appendix A. Our main results are very robust to these alternative correction methods. A second issue is that of top-coding in the DMSP annual night light composites: an upper limit to the DMSP-OLS sensor results in saturation of recorded light intensity at DN63 (Small et al., 2005). This implies that any light intensity above this saturation threshold is not captured in the data. As a result, predominantly bright

[7] The distribution of damages by county is also reported in Figure A1 of Appendix A.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

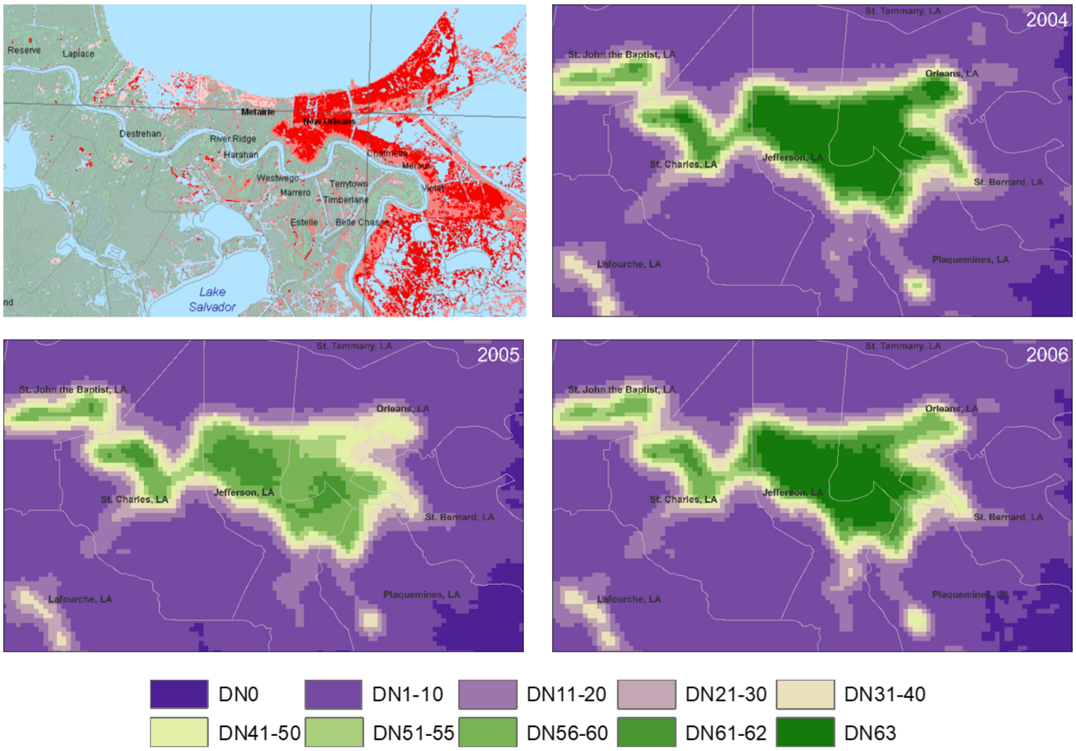

Figure 2. Night lights for the City of New Orleans before and after Katrina. Excerpt of the Darmouth Flood Observatory flood map reported in 1 as reference area (top left). Night lights as observed from space by DMSP-OLS, raw uncorrected data from satellite F15. Brighter areas are indicated by green, whereas purple implies darker areas. Much of the city was at maximum brightness of DN63 in 2004 (top right) but fell below this threshold in the year 2005 (bottom left). Note how especially the eastern part of the city dims and has only partly recovered by 2006 (bottom right). As will be discussed below, it took almost a decade to recover light levels to their old intensities in these neighborhoods.

urban centers are top-coded, as is also the case for the city of New Orleans.[8] This is problematic for several reasons, but specifically results in problems in our case when assessing decreases in night light intensity as a result of Katrina for a high-income area with bright urban centers such as New Orleans: true decreases in night light intensity that takes place above this saturation threshold may be obscured in these pixels.[9] We therefore investigate the importance of top-coding for our results in this section.

[8]Bluhm and Krause (2018) propose a method to impute true light values for top-coded pixels by assuming a Pareto distribution on top lights. Although this approach may be of great value to the general literature that studies economic growth and the spatial distribution of economic activity, we cannot make use of any imputed measures as we study a shock.

[9]The problem is much less severe in low and middle-income countries. There the share of top-coded pixels is close to zero. See Felbermayr et al. (2022) and Kocornik-Mina et al. (2020) for a discussion.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Discussions

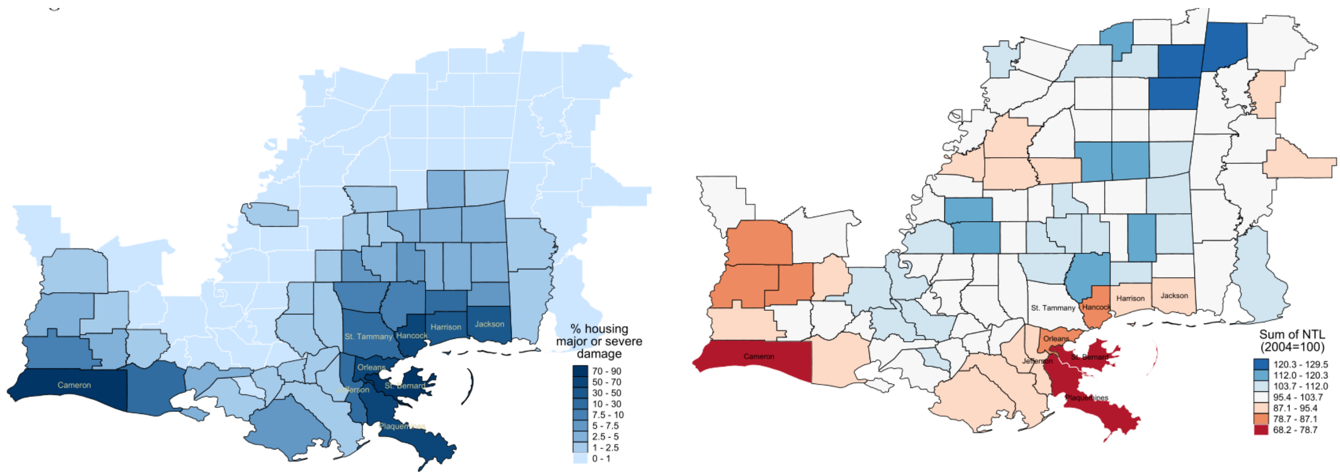

Figure 3. Housing damage and night lights in 2005. Left: Percentage of occupied housing units with major or severe damage from Hurricane Katrina. Own calculations, based on U.S. Department of Housing and Urban Development (2006) data from FEMA Individual Assistance Registrants and Small Business Administration Disaster Loan Applications. Counties with major/severe damage of 15% or more are labelled in the map. Damages for the counties in Western Louisiana (most notably Cameron, Vermillion and Calcasieu) are related to hurricane Rita that made landfall at the coastline of Texas later in the year 2005. These are not to be related with the impact of Katrina, but show a similar pattern of damages and night light intensity reductions. Right: Immediate night light reduction by county (2005 w.r.t 2004). Based on own calculations. Sum of night light based on calibrated light series using the Elvidge et al. (2014) method, discussed in detail in Section 2.2 below. Colour-coding based on the standard deviation method (see Appendix Figure A2 for the distribution of night light changes)

The distribution of night light intensity values in the study region is presented in Figure 5. Clearly the majority of New Orleans city is top-coded, with only its edges falling below the saturation threshold prior to Katrina.[10] Note how similar top-coding is present along the urbanized coastlines of Harrison and Jackson County. Of course, this issue is not unique to our particular study area, but is true more generally for high-income countries like the United States. Taking the substantial top-coding in the study area as a matter of fact, we turn to assessing changes in light intensity after Katrina.

Two panels of images now follow to compare the changes over time in 2005 and 2006. First, the left panel of Figure 6 gives the distribution of night light intensity across the study region for 2005. The right panel then plots absolute decrease in night light intensity (the digital number for 2004 subtracted from 2005 for each pixel). Figure 7 does the same, but then for 2006 (see below). Focusing first on New Orleans, the immediate effects of Katrina become apparent in the eastern part of the city

[10] There is a third issue with the DMSP data that revolves around overglow, or otherwise referred to as blooming (Bennett and Smith, 2017; Gibson et al., 2020, 2021). Overglow, related to geolocation errors in the DMSP data, results in light intensity being recorded slightly away from its point source, such that urban areas have a larger extent of lit pixels than actual built-up land. This is an issue particularly in studies that use DMSP night light data at high spatial detail, up to the pixel level of the data (e.g. Bertinelli and Strobl, 2013; Kocornik-Mina et al., 2020). Moreover, local economic activity arguably does not reside on square kilometers, but rather in larger economic and administrative (spatial) units. In order to be able to draw a parallel between measured economic activity and night lights, we therefore aggregate night light intensity to the sum of light at the county level. As such, the issue of blooming and geolocation errors is of limited concern in our context.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
Discussions

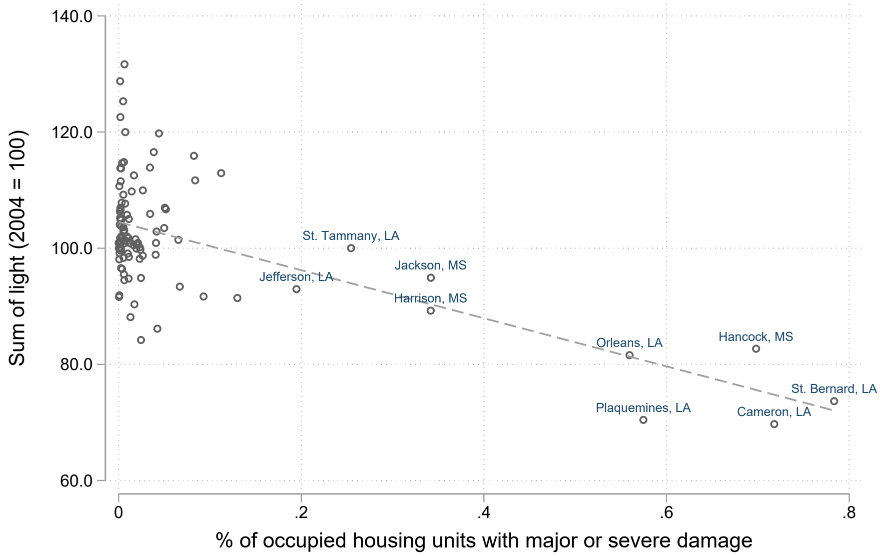

Figure 4. Correlation plot of housing damage and night light reduction in 2005. Housing damage in 2005 for Lousiana and Mississippi from the U.S. Department of Housing and Urban Development (2006). Night time lights for 2005 are calibrated using the Elvidge et al. (2014) method, discussed in detail in Section 2.2 below, indexed to 2004=100. Note that the damage and associated night light reduction for Cameron Parish (Louisiana) is associated with hurricane Rita that made landfall at the coastline of Texas in 2005. We do not focus on this particular example in the remainder of the paper, as our focus is on hurricane Katrina.

and in the suburbs of Chalmette, as we saw before even in the raw data in Figure 2. Reduction in light intensity is most severe in the northeastern tip of the city, with light reductions 30 up to 50 points, translating in reductions that amount to well over 50 percent. Moreover, notable reductions occur in previously top-coded parts of the city. While we cannot exclude the possibility that the true decrease in light intensity is even stronger, here too reductions run well over 10 percentage points. Note that in the west of the city hardly any change is detected, which is very much in line with the geographical spread of flooding (see Figure 1).

Two other main areas that suffer heavy light reduction can be clearly identified from these figures. First, Plaquemines Parish has a long inhabited strip along the Mississippi River ending at the town of Venice, Louisiana, which was suffered enormous damages from Hurricane Katrina. Light reductions are evident along the entire river, with the highest reduction located in Venice. Note that no top-coding was present in this area in 2004. The second area is Bay St. Louis, Mississippi, and the coastline along Harrison County. Major light reductions are visible in all urban zones around the bay, notably in Waveland, Diamondhead, and Pass Christian. Reductions in the order of 10-20 points are also visible further along the coastline in Long Beach and Gulfport. Again, no top-coding was present here in 2004.[11]

[11]These reductions match closely with the damage maps from FEMA for this area, described in detail in Basker and Miranda (2018). Extensive damage along the coastline is reflected by large drops in light intensity, while milder reductions in light intensity are matched by mild damage from the FEMA maps.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

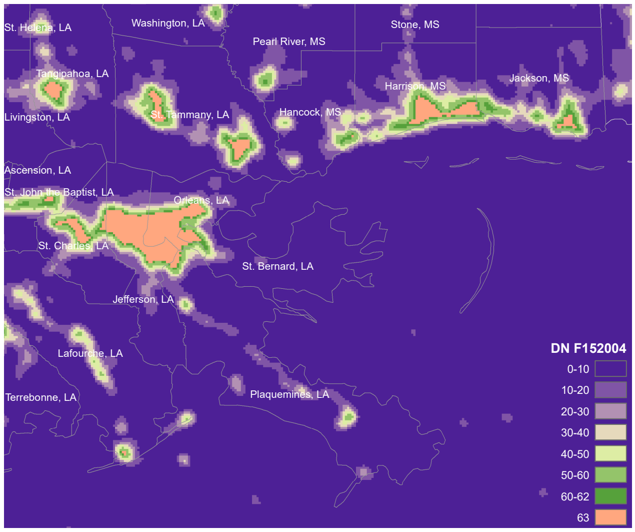

Figure 5. Night light intensity in the study region prior to Katrina, 2004. Based on own calculations using satellite F15, corrected with the Elvidge et al. (2014) calibration method. Top-coded pixels are indicated in orange. County names in white.

Next we turn to the year 2006, depicted in Figure 7. A first observation is that the worst reductions in night light have largely disappeared from the map: reduction over 20 points – compared to 2004 – are rare in 2006. However, the eastern part of New Orleans remains depressed, notably also along the Mississippi river near Chalmette. While a substantial part of the city returns to being top-coded, this is clearly not the case for the north-eastern neighborhoods of the city. This is true even for a large strip that was top-coded in 2004. In a similar vein, the riverbed of Mississippi still shows depressed night light values all the way to the town of Venice. There are signs of recovery around the St. Louis Bay, but light intensity is still 10 to 20 points lower in many parts of the metropolitan area around the bay. Top-coding thus mainly affects the changes that we observe in New Orleans city, thereby affecting the observed changes in light intensity for the Parishes Orleans, St. Bernard, and Plaquemines – which, as will be discussed below, are the counties for which we observe permanent reductions in population and employment. This means that we have to interpret our comparison of changes in night light intensity to changes in economic indicators for these areas with care. It is likely that the observed reductions in night lights are an underestimate of the true effect on night light intensity. However, even with this caveat in mind, the overall patterns of direct impact and recovery in terms of night light changes are closely in line with our expectations, based on the geographical spread of flooding and on the impact numbers that we know from previous studies.

This is not the end of the story. Our analyses in the subsequent section focus on the following two issues: (1) the extent to which this reduction in night light intensity corresponds to reductions in economic activity, as captured through county level income, employment, population, and GDP, and (2) the extent to which recovery of night light intensity over time corresponds

As with New Orleans city, we find close correspondence between flood zones, property damage, and night light reduction. For a detailed discussion on the FEMA damage maps, see Jarmin and Miranda (2009)

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

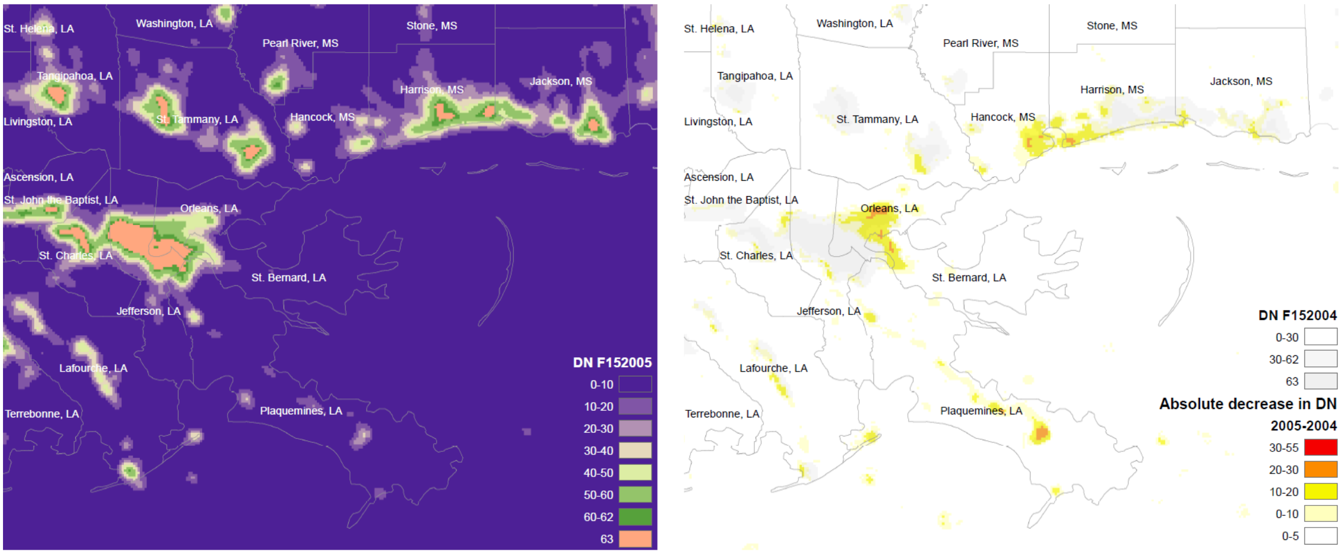

Figure 6. Absolute change in night light intensity from 2004 to 2005. Based on own calculations using satellite F15, corrected with the Elvidge et al. (2014) calibration method. *Left:* Night light intensity in the study region, year of Katrina 2005. Top-coded pixels are indicated in orange. *Right:* Absolute difference of pixel DN value between 2004 and 2005.

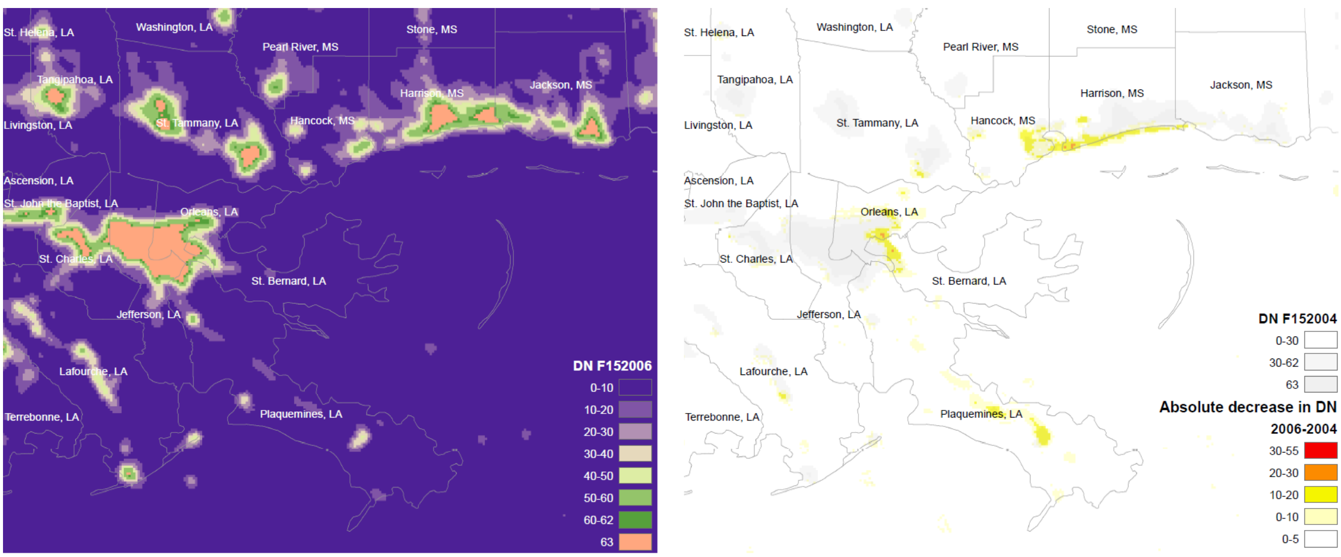

Figure 7. Absolute change in night light intensity from 2004 to 2006. Based on own calculations using satellite F15, corrected with the Elvidge et al. (2014) calibration method. *Left:* Night light intensity in the study region, year of Katrina 2006. Top-coded pixels are indicated in orange. *Right:* Absolute difference of pixel DN value between 2004 and 2006.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
Discussions

to recovery in these economic indicators. Since the impacts are clearly largest in the defined core group of 8 coastal counties, we collect for these counties annual data on their economic indicators and assess the longer-run impacts of Katrina on their economies. We then compare these developments to changes in night light intensity over time.

3 Relating night light changes to economic indicators

The economic impact of hurricane Katrina on the county economies along the coast becomes evident from the graphs in Figure 8 (see below), which plot population, aggregate employment and income, real GDP, and night light intensity by county for the years 2000-2018.[12] To allow comparison of impacts with recovery over time, we standardize the series of each county to their respective levels in 2004 (2004=1). The graphs are sorted by normalized housing damage, expressed as percentage of total occupied housing units with major or severe damage. Some notes are warranted before discussing the graphs. First, the economic data collected from the Bureau of Economic Analysis are aggregates for calendar years. Hurricane Katrina made landfall in August of 2005, and is therefore only captured in the final quarter of 2005. The majority of losses from the hurricane are therefore captured in the records for 2006. We stress that this includes any short-term recovery as well, implying that immediate losses in the first weeks after the hurricane may be partly offset by recovery in subsequent months. Second, a similar notion is important when assessing loss in night light intensity for the counties for 2005 with respect to 2004. As the DMSP night light composites are annual averages, only the months September-December are affected by Katrina's impact – i.e. only one-third of the year. This implies that reduction in night light in the months directly after the impact may be considerably larger than the currently presented figures. Third, population figures come from the Census Bureau midyear population estimates. As these are assessed midyear, the population effect of Katrina is only captured in 2006. As such, all reported figures represent a lower bound of the true short-run effects of Katrina. We now turn to assessing the impact of Katrina on the worst-affected counties. We first point to some general observations. The general patterns are clear and reassuring: reductions in night light intensity are clearly strongest for the most affected counties of St. Bernard, Hancock, Plaquemines, and Orleans, as was also shown in Figures 6 and 7. All counties experience major or severe damage to housing units of over 50 percent, which is associated with reductions in light intensity of 20 to 30 percent. These reductions are clearly in line with large losses in population. In contrast, the bottom four counties in Figure 8 experience smaller housing damage of 20 to 35 percent, and experience much smaller population losses. Harrison, Jackson, St. Tammany, and Jefferson experience smaller economic impacts in comparison to the top four counties in Figure 8, and in line with these patterns reduction in night light intensity is smaller at 3 to 13 percent.

3.1 Population changes and night lights

To guide the discussion, we now separate the counties into three groups, based on population effects. We first discuss the relation between population effects and changes in night light intensity, before turning to the other economic indicators. The

[12] The DMSP night light series run up to 2012 only, following the calibration results of Elvidge et al. (2014). Note that the annual stable night light composites from the DMSP-OLS instrument were discontinued after 2013.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences Discussions

three groups are (1) permanent reduction in population, (2) temporary reduction in population, and (3) no substantial change. The first group consists of the three most-affected counties in Louisiana – St. Bernard, Plaquemines, and Orleans Parish – plus the less-affected county of Jefferson. The former three experience population losses in 2006 of 24%, 53%, and 76% respectively. This population loss is recovered in part, but population levels off at 80% of pre-Katrina levels by 2018 for Plaquemines and Orleans, and for 65% in the case of St. Bernard. In tandem with this development, night light intensity drops between 20 to 30 percent in 2005 and remains depressed below pre-Katrina levels thereafter. However, the decline in night light intensity does not appear to be strictly proportional to population loss; while night light intensity does not decline further than 30 percent, population losses for St. Bernard and Orleans are well over two-fold of their loss in light. Strikingly, the recovery paths of night light compared to population for these two counties do show remarkable similarity. Growth rates are comparable in the first years following Katrina, which leads St. Bernard to recover its night light intensity to pre-Katrina levels by 2008, and leveling off after that, even though St. Bernard is still 60 and 40 percent below its pre-Katrina population level in 2008 and 2012 respectively. Instead, night light intensity remains permanently depressed at roughly 10 percent below pre-Katrina levels in Orleans. The third county, Plaquemines, experiences an immediate and also permanent reduction of roughly 20% of its population. Night light intensity declines by roughly 30 percent, but shows fast growth in 2006 and 2007. After that, light levels remain permanently depressed slightly below pre-Katrina levels. The fourth county with a permanent reduction in population – albeit less severe at around 7% - is Jefferson, Louisiana. Night light intensity falls by about roughly 5% in 2005, and remains permanently depressed until the end of the series in 2012.

The second group consists of counties that experience smaller and only temporary reductions in population: Hancock, Harrison, and Jackson. Population reduction is 14%, 11%, and 3% matched by a reduction in night light intensity of 20%, 13%, and 8% respectively. For all three counties, night light intensity recovers to or overshoots pre-Katrina levels by the next year, and remains above pre-Katrina levels in subsequent years.

The third classification applies only to St. Tammany, which experiences no population loss at all, even though 25 percent of its occupied housing units had major or severe damage. Population was steadily growing prior to Katrina hit in 2005 at an average rate of 2.5% between 2000-2005, compared to 2.7% in 2006. However, the growth rate does decline substantially in the years after. In line with a lack of any apparent immediate population effect, there is no change in light intensity with respect to 2004. Population growth seems unrelated to light growth before Katrina, while the three years after Katrina are associated with both positive population and light growth. However, while population continues to grow at roughly 1% per year after 2008, night light intensity remains roughly constant at roughly 12 percent above pre-Katrina levels.

As a preliminary conclusion, the effects of Katrina on counties' night light intensity corresponds with their respective changes in population, although more so qualitatively than quantitatively. Reductions in light intensity are roughly a third at maximum, whereas population losses were over twofold in some counties. However, recovery patterns in population numbers closely match those of recovery in light intensity.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

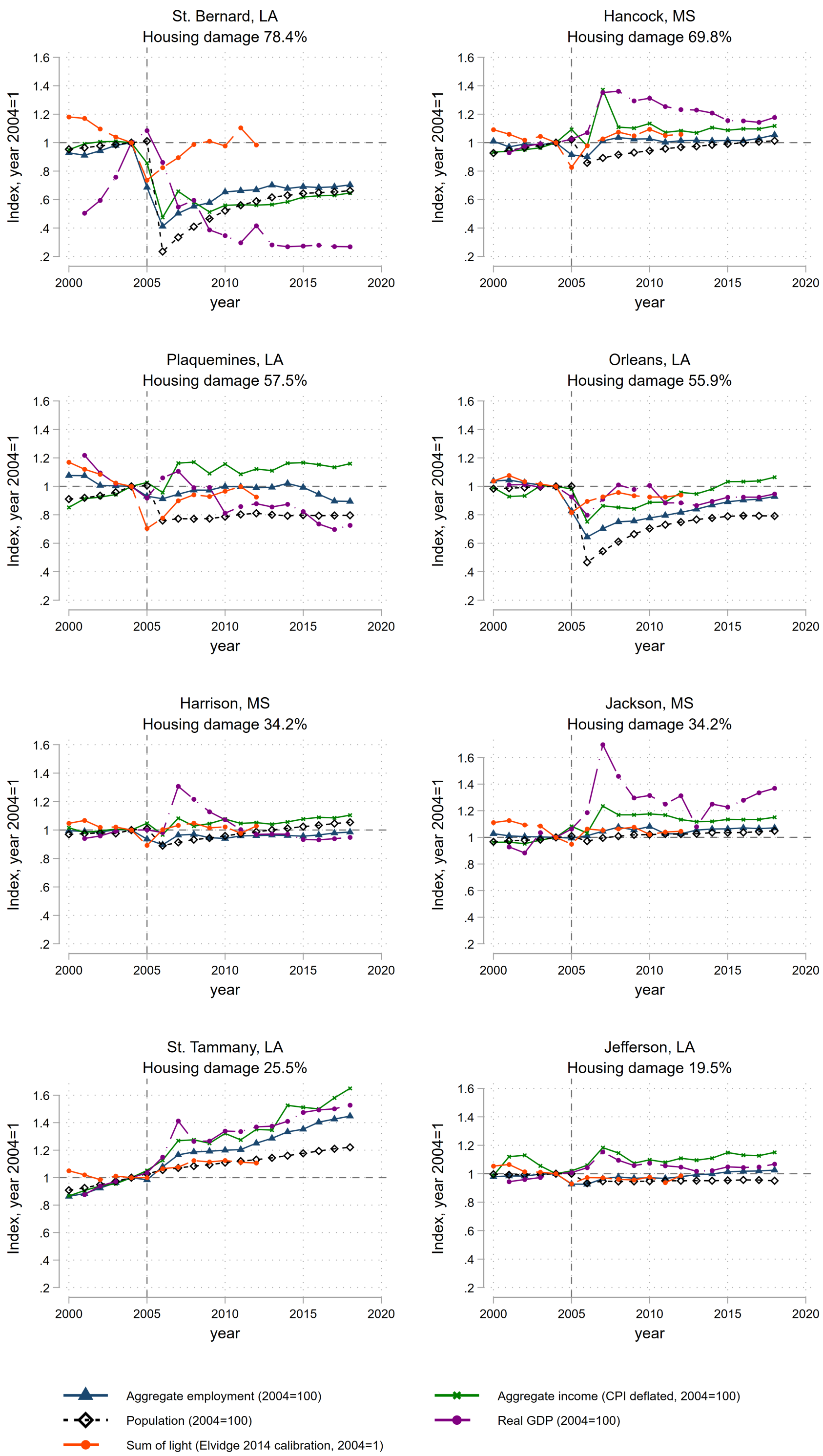

Figure 8. Night light and economic indicators following Katrina for the 8 most-affected counties. Based on own calculations. All variables are indexed with 2004=1. Aggregate employment, income, population, and real GDP data come from the U.S. Burea of Econonomic Analysis (2020). Night lights are calibrated using the Zhang et al. (2016) method.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Discussions

3.2 Other indicators: employment, income, and GDP

We now extend the discussion to include effects of Katrina on economic activity in the counties, reflected by aggregate employment, income, and GDP. A first observation is that in the first group of counties the loss in employment is considerably smaller than that of total population. Nonetheless, employment losses overall are roughly proportional to losses in total population, and are therefore also closely related to changes in night light intensity.[13] With the exception of all counties experiencing a spike in income in 2007, related to the massive federal recovery assistance funds disbursed in that year (Xiao and Nilawar, 2013), aggregate income changes in relation to Katrina are more heterogeneous. For St. Bernard and Orleans Parish, income changes follow declines in population and employment closely. The six other counties instead experience a slight increase of aggregate income of up to 10% relative to 2004. In both Hancock and Plaquemines, aggregate income remains 10 to 15 percent above 2004-levels for the entire duration of the study period, even though both counties lost a substantial proportion of their population. In both cases, the increase in income – combined with a substantial growth in GDP in Hancock – may partly explain fast recovery of total night light intensity. The bottom four counties in Figure 8 show a consistent pattern: no signs of very substantial impact in either of the economic indicators, and corresponding patterns in aggregate income and GDP, with again a shared spike in 2007. Aggregate income and GDP show a strong correlation for Hancock and Orleans as well, but in St. Bernard and Plaquemines GDP is a lot more variable. Both counties show a notable decline in GDP after 2008, which is not explained by either employment or aggregate income.

In summary, the impact of Katrina on the counties' economies has clearly not been uniform. While the size of economic effects is related to the extent of damages, there is no single coherent explanation that captures economic changes in terms of population and income as a function of damages. Some counties experienced lasting population losses, where others – most notably Hancock – recovered fairly quickly and experienced (temporary) booms in income and GDP. In turn, night light intensity does not do a perfect job at capturing these dynamics, but performs as expected in qualitative terms: the heaviest-hit counties show the largest declines in night light intensity, and light intensity recovers to pre-disaster levels in the subsequent years. However, recovery of night light intensity towards pre-Katrina levels is much faster than for population and employment and income in the heaviest hit counties of St. Bernard and Orleans. Growth in income and employment after Katrina is positively correlated with night light intensity as well. The relation with GDP seems less evident across the 8 counties, compared to the other indicators. However, overall the qualitative patterns are promising: night light intensity can inform us about regional economic downturns in this case study.

3.3 Correlations between night lights and economic indicators

To further structure the discussion, we assess the correlation between the change in total sum of light and the change in economic indicators for the eight affected counties. We distinguish two periods: the period before Katrina (2000-2004), and

[13] While employment is proportional to total population, displacement of population may affect the working population differently than the non-working population. As discussed in the effects of Katrina in New Orleans, we know that the low-income segment of New Orleans' population was disproportionally displaced (Logan, 2006).

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Discussions

the period starting in the year of Katrina (2005-2012). Since the population record for 2005 is based on the midyear estimate in July, we limit the population to 2006-2012 for the second period for this indicator only.[14] Results are reported in Figure 9.

The results are rather striking. In the period before Katrina, the correlations are weak and predominantly negative (see Figure 9). The correlation with population is strongest – and negative – driven by light levels that are higher in the period prior to 2004 in all 8 counties. This pattern is visible in all of the counties, while population was either growing or stagnant in these years. This is not the case for employment, which instead shows close to no correlation with light intensity before Katrina. For both income and GDP, the correlation is again negative but weaker than with population. Note that this likely has to do with top-coding in the night light data, making light intensity unresponsive to economic changes prior to the negative shock caused by Katrina. For GDP specifically the negative correlation is purely driven by St. Bernard Parish – when excluding St. Bernard, the correlation is weak and positive at 0.22.

In stark contrast, there is a clear positive and substantially stronger correlation in the years after Katrina for all 4 indicators (see Figure 9). Unconditional pairwise correlations of 0.65 and 0.54 respectively indicate that the change in night light as a result of Katrina is most closely related to population and employment respectively. The scatterplots clearly reflect that reductions in night light underestimate the reductions in population and employment in some of the counties, as discussed in the previous section. Again, this likely relates to the top-coding issue, and may also be partly explained by the timing of the hurricane in the last part of the calender year. Still, the correlation between the change in light intensity and population is strong, while it is moderate for employment.

While similarly positive, the correlation between indexed light intensity and income and GDP is weaker at 0.38. The lower correlation can be explained by developments in the counties Hancock, Harrisson, Jackson, St. Tammany, and Jefferson, all of which had income and GDP levels (far) exceeding pre-Katrina levels. Instead, growth in light intensity was much lower for these counties. A notable spike that is visible in all counties is the year 2007, in which relief transfers boost both income and GDP. There appears to be no correlation between these transfers and light intensity for this year, further lowering the correlation with income and GDP. In fact, the correlation between the change in income and GDP between 2006 and 2007 with the total sum of light is 0.27 and -0.58 respectively – i.e. for GDP there is even a strongly negative correlation with light intensity for this particular year.

The main findings are then twofold: first, the correlation between night light intensity and the four considered economic indicators is much stronger after Hurricane Katrina struck than before.[15] The positive and – in the case of population and

[14] Including the 2005 data for population dramatically reduces the correlation from 0.65 to 0.34, purely as a result of the 2005 population figure being unresponsive to the Katrina shock in 2005 by construction – population estimates are midyear and thus precede the landfall of the hurricane.

[15] Within the scope of our paper, we cannot answer why the relation between night light and economic activity is rather weak in equilibrium times before the disaster shock, and what can explain the negative correlation with population and income we observe prior to the shock. However, top-coding in the night light data is arguably one important factor. This discussion speaks to a broader literature that uses night light intensity in equilibrium growth regimes to proxy GDP or economic activity more broadly at the subnational level (e.g. Michalopoulos and Papaioannou, 2013; Hodler and Raschky, 2014; Storeygard, 2016). Part of the explanation may be that top-coding in much of the affected areas prior to the landfall of Katrina obscures otherwise meaningful relations between night lights and income and GDP. Future research can aim to answer these questions by focusing on an event that affected urban areas with a lower degree of top-coding. Alternatively, the results presented in this paper may be indicative of a stronger relation between changes in night light intensity and economic indicators in shock times versus equilibrium times in a high-income country like the United States.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

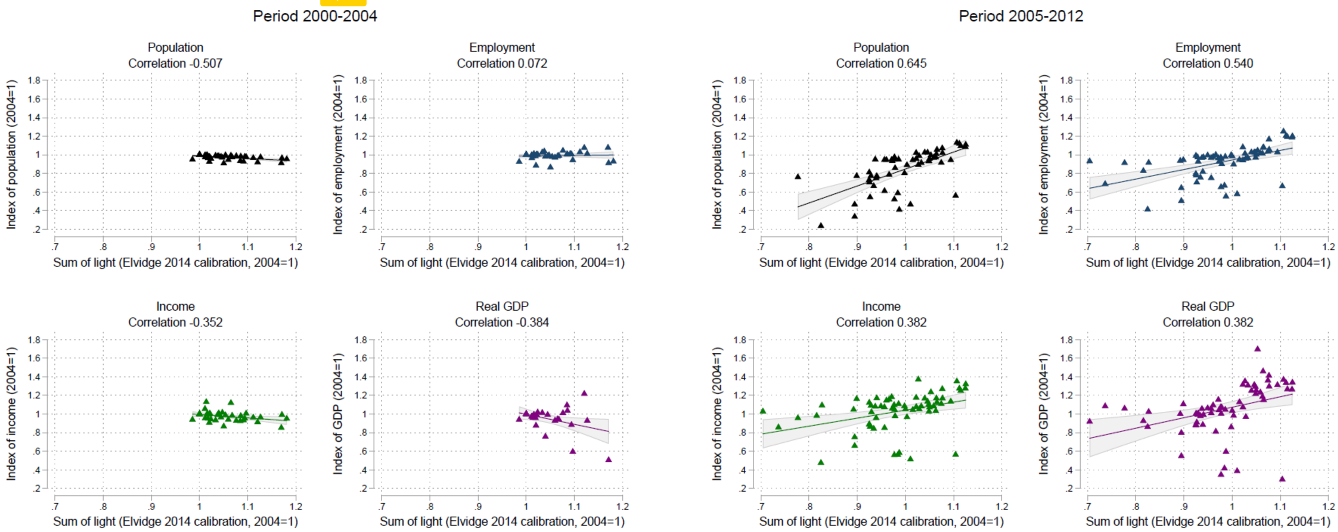

Figure 9. Indexed economic indicators and total sum of light by the 8 affected counties before Katrina. Based on own calculations. *Right panel:* Population data is for 2006-2012 only.

employment – strong correlations with economic activity show that changes in night light intensity can be used successfully to capture local effects on economic activity of a large shock such as Hurricane Katrina. Second, and within the limits of our study, our results suggest that change in light intensity is mostly reflective of changes in resident population and the total number of employed people within the affected area, and less so but positively related to aggregate income and real GDP. We test robustness of these findings to the use of the alternative calibration method by Zhang et al. (2016), as well as to the fixed-effects corrected light data. Results are reported in Appendix A. For the Zhang et al. (2016) calibrated data all correlations for the period 2005-2012 are lower than for the baseline results using the Elvidge et al. (2014) calibration. This can be explained by the anomalous year-corrections in 2010 and 2012, discussed in detail in Appendix B. When excluding 2010-2012, we find similar correlations for the two calibration methods (results available upon request). Alternatively using an econometric fixed-effects approach overall yields comparable results (see Appendix B for a discussion on the methodology), but correlations between indexed light and income and real GDP are considerably higher at 0.57 and 0.68 respectively. This puts their correlation in a similar range as population (0.55). However, the correlation with employment is still considerably stronger at 0.75.

4 Discussion

An emerging literature has used night lights to study the local impacts of natural disasters and used changes in night lights as an indicator primarily of local economic activity. Night light analysis of impacts of natural hazards is especially useful in areas that lack local data of population and economic activity. But often it remains an open question what observed night

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Discussions

light changes actually represent, especially in the case of downturns (Bennett and Smith, 2017). In our study we examined changes in night lights following the impacts of Katrina on New Orleans and the coastline of Louisiana and Mississippi. This is a relevant case study for analyzing what changes in night lights represent since for New Orleans both night light data and local population and economic statistics exist. Moreover, a variety of studies examined the direct and indirect socioeconomic impacts of Katrina, which allows for placing our insights into a broader picture of the various effects of the hurricane. The following main lessons emerge from our study.

The immediate effects observed in night lights reflect well the heterogenous severity of direct impacts of the hurricane in the different geographical areas. Flooding and direct damage data indicate that the most severely hit parishes are Orleans and St. Bernard, for which also severe drops in night lights can be observed shortly after Hurricane Katrina. This observation suggests that night lights can be used as an indicator for the short-term severity of a natural disaster and reveal worst hit areas, echoing findings reported by Gillespie et al. (2014) on the impacts of the 2004 Indian Ocean Tsunami in Sumatra.

Moreover, short run changes in night lights reflect observed changes in the population over time. However, there are some limitations to the night light approach. Population losses in some counties, such as Orleans were much more severe than the night lights showed. This may be explained by the fact that Katrina made landfall in August, thus making up only a third of the mean annual night light intensity of the area. Population recovery patterns are overall also seen in the night lights, but the recovery in lights is faster and do not accurately reflect permanent population decline. Economic studies have mainly interpreted changes in night lights as representing changes in economic activity. Our study confirms that there is also a correlation between night lights and income and GDP, although the relation with the latter indicators and light intensity fits less well than with population and employment. Also here the recovery of night lights is more optimistic in hard hit counties compared with the actual recovery in income and GDP. Overall, we find that night light changes more strongly reflect population and employment impacts, and less so GDP changes.[16]

However, top-coding in urban centers makes part of the change in light invisible to the censor and is thus not captured in the night lights data. In future research, the newer VIIRS data could be used to address the issue of top-coding (see Elvidge et al., 2013).[17] Recent examples are Zhao et al. (2018) and Gao et al. (2020), who study the effects of hurricanes Irma and Maria on light intensity in Puerto Rico and the 2015 Ghorka earthquake in Nepal respectively. However, although the time series for the VIIRS data product is steadily expanding, only disasters after 2012 can be studied with this data. Understanding the effects of more historical examples thus still requires the DMSP data that we use in the current study. We stress that even though top-coding is an issue in the studied area, we can still observe the impacts of the hurricane quite clearly. Studying areas with a

[16] In Appendix A, we assess correlations between the change in the sum of light intensity and the change in income and GDP with the correction approach using fixed effects in a panel regression framework. In this approach, both the night light and economic variables are demeaned with year fixed effects, and then transformed into index numbers. As discussed in Appendix A, the year fixed effects take out the satellite measurement error, but also all other common temporal variation in the panel of all U.S. counties. As such, the correlation results for the fixed effects approach cannot be compared directly to those with the calibration correction. Still, we stress that the correlation between change in total light intensity and aggregate income and aggregate real GDP is 0.57 and 0.68 respectively for the fixed effects method (see Figure A6), compared to 0.55 and 0.75 for population and employment respectively.

[17] Although less important in the context of the present study, the newer VIIRS data also address the issue of blooming and the rather coarse native resolution of the DMSP satellite.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

lower degree of top-coding, which is a much smaller problem even within urban areas in developing countries (Kocornik-Mina et al., 2020), may therefore reveal stronger relations between light intensity and economic indicators.

Furthermore, most studies in this field report a negative impact of natural disasters on local night lights only in the year of occurrence (e.g. Bertinelli and Strobl, 2013; Gillespie et al., 2014; Elliott et al., 2015; Kocornik-Mina et al., 2020). First, we show here that decreases in night light intensity after severe disasters can span beyond this period for a disaster of this magnitude. This confirms that changes in night light intensity do not just come from temporary power outages, which remains a worry in some of the studies. Second, we show that even for this extreme case recovery of night light intensity is rather quick – in the order of a one to a few years – whereas recovery in the economic indicators is much slower. This places conclusions in the literature about fast local recovery based on rebounding of night light in a different light. For example, Kocornik-Mina et al. (2020) find that economic activity within cities does not relocate to less risky areas after the occurrence of a major flood in the city, based on the finding that on average no negative effects on light intensity exist beyond the year of the flood. This is the case, even though the authors limit their study to large-scale urban floods that displaced at least 100,000 people. Our results suggest that night light intensity may reflect reduction in population and economic activity only partly, such that relocation of economic activity and population may in reality have occurred. For the case of Katrina, we indeed show that this happens. We again stress that night lights serve as a means to proxy local economic impacts in areas where no alternative data is available, but that this only provides part of the picture.

Concluding, even though we observe that night lights seem to be able to capture general patterns in population and economic impacts that can be useful in data scarce regions, they are no substitute for assessments of economic data if the aim is to have a profound understanding of the economic consequences of a natural disaster. In-depth analysis of economic data, such as sectoral impacts and wage development, provides more detailed insights than night light data. For instance, economic impacts of Hurricane Katrina were a complex combination of disruptions in certain sectors and positive effects for sectors involved in reconstruction as well as substitution effects between companies within a sector (Vigdor, 2008; Hallegatte, 2008). Such a complexity cannot be disentangled with night light data. Moreover, real wage growth may not follow the GDP and employment patterns that night light data partly capture. For example, Deryugina et al. (2018) show based on tax return data that Katrina victims eventually experienced higher wage growth than non-victims. These in-depth analyses of economic data indicate positive long run economic effects for households of the hurricane that cannot be directly derived from analyses of night light data. Combining the insights from these studies on the effects of Katrina is important to understand the value of night light data in this context for two reasons. First, night light intensity is spatially explicit and highly detailed, but reflects an immobile area rather than its mobile residents. Focusing on the impacted counties alone therefore makes the analysis blind to general equilibrium effects and potential spillovers of population and economic activity towards neighboring counties. Xiao and Nilawar (2013) provide an example of how such effects occurred in less-affected counties in the case of Katrina, and Felbermayr et al. (2022) apply this framework more generally in a global analysis of disaster impacts on local economic activity. Second, displaced population results in lower population numbers in the affected areas, and recovery of an area's economy depends on a combination of return migration, reconstruction, and recovery of and/or new economic activity. Using night light intensity, we can only see the combined derivative of these processes.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
Discussions

Finally, an important consideration for the interpretation of disaster impacts from night light data is whether or not population and economic trends move in the same direction. In our case these trends did not have opposite effects on night light activity. However, interpretation of night light changes is more ambiguous in case opposite trends occur. For example, several studies find population growth after disasters (Vigdor, 2008), which combined with adverse economic impacts of a disaster would obscure clear trends and hamper a straightforward interpretation of night light data.

5 Conclusions

The use of night light data is becoming increasing popular in studies that aim to estimate the impacts of natural disasters on local economic activity. However, it is often unclear what observed changes in night lights exactly represent since they have been used as a proxy for changes in GDP levels or growth, urbanization, and temporary and permanent population movements. Our study contributes to this emerging literature by providing insights into the interpretation of night light changes. In particular, we examined how these changes following a severe hurricane relate with local population, employment, and income statistics. For this purpose we used Hurricane Katrina as an exemplary case since both detailed night light data and sub-national economic and population statistics are available for the areas impacted by Katrina. Moreover, various previous studies have analysed the social and economic consequences of Katrina, which allows for placing our night light findings in the context of this broader evidence on impacts of this disastrous hurricane.

We find that overall the night light changes reflect the general pattern of direct impacts of Katrina as well as the subsequent recovery. The heaviest-hit counties show the largest declines in night light intensity, and light intensity recovers to pre-disaster levels in the subsequent years. However, recovery of night light intensity towards pre-Katrina levels is much faster than for population and employment and income in the heaviest hit counties. Moreover, our results show that change in light intensity is mostly reflective of changes in resident population and the total number of employed people within the affected area, and less so but positively related to aggregate income and real GDP. The correlation between night light intensity and the considered economic indicators is much stronger after Hurricane Katrina struck than before. The positive and – in the case of population and employment – strong correlations with economic activity show that changes in night light intensity can be used successfully to capture local effects on economic activity of a large natural disaster, such as Hurricane Katrina.

Based on our main results, we conclude that changes in night light intensity prove a valuable proxy for changes in local economic activity following a natural disaster, despite its various shortcomings discussed in this paper. Analysis of disaster impacts using night light data are ideally complemented with detailed analysis of economic data which provide additional more in-depth insights into disaster impacts, like we discussed for our case. Nevertheless, in areas where such economic data is unavailable, our results suggest that night light data can be used to approximate the impacts of natural disasters on regional economies. Future research can conduct similar analyses as conducted in this paper for other natural disasters to improve our understanding of the interpretation of night light data for direct impact and recovery, especially for disaster events of a less extreme nature than Hurricane Katrina.

Code and data availability. Code and data will be made available in a publicly accessible repository.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
Discussions

Appendix A: Appendix A: Figures and Tables

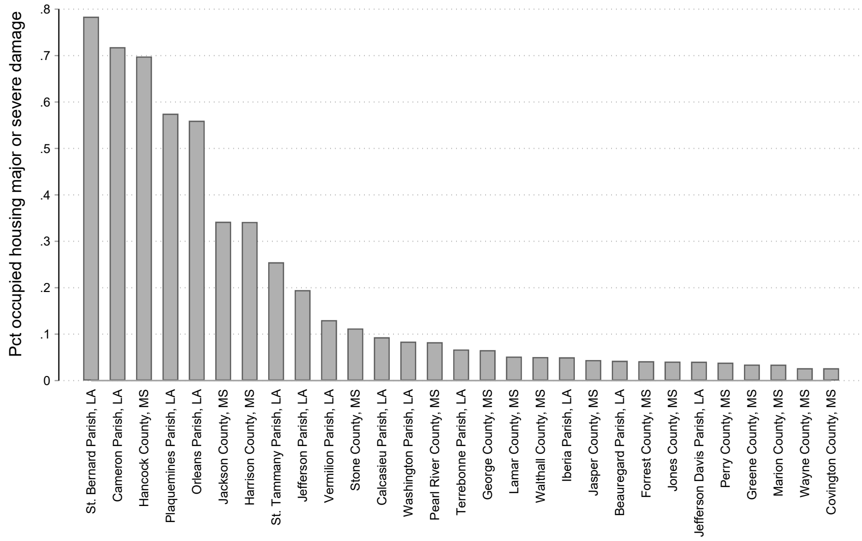

Figure A1. Distribution of damage to occupied housing units. Based on own calculations. Damage figures from the U.S. Department of Housing and Urban Development (2006). Note that the extremely high housing damage figure for Cameron Parish relates to hurricane Rita rather than Katrina, as is the case for the counties Vermilion and Calcasieu.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
Discussions

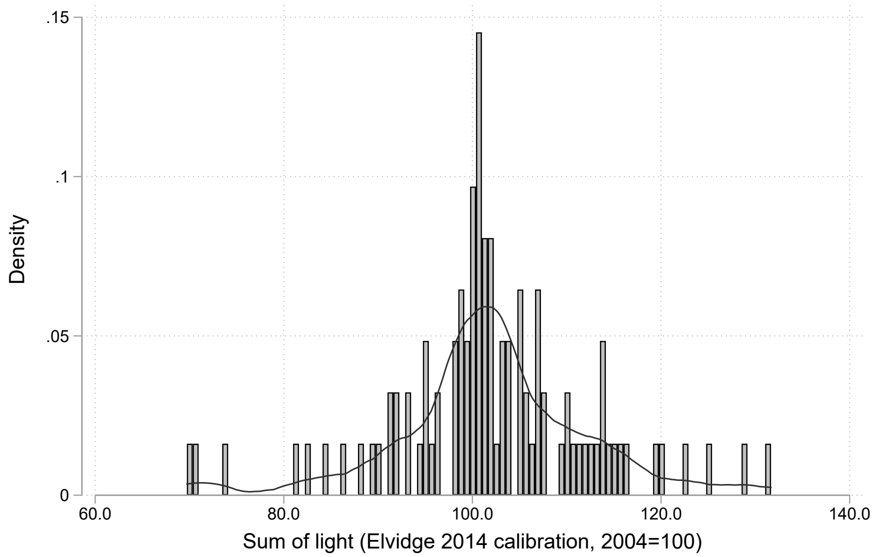

Figure A2. Histogram of changes in night light intensity between 2004 and 2005 for the affected area. Based on own calculations. Affected area refers to all counties with non-missing housing damage based on the report from the U.S. Department of Housing and Urban Development (2006), i.e. those included in Figure 3. Night time lights are calibrated using the Elvidge et al. (2014) method, and indexed with 2004=100. A kernel density is plotted on top. Given the approximate normality of the distribution, the maps about changes in night lights make use of a standard deviation method for color-coding.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

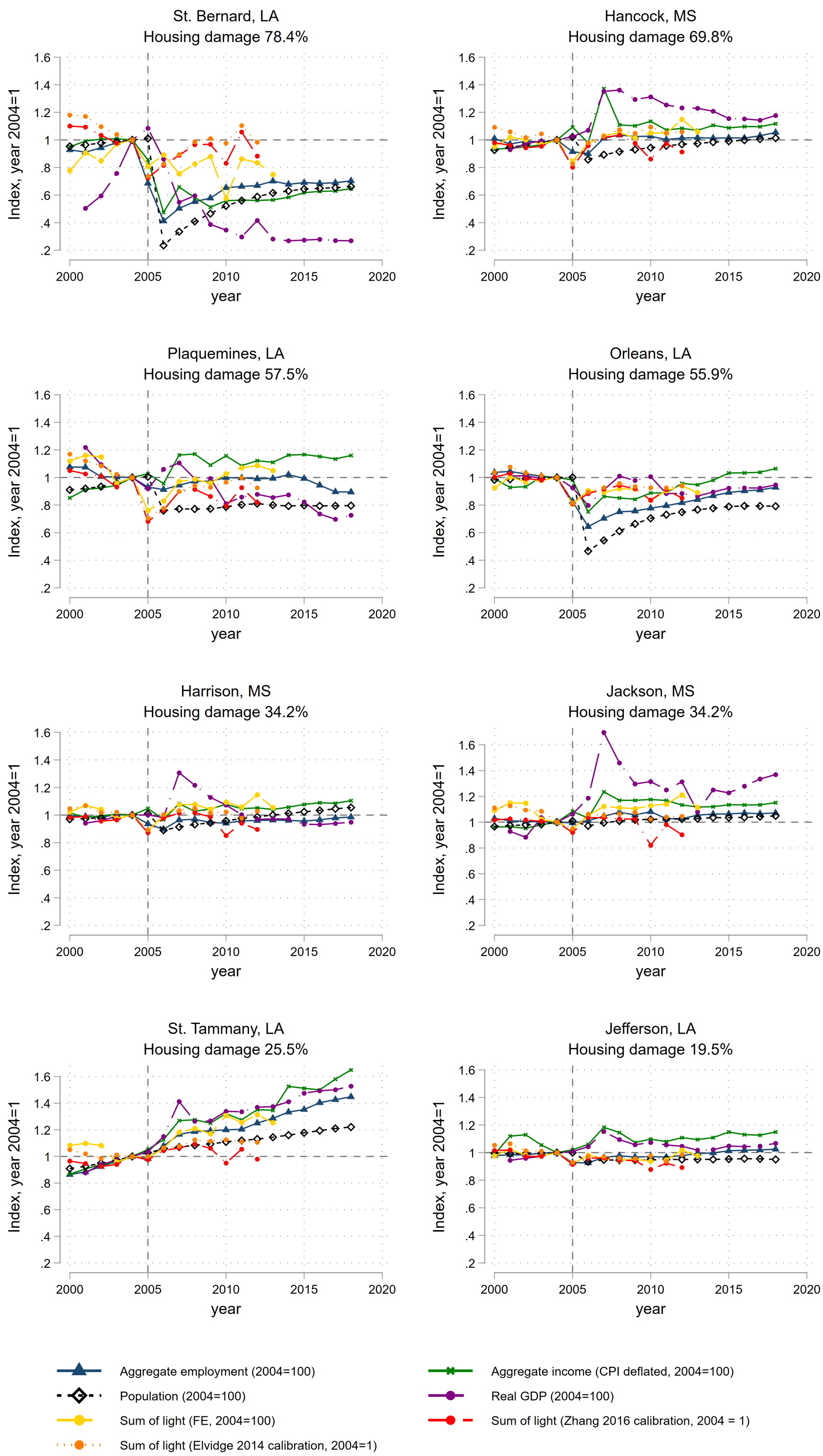

Figure A3. Night lights and economic indicators, including alternative light corrections

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
Discussions

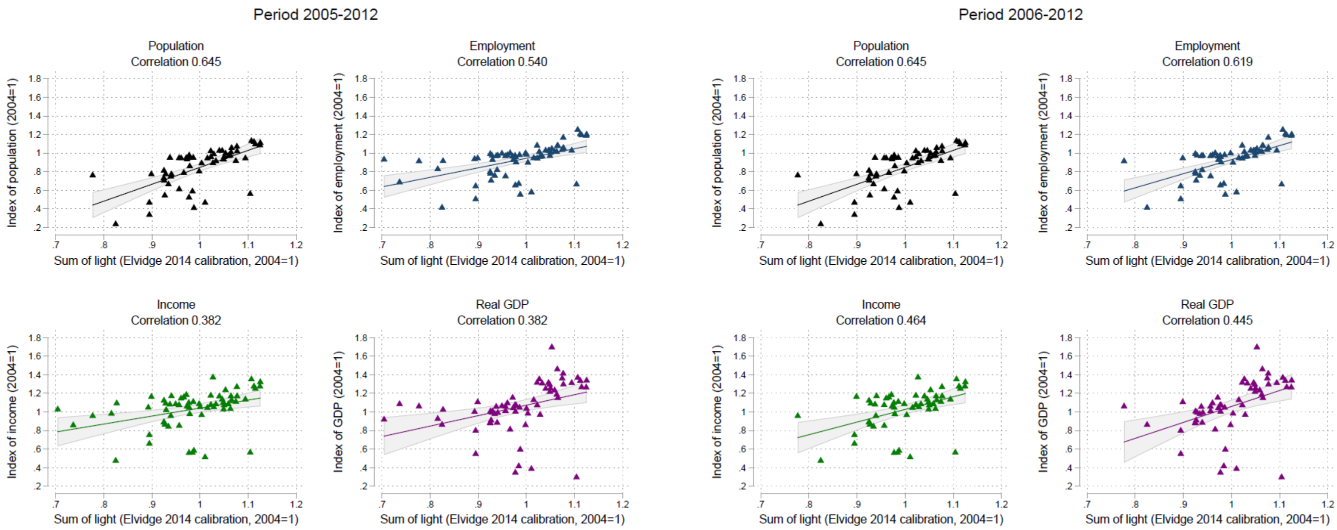

Figure A4. Indexed economic indicators and total sum of light by the 8 affected counties after Katrina (starting in 2005 vs 2006). Correlations economic indicators and night lights (varying years). Night lights based on Elvidge et al. (2014) calibration, indexed to 2004 = 1. *Right panel:* Population data is for 2006-2012 only.

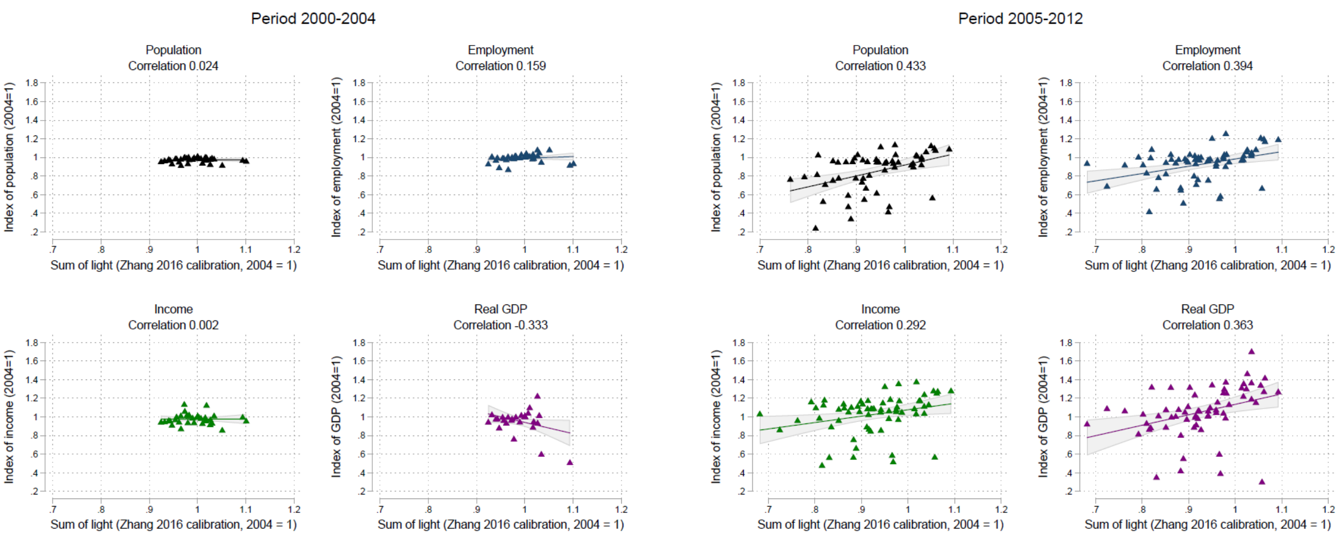

Figure A5. Indexed economic indicators and total sum of light by the 8 affected counties before Katrina. Correlations economic indicators and night lights (Zhang calibration). Night lights based on Zhang et al. (2016) calibration, indexed to 2004 = 1. *Right panel:* Population data is for 2006-2012 only.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Discussions
Open Access

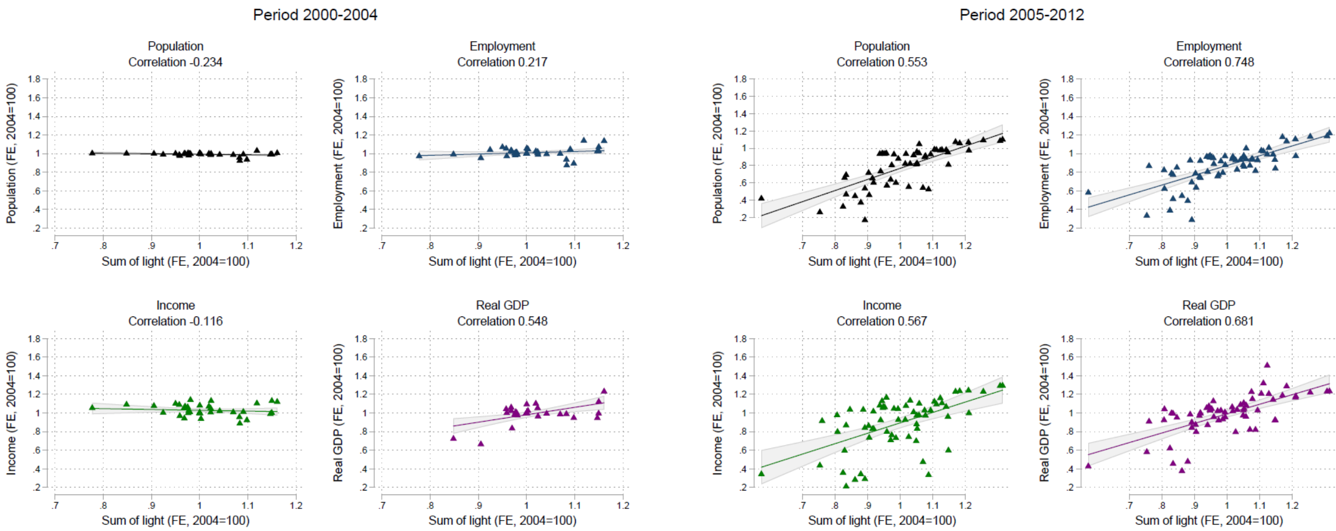

Figure A6. Indexed economic indicators and total sum of light by the 8 affected counties before Katrina. Night lights based on fixed-effects correct, indexed to 2004 = 1. See Appendix B for methodology. *Right panel:* Population data is for 2006-2012 only.

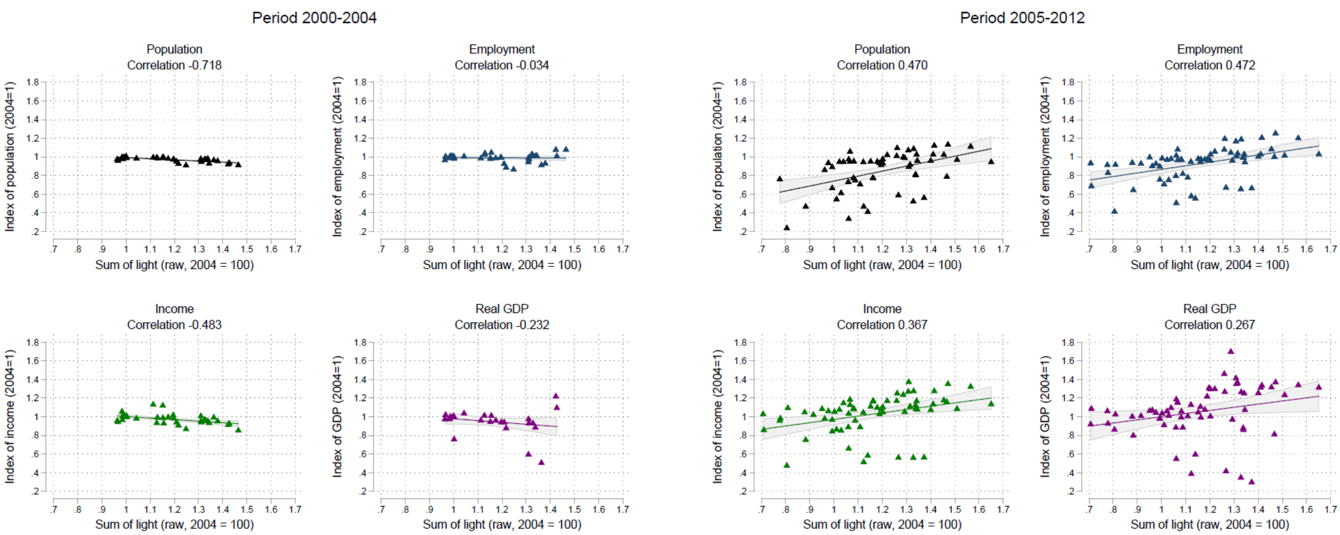

Figure A7. Indexed economic indicators and total sum of light by the 8 affected counties before Katrina (raw data). Correlations economic indicators and night lights (raw data). Raw night light data, indexed to 2004 = 1. *Right panel:* Population data is for 2006-2012 only.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Discussions

Appendix B: Appendix B: Cleaning of the night light series

The DMSP annual composite data is known for its problematic intertemporal and between-satellite measurement differences, making it difficult to compare night light intensity over an area across time. The problem stems from the lack of systematic recording of changes in gain settings of the DMSP-OLS sensor that vary across time and between satellites. The reason for this is the main function of the satellite being to detect moonlight clouds, rather than that of artificial night light per se (Elvidge et al., 2009a). As a result, while the annual composites retain a range of DN0 to DN63 (with DN meaning digital number), the true respective radiance associated with these digital numbers varies between the different satellite-year composites. This makes direct comparison of raw digital numbers across years problematic.

A number of approaches have been suggested in the literature, which can be generally grouped into two main classes. First, the approach from remote sensing is to calibrate the annual composite images to a reference image, being either an area that is assumed to have invariant night light intensity over time (e.g. Elvidge et al., 2009a, 2014; Wu et al., 2013), or by making use of a globally or regionally consistent bias across images (e.g. Zhang et al., 2016; Li et al., 2013). The basic idea of the invariant area method is that any differences in night light intensity between yearly images is the result of measurement error, and thus contains the difference in gain settings between the various satellite-year images. By globally calibrating the year-images to this reference area, a 'corrected' time series is produced. A meta-analysis of this approach is discussed in detail by Pandey et al. (2017), who find that among the existing calibration studies Zhang et al. (2016) and Elvidge et al. (2014) produce the most consistent calibration results, with only marginal differences between the two when assessing the global images.[18]

The second approach finds its origin in the economic literature that makes use of night lights, and applies a panel fixed effect setting to address measurement error in night light intensity over time (e.g. Chen and Nordhaus, 2011; Henderson et al., 2012). The basic idea here is that the gain setting changes affect the images in a globally consistent manner, such that estimating a dummy coefficient for changes across years to a reference base year effectively takes out any difference in sensitivity to light intensity across satellite-years.[19] It is important to note that this correction is applied at the aggregated county level, rather than at the pixel-level, as is the case for the intercalibration methods. We thus first compute the sum of light intensity by county-year based on the uncorrected images. We know from Strobl (2011) that hurricanes do not affect national GDP growth rates in the US, and moreover that impacts at the county level net out at the state level within a year. It is therefore safe to assume that we can use the universe of U.S. counties to control for common changes in night light intensity, that are unrelated to the landfall of hurricane Katrina. Note that this also takes out all other changes that are common to the entire United States in night light

[18]For example, Elvidge et al. (2009a, 2014) propose Sicily as a candidate invariant area. This area is found to have the best spread of night light intensity across the spectrum of DN0 to DN63. Moreover, and most importantly, true light intensity is found to be largely stable for 1992-2013 for this area. Relying on the resulting invariant area assumption, all images are then calibrated to the image for this area in 1999 (satellite F12) using a second-order polynomial fit. Calibrated digital values that exceed the maximum range of DN63 are truncated at DN63. When assessing the global performance of this calibration method, Pandey et al. (2017) also truncate the lower-bound of the digital values at DN0. I follow their example here.

[19]Chen and Nordhaus (2011) separately control for satellite fixed effects, besides the common year fixed effects. We do not do so here since we make use of single satellite-years rather than taking the average of satellite-years when multiple satellite images are available in a year (see Felbermayr et al. (2022) for a discussion on this issue). We use the following satellite-years: F101992-94, F12 1995-98, F141999, F152000-06, F162007-09, F182010-13.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
Discussions

intensity, resulting from country-wide economic conditions, technological advance, and energy costs Henderson et al. (2012).[20] While commonly accepted in the economic literature, the fixed effect approach relies on the assumption that taking out the mean of changes across years is sufficient to correct for measurement changes across time, whereas the calibration method allows for a non-linear effect of the gain settings on the range of digital values in the light composites. This makes the two methods slightly different in their approach for correcting for the measurement differences across time. While not explicitly accounting for non-linearities, however, the fixed effect approach does not rely on assumptions of an invariant area.

In this appendix we compare the results of the calibration and fixed effects corrections to the raw data for the 8 counties that were most heavily affected by Hurricane Katrina. The calibration series were produced with the coefficients for the second-order polynomial fits reported in Zhang et al. (2016) and Elvidge et al. (2014) respectively. The raw image digital values for each satellite-year composite are then recalculated using the coefficients from the respective studies. In both cases, values were truncated to DN0 at the lower end and to DN63 at the upper end, before aggregating the images to sum of light (SOL) for the U.S. counties (following Elvidge et al., 2014; Pandey et al., 2017).

The series corrected with the year fixed effect approach were constructed by first computing the SOL for all U.S. counties (3079 in total) based on the raw images, and then adjusted as follows: (1) We estimate a general OLS model, with SOL from the raw images as the dependent variable, and a set of year dummies as the explanatory variable (2) From this linear model we compute corrected night light intensity by subtracting the estimated coefficients for the year dummies from each county-year observation

We now discuss the results of the various correction methods. In figures B1 and B2 below, we plot the raw series combined with the two calibrated series, and the series corrected with the year fixed effects. Figure B1 reports the total sum of light by county. The first and most important observation is that the three alternative corrections to the raw night light data show a high degree of similarity. Note how they are more stable over time than the raw series, notably in the period 2002-2007, and how – with the exception of St. Bernard – the two classes of correction methods follow each other closely. Especially the dip from 2003-2007 in the raw data is evident when compared to the corrected series. This dip is not specific to the affected counties, but instead is a feature shared by the entire panel of U.S. counties and is thus taken out in the corrected series.

The case of St. Bernard stands out, since its year fixed effect correction deviates strongly from the other three series in both absolute terms and in terms of qualitative behavior. This can be explained by its low level of average light intensity with respect to the other counties. In 2004, St. Bernard has an average DN value of DN4.5, compared to the U.S. mean of DN7.3, while the mean of the other 7 main affected counties is DN14.9. As such, the fixed effects correction likely under-corrects the digital values for the latter 7 counties, while it over-corrects the values for St. Bernard. This also explains why we find no such deviations between the fixed effects correction and the calibration corrections for the other counties. While the fixed effect method relies on fewer assumptions and may be preferred in impact regression frameworks where the focus is on causal impact identification (such as in Bertinelli and Strobl, 2013; Elliott et al., 2015; Felbermayr et al., 2022), the calibration corrections prove more reliable in producing stable county-specific series for the current application. Since our focus is on absolute light

[20]This also implies that when we relate changes in fixed-effects corrected night light intensity to the respective economic indicators in Section 2.2, we also demean the economic indicators on year dummies.

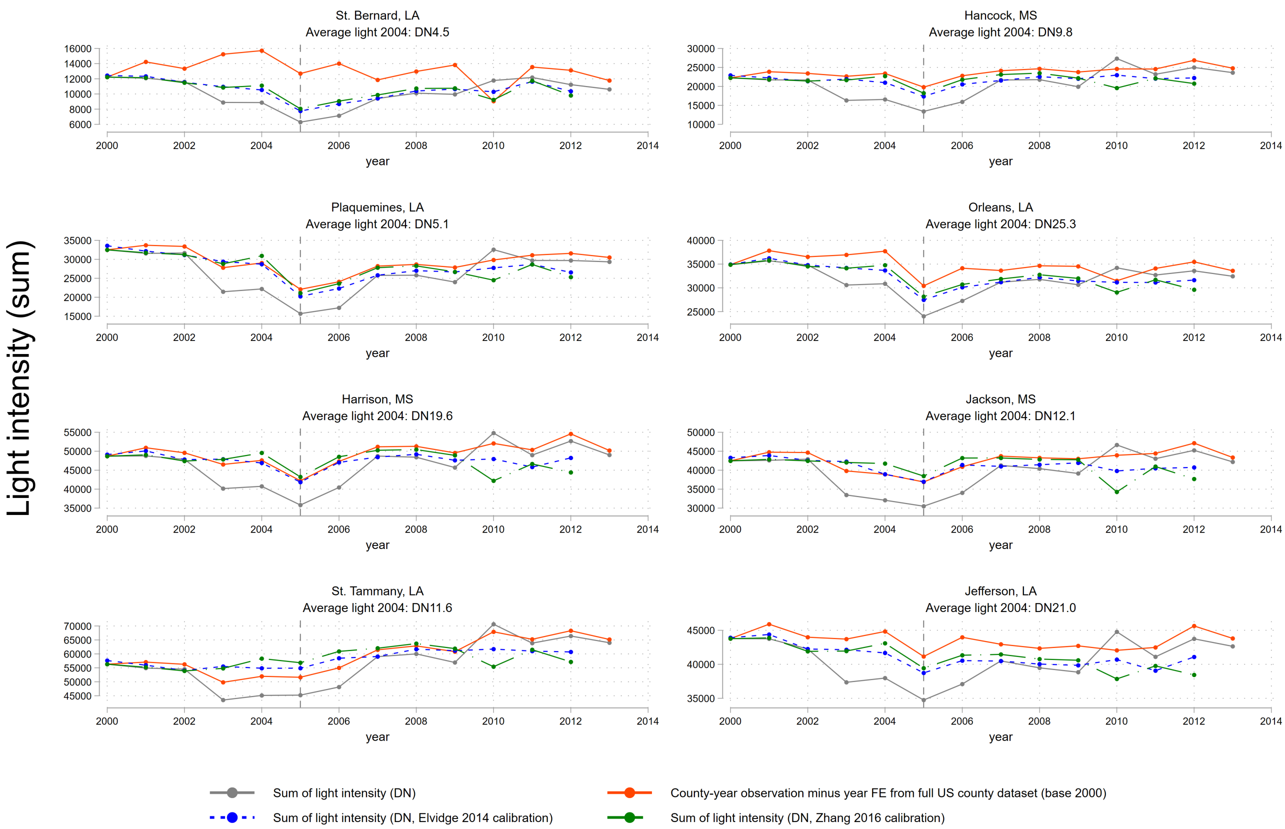

Figure B1. Corrected night light data (absolute sum of light). 4 series: raw data (gray), fixed-effect adjustment, invariant area calibration (Elvidge et al., 2014), and global consistent bias calibration (Zhang et al., 2016). Total sum of light by county (SOL).

levels, the excessive measurement error for individual cases – such as the clear overcorrection of light changes in low-light counties such St. Bernard – hinders the analysis.

Even though corrected absolute levels help us when assessing recovery after Katrina, we can show that regardless of the correction method the changes over time are fairly stable across the correction methods. Figure B2 reports changes over time in indexed series, with 2004 = 1. A number of observations are to be made: (1) the immediate impact of Katrina on the total sum of light in the 8 affected counties is close to identical between the 4 series. That is, while absolute levels may differ, the relative change from 2004 to 2005 is identical across the various series; (2) again, the two calibration methods show striking similarity; (3) as with the absolute levels in Figure B1, St. Bernard stands out with its fixed effect correction performing clearly not performing as intended. Another important feature of the raw data becomes evident when setting it off against the corrected series: while the raw data suggests a relatively quick recovery from Katrina in the subsequent years, both the calibration and fixed effect correction methods indicate that growth in night light intensity is not specific to these counties (suggesting

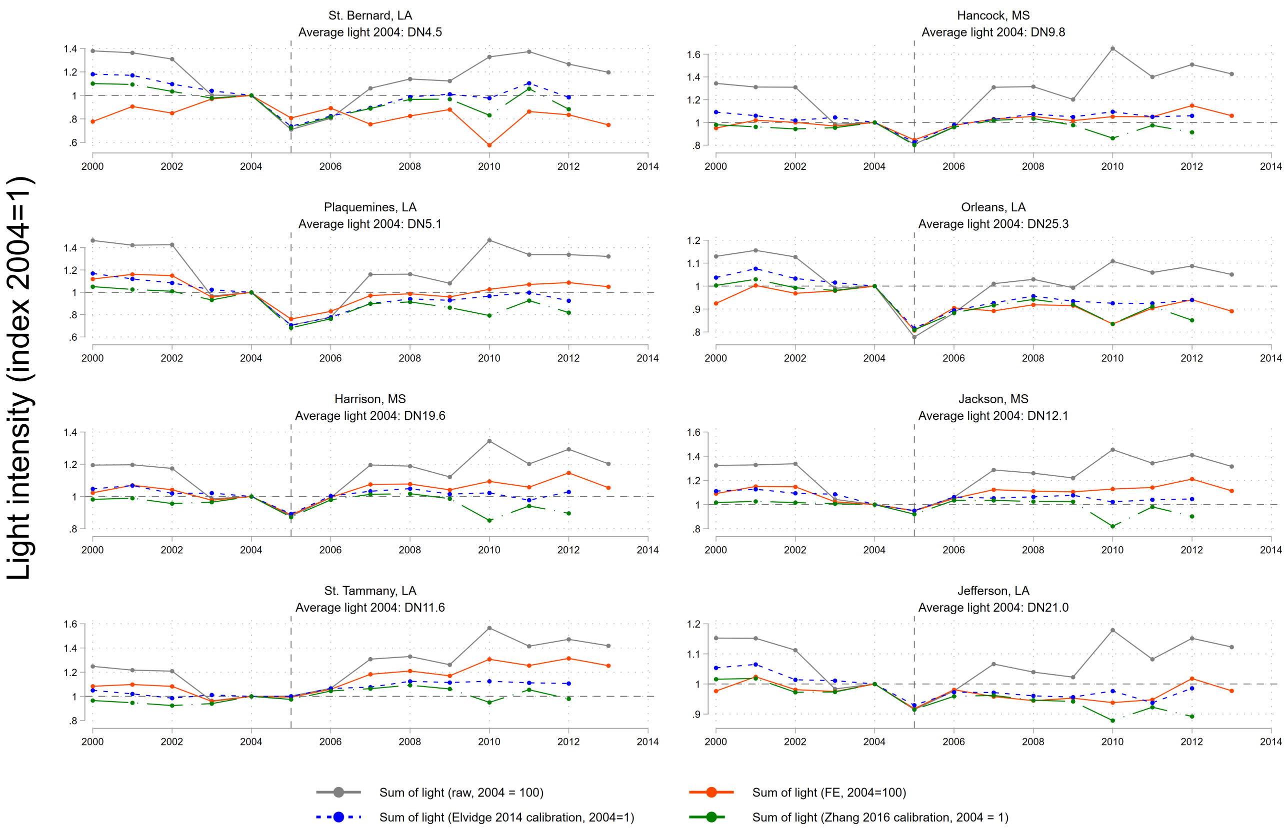

Figure B2. Corrected night light data (indexed to 2004 = 1). 4 series: raw data (gray), fixed-effect adjustment, invariant area calibration (Elvidge et al., 2014), and global consistent bias calibration (Zhang et al., 2016). Total sum of light by county, indexed to 2004=1.

a recovery from the negative shock), but is shared by the entire United States. Especially the year 2010 is associated with a massive increase in light intensity, which seems to stem mostly from the switch to a new satellite (F18), and thus a new instrument with different gain settings. Once we correct for this common feature in the data, recovery appears in fact slower and for a number of counties the sum of light does not return to pre-Katrina levels at all within the available data period.

Although the two calibration methods produce comparable results, the years 2010 and 2012 are important exceptions. Pandey et al. (2017) report that in a global sample, the calibration methods by Zhang et al. (2016) and Elvidge et al. (2014) produce only marginally different results. However, for a subset of countries, among which importantly is the U.S., the Zhang et al. (2016) method performs worse than Elvidge et al. (2014) in smoothing the time series specifically for the years 2010 and 2012. This is reported in detail in Zhang et al. (2016, pp. 5826-5827). This pattern is clearly visible for the subset of counties considered in this study (see Figure B1 and B2). While the Elvidge calibration produces rather smooth series for the period 2009-2012, the Zhang calibration series clearly show drops in 2010 and 2012, which for e.g. the Mississippi counties are comparable in size to the declines in night light intensity in 2005 as a result of Katrina. Comparison to county figures for population, income, and GDP indicate no apparent reason for this dip, and no other natural disaster or adverse event is able to explain this substantial reduction in night light intensity suggested by the Zhang calibration series. This is further supported by a similar stability in the fixed-effects corrected series for the respective Mississippi counties. As a result of this, we use only the calibration method of Elvidge et al. (2014) in the main results, and test robustness of our findings to the fixed effects correction and to the alternative Zhang et al. (2016) calibration in Appendix A. Results prove to be rather stable.

Author contributions. Vincent Schippers: conceptualization, data curation, formal analysis, investigation, methodology, software, visualization, writing - original draft and editing. Wouter Botzen: conceptualization, investigation, methodology, supervision, writing - original draft and editing.

Competing interests. The authors declare no competing interests.

Acknowledgements. We thank Mark Sanders, Bas van Bavel, and Bram van Besouw for helpful suggestions and feedback. All remaining errors are our own.

References

Aerts, J. C., Botzen, W. W., Emanuel, K., Lin, N., De Moel, H., and Michel-Kerjan, E. O.: Evaluating flood resilience strategies for coastal megacities, Science, 344, 473–475, 2014.

Basker, E. and Miranda, J.: Taken by storm: Business financing and survival in the aftermath of Hurricane Katrina, Journal of Economic Geography, 18, 1285–1313, 2018.

Bennett, M. M. and Smith, L. C.: Advances in using multitemporal night-time lights satellite imagery to detect, estimate, and monitor socioeconomic dynamics, Remote Sensing of Environment, 192, 176–197, 2017.

Berlemann, M. and Wenzel, D.: Hurricanes, economic growth and transmission channels: Empirical evidence for countries on differing levels of development, World Development, 105, 231–247, 2018.

Bertinelli, L. and Strobl, E.: Quantifying the local economic growth impact of hurricane strikes: An analysis from outer space for the Caribbean, Journal of Applied Meteorology and Climatology, 52, 1688–1697, 2013.

Bickenbach, F., Bode, E., Nunnenkamp, P., and Söder, M.: Night Lights and Regional GDP, Review of World Economics, 152, 425–447, 2016.

Bluhm, R. and Krause, M.: Top lights-bright cities and their contribution to economic development, CESifo Working Paper No. 7411, 2018.

Botzen, W. W., Deschenes, O., and Sanders, M.: The economic impacts of natural disasters: A review of models and empirical studies, Review of Environmental Economics and Policy, 13, 167–188, 2019.

Cavallo, E., Noy, I., et al.: Natural disasters and the economy — A survey, International Review of Environmental and Resource Economics, 5, 63–102, 2011.

Cavallo, E., Galiani, S., Noy, I., and Pantano, J.: Catastrophic Natural Disasters and Economic Growth, Review of Economics and Statistics, 95, 1549–1561, 2013.

Chen, X. and Nordhaus, W. D.: Using Luminosity Data as a Proxy for Economic Statistics, Proceedings of the National Academy of Sciences, 108, 8589–8594, 2011.

Dartmouth Flood Observatory: DFO Event 2005-114 - Hurricane Katrina: New Orleans area - Rapid Response Inundation Map 1, https://floodobservatory.colorado.edu/2005114.html, 2005.

de Ruig, L. T., Barnard, P. L., Botzen, W. W., Grifman, P., Hart, J. F., de Moel, H., Sadrpour, N., and Aerts, J. C.: An economic evaluation of adaptation pathways in coastal mega cities: An illustration for Los Angeles, Science of the Total Environment, 678, 647–659, 2019.

Del Valle, A., Elliott, R. J., Strobl, E., and Tong, M.: The short-term economic impact of tropical cyclones: Satellite evidence from Guangdong province, Economics of Disasters and Climate Change, 2, 225–235, 2018.

Deryugina, T., Kawano, L., and Levitt, S.: The economic impact of Hurricane Katrina on its victims: Evidence from individual tax returns, American Economic Journal: Applied Economics, 10, 202–33, 2018.

Donaldson, D. and Storeygard, A.: The View from Above: Applications of Satellite Data in Economics, Journal of Economic Perspectives, 30, 171–98, 2016.

Ebener, S., Murray, C., Tandon, A., and Elvidge, C. C.: From Wealth to Health: Modelling the Distribution of Income Per Capita at the Sub-National Level Using Night-Time Light Imagery, International Journal of Health Geographics, 4, 2005.

Elliott, R., Strobl, E., and Sun, P.: The Local Impact of Typhoons on Economic Activity in China: A View from Outer Space, Journal of Urban Economics, 88, 50–66, 2015.

Elvidge, C. D., Baugh, K. E., Kihn, E. A., Kroehl, H. W., Davis, E. R., and Davis, C. W.: Relation Between Satellite Observed Visible-Near Infrared Emissions, Population, Economic Activity and Electric Power Consumption, International Journal of Remote Sensing, 18, 1373–1379, 1997.

Elvidge, C. D., Sutton, P. C., Ghosh, T., Tuttle, B. T., Baugh, K. E., Bhaduri, B., and Bright, E.: A Global Poverty Map Derived from Satellite Data, Computers & Geosciences, 35, 1652–1660, 2009a.

Elvidge, C. D., Ziskin, D., Baugh, K. E., Tuttle, B. T., Ghosh, T., Pack, D. W., Erwin, E. H., and Zhizhin, M.: A Fifteen Year Record of Global Natural Gas Flaring Derived from Satellite Data, Energies, 2, 595–622, 2009b.

Elvidge, C. D., Baugh, K. E., Zhizhin, M., and Hsu, F.-C.: Why VIIRS data are superior to DMSP for mapping nighttime lights, Proceedings of the Asia-Pacific Advanced Network, 35, 62, https://doi.org/10.7125/APAN.35.7, 2013.

Elvidge, C. D., Hsu, F.-C., Baugh, K. E., and Ghosh, T.: National Trends in Satellite Observed Lighting, Global Urban Monitoring and Assessment through Earth Observation, 23, 97–118, 2014.

Fan, X., Nie, G., Deng, Y., An, J., Zhou, J., and Li, H.: Rapid detection of earthquake damage areas using VIIRS nearly constant contrast night-time light data, International Journal of Remote Sensing, 40, 2386–2409, 2019.

Felbermayr, G. and Gröschl, J.: Naturally Negative: The Growth Effects of Natural Disasters, Journal of Development Economics, 111, 92–106, 2014.

Felbermayr, G., Gröschl, J., Sanders, M. W., Schippers, V. G., and Steinwachs, T.: The Economic Impact of Weather Anomalies, World Development, 151, 105 745, 2022.

Fomby, T., Ikeda, Y., and Loayza, N. V.: The Growth Aftermath of Natural Disasters, Journal of Applied Econometrics, 28, 412–434, 2013.

Gao, S., Chen, Y., Liang, L., and Gong, A.: Post-earthquake night-time light piecewise (PNLP) pattern based on NPP/VIIRS night-time light data: A case study of the 2015 Nepal earthquake, Remote Sensing, 12, 2009, 2020.

Ghosh, T., L Powell, R., D Elvidge, C., E Baugh, K., C Sutton, P., and Anderson, S.: Shedding light on the global distribution of economic activity, The Open Geography Journal, 3, 147–160, 2010.

Ghosh, T., Anderson, S. J., Elvidge, C. D., and Sutton, P. C.: Using nighttime satellite imagery as a proxy measure of human well-being, sustainability, 5, 4988–5019, 2013.

Gibson, J., Olivia, S., and Boe-Gibson, G.: Night lights in economics: sources and uses, Journal of Economic Surveys, 34, 955–980, 2020.

Gibson, J., Olivia, S., Boe-Gibson, G., and Li, C.: Which night lights data should we use in economics, and where?, Journal of Development Economics, 149, 102 602, 2021.

Gillespie, T. W., Frankenberg, E., Fung Chum, K., and Thomas, D.: Night-time lights time series of tsunami damage, recovery, and economic metrics in Sumatra, Indonesia, Remote Sensing Letters, 5, 286–294, 2014.

Groen, J. A. and Polivka, A. E.: The effect of Hurricane Katrina on the labor market outcomes of evacuees, American Economic Review, 98, 43–48, 2008.

Groen, J. A., Kutzbach, M. J., and Polivka, A. E.: Storms and jobs: The effect of hurricanes on individuals' employment and earnings over the long term, Journal of Labor Economics, 38, 653–685, 2020.

Hallegatte, S.: An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina, Risk analysis, 28, 779–799, 2008.

Hallegatte, S., Green, C., Nicholls, R. J., and Corfee-Morlot, J.: Future flood losses in major coastal cities, Nature climate change, 3, 802–806, 2013.

https://doi.org/10.5194/nhess-2022-23
Preprint. Discussion started: 17 February 2022

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

Heger, M. P. and Neumayer, E.: The impact of the Indian Ocean tsunami on Aceh's long-term economic growth, Journal of Development Economics, 141, 102 365, 2019.

Henderson, J. V., Storeygard, A., and Weil, D. N.: Measuring Economic Growth from Outer Space, American Economic Review, 102, 994–1028, 2012.

Henderson, J. V., Squires, T., Storeygard, A., and Weil, D.: The Global Distribution of Economic Activity: Nature, History, and the Role of Trade, Quarterly Journal of Economics, 133, 357–406, 2017.

Henderson, M., Yeh, E. T., Gong, P., Elvidge, C., and Baugh, K.: Validation of urban boundaries derived from global night-time satellite imagery, International Journal of Remote Sensing, 24, 595–609, 2003.

Hodler, R. and Raschky, P. A.: Regional Favoritism, Quarterly Journal of Economics, 129, 995–1033, 2014.

Hornbeck, R. and Naidu, S.: When the levee breaks: black migration and economic development in the American South, American Economic Review, 104, 963–90, 2014.

Hsiang, S. M. and Jina, A. S.: The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones, Working Paper 20352, National Bureau of Economic Research, https://www.nber.org/papers/w20352, 2014.

IPCC: Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, Pachauri, R.K., Meyer, L.A. (Eds.)]. IPCC, Geneva, Switzerland, p. 151, 2014.

Ishizawa, O. A., Miranda, J. J., and Strobl, E.: The Impact of Hurricane Strikes on Short-Term Local Economic Activity: Evidence from Nightlight Images in the Dominican Republic, International Journal of Disaster Risk Science, 10, 362–370, 2019.

Jarmin, R. S. and Miranda, J.: The impact of Hurricanes Katrina, Rita and Wilma on business establishments, Journal of Business Valuation and Economic Loss Analysis, 4, 2009.

Klomp, J. and Valckx, K.: Natural disasters and economic growth: A meta-analysis, Global Environmental Change, 26, 183–195, 2014.

Knabb, R. D., Rhome, J. R., and Brown, D. P.: Tropical Cyclone Report Hurricane Katrina, Technical report, National Hurricane Center, https://www.nhc.noaa.gov/data/tcr/AL122005_Katrina.pdf, 2005.

Kocornik-Mina, A., McDermott, T. K., Michaels, G., and Rauch, F.: Flooded cities, American Economic Journal: Applied Economics, 12, 35–66, 2020.

Kohiyama, M., Hayashi, H., Maki, N., Higashida, M., Kroehl, H., Elvidge, C., and Hobson, V.: Early damaged area estimation system using DMSP-OLS night-time imagery, International Journal of Remote Sensing, 25, 2015–2036, 2004.

Li, X. and Li, D.: Can night-time light images play a role in evaluating the Syrian Crisis?, International Journal of Remote Sensing, 35, 6648–6661, 2014.

Li, X., Chen, X., Zhao, Y., Xu, J., Chen, F., and Li, H.: Automatic intercalibration of night-time light imagery using robust regression, Remote sensing letters, 4, 45–54, 2013.

Li, X., Zhang, R., Huang, C., and Li, D.: Detecting 2014 Northern Iraq Insurgency using night-time light imagery, International Journal of Remote Sensing, 36, 3446–3458, 2015.

Logan, J. R.: The impact of Katrina: Race and class in storm-damaged neighborhoods, unpublished manuscript. Spatial Structures in the Social Sciences, Brown University, 2006.

Ma, T., Zhou, C., Pei, T., Haynie, S., and Fan, J.: Quantitative estimation of urbanization dynamics using time series of DMSP/OLS nighttime light data: A comparative case study from China's cities, Remote Sensing of Environment, 124, 99–107, 2012.

Mård, J., Di Baldassarre, G., and Mazzoleni, M.: Nighttime light data reveal how flood protection shapes human proximity to rivers, Science Advances, 4, eaar5779, 2018.

Michalopoulos, S. and Papaioannou, E.: Pre-Colonial Ethnic Institutions and Contemporary African Development, Econometrica, 81, 113–152, 2013.

Michalopoulos, S. and Papaioannou, E.: National Institutions and Subnational Development in Africa, Quarterly Journal of Economics, 129, 151–213, 2014.

Miranda, J. J., Ishizawa, O. A., and Zhang, H.: Understanding the Impact Dynamics of Windstorms on Short-Term Economic Activity from Night Lights in Central America, Economics of Disasters and Climate Change, 4, 657–698, 2020.

Mohan, P. and Strobl, E.: The short-term economic impact of tropical Cyclone Pam: an analysis using VIIRS nightlight satellite imagery, International Journal of Remote Sensing, 38, 5992–6006, https://doi.org/10.1080/01431161.2017.1323288, 2017.

National Hurricane Center: Costliest U.S. tropical cyclones tables updated, Tech. rep., National Hurricane Center, https://www.nhc.noaa.gov/news/UpdatedCostliest.pdf, 2018.

Nguyen, C. N. and Noy, I.: Measuring the impact of insurance on urban earthquake recovery using nightlights, Journal of Economic Geography, 20, 857–877, 2020.

Noy, I.: The Macroeconomic Consequences of Disasters, Journal of Development Economics, 88, 221–231, 2009.

Pandey, B., Zhang, Q., and Seto, K. C.: Comparative evaluation of relative calibration methods for DMSP/OLS nighttime lights, Remote Sensing of Environment, 195, 67–78, 2017.

Paxson, C. and Rouse, C. E.: Returning to New Orleans after Hurricane Katrina, American Economic Review, 98, 38–42, 2008.

Pistrika, A. K. and Jonkman, S. N.: Damage to residential buildings due to flooding of New Orleans after hurricane Katrina, Natural Hazards, 54, 413–434, 2010.

Skoufias, E., Strobl, E., and Breivik Tveit, T.: Flood and Tsunami Damage Indices Based on Remotely Sensed Data: An Application to Indonesia, Natural Hazards Review, 21, 04020 042, 2020.

Skoufias, E., Strobl, E., and Tveit, T.: Can we rely on VIIRS nightlights to estimate the short-term impacts of natural hazards? Evidence from five South East Asian countries, Geomatics, Natural Hazards and Risk, 12, 381–404, 2021.

Small, C., Pozzi, F., and Elvidge, C. D.: Spatial analysis of global urban extent from DMSP-OLS night lights, Remote Sensing of Environment, 96, 277–291, 2005.

Storeygard, A.: Farther on Down the Road: Transport Costs, Trade and Urban Growth in Sub-Saharan Africa, Review of Economic Studies, 83, 1263–1295, 2016.

Strobl, E.: The Economic Growth Impact of Hurricanes: Evidence from US Coastal Counties, Review of Economics and Statistics, 93, 575–589, 2011.

Strobl, E.: The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions, Journal of Development economics, 97, 130–141, 2012.

Sutton, P. C. and Costanza, R.: Global Estimates of Market and Non-Market Values Derived from Night-Time Satellite Imagery, Land Cover, and Ecosystem Service Valuation, Ecological Economics, 41, 509–527, 2002.

Sutton, P. C., Elvidge, C. D., and Ghosh, T.: Estimation of Gross Domestic Product at Sub-National Scales Using Night-Time Satellite Imagery, International Journal of Ecological Economics and Statistics™, 8, 5–21, 2007.

U.S. Burea of Enonomic Analysis: Regional Economic Accounts, https://www.bea.gov/data/economic-accounts/regional, 2020.

U.S. Department of Housing and Urban Development: Current Housing Unit Damage Estimates: Hurricanes Katrina, Rita, and Wilma, https://www.huduser.gov/publications/pdf/gulfcoast_hsngdmgest.pdf, 2006.

Vigdor, J.: The economic aftermath of Hurricane Katrina, Journal of Economic Perspectives, 22, 135–54, 2008.

Wu, J., Wang, Z., Li, W., and Peng, J.: Exploring Factors Affecting the Relationship Between Light Consumption and GDP Based on DMSP/OLS Night-Time Satellite Imagery, Remote Sensing of Environment, 134, 111–119, 2013.

Xiao, Y. and Nilawar, U.: Winners and losers: analysing post-disaster spatial economic demand shift, Disasters, 37, 646–668, 2013.

Zhang, Q. and Seto, K. C.: Mapping urbanization dynamics at regional and global scales using multi-temporal DMSP/OLS nighttime light data, Remote Sensing of Environment, 115, 2320–2329, 2011.

Zhang, Q., Pandey, B., and Seto, K. C.: A robust method to generate a consistent time series from DMSP/OLS nighttime light data, IEEE Transactions on Geoscience and Remote Sensing, 54, 5821–5831, 2016.

Zhao, X., Yu, B., Liu, Y., Yao, S., Lian, T., Chen, L., Yang, C., Chen, Z., and Wu, J.: NPP-VIIRS DNB daily data in natural disaster assessment: evidence from selected case studies, Remote Sensing, 10, 1526, 2018.