CLIMATE-SENSITIVE HAZARDS IN FLORIDA

Identifying and Prioritizing Threats to Build Resilience against Climate Effects

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IDENTIFYING AND PRIORITIZING THREATS TO BUILD RESILIENCE AGAINST CLIMATE EFFECTS

1. PROJECT INTRODUCTION

An uncertain climate future, and perhaps more importantly, impacts from a changing climate, loom before us. Today's climate was influenced by millions of years' worth of shifts in weather patterns, warming and cooling trends, and more recently by human influences on land and technology growth. Climate futures are also clouded by rhetoric and incomplete science. Fortunately, a focus on climate-sensitive hazards[1] does not require a connection between the reasons behind climate change and the effects of such change. Therefore, we do not focus on changing climate from the standpoint of "who is responsible" for "what portion" of "what pollution" that is causing the earth to change. Rather, this report will focus on the possible outcomes from a changing climate and the likely consequences of those outcomes as they manifest themselves across the state of Florida.

Simply put, hazard losses (even when controlling for population and inflation) have been increasing at a steady pace in this country since 1960, and Florida is no exception to this trend. Since many hazards are dynamically linked to the earth's weather processes, we can connect any subsequent aberrations in local, regional, or national weather to a variety of disaster consequences for which we are currently often ill-prepared. Included here are the devastating impacts from flooding, drought, and hurricanes that continue to affect the lives and livelihoods across the nation every year. Impacts and outcomes from these current incidents coupled with the fact that considerably more people are living within "hazard zones," especially within the state of Florida, mean that impacts from future expanded, and possibly more devastating, events might be seen as disasters waiting to happen. These must be assessed and adapted to if public health resilience is to be achieved.

The goal of this project is twofold. First, we will provide an expert overview of climate-sensitive threats[2] to lives and livelihoods within the state of Florida that is grounded in science and supported by pre-existing studies at the state and regional level. Second, we will assess and analyze priority climate-sensitive hazards for spatial and population impacts across the state. To that end, this report will focus on identifying, describing, and detailing multiple climate-sensitive events that will be influenced either positively or negatively by changes in Florida's climate. This review provides the scientific justification for identifying priority climate hazard threats to health for Florida's populations. The following sections will discuss a general background of hazards and losses for Florida, including an overview of hazards related to an overabundance of water (rain, flooding, and severe storms), severe and large scale events (storm surge and sea level rise), and those related to a lack of water (drought, heat, and wildfire). A short conclusion will highlight the findings and tease out those hazards that pose a threat to the most people across the state.

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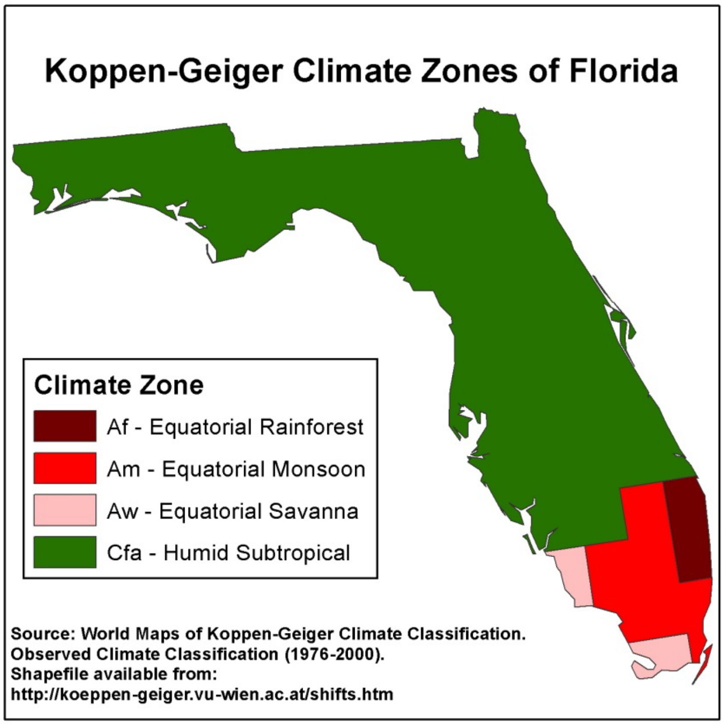
[1] Climate-sensitive hazards/threats refer to those hazard events that would be influenced by changes in climate conditions. Some examples include drought, hurricanes, flooding, sea level rise, wildfires, and extreme precipitation.

[2] See climate-sensitive hazards.

PROJECT BACKGROUND

Though climatic conditions vary across geographic regions of Florida, most of the state lies within the southernmost portion of the mid-latitude humid subtropical climate zone, characterized by a long, hot, and humid summer, and a mild, wet winter. In the southernmost section of the peninsula, weather patterns are generally designated by the tropical savanna[3], sharing many characteristics observed in the Caribbean islands (subdivided further as equatorial monsoon, equatorial savanna, and equatorial rainforest in Figure 1 below). Tropical savanna precipitation follows monsoon seasonality, highly concentrated during summer months, with a distinct decrease in rainfall throughout the winter season. Geographic factors governing Florida’s climate include latitude, prevailing wind and pressure systems[4], land and water distribution, ocean currents, storm prevalence, and topography (Winsberg, 2003a). While statewide relief reaches a maximum elevation of approximately 345 meters above sea level (Britton Hill, along the Florida-Alabama border), subtle topography characterizes the Florida shoreline, providing nominal natural barrier to mitigate the impacts of floods, hurricanes, and extreme coastal events.


Koppen-Geiger Climate Zones of Florida

Source: World Maps of Koppen-Geiger Climate Classification.
Observed Climate Classification (1976-2000).
Shapefile available from:
http://koeppen-geiger.vu-wien.ac.at/shifts.htm

Figure 1: Koppen-Geiger climate zone map of Florida.

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[3] Tropical savanna climate is a climate type that has monthly mean temperature above 18 °C (64 °F) all year and generally has a pronounced dry season, where precipitation during the driest months is less than 60 mm and where total precipitation is also less than (100 − [total annual precipitation {mm}/25]). A tropical savanna climate generally either has less rainfall than a tropical monsoon climate or more pronounced dry seasons.

[4] A pressure system is an area atmosphere where air pressure is unusually high or low. High and low pressure systems develop and dissipate continuously due to thermodynamic interactions of temperature differentials in the atmosphere and water of oceans and lakes.

Historically, Florida has been no stranger to hazards and disaster events, enduring 65 major presidential declarations and 12 declared emergencies since 1953 (FEMA, 2013). Among the most common hazards are severe thunderstorms, wind, lightning, tornadoes, tropical storms, and floods. In many cases, these hazards outnumber similar events across the country in frequency, magnitude, and impacts. From 1959 to the present, Florida has experienced more lightning fatalities than any other state (Vaisala, 2012), and has exhibited the highest annual average number of tornadoes per 10,000 square miles (NCDC, 2011). Florida is also among the wettest states in the country, consistently ranking among the top five in average annual precipitation (CoCoRaHS, 2011; Winsberg, 2003a). By comparison, Florida's shoreline is nearly as long as the combined strands of all other Gulf and Atlantic coast states from Virginia to Texas (Winsberg, 2003a). Because of the state's unique peninsular geography, it is exposed along both the Atlantic Ocean and the Gulf of Mexico, creating what Bossak (2004) refers to as the "hurricane bull's eye" (p.541). Consequently, more tropical systems make landfall in Florida than any other state (Malmstadt et al., 2009). Unsurprisingly, hurricanes and tropical storms represent the costliest hazard in Florida's history, accounting for 86% of the state's total hazard losses from 1960 to 2012 (HVRI, 2013). Disaster loss data in the United States is collected by a variety of first order data collection services including the National Climatic Data Center, the United States Geological Survey, and other government entities. Many of these data sources are compiled and combined with spatial enumeration data at the county level as the base data for the Spatial Hazard Events and Losses Database for the United States (SHELDUS). Table 1 below illustrates monetary losses and casualties by hazard type for the 53-year period. Measured by injuries, impacts from hurricanes and tropical storms are second only to tornadoes. Examining total fatalities, however, lightning and combined coastal hazards (including storm surge, rip currents, etc.) represent the deadliest hazards in the state.

Table 1: Florida hazard profile, 1960 to 2012.

Hazard Type	Monetary Losses (2012 adjusted)	Fatalities	Injuries
Hurricane/Tropical Storm	$ 87,373,452,167	148	2,940
Wind	$ 3,932,003,179	86	473
Flooding	$ 3,436,397,989	19	5
Winter Weather	$ 2,354,049,615	36	2
Tornado	$ 2,044,959,759	168	3,070
Wildfire	$ 834,628,358	0	255
Severe Storm	$ 740,811,980	47	228
Hail	$ 592,629,556	10	31
Coastal	$ 555,793,597	296	349
Lightning	$ 119,672,074	458	1,564
Fog	$ 2,350,860	6	47
Heat and Drought*	$ 129,666,151	12	10
TOTAL	**$102,116,415,285**	**1,288**	**8,974**

Source: The Spatial Hazard Events and Losses Database for the United States. (HVRI 2013)

* Impacts for heat and drought are combined. Casualties represent fatalities and injuries resulting directly from exposure to the hazard and may not represent the total medical impact from extreme heat events.

Temporal trends[5] for all hazard losses in Florida are generally concurrent with those tabulated throughout the United States (Cutter and Emrich, 2005; Gall et al., 2011), representing an increasing and unsustainable pattern of damage. Figure 2 illustrates the long-term trend of hazard losses for Florida, which, when smoothed, suggests an overall increase in annual total costs over time. This tendency relates to both an increase in hazard frequency and an ever-inflating coastal population, leaving more people and infrastructure exposed to future disasters (Malmstadt et al., 2009).

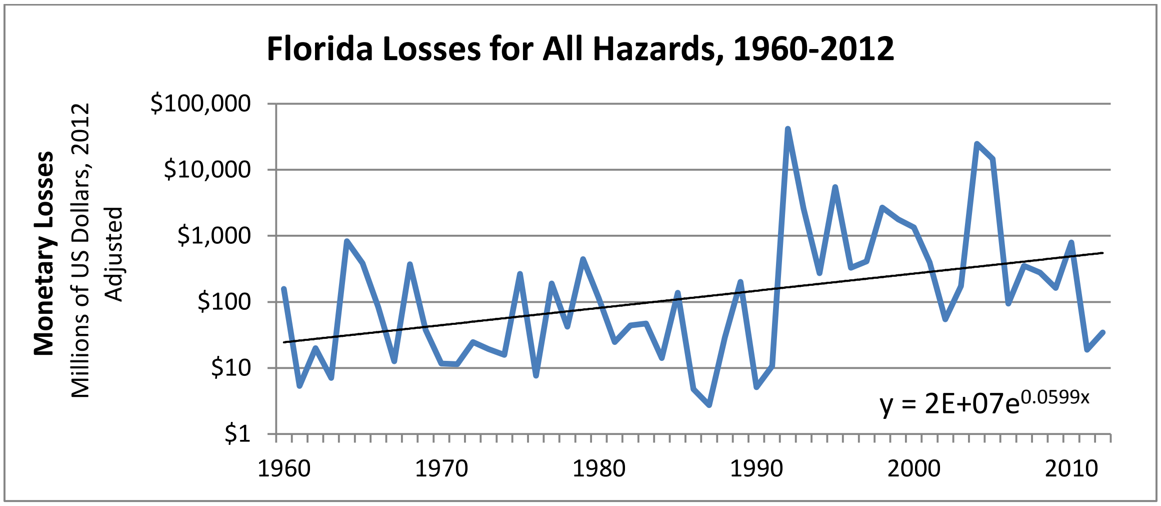

Figure 2: Long-term pattern of hazard losses in Florida plotted on a logarithmic scale.

Source: The Spatial Hazard Events and Losses Database for the United States (HVRI 2013).

The threat of future losses from hazards and disasters is compounded when taking into account the projected scenarios of global environmental change. Florida currently has frequent loss-causing flood and wind events in relation to seasonal rain, thunderstorms, and tornadoes; periods of chronic drought; and storm surge from hurricanes, tropical storms, and other coastal storms. While a new hazard regime may manifest itself in the years to come, the incidence of climate-sensitive hazards is generally expected to increase in severity and impact in the Southeastern United States (Emrich and Cutter, 2011; Ingram et al., 2012). In simplest terms, these events are likely to include increases in wind, rain, and storm surges linked with rising atmospheric and sea surface temperatures, and an overall rise in sea level (Ingram et al., 2012).

However, with considerable uncertainty surrounding the interpretation of long-term climatological trends, it is difficult to anticipate where and how future climate hazards will have the greatest impacts, and which populations are at greatest risk. The following subsections review the prevalent literature on climatological trends, future projections, and implications for extreme events, focusing particularly on the Southeast United States and Florida. While most of the extant climate analyses occur in the context of larger oceanic and atmospheric systems rather than by state, this review will extrapolate from

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[5] Trends over a specific time period. For Florida, the temporal trends in hazard losses from 1960 – 2012 do not generally deviate from those of the nation.

those pertinent projections for climate-sensitive hazards made in regards to the North Atlantic and Caribbean Ocean Basins where local climate predictions are limited or unavailable.

Precipitation, Floods, and Severe Storms

In general, researchers discern no long-term trends in the time series of annual or summer season precipitation across the Southeast during the last 100 years, with the exception of the northern Gulf Coast (Ingram et al., 2012; Kunkel et al., 2012). However, some researchers note that inter-annual variability has increased in recent decades across much of the region, with noticeable increases in the incidence of exceptionally wet and dry summers in comparison to the middle twentieth century, likely in relation to the positioning of the Bermuda High[6] (Groisman and Knight, 2008; Wang et al., 2010). When the system shifts southwest, precipitation tends to increase in the Southeastern United States, and similarly during northwest shifts, precipitation tends to decrease. At the local scale, this relationship is tempered by variations related to the strength of sea breeze circulation[7] (Ingram et al., 2012). Along the Florida panhandle, increased precipitation is linked to stronger sea breeze circulation, corresponding to the westward expansion of the Bermuda High (Misra et al., 2011). Additionally, Marshall et al. (2004) note the influence of anthropogenic land cover change across the Florida Peninsula on the increasing frequency and intensity of sea breeze precipitation.

Sea surface temperature anomalies in the equatorial Pacific produced by the El Nino-Southern Oscillation (ENSO)[8] correlate with precipitation variations throughout all seasons in south Florida (Jury et al., 2007; Winsberg, 2003b). It is important to note that ENSO is a natural, inter-annual climate variation that amplifies climate-sensitive hazard events. The exact timing of this oscillation, however, does not occur on an absolute schedule. Specifically, this can be explained in terms of a warm anomaly (El Niño) and a cold anomaly (La Niña). El Niño is associated with above average precipitation across all seasons, increased severe weather events, and cooler temperatures. Pervasive El Niño events can yield significant hazards, as was the case in June 1998, following the strong 1997-98 El Niño event, when numerous wildfires broke out during dry summer conditions, fueled by a dense vegetation growth triggered by heavy winter precipitation (Changnon, 1999; Ingram et al., 2012). In contrast, La Niña is tied to unseasonably dry conditions in late fall, winter, and early spring; above average temperatures; and warmer water in the Atlantic Ocean, substantially increasing hurricane activity (Winsberg, 2003a).

In terms of extreme precipitation, Ingram et al. (2012) note that frequency of heavy rain events has been increasing across the Southeastern United States, particularly over the

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[6] A semi-permanent area of high pressure located over Bermuda in summer and fall that steers many storm systems westward across the Atlantic. This is important for Florida because this steering guides hurricanes, tropical storms, and other systems towards the state.

[7] A pattern of wind occurring in coastal areas where winds blow from the ocean/gulf towards land. This type of breeze occurs most often in the spring and summer months because of the greater temperature differences between the ocean and nearby land, particularly in the afternoon when the land is at maximum heating from the sun.

[8] A band of warm ocean water temperatures that periodically develops off the western coast of South America. ENSO also causes extreme weather (such as floods and droughts) in many regions of the world.

past two decades. In Florida, the incidence of torrential rain is closely linked to La Niña conditions (Winsberg, 2003b). Across the Southeastern United States, an increase in extreme precipitation, coupled with increased runoff due to the expansion of impervious surfaces and urbanization, has led to an increased risk of flooding in urban areas of the region (Shepherd et al., 2010). Though researchers note a discernible increase in the number of severe storms and tornadoes over the last 50 years, it is likely that the upsurge is associated with improvements in storm observation and reporting (Ingram et al., 2012). Brooks and Doswell (2001) suggest that annual frequencies of strong tornadoes have remained relatively constant over the last half century.

Ingram et al. (2012) and others (Keim et al., 2011; Kunkel et al., 2012; Li et al., 2011) describe model simulations for future precipitation patterns using the A2 and B1 emissions scenarios from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

> The A2 marker scenario (A2-ASF) was developed using an Atmospheric Stabilization Framework (ASF) modeling approach applied to each of nine world regions. This integrated set of modeling tools was also used to generate the first and the second sets of IPCC emission scenarios. Overall, the A2-ASF quantification is based on the following “business as usual” assumptions (Sankovski et al. 2000):
> a. Relatively slow demographic transition and relatively slow convergence in regional fertility patterns,
> b. Relatively slow convergence in inter-regional GDP per capita differences,
> c. Relatively slow end-use and supply-side energy efficiency improvements (compared to other storylines),
> d. Delayed development of renewable energy, and
> e. No barriers to the use of nuclear energy.
>
> The B1 marker scenario (de Vries et al., 2000) was developed using the Integrated Model to Assess the Greenhouse Effect (IMAGE) 2.1, which assesses anthropogenic influences on climate change. Earlier versions of the model were used in the first IPCC scenario development effort. B1 illustrates the possible emissions implications of a scenario in which the world chooses consistently and effectively a development path that favors efficiency of resource use and "dematerialization" of economic activities. In particular, the scenario entails:
> a. Rapid demographic transition driven by rapid social development, including education;
> b. High economic growth in all regions, with significant catch-up in the presently less-developed regions that leads to a substantial reduction in present income disparities;
> c. Comparatively small increase in energy demand because of dematerialization of economic activities, saturation of material- and energy-intensive activities (e.g., car ownership), and effective innovation and implementation of measures to improve energy efficiency; and
> d. Timely and effective development of non-fossil energy supply options in response to the desire for a clean local and regional environment and to the gradual depletion of conventional oil and gas supplies.

While average annual precipitation is projected to decrease between 2-4% across regions of south Florida and Louisiana, an increase in seasonal rainfall, up to 6%, is generally expected throughout every season except summer. Keim et al. (2011) note little change in the annual frequency of extreme precipitation across the southern tier of the southeast region, with more dry days expected across the northern Gulf Coast. This expected drying may point to an increase in the frequency and severity of hydrologic drought[9] (Biasutti et al., 2009; Ingram et al., 2012). Overall, however, there is much uncertainty in precipitation projections, resulting from inadequacies in climate model resolution, which is often too coarse to account for regional and local-scale processes and inter-annual variability in the climate system (Ting et al., 2009; Stefanova et al., 2012).

Similarly, future projections for the frequency and intensity of severe storms and tornadoes are highly indefinite, as they cannot be resolved simply by global or regional climate models (Diffenbaugh et al., 2008). Generally, severe thunderstorms, including those that produce tornadoes, require large amounts of convective available potential energy (CAPE)[10], which is tied to atmospheric warming and moistening (Ingram et al., 2012). Though CAPE is generally projected to increase throughout the twenty-first century (see Trapp et al., 2007), global climate model simulations indicate significant inter-annual variability due to internal climate dynamics, such as ENSO (Marsh et al., 2007). In addition to CAPE, tornadoes also require strong vertical wind shear, which Diffenbaugh et al. (2008) suggest may decrease over much of the mid-latitudes due to a weakening of the pole-to-equator temperature gradient[11] (see also Ingram et al., 2012). Cloud-to-ground lightning represents a significant hazard across the Florida peninsula, both as a leading cause of hazard-related fatality in the state, and as a source of wildfire ignition (Ashley and Gilson, 2009; Ingram et al., 2012). While some research generally suggests that warmer temperature and increased convective[12] activity could result in increased lightning activity (Price and Rind 1994), Ingram et al.'s (2012) Southeast Region Technical Report to the National Climate Assessment does not mention definitive projections for lightning frequency.

With all of the uncertainty surrounding future scenarios of precipitation, flooding, and severe storms, there is a high degree of difficulty in drawing concrete conclusions about the frequency and intensity of extreme weather events in Florida. In regards to future precipitation, however, there is some consensus throughout the research that suggests a decrease in average annual precipitation and an increase in the number of dry days, which could heighten the severity and duration of drought (Ingram et al., 2012).

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[9] One of the four main types of drought where periods of precipitation shortfalls decrease the surface or subsurface water supply. Hydrologic droughts can impact water supply for farming, power production, and human consumption.

[10] The amount of energy a parcel of air would have if lifted a certain distance vertically through the atmosphere. This energy indicates atmospheric instability. Such indication is valuable in predicting severe weather.

[11] Describes how changes to temperatures in the higher latitudes (even minute) impact temperatures, weather, and possibly climate in the lower latitudes.

[12] Manifestations of upward air and moisture movement in the atmosphere including the development of convective clouds and resulting weather phenomena, such as rain showers, thunderstorms, squalls, hail, and tornadoes.

Hurricane Storm Surge, Winds, and Rising Sea Level

While recent events such as Hurricanes Katrina, Isaac, and Sandy highlight the vulnerability of the greater Gulf Coast and Mid-Atlantic regions to climate-sensitive hazards, Florida has experienced the largest number of hurricane landfalls in comparison to any other state (Malmstadt et al., 2009). Although the potential for hurricanes under current climatic conditions continue to threaten communities, there is growing concern that climate change could influence the likelihood and/or impacts of future hurricanes. Understanding if and how climate change may influence future hurricanes are critical questions as coastal communities develop long-term comprehensive land use plans to accommodate the continual increase in populations (Frazier et al., 2010).

Analyses of hurricanes and tropical cyclones over the entire Atlantic basin provide differing perspectives regarding long-term trends (Ingram et al., 2012). Holland and Webster (2007) and Mann and Emmanuel (2006) noted increasing trends in tropical cyclone activity in the Atlantic basin extending back to 1900 and 1880, respectively. Landsea (2007), however, warns that hurricane monitoring has improved drastically since the 1940s, with the arrival of airplane reconnaissance, and even more since the 1960s thanks to satellite imagery. Still, after adjusting for reporting biases, Landsea et al. (2009) identified a slight upward trend in tropical cyclone frequency between 1878 and 2008. Some research posits that the higher frequency of Atlantic hurricanes since 1995 is evidence of long-term climate change (Anthes et al., 2006; Emanuel, 2005; Pielke et al., 2005; Webster et al., 2005), while other studies suggest that the increased activity simply represents multi-decadal variability (Emanuel et al., 2008; Goldenberg et al., 2001; Gray et al., 1996; Landsea et al., 1999).

Though some researchers warn against linking climate change to hurricane impacts (Pielke et al., 2005), current climate projections suggest a fundamental shift in hurricane regimes. Recent work by Knutson et al. (2010) projects an overall reduction in hurricane event frequency given the current climate trajectory. At the same time, many researchers suggest increased sea surface temperatures could heighten hurricane intensity (Emanuel, 2000; Emanuel, 2005; Knutson and Tuleya, 2004; Pielke et al., 2005; Webster et al., 2005). Concurrent with this view, a recent study by Bender et al. (2010) anticipates a decrease in hurricane formation in the North Atlantic basin, coinciding with an increase in storm severity correlating with warming sea surface temperatures. The projected result is an upsurge in the number of hurricanes reaching category 4 or 5 on the Saffir-Simpson scale[13]. Although research on the frequency and intensity of future hurricanes is still under debate (Shepherd and Knutson, 2007), Frazier et al. (2010) note an emerging consensus in support of Bender et al.'s (2010) conclusions. Climate change may result in fewer tropical cyclones but with increasing intensities and precipitation totals (Bengtsson et al., 2007; Edwards, 2008; Landsea et al., 2006). However, recent research utilizing downscaled climate models and scenarios points to more frequent tropical cyclone activity (Emanuel, 2013; Strazzo et al., 2013). Even if future hurricane frequency or intensity remains constant, numerous researchers suggest that the rise in sea level could result in coastal populations previously outside of

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[13] A hurricane wind scale ranging from 1 to 5 based on a hurricane's sustained wind speed. This scale estimates potential property damage. Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 storms are still dangerous and require mitigation and preventative measures.

contemporary storm-surge zones to be exposed to future land-falling hurricanes (Emrich and Cutter, 2011; Frazier et al., 2010; Kleinosky et al., 2007; Wu et al., 2002).

Long-term records suggest that sea levels have exhibited a rising trend across the coastline of the Southeastern United States (Konrad and Fuhrmann, 2012). Satellite altimetry records, however, reveal spatial and temporal variations in the rates of sea level rise due to both land subsidence and short-term climate variability, including ENSO (Mitchum et al., 2010). Trends in global sea level dating back nearly 500,000 years have been assessed using coastal sediment cores (Rohling et al., 2008). These records indicate variations in global sea level of as much as 100 meters that correspond with glacial and inter-glacial cycles (Church et al., 2010; Ingram et al., 2012).

For most of the twentieth century, tidal gauge records indicate an average increase of 1.7 mm per year (Kunkel et al., 2012). Examining more advanced satellite altimetry data, the rate of sea level rise is estimated to have increased to a rate of 3.0 to 3.5 mm per year since the early 1990s (Prandi et al., 2009). Variations in sea level rise are driven primarily by thermal expansion[14] from warming of ocean waters and glacial melt (Domingues et al., 2008; Pritchard et al., 2009). Mote's (2007) recent analysis of glacial melting on Greenland shows that the melt rate from 1996 to 2007 was above the long-term average (1973 to 2007), with 2007 exhibiting the highest melt rate on record by more than 60%.

In Ingram et al.'s (2012) technical review, the authors note that the southeastern region displays an extensive and complex coastline that is especially vulnerable to sea level rise. As the sea level rises, storm surge and coastal erosion is likely to increase in magnitude. Sea level rise models from the IPCC AR4 project a mean rise of between 18 and 59 cm by the end of the twenty-first century, with the potential of an additional rise of between 10 and 20 cm from a rapid dynamic melting episode of the Greenland or West Antarctic ice sheets (Mitchum et al., 2010). Other recently modified projections suggest global sea level will rise by 80 to 200 cm by 2100 (Overpeck et al., 2006; Pfeffer et al., 2008). Such an event could result in complete inundation of various low-lying areas in south Florida (Milliken et al., 2008).

Climate Central's (2013) Surging Seas project presents a contemporary analysis of sea level rise impacts combined with tidal maximum and storm surge from hurricanes for all exposed coasts in the United States. From this study, projected new sea level rise by the year 2050 is expected to reach 33 cm in Florida. With this projection, Climate Central estimates over a 1 in 6 chance that sea level rise, in combination with hurricane storm surge and high tide, could overtop areas lying 2.4 meters above sea level. In this scenario, approximately 25% of the state's total population and housing stock is exposed. The study takes into account special considerations specific to Florida geography, including the porous limestone bedrock underlying much of the state, and a unique concentration of development within the first few feet above high tide[15] that make Florida especially vulnerable to sea level rise. Of particular importance in the discussion of sea level rise are coastal communities that are currently experiencing land subsidence from natural or anthropogenic processes (e.g., groundwater extraction, sediment

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[14] As water heats, it also expands, meaning that as the oceans warm the volume of water also increases influencing sea level rise.

[15] Higher porosity of underlying bedrock allows more saltwater intrusion at a faster rate and increases the possible land subsidence related to sinkhole development. As the study notes, the reverse is true for almost all other coastal states (Climate Central 2013).

redistribution). Ericson et al. (2006) warn that these areas of the coast will be most affected by sea level rise. Some impacts of sea level rise are already visible in Florida. In simple terms, these include saltwater contamination of freshwater aquifers, flooding at extreme high tide, and an observed diminishment in the effectiveness of the Southeast Florida canal system (Climate Central, 2013).

In addition to increases in storm surge inundation zones due to sea level rise, the potential for future hurricane impacts is exacerbated by the continuing growth of populations migrating to coastal Florida, increasing the number of people, homes, and infrastructure in storm surge hazard zones (Cutter et al., 2007; Frazier et al., 2010; Whitehead et al., 2000). As Frazier et al. (2010) and others note (Cutter et al., 2007; Emrich and Cutter, 2011), the combined factors of hurricane storm surge inundation, the potential of sea level rise to extend inundation zones, and the continuing development of the coast indicate a pressing need for coastal communities to conduct comprehensive vulnerability assessments[16] for new threats presented by climate-sensitive hazards (Cutter et al., 2007; Frazier et al., 2010).

Heat, Drought, and Wildfires

Most climate scientists agree that climate change will bring an overall increase in global temperatures (IPCC, 2007). While there is no consistent agreement on its extent, future climate scenarios indicate less cold weather and more hot weather (IPCC, 2012; McMichael et al., 2006). These assessments also anticipate an increase in extreme heat events and with them the increased potential for drought and wildfires (IPCC, 2012).

As climate change persists, heat events will likely become more dangerous (Meehl and Tebaldi, 2004). Over the past two decades, extreme heat events in the United States and Europe have caused thousands of fatalities in older adults and other vulnerable populations (McMichael et al., 2006). While studies predict more intense extreme heat events (IPCC, 2007, Meehl and Tebaldi, 2004), the impact of these events in Florida is historically minimal, due to the population's acclimation to hot weather (Luber and McGeehin, 2008). Therefore, it is reasonable to expect that, in general, extreme heat events pose a relatively small risk to the state's residents, but may be problematic for certain population segments, such as older adults and homeless who may be effected more quickly or do not have adequate access to air conditioning.

Historically, Florida droughts are shorter in duration than those experienced in other parts of the country, owing in part to tropical cyclone activity during potential drought months (Maxwell et al., 2011; Seager et al., 2009). Climate change projections suggest a fundamental change in drought potential in Florida. A study by Strzepek et al. (2010) projects increases in drought risk throughout the United States, including the southeast region. Other factors could compound drought risk, including increased water demand and projected decreases in tropical cyclone frequency (Knutson et al., 2010; IPCC, 2012). Beyond the more obvious ramifications of drought, the potential exists for the spread of diseases such as malaria (Epstein, 2001) and West Nile virus (Shaman et al., 2005) within the state. As Shaman et al. (2005) explain, periodic drought and subsequent rewetting can bring avian hosts and mosquitoes into close contact, facilitating epizootic cycling and amplification of the arboviruses, supporting higher levels

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[16] An assessment of potential adverse impact/loss from a threat, risk, hazard, or disaster.

of transmission[17]. Consequently, the authors suggest that widespread spring drought followed by summertime rewetting may yield epidemic levels of West Nile virus transmission in southern Florida.

Drought and potentially drier environments may lead to other dangers (IPCC, 2007). Wildfire is another potential risk in a changing climate, endangering human lives and altering regimes of both flora and fauna (Dale et al., 2001; Williams et al., 2010). The state experiences roughly 5,000 wildfires annually, ranking second in national frequency (Wyman et al., 2012). Projections indicate that the entire United States will see an increase in frequency, size, and season severity of wildfires (Brown et al., 2004; Le Page et al., 2010; Hessl, 2011; Flannigan et al., 2000). In particular, Florida's fire season could potentially increase from four to seven months (Liu et al., 2010; Liu et al., 2013). Changes to fuel condition brought on by lengthier drought events (Gedalof et al., 2005), increased lightning activity (Hessl, 2011; Price and Rind, 1994), or climate change-induced vegetation shifts[18] could also increase the risk of wildfire (Hessl, 2011). Considering these factors, wildfires could pose a more serious risk to Florida residents living in close proximity to areas of dense vegetation.

Past impacts from wildfires indicate that, while wildfires will continue to pose a threat, the severity of impacts and the population directly at risk is disproportionately lower when compared to those currently residing in storm surge/sea level rise impact zones. However, the deleterious air quality effects of wildfire smoke and particulate matter continue to pose a threat to human health in and around wildfire areas, especially to those who have pre-existing respiratory problems.

Priority Climate-Sensitive Threats

In this review, we have identified and discussed many different hazards and disasters that impact Florida's populations and infrastructure at present, and those that will become even more disastrous for the state if current trends in temperature and climate variation continue as expected. From these main climate-sensitive threats, we focus on seven that will likely cause the largest disruptions to lives and livelihoods across the state in the coming years, namely coastal flooding from storm surges, more intense hurricane winds, sea level rise, wildfires, flooding, drought, and extreme temperature. Although the most devastating of these is related to an overabundance of water, each is also characterized by a different speed of onset, duration, and a host of divergent threats to people, health, and longer-term adaptation strategies. A hurricane's volatile nature causes vast damage within a knowable area and provides an opportunity to pre-plan and mitigate health, population, and infrastructure effects while the subtle onset of sea level rise makes long term planning, mitigation, and adaptation more nebulous and often more difficult to translate into realistic and actionable adaptation steps. Impacts from each can be modeled and analyzed with a high degree of precision, meaning that we can identify where inundation will occur, the extent of impact, the depth of water, and the people and things that will be or are in the hazard zone. However, in neither instance can we concretely estimate the amount of sea level rise that will exist in the future or the precise

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[17] The process by which the population of infected vector mosquitoes could greatly increase in relation to drought extremes and subsequent heavy precipitation events.

[18] Changes to predominant land cover types related to climate changes. The types and quantities of flora have a distinct impact on fuel source for wildfires.

location of future landfalling hurricanes. This fact supports the need for comprehensive planning across all jurisdictions using the best available data and most appropriate spatial analytic methods. Such analysis will be vital for sustaining adequate adaptation planning for future climate threats.

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