The Vulnerability of America's Gulf Coast and the Caribbean Basin

FIGHTING for SURVIVAL

Commissioned Papers Briefing Book

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Columbia University

National Center for Disaster Preparedness
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COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

THE EARTH INSTITUTE

August 2010

Dear Colleagues,

On August 26, 2010, the Earth Institute at Columbia University, with the National Center for Disaster Preparedness (NCDP) at Columbia University Mailman School of Public Health, and New Orleans Mayor Mitch Landrieu, will host *Fighting for Survival: The Vulnerability of America's Gulf Coast and the Caribbean Basin*.

Fighting for Survival brings together political and thought leaders to discuss the vulnerability of the Gulf to natural and human-induced hazards, including the recent oil spill, the earthquake in Haiti, and the effects of climate change. The meeting also offers an occasion to reflect more deeply on the five-year anniversary of Hurricane Katrina, and the lessons learned from that tragedy. *Fighting for Survival* is predicated on the reality that climate change, environmental degradation, and the high-risks of natural disasters and industrial accidents pose enormous and growing risks to the region, and that we must prepare far more systematically for those risks. As we saw after Katrina, the Haitian earthquake, and the oil spill, disasters disproportionately impact the most vulnerable segments of society. Only through coordinated planning can the risks be reduced and preparedness be increased for the shocks that will inevitably arise.

The briefing papers herein, made possible by the Baton Rouge Area Foundation and produced by leading scientists at Columbia University, provide a scientific basis for the discussions. When the Conference was initially conceived, we held climate change at the center of the risks facing the Gulf. Hurricanes, heat waves, and precipitation have all become stronger and longer in duration, and consequently have strained and broken the systems that have historically responded to such risks. From this, we see destabilized populated regions, coastal erosion, weakened landmasses, and an increasingly fragile built infrastructure not able to withstand the pressures of the changing environment. The earthquake in Haiti and the oil spill caused us to expand the range of discussion to include natural disasters and industrial accidents when discussing the vulnerability of the region. Our belief is that we must take a holistic view of the sustainable development challenges facing the Gulf.

We invite you to consider the enclosed papers, support and challenge them, and join us in a discussion at the Conference. We look forward to seeing you in New Orleans.

Warm regards,

Jeffrey D. Sachs, PhD
Director, Earth Institute

Irwin Redlener, MD
Director, National Center for Disaster Preparedness

Projected Changes in the Physical Climate of the Gulf Coast and Caribbean

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Abstract

As the global climate warms due to increasing greenhouse gases, the regional climate of the Gulf of Mexico and Caribbean region will also change. The expected changes in temperature, precipitation, tropical cyclone activity, and sea level are described. Changes in temperature and precipitation are derived from climate model simulations produced for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4), by comparing projections for the mid- and late-21st century to the late 20th century and assuming a ”middle-of-the-road” scenario for future greenhouse gas emissions. Changes in tropical cyclones and sea level are more uncertain, and our understanding of these variables has changed more since IPCC AR4 than in the case of temperature and precipitation. For these quantities, the current state of knowledge is described based on the recent peer-reviewed literature.

1 Introduction

The nations of the Gulf Coast and Caribbean lie in the region comprised by the Gulf of Mexico, Caribbean Sea, and the tropical portion of the western Atlantic ocean; the coastal portions of the North, Central, and South American land masses that enclose them on three sides; and the Caribbean islands. This is a low-latitude region of the earth, whose proximity to the equator and maritime geography render its climate generally warm and humid. Rainfall is present throughout the year, evenly distributed between the seasons in the Gulf region but more concentrated during the summer and fall rainy season in the Caribbean, and nearly the whole region is threatened (to varying degrees) by hurricanes during the months between May and October. Yet much of the region lies in the subtropical latitudes which, elsewhere on the earth, feature deserts, and parts of the Gulf Coast and Caribbean region can also be threatened by drought.

As the global climate changes, the regional climate of the Gulf Coast and Caribbean will change as well. Some of the ways in which it will change are fairly certain, while others are much less so. We cannot predict with precision all the ways in which the nations, people, and economies of the region will be harmed (or will benefit) from climate change. Some of the vulnerabilities are clear, however.

In a region that is already warm, increases in temperature — accompanied almost inevitably by increases in specific humidity — may constitute the most obvious and predictable hazard. Precipitation is a more subtle matter, predicted to increase in some places and decrease in others, and in any case predicted with less certainty than temperature. Whether an increase or a decrease in precipitation is considered harmful or beneficial may also vary across the region. Hurricanes may be the most feared hazard in the present climate. How they will change as the climate warms is relatively uncertain, but very focused research from the last several years suggests they will be fewer, but more intense. Sea level rise is a major threat to this region of coasts and islands, both on its own and when coupled with hurricane-induced storm surge; it is inexorable, but the speed with which it will occur is very difficult to predict, depending not only on the rate of global warming but also on the subtle dynamics of polar ice sheets far away.

In this paper, we review the current state of knowledge about what changes in climate are expected in the Gulf Coast and Caribbean. We focus on temperature, precipitation, hurricanes, and sea level. We do not attempt to characterize what the impacts of these changes will be, instead limiting ourselves to a discussion of the physical climate alone. We do describe the changes in terms that we expect to be relevant to a variety of societal impacts.

2 Data and Methodology

For temperature and precipitation, we make use of the global climate model simulations performed under the Third Coupled Model Intercomparison Project (CMIP3; Meehl et al. 2007) for the purpose of the Fourth Assessment Report (AR4; IPCC 2007) of the Intergovernmental Panel on Climate Change (IPCC). These simulations, and the models used to produce them, are described in greater detail in IPCC AR4 (and the peer-reviewed literature on which that report is based). Some regional assessment reports making use of the same information have been produced, e.g., for the US (Karl et al. 2009) or the Caribbean (Bueno et al. 2008). Our treatment here differs in focusing on the Gulf coast and Caribbean together, in our treatment of tropical cyclones and sea level, and perhaps in some other aspects of our interpretation. The essential elements of our discussion are, however, consistent with the broad scientific consensus reflected in IPCC AR4, particularly regarding temperature and precipitation.

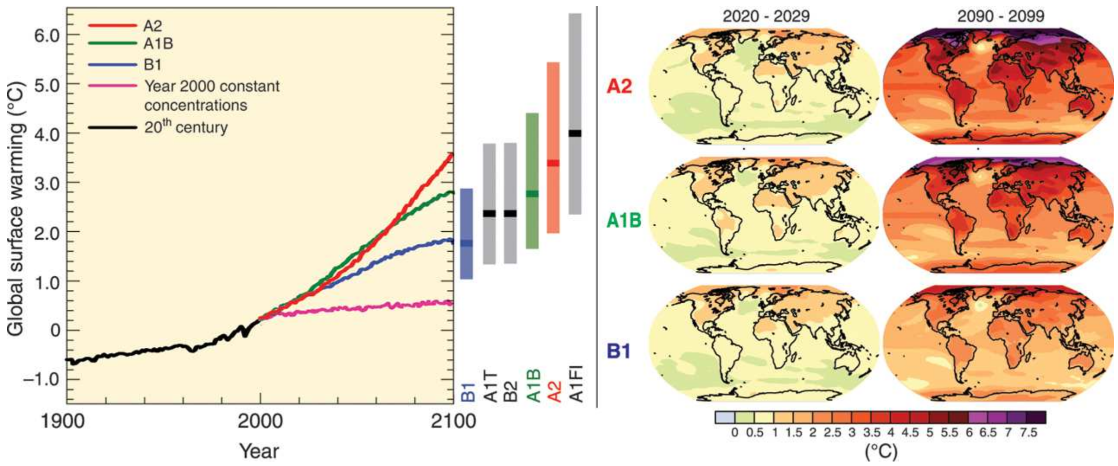

Figure 1: Global surface temperature changes in multi-model projections from IPCC (2007); the figure and description are taken from that report. Left panel: Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099 relative to 1980-1999. Right panels: Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020-2029 (left) and 2090-2099 (right).

The large set of global climate model simulations done for IPCC offers the best scientific basis we have for making detailed projections about how climate will change in a specific region. They are not predictions, but scenarios, contingent on assumptions about how anthropogenic emissions of greenhouse gases, as well as other factors which are external to the climate system but which influence it, will evolve in the future. It is virtually certain that anthropogenic emissions of greenhouse gases have been warming the global climate for some time and will continue to do so (most likely at a greater rate) in the future. The precise *rate* of warming we expect in the future is somewhat more uncertain. One source of uncertainty is our incomplete understanding of the climate system, as manifest by the fact that different climate models project different rates of global mean warming even for the same increases in greenhouse gas concentrations. Another — probably greater — source of uncertainty is that due to our uncertainty about future greenhouse gas emissions. This results from our inability to predict economic and political developments rather than the physics of the climate system.

In this report we use results from the A1B scenario of the IPCC AR4. This is considered a “middle-of-the-road scenario, neither worst-case nor best-case (see fig. 1). It is possible (though it seems unlikely in the short term) that reductions in emissions will cause the rate at which greenhouse gases increase to be less than that in A1B, leading to less warming. It is also quite possible that the increases in greenhouse gases will be significantly more rapid than in A1B, leading to faster warming than that in the A1B projections. Many (though not all) of the results are to some degree linearly proportional to the global mean surface temperature change: if the rate of global warming is less or greater than that in A1B by some factor, the change in local temperature or precipitation in the A1B projections is also likely to be less or greater by a similar factor.

The changes we show are computed by averaging the physical quantity (e.g., temperature, precipitation) for a future period in the A1B projections, and subtracting the same quantity averaged over a period of the same duration in the 20th century[2]. We subtract the 20th century average values as computed by the models, rather than the observed values, so that any imperfections in the models representations of the past climate are not misinterpreted as projections of climate changes.

All results we present are multi-model ensemble means, or averages over the large set of model simulations, using 24 different climate models[3], submitted to the IPCC for the A1B scenario. Ensemble averaging is the most straightforward way to handle the uncertainties in both the global climate sensitivity and the ways in which global climate change will be manifest differently in different regions. Some models predict greater changes (both globally and regionally) than the ensemble mean, while some predict smaller ones. The degree to which different models agree on specific aspects of the projected climate change is one measure of our confidence in the likelihood that that specific change will occur in response to increasing greenhouse gas concentrations. If different models differ widely, our confidence is low. If most or all of them agree closely, we are still not entirely certain that they are correct (because the models are not perfect representations of the real climate system), but our confidence is substantially greater.

Tropical cyclones and sea level are important facets of climate for the Gulf Coast and Caribbean. The combination of the two —rising sea level leading to greater flooding from storm surge when hurricanes make landfall — is potentially one of the most serious long-term risks for the region. Unfortunately, current climate models, such as those from the CMIP3 ensemble from which we derive projections of temperature and precipitation change, are not up to the task of making quantitative projections of regional changes in either tropical cyclones or sea level. In the case of tropical cyclones, the coarse grid resolution of the models prevents the models from simulating tropical cyclones adequately even in the present climate; thus changes in tropical cyclones in model projections of the future are not reliable. In the case of sea level, any projection depends critically on the dynamics of ice sheets on land, something not yet simulated well (or not simulated at all) by the models. Thus, our discussions of tropical cyclones and sea level are not based directly on climate model projections of these quantities. Rather, we summarize results from the recent literature, including that written after IPCC AR4. Both topics are subjects of intense research, and understanding of both has evolved considerably even since the release of IPCC AR4 a few years ago. Nonetheless there are still very substantial

[2]Due to the variations in the availability of data, slightly different periods are used for the computation of some different statistics. For time-averaged fields, the period 2075-2099 is compared to 1975-1999. For extremes (figs. 3, 4, 7, 8, and 9) the normals are defined over 30 years, so those are compared to 30-year averages for the models, 2020-2049 and 2070-2099

[3]For extremes, as shown in figs. 3, 4, 7, 8, and 9, data were not available for all models; results shown are computed from the 9 models for which these data were available.

uncertainties in both these areas and our discussion characterizes that.

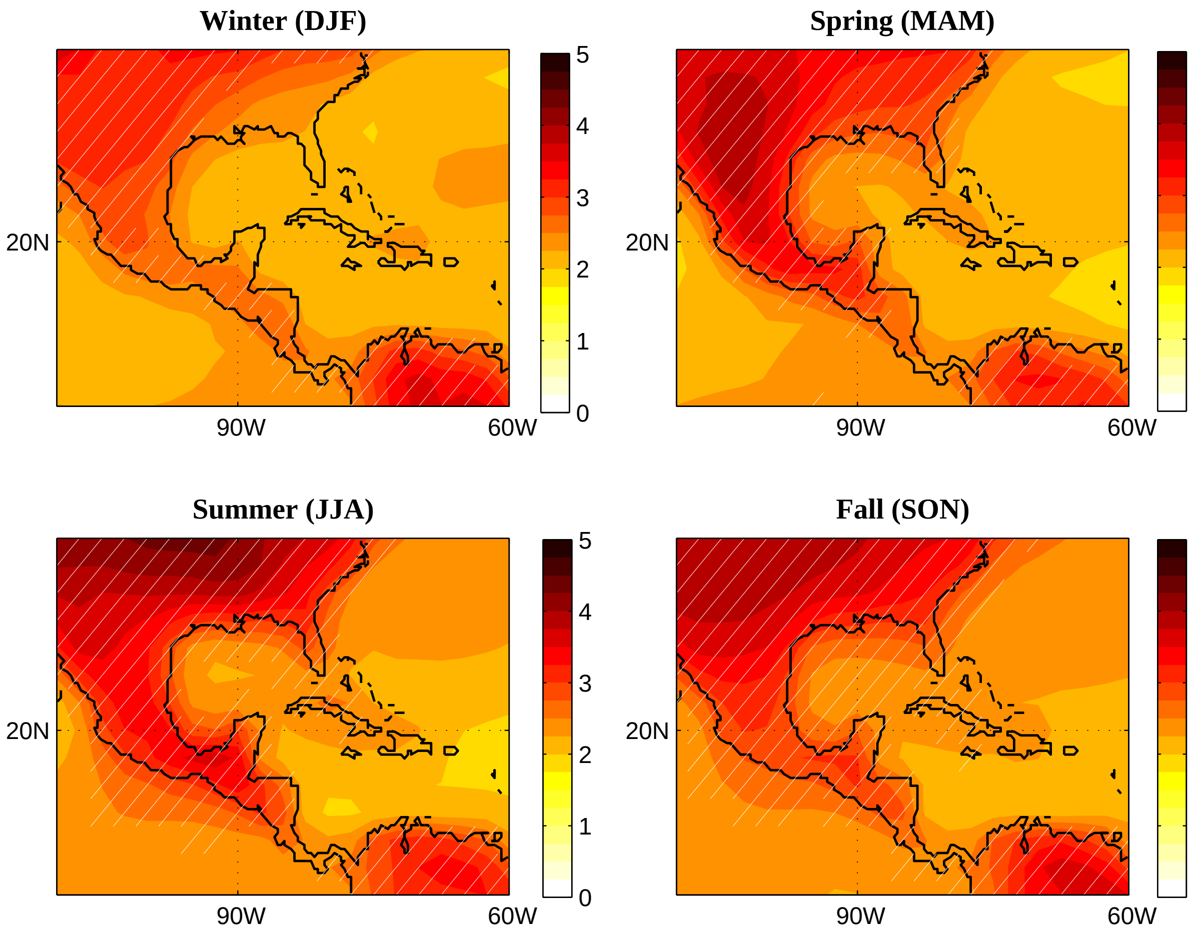

Figure 2: Multi-Model mean of seasonal temperature anomalies A1B(2075-2099) minus 20C(1975-1999). The anomalies are positive and statistically significant everywhere for all models. The hatching indicates regions where 75% of the models agree that warming will be larger than 2 °C (3.6 °F).

In summary, this report presents what current science has to tell us about the risks for the US Gulf coast and the Caribbean under climate change. To quantify this risk, we use climate model-based projections produced for the IPCC AR4, under one particular scenario for increases in greenhouse gases, comparing the projected late-21st century climate to that in the late 20th century. Because of uncertainty in future greenhouse gas emissions, uncertainties associated with the models imperfect representations of the climate system, and the different time horizons which may be of interest for different applications, the results below should not be interpreted as precise quantitative predictions. Rather, they should be taken as broadly indicative of the kinds of changes that are likely to occur as the climate warms. Our discussions of changes in tropical cyclones and sea level are, due to the nature of the subject, more qualitative than our discussions of temperature and precipitation, and are based on surveys of the recent peer-reviewed literature rather than directly on the climate model projections from IPCC AR4.

3 The regional climate

3.1 Temperature

The most robust response to increased greenhouse gases in the Gulf and Caribbean region, as elsewhere, is a marked warming. This is manifest in increases in seasonal mean surface temperature, in the number of warm nights, in record high temperature, in the duration of heat waves, and a corresponding decrease in days below freezing, record lows, and cold snaps.

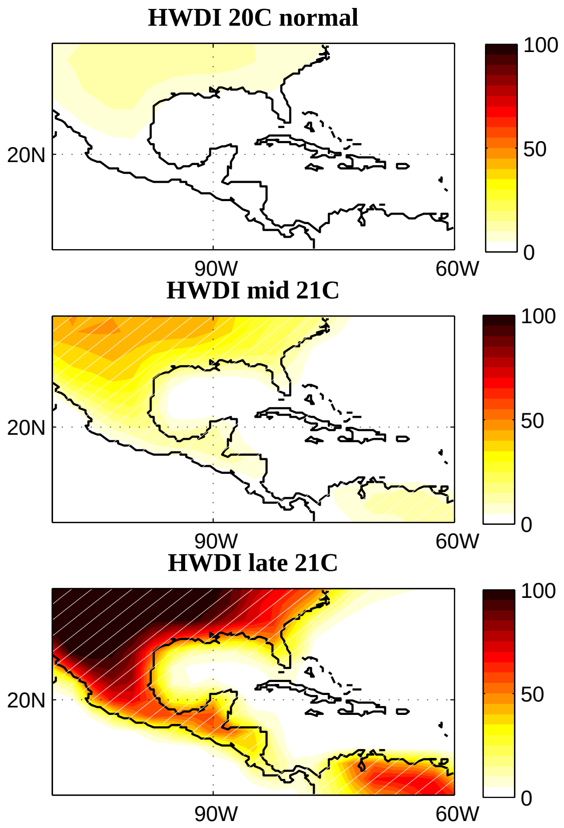

Figure 3: Average heat wave duration index (HWDI) as simulated by 9 climate models. The HWDI measures the maximum (over the course of a year) period longer than 5 consecutive days with maximum temperature more than 5C above the 19611990 daily normal. Top: 1961-1990 average in the 20C integrations. Middle: 2020-2049 average in the 21C (A1B) integrations. Bottom: 2070-2099 average in the 21C (A1B) integrations. Hatching in the bottom panels indicates areas in the increase with respect to the climate normal is statistically significant at the 95% level for at least 2/3 of the models.

Figure 2 shows the differences, or "anomalies" in seasonal mean surface air temperature between the late 21st century and the late 20th century. As discussed above, the results from both periods are computed from the ensemble mean of the 24 climate models used in IPCC AR4. The warming is statistically significant everywhere if computed for each model individually, as well as for the ensemble mean. In all seasons, the continent warms more than the ocean, and 75% of the models project more than 2°C (3.6 °F) of mean warming. The details of the warming vary with the seasons. During spring, the maximum warming follows the topography and is likely associated with earlier snow-melt. During summer and fall the land-sea contrast is maximum, and the warmest temperatures are in the interior of the continent.

Figure 3 show the maximum duration of a heat wave as simulated by 9 climate models for the 20th century climate normal period (1961-1990), early in the 21st century (2020-2049) and late in the 21st century (2070-2099). Here a heat wave is defined as a period of at least 5 days when temperatures exceed the normal for that calendar day by 5°C (9°F). In the US interior, by the end of the century, entire seasons will be as warm as what we now consider a heat wave. The increase is not so dramatic for more maritime regions, but even along the Gulf we can expect "heat waves" of more than 2 months.

The increase in the number of warm nights (fig. 4) is also widespread, but is expected to be greater in the deep tropics and Caribbean, less so over the US. Nights as warm as the 10 warmest nights of a typical year in the 60s 70s or 80s will be 4 times as frequent in the Gulf states (8 times, in Hispaniola) by the end of this century.

Warm nights and heat wave duration are both relevant to the visceral human experience of climate, and also likely related to energy use in regions where air conditioning is widespread.

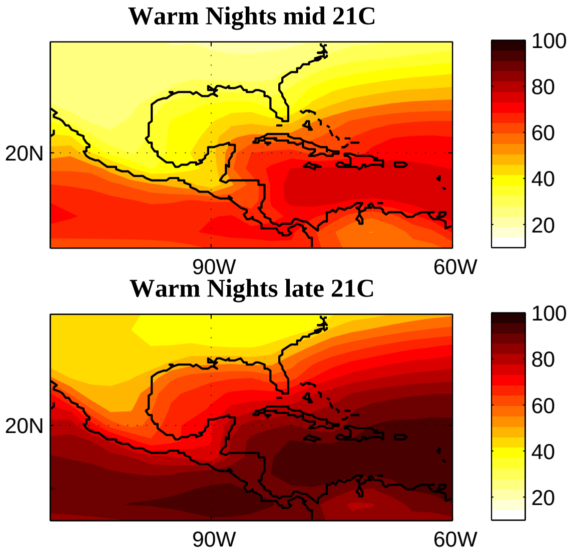

Figure 4: Average percentage of warm nights as simulated by 9 climate models. A warm night is one when the minimum daily temperature is warmer than the 90th percentile of daily minimum temperature during the 1961-1990 climate normal. By definition, the percentage of warm nights during 1961-1990 is 10%. Top: 2020-2049 average in the 21C (A1B) integrations. Bottom: 2070-2099 average in the 21C (A1B) integrations. The anomalies are significant everywhere.

The temperature increases alone are underestimates of the extent to which it will feel warmer, as humidity will increase as well. Particularly over the oceans and coastal regions (which describes most of the Gulf coast and Caribbean), the models project little change in relative humidity. This projection — which is also robustly supported by our understanding of the physics of near-surface climate, and by observations of variability in the mean climate — means that as temperature increases, there will also be significant increases in specific humidity.

Another way to get a sense for how a mean warming of about 3°C (6°F) feels is to look at the historical anomalies in seasonal mean temperature and ask how an average summer or winter in 2090 will compare to a hot season in the 20th century. Following Battisti and Naylor (2009) we derive the frequency distribution of seasonal temperature anomalies from observations of the 20th century and construct a similar distribution for the 21st century by adding the 21C-20C changes simulated by the model. Because of scatter in the models' projections, the distribution for the 21st century is wider than the observed for the 20th century. The results of this computation for winter and summer temperature in the Gulf states and the Caribbean are shown in Figure 5. In the Gulf, a typical winter in the last decades of this century will be as warm as the warmest winter ever recorded and the coolest summers will be as hot or hotter than any summer in the last century; in 95% of the years, summer temperatures will be unprecedented. A similar picture emerges for the Caribbean: here the interannual variability is much smaller (reflecting both the tropical location and the maritime climate), making all summers and 90% of winters at the end of the century warmest than ever in the past.

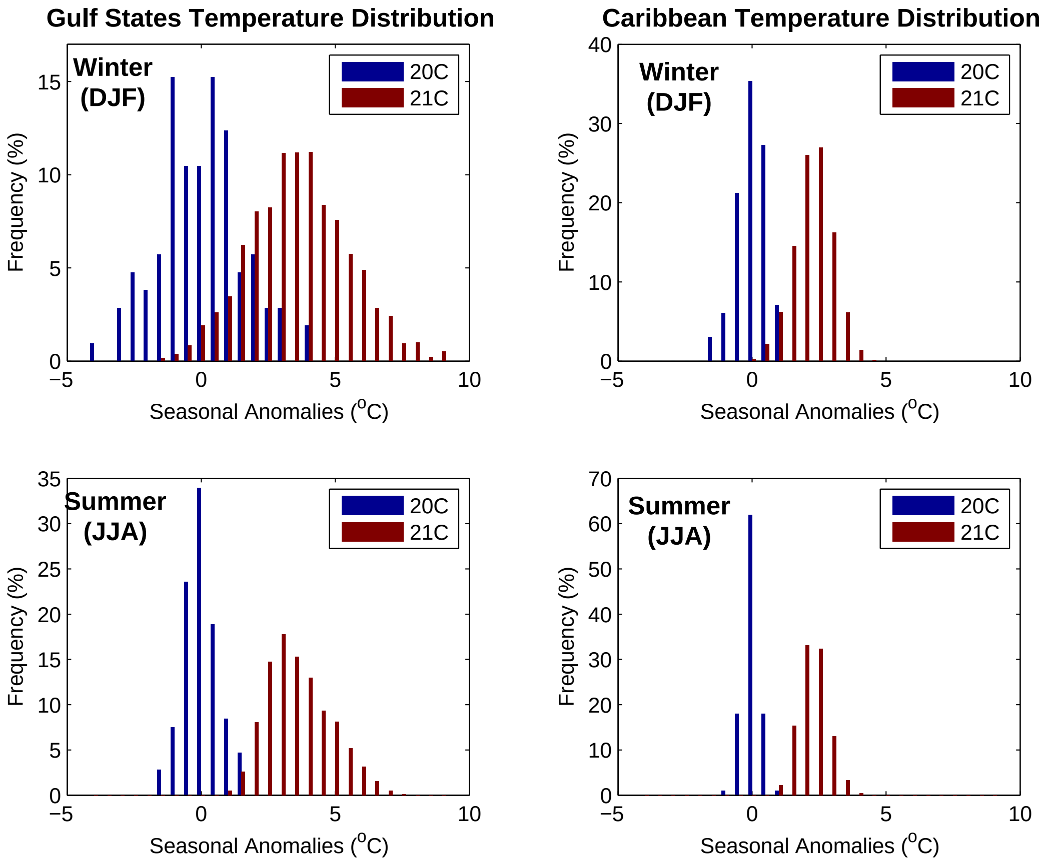

Figure 5: Frequency distribution of seasonal mean surface temperature anomalies in observations (1900 to 2005, labeled 20C, in blue) and estimated for the end of the 21st century (labeled 21C, in red). The 21C distribution is obtained by adding the 20C observed anomalies to the difference 2075-2099 minus 1975-1999 as simulated by each of the 24 models in the CMIP3 archive. The top panels are for winter (DJF) and the bottom panels are for summer (JJA). The left panels are for a box comprising Louisiana, Mississippi and Alabama (95W-85W; 30N-35N), the right panels are for a box centered over the Caribbean (85W-70W; 15N-25N). Observations over the US are from the NOAA NCDC CIRS Climate Division (1900-2005); over the Caribbean they are NOAA NCDC GCPS gridded anomalies derived from the Global Historical Climate Network (1894-1993).

3.2 Rainfall

The mean rainfall response to greenhouse gas increases in the Gulf and Caribbean can be broadly described as a drying of the latitude band between 10°N and 30°N, with wetting to the south and to the north (fig. 6 and also fig. 11).

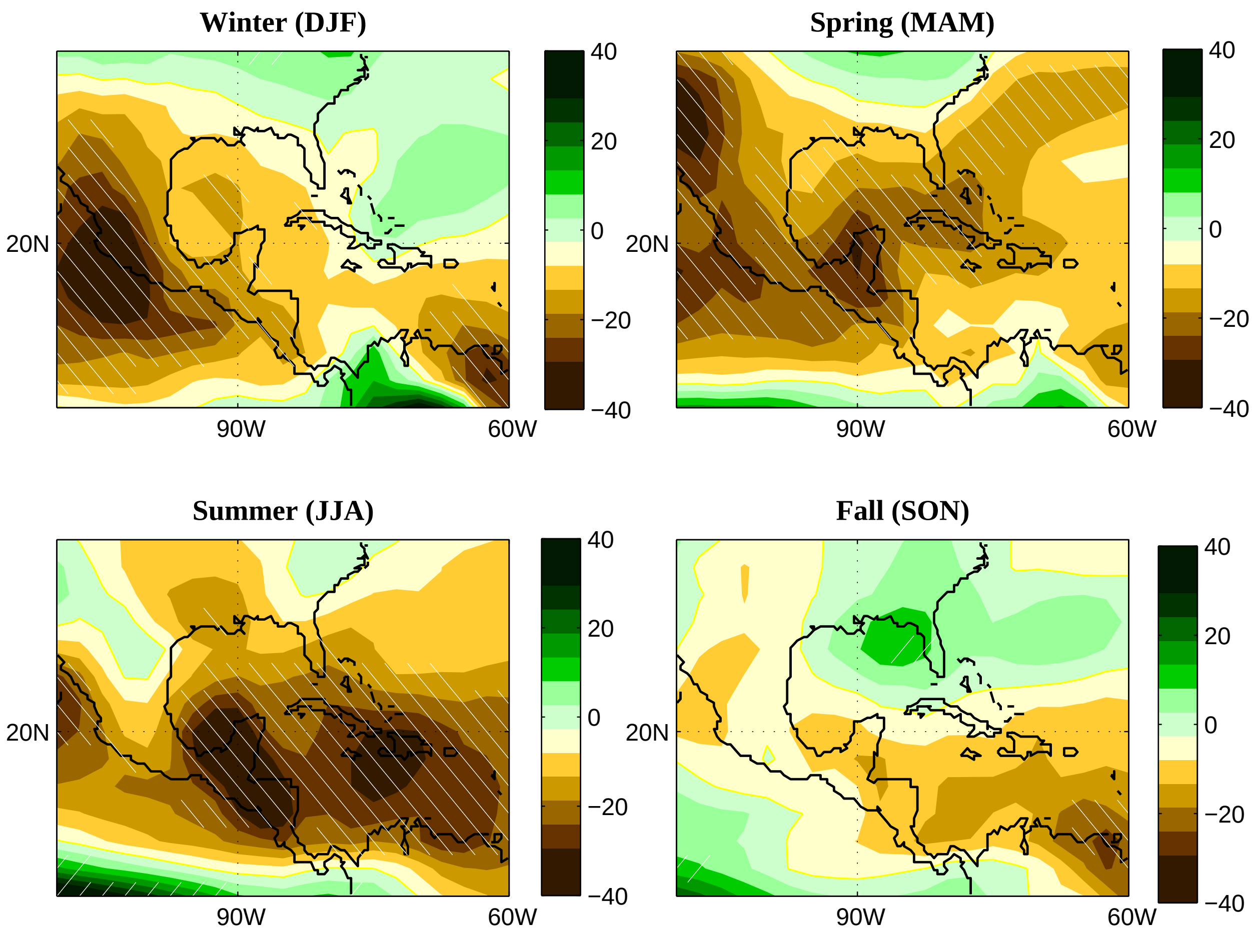

Figure 6: Multi-Model mean of seasonal rainfall anomalies A1B(2075-2099) minus 20C(1975-1999). The hatching indicates regions where 75% of the models agree on the sign of the anomalies.

Looking more carefully at the seasonal evolution and the spatial detail of the anomalies, we are confronted with much more uncertainty than for the temperature response. In the mean, models project moderate drying along the Gulf coast for most of the year, except the fall, but because the Gulf states are located at the latitude where we expect rainfall anomalies to switch from negative to positive, the outlook is uncertain. Our certainty is greater for the Caribbean, at least in spring and summer for which the models project a robust 30% drying.

Analysis of daily data suggests that the character of precipitation will also undergo small changes.

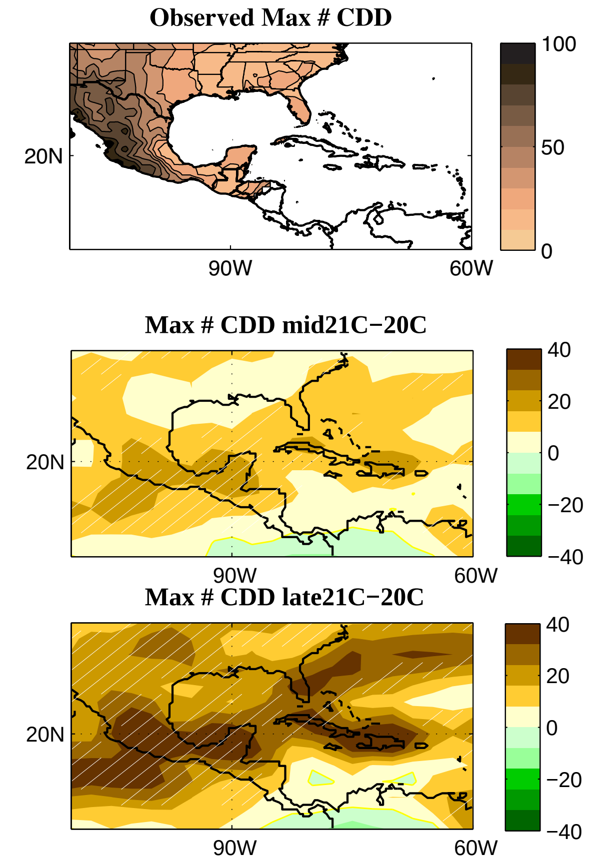

Figure 7: Top: Observed average maximum number of dry days (accumulation less than 1mm) during 1961-1990 calculated from daily gridded data at 1° × 1° resolution (http://www.cpc.ncep.noaa.gov/products/precip/realtime/GIS/retro.shtml). White areas indicate regions not covered by this analysis. Middle: Multi-model difference between the 2020-2049 average in the 21C (A1B) integrations and the 1961-1990 average in the 20C integrations, expressed in percentage of the 20C normal. Bottom: as in Middle, but for 2070-2099. Hatching indicates regions where the multi-model mean anomalies are larger than the scatter (standard deviation) among the models.

The maximum number of consecutive dry days over the course of a year is expected to increase, especially over the Caribbean and consistent with a lengthening of the dry season (fig. 7), while the number of days with rainfall larger than 10 mm (about 0.4 inches, a typical daily rainfall amount in this region, see fig. 9,top) is projected to decline over the entire region (fig. 8, middle and bottom). The intensity of precipitation is projected to increase slightly over the continent, but these anomalies are not significant (fig. 9, middle and bottom).

Figure 10 shows 20th and 21st century frequency distributions for seasonal precipitation, analogously to Figure 5. We see that the much larger observed variability and the more modest mean change in rainfall projected for the 21st century combine to give similar frequency distributions over the past and the future. Although the record driest seasons will be unprecedentedly dry, seasonal mean precipitation in most years will be within the historical range. This does not mean that hydrological droughts — shortages of water in soils, reservoirs, lakes and streams — will not become more frequent or more severe than in the past, in the Caribbean in particular. Severe hydrologic drought tends to result from a long sequence of many years in which precipitation is less than normal, rather than from just one very dry year. The projected shift in the frequency distribution of seasonal precipitation in the Caribbean suggests that the likelihood of multiple dry years in sequence will increase there.

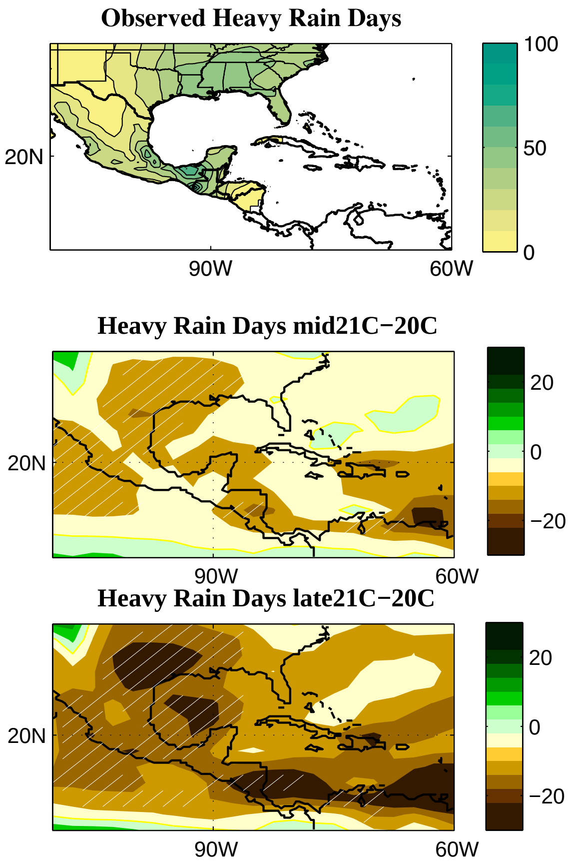

Figure 8: As in Figure 7, but for the number of days with heavy rain (accumulation larger than 10mm).

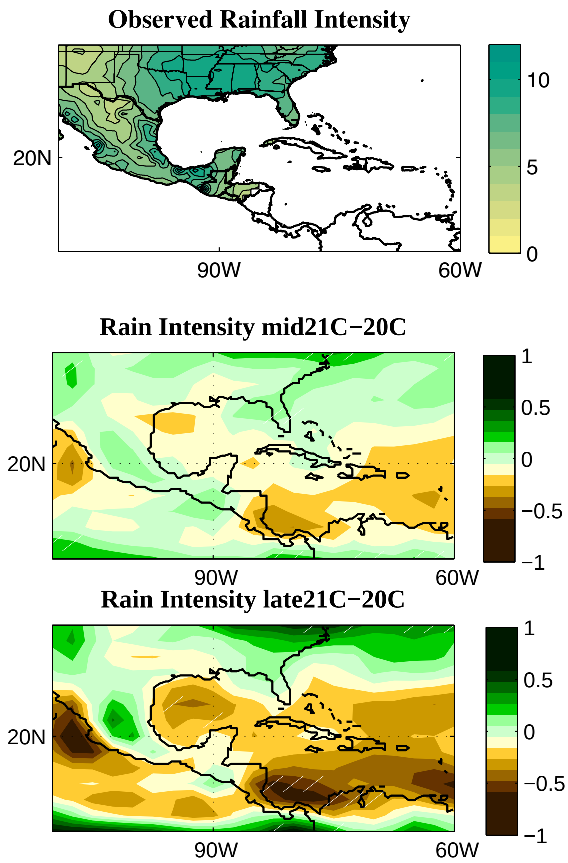

Figure 9: As in Figure 7, but for the average rainfall intensity on rainy days (accumulation larger than 1mm).

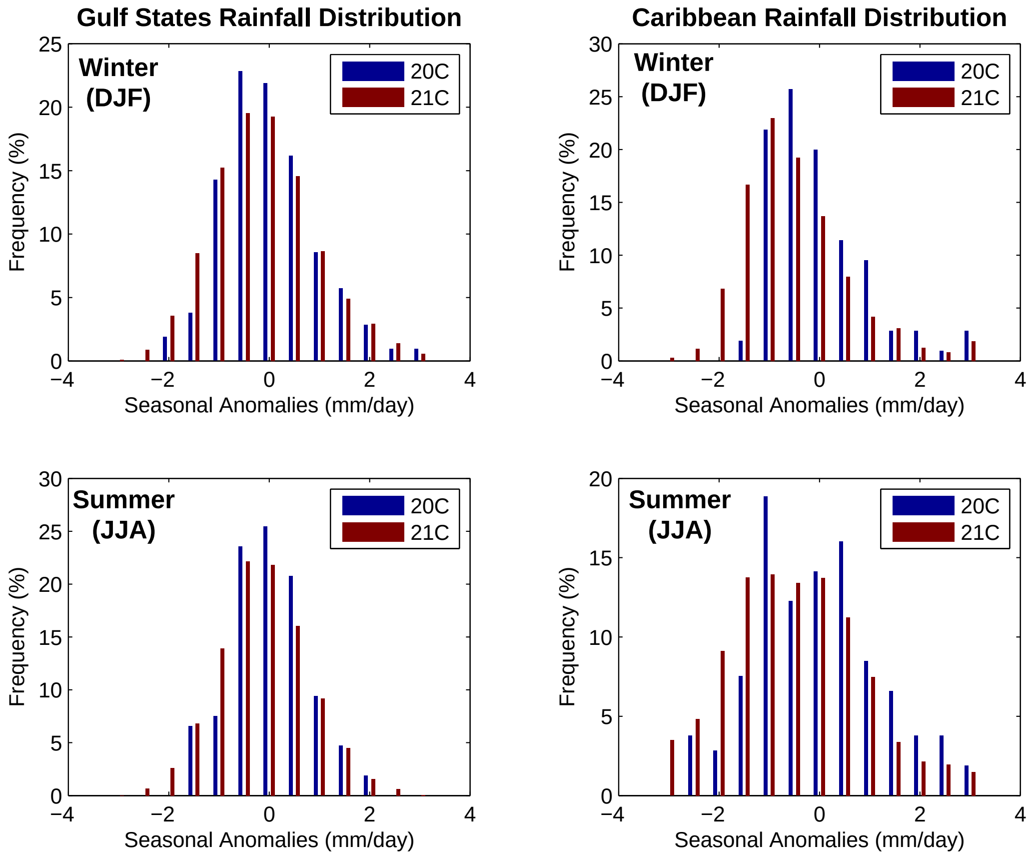

Figure 10: As in Figure 5, but for seasonal precipitation. Observations for the 20th century are from the Global Historical Climatology Network (http://www.ncdc.noaa.gov/oa/climate/ghcn-monthly/index.php).

3.3 The physical basis

To place the Gulf and Caribbean in the context of broader regional-scale changes, we expand our outlook to include the tropical band from Africa to the East Pacific. In Figure 11 we show the 21C-20C anomalies in annual mean sea surface temperature (SST) and rainfall. The surface ocean warming in the Atlantic is not uniform, but has a clear spatial structure that is very robust across the models (Leloup and Clement, 2009; Xie et al., 2010). The warming has a relative minimum in a southwest-northeast band from the Caribbean to North Africa and Spain. Greater warming is found to the south and north of this band, in the region of the "Intertropical Convergence Zone" between northeast Brazil and West Africa, and over the northwest tropical Atlantic. A strong local maximum in surface ocean warming is also found in the equatorial eastern Pacific; in this respect the future climate is projected to bear some resemblance to an El Niño event (Philander, 1990; Sarachik and Cane, 2010) in the present climate. This too is a robust response of the models, with a clear physical interpretation involving the weakening of the tropical atmospheric circulation in response to warming (Vecchi et al., 2006; DiNezio et al., 2009).

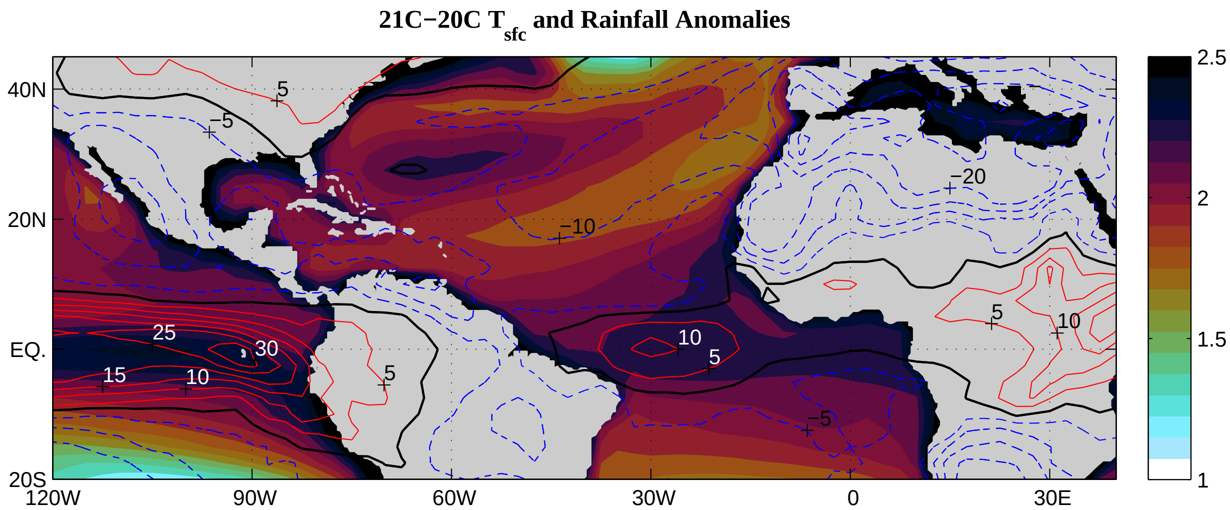

Figure 11: Multi-model mean of the difference between 21C(2075-2099) and 20C(1975-1999) in annual mean sea surface temperature (shaded, in °C) and rainfall (contours, in percentage of 20C values; red solid contours indicate wet anomalies, dashed blue contours indicate dry anomalies).

It is clear from the the correspondence between the spatial patterns of precipitation change and SST change that the two are related. Precipitation is projected to increase strongly over the near-equatorial regions of the east Pacific and Atlantic in which SST rises the most, and to decrease over the band of minimum increase, which includes most of the Caribbean and Gulf. In the current tropical climate, there is a close and well-known correspondence between spatial variations in SST and precipitation, with greater precipitation, on average, over regions of higher SST. The relevant quantity for precipitation is not absolute SST, but *relative* SST, that is, the difference between the local SST and the average over the rest of the tropics; this controls the stability of the atmospheric column, thus the tendency for deep convection (tropical rainstorms), and thus also the atmospheric circulation which moves atmospheric moisture from some regions to others, causing rainfall to be much more variable than surface evaporation (e.g., Sobel, 2007). If SST were uniform in space, any warming would be expected to lead to a modest increase in precipitation, on the order of 2% per degree of surface warming (e.g., Held and Soden, 2006). The regional changes shown in Figure 11 are considerably different, and in many places larger than this, clearly due to the SST changes. The drying of the Caribbean shown in the preceding figures is thus part of a coherent, large-scale pattern of regional climate change that is manifest in multiple variables and that can be understood in the context of mechanisms operating in the present climate.

4 Tropical Cyclones

The risk of societal harm from tropical cyclones (TCs) is a function not only of the storms themselves, but also of a variety of physical and societal factors. These other factors are likely to change as much or more than the storms themselves. For example, rising sea level increases the risk associated with storm surges, while increasing coastal development increases economic damage for a given storm (e.g., Pielke and Landsea, 1998). To provide a baseline for considering these issues, we first briefly describe the present climatology of tropical cyclones in the Gulf and Caribbean, before continuing to discuss the current state of the science regarding how tropical cyclones in this region may change in the future as the climate warms.

4.1 Present climatology

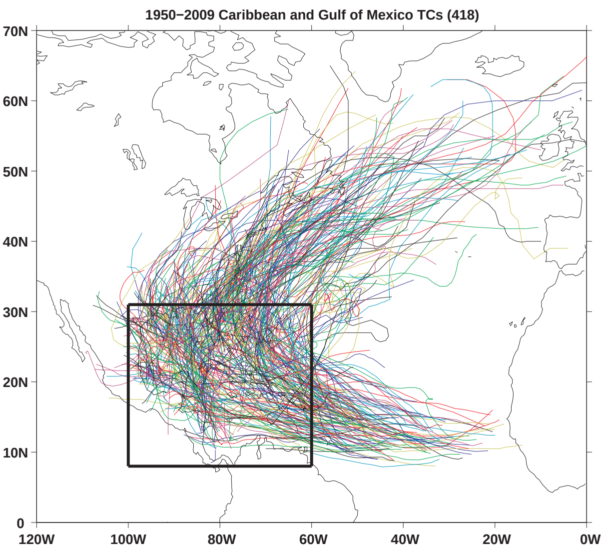

Figure 12: Tracks of all tropical cyclones which entered the Gulf of Mexico - Caribbean region (shown in the box) during the period 1950-2009. Colors arbitrary, varied to make it easier to distinguish the curves.

Figure 12 shows the tracks of all 418 Gulf of Mexico-Caribbean TCs (defined here as those reaching tropical storm strength or greater and passing through a box bounded by latitudes 8N-31N and longitudes 100W-60W) which occurred in in the period 1950-2009. The greatest hurricane activity occurs in the period from August to October, with a maximum in September (not shown). The number of storms each year in the region since 1950 is shown in Figure 13.

Gulf and Caribbean storms comprise 71% of all TCs in the period 1851-2009 in the North Atlantic basin. Given this majority, as well as the fact that most research on future tropical cyclone changes considers entire basins rather than smaller sub-regions, we describe below the results from recent research on North Atlantic variability as a whole. It is reasonable to assume that if TC activity increases or decreases basin-wide, similar increases or decreases will occur in the Gulf and Caribbean, on average.

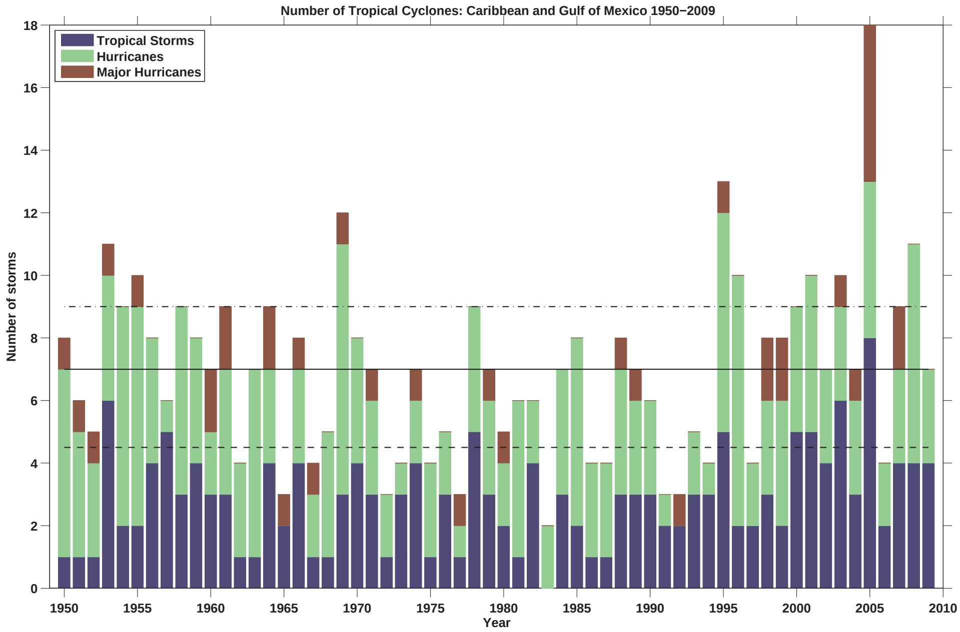

Figure 13: Total number of tropical storms, hurricanes and major hurricanes (categories 3-5) per year in the Gulf of Mexico - Caribbean region (1950-2009). The mean number of TCs is shown by the black continuous line. Colors indicate the number of storms whose maximum intensity was tropical storm, hurricane (category 1-2) or major hurricane (category 1-3). The top (bottom) broken line shows the 75th (25th) percentile of the the distribution of total storm number over the whole record.

4.2 Trends and future changes

Our ability to make projections of changes in TC activity as the climate changes derives from several sources of information: analysis of historical variations in observed TC activity leading up to the present; simulation with computer models; and our understanding of the physics of tropical cyclones, which provides some insight into the expected relationships between large-scale climate changes (such as those shown above in Section 3) and TC activity .

4.2.1 Observational evidence

In the north Atlantic, in the decades since the 1970s (the best observed region and time period in the global TC record) there has been an increasing trend in the number of intense storms (Webster et al., 2005), as well as in the power dissipation index (PDI), a measure which combines the number, intensity, and lifetime of all storms in a season (Emanuel, 2005). These recent Atlantic trends (visible by eye in Figure 13, if one focuses on the last few decades) appear real, as opposed to being artifacts of inadequate data sets. They remain present when a homogeneous data set based only on satellite observations is used (Kossin et al., 2007; Elsner et al., 2008), as opposed to the possibly inhomogeneous "best track" data sets, produced using a variety of different types of observations, used by the earlier studies. It is more difficult to say whether these trends have an anthropogenic component, or are simply a natural upswing following earlier decreases, part of a multi-decadal oscillation that is inherent to the Atlantic climate system (Goldenberg et al., 2001). The argument for an anthropogenic component involves a possible role for aerosols (Evan et al., 2009) as well as greenhouse gases (Mann and Emanuel, 2006). It is quite possible that both anthropogenic and natural mechanisms are contributing (Ting et al., 2009).

One approach to quantify the anthropogenic trend would be to look at the entire data record since the mid-19th century: presumably trends over this longer period would be more likely to be anthropogenic in origin than would shorter-term trends. Unfortunately, attempts to identify trends over these longer periods are rendered inconclusive by the greater inhomogeneity of the data in the early record (Landsea, 2005; Landsea et al., 2006; Landsea, 2007). It is quite possible that storms occurring at sea could have gone unobserved in the 19th or early 20th centuries. In more recent years this is less likely due to increased ship traffic and, since 1970, satellites. These changes in observational capacity may be expected to introduce an artificial upward trend, potentially as large as those actually found in the data (Chang and Guo, 2007; Mann et al., 2007; Vecchi and Knutson, 2008; Landsea et al., 2010).

4.2.2 Influence of SST and other environmental changes

We can use our physical understanding of the mechanisms by which specific aspects of the climate influence the formation and intensification of TCs, together with historical relationships between TC formation and intensification and climate at interannual time scales, to inform our expectations of the response of TC activities to a given change in climate. Tropical cyclones form only in regions of relatively high sea surface temperature (SST). SST has long been recognized as one of the factors that influences both TC formation (Gray, 1979) and the maximum intensity attainable by a mature TC (Emanuel, 1987; Holland, 1997). This relationship has spurred the concern that future SST increases in response to increased greenhouse gases will be associated with increases in the number and intensity of TCs. Yet, much of the observed relationship between SST and TC activity in the historical record can be explained as well or better by relative SST — the difference between the local SST at a given location and the tropical mean — than by absolute SST (Vecchi and Soden, 2007b; Vecchi et al., 2008). There are also good physical reasons to expect relative SST to be the more important quantity for TC activity, as was the case for mean precipitation, discussed above (Sobel et al., 2002; Vecchi and Soden, 2007b; Swanson, 2008). This is true for the the north Atlantic in particular. Recent increases in TC activity have been simultaneous with SST warming there (Emanuel, 2005, 2007), but the more important fact may be that the tropical north Atlantic SST has increased more than the northern hemispheric average in this period.

If the absolute value of SST were considered the primary variable controlling TC activity, one would expect dramatic increases in TC activity as the climate warms. On the other hand, the picture is very different if one considers relative SST to be the more relevant variable. There is no reason to expect that future changes in relative SST will be anywhere near as large as changes in absolute SST. Future SST patterns are projected to be be broadly similar to those today (with changes in spatial structure that are significant, but still small compared to the mean change, as can be seen from Figure 11), except warmer. If one were to assume that statistical relationships between relative SST and TC activity from the present will continue to hold in the future, one would then expect relatively little change in TC activity, as shown in Figure 14 (Vecchi and Soden, 2007b; Vecchi et al., 2008).

Other environmental factors besides SST also play a role in controlling TC activity. One important one is the vertical wind shear, (the difference in the winds at low and high levels in the atmosphere). Future climate projections with the CMIP3 models robustly indicate increases in vertical shear in much of the North Atlantic (Vecchi and Soden, 2007a). All else equal, this would tend to reduce TC activity.

4.2.3 New modeling evidence and changes in risk

As available computing power has increased, models have improved, and new simulation strategies have been developed, rapid new progress has been made in the last few years (particularly since 2005, when Katrina occurred simultaneously with the publication of two influential studies indicating climatically-driven increases). Several new models have resolutions sufficiently high to represent TCs with reasonable fidelity — representing to some degree the eyes and other key structural features of TCs that cannot be captured by the low-resolution models used for IPCC AR4 — while still representing global or at least large regional domains for long enough time periods that the large-scale climate is also organically simulated. Another new approach involves sophisticated "downscaling" methods which take information about the large-scale climate from low-resolution global climate models and use it as input for higher-resolution simulations of tropical cyclones to produce projections incorporating advantages of both elements.

Results from studies with both of these new methodologies show considerable diversity, but also an emerging consensus on the broad outlines of the changes in global TC activity that are expected in the warming climate. On average across the globe, assuming global climate changes within the range deemed most likely, the average intensity of tropical cyclones is expected to increase by 2-11% while the frequency of TC occurrence is expected to decrease by 6-34% (Knutson et al., 2010). This projected decrease in frequency of *all* storms (from tropical storm up to category 5 hurricane strength) is not comforting, because the frequency of the *most intense storms* in particular is projected to increase. The most intense storms produce by far the greatest damage.

These projections are considerably more robust than those of just a few years ago, but they apply only to global average TC activity. We are not able to make projections with any confidence for individual regions such as the North Atlantic: when applied to individual regions, the available methodologies give results which vary too widely. Similarly, we cannot make with confidence any statements about changes in other aspects of tropical cyclone activity, such as genesis location, duration, and tracks.

What is clear, on the other hand, is that increasing development in cyclone-prone coastal regions will increase vulnerability regardless of any changes in tropical cyclone activity. Studies of damages from past storms indicate that increasing concentration of population and economic assets along the coast was the dominant cause of increasing trends in economic losses from

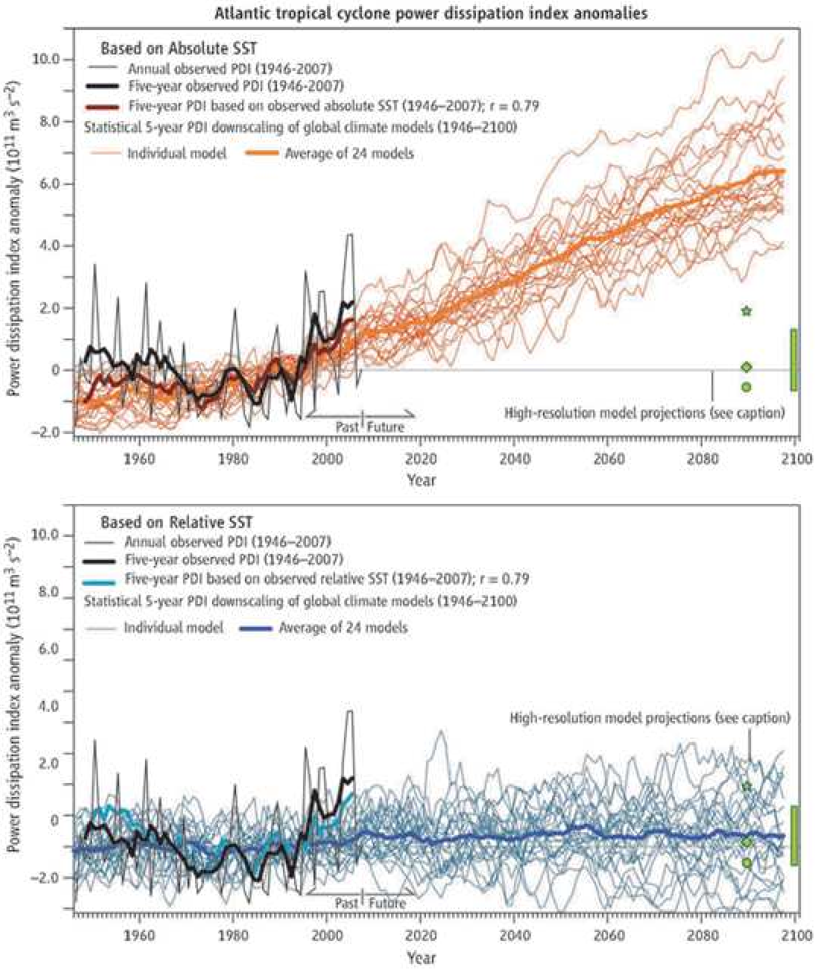

Figure 14: Past and extrapolated changes in Atlantic hurricane activity. Observed anomalies in power dissipation index (PDI; an integrated measure of tropical cyclone activity that combines the number, intensity and duration of all storms each year) are regressed onto observed absolute (top) and relative (bottom) Atlantic SST over the period from 1946 to 2007, and these regression models are used to estimate PDI from output of global climate models for historical and future conditions. Anomalies are shown relative to the 1981 to 2000 average. The green bar denotes the approximate range of PDI anomaly predicted by calculations using another method combining statistical and dynamical methods, and the green dots denote the approximate values suggested by high-resolution dynamical models. SST indices are computed over the region 70W-20W, 7.5N-22.5N, and the zero-line indicates the average over the period from 1981 to 2000. Figure from Vecchi et al. (2008).

tropical cyclones over the 20th century in this region (Pielke and Landsea, 1998; Pielke et al., 2003). Even if significant changes in tropical cyclone activity occur in the future, coastal development may well remain the greater factor driving changes in the risk to Gulf and Caribbean nations. Thus while there is still considerable uncertainty in projections of tropical cyclone activity, there is little uncertainty in the projection that the risk of damage due to tropical cyclones will increase, assuming coastal population and economic development continue to increase.

5 Sea Level

Worldwide, sea level rise is driven by processes occurring in the ocean and by transfer of water currently on land into the oceans (IPCC, 2007). The two specific processes that contribute most are thermal expansion of ocean water and melting of land ice[4]. Because seawater density depends on temperature, with warmer water having lower density, water in the ocean basins will expand as global mean temperature increases. The amount of expansion varies with location because warmer water expands more per unit temperature increase than does colder water, and the temperature of the ocean currently varies greatly with both depth and geography. Nonetheless, the contribution to sea level rise from thermal expansion is both well-understood and relatively small. The much larger and less-constrained contribution is the addition of water to the ocean from melting ice sheets and glaciers on land. Presently, the large ice sheets contain a total sea level equivalent of approximately 70 m (Bamber et al., 2007), meaning that sea level would rise by that much if the large ice sheets were to melt completely. While complete melting of all land ice is unlikely in the near future, this number gives a sense of the magnitude of the potential problem in the long term.

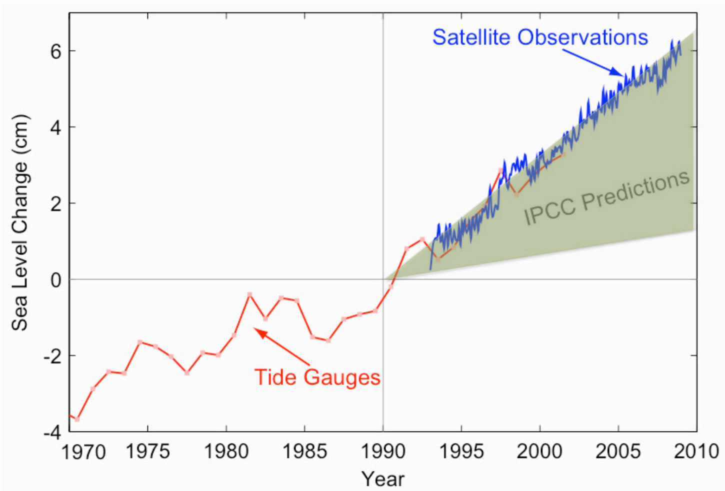

Figure 15: Sea level change during 1970-2010. The tide gauge data are indicated in red (Church and White 2006) and satellite data in blue (Cazenave et al. 2008). The grey band shows the projections of the IPCC Third Assessment report (IPCC, 2001) for comparison. Figure from Allison et al., 2009.

The rate at which land ice is lost to the oceans ultimately depends on temperature, but not in a simple or obvious way. Simple melting of the ice on land is only one factor; the greater one is the possibility for large portions of marine-based ice sheets (ice resting on land whose base is below sea level but with a surface above sea level) to become unstable and retreat rapidly

[4]Melting of *sea ice* — ice currently floating on the surface of the ocean — does not increase sea level, because the floating ice already displaces its weight in liquid water by Archimedes' principle, and that weight does not change when the ice melts.

(Schoof, 2007). Globally averaged sea level rises by an amount of water equal to the volume of ice above an equivalent sea level. However, meltwater from rapid retreats is not distributed equally across the globe. Large changes in ice volume in Antarctica, for example, yield sea level changes 15 to 30% higher than the global average for the Gulf of Mexico and Caribbean (Mitrovica et al., 2009). The likelihood that a collapse will happen for any given ice sheet depends on ice sheet surface snow accumulation rates, magnitude of sea level rise to date, ocean temperature along a marine margin of an ice sheet, and both ice sheet configuration and sub-ice topography. The first three of these processes are linked intimately to temperature. Large scale ice sheet models that incorporate these features show tendency for rapid retreat (Pollard and DeConto, 2009). However, at present no climate models incorporate these processes.

New semi-empirical approaches provide an alternative way to climate models to estimate sea level rise. These are based on the idea that the rate of sea level rise is proportional to the amount of global warming—the warmer it gets, the faster ice melts—and they use past sea level and temperature data to quantify this effect. Extrapolating into the future, these models suggest global sea level rises of about a meter by 2100 under the A1B scenario, three times that projected by IPCC models (Vermeer and Rahmstorf, 2009; Horton et al., 2008; Grinsted et al., 2009; Jevrejeva et al, 2010, summarized in Rahmstorf, 2010). Yet, while these models take into account contributions from land ice of the kind recently observed, they still do not directly include the possibility of the non-linear ice dynamics described above producing extreme future changes in sea level.

The average rate of sea level rise over the 20th Century was 1.7±0.3 mm yr^{-1} from analysis of tide-gauge data (Church and White, 2006). The rate has increased in recent years, however. From 1993–2003, the average rate of sea level rise was approximately 3.1 mm yr^{-1} with approximately half that rate coming from thermal expansion (IPCC, 2007, Chap. 5). Sea level is presently rising at a rate of 3.4–3.5 mm yr^{-1} based on satellite-based sea-surface altimetry, tide gauges, and global gravity measurements (Figure 15, Cazenave et al, 2009; Prandi et al., 2009). Since 2003, contributions from thermal expansion have reached a plateau and acceleration of sea level rise has increased as water is moved from storage in land ice to the ocean (Cazenave et al., 2007).

Information about the dependence of sea level on climate can be gained by studying evidence of sea level changes associated with fluctuations in climate in the distant past, especially the cycles of ice ages and deglaciations of the late Pleistocene and Holocene (roughly, the last million years). A recent compilation of rates of sea level rise for the northern Gulf of Mexico region gives rates over for the past four millenia as 0.4–0.6 mm/yr (Milliken et al. 2008). From 4000–7000 years before the present time (BP), this rate was about 1.4 mm/yr, and for 7000–10 000 yr BP, the rate of sea level rise was 4.2 mm/yr. Data from other areas of the Gulf of Mexico show much the same rates (Milliken et al. 2008) and these rates correspond reasonably well to the IPCC synthesis for the same time period (IPCC, 2007). During the most recent highstand, approximately 115–125 thousand years BP., sea level was 3–8 m higher than present (Blanchon et al., 2009; Kopp et al., 2009). Rates of sea-level rise entering this time period could have been as high as 36 mm/yr for brief episodes (Blanchon et al., 2009; Waelbroeck et al., 2002), but were likely near 5 mm/yr (Kopp et al., 2009).

Within their sea-level curves, Milliken et al. (2008) note large jumps above the average rate during the period 7000–10 000 years BP that account for as much as 4 m of sea level rise.

While there is no direct evidence, these jumps are consistent with episodic deglaciation of either the remaining and now gone Laurentide Ice Sheet (the one which covered much of North America in the last ice age) or regions of the modern ice Sheets (Greenland, West Antarctica, East Antarctica). Because modern sea-level rise is now dominated by land ice loss, it is possible that similar rapid increases in sea level could occur in the future. Presently, outlets of Greenland and Antarctica in contact with warm ocean water are losing mass at extremely high rates (*e.g.,* Pritchard et al., 2009; Rignot et al., 2008; Rignot and Kanagaratnam, 2006). For sea level to inundate low lying areas of the Caribbean or Gulf coast, loss of mass from only one of a few sensitive basins in an ice sheet would be necessary, such as Pine Island Glacier in West Antarctica (Wingham et al., 2009). The US Gulf coast and Florida, for example, have large areas no more than a meter or two above sea level (Figure 16).

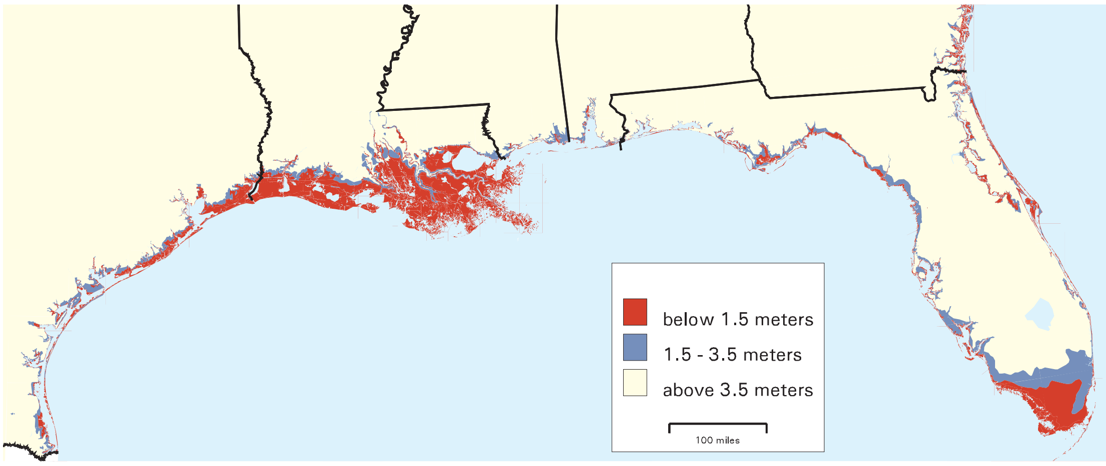

Figure 16: Lands vulnerable to sea level rise. Regions shown in red are some of the areas that could be flooded at high tide if global warming causes sea level to rise 2 feet in the next 100 years. The indicated areas account not only for the effects of global warming, but also for other effects such as tidal variations and land subsidence. From Titus and Richman, (2001), available from the EPA website: `http://www.epa.gov/climatechange/effects/coastal/slrmaps_gulf.html` .

Besides direct inundation, sea level rise increases the risk to coastal areas from storm surge associated with tropical cyclones (even if the risk that a storm of a given intensity will strike does not increase). A large part of the damage due to hurricanes in many coastal areas results from storm surge, as the tropical cyclone winds blowing over a large surface of water bounded by a shallow basin cause the water to pile up and move onshore. The total water elevation that can occur at particular coastal location associated with tropical cyclones is due to the combined effects of storm surge, the astronomical tide, and breaking waves (Rao et al., 2008). The magnitude of the storm surge is dependent on the track, intensity, speed of movement and size of the hurricane, as well as coastal characteristics such as bathymetry (the depth and topography of the ocean floor) and the presence of rivers and deltas, and the level of the astronomical tide (Dube et al., 2004, 2009). These factors vary greatly from place to place and storm to storm. Nonetheless, in all cases increases in sea level raise the baseline to which storm surge adds to create the total water level experienced when a hurricane makes landfall or passes sufficiently close offshore. Thus coastal areas sufficiently high to avoid outright inundation will still be affected by sea level rise in that it will increase their risk of flooding due to storm surge.

6 Conclusions

We have described the changes in the climate of the Gulf of Mexico and Caribbean region that are expected to occur in the 21st century, assuming continued increases in greenhouse gas concentrations in the middle of the range considered in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4). We have considered changes in temperature, precipitation, tropical cyclones (hurricanes) and sea level. We showed projections for temperature and precipitation based on the ensemble of climate model simulations performed for the IPCC AR4. Our discussions of tropical cyclones and sea level were based on surveys of the recent literature, including much that postdates IPCC AR4. The most certain and well-understood threat to the Gulf and Caribbean region from climate change is simply the increase in temperature. The region is already warm, but by the end of the 21st century, the typical summer will be warmer than any summer, even the most extreme, experienced in the past. The warming will be manifest not only on average but in the extremes (such as heat waves and warm nights) which will also be outside the experience of those living in the region today.

Projected changes in precipitation are more varied geographically than those in temperature. The Caribbean is projected to become significantly drier. The reduction in precipitation, unlike the increase in temperature, is not expected to be so large as to make the mean season outside the range of conditions experienced in the past. However, water resources at a given time can be sensitive to rainfall over longer periods, so there can be serious consequences from multiple consecutive drier-than-normal years even if one such year would not be particularly harmful. Projected precipitation changes in the Gulf are small, but also highly uncertain.

The latest modeling evidence suggests that on a global basis, tropical cyclones will become less frequent, but more intense. The most intense storms, which are relatively infrequent at present but which do by far the most damage, are projected to become more frequent. Even on a global basis, these projected changes to the risk from tropical cyclones are considerably more uncertain than those in temperature or precipitation. For a single region such as the Gulf and Caribbean, the uncertainty is greater still. Some factors, such as projected changes in wind shear, may be expected to reduce the number and intensity of tropical cyclones in the region. Nonetheless, given the expected global tendency towards more of the most severe storms, as well as near-inevitable increases in risk driven purely by increasing population and economic development in vulnerable coastal regions, there is little reason for complacency.

Sea level rise may ultimately be the greatest threat to the coasts and islands of the Gulf and Caribbean. The loss of even a small fraction of either the Greenland or Antarctica ice sheets would raise sea level enough to inundate significant areas of the region, and place larger areas at increased risk of storm surge from tropical cyclones (even if there were no change in the risk of tropical cyclone occurrence itself). The likelihood that such rapid ice loss and sea level rise will occur in the 21st century is very difficult to estimate, but there is evidence from the geologic record that they have occurred in the past in periods of warming. The probability becomes greater as the time horizon one considers increases, assuming continued warming. If greenhouse gas increases continue, the question over the long term becomes not whether sea level will rise greatly, but simply how soon it will do so.

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Multi-hazard Risks and Vulnerable Populations in the Caribbean and Gulf of Mexico Region: Implications of Spatial Population and Land Cover Dynamics[1]

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Abstract

Dynamics of climate vulnerability are determined by the interaction of climate, land-use, and socioeconomic change. Measurements and projections of climate change are difficult at the local scale but necessary for effective planning. However, new data sources and methods make it possible to observe land-use and socioeconomic trends that are directly relevant to understanding shifting patterns of climate vulnerability. In this paper we explore novel time series data sets to understand trends in the spatial patterns of climate vulnerability in the Caribbean/Gulf of Mexico Region. In particular, we examine spatial time series data on human population, over 1990-2000, time series data on land use and land cover, over the period 2000-2009, and IMR series as a proxy for poverty, also for the 2000-2008 period. We compare the spatial trends for these measures to the location of climate-related natural disaster hotspots (cyclones, floods, landslides, and droughts) in terms of frequency, mortality and economic losses. We use these data to identify areas where climate vulnerability is increasing and where it is decreasing. Areas where trends and patterns are especially worrisome include coastal areas of Guatemala and Honduras.

1. Introduction

Hazard mitigation and disaster risk reduction require integrated analysis of risk and vulnerability at different spatiotemporal scales (Turner et al. 2003; Cutter and Finch 2008; Nicholls et al. 2008). Recent geographic analyses of hazards data at the global scale have derived relative risk estimates, thus improving our understanding of the multi-hazard risks that threaten human life, well-being, livelihoods, and assets (Dilley et al. 2005; Lerner-Lam 2007; Mosquera-Machado and Dilley 2009). However, more detailed and robust assessments are needed at regional and subnational scales (Lerner-Lam 2007). This study takes a step towards meeting this challenge by examining climate-related multi-hazard risks and human vulnerability within the coupled human-environment systems of the Caribbean/Gulf of Mexico Region. The paper provides a regional synthesis of social and environmental geospatial data collected on 35 countries and reports the results of a disaster vulnerability assessment conducted through the use of rich, multi-hazard scenario analysis.

Climate-related multi-hazard risks result from the dynamic interactions of meteorological and geophysical hazards (e.g., storms, floods, landslides, and droughts), land-use characteristics (e.g., changes in agricultural land-use, forest cover, wetlands, and urban extent), and socioeconomic factors (e.g., the spatial distribution and morphology of settlements; population size, distribution and density; population change; poverty; measures of public health; economic activities; and the presence or absence of critical built infrastructure). Meteorological and geophysical hazards include droughts, heat waves, storm activity, coastal storm surges, floods, landslides, erosion, and salinity intrusion. In turn, many of these hazards affect the availability of freshwater water resources, both in quantity and quality, and increase the risk of certain diseases. Making matters even more complex, human-induced events and processes—such as oil spill damage (Webler and Lord 2010), chemical contamination of surface and groundwater, and wetland loss—are modifiers of climate risk.

Risk profiles within a given region vary, and place-based climate vulnerability can exist in a variety of configurations. Spatial distributions of poverty and wealth shape spatial patterns of climate vulnerability, as do inequalities in the capacities of individuals and groups to manage stress and to avoid, prepare for, and respond to disasters. A hotspot of climate vulnerability may be a place where high exposure to meteorological and geophysical hazards intersects with high population densities, high levels of poverty, inadequate built infrastructure, hazardous industries, and low levels of capacity to manage risks. Another plausible type of climate vulnerability hotspot is an area exposed to natural hazards and characterized by concentrated valuable coastal real estate, associated economic assets, wetland loss, and high sensitivity to climate-related economic damage and property loss.

The objective of this study is to explore the spatial-temporal dynamics of climate vulnerability and to advance GIS-based climate vulnerability modeling to facilitate scenario analysis. To achieve this aim, we construct a spatial time series data set in ArcGIS 9 (ESRI Inc.) that integrates the best available county-level data for the spatial-temporal analysis of demographic, socioeconomic, land-use, and climate dynamics in the Caribbean and Gulf of Mexico Region. We use the county as the administrative unit of analysis to investigate spatial patterns of multi-hazard risk and vulnerability and to identify areas where climate vulnerability is increasing or decreasing. Specifically, we examine spatial trends for: meteorological and geophysical hazards over the period 1980-2000; human population over the period 1990-2000; infant mortality rate over the period 2000-2008; and land use/cover over the period 2000-2009. In an ideal world we would have perfectly matched information that aligns in common administrative units over matching time periods. We do not yet live in such a world, though it is easier to approximate it today than it ever has been.

Geographic Information Systems (GIS) allows us to integrate empirical spatial data to calculate multi-hazard risk at the county-level and to produce regional multi-hazard risk maps that help us visualize shifting patterns of vulnerability. Recognizing that internal and external conditions will continue to shift over time in uncertain ways, GIS also enables us to model contingencies and to develop possible scenarios. Such analytical tools are needed to inform planning and decision-making among stakeholders interested in identifying opportunities to reduce climate vulnerability in the near-, medium-, and long-term. As international institutional capacities evolve, geospatial and information technologies improve, and new data become available, our first attempt at a multi-hazard risk assessment for the Caribbean/Gulf of Mexico Region can be updated and expanded within a GIS framework. Multi-hazard risk assessment methodologies can be refined, shared, and coordinated with research teams working on assessments for other regions to produce future global syntheses.

This paper is organized as follows. Section 2 reviews relevant theoretical and methodological frameworks and defines key concepts. Section 3 outlines the spatial data and methods used to study hazardous events and processes within a multi-scalar and multi-temporal dynamic spatial framework. Section 4 presents the results of the analysis. Section 5 provides a discussion of the results. Section 6 presents our conclusions and plans for future research.

2. Frameworks

The Gulf of Mexico/Caribbean Basin region faces multiple challenges. These include: climate change impacts on the availability of freshwater water resources (both quantity and quality; e.g., drought and salinity intrusion), sea-level rise, storm surges, expected increase in the frequency and intensity of extreme rainfall events (e.g., cyclones, hurricanes, and tropical storms), floods, landslides, climate-related disease outbreaks, rapid (and sometimes unplanned) population growth in coastal as well as inland landfall locations. What can be done to reduce vulnerability and disaster risk? The causes of vulnerability are diverse and complex.

a. Theoretical, conceptual, and methodological frameworks

Vulnerability to climate change can be analyzed as a function of the interaction of multiple linked systems, including both biophysical and socioeconomic (Turner et al 2002; Cutter 1996).

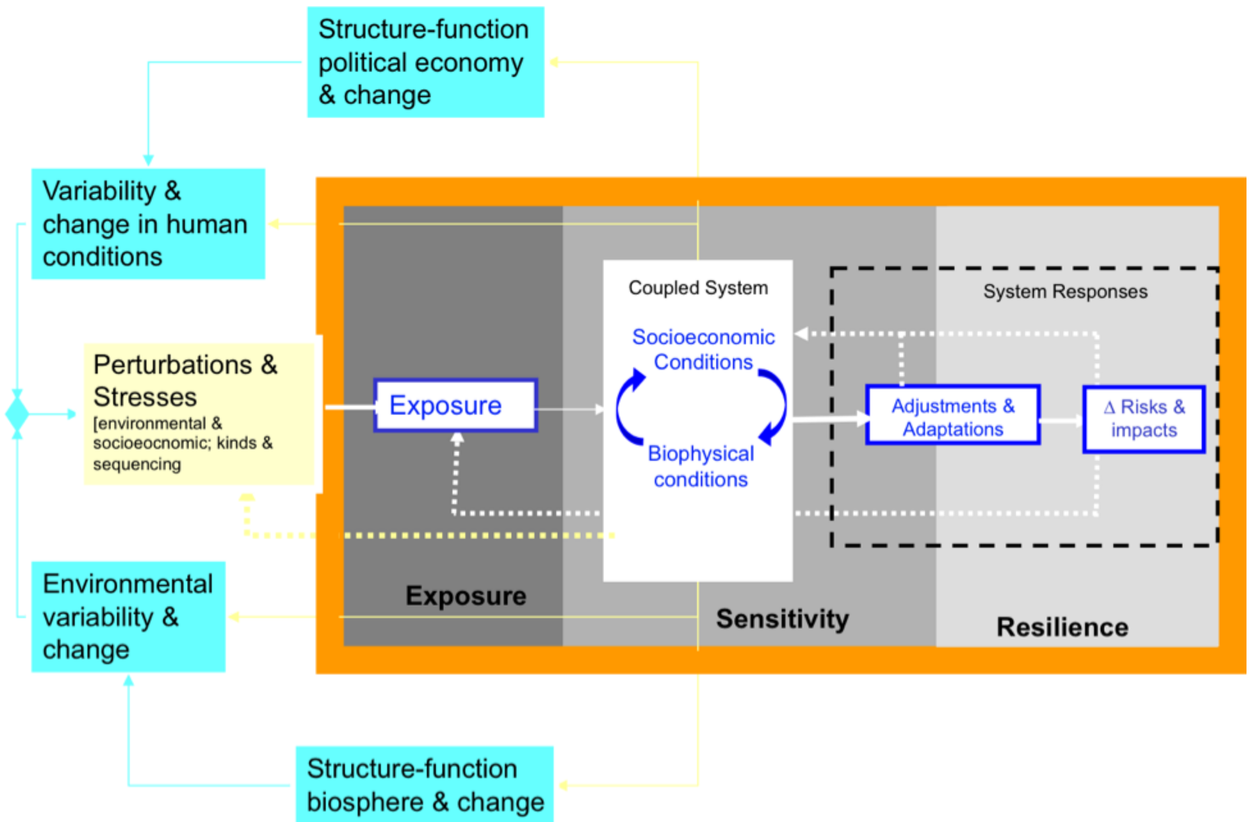


Figure 1. Adapted from Turner et al, 2002.

Boruff and Cutter (2007) remark on the lack of agreement and understanding concerning the methods or techniques for comparing hazard vulnerability within or between places (especially small-island developing states). Refinement of vulnerability assessment methods and the delineation of highly vulnerable hot spots can help governments, donor organizations, and others interested in vulnerability reduction use their resources more efficiently.

In practice, it is often difficult to obtain reliable measurements across each of the elements in vulnerability models in a way that is faithful to differences across time and space. As a result, our understanding of the critical dynamics that occur where the social and physical systems are coupled remains fragmented.

For example, Louise Comfort (2006) emphasizes that complex metropolitan regions confront a dual hazard—the number and severity of extreme events are increasing while simultaneously populations are moving into more vulnerable land areas; aging, poorly maintained infrastructure may exacerbate these interacting hazards. Yet even this basic insight is poorly understood because of data limitations.

A key premise of this paper is that one path toward improved understanding of vulnerability to climate change likes in better understanding of how climate risks have affected regions in the recent past, at integrating information regarding key drivers of vulnerability in a consistent spatial framework. Below we review some past efforts along similar lines.

b. Key findings by sub-region

U.S. GULF COAST

Rappaport (2000) constructed a database of Atlantic tropical cyclone fatalities for the 1970–99 storm seasons that identified the date, cause, and location of each fatality (65 Atlantic tropical cyclones affected the contiguous U.S. during this period; Rappaport estimated a total of 600 direct fatalities with approximately 60% of these fatalities occurring in inland counties). Czajkowski and Kennedy (2010) use Rappaport's study as their baseline. There have been significant population increases in high hurricane risk U.S. coastal areas since 1970 (Czajkowski and Kennedy 2010). The purpose of this research is to address the hurricane risk information gap (limited information on hurricane-induced fatalities, injuries, and property damage) in regard to fatalities through an empirical analysis of hurricane fatalities in landfall coastal counties during 1970–2007 that accounts for the location of fatality, as well as for the role of evacuation in the analysis. They model U.S. hurricane direct fatalities over time, by landfall county, and by storm, as a function of various geographical considerations, storm characteristics, socio-economic demographics, forecasting technology, and evacuation. They identify a total of 68 landfalling hurricanes from 1970 to 2007; 12 in the 1970s, 18 in the 1980s, 17 in the 1990s, 21 during the period 2000-07. The lethality of hurricanes hitting the U.S. has generally declined since 1950, however, this may be overstated considering the impact of evacuation levels achieved; the potential risk for amplified casualties has actually increased due to the growing coastal populations. They find a higher expected count of fatalities for more frequently struck counties, especially those in the Gulf of Mexico. Contrary to conventional wisdom, they find a lower expected count of fatalities for counties with higher percentages of the population over 65, less than 18, in poverty, and male. An increase in median household income reduces the count of fatalities. They find that a higher frequency of a county being struck over time, as well as being located in the Western and Central portion of the Gulf of Mexico, lead to higher expected counts of fatalities. Improved forecasting technology seem to have only a minor effect on the expected count of fatalities. Long-term mitigation efforts include stricter building codes and improved forecasting technologies. More immediate mitigation efforts include household protective action measures or well-planned and coordinated evacuations. Roughly 75% of direct fatalities attributed to hurricanes actually occurred outside of landfall counties. Once the 1,078 direct fatalities during Hurricane Katrina are included in the analysis, they find that the declining nature of hurricane lethality since 1970 no longer holds.

Comfort (2006) on Hurricane Katrina in late August 2005 (reached a Category 5 with winds of 175 miles/hr) and New Orleans discusses the vulnerabilities caused by the interactions of the physical environment, aging infrastructure, and declining economic and social structure. Was the damage in New Orleans due to Hurricane Katrina or some combination of human and technical factors that failed under the stress of the hurricane? Public Health Emergency was declared for the States of Alabama, Florida, Louisiana, and Mississippi; later, with about 229,000 evacuees, a state of emergency was also declared in Texas. The costs: more than 1,300 fatalities (according to Blake et al. 2007 there were 1,500 total fatalities from Hurricane Katrina); 1.5 million people displaced from their homes; 60,000 homes totally destroyed; an estimated $200 billion in disaster assistance and rebuilding costs in addition to the $52 billion already apportioned by Congress; possible long-term negative impact on the U.S. economy, given the damage to the oil refineries and production operations of the Port of New Orleans. Comfort examines the conditions, policies, and practices that led to the damage, in particular, the cumulative decision processes and public organizations that failed to take timely action to prevent danger. The destruction in New Orleans left the entire city uninhabitable with no functional services—communications, water, electrical power, sewerage, transportation, gas distribution—for weeks. Mandatory evacuation was the only possible course of action. About 25% of the city's inhabitants were living in poverty and many (150,000 people) did not have transportation or any means to evacuate the city. Approximately 60,000 people sought refuge in the Superdome and 20,000 in the Convention Center. About 25,000 evacuees were transferred to the Houston Astrodome. Comfort points out that coordination within and between multiple jurisdictions is difficult to achieve in practice although policies and procedures have been developed over recent decades. Hurricane Katrina exposed the weaknesses of disaster management priorities and practices at all four jurisdictional levels (municipal, parish, state, and federal levels of jurisdiction). The time line of actions (August 23 to September 2, 2005), taken by governmental actors, documents the remarkable series of delays and omissions that characterized the preparedness and response actions for Hurricane Katrina.

Finch et al. (2010) examine how the pre-existing social vulnerabilities within New Orleans interacted with the level of flood exposure to produce inequities in the socio-spatial patterns of recovery. The social vulnerability of communities influenced the pre-impact response (e.g., who evacuated and who remained). Pre-existing levels of social vulnerability and the impact of the storm in terms of flood levels combine to create a synergistic effect. They find a distinct geographical pattern to the recovery; the less flooded and less vulnerable areas are recovering faster than tracts with more vulnerable populations and higher levels of flooding. They also uncover a more nuanced story, which suggests that recovery is lagging in the neighborhoods in the mid-range of social vulnerability (the 'in-between' neighborhoods). While private resources and government programs help groups in the high and low categories of social vulnerability, the middle group shows the slowest rates of recovery. Those in the middle group are not poor to qualify for outright assistance, but they are too poor to recover using their own resources. The inequalities between wealthy and poor are becoming more pronounced.

Hassett and Handley (2006) describe the disaster response efforts of cities in Mississippi following Hurricane Katrina in the context of a state-level coordinated strategy to implement an intergovernmental regional recovery plan including the recovery of casinos, tourism, and transportation infrastructure. State leaders provided a framework for city-level recovery plans along the Gulf Coast. Local decisions were encouraged and coordinated through the governor's recovery plan organized by the Governor's Commission on Recovery, Rebuilding and Renewal. Some have estimated the damage caused by Hurricane Katrina in Mississippi at $125 billion. There were 200 deaths across the state. In southern Mississippi, more than 65,300 homes were destroyed. Hurricane Katrina was particularly devastating to the state's Gulf Coast region where three coastal counties contain eleven cities and several unincorporated communities. The Federal Emergency Management Agency (FEMA) has updated its flood advisory map, incorporating satellite data. According to Hassett and Handley, there has been strong democratic citizen involvement in public discussions about how the Mississippi Gulf Coast should be rebuilt.

CENTRAL AMERICA

Hurricane Mitch in late October 1998 caused flooding and landslides across Central America resulting in total direct losses of US$ 6 billion; 11% of the population of Central America (3.2 million people) were affected; the death toll was 9,000; losses in Honduras were about 80% of GDP (Holcombe and Anderson 2010: 798)[3]

According to Pielke Jr. et al. (2003), Hurricane Mitch caused more than 10,000 fatalities and as much as $8.5 billion in damage. Pielke Jr. et al. ask: What accounts for the extent of the losses experienced in Hurricane Mitch? Is Mitch a harbinger of future disasters in the region? What might be done in response? The authors examine the historical and geographic context of hurricane vulnerability in Latin America and the Caribbean. They conclude that the impacts of Mitch were the result of a powerful storm that encountered profound human vulnerability and that Mitch is indeed a harbinger of future disasters unless actions are taken to reduce societal vulnerability (i.e., sustainable development).

Until recently it was hard to say with any uncertainty how the physical stress from future hurricane trends would affect the region, because climate models lacked the necessary precision. Recent work, however, suggests that there is a significant possibility that there may be more severe hurricanes in the future, as a consequence of climate change (Knutson et al, 2010). The overall impact of climate change is complicated by the fact that the number of storms may decline, yet the most damage is normally done by the most severe storms, therefore the possibility that severe storms will become more common is important .

Kok and Winograd (2002) explore near-future land-use changes in Central America by applying the CLUE modeling framework. The CLUE modeling framework is a dynamic, multi-scale land-use change model that mimics the complexity of land-use systems. For their study area, they selected six countries that, while similar in climatic and biophysical land-use potential and recent political history, display large economic

[3] Holcombe and Anderson (2010) cite their source for this data as: United Nations, 1999. Economic commission for Latin America and The Caribbean. Report lc/mx/l.375.

and political differences: Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. Natural hazards (hurricanes in particular) are a threat to this region, especially to its northern and eastern portion. Scenario assumptions are based on actual data that became available after Hurricane Mitch. The extreme rainfall during Hurricane Mitch flooded extensive lowland areas, washed away many roads and bridges, destroyed tens of thousands of homes leaving hundreds of thousands of people homeless. Results of the Natural Hazard scenario for Honduras as well as for Central America as a whole indicate that the effects of a hurricane on land-use patterns, though initially strong, are likely to largely disappear within 10 years at which point land-use patterns resemble the Base scenario. In other words, the land-use dynamics under the Natural Hazard scenario illustrate the resilience of the land-use system.

Winograd (2007) applies a methodology for vulnerability assessment to the case of Honduras (pre- and post-Hurricane Mitch). The methodology is based on the development of different vulnerability indices (environmental vulnerability index, population vulnerability index, social vulnerability index, and infrastructure vulnerability index). The paper demonstrates how to define and use indicators to support decision-making to reduce vulnerability and increase sustainability and to close the gap between research and action (reconstruction, rehabilitation, mitigation, adaptation, land use, urban planning, and early warning systems). This work was developed under a collaborative project between CIAT (Land use unit), the World Bank (Disaster Management Facility Unit), and the Government of Honduras (Secretaria de Recursos Naturales y del Ambiente, SERNA). The main goal of the project was to determine the areas with a high degree of vulnerability to climate-related hazards, in order to prioritize the different municipalities and identify reconstruction and mitigation options after Mitch and adaptation and coping strategies in anticipation of possible further events.

Manuel-Navarrete et al. (2007: 209) explain that syndromes of sustainable development (SSD) "are defined as functional patterns of causal interactions in coupled socio-ecological systems, or characteristic constellations of natural and anthropogenic trends of change and their respective interactions, affecting (in negative but also in positive ways) the sustainability of development." They argue that there is a need for a comprehensive understanding of the reasons for increased vulnerability in Central America and the Caribbean, and that SDD representations provide easily communicable and eventually generalizable accounts of the relationships between patterns of development and vulnerability to environmental changes. The UN Commission for Latin America and the Caribbean (ECLAC) modified the syndrome concept in order to adapt it to the regional context of sustainable development in Latin America. The characterization of SSD proceeds from the bottom-up; it identifies place-based patterns of sustainability of development which, if they happen to replicate in several places, can constitute a syndrome. Manuel-Navarrete et al. (2007: 210) identify 13 interrelated and recurrent factors for explaining vulnerability to hydrometeorological disasters in Central America and the Caribbean: (1) poverty and socio-economic marginalization; (2) institutional and democratic weakness; (3) rapid, unregulated, and unplanned urbanization; (4) formation of slums and occupation of hazardous areas; (5) population growth; (6) migration from rural to urban areas; (7) increasing population affected by disasters, (8) ecosystem conversion; (9) erosion; (10) increasing intensity of hydrometeorological events causing disasters; (11) increasing economic damage due to disasters; (12)failure to communicate scientific knowledge effectively; and (13) expansion of agriculture. The SSD approach can help identify vicious circles or socio-ecological traps that increase vulnerability to disasters and thus help design integrated actions and solutions addressing clusters of symptoms rather than isolated problems.

CARIBBEAN ISLAND NATIONS

Cashman et al. (2010) address water supply management and concerns over declining freshwater availability in the Caribbean region with a focus on the eastern Caribbean states. They consider how population pressures, urbanization, economic development, and growth in tourism have all increased pressures on and demand for freshwater resources. What capacity do Caribbean states have to cope with a growing water stress imbalance? What are the consequences for their social and economic well-being? Concentrations of people have increased in environmentally sensitive areas such as coastal zones and hillsides; urbanization, a growing middle-class, and increased migration toward urban areas trigger an increased demand for water, and concurrently, increase problems with stormwater management, urban runoff, and waste management. Expected climate change impacts for the Caribbean region include decreased rainfall (increased frequency of drought; lengthening of dry seasons), temperature increases, more intense rainfall events resulting in flashier run-off and potentially greater occurrence of flash flooding, inundation of low-lying coastal areas due rising sea level, and salinity intrusion into groundwater aquifers. The IPCC Fourth Assessment Report projects a bleak future for water resources availability in the Caribbean region; projects decreases in mean annual precipitation. During the 20^{th} century, sea level rise occurred at a rate of approximately 1mm/year. The vulnerability of Caribbean island nations is also a result of a lack of relevant information, data gathering, and monitoring; institutional weakness in responding to a changing environment; difficulties in mobilizing and making available resources. The impact on agriculture and the viability of farming as an economic activity is in the Caribbean region has not been thoroughly researched. Some solutions may include rainwater harvesting (collection systems; increasing the available storage), adopting water reuse measures and technologies, desalination, improved maintenance of water service infrastructure, and increase water use efficiency.

Holcombe and Anderson (2010) address the problem of unstable slopes in densely populated urban communities and the need for landslide risk reduction through changes in policy and practice, especially community-focused, cost-effective preventative measures (i.e., pre-disaster investment) in places characterized by rapid and unplanned urbanization. They focus on the management of surface water on high-risk slopes as a key message for communities, governments, and development agencies. They report a successful landslide risk reduction approach, called MoSSaiC (Management of Slope Stability in Communities), demonstrated in the Eastern Caribbean. MoSSaiC targets landslide risk at the community level encouraging community engagement/ownership and participatory planning, execution, and maintenance; government engineers, community officers, researchers, and residents work together to create detailed community maps that serve as inputs to identify potential landslide triggering mechanisms. They found that in most cases, landslide risk reduction could be achieved simply and at low-cost by building an open drainage network and by carrying out slope management practices at the household level. In October 2008, MoSSaic interventions were successful in maintaining slope stability in Saint Lucia and Dominica. In the case of MoSSaic, more than 80% of funds were spent in communities (labor costs and construction materials for the drainage infrastructure). Further, the introduction of slope water management measures delivers additional benefits such as rainwater harvesting and reduction in mosquito breeding sites. By fostering transparency and links between planning agencies, public works departments, national emergency organizations, and central government, the community-based approach can also help inform land use policies and the planning agenda. Holcombe and Anderson note that the full impact of landslides is often underestimated. Because landslides occur on a relatively small scale, they are often left unreported or not recognized in most registers of natural disasters. However, it is important to recognize that high frequency, small and medium size disasters can have as great an impact on poor populations as larger disasters. Disasters affect development, and development can generate new landslide risk; development activities (both 'planned' and 'informal' road and building construction) change slope geometry, strength, loading, vegetation cover, surface water and groundwater regimes. They are interested in how to develop realistic land use policies and practices for landslide-prone areas in urban settings of the Eastern Caribbean. They argue that scientifically based landslide risk reduction strategies can be effective. In the Eastern Caribbean construction of drainage networks in communities afforded an improvement in slope stability. They point out that, in developing nations (particularly in cities where migration and urbanization link poverty with vulnerability to landslides), landslide disasters can lead to the stagnation of economic growth or, in some cases, recession. The humid tropics are especially prone to landslides due to the formation of deep soils on steep slopes. Landslide risk is still increasing despite the efforts of international development agencies to formulate disaster risk reduction policies and programs (often integrated with sustainable development or climate change adaptation). Hazard mapping is often associated with planning approaches that are top-down, and at national or regional scales inappropriate for identifying highly localized processes.

As part of the larger effort to understand the place vulnerability of small island developing states (SIDS) to multiple hazards, Boruff and Cutter (2007) studied the two Caribbean nations of Saint Vincent and Barbados to determine which island has the greater level of hazard vulnerability and why. They provide a spatially based method for identifying vulnerable populations and comparing their levels of vulnerability at multiple scales. Using comparative metrics, they found that Barbados is the more vulnerable of the two islands based on the percentage of Barbadians living in risk-prone areas as well as the percentage of land in each hazard category. They found that the majority (73.6%) of Saint Vincentians live in low-vulnerability zones while 45.9% of Barbadians live in low-vulnerability zones. On Saint Vincent, population exposures are greatest for landslides and volcanic eruptions.

Bultó et al. (2006) assess the potential human health impacts of climate variability and climate change in Cuba and offer tools for the development of appropriate and effective adaptation options to address increased climate variability. They analyze patterns of climate-sensitive diseases, particularly dengue fever and highlight current vulnerability to climate variability by analyzing the associations between climatic anomalies and disease patterns. The current adaptations discussed include using climate forecasts to predict and prevent outbreaks of climate-sensitive diseases. They discuss the development of complex climate indices to reflect climate anomalies at different scales and to explain the mechanisms and relationships between climatic conditions and diseases. They find that disease risks vary by geographic region, as described by the indices, therefore, climate projections can be used to inform the design and development of prevention activities (anticipatory prevention) to reduce the burden of climate-sensitive diseases, thus increasing adaptive capacity to climate variability.

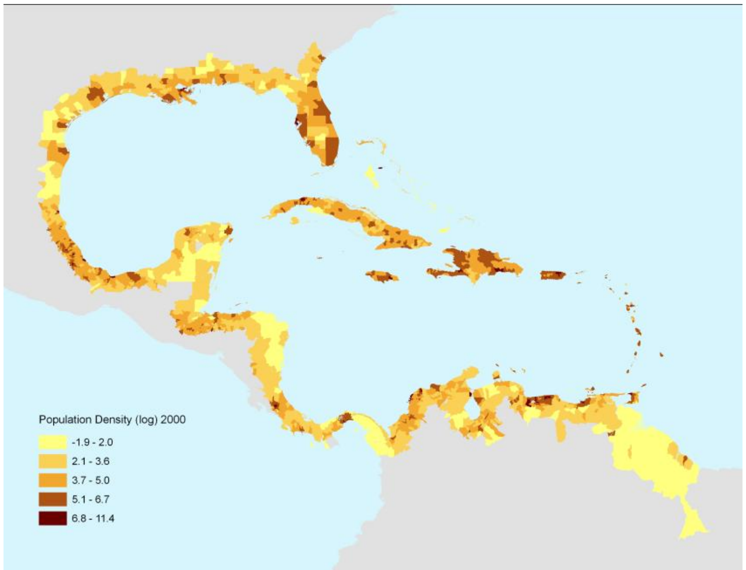
c. General recommendations

On the infrastructure that supports human activity Lugo (2000: 249) writes, "Strategies are needed to improve infrastructure while not harming natural ecosystems nor increasing their vulnerability to disturbances"

Comfort (2006) suggests removing constraints on development. She highlights the comprehensive failure of urban infrastructure under stress, and offers five recommendations for redesign and reconstruction: (1) strengthen the ecology of the metropolitan region (central city and its surrounding suburban parishes); (2) rebuild and maintain civil infrastructure (i.e., roads, bridges, electrical power, communications, water, sewer, and gas distribution systems) on a regional basis; (3) design scalable investments for organizations (public, private, and nonprofit organizations) with different capacities; (4) invest in a regional information infrastructure and knowledge base for the region; and (5) shared risk means shared responsibility for disaster risk reduction which can be accomplished by adopting a governance approach that engages public, private, and nonprofit organizations. Comfort (2006: 508) rejects hierarchical models of control and argues that "a resilient city requires a different model of civic engagement that includes all sectors of its population in a socio-technical framework that enables individual and organizational learning. Such a model is self-organizing and based on a strong information infrastructure that allows rapid and candid feedback among the participants." Protection of the city can no longer be considered only a function of public organizations. Private and nonprofit organizations, as well as households, have significant roles to play. The process can more accurately be redefined as *governance* in which all entities in a community engage in a conscious, collective effort to reduce disaster risk over time. Developing the capacity for a city to manage its own risk requires a systems approach.

3. Data and methods

The area under consideration includes coastal level-2 administrative units (municipalities, counties and other equivalent units) in the Gulf Coast and the Caribbean Basin. The administrative units were chosen by drawing a 100km buffer from the coastal line, and then selecting all those units with any portion of their area within the buffer zone.



Map 1: Population Density, Gulf Coast/ Caribbean Study Area (persons per square kilometer, log scale)

Table 1: Scope of Study Area

Country	**Number of Administrative Units**	**2000 Population**
Anguilla	1	11,410
Antigua and Barbuda	2	64,848
Aruba	1	100,572
Bahamas	17	303,664
Barbados	1	267,498
Belize	6	240,204
British Virgin Islands	4	21,811
Cayman Islands	3	40,746
Colombia	158	7,532,287
Costa Rica	55	2,805,939
Cuba	169	11,217,100
Dominica	10	69,312
Dominican Republic	32	8,253,088
Grenada	1	93,502
Guadeloupe	30	427,258
Guatemala	59	1,929,576
Guyana	9	726,909
Haiti	142	8,149,044
Honduras	144	3,203,718
Jamaica	14	2,583,253
Martinique	1	383,385
Mexico	422	15,255,084

Montserrat	1	3,749
Netherlands Antilles	66	175,226
Nicaragua	34	977,230
Panama	56	2,684,972
Puerto Rico	76	3,751,312
Saint Kitts and Nevis	2	38,473
Saint Lucia	1	147,783
Saint Vincent and the Grenadines	1	113,279
Trinidad and Tobago	30	1,225,092
Turks and Caicos Islands	1	16,699
United States Virgin Islands	31	103,918
USA	204	32,558,101
Venezuela	250	18,314,819
TOTAL	2034	123,790,861

The data for this paper come from several sources:

- *Hazards*. Data on frequency, mortality risk and risk of economic losses associated with cyclones, flooding, droughts and landslides were taken from the Natural Disaster Hotspots project (Dilley et al. 2005).[4] Collectively, we considered areas that were globally in the top three deciles of magnitude for these climate-related risks to be climate hotspots. These risk measures were based on historic data covering the period roughly 1980-2000. Exposure hotspots are based on the intensity of purely physical climate-related hazards. Mortality hotspots are based on the number of deaths associated with such hazards. Economic loss hotspots are based on the proportion of a region's GDP lost due to such hazards.

- *Population and administrative boundaries*: population estimates for 1990 and 2000 come from the a collaborative research project involving Columbia University, University of Puerto Rico, Sonoma State University, University of California, Santa Barbara, and Universidad Nacional de Tucumán (Argentina), "The Impact of Economic Globalization on Human Demography, Land Use, and Natural Systems in Latin America and the Caribbean," (NSF 0709606). This geodatabase carefully matches population and boundaries of administrative units at level 2 or equivalent for 1990 and 2000, allowing accurate delineation of spatial demographic change.

- *Poverty*. The comparison of poverty across countries presents a number of challenges in terms of conceptualization of poverty, availability of data and methodologies. Because of this, it was decided to use the infant mortality rate (IMR) for 2000 and 2008 as an indirect measure of poverty easily comparable across countries (Storeygard et al. 2008)[5]. The IMR database we used is one of the only measures of poverty available in comparable form at a subnational level of analysis.

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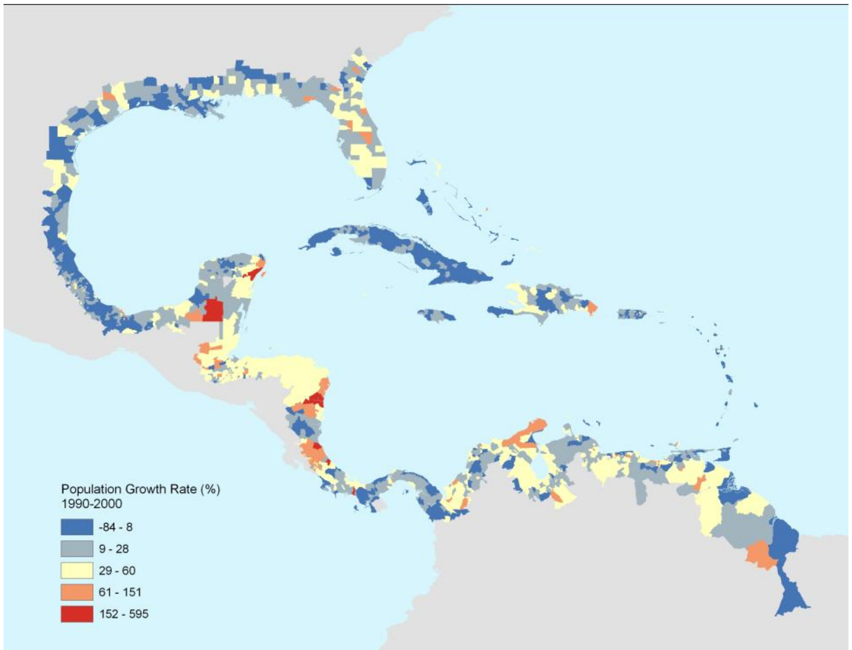
[4] The data are available at http://www.ldeo.columbia.edu/chrr/research/hotspots/

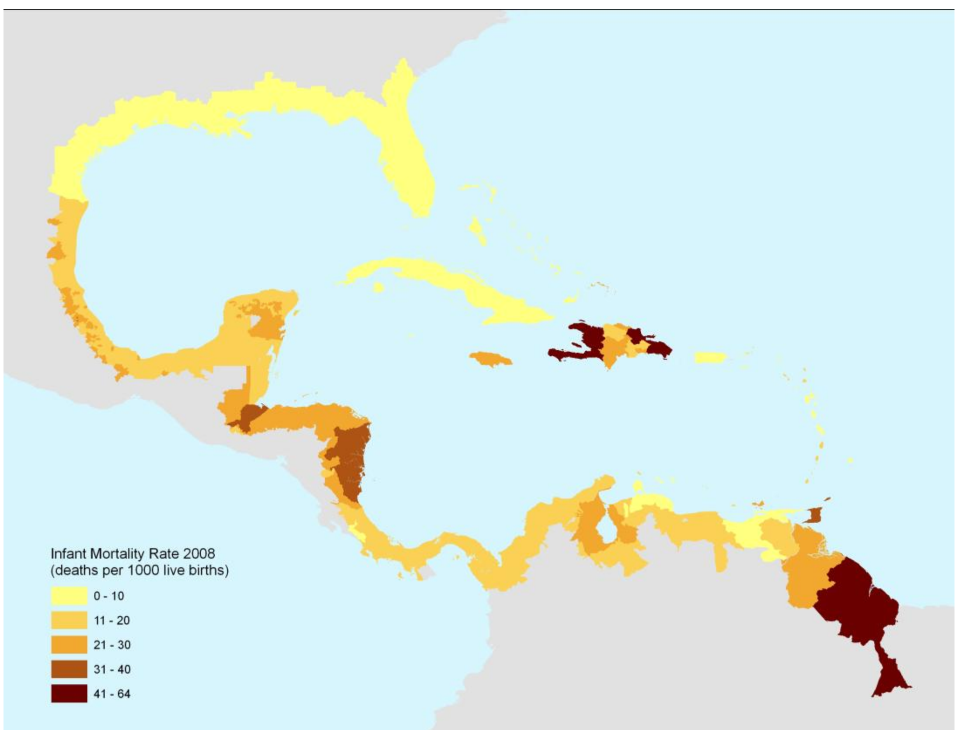
[5] The data for 2000 is available at http://sedac.ciesin.columbia.edu/povmap/ds_global.jsp.

- *Land Cover*: For this analysis we utilized land cover data from a research project focused on Latin America and the Caribbean; consequently the U.S. Gulf Coast is not presently included. Land cover classification for 2001 and 2009 were derived from MODIS MOD13Q1 vegetation indices 250m product. Mapping methods were based on Clark et al. 2010, with some modifications: statistics of mean, standard deviation, minimum, maximum and range for Enhanced Vegetation Index and red, NIR and MIR reflectance were calculated for all 12 months (annual), 2 six-month periods (bi-annual), and 3 four-month periods (tri-annual) from calendar years 2001 to 2009; there were 16,596 reference samples collected using Google Earth; Random Forest classifiers were trained with reference data for separate biomes delineated by municipalities in Mexico, Central America, Caribbean islands, and South America; ten separate maps were made for each year, with the eight classes defined in Clark et al., 2010, yet in this paper, we reclassified the maps into a five-class scheme of Bare and Built-up, Agriculture and Herbaceous vegetation, Water, Woody vegetation and perennial agriculture (e.g., plantations) and Mixed woody vegetation; and, final overall map accuracy with 5 classes ranged from 73-89%.

In order to integrate these different sources, hazards, land cover and IMR grids were resampled to 1-km resolution in order to match the master area grid, while the GIS polygon layer containing administrative boundaries and population information was gridded to the same resolution. Zonal statistics were then used to calculate the total area of the administrative units; the area of each administrative unit within the different hazard categories differentiated by type (cyclones, droughts, floods and landslides), aspect (frequency, mortality risk and risk of economic loss) and level of risk (low, medium and high); the area of each administrative unit within each of the land cover classes in 2001 and 2009; and the mean IMR for the administrative unit in 2000 and 2008.

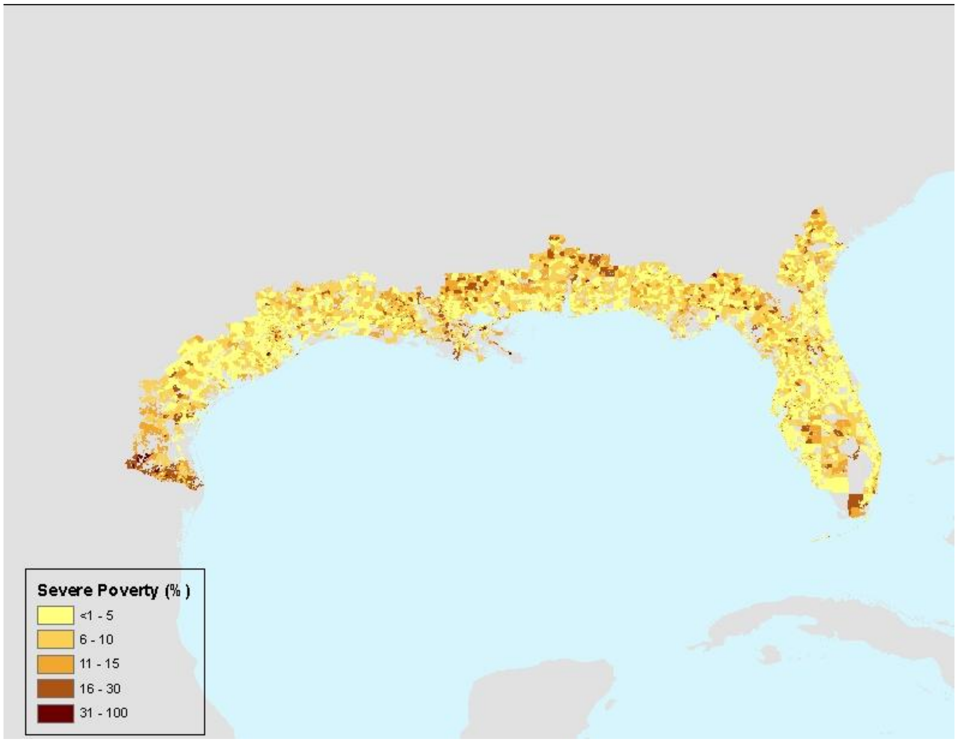


Population Growth Rate, 1990-2000 (%)

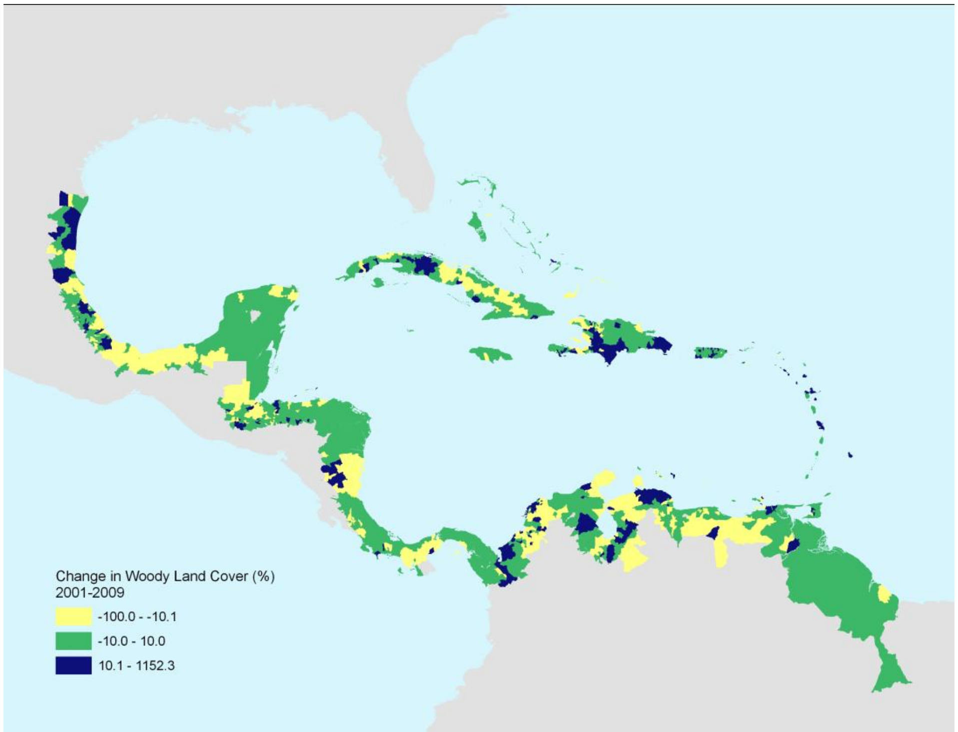


Infant Mortality Rate, 2008 (Deaths per 1000 live births)

Because infant mortality rates exhibit low levels of variation across the U.S. Gulf Coast region, compared to the region as a whole, infant mortality does not do a good job at discriminating different levels of socioeconomic vulnerability to climate risks. We provide a map showing the percentage of families living in severe poverty to illustrate variation within the U.S. counties more precisely.



Percentage of households living in severe poverty, 2000 (U.S. Census).



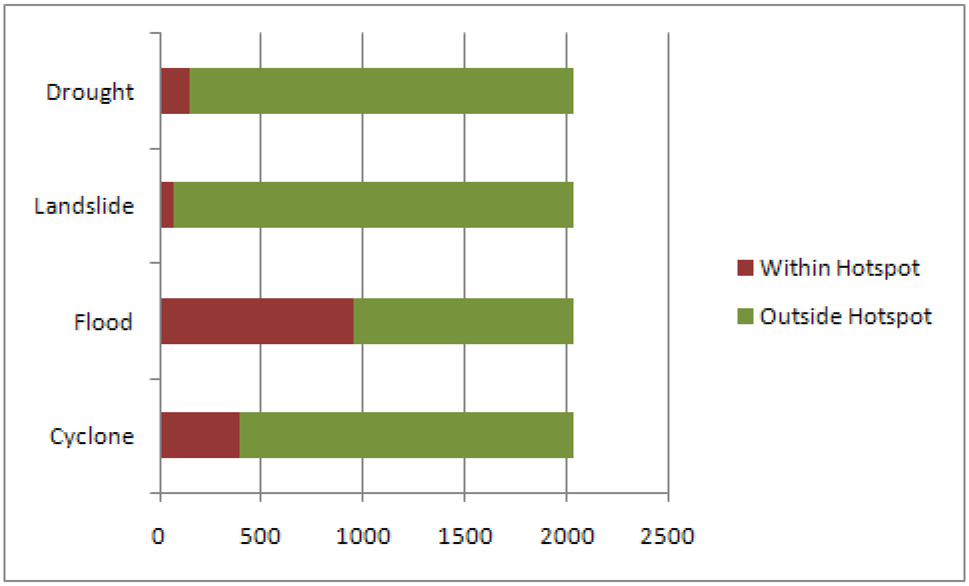
Change in Woody Land Cover, 2001-2009 (%)

The following variables were derived from the integrated database: population density in 1990 and 2000; population change (absolute and relative) between 1990 and 2000; proportion of the area of the administrative units in (1) each of the hazard categories and (2) land cover classes. Three summary multihazard binary variables were also created, coding "1" those administrative units with 25% or more of their area exposed to high (1) frequency, (2) risk, or (3) risk of economic loss from any of the hazards considered in the paper.

4. Analysis

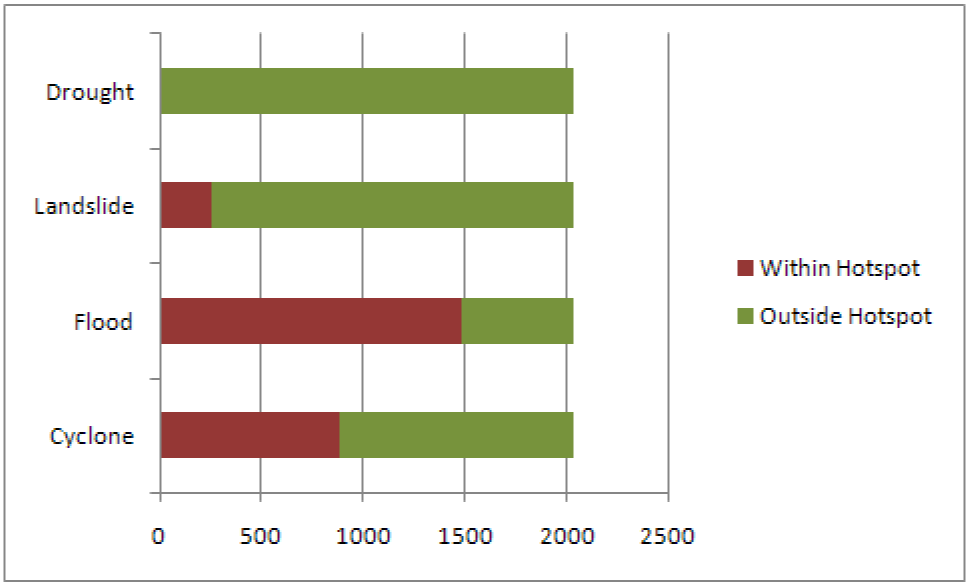
Measured purely in physical terms, the Gulf-Caribbean region is exposed to high levels of climate risk. More than two thirds of the counties are in at least one exposure hotspot. Because the global hotspots are defined as being in the top three deciles, the Gulf-Caribbean can be considered to have climate hazards that are about twice as severe as average, measured purely in physical terms.

For these exposure hotspots, flood hazards dominate.



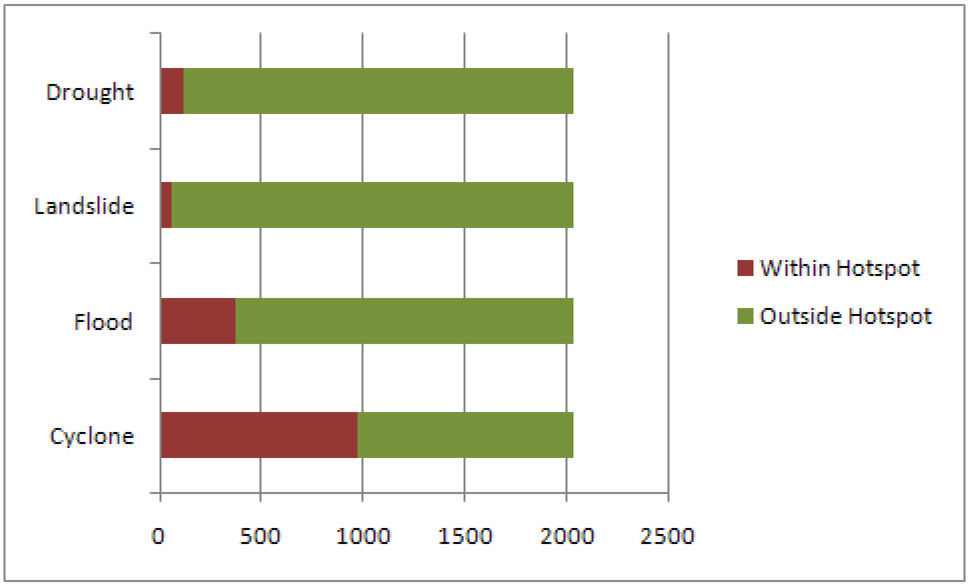
Number of Administrative Units Falling within Exposure Climate Hotspots (25% threshold)

The impacts from these climate risks are disproportionately high. A little more 80% of the units are within at least one mortality-defined climate hotspot



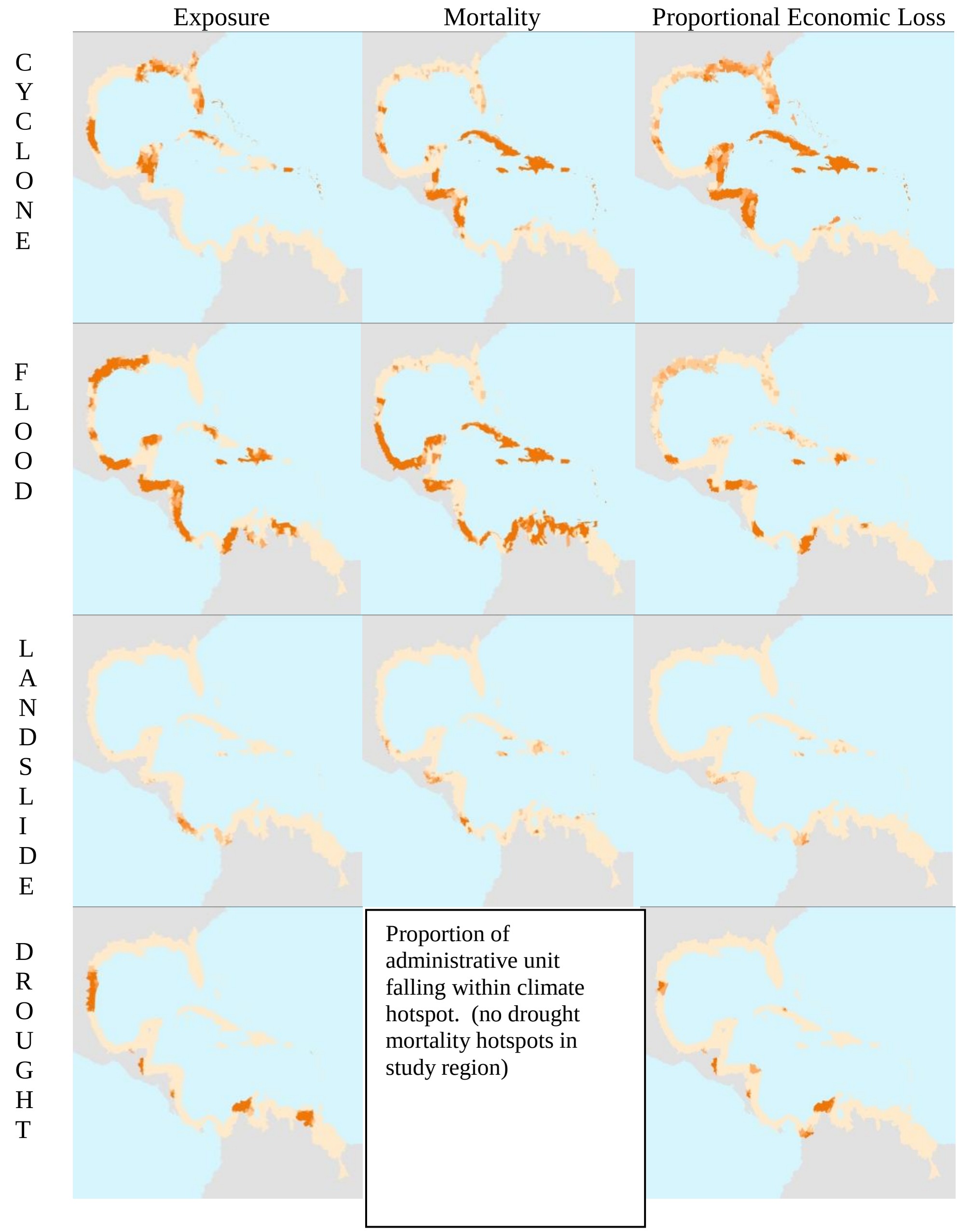
Number of Administrative Units Falling within Mortality Climate Hotspots (25% threshold)

Economic hotspots are less prevalent than mortality hotspots, but still affecting 60% of the units.

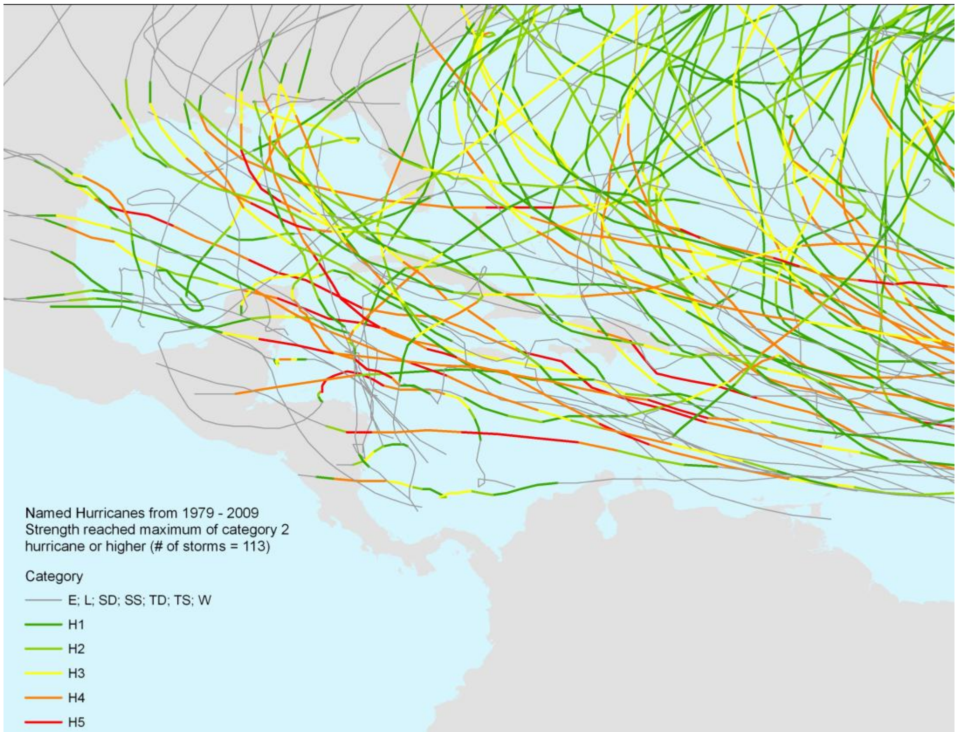


Number of Administrative Units Falling within Economic-Loss Climate Hotspots (25% threshold)

If we turn to the maps, we can see that mortality hotspots dominate the poorer regions and economic hotspots dominate the wealthier regions.



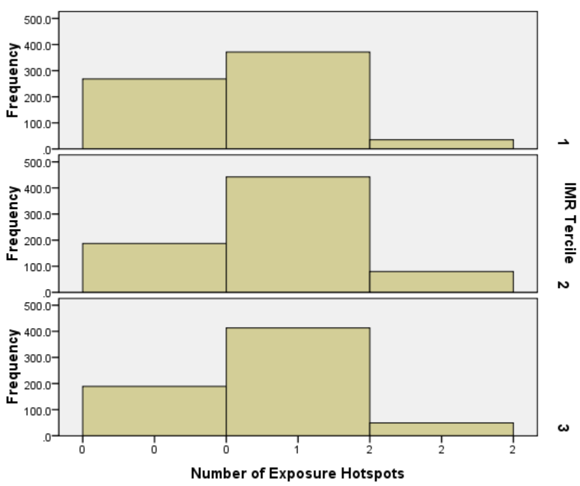
These patterns are related to the hurricane patterns. The southern Caribbean has few cyclone and landslide hotspots, but does have flood and drought hotspots.



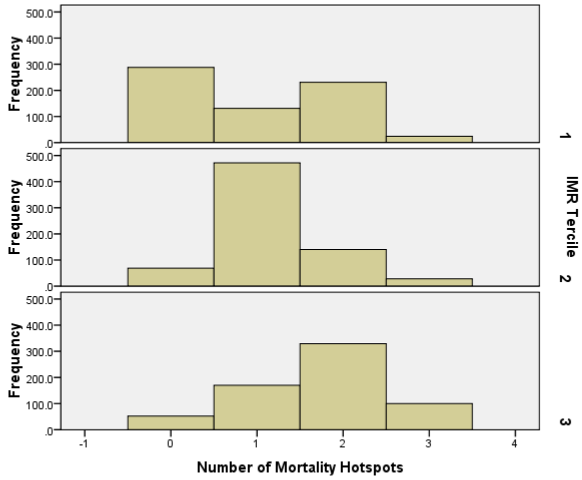
Hurricanes Reaching Category 2 or Higher, 1979-2009. Each segment is colored according to wind speed.

To explore more systematically the effect of poverty on climate risk, we divide the administrative units into three approximately equal groups based on their levels of infant mortality. Low IMR is defined as under 10, medium as 10-20, and high as 20 and up.

If we compare distribution of exposure hotspots across IMR groups, we see no significant differences.

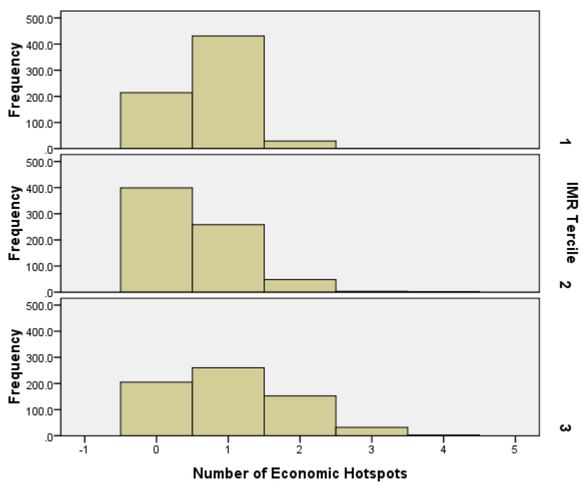


However, if we compare mortality hotspots, we clearly see the impact that poverty has.



In the low-poverty group (the first IMR tercile), a plurality of units fall outside of all mortality hotspots. In the middle group a plurality falls within one mortality hotspot. And for the most poor units, more fall within two mortality hotspots than any other number.

As expected, the distribution of economic-loss hotspots follows a different pattern.



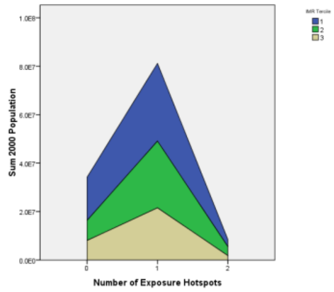
Here, wealthier units are more likely to fall within an economic-loss hotspot, though economic losses are a problem across all poverty levels. The greater prevalence in wealthier regions is not strictly because wealthy areas have more economic assets exposed, because the economic loss hotspots are calculated using economic loss as a fraction of GDP. More work is required to explain this pattern.

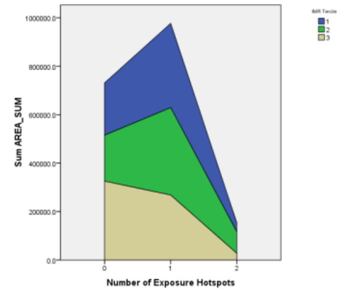
The following figure summarizes the distribution of population and area by all categories of hotspots.

Distribution of Population and Land Area by Number of Climate Risk Hotspots

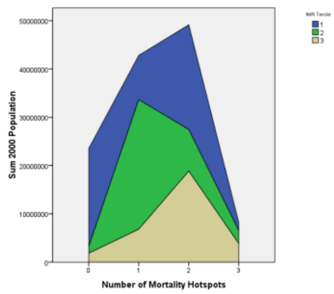
Population | Land Area

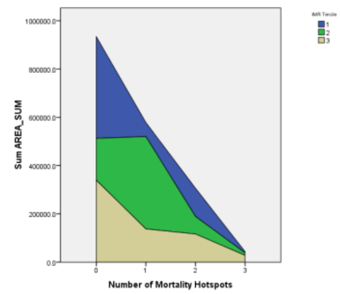
Exposure



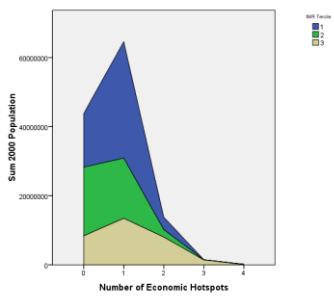


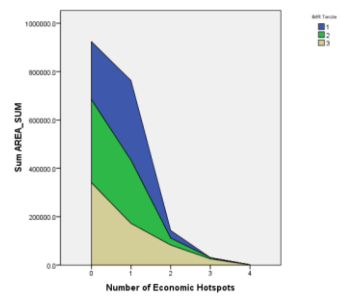
Mortality





Economic Loss

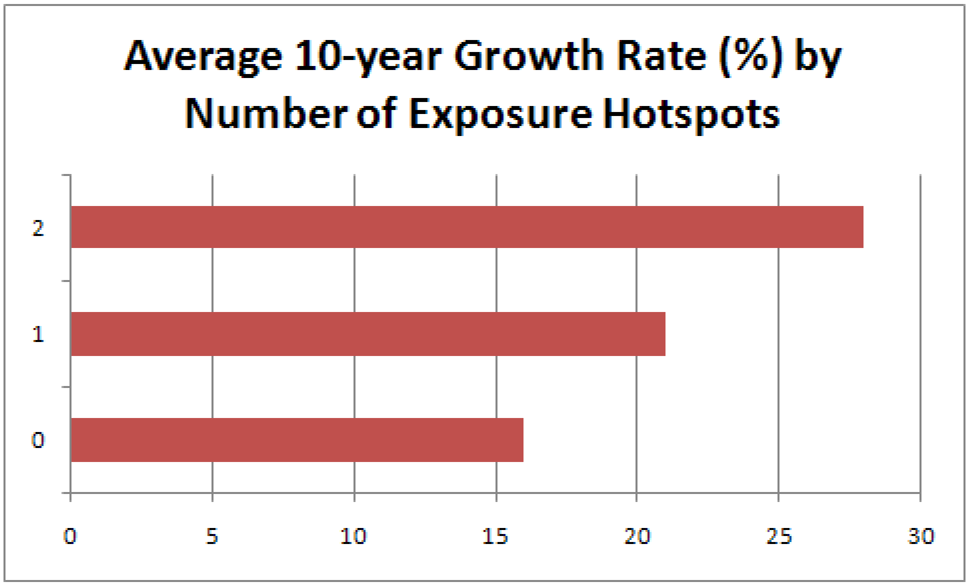




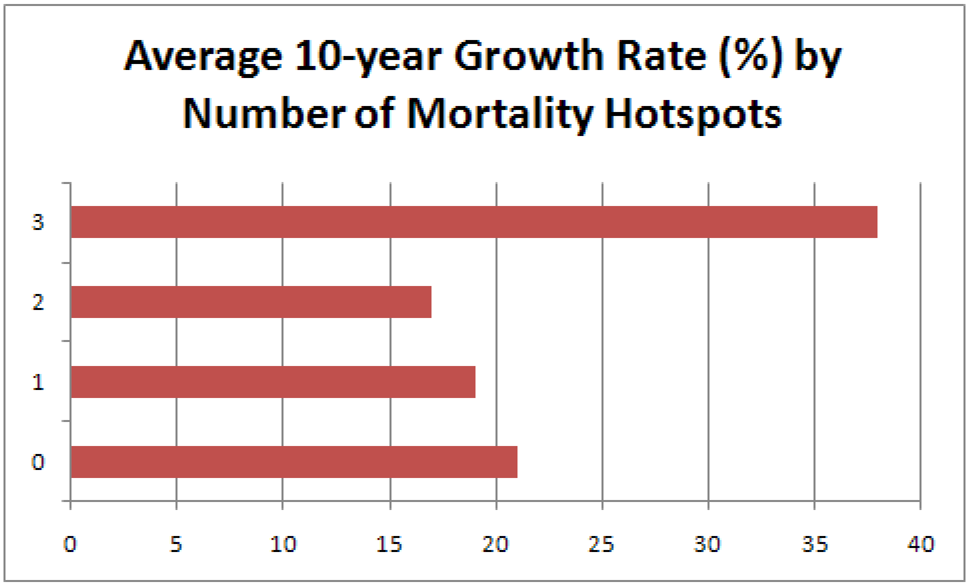
The mortality hotspots show the biggest difference across poverty groups, revealing the high impact that level of economic development has on climate risk expressed in terms of direct threat to human life.

Socioeconomic Trends

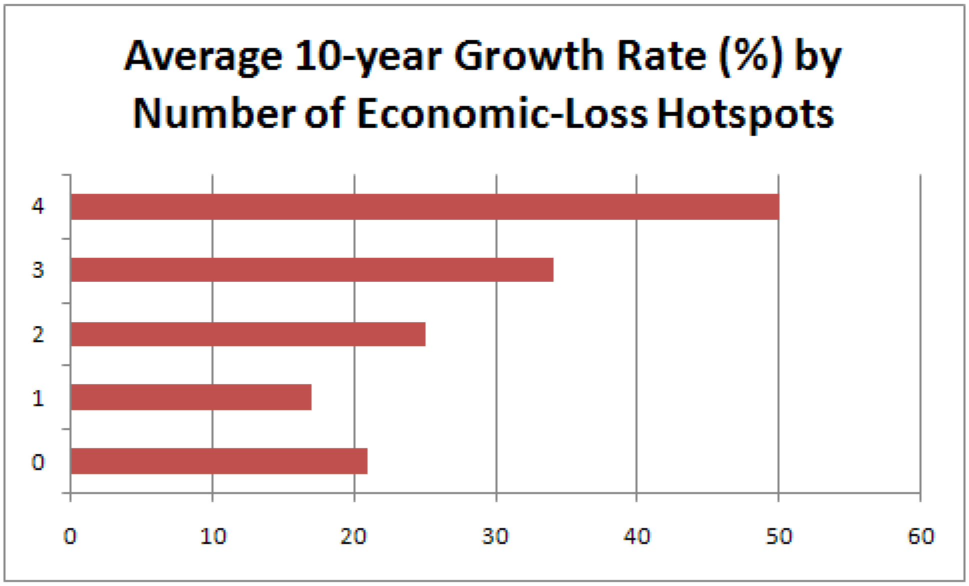
Our subnational calculations of demographic change permits us to explore the degree to which socioeconomic trends are moving the region in a favorable or unfavorable direction. *Ceteris paribus*, it is more favorable for growth rates to be higher outside the hotspots than inside them.



Here we see that for exposure hotspots, trends are not favorable – growth rates are higher where exposure hotspots are more numerous.



A similar picture emerges for mortality hotspots – growth rates are highest in the areas where the number of mortality hostpots are more prevalent.

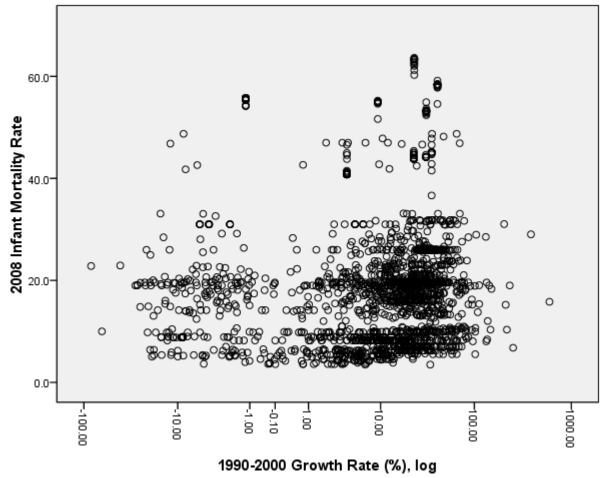


Finally, the same trend is present with respect to economic-loss hotspots. Population is growing faster where economic loss risk is highest (note that the trend in the units with four economic loss hotspots falls covers only three administrative units).

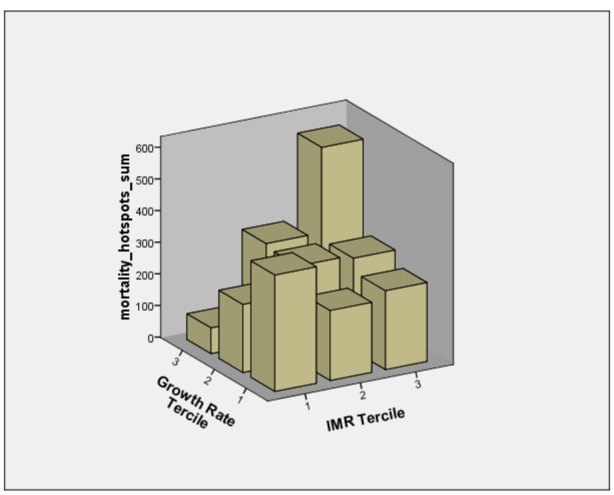
Therefore we can conclude that socioeconomic trends are likely to make the Gulf/Caribbean even more dangerous over time, because population growth is perversely higher where the risk is greatest.

If we take into account both population growth rates and current levels of infant mortality, we see that there is a large number of people located in areas with high growth rates, high infant mortality rates, and high exposure to climate risk.

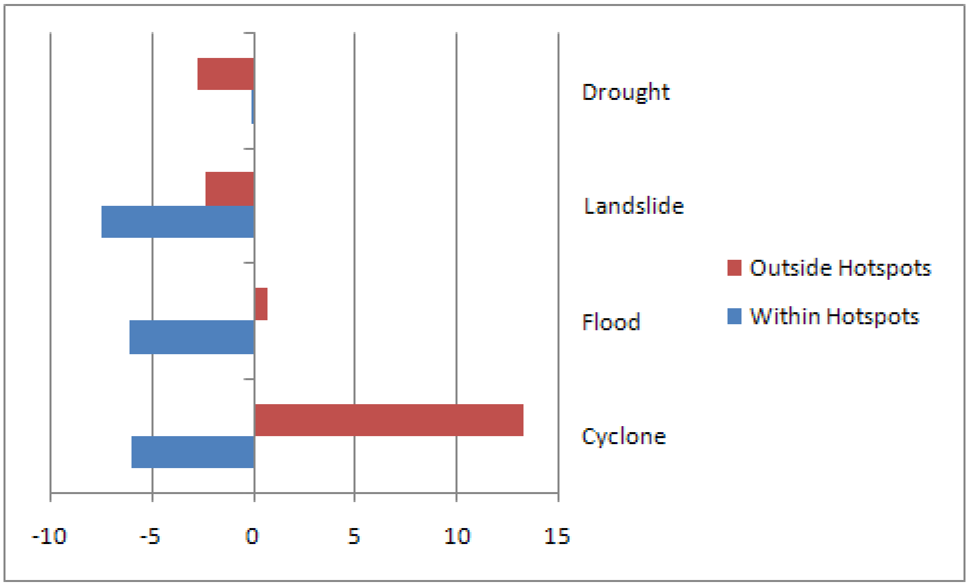
At a national level, growth rates are heavily determined by fertility rates, which in turn are strongly connected to levels of development. At a national scale, therefore, growth rates are largely correlated with poverty levels. At a subnational scale, however, this relationship is less ironclad, because there is more room for migration to affect growth rates. It is therefore instructive to look separately at how levels of infant mortality are related to growth rate patterns.



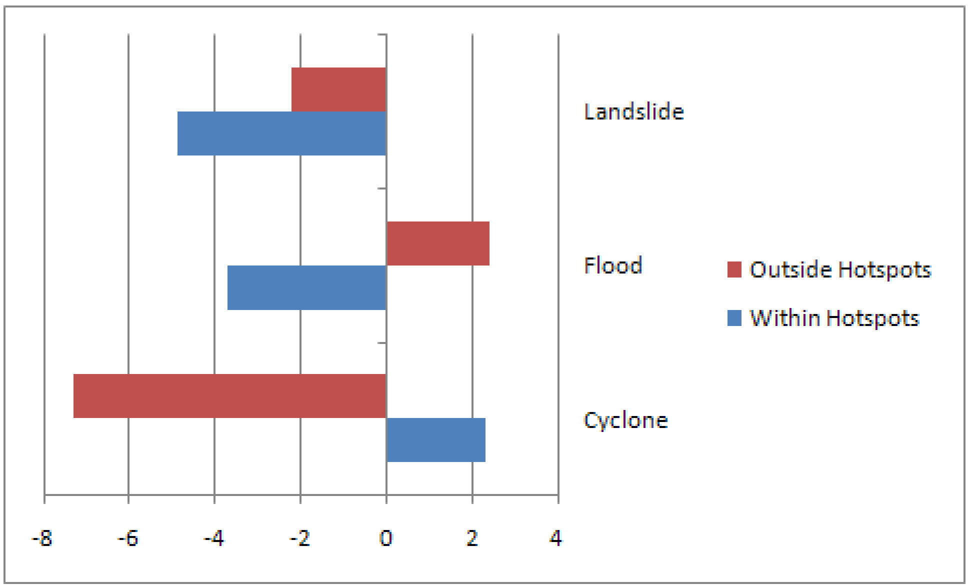
What we find is that where high growth rates overlap with high levels of climate risk, infant mortality rates are highest. For the mortality hotpots, more units are in the overlap of high growth and high infant mortality than in any other combination.



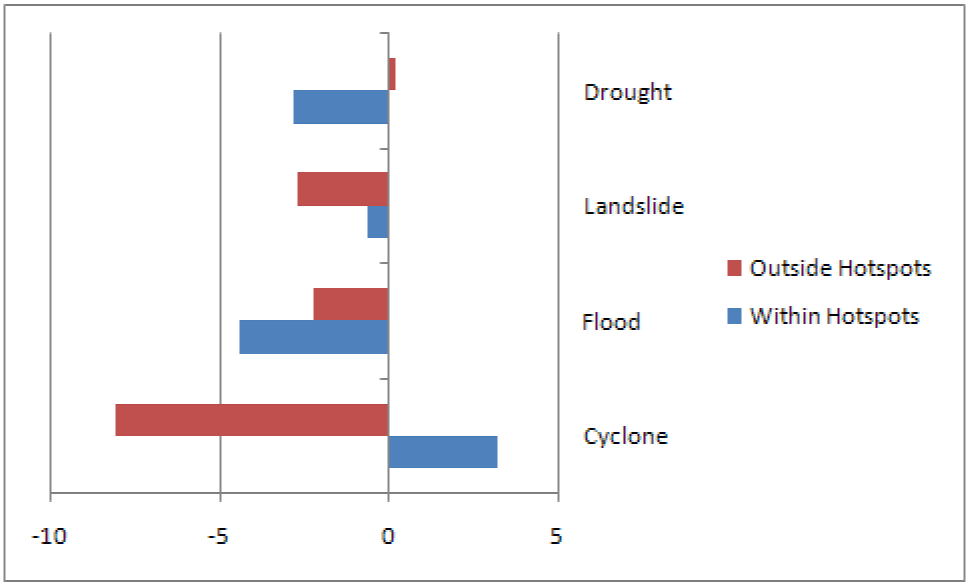
For the portion of the Gulf/Caribbean region that falls outside of the U.S., we have access to time series data on land cover change that enables us to further explore patterns with regard to deforestation, which has been shown to increase risk of severe storms and floods. *Ceteris paribus*, areas that are deforesting are going to experience more severe climate risk impacts in the future.



Change in Woody land cover, 2001-2009, (%), Exposure Hotspots



Change in Woody land cover, 2001-2009, (%), Mortality Hotspots



Change in Woody land cover, 2001-2009, (%), Economic-Loss Hotspots

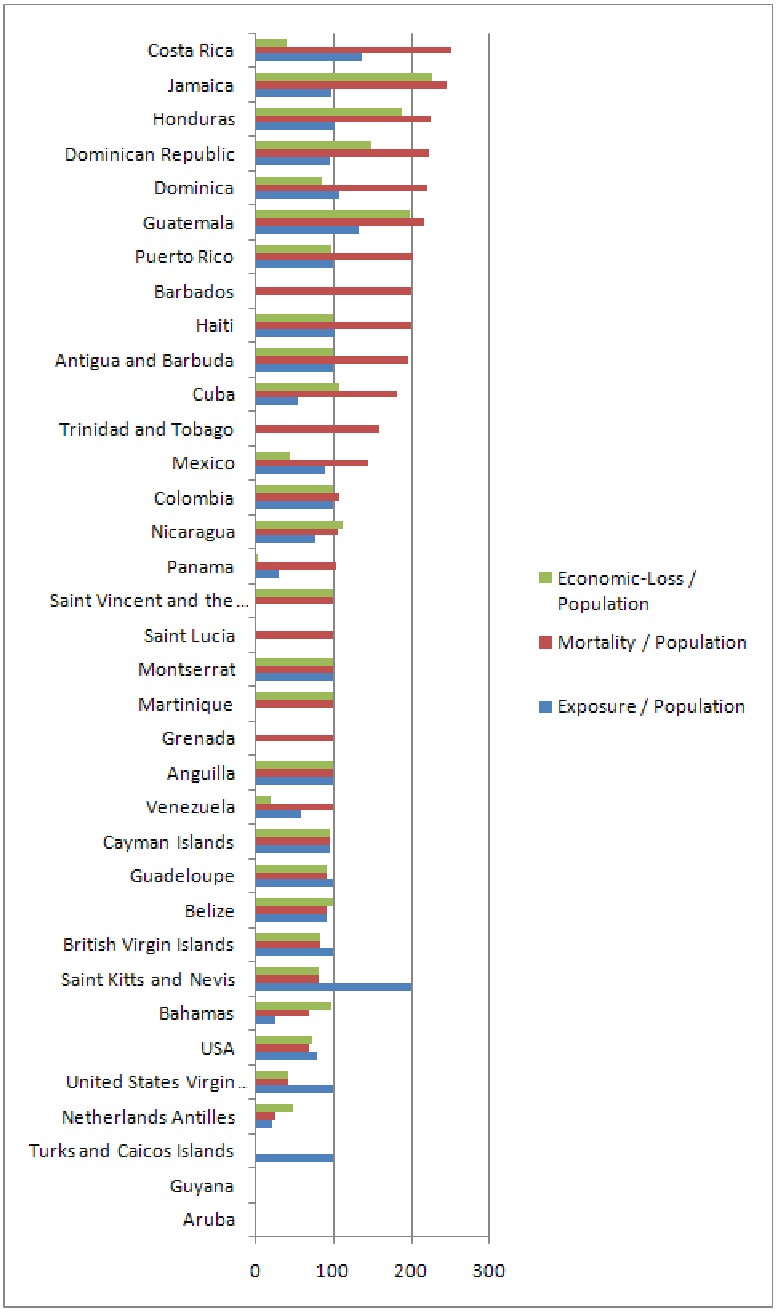
Because the deforestation measure is based on data from 2001 onward, and the hotspots are derived from hazard data prior to 2000, these patterns should not be used to infer cause and effect. Instead, they help characterize trends that have the potential to dampen or amplify climate risks.

What we observe is that in the cyclone hotspots the land cover trends are overall favorable. These areas are experiencing some reforestation which will help dampen future risks. In areas at risk of landslide and flooding, however, the trends are not favorable. In the exposure and mortality hotspots deforestation rates are higher than average.

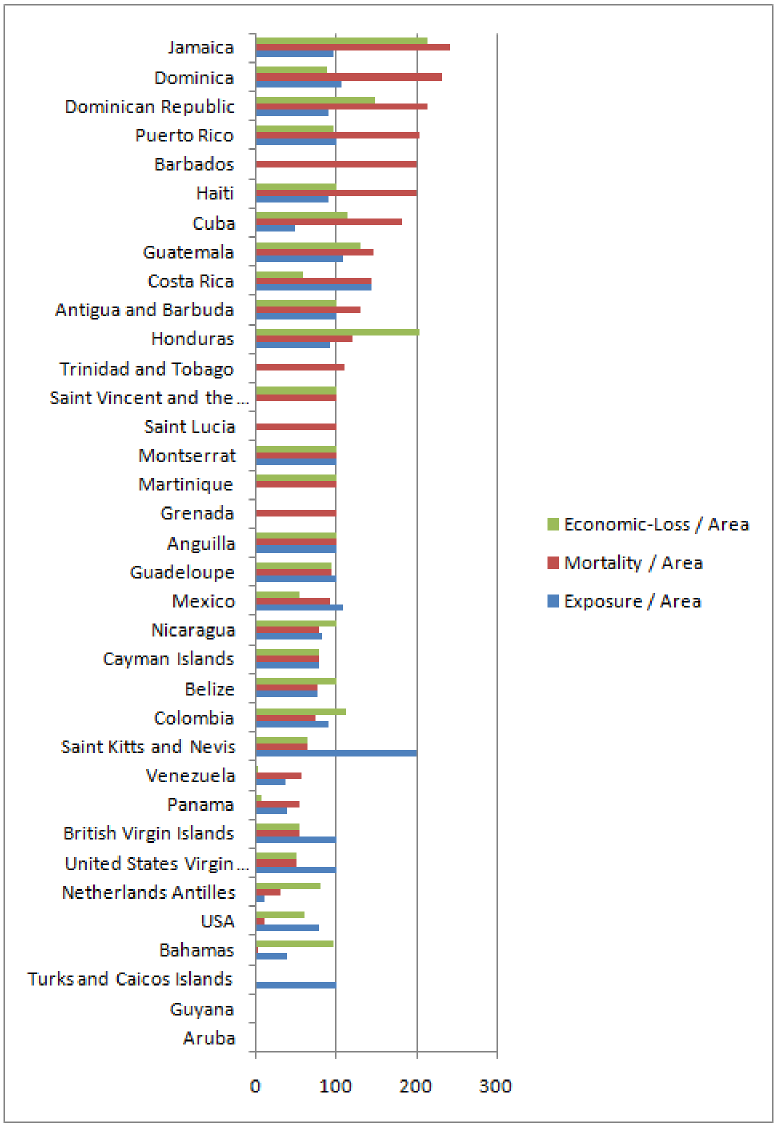
The difference between the cyclone hotspots and the other hotspots deserves further attention.

Country-level summaries

Here we summarize the climate risk hotspots and the patterns and trends that will affect their severity moving forward. The calculations reported here refer only to the study area, which for some countries is less than the entire country.



Index of Climate Hotspot Incidence, by country, sorted by Mortality hotspot incidence. Index is the sum of each climate risk hotspot divided by the total area, multiplied by 100. Values can exceed 100 if multiple hotspots are present.



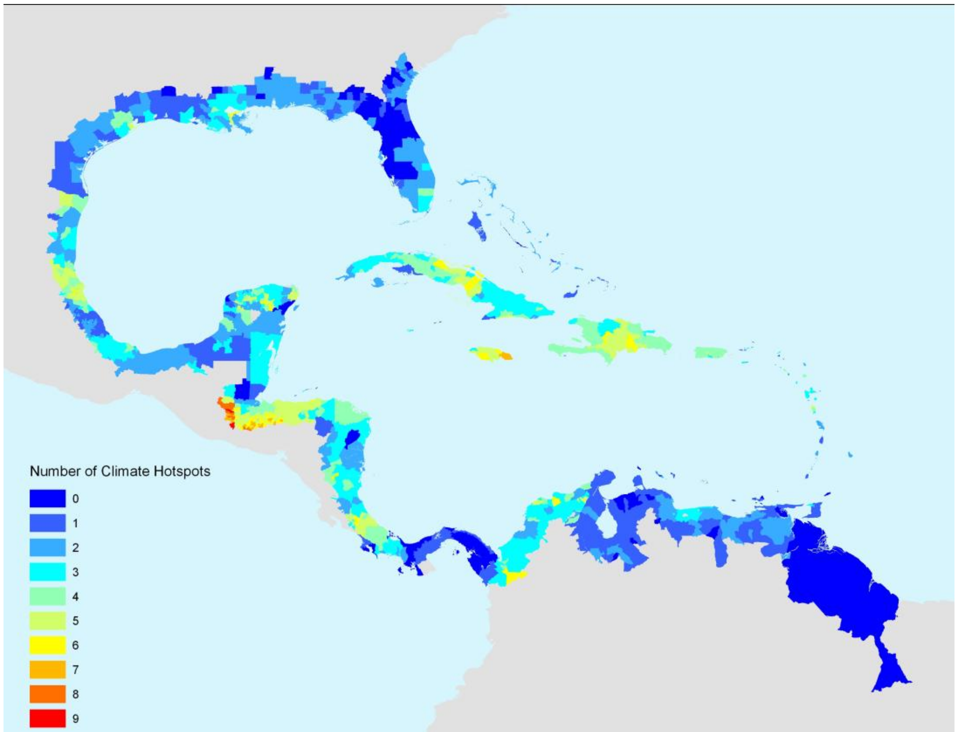
Index of Climate Hotspot Area Incidence, by country, sorted by Mortality hotspot incidence. Index is the sum, over all administrative units that fall within a climate hotspot, of land area, divided by the total land area, multiplied by 100. Values can exceed 100 if multiple hotspots are present.

These country-level summaries reflect the various drivers that affect overall patterns of climate vulnerability, including physical exposure and socioeconomic vulnerability.

Specific municipalities of special interest

If we focus at the municipality level, we can identify areas at highest level of climate risk, based on the hotspots data. As a simple index we can sum the total number of climate hotspots that touch at least 25% of the area. The municipalities with the highest such index are located primarily in Guatemala and Honduras, as seen in the following map.

This is attributable to the high level of physical exposure driven by the location of these countries with respect to hurricane and storm tracks, and by the combination of population density and poverty for the settlements located in harm's way, and probably by topography and other place-specific factors.



5. Conclusions

We have utilized a unique collection of spatial time series data, integrated across socioeconomic and physical systems, to characterize patterns and trends with respect to climate risks in the Gulf of Mexico / Caribbean region. Our main findings can be summarized as follows:

- The region can already be said to suffer very high levels of climate risk.
- The physical climate hazards are magnified by socioeconomic conditions in such a way that the impacts from these current climate risks are disproportionately high.
- In common with other coastal areas, the region is growing rapidly in population. The areas of population growth are highest where the climate risks are most severe. Therefore even in the absence of climate change one would expect climate risk impacts to increase in the future.
- Although small island states are justifiably pointed to as facing very high levels of climate risk, in this region there are also very extremely high levels of climate risk in some inland communities in Central America that deserve further attention.

- The distribution of capacities, drivers, and impacts are such that a collective response is more likely to succeed than if each country tries to manage on its own. There are too many places where high impacts go hand in hand with low capacity and rapidly increasing pressures for self-reliance to have a chance.

Although the regional and global data sets we utilized to carry out this analysis have been instructive, they have limits. Good planning requires more in-depth investigation of the determinants of climate vulnerability at more local scales. Moreover, past is not necessarily prologue. The experience of Hurricane Katrina in 2005 and the unusually high number of severe storms in 2008 in many Caribbean countries suggests that preparing for the future requires understanding how complex systems may be changing, and how they may change in novel ways.

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Climate Change and Infrastructure in the Gulf of Mexico and Caribbean Basin: New Risks to Building Blocks of Resilience

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Abstract

The countries in the Gulf of Mexico and Caribbean Basin regions depend upon a range of infrastructure to enable critical economic sectors and protect against extreme weather events, particularly storms and floods. Natural infrastructure, including wetlands, barrier islands and coral reefs, play a critical role alongside built infrastructure. Drawing upon existing literature, this paper examines current climate-related risks and potential implications of climate change for critical infrastructure functions and their implications for key services and economic sectors. For three key infrastructure functions (flood and storm protection, transportation, and water supply and sanitation), current risks are dominated by hurricane and flood damages. These may be heightened by a changing climate, such as by sea level rise, which may compound on-going land subsidence, leading to inundation of larger areas and increased storm surges. Wetlands play a crucial role in maintaining resilience in the face of storm and flooding risks, and climate change is expected to add to the risks for this already stressed natural infrastructure. Loss of infrastructure functions may have serious implications for critical economic sectors and services; fisheries, tourism, energy production and urban services are examined here. These depend upon multiple types of infrastructure whose functions are often closely connected. In the case of dense urban areas, the failure of infrastructure-related services can have cascading impacts on communities, livelihoods, and economic development. Overall, climate change is one of multiple risks to infrastructure in the region, and impacts of climate change must be examined in the context of an integrated analysis that accounts for a wide range of climate and non-climate stressors. The interactions between them, and the potential for multiple pressures to push natural and built systems beyond their capacity, may present the greatest risks.

1. Introduction

Infrastructure plays a crucial role in sustaining human well-being. In addition to ensuring basic services such as water, sanitation, electricity, and mobility, it enables diverse economic activity in the Gulf of Mexico and Caribbean Basin, including energy production, tourism, and fisheries. The value of many types of infrastructure lies partly in the protection it provides against extremes. For example, water supply infrastructure helps ensure water availability during extremely dry periods, as well as protect against flooding in wet periods. The importance of infrastructure for resilience is all the more clear when we consider "natural" infrastructure, such as wetlands, barrier islands, and coral reefs. The aftermath of recent natural disasters in the Gulf of Mexico region, such as the recent earthquake in Haiti and hurricanes Katrina and Rita of 2005, has shown the kind of devastation that can occur when infrastructure, both built and natural, is inadequate or overwhelmed.

Various aspects of climate change, particularly sea level rise, and increased temperature, and changes in precipitation patterns, are anticipated to directly affect infrastructure performance. At the same time, climate change may alter the very patterns of extremes that much infrastructure helps to protect against. This may have serious implications for the already flood- and storm-prone Gulf of Mexico region. In addition to accounting for possible impacts to existing infrastructure, we must also understand how this affects future infrastructure needs. This is timely, given increasing recognition of the need to renew aging infrastructure in the United States, and the pressing need in other countries across the region for infrastructure to support economic development. The climate is not the only risk the region faces - a point made abundantly clear by the catastrophe that has unfolded in the Gulf following the massive BP oil spill this year. Understanding how a combined set of pressures will affect built or natural infrastructure may be one of the most significant challenges presented by climate change.

2. Assessing risks to infrastructure functions: scope and approach

Infrastructure has been variously defined, but in general refers to physical assets or networks that provide certain critical functions to society.[7] The value of infrastructure derives from the services it provides, such as mobility, energy supply, water, connectivity, and flood protection, and economic activity that it enables, ranging from production and transport of goods to providing an attractive environment for tourists. Research indicates that high economic productivity is difficult to sustain without quality infrastructure (National Research Council, 2009). In addition to built infrastructure, the services of "natural infrastructure" (sometimes called "natural capital,") such as wetlands,

[7] See, for example, the definition in the Online Compact Oxford English Dictionary, http://www.askoxford.com/concise_oed/infrastructure.

watersheds, and coral reefs, are gaining increasing recognition (Costanza, 1997). It is useful to consider natural and built infrastructure together, particularly in the context of resilience. First, natural infrastructure provides certain services that if lost, built infrastructure would have to be created to replace. This is particularly evident in water management, where wetlands provide water quality services and flood protection that can be hard to match. Second, built infrastructure can sometimes lead to unintended consequences for natural infrastructure, which can reduce resilience (Smith and Barchiesi, 2009). For example, much wetland loss in Louisiana is related to navigation and flood control infrastructure built over the past century. Yet, this wetland loss has left the region more vulnerable to storm surge flooding (van Heerden, 2007). Finally, in some cases, natural services are simply irreplaceable, as may be the case for the Caribbean coral reefs that protect against storms, support fisheries, and attract tourists (WRI, 2004).

This paper is chiefly concerned with the risks that climate change may pose to infrastructure functions. There are many different types of infrastructure, often interconnected and serving multiple purposes. This paper does not seek to be comprehensive, but rather focuses on several core infrastructure functions that are critical for the region: **flood and storm protection**, **transportation**, and **water and sanitation**. For each, the impacts of selected aspects of climate change are discussed, particularly sea level rise and changes in temperature and rainfall patterns. Next, several examples highlight how economic activity and community life may be affected by the loss of infrastructure functions: **fisheries**, **tourism**, **energy production** and **urban services** are the selected areas of focus. A final section concludes.

Given the complexity of the climate system, linkages with other biophysical and socio-economic processes, and the potential for non-linear responses, assessing the vulnerability of a particular system or place to climate change is a complex task (Turner et al., 2003). In addition to understanding physical exposure to risks, a vulnerability assessment may require analysis of how socio-economic and institutional factors affect the capacity of particular groups to adapt. This paper does not attempt this, but instead focuses on exposure of infrastructure to stressors related to climate change, and general implications for impacts on livelihoods and the economy.[8] Accompanying papers address some of these other aspects.

Climate change impact studies often combine an overview of current climate-related risks with a review of studies of how these risk patterns may be affected by future climate change.[9] Broadly, the paper takes this approach. Rather than providing an exhaustive review, it seeks to highlight some of the most critical aspects of climate change risk in the context of infrastructure. With regard to future climate projections, studies cited here have used a variety of modeling approaches, and it should be kept in mind that climate projections vary greatly in their assumptions and ranges of uncertainty (an accompanying

[8] The approach of this paper is closer to the *risk-hazard* model of impact analysis, which analyzes exposure to hazards to understand impacts, compared to the *pressure-and-release* model, which incorporates analysis of differential vulnerability of exposed groups (Turner et al., 2003).
[9] There is evidence that climate change has already altered some climate patterns, particularly temperature, and that these changes are already affecting certain systems (Rosenzweig et al., 2007).

paper addresses these questions). This desk review draws upon existing research as represented in peer-reviewed and gray literature, including from academic researchers, US federal and state government agencies, relevant agencies in Mexico and Caribbean nations, multi-lateral agencies such as the World Bank, Inter-American Development Bank, and the United Nations, non-governmental organizations, and the private sector. In general, more research is available focused on the U.S. Gulf states and Mexico, compared to Belize, Cuba, Dominican Republic, Haiti, and the Caribbean island countries. The review inevitably reflects this.

3. Climate change risks to critical infrastructure functions

This section examines how three critical infrastructure functions – flood and storm protection, transportation, and water and sanitation – may be affected by climate change. These are not the only ways that infrastructure helps meet basic needs and enable economic activity – power and telecommunications are also critical (National Research Council, 2009). However, these illustrate some of the ways in which climate change may affect infrastructure, and the critical role of natural infrastructure in the region, particularly in storm and flood protection. They also highlight the importance of understanding interactions between climate change and other stressors.

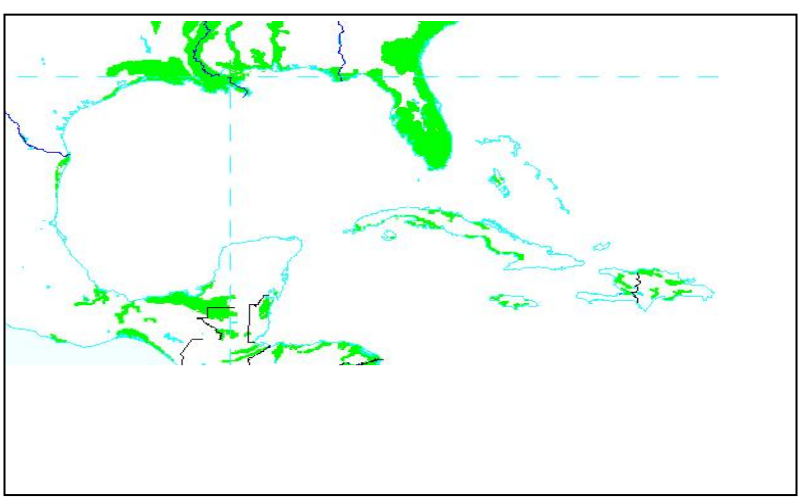
3.1 Flood and storm protection

Protection against flooding, waves and high winds is a particularly critical role for infrastructure in the hurricane-prone Gulf Coast and Caribbean. The Gulf Coast is among the highest disaster loss regions in the United States, with hurricanes and coastal hazards (flooding, storm surge inundation, and erosion) as the leading risks (Cutter et al., 2007). In the Caribbean, aggregate economic losses from hurricanes during the period 1979-2005 are estimated at $613 million per year, of which infrastructure damage accounts for a significant portion (World Bank, 2008). Over the past several decades, hurricane losses have increased in both the U.S. Gulf Coast and Caribbean. However, normalization of these trends suggests that this is due to increasing social vulnerability rather than increased intensity or frequency of hurricanes (Pielke Jr. et al., 2008, 2003). In the United States, increasing losses are partly attributed to the increasing value of infrastructure at risk, especially along the coast (Field et al., 2007, Cutter et al, 2007).

Along the U.S. Gulf Coast, built infrastructure has provided important protection against flood and storm damages. Major federal and state projects to construct levees, canals and floodgates over the past century, such as those in the Mississippi Delta and South Florida, have helped protect human settlements. Storm damage to these structures can be costly; during the 2005 hurricane season, federal costs for repair due to Katrina alone have amounted to $125 billion in Mississippi, Louisiana, and Alabama (USACE, 2009). However, in recent decades, awareness has increased about the unintended consequences of these structures for wetlands, which also provide critical flood protection (Twilley, 2007). It has become clear that in the future, particularly as climate change emerges as an additional threat, we cannot do without protection from natural infrastructure, and this is the focus of discussion here.

Barrier islands, wetlands, and coral reefs are three types of natural infrastructure that play a prominent role in storm and flood protection in the Gulf of Mexico and Caribbean region. Barrier islands, such as the Galveston and Pelican Islands near Galveston, Texas and the Chandeleur Islands off the coast of Louisiana, serve to break waves, slow windspeeds, and reduce inundation in the surrounding mainland (Stone et al., 2004). Coastal wetlands help reduce waves and erosion resulting from storms (Twilley, 2007). Analysis based on Hurricane Rita indicates that wetlands reduce storm surge by about one foot for every 1.4 miles that a hurricane travels over these natural systems (Wilkins et al., 2008). Another recent study has estimated the annual value of wetlands for reducing hurricane damage at $3300 per acre (Costanza et al., 2008). Over half of all wetlands in the United States are located along the Gulf Coast, concentrated in Louisiana and Florida (National Ocean Service, 2008). Mexico's Gulf Coast contains about 75% of the country's coastal wetlands (Vergara, 2009). Map 1 provides an approximate estimate of the extent of wetlands in the region. Finally, in the Caribbean, coral reefs play a critical role for coasts, protecting approximately 20% of island coastlines by reducing wave energy and creating lagoons in which sea grasses and mangroves bind sediments and reduce coastal erosion. The value of this protection has been estimated as ranging from $740 million - $2.2 billion per year for the Caribbean region (WRI, 2004).

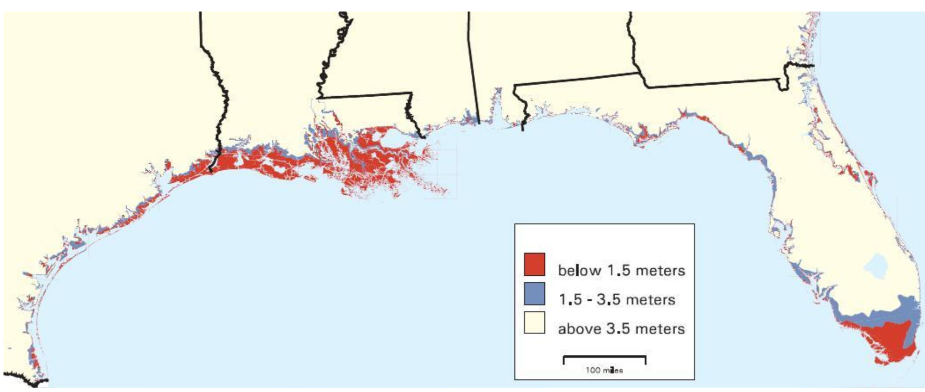
Wetland and barrier island loss is already a serious problem due to coastal development, river diversions, oil and gas extraction, and land subsidence. In Louisiana, an average of 34 square miles (88 km^2) of coastal wetlands is lost each year, totaling 1,900 square miles since the 1930s (USGS, 2003). Wetlands in Mexico are also seriously threatened, disappearing at a rate of about 96 square miles (250 km^2) per year, due to tourism development, urbanization, agriculture, and other factors (Levina et al., 2006, Yáñez-Arancibia and Day, 2004). The impact of these losses is already being felt in terms of reduced storm protection. A major study on the failure of New Orleans' levees during Hurricane Katrina concluded that wetland and barrier island losses left the city more vulnerable to levee failure (van Heerden 2007). Another study comparing impacts of Hurricane Rita with those of Katrina suggests that some of Rita's impact was dampened by the fact that it traveled over 30-50km of the Chernier Plain wetlands (Day et al., 2007).



Map 1. Extent of wetlands in the Gulf of Mexico region. Adapted from the Global Distribution of Wetlands Map, USDA Natural Resources Conservation Service. Green area represents five wetland classes, combined. http://soils.usda.gov/use/worldsoils/mapindex/wetlands.html

Combined with these other stresses – including major new ones such as the current oil spill in the Gulf – the additional effects of climate change may decrease the ability of wetlands and coral reefs to protect against storm impacts. Sea level rise and increased storm intensity, the focus of discussion in this section, pose some of the most significant risks (Karl et al. 2009). Rising ocean temperatures are linked to coral reef damage; this will be discussed in Section 3 under impacts on tourism. Changing precipitation patterns may also have an effect on wetlands, but these are more uncertain (discussed briefly in Section 3 under impacts on fisheries).

Globally, mean sea level rose 1.7 +/- 0.5 mm/year during the 20th century, and recent rates for 1993-2003 are higher, at 3.1 +/- 0.7 mm/year (Bindoff et al., 2007). Rates of sea level rise are anticipated to increase as a result of climate change, but the size of the increase is still uncertain (see accompanying paper, Sobel et al. 2010, for further discussion). In addition, many locations across the Gulf and Caribbean have already experienced significant land subsidence, often exceeding the current rate of sea level rise. Subsidence has long been a problem in the Houston-Galveston Bay region, where groundwater and oil extraction led to an average of 1 inch of subsidence per year over the last century (Coplin and Galloway, 1999). In New Orleans, land subsidence averages about 5mm/year, and in certain parts of the city, it as much as 25 mm/year (Dixon et al., 2006). In four sites monitored along the Mexican coast of the Gulf, observations range from about 2mm/year in Veracruz to over 9mm/year in Tamaulipas (SEMARNAT-INE, 2009).



Map 2. Lands close to sea level, U.S. Gulf Coast (based on modeled elevations). Regions shown in red are some of the areas that could be flooded at high tide if global warming causes sea level to rise 2 feet in the next 100 years. The indicated areas account not only for the effects of global warming, but also for other effects such as tidal variations and land subsidence. Titus and Richman, 2001. Available at: http://www.epa.gov/climatechange/effects/coastal/slrmaps_gulf.html

Accelerated sea level rise due to climate change may to lead to inundation of larger areas and increased storm surges. Map 2 shows low elevation areas along the U.S. Gulf Coast, which may be at risk of flooding through a combination of climate change-induced sea level rise and continued land subsidence (Titus and Richman, 2001). The map highlights large vulnerable areas in Louisiana, Florida and Texas. The extent of wetlands is also considerable in these areas (see Map 1).

There have been several studies projecting rates of sea level rise for specific locations and land areas that would be inundated in the coming decades.[10] A study on six counties in Florida projected relative sea level rise ranging from 0.23-0.29 feet by 2030 and 0.83-1.13 feet by 2080. In Dade County in South Florida, 1.02 feet of rise by 2080 is estimated to inundate over 15,000 acres valued at $6.7 billion, in 2005 dollars. A 7-foot storm surge, currently expected once every 76 years, would be expected once every 21 years with one foot of sea level rise (Harrington and Walton, 2008). A study on member states of the Caribbean Community (CARICOM) indicates that sea level rise of 1m would inundate approximately 2,700 km^2, with greatest total land loss in the Bahamas, amounting to 10% of its land area. Significant percentages of wetland areas in Belize (17%), Jamaica (22%), and the Bahamas (15%), would be inundated (Simpson et al. 2009). Additional areas would be subject to higher storm surges. A study of the effects of 1 meter of sea level rise in Mexico indicates that of the eight states with largest affected land areas, six are on the Gulf Coast (Campeche, Quintana Roo, Veracruz, Tabasco, Yucatán, and Tamaulipas). In these states, it is estimated that a total of 17,413 km^2 would be impacted (INE, 2008).

Wetlands, beaches, and barrier islands have some capacity to adapt as they evolve and migrate according to natural cycles of erosion and accretion, which depend upon varying rates of sea level rise, wave action, and sediment deposits from rivers. However, the acceleration of sea level rise will likely speed up erosion, and in locations with considerable coastal development, or where the land slope is too high, wetlands and beaches may not be able to migrate inland, a problem termed the “coastal squeeze” (Scavia et al., 2002, Field et al., 2007). It has been estimated that a one foot sea level rise in Florida would erode 100-200 feet of most beaches (US EPA, 2002). While building sea walls and replenishing beach sand are possible options, these have high costs, and in some cases, structures along the coastline can themselves increase erosion rates, as has occurred in Galveston (Yoskowitz et al., 2009). Finally, wetlands may be further stressed by rapid increases in water salinity due to sea level rise. The contribution of this effect to wetland loss will depend upon local features, such as the mix of fresh and salt water sources, the speed of salinity change, and the adaptability of local grass species (Nicholls et al. 2007).

Another potential effect of climate change is increased storm intensity. Some research suggests that an increase in hurricane destructiveness in the North Atlantic may already be occurring (Emanuel 2005), although the contribution of climate change in this trend remains uncertain (see accompanying paper, Sobel et al., 2010). Increased storm intensity could have important impacts on wetlands and barrier islands. The USGS estimates that in Louisiana, hurricanes Katrina and Rita converted 217 square miles of marsh into open water, and eliminated 85% of the above-water land mass of the Chandeleur Islands; some

[10] These studies have used varying modeling approaches, and ranges of uncertainty differ. Please see specific studies for further information.

of this damage is likely to be permanent (Barras 2007). While storm disturbance can play a productive role in the evolution of wetlands and barrier islands, in the context of coastal development pressures, storms can have negative effects (Burkett et al., 2005). Increases in storm intensity could worsen this effect. This illustrates the need to understand climate change impacts on natural and built infrastructure in the context of the multiple stresses that they face.

3.2 Transportation

Transportation infrastructure is crucial for economic activity, and the Gulf of Mexico region's interconnectedness across the United States, Mexico, and beyond, means that impacts can have much broader ripple effects. Air and road transportation are critical for tourism, and commerce depends heavily upon ports, roads, and railways. The Mississippi River and the Gulf Intracoastal Waterway (a more than 1000-mile dredged canal running from Florida to Texas) are some of the most important commercial corridors in the U.S. (National Ocean Service 2008). The Gulf accounts for about 70% of waterborne commerce ton-miles in the United States, and 7 of the 10 largest ports in the U.S., measured by tons of traffic, are located in the Gulf (Adams et al, 2004, National Research Council 2008). Mexico's Gulf Coast has three of the country's five most important industrial ports, and about 75% of the tonnage of Mexican imports and exports come through ports on the Gulf (Sánchez-Gil et al., 2004).

The most serious and certain climate-related risks to transportation infrastructure are flooding and storm damage, particularly to highways, ports, and railways (Wilbanks et al., 2007, Kafalenos et al., 2008). Currently, 27% of major roads, 9% of rail lines, and 72% of ports in the coastal and neighboring counties in the U.S. Gulf states are below 4 feet in elevation, at risk of inundation, and more than half of major highways, half of rail miles, 29 airports, and virtually all ports are below 23 feet (CCSP 2008). Costs of flood damage and transportation disruptions can be significant. In Louisiana, the cost of repairs after long-term submersion of roadways is estimated at $50 million for 200 miles of highway. During Hurricane Katrina, over 1,800 miles of highway were submerged (Kafalenos et al., 2008).

For the Caribbean Basin, many countries have significant transportation infrastructure in located along the coast, at risk to sea level rise (Lewsey et al., 2004). A recent UNDP-supported study of risks of sea level rise (Simpson et al., 2009) shows that countries most exposed to impacts from sea level rise, based on their geophysical characteristics and coastal topography, include Antigua and Barbuda, the Bahamas, Belize, and Jamaica. While estimates of the percentage of road networks affected by sea level rise are relatively low (greatest in the Bahamas, where an estimated 11% of the road network would be affected by 3m of sea level rise), airports in these countries are very vulnerable. With 3m of sea level rise, the international airports of Antigua and Barbuda and Belize would be completed inundated, and the Bahamas and Jamaica would lose an estimated 40% of their airport functions (Simpson et al., 2009). Another study estimates that by 2080, sea level rise will necessitate an additional $76 million investment annually to repair lost roads in CARICOM countries (Toba, 2009).

In addition to flooding due to rising sea levels, hurricane winds, wave action, and storm surges also cause significant damage. These impacts may increase if climate change does lead to increased storm intensity. Following hurricanes Katrina and Rita, Louisiana's Department of Transportation spent $74 million to clear debris, and upwards of $700 million on bridge and road replacement and repair (USGCRP, 2008). Katrina also halted grain exports, barge shipping was stopped, gas and petroleum pipelines were shut down, and CSX freight train service along the Gulf Coast took five months to re-open (CCSP, 2008).

Finally, increased average temperatures, as well as increased number of hot days – climate change trends with a relatively high degree of certainty – are an important consideration for transportation infrastructure, leading to increased repair and maintenance costs. For example, asphalt softens in high heat, leading to increased rutting in roads, rail tracks can buckle, and bridge joints can expand (USGCRP, 2008).

3.3 Water supply and sanitation

Water supply and sanitation infrastructure are essential for health and livelihoods. To meet urban, agricultural, industrial, and environmental demands, infrastructure may include ground water pumps, reservoirs, desalination plants, water pipelines, irrigation systems, filtration systems, and sewage treatment plants. This infrastructure is the focus of many development projects in countries whose populations still lack access to these basic services. Also critical are the natural infrastructure that capture, store, and clean water, including watersheds, wetlands, and groundwater aquifers. These are increasingly being accounted for through approaches such as integrated water resources management (Lenton and Muller, 2009).

A key function of water infrastructure is to buffer against extremes, ensuring that water is available in dry periods, and minimizing floods. The diversity of contexts in the Gulf of Mexico and Caribbean region highlight this. The U.S. Gulf Coast relies on a combination of surface and groundwater, with the Floridian and Gulf Coastal Plain aquifers playing an important role in some regions (Kenny et al., 2009). The challenge is to ensure an uncontaminated supply while managing potential coastal flooding and periodic droughts, particularly as water demand grows. In contrast, freshwater supplies are sharply limited across much of the Caribbean, particularly for atoll and coral reef islands such as Barbados and the Bahamas that have little to no surface water. They rely almost exclusively on groundwater, recharged by rainfall that comes only during a few months in the year. Barbados and Trinidad Tobago have resorted to desalinization to supplement groundwater sources (Simpson et al., 2009, Cashman et al., 2009). In both cases, the natural and built infrastructure that helps moderate these extremes faces new risks from climate change, presenting a challenge for water managers to maintain resilience.

Like transportation infrastructure, water infrastructure can be directly impacted by flooding and storm damage, and this may increase with accelerated sea level rise and or increased storm intensity. A study on the impacts of sea level rise in Galveston indicates that under two sea level rise scenarios projected for the coming 100 years (0.69 meters and 1.5 meters), 10 and 16 waste water treatment plants and 5 and 9 solid waste sites, respectively, would be impacted or threatened (Yoskowitz et al., 2009). A study assessing economic costs of sea level rise in the Caribbean offers the rough estimate that by the year 2080, the loss of water and sanitation connections in the 13 CARICOM countries would result in an annual cost of about $15.6 million, in 2007 US dollar prices (Toba, 2009).

Salt water intrusion into groundwater aquifers and water supply systems is already a problem in Texas, Louisiana, Florida, and some Caribbean islands, and sea level rise may worsen this. In South Florida, most communities depend upon groundwater, and salt water intrusion already occurs in the region from Miami to Palm Beach. Water managers in this area use water control structures to discharge water into the ocean and maintain the level of water in canal networks. Sea level rise may reduce the effectiveness of these structures to protect against salt water intrusion into wellfields, as well as floods (SFWMD, 2009). There is also concern about salt water intrusion into the Everglades, which currently recharges the Biscayne aquifer that supplies water to Miami-Dade, Monroe, and parts of Broward counties (US EPA, 2002).

Higher temperatures and greater extremes in rainfall are also of significant concern for current water infrastructure, as well as future infrastructure needs. Higher air temperatures contribute to faster evaporation rates, which will increase water storage requirements. Higher evaporation rates can also reduce the ability of water treatment plants to remove phosphorous (SFWMD, 2009). Projected changes in rainfall patterns are still fairly uncertain. Current research is not conclusive about whether precipitation will increase or decrease in particular regions as a result of climate change (IPCC, 2007). Modeling over the Caribbean region suggests an overall decrease in precipitation levels, a serious worry for countries that are already water-scarce (Simpson et al 2009). In the U.S. Gulf states, as well as other parts of the region, there is greater concern over the increase in precipitation extremes (USGCRP, 2008). Managing these extremes may require additional investments in built and natural infrastructure. For example, more frequent urban flooding can overwhelm storm drain systems, threatening water quality by sending untreated water directly into water bodies, and increasing flood risks (USGCRP, 2008, US EPA, 2008, Bates et al., 2008).

4. Impact of infrastructure damage on economic activity and urban services

As noted earlier, the value of infrastructure stems from the economic activity and community life that it supports. Infrastructure, both natural and built, is so integral to the functioning of society that its value is difficult to quantify (ASCE, 2009). This section examines the potential implications of climate change for infrastructure in terms of several important sectors in the region: fisheries, tourism, and energy production. In each, multiple types of built and natural infrastructure are important, and their functions are often closely linked. A brief section on climate-related risks to urban services highlights how the spatial concentration of infrastructure can magnify risks. In all cases, climate change is one of many risk factors. A key challenge is to understand the interplay between them, and to identify situations in which multiple stressors might lead to more dramatic economic and social impacts.

4.1 Fisheries

Fisheries are an important livelihood source across the Gulf and Caribbean Basin. The recent oil spill along the U.S. Gulf Coast, which has all but halted fishing activities, has highlighted how crucial this industry is for the Gulf States, particularly Louisiana. In 2006, three of the top six commercial fishing ports in the U.S. were located in the Gulf, which was the source for 83% of the annual U.S. shrimp catch, and 56% of the oyster catch (National Ocean Service, 2008). In addition to the transportation infrastructure needed for the catch to reach consumers, fishing vessels are another crucial infrastructure element; an estimated that one-third of the U.S. commercial fishing fleet is in the Gulf of Mexico. The region contains one-fourth of all seafood processing plants in the United States, the majority located in Louisiana and Florida (Adams et al., 2004). In the Caribbean, an estimated 300,000 people depend upon fishing and related activities for their livelihoods (UNEP, 2008). However, infrastructure plays less of a role since on many islands, fishing is largely artisanal rather than industrial, and much of the catch is consumed domestically rather than exported.

Hurricanes routinely disrupt fishing operations in the Gulf and Caribbean through damage to fishing vessels, processing plants, ports, and other transportation infrastructure. Hurricane Katrina led to the loss of thousands of fishing vessels, $1.3 billion of lost revenue in Louisiana’s seafood industry, $101 million in damages to Mississippi’s seafood processing plants and dealers, and the loss of 90% of Mississippi’s primary oyster reefs (IAI 2007). If the intensity of storms increases as a result of climate change, serious, periodic losses such as these could be expected to increase.

Sea level rise, temperature increases, and precipitation changes also may impact fisheries, although effects are currently uncertain. Fisheries in the Gulf are highly dependent upon wetlands; 95% of the fish and shellfish harvested in Louisiana depend upon coastal wetlands, especially as “nursery grounds” (Twilley et al. 2001). The impacts on estuaries from a changing climate are multiple and uncertain, depending heavily upon local conditions as well as how climate change scenarios unfold. For example, an increase in air temperature also raises the water temperature in an estuary, which in turn effects the mixing of salt and freshwater. If precipitation increases, then more freshwater runoff may enter estuaries, but this may be counter-acted by sea level rise. Changing conditions could favor some species over others (Turner, 2003). Wetlands also help buffer nutrient levels in water, and with the loss of wetlands through either sea level rise or other drivers, increased nutrient flows into water bodies can cause algal blooms and hypoxia, already an enormous problem in the Gulf of Mexico (Twilley et al., 2001).

Fisheries in the U.S. Gulf states are currently coping with massive losses due to oil spill in the Gulf, and for the time being, these impacts will dwarf those that might be attributed to climate change. However, uncertainties about changing future storm patterns, or new stresses on wetlands that support fish growth, add yet another challenge for those seeking to rebuild fishing livelihoods and industries seriously weakened by the spill.

4.2 Tourism

Tourism is a $20 billion industry in the Gulf of Mexico (US EPA, 2010). In the U.S. Gulf states, tourism employs 620,000 people and accounts for $9 billion in wages (National Ocean Service, 2008). In Caribbean countries, tourism employs over 2 million people and represents a sizable portion of economic activity (UNEP, 2008). In 2004, tourism accounted for over 30% of GDP in Antigua and Barbuda, Bahamas, Barbados, Jamaica, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines (European Commission, 2007). This is supported by a range of built and natural infrastructure. For example, in 2009, 22 million tourists visited the Caribbean, using airports, boats, and roads to reach their destinations, where they made use of water and sanitation services, electricity, and beachfront properties (Caribbean Tourism Organization, 2009). Many of risks from climate change to this built infrastructure have been discussed above. Toba (2009) projects that by 2080, climate change will cost CARICOM countries $447 million annually in lost tourist expenditures.

Tourism also depends upon natural features, particularly coral reefs and beaches. The net revenue from reef-related tourism in the Caribbean was estimated at $2.1 billion in 2000 (WRI, 2004). Wetlands and coral reefs are also crucial for recreational fishing in the Gulf, which represents over 40% of the recreational catch in 2008 (NMFS, 2009). This natural infrastructure, upon which tourism depends, faces several risks related to climate change. Coral bleaching is an important problem related to an increase in ocean temperatures. This expulsion of coral algae can kill coral if the bleaching event is prolonged (WRI, 2004). Bleaching has been observed since the 1980s, and events are often associated with El Niño events, which raise ocean temperatures for a number of months. There is concern that climate change, by raising ocean temperatures, will worsen this problem (Nicholls et al., 2007). Coral can also be harmed by ocean acidification, caused by increased dissolved carbon dioxide, which may reduce calcification and retard reef growth (USGCRP, 2008).

Reefs in the Caribbean, and elsewhere, also face other threats, such as overfishing, coastal development, and water pollution, and hurricane damage (WRI, 2004). Recent studies suggest that the combination of stresses from climate change and other sources present a serious challenge to reef survival, particularly in the Caribbean. The region contains the largest proportion of threatened species among coral reef regions in the world, and Caribbean reefs have already been in decline for several decades (Carpenter et al., 2008, Gardner et al., 2003). While a single threat may not destroy a reef on its own, one additional stress on top of others may be sufficient to push a reef beyond its threshold for survival. For example, reefs may be well-adapted to hurricane patterns, but recent studies have shown that a series of hurricanes may trigger long-term coral decline in the face of other threats (Mumby et al., 2007).

4.3 Energy

The Gulf of Mexico is a major source of oil and natural gas, which forms a crucially important part of the regional economy, particularly in the U.S. Gulf states. The Gulf accounts for 30% and 20% of U.S. crude oil and natural gas production capacity, respectively (Bull et al., 2007). There are 33,000 miles of oil and gas pipelines on the ocean floor of the Gulf, over 185,000 miles of pipeline onshore, and over 4,000 oil and gas platforms (EEA, 2005). Other critical energy production infrastructure includes oil refineries, gas processing plants, supply bases for offshore production plants, and construction yards for platforms and pipelines. Much of this infrastructure is located in the coastal areas of Louisiana and eastern Texas (Adams et al., 2004). Transportation infrastructure over land and water are also crucial to ensuring regular energy supply regionally, domestically, and internationally. Rail lines transport coal and natural gas, while a substantial portion of oil is transported by barge. Almost all of Florida’s oil is transported through three ports (Bull et al., 2007). Many islands in the Caribbean also depend heavily upon oil brought in by boat for electricity generation and fuel (Contreras-Lisperguer and de Cuba, 2008).

In the Gulf of Mexico region, severe storms present the greatest current and future climate-related risk to energy production and distribution. Hurricanes Katrina and Rita led to $15 billion in direct losses to the energy industry, destroying over 100 platforms, and damaging over 550 pipelines. In many cases, production was halted or slowed for months, leading to fuel price hikes nationwide. Distribution of energy was severely impacted due to strong linkages between distribution of gas, transportation fuel, and electricity generation and distribution. The largest gas transmission hub, located in Louisiana, had to be shut down for several weeks (Bull et al., 2007). Severe weather can also hamper the ability of industry and government to respond other risks, as we have witnessed this year with respect to the intensive effort to halt and mitigate damages of the current oil spill in the Gulf.

Sea level rise and increased flooding are a concern for a wide range of energy production, generation, and distribution infrastructure located in low-lying coastal areas, and may be at risk of inundation. One third of U.S. refining and gas processing plants are located on the coastal plains of the Gulf, close to sea level (Bull et al., 2007, National Ocean Service 2008). Florida, in particular, has a number of major power plants located close to the coast, such that 3.6% of generating capacity in the 48 contiguous states could potentially be impacted by 1 meter of sea level rise (Bull et al., 2007). The United States’ Strategic Petroleum Reserve Storage sites are located in the Gulf states, in order to take advantage of proximity to national transportation networks. Although the oil is stored 2000-4000 feet below the surface in old salt caverns, these four sites are all located along the coast, within regions mapped by USGS in 2000 to be susceptible to flooding due to sea level rise (US DOE, 2010; Bull et al., 2007)

4.4 Urban services

Urban areas are now home to almost 80% of the U.S. population, and the U.S. Gulf Coast is one of the most densely populated regions. At 20 million in 2008, the Gulf Coast population is expected to increase by 10% by 2015, with the highest density located along the coast (National Ocean Service, 2008). In the Caribbean, over 60% of the region's 42 million people live in urban areas, and there are four cities with populations larger than 2 million: Havana, Port au Prince, San Juan, and Santo Domingo. Mexico's Gulf Coast states are home to approximately 17 million people, although cities are smaller, with the largest being Tampico at 760,000 (UN DESA, 2009). However, the coastal zone has also seen disproportionate growth. Between 1990 and 2000, the coastal zones of states of Quintana Roo and Campeche grew 5.9% and 2.6%, respectively, compared to an average 1.8% for the region (Sánchez-Gil et al., 2004).

Urban residents are heavily dependent upon a range of infrastructure, particularly in the U.S. Gulf states. Transportation, energy, communication, water supply and sanitation, flood control structures, residential and office buildings and public spaces must all be well-integrated to provide services to densely populated urban centers as well as increasingly geographically dispersed metropolitan and suburban areas. Access to these services is not equitably distributed, with some neighborhoods lacking sufficient transportation access, for example. On the other hand, close proximity to other infrastructure, such as oil and gas refineries, sometimes imposes greater health risks in lower-income and minority neighborhoods (Borden et al., 2007). While individual systems are designed to function within "normal" climate conditions and handle certain extremes, a failure in one system can in turn affect others, creating ripple effects throughout an urban area. These inter-dependencies may be physical, spatial or temporal (Comfort 2006). Climate change may bring a shift in "normal" conditions as temperatures increase or precipitation patterns change, as well as the possibility of increased extremes. We must account for the impact of such change not only to a single type of infrastructure, but to the entire system that serves a metropolitan region (Kirshen et al., 2006).

Flooding and wind damage from storms are probably the most serious climate risk today, which may increase with climate change. Damage to buildings – commercial, residential, and public – already accounts for a major portion of costs of hurricanes and floods, and this may increase. For example, in the Galveston Bay region it has been projected that over 60,000 buildings would be impacted by a 0.69m sea level rise over the next 100 years; over 75,000 would be affected by a 1.5 meter rise, creating economic losses of $9 and $12 billion, respectively (Yoskowitz et al., 2009). In many urban areas in Mexico and some Caribbean countries, urbanization has led to the expansion of informal settlements, often in low-lying, flood prone areas. Basic infrastructure is often lacking in such settlements, but whatever minimal shelter or services do exist may be entirely wiped out by flooding or storms, making their impact particularly severe for the urban poor (Parkinson, 2003). Transportation networks in dense urban areas can be seriously affected by flooding. Studies in some U.S. cities have suggested that additional investment in the drainage systems of transportation networks will be required to address increasing flood risks due to more frequent intense rainfall events (Bates et al., 2008). Winds and flooding can cause serious damage to electricity and other energy systems. Hurricanes Katrina and Rita resulted in 35 million customer-days of power outage between August and October 2005, including 17 million customers in Louisiana (EEA 2005).

The tragic experience of New Orleans during Hurricane Katrina reminds us just how dependent we are upon these interconnected infrastructure systems for our livelihoods and community life. In parts of New Orleans and surrounding communities, not only were housing units destroyed, but damage to electricity and communication lines, water supply systems, and waste treatment plants meant no access to basic water and energy services. Other infrastructure critical to community life – schools, hospitals, fire and police stations, and parks – was also gone. Transportation infrastructure failed to enable many to escape. The tragic consequences highlight the need to understand and plan for the interdependencies between infrastructure elements providing these vital services. They also point to the need to understand and account for socio-economic aspects of vulnerability that shape who may be most affected, and relative capacity to cope with infrastructure failures (Comfort, 2006).

5. Conclusion

Infrastructure, both built and natural, plays a crucial role in determining the resilience of societies to climate-related risks today, and will continue to do so as the range of potential future climate conditions broadens. An understanding of future risks of climate change requires examining infrastructure performance and consequences of failure in the context of an integrated analysis, accounting for a wide range of climate and non-climate stressors. The interactions between them, and the potential for multiple pressures to push natural and/or built systems beyond their capacity, may present the greatest risks. For example, in the Gulf of Mexico, the combination of development pressures on coastal wetlands with the threat of sea level rise and the possibility of increases in storm intensity may present serious challenges to resilience to floods. This has implications for other infrastructure systems, particularly transportation, and in turn can impact the region's key economic sectors, including fishing, tourism, and energy production. Risks in urban areas are magnified, as multiple types of infrastructure are physically, spatially, and temporally inter-dependent.

Addressing these risks will be a significant challenge. Infrastructure planning requires substantial investments, whose payoffs are realized over the long-term. Many countries in the region have insufficient infrastructure to manage current risks, and it will be critical to integrate into development planning an understanding of multiple risks, including climate change. In the United States, the need to update aging infrastructure in the United States has drawn increased attention to infrastructure's value for economic growth, and offers an important opportunity to account for risks of climate change in plans for infrastructure renewal (ASCE, 2009). Finally, throughout the region, building resilience to the range of future climate change scenarios will require attention to the role of natural infrastructure, particularly wetlands in the region. The 2005 hurricane season provided a vivid reminder of their importance for this storm and flood-prone region. The current oil spill in the Gulf, combined with a forecast of a very active hurricane season this year, points again to the urgent need to restore and protect them.

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Review of Adaptation Policies and Financing in the Gulf of Mexico and the Caribbean Region

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Abstract

Given the diversity of development experiences, institutional capacities and climate risk characteristics, adaptation policies in the countries of the Gulf of Mexico and the Caribbean include an array of considerations, from short term disaster responses to long term resiliency planning. Adaptation policies to date have been shaped both by emergent international (negotiated) frameworks and by existing regional, national, state and city-level institutions and planning processes. This paper reviews the current status of these efforts, highlighting examples from regional to local levels. These include a regional strategy for Caribbean Community (CARICOM) nations, a national strategy for adaptation in Belize, an adaptation strategy for the tourism sector in Barbados, adaptation planning promise of the multi-state Gulf of Mexico Governor's Action Plan, state-level plans in Florida and Louisiana, and city-level efforts in Galveston, Texas. Assessing the costs of adaptation is a challenging task, and global, regional, national and sub-national cost estimates are reviewed, along with current data on amounts and sources of financing to date. Given the multiple definitions of adaptation, and the fact that adaptation is also counted in "good development" programs it is challenging to assess the level of resources specifically being targeted for managing climate risks. It is clear, however, that while there is widespread recognition of the need for adaptation, current levels of financing lag far behind cost estimates, and that funding for mitigation programs continues to outpace the levels dedicated to adaptation.

1. Introduction

Adaptation to climate change requires the adoption of anticipatory risk management, prior to actual impacts, at a range of temporal and spatial scales. Adaptation policies in the countries of the Gulf of Mexico and Caribbean vary from reactive programs in response to disasters, building infrastructural resiliency, to considerations of long term anticipatory planning for potential climate risks. They include regional efforts, as in the Caribbean Community Climate Change Centre's Regional Strategy for Achieving Development Resilient to Climate Change, national policies such as in Barbados, Dominican Republic, Mexico and Belize, delineations at sub-national levels as in Florida and the Yucatan, and city level planning as in Miami, Florida and Galveston, Texas. In the framing of adaptation policies, some efforts have hewed to the definition of adaptation adopted by the UN Framework Convention on Climate Change (UNFCCC), which focuses on reducing climate risks attributable to anthropogenic forcing. Others have taken on a broader frame (perhaps following the IPCC framing), to include a wide range of climate risks related to both natural variability and human induced climate change. For policy makers who need to draw up and implement adaptation efforts, whether an impact is natural or human induced is of less import, although these distinctions do become important in formulating decisions on who pays (Someshwar, 2008).

This review is organized into three sections. In the first, we review selected policy frameworks and action plans for adaptation in the Gulf of Mexico and Caribbean, highlighting examples at regional, national, state, and city levels. This is followed by a review of the costs and the current and anticipated financing to date for adaptation in the region. A final section concludes, highlighting key themes.

This limited review exercise does not attempt to summarize all of the literature on adaptation policy and financing in the Gulf of Mexico and Caribbean. It is to be read alongside other companion reviews that have been drafted on climate, potential impacts and vulnerabilities in the region. Given that this review is to serve as a background paper for a conference of policy makers from the region, each of whom have specialized knowledge of adaptation in their own countries, the review offers a sampling of the diversity and common approaches.

2. Selected Policy Frameworks and Action Plans for Adaptation

This section reviews several existing policy frameworks, strategies, and action plans that address climate change adaptation at a range of scales and within diverse sectors. For the most part the review is focused on policies and plans that are self-conscious of the need to better manage climate risks, and not on those that are seeking to advance "sustainable development" more broadly. It is, however, true that climate is but one source of risk to sustainable development (amongst a host of other interacting risk drivers that include political, social, ecological, economic and technological, as the recent catastrophic

Deepwater Horizon oil spill reminds us). The varying scales of these adaptation frameworks reflect the dizzying array of existing institutional arrangements, felt needs and capacities among the countries in the region. For example, regional processes are important in Caribbean countries, through the leadership of the Caribbean Community Climate Change Centre (CCCCC), which is coordinating responses to climate change for the Caribbean Community (CARICOM) member countries. Strategies in the Caribbean, crafted with participation from global institutions with financing and technical assistance, are leading to the development of national adaptation action plans, often focused on specific sectors.[12] In the United States, the US Global Change Research Program has advanced research on climate change mitigation and adaptation. A regional group of states, in the Gulf of Mexico Alliance, has launched the Governors' Action Plan for Climate Change. Finally, state and local level actions have begun to emerge in Mexico and the U.S., involving state and local agencies for which climate change may have implications. Some of these are formulated specifically around adaptation, while others especially in the U.S. Gulf States, are not explicitly framed for adaptation, but are a response to the challenges of crafting hydro-meteorological disaster risk reduction strategies. This section provides a sampling of some of the on-going efforts within this dynamic process.

a. Regional Level: Climate Change and the Caribbean: Regional Strategy for Achieving Development Resilient to Climate Change (2008-2015)

This strategy was prepared by the CCCCC at the request of the CARICOM Heads of State. It recognizes the "threat posed to the socio-economic development and well-being of the region and its people by climate change," and that its adverse effects "demand an urgent response from decision makers at the highest levels in national governments, regional organizations and the region's private sector and other key stakeholders" (p. 25). The normative strategy recognizes two essentials: the new emergent risks from climate change, and the current lack of adaptive capacity in the region. The strategy notes a range of potentially serious impacts, such as "[S]ea level rise with associated coastal erosion and salt water intrusion, an escalation in the frequency and intensity of tropical storms and hurricanes and disruptions in precipitation and to fresh-water supply that threaten the very existence of CARICOM States" (p. iv) Further, "[T]hese impacts would be reinforced due to the limited adaptive capacity of the CARICOM small island states"[13] (iv). The Strategy considers disaster risk reduction and adaptation as integrally related,

[12] They include, over the years, a diversity of projects and programs such as CIDA (undated) "Adapting to Climate Change in the Caribbean, 2002-2005". Inter-American Development Bank, (undated) "Program in Support of Mexico's Climate Change Agenda." GEF-UNDP (2000) "Capacity Building for stage II Adaptation to Climate Change in Central America, Mexico and Cuba." Inter-American Development Bank (2006) "IDB Regional Strategy for support to the Caribbean Community for 2007-2010." GEF-World Bank (2007) "Mainstreaming Adaptation to Climate Change", Government of Mexico (2007) "National Strategy on Climate Change", and GEF (2008) "Mexico Adaptation to Climate Impacts in the Gulf of Mexico".

[13] Total economic losses in the Caribbean Basin due to storms in the period 1979-2005 have been estimated to be about US$613 million annually (World Bank, 2008).

and “envisages that financing of disaster risk reduction initiatives will be treated as a development priority within the budgeting process” (p.19).

Two strategy elements related to adaptation include:

(1) Mainstreaming adaptation strategies into the sustainable development agendas of CARICOM Member States. Key adaptation-related goals include helping build regional capacity for vulnerability and risk assessment, improving vulnerability reduction via adaptation policies and multi-sectoral strategies, mobilizing financial resources, supporting a public education and outreach program, and building capacity of CCCCC’s for strategy implementation.

(2) Reducing the vulnerability of natural and human systems to impacts of changing climate. Key activities include revising building code and infrastructure standards, new regulatory approaches for insurance, integrated land-use planning, and development of crops more tolerant to weather extremes.

The total estimated cost of implementation over the period 2009-2015 is approximately US$22.91 million. The CCCCC is envisaged to coordinate strategy implementation in collaboration with relevant regional and national institutions and to provide technical support and guidance.

b. National-level adaptation policies

The wide spread and general recognition that “good development policy is good adaptation policy”, unfortunately, is used more to counter criticism of inaction than as a pragmatic stimulus for targeting various climate risks[14]. Many countries in the region, including Mexico, Dominican Republic, Belize, Cuba and Haiti, have national-level policy documents on climate change adaptation. Many of them are a result of international processes, and as follow-ons to the UNFCCC national communication efforts. Others, such as Barbados and Jamaica, have specific, sector-related adaptation policy documents. We review here one national and one sectoral policy document, for Belize and Barbados, respectively. The U.S. does not have a national adaptation strategy document. The recent report of the Council on Environmental Quality Climate Change Adaptation Task Force notes that while there is “substantial U.S. government and non-government activity towards adapting and building resilience to climate change risks,” significant gaps exist which, the Taskforce feels, could be addressed by a national strategy for climate change adaptation and resilience (U.S. CEQ, 2010, p .3). There are, however, significant adaptation policy outputs at state and local levels, which are reviewed in the next section.

Adaptation to Climate Change in Belize

The Government of Belize’s Policy Statement on adaptation to climate change emerges from an assessment of key vulnerability and adaptation options undertaken in the country’s first National Communication submitted to the UNFCCC Secretariat in 2001.

[14] A wide swath of development policies are cited, from enhancing climate observation systems and developing weather forecasting tools to strengthening financial markets and social safety nets (de la Torre et al., 2009).

These documents, required periodically from signatories to the Framework Convention on Climate Change, have been supported through Global Environment Facility (GEF) funding for developing countries, and form the initial basis for certain national-level initiatives and for projects funded by multi-lateral and bilateral donors.

The Belize Policy Statement acknowledges that the precise impacts of climate change at the regional and national levels are unknown at this stage. It stresses that, however, the "best scientific evidence indicates that there could be significant repercussions on the productive sectors of Belize…" (p.1), such as in agriculture, coastal zones, energy, fisheries, forestry, human settlements, and water resources (Government of Belize 2008). The key emphasis of the statement is to encourage "all agencies in Belize to explore and access the opportunities being developed by the climate change negotiation process such as capacity building, new sources of funding, and technology transfer. It also mandates the relevant government agencies to "prepare adaptation policy options for their sectors" (p.1). It directs key impacted sectoral ministries to undertake specific vulnerability studies, prepare adaptation plans, and promote specific adaptation options. The Policy Statement also directs the Belize National Climate Change Committee, with the Chief Meteorologist as its convener and membership drawn from a range of ministries, academia and non-governmental communities, to provide advice to the government on all aspects of climate change, assist in required studies, promote public awareness, and supervise climate change projects in the country.

A national adaptation strategy for the water sector was drafted in Belize, as part of a large, Global Environment Facility/World Bank-funded project called Mainstreaming Adaptation to Climate Change (Belize Enterprise for Sustainable Technology, 2009). Recognizing the potential climate-related vulnerabilities to the availability and use of fresh water, the strategy recommends several adaptation actions, with an emphasis on strengthening institutions and enhancing their capacities to undertake adaptation measures in the water sector.

As part of the Second National Communication process, adaptation strategies were formulated for sugarcane and citrus crops (Santos and Garcia, 2008). Some of the key recommendations include: (a) climate change related efforts, such as strengthening data collection and monitoring of climate and agriculture sectors, improved management of current climate risks, mapping of climate risks and vulnerabilities, developing insurance, incentive and public outreach/awareness programs; and (b) "no regret" measures, such as to strengthen research, promote better land use management, improve information access and inter-agency cooperation, and update and revise sector legislations, policies and strategies.

<u>Barbados National Adaptation Strategy for the Tourism Sector</u>

The Caribbean has been recently identified as a 'tourism vulnerability hotspot' due to climate change (Simpson et al., 2008). Over the last 20 years, tourism earnings in Barbados have accounted for well over 60% of total export earnings. Employment figures also point to the importance of tourism, which now employs more than the manufacturing or agriculture sectors. In Barbados, as in other Caribbean island countries, the key impacts of climate change are identified to be sea level rise, increased temperatures (land and sea), and potential changes in patterns of hurricanes and other extreme events. Climate-induced ecological changes are also expected to impact marine, coastal and terrestrial habitats and their diversity, infrastructure, food production, water resources and human health. The Adaptation Strategy notes, "It is imperative therefore, that Barbados implements adaptation strategies to address the potential impacts on its tourism sector arising from the effects of climate change" (University of West Indies, 2009, p. 7).[15]

The strategy suggests a number of key changes to policy and legal instruments, investments, and institutions in the tourism sector, and that physical infrastructure comply with existing planning regulations and policies. On the legislative front, a key recommendation is to formulate a (new) Climate Change Act that would include specific provisions for adaptation plans, and would enable the establishment of a government body (National Climate Change Unit) responsible for the administration and enforcement of the Act. In addition, the strategy suggests the establishment of a high-level scientific and technical advisory body to prioritize mitigation and adaptation efforts, and to guide research and formulation of sector- and policy-relevant climate change projections and scenarios. Improvements to the knowledge base are also suggested, particularly critical, downscaled information needed for adaptation planning such as geo-referenced bathymetric and topographic data to predict storm surges, erosion and flood zone mapping, updated hazard maps for use in contingency planning and disaster preparedness, and an inventory of critical infrastructure and land values. The Barbados Tourism Adaptation Strategy is to be aligned closely with on-going disaster management projects, and institutional stakeholders, government as well private, are also expected to implement a range of efforts to help mainstream adaptation measures.[16]

c. Sub-national multi-state efforts: Gulf of Mexico Alliance, Governors' Action Plan II: For Healthy and Resilient Coasts, 2009-2014

This Action Plan, developed through the Gulf of Mexico Alliance involving the five mainland U.S. Gulf states, in collaboration with the six Mexican states bordering the Gulf, follows the Governors' Action Plan for Healthy and Resilient Coasts (2006). "Mitigating the impacts of and adapting to climate change" is one of four challenges identified in the Governors' Action Plan II (Gulf of Mexico Alliance, 2009). The plan explicitly recognizes that "Climate change and the associated predicted sea-level rise cause physical changes to the Gulf Coast that adversely impact communities, infrastructure, and natural resources…. Certainly, the Gulf will continue to experience significant destructive coastal storms, but mitigation methods such as accurate mapping, tide level predictions, resilient land use plans, and habitat conservation and restoration

[15] University of West Indies, 2009. The strategy draws on four recent studies of the tourism sector of Barbados: economic review, institutional assessment, review of climate change threats, and an assessment of key climate change policy options.

[16] The strategy calls for the coordinated efforts of a number of agencies, including the Ministry of Tourism, Barbados Hotel and Tourism Association, Environmental Unit of the Ministry of Environment, Coastal Zone Management Unit, Town and Country Planning Development Office, Central Emergency Relief Organisation, and Barbados Building Standards Authority.

can increase a community's ability to "bounce back" after such events.[17] The actions provided in the Governors' Action Plan II present methods for predicting ecological changes and enhancing both natural and built resources, thus creating more sustainable coastal communities" (p.8). In addition to the five Gulf States, key U.S. partners in this Alliance include 13 federal agencies working under the leadership of EPA, NOAA and the Department of the Interior and a number of NGOs including academia, non-profit organizations and businesses, and partners from Mexico.

Of the six priority areas that have been identified in the Governors' Action Plan II, three are related to adaptation areas of activities. They are: "Habitat conservation and restoration focus areas", "Ecosystems Integration and Assessment Focus Areas," and "Coastal Community Resilience Focus Areas." Under Habitat conservation and restoration, action steps are indentified for Policy Changes and Technology Development, including recommended revisions to the federal standards on calculating costs and benefits of conservation efforts, identifying policy and economic limitations restricting private landowner participation, hold working sessions on uncertainties (e.g., sea level rise) that limit the state of conservation science and the development of science-based management (p.16). The development of a "natural resource data portal and information system that will enable resource managers to develop sound recommendations for managing valued coastal resources" is prioritized in the Ecosystems Integration and Assessment, along with the development of an "Emergent Wetlands Status and Trends Report to provide scientists and decision makers with regional information to guide management decisions" (p.21). In addition to "the economic, ecological, and social losses from coastal hazard events" that "have multiplied as development and population growth increasingly place people in harm's way and as the ecosystems' natural resilience is compromised by development and pollution" attention is also drawn to the "latest climate change research" that "suggests that new challenges are on the horizon from sea level rise and other impacts."

Citing resilience building as an "economic imperative for the Gulf region," the focus areas identified include Risk and Resilience Assessment, Risk and Resilience Management Toolbox, and Risk and Resilience Communication. Key specifics of note include the development of a Master Plan to enhance region-wide observing systems and measurement of "millimeter-scale changes in land elevations and water level," a data platform on coastal hazards, identification of cost/benefit assessment models associated with coastal hazards and climate change, an inventory of capabilities and tools to address coastal hazards in the Gulf Region, and recommendations to enhance resilience and promote best management practices at marinas. (p. 27-29). Information on potential next steps being envisaged to help realize the bold vision of the Governors' Action Plan II is not publicly available.

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[17] "Mitigation" is used here to convey reduction of (disaster) impacts rather than in the climate change community usage of GHG emission reduction.

d. State-level policies and programs

In contrast to efforts by Latin American and Caribbean countries, the need for adaptation planning does not seem to have gained broad acceptance amongst all of the U.S. states. While over 32 states have initiated action to reduce GHG emissions, only 10 are in the process of planning for adaptation (Cruce, 2009). Amongst the Gulf states, only Florida has investigated adaptation needs and plans, as part of its Energy and Climate Change Action Plan. This effort is examined in detail below. In other states, for the most part, adaptation to climate change is yet to receive sustained official efforts at the state level. We examine Louisiana's Comprehensive Master Plan for a Sustainable Coast as an example of the latter.

Florida's Energy and Climate Change Action Plan: Adaptation strategies

The Florida Action Plan was prepared by the Center for Climate Strategies for the Governor's Action Team on Energy and Climate Change.[18] While the key focus of the Florida Action Plan is on emission mitigation and energy, it includes one chapter on Adaptation Strategies. It identifies 14 issues, along with specific goals, objectives, and early action items. Nine of them are related to themes/sectors (such as climate impacts, ecosystems, water, built environment, health, insurance, emergency preparedness etc.), and the rest focus on planning, institutional architecture, financing and education. The Action Plan lays out a very detailed and ambitious agenda, stressing the need to integrate knowledge of climate change and impacts within existing regulatory and planning processes. It notes that while there is much to be understood regarding climate change trends, potential consequences of sea level rise, and hurricane activity, "there is sufficient information to justify implementing many adaptations." (Pg. F-3). Other elements of the Florida Action Plan focus on specific areas of potential climate impacts and socio-economic vulnerabilities such as water management, built environment, emergency response, health, ecosystems, etc. For example, under Water Resources Management, a number of goals are identified that cover a range of issues, such as quantifying vulnerability of existing water supplies to climate change, formulating water demand projections accounting for potential climate change impacts, and integrating this knowledge into a range of programs. The early policy actions identified for water resources management include conducting a study of the impacts of different climate change scenarios on high risk utilities and potential adaptation strategies, and planning for the relocation or protections of freshwater resources from saltwater intrusion. For Economic Development, the key policy recommendations are to investigate the potential impacts of climate change on critical economic sectors (such as tourism, agriculture, forestry, marine resources, construction etc.), examine new opportunities, and draw up adaptation options. The Florida Action Plan consists of a mix of policy recommendations, including those that are good practice even in the absence of climate change considerations (such as developing conservation programs that incentivize water

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[18] The Center for Climate Strategies is described on its website as "a public purpose, nonpartisan, nonprofit 501(c) (3), partnership organization that was formed in 2004 and is funded by private foundations, donors and governments at the program and project levels. We are headquartered in Washington, DC with over 30 national and field experts across the U.S, Canada and Mexico." http://www.climatestrategies.us/Who_We_Are.cfm

and energy usage efficiencies and strengthening vaccine campaigns) and those that are specifically targeted for better adaptation to potential climate change impacts (such as examining alternative financing methods to meet climate change demands and creating incentives for businesses to use latest technologies to adapt to climate change).

Louisiana's Comprehensive Master Plan for a Sustainable Coast

The above are examples of policy documents framed explicitly around adaptation to climate change. A key goal of many of them is to initiate processes to incorporate climate change into planning and policy across sectors. Louisiana's Comprehensive Master Plan for a Sustainable Coast, developed from 2005-2007 in the wake of hurricanes Katrina and Rita, offer an example of some of the challenges involved in incorporating climate change into existing planning and programs.

The development of the Master Plan was led by the Coastal Protection and Restoration Authority (CPRA), established in 2005 for the purpose of "coordinating the efforts of local, state, and federal agencies to achieve long-term and comprehensive coastal protection and restoration" (CPRA, 2007, Executive Summary). The Master Plan "portrays the State's desires and needs relative to hurricane protection and coastal restoration, integrating these efforts in order to achieve long-term and comprehensive coastal sustainability" (Appendix A, p. 4).

The Master Plan considers climate change in a fairly limited manner. In "Chapter 2: Assumptions, Tradeoffs, and Challenges" in a section on "Climate Change," the report notes that "Coastal Louisiana will be among the first places in North America to feel the effects of global warming. Its low-lying coast will be directly impacted by rising sea level and more frequent hurricanes. Longer dry periods and more intense storms linked to global climate change would further stress some of the more highly managed wetland areas of coastal Louisiana. Larger storms will drive more salt water into fresh systems that are unable to flush it back out because of the lack of drainage, rainfall, and fresh water input from rivers. And the longer salt water remains in the wetland system, the harder it will be for the vegetation to recover after a storm surge" (pg.25-26). The section concludes with "the need for the Master Plan to explore aggressive ecosystem restoration measures. In addition, the actions of this comprehensive restoration and protection program must be effective under a range of climate change scenarios" (pg. 27).

The Master Plan (Chapter 3) discusses key project components, including "Restoring Sustainability to the Mississippi River Delta," "The Mississippi River Gulf Outlet," "Restoring Sustainability to the Atchafalaya River Delta and Chenier Plain," and "Hurricane Protection." Sea level rise, however, is not explicitly mentioned, nor is there any discussion of the potential implications of sea level rise on the delta regions. Climate change is mentioned briefly in the context of water management in the Mermentau Basin, where it is noted that "climate change-induced shifts in rainfall patterns may intensify the problem of salinization and make resolution of these water management challenges more crucial than ever." In the section on Decision Support, "potential impacts of climate change on program recommendations" is mentioned as one of the areas in which further research and demonstration projects are needed (Appendix A, p. 65-66).

A number of public comments submitted on the draft plan raise issues related to climate change, such as on the need to be more explicit in addressing climate change, on sustainability challenges given climate change, on the implications of sea level rise etc. However, it is difficult to fully understand the extent to which climate change and adaptation to its potential impacts were fully imbricated in the Plan. To paraphrase the submission of the Environmental Defense, National Audubon Society, and National Wildlife Federation during the Public Comment period of the draft plan, "Global climate change is addressed briefly in the draft plan, but it is unclear how the Plan has been changed, and will be changed in the future, to address climate change." (EDF, 2007)

e. City-level efforts

A number of cities, especially in the U.S., have begun to undertake efforts to better integrate adaptation efforts within their long-range planning frameworks, mainly in the context of disaster risk reduction efforts (see Annex 1 for an overview of efforts in the coastal cities in the U.S. Gulf Coast). To informally assess the degree to which adaptation is being considered, these city-level plans were perused for their use of specific terms in the following categories:

Climate change: climate, change, climate change, global warming, adapt
Sea level rise: sea level rise, rising, coast, melt, elevation, intrusion
Subsidence: subsidence, sinking, elevation
Climate-related disasters: flood, storm, surge, hurricane, disaster, emergency, hazard, risk

The review reveals that while adaptation as a central component is rare, climate change related issues, especially from hazards such as hurricanes and flooding are considered by many. Rather than a lack of awareness of climate change impacts, a key challenge seems to be the difficulty of identifying and integrating adaptation/risk management activities in the plans. We briefly explore planning for climate change adaptation in the context of the City of Galveston to better appreciate some of the challenges.

<u>City of Galveston efforts to manage climate-related risks</u>

For residents of Galveston, as for many Gulf Coast residents, the devastation caused by recent hurricanes has drawn attention to climate change related vulnerabilities. Planning for climate change impacts does not find mention in the Comprehensive Plan for the City (City of Galveston, 2001). However, in more recent city-wide efforts the issues have come strongly to the fore. On September 13, 2008, Hurricane Ike made landfall on Galveston Island, Texas, causing wide-spread devastation. In the weeks that followed, The Galveston Council appointed the Galveston Community Recovery Committee to help identify projects that would move Galveston along the road to full recovery. Given the temporal context of the planning process, reducing the impacts from future flooding events, wetland loss and hurricane surges, are high on the agenda of the Action Plan (City of Galveston, 2009).[19] In formulating of the Hazard Mitigation Plan, for example, there is explicit recognition of the need to inform decision makers regarding natural and man-made hazards (current and future) affecting Galveston Island, in order to make informed decisions to reduce risk exposure. A key aspect is to "map probability-surge inundations incorporating long-term effects of sea level rise and storm probability models, as well as beach and wetland loss erosion due to projected sea level rise." (p. 121)

3. On costing and financing of adaptation

A number of attempts have been made, at the global, national and local levels on getting a handle on the costs involved in adapting to climate change (Bueno et al 2007, Tol 2002, OECD 2008, Oxfam 2007, UNFCCC 2007, World Bank 2009). Two distinct approaches have been employed in such estimates. One has been to focus only on the adaptation costs to cope with future climate change. The World Bank's study of the costs to developing countries of adapting to climate change follows this method (World Bank 2009). The other method is to include the costs needed to build resilience to current climate variability, the costs of the so-called "adaptation deficit". As Burton notes, "Failure to adapt adequately to existing climate risks, largely accounts for the adaptation deficit. Controlling and eliminating this deficit in the course of development is a necessary (but not sufficient) step in the longer run project of adapting to climate change" (Burton, 2005). However, irrespective of cost calculation methods, the nature and degree of adaptation efforts makes comparison of cost estimates quite challenging. As Iyahen and Young note, the adaptation portfolio "could range from technological (*e.g.* sea defenses), through to behavioral (*e.g.* altered food and recreational choices), to managerial (*e.g.* altered farm practices) and to policy (*e.g.* planning regulations). In fact, there is no clear picture of the limits to adaptation, or the cost…" (Iyahen and Young 2009, p. 3). The observation of the recent U.S. National Academy of Sciences adaptation report (2010) on the limited utility of such cost estimates "in the context of the wide variety of U.S. decision processes" (p. x) holds true for other countries as well.

Further, "[E]stimating the costs of adaptation with precision is even more difficult, not only because adaptation measures will be widespread and heterogeneous, but also because these measures need to be embedded in broader development strategies.." (UN 2009, p. 155). The UNFCCC secretariat estimates the additional annual investments needed globally for adaptation to be in the range of US$49-171 billion in 2030, with the portion needed in developing countries to be US$34-57 billion, both in 2005 US dollars (UNFCCC 2007). In its recent study of the costs of adaptation, the World Bank estimates that the global cost of adapting developing countries by 2050 (to approximately 2 degree

[19] Examples include: "Wetland loss is a major threat to the Galveston Bay Estuary. Throughout the Estuary between the 1950s and 1990s, there was a net decrease of approximately 19 percent of the total vegetated wetlands. Losses on Galveston Island have been the result of man-induced subsidence and related sea level rise, erosion, filling, and dredge-and-fill activities. On Galveston Island, subsidence caused by the excessive withdrawal of subsurface fluids, principally groundwater has ranged from one- to two-feet since the early 1950s." "Protect the entire Houston-Galveston Bay/Beach Region from hurricane surge using a coastal barrier solution similar to the Dutch Delta Works." (City of Galveston, 2009. Galveston Long-Term Community Recovery Plan. P. 109)

C) will be in the range of $75-100 billion per year (World Bank, 2009. pg. 4). For the Latin America and the Caribbean region, the range is estimated to be between US$16-23 billion a year. In the study, while the costs of adaptation increase over time, they fall as a percentage of GDP, suggesting that "countries become less vulnerable to climate change as their economies grow" (pg. 6).

Studies have also assumed different baseline estimates, making comparison arduous. The World Bank study (2009) assumes a 2050 timeframe, with sector baselines both with and without climate change, and using both GDP and population projections. However, another World Bank study for the LAC region estimates the potential economic impacts of climate change in the Caribbean estimates climate impacts in 2080 compared to 2007 population and prices (Toba, 2009). In the latter study, the estimated total annual impacts of potential climate change on CARICOM countries alone, for 2080, is $11.2 billion per year (in 2007 US$). This is in contrast to the LAC estimate of the World Bank's global study in 2009, which estimates $16-23 billion a year for the entire LAC region by 2050.

Another study on climate change costs in the Caribbean considers hurricane damages (extrapolated from past), tourism losses, and infrastructure damages due to sea-level rise (Bueno et al 2007). Total cost estimates are in the range of $5.7-27.6 billion (2007 US dollars).[20] Drawing attention to the diversity of adaptation cost estimates for the Caribbean region, and perhaps the futility of such exercises, the Executive Director of the CCCCC notes that "The UN's latest Human Development Report (HDR) estimates that additional adaptation finance needs will amount to US$86 billion annually by 2015. Oxfam puts the price tag at US$50 billion per year, and the UNFCCC puts it at US$2867 billion by 2030. Based on the Oxfam estimate of US$50 billion and a population of 40 million the Caribbean region will require some US$430 million annually to meet its adaptation needs. (Leslie, 2008 p. 8-9).

Sub-national costs from specific sectoral impacts of climate change are relatively rare in the developing countries of the Caribbean (Borisova et al 2008, CCS 2009, Stanton and Ackerman 2007). For the U.S. Gulf States, a number of such studies have been taken up. In the case of Florida, an oft-quoted study estimates the loss from future sea level rise for the year 2080 (Harrington and Walton, 2007). Extrapolating from current trends, sea levels are expected to rise in the range of 0.23-0.29 feet by 2030 and 0.83-1.13 feet by 2080 (lower than the IPCC estimates). Even if hurricane intensity and frequency remain unchanged, more frequent storm surge events can be expected. The study notes that "…the 7-foot high storm surge experienced in Dade County during Hurricane Wilma would -- under present conditions -- be expected to recur only once every 76 years. With a sea level rise of 1 foot, the expected frequency of a similar storm surge increases three-fold—to once every 21 years." This is expected to lead to increased storm damage costs, anywhere from 10 to 40 percent. Not accounting for increases in coastal population or

[20] "The potential costs to the Caribbean nations if greenhouse gas emissions continue unchecked is derived by comparing two scenarios of the IPCC, an optimistic scenario (rapid stabilization) and a pessimistic one ("business as usual). The cost of inaction, or the difference between these two scenarios, is seen in this study as "the potential savings from acting in time to prevent the worst economic consequences of climate change". Bueno et al. 2007.

property values, the study suggests that potential property losses would be over $1 billion (in 2005$) in Dade County alone with a 0.16 feet sea level rise.

Assessing the current and likely future financing for adaptation can be equally challenging. Charts 1 indicates the amounts pledged, deposited and disbursed in international funding initiatives designed to help developing countries address the challenges of climate change for both mitigation and adaptation (Climate Funds Updates, 2009).[21]

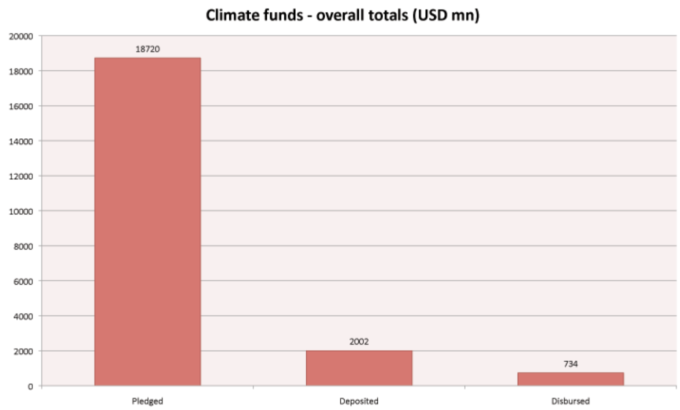

Chart 1. Overall pledged climate funds (mitigation and adaptation). Source: Climate Funds Updates, 2009.

[21] The funds are current up to Dec. 2009. **Pledges** represent verbal or signed commitments from donors to provide financial support for a particular fund. **Deposits** represent the funds that have been transferred from the donor into the account(s) of the fund. **Disbursed** funds represent those funds that have been spent, either through administrative means or directly to an implementation programme or project, with proof of spend. http://www.climatefundsupdate.org

Table 1 provides an overview of international funds for adaptation, providing some operational details of amounts pledged and disbursed, and the key adaptation activities proposed. There is a diversity of funds, set up by a range of governments and in some cases inter-governmental entities. A more or less common feature seems to the low percentage of disbursed to pledged

Name of Fund	Operational from date	Proposed life of fund	Fund administrator	Funds pledged / received	Funds disbursed to date	Adaptation activities supported
The Kyoto Protocol Adaptation Fund (Adaptation Fund)	Established Nov. 2001, Proposal call in 2010	Indefinite	Adaptation Fund Board / World Bank	US$33.9 million (Nov. 2009)	US$5.64 million for operational expense (Nov. 2009)	Monitoring diseases & vectors; capacity building related to disasters; national/ regional centers and information networks for rapid response to extreme weather events
Cool Earth Partnership	Proposed Jan. 2008;	2008-2010	Japanese Ministry of Finance	US$2 billion for adaptation of total US$10 billion		Afforestation, disaster prevention, adaptation planning, rural development through clean energy electrification, drought management, and flood prevention
The Environmental Transformation Fund – International Window	July 2008	Contingent upon development of new financial architecture	Det. for International Development (DFID) and Dept. Energy & Climate Change, UK	£800 million	£300 million as of 2010	Supports the Pilot Programme for Climate Resilience, World Bank's Strategic Climate Fund (see below)
The GEF Trust Fund - Climate Change focal area	1994		Global Environment Facility (GEF)	US$3.13 billion for 2006-2010	US$ 2.55 billion since 1994	To provide benefits and may be integrated into national policies and SD planning; Adaptation activities through Least Developed Country Fund and Special Climate Change Fund.
Global Climate Change Alliance	2008	2008-2010 (initial)	European Commission's Co-operation Office: EuropeAid	€139.6 million (Dec. 2009)		Adaptation plans; financing pilot projects (water, ag., natural resource management); climate monitoring, forecasting and information systems; implementing Hyogo Framework
International Climate Initiative (ICI)	July 1, 1909	2008-2011 (initial)	Federal Env. Ministry(BMU), German Government	€120 million per year (half for adaptation)	€150.06 million	Biodiversity conservation and climate protection
Least Developed Countries Fund	2002		Global Environment Facility (GEF)	US$176.5 million pledged (May 2009)	US$ 111.9 million (Nov. 2009)	Preparation and implementation of National Adaptation Programmes of Action (NAPAs)
MDG Achievement Fund - Environment and Climate Change thematic window	2007	2007-2010	United Nations Development Programme (UNDP)	US$90 million (Nov. 2009)		Environmental issues in national and sub-national policy, planning and investment frameworks; Local management of environmental resources and service delivery; enhancing adaptation capacity
Pilot Program for Climate Resilience (PPCR)	2008	2008-2012	World Bank	US$208 million (Jan. 2009)		Country specific components in pilots, region-wide activities of climate monitoring, institutional strengthening, capacity building and knowledge sharing
Special Climate Change Fund	2002		Global Environment Facility (GEF)	US$121.1 million (May 2009)	US$91.20 million (Nov. 2009)	Climate change risk reduction strategies, policies, and practices in sectors; institutional & constituency capacity building in water, agriculture, health & infrastructure development
Strategic Priority on Adaptation (SPA)	2004	2004-2007 (complete as of 2008)	Global Environment Facility (GEF)	US$50 million (Dec. 2009)	US$50 million (Dec. 2009)	Capacity building for sustainable use of natural resources; vulnerability reduction & adaptive capacity enhancement of vulnerable communities and ecosystems

Table 1. International Funds for Adaptation

Source: Adapted from Climate Funds Update <http://www.climatefundsupdate.org>., updated where possible from publicly available data on fund websites

Table 2 provides data on the fund amounts received from the GEF Trust Funds in the Caribbean by country-level projects, for regional projects and as part of global efforts.

Country	Adaptation Projects	Fund amount (millions of USD)
Antigua And Barbuda	2	0.26
Bahamas	2	0.29
Barbados	2	0.29
Belize	1	0.19
Cuba	1	0.15
Dominica	2	0.27
Dominican Republic	2	0.45
Grenada	2	0.28
Haiti[1]	4	4.14
Jamaica	2	0.33
Mexico	2	15.0
Niue	2	0.4
St. Kitts And Nevis	2	0.26
St. Lucia	2	0.27
St. Vincent and the Grenadines	2	0.45
Trinidad and Tobago	2	0.32
Total	**32**	**23.35**

Region-specific projects	Adaptation Projects	Fund amount (millions of USD)
Total	**4**	**14.64**

Global projects with activities in the region	Adaptation Projects	Fund amount (millions of USD)
Total	**3**	**9.12**

Note (1): All projects are funded by the GEF Trust Fund, with the exception of two projects in Haiti. These two projects are funded by the Least Developed Country Fund and account for US$3.7 million of the total.

Source: Adapted from Climate Funds Update <www.climatefundsupdate.org>

A few key features of adaptation financing are worth noting.

- Currently, despite widespread recognition of the urgent need to advance climate change adaptation, current dedicated climate funds that have been pledged heavily favor mitigation (to the tune of about 80:20).
- Despite the large number of funds that have been declared over the past few years the amounts that have been pledged are quite inadequate relative to the costs of adaptation.
- The amounts actually disbursed for adaptation activities are a small proportion of the amounts pledged.

These characterizations are not unique to the developing countries in the Caribbean region. They hold true for other developing regions as well.

In the Copenhagen Accord, developed countries collectively committed to provide new (and additional) resources to developing countries for adaptation and mitigation efforts. These resources involve two funding initiatives. The first is "approaching USD 30 billion for the period 2010-2012 with balanced allocation between adaptation and mitigation. Funding for adaptation will be prioritized for the most vulnerable developing countries, such as the least developed countries, small island developing States and Africa." (#8, page 3). The second is "a goal of mobilizing jointly USD 100 billion dollars a year by 2020 to address the needs of developing countries. This funding will come from a wide variety of sources, public and private, bilateral and multilateral, including alternative sources of finance." (#8, page 3). No action is discernable on the first declaration. In the months following the Copenhagen Accord some action has been evident on the second. In early February of this year, the UN Secretary General appointed a High Level Advisory Group on Climate Change Financing. The first meeting was in London on March 21, with an expectation that "a final report will be submitted to the UN Secretary-General and to the current (Denmark) and next (Mexico) president of the UNFCCC Conference of the Parties by November 2010" (UN AGF 2010).

Given the lack of clearly defined programs on climate change adaptation at the state or local levels, in the US Gulf states, it is difficult to put a figure on the ongoing efforts in the region. Building infrastructural resilience to climate variability continues to be funded at the federal, state and local levels. However, as a perusal of the state and local plans reveals, cataloging specific adaptation efforts and linking them to specific program funds is challenging.

4. Conclusion

In the developing countries of the Caribbean, adaptation to climate change is getting a high degree of policy attention, often driven by the imperatives of international negotiations. Unlike in the first generaiton of efforts, the focus, increasingly, is not only on the long term (century scale), but includes current needs to better anticipate and respond to climate variability. While many policy documents have been drafted, action locally, is often slow perhaps due to relatively low capacities and inadequate resourcing. The reverse, as it were, seems to hold true in some U.S. states. In Florida, for example, a higher political legitimacy seems afforded to climate change. However, a common characterization, in the developing countries of the Gulf of Mexico and the Caribbean and in the U.S., is the lack of a clear, science-informed and stakeholder driven process that aims to advance pragmatic adaptation solutions at a range of spatial and temporal scales.

Deliberations of costs and benefits of adaptation are driven to some extent clouded by ideology, and on occasions seem driven more by the needs of negotiations. The limited funding likely available for adaptation is far outstripped by funding for mitigation purposes. Assessing funding levels is further complicated since mainstream development programs (such as for social safety nets) are considered in some countries (in some instances) as adaptation, while in some others, programs to manage current climate risks are not considered.

While policy efforts are being advanced at national levels, perhaps a greater emphasis may be needed to distill and share local level advances within the Gulf of Mexico and the Caribbean region. While the uncertainty surrounding local climate change impacts certainly presents a challenge in policy development, some opportunities do exist today. For example, even conservative estimates suggest that climate change will likely inundate large wetland areas, and new areas will be transformed into wetlands as water levels rise (Jacob and Showalter, 2008). However, few restoration projects are designed with future sea level rise in mind. In the Caribbean and U.S. Gulf States, there are currently no policies to conserve future wetlands from sea level rise. As the authors note, the rolling easement provisions (for example, in the Texas Open Beaches Act) offer a promising approach for identifying and helping preserve inundatable lands for the entire region.

Many aspects of managing climate risks are based on sound science, are well understood, and show high potential for replication. A solution oriented regional network can help provide focus and heft, share learning and build local and national capacities for high priority efforts such as the adapation of most vulnerable communities, buffer critical ecosystems and build climate resiliency of high value economic assets in the Caribbean and Gulf of Mexico region.

ANNEX 1
Example of City-level efforts in the US Gulf States

A number of cities in the US have begun to undertake efforts to better integrate adaptation efforts within their long range planning frameworks, mainly in enhance disaster risk reduction efforts citywide. This Annex presents information that is available on the web for some of the coastal cities in the US Gulf Coast. City/regional plans that were currently available on the web were perused using specific key terms including:

> **References to Climate Change:** climate, change, climate change, global warming, adapt
>
> **References to Sea Level Rise:** sea level rise, rising, coast, melt, elevation, intrusion
>
> **References to Subsidence:** subsidence, sinking, elevation
>
> **References to Climate-related Disasters:** flood, storm, surge, hurricane, disaster, emergency, hazard, risk

Reproduced below are the references found in the textual review of the plans.

City/Region: Houston - Galveston Region
Plan(s) Consulted: Houston - Galveston Regional Transportation Plan – 2007
References to Climate Change:

> "Although the total future impacts of climate change remain unknown, possible future impacts include an increase in sea level and extreme weather conditions, such as droughts and flooding. These changes in climate conditions also have potential impacts on transportation systems.
>
> Potential impacts of climate change upon our region's transportation system include changes in the safety, operations, and maintenance of the region's transportation infrastructure and systems. The H-GAC region is particularly vulnerable to hurricanes/tropical storms and flooding, which may be intensified by sea level rise and/or land subsidence.
>
> H-GAC, in coordination with the Department of Transportation and other entities are working to identify the potential impacts of climate change and variability on our region's transportation system and ultimately to develop strategies and policy options to
>
> adapt to any future changes. Due in December 2007, the U.S. Department of Transportation study "The Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study" will be particularly beneficial in assisting H-GAC's transportation and climate change planning efforts.
>
> The 2035 RTP represents the first steps in H-GAC's integration of climate change into the transportation planning process."
>
> (Houston - Galveston Regional Transportation Plan – 2007, 49)

References to Sea Level Rise: See above
References to Subsidence: See above
References to Climate-related Disasters: See above

City: Corpus Christi

Plan(s) Consulted: Metropolitan Master Plan**;** Metropolitan Transportation Plan 2010-2035**;** Comprehensive Plan**;** Parks, Recreation and Open Space Plan**;** Future Land Use Plan

References to Climate Change:

Metropolitan Transportation Plan - Mentions in chapter on Air Quality and Climate Change; the only discussion concerns mitigation options in transportation planning -

"Broadly, Climate change considerations should be integrated throughout the transportation decision-making process–from planning through project development and delivery. However, addressing climate change mitigation and adaptation up front in the planning process will facilitate decision-making and improve efficiency at the program level, and will inform the analysis and stewardship needs of project level decision-making. Climate change considerations can easily be integrated into many planning factors, such as supporting economic vitality and global efficiency, increasing safety and mobility, enhancing the environment, promoting energy conservation, and improving the quality of life."
(Metropolitan Transportation Plan 2010-2035, 77)

References to Sea Level Rise: None
References to Subsidence: None
References to Climate-related Disasters:

Parks, Recreation and Open Spaces Master Plan - "City policy should continue to require no construction, except as provided below in compliance with the City of Corpus Christi Flood Hazard Prevention Code, be allowed to occur within the 100-year flood plain as delineated on Flood Insurance Rate maps. This will help to minimize damage to development during times of flooding. In addition, the City may accept the donation of low lands adjacent to the creek and bay to create a buffer and to preserve natural habitats.
...
It should be noted that the Federal Emergency Management Agency (FEMA) is updating the existing Flood Insurance Rate maps. The new maps could change the width of the flood plain which will have an effect on the wetlands and the amount of land available for parks and open space."
(Parks, Recreation and Open Space Plan, page D-9)

"Designation of the entire 100-year floodplain of the creek and natural tributaries as a buffer to protect the aesthetics and habitat of the creek, provide for bio-filtering of runoff and non-point source pollution, and protect homes from flooding."
(Parks, Recreation and Open Space Plan, page D-7)

"The dunes on Mustang Island help to protect the area from hurricane storm surge."
(Comprehensive Plan Update Requests, 25)

City: Galveston

Plan(s) Consulted: Long-Term Community Plan; Comprehensive Plan – 2001 Capital Improvement Program; Master Drainage Plan**;** Mobility Plan**;** Master Park Plan

References to Climate Change:

"Map impact areas of existing and probable future hazards on Galveston Island...Revise existing maps based on data from reliable sources and from Hurricane Ike, incorporating projections of future climate change."

(Long-Term Community Plan, 121)

References to Sea Level Rise:

"Map impact areas of existing and probable future hazards on Galveston Island...

• Probability-surge inundation maps incorporating long-term effect of sea level rise and storm probability models.

• Erosion mapping: beach loss and wetland loss due to annual and event-driven natural phenomena; Projections of future losses will include effect of sea level rise." (Long-Term Community Plan, 121)

"Wetland loss is a major threat to the Galveston Bay Estuary. Throughout the Estuary between the 1950s and 1990s, there was a net decrease of approximately 19 percent of the total vegetated wetlands.8 Losses on Galveston Island have been the result of man-induced subsidence and related sea level rise, erosion, filling, and dredge-and-fill activities." (Comprehensive Plan - 2001, 110)

References to Subsidence:

"Elements of Port Capital Planning ... Needs assessments and pre-engineered infrastructure projects such as bulkheads, subsidence repairs and other existing facilities"

(Long-Term Community Plan, 33)

"The island currently suffers from a sediment deficit, erosion and subsidence, which is the predominant factor in wetland loss." Proceeds to discuss action steps for habitat restoration - and notes, "Mitigating hazards through natural processes is the most cost effective way to prepare for future flooding events and is considered an extremely valuable method by the federal government and state mandates. These programs can be implemented immediately....

This project will create jobs and protect the environment to preserve and increase the annual income for Galveston's Eco-Tourism, which relies heavily on recreational fishing, bird watching and the beaches. Commercial fisheries are estuarine dependent."

(Long-Term Community Plan, 39)

As in Sea Level Rise - "Wetland loss is a major threat to the Galveston Bay Estuary. Throughout the Estuary between the 1950s and 1990s, there was a net decrease of approximately 19 percent of the total vegetated wetlands. Losses on Galveston Island have been the result of man-induced subsidence and related sea level rise, erosion, filling, and dredge-and-fill activities. On Galveston Island, subsidence caused by the excessive withdrawal of subsurface fluids, principally groundwater has ranged from one-to two-feet since the early 1950s.

A number of actions should be taken by the City of Galveston in order to preserve and protect its wetlands in the future. These actions should focus on expanding and enhancing staff capabilities; more effective enforcement of existing wetland regulations; and instituting a process for considering protective buffers adjacent to all wetlands" (Comprehensive Plan - 2001, 110)

References to Climate-related Disasters:

The Comprehensive Plan offers some discussion of preserving wetlands and dunes for their protection against floods and storm surge. (Comprehensive Plan - 2001.pdf)

"Living shorelines provide the most cost effective natural environmentally-safe means for storm surge abatement, flood water protection, sediment retention and ecological sustainability. One mile of wetlands provides a decrease of a foot during flooding events, and one acre of wetlands decreases property losses by $30,000. " (Long-Term Community Plan, 39)

Plant trees to "Create “Green Streets” that reduce stormwater runoff, flooding, and improve water quality" (Long-Term Community Plan, 44)

For West Galveston Island, "The stakeholders established their top five goal categories and established their weights of importance as follows: Protect Habitat 28%; Protect Shoreline 27%; Provide Drainage and Flood Management 16%; Preserve Island’s Local Character 18%; Provide Access and Connectivity for Public Recreation 11% "(Long-Term Community Plan, 46)

"Goal: Develop mitigation guidelines to reduce the damage from wind and flood events to historic properties while maintaining their historic integrity... Detailed guidelines are required on Galveston Island for elevating and flood proofing historic properties...Because activities affecting historic districts often involve subjective decision-making, these guidelines are intended to be applied, as appropriate, by the reviewing body that retains authority to examine proposals on a case-by-case basis." (Long-Term Community Plan, 68)

Structural solution:

"Protect the entire Houston-Galveston Bay/Beach Region from hurricane surge using a coastal barrier solution similar to the Dutch Delta Works. Major Project Components include

• Galveston Island Seawall extension to San Luis Pass (~18 miles)
• Bolivar Peninsula Seawall from Bolivar Roads to High Island (~35 miles)
• Seawall Inland “wrap-around” or extension at each end
• Floodgates at Bolivar Roads Ship Channel, San Luis Pass, and the Intracoastal Waterway
• Ongoing maintenance plan creation" (Long-Term Community Plan, 109)

City: Houston
Plan(s) Consulted: Capital Improvement Plan; Consolidated Plan and Action Plan**;** Comprehensive Drainage Plan**;** Emergency Plan**;** General Plan Report**;** Mobility Plan; Major Thoroughfares and Highways Plan**;** Parks and Recreation Plan**;** Transit Corridor Plan**;** Hobby Airport Plan**;** IAH Airport Plan
References to Climate Change: None
References to Sea Level Rise: None
References to Subsidence: None

References to Climate-related Disasters:

"Other work plans may be defined in the future which could address other agenda items…[including] more stringent restrictions on construction in the floodplain" (General Plan Report, 1)

"Identify various areas and zones that are prone to various hazards such as flooding, high tides, etc that will need immediate evacuation. " (Emergency Plan - Transportation, S-2)

"Flood plain management, the adoption and enforcement of safe land use regulations and construction standards are considered as highly appropriate mitigation actions. " (Emergency Plan – Hazard Mitigation, P-8)

Planning responses for floods (primarily structural and continuing with status quo) - "1. Identify flood hazard areas and develop engineered facilities for transport of storm drainage 2. Maintain drainage channels to facilitate storm water runoff ...Continue expansion and improvements to an automated flood warning system "

(Emergency Plan – Hazard Mitigation, P-5)

Develops and maintains computer models to perform flood forecasting based on past and predicted rainfall, creek flow and physical characteristics of watersheds. (Emergency Plan, 79)

"The projects selected to start this program have the highest numbers of flood-damaged properties by drainage area. Each project will be designed to keep the localized drainage in the piping or street sheet flow system to protect the structures from flooding during the 100-year rainfall event. Properties within a riverine 100-year flood zone will be protected from local drainage flooding, but may not be protected from the riverine flooding until the Harris County Flood Control District projects are completed. " (Capital Improvement Plan, 88)

City: Lake Charles
Plan(s) Consulted: 5 Year Strategic Plan**;** Riverfront Parkway and Redevelopment Plan**;** Tuten Park Master Plan
References to Climate Change: None
References to Sea Level Rise: None
References to Subsidence:

"The initiative also includes implementation of small-scale projects to restore and enhance forest sustainability, such as those that reduce impoundment, help offset subsidence, and reforest disturbed sites." (Riverfront Parkway and Redevelopment Plan, 5)

References to Climate-related Disasters:

"Lake Charles is surrounded by wetlands; however, many of these systems have degraded and represent opportunities for restoration. ... The conservation, restoration, and sustainability of coastal Louisiana's swamps, wooded cheniers (maritime forests), and natural levee forests are increasingly recognized as key to the overall sustainability and ecological diversity of southern Louisiana. Part of the Draft Louisiana Coastal Impact Assistance Plan (CIAP) [Louisiana Department of Natural Resources (LDNR) 2007], the Coastal Forest Conservation Initiative includes several measures focused on those goals. The primary thrust of this initiative is to acquire from willing landowners the land rights (primarily conservation easements) on coastal forest tracts, in order to address demonstrated threats and/or opportunities for restoration or enhanced sustainability." (Riverfront Parkway and Redevelopment Plan, 4-5)

"The elevation of the parkway is proposed to be above the 100-year floodplain, but a portion of the Research Park Complex does flood during major storm events and would not be suitable for development without protection measures. Therefore, the concept for the complex is to maintain the open green space on the west as floodable and provide natural views as an amenity for the Mixed-Income Housing District to the south and east. "(Riverfront Parkway and Redevelopment Plan, 23)

City: Baton Rouge
Plan(s) Consulted: Comprehensive Plan
References to Climate Change: None
References to Sea Level Rise: None
References to Subsidence: None
References to Climate-related Disasters:

"Drainage problems must be alleviated by storm water management planning and floodplain development regulations." (Comprehensive Plan, 5)

"Flood damages are caused by the natural potential for flooding due to excessive rainfall and many low lying areas, the manmade alteration of natural drainage patterns, and the location of development in flood prone areas."(Comprehensive Plan, 30)

"Maintain a reliable and easily recognizable warning and notification system for emergency and disaster situations " (Comprehensive Plan, 46)

"Too often floodplain management policies and programs are based on the assumption that flood damages result from nature's actions, whereas in fact the damages are mostly caused by human actions, especially by unwise land management and short sighted flood-control efforts. A floodplain management strategy that avoids placing structures where they will be inundated by floods is the only effective method in the long run. The new floodplain management ordinances adopted by the City-Parish in 1990 establish
such a strategy for East Baton Rouge Parish by restricting the placement of new structures, or substantial renovation or repair of existing structures, below the 100-year flood level." (Comprehensive Plan, 46)

"GOAL D1: (Reword) Minimize the risk of flooding of existing and future structures without placing undue burden on or damaging the function or quality of existing natural and man-
made drainage systems " (Comprehensive Plan, 144)

"Action D5.A: Flood Prone Structures. Utilizing FEMA guidelines, develop a long range plan and implementation program utilizing appropriate funding sources to acquire and/or relocate floodprone structures within the designated floodplain where appropriate. " (Comprehensive Plan, 150)

City/Region: Mississippi Gulf Region (includes Biloxi, Gulfport and others)

Plan(s) Consulted: Mississippi Gulf Region Transportation Improvement Plan
References to Climate Change:

> "The MPO will continue its work on the study of environmental conditions and transportation planning. Climate variability, coastal changes and air quality will be the focus of study to monitor environmental conditions and changes, assess mitigation measures and impacts as they relate to transportation planning and project development within context of the long range plan and TIP." (Mississippi Gulf Region Transportation Improvement Plan, 11)

References to Sea Level Rise: None
References to Subsidence: None
References to Climate-related Disasters:

> The MPO staff will work with federal, state and local resource agencies, including academia, to discuss the long term implications of changes to the coastal environmental and effective measures to mitigate damaging or disruptive impacts to the transportation system. This will be a component of the long range plan. (Mississippi Gulf Region Transportation Improvement Plan, 11)

City: Gulfport
Plan(s) Consulted: Community Plan for Old Gulfport**;** Community Plan for Mississippi City**;** Stormwater Management Plan
References to Climate Change: None
References to Sea Level Rise: None
References to Subsidence: None
References to Climate-related Disasters:

> "The Flood Hazard Overlay Zone as defined within the Existing Codes of the City of Gulfport shall continue to apply to areas within the Mississippi City Community Planning Area...
>
> Within the Conservation District, use of the U.S. Environmental Protection Agency's Best Management Practices for Stormwater Management shall be required; use of narrower paved roads and driveways, and increased use of pervious paving materials shall be encouraged. " (Community Plan for Old Gulfport, A-21)

City: Biloxi
Plan(s) Consulted: Action Plan**;** Consolidated Plan**;** Vision 2020 - Comprehensive Plan
References to Climate Change: None
References to Sea Level Rise: None
References to Subsidence: None
References to Climate-related Disasters:

> Biloxi Vision 2020: Comprehensive Plan provides a discussion of storm water drainage, including a study to assess current needs and existing plans to make improvements at individual drainage sites
>
> Uses the flood hazard maps from FEMA
>
> "Table 3-2 pages 4 through 6 also present computations of the maximum additional resident population that could be accommodated at present inhabitance densities in light of flooding influences on the likelihood of development for each

flood prone situation. It is important to these computations to understand that full development of the city is unlikely to ever occur because of factors other than just potential for flooding. Within the presently configured city, it is estimated using this methodology that an additional 13,860 persons could be accommodated if the land mass of the city was as fully developed as possible…...

It indicates that 187 acres within the presently configured city, and 2,623 acres in the planning area balance are hydric soils that do not overlay delineated flood prone areas. Absent mitigation for loss of wetlands, this information would tend to reduce the amount of potentially developable land in both the city and the planning area balance.” (Vision 2020 - Comprehensive Plan, Sec 3, Page 6)

City: Mobile
Plan(s) Consulted: Consolidated Plan and Strategy (2003 draft – no final version found)**;** Community Facilities Plan; Transportation Plan**;** General Land Use Plan**;** Overview of planned Comprehensive Plan
References to Climate Change: None
References to Sea Level Rise: None
References to Subsidence: None
References to Climate-related Disasters:

"There are no special restrictions on construction except in floodplains and historic districts."(Consolidated Plan and Strategy, 71)

Unmet need even without changes in climate

"In 1989 the City completed a metropolitan drainage needs study. The study concluded that over $160 million in flood drainage and related street improvements was necessary to substantially reduce the probability of flood-related drainage problems. Ninety-six million ($96,000,000) dollars of this total lies within nine of the community development neighborhoods. The City has instituted a capital improvements program. Since that time the City has responded to public outcry and initiated a bond issue for $33,000,000 for flood drainage improvements." (Consolidated Plan and Strategy, 86)

City: Pensacola
Plan(s) Consulted: Comprehensive Plan (draft)
References to Climate Change: None
References to Sea Level Rise: None
References to Subsidence: None
References to Climate-related Disasters:

"In accordance with the City's land development code, the City shall continue to direct high density population developments away from the City's CHHA."(Comprehensive Plan – draft, 2)

"The City shall develop regulatory or management techniques for general hazard mitigation including regulation of: beach alteration; stormwater management; and sanitary sewer facilities."(Comprehensive Plan – draft, 4)

"The City will actively enforce minimum building standards identified in the adopted Flood Plain Management Ordinance for construction within the 100-year flood plain.

Policy 1.5.3: The City shall cooperate with the Federal Emergency Management Agency (FEMA) to regularly update the 100-year flood plain and to continue FEMA regulations." (Comprehensive Plan – draft, 48)

The City shall periodically review the natural disaster population plan, taking into consideration the capacity of evacuation routes as compared to the predicted population density listed in the Future Land Use Plan Element and other publications relating to natural disaster planning. (Comprehensive Plan – draft, 4)

City: Panama City
Plan(s) Consulted: Comprehensive Plan
References to Climate Change: None
References to Sea Level Rise: None
References to Subsidence: None
References to Climate-related Disasters:

"Flood-prone areas are those areas which are subject to inundation during a 100-year storm event...As mentioned previously, there is not extensive structural development within the flood-prone areas. " (Comprehensive Plan, 1-8)

"A review of available hazard mitigation reports did not reveal any specific recommendations for Panama City. However, the City has participated in the preparation of the Bay County Hazard Mitigation Strategy..." Then continues with primarily structural recommendations and a general comment regarding development regulations. (Comprehensive Plan, 1-9 - 1-10)

"The City will use its land development regulations to prohibit the location of hospitals, nursing homes, mobile homes and other similar structures and high risk uses in the 100-year flood zone and the Coastal High Hazard Area (CHHA). The CHHA is the area below the elevation of the Category 1 storm surge line as established by a Sea, Lake, and Overland Surges from Hurricanes (SLOSH) computerized storm surge model (Map 5-1)...

The City will direct population concentrations away from known Coastal High Hazard Areas (as defined in this element) through the Future Land Use Map by not increasing densities within the CHHA, unless appropriate mitigation measures are undertaken as described in § 163.3178, F.S. (2007). Such mitigation measures shall include, without limitation, payment of money, contribution of land, and construction of hurricane shelters and transportation facilities. " (Comprehensive Plan, 5-4)

City: Miami
Plan(s) Consulted: Climate Action Plan**;** Miami 21 Land Use Codes**;** Comprehensive Plan
References to Climate Change:

Not mentioned in Comprehensive Plan up through Oct 2009. However, a separate Office of Sustainable Initiatives developed the City of Miami Climate Action Plan in June 2008. The report focuses almost entirely on emissions mitigation -

"Based on current scientific predictions that a rise in sea level is inevitable in the next century and because of Miami's low elevation, even a small sea level rise will have an impact on the City, including the flooding of some areas and saltwater intrusion on the drinking water supply. It is imperative that City government begin to consider the impact of climate change in future planning and land use decisions.

Action 5-1: Begin process of planning for climate change impacts. Specific actions:

• Incorporate climate change into long-term planning, including the likely impacts of sea level rise on current and future infrastructure, flood mitigation, water supply risk, and health impacts of increased temperatures.

• Increase water management efforts including water conservation, pollution prevention, and water resource planning." (Climate Action Plan, 33)

Miami 21 zoning codes adopted Oct 2009 intended to address climate change - but only considers emissions reduction, energy efficiency and green building - no mention of climate change or impacts or adaptation. (Miami 21 Land Use Codes)

References to Sea Level Rise:

"Rising sea levels have the potential to erode beaches, flood low-lying buildings, and contaminate drinking water. " (Climate Action Plan, 1)

"A task force of Miami area scientists has projected a sea level rise of at least 18 inches in the next 50 years and 36 to 60 inches by 2100." More discussion regarding vulnerability

(Climate Action Plan, 4)

Action - "Incorporate climate change into long-term planning, including the likely impacts of sea level rise on current and future infrastructure, flood mitigation, water supply risk, and health impacts of increased temperatures." (Climate Action Plan, 33)

References to Subsidence: None

References to Climate-related Disasters:

Plans for flooding management and stormwater drainage appear to be based on a 25-year old master plan.

"Goal SS-2: Provide adequate stormwater drainage to reasonably protect against flooding in areas of intensive use and occupation, while preventing degradation of quality in receiving waters...

Objective SS-2.3: As the City implements the storm water management improvements specified in the 1986 Storm Drainage Master Plan, it will ensure that stormwater management contributes to the conservation of ground water as a future potable

water supply. "(Comprehensive Plan, 33-34)

City: Tampa

Plan(s) Consulted: Comprehensive Plan

References to Climate Change:

"Climate change threatens to increase the intensity of hurricanes, which would cause more coastal flooding and wind related damages. It also threatens more irregular rainfall, which could reduce supplies of potable water. "(Comprehensive Plan, 13)

Only other mention is in section on Living Marine Resource / Coastal Marine Habitat - "Looming on the horizon are new threats caused by ozone depletion and human-induced climate change, whose potential negative impacts on whole ecosystems add further to the impact of already existing threats caused by other human activities. "

The associated objective is "The City shall maintain and enhance the abundance and diversity of living marine resources in Tampa Bay. " (Comprehensive Plan, 269)

References to Sea Level Rise: None

References to Subsidence: None

References to Climate-related Disasters:

Some discussion of evacuation routes and post disaster assistance, but primarily -

Focuses on minimizing risks from storms by limiting development and growth in vulnerable coastal regions

"Creating a more disaster resistant community by: Requiring new development to build and damaged structures to re-build to withstand potential hurricane impacts; Establishing procedures to guide redevelopment following a catastrophic disaster; Limiting public infrastructure improvements in vulnerable areas; and Evaluating and strengthening land development regulations, where appropriate." (Comprehensive Plan, 290)

Establishes restrictions for development based on following definition - "The Coastal High Hazard Area (CHHA) is hereby defined as the area below the elevation of the category 1 storm surge line as established by a Sea, Lake, and Overland Surges from Hurricanes (SLOSH) computerized storm surge model." (Comprehensive Plan, 290)

Possible avenue for considering change - "The City will evaluate recommendations contained in Interagency Hazard Mitigation Reports and modify, where appropriate, the Future Land Use Map, land development regulations and/or building codes so that future development will better withstand natural disasters. " (Comprehensive Plan, 294)

Discussion of role of wetlands and natural systems in flood mitigation, includes emphasis on supporting these systems and avoiding actions/development that degrade the

Flood risk and stormwater management are based on 100-year flood and knowledge of existing areas with high flood risk (Comprehensive Plan, 369-72)

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Researching Adaptation: An Overview of Climate Change Adaptation Research in the Gulf of Mexico and Caribbean Basin

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Abstract

Adaptation to climate change will be essential to the health and prosperity of the Gulf Coast and Caribbean basin. Unfortunately, identifying and enacting effective adaptation measures will not be easy. Given this context, research on adaptation will be required to meet the challenges posed to the region. After briefly exploring expected climate change impacts, this paper reviews the vulnerability assessments and adaptation policy assessments that have contributed to our current understanding of needs and opportunities vis-à-vis adaptation. It also considers priorities that should guide future research on adaptation in the region.

1. Introduction

Climate change is already affecting human and biological systems in the Gulf of Mexico and Caribbean basin. Shifts in sea levels, sea surface temperatures, and precipitation – along with knock-on effects including coral bleaching and the increased incidence of dengue fever – have been observed throughout the region (Bove et al., 1998; Burke & Maidens, 2005; Hopp & Foley, 2003; Karl et al., 2009; Lesser, 2007; Mullholland et al., 1997). There is evidence to suggest the region may also be experiencing an increase in climate variability and in the incidence of extreme events (Poore et al., 2008). Past emissions guarantee that these changes will continue far into the future even if the international community is able to quickly agree to drastic emission cuts (IPCC, 2007).

As the climate continues to change, impacts will interact with, and magnify, existing pressures on human and natural systems in the Gulf Coast and Caribbean basin. Throughout the region, human activities including dam construction, pollution, and shoreline development have dramatically altered natural landscapes and compromised the resilience of natural ecosystems (Twilley et al., 2001; Yanez-Arancibia & Day, 2004). Human systems face their own set of stressors, including energy constraints, poverty, and population growth (Adams et al., 2004; PielkeJr. & Sarewitz, 2005; PielkeJr. et al., 2003). Against this changing backdrop, evolving climate risks – including increased variability, flooding, hurricanes, and sea level rise – will exact an ever-greater human and economic toll (PielkeJr. et al., 2003).

Given the context, adaptation to climate change will be essential to the health and prosperity of the Gulf region. Unfortunately, identifying and enacting adaptation measures will not be easy. Adaptation requires systems to respond simultaneously to a number of different pressures, many of which are not fully understood; at the same time, it encompasses a range of integrated activities that will require the coordination of a diverse array of stakeholders. Given the complexity of the issue, adaptation research is an essential step in meeting the challenges associated with climate change.

After briefly reviewing expected climate change impacts in the Gulf and Caribbean basin, this paper explores the two separate but related lines of inquiry that have contributed to our understanding of needs and opportunities with regards to climate change adaptation in the Gulf Coast and Caribbean basin. It also briefly outlines the priorities that should guide future research on adaptation in the region, including ways to address the fundamental limitations of available information.

2. Identifying Expected Impacts in the Gulf and Caribbean Basin

In order to prepare for future climate change, planners must have a general sense of the changes the region can expect. Though a great deal of scientific uncertainty still surrounds this issue, a range of actors have begun the process of identifying possible impacts on the region by comparing the effects of large-scale climate change scenarios to hypothetical constant scenarios. Such studies help define the range of possible future climates and illuminate ways in which these climates will impact human and natural systems in specific areas. In this way, impact studies give a sense of the broad landscape on which adaptation will take place.

One of the most comprehensive impact studies of the Gulf Coast and Caribbean basin is found in the US Global Change Research Program's *Global Climate Change Impacts in the United States*, which uses large-scale global circulation models (GCMs) to forecast climate-related impacts throughout the United States, including the Southeast, islands, and coasts (USGCRP, 2009). Another such study is Turner's *Coastal Ecosystems of the Gulf of Mexico and Climate Change*, conducted under the auspices of the Gulf Coast Climate Change Assessment Council. This report uses GCMs to anticipate the ways in which future climate change will impact Gulf ecosystems; it is particularly concerned with estuarine salinity, salt marsh sustainability, commercial fisheries, and low oxygen zones in 2100 (Turner, 2003).

The Costs of Inaction, a two-part research project conducted by a team at Tufts University, evaluates the potential economic costs to both Florida and the Caribbean basin if climate change continues unchecked; comparing this with a hypothetical no-change scenario, the authors elaborate the regional costs of delayed mitigation (Bueno et al., 2008; Stanton & Ackerman, 2007). Other studies of climate change impacts in the region include Scavia et al., 2002 and Tchounwou, 1999. Analyses of the effects of climate change on specific regional processes – including biophysical studies that explore climate change vis-à-vis biological systems – are found in (Mendoza et al., 1997 ; Mendoza et al., 2009; Purcell et al., 2008; Wang, 2008).

For the most part, impact assessments of the Gulf and Caribbean basin are based on climate change projections developed by the UK's Hadley Centre and/or the Canadian Centre for Climate Modeling and Analysis. In some cases, information is also drawn from the IPCC, the National Center for Atmospheric Research, the National Oceanic and Atmospheric Administration, NASA's Goddard Institute for Space Studies, or from independent research. Unfortunately, these sources do not always agree on future climate change scenarios. As a result, impact studies of the Gulf and Caribbean represent a relatively wide range of plausible climate change scenarios.

The most dramatic example of this involves precipitation. The Canadian GCM shows the Gulf and Caribbean experiencing a high degree of warming that translates into reduced soil moisture when higher temperatures increase evaporation. Meanwhile, the Hadley model simulates less warming and a significant increase in precipitation. As a result, the assessments show an array of future scenarios of precipitation (Bueno et al., 2008; Stanton & Ackerman, 2007; Turner, 2003; USGCRP, 2009). Climate models also show little agreement on how climate change will impact the El Niño Southern Oscillation (ENSO); given the role that ENSO plays in regional precipitation and hurricane activity, it is nevertheless clear that any changes to ENSO will be of great importance to the Gulf and Caribbean region.

Despite the uncertainty surrounding El Niño, it is likely that hurricane rainfall and wind speeds will increase in the Gulf and Caribbean in response to global warming (Kunkel et al., 2008), leading to an increase in the frequency of the most intense storms (Knutson et al., 2010). Models also generally agree on the direction, if not the rate, of sea level change in the region. The result of both global and local processes, sea level rise is generally calculated by adding the acceleration in historical global sea-level rise to historic local trends; predictions for the Gulf Coast range from 8.4 to 12.9 inches over the next 100 years (Bueno et al., 2008; Burke & Maidens, 2005; Deyle et al., 2007; Lewsey et al., 2004; UNEP, 2008).

3. Adapting to an Uncertain Climate

Given the level of uncertainty that remains, it is clear that adapting to climate change in the Gulf and Caribbean basin will not be easy. Even in cases in which researchers are more certain of the sorts of changes to expect, adaptation poses serious challenges. Adaptation is a complicated process that encompasses a wide range of activities, including the development of practices, processes, legislation, regulations, and incentives (UNEP, 2008). It also describes engineering solutions, such as the construction of sea defenses, hurricane-resistant buildings, and the provision of water storage; legislative solutions such as revised building codes, land zoning, and water policies; and technological solutions including the development of advanced predictive techniques and more resilient crop varieties (UNFCCC, 2007).

More generally, the process of adaptation is also complicated by the fact that systems will be forced to respond simultaneously to a wide range of pressures, many of which are not fully understood (Dessai & Hulme, 2007). Adaptation strategies that operate in a variety of social, political, economic, geographic, and environmental conditions will be carried out in specific regions and specific sectors with the goal of reducing the vulnerabilities of environmental, social, and economic systems of specific locations (CIER, 2007). In this context, criteria for success will be both contested and context-specific (Debels et al., 2009).

Adaptation will also require the collaboration of a range of actors. Because climate change will impact a variety of overlapping systems, efficient adaptation will necessarily involve coordination among and between these systems (ICCATF, 2010). Similarly, adaptation efforts must take into account the characteristics of ecosystems, populations, and societies; efforts must be developed in an integrated manner in order to ensure that measures taken in certain sectors do not have negative impacts on others (Rivington et al., 2007; Tompkins et al., 2005). In this sense, adaptation strategies that are essentially local must respond to a wide range of factors and be negotiated by a diverse group of stakeholders.

Given the intense challenges posed by adaptation, and the immense costs of inaction, it is not surprising that the research community has turned its attention to questions of adaptation and climate change. What was once dismissed as the cost of failed mitigation is now a thriving field of intellectual inquiry (PielkeJr. et al., 2007).This is nowhere more true than the Gulf Coast and Caribbean basin – a region whose unique geographic and socioeconomic conditions make it particularly vulnerable and one in which climate-related impacts have recently garnered a great deal of attention. As a result, the last two decades have witnessed a relative explosion of research on adaptation in the Gulf Coast and Caribbean basin.

4. Adaptation Research in the Gulf and Caribbean

In the Gulf Coast and Caribbean basin – as in other regions – research on adaptation has focused on two separate but related fields of inquiry. This first combines natural and social science perspectives to assess the degree to which individual systems are susceptible to the adverse effects of climate change. Documents that employ this line of research are called vulnerability assessments. The second line of inquiry produces adaptation policy assessments, which more explicitly shift the conversation from net impacts to questions of how and where to deploy adaptation responses (Burton et al., 2002). Both have and continue to contribute to our understanding of the challenges and opportunities associated with adaptation in the Gulf and Caribbean basin. Below is an exploration of both types of studies and the information they produce in the Gulf Coast and Caribbean basin.

4.1 Assessing Vulnerability in the Gulf and Caribbean Region

There have been several important vulnerability assessments of the Gulf Coast and Caribbean basin. In 2001, the Union of Concerned Citizens and the Ecological Society of America produced *Confronting Climate Change in the Gulf Coast Region*. In addition to assessing the impacts of climate change on the region, the study discusses ways to minimize impacts by reducing other non-climatic stressors and briefly lays out possible adaptation strategies for water resources, agriculture, forestry, land use and coastal communities. It also discusses adaptations to current climatic hazards and the ways in which these adaptations have contributed overall vulnerability (Twilley et al., 2001).

Bulto's assessment of climate change and human health in Cuba also falls into this category. While the study uses climate change scenarios to forecast future disease burden, it also explores adaptation measures and the capacity of Cuba to response to such changes (Bulto et al., 2006). An interesting vulnerability assessment was also carried out recently by the US Department of Transportation (DoT). The study focuses on the vulnerability of the transportation system – including ports, highways, airports, and rail routes – to climate change. It not only models the impacts of climate change on this important infrastructure, but also explores the capacity of the transportation system to use and respond to the information. While the document does not make specific adaptation recommendations, it collects and explicates information about these strategies and thus contributes to more informed decision-making (Potter et al., 2008).

Importantly, the DoT document is only the first of a three-part study of climate change and transportation in the Gulf Coast. The second and third documents, commissioned by

DoT but not yet completed, will further explore adaptation. The second will be an in-depth assessment of climate risk and their impact on safety, operations, and maintenance in the region, while the third more directly assess adaptation policy. This document will identify and analyze adaptation strategies and develop tools to assess them. It will also enumerate future research needs in this area (Potter et al., 2008).

The progression of these documents shows the connection between vulnerability assessments and adaptation policy assessments. Specifically, vulnerability assessments lay the groundwork for adaptation policy assessments by identifying the extent to which adaptation can mitigate the impacts of climate change. Vulnerability assessments thus provide researchers with an overview of impacts and vulnerabilities that can be explored in depth in order to contribute to adaptation policy development.

4.2 Assessing Adaptation Policy Options

While vulnerability assessments are useful in providing information regarding net impacts, they do not directly address all of the information needs of adaptation policymakers. To meet the policy evaluation needs of decision-makers, adaptation policy assessments must address questions of how and where to deploy adaptation responses (Burton et al., 2002). The main purpose of these documents is to contribute to policymaking by providing specific recommendations on the enhancement of adaptive capacity or the implementation of adaptation policies (Fussel & Klein, 2006). Adaptation policy assessments do this in a variety of ways that are currently being developed and are explored in brief below (Burton et al., 2002).

One way that several studies have contributed to our understanding of policy development is by concentrating on the immediate concerns that shape near-term decisions. A recent example is Twilley's 2007 assessment of vulnerability of Gulf Coast ecosystems for the Pew Center on Climate Change. Twilley explains that largely because of engineered modifications to regional watersheds and coastal landscapes, the region is experiencing one of the highest rates of wetland loss in the United States. He then projects climate impacts into the future and develops adaptation policy recommendations that confront current levels of degradation (Twilley, 2007).

A related study was conducted by a team from the US National Oceanic and Atmospheric Administration in the Eastern Caribbean. This study outlines the expected impacts of climate change on the region before examining the impact of anthropogenic trends including urbanization and land use, and the siting of vulnerable infrastructure. It also points to various economic trends that will complicate adaptation efforts. Finally, the paper offers recommendations to reverse human impacts of environmental degradation and thus make the environment more resilient to climate-related impacts (Lewsey et al., 2004).

Another example comes from Veracruz, Mexico. As part of a study exploring the impacts of climate on coffee production, Cambers reveals that the factors most limiting to farmers in this area are a lack of money/credit, land availability, government support, and tradition (Cambers, 2009). A similar study is conducted by Lopez-Marrero & Yarnal, whose study of flooding in Puerto Rico emphasizes the need to understand the everyday risks to which people are exposed in order to make effective adaptation policy. This study highlights the fact that flooding is only one of the risks faced by people in this region, and not the most important. The authors conclude that there is need to address both flood risk and the wider concerns that aggravate flood vulnerability, including health conditions, livelihood constraints, social relations, community infrastructure, and land-tenure. By focusing on contemporary natural hazards, they illuminate limits to practical adaptation planning (Lopez-Marrero & Yarnal, 2010).

In their exploration of disaster vulnerability and small-island developing states in the Caribbean, Pelling and Uitto highlight the role that global pressures and local dynamics play in adaptation. The authors examine the ways in which international trade regulations, foreign direct investment, structural adjustment, migration, and insurance flight contribute to vulnerability and point out that larger, least globally connected states (e.g., Haiti and Jamaica) are more severely affected by disaster. They conclude that globalization is, in some cases, an impediment to adaptation (Pelling & Uitto, 2001).

Tucker and others' study explores the role that risk perception plays in adaptation in Central America and Mexico. The authors hypothesize that farmers who consider climate variability and changes to be very risky would be more likely to make adaptations than those who saw the events as part of normal variation. They found this was not the case, however. Instead, those more likely to engage in adaptations were those with the means to do so, regardless of their risk perception. This led the authors to conclude that adaptive responses were associated more with access to land than anything else (Tucker et al., 2010). This study, and the others mentioned above, focus on current conditions and pressing concerns in the Gulf of Mexico in an attempt to inform adaptation policy.

4.3 Exploring Local Policy Integration

Importantly, adaptation policy assessments in the Gulf Coast and Caribbean basin have begun to engage with context-specific issues of policy integration. Adaptation research must explore the real context in which adaptation is going to take place in order for adaptation policies to achieve their intended results. Research must focus on the mechanisms for guiding and implementing adaptation; the formulation of policies for adapting to climate change or the modification of existing policies to take adaptation into account; and the explicit incorporation of adaptation measures at the project level.

Current Policy Frameworks. To this end, a few studies explore current policy and institutional frameworks as a way to contribute to adaptation policy development. An example of this is the 2007 OECD document *Policy Frameworks for Adaptation to Climate Change in Coastal Zones: The Case of the Gulf of Mexico*. This paper identifies and analyzes policy frameworks important for the facilitation of adaptation to climate change in the US and Mexico. It considers the ability of both countries' legal frameworks to deal with changing impacts on coastal and urban systems (Levina & Jacob, 2007).

Another document that examines the current policy and institutional framework in order to shed light on possible adaptation strategies was conducted by the Environmental Protection Agency, in conjunction with researchers at Texas A&M, the University of New Orleans, the University of Louisiana-Lafayette, and Florida A&M. The report, titled *The Use of Science in Gulf of Mexico Decision Making Involving Climate Change*, explores current and potential ways to engage various stakeholder groups in making decisions to address potential climate change impacts. It investigates the role of science in the decision-making process of specific actors and outlines ways in which the interface between climate science and decision makers be made more effective (Vedlitz et al., 2007).

A third and final example of this kind of adaptation policy assessment is Tompkins and others' exploration of the ways in which changes to the institutions on the Cayman's Islands have altered the ability of the government to respond to and prepare for hurricanes. The paper examines contemporary responses to tropical storm risk in order to gather lessons for adaptation; the authors also conduct interview to see what motivates institutional change. The paper concludes that previous exposure and the presence of institutions' persuasive power in society are important determinants of resilience to climate impacts (Tompkins et al., 2005).

***Policy Options*.** In some cases, Gulf Coast adaptation policy assessments explicitly consider a range of different policy options. The US Climate Change Science Program, for instance, has attempted to do this in a report entitled *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources*. The report, which focuses on federally managed lands and waters including along the Gulf Coast and Islands, was designed to advance decision-making on climate change-related issues by evaluating known and potential adaptation options in the context of a desired ecosystem condition or natural resource management goals (CCSP, 2008).

A similar, though less thorough, effort is found in the Gulf Coast's Regional Assessment, *Preparing for Climate Change*. The authors of this document used climate models to identify impacts associated with climate change; they followed this with a qualitative assessment of the socioeconomic implications of the projected ecological changes. Through an array of interviews, questionnaires, and outreach activities, the team explored current and potential coping strategies, eventually analyzing these with respect to institutional constraints and other barriers. They also used case studies to explore the potential viability of different adaptation options (Ning et al., 2003).

Frequently, examining larger-picture policy options is a difficult prospect given the range of stakeholders and influences that must be considered. To address this challenge, Eakin and others developed a participatory approach to identify and evaluate adaptations for the capital of Sonoro, Mexico (Eakin et al., 2007). As the authors explain, the iterative process allowed the investigation to address concerns related not just to climate change, but also to the immediate and pressing concerns about development patterns and water use in the city. Importantly, the authors suggest that the simplicity of their models would allow it to be used for other adaptation initiatives throughout the region.

In places where this kind of participatory structure has not yet been worked out, adaptation policy assessments in the Gulf Coast and Caribbean basin have focused on adaptation strategies already underway. By reviewing and evaluating adaptation practices currently in use, as well as the absence of others than might be useful, these studies provide an “adaptation baseline” against which to measure progresses and development of adaptation policy (Burton et al., 2002).

This kind of benchmarking is found in an United Nations Environmental Programme review of how Caribbean countries are responding to a changing climate (UNEP, 2008). Monitoring current adaptation policy has also been undertaken by the Caribbean Community Climate Change Centre, through its experience with projects including Caribbean Planning for Adaptation to Climate Change project, Adaptation to Climate Change in the Caribbean, Mainstreaming and Adaptation to Climate Change and the Special Program on Adaptation to Climate Change (CCCCC, 2010; CCCCC, 2009).

Another example is Camber’s exploration of two case studies of beach erosion adaptation. The paper explores lessons learned from coastal planning measures in Anguilla and Nevis and from the rehabilitation of coastal forests in Puerto Rico. From these case studies, Cambers suggest structural, planning, and ecological adaptations to confront similar problems under climate change (Cambers, 2009).

Adaptive Capacity. In addition, several adaptation policy assessments of the Gulf region address the concept of adaptive capacity. Adaptive capacity describes the ability of a system to adjust to climate change, including changes in climatic variability and extremes, in order to moderate potential damages, take advantage of opportunities, or cope with consequences (Burton et al., 2002). The forces that influence this ability of systems to adjust are the drivers or determinants of adaptive capacity. While many of these drivers are local (e.g., infrastructure, institutional environment, political influence, access to resources, etc.), others reflect more general socioeconomic and political conditions. Importantly, a system’s adaptive capacity is not static. Adaptive capacity is context-specific and varies from country to country, community to community, between social groups and individuals, and over time (Smit & Wandel, 2006).

Because of this, context-specific analyses of adaptive capacity are required to inform adaptation policies decisions in the Gulf Coast and Caribbean basin. Unfortunately few such analyses have been conducted to date. One is Deyle’s analysis of adaptive response to sea level rise in Florida. This paper outlines perceived importance of sea level rise, efforts to address the issue, and ways in which the state can effectively facilitate more effective adaptive response planning. It discusses adaptive capacity of the state vis-à-vis resources, capital facilities and infrastructure and water resource planning (Deyle et al., 2007).

Another example is Luers’ exploration of vulnerability and adaptive capacity of farmers in Mexico’s Yaqui Valley. The authors suggests that farmers’ ability to cope with changing climatic conditions will depend on a range of social, political, and biophysical factors. Though their analysis is not able to completely explain the total range, it does establish a mathematical framework that can be used to explore the various contributions of these factors to adaptive capacity (Luers et al., 2003). Lopez-Marrero and Yarnal also consider the adaptive capacity with respect to flood response in Puetro Rico (Lopez-Marrero & Yarnal, 2010).

In their study of disaster risk reduction in the Cayman Islands, Tompkins and others find that good governance mechanisms – including stakeholder participation, access to knowledge, accountability, and transparency – are conducive to the kind of structural reform needed to build long-term adaptive capacity to climate-driven impacts. They also identify factors critical to improving disaster management and suggest the role that these might play in adaptive capacity (Tompkins et al., 2008).

By addressing adaptive capacity, a range of policy options, and the current policy and institutional framework, these documents are designed to help decision-makers translate impact and vulnerability assessments into adaptation policy responses. However, considerably more specificity on the screening and prioritization of adaptation measures needs to take place. Policies already in place that are synergistic with climate change adaptation should also be explored in more depth. Where this kind of discussion has taken place, it mostly focuses on coastal zone and hazard management. In the discussion of policy that might be synergistic with adaptation, what is generally not discussed is whether the existing measures are adequate, or what if any tweaking might be needed to cope with any additional risks posed by climate change.

4.4 Addressing the Problems of Information

In several cases, Gulf Coast adaptation policy assessments have tried to directly address problems associated with the use of climate change scenarios for adaptation planning. These problems stem from issues related to the spatial and temporal scale of information, persistent uncertainties, and the difference between climatic averages and observed variability. Though they are inherent to the information on which vulnerability assessments are based, these problems severely constrain the extent to which such assessments can be used to develop adaptation policy.

One problem is related to the fact that climate change scenarios project climate change impacts on time scales much further in the future than those typically used for decision-making. While policymakers are pressured to respond to the more-or-less immediate needs of their constituents, the scientific community has focused its climate change research on the production of climate scenarios for 70-100 years in the future. While this research has been critical for raising awareness, it is hard to operationalize in the 2-5 year timeframes on which decision makers tend to act. Rather, this research methodology identifies climate change as a problem facing societies far beyond the time horizon of current decision-makers (Baethgen, 2010).

A related problem has to do with spatial scales. Though adaptation measures are local and site-specific, the best climate change scenarios are produced on global or regional scales. As a result, these scenarios provide information that is not sufficiently precise for adaptation planning. Though downscaling techniques have been developed, such methods provide information that is more precise but less accurate (Burton et al., 2002). Baethgen (2010) has called this mismatch between the requirements of adaptation planners and the spatial and temporal scale of current information about climate change a "double conflict of scales."

The high levels of uncertainty inherent in climate change scenarios also pose challenges to decision-makers. Some of this uncertainty stems from our limited understanding of the climate system; some is inherent in the climate system and will not be resolved even with perfect knowledge and representation of the physical processes involved in climate feedbacks. Still more uncertainty is the result of socioeconomic assumptions (including population growth and greenhouse gas emissions) built into the climate change models (Baethgen, 2010).

Incorporating information from climate change scenarios into adaptation planning is also complicated by the fact that adaptation is more driven by the variability and extremes of climate than the averages. While climate change itself will likely lead to small changes in means and large change in extremes, climate scenarios specify mostly average conditions for a few variables that may or may not be those most important to adaptation decision-makers (Burton et al., 2002; Smit et al., 1999).

Given this, adaptation policy assessments face the task of making information about uncertainty accessible and useful to decision-makers. To date, few assessments have attempted this in the Gulf Coast or Caribbean basin. In a study of drought in Mexico, (Boyd & Ibarraran, 2008) sidestep the issue by running their computable general equilibrium model with information about modern-day drought conditions. In this way, they are able to illustrate the costs of increased drought to the economy without incorporating uncertainties associated large-scale climate change scenarios.

Another example of the use of information at more appropriate scales for adaptation planning in the Gulf region is found in Alexandrov and Hoogenboom's study of vulnerability and adaptation in agriculture. The authors set out to determine the potential impacts of climate change local levels. To do this, they incorporate weather data recorded at more than 500 remote locations into climate change scenarios. This helps limit the spatial scale of their projections (Alexandrov & Hoogenboom, 2000).

A final example is CATHALAC's study of adaptation to climate change in Central America, Mexico, and Cuba. In this study, the authors analyzed adaptation strategies developed by maize producers to response to current climatic variability. Climate change scenarios were also constructed for 2020 and 2050. The team then worked with locals to test different adaptation methods. By using information on more immediate timescales and working with farmers on adaptation strategies that responded to current conditions, this study avoided problems of uncertainty and the double conflict of scales (Conde et al., 2006). The challenge for this type of studies however, is that the best available climate models do not represent adequately the climate variability at decadal timescales which are crucial for establishing scenarios for the next 10-30 years.

These studies closely address the most important topics in terms of information constraints on the development of adaptation strategies. However, a few other studies focus on the use of information for adaptation in the region as well. For instance, Aron's study of barriers to geospatial information explains how social and political constraints – including the principle that the rights of individual property owners to the economic value of coastal land take precedence over hazard management – create barriers to the use of critical geospatial information (Aron, 2006). Cherrington also explores the role that overall capacity in environmental information can play in adaptation in the Caribbean (Cherrington, 2007).

5. Conclusion

Research on adaptation in the Gulf Coast and Caribbean explores a range of important issues. For instance, researchers have started to illuminate expected impacts by comparing the effects of large-scale climate change scenarios to hypothetical constant scenarios. Researchers are also using natural and social science perspectives to assess the degree to which individual systems are susceptible to the adverse effects of climate change. Importantly, adaptation research now also involves explicit consideration of how and where to deploy adaptation responses. This includes in-depth exploration of local policy integration and of issues surrounding the inherent limitations of information.

Despite great progress on these topics, a great deal more research is needed to help the Gulf and Caribbean basin meet the challenges of climate change in a timely and sustainable manner. In addition to determining the best way to integrate adaptation efforts with current policies, research must also confront the fundamental limitations of information.

One emerging method for dealing with these informational limitations is to consider longer-term climate variations as part of the continuum of total climate variability, from seasons to decades to centuries, and to generate information at the temporal scale that is relevant and applicable for the particular time frames or planning horizons for different decision-makers. This would allow planners and researchers to consider climate change a problem of the present as opposed to one of the future. As such, current information could be used to inform the decision-making, planning, and policy-making processes to reduce current and potential future vulnerabilities to climate variability and change (Baethgen, 2010). A key premises of this approach is that improving year-to-year planning activities and decisions helps create societies that are better adapted to longer-term climate change (Hansen 2007).

It is also important to consider the decisions systems that need information and climate projections at time scales of 10 to 30 years (i.e., transportation, infrastructure, water reservoir, etc.). These timeframes require the consideration of decadal climate variability, which still poses important scientific challenges. While the climate science community is investing huge efforts in exploring ways to improve ability to predict it, in the meantime much can be gained by interpreting and characterizing the decadal trends in observed historic records and on methods for producing seasonal forecasts under a changing climate baseline (Baethgen, 2010).

To do this, information about climate change will need to be generated at the temporal scales that are relevant and applicable for the particular time frames of planning horizons of the future. There are research gains to be made from interpreting and characterizing the decadal trends in the observed historical records and on methods for producing seasonal forecasting under a changing climatic baseline as opposed to a static baseline. In the meantime, an effective manner for assisting the region to adapt to changing climate is to help it better prepare for existing conditions, focusing on seasons and decades rather than centuries.

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Climate Change and the Public's Health: The Coming Crisis for the U.S. Gulf Coast

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Abstract

This paper reviews the scientific consensus as to how climate change will affect human health on a global scale and describes the limited, emerging research findings concerning climate change health impacts along the U.S. Gulf Coast. Through myriad pathways, climate change is likely to make the Gulf Coast less hospitable and more dangerous for Americans, and may prompt substantial migration from and into the region. The paper also summarizes the primary prescriptions and adaptations found in the public health literature for meeting climate change's threats to human health, along with several recent findings that America's state and local public health agencies recognize the approaching problems but lack the resources to make climate change preparedness, education, needs assessment or adaptation high priorities. It also should be noted that several factors besides climate change are converging to exacerbate the fragility of this region, including coastal erosion and subsidence and the ongoing threat of energy infrastructure failure (such as the Deepwater Horizon oil spill catastrophe). This paper provides a comprehensive survey of current U.S. federal government activities—as yet uncoordinated and inadequately funded—to elucidate the public health implications of climate change and to help all levels of government create the tools and institutional structures necessary to adapt to the coming crisis. Finally, it considers pending legislation and executive branch actions to jump start public health adaptation to climate change.

1. Introduction

There is a growing literature regarding the health and public health consequences of climate change, a crisis considered by some leading experts to be “the biggest global health threat of the 21st century” (Costello, 2009). Published articles and reviews point to greater morbidity and mortality from direct exposure to more frequent and more severe storms, heat waves and floods (CCSP, 2008B; Costello, 2009; IPCC, 2007; Levi & Vinter, 2009; Luber, 2009). They also predict increased risk from vector, rodent and water-borne infectious agents, ozone, particulates, aeroallergens, ultraviolet radiation, toxic plants and seafood, and surface contaminants. Furthermore, concerns have been raised about deteriorating water supply and quality and diminishing agricultural productivity, factors which may combine to increase malnutrition and susceptibility to illness and disease. Climate change-induced or exacerbated disruptions of local ecosystems, infrastructure and economies likewise will increase joblessness, poverty, undernourishment and vulnerability to diseases.

Finally, this literature emphasizes that climate change will cause widespread migration away from areas that can no longer provide sufficient food, water and shelter for the current human populations (Brown, 2008). In the most extreme cases, rising seas will claim some current human settlements, including some that would be viable but for their elevation.

A large body of research focuses on particular manifestations of climate change along the Gulf Coast and other parts of the Caribbean basin (e.g., sea level rise, coastal erosion, saltwater intrusion, extreme heat events and these items in various combinations).[i] To date, however, no single study or group of studies has focused primarily on the impacts of climate change on the health of the residents of the U.S. Gulf Coast, whether from direct exposure, out-migration or in-migration. No scholar has yet linked the variegated physical manifestations of climate change with an intimate knowledge of regional conditions, to generate health scenarios for the states, counties, parishes, and municipalities in this part of the country. This paper will help explain why this deficiency exists.

In addition to naming the generic categories of potential health impacts that scientists expect to observe on a global scale, the literature on the health impacts of climate change has several other broad, recurring themes. First, climate change already is occurring. Chameides writes that “because of the inertia of the climate system, the climate changes of the next 20 to 30 years are already in the ‘pipeline’” (Chameides, 2009), or as climate scientists would say, “committed” (IPCC, 2007A; UCAR, 2005). However, such locked in changes do not, in and of themselves, condemn Americans to suffer negative health impacts on a vast scale. Recent reports from United States Global Change Research Program (USGCRP)[ii] emphasize that “whether or not increased health risks due to climate change are realized will depend largely on societal responses and underlying vulnerability” (GCRP, 2009, p. 89).

Second, the development of the tools needed to cope effectively with climate change—regional and local scale climate models, research on the impacts of climate change on local and regional ecosystems, research on the effectiveness of specific adaptations, comprehensive surveillance of risk factors, early warning systems and incentives or regulations to induce people to change their lifestyle (CCSP, 2008B)—has not kept pace with advances in climate science itself. The scientific community has a better understanding of how and why the global climate is changing, than of how changes will play out in any particular location or how to prepare in advance for whatever changes may arise locally. According to Eric J. Barron, director of the National Center for Atmospheric Research:

> "The research strategies and investments needed to define impacts and vulnerabilities and to enable wise decisions are not in place…Currently, 40 years of intensive climate model development is being coupled to what amounts to a cottage industry of impact sciences. The result is that our understanding of how ecosystems, water, human health, agriculture, and energy will respond to climate change advances only slowly"' (Barron, 2009, p. 643).

Even with a much more robust and well-funded research program than exists today, uncertainty about the impacts of climate change on human society, in general, and on human health, in particular is likely to increase (California Natural Resources Agency, 2009; Costello, 2009, p. 27). In other words, adaptation science, policy and practice will be playing catch up with climate change indefinitely. Consequently, there is still fairly limited ability to predict the specific climate-change related health issues that may develop along the Gulf coast, and limited awareness and understanding of how communities on the Gulf Coast can adapt to climate change so as to minimize negative health consequences.

At the same time, the prospect of developing the necessary tools, dedicated funding sources, institutional arrangements and changes in governance appears daunting. In a 2009 report entitled Managing the Health Effects of Climate Change, the Lancet argued that "management of the health effects of climate change will require inputs from all sectors of government and civil society, collaboration between many academic disciplines, and new ways of international cooperation that have hitherto eluded us" (Costello, 2009, p. 1693). Although there have been some recent positive signs, the American political system, as is the case for the health and public health systems, has not yet embraced climate change adaptation with anywhere near the requisite urgency.

Third, little work has been done to date which attempts to analyze or integrate the range of threats facing the coast-line of the Gulf states, where complex hazards include not merely climate change, but also severe erosion, subsidence and—given the immense amount of energy production infrastructure—the ever-present potential for large-scale industrial accidents. Populations in the region which are already vulnerable because of economic or other disparities will face extraordinary risk to health and well-being as the consequences of complex threats conspire to create new levels of concern for political and public health leaders. Finally, echoing an observation from the disaster research literature, the world's poor and powerless are likely to suffer not just disproportionately from climate change, but fatally.

This paper reviews the scientific consensus as to how climate change will affect human health on a global scale and describes the limited, emerging research findings concerning climate change health impacts along the U.S. Gulf Coast. It next discusses the primary prescriptions found in the public health literature for meeting climate change's threats to human health and summarizes the results of several recent studies that have highlighted a lack of preparedness within America's state and local public health agencies. Finally, this paper surveys U.S. federal government activities to elucidate the public health implications of climate change and to help all levels of government create the tools and institutional structures necessary to adapt to this oncoming environmental catastrophe.

2. How Climate Change May Adversely Affect Human Health

2.1 Global Health Impacts

The main physical manifestations of climate change are increasing atmospheric concentrations of carbon dioxide and other greenhouse gases; rising surface temperatures on both land and water; sea level rise; changes in atmospheric and oceanic energy circulation patterns such as the El Nino Southern Oscillation and the Atlantic Thermohaline Circulation (NOAA, 2010; Rahmstorf, 2006); increased climate variability; and increased frequency, intensity and severity of storms and floods, heat waves and droughts (Costello, 2009, pp. 1698-1700). IPCC's Fourth Assessment Report contains a foundational chapter on the human health impacts of such changes (IPCC, 2007, pp. 391-431). It associates the following health trends with climate change and assigns a confidence level to each statement (TABLE 1).

TABLE 1. IPCC Health Trends with Confidence Ratings

Very High	In some places the geographical range of malaria will contract, elsewhere the geographical range will expand and the transmission season may be changed.
High	An increase in malnutrition and consequent disorders, including those relating to child growth and development
	An increase in the number of people suffering from death, disease and injury from heat waves, floods, storms, fires and droughts
	Continued changes in the range of some infectious disease vectors
	A decline in deaths from cold, and other minor health benefits
	An increase in cardio-respiratory morbidity and mortality associated with ground-level ozone
Medium[iii]	An increase in the burden of diarrheal diseases
Low	An increase in the number of people at risk of Dengue

Source:(IPCC, 2007)
"High confidence" means the authors believed there was "about an 8 out of 10 chance" the assertion was correct, very high "at least 9 out of 10" (IPCC, 2007, p. 4). USGCRP's most recent summary of health impacts (GCRP, 2009, pp. 89-98) is generally consistent with IPCC's Medium to Very High confidence list, but also emphasizes increases in allergies and mental health problems.

Other potential health impacts that the IPCC was unable to rate using its confidence level guidelines include increased:

- Mental health problems arising from more frequent and severe extreme events;
- Exposure to other infectious diseases;
- Direct exposure to lead, volatile organic compounds, and other chemical contaminants and toxic materials due to extreme flooding events;
- Failure of sanitary systems;
- UVR-related illnesses including melanomas, cataracts and sunburn;
- Incidence of pneumonia, chronic obstructive pulmonary disease and asthma due to exposure to ozone and particulates;

Adverse health effects also are likely to result from:

- Changes in the seasonality of allergies due to changes in pollen seasons;
- Decreased food production due to saltwater intrusion, drought, flood destruction of crops, change in crop pests and diseases, severe event disruption of food supply chains; and
- Changes in ecosystems, agriculture, livelihoods and infrastructure (IPCC, 2007, pp. 393-405).

Some of the health impacts envisioned in these studies are intuitive. Without adaptations such as more rational land use patterns, better evacuation plans and more effective hazard and warning communications, more severe hurricanes will lead to more floods, injuries and drowning. Likewise, without more air conditioning, public cooling stations, early warning systems, or other adaptations such as the neighborhood-based response plan that Philadelphia instituted fifteen years ago (GCRP, 2009, p. 91), longer heat waves at higher summer temperatures may produce mortality on the scale of a 1995 heat wave in Chicago that caused nearly 500 deaths (Klinenberg, 2002; Naughton, et al., 2002, p. 221) and a 2006 California heat wave that may have killed up to 450 people (Ostro, Roth, Green, & Basu, 2009, p. 614).

But there are complex pathways from climate change to health impacts that are not as obvious. A USGCRP study estimated that over the next 50-100 years, a sea-level rise of 4 feet[iv] could permanently inundate 2400 miles (27%) of the major roads between Mobile and the Houston/Galveston area--including roads that currently are designated as major evacuation routes--and 246 miles of freight rail lines (GCRP, 2009, pp. 62-63; Savonis, et al., 2008). Coupled with hurricanes that would drop more rainfall and generate stronger winds and higher storm surges, such a rise in sea level also would reduce life expectancy and dramatically increase maintenance and repair expenditures for roads, rail lines, pipelines, bridges, airports and other transportation and communications systems on which the Gulf Coast economy depends (GCRP, 2009, p. 68). The impacts of individual floods and storms on illness, injury and death will be all too apparent. The less obvious long-term effects could include the exodus of a tax base, the physical deterioration and under-maintenance of drinking water, sanitation systems and power supplies and the constriction of both public and private health services. The remaining population could be far more vulnerable and exposed than today's coastal population.

Climate change-induced migration also may adversely affect human health in numerous ways. Besides creating the potential for violent conflicts over land, food and water, migration may increase crowding and unhealthy conditions at the destination locales, and overwhelm the existing public health infrastructure. Migration that results in the spread of densely developed cities is likely to increase the prevalence of the "urban heat island effect," in which the built up portions of an urban area can be significantly warmer than their surroundings (EPA, 2010). The International Organization for Migration (IOM) anticipates that depopulation of compromised areas will result in "hollowed economies," as individuals and families with the least capital, education and skills will be the last ones able to move away (Brown, 2008, p. 33), and could accelerate the "brain drain" that is already a huge problem for many developing countries (Brown, 2008, p. 33). These dynamics could leave behind increasingly impoverished communities that are incapable of providing for their basic nutritional, water and health needs.

2.2 Climate Change's Impact on Health along the U.S. Gulf Coast

Table 2 summarizes USGCRP's discussion of climate change's major impacts on the "Southeast" region (which includes Arkansas, Tennessee, Kentucky, Virginia, Georgia and the Carolinas as well as the Gulf Coast) for the remainder of the 21st century.

The physical impacts of climate change in Louisiana are expected to be especially severe. It is widely recognized that portions of the Gulf Coast—particularly coastal Louisiana and South Florida—are extremely exposed to sea level rise due to their low elevation and that the entire coastal region is vulnerable to more intense hurricane winds, rainfall and storm surges. Additional factors make coastal Louisiana triply vulnerable to these climate change impacts. The first is subsidence. Due to "massive oil and gas extraction, the continental shelf is collapsing like a deflating balloon," at a rate of up to 10 millimeters per year (Lemonick, 2010). As the sea is rising along the Gulf Coast, the land also is falling.

Second, long-term land use patterns coupled with powerful hurricanes have substantially eroded barrier islands and wetlands that are coastal communities' first line of defense against winds, waves and storm surge. "Since the 1930s, over 2,400 square miles of wetlands in coastal Louisiana have been lost," at a rate of 15 to 40 square miles each year(LCPRA, 2010, p. 2), with virtually the entire Louisiana shoreline (more than 95%) "suffering some form or level of erosion" (USACE, 2009, p. 17). In a Congressionally-mandated study to address hurricane protection and coastal restoration in Louisiana and

TABLE 2: CLIMATE CHANGES AND THEIR IMPACTS ON THE SOUTHEAST DURING THE 21ST CENTURY

Average temperatures will rise 4.5 – 9 degrees F, depending upon the greenhouse gas (GHG) emissions scenario. Summer temperatures will rise as much as 10.5 F.
Spring and summer rainfall in Florida will decline; in the other Gulf states, there will be less rainfall in winter and spring
Generally, less water will be available. The frequency, duration and intensity of droughts will continue to increase
Average sea level will rise up to 2 feet[v]
Atlantic hurricanes will have higher peak winds, rainfall intensity, storm surge height and strength
More frequent and intense wildfires
Significant deterioration and disruption of ecosystems
Increased salinity of estuaries, coastal wetlands and tidal rivers, and potentially abrupt saltwater intrusion into coastal forests and freshwater aquifers
Intense outbreaks of insects that had not previously been pests

Source:(GCRP, 2009, pp. 111-116)

Mississippi following Hurricanes Katrina and Rita, the U.S. Army Corps of Engineers concluded that "continuing erosion of coastal wetlands reduces the natural buffer separating coastal communities from the Gulf of Mexico. As coastal wetlands disappear, these communities will face a choice of building higher and stronger structural defenses; relocating to areas with lower risks; or continuing to live in areas under ever-increasing risk"(USACE, 2009, p. 242).

Finally, over a century of navigation, flood control, hydropower and water storage projects on the Mississippi and its tributaries has captured much of the river's annual sediment load behind dams, cut the amount that reaches the river's delta by half (Blum & Roberts, 2009, p. 488) and thereby contributed to the conversion of wetlands into open water. Scientists at Louisiana State University recently estimated that without efforts to divert significant amounts of river sediment back towards the delta, approximately 3,800 to 5,200 square miles of the delta will be lost during this century, and that "significant drowning is inevitable, even if sediment loads are restored, because sea level is now rising at least three times faster than during delta-plain construction" (Blum & Roberts, 2009, p. 488). Looking at this issue a decade ago, Burkett et al warned that these factors "portend serious losses of life and property in the New Orleans MSA unless flood-control levees and drainage systems are upgraded" (Burkett, Zilkowski, & Hart, 2003, p. 70).

One has to search a diverse research literature simply to find suggestions of how these regional climate changes may manifest themselves in adverse regional public health trends. The state health department websites generally do not discuss these issues in any depth, and it appears that even for scientists who can anticipate the physical consequences of storms, droughts, sea level rise and changes in ecosystems, making the leap to the associated health consequences is anything but straightforward.

The previously-cited USCGRP analysis of Gulf Coast transportation infrastructure does not attempt to link the inundation of transportation resources and regional health (Savonis, et al., 2008). A 2001 EPA scoping exercise concluded that salt water contamination of surface drinking water sources along the Gulf Coast (due to sea level rise) was a minor concern, yet it did not explore the potential health implications of the four water systems—serving in aggregate over 90,000 people—that it found to be “at high risk of salt water intrusion” (Furlow, Scheraga, Freed, & Rock, 2002, p. 4; Scheraga, 2007, p. 13). As another example, a March 2010 international conference on sea level rise in the Gulf of Mexico included thirty presentations (Harte, 2010), but only two described a specific pathway by which sea level rise could impair health (Dokken, 2010; Maslin, 2010). Lastly, a new report by organizations representing drinking water, wastewater and sanitary systems (AMWA, 2010; NACWA, 2010) estimates that USGCRP’s Southeast region will need to spend \$21-\$47 billion over the next 40 years to adapt its wastewater systems to climate change, and \$78-\$149[vi] billion for its drinking water systems (NACWA, 2009, pp. 3.7-3.10). The authors unquestionably understand that failure to make these immense investments could have extraordinary impacts on health, yet did not attempt to identify or quantify them.

Among the specialists in emerging infectious diseases who have highlighted climate change’s potential to change the geographic range of known vectors (Gage, Burkot, Eisen, & Hayes, 2008; Greer, Ng, & Fisman, 2008), several recently have highlighted the reappearance in the United States—particularly in the southeast—of Dengue fever, a painful viral disease (Barclay, 2008; Hayden, 2009; Knowlton, 2010; Morens & Fauci, 2008, p. 215). Morens and Fauci called Dengue “one of the world’s most aggressive reemerging infections” and asserted that “widespread appearance of Dengue in the continental United States is a real possibility” (Morens & Fauci, 2008, p. 214). During a Congressional briefing last fall, Mary Hayden of the National Center for Atmospheric Research documented the explosion of WHO-reported cases of Dengue throughout South America, Central America and Mexico since the late 1970s and noted that in the 2005 Dengue outbreak on the South Texas border, 38% of the residents of Brownsville and 77% of the residents of Matamoros, Mexico were exposed to the virus (Hayden, 2009). Florida health officials have confirmed more than twenty cases of locally contracted Dengue in the summer and fall of 2009, “the first locally-transmitted infections in Florida in more than 40 years” (Knowlton, 2010). CDC and University of Florida entomologists have documented the spread of one of the two Dengue-carrying mosquito vectors throughout the Southeast and most of southeast Texas by 2001 (Benedict, Levine, Hawley, & Lounibos, 2007, p. 11).

While acknowledging that global warming may have contributed to the expansion of a Dengue vector along the Texas border, USGCRP was cautious about describing Dengue as a public health concern because “most people [in the United States] are protected living indoors due to quality housing”[vii] (CCSP, 2008, p. 44). Nonetheless, this statement indicates the risk to Gulf residents who may be unaware of Dengue's presence or—like the citizens of Matamoros—unable to afford housing that will protect them.[viii]

2.3 Migration

The impacts of climate change-induced migration away from, or to the Gulf Coast have not received systematic attention, either. In spite of certain dire prognoses for continued loss of land and habitat, few studies describe scenarios involving the loss of current Gulf Coast communities, economic dislocations, deterioration of water resources or other factors that might induce out-migration. Nor have there been significant published reports that project where an exodus from the Gulf Coast would go in the near and long term, suggest which receiving communities might bear that burden or consider the long-term psychological impacts on the affected populations. As climate change has the potential to destroy or dramatically alter communities, it is important to consider how a "loss of place" may impact community resilience as time goes on.

As noted by Stedman (Stedman, 2002, p. 561), place attachment is a bond between people and their natural environment, based on cognition and affect. The subsequent loss of this bond can have a negative impact on mental health. This feeling of anguish is particularly acute among children, who most associate a loss of place with feelings of instability. Research has shown that people understand geographic places not simply as physical settings, but as the totality of the human activities and human social and psychological processes rooted in the setting. These findings led Ryden to assert that "the place has become a shaping partner in our lives, we partially define ourselves in its terms, and it carries the emotional charge of a family member or any other influential human agent" (Ryden, 1993, p. 66). In this regard, the issues surrounding Hurricane Katrina offer a prominent warning of what the future may hold. With up to 35,000 children still seeking treatment for mental health issues associated with the storm two years later (Dewan, 2007), it is necessary to consider how new climate change oriented problems will exacerbate psychological needs.

Additionally, few studies address the possibility that the Gulf Coast might receive new inhabitants from other impacted nations in the Caribbean Basin. Perhaps this shouldn't be surprising given IPCC's position that migration is an extremely complex phenomenon and that "estimates of the number of people who may become environmental migrants are, at best, guesswork"(IPCC, 2007, p. 365). That being said, the low elevation and vulnerability to tropical storms of most of the Caribbean basin is a prima facie basis for paying close attention to this issue.

The degree to which humans may be able to prevent the inundation of coastal transportation infrastructure, deterioration of drinking water and sanitary facilities, and ecosystem changes that permit the spread of infectious disease vectors through reduction in GHG emissions, engineering solutions or changes in land use patterns is subject to debate and beyond the scope of this paper. To the extent such impacts of climate change materialize, they would make the Gulf Coast a harsher, less hospitable and more dangerous natural environment for humans than it is today.

3. What is Needed?

3.1 The mainstream consensus

Several leading experts have expressed a high degree of confidence that the basic tenets and tools of the public health discipline are up to the challenges of climate change (Ebi, Kovats, & Menne, 2006; Ebi & Semenza, 2008; Frumkin, Hess, Luber, Malilay, & McGeehin, 2008; Luber, 2009). They view climate change adaptation as analogous to public health preparedness, i.e., "actions taken in advance of climate change impacts or reactions in response to perceived or real health risks" (Ebi & Semenza, 2008, p. 501), in either case to reduce the health burden of climate changes that society no longer can prevent from occurring. These observers also are comfortable that the public health profession's "Ten Essential Services" is a sufficient analytical and ethical platform on which to mount a compelling response (Frumkin, et al., 2008, pp. 438-442; Keim, 2008). In their view, the profession mainly needs more and better resources devoted to these essential functions, particularly in relation to surveillance, monitoring, communications and localized climate change models.

But they also espouse substantially more interaction and coordination with other disciplines. Frumkin, for example, writes that "new collaborations must be developed…with architects and city planners (whose design work can reduce energy demand and limit vulnerability to heat, flooding, and other risks) [and] transportation planners (who can design transportation systems that reduce greenhouse gas emissions and promote safe, healthy travel)" (Frumkin, et al., 2008, p. 440). Ebi et al recapitulate a USGCRP recommendation (CCSP, 2008) for "enhance[d] collaboration across the multiple agencies and organizations with responsibility and research related to climate change-related health impacts, such as weather forecasting, air and water quality regulations, vector control programs, and disaster preparedness and response" (Ebi, et al., 2009, p. 858). The need for state public health collaboration and interagency relationships is prominent in the California Climate Adaptation Strategy (California Natural Resources Agency, 2009). By and large, however, the calls for more collaboration, interagency cooperation and interdisciplinary approaches have not delineated how such partnerships might function—and be funded—and what the roles of public health professionals should be.

There is also substantial overlap among the recommendations of the IPCC, the USGCRP and the Lancet report entitled <u>Managing the Health Effects of Climate Change</u>. In USGCRP's <u>Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems,</u> a summary table (CCSP, 2008, pp. 69-71) outlining "community, state and national agency roles and responsibilities for adaptation to climate change health risks" has five recurring themes across multiple categories of health threats:

- providing scientific and technical guidance;
- implementing and enhancing early warning and alert systems;
- improving surveillance and monitoring;
- conducting research;

- increasing and improving education, outreach, dissemination of information and risk communications.

All the major reports emphasize the importance of increasing nations' and communities' "adaptive capacity," defined as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (CCSP, 2008, p. 177; IPCC, 2007, p. 869).

In regard to the issue of adaptive capacity, it is worth noting that USGCRP states that "the most important adaptation to ameliorate health effects from climate change is to support and maintain the United States' public health infrastructure" (CCSP, 2008B, p. 8). Maintaining a system that already exists and that has evolved largely independent of concerns about climate change is a peculiar use of the term adaptation, but it usefully highlights the difficulties that some within the public health profession are having in imagining societal responses to climate change that are different in <u>kind</u> rather than simply different in <u>scale</u> from the current system. Various articles describe as "adaptations to climate change health impacts" activities that public health professionals in other contexts would simply consider business as usual: a community workshop, public-private partnerships, planning and needs assessments, and preparedness (Ebi, et al., 2006; Ebi & Semenza, 2008; Keim, 2008). Furthermore, the list of "adjustments" for individuals, families and communities on the CDC Climate Change Program website[ix] is quite generic, and amounts essentially to eating better, exercising more, reducing one's carbon footprint and utilizing the resources available at Ready.gov (CDC, 2009).

Other oft-repeated prescriptions include capacity building; improving primary health care systems; creating tools to model climate changes and predict health impacts at all levels of spatial aggregation; obtaining massive and low carbon increases in food production and improvements in water management; reducing—not just limiting the spread of—urban heat islands; improving the coordination and accountability of global governance; and identifying and promoting "co-benefits" (Costello, 2009, pp. 1694-1696).

3.2 Co-Benefits

"Co-benefits" refers to improvements in public health that should result from policies and activities designed to reduce GHG emissions. The improvements would appear as reductions in the social burdens of heart disease, obesity, mental health problems and other conditions about which Americans (and other wealthy country citizens) are deeply concerned, regardless of what they believe or dispute about climate change. The rallying cry for co-benefits is simple: "Overall, what is good for tackling climate change is good for health" (Gill & Stott, 2009, p. 1953). Health professionals have an obligation to communicate all scientifically supportable co-benefits to a wide public audience and ensure that such benefits are counted when policy-makers debate the costs of climate change mitigation efforts (Roberts, 2009, p. 213).

A recent six-article series in The Lancet and an unrelated survey of mental health literature (Gill & Stott, 2009; Haines, Wilkinson, Tonne, & Roberts, 2009; Horton, 2009; Nilsson, Beaglehole, & Sauerborn, 2009; Nurse, Basher, Bone, & Bird, 2010; Smith, et al., 2009; Watts, 2009) present evidence that even in a rich countries, varied measures to reduce GHG emissions could generate significant reductions in certain health burdens (TABLE 3):

TABLE 3: HEALTH CO-BENEFITS OF GHG MITIGATION MEASURES IN DEVELOPED COUNTRIES

Mitigation (GHG Emission Reduction) Measure	Types of Health Benefits Expected
More house insulation; better ventilation and heat recovery; switch to electric heat; lower thermostat by 1^oC*****	Reduced exposure to fine particulates, radon and CO2 poisoning.
Less car use accompanied by "safe urban environments for more active travel" i.e., walking and bicycling*****	Reduced heart disease, stroke, breast cancer, dementia and depression
Low carbon electricity generation such as wind, tide, solar*****	Reduced cardiopulmonary and respiratory disease & lung cancer
Reduced livestock production and meat and dairy consumption*****	Reduction in heart disease, obesity and diet-related cancers
"Increases in green spaces and natural environments"[†]	Enhanced cognition and emotional development in children; reduced stress and anger, crime and violence; better work performance and concentration; faster recovery from medical procedures.

Sources: * (Chan, 2009; Gill & Stott, 2009; Horton, 2009; Nilsson, et al., 2009; Smith, et al., 2009; Watts, 2009); †(Nurse, et al., 2010)

3.3 Costs

How much would an adequate program of climate change adaptation cost just in the United States? To the authors' knowledge, nobody has attempted such an analysis. Presumably, the previously discussed gaps in understanding of how climate change will manifest itself and affect health at local and regional levels, and the limited understanding of what adaptations may be effective, are huge obstacle to any kind of informed estimate of adaptation costs. But at least one group of analysts has put a price on an adequate research program to begin to fill those gaps. Ebi et al estimated that the U.S. federal government would need to spend at least $250 million per year to fund an adequate research program on the health impacts of climate change, as outlined in TABLE 4.

TABLE 4: A PROPOSED RESEARCH BUDGET FOR CLIMATE CHANGE-RELATED HEALTH IMPACTS AND ADAPTATION

Research Category	Annual cost ($millions)
"A comprehensive surveillance and monitoring system to address the health risks of climate change that included indicators for climate, atmospheric, and ecosystem conditions as well as the health of domestic animals, wild animals, and humans…"	>$100 million
Supplemental "field, laboratory and epidemiology research programs" above and beyond existing research in climate sensitive health problems like ozone, particulates and asthma.	
For at least 10 regional centers of excellence at $5 million/center	$50 million
For investigator-initiated intramural and extramural research	$100 million
Software and models to simulate and predict public health impacts of climate change at national, state and local scales.	At least $2 million

Source: (Ebi, et al., 2009, p. 861)

It is important to emphasize that this is the recommended budget for data collection, surveillance, monitoring, analysis, research and evaluation only. It doesn't even scratch the surface of the investments that will be required to implement adaptations that are based upon sound scientific evidence. The cost of defending vulnerable coastlines through engineering solutions or, alternatively, relocating vulnerable communities further inland, will entail costs many orders of magnitude greater. One can say the same with regard to retrofitting residential and commercial buildings to dissipate heat, increasing urban vegetation to increase shade, building infrastructure to accommodate bicycle commuting, creating new vaccines and medical treatments to deal with emerging infectious diseases, providing health services to arriving environmental refugees and providing climate change adaptation assistance to poorer nations.

The United States' drinking water and wastewater facilities are a critical category of infrastructure—although hardly the only one—that will require massive capital investment to adapt to climate change. A preliminary estimate of the national adaptation costs for that sector alone is $448-$944 billion over the next 40 years (NACWA, 2009, pp. ES-8). These and other adaptations will entail significant expenditures at all levels of government. Adaptation will have to compete for funding with other urgent social priorities and with economic growth, and will have to be more or less consistent with Americans' distaste for governmental restrictions on their freedom of action.

3.4 Local and State Preparedness

The scope and costs of a full-throated public health response to climate change are particularly important at the state and local level, where financial resources and staffing limitations are the most pronounced. For example, during the winter of 2008, the Environmental Defense Fund, George Mason University and the National Association of County and City Health Officials (NACCHO) conducted a structured phone survey of 133 local public health agency directors (Balbus, Ebi, & Finzer, 2008, pp. 7-8). One year later, the Association of State and Territorial Health Officials (ASTHO) conducted a

TABLE 5: NACCHO AND ASTHO SURVEY KEY RESULTS

	Percent Respondents
NACCHO: Local Public Health Directors Perceptions **Source: (Balbus, et al., 2008, pp. iv-v)**	
My jurisdiction has experienced/**will experience** climate change in the past/**next** 20 years	70/**78**
One or more serious public health problems will occur in my jurisdiction in the next two decades as a result of climate change	60
Preventing or preparing for climate change is an important/**TOP 10** priority for my department	51/**19**
My department has ample expertise to assess local health impacts of climate change/**craft adaptation plans**	23/**17**
My state health department/**CDC** has the needed expertise to develop adaptation plans	26/**34**
ASTHO: State and Territorial Chief Health Officers Perceptions **Sources: (ASTHO, 2009, 2009A)**	
My state/territory will experience one or more serious climate-change related public health problems in the next 20 years	73
Climate Change is one of my agency's Top 10/**TOP 5** Priorities	23/**19**
My agency has sufficient expertise to educate the public on climate change	67
My agency has sufficient expertise to conduct climate change needs assessments/**undertake response activities**	42/**26**
My agency has adequate surveillance capacity to address health impacts of ozone and particulates/**mental health issues**	26/**26**
My agency currently uses long-range weather/climate information to inform programmatic activity	37
The respondent is involved in multi-agency initiatives to address climate change, in her/his state or territory	33

similar survey of the chief health officers of 43 state and territorial health agencies (ASTHO, 2009A, p. 19). The key findings of these surveys are shown in TABLE 5. The local health department executives exhibited widespread recognition of and concern about climate change's health implications at the local level, coupled with a pervasive belief that neither local departments, state health departments nor the CDC were yet up to the challenge of facing those implications. The state-level officials exhibited a somewhat higher level of confidence than their local counterparts, yet their responses suggest that state public health departments have inadequate surveillance capabilities, are not widely involved in interagency climate-change initiatives and lack the staff and tools to engage in climate change needs assessments and response activities.

A 2009 analysis by Trust for America's Health utilized some simple indicators to conduct a preliminary review of states' readiness to address climate change health impacts. The indicators included the creation of a state climate change plan or strategy that "included a detailed vision of the role public health would play in preventing and preparing for climate change;" creation of a state climate change commission or advisory panel reporting to the governor or legislature, including a representative from state or local public health departments; receipt in fiscal year 2009 of a CDC Environmental Public Health Tracking Program[x] or National Asthma Control Program grant;[xi] and receipt in fiscal year 2008 of CDC funding to participate in the "ArboNet"[xii] vector-borne disease surveillance system (Levi & Vinter, 2009, pp. 35-39). While acknowledging that this set of indicators was not conclusive, the study authors believed that it did "help identify gaps in current climate change preparedness and response" (Levi & Vinter, 2009, p. 33).

The five Gulf Coast states all participated in ArboNet, but only two had received asthma grants (Mississippi and Texas) or Environmental Public Health Tracking grants (Florida and Louisiana). None of the five had a plan or an advisory body that completely matched the above criteria. Although Florida had created both a plan and an advisory board, the study found them lacking the requisite public health component and participation. The other four states had not created any climate change plan or advisory body (Levi & Vinter, 2009, p. 34).

We applied a simplistic test to determine if state health departments are educating their citizens about the health dimensions of climate change. In March 2010 we searched the websites of the five Gulf state health departments[xiii] for "hits" on the terms "climate change" and "global warming," for links to the CDC Climate Change program website and links to the major climate change research programs (USGCRP and IPCC). Except for Florida, we came up almost empty-handed (TABLE 6). Today, a resident of Alabama, Louisiana, Mississippi or Texas could be excused for concluding that her state health department is not particularly concerned about climate change. Regardless of what those state governments are actually doing, their health departments' portals don't communicate that there is a profound link between climate change and human health.

TABLE 6: SEARCH RESULTS FOR GULF STATES DEPARTMENTS OF HEALTH WEBSITES MARCH 26, 2010

Climate Change Related Subject	**AL**	**FL**	**LA**	**MS**	**TX**
Number of hits for "climate change"/ **"global warming"**	0/**0**	8/**1**	0/**0**	0/**0**	8*/**2**
Number of hits for "sea level rise"	0	1	0	0	0
Number Hits For Dengue	0	1	0	0	0
Links to www.cdc.gov/climatechange	0	1	0	0	0
Links to Global Change Research Program, Climate Change Science Program or IPCC (full name or acronym)	0	0	0	0	0
*Only 2 links directed the viewer to information about climate change and health					

None of these findings should be surprising, given the lack of federal resources to help state and local governments staff up for climate change, a competing decade-long federal emphasis on pandemic and all-hazards public health preparedness, some governors' overt hostility to the concept of climate change and the absence of a cohesive federal policy, approach or strategy for addressing the health implications of climate change.

3.5 Another perspective

Finally, the discussion within the public health profession over climate change includes a persistent voice which suggests that the dedication of more resources to the "Ten Essential Services of Public Health," even if coupled with more coordination and collaboration, may be an inadequate societal response. This position argues that "a new advocacy and public health movement is needed urgently to bring together governments, international agencies, non-governmental organizations (NGOs), communities and academics from all disciplines to adapt to the effects of climate change on health" (Costello, 2009, p. 1693). Just below the surface lurks the belief that only a radical redistribution of wealth towards the worlds' poorest, coupled with commensurate curtailment of carbon-intensive consumption by the "developed" world, can avert widespread misery from climate change's predictable global health impacts (McMichael & Kovats, 2000, p. 57).

This argument has an implied warning that by themselves, more of the public health tools and techniques that have served the developed world so well will not inoculate the richer nations against unwelcome, involuntary changes in their lifestyle and limitations on their freedom of choice**.** For instance, Smith writes that "the rich will find their world to be more expensive, inconvenient, uncomfortable, disrupted, and colorless—in general, more unpleasant and unpredictable, perhaps greatly so" (Smith, 2008, p. 1). Capon et al imply that attaining a "healthy way of life" in the face of climate change may necessitate a narrower spectrum of urban settlements in which, regardless of preferences, everyone must walk, bike or ride the bus everywhere and seek cultural enrichment in a more limited geographic space (Capon, Synnott, & Holliday, 2009, p. 25).

The Lancet report entitled "Managing the Health Effects of Climate Change" makes this point directly: "the biggest sociopolitical challenge affecting the success of climate change mitigation is the lifestyle of those living in rich nations and a small minority living in poor nations, which is neither sustainable nor equitable" (Costello, 2009, p. 1696). Although this statement refers to reduction of greenhouse gas emissions rather than climate change adaptation, its message is unambiguous. Health impacts unavoidably will compound and worsen unless the richer nations learn to live with less.

4. U.S. Federal Government Preparedness for Climate Change Health Impacts

4.1 Where we are today

Several experts have observed that current federal research efforts on climate change and human health are unfocused and inadequate, and have called for a major overhaul in funding and priorities. For instance, at a January 2009 Institute of Medicine workshop on a research agenda for climate change and human health, John Balbus characterized the current state of affairs as "wheels spinning, no movement" (Balbus, 2009, p. 29). Around the same time, Ebi and her colleagues concluded that research funding for climate change health impacts across the entire federal government was just a small fraction of their previously-noted recommendation of at least $250 million per year (Ebi, et al., 2009, p. 861). It also is clear that the elaborate institutional mechanisms created over the last decade in the National Infrastructure Protection Plan (NIPP) to address the "all hazards" vulnerability of health and public health, transportation, agricultural, water system and sanitary system infrastructure scarcely recognize climate change as a threat (DHS, 2009). The same is true of the Department of Health and Human Service's recent "National Health Security Strategy" (DHHS, 2009). Agencies like CDC and NIH are funding very limited amounts of research and capacity building in state and local governments (CDC, 2010A; GAO, 2009A, p. 49; NIH, 2010A).[xiv] Unfortunately, however, the Government Accountability Office recently concluded that "the federal government's emerging adaptation activities are carried out in an ad hoc manner and are not well coordinated across federal agencies, let alone state and local governments" (GAO, 2009B, p. 58).

4.2 Where we may be heading

In the summer of 2009, the House of Representatives passed an energy and climate bill known as Waxman-Markey (Clerk of the House, 2009),[xv] and several months later, a Senate Committee reported a similar bill (known as Kerry-Boxer)[xvi] to the full chamber (Boxer, 2009). These bills would have allocated approximately $1 billion over ten years to fund new climate change-related public health adaptation, research and capacity-building initiatives in the Department of Health and Human Services **(CBO, 2009, 2009A).** It should be noted that the new contemplated HHS funding—about $100 million per year—is barely 40% of the previously-noted recommendation for research, surveillance and monitoring alone (Ebi, et al., 2009). The bills also would have provided complementary funding for a new National Climate Service, a revamped and expanded Global Change Research Program, a program of grants to states to build climate change resilience and programs focused on adapting to climate change impacts on water supplies and natural resources (Pew Center, 2009). The additional funding would have come from government revenues under a "cap-and-trade" program. Last October, numerous scientific, environmental and health organizations strongly endorsed the public health provisions of these bills (ASPH, 2009).[xvii]

There is great uncertainty about what will happen on the legislative front in the second half of 2010. According to a multi-year opinion study by Yale and George Mason Universities, "the American people are becoming less—not more–convinced that climate change is real and serious" (Maibach, 2010, p. 16). There also has been a substantial increase in the percentage of Americans who "view global warming as a more distant threat—primarily to other people—that won't manifest for another decade or two" (Leiserowitz & Maibach, 2008; Leiserowitz, Maibach, & Roser-Renouf, 2010, p. 2). The American Power Act, the new energy and climate act that Senators Kerry and Lieberman introduced in early May (U.S. Senate, 2010), did not include the funding and programs for climate change-related health research and adaptation contained in the 2009 bills.

While Congress has hesitated on energy and climate legislation, other units of the federal government have been trying to advance a climate change research and adaptation agenda in various ways. An "Interagency Working Group on Climate Change and Health" released a report entitled "A Human Health Perspective on Climate Change" on Earth Day 2010 (NIH, 2010C). This report is notable for presenting climate change health research on which IPCC, USGCRP and others previously have reported, in terms of cancer, cardiovascular disease, stroke, allergies, asthma, COPD, mental health and stress, nutrition, human development, neurological disorders, infectious diseases and other ailments. In so doing, it implicitly has aligned climate change health impacts with political actors—various NIH institutes and centers, members of Congress and advocacy groups interested in particular diseases and health risks. This report also cautions that substantial research is still needed on the potential negative health consequences of widely-heralded GHG mitigation approaches (such as biofuels, electric cars, hydrogen fuel cells and solar electric power) and potential adaptations such as increased wastewater recycling, genetic modification of crops and greater use of air conditioners.

A National Academies Project called "America's Climate Choices" released its initial reports in late May 2010 (National Research Council, 2010A, 2010B). These reports propose a set of broad and generic recommendations—including the development of a national climate change adaptation strategy—for how government and civil society in the United States should organize a national adaptation effort (National Research Council, 2010A, pp. 191-203). Unfortunately, neither the new National Academies reports nor the interagency report offers any analysis or estimate of the federal funding that would be necessary to pursue an adequate research program, or prioritizes a diverse array of recommended research projects.

A final major initiative is the Interagency Climate Change Adaptation Task Force that President Obama created last year (White House, 2009). There is little public information about this Task Force beyond its stated mission to form recommendations towards a national adaptation strategy, to integrate climate change resilience and adaptive capacity into federal government operations and to promote adaptation at the local level (White House, 2010A).

5. Conclusion

There is a strong consensus within the scientific community that climate change will profoundly (and mostly negatively) affect human health for generations to come. Some direct and indirect paths between climate change and poorer health already are well-established and well-documented, while many other paths are strongly suspected and supported by theory and preliminary evidence. Scientists expect climate change to exacerbate virtually all the categories of illness which cause the majority of morbidity and mortality in the United States. Each year, the public sector spends billions of dollars to prevent and treat these illnesses through research and public health programs--a significant burden on federal, state and local budgets. The illnesses themselves take a huge toll on the U.S. economy and on household savings and wealth. On the other hand, there is a strong and compelling scientific consensus that America could protect itself from many of the worst anticipated health impacts of climate change by putting in place a robust program of adaptation policies and programs. Although the cost of such adaptations would likely be immense, the cost of a comprehensive research program to maximize the efficiency (and minimize the cost) of climate change adaptations would be small compared to the $32 billion that the Department of Health and Human Services (largely NIH) spends on research each year.

Even so, in the United States climate change and its potential impacts on health do not command nearly the attention, interest or media coverage as the economic crisis, the Deepwater Horizon Gulf oil spill crisis or America's ongoing wars. There is hardly a groundswell of popular support or advocacy for governmental leadership to address this slowly unfolding and insidious catastrophe. Government reports, such as the recent volumes from NIH and the National Research Council, convey the magnitude of the problem but scrupulously avoid alarmist terminology and prescriptions for large scale governmental intervention. Upon the occurrence of a series of catastrophic weather events that caused untold human suffering, Americans might rally to the cause if they strongly associated those events with climate change. Absent such events, it will be an immense challenge for concerned leaders to muster a political coalition sufficient to join the battle.

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The only relatively recent study to present a comprehensive survey of climate change's myriad physical effects just in the five states that border the Gulf of Mexico was a 2001 report by the Union of Concerned Scientists and the Ecological Society of America (Twilley, Barron, Gholz, & Harwell, 2001). The United States Global Change Research Program's (USGCRP) 2009 report entitled Global Climate Change Impacts in the U.S. includes a chapter on the generic types of climate changes that can be expected in a twelve-state area referred to as "the Southeast" (GCRP, 2009, pp. 111-116). This chapter, however, does not restrict its focus to coastal states, nor does it discuss the human health impacts of climate change in the Southeast region.

[ii] USGCRP "was known as the U.S. Climate Change Science Program from 2002 through 2008." See (GCRP, 2010) In this report, USGCRP is used in discussing reports published under both names, although the citations will include the title in effect at time of publication.

[iii] Medium confidence signifies "about 5 out of 10;" and low "about 2 out of 10" (IPCC, 2007, p. 4)

[iv] The authors of this study provide a detailed technical analysis of their sea level rise assumption. They note that "the projected rate of relative sea level rise for the region is consistent with historical trends, other published region-specific analyses, and the IPCC 4th Assessment Report findings, which assumes no major changes in ice sheet dynamics." (Savonis, Burkett, & Potter, 2008, pp. ES-4)

[v] For a discussion of the uncertainties in estimating sea level rise and the expected variability of sea level rise even in a limited region such as the Gulf Coast, see (Lemonick, 2010)

[vi] Both amounts expressed in present value terms.

[vii] As noted in TABLE 1, the IPCC also assigned a relatively low level of concern to Dengue.

[viii] Early in 2010 CDC added Dengue to the list of nationally notifiable infectious diseases (CDC, 2010).

[ix] http://www.cdc.gov/climatechange/prevention.htm

[x] The CDC website provides the following: "EPHT is the ongoing collection, integration, analysis, interpretation, and dissemination of data on environmental hazards, exposures to those hazards, and health effects that may be related to the exposures. The goal of tracking is to provide information that can be used to plan, apply, and evaluate actions to prevent and control environmentally related diseases." Retrieved June 14, 2010 from http://www.cdc.gov/nceh/tracking/pib.htm.

[xi] A description of this grant program is available at http://www.cdc.gov/asthma/nacp.htm.

[xii] Described in the TFAH report as "an internet-based national arboviral surveillance system developed by state health departments and CDC in 2000 to provide public health officials and health care providers with information about disease activity in their states."

[xiii] Using each site's internal search engine.

[xiv] As of April 8, 2010, NIH had awarded four grants totaling $1,336,369 during the initial fiscal year.

[xv] The House vote on Waxman-Markey was extremely close—219 to 212--(Clerk of the House, 2009) and of the 75 Members representing the five Gulf Coast states, only 19 (one fourth) voted in favor (APHA, 2010).

[xvi] The formal names and numbers of the House and Senate bills, respectively, are American Clean Energy and Security Act (HR 2454) and the Clean Energy Jobs and American Power Act (S 1733).

[xvii] Signatories included the American Public Health Association, the National Association of County and City Health Officials, the Association of State and Territorial Health Officials, American College of

Preventive Medicine, the American Academy of Pediatrics, the Association of State and Territorial Directors of Nursing, Council of State and Territorial Epidemiologists and Association of Schools of Public Health.