Climate Scenarios: A Florida-Centric View

A White Paper on Climate Scenarios for Florida

November 2011

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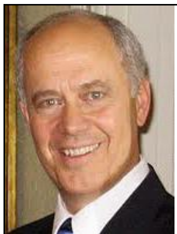

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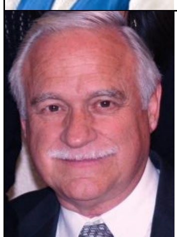

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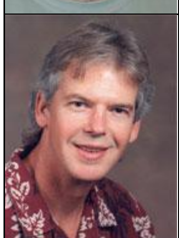

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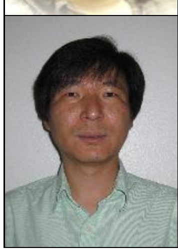	**Sang-Ik Shin** Assistant Professor of Physical Oceanography University of South Florida – College of Marine Science

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Foreword

The purpose of this document is to provide an informed opinion on future climate scenarios relevant to Florida. It offers a primer on Florida's vulnerabilities to climate variability and change. The document is an excellent compilation of diverse viewpoints on future climate projection. It implores the readers to be cognizant of the associated uncertainty but not to use that as an excuse for inaction in climate adaptation and mitigation.

Experts in diverse fields employed in institutions across Florida have contributed to this document and provided candid and informed assessments of future climate variation and change. The uniqueness of this document is that it broadens the discussion of a rather restrictive sounding title like "climate scenarios" to involve experts in sociology, environmental law, and economics, in addition to oceanography and meteorology.

The earth's climate is a very complex system. Climate is intimately interrelated to many components of the earth system. However, climate is not limited to these interactions alone. It also includes the modulation of these interactions by external factors such as anthropogenic influence (or interference), volcanic eruptions, changes in solar activity, and changing planetary factors like orbital eccentricity, obliquity, and precession.

Against this backdrop of complexity, this paper has tried to distill the information that is relevant to Florida. It is well understood that climate has no borders, and yet we focus here on Florida because of the huge demand for locally applicable information on climate change and variation. Therefore, time and again throughout this paper the impact of remote climate variations and change on Florida is emphasized.

Finally this document provides some initial suggestions to further fortify our understanding of the impact of global climate change on Florida. The caveat however, is that these fledgling suggestions will have to be further molded by a developing synergy between the federal, state, private stakeholders and university researchers.

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Executive Summary

This document comprises the viewpoints of experts in Florida from diverse fields on climate scenarios of the future with a focus on potential impacts on the state of Florida. A general perception of climate change is associated with uncertainty that entails different viewpoints and an implied limited understanding of the impacts of climate change. This notion is amplified further when impacts of climate change are assessed locally over a region like Florida. It is the collective opinion of this group that we cannot wish away this uncertainty. The nature of the problem warrants a probabilistic projection although a deterministic answer to the impact of climate change is most desirable. In fact the uncertainty in our understanding and predictions of climate variations is a natural outcome of the increasingly complex observing and modeling methods we use to examine interactions between the biosphere, atmosphere, hydrosphere, and cryosphere.

It is shown that Florida represents a good example of a complex regional climate system, where relatively slow natural climate variations conflate or deflate the multiple sources of anthropogenic climate influences. Climate change in this document refers to all sources of anthropogenic influences, including greenhouse gas (GHG) emissions, aerosols, and land cover and land use change. In fact assessing climate change over Florida is so complex that *climate change occurring remotely may have a larger impact than the direct influence of climate change on Florida*. However the basic fact irrespective of the source of these variations and change is that Florida, with its vast and growing coastal communities and changing and growing demography will make itself more vulnerable to weather and climate events. With anticipation of further rapid increase in GHG emissions, it is prudent to act now in applying the necessary regional climate information that we have to educate the public and implement adaptation and mitigation plans. Some of the most apparent impacts of climate change and variability for Florida are as follows:

(i) Salt water intrusion from sea level rise is already becoming an issue for the freshwater demands of highly populated areas along the southeast coast, from the Florida Keys to Palm Beach. This issue may further worsen and become more widespread over time with climate change.

(ii) The displacement of communities, destruction of infrastructure and terrestrial ecology, and increased prospects of damage from storm surge would be additional consequence of sea level rise.

(iii) The likelihood of the change in the statistics of Atlantic tropical cyclone intensity has a huge implication for the sustenance of coastal and inland communities in terms of damage to infrastructure and property, human mortality, and the modulation of the accumulated fresh water source in the summer, especially in South Florida.

(iv) Remote impacts of any perceived climate change in the characteristics of El Niño and Southern Oscillation (ENSO; although none have been conclusively found so far) will have an implication on the seasonal climate variability over Florida, especially in winter and spring seasons.

(v) Likewise remote impact of climate change over North Africa can have implications on dust transport across the Atlantic Ocean, which can change the air quality and health of Florida's neighboring oceans.

(vi) The uncertainty in the anticipated changes in Florida red tide (a harmful algal bloom) due to changes in ocean temperatures, long term variations of local scale terrestrial runoff can make the fishing industry and the human population vulnerable.

(vii) Florida's coastal reefs, which serve as a habitat for a variety of biota, are threatened by ocean acidification from increased levels of dissolved carbon dioxide.

(viii) There is anticipation of inevitable future increases in the wealth of Florida coastal communities, which would lead to further infrastructure development that will make the coastal regions far more susceptible to even moderate (and unanticipated) changes in climate.

It is recommended that, with existing climate information, effective climate scenarios could be developed in the near term that would be useful to plan and test sustainable strategies for adaptation and mitigation of climate-related vulnerabilities. Ongoing scientific research is bound to further improve our ability to understand and predict our climate system to meet the strident demands for accurate climate projection.

In addition the growing and aging population of Florida would make this State more vulnerable to climate variations and change. The demand for energy and water will proportionately grow, while changes in land cover, air quality, coastal waters from urbanization, industrialization and agriculture will be inevitable.

Although it is pointed out in this document that sea level rise is one of the main issues confronting Florida in terms of the immediate impact of climate change, we have not included a description of it in this document. This is because there are several reports that have recently been released on sea level rise. They are listed below for our interested readers:

(i) Sea Level Changes in the Southeastern United States: Past, Present and Future (Mitchum 2011; available from http://coaps.fsu.edu/~mhannion/201108mitchum_sealevel.pdf)

(ii) Past and projected trends in climate and sea level for South Florida (Obeysekera et al. 2011; available from http://my.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/ccireport_publicationversion_14jul11.pdf)

(iii) IPCC workshop on sea level rise and ice sheet instabilities (Stocker et al. 2010; available from http://www.ipcc.ch/pdf/supporting-material/SLW_WorkshopReport_kuala_lumpur.pdf)

(iv) Thirsty for answers: Preparing for the water-related impacts of climate change in American cities (Dorfman et al. 2010; available from http://www.nrdc.org/water/thirstyforanswers.asp

SECTION 1

Anthropogenic Influences on Florida's Climate

V. Misra

The phrase "anthropogenic influence on climate" immediately creates a vision of increasing Green House Gas (GHG) emissions, which are by far the strongest anthropogenic influence on the global climate, especially when one examines the global mean surface temperature trends. Even regionally, especially in the northern latitudes of the northern hemisphere, the warming trends in the surface temperature are clearly attributed to increasing GHG emissions. However, in other regions there are other competing anthropogenic influences, such as changes in aerosol concentrations, land cover and land use, and ozone concentration, as well as the nutrient loading of stream flows and coastal waters due to increased terrestrial runoff.

The southeastern United States (SE US), including Florida, is one of those rare regions in the planet that exhibit cooling trends in the terrestrial surface temperature in the second half of the 20th century (Trenberth et al. 2007; Portmann et al. 2009; DeGaetano and Alen 2002; Figs. 1.1A and B). This cooling seems to be strongest in the late spring-early summer period of May-June. Many studies have tried to attribute this cooling trend (sometimes referred to as a "warming hole") to changes in sea surface temperature (SST; Robinson et al. 2002), land-atmosphere feedback (Pan et al. 2004), and/or internal dynamics (i.e., chaotic behavior of the climate system; Kunkel et al. 2006). Portmann et al. (2009) suggest that these cooling trends relate to the fact that the May-June period in the SE US represents a period of abundant rainfall (Fig. 1.1C), which causes more evaporation and cloudiness that could result in a cooling trend, thus compensating for local greenhouse warming.

In a more recent study, Misra et al. (2011) show that the inhomogeneous distribution of the surface temperature trends in the SE US is related to the degree of urbanization (Fig. 1.2a) and irrigation done on croplands (Fig. 1.2b and c). The argument put forth here is that the heat capacity and conductivity of building and paving materials allow for more heat to be absorbed during the day in urban areas than in rural areas. The absorbed heat then becomes available at night in urban areas to partially compensate for the nocturnal upwelling, leading to net decrease in long-wave radiation loss. So in Fig. 1.2a the linear fit to the scatter between the temperature trends and urbanization shows a positive slope, suggesting that with increasing urbanization there is an increase in temperature trends.

Irrigation increases evaporation from the surface, resulting in cooling daytime surface temperatures (T_{max}; Fig. 1.2b). On the other hand, nighttime minimum temperature can increase from irrigation, because wetting of soil raises its heat capacity and conductivity under weak wind conditions. Furthermore, daytime irrigation can also result in more moisture and cloudiness, which may compensate for nighttime long-wave radiation loss and lead to further warming of nighttime minimum temperatures (Fig. 1.2c).

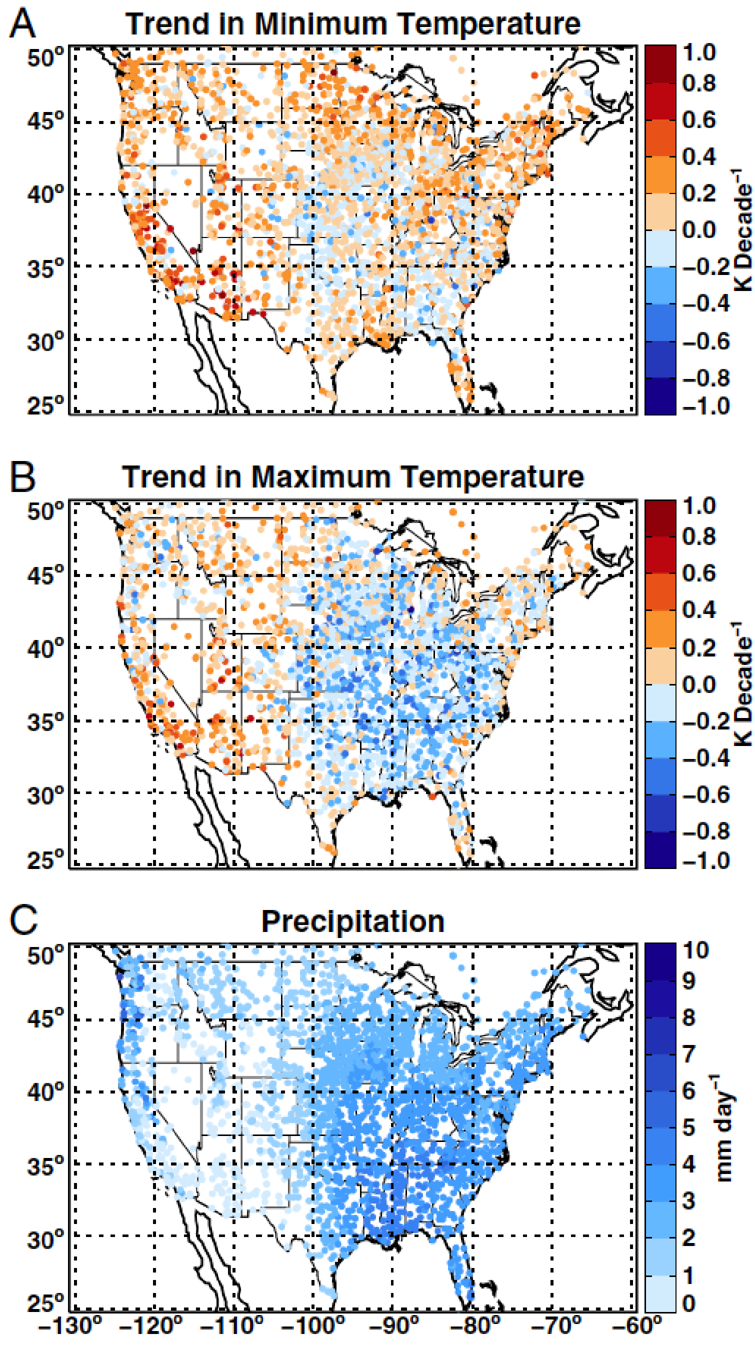

Figure 1.1: (A) Minimum and (B) maximum temperature trends for May-June, and (C) mean precipitation for March-June. The data are from Global Historical Climatology Network Daily version 1 (GHCND). From Portmann et al. 2009.

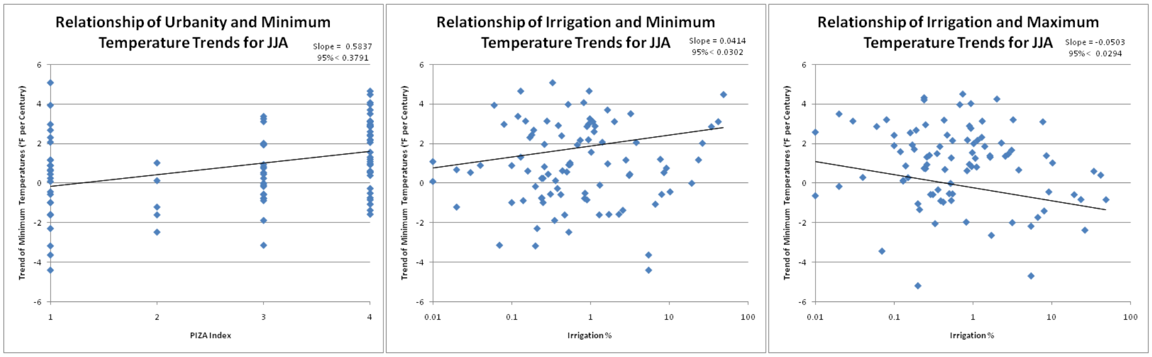

Figure 1.2: The scatter plot of the linear trends (in ^{0}F/century) of T_{min} over (A) the southeastern US (which includes Florida, Alabama, Georgia, South Carolina and North Carolina) with Population Interaction Zone for Agriculture (PIZA; USDA-ERS 2005). A PIZA index of 1 is representative of rural areas, while 5 indicates urban areas. (B) Same as (A) but with irrigation index (Siebert et al. 2006). (C) Same as (B) but with T_{max}. The slope and its 95% confidence level obtained from the Monte Carlo approach are shown in the right top corner of all 3 panels. In all 3 panels, the trends for the June-July-August (JJA) season, when the impact of urbanization and irrigation is found to be strongest, are shown.

There are a growing number of studies suggesting a future climate of unprecedented increases in GHG concentrations leading to heat waves, prolonged droughts, and more intense rain bearing systems, such as thunderstorms and hurricanes, in the SE US (Seager et al. 2009; Li et al. 2011; Ortegren et al. 2011). In fact, from the analysis of the climate model projections that contributed to the International Panel for Climate Change (IPCC) Assessment Report 4 (AR4), Seager et al. (2009) found summer precipitation increases over the SE US. However, there is a corresponding increase in evaporation from the increased surface temperatures of the continental region, which results in a net water deficit in the atmosphere, leading to a drier environment. However, reconstruction of drought indices from tree rings suggests that droughts over the SE US in the medieval period (which included 20 uninterrupted years of drought from 1555-1574) dwarf the drought of the 20th century in their persistence (Seager et al. 2009). In recent decades, Li et al. (2011) indicate that the North Atlantic Subtropical High has become more intense, moved further westward with enhanced north-south movement, which has resulted in the increased interannual variability of summer precipitation (the rainy season) in the SE US.

Karl et al. (2009) using the suite of models in the Coupled Model Intercomparison Project 3 (CMIP3) used in IPCC AR4 found that they project continued warming in all seasons across the SE US with rising rates of warming through the end of the 21st century. For low emission scenario Karl et al. (2009) diagnosed that the CMIP3 models projected a rise of 4.5^{0}F by the 2080s and to about 9^{0}F for projections from high emission scenario. The model projections for precipitation is not discussed as they are relatively more uncertain to make a conclusive statement.

- Frequently Asked Questions -

What is land-atmosphere feedback?

Land-atmosphere feedback refers to the interaction between the land and the atmosphere that leads to growth, decay, or sustenance of a weather or climate anomaly. The re-evaporation from the land surface of the falling precipitation back in to the atmosphere is an example of positive land-atmosphere feedback. An example of negative land-atmosphere feedback is the spinning down or weakening of a hurricane that moves onshore (landfalls) due to a relative increase in friction with the rough land surface and a cutoff of the abundant moisture that was formerly available in the open ocean.

Why are maximum (T_{max}) and minimum (T_{min}) surface temperatures preferred for examining surface temperature trends instead of the mean surface temperature (T_{mean})?

T_{mean} is generally obtained by averaging T_{max} and T_{min} (although this definition of T_{mean} can vary in other parts of the world). Meteorological stations are equipped to measure T_{min} and T_{max}. Furthermore, surface temperature trends and variations in T_{max} and T_{min} represent different physical processes. T_{mean} trends may not be true representations of these physical processes. For example, T_{max} generally represents a thicker layer of atmospheric behavior because T_{max} is usually measured during the daytime, when the surface is relatively well coupled to the overlying atmosphere with a deeper atmospheric boundary layer (a distinct layer in the atmosphere). However, $T_{min,}$ which usually occurs at night, is measured when the atmospheric boundary layer is shallow and decoupled from the rest of the atmosphere, and thereby represents surface characteristics more than the overlying atmosphere.

How to reconcile with the weak climate change signal in surface temperature over the southeast US from past observed data with climate model projections which show a significant increase in temperature by the end of the century?

Indeed the surface temperature does not show a spatially coherent region of rising temperature trends in the last 60-50 years of available station data in the SE US. A spatially coherent warming trend as in the higher latitude regions provides persuasive evidence in itself of climate change. In the SE US there are pockets of rising surface temperature trends alongside regions of cooling temperature trends. Or adjacent observing stations have very different rates of linear temperature change. These features as pointed earlier suggest the impact of local features of SE US that either conflate or deflate the background linear temperature trends imposed by the increasing concentration of green house gases. Despite questionable climate model fidelity, the model projections suggest a significant rise in temperature under emission scenarios that are unprecedented in the recent past. Qualitatively the results of these model projections are persuasive because of our theoretical understanding of the way the climate system could behave under such increased concentrations of green house gases (including the possibility of the broadening of the tropical climate belt) but quantitatively they remain a big question.

SECTION 2

Uncertainty of Climate Projections

B. Kirtman, V. Misra, and D. Letson

Weather and climate predictions are necessarily uncertain. The uncertainty comes from several sources:

(i) Initial condition uncertainty (chaotic behavior of the climate system or internal variability in Fig. 2.1) associated with errors in our observing systems or in how the observational estimates are used to initialize prediction systems (model errors play a significant role here);

(ii) Uncertainty in external forcing (scenario uncertainty in Fig. 2.1). This can be either natural (changes in solar radiation reaching the top of the atmosphere; changes in atmospheric composition due to natural forcing, such as volcanic explosions; and/or changes in the shape and topography of continents or ocean basins) or anthropogenic (changes is the atmospheric composition and land surface properties due to human influences);

(iii) Uncertainties in the formulation of the models (model uncertainty in Fig. 2.1) used to make the predictions and assimilate the observations. These uncertainties are associated with a discrete representation of the climate system and the parameterization of sub-grid physical processes.

In the language of uncertainty quantification, all three of these sources of uncertainty have elements that are aleatoric and epistemic. Aleatoric uncertainties are irreducible – they cannot be completely suppressed by more accurate measurements. For example, if we use a discrete numerical model for the forecast problem but continually reduce the initial condition uncertainty by more accurate observations, the prediction will always be uncertain. This is because a discrete representation of the climate will always have an irreducible discretization error and therefore an associated irreducible uncertainty. In contrast, epistemic uncertainties are reducible and may be due to inaccurate measurements or known model errors. In this case, if we know how to reduce the model errors, we can reduce the uncertainty or perhaps quantify how much of the uncertainty is due to known model errors and how much we can expect to be able to reduce the uncertainty.

To account for these sources of uncertainty, it is now accepted practice in the weather and climate communities to run ensembles of predictions using perturbed initial conditions, perturbed external forcing, and multiple models (including multiple different models and versions of the same model with perturbed or stochastic physics). For example, there have been systematic attempts – through model sensitivity experiments – to quantify how poorly constrained parameters in the atmosphere, land, and sea-ice component models impact the uncertainty in transient climate change projections (Collins et al. 2006) or how uncertainties in GHG emission/concentration scenarios impact the projection/prediction.

For the seasonal-to-interannual prediction problem, the natural variability of the climate system is larger than the forced climate change, and therefore the uncertainty is typically quantified by perturbing initial conditions and applying the multi-model or stochastic physics approach (i.e., assessing uncertainty due to model formulation), with little attention paid to the uncertainties in the external forcing. As the prediction problem extends to longer time scales (i.e., decadal), the forced signal becomes comparable to the natural variability, and all three sources of uncertainty need to be considered.

The prediction lead time, and the spatial and temporal averaging scale all have a bearing on the relative importance of the three sources of uncertainty (Hawkins and Sutton 2009). Fig. 2.1 shows that at prediction time horizons of a decade or more, the model and scenario uncertainty take precedence over internal variability generated from initial condition uncertainty. However, at shorter spatial and temporal scales, internal variability becomes quite an important source of uncertainty, while scenario uncertainty is diminished (Fig. 2.1). This is reminiscent of the committed climate change (Meehl et al. 2009; discussed later in section 9.0), where projections for the near term (10-30 years) are rather insensitive to the chosen scenario of GHG concentrations.

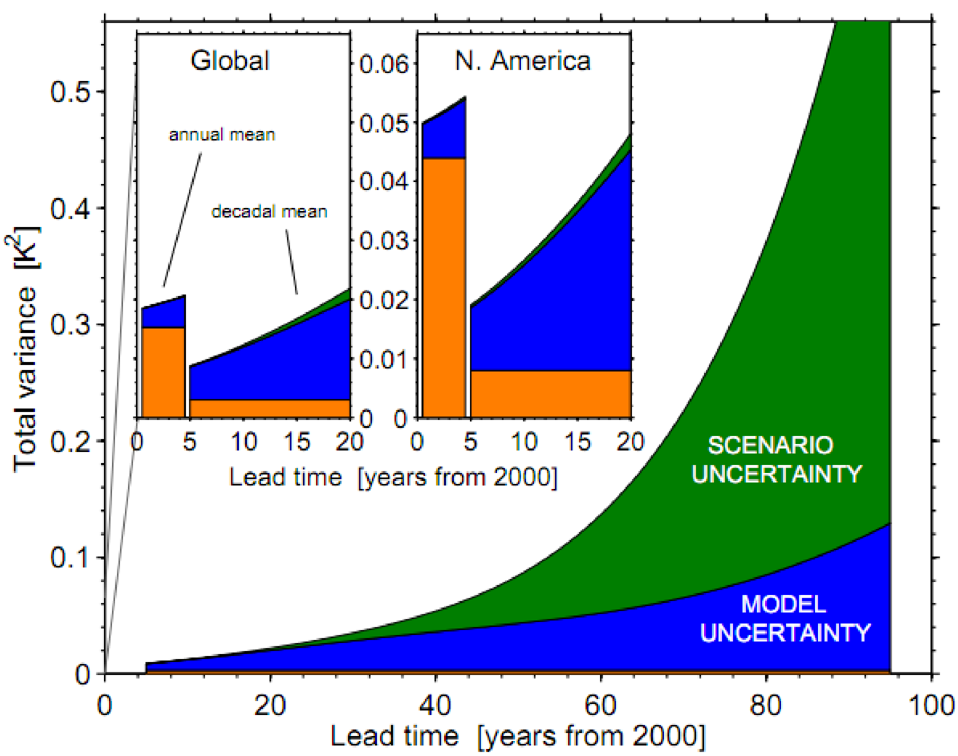

Figure 2.1: Main panel: Total variance of the decadal-global mean surface air temperature split into the three sources of uncertainty (orange: internal variability; blue: model uncertainty; green: scenario uncertainty). Insets: Same as main panel but for lead times less than 20 years for (left) global mean and (right) North American mean. From Hawkins and Sutton (2009).

Hawkins and Sutton (2009) point to an interesting difference in the growth of the uncertainty between globally averaged variables and regionally averaged variables. If one examines the fractional uncertainty (defined as the ratio of prediction uncertainty to expected mean change; Hawkins and Sutton 2009) for a global mean (Fig. 2.2A) versus a given region, say, in this case the British Isles (Fig. 2.2B), the total fractional uncertainty is at a minimum for a forecast of lead time of 40 and 60 years respectively. This minimum is associated with the increasing dominance of model and scenario uncertainty with longer lead times. And the difference in the time at which minimum fractional uncertainty occurs between the global mean (40 years) and the British Isles (60 years) stems largely from a slower rate of reduction of internal variability at regional scales. This objective measure of the time-varying behavior of total uncertainty gives substantive evidence for targeting such forecast periods in order to harvest useful prediction skill at the global and regional scales.

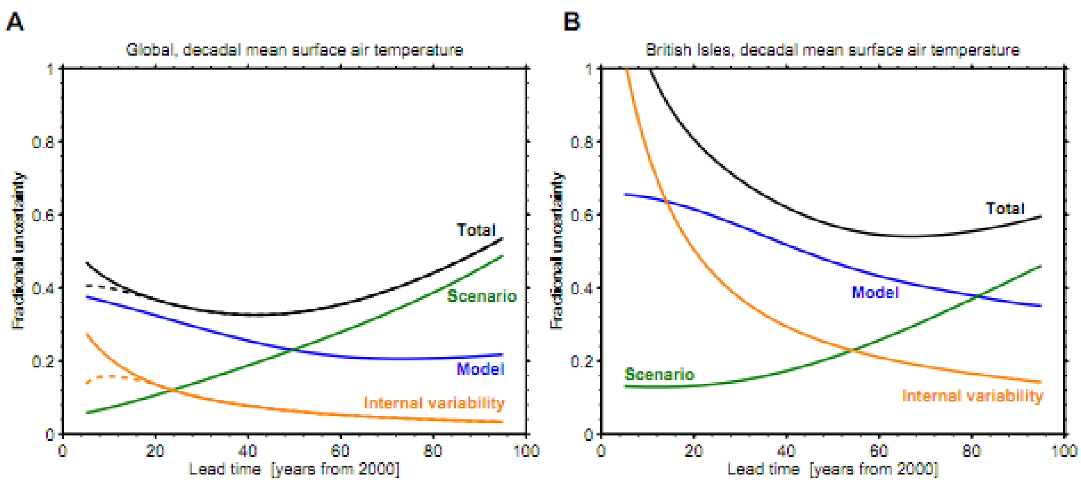

Figure 2.2: Fractional uncertainty of the global and decadal mean surface air temperature for (A) global mean and (B) British Isles mean relative to the warming from the 1971-2000 mean. From Hawkins and Sutton (2009).

In Fig. 2.3, Hawkins and Sutton (2009) show that, for predictions of the next decade, internal variability accounts for 40-60% of the total uncertainty in most regions. Some reduction of this initial condition uncertainty can be achieved through proper initialization of the climate components, especially of the oceans (Smith et al. 2007). For predictions of the fourth decade, model uncertainty is the dominant contribution over most parts of the planet; for the ninth decade scenario, uncertainty takes the precedence. Likewise, model uncertainty could be narrowed further by attempts to improve the models. It may be noted that, even by the end of the century, the emissions scenario is less important than model uncertainty at higher latitudes, where climate feedbacks are quite important (Hawkins and Sutton 2009).

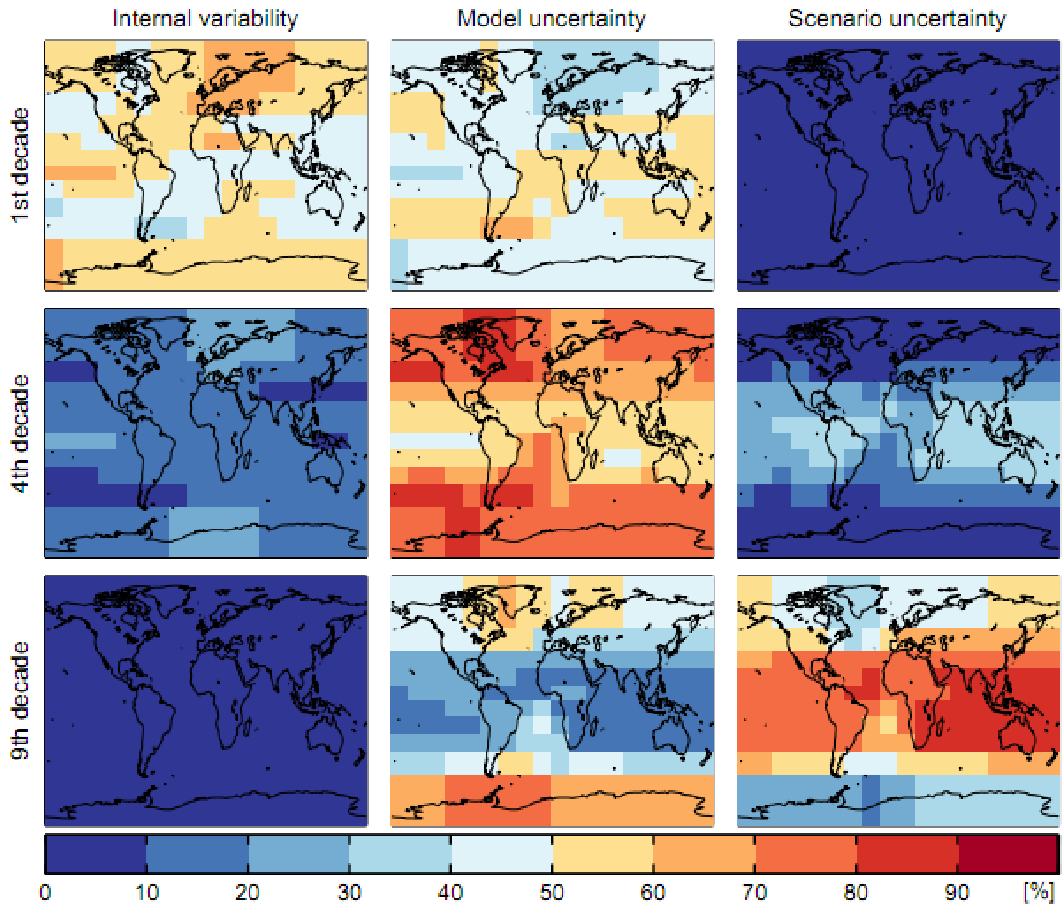

Figure 2.3: The total variance of surface air temperature explained by *left column*: internal variability; *middle column*: model uncertainty; and *right column*: scenario uncertainty for *first row*: first decade; *middle row*: fourth decade; and *bottom row*: ninth decade. From Hawkins and Sutton (2009).

The scenario uncertainty, especially the linkage of carbon emissions associated with economic activity is fuzzy for a host of reasons. Uncertainty in projecting future levels of human activities and technological change is inevitable and to a large extent irreducible. Choosing meaningful or relevant climate scenarios for research depends upon our current ability to predict social and economic processes—such as the future course of globalization, economic priorities, regulation, technology, demographics, and cultural preferences. The evaluation of uncertainty in economic and technological factors and the effects on forecasts of carbon dioxide emissions have a relatively long history (e.g., Nordhaus and Yohe 1983; Reilly et al. 1987).

Trends in CO_2 emissions and in the carbon intensity of the world economy can offer both a baseline and a historical range of variability. Recent growth of the world economy combined with an increase in its carbon intensity have led to rapid growth in fossil fuel CO_2 emissions since 2000: comparing the 1990s with 2000–06, the annual emissions growth rate increased from 1.3% to 3.3% (Canadell et al. 2007). Together, these effects characterize a carbon cycle that is generating stronger-than-expected climate forcing sooner than expected.

The utilization of a specific scenario from the many scenarios the IPCC considers for its projections is usually based on the proposed application of the climate projection. For example, if the concern is to prevent or plan for a low probability, high impact outcome, then one could choose a pessimistic scenario, such as the A2 scenario of the IPCC AR4. The A2 scenario—developed on the premise of a future world of independently operating, self-reliant nations with continuously increasing populations, regionally oriented economic development, and slower and more fragmented technological development—projects a near doubling of the CO_2 concentration by the end of the 21^{st} century from its present levels.

- Frequently Asked Questions -

If weather is hard to predict beyond 5-7 days, then what is the basis for projecting climate out to 100 years in the future?

The basis for projection of climate change is that the substantially increasing GHG concentrations exert an increasing radiative forcing on the earth's climate, so that any future change forced by this increased radiative forcing can be detected from its comparison with the present climate. Furthermore, weather prediction, which dwells on predicting the location, timing, and intensity of the weather (from 1-7 days duration) is overwhelmed and limited by the chaotic nature of the atmosphere that dominates with increasing lead time of the weather forecast. Climate predictions, far from predicting individual weather events, try to predict mean characteristics averaged at least over a month or beyond. Alternatively, climate projection could also dwell on change in the probability distribution function (pdf) of the variable of interest or low frequency variations of extreme weather events. The premise in climate prediction is that the slowly varying boundary conditions of the ocean surface, land surface, changes in orbital parameters (Milankovitch cycles), and GHGs, condition the chaotic atmosphere to behave in a particular manner so that the change in their mean characteristics averaged over a period of time are predictable.

How to make use of climate projections for hydrological applications, given that climate prediction or projection is based on changes to mean characteristics?

In fact hydrological applications of climate projection is most suited as they typically examine aggregate (averaged over a watershed or a riverbasin) changes. Hydrology has developed sophisticated disaggregation schemes to use coarse resolution meteorological data to compute for example, robust probabilistic estimates of integrated stream flow projections. Similarly, hydrology has developed techniques to upscale to continental scale.

Does uncertainty of climate projections increase with complexity of the numerical climate models?

This is not necessarily true. It depends on the nature and dominance of the climate feedbacks prevalent in the model for the variable in question. The multitude of climate feedbacks prevalent in the current state of the art climate models can either damp or amplify the climate change signal in any given model depending on the dominating feedback mechanisms.

SECTION 3

Mid-Century Expectations for Tropical Cyclone Activity and Florida Rainfall

D. Enfield, S.-K. Lee, F. Marks, and M. Powell

The question of future rainfall and Atlantic tropical cyclone (TC) activity and their probable impact on Florida water supplies and infrastructure on a greenhouse-warmed earth is complex and has been the subject of considerable research since about 2005. TCs and rainfall are intertwined, because not only do TCs cause devastation to lives and infrastructure, they also contribute a significant part of the overall rainfall in Florida, which also includes contributions from frontal passages, tropical waves, and sea breeze frontogenesis. Moreover, it is likely that sea level rise and population growth will further exacerbate the negative impacts of future rainfall and TC activity on infrastructure and water supplies. Finally, natural multidecadal variability in both TCs and rainfall will probably modulate strongly the human-induced trends. Without going into great detail, this section will summarize what we presently know and expect over the coming century.

3.1 Tropical Cyclone Activity

"Top researchers now agree that the world is likely to get stronger but fewer hurricanes in the future because of global warming (Borenstein 2010)." According to Knutson et al. (2010), future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100. However, modeling studies also consistently project decreases in the globally averaged frequency of tropical cyclones, and this projection is particularly applicable to the tropical Atlantic sector. The latest research published by Bender et al. (2010) builds on and is consistent with most of the previous work and is perhaps the best statement to date of what can be expected by the last decade of this century. The Bender et al. (2010) study uses two of the best high-resolution models, which both predict tropical cyclone development from observed initial conditions and which reproduce 20th-century tropical cyclone statistics well. By comparing the model storm statistics of 2080-2100 AD with 2000-2020 AD, the authors have drawn conclusions regarding the likely changes in tropical cyclone statistics over that 80-year interval. **Qualitatively, the results bear out the conclusions of the previous consensus: fewer total storms but more of the most intense ones.** The Bender et al. (2010) results may be summarized as follows:

(i) **There is no evidence that global warming has already affected hurricane activity.** According to this study, the large multi-decadal variability in TC activity seen over the latter half of the 20th century may be largely natural and dwarfs any late-century changes that greenhouse warming might have produced. This analysis suggests that anthropogenic changes may not be distinguishable from natural variability until about 2070, a conclusion that is consistent with several other credible studies (e.g., Vecchi and Knutson 2011).

(ii) **The number of category 4 and 5 storms (intense hurricanes comparable to Hurricane Andrew) forming in the Atlantic basin roughly doubles after 80 years of greenhouse warming.** The average number of major Atlantic hurricanes in the late 20th century was about 14 per decade. Of these, only a small percentage typically threatened or impacted Florida. In the last 30 years, only one such storm (Andrew) impacted South Florida, and the best estimate is that the frequency of hits by Category 5 storms is about once in 80 years (Landsea et al. 2004). If the Bender et al. (2010) estimates are accurate, the state might expect to see two storms like Andrew over a **s**imilar period centered on 2090.

(iii) **The total counts of all Atlantic storms decreases, becoming 28% fewer according to the 18-model IPCC ensemble.** As this includes the increase in the number of intense storms, it means there is a larger decrease in the number of tropical storms and weak hurricanes. Because a typical 20th-century decade had about 90 total storms, the Atlantic basin should see about 25 fewer total storms per decade by the end of the 21st century. Taking into account the increase in severe storms, the number of storms per decade of Category 3 and below will decrease on average from 76 to 47, or 38% fewer. Such storms include all of the ones that have impacted South Florida in the last 10 years.

(iv) **In spite of the decrease in total storms, the damage caused by future storms is expected to increase by about 30%.** This is because damage increases exponentially with storm intensity such that even a moderate increase in the number of severe storms will outweigh the larger decrease in weaker storms. Major hurricanes (categories 3- 5) have accounted for 86% of all US damage despite constituting only 24% of US landfalls. According to Kerry Emanuel, co-author of the Knutson et al. (2010) study, "an 11% increase in wind speed translates to roughly a 60% increase in damage" (Borenstein, 2010).

The least accurate result of the Bender et al. (2010) analysis is probably the estimate of increased future damage (30%), which is almost assuredly too low for Florida. That is because the study did not take into account the augmenting effects of sea level rise on storm surge damage, nor the inevitable future increase of wealth and infrastructure of exposed coastal communities. *The most significant improvement in projections of TC activity will come from the incorporation of storm surge models with GIS overlays of future sea levels, combined with estimates of demographic changes.* It is in the state's interest to recommend to the climate research community that this be given a high priority.

3.2 Future Rainfall

3.2.1 Projections of Generalized Rainfall

According to the externally forced model simulations (A1B "middle-of-the-road" scenario) for the 21st century used in the IPCC AR4, eastern North America (25°N – 50°N and 85°W – 50°W) will experience about a 3.6°C increase in the surface temperature and a 7% *increase* in rainfall by the end of the 21st century (2080 – 2099). On the other hand, the IPCC AR4 projects that the Caribbean islands (10°N – 25°N and 85°W – 60°W) will experience about a 14% *decrease* in rainfall by 2080-2099 with a larger decrease of 20% from June to August. This sharp discontinuity of the projected rainfall change across 25°N suggests that the 21st-century climate projection for the state of Florida is quite complex and uncertain.

Figure 3.1 shows the composite maps of the projected changes in rainfall in the 21st century for four seasons: (a) December, January, and February (DJF), (b) March, April, and May (MAM), (c) June, July, and August (JJA), and (d) September, October, and November (SON). Ten IPCC AR4 models under the A1B greenhouse forcing scenario are used to create these maps. As shown, Florida is expected to have an overall much drier climate in the 21st century. However, this drying condition is highly dependent on geographic location and also on season. During the winter season, the drying seems to be limited to the Florida Panhandle area. But, in spring, the entire region of Florida is projected to be much drier. In summer, the drying condition seems to be alleviated in northern Florida. However, southern Florida is expected to have a severe drying condition. During fall, all regions in Florida are subject to a weakly wet condition. As an average for Florida, the models project an 11% decrease in rainfall in MAM, an 8% decrease in JJA, a 5% decrease during DJF, and a 3% increase in SON.

It appears that the projected impact of climate change on Florida is most severe in South Florida in JJA and is linked to the broad drying in the Caribbean region, which is a robust feature in all IPCC AR4 models. Recent studies by Lee et al. (2011) and Rauscher et al. (2011) provide a physical explanation for the projected summer drying of the Caribbean region. They argue that the so-called differential inter-ocean warming is the main cause of the projected drying over the Caribbean in the 21st century. Specifically, they use idealized climate model experiments to show that the preferential warming of the tropical Indo-Pacific in the 21st century induces a global average warming of the tropical atmosphere, thus increasing atmospheric static stability and decreasing convection over the tropical North Atlantic region of weaker warming.

In summary, the IPCC projections are for less generalized (due to all sources) rainfall over the tropical North Atlantic and Florida, but with Florida near the transition from less rainfall to the south to greater rainfall in the north. Improved global climate models and dynamical downscaling (or high resolution climate modeling) studies targeted at Florida should be conducted to improve our projections for generalized rainfall.

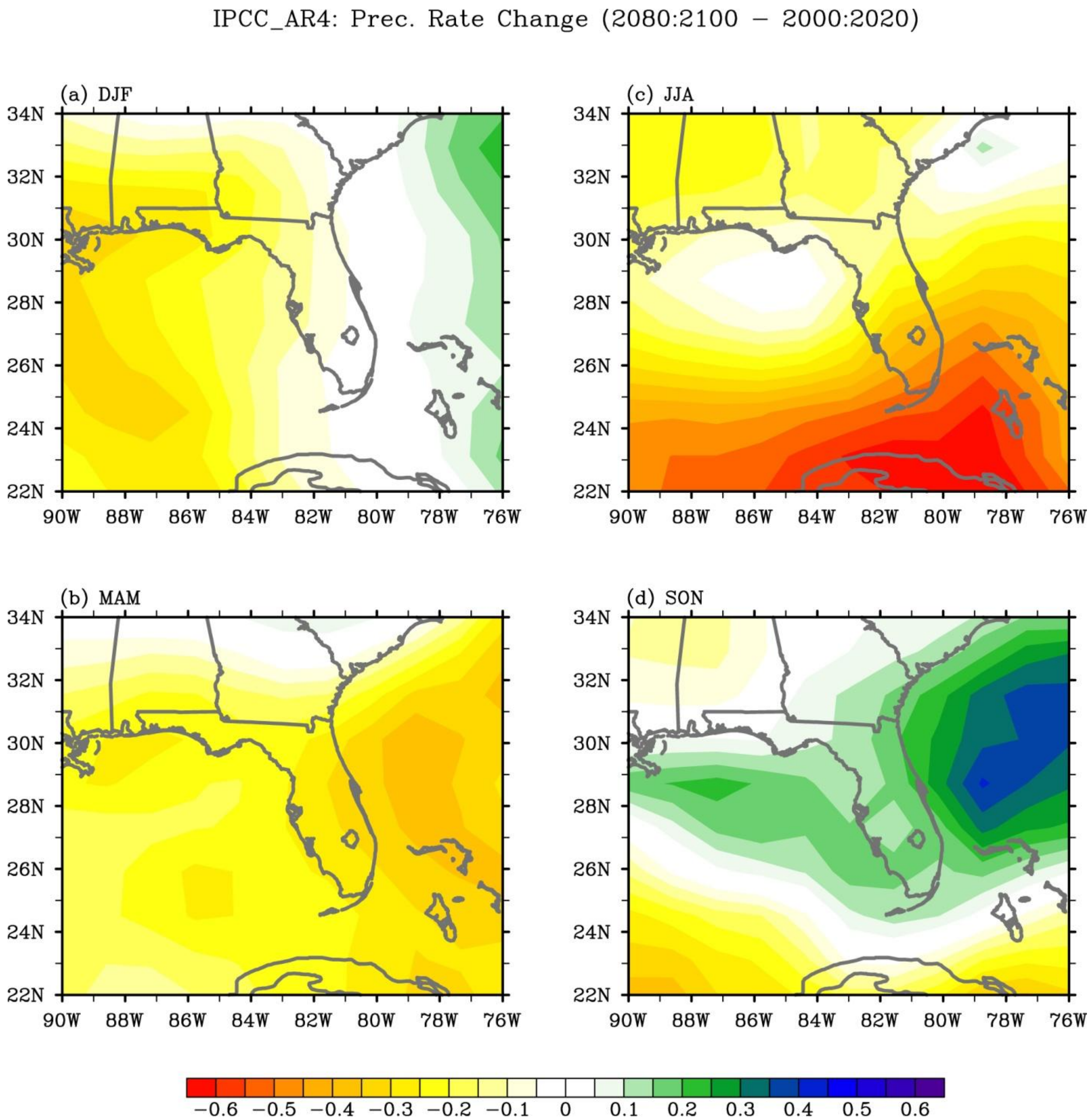

Figure 3.1: The composite maps of the projected changes in rainfall between periods 2080–2100 and 2000–2020 for (A) December, January, and February (DJF); (B) March, April, and May (MAM); (C) June, July, and August (JJA); and (D) September, October, and November (SON), computed from ten IPCC AR4 model simulations under the A1B scenario. The unit is mm/day.

3.2.2 Rainfall Components

Unfortunately, rainfall is one of the least certain aspects of global climate models (especially at the regional level), which do not resolve many of the fine-scale interactions that produce rainfall over Florida, such as tropical cyclones and sea breeze frontogenesis. In this section we examine the logical expectation for several components of Florida rainfall to see how compatible they are with the IPCC projection.

Frontal passages produce rain mostly from late fall to early spring and more so in northern Florida, whereas in South Florida those months comprise the dry season. According to Held and Soden (2006), part of the global pattern of climate change is the migration of storm tracks farther poleward, which expands the dry subtropics and produces more rain at higher latitudes. The likely consequence of this is to reduce the influence of frontal passages on Florida rainfall, especially in northern Florida and preferentially in the cooler months. This seems qualitatively consistent with the IPCC projections (Figure 3.1).

Tropical cyclones, including hurricanes of all intensities, are a major contributor to Florida rainfall during the warm season (June through October). Even relatively weak tropical storms can significantly add to water supplies. Thus, in August 2008, a severe drought threatened water supplies and augured draconian conservation measures for populous coastal counties. The Lake Okeechobee reservoir, the flywheel for South Florida water management, was at record low levels. Then, on August 18-20, 2008 a single tropical storm ("Fay") raised the lake to optimal levels for management, almost overnight. Because such storms are expected to become considerably less frequent, droughts are likely to become more frequent and/or severe, over the next century, due to the reduction of water supplies toward the beginning of the cooler dry season in central and South Florida. Because less intense storms tend to produce copious rain, out of proportion to their wind intensity, and because significantly fewer such storms are expected, we would expect wet season rainfall to be less at the end of the 21st century due to the tropical cyclone component. This also is qualitatively consistent with the IPCC projections, especially for the summer months in South Florida.

Despite the uncertainty of rainfall in global climate models, one particular consequence of greenhouse warming is much more certain: sea level rise. Most current estimates are for at least two feet and as much as five feet of rise by 2110 AD, and this can plausibly diminish water supplies in Florida's two most populous counties — Miami-Dade and Broward — through two mechanisms: (1) salt water infiltration of the Biscayne aquifer from higher sea level on the Atlantic seaboard and from marine inundation of the Shark Valley Slough (Everglades) east of the coastal ridge; and (2) decreased rainfall from sea breeze frontogenesis, also due to inundation of the Shark Valley Slough. The latter factor is another important component of summer rainfall in South Florida, and is also consistent with the IPCC projections of drying for that season. However, the global models do not resolve the convective processes at this reduced scale of interaction nor do they take into account the effect of marine inundation on the diurnal land heating. The amount of the rainfall decrease due to reduced sea breeze frontogenesis can best be estimated by running embedded mesoscale models with GIS overlays for increments of sea level rise.

3.3 Multidecadal Variability

Since instrumental records began in the late 19th century, SSTs in the North Atlantic have undergone several slow oscillations between relatively warm and cool conditions, with well documented impacts on North American rainfall (Enfield et al. 2001) and Atlantic hurricane activity (Goldenberg et al. 2001). For 2-3 decades at a time, the North Atlantic is predominantly warm, with more tropical cyclones and more rainfall in Florida, or cool, with fewer hurricanes and less rainfall. The rainfall variations in Florida have been reflected in the changing hydrology of aquifers and the amount of inflow to Lake Okeechobee from central Florida (Figure 3.2). This Atlantic Multidecadal Oscillation (AMO) has been registered in tree ring chronologies from around the North Atlantic basin dating back at least four centuries. It is generally considered to be a natural, internal climate mode of the ocean-atmosphere system and is therefore likely to continue during the coming centuries, alternately enhancing or diminishing the expected trends in impacts due to greenhouse warming (Ting et al. 2009). The strength of the AMO and its impacts are the primary reason that many of the impacts of long-term climate change (such as discussed above for tropical cyclones) cannot be reliably detected during the 20th century, a situation that's likely to persist for decades to come.

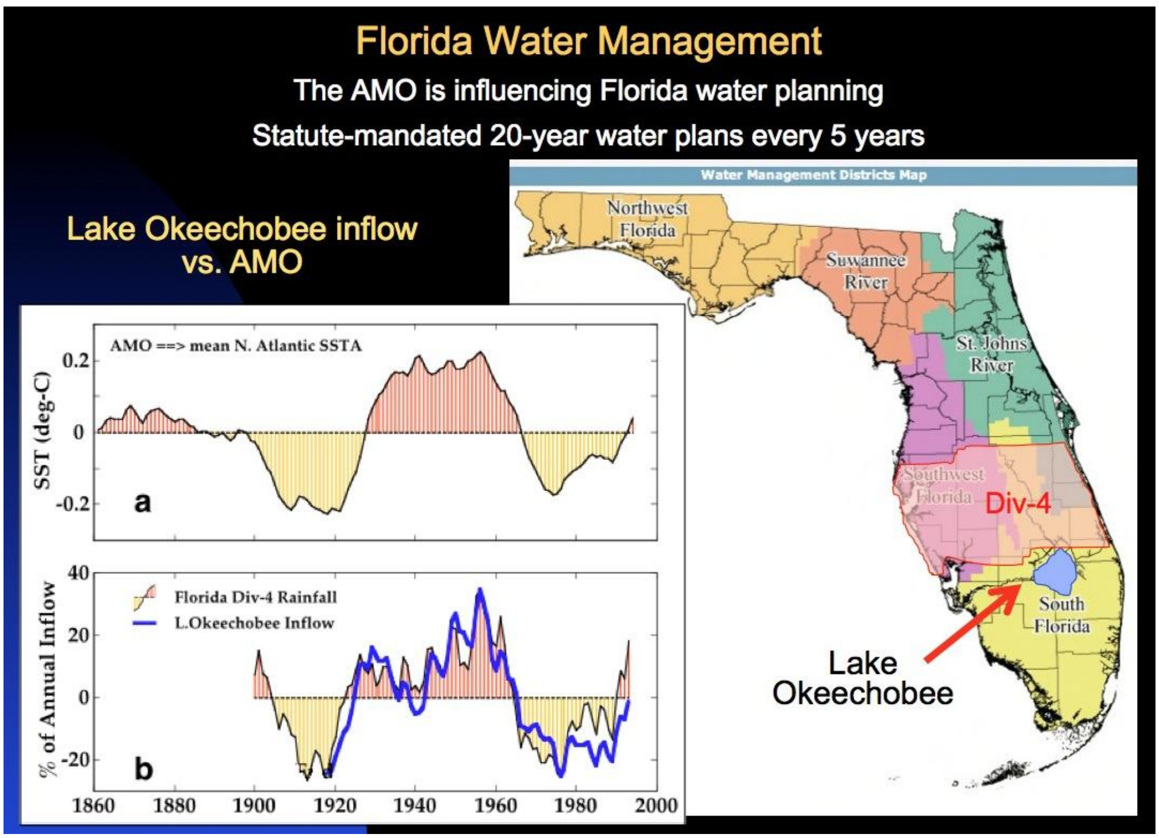

Figure 3.2: Florida rainfall tends to go in lock step with the North Atlantic sea surface temperature, being greater (less) during positive (negative) Atlantic Multidecadal Oscillation (AMO). Here we see the AMO (top left) compared with Florida Division-4 rainfall (shaded region, right) and the inflow to Lake Okeechobee computed from lake-level data and controlled outflows. This relationship is of fundamental importance for water management in South Florida. (Enfield et al. 2001)

It is important to realize that the IPCC AR4 projection shown in Figure 3.1 does not account for the impact of internal variability such as the AMO because the internally generated multidecadal signals are canceled out after applying the composite mean of the IPCC AR4 models (Knight 2009; Ting et al. 2009). The inability of most global climate models to simulate the AMO and its superposition on long-term trends is an impediment to our ability to accurately project future climate for the next few decades. It is likely that the model-projected changes in rainfall over Florida, induced by anthropogenic greenhouse forcing (Figure 3.1), will be alternately amplified or diminished by the AMO for the foreseeable future. For instance, it is widely believed that a warm AMO phase and anthropogenic warming coexisted with comparable amplitude during the past two decades, with the AMO accounting for greater tropical cyclone activity and rainfall. On the other hand, if the AMO switches to a cool phase in future decades (as appears likely), then the effect of man-made warming will be amplified in such a way that the projected drying of South Florida in JJA shown in Figure 3.1c will become more severe.

As of 2011 the AMO has been in its warm phase for 16 years, since 1995. Assuming that tree rings accurately represent past fluctuations of the AMO, it is possible to estimate the probability that the AMO will shift to its cool phase within a given future period (Enfield and Cid 2006). Using this method, the probability is 80% for a reverse shift occurring by 2026. Once that happens Florida can expect 2-3 decades of greater drought conditions and fewer tropical cyclones due to natural variability, which will enhance the long-term effects expected due to greenhouse warming (discussed above). It therefore appears probable that water supplies in Florida will be become more constrained on the supply side within 30 years (by 2040), and face challenges on the demand side as well due to development and population increases. However, while reduced water supply may affect some areas of Florida, other areas, e.g., north Florida, may get less impact or even see added precipitation, especially in winter. Individual water management districts will have to assess these threats on a case-by-case basis and decide what, if any, measures will be required to increase efficiency of water extraction, conservation and delivery in order to offset future negative trends.

- Frequently Asked Questions -

How does sea level rise affect hurricane damage?

Along an undeveloped coastline the geological equilibrium point where land meets the sea must migrate inland about 100 feet for every foot of sea level rise. Hence, on a developed coast, the erosive power of waves and storm surges will increasingly batter immovable structures and cause inland flooding.

Why will future tropical cyclone activity be skewed toward stronger storms with fewer weak ones?

The maximum potential strength of a hurricane increases with increasing sea surface temperature, which favors the stronger storms in the future. However, our models show that the upper level winds (where jets fly) will become stronger, which shears the developing storms apart, causing weak storms to be less frequent. However, those storms that escape destruction by wind shear will be able to reach greater intensities.

How does the AMO affect rainfall and droughts?

Recent research suggests that the AMO is related to the past occurrence of major droughts in the Midwest and the Southwest US. When the AMO is in its warm phase, these droughts tend to be more frequent and/or severe (prolonged?), and vice-versa for a negative AMO. Two of the most severe droughts of the 20th century occurred during the positive AMO between 1925 and 1965: the Dustbowl of the 1930s and the 1950s drought. Florida and the Pacific Northwest tend to be the opposite, with a warm AMO and more rainfall.

How are future water supplies likely to be affected?

With less rainfall, freshwater levels in the Everglades decrease while saline water pushes inland from Florida Bay as sea level rises and feeds the Biscayne aquifer with brackish water. At the same time, sea level rise causes the subsurface marine salt wedge to migrate inland from the Atlantic into what is now the freshwater aquifer where drinking water is pumped. Salinification of the coastal aquifer will be a factor along most of the Florida coastline. Water managers will have to plan for desalination and impose more rationing during droughts.

How important is the AMO when it comes to hurricanes? Is it one of the biggest drivers or just a minor player?

During warm phases of the AMO, the number of tropical storms that mature into severe hurricanes is at least twice as much as the number that occur during cool phases. Since the AMO switched to its warm phase around 1995, severe hurricanes have become much more frequent, and this has led to a crisis in the insurance industry.

SECTION 4

Changing Characteristics of El Niño and the Southern Oscillation and the Pacific Decadal Oscillation

S.-I. Shin and S.-K. Lee

4.1 El Niño and the Southern Oscillation

El Niño-Southern Oscillation (ENSO), the dominant tropical coupled atmosphere-ocean phenomenon on interannual time scales, is known to impact the climate not only over the Tropics but also over the globe through its atmospheric teleconnections (e.g., Alexander et al. 2002 and many others). ENSO impacts the hydroclimates of Florida through these teleconnections. During the Florida dry season (late October to May), the substantial precipitation is mainly provided by traveling extratropical disturbances or stalled frontal boundaries (Hagemeyer 2006). The observations indicate that winter-spring storminess is generally increased over Florida and the Gulf of Mexico during the later stages of strong El Niño episodes (e.g., 1982-1983 and 1997-1998) and leads to well above average precipitation and widespread flooding. The conditions are nearly opposite during strong La Niña years. The year-round impact of ENSO is, however, generally small because the precipitation responses to ENSO are often opposite in sign for dry and wet seasons (Mo and Schemm 2008). Thus, even a prolonged ENSO event does not always favor either drought or wet spells unless the SST anomalies in the tropical Pacific and North Atlantic are opposite in phase. A cold (warm) tropical Pacific in concert with a warm (cold) Atlantic amplifies the impact of the cold (warm) ENSO on Florida hydroclimate (Shin et al. 2010). The ENSO impact on Florida hydroclimate is much weaker when the SST anomalies in the tropical Pacific and in the North Atlantic are in phase (Mo et al. 2009).

Historically, El Niño has been monitored and predicted as the appearance of warm surface waters in the eastern tropical Pacific, including the “Niño3” region (5°S-5°N and 150°W-90°W). However, some El Niño events, particularly since the 1960s, have appeared different from the historically typical event, with maximum warm SST anomalies located primarily in the central tropical Pacific “Niño4” region (5°S-5°N and 160°E-150°W; Fig. 4.1). Yeh et al. (2009) analyzed El Niño in the IPCC AR4 future climate projections and suggested that central Pacific-El Niño occurrences might increase in response to ongoing greenhouse warming. Though the cause of the observed ENSO pattern changes since the 1960s, whether anthropogenic or natural, is still in debate (e.g., Newman et al. 2011), the corresponding atmospheric teleconnections have shifted centers of action and impacts quite differently from those of the canonical ENSO such that the Florida dry season precipitation is less severe than the canonical one suggested by Mo (2010; Fig. 4.2).

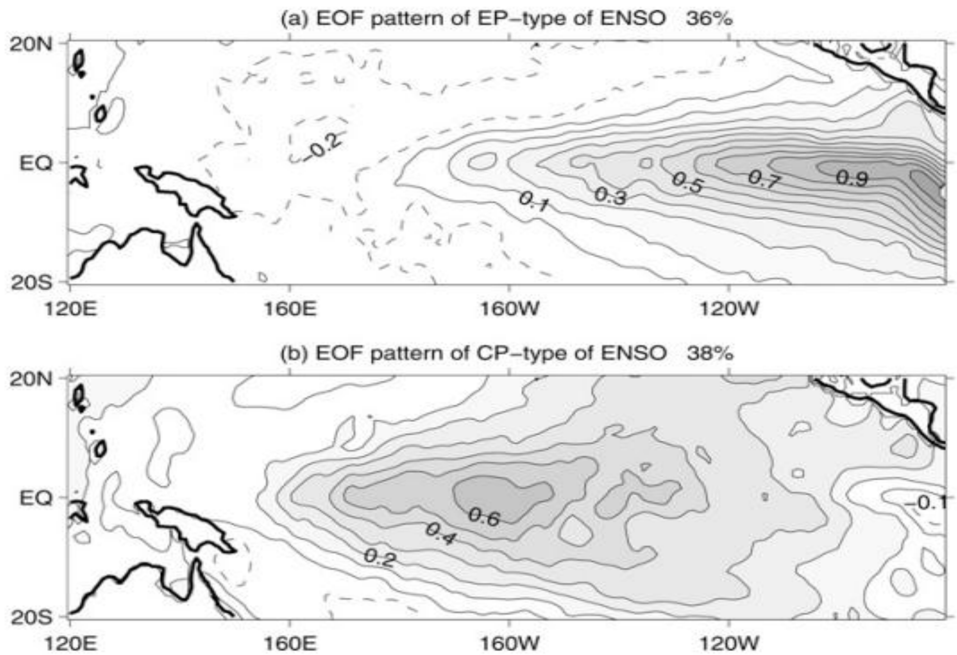

Figure 4.1: Dominant spatial patterns of SST variability obtained as leading patterns of combined EOF-regression analysis for a) Eastern Pacific (traditional) type of ENSO and b) Central Pacific (Modoki) type of ENSO. The variance explained by each of the dominant modes is also shown in percentage. From Kao and Yu (2009).

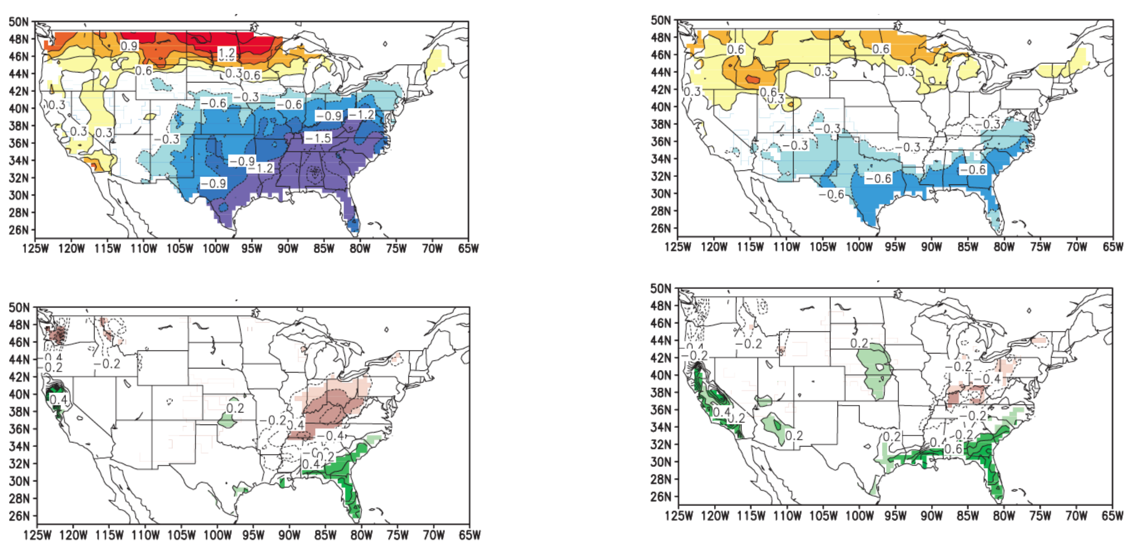

Figure 4.2: Weighted composite difference between warm and cold ENSO events for Jan-Feb-Mar season for a) surface air temperature (T_{air}) in 1951-1960 (when traditional ENSO is more prevalent), b) T_{air} in 1961-2006 (when central Pacific type ENSO is more prevalent) and c) rainfall in 1951-1960, and d) rainfall in 19161-2006. The units are 0C for Tair and mm day-1 for rainfall. Statistically significant values are shaded. From Mo (2010).

Moreover, Kim et al. (2009) argued that the recent warm SST events in the central Pacific Ocean affect the location of hurricane formation and the tracks and lead to more frequent hurricane landfall in the Gulf of Mexico and central America, although this may not be conclusive yet mainly due to the limited length of the climate record as discussed in Lee et al. (2010).

There have been multi-decadal oscillations in the ENSO index (conventionally defined as a mean SST anomaly in the east-central equatorial Pacific -- Niño3) throughout the 20th century, with more intense El Niño events since the late 1970s. This may reflect in part a mean warming of the eastern equatorial Pacific. However, to date, there is no detectable change in ENSO variability in the observations and no consensus on how ENSO might be changed in response to anthropogenic GHG increase. While some simulations have shown an increase in ENSO variability, others have shown no change or even a decrease in ENSO variability in response to the radiative forcing changes due to GHG increases (IPCC 2007).

4.2 Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) was first suggested by fisheries scientist Steven Hare in 1996, based upon the Pacific fisheries cycles. The PDO is a pattern of Pacific climatic variability that somewhat resembles ENSO. While the two climatic oscillations have similar spatial patterns, they have very distinctive temporal behavior: PDO events during the 20th century have persisted for 20 to 30 years, while typical ENSO events last only a few years. The climatic fingerprints of the PDO are most visible in the North Pacific/North American sector, while secondary signatures exist in the Tropics. The nearly opposite fingerprints occur for ENSO. The PDO index is calculated from SSTs and sea level pressures. A comprehensive overview of the PDO is given by Nathan Mantua (see his website: http://www.atmos.washington.edu/~mantua/REPORTS/PDO/PDO_egec.htm). To date, the causes of such oscillation are unknown.

Many studies have shown that the major climatic events over the United States are linked to the PDO cycles. Here are some examples:

- The prolonged drought of the 1930s was attributed to the cooler tropical Pacific SSTs and warmer tropical Atlantic SSTs (see section 3.iii on AMO) that weakened low-level jet and changed its course (Schubert et al. 2004). The low-level jet normally flows westward over the Gulf of Mexico and then turns northward, transporting moisture onto the Great Plains. As the low-level jet weakened, it traveled farther south than normal, dried the Great Plains, and generated dust storms. Analyses of other major US droughts of the 20th century suggest that a cool tropical Pacific was a common factor (Seager et al. 2005).
- In 1976, the North Pacific Ocean and surrounding land masses underwent a dramatic shift to a climate regime. This shift in the climate regime is now known to have coincided with a shift in the phase of the PDO.

The PDO affects the Florida climate as ENSO does, except that the frequency of the oscillation is on decadal time scales instead of the interannual time scales of ENSO. Thus, Florida tends to experience above-normal precipitation during the dry season in the warm phase of the PDO.

A recent study of Furtado et al. (2010) indicates that the PDO does not exhibit significant changes in spatial and temporal characteristics under greenhouse warming derived from coupled climate model simulations used in the IPCC AR4 for the past (20th century; 20C3M scenario) and future (21st century; SRESA1B scenario) climates. However, considering the limited ability of the models to capture the dynamics associated with the PDO and the differences between the observed and simulated PDO patterns of the 20th century, their findings are not conclusive.

Finally, it is noteworthy that ENSO, the PDO and the AMO (see section 3) are not entirely independent of each other. Newman et al. (2003) show that the PDO is highly influenced by ENSO. In their study, the PDO can be well modeled as the sum of the direct forcing by ENSO, the reemergence of North Pacific SST anomalies in subsequent winters, and atmospheric noise forcing. The phase correspondence with the AMO is the influencing factor of ENSO, with the warm AMO phase being related to weaker ENSO variability (Dong et al. 2006). Moreover, it is shown that more than half of the spatial and temporal variance in multidecadal drought frequency over the contiguous US is attributable to the PDO and AMO as manifested in the recent US droughts (1996, 1999–2002) associated with North Atlantic warming (positive AMO) and northeastern and tropical Pacific cooling (negative PDO; McCabe et al. 2004). Therefore, combining ENSO, PDO, and AMO information may enhance the understanding of the oceanic influence on the Florida climates and prediction of future changes. ENSO impacts on Florida climate are strongly dependent on the phase of the PDO and AMO, so that the “canonical” El Niño and La Niña impacts on Florida climate tend to be modified by the phase of PDO and AMO. It is noteworthy that the South Florida Water Management District (SFWMD) currently uses all three of these climate factors in their short-term management and long-term planning.

- Frequently Asked Questions -

What are some useful websites to monitor current states of ENSO, AMO, and PDO?

The National Oceanic and Atmospheric Administration (NOAA)'s Earth System Research Laboratory (ESRL) maintains a comprehensive data service website. Users can either download the time series of ENSO, AMO, PDO and other climate time series or make their plots on the screen: http://www.esrl.noaa.gov/psd/data/climateindices

NOAA's Climate Prediction Center (CPC) is another comprehensive website to monitor current states of climate indices. http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml#current

CPC's monthly ocean briefing provides an excellent summary of current climate states with in-depth discussions offered by the experts at CPC: http://www.cpc.ncep.noaa.gov/products/GODAS

Is the transition from one phase to another of these oscillations known right away?

The irony is that transition of these oscillations is known after the fact. For example, as per CPC, an ENSO event is declared when 5 overlapping 3 month seasons of Niño3.4 SST anomaly exceeds ± 0.50°C. Likewise AMO is defined as the 11-year running mean of SSTA over the North Atlantic Ocean. Similarly, PDO is operationally defined as the leading principal component of monthly SST anomalies in the North Pacific Ocean north of 20°N.

Currently, a skillful prediction is possible only for ENSO with up to 6 months of the lead-time using the so-called multi-model ensemble forecasts. The International Research Institute for Climate and Society (IRI)'s website provides forecasts for ENSO for nine overlapping 3-months periods made by 16 dynamic models and 8 statistical models:
http://iri.columbia.edu/climate/ENSO/currentinfo/SST_table.html

What is 'Modoki' El Niño?

Modoki in Japanese means "similar but different". Modoki El Niño that is often referred as central Pacific El Niño because the SST anomaly appears near the dateline (Fig. 4.1b), differs from the traditional El Niño where the SST anomalies appear in the far eastern equatorial Pacific Ocean. It may however be noted that the La Nina following a Modoki El Niño is not different from the La Niña following the traditional El Niño (Kug and Ham, 2011).

SECTION 5

Impact of Aerosols

W. Landing

Higher concentrations of atmospheric aerosols resulting from global climate change will affect Floridians in at least two significant ways:

(i) Human respiratory health could be adversely affected by higher levels of small aerosol particles (so-called PM2.5) from wildfires and long-range desert dust transport.

(ii) The frequency and intensity of Harmful Algal Blooms (HAB) and toxic bacteria blooms may increase due to enhanced input of dissolved iron from desert dust.

5.1 Particle Pollution

"Particle Pollution" includes acids (such as sulfates and nitrates), organic chemicals, metals, soil or dust particles, and allergens (such as fragments of pollen or mold spores). When breathed, both fine and coarse particles can accumulate in the respiratory system and are associated with numerous adverse health effects. Exposure to coarse particles is primarily associated with respiratory conditions, such as asthma. Fine particles are associated with increased hospital admissions and emergency room visits for heart and lung disease, increased respiratory symptoms and disease, decreased lung function, and even premature death. Sensitive groups at the greatest risk include those with heart or lung disease, older adults, and children.

Small particles pose the greatest threat to human health. PM2.5 refers to fine particles (found in smoke and haze) that are 2.5 micrometers in diameter or less. Fine particles come from emissions from motor vehicles, power generation, and industrial facilities, as well as residential fireplaces and wood stoves. Gases such as sulfur dioxide, nitrogen oxides, and volatile organic compounds interact with other compounds in the air to form fine particles. PM10 refers to all particles less than or equal to 10 micrometers in diameter. Coarse particles are generally emitted from vehicles traveling on unpaved roads, materials handling, crushing and grinding operations, and windblown dust.

5.2 Wildfires

Due to decreased future rainfall (Section 3), the frequency of wildfires in Florida would increase due to more and prolonged droughts. Several hundred toxic substances are released to the air during wildfires along with the fine particles that cause respiratory distress. Smoke can irritate the eyes, nose, and throat and worsen conditions such as chronic lung disease and asthma. Breathing outdoor air that has been impacted by wildfires is comparable to sitting in a room with a person smoking and inhaling the second-hand smoke. Sensitive groups, including pregnant women, infants, the elderly, and those with respiratory problems, should not be exposed to such degraded air quality. Even areas free of haze could be harmful due to microscopic, wind-swept particles from the wildfires.

5.3 African Dust

Since the mid-to-late 1960s, the Sahel region of North Africa has been undergoing a significant decrease in rainfall with persistent droughts (Nicholson 1989; Folland et al. 1986; Ward 1998; Giannini et al. 2003). Models predict that the Sahel will continue to experience drier conditions through at least 2100 due to increasing GHGs (Held et al. 2005). Monitoring data show that large quantities of dust are carried by winds from the west coast of Africa to the western Atlantic, SE US, Gulf of Mexico, and Caribbean (Prospero and Lamb 2003; Dunion and Velden 2004; Prospero 1999; Perry et al. 1997), especially in summer months. Satellite imagery shows dust arriving in southern Florida and the Caribbean region in episodes of 3-5 days. High levels of fine particles are further carried into the Gulf of Mexico and the SE US.

Saharan dust contains significant levels of iron, averaging 3-5% w/w (Duce and Tindale 1991), and therefore provides an episodic source of this critical trace element to the ocean surface, where iron occurs in very low concentrations in a bioavailable (soluble) form. In iron-limited waters, bacteria (including *Vibrio* spp.) can respond quickly to the influx of iron (e.g., Tortell et al. 1999, Pulido-Villena et al. 2008). Additionally, African dust provides an external source of nitrogen and phosphorous, critical to support primary (phytoplankton) and secondary (heterotrophic bacteria) production. Iron-rich dust also stimulates nitrogen-fixing phytoplankton (Walsh et al. 2006). This in turn may stimulate phytoplankton production, which would provide substrate for attachment and a rich source of organic matter in support of further bacterial growth, including *Vibrio* spp. (Mourino-Perez et al. 2003; Turner et al. 2009). Biomass burning south of the Sahara also transports NO_3^- and SO_4^{2-} across the Atlantic in clouds of Saharan dust (Talbot et al. 1990).

5.4 Harmful Bacteria Blooms

Twelve species of *Vibrio bacteria* spp. are known to cause disease in humans (Janda et al. 1988). *Vibrio vulnificus*, *V. parahaemolyticus*, and *V. cholerae* are associated with illness and death from the consumption of raw or undercooked shellfish (Lynch et al. 2006; Vugia et al. 2006; Rippey 1994). *V. alginolyticus* is primarily associated with wound infections as well as infections of the eyes, ears, nose, and sinuses, especially among younger age groups (Dziuban et al. 2006; Dechet et al. 2008). While the overall incidence of illness from *Vibrio* infections remains low compared to other bacterial pathogens like *Salmonella* and *Campylobacter*, the rate of infection increased 47% between 1996 and 2008 (Vugia et al. 2009). This is a significant increase above baseline values and was the only pathogen reported by the Center for Disease Control's FoodNet states to show a consistent increasing trend (Vugia et al. 2006; Vugia et al. 2009). Pathogenic *Vibrio* spp. are well-adapted to coastal waters and proliferate at warm temperatures, particularly above 15^{o} C (e.g., Janda et al. 1988); human infections are more frequently observed in warm climates (e.g., Janda et al. 1988; Lipp et al. 2002). Reported human cases also peak during summer months, corresponding with warm temperatures and increased human exposures through seafood and recreational water use (Dzuiban et al. 2006; Yoder et al. 2008). Additionally, in the US, human illness reports from Gulf Coast states and southeastern Atlantic states include a greater overall diversity of reported *Vibrio* spp. associated with infection (Dechet et al. 2008).

5.5 Harmful Algal Blooms

A 2001 news story titled, “Desert Dust Kills Florida Fish: New research links huge African dust clouds with the ‘red tides’ that kill millions of fish along the Florida coast each year”, described a NASA-funded study that revealed a connection between red tides in the Gulf of Mexico and dust that blows across the Atlantic Ocean from the Sahara Desert (Lenes et al. 2001). Red tides, which are actually blooms of toxic algae, have in the past killed huge numbers of fish, shellfish, marine mammals, and birds. They can also trigger skin and respiratory problems in humans. The study showed that the desert dust fertilized the water off the West Florida coast with iron. When the iron levels went up, a *Trichodesmium* bacteria bloom developed. These bacteria convert unreactive nitrogen gas into bioavailable forms that can be usable by other marine life. In October 2001, after a 300 percent increase of this biologically-accessible nitrogen, a huge bloom of toxic red algae (*Karenia brevis*) had formed within the study area between Tampa Bay and Fort Myers, Florida. Humans who swim in the Gulf during a red tide can experience respiratory problems by breathing toxins from *K. brevis* that get in the air. Also, eating shellfish poisoned by red tides can lead to paralysis and memory problems. Around the Gulf of Mexico, scientists and others have recorded fish kills totaling in the millions and manatee deaths in the hundreds resulting from a single red tide bloom.

All of these potential impacts of aerosols on Florida suggest how remote changes in the climate may have a consequence on this state. When it comes to climate anomalies, one cannot afford to be parochial. We have to be cognizant of the global evolution of climate anomalies and trends.

- Frequently Asked Questions -

What is the residence time of aerosols in the atmosphere?

The residence time of aerosols depends on its size and the atmospheric environment. Large aerosols fall out while smaller aerosols can reside in the atmosphere for a long period of times ranging anywhere from minutes to several days. But this is all dependent on the state of the atmospheric environment, with strong thundershowers having a tendency to wash out the aerosols, while stable atmosphere can promote the residence time of the aerosols.

Did the CMIP3 models used in IPCC AR4 incorporate the effect of aerosols?

The treatment of aerosols in the CMIP3 suite of models was unfortunately not uniform. A few of the CMIP3 models (like MIROC, HadGEM1) incorporated the impact of aerosols while most others did not. In MIROC both direct and indirect effect of aerosols was incorporated while in HadGEM1 only the direct effect of aerosols was incorporated. Furthermore, the concentration of aerosols prescribed in these models was not uniform across these models. In CMIP5 there are separate experiments to examine the impact of aerosols for specified concentration of aerosols (http://www.iiasa.ac.at/web-apps/tnt/RcpDb/dsd?Action=htmlpage&page=welcome).

SECTION 6

The Inadequacies of IPCC AR4 Models to Project Climate over Florida

V. Misra and J. Obeysekera

Regional climate refers to the aggregate weather over a period of time (generally anything over or equal to a month) over a specific region. There are natural causes for the climate to vary from region to region, including:

- the uneven distribution of solar heating on the earth's surface;
- the different responses and interactions of the lithosphere, cryosphere, atmosphere, hydrosphere, and biosphere to solar heating;
- the location of the region with respect to oceans (coastal or inland); and
- the altitude of the region (mountain or valley);
- the different composition of the atmosphere that vary geographically especially of the various pollutants like aerosols.

All of these factors would make Florida's regional climate rather unique. The closest proximity of the peninsular Florida to the equator in the continental US, its rather flat terrain, its nearness to relatively warm ocean water, and insignificant contribution of the snow melt to its fresh water sources make Florida's regional climate distinctive to the rest of the US. Florida is also one of the few regions of the US that displays a strong seasonality in precipitation and surface temperature. One would therefore assume that most of the climate models used for projection to the 21st century would have many of these features in their simulations of the 20th century climate of Florida. Unfortunately, a majority of the models in the IPCC AR4 were of very coarse horizontal resolution (~200 km grid resolution). As a consequence, in many of the AR4 models, most parts of South Florida were not resolved (Fig. 6.1). However, there were a few models, such as the Japanese MIHR model (Fig. 6), that had reasonable resolution to resolve the coastlines of Florida, but they had other issues with global climate variations, which we will argue later in this section, would make them potentially unreliable for projections over Florida.

The relatively periodic appearance of warm and cold SST anomalies (SSTAs) in the eastern equatorial Pacific, more commonly referred as ENSO, is one of the most well known natural variations of global climate. ENSO has a very strong influence on the winter and early spring climate over a broad region of the southeast US, including Florida. Typically in warm ENSO years the SE US experiences cold and wet winters while in cold ENSO (La Niña) years warm and dry winters ensue (see Section 4). It may be mentioned that the response of the SE US climate is not linear to the ENSO forcing nor is it symmetrical between the El Niño and La Niña years. Given such a predominant influence of ENSO, it is imperative to understand if ENSO is changing its character in a changing (warming) world of the 21st century and thereby also forcing a change in the climate variations over Florida.

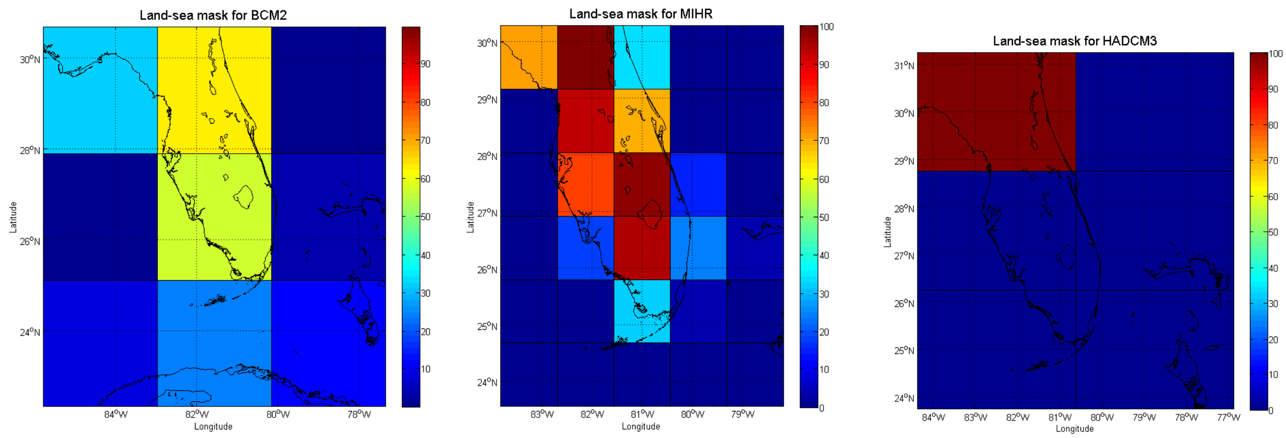

Figure 6.1: The land-sea mask of three climate models (left: BCM2, middle: MIHR, and right: HADCM3) that contributed to the IPCC AR4. The deep blue color represents the ocean, and the rest of the colors represent the vegetation mask of the terrestrial surface.

Unfortunately none of the climate models in the IPCC AR4 were able to simulate ENSO with all the observed features (Fig. 6.2). Fig. 6.2 displays the lag/lead regression of equatorial Pacific SST on the Niño3 SST index (area averaged SST over 5^0S-5^0N; 150^0W-190^0W). These lead/lag relationships allow us to examine the in-phase and out-of-phase features between the dependent (equatorial Pacific SST) and the independent (Niño3 SST index) variables of the linear regression. The top three panels are from observations, with Fig. 6.2a showing the relationship over the 50-year period 1950-1999. Figs. 6.2b and c show the same observed relationship for two periods from 1950-1976 and 1977-1999, with a subtle decadal shift in ENSO behavior between the two epochs. In the pre-1976 period the equatorial Pacific SSTA show a distinct westward propagation with far more asymmetry between the El Niño and La Niña phases than in the post-1976 period. The cause for decadal variability of ENSO is still an ongoing research topic (see Section 4). A majority of the IPCC AR4 models showed the erroneous extension of the equatorial Pacific SSTA west of the dateline. The GISS and MIROC3.2 (hires) did not show this oscillation in at least a 42-month window as the observations distinctly display them. The CCSM3 showed ENSO with a relatively short period (~2 years) that is unsubstantiated by observations. The GFDL (CM2.1) showed the oscillation with a very high amplitude and very broad period, which is again unsupported by observations. All of these features of ENSO (periodicity, duration, spatial extent of the SSTA in the equatorial Pacific, and amplitude) contribute critically to the establishment of the teleconnection with the winter climate over Florida. Therefore it is not difficult to conceive that with such varied representation of a robust natural phenomenon like ENSO, the projection of the mean climate and its variations over Florida can be uncertain across models.

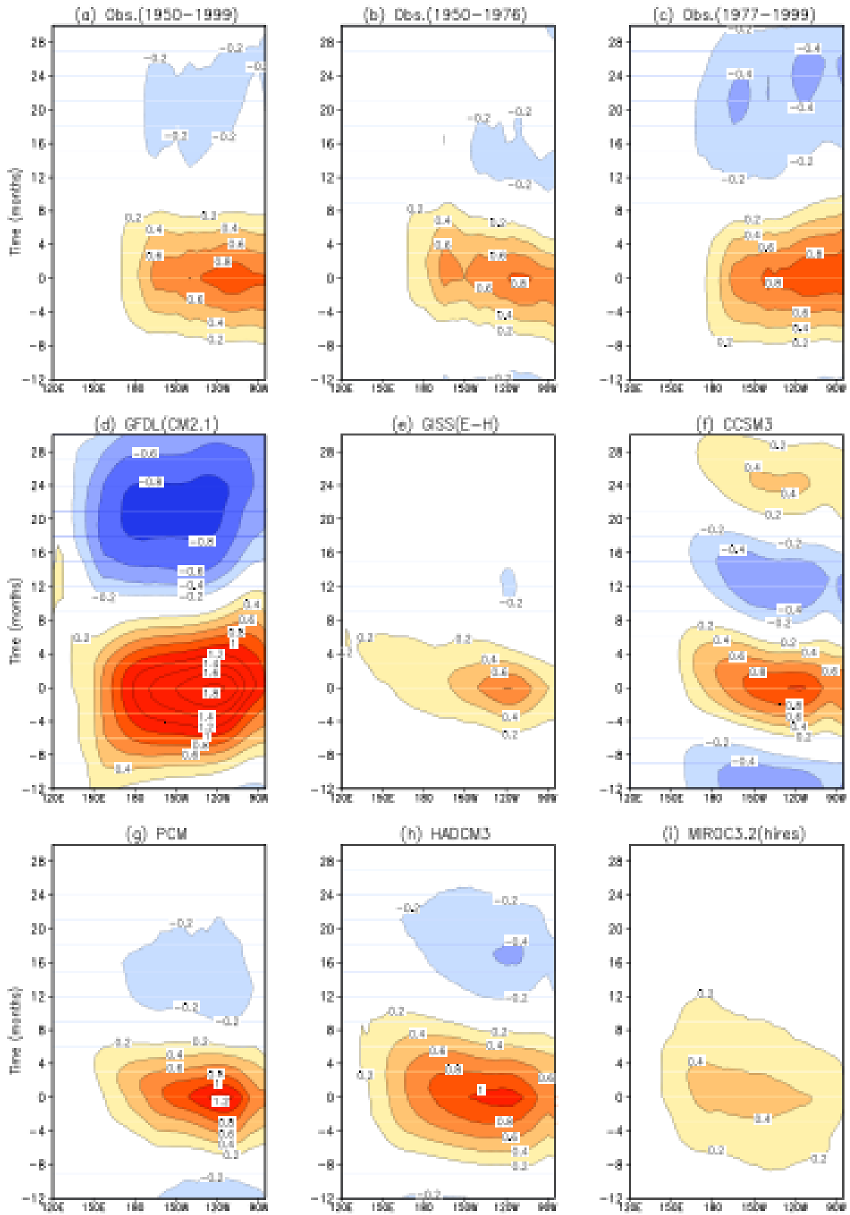

Figure 6.2: ENSO SST evolution at the equator (5°S-5°N), obtained from lead/lag regressions of the Nino3 SST index over a 42-month period. Top panels show observed SST evolution in the full record (top-left), pre-climate-transition period (1950-1976, top-middle), and post-transition period (1977-1999, top-right). All six model regressions are from the full 50-year period. The contour interval is 0.2K and the zero contour is suppressed; the shading threshold is 0.2K. Note: time markings have no unique correspondence with calendar months. From Joseph and Nigam (2009).

The Atlantic Ocean also is known to play an influential in the regulation of climate variability over Florida. The amalgam of variations across spatial and temporal scales that comprise the variability of the Atlantic Ocean, sometimes in association with ENSO forcing from the Pacific, makes the interaction of the Atlantic Ocean variability with Florida's climate rather complex (see Section 4). To further compound this issue, the IPCC AR4 models exhibited some very grave errors over the tropical Atlantic Ocean (Richter and Xie 2008; Misra et al. 2009). Unlike observations, all AR4 models (without exception) showed the western tropical Atlantic to be colder than the eastern tropical Atlantic Ocean (Fig. 6.3; Richter and Xie 2008). Similarly, Misra et al. (2009) showed that a majority of the AR4 models had a cold bias over the Gulf of Mexico and Caribbean Sea in the summer and fall seasons, a region and time period prone to genesis of hurricanes.

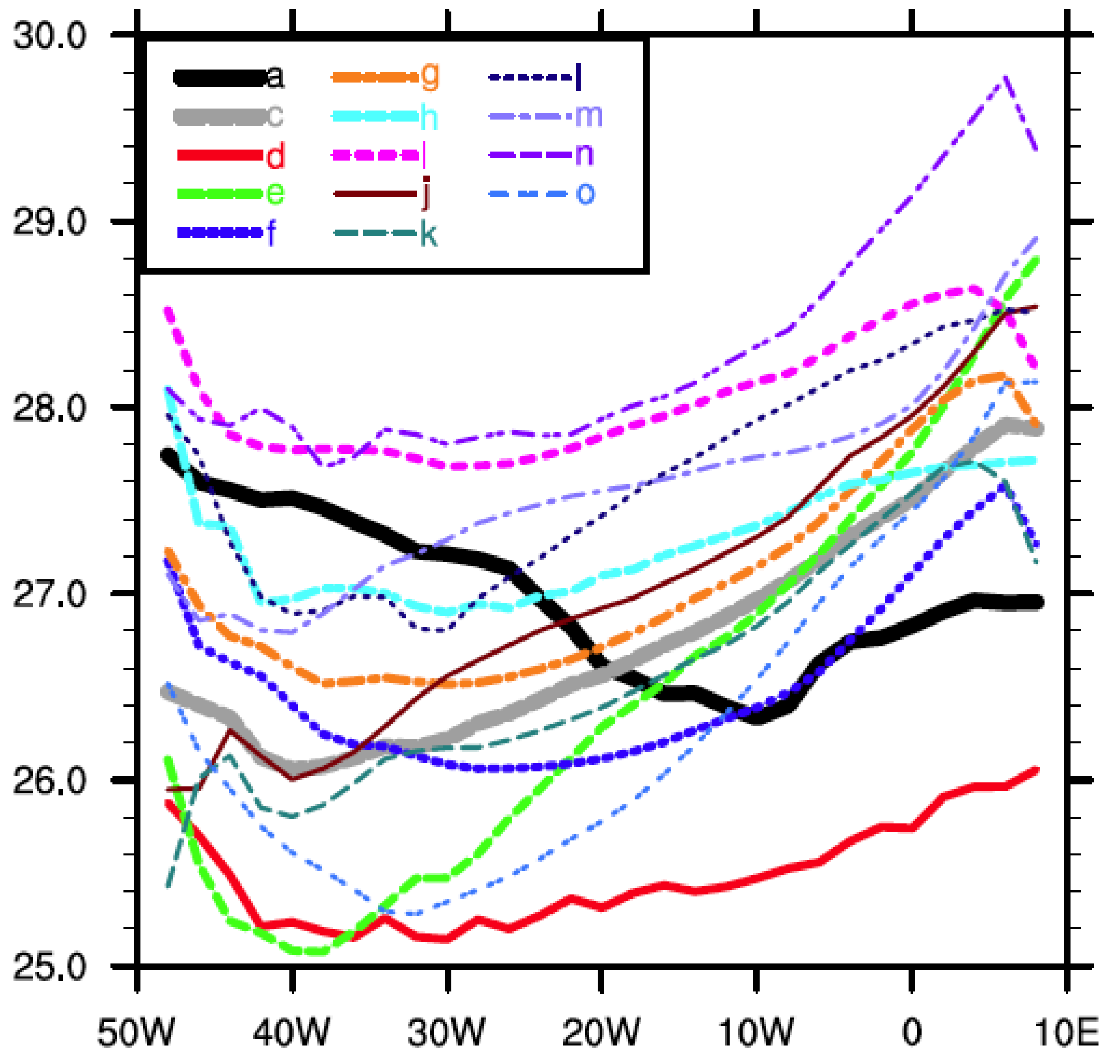

Figure 6.3: Annual mean equatorial Atlantic SST (in °C) for various IPCC AR4 models (d-o). The thick black line represents the observations based on the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). From Richter and Xie (2008).

Choosing the "best" IPCC AR4 models that simulate the 20th-century climate with the highest fidelity is fraught with a number of issues. For example, Shukla et al. (2006) suggest that models with higher skill in simulating the present climate produce higher rates of change in surface temperature for a doubling of CO_2. They therefore conclude that the projected warming of the surface temperature due to increased CO_2 is likely to be closer to the highest projected estimates among the current generation of climate models. On the other hand, Reifen and Toumi (2009) conclude that there is no evidence of future prediction skill delivered by past performance based model selection. They argue that models that respond accurately in one period are likely to have the correct feedback strength at that time. However, the feedback strength and forcing are not stationary on account of the changing concentrations of the GHGs, and favor no particular model or groups of models consistently. Similarly, many other studies have shown that the consideration of metrics of model skill for detection or attribution or for representing likely future change has generally made little difference (Brekke et al. 2008; Pierce et al. 2009; Santer et al. 2009; Mote and Salathe 2010). There are several studies, however, that have applied weighting schemes that preferentially rank models higher with simulations that verify with the present climate and show separation in future responses (Walsh et al. 2008; Raisanen et al. 2010; Matsueda and Palmer 2011).

In view of the fact that General Circulation Models of AR4 are too coarse for most water resources investigation at regional scales, multiple downscaling approaches have been developed to derive regional climate predictions from the coarser global models. They fall into two categories: (a) statistical downscaling (Wood et al., 2004; Maurer, 2007) and (b) dynamical downscaling (e.g., North American Regional Climate Change Assessment Program [NARCCAP]; http://www.narccap.ucar.edu/). Investigations to date indicate that, although both types of downscaled data simulate the precipitation and temperature patterns of the last century reasonably well, significant spatial and temporal biases exist and, consequently, the predictions in the 21st century may be highly uncertain (Obeysekera et al. 2011).

- Frequently Asked Questions -

What qualifies as an IPCC model?

There are no qualifying tests as such for models to contribute to the IPCC assessment process. However the model integrations have follow the protocol laid out by the Coupled Model Intercomparison Project (CMIP) of the World Climate Research Program (WCRP). This includes at a minimum of having a global climate model capable of freely integrating in time without prescribing any of the parameters except for the greenhouse gas concentrations, aerosols and some land surface properties. Furthermore, it is required by all contributing modeling groups to carry out the core experiments on schedule as decided by the CMIP. Please refer to Taylor et al. (2009) for further details on protocols laid out by CMIP5, which will be used in AR5.

What does peer reviewed article mean?

All articles that appear in scientific refereed (or peer reviewed) journals are usually critically assessed (generally anonymously) by other (peer) experts in the author's field for its validity, lucidity and relevance to the subject before it is approved for publication. This review process can go through several rounds of assessment before the editor of the journal is fully satisfied with the revisions of the article and approves for final publication. The IPCC assessment exclusively uses these peer reviewed literature in preparing their assessment reports. There is no comprehensive source for identifying all peer-reviewed journals. To help determine if a particular journal is peer-reviewed, refer to the journal itself (either to an individual issue of the journal or to the publisher's web site) or to Ulrich's International Periodicals Directory (volume 5 of Ulrich's lists the major peer-reviewed journals within the "Refereed Serials" section).

SECTION 7

What Can We Anticipate from the IPCC AR5?

B. Kirtman

The strategy in the IPCC AR4 for providing climate change information over the next several decades was to look at those time periods in ensemble averages of forced climate change simulations using various future emission scenarios that typically are run to 2100. Using this technique, it was that found that some regional climate change information on decadal time scales can already be obtained from two main sources: 1) climate change commitment, and 2) the forcing from increasing GHGs. Climate change commitment arises because at any point in time the slower warming oceans are lagging behind the land areas. Thus, the oceans provide thermal inertia for the climate system. The time scale of this lag for the upper ocean is decades, and for the deep ocean it is 1,000 years or more. This implies that even if GHG concentrations were stabilized today, the climate system would continue to warm at a rate of about 0.1°C per decade for the next several decades for a total of about 0.6°C after 100 years. There also would be additional climate change due to further anticipated increases in GHGs.

While the above strategy has proven useful in projecting regional climate change, it has been recently recognized that more detailed near-term (i.e., the next 10-30 years) information is required. For example, prolonged drought in the Southwest US, increased hurricane activity in the tropical Atlantic since the late 1990s, changing fisheries regimes, extreme events such as the 2003 European heat wave, and the need to adapt to time-evolving climate change and increasing temperatures have raised concern among policy and decision makers about climate change in the near term (often referred to as the "decadal" time scale). Impacts resulting from these conditions have significant social, economic, and environmental implications and are consistent with 20th-century climate simulations and some 21st-century climate model projections. Some aspects of observed changes have been attributed to naturally occurring decadal variability (see Sections 3 and 4). Anthropogenically forced climate change, intrinsic climate variability, and natural external forcings (e.g., major volcanic eruptions or possibly the solar cycle) act together to produce the time-evolving climate. Given no future information on the third, the first two must thus be addressed to provide the best information on climate shifts over the coming several decades.

The new CMIP5 protocol (see Meehl et al. 2009) for coordinated climate change experiments to be performed over the next 5 years includes an experimental design that focuses on decadal predictability and prediction. The goal is to provide a research framework for exploring the question of how predictable climate is from one to three decades in advance and how skillful decadal predictions out to about the year 2035 might be. The detailed requirements for the project are described by Taylor et al. (2008) (see also http://www.pcmdi.llnl.gov/). Only a brief overview is given here.

There are two core experiments that are considered essential to a meaningful decadal predictability/prediction exercise, and there are a number of tier-1 experiments that add additional insight into the science questions involved with decadal prediction. The first core experiment is to make a series of 10-year hindcasts with initial observed climate states every 5 years, starting near 1960. How to create the initial climate states is left to the discretion of the modeling groups because, as noted above, how best to initialize models is one of the central unanswered questions involved with decadal prediction. These 10-year hindcasts should allow estimates of both the theoretical limits of decadal predictability and our present ability to make decadal predictions, accounting for both the regional decadal phenomena discussed earlier and the climate change commitment from previous increases of GHGs. The minimum ensemble size from any given starting point is 3 members, although 10 or more ensemble members are desirable.

The second core experiment extends the integrations starting from 1960, 1980, and 2005 to 30 years and explores predictability and prediction over time scales thought to be more influenced by external forcing from increasing GHGs. Depending on how the initial conditions are prepared, the experimental design for the 30-year integrations does not necessarily require long control runs of the coupled model and thus opens the door for a wider class of models to be used in short-term climate prediction. In both core experiments, volcanic aerosol and solar cycle variability are prescribed during each integration using actual values for the past and assuming a climatological 11-year solar cycle and no eruptions in the future. These forcings allow an assessment of the predictability and prediction of the internal variability of the climate system, and a clean comparison with the standard CMIP5 20th-century runs. They allow an estimate of the skill of decadal predictions when the forcing is known, which for the future means an estimate conditional on no major volcanic eruptions.

The tier-1 integrations include simulations that start from initial climate states representing each of the years in this century when the ocean data coverage is much better than in previous years, in particular due to the Argo float data. There is also the option to perform high atmospheric resolution time slice experiments where the historical SSTs are either derived from observations or models. Further runs can study the impact of volcanoes, and others can include interactive atmospheric chemistry to investigate the impact of various short-lived species and pollutants on the predictions.

It is intended that this CMIP5 activity will not only set up a framework for coordinated multi-model experiments to address various science questions involved with decadal predictability/prediction, including the effect of model simulation errors on decadal prediction skill, but also provide the foundation for the simulations to be assessed as part of the IPCC Fifth Assessment Report (AR5). Decadal prediction is very much a research question at this early stage. Therefore, results from decadal prediction experiments must be carefully evaluated in the AR5 process so that results from CMIP5 are not misused.

- Frequently Asked Questions -

When is the IPCC AR5 due?

The following is the schedule of the Working Group I (The physical science basis) of IPCC AR5 obtained from http://cmip-pcmdi.llnl.gov/cmip5/availability.html

Provisional Schedule for the Working Group I contribution to the IPCC Fifth Assessment Report	
2010	
Nov	First Lead Authors Meeting (LA1), **8-11 November 2010**, Kunming, China
2011	
Jul	Second Lead Authors Meeting (LA2), **18-22 July 2011**, Brest, France
Dec	Expert Review of the First Order Draft (FOD), **16 December** – 10 February 2012
2012	
Feb	Expert Review of the First Order Draft (FOD), 16 December – **10 February 2012**
Apr	Third Lead Authors Meeting (LA3), **16-20 April 2012**, Marrakech, Morocco
Jul, 31	WGI AR5 literature cut-off for submitted papers, **31 July 2012**
Oct-Nov	Expert and Government Review of the Second Order Draft (SOD), **5 October – 30 November 2012**
2013	
Jan	Fourth Lead Authors Meeting (LA4), **14-19 January 2013**, Australia (TBC)
Mar, 15	WGI AR5 literature cut-off for accepted papers, **15 March 2013**
Jun-Aug	Final Government Distribution of the WGI AR5 SPM, **7 June – 2 August 2013**
Sep	Preparatory Meeting of WGI AR5 SPM/TS Writing Team & CLAs, **20-21 September 2013**
Sep	WGI AR5 SPM Approval Plenary (WGI-12), **23-26 September 2013**, Stockholm, Sweden

Where can we obtain the CMIP5 (model integrations used in IPCC AR5) datasets?

It is recommended that you monitor the following website of the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for CMIP5 datasets:
http://cmip-pcmdi.llnl.gov/cmip5/forcing.html

What is National Climate Assessment?

The National Climate Assessment (NCA; http://assessment.globalchange.gov) may be viewed as a type of IPCC assessment of climate, but specific to US climate. The NCA is administered by the US Global Change Research Program and is supposed to come out with a report every 4 years. The next report of the NCA is due in 2013.

SECTION 8

Population Trends in Florida, 2000 to 2030

E. Carlson

Responding to challenges caused by a changing climate will require broader participation in the understanding of geosciences (Pandya et al. 2007; Hoffmann and Barstow 2007). Davis et al. (2006) noted that Hurricane Katrina was a well-forecasted storm; however, the forecast did not reach the minority population. The destruction of New Orleans in Katrina's wake exposed failures in the decision-making process at individual, societal, and governmental levels and highlighted the need for additional education and outreach. The composition of the population of a region is quite pertinent to assess its vulnerability to climate change and variations (Leiserowitz 2007; Leiserowitz and Akerlof 2010). For example, an elderly population is at higher health risk from extreme weather events like heat waves and air pollution. Hoffman and Barstow (2007) suggested that successful application of knowledge and problem-solving skills to real-world issues is possible only when there is a public understanding of the earth's interconnected systems.

Until the Great Recession late in the first decade of the new century, Florida had one of the fastest-growing state populations in the US. Between 1950 and 2000 the state's population jumped from less than three million to 15.6 million, lifting Florida from twentieth to fourth place among states ranked by population. The state continued to grow rapidly in the first few years after 2000, but, in the second half of the decade, growth slowed dramatically and is not expected to speed up again in the near future. To see where the state's population might be by 2030, a generation from now, consider the official population projections for Florida as estimated in 2006 (before the recession) and then again in 2010 (after the slowdown in growth had taken hold).

In the last years of rapid growth, the official state projections released in 2006 estimated that, by 2010, Florida would be home to 19.9 million people. By 2030 the total was expected to swell to 25.6 million, an increase of about 64% over the 2000 starting population. This estimate was based on birth and death rates measured in the state around 2000 and the migration patterns that had been observed between 1995 and 2000. The projection for 2010 released in 2006 proved too high, however. Instead of the expected 19.9 million from the projection, only 18.8 million people were counted in Florida in the 2010 census. About one-fourth of the growth expected in 2005 never happened, and most of the growth that did occur happened before the recession hit the state.

Once the sputtering economy reduced Florida's population growth rate, official estimates began to take these changes into account. As a result, the 2010 population projections forecast only a 47% increase between 2000 and 2030, with a considerable share of that growth already having taken place in the first decade of the new century. Instead of 25.6 million people, the forecast was for only 23 million Floridians—a decrease of more than ten percent from the projected population that had been estimated only a few years before.

Even if the economy recovers, birth rates rise again, and migration to Florida moves back toward old levels, the period of slower growth so far will almost certainly make the 25.6 million an unreachable total. The population of the state by 2030 will likely be closer to the 23 million estimated in 2010 than to the earlier figure. If true, this population growth would represent an average rate of growth of about 1.3 percent per year, fairly slow growth by historical standards for Florida, but still positive growth.

The composition of the population also will change dramatically by 2030, in particular with respect to age and ethnicity. The accompanying Fig. 8.1 shows the actual population as it was in 2000 (white bars) and the projected 2030 population from 2010 projection estimates (white plus additional shaded bars). This figure shows that the White non-Hispanic population of the state will grow very slowly, and that virtually all such growth will take place among people over 65 years old—both by net in-migration of older adults and by aging in place of the population already in the state.

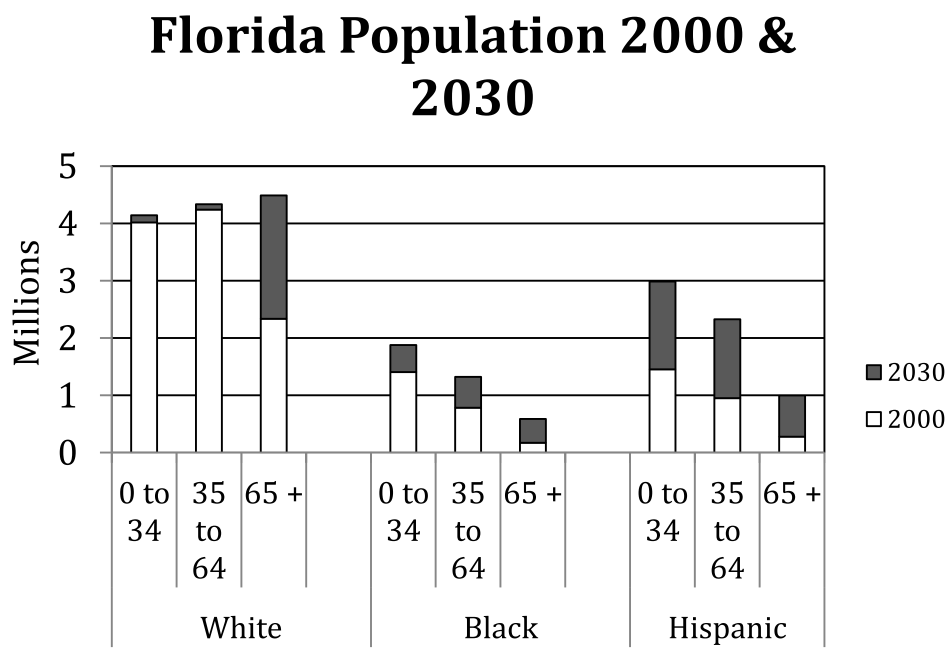

Figure 8.1: Human population trend in Florida.

White non-Hispanics will retain majority status by a small margin, dropping from 68 percent to 56 percent of the state's total population. The Black non-Hispanic population will grow slightly faster, increasing from 15 percent to 16 percent of the total. Florida's Hispanic population, more than doubling from 2.7 million to 6.3 million people, is projected to increase from 17 percent to over 27 percent of the state's people, nearly double the black population by 2030. Fully half of the growth expected over these 30 years represents an increasing Hispanic population.

The age patterns visible in the figure help to explain these dramatic shifts in ethnic balance over coming decades. Three age ranges split the population into young families (those under age 35 and their children), mature workers (people from 35 to 64, usually established in occupations and approaching the peak of their careers), and older adults (those over 65, dominated by retired persons and, at the oldest ages, experiencing rapid increases in health care needs).

The three age bars for non-Hispanic Whites are almost the same size by 2030. In fact, the number of people over 65 is expected to exceed the numbers in either of the other two age ranges. This is the unmistakable mark of a population with very low birth and death rates. In contrast, by far the largest segments of the Black and Hispanic populations in Florida are expected to be young families in 2030, just as they are today. The number of older adults among both non-Hispanic Blacks and Hispanics is expected to remain less than half the number of mature workers (35 to 64) in each of these ethnic groups. This age pattern for both Black and Hispanic Floridians reflects the assumption that birth rates for these groups will remain considerably higher than for Whites, in addition to the higher net migration expected for the Hispanic population. The 2030 projections point to a population where less than half of the young families under 35 and about half of the mature workers 35 to 64 are white non-Hispanics, while three-fourths of the people over age 65 are expected to be white non-Hispanics.

Since these broad life stages are linked to quite different lifestyles, as reflected in residential arrangements and other consumer patterns, both the sharpening ethnic contrasts in age structure and the continued aging of the entire population will have important environmental implications, over and above the simple fact that Florida's population is expected to grow by almost fifty percent between 2000 and 2030, reaching a total of some 23 million people by the latter date.

This growing trend of population in Florida is in itself exposing the state to potential vulnerability to climate variations and change. For example, Seager et al. (2009) suggest that the recent multi-year droughts in the southeast US, were typical in amplitude and duration compared to the historical record and yet its effects were aggravated from the increased demand of a comparatively large population.

The projected increase in the population of people of age over 65 years old is significant in terms of potential increase in the vulnerability to climate variability of a warming climate. Indeed, turning age 65 does not in itself make a person more vulnerable; rather, more proximate physiological and social factors that are associated with aging may produce greater vulnerability to the negative impacts of climate change and variability (Geller and Zenick 2005). For example, factors such as lack of physical mobility (Haq et al. 2008), pre-existing (sometimes multiple) chronic conditions (Haq et al. 2008), and social isolation with small or restricted social networks (Wilkinson and Marmot 2003) are disproportionately concentrated among older populations, which raise their vulnerability to climate variability. Zimmermann et al. (2007) indicate that 20% of the older population in the US resides in a county that is exposed to threat of a landfalling hurricane or tropical storm in a ten-year period. Their study also suggests that there is a higher concentration of low-income older people in these vulnerable counties.

- Frequently Asked Question -

What is climate literacy?

According to American Association of Advancement of Science (Atlas of Science Literacy, Volume 2, Project 2061) climate literacy refers to:

"People who are climate science literate know that climate science can inform our decisions that improve quality of life. They have a basic understanding of the climate system, including the natural and human-caused factors that affect it. Climate science literate individuals understand how climate observations and records as well as computer modeling contribute to scientific knowledge about climate. They are aware of the fundamental relationship between climate and human life and the many ways in which climate has always played a role in human health. They have the ability to assess the validity of scientific arguments about climate and to use that information to support their decisions."

SECTION 9

Water Supply and Climate Change in Florida

R. Craig and J. Obeysekera

Under the 1972 Florida Water Resources Act (FWRA), Florida manages its freshwater on a state and regional basis. The Act divides the state into five Water Management Districts (WMDs) based on watersheds (see Figure 9.1). At the state level, the Florida Department of Environmental Protection (FDEP) oversees the WMDs' implementation of water withdrawal permitting, water planning, and the establishment of minimum flows and levels, which designate the minimum amount of surface water (minimum flows) and ground water (minimum levels) required to maintain ecological and other functions and services.

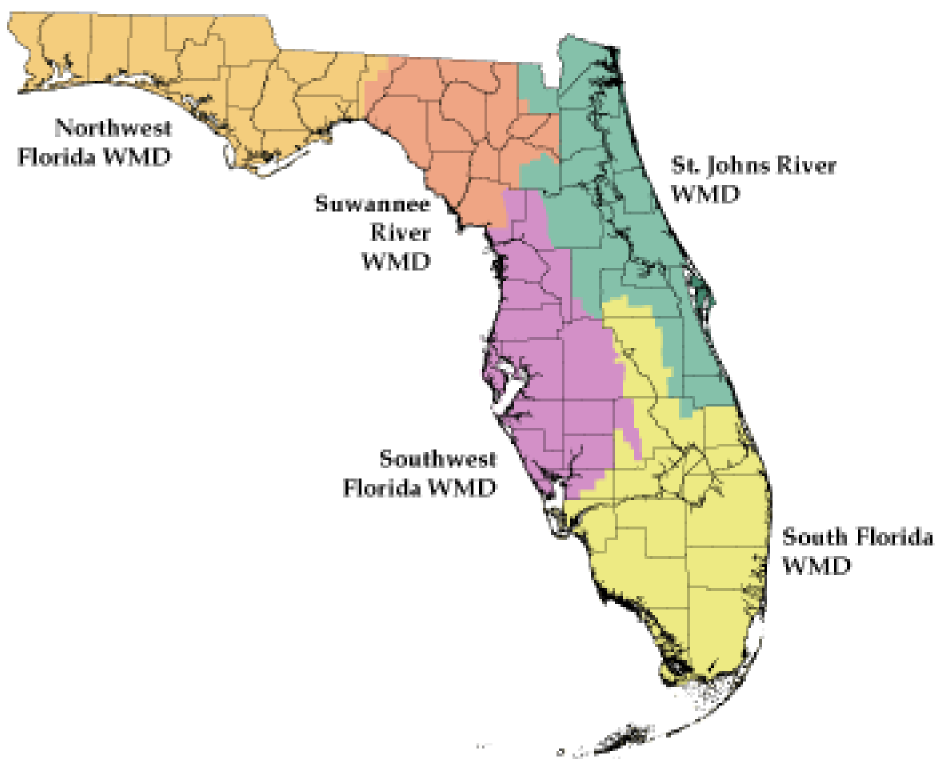

Figure 9.1: Florida's Water Management Districts. (Map care of Florida Department of Environmental Protection).

According to the FDEP in 2007, Floridians used 6.5 billion gallons of fresh water per day in 2005, mostly for agriculture (43%) and public water supply (37%; Florida Department of Environmental Protection 2007). By 2025, FDEP projects Floridians will need 8.5 billion gallons per day, with agricultural demand dropping to 35% and public water supply demand increasing to 43% of total use (Florida Department of Environmental Protection, 2007). However, while the report identified many ways of meeting this increased demand in terms of financing, water supply projects, and conservation, it did not address the possible impacts of climate change on water supply, which are likely to be significant.

Florida receives, on average, 54.57 inches of rainfall each year, making it the fifth wettest state in the US. Nevertheless, there are significant water resource differences between north and south Florida. First, Florida has a hydrological divide between north and south Florida, running across the peninsula roughly through Orlando, from Cedar Key on the west coast to New Smyrna Beach on the east. While fresh water flows into northern Florida from Georgia and Alabama, none of it flows south past the hydrological divide. As a result, southern Florida is completely dependent on rainfall. Second, in general, less rain falls in southern Florida than in northern Florida. Key West, for example, receives only about 39 inches per year on average; Tampa receives about 45 inches per year[1], while Gainesville and Orlando each receive a bit more than 48 inches per year on average. In contrast, Tallahassee receives more than 63 inches per year and Pensacola more the 64 inches. Given that Florida's population is concentrated south of the hydrological divide, the mismatch of population and water supply is obvious.

All parts of Florida are already vulnerable to drought but in different ways. In the north, drought becomes important because it reduces the flow of rivers coming from Alabama and especially Georgia. In the area's 2006-2008 drought, for example, management of the Apalachicola-Chattahoochee-Flint River basin became a tristate southeastern legal "water war" that pitted Atlanta's need for public water supply against Florida's desire for a water regime that could support healthy oyster and other seafood industries in Apalachicola Bay. However, sufficient public drinking water supply for northern Florida was not a significant issue. In southern Florida, in contrast, drought has a direct effect on public water supply as well as ecological needs. As a result of reduced rainfall in the first half of 2011, for example, more than half of the Everglades water conservation areas had gone dry by May and water levels in Lake Okeechobee had dropped by one foot by June. Agricultural water users in southern Florida had to cut back their irrigation by 45% when water levels in Lake Okeechobee fell to 10.5 feet above sea level (by June 9, the lake had dropped to 9.81 feet above sea level), while emergency restrictions on residential users' water use for certain activities, such as lawn watering, remain in place. West Palm Beach, the only city in Palm Beach County that relies on surface water, lost its supply and had to begin buying water from the county.

Climate change is projected to reduce rainfall in southern Florida (Section 3.2), which will increase pressures on water supply while population growth increases demand (Section 8). According to the U.S. Global Change Research Program, spring and summer rainfall throughout the Florida peninsula has been decreasing over the last century, and, in southern Florida, fall rainfall has decreased as well (U.S. Global Change Research Program

[1] It may be noted that area average rainfall over near by St. Leo, Plant city and Tarpon Springs gauges is closer to 51 - 52 inches per year. The Tampa International Airport (TIA) gauge has always been very low. This is especially important to Tampa Bay Water since watersheds for river flows are more inland than represented by the TIA gauge so for water supplies, using the TIA gauge does not provide representative rainfall.

2009). While summer temperatures could increase as much as 10.5°F over the next century, "[s]pring and summer rainfall is projected to decline in South Florida during this century" (U. S. Global Change Research Program, 2009).

Florida is also vulnerable to sea level rise. Most coastal communities in South Florida depend on wellfields that tap underground freshwater aquifers for their water supply. Saltwater intrusion into these aquifers due to the current sea level and coastal development already threatens the region's water supply. Between the years 1995 and 2000, a compilation of county data has resulted in an approximate location of the freshwater/saltwater interface on the Lower East Coast with measured chloride levels of 100 mg/L to 250 mg/L and above at the base of the aquifer (Figure 9.2). The highly populated area from the Florida Keys to Palm Beach is considered especially vulnerable. Many coastal wellfields, which withdraw freshwater from the highly productive Biscayne aquifer, are located along the coastal belt along the Lower East Coast and will be highly vulnerable if the saltwater intrusion is accelerated due to rising sea level. A more detailed analysis is needed to identify the impact of projected sea level rise on selected utility wellfields at risk of saltwater intrusion.

Figure 9.2: Estimated freshwater/saltwater interface in the lower east coast for the years 1995 through 2000 based on measurements from 100 mg/L chloride to 250 mg/L chloride and above. The blue dots indicate the locations of major wellfields for water supply.

The complex water management system in South Florida is operated for multiple purposes, including flood control, water supply, and environmental uses. Water moves from Lake Okeechobee, a major water supply source in the region, to the east and west for flood control, and to the south for water supply, environmental requirements, and flood control. Canal levels along the urbanized areas of the coast are kept at levels high enough to prevent saltwater intrusion to the surficial aquifer that serves as the major source of water supply for coastal urban areas. Coastal discharge structures are also operated to dispose of excess water from the water management system to the Atlantic Ocean to protect coastal urban areas from flooding. Consequently, sea level rise due to climate change may pose a major impact to the coastal region of South Florida's water management system; namely, reduced discharge capacity on structures mainly designed for flood control, increased vulnerability for saltwater intrusion, and possible loss of coastal environment.

Moreover, as the U.S. Global Change Research Program has pointed out, there are likely to be synergistic interactions between reduced rainfall and saltwater intrusion into aquifers in Florida and throughout the SE US:

> During droughts, recharge of groundwater will decline as the temperature and spacing between rainfall events increase. Responding by increasing groundwater pumping will further stress or deplete aquifers and place increasing strain on surface water resources. Increasing evaporation and plant water loss rates alter the balance of runoff and groundwater recharge, which is likely to lead to saltwater intrusion into shallow aquifers in many parts of the Southeast (U. S. Global change research program 2009).

- Frequently Asked Questions -

What is Global Change Research Act of 1990?

This is a US law requiring research into global warming and related issues, with updated reports generated every 4 years for the US congress. The first National Climate Assessment (NCA) report was published in 2000 followed by another in 2009 and the third report is due by March 2013. The law codified US Global Research Program, set up initially by presidential authority in 1989.

What is environmental justice?

According to U. S. EPA (2009), 'environmental justice is "fair" treatment and meaningful involvement of all people regardless of race, color, national origin or income with respect to the development, implementation, and enforcement of environment laws, regulations and policies'.

SECTION 10

The Way Forward

This section describes some initial strategies to develop a climate research and application framework for active participation of university, federal, and state laboratory researchers and private industry to help Florida adapt and mitigate impacts of climate change. These strategies are in no way cast in stone, as the synergy will have flexibility to chart its own course from discoveries, success, failures, and impediments felt during the development of this collaboration. But it is well recognized that Florida will benefit significantly from these attempts, given that Florida is one of those unique regions in the US where the population is bound to grow with a changing demography. Finding ways to make Florida less vulnerable in a future world exposed to climate anomalies will put this state on a strong footing along the path of progressive development.

10.1 In the Near-Term

Planning for climate variability and change is not an easy task, especially when predictions are uncertain. In a region like Florida this is an even bigger challenge as it is routinely exposed to frequent weather extremes like freeze events, Atlantic tropical storms, strong thunderstorm activity, droughts, and heat waves. As discussed earlier in section 2, such high frequency events are overwhelmed by chaotic internal variability. The hope, however, is that the low frequency variations of these weather extremes respond to the external forcing of the climate system. This hope is validated to an extent by the success of both seasonal-to-interannual predictions of Atlantic tropical cyclone activity (Vecchi et al. 2011; LaRow et al. 2010; Zhao et al. 2010; Knutson et al. 2010; Chen and Lin 2011) and longer-term tropical cyclone projections (Knutson et al. 2010; Bender et al. 2010). Beyond overcoming the inadequacies of our tools and lack of understanding of the variations and impacts of climate change on these extreme weather events, we also have to reconcile their ephemeral nature and associated uncertainty. In other words, we will have to adapt our planning strategies to this inherent uncertainty as we continue to make progress in narrowing it.

There is sufficient evidence to suggest that anticipated climate impacts over Florida would occur from variations and change in remote regions. Some examples include but are not limited to:

- Sea level rise from melting glaciers in the polar latitudes in addition to the thermal expansion of the warming ocean waters
- African easterly waves and the easterly flow associated with the subtropical high pressure systems in the Atlantic Ocean that transport dust across the Atlantic to the shores of Florida, causing HABs, HBBs, and air quality issues

- The Atlantic hurricane activity is influenced by ENSO, AMO, rainfall variability in the sub-saharan region of North Africa

- ENSO variability impacts winter and spring temperature and rainfall over a broad region of the SE US, including Florida and Atlantic tropical storm activity in the summer

- The PDO has some similar impacts on SE US as ENSO, though on decadal scales

- Remote climate patterns in winter and spring force SSTAs in the tropical western Atlantic that subsequently influence summer climate and extreme events

The interesting aspect of these examples is that many of these variations are slowly varying and have large spatial scales. As illustrated in many sections of this document, there is some modicum of success in understanding the global impacts of these variations even with the limitations of our numerical climate models and our limited ability to recover their historical variations from observed data. The Coupled Model Intercomparison Project (CMIP) of the World Climate Research Program (WCRP) has offered an unprecedented opportunity in AR4 and in AR5 to provide ready access to carefully co-ordinated and standardized climate model integrations across more than 20 modeling groups around the world. They provide an incredible amount of information to develop potential future climate impact scenarios for regions around the world including Florida to assess cross-sectoral impacts with robust uncertainty bounds. The various emission scenarios, geo-engineering experiments, decadal predictions are but a small example of a much wider set of experiments that are planned in the CMIP5 as part of IPCC's AR5 (Taylor et al. 2009).

10.1.1 Climate Scenarios

As mentioned earlier CMIP offers a large spread of data sets of climate model integrations for various emission scenarios and from several modeling centers around the world. There are several studies (Raisanen 2010; Matsueda and Palmer 2011), which indicate the merit of multi-model mean projection over any single model projection. The premise here is that by averaging over many model estimates of the future, a reduction in the model uncertainty is achieved while the estimates of the anomalies in many instances are improved. The caveat, however, is that overall the variance may get artificially reduced compared to individual models.

Indeed the reliability of the AR4 and even possibly AR5 climate model projections for relatively small regions like Florida is questionable. However, as emphasized before, we can leverage from the fact that Florida's climate variability are to some extent dictated by some of the more well known large-scale phenomenon like ENSO, AMO and others. Therefore even if these models are unrealistic in their rendition of the mean climate and variation over a region like Florida, some useful information on the large-scale oscillations can still be gleaned from these models. There has been significant recent progress in the simulations of ENSO variations in some of the climate models (Rao and Sperber 2006; Saha et al. 2006; Neale et al. 2008).

As in AR4 of the IPCC, AR5 also plans to run several emission scenarios. The choice of the climate projection to use pertaining to an emission scenario in majority of cases will depend on the application that it is used for. For example, an application for a high risk but rare climate or weather event(s) would optimally require that all projections be examined, and the most extreme projections of the rare event be considered. The guiding principle here is that you plan most conservatively for these perceived high risk events.

The demand for climate forecasts from stakeholders in Florida can be largely divided in to 4 temporal scales owing to the different time horizons for decisions and policies that they make. These are 1) subseasonal time scales from one to ten weeks (e.g. but not limited to "is the onset of the rainy season this summer a week or two ahead?"), 2) seasonal to interannual time scale (e.g. but not limited to "if the season ahead is going to be warmer/colder or wetter/drier than usual?"), 3) 10-30 years (e. g. but not limited to "is the decade ahead going to be more active in Atlantic tropical cyclone activity than the previous decade?"), and 4) greater than 30 years including end of the century projections (e.g. but not limited to "what is the sea level rise by 2100?"). Interspersed in these stakeholder needs are forecast demands of the extremes, which are often valued much more than that of the changes to the seasonal, decadal or the centennial mean. In other words this demand for forecasting the extreme events relate to the shifts in the tail ends of the probability distribution function. Keeping in mind the stakeholder needs of Florida, we have come up with the following Table 10.1 that points to the drivers for the climate variability or change and the resources available to forecast them.

Temporal scale	Driver	Forecast resources	Comments
Intra-seasonal: 1 to 10 weeks	Not known		Intraseasonal variability in the SE US has not been investigated extensively as thus far there is very little observed evidence of such variability in the SE US. Although there is some evidence of the intraseasonal variation of the Atlantic hurrican activity (Maloney and Hartmann 2001). There is however quite a bit of work done on these scales for the tropical latitudes and the monsoons.
Seasonal to Interannual	ENSO	http://iri.columbia.edu/climate/ENSO/currentinfo/SST_table.html	ENSO is the largest driver of climate variability on these time scales over the SE US in boreal winter and Spring. It also has a bearing on the Atlantic seasonal hurricane activity. It may be mentioned that although the winter of 2010 despite a strong La Niña ended up being a rather cold winter because of the supposedly strong negative North Atlantic

			Oscillation (NAO). On seasonal time scales the predictability of the NAO is unknown. Therefore despite such forecast failures over SE US we continue to rely on the ENSO as the dominant predictable signal. There is also an effort to have US national multi-model ensemble forecast, which is already underway. The readers are encouraged to go to this link for more information on it: http://www.cpc.ncep.noaa.gov/products/ctb/meetings/2011/CTB-PI/kirtman_ben_2.pdf
Decadal	AMO/PDO	http://cmip-pcmdi.llnl.gov/cmip5/index.html?submenuheader=0	The decadal CMIP5 prediction experiments will serve to quantify current predictive capability, although preliminary results indicate very modest skill.
Climate change (Centennial scale)	Greenhouse gas emission	http://cmip-pcmdi.llnl.gov/cmip5/index.html?submenuheader=0	The increase in the greenhouse gas concentration offers a strong external forcing for global climate change. However local land cover and land use change, aerosols can also offer strong external forcing to drive the local climate.

Table 10.1: Major Drivers of climate variation and change over Florida

The prediction of extremes at any of the above four time scales is a challenge by their infrequent occurrence. Karl et al. (2008) define weather extremes as weather events that are unusual in their occurrence (minimally the event must lie in the upper or lower ten percentile of the distribution) or have destructive potential such as hurricanes or tornadoes. Similarly climate extremes are defined as the same type of events (as weather events) but viewed over seasons (e.g. droughts) or longer periods (Karl et al. 2008). As a result sampling such events become an issue both from historical observations and the small finite number of ensembles of climate model forecasts. Furthermore, many climate models have poor skill in simulating the extremes owing to their coarse spatial resolution and issues with the micro-scale (or sub-grid scale) physics. The US National Multi-model Ensemble Effort for seasonal prediction may offer some improvement in our dynamical prediction skill of seasonal extremes as the number of ensemble members are significantly enhanced while also giving a measure of model uncertainty. Likewise the CMIP5 offers a larger sample size to investigate extremes in a future world.

10.1.2 Cross-sectoral impact

The SE US is beset with one of the strongest variability in surface meteorological variables especially of the precipitation and temperature. A large fraction of this variation is dictated by ENSO variations, which has been exploited for successful cross-sectoral applications by several organizations (e.g. Southeast Climate Consortium; http://www.seclimate.org/sucesStory.php#nowhere). It is suggested that emphasis on prediction of climate variations in the SE US including Florida continue as we ramp our efforts on projecting future climate change in the region. These efforts may also yield on how uncertainty percolates in these other sectors and possibly allow new insights to uncertainty of climate projection.

Florida is a unique region of the US that has a growing and changing population (Section 8.0). This in itself warrants an early beginning to assess, adapt to, and/or mitigate vulnerabilities to climate change and variability. In light of the changing demography of Florida, some of the earlier strategies to climate adaptation and mitigation may be inadequate even if we use a scenario that assumes stationarity of the mean climate and its variability over Florida. For example, an aging population could be susceptible to modest variations in air quality. Likewise, anthropogenic nutrient loading to the oceans from a growing population may become an important issue for human and ocean health in and around Florida.

Given this complex interaction of human and natural systems, it would be rather voluminous to delineate all potential cross-sectoral impacts of climate variability and change. Here we suggest a minority of such impacts to consider initially. Although it is easier to compartmentalize these impacts, one has to be aware of the interaction amongst these sectors. One such example is the nexus between the water and the energy sectors. One the one hand it takes huge quantities of water to produce electricity from a plant powered by nuclear energy or fossil fuels. On the other hand it also takes lots of energy to pump and process the water that irrigates fields and supplies to cities.

Agriculture: is one of the major industries of Florida growing a diverse set of crops and livestock. They are extremely sensitive to climate variations and change. For example changes to seasonality (like early freeze events) can have devastating impact on the citrus crops. Likewise Frank (2001) indicate that the milk productivity of cows and beef cattle rearing could also be affected by rising temperatures.

Water resources: The future of fresh water resources cannot be stressed enough for a stable future of Florida. While it is important to realize that there are significant primary and secondary water stress to Florida's resources, understanding the impact of climate variations and change on water resources can play a vital role in the adaptation, mitigation and efficient management of water resources. It is important that the climate projections are thoroughly examined for their hydrological application to ascertain the full spectrum of the future potential scenarios of water resources in Florida. This interaction is already occurring through the formation of the public water utilities climate impact working group (http://waterinstitute.ufl.edu/workshops_panels/PWSU-CIWG.html).

Ecosystem: Florida is host to the Everglade system, which signifies the epitome of biodiversity. It is now threatened by sea level rise. The threat of droughts, floods, early freeze events has major impact on the forests of the region. Climate change can warrant additional thermal stress and declining soil moisture (Karl et al. 2009) that can potentially reduce net forest productivity. Ryan et al. (2008) however find that increasing CO_2 concentrations may lead to forest growth.

Human health: Given the changing demography and global climate change the vulnerability of the human health has to constantly assessed and planned for. Florida as discussed in Section 3 is in the transition region of differing climate change impacts on the deep tropics and middle latitudes, which makes the application of climate projections on human health studies challenging. It may also be mentioned that the health of the neighboring oceans in a changing climate is also closely tied to the health of the burgeoning coastal communities of Florida.

Climate literacy: According to a survey 81% of the Floridan's believe in global warming and 72% think that it is mostly or partly due to human activity (Kosnik 2010). In our quest for successful adaptation and or mitigation strategies to climate variability and change it is important to take the citizens of Florida in confidence. For that climate literacy is very important. Our research application results need to be exchanged periodically through public media. This will require a dedicated effort.

Renewable energy: While greenhouse gases continue to increase and global climate models continue to improve, we need to understand the rates of temperature increase under different stabilization and clean energy source adoption scenarios. Confidence in model predictions will help foster leadership in and unification in policies for massive scale adoption of clean energy. Wind and solar farms are on track to become cost competitive in Florida within the next 10-15 years, even without carbon pricing or consideration of external costs of fossil fuels. Solar and wind energy density is such that large land and water areas will be needed to accommodate the farms. These farms will be a major contributor to reducing greenhouse gases but may have both positive and negative impacts. For example, offshore wind farms may supplant a polluting coal plant and reduce healthcare costs, clean the air, and encourage healthy fisheries (the foundations may attract fish) but their 100 m towers extract momentum which could affect local weather and climate. As more renewable energy is integrated into what is becoming a "smart (electricity) grid", its important to know how solar energy and wind vary on seasonal and interannual scales, so that load balancing authorities can plan future energy source allocations. In addition, a smart transmission grid will be capable of moving energy from areas where more is generated than needed (e.g. sunny and windy) to areas where generation is lagging demand (cloudy, cold, and calm). Therefore we will need enhanced predictions of weather system size, duration and long term variability to understand what times of year in which direction of energy will be transferred within Florida and the rest of the country.

10.2 In the Extended Future

10.2.1 IPCC AR5

As mentioned, the fifth assessment report of the IPCC (AR5) is due in later half of 2013. This assessment will be based on a set of new generation of climate models at a slightly higher spatial resolution than the AR4 models. In addition, it is anticipated that the report will have a better comprehension of sea level changes by including projected impacts of melting glaciers, a new set of estimates of near term (10-30 year) climate predictions that may have some skill at predicting natural decadal change, and possibly an improved emphasis on regional projections. One of the immediate tasks would be to synthesize the information from AR5 that would be relevant to Florida.

10.2.2 Low Frequency Variations of Local-Scale Phenomena

Florida is exposed to several local-scale phenomena, including sea breeze, lake breeze, tropical cyclone activity, and ocean eddies in the Gulf of Mexico. All of these have important roles in the overall climate of the region that become quite apparent when aggregated over time. Therefore, understanding the responses of these phenomena to large-scale changes in climate would be pertinent to develop Florida-relevant climate scenarios. These would require the resolutions of the model to be increased appreciably from current practices.

10.2.3 Unraveling the Complex Interactions of Natural Variability and Climate Change

Our understanding of the natural variations of the AMO and PDO are still nascent, which is accentuated by limited observations of the deeper oceans. As a result, discerning the actual impact of climate change from these very slow naturally varying oscillations is sometimes quite difficult. The computationally expensive long model integrations required to resolve the decadal oscillations will become necessary, as there is growing evidence to show that Florida is directly impacted by the interactions of these oscillations with the climate change signal.

10.2.4 Quantifying and Attributing the Sources of Regional Climate Uncertainty

The irreducible and reducible uncertainties of climate projections over Florida will have to be ascertained. This information is not only of academic interest but is also necessary for conveying the limits of climate projection to a potentially growing but restive population in a likely tighter economy. Carefully thought out, hypothesis driven experiments with climate models that can resolve the features relevant to Florida will have to be conducted to get a bearing on this issue.

10.2.5 Reconstruction of the Past Observations

Resources to reconstruct historical evolution of climate in a region like Florida would be an invaluable contribution to supplement the understanding of future climate projection. The low frequency variations detected from these long time periods of reconstructed observations would also help in evaluating the projections from the climate models. Pielke et al. (2011) suggest that assessment of climate risk needs to start from using current socio-economic conditions under past anomalous climate and weather events. They also suggest of a bottom up resource based approach wherein they superimpose realistic changes to the climatology of a region incrementally to assess the threshold of significant vulnerability to the change.

- Frequently Asked Questions -

When climate models have issues with ENSO simulation in the 20th century, then how can their projections in the 21st century be reliable?

Indeed as illustrated in Section 6 biases exist in the IPCC models to simulate ENSO. However a majority of them show the evolution of ENSO consistent with some well known theoretical models and observations. This has been a huge improvement in the models of IPCC AR4 from the AR3. Therefore despite the fact that these climate models are unable to replicate some of the observed ENSO features, we are more confident of their evolution and are capable of detecting any change from the traditional (or currently known theoretical) evolution of ENSO. In addition, the 20th century simulation of all CMIP3 models used in IPCC AR4 show a positive correlation of rainfall over Florida with Niño3 SST index in the winter season as in observations (personal communication, Kathryn Hayhoe, Texas Tech University).

Is climate stationarity dead? In other words, is it worthwhile to look in climate history to project for the future climate?

This notion of the death of climate stationarity (Milly et al. 2008) stems largely from the observed linear increase in the global mean temperature as a result of the unprecedented increase in the rate of change of the greenhouse gases since the industrial revolution or due to very slowly varying natural variability like the Atlantic Multidecadal Oscillation. However, there are other variables like global mean precipitation of the past 70 or more years, which have shown no statistically significant linear trend. Likewise the stationarity (or lack of a linear trend) in the total number of yearly tropical cyclones in the global tropics from the recorded history of the past 70-80 years is also a very interesting feature of our climate system. These examples suggest that stationarity of the climate system does depend on the variable in question despite the unprecedented increase in the rate of greenhouse gases since the industrial revolution. The climate stationarity also depends on the spatial scales as some regions show very strong warming rates of the surface temperature, while some other regions show cooling rates and many other regions showing no trend at all. Therefore we have to examine the future time period over shich climate projections are being made, the climate variables in question, and the region of interest to cautiously determine the validity of using past observations for such purposes. However there is merit in supplementing the historical climate information with model projections under various emission scenarios for describing the future climate evolution.

Can we attribute weather and seasonal climate anomalies to natural variability or climate change?

Historically the community of climate scientists felt that attributing a specific weather or seasonal anomaly (e.g. unusually cold winter of 2010 in southeast US) to natural or anthropogenic climate change would be impossible to make. This is because conceptually weather events are thought of as initial value problems, i.e., given the current state of the atmosphere we could integrate our numerical weather prediction models up to 5-7 days in to the future to reliably predict the weather event after which atmospheric chaos takes over. In the case of seasonal prediction too, it is increasingly felt that the initial conditions of soil moisture, snow cover, SST and other surface boundary conditions are as important to forecast the following seasonal climate as the initial condition of the atmosphere is for weather prediction. However the longer-term change signal is attributed to the boundary forcing of the increases in concentration of the greenhouse gases and is insensitive to the initial conditions of the atmosphere, land and the upper ocean. However with greater demand for such attribution stemming for various reasons including libel suites for damages (if it is human caused) the World Climate Research Program (WCRP) has developed an initiative called the International Attribution of Climate-related Events (ACE; http://www.wcrpclimate.org/conference2011/documents/Stott.pdf) to develop the science for authoritative explanations of extreme events. This is at a very nascent stage of this WCRP initiative and will have to be watched very cautiously as it matures.

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