Report on the Past, Present, and Future Climate Change Drivers and Everglades Restoration Workshop

Workshop date: 30 October 2009

Report date: 30 November 2009

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Executive Summary

The natural condition of the Everglades has varied as a function of interannual to century-scale climate variations over the last five to six thousand years (Bernhardt and Willard, 2009). Because of its geography, Florida experiences a range of climate with strong north-south gradients in temperature during the winter, and precipitation during the summer (Henry et al., 1994). Those wide ranges in precipitation can be further exaggerated by the geographic and temporal distribution of landfalling tropical storms and hurricanes in Florida.

On time scales of interannual to multidecadal, climate variability in South Florida is driven by a combination of several broad-reaching teleconnections between Atlantic and Pacific climate forcing mechanisms operating across a range of time scales. The Atlantic Multidecadal Oscillation (AMO) is closely linked to precipitation in the Lake Okeechobee basin and influences precipitation in wet or dry cycles that last 60-70 years (Enfield et al., 2001). El Niño-Southern Oscillation (ENSO), with a period of 2-7 years affects the precipitation in the Everglades during the dry season (November-May) from the Pacific Ocean through teleconnections (Enfield, 1996).

Despite our understanding of various interannual to multidecadal climate oscillations and drivers, we need to improve our ability to place them into a management context for successful Everglades restoration. The South Florida Water Management District (SFWMD), in collaboration with the Florida Coastal Everglades Long Term Ecological Research Program (FCE-LTER) hosted this workshop in an effort to bring together scientists from around South Florida to address past, present, and future Everglades climate drivers in a management framework, and to build collaborations between specialists. This one-day workshop was held on October 30, 2009, and consisted of presentations by experts and discussions of critical topics. The findings of the workshop identified paradoxes and gaps in our knowledge of climate drivers in South Florida, and began to formulate multi-institutional collaborative efforts to advance our understanding of those issues.

Online Resources:

- Workshop homepage.
    - http://fcelter.fiu.edu/about_us/workshops/2009_10_30_Climate/
- Workshop presentations.
    - http://fcelter.fiu.edu/about_us/workshops/2009_10_30_Climate/presentations/
- This report.
    - http://fcelter.fiu.edu/about_us/workshops/2009_10_30_Climate/fce_climate_workshop_report.pdf

Purpose of the Workshop and this Report

This workshop on past, present, and future climate change drivers that impact the Everglades was a joint effort between SFWMD and FCE-LTER. Various types and quality of climate data is available for the Everglades region, and numerous local area scientists are collecting and using data for thus-far relatively disconnected purposes. This workshop was intended as an opportunity to bring together experts from diverse scientific specialties in an effort to reduce the number of gaps in our understanding of past and present Everglades climate, and improve our ability to model the impacts of future climate scenarios.

Definitions and Abbreviations

AMO – Atlantic Multidecadal Oscillation. The AMO is an index of sea surface temperature anomalies measured over the entire North Atlantic from the Equator to 70° N. The AMO has a period of around 60-70 years.

DJF – Climatological shorthand for a seasonal period spanning the months of December, January, and February.

ENSO – El Niño-Southern Oscillation. ENSO is a climate phenomenon indicated by relaxing of the trade winds in the Pacific Ocean, and a warming of the sea surface temperatures in the eastern Pacific. ENSO (or "El Niño") events typically occur every 2-7 years and last from 9-18 months. The opposite condition when the eastern Pacific is cooler than normal and trade winds are enhanced is referred top as "La Niña."

FCE-LTER – Florida Coastal Everglades Long Term Ecological Research Program. The FCE-LTER Program is part of the Long Term Ecological Research (LTER) Network established by the National Science Foundation in 1980. The FCE LTER Program was established in 2000 in south Florida. The program is based at Florida International University and includes 67 senior scientists from 29 institutions.

GCM – General circulation model. GCMs are typically coarse resolution (1° or 2° resolution) multilayer models of the global ocean-atmosphere climate system that incorporate complicated physical processes (e.g., wind, evaporation, amount of sunlight, etc.) to model expected changes in climate. GCMs are often used to set the initial conditions or boundary conditions for higher resolution models.

IPCC – Intergovernmental Panel on Climate Change. The IPCC is an international body that does not do its original own research, but instead evaluates and synthesizes the research of others for the purpose of producing peer-reviewed reports that provide "best estimates" of climate change scenarios around the world.

ITCZ – Intertropical Convergence Zone. The generally east-west trending zone of strong atmospheric convection and associated heavy precipitation that seasonally migrates north-south through the tropics.

JJA – Climatological shorthand for a seasonal period spanning the months of June, July, and August.

HURDAT – NOAA Atlantic hurricane database.

NOAA – National Oceanic and Atmospheric Administration.

SFWMD – South Florida Water Management District.

SST – Sea surface temperature.

Introduction to Florida Climate and Weather

Patterns of Modern Florida Climate

Florida has a wide range in most climate metrics (e.g., temperature, precipitation, etc.) due to its north-to-south elongation and long coastline along two different water masses. Government climatologists have divided the continental U.S. into 344 Climatic Divisions largely based on agricultural reporting needs. Florida has seven such climate divisions, beginning with Division 1 in the western panhandle, and counting east, then southward to Division 7 in the Florida Keys. Of particular interest to this report are Division 4 (immediately north of Lake Okeechobee), Division 5 (Everglades and southwest coast), Division 6 (the developed lower east coast from Miami-Dade to Martin County), and Division 7 (Florida Keys). Modern climate division data for temperature, precipitation, and drought can accessed through the NOAA Earth System Research Lab (ESRL) website: http://www.esrl.noaa.gov/psd//cgi-bin/data/getpage.pl .

Temperature

The average annual temperature in Florida ranges from about 68° F in Division 1 to about 78° F in Key West in Division 7 (Figure 1). The winter (DJF) temperature range is substantial, spanning 52.7° F (Division 1) to 70.1° F (Division 7), but that difference is greatly reduced in the summer (JJA) to 80.4° F to 83.6° F. In the region of interest for this workshop (Divisions 4-7), the air temperatures vary most on a gradient from the coast inland, with the coast having a more mild annual range than inland. In the winter, areas along the Atlantic coast are typically 2-3° F warmer than corresponding areas on the Gulf coast because of the Gulf Stream (Henry et al., 1994), but in the summer, this contrast between the two coasts disappears.

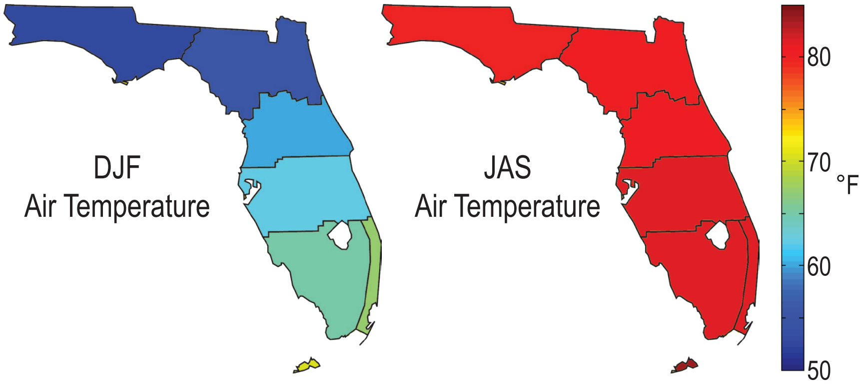

Figure 1. Three-month mean air temperature by climate division. Note the considerable winter gradient compared to nearly identical summer temperatures.

Precipitation

All Climate Divisions in Florida have a pronounced wet season (Nov-Apr) and dry season (May-Oct). However, the seasonality is reduced in Divisions 1 & 2 where only 55% of the total rain comes during the wet season, compared to Divisions 5 & 6 that receive 71% of their precipitation during the wet season (Figure 2).

Rainfall in southern Florida is also notoriously patchy in both distribution and quantity on any given day. The patchy nature of precipitation has important implications for some parts of the ecosystem, and also impacts the strength and position of the seabreezes by cooling the ground in the area of precipitation (Henry et al., 1994). Most of the precipitation in South Florida is the result of atmospheric convection. The convection drives the seabreezes onshore in the daytime from the

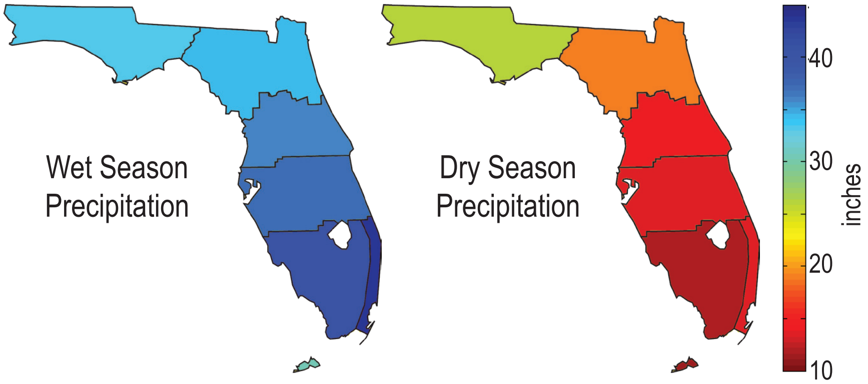

Figure 2. Comparison of wet vs. dry season precipitation by climate division. There is a significant difference between Divisions 4-7 during both wet and dry seasons.

opposing Gulf and Atlantic coasts (Henry et al., 1994), and the strength of that convection and resulting seabreeze is critical to rainfall location across the peninsula. In fact, Division 7 has much less wet season precipitation than Division 6 (752 mm vs. 1,099 mm, respectively) because of the lack of land for generating the convection needed for a seabreeze.

Hurricanes

Because of its peninsula, Florida, and particularly South Florida makes an easy target for tropical storms and hurricanes. In the North Atlantic, tropical cyclones rotate counter-clockwise and often begin their formation as tropical waves near the Cape Verde Islands off the west coast of Africa. The wave becomes a tropical storm when there is a closed surface circulation, and maximum one-minute sustained winds are in the range of 39-73 mph (72-135 km/hr), and at speeds above that is classified as a hurricane. Landfalling tropical cyclones can impact South Florida and the Everglades in a variety of ways, including property destruction, excessive precipitation, erosion of shorelines, and transport of nutrients. Detailed information on recent and historical storms back to the mid-1800s is available on NOAA's hurricane database (HURDAT).

Despite media excitement about linear trends in hurricane frequency that became popular since the busy tropical cyclone seasons of 2004 and 2005 (15 and 28 storms, respectively), there is no evidence to support long-term linear trends in activity. Instead, hurricane and tropical storm research indicates that activity varies on multidecadal time scales (Goldenberg et al., 2001; Landsea et al., 1999).

Changes Since the Late Holocene

Since the Late Holocene there appears to have been a general wetting of South Florida (Bernhardt and Willard, 2009; Willard et al., 2006), as well as the establishment and strengthening of the modern-style ENSO events (Donders et al., 2005; Rodbell et al., 1999). Paleohydrologic indicators strongly suggest that the increases in winter precipitation over the last 5 ka have been driven by this strengthening of ENSO teleconnections in Florida (Donders et al., 2005). Strengthening of ENSO events over the last 4-5 ka, and large century-scale variations in precipitation from 3.8 and 2.8 ka are also supported by evidence from the Cariaco Basin, despite indications for regional drying trends there over the last 3-4 ka due to inferred southward migration of the Intertropical Convergence Zone (ITCZ) (Haug et al., 2001). Evidence from Florida and Caribbean lakes suggests century-scale variability in frequency or position of landfalling major hurricanes, which could be explained by gradual shifts in the mean longitudinal position of the Bermuda High over the last 3 ka (Liu and Fearn, 2000), or prolonged periods of increased ENSO strength (Donnelly and Woodruff, 2007). There is no evidence of a millennial-scale linear increase or decrease in hurricane activity in South Florida during the late Holocene (Donnelly and Woodruff, 2007; Mann et al., 2009).

Climate Indices and Teleconnections

The inherently complex relationships of climate are often simplified by creating indices that highlight certain predictable associations (e.g., El Niño-Southern Oscillation, Atlantic Multidecadal Oscillation, North Atlantic Oscillation, Tropical North Atlantic Index, etc.). The forcing that the associated mechanisms of a given index may have in an area geographically removed from the source area are referred to as teleconnections. The impact of El Niño-Southern Oscillation (a Pacific phenomenon) on South Florida precipitation is an example of a teleconnection.

Atlantic Multidecadal Oscillation (AMO)

The AMO is a measure of North Atlantic sea surface temperature (SST) anomalies between the Equator and 70° N. After applying a 10-year moving average to eliminate seasonal and annual variability, the AMO index represents a multidecadal oscillation of North Atlantic SST of about ±0.2° C with a period of 60-70 years (Enfield et al., 2001). AMO warm (+) phases occurred during 1860-1880 and 1940-1960, and cool (-) phases during 1905-1925 and 1970-1990 (Enfield et al., 2001), with the most current warm phase beginning ~1995 (Figure 3).

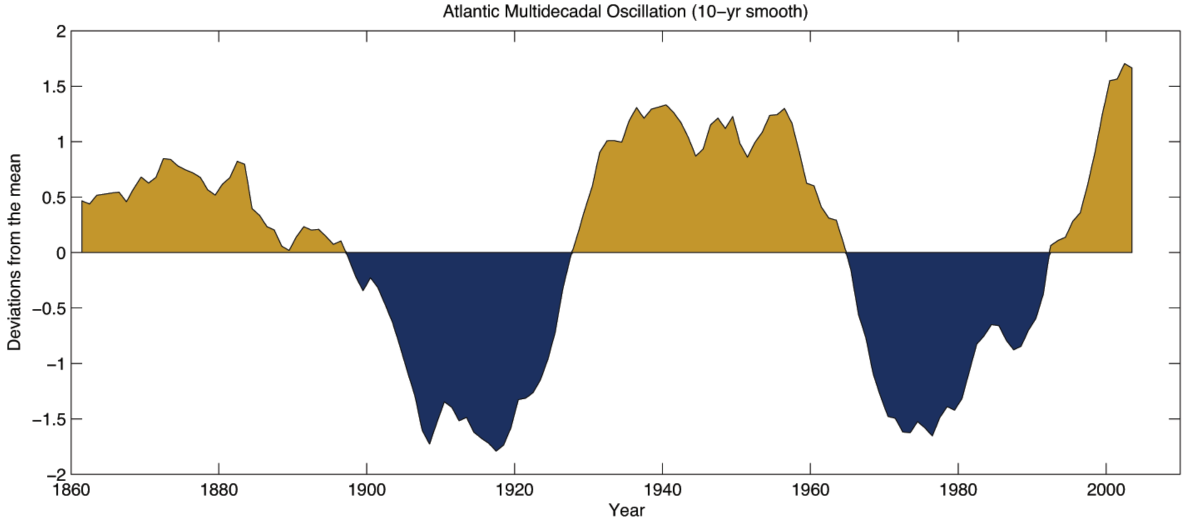

Figure 3. The AMO Index illustrated using a 10-yr running mean.

Enfield et al. (2001) demonstrated a strong positive correlation between the AMO and Division 4 rainfall (measured as outflow from Lake Okeechobee), with weaker positive correlations in Division 5. These relationships indicate that during multidecadal periods of warmer than average SST in the North Atlantic, there is typically a proportional increase in precipitation in Division 4 & 5.

The instrumental record extends the AMO back to the 1850's (Enfield et al., 2001), and reconstruction from tree rings scattered around the northern hemisphere suggest a coherent multidecadal cycle in North Atlantic SST back as far as 1567 (Gray et al., 2004). However, there is difficulty in predicting the next change of phase for the AMO, despite the substantial implications it may have for South Florida (Enfield and Cid-Serrano, 2006).

El Niño-Southern Oscillation (ENSO)

ENSO is the periodic oscillation in the strength of winds across the equatorial Pacific, which is reflected by corresponding changes in SST in the eastern tropical Pacific. During the El Niño (La Niña) phase, trade winds in the Pacific are relaxed (strengthened) and the eastern tropical Pacific SST is warmer (cooler) than normal (Diaz et al., 2001; Trenberth, 1997). ENSO events generally occur with a period of 2-7 years and last 9-18 months (Figure 4). During El Niño phases, precipitation is increased in South Florida during the dry season, but remains unaffected during the wet season (Diaz et al., 2001; Donders et al., 2005; Enfield, 1996). This influence of an El Niño (warm) phase event increases the overall annual precipitation in the Everglades during that period.

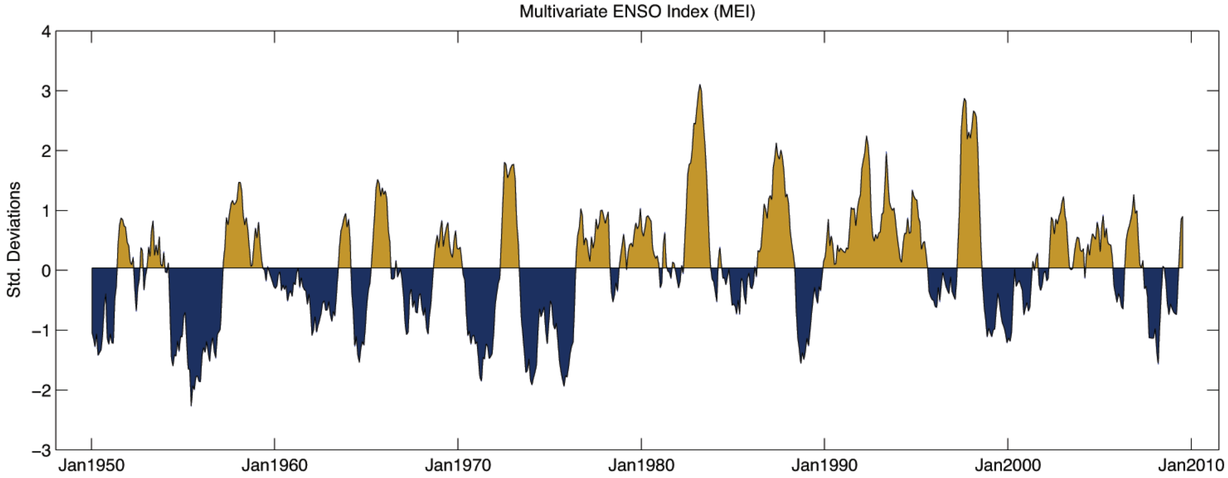

Figure 4. The Multivariate ENSO Index (MEI) illustrates the major ENSO events during the last ~60 years.

Workshop Discussions and Conclusions

After a series of presentations during the morning (see Appendix A), the group was divided into two break-out groups for the afternoon. One group focused on data and analysis needs for capturing paleoclimate and ecological variability during the Late Holocene, including the instrumental period. The other group described critical climate and ecological needs in the context of modeling and prediction. The break-out groups were provided with the following questions to answer regarding their respective topics:

- What are the issues, disagreements, paradoxes, and points of contention that are associated with the break-out group topic, relative to South Florida?
- What is the information needed to better understand the break-out group topic in a management context for South Florida?
- What research programs, designs and collaborations can best address items the answers to the previous two questions?

Paradoxes and Gaps

Paleoclimate and Instrumental Period

Not listed in order of importance, paradoxes and gaps identified by this group included:

- The lack (or apparent lack) of any "long-term" ecological archives;
  - Specifically this refers to the fact that a lot of data over various periods does exist, but the records are not connected or collected in a place where they can be easily found and studied.
  - The biological community needs to be more informed about, or attentive to, potential relationships between ecological systems and climate variability.
- Confusion between climate *change* and climate *variability*;
  - Many managers and scientists, and especially the media, who are not climatologists are focused on climate change – a more or less unidirectional process of change (e.g., the media version of global warming).
  - In reality, many climate drivers are periodic over relatively long time scales (e.g., the AMO, hurricane frequency) and short term observations of an increase or decrease in a given index may not actually reflect the behavior of the system on time scales relevant for management decisions.
  - In many cases, the evidence for climate *change* versus climate *variability* is not well established because of a lack of evidence and a poor understanding.
- Poor agreement on the existence or non-stationarity of the AMO in the pre-instrumental record;
  - The most widely cited pre-instrumental record of the AMO is that of Gray et al. (2004) which is based on tree ring records from around the northern hemisphere. However, other studies, such as Kilbourne et al. (2008) provide some evidence of a different pattern of SST variability during the pre-instrumental period.
  - Additionally, there are concerns about the differences in the regional expression of the AMO. For example, Gray et al. (2004) did not sample any trees from Florida to establish their pre-instrumental record of the AMO… perhaps a local proxy would provide a more applicable record?
- A need for a Florida centric climate data center;

    - While national and international climate databases do exist, searching for locally relevant data can be difficult.
- Design of long-term monitoring of ecology and environment to detect climate variability;
    - Many currently (growing) data sets are not optimized, or even useful, to resolve climate variability. This includes spatial positioning, temporal resolution, and types of data being collected.
    - For example, precipitation data is collected around South Florida, but there is a lack of data on certain aspects of climatically variable rain water chemistry (e.g., nitrate content, particulate content) that are ecologically relevant.
- Lack of physical oceanographic and coastal data;
    - Data on SST, currents, circulation, salinity, etc., most of which is readily available through various NOAA outlets, is often not considered when evaluating terrestrial evidence of climate variability in South Florida.

Modeling and Prediction

Not listed in order of importance, paradoxes and gaps identified by this group included:

- Difference in spatial or temporal resolution between many proxies and the AMO;
    - Many proxies record data that is only relevant at one geographic location, while effects of the AMO are generalized over entire climate divisions in Florida. Other proxies have temporal resolutions or lengths of record that are inappropriate for analysis of the AMO with cycles of 60-70 years.
    - The spatial and temporal limitations of proxies must be well understood to incorporate that proxy data into models.
- Land-use effects;
    - Many land-use effects are poorly understood and are not well or consistently represented in models.
- Problems with data that drives the general circulation models (GCMs) used to set boundary conditions for the higher-resolution models applied to South Florida;
    - Specifically, there are limitations with how GCMs handle gaps in data during World War II, changes in aerosol content due to industrialization, and other known data issues.
    - It should be noted that issues with GCMs are beyond the scope of this workshop since their focus is at broader spatial scales than this workshop.
- No monotonically increasing temperature of precipitation trend in South Florida over the last 100 years;
    - Many of the GCMs used to initiate the boundary conditions for local South Florida models incorporate Intergovernmental Panel on Climate Change (IPCC) scenarios that indicate monotonically increasing temperatures.

    Since this disagrees with certain evidence from South Florida, it calls into question the accuracy of models based on certain IPCC scenarios.

    - There is a general lack of consensus on future climate scenarios. If every model is based on different IPCC or local scenarios, then direct comparison of the predictions is often difficult.

- Source-sink contraindications;
    - Many times the source (e.g., precipitation) for groundwater or surface water occurs in a different region or model cell than the data that was collected at the sink (e.g., river outflow, etc.) for the purpose of study. This creates a gap between what was empirically measured and what needs to be modeled.
    - This condition creates a problem where the observed/modeled net inputs to a system do not equal the observed/modeled net outputs from the system.
- The scale of GCMs is inappropriate for South Florida;
    - Some GCMs have such coarse resolutions that all of South Florida is calculated as shallow ocean, others recognize land, but are too coarse to model the essential seabreeze.
    - We need better regional-scale predictions of climate variability and sea level rise.
- Model uncertainties are high;
    - The uncertainties of model inputs are fairly high, so the uncertainties in the model predictions (outputs) are substantial, making predictions difficult to be trusted for management decisions.
    - Uncertainties include:
        - ice-dynamics
        - “conveyor belt” changes (i.e., global ocean circulation patterns)
        - sea level rise
        - hurricanes (frequency and severity)
        - land-sea interactions and associated buffering capacities and feedbacks
        - “tipping points” for the climate system
        - temperature effects on evapotranspiration
        - carbon budgets and nutrient budgets
- The paleoclimate data used to model conditions do not always agree;
    - As indicated in the synopsis of Late Holocene climate records (Saunders), the evidence from various proxies does not always tell the same story. This presents a challenge for modelers to determine the “most correct” interpretation, or results in differing model predictions if different paleoclimatic

    scenarios are used.
    - We need better temporal resolution (ideally annual or interannual) in paleoclimate records to be able to resolve interannual and decadal climate variability.
    - We need a better overall understanding of historical climate and ecological data and trends.
- Regional-scale predictions for South Florida precipitation and temperature can be highly variable;
    - We need to focus energy on improved down-scaling techniques, better model culling, and improved modeling of teleconnections.
- Hydrologic extremes are poorly understood or accounted for;
    - The frequency and distribution of hydrologic extremes (e.g., tropical storm precipitation, drought, etc.) are difficult to predict. These events can be essential for ecosystem functioning, but often appear as random outliers in data sets.
- Poor predictive ability for management decisions based on predicted shifts in the phase of decadal scale climate drivers;
    - The AMO is known to influence South Florida climate. If managers need to produce a 50-year plan, our ability to predict the occurrence and duration of changes in the phase of the AMO is very limited. Enfield and Cid-Serrano (2006) demonstrated some methods for predicting the next AMO phase shift, but that needs to be improved on for management purposes.

Next Steps

Neither break-out group had time to complete the third task of identifying specific experimental designs or collaborations that will improve the problems that were identified. However, the two groups made common inroads toward advancing the state of our understanding. Perhaps the most significant development from the break-out groups was a recognition of the need for the periodic continued meeting of the group assembled for this workshop. The participants in the workshop represent diverse fields of study that otherwise seldom interact, but in this case they are geographically linked by their studies in South Florida and topically interconnected by their need for various scales of climate understanding or prediction. Many participants suggested developing informal working groups focused on resolving specific gaps that were identified during this workshop. Participants, and in particular C. Moses, will work to coordinate and analyze available climate-relevant data sets across institutions for the purpose of advancing FCE-LTER and SFWMD understanding of climate variability.

Online Resources

- Workshop homepage.
  - http://fcelter.fiu.edu/about_us/workshops/2009_10_30_Climate/
- Workshop agenda.
  - http://fcelter.fiu.edu/about_us/workshops/2009_10_30_Climate/agenda_20091028.pdf
- Workshop presentations.
  - http://fcelter.fiu.edu/about_us/workshops/2009_10_30_Climate/presentations/
- Suggested References.
  - http://fcelter.fiu.edu/about_us/workshops/2009_10_30_Climate/critical_reading/
- This report.
  - http://fcelter.fiu.edu/about_us/workshops/2009_10_30_Climate/fce_climate_workshop_report.pdf
- FCE-LTER climate data for South Florida.
  - http://fcelter.fiu.edu/data/climate/

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Appendix A: Workshop Agenda

Past, Present, and Future Climate Change Drivers and Everglades Restoration

October 30, 2009

Organized by FIU Florida Coastal Everglades LTER

South Florida Water Management District

West Palm Beach, Florida

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Workshop Objectives:

1. Define the critical issues that can improve our understanding of intradecadal to multidecadal climate in a management framework for South Florida.
2. Identify existing gaps in understanding of climate change drivers in South Florida.
3. Promotion of scientific collaborations between Federal, State and local institutions addressing impacts of intradecadal and multidecadal climate on the South Florida region.

Friday, October 30, 2009

8:00 Coffee and muffins -- Atrium

SFWMD Building B1 Auditorium

8:30	Fred Sklar (SFWMD)	*Welcome, introductions, and workshop goals*
8:40	Dave Enfield (NOAA)	*Long-term climate changes & their impact on Florida*
9:05	Chris Landsea (NOAA)	*The recent active hurricane period: Natural variability or global warming induced?*
9:30	Jayantha Obeysekera (SFWMD)	*Climate change and water management*
9:55	Rob Burgman (RSMAS)	*Modeling variability in the tropical Atlantic*

10:20	Coffee Break -- Atrium	
10:35	Colin Saunders (SFWMD)	*South Florida climate over the last 5,000 years: inferences from paleoecological studies*
11:00	Peter Swart (RSMAS)	*Climate variability from corals and sclerosponges in South Florida over the past 600 years*
11:25	Evelyn Gaiser (FIU)	*Ecological response to climate variability in South Florida during the instrumental period*
11:50	Discussion	
12:30	Lunch -- SFWMD cafeteria (on own)	

Afternoon break-out groups

1:30	Reconvene in auditorium to prepare for break-out groups	
1:40	Group #1	*Needs for understanding paleoecological and paleoclimate variability during late Holocene and instrumental period (Building B1; Room 2B)*
1:40	Group #2	*Critical climate and ecological modeling & prediction needs (Building B1; Room 3A)*
3:15	Coffee Break -- Atrium	
3:35	All groups	*Group presentations and discussions of gaps and promotion of future research avenues*
5:30	Adjourn	

Appendix B: Workshop Participants

Name	Affiliation	Specialty	Phone	Email
Anderson, Bill	FIU	High resolution proxy records	(305) 348-2693	andersow@fiu.edu
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