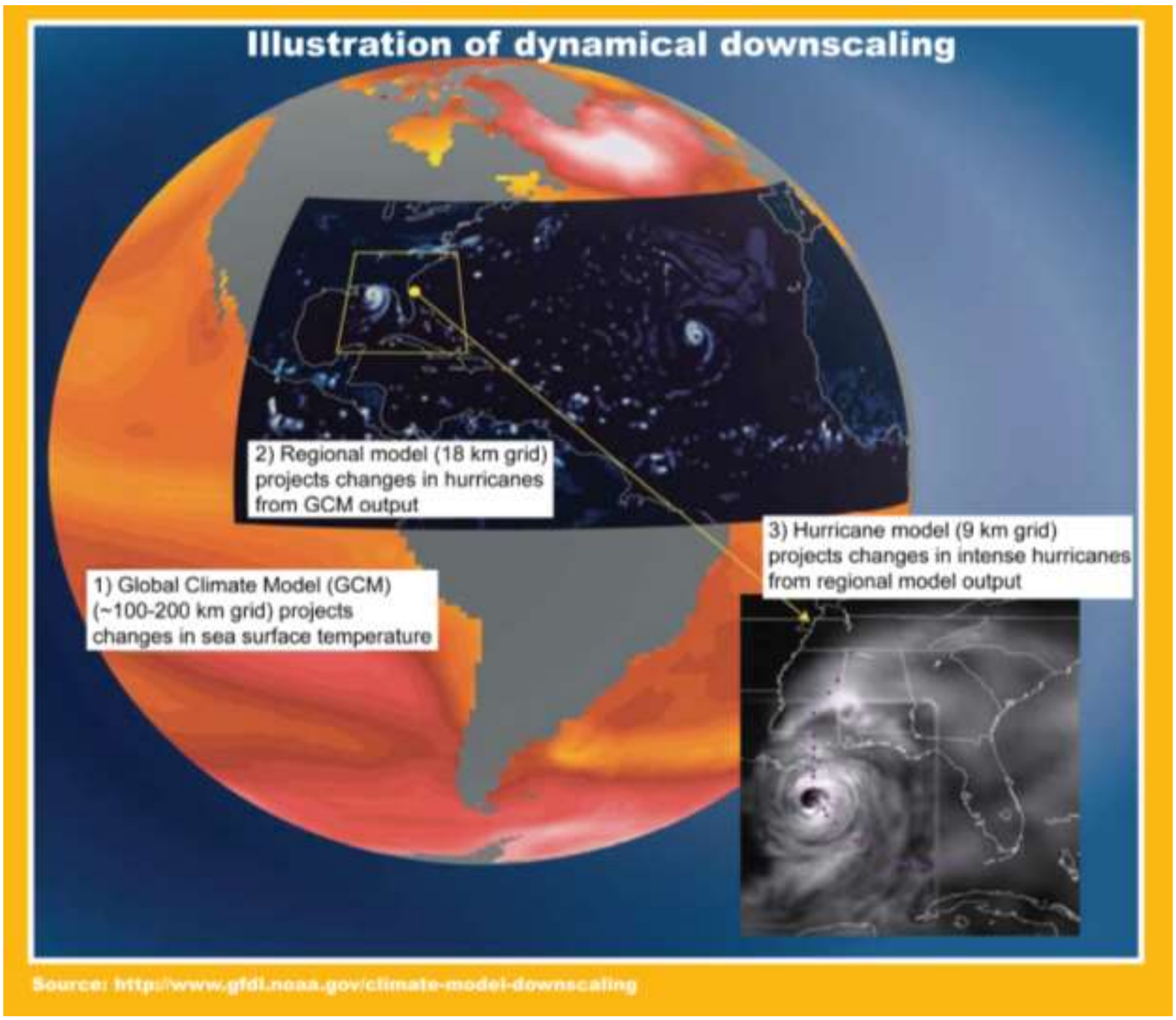
USGS-FAU Precipitation Downscaling Technical Meeting

Monday June 22 & Tuesday June 23, 2015

Florida Atlantic University Davie Campus



FAU
FLORIDA CENTER FOR ENVIRONMENTAL STUDIES
Charles E. Schmidt College of Science
Florida Atlantic University

USGS
science for a changing world

Sea Grant
Florida

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USGS-FAU Precipitation Downscaling Technical Meeting

Monday June 22 & Tuesday June 23, 2015 ▪ FAU Davie Campus

www.ces.fau.edu/climate_change/downscaling

Executive Summary

The spatial resolution of General Circulation Models (GCMs) is too coarse for accurately characterizing future climates for a landmass as small as Florida. Therefore "downscaling" techniques are needed to translate the coarse-scale projections to the smaller spatial extents of interest to Florida's environmental scientists, managers, and other users of climate model output. Yet the user community is largely unaware of how the downscaling process works. Moreover, the climate modelers are generally unaware of how their GCM output could be tailored to improve environmental analysis and decision-making in Florida.

Seventy-four scientists, managers, and policy-makers gathered at the Florida Center for Environmental Studies (CES) in Davie with the goal of communicating the state-of-the-art in downscaling science such that potential users (e.g., ecologists, hydrologists, managers, decision-makers) of downscaling results will better understand the nature of the output. That way, the users will feel more confident that the downscaling output is salient, credible, and as accurate as possible for their applied needs. In turn, these interactions will help the producers of the downscaling improve the utility of their products. The primary emphasis was on improving models of Everglades precipitation; other climate parameters and study areas were also discussed.

The two-day meeting was structured to facilitate an ongoing exchange between the producers and users of downscaling data. On the first day, the meeting started with a brief foundation on current downscaling methods and results, both globally and specific to Florida. Next, members of the GCM output user community described their needs with respect to spatial resolution and other model features. Finally, a panel of climatologists responded to the stated user needs in light of what is feasible to produce in the coming few years. The climatologists agreed that most of the presented user needs could be realistically addressed relatively quickly, if the necessary resources and collaboration networks were available. On the second day, the participants self-divided into two groups to focus on prioritizing which specific needs deserve immediate attention from funding agencies. The two groups focused on tailoring GCM output to 1) hydrological models primarily centered on the region's water conveyance infrastructure and policy demands, and 2) ecological models primarily centered on the Everglades and associated restoration questions.

This report describes the event, feedback, and recommendations for future directions. A brief overview is followed by more detailed explanations of overarching themes that arose from the conversations. Finally, evaluation results are shown to reflect overwhelming satisfaction with the relevance and credibility of the speakers and content. Participants felt that the goals were reached and that the knowledge exchange successfully laid the groundwork for productive future collaboration to fill gaps related to climate projections for environmental analysis and decision-making in Florida.

1. Description of Event

The meeting objectives below shaped the intentions of the event.

Meeting Objectives

- **Climate modelers/downscalers will:**
  - **(a) inform other scientists and decision-makers what downscaling products are feasible today**
  - **(b) learn from other scientists and decision-makers what downscaling products are desired such that future downscaling efforts may be tailored to 'user' needs.**
- **Participants will imagine a future RFP that integrates downscaling, ecological issues, and/or water management**

The website www.ces.fau.edu/climate_change/downscaling was created for the event to provide information, the agenda, and the presentations. The agenda and participant list can be accessed in the appendix.

Meeting Structure

- **Downscaling 101: Connecting producers and users of downscaled climate data**
- **Downscaling 201: Downscaling issues, considerations, and projects in Florida**
- **User community discussion**
- **Climatologists respond panel**
- **RFP drafting/writing**

2. Background: Downscaling 101 & 201

2.1 Downscaling 101: Making Climate Forecasts Matter

In referencing the 1999 National Research Council (NRC) report, Dr. Colin Polsky presented the basic challenge for modeling of future climates as one of remaining vigilant that users' information needs are supported by the models' output. One way in which user needs are often not met is in the spatial resolution of the model output: models typically characterize climate for a large area, but stakeholders typically demand information for their local settings. Polsky then introduced the classic statistical downscaling method as entailing two main steps. First, derive a fine-scale transfer function, for example, between observed circulation-humidity and observed precipitation. Then, apply the fine-scale transfer function to output from a coarse-scale General Circulation Model (GCM). The advantage of statistical downscaling is that it can be conducted quickly. In addition, it circumvents some of the difficult aspects of the models and parameterization, such as clouds. The downside is that it assumes stationarity, i.e., that the statistically estimated relationships will hold under a changed climate.

Statistical Downscaling - A transfer function comparing observed variations
Dynamical Downscaling - Embedding a higher resolution model within a GCM

2.2 Downscaling 201: Distinct weather regimes and synoptic states

Dr. Michael Mann explained that ideally, the sorts of results one would use to inform stakeholders would be robust with respect to how the downscaling is conducted. Self-organizing maps (SOMs) are one statistical means of parsing large-scale atmospheric information into component synoptic weather systems. This approach is location-specific; for example, what are the basic weather patterns to be expected for a place like Florida? Real-world data is input to the model, and gaps are filled with a fuzzy clustering algorithm using empirical synoptic states. The distinct synoptic weather regimes are applied to National Centers for Environmental Prediction (NCEP) reanalysis data.

Dr. Michael Mann

Dr. Ben Kirtman argued that there is no uniform approach on how to downscale global models. The method used should depend on the application being considered, whether for decision-making or further modelling of physical processes. Statistical and dynamic modelling are often presented as competing and conflicting approaches. In fact, many climate modelers do not argue about whether dynamical or statistical downscaling is better. Instead, it is preferable to consider combining methods into a toolbox that produces credible and accurate output. One might even consider using different methods for different seasons.

Dynamical downscaling involves using global model output (relatively coarse-scale) as the partial input to a regional model (relatively fine-scale). Thus as improvements in computational power lead global models to operate with finer spatial resolution, the spatial resolutions of the regional models are also improving.[1] This dynamical approach has the advantage of explicitly capturing the physics associated with changing energy budgets, unlike the more black-box statistical downscaling approach. But the dynamical downscaling carries the challenge that the embedded regional models cannot correct any errors in large-scale forcing embedded in the global models.

Dr. Ben Kirtman and Ph.D. student Johnna Infanti introduced the North American multi-model ensemble (NMME)[2], a collaborative experimental multi-model forecasting system with coupled climate models from a range of North American Forecasting centers.

[1] Recent developments leading to smaller grid size also include running climate models on volunteer home computers distributed around the world (e.g., Climateprediction.net). See also Mote, Philip W., Myles R. Allen, Richard G. Jones, Sihan Li, Roberto Mera, David E. Rupp, Ahmed Salahuddin, and Dean Vickers (2015) "Superensemble regional climate modeling for the western US." *Bulletin of the American Meteorological Society*.
[2] www.cpc.ncep.noaa.gov/products/NMME/

NMME is currently used as guidance for operational NOAA Climate Prediction Center (CPC) forecasts. The benefits of using a multi-model system such as NMME is prediction improvements, and vast amounts of data available to provide a statistically reliable probabilistic forecast. NMME became operational July 1, 2015 with plans to run through to July 2018. Leading up to the operation, two phases were required. Phase-1 began in 2011 and integrated models' experimental real-time and hindcast predictions[3]. Phase-2 attempted to make the daily atmospheric and land surface fields available for real-time predictions as well.

Results from the hindcasts and other sources for data access and availability include:

- Phase 1 Hindcasts:
  - Hosted through the International Research Institute Data Library http://iridl.ldeo.columbia.edu/SOURCES/.Models/.NMME/
- Phase 2 Hindcasts:
  - Hosted through Earth System Grid www.earthsystemgrid.org/search.html?Project=NMME
- Realtime Forecast Anomalies (FTP):
  - ftp://ftp.cpc.ncep.noaa.gov/NMME/realtime_anom/
- Users Guide:
  - www.cpc.ncep.noaa.gov/products/NMME/users_guide.html

Scientists interested in running a regional model using NMME input as the boundary conditions can contact the forecasting centers for help finding the necessary input data. The Community Climate System Model 4.0 (CCSM4) is a coupled climate model consisting of atmosphere, ocean, land surface, and sea ice components. It provides real-time and hindcast data available as part of NMME Phase-2, and highlights a collaboration between University of Miami (RSMAS), the National Center for Atmospheric Research, and the Center for Ocean Land Atmosphere Research. In the southeastern United States, hindcast skill was tested using anomaly correlation, which involves measurement of the quality of a forecast system by correlating forecasts and observations[4]. One CCSM4 case study tested forecasting skills for land-based precipitation during a range of El Nino events from 1982 to 2009. Results were applied to accurately predict below normal rainfall in 2007 using the CCSM4 hindcasts.

Dr. Ramesh Teegavarapu (Florida Atlantic University) discussed statistical downscaling in terms of understanding issues with precipitation extremes, the Atlantic Multidecadal Oscillation (AMO), El Niño/Southern Oscillation (ENSO), and spatial variability[5,6]. These issues are vital when designing models to project the precipitation variability, teleconnections and trends associated with climate

[3] Kirtman, B. P. et al. (2014) The North American Multimodel Ensemble: Phase-1 Seasonal-to-Interannual Prediction; Phase-2 toward Developing Intraseasonal Prediction, Bull. Amer. Meteor. Soc., 95(4), 585–601

[4] http://old.ecmwf.int/products/forecasts/guide/Measure_of_skill_the_anomaly_correlation_coefficient.html

[5] Ramesh S. V. Teegavarapu, Aneesh Goly and Jayantha Obeysekera (2013) Influences of Atlantic Multi-Decadal Oscillation on Regional Precipitation Extremes, Journal of Hydrology, 495, 74–93.

[6] Ramesh S. V. Teegavarapu and Anurag Nayak (2015) Evaluation of Long-term Trends in Extreme Precipitation: Implications of Infilled Historical Data and Temporal-Window based Analysis, Journal of Hydrology.

change[7]. Another main issue is the propagation of uncertainties in hydrologic simulation and determination of climate change-sensitive hydrological design[8].

3. User community discussion

Dr. Stephanie Romañach (USGS) led a discussion on the climate model output needs of the user community. Given that climate is changing and that Florida hydrology will be affected, many important ecosystem processes will also be modified. The most important unknowns in this equation are the timing, amount, and intensity of future rainfall patterns. The discussion included an illustration of some recently-used climate model output in Florida-based ecohydrological models:

- **Precipitation**
    - **Monthly means**
    - **Precipitation in the wettest month/quarter**
    - **Precipitation in the driest month/quarter**
- **Temperature**
    - **Monthly maximum**
    - **Mean diurnal range**
    - **Max/min in warmest/coldest month**

A 'wish list' of further climate model outputs was then drafted by the group as a means for specifying additional needs and data formats. Not surprisingly, different scientists expressed an interest in having climate model output reflecting differing temporal and spatial scales. Several participants expressed an interest in having improved access to modeled extreme precipitation events. Wide support was expressed for improving the accessibility of the climate model output – the file formats are often difficult to manipulate by non-climate modelers. Participants also hoped for better constraining future flooding probabilities, and for better understanding associated future groundwater dynamics.

4. Panel: The Climatologists Respond

The climatologists responded by saying that while none of the requests appeared unrealistic, further discussions are needed to refine exactly what information stakeholders are seeking, and to clarify each model's accuracy and reliability for the end-users. To this end, even seemingly simple definitions can become challenges if not properly examined at the outset. For example, what does the term "daily" mean? Daily measures can be calculated in a variety of ways, producing a potentially heterogeneous set of statistics for what appears on the surface to be a singular concept.

[7] Ramesh S. V. Teegavarapu (2013) Floods in a Changing Climate: Extreme Precipitation. Cambridge University Press.

[8] Ramesh S. V. Teegavarapu (2013) Climate Change-Sensitive Hydrologic Design under Uncertain Future Precipitation Extremes, Water Resources Research, 49(11), 7804-7814.

Dr. Ramesh Teegavarapu, Dr. Michael Mann, Dr. Ben Kirtman & Johnna Infanti

Model limitations also need to be properly communicated. At present, for Florida, these limitations include specific uncertainties associated with sea-level rise projections, future patterns of tropical storms/hurricanes, and dynamical ocean topography changes due to a potential Gulf Stream weakening. In general terms, uncertainties can also be explored and reduced by comparing different models' results. Other uncertainty examination approaches include hindcasting (checking how well we can simulate the past helps inform how well we can simulate the future), anomaly correlation (measurement of the quality of a forecast), and multi-modeling that produces a probability distribution function of future climate conditions (e.g. the NMME climate forecasting prediction products already discussed in this report). Both climate modelers and participants stressed that uncertainties must be quantified to include in any decision support system.

Some additional notable mentions from climate modelers included:

- Some high-resolution models have tropical systems resolved, but not (yet) among the IPCC models.
- The Florida current and Gulf Stream are currently overlooked by IPCC sea-level rise projections.
- Ocean bias needs to be addressed.
- Atlantic Multidecadal Oscillation (AMO) isn't linear.
- AMO is important for Florida, and the link to rainfall is different for the north and south.
- A principal limiting factor on grid cell resolution is computational.
- Convective precipitation is not well-represented in present models.

5. Moving Forward: Breakout groups present their findings

The second day of the event started with a brief summary discussion of future needs in the various groups. It is clear that both the hydrology and ecology end-users need finer resolution GCM downscaled variables, but it is not so clear how the new data should be presented and delivered. Participants stressed how it is currently a challenge for end-users to not only find data, but to find data in a familiar format. End-users would benefit from:

- A centralized online portal for where Florida GCM output can be easily obtained
- Consistency in file types
- Consistency in procedures for calculating uncertainty
- Consistency in detailed, accurate and informative metadata that accompany GCM downscaled output data

Following this discussion, participants divided into groups to further detail the most pressing needs for downscaling output in two domains: 1) hydrological models, and 2) ecological models.

5.1 Hydrological group

The hydrological group began by confirming their needs to improve coastal resilience by improving climate data inputs to the existing South Florida Water Management Model (SFWMM). This model simulates South Florida's hydrological cycle on a daily basis using climatic data such as precipitation and evapotranspiration (ET). SFWMM users would benefit from downscaled values of these variables (50-100 yr projections of 24 hr daily values) to improve their simulations of future water shortages affecting urban, agricultural and environmental water use policies. It was stressed that additional fundamental understanding is needed to relate daily measurements of ocean boundary conditions with sea-level rise. A challenge for the climate modelers is that 5.6-11.2 mile (9-18 km) grids are currently their finest resolutions for regional downscaling, and the SFWMM requires a 2 mile (3.2 km) resolution grid. Downscaling to a 3.2 km grid is relatively straightforward to do, but before the new output is used a thorough validation exercise is required. Such an approach might be doable with funding for two full-time postdoctoral professionals, for 2-3 years, plus an institutional mechanism to ensure that the stakeholders from the various area institutions can dedicate the necessary time to interact and communicate on a sustained basis.

Following this two-day event, the hydrological group will consider arranging a meeting with potential partners, potentially to include the South Florida Water Management District (SFWMD), the Department of the Interior (DOI), the United States Army Corps of Engineers (USACE), the National Oceanic and Atmospheric Administration (NOAA), the US Geological Survey (USGS), and the Everglades National Park (ENP). To engage the potential partners it may first be necessary to produce a concept paper that adds some detail to this meeting summary report. The details would build on this group's top needs, as described in this text box:

Hydrological group's leading climate model needs:

1. Daily precipitation, at existing 3.2 km grid, for the coming 50-100 yrs, to enable the tabulation of local extreme events statistics.
    - This need appears doable now, including the necessary downscaling
2. ET & related climate variables.
    - This need appears doable now, including the necessary downscaling
3. Daily values of SLR & ocean boundary conditions.
    - Before this need can be advanced, some additional fundamental understanding is first required

5.2 Ecological group

The ecological group was looking for better climate input to their models, to permit better insight into how certain species will be impacted. Such information would help decision-makers in their efforts to support specific groups of target species, under the changing climate and other conditions.

The key pathway to this goal was to improve spatially-explicit species models (SESM). SESM allow for a rigorous assessment of the impacts of water use policies, environmental management, and climate scenarios on species and their habitats. These models use GCM output variables such as precipitation, ET, temperature, and occasionally spatially-explicit hydrological data from SFWMM. SESM would also benefit from using inputs from GCM downscaled variables (but for 1-9 month projections of daily values) to evaluate future scenarios of, for example, water shortages affecting wading birds' populations across the Everglades. It was stressed that additional fundamental understanding is needed of land and near-shore process coupling such as longer-term sea breeze patterns. In addition to GCM downscaling, another consideration that is readily available is the 100-km North American Multi-Model Ensemble (NMME). NMME is a seasonal forecasting system of coupled models from US modeling centers. The predictive quality of NMME is better than any single model, thus it would be practical to extend the multi-model to include daily fields of precipitation, temperature, and ET along with quantifying prediction uncertainty. A question similar to downscaling GCMs would be how to improve the resolution on the NMME grid. Some of these needs could likely be supported with a one-year postdoctoral fellow.

Participant Input

Ecological group's leading climate model needs:

1. Daily precipitation, < 100 km grid (1^0 x 1^0), 1-9 month forecast.
    - Doable now, but downscaling needs to be done first
2. ET & related climate variables.
    - Doable now, but downscaling needs to be done first
3. Land/near-shore process coupling (longer-term, sea-breeze).
    - Needs some additional fundamental understanding (not NMME)

6. Survey Results

Figure 1 illustrates the results from the analysis of the evaluation form, which was distributed at the event and emailed after the event. Respondents had the option to remain anonymous. Responses indicate that the meeting met its primary goal of facilitating interactions between producers and users of downscaled climate data. There was slightly less agreement that the second goal of writing an RFP was achieved. The least agreement resulted with the statement that the meeting succeeded in cataloging, describing, and critiquing of Florida examples of Global Circulation Model downscaling. The sessions that had the most positive feedback were Downscaling 101, the User Needs Discussion, and the Climatologists Respond Panel.

Participants felt most strongly that the information was relevant and applicable for research purposes, but also in the context of management and policy considerations. This increased level of salience provides support for the meeting's unique characteristics in terms of being transdisciplinary. More than 80% "strongly agreed" that "Participants were engaged and enthusiastic," which suggests that many stakeholder perspectives were successfully addressed. There was solid agreement that the nature of the conversations was solutions-oriented.

Open-ended responses included many positive remarks, some of which included:

- "This was a unique opportunity to consider both the natural Everglades and human built environments while addressing downscaling of models, and model outputs to sere users."
- "While an RFP wasn't written, specific goals and specific data sets were written with summaries of feasibility and great coordination."
- "Well-designed, efficient use of people's time."
- "A good framework was developed and steps outlined on how to engage potential funding sources in its design and completion."
- "I learned a great deal and really benefited from the networking opportunity & off-line discussions."
- "This was a great learning experience in terms of proving understanding of GCM's, their limitations, and needs of various users."
- "Outstanding workshop! There is great potential here for something big and important."

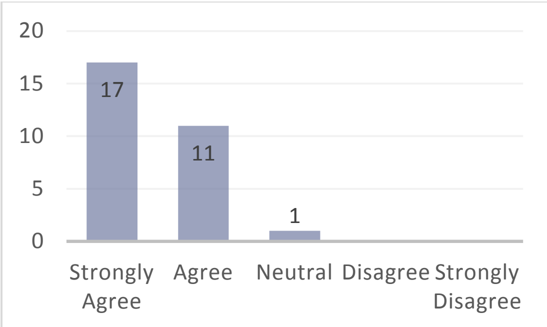
In conclusion, this meeting was informal, but in-depth. Conversations were high-level and inter-disciplinary. Attendees left with advanced knowledge of the state-of-the-science for, and potential ecological modeling and monitoring applications of, precipitation downscaling. Attendees also met potential scientific and management colleagues with whom new collaborations might be launched.

This meeting was convened by Florida Atlantic University Center for Environmental Studies, and sponsored by USGS and Florida Sea Grant. The Florida Climate Institute also lent support. (https://floridaclimateinstitute.org/)

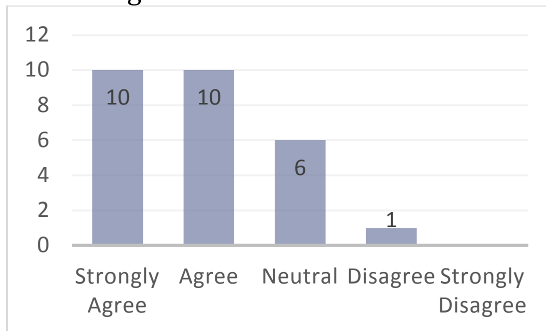
Figure 1: Survey Results for Overall Meeting goals and Overall Quality (N=22-29)

The meeting met the goals to:

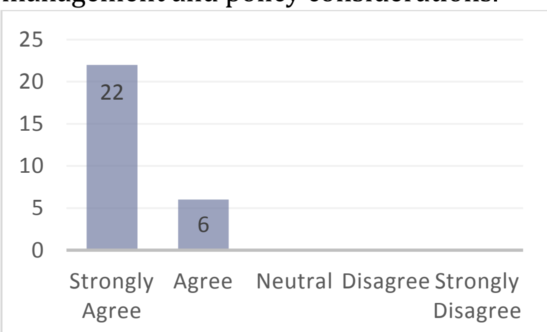
Facilitate an exchange between producers and users of downscaled climate data.



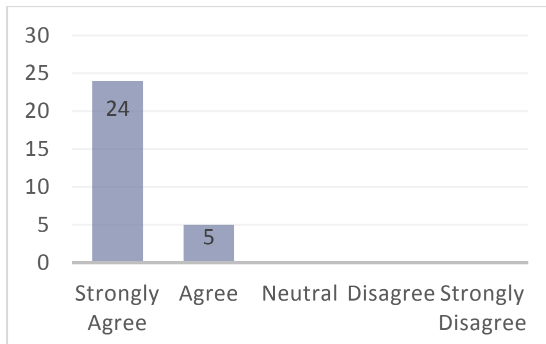
Draft a potential RFP that integrates downscaling and ecological issues.



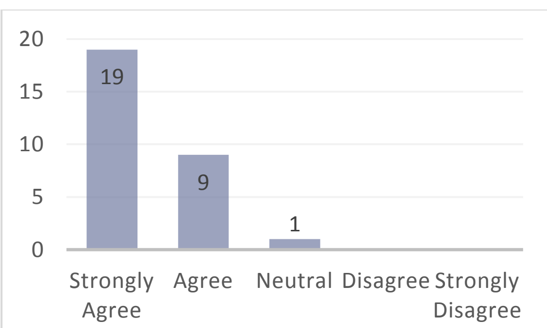
The information was relevant and applicable for research purposes, but also in the context of management and policy considerations.



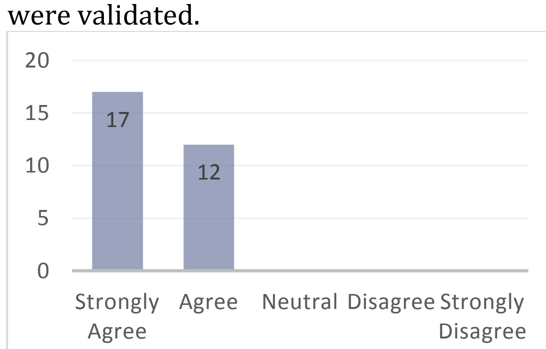
Participants were engaged and enthusiastic.



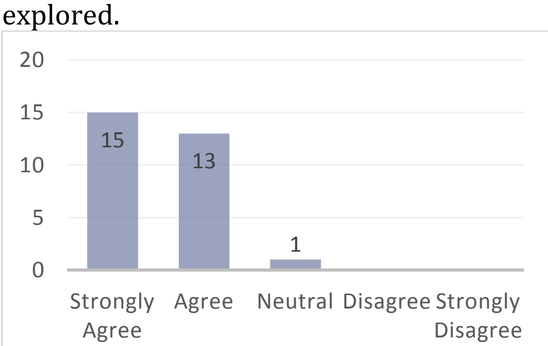
Local knowledge beyond academia was discussed.



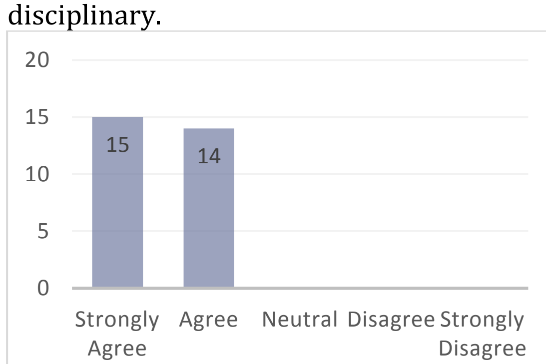
Quality of shared research was high, and methods were validated.



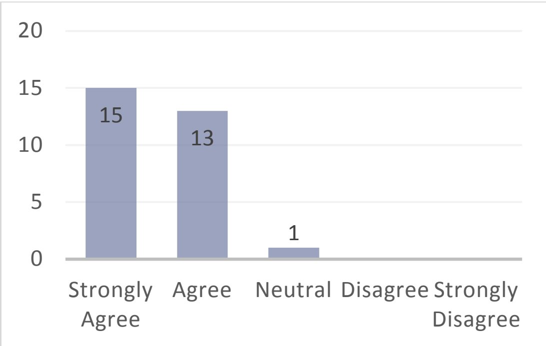
A variety of perspectives and backgrounds were explored.



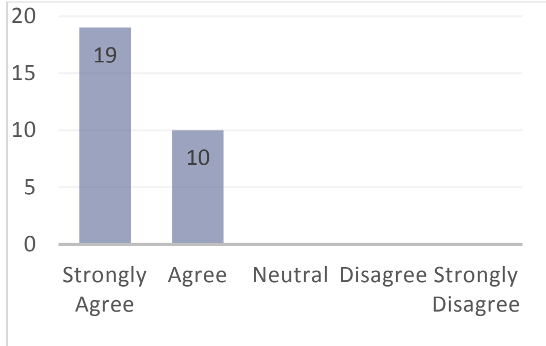
Research shared was innovative and cross-disciplinary.



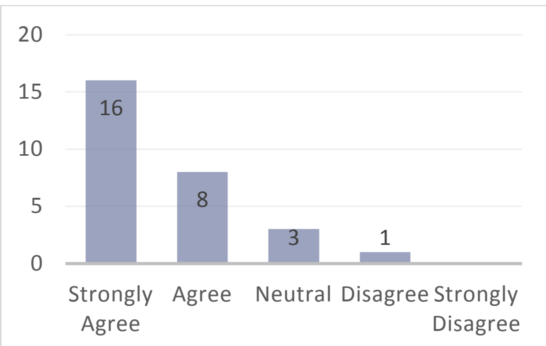
Research shared was centered on addressing specific problems.



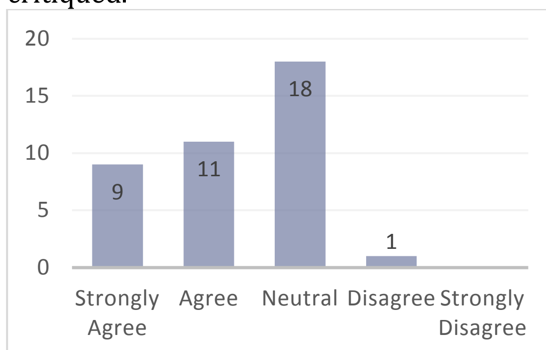
Downscaling 101 successfully linked user and producer perspectives, drawing from social science and common sense.



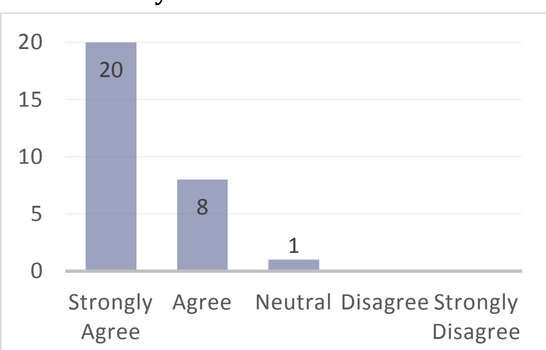
Downscaling 201 comprehensively covered dynamical and statistical modeling.



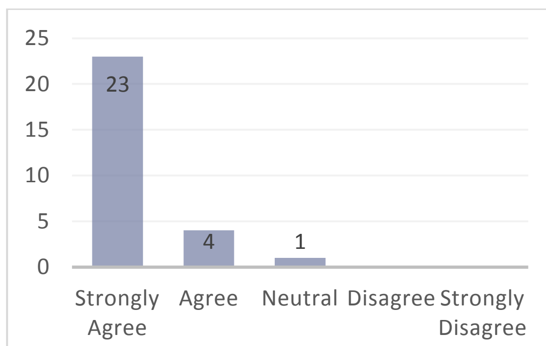
Florida examples of Global Circulation Model downscaling were cataloged, described, and critiqued.



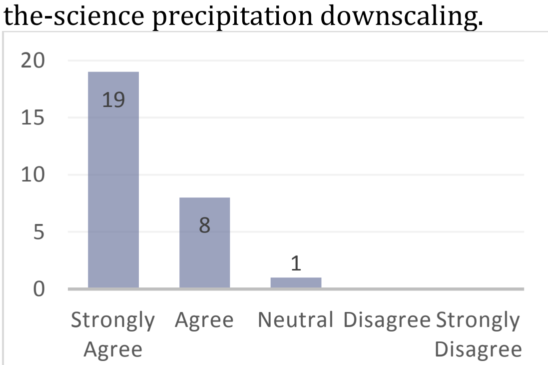
Specific input from the data user community were addressed in terms of specific climate elements would ideally be downscaled.



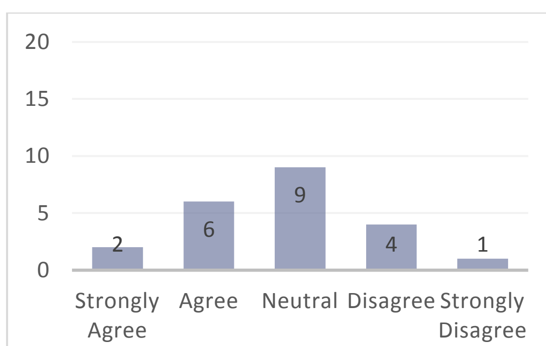
Climatologists responded in panel which described which downscaling topics appear feasible to advance over time in order to fit user needs.



We successfully advanced knowledge of the state-of-the-science precipitation downscaling.



We wrote an outstanding RFP.



Appendix A: Agenda

USGS – FAU Precipitation Downscaling Technical Meeting
Monday June 22, 2015 to Tuesday June 23, 2015
www.ces.fau.edu/climate_change/downscaling

AGENDA

Overview: This event is an opportunity for climate modelers/downscalers to (a) inform other scientists and decision-makers what downscaling products are feasible today, and (b) learn from other scientists and decision-makers what downscaling products are desired such that future downscaling efforts may be tailored to 'user' needs.

Location – This meeting will be held on the Davie Campus of Florida Atlantic University - 3200 College Avenue, Davie, FL 33314. The meeting will be held in Room 109 (Heritage Hall) in the Student Union building. www.ces.fau.edu/climate_change/downscaling/logistics.php

DAY 1

The goal of day 1 is to facilitate an exchange between producers and users of downscaled data.

09:30am – 09:40am **Colin Polsky, FAU & Nick Aumen, USGS**
Welcome & meeting goals

09:40am – 10:00am **Colin Polsky, FAU**
Downscaling 101: linking user and producer perspectives

10:00am – 11:00am **Michael Mann, Penn State**
Ben Kirtman, UM RSMAS
Downscaling 201: Statistical and Dynamical Downscaling

11:00am – 11:15am **BREAK**

11:15am – 11:45am **Johnna Infanti, UM RSMAS**
More on Dynamical Downscaling - Q&A on entire morning

11:45am – 12:15pm **LUNCH**

12:15pm – 01:15pm **Stephanie Romañach, USGS**
Input and needs from the data user community

Ramesh Teegavarapu, FAU
Statistical Downscaling of Precipitation in FL: Experiments & Observations

01:15pm – 01:45pm	**Moderator: Colin Polsky, FAU** Panel: The Climatologists Respond
01:45pm – 02:00pm	**BREAK**
02:00pm – 02:30pm	**GROUP Discussion: Imagining a future RFP that integrates downscaling with ecological and other research domains.**
02:30pm – 03:00 pm	**Plan for DAY 2 Discussion and RFP drafting/writing**
03:00pm – 04:00pm	**Networking Reception**

DAY 2

The goal of day 2 is to draft a potential RFP that integrates downscaling with other research domains.

09:30am – 09:40am	**Colin Polsky & Nick Aumen** Welcome
09:40am – 12:00pm	**Resume breakout groups from Day 1**
12:00pm – 12:30pm	**LUNCH**
12:30PM – 01:30PM	**Breakout groups present their findings**
01:30pm – 02:00pm	Reflection

Steering Committee:

- Colin Polsky, Director, Florida Center for Environmental Studies; Professor, Geosciences, FAU
- Nick Aumen, Regional Science Advisor, USGS
- John "Jay" Baldwin, Professor, Biological Sciences, FAU; Assoc. Director, Florida Center for Environmental Studies, FAU
- Ben Kirtman, Associate Dean, Professor, Department of Atmospheric Sciences, RSMAS
- Leonard Pearlstine, Landscape Ecologist, Everglades National Park
- Stephanie Romañach, Research Ecologist, USGS
- Jayantha Obeysekera, Chief Modeler, Hydrologic & Environmental Systems Modeling, South Florida Water Management District
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