Department of Geography, University of South Carolina Summer 2013

Carolinas Climate Connection

Carolinas Integrated Sciences & Assessments

Integrating Climate Science and Resource Management in the Carolinas

Focus on Climate Modeling

This edition of the Carolinas Climate Connection is formatted slightly differently from previous ones. We produced a 'Climate Modeling Information Sheet' in order to provide a general overview of climate modeling, how output is generated to produce future climate scenarios, and how models are being downscaled to regional and local levels.

Decision makers are increasingly interested in the availability of regionally or locally downscaled future climate scenarios to support their planning efforts to address the impacts of climate change. Both global and regional climate models are becoming increasingly sophisticated. Efforts to support the demand for information to inform local and regional adaptation plans are also increasing. However, understanding the intricacies of climate modeling in order to determine their suitability for adaptation planning and decision-making can be a daunting task. Despite the climatological and technical expertise required to fully understand the intricacies of climate modeling, it is possible for the non-climate modeler to use a range of future scenarios produced by climate models to make meaningful management decisions and develop adaptation strategies.

A decision making framework, adapted from Weaver et al. (2013), which uses climate model projections within a bottom-up approach to developing adaptation plans and strategies is outlined on page 6. This framework allows for more robust decision-making to address a broader range of possible future scenarios without extremely specific regional or local projections which may not be available.

We have also provided some information on how CISA is using climate models, integrated with hydrologic models, for several decision support efforts. And finally, we have provided resources to learn more about climate models as well as sources for climate model output and future climate projections for the Southeast.

Newsletter Contents

Upcoming Events

South Atlantic LCC Conservation Blueprint Design 1-Day Workshops
Raleigh, NC
October 22 & 23, 2013
Savannah, GA
November 19 & 20, 2013

2013 Environmental Health Summit
Public Health and Climate Change: Focusing North Carolina Forward
Raleigh, NC; October 29-30, 2013
Contact Martin Armes for more info

Announcements

Carolinas Climate Listserv Launched!
Click here to subscribe

Two new CISA articles published

The role of ad hoc networks in supporting climate change adaptation: a case study from the Southeastern United States

Negotiating a mainstreaming spectrum: climate change response and communications in the Carolinas

NC Sea Grant & WRRI Seek Deputy Director
Application review begins Sept. 3

NOAA Climate Program Office funding opportunity now available
Letters of Intent due Sept 10

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What are Climate Models?

How do climate models work?

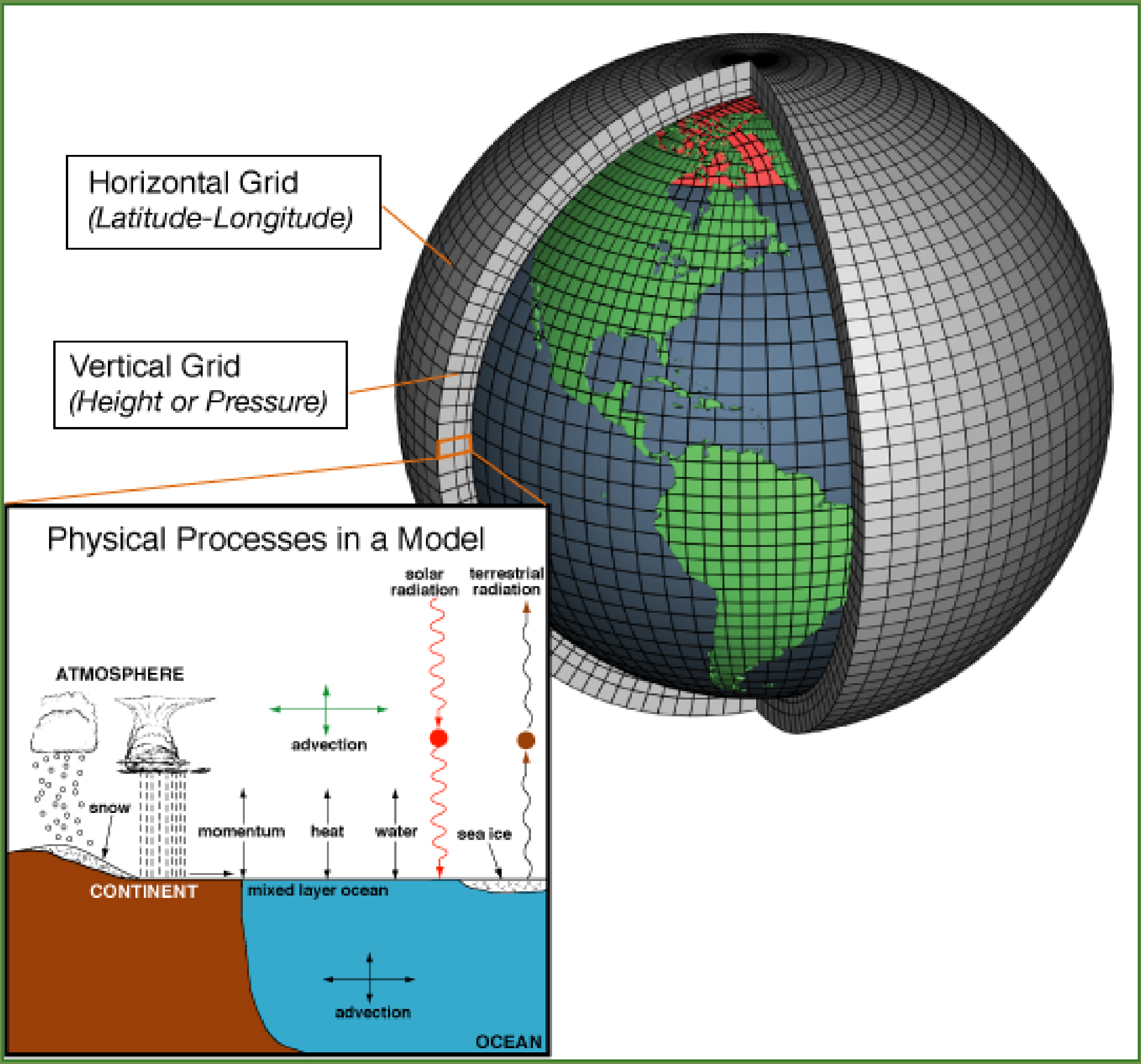
Global climate models (GCMs) use computer codes to solve mathematical equations based on our scientific understanding of the physical processes that govern the Earth's climate and model the atmosphere, oceans, land surface and sea ice.

Who develops climate models?

Climate modelers, in general, work at national meteorological services, universities, and national or international laboratories. Some of the organizations within the United States that work on the development of climate models include the National Center for Atmospheric Research (NCAR), the Geophysical Fluid Dynamics Laboratory (GFDL), and the Goddard Institute for Space Studies (GISS).

How are climate models developed?

- The building blocks of climate models are 3D grid cells, which contain climate-related information about the location within the cell.
- Physical, chemical, geological, and biological climate-related processes are represented by mathematical equations, many of which are based on physical laws such as the conservation of momentum, mass and energy. Computer code is generated from these mathematical equations, and organized by climate components such as atmosphere, ocean, clouds, land surface, sea ice, etc.
- Because the various climate components interact with one another in the real world, additional computer code is developed to allow these different components to interact within the model, both between components and from grid cell to grid cell.



Source: NOAA

Back to Page 1

Climate Model Output

Creating Future Climate Scenarios

Scientists incorporate different levels of greenhouse gas emissions into climate models to develop projections of future climate scenarios. Different projections are developed using different emissions scenarios or future greenhouse gas concentrations. Emissions scenarios provide ranges of emissions determined by factors such as population growth, energy conservation and technology, land use and development, and economic activity. When different levels of greenhouse gas emissions are input into climate models, climate variables such as temperature and precipitation are affected, changing Earth's climate system.

How have scientists used climate models to attribute increasing global average temperatures to increases in greenhouse gas concentrations in the atmosphere?

Climate modelers differentiate natural climate variability from climate trends caused by increased levels of greenhouse gases (GHGs) in the atmosphere through detection and attribution methods, which combine the observed climate record with the results of model simulations. Climate model simulations are run with GHGs at pre-industrial levels, then with GHGs at observed concentrations. Models run with pre-industrial GHG levels do not simulate the warming trends in the observed record. Therefore, the warming is attributed, in part, to increased levels of GHGs in the atmosphere.

The image below depicts various components that influence regional and local climate. Models use computer code to represent these components and their interactions.

Sources of Uncertainty in Future Scenarios

There are 3 main types of uncertainty to keep in mind when considering what models can tell us about future climate:

1. The climate system itself is extremely complex and scientists do not have perfect knowledge of all climate processes.

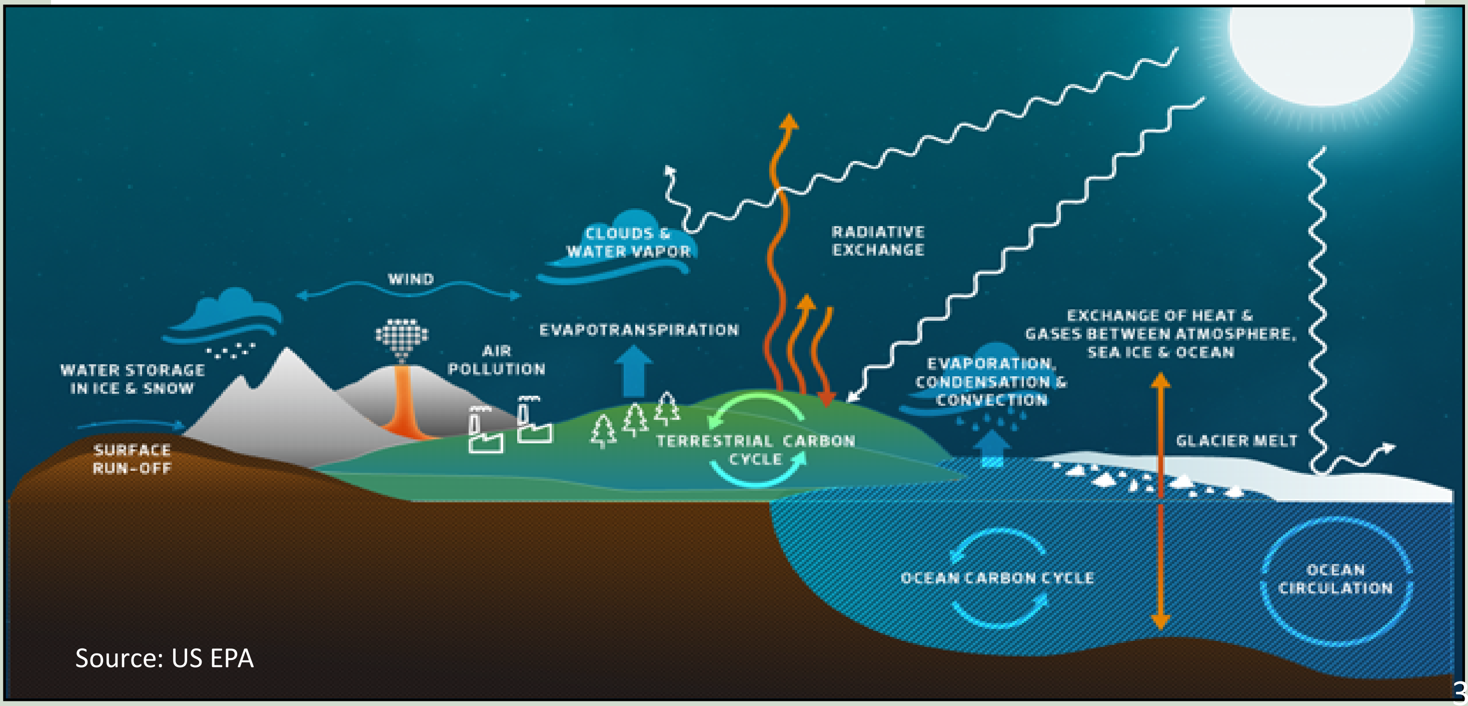
2. Human behavior and decisions will dictate future greenhouse gas concentrations in the atmosphere. Factors which can influence future concentrations include population growth, economic activity, energy technology and conservation, and land use and development. It is impossible to know what future concentrations will be, although we do know that they will influence future climate.

3. The response of the climate system to future concentrations of greenhouse gas emissions is also not fully understood. The observed record indicates a warming trend as emission concentrations have increased in the atmosphere. However, the extent to which these emissions will affect various aspects of climate, such as precipitation trends, is not known.

Why use future climate scenarios?

Despite inherent uncertainties, climate models can be very useful in understanding *a range of future climate scenarios* which can, in turn, be used to *assess risk and plan* mitigation and adaptation strategies to address potential climate change impacts.

Representative concentrations pathways (RCPs) have replaced the SRES emissions scenarios in developing future climate projections for the IPCC 5th Assessment (AR5). RCPs were developed to represent a range of radiative forcings rather than emissions concentrations, and allow climate model simulations to be developed in parallel to emissions scenario developments. The RCPs and SRES scenarios are similar and show comparable median temperatures by 2100.



Back to Page 1

Downscaling

What is 'downscaling'?

- As climate models have improved, the demand for more regional and local information on the impacts of climate change has grown.
- Decision makers who may be affected by the potential impacts of climate change need information that is at a scale suited to the resources for which they are responsible.
- Large grid scale GCMs (100km/62mi scale) are not able to represent climate processes which occur at more local scales, such as convective thunderstorms.
- Therefore, regional climate models (RCMs), which function at resolutions of 10-50km (6-30mi) and incorporate regional and local scale climate processes, are linked to the GCMs through downscaling methods.
- Downscaled climate models simulate the behavior of local processes, as well as the effects of other local interactions such as coastlines and mountains, on local and regional climate.

Are RCMs better than GCMs?

Dr. Erik Kabela's dissertation, *NARCCAP Model Assessment and Future Projections for the Southeast United States*, assessed the skill of nine dynamically downscaled regional climate models (RCMs) with respect to minimum and maximum temperature and mean precipitation.

One of the important aspects of Dr. Kabela's work included assessing the '*value added*' of the regionally downscaled climate models used in his analysis, which is *whether or not the RCMs at a resolution of 15-30 miles are better at recreating the historical climate record than the global models*. Although Dr. Kabela notes that a blanket statement that RCMs have value added is not possible, different models do show value added with respect to different climate variables (e.g. temperature, precipitation) meaning that some RCMs do better represent local climatological and topographical features than their GCM counterparts. Having the information available to show which RCMs are better at modeling different climate variables can help modelers and decision makers determine which models will provide the most meaningful future projections for impact assessment and adaptation planning.

Assessment of RCM value added was only one component of Dr. Kabela's research. Watch the presentation of his dissertation findings at the 2013 AMS annual meeting here.

Models continue to improve in their ability to replicate the climate system as downscaling techniques improve in their ability to reproduce regional and local climate processes.

How are climate models downscaled?

There are 2 basic types of climate model downscaling:

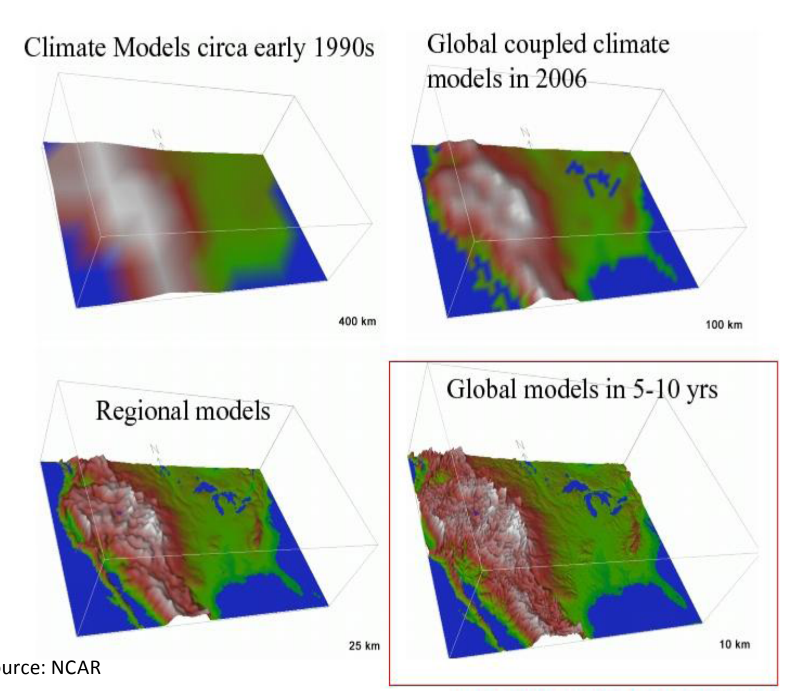
1. Statistical downscaling involves the development of empirical mathematical relationships between an observed local climate variable and the GCM variable.

- Advantages of statistical downscaling include relatively low computational costs and simple implementation.
- However, the mathematical relationships used in statistical downscaling are based on historical climate and may not represent future relationships under changing climatic conditions.

2. Dynamical downscaling uses regional climate models that are nested within and driven by global climate models.

- This is the more physically-based method of downscaling and better represents more localized geographic and climatological processes.
- However, dynamical downscaling requires quite a bit more time and computational hardware than statistical downscaling.

It is important to note that neither statistically nor dynamically downscaled climate models decrease the uncertainty inherent in large-scale global climate models, such as poor simulation of the impact of El Niño on precipitation trends in the Southeast. Additional layers of uncertainty are added to climate scenarios created with downscaled models, through the different downscaling processes. For instance, the development of convective thunderstorms is not very well understood, which makes their simulation in regional climate models difficult.



Source: NCAR

Back to Page 1

Climate Model Ensembles

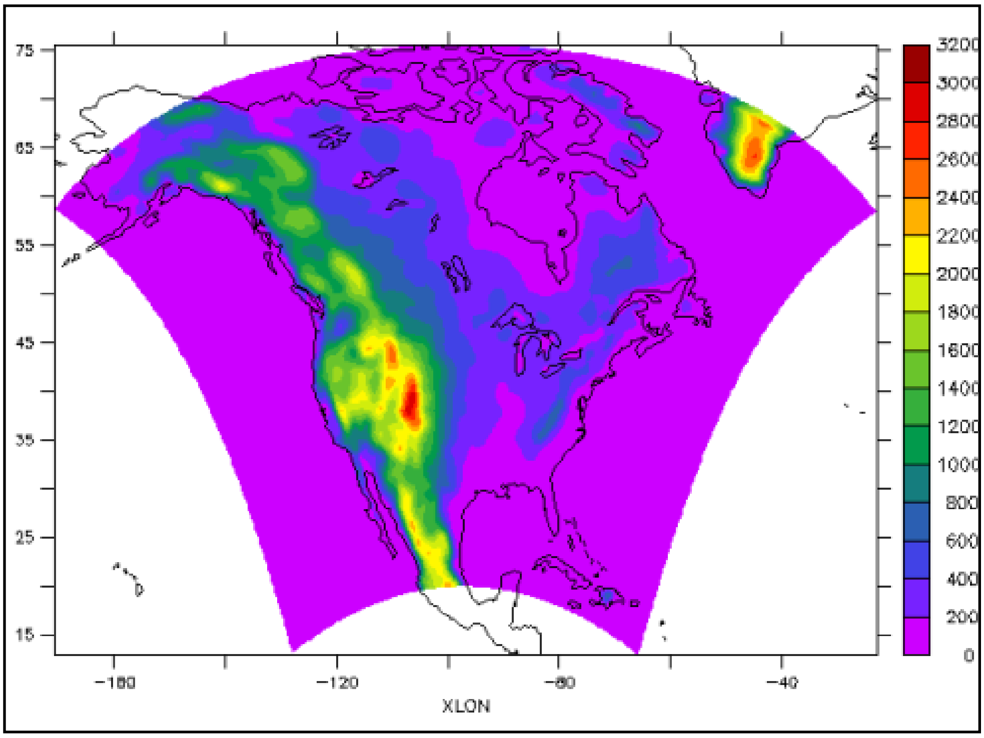
What are Climate Model Ensembles?

Climate model "ensemble" data can either be produced by multiple runs of a single model or combined simulations from several models. These model runs create scenarios based on the mean and spread of a model or multi-model projections. Ensembles are used to address some of the inherent uncertainties in climate models. By using multiple runs of one or several models, a series of plausible future climate projections is produced.

Pros and Cons of Model Ensembles

- Future climate scenarios produced by multi-model ensemble runs often outperform individual models in reproducing the historical climate record. This is because the multi-model runs overcome limitations of the single models of which they are comprised.
- However, global climate models are often developed using mathematical equations adopted from other models, so that many of them share the same or similar biases and uncertainties in reproducing some physical processes.
- The optimal number of models to include in an ensemble also poses a challenge. The number of models needed to produce a robust climate change signal is influenced by the climate variable being analyzed (e.g. temperature, precipitation), the season, and the lead time.

The image below represents the 'domain' of the NARCCAP program. The NARCCAP program uses dynamically downscaled models, which are regional climate models nested within global climate models, in order to better replicate regional climate processes. The models are run at a resolution of 50 km or about 31 miles.



Model Ensemble and Comparison Projects

Climate models take quite a bit of computational power to run. Therefore, joint efforts are underway to improve the efficiency of analyzing and improving climate models around the globe. There are several international downscaling and model comparison projects. These groups study the output of global climate models in an effort to improve model development. Some of these research groups include:

- The Coupled Model Intercomparison Project (CMIP), which is aimed at systematically analyzing global climate models in order to facilitate model improvement. Model runs include simulations for the historic period, simulations out to 2300, and past simulations for the last 1000 years. CMIP model simulations have been an integral part of the Intergovernmental Panel on Climate Change's assessment reports. The next IPCC Assessment report will be released in Fall 2013. More than 20 climate modelling groups are working on this fifth iteration of the CMIP project.
- The World Climate Research Programme sponsored Coordinated Regional Climate Downscaling Experiment (CORDEX), which is working to create a framework for evaluating and comparing different downscaling techniques used around the world. Research teams are also working to provide regional climate projections and increase the science capacity in developing nations.
- The North American Regional Climate Change Assessment Program (NARCCAP), which is an international program to produce climate change simulations at a higher resolution than global climate models (GCMs) in order to investigate uncertainties in regional scale projections of historic climate observations and future climate. The program also aims to produce regional climate change scenarios for use in impacts research.

CMIP3 and NARCCAP ensembles were used in development of the regional climate trends and scenarios technical inputs for the 3rd US National Climate Assessment (NCA). These technical inputs provide information on historical climate trends and future climate projections. The reports were used by NCA author teams to assess regional and sectoral vulnerabilities and potential climate change impacts for inclusion in the 3rd NCA report, to be released in Spring 2014.

Back to Page 1

Using a Robust Decision Framework to Incorporate Future Climate Scenarios into Decision Making & Long-Term Planning

As the ability to recreate climate processes through models improves, so too will the ability to support decision making to plan for future climate conditions. However, adaptation strategies can be developed without perfect knowledge of future conditions.

One strategy which is becoming increasingly popular in order to address climate change adaptation planning involves a bottom-up approach to decision making. Adapted from Weaver et al. (2013), this diagram represents the type of bottom-up, robust decision making framework needed to incorporate future climate scenarios into long-term planning.

Step 1: Identifying Vulnerabilities

First, potential vulnerabilities to changes in climate are identified. For example, estuarine plants and animals might be impacted by higher salinity levels during periods of drought. Stormwater infrastructure might be impacted by an increasing number of rain events exceeding 1 inch in a 24 hour period.

Incorporating stakeholder input and various perspectives regarding the utility and vulnerability of a given system is an important component of this process. For example, in developing long-term plans for reservoir management, water usage by the local water authority, as well as ecosystem needs and recreational activities, would be uses to consider when identifying potential vulnerabilities.

Step 2: Considering Future Climate Scenarios

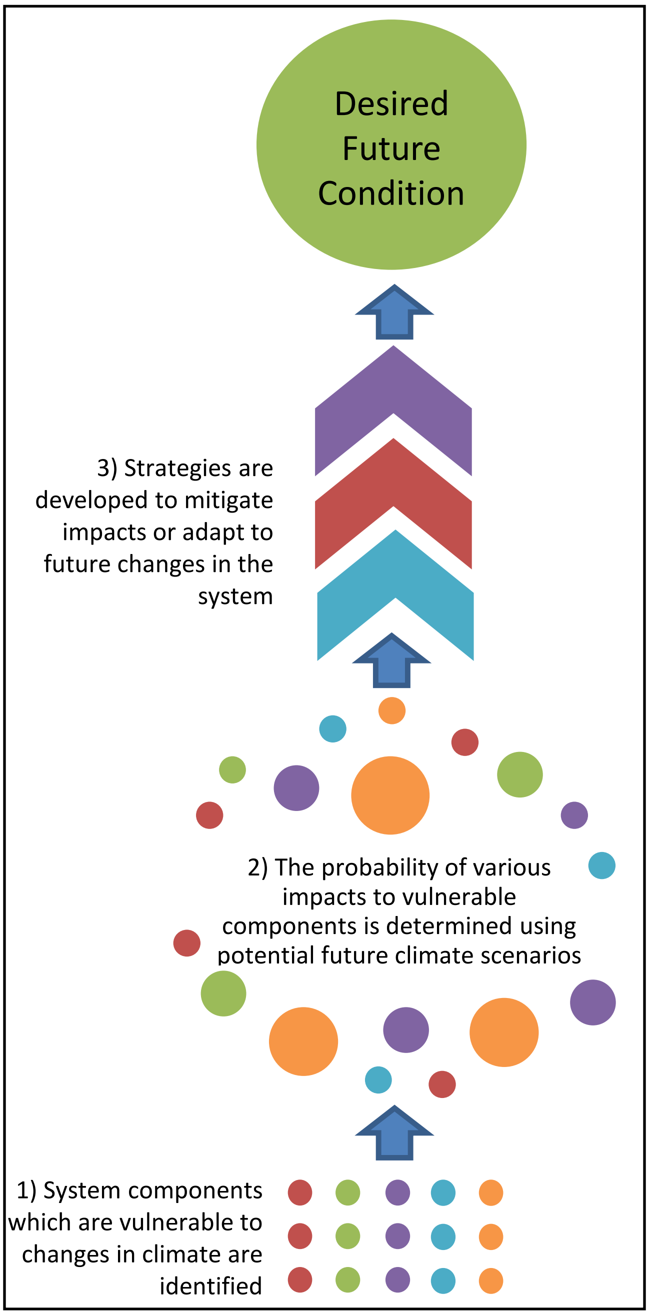
Future climate scenarios generated by climate models can then be used to determine the likelihood of changes in climate variables which would lead to unwanted impacts. Projections of changes for specific climate variables (e.g. temperature, precipitation) might be used to determine impacts to different vulnerable system components. For example, some plants might be more susceptible to changes in long-term precipitation trends than they would be to changes in temperature.

Additionally, impacts to some vulnerable components may be more or less likely under different future climate scenarios. These are represented in the diagram below by the different size circles. The bigger circles represent vulnerable components to which impacts are less likely. For example, the likelihood of a category 5 hurricane which would destroy all vulnerable structures along a stretch of coastline may be small. The smaller circles are more likely, and therefore more numerous in the diagram, but the impacts to these vulnerabilities caused by changes in climate are less severe so that these impacts can be more easily managed.

Step 3: Developing Mitigation & Adaptation Strategies

Strategies to address these impacts can be developed based on the likelihood of the impact, weighed against the costs and benefits of the adaptation strategy. A combination of strategies may be required to achieve any given desired future condition. Different strategies may address more than one vulnerability, thereby increasing that strategy's benefit when weighed against its cost. The cost of addressing some potential impacts may be too great to warrant an adaptation strategy, enabling decision makers to determine potential limits to adaptation.

In contrast to first determining a set of climate scenarios prior to identifying vulnerabilities, a bottom-up approach to understand the system first allows for flexibility in climate adaptation planning and focuses on developing resilience by determining response options for a broad range of possible future scenarios.



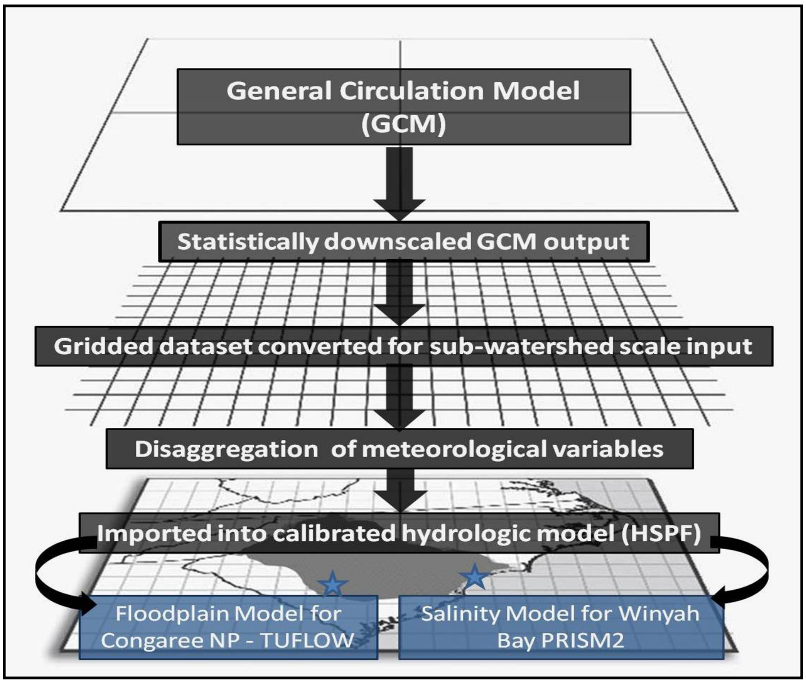
Reference: Weaver, C. R. Lempert, C. Brown, J. Hall, D. Revell, and D. Sarewitz. 2013. Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks. *WIREs Climate Change*. DOI: 10.1002/wcc.202

Back to Page 1

Using climate and hydrologic model output for decision support

CISA's work with climate models is integrated with work to improve hydrological models for use in several projects. These hydrological models address a regional need for comprehensive analysis of watersheds to understand how climate variability and change affect not only water quality and supply, but the associated impacts to water utility authorities and other stakeholders, plant and animal species, public health, and infrastructure.

The graphic below depicts the process of integrating global climate model output into hydrological models. The more regional and local information provided by hydrologic models can be used to determine impacts to plants, animals and people caused by changes in hydrology under future climatic conditions.



Integrating disaggregated climate data into hydrological models

Downscaling efforts have centered on processing and using statistically downscaled data from the Department of Interior/ United States Geological Survey (DOI/USGS) as input for several hydrological modeling projects. These downscaling efforts address the fundamental issues of disaggregating precipitation data to a local spatial scale and hourly temporal scale for input into the hydrological models. Disaggregated climate data has been used as input for several different analyses using the EPA's BASINS Hydrological Simulation Program Fortran (HSPF) model. The two projects described below used HSPF model output for decision support.

Saltwater Intrusion Impact Assessment

This project, conducted in partnership with USGS and SC Sea Grant, used the HSPF and Pee Dee River and Intracoastal Waterway Salinity Intrusion Model (PRISM) to assess the likelihood of variability in streamflow and changes to surface water salinity levels under different climate scenarios and with projected sea level rise in Winyah Bay at the mouth of the Pee Dee River. A stakeholder workshop was held to share future scenarios and consider the impact of reduced flow and sea level rise on different management decisions. Read the full report.

Assessing Potential Public Health Impacts of Climate Change in Coastal Regions of the Carolinas

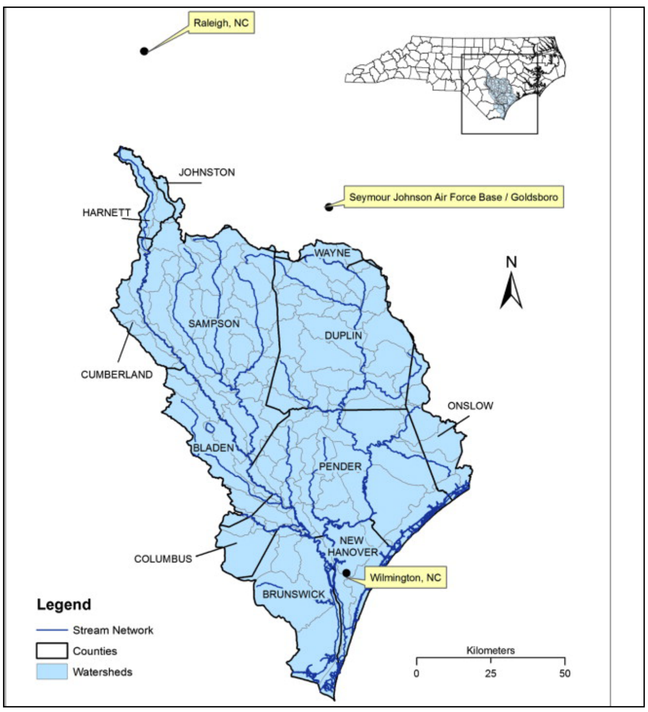
CISA researchers and collaborators at NOAA's Center for Coastal Environmental Health and Biomolecular Research investigated the influence of projected future climate scenarios on the human health threats posed by the marine bacterium *Vibrio* in shellfish. The spread of *Vibrio* is believed to be associated with changing temperature and salinity conditions. Analysis of samples taken determined the conditions in which *Vibrio* is present and at what levels. These findings were then used in conjunction with future climate projections of temperature and precipitation trends to determine the potential for increased exposure under changing salinity trends.

Vibrio vulnificus, a water-borne pathogen, causes illness when consumed by eating undercooked seafood such as oysters. Exposure can also cause infection in open wounds. Using climate projections of future temperature and precipitation trends in coastal regions of the Carolinas and associated changes in salinity, CISA researchers and collaborators are working to identify the potential for increased exposure to *Vibrio* bacteria under future climatic conditions.

Climate Impacts on Congaree National Park

Disaggregated data has also been used as input to the HSPF model, which will be used for analysis of the effects of altered river hydrology on floodplain inundation and resultant impacts to plant and animal species in Congaree National Park. One of the key objectives of this project includes producing maps of potential habitat for key indicator species at Congaree National Park under current conditions and projected future climate scenarios.

The regular flooding of the Congaree River, which flows through Congaree National Park, plays an important role in the health of the park ecosystem by carrying nutrients and sediments that support life through the floodplain in the old growth, bottomland hardwood forest.



Lower Cape Fear Watershed Study

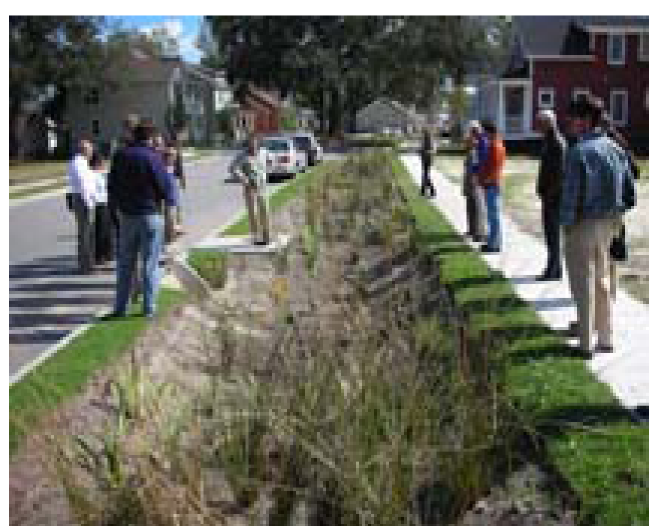
Conducted by CISA collaborators in the Department of Geography at East Carolina University, this project sought to estimate future water availability and use in the Lower Cape Fear basin using changes in climate, land use, and population growth. Researchers identified at-risk areas and evaluated water availability under various future climate scenarios. Workshops were held with groups of decision makers to work through the alternatives, impacts, and scenarios. This allowed for exploring similarities and differences in priorities and preferences among different groups of stakeholders and developing an understanding of the adaptive capacity of the region.

The map to the left shows the study area for the Lower Cape Fear Watershed project. Analysis to determine areas which may be at risk of future decreased water availability used projections of land use and development, population growth, and changes in climate which would impact the hydrology of the basin.

Incorporation of Climate Projections in a Low Impact Development Manual for SC Coastal Counties

The ACE Basin and North Inlet-Winyah Bay National Estuarine Research Reserves are currently working on the design of a low impact development (LID) manual for coastal counties in South Carolina. CISA researchers are assisting the project team in incorporating within the manaul adaptation strategies to enhance the resilience of recommended best practices against future changes in climate and sea level along the SC coastline. A workshop with stakeholders to identify vulnerabilities and potential adaptation strategies is scheduled for September 2013.

Bioswales are one stormwater management practice that may reduce flooding during potentially increased heavy precipitation events.



Back to Page 1

Climate Model Resources

Climate Modeling Resources

Designed for the non-climate modeler, the resources listed below provide training modules and tutorials on how climate models and future climate projections are developed.

Climate Modeling 101

Based on reports from the National Research Council's Board of Atmospheric Sciences and Climate, this site provides a primer on how climate models work. It also includes a list of organizations in the United States who develop climate models with links to each of their webpages where model output is available.

NOAA Geophysical Fluid Dynamics Laboratory Climate Modeling Video Series

This webpage contains several videos that provide more detail on how climate models are developed and the costs and benefits of higher resolution global climate models.

Climate Models and Scenario Development

This slideshow, developed by the Koshland Science Museum of the National Academy of Sciences and found on the EPA Future Climate Change webpage, describes how climate models are used to develop future climate scenarios.

Climate Scenario Development and Applications for Local/Regional Climate Change Impact Assessments: An Overview for the Non-Climate Scientist

Winkler et al. have published a two-part paper geared towards non-climate scientists which explains scenario development using downscaling methods and considerations for using different climate change scenarios.

Selecting a downscaled dataset

Several factors should be considered when determining which climate model projections to use for decision making and future planning.

- The ability of the model to replicate historical climate for the region and climate variable of interest is an indication of how well the model replicates regional and local scale climate processes, an important feature in assessing the relevance of future projections.
- Consider using a multi-model ensemble rather than a single model as model ensembles often outperform individual models in reproducing historical climate and overcome the limitations of individual models.
- Use a range of future scenarios, rather than one single scenario, to allow for planning for future conditions within that range and increasing the resiliency of the plan.
- Choice of emissions scenario (high or low) may be determined by the planning timescale. Cumulative emissions do not begin to generate significant changes in climate until the mid 21st century. So, shorter term decisions do not need to be as concerned about emissions scenarios. Using both low and high scenarios to produce a range of future scenarios will improve the resiliency of the plan.

Where to find regional climate scenarios

Most modeling research programs provide findings from their models on their respective websites. Although, the format in which many of these model simulations is presented is not always friendly to the non-climate modeler.

Regional projections that have been part of efforts such as the National Climate Assessment, are often presented for a more general audience and include less technical language and graphics.

The table below provides a list of several sources of accessible climate projections.

Sources of Climate Model Output	
Climate Wizard	Allows users to create maps of historic temperature and precipitation trends as well as future projections using different emissions scenarios and ensemble or individual model runs.
NARCCAP	Dynamically downscaled data covering the conterminous US and most of Canada is available at 50km (~31mi) resolution for multiple pairings of regional and global models using one of the higher (SRES A2) emissions scenario.
NCA Southeast and Caribbean Regional Climate Trends & Scenarios Technical Inputs	The Southeast region technical report used ensemble runs from the CMIP3 and NARCCAP projects to generate future projections for the region. A list of useful maps generated from the projections as well as the link to the full report can be found at this link.
Individual Model Output	Climate modeling research centers and institutions in the US, such as the Geophysical Fluid Dynamics Laboratory and the National Center for Atmospheric Research, and around the world provide free access to data generated by their models. This webpage provides a list of additional climate modeling groups in the US.

Back to Page 1