Waquoit Bay National Estuarine Research Reserve

Climate Change Vulnerability Assessment Exercise Summary Information

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Management Context

Waquoit Bay National Estuarine Research Reserve (WBNERR) is a living laboratory and regional resource at one of the Northeast's most studied estuaries. Slated for development, most of the Reserve lands were bought by the Commonwealth of Massachusetts at the urging of the Citizens for the Protection of Waquoit Bay in the early 1980s (Figure 1). In 1988, the Reserve was designated as a NERR for the purpose of studying this area in order to improve the understanding of coastal ecosystems and human influences on them. Waquoit Bay is a representative example of shallow bays throughout the Northeastern United States. (www.waquoitbayreserve.org)

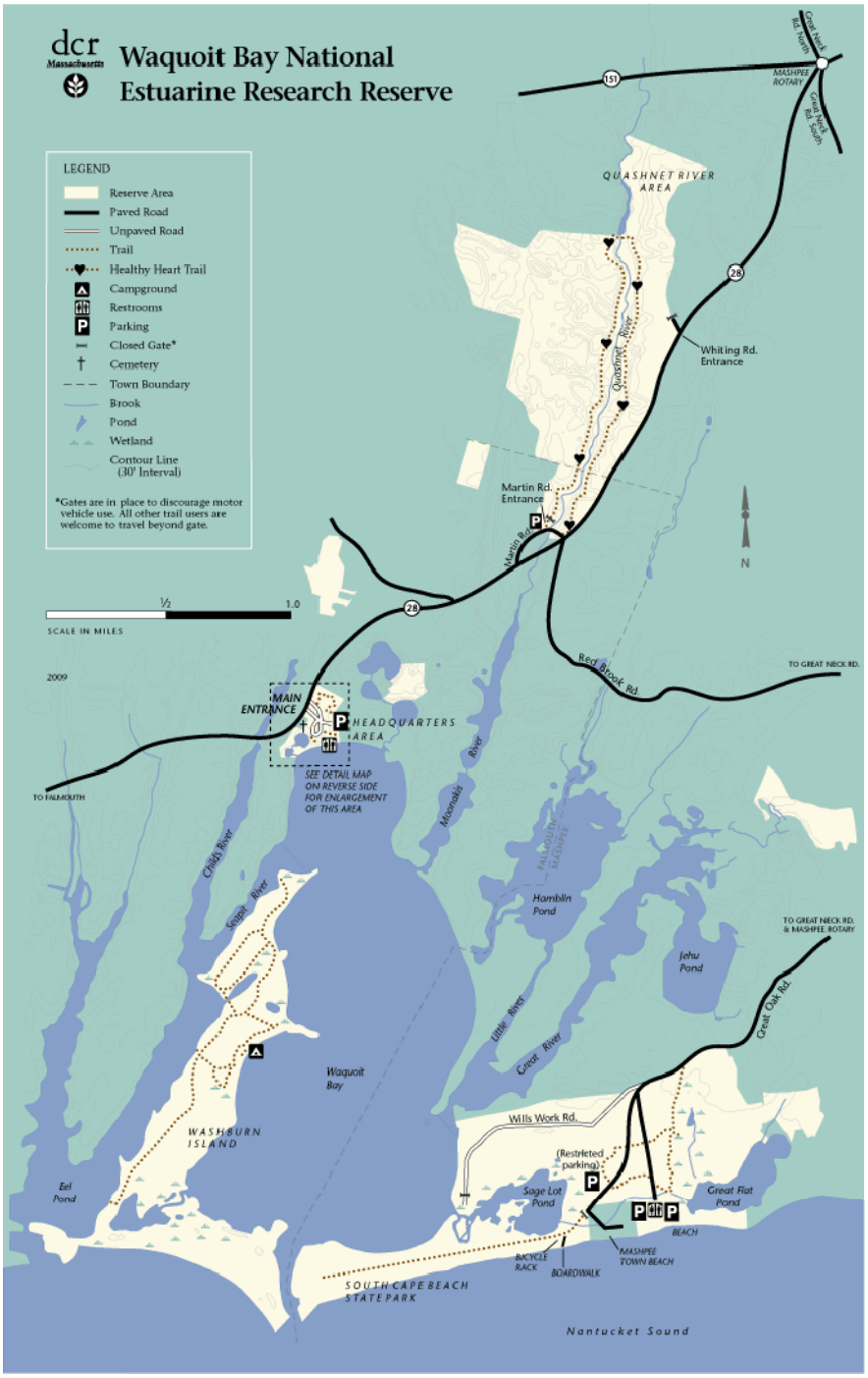


Figure 1

Jurisdictional Context

The Reserve is part of the Massachusetts State Parks system and is administered by the Massachusetts Department of Conservation and Recreation (DCR) in partnership with the National Oceanic and Atmospheric Administration (NOAA) (www.waquoitreserve.org). In 1995, the WBNERR joined in cooperation with the Massachusetts Division of Fisheries and Wildlife, U.S. Fish and Wildlife Service, the towns of Mashpee and Falmouth, Orenda Wildlife Land Trust, Falmouth Rod and Gun Club, and the Mashpee Wampanoag Indian Tribal Council to form the Mashpee National Wildlife Refuge Partnership.

The Stewardship Focus Area (SFA) is the geographic planning area identified by WBNERR that contains those lands and resources that, if altered, are likely to change (improve or degrade) the quality of resources and/or uses within the Reserve boundary. The SFA includes the designated lands and waters of the Reserve, as well as other lands outside the reserve. In particular, research at WBNERR has clearly demonstrated that changes in land use within an outside the watershed are capable of causing serious degradation within the Waquoit Bay estuary. Thus, WBNERR is concerned with land use planning throughout the Waquoit Bay watershed. However, the Reserve has no management authority over the open waters of the Bay or upstream freshwater resources. The Reserve cooperates with outside groups, including municipalities and other state and Federal agencies.

Waquoit Bay and some of surrounding uplands were designated as an Area of Critical Environmental Concern (ACED) in 1979. ACECs are places in Massachusetts that receive special recognition because of the quality, uniqueness, and significance of their natural and cultural resources. The Massachusetts DCR administers the ACEC Program and closely coordinates with the Massachusetts Office of Coastal Zone Management regarding coastal ACECs. The Waquoit Bay ACEC has boundaries nearly identical to the Reserve, mainly differing in the extent of tidal river protection. In relation to the WBNERR boundary, the ACEC includes greater extents of the Childs and Quashnet Rivers; Red Brook; Jim, Little, Flat, and Witch ponds; and a few tributaries. However, the Reserve boundary includes Great and Little Rivers and the ACEC boundary does not. The goals of the ACEC designation are achieved through the application of stricter standards under existing state regulations, through priority attention from state agencies for technical assistance, grants, or other programmatic means, and through cooperative stewardship efforts from citizens to Federal agencies. ACEC designation does not create new regulations, nor does it supersede local regulations or zoning.

Existing Mission/Goals

The mission of the WBNERR is to improve the stewardship of the region's estuarine and coastal watershed ecosystems (Valentine et al. 2005). The vision: To be recognized as a vital regional resource for expertise on sustainable coastal management provided through integrated programs of coastal ecosystem research and monitoring; management and stewardship; and education and training aimed at coastal communities, organizations, and individuals.

The Reserve's goals and objectives are as follows:

- Goal 1. Improve the understanding of coastal ecosystems and the human influences on them. The Reserve fulfills this role by providing a dedicated, stable natural ecosystem representative of the biogeographic region as a platform for scientific investigation, providing scientists with infrastructure and information that supports and guides their work, and communicating the results to coastal communities to aid their decision-making. Currently, the Reserve's Research Priority Areas are:
    - *Water Quality/Eutrophication/Watershed Land-use.*
    - *Climate Change/Sea-level Rise/Shoreline Change.*
    - *Assessment of Ecosystem Response to Natural Variability and Human* Impacts.

- Goal 2. Improve environmental literacy in our communities to enable environmentally-sustainable decision-making. The Reserve had assumed for years that providing information through courses, workshops, materials, and presentations – in other words, educating people – would result in changed behavior and lead to better coastal management. However, research and discussions have suggested that information alone does not change behavior. Rather, programs that actively engage people in explorations and problem solving over time develop participants' sense of personal investment in the issue. Therefore, the Reserve will focus more resources on longer, more involved programs that systematically present environmental literacy concepts and involve people in hands-on problem solving activities, preferably out in the field.

- Goal 3. Demonstrate sustainable stewardship of the land and water ecosystems within the Reserve to serve as a model for community stewardship in the region. WBNERR is engaged in activities to protect the land and water resources of the Waquoit Bay watershed through land stewardship zoning, regulatory mechanisms, land management techniques, the management of public access, restoration activities, efforts to acquire and protect additional lands, and strategies to exert influence over the management of waterbodies. Adaptive natural resource management on the Reserve is guided by results of research conducted by the Reserve and elsewhere and is shared throughout the community through education and training. The Reserve also serves a role as a model of resource management practices for similar coastal lands in the region. Activities fall under several categories:
    - *Land Management*.
    - *Public Access Plan.*
    - *Ecological Restoration Activities.* Habitat restoration at WBNERR is intended to improve the ecological integrity and biogeographical representative character of the Reserve, provide additional habitat for threatened and endangered species, and address information gaps in the science of habitat restoration.
    - *Land Acquisition.*
    - *Marine and Freshwater Resources.*
    - *Modeling Conservation Practices*.

- Goal 4. Foster dialogue and development of coastal ecosystem management solutions through sustained community engagement. Activities in support of the preceding three goals – understanding coastal ecosystems, improving environmental literacy, and demonstrating sustainable stewardship – will ultimately be judged successful if they motivate local communities to increasingly take responsibility for the development of solutions to coastal ecosystem management issues. WBNERR's role in this context is to foster community action that is consistent with – and may even shape – state and Federal coastal management agencies.

- Goal 5. Improve the operations, infrastructure, and stature of the Reserve. The administration of the Waquoit Bay NERR supports and enables the implementation of the Reserve's principal functions: research and monitoring, education and training, and stewardship.

Management in the WBNERR is based on DCR's Land Stewardship Zoning Guidelines to consistently direct land management policy on Reserve lands. The three zone designations guide the level of activity allowed in various areas of the Reserve and assist Reserve staff with balancing research, education, and recreation activities with resource protection by restricting inappropriate activities and directing higher impact activities away from sensitive areas.

Ecological Context

The Waquoit Bay Reserve on Cape Cod Massachusetts is composed of open waters, salt and fresh marshes, barrier beaches, sand dunes, rivers, mixed pine and oak forests, and sandplain grasslands (www.waquoitreserve.org). The more than 2,700 acres of aquatic and terrestrial habitat in the Reserve are representative of the New England portion of the Virginian biogeographic province. The Reserve also includes approximately 1,359 acres of estuarine waters, several freshwater ponds, tributary streams, vernal pools and substantial groundwater resources beneath its lands. The lands and waters of the Reserve support a range of fish and wildlife species and provide valuable recreational activities, including fishing, birding, swimming, boating, windsurfing, and kiteboarding.

Key Habitats

- Pine Barrens. Pitch pine/scrub oak (*Pinus rigida*/*Quercus illicfolia*) barrens occur on dry, acidic, nutrient poor, well drained soils in the Waquoit Bay watershed and other coastal outwash plains. Examples of pitch pine/scrub oak barrens are found throughout the reserve. Typically, a dense understory of scrub oaks and huckleberry (*Gaylussacia baccata*) grows beneath the pitch pines and excludes other plants. Often patches of lowbush blueberry (*Vaccinium augustifolium*), bearberry (*Arctostaphylos uva-ursi*), sweetfern (*Comptonia peregrine*), or lichen grow in the open spaces between oaks. This pine barren community has adapted to occasional fires for its maintenance as nutrients, generally scarce in the poor soils, become more available in the ashes of a fire.

- Sandplain Grasslands. Sandplain grasslands are open, treeless grasslands on dry, sandy soils. These grasslands are found in areas of glacial deposits in southeastern Massachusetts, including Cape Cod and the Islands, and a few places in Connecticut. Prairie grasses are the dominant species of these grasslands. Bird's foot violet (*Viola pedata*), which grows extensively on the Sargent Estate within the Waquoit Bay Reserve, is an indicator of sandplain grasslands. A large population of New England blazing star (*Liatris scariosa* var. *novae-angliae*) inhabits Washburn Island. This species is listed as a Species of Special Concern in Massachusetts. The federally endangered sandplain gerardia (*Agalinis acuta*) is also found within the Reserve. The Reserve uses mechanical methods of prescribed fire to control natural succession and restore sandplain grassland habitat on Washburn Island and at the headquarters site.

- Open Water/Eelgrass Beds. Waquoit Bay, with an area of approximately 825 acres, is the dominant feature of the Reserve. With a maximum depth of 8.9 feet and mean depth of 2.6 feet, the shallow bay is warmer in the summer and colder in the winter than neighboring Vineyard Sound. Salinity ranges from 0 parts per thousand (ppt) in the upper reaches of rivers to about 32 ppt in the open Bay. Eelgrass (*Zostera marina*) covered extensive areas of the Waquoit Bay estuarine complex until recent decades when disease and Eutrophication caused rapid declines in abundance and distribution (Figure 2).

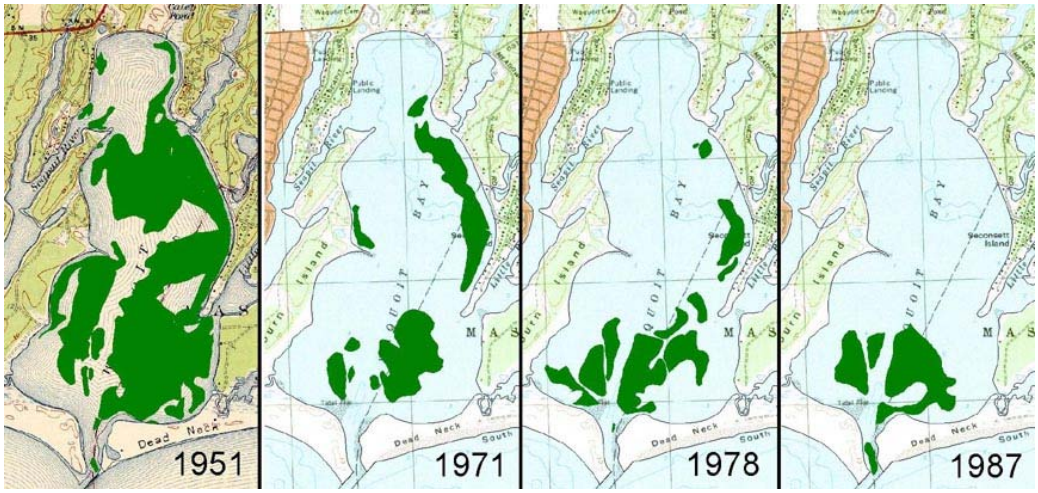


Figure 2

- Salt Marsh. Approximately 300 acres of salt marsh are located within WBNERR, mainly around Hamblin, Jehu, and Sage Lot ponds, at the head of Great River, along the shores of Washburn Island, at the head of Waquoit Bay and Eel Pond, and at the mouth of the Childs and Moonakis rivers. Cordgrass (*Spartina alterniflora*) is a primary foundation species in New England salt marshes because of its ability to build marsh peat through biogenic binding of sediment and to ameliorate physical and abiotic stresses that would otherwise limit other marsh species (Holdredge et al. 2008). Recent significant die off of cordgrass in Cape Cod has been attributed in part to increased grazing pressure by the native, nocturnal burrowing crab *Sesarma reticulatum*. This species has increased in abundance due to a decline in primary predators such as tautog (*Tautoga onitus*), a fish that primarily feeds on intertidal invertebrates, black-crowned night herons (*Nycticorax nycticorax*), and blue crabs (*Callinectes sapidus*).

- Estuarine Channels, Tidal Creek and Riverine Habitats. Estuarine channels and tidal creek habitats link the open bay environment to the smaller, more tidally restricted salt ponds and their associated salt marshes. Their beds are primarily sandy mud with a layer of macroalgae growing over the bottom. They are home to ribbed mussels (*Geukensis demissa*), blue crabs (*Callinectes sapidus*), and lady crabs (*Ovalipes ocellatus*). The Quashnet River, which stretches from the Bay to John's Pond in Mashpee, is an important migratory run for alewife (*Alosa pseudoharengus*) and trout (*Salvetinus fontinalis*), and white perch (*Morone americana*) have also been seen in the area.

- Beach and Sand Dunes. About 2.5 miles of beach and sand dunes extend along the southern shore of Washburn Island and South Cape Beach. A portion of the barrier beach at South Cape Beach State Park is used for public recreation. The balance is undeveloped and supports a diverse community of species. On the limited-access Washburn Island, beach plants grow in profusion.

- Freshwater Wetlands. The freshwater wetlands of the Waquoit Bay watershed are rich in plant and animal species. At South Cape Beach, freshwater marsh species include the common cattail (*Typha latifolia*) and reed grass (*Phragmites australis*) as well as twig rush (*Cladium marascoides*) and water lily (*Nymphaea odorata*). Patches of bogs have such species as sheep laurel (*Kalmia augstifolia*), sweet gale (*Myrica gale*) and *Sphagnum* sp.

Key Fish and Wildlife Species

- Birds. There are two species of concern on Reserve property: the piping plover (*Charadrius melodus*) and the least tern (*Sterna antillarum*). The Federal government lists the piping plover as a threatened species of shorebird. Piping plovers presently nest in limited numbers on South Cape Beach and the beach at the southern end of Washburn Island. Because their eggs are laid on the ground and are well camouflaged, they are often accidentally damaged or destroyed by human actions. Nests on the ground also make the eggs easily accessible to predators. Numerous other shorebirds appear in abundance in the spring and fall on Waquoit Bay's barrier beaches, including: black-bellied (*Squatarola squatarola*) and semipalmated (*Charadrius semipalmatus*) plovers; sanderlings (*Crocethia alba*); dunlin (*Calidris alpina*); semipalmated (*Ereunetes pusillus*), least (*Pisobia fusicollis*), and western sandpipers (*Pisobia minutilla*); ruddy turnstones (*Arenaria interpres*); willets (*Cataptrophorus semipalmatus*); lesser (*Totanus flavipes*) and greater (*Tringa melanoleuca*) yellowlegs; and short-billed dowitchers (*Limnodromus griseus*) (U.S. EPA 2002).

- Fish. The open waters of the bay once supported one of the most diverse estuarine fish communities in the state. These waters are still significantly important to commercial and recreational shellfish and fin fish fisheries. About 30 species commercially harvested spend part of their lives or visit Waquoit Bay estuarine waters (www.eoearth.org). Of note are American eel (*Anguilla rostrata*), rainbow smelt (*Osmerus mordax*), winter flounder (*Pseudopleuronectes americanus*), blueback herring (*Alosa aestivalis*), striped bass (*Morone* saxatilis), sea-run brook

trout (*Salvetinus fontinalis*), scallops (*Argopecten irradians irradians*), and blue crabs (*Callinectes sapidus*). The area also provides important habitat for the shortnose sturgeon (*Acipenser brevirostrum*), which is the only federally endangered freshwater fish species in New England.

- Other Notable Species. The reserve is home to a number of protected plant species, including the federally-endangered sandplain gerardia (*Agalinis acutus*) (Figure 3), bushy rockrose (*Helianthemum dumosum*), thread-leaved sundew (*Drosera filiformis*), New England blazing star (*Liatris borealis*), butterfly-weed (*Asclepias tuberosa*), and little ladies tresses (*Spiranthes tuberosa*).

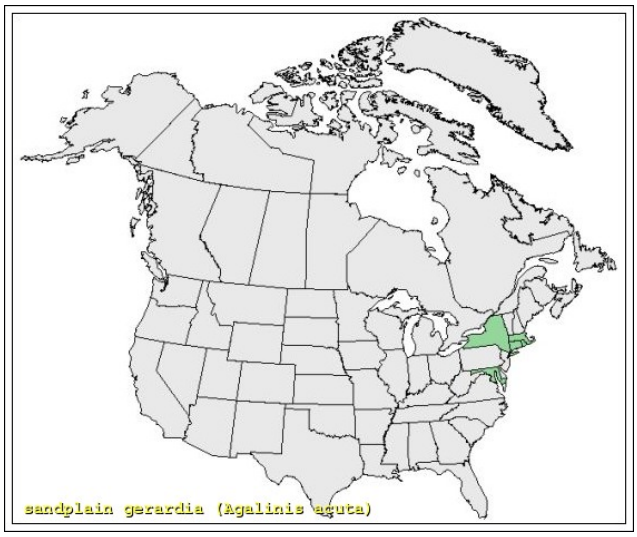


Figure 3

Key Ecosystem Processes

- Tide Range and River Flow. (Source: www.eoearth.org). The morphology of Waquoit Bay is like that of other New England coastal bays, which typically feature asymmetric-shaped bays, fringing marshes, fronting barrier spits or beaches and inlets. The amount of water that enters and exits the bay is determined by the magnitude of the tides as well as by the morphology of the Bay and its inlets. Tidal range of Waquoit Bay is about 0.6 meters. As a Cape Cod embayment, Waquoit Bay is unusual in that it is fed by two sizeable rivers – the Childs and Quashnet – entering Eel Pond and Waqouit Bay, respectively. Fifty percent of the freshwater entering Waquoit Bay comes from these rivers. Groundwater is another major contributor of freshwater to Waquoit Bay. The rivers themselves are groundwater-fed; groundwater enters the rivers through the sediments and through springs in embankments along the floodplain.

- Fire. The Reserve's pine barren and sandplain communities are adapted to occasional fires, which help restore nutrients to soils. Some selected thinning and prescribed fire has been conducted in parts of the Reserve to help maintain fire-dependent habitats, maintain low forest fuel, and prevent catastrophic fire. In addition, these burns have served as training for fire response crews in southeastern Massachusetts. Experimental burns are also considered important to attempt to determine how the state-listed New England blazing star – and the whole island community – respond to different types of fire events (i.e., sustained hot fires vs. periodic, less intense fires).

- Marsh Processes. Research indicates that stochastic events related to beach formation and inlet dynamics are the major factors influencing the development of the Waquoit Bay tidal marshes, where tidal exchange is limited to one or two small inlets (Orson and Howes 1992). This is in contrast to nearby marshes, such as at Barnstable Marsh, where direct unrestricted exchange with Cape Cod Bay has smoothed the effects of stochastic events on vegetation development. In Waquoit Bay, vegetation development appears to be dominated by abiotic factors (e.g., storms, sedimentation rates, etc.).

Existing Threats/Stressors

- Eutrophication. Eutrophication is the most significant issue affecting the Waquoit Bay ecosystem. Continually increasing nitrogen loads from wastewater, fertilizer, and atmospheric sources have led to drastic shifts in estuarine habitats. Eelgrass habitat, critical to fish and shellfish communities, was once plentiful. It is now completely missing from the main Bay and is disappearing from the few subembayments where it remains. In addition to eelgrass loss, Eutrophication has led to a variety of other changes that affect benthic communities throughout the estuary by changing dissolved oxygen conditions and bottom substrate (www.waquoitbayreserve.org). According to Bowen and Valiela (2001), nitrogen loading into Waquoit Bay more than doubled between 1938 and 1990. The predominant source of nitrogen added to the bay changed from atmospheric deposition to wastewater disposal during the 1980s, reflecting the increasing urbanization of Cape Cod.

- Water Quality and Quantity. In addition to Eutrophication, freshwater resources are threatened by toxic contamination moving through groundwater from the nearby Superfund site at the Massachusetts Military Reservation. Future population growth on Cape Cod also threatens the quantity of freshwater resources. Groundwater withdrawal from the Waquoit Bay watershed's sole source aquifer could potentially lead to drops in water levels that could seriously impact habitats in streams, ponds, and vernal pools.

- Land-use Change. Research at the reserve has shown that land use change, particularly residential development, in the Waquoit Bay watershed has resulted in drastic impacts to estuarine resources. A key component of the Reserve's efforts to protect the quality of the land and water ecosystems within the Reserve is the preservation of undeveloped land in and around the Waquoit Bay watershed. Roads and other infrastructure have also limited the flow of salt water on to salt marsh habitat and contributed to a loss of salt marsh cordgrass (*Spartina alterniflora*) and salt marsh hay (*Spartina patens*).

- Invasive Species. Areas of salt marsh have been encroached upon by *Phragmites* sp., which is considered less desirable than marsh grasses as wildlife habitat. *Phragmites* also produces less material for the detrital food chain and is thought by some to be a fire hazard because it dries at the end of the growing season.

Climate Change Context

The following scenarios are from multiple sources, as indicated. There are notable inconsistencies across various studies.

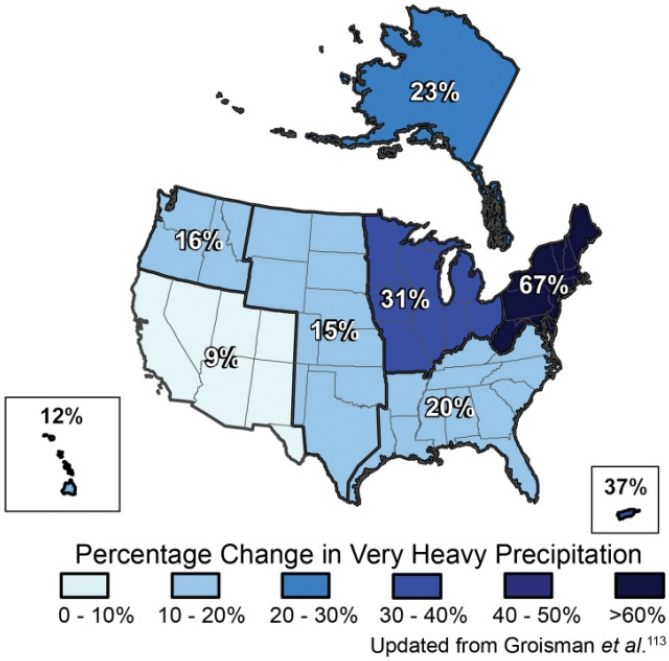
Air Temperature

- Recent Changes. Across the Northeast, the average annual air temperature has risen 1.5º F since 1900, with much of the increase having occurred over the past 30 years (Frumhoff et al. 2006, 2007; Hayhoe et al. 2006). The rate of temperature increase has been particularly pronounced in winter months, which experienced a 4º F increase between 1970 and 2000. On average, coastal regions of Massachusetts, New Jersey, New York, Connecticut, and Maine have warmed more than the Northeast as a whole (CACP and Wake 2005). Heat waves are also becoming more prevalent across the region, as the number of days per year with temperatures exceeding 90º F has doubled over the past 45 years. In addition, from 1915 to 2003, the length of the growing season (measured from the date of last spring frost to the date of first spring frost) has increased at an average rate of 0.7 days per decade, with the rate accelerating to 2.5 days per decade since the 1970s.

- Projections. Using the IPCC's lower B1 and higher A1FI emissions scenarios and statistical and dynamical downscaling techniques, scientists project that average temperatures across the northeast will continue to increase from 2.5-4º degrees F in winter and 1.5-3.5º F in summer within the next two decades (Frumhoff et al. 2007). By mid-century, winter temperatures are projected to be 4-7º F warmer than the historic average and summers 4-8º F warmer under the higher emission scenario, and 4-5º F in winter and 2-5º F for summer under the lower scenario.

Precipitation

- Recent Changes. Average annual precipitation in the Northeast has increased about 10 percent over the past 50 years, with more falling in winter in the form of rain (Frumhoff et al. 2006; 2007; Hayhoe et al. 2006; Keim et al. 2005). In addition, across northern coastal New England, there has been a significant increase in extreme precipitation (defined as the annual maximum daily precipitation depth) since the 1970s (Douglas and Fairbank 2011). And New England as a whole has seen a considerable increase in the percentage of rain falling in heavy downpours (Figure 4).



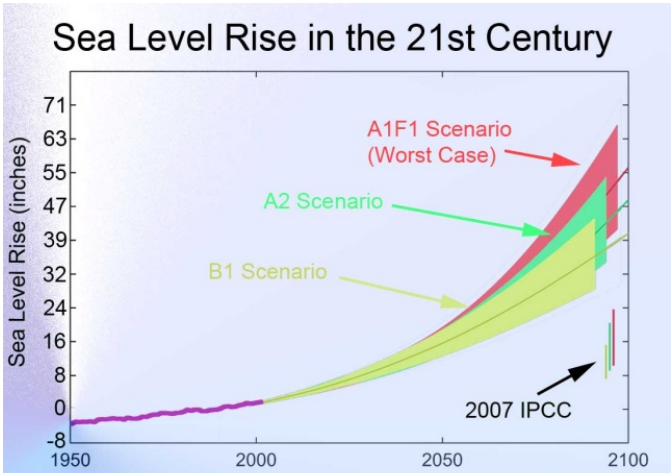
The map shows the percentage increases in very heavy precipitation (defined as the heaviest 1 percent of all events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

Figure 4

- Projections. Although regional projections for total precipitation are less certain than those for warming, the Northeast is projected to see a steady increase in annual precipitation under both the low and high IPCC emissions scenarios, with a total increase of around 10 percent (4 inches per year) by the end of the century. Winter precipitation could increase an average of 20-30 percent by end of century, with more precipitation expected to fall as rain than snow. The number and intensity of heavy precipitation events are also projected to increase – wet days will become wetter, and when it does rain it will be heavier.

Sea-level Rise

- Recent Changes. Climate change is contributing to an increase in the rate of sea-level rise due to the thermal expansion of ocean waters and melting glaciers and ice fields. The average global (eustatic) sea level rise 6.7 inches over the 20th century, at an average rate of 0.07 inches (1.7 mm) per year. This was 10-times faster than the average rate of sea-level rise during the last 3,000 years (IPCC 2007). Importantly, eustatic sea-level rise is not uniform across the globe – it can vary based on a range of factors, such as ocean circulation patterns, variations in temperature and salinity, and the earth's rotation and shape. Evidence suggests that the area off the Atlantic Coast of North America, for example, is a "hot spot" for a relatively higher rate of eustatic sea-level rise than the global average (Sallenger et al. 2012). In the coming decades, the average rate of sea-level rise is expected to accelerate, even under the most aggressive scenarios for reducing global emissions of greenhouse gases. For coastal management purposes, it is important to also understand the potential changes in relative sea level, which includes the eustatic rate as well as localized factors that determine changes in vertical land elevation, such as land subsidence, sedimentation, and marsh accretion. The estimated rate of relative sea-level rise in Massachusetts from 1921 to 2006 was 2.6 mm annually (0.10 inches per year). This is about 1mm/yr higher than the range of global (eustatic) sea-level rise due to local lands subsidence (Donnelly et al. 2004).



New modeling, based on the temperature / sea level relationship for the last 1,000 years, shows up to three times the sea level rise as predicted by the 2007 IPCC. The model was confirmed with tide gauge and temperature data from 1880 to 2000 with a correlation of greater than 0.99 (very accurate.)
Vermeer and Rahmstorf, Global sea level linked to global temperature, PNAS, 2009.

Figure 5

- Projections. The most recent estimates from the 2007 IPCC assessment show an additional 18 to 59 cm (7- to 23-inch) rise in global average sea level by the 2090s, with an additional 10 to 20 cm possible by taking into consideration the current rate of ice flow from Greenland and Antarctica. There is compelling new evidence, however, that

because these figures ignored the recent dynamic changes in Greenland and Antarctica ice flow, it is likely to that they significantly underestimate the rate of global sea-level rise we will experience in the coming decades (Jevrejeva et al. 2010; Otto-Bliesner et al. 2006; Overpeck et al. 2006; Overpeck and Weiss 2009; Rahmstorf 2007; Rignot and Kanagaratnam 2006; Vermeer and Rahmstorf 2009) (Figure 5). While future projections vary, Rahmstorf (2007) proposes that, taking into account possible model error, a feasible range by 2100 is a rise of 50-140 cm. More recently, this work was updated and the ranges were increased to 75 to 190 cm (Vermeer and Rahmstorf 2009).

Coastal Storms

- Recent Changes. Several studies have found a correlation between warmer average ocean temperatures and an increase in the intensity of tropical storms and hurricanes, and there is evidence of an increase in intense tropical cyclone activity in the North Atlantic over the past 40 years (Emanuel 2005; Meehl et al. 2007; Trenberth 2007; Webster et al. 2005).

- Projections. A number of scientists believe the trend toward more intense storms will continue in the coming decades as the oceans continue to warm (Holland and Webster 2007; Mann et al. 2007; Oouchi et al. 2006; Trenberth 2007). While the number of storms is expected to decrease globally by the end of the century, Oouchi et al. (2006) suggest that the number of storms in the North Atlantic could increase by as much as 34 percent over the same period. Further, storms are likely to become more destructive in the future as sea-level rise contributes to higher storm surge (Anthes et al. 2006). Climate change may lead to more storms in the marine environment, resulting in increased strength and

frequency of waves, and an increase in coastal erosion and deposition. Storms affect lagoons through Overwash events and erosion from wind and waves. Given the region's relatively narrow, low-profile barrier islands, there is likely to be a high degree of change in these systems (Anthony et al. 2009).

Sea Surface Temperature and Chemistry

- Recent Changes. Average sea surface temperatures in the northwest Atlantic Ocean have increased 1º F since 1900, with some coastal areas (e.g., Boothbay Harbor) experiencing an even greater change (1.8º F) over the past several decades (Frumhoff et al. 2007). In addition, as oceanic carbon dioxide has increased in recent decades, the world's oceans have become more acidic, with pH decreasing by 0.1 standard units since 1750 (Archer 2005). This represents a 30 percent increase in ocean acidity.

- Projections. Scientists project that sea surface temperatures will increase an additional 4-5º F under the low emissions scenario and 6-8 F under the high scenario towards the end of this century. The average pH of the world's oceans may decrease by as much as 0,1 to 0.4 pH units over the next 90 years, due to increasing absorption and solution of carbon dioxide into warmer ocean waters (Royal Society 2005; Kuffner et al. 2008; Ishimatsu et al. 2005).

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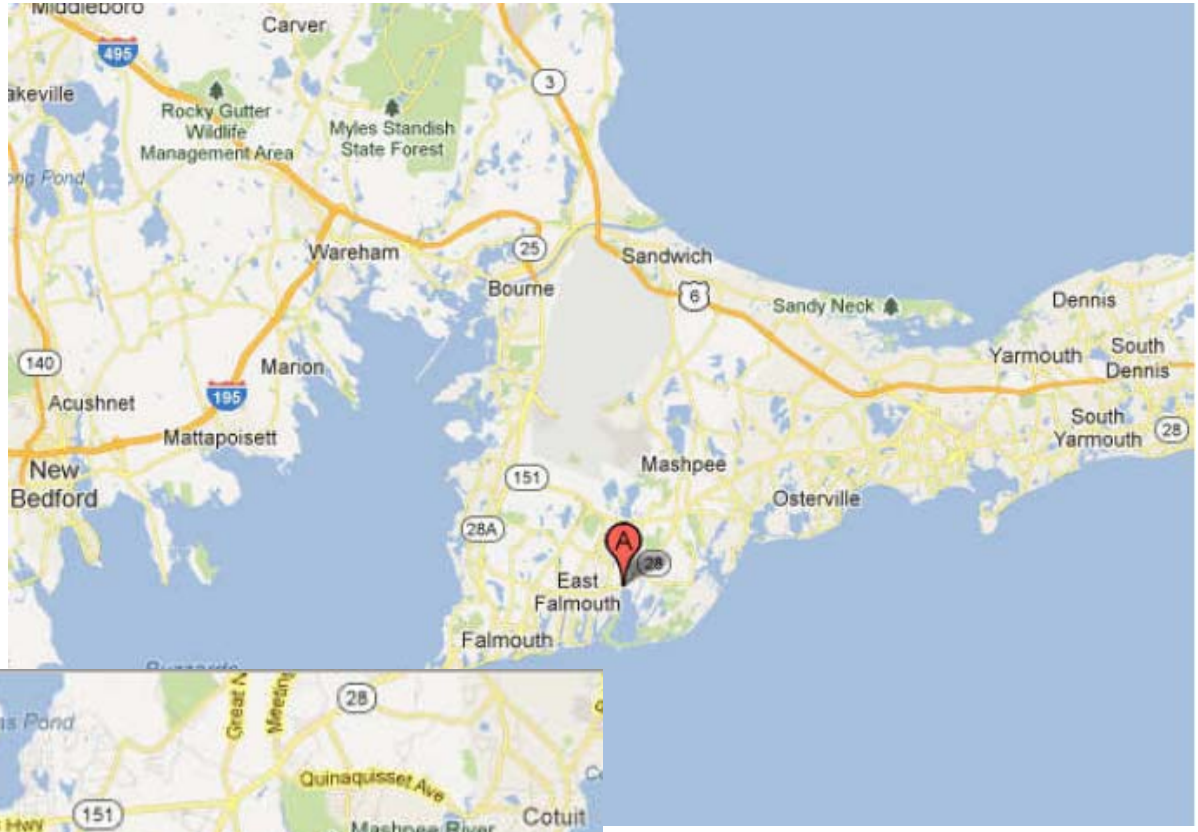
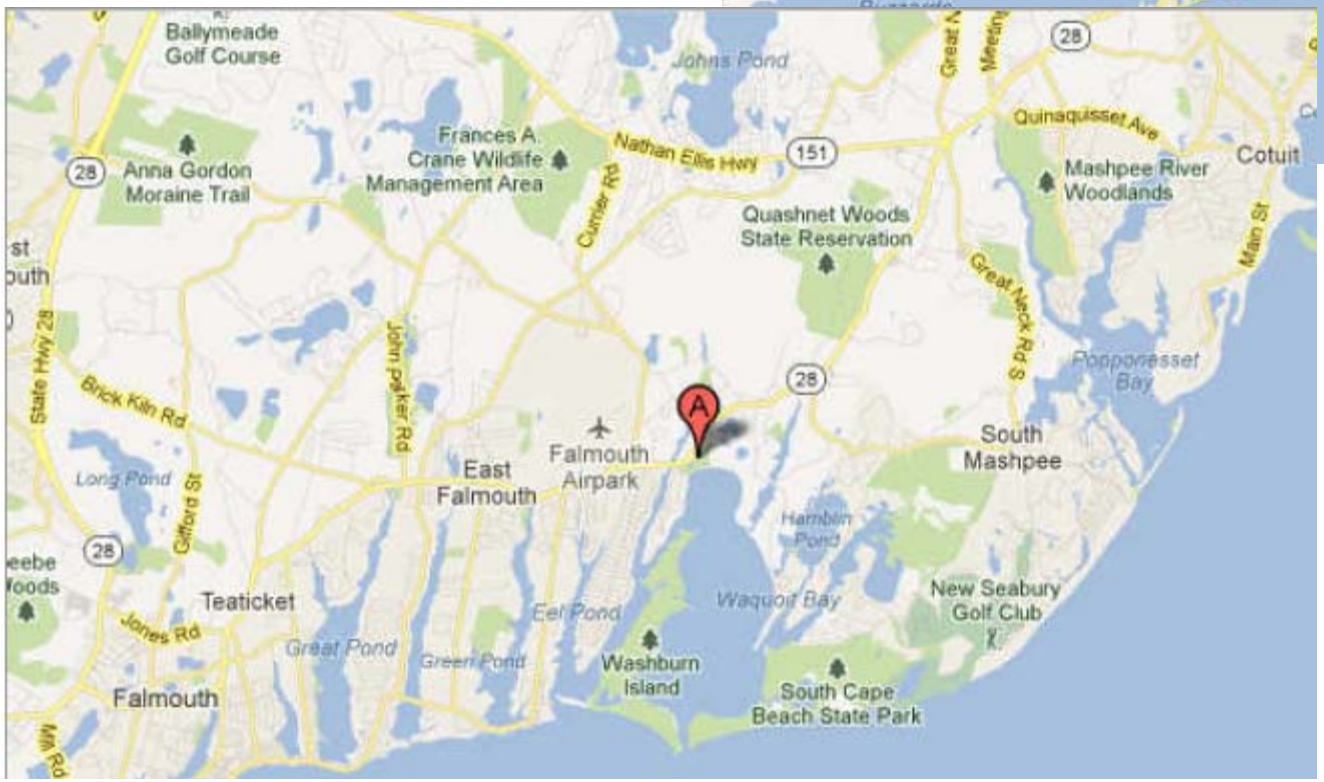
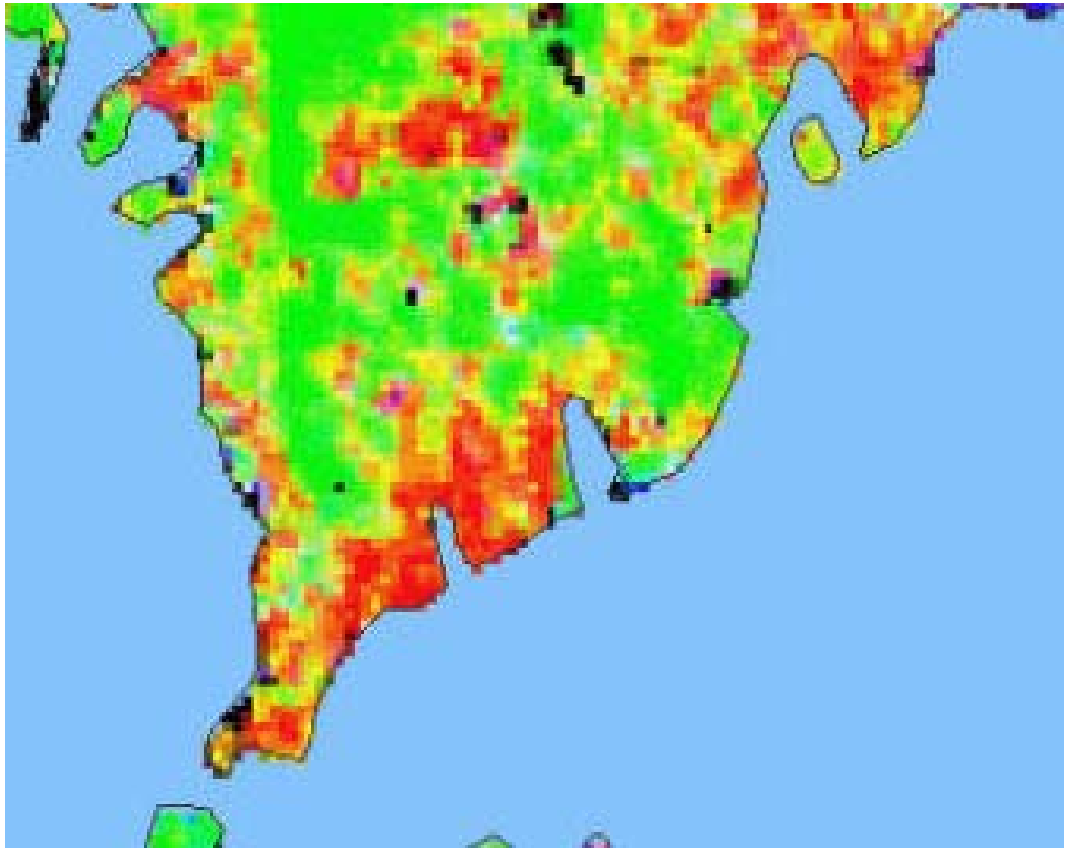

Middleboro
Carver
495
Rocky Gutter Wildlife Management Area
Myles Standish State Forest
3
Wareham
25
Sandwich
Bourne
6
Sandy Neck
Dennis
Yarmouth
South Dennis
140
Marion
Acushnet
195
Mattapoisett
South Yarmouth
28
New Bedford
151
Mashpee
Osterville
28A
A
28
East Falmouth
Falmouth


Ballymeade Golf Course
Johns Pond
28
Quinaquisset Ave
Frances A. Crane Wildlife Management Area
Nathan Ellis Hwy
151
Cotuit
Anna Gordon Moraine Trail
Mashpee River Woodlands
Quashnet Woods State Reservation
Main St
Great Neck Rd S
State Hwy 28
Brick Kiln Rd
John Parker Rd
Popponesset Bay
A
Falmouth Airpark
South Mashpee
East Falmouth
Long Pond
Gifford St
Hamblin Pond
Teaticket
Eel Pond
Waquoit Bay
New Seabury Golf Club
Jones Rd
Great Pond
Green Pond
Washburn Island
South Cape Beach State Park
Falmouth

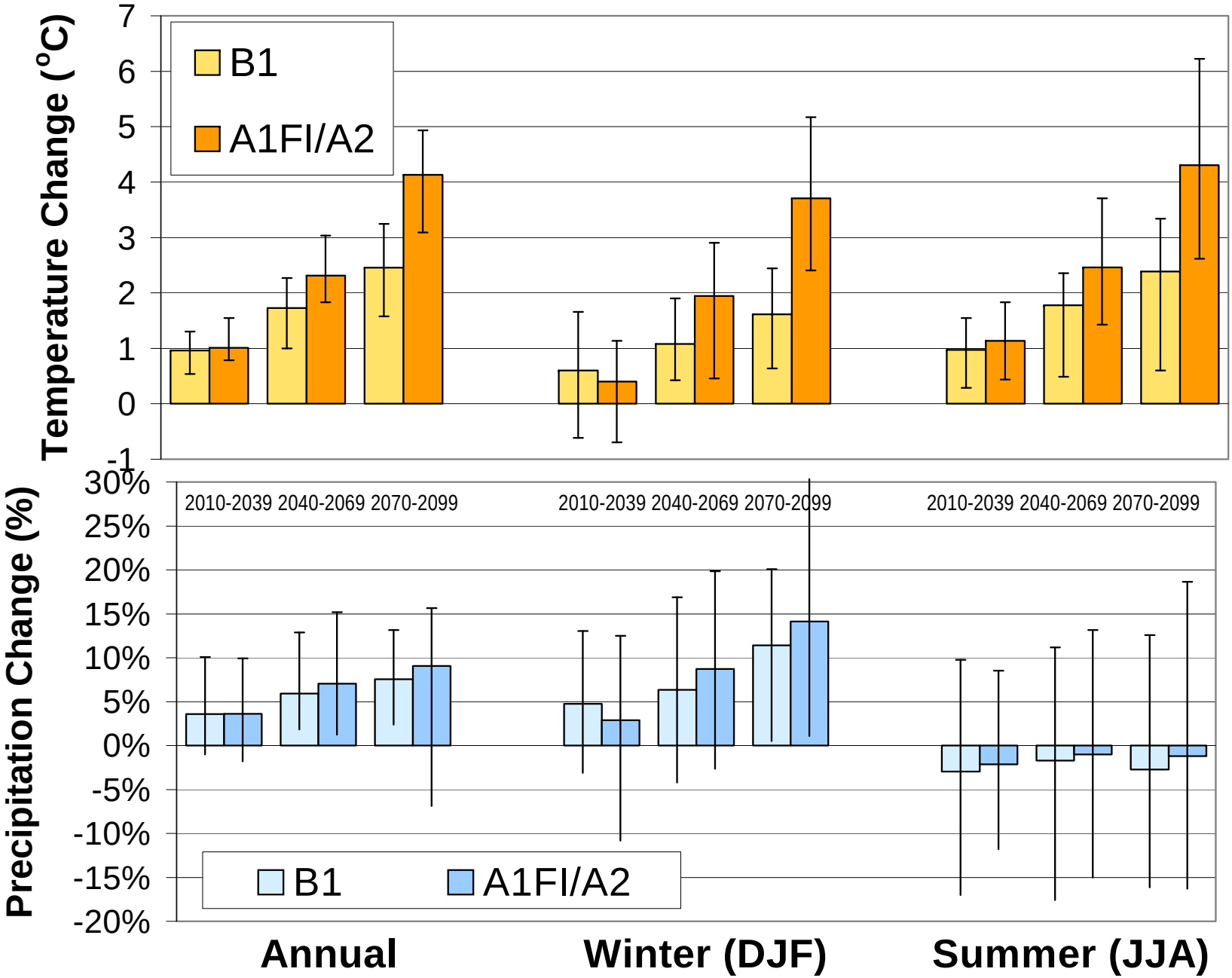
- Hazardous Waste Handlers
- Water Discharge Permits
- Air Releases
- Toxics Release Inventory
- Superfund National Priorities List Sites

Point sources of pollution
From the National Atlas
http://www.nationalatlas.gov/



Forest cover
From the National Atlas
http://www.nationalatlas.gov/

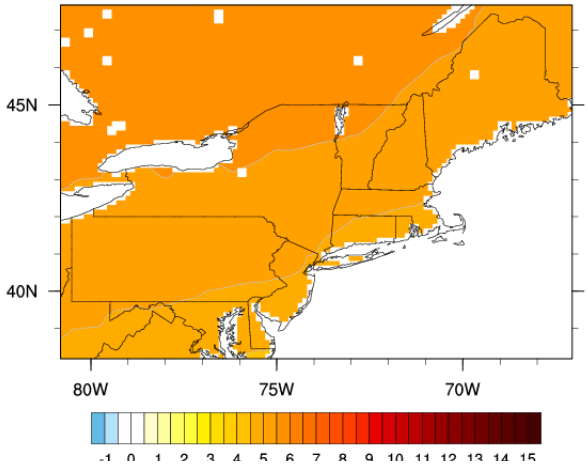
From UCS's Climate Change in the Northeast http://www.climatechoices.org

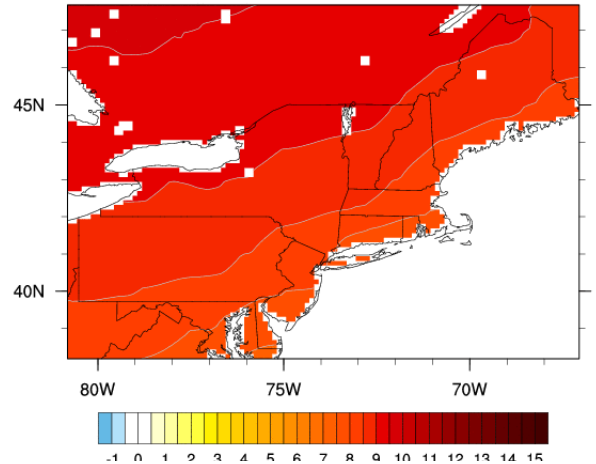


LOWER EMISSIONS

MID-HIGH EMISSIONS

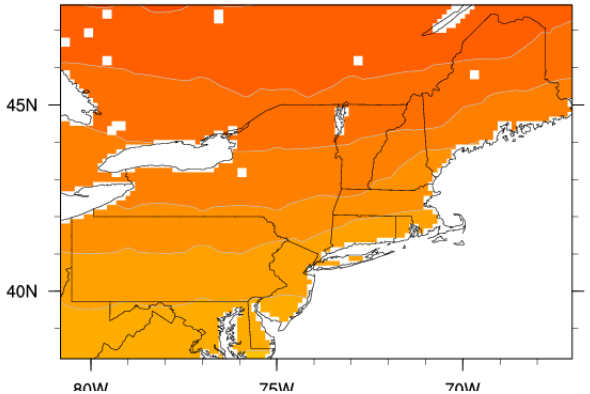
2080-2099

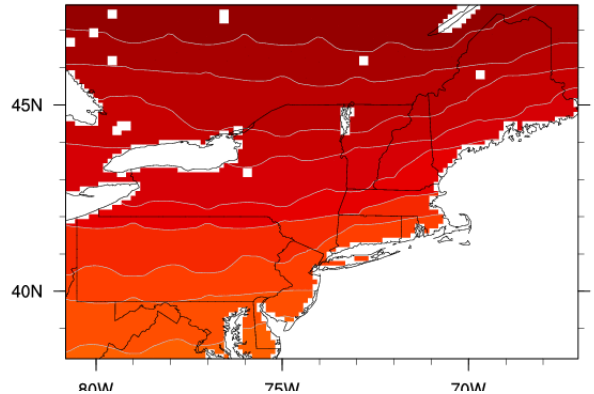




ANNUAL AVERAGE TEMPERATURE: CHANGE RELATIVE TO 1971-2000 (degF)

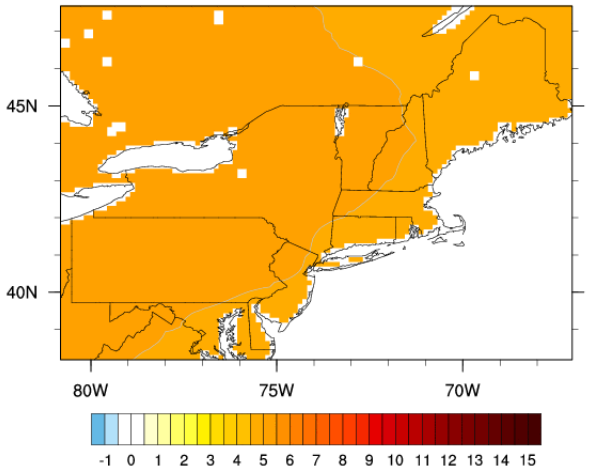
2080-2099

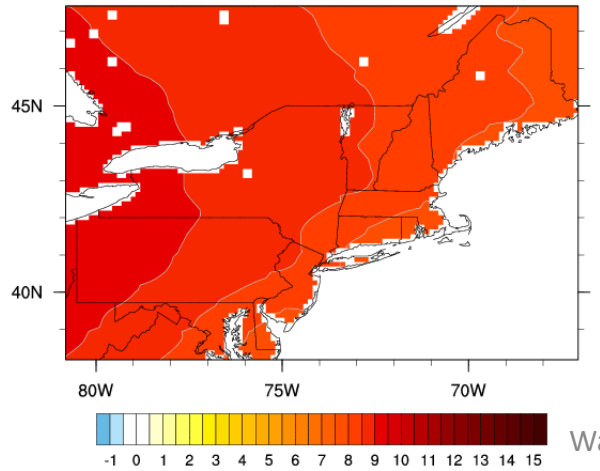




% change WINTER (DJF) AVERAGE TEMPERATURE

2080-2099



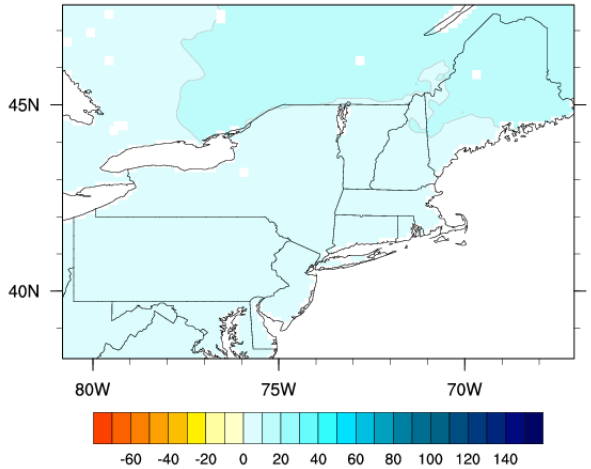


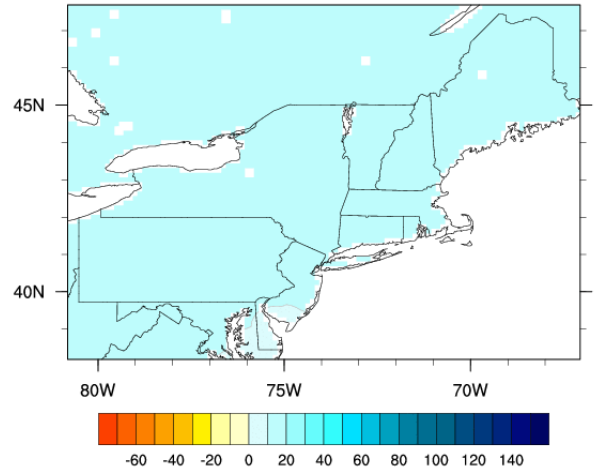
% change SUMMER (JJA) AVERAGE TEMPERATURE

LOWER EMISSIONS

MID-HIGH EMISSIONS

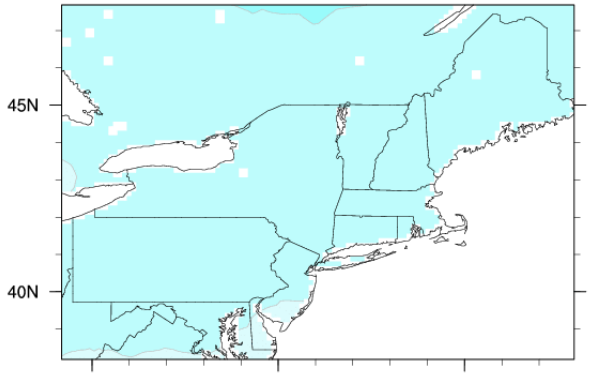
2080-2099

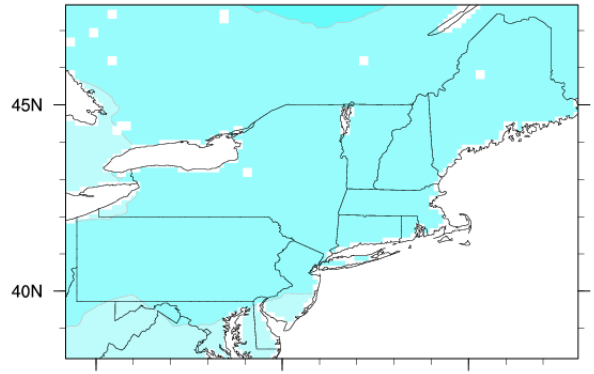




ANNUAL AVERAGE PRECIPITATION: PERCENTAGE CHANGE RELATIVE TO 1971-2000

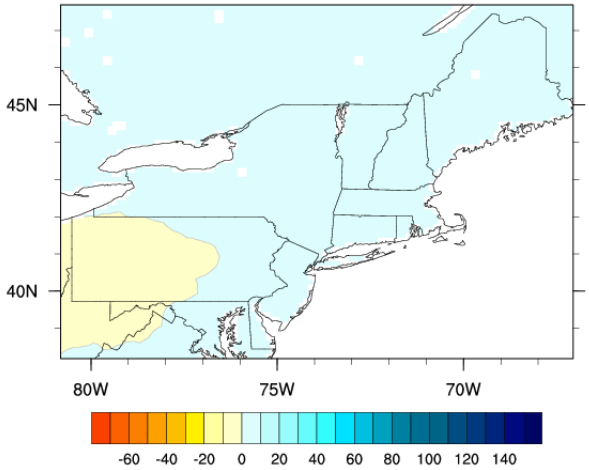
2080-2099

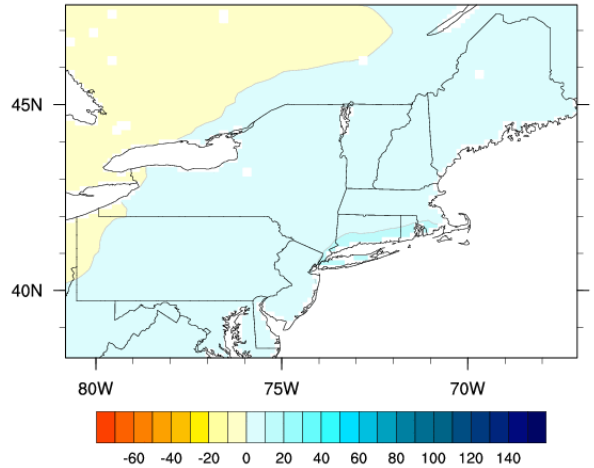




% change WINTER (DJF) AVERAGE PRECIPITATION

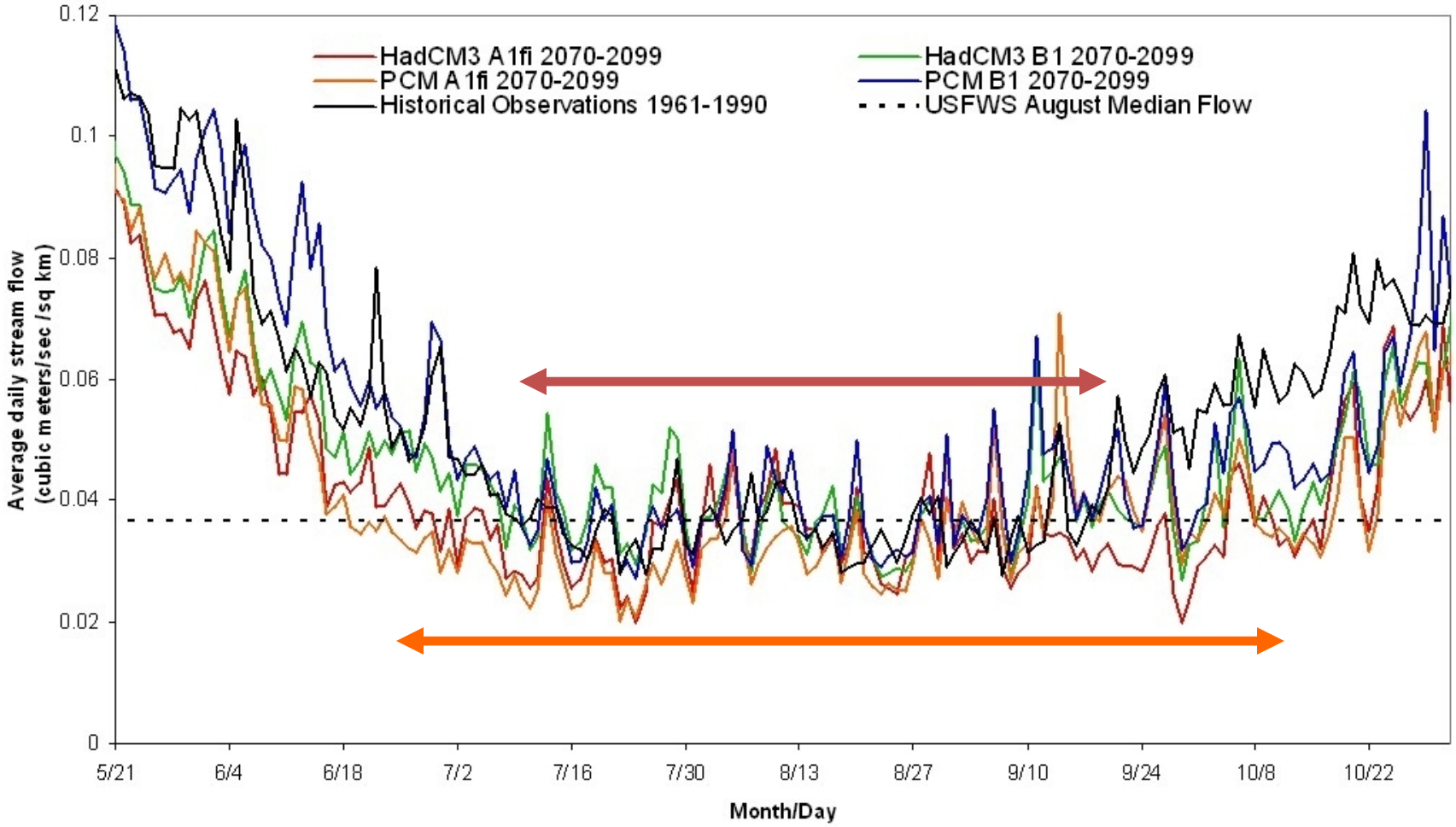
2080-2099





% change SUMMER (DJF) AVERAGE PRECIPITATION

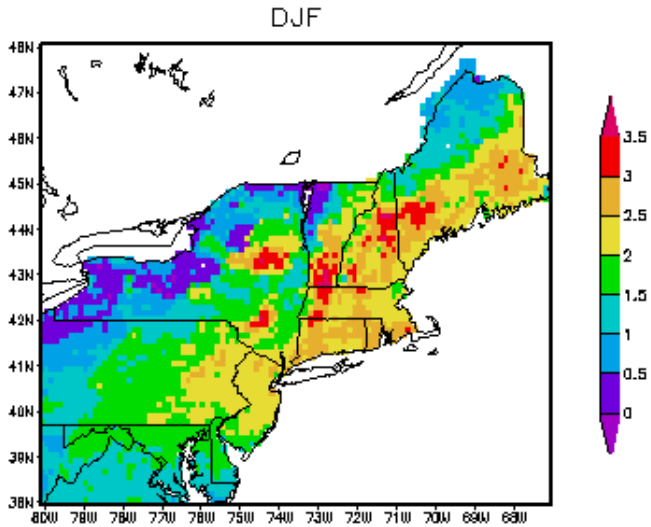
Increase in Duration of Summer Low Flow Periods

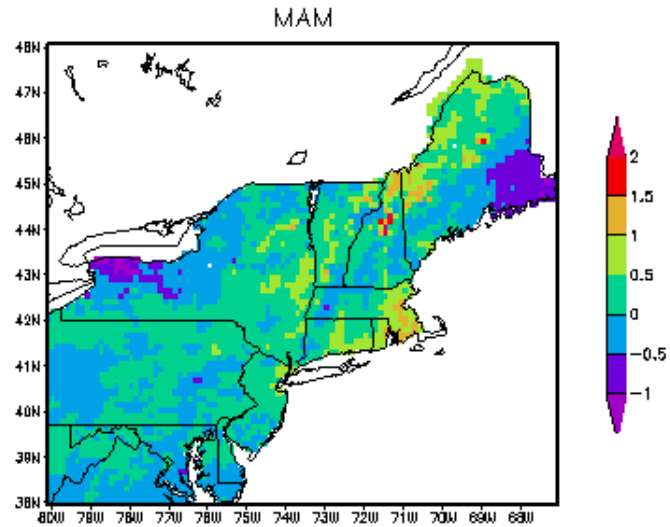


Seasonal Changes in Soil Moisture

2030-2060 relative to 1970-1999

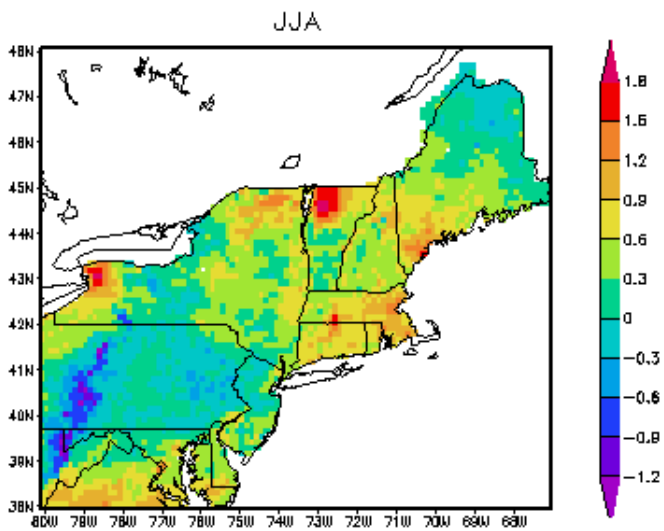
Winter

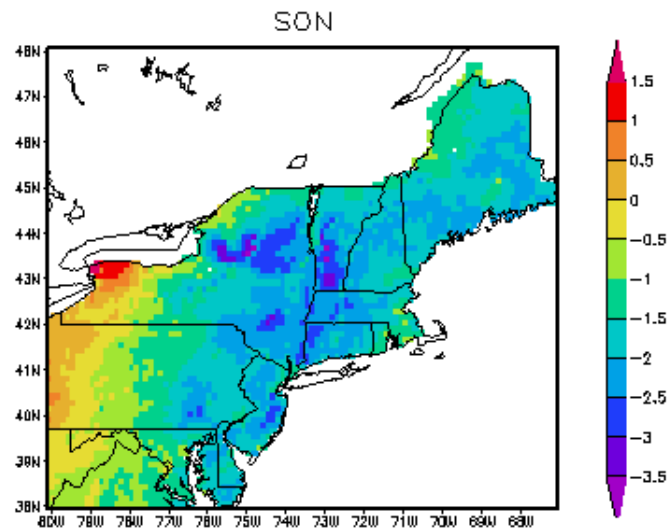




Spring

Summer





Fall