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Methodology: Projected changes in climate indicators for the US Northeast

This document describes the methodology used to analyze projected changes in climate indicators for the Northeastern US over the twenty-first century under Global Mean Temperature (GMT) change scenarios.

1. Global Climate Models (GCMs):

Nine GCM simulations from the latest generation Coupled Model Intercomparison Project Phase 5 (CMIP-5) models were used in this study (Table 1). The GCM simulations comprising the historical period (1900-2005) and future periods (2006-2100) under two radiative forcing scenarios such as mid-low (representative concentration pathway; RCP4.5) and high (RCP8.5) were used. In RCP8.5 scenario, the radiative forcing levels of greenhouse gases and other forcing agents are projected to increase throughout the twenty-first century before reaching a level of about 8.5 W m^{-2} (more than threefold increase in carbon dioxide relative to pre-industrial levels) at the end of the century. In RCP4.5 scenario, the radiative forcing levels are projected to reach a level of 4.5 W m^{-2} at the end of the century, which corresponds to an approximate doubling of carbon dioxide levels relative to pre-industrial levels (Van Vuuren et al., 2011; Taylor et al., 2012).

Table 1. CMIP-5 model simulations used in this project.

GCM Simulations	Ensembles	Scenarios
CCSM4	r1i1p1	Historical, RCP4.5 and RCP8.5
CNRM-CM5	r1i1p1	Historical, RCP4.5 and RCP8.5
CSIRO-Mk3-6-0	r1i1p1	Historical, RCP4.5 and RCP8.5
HadGEM2-CC	r1i1p1	Historical, RCP4.5 and RCP8.5
inmcm4	r1i1p1	Historical, RCP4.5 and RCP8.5
IPSL-CM5A-LR	r1i1p1	Historical, RCP4.5 and RCP8.5
MIROC5	r1i1p1	Historical, RCP4.5 and RCP8.5
MPI-ESM-LR	r1i1p1	Historical, RCP4.5 and RCP8.5
MRI-CGCM3	r1i1p1	Historical, RCP4.5 and RCP8.5

2. GCM-based climate indicators:

The following climate indicators were computed using CMIP-5 GCM historical and future (RCP4.5 and RCP8.5) simulations:

- Annual average temperature
- Number of days per year over 95°F
- Average seasonal maximum temperature (Tmax; winter, spring, summer, and fall)
- Average seasonal minimum temperature (Tmin; winter, spring, summer, and fall)
- Tmax on the hottest day of year
- Tmin on the coldest day of year
- Annual average precipitation
- Number of days per year over 2” of rain
- Number of days per year over 3” of rain
- Average seasonal precipitation (winter, spring, summer, and fall)
- Precipitation on the wettest day of year
- Precipitation in the wettest week of the year

Precipitation-related indicators were calculated from daily precipitation (pr) GCM simulation and temperature-related indicators were calculated from daily temperature (tas, tasmax, tasmin) GCM simulations. The GCM-derived indicators were then regridded to a uniform 1/16th of a degree latitude-longitude to match the grid size of the observed data.

3. Observed Climate Indicators:

The climate indicators as listed above (in section 2) were also calculated using gridded (1/16th of a degree latitude-longitude) observational derived daily Tmax, Tmin, and precipitation data (Livneh et al., 2013).

4. Global Mean Temperature (GMT) change scenarios:

In this study, the projected future changes in the climate indicators were quantified under GMT change scenarios (GMT +1°C, GMT +2°C, and GMT +3°C) relative to the GMT of a historical base period (1971-2000). For example, GMT +1°C indicates a future 20-year period when the average GMT is projected to exceed 1°C than that during 1971-2000 period. Detailed description regarding the computation of GMT change scenarios is given in Swain and Hayhoe (2015). In this study, GMT change framework was computed for each of the 9 GCMs and 2 scenarios (9×2=18 individual model/scenario combination) and the time periods when the average global mean temperature is projected to exceed 1°C, 2°C, and 3°C (GMT +1°C, GMT +2°C, and GMT +3°C, respectively) were identified (Table 2).

Table 2. 20-year period when the average GMT is projected to exceed +1°C, +2°C, and +3°C relative to the 1971-2000 period for each CMIP5 GCM model/scenario combination used in this study.

CMIP5 GCM Simulations	Ensembles	Scenarios	GMT +1°C	GMT +2°C	GMT +3°C
CCSM4	r1i1p1	RCP 4.5	2020–2039	NA	NA
CCSM4	r1i1p1	RCP 8.5	2013–2032	2043–2062	2063–2082
CNRM–CM5	r1i1p1	RCP 4.5	2024–2043	2070–2089	NA
CNRM–CM5	r1i1p1	RCP 8.5	2020–2039	2046–2065	2067–2086
CSIRO–Mk3–6–0	r1i1p1	RCP 4.5	2022–2041	2051–2070	NA
CSIRO–Mk3–6–0	r1i1p1	RCP 8.5	2021–2040	2043–2062	2063–2082
HadGEM2–CC	r1i1p1	RCP 4.5	2015–2034	2048–2067	NA
HadGEM2–CC	r1i1p1	RCP 8.5	2009–2028	2034–2053	2050–2069
inmcm4	r1i1p1	RCP 4.5	2052–2071	NA	NA
inmcm4	r1i1p1	RCP 8.5	2035–2054	2060–2079	NA
IPSL–CM5A–LR	r1i1p1	RCP 4.5	2014–2033	2046–2065	NA
IPSL–CM5A–LR	r1i1p1	RCP 8.5	2011–2030	2034–2053	2053–2072
MIROC5	r1i1p1	RCP 4.5	2021–2040	NA	NA
MIROC5	r1i1p1	RCP 8.5	2017–2036	2047–2066	2069–2088
MPI–ESM–LR	r1i1p1	RCP 4.5	2023–2042	NA	NA
MPI–ESM–LR	r1i1p1	RCP 8.5	2019–2038	2046–2065	2068–2087
MRI–CGCM3	r1i1p1	RCP 4.5	2037–2056	NA	NA
MRI–CGCM3	r1i1p1	RCP 8.5	2029–2048	2052–2071	2076–2095

5. Analyses of climate indicators under Global Mean Temperature (GMT) change scenarios:

The following steps were used to calculate the projected changes in each climate indicator under GMT change scenarios:

a. *Historical and projected climate indicators:* Baseline value for historical period (1971–2000 mean) was calculated for each historical GCM simulation. Projected values for GMT +1°C, GMT +2°C, and GMT +3°C were extracted for each model/scenario combination using the 20-year periods listed in Table 2. The time series values of 20 years were averaged to get the mean projected values under GMT +1°C, GMT +2°C, and GMT +3°C for each model/scenario combination.

b. *Statistical Downscaling:* Delta method was used to generate downscaled projections under GMT +1°C, GMT +2°C, and GMT +3°C scenarios for each model/scenario combination. The delta downscaling method is given below:

Delta Downscaled GMT +1°C = *(Future GCM under GMT +1°C - Historical*$_{1971\text{-}2000mean}$ *GCM simulation) + Historical*$_{1971\text{-}2000mean}$ *observed*

Delta Downscaled GMT +2°C = *(Future GCM under GMT +2°C - Historical*$_{1971\text{-}2000mean}$ *GCM simulation) + Historical*$_{1971\text{-}2000mean}$ *observed*

Delta Downscaled GMT +3°C = *(Future GCM under GMT +3°C - Historical*$_{1971\text{-}2000mean}$ *GCM simulation) + Historical*$_{1971\text{-}2000mean}$ *observed*

6. Combining the results and map creation:

Delta downscaled GMT +1°C projections (N=18) for individual model/simulation combination were averaged to generate mean GMT +1°C projection. Similarly, Delta downscaled GMT +2°C (N=13) and GMT +3°C (N=8) projections for individual model/simulation combination were averaged to generate mean GMT +2°C and GMT +3°C projections, respectively. The results were then exported to .img format (from native netCDF) and maps were created using ArcGIS 10.2.

Metadata of GIS-based Raster Files (.img format)

Map coordinate system: Geographic Coordinate System; Datum: The World Geodetic System, 1984 (WGS_1984)

Spatial units: Decimal Degrees

Resolution (grid size): 0.0625 (Latitude), 0.0625 (Longitude)

Spatial extent: Latitude: 47.75°N to 37.31°N; Longitude: 82°W to 67°W

Date created: March 2014

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Restriction on data usage: Citation of data source is requested.

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Literature Cited

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