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Regional Climate Change Projections: Potential Impacts to Nuclear Facilities

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Project overview

- Objective: develop documents to summarize
  - Recent scientific findings on climate change and its impacts
  - Activities of federal agencies with direct responsibility on climate change science
  - Quality assessment of the above relevant to NRC concerns on regional level
- Progress:
  - Delivered and updated annual letter reports for the first three years, focusing on recent scientific findings on climate change and regional impacts in the US and climate change and hydrologic impacts in southeastern and midwestern US
  - Fourth year efforts focus on climate change and hydrologic impacts in northeastern US
    - Temperature, precipitation, extratropical cyclones, summer convective storms, tropical cyclones, sea level rise, storm surge, floods and droughts, Great Lakes water level

Background and context

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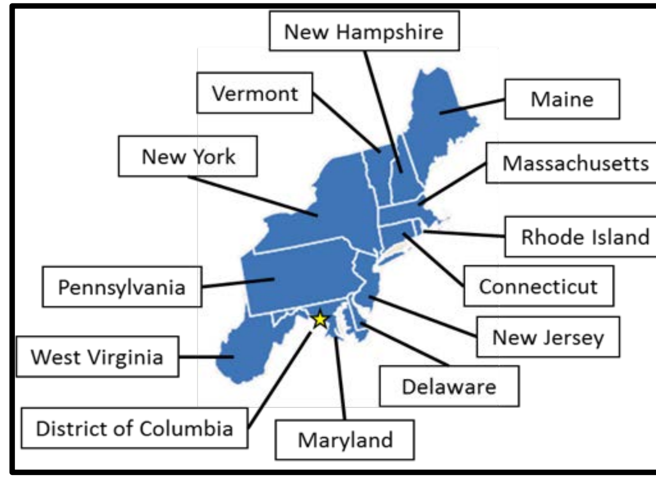
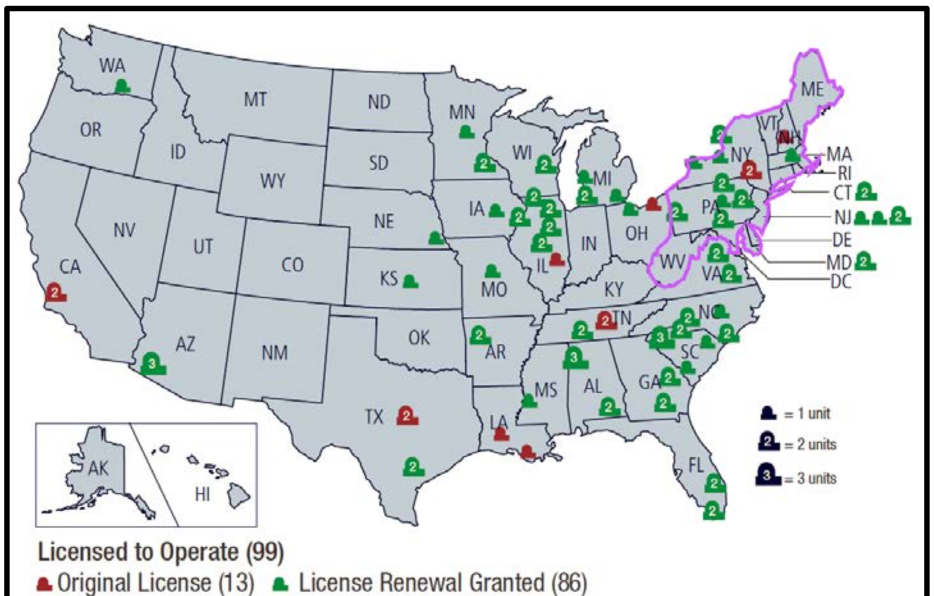
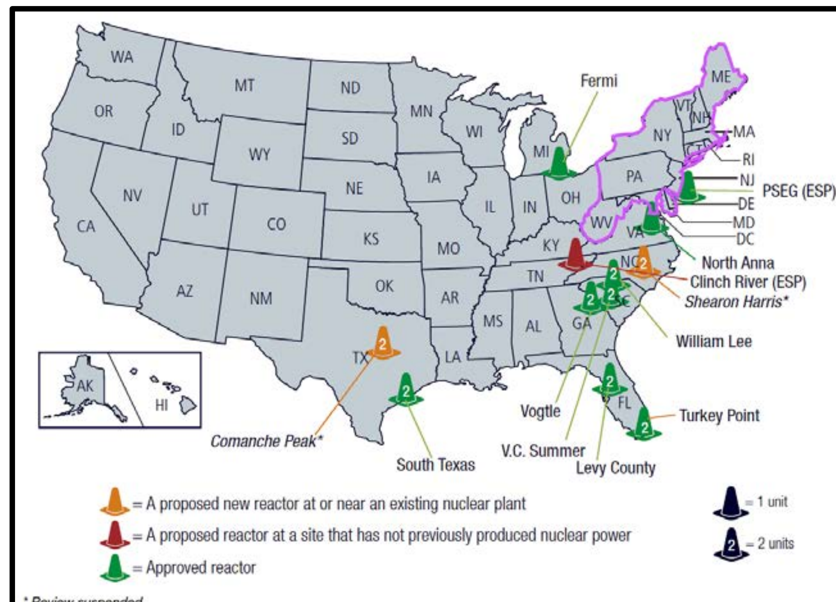
- Connecticut, Maryland, Massachusetts, New Hampshire, New Jersey, New York, and Pennsylvania have operating nuclear power plants
- One permit in New Jersey was approved

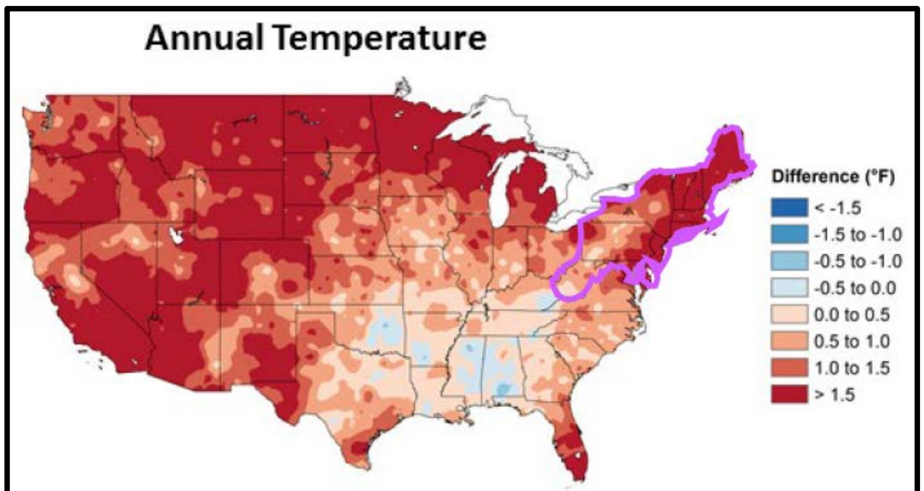






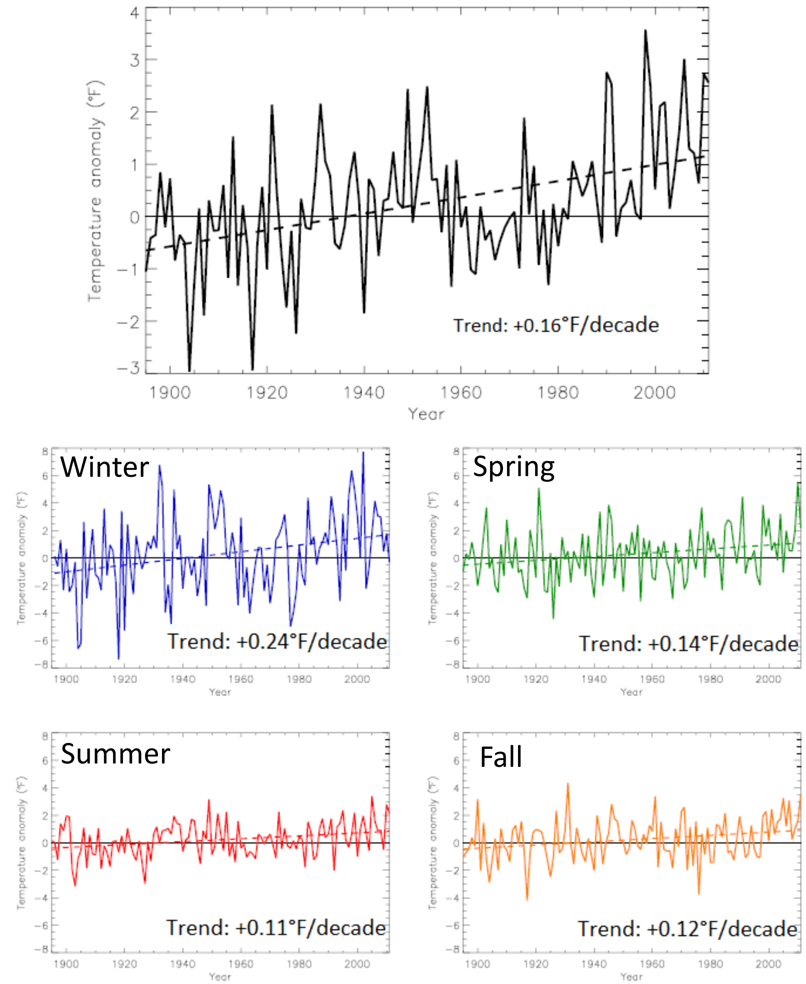
Observed temperature trends

Observed changes between (1986 to 2015) and (1901 to 1960)



(Voss et al. 2017)

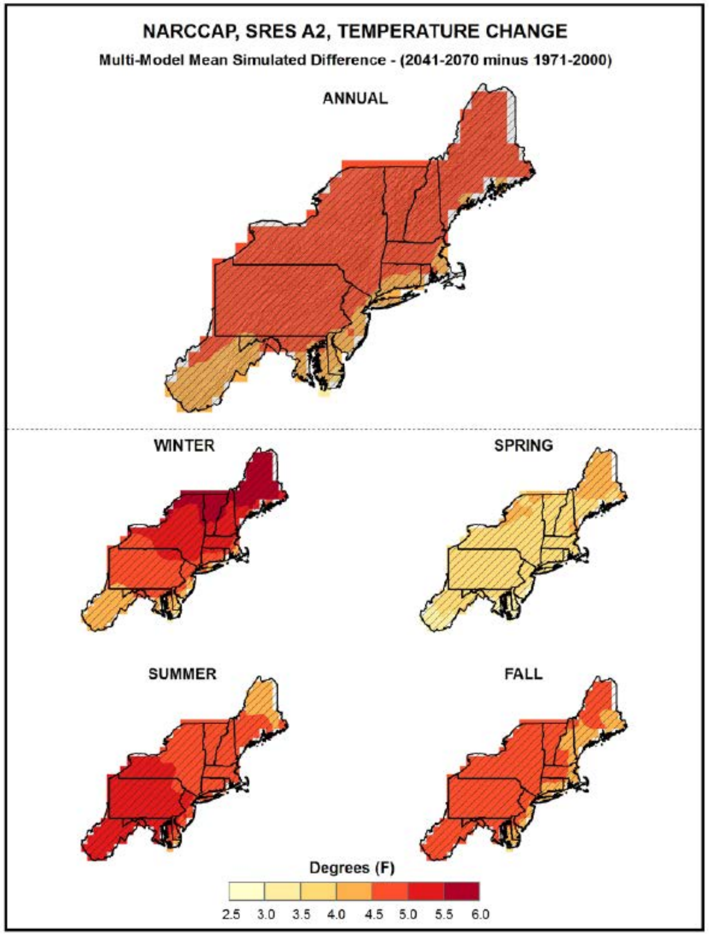
Observed temperature trends in the NE (deviations from 1901-1960 average)

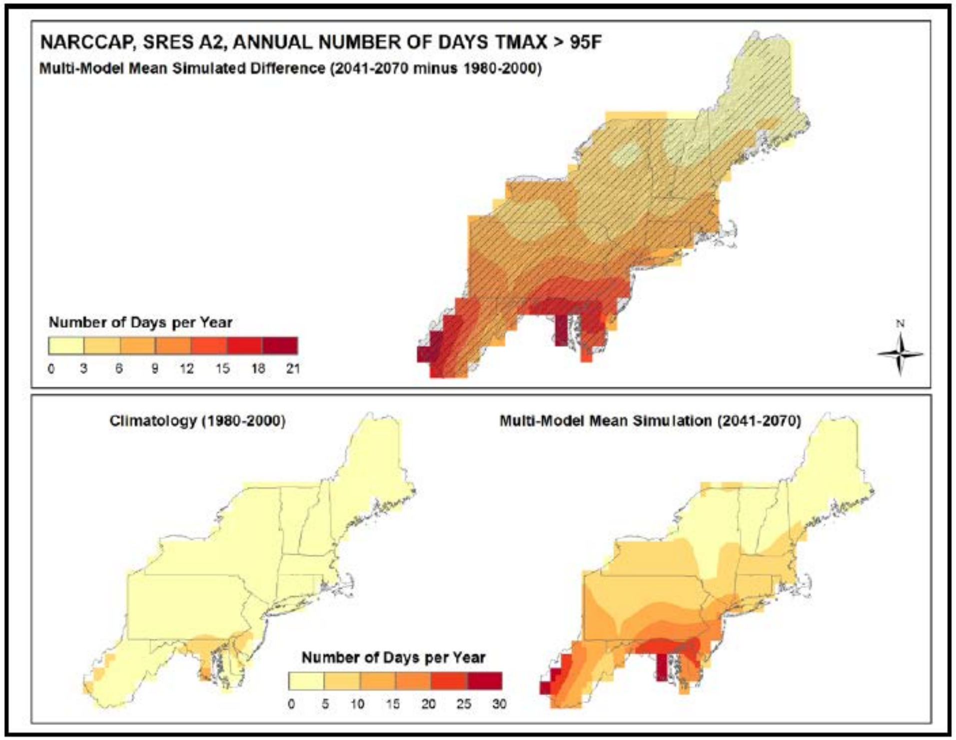


(Kunkel et al. 2013)

Projected temperature trends

- Projected warming ranges between 3-6°F, with the largest warming in winter





Historical seasonal precipitation changes

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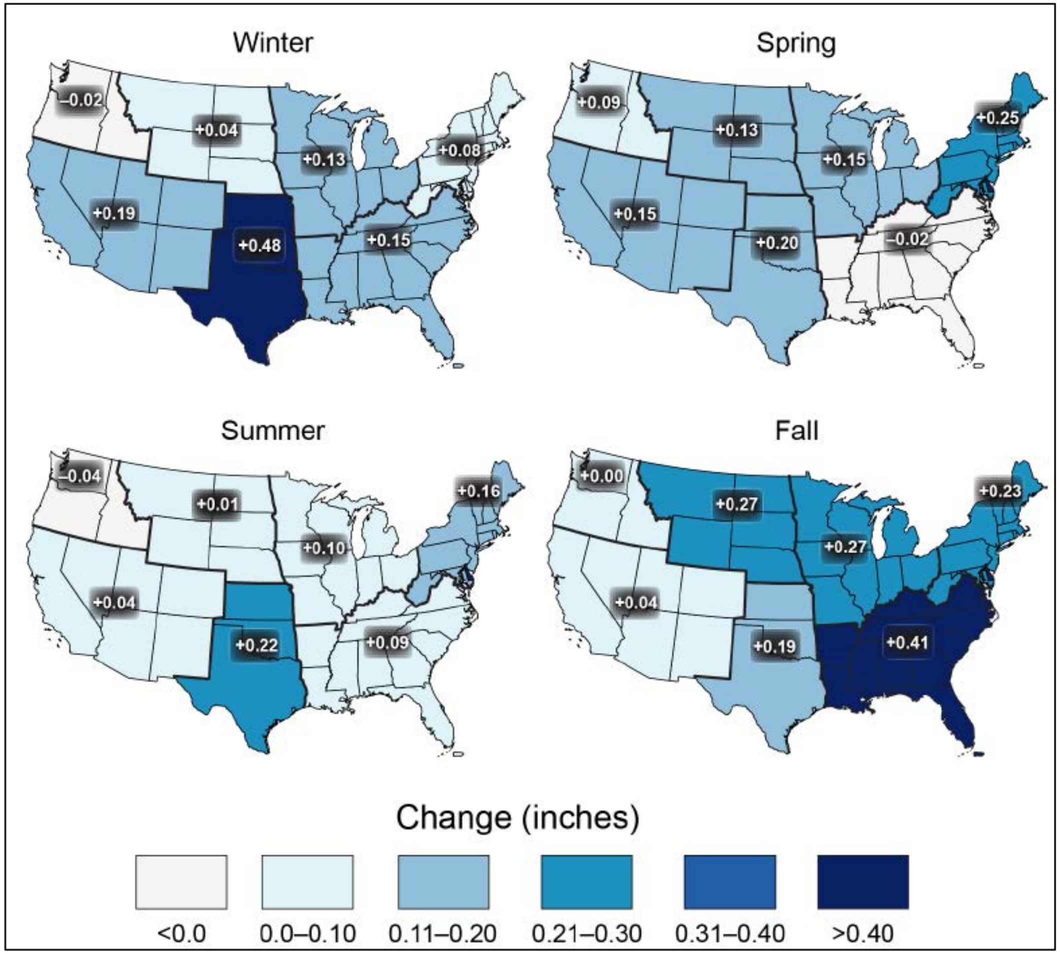
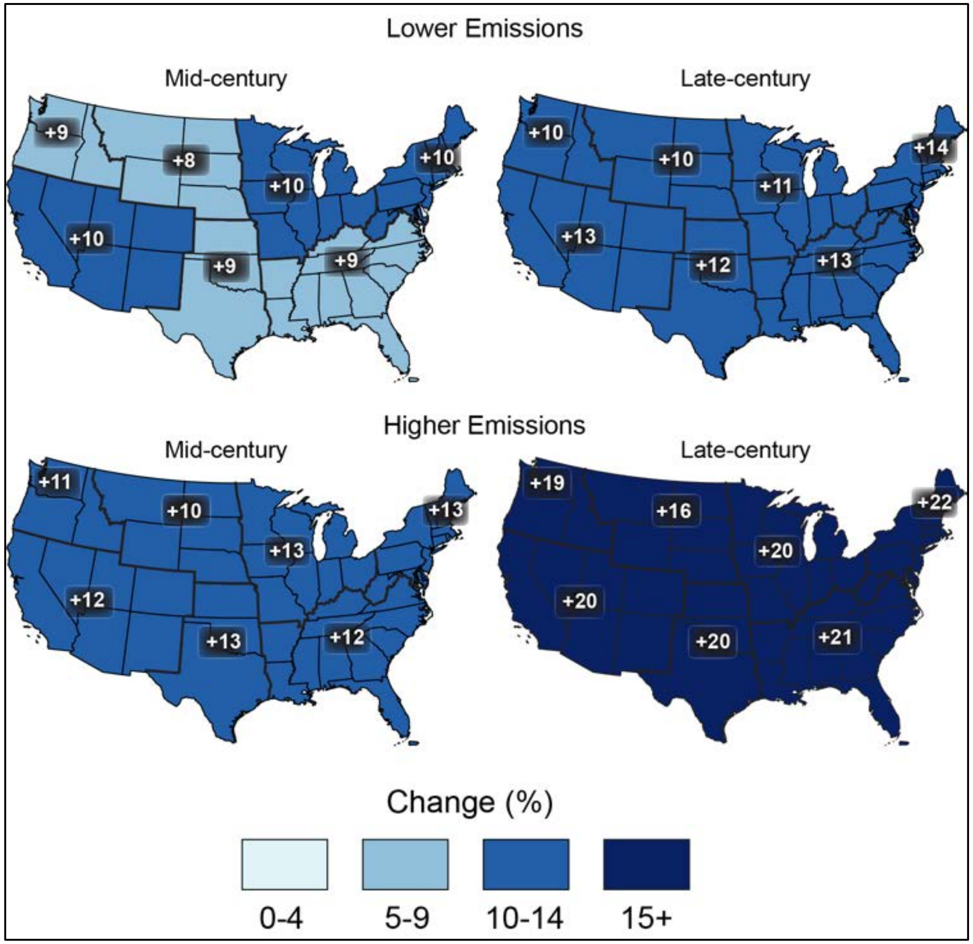
- Annual precipitation in the NE has increased by 0.39 in/decade from 1901-2015, mainly associated with spring and fall seasons
- 0.05 AEP daily precipitation has also increased, mainly in spring and fall (1948-2015)



(Easterling et al. 2017)

Projected changes in extreme precipitation

Projected change in 0.05 AEP daily precipitation using Localized Constructed Analog downscaled data

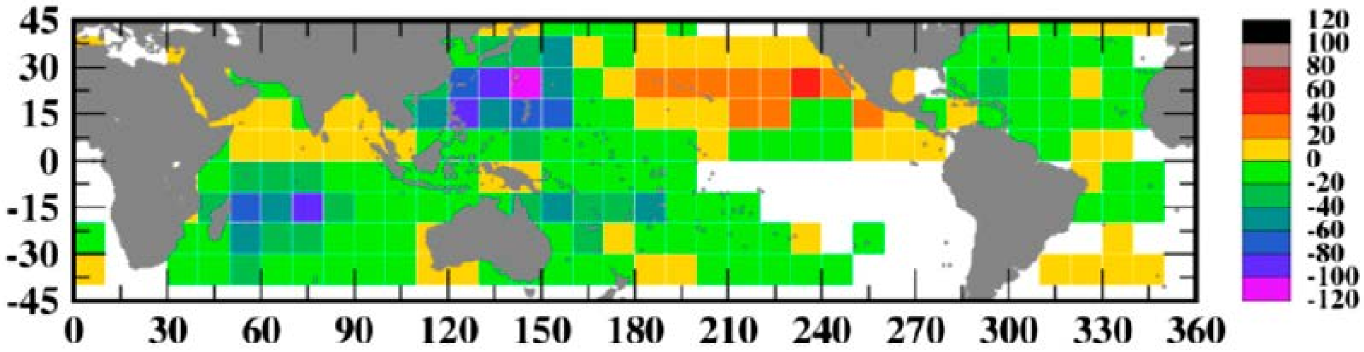


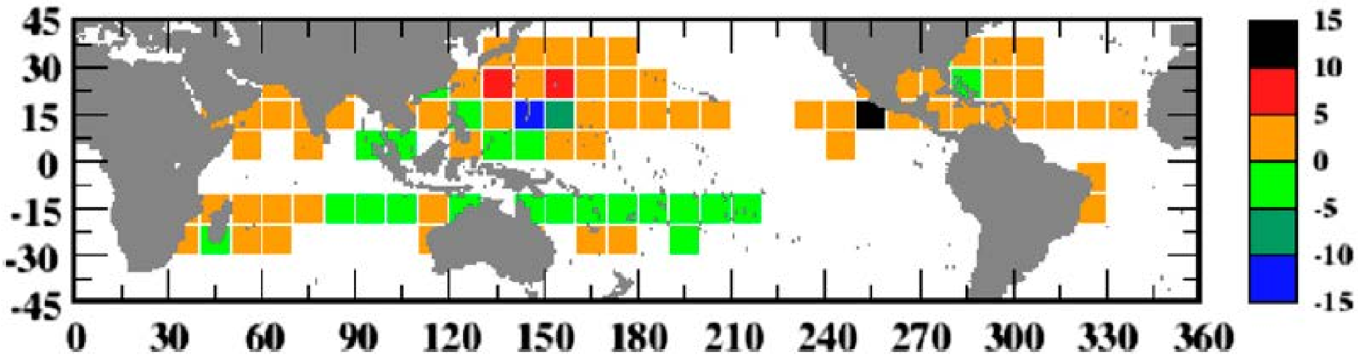
(Easterling et al. 2017)

Projected changes in tropical cyclones

Simulations by GFDL hurricane model (6 km) used to downscale the HiRAM model (50 km)

Change in occurrence (#/decade) of all storms (upper) and cat 4-5 storms between late 21st century and present based on RCP4.5

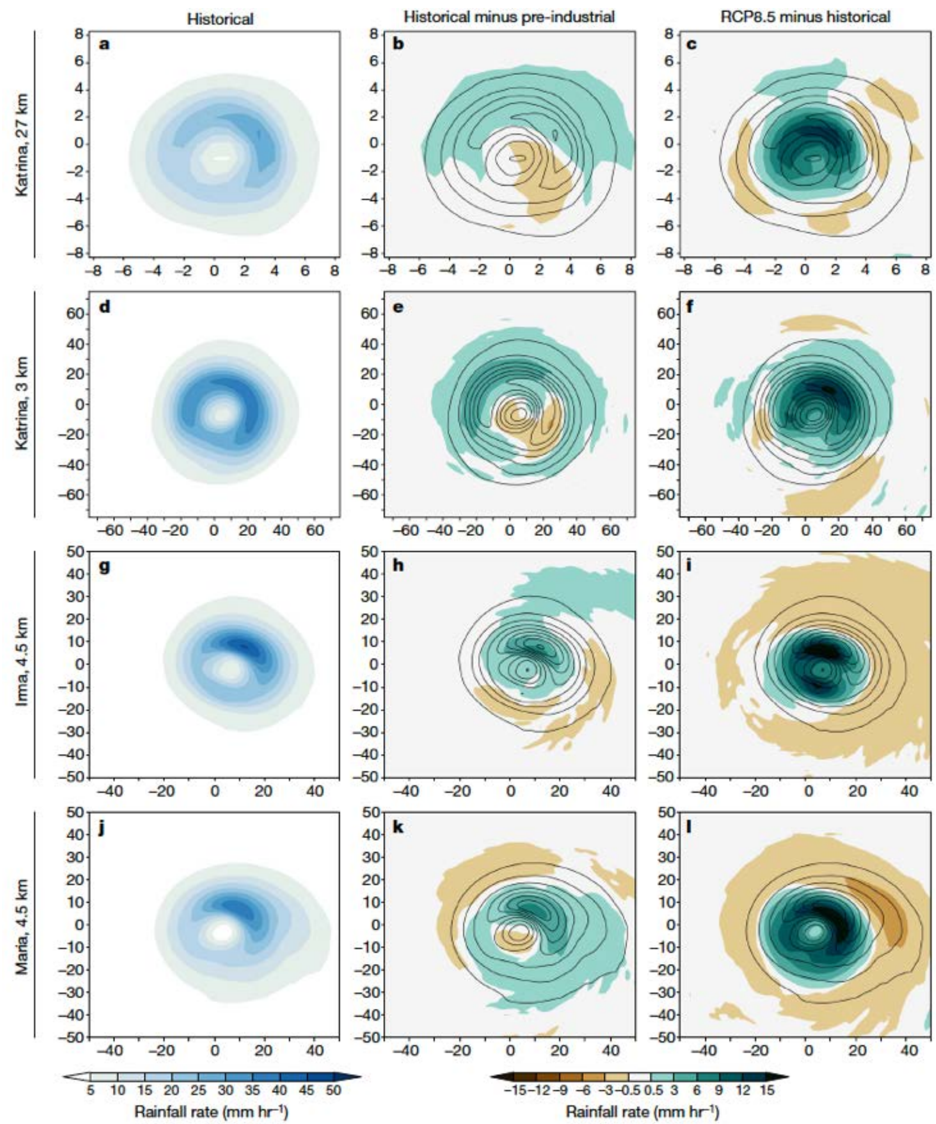




(Knutson et al. 2015 J. Clim.)

Projected changes in tropical cyclones

- WRF model used to simulate selected historical TCs
- Perturb boundary conditions to simulate the same storms under pre-industrial and RCP8.5 scenario
- Climate change so far did not change TC intensity, but warming in the future robustly increase TC intensity
- TC rainfall increases from pre-industrial to present and from present to future

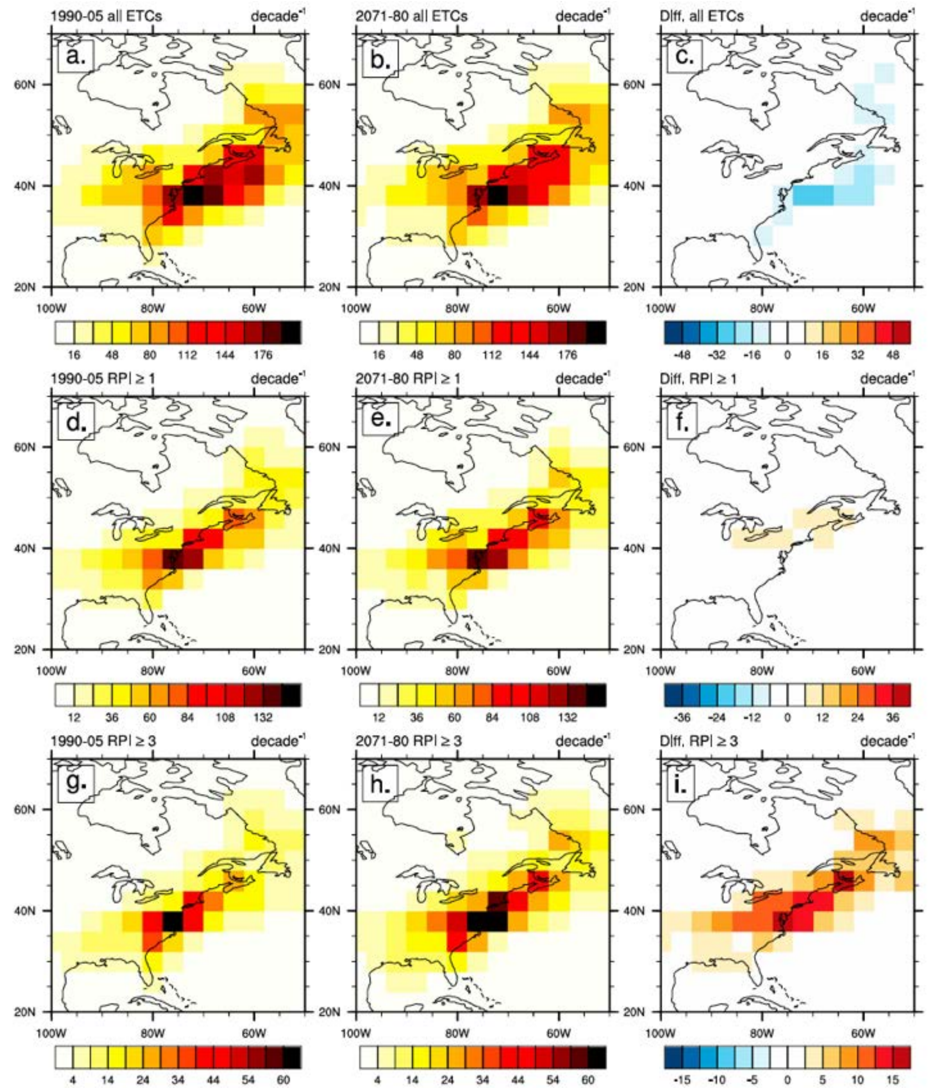


(Patricola and Wehner 2018 Nature)

Projected changes in extratropical cyclones

- Analyze CESM LENS simulations for RCP8.5
- Track ETCs in the simulations and define an RPI index that applies area and population weightings to the precipitation
- Track density decreases when all storms are considered
- Track density increases mainly for intense storms

End of century (2071–2080) minus present day (1990–2005)

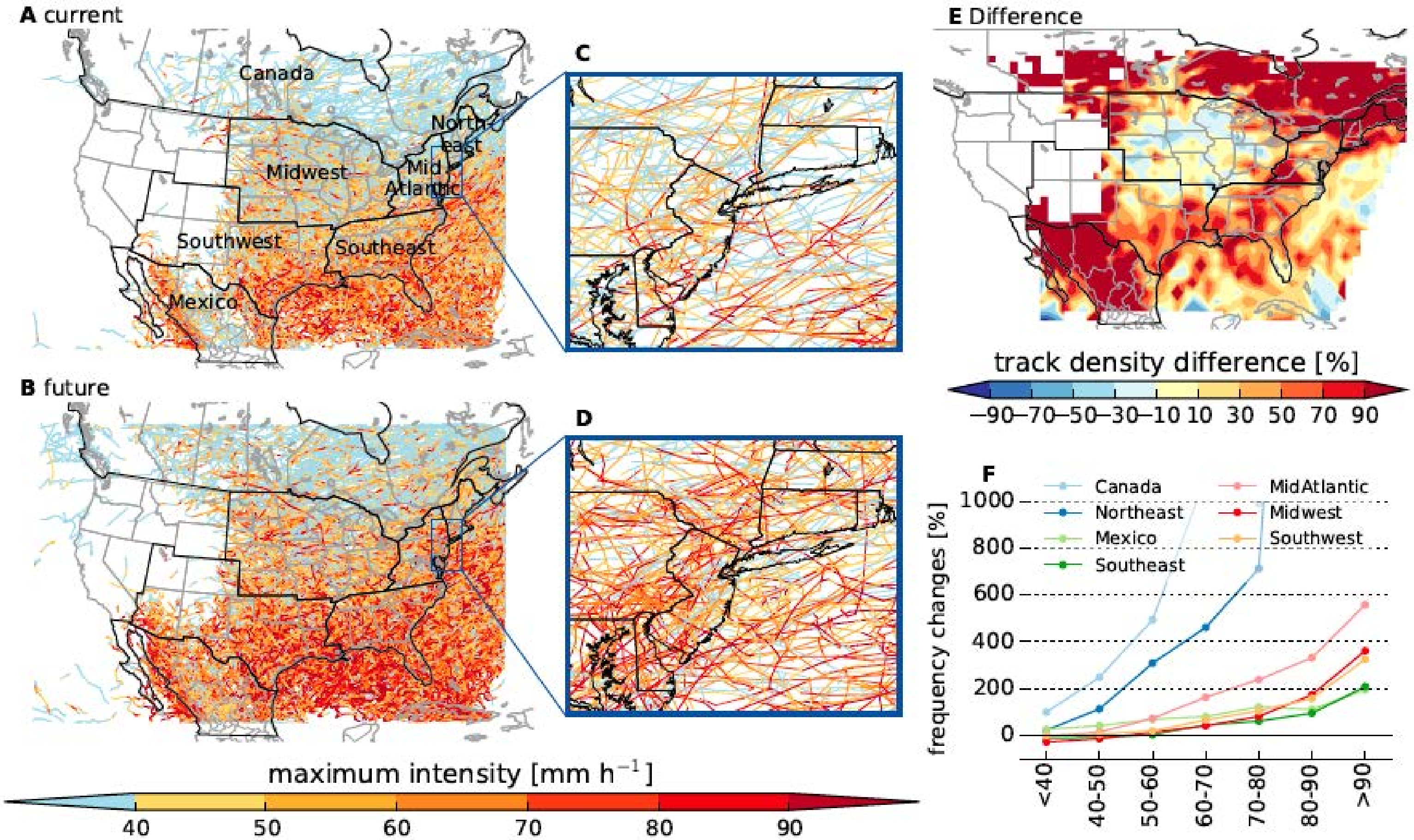


(Zarcycki 2018 GRL)

Projected changes in convective storms

Larger increase in frequency for more intense storms

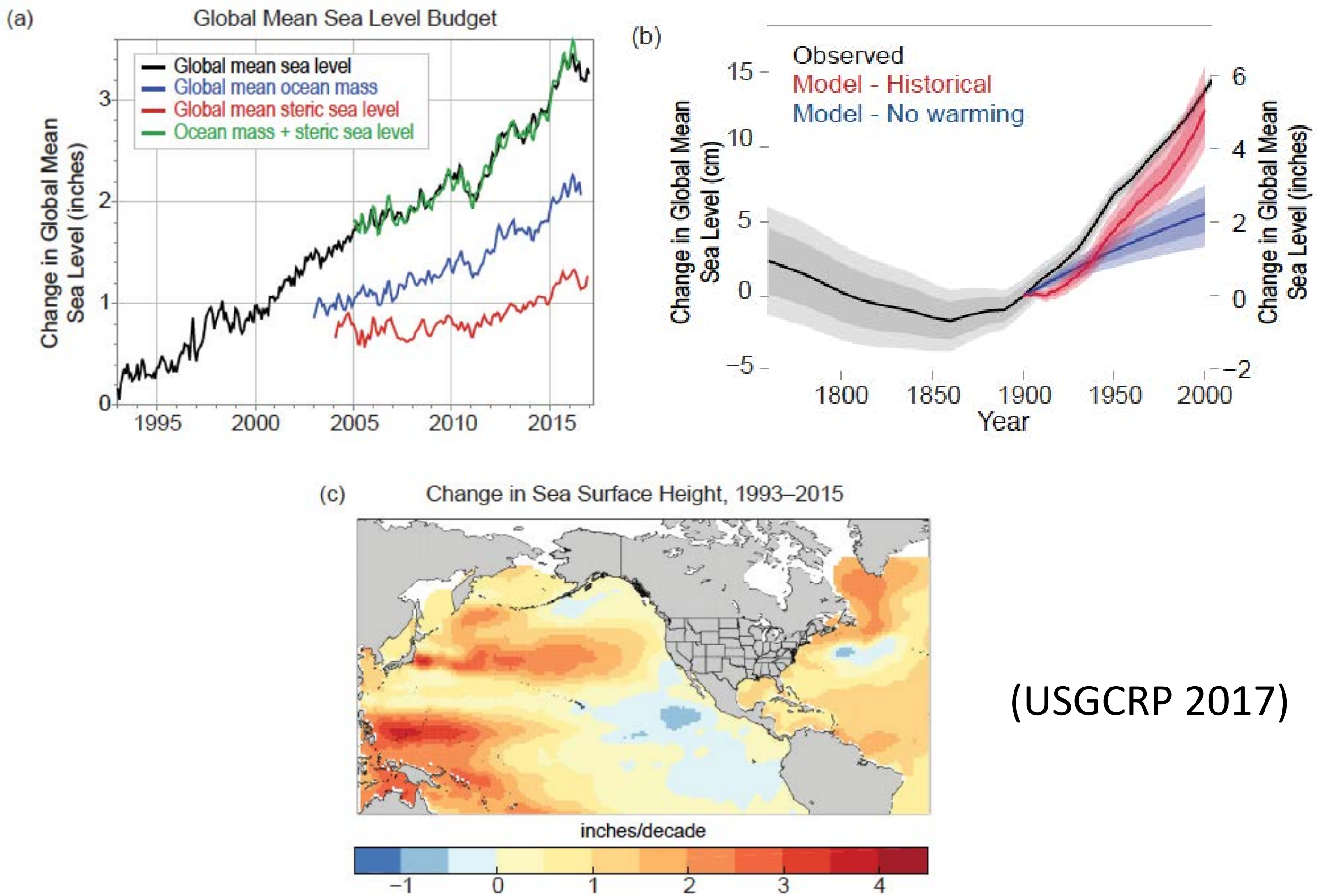
MCS tracks at the end of century (2071-2100) under RCP8.5 and present day (1976–2005)



(Prein et al. 2017 Nature Clim. Change)

Historical changes in global and regional sea level

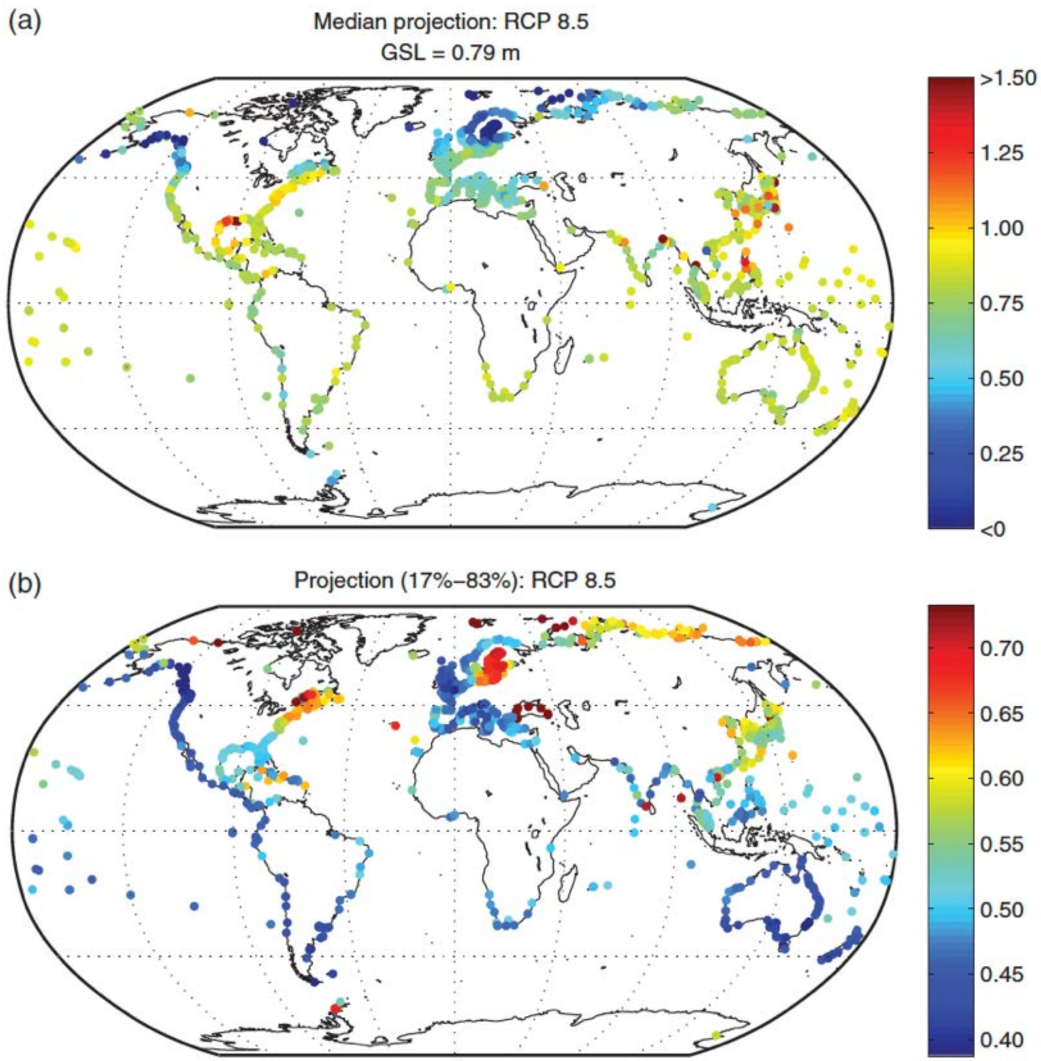
The higher LSL rise in northeastern U.S. has been attributed to land subsidence induced by GIA and weakening of the Gulf Stream that may be related to the weakening of the Atlantic meridional overturning circulation (AMOC)



(USGCRP 2017)

Projection of future sea level

Local sea level rise (m) in 2100 under RCP8.5

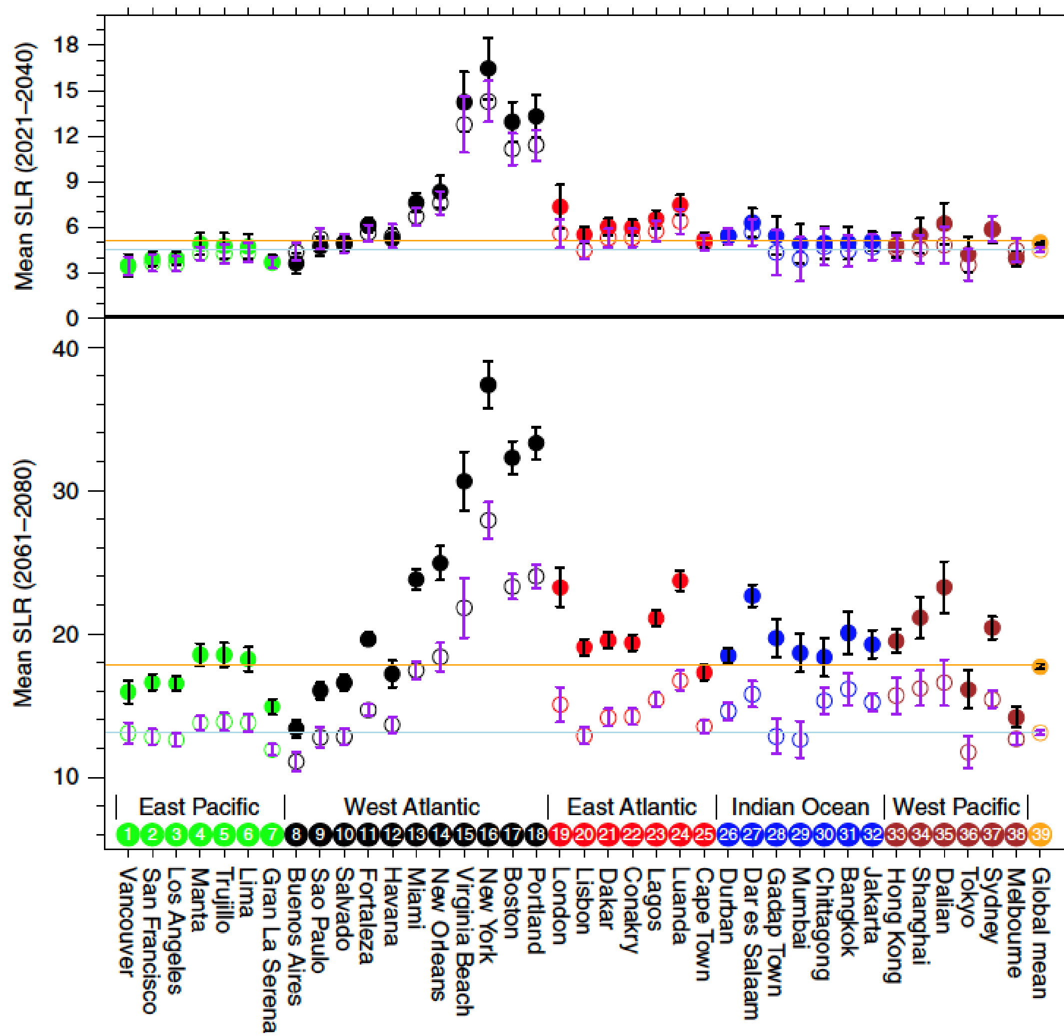


(Kopp et al. 2014 Earth's Future)

Projection of future sea level

- Analyze CESM LENS simulations for RCP4.5 (open circles) and RCP8.5 (solid dots)
- Cities along the NE will experience the largest local sea level rise compared to other cities around the world
- SLR increases from RCP4.5 to RCP8.5
- The large SLR in the NE is related to weakening of the AMOC by freshening (larger increase in P than E and melting of sea ice)

Twenty-year mean sea-level rise relative to the mean of the 1986–2005

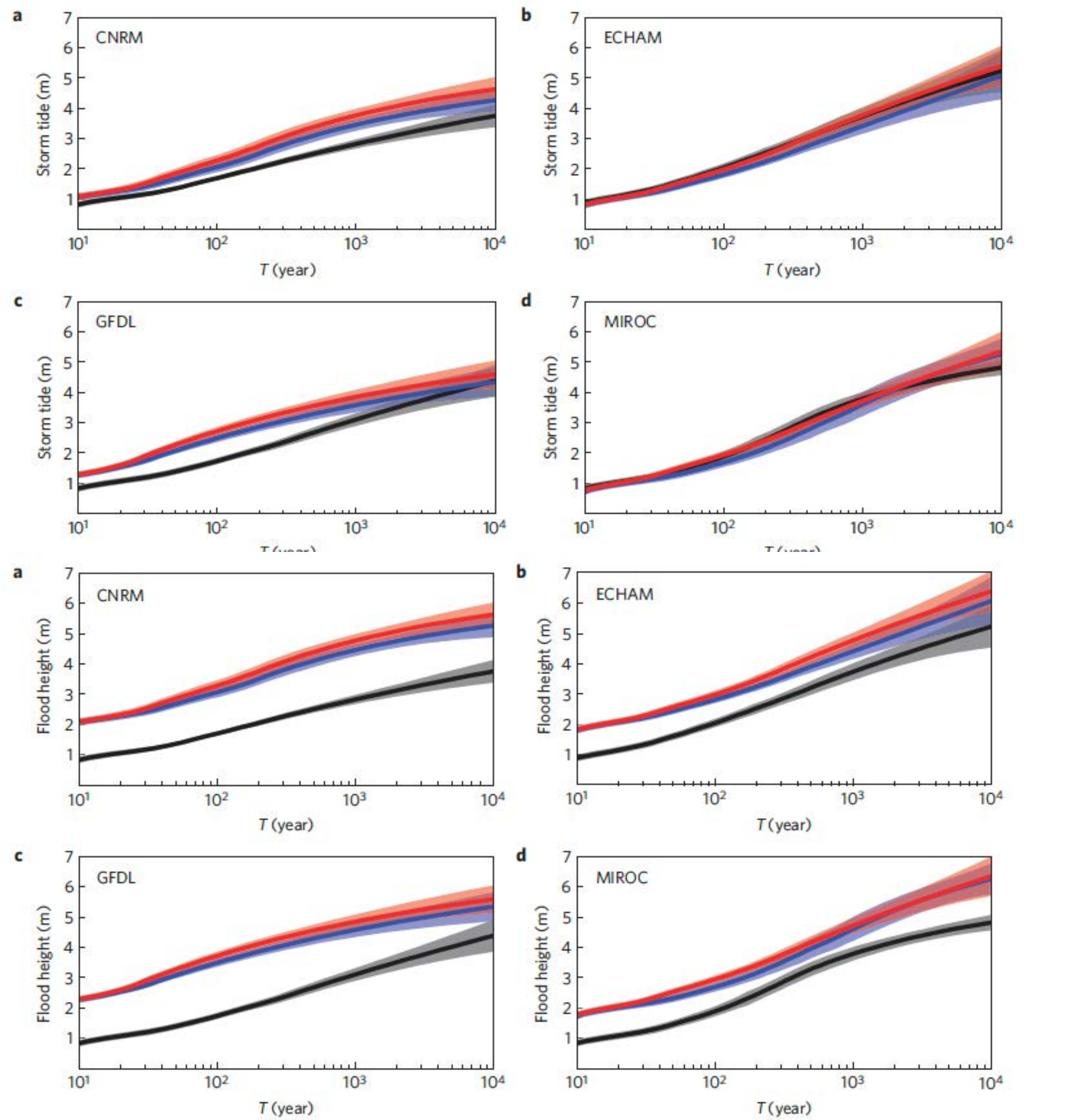


(Hu and Bates 2017 Nature Commun.)

Projection of storm surge and flood height

Estimated storm tide return levels for the Battery. Black (present - 1981-2000), blue (A1B - 2081-2100) and red (A1B with R_o increased by 10 percent and R_m increased by 21 percent). Shade shows the 90% confidence interval.
*A1B ~ RCP4.5

Estimated flood return levels for the Battery. The sea-level rise for the A1B climate is assumed to be 1 m.

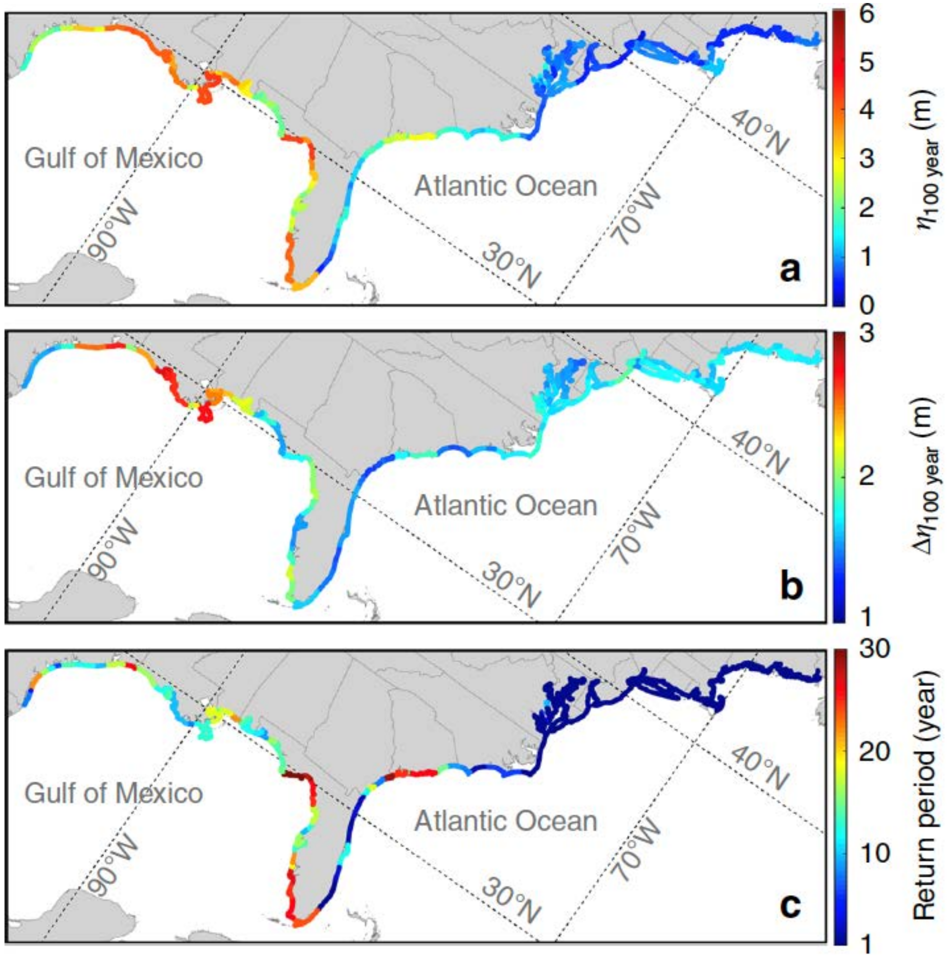


(Lin et al. 2012 Nature Clim. Change)

Projection of storm surge and flood height

- Using a similar method as Lin et al. and Garner et al., but extending the TC and hydrodynamics modeling over the entire U.S. coast along the Gulf of Mexico and Atlantic
- Use 6 CMIP5 models (CCSM4 GFDL5, HadGEM5, MIROC, MPI5, MRI5) with RCP8.5 scenario and weigh the models based on skill in simulating storm tide
- Use probabilistic SLR projections
- Also compare TC vs. SLR effects on storm tide

100-yr flood height will have a return period of 1-yr in the east coast by end of this century



(Marsooli et al. 2019 Nature Commun.)

Projection of storm surge and flood height

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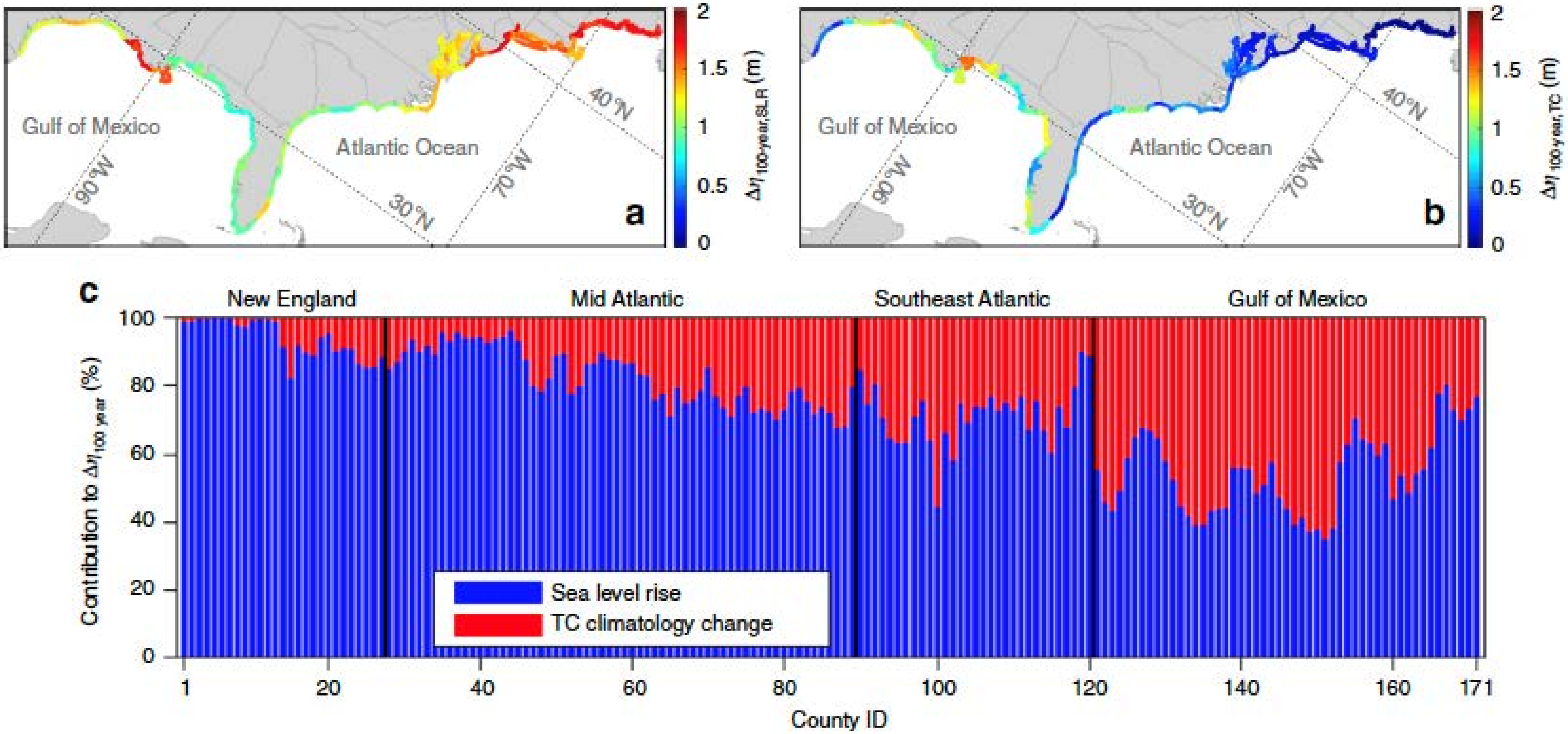
SLR dominates future changes in storm tide in the NE U.S. mainly because LSR is much larger in the NE than in Gulf of Mexico, but also TC changes such as maximum winds and intensity-size are smaller



(Marsooli et al. 2019 Nature Commun.)

Hydrologic characteristics of the Northeast region

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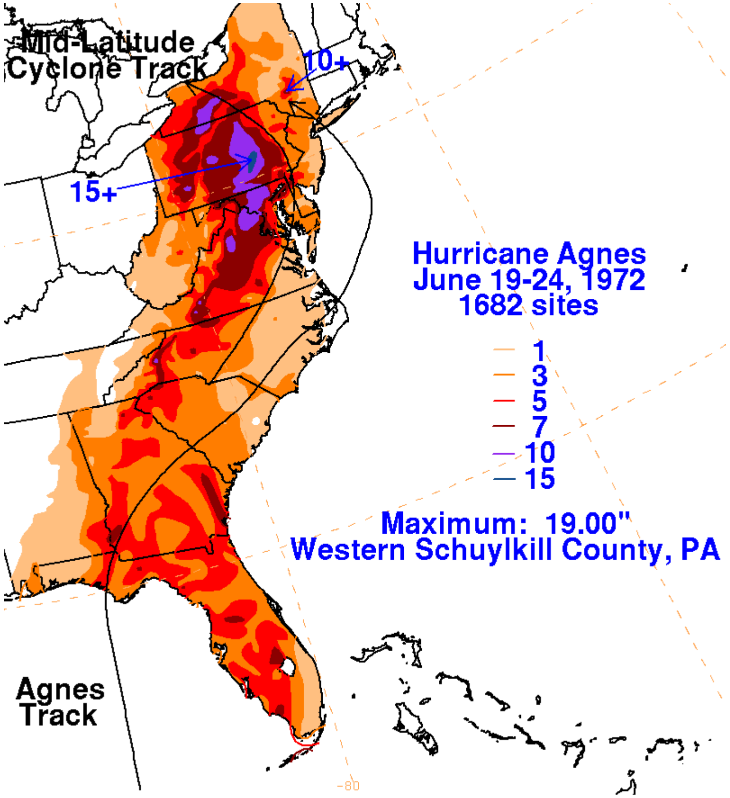
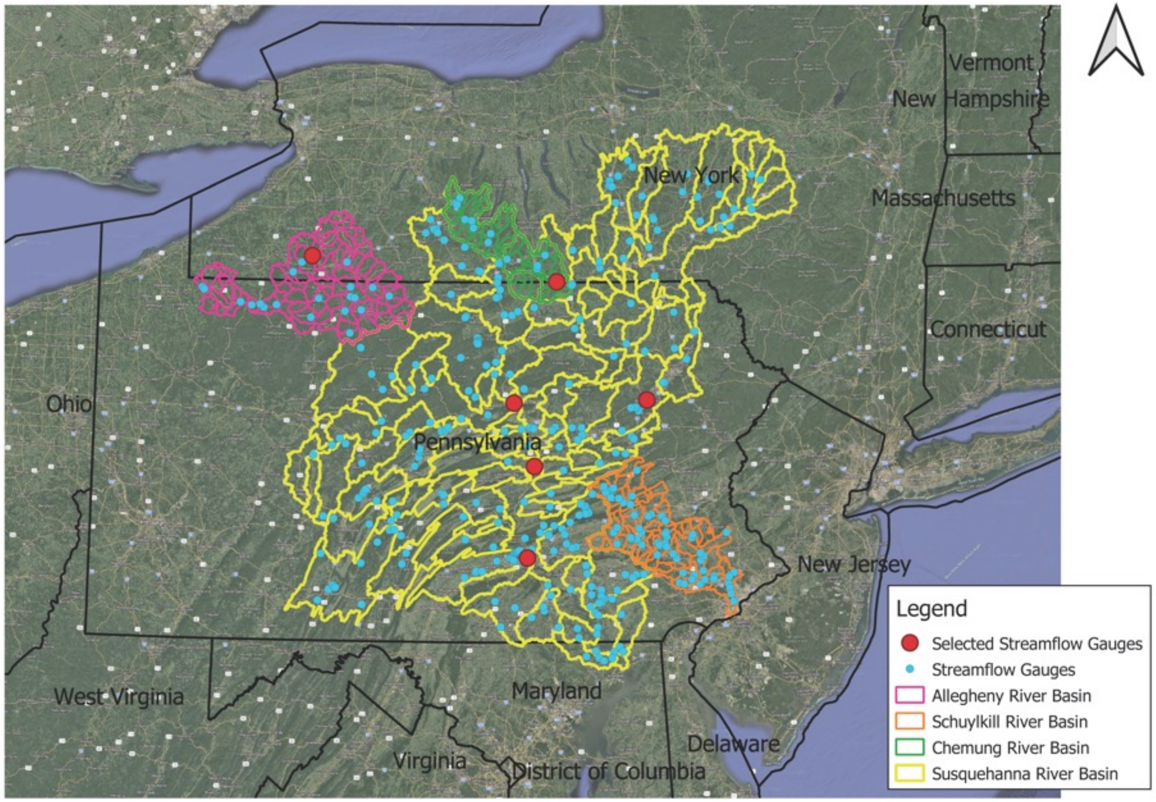
- Floods in the northeast region can be produced by
  - locally heavy precipitation
  - regionally persistent rainfall
  - slow-moving extratropical cyclones
  - remnants of tropical cyclones during summer and fall, and
  - late spring rainfall on snowpack.
- Examples of historical floods
  - June 1972 floods from Hurricane Agnes
  - April 2005 floods
  - April 2007 floods
  - February-March 2010 floods
  - February-September 2011 floods
  - October 2012 floods from Hurricane Sandy

June 1972 floods from Hurricane Agnes

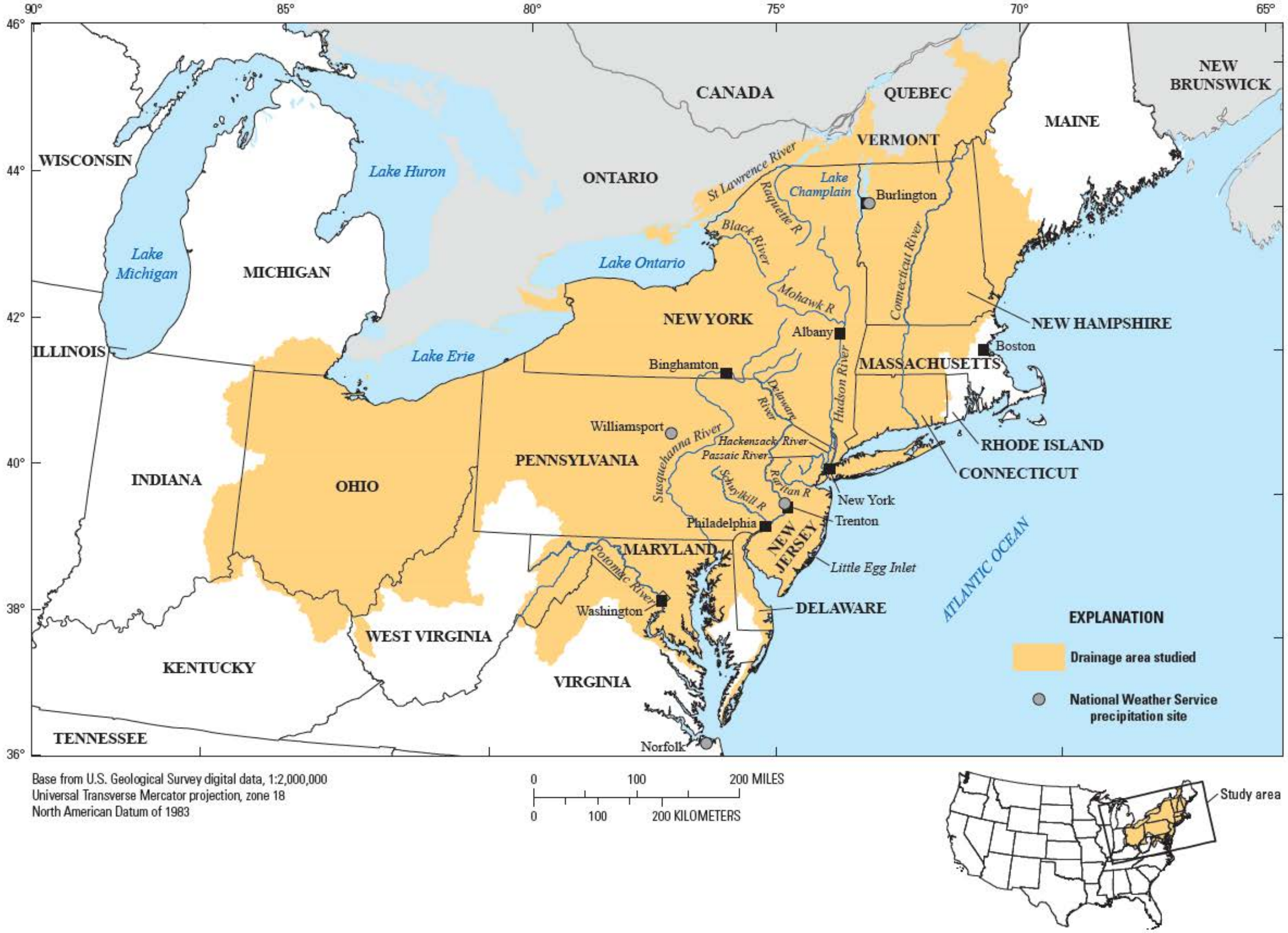
- Precipitation and flooding
  - Extensive flooding in the northeast U.S., particularly in the Susquehanna River Basin
  - Schuylkill River at Philadelphia, PA: 14.65 ft on 6/23 (recorded 14.7 ft on 8/24/1933)
  - Chemung River at Chemung, NY: 31.62 ft, over 7.5 ft higher than pervious record
  - Susquehanna River at Wilkes-Barre, PA: 40.91 ft (previous record 33.1 ft on 3/18/1865)
  - West Branch Susquehanna River at Willamsport, PA: 34.75 ft (previous record 33.57 ft on 3/18/1936)





February-September 2011 floods

- Precipitation and flooding
  - Widespread flooding in the northeast U.S. during 2011
  - Flooding occurred in the months February through May and July through September



October 2012 floods from Hurricane Sandy

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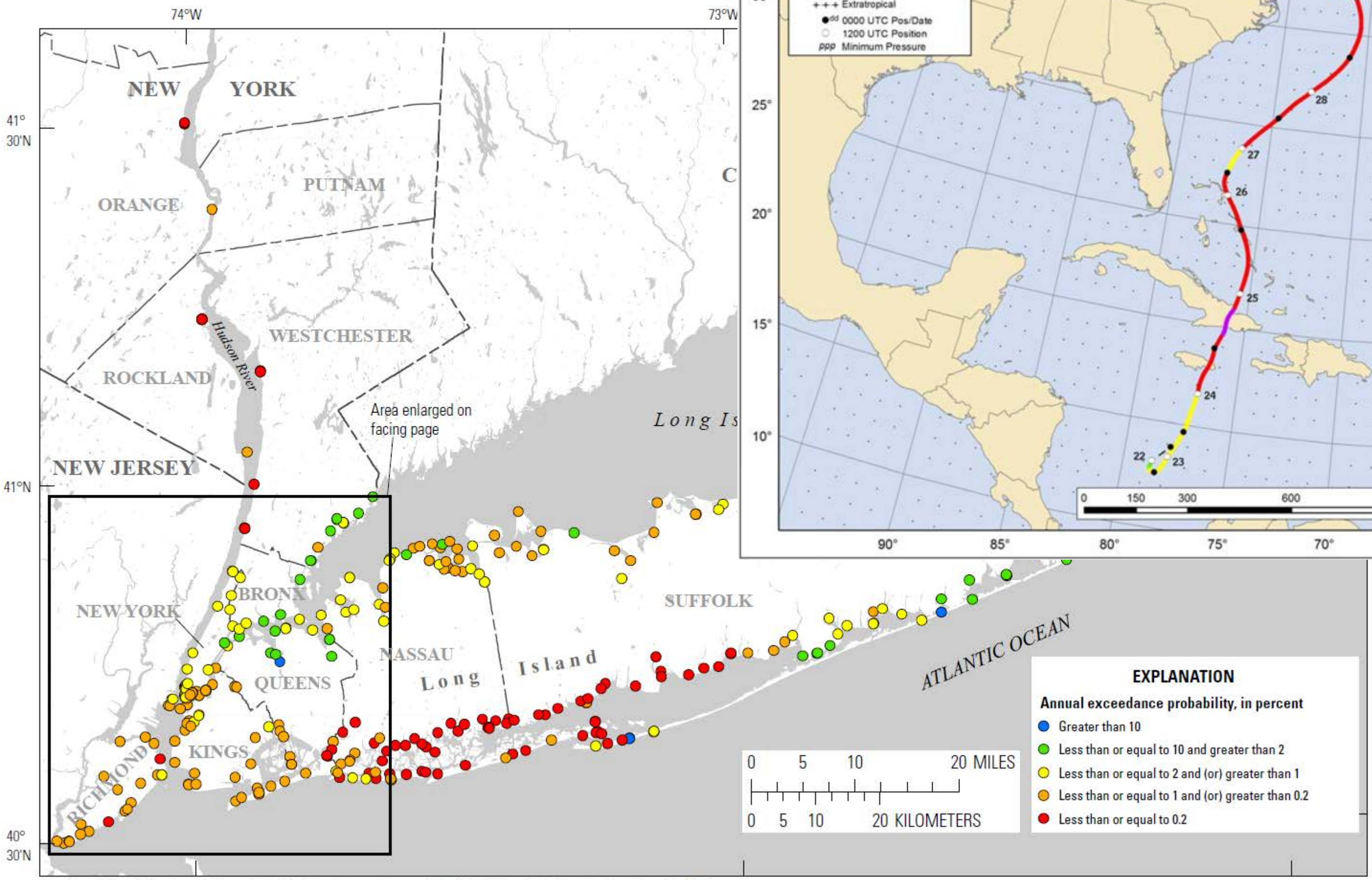
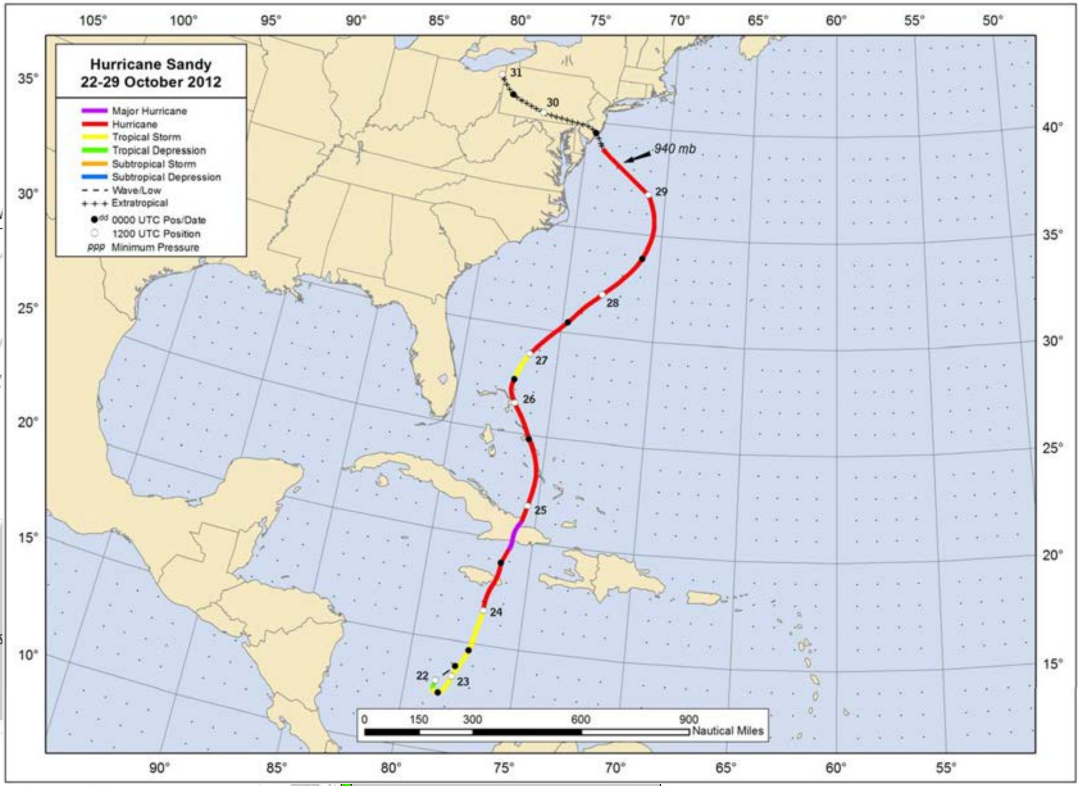
- Sandy floods



Base from National Oceanic and Atmospheric Administration medium-resolution 1:70,000-scale digital vector shoreline data, 1994
Universal Transverse Mercator, zone 18N projection



Observed and Predicted Changes in Streamflow in the Northeast Region

- Observed Changes
  - The northeast U.S. experienced a dry period in the 1960 and wet periods in the 1970s and 2000s. The mean annuals cycle of streamflow for three river basins in the northeast U.S. seem to be caused by annual cycles of evapotranspiration and snowmelt, not precipitation. Some, although weak, correlations between NAO, AO, and AMO and the three river basins' hydrology exist, both in undisturbed, small and larger, more regulated drainage areas.
  - The streamflow peak during spring shows a clear shift to earlier in the season, by as much as 10 days in 2014 compared to mid-20th century. There seems to be periods in the historical record when frequency of floods increased-these periods occurred around 1970, 1990, and 1995.
- Projected Changes
  - The winter-spring mean temperature in drainage areas of selected tributaries to the St. Lawrence River, depending on their latitude, will cross the freezing threshold during various decades of the 21st century resulting in projected reduced snow to total precipitation ratio and large shifts of winter-spring center-volume date to earlier in spring.
  - Peak streamflow magnitude is projected to increase and low flow magnitudes is projected to decrease in the northeast region as the 21st century progresses, particularly for RCP 8.5 scenario.

Observed Changes in Streamflow in the Northeast Region

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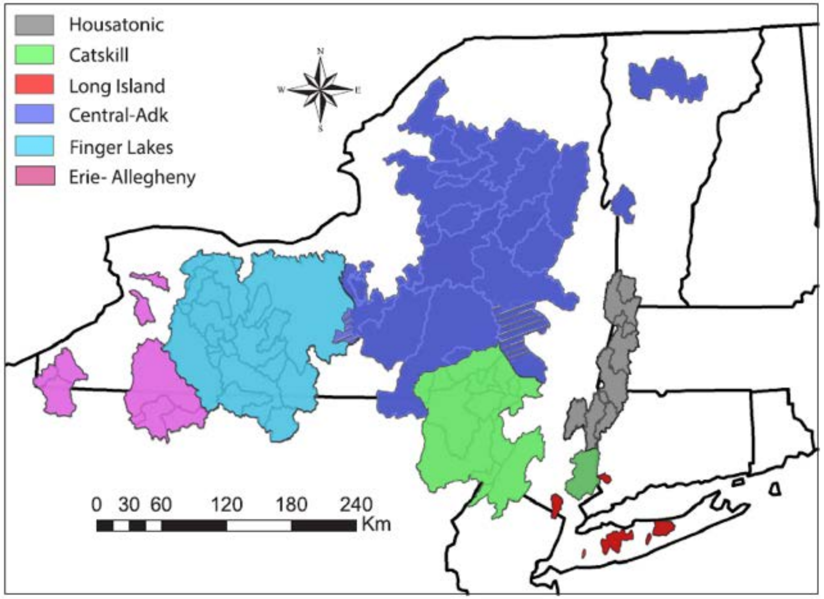
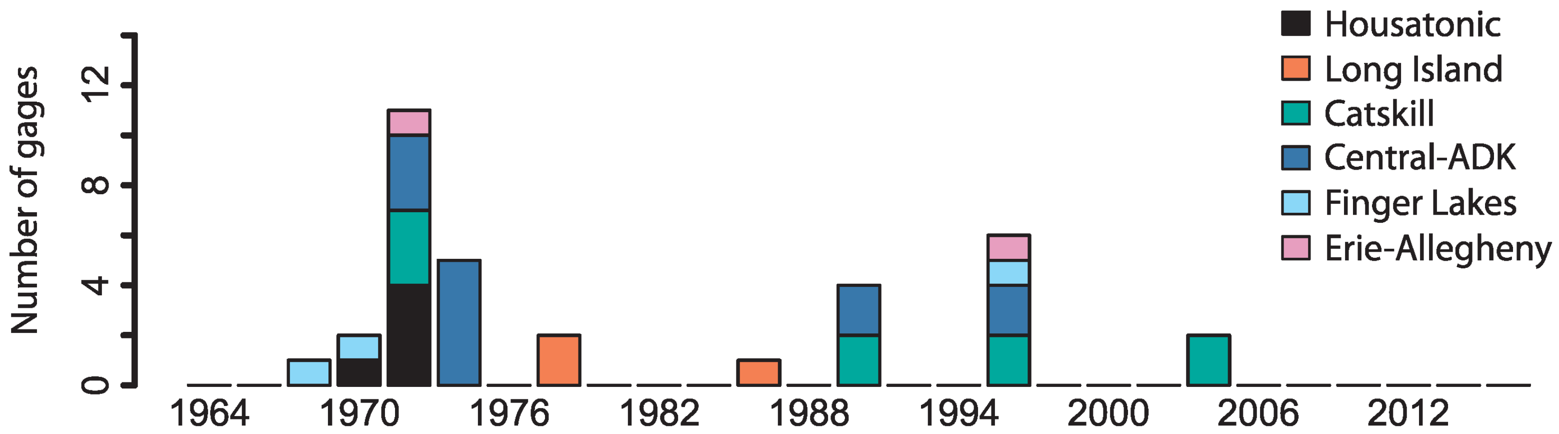
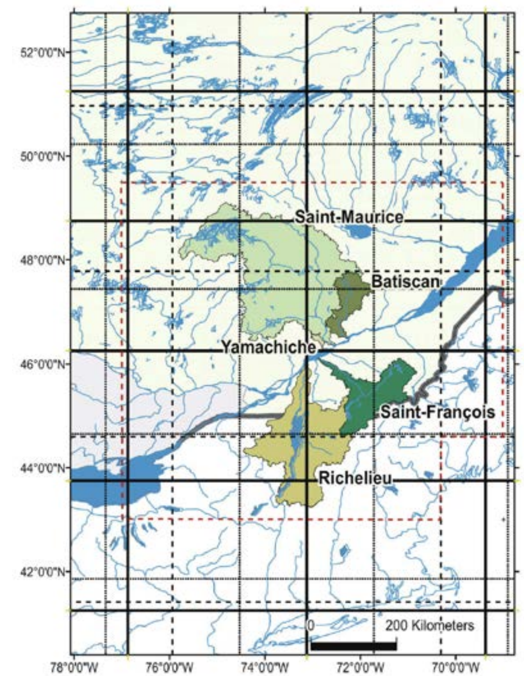
- Glas et al. (2019)
  - Correlations between historical streamflow and climate at mesoscale; 97 gauges; 16 undisturbed; six clusters used to represent topography-climate regions
  - Change point analysis of peaks-over-threshold data for the clusters indicated shifts to more frequent peaks in all clusters
  - Shifts occurred in 1968-73, 1990, and 1995

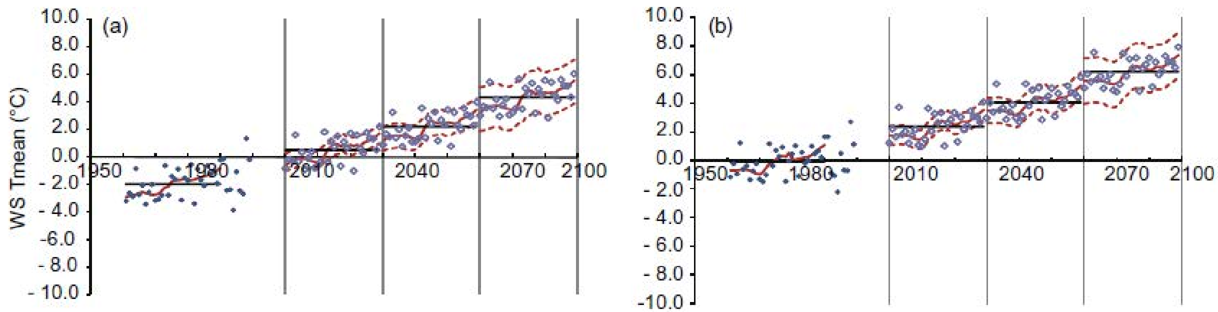




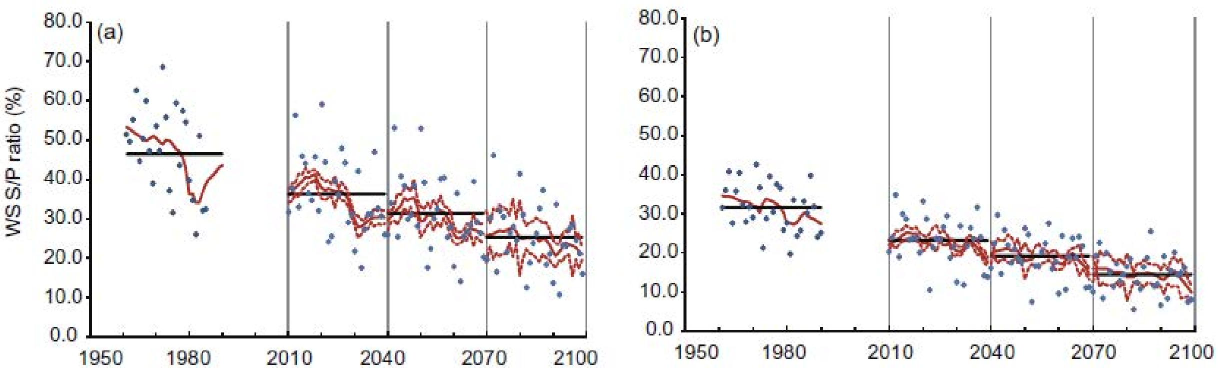
Projected Changes in Streamflow in the Northeast Region

- Boyer et al. (2010)
  - Changes in hydrology of tributaries to St. Lawrence River in Québec, Canada; 3 GCMs and 2 scenarios (SRES A2 and B2); projected daily climate series using perturbation factors
  - Lumped hydrologic model, Service Hydrométéorologique Apports Modules Intermédiaires (HSAMI) for 18 future hydrologic simulations

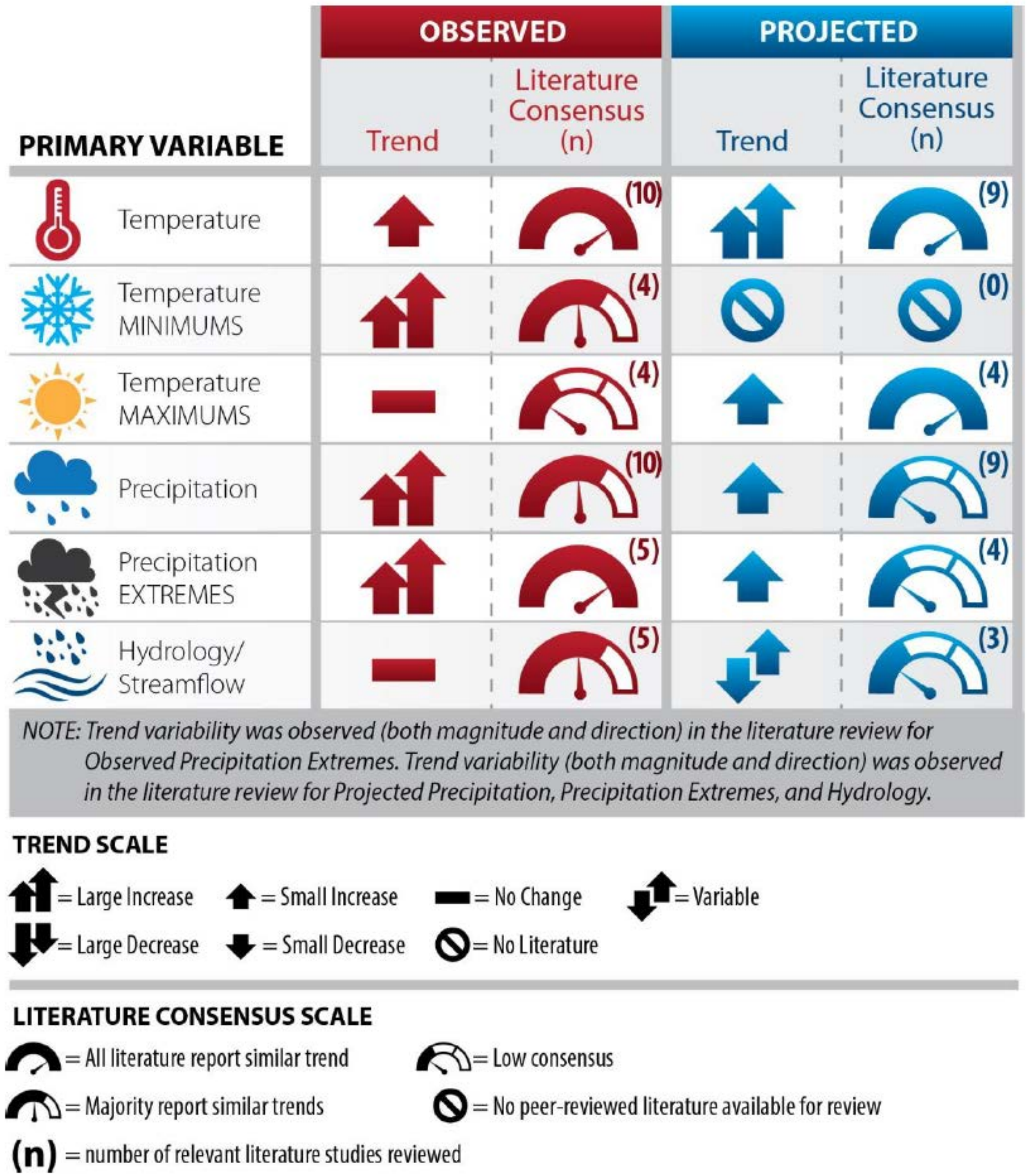




(a) St-François (b) Richelieu



Summary of observed and projected climate trends in USACE Water Resources Region 01



Contact Information

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