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Designing Resilient Transportation Infrastructure in a Changing Climate

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VIRTUAL | VIRTUEL
XVI WORLD WINTER SERVICE AND ROAD RESILIENCE CONGRESS
XVIe CONGRÈS MONDIAL DE LA VIABILITÉ HIVERNALE ET DE LA RÉSILIENCE ROUTIÈRE
XVI CONGRESO MUNDIAL DE VIALIDAD INVERNAL Y RESILIENCIA DE LA CARRETERA

PIARC Calgary Canada

Current Codes & Standards and Impacts of Climate Change

- Canada's transportation infrastructure is designed and evaluated using codes, standards and guides that are based on historical climatic data and climatic loads that do not consider the impacts of climate change
- Between 1948 and 2016, mean annual temperature increased by 1.7°C for Canada and 2.3 °C for northern Canada
- Canada's past and future climate is warming on average about double the magnitude of global warming.
- Precipitation is projected to increase for most of Canada with a shift toward less snowfall and more rainfall
- Current codes and standards assume climatic data and associated climatic loads as stationary (time-invariant) within the design life of transportation infrastructure systems. Climatic data and loads are not stationary

Current Codes & Standards and Impacts of Climate Change

- Regional differences in uncertainties or coefficients of variation of climatic data (e.g. wind and snow) lead to non-uniform levels of reliability across Canada using current uniform hazard design approach (e.g. 50-yr return nominal climatic load for all Canadian regions multiplied by a constant climatic load factor, e.g. 1.4 for wind and 1.5 for snow)

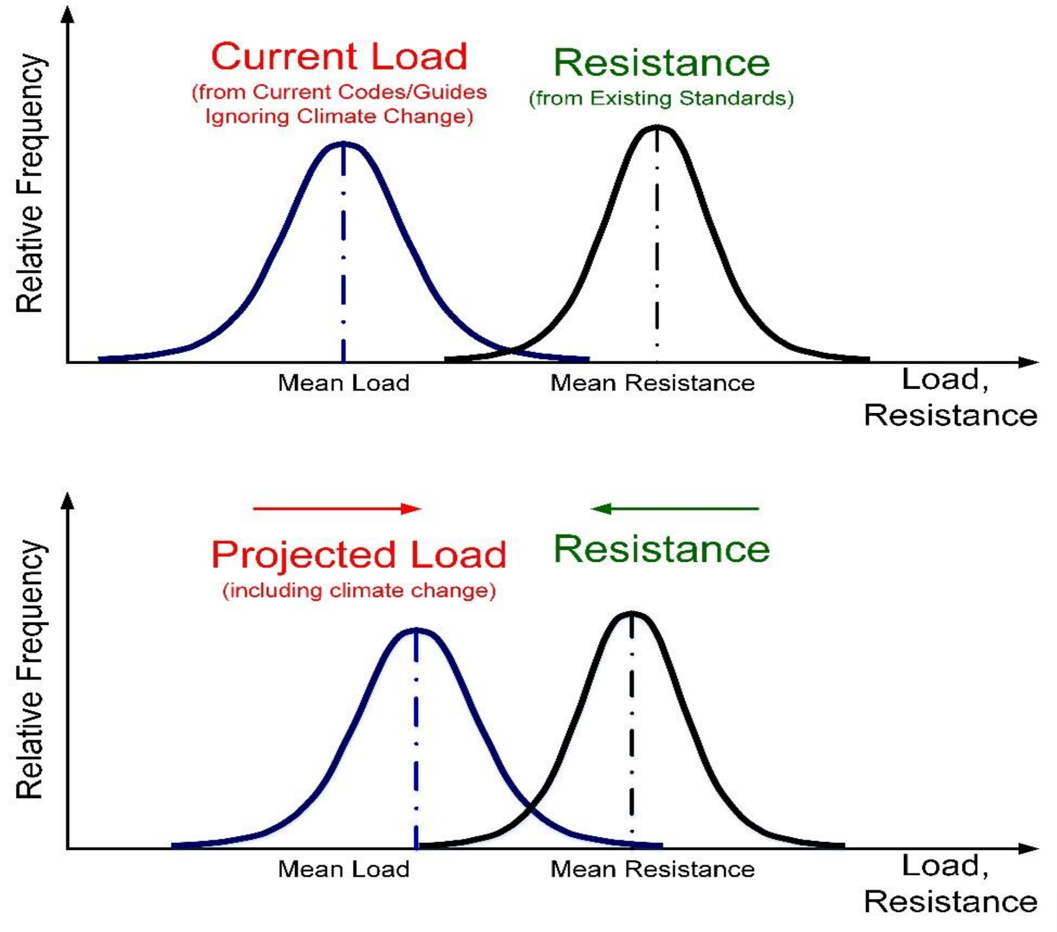
- Need to adopt uniform risk design approach for some transportation infrastructure systems by mapping the design-basis climatic parameter used in determining the required strength with a climatic load factor of 1.0 to ensure that infrastructure codes and guides yield more uniform and acceptable reliability across Canada (concept of ultimate return period)

- Need to define reliability and risk targets in a changing and non-stationary climate

Impacts of Climate Change

- Increased climatic loads on structures lead to reduced safety, serviceability and functionality
- Higher probability of failure of structures due to increased intensity and/or frequency of extreme weather events (floods, extreme heat, extreme winds)
- Increased rate of deterioration of structures due accelerated aging will yield reduced capacity and shorter service life (e.g. increased rate of steel corrosion- may follow Arrhenius model for temperature dependence of reaction rates)
- Increased disruption or loss of service / function
- Higher maintenance, rehabilitation, adaptation & replacement costs
- Climate change is a multi-billion dollar problem for Canada ($21 to $43 billion per year by 2050 according to NRTEE 2011)

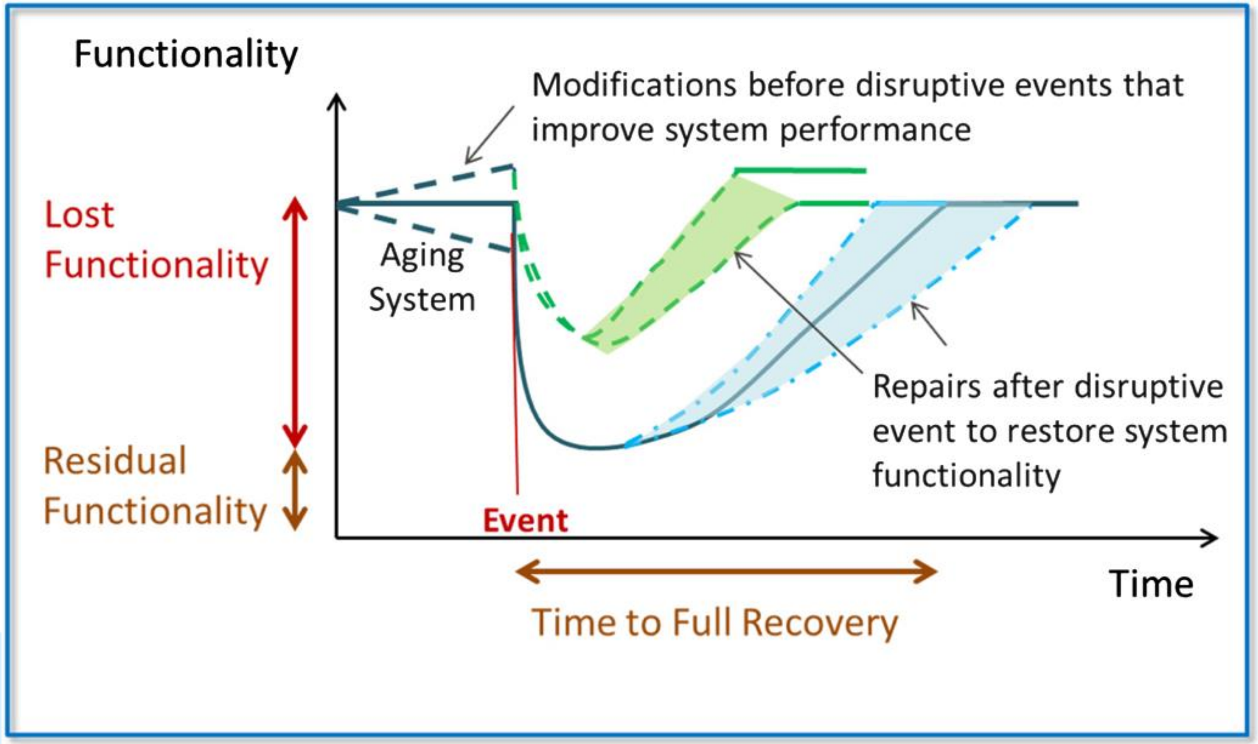
Impacts of Climate Change



- Climate change can lead to:
  - Increased climatic loads
  - Decreased resistance due to accelerated degradation
  - Increased load and decreased resistance
  - Increased probability/risk of failure

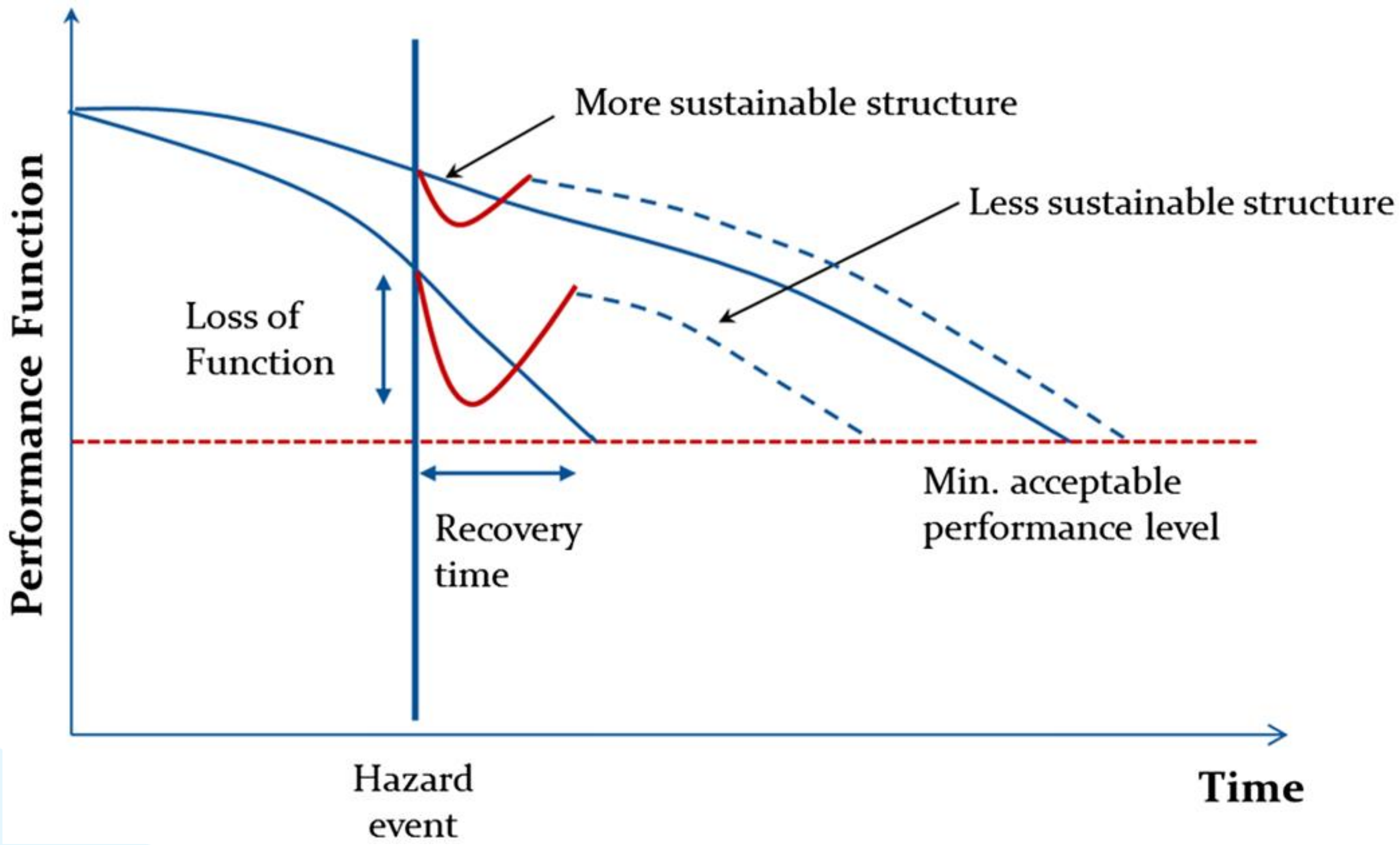
Climate-Resilient Transportation Infrastructure

- Need to develop codes, standards and guides for design and management of climate resilient transportation infrastructure based on future climatic loads that will satisfy safety, serviceability, durability and functionality and will minimize the loss of performance and level of service and will shorten the recovery time after disruptive weather events.



From Lounis & McAllister 2016

Climate-Resilient and Sustainable Transportation Infrastructure



From Lounis & McAllister 2016

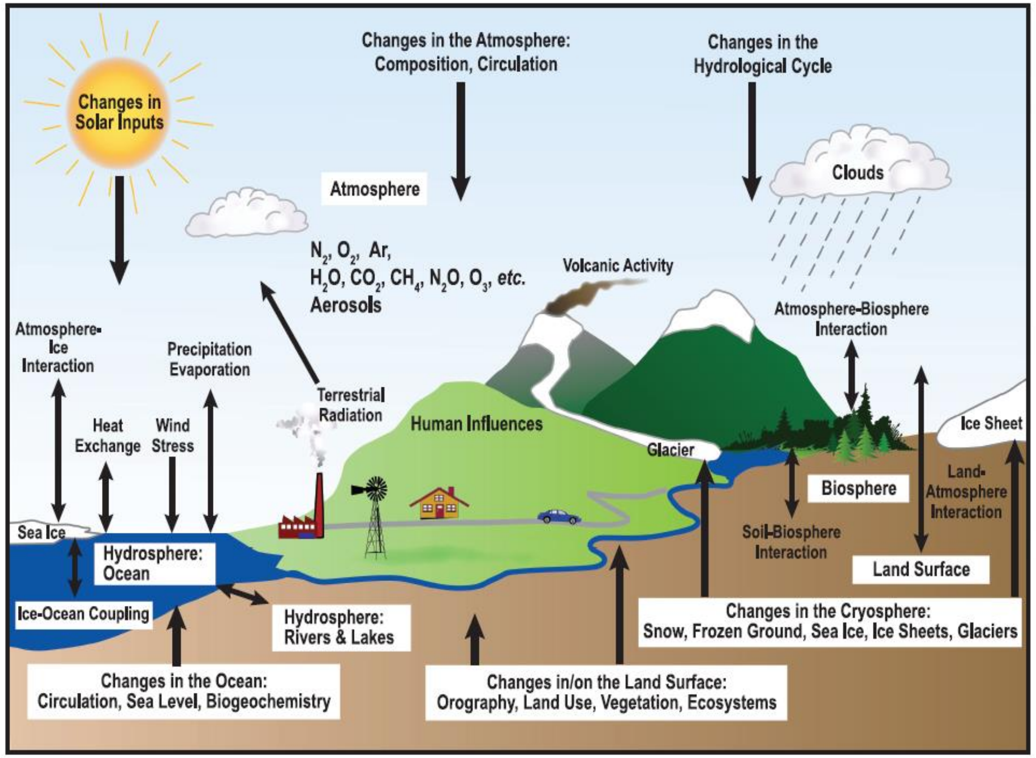
Climate-Resilient and Sustainable Transportation Infrastructure

Sustainability

Society	Economy	Environment
Public safety	Lifecycle cost	GHG emissions
Public health	Asset value	Resource conservation
Public security	Service level	Climate change adaptation
Social equity	Functionality	

From Lounis & McAllister 2016

Projections of Future Climatic Data & Loads



Climate system

Climate Models – Earth System Models

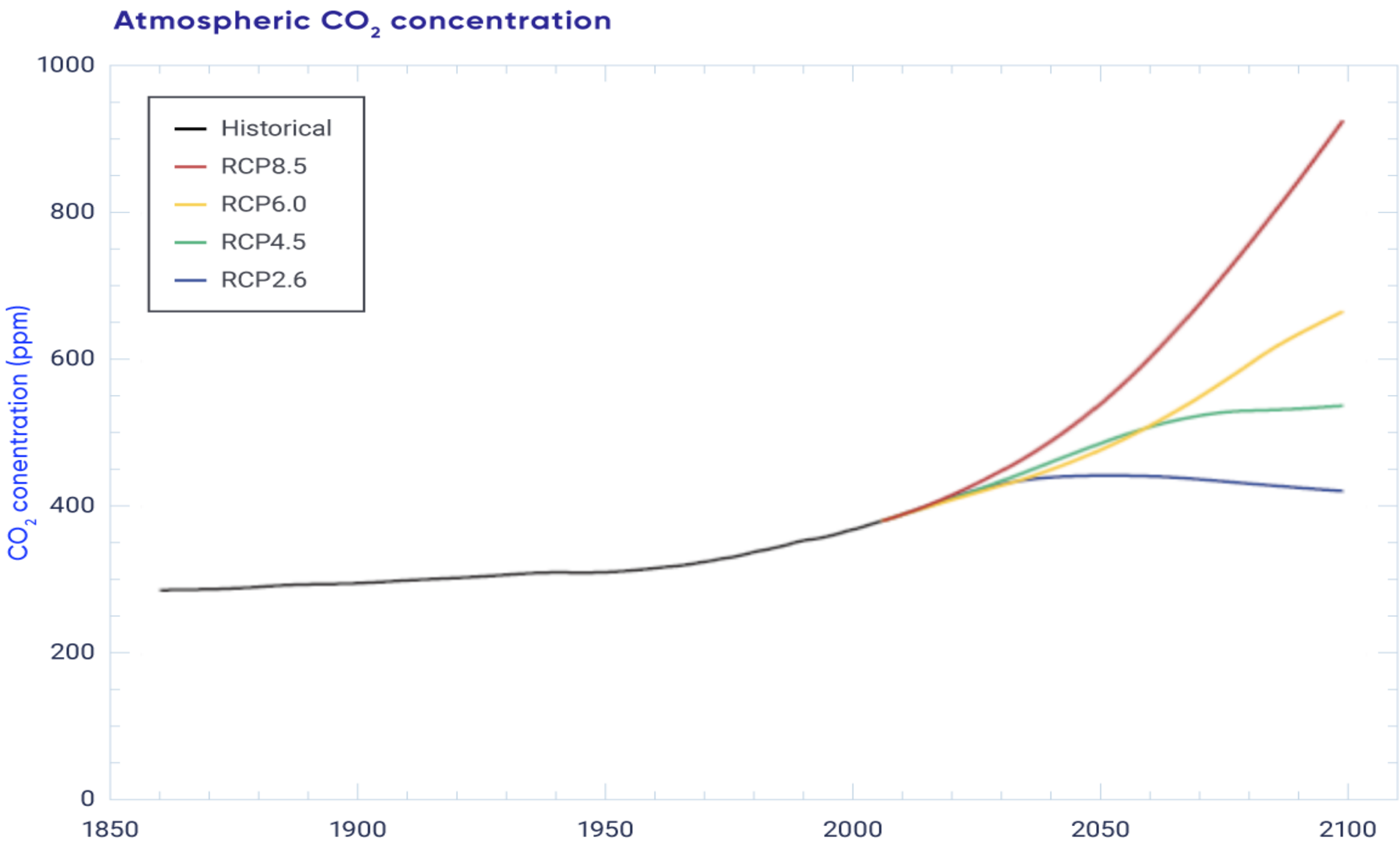
Climate Models project future climatic data under future RCP emission scenarios

Atmosphere | Ocean | Land | Ice | Carbon cycle

Projections of Future Climatic Data & Loads

- Partnership between National Research Council Canada, Environment and Climate Change Canada (ECCC), Pacific Climate Impacts Consortium PCIC) and Infrastructure Canada to develop future climatic data and loads for design of buildings and core public infrastructure
- Projections of future climatic parameters used in National Building Code of Canada (NBC), Canadian Highway Bridge Design Code (CSA-S6), and other infrastructure systems over 660 locations, including:
  - Mean temperature, Minimum mean daily temperature, Maximum mean daily temperature, January and July design temperature, degree days below 18°C
  - 15 min rain, one day rain, annual rain, annual total precipitation, annual relative humidity
  - Driving rain wind pressures
  - Snow loads
  - Ice accretion
  - Hourly wind pressures
  - Seven (7) global warming levels investigated: 0.5°C, 1.0°C, 1.5 °C, 2.0°C, 2.5°C, 3.0°C, and 3.5°C

Projections of Future Climatic Design Data- Emissions Scenarios



From CCCR (2019)

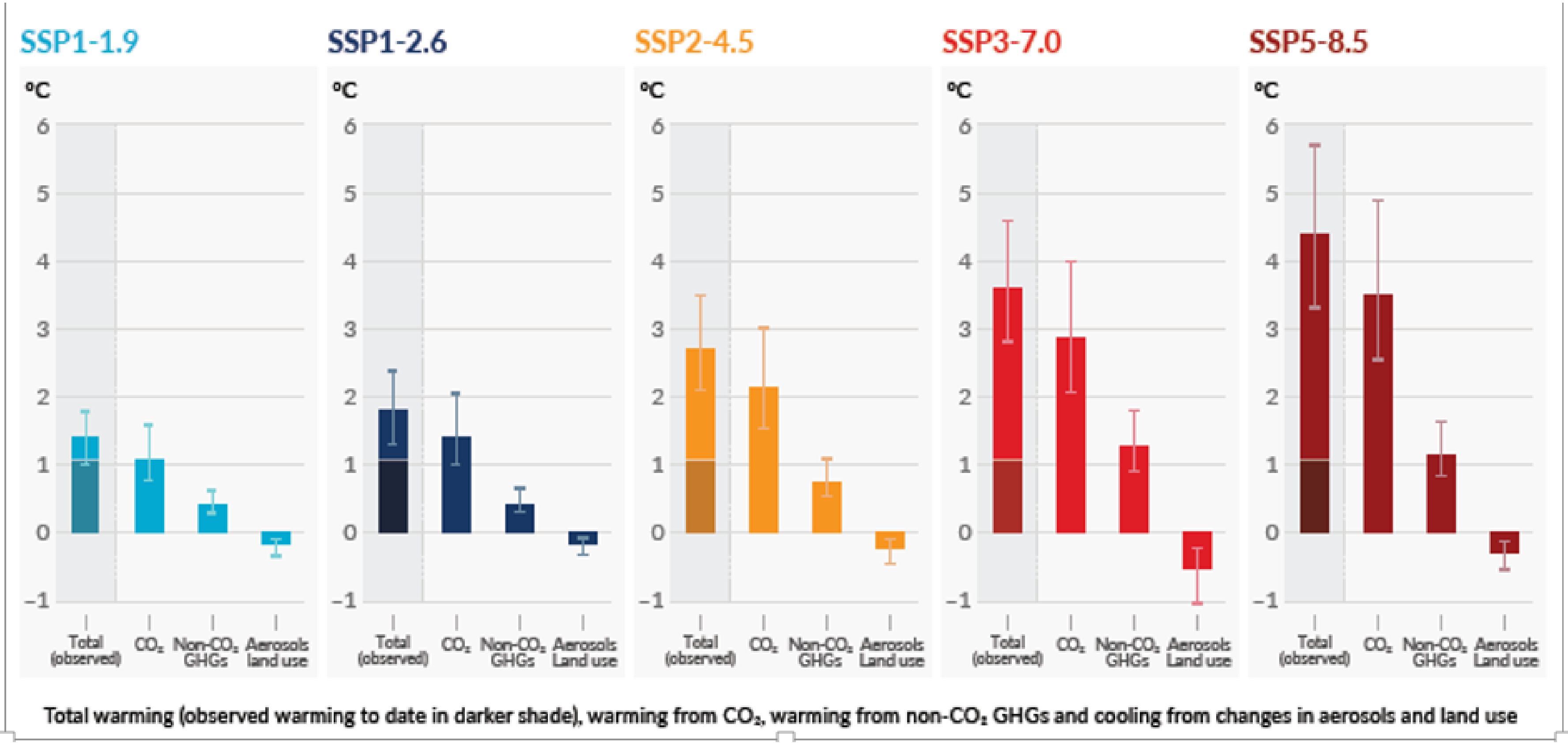
Projections of Future Climatic Design Data - Emissions Scenarios

- **<u>RCP-Representative Concentration Pathway:</u>** Provide future GHG emissions and concentration.

Global warming for end of century (2081-2100) relative to 1986-2005

Scenario	Warming
RCP2.6	0.3°C – 1.7°C
RCP4.5	1.1°C – 2.6°C
RCP6.0	1.4°C – 3.1°C
RCP8.5	2.6°C– 4.8°C

Projections of Future Climatic Design Data - Emissions Scenarios-IPCC 6th Assessment Report-Shared Socio-economic Pathway -SSP

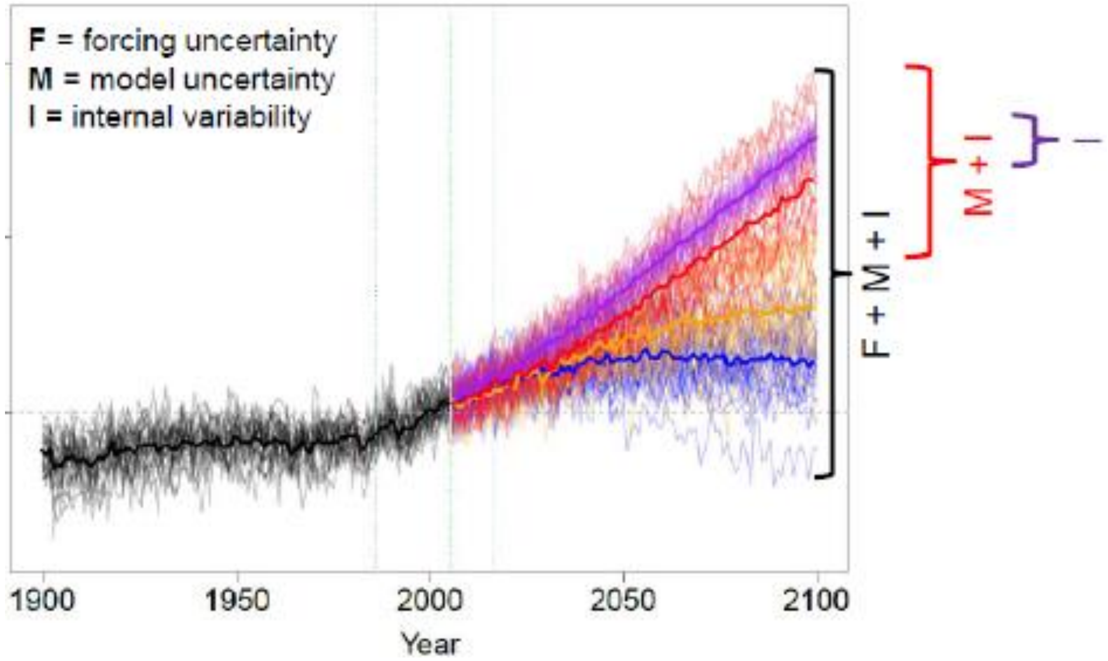


from IPCC 6th Assessment Report 2021

Projections of Future Climatic Design Data - Uncertainty

Sources of Uncertainty

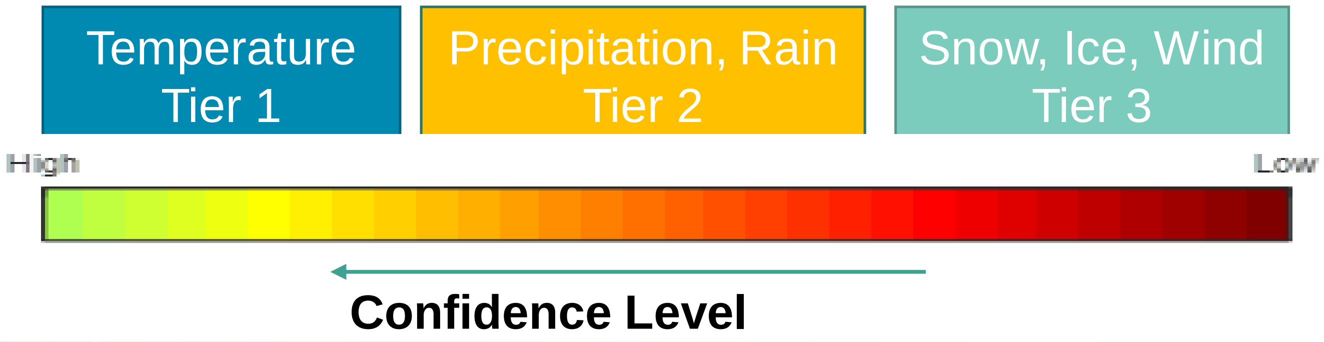
- **Climate Model**
  - ➢ Complex processes
  - ➢ Resolution
  - ➢ Parametrization
  - ➢ Details (e.g. land use)
- **Emission Scenario**
  - ➢ RCP Emission Scenario
- **Climate Internal Variability**
  - ➢ Chaotic climate system



- Cannon et al use output of CanRCM4 - Canadian Reginal Climate Model.
- 50 simulations of CanRCM4 under RCP8.5 are used.
- Resolution ~50km.

Projections of Future Climatic Design Data - Uncertainty

- Level of confidence in projections varies for different climatic variables - 3 tiers:
  - Tier 1 – Temperature: max & min mean daily temperature, hourly design temp
  - Tier 2 – Precipitation and moisture: (annual precip., annual max 1-day rain)
  - Tier 3 – Snow, ice accretion, wind, permafrost.
- Design value statistics
  - mean/cumulative
  - extreme
- Individual parameters or compound events.



Projections of Future Climatic Design Data - Impact of Design Life or Planning Horizon

Design Life / Planning Horizon : 50 years or less

- RCP8.5 scenario can be adopted.
- Incremental change in design values relative to those for RCP4.5 or RCP6.0 is not large for this time frame.

Design Life / Planning Horizon ≥75 years (Bridges)

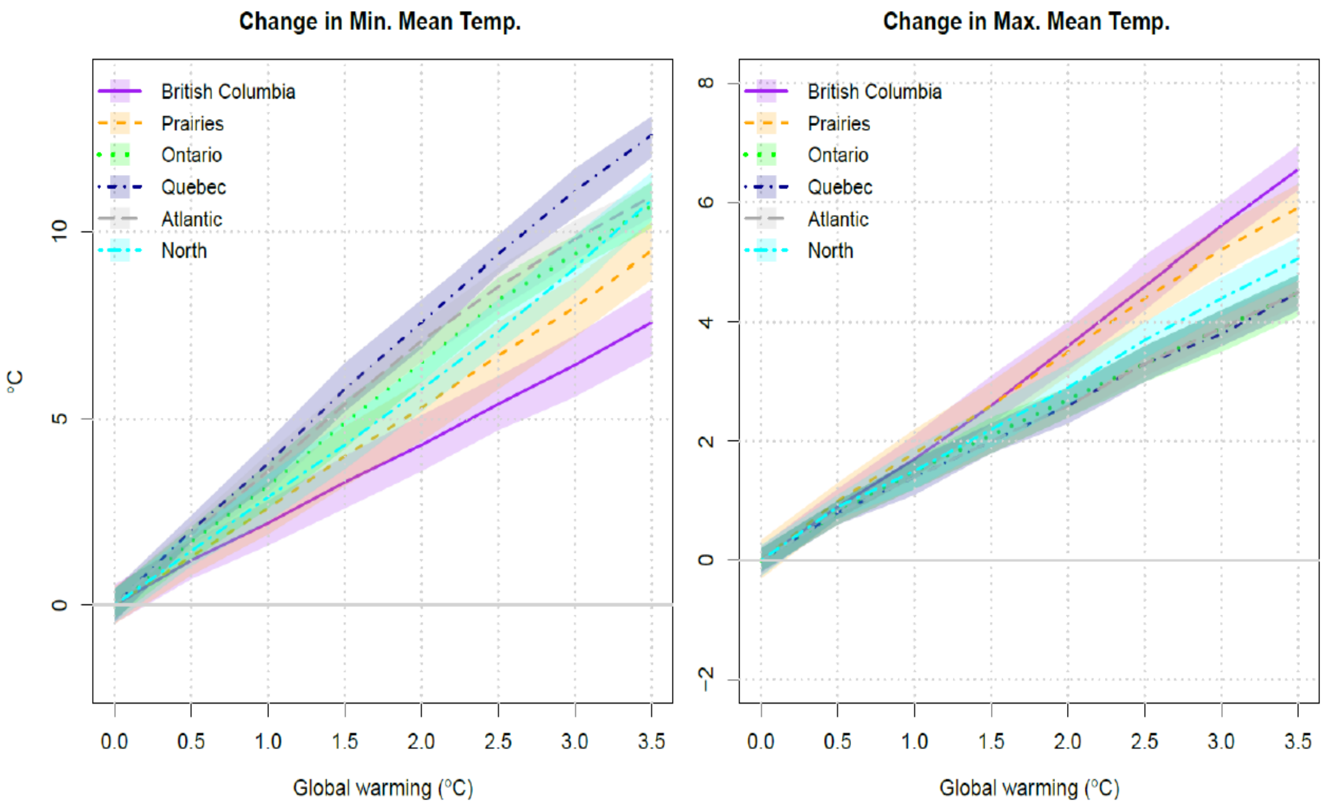
- Selection of RCP scenario is more complicated.
- Difference in design values of future climatic loads between various scenarios can be quite large especially near the end of century.

Projections of Future Climatic Design Data- Timing of Global Warming

ΔT	RCP8.5	RCP6.0	RCP4.5	RCP2.6
+0.5°C	2023			
+1.0°C	2035	2046		–
+1.5°C	2047	2070		–
+2.0°C	2059	2087	–	–
+2.5°C	2069	–	–	–
+3.0°C	2080	–	–	–
+3.5°C	2090	–	–	–

From Cannon et al. (2020)

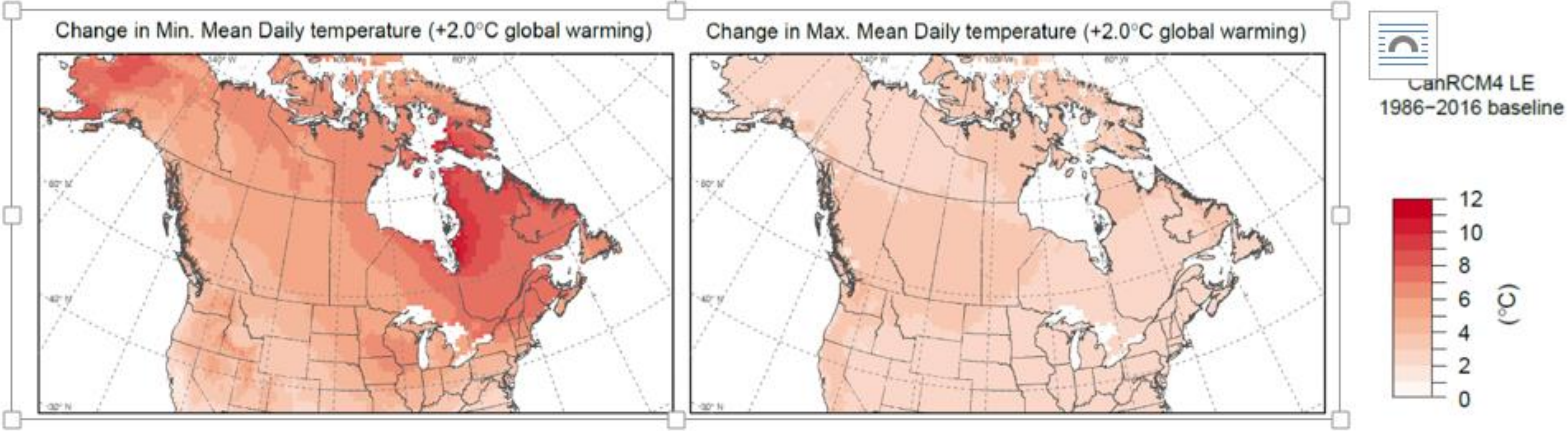
Projected Changes in Future Climatic Design Data- Minimum and Maximum Daily Temperature



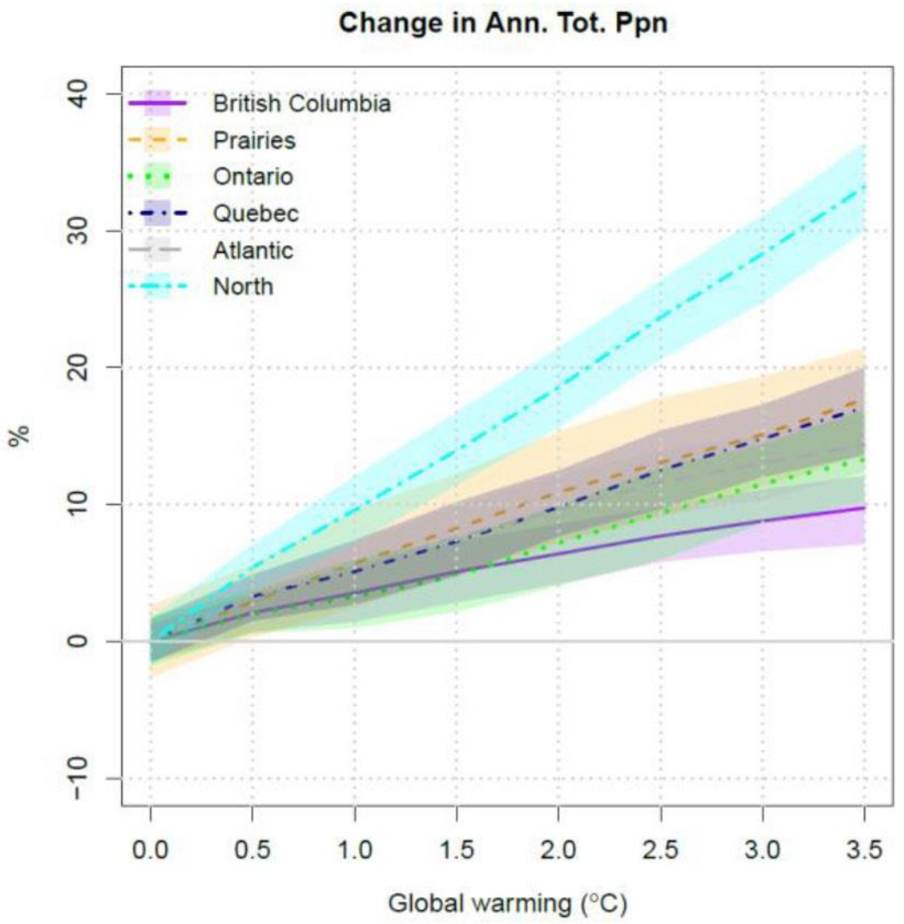
From Cannon et al. (2020)

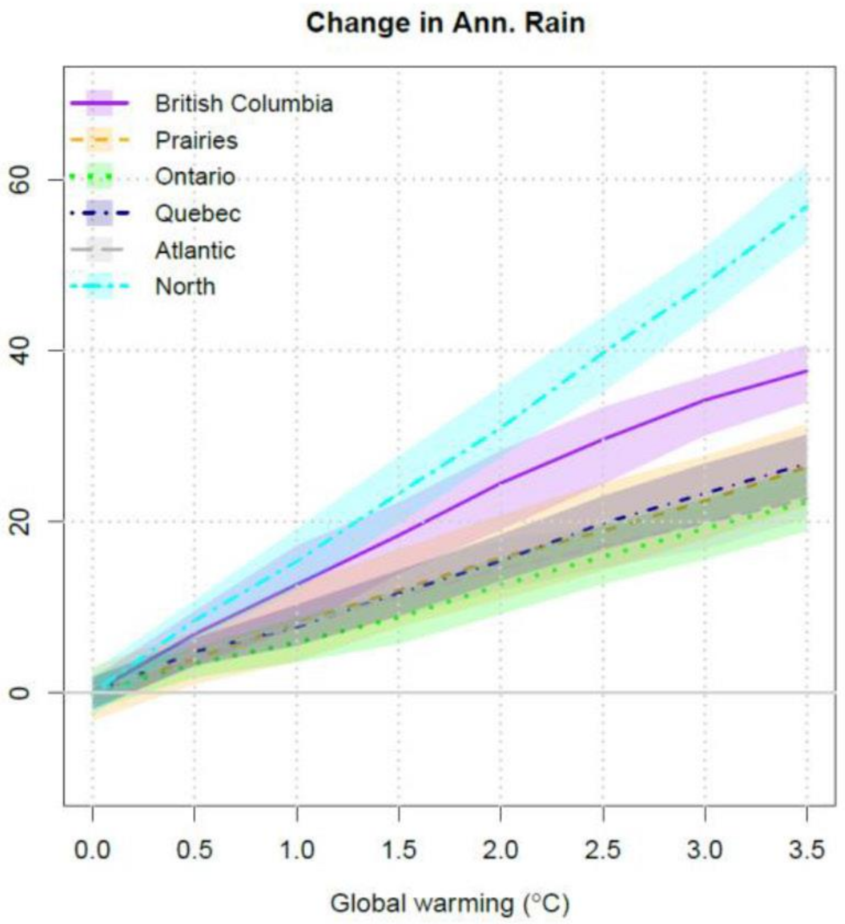
Projected Changes in Minimum and Maximum Daily Temperature for +2.0°C Global Warming

From Cannon et al. (2020)



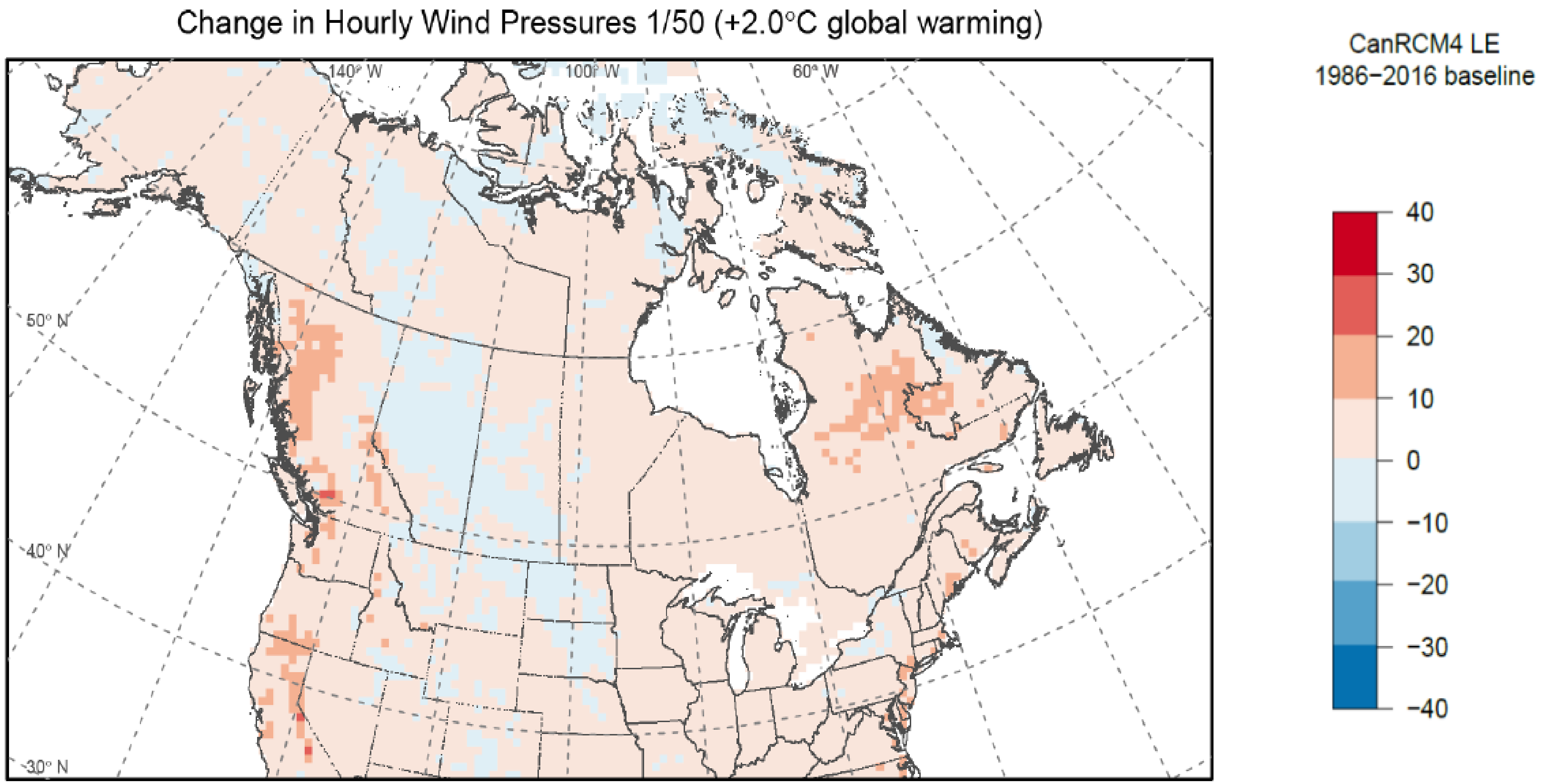
Projected Changes in Annual Total Precipitation and Annual Rainfall





From Cannon et al. (2020)

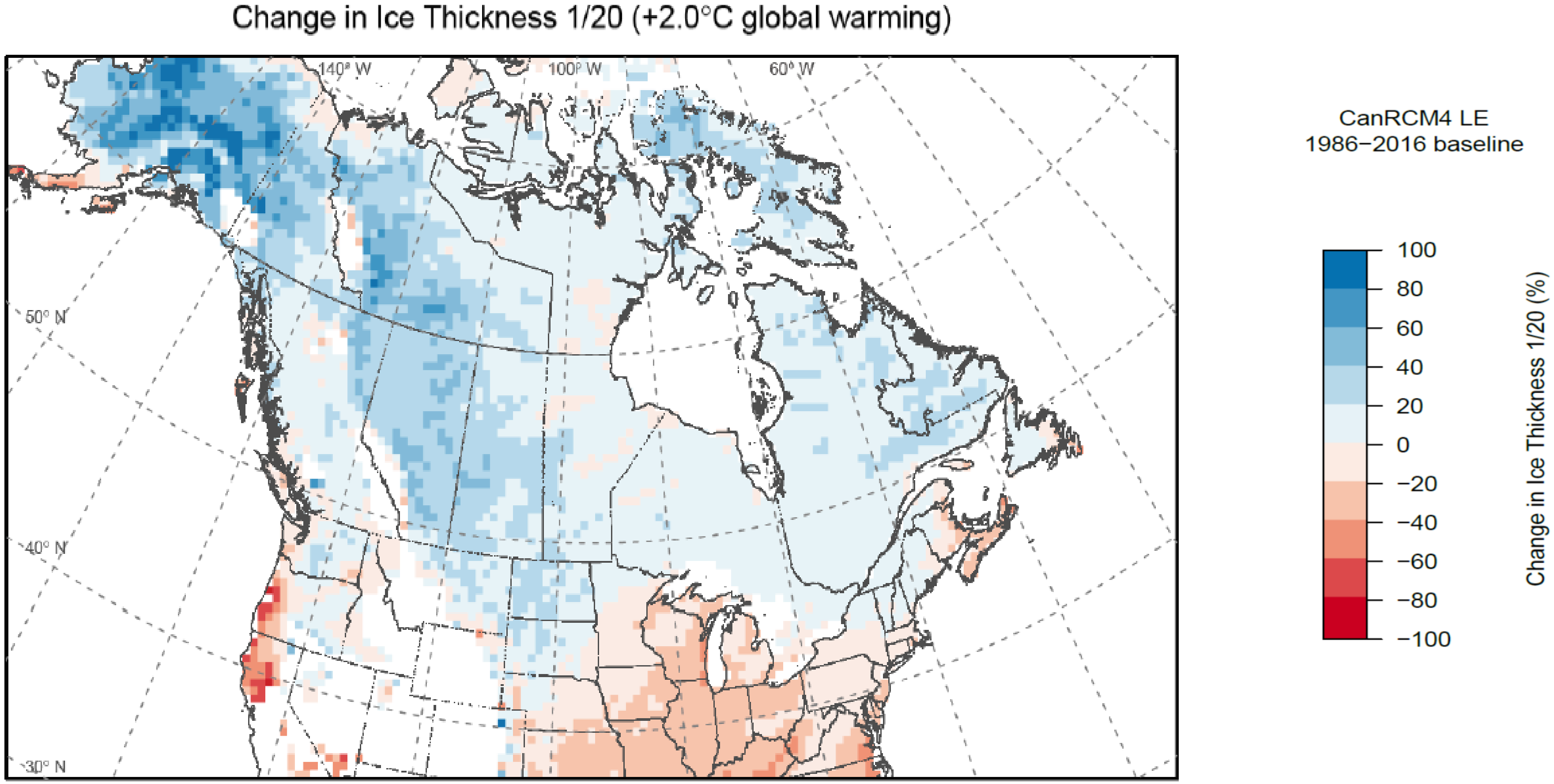
Projected Changes in 50-yr Wind Pressure for +2.0°C Global Warming



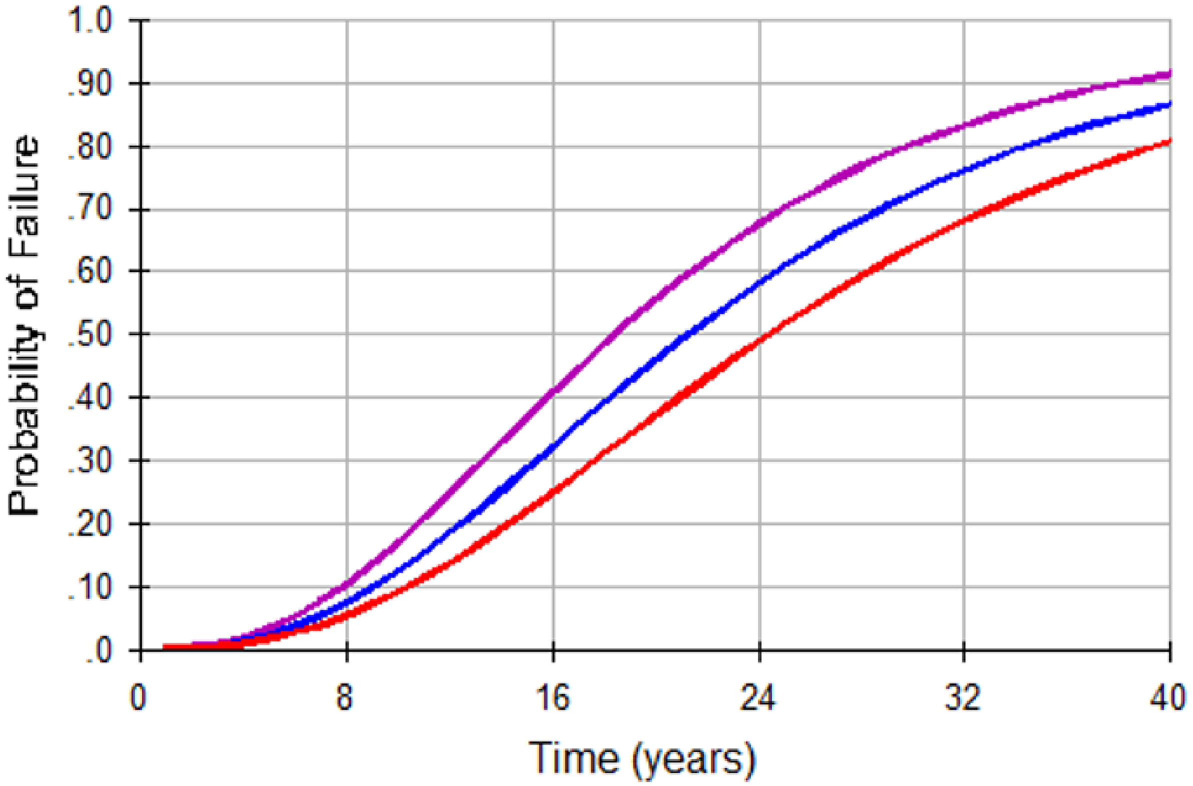
From Cannon et al. (2020)

Projected Changes in 20-yr Ice Accretion for +2.0°C Global Warming

From Cannon et al. (2020)



Impact of Climate Change on Probability of Corrosion of Highway Bridge Decks



	Base Case: No Temperature Change
	CC1 Case: Temperature Rise = 2°C
	CC2 Case: Temperature Rise = 4°C

Conclusions

- Climate change will lead to increased temperature and precipitation across Canada with more warming in the North
- Climate change can lead to increased climatic loads on transportation infrastructure which can result in reduced safety, serviceability, durability and functionality
- Increased rate of deterioration of infrastructures due accelerated aging will yield reduced capacity and shorter service life
- Need to design and maintain transportation infrastructure using future climatic design data and loads to ensure climate-resilient and sustainable transportation infrastructure
- Selection of appropriate RCP emission scenario for projection of changes in climatic design values depend on infrastructure design life and planning horizon.
- Special attention should be given to the uncertainties associated with projected changes in climatic design values, especially for wind, snow, and ice.