Environment and Climate Change Canada / Environnement et Changement climatique Canada

Key Climate Research Activities @ CCCma

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Canadian Centre for Climate Modelling & Analysis

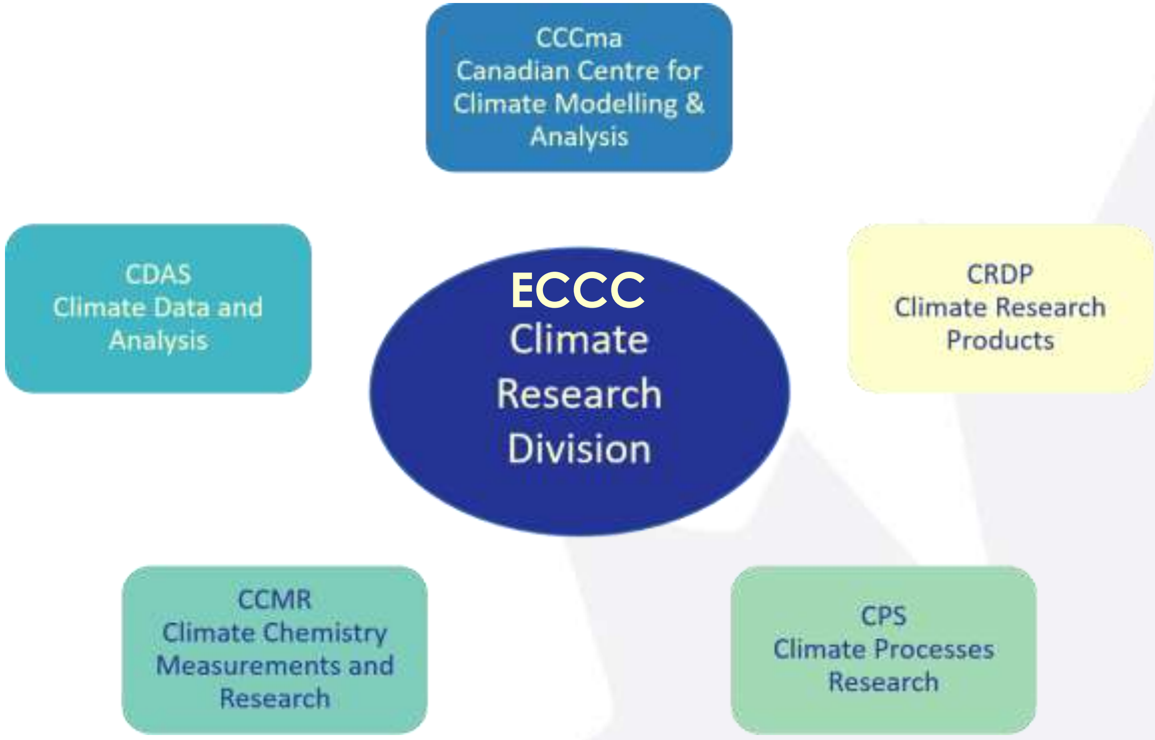
ECCC Climate Research Division

7 November 2020

Canada

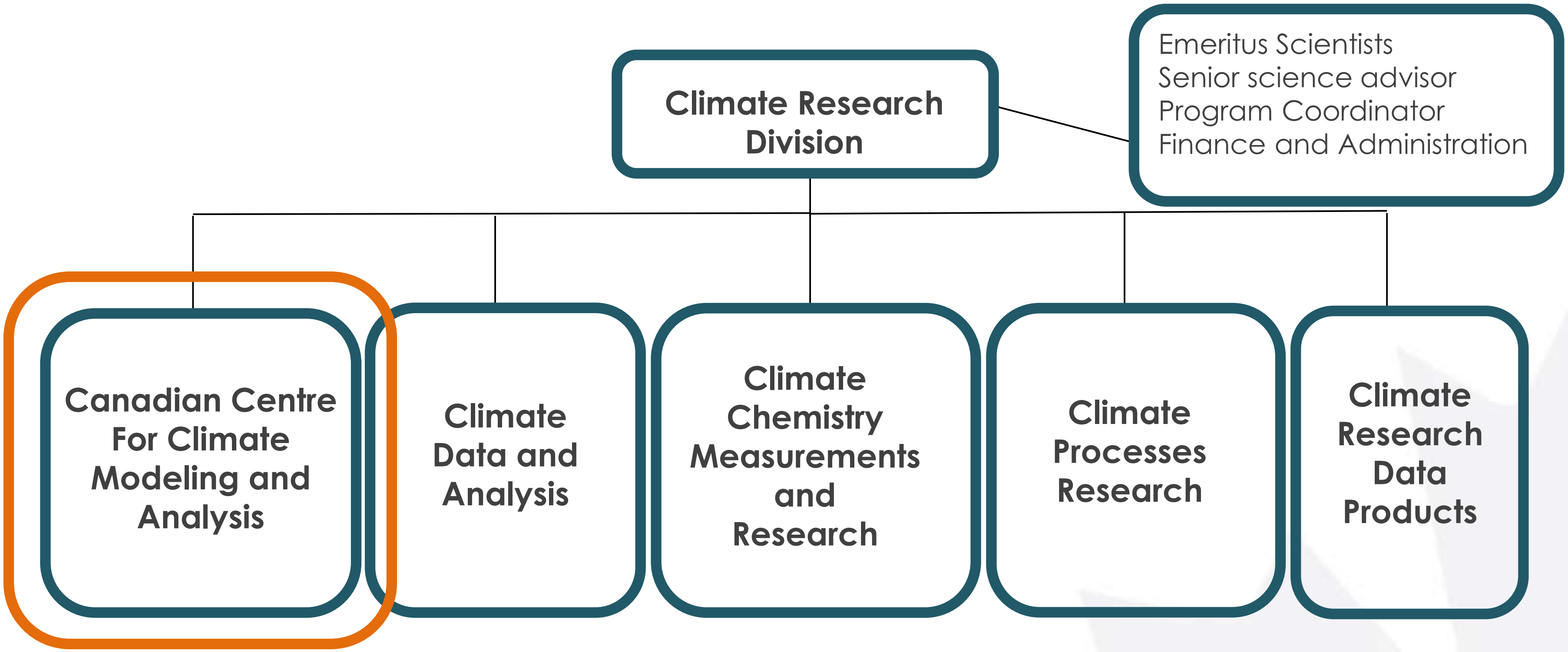
Who we are

Canadian Centre for Climate Modelling and Analysis



ECCC Climate Research Division

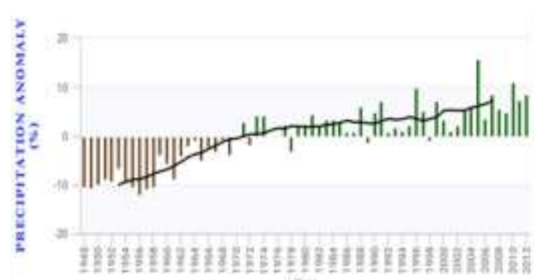
An integrated climate research program of ~100 FTEs

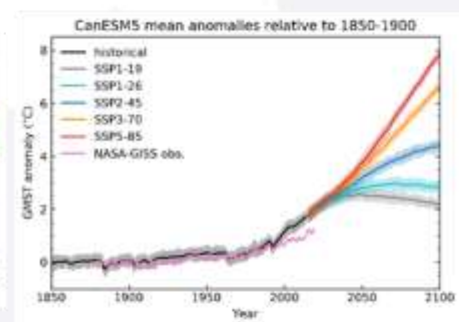


Our Program Objective

To understand the Earth's climate system and its response to external forcings in order to respond to society's growing need for information on how the climate is projected to change

Monitoring → Targeted Earth System Research → Retrospective Analyses → Climate Projections





Our Primary Drivers

- **'Science' driver**
  Analysis of observations and model output (ours and others) to understand how the climate system works and how it responds to external forcing.

- **'Service' driver**
  Respond to the growing need for climate information, by national and international stakeholders (e.g. IPCC, WMO, AMAP, CCCR, …), to support decision-making, adaptation action, and mitigation policy development.

Program Delivery and Outcomes

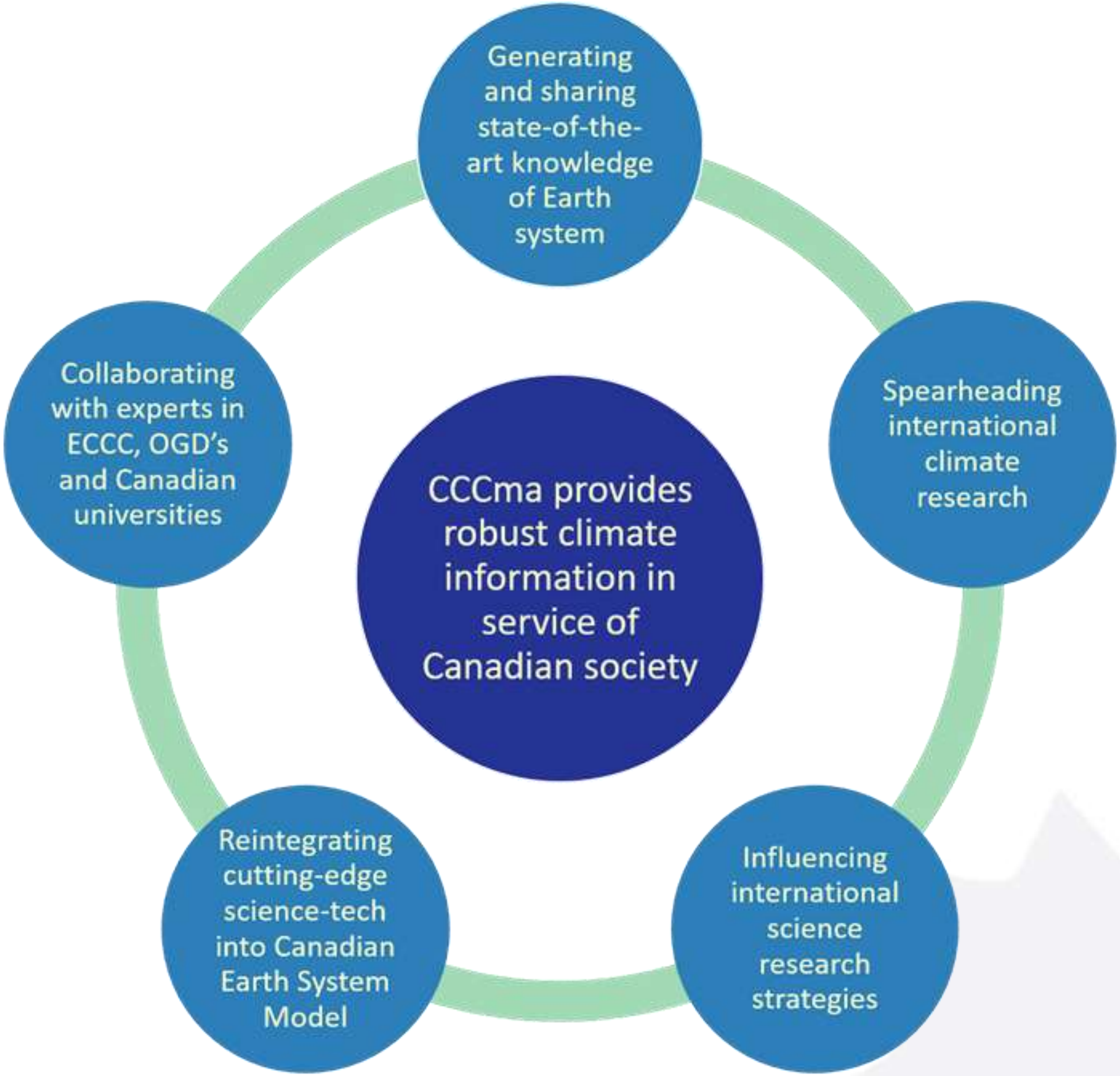
- Delivery via continuous development, analysis and application of a tightly integrated, world-class, global and regional earth system modelling system
- Outcomes:
  - robust climate change projections at seasonal to centennial timescales for Canada and the globe; and
  - quantification of climate impacts and risks that arise from these changes both in terms of overall climatic conditions and changes in the frequency and magnitude of extreme weather and climate events

CCCma Team

- We have a very specialized team with expertise in atmosphere, ocean and terrestrial physics, biogeochemistry, numerical methods, and high-performance computing.
- CCCma has embedded staff from 3 other sections within CRD, insuring a cohesive effort that draws on the entire division. We also have CCCma staff embedded in other locations.
- We have embedded staff (and post-docs) from DFO - ocean biology and chemistry expertise.
- We use roughly ¼ of the Department's research supercomputing resource.

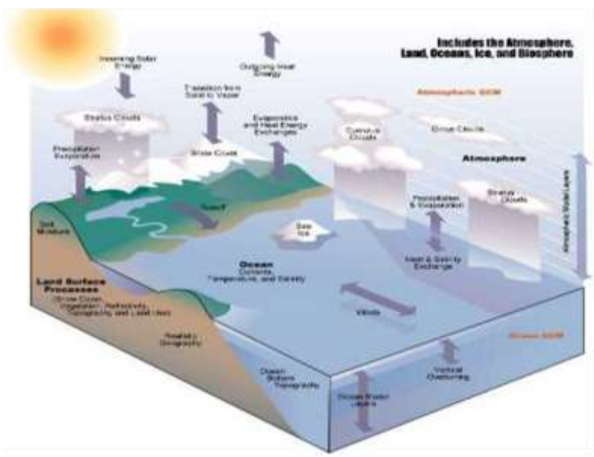
Relevant Statistic

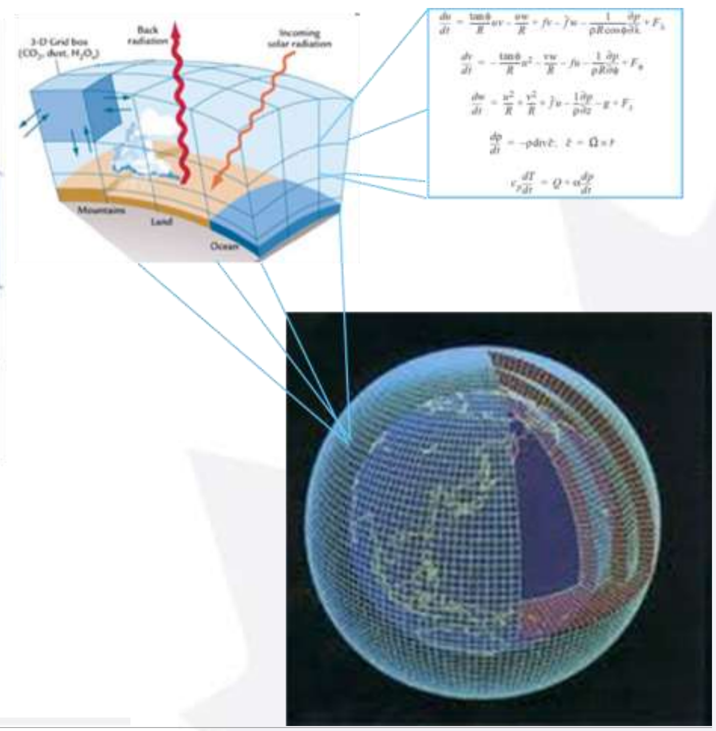
- About **40** people on site, plus some in Toronto and Montreal
- **>350** peer-reviewed publications over last 5 years (many in high-profile journals).
- Results from our second generation Earth System model submitted to CMIP5 and used in the IPCC's 5th Assessment have been cited in **525** published papers.
- Roughly **56 Tb** of model output available to the scientific community and the public.


Generating and sharing state-of-the-art knowledge of Earth system
Spearheading international climate research
Influencing international science research strategies
Reintegrating cutting-edge science-tech into Canadian Earth System Model
Collaborating with experts in ECCC, OGD's and Canadian universities
CCCma provides robust climate information in service of Canadian society

What we do

Canadian Earth System Model

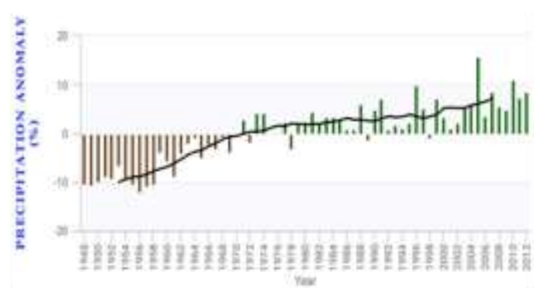


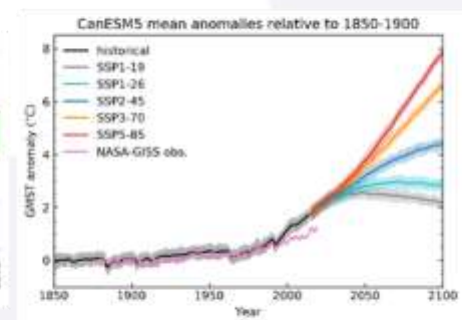


Our Earth System Modelling Program is a central element of CRD’s Climate Research Program

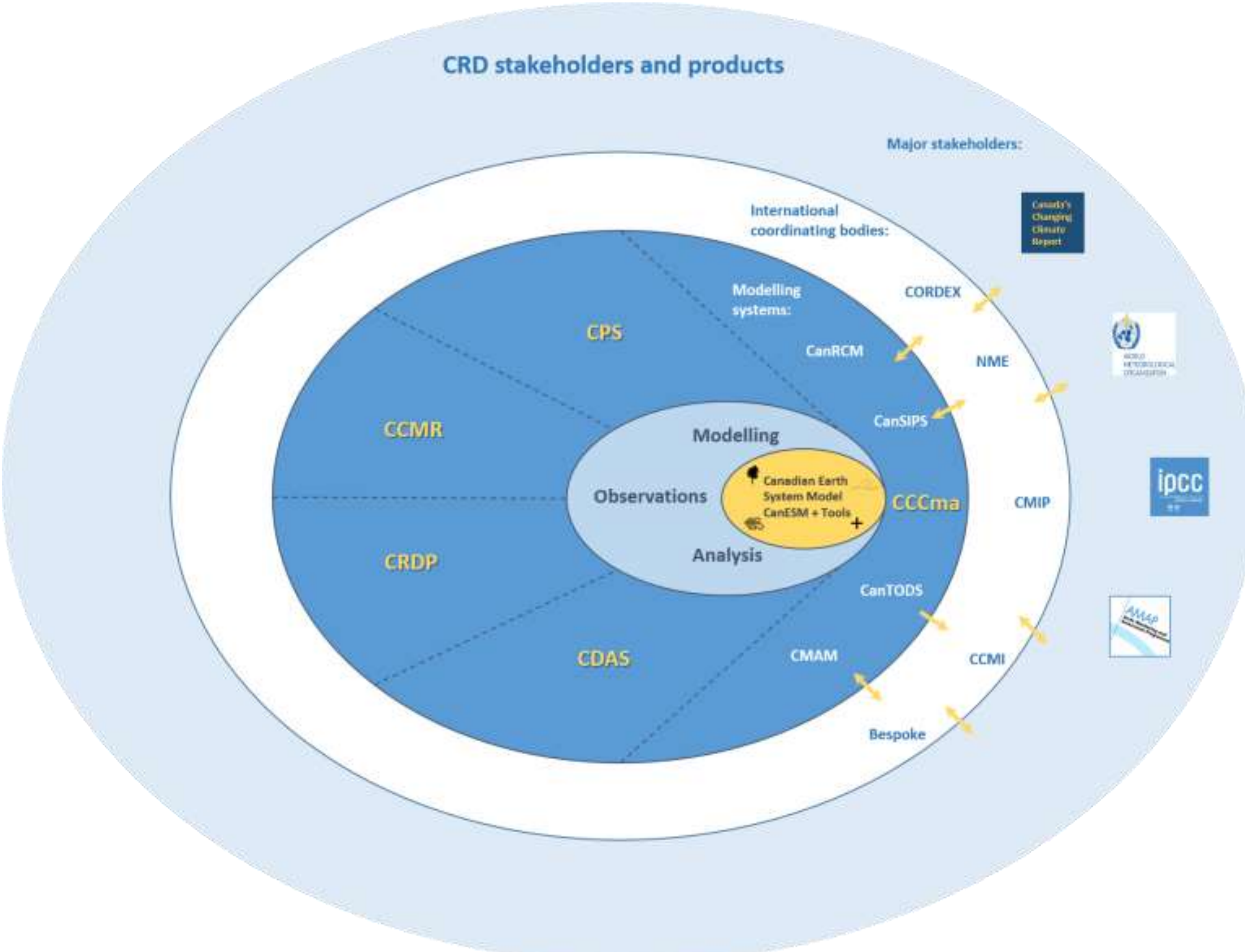
- CCCma is the only agency in Canada to develop and apply an Earth System Model to project climate change.
- Canadian Earth System Model, **CanESM**, is a key integrator and contributor of information to CRD’s integrated climate research program.

Monitoring → Targeted Earth System Research → Retrospective Analyses → Climate Projections





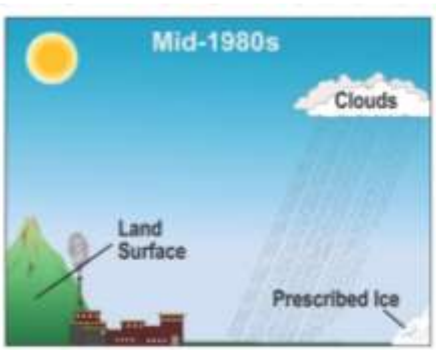
CCCma Climate Modelling Systems



Evolution to Earth System Models

Atmosphere Only Models

Represent only atmospheric physics



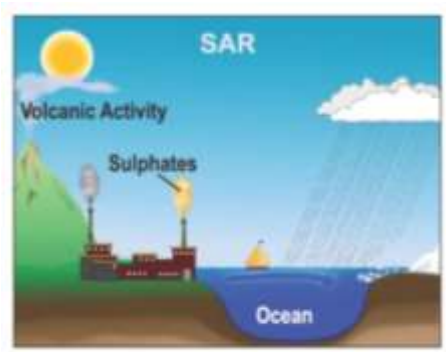
CanAM (CRD)

GEM (MRD)

- Specified ocean temperatures
- Specified GHG concentrations
- No carbon cycle feedbacks

Coupled Atmosphere-Ocean Models

Couple physical atmosphere and ocean models, to represent physical feedbacks



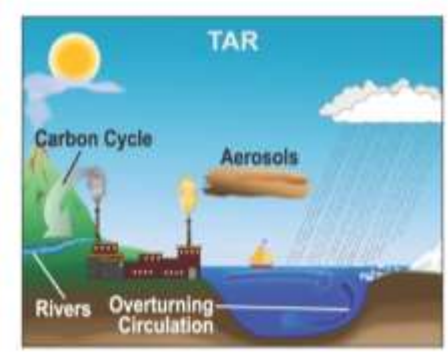
CanCM (CRD)

GEM-NEMO (MRD)

- Dynamic ocean
- Specified GHG concentrations
- No carbon cycle feedbacks

Earth System Models

Include a carbon cycle, and possibly other cycles (nitrogen, methane, ozone, etc.) to represent biogeochemical feedbacks

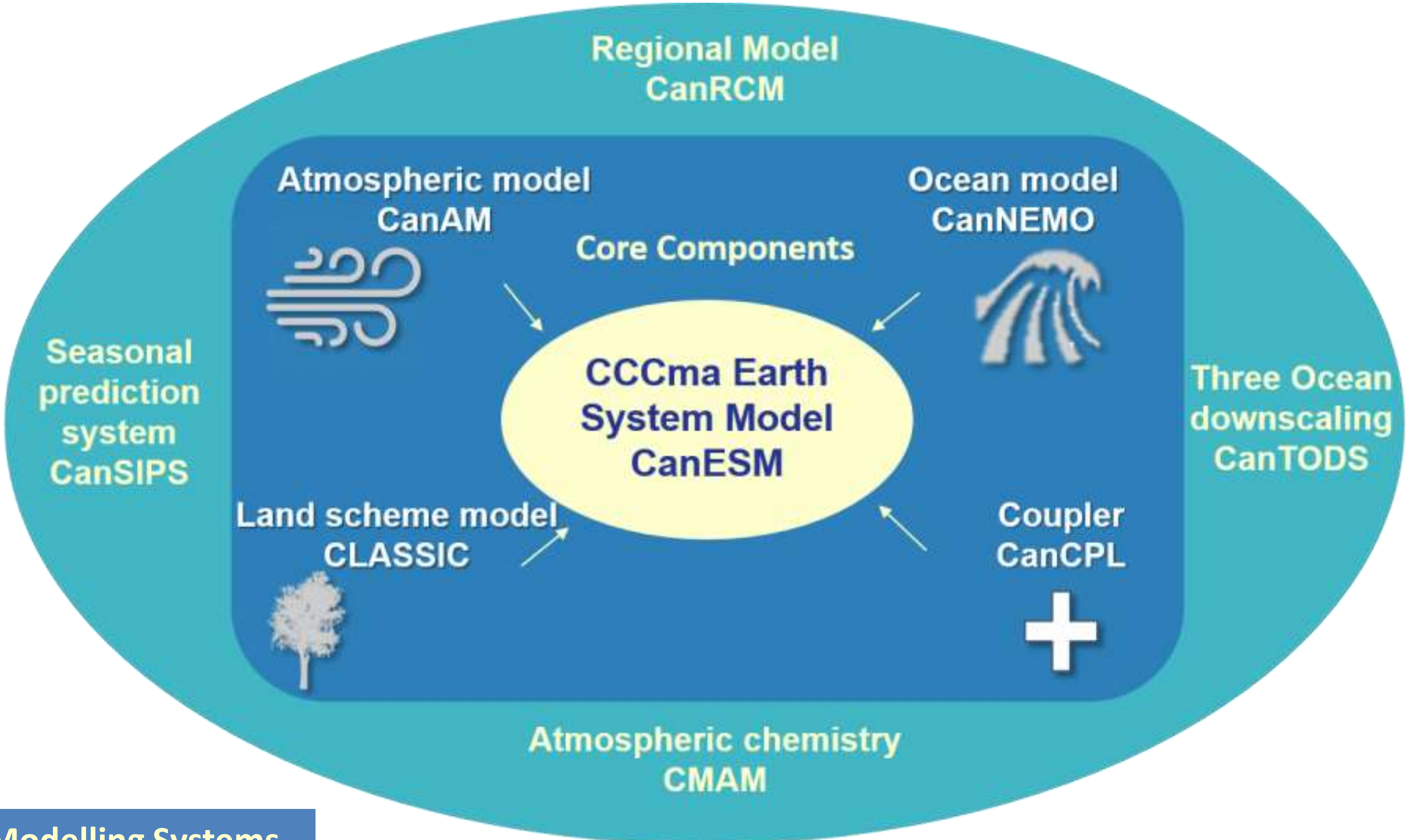


CanESM5 (CRD)

- Dynamic ocean
- Dynamic GHG concentrations
- Explicit carbon cycle feedbacks

Increasing complexity of models and scientific questions

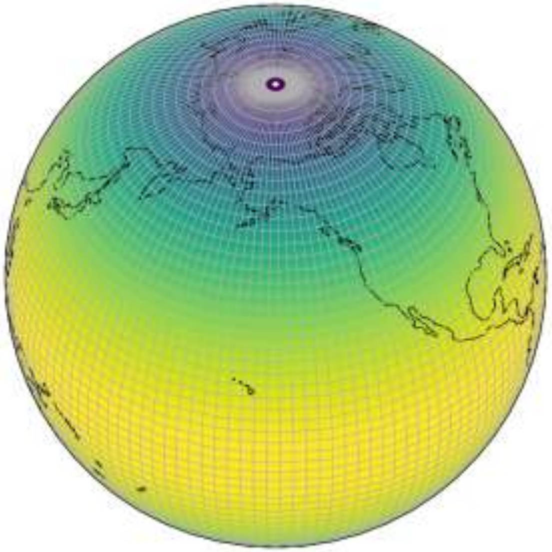
CanESM: Canada's Earth System Model

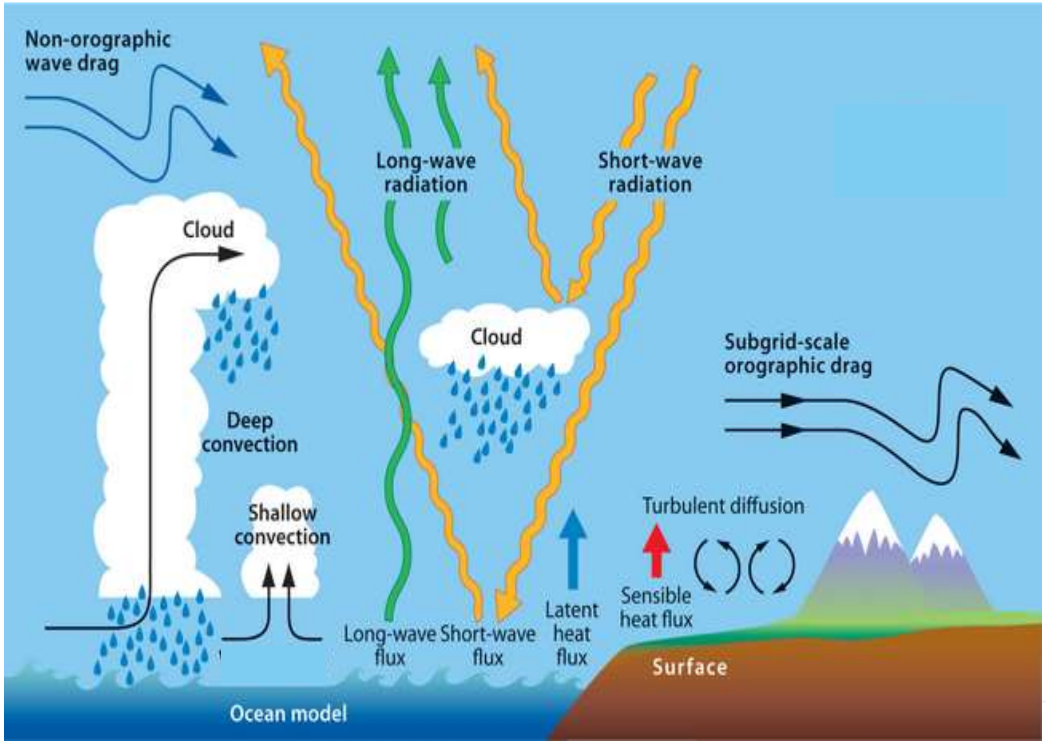


Modelling Systems
Core Components

Atmosphere: CanAM5

- Dynamics of the model with spectral dynamical core
- Resolution:
  - T63 ≈ 2.8° horizontal resolution (≈ 250 kms)
  - 49 vertical levels with a 1 hPa lid



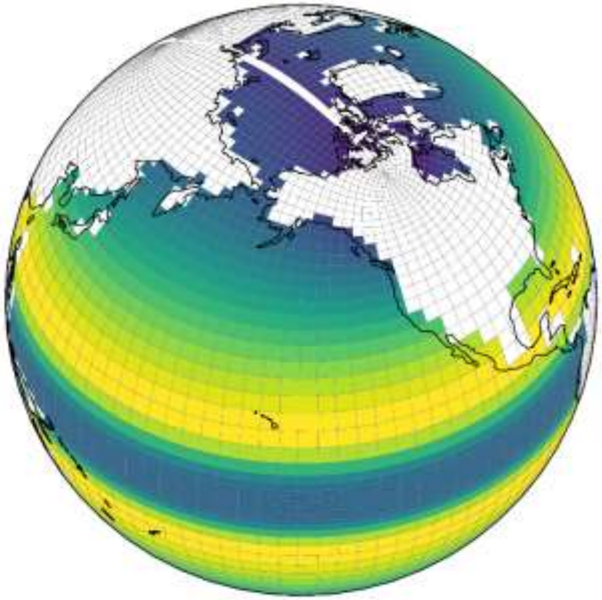


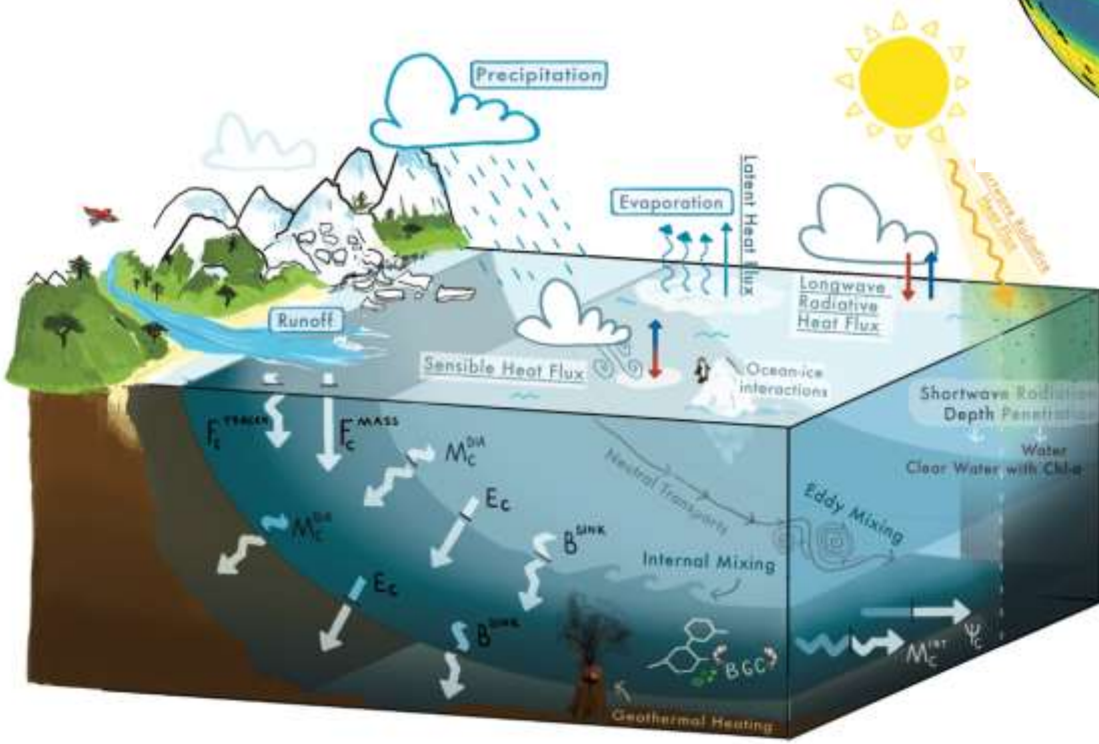
Physics represented by various parameterizations ("CCCma physics"). This is where most work is done, e.g.:

- Radiation
- Convection and clouds
- Gravity waves
- Surface boundary layer fluxes

Ocean: CanNEMO

- NEMO model used for ocean physics
    - Configured and modified for climate
- CCCma-DFO in house biogeochemistry
- Resolution:
    - nominal 1°(100 km) refining to 1/3° in tropics
    - 45 vertical levels

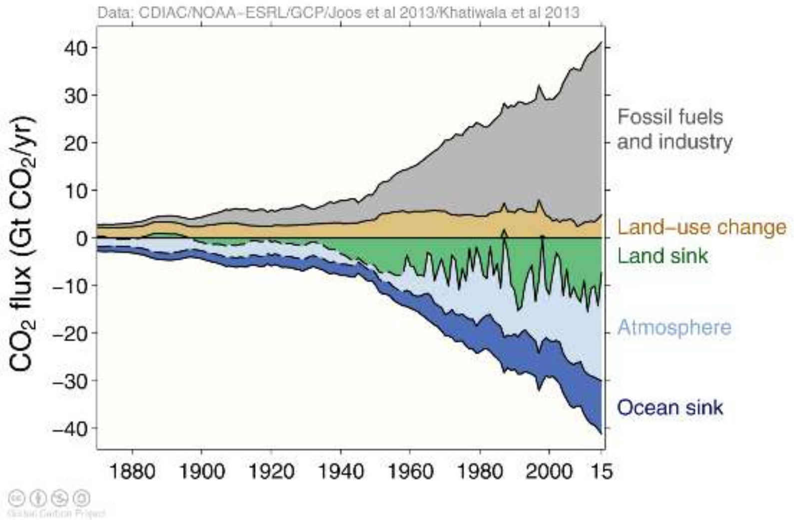




Ocean Biogeochemistry

Why?

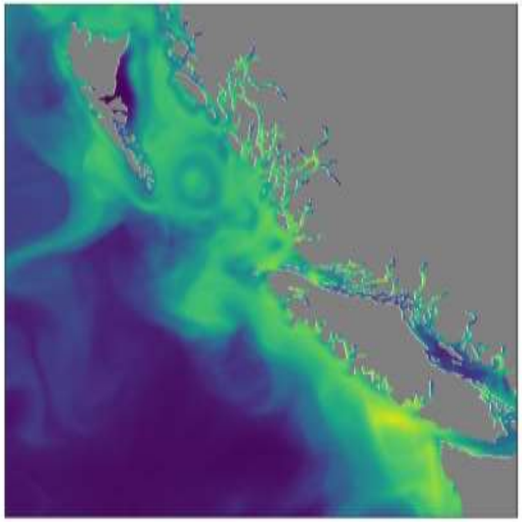
- Ocean currently absorbs +25% of human CO_2 emissions yearly
- CO_2 budget is needed to inform policy making / set climate targets
- Ocean acidification results from absorbing CO_2, impacting ecosystems
- Ocean ecosystems also respond to climate change



How?

- By including representations of:
  - I. carbon chemistry and
  - II. simple ocean ecosystems

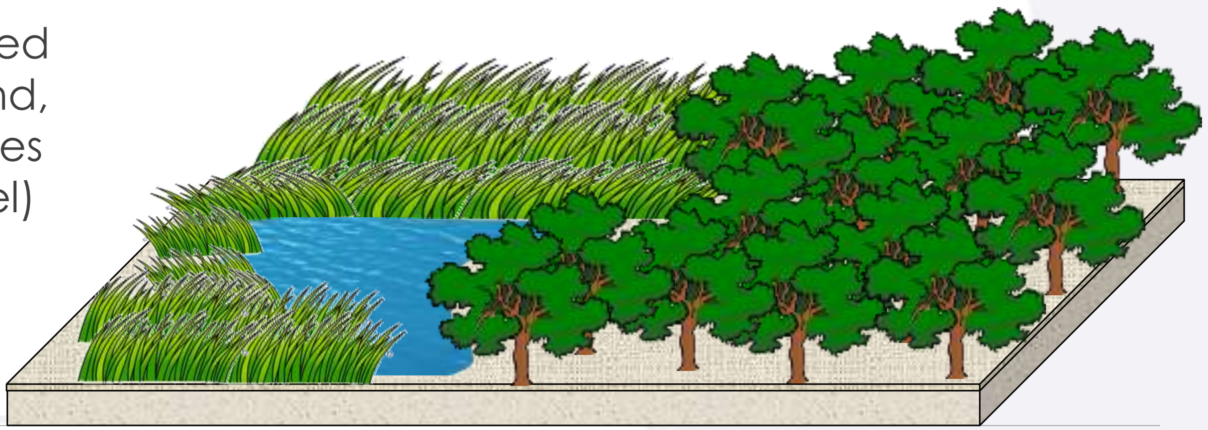
in global models (CanESM) and regional downscaled models (e.g., NEP36).



CLASSIC
Land Surface and Terrestrial Ecosystem Model

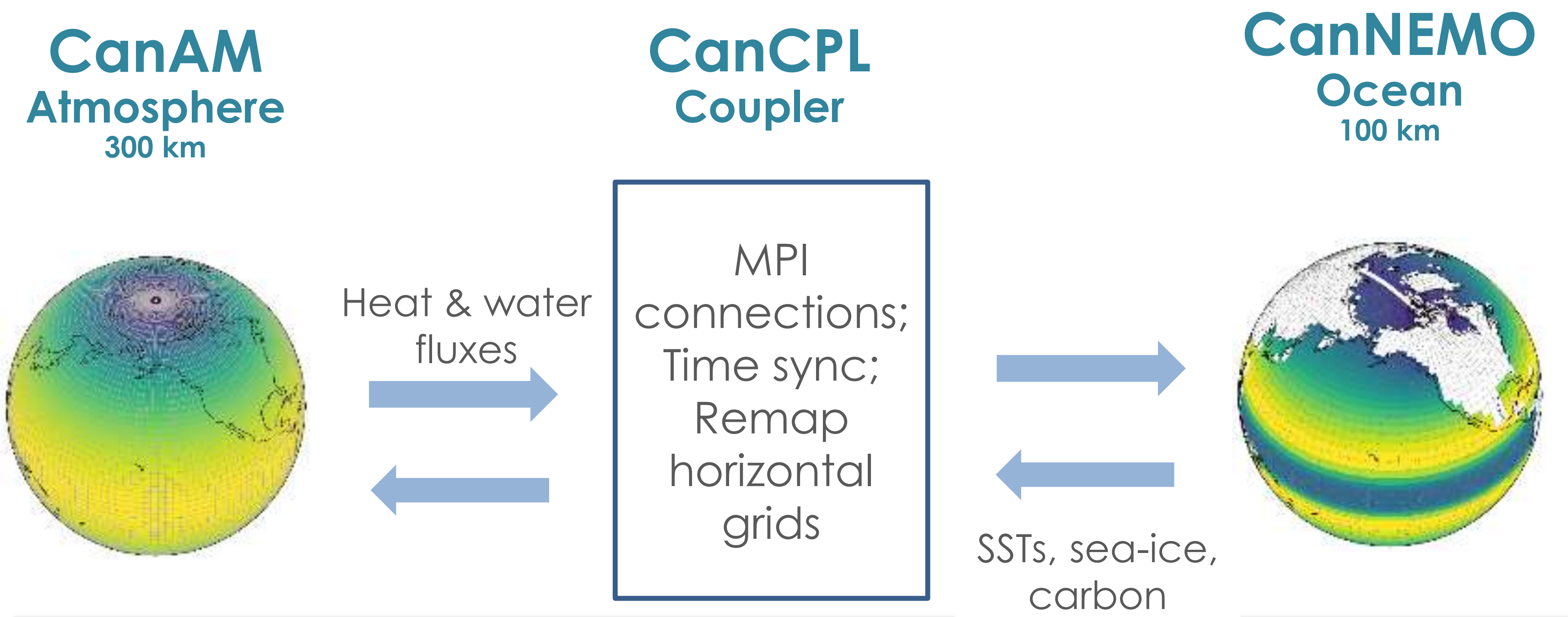
- Canadian Land Surface Scheme (CLASS) simulates physical land surface processes including energy, water and momentum exchanges between the atmosphere and the land surface
- Canadian Terrestrial Ecosystem Model (CTEM) simulates biogeochemical processes including atmosphere-land exchange of CO_2 and CH_4, dynamic vegetation, and wetlands.

These processes are modelled over vegetated, bare ground, snow and sub-grid scale lakes (through a small lakes model)



Coupler: CanCPL

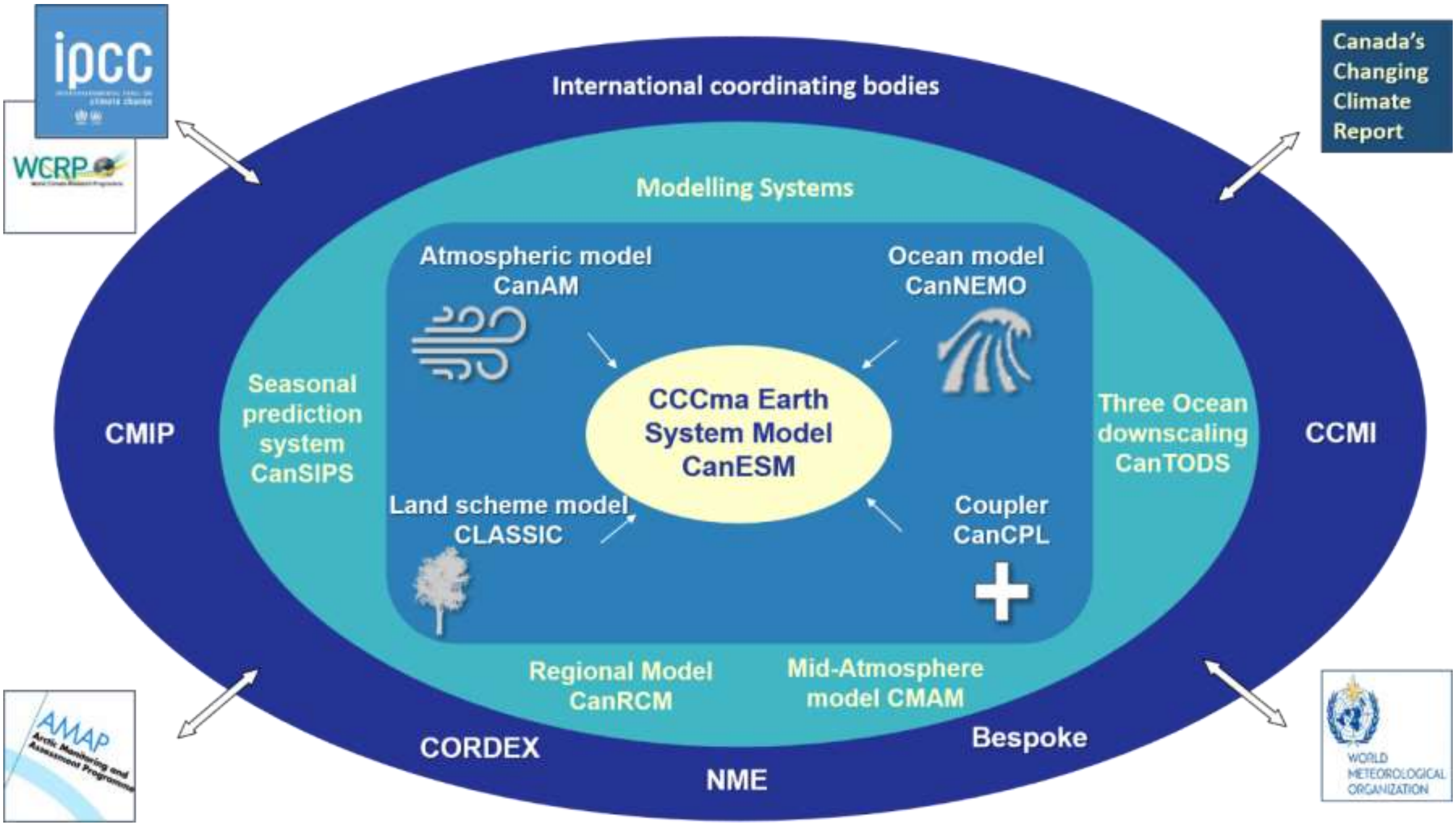
- Connects the independent atmosphere and ocean models
- Exchanges information between models (e.g. carbon flux from ocean to atmosphere), and remaps between different model grids (resolution)
- Optimized communication for HPC (Message Passing Interface or MPI)



Other ESM Modelling Tools

- Software systems to:
  - Run CanESM and subcomponents on HPC systems
  - Create useful scientific output from raw model output (diagnostic post-processing)
  - Archive and retrieve petabyte scale input and output data between various disks and tapes
  - Control and manage source code and dependencies (version control, etc.)
  - Create executable programs from raw model source code (compilation)
- Without tools, no models will run, and no scientific results will be produced

CanESM is Canada's contribution to the IPCC and other domestic and international fora

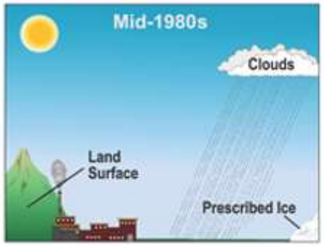


History of CCCma Modelling and Science

Models

AGCM

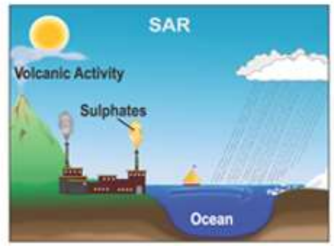
Atmosphere only global climate model



Atmosphere only

CGCM

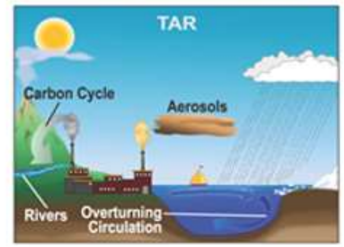
Coupled atmosphere-ocean global climate model



Coupled to ocean

CanESM

Earth system model with biogeochemistry



Carbon cycle

1970 1980 1990 2000 2010 2020

CCCma model development

AGCM1 AGCM2 CGCM1 CGCM2 CanESM2 CanESM5

Coupled Model Intercomparison Projects

CMIP1 CMIP2 CMIP3 CMIP5 CMIP6

IPCC Science Assessments

1990 1995 2001 2007 2013 2021

Canadian Climate Assessments

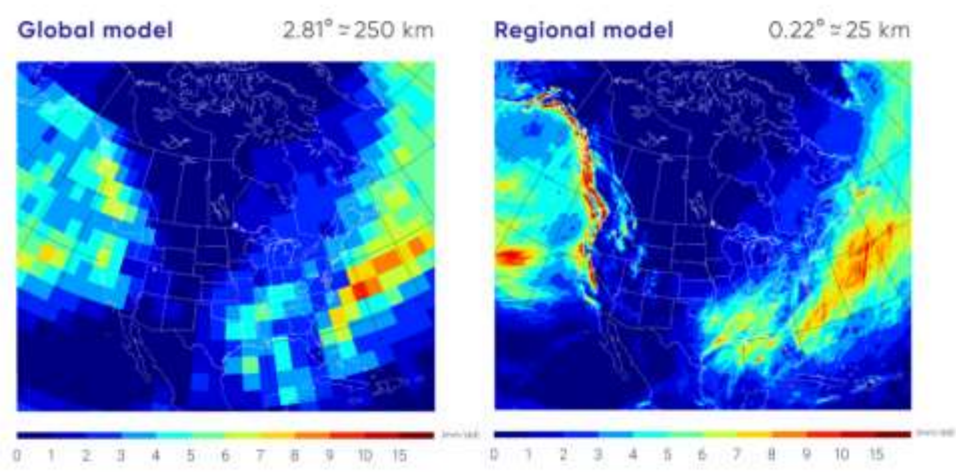
2007 2014 CCCR 2019

WMO Ozone Depletion Assessments

2006 2010 2014 2018

Canada’s Regional Climate Model

- Climate Change is a global phenomenon with implications at regional and local scales
- In order to understand climate change in Canada, one must understand global climate change
- As such, CanESM is a necessary precursor to Canada’s Regional Climate Model, **CanRCM**

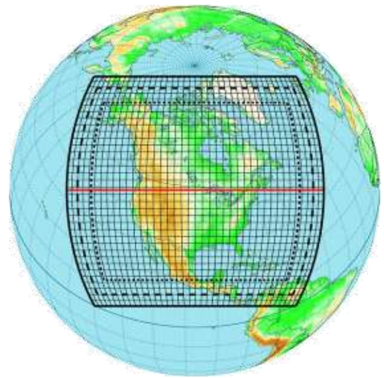


Regional Model Development

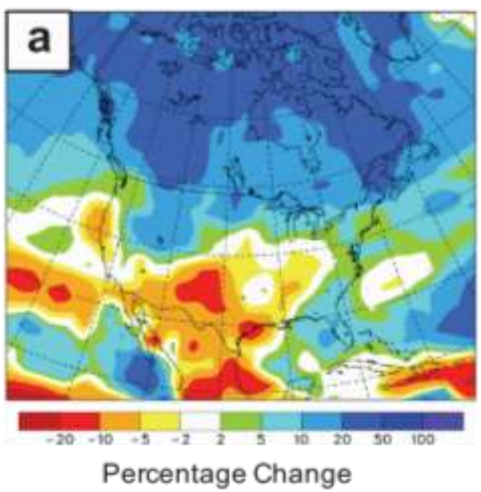
Global model
2.81° ≈ 250 kms

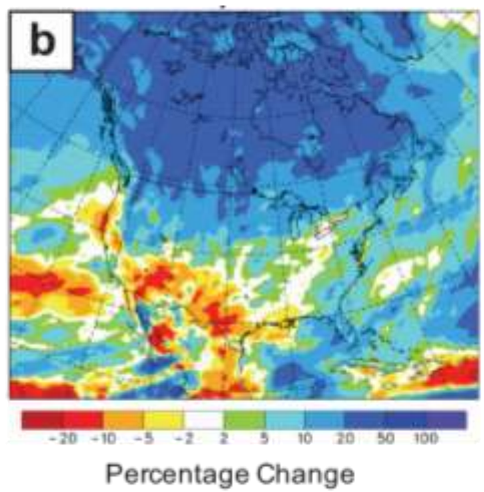
CanESM2

Regional model
0.22°, 0.44° ≈ 25, 50 kms



CanRCM4





- As of 2010, regional modelling capacity has been wholly developed within ECCC
- Dynamical Core: GEM (Cote et al. 1998)/GEM-LAM (Zadra et al. 2008)
- Physics Package: CanAM4 (von Salzen et al. 2013)

Scinocca J. et al, 2016

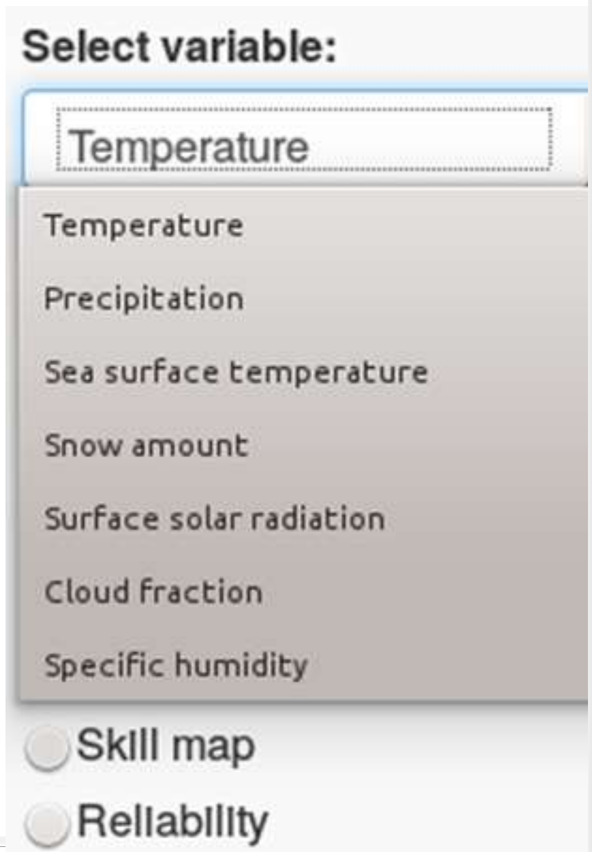
Seasonal-Decadal Climate Forecasting: CanSIPS

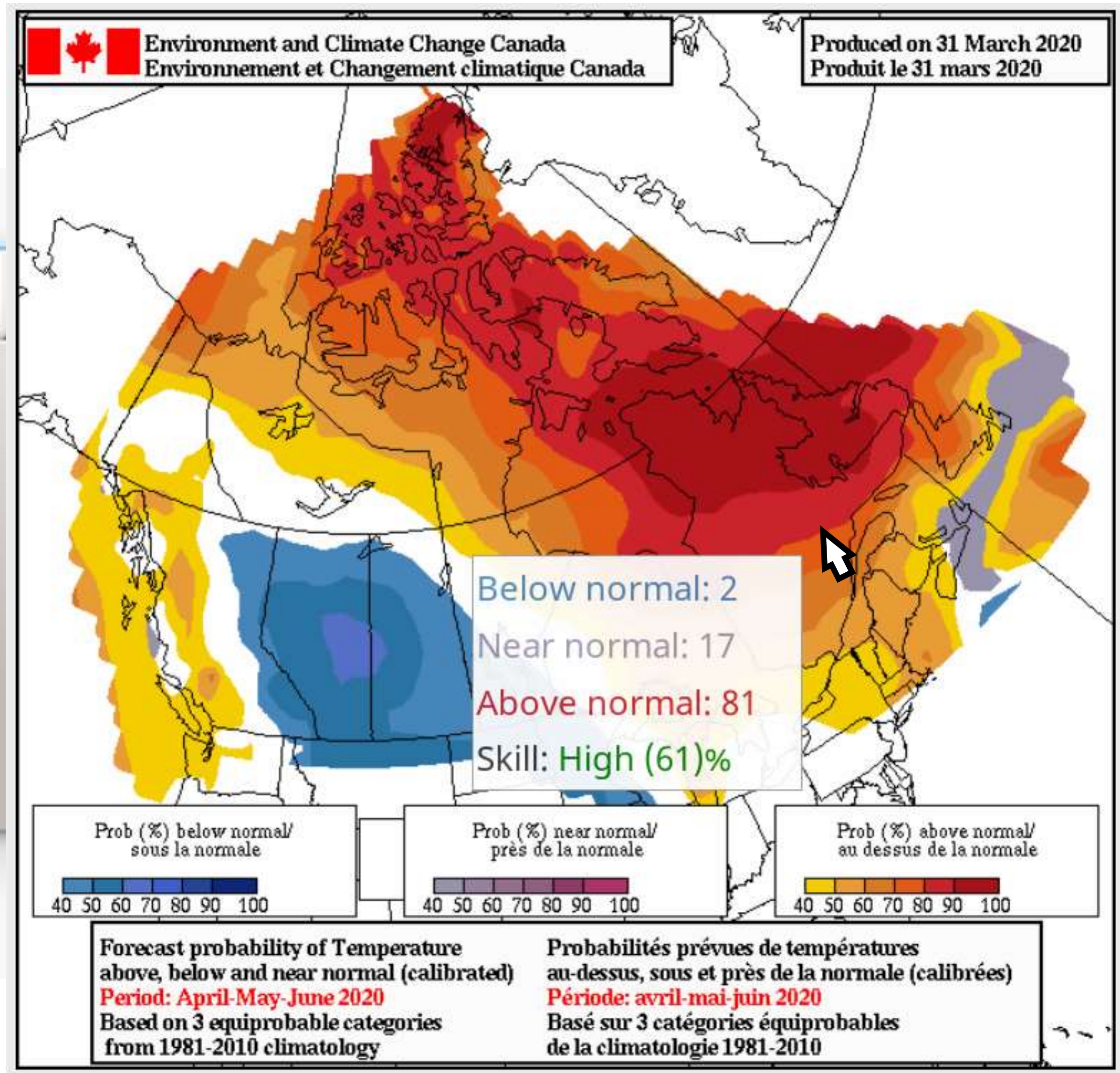
- Near-term planning in most sectors spans 5 to 10 years
- In order to account for climate change in these plans, decision makers need multi-year to decadal climate predictions and regionally-specific information
- CanSIPS was developed to bridge the gap between short-term weather forecasts and long-term climate projections

Seasonal to Decadal Climate Prediction

CCDS website now provides additional information vs weather.gc.ca:

- 5 new variables
- global forecast maps
- all maps interactive





CCCma/MSC collaboration

Applications of Model Output and Observations

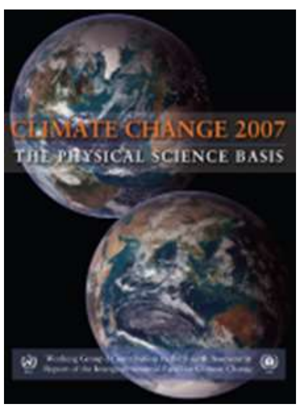
- Results from ESMs have many applications beyond climate projections
- When used in combination with observations, many questions related to our understanding of the earth system and the impacts of climate change can be answered
- In addition, observations are used to assess model performance

Canada's Changing Climate Report

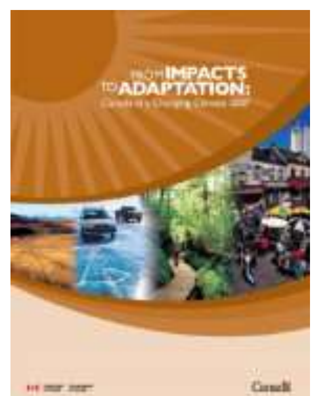
What we have learned

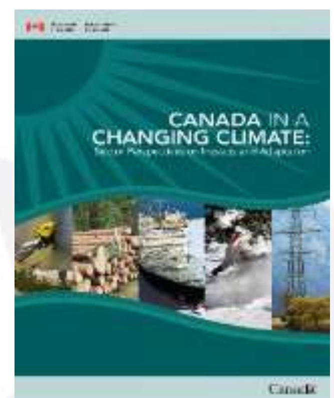
Science assessments are a critical means of informing decision-makers

- Select recognized experts as lead authors
- Identify topics relevant to decision-makers
- Critically analyze and synthesize recent developments in the published, peer reviewed scientific literature
- Provide an **assessment** of the state of scientific understanding on these topics
- Expert review of report drafts: open process
- Communicate key results to decision-makers



International assessments of climate change





National assessments of climate change

Canada's National Assessment on Climate Change

Canada in a Changing Climate: Advancing our Knowledge for Action

Interactive Website
(ChangingClimate.ca/CCCR2019)

Laying a climate science foundation for the forthcoming reports of the national assessment.

10 HEADLINE STATEMENTS FOR THE WHOLE REPORT

Statements all associated with high confidence or more

KEY MESSAGES FOR EACH MAJOR CHAPTER

Assessed confidence in findings and likelihood of results

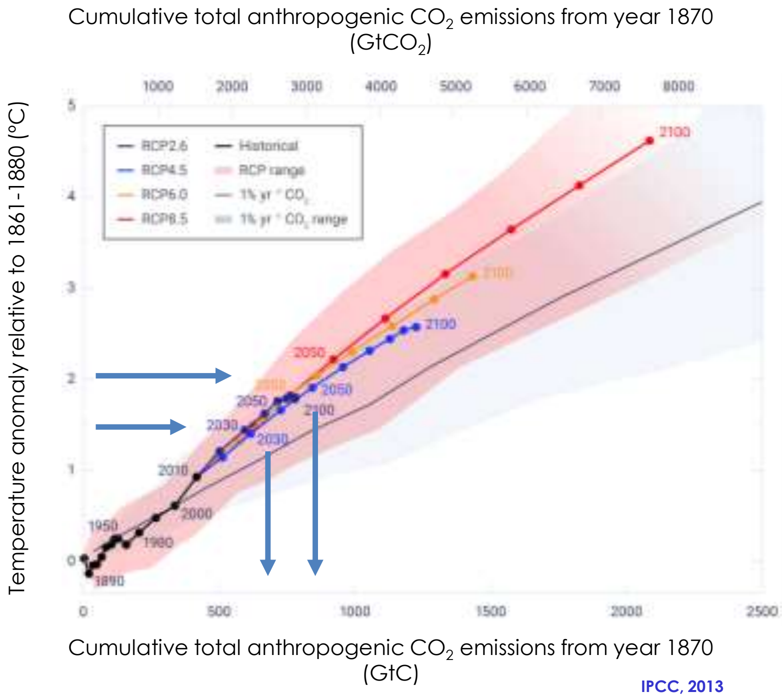
Canada's Changing Climate Report Headline statement #1

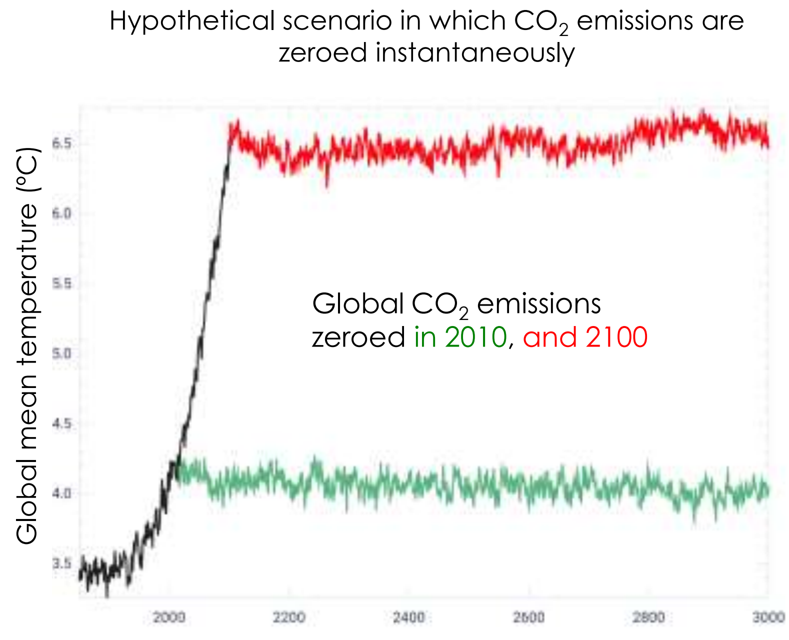
Canada's climate has warmed and will warm further in the future, driven by human influence.

Global emissions of carbon dioxide from human activity will largely determine how much warming Canada and the world will experience in the future.

This warming is effectively irreversible.

Human Influence on Global Climate

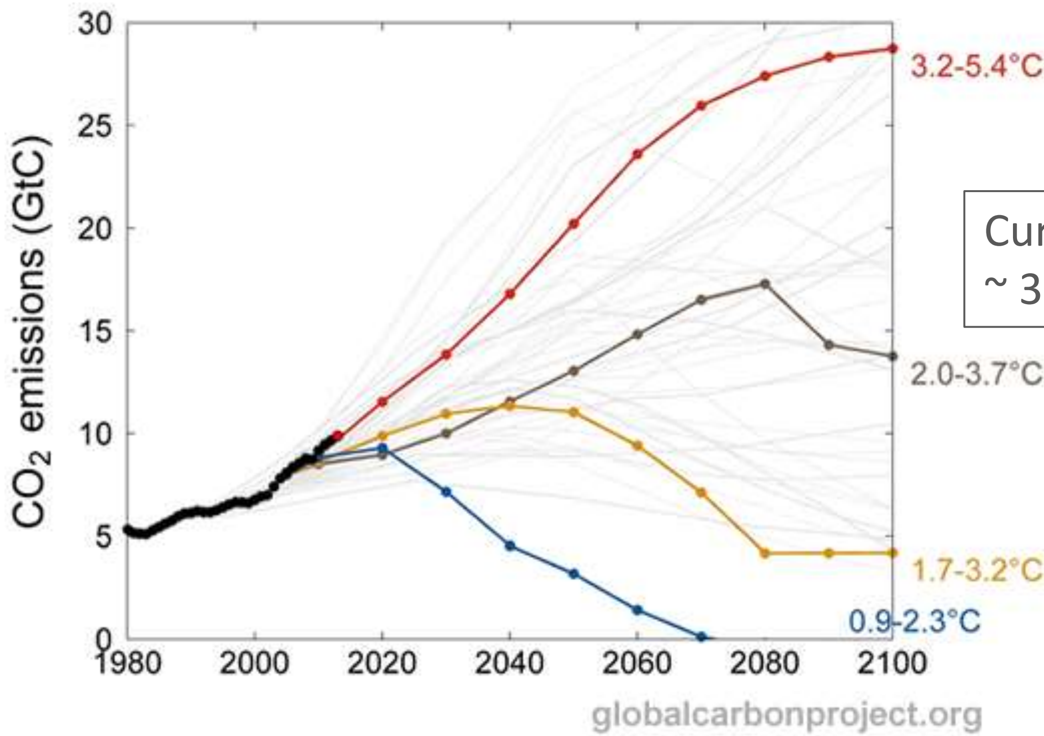




- Human emissions of CO_2 are the main determinant of future warming
- Different temperature limits have different 'carbon budgets' – total remaining cumulative CO_2 emissions
- A finite carbon budget implies CO_2 emissions must achieve 'net zero'
- Global warming will persist for centuries to millennia after emissions are zeroed

Keeping warming well below 2°C will require rapid global emissions reductions

Observed Emissions and Future Scenarios



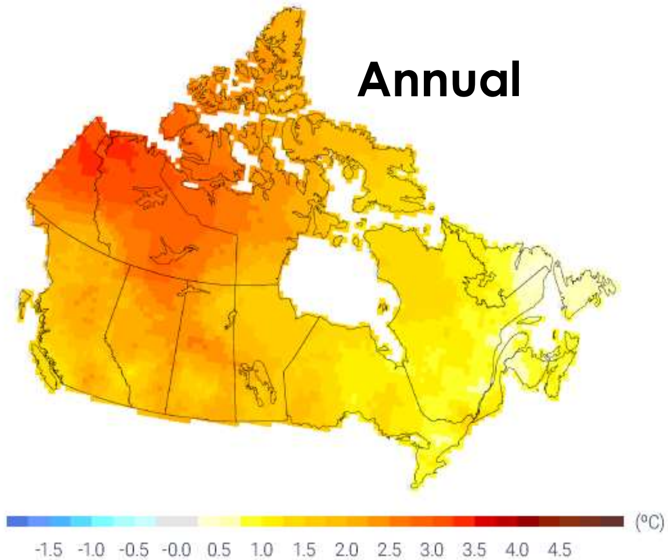
High emissions
No climate policy
Mean warming of ~4.3°C

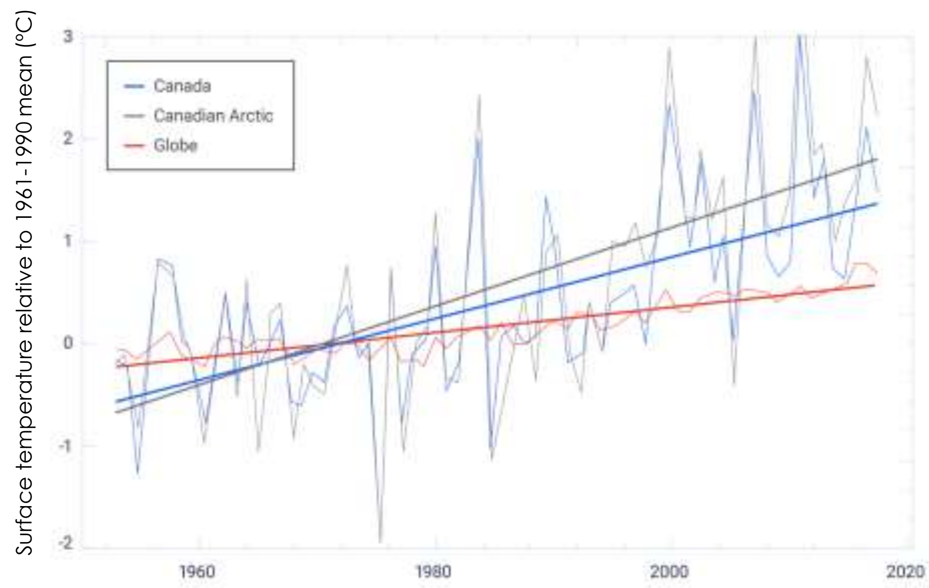
Current commitments lead to ~ 3°C by 2100 (IPCC, 2018)

Low emissions
Ambitious policy
Mean warming of ~1.6°C

- The low emission scenario will *likely* keep global temperature change < 2°C. Net zero CO_2 emissions occur around 2070. (IPCC, 2013)
- 1.5°C emission pathways reach net zero CO_2 emissions around 2050. (IPCC, 2018)

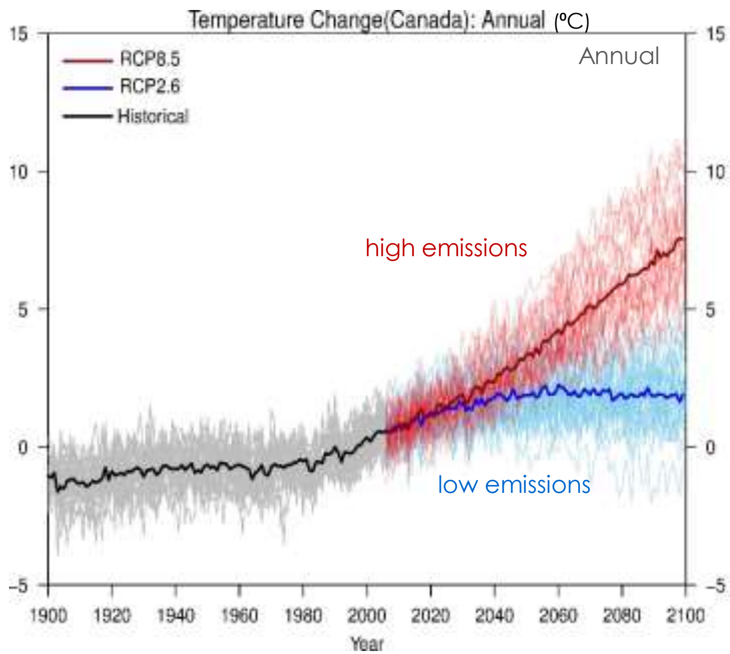
Both past and future warming in Canada is, on average, about double the magnitude of global warming

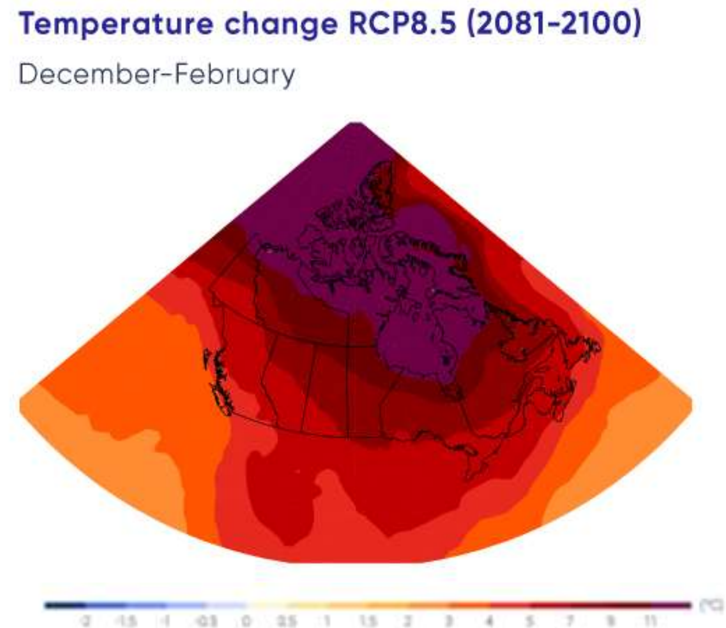




- Annual average temperature in Canada has increased by 1.7°C between 1948 and 2016.
- Canada has warmed about two times the global rate.
- Warming is not uniform across Canada. Northern Canada has warmed by 2.3°C, about three times global warming.
- Most of the observed increase in annual average temperature in Canada can be attributed to human influence.

Future warming in Canada depends directly on global emissions

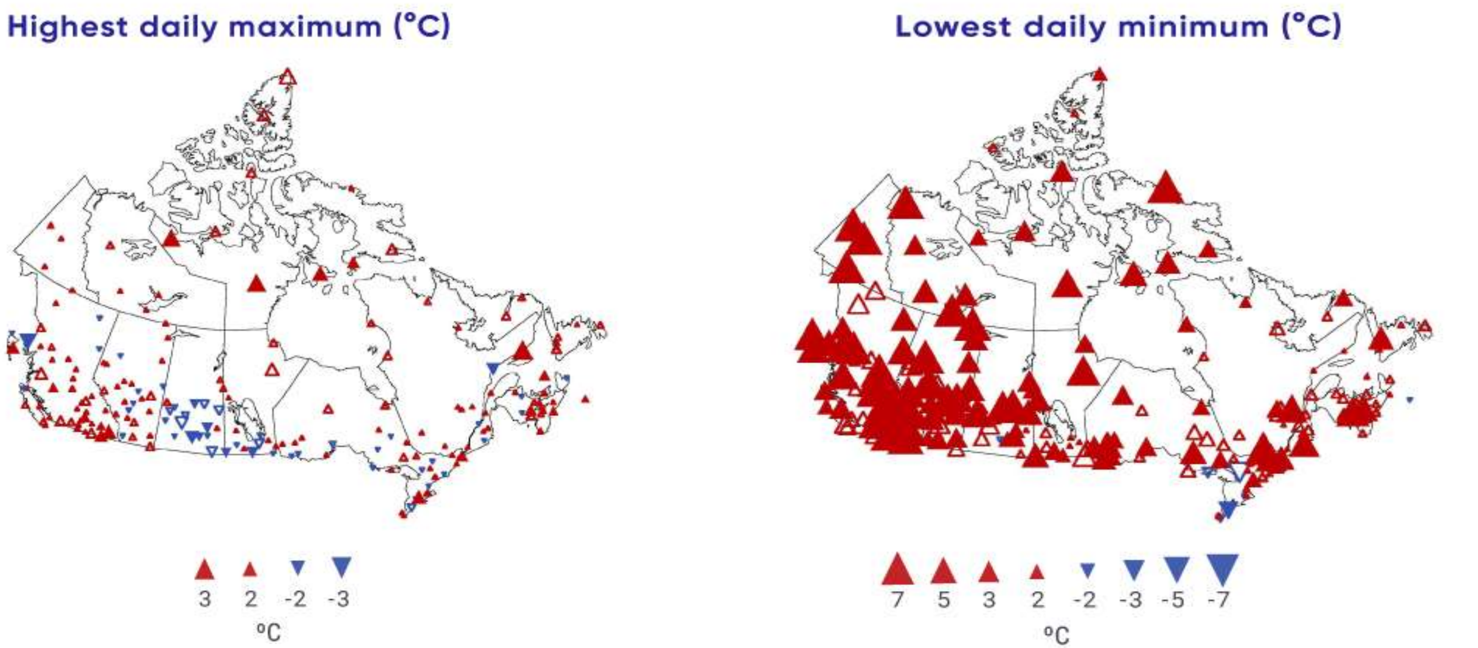




- Low emission scenario: an <u>additional</u> annual warming of about 2°C is projected by mid-century, with temperatures steady after that
- High emission scenario: temperature increases will continue, reaching more than 6°C by late century
- Consistent with observed warming, future warming will be strongest in winter and in northern Canada
- Changes shown are for the late 21st century, under a high emission scenario, relative to the 1986-2005 reference period

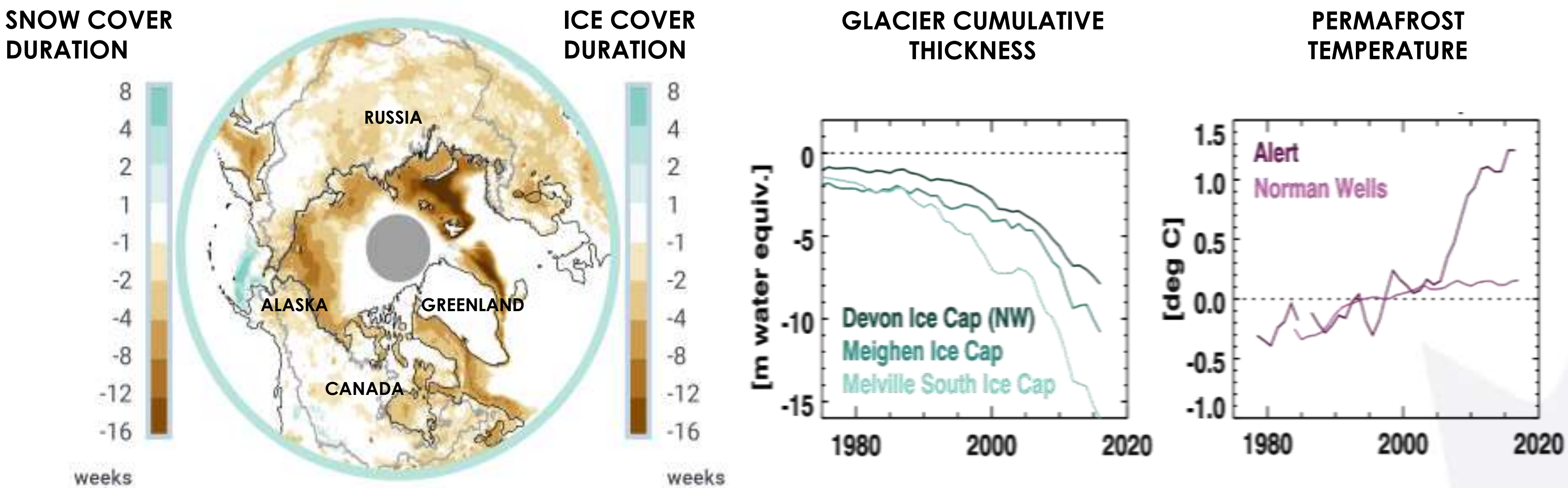
- Across Canada, we are experiencing:
  - -more extreme heat/less extreme cold
  - -less snow and ice cover
  - -thinning glaciers
  - -warmer and more acidic oceans
  - -increased precipitation
  - -earlier spring peak streamflow
  - -thawing permafrost
  - -rising sea level
- Because some further warming is unavoidable, these observed trends will continue.

More extreme heat and less extreme cold have been observed in Canada



- The annual highest daily maximum temperature, averaged over Canada, increased by 0.61°C between 1948 and 2016
- The annual lowest daily minimum temperature, averaged over Canada, increased by 3.3 °C between 1948 and 2016
- Most of the observed increase in the coldest and warmest daily temperatures in Canada can be attributed to human influence

A warmer world – declines in snow, ice, and permafrost

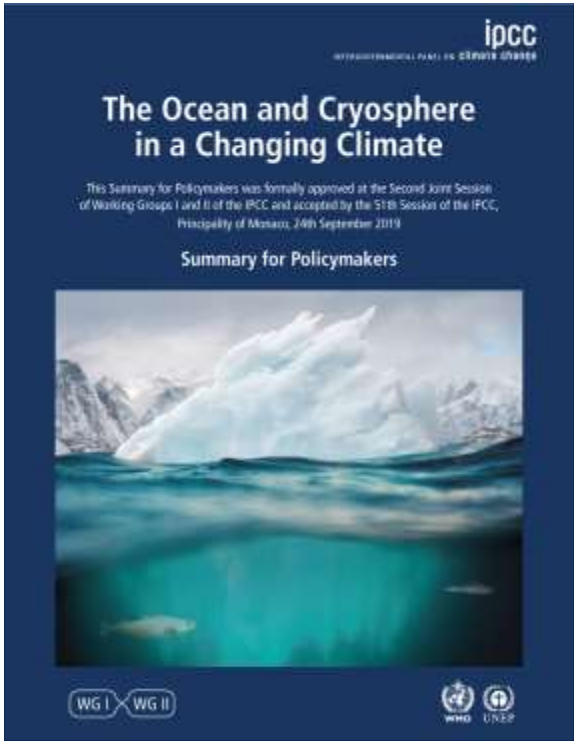


Over the past three decades, the proportion of Canadian land and marine areas covered by snow and ice have decreased, permafrost temperatures have risen, and Arctic and alpine glaciers have thinned at rates unprecedented for several millennia

- The world's ocean and cryosphere have been 'taking the heat' from climate change for decades
- Consequences for nature and humanity are sweeping and severe
- The more decisively and earlier we act, the more able we will be to address unavoidable changes, manage risks, improve our lives and achieve sustainability for ecosystems and people around the world – today and in the future

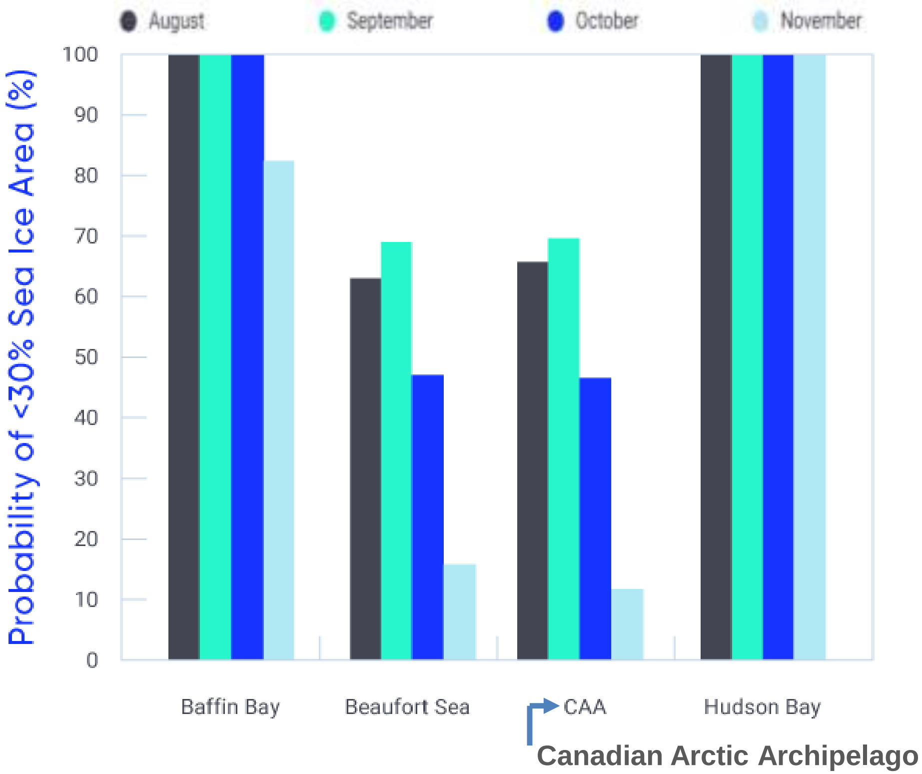
Cryosphere changes in Canada are consistent with those across northern countries

Over the last decades, global warming has led to widespread shrinking of the cryosphere, with mass loss from ice sheets and glaciers, reductions in snow cover and arctic sea ice extent and thickness, and increased permafrost temperature



Extensive ice-free periods are also projected for the Canadian Arctic Ocean

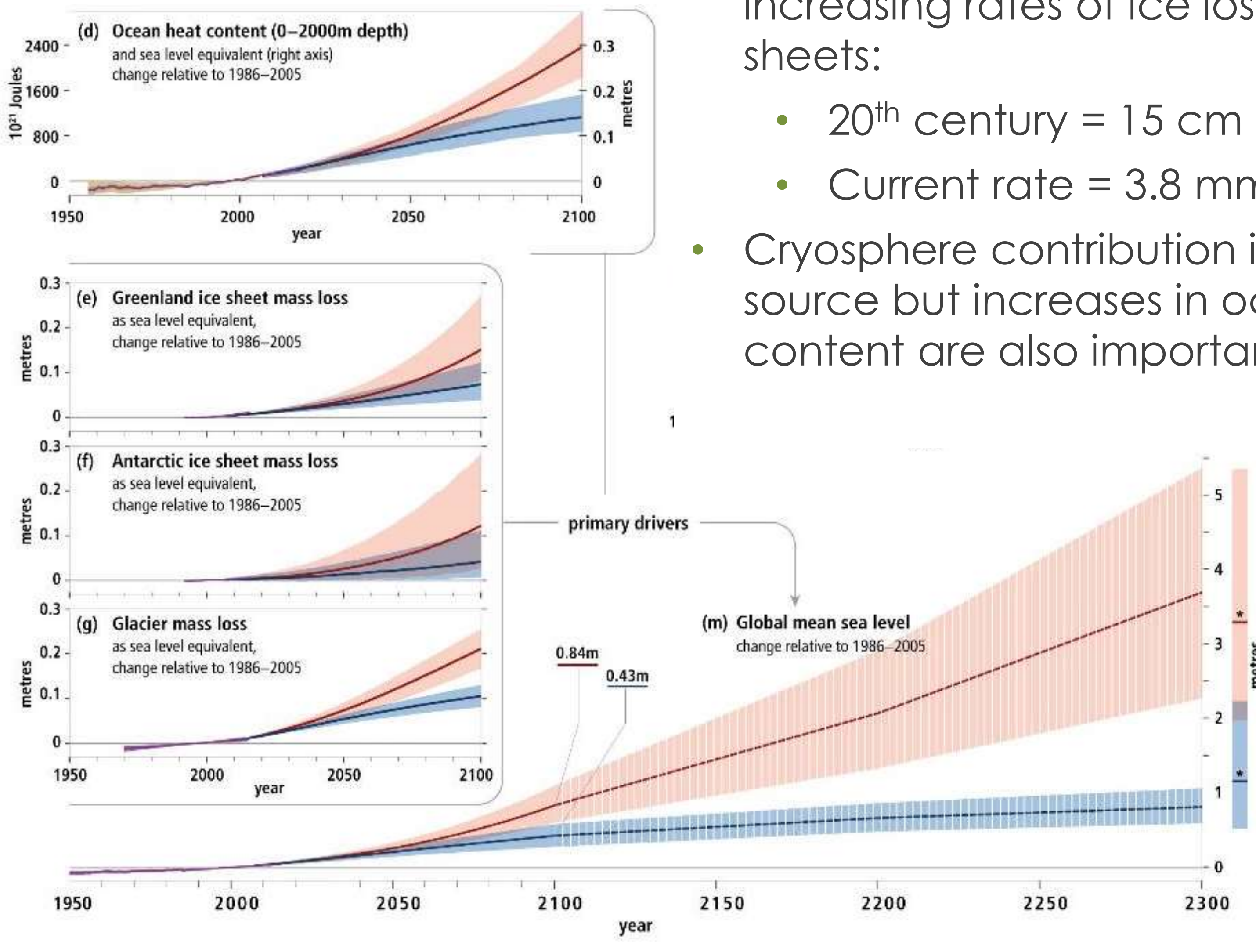
Probability of sea ice–free conditions by 2050



Schematic: last ice area of the Arctic Ocean

- Probability of ice-free conditions in different regions of the Canadian arctic under a high emission scenario
- The likelihood of summer ice-free conditions in the central Arctic rises with the magnitude of global temperature increases

IPCC Special Report on the ocean and cryosphere in a changing climate.



- Global mean sea level is rising with acceleration in recent decades due to increasing rates of ice loss from the ice sheets:
  - 20th century = 15 cm sea level rise
  - Current rate = 3.8 mm per year
- Cryosphere contribution is the dominant source but increases in ocean heat content are also important

- Sea level rise projections to 2300 are subject to ‘deep uncertainty’

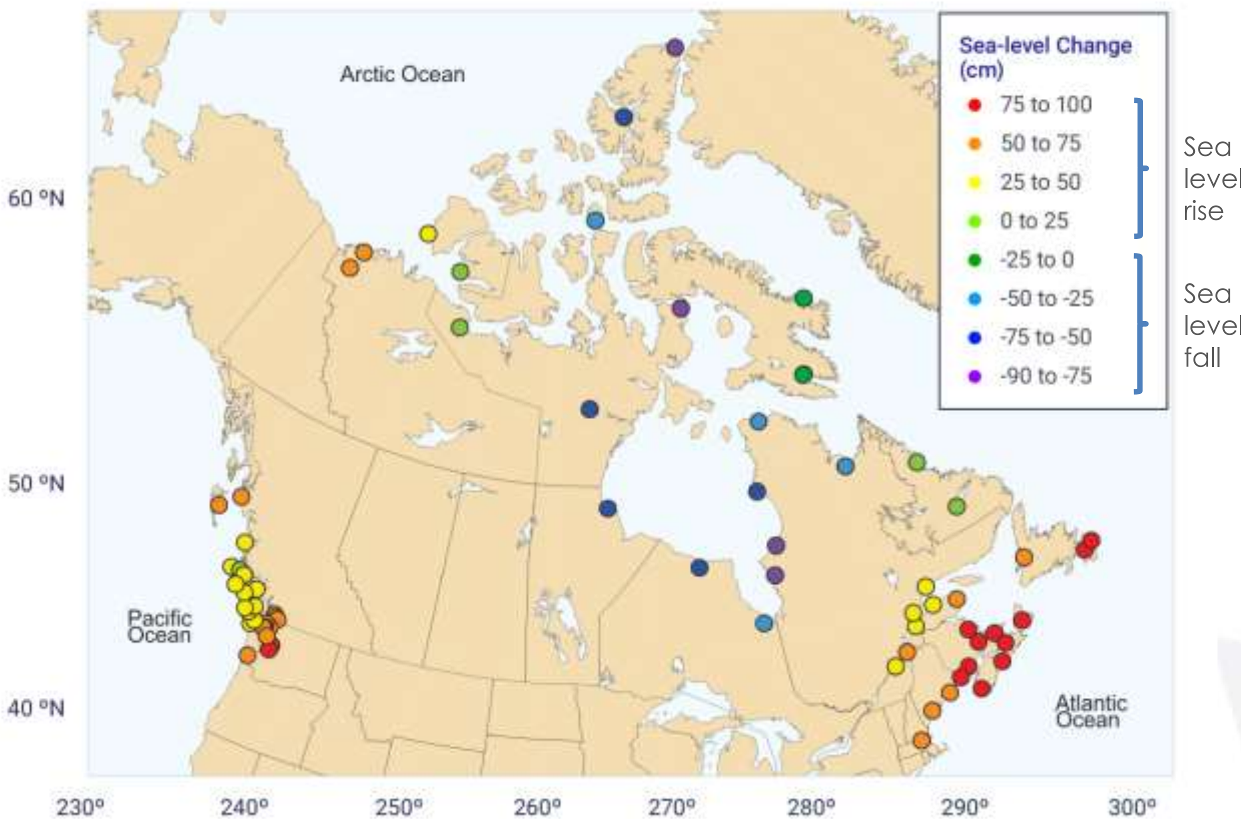
Coastal flooding is expected to increase in many areas of Canada due to local sea level rise

- Changes in local sea-level are a combination of global sea level rise and local land subsidence or uplift.
- Local sea level is projected to rise, and increase flooding, along most of the Atlantic and Pacific coasts of Canada and the Beaufort Sea coast in the Arctic.

Davis Bay, B.C. Photo courtesy of B. Oakford.

- The loss of sea ice in Arctic and Atlantic Canada further increases the risk of damage to coastal infrastructure and ecosystems due to larger storm surges and waves.

Global mean sea level is projected to rise, but along Canada's coastlines, sea level will rise in some places, fall elsewhere

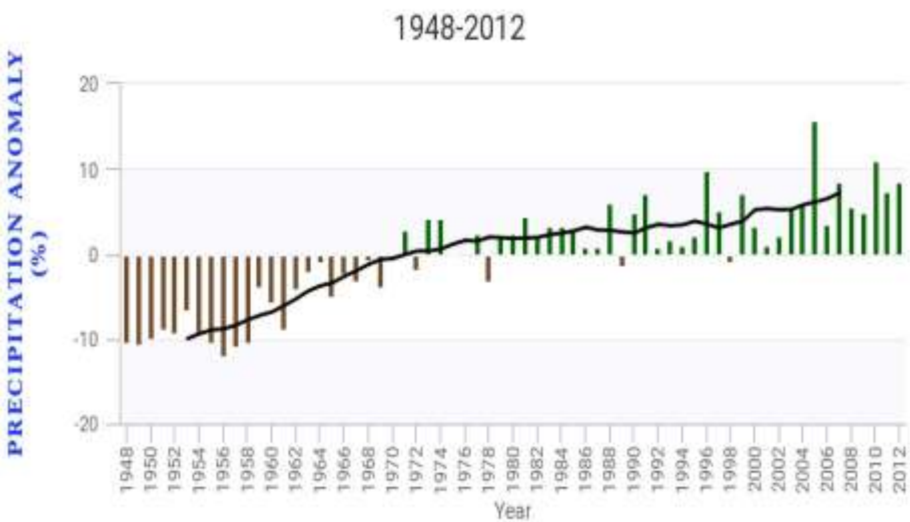


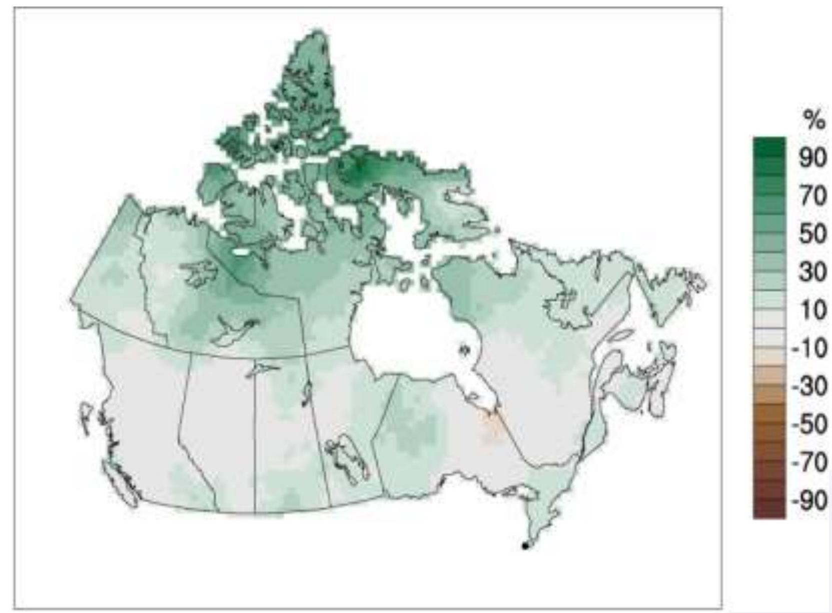
End-of-century projected relative (local) sea-level change under a high emission scenario, relative to 1986-2005 reference period

In southern Atlantic Canada, relative sea level rise is expected to be close to 1 m

A warming climate has been associated with more precipitation on average

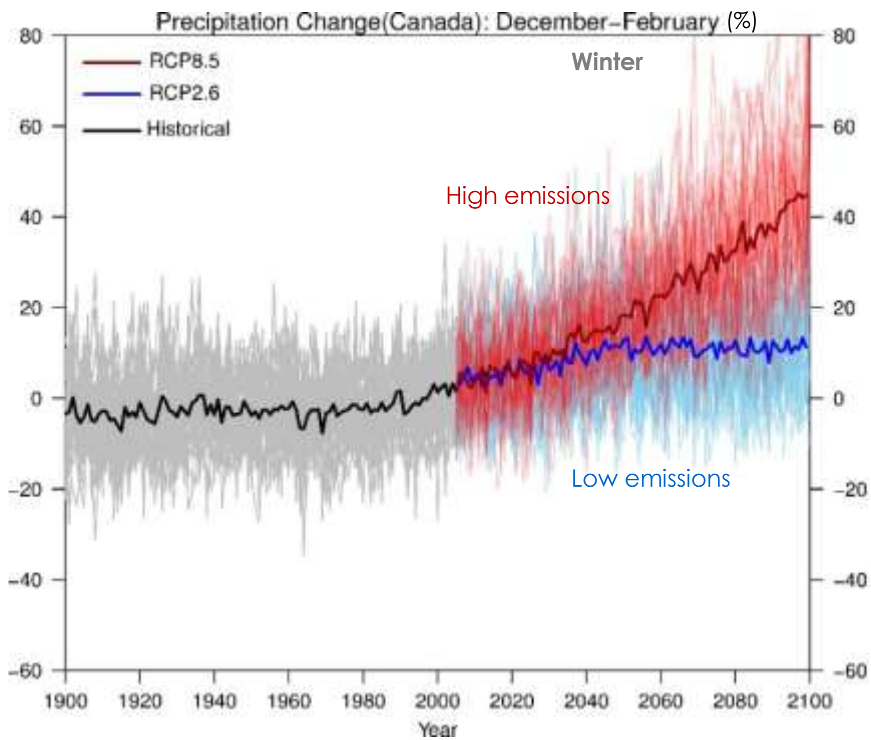
Changes in annual precipitation, 1948–2012





- Annual precipitation has increased in many regions since 1948, with larger percentage increases in northern Canada.
- Averaged over the country, normalized precipitation has increased by about 20% from 1948 to 2012.
- There is less confidence in observed changes in precipitation than temperature but observed increases are consistent with physical expectations.

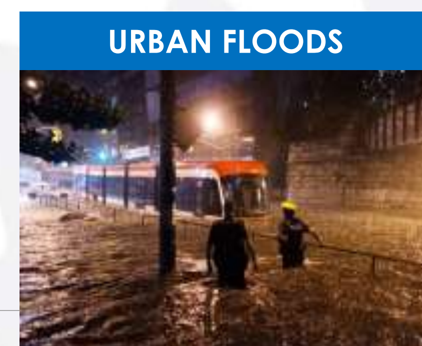
A warmer climate will bring more precipitation on average



- Annual and winter precipitation is projected to increase everywhere in Canada over the 21st century, with larger changes under a high emission scenario.
- Larger percent changes are projected for northern Canada.

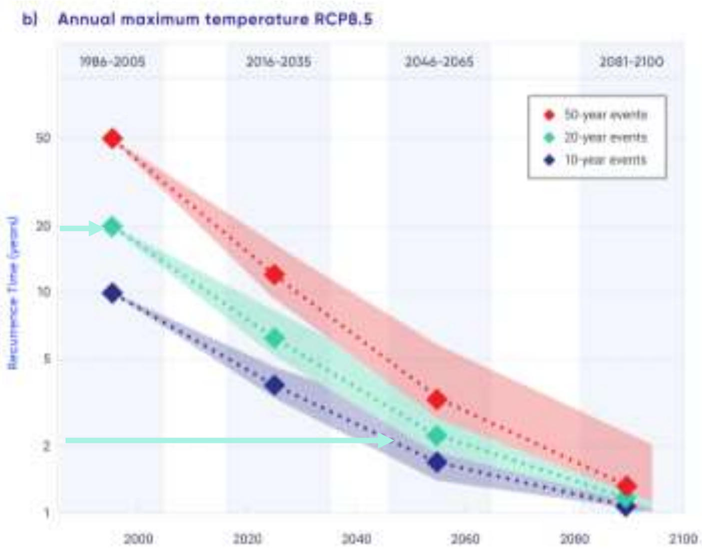
A warmer climate will intensify some weather extremes in the future

- Extreme hot temperatures will become more frequent and more intense. This will increase the severity of heatwaves, and contribute to increased drought and wildfire risks.
- While inland flooding results from multiple factors, more intense rainfalls will increase urban flood risks.
- It is uncertain how warmer temperatures and smaller snowpacks will combine to affect the frequency and magnitude of snowmelt-related flooding.



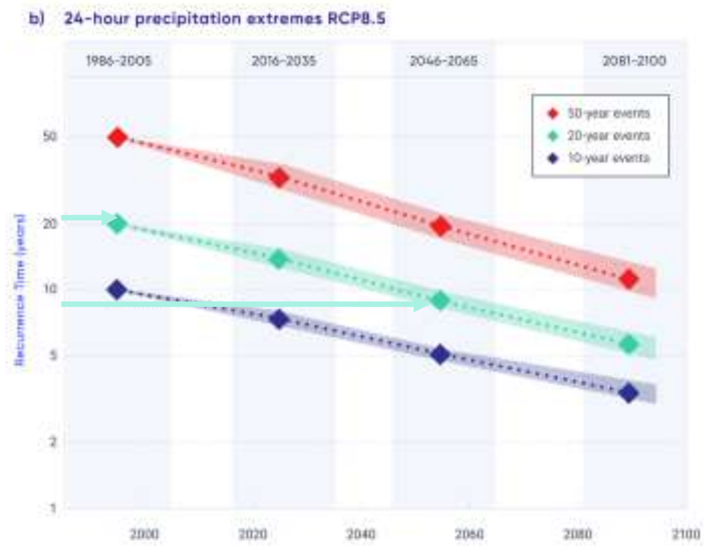
Future increases in the frequency and intensity of extreme events

Change in temperature extremes High emission scenario



- A current 1 in 20-yr hot extreme will become a once in 2-year event by mid-century under a high emission scenario (a ten-fold increase in frequency).

Change in precipitation extremes High emission scenario



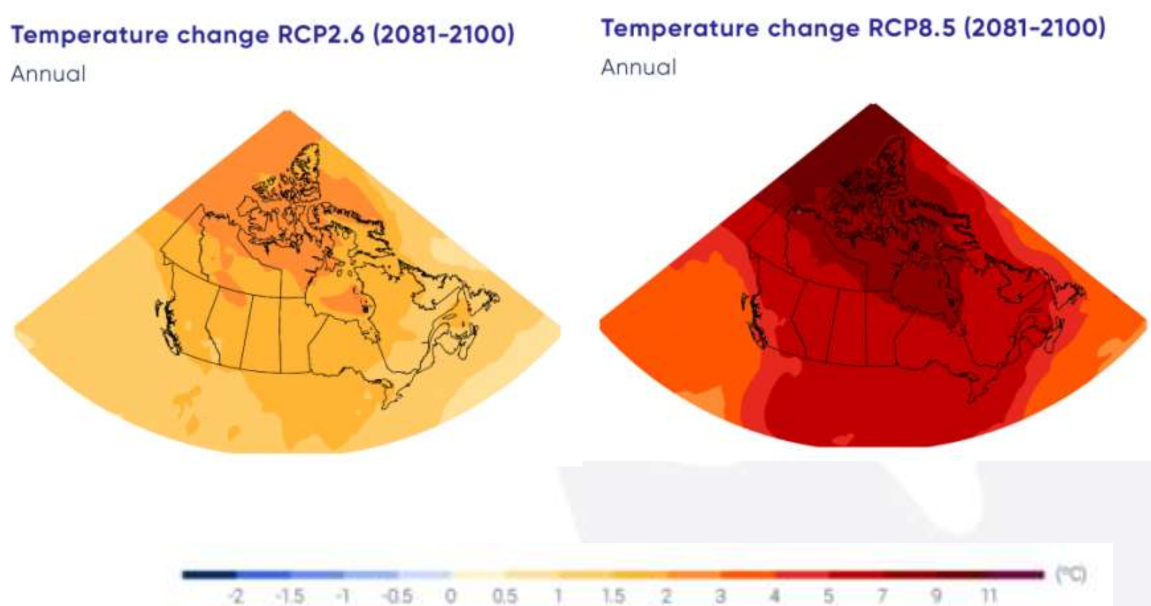
- A current 1 in 20-yr rainfall extreme will become a once in 10-yr event by mid-century under the high emission scenario (a two-fold increase in frequency).

The rate and magnitude of climate change under high versus low emission scenarios project two very different futures for Canada

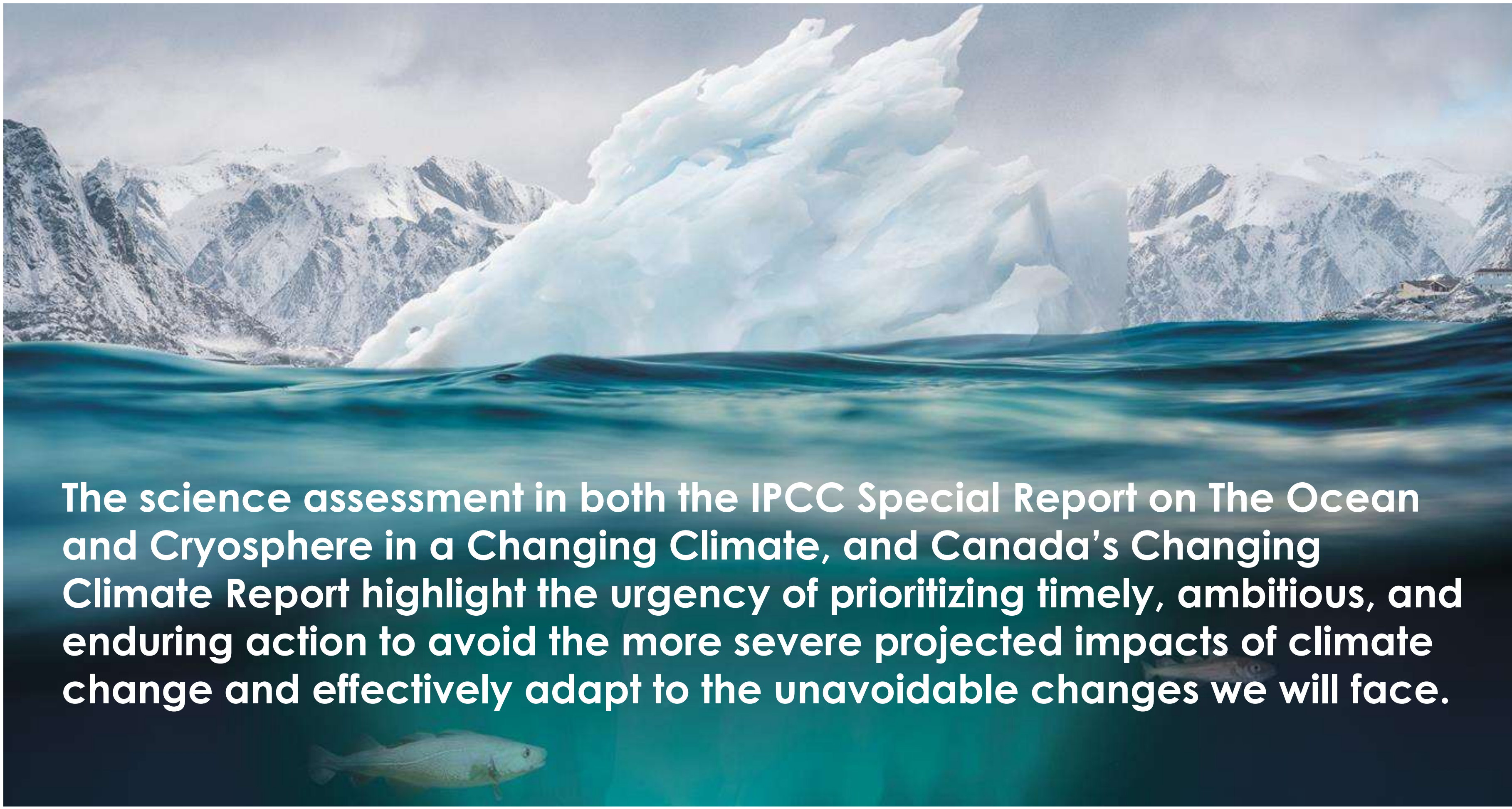
- Scenarios with large and rapid warming illustrate the profound effects on Canadian climate of continued growth in GHG emissions.
- Scenarios with limited warmin will only occur if Canada and t rest of the world reduce carbo emissions to near zero early ir the second half of the century and reduce emissions of other GHGs substantially.

Low global emissions limited warming

High global emissions large warming



Climate change is real, and we are seeing clear evidence of it across Canada. Additional warming and further changes in climate are unavoidable.



The science assessment in both the IPCC Special Report on The Ocean and Cryosphere in a Changing Climate, and Canada's Changing Climate Report highlight the urgency of prioritizing timely, ambitious, and enduring action to avoid the more severe projected impacts of climate change and effectively adapt to the unavoidable changes we will face.

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CCCma Future Timeline