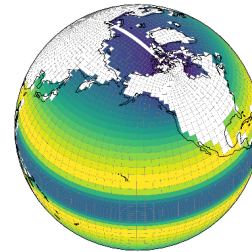
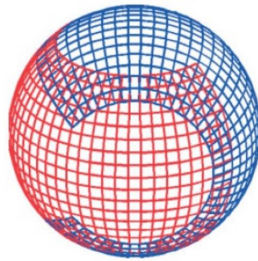




# Canadian Focused Projections using the CCCma Integrated Climate Modelling System



**Neil Swart** and the model development team

Clint Seinen, Deji Akingunola, Jason Cole, John Scinocca, Slava Kharin, Mike Lazare, Cathy Reader, Michael Sigmund, James Anstey, Vivek Arora, Nicolas Lambert, Duo Yang, Carsten Abraham, Yanjun Jiao, Barbara Winter, James Christian, Knut von Salzen,...

PCIC seminar September 2023

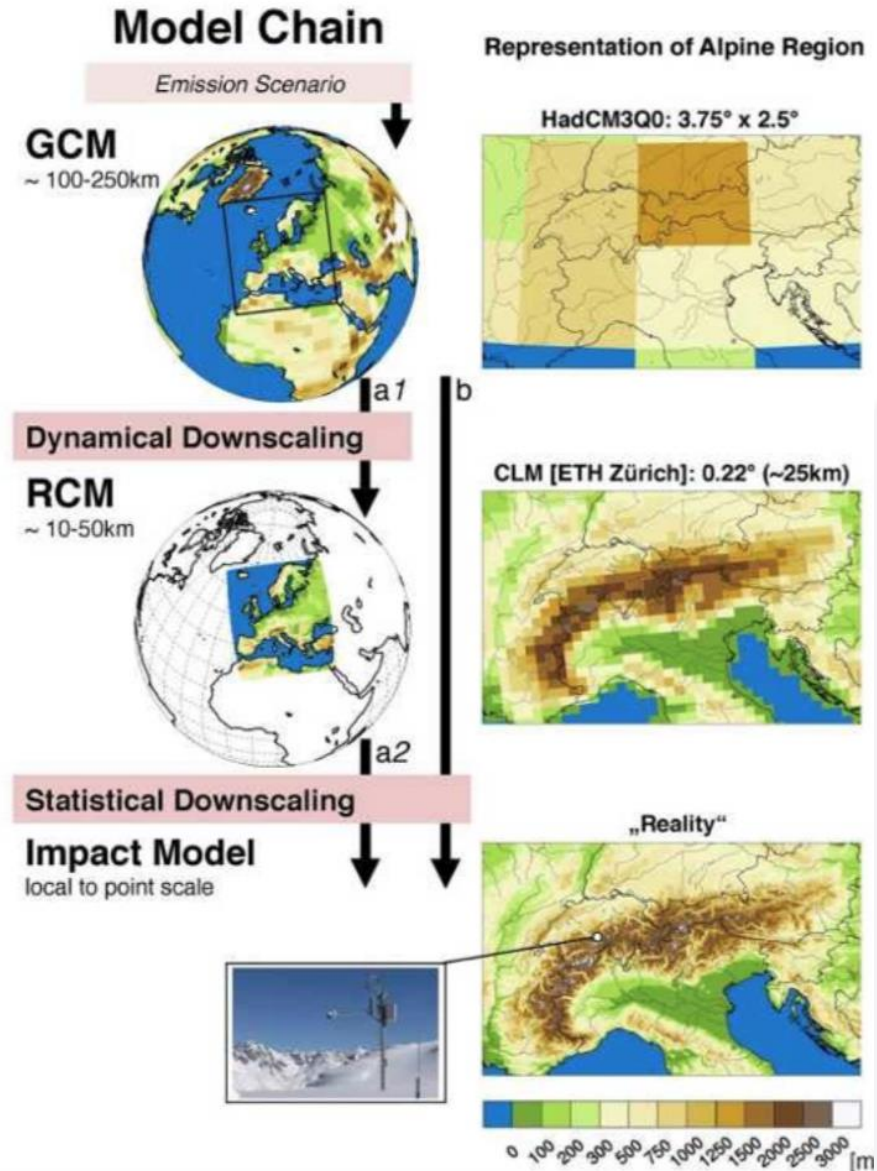
# Outline

- Introduction
  - History of CCCma science & deliverables
  - National Adaptation Strategy and new directions
- Strategy for Canadian Focused Projections
  - Modernized infrastructure & collaborative development
  - Global modelling – from CanESM5 to CanESM6
  - Regional Downscaling – Atmosphere, Land, Ocean & Coupled
  - Data delivery & refinement

# The climate modelling value chain

## Most historical effort @ CCCma

- Fundamental understanding of processes & drivers of climate change
- Future projections/predictions at coarse scale (>100 km)
- Global climate policy / emissions quotas



# History of CCCma modelling & science

Models

**AGCM1**  
Boer and McFarlane  
(1979)

**CMAM**  
Beagley et al. (1997)

**CGCM2**

**CanRCM4**  
Scinocca et al. 2016

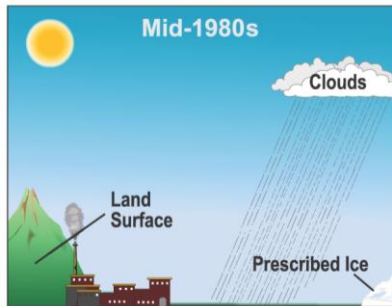
**CanESM1**  
Christian et al. 2010

**AGCM2**  
McFarlane et al. (1992)

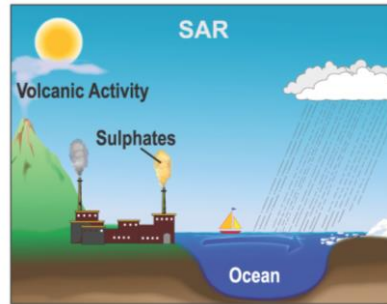
**CGCM3**  
McFarlane et al.  
(2005)  
Scinocca et al.  
(2008)

**CanESM2 / CGCM4**  
Swart et al. 2019

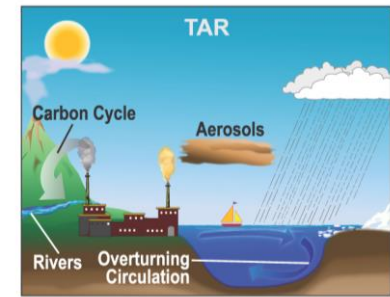
**CanESM5**  
Swart et al. 2019



Atmosphere only



Coupled to ocean



Carbon cycle



1970                      1980                      1990                      2000                      2010                      2020

Assessments & MIPs

<b>WCRP MIPs:</b>	CMIP1	CMIP2	CMIP3	CMIP5	CMIP6		
<b>IPCC assessments:</b>	AR1 1990	AR2 1995	TAR 2001	AR4 2007	AR5 2013	SR15 2018 SROCC 2019	<b>AR6 2021</b>
<b>Canadian climate assessments:</b>				CCC 2014	CCCR 2019		
<b>Assessment of Ozone Depletion:</b>			2006	2010	2014	2018	
<b>Operational seasonal prediction systems:</b>	HFP1		HFP2	CanSIPsv1	CanSIPsv2		

# CCCma has an expanding mandate and staffing under NAS



Government  
of Canada

Gouvernement  
du Canada

[Français](#)



MENU ▾

[Canada.ca](#) > [Environment and Climate Change Canada](#)

## Canada's National Adaptation Strategy will protect communities and build a strong economy

From: [Environment and Climate Change Canada](#)

### News release

November 24, 2022—St. Peters Bay, Prince Edward Island

As Canadians feel the impacts of climate change—from extreme heat and wildfires to floods and storms—this is the moment to build resilient communities for a strong economy.

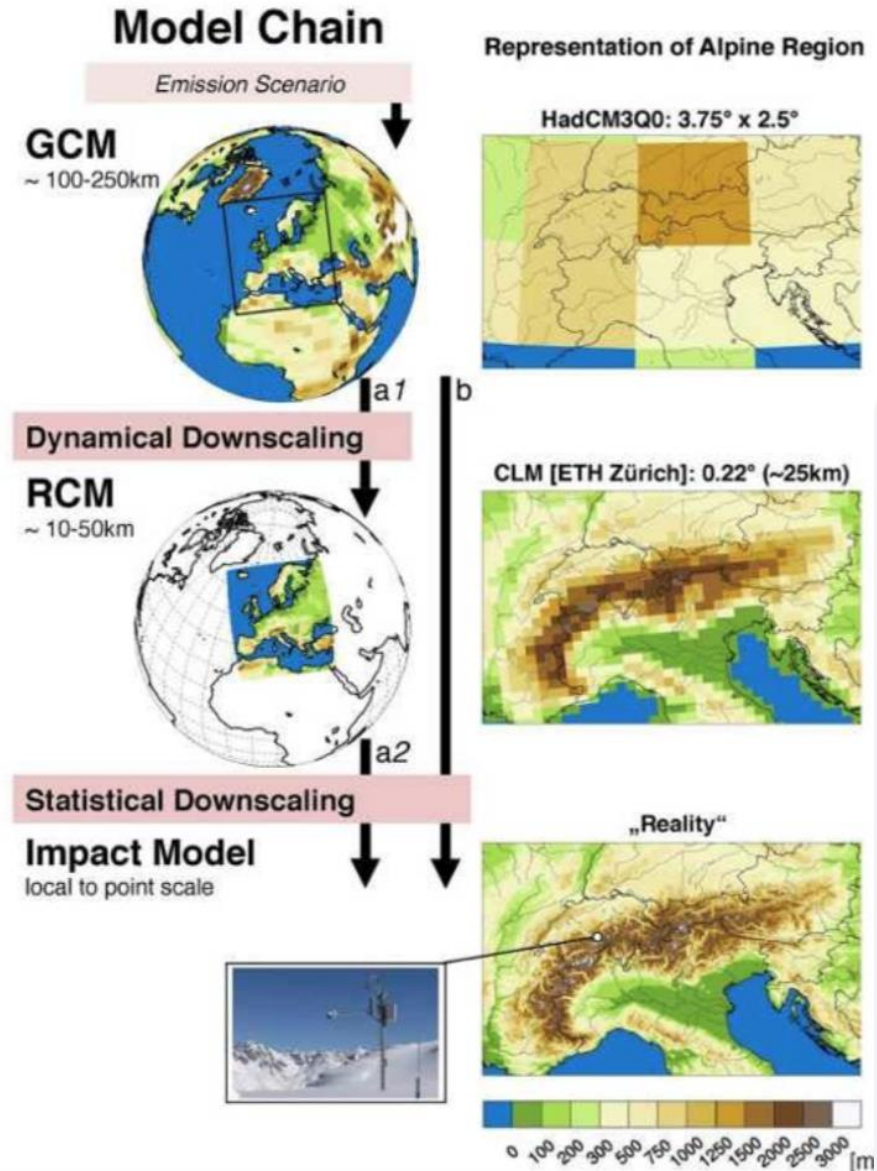
# The climate modelling value chain

## Most historical effort @ CCCma

- Fundamental understanding of processes & drivers of climate change
- Future projections/predictions at coarse scale (>100 km)
- Global climate policy / emissions quotas

## Increasing demand and NAS

- Enhanced resolution information at regional to local scale (<25km)
- Poll 1: Have you used our model output?

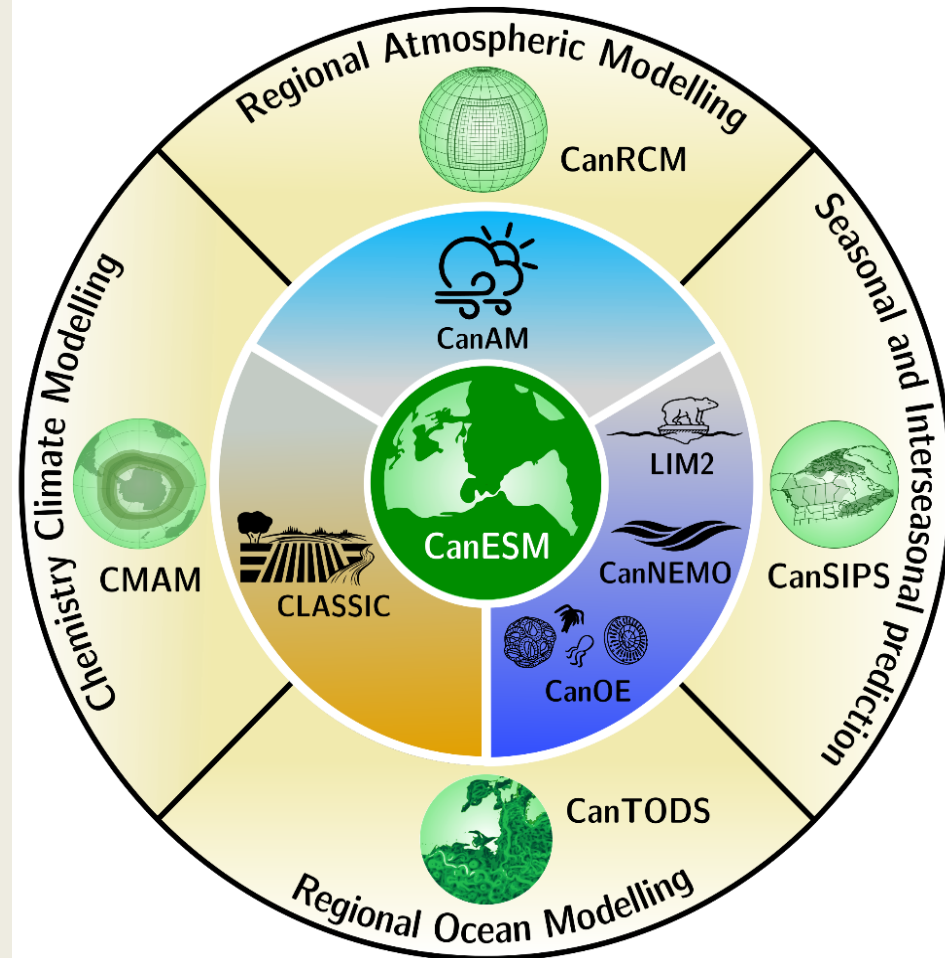




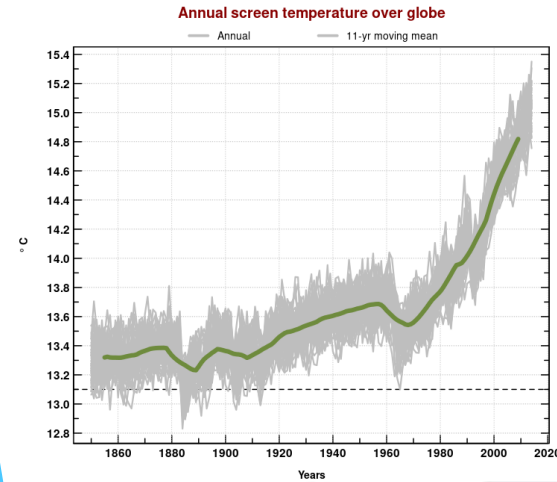
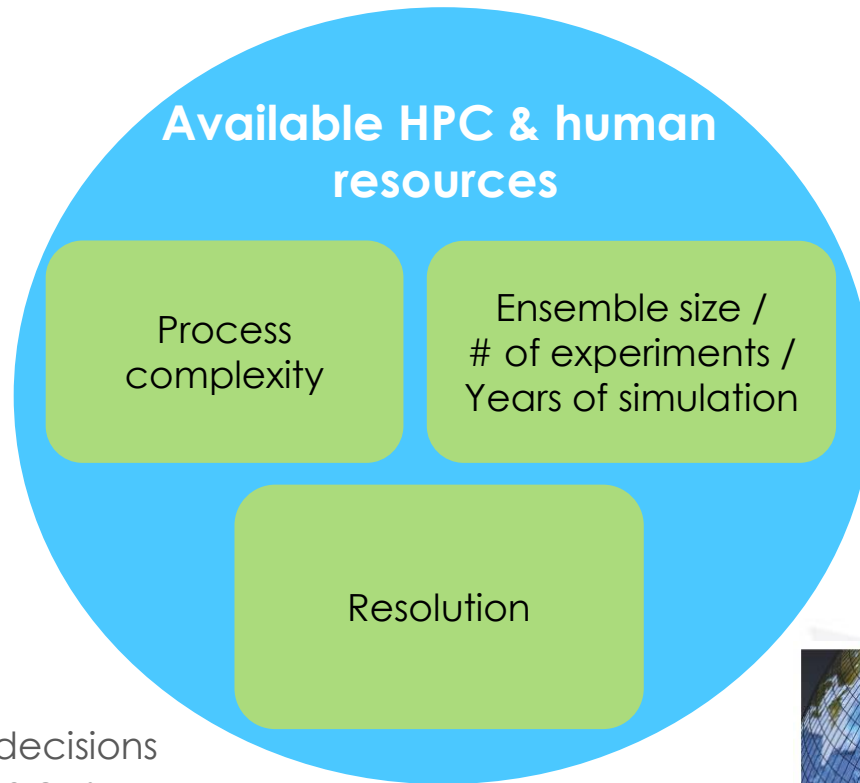
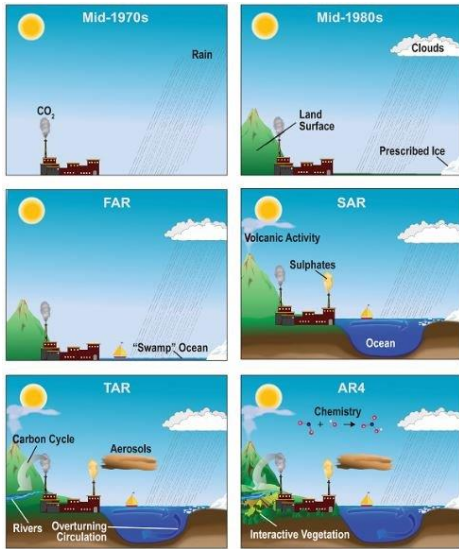
# Strategy for Canadian focused projections

- **Common infrastructure & HPC/HR resources**
  - Foundational tools that enable configuration, running, and exchange.
  - Leverage expertise from the broader Canadian climate science community.
- **Global modelling (CanESM) – 100 km**
  - Improve quality through better physics
  - Increase resolution (to 25-100 km)
  - Improve efficiency (GEM dycore)
- **Regional downscaling -10-25 km**
  - Extend atmospheric downscaling with **CanRCM** to more projections and predictions from CanESM
  - Develop **ocean downscaling** capacity via **CanTODS**
  - Coupling CanRCM and CanTODS for a hi-res regional model
- Statistical downscaling & impacts (CDAS)
  - Statistical downscaling and bias correction
  - Canadian climate scenarios
- Climate services & info dissemination

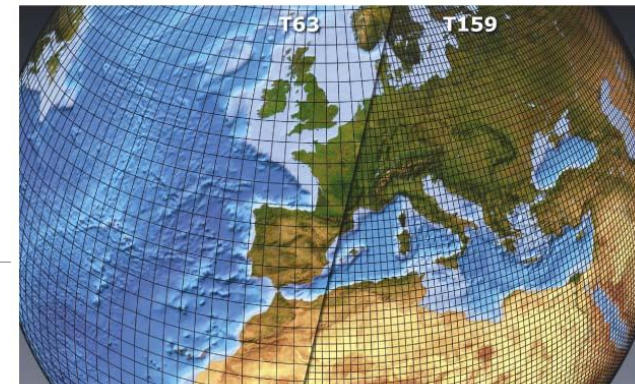
CCCma integrated Modelling System



# Compromises in climate modelling



- We must make hard decisions about how to partition our resources.
- Poll 2 asks what is most valuable to you as users.



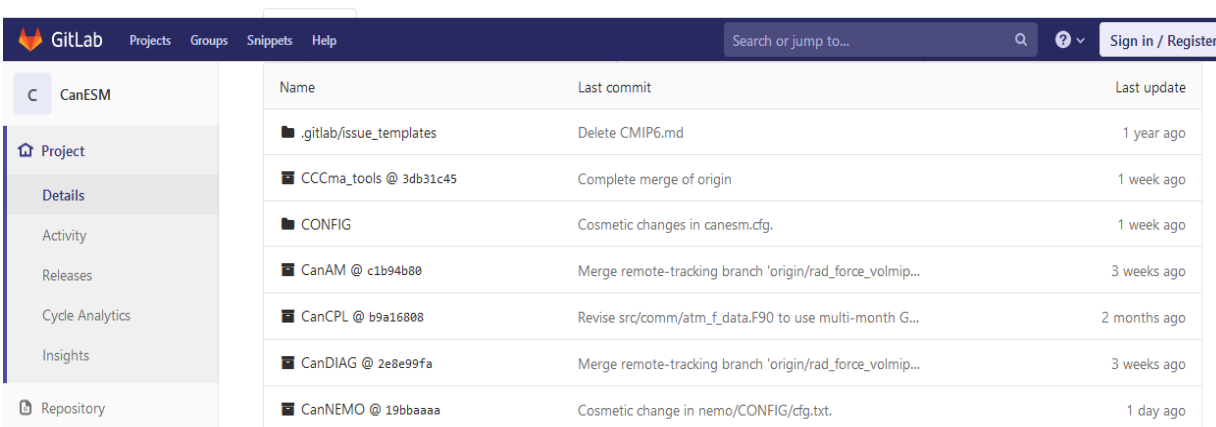


# A modern collaborative model

- Over the past 10 years we have been working very hard to:
  - Publish open access model output
  - Create a fully open source code base for CanESM
  - Create up to date user guides, documentation and open access documenting publications
  - Modernize the mode code and diagnostics (e.g. modern Fortran)
  - Build modern, efficient and portable infrastructure, allowing the model to be run across a range of HPC platforms.
  - Engaging with the Canadian modelling community

Fully version controlled, open source code:

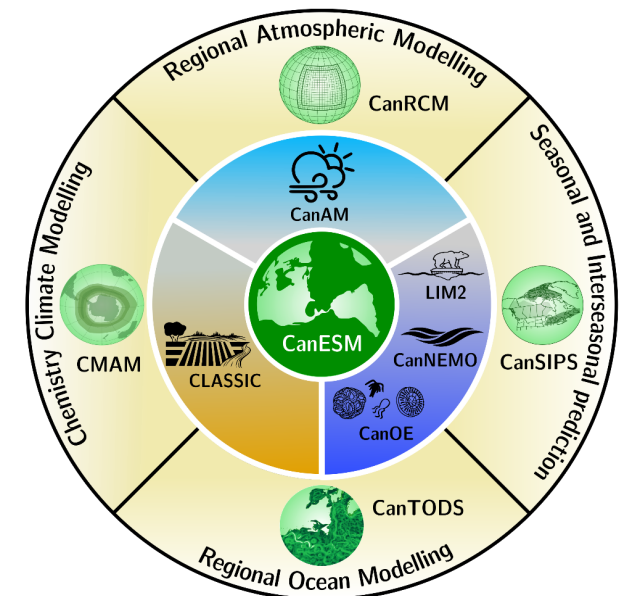
[gitlab.com/cccma/canesm](https://gitlab.com/cccma/canesm)



The screenshot shows the GitLab web interface for the 'CanESM' repository. The top navigation bar includes 'GitLab', 'Projects', 'Groups', 'Snippets', and 'Help'. A search bar and 'Sign in / Register' button are also present. The left sidebar shows navigation options: 'Project', 'Details', 'Activity', 'Releases', 'Cycle Analytics', 'Insights', and 'Repository'. The main content area displays a table of repository items with columns for Name, Last commit, and Last update.

Name	Last commit	Last update
<code>._gitlab/issue_templates</code>	Delete CMIP6.md	1 year ago
<code>CCCma_tools @ 3db31c45</code>	Complete merge of origin	1 week ago
<code>CONFIG</code>	Cosmetic changes in canesm.cfg.	1 week ago
<code>CanAM @ c1b94b80</code>	Merge remote-tracking branch 'origin/rad_force_volmip...	3 weeks ago
<code>CanCPL @ b9a16808</code>	Revise src/comm/atm_f_data.F90 to use multi-month G...	2 months ago
<code>CanDIAG @ 2e8e99fa</code>	Merge remote-tracking branch 'origin/rad_force_volmip...	3 weeks ago
<code>CanNEMO @ 19bbaaaa</code>	Cosmetic change in nemo/CONFIG/cfg.txt.	1 day ago

## CCCma integrated Modelling System





# Collaborative Platform for CanESM (CP4C)

- CCCma commits to using open standards and having a portable model
- CanESM5-0 & 5-1 have been ported and tested on Digital Research Alliance machines (Cedar, Niagara) & commercial cloud
- CP4C initiative w/ Paul Kusher @ UofT offers a community of practice and compute resources to help advance this work
- Increasing interest in using CanESM from researchers at universities & consortia across Canada

CanESM user guide  
latest

Search docs

CONTENTS:

- Quickstart guides
- Overview of CanESM
- CanESM code structure
- Contributing to CanESM (Developers guide)
- Advanced topics

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<https://gitlab.com/CP4C/cp4c-docs/-/wikis/home>

Last edited by Neil Swart 1 month ago

## Home

### CP4C documentation

This project wiki provides documentation on the Collaborative Platform for CanESM (CP4C)

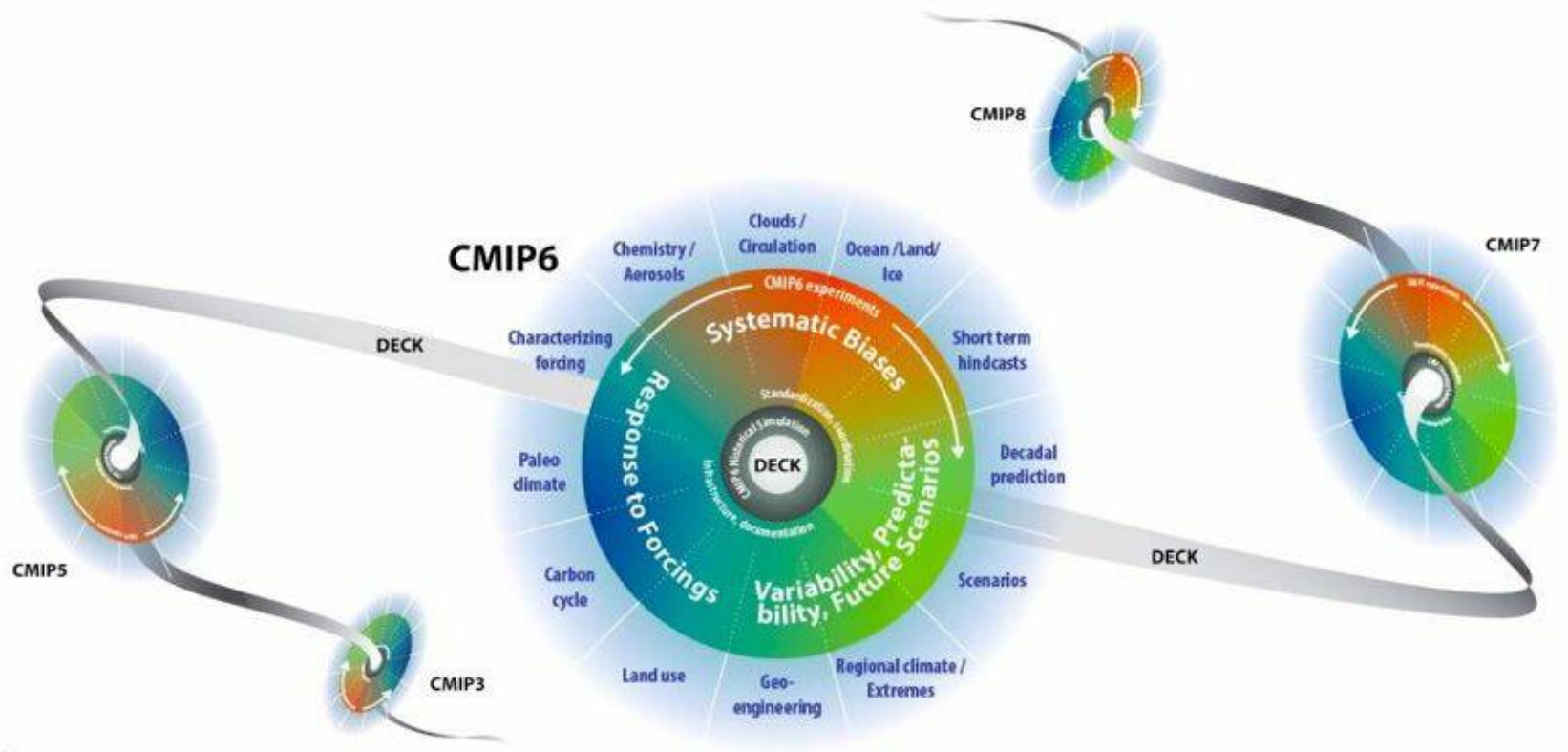
- [Overview](#)
- [Technical meeting minutes](#)
- [Policies](#)
- [Reference runs table](#)
- [CanAM variable dictionary](#)

### Useful links

- [Niagara quickstart guide for CanESM](#)
- [CanESM user guide](#)
- [RTD browser for Niagara CP4C runs \(Arbutus cloud\)](#)
- Example ipython notebooks for converting/reading CCCma format data are [here](#)

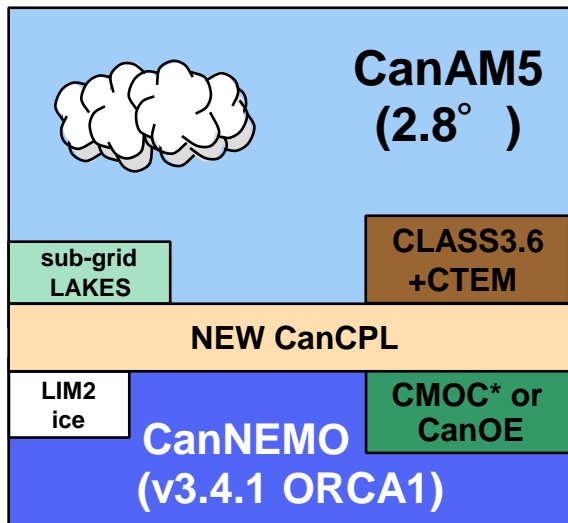
# Global Modelling

# Coupled Model Intercomparison Project




# CanESM5 & CMIP6

## CanESM5.0 (CMIP6)

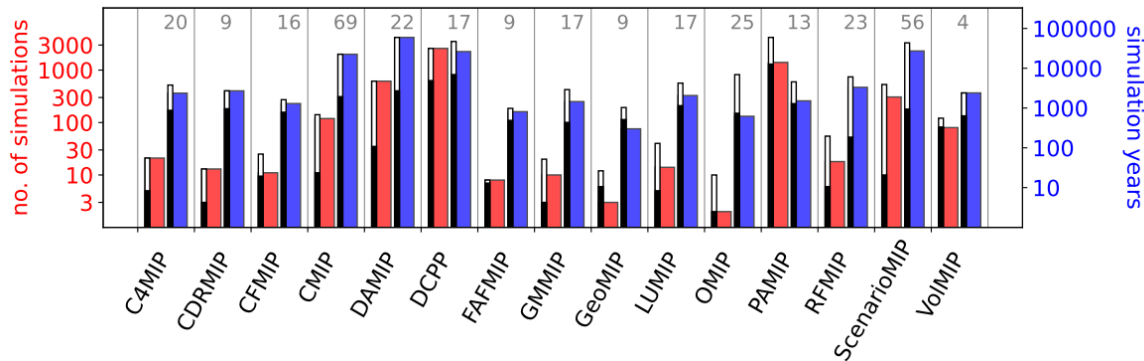


CCCma environment + tools

 **Canadian Earth System Model 5 (CanESM5)**  
My CMIP6 statistics so far:

- 200,000 years of simulation
- 105 experiments across 15 MIPs/Activities
- 100 million+ core-hours of computation
- 30 PB of data on tape
- 5 PB of data on disk
- 0.5 PB of data on ESGF

...and counting... **666**



**Geoscientific Model Development**  
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https://doi.org/10.5194/gmd-2019-177  
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Submitted as: model description paper

**The Canadian Earth System Model version 5 (CanESM5.0.3)**

Neil C. Swart<sup>1,3</sup>, Jason N. S. Cole<sup>1</sup>, Viatcheslav V. Kharin<sup>1</sup>, Mike Lazare<sup>1</sup>, John F. Scinocca<sup>1</sup>, Nathan P. Gillett<sup>1</sup>, James Anstey<sup>1</sup>, Vivek Arora<sup>1</sup>, James R. Christian<sup>1,2</sup>, Sarah Hanna<sup>1</sup>, Yanjun Jiao<sup>1</sup>, Warren G. Lee<sup>1</sup>, Fouad Majaess<sup>1</sup>, Oleg A. Saenko<sup>1</sup>, Christian Seiler<sup>1,4</sup>, Clint Seinen<sup>1</sup>, Andrew Shao<sup>3</sup>, Larry Solheim<sup>1</sup>, Knut von Salzen<sup>1,3</sup>, Duo Yang<sup>1</sup>, and Barbara Winter<sup>1</sup>

<sup>1</sup>Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Victoria, BC, V8W 2P2, Canada  
<sup>2</sup>Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canada  
<sup>3</sup>University of Victoria, 3800 Finnerty Rd, Victoria, BC, V8P 5C2, Canada  
<sup>4</sup>Climate Processes Section, Environment and Climate Change Canada, Victoria, BC, V8P 5C2, Canada

Received: 22 Jun 2019 – Accepted for review: 21 Jul 2019 – Discussion started: 23 Jul 2019

**Abstract.** The Canadian Earth System Model version 5 (CanESM5) is a global model developed to simulate historical climate change and variability, to make centennial scale projections of future climate, and to produce initialized seasonal and decadal predictions. This paper describes the model components and their coupling, as well as various aspects of model development, including tuning, optimization and validation. The model components include the atmospheric general circulation model, the ocean general circulation model, the land surface model, the ice sheet model, and the biosphere model. The model is designed to be flexible and extensible, allowing for the inclusion of new components and the modification of existing ones. The model is currently being used for a wide range of climate change studies, including the assessment of the impact of greenhouse gas emissions on the climate system, the development of climate change adaptation strategies, and the evaluation of climate change mitigation options.

**Review status:** This discussion paper is a preprint. A revision of the manuscript is under review for the journal Geoscientific Model Development (GMD).

**Search articles:** Search Author

**Special issue:** The Canadian Earth System Model version 5

**Download:** PDF XML

**Short summary:** The Canadian Earth System Model version 5 (CanESM5) is a global model developed to simulate... Read more

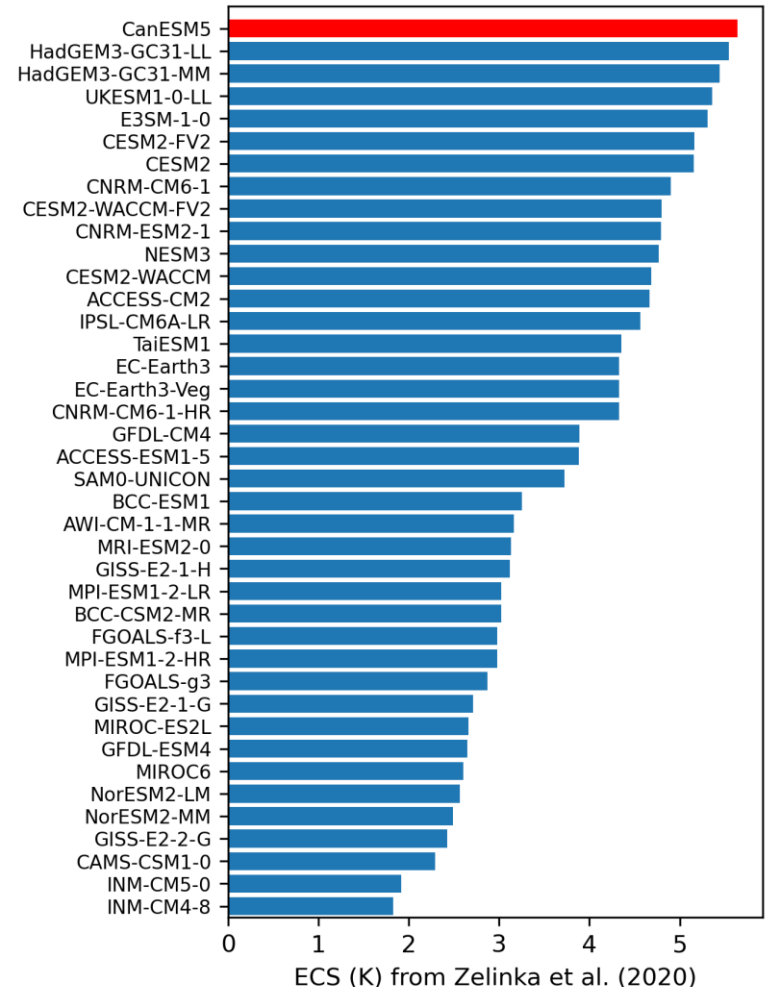
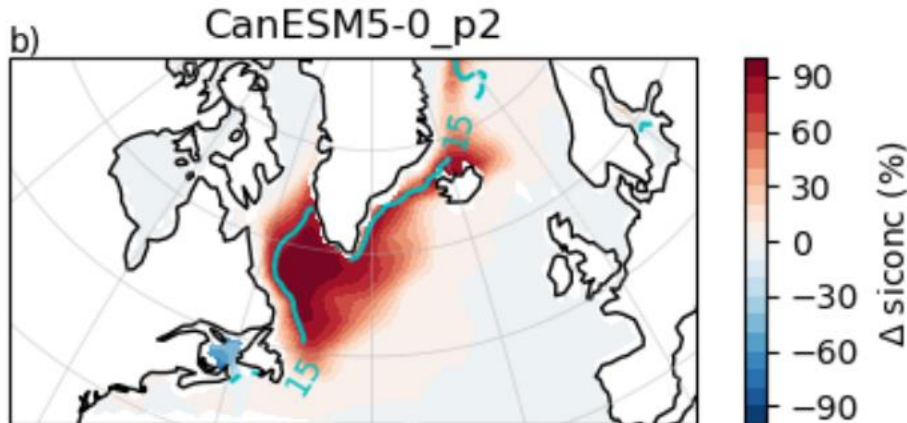
User ID:  Password:  Lost login?



# CanESM5 vs the world

- Objective skill measures show CanESM5 climatologies are better than CanESM2, and compare well against other CMIP6 models (despite being the coarsest atmospheric resolution).
- There are nonetheless various significant biases relative to observations, e.g. Labrador Sea ice cover.

- High climate sensitivity / rapid historical warming is notable feature of CanESM5



# Analysis for Development (A4D)

## Preprint

Preprints / Preprint gmd-2023-52

<https://doi.org/10.5194/gmd-2023-52>

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Abstract

Discussion


Metrics

Submitted as: model evaluation paper | 

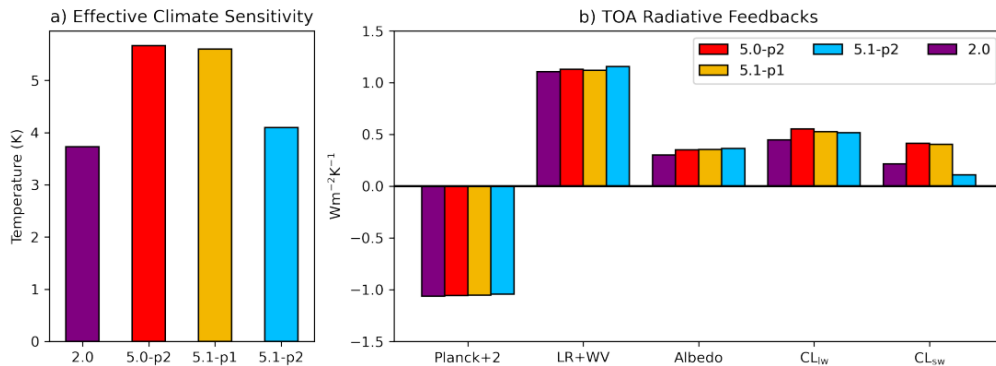
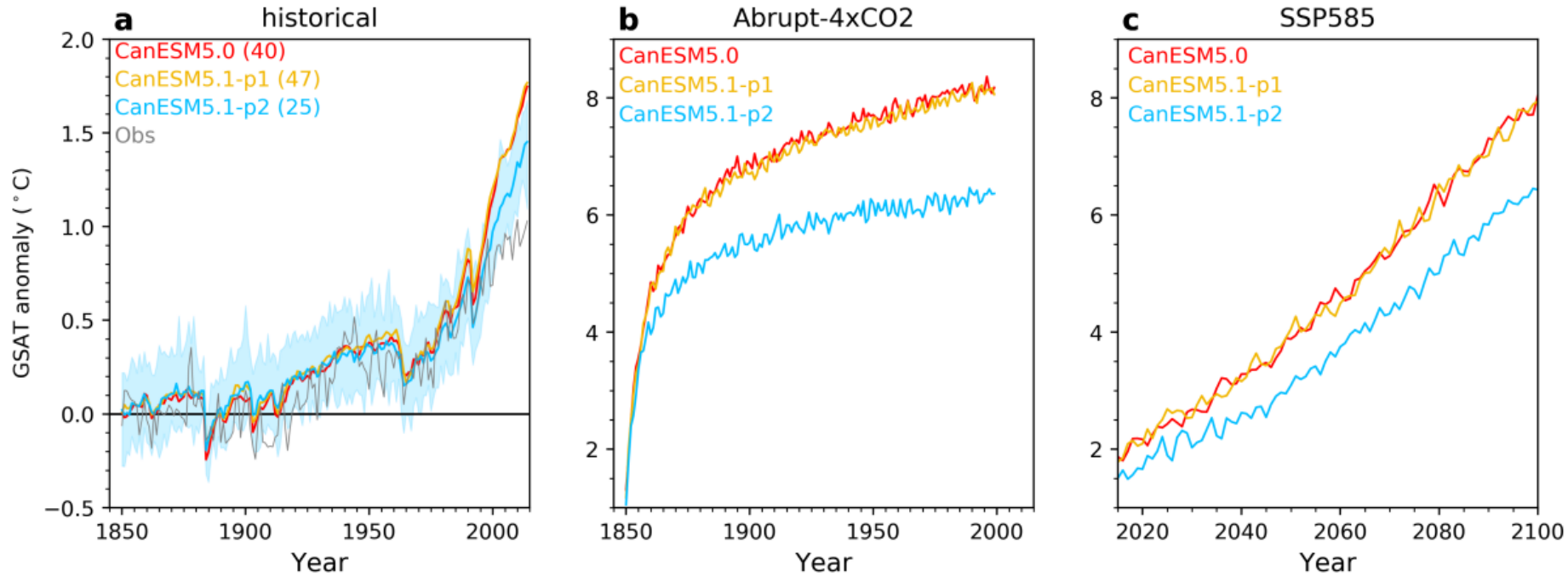
04 Apr 2023

**Status:** this preprint is currently under review for the journal GMD.

## Improvements in the Canadian Earth System Model (CanESM) through systematic model analysis: CanESM5.0 and CanESM5.1

Michael Sigmond , James Anstey, Vivek Arora, Ruth Digby, Nathan Gillett, Viatcheslav Kharin, William Merryfield, Catherine Reader, John Scinocca, Neil Swart, John Virgin, Carsten Abraham, Jason Cole, Nicolas Lambert, Woo-Sung Lee, Yongxiao Liang, Elizaveta Malinina, Landon Rieger, Knut von Salzen, Christian Seiler, Clint Seinen, Andrew Shao, Reinel Sospedra-Alfonso, Libo Wang, and Duo Yang

# Reduced Climate Sensitivity in CanESM5-1 p\_2



From Sigmund et al.

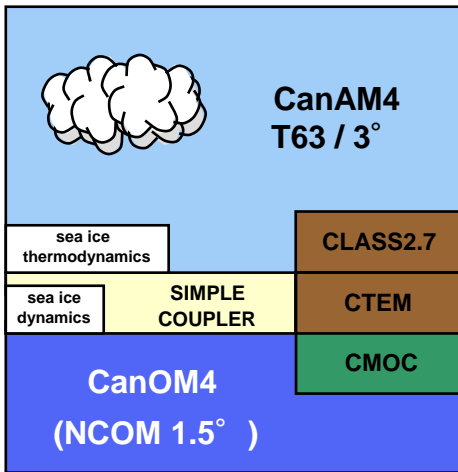
# The path to CanESM6

2011

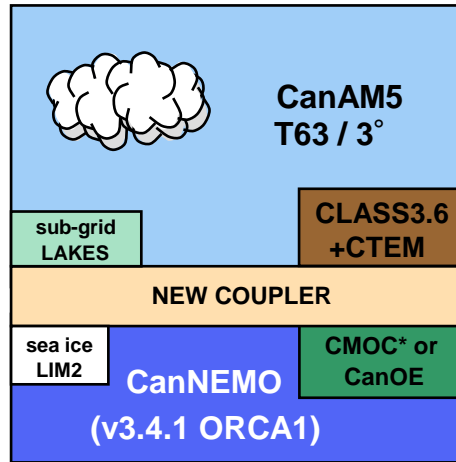
2018

2025

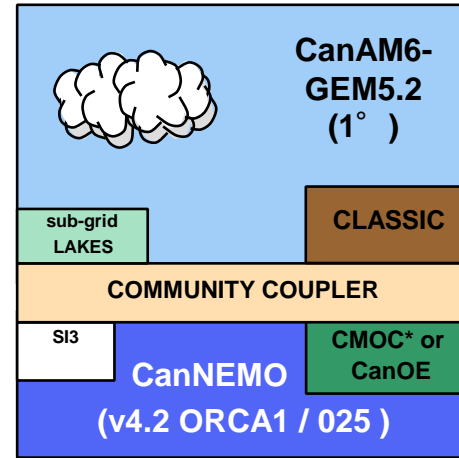
**CanESM2.0 (CMIP5)**



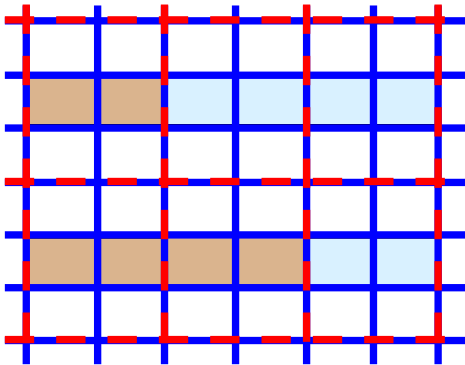
**CanESM5.0 (CMIP6)**



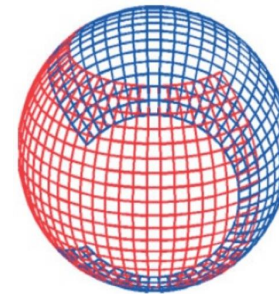
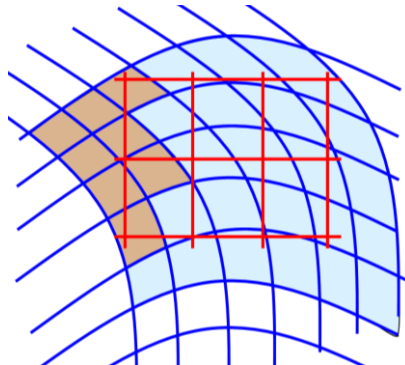
**CanESM6.0 (CMIP7)**



Co-incident grids



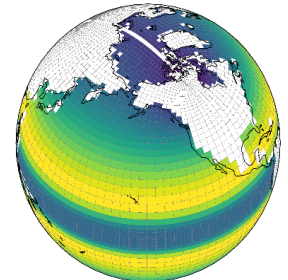
Gaussian to tripolar



Yin-Yang

to

tripolar



# CLASSIC update for CanESM6

## New geophysical fields

20 layers down to 60 m, as opposed to 3 layers down to 4.1 m in CanESM5.	Done and effect evaluated in CanESM5.1
New land cover (based on European Space Agency Climate Change Initiative, ESA-CCI, product) for specified land cover simulations	Done and effect evaluated in CanESM5.1

## New processes

Fire	Evaluated offline including with CanESM5 climate
N cycle	Evaluated offline but not with CanESM5 climate yet.
Competition between PFTs	Currently evaluating and retuning offline.
Permafrost carbon	Code implemented, waiting on parameter values.

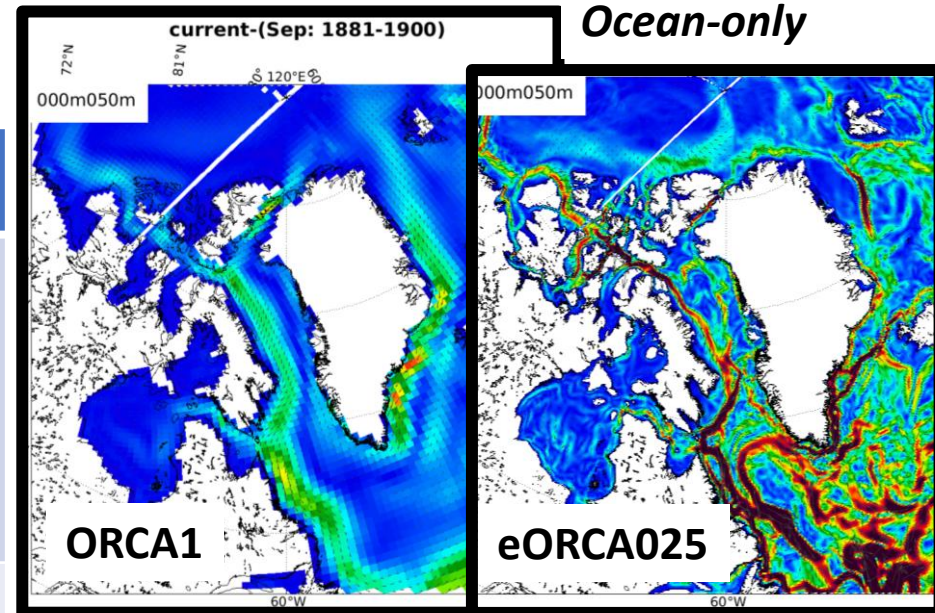
## Integration into CanESM

Implementation of CLASSIC in the CanESM framework	<ul style="list-style-type: none"><li>Coupled feedbacks make integrating the changes above and maintaining an acceptable climate a huge challenge. This work is proceeding.</li></ul>
---	---



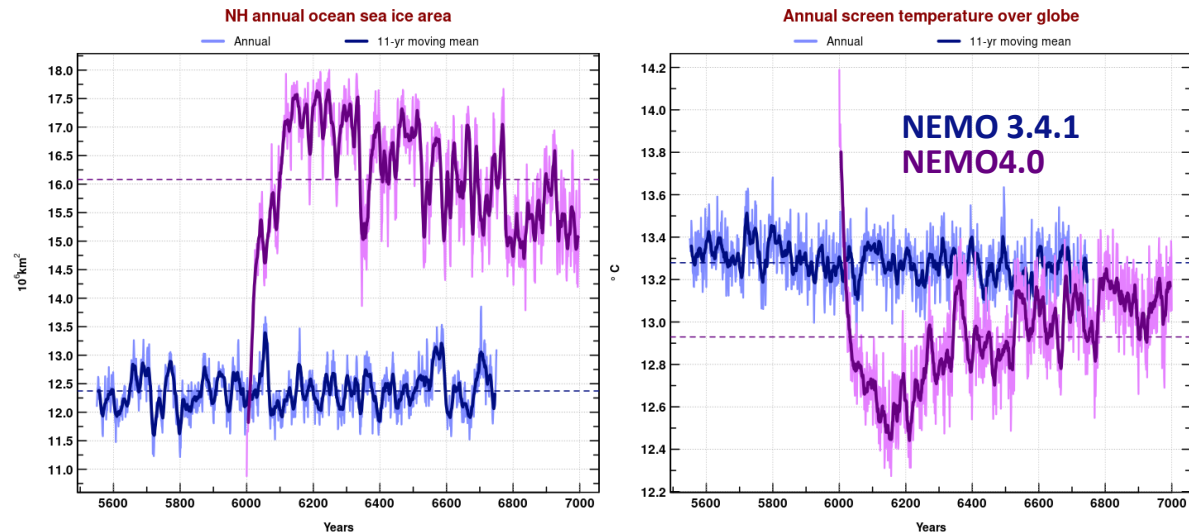
# CanNEMO development

CanESM5.X	CanESM6.0	
NEMO 3.4.1	<b>NEMO 4.x</b> <ul style="list-style-type: none"> <li>New ice model SI<sup>3</sup></li> <li>Lee wave mixing</li> <li>New tidal mixing</li> <li>Ice shelf cavities</li> <li>Icebergs</li> <li>NEMO 4.2</li> </ul>	used testing testing planned planned planned
1° grid ORCA1	<ul style="list-style-type: none"> <li>1° grid eORCA1</li> <li>¼° grid eORCA025</li> </ul>	testing testing
CMOC & CanOE	Port CMOC & CanOE	testing



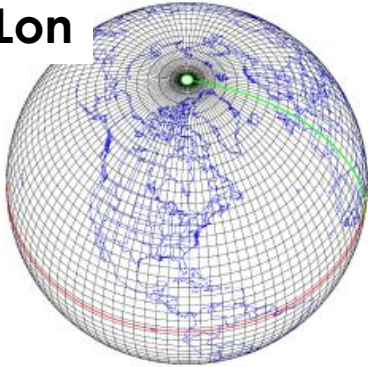
CCCma is currently in the process of hiring new sea-ice and ocean modelling scientists

## Coupled piControl

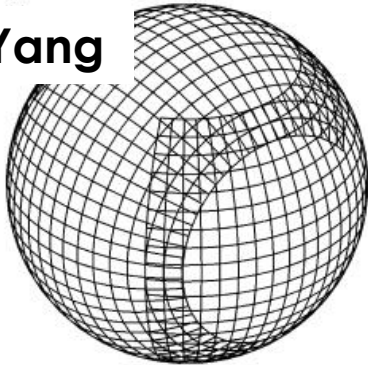


# GEM as the dynamical core of CanAM6

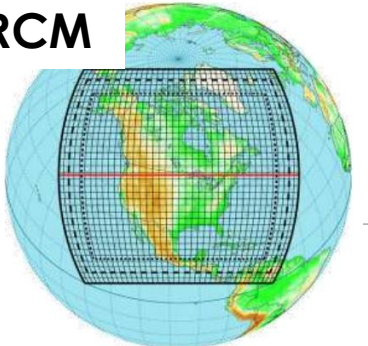
**Lat-Lon**



**Yin-Yang**

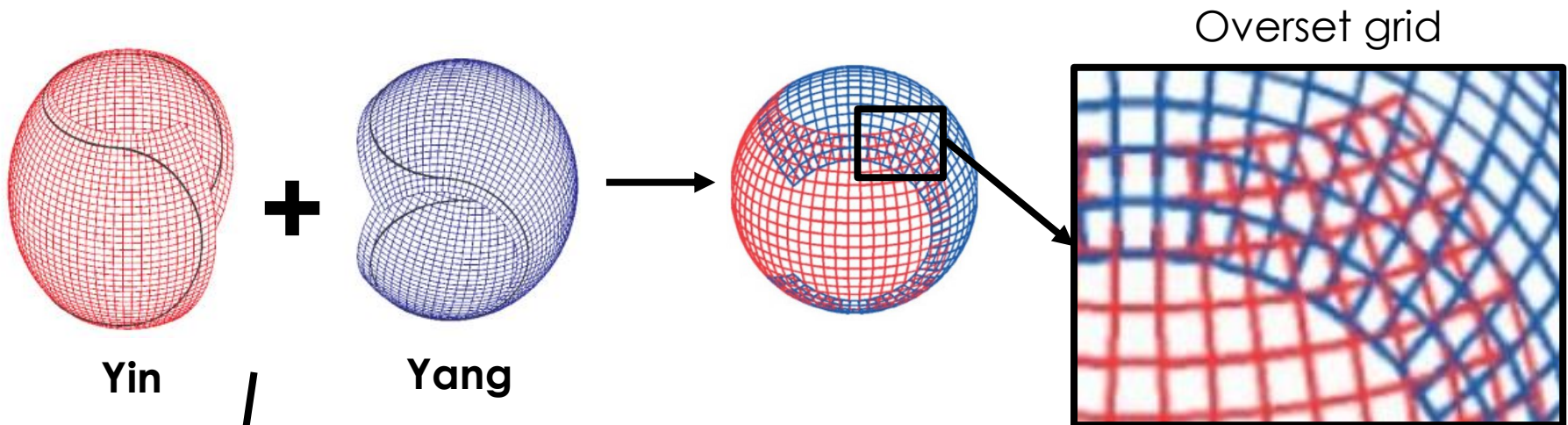


**CanRCM**



- GEM is the atmospheric model developed by our ECCC colleagues in Meteorological Research (e.g. Qaddouri and Lee 2011).
- GEM comprises of a dynamical core, as well as RPN physics used for weather prediction
- At CCCma we plan to use the GEM dynamical core with our CCCma physics – which are different and designed particularly for climate applications.
- We have used the GEM dynamical core with CCCma physics to do regional downscaling for several years.
- The GEM dynamical core + CCCma physics offers a route to a very unique, built in Canada atmospheric model, whose independent genealogy is highly valuable in the international climate model ensembles.
- Using GEM offers the opportunity for collaboration and some integration of effort between Climate and Meteorological Research Divisions.
- The big change here is integrating the GEM dynamical core into the global CanESM system for climate projection.

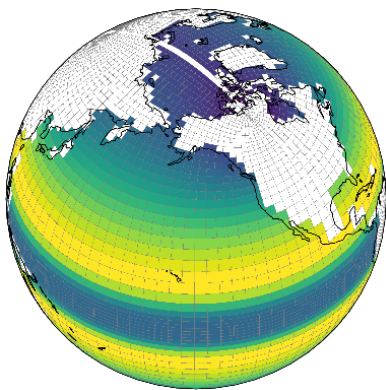
# Using GEM and the Yin Yang grid for climate?



Yin

Yang

Overset grid



ORCA1  
(ocean)

- Global GEM simulations use the Yin Yang grid. These are two local area models, which together cover the globe. Singularities at the poles are avoided.
- However, the combination of Yin and Yang is an overset grid, and there are deep questions about conservation (and no use of them elsewhere for climate)
- Not only must we conserve mass/energy on the YG grids, but we need to conservatively remap fluxes of mass/energy to the global ocean grid.
- Traditional conservative remapping (e.g. scrip/ESGF) does not support multiple source grids, nor does it have any possible way to resolve overlaps.

# Major Projects for CanESM6+

Atm chemistry

## GEM integration

Coupler upgrades (NEMO4, GEM, NUOPC?)

CanAM physics

Diagnostics refactor

Test

## CLASSIC integration

Parameter screening (tuning)

## NEMO4 integration

NEMO4 BGC

Sea-ice coupling

New sequencer (maestro/cylc)

New configuration / tools (imsi)

CMIP7 →

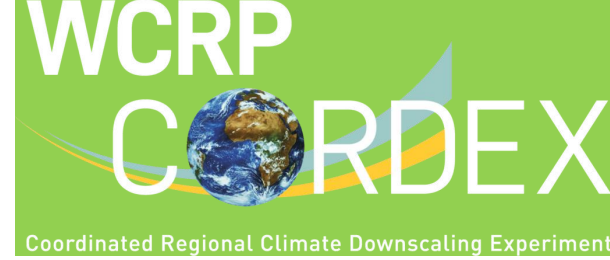
2020

2025

# Regional Downscaling



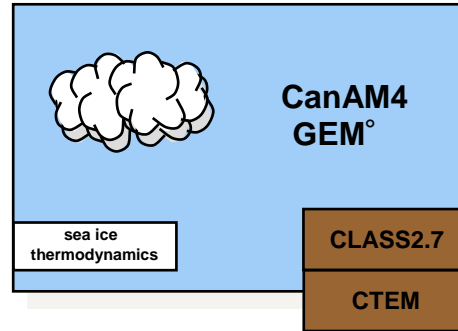
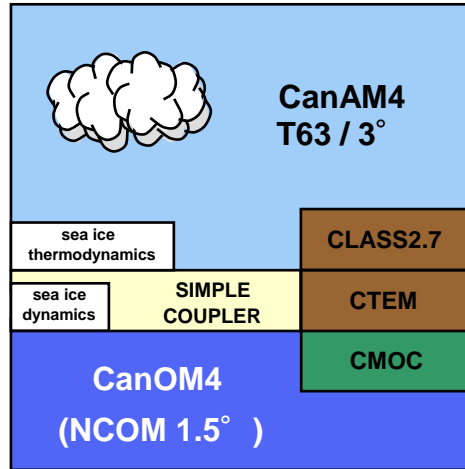
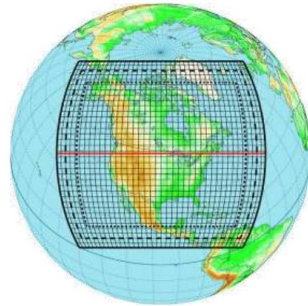
# Canadian Regional Climate Model (CanRCM)



## CanESM2 (CMIP5)

## CanRCM4 (CORDEXI)

Dynamically  
downscale



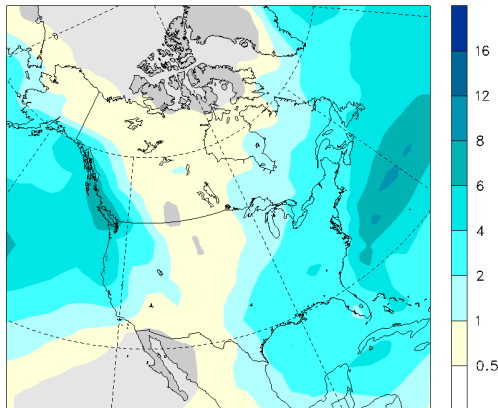
Coordinated Global and Regional Climate Modeling\*

J. F. SCINocca, V. V. KHARIN, Y. JIAO, M. W. QIAN, M. LAZARE,  
L. SOLHEIM, AND G. M. FLATO

Canadian Centre for Climate Modelling and Analysis, Environment Canada, Victoria,  
British Columbia, Canada

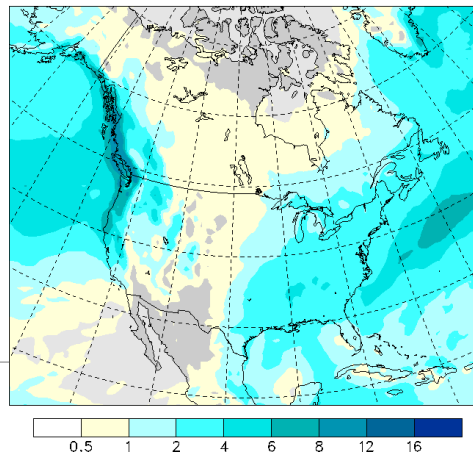
## CanAM4 T64 / 3°

CanESM2 exp=HISTORICAL precip.(mm/day) 1986-2005 Jan



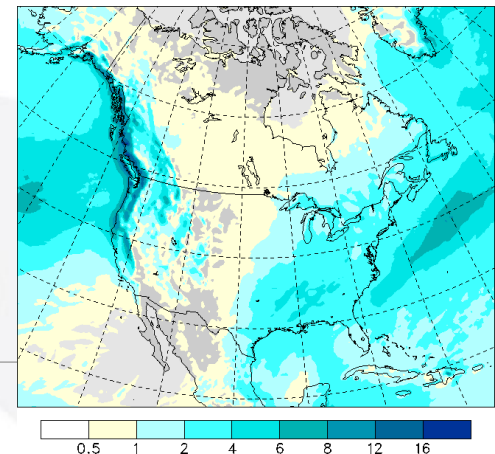
## CanRCM4 0.44°

CanRCM4 evaluation precip.(mm/d) 1989-2008 Jan



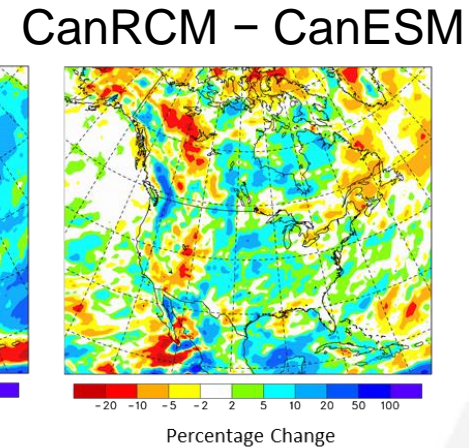
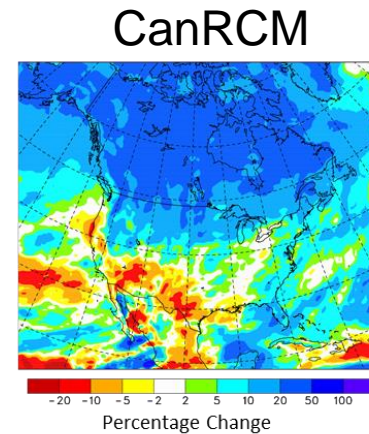
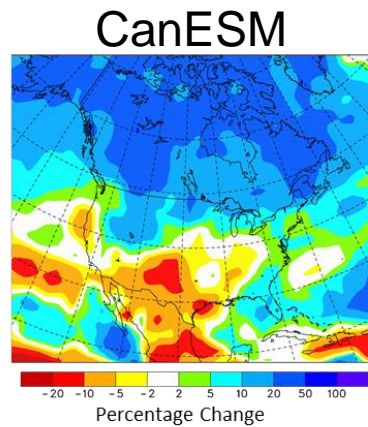
## CanRCM4 0.22°

CanRCM4 evaluation precip.(mm/d) 1989-2008 Jan



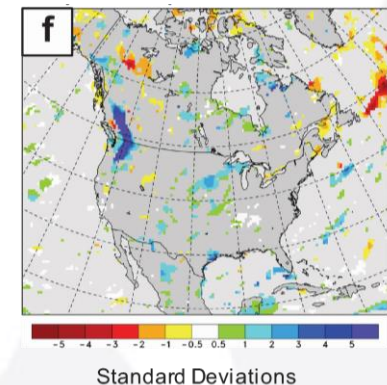
# CanRCM4 Added Value

**Precipitation Response**  
Mar-Apr-May  
(2100-2081) – (2005-1986)  
RCP4.5  
(5 ensemble members)



- **Climate Information:** “*What is the probability that the change in precipitation falls within a certain range of values?*”
- **Appreciable Difference Analysis:** where does the answer to such questions differ between the models?

*Primary source of RCM added value comes from improved representation of surface processes*

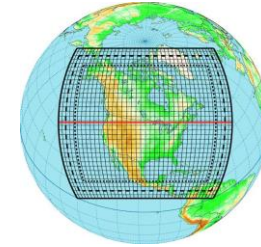


Coordinated Global and Regional Climate Modeling\*

J. F. SCINOCCA, V. V. KHARIN, Y. JIAO, M. W. QIAN, M. LAZARE,  
L. SOLHEIM, AND G. M. FLATO

Canadian Centre for Climate Modelling and Analysis, Environment Canada, Victoria,  
British Columbia, Canada

# CanRCM4 Applications



North American domain

<b>CORDEX</b>	<b>Resolution</b>	<b>Ensemble Members</b>	<b>Years</b>
<b>Evaluation</b>	0.44° (50km)	1	1989-2009
	0.22° (25km)	1	1989-2009
<b>Historical</b>	0.44° (50km)	5	1950-2005
	0.22° (25km)	5	1950-2005
<b>RCP4.5</b>	0.44° (50km)	5	2005-2100
	0.22° (25km)	5	2005-2100
<b>RCP8.5</b>	0.44° (50km)	5	2005-2100
	0.22° (25km)	5	2005-2100

## CanSISE large ensemble

<b>Historical</b>	0.44° (50km)	50	1950-2005
	0.22° (25km)	1	1950-2005
<b>RCP8.5</b>	0.44° (50km)	50	2005-2100
	0.22° (25km)	1	2005-2100

Centerpiece of GoC report that updated Canada's Buildings and Core Public Infrastructure codes and standards

*"Climate-Resilient Buildings and Core Public Infrastructure"*  
Cannon et al. 2020

## CanSIPS hindcast downscaling (proof of concept)

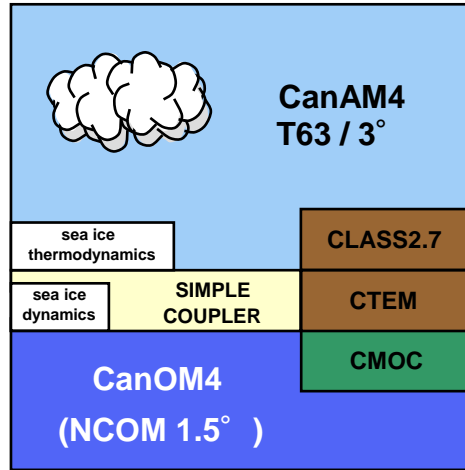
0.44° (50km)	JFM, JAS	1981-2010
0.22° (25km)	JFM, JAS	1981-2010

(Collaboration of ECCC's Climate Research Division (CCCma and CDAS), the Pacific Climate Impact Consortium, and the National Research Council in support of the Pan Canadian Framework on Clean Growth and Climate Change, and in support of the Green Infrastructure objectives of the GoC)

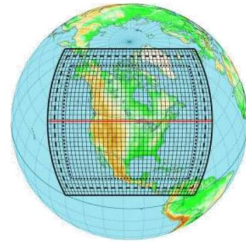
**CanRCM4** model output has been used for more than 100 national and international peer-reviewed scientific studies and assessments. Canadian users include, 12 Canadian Universities; two regional climate impacts Consortia (the Pacific Climate Impacts Consortium and the Consortium on Regional Climatology and Adaptation to Climate Change); multiple federal departments of Agriculture and Agri-Food Canada, Environment and Climate Change Canada, Fisheries and Oceans Canada; the Public Health Agency of Canada; and the provincial ministry of Natural Resources and Forestry (Ontario).

# Empirical bias correction

## CanESM2 (CMIP5)

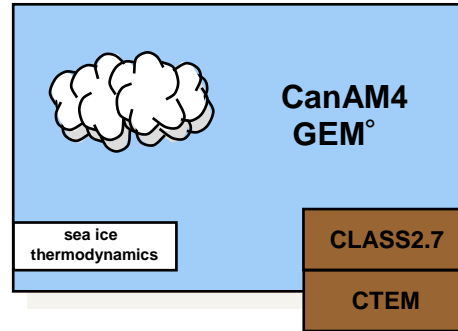


Dynamically  
downscale



Runtime bias  
correct

## CanRCM4 (CORDEXI)



Offline bias  
correct



CanLEAD

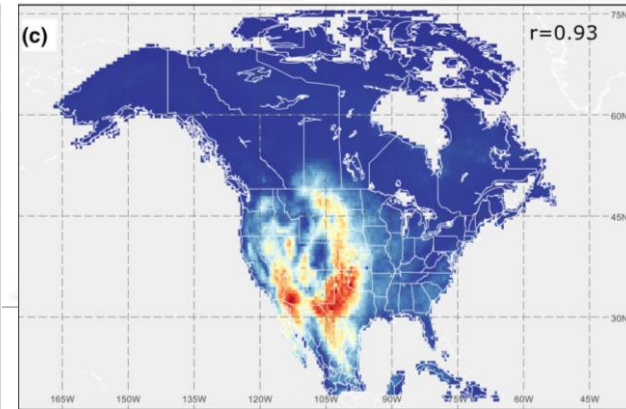
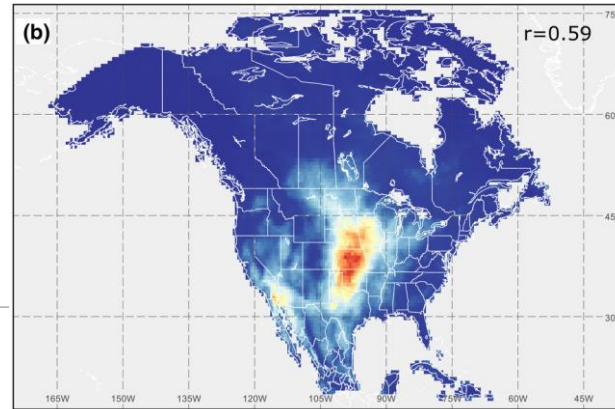
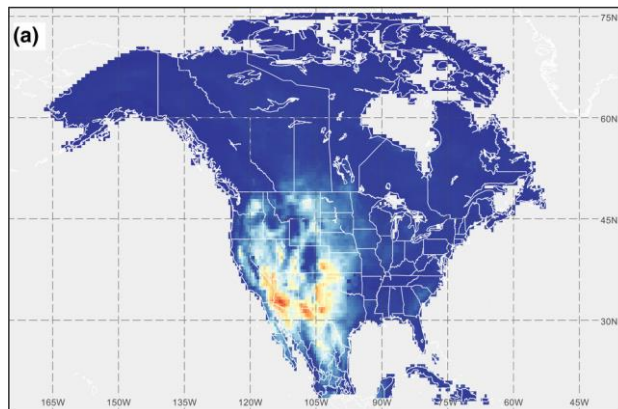
Canadian Large Ensembles Adjusted Dataset version 1 (CanLEADv1): Multivariate bias-corrected climate model outputs for terrestrial modelling and attribution studies in North America

Alex J. Cannon, Hunter Alford, Rajesh R. Shrestha, Megan C. Kirchmeier-Young, Mohammad Reza Najafi

## Observations

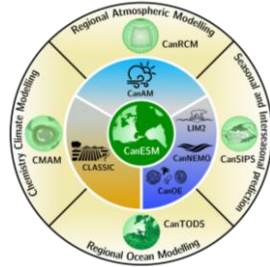
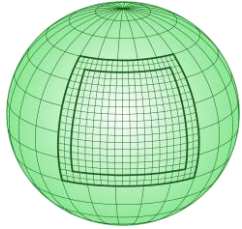
## CanRCM4 0.44°

## CanRCM4-S14FD-MBCn





# CanRCM5+

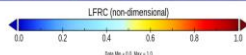
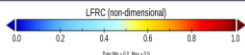
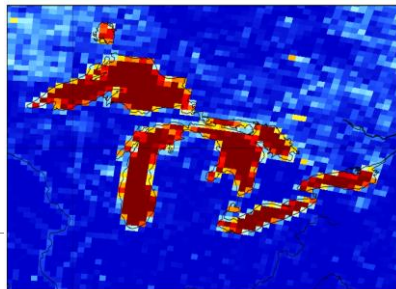
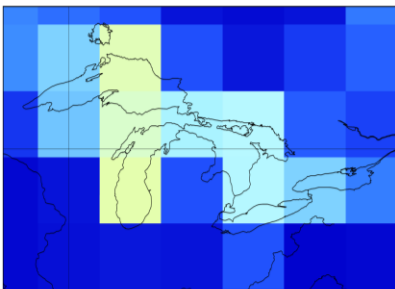


- operational resolution  $0.22^\circ$  (25km) with  $0.11^\circ$  (12km) for special applications
- coordinated global/regional modelling: all physical improvements made to **CanAM5** are inherited by **CanRCM5**
- Improved surface processes for enhanced value added: improved treatment of **fresh-water lakes**

## Lake Fraction

CanAM5 ( $\sim 2.8^\circ$ )

CanRCM5 ( $0.22^\circ$ )



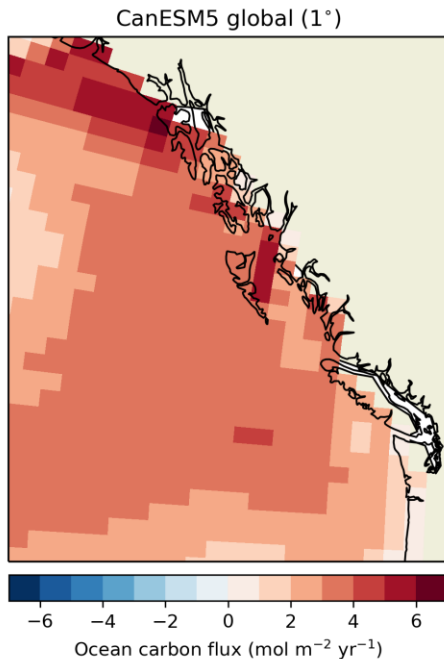
## Current & future downscaling activity

- CORDEX-CMIP6 contribution: Downscale CanESM5 over North America at  $0.22$  and  $0.11$  (experimental)
- Coordinate downscaling multiple GCMs, using CanRCM5 and CRCM5 (Ouranos via G&C), for North America, and distribute via CCCS
- Runtime bias correction on SST & sea-ice
- Deeper integration of CanRCM5 with routine downscaling of seasonal predictions and projections
- Downscaling over larger domains to support ocean downscaling etc.
- Apply offline bias correction (as in CanLEAD), and more advanced ML approaches trained on convection resolving simulations.

# Downscaling Ocean Climate in Canada

Actionable information on ocean climate change at regional to local scales requires **downscaling** of predictions made by coarse global climate models.

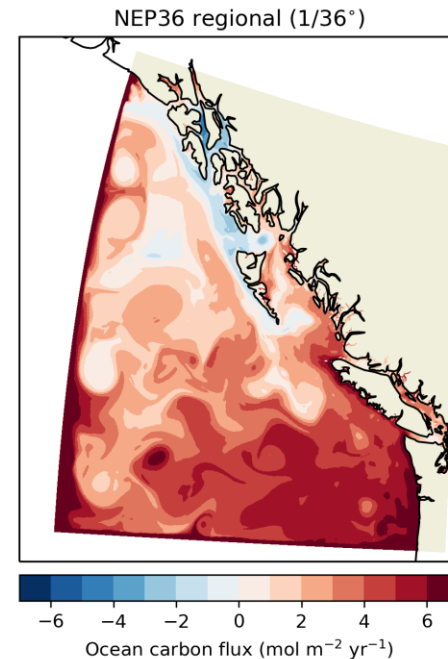
All climate projections are necessarily global & mostly coarse resolution due to large area / high computing cost



Downscale



To better resolve:  
- Coastline  
- Bathymetry  
- Physics



Downscaling refines from the global to regional scale, but requires boundary conditions at the edges & surface

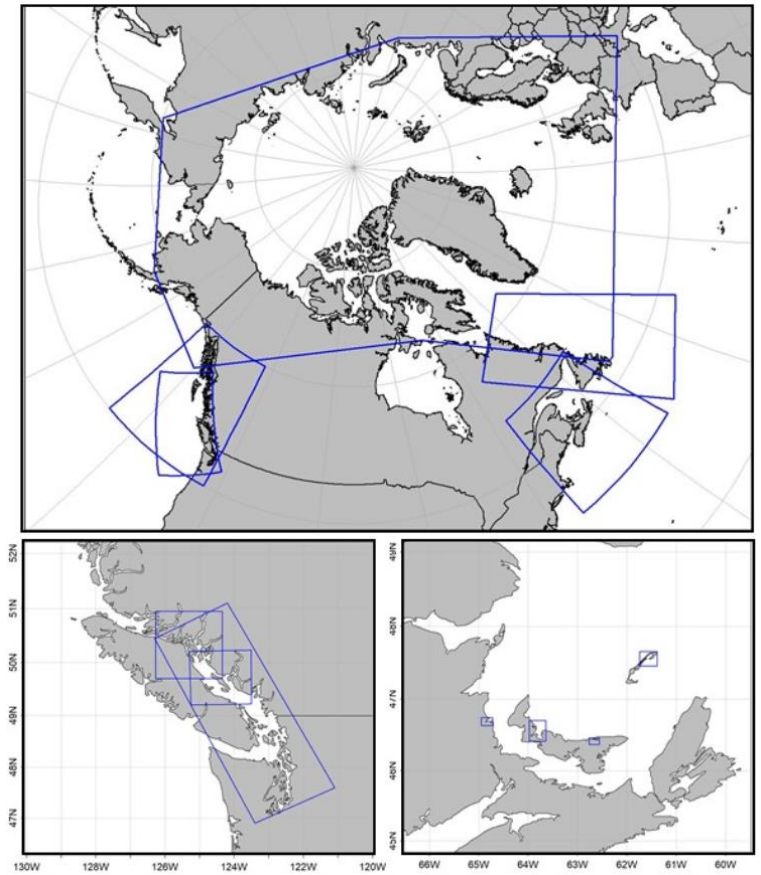
Regional downscaling capacity exists in DFO/ECCE/Universities,  
**but there are issues...**



# Ocean downscaling challenges

Courtesy Diane Lavoie, DFO

- Existing regional models at DFO/Universities have incomplete coverage and are inhomogeneous – interconnections are vital but missing.
- Reliable boundary conditions at both the surface and lateral boundaries.
  - Global models have biases & lack resolution
  - Delta-like methods have issues as delta's do not align with reanalysis climatologies.
  - Surface forcing from RCMs has resolution but not feedbacks
- Coordination across organizations / efforts.



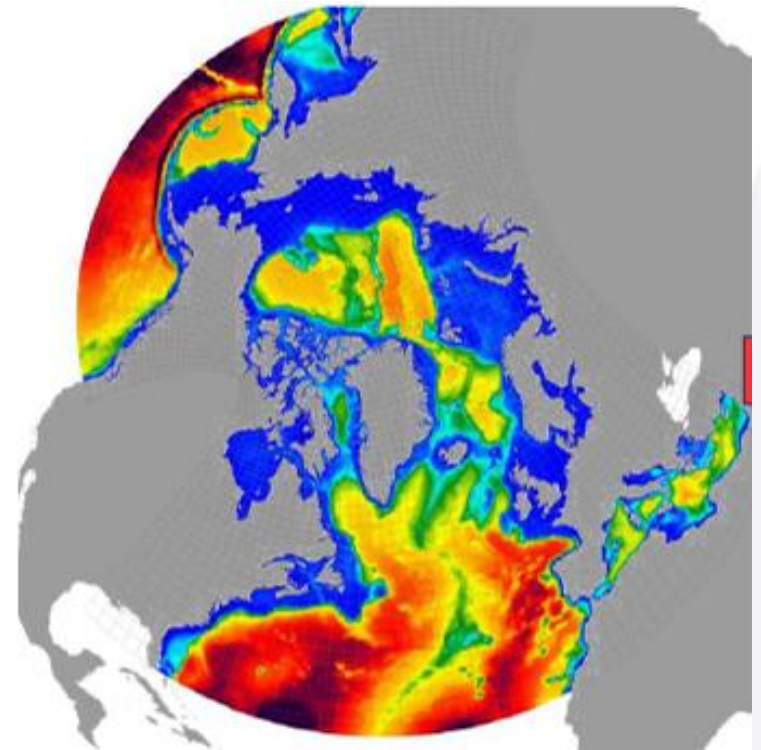
Existing downscaling  
domains in DFO/Universities

# What is CanTODS?

## Canadian Three Ocean Downscaling System

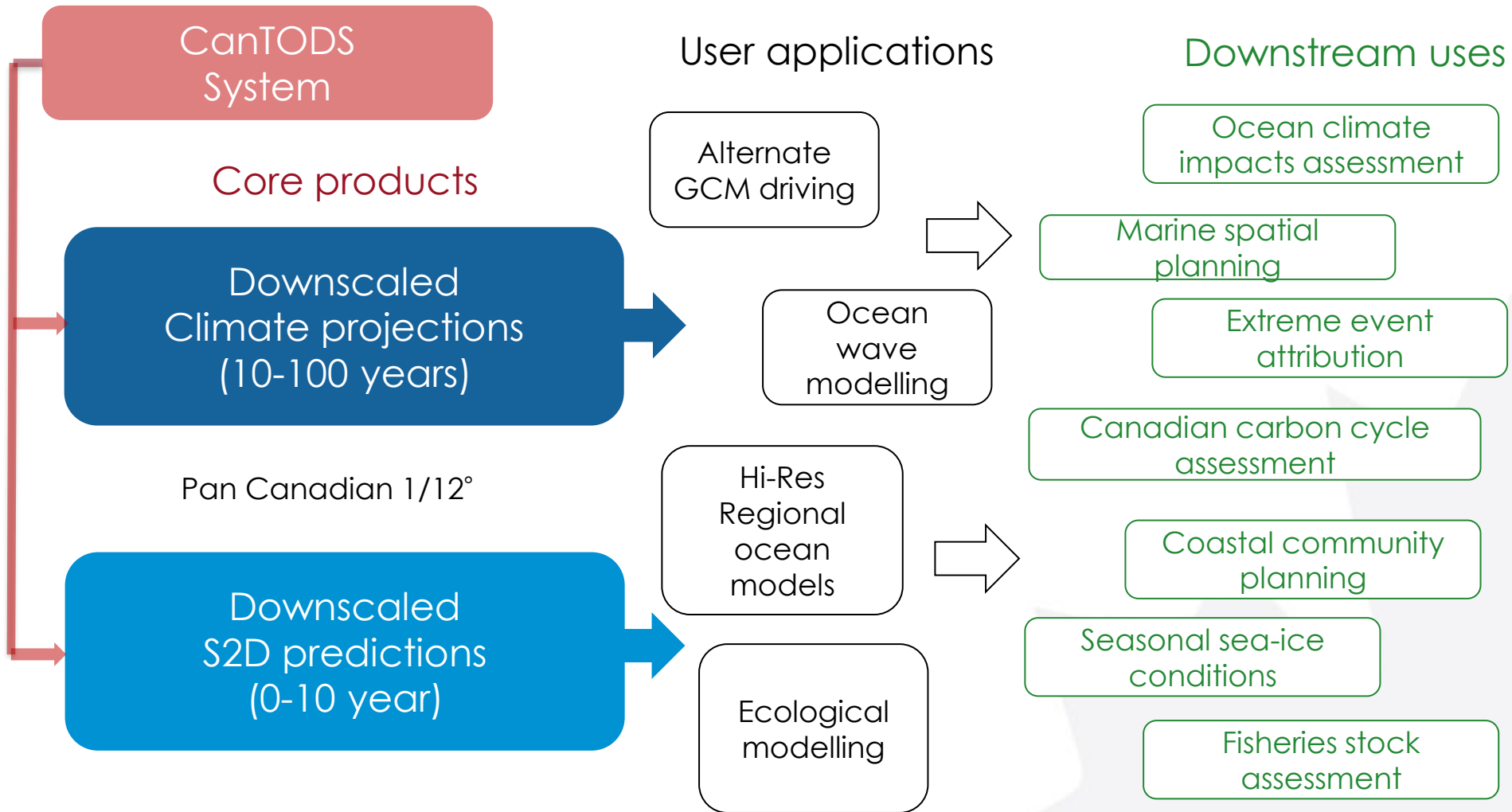
A (proposed) community **system** for spatially consistent downscaling of **climate projections and seasonal forecasts** across Canada's three oceans.

- NEMO physical ocean, building from existing efforts, adapted for climate scales.
- Ocean biogeochemistry (CanESM BGC models CMOC and CanOE are options).
- Tools/procedures for developing surface and lateral boundary conditions and running simulations.
- Leverages development of CanESM, CanRCM, CanSIPS, CONCEPTS, DFO regional models.
- An open source, community tool, co-developed by ECCCC/DFO & Universities.



CONCEPTS extended RIOPS grid (1/12° )

# Applications of CanTODS



Note the modelling approach for climate differs from short term predictions e.g. OPP/CONCEPTS, so there are synergies, but also important distinctions.

# Future of CCCma modelling & science

