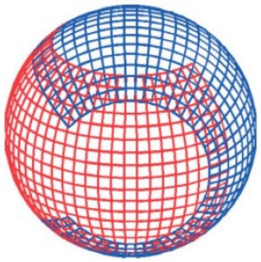
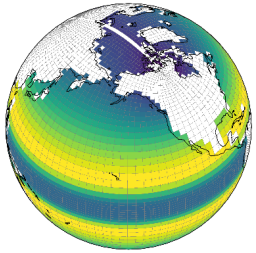
Canadian Focused Projections using the CCCma Integrated Climate Modelling System





Neil Swart and the model development team

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

PCIC seminar September 2023

CCCma = Canadian Centre for Climate Modelling and Analysis

Outline

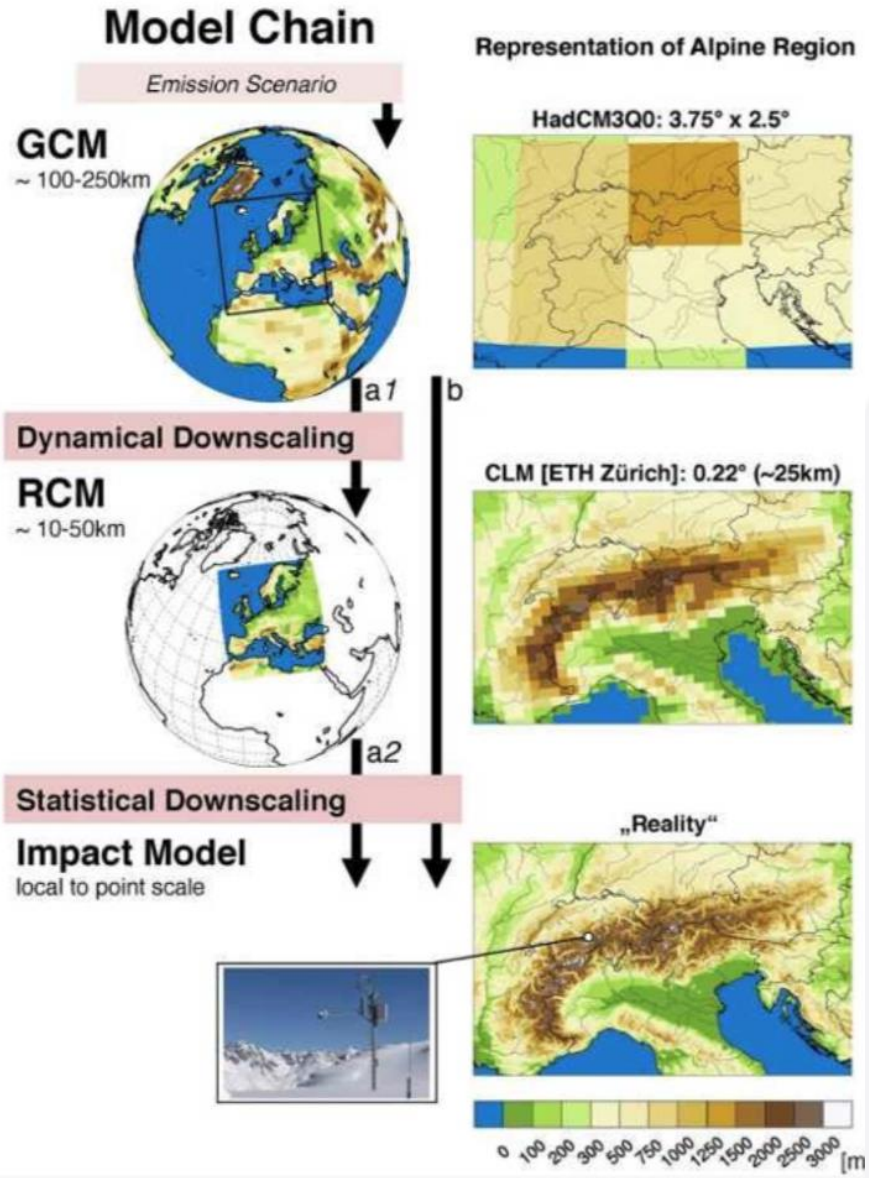
- Introduction
  - History of CCCma science & deliverables
  - National Adaptation Strategy and new directions

- 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)

AGCM2
McFarlane et al. (1992)

CGCM2

CanESM1
Christian et al. 2010

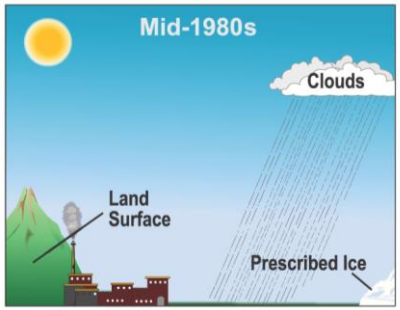
CanRCM4
Scinocca et al. 2016

CanESM5
Swart et al. 2019

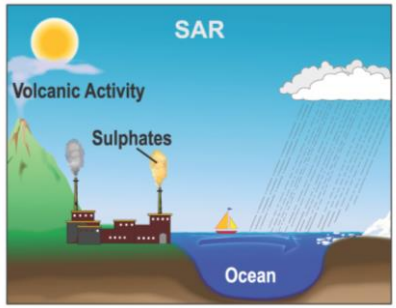
CGCM3
McFarlane et. al (2005)
Scinocca et al. (2008)

CanESM2 / CGCM4

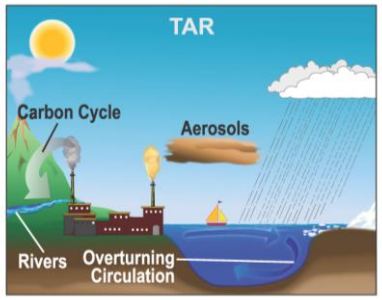
CGCM1
Flato et. al (2000)



Atmosphere only



Coupled to ocean



Carbon cycle

1970 1980 1990 2000 2010 2020

Assessments & MIPs

WCRP MIPs: CMIP1 CMIP2 CMIP3 CMIP5 CMIP6

IPCC assessments: AR1 1990; AR2 1995; TAR 2001; AR4 2007; AR5 2013; SR15 2018; SROCC 2019; **AR6 2021**

Canadian climate assessments: CCC 2014; CCCR 2019

Assessment of Ozone Depletion: 2006; 2010; 2014; 2018

Operational seasonal prediction systems: HFP1; HFP2; CanSIPSv1; CanSIPSv2

CCCma has an expanding mandate and staffing under NAS

Français

Government of Canada | Gouvernement du Canada

Search ECCC

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

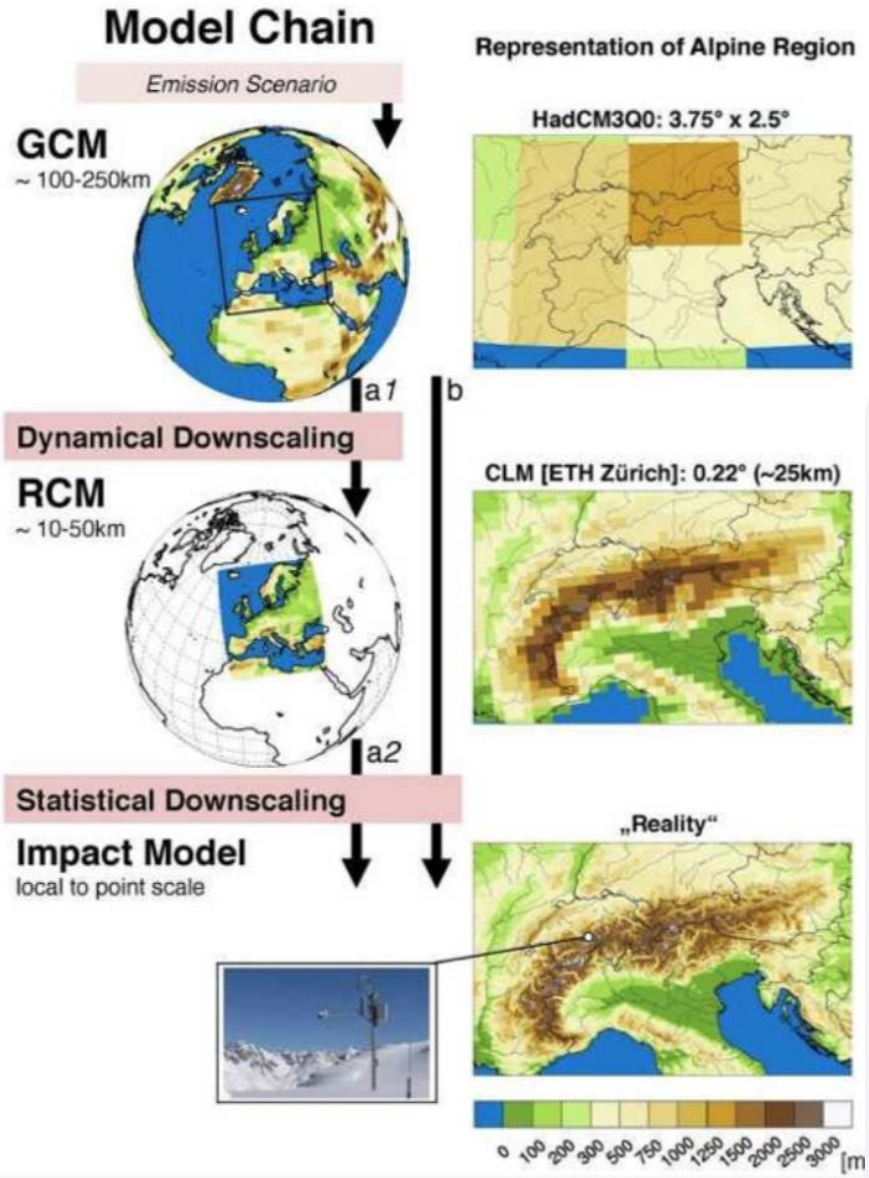
Most historical effort @ CCCma

- 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

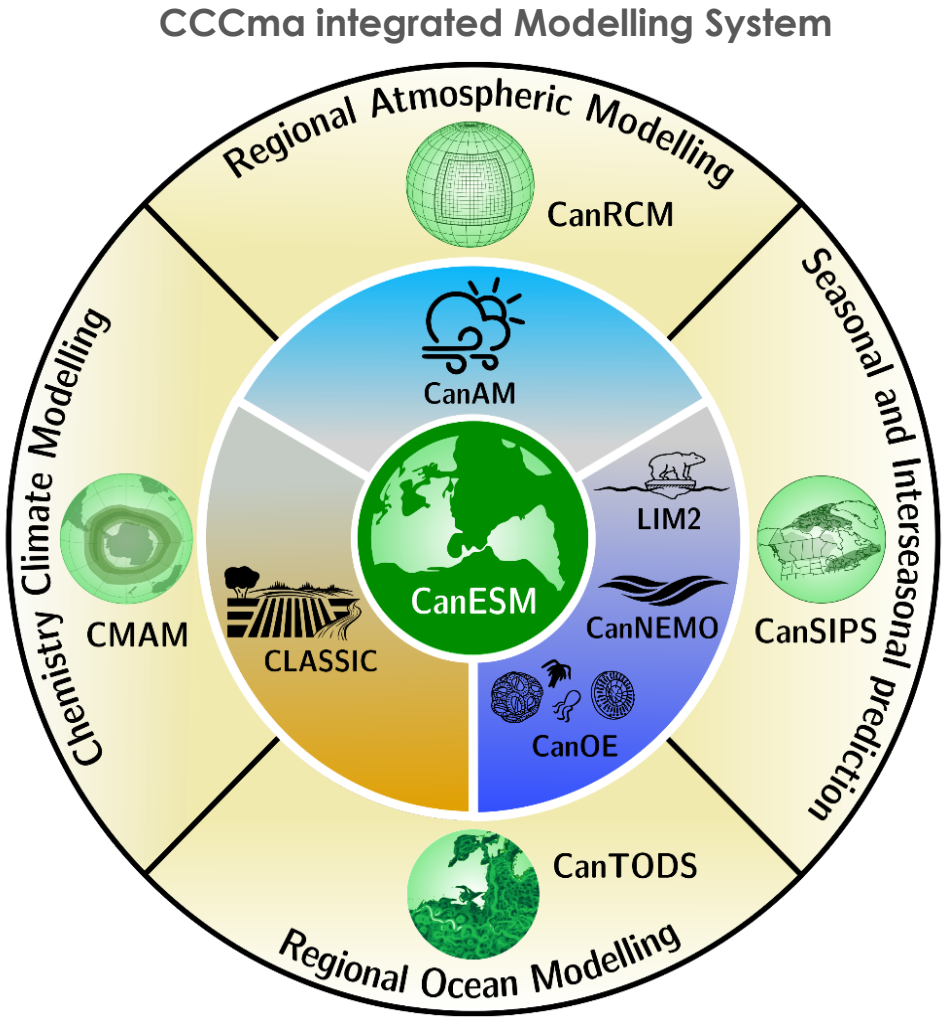
- Enhanced resolution information at regional to local scale (<25km)

- Poll 1: Have you used our model output?

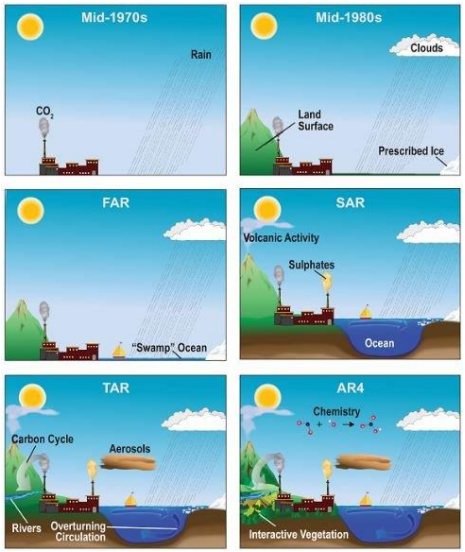


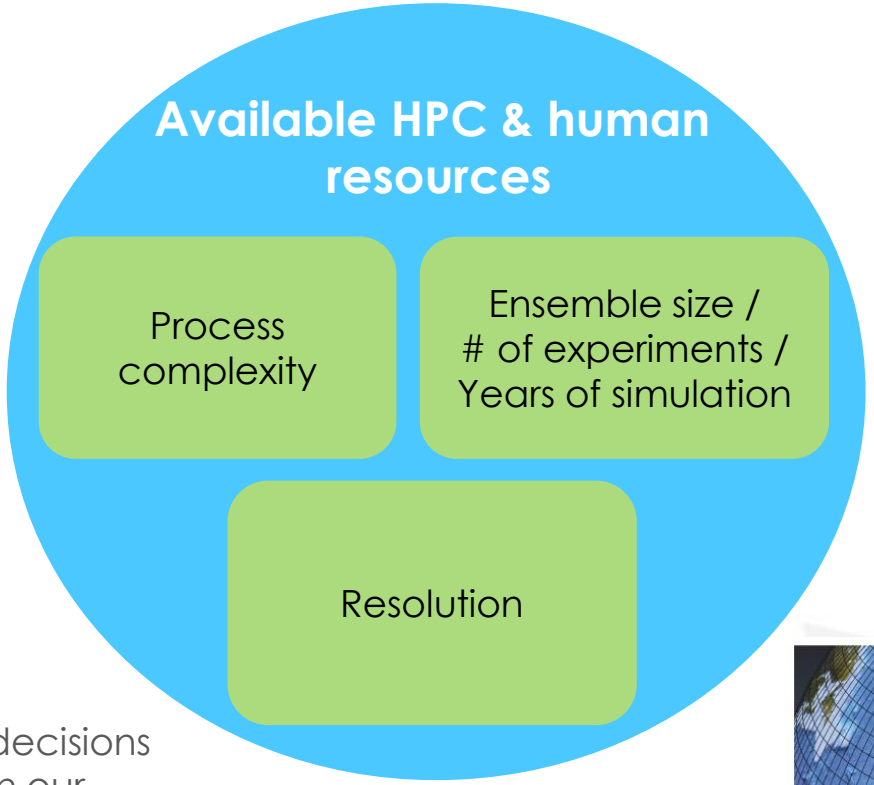
Strategy for Canadian focused projections

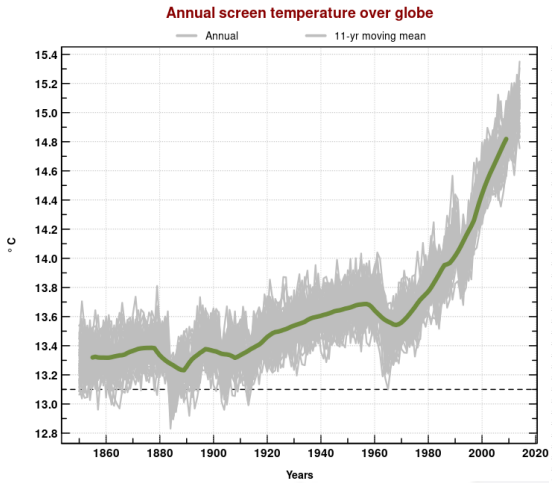
- **Common infrastructure & HPC/HR resources**
  - Foundational tools that enable configuration, running, and exchange.
  - Leverage expertise from the broader Canadian climate science community.
- **Global modelling** (**CanESM**) – **100 km**
  - Improve quality through better physics
  - Increase 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



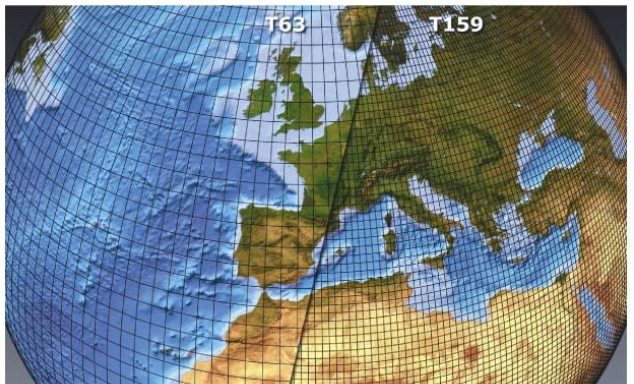
Compromises in climate modelling







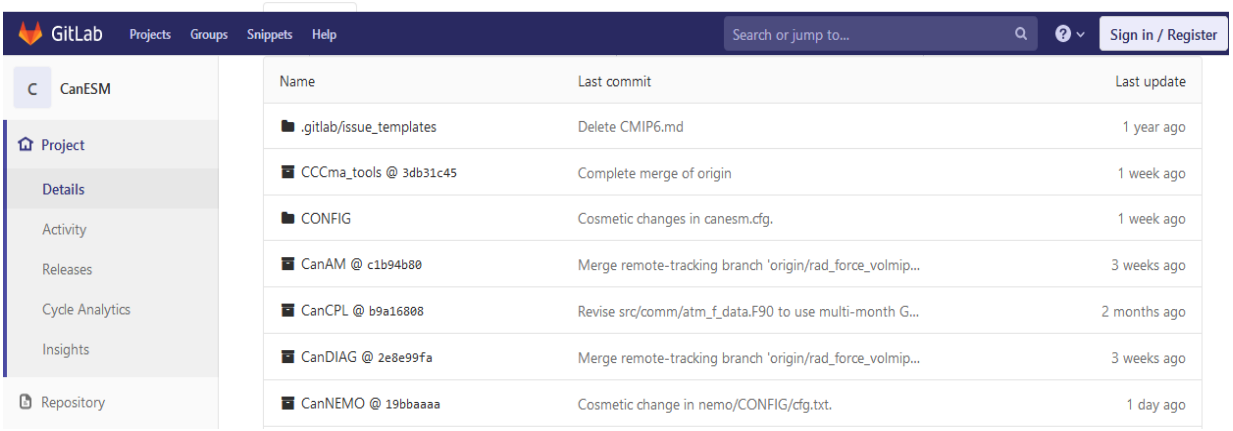
- We must make hard decisions about how to partition our resources.
- Poll 2 asks what is most valuable to you as users.



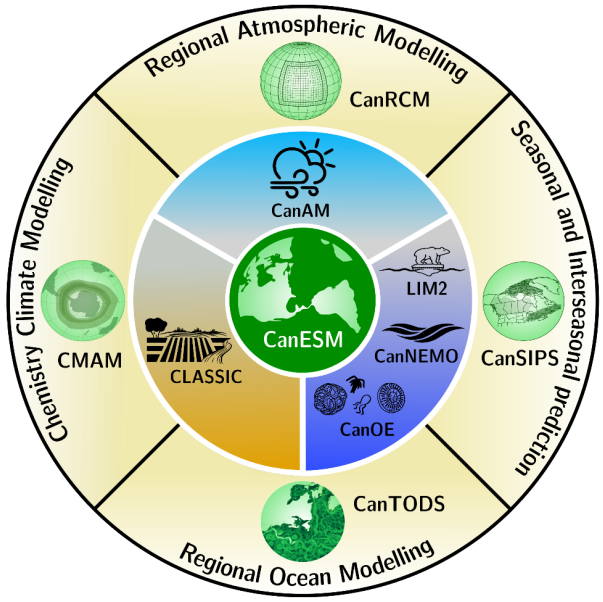
A modern collaborative model

- 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



CCCma integrated Modelling System

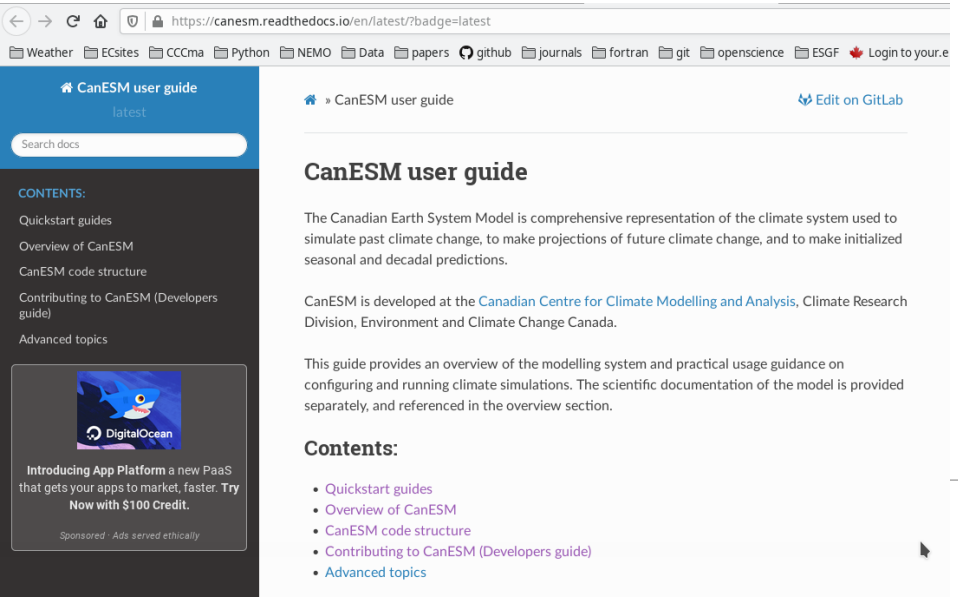


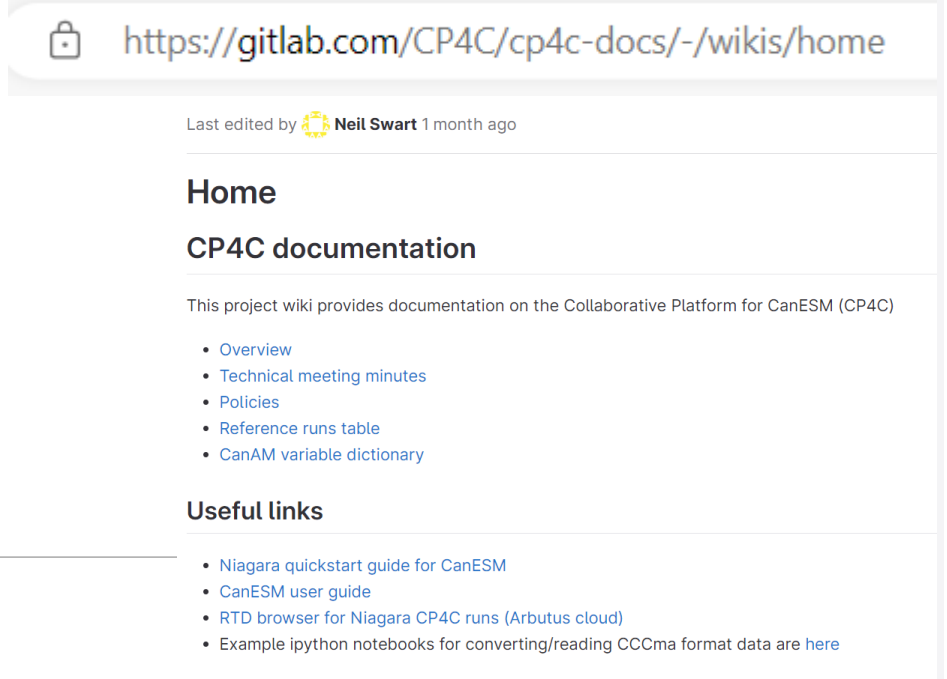
Digital Research Alliance of Canada | Alliance de recherche numérique du Canada

Google Cloud Platform

Collaborative Platform for CanESM (CP4C)

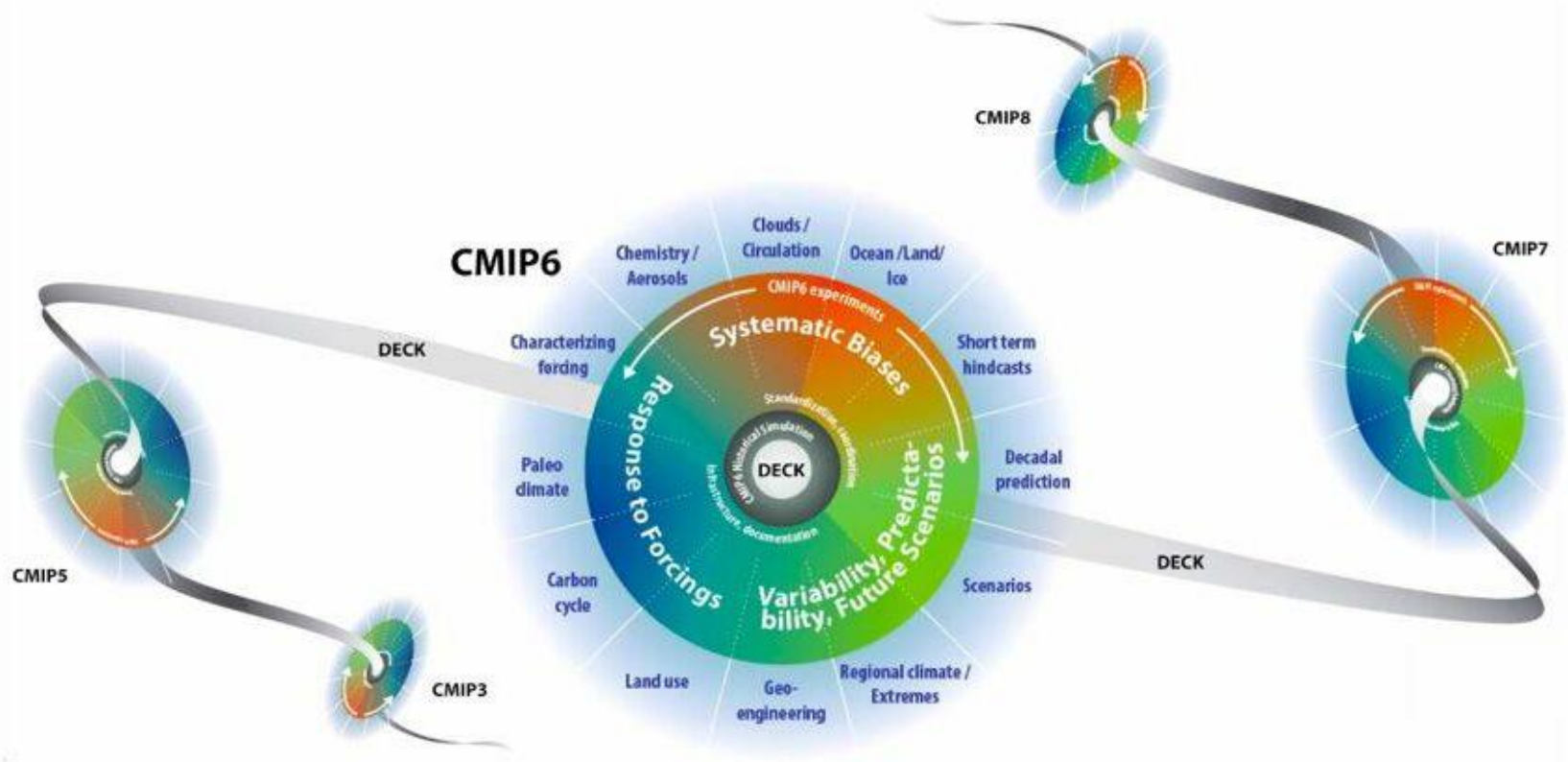
- CCCma commits to using open standards and having a portable model
- CanESM5-0 & 5-1 have been ported and tested on Digital Research Alliance machines (Cedar, Niagara) & commercial cloud
- CP4C initiative w/ Paul Kusher @ UofT offers a community of practice and compute resources to help advance this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





Global Modelling

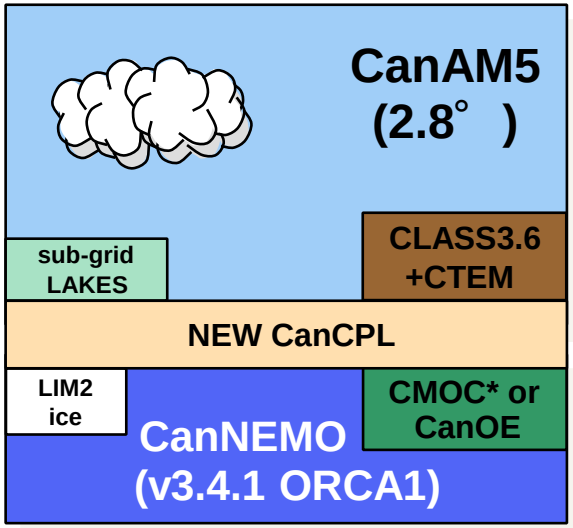
Coupled Model Intercomparison Project



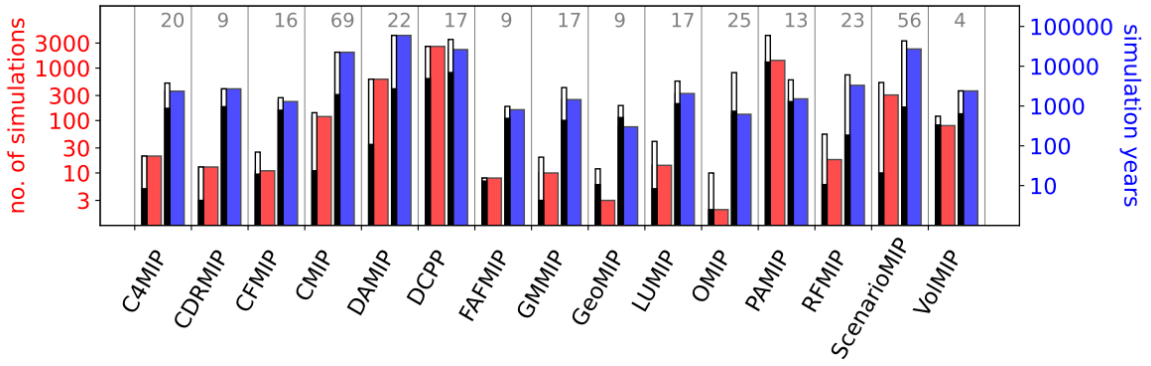
WCRP
World Climate Research Programme

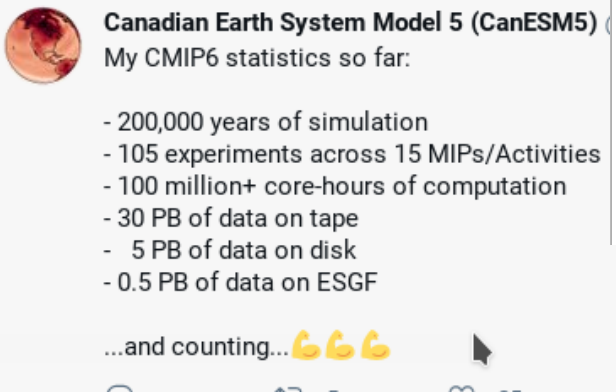
CanESM5 & CMIP6

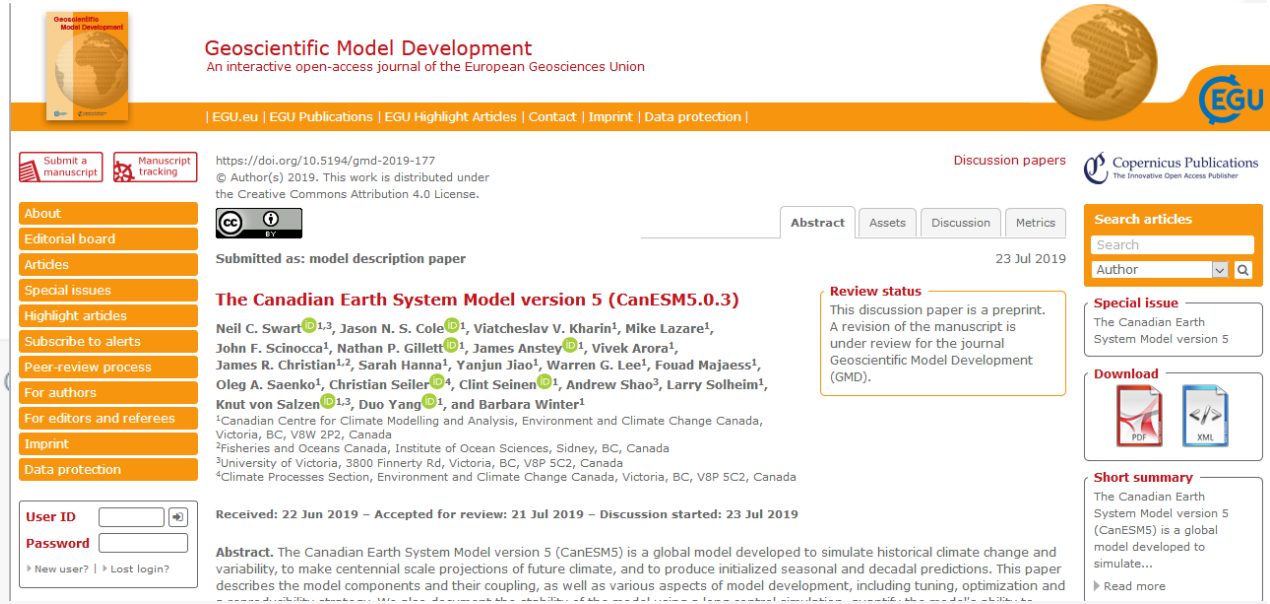
CanESM5.0 (CMIP6)



CCCma environment + tools



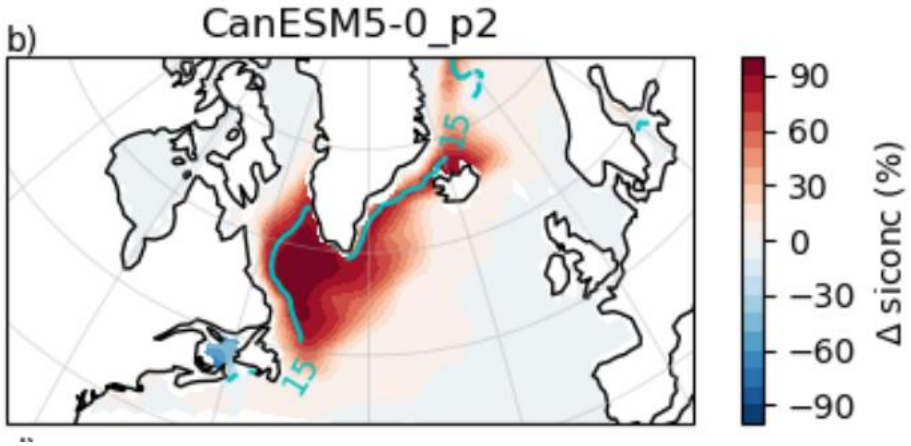




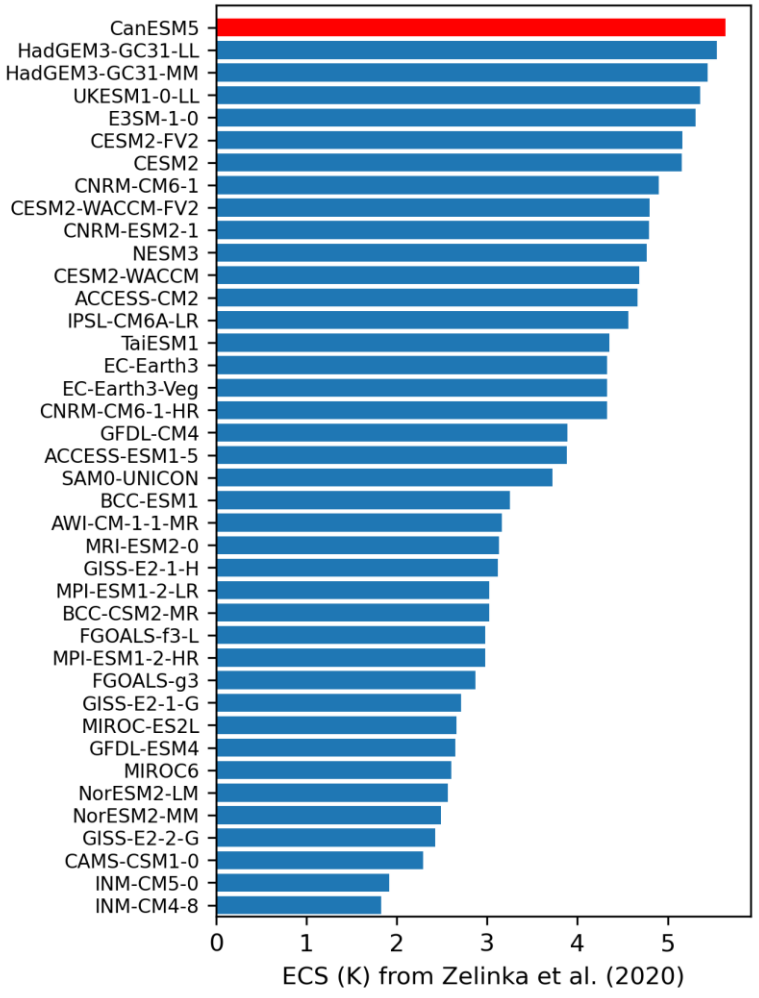
CanESM5 vs the world

- 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

Search

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

Abstract | Discussion | Metrics

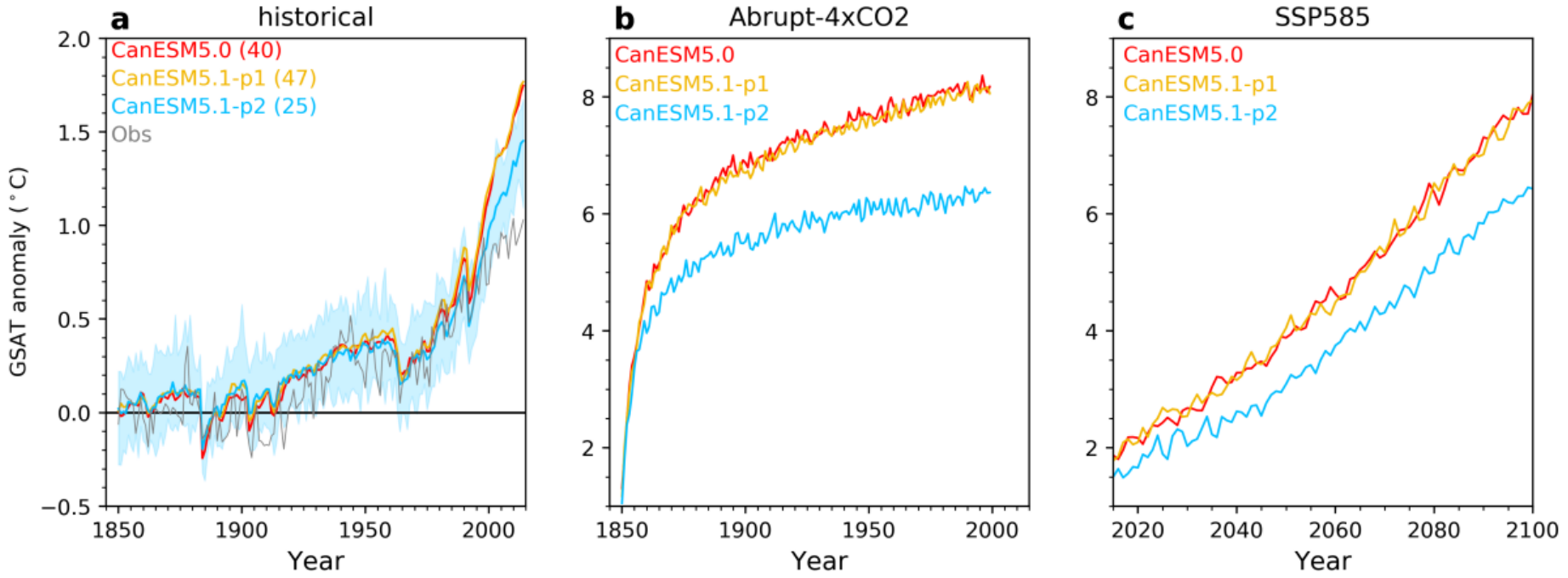
Submitted as: model evaluation paper | 04 Apr 2023

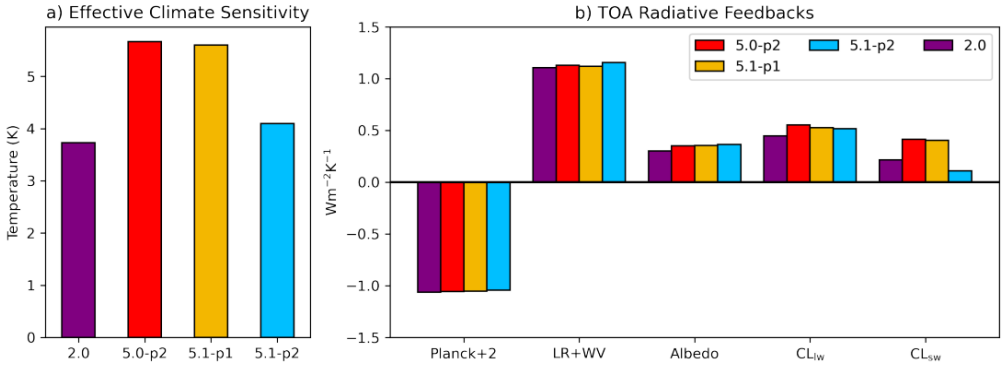
Status: this preprint is currently under review for the journal GMD.

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



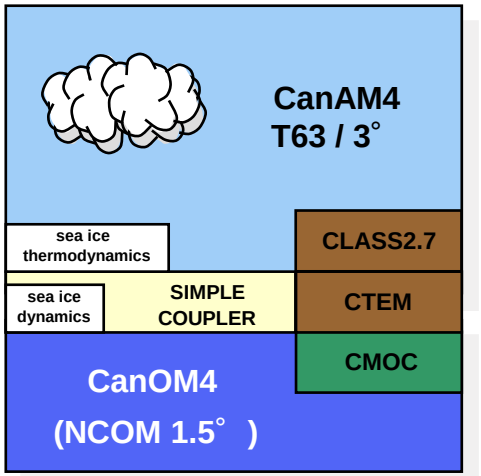


From Sigmond et al.

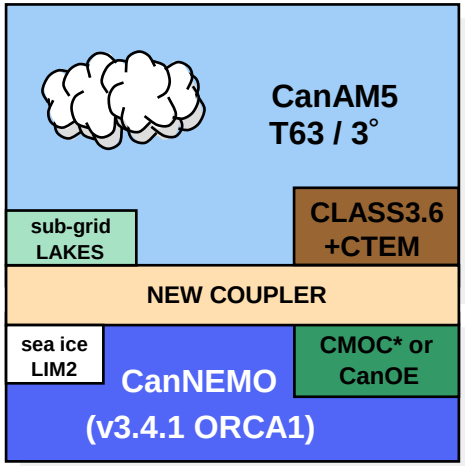
The path to CanESM6

2011 → 2018 → 2025

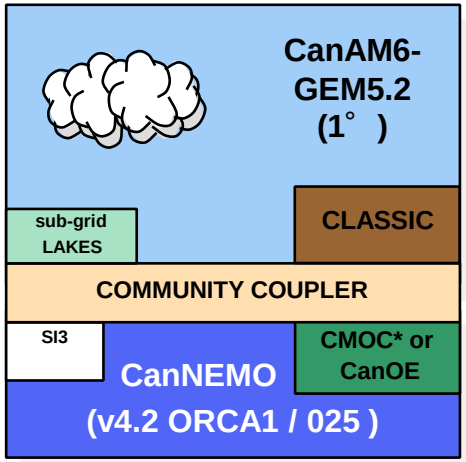
CanESM2.0 (CMIP5)



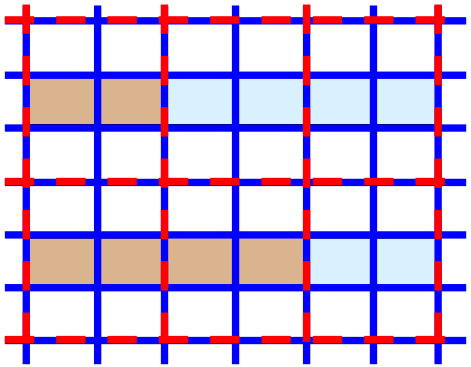
CanESM5.0 (CMIP6)



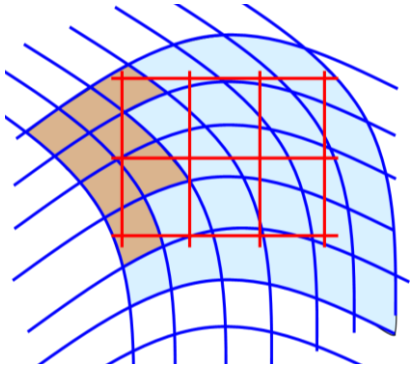
CanESM6.0 (CMIP7)

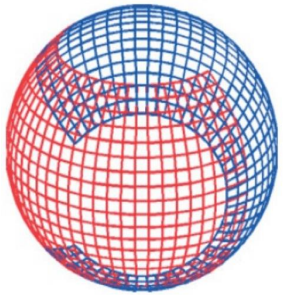


Co-incident grids



Gaussian to tripolar

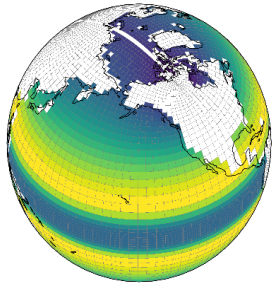




Yin-Yang

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.

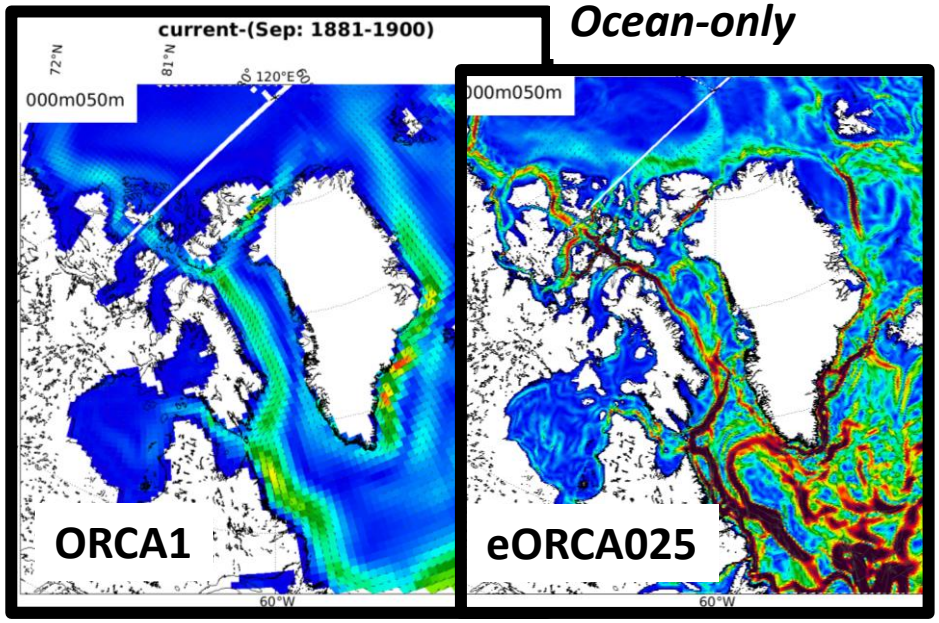
Integration into CanESM	
Implementation of CLASSIC in the CanESM framework	• Coupled feedbacks make integrating the changes above and maintaining an acceptable climate a huge challenge. This work is proceeding.

Slide thanks to Vivek

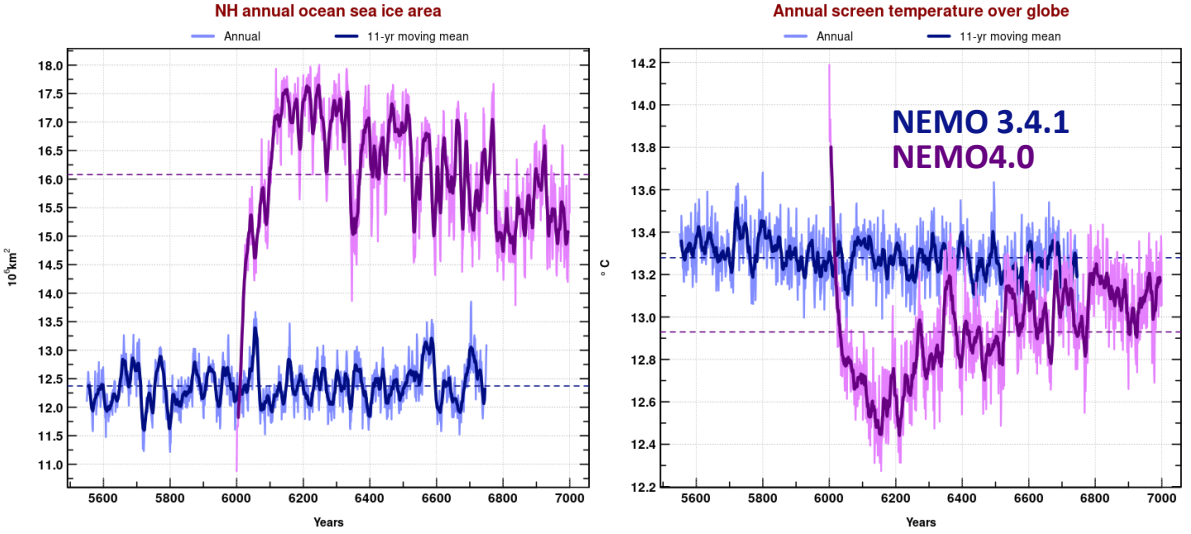
CanNEMO development

CanESM5.X	CanESM6.0	
NEMO 3.4.1	**NEMO 4.x**	
	• New ice model SI³	used
	• Lee wave mixing	testing
	• New tidal mixing	testing
	• Ice shelf cavities	planned
	• Icebergs	planned
	• NEMO 4.2	planned
1 ° grid ORCA1	• 1° grid eORCA1	testing
	• ¼° grid eORCA025	testing
CMOC & CanOE	• Port CMOC & CanOE	testing

Ocean-only



Coupled piControl

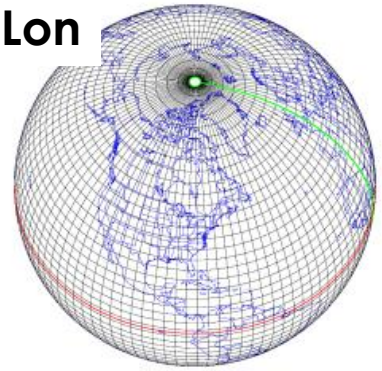


CCCma is currently in the process of hiring new sea-ice and ocean modelling scientists

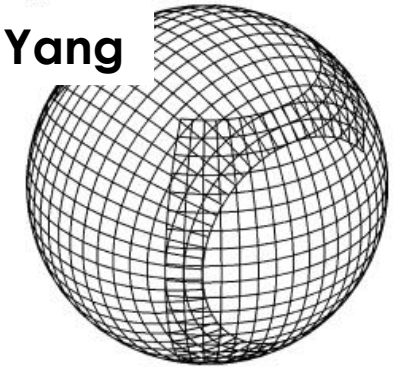
Slide modified from Nicolas Lambert

GEM as the dynamical core of CanAM6

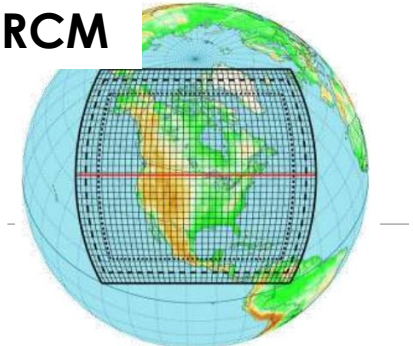
Lat-Lon



Yin-Yang

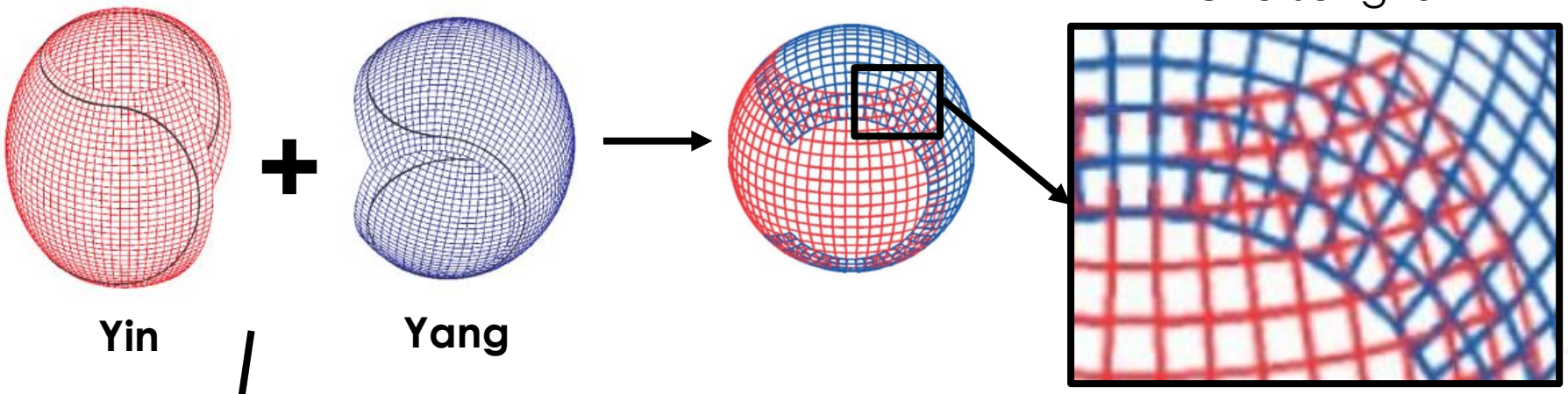


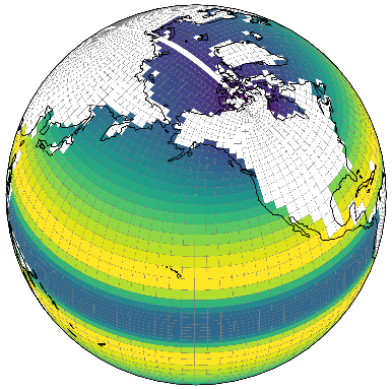
CanRCM



- 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?

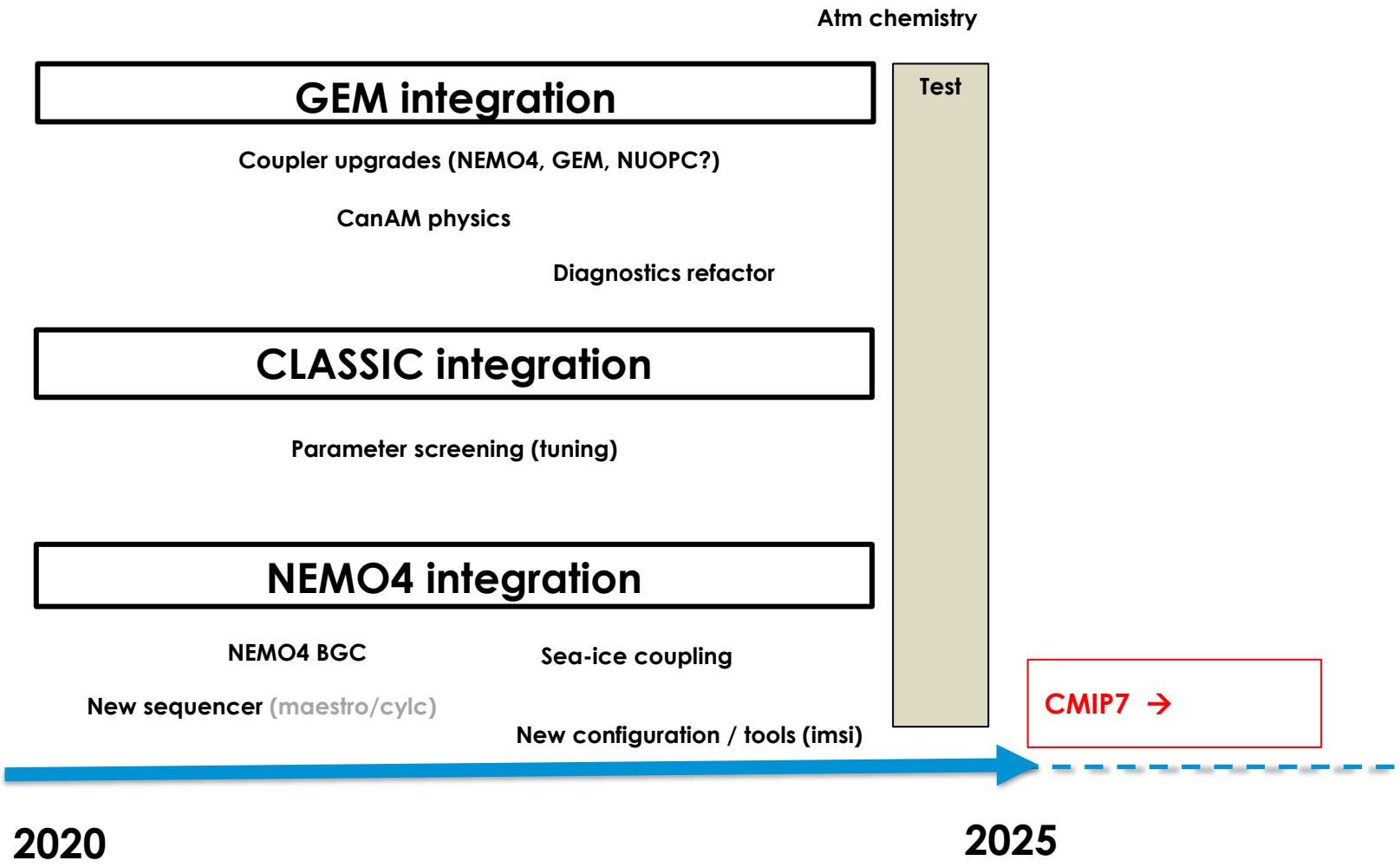




ORCA1 (ocean)

- 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+

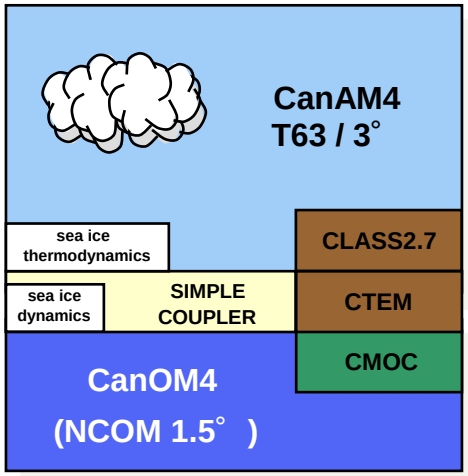


Regional Downscaling

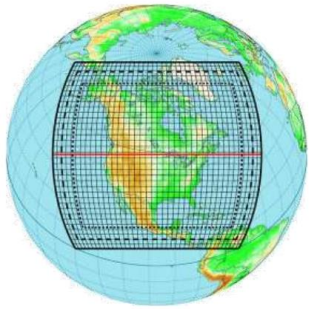
Canadian Regional Climate Model (CanRCM)

WCRP CORDEX
Coordinated Regional Climate Downscaling Experiment

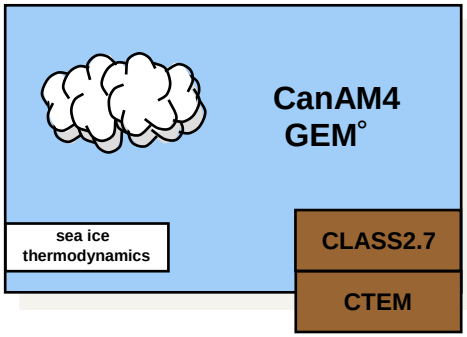
CanESM2 (CMIP5)



Dynamically downscale



CanRCM4 (CORDEXI)

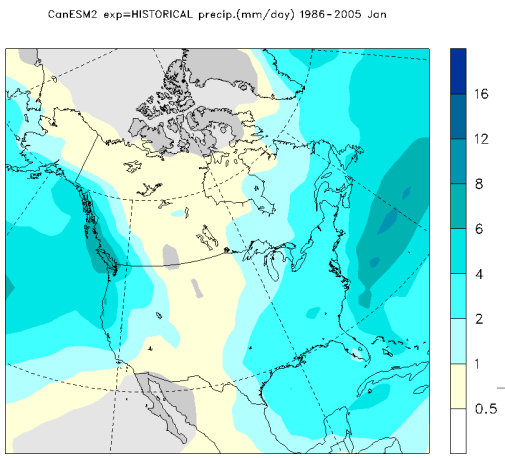


Coordinated Global and Regional Climate Modeling*

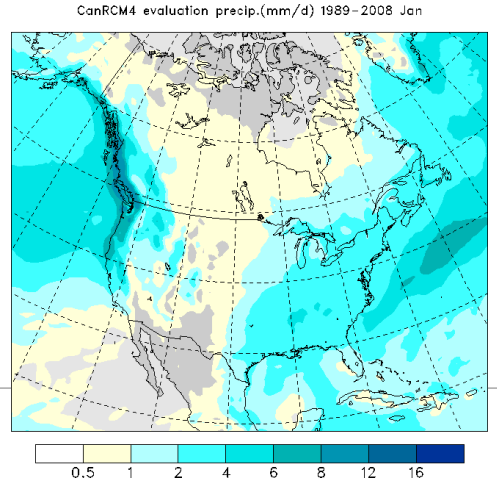
J. F. Scinocca, V. V. Kharin, Y. Jiao, M. W. Qian, M. Lazare, L. Solheim, and G. M. Flato

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

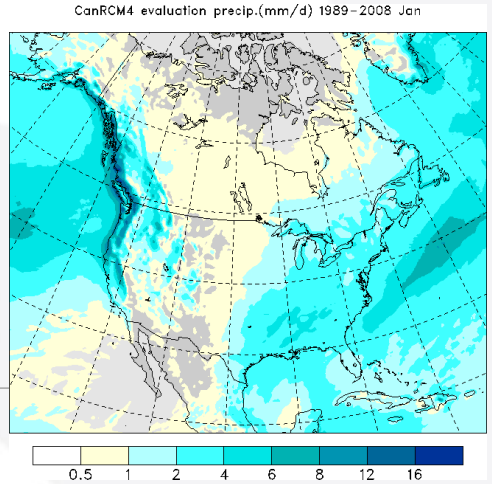
CanAM4 T64 / 3°



CanRCM4 0.44°



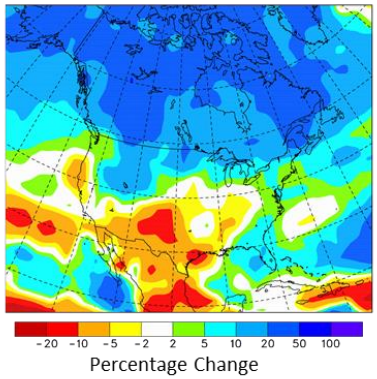
CanRCM4 0.22°



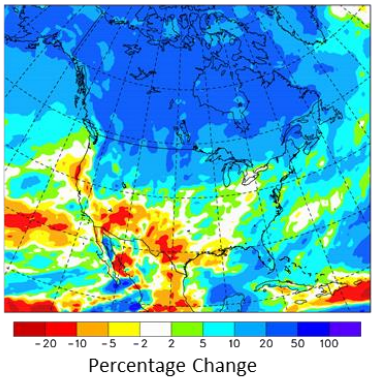
CanRCM4 Added Value

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

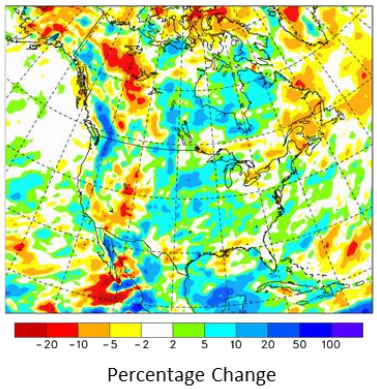
CanESM



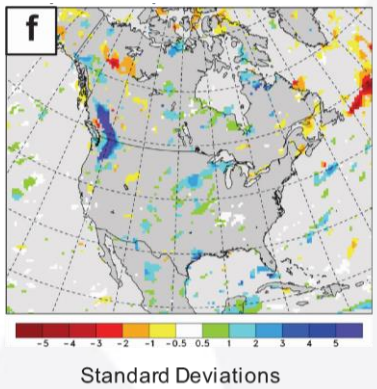
CanRCM



CanRCM − CanESM



- 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*

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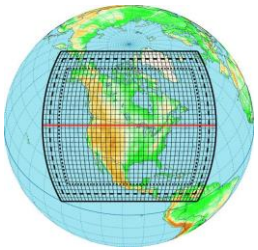
Canadian Centre for Climate Modelling and Analysis, Environment Canada, Victoria, British Columbia, Canada

Slide courtesy John Scinocca

CanRCM4 Applications

CORDEX	Resolution	Ensemble Members	Years
Evaluation	0.44⁰ (50km)	1	1989-2009
	0.22⁰ (25km)	1	1989-2009
Historical	0.44⁰ (50km)	5	1950-2005
	0.22⁰ (25km)	5	1950-2005
RCP4.5	0.44⁰ (50km)	5	2005-2100
	0.22⁰ (25km)	5	2005-2100
RCP8.5	0.44⁰ (50km)	5	2005-2100
	0.22⁰ (25km)	5	2005-2100
CanSISE large ensemble			
Historical	0.44⁰ (50km)	50	1950-2005
	0.22⁰ (25km)	1	1950-2005
RCP8.5	0.44⁰ (50km)	50	2005-2100
	0.22⁰ (25km)	1	2005-2100
CanSIPS hindcast downscaling (proof of concept)	0.44⁰ (50km)	JFM, JAS	1981-2010
	0.22⁰ (25km)	JFM, JAS	1981-2010



North American domain

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

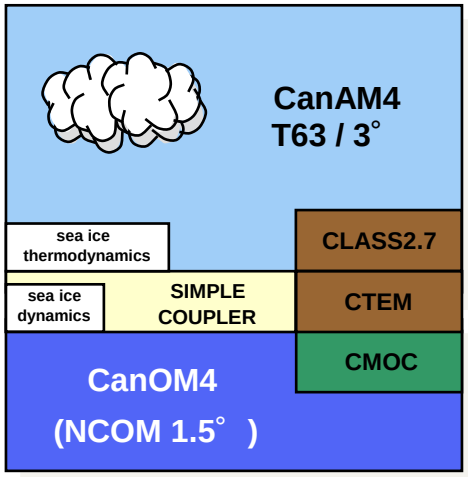
(Collaboration of ECCC's Climate Research Division (CCCma and CDAS), the Pacific Climate Impact Consortium, and the National Research Council in support of the Pan Canadian Framework on Clean Growth and Climate Change, and in support of the Green Infrastructure objectives of the GoC)

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).

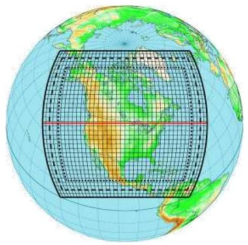
Slide courtesy John Scinocca

Empirical bias correction

CanESM2 (CMIP5)

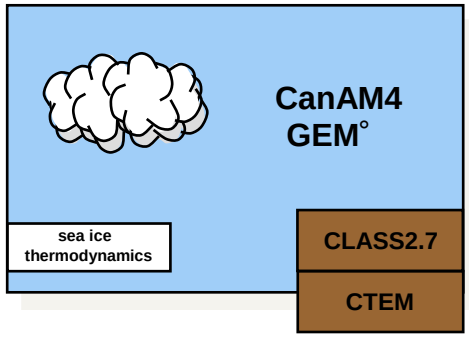


Dynamically downscale



Runtime bias correct

CanRCM4 (CORDEXI)



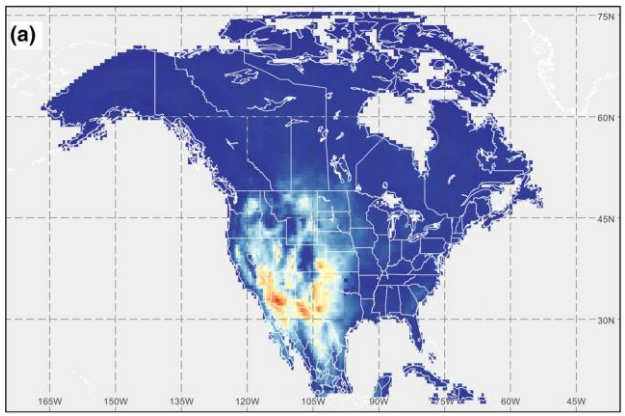
Offline bias correct

CanLEAD

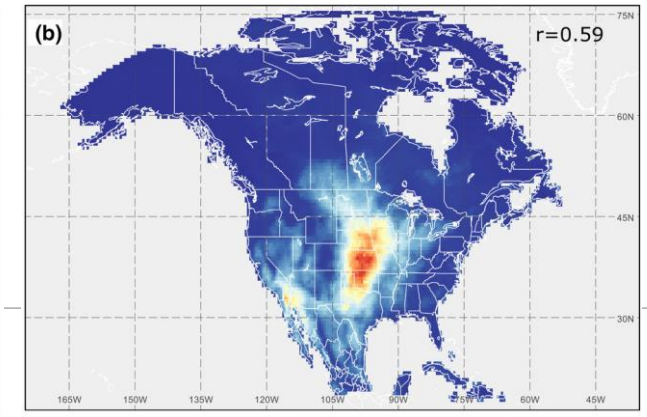
Canadian Large Ensembles Adjusted Dataset version 1 (CanLEADv1): Multivariate bias-corrected climate model outputs for terrestrial modelling and attribution studies in North America

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

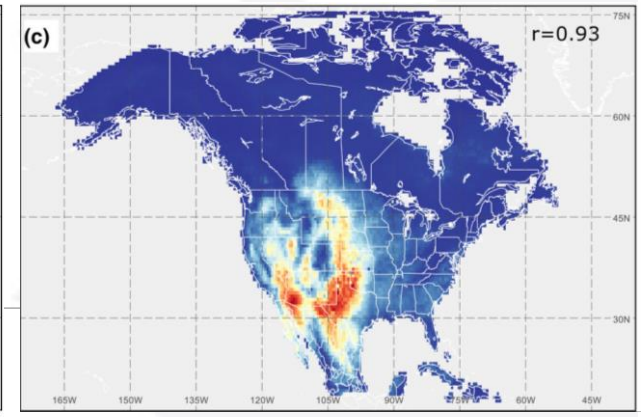
Observations



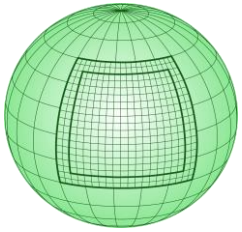
CanRCM4 0.44°

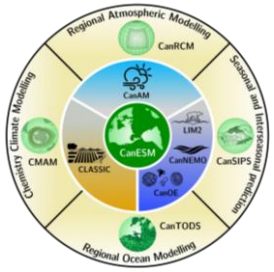


CanRCM4-S14FD-MBCn



CanRCM5+

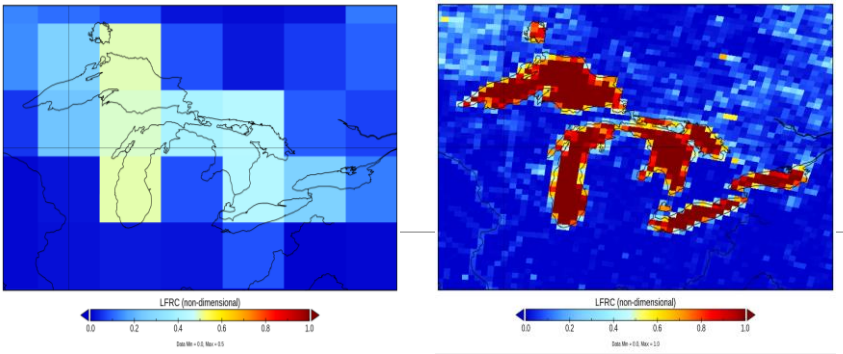




- operational resolution 0.22° (25km) with 0.11° (12km) for special applications
- coordinated global/regional modelling: all physical improvements made to **CanAM5** are inherited by **CanRCM5**
- Improved surface processes for enhanced value added: improved treatment of **fresh-water lakes**

Lake Fraction

CanAM5 (~2.8°) CanRCM5 (0.22°)



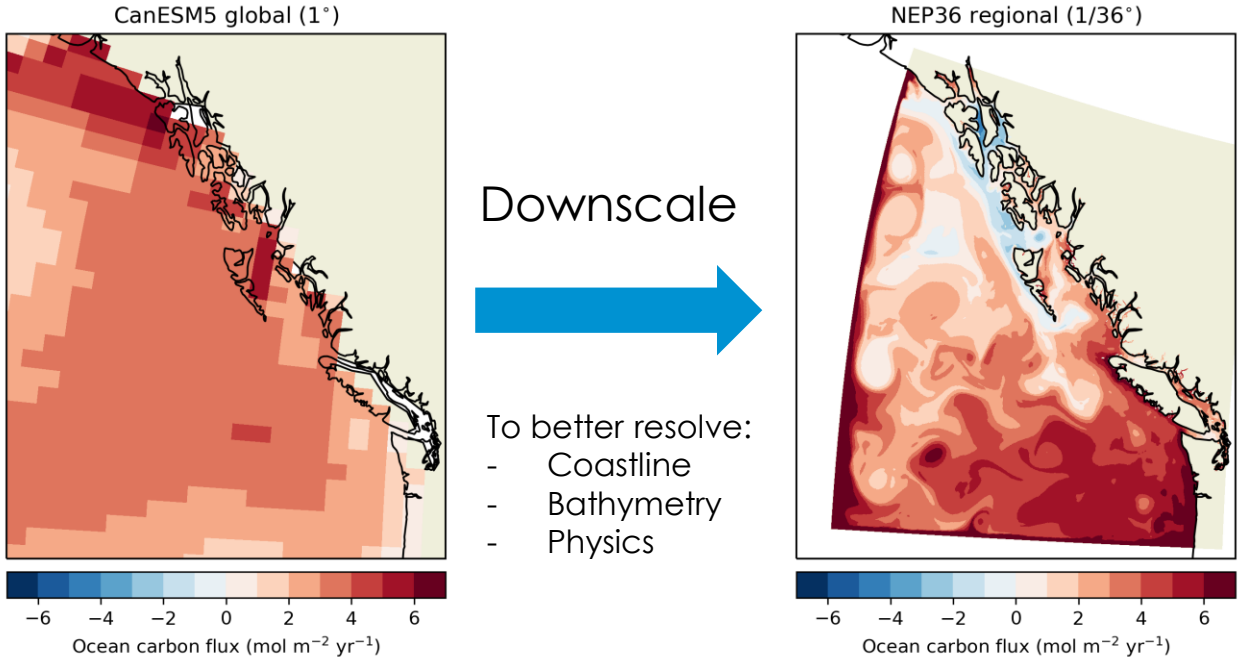
Current & future downscaling activity

- 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 CanRCM 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



To better resolve:
- Coastline
- Bathymetry
- Physics

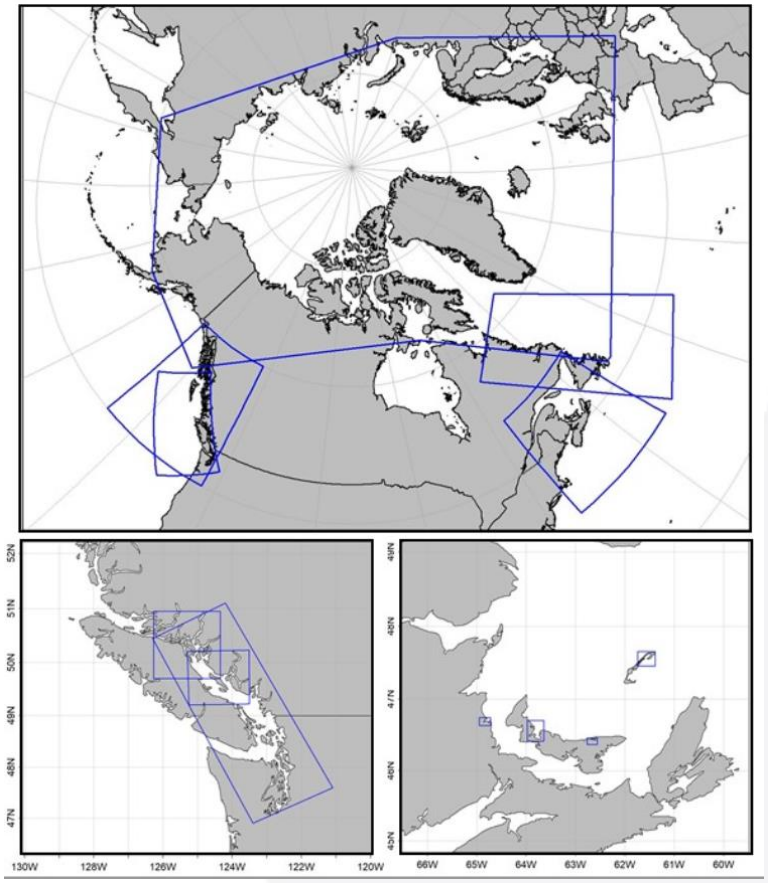
Downscaling refines from the global to regional scale, but requires boundary conditions at the edges & surface

Regional downscaling capacity exists in DFO/ECCC/Universities, **but there are issues**…

Ocean downscaling challenges

- 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.

Courtesy Diane Lavoie, DFO



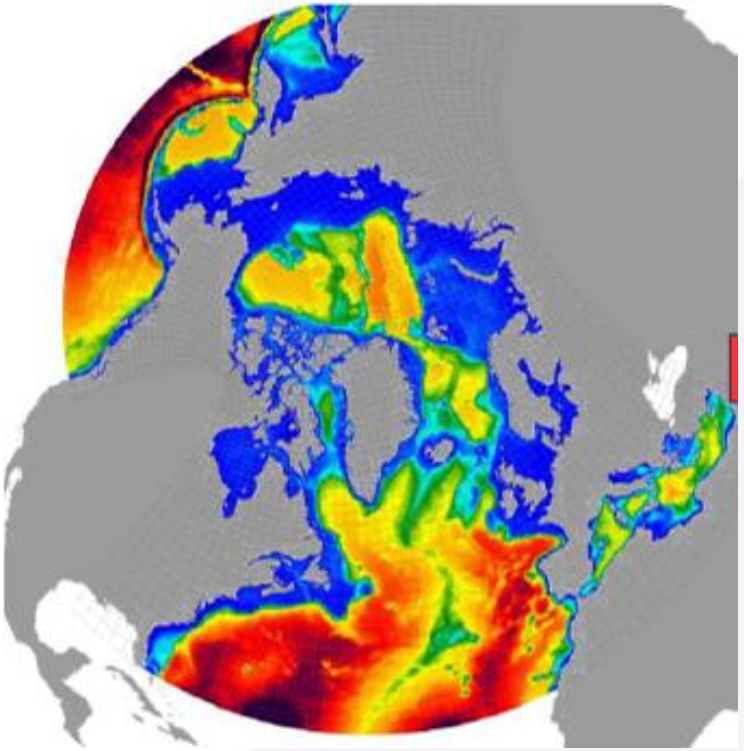
Existing downscaling domains in DFO/Universities

What is CanTODS?

Canadian Three Ocean Downscaling System

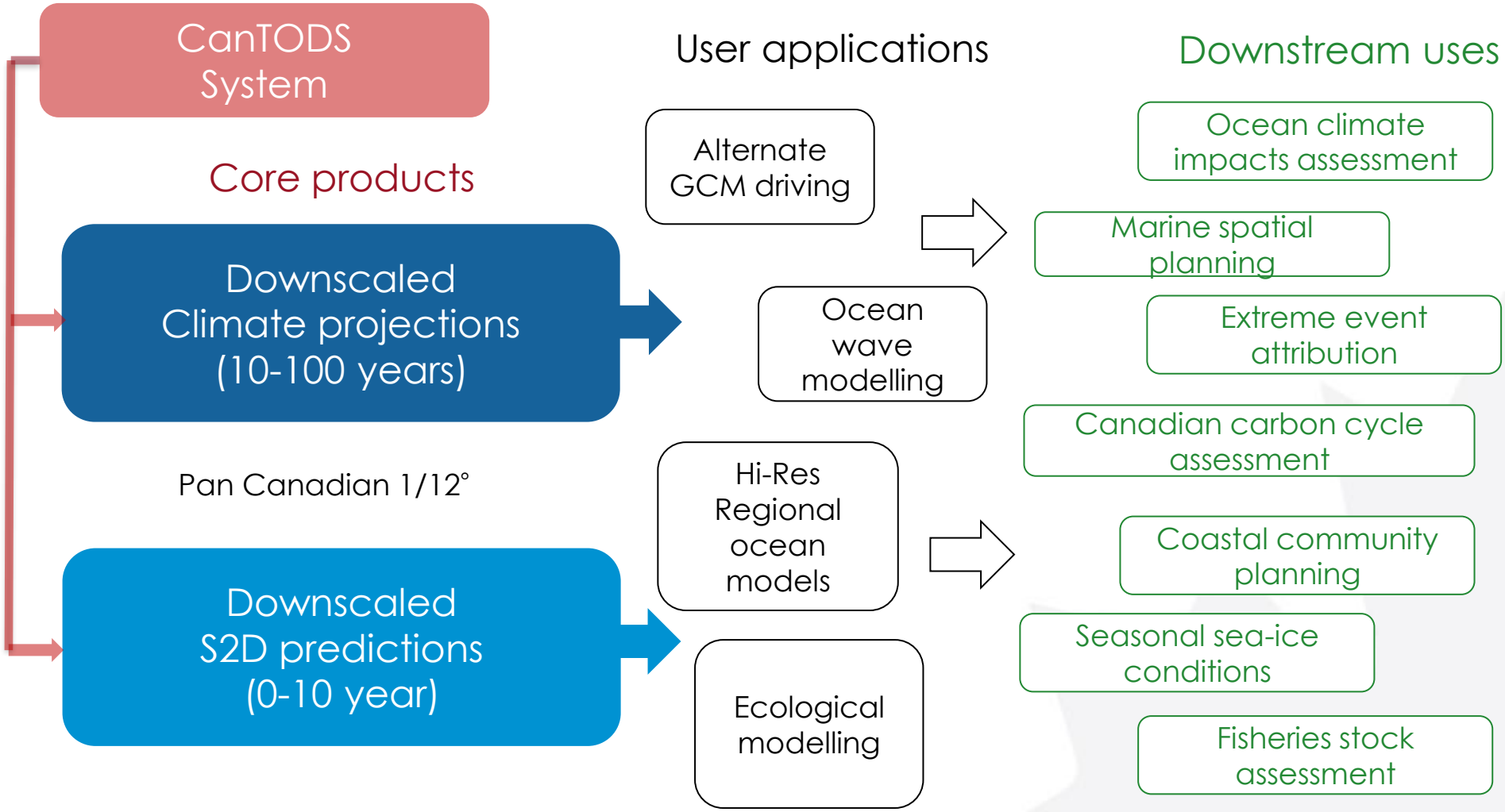
A (proposed) community **system** for spatially consistent downscaling of **climate projections and seasonal forecasts** across Canada's three oceans.

- 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 ECCC/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

Global ESM

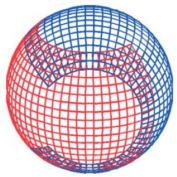
CanESM5
Swart et al. 2019

CanESM5-3?

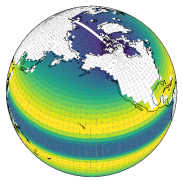
CanESM5-2

CanESM5-1
Spectral-NEMO3

CanESM6
GEM-NEMO4



C. Goddard

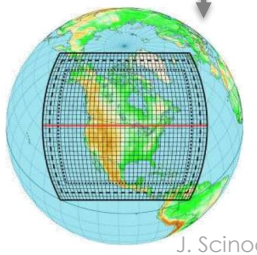


N. Swart

CanESM6-chemistry

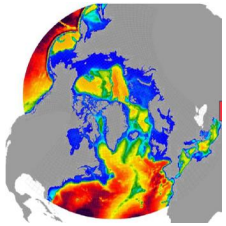
RCMs

CanRCM5



J. Scinocca

CanTODS



G. Smith

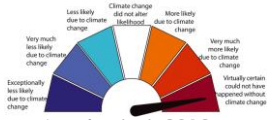
CanRCM6

CanRESM

Applications

Extreme event attribution system

CanSIPS update



Lewis et al. 2019

Downscaled A & O seasonal/decadal predictions

2023

2025

CCCR v2.0

CMIP7

AR7 2028