Ocean climate modelling at CCCma / ECCC

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BECI workshop
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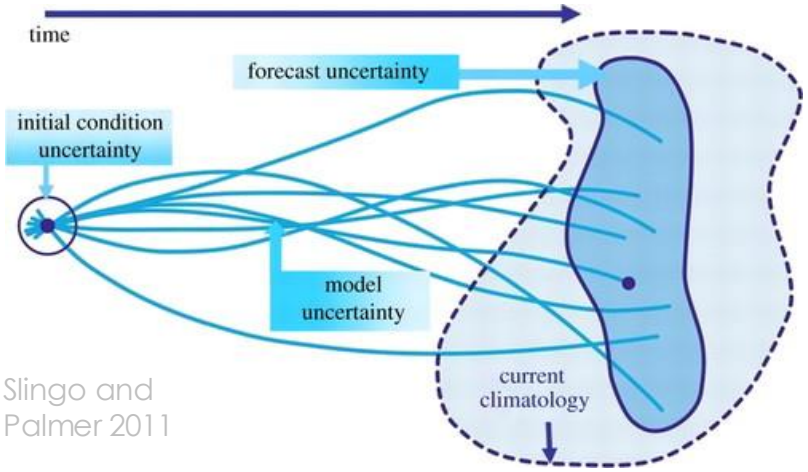
Overview

1. Context: Climate prediction, projection and the modelling value chain

2. The CCCma integrated modelling system

3. The (proposed) Canadian Three Ocean's Downscaling System

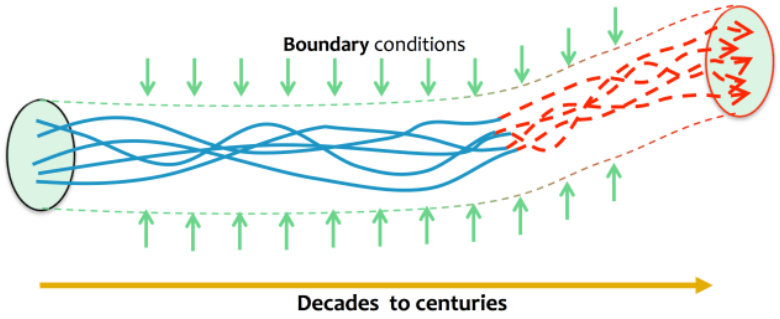
Prediction vs projection



Slingo and Palmer 2011

- **Predictions** are near-term (days to weeks)
- The goal of a prediction is to beat climatology (aka having skill), by forecasting the precise evolution of the real system.
- Predictions depend on initial conditions, and their skill degrades rapidly with increasing lead-time.
- There is a "limit to predictability" imposed by the chaotic system

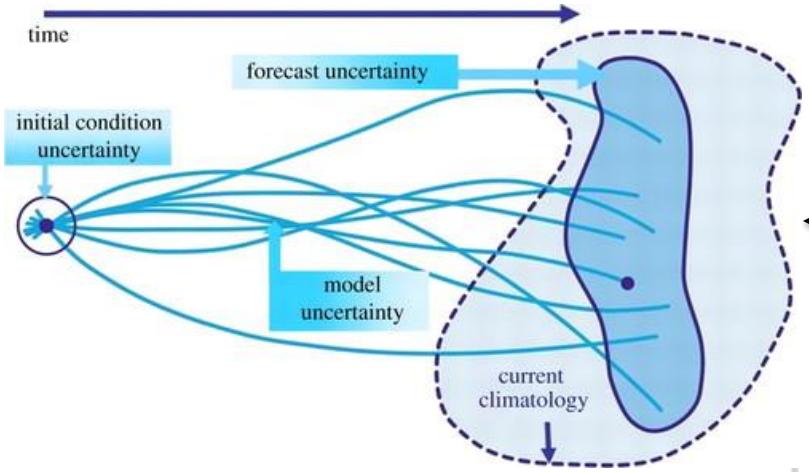
Prediction vs projection

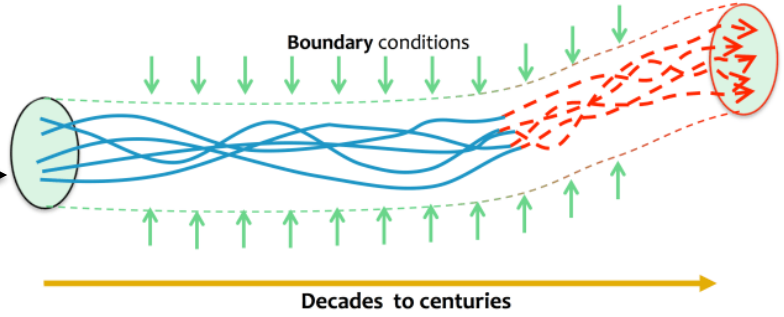


https://www.easterbrook.ca/steve/2014/02/weather-balloons-vs-climate-balloons/

- **Projections** are long term (decades to centuries)
- The goal of projections is to capture the change in the statistics of events, not to forecast the precise evolution of the real system.
- Projections depend on changing boundary conditions – future human emissions are uncertainty, and rely on "scenarios" to capture the range of possibilities.

Prediction vs projection





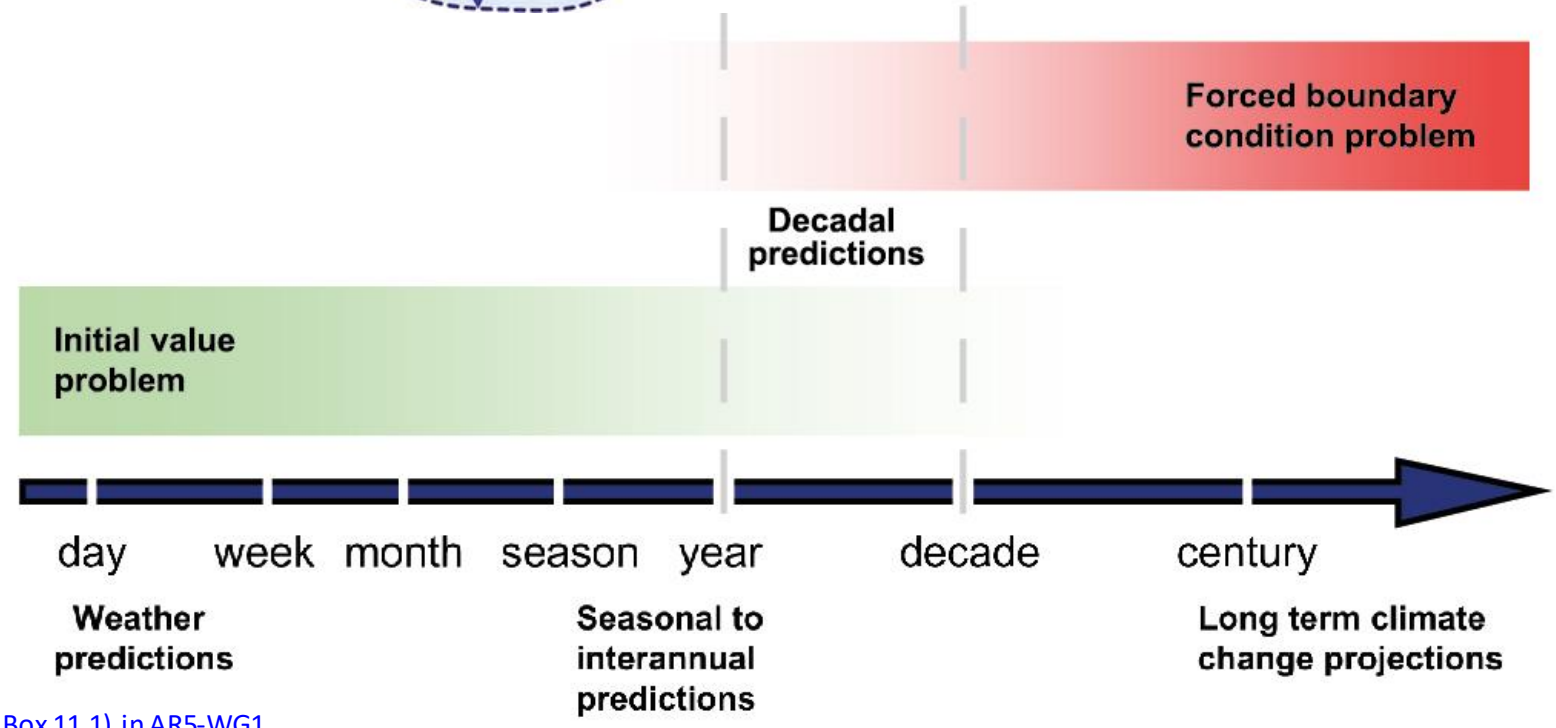
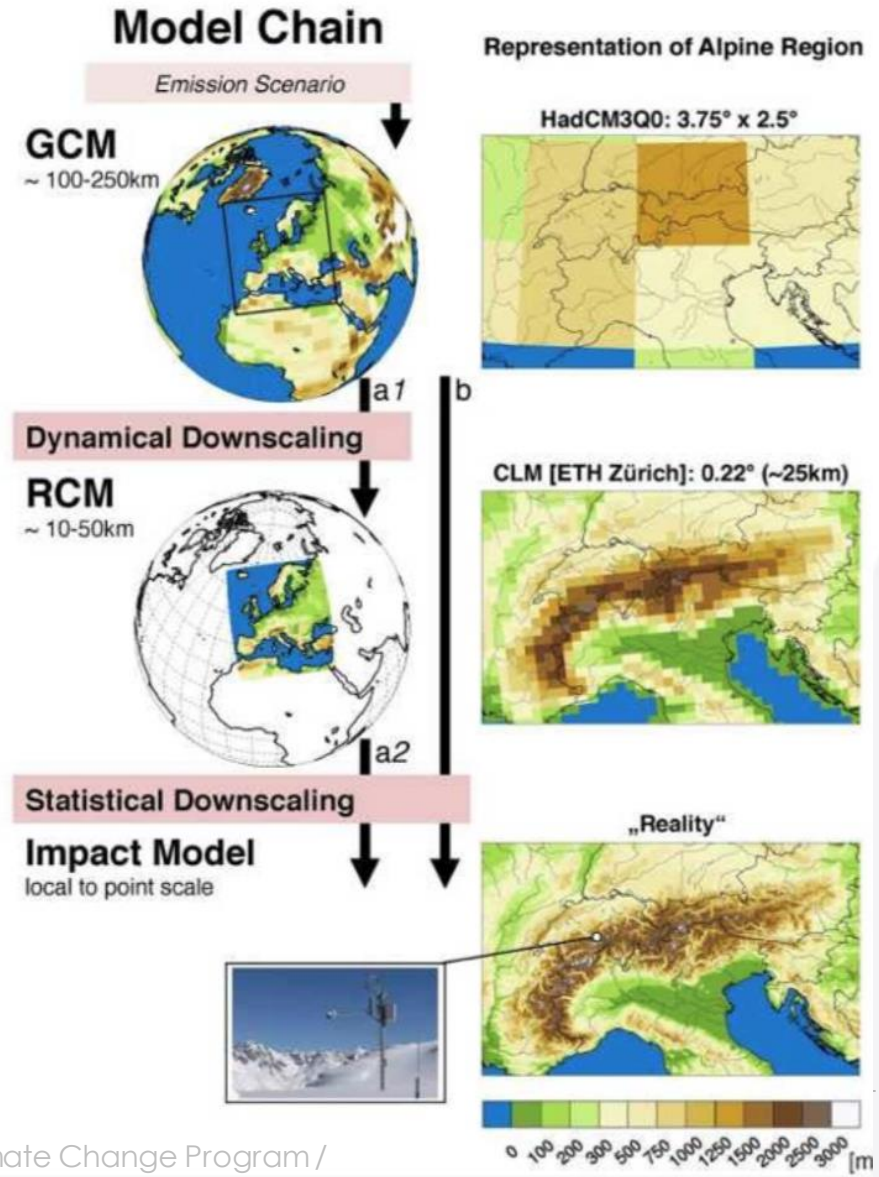


Fig. 2 (Box 11.1) in AR5-WG1

The climate modelling value chain

- Weather and climate predictions require global coverage, which is computationally constrained to coarse resolution.
- Dynamical and statistical downscaling improve resolution, but depend on global models and inherit (and expand) their uncertainties.



CCCma integrated Modelling System

CCCma develops multiple application-specific climate modelling systems.

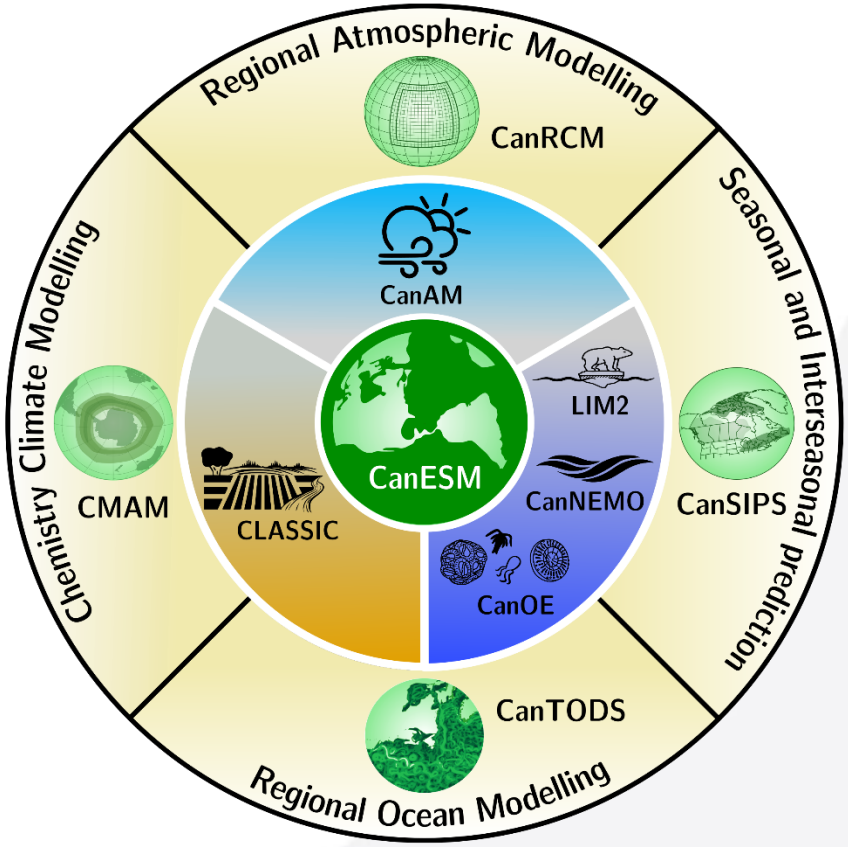
CanESM Canadian Earth System Model

CanRCM Atmospheric Regional Climate Modelling downscaling system

CanSIPS Seasonal and Interannual Prediction System

CMAM Stratosphere/troposphere chemistry climate system

CanTODS Canada's Three-Ocean Downscaling System



History of CCCma modelling & science

Models

AGCM1
Boer and McFarlane (1979)

AGCM2
McFarlane et al. (1992)

CGCM1
Flato et. al (2000)

CGCM2

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

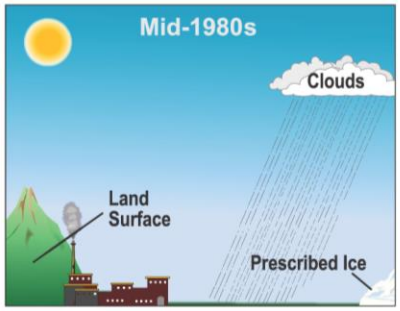
CanESM1
Christian et al. 2010

CanESM2 / CGCM4

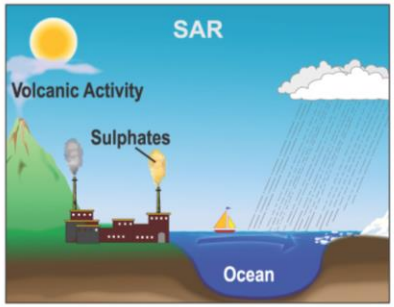
CanSIPSv1
Merryfield et al. 2013

CanESM5
Swart et al. 2019

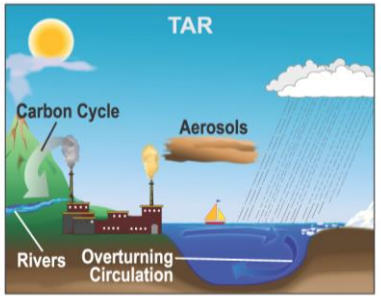
CanSIPSv2
Lin et al. 2020



Atmosphere only



Coupled to ocean



Carbon cycle

1970 1980 1990 2000 2010 2020

Assessments & MIPs

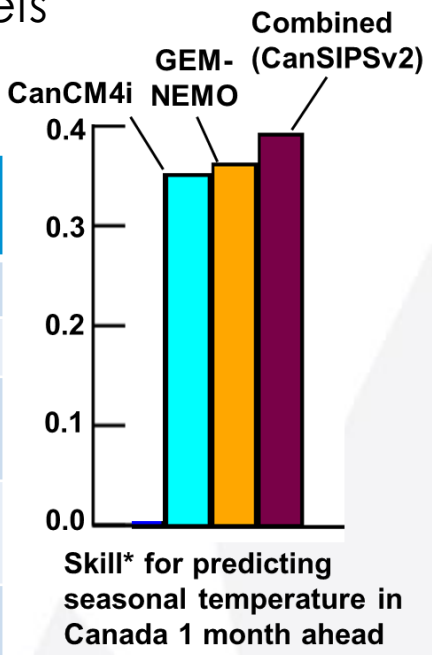
WCRP MIPs:			CMIP1	CMIP2	CMIP3		CMIP5	CMIP6
IPCC assessments:	AR1 1990	AR2 1995		TAR 2001		AR4 2007	AR5 2013	SR15 2018 SROCC 2019 **AR6 2021**
Canadian climate assessments:							CCC 2014	CCCR 2019
WMO Scientific Assessment of Ozone Depletion:						2006	2010 2014	2018

Seasonal forecasting at ECCC

- Better forecasts are obtained by combining multiple models
- ECCC is the only operational centre using multiple models

System	Debut	CRD models	MRD models	Coupled ?	Range
HFP	1996	GCM2	SEF	N	3 mon
HFP2	2008	GCM2, GCM3	SEF, GEM	N	4 mon
CanSIPS	2011	CanCM3,CanCM4	-	Y	12 mon
CanSIPSv2	2019	CanCM4i	GEM-NEMO	Y	12 mon
CanSIPSv2.1	2021 Dec	CanCM4i	GEM5-NEMO	Y	12 mon

Coupled



* Spatial mean anomaly correlation, averaged over all 12 initialization months

Lin et al., *Weather and Forecasting* (2020)

HFP = Historical Forecasting Project
CanSIPS = Canadian Seasonal to Interannual Prediction System

Slide courtesy Bill Merryfield

Operational seasonal forecasts

Canada.ca > ... > Climate modelling, projections and analysis > Canadian climate data and scenarios > Seasonal forecasts

Seasonal forecasts for Canada

Current forecasts

Select variable:

Sea surface temperature

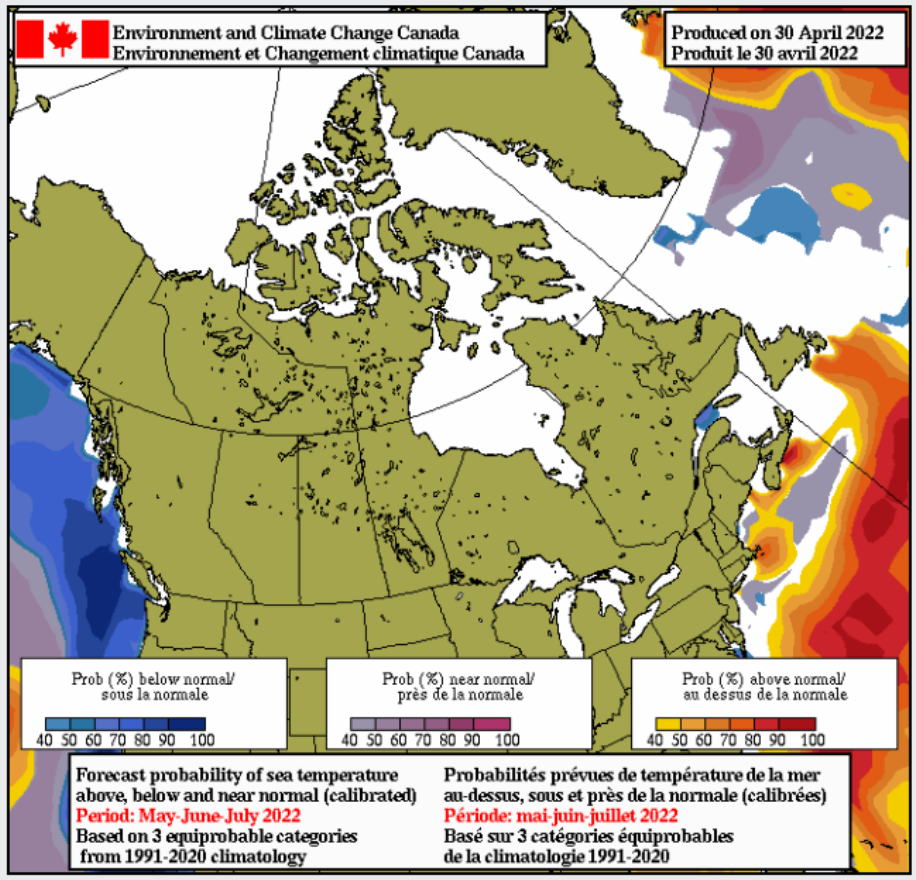
Select period:

May-Jun-Jul ==> 1-3 month

Output options

- (•) Forecast map
- ( ) Skill map
- ( ) Reliability

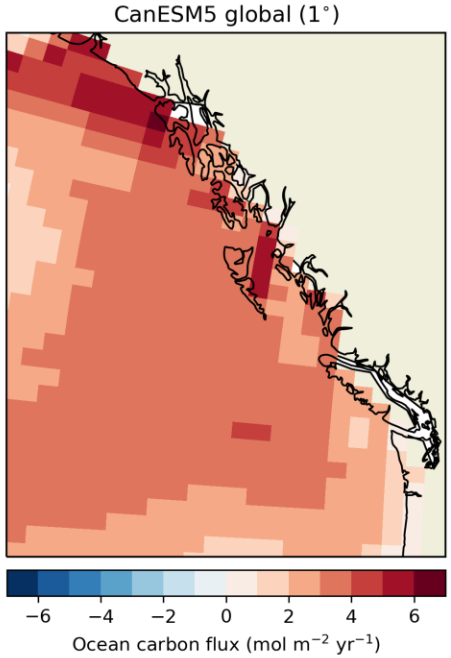
Download data



Downscaling challenges?

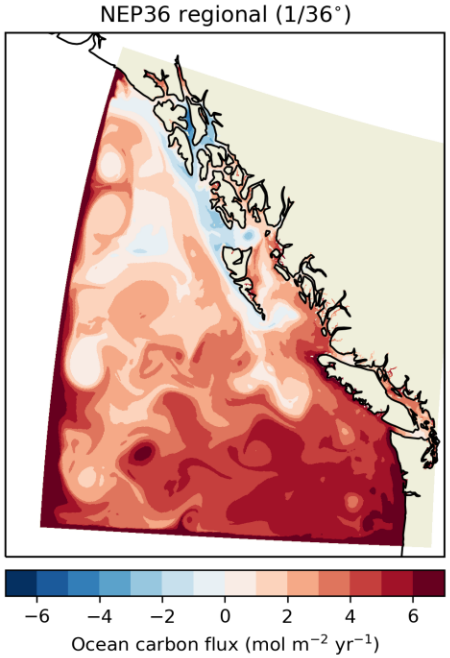
Actionable information on ocean climate change at regional to local scales requires **downscaling** of predictions made by coarse global climate models.

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



Downscale

To better resolve:
- Coastline
- Bathymetry
- Physics



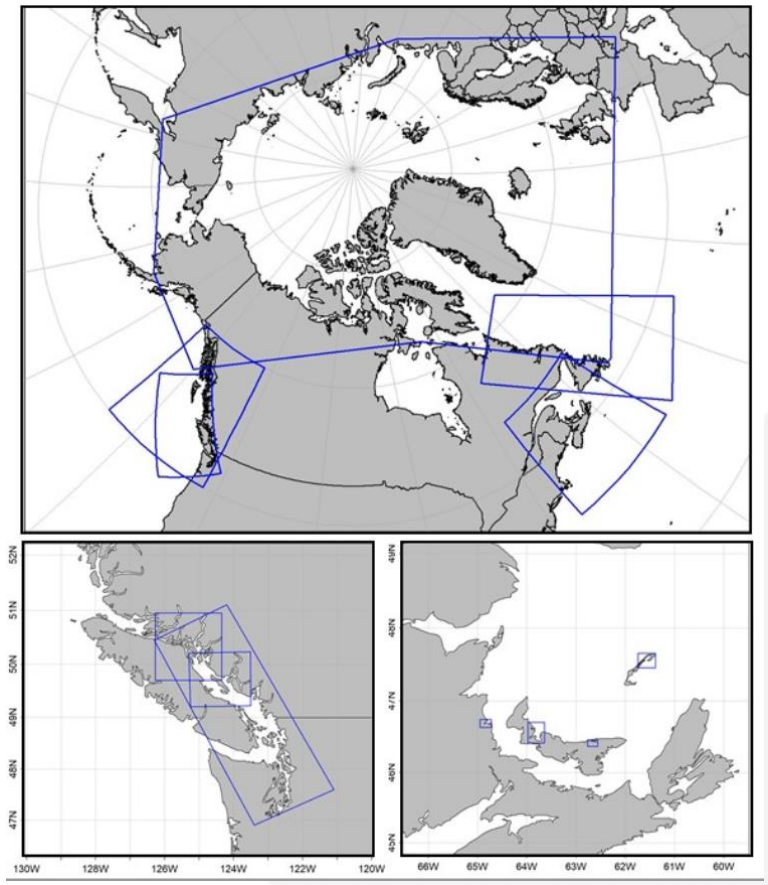
Downscaling refines from the global to regional scale, but requires boundary conditions at the edges & surface

Regional downscaling capacity exists in DFO/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



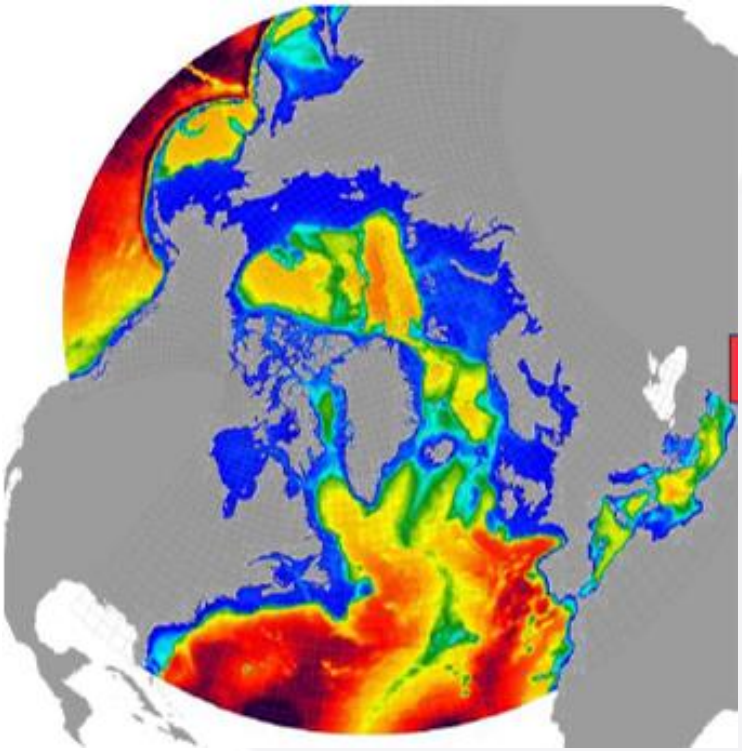
Existing downscaling domains in DFO/Universities

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.

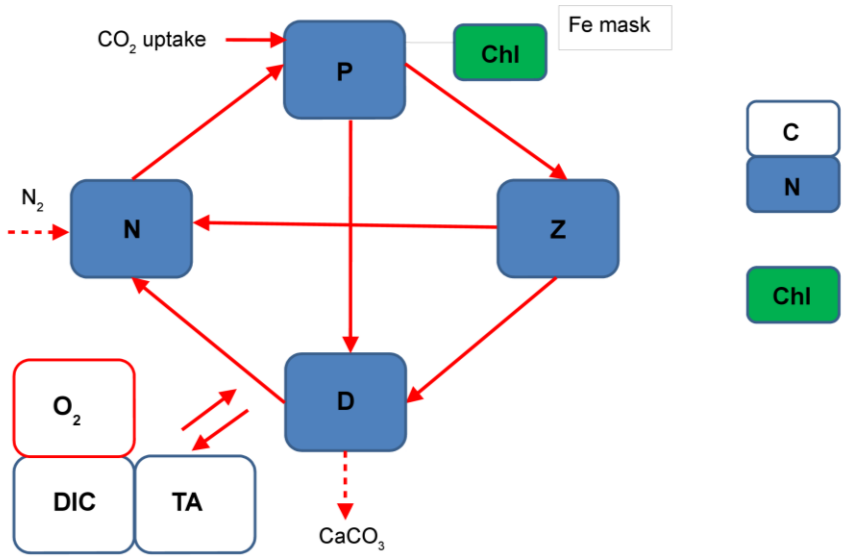
- NEMO physical ocean, building from existing efforts, adapted for climate scales.
- Ocean biogeochemistry (CanESM BGC models CMOC and CanOE are options).
- Tools/procedures for developing surface and lateral boundary conditions and running simulations.
- Leverages development of CanESM, CanRCM, CanSIPS,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



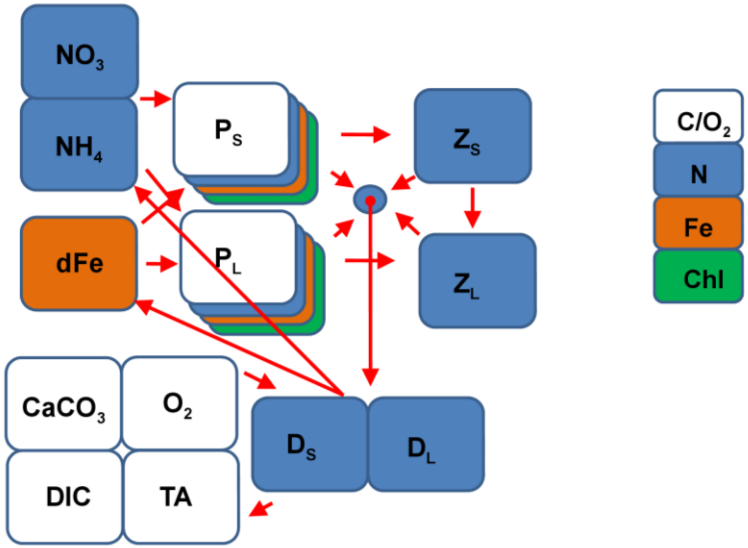
CONCEPTS extended RIOPS grid (1/12°)

CCCma Ocean biogeochemistry: CMOC or CanOE

Canadian Model of Ocean Carbon (CMOC)

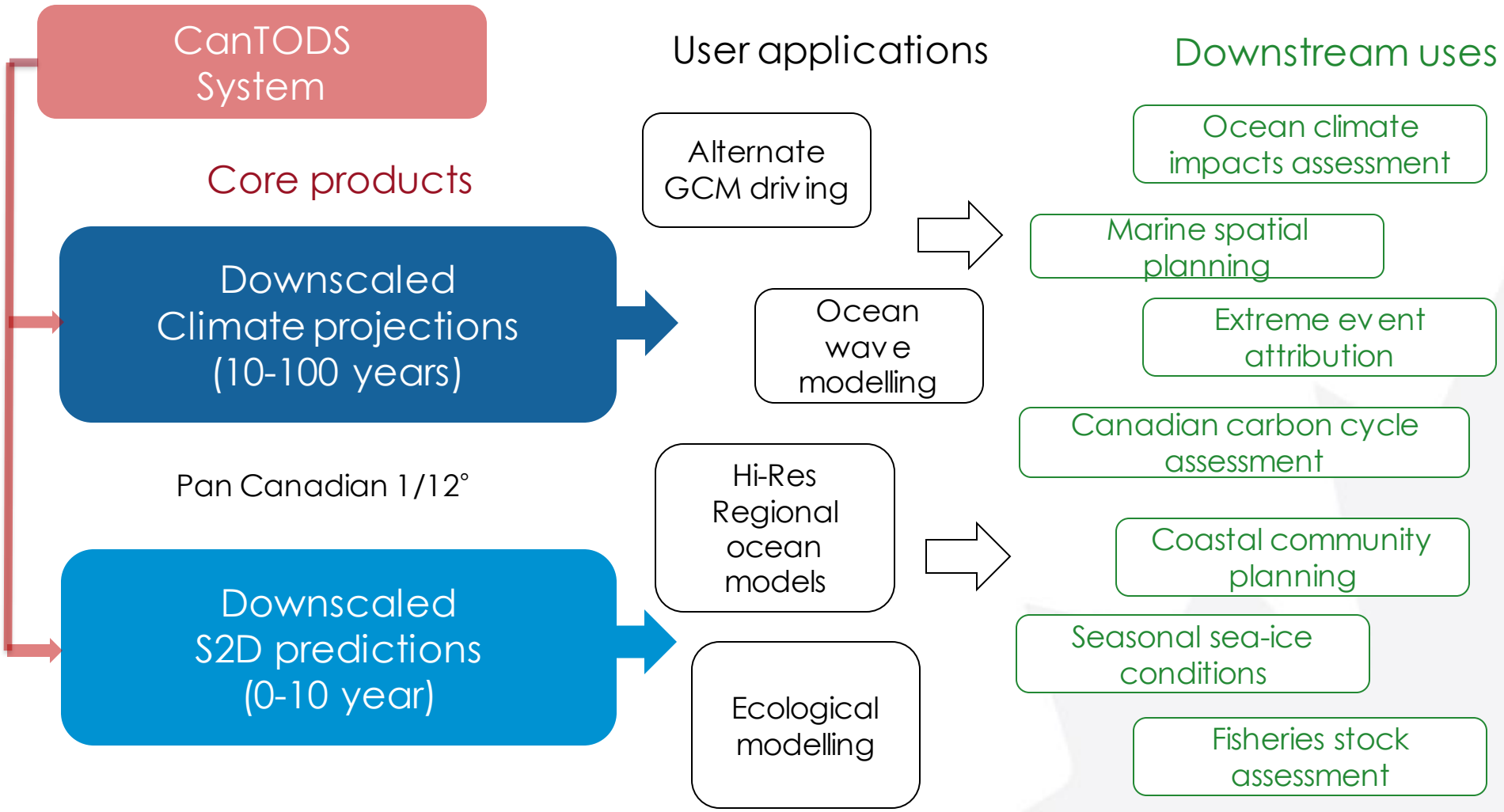


Canadian Ocean Ecosytem (CanOE)



- BGC models developed for use in climate simulations collaboratively between DFO and ECCC.

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.

Resource requirements

- Compute resources
  - With 260m grid-points, CanTODS is very computationally expensive.
  - ECCC has HPC capacity earmarked for (limited) CanTODS development/application.

- Human resources
  - Ad hoc limited-term positions have been funded through competitive calls within DFO.
  - ECCC/CCCma positions have not been funded so far.

Progress

CanTODS February 2021 workshop report

Edited by Neil Swart[1],Amber Holdsworth[2], Nadja Steiner[1,2], James Christian[1,2]

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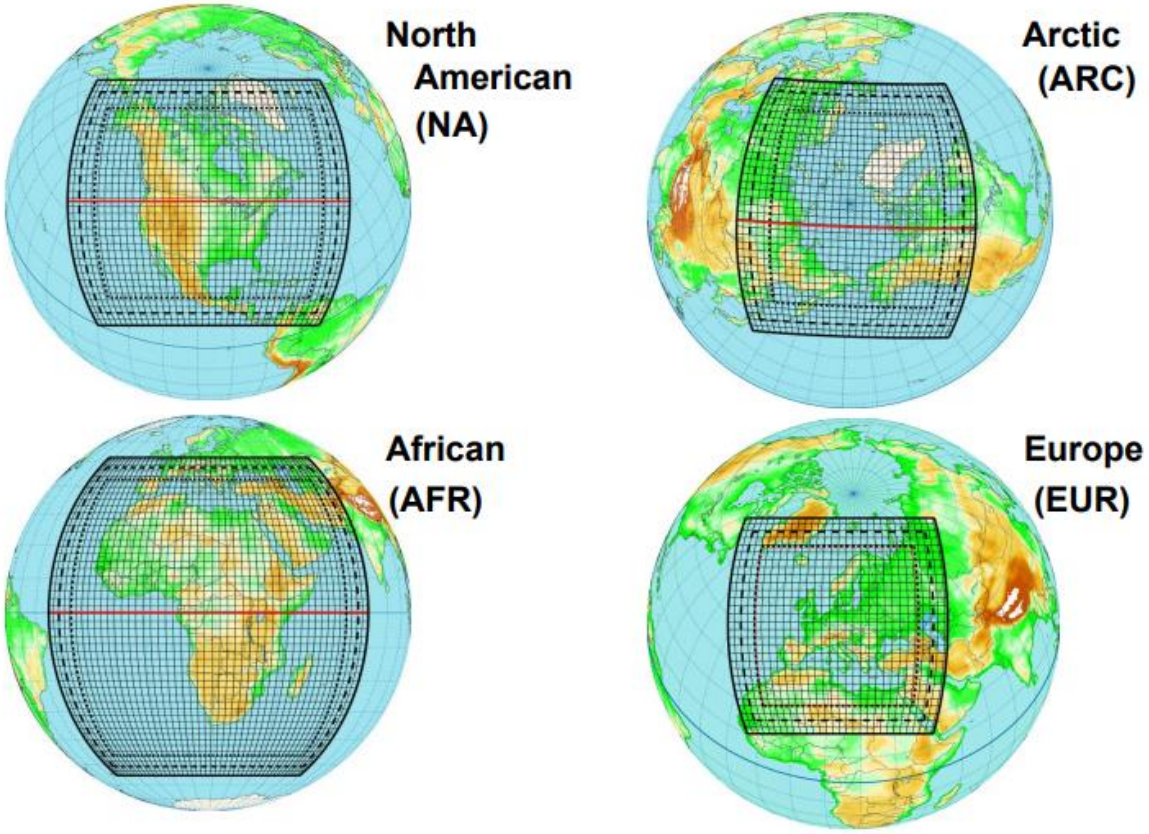
[2]Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC.

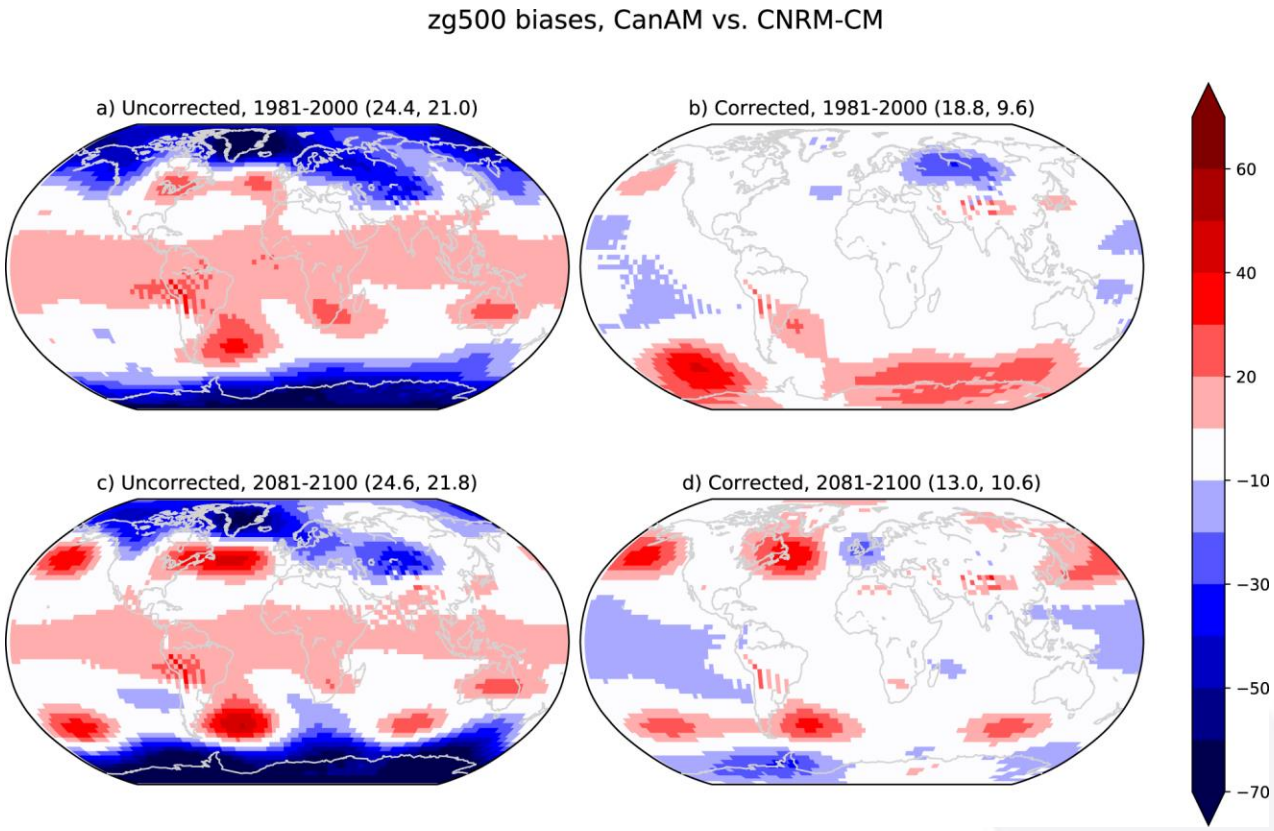
- 3 day workshop held between ECCC/DFO/Universities in early 2021
- Projects underway on development of the physics grid, and implementing CCCma biogeochemistry.
- Bias correction work proceeding in atmosphere and ocean.

Expanded CanRCM domain for boundary conditions

- **Four CORDEX domains – resolution 0.22°/0.44° or 25/50km**



Online bias correction within parent ESM/RCM

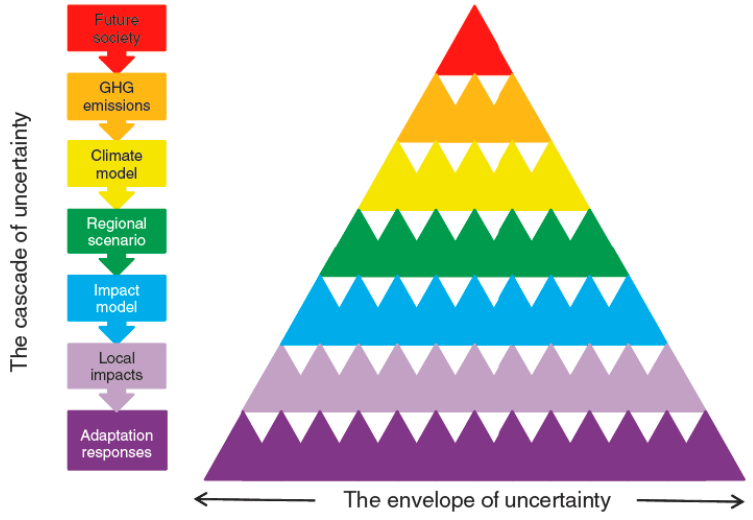


Online bias correction could circumvent the need for using deltas

Krinner et al. (2020)

Some general considerations

- Uncertainties are significant, are magnified during each stage of downscaling, and important to consider for impact studies.
- GCM/ESMs are rigorously compared in CMIP, and A-RCMs in CORDEX. No equivalent exists for ocean RCMs, and domains / experiments seldom overlap.
- Ultimately, coupled regional models are needed to resolve tightly coupled feedbacks.
  - The CCCma strategic plan proposes a coupled Regional Earth System Model (CanRESM) – based on CanRCM+CanTODS with full field, bias corrected driving from CanESM



Wilby & Dessai (2010)

Conclusions

- CanTODS is proposed as a Canadian ocean downscaling ***system*** *for community use*, designed to fill capacity gaps by building on existing systems.

- CanTODS will improve the quality of information on regional changes in the oceans, sea-ice and marine ecosystems from **seasonal** to **climate** (10+ years) time scales.

- CanRCM can provide downscaled atmospheric driving, and could ultimately be coupled to CanTODS to for CanRESM.

- Funding for HQP is the main limiting factor of CanTODS / CanRESM development at present.