From Past to Future: ECCC's HPC and the Transformation of Weather Services

Luc Corbeil, Vincent Fortier, Stéphane Gaudreault, Matthew Holly, Hugo Landry, Jeffrey Miller, Radenko Pavlovic, and Janti Reid

Meteorological Service of Canada, ECCC

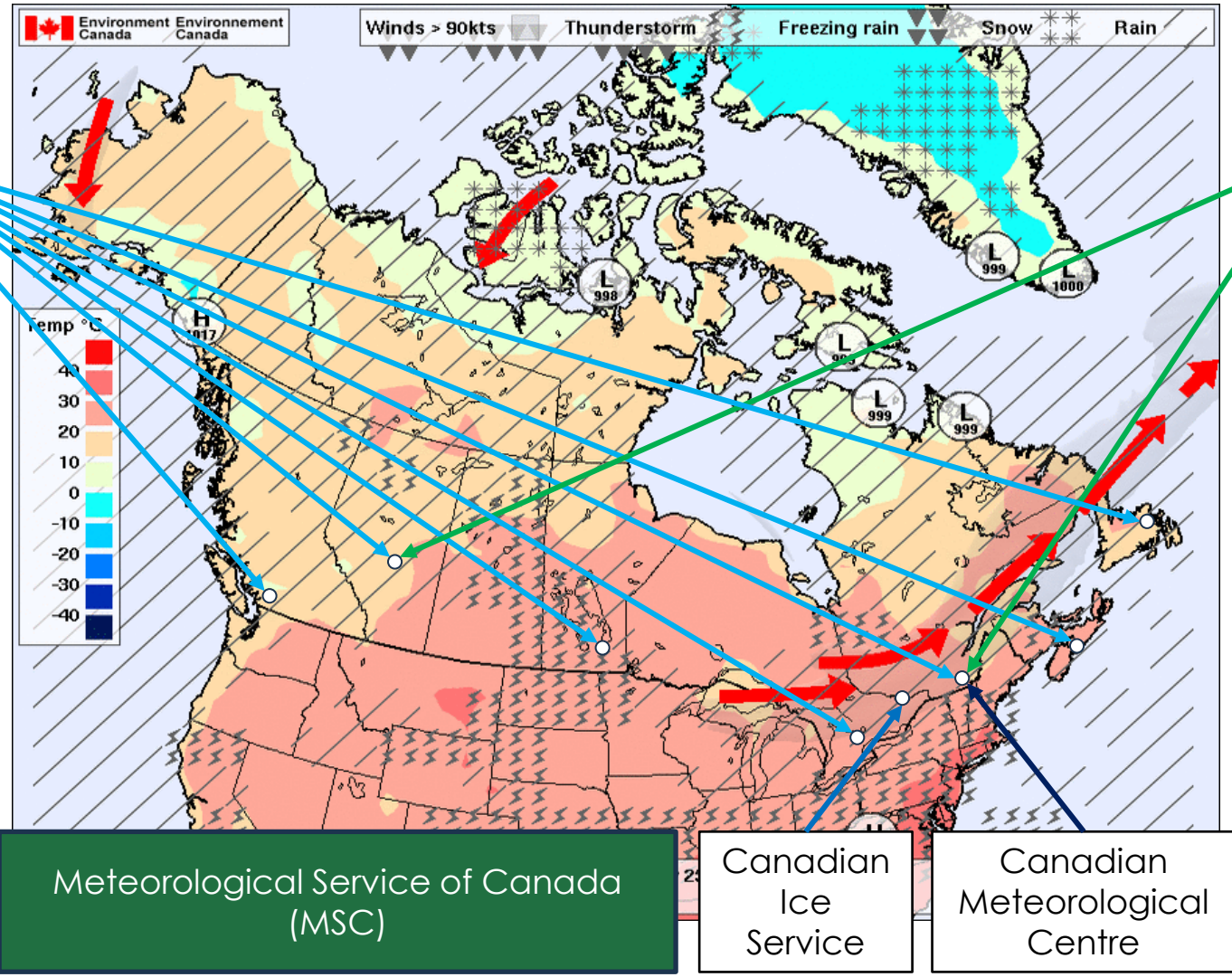
21st ECMWF Workshop on High Performance Computing in Meteorology, Bologna, Italy

September 15-19, 2025

Bienvenue au Canada / Welcome to Canada

Storm Prediction Centres (7)

Canadian Meteorological Aviation Centres (2)



Meteorological Service of Canada (MSC)

Canadian Ice Service

Canadian Meteorological Centre

From Science to Service to Canadians

R Research

Meteorological Research

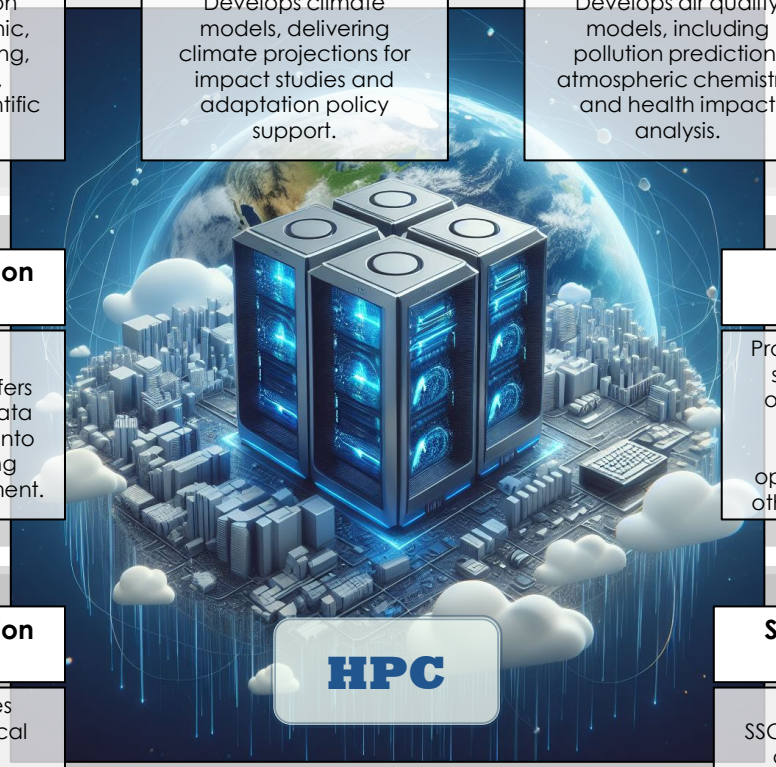
Applied research on atmospheric, oceanic, and surface modeling, data assimilation, algorithms, and scientific innovation.

Climate Research

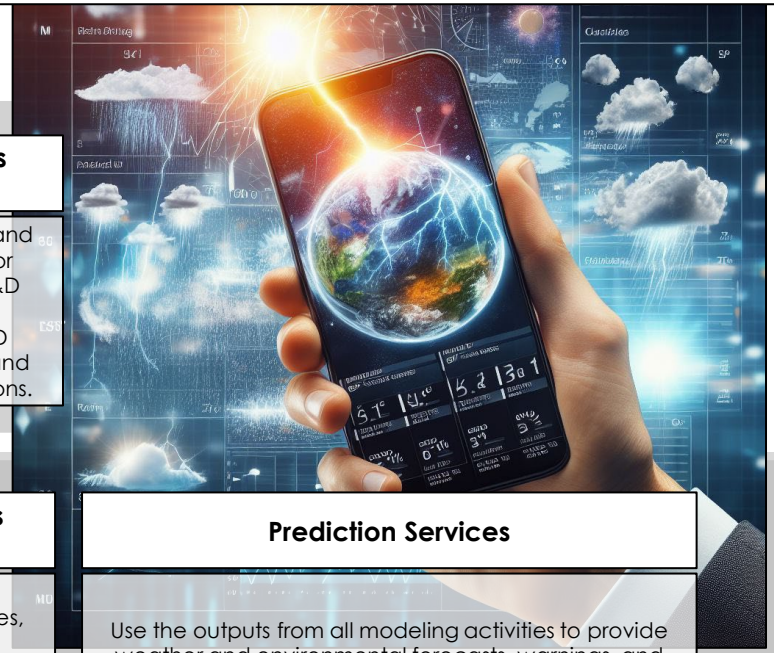
Develops climate models, delivering climate projections for impact studies and adaptation policy support.

Air Quality Research

Develops air quality models, including pollution prediction, atmospheric chemistry, and health impact analysis.



Canadians | Safety, health, and transport | Canadian coastguard and National defense | Scientific community | Policymakers



D Development

National Prediction Development

Develops, tests, optimizes, and transfers new forecast and data assimilation systems into operations, ensuring continuous improvement.

Digital Services Branch

Provides ongoing IT and software support for operational and R&D activities, directly supporting the PSD operational teams and other scientific divisions.

O Operations

National Prediction Operations

Runs and manages operational numerical weather and environmental prediction models 24/7, delivering real-time analyses and forecasts.

Shared Services Canda

SSC provides, operates, and maintains the underlying HPC infrastructure and IT services.

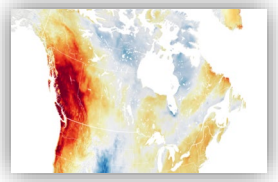
Prediction Services

Use the outputs from all modeling activities to provide weather and environmental forecasts, warnings, and public services to Canadians, government partners, and critical sectors like safety, health, and transport

Extreme Weather Events

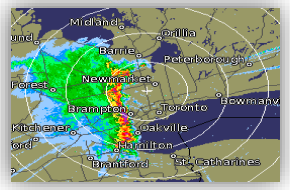
2020 | 2021 | 2022 | 2023

Calgary Region Hailstorm/ Prairie Winds



West Coast Heat Wave

British Columbia Flooding



Ontario & Quebec Derecho

Hurricane Fiona, Atlantic provinces

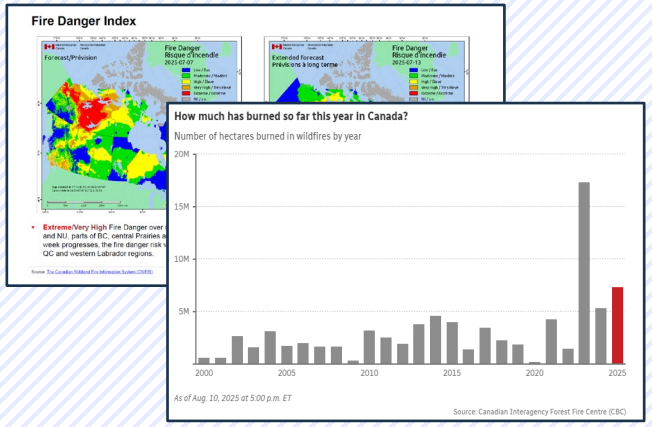
Record Wildfires across Canada
credit : Gabor Fricska

Southern Ontario-Quebec Tornadoes
credit : Sébastien Magny

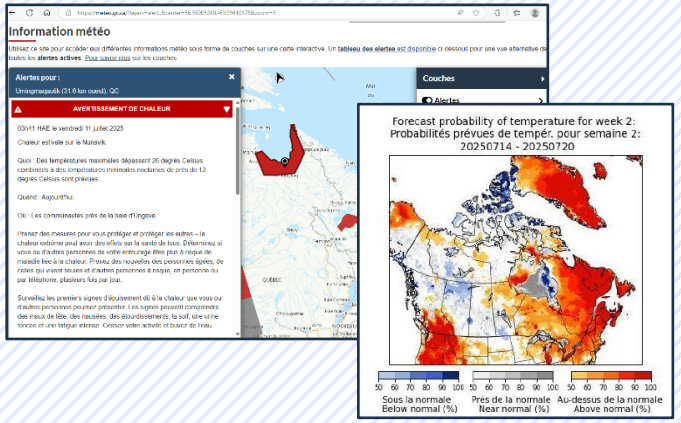
Extreme flooding in Nova Scotia
credit : Lexie Barkhouse

A busy week in 2025…

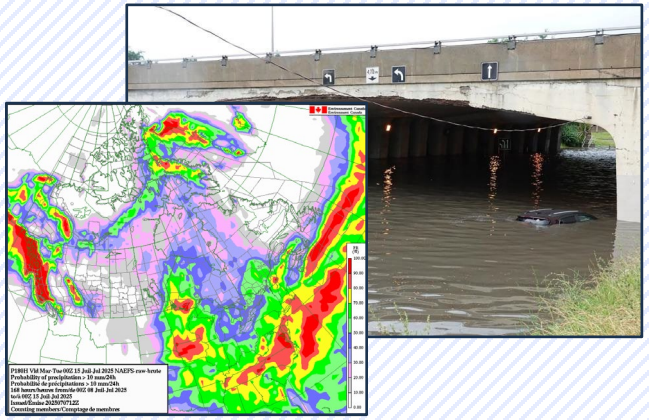
On pace for the 2nd most active wildfire season on record



First ever heat warning over Nunavik region of Northern Quebec



Intense rainfall leading to flash flooding in Montreal



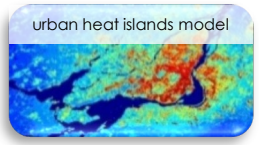
Forecaster's focus shifting on high-impact weather

HPC History at ECCC

Montreal Central Analysis Office

Canadian Meteorological Centre (CMC)

CRAY

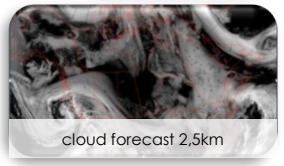


1984 - Regional model at 190 km
1990 - 1st Ocean wave model

2007 1st iPHONE

calculation power equivalent to the CRAY from early 80's

POWER 775
~425
TFlop/s



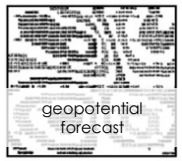
U1 XC50 ~5.2 PFlop/s

- Regional model at 10km
- Global model at 15km
- GEM5 - unified physics
- Hi-res model national at 2.5km
- Producing reanalysis
- Producing reforecasts

U3
LAST UPGRADE IN CONTRACT
moira **conrad**

1960 — Bendix G20
1963

1963- Forecast extended from 48h to 72h



1973 — CDC 7600

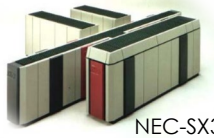
1973 - André Robert 1st CMC Director
- Global atm. model at 650 km of resolution

End 70s - 1st Climate model

Commodore 64 (1983) calculation power roughly five times the Bendix G-20 from 1961.

1984 — CRAY
1991

1995 - Automated seasonal forecast
1997 - Satellite data assimilation
1999 - 1st Air Quality model

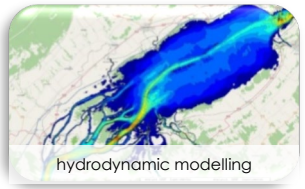


NEC-SX3

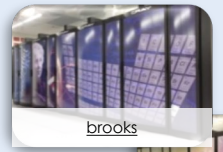
NEC-SX5

NEC — IBM
2004

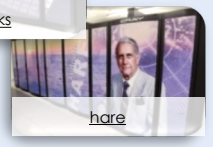
2004 - Regional model at 15 km
2007 - National Air Quality Index forecast program
2009 - Official forecast extended to day 7
2010 - Increasing development of environmental models (water, ice, waves, forest fires)



2013 — IBM-CRAY
2017

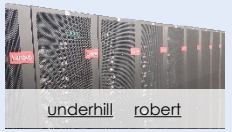


U0
XC40
~2 PFlop/s



2018 – Atmospheric-Ocean coupled Global model at 15 km
Beyond 2018 - aiming for Earth system models

2020 — IBM-LENOVO
2022



U2
THINKSYSTEM SD650
~15.5 PFlop/s

2025 — IBM

CURRENT CONTRACT

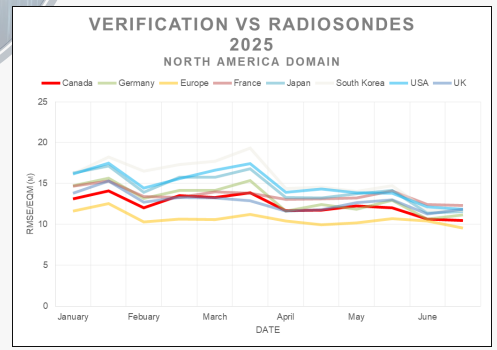
Highlights:

- Explosion of models, services and data offerings
- Model interconnectivity increases leading to greater complexity

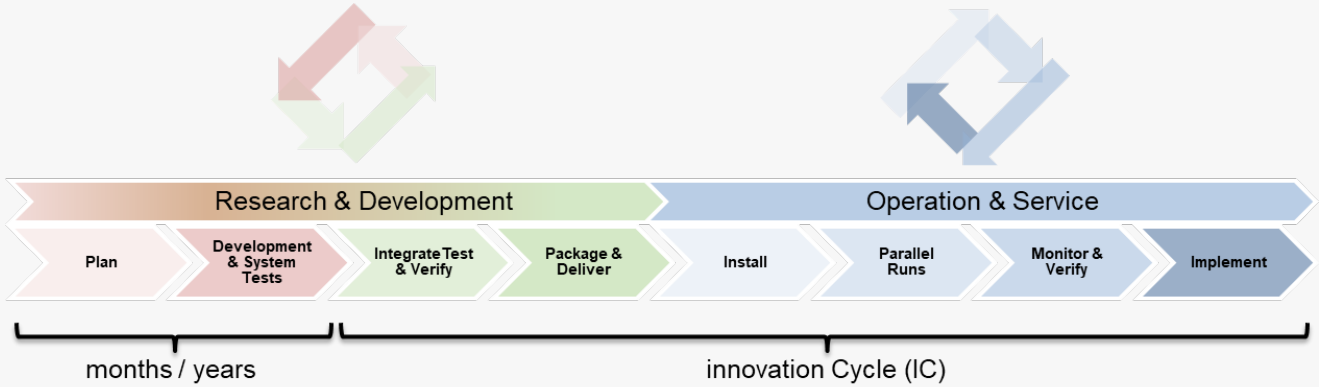
High Performance Computing supercomputers - Canada.ca

Environment Canada | TOP500
Shared Services Canada | TOP500

HPC and Scientific Innovation



2nd best performing for 2025 objective scores over North America



30-month cycle duration is comprised of:

- 18 months spent on delivering next major Innovation Cycle (IC)
- 12 months spent on Upgrade Cycle (UC) e.g. full rip & replace

Initial — June 2017

Upgrade Cycle 1 — December 2019

Upgrade Cycle 2 — June 2022

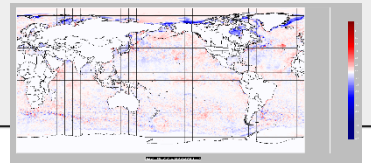
Upgrade Cycle 3 — December 2024 → 2025

NEW HPC CONTRACT — NEXT

IBM-CRAY | IBM-LENOVO | IBM-LENOVO | IBM-LENOVO

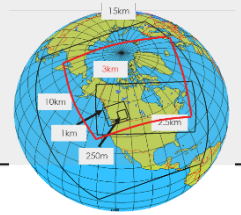
Innovation Cycle 2

GEPS fully coupled with NEMO Ocean model, advancing **interconnectivity of Earth system** in models



Innovation Cycle 3

Complete overhaul of uncertainty simulation in **core physics model** GEM



Innovation Cycle 4

Reduction in **general system complexity** by integrating RDPS into GDPS and merging 2 AQ forecast systems

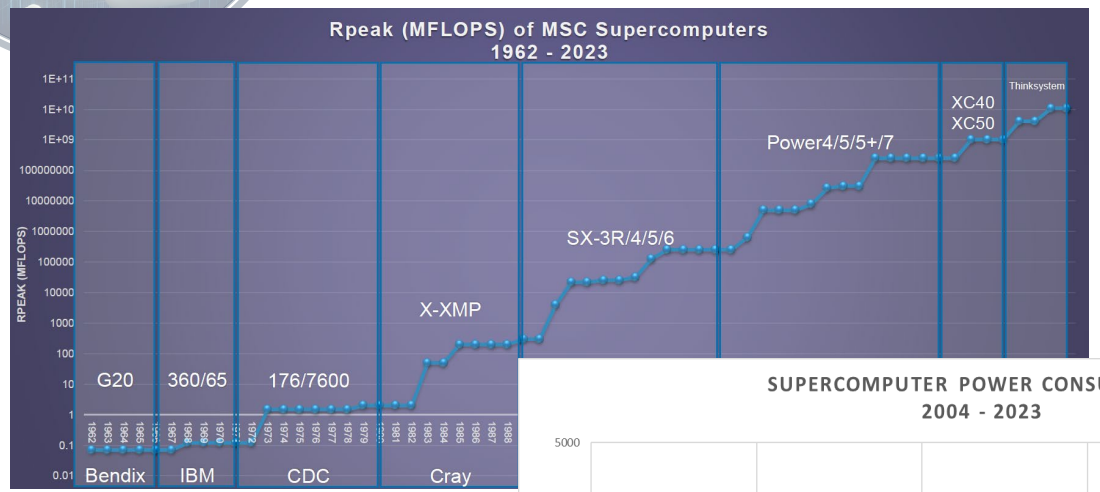
Innovation Cycle 4.x
GDPS-SN

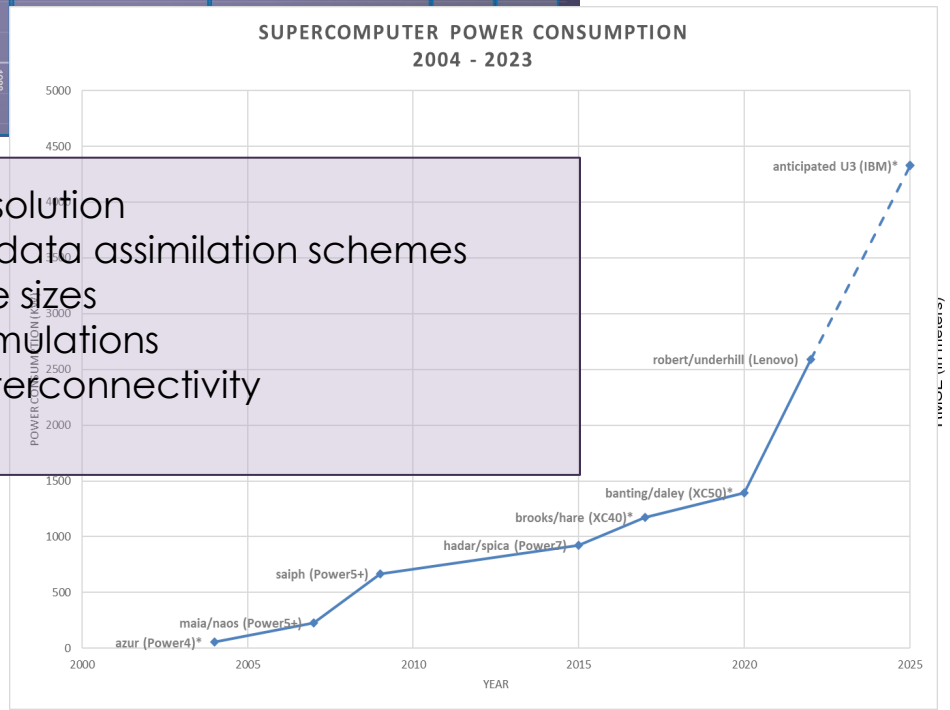
Innovation Cycle 5

…

Current implementation

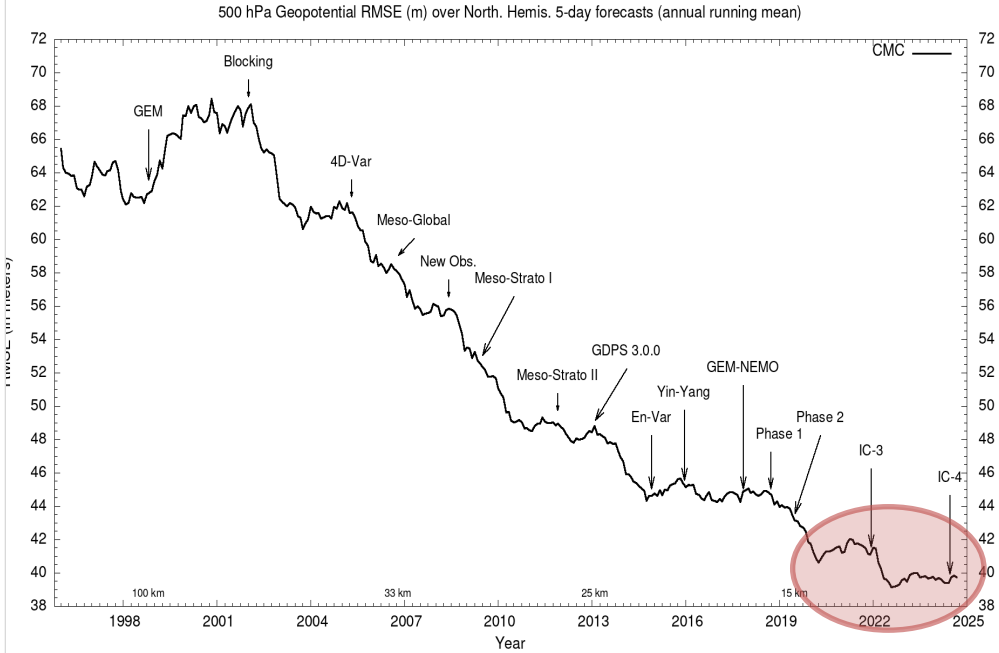
Powering Performance





- improving model resolution
- more sophisticated data assimilation schemes
- increasing ensemble sizes
- improving physics simulations
- increasing model interconnectivity
- etc

- ✓ Our HPC computational capacity has improved dramatically over the last 60-years
- X Supercomputer power consumption has increased dramatically over that period.
- X Improvements through objective verification scores are getting smaller and smaller.

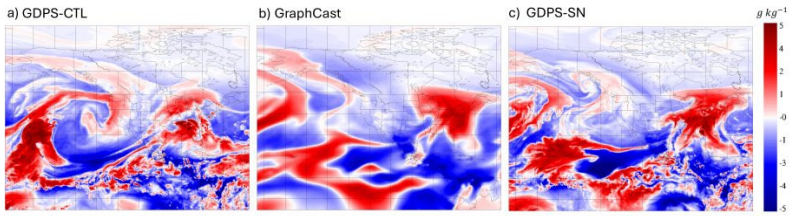


We can't continue throwing CPUs at this problem. Something has to change.

The AI (re)evolution in NWEP

GDPS-SN

Global Deterministic Prediction System with AI Spectral Nudging

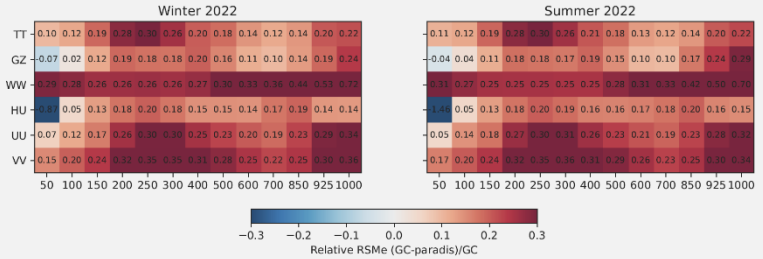


Operationalization of a hybrid AI–physics forecasting system using a spectral nudging technique expected in winter 2026 (currently in parallel-operations).

PARADIS

Development of a Canadian AI global weather forecast model

Preliminary results



Red: PARADIS better **Blue**: GraphCast better

On track to replace AI Spectral Nudging method by end of 2026.

… AND BEYOND

Deployment of AI-centric, data-driven methods to augment and accelerate traditional physical modeling.

- AI-driven paradigm shift in physical sciences enabled by rapidly changing HPC landscape.
- How do we balance operational and research efficiency with growing demands for advanced AI development?

Physics driven … | … physics inspired … | … data driven.

The next innovation cycle (IC-5) will be instrumental in determining how to improve our technology transfer process in order to become more agile and adapt to this new era, while maintaining the same rigor in assessing the impact of innovations and ensuring continuous improvement in service quality.

Current HPC Upgrade (Gen7-U3)

CPUs

297k cores → 467k cores

Supercomputers (per SC):
- GR-AP 128C ×2 = 256C/node
- 240 nodes @ 1536GB (MCRDIMM 8800Mhz)
- 496 nodes @ 768GB (MCRDIMM 8800Mhz)
- NDR400
- RedHat 9

Pre-Post-Processors (per PPP)
- Similar to SC, 768GB DDR5 RAM RDIMMs
- 178 nodes

Hot Storage

178 PB → 298 PB

Archive

1613 PB → 3362 PB

GPUs

16 NVIDIA A100 → 216 NVIDIA H100

GPU Nodes:
- Xeon 8568Y+ 48C ×2 = 96C/node
- 512GB DDR5 RAM RDIMMs
- 4x NDR200 / node (800Gbps combined)
- 4x NVIDIA H100 / node
- 22/32 config (SC1/SC2)

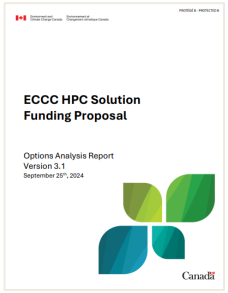
SBS

40 NVIDIA H100

Science Booster System
To accelerate climate, nature, regulatory agendas and environmental research (aimed for non-traditional HPC users)

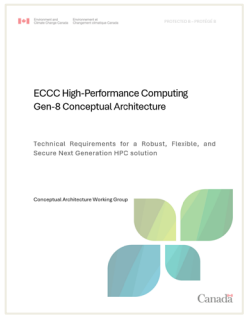
Gen-8 Timeline

URD
User Requirements Document
(Nov 2023)



HPC Options Analysis Report
(Jun 2024)

Independent Peer Review
(Oct 2024)



Conceptual Architecture
(Mar 2025)

Today

Review
Refine
Requirements
RRR

New
Contract
in
place

GC-EARB
Endorsement
(Nov 2023)

link to GC EA Framework

Hosting
RFI
(Aug 2024)
link

Tech Scan
RFI
(Feb 2025)
link

ITQ
Invitation
To
Qualify
(Sep 2025)
link

RFP
Request
For
Proposals

Gen-8
Operational

- **Responsible for securing funding** for the next HPC solution.
- **Responsible for providing forward-looking HPC user requirements**
- **Key player** in SSC's enterprise procurement of ECCC's next HPC

✓ **ECCC**

- **Manages HPC operations, procurement, and contracting** for ECCC since 2011
- **Maintains and operates 24/7** IT infrastructure supporting hydrometeorology services
- **Leads planning and design** of ECCC's next HPC solution (Gen8)

✓ **SSC**

Considerations

Upgrade Cycle

- Rapid 30-month UC limit the number of IC over an HPC lifespan

Enhanced Resiliency

- Near real-time synchronization of critical data
- SC+PPP
- upstream & downstream

Architecture & Workloads

- Uncertainty around future GPU requirements
- Transition from homogeneous → heterogeneous environment
- Right-sizing operations vs. maximizing development capacity
- Benchmarking the entire workflow
- Cloud?

Data & Storage

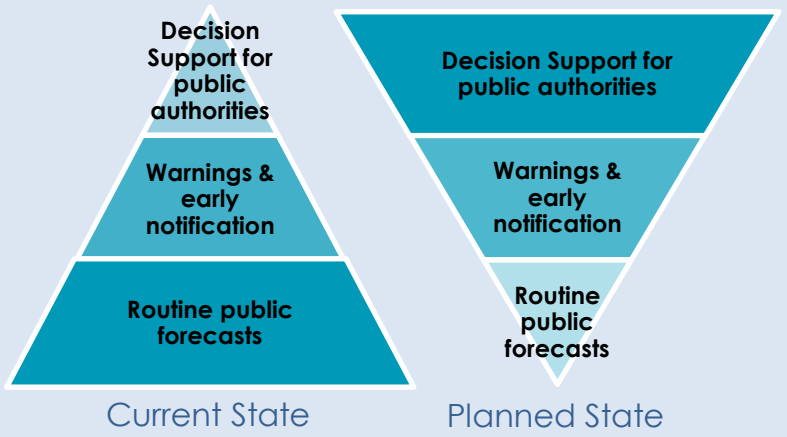
- New data-access patterns
- Storage growth, especially tape, remains a challenge

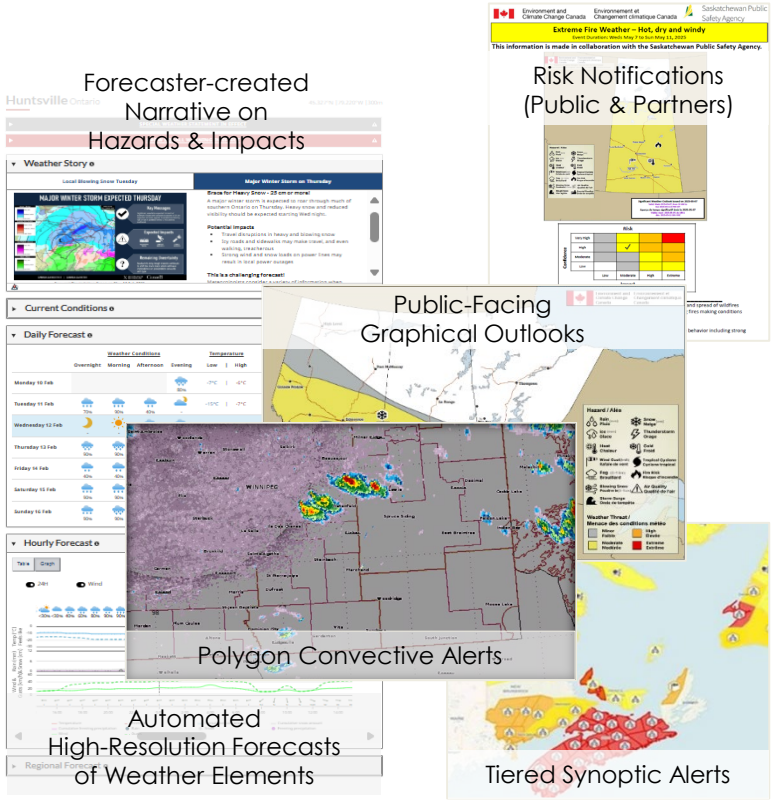
Make it so!

On-going Transformation

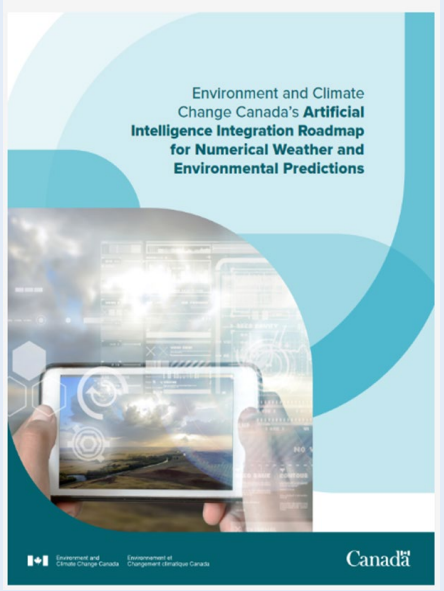
Service delivery is evolving to further leverage NWEP

Move away from "what the weather will be" to "what the weather will do"





Shifting Science Strategy



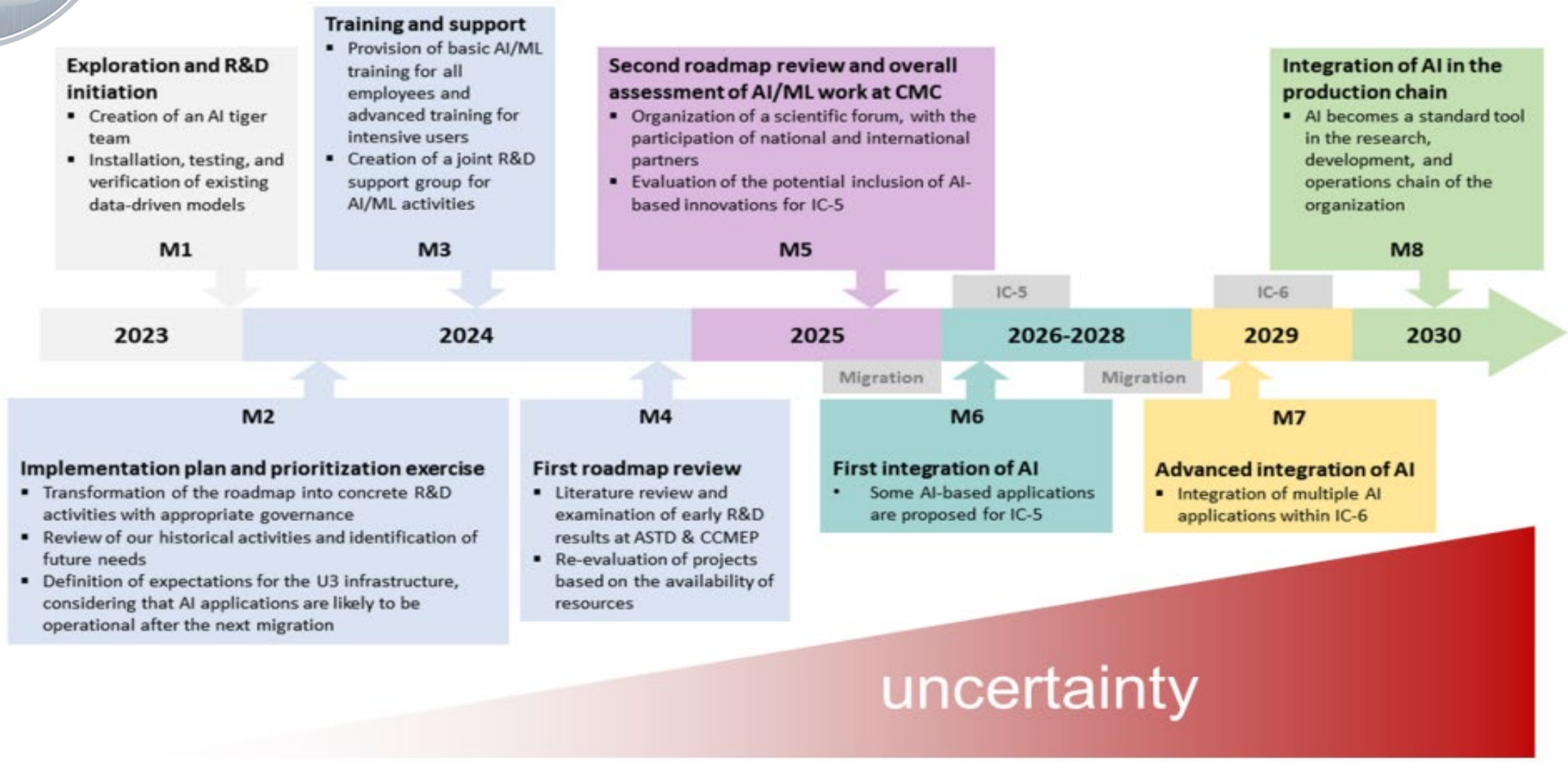
Maximize the use of automation, HPC and AI, while leveraging meteorologists' expertise in high-impact weather, public communication, and decision support for public safety and emergency management partners.

Council of Canadian Academies | CCA | The Future of Hydrological and Meteorological Services in Canada

Thankyou!

Annex

ECCC AI-Roadmap



[Artificial intelligence integration roadmap for numerical weather and environmental predictions - Canada.ca]

Spectral Nudging (1/2)

Physics-based

R&D **Operations**

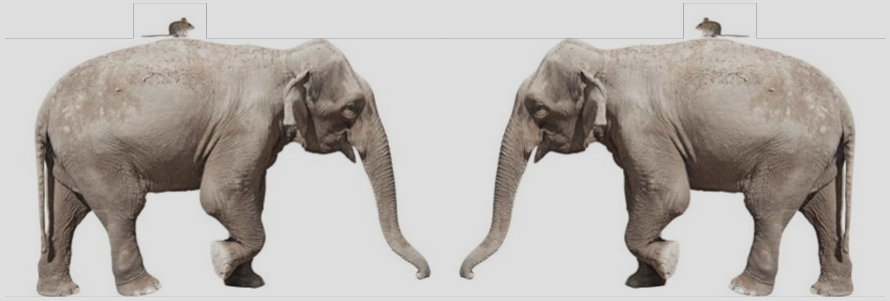
Operation intensive …

AI models

R&D Operations

… ML intensive …

Spectral nudging



R&D **Operations**

Everything Everywhere All at Once

Spectral Nudging Summarized: AI + physics models → better forecasts

- AI guides the big picture; physics keeps the details
- More accurate after day 4 in 10-day forecasts
- Improves extreme event prediction (e.g., cyclones, earlier warnings)

Spectral Nudging (2/2)

GEML (AI Model)

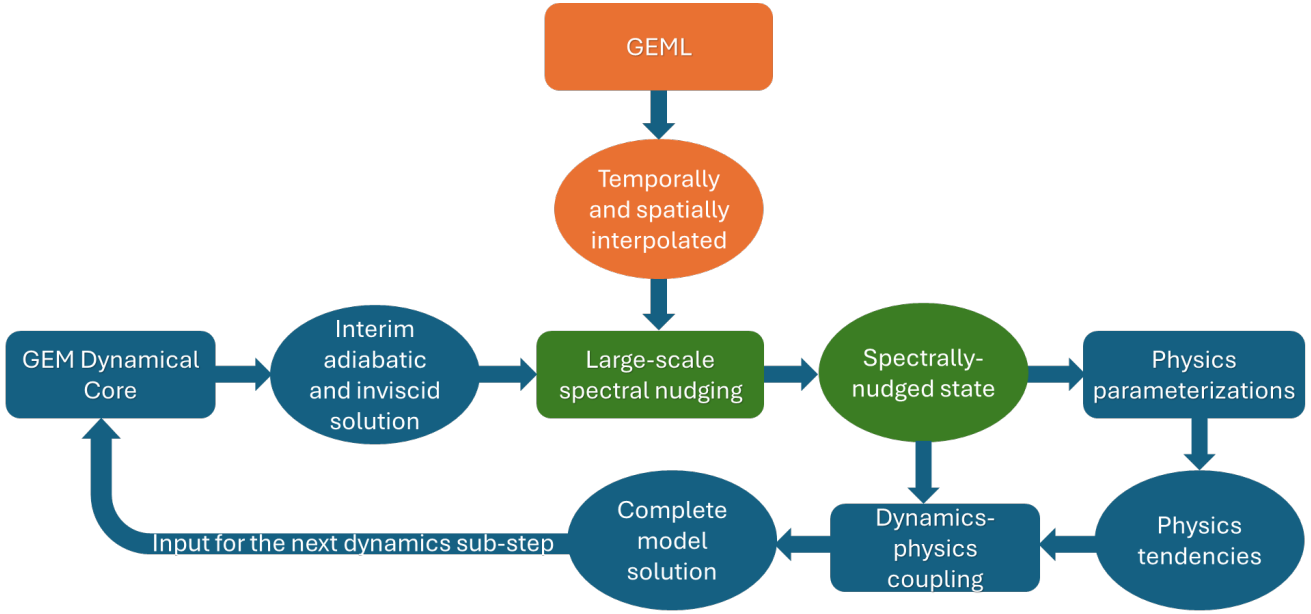
Training data: ERA5 reanalyses (1979-2015) at 0.25° global
+ fine-tuned with ECWMF analyses (2016-2021)
Training variables: 6 atmospheric variables (temperature, U and V components of wind, geopotential, specific humidity vertical wind speed) along with 5 surface variables (2-m temperature, 10-m U and V wind components, mean sea-level pressure, and total precipitation).
Vertical levels for atmospheric variables: 13
Output AI variables: Same as training variables
Horizontal grid resolution: 0.25° global
Output frequency: 6 hours

Spectral nudging (blending technique)

Variables used from the AI model:
U and V wind components, temperature
Vertical extent:
Between 250 hPa and 850 hPa
Nudging scales:
Larger than 2500 km

GDPS (Based on the GEM model)

Output variables:
More than 100 (atmospheric and surface) related to dynamics and physics
Horizontal grid resolution: 0.14° global
Vertical levels for atmospheric variables: 84
Output frequency: 1 hour
Can be as small as the model time step which for GDPS is 450 s



GDPS-SN (Hybrid AI-NWP model)

All attributes of GDPS-SN are identical to GDPS
e.g., number of output variables, horizontal grid resolution, vertical resolution, output frequency, etc.

Abstract

Canada's vast geography and wide range of weather conditions present unique challenges for the continual and timely delivery of weather forecasts, alerts, severe weather warnings, and climate projections. As rapidly changing climate and unprecedented weather events become the new normal, the importance of embracing advances in High-Performance Computing (HPC) technology to enhance weather, environmental, and climate services has never been more critical.

For over six decades, Canada has invested in developing world-class numerical modeling and data assimilation capabilities — a 24/7 mission-critical capacity underpinned by Environment and Climate Change Canada's (ECCC's) robust, dedicated HPC infrastructure. Following a well-established strategy of driving scientific innovation via uninterrupted HPC capacity growth, ECCC continually adapts its services in response to ever-expanding and increasingly sophisticated demands.

Beginning with a retrospective look at the history of HPC at ECCC, then gazing forward towards adoption of emerging technologies, and finally beyond to future paradigm shifts, this presentation highlights the essential and evolving role of HPC in ECCC's integrated weather enterprise.