Wave Models at the Canadian Meteorological Centre (CMC)

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Introduction

- Canada has longest coastline along 3 oceans with various challenges:
  - Common: navigation, traditional and commercial fisheries, tourism, rogue waves, coastal flooding, sheltered and semi-enclosed seas
  - NE Pacific: ferries, Southern Ocean swells
  - NW Atlantic and Gulf of St. Lawrence: ferries, seasonal ice, oil and gas, hurricane and post-tropical storms
  - Arctic: persistent sea ice, remote population, resupply by sea lift NW Passage, oil and gas
- Local considerations under a changing climate:
  - Likelier coastal flooding with sea level rise & less ice (longer fetch)
  - Traditional knowledge could be misleading in changing climate/ice.
  - Extended Arctic shipping season: increased risk of spill, noise impact on wildlife, limited search & rescue resources and long response.

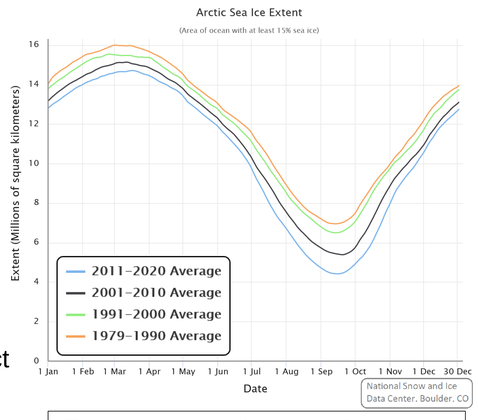

Figure above: Average Arctic sea ice extent per decade (10^6 km²)

Photo left: Fiona (2022) at Port-aux-Basques

- From 2017 to 2021, CMC overhauled its operational wave modelling capability
  - Global model to get missing swell signal, evolving ice (Bernier 2016)
  - Great Lakes models for Toronto PanAm games and testbed for high resolution on demand systems (250 m) tailored to coastal management
  - Regional NW Atlantic model to complete retirement of old models
  - Regional NE Pacific unstructured model for fjords and busy Salish Sea
  - Global Ensemble for long range and sampling of uncertainty

Canadian Meteorological Centre (CMC)

- 1871: Creation of the Meteorological Service of Canada
- 1974: Creation of the Canadian Meteorological Centre, in Dorval (Montréal)
  - Consolidation in a single building of R&D, operation and IT services necessary to operate and upgrade the production of numerical weather prediction (NWP), analysis and post-processing
- In last decade, CMC added or upgraded many environmental numerical analysis and prediction systems:
  - Wave, ice-ocean, storm surge, land surface, hydrology

Acronym	Name	Type	Resolution
GEPS	Global Ensemble Prediction System	A-IO	39 km-1/4º
GDPS	Global Deterministic Prediction System	A-IO	15 km-1/4º
REPS	Regional Ensemble Prediction System	A	10 km
HRDPS	High Resolution Deterministic Prediction System	A	2.5 km
RIOPS	Regional Ice Ocean Prediction System	IO	1/12º
CIOPS	Coastal Ice Ocean Prediction System	IO	1/36º
WCPS	Water Cycle Prediction System	A-IO-R	10 km-1/36º-1 km

Table above: CMC main atmosphere and ocean systems (2023). Type legend:
- A: atmosphere, driven by GEM (Global Environmental Multiscale)
- IO: ice-ocean, driven by NEMO-CICE
- R: river routing, driven by Watroute

CMC Wave Models Timeline

1991
CSOWM NE Pac and NW Atl at 0.4º-1º

1996
WAM NE Pac and NW Atl at 1º

2005
WAM Great Lakes at ~0.05º
WAM NE Pac and NW Atl at 0.5º
WAM Physics upgrade

2012
WAM Arctic at 0.5º
WAM NW Atl at 0.15º with larger domain
WAM Gulf of St. Lawrence at 0.05º

2015
Experimental GDWPS
Great Lakes RDWPS and REWPS pilot for Toronto PanAm games

2018
Operational GDWPS, RDWPS and REWPS.
End of WAM NE Pac, Arctic and Great Lakes

2021
GEWPS
RDWPS NW Atl and NE Pac.
End of WAM NW Atl and Gulf of St. Lawrence

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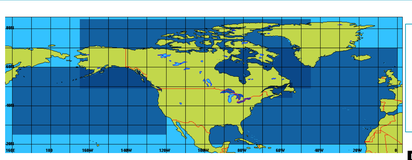
Ocean Data Gathering Program (ODGP)
1st generation model (Cardone et al. 1976)
Key people: M.L. Khandekar and R. Lalbeharry



WAM
3rd generation model (WAMDIG 1988)
Key people: R. Lalbeharry and J. McLean

Figure left: WAM domains

WaveWatch III®
3rd generation model (Tolman 1999)
Key people: N. Bernier, S. Peel, B. Pouliot and P. Timko

Current Wave Forecasts (2023)

- Physical wave prediction systems using WaveWatch III® (WW3DG 2019)
  - Global and regional, deterministic and ensemble
  - Domain aligned with parent atmospheric model
  - Pre 2018: Pre-tested parameterization adjusted by trial and error
  - Since 2018: Parameterization optimized with Cyclops (Gorman 2018)
- Weather Element on Grid (WEonG) post-processing for waves in smaller lakes
  - Using fetch-limited formula interpolated from Breugem and Holthuisjen (2007) nomogram.

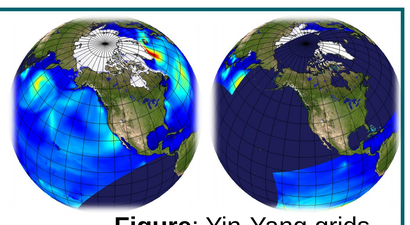
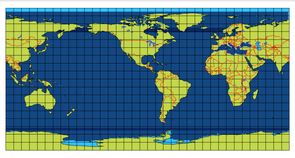
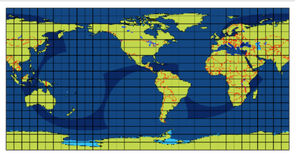
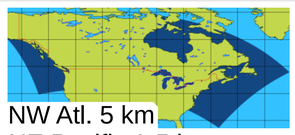


Figure: Yin-Yang grids

System	GDWPS	GEWPS	RDWPS	REWPS
Name	Global Deterministic Wave Prediction System	Global Ensemble Wave Prediction System	Regional Deterministic Wave Prediction System	Regional Ensemble Wave Prediction System
Domain	 Global (80S – 86N) 1/4º	 Global (Yin-Yang) 39 km	 NW Atl. 5 km NE Pacific 1-5 km unstr. Great Lakes 1 km	 Great Lakes 2.5 km
Members		20 + 1 control		20 + 1 control
Duration	Forecast: 240 hours Pseudo: 6 hours	384 hours	Forecast: 48 hours Pseudo: 6 hours	72 hours
Wind	Forecast: GDPS F. Pseudo: GDPS A.	GEPS F.	Forecast: HRDPS F. Pseudo: HRDPS A.	REPS F.
Ice	Forecast: GDPS F. Pseudo: GDPS A.	GEPS F.	Lakes F.: WCPS F. Ocean F.: RIOPS F. Pseudo: HRDPS A.	WCPS F.

- Spectral resolution: 36 direction bins; 36 frequency bins for the ocean and 40 for the Great Lakes
- Input and dissipation is ST4 – Great Lakes dissipation is T500 (Filipot 2010)

Wave Model Verification

- New user-friendly suite to streamline verification
  - Scores deterministic models, ensembles and super-ensemble
  - Scores using buoys or altimeters

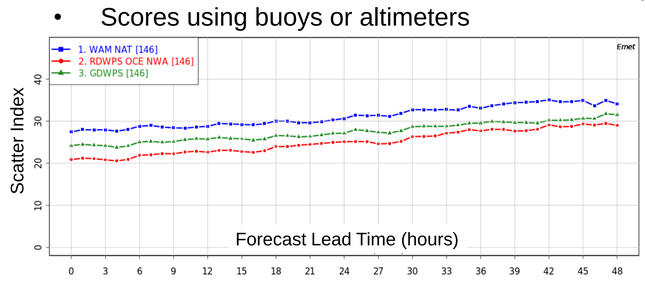
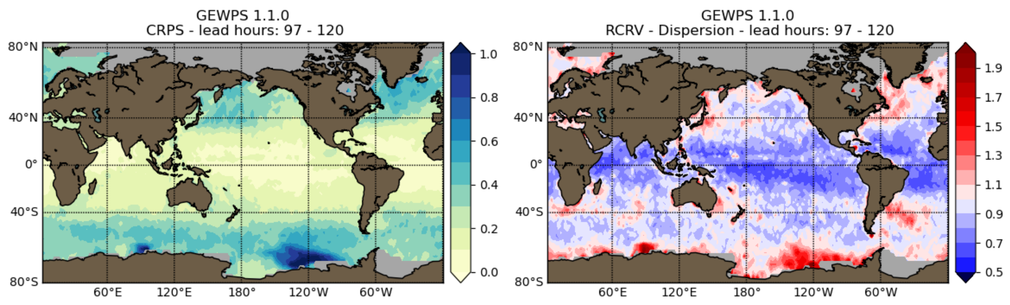


Figure left
- Scatter Index of H_{sig}
- Evaluation period: 2021-07-07 to 2021-09-18
- At buoys off North American East Coast
- WAM, RDWPS, GDWPS



Figures above (from CMC-GEWPS-1.1.0, 2023)
- **Left**: Continuous Rank Probability Score (CRPS) of H_{sig} for GEWPS
- **Right**: Reduced Centered Random Variable (RCRV) – Dispersion of H_{sig} for GEWPS
- 8 altimeters: SARAL, Cryosat-2, HaiYang-2B, Jason-3, Sentinel-{3A,3B,6A}, CFO
- Evaluation period: 2021-12-01 to 2019-08-31

MSC Open data

- Government of Canada has open data policy
- MSC Open Data portal: https://eccc-msc.github.io/open-data/
  - Documentation of models
  - Datamart: raw data retrieval and push notification with AMQP
  - GeoMet: data access through API
  - Animet: create custom animations using GeoMet

Future Wave Models

- Coastal applications: e.g., finer resolution grids and wave runup
- Coupling with ice, ocean, storm surge and atmospheric models
- New services: risk to navigation (e.g. rogue waves)
- Data assimilation
- Reanalysis/hindcast
- AI/Machine Learning

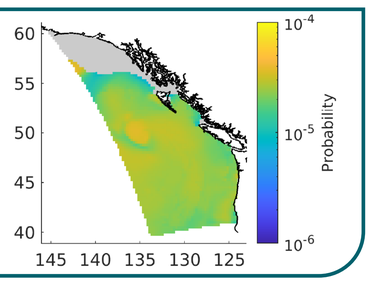


Figure right: probability of rogue wave ($H > 2.2\ H_{sig}$) on 2021-10-22. Grey where $H_{sig} < 3$m. From Cicon et al. in press

Summary

- From 2017 to 2021 the CMC wave systems went from a collection of aging deterministic regional models to a coherent set of global and regional models in deterministic and ensemble versions.
- Resulting forecast quality improvement and expanded capability allow us to provide earlier and more accurate warnings of hazardous situations at sea and near shore.
- CMC contributes GEWPS to wave component of North American Ensemble Forecast System (NAEFS). Combined CMC-NCEP-FNMOC wave ensemble is generally best.
- Wide array of data available through MSC Open Data.
- Increased complexity and leveraging rapidly evolving technologies are under investigation to further develop and improve services.

Acknowledgements & References

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