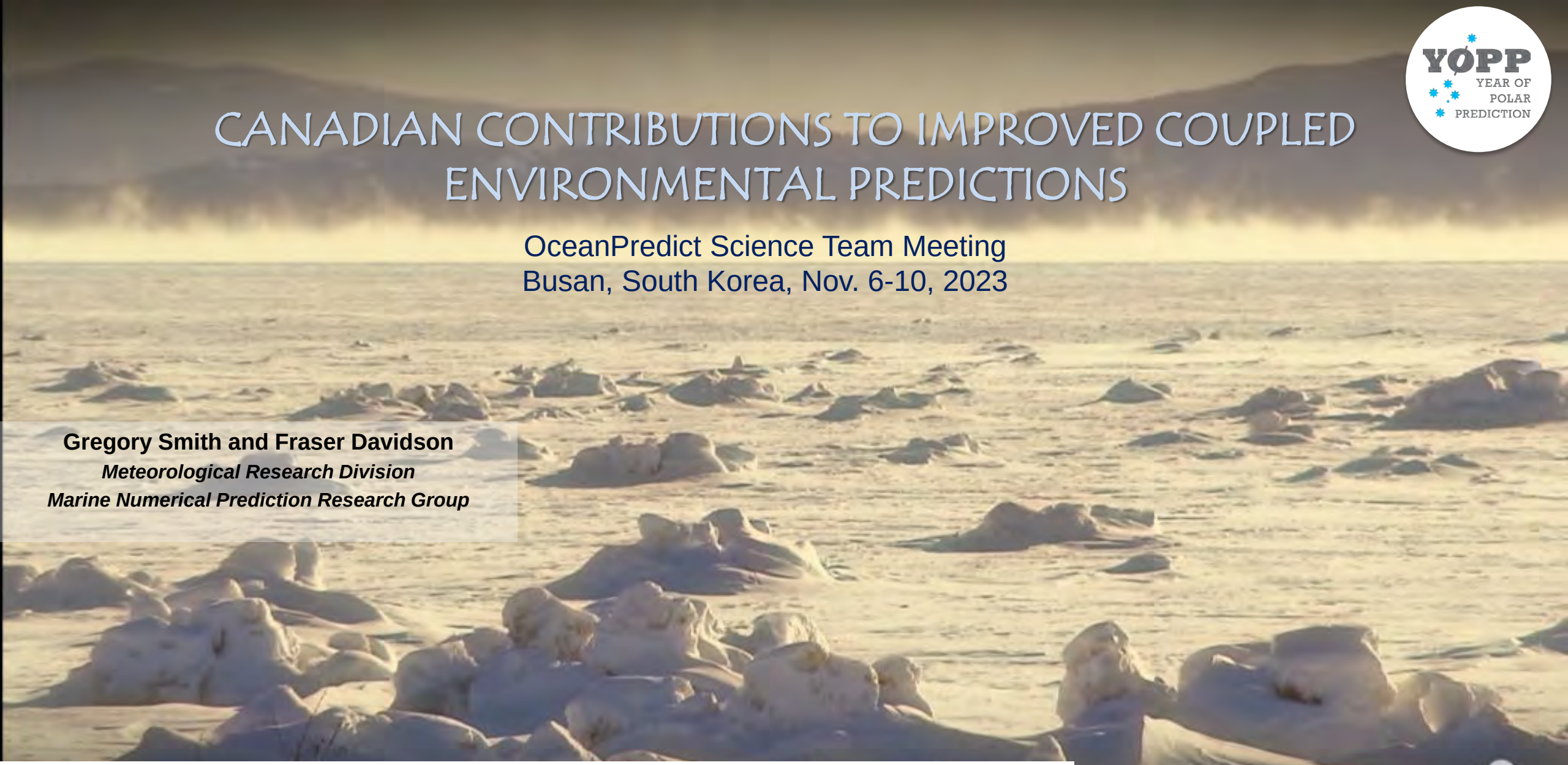
CANADIAN CONTRIBUTIONS TO IMPROVED COUPLED ENVIRONMENTAL PREDICTIONS

OceanPredict Science Team Meeting
Busan, South Korea, Nov. 6-10, 2023

Gregory Smith and Fraser Davidson
Meteorological Research Division
Marine Numerical Prediction Research Group



Environmental Prediction Users and Applications

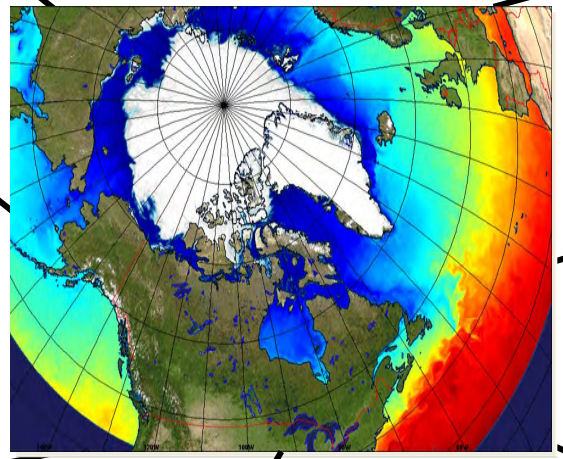
DFO Applications

- Fisheries and Aquaculture management
- Ocean climate monitoring

METAREAS 17&18

DND Applications

- Situational awareness
- Anti-submarine warfare
- Operational support



Canadian Ice Service Operations

- High-pressure ridges
- Automated analyses
- Iceberg drift

Canadian Coast Guard

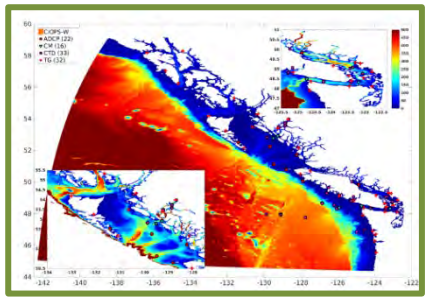
- Search and Rescue
- Environmental Emergency Response

Downstream systems
CIOPS, e-Nav, Waves, Storm surge
NWP (coupling)

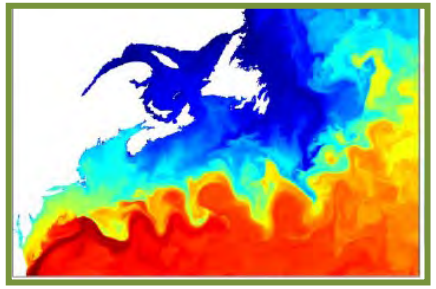
CONCEPTS

National Environmental Emergency response Centre (NEEC)

- Oil spill



CIOPS-West

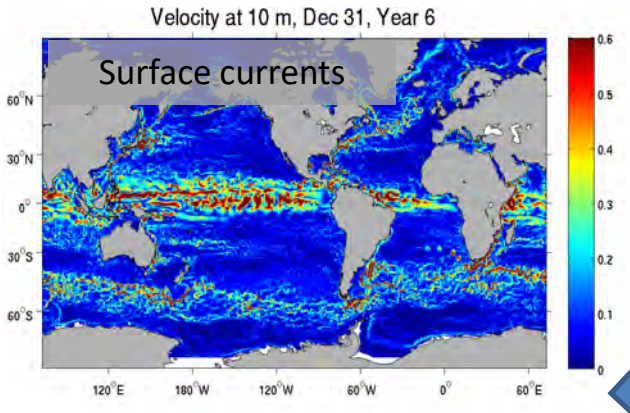


CIOPS-East

CONCEPTS - Science.gc.ca

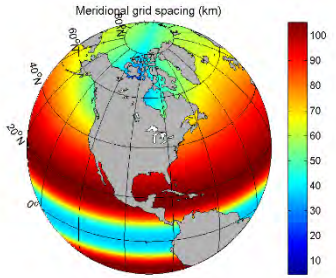
CONCEPTS ICE-OCEAN FORECASTING WITH NEMO + CICE

Operational
Experimental

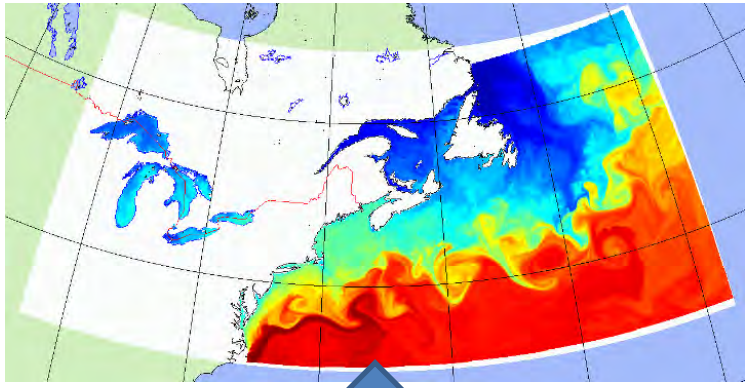


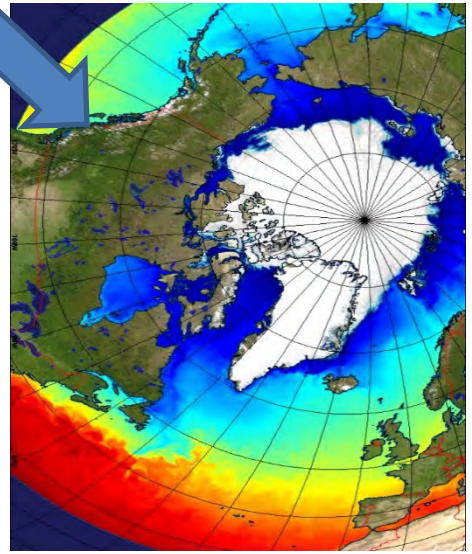
GIOPS: 1/4° Global, Coupled to GDPS (10day) and GEPS (16day and monthly)

Seasonal 1°

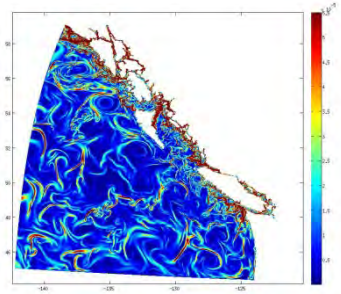


Water Cycle Prediction System
Great Lakes 1km+East Coast (1/36 °)

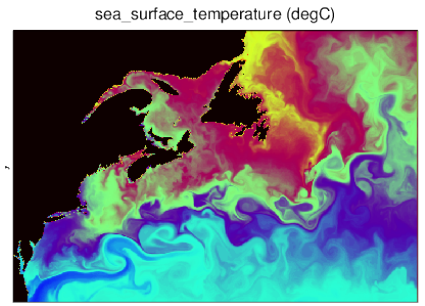




RIOPS: Regional 1/12°
Coupled for YOPP (3km atm)



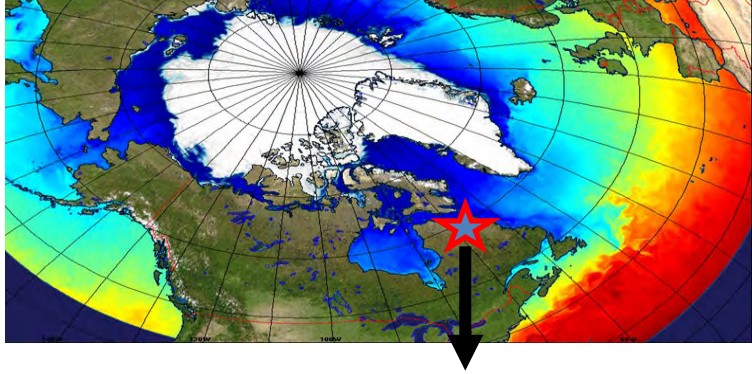
CIOPS-W: Northeast Pacific 1/36° + 500m Salish Seas



CIOPS-E: Coastal East Coast 1/36°

CONCEPTS

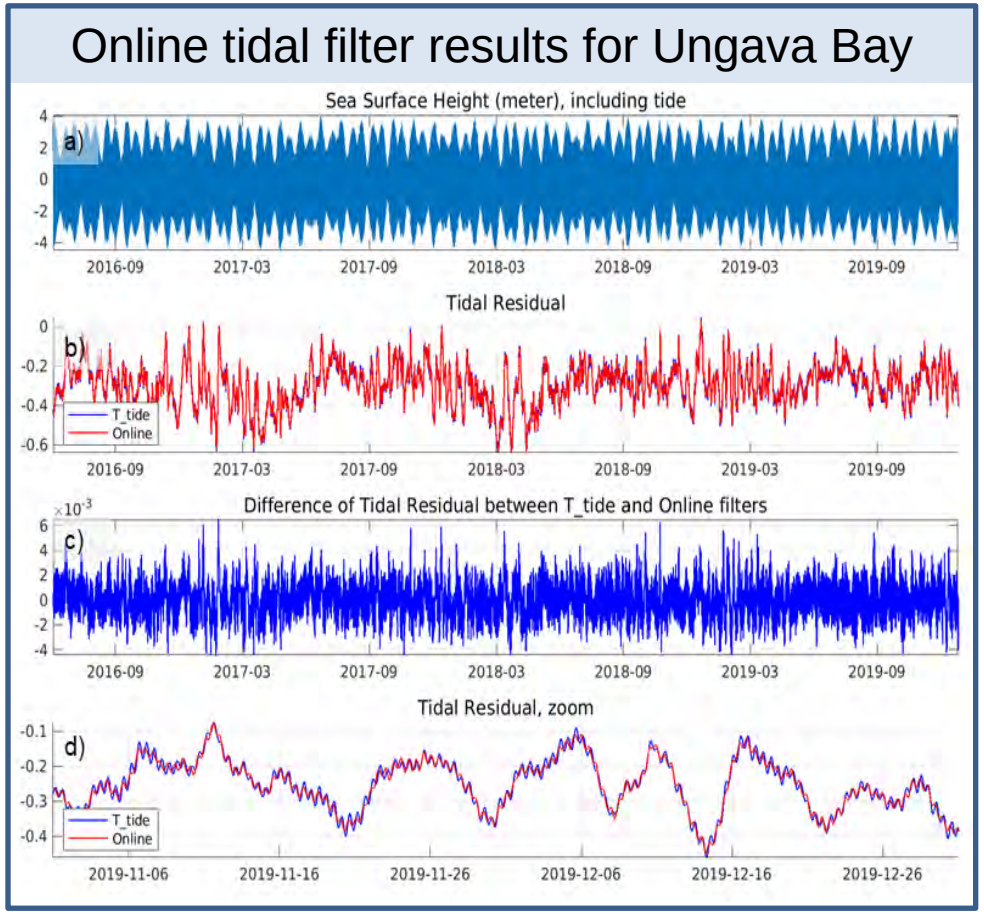
ECCC OCEAN DATA ASSIMILATION



ECCC has two operational ocean assimilation systems:

- GIOPS (1/4°)
  - Coupled A-I-O (10d; 21 member 16d and 32d fcsts)
- RIOPS (1/12°)
  - 84hr Ice-ocean forecasts, also used for CAPS
- Data Assimilation
  - Multivariate SEEK filter (SAM2)
  - Background error from multi-year hindcasts
  - Assimilates SLA, SST, in situ T/S profiles
  - Blended with 3DVar ice analysis (CIS charts, SSMI, SSMI/S, AVHRR, AMSR2)
  - 3DVar T/S bias correction
  - IAU: GIOPS (1d), RIOPS (7d)
- Key development for YOPP
  - RIOPS includes tides and atm pressure
    - online sliding window tidal filter allows non-stationary tides (e.g. due to sea ice)
    - Permits the improved use of satellite altimetry to constrain surface currents

Smith et al. (QJRMS2015, MWR2018, GMD2021)



[G,R]IOPS = [Global, Regional] Ice Ocean Prediction System

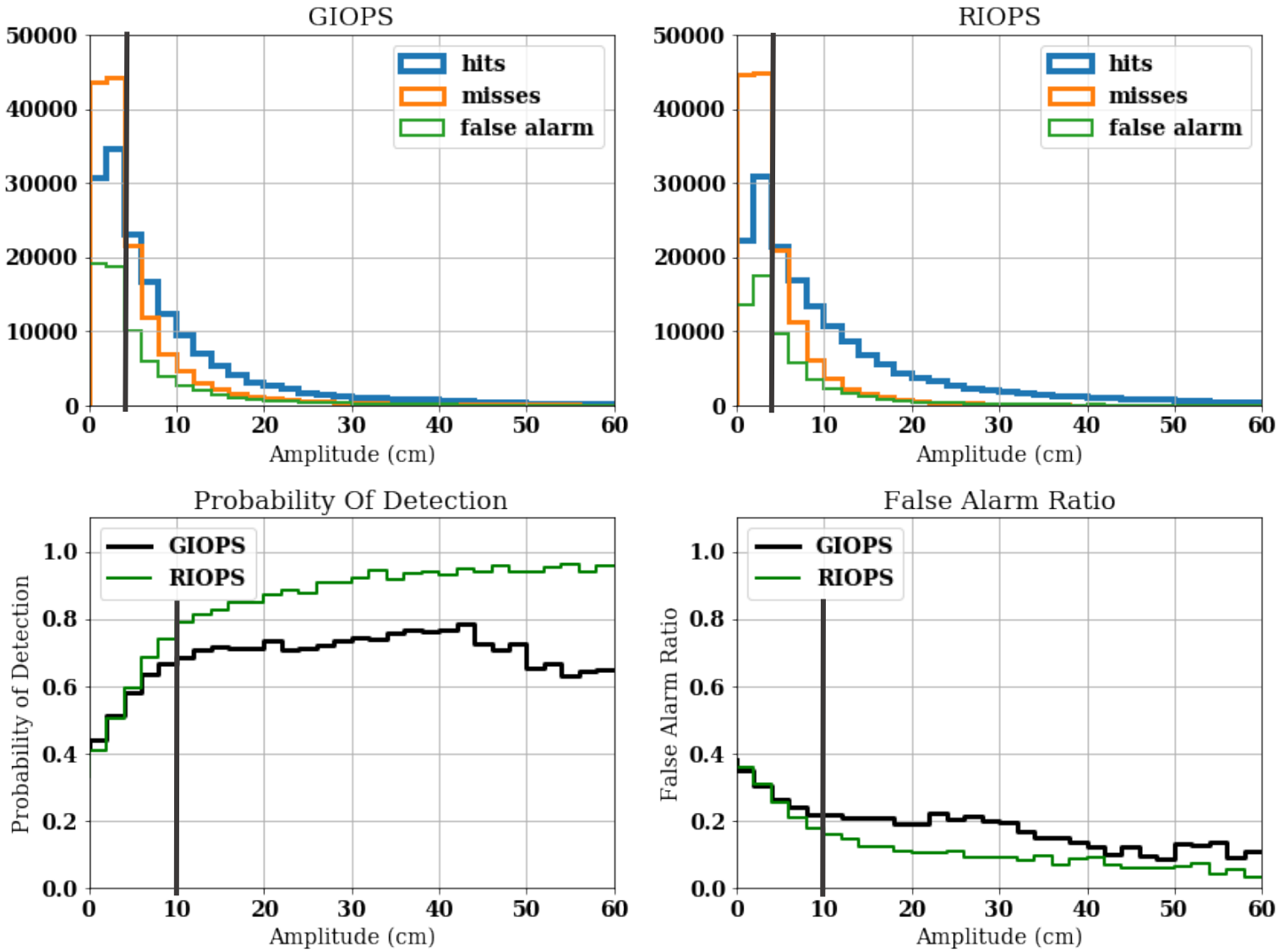
$$POD = \frac{Hits}{Hits + Misses}$$

$$FAR = \frac{False\ Alarms}{Hits + False\ Alarms}$$

Can we demonstrate added-value of regional systems in terms of eddy features?

- Apply py-eddy-tracker, a closed-contour approach (Mason et al., 2014)
- Use AVISO L4 SSH as truth
- Once eddies have been identified, match them between products using a cost function based on amplitude, radius and distance
- Use dichotomous verification metrics
- For eddies of amplitude greater than 10 cm:
  - RIOPS has POD values 10-30% higher with FAR values 5-10% lower than GIOPS
- Accuracy of "truth" a limiting factor
  - Potential for SWOT?

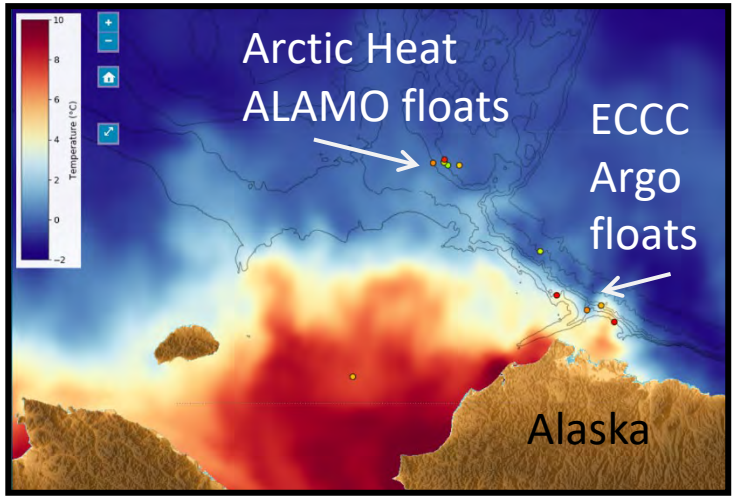
Smith & Fortin (Oc. Mod. 2022)

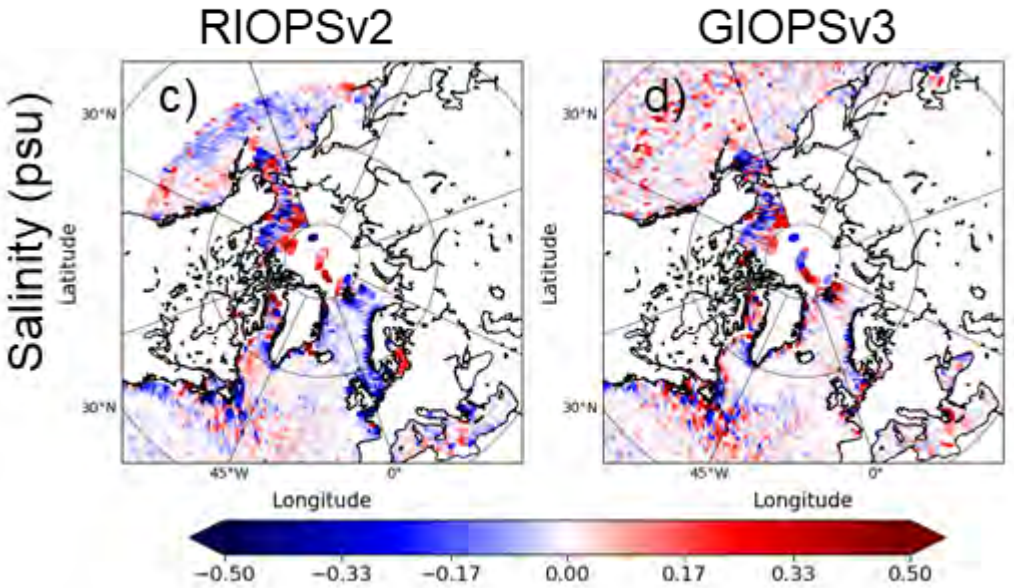


***User need**: Improved water mass properties*

Arctic Observing System Experiments (OSE)

- Despite addition of improved physics in regional ocean model, significant errors remain in water mass properties in the Beaufort Sea
- These errors likely related to various sources
  - Model error, uncertainty in river runoff, atmospheric forcing, sea ice cover
- Take advantage of increase of in situ observations deployed for Year of Polar Prediction (2017-19), e.g.:
  - Argo – ECCC
  - ALAMO floats – ArcticHeat project (NOAA)
- Expected outcomes:
  - Improved water mass properties should provide more accurate sea ice formation and melt dates, and surface drift properties





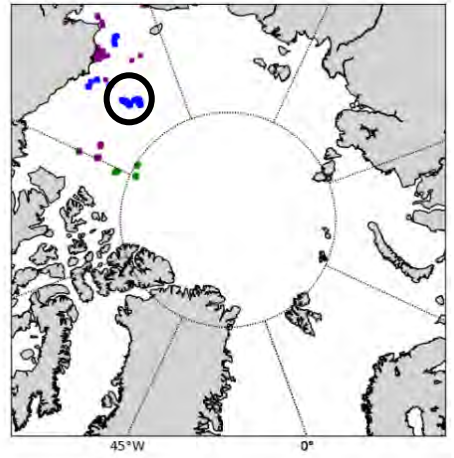
Observation-minus-model mean differences for salinity over upper 500m for the period 2016 to 2019.

How can we make the best use of Arctic ocean profile observations given their sparseness and seasonality?

Smith et al. (Frontiers, 2019)
Smith et al. (GMD, 2021)

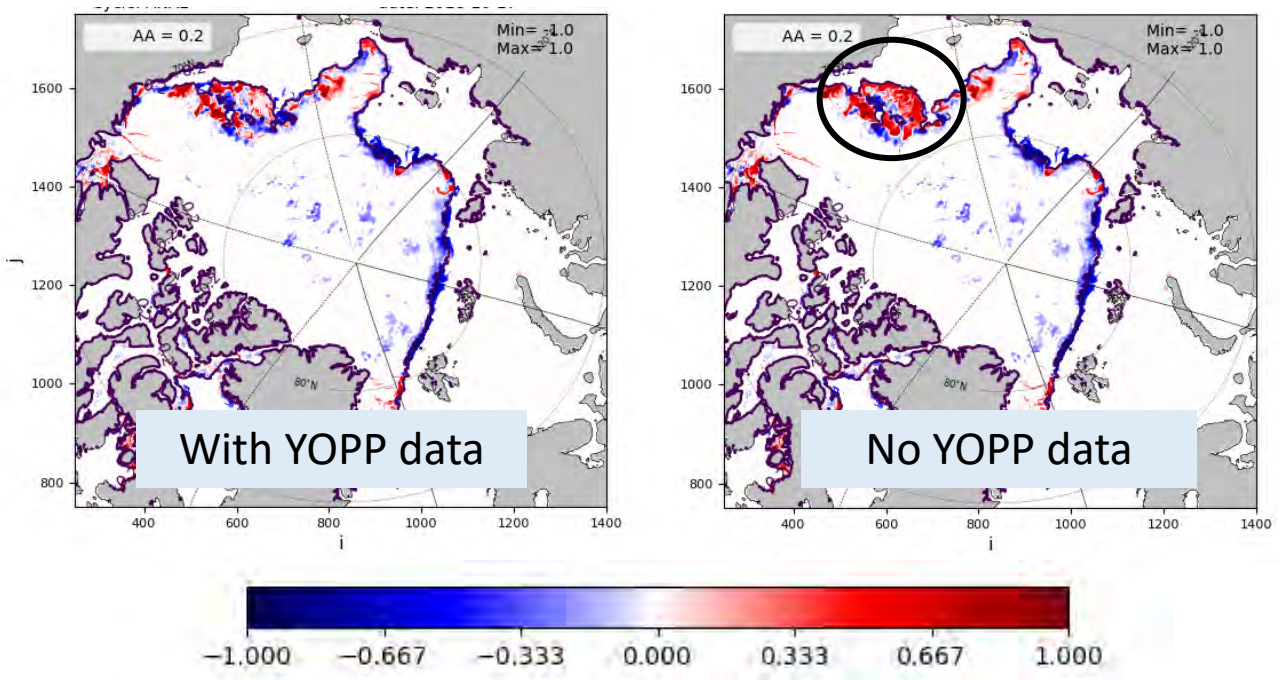
***User need**: More accurate representation of rapid freeze-up events*

Arctic OSE results



- Data withholding experiments performed using YOPP in situ observations over summer 2018 using regional ocean analysis system (RIOPS).
- With YOPP data, sea ice increments are smaller for a rapid freeze up event suggesting 7d trial fields provided a more accurate estimate of conditions.
- Salinity increments using YOPP data freshen and stratify mixed layer allowing faster surface cooling leading to **better representation of rapid ice formation** event in Beaufort/Chukchi Sea

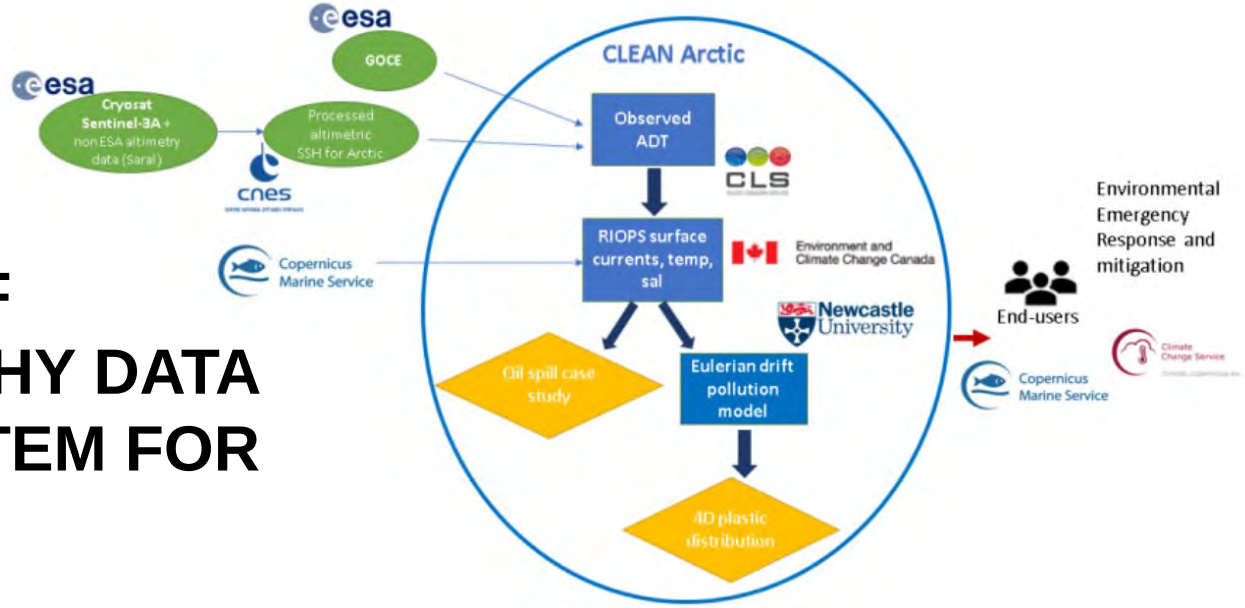
Sea ice concentration increment for 2018-10-17



Environment and Climate Change Canada | Environnement et Changement climatique Canada

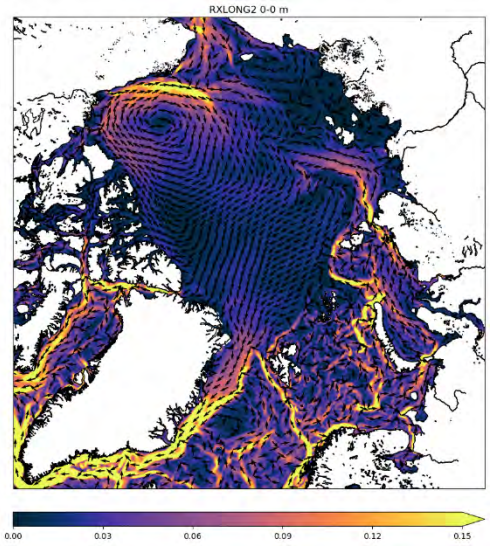
esa | CLS | Newcastle University | CONCEPTS

CLEAN ARCTIC: ASSIMILATION OF ABSOLUTE DYNAMIC TOPOGRAPHY DATA IN AN OCEAN ASSIMILATION SYSTEM FOR THE ARCTIC

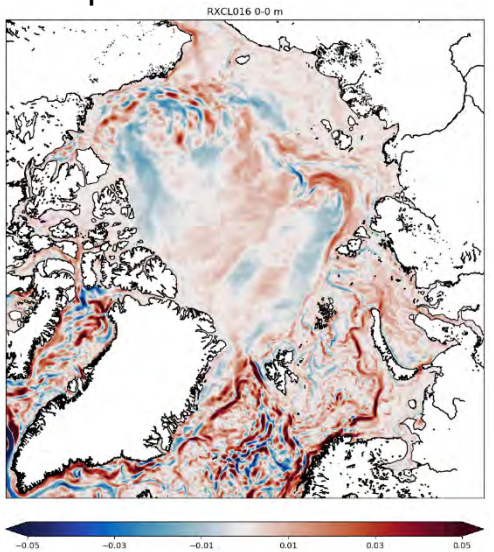


- Developed new Absolute Dynamic Topography (ADT) dataset over the Arctic.
  - Avoids the need for Mean Dynamic Topography (as for SLA assimilation)
- Assimilated ADT in Regional Ice-Ocean Prediction System
  - Required various adaptations for spatial scales and under-ice assimilation
- Significant impact on basin-scale sea level and transports through key Arctic gateways

Mean sfc currents



Impact of ADT assim

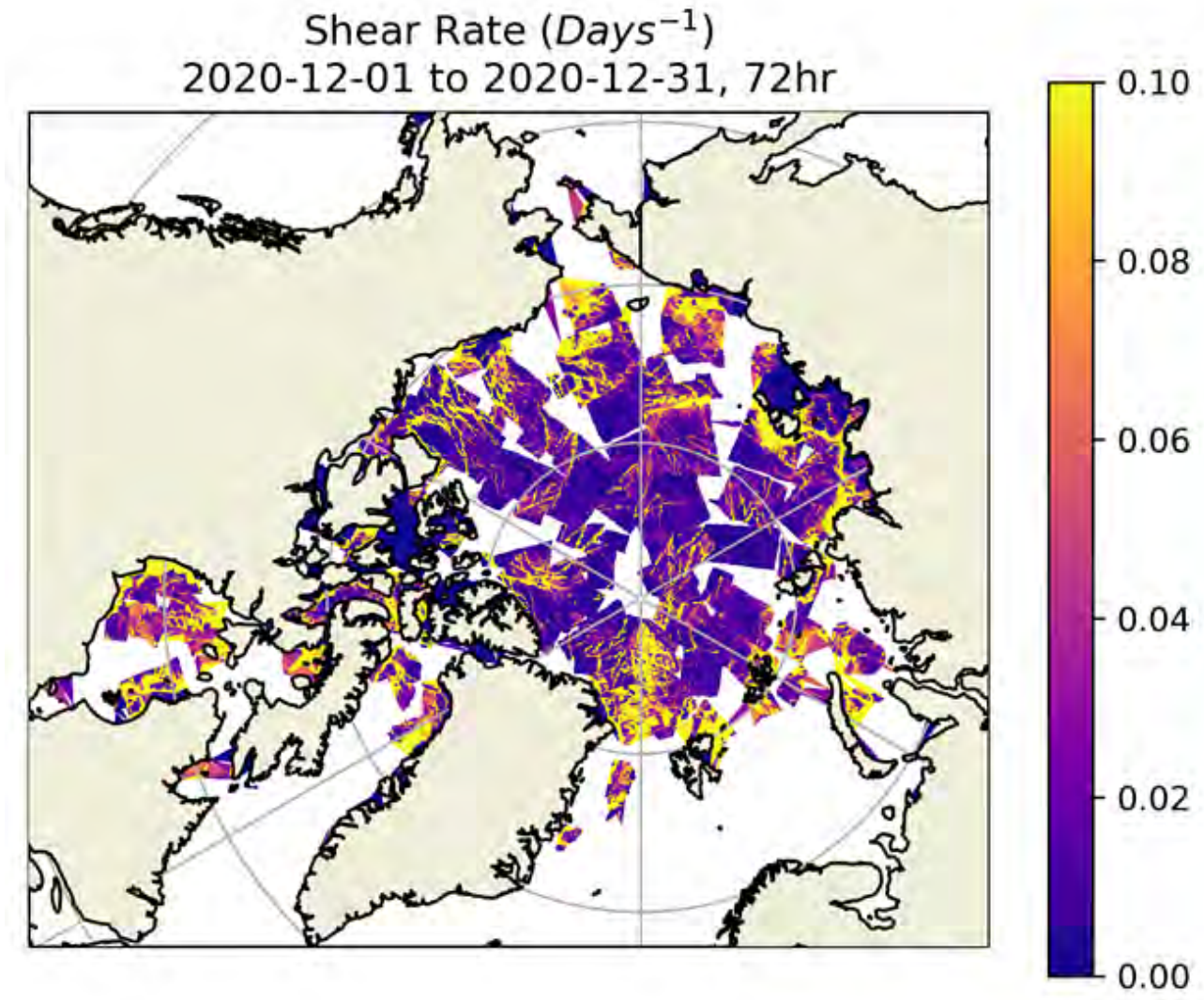


G. Smith[1], C. Hébert-Pinard[1], A.A. Gauthier[2], A. Peterson[1], F. Roy[1], P. Veillard[3], Y. Faugère[3], S. Mulet[3], Miguel Morales Maqueda[4]

[1] Meteorological Research Division, ECCC ; [2] Meteorological Service of Canada, ECCC; [3] Collecte Localisation Spatiale (CLS), France; [4] Univeristy of Newcastle, UK

New sea ice deformation dataset based on RCM and Sentinel-1

- ECCC ice tracking system (Howell et al. 2022) uses RCM and Sentinel-1 data to monitor ice drift in the Arctic.
- We added the capability to calculate deformations: shear, divergence and vorticity.
- The period covered is 2017-2022 with a spatial resolution of ~10 km and temporal resolutions of 24 and 72 hr.
- Can be used for evaluation of sea ice model deformation statistics as well as to improve our understand of ice mechanics
- Considering extension to real-time production



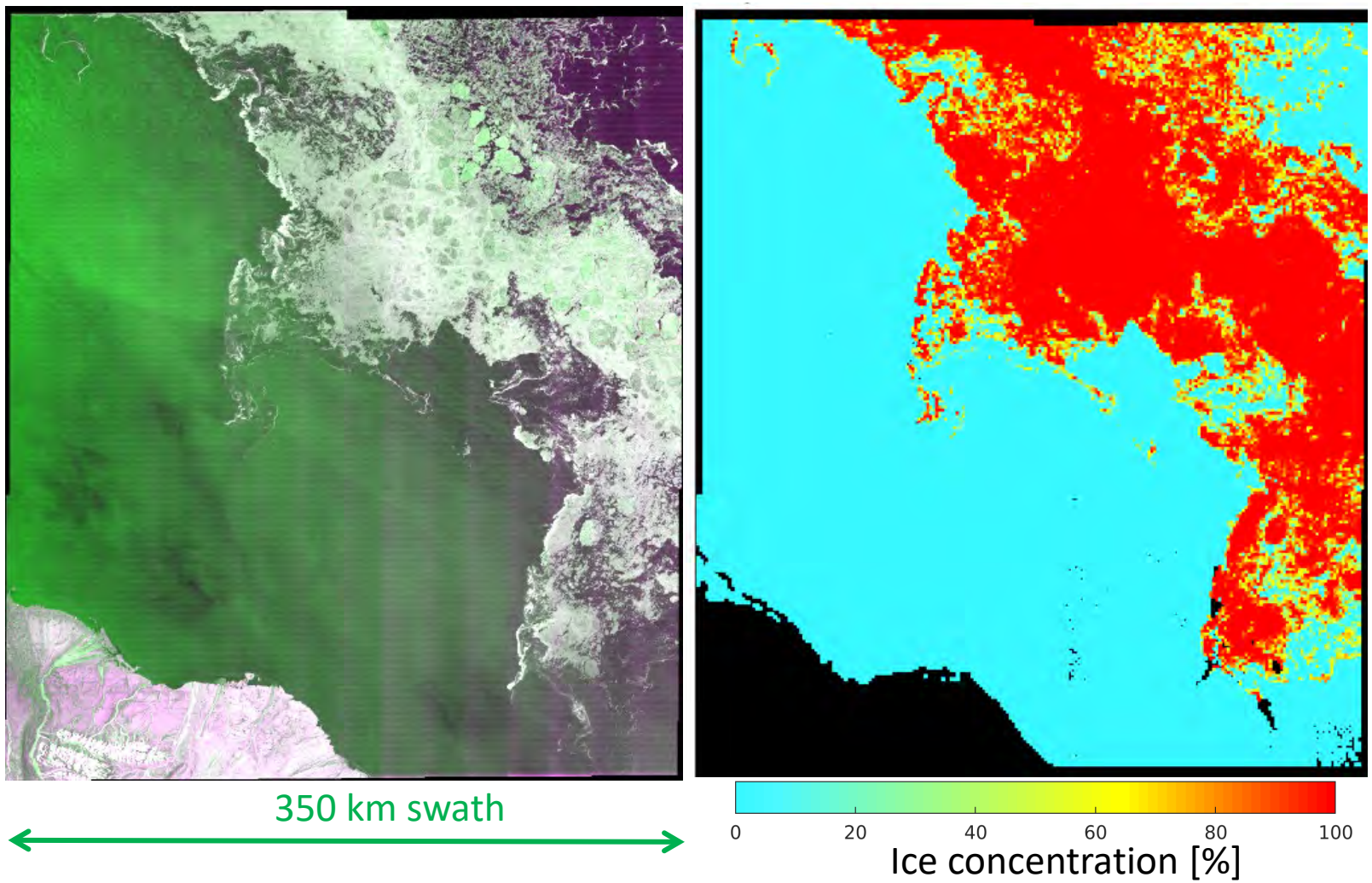
***User need**: High-resolution sea ice analyses for ice services*

RCM Data Assimilation in ECCC RIOPS

Synthetic Aperture Radar (SAR) Ice concentration retrieval approach

- Retrieval approach was developed based on 15,000+ RADARSAT-2 images and CIS ice charts. [Komarov and Buehner, TGRS, 2017], [Komarov and Buehner, GRSL, 2018]
- Probability of ice presence at different scales changing from 5 x 5 pixels to 41 x 41 pixels (1 pixel = 40 m) is calculated as function of three predictor parameters: (1) difference between SAR and NWP wind speed, (2) spatial correlation between HH and HV channels, (3) standard deviation of SAR wind speed [Komarov and Buehner, TGRS, 2021].
- The approach was adapted from RADARSAT-2 to RCM by introducing the new ocean surface wind speed retrieval models developed specifically for RCM SC50M and SCLN beam modes [Komarov et al, TGRS, 2022].

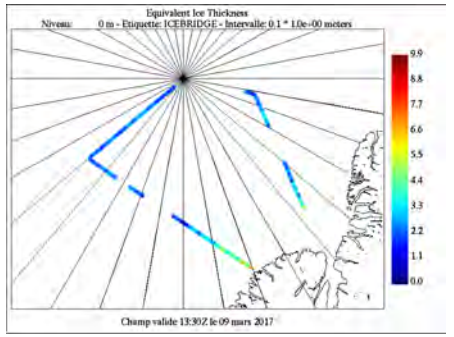
Example: September 15, 2020, Southern Beaufort Sea



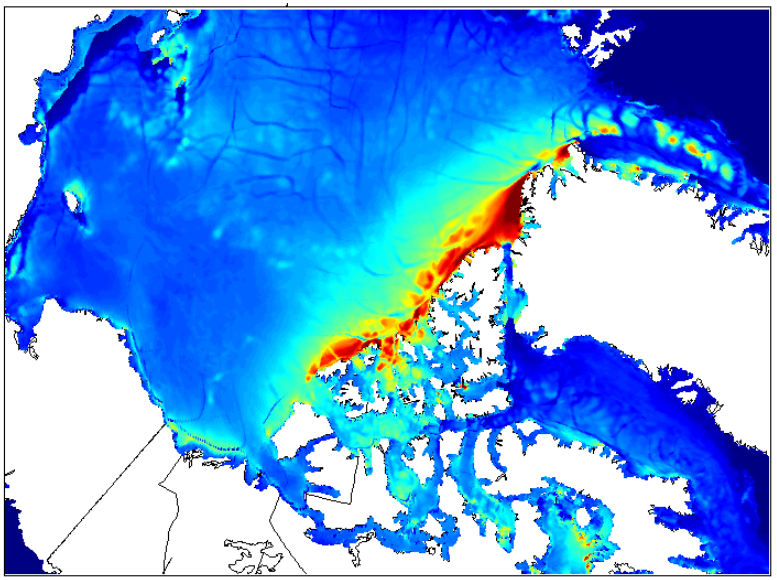
***User need**: Improved long-range sea ice forecasts*

Development of Ice thickness analyses

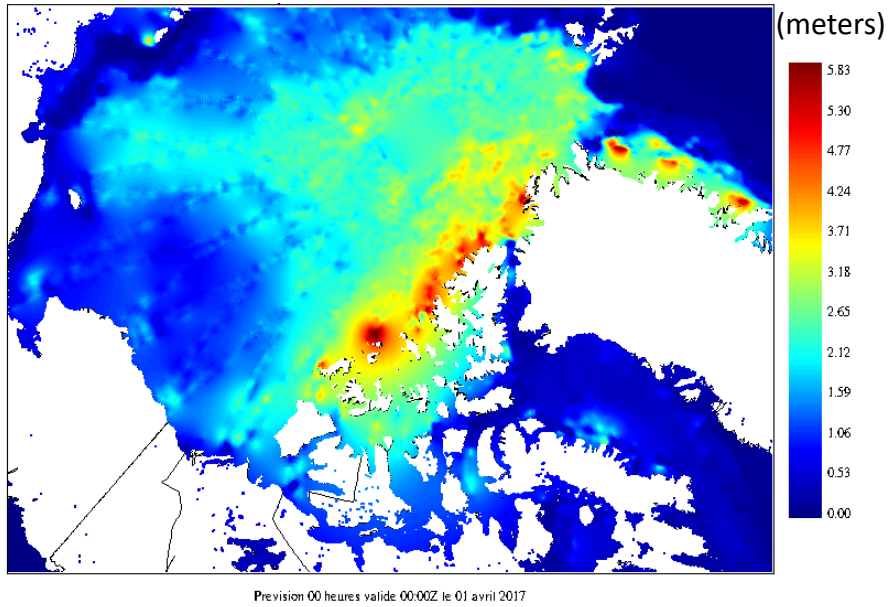
- Assimilation of SMOS and CryoSat-2 ice thickness retrievals on a 5-km grid with 3DVar every 6 hours, with previous analysis as background
- Helps to constrain large areas of overly-thin ice
- Expected to improve week 2 and 3 sea ice forecast skill in coupled GEPS



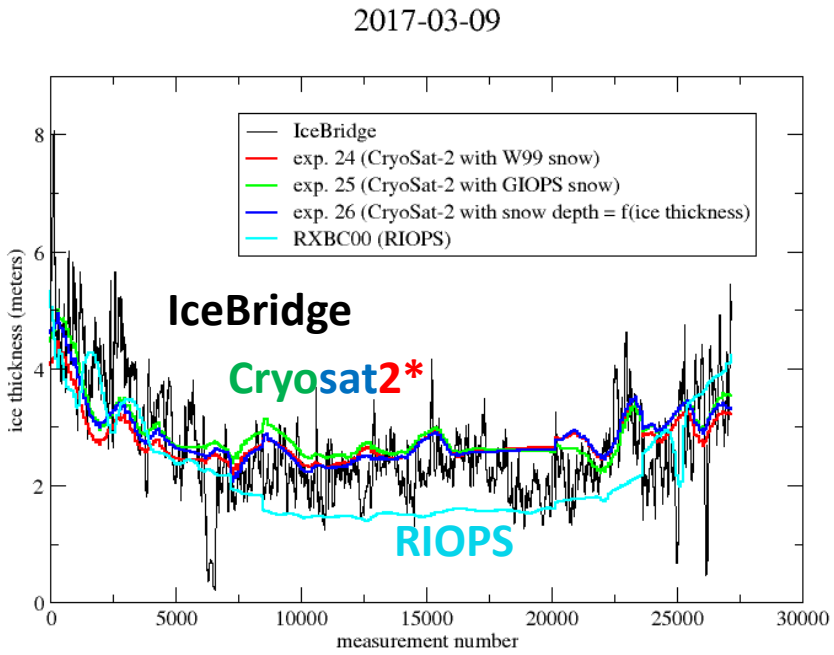
RIOPS



3DVar analysis



Comparison with NASA IceBridge



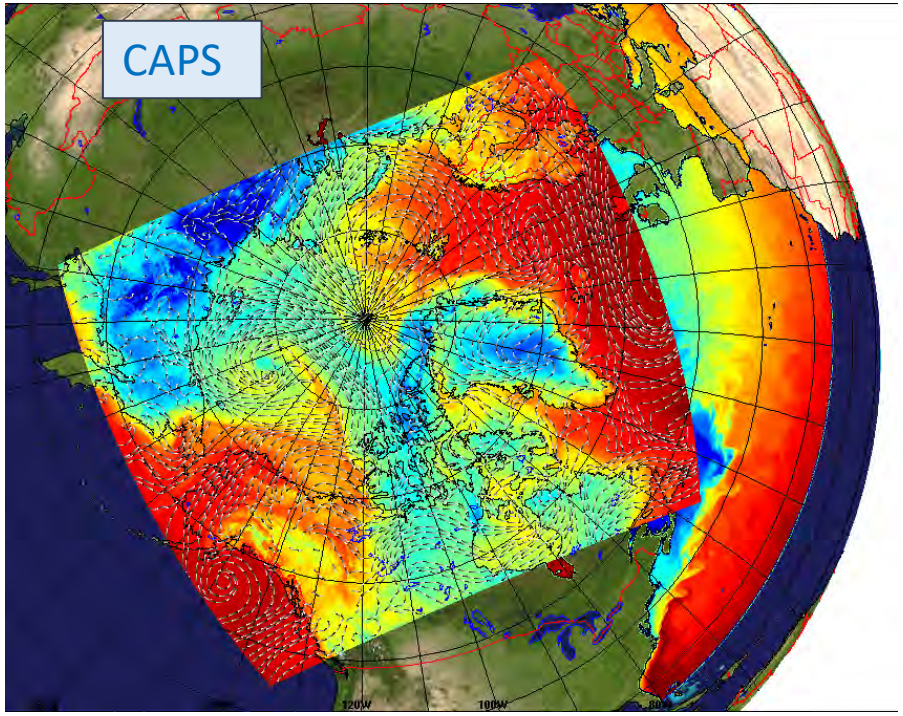
** 3 experiments showing sensitivity to snow*

Canadian Arctic Prediction System (CAPS)

High-resolution coupled atmosphere-ice-ocean prediction system

- In support of :
  - Weather prediction for northern Canada
  - EC METAREAs Services
  - Marine emergency response
  - Study impact of fine-scale interactions
  - YOPP Community support
- Coupled atmosphere-ice-ocean model
  - Ice-ocean: NEMO-CICE (3-8 km)
    - Tides, landfast ice
  - Atmosphere: GEM (3 km)
    - Predicted particle properties microphysics
  - 48 h forecasts (2/day)
  - Uncoupled since Jan. 24, 2018
  - Coupled since Jun. 28, 2018
  - Decommissioned in Feb. 2022
  - To be re-instated in 2024!

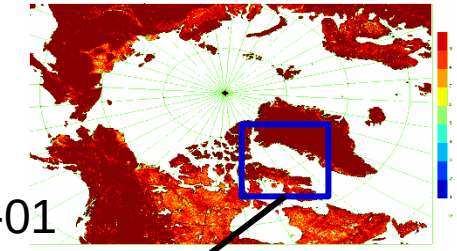
Strong desire from National Defence for knowing acoustic environment in Artic



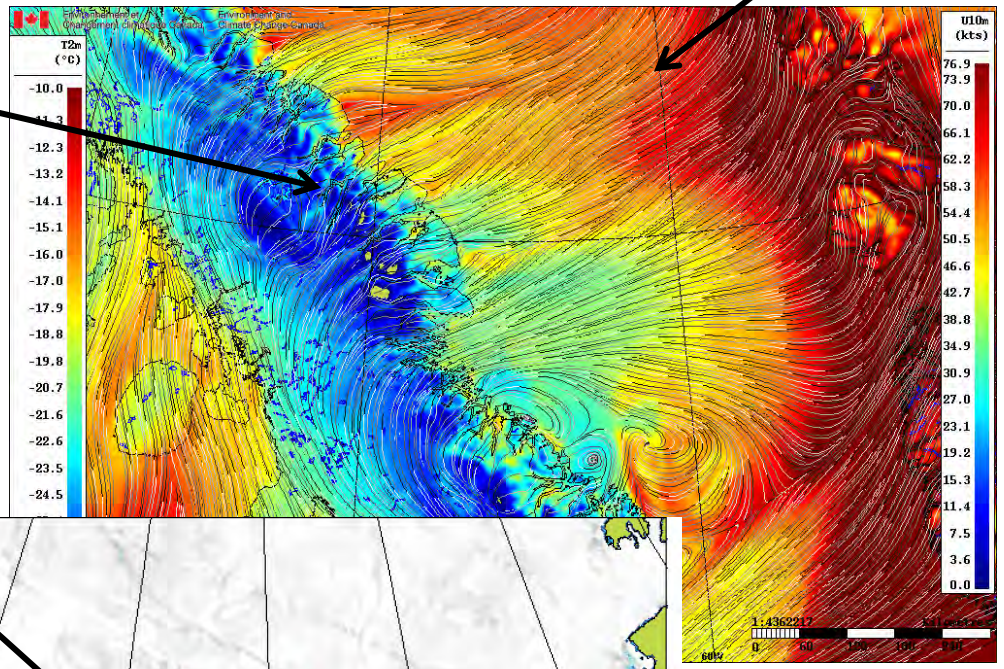
Casati et al. (Atm-Ocean, 2023)

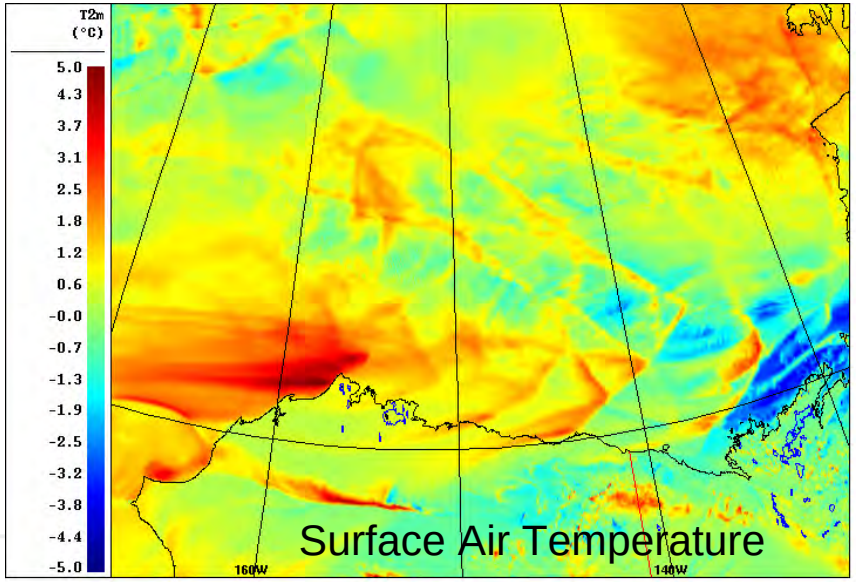
Impact of small-scale coupled atmosphere-ice-ocean interactions in the Canadian Arctic Prediction System (CAPS)

- Orographic features better represented
  - Flow through fjords
  - Potential impact on local ice drift
- Imprint of small-scale features on surface fluxes
  - Boundary layer interactions in marginal ice zone
  - Coastal polynyas and leads in sea ice

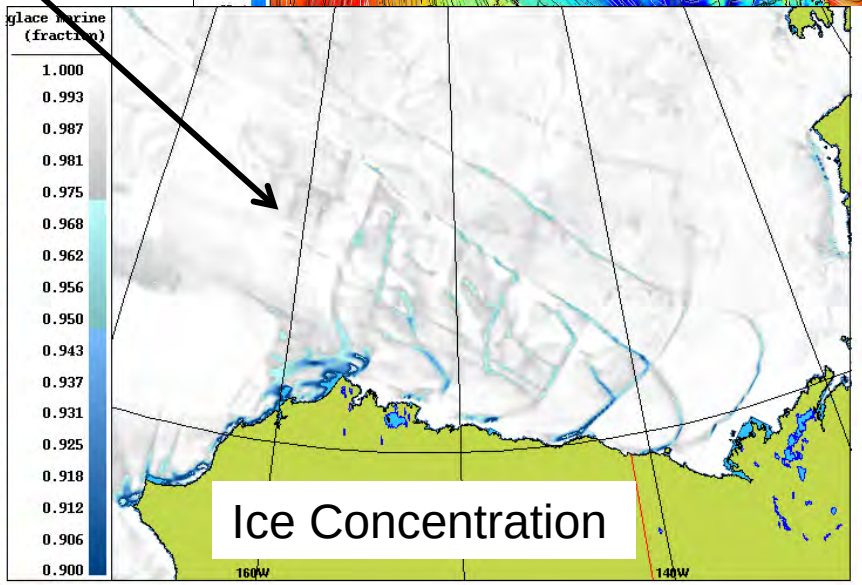


Forecast for 2017-01-01





Surface Air Temperature



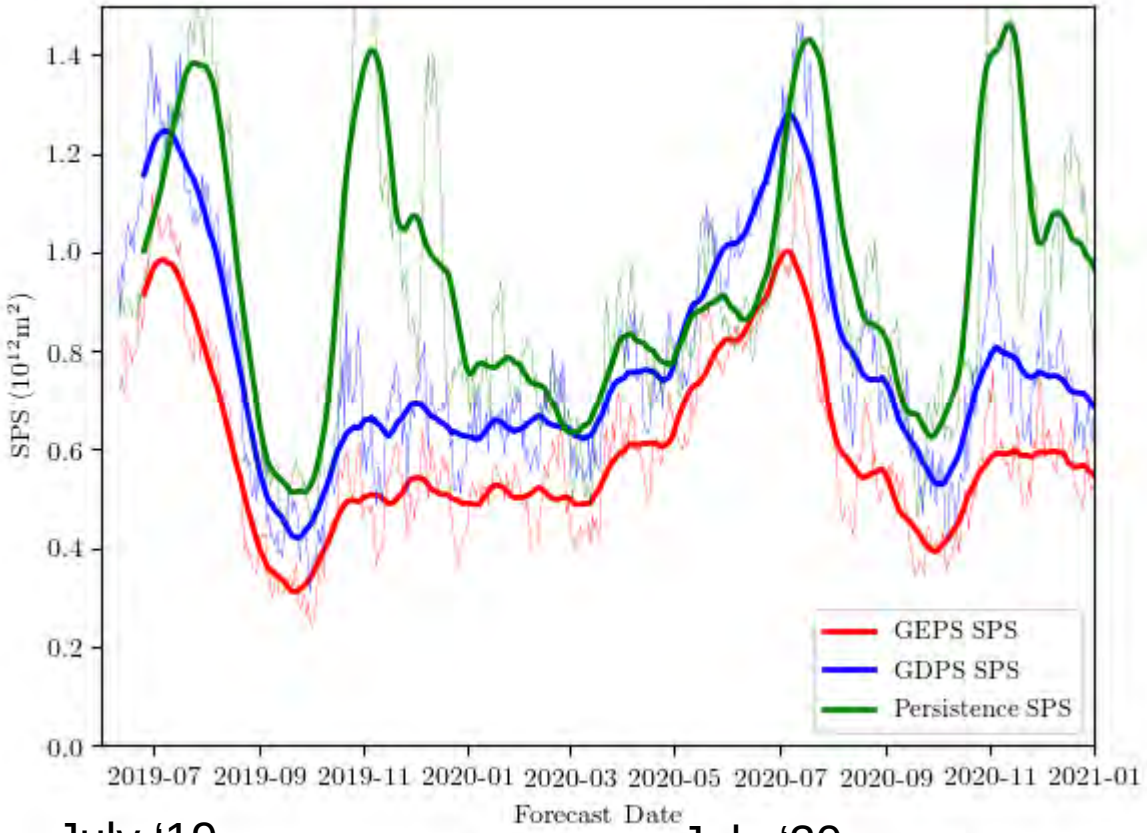
Ice Concentration

***User need**: Improved long-range sea ice forecasts*

GLOBAL ENSEMBLE COUPLED SEA ICE FORECASTS

- Developed in response to need by Ice services for long-range forecast guidance
- 32d coupled forecasts now produced operationally with 21 members weekly
- Required new verification metrics
  - Integrated Ice Extent Error (Goessling et al., 2016)
  - Stochastic probability score(SPS; Goessling and Jung 2018)
- System is underdispersive due to use of a single ice-ocean initial condition
- Nonetheless, it shows valuable skill w.r.t deterministic system and persistence throughout the year.
  - Largest errors during melt season

Forecast errors over the Northern Hemisphere



July ‘19 July ‘20

Peterson et al. (QJRMS, 2022)

PRODUCT DISSEMINATION

- MSC Open data:
  - GIOPS
    - Readme giops en - MSC Open Data / Données ouvertes du SMC (eccc-msc.github.io)
  - RIOPS
    - Readme riops en - MSC Open Data / Données ouvertes du SMC (eccc-msc.github.io)
- GeoMet (WMS)
- MSC AniMet (eccc-msc.github.io)
- Ocean Navigator https://navigator.oceansdata.ca
- Internal feeds for Government of Canada clients
  - Ice services, National Defense, Fisheries and Oceans, Coast Guard

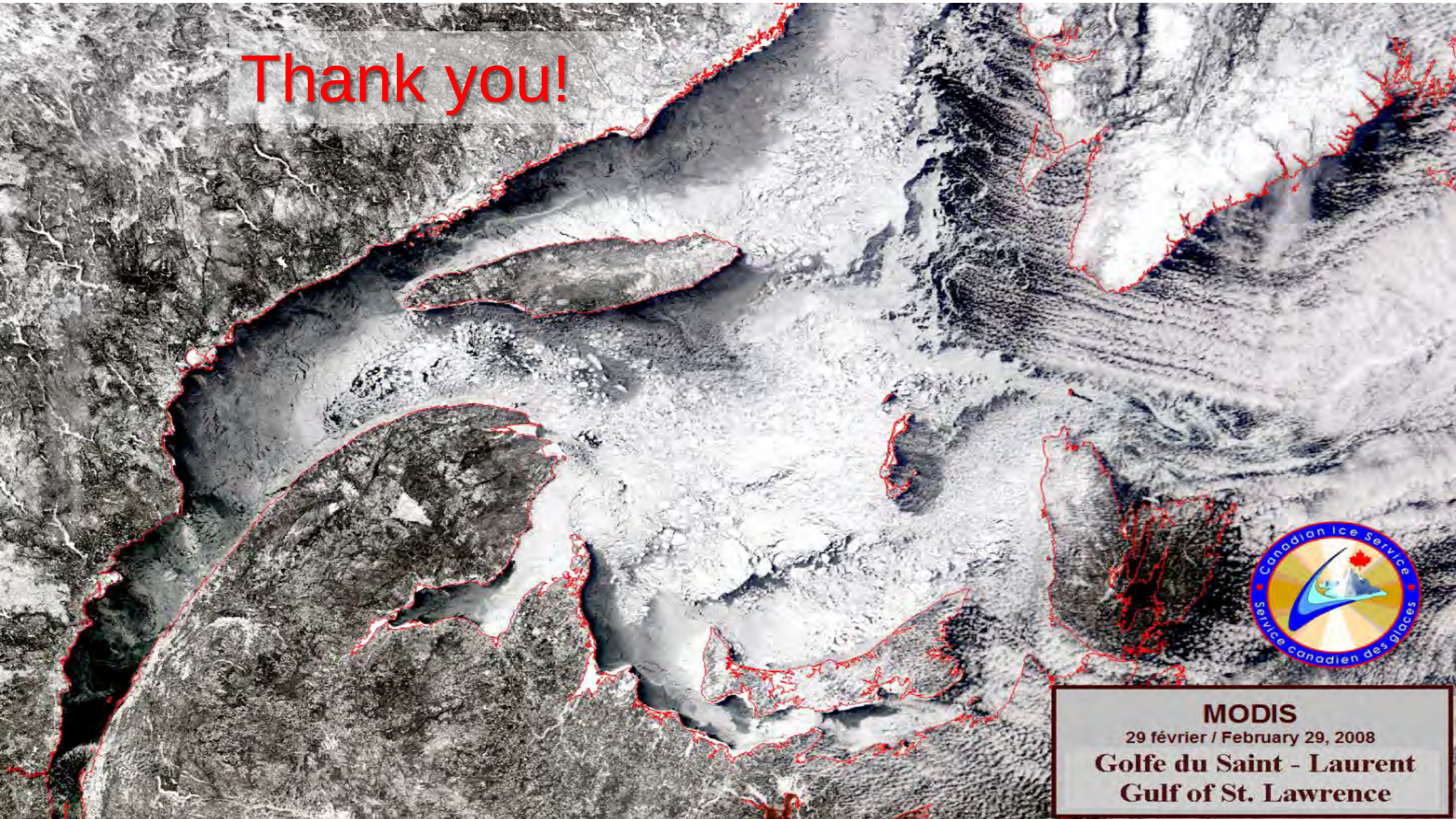
CURRENT AND FUTURE R&D OCEAN MODEL

- Ensemble analysis (LETKF)
- Development of coupled atmosphere-ice-ocean assimilation system
- Preparations for SWOT
  - OSSEs underway, OSEs to begin soon
- Development of higher resolution configurations
  - 1/12° global and 1/36° for NAtl/Arctic/NPac
- Study coupled atm-ice-ocean interactions in the Arctic
- Uncertainty estimation for users
  - especially Surface Drift Applications (SAR, EER)
- Reanalysis (ocean and sea ice)
- Adding 100 TB for science collaboration computer for sharing results in Synobs.

OCEAN RELATED PREDICTION

- Regional ensemble storm surge reanalysis (reduced level NEMO model (12 vertical levels)
- New Project AI forecasting for storm surge (Pengcheng Wang/Natacha Bernier)
- Port Prediction Systems: 6 ports developed (100 – 25 m)
  - looking to operationalise
- Proposal for coastal wave runup forecasts

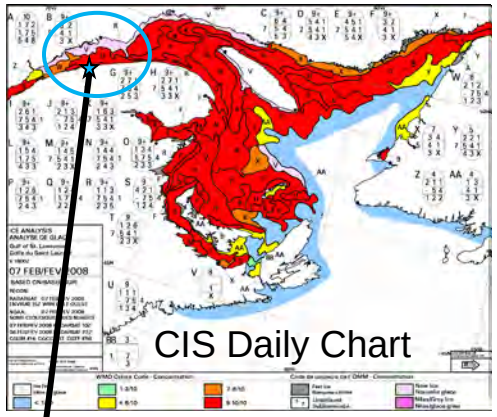
Thank you!


Canadian Ice Service
Service canadien des glaces
MODIS
29 février / February 29, 2008
Golfe du Saint - Laurent
Gulf of St. Lawrence

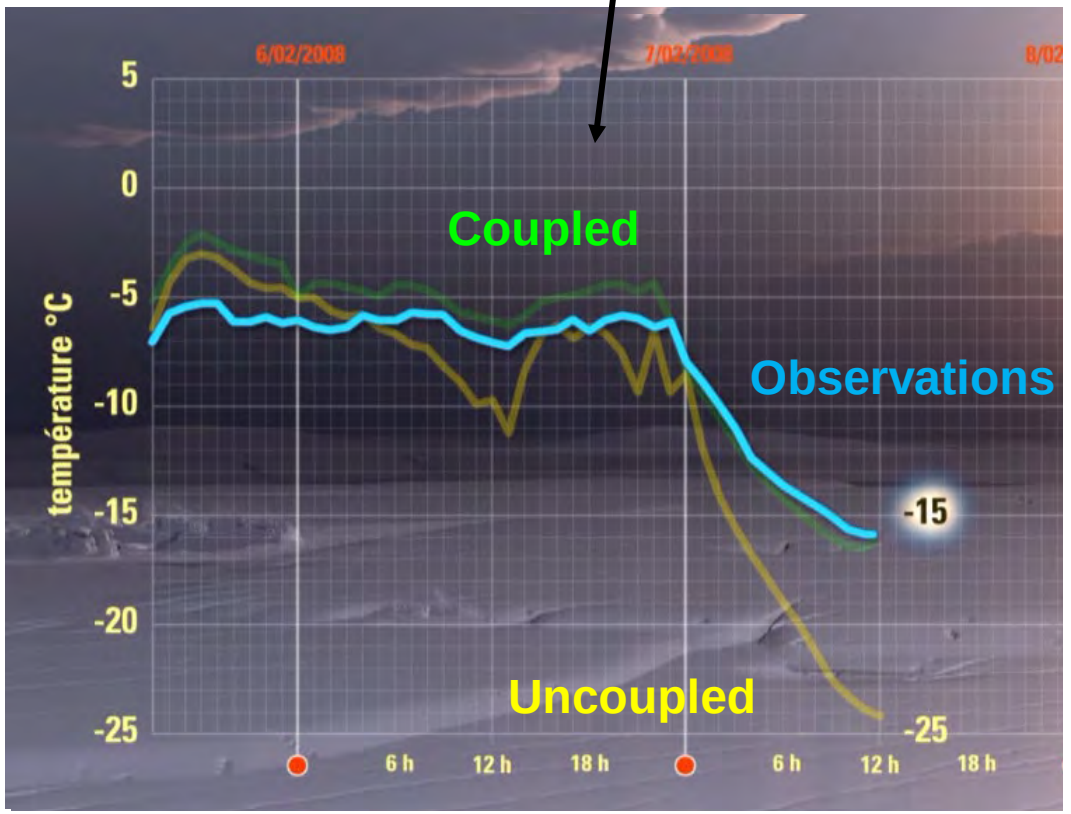
Extra slides

Where we were pre-YOPP…

The Gulf of St. Lawrence (GSL) Coupled Atmosphere-Ice-Ocean Forecasting System



- Running Operationally at the Canadian Meteorological Centre since 2011
- A dynamic representation of sea surface conditions improves the meteorological forecast locally
- Time-evolving ice cover in coupled model allows vast stretches of ice-free water to open up, buffering atmospheric temperatures
- Use of coupled model results in significantly improved forecasts all around the GSL
- Demonstrates importance of air-sea-ice coupling even for short-range weather forecasts

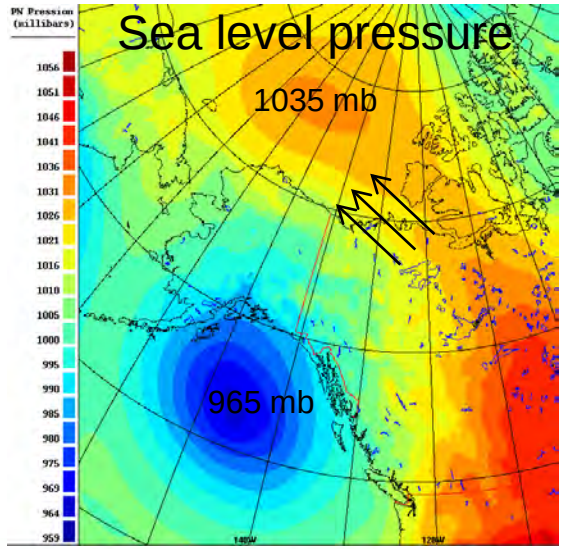


Courtesy Radio-Canada

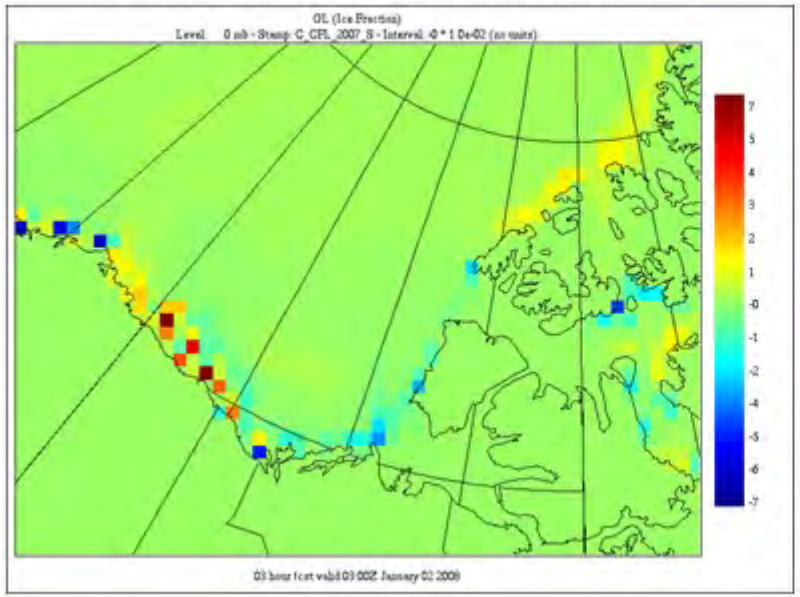
How can we expand this effort across the Canadian Arctic? How can it be used to benefit various marine users?

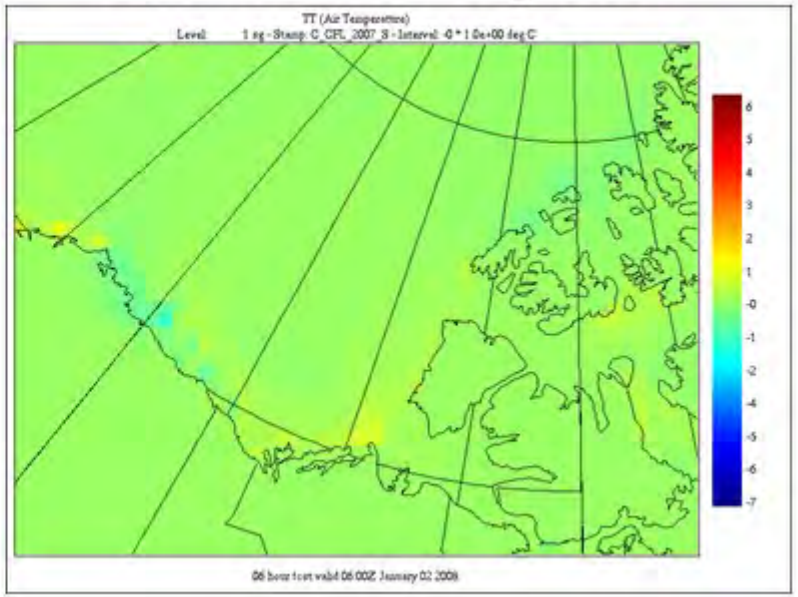
Where we were pre-YOPP…

IMPACT OF A DYNAMIC ICE COVER ON COUPLED FORECASTS OVER THE BEAUFORT SEA



Difference in ice fraction (CPL-UNCPL) Difference in 2m temperature





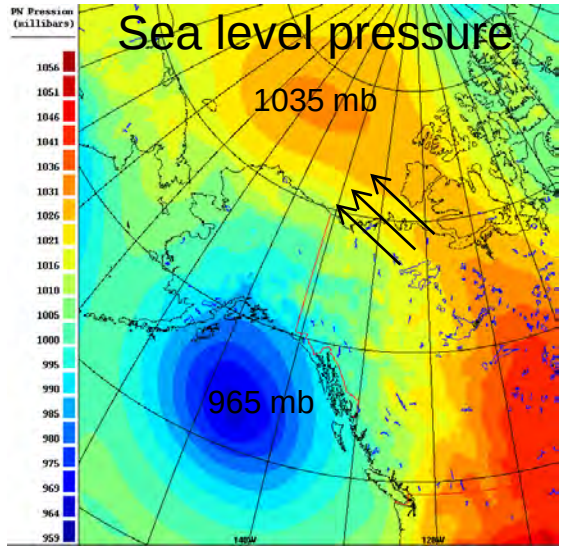
Forecast from global coupled model (GEM-NEMO-CICE; Atm (33km)-Ice-ocean (15km) resolution)

R. Muncaster, J.-M. Belanger

Where we were pre-YOPP…

IMPACT OF A DYNAMIC ICE COVER ON COUPLED FORECASTS OVER THE BEAUFORT SEA

- Coastal polynya formation sensitive to:
  - Atmosphere-ice and ice-ocean stresses, ice thicknesses, parameterization of ice strength (all things we know poorly!)



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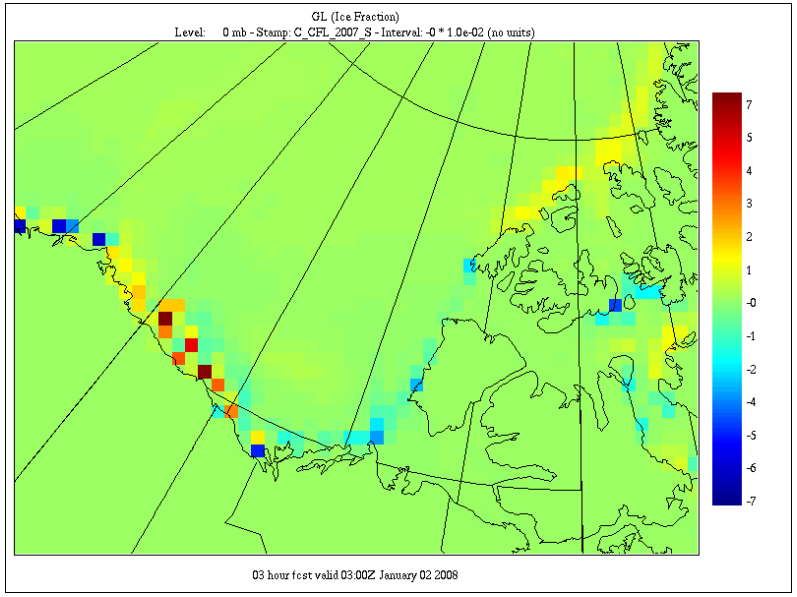
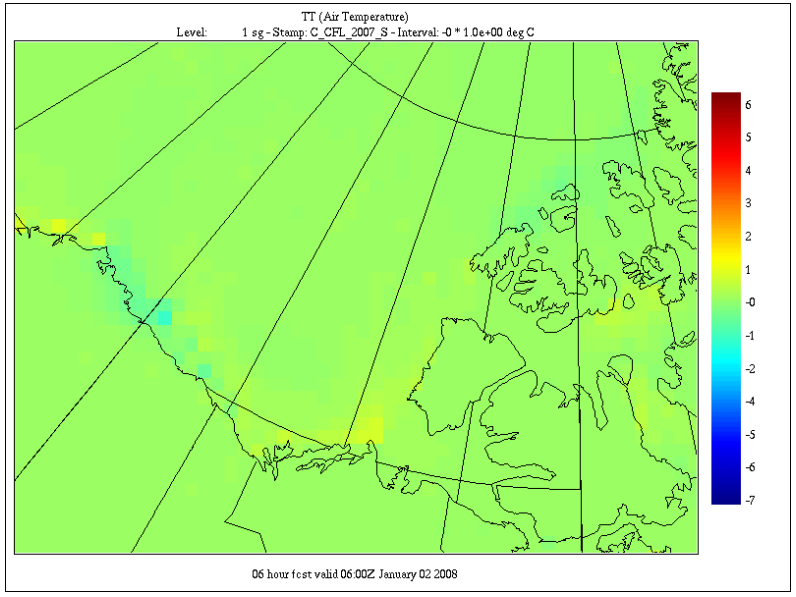




Forecast from global coupled model (GEM-NEMO-CICE; Atm (33km)-Ice-ocean (15km) resolution)

R. Muncaster, J.-M. Belanger

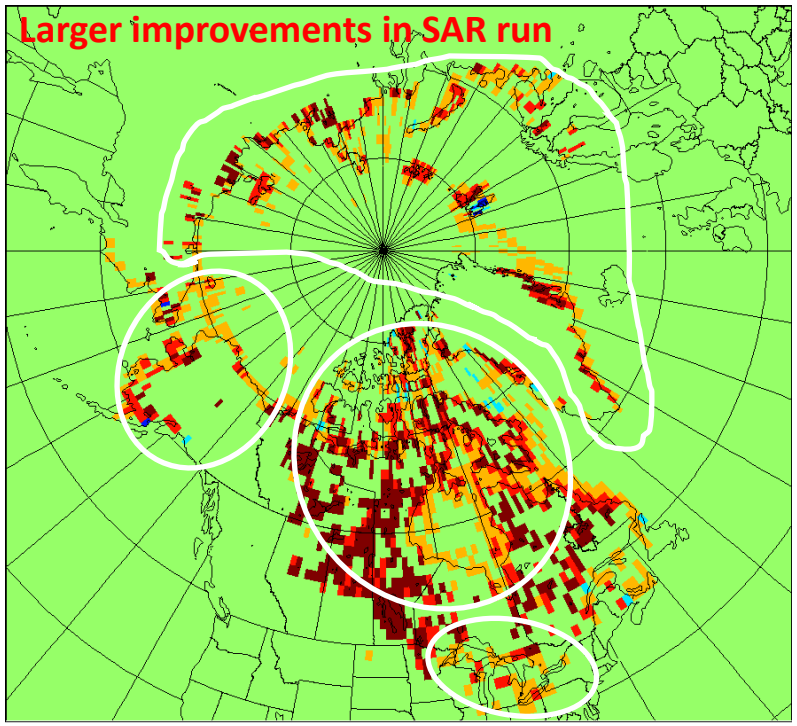
***User need**: High-resolution sea ice analyses for ice services*

RCM Data Assimilation in ECCC RIOPS

Difference in percentage correct total between SAR/Charts/SAR&Charts and Control run (no SAR information) when compared against IMS (entire year: August 1, 2020 – July 31, 2021)

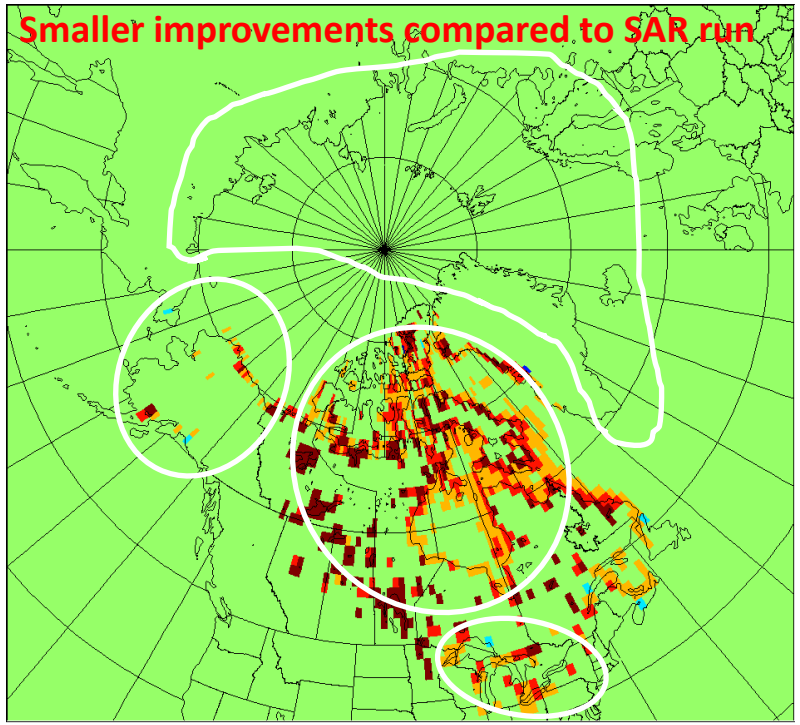
SAR retrievals assimilated, no charts

SAR – Control



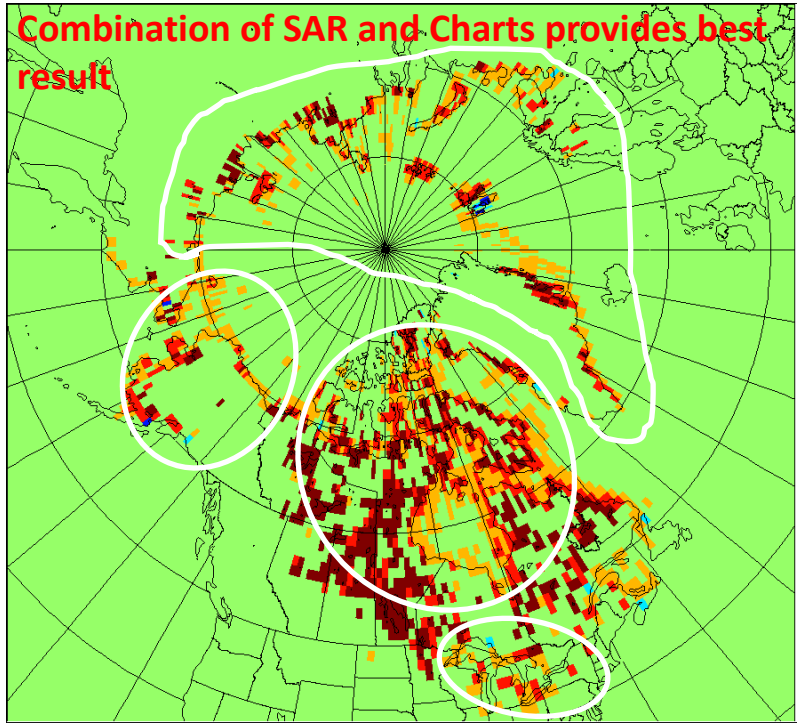
CIS ice charts assimilated

Charts – Control



SAR retrievals + charts assimilated

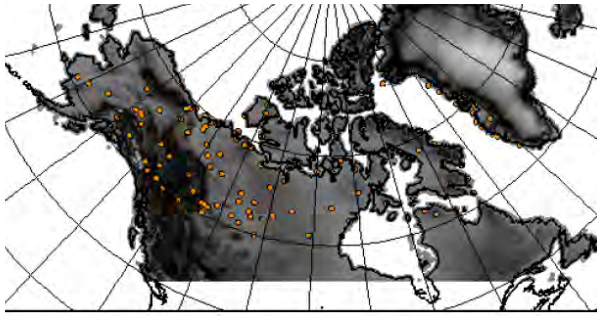
SAR & Charts – Control



- SAR retrievals from ~65,000 RCM images over a year period
- Main improvements are observed in situations where high spatial resolution is important (near land and over lakes) and where CIS ice charts are not available (e.g., the Eurasian Arctic)

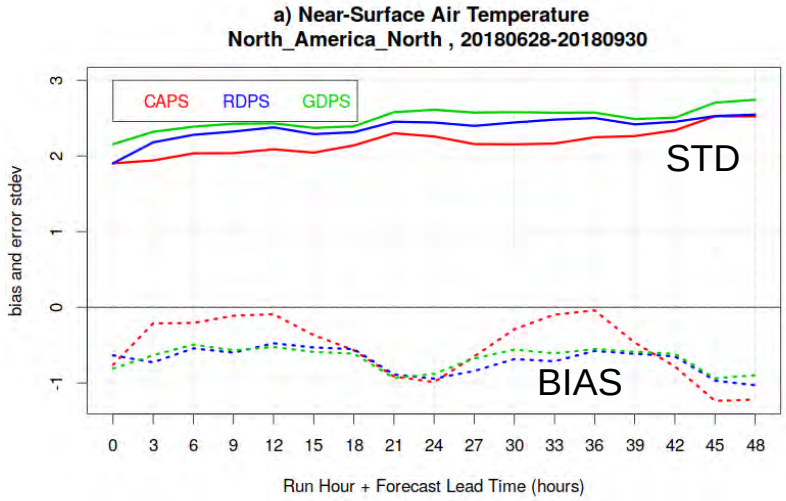
***User need**: Improve representation of fine-scale air-sea-ice interactions for NWP*

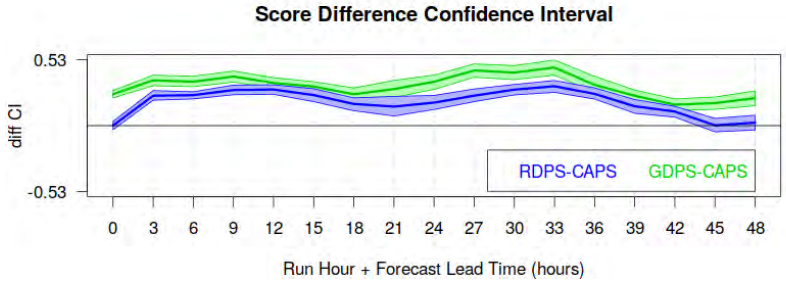
IMPACT OF MODEL RESOLUTION ON FORECAST SKILL



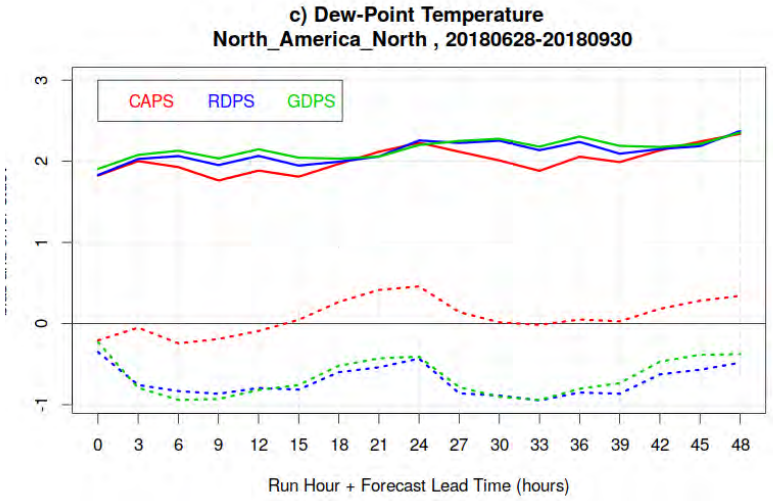
CAPS, Regional forecasts (RDPS), Global forecasts (GDPS)
over Northern N. America

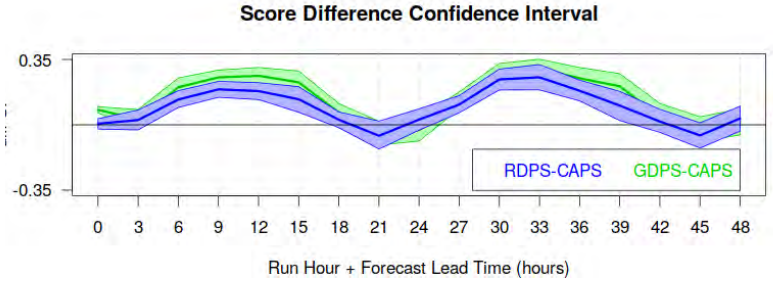
Near-surfaceTemperature



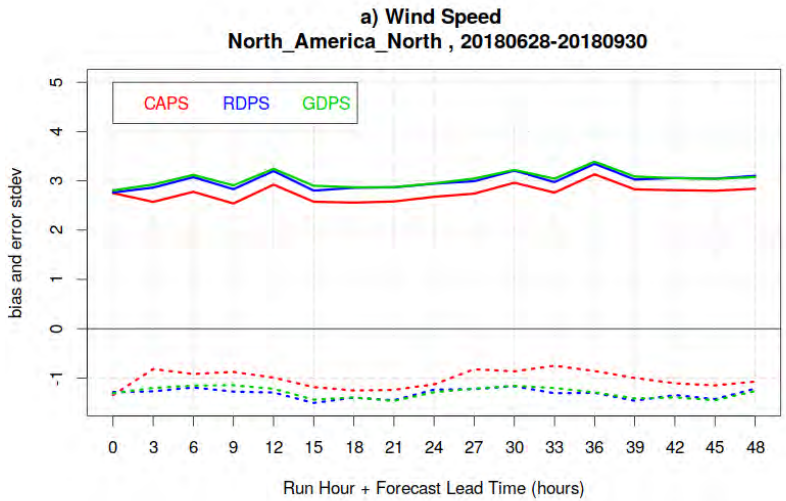


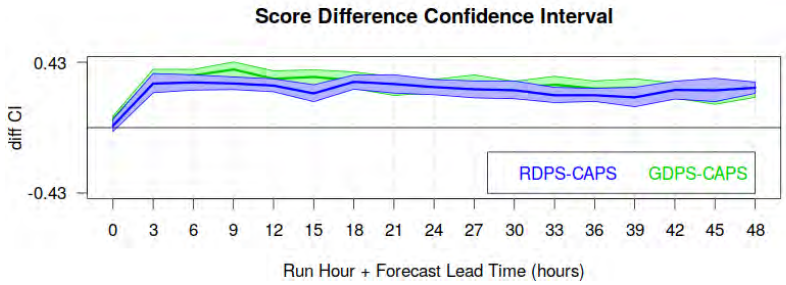
Dewpoint





Wind speed





Casati et al. (2022)

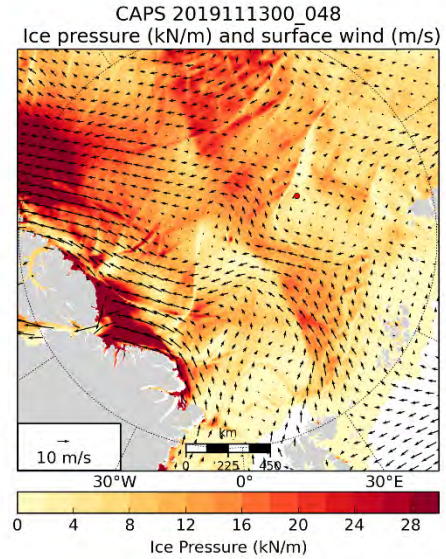
**See presentation by B. Casati for more details*

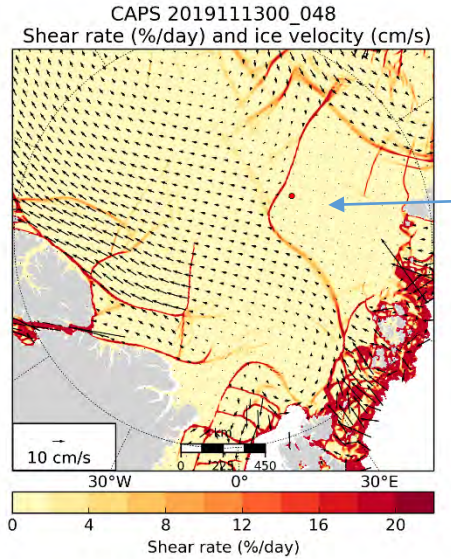
See Køltzow et al. (2019) for comparison with forecasts from Met.no, Meteofrance and ECMWF

New CAPS products

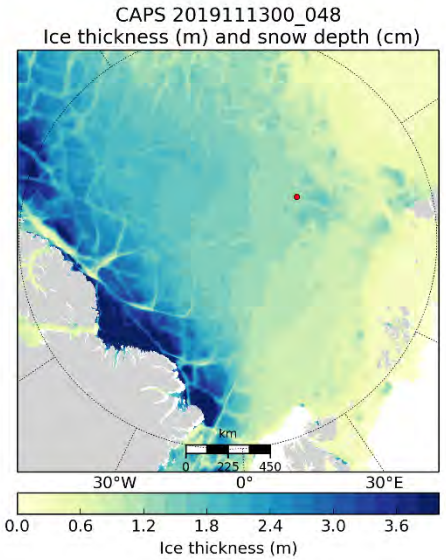
- Daily image production:
  - Internal ice pressure
  - Tendency of internal pressure
  - Shear rate
- Images produced in real-time and sent to ftp server for use on Polarstern for MOSAIC
- Investigate usefulness for scientific planning
- Study interesting cases
  - Forecasted significant divergence around Polarstern for storm on Nov. 17, 2019
  - Lead opened up between Polarstern and on-ice camps

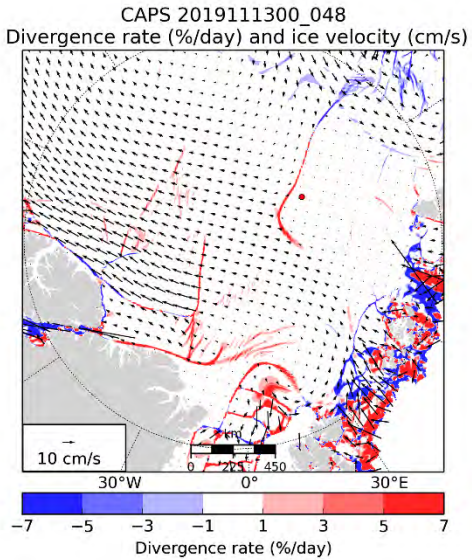
Wide-view





Polarstern





Forecast valid:
Nov. 15, 2018

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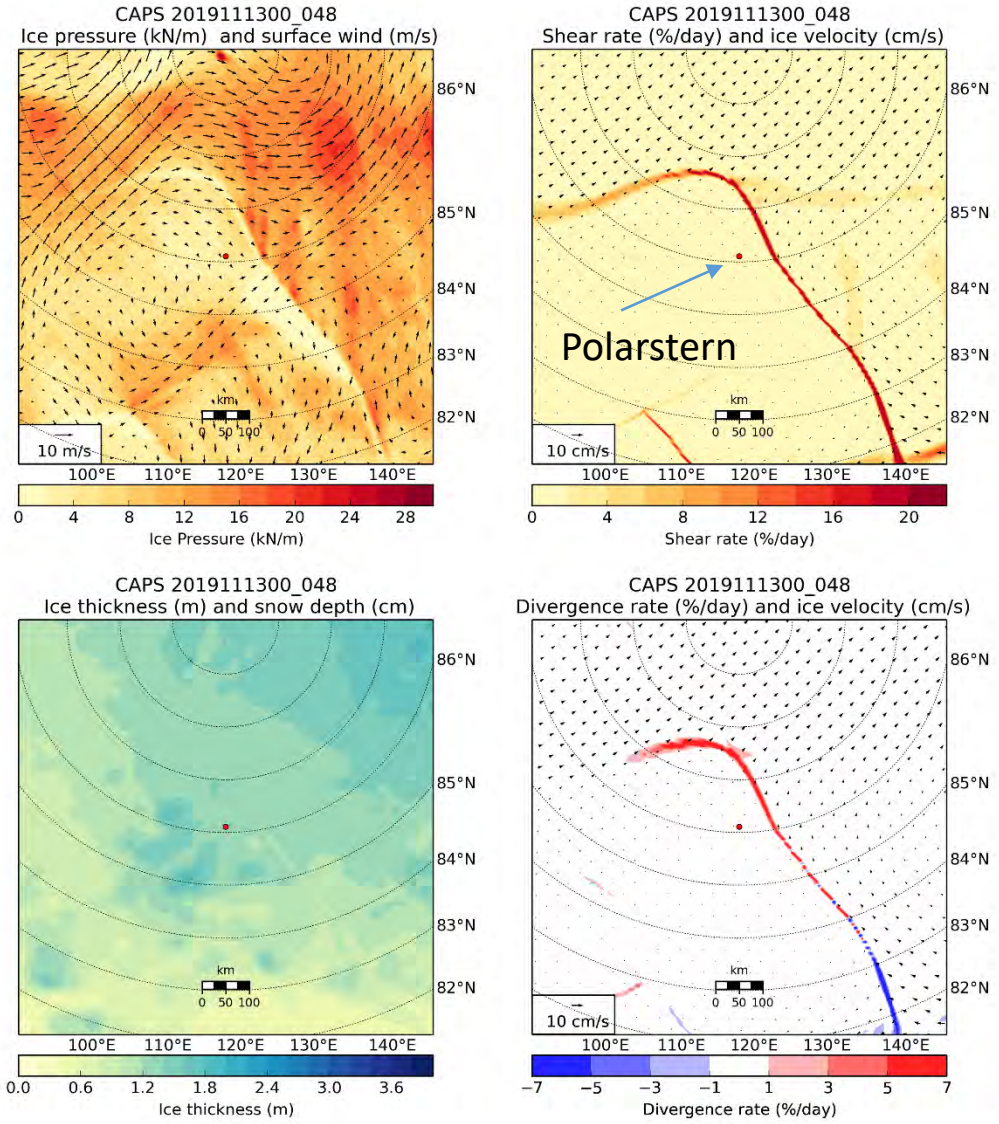
Zoom



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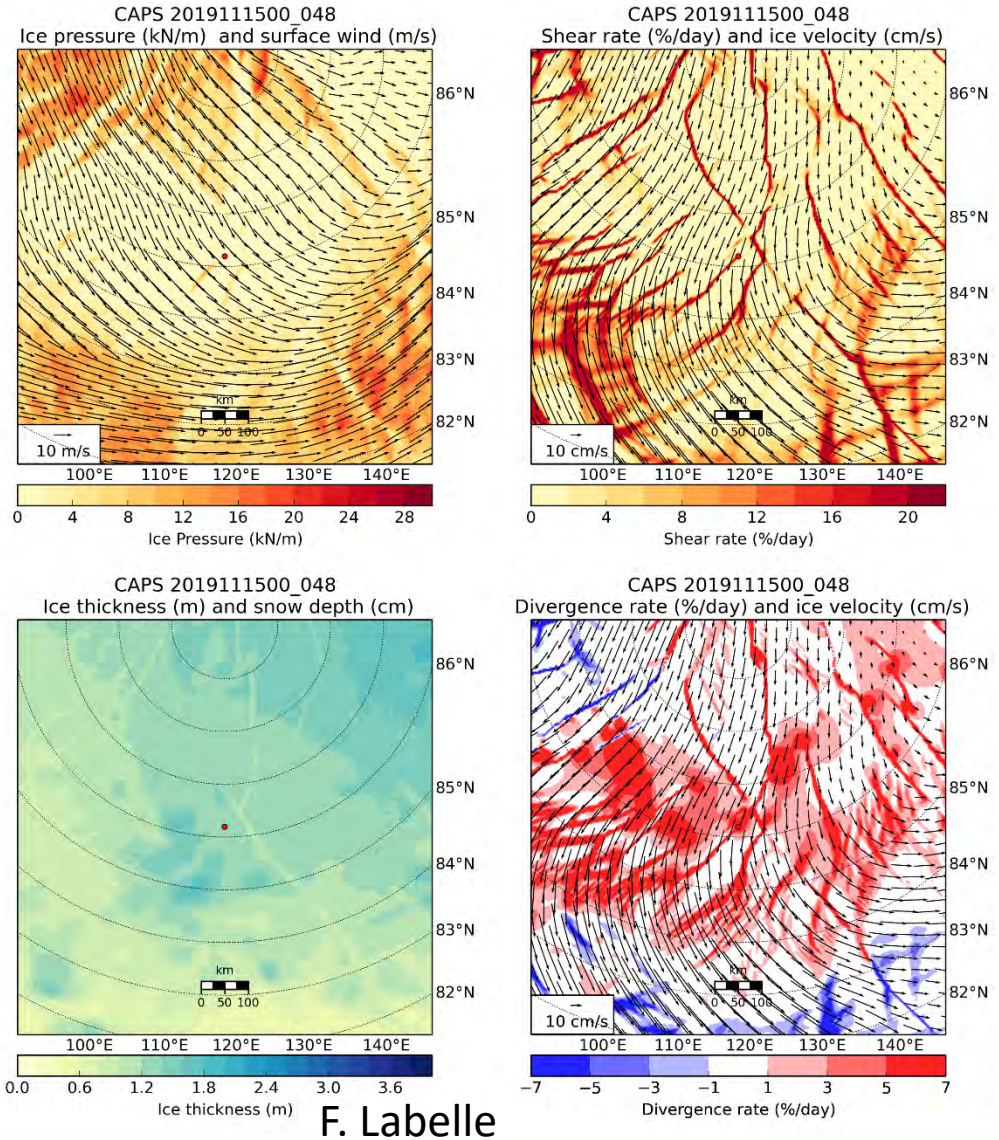
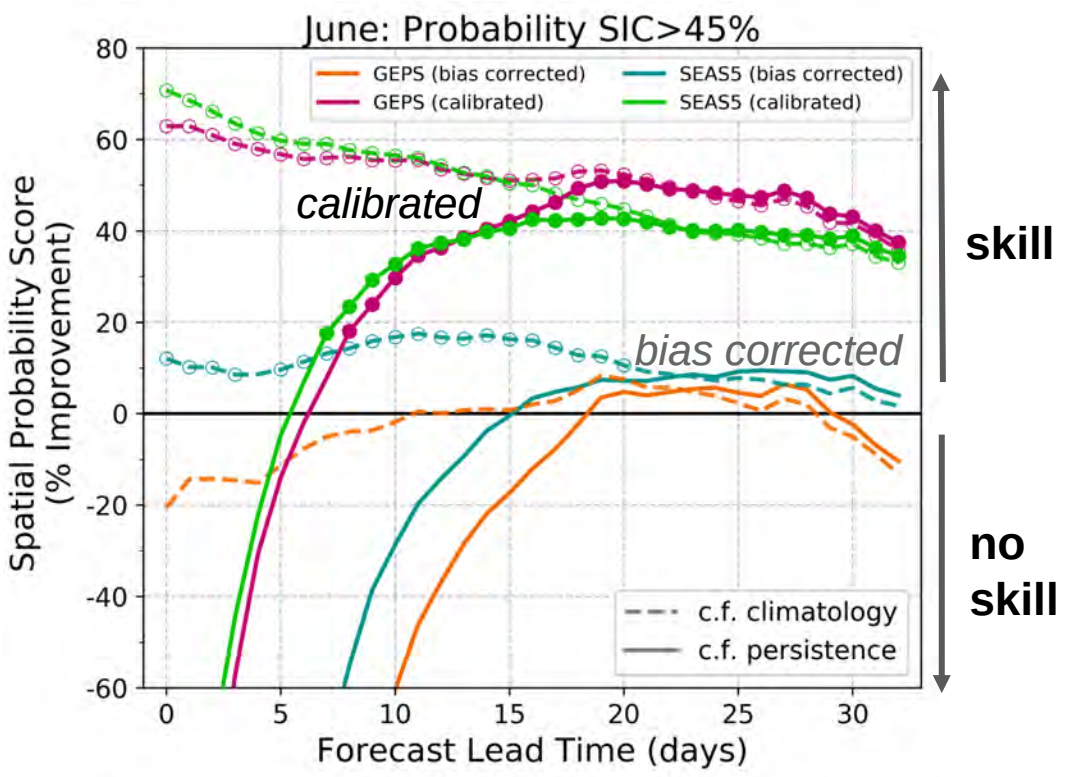


Forecast valid: Nov. 17, 2018

F. Labelle

Calibration of 1-month daily sea ice concentration forecasts

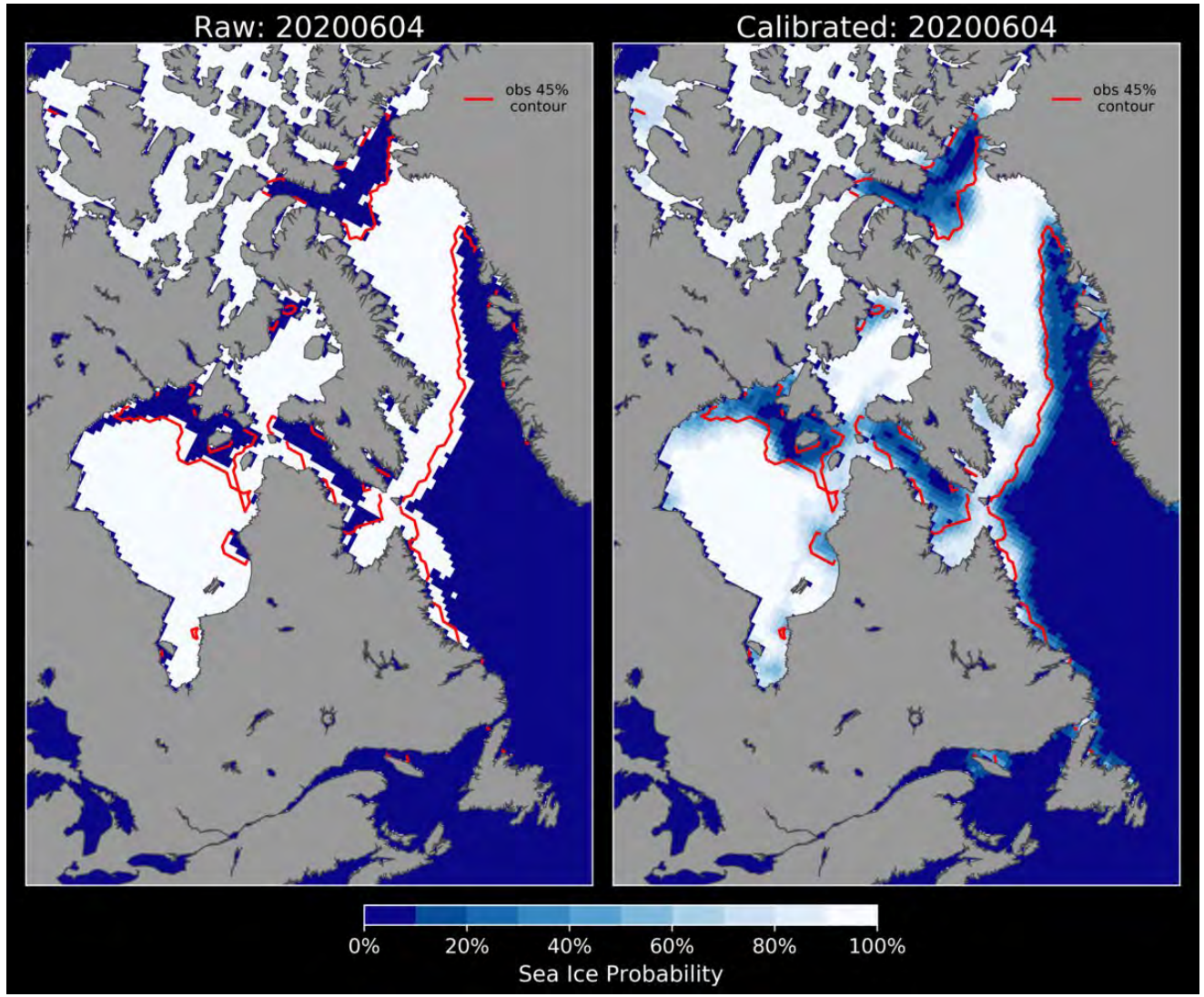
New censored Gaussian calibration approach developed and applied to ECCC GEPS and ECMWF SEAS5 Sea ice concentration in the Canadian Arctic Hindcast Skill: 1998-2017



- ➔ *Bias corrected forecasts comparable to climatology*
- ➔ *Calibrated forecasts beat climatology (- -) at all lead times*
- ➔ *Calibrated “ ” persistence (-) after 1 week*

Dirkson et al., 2022; QJRMS

Calibration applied to real time probabilistic GEPS forecast of SIC>45% from June 4, 2020



YOPP-endorsed FRAMS project

- **F**orecasting **R**egional **A**rctic Sea Ice from a **M**onth to **S**easons

- Funded by Canadian Marine Environmental Observation, Prediction and Response (MEOPAR) Network and Polar Knowledge Canada (POLAR), concluded March 2022.

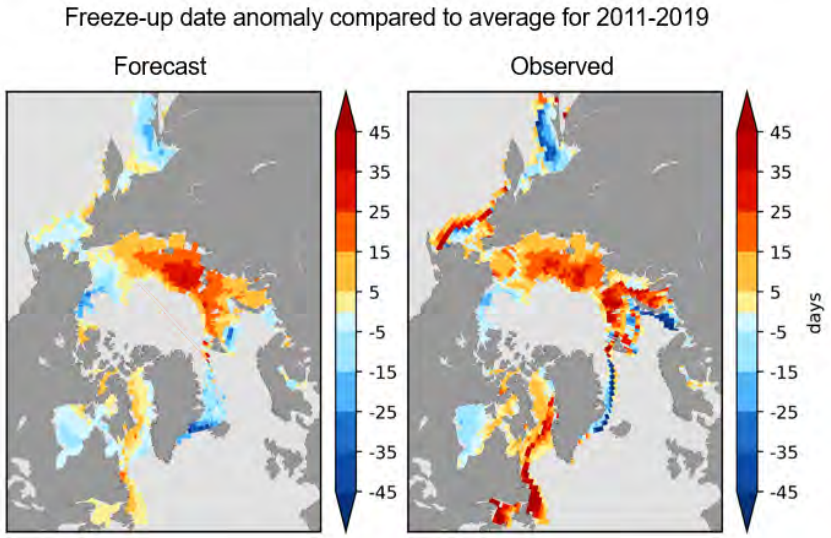
- Objectives:
  - Investigate sources of Arctic sea ice **predictability**
  - Develop **user-relevant** subseasonal to multi-seasonal Arctic sea ice forecast products
  - Incorporate **best practices** (probabilistic information, calibrated for reliability, including skill assessments)
  - Support ECCC's commitment for providing seasonal sea ice forecasts to the WMO **Arctic Climate Forum**

ACF
Arctic Climate Forum

FRAMS Outcomes – Predictions for ACF

ACF
Arctic Climate Forum

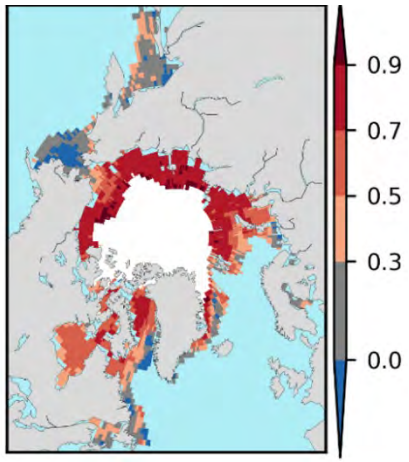
- Held twice yearly, in **May** and **October**
  Example: Oct 2020 forecast with verification



Freeze-up date forecast ← (deterministic)

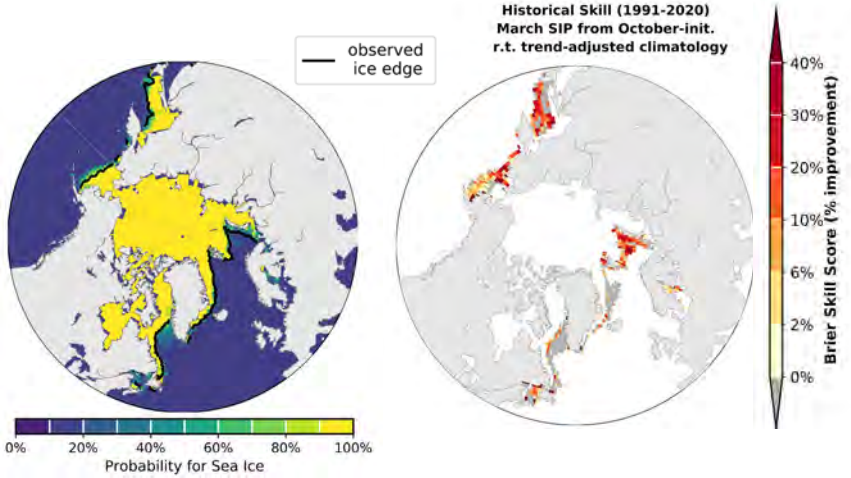
Sigmond et al. GRL (2016)

Historical skill (detrended Anomaly Correlation for 1981-2019)



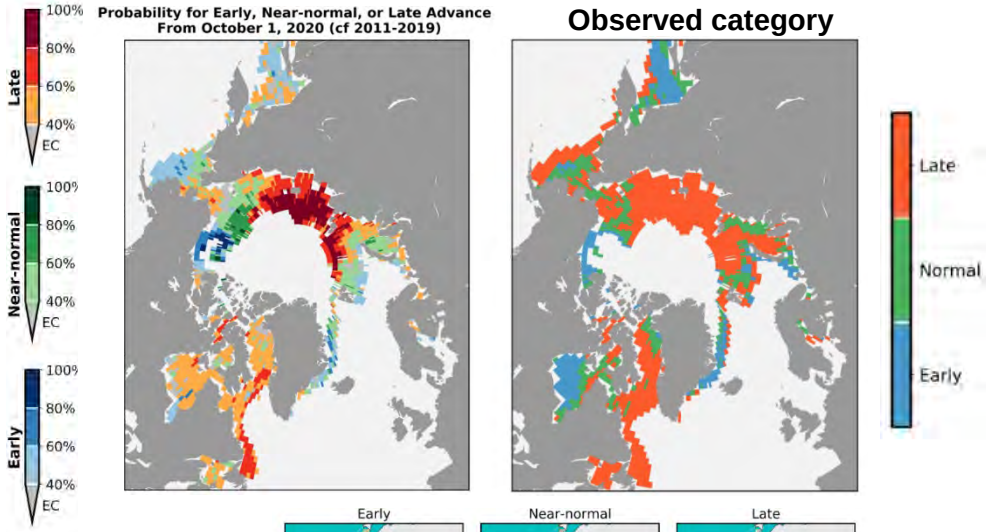
Freeze-up date forecast (probabilistic) →

Dirkson et al. Wea. Forecasting (2021)



Probability for March 2021 ← concentration >15%

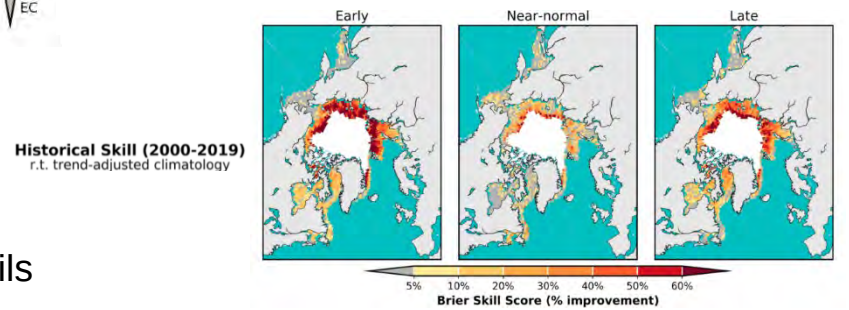
Dirkson et al. J. Clim (2019)



These forecasts are from ECCC models and can be improved by using a larger set of models, e.g. from Copernicus:

A Multimodel Approach for Improving Seasonal Probabilistic Forecasts of Regional Arctic Sea Ice

A. Dirkson[1], B. Denis[2], and W.J. Merryfield[3] *GRL (2019)*



* See presentation by Jelmer Jeuring for more details

SUMMARY REMARKS

Outcomes from YOPP

- Various improvements to ECCC ocean and sea ice analyses
  - Online tidal harmonic analysis, Arctic OSEs
  - RCM sea ice concentration analyses, Cryosat2+SMOS combined 3DVar ice thickness analysis
- Improved sea ice model physics
  - Landfast ice parameterization, improved sea ice rheology
  - See presentation by J.-F. Lemieux for details
- Put in place a high-resolution pan-Arctic coupled prediction system
  - Demonstrated benefit for near-surface NWP (See presentation by B.Casati)
  - Impacts of fine-scale interactions under study…
  - CAPS dataset freely available
- Global coupled ensemble forecasts
  - New calibrated products for Ice services
  - See presentation by K.A. Peterson for details
- Contributions to Arctic Climate Forum
  - Calibrated freeze-up, multi-model approach
- Improved NWP products
  - See presentation by W. Burrows

Key challenges going forward

- Increased understanding of polar dynamic and physical processes to allow improved formulation of environmental prediction models and parameterization schemes in the polar regions
- Recommendations for an optimized Arctic and Antarctic observing system to benefit predictions in polar regions and beyond.