Environment and
Climate Change Canada

Environnement et
Changement climatique Canada

Canadian Arctic Prediction System

(CAPS Version2)

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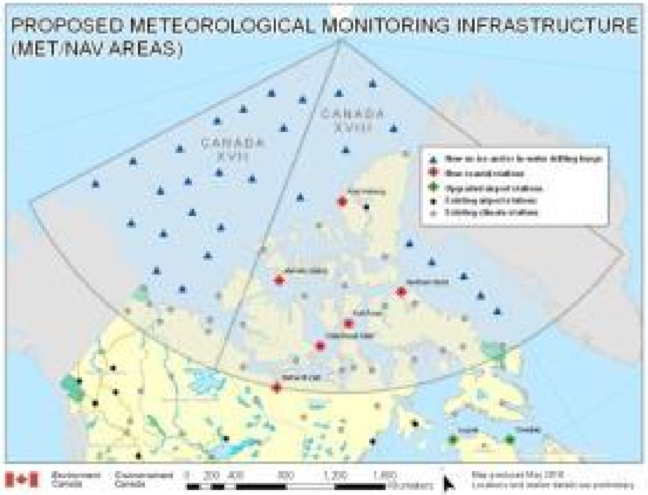
(CMD-EM, CMD-N, RPN-EM, RPN-A)

ECMWF – Bonn
April 2025

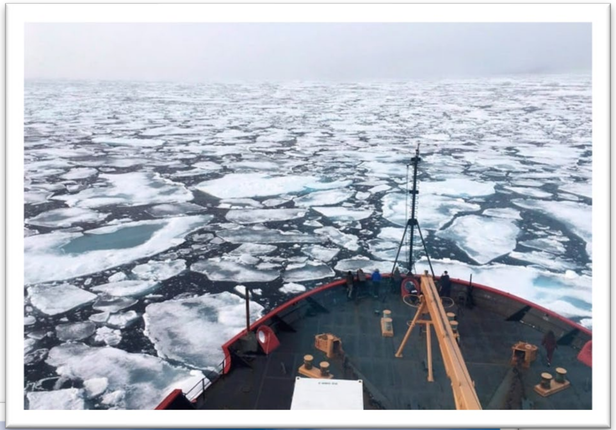
Canada

Context – A changing Arctic



Current ECCC's Responsibilities in the Arctic

- Canada responsible for METAREAS 17&18
- Environmental emergency response (atmospheric pollutants, oil spill, etc.)
- Supports Canadian Ice Services for navigation safety
- Supports Coast Guard for Search&Rescue



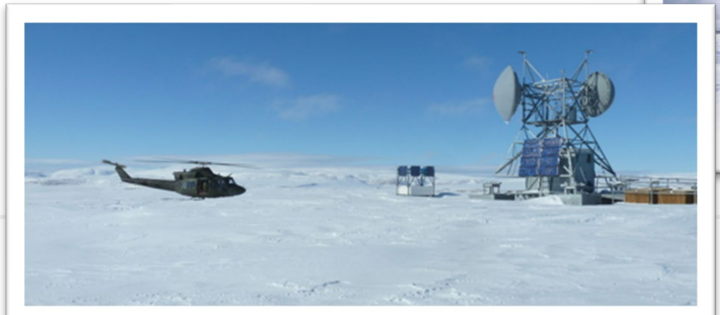
Arctic Forecasts rely on

(i) **Global system** (GDPS coupled 15 km; G0 uncoupled 10km)
(ii) **Regional Arctic** (**HRDPS;** uncoupled atm. 3 km)

- Sea ice & Ocean forecasts done with Regional Ice-Ocean Predictions System **RIOPS** (3-5km; forced by GDPS-G0)

Requests from National Defense

- High-resolution pan-Arctic **coupled** atmosphere-ice-ocean system for short-term predictions
  - Flight operations (esp. in Canadian Arctic Archipelago)
  - Harsh & rapidly changing conditions
  - Navigation Hazards in ice infested waters
  - Acoustic detection
- Require system in operations for development of specific applications

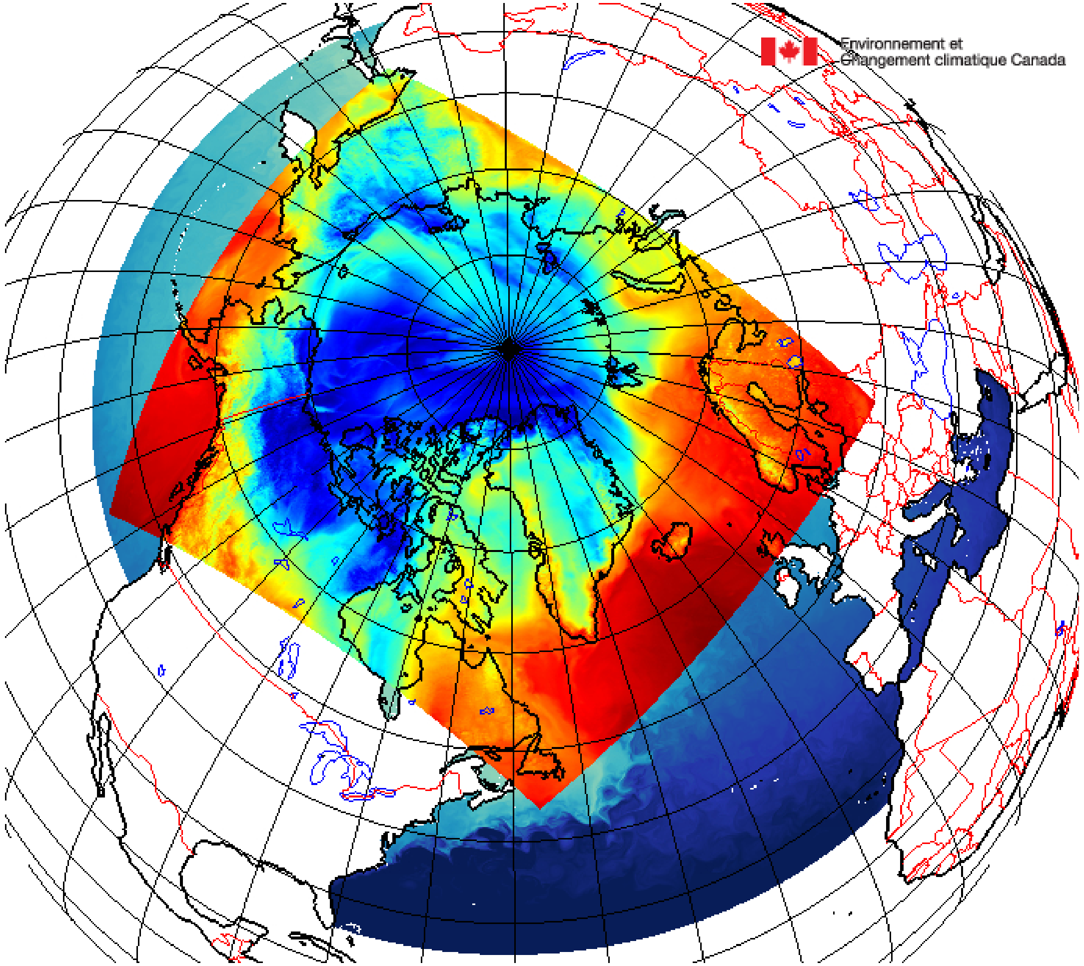


Canadian Arctic Prediction System (CAPS$_{v2}$)

- **Atmosphere : GEM5.2** (Côté et al. 1998; McTaggart-Cowan et al. 2019)
  - **HRDPS-Nord**
  - **3km** horizontal grid size; 62 vert. lvls (Dyn 35m, Thermo 17.5m)
  - **Microphysics**: Predicted Particle Properties (P3; Morrison& Milbrandt 2015)
  - Radiative Transfert: cccmarad (Li 2002, Li & Barker 2005, Li et al. 2005)
  - PBL: Moistke (Bélair et al. 1999, McTaggart-Cowan & Zadra 2015)
  - Convection: Kain and Fritsch (1990, 1992)

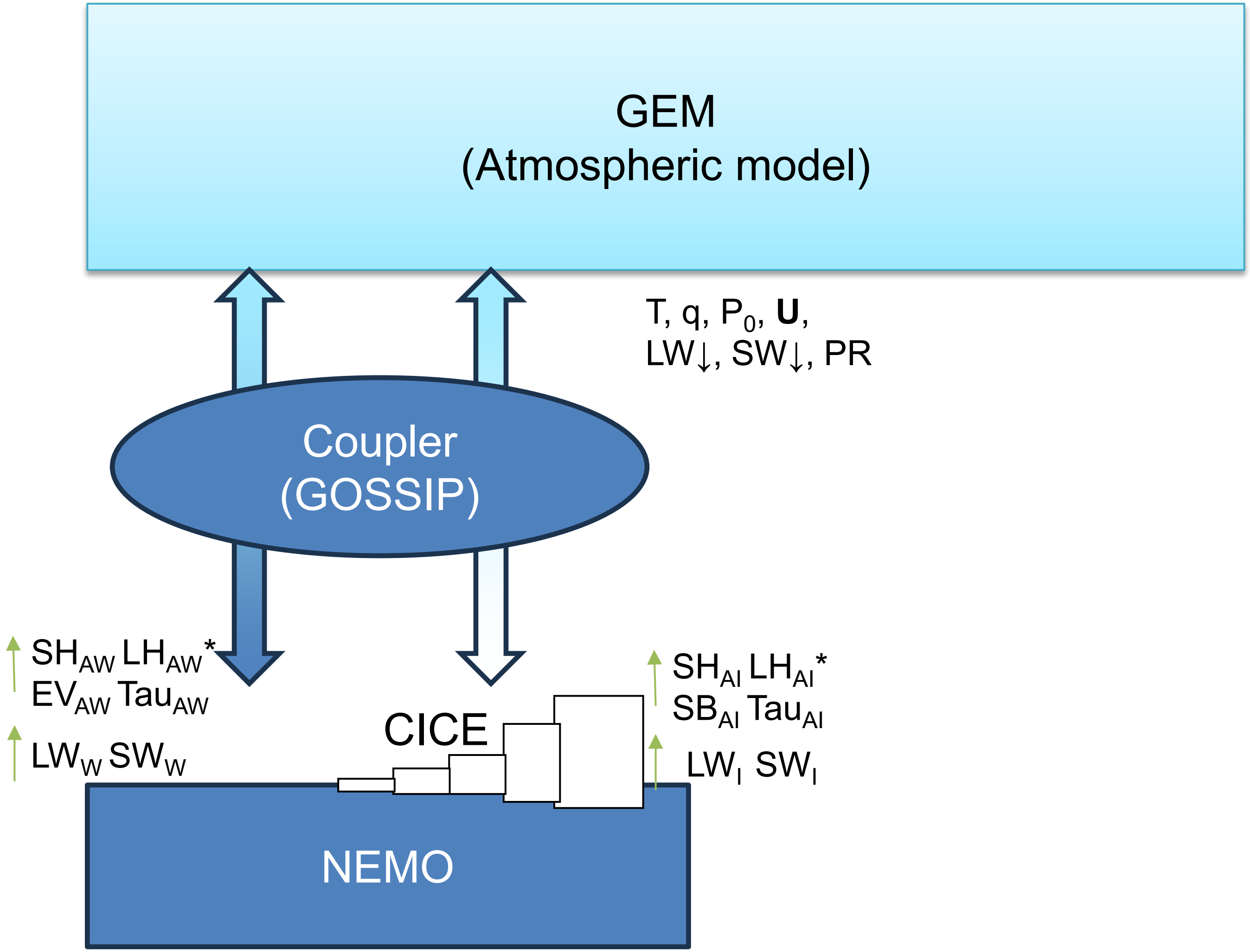
- **Ocean-Ice : NEMO3.6 – CICE6**
  - **RIOPS** (Dupont et al. 2015; Smith et al. 2021, Smith et al. 2024)
  - **2-8 km** horizontal grid size (ORCA 1/12° tri-polar)
  - VP rheology (EVP with 900 subtimesteps), 10 ice thickness categories
    Landfast ice (Lemieux et al. 2015, 2016, 2018)
  - Tides
  - Atmospheric pressure effect (storm surge)
  - River runoffs: Dai & Trenberth + Glacier melt from Mercator
  - Initialized from RIOPS-analysis (SAM2; Ice Cover Analysis)

Short-term forecasts (48h) 2xday (00Z & 12Z)



Evaluation: 1-year (2021-2022)
– Coupled (CAPS) vs Uncoupled (HRDPS)
48h forecasts (every 36h)

Coupling Strategy in CAPS



- Coupling **every common time step** ($\Delta t_{coupling}$=300 s; GEM:100s, NEMO: 300s)
- Fluxes calculated on ocean grid & aggregated
- Fluxes calculated over the 10 ice thickness categories (0.0, 0.1, 0.15, 0.30, 0.50, 0.70, 1.20, 2.0, 4.0, 6.0+)
- Flux calculations consistent between GEM & NEMO-CICE (in & out of coupling zone)

5. Changes in surface Temperature (1.5m)

CAPS – HRDPS (at t=48h)

Over Sea ice

- Large-scale wintertime warming (2-5^{o}C)
- No significant differences in summer

Over Ocean

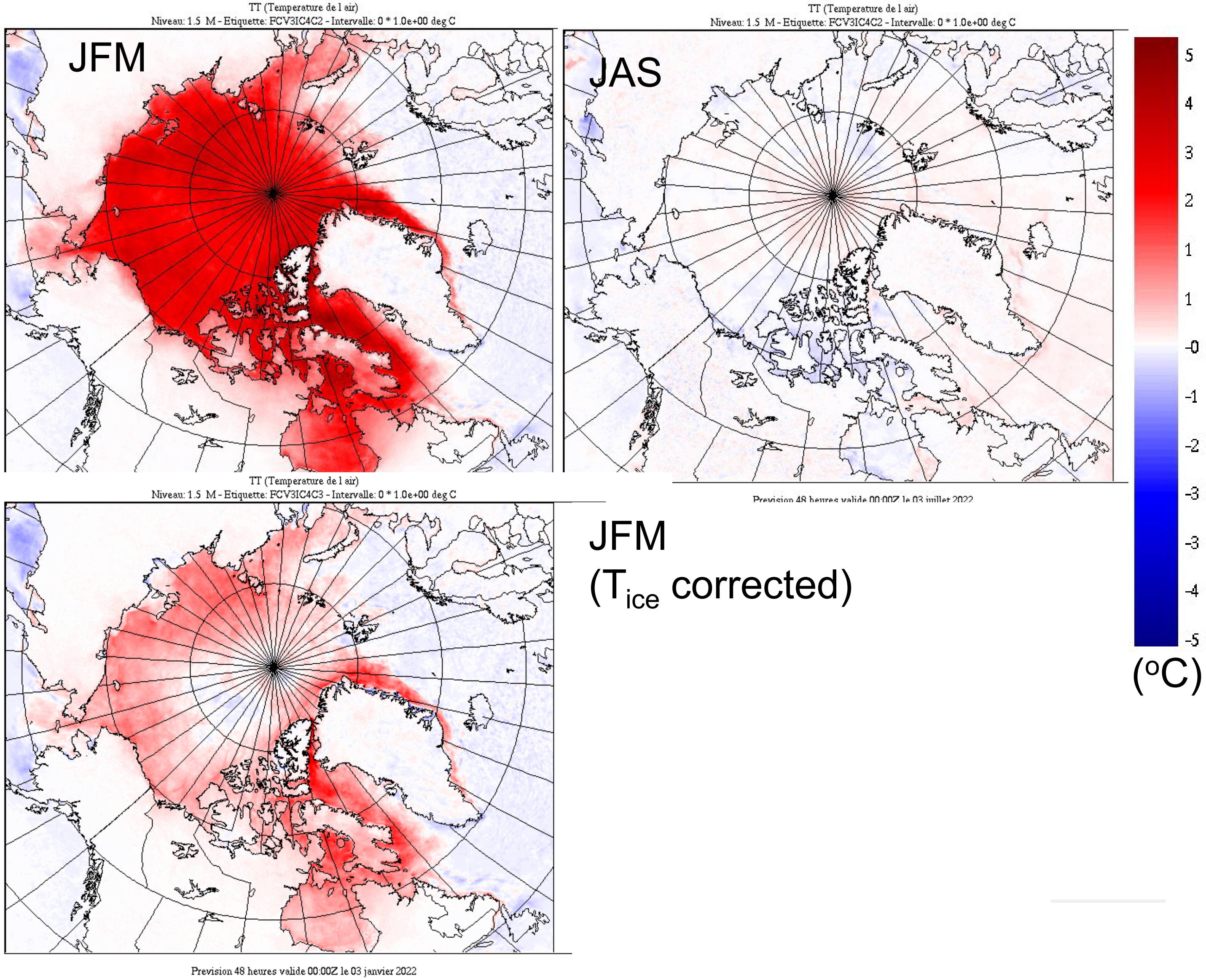
- Cooling in fall-winter-spring

Over land

- No clear signal except coastal areas

Explained by:

- HRDPS unrealistic ice temperature profile
- Leads under-represented in ice analysis
  - Initial conditions in HRDPS
- Opening of leads in coupled forecasts
  - vs. persistence in HRDPS
- **Large-scale differences in surface fluxes**
- **Fluxes through the ice**
- Representation of snow-on-ice (small impact)

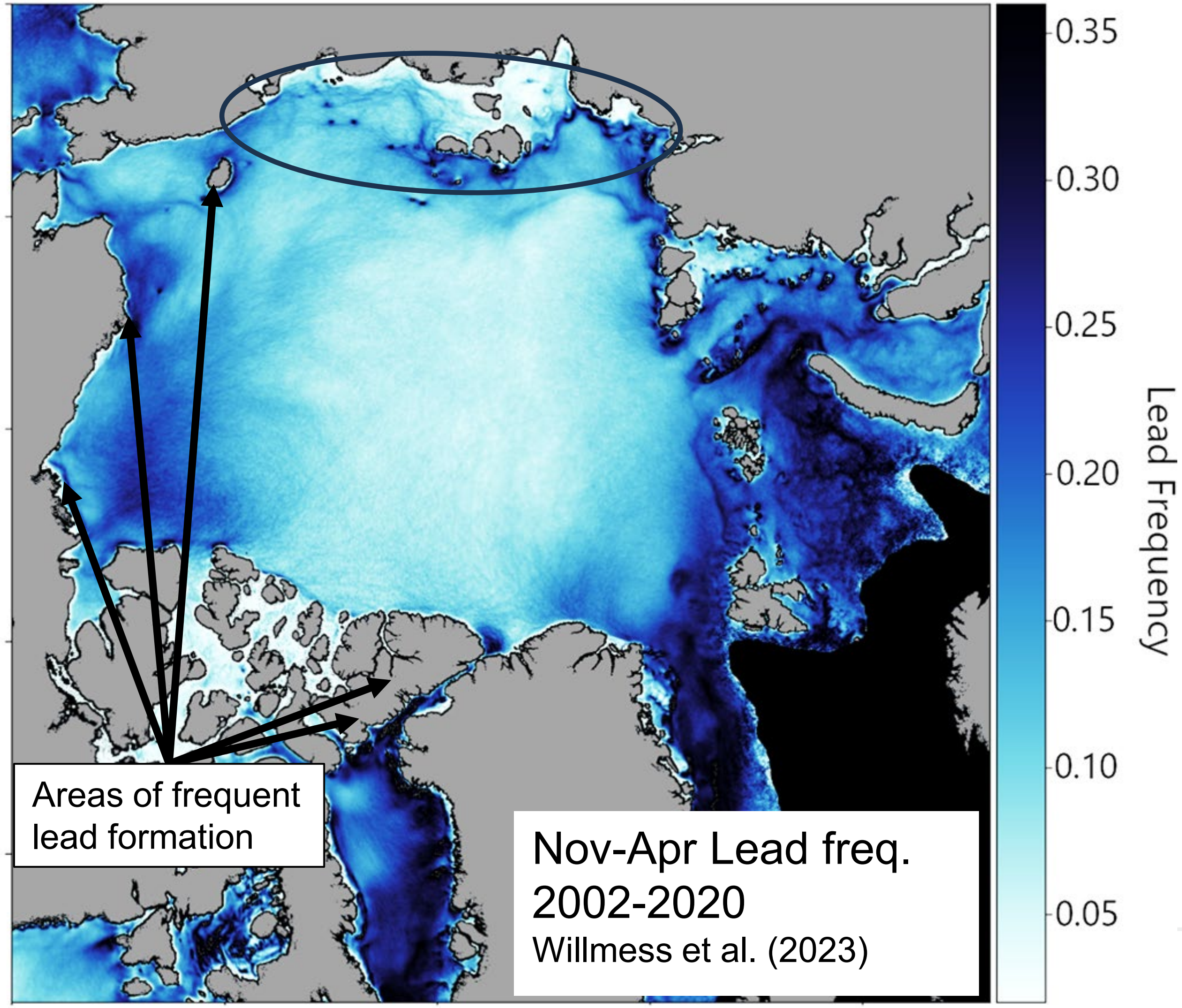


JFM (T$_{ice}$ corrected)

5. Changes in Turbulent Heat Fluxes

Winter (JFM) turbulent heat fluxes differences (at 48h)
CAPS – HRDPS

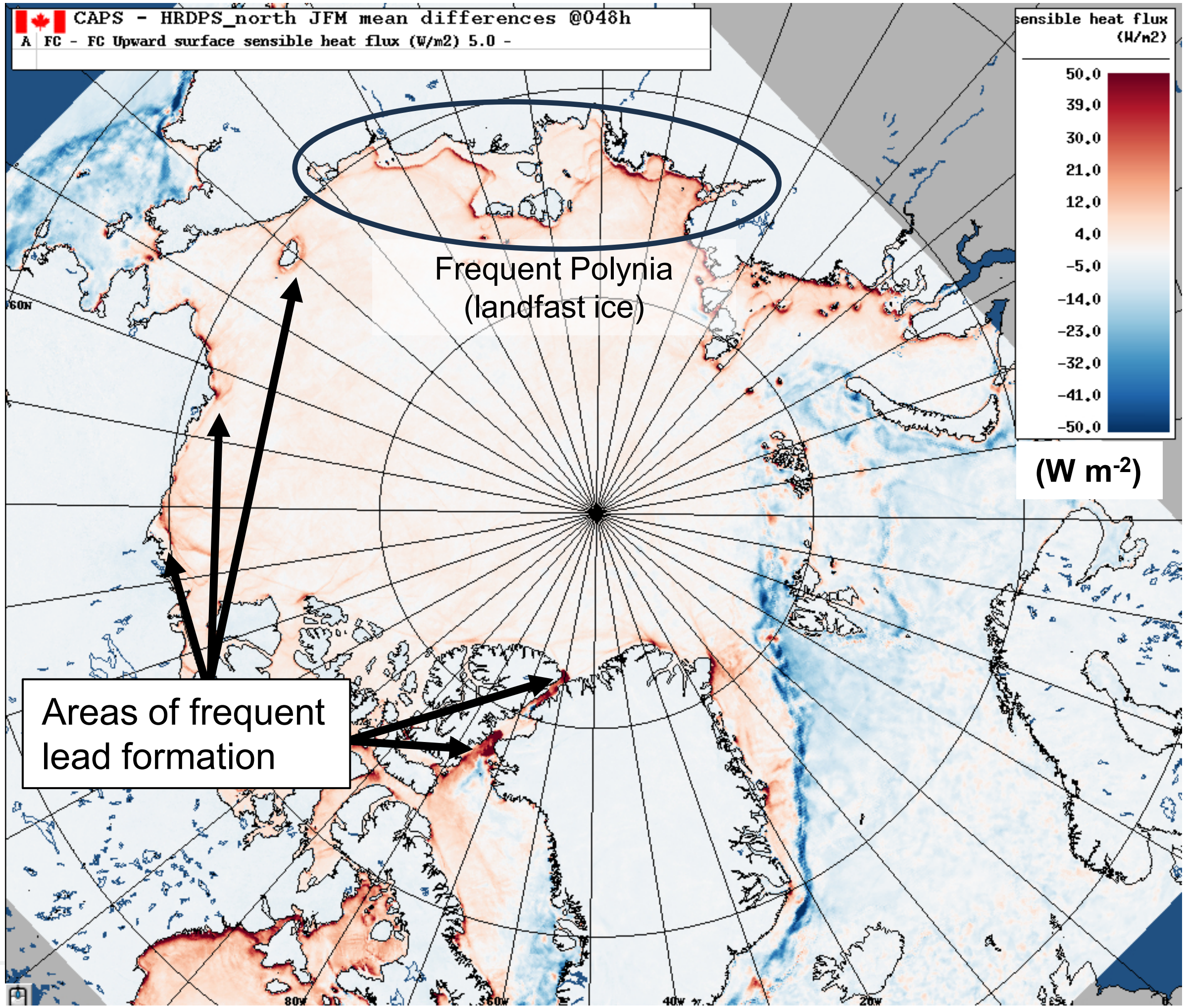
(b) ArcLeads mean lead frequency



Areas of frequent lead formation

Nov-Apr Lead freq.
2002-2020
Willmess et al. (2023)

Sensible heat flux differences



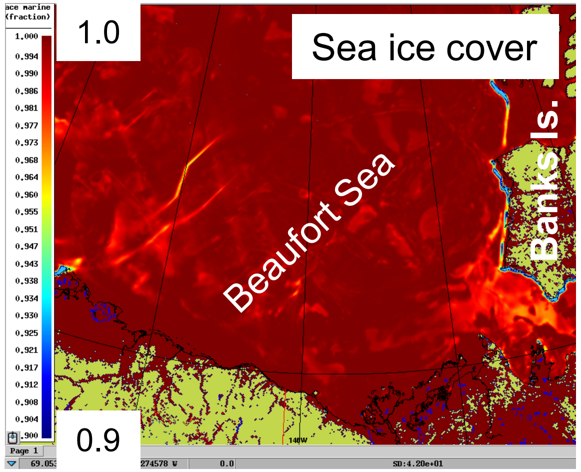
($W\ m^{-2}$)

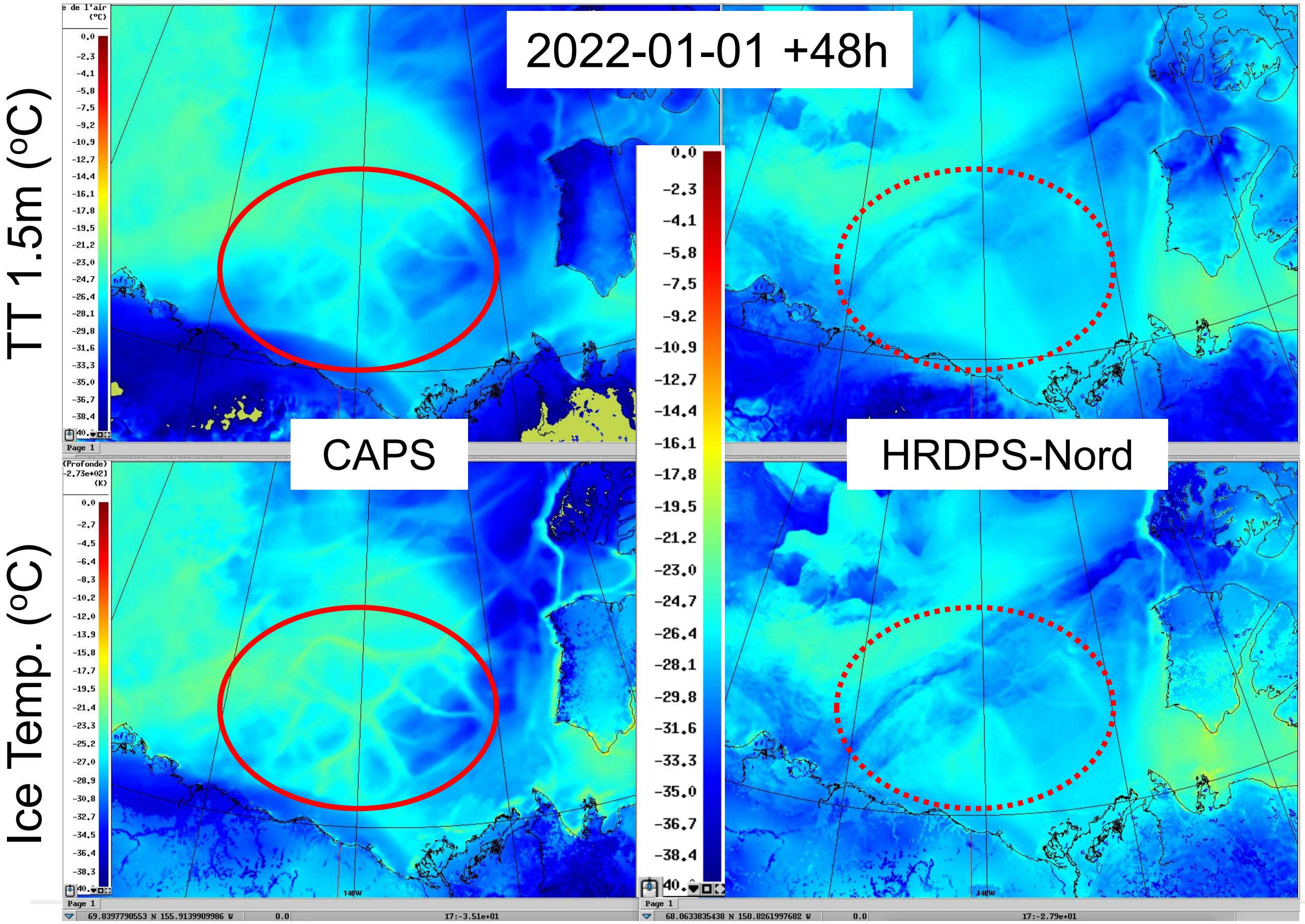
Frequent Polynia
(landfast ice)

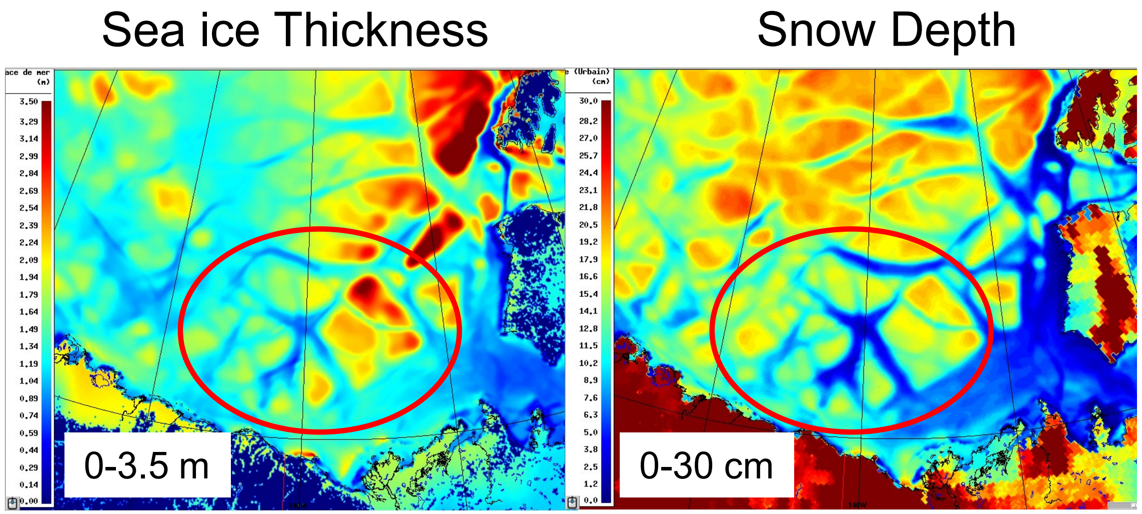
Areas of frequent lead formation

5. Heat flux through the ice – Case study 2022-01-01

- Stable Sea ice cover: >90%; no leads opening during forecast
- CAPS: Warmer & patterns from ice thickness & snow depth
- HRDPS: Colder both atm & ice temperatures
  warming patterns mostly absent



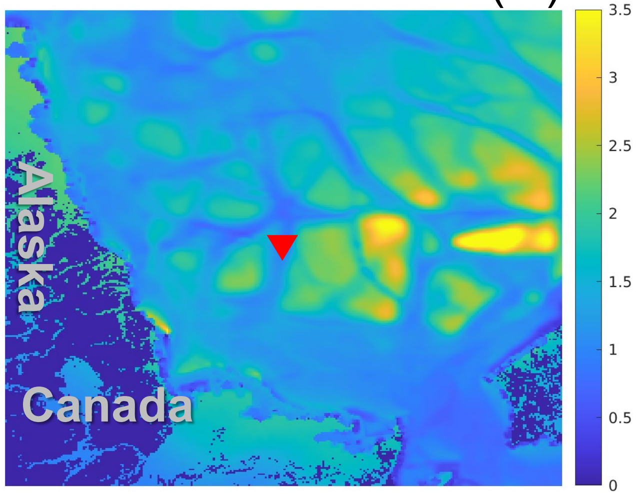




N.B.
- CAPS&HRDPS-Nord: SIT & SD initilized from RIOPS
- CAPS: evolving (longer time-scales)
- HRDPS-Nord: Persistence over 48h

5. Heat flux through the ice – Case study 2022-01-01

Sea ice thickness (m)

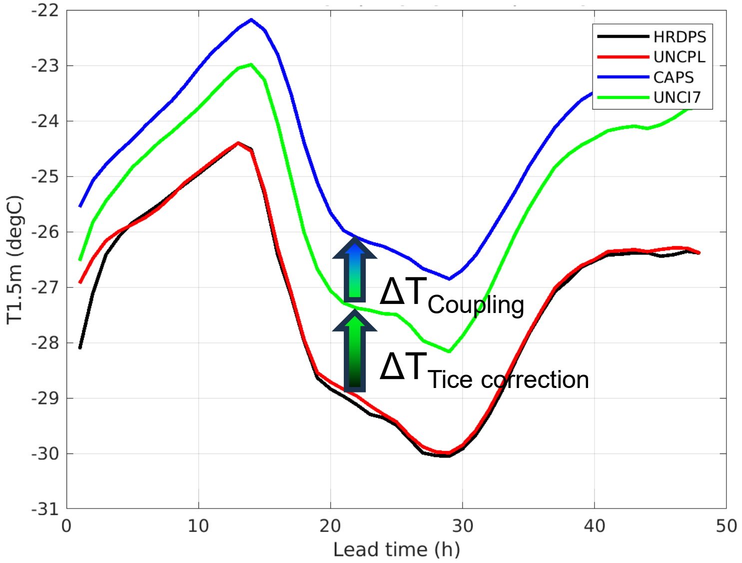


Time series extracted at: ▼

Sea ice cover 99%

Sea ice thickness 0.92m

Evolution Sfc Air Temp (1.5m)



HRDPS-Nord

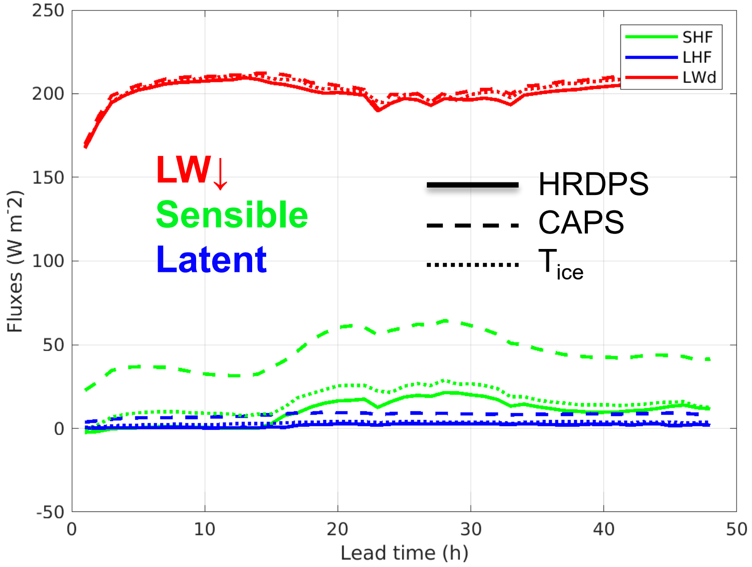
uncoupled (SD_{RIOPS})

CAPS

T_{ice} (uncoupled)

- CAPS warmer (at t=0h; air temp identical)
- T_{ice} warmer vs HRDPS (closer to CAPS)

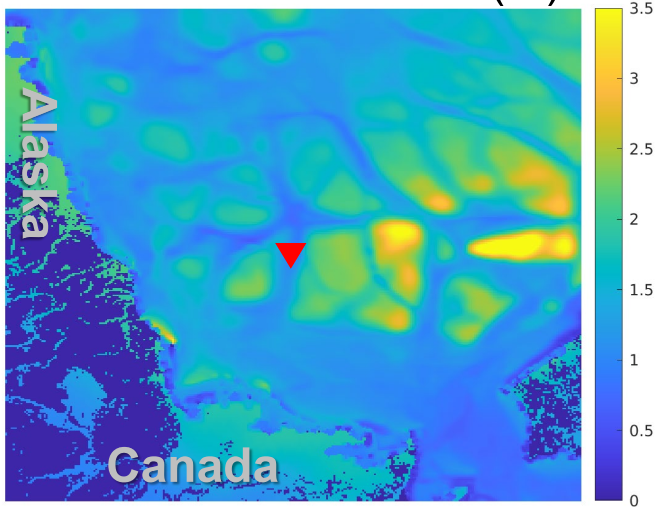
Aggregated fluxes



- Increased Sensible HF in CAPS
  - even with sea ice cover >99%
- Small increase in Latent HF
- No significant change in LW↓ at the surface

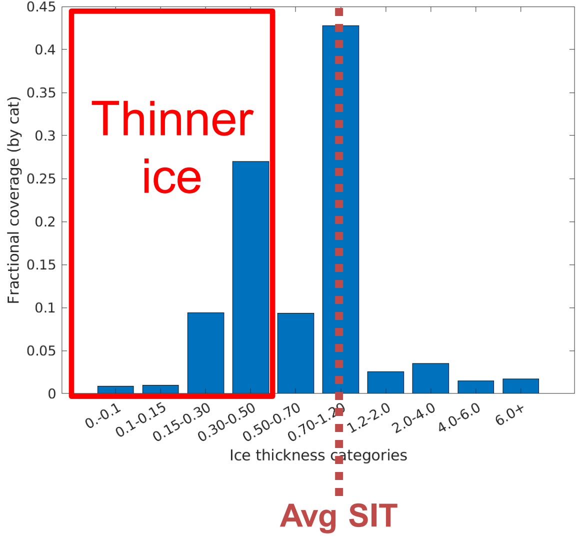
5. Heat flux through the ice – Case study 2022-01-01

Sea ice thickness (m)

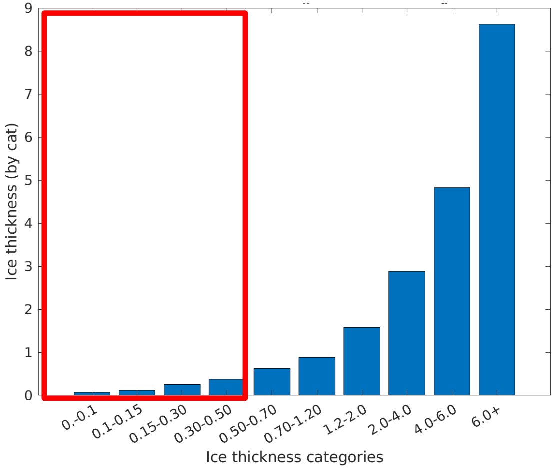


Time series extracted at: ▼
Sea ice cover 99%
Sea ice thickness 0.92m

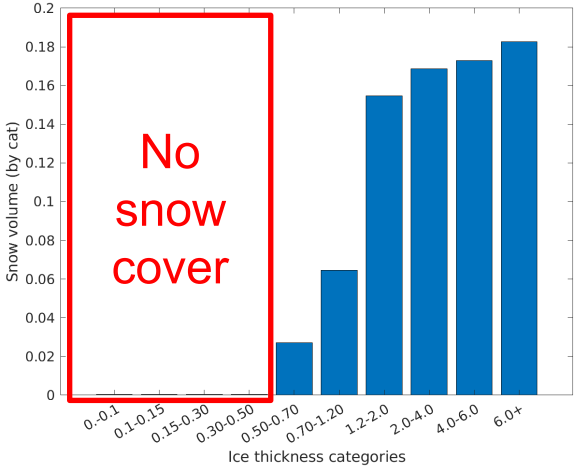
Sea ice cover
per thickness category



Ice thickness by cat.



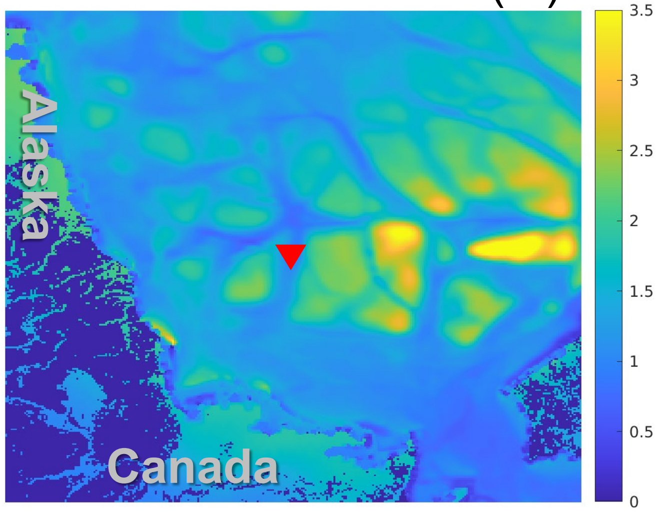
Snow thickness by cat.



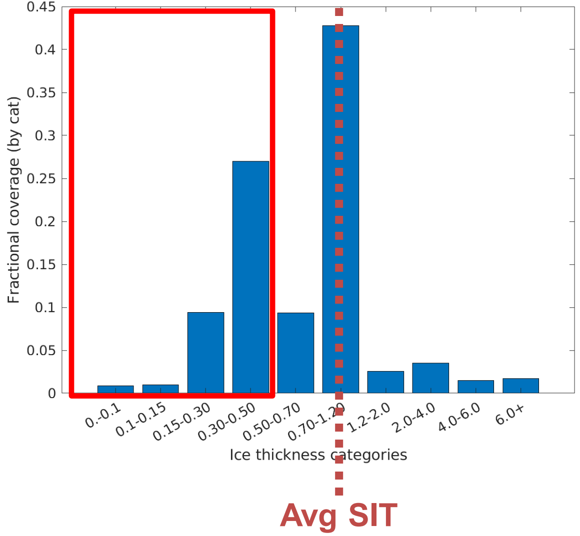
- CAPS (CICE) represents 10 ice thickness categories
  ~40% of thin ice (<0.5m) & no snow on thin ice
- HRDPS sees averaged sea ice (···· 0.92m) & snow (9cm) thicknesses

5. Heat flux through the ice – Case study 2022-01-01

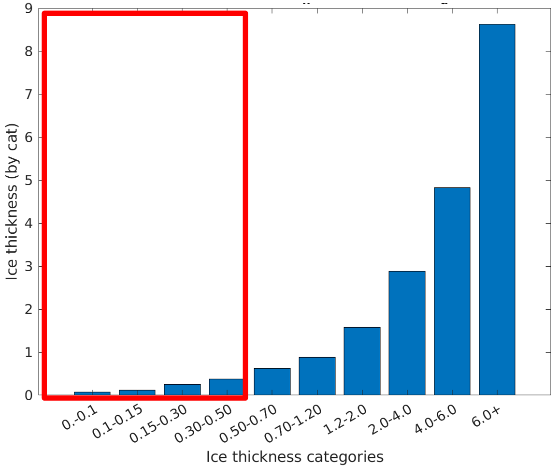
Sea ice thickness (m)



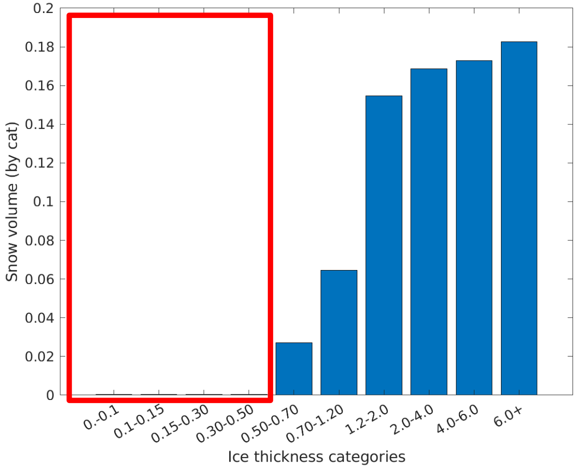
Sea ice cover per thickness category



Ice thickness by cat.



Snow thickness by cat.

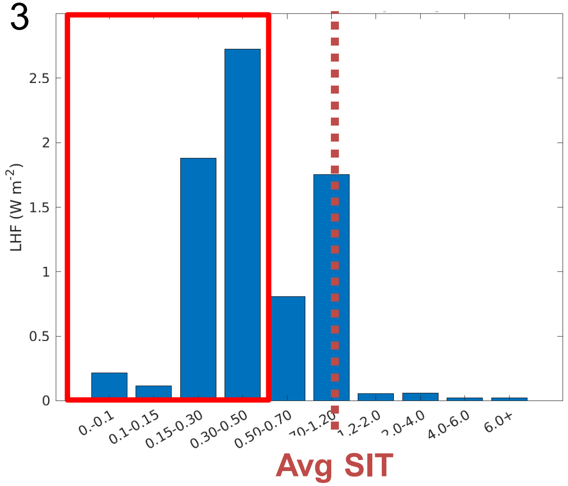


Time series extracted at: ▼

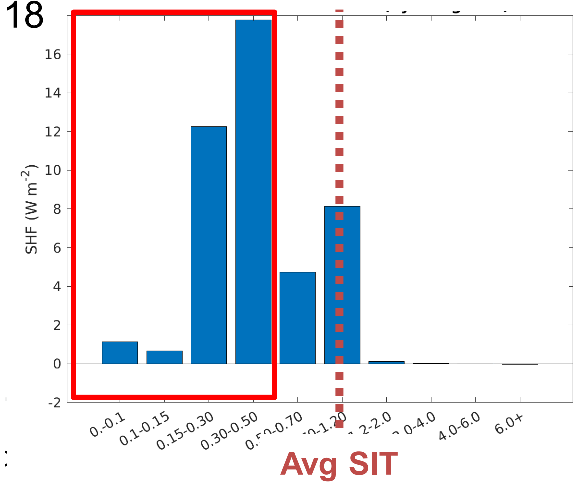
Sea ice cover 99%

Sea ice thickness 0.92m

Normalized Latent HF per ice category (Wm^2)



Normalized Sensible HF per ice category (Wm^2)



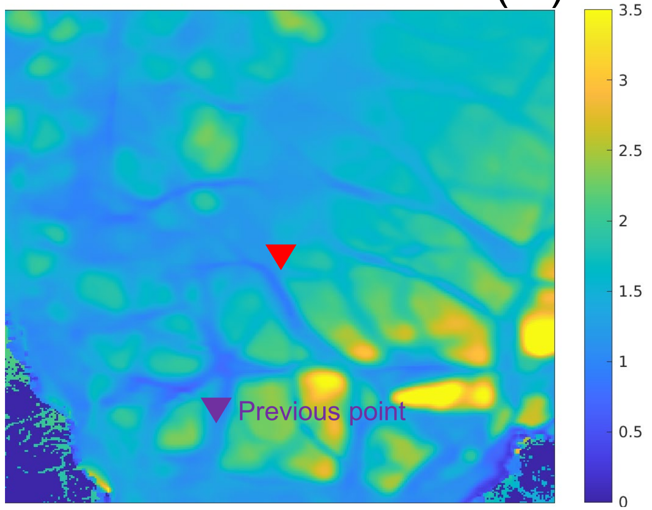
SHF

CAPS = 45 Wm^{-2}

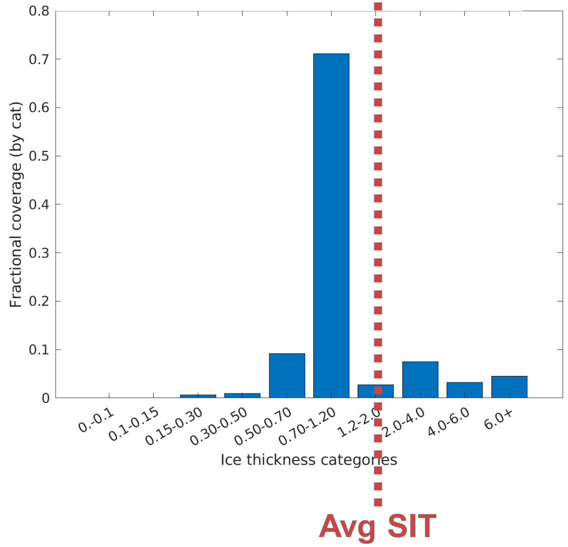
HRDPS = 9.8 Wm^{-2}

5. Heat flux through the ice – Case study 2022-01-01

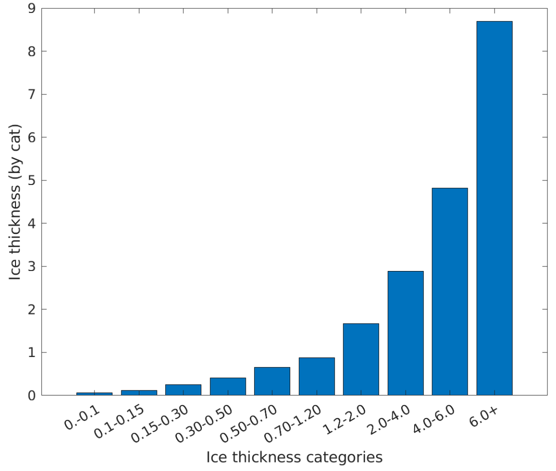
Sea ice thickness (m)



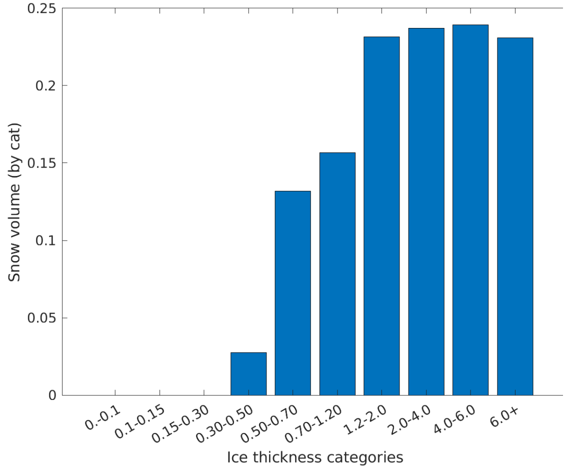
Sea ice cover per thickness category



Ice thickness by cat.



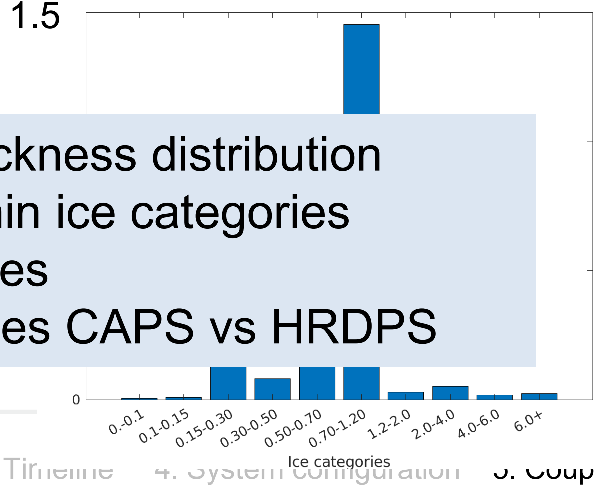
Snow thickness by cat.



Time series extracted at: ▼

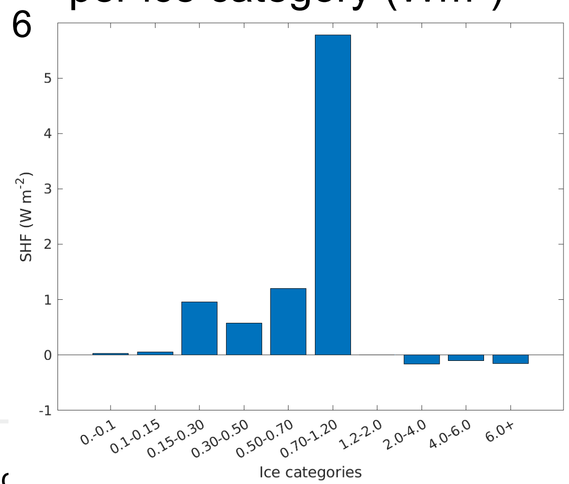
Sea ice cover	99%
Sea ice thickness	1.5m

Normalized Latent HF per ice category (Wm^2)



- More uniform thickness distribution
    - Almost no thin ice categories
- Smaller heat fluxes
- Smaller differences CAPS vs HRDPS

Normalized Sensible HF per ice category (Wm^2)



SHF average

CAPS = 8.2 Wm^2

HRDPS = 2.3 Wm^2

7. Summary

- Upcoming **proposition** to install **CAPS** in operations to replace current uncoupled system (**experimental status**)

- National Defense meteorological and environmental applications require high-resolution coupled pan-Arctic predictions
    - Improves representation and coherence of boundary layer fields (atm&ocean)
    - Fine-scale orography & sea ice cover has large impact on near-surface winds in the Canadian Archipelago

PHYSICS

- Uncoupled : Winter warm surface temperature bias/drift
    - Potentially due to overprediction of clouds
    - Ice temperature initialization error keeps ice covered areas artificially cold (error compensation)
- CAPS warmer in winter – allows for more physical processes to be represented
    - Ice deformation (leads opening)
    - Impact ice thickness distribution on heat fluxes throught thin ice
- CAPS generally **neutral** scores against Ice-Ocean prediction system & inland met. stations

7. Future work

CAPS – Improvements to model components

- Improved winter arctic clouds
- Update physical parameterization package (HRDPS-Nat)
- Coupled processes & boundary layer
- Wave-ocean & wave-ice interactions
- Improved sea ice rheology
- Form drag in CICE
- Mushy-layer thermodynamics
- Ice thickness insertion
- Landfast Ice : refinement of the probabilistic seabed-ice keel interactions (Dupont et al. 2022)

Experimental configuration changes & potential applications

- Improve CAPS initialization
- Impact of extended coupled forecasts from 48h to 84h (eventually replacing RIOPS-f)

7. Future work – In-depth evaluation

Special observing periods

2018	Iceland-Greenland Seas Project (IGSP)	winter collocated A-I-O observations
2019-20	MOSAiC	1-year collocated A-I-O observations
2024/25	Svalbard Marginal Ice Zone (SvalMIZ)	obs + model intercomparison project
2026	PONEX	clouds&microphysics (Beaufort Sea)

Additional diagnostic & new methods

- Conditional evaluation (coastal stations vs wind directions)
- Evaluation against CM-SAF clouds & radiation products
- SST & Ice surface temperature data
- Ice thickness distribution: Upward-looking sonars (Beaufort Gyre; Fram Strait)
- Ice drift against Sea Ice Deformation and Rotation Rate (SIDRR; Plante et al 2025)
- Impact of resolution on winds in orographically controlled areas & MIZ (i.e. CAA, Greenland)

Reference

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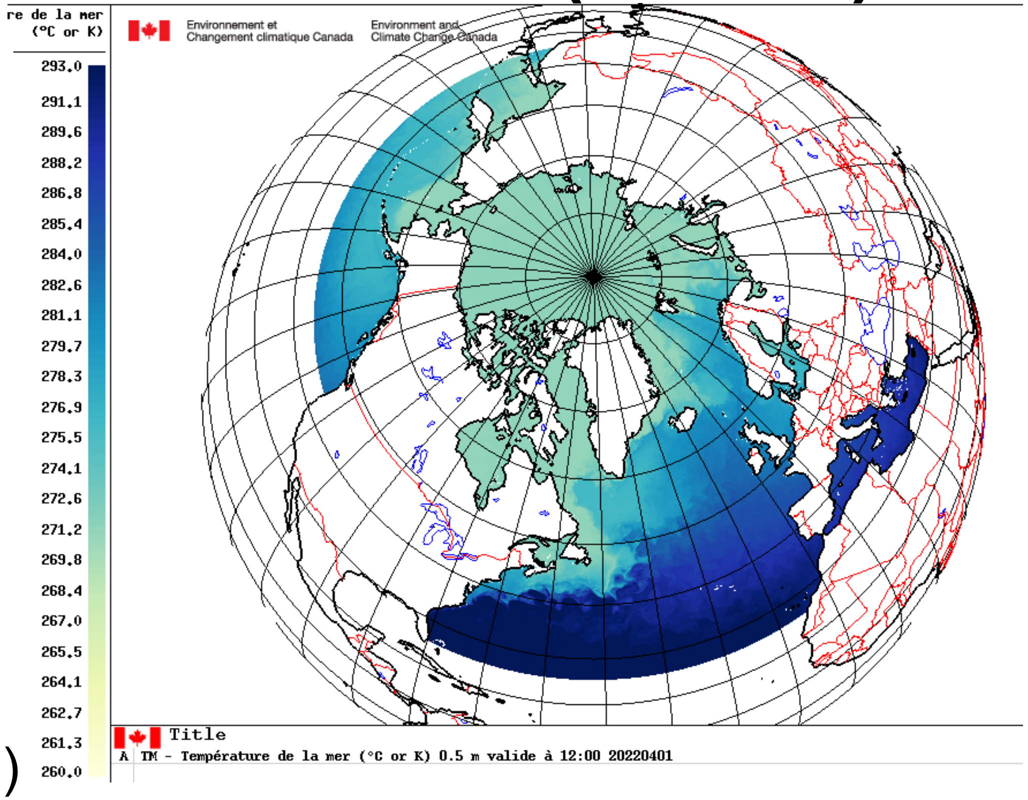
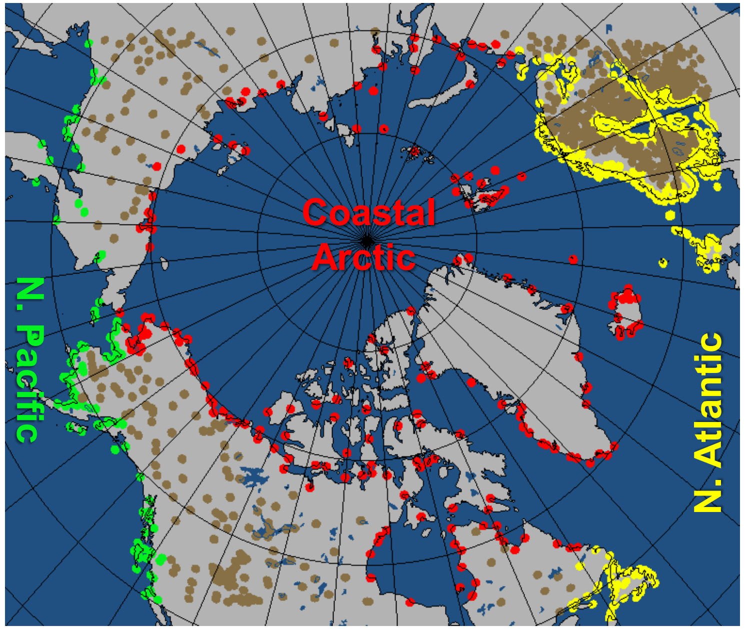
REGIONAL ICE-OCEAN PREDICTION SYSTEM (RIOPS)



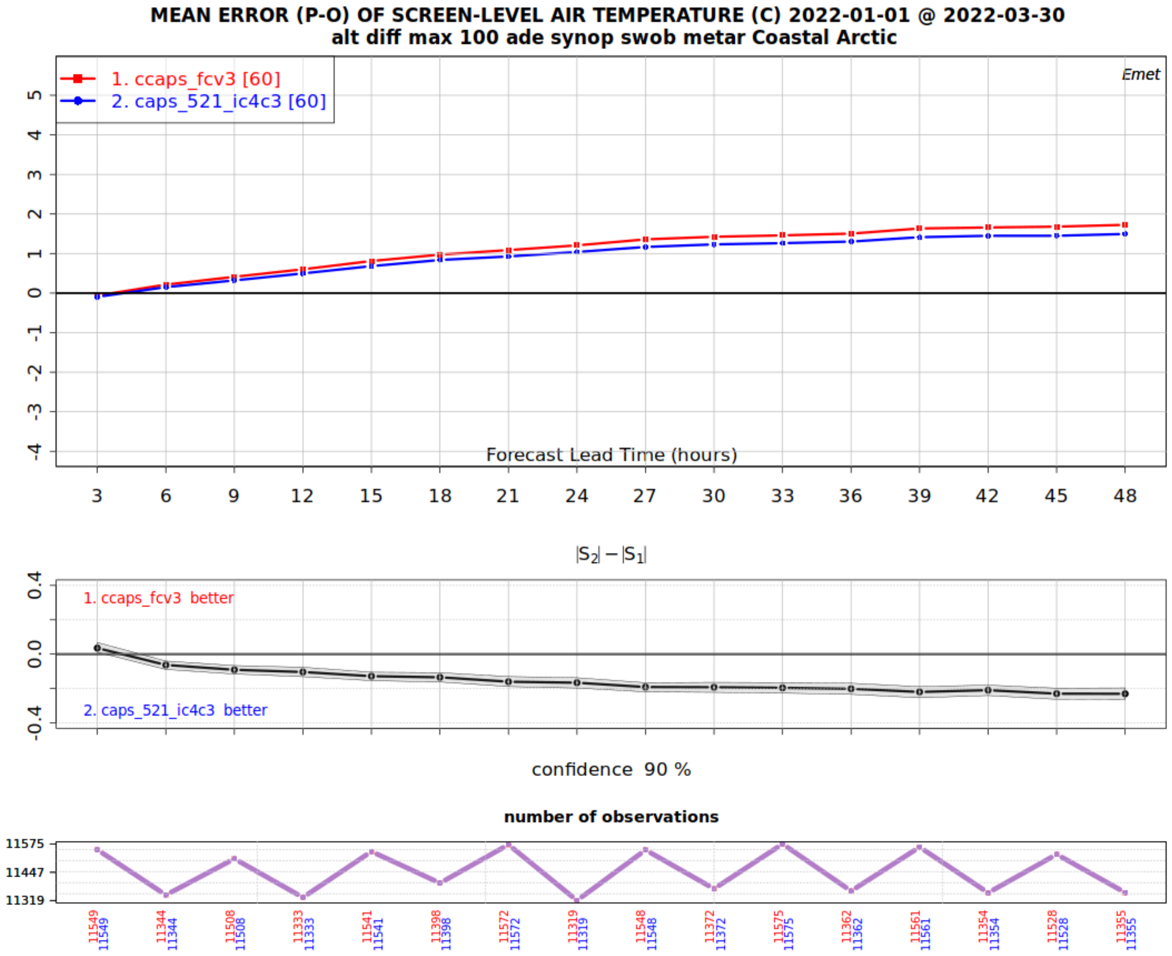
NEMO – CICE (same as used in CAPS) - 3-8 km

- Improved ice model physics
  - Landfast ice, tensile strength
- SAM2 ocean data assimilation
  - T&S (Argo, CTD, XBT, moorings, marine mammals)
  - SST (satellite & in situ observations)
  - SLA from satellite altimeters (AVISO)
- Tidal online harmonic analysis
- Updated Mean Dynamic Topography (Smith et al. 2024)
- Ice initialization
  - Rescale Forecast Tendencies (RFT; Smith et al. 2015)
  - Blending with RIPS ice analysis + Coherence check SST & ice
    - 5km resolution, 4x daily
    - SSMI, SSMI/S,AVHRR, ASCAT, AMSR2,CIS charts, RCM images
- Atmospheric forcing
  - Global Deterministic Forecasting System (10km)
  - T, q, winds (at 1st prognostic lvl); SW&LW↓, precip, MSLP
- **Short-term forecasts (84h) 4xday**

6. Temperature drift in atmospheric component – CAPS vs HRDPS



CAPS vs HRDPS (I7 corrected)



New control (HRDPS-Nord) under way

- Corrected Ice temperature profiles

Preliminary results:

- Winter bias over Coastal Arctic now very similar between HRDPS & CAPS
- Next Step: better understand & fix the drift

SEA ICE – LANDFAST ICE & RHEOLOGY

Adding a new term in sea ice rheology

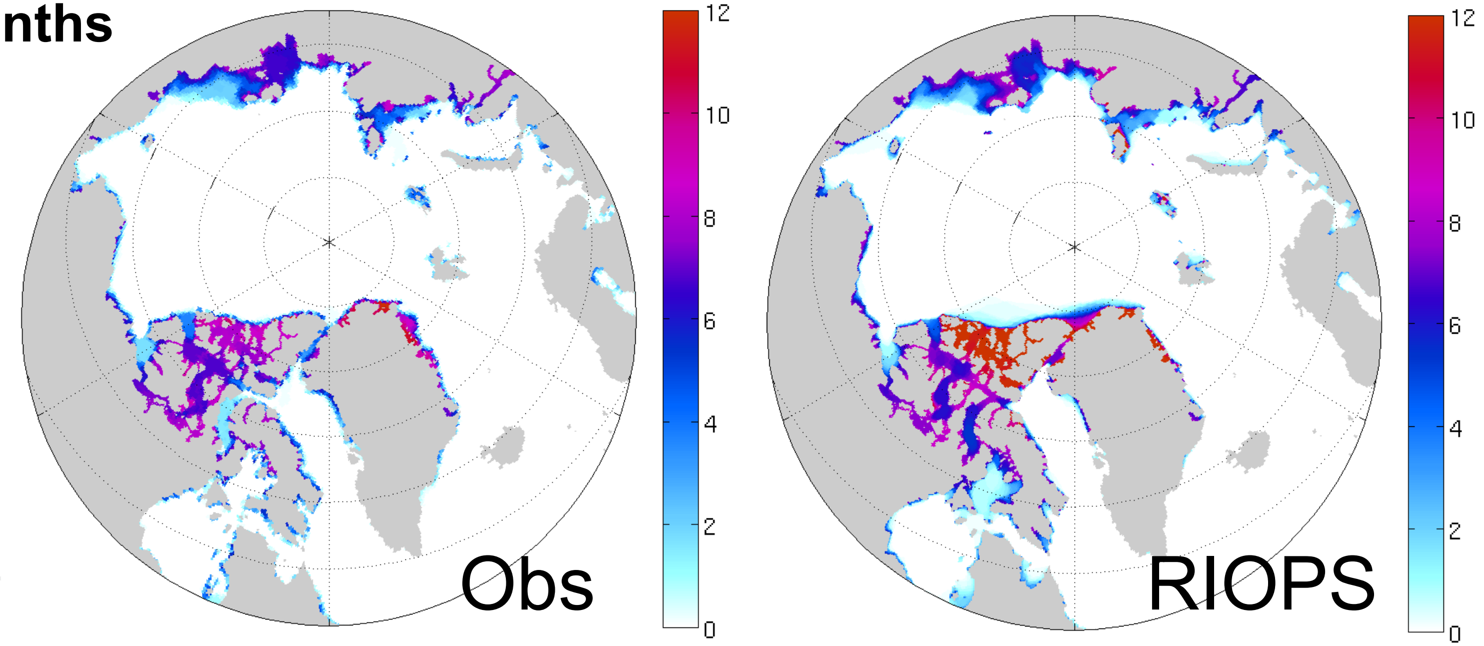
$$m\frac{D\boldsymbol{u}}{Dt} = -mf\hat{k}\times\boldsymbol{u} + \boldsymbol{\tau}_a + \boldsymbol{\tau}_w + \boxed{\boldsymbol{\tau}_b} - mg\nabla H_d + \boxed{\nabla\cdot\sigma}$$

seabed stress

rheology

Lemieux et al., 2016

Number of months per year with landfast ice



Lemieux et al., 2018

RIOPS - SEA ICE VERIFICATION

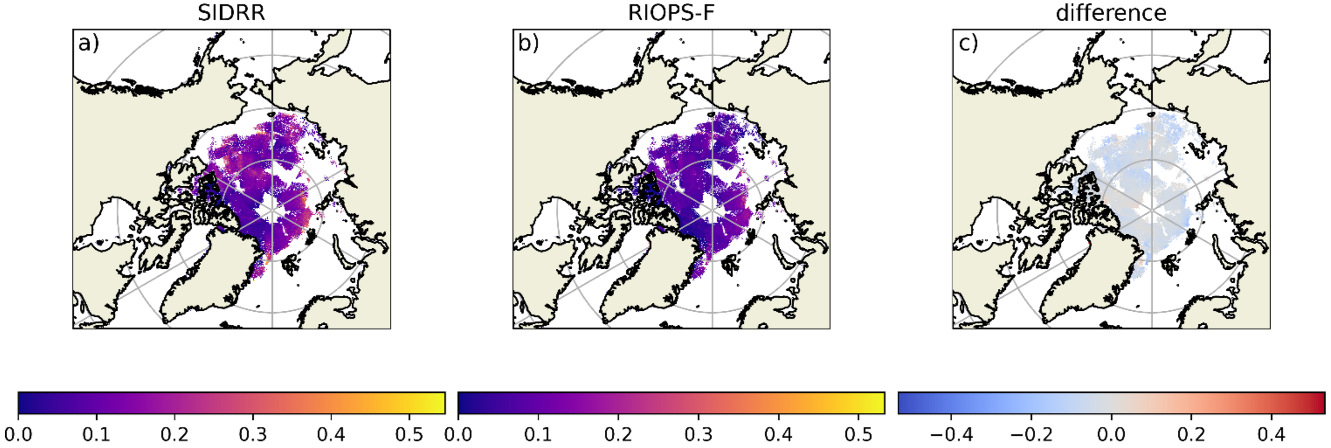
Sea Ice Rheology Experiment (SIREx)

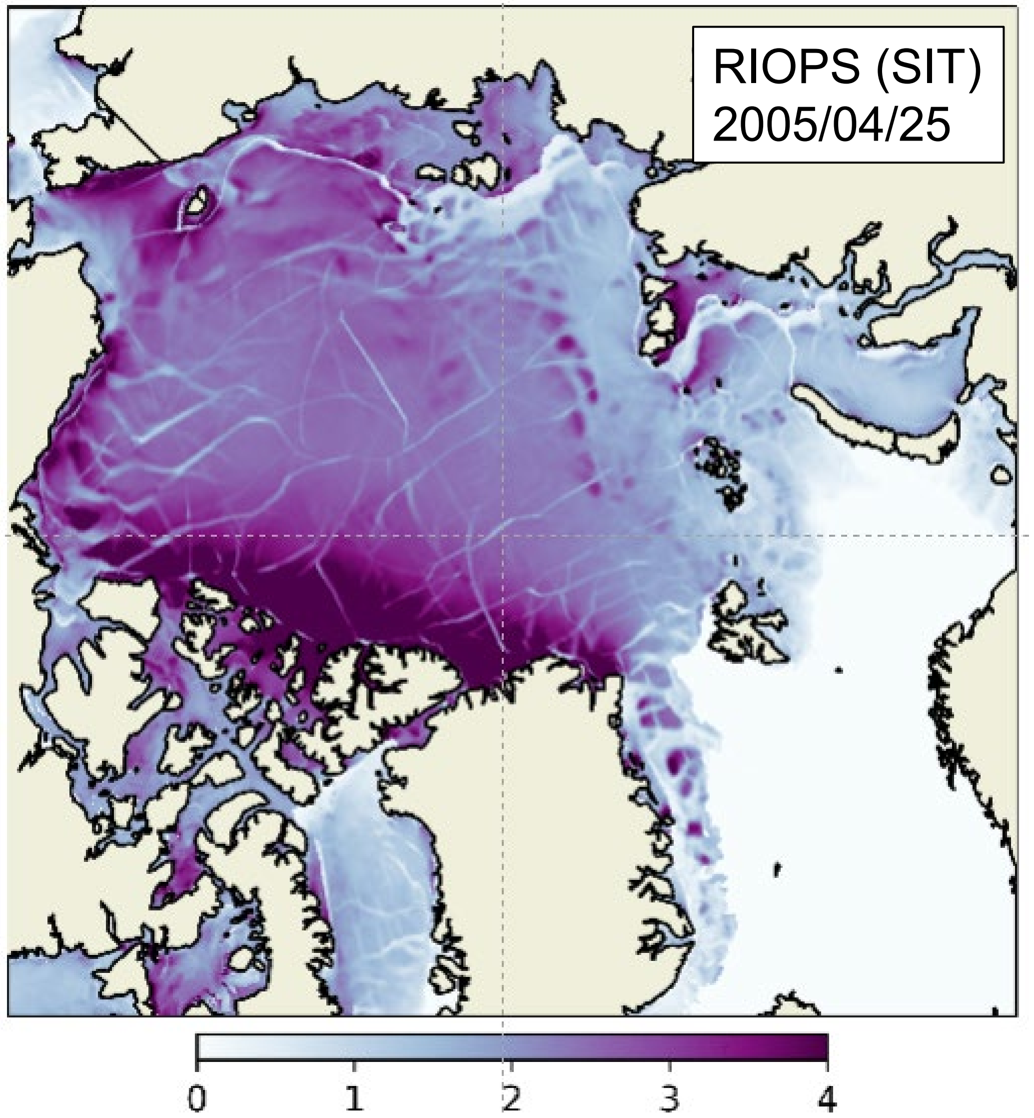
(Bouchat et al. 2002; Hutter et al. 2022)

- RIOPS - good performance
    - Modified **rheology parameters** (e=1.5) (good representation of LKFs)
    - Good numerical **convergence** (900 subcycles)

Current work

- Investigation of misrepresentation of angles between fault lines (common to most ice models)
- Ice drift evaluation using RCM data

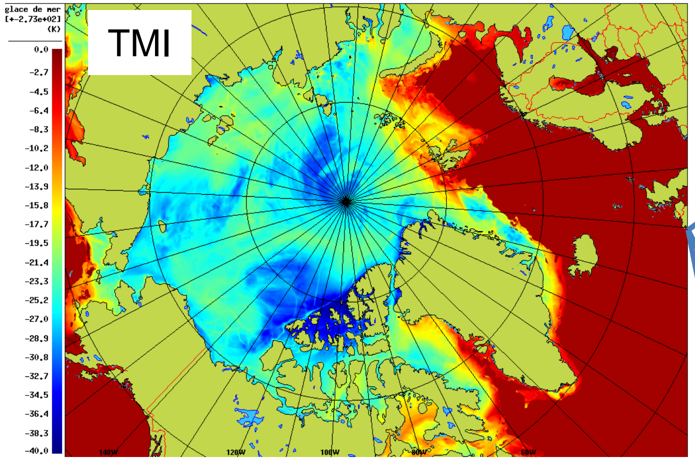




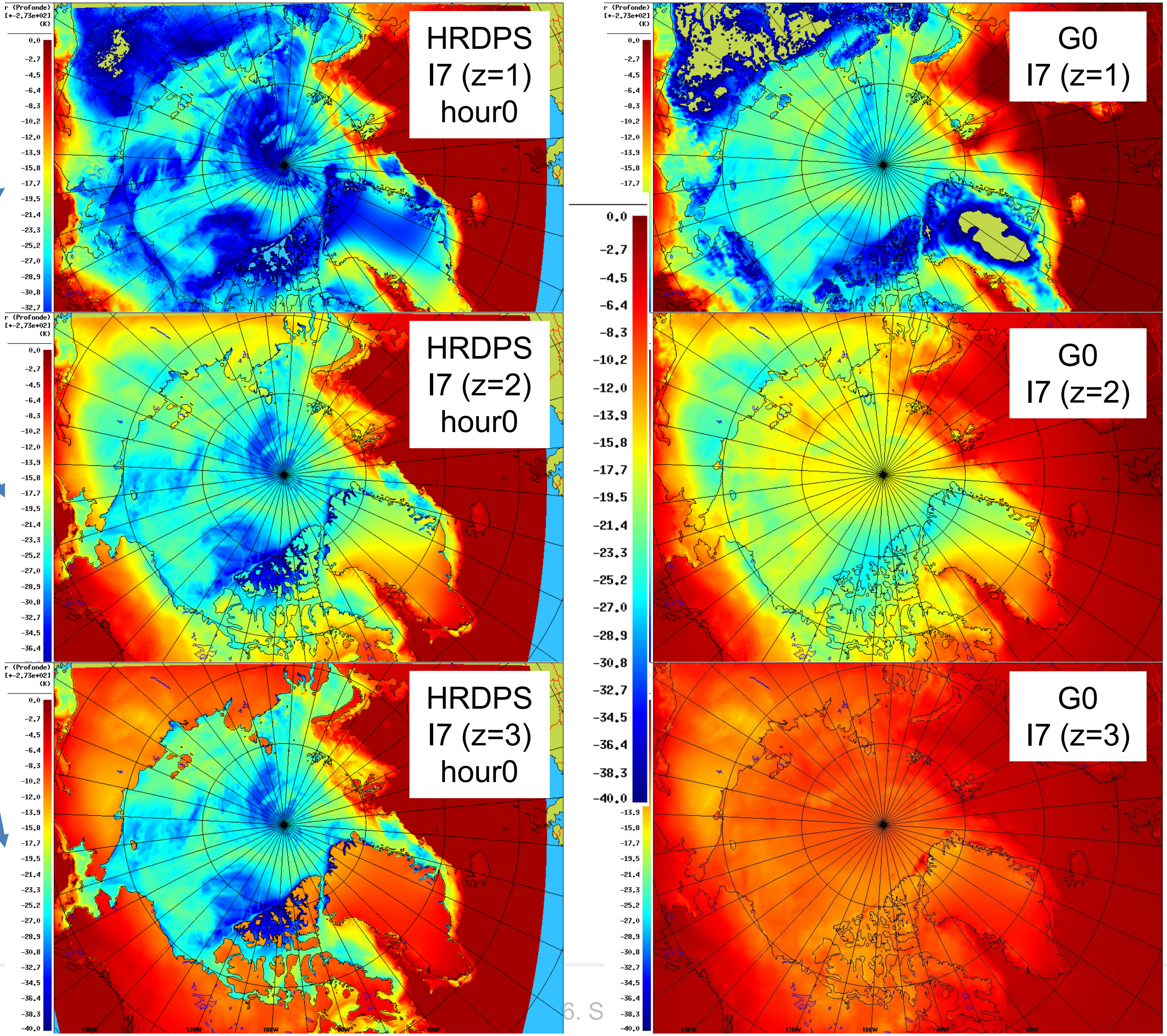
RIOPS (SIT)
2005/04/25

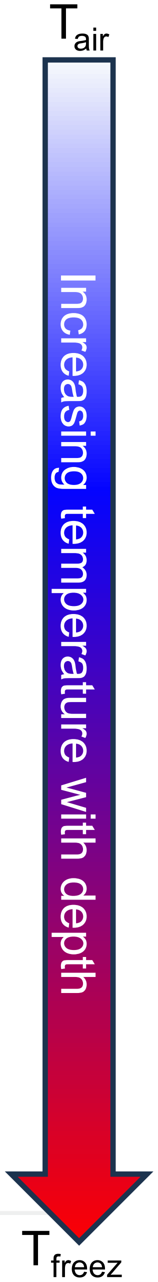
5. Ice temperature initilization – issue in HRDPS-Nord

RIOPS atmosphere-ice/snow interface



- TMI is CICE temperature at atmosphere ice/snow interface
- TMI is used to initialize 3 ice levels in HRDPS-Nord (seaice.F90)
    - for **final cycles**
    - Also in **operations**
- Makes ice temperatures unrealistic (esp. at level close to ocean sfc)
- Thermal inertia was added to Semtner-type ice model



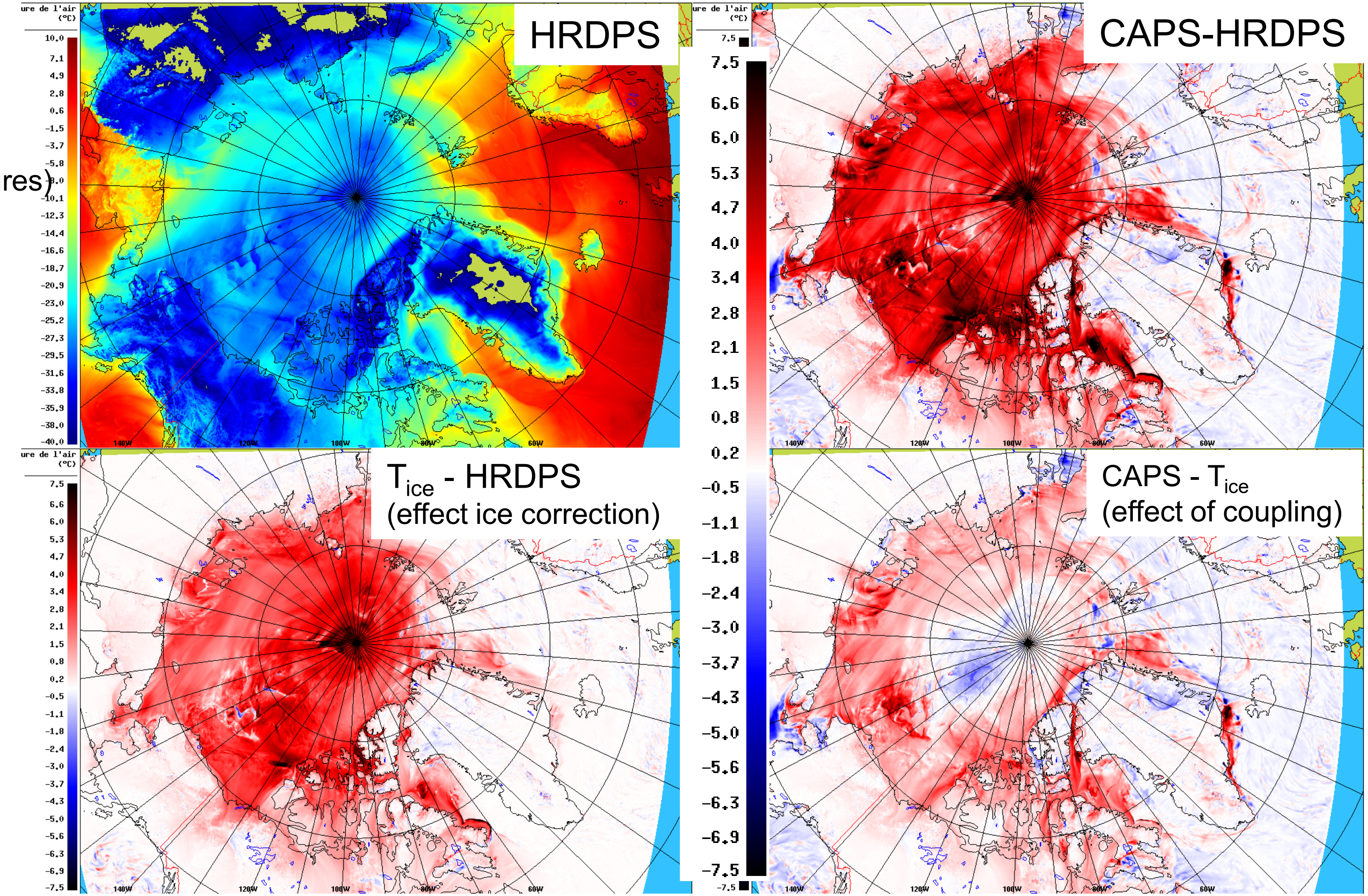


5. Ice temperature initilization – issue in HRDPS-Nord

Test case 2022-01-01 (48h forecast)

1. HRDPS (ref)
2. CAPS
3. T_{ice}: Uncoupled (corrected ice temperatures)
   - 1st level: from RIOPS
   - 2nd & 3rd: from G0

- Correcting ice temperature profile large-scale warming TT (1.5m)
- magnitude of diff. similar between T_{ice} & CAPS
- Effect of coupling visible
  - Areas of ice deformation & thinner ice
  - Advection of warmer temperatures



at h48