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Sea Ice Data Assimilation for Coupled Prediction at Environment and Climate Change Canada

International Workshop on Coupled Data Assimilation

Toulouse, France

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18-21 October 2016

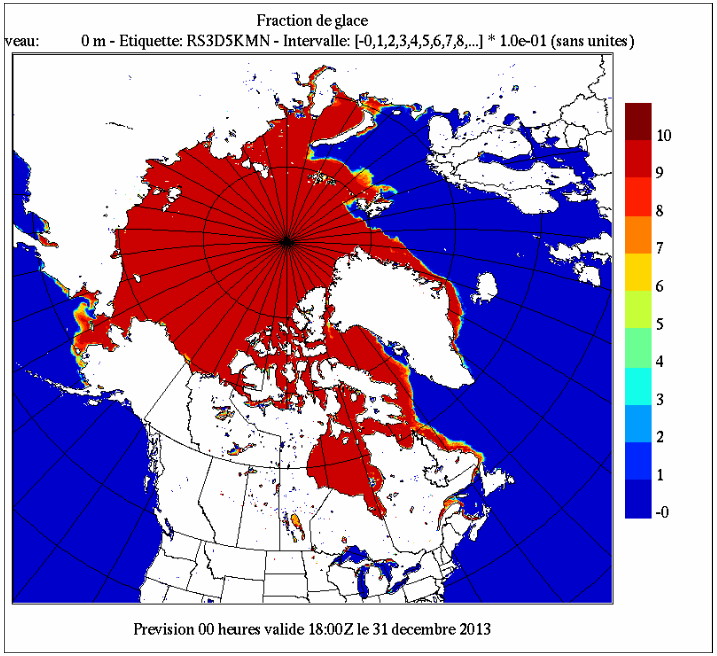
Contents

- Regional Ice Prediction System
  - System overview
  - Recent addition of new observations
- Ensemble covariances for strongly coupled assimilation
- Initialization of global coupled forecasts
- Conclusions

Regional Ice Prediction System

Originally created for supporting operational ice service

- RIPS v2.2.1:
  - ~ 5.0 km resolution
  - 4 analyses and forecasts per day
- Analysis system (Buehner et al. 2016)
  - estimates total ice concentration and analysis error stddev
  - background = analysis 6 hours earlier
  - observation types assimilated:
    - CIS image analyses, CIS daily and regional ice charts, lake bulletins
    - SSM/I, SSM/IS (3 satellites), AMSR2, ASCAT, AVHRR
  - ice removed where SST > 4°C
  - ice field corrected where analysis-error is high

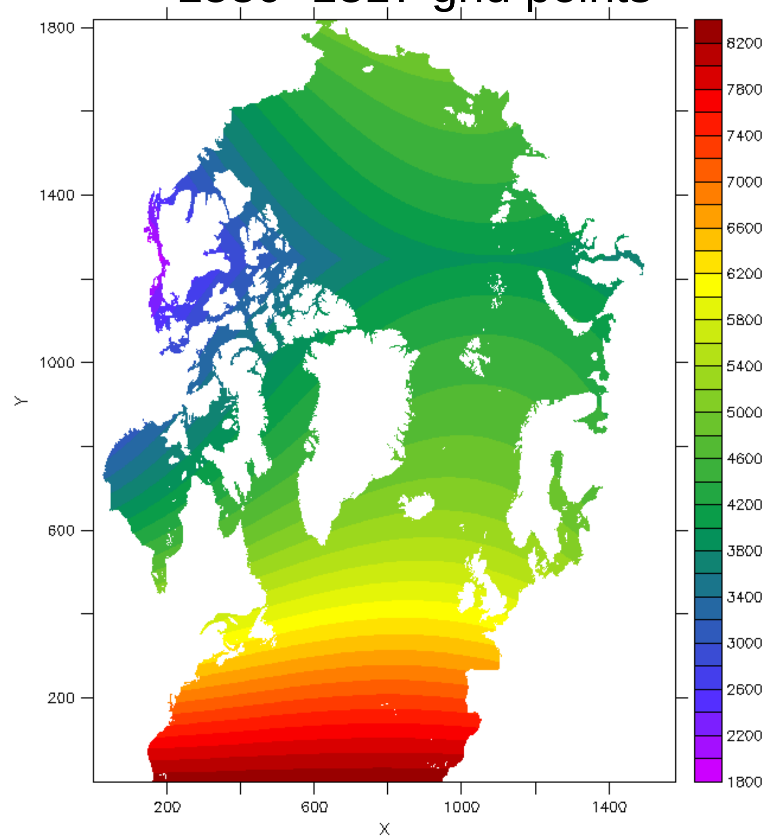


1768 × 1618 grid points

Forecast system

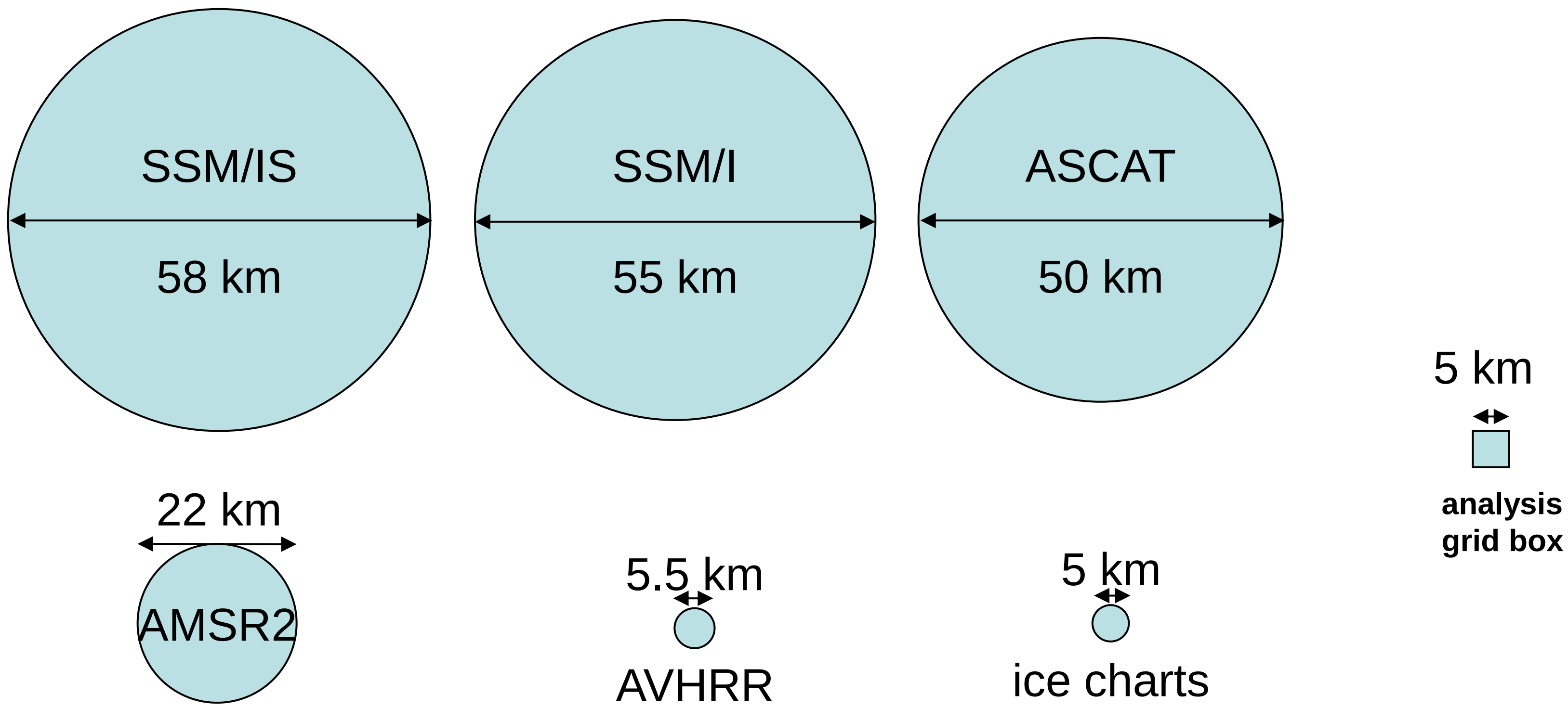
- CICE sea ice model coupled with NEMO
- Subset of ORCA grid, 1/12° spacing
- Spectral nudging of ocean T&S to Global Ice Ocean Prediction System (in lieu of ocean assimilation)
- 48 hour forecasts
- Lemieux et al. (2014) for more details

1580×1817 grid points

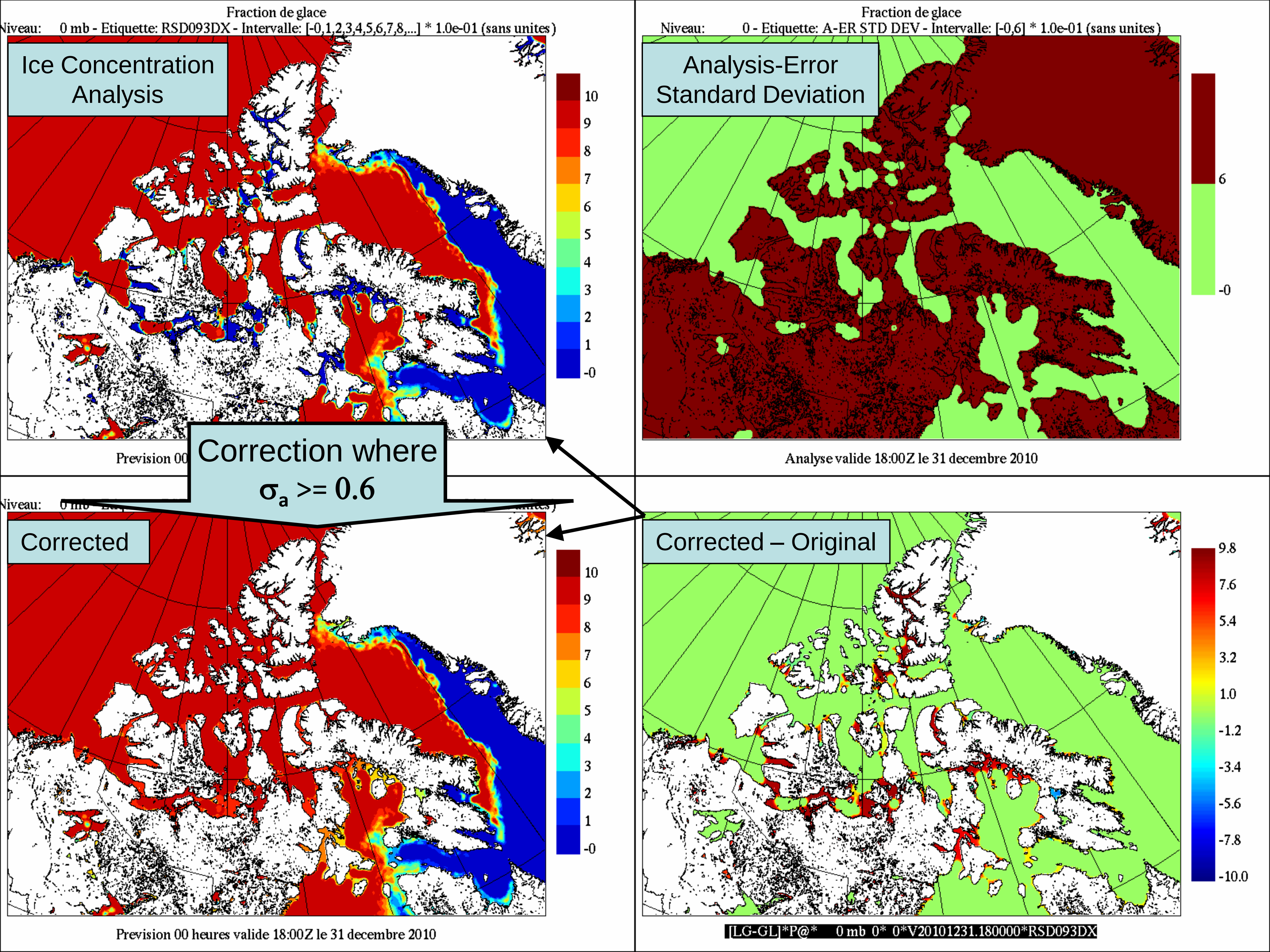


Resolution (m)

Observation footprints



Observations must be rejected if footprint touches land, removing many obs near coast and in narrow channels


Fraction de glace
Niveau: 0 mb - Etiquette: RSD093DX - Intervalle: [-0,1,2,3,4,5,6,7,8,...] * 1.0e-01 (sans unites)
Ice Concentration Analysis
10
9
8
7
6
5
4
3
2
1
-0
Prevision 00
Fraction de glace
Niveau: 0 - Etiquette: A-ER STD DEV - Intervalle: [-0,6] * 1.0e-01 (sans unites)
Analysis-Error Standard Deviation
6
-0
Analyse valide 18:00Z le 31 decembre 2010
Correction where $\sigma_a >= 0.6$
Niveau:
Corrected
10
9
8
7
6
5
4
3
2
1
-0
Prevision 00 heures valide 18:00Z le 31 decembre 2010
Corrected – Original
9.8
7.6
5.4
3.2
1.0
-1.2
-3.4
-5.6
-7.8
-10.0
[LG-GL]*P@* 0 mb 0* 0*V20101231.180000*RSD093DX

Passive microwave data

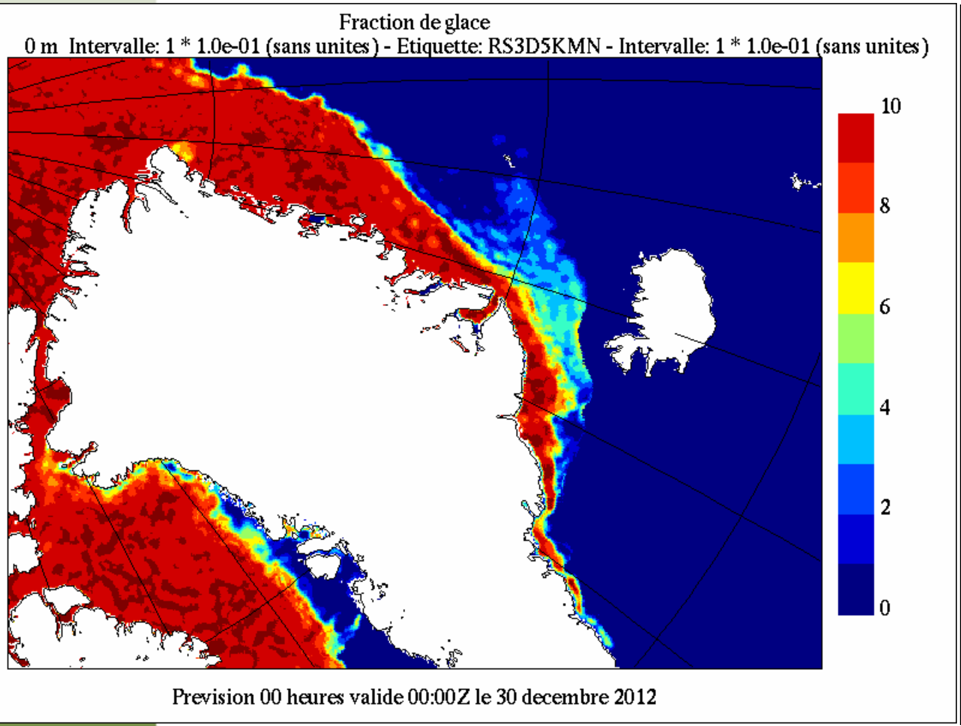
SSMI, SSMIS, AMSR2

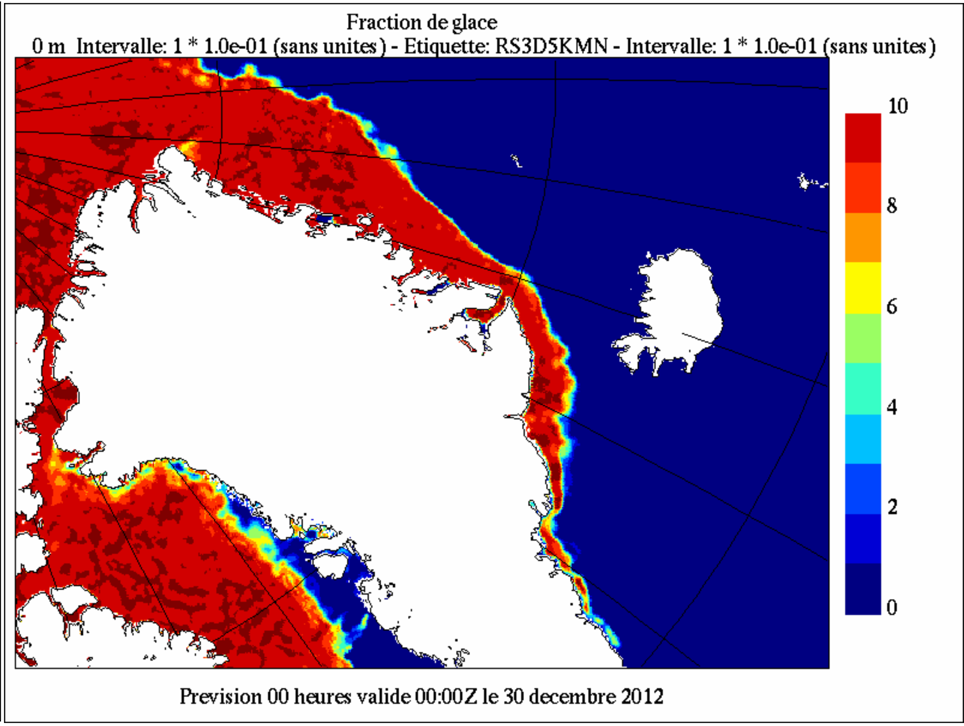
- Assimilation:
  - Ice concentration from NASA Team 2 (NT2) retrieval algorithm
  - Use "footprint" observation operator that aggregates gridded ice concentration over the larger footprint of instrument
- Reject data when:
  - Surface Air Temperature above 0°C, to reduce bias
  - Retrieved ice concentration is not zero AND
    - Sea Surface Temperature (SST) is above 4°C OR
    - Historical frequency of occurrence is 0 OR
    - Wind filter: Wind speed > 25 knots
- Background check:
  - Reject entire observation swath with bad/corrupted data (based on average RMS difference with background state)

Effect of wind filter on the sea ice analysis

No wind filter for SSMI(S)

With wind filter for SSMI(S)



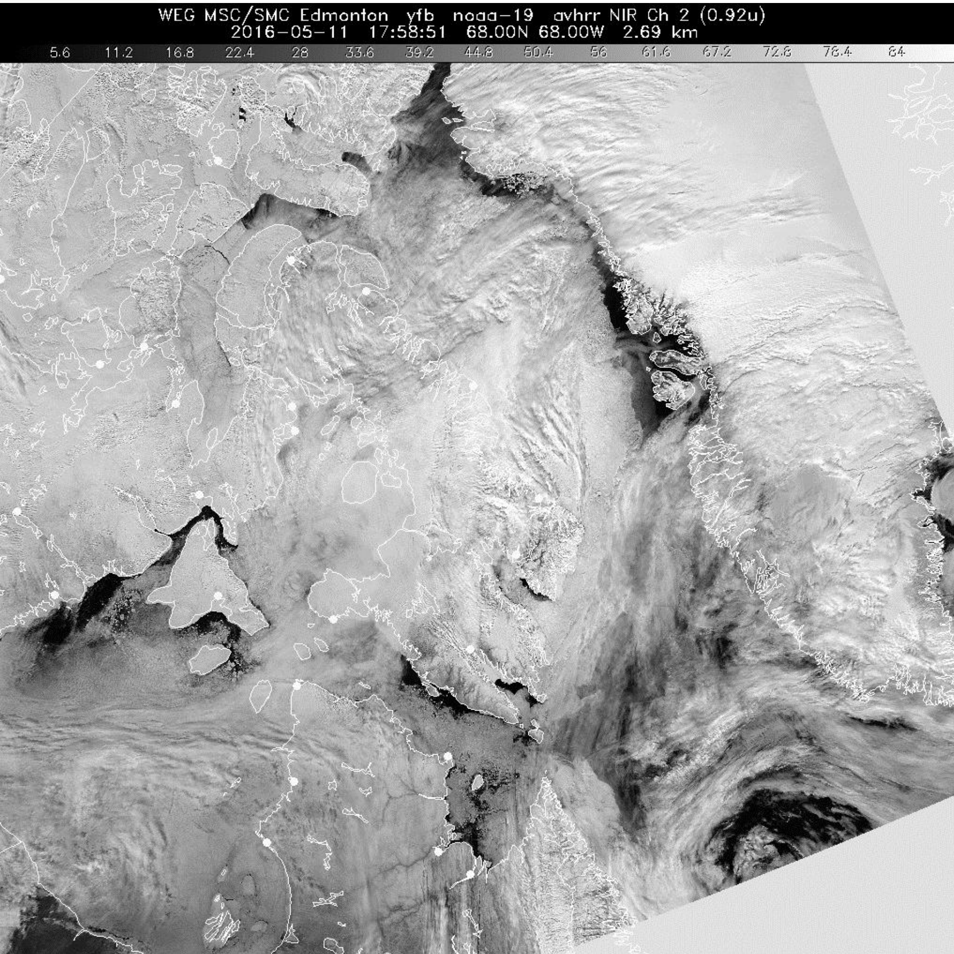


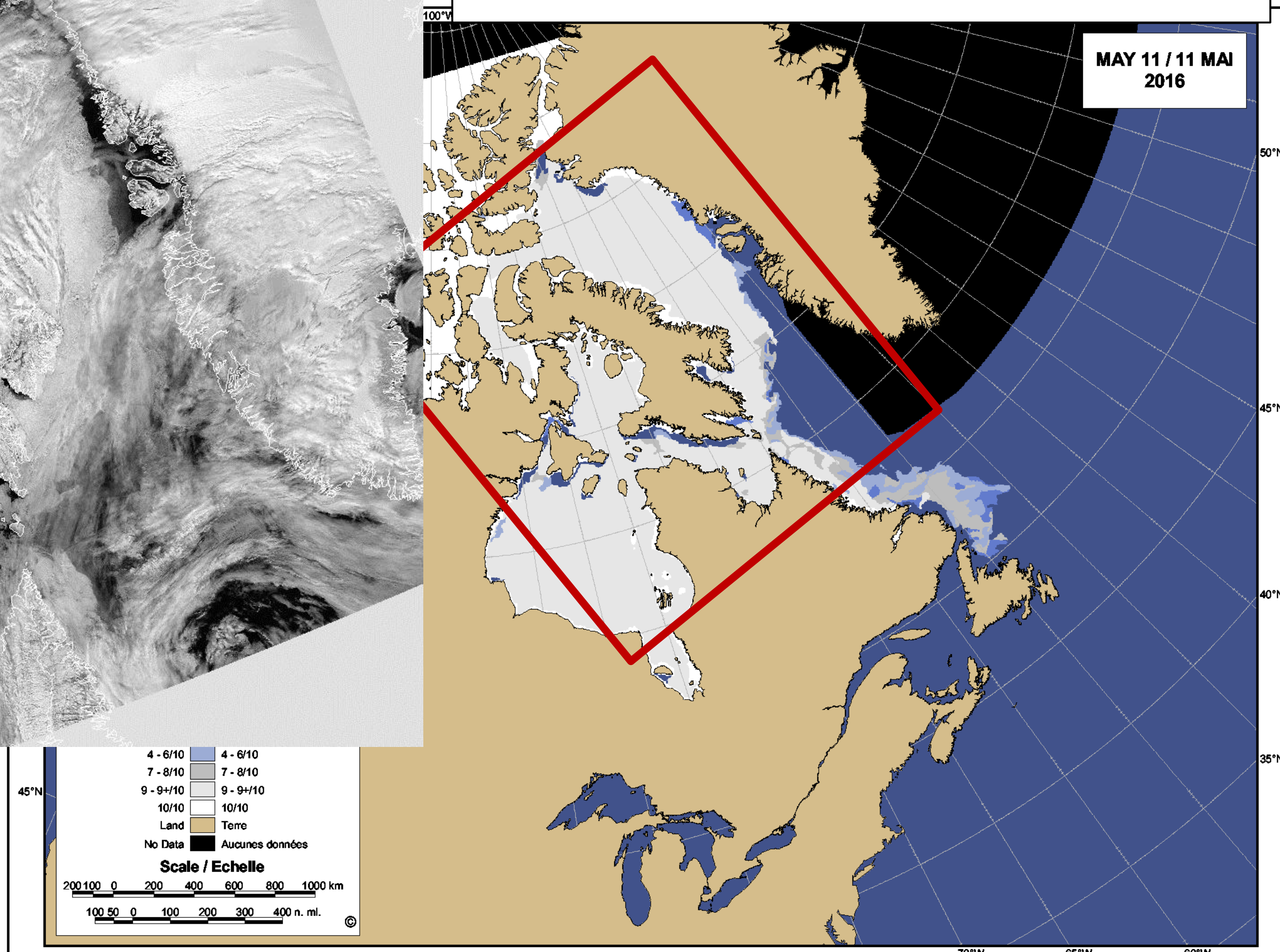
High-resolution AVHRR data

Developed an improved algorithm to filter out most clouds

Developed a simple classification:

ice / water / ambiguous / thin cloud



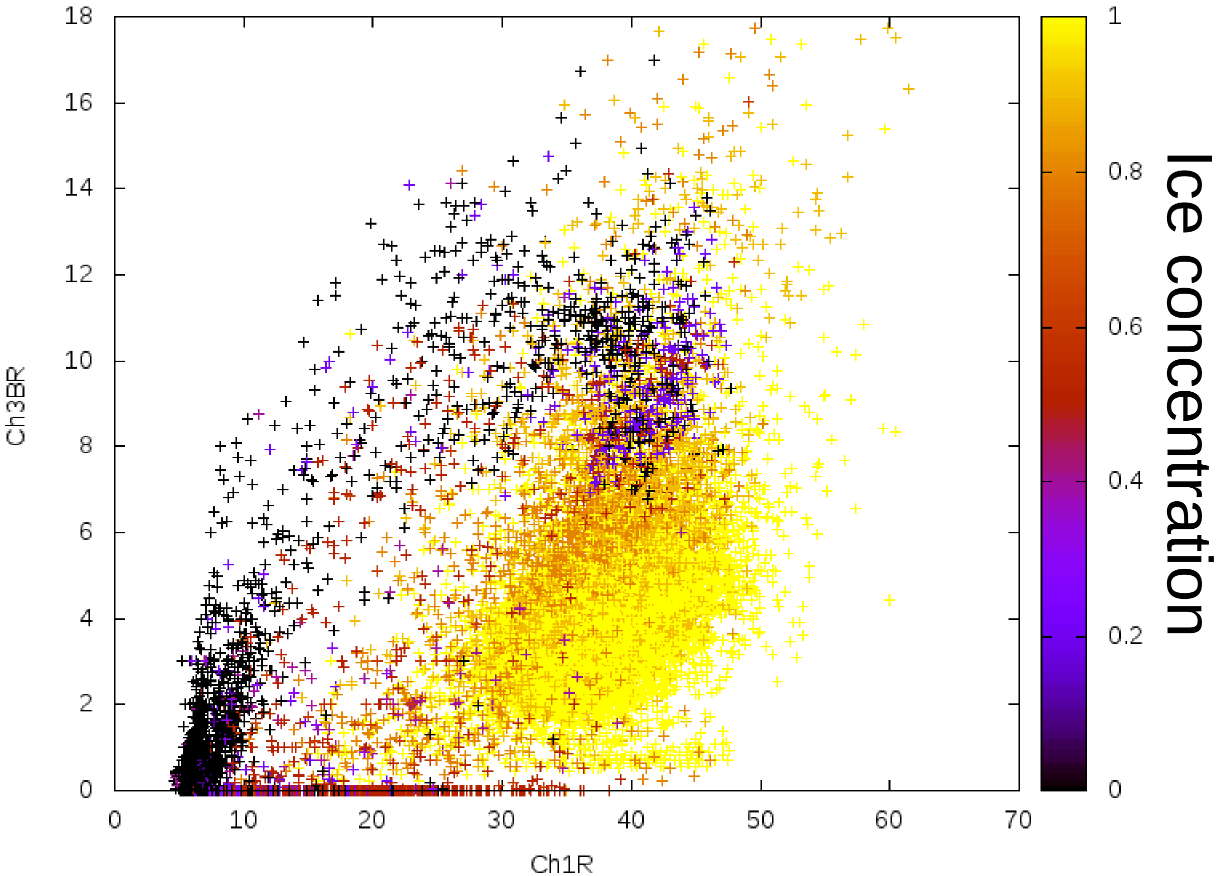


SOURCE: CIS DAILY AND REGIONAL ICE CHARTS / SOURCE: CARTES QUOTIDIENNES ET RÉGIONALES DES GLACES DU SCG

Example: 2011-08-05 16Z Western Arctic

(after thick cloud removed)

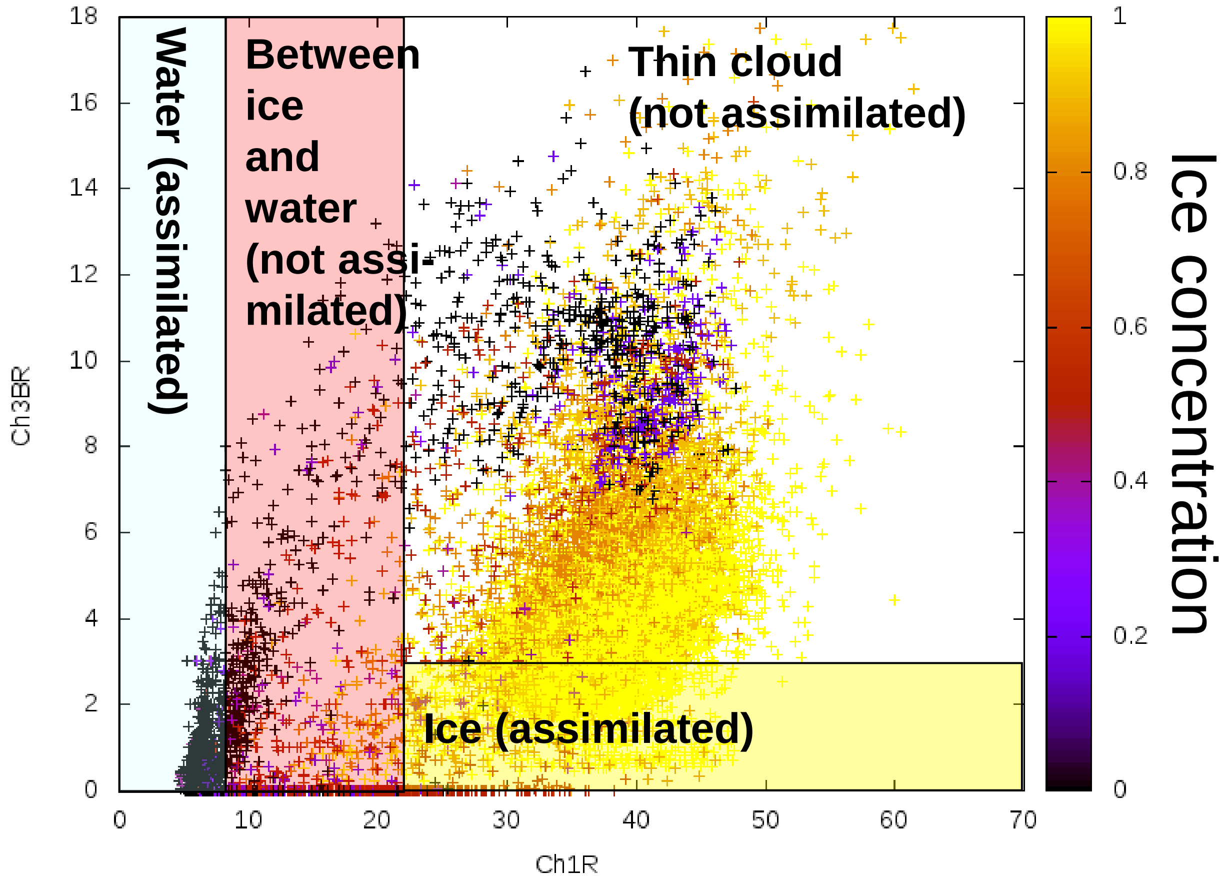
Ice concentration from CIS image analysis



Example: 2011-08-05 16Z Western Arctic

(after thick cloud removed)

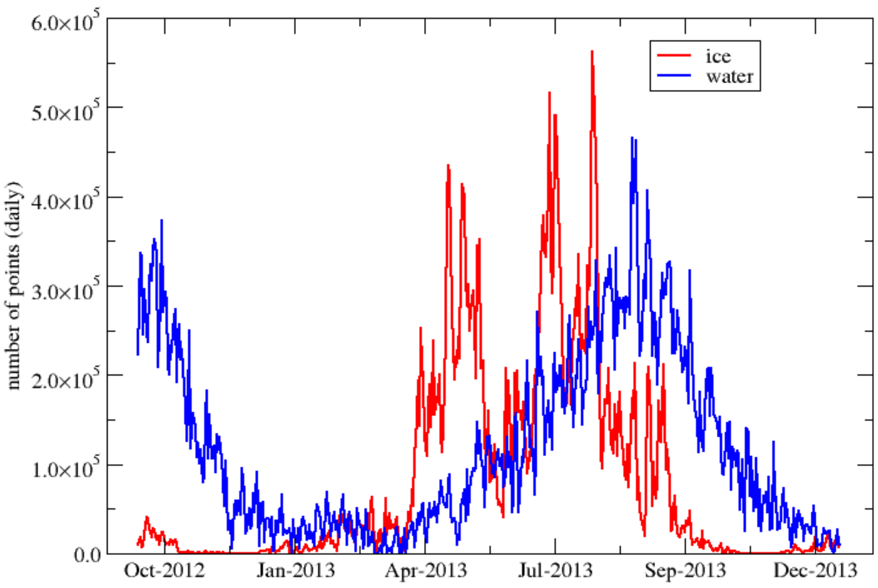
Ice concentration from CIS image analysis



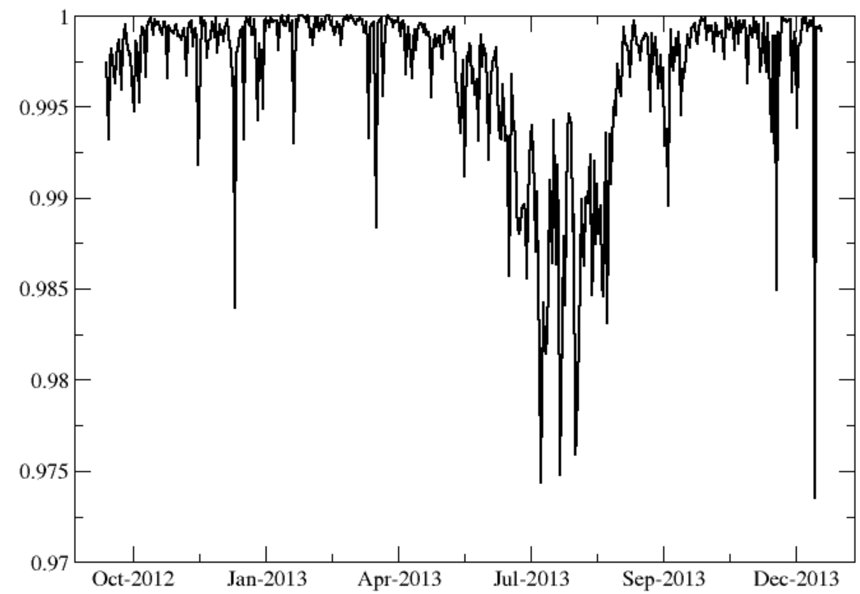
- Most tests done assimilating *Ice* as 100% concentration and *Water* as 0%
- Slightly improved when *Ice* assimilated as:
  - 85% when background concentration < 85%
  - Otherwise, rejected (background already consistent with obs)

Retrieval of Ice and Open water from AVHRR data

Number of AVHRR retrievals:
Ice and open water



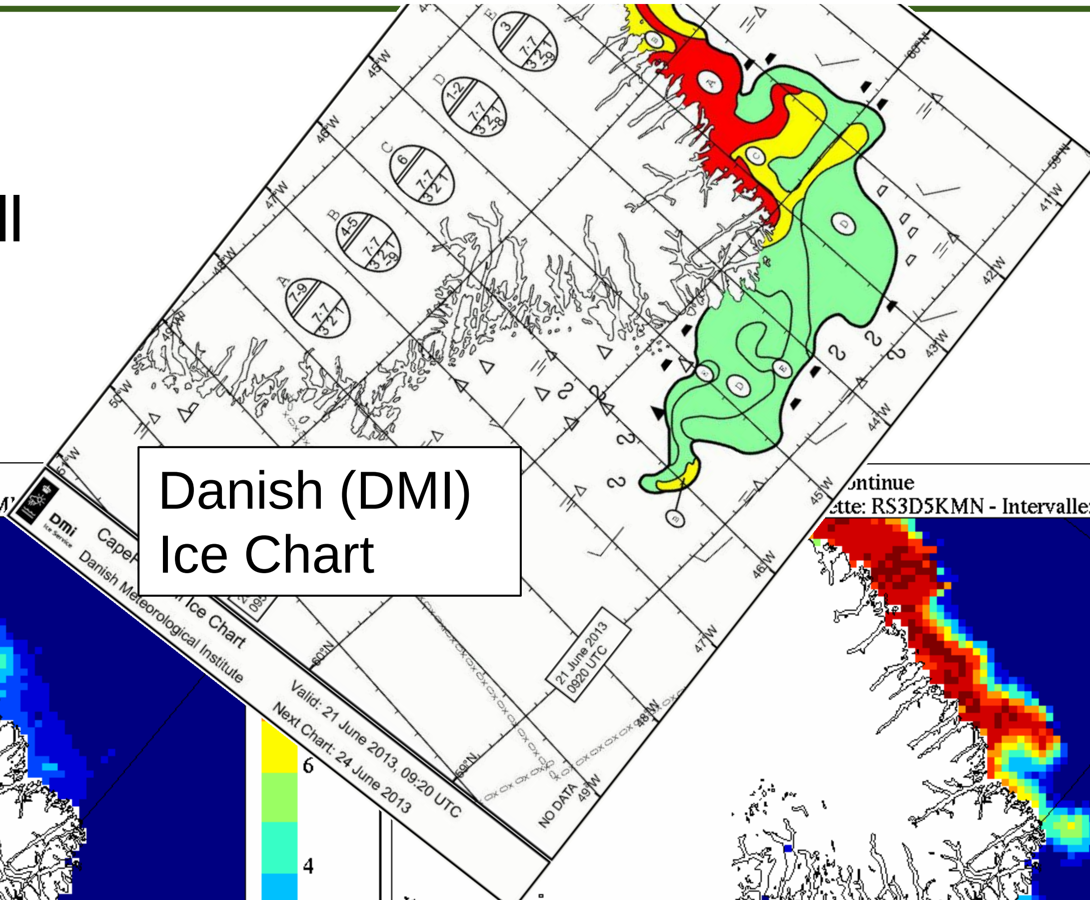
AVHRR retrievals:
Total proportion correct
(relative to IMS)

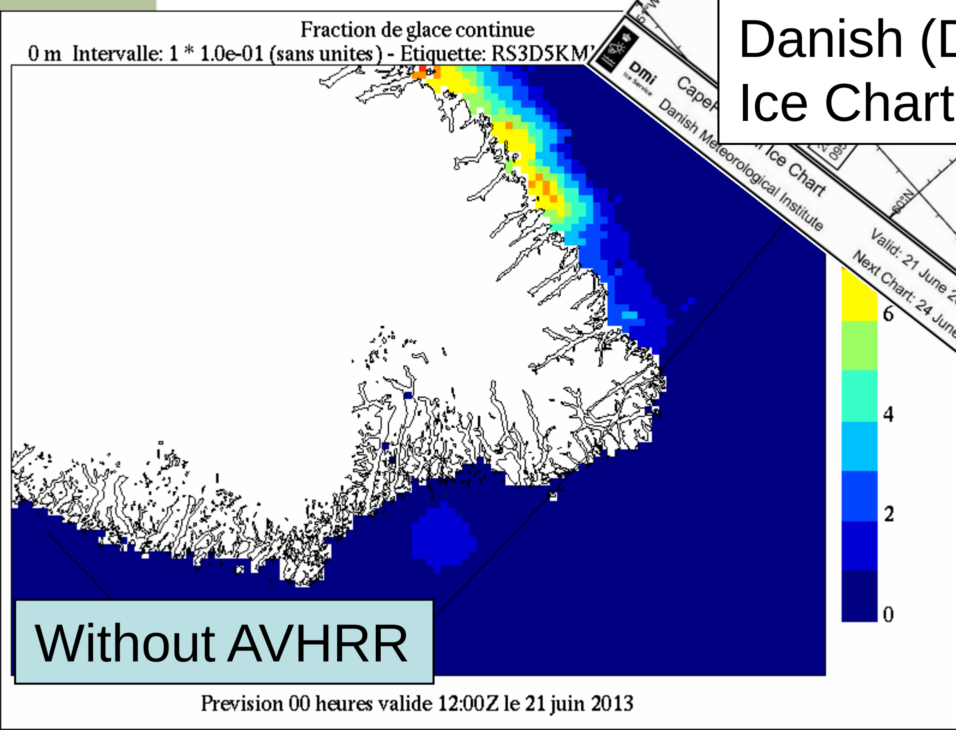


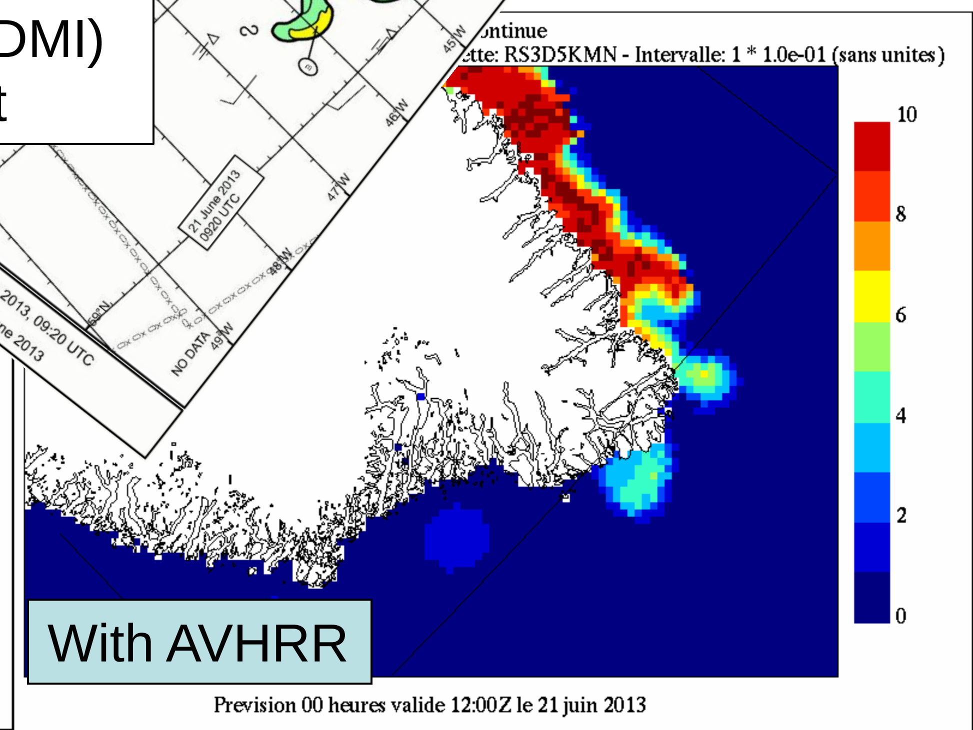
Impact of AVHRR data on the ice concentration analysis

Cape Farewell

21 June 2013





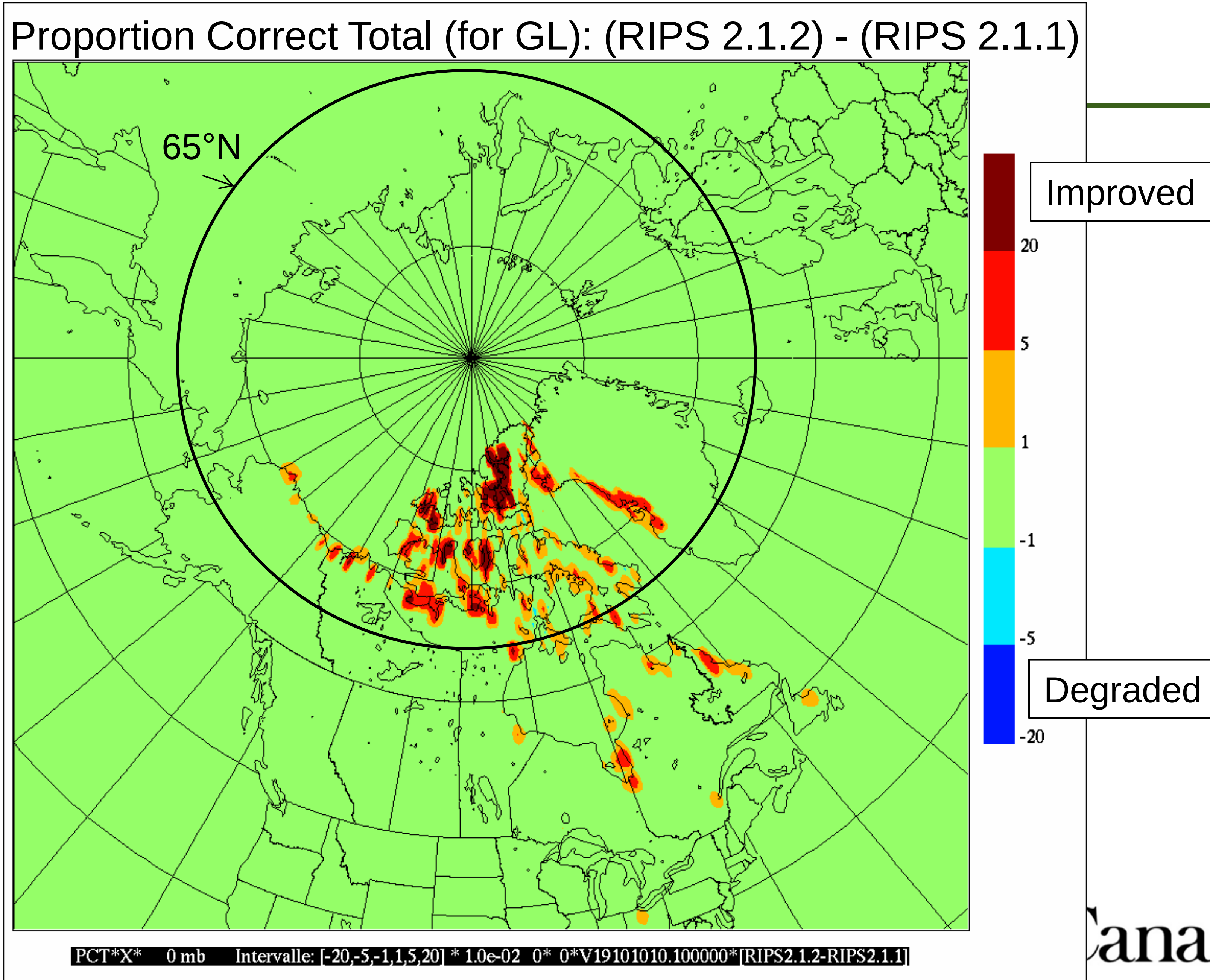


Runs from 2012-09-01 to 2013-12-31

- RIPS 2.1.1: control run

- RIPS 2.2.1: control run
  - + assimilation of CIS regional charts data
  - + assimilation of AMSR2 data
  - + assimilation of AVHRR data (ice / open water)
  - + wind filter on all passive microwave data

Impact of CIS REG (2012/09/01 – 2013/12/31)



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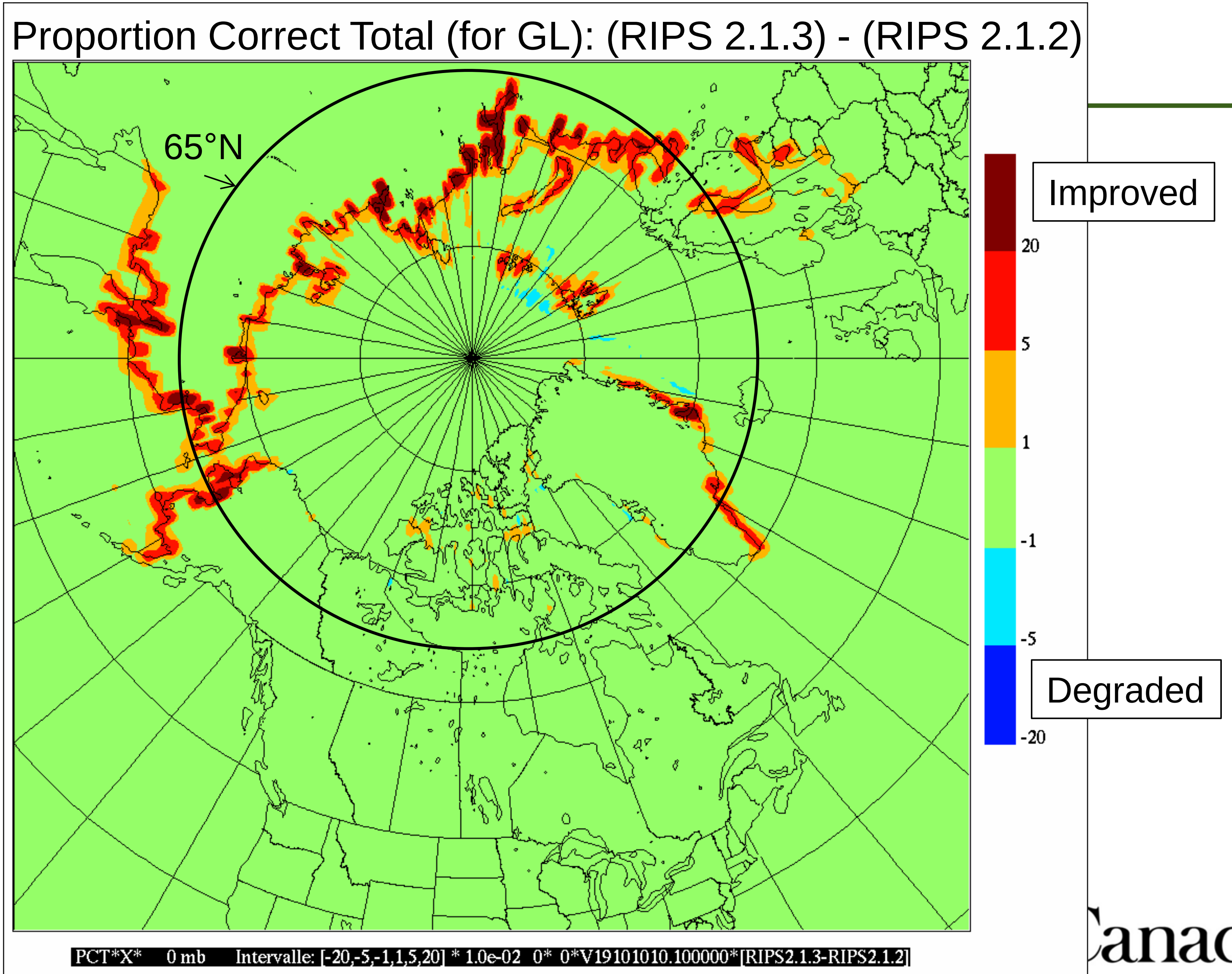
Impact of AMSR2 data (2012/09/01 – 2013/12/31)



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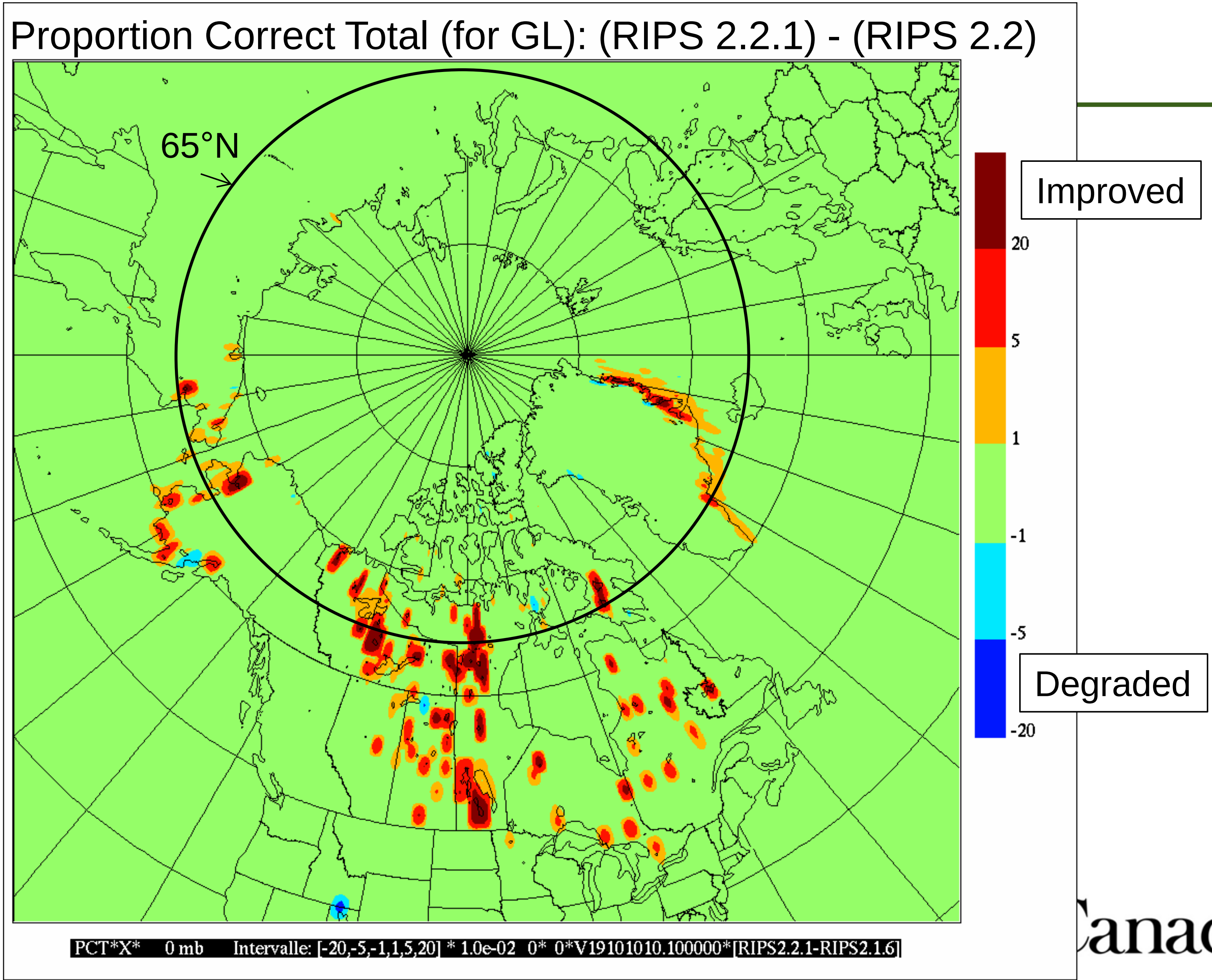
Impact of AVHRR (2012/09/01 – 2013/12/31)



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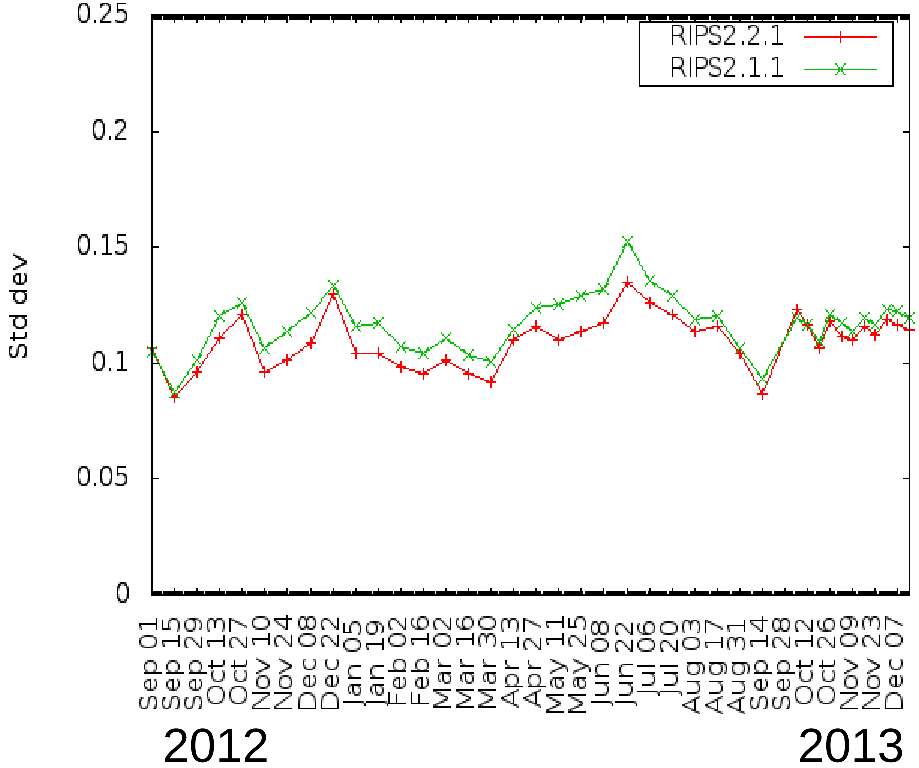
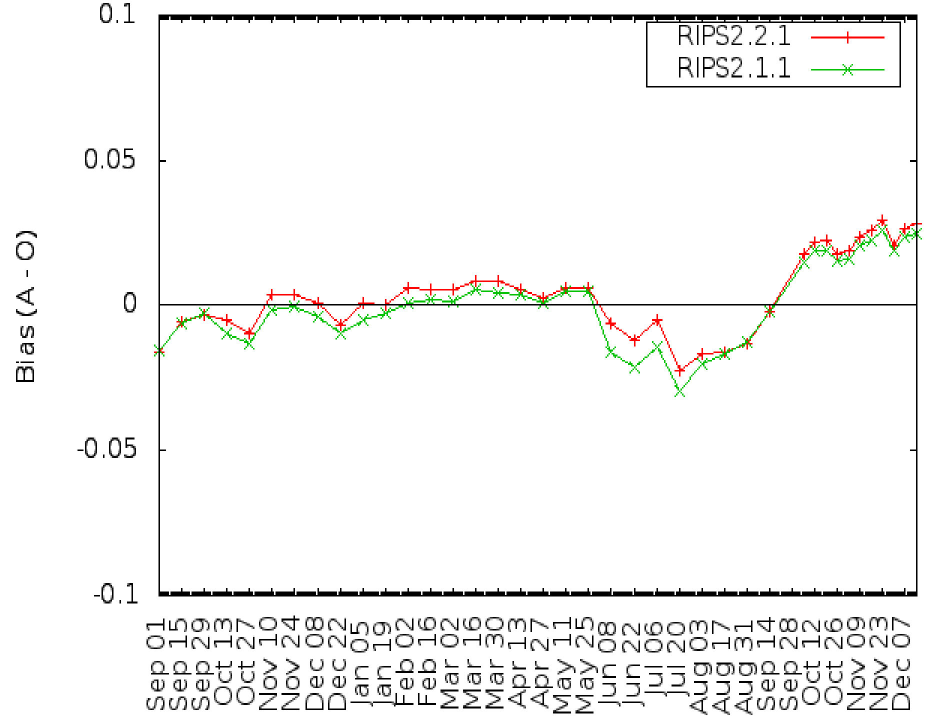
Ice concentration

- Bias and Stddev vs. NIC ice charts





Summary

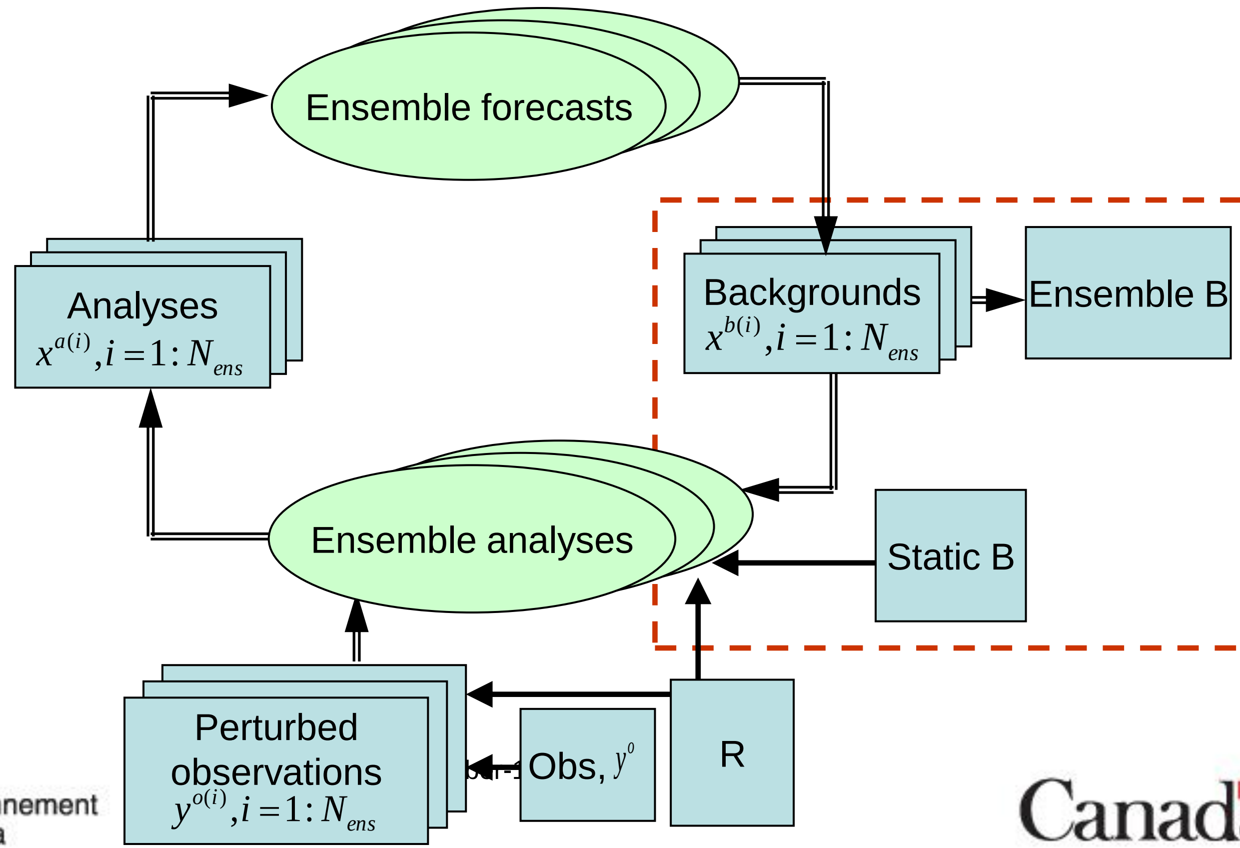
- Numerous types of sea ice concentration observations are assimilated, most have own particular limitation
- Assimilating higher resolution obs (small footprint) improves analyses near coasts, in narrow passages
- Future: Incorporate forecast model in the assimilation cycle AND assimilate sea ice thickness (e.g. SMOS)
- Work towards coupled assimilation to better use sea ice observations to correct ocean and atmosphere:
  - Few ocean and atmospheric obs near sea ice
  - Lack of ice-ocean-atmosphere consistency can significantly degrade subsequent forecasts

Motivation to use Ice-Ocean Ensembles
(Shlyaeva et al. 2016, QJRMS)

- Provide an estimate of the uncertainty in the analysis and background/forecast states
- Improve assimilation with coupled ensemble-based ice-ocean background-error covariances
- Sea ice covariances have strong heterogeneity and important cross-covariances with ocean and atmosphere
- CICE sea ice model and simple mixed layer ocean model

First step: Ensemble of 3DVars (static B)

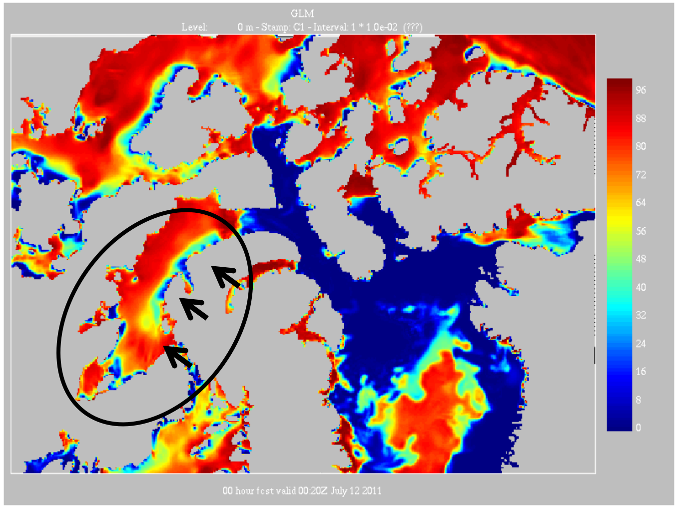
- Use ensemble atmospheric forecasts for forcing
- Perturb SST and mixed layer depth with NMC-like method
- Randomly perturb ocean current velocity



Model biases prevent spread-skill consistency

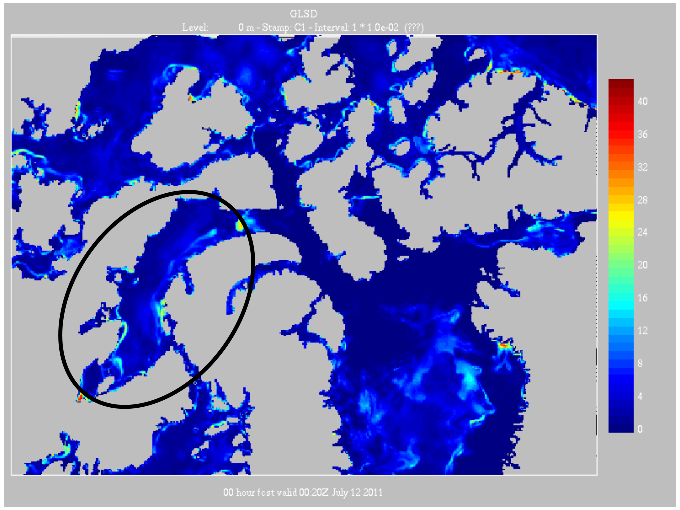
- Problem 1: model doesn't represent fast ice

Canadian Arctic Archipelago, July 2011



Ensemble mean

Strong winds incorrectly cause the ice to move in all ensemble members



Ensemble spread

Ensemble spread is very low, but mean error is very high

- Problem 2: model bias introduced through biases in atmospheric and ocean forcing (SST, currents, winds)

Extreme sea ice model error parametrization (a temporary measure)

- 21 ensemble members:
  - 7 members: full CICE model
  - 7 members: CICE dynamics only
  - 7 members: CICE thermodynamics only
- Motivation
  - Dynamics: 1/3 of ensemble members don't move: increased ensemble spread in the 'ice shouldn't move, but it's moving' case
  - Thermodynamics: 1/3 of ensemble members don't melt/freeze: increased ensemble spread in the case of SST bias

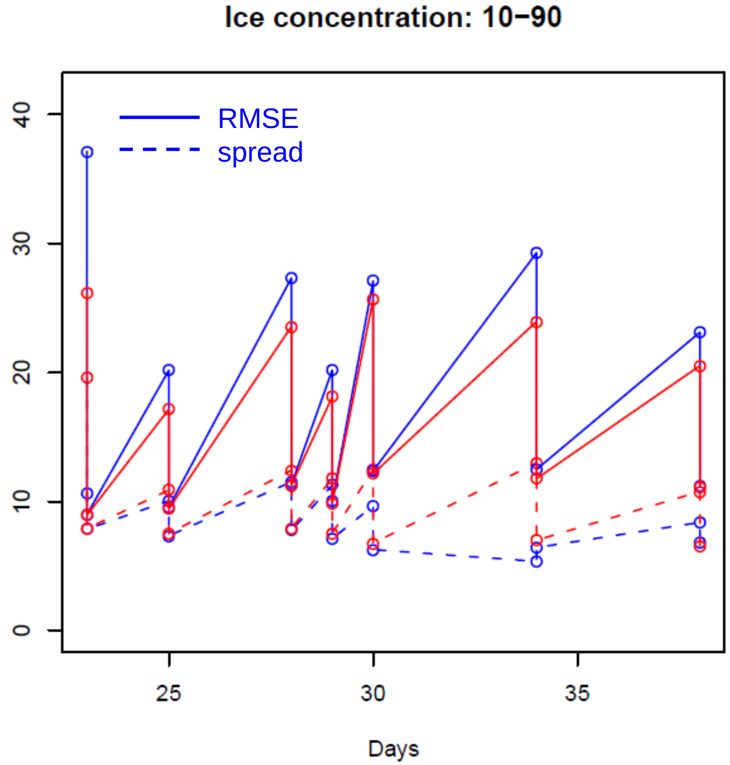
Ensemble of 3DVars experiment

- Experiment June 8, 2011 – September 30, 2011
- Obs perturbed with state-dependent correlated errors (largest perturbations for intermediate concentrations)
- Verification based on CIS daily ice charts (available for different regions)

Background ensemble spread and RMSE of ensemble mean time series

- Statistics averaged over Foxe Basin ice charts for ice points with 10%-90% ice concentration

Full ensemble vs 7 members using full model



Extreme model error parametrization:

- Improves consistency between ensemble spread and error of ensemble mean (similar growth rates during forecast)

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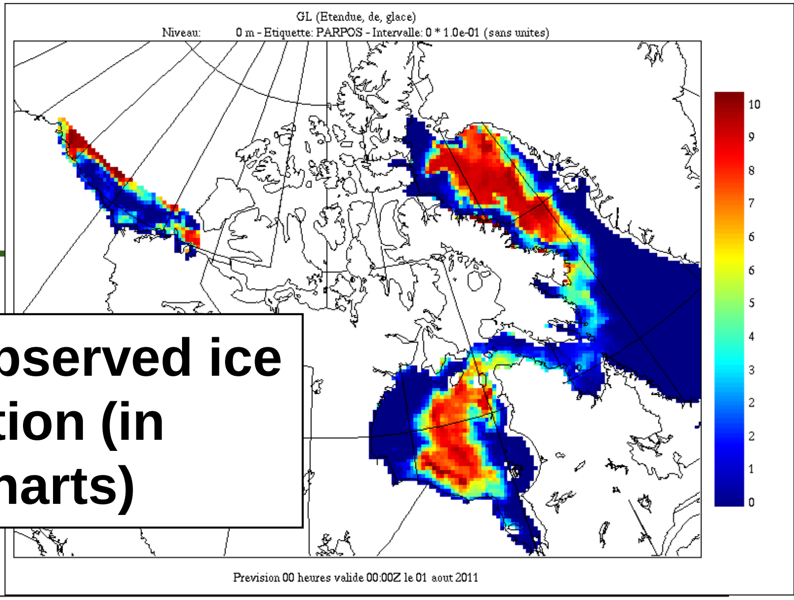
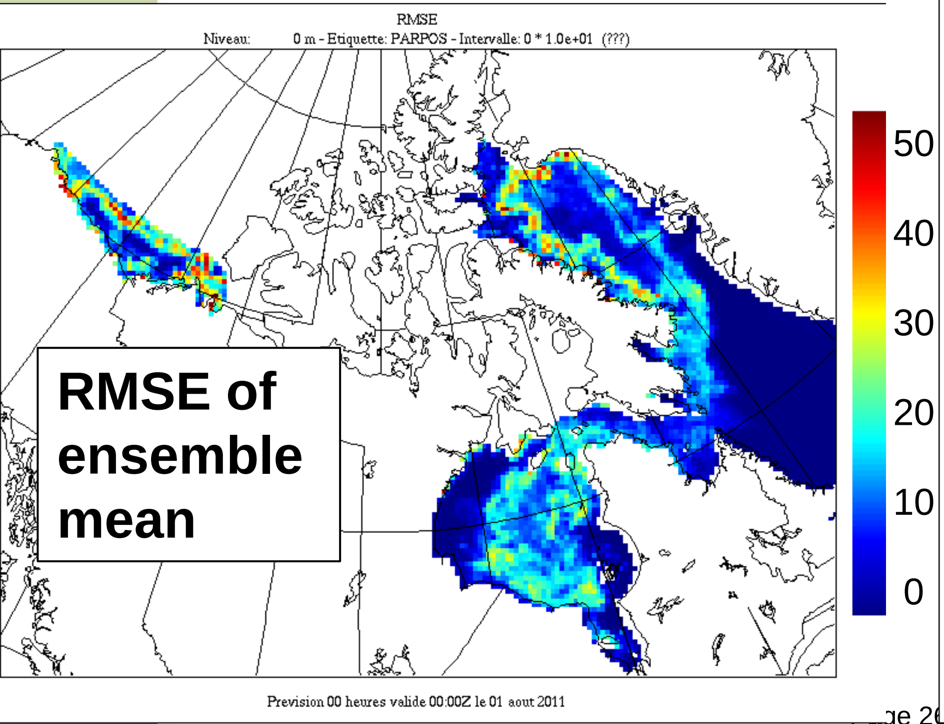
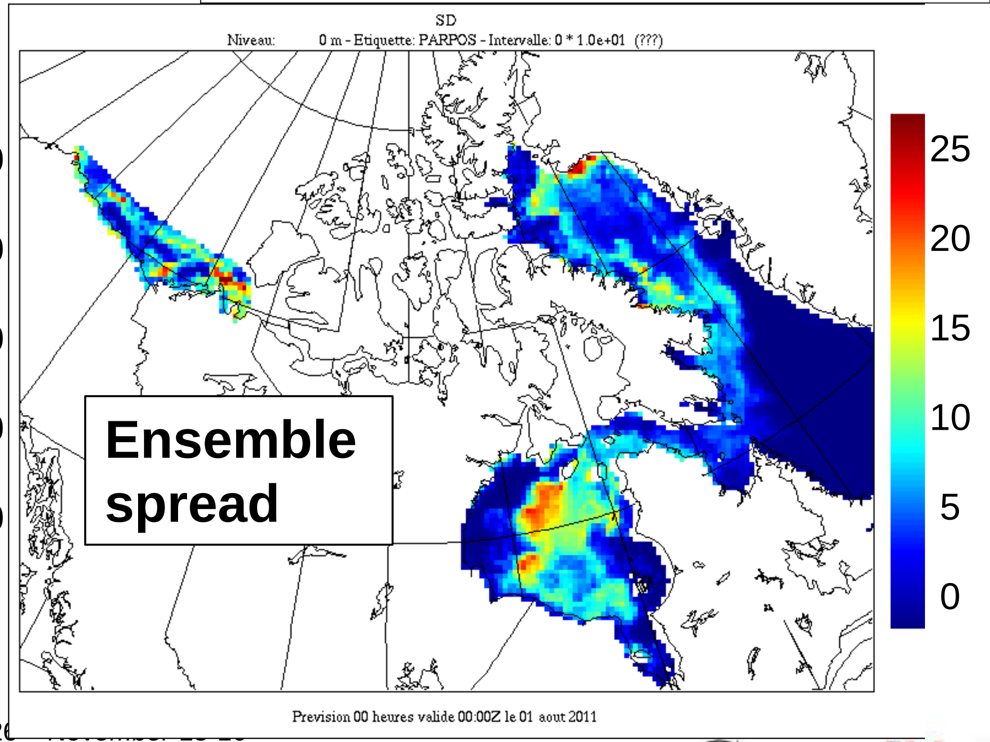
Time-averaged ensemble spread and RMSE maps



Average observed ice concentration (in daily ice charts)

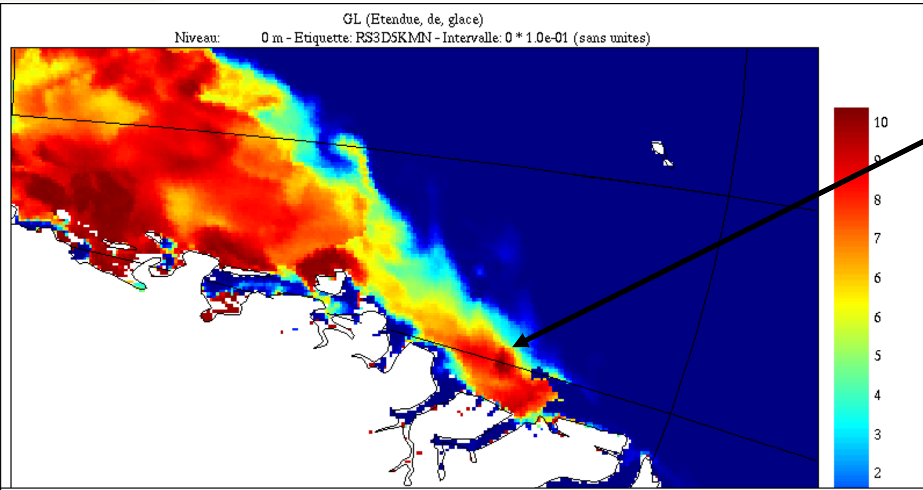


RMSE of ensemble mean



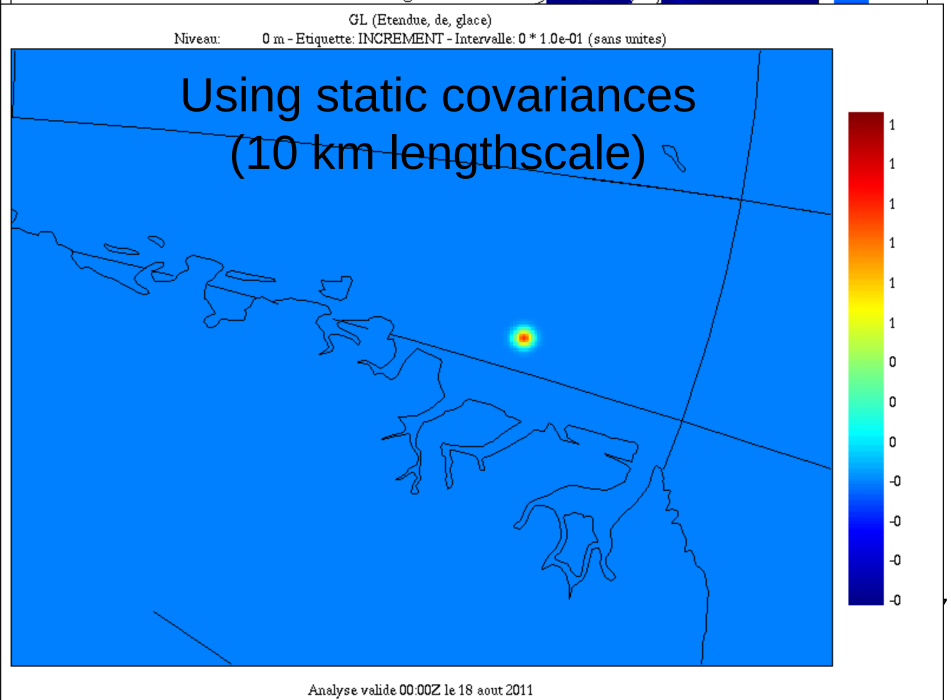
Ensemble spread

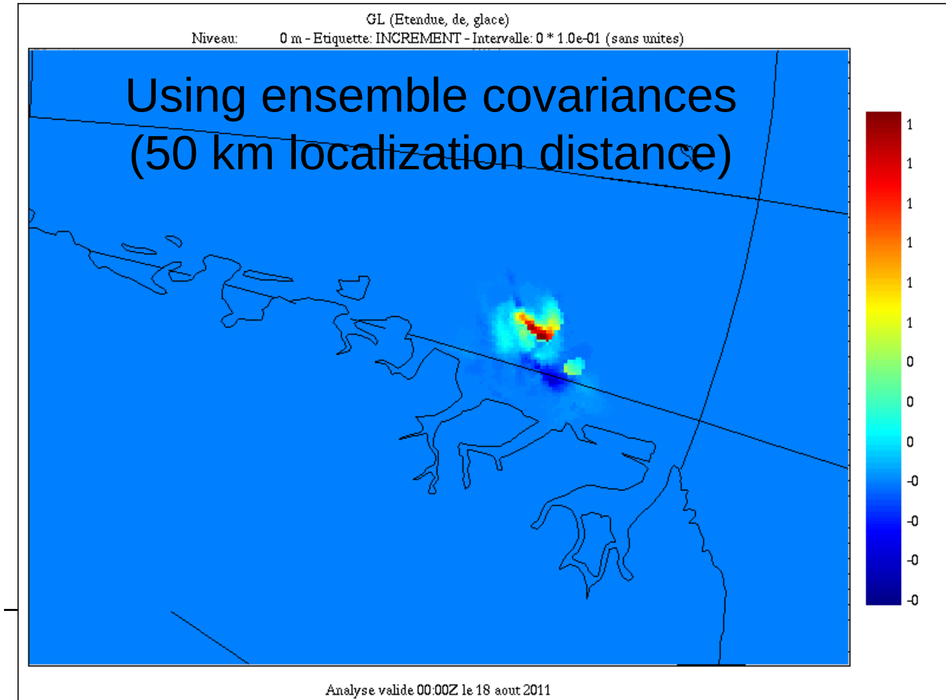
EnVar: Single observation experiment



Observation=55%;
Background=30%

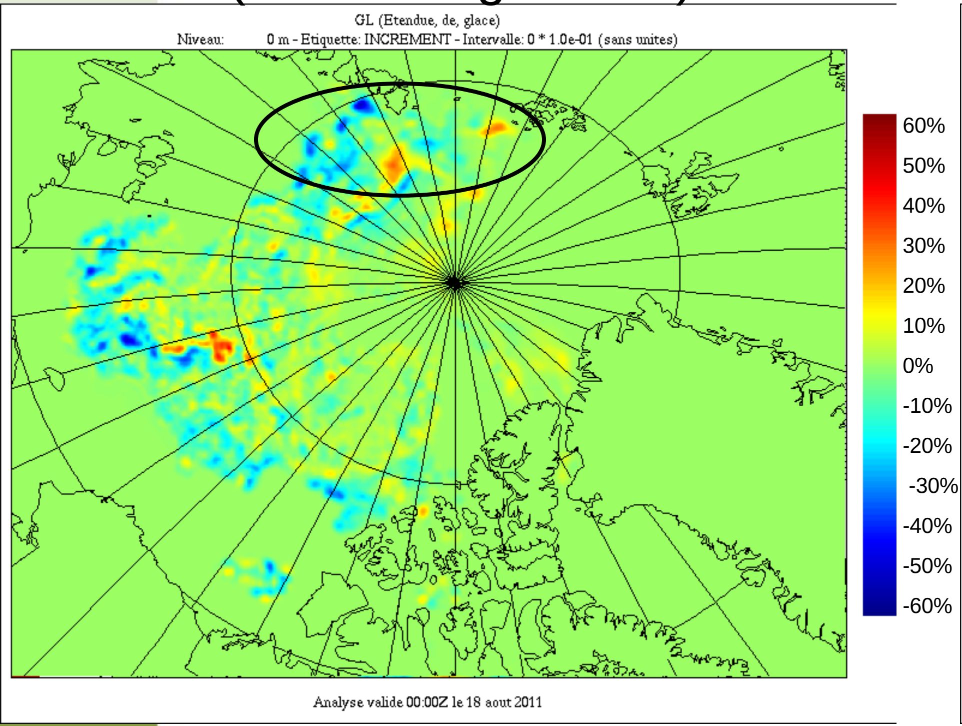
Left: Background ice concentration



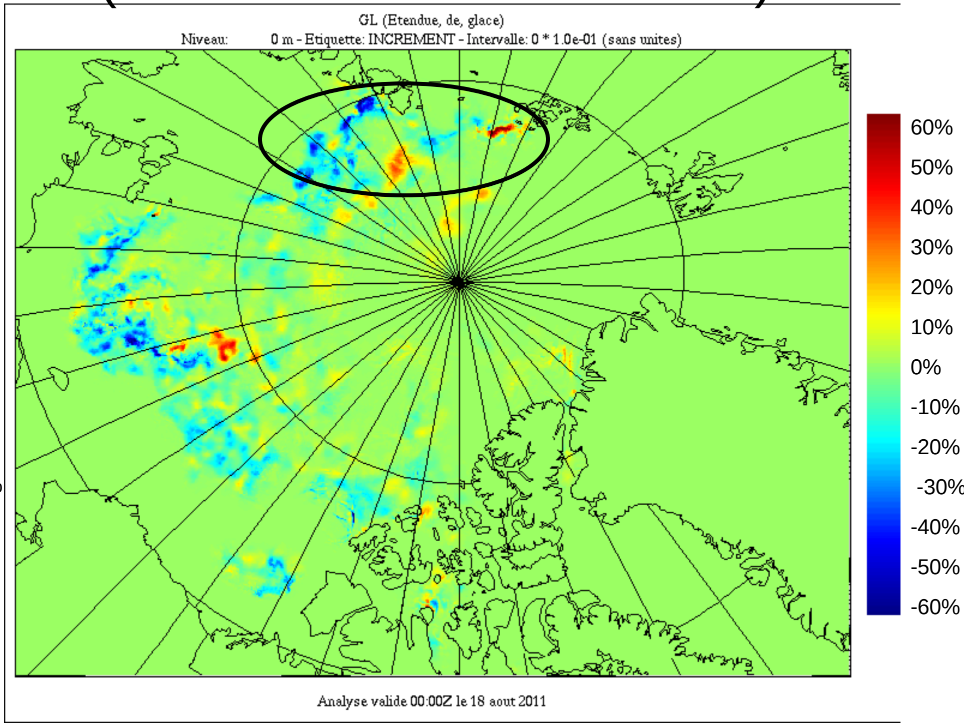


EnVar ice concentration analysis increment example (July 18, 2011)

Using static covariances
(10 km lengthscale)



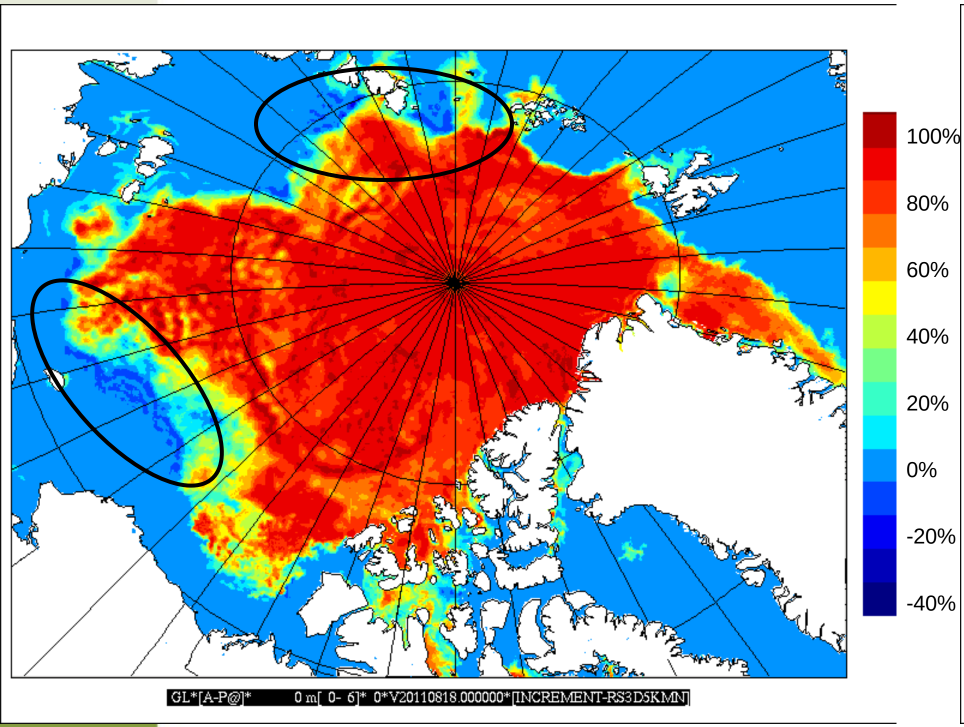
Using ensemble covariances
(50 km localization distance)



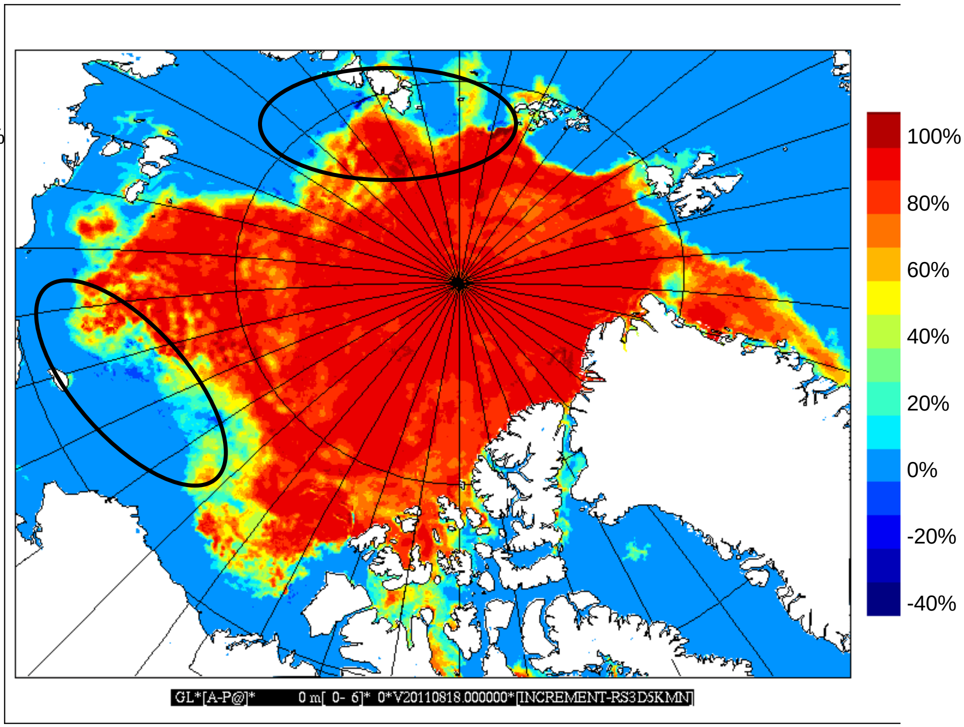
Sharper and stronger increments close to the ice edge in the ensemble covariances case

EnVar ice concentration analysis example (July 18, 2011)

Using static covariances



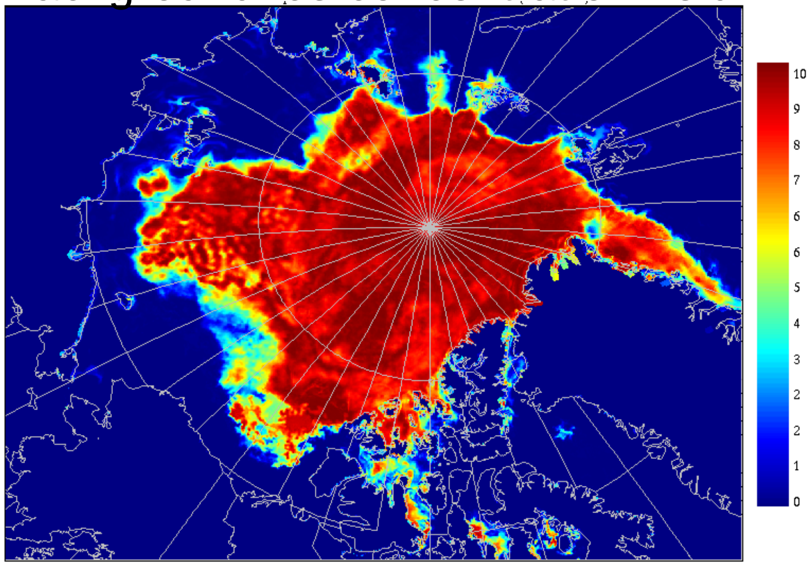
Using ensemble covariances



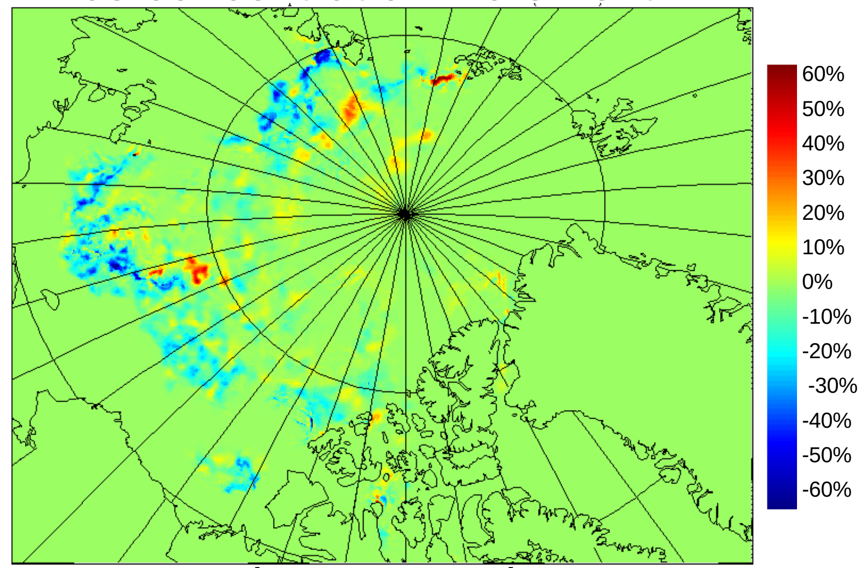
Less negative ice concentration artefacts in analysis in the ensemble covariances case

EnVar analysis example: updating unobserved variables

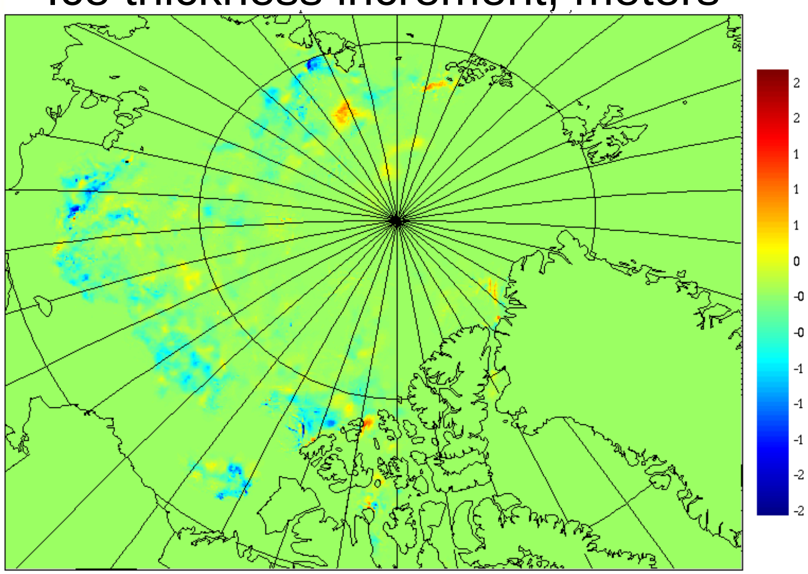
Background ice concentration field



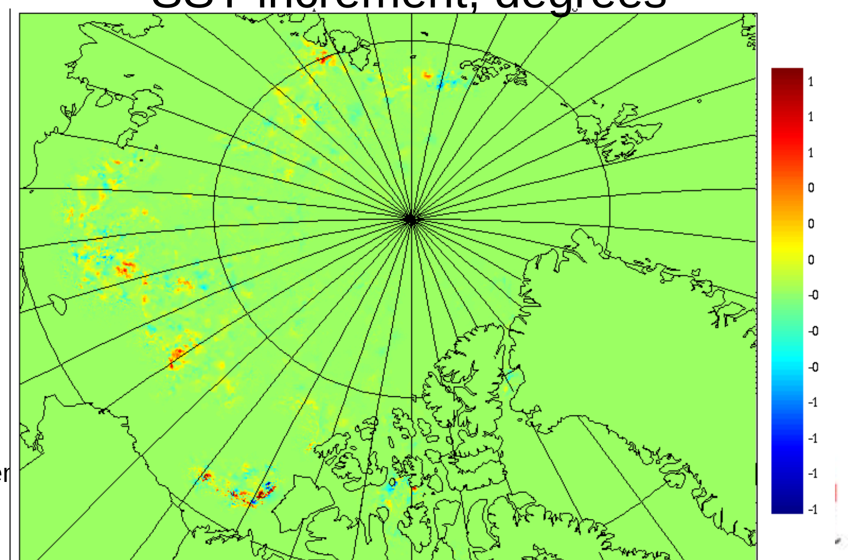
Ice concentration increment



Ice thickness increment, meters

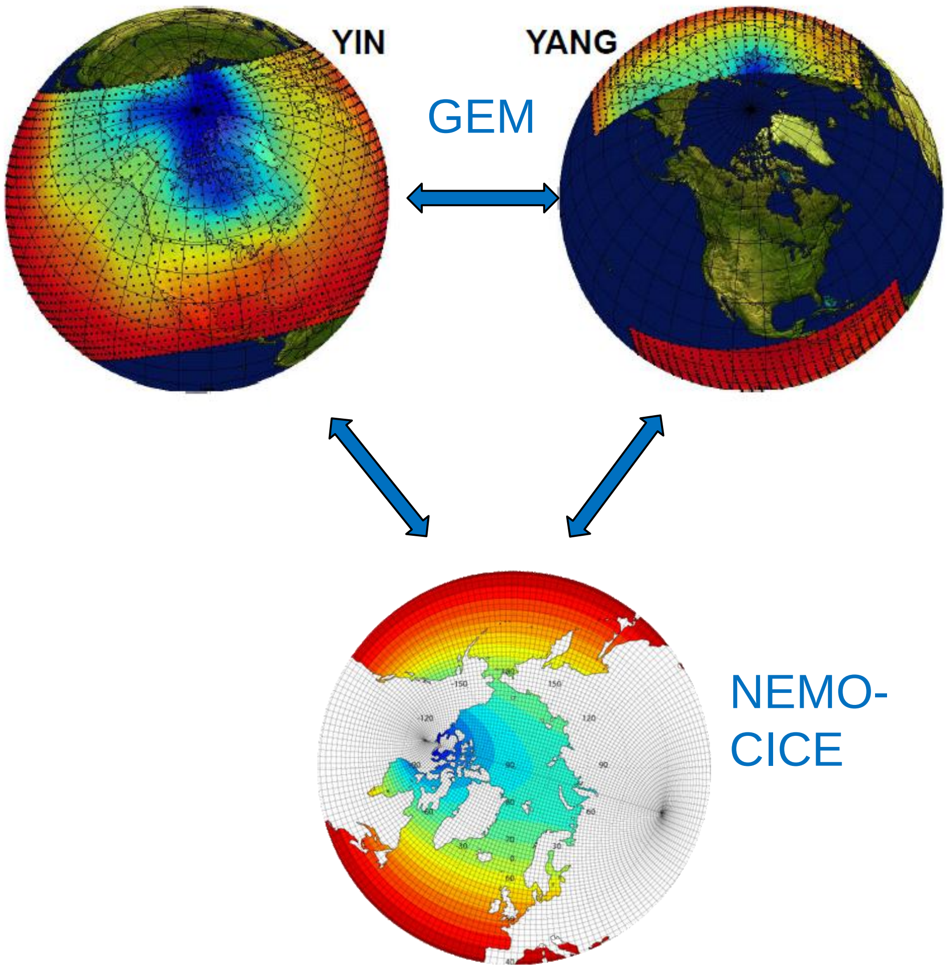


SST increment, degrees



Global Coupled Medium-range Deterministic Forecasts

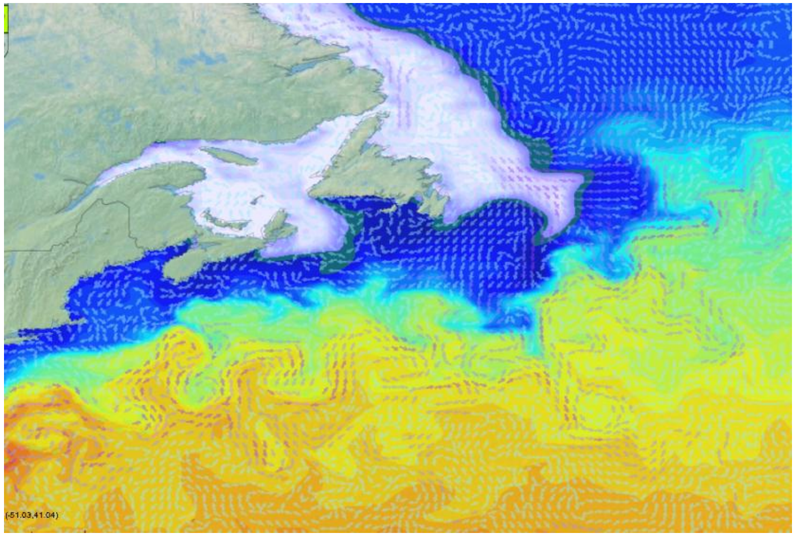
- Running since 8 July 2016
  - GDPS coupled to GIOPS
  - Fully-coupled A-I-O, 25km(A)-1/4deg(I-O),
  - 10 day fcst (2 per day)



Global Ice-Ocean Prediction System

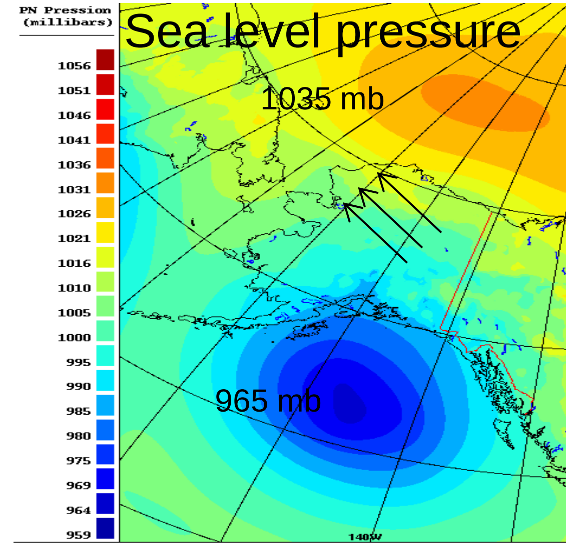
Dorina Surcel Colan, Yimin Liu, Matt Reszka, Francois Roy, Barbara Winter …

- Produces daily ice-ocean analyses and 10 day forecasts
- Mercator Ocean Assimilation System (SAM2):
  - Sea surface temperature
  - Temperature and salinity profiles
  - Sea level anomaly from satellite altimeters
- 3DVar ice analysis
  - Similar to regional ice analysis
  - Combined with background state

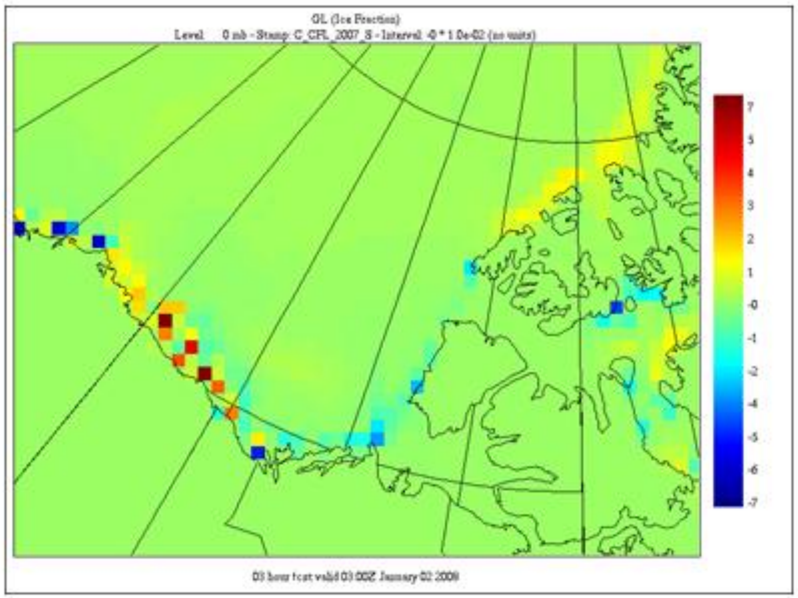


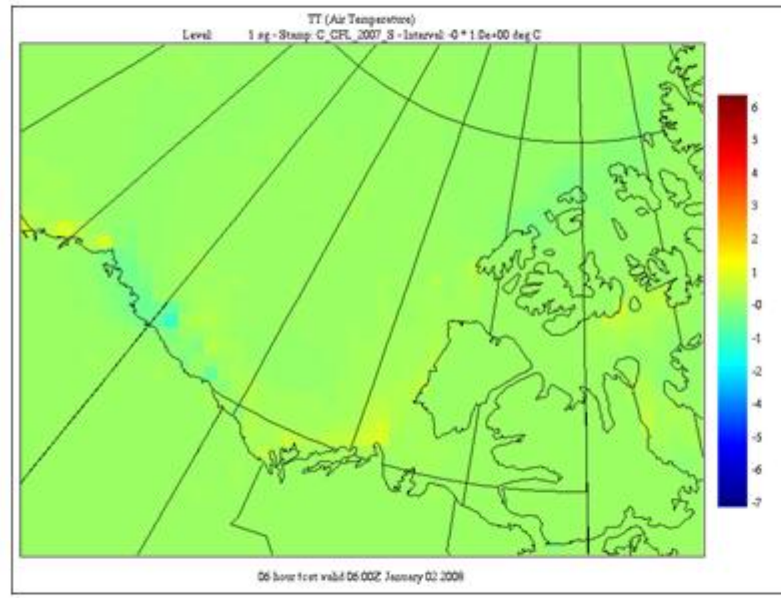
Smith et al., QJRMS, 2015

Impact of a dynamic ice cover on coupled forecasts over the Beaufort Sea



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





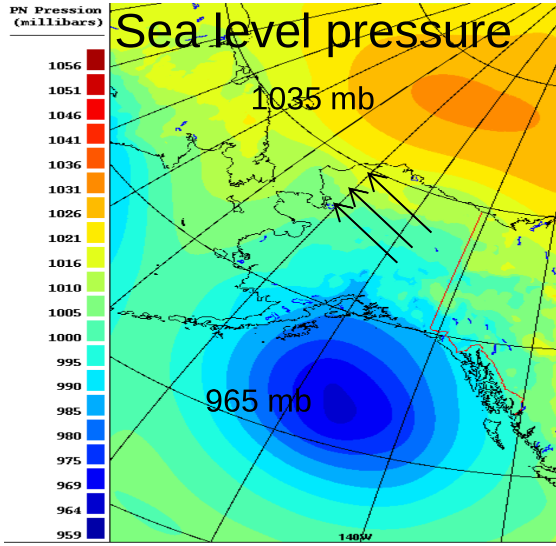
Forecast from global coupled model (GEM-NEMO-CICE; 33km-15km resolution)

Environment Canada Environnement Canada

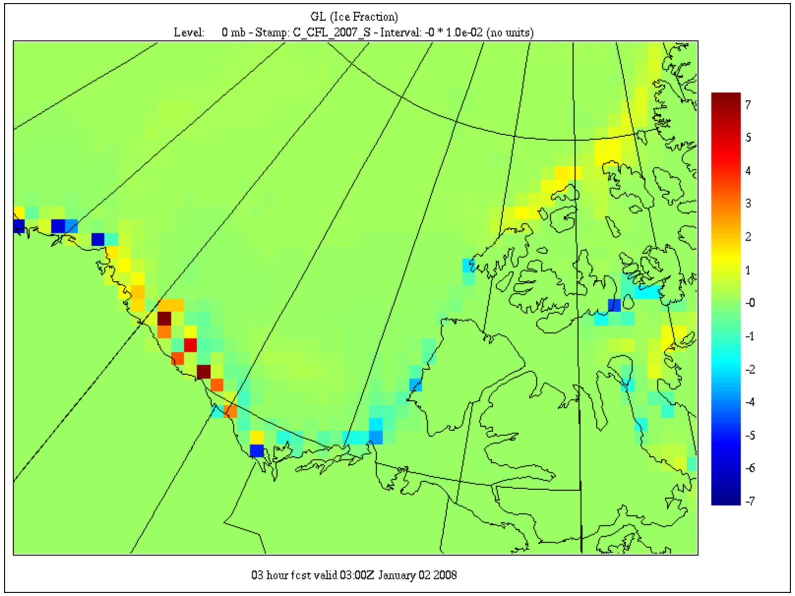
R. Muncaster, F. Roy, J.-M. Belanger

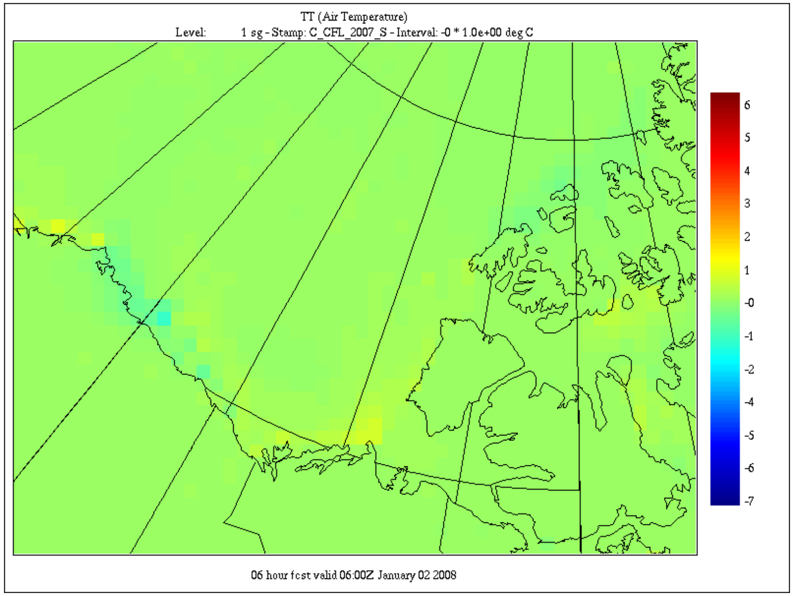
Impact of a dynamic ice cover on coupled forecasts over the Beaufort Sea

- Coastal polynya formation sensitive to:
  - Atmosphere-ice and ice-ocean stresses, ice thicknesses, landfast ice parameterization



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





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

Environment Canada Environnement Canada

R. Muncaster, F. Roy, J.-M. Belanger

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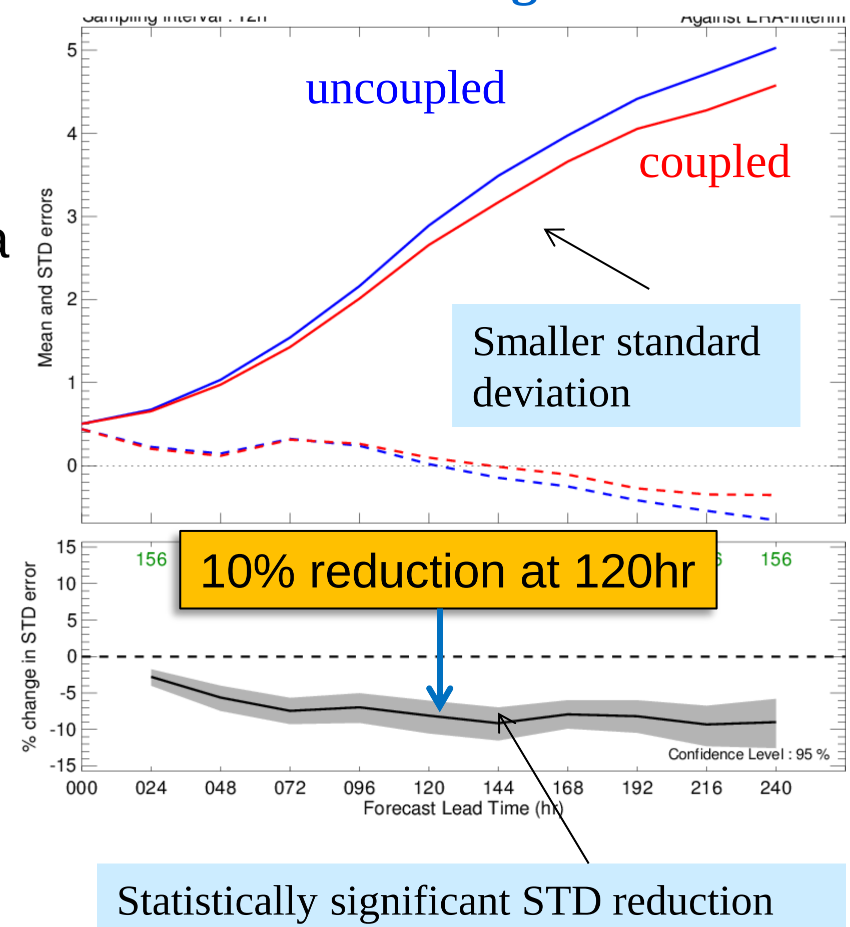
Coupled Global Forecast Trials

J-M Belanger, F Roy, …

- Evaluation of summer trials
  - 15 Jun – 31 Aug, 2014
  - Verification against ERA-Interim for geopotential height at 850hPa over Asia

Asian region

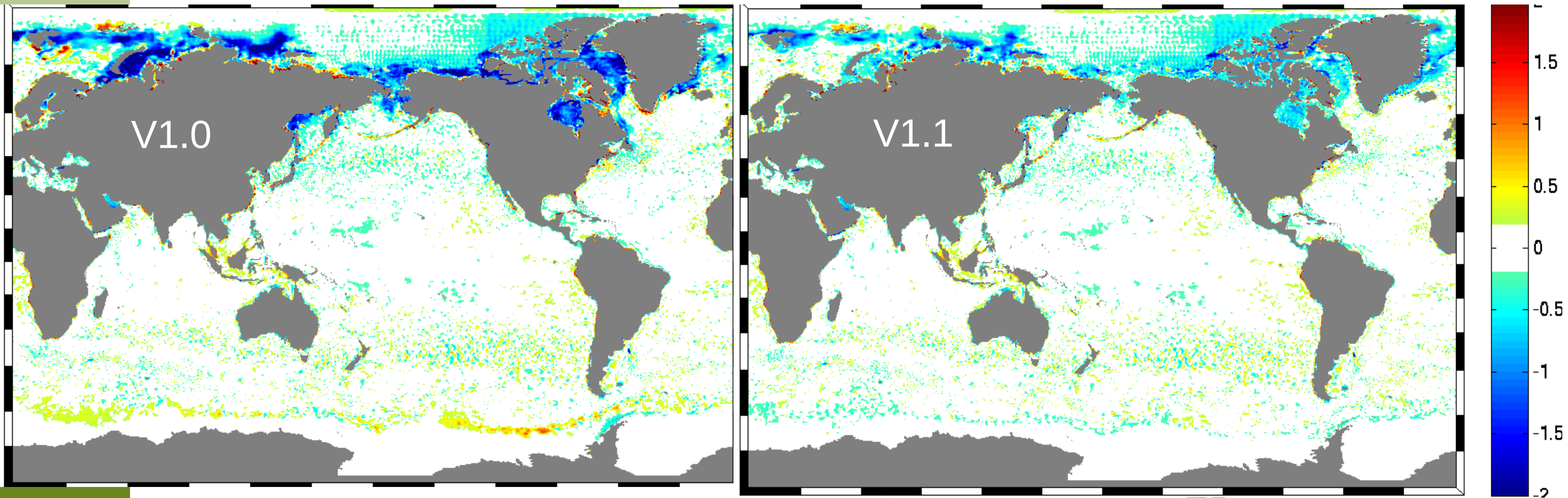


Improvement in GIOPS v1.1 (June 2014)

Under-ice SST assimilation:

- Set: SST obs=freezing point temperature, if IC>20%
- Improved under-ice SST assimilation substantially reduces differences with SST analysis

Mean differences for NH summer 2011



Environment Canada

Fisheries and Oceans Canada

Mercator Ocean
Ocean Forecasters

CONCEPTS

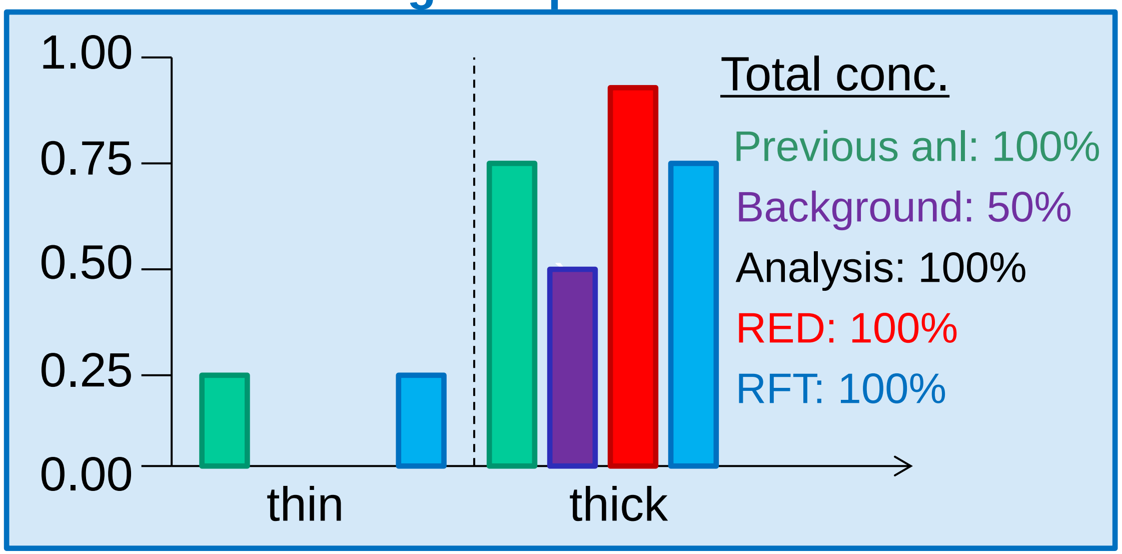
National Defence

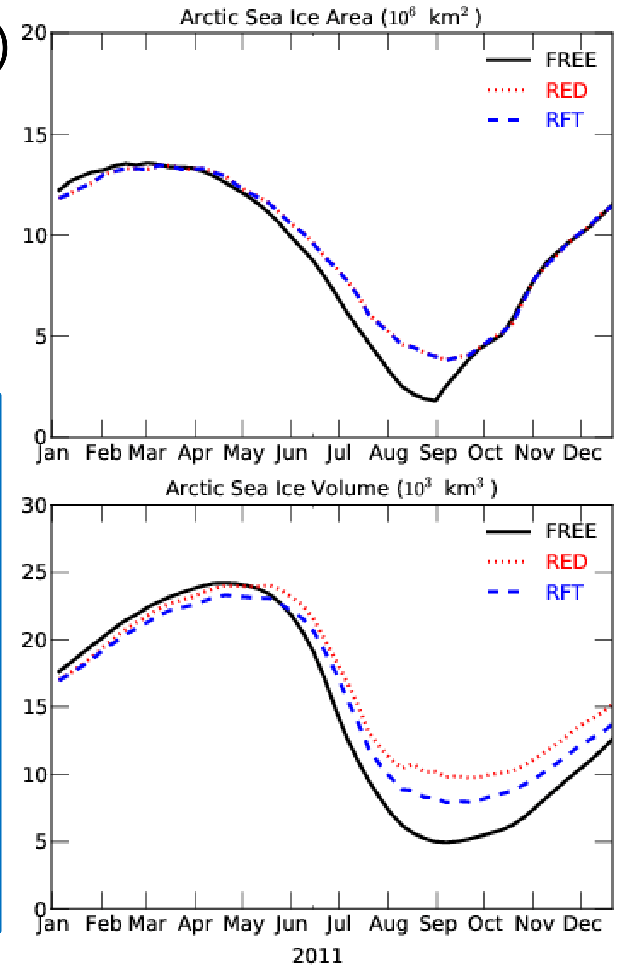
Blending with 3DVAR ice analyses

CICE requires Ice Thickness Distribution Smith et al., QJRMS, 2015

- Method 1: Rescale thickness Distribution (RED)
- Method 2: Rescale Forecast Tendency (RFT)
- Use of RFT results in a smaller impact on total ice volume

Thought experiment





Environment Canada Fisheries and Oceans Canada Mercator Ocean Ocean Forecasters CONCEPTS National Defence

Conclusions

- Ice concentration analysis for initializing coupled forecasts should ensure consistency between analyses:
  - SST adjusted when sea ice introduced by assimilation
  - Complete Ice Thickness Distribution adjusted to match ice concentration analysis
- Other simple approaches possible: e.g. correcting winds and currents by assimilating ice drift observations (Barth et al. 2015) – assumes these are primary error sources
- Work towards weakly coupled DA, then a simple way to start strongly coupled…
- … in the context of high-resolution deterministic systems (EnVar) that rely on lower resolution ensembles (EnKF)

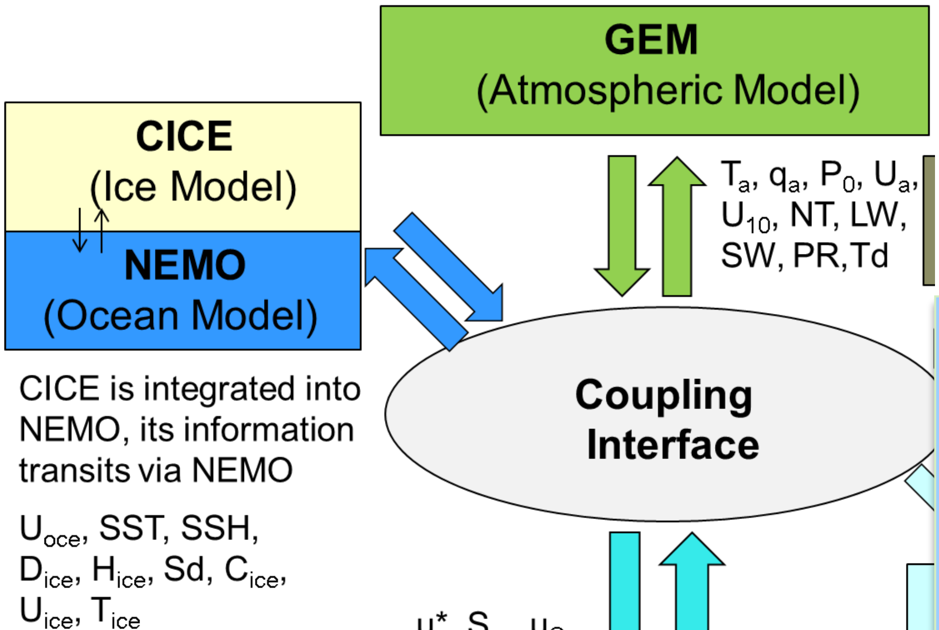
Sea Ice DA and Prediction

Some interesting aspects

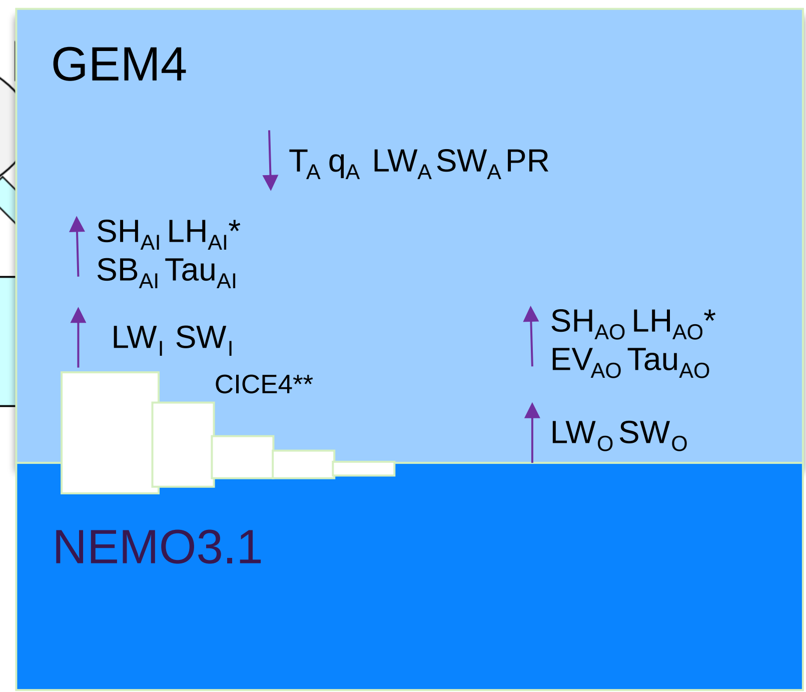
- Ice concentration well observed by many types of sensors, though with limitations in summer, near land, thin ice, from high winds
- Ice drift well observed, from sequential satellite images, but challenge knowing what to correct: winds, currents, drag coeffs, ice strength, etc.
- Thickness less well observed, but important for atm-ocean interaction and longer term prediction
- Ocean (SST, currents) and atmosphere (winds, air temperature) errors can dominate ice forecast errors, both poorly observed near ice
- Simple *"coupled"* approaches can help a lot:
  - Ice obs used to impose consistent SST, correct winds/currents
  - Air temperature and winds used for ice obs QC
- Linear approaches for strong coupling may not always work, e.g. near freezing point, creation of ridges when ice fails in compression

Coupling Method

Same method used by Gulf of St. Lawrence, Great Lakes, GDPS and Seasonal Systems



Flux Coupling via GOSSIP socket server



- Coupling every timestep
- Calculate fluxes on fine-scale grid and aggregate

Jean-Marc Belanger, Francois Roy, Natacha Bernier

Ice drift from sequential images

 1997!!!

An Inverse Method for Tracking Ice Motion in the Marginal Ice Zone Using Sequential Satellite Images

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