Development of a variational data assimilation system for coupled ice-ocean models and sea ice analysis

Seminar
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  - 3D-Var sensitivity experiments with CIOM
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Motivations

- Project Goal: to develop an automated ice analysis system for:
  - Canadian Ice Service (CIS): ice concentration, thickness/type distribution, pressure, strength and edge, deformed ice at ~1-2 km resolution
  - NWP: ice concentration, thickness, albedo, surface emissivity, roughness at ~5 km resolution
  - Coupled atmosphere-ice-ocean models
- Collaboration between CIS and the Meteorological Research Division

3D-Var data assimilation formulation

$$J(\xi) = \frac{1}{2}\xi^{\mathsf{T}}\xi + \frac{1}{2}\left(\mathbf{y} - H(\mathbf{x}^{\mathbf{f}}) - \mathbf{H}\mathbf{B}^{1/2}\xi\right)^{\mathsf{T}} \mathbf{R}^{-1}\left(\mathbf{y} - H(\mathbf{x}^{\mathbf{f}}) - \mathbf{H}\mathbf{B}^{1/2}\xi\right)$$

$$\mathbf{x}^{\mathbf{a}} = \mathbf{x}^{\mathbf{f}} + \mathbf{B}^{1/2}\xi^{\mathbf{a}}$$

- Incremental, preconditioned
- First Guess at Appropriate Time
- Analysis grid:
  - independent of the model grid
  - Rotated lat-lon

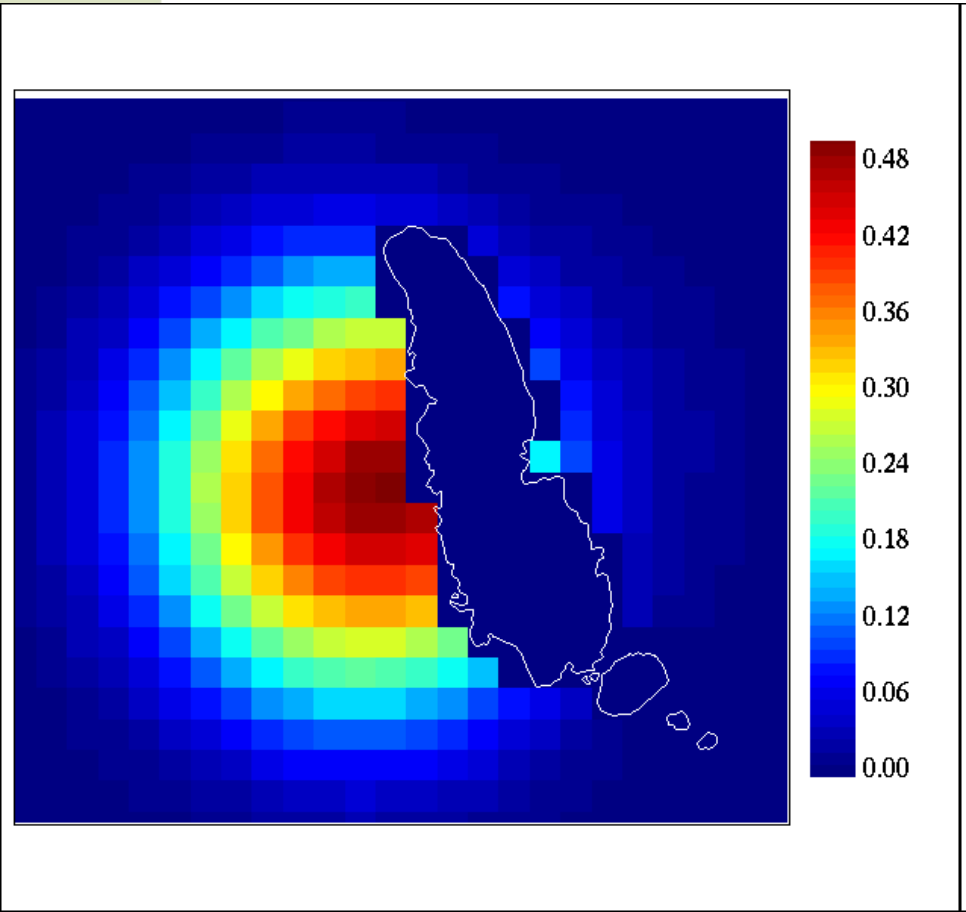
3D-Var background-error covariances modeling

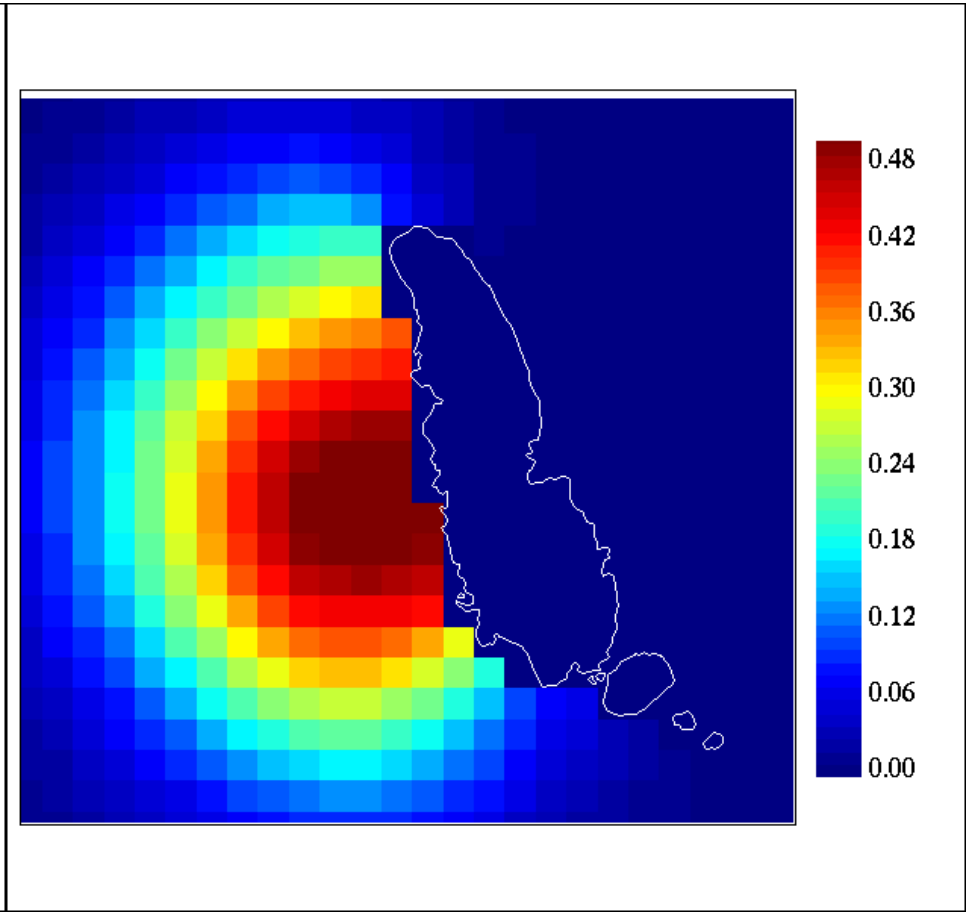
- Errors are assumed to be Gaussian, even for ice concentration which varies only between 0 and 1
- Stationary
- Covariance matrix for ice concentration, and ocean temperature and salinity on 32 depth levels:
  - 65 x 65 covariance matrix
  - Horizontally homogeneous
  - Time and horizontal average (over points with ice only) of the EnKF statistics
- Horizontal correlations applied separately using a diffusion operator (Weaver and Courtier, 2001)
  - Gaussian shape
  - Length scale is estimated from EnKF horizontal correlations

Background-error horizontal correlations

Function of separation

Modeled using a diffusion operator





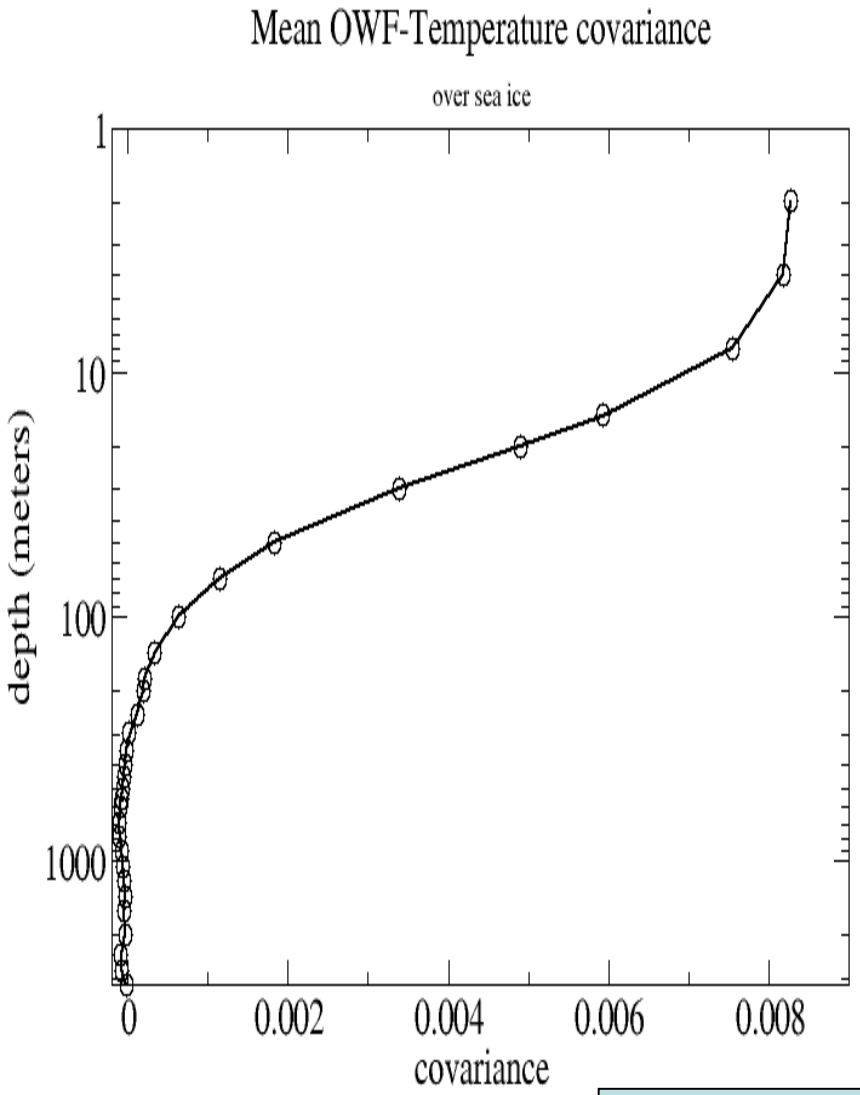
Community Ice-Ocean Model

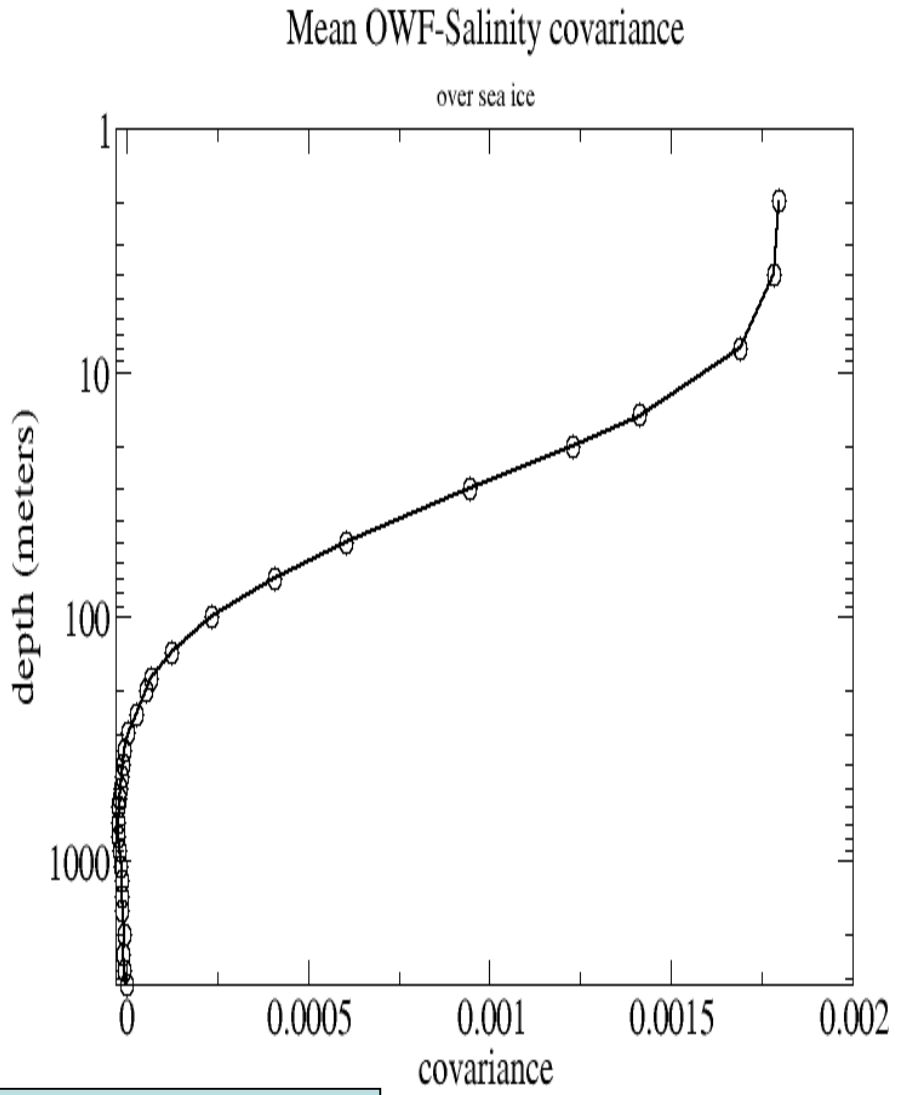
- Multicategory sea ice model coupled to the Princeton ocean model (Yao et al., *J. Geophys. Res.* 2000).
- Viscous plastic rheology (Hibler, *J. Geophys. Res.* 1979).
- Global Environmental Multiscale model atmospheric forcing every 3 hours.
- Grid resolution: 1/5º longitude x 1/6º latitude.
- Grid size: 140 x 166, 16 sigma levels.
- Domain: Labrador Sea, Canadian East coast.

- Background-error statistics estimated with an EnKf.

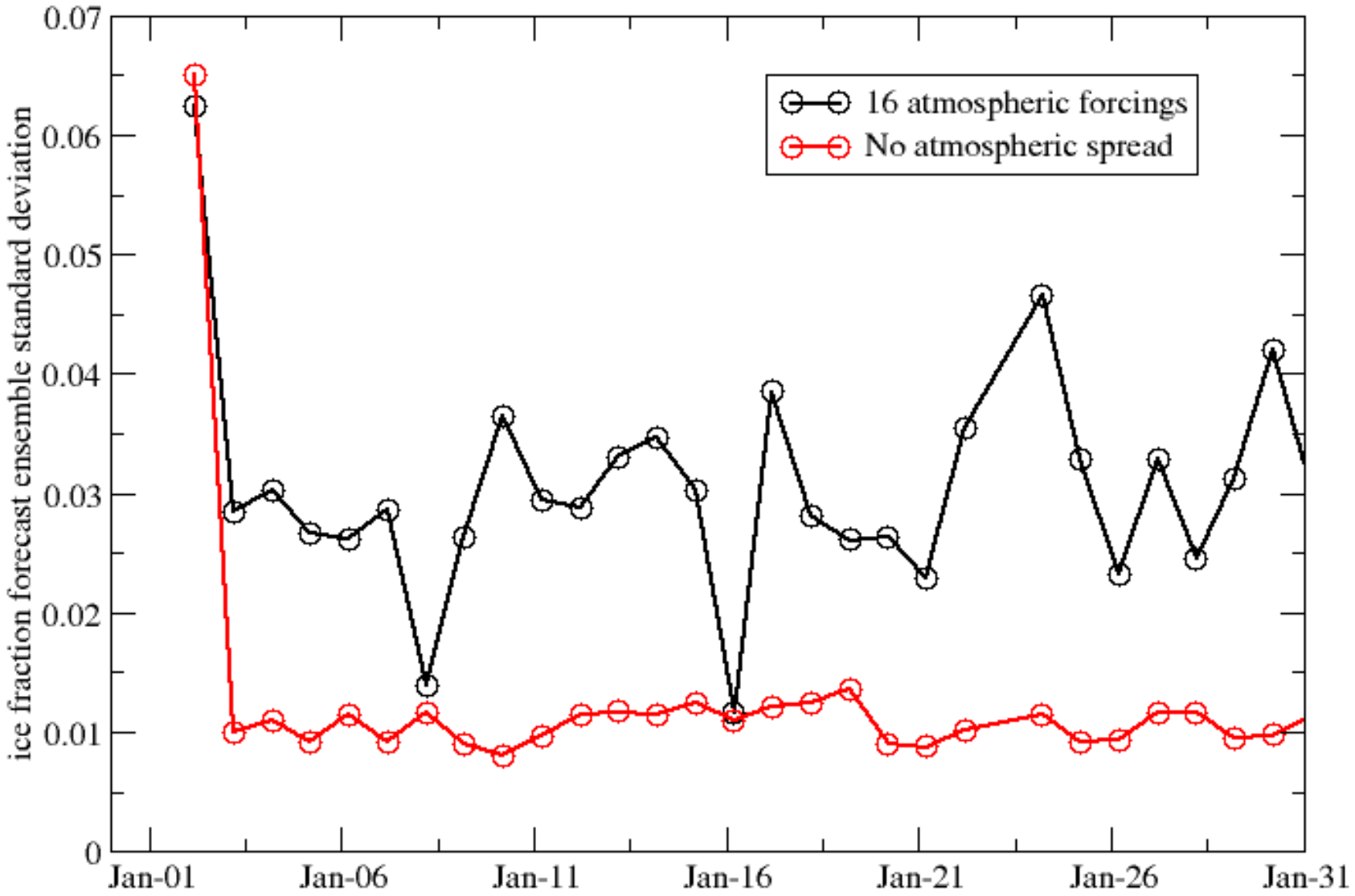
Vertical covariances

averaged (spatially and temporally)





OWF Standard deviation = 0.093


Effect of atmospheric forcing uncertainty
on ice fraction ensemble spread
ice fraction forecast ensemble standard deviation
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Jan-01
Jan-06
Jan-11
Jan-16
Jan-21
Jan-26
Jan-31
16 atmospheric forcings
No atmospheric spread

Background-error horizontal correlation

- The background-error horizontal correlation length scale for ocean temperature and salinity does not vary much with depth.
- The length scale for T, S, and ice concentration is around 20 km.
- For the following 3D-Var data assimilation experiments, we assume the same length scale for all analyzed variables at all depths.

3D-Var experiments setup

- Assimilation of daily ice concentration analysis prepared by CIS
- 2003 season (January 1st → April 30th)
- Make sure that ice concentration is [0, 1]
- Partial concentrations are adjusted by the same multiplicative factor
- 24 hour forecast from CIOM

3D-Var sensitivity experiments

Experiment name	Horizontal correlation length (km)	Factor multiplying the background-error standard deviations	Ocean variables update	Time-averaged rms of F-O	Time-averaged rms of A-O
Exp1	0	1	No	0.0994	0.0611
Exp2	0	1	Yes	0.0935	0.0575
Exp3	0	2	Yes	0.0875	0.0196
Exp4	0	4	Yes	0.0875	0.0059
Exp5	10	1	Yes	0.0879	0.0381
Exp6	20	1	Yes	0.0862	0.0375
Exp7	30	1	Yes	0.0864	0.0459
Exp8	20	2	Yes	0.0856	0.0255
Exp9	20	4	Yes	0.0855	0.0176

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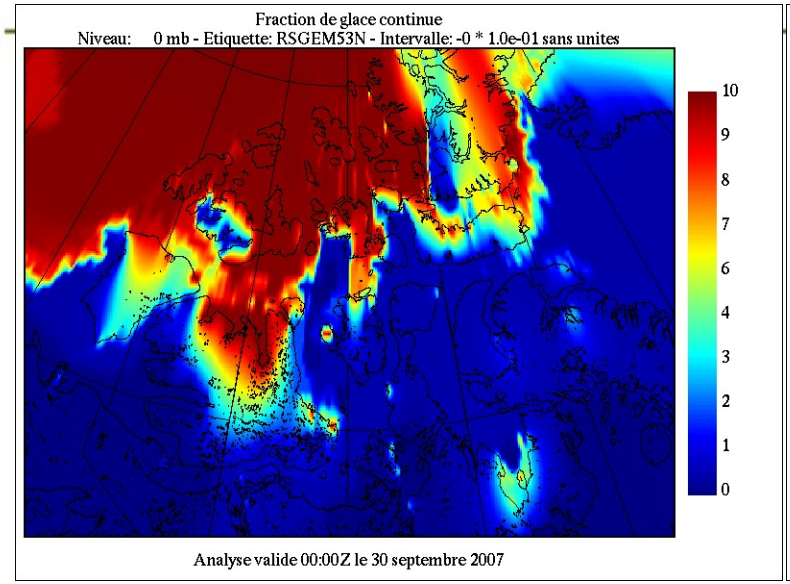
Canadian Arctic Archipelago

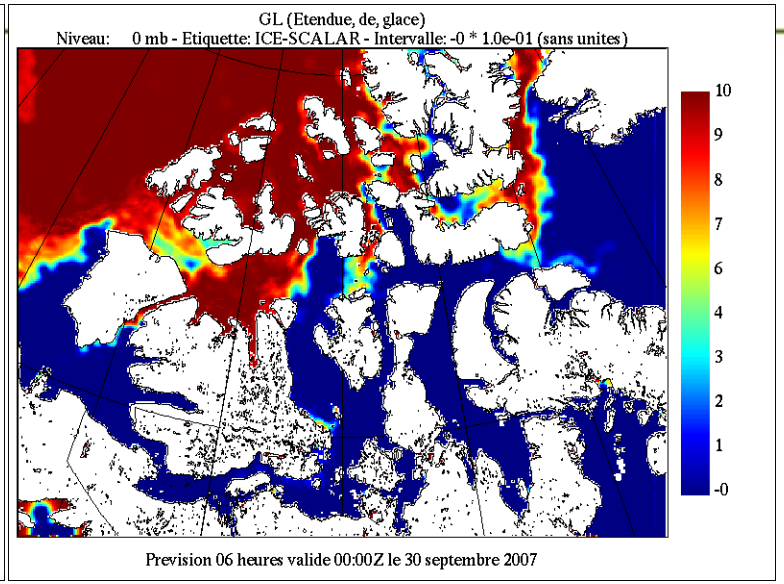
- 5-km horizontal resolution on a rotated grid
- 12-h assimilation windows, twice a day
- Assimilation of total ice concentration from
  - AMSR-E NT2 (σ_o = 0.2)
  - CIS daily ice charts (σ_o = 0.1)
  - radarsat image analyses (σ_o = 0.1)
- First guess is 100% ice concentration everywhere at start of experiment, 16 March 2007
- Persistence is assumed between assimilation windows
- Background-error horizontal correlations are modeled using the diffusion operator with a 20-km correlation length scale
- Background-error standard deviations for ice concentration is 0.16

Canadian Arctic Archipelago

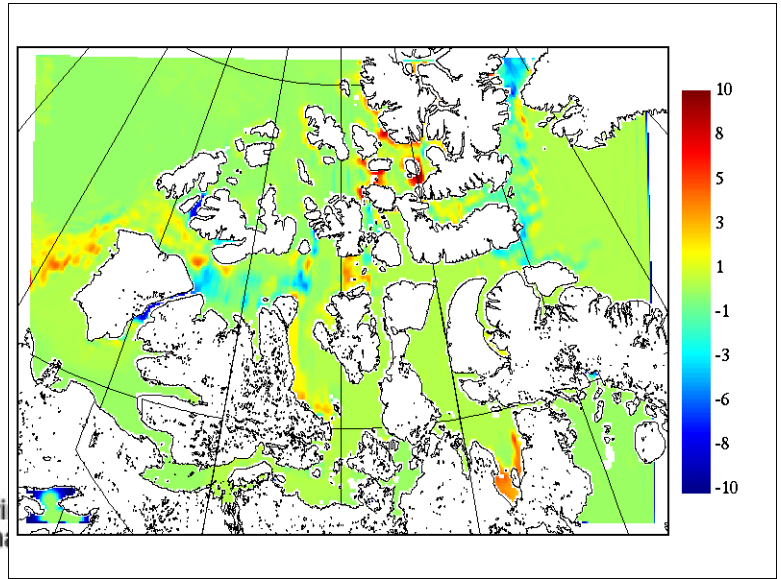
CMC 35-km analysis with SSM/I



3D-Var analysis



Difference:



Summary

- Background-error statistics from the EnKF can be extracted and are useful for 3D-Var
- Modeling of background-error horizontal correlation with a diffusion operator is efficient and appropriate in the presence of complex lateral boundary conditions
- For the Labrador Sea application,
  - the use of the background-error correlation between ice concentration, ocean temperature and salinity leads to improved forecasts;
  - the best forecasts are obtained when the background-error standard deviations, estimated by time and space averaging the enKf statistics, are at least doubled and simultaneously with background-error horizontal correlation length of 20 km

Ongoing and future work

- Assimilation and analysis of ice thickness
- Assimilation of passive microwave data with a radiative transfer model
- Displacement error for ice concentration field
- Apply the 3D-Var analysis to the coupled atmosphere-ice-ocean forecast system for the Gulf of St. Lawrence
- Include ocean current in the analysis variables:
  - Development of balance relationships
- Assimilation of high resolution satellite data (VIS/IR and SAR)

MERCI! THANK YOU!