# Sea Ice Data Assimilation for the Canadian East Coast

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Funding support: NSERC, CFCAS (GOAPP)
Travel assistance: J Gordin Kaplan Graduate Student award, CMOS student travel bursary

NSERC CRSNG

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

GOAPP
Global Ocean-Atmosphere Prediction and Predictability

# Outline

I. Sea ice on the Canadian East Coast.

II. Model details and results of the prognostic simulation.

III. Implementation of two data assimilation techniques:
- A simple sea ice concentration Nudging.
- A 1-D data assimilation with corrections to sea ice thickness and the underlying T and S.

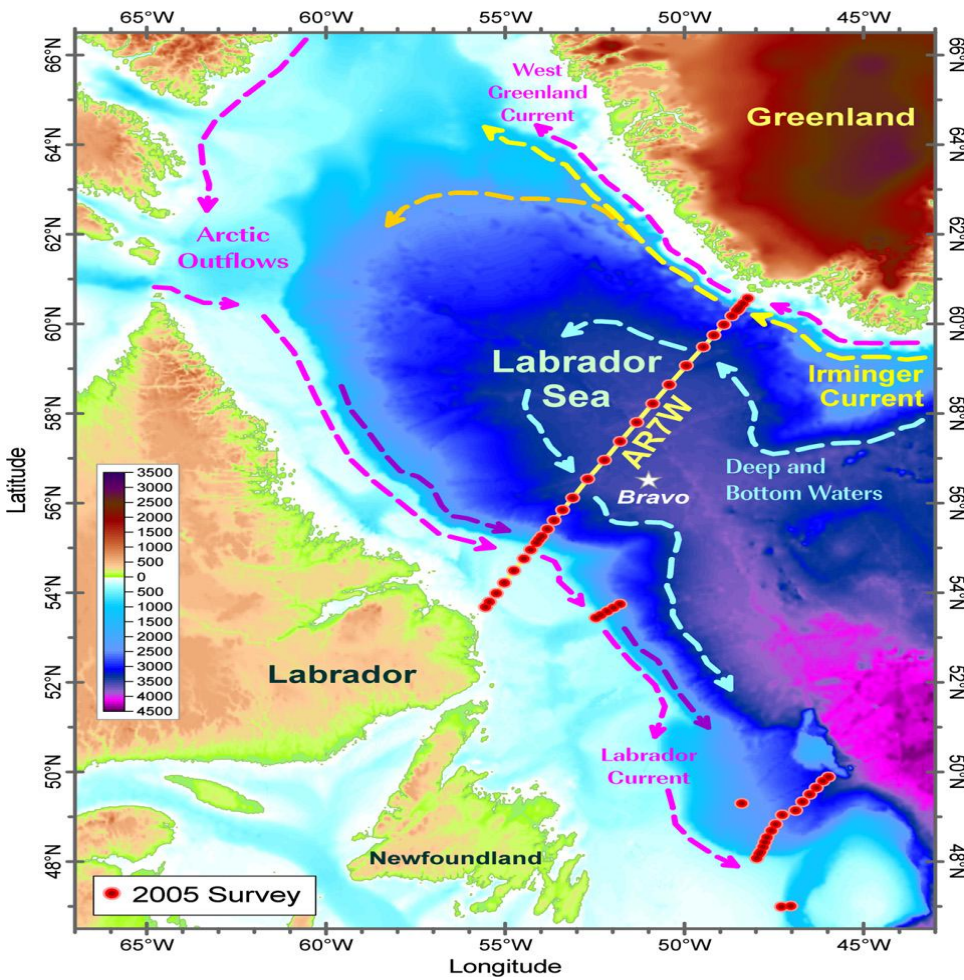
IV. Results of Nudging and 1-D data assimilation:
- Occurring every model's time step.
- Occurring every 5 days.

V. Conclusions and Future work.

# Canadian East Coast (below 60°N)

Labrador and Newfoundland shelves:

- 45ºN to 60ºN.
- Very shallow in contrast with the interior.
- Sea Ice exist only along the coast.
- Sea Ice appears in winter and disappears by the end of June.




I.Yashayaev, *Hydrographic changes in the Labrador Sea*, 1960–2005, Prog. Oceanogr., 73, 242–276, 2007.

# Model details

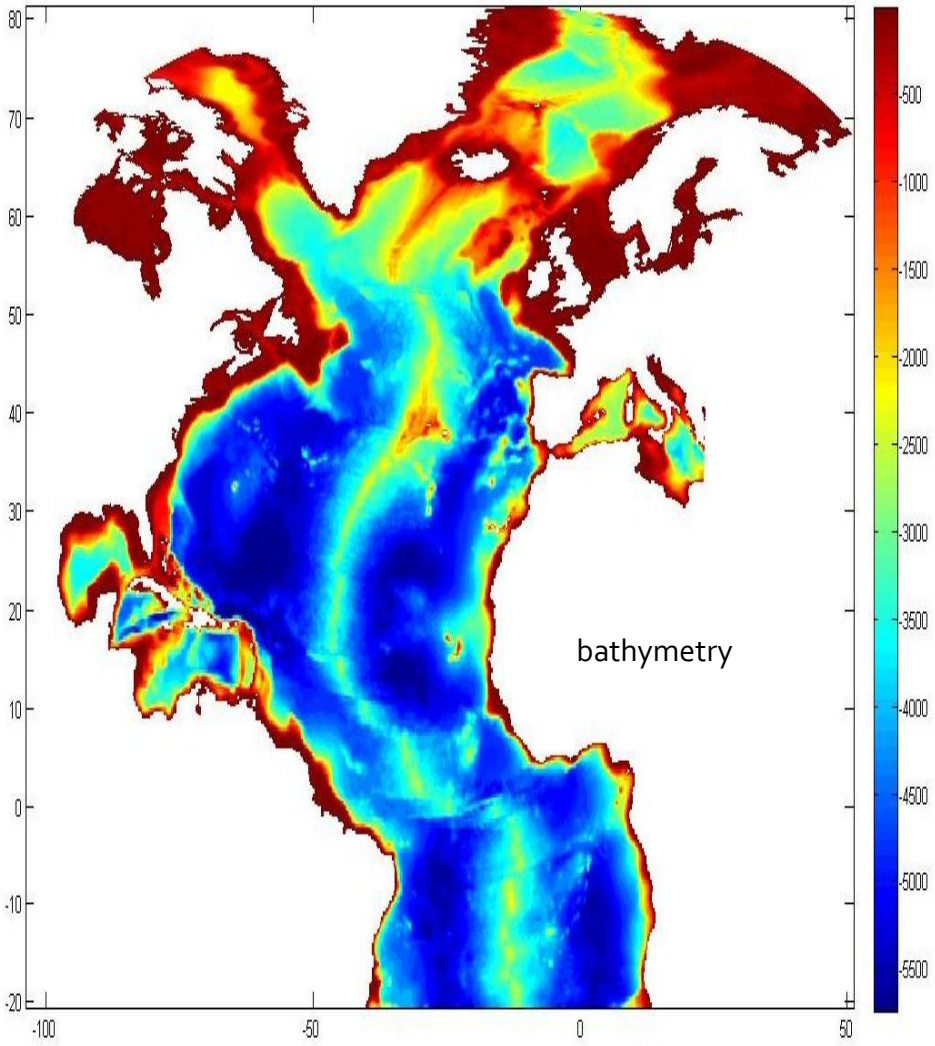
NEMO v2.3 ocean/sea ice coupled model (OPA9 ocean model coupled with LIM2 sea ice mode):

- Configuration: North Atlantic/Nordic Seas (NATL4) (DRAKKAR group).
- Resolution: ¼ degree horizontal, 46 vertical levels.
- Eddy permitting.

LIM2 sea ice model:

- Dynamic-thermodynamic model
- Three layer model: One layer for snow, two for ice.

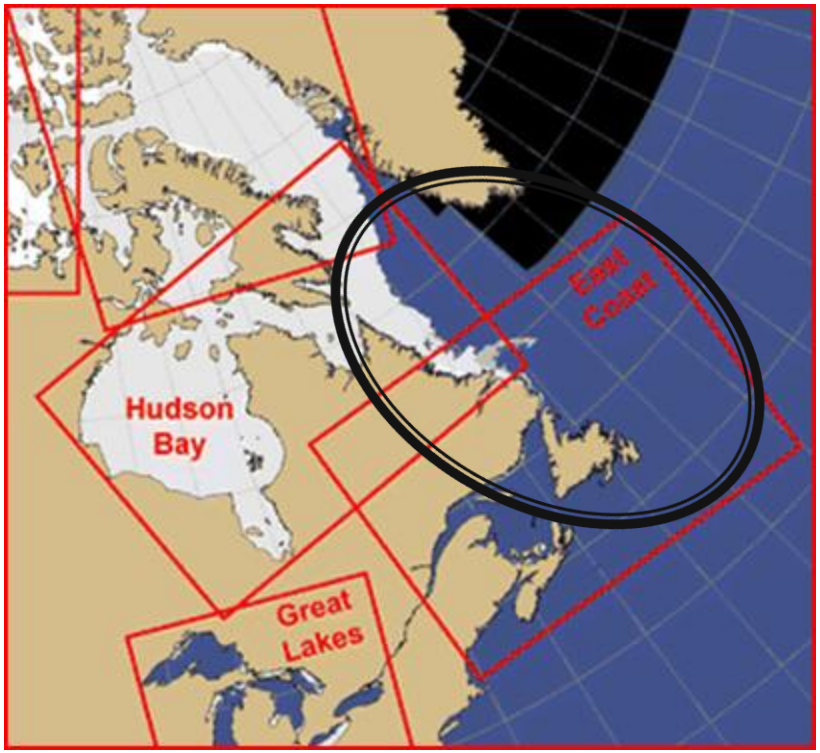
Forcing: CORE (Coordinated Ocean Reference Experiment  Forcing set)



# Canadian Ice Service ice fields (CIS)

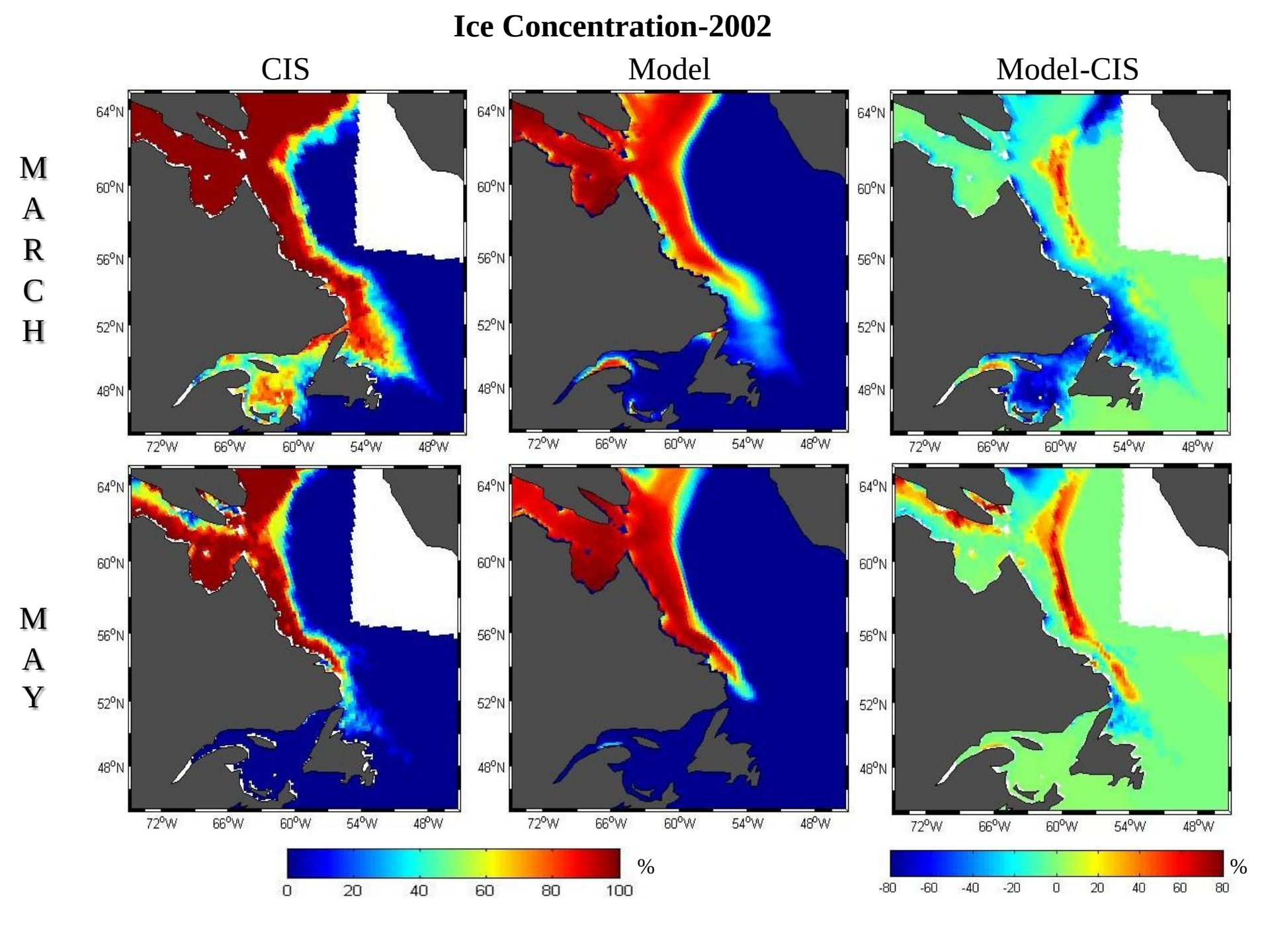
Weekly regional ice charts for the Canadian east coast (below 57º N) and for Hudson bay (above 57ºN).

Years used in our study: 2002-2005



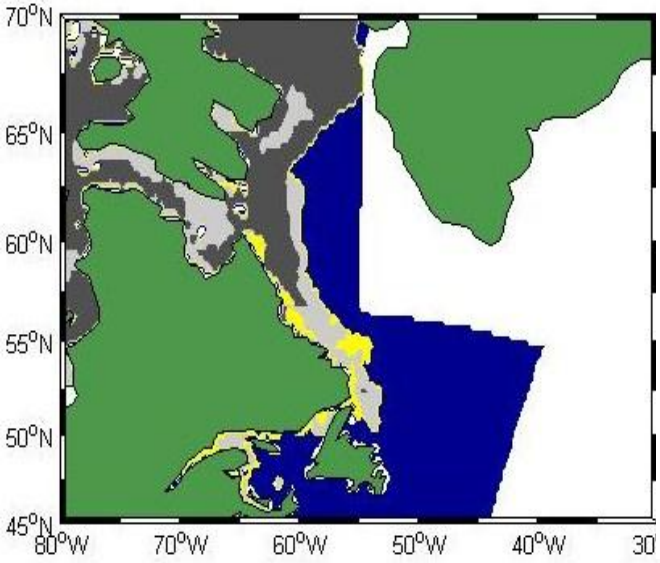
| Experiment | Years of simulation | Nudging | Corrections to tracers | Nudging coefficient | Assimilation time step |
|---|---|---|---|---|---|
| Free run 001 | 2002-2003 | No | No | - | - |
| Free run 002 | 2004-2005 | No | No | - | - |
| Nudging 003 | 2002-2003 | Yes | No | 1/5*86400 | Model’s time step |
| Nudging 004 | 2004-2005 | Yes | No | 1/5*86400 | Model’s time step |
| 1-D 005 | 2002-2003 | Yes | Yes | 1/5*86400 | Model’s time step |
| Nudging 007 | 2002-2003 | Yes | No | 1/5*1200 | 5 days |
| 1-D 010 | 2002-2003 | Yes | Yes | 1/5*1200 | 5 days |

# Ice Concentration-2002

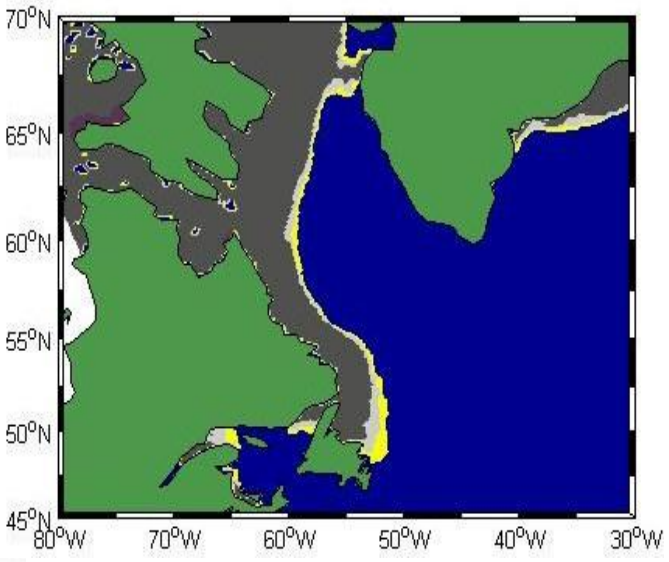


# Sea Ice Categories

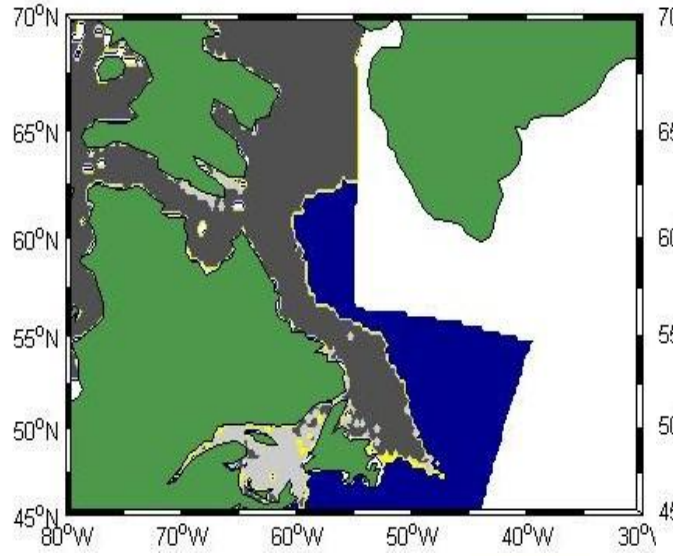
CIS January-2002



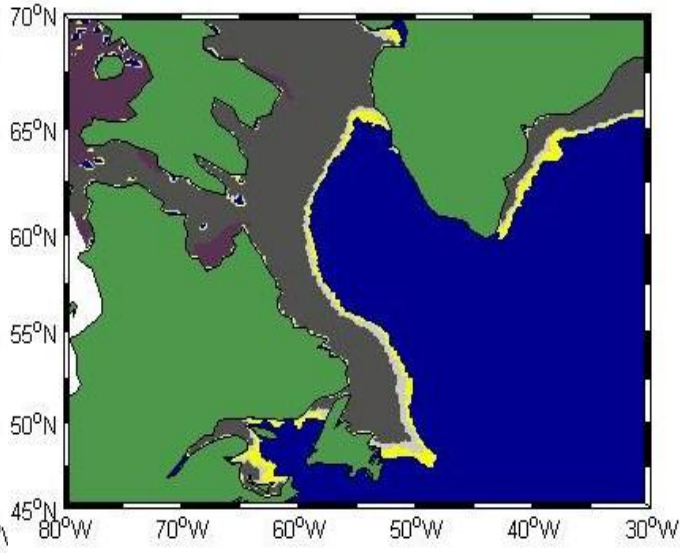

Model January-2002




CIS March-2002



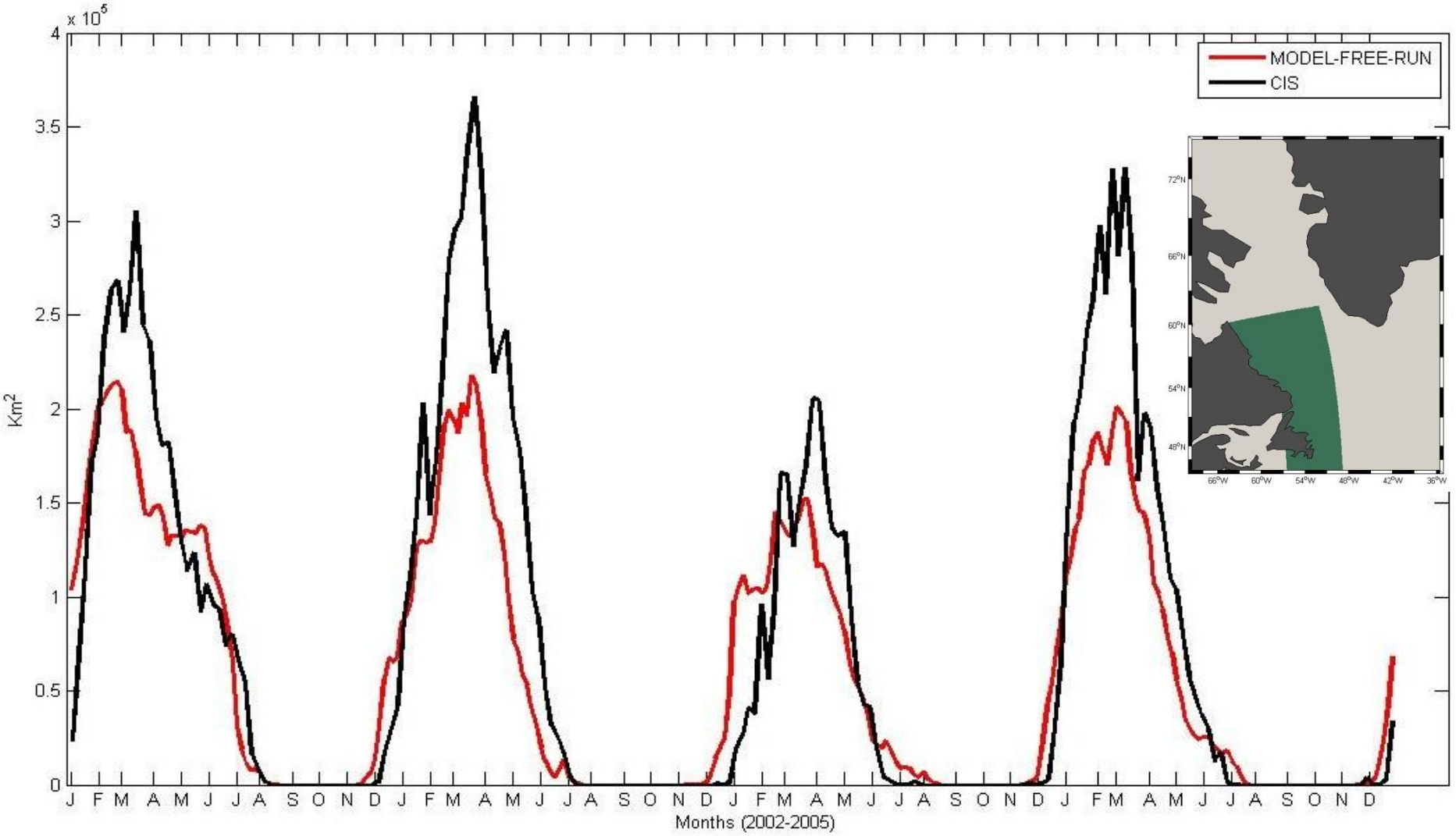

Model March-2002





| Stage of development | Ice thickness range |
|---|---|
| New ice or nilas | <0.1 meters |
| Young ice | 0.1-0.3 meters |
| First year ice | 0.3-2.0 meters |
| Old ice* | >2.0 meters |

# Sea Ice Covered Area




- Sea ice covered area is underestimated by the model for most months and in all years.
- Exception: When the formation of ice is initiated (December-January).

# Nudging

The model is pushed gently towards CIS sea ice concentration field by adding an additional term to the model's sea ice concentration prognostic equation. This term is proportional to the difference between the CIS sea ice concentration values and the estimations by the model

Prognostic equation: $$\frac{\partial x}{\partial t} = F(x,t) + K * (x_{obs} - x)$$

Where K the nudging coefficient

# 1-D Data Assimilation

Ice thickness, Salinity and Temperature are corrected within the water column.

Corrections are based on correlations obtain by using a ten member ensemble with random perturbation in the forcing fields:
Create perturbation using EOFs:

Eq. 1 $\mathbf{R=F^T*F}$, where R=covariance matrix

Eq. 2 $\mathbf{R*EOFs=EOFs*\Lambda}$, where $\Lambda$ contains the eigenvalues and EOFs the eigenvectors.

Eq. 3 $\mathbf{a_j=FxEOF_j}$ , where $a_j$ is the expansion coefficient (the time evolution of the EOFs).

Eq. 4 perturbation= $\sum_{J}^{50} \mathbf{R_j*EOF_j\,(x,y)*a_j\,(t)}$ , where $R_j$ is a random number taken from a Gaussian distribution with mean zero.

- Add the perturbations to the original forcing fields and run our model.

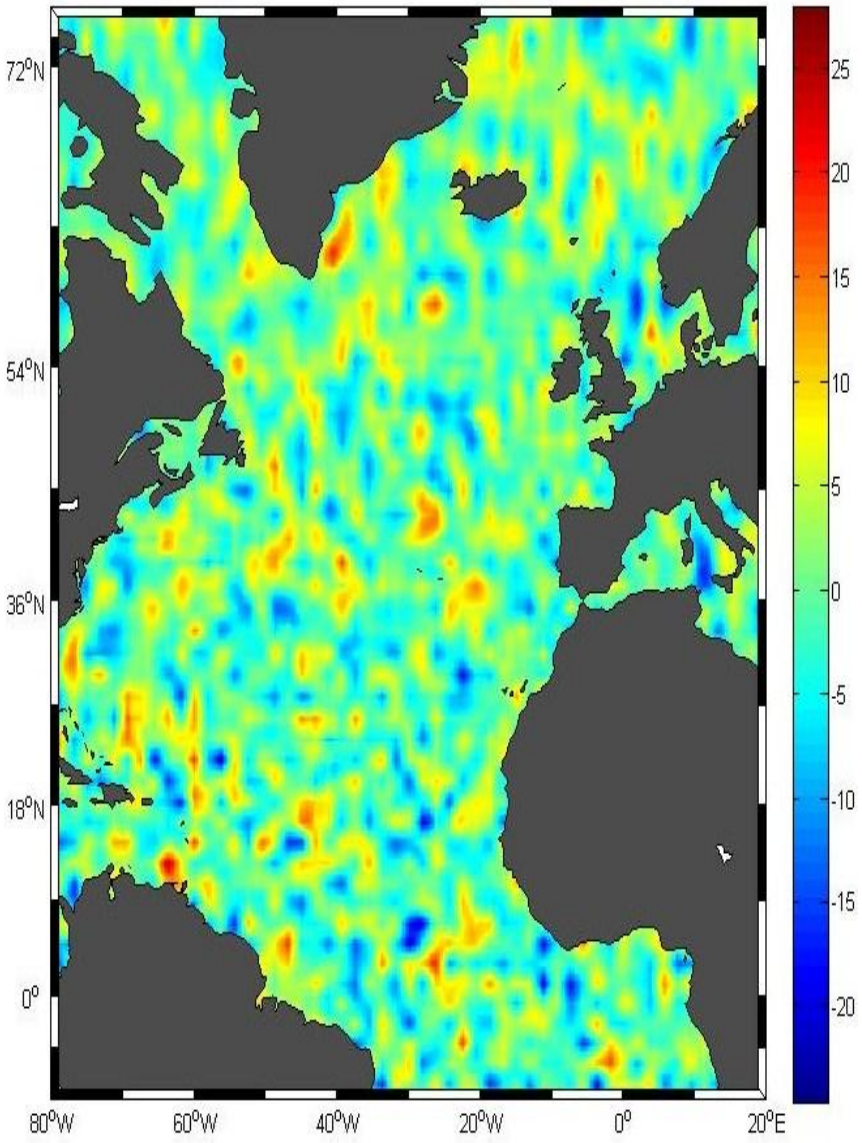
- 10 member ensemble of model results each with slight differences.

- Based on this 10 member model ensemble, we find the cross-covariances between ice concentration and ice thickness, temperature and salinity at each grid point and at each depth for the first 15 days of January of each year.

- These cross-covariances are used for corrections of sea ice thickness and underlying salinity and temperature.

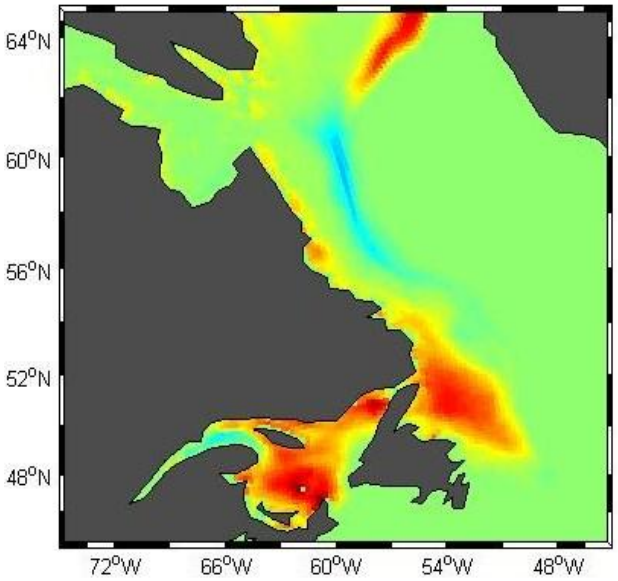
- Ice concentration-salinity and the ice concentration-temperature covariances are both negative and ice concentration-ice thickness covariances are positive.

Example :Thermal radiation perturbation January 1

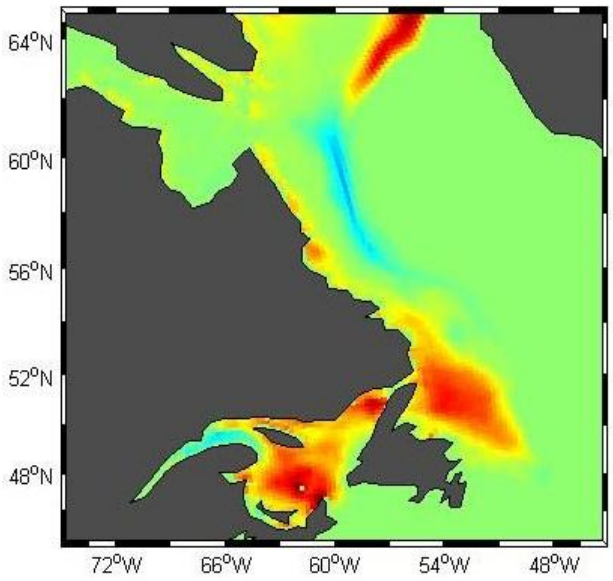


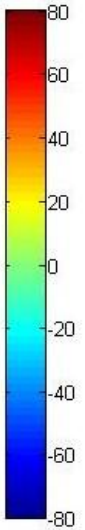
# Ice Concentration differences-March2002

Nudging(003)-Free run




1D(005)-Free run

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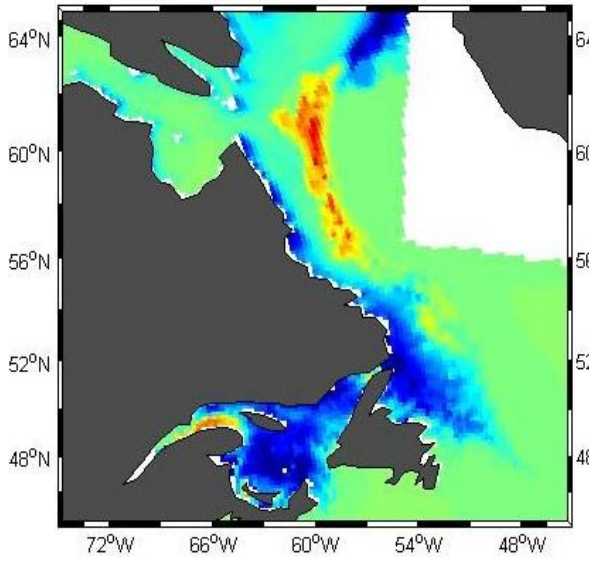
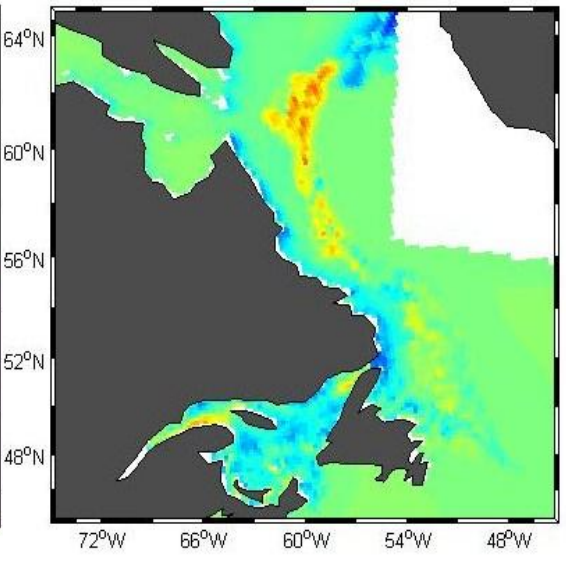
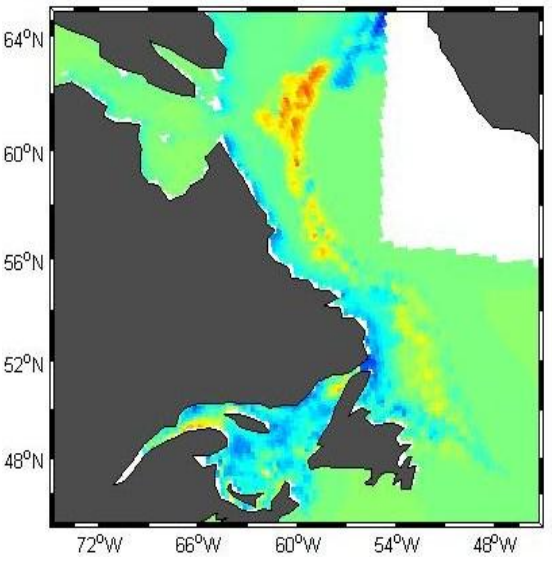
Free run-CIS

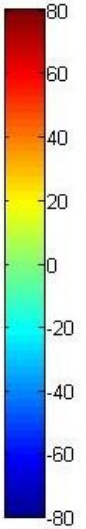



Nudging(003)-CIS




1D(005)-CIS

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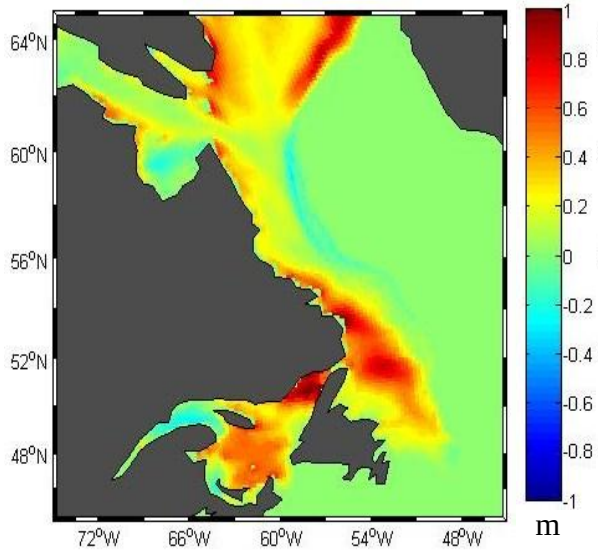
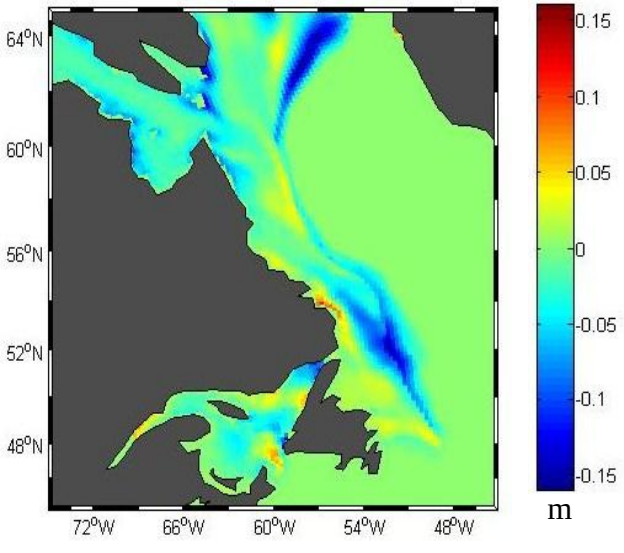
Nudging(003)-Free run
Ice Thickness



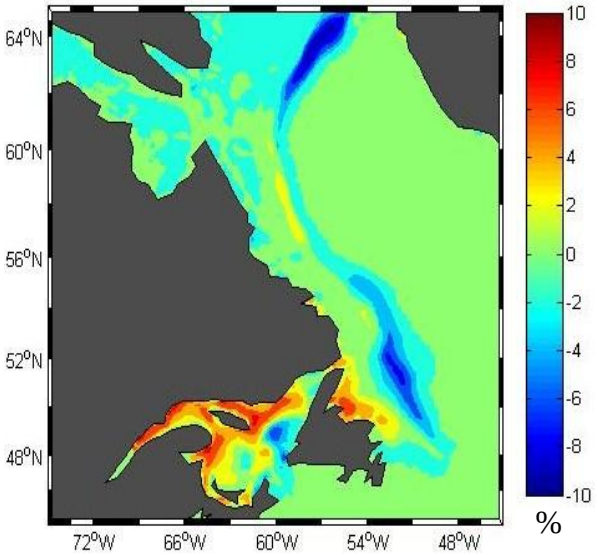

Nudging(003)-1D(005)
Ice Thickness



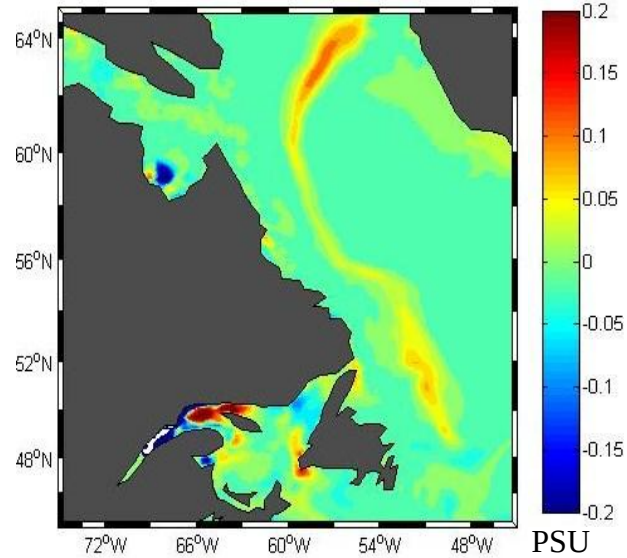

**March 2002**

In January (not shown) sea ice thickness result from 1D lower, still not as low as CIS sea ice thickness

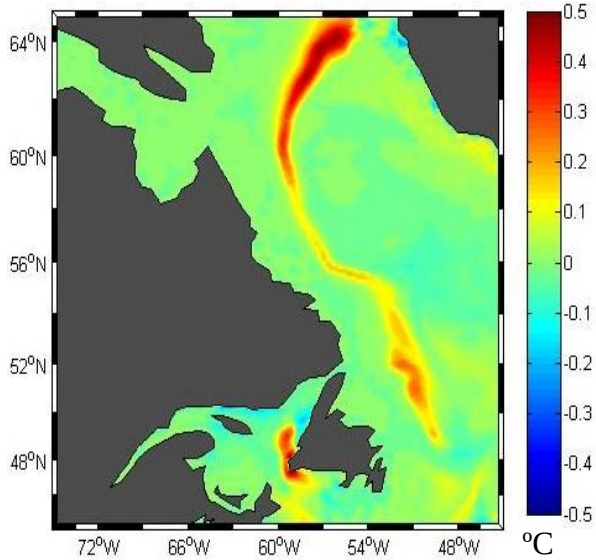
Nudging(003)-1D(005)
Ice Concentration



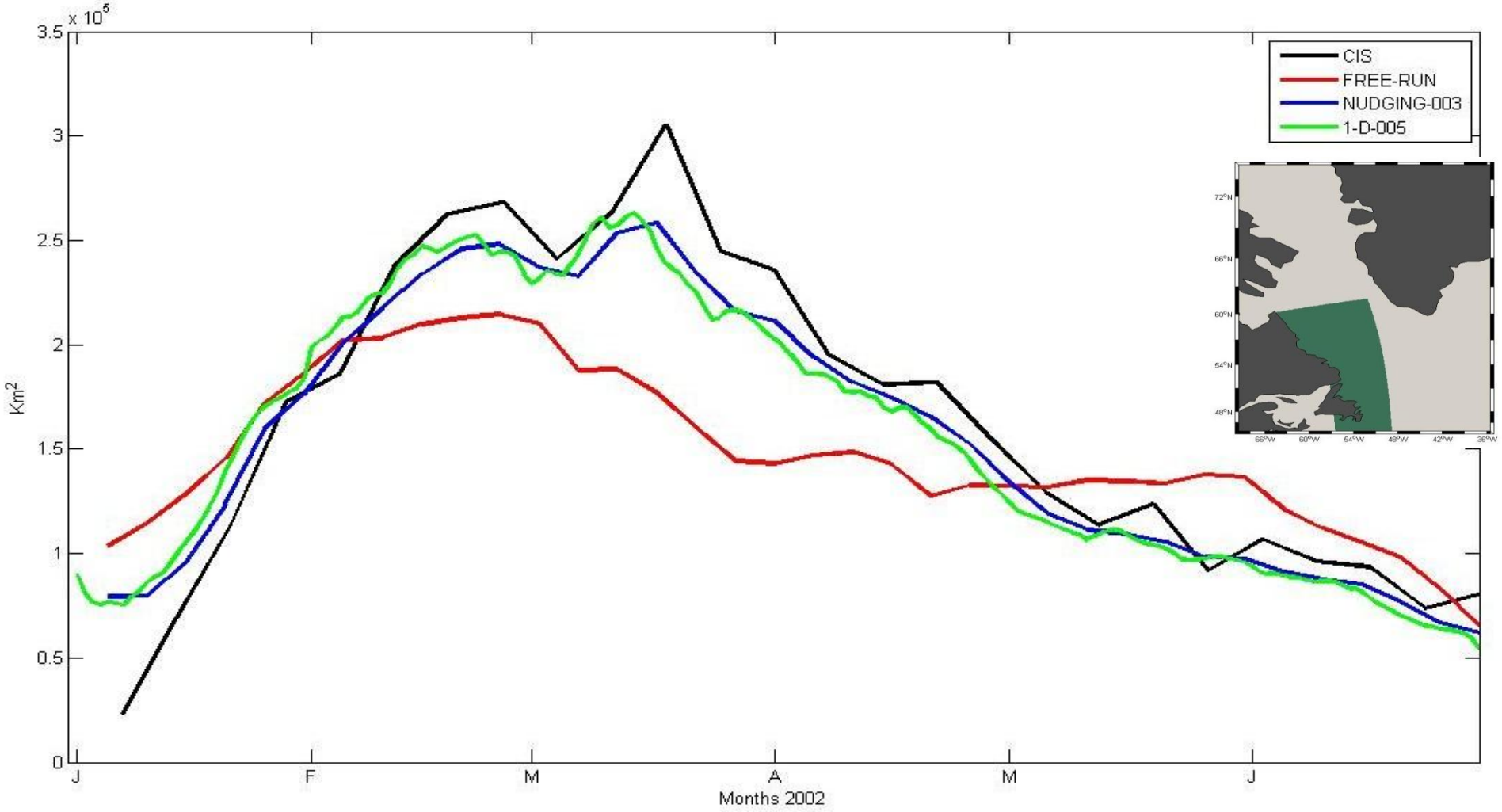

Nudging(003)-1D(005)
Salinity




Nudging(003)-1D(005)
Temperature



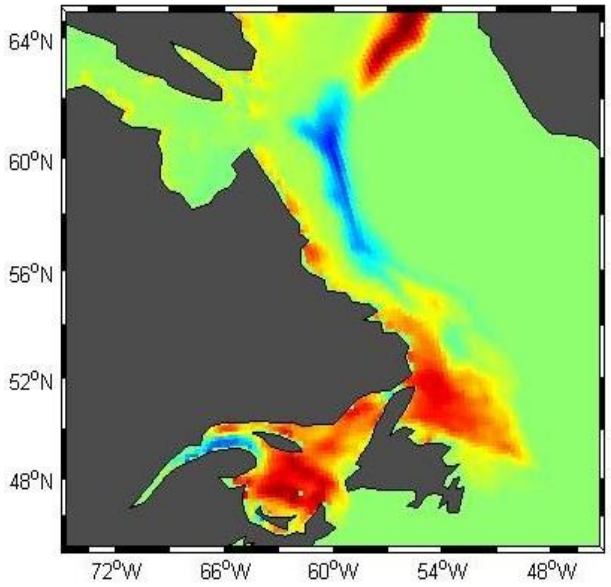
# Sea Ice covered area 2002



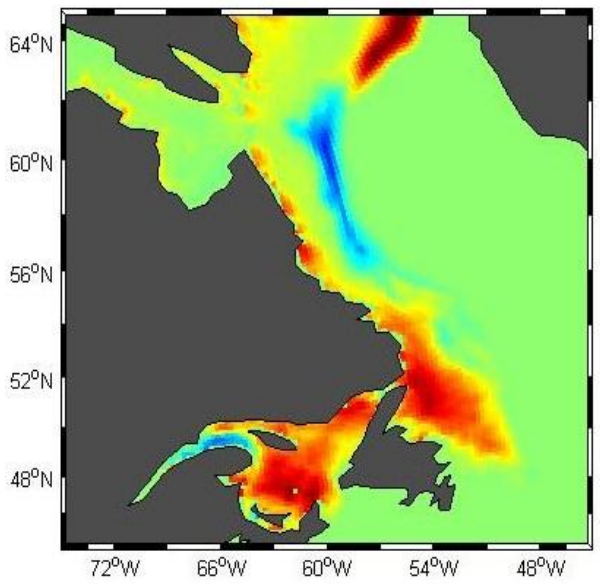

Nudging and 1D results are very similar.

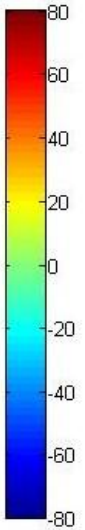
# Ice Concentration differences-March2002

Nudging(007)-Free run




1D(010)-Free run

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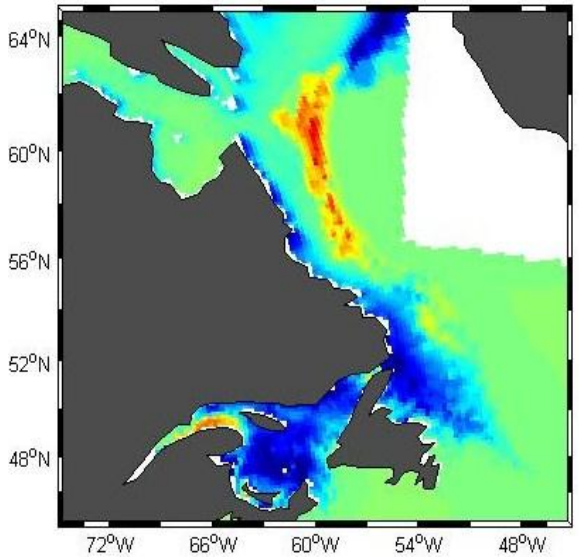
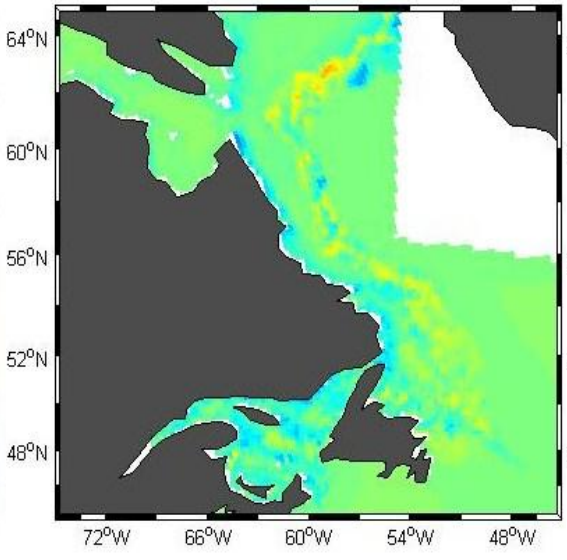
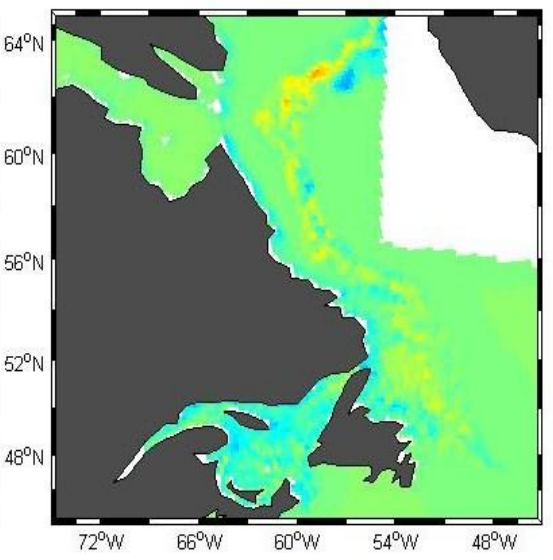
Free run-CIS

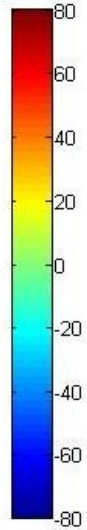



Nudging(007)-CIS




1D(010)-CIS

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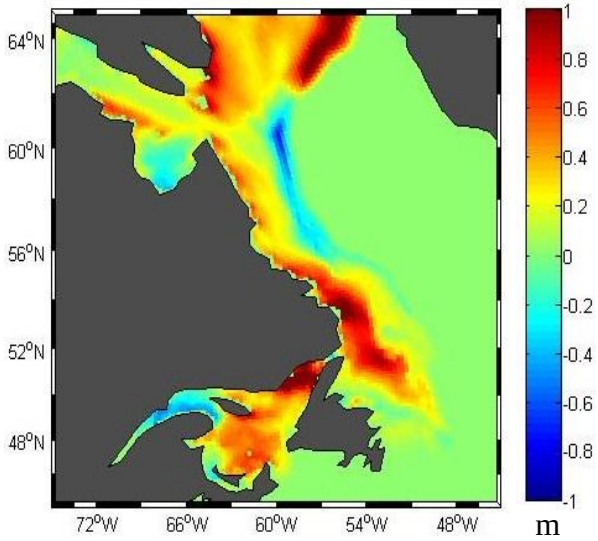
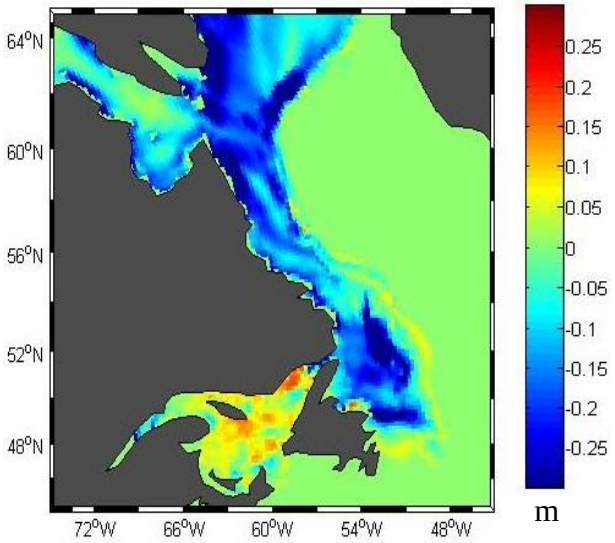
Nudging(007)-Free run
Ice Thickness



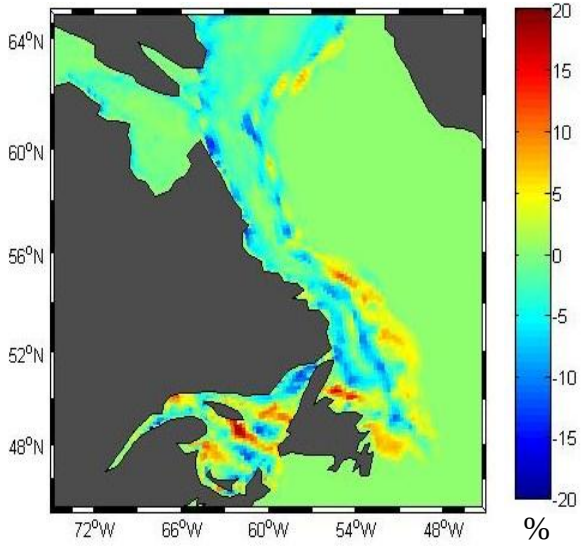

Nudging(007)-1D(010)
Ice Thickness



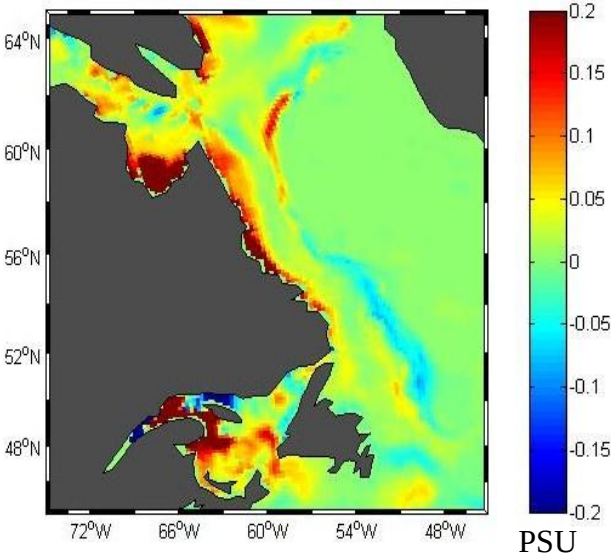

**March 2002**

South (gulf of St Lawrence) 1D experiment result lower sea ice thickness, still not as low as the CIS charts indicate

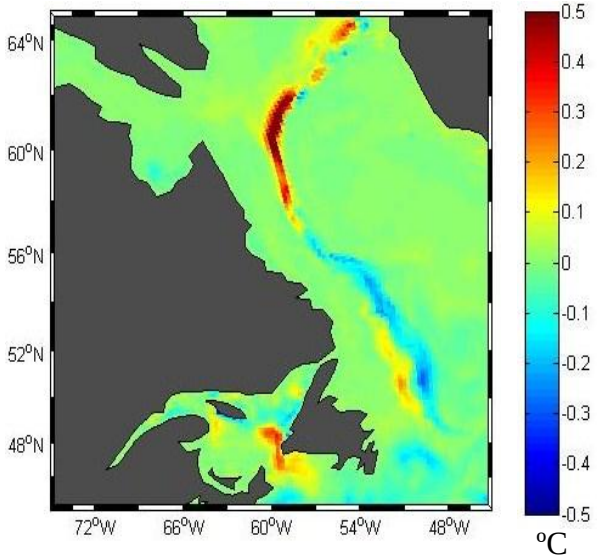
Nudging(007)-1D(010)
Ice Concentration



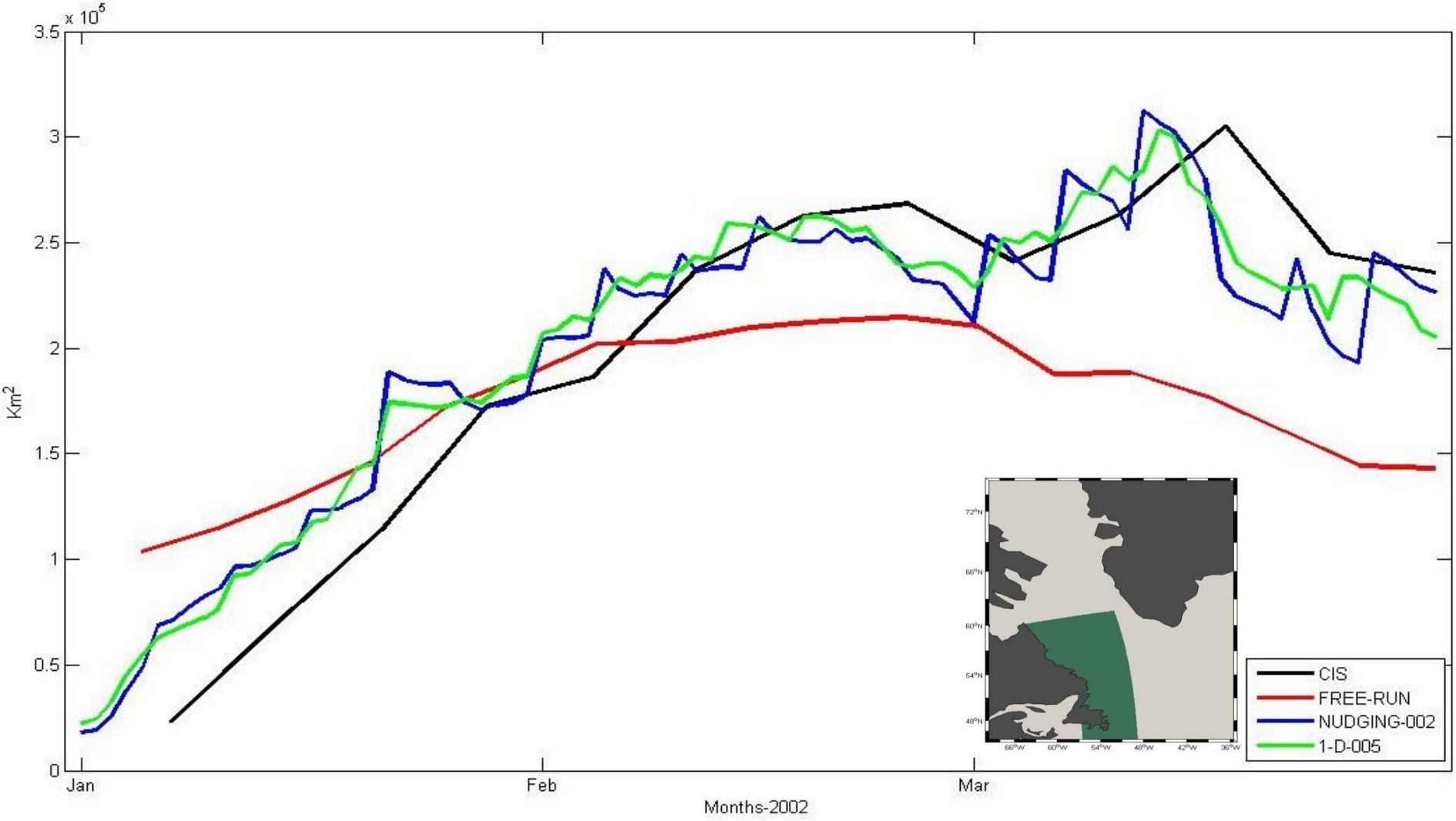

Nudging(007-1D(010)
Salinity




Nudging(007)-1D(010)
Temperature



# Sea Ice covered area 2002




Nudging and 1D results very similar

# Conclusion

- Using the EOFs is a vital approach to find correlations between ice concentration and traces.

- Nudging and 1D data assimilation experiments have similar results as concern sea ice concentration

- Nudging and 1D data assimilation experiments differences in salinity, temperature and ice thickness are more notable in the case where the experiments occur every five days.

- It seems that the 1D data assimilation  experiment result sea ice thickness fields in better agreement with CIS

**Future work:** repeat the procedure for the year 2004 (low sea ice year) and explore the results.