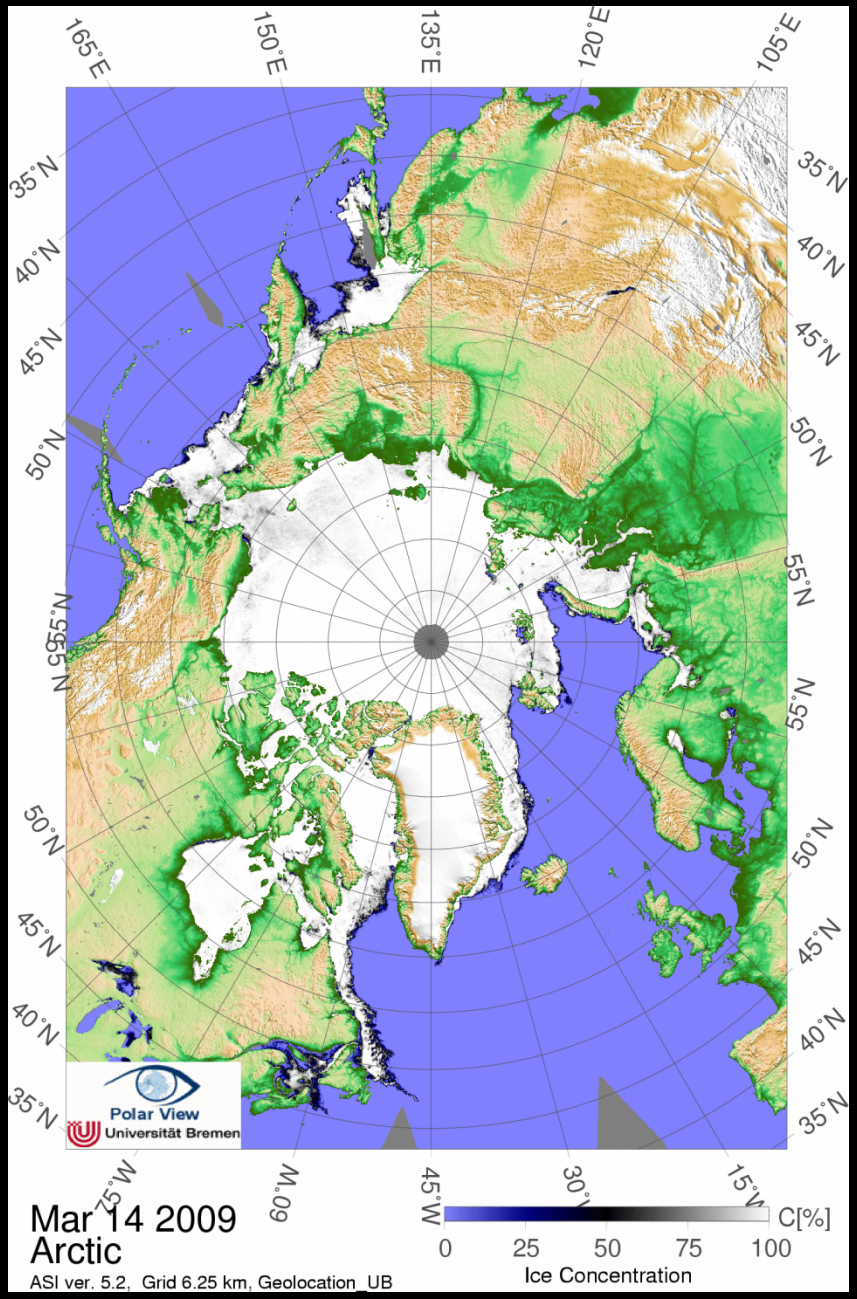


Assimilation of Sea Ice Concentration Observations in a Coupled Ocean-Sea Ice Model using the Adjoint Method

Section 1

OCEAN-SEA ICE STATE ESTIMATION USING ADJOINT METHOD

Ocean - Sea Ice State Estimation

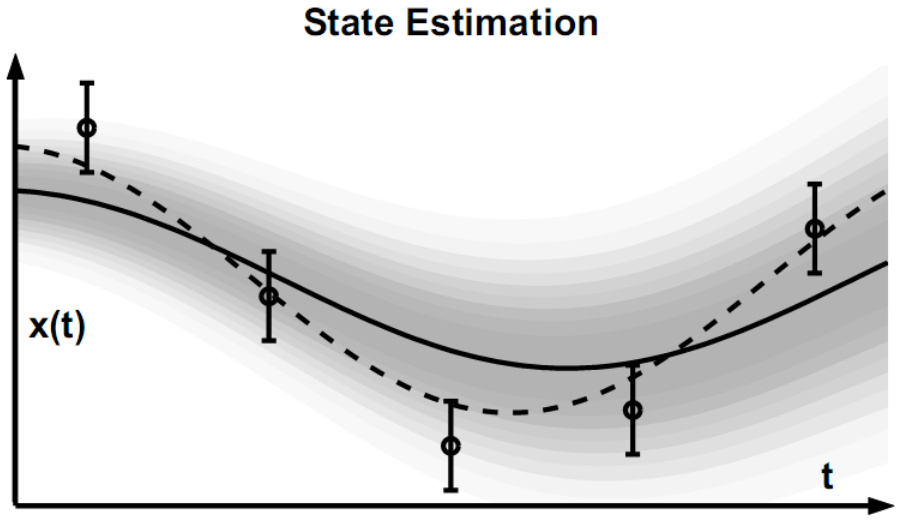
Methodology:
Adjoint Method

Goal is to generate a dynamical reconstruction of the three dimensional time-varying ocean-sea ice system : state estimate

Essentially , model and observations are reconciled in a least-squares sense

System evolves on the merits of the physics and thermodynamics encoded in the numerical model given *initial* and *boundary* conditions

Iteratively adjust *initial* and *boundary* conditions using information provided by the Lagrange multipliers of the system, as provided by model adjoint.



J. Gebbie 2004 Thesis

Circle/bars : observations + uncertainties
Solid : initial state trajectory
Dashed : improved state estimate

Practical Lagrange Multipliers for Thermodynamic Sea Ice Model

Information in the Lagrange multipliers is used to choose adjustments to model initial and boundary conditions so as to reduce model-data misfit

Lagrange multipliers evolve through the ocean-ice adjoint model, which is itself driven by model-data misfit

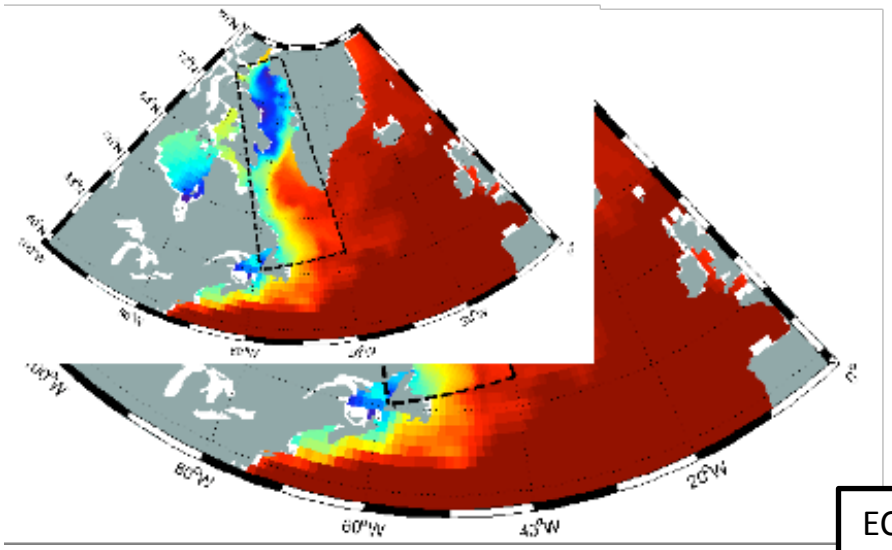
Thermodynamic sea ice model adjoint driven by sea ice concentration misfit

Complications arise when an observation indicates sea ice but forward model trajectory is ice free.

In this case the Lagrange multipliers evolving through the pure sea ice adjoint are zero.

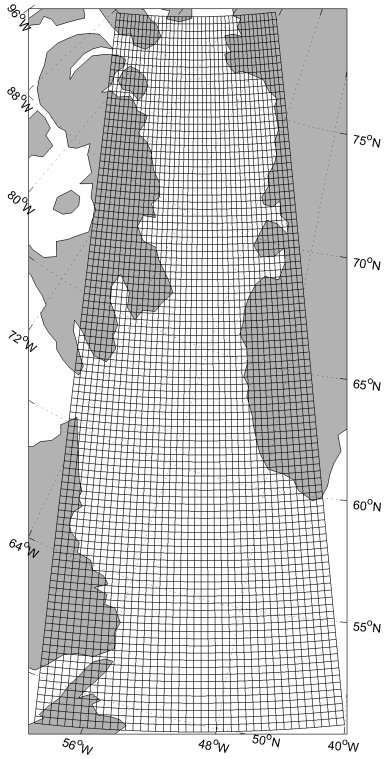
- Assume model is ice-free because of ocean has not yet been forced to the freezing point
- Sea ice concentration observations →
  - Proxy SST
  - Proxy upper ocean stratification
- Proxy SST
  - Assume SST under sea ice is at the salinity determined freezing point
  - Effect is to change atm. state so as to increase air-sea heat fluxes and decrease initial thermal reservoir in the upper ocean
- Proxy Stratification
  - Assume a well stratified ~ 50 m stratified mixed layer beneath ice, stratified by salinity
  - Effect is to modify initial and lateral open boundary ocean conditions.

Model, Initialization, and Boundary Forcing



ECCO SOLUTION

Regional Domain



Ocean : 3-D prognostic Ocean Model (MITgcm) + KPP Mixed Layer

Ice: Hibler VP + Semtner 0-Layer Ice Thermo + Snow

Initial Condition Guess : ECCO ocean state estimate

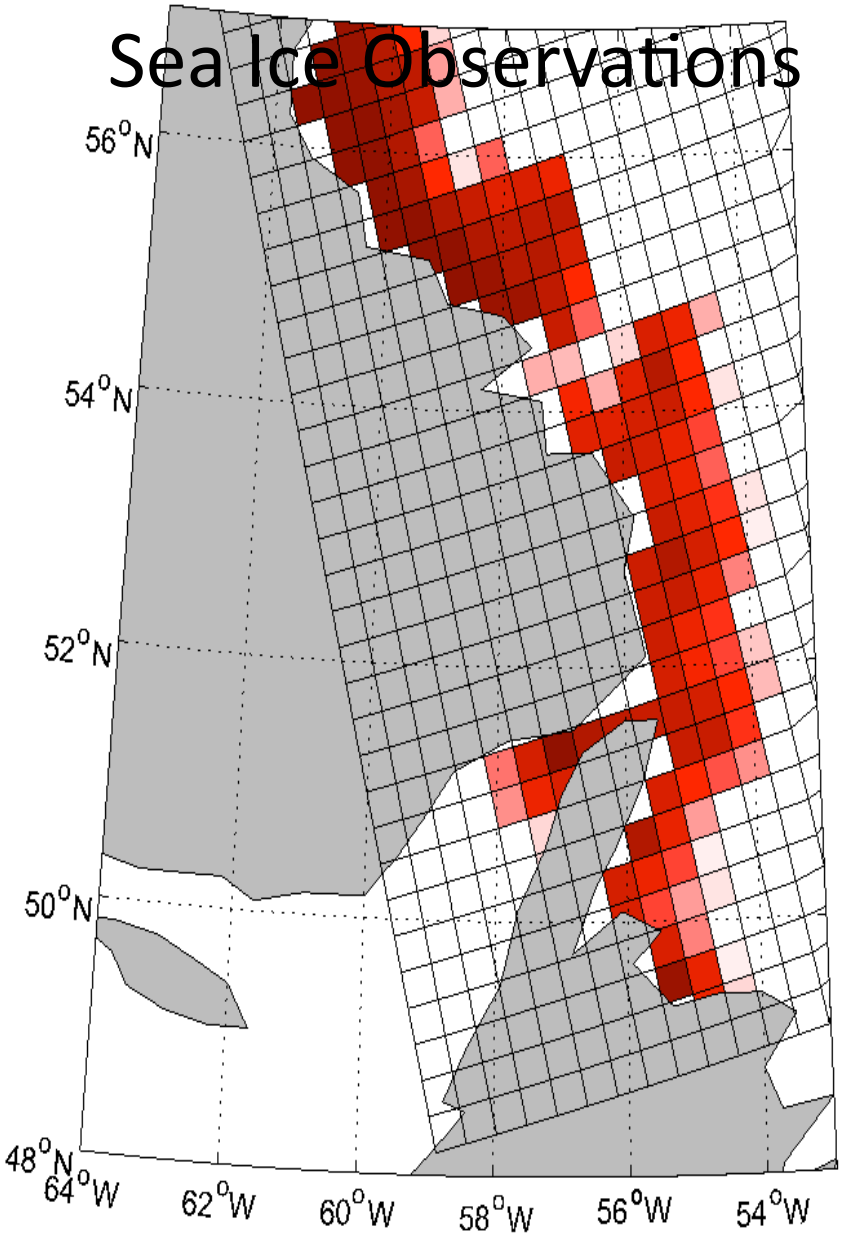
NCEP 6 hourly reanalysis (Fluxes calculated by model)

Time Window : 1 year and 12 years

Section 2

ATMOSPHERE-OCEAN-SEA ICE OBSERVATIONS AND THEIR UNCERTAINTIES

SSM/I



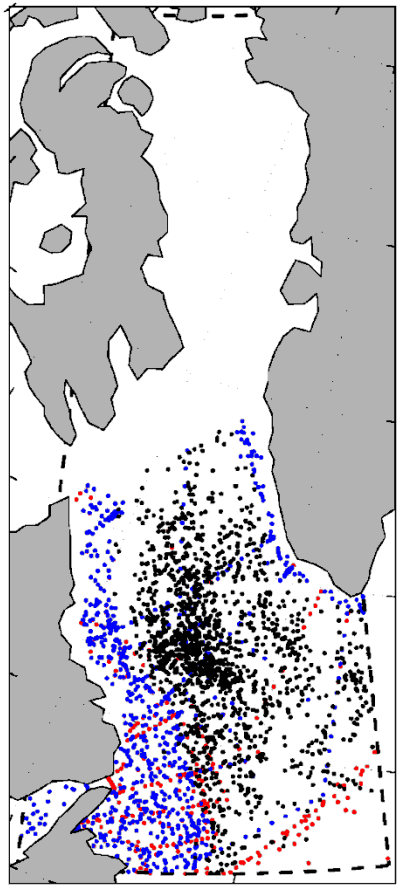
MODIS : May 9, 1999

Credit
Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE

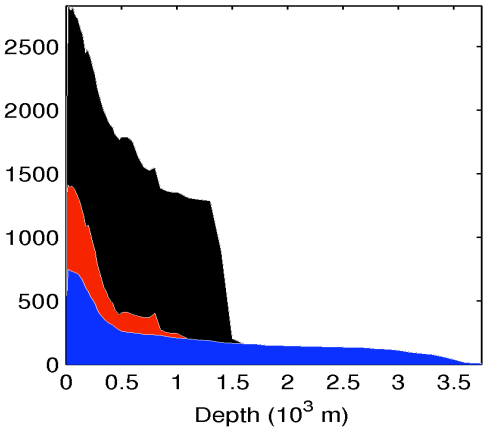
in situ ocean observations

[Sep 1996 -August 1997]

Observation Locations



Number of Observations with depth

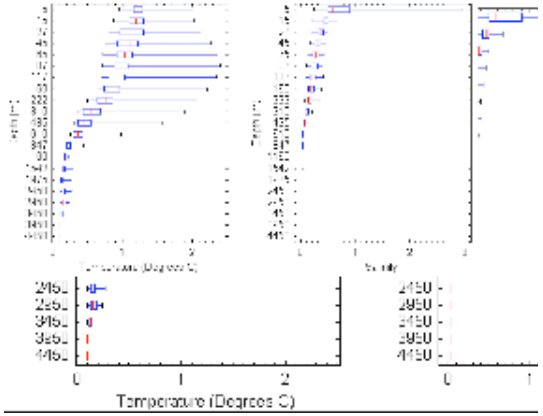


Blue = CTD

Red = XBT

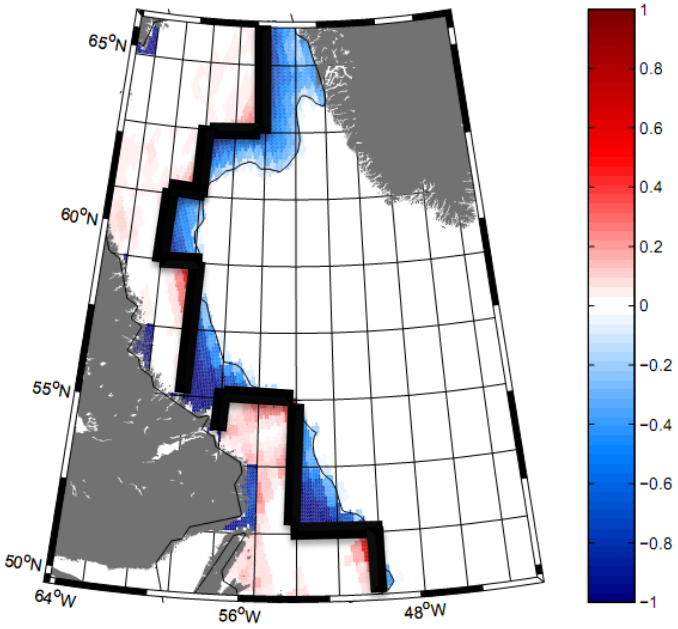
Black = Profiling Floats (PALACE, ARGO, etc)

Temperature Uncertainty



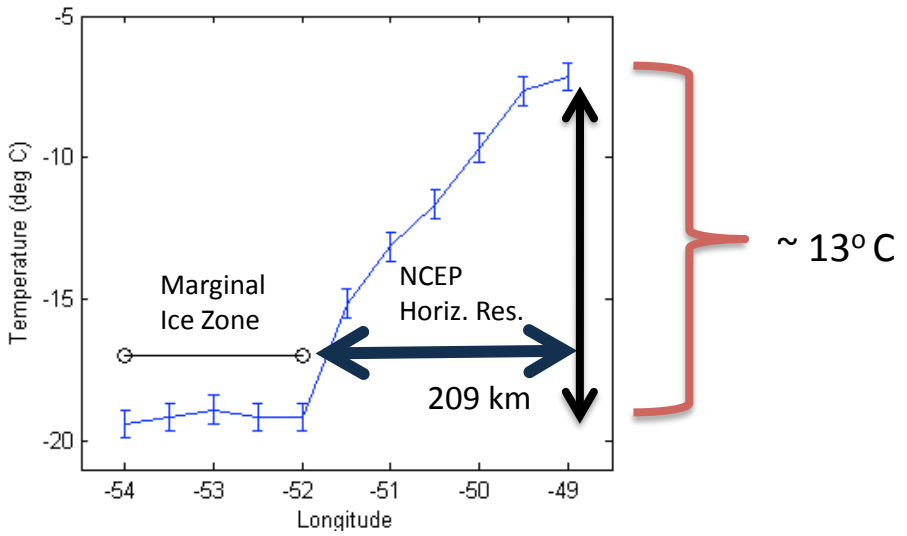
NCEP Reanalysis errors across the MIZ

Reanalysis ice mask -
SSM/I Ice Concentrations



(3/10/1992)

Observed near surface air temperature acoss marginal ice zone

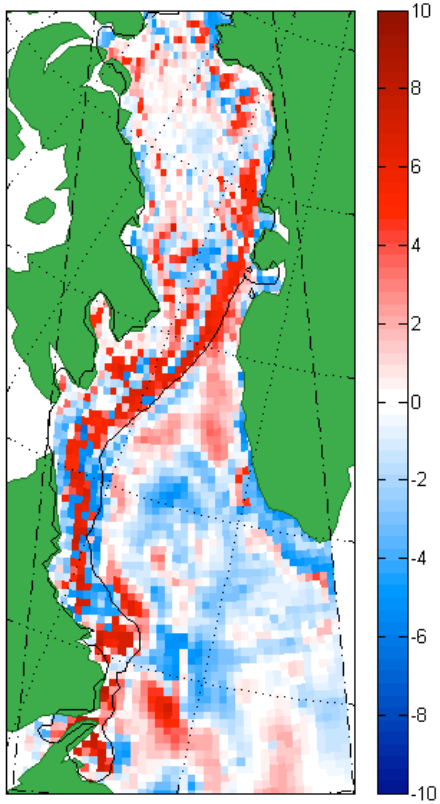


Adapted from Renfrew et al 1999

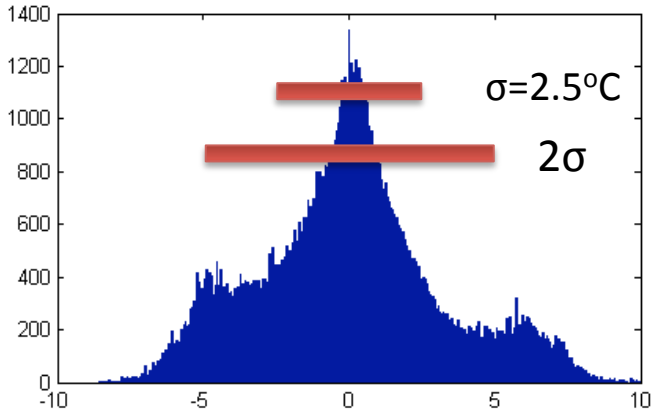
Section 3

ADJUSTMENTS TO MODEL CONTROLS

Adjustments to NCEP Surface Air Temperature
[Time Varying]



May 7-14, 2007



Adjustments compensate for errors in Ocean-ice model and atmospheric forcing errors

- Reanalysis : Crude sea ice mask
- Model : Unresolved MIZ eddy motion

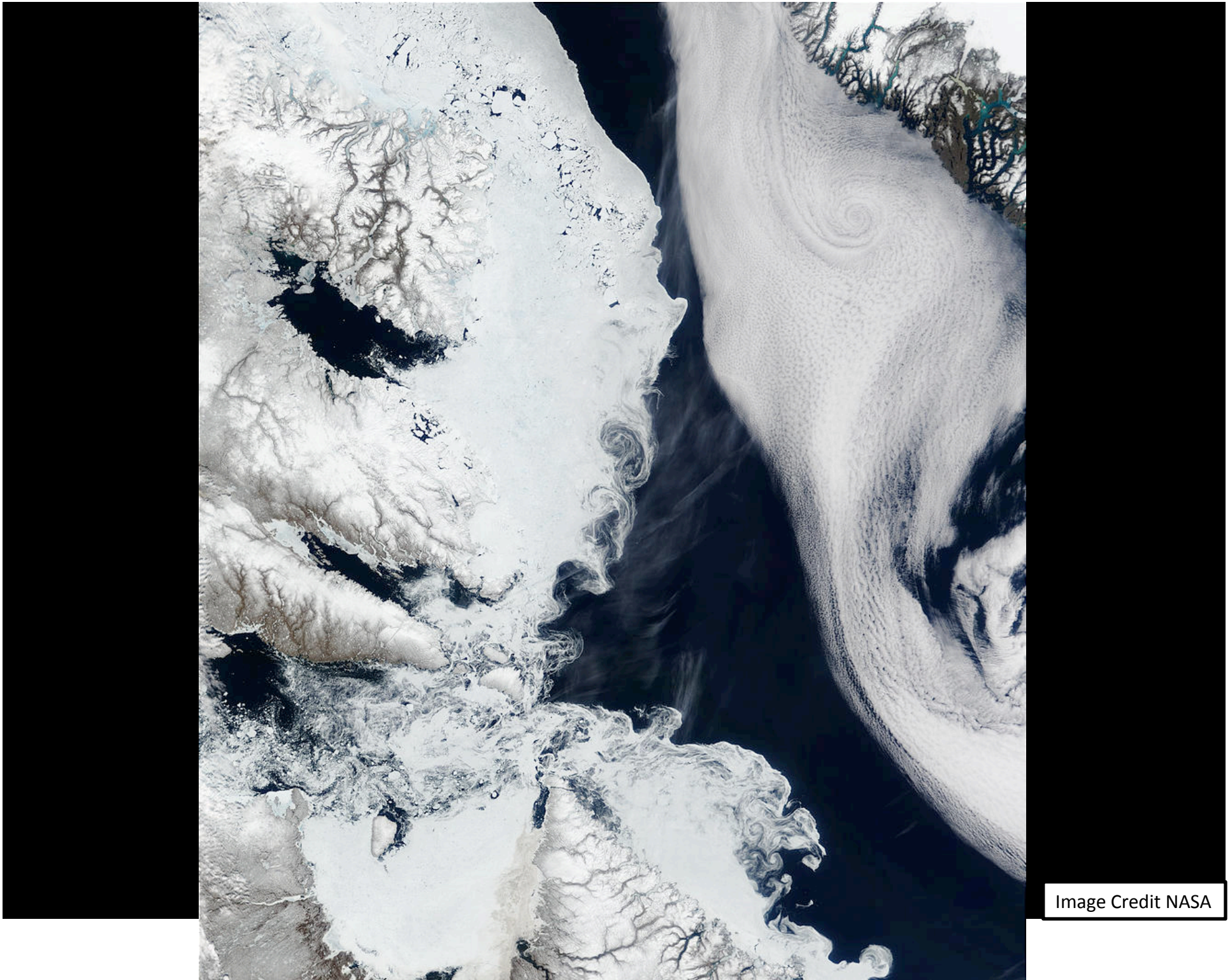
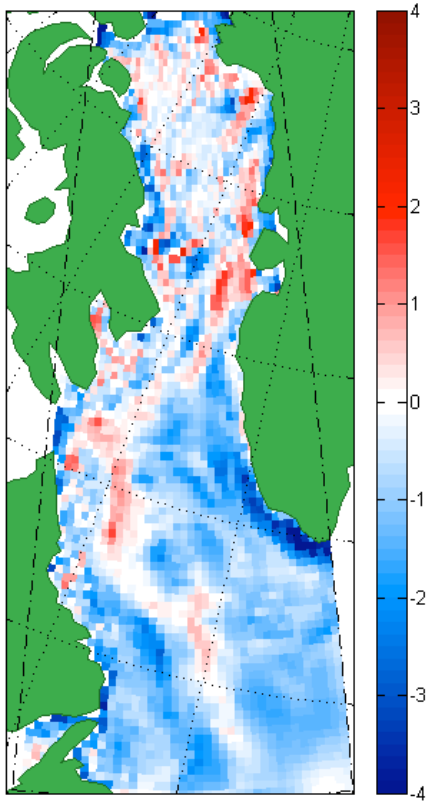
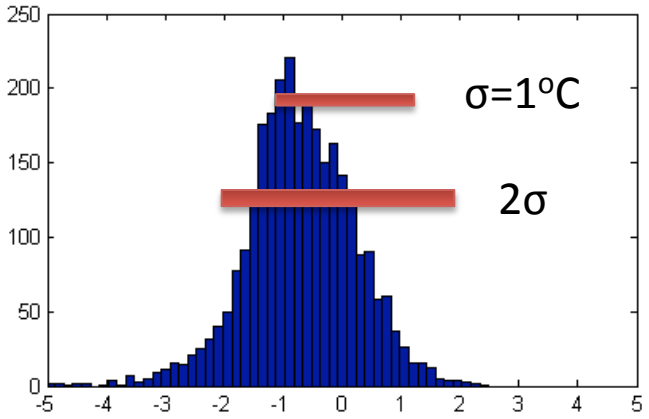


Image Credit NASA

Adjustments to NCEP Surface Air Temperature
[Annual Bias]





Adjustments compensate for errors in Ocean-ice model and atmospheric forcing errors

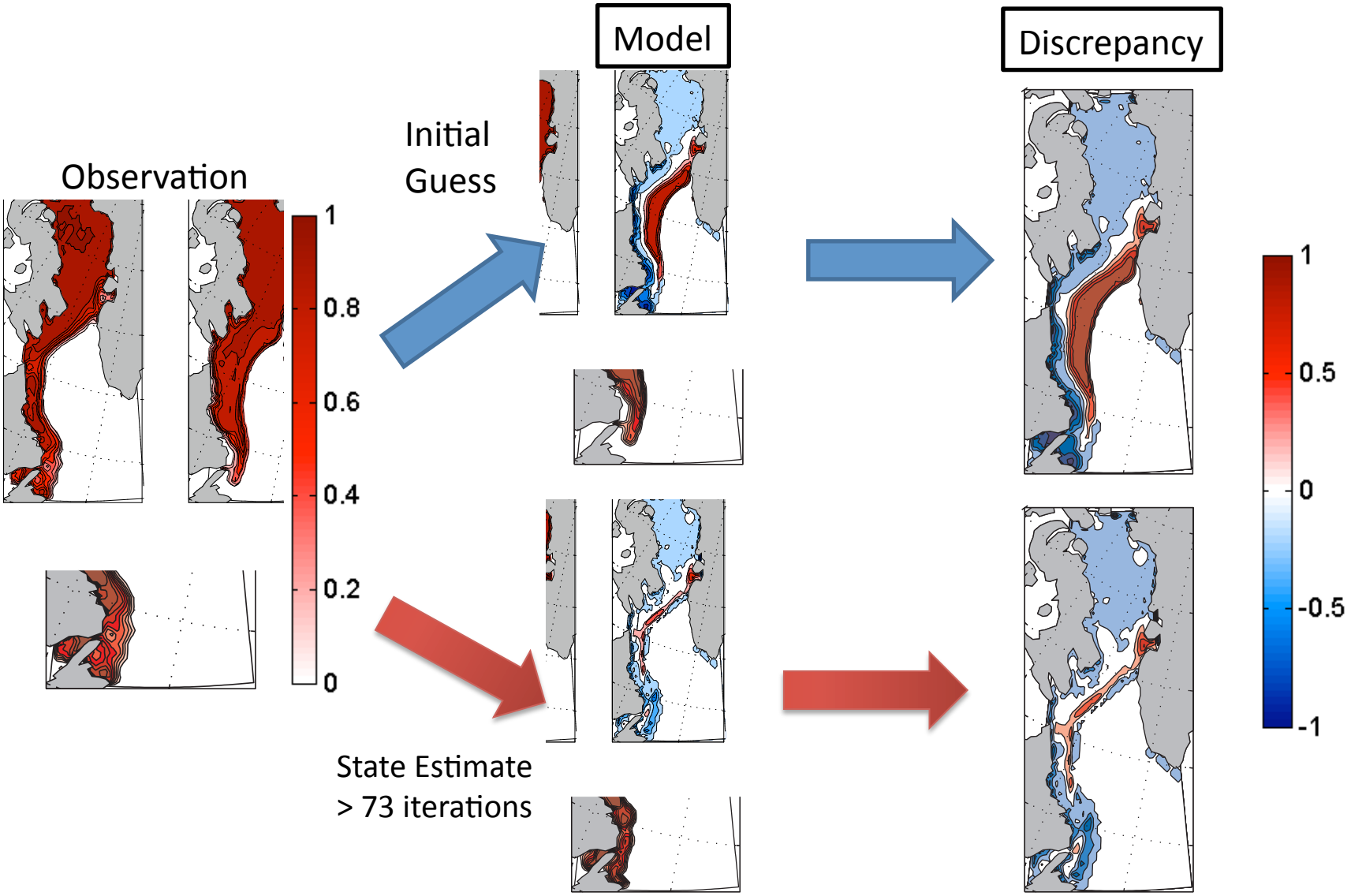
- Reanalysis : Warm Bias
- Model : 1) WGC inflow too warm
  2) Incomplete penetration of WGC through Davis Strait

Section 4

IMPROVEMENTS ON FIRST-GUESS MODEL TRAJECTORY

Improvement of Sea Ice Concentration

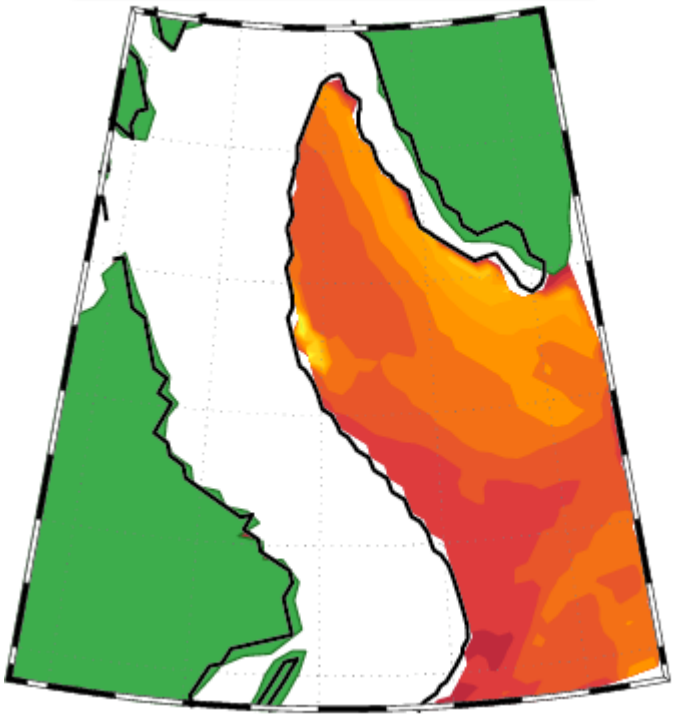
[March 2004]



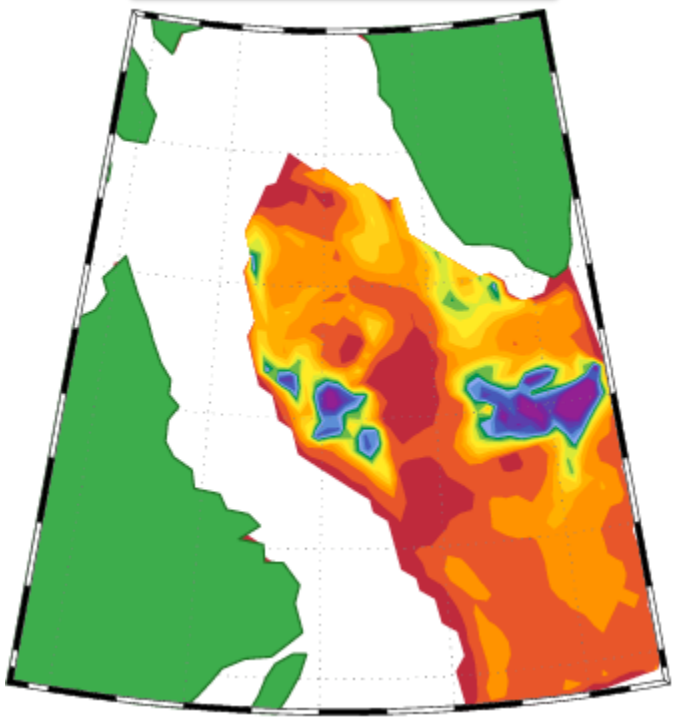
State Estimate vs. Forward Model Run

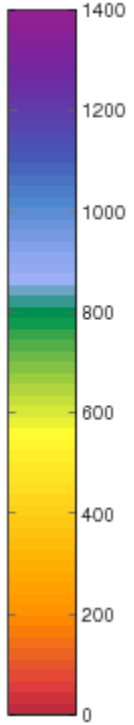
Feb 97 – Mar 97

Model Initial Guess MLD



State Estimate MLD

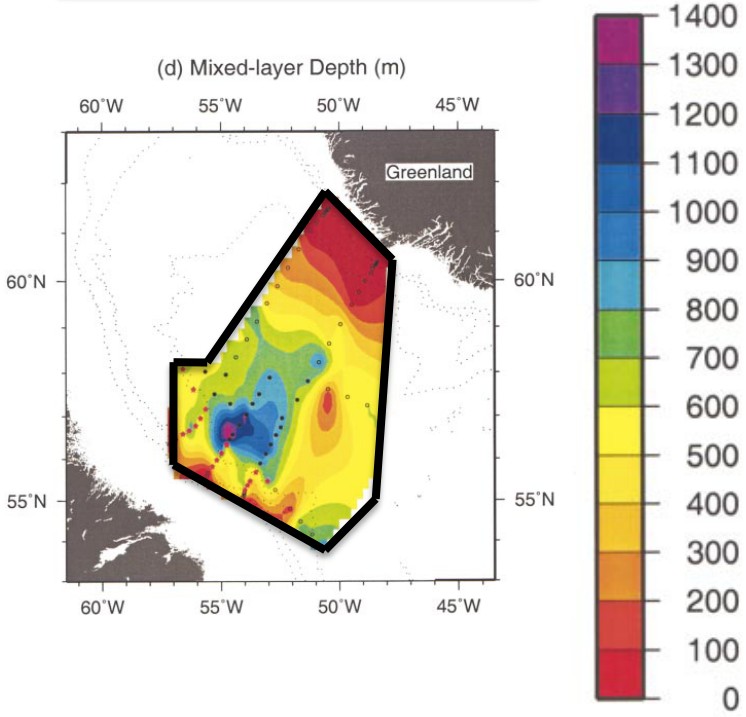




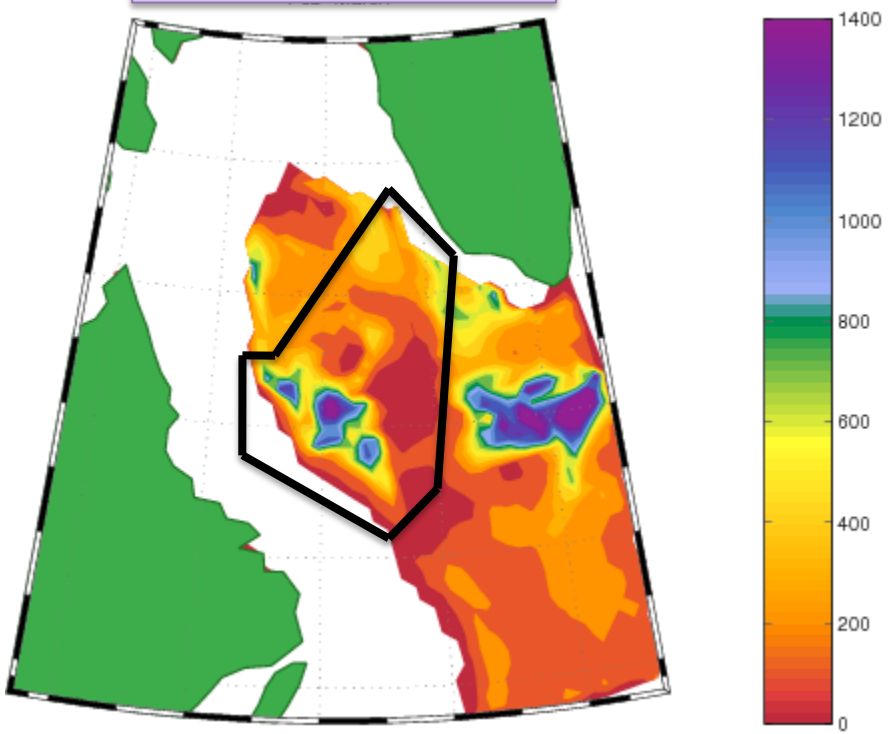
State Estimate vs. Profiling Floats + CTD

Feb 97 – Mar 97

Interpolated from CTD



State Estimate MLD

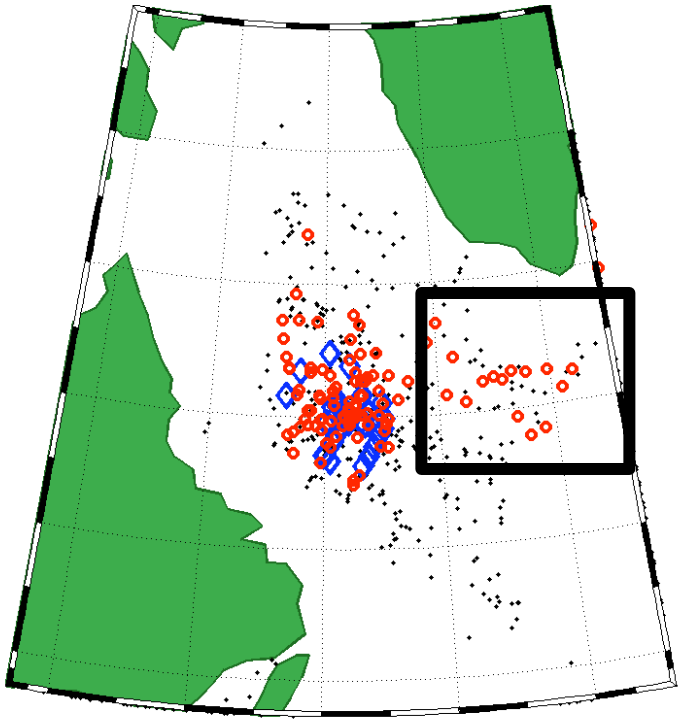


Pickard et al 2002

State Estimate vs. Profiling Floats + CTD

Feb 97 – Mar 97

MLD from Floats + CTD

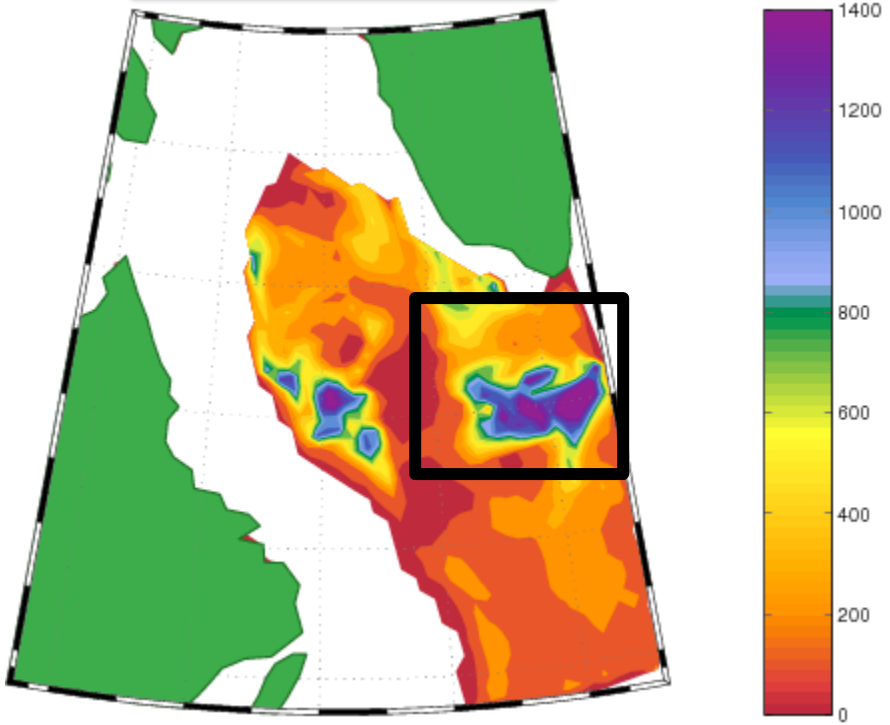


: < 500 m

: > 500 m < 1000 m

: > 1000 m

State Estimate MLD



Conclusions

- Sea ice concentrations assimilated into ocean-Sea ice state estimate using the adjoint method
- State estimate using ice and ocean observations in the Labrador Sea modifies NCEP reanalysis atmospheric state in ways which are consistent with estimated reanalysis errors
- Inclusion of sea ice concentration leads to an state with significantly improved sea ice concentrations and mixed layer depths