Assessment of the ECCO2 Coupled Ocean and Sea Ice Solution in the Arctic (U31C-0504)

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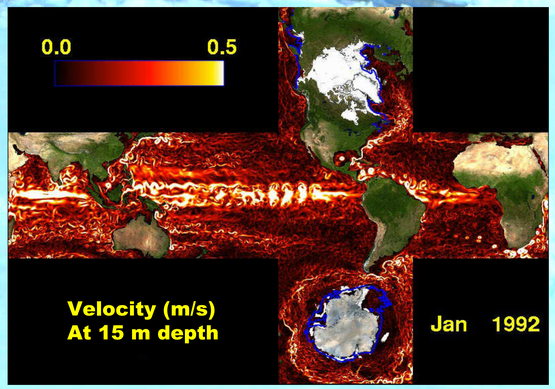
1. Introduction:

The Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2) project aims to produce increasingly accurate, physically consistent, time-evolving syntheses of most available global-ocean and sea-ice data at resolutions that start to resolve ocean eddies and other narrow current systems. ECCO2 syntheses are obtained by least squares fit of a global full-depth-ocean and sea-ice configuration of the Massachusetts Institute of Technology general circulation model (MITgcm) to the available data. In this study, we assess the Arctic Ocean component of three early ECCO2 solutions. The model's ability to produce and maintain important water masses, such as the warm Atlantic Water (AW) and the cold halocline (CHL), is discussed.



2. ECCO2 Model Configuration:

Ocean model:

- 18-km horizontal grid spacing, 50 vertical levels
- volume-conserving, C-grid
- bathymetry: ETOPO2
- KPP mixing [Large et al., 1994]

Sea-ice model:

- C-grid
- 2-catergory zero-layer thermodynamics [Hibler, 1980]
- Viscous plastic dynamics [Hibler, 1979]
- Prognostic snow and sea-ice salinity

3. Optimized Solutions:

A0: 1992-2002 baseline solution: WOA01 initial conditions, NCEP BC's, 30-yr spin-up.
A1: First optimization based on a Green's functions approach and a set of 30 sensitivity experiments.
A2: Second optimization based on a set of 50 sensitivity experiments.

4. Data:

I. Sea-ice

a) Fluxes: [Kwok, 2004, 2006]
b) Thickness: Upward Looking Sonar (ULS) [NSIDC]
c) Extent / Concentration: Special Sensor Microwave Imager (SSM/I) 3-day average [NSIDC]

II. Ocean Hydrography

a) Conductivity-Temperature-Depth (CTD) profiles: AWI Polarstern Expeditions [PANGAEA], Arctic-Subarctic Ocean Flux Array for European Climate, North (ASOF-N) [PANGAEA], Beaufort Gyre Exploration Project [WHOI]

III. Integrated

a) Freshwater volume / fluxes: Moorings [Holland, 2006, Woodgate, 2004]
b) Heat budget / fluxes: Moorings, ASOF-N, [Woodgate, 2004, Schauer, 2004]

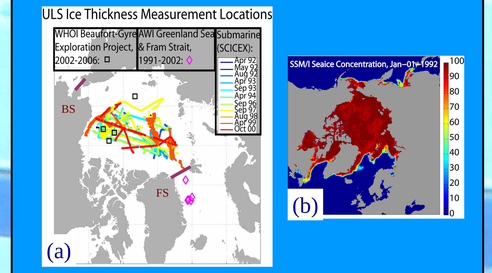


Fig 4-1: Distribution of data for (a) sea-ice thickness and (b) sea-ice extent / concentration. Locations of Bering Strait (BS) and Fram Strait (FS) are shown in (a) and will be used for discussion of fluxes later.

5. Sea-ice Assessment [1992-2002]:

a) Ice Fluxes (Fig 5-1)

- Consistent with data, with high and low fluxes in [1994,1996] and [1993,1995] well captured in the model.
- Fluxes in optimized solutions **A1** and **A2** are higher than data.

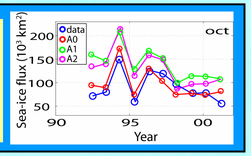


Fig 5-1: Ice fluxes across Fram Strait for the month of October showing consistent patterns of high and low fluxes between data and ECCO2 solutions. Location of Fram Strait is shown in Fig. 4-1a.

b) Extent / Concentration (Fig 5-2)

- ECCO2 solutions can reproduce well the seasonal cycle of sea-ice coverage. However, the model over-estimates maximum ice extent during winter in the Greenland Sea and under-estimates during the summer near the Chukchi Sea.

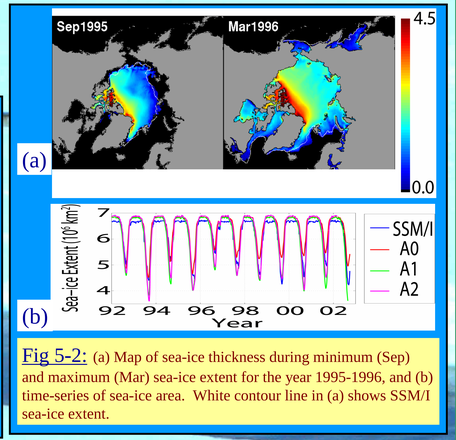


Fig 5-2: (a) Map of sea-ice thickness during minimum (Sep) and maximum (Mar) sea-ice extent for the year 1995-1996, and (b) time-series of sea-ice area. White contour line in (a) shows SSM/I sea-ice extent.

c) Thickness (Fig 5-2a, 5-3)

- In the Greenland Sea, ECCO2 sea-ice thicknesses agree well with data with near-zero mean differences ΔH (Fig 5-3a).
- In the Arctic, the mean differences are between [-1,0] *m* and are within the data uncertainty of ±1*m* (Fig 5-3b).

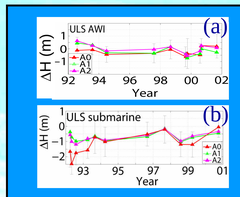


Fig 5-3: Ice thickness difference (Model minus Data) in Greenland Sea (a) and the Arctic (b). Locations of the data in Greenland Sea (ULS-AWI) and the Arctic (ULS-submarine) are shown in Fig 4-1a.

6. Arctic Ocean Assessment [1992-2002]:

Hydrography

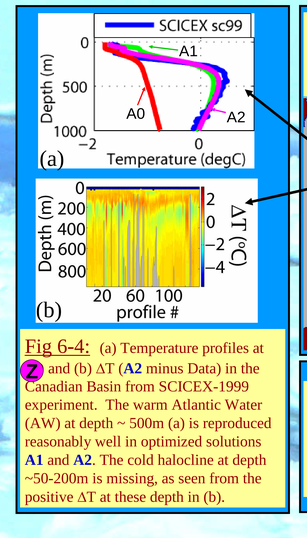


Fig 6-4: (a) Temperature profiles at Z and (b) ΔT (**A2** minus Data) in the Canadian Basin from SCICEX-1999 experiment. The warm Atlantic Water (AW) at depth ~ 500m (a) is reproduced reasonably well in optimized solutions **A1** and **A2**. The cold halocline at depth ~50-200m is missing, as seen from the positive ΔT at these depth in (b).

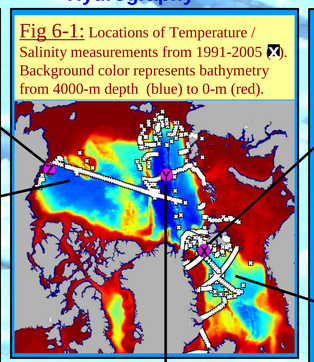
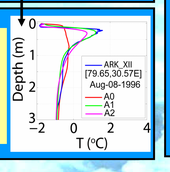


Fig 6-1: Locations of Temperature / Salinity measurements from 1991-2005 (X). Background color represents bathymetry from 4000-m depth (blue) to 0-m (red).

Fig 6-3: Temperature profiles at Y showing ECCO2 predicting reasonable AW in the Eurasian basin.



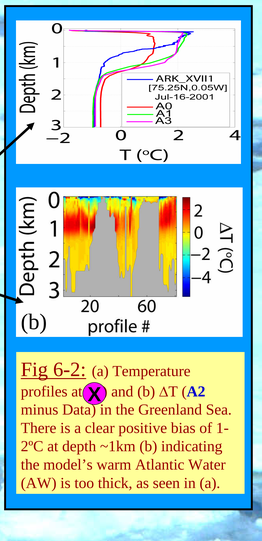


Fig 6-2: (a) Temperature profiles at X and (b) ΔT (**A2** minus Data) in the Greenland Sea. There is a clear positive bias of 1-2ºC at depth ~1km (b) indicating the model's warm Atlantic Water (AW) is too thick, as seen in (a).

Fresh water fluxes

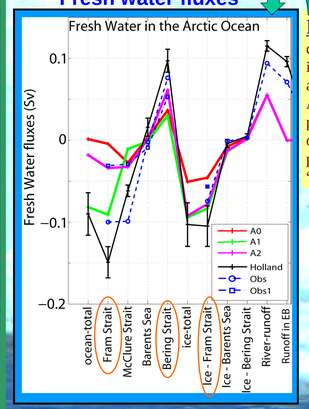


Fig 6-5: Fresh Water fluxes across different gates in the Arctic compared to independent observations Obs and Obs1 and model outputs of Holland et al. [2006]. Across Fram Strait, both **A1** and **A2** produce fresh water fluxes within the two observations. Across Bering Strait, **A2** produces realistic estimates of fluxes. "EB" abbreviates Eurasian Basin.

Heat fluxes

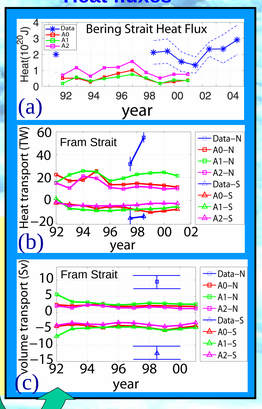


Fig 6-6: Northward (+) and southward (–) depth-intergraded heat fluxes across (a) Bering Strait and (b) Fram Strait, and (c) volume transport across Fram Strait. In (a), **A2** produces heat fluxes closest to data, although there is still a negative bias. The low Northward transports of heat across Fram Strait in (b) are due to low volume transports as seen in (c).

7. Summary and Ongoing Work:

- The work described herein aims to establish observational metrics for Arctic Ocean circulation and sea ice distribution, a key requirement for improving the representation of polar processes in numerical models.
- Within the ECCO2 project, this work is a first step toward obtaining an optimized solution for the Arctic ocean and sea ice through data-model residual minimization.

8. Acknowledgments:

ECCO2 is a contribution to the NASA Modeling, Analysis, and Prediction (MAP) program. We gratefully acknowledge computational resources and support from the NASA Advanced Supercomputing (NAS) Division and from the JPL Supercomputing and Visualization Facility (SVF).

9. References:

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8) PANGAEA: the Publishing Network for Geoscientific & Environmental Data <http://www.pangaea.de>
9) SSM/I data, ULS data: <http://nsidc.org>
10) SCICEX data: <http://boreas.coas.oregonstate.edu/scicex/scicex.html>
11) WHOI: <http://www.whoi.edu/beaufortgyre>

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