Assessment of the ECCO2 Coupled Ocean and Sea Ice Solution in the Arctic

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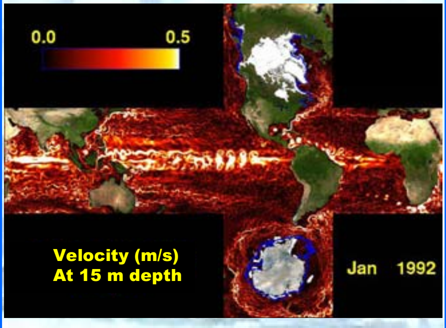
1. Introduction:

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 the optimized global and regional ECCO2 solutions. The model's ability to produce and maintain important water masses, such as the warm Atlantic Water and the cold halocline, is discussed.



2. ECCO2 Model Configuration:

Ocean model:

- 18-km horizontal grid spacing, 50 vertical levels
- volume-conserving, C-grid
- bathymetry: S2004 blend of GEBCO and Smith and Sandwell [1997] [Marks and Smith, 2006]
- 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: 1992-2006 global solution: optimized based on a Green's functions approach and a set of 70+ sensitivity experiments.

A1: First regional optimization using all available sea-ice velocity and ocean temperature & salinity data for the Arctic.

4. Data:

I. Sea-ice

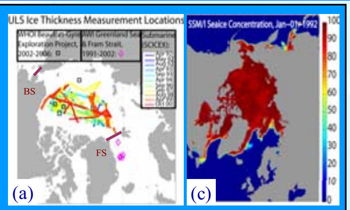
a) Fluxes: [Kwok, 2004, 2006]
Velocity: Passive microwave [http://www-radar.jpl.nasa.gov/rgps/ice_motion_3.html]
b) Thickness: Upward Looking Sonar (ULS) [NSIDC]
c) Extent / Concentration: Special Sensor Microwave Imager (SSM/I) 3-day average [NSIDC]

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], SCICEX [http://boreas.coas.oregonstate.edu/scicex/scicex.html], 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]



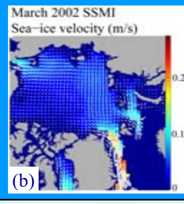


Fig 4-1: **Distribution of data for (a) sea-ice thickness, (b) sea-ice velocity, and (c) sea-ice extent / concentration. Locations of Bering Strait (BS) and Fram Strait (FS) are shown in (a) and will be used for discussion of fluxes later.**

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

a) Ice Velocity and Fluxes (Fig 5-1)

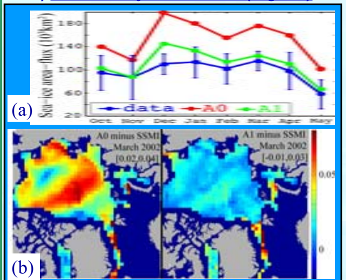


Fig 5-1: **(a) Monthly ice fluxes across Fram Strait showing ECCO2 regional optimized solution A1 producing results that are more consistent with observations compared to A0. (b) Sea-ice velocity difference (m/s, Model minus Data) for March 2002. Numbers in brackets are [MEAN,STD].**

b) Thickness (Fig 5-2)

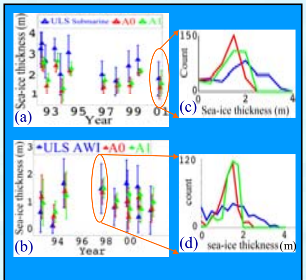


Fig 5-2: **Mean sea-ice thickness in the Arctic (a) and Greenland Sea (b). Locations of data in the Arctic (ULS-submarine) and Greenland Sea (ULS-AWI) are shown in Fig 4-1a. The long tails in the histograms of data thickness in (c) and (d) (blue lines) are typically absent in ECCO2 solutions.**

c) Extent / Concentration (Fig 5-3)

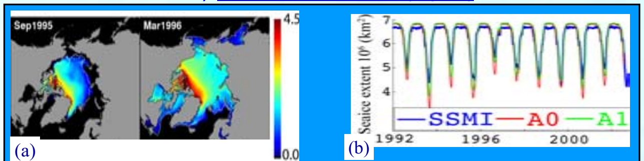


Fig 5-3: **(a) Map of sea-ice thickness during minimum (Sep) and maximum (Mar) sea-ice extent for the year 1995-1996, and (b) time-series of sea-ice extent. White contour line in (a) shows SSM/I sea-ice extent. Both solutions A0 and A1 reproduce well the seasonal cycle of sea-ice coverage. A1 reproduces more realistic minimum sea-ice extent in the summer compared to A0 (b). However, both solutions over-estimate maximum sea-ice extent during the winter (b).**

6. Arctic Ocean Assessment [1992-2005]:

Hydrography

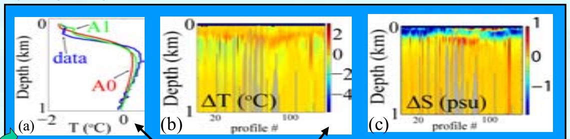


Fig 6-2: **(a) Temperature profiles at location (X) from Fig 6-1, (b) ΔT and (c) ΔS vertical sections (A1 minus Data) in the Canadian Basin from SCICEX-1999 experiment. The warm Atlantic Water at depth ~500m and cold halocline at depth ~50-200m are better reproduced in the Arctic optimized solution A1 than in A0 (a). However, positive ΔS at depth ~0-50m and negative ΔS at depth ~50-200m in (c) indicate salinity gradients that are still too shallow in A1 compared to those in the cold halocline.**

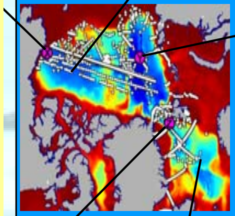


Fig 6-1: **Locations of Temperature / Salinity measurements from 1991-2005. Background color represents bathymetry from 4000-m depth (blue) to 0-m (red).**

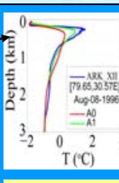


Fig 6-3: **Temperature profiles at location (Y) showing solution A1 predicting much more realistic Atlantic Water in the Eurasian basin compared to A0.**

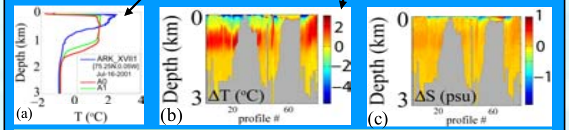


Fig 6-4: **(a) Temperature profiles at (Z), (b) ΔT and (c) ΔS (A1 minus Data) in the Greenland Sea. There is a clear positive bias of 1 to 2ºC at depth ~1km (b) indicating the model's warm Atlantic Water is too thick, as seen in (a).**

Fresh water fluxes

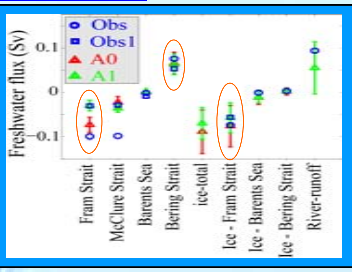


Fig 6-5: **Fresh Water fluxes across important gates in the Arctic compared to independent observations Obs and Obs1 [Holland et al., 2006]. Across Fram Strait, A1 produces sea-ice equivalent fresh water fluxes most consistent with observations [Kwok, 2004]. Across Bering Strait, both solutions A0 and A1 produce realistic estimates of fluxes [Woodgate et al., 2006].**

Heat and volume fluxes

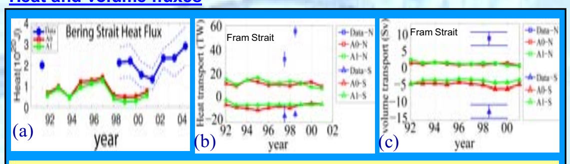


Fig 6-6: **Northward (+) and southward (–) depth-integrated heat fluxes across (a) Bering Strait and (b) Fram Strait, and (c) volume transport across Fram Strait. Both solutions A0 and A1 under-estimate heat fluxes across Bering Strait (a). Transports across Fram Strait are too low overall compared to data in both directions (b,c). The low Fram Strait transports are a consequence of too low velocities compared to ASOF mooring velocity data (not shown here).**

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) ECCO2 project: <http://ecco2.jpl.nasa.gov>
9) PANGAEA: the Publishing Network for Geoscientific & Environmental Data <http://www.pangaea.de>
10) SSM/I data, ULS data: <http://nsidc.org>
11) SCICEX data: <http://boreas.coas.oregonstate.edu/scicex/scicex.html>
12) WHOI: <http://www.whoi.edu/beaufortgyre>

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