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# Arctic Ocean Model Intercomparison Using Sound Speed

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## Introduction

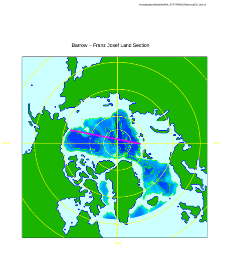


Fig. 1

The purpose of this presentation is to compare the behavior of several Arctic Ocean (AO) models. The present study is part of the Arctic Ocean Model Intercomparison Project (AOMIP). In this study we are motivated by acoustic experiments in the Arctic that measured the recent warming of the Atlantic layer [Morison, 1996; Mikhalevsky et al., 1995]. These experiments showed that acoustics integrate the hydrography over great distances, reducing small−scale noise, and revealing any large−scale variability. Here we introduce an approach for exploring model behavior by integrating sound speed across the central Arctic Basin, and present a statistical comparison of integrated sound speed produced by different models. For completeness, we also compare integrated temperature, salinity, and density fields with observations.

The outputs from three models have been used in this study. A summary of the ocean model characteristics is provided in Table 1. Observational data used in the study were taken from the Arctic Ocean Atlas of the Environmental Working Group (EWG) for the summer period (EWG data set) [EWG, 1997/1998]. The EWG data set is a 3−D grid of summer (July − September) mean temperature and salinity fields (averaged over the period 1948 − 1993) for the AO. All model and observational data sets were interpolated onto the line shown in Fig. 1. The line extends from the proposed location for the Arctic Climate Observation Using Underwater Sound (ACOUS) receive array off Barrow (72.6 N, 156.0 W) to the sound source deployed in October 1998 off Franz Josef Land (FJL) (81.9 N, 38.7 W). The model data cover the period January 1979 to December 1997. Each model data set has different vertical and horizontal resolution, different bathymetry. Therefore we have interpolated the model data using a spline fit onto a standard grid. Sound speed was calculated using Del Grosso algorithm [Del Grosso, 1974].

**Table 1. AOMIP Ocean Model Description[a]**
WOA - World Ocean Atlas of the National Oceanographic Data Center (NODC)[e] [Boyer et al., 1998];
AOA - Arctic Ocean Atlas produced by the Environmental Working Group [EWG 1997/1998];
PHC - Polar Science CEnter Hydrographic Climatolagy [Steele et al., 2000].

| Institution | Restoring time constant | Domain/laterl B.C.'s | Grid Size | Vertical coord. | River discharge | Atmosphere forcing data |
|---|---|---|---|---|---|---|
| AWI *Karcher*[a] | S: 180d at 10 m (WOA94 + *AOA*)[b] | close Bering Str. 50oN. Atl.inflow and T,S from a larger domain model | 1/4 x1/4o | z-coor (30 levels) | none | ECMWF: reanalysis (1979 - 1993)+ operational (1994-1999) |
| UW *Zhang*[c] | S: 5 y at 5 m and below 800 m T;5 y below annual WOA82 | Bering St.=.8 Sv in C.Arch=1.5Sv out E/W Iceland=0.7 Sv in restore T,S to WOA82 | 40 km | z-coor (21 levels) | major rivers + ungauged (4339 $km^3$/yr | IABP/POLES (1979-1998) |
| IARC *Polyakov*[d] | none | Denmark str.=7 Sv out Norwegian Sea=8Sv in Bering Sea=1 Sv | 55.56 km | z-coor (29 levels) | averaged annual cycle | Daily wind stresses are computed from the NCAR SLP Monthly climatic SAT and cloudiness from [Gorshkov, 1980] |

a. Descriptions for Karcher and Zhang's models are taken from [Steele et al., 2001] and [Zhang et al., 1998].
b. This model uses an annual average linear combination of WOA94 and AOA.
c. [Zhang et al., 1998].
d. [Polyakov et al., 1999].
e. Descriptions and comparison of the data from WOA and PHC is given in [Steele et al., 2001].

## Observed and Simulated Potential Temperature, Salinity and Potential Density Fields

Figure 2 compares the distributions of the mean observed (Fig. 2.1) and simulated (Figs 2.2 − 2.4) potential temperature, salinity and potential density along the section in summer period (July − September). Due to the temperature effect on compressibility, we compared potential densities using a 3000 m reference level for the deep layer (similar to Aagaard et al., 1985). A visual comparison shows that none of the models reproduced all the characteristic features of the observed hydrographic distributions in the AO shown on Fig.2.1.

It can be seen, from the upper plate in Fig. 2.1, that the deep Eurasian Basin is filled with homogeneous cold water with temperature about −0.94C (minimum is −0.98C). This agrees with Aagaard et al., 1985. The patterns presented in Fig. 2.2 − 2.4 differ from the observations. For example, Zhang's model simulates slightly warmer Eurasian Basin Deep Water (EBDW) (T > −0.78C). In Karcher's model, cold EBDW overflows over the Lomonosov Ridge and fills the Fletcher Abyssal Plain. This suggests that the sill depth

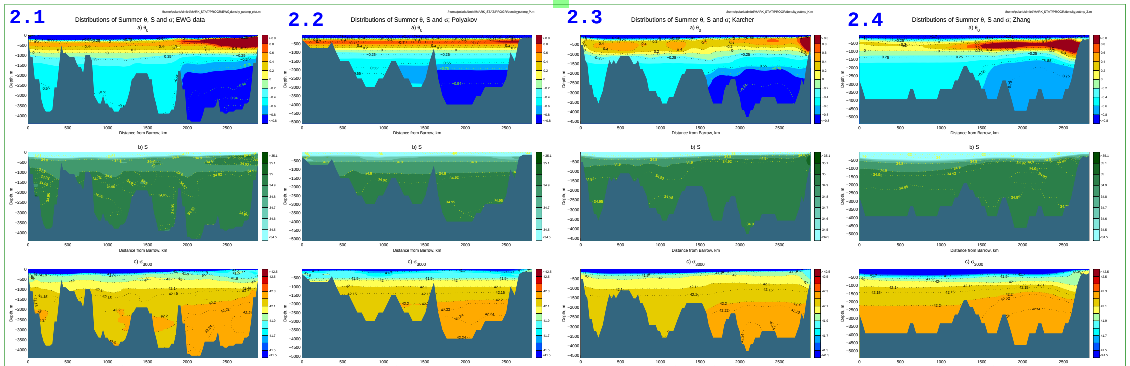


Fig. 2

is too deep. In Polyakov's model (Fig. 2.2) temperature outputs for the deep AO are similar to the EWG data.

Simulated salinity distribution in the deep AO varies between the models (middle panels, Fig. 2.2 − 2.4). All simulations look different from the observational data (middle panel, Fig. 2.1). The EWG data reveals that the Canadian Basin is saltier than the Eurasian Basin. The Canadian Basin Deep Water (CBDW) has a salinity higher than all other deep−water masses in the Arctic Mediterranean. Each model reproduced different salinity patterns, but none reproduced this maximum salinity in the CBDW. Salinity of the deep−water layer was homogeneous in all the models.

From Fig 2.1 one can see that when the relative compressibilities are taken into account, the EBDW is denser than the CBDW. Karcher and Zhang's models do not reproduce this feature. The density field in Polyakov's model is similar to the observed pattern. Many of these differences may be due to differences among the forcing and initialization data sets being used.

## Data Analysis

This study poses two major questions. How do model outputs differ from each other? Are these distinctions significant enough to say that the models are different?

Each of the data sets used for comparison consists of 228 monthly sound speed (C) values averaged over the cross−section in the upper (10 − 50 m) and deep (1000 m to bottom) layers. The visual comparison of the time series reveals significantly different long−term variability (trends) (left panels on Fig. 4.1 and 4.2). Due to different trends in the time series we detrended the data using polynomial regression (with zero intercept to keep their means) prior to analysis (right panels on Fig. 4.1 & 4.2). The autocorrelations did not reveal any significant dependence within the annual means of the detrended data sets (Fig. 3). The bootstrap subsampling method [Rice, 1995; Elsner and Tsonis, 1991] was applied to compare the parameter statistics of the annual mean populations from the models.

The average annual sound speed in the upper and lower layers varied between the models (Tables 2 and 3). The bootstrap method revealed that these annual means are from different populations. None of the confidence intervals overlap, showing that these sound speed means are statistically significantly different (Fig. 5).

**Table 2. Model Sound Speed Mean Estimates and 95%CI, Upper Layer**

| Model | Mean Estaimte (m/s) | 95% Confidence Interval |
|---|---|---|
| Polyakov | 144.77 | $144.762 < \mu < 1444.778$ |
| Karcher | 1445.61 | $1445.56 < \mu < 1445.65$ |
| Zhang | 1442.29 | $1442.24 < \mu < 1442.34$ |

**Table 3. Model Sound Speed Mean Estimates and 95%CI, Deep Layer**

| Model | Mean Estaimte (m/s) | 95% Confidence Interval |
|---|---|---|
| Polyakov | 1480.86 | $1480.8595 < \mu < 1480.8599$ |
| Karcher | 1481.027 | $1481.021 < \mu < 1481.033$ |
| Zhang | 1481.108 | $1481.105 < \mu < 1481.111$ |

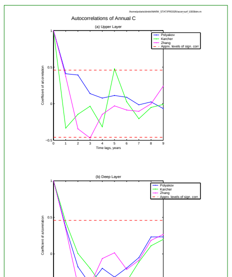


Fig. 3

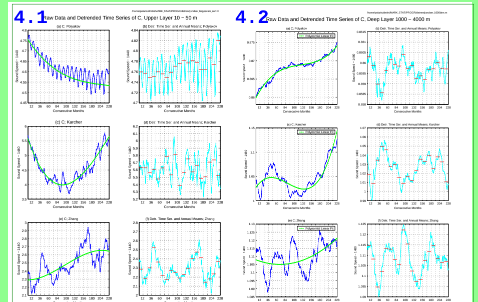


Fig. 4

## Conclusions

(1) Although in general simulated T, S and density fields have some resemblance to the observational (EWG) data, the models do not reproduce the characteristics features of the deep Arctic Ocean.
(2) Temperature, salinity and density are differently distributed in different models.
(3) The bootstrap method has shown that the annual means of sound speed in the upper and deep layers are significantly different in the models.

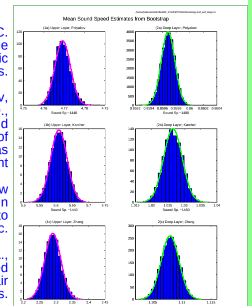


Fig. 5

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