GC51A−06: Streamfunction, Freshwater and Heat Content in the Arctic Ocean − Results from the Arctic Ocean Model Intercomparison Project

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JPOD: Joint Program in Ocean Dynamics

Introduction: Within the framework of the Arctic Ocean Model Intercomparison Project results from several coupled sea ice − ocean models (Alfred− Wegener Institut, AWI, M.Karcher; New York University, NYU, D. Holland; NASA/ Goddard Space Flight Center, GSFC, Sirpa Häkkinen; University of Washington, UW, J. Zhang, Naval Postgraduate School, NPS, W. Maslowski; and Institute of Ocean Sciences ,IOS) are compared in order to investigate vertically integrated properties of the Arctic Ocean . In this first stage of the project, only readily available outputs are compared, accepting that forcing as well as numerical parameterizations are essentially different. Depending on availability, results from timeseries runs (year 1998, denoted with _98) are compared as well as results from climatological mean forcing (denoted with _c). Annual means of streamfunction, freshwater and heat content are shown together with annual cycles, averaged over certain areas. Thereby for streamfunction the entire water column is integrated, whereas for heat and freshwater content integration is over the upper 1000m. Polar Science Center Hydrographic Climatology (PHC) has been added for a comparison. The study represents only a first step toward identifying biases between different model approaches and will serve as a base for the upcoming AOMIP phase where all participants agreed upon common forcing data sets, initial conditions, restoring and bathymetry. The current intercomparison will then be repeated to distinguish between responses to forcing and effects arising from model parametrizations. Information on the project can be found on: (http://fish.cims.nyu.edu/project_aomip/experiment/spinup_expt.html).

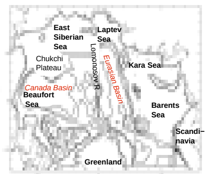


Fig.1 Model domain

Model description: All participating models have a dynamic−thermodynamic sea−ice component coupled to the ocean and cover the entire Arctic Ocean. For intercomparison, the different model results are interpolated to a common domain (Fig.1). Forcing differs as well as the modeled timeperiods. Moreover monthly as well as daily forcing are applied.

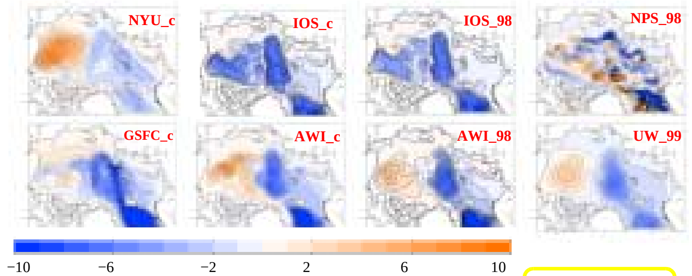


Fig.2: Model representations of annual mean streamfunction in Sv.

Streamfunction

$$k \times \nabla\psi = \int_0^{bottom} u \; dz$$

Streamfunction exhibits obvious differences among the models. However, most models show a clear separation between Eurasian and Canada Basin. The high−resolution NPS_98 model pattern is dominated by smaller scale eddies, where the eddy locations are rather persistent over time. IOS and AWI streamfunctions in 1998 are quite similar to their climatological mean. The coarser NYU model shows an extremely weak Eurasian Basin circulation.
In the Canada Basin most models show positive streamfunction values. The NYU model with a maximum of 8.4 Sv, shows the highest value in the annual mean. However, it exhibits a profound annual range in the Canada Basin, with about 20 Sv in December, and cyclonic mass transport with up to −7Sv in August/September. This annual cycle corresponds to strong annual changes in the upper layer velocities, caused by strongly anticyclonic winds in winter, compared to cyclonic components in summer. The transport at depth does not change greatly. The IOS model shows cyclonic mass transport in the Canada Basin the whole year round. The annual range is extremely low (below 0.5 Sv). In the IOS model, anticyclonic surface circulation changes at depths lower than 200 m into a strong, cyclonic circulation, which dominates the streamfunction.

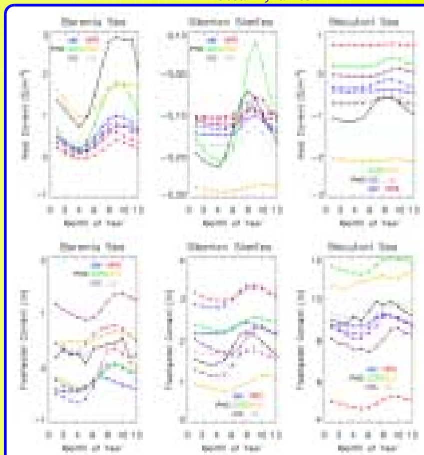
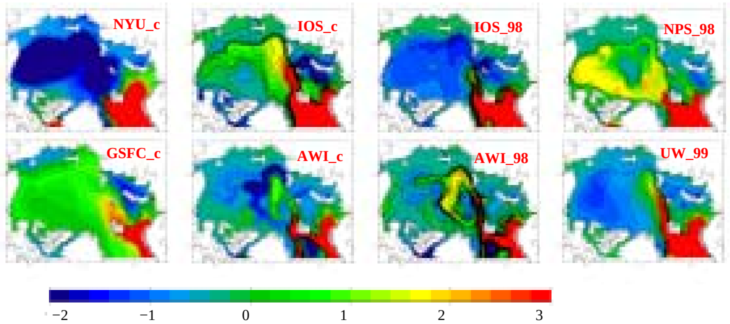


Fig.6: Annual cycle of heat (top panel) and freshwater content (lower panel) in the top 1000m, averaged over the regions of Barents Sea (<80N,20W−55W), Siberian Shelfes (<75N,55W−180W) and Beaufort Sea (<80N,130E−160E). Triangles denote 1998/99 results , asterisk denotes climatology.

Obvious biases are visible in the annual ranges over specified regions. PHC shows a larger seasonal range in heat content than any of the models, only on the Siberian Shelves the GSFC model outranges PHC. Compared to PHC, the Barents Sea heat content is underestimated for most models the whole year round, from June to September by all models. All but one model overestimate the heat content in the Beaufort Sea.

Discussion:
In the current stage of AOMIP, where atmospheric forcing is not standard, forcing appears to be the main contributor in creating differences between model results. E.g., it turned out that the OMIP−forcing (AWI_c in this study) leads to very cold intermediate water produced in the Barents Sea which enters the Arctic Ocean via St. Anna Trough. Using the same OMIP−forcing the IOS−model produces a similar pattern as the AWI−model with cold water production in the Barents Sea. Responses of the heat and freshwater content to different windstress representations account for differences of up to 1 GJm^{-2} and changes in the range of a few meters. Differences attributed to model parameterisations are few, so far. Streamfunction is strongly affected by parameterizations for eddy−topography interaction (neptune), leading to negative streamfunction values in the Canada Basin for IOS model.Without neptune the IOS model leads to a pattern quite similar to the NYU annual mean, with an equally weak Eurasian Basin circulation and anticyclonic circulation with a maximum of about 2 Sv in the Canada Basin. Other ideas related to the influence of resolution, as well as the influence of mixing are too speculative at this stage and will be addressed more carefully in the upcoming AOMIP−phase.



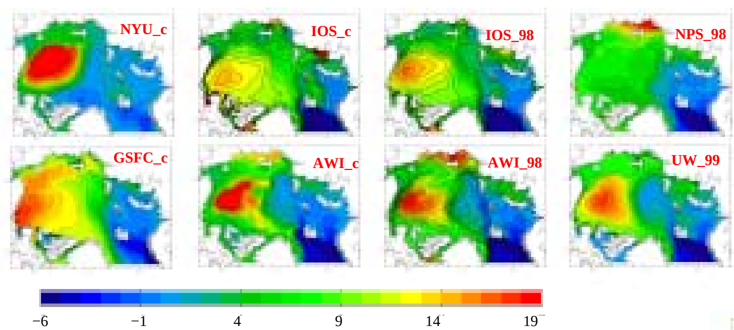
Heat content in the top 1000m

$$H = \int_0^{1000m} \rho \, c_p \, (\theta - \theta_{ref}) \; dz$$

$\theta_{ref} = 0\,^{o}C$

Fig.3: Model representations of annual mean heat content in the top 1000m, given in GJm^{-2}.

Heat content: All models show the offshoot of warm and salty Atlantic water penetrating into the Arctic Ocean via Fram Strait and Barents Sea, but obvious differences are visible in the Eurasian and Canada Basin. The heat content varies from −3.8 to 0.8 GJm^{-2} in the eastern Nansen Basin and from −3.5 to 1.8 GJm^{-2} in the Canada Basin, showing both too high heat contents and too low heat contents compared to PHC values of 0.15 and −0.8 GJm^{-2} in the Nansen and Canada Basin. Differences between the simulated heat contents can be, at least partially, related to differences in the representation of the Atlantic water pathways through Fram Strait and Barents Sea. The lowest values are correlated with a sharp front already in Fram Stait, suggesting an underestimation of the Atlantic water inflow via Fram Strait (e.g. NYU). However an overestimation of the heat loss at the surface leads to a similar picture. Too low heat content can also be caused by too cold water entering the Eurasian Basin via St. Anna Trough. The Barents Sea branch of the Atlantic water inflow thus becomes very cold and fills the Eurasian Basin at mid depth with an extreme water mass (AWI_c). The largest heat content can be found in the NPS model, which is partially related to the vertical heat transport and underestimations of the eastward propagation along the Laptev Sea shelf. However in 1998 warm water, which entered the Eurasian Basin in the late 1980s and the early 1990s may still be represented slowly moving around the Canadian Basin to exit back through Fram Strait. AWI_98, as well, shows exceptionally warm water in 1998 in the Eurasian Basin.



Freshwater content in the top 1000m

$$F = \int_0^{1000m} (S_{ref} - S)/S_{ref} \; dz$$

$S_{ref} = 34.8$

Fig.4: Model representations of annual mean freshwater content in the top 1000m, given in m.

Freshwater content shows differences mostly in the Canada Basin where maximum values vary between about 6 m and 24 m, compared to about 18 m in PHC. Within the Eurasian Basin, almost any model shows a close correspondence between high heat and low freshwater content, related to the Atlantic inflow. In the Canadian Basin, however, the freshwater content is influenced by other processes as well. A sensitivity study, carried out with the IOS model, shows that, e.g., river discharge affects the freshwater maximum in the Beaufort Sea less effectively than changes in the windstress formulation. However, a change from 2445km^3 to 3249km^3 yearly discharge by including ungauged river runoff along the coast increases the freshwater content in the Beaufort Sea by 0.9 to 1 meter (Fig.5).

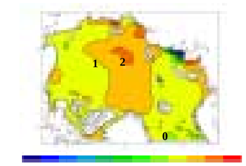


Fig.5: Difference in the annual mean freshwater content due to a change from 2445km^3 to 3249km^3 yearly discharge by including ungauged river runoff along the coast.