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Variability of Winter Sea Ice in Greenland-Iceland-Norwegian Sea in a Regionally Coupled Climate Model

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Abstract: To investigate interaction and feedback mechanisms of different climate components in the Arctic, we use a regional atmosphere-ocean model setup, consisting of the global ocean – sea-ice model MPIOM with high resolution in the Arctic coupled to the regional atmosphere model REMO. We perform an experiment using reanalysis data from the European Center of Medium Range Weather Forecast (ERA-40) as external forcing to simulate the climate of the last decades (1958–2001). We analyze this experiment in order to improve our understanding of ocean – sea-ice – atmosphere processes at the marginal ice zone in the Greenland-Iceland-Norwegian (GIN) Sea. We present first results on the variability of the marginal ice zone in GIN Sea, where in the last century the commonly named Arctic Odden has been observed frequently, an ice tongue with large daily variability in size and shape. We are interested in the dynamics of the formation of such a sea-ice tongue and show that in our model advection of ice rather than new ice formation is the driving mechanism.

Zusammenfassung: Um das Zusammenspiel und Rückkopplungseffekte zwischen den arktischen Klimakomponenten zu analysieren, verwenden wir ein regional gekoppeltes Atmosphären – Ozean-Modell, bestehend aus dem globalen Ozean – Meereis-Modell MPIOM mit hoher regionaler Auflösung in der Arktis und dem regionalen Atmosphärenmodel REMO. Als Randdaten für dieses Modell verwenden wir Reanalyse-Daten (ERA-40) des europäischen Zentrums für mittelfristige Wettervorhersagen ECMWF und simulieren das Klima der letzten Dekaden (1958–2001). Wir präsentieren erste Ergebnisse über die Meereisvariabilität in der Grönland-Island-Norwegen-See, in der im letzten Jahrhundert regelmäßig der sogenannte arktische Odden, eine Zunge aus Meereis mit großer täglicher Variabilität in Größe und Form, beobachtet wurde. Diese Eiszunge hat direkten Einfluss auf den Wärme- und Salzhaushalt in dieser Region und dadurch auf die Dynamik der darunterliegenden Wassermassen und die Tiefenwasserproduktion. Wir sind daran interessiert, wie solche arktischen Odden entstehen und zeigen, dass in unserem Modell eher Advektion von Eis als Bildung von neuem Eis der zugrunde liegende Mechanismus ist.

INTRODUCTION

The Arctic climate shows large annual and interannual variability. This variability and the interplay of the atmosphere, ocean and sea ice are poorly understood. Furthermore, large changes have been observed in recent years, such as the summer sea ice minimum in 2012. Observational time series are short and the resolution of global general circulation models is too coarse to adequately resolve small-scale processes and complex topography such as the Canadian archipelago. Hence, we use a high-resolution regionally coupled climate model to simulate the Arctic climate. Here we present first results on the variability of the marginal ice zone in the Greenland-Iceland-Norwegian (GIN) Sea, where in the last century the commonly named Arctic Odden has been observed frequently, an ice tongue with large daily variability in size and shape. Affecting the heat and salinity budgets and thereby the dynamics of the underlying water masses, this ice tongue has a direct influence on the deep-ocean convection (Paluszkiewicz et al. 1994, Wadhams et al. 2002). We are interested in the dynamics of such a sea ice tongue and how it is formed within our model. Is it Polar surface water diverted eastward from the East Greenland Current, leading to new ice formation or is eastward advection of multi-year sea ice or sea ice advected from the main pack the driving mechanism?

MODEL SETUP

Our regionally coupled model consists of the global ocean – sea-ice model MPIOM (Marsland et al. 2003) with shifted grid poles over North America and Russia, leading to high resolution in the Arctic (approximately 15 km in the mean and up to 5 km horizontal resolution in the coupled domain). The ocean model is coupled to the regional atmosphere model REMO (Aldrian et al. 2005, Mikolajewicz et al. 2005, Sein et al. 2014). The horizontal resolution of the atmosphere model is about 55 km. The domain of the atmosphere model covers the full catchment area of the Arctic rivers and a discharge model, providing lateral terrestrial water flows, is included. The model domains are shown in Figure 1. As external forcing needed for the ocean model in the uncoupled domain as well as for the atmosphere model at the lateral boundaries, we use the ERA-40 reanalysis dataset (ECMWF, 2002) from the European Center for Medium-Range Weather Forecasts. Our experiment covers the time period 1958–2001. The simulation was started from a pre-existing present-day state from a similar setup and was spun up for 40 years, using the 1960–1999 ERA-40 forcing. The model simulation shows a realistic mean state of the Arctic climate of the second half of the 20th century. An earlier version of the model setup has been validated in Niederdrenk (2013). The sea-ice extent is well represented (Fig. 2), especially in winter.

However, the number of months with a mean sea-ice concentration larger than 0.15 is slightly underestimated (Fig. 2), due to an underestimation of September sea-ice volume (not shown). In contrast to most global climate models, this regional model is capable to simulate an ice tongue in the marginal sea-ice zone in GIN Sea, namely the Arctic Odden, with large daily variability in shape and size.

RESULTS

Similar to the Nordbukta index defined by Germe et al. (2011), we define an Odden index as the difference between

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sea-ice concentration exceeding 0.15 in the region of the ice tongue (4.5° - 3° W, 72.8° - 73.5° N), when apparent, and in the Nordbukta region (8° - 6.8° W, 74.3° - 75.1° N). Since we are mainly interested in the Arctic Odden in a tongue form rather than large ice accumulations in the Nordbukta region, only positive values of the daily Odden index are presented (Fig. 3). In our model and similar to observations, the appearance of such an Odden persists from few days to several months. The earliest appearance can be found in December, the latest in April, almost equally distributed within these months. Some of the events in Figure 3, however, do not show a typical ice tongue but large ice deformations (in 1967 and 1979), sometimes even reaching the northern coast of Iceland (in 1965). In addition, there are winters, when instead of a tongue a large island evolves or splits from the ice east of Greenland, wobbling in the Greenland Sea for a few days and then melting or reattaching to the ice edge (in 1983). Since we are using a regionally coupled climate model, simulating a considerable internal variability, we are not able to simulate specific observed Odden events. However, the above-mentioned Odden formations all have been observed in the last century (Comiso et al. 2001, Rogers & Hung 2008). A specific example of an Odden ice tongue in January 1962 is given in Figure 4.

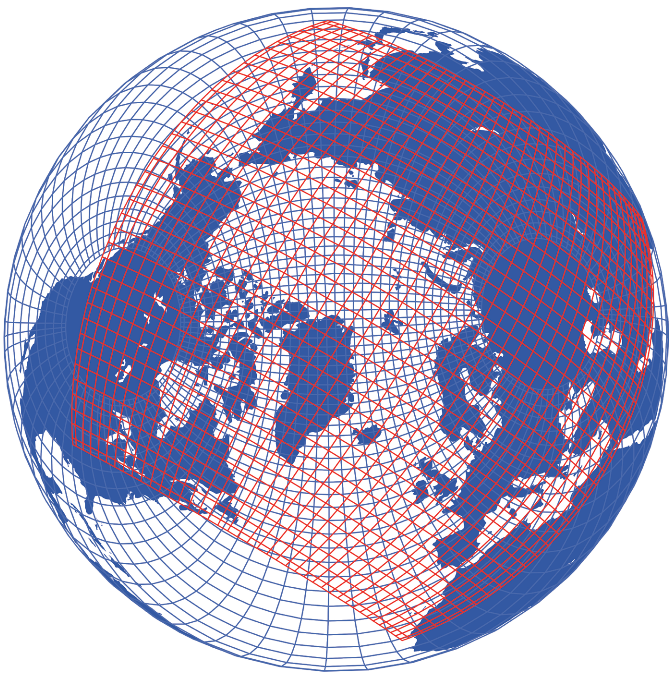

Fig. 1: Computational grids of the ocean – sea-ice model MPIOM (in blue) and the atmosphere model REMO (in red). Not every grid line is shown.

Abb. 1: Modellgitter des Ozean – Meereis-Modells MPIOM (in blau) und des Atmosphärenmodells REMO (in rot). Nicht jede Linie Gitterlinie wird gezeigt.

The formation of the Arctic Odden can be caused either by eastward advection of sea ice or due to freezing of cold polar water, which has been diverted eastward from the East Greenland current (Wadhams & Comiso 1999). Thus, the change of sea-ice thickness H is given by divergence of sea-ice transport Hv and freezing or melting due to oceanic and atmospheric fluxes ($F_{Oc} + F_{At}$):

$$\frac{\partial H}{\partial t} = -\nabla \cdot (Hv) + F_{Oc} + F_{At}$$

In contrast, previous studies state that especially in early winter, the Odden is a result of new ice formation associated with moderate westerly winds, bringing cold air from the Greenland Ice Sheets (Shuchman et al. 1998, Comiso et al. 2001, Rogers & Hung 2008). Wadhams & Comiso (1999), however, define a second Odden type and show that especially in late spring, when the thermodynamic conditions do not permit new ice growth in that region, also advection can be the driving mechanism for an Odden formation.

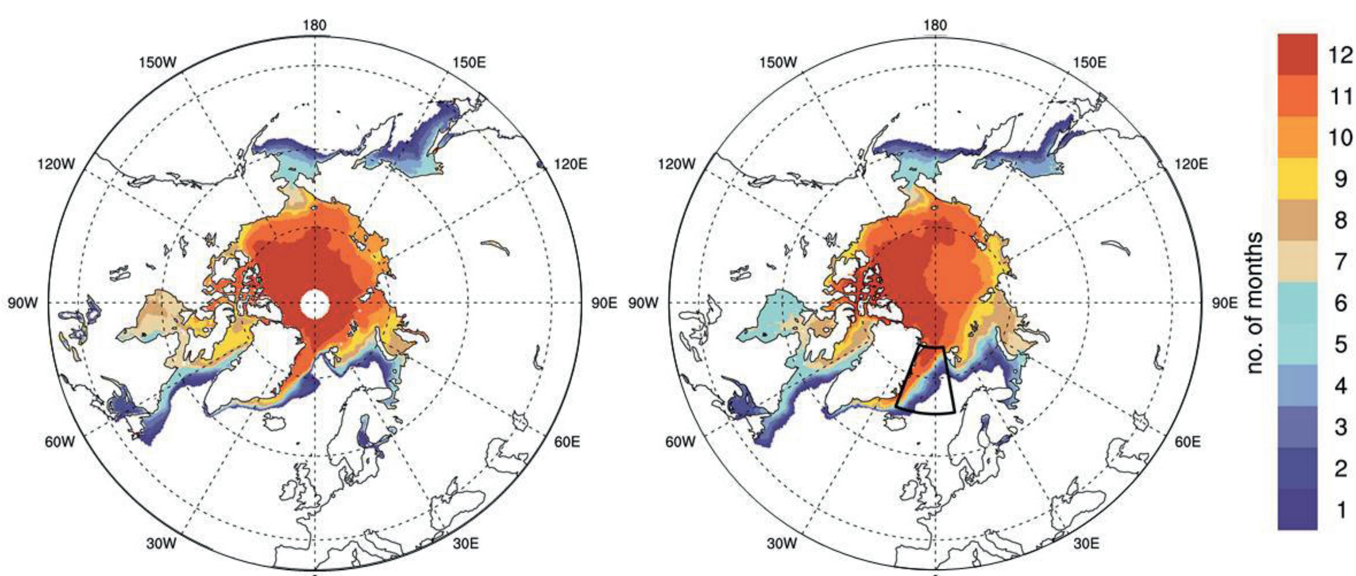

Fig. 2: Number of months with a sea-ice concentration larger than 0.15 for the years 1980–1999 of observations (SSM/I, left) and the model (right). The black box in the right panel is indicating the region shown in Fig. 4 and Fig. 5.

Abb. 2: Anzahl der Monate mit einer Meereiskonzentration größer als 0.15 für die Jahre 1980–1999 von Beobachtungen (SSM/I, links) und vom Modell (rechts). Die schwarze Box in der rechten Grafik zeigt die Ausschnittsregion, die in den Abbildungen 4 und 5 gezeigt ist.

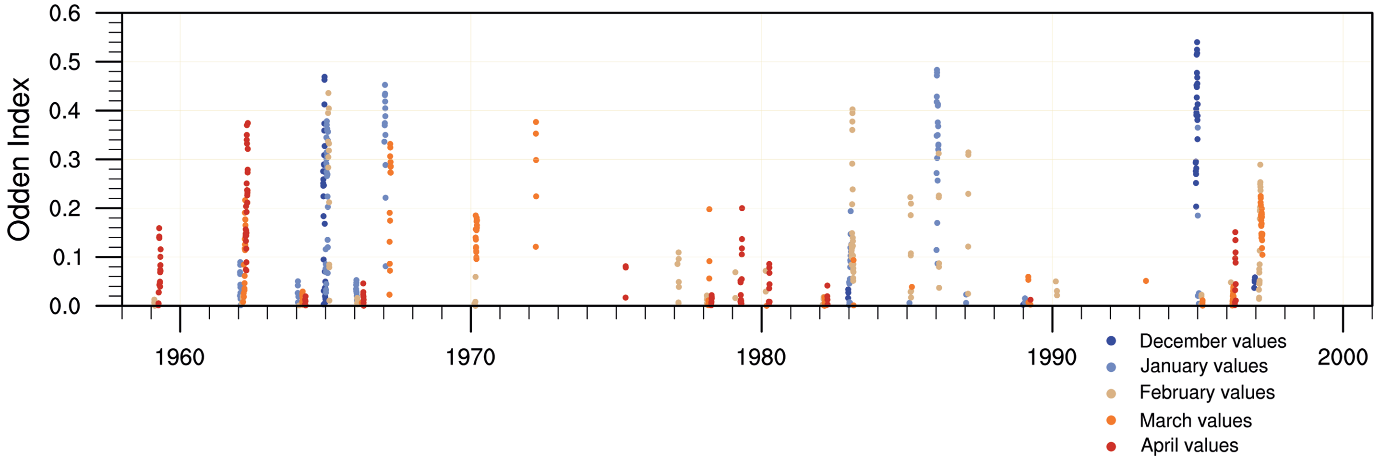

Fig. 3: Time series of an Odden Index calculated with daily data for the winter months (December to April) of the years 1958–2001. The index is defined as the difference of sea-ice concentration exceeding 0.15 in the region of the ice tongue (4.5° - 3° W, 72.8° - 73.5° N) and in the Nordbukta region (8° - 6.8° W, 74.3° - 75.1° N). Only positive values are shown.

Abb. 3: Zeitserie eines Odden Index von täglichen Daten der Wintermonate (Dezember bis April) der Jahre 1958–2001. Der Index ist als die Differenz der Meereiskonzentration größer als 0.15 der Region der Meereiszunge (4.5° - 3° W, 72.8° - 73.5° N) und in der Nordbukta Region (8° - 6.8° W, 74.3° - 75.1° N) definiert. Es sind nur positive Werte gezeigt.

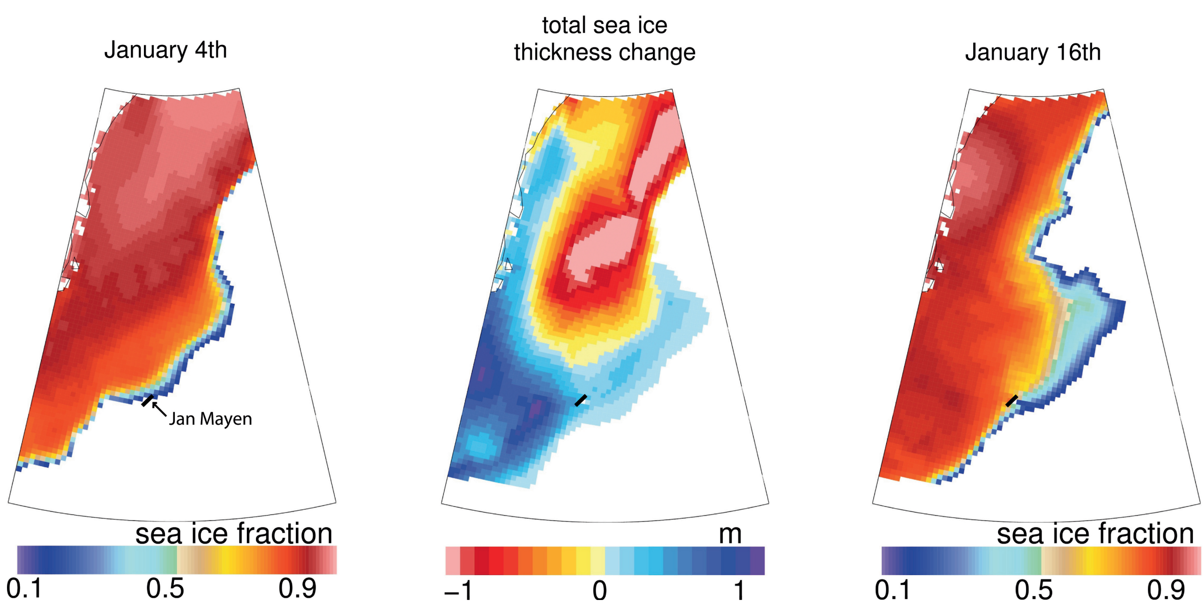

Fig. 4: Sea-ice concentration of one specific Arctic Odden event, at the beginning (left) and at the end (right). Change of sea-ice thickness (difference of end and beginning, in m) during this event (middle). The geographical domain covers the region from 67° to 81° N and from 20° W to 8° E.

Abb. 4: Meereiskonzentration für ein charakteristisches arktisches Odden-Ereignis, zu Beginn (links) und am Ende (rechts). Änderung der Meereisdicke (in m) während des Ereignisses (Mitte). Das dargestellte Gebiet reicht von 68° bis 81° N und von 20° W bis 8° E.

In our model we investigated several Odden events and find that in contrast to observations, Arctic Odden formation is mainly due to advection of sea ice from the Greenland coast and eastward advection from the main ice pack in GIN Sea irrespective of the time when it occurs. Again, to highlight the main mechanism behind the Odden formation within the model, the example of January 1962 is given in Figure 5. The behavior of this specific event is coherent with other investigated Odden events. While in the mean southward ice drift freezing is dominating, in the north-eastern marginal ice zone it is melting that supports the Arctic Odden formation (Fig. 5, right panel). This leads, in some events more than in others, to the tongue shape of the Odden. The Odden itself (the south-eastern part of the ice edge) shows only small changes due to melting and freezing. However, freezing seems to strengthen the center of the southern shape of the Odden (north of Jan Mayen) in most of the events. Within our coupled model, the Arctic Odden formation is coherent with a weak Icelandic low as well as with a strong gyre circulation of sea ice in the Central Arctic. This indicates a linkage to the large-scale Arctic sea-ice variability and the appearance of such Odden. As previously suggested by, e.g., Germe et al. (2011), the marginal ice-zone variability might be to some extent linked with large-scale processes which impact the whole Arctic, but the regional atmospheric and oceanic forcing is also responsible for the Odden formation. Consequently, the large-scale atmospheric conditions as well as the small-scale processes in the region of interest in both, the atmosphere and in the ocean should be taken into account when further analyzing the Odden formation.

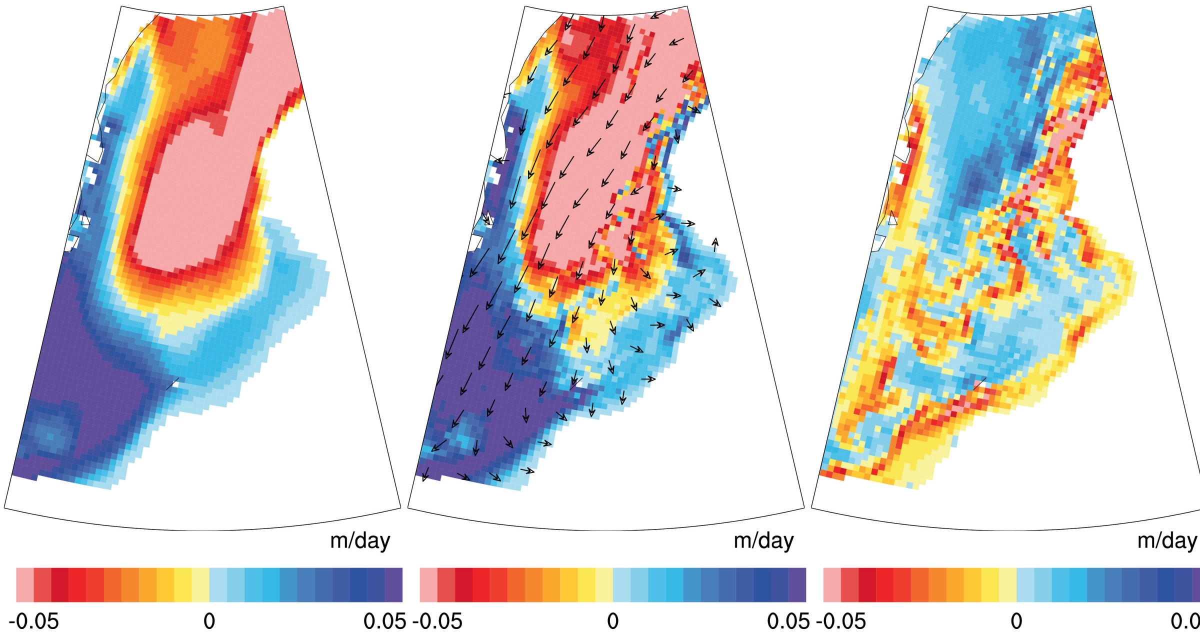

Fig. 5: Mean sea-ice thickness (*H*) change per day (left), divergence of sea-ice transport (*Hv*) and superimposed sea-ice transport (middle). The residual term (right) includes oceanic and atmospheric fluxes ($F_{Oc} + F_{At}$) that cause melting (negative values) and freezing (positive values). The geographical domain covers the region from 67° to 81° N and from 20° W to 8° E.

Abb. 5: Änderung der Meereisdicke (*H*) pro Tag (links), Divergenz des Meereistransports (*Hv*) und überlagert der Meereistransport (Mitte). Das Residuum (rechts) beinhaltet ozeanische und atmosphärische Flüsse ($F_{Oc} + F_{At}$), die zu Schmelzen (negative Werte) und Frieren (positive Werte) von Meereis führen. Das dargestellte Gebiet reicht von 68° bis 81° N und von 20° W bis 8° E.

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