Ocean Modelling 87 (2015) 67–80

Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod

Interactions between wind-blown snow redistribution and melt ponds in a coupled ocean–sea ice model

Olivier Lecomte [a],*, Thierry Fichefet [a], Daniela Flocco [b], David Schroeder [b], Martin Vancoppenolle [c]

[a] Georges Lemaître Center for Earth and Climate Research, Earth and Life Insitute, Université Catholique de Louvain, Place Louis Pasteur 3 – Boîte L4.03.08, 1348 Louvain-la-Neuve, Belgium
[b] Department of Meteorology, University of Reading, Earley Gate, PO Box 243, Reading RG6 6BB, UK
[c] Laboratoire d'Océanographie et du Climat (LOCEAN-IPSL), Centre National de la Recherche Scientifique (CNRS), Sorbonne Universités (UPMC, Univ Paris 06), 4 Place Jussieu, F-75005 Paris, France

ARTICLE INFO

Article history:
Received 12 May 2014
Received in revised form 28 November 2014
Accepted 3 December 2014
Available online 24 December 2014

Keywords:
Snow
Sea ice
Melt ponds
Model

ABSTRACT

Introducing a parameterization of the interactions between wind-driven snow depth changes and melt pond evolution allows us to improve large scale models. In this paper we have implemented an explicit melt pond scheme and, for the first time, a wind dependant snow redistribution model and new snow thermophysics into a coupled ocean–sea ice model.

The comparison of long-term mean statistics of melt pond fractions against observations demonstrates realistic melt pond cover on average over Arctic sea ice, but a clear underestimation of the pond coverage on the multi-year ice (MYI) of the western Arctic Ocean. The latter shortcoming originates from the concealing effect of persistent snow on forming ponds, impeding their growth. Analyzing a second simulation with intensified snow drift enables the identification of two distinct modes of sensitivity in the melt pond formation process. First, the larger proportion of wind-transported snow that is lost in leads directly curtails the late spring snow volume on sea ice and facilitates the early development of melt ponds on MYI. In contrast, a combination of higher air temperatures and thinner snow prior to the onset of melting sometimes make the snow cover switch to a regime where it melts entirely and rapidly. In the latter situation, seemingly more frequent on first-year ice (FYI), a smaller snow volume directly relates to a reduced melt pond cover.

Notwithstanding, changes in snow and water accumulation on seasonal sea ice is naturally limited, which lessens the impacts of wind-blown snow redistribution on FYI, as compared to those on MYI. At the basin scale, the overall increased melt pond cover results in decreased ice volume via the ice-albedo feedback in summer, which is experienced almost exclusively by MYI.

1. Introduction

Soon after the initiation of the summer surface melt on Arctic sea ice, meltwater starts accumulating in pools called melt ponds that usually cover up to 50–60% of the sea ice area during summer. The processes driving the formation and evolution of those melt ponds are well documented (e.g., Fetterer and Untersteiner, 1998; Perovich et al., 2002; Polashenski et al., 2012). The most important consequence of the pond formation with respect to the sea ice energy and mass balance is the critical drop in surface albedo wherever ponds form, triggering further ice surface and basal melt through the ice-albedo feedback. The crucial role of melt ponds in controlling the evolution of the sea ice albedo thus make them a key component of the polar climate system.

Serious efforts have already been invested in the representation of melt ponds in large-scale sea ice models (e.g., Pedersen et al., 2009; Flocco et al., 2010, 2012; Holland et al., 2012; Hunke et al., 2013). Those studies gave evidence that models are sensitive to the representation of melt ponds and showed that actually accounting for their influence on the ice-albedo feedback leads to consequential sea ice volume reductions. Even so, those models are not comprehensive yet and still lack a few of the processes driving the formation and evolution of melt ponds. Among them are snow-related processes.

The sea ice snow cover is one of the main short- and long- term controlling factors for melt pond distributions, for several reasons. The first is that freshwater from snow melt on sea ice participates to feeding the ponds as they start forming. Secondly, pooling

---

* Corresponding author.
E-mail address: olivier.lecomte@uclouvain.be (O. Lecomte).

http://dx.doi.org/10.1016/j.ocemod.2014.12.003
1463-5003/© 2014 Elsevier Ltd. All rights reserved.

meltwater may remain hidden by a thick snow cover as long as it has not melted entirely, affecting both the timing and intensity of the local albedo feedback that is triggered when ponds become visible. Lastly, the refreezing of meltwater at the base of the snow pack has been shown to create superimposed ice atop sea ice. Those locations of surficial ice formation may then turn into topographic high spots under snow dunes, between which ponds form (Freitag and Eicken, 2003; Polashenski et al., 2012; Petrich et al., 2012). Snow also has a more indirect but important impact on melt pond formation through its influence on ice permeability and surface topography. Superimposed ice formation (e.g., Eicken et al., 2004) and interposed ice formation within brine channels (e.g., Polashenski et al., 2012) alter the permeability of ice and thus the way meltwater is drained through the ice. Besides, by exerting control over the ice growth due to its insulating power, snow constrains the ice thermodynamic growth and thickness distribution. Melt pond formation is also very sensitive to the geometry and scale of snow depth distributions, which are extremely heterogeneous (e.g., Sturm et al., 2002), mostly due to blowing snow effects and to a frequently uneven sea ice surface topography. Depending on the nature of an ice floe, whether it is multi-year or seasonal, level or deformed, the wind tends to draw manifold snow drift features at its surface, such as dunes, sastrugi or accumulation patterns under the lee of sea ice pressure ridges (Sturm and Massom, 2009). In light of those elements, the question of the indirect influence of blowing snow on melt pond formation through the reshaping of the snow cover becomes legitimate, and may lead to different answers for different ice types.

In the present paper, we therefore aim at (1) simulating a realistic melt pond cover on Arctic sea ice, (2) understanding the large-scale influence of snow depth changes due to wind-blown snow redistribution on melt pond formation and evolution and (3) assess the similarity or dissimilarity of those impacts on first-year ice (FYI) and multi-year ice (MYI). Both because melt ponds are relatively uncommon and because their extensive observation is nonexistent in the Southern Ocean, our study focuses on the Arctic. So as to achieve this work, the explicit melt pond formalism of Flocco and Feltham (2007) was incorporated into the Louvain-la-Neuve Sea Ice Model (LIM), which is fully coupled with the ocean general circulation model (GCM) NEMO-OPA (Nucleus for European Modelling of the Ocean – Ocean PArallelisé). In particular, LIM includes a snow scheme of intermediate complexity (Lecomte et al., 2013) and a newly developed parameterization of blowing snow effects, a novelty for such kind of model. The following section introduces the model, before the forcing and observations used in this study are described in Sections 3 and 4. In Section 5 and 6, we proceed to the assessment and intercomparison of two forced-atmosphere configuration simulations. The first one is a control run evaluated against observations and the second is a simulation designed to appraise the effects of enhanced snow drift on snow depth, melt pond area and sea ice volume. The analyses are performed using long-term mean sea ice and snow diagnostics over the Arctic Basin. Section 7 finally summarizes the results.

2. Model description

2.1. Ocean and sea ice

NEMO-LIM (Nucleus for European Modeling of the Ocean – Louvain-la-Neuve Sea Ice Model) is a state-of-the-art global coupled ocean–sea ice model. Its ocean component is the GCM OPA (Ocean PArallelisé, version 9) and is fully documented in Madec (2008). The thermodynamic-dynamic sea ice model, on the other hand, is LIM3 (LIM, version 3) and is coupled to the ocean component following Goosse and Fichefet (1999). This model, comprehensively described in Vancoppenolle et al. (2009), includes an explicit representation of the subgrid-scale distributions of ice thickness, enthalpy, salinity and age. Sea ice thermodynamics are computed for each sea ice thickness category following Bitz and Lipscomb (1999) and halodynamics use empirical parameterizations for gravity drainage and percolation of brines. The elastic-viscous-plastic (EVP) rheology of Hunke and Dukowicz (1997) in the C-grid formulation of Bouillon et al., 2009 is used to solve the sea ice dynamics. We run the model in the same configuration as in Lecomte et al. (2013), i.e., on the global tripolar ORCA1 grid of the ocean model (1 degree resolution), with 5 ice thickness categories (each of them being divided into 5 layers for sea ice halo-thermodynamics) and 42 vertical levels in the ocean. Spurious model drift in salinity is prevented by a sea surface restoring term (Levitus, 1998, toward climatological values of) in the freshwater budget.

2.2. Snow and melt ponds

To account for the interactions between snow drift and melt pond formation, a parameterization of wind-blown snow redistribution and an explicit melt pond scheme were incorporated to NEMO-LIM. With regard to the melt pond component, new sea ice tracers (i.e., melt pond fraction, melt pond volume and ice lid volume atop melt ponds) are technically required to track the evolution of the total liquid water volume and melt pond properties in time and space. As all sea ice tracers, these variables are affected by sea thermodynamic and dynamic redistribution processes. However, melt ponds in the model remain "virtual" since their proper physical treatment as concrete liquid layers on sea ice is not taken into account. They are used for sea ice albedo computation only. Here, in order to include the impact of the presence of liquid water on snow thermodynamics, the snow scheme we use was modified. We thus first introduce the main characteristics of this snow thermodynamic scheme (Section 2.2.1) before presenting the changes made with respect to the latter processes (Section 2.2.2). In the following subsection, the melt pond model and the way melt pond-related variables are used to calculate the albedo are described, before finally documenting the blowing snow parameterization.

2.2.1. Initial thermodynamic snow model

The thermodynamic snow scheme we use was developed in previous studies (Lecomte et al., 2013, for its comprehensive description, see). It is multilayer, with time and space dependent snow thermo-physical properties (i.e., density and thermal conductivity) and includes heat conduction through the snow, penetration and absorption of solar radiation in the uppermost snow layers (Järvinen and Lepparanta, 2011, following Beer's law and extinction coefficient from), surface melt or sublimation based on the imbalance of the surface heat budget and a representation of snow ice formation based on Fichefet and Morales Maqueda, 1997.

2.2.2. Water infiltration into the snow

So as to account for wet snow properties and the refreezing of freshwater into the snow, the following model modifications were made, as compared to Lecomte et al. (2013). Because snow gets saturated with water very quickly (Jordan et al., 2008; Sturm and Massom, 2009), we assume that the snow cover is wet whenever the liquid water reservoir is not empty (for a given ice category, in a single grid cell). As in Hunke et al. (2013), water infiltration in the snow is computed based on the amount of water available and the volumes being possibly occupied in snow, depending on its density. The mass fraction of liquid water relative to the total mass of water and snow in a layer is then used to alter the snow thermal conductivity, calculated as a weighted mean of snow and freshwater thermal conductivities. Finally, freshwater that may