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Utilizing CryoSat-2 sea ice thickness to initialize a coupled ice-ocean modeling system

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Abstract

Two CryoSat-2 sea ice thickness products derived with independent algorithms are used to initialize a coupled ice-ocean modeling system in which a series of reanalysis studies are performed for the period of March 15, 2014–September 30, 2015. Comparisons against moored upward looking sonar, drifting ice mass balance buoy, and NASA Operation IceBridge ice thickness data show that the modeling system exhibits greatly reduced bias using the satellite-derived ice thickness data versus the operational model run without these data. The model initialized with CryoSat-2 ice thickness exhibits skill in simulating ice thickness from the initial period to up to 6 months. We find that the largest improvements in ice thickness occur over multi-year ice. Based on the data periods examined here, we find that for the 18-month study period, when compared with upward looking sonar measurements, the CryoSat-2 reanalyses show significant improvement in bias (0.47–0.75) and RMSE (0.89–1.04) versus the control run without these data (1.44 and 1.60, respectively). An ice drift comparison reveals little change in ice velocity statistics for the Pan Arctic region; however some improvement is seen during the summer/autumn months in 2014 for the Bering/Beaufort/Chukchi and Greenland/Norwegian Seas. These promising results suggest that such a technique should be used to reinitialize operational sea ice modeling systems.

Keywords: CryoSat-2; Ice thickness; Coupled ice-ocean model; Ice drift

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1. Introduction

Arctic sea ice extent has been on the decline for the past several decades (Parkinson and Cavalieri, 2008). The March and September Northern Hemisphere sea ice extent has declined on average 2.7% and 13.3% per decade, respectively, for the period of 1979–2016 (Perovich et al., 2016). Multi-year ice (MYI) has been in decline for the past 3 decades, with ice older than 4 years accounting for 20% of the total ice composition in the mid-1980s compared to only a few percent since 2012 (Perovich et al., 2016;

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Tschudi et al., 2016). Also, first-year ice (FYI) has accounted for 60–70% of the March ice pack since 2008. Markus et al. (2009) investigated passive microwave satellite data for the period of 1979–2008 and found the average length of the melt season had increased by 6.4 days per decade over the 30-year period for the entire Arctic, with the Chukchi/Beaufort and Laptev/East Siberian Seas showing trends of 12.0 and 11.3 days per decade, respectively.

The observed changes in Arctic sea ice provide motivation to assess and improve sea ice forecasting capabilities. The following three paragraphs describe ice thickness measurements obtained from European Remote Sensing (ERS-1 and -2) platforms, Ice, Cloud, and land Elevation Satellite (ICESat), CryoSat-2 and NASA Operation IceBridge (OIB). An overview of seasonal forecasting since 2008 follows, with the remaining paragraphs describing models and modeling systems and how they have been used to measure the decline in sea ice extent and volume. We also include a paragraph describing the importance of snow depth on ice thickness retrievals.

Measurements from radar altimeters on the ERS-1 and ERS-2 platforms provided the first basin-scale mappings of Arctic sea ice thickness for the period 1993–2001 (Laxon et al., 2003), although to a latitudinal limit of 81.5°N. Laser altimeter data from ICESat extended the observations to nearly Arctic-wide coverage, and provided seasonal (autumn and winter) ice thickness mappings from 2003 to 2008 (Kwok et al., 2007, 2009). Kwok and Rothrock (2009) examined submarine data for the period of 1958–2008 and available ICESat data and found a significant decline in mean winter ice thickness from 3.64 m in 1980 to 1.89 m in 2008. Haas et al. (2008) collected helicopter-borne electromagnetic measurements of ice thickness in the Transpolar Drift for the years 2001, 2004 and 2007, and found a 44% reduction in mean ice thickness since 2001.

CryoSat-2 (Laxon et al., 2013; Kurtz et al., 2014), launched in April 2010, provides surface elevation, which can be converted to ice freeboard, during the months of January–May and October–December of each year. CryoSat-2 (CS2) data is not available during summer months due to signal contamination resulting from snow/ice melt, open water and melt ponds.

NASA OIB (Kurtz et al., 2013; Richter-Menge and Farrell, 2013) initiated the collection of Arctic ice thickness and snow depth measurements from airborne platforms in March/April 2009 to bridge the gap in satellite-borne measurements of ice freeboard between ICESat and the planned 2018 launch of ICESat-2. Antarctic OIB surveys were also initiated in 2009 and are conducted in the October/November time frame. This paper focuses on the assimilation of Arctic data. OIB provides freeboard estimates derived from an airborne LIDAR which when combined with snow depth estimates from an ultra-wideband snow radar are converted to ice thickness (Farrell et al., 2012; Kurtz et al., 2013, 2014). The OIB surveys were designed to complement the satellite-based estimates of ice thickness from CS2 and helicopter- and aircraft-mounted electro-magnetic (EM) measurements (Haas et al., 2008, 2010) of ice thickness. For example, a comparison of OIB sea ice thickness data collected during the March-April 2014 survey with CS2 thickness estimates (Laxon et al., 2013) for the same period is shown in Fig. 1. There is excellent agreement (mean difference of 0.15 m, and correlation coefficient of 0.71) between the two independent measures of Arctic ice thickness, with both clearly showing a gradient from thicker, older ice north of Greenland and the Canadian Arctic Archipelago, to thinner ice in the FYI regions of the Beaufort, Chukchi, East Siberian, Laptev, Kara and Barents Seas. Richter-Menge and Farrell (2013) examined OIB data in the western Arctic Ocean for the period of March/April 2009–2013. They found that the central Arctic was dominated by MYI with a mean thickness of 3.2 m, while the southern Beaufort and Chukchi Sea region containing a mixture of 75% FYI and 25% MYI, and found mean thicknesses decreased from near 2.5 m to a low of 1.6 m during the five-year period.

The importance of sea ice thickness for seasonal and longer-term forecasts of sea ice extent has been investigated by several researchers. Lindsay et al. (2008) utilized the Pan-Arctic Ice-Ocean Modeling and Assimilation System (PIOMAS) to study seasonal predictions of sea ice extent. They found that the pan-Arctic forecast skill relative to climatology was 0.77 with a six month lead time for a forecast initialized in March. They determined that ice concentration was the dominant factor in the first 2 months and the ocean temperature of the model layer with a depth between 200 and 270 m was most important for longer lead times. Holland et al. (2011) used the Community Climate System Model version 3 to study the predictability of the summer sea ice extent. They found that winter preconditioning provides some summer ice area predictability and stressed the importance of feedback to the atmosphere. Day et al. (2014) performed experiments with the Hadley Centre Global Environmental Model version 1.2 (HadGEM1.2) coupled atmosphere-ocean-ice modeling system. Twin experiments revealed that initializing the sea ice model on July 1 showed improved skill in predicting the September sea ice extent compared to a control climatological initialization. Blanchard-Wrigglesworth and Bitz (2014) studied fully coupled General Circulation Models (GCMs) and sea ice-ocean models that were forced with observation estimates derived from atmospheric reanalysis and satellite measurements. They found that sea ice thickness anomalies have a typical time scale of approximately 6–20 months with a typical length scale of 500–1000 km. They hypothesized that the number of ice monitoring locations needed to characterize the full Arctic basin sea ice thickness is model dependent and the variability would vary between 3 and 14 locations. Guemas et al. (2016) presented a review of Arctic sea-ice prediction on seasonal to decadal time-scales. Using dynamical and ensemble-based forecasting systems designed to run on decadal time-

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