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Prediction of Arctic Sea Ice Melt Date as an Alternative Parameter for Local Sea Ice Forecasting

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1. Introduction

Accurate seasonal prediction of Arctic sea ice is an essential need for stakeholders in that region. However, current commonly used metrics of sea ice extent or sea ice area, which provide an integrated total over the entire Arctic, are of limited use to those who seek information on a more local scale. Shipping operations in the Arctic are concerned with the sea ice melt in the summer which impacts transportation routes. As Arctic warming continues, a greater region will experience melt, which will lead to a thinner winter ice pack. More frequent melting will also enhance the Arctic albedo feedback leading to additional warming and thus more melting (Stroeve *et al.* 2011 and references within). Therefore, an accurate prediction of sea ice melt on a local scale will prove valuable for a variety of Arctic initiatives.

Previous studies have examined passive microwave satellite data to determine the observed first sea ice melt day (IMD) (Smith 1998; Kwok *et al.* 2003; Belchansky *et al.* 2004; Howell *et al.* 2009; Markus *et al.* 2009; Stroeve *et al.* 2014; and others). Observed trends generally show earlier ice melt dates. Specifically Markus *et al.* (2009) and Stroeve *et al.* (2014) show mean trends in IMD of -2.5 and -1.9 days/decade respectively across the Arctic. The goal of this work is to analyze the performance of the Climate Forecast System version 2 (CFSv2, Saha *et al.* 2014) in representing IMD using both the operational settings and an experimental configuration.

2. Data and methods

Modeled sea ice concentration data from CFSv2 hindcasts are used. Two model configurations are used, the operational setting (CFSv2CFSR) which uses initial conditions from the Climate Forecast System Reanalysis (CFSR, Saha *et al.* 2010), and an experimental version (CFSv2PIOMp) used in Collow *et al.* (2015). CFSv2PIOMp proved to be more representative of the downward trend in sea ice during later years than CFSv2CFSR. For CFSv2PIOMp, the model was initialized with sea ice thickness from the Pan-Arctic Ice Ocean Modeling and Assimilation System (Zhang and Rothrock 2003) and additional modifications were made to the internal physics settings. Observed data used are the NASA Team sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I (available at ftp://sidads.colorado.edu/DATASETS). Observations were studied from 1985-2014 to get a sense of changes in the last 30 years. Model runs were then initialized 8-12 March 00 UTC 2005-2014 and run through 31 December for a total of 50 simulations for each model configuration, five for each year. The melt season from 1 April through 30 September is analyzed and compared with observations from this period to assess model performance.

CFSv2 sea ice concentrations are output at 12-hour intervals. Therefore, these are interpolated to match the daily frequency of the NASA Team data by averaging the two model data time steps on each day. NASA Team data prior to August 1987, which is available every other day, is linearly interpolated to a daily resolution. For all years, IMD is determined as the first day sea ice concentration drops below 15% after 1 April following the traditional definition of sea ice extent from the Intergovernmental Panel on Climate Change assessment report (Vaughan *et al.* 2013). Points that never cross the 15% threshold (permanently frozen or permanently melted) are set to undefined, thereby limiting data to seasonal sea ice regions only. Means are determined for modeled and observed IMD for each grid point. For modeled data, IMD from each of the 5 ensembles is averaged to determine the mean for that year to compare to observations.

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3. Comparison of modeled and observed means

First observed NASA Team IMD means are compared over two different time periods, 1985-1994 and 2005-2014. As seen in Figure 1b, the later period has a more expansive region of ice melt over the Arctic Ocean than in the early period (Figure 1a). Differences (Figure 1c) show generally earlier ice melt days throughout the entire Arctic. Using a t-test, significant differences at 95% confidence are found over the Hudson Bay, Davis Strait, Barents Sea, and somewhat over the Chukchi Sea. There are some regions which experienced later melt in 2005-2014 than in 1985-1994, specifically in the Bering Strait and the East Siberian Sea but changes in these regions do not show significance.

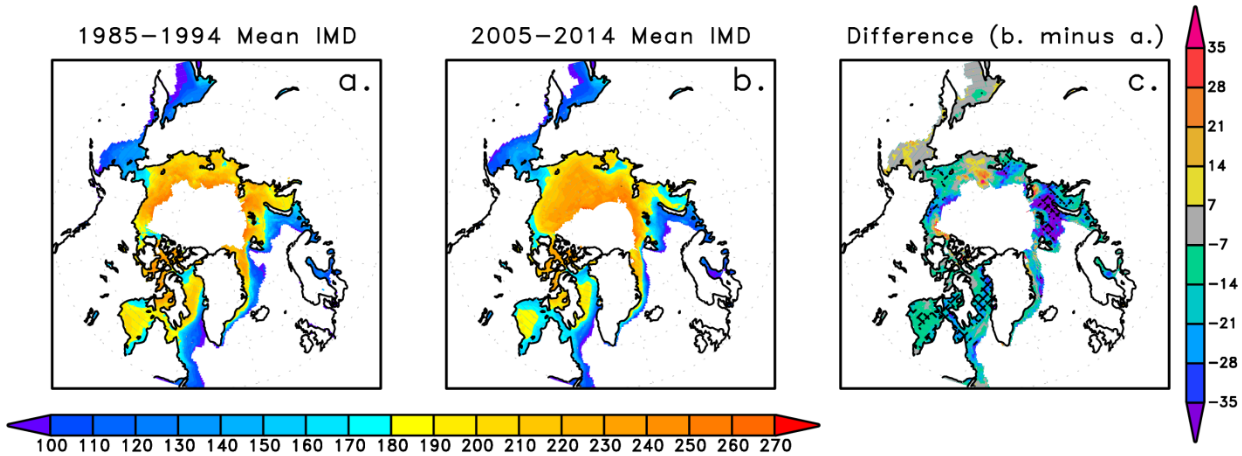

Fig. 1 Mean of observed IMD from NASA Team for the 1985-1994 period (a) and the 2005-2014 period (b). Difference between the two (b minus a) is shown in c. Hatching in c denotes differences are significant at 95% confidence based on a t-test.

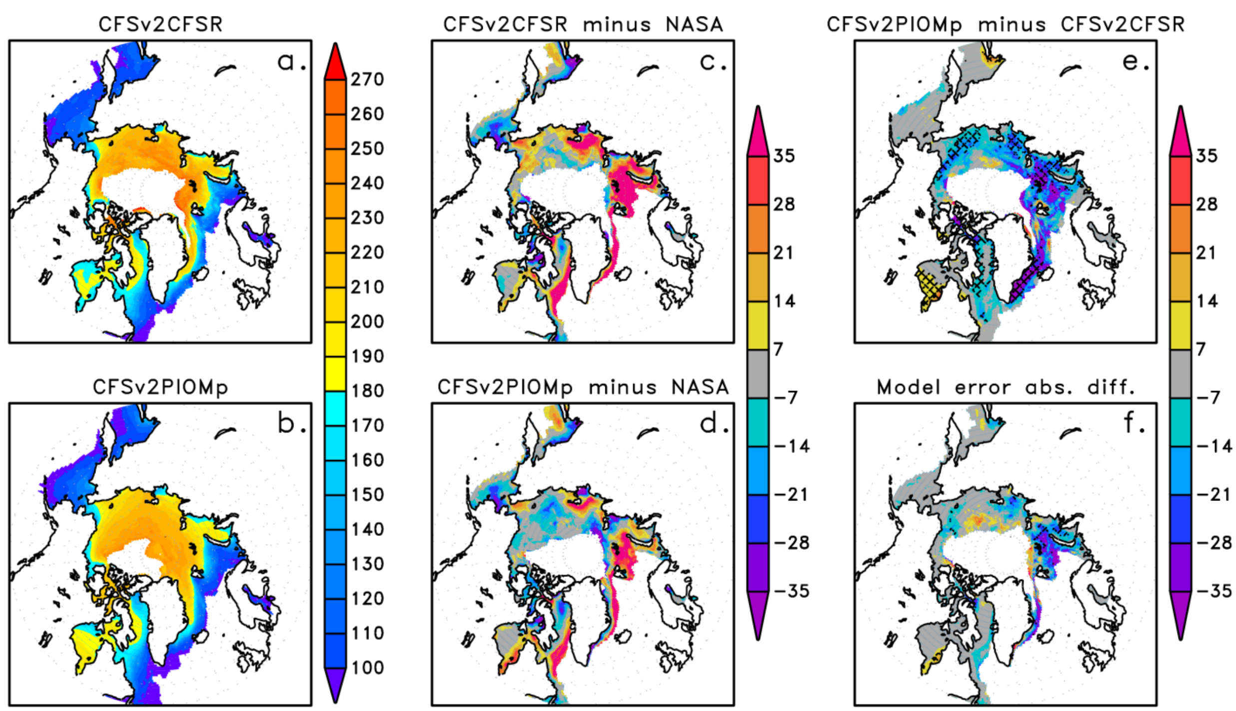

Fig. 2 Mean 2005-2014 IMD from CFSv2CFSR (a) and CFSv2PIOMp (b); CFSv2CFSR bias with respect to NASA Team observations (c); CFSv2PIOMp bias with respect to NASA Team observations (d); Difference between CFSv2PIOMp and CFSv2CFSR (e); mean absolute error difference between CFSv2PIOMp and CFSv2CFSR (abs[CFSv2PIOMp-NASA] minus abs[CFSv2CFSR-NASA]) (f.).

Using CFSv2 hindcasts to compare with the observations during the 2005-2014 period, it is evident from Figure 2 that CFSv2PIOMp has more extensive sea ice melt (Figure 2b) than CFSv2CFSR (Figure 2a) in the Arctic which is in line with the observations for this period. Differences with respect to the observations show that positive biases in the modeled IMD are smaller for CFSv2PIOMp (Figure 2d) than CFSv2CFSR (Figure 2c). However, both model configurations show ice melt occurring too early over the Bering Strait. Across the Arctic Ocean and Barents Sea, CFSv2PIOMp has a significantly earlier IMD than CFSv2CFSR (Figure 2e). There is a significant increase in IMD over southern Hudson Bay. Improvements in the prediction of IMD from each model configuration were determined using mean absolute error differences and it was found that CFSv2PIOMp significantly improved IMD prediction over the Barents Sea and a small part of the Chukchi Sea (Figure 2f). However, the skill using CFSv2PIOMp was degraded over southern Hudson Bay. One caveat is that taking differences only accounts for points that appear in both datasets or are common to the two time periods, which will not quantify differences over places with new melt over the last decade such as the interior Arctic Ocean. Changes in this region are addressed in the next section.

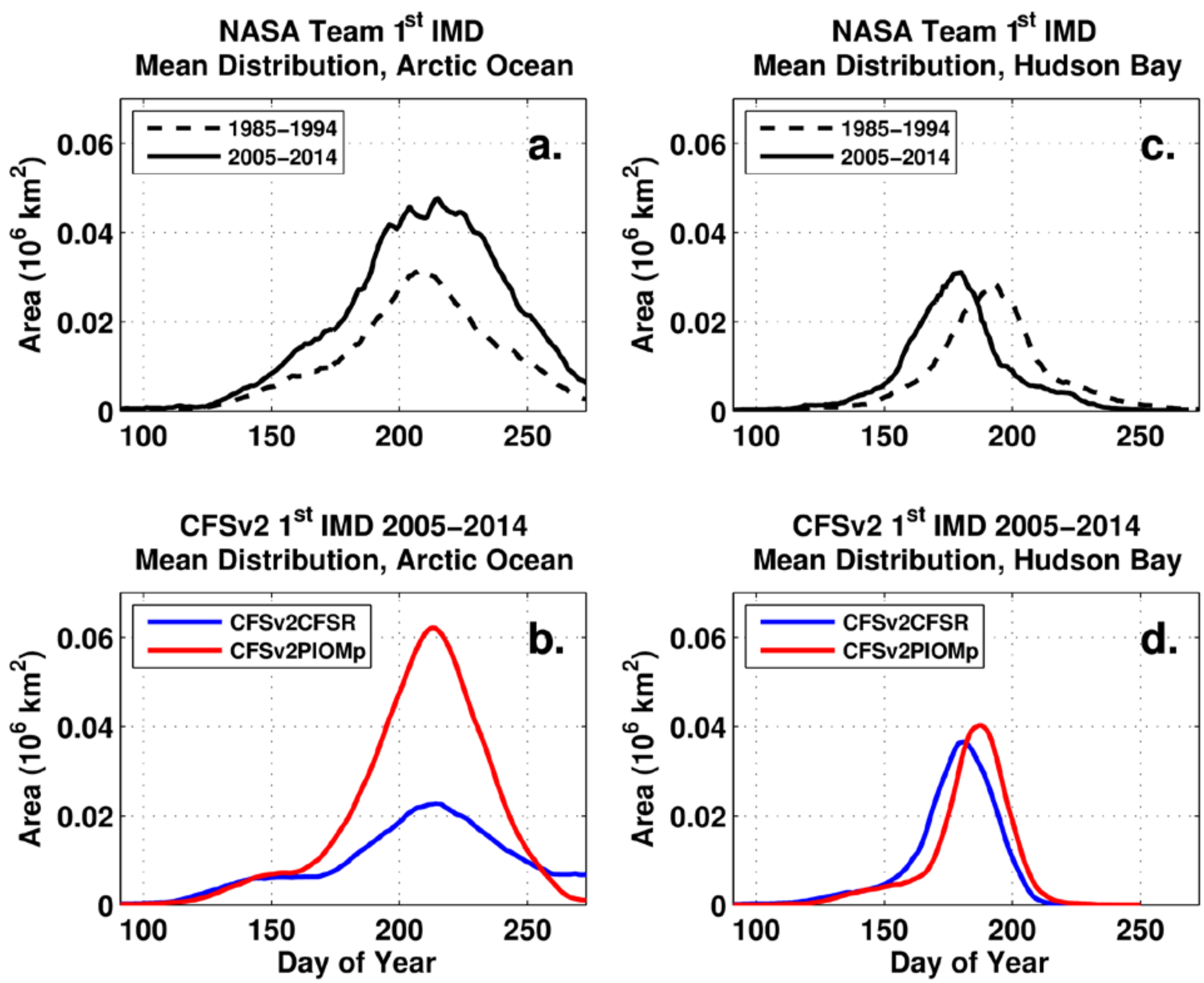

Fig. 3 Histogram showing the mean area of sea ice melt for each day of the year over the Arctic Ocean (a, b) and Hudson Bay (c, d); Panels a and c show the mean distribution for the NASA Team data for 1985-1994 (dashed line) and 2005-2014 (solid line); Panels b and d show the mean distribution for the CFSv2 2005-2014 hindcasts for CFSv2CFSR (blue line) and CFSv2PIOMp (red line). A 15-day smoothing was applied to all lines.

4. Distribution over the Arctic Ocean and Hudson Bay

Looking at the mean distribution of IMD over the Arctic Ocean, it is apparent that there has been a substantial increase in the area of the observed melt region in the 2005-2014 period over the 1985-1994 period (Figure 3a). CFSv2PIOMp shows the large area of melt in the Arctic Ocean but CFSv2CFSR fails to do so (Figure 3b) highlighting that the experimental modeling system is superior for this region. The peak melt days for the NASA Team observations for 1985-1994 and 2005-2014 are 207 and 209 respectively indicating little change in the timing of melt. The peak melt day in the models is also very similar (206 for CFSv2CFSR and 207 for CFSv2PIOMp) indicating that the issue is not necessarily in the temporal cycle of sea ice melt, but in the magnitude. Similar distribution plots are also shown for Hudson Bay. There is a noticeable shift in the observed distribution toward an earlier peak melt (Figure 3c, peak melt was 192 in the 1995-2004 in the early period and 178 in the 2005-2014 period). However, as previously shown in the last section, CFSv2PIOMp was not as skillful in this region and it is reflected in Figure 3d. For CFSv2CFSR the peak melt day for the 2005-2014 period was 177, closely matching the observed. For CFSv2PIOMp this increased to 183, which is actually further from the observed.

5. Summary and conclusions

The largest observed changes in IMD between the 1985-1994 and 2005-2014 periods occur over select regions of the Arctic, namely the Hudson Bay, Davis Strait, Barents Sea, and the Arctic Ocean. The operational system (CFSv2CFSR) does not capture early melting over the Arctic Ocean and Barents Sea but performs better over the Hudson Bay. Conversely the experimental set-up (CFSv2PIOMp) improves prediction over the Arctic Ocean and Barents Sea but degrades the prediction slightly over Hudson Bay. The improvements in the Arctic Ocean are mostly seen in the distribution, not direct differences, where there are only a small number of common IMD points between the two periods. The more realistic melting in the Arctic Ocean in CFSv2PIOMp is likely attributed to a better representation of initial sea ice thickness, which is covered in detail in Collow *et al.* (2015). Overall, exact IMD dates are hard to predict, primarily due to issues in model resolution and atmospheric influences that cannot possibly be predicted months in advance. However, by removing model biases and quantifying spread, it is possible to issue forecasts of IMD which can be used by stakeholders for decision making.

Work is ongoing in extending CFSv2 hindcasts back through 1980 to compare modeled and observed trends in not only IMD, but also the first ice freeze date and the melt season length.

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