7. SEPTEMBER 2012 ARCTIC SEA ICE MINIMUM: DISCRIMINATING BETWEEN SEA ICE MEMORY, THE AUGUST 2012 EXTREME STORM, AND PREVAILING WARM CONDITIONS

Virginie Guemas, Francisco Doblas-Reyes, Agathe Germe, Matthieu Chevallier, and David Salas y Mélia

Introduction. On 18 September 2012, the Arctic sea ice extent hit a new record low of 3.41 million km^2 as reported by the National Snow and Ice Data Center (NSIDC), i.e., about half of the 1979–2000 September mean. From 6 August to 8 August 2012, an extreme storm (Simmonds and Rudeva 2012) also transited over the Arctic. Such an intense storm had the potential to accelerate the sea ice loss through increased ice breaking and transport toward warmer regions (Parkinson and Comiso 2013) and through increased ocean mixing (Zhang et al. 2013). None of the forecast systems participating in the Study of Environmental ARctic CHange (SEARCH) program were able to predict the extreme 2012 summer sea ice melting at lead times greater than one month. Was this record low extent preconditioned by the sea ice loss from previous years but missed by the climate models because they underestimate the rate of radiatively forced sea ice loss (Stroeve et al. 2012)? Was this record largely driven by the extreme storm?

Reproducing the Arctic sea ice minimum. We performed an experiment, called CTRL, with the Louvan-la-Neuve 2 (LIM2) sea ice model (Fichefet and Maqueda 1997; Goosse and Fichefet 1999) embedded into the Nucleus for European Modelling of the Ocean 3.2 (NEMO3.2) ocean model (Madec et al. 2008) forced with ERA-Interim (Dee et al. 2011) atmospheric surface fields through the Large and Yeager's (2004) bulk formulae. Five members were initialized every 1 June from 2000 to 2012 from a five-member sea ice reconstruction described and validated extensively

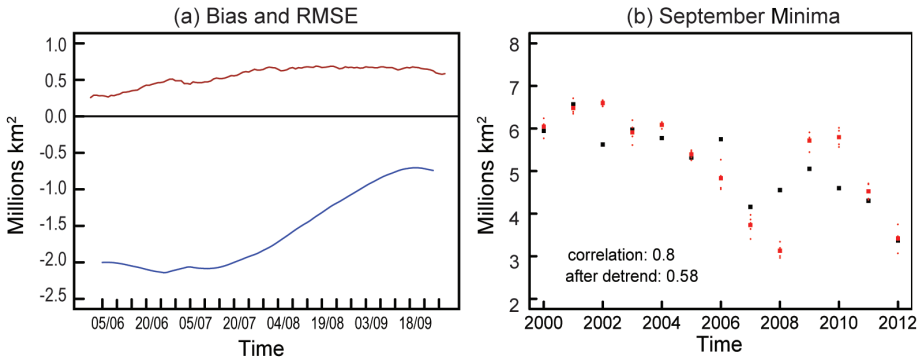

Fig. 7.1. CTRL performance in capturing the Arctic sea ice extent (×10⁶ km²). (a) Mean 2000–12 bias as compared to the NSIDC daily observations (http://nsidc.org/data/seaice_index/archives.html) in blue and RMSE of the anomalies after bias correction (Kharin et al. 2012) in brown as a function of the simulation day. (b) Sep minima in the NSIDC daily observations in black and in CTRL after bias correction (Kharin et al. 2012) in red as a function of the year. A big square is shown for the ensemble mean, small dots for the ensemble members. The method from Kharin et al. (2012) consists in correcting, not only the mean bias shown in panel (a), but also the differences in the long-term trend between the model and the observations, both obtained by a least square linear regression as a function of the calendar day.

in Guemas et al. (2013; HistEraNudg simulation) and described briefly in the Supplemental materials.

The mean bias in CTRL daily sea ice extent, computed over the 2000–12 period, as a function of the boreal summer day (Fig. 7.1a, blue curve) shows an underestimation as compared to the NSIDC estimates (Fetterer et al. 2009). After bias correction following the Kharin et al. (2012) method, which accounts for the influence of the long-term trend on the model bias, the RMSE of the anomalies (Fig. 7.1a, brown curve) shows an error of about 0.25 million km² at the beginning of the summer that increases to about 0.75 million km² at the end of the summer. The September minima in sea ice extent (Fig. 7.1b) are captured with a correlation of 0.80, reduced to 0.58 after linear detrending, both significant at the 95% level. The observed 2012 September minimum is 2.01 million km² lower than the 2000–11 average September minimum. This excess sea ice loss is underestimated by 0.05 million km² (2.5%) by our ensemble mean 2012 CTRL minimum when using the Kharin et al. (2012) method for bias correction (Fig. 7.1b) while it is overestimated by 0.43 million km² (21%) if we bias correct by subtracting the climatology shown in Fig. 7.1a, indicating that our climate model overestimates the long-term trend in sea ice extent. We aim here at attributing the observed 2.01 million km² excess loss to either the extreme August cyclone, the warmer than usual atmospheric conditions, or the persistence of 1 June 2012 sea ice initial conditions.

Attribution through sensitivity experiments. We performed a first sensitivity experiment, called STORM, (Fig. 7.2; blue) in which we replaced all the global atmospheric forcing fields during 5 August–8 August 2012, when the extreme storm occurred, by the global atmospheric forcing fields from the 5 August–8 August 2011. The simulated excess sea ice loss relative to the 2000–11 average is reduced by 0.02 million km² (1%; blue-red in Fig. 7.2) only in STORM as compared to CTRL. We, therefore, conclude to a negligible contribution of the extreme 2012 summer cyclone to the Arctic sea ice extent minimum, which is consistent with Zhang et al. (2013)'s results. However, sea ice fracturation processes and melt ponds are not represented in our model, which can be responsible for an underestimated response to the extreme storm, through an underestimation of the shortwave radiation absorption (Screen and Simmonds 2012) and of the heat

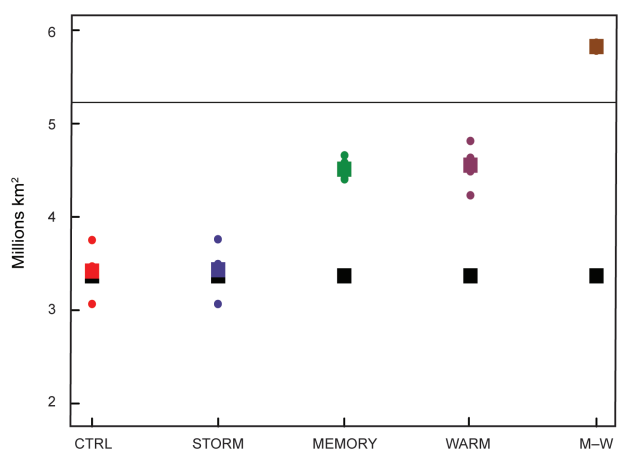

Fig. 7.2. Sensitivity experiments of 2012. Black squares indicate the observed 2012 minimum (×10⁶ km²). The black line indicates the 2000–11 average minimum. Red is the same 2012 CTRL minimum as in Fig. 7.1b. Blue, green, purple, and brown are the September minima from the STORM, MEMORY, WARM, and M-W sensitivity experiments respectively. A square indicates the ensemble mean, small dots the ensemble members.

exchanges between the sea ice and ocean components. Indeed, the study by Parkinson and Comiso (2013) suggests a larger contribution from the extreme storm. Hence, the robustness of those conclusions should be assessed with more sea ice models.

We performed a second sensitivity experiment, called MEMORY, (Fig. 7.2; green) in which we replaced the observed sea ice initial conditions for 1 June 2012 with the climatology of 1 June 2000–11. The simulated excess sea ice loss relative to the 2000–11 average is reduced by 1.09 million km^2 (54%; green-red in Fig. 7.2) in MEMORY as compared to CTRL. We, therefore, conclude that about half of the excess sea ice loss during the 2012 summer was preconditioned by the previous history of the sea ice cover. However, the 1 June 2012 sea ice extent is underestimated in CTRL, which might lead to an overestimated role of the sea ice memory.

A third sensitivity experiment, called WARM, (Fig. 7.2; purple) was performed in which we introduced an offset in the near-surface atmospheric temperature and humidity computed as the difference at the grid-point level between the average over the 2000–11 melting season and the 2012 melting season. The simulated sea ice loss relative to the 2000–11 average is reduced by 1.14 million km^2 (56%; purple-red in Fig. 7.2) in WARM as compared to CTRL. We, therefore, conclude that about half of the excess sea ice loss during the 2012 summer was induced by the warmer-than-usual atmospheric conditions. Those warmer atmospheric conditions over the Arctic might have been, however, themselves partly forced by the feedback of the sea ice loss into the atmosphere.

We, therefore, performed a last sensitivity experiment, called M-W (Fig 7.2, brown) which combines both the characteristics of the MEMORY and WARM experiments to assess the contribution of the interaction between the sea ice memory and the warmer atmospheric conditions. We replaced, in this M-W experiment, the observed sea ice initial conditions for 1 June 2012 with the climatology of 1 June 2000–11, and we introduced an offset in the near-surface atmospheric temperature and humidity computed as the difference at the grid-point level between the average over the 2000–11 melting season and the 2012 melting season. The simulated sea ice loss is reduced by 2.41 million km^2 in M-W as compared to CTRL, i.e., 0.17 million km^2 (8%) in excess compared to the sum of the individual contributions from the preconditioning by the previous history of the sea ice cover (1.09 million km^2) and from the 2012 warmer atmospheric conditions (1.14 million km^2). We, therefore, conclude that the positive retroaction between the sea ice memory and the warm atmospheric conditions explain a few percentage of the excess sea ice loss during the 2012 summer.

The 2012 sea ice loss we attributed to the storm, to the sea ice memory, to the atmospheric warming, and to the interaction between sea ice memory and atmospheric warming amount respectively to 0.02 million km^2, 1.09 million km^2, 1.14 million km^2, and 0.17 million km^2. This makes a total of 2.42 million km^2, which overestimates the 2012 observed sea ice loss by 0.41 million km^2. This amount of 0.41 million km^2 corresponds approximately to the bias corrected by the Kharin et al. (2012) method to account for the overestimated long-term trend in sea ice extent in CTRL. This overestimation by 0.41 million km^2, therefore, corresponds most probably to an overestimation of the contribution from the sea ice memory and the warm atmospheric conditions (and their positive retroaction).

Conclusions. The Arctic sea ice extent experienced an extreme low on 18 September 2012, 2.01 million km^2 below the 2000–11 mean September minimum. This study aimed at estimating the contributions from three different factors to this 2.01 million km^2 excess sea ice loss: (i) the extreme August summer storm that transited over the Arctic, fracturing sea ice, transporting it toward warmer regions, and increasing the ocean mixing; (ii) the preconditioning by the history of the sea ice cover prior to the beginning of the melt season (among which the sea ice thinning related to the long-term warming); and (iii) the warmer-than-usual surface atmospheric conditions (also partly related to the long-term warming). Our modeling results indicate that the exceptional 2012 sea ice loss was primarily due to the sea ice memory and to the positive feedback of the warm atmospheric conditions, both contributing approximately equally. Our results also point at a negligible contribution of the extreme 2012 summer storm. However, our model fails to reproduce the abrupt fall in daily sea ice extent observed by satellite at the storm passage (not shown), which suggests that we underestimate its contribution in this study.