Response for Referee 1 (L. Rontu)

01 April 2014

We thank the reviewer for taking time to comment on our paper and for providing comments that will significantly improve the manuscript. We have provided answers to the comments below the respective comments. The answers are provided in bold.

This is a modelling study on future changes of ice conditions over the Northern European lakes. A stand-alone single-column lake model MyLake was driven by downscaled reanalysis and regional climate model output. The simulation results show decrease of the ice duration up to 14 weeks till the end of 21st century compared to the control period 1961-1990. The MyLake model and the other methods were preliminarily tested against detailed lake observations on one Norwegian lake and against freezing and break-up dates over several Finnish and one Swedish lake. Forcing by synoptic observations as well as by climate simulations was applied for testing. The authors conclude that the model validated well and could be used for estimation of the changes in lake (surface) state between the present and future climate. The manuscript contains a comprehensive and detailed report of the data, methods and results, which are worth for publication in the Journal. However, a thorough revision is needed in order to focus in the most important issues of the study and to analyse the results and their uncertainties more systematically.

General comments

There exist quite a lot of studies and reports on handling of lakes in numerical weather prediction and climate models, relevant for the present study, which seem to remain unknown to the authors. Since 2008, three workshops on "Parameterization of Lakes in Numerical Weather Prediction and Climate Modelling" have been arranged. Their presentations as well as the follow-up papers have been published in internet and in three special issues of Bor.Env.Res and Tellus A. The web page of the latest seminar can be used as a starting point: http://netfam.fmi.fi/Lake12/ The journal publications can be found at http://www.tellusa.net/index.php/tellusa/pages/view/thematic and http://www.borenv.net/BER/ber152. In these materials, several articles relevant to the present study are included, and perhaps could be discussed in its revised version, e.g. Samuelsson et al., 2010, Kourzeneva et al., 2012, Martynov et al., 2012 and others. One more possibly interesting reference, not seen via the above links: Yang, Y., Cheng, B., Kourzeneva, E., Semmler, T., Rontu, L., Leppäranta, M., Shirasawa, K. & Li, Z. J. 2013: Modelling experiments on air–snow–ice interactions over Kilpisjärvi, a lake in northern Finland. Boreal Env. Res.18: 341–358.

We have missed the special issues of Tellus and Boreal Env. Res. which could be of interest to the current work. We thank the reviewer for this information, and as advised we will include a discussion of the additional materials suggested above in the revised manuscript.

The results about the future change of the Northern lake ice cover are obtained here within quite a complicated chain of simulations: ERA reanalysis is first downscaled by RCA (to a horizontal resolution of ca 25 km), then near-surface atmospheric variables are extracted for driving of one-column MyLake simulations in hypothetical mini-lakes. This kind of downscaling procedure can be justified by practical considerations. However, it is known that the climate models like RCA contain advanced integrated lake parametrizations, which would produce similar lake ice/water output with a simpler and arguably more physical basis. It would be good to compare the present offline results with such online climate model simulations if they are available (from the Rossby centre?). On the other hand, there exist vast amount of literature where offline lake models have been driven by NWP or climate model output in a similar way as here, but mostly for shorter periods of time. However, these studies contain discussions about the choice and importance of the different atmospheric forcing variables and the sensitivity of the lake models to them. For example, it is not easy to understand why the available lowest model level temperature, humidity and wind have not been used instead of the diagnostic screen-level variables or anemometer-level wind, why available simulated downwelling radiation fluxes have been replaced with simplified combination of cloud cover with solar radiation annual/diurnal cycles. The usage of precipitation, in particular snow precipitation, which are generally believed to be important forcing parameters for which the lake models are sensitive, has not been discussed sufficiently.

We agree that a number of steps have been taken to arrive at the changes in lake ice cover. This has become necessary, at least in this study, due to the fact that the environmental variables required for computing the energy balance are not available as gridded datasets with the exception of temperature and precipitation. The ERA-40 reanalysis dataset has then become the only source of gridded data to enable us carry out region-wide analysis. As the ERA-40 reanalysis dataset has a very coarse spatial resolution (~250 km), we needed to use a downscaled dataset to carry out the analysis at a finer spatial resolution. We have tried to include a discussion of previous applications of offline lake models in the introduction as well as in the discussion of results. We will make additional efforts to include more while revising the manuscript. It would have been great if some of these references were outlined. Regarding the use of screen-level variables, it was necessitated by data availability.

The use of offline lake model has the advantage that it can be tested by available data and calibrated easily compared to parameterizations in Regional Climate Models. It will be interesting, as suggested by the reviewer, to compare results from the offline model simulation with online simulations from an RCM. But in our search for published data on lake ice modelling, we haven't found data for specific lakes simulated by RCA RCM to compare our results with.

Precipitation, in particular, snow precipitation is known to be a very important factor in the thermal and ice cover regime due to its higher albedo as well as insulation effect. One of the reasons we chose the MyLake model was because snow effects (for example insulation on the one hand and snow-ice formation on the other) are parameterized in the model, and we still have a model that is computationally inexpensive for the level of regional detail we needed, reasonable in the needed model parameters and still produces results comparable to observations. However, as suggested (also by the other reviewers) we agree that there needs to be a thorough discussion of precipitation/snow effects on the ice regime which we will include in the revised manuscript.

The connection between the increase of near-surface temperature and lake ice cover changes is mentioned in many places of the manuscript. However, without a more systematic analysis of the surface energy balance over lakes, the reader remains with an impression that the screen-level air temperature change is the cause of decreasing ice cover in the future climate. This is also related to the forcing variables for lake simulations, where the authors show that MyLake is most sensitive to the changes of T2m. This is most probably due to the assumption of the lake model, not because in the nature the direct sensible heat flux between air and lake would be most important component of the energy balance. In the nature (and in the climate models, too), we are most probably dealing with more complicated dynamical and radiational interactions in the atmosphere and in the lakes. It would be good to discuss these interactions in the introduction or in the summary, to give a wider perspective and envisage the way for further studies, where it might be possible to study the predicted changes in the lake surface energy balance components (SWnet, LWnet, sensible and latent heat flux, heat flux from lake water (ice + snow) to the surface) during different seasons? The results of climate models surely contain this information, produced without or even with lake parametrizations, also the stand-alone MyLake model output should most probably contain these variables. From the side of the hydrological cycle, the influence of precipitation and especially snow precipitation on the results of lake ice evolution will surely deserve further study. Here, the related assumptions should be discussed.

It is true that MyLake computes the lake surface energy balance components (SWnet, LWnet, Sensible and Latent heat fluxes). MyLake is more sensitive to T2m arguably because T2m is used in the computation of down-welling long wave radiation and latent heat fluxes in addition to the sensible heat flux. We will include a discussion of the seasonal energy balance in the revised manuscript. As we outlined in our response above, the importance of snow precipitation which is parameterized in the lake simulations will also be discussed. But we agree with the reviewer that there are a number of interesting future studies on lake ice if energy flux data from the global models can be obtained on a level of detail that would allow us to utilize it on individual lakes.

I agree with the comment by Jari Haapala that the description of MyLake model in Section 2 is large and technical. However, it seems that the original publication by Saloranta and Andersen is not easily available (e.g. I could not reach it via internet). Thus I would not suggest removing this description but perhaps condensing it in the main manuscript and leaving the more comprehensive documentation for an Appendix, which will stay available via this open access Journal. I cannot comment how good the MyLake description in the present manuscript is, hopefully the authors have checked this carefully (perhaps together with the author of MyLake whose name is mentioned in the acknowledgements?). As a reader, I think I have now understood the main principles of the model, that seems to be both quite simplified in some aspects (e.g. with respect to the treatment of atmospheric forcing) and quite ambitious in others (e.g. in the attempt to treat horizontal exhange including in- and outflow, different areas of the layers in depth inside the lake, which would imply the existence of detailed bathymetries of lakes – hope I understood this point correctly - etc). My impression is that the chosen model is one among the many existing (single-column) lake models, some of which have recently been compared e.g. within the LakeMIP intercomparison (http://www.unige.ch/climate/lakemip), each with its own weak and strong points. It is evidently not the task of the present manuscript to compare the lake models, but it would be good to shortly motivate why just this choice has been made for this study, and to discuss the possible uncertainties caused by the assumptions of MyLake on the present results.

We will include a condensed model description in the paper, and put the detailed model description as supplementary material for interested readers. As rightly said, MyLake is one of many offline lake models available. It has been chosen in this study among other things because snow and ice cover dynamics are included and the source code is available for flexible model application. We will include a justification of why MyLake was chosen as well as a discussion of model uncertainties.

Specific comments

I have written some detailed comments as notes into the pdf file extracted from the Journal site. The notes were written and should be readable by using a new version of Adobe reader (I used the version XI in a Windows system). The commented pdf is attached as supplementary material. I found the presentation and the language of the manuscript good and understandable, however there seem to be minor mistakes and typos which the authors should check, perhaps together with the Editorial office. I have only marked some of them, not systematically all. Also, I would agree with the earlier online discussion comments by Jari Haapala and suggest the authors to take them into account when writing the revised version.

We will make a thorough check of any editorial flaws including the ones suggested by the reviewer while preparing the revised manuscript.