Observational needs for sea ice models
Short note

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1 Scope

This note summarizes discussions held during a 2-day meeting of the CLiC Arctic Sea Ice Working Group, in Boulder, CO (31^{st} Oct. – 1^{st} Nov., 2011). It is not intended to be exhaustive, but seeks to identify gaps in the observations of the Arctic sea ice cover[1] that, if closed, could significantly help to evaluate and improve the process- to large-scale sea ice models. Any comments or questions about this note are welcome and should be addressed directly to the authors.

This note is available online at `http://www.astr.ucl.ac.be/users/fmasson/obs_CLIC_note.pdf`

2 General remarks

1. **Converging to a common language.** One of the main obstacles between the "observer" and the "modeler" communities is that they do not speak the same "language". One example is the *ice age* viewed by a satellite (Fowler et al., 2004), which is often defined differently to that of a model (Lietaer et al., 2011; Hunke and Bitz, 2009). Another example is the *multiyear ice coverage*, which can differ substantially depending on whether it is calculated as an extent (with a cutoff value for ice concentration), or as an area (Jahn et al., 2012). Yet another example is the *mean ice thickness* in a grid box/area, which is not a precisely defined quantity unless the treatment of open water has been specified explicitly. We believe that addressing the question of terminology is a prerequisite for correctly comparing observations and models, and strongly recommend that a list of "controlled vocabulary" be set up to bridge the two communities.

2. **Different users, different needs.** Different kinds of modelers/model applications benefit from observations of the sea ice cover:

    - The small-scale (or process-scale) model developers include new parameterizations and processes in the sea ice models (e.g. the evolution of snow temperature profiles on top of sea ice (Lecomte et al., 2011)). They often focus on small-scale effects and might even use single column models, so they need data that they can reproduce with a forced model under particular conditions (time, location, atmospheric and/or oceanic state).
    - The regional modelers use forced regional (and sometimes global) ocean-sea ice models to study processes and variability in the Arctic. Similar to the small- or process-scale modelers these modelers need data that they can reproduce with a forced model in order to validate or evaluate their models (e.g Massonnet et al., 2011), but they often need data with a larger spatial and temporal scale than process-scale modelers.

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[1] A similar note has been written last year for Antarctic sea ice (M. Vancoppenolle) and is available at `http://www.astr.ucl.ac.be/users/fmasson/ASPECT_request_modelers_v1.1.pdf`

- The large-scale modelers look at the behavior of sea ice in global coupled climate models. For the purpose of model validations, they therefore compare climatological features of the simulated sea ice cover against observations, so that the natural variability of the climate model is not interfering with the comparison against observations. These modelers/users are therefore looking for statistics of the sea ice cover (e.g. September Arctic sea ice area and its variance or the climatological seasonal cycle) as well as for data that covers large spatial scales, rather than for exact realizations for a particular year at a particular point (Jahn et al., 2012; Kwok, 2011; Rampal et al., 2011).

Based on these general categorizations, which are not mutually exclusive but often include the same individuals in two or more groups, in situ observations usually benefit mainly the first and second class of modelers, because of their high resolution for specific times/locations; remote observations (e.g., from satellites) and gridded data sets are the most useful to the second and third class of modelers because of their large spatial and/or temporal coverage.

3 Variables relevant to modelers

- **Sea ice thickness and its distribution (ITD).** Great progress has been made over the past years to monitor the ITD through the use of (radar) altimeters (e.g. ICESat (Zwally et al., 2003)) and radiometers (SMOS), especially in the Arctic. We recommend that such campaigns be continued with even larger sampling areas (so far, the Central Arctic is well sampled, but marginal ice zones tend to be under-sampled), and for longer time periods during the year (ideally, continuous sampling). Integrated quantities derived from these products, such as gridded sea ice volume/mean thickness (e.g. Kwok and Cunningham, 2008) are extremely valuable for large-scale modelers and should be encouraged. In order to get a better idea of past sea ice thicknesses, gridded data products constructed from existing in situ, upward looking sonar, and electro-magnetic induction techniques would be highly desirable.

  A general request would be that both modelers and observers use the same standard bins for distinguishing between different ice categories. Models preferentially use 5 (Bitz et al., 2001; Vancoppenolle et al., 2009). Since the observations of ITD in the Arctic are mostly carried out by instruments (i.e. not observed visually), it should not be difficult to converge to common threshold values. This requirement will allow accurate, numerical comparison of the ITDs (going a step further than the classical visual inspection of two probability density functions).

- **Sea ice fluxes.** Areal and volume fluxes of sea ice through a defined section are very useful for modelers, as they characterize both the mass balance and the transport diagnostics. Areal fluxes are in general well sampled (Kwok et al., 2004; Agnew et al., 2008) through the main Arctic gates (Fram Strait and the Canadian Arctic Archipelago). Currently available sea ice volume fluxes (Spreen et al., 2009) are partly based on the satellite altimetry data and are often limited in time. Volume fluxes from May to September are missing and would be highly welcome to evaluate large-scale models, since the exports of mass during the spring and summer could potentially impact the following late summer sea ice properties.

- **Snow.** Because of its important properties, the representation of snow on top of sea ice is crucial for process- to large-scale modelers. Process-scale data are available through in situ measurement campaigns and should be continued. On the large-scale, a global view of the snow depth is clearly missing, yet some recent studies have started such investigations using airborne radars (e.g. Kurtz and Farrell, 2011), yielding highly valuable estimations of the snow thickness distribution on top of sea ice along basin-wide transects. Variables that would be most useful for modelers, especially if they were available on larger scales, are the mean snow thickness, snow thickness distribution, fractional snow coverage, snow density, and snow conductivity.

- **Melt pond statistics.** Data on the time-varying depth and concentration of melt ponds for different ice categories (e.g., land fast ice, first year ice, multi-year ice, ...) would be very useful for improving model parameterizations of melt ponds, which would allow models to better represent the albedo evolution of sea ice - an area that still needs improvements. While some data on melt ponds exists, more data for different ice categories, different regions in the Arctic, and for longer periods of time would be very welcome.

- **Sea ice biogeochemistry.** Biogeochemical modules with an explicit representation of the brine and algae dynamics are now developed (Vancoppenolle et al., submitted) and will be included in large-scale models in the future years. Therefore the need for in situ as well as for large-scale data for their validation will increase in the future. Current data are nearly nonexistent, yet some projects are now planned. Records of chlorophyll, nutrient, trace metals and gas exchange time series are encouraged. On the large scale, there are no data relative to sea ice biogeochemistry; those would be welcome to validate the biogeochemical components in the models.

- **Atmosphere- and Ocean-Ice fluxes.** More measurements of fluxes between the atmosphere/ocean and the sea ice are needed to validate model simulated fluxes. Currently the atmospheric fluxes are only available from reanalysis products , with potentially large biases due to the lack of observations over the ice that is included in these products. Ocean-ice fluxes are nearly nonexistent but would be highly valuable (especially for each type/category of ice), to better constrain current model developments.

- **Atmospheric boundary conditions.** It is important to remember that simulations from sea ice models can only be as good as the atmospheric forcing they are forced with. For coupled models this means the atmospheric models need to prove realistic, while for forced models it means that the prescribed atmospheric forcing needs to be accurate, which we know it often is not (e.g. Bromwich et al., 2007; Screen and Simmonds, 2011). To improve the forcing data for forced models, more remotely sensed and in-situ observations of air temperature, humidity, incoming radiative fluxes etc. would be extremely useful.

- **Sea ice age.** Data on multi year versus first year as well as detailed ice ages are a useful diagnostic to validate models, beside the definition issue (see General Remarks, Section 2). More data and further refinement of the ice age diagnostics would therefore be extremely useful.

- **Sea ice concentration/extent.** Sea ice concentration and extent are probably the most widely used sea ice variables for model validations and have the longest time series. Continued monitoring, further improvements of the products, and investigations into the differences between different products would be very useful for modelers (see also Section 4).

- **Melt onset and freezeup dates.** Data on the melt onset and freezeup dates have proven useful for assessing season lengths in the models and observations Arctic sea ice cover evolution (Jahn et al., 2012; Markus et al., 2009), but care must be taken to assure that the definition of these dates is consistent in different data sets as well as between data and models.

- **Sea ice motion and deformation.** Sea ice motion and deformation are relatively well observed through buoys arrays, RGPS, and satellites. The available data is very useful for all kinds of modelers and has made it possible to diagnose biases in the simulated statistics of deformation and kinematics in large-scale models. Further monitoring is needed to study changes in the Arctic and to validate future models.

4 Statement of uncertainties

We advocate that any kind of observation should come with uncertainty ranges (e.g. for data assimilation, model assessment, etc.). Producers of the data sets –not the users– are in the best position to determine whether their products have 5, 10 or 20 % of uncertainty. When possible, those uncertainties should be time- and space- dependent. Their nature should also be specified: do they correspond to the standard deviation of different samples? Or were they computed analytically taking into account each step of the algorithm that led to the estimate?

We also suggest the idea of a "Arctic Observational Intercomparison Project". The following example, underlined by Kattsov et al. (2010), illustrates the problem: on the 12^{th} of September, 2009, the Arctic sea ice extent was simultaneously observed to be 5.1 and 6.0 million km^2, by two independent centers. These differences in the observational estimate show some of the uncertainty in the data, but might not show the full range of the uncertainty. Knowing the range of uncertainty, and if possible the causes for the differences in the observational estimates, are important for accurate model validations. Hence, we recommend that an intercomparison project be set up with the aim to compare the different estimates and investigate what causes the differences (for example, the differences in the sea ice extent from different satellites and algorithms). Then modelers could make an informed decision as to which data to compare to (i.e., a high resolution data set for a high resolution model, a lower resolution data set for a coarser model). And if they compare to all the available data, the outcomes from such an intercomparison project would allow them to analyze whether it makes sense that their model is closer to one estimate than another.

5 Technical requirements

A complete documentation should be provided besides the products themselves, including the techniques and algorithms used for deriving the data. We point out three specific requirements:

- **Format.** A very large part of the modeling community is now using the free NetCDF format. To make comparison easier with the observations, we suggest that the same file format be used when recording the observations, in particular for gridded data. If, for some reason, this is not feasible, we suggest that the observations be recorded in an ASCII-like format, with one row for each observation. No matter which data format is used, it is important that accurate meta data (including methods, data encoding type, type of variables, etc.) is supplied, which allows the user to understand the data structure and format.
- **Availability.** Naively, we encourage all groups to publish their observations without restrictions, as long as the users cite and quote the use of these products. This would allow more people to use and give feedback on those products, with an overall benefit on the whole sea ice community. In order to make it easy to find the data, a website that points to different data sets archived at data centers (e.g., NSIDC) or institutional websites would be very useful. One possible way to make different sea ice data easy to find would be to add links and descriptions to the data to the new Climate Data Guide at `https://climatedataguide.ucar.edu/`.
- **Data structure.** As mentioned earlier, the data structure should be made clear. For the case of gridded data, we suggest the use of flags for points that do not contain measured data (e.g. -1e9=land; 1e9=missing data), preferably with sufficiently large values for these flags so that they can be easily distinguished from regular data points. As model data is regularly gridded, making observational data available on a regular grid is a huge advantage for model-data comparisons.
- **Tools.** Observational data are most useful to many modelers as gridded data. However, grids and resolutions of both data and models differ widely, making tools for the re-gridding of datasets highly desirable. If these tools could be archived together with the data, this would facilitate the use of the data.

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