Observational needs for sea ice models
Short note

F. Massonnet*, A. Jahn†

January 10, 2012

1 Scope

This note summarizes discussions held during a 2-day meeting of the CLiC Arctic Sea Ice Working Group, in Boulder, CO (31st Oct. – 1st Nov., 2011). It does not mean to be exhaustive, but seeks to identify gaps in the observations of the Arctic sea ice cover 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.

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": the *ice age* viewed by a satellite (Fowler et al., 2004) is often defined differently to that of a model (Lietaer et al., 2011; Hunke and Bitz, 2009); in addition, the *multiyear ice coverage* 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). Even simpler, the *mean ice thickness* over a parcel is not a precisely defined quantity as long as the treatment of open water has not been specified explicitly. We believe that addressing this 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:** Two subsets of modelers 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)).

*Georges Lemaître Centre for Earth and Climate Research Earth and Life Institute, Université catholique de Louvain (Belgium), francois.massonnet@uclouvain.be

†National Center for Atmospheric Research, Boulder, Colorado (USA), ajahn@ucar.edu

They need data that they can reproduce with a forced model under particular conditions (time, location, atmospheric and/or oceanic state).

- The large-scale modelers/users usually look at the climatological behavior of sea ice. Accordingly, they evaluate long-term averages of the simulated sea ice cover, so that the natural variability of the model is not interfering with the comparison against observations. These modelers/users are therefore looking for statistics (e.g. mean September Arctic sea ice area or climatological seasonal cycle), rather than exact realizations for a particular year (Massonnet et al., 2011; Jahn et al., 2012; Kwok, 2011; Rampal et al., 2011).

In situ observations usually benefit the first class of modelers, because of their high resolution under well-known conditions; remote observations (e.g., from satellites) are the most useful to the second class of modelers because of their large spatial and 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 on global scales through the use of (radar) altimeters (e.g. ICESat (Zwally et al., 2003)) and radiometers (SMOS). 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 sea ice volume/mean thickness (e.g. Kwok and Cunningham, 2008) are extremely valuable for large-scale modelers and should be encouraged. There are no additional specific requests regarding the observations of ice thickness at smaller scales (e.g. in situ and airborne electro-magnetic induction techniques).

  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, 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 PDFs).

- **Sea ice fluxes.** Areal and volume fluxes of sea ice through a defined section are the most useful to large-scale 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 are partly based on the satellite altimetry data and are often limited in time. The May-to-September volume fluxes would be highly welcome to evaluate large-scale models, since the exports of mass during the spring and summer could potentially impact the following September 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.

- **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. XXXXXX

The other following variables are currently relatively well observed and their monitoring should be continued, in order to provide long timeseries.

- **Sea ice age** (multi year versus first year, and detailed ages), is a useful diagnostic to validate models, beside the definition issue (see General Remarks, Section 2).

- **Sea ice concentration**, which is probably the most widely used sea ice variable for model validations and which has the longest time series.

- **Melt onset and freezeup dates:** as long as the definition is consistent (e.g. distinguishing between single melt events irrespective to their duration and continuous melt events), this variable has proven useful for assessing season lengths in the models and observations Arctic sea ice cover evolution (Jahn et al., 2012; Markus et al., 2009).

- **Sea ice motion and deformation** are well observed (buoys arrays, RGPS, satellite): no additional information is currently needed since large-scale models poorly match the observed statistics of deformation and kinematics.

4 Statement of uncertainties

We advocate that any kind of observation should come with uncertainty ranges. 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. This would allow the sea-ice data to be easily and freely accessible, just like the CMIP database.

- **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.

6 Acknowledgements

We are thankful for the CLiC Arctic Sea Ice Working Group for stimulating discussions during the workshop, and to the following people that helped improve this note: M. Vancoppenolle (LOCEAN, Paris), T. Fichefet and H. Goosse (UCL, Belgium), XXXXXX

References

T. Agnew, A. Lambe, and D. Long. Estimating sea ice area flux across the Canadian Arctic Archipelago using enhanced AMSR-E. *Journal of Geophysical Research*, 113:C10011, 2008.

C. M. Bitz, M. M. Holland, A. J. Weaver, and M. Eby. Simulating the ice-thickness distribution in a coupled climate model. *Journal of Geophysical Research*, 106:2441–2463, 2001.

C. Fowler, W. Emery, and J. Maslanik. Satellite-derived evolution of Arctic sea ice age: October 1978 to march 2003. *IEEE Geosci. Remote Sens. Lett.*, 1 (2):71–74, 2004.

E. C. Hunke and C. M. Bitz. Age characteristics in a multidecadal Arctic simulation. *Journal of Geophysical Research*, 114:C08013, 2009.

A. Jahn, K. Sterling, M. M. Holland, J. E. Kay, J. Maslanik, C. M. Bitz, D. A. Bailey, J. Stroeve, E. C. Hunke, W. H. Lipscomb, and D. A. Pollak. Late 20th century simulation of Arctic sea ice and ocean properties in the CCSM4. *Journal of Climate*, in press, 2012.

V. Kattsov, V. Ryabinin, C. M. Bitz, A. Busalacchi, J. E. Overland, M. Serreze, M. Visbeck, and J. E. Walsh. Rapid loss of sea ice in the Arctic. WCRP White Paper, 2010.

N. T. Kurtz and S. L. Farrell. Large-scale surveys of snow depth on Arctic sea ice from operation IceBridge. *Geophysical Research Letters*, 38:L20505, 2011.

R. Kwok. Observational assessment of Arctic sea ice motion, export and thickness in CMIP3 climate simulations. *Journal of Geophysical Research*, 116: C00D05, 2011.

R. Kwok and G. F. Cunningham. Icesat over Arctic sea ice: Estimation of snow depth and ice thickness. *Journal of Geophysical Research*, 113:C08010, 2008.

R. Kwok, G. F. Cunningham, and S. S. Pang. Fram Strait sea ice outflow. *Journal of Geophysical Research*, 109, 2004. doi: 10.1029/2003JC001785.

O. Lecomte, T. Fichefet, M. Vancoppenolle, and M. Nicolaus. A new snow thermodynamic scheme for large-scale sea-ice models. *Annals of Glaciology*, 52(57):337–346, 2011.

O. Lietaer, E. Deleersnijder, T. Fichefet, M. Vancoppenolle, R. Comblen, S. Bouillon, and V. Legat. The vertical age profile in sea ice: Theory and numerical results. *Ocean Modelling*, 40:211–226, 2011.

T. Markus, J. Stroeve, and J. Miller. Recent changes in Arctic sea ice melt onset, freezeup, and melt season length. *Journal of Geophysical Research*, 114:C12024, 2009.

F. Massonnet, T. Fichefet, H. Goosse, M. Vancoppenolle, P. Mathiot, and C. König Beatty. On the influence of model physics on simulations of Arctic and Antarctic sea ice. *The Cryosphere*, 5(3):687–699, 2011. doi: 10.5194/tc-5-687-2011. URL `http://www.the-cryosphere.net/5/687/2011/`.

P. Rampal, J. Weiss, C. Dubois, and J.-M. Campin. Ipcc climate models do not capture Arctic sea ice drift acceleration: Consequences in terms of projected-sea ice thinning and decline. *Journal of Geophysical Research*, 116:C00D07, 2011.

M. Vancoppenolle, T. Fichefet, H. Goosse, S. Bouillon, G. Madec, and M. A. Morales Maqueda. Simulating the mass balance and salinity of Arctic and antarctic sea ice. 1. model description and validation. *Ocean Modelling*, 27: 33–53, 2009.

H. Zwally, R. Schutz, C. Bentley, J. Bufton, T. Herring, J. Minster, J. Spinhirne, and R. Thomas. Glas/icesat l2 sea ice altimetry data v018 digital media., 2003. URL `http://nsidc.org/data/gla13.html`.