CFSR 30-Year Sea Ice Concentration Climatology

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ABSTRACT

A 30 year sea ice climatology from the Climate Forecast System Reanalysis sea ice is discussed. More importantly, methods for deriving sea ice climatology from sea ice history are developed and compared. Methods commonly used for surface air temperature, for example, are not suited for sea ice and lead to substantial errors. A conditional climatology produces much more reasonable results. This approach has also already found operational use in NOAA/NWS/NCEP for Great Lakes wave modeling.

1. Introduction

The Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010) used sea ice concentration history (daily or near-daily observations of ice conditions) in its climate run. In this note, the climatology (what we may expect about sea ice) is discussed as opposed to the history. What, exactly, 'climate' means in the context of a field which is undergoing marked climate change, such as Arctic sea ice (Cavalieri et al. 1997), is a question that will not be addressed here. As climatology of ice cover, as opposed to history, is itself a relatively immature field (compared, say, to determining a climatology for 2 meter surface air temperatures), this note is also an exploration of how to construct a sea ice climatology.

The data source used is the Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010) sea ice concentrations. The data are global, on a half degree latitude-longitude grid, daily, and attempt to analyze ice for all potentially ice-covered waters, including inland bodies. For some of the additional discussion on this, see (Grumbine 2009). Ice concentrations were derived from (Cavalieri et al. 2013; Grumbine 1996, 2014, in preparation). The multiple sources, and differing data sources and algorithms within each source lead to discontinuities in the ice cover fields which become more apparent in considering integrals and climatology of the fields (see also, e.g. (Screen 2011)).

2. Climate Analysis Modes

Sea ice concentration differs from climate parameters like sea surface temperature or 2 meter air temperature in that ice may not be present at all in a location. On the other hand, when it is present, it typically, at least at continuum scale, forms a connected domain – unlike precipitation which can be extremely patchy in both space and time.

A traditional climatology, as for 2 m air temperature, simply averages all values through time for the given day (or month) at each location. This is one mode of analysis illustrated here. Sea ice concentrations, though, are highly bimodal. They are either zero or very high

(70% of the area of sea ice cover is greater than 80% concentration, half is above 90%). Therefore 15 years of ice-free conditions and 15 years of ice cover will average to 40-50% concentration in this method – values which are never seen in the area. To the extent that climate is what we (can) expect, this misleads us.

To try to address this issue, consider a 'conditional climatology'. It leads to more complexity, as now one needs two fields, at least temporarily. One field is the probability of a nonzero sea ice cover, or, more simply, the number of years in which an ice cover was observed during the period of climatology. The second field is the average concentration *for those years when there was nonzero ice cover*. The traditional climatology's concentration can be retrieved simply, by multiplying these two fields together. Or, one can declare the climatological concentration to be 0 if ice is seen in fewer than half the years, and the conditional concentration if ice is seen half or more of the time.

Results

Hemispheric or global area and extent are two common integrals used for describing sea ice cover. Area is the area of the ocean that actually has ice on it. The extent is computed by summing the area of all grid cells in the analysis which have any (over some criterion concentration, 15% here) ice cover.

The concentration histogram (figure 1) shows the most striking difference between the two approaches. This histogram is derived by examining the concentrations in each day's analysis for the 30 years of the climatology, 1981-2010. The area of each cell with a given concentration of sea ice is summed, in 1% concentration bins, and then averaged throughout the full history of observation. The resulting extent histogram is markedly between the two approaches to climatology. The history has a floor of 15% concentration, but the traditional climatology has several million km^2 ice extent below this. That arises because, for instance, 3 years of 100% cover average to 10% over 30 years. The histogram from the traditional climatology is, therefore, always far above that from the historical observations.

The conditional climatology (* in the figure) meets the observed history at the 15% floor, and has the same total extent at 100% concentration. For concentrations below about 75%, the conditional climatology has less area than the history does, while for higher concentrations (but below 100%) is lies above the observations. This arises because the concentrations from the conditional climatology are those for the points which show at least 15 years of ice cover – and those are, apparently, biased towards higher concentration. Nevertheless, even this simple approach gives a much more realistic concentration distribution for representing climatology.

Figures 2 and 3 show the global area and extent, respectively, from the two climatology approaches and the observed history between 1992-2001 (Julian days from 1 January 1981 are shown on axis). The traditional climatology provides generally ok areas, as does the conditional. The traditional shows better performancy early in the record, while the conditional is better later in the period (which is true when viewing the entire span). The time of transition is when the ice concentration algorithm changed (seen by (Screen 2011), changes documented in (Grumbine 2014, in preparation)).

For extents, on the other hand, traditional climatology is always far too extensive. The conditional climatology lies near the observed history. While areas showed important historical features in Screen (2011), it is extents which are most informative here. Both, therefore, should be attended to.

Daily figures from both climatologies, and annual animations of both the climatologies and the observed histories, are available at `http://polar.ncep.noaa.gov/seaice/climatology1/`.

Animations of annual Arctic and Antarctic sea ice concentrations from traditional climatology and from conditional using 50% cutoff are also at `http://polar.ncep.noaa.gov/seaice/climatology1/`. The latter look much more like animations of observed sea ice (e.g. `http://polar.ncep.noaa.gov/seaice/Historical.shtml`).

3. Applications

One of the motivators for developing a sea ice climatology is to have a back stop for a case in which it is not possible to construct a global sea ice concentration analysis. This is implemented in operations by program 'noice'. If there are no observations at all, we have two options. We could use the traditional climatology, or we could use the conditional climatology. The former is obvious. In the latter case, we use the concentration for when there is ice greater than some fraction of the time. If climate were invariant, 50% is the obvious choice. In the Arctic, with ice cover retreating, we might want a higher value (how high?) and in the Antarctic, with some tendency towards expansion, we might want a lower (but how low?). The conditional climatology with a 50% cutoff is implemented in program noice.

A second case is where ice concentration fields cannot be analyzed automatically, but there is an analyzed ice/no-ice mask available, as is typically the case from the IMS ice analysis (Chen et al. 2012). For this case, program imsice will use the IMS mask to determine presence of ice, and the conditional average to assign concentration.

Spinning up an ocean or climate model is a different situation where the conditional climatology may be useful. It is best, of course, to simply use the observed history of ice cover. But this may not always be available or practical. The traditional climatology creates very large extent biases, which then feed back to the atmosphere and ocean in a coupled model. On the other hand, the climate does experience ice cover at some times in that area during the spinup period. One may use (with caution) the frequency of occurrence field and conditional concentration. Each model year, take a random number 0-30, and use the conditional concentration for areas which have ice that many or more years of the 30 used in constructing this climatology. The caution is that regions within the Arctic and Antarctic often vary opposite to each other, so that a heavy ice year on the Pacific side of the Arctic is often a light ice year on the Atlantic side (Gloersen et al. 1992). When such pairs of regions are known, it would be more suitable to use 30 - N for the second region, where N is the random number generated for the first region.

Sea ice models themselves present a different need for a climatology. Namely, to evaluate the quality of the sea ice model's predictions. In meteorology, numerical weather prediction models are often evaluated against their successful prediction of deviation from climatology, for instance with the 500 hPa height field. The field itself is well-known – it is hot in the tropics and cold in the poles – which would give overwhelmingly good correlations between the model and observations even for very bad models. All they need to do is have hot tropics and cold poles. For sea ice, most of the area of the globe never has an ice cover (at any time of year, much less for a given day of the year), and a large fraction of the area that ever has ice always has ice at a given time of year. A sea ice model should not get (much, if any) credit for 'successfully' predicting that there's no ice near Hawai'i, or that there is ice in the high Arctic in late winter.

This conditional approach also lends itself to other fields, like precipitation, which are intermittent in time. The observation is that that although mean rainfall has been relatively constant, amount of rain in large events is increasing (Karl and Knight 1998). In traditional climatology, the stable mean is all that is represented. In a conditional climatology, the conditional means are rising.

4. Conclusion

The CFSR climatology discussed here is available graphically and in data files from `http://polar.ncep.noaa.gov/seaice/climatology1/`. The conditional climatology approach shows itself to be superior for climatological purposes, but the traditional is also available for users to determine how the difference affects them. In developing this climatology, some features were seen which point to better methods for constructing both sea ice history and sea ice climatology, which will be implemented and discussed in future work.

While this paper was in development, the Great Lakes wave model (Alves et al. 2014) at

NCEP encountered problems with the winter 2013-2014 ice on the Great Lakes. It had been using an ice mask from the IMS (Chen et al. 2012) analysis. But the physics of wave growth and decay include wave damping by ice concentrations. Because the IMS ice mask flags any cell that has any observable ice as being ice covered, waves were being damped excessively and fetches were too limited to produce realistic waves, which lead to inferior model guidance [Alves, 2014 personal communication]. Therefore a Great Lakes ice conditional climatology was developed using data from (Assel 2003; Wang et al. 2012) for 1976-2006 (a span with constant grid representation, and which includes years with extensive ice cover, as winter 2013-2014 did). And the Great Lakes wave model now uses this climatology and program imsice for ice concentrations. This conditional climatology is also available at the same URL.

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List of Figures

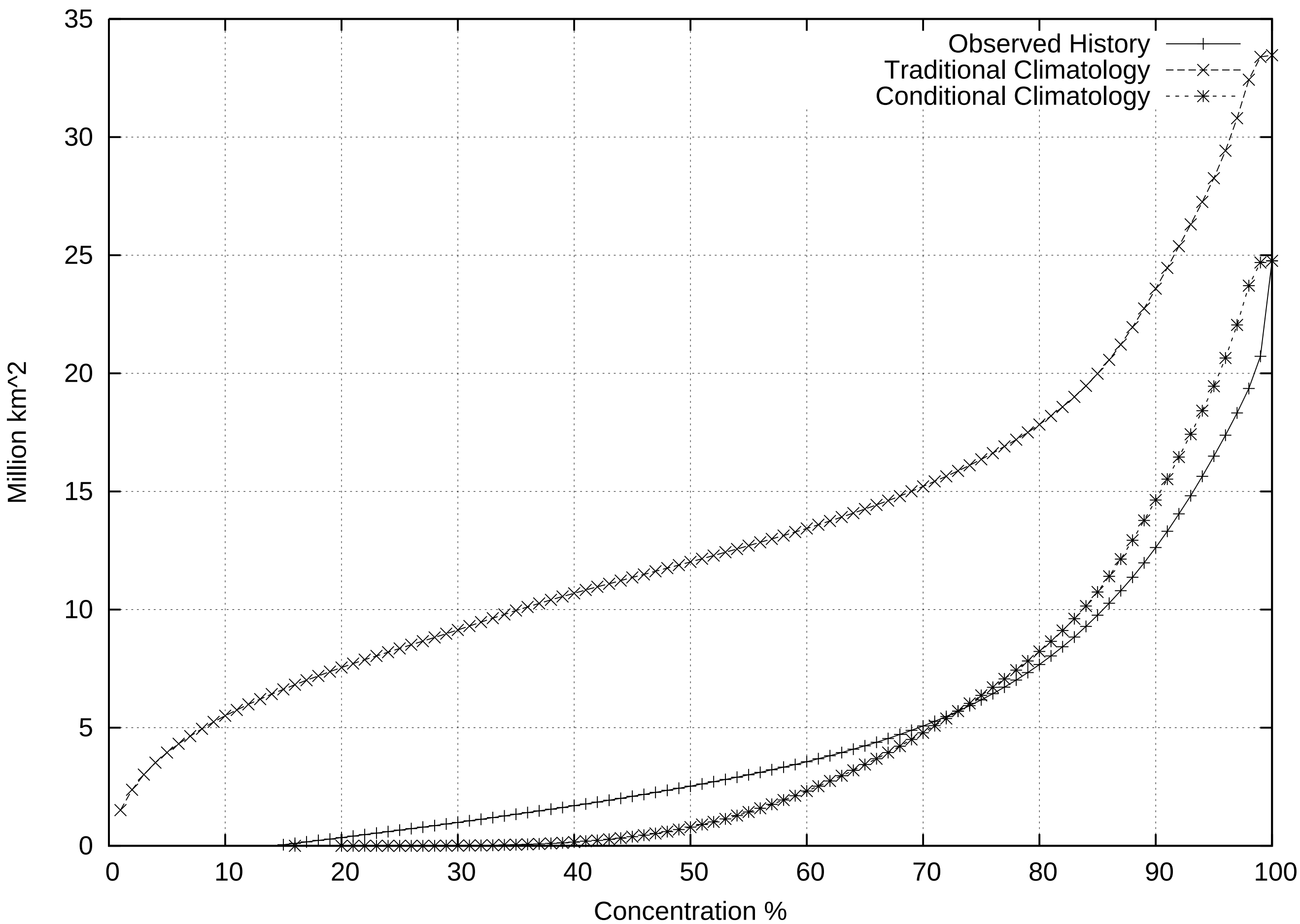

Fig. 1. Cumulative histogram of extents in each concentration bin

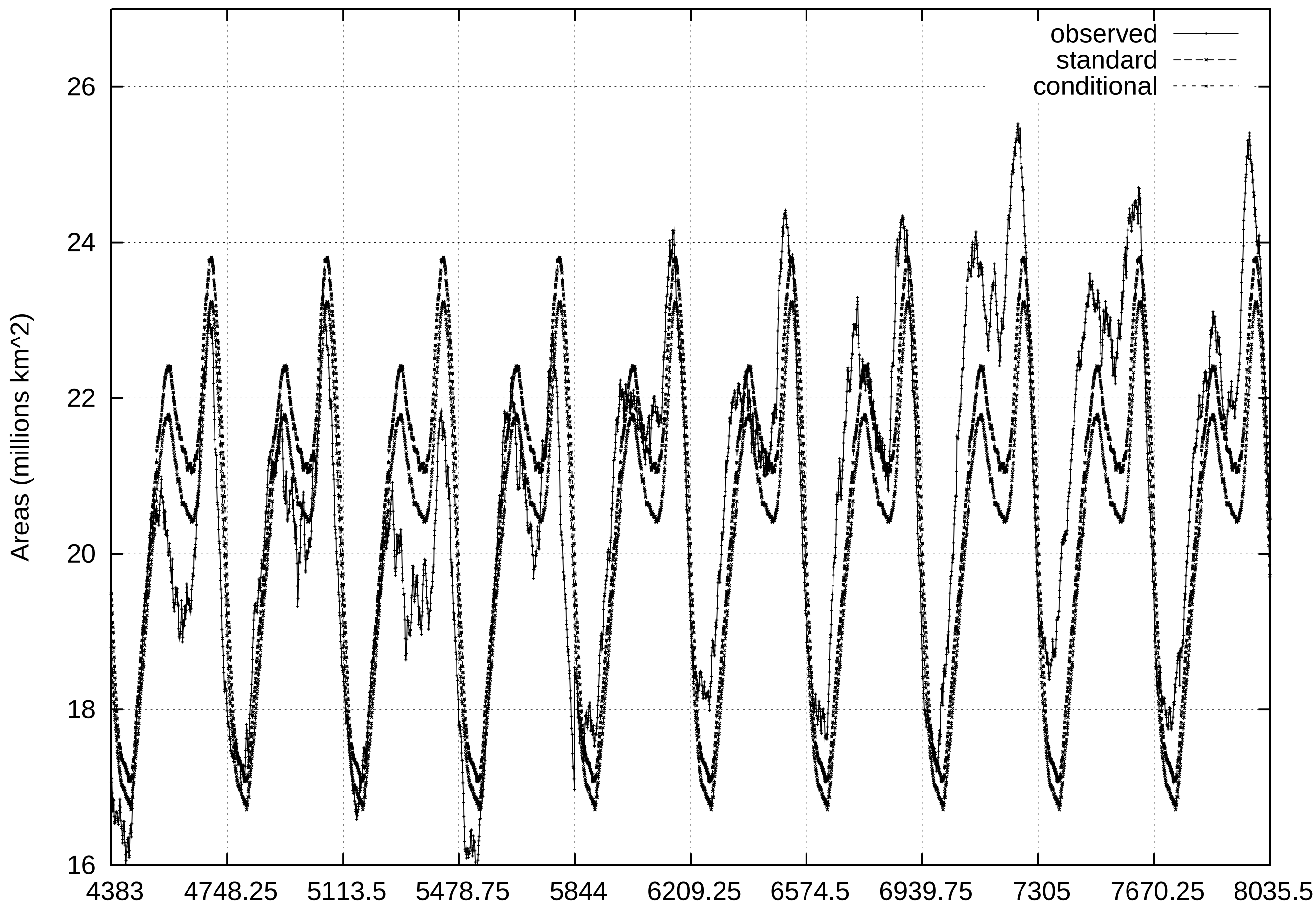

FIG. 2. Global ice area 1992-2001 observed, and from climatologies

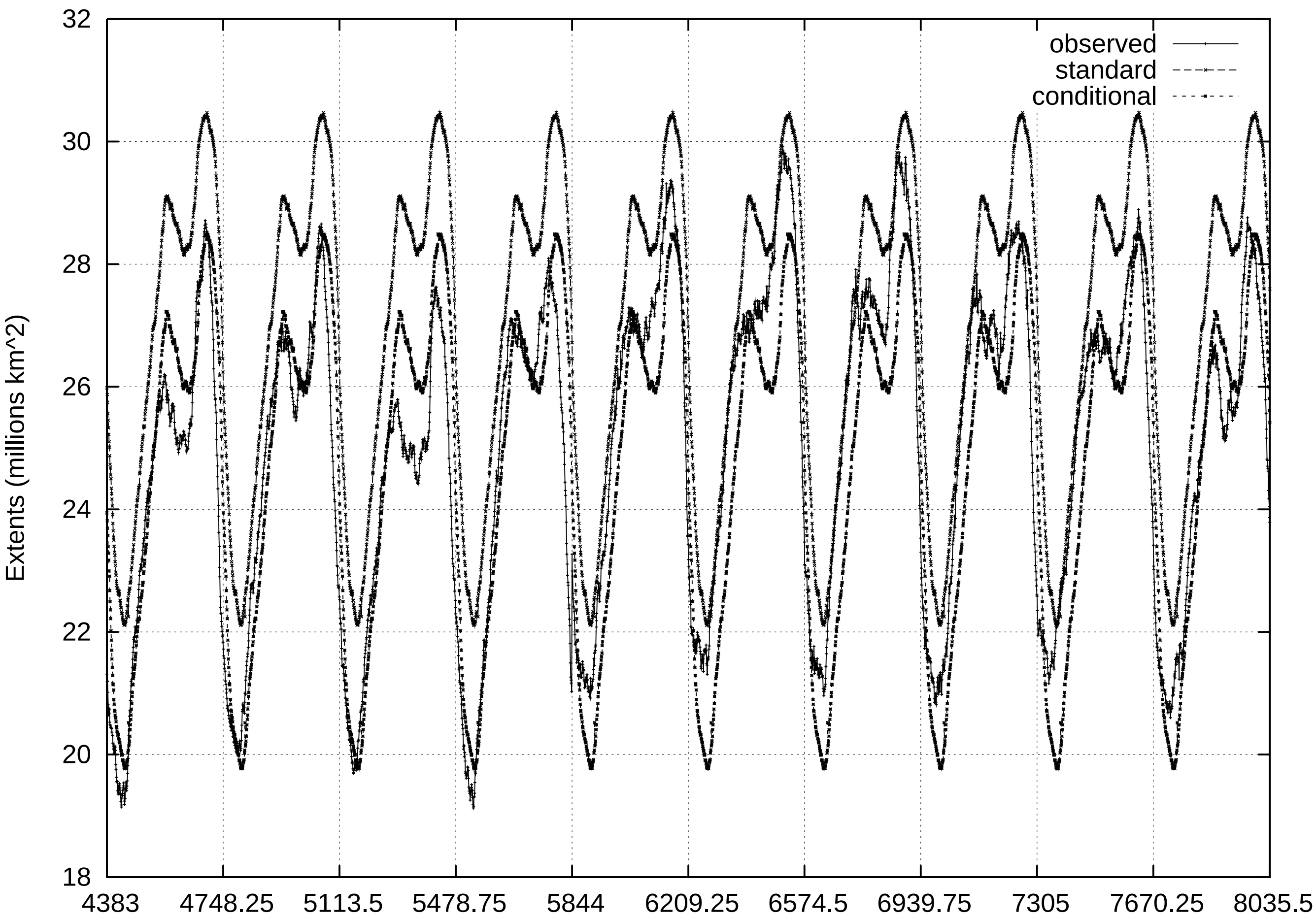

Fig. 3. Global ice extent 1992-2001 observed, and from climatologies