Summer Arctic sea ice and European winters in the pre-industrial EC-Earth control run

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Open questions and rationale

- The possible association between recent **Arctic sea ice loss** and the frequent **extreme winters at lower-latitudes** has received a lot of mediatic and scientific attention [1].
- It is still to be demonstrated whether such a link is **robust** (in terms of signal-to-noise ratio), and whether it is **causal** (the former implying the latter). Indeed, both phenomena could occur concomitantly by chance, or be responding together to a third, external driver.
- Here, we examine whether « low ice/cold mid-latitudes » relationships hold in a **pre-industrial** control run. Working under pre-industrial conditions has two advantages:
  - 450 years of simulation are available, making **statistics robust**. In comparison, the observational period for which a link is thought to exist is about 10-yr long, so that it has been difficult so far to disentangle signal and noise from each other [2].
  - In the absence of the strong externally-forced anthropogenic signal present in historical and RCP scenarios, it is possible to **investigate whether the model spontaneously produces extreme winters** in association to anomalously low sea ice areas.

Main findings

- Under pre-industrial conditions, we find no evidence for low sea ice/cold European winters association
- Wintertime near-surface temperature variability in Europe is rather associated to SST variability during preceding fall, under these experimental conditions.
- The results suggest that the possible existence between recent observed Arctic sea ice loss and colder European winters is not trivial and, if it exists, subject to a low signal-to noise ratio.

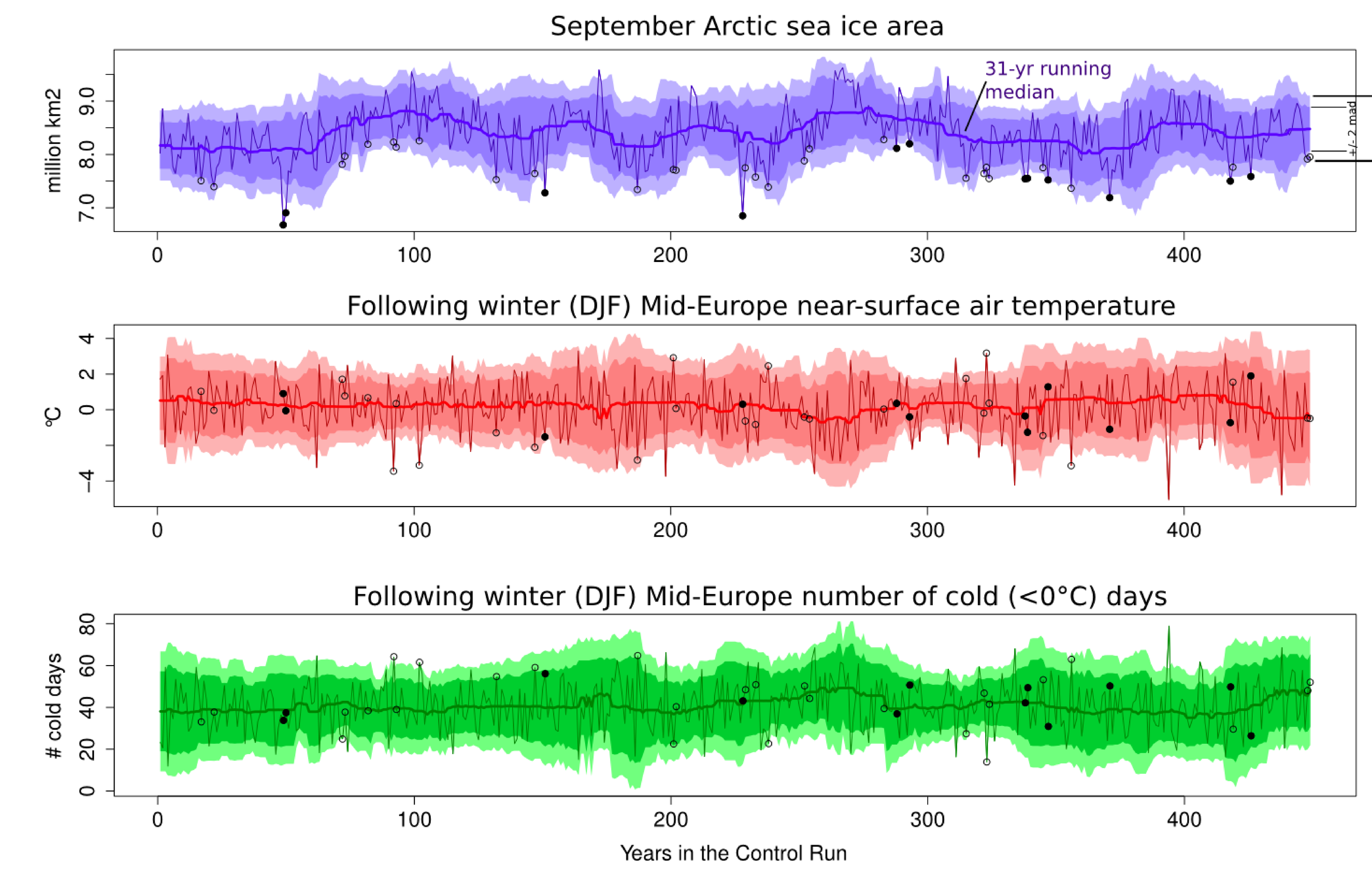


Figure 1. (Top) September Arctic sea ice area, (middle) the following DJF near-surface average temperature in the Mid-Europe sector (see inset on the right), and (bottom) the number of cold days over DJF averaged in this sector. The bold lines are the respective 31-yr running medians of the time series. Shading indicates two and three times the *median absolute deviation* (MAD, see methods). Empty and black dots coincide with years during which sea ice area drops below the median by more than 2 and 3 times the MAD, respectively.

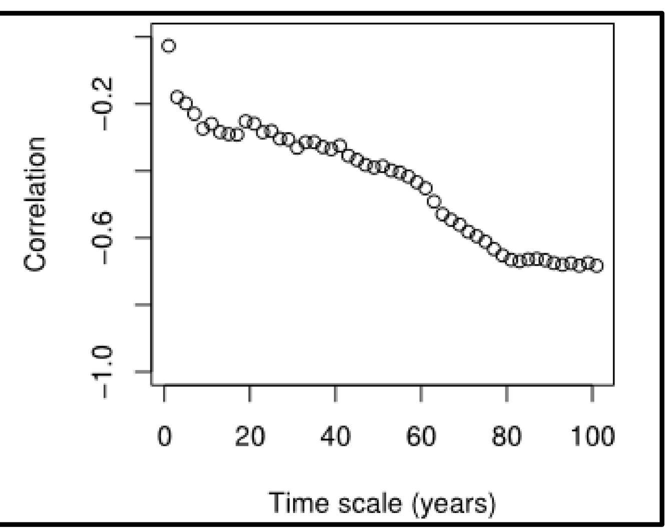
Seasonal relationships

Under pre-industrial conditions, **episodes of low sea ice area are not followed by winters with anomalously cold temperatures** in the sector of interest (Fig. 1).

More generally stated, the year-to-year fluctuations of September Arctic sea ice area are **poor predictors** for the year-to-year variations of Mid-Europe winter temperatures **under pre-industrial conditions** (Fig. 2, below). Only when longer time scales are considered does a signal emerge: lower Arctic sea ice areas are associated to *warmer* European winters. It is speculated here that, at these time scales, both Arctic sea ice and mid-Europe temperatures respond to a third driver, possibly the North Atlantic oceanic heat content.

Resorting to more adapted metrics to define winter severity and high-impact events, such as the number of cold days in a season, does not alter the conclusions (Fig. 1, bottom). Likewise, no significant relationship is found when other sectors (Barents Sea instead of Arctic, Japan/Northern-USA instead of Europe), are considered (not shown here).

Figure 2. Correlation between September Arctic sea ice area and the subsequent DJF Mid-Europe near-surface temperature, as a function of the length of the running window used to smooth both signals. The leftermost dot corresponds to no smoothing at all (raw time series), while the rightermost represents the correlation obtained when both signals are smoothed using a 101-yr window.



Interpretation

No clear connection is found between Arctic sea ice area and European cold winters in the pre-industrial EC-Earth run.

• Option 1: The model **does not include the correct processes**, or does not have a sufficient resolution (see methods) to allow for a correct representation of high- to mid-latitudes linkages.

• Option 2: The « low ice/cold mid-latitudes » linkage exists in the model, but only for a certain range of sea ice areas which are not simulated under pre-industrial conditions. This would support the idea of **nonlinear response** of the mid-latitude circulation to Arctic sea ice area variations, as identified by Petoukhov and Semenov (2009) or under climate change experiments by Yang and Christiensen (2012).

• Option 3: The linkage exists, but it is **masked by other, remote connections**. The map on the right shows that mid-european air temperatures in winter are associated to sea surface temperatures during preceding fall. Other agents, such as the high-latitude snow cover in late fall, could also be important predictors [1] to take into account

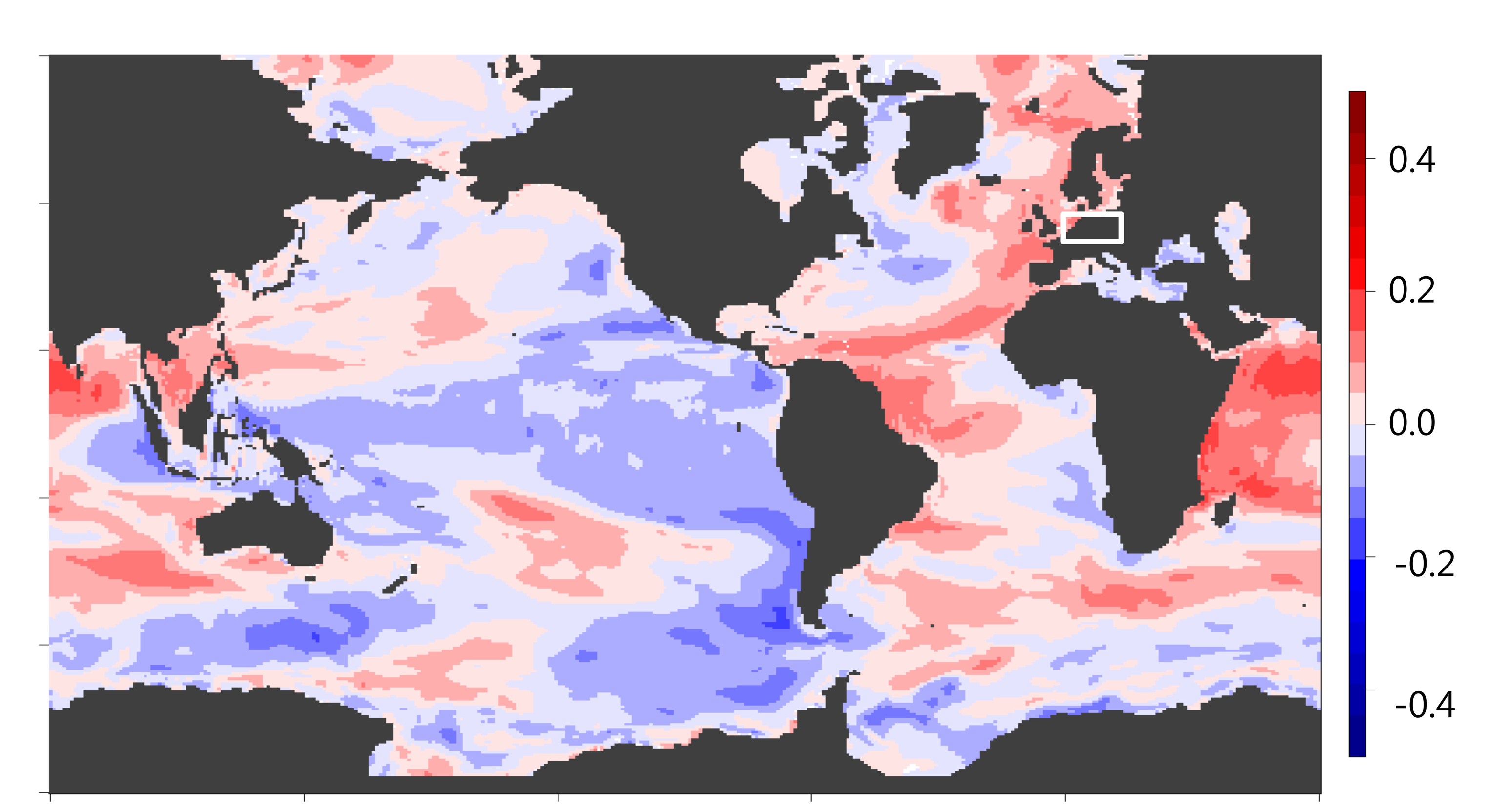


Figure 3. Correlation between Mid-Europe (box) DJF near-surface air temperature and the preceding SON sea surface temperature. Correlations are estimated on the raw time series (no smoothing applied). Correlations above 0.09 are significant following a two-tailed t-test with a p-value of 5%

Methods

1. The variables *sic* (sea ice concentration), *tos* (sea surface temperature) and *tas* (near-surface air temperature) were downloaded from the CMIP5 database, for the *piControl* simulation of EC-Earth v2.3 [4] (T159 in the atmosphere, ~1° in the ocean). Monthly output was used to compute sea ice area and and near-surface temperatures.
2. Daily output of *tas* (near-surface temperature) was used to determine the number of cold days in a season. First, the number of days with near-surface temperature less than 0°C were counted for each month and at each grid point. Then, this quantity was averaged over the regional sector of interest for each month. Finally, the December, January and February spatially-averaged numbers of cold days were added up to provide the number of cold days in the winter season.
3. The Mid-Europe sector is defined as in Christiensen and Christiensen (2007) and shown in Fig. 1. Only land-covered grid points are considered to compute the average near-surface temperature and number of cold days.
4. Extreme detection for the sea ice area time series is conducted as follows: (1) the running median of the signal is estimated as a background signal over consecutive 31-yr time windows, simultaneously with the median absolute deviation (MAD, the median of absolute difference between the time series and the median). Both estimators are robust to extremes, unlike the running mean and standard deviation. Note that the timeseries are mirrored at the edges to compute the median and the MAD over the first and last 14 data points. (2) Extremes are defined as events during which the time series drops by more than 2 or 3 times the MAD below the background signal.

Contact & references

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