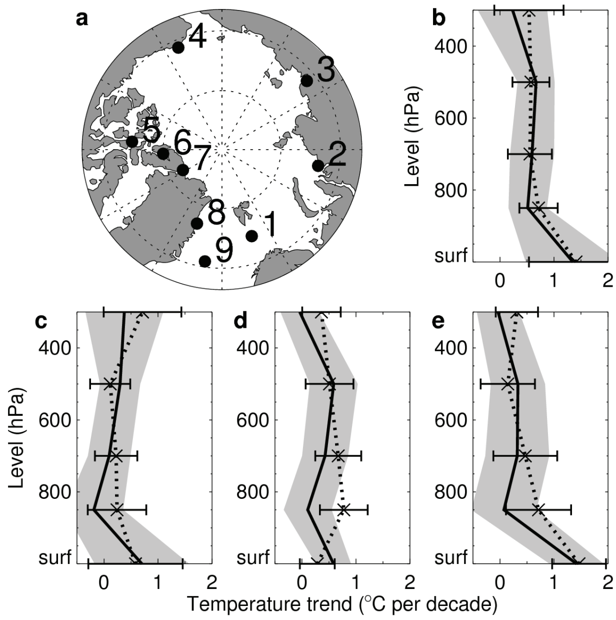
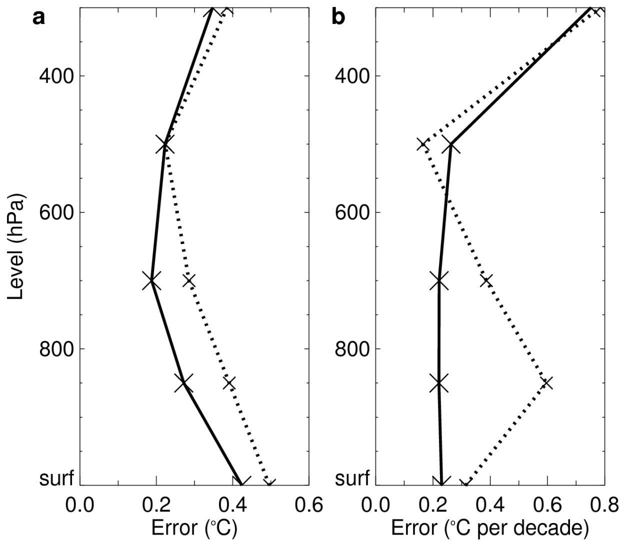
## SUPPLEMENTARY DISCUSSION

Our results and conclusions are based on the ERA-Interim reanalysis (see Dee & Uppala[1] and references therein). ERA-Interim is the latest global atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), covering the data-rich period since 1989. It succeeds the older ERA-40 reanalysis[2] which covers the period 1979-2001 and upon which Graversen *et al.*[3] draw their conclusions. The ECMWF, applying lessons learned from ERA-40 and well-documented weakness in other first- and second-generation reanalyses, have implemented a number of improvements in ERA-Interim. These include an assimilating model with higher spectral resolution (T255 from T159), improved model physics, a more sophisticated hydrological cycle, and data assimilation based on a 12-hourly four-dimensional variational analysis (4D-Var) that includes adaptive estimation of biases in satellite radiance data. Arguably, the single biggest concern of using reanalyses for climate monitoring is that changes in the observing system, combined with the presence of biases in models and observations, can cause shifts and trends in reanalyses that interfere with the true climate signal[4]. ERA-Interim is the first reanalysis to include an assimilation scheme that adjusts for biases that change in time, for instance due to changes in the observing network or the decay and drift of satellite orbits.

The ERA-Interim reanalysis only became available to the scientific community in 2009. Consequently, the validation and evaluation of the output is in its early stages, which imposes some uncertainty in our results. The only previous assessment of ERA-Interim performance in the Arctic found that the vertical temperature profile north of 70ºN shows improved fit to radiosonde temperatures in comparison to ERA-40[1]. In order to further evaluate the performance of ERA-Interim in the Arctic region, and to reduce the uncertainties in our conclusions, we have compared the reanalysis data with observations. We have used monthly radiosonde temperature anomalies from the United Kingdom Meteorological Office (UKMO) Hadley Centre atmospheric temperature analysis (HadAT)[5]. Since HadAT contains no surface data, we have used surface temperature observations from the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies surface temperature analysis (GISTEMP)[6]. Data were extracted for all meteorological stations north of 70ºN which had near-complete records (at least 90% coverage over the period 1989-2008). Missing data were not interpolated. The selected stations provide reasonable circumpolar coverage in the latitudes 70-80ºN (locations in Supplementary Fig. 1a). Few stations exist north of 80ºN. We first calculated seasonal means (no missing months allowed) and then averaged over all the circumpolar stations. Linear trends and their uncertainties were calculated as a function of season and height. The same procedure was applied to the ERA-Interim temperature fields after sub-sampling at the locations, levels and times of available observations. The vertical structures of temperature trends in ERA-Interim and observations are in close agreement (Supplementary Fig. 1). In all seasons except summer, both observations and ERA-Interim display strongest warming at the surface, consistent with the results in the main material. In contrast, significant discrepancies have been identified between the vertical profiles of Arctic temperature trends in ERA-40 and radiosondes[7,8]. There are quantitative differences between the trends in ERA-Interim and observations, particularly at the 850hPa level during summer and autumn (Supplementary Fig. 1). However, the magnitudes of the trends in the reanalysis and in the observations are not significantly different when their uncertainties are taken into account. Furthermore, our conclusions are based on the qualitative vertical structure of the temperature trends and not on absolute magnitudes.




**Supplementary Figure 1 | Comparison of the vertical structures of temperature trends in ERA-Interim and observations, 1989-2008.** Trends are averaged from meteorological stations north of 70ºN (locations in **a**) for winter (December-February; **b**), spring (March-May; **c**), summer (June-August; **d**) and autumn (September-November; **e**). In **b** to **e**, solid lines show trends from observations whereas the dotted lines show trends from ERA-Interim sub-sampled at the locations and times of available observations. Also shown are the 95% confidence intervals (grey bands for observations and error bars for ERA-Interim). In **a**, the Arctic stations are: 1. Bjornoya, 2. Ostrov Dikson, 3. Tiksi, 4. Barrow, 5. Resolute, 6. Eureka, 7. Alert, 8. Danmarkshavn, 9. Jan Mayen.




**Supplementary Figure 2 | Comparison of the mean errors in ERA-Interim and ERA-40 relative to observations, 1989-2001.** (**a**) the root-mean-square error of seasonal temperature anomalies as a function of height calculated from observations minus reanalyses. The solid line is for ERA-Interim and the dotted line for ERA-40. (**b**) as in **a** but for the seasonal temperature trends.

To further test our hypothesis that ERA-Interim offers a more realistic depiction of Arctic temperature trends than ERA-40, we have compared the two reanalyses with observations during the period of overlap, 1989-2001. Using the same set of observations and sub-sampled ERA-Interim fields discussed above, plus sub-sampled ERA-40 fields, we subtracted the seasonal mean temperature anomalies (relative to the 1989-2001 mean) in the two reanalyses from the corresponding anomalies in the observations. The root-mean-square error (RMSE) of these seasonal temperature anomalies is shown as a function of height in Supplementary Figure 2a. At all levels, the ERA-Interim temperature anomalies are considerably closer to observations than are the ERA-40 anomalies. The improved accuracy in ERA-Interim compared to ERA-40 is most pronounced in the mid- to lower-troposphere. A similar pattern is revealed with respect to the seasonal temperature trends (Supplementary Fig. 2b). The mid- to lower-tropospheric trends in ERA-Interim are more realistic than those depicted in ERA-40. It is at these levels that ERA-40 displays amplified warming[3] that is not apparent in ERA-Interim or in the radiosonde data (over the 1989-2008 or 1979-2001[8] periods).

An additional aspect of ERA-Interim performance we have tested is its representation of Arctic cloud cover trends. We have compared the trends in ERA-Interim with those in the International Satellite Cloud Climatology Project (ISCCP) D2 data set[9]. Both the satellite product and ERA-Interim show significant decreases in spring cloud cover over the 1989-2008 period (Supplementary Table 1). We note that conflicting spring trends have been found over different time periods[10] suggesting substantial decadal-scale variability in Arctic cloud cover. The direction of the winter and summer trends (downward and upward, respectively) are also in agreement between ISCCP and ERA-Interim. The autumn trends differ in sign but are both small and not statistically different from zero. Thus, ERA-Interim faithfully represents the cloud trends shown by satellites, at least in respect to total cloud cover and over this period.

| | DJF | MAM | JJA | SON |
|---|---|---|---|---|
| ERA-Int | -0.75 +/- 1.94 | -2.44 +/- 0.63 | 0.89 +/- 0.96 | 0.26 +/- 0.56 |
| ISCCP | -1.16 +/- 1.03 | -2.04 +/- 1.24 | 0.55 +/- 1.60 | -0.18 +/- 0.84 |

**Supplementary Table 1 | Comparison of Arctic cloud cover trends from ERA-Interim and satellites, 1989-2008.** Area-weighted Arctic-mean total cloud cover trends (% per decade) and their 95% confidence limits for the four seasons.

In summary, ERA-Interim and ERA-40 depict differing vertical profiles of Arctic temperature trends. Based on the discussions above we find that ERA-Interim temperature trends are more reliable than those in ERA-40. ERA-Interim and radiosondes are in agreement in showing strongest Arctic warming at the surface. Additionally, differences in the magnitudes and structures of temperature trends between ERA-40 and ERA-Interim may arise because the two reanalyses cover non-identical time periods. Given that we find strong associations between near-surface warming and the loss of sea ice cover, and that sea ice retreat has accelerated in the past decade relative to the preceding two decades, it follows that the near-surface Arctic warming signal is more pronounced over the 1989-2008 period than over the 1979-2001 period. The improved representation of Arctic temperature trends in ERA-Interim, combined with the emergence (or strengthening) of surface-based temperature amplification in the past decade[11], help reconcile the differences between our results and those of Graversen *et al.*[3].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