Arctic influence on subseasonal mid-latitude prediction

Thomas Jung[1], Marta Anna Kasper[1], Tido Semmler[1], and Soumia Serrar[1]

Corresponding author: Thomas Jung, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bussestr. 24, D-27570 Bremerhaven, Germany. (Thomas.Jung@awi.de)

[1]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany.

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Forecast experiments with the ECMWF model with and without relaxation of the Arctic troposphere towards reanalysis data are carried out in order to explore the influence that improved Arctic forecasts during wintertime would have on the skill of medium-range and extended range prediction of 500 hPa geopotential height in the Northern Hemisphere mid-latitudes. It turns out that the largest mid-latitude improvements are found over eastern Europe, northern Asia and North America; no discernible impact is found over the North Atlantic and North Pacific, where mid-latitude and tropical dynamics appear to be more important. The strength of the linkage between the Arctic and the mid-latitudes is found to be flow-dependent, with anomalous northerly wind leading to a stronger Arctic influence. Finally, the results are discussed in the context of the possible impact of Arctic sea ice decline on mid-latitude weather and climate.

1. Introduction

Due to harsh conditions, taking in situ observations in the polar regions is a challenging and resource intensive task. Satellite remote sensing techniques also have their limitations for the lower atmosphere when ice or snow is present at the surface. The sparse observational data base contributes to relatively large analysis uncertainty [*Jung and Leutbecher*, 2007] and the fact that our understanding of polar key-processes — and therefore their representation in models — is still limited [e.g. *Sandu et al.*, 2013], especially when compared to the situation in lower latitudes.

The opportunities and risks associated with recent Arctic climate change [*Emmerson and Lahn*, 2012] will require advanced environmental predictive information for reliable decision making. In fact, international activities such as the Polar Prediction Project of WMO's World Weather Research Programme are underway to advance environmental prediction capabilities in polar regions (see *http://polarprediction.net*).

The aim of this study is to answer the question whether improved Arctic predictions would lead to more skilful medium-range and extended-range forecasts in the Northern Hemisphere mid-latitudes as well. To this end a series of forecast experiments with the ECMWF model is carried out with and without relaxation of the Arctic atmosphere towards reanalysis data during the course of the integration. By relaxing the Arctic atmosphere towards reanalysis data, forecast error in the Arctic can artificially be reduced and the influence on mid-latitude forecast skill investigated.

The relaxation approach has been sucessfully used in previous studies to explore remote origins of Northern Hemisphere forecast error [*Ferranti et al.*, 1990; *Jung et al.*, 2010a] and circulation anomalies [*Douville*, 2009; *Jung et al.*, 2010b].

2. Methods

The numerical experiments described in this study were carried out with a cycle 36r3 of the European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric model at a horizontal resolution of T_L159 ($\approx$ 120 km) with 60 levels in the vertical. Initial conditions were taken from the ERA-40 reanalysis and observed daily sea surface temperature and sea ice fields were prescribed as lower boundary conditions.

In one set of experiments regular 30-day forecasts with the model were carried out (control integration); in the other set the model was relaxed towards 6-hourly ERA-40 reanalysis data in the Arctic troposphere (north of 70^o and below 300 hPa) during the course of the forecast while leaving the model unchanged elsewhere. The relaxation approach is implemented by adding an extra term to the model:

$$\frac{d\mathbf{x}}{dt} = F(\mathbf{x}) - \alpha(\mathbf{x} - \mathbf{x}^{ana}), \tag{1}$$

where $\mathbf{x}$ denotes the model state, $\mathbf{x}^{ana}$ represents reanalysis data and $\alpha = \alpha(\phi, \lambda, z)$ is a relaxation parameter that determines the strength and domain of the relaxation. Here a value of $\alpha = 0.1$ is used which implies that at each time step (1 hour) the model tendencies is modified using 10% of the difference between the current model state and the corresponding values from the reanalysis. Relaxation is carried out in gridpoint space for the wind components, temperature and the logarithm of surface pressure. In order to reduce adverse effect close to the relaxation boundaries a smoothing is carried out in the vertical (≈ 100 hPa) and horizontal (≈ 5 degrees latitude). Further details of the relaxation formulation used are given elsewhere [*Jung et al.*, 2010a, b]. An assessment of this approach is provided by *Jung* [2011] and *Hoskins et al.* [2012].

For each of the experiments a total of eighty-eight 30-day forecasts were conducted. Forecasts were started on the 15^{th} of each of the months November through February for each of the winters from 1980/81 to 2000/01.

3. Results

The influence of Arctic relaxation on Northern Hemisphere forecast skill during winter can be inferred from Figure 1a–c, which shows the relative reduction (in %) of the root mean square (RMS) error of 500 hPa geopotential height forecasts (Z500) when the Arctic atmosphere is relaxed towards reanalysis data. Not surprisingly, the largest RMS error reduction of about 70–90% is found in the central Arctic, where the model is relaxed.

There are also regions in the mid-latitudes where Arctic relaxation leads to a reduction of Z500 forecast error, namely northern North America, eastern Europe and especially northern Asia. Hardly any reduction is found over the North Atlantic and North Pacific. There is a tendency for the impact to spread southward during the first ten days or so of the forecast; in general, however, the pattern is remarkably consistent throughout the whole 30-day period considered here.

The lack of impact in the North Atlantic region is interesting given that the Arctic Oscillation/North Atlantic Oscillation (AO/NAO) is known to extent well into the high-latitude Arctic [*Hurrell*, 1995; *Thompson and Wallace*, 1998]. Our results suggest that the high-latitudes play a minor role in terms of the dynamics of the AO/NAO, at least on the time scales considered here. Similar arguments hold for the North Pacific region.

In order to put the mid-latitude response into perspective, relaxation experiments for the Arctic were compared with those for the tropics (Figure 1d). A more comprehensive discussion of tropical relaxation is given by [*Jung et al.*, 2010a]. The results clearly indicate that the Arctic has a larger influence on the atmosphere than the tropics over eastern Europe and northern Asia, at least during the first 30 days of the forecast. The same is true for the northeastern part of Canada. On the other hand, the tropical influence dominates over the North Atlantic and the North Pacific. In summary, our results suggest that there are regions in the Northern Hemisphere mid-latitudes, especially over the continents, where the Arctic atmosphere has a role to play in medium-range and extended-range prediction.

A more detailed picture of the influence of Arctic relaxation on forecast skill for different regions in the Northern Hemisphere mid-latitudes can be obtained from Figure 2. For all regions considered RMS error of Z500 forecasts without relaxation increases with lead time. The fact the RMS errors in northern Asia are lower than those other regions simply reflects that Z500 variability is relatively low; in terms of RMS error growth northern Asia behaves similar to the other regions. In the Northern Hemisphere mid-latitudes as a whole the influence of Arctic relaxation is comparable to that in the tropics (Figure 2a). However, the influence of the Arctic over Europe and northern Asia is substantially reduced if the relaxation is restricted to latitudes north of 80^oN suggesting that subpolar processes are key. For northern North America a larger influence of the high north can be found.

So far, the average impact of Arctic relaxation has been considered. It seems plausible, however, to assume that the Arctic influence on the mid-latitudes varies for different flow types [e.g., *Ferranti et al.*, 2002]. In fact, Figure 3 shows that the influence of Arctic relaxation on northern Asia in medium-range and extended-range forecasts increases, if anomalously northerly flow prevails in the region. This anomalous flow configuration provides a more direct link to the Arctic and reduces the upstream influence which is more strongly influenced by middle and lower latitude dynamics. Similar anomalous local circulation anomalies are also found for eastern Europe and northern North America (not shown).

4. Discussion

The relaxation experiments described in this study provide some guidance for future forecasting system development. It could be argued, for example, that an improved Arctic observing system and enhanced representation of high-latitude processes in models will lead to more skilful forecasts for northern parts of Europe, Asia and North America.

In contrast, the relatively weak link found over the North Pacific and North Atlantic ocean suggests that Arctic processes play a relatively minor role when it comes to medium-range and extended-range atmospheric predictions in the North Pacific and North Atlantic region. This seems quite reasonable, given that atmospheric variability in the North Atlantic and North Pacific is strongly driven by mid-latitude dynamics involving the storm tracks. It should also be noted, that 500 hPa geopotential height used in this study reflects relatively large-scale atmospheric motion; therefore the influence of the Arctic on the prediction of meso-scale features such as polar lows could be different.

It could be argued that the ERA-40 reanalysis fields in the Arctic used for relaxation suffer from relatively poor observational coverage. While uncertainties in polar regions are generally higher than those in the mid-latitude Northern Hemisphere oceans, *Jung and Leutbecher* [2007] show that individual synoptic systems are well enough constrained by the available observations to justify the use of ERA-40 as a proxy for the true atmospheric circulation.

The rapid Arctic climate change in recent years along with an increased frequency of occurrence of extreme heat waves and cold snaps in the Northern Hemisphere mid-latitudes has sparked considerable interest into the question as to whether the Arctic influences non-polar weather and climate [e.g. *Francis and Vavrus*, 2012; *Yang and Christensen*, 2012; *Semmler et al.*, 2012]. We would argue that this study sheds some light on the main atmospheric pathways that link the Arctic with the mid-latitudes, at least when it comes to relatively fast (hourly to weekly) atmospheric dynamics. These pathways are most strongly developed over North America, eastern Europe and especially northern Asia. Our results, therefore, provide indirect support for the existence of a link between sea ice reduction in the Arctic and anomalous anti-cyclonic circulation over eastern European and Russia [e.g. *Semmler et al.*, 2012; *Yang and Christensen*, 2012].

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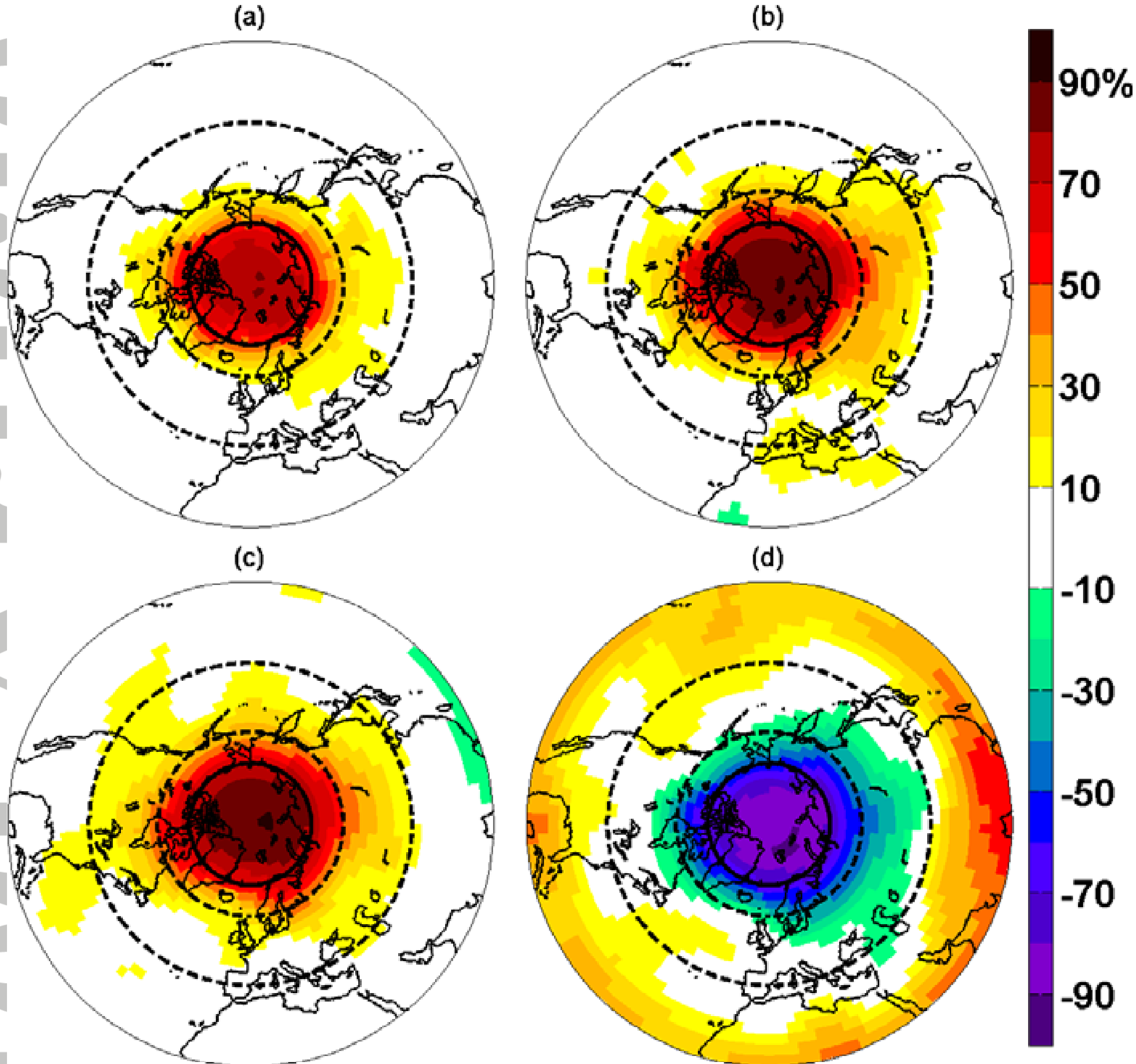

Figure 1. (a)–(c): Relative reduction (in %) of the root mean square error of 500 hPa geopotential height forcasts during wintertime through Arctic relaxation (north of 70^{o}N, solid circle) for (a) day 1–5, (b) day 6–10, and (c) day 11–30 forecasts. (d) Difference in the relative reduction of forecast error for day 11–30 between experiments with tropical and Arctic relaxation. Negative values in (d) indicate that Arctic relaxation is more efficient than tropical relaxation in reducing Z500 forecast error. The dashed circles indicate the mid-latitudes as defined in this study

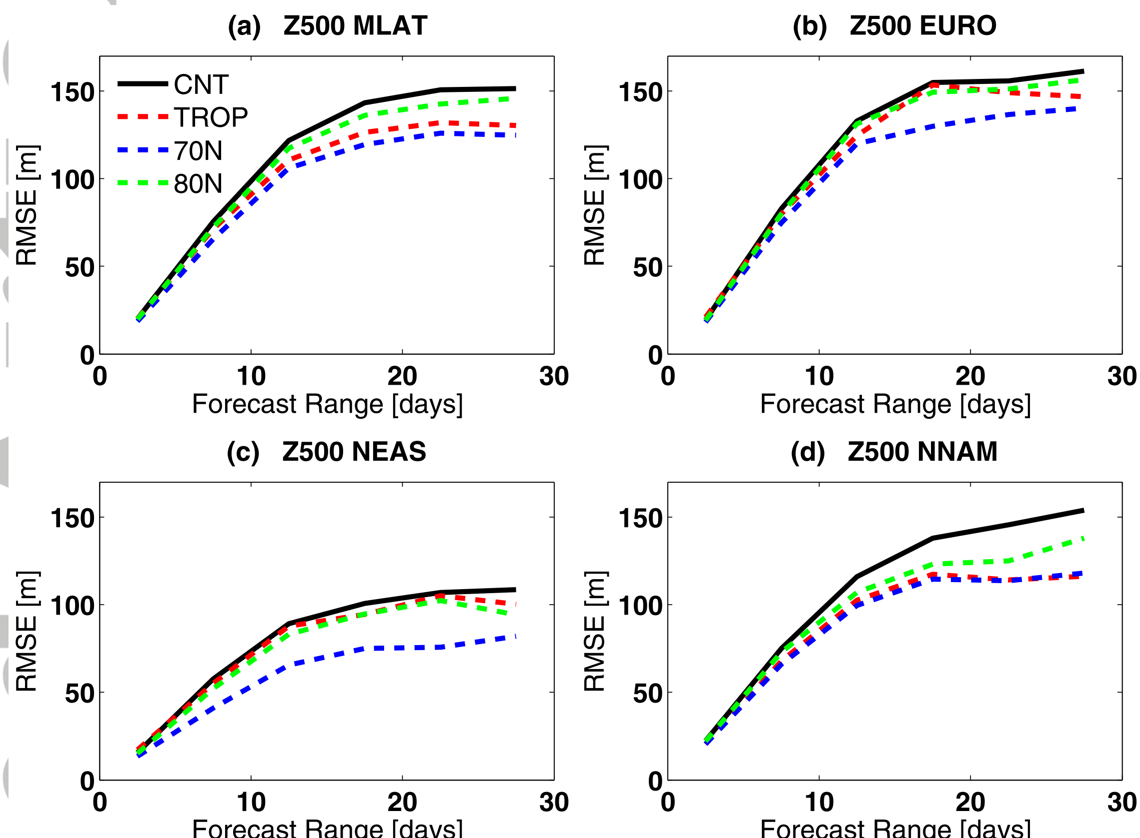

Figure 2. Root mean square error of 500 hPa geopotential height forecasts during wintertime for (a) the Northern Hemisphere mid-latitudes (40^o–60^oN), (b) Europe (40^o–60^oN, 20^oW–40^oE), (c) northern Asia (40^o–60^oN, 60^o–120^oE), and (d) North America (40^o–60^oN, 70^o–130^oW). Results are shown for the control forecast (black) and experiments with relaxation in the Arctic north of 70^oN (blue) and north of 80^oN (green) as well as with relxation of the tropical belt from 20^oS to 20^oN (red).

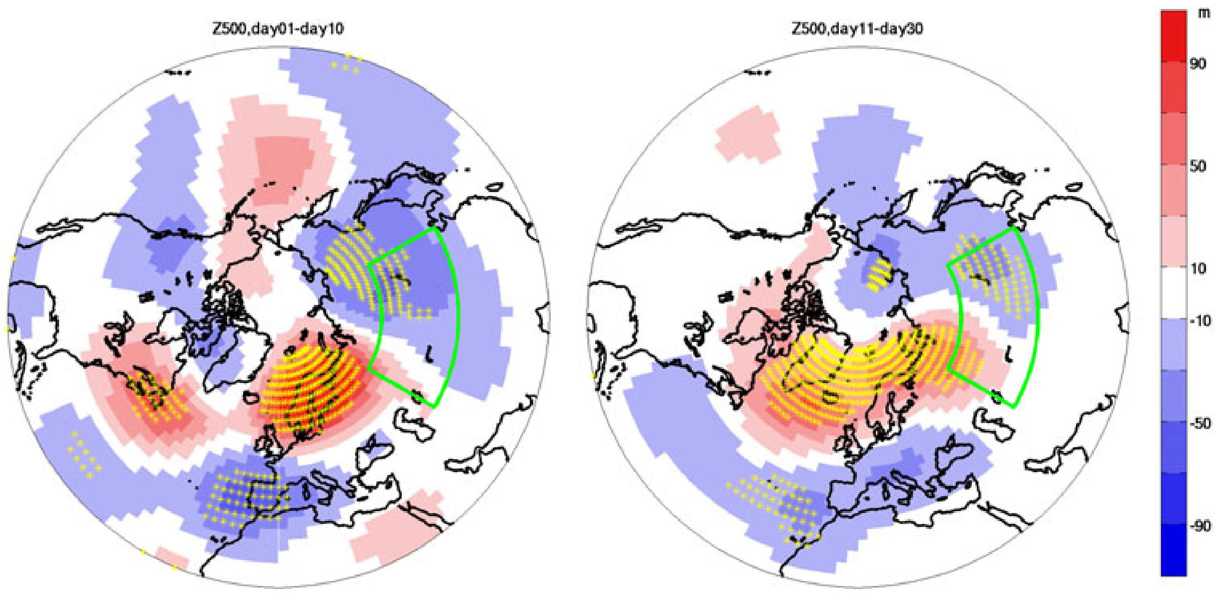

Figure 3. Mean geopotential height anomalies at the 500 hPa level (m) for periods during which Arctic relaxation is particularly efficient in reducing root mean square forecast error of 500 hPa geopotential height forecasts over Asia (indicated by the green box) for (left) day 1–10 and (right) day 11–30 forecasts. Arctic relaxation is defined as being particularly efficient in reducing forwcast error when the anomalous RMS error is lower than -1 standard deviation of its long-term mean value. Differences statistically significant at the 95% confidence level using a Wilcoxon rank-sum test are indicated by yellow asterisks.