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Enhanced extended-range predictability of the 2018 late-winter Eurasian cold spell due to the stratosphere

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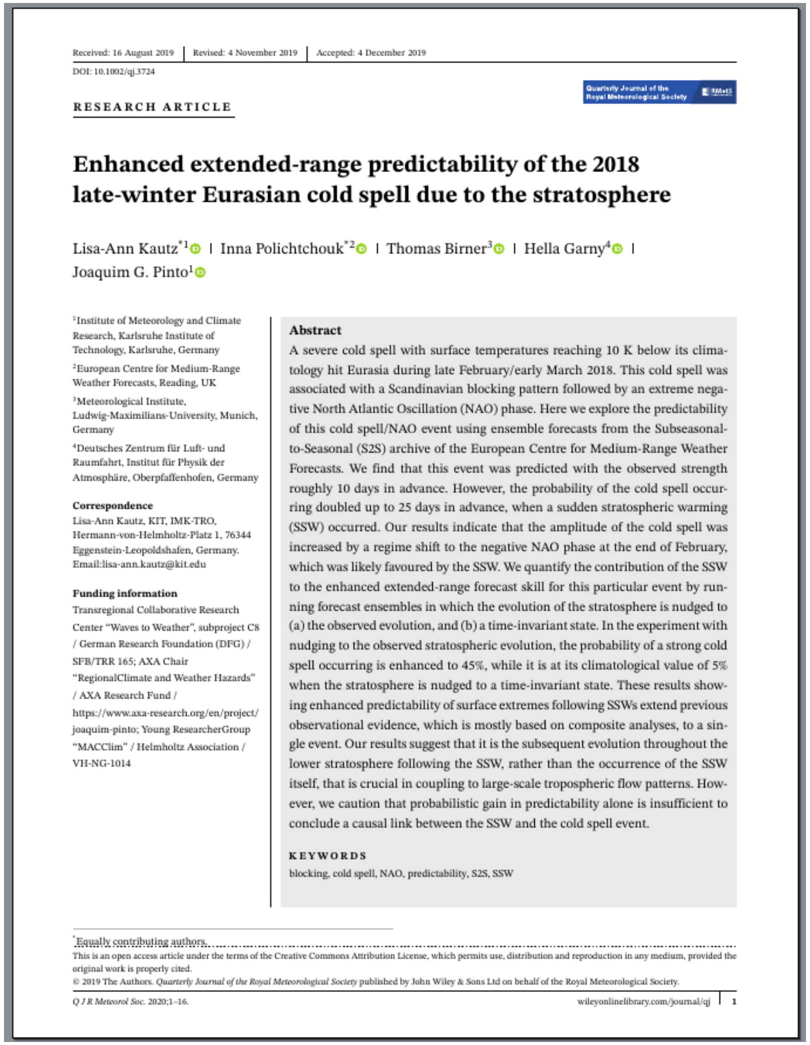
Abstract

A severe cold spell with surface temperatures reaching 10 K below its climatology hit Eurasia during late February/early March 2018. This cold spell was associated with a Scandinavian blocking pattern followed by an extreme negative North Atlantic Oscillation (NAO) phase. Here we explore the predictability of this cold spell/NAO event using ensemble forecasts from the Subseasonal-to-Seasonal (S2S) archive of the European Centre for Medium-Range Weather Forecasts. We find that this event was predicted with the observed strength roughly 10 days in advance. However, the probability of the cold spell occurring doubled up to 25 days in advance, when a sudden stratospheric warming (SSW) occurred. Our results indicate that the amplitude of the cold spell was increased by a regime shift to the negative NAO phase at the end of February, which was likely favoured by the SSW. We quantify the contribution of the SSW to the enhanced extended-range forecast skill for this particular event by running forecast ensembles in which the evolution of the stratosphere is nudged to (a) the observed evolution, and (b) a time-invariant state. In the experiment with nudging to the observed stratospheric evolution, the probability of a strong cold spell occurring is enhanced to 45%, while it is at its climatological value of 5% when the stratosphere is nudged to a time-invariant state. These results showing enhanced predictability of surface extremes following SSWs extend previous observational evidence, which is mostly based on composite analyses, to a single event. Our results suggest that it is the subsequent evolution throughout the lower stratosphere following the SSW, rather than the occurrence of the SSW itself, that is crucial in coupling to large-scale tropospheric flow patterns. However, we caution that probabilistic gain in predictability alone is insufficient to conclude a causal link between the SSW and the cold spell event.

Results have been already published...



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RESEARCH ARTICLE

Enhanced extended-range predictability of the 2018 late-winter Eurasian cold spell due to the stratosphere

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Abstract
A severe cold spell with surface temperatures reaching 10 K below its climatology hit Eurasia during late February/early March 2018. This cold spell was associated with a Scandinavian blocking pattern followed by an extreme negative North Atlantic Oscillation (NAO) phase. Here we explore the predictability of this cold spell/NAO event using ensemble forecasts from the Subseasonal-to-Seasonal (S2S) archive of the European Centre for Medium-Range Weather Forecasts. We find that this event was predicted with the observed strength roughly 10 days in advance. However, the probability of the cold spell occurring doubled up to 25 days in advance, when a sudden stratospheric warming (SSW) occurred. Our results indicate that the amplitude of the cold spell was increased by a regime shift to the negative NAO phase at the end of February, which was likely favoured by the SSW. We quantify the contribution of the SSW to the enhanced extended-range forecast skill for this particular event by running forecast ensembles in which the evolution of the stratosphere is nudged to (a) the observed evolution, and (b) a time-invariant state. In the experiment with nudging to the observed stratospheric evolution, the probability of a strong cold spell occurring is enhanced to 45%, while it is at its climatological value of 5% when the stratosphere is nudged to a time-invariant state. These results showing enhanced predictability of surface extremes following SSWs extend previous observational evidence, which is mostly based on composite analyses, to a single event. Our results suggest that it is the subsequent evolution throughout the lower stratosphere following the SSW, rather than the occurrence of the SSW itself, that is crucial in coupling to large-scale tropospheric flow patterns. However, we caution that probabilistic gain in predictability alone is insufficient to conclude a causal link between the SSW and the cold spell event.

KEYWORDS
blocking, cold spell, NAO, predictability, S2S, SSW

*Equally contributing authors.

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Introduction

- Observational evidence that the stratospheric extremes may impact the tropospheric circulation and surface extremes (e.g. Baldwin and Dunkerton 2001) → the occurrence of SSWs favors NAO- often associated with Eurasian cold spells
- Stratosphere is important source of enhanced probabilistic predictability → for subseasonal-to-seasonal predictions of NAO (e.g. Sigmond et al. 2013)
- Feb/Mar 2018:
  - Stratospheric state: major **SSW** (central date: 12 Feb)
  - Large-scale flow: **Scandinavian blocking, NAO-**
  - Strong **cold spell** over northern Eurasia
- Research questions:
  - **Did the cold spell in northern Eurasia develop independently from the NAO- phase?**
  - **What role did the stratosphere play in triggering the NAO event?**

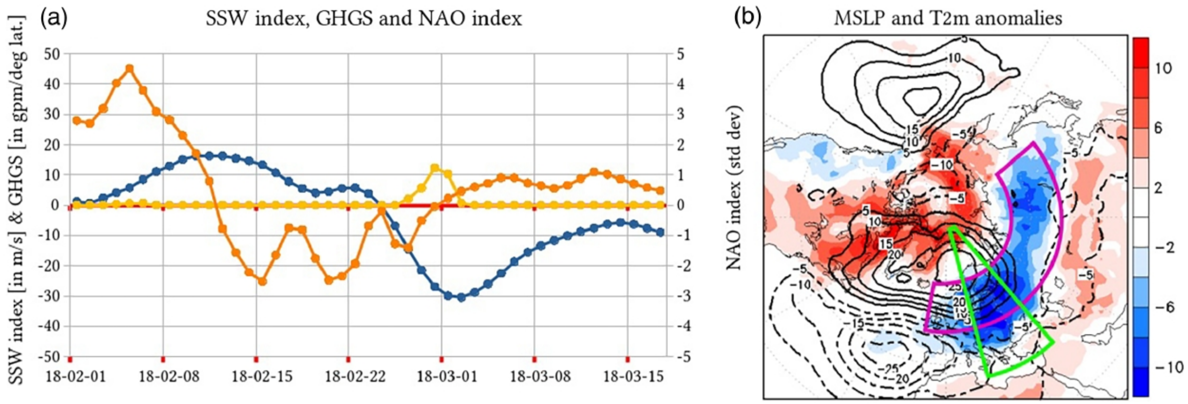

Figure 1. (a) Time series of the SSW index (in m·s^{-1}, orange line), mean blocking strength (GHGS) between 15°E and 40°E [in gpm (°latitude)$^{-1}$, yellow line] and NAO index (in standard deviation, blue line) from ERA-Interim from February 1 to March 17, 2018. (b) Mean sea level pressure (MSLP, in hPa, contours) and 2-m temperature (T2m, in K, shading) anomalies averaged over a time period from February 25 to March 6. The magenta box in (b) marks the area that was used to calculate the T2m anomaly over Eurasia, and the green box indicates the area used to calculate the Scandinavian blocking strength.

Data and Methods

- Reanalysis (Dee et al. 2011): → *for verification*
  - **ERA-Interim**
- **S2S** ensemble forecasts (Vitart et al. 2017): → *to investigate NAO- and cold spell predictability*
  - Ensemble prediction system: **ECMWF**
  - Ensemble size: 51 members
  - Forecast length: 45 days
  - Initializations: Jan 25 and 29, Feb 1, 5, 8, 12, 15, 19 and 22, 2018
- **Nudging forecasts** (50 members): → *to quantify the impact of the stratosphere*
  - Two sets of nudged forecasts (both are performed for the Feb 1 initialization)
  - Set 1: vorticity, divergence and temperature fields above 70 hPa are relaxed on a 6-hr time-scale to ERA-Interim reanalysis (up to a total wave number of 21)
  - Set 2: stratosphere is nudged to Feb 1, 2018 (when stratosphere was close to its climatological state)
- **Indices**: → *to identify certain patterns/phenomena*
  - Eurasian T2m anomaly
  - Blocking index of Tibalidi and Molteni (1990) averaged over Scandinavia
  - NAO index (EOF based, Weisheimer et al. 2017)
  - NAM index (area-weighted polar-cap averaged geopotential height anomaly)
  - SSW index (daily mean zonal-mean zonal wind at 10 hPa and 60°N)
- **Statistical Clustering**: → *to compare different tropospheric and stratospheric conditions*
  - Members with/without SSW
  - Members with varing Scandinavian blocking strength
  - Members with NAO+/-

How predictable was the cold spell & the NAO?

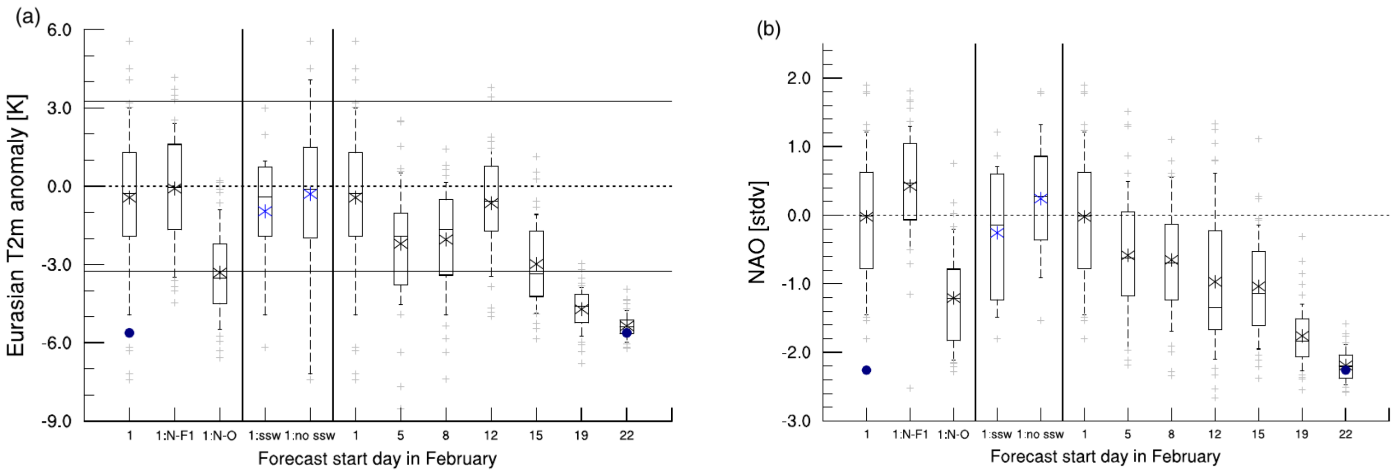

Figure 2. (a) Boxplots of the northern Eurasian T2m anomaly (in K), averaged between February 25 and March 6, 2018, for different initialization dates of the Subseasonal-to-Seasonal (S2S) ensemble forecasts. The boxes show the lower and upper quartiles, the band inside each box is the median and the ensemble means are indicated by asterisks. The whiskers show the 10th and 90th percentiles, while the outliers are grey crosses. The boxes labelled “1:N-F1” and “1:N-O” represent the nudged forecasts initialized on February 1, where the stratosphere above 70 hPa is nudged to February 1, 2018 and to the reanalysis, respectively. The box labelled “1:ssw” shows only those members that predicted SSW (within +/− 3 days from the central date) in the February 1 forecasts and “1:no ssw” shows those that did not (18 and 23 members, respectively). The solid black horizontal lines show +/− one standard deviation obtained from ERA-Interim daily northern Eurasian T2m anomalies between January and March 1979–2018. (b) The same as (a), but for the NAO index (in standard deviation). Blue dots show the observed values.

- Observed strength of T2m anomaly and NAO- only predicted in forecasts initialized on Feb 19 and 22
- Probabilistic skill in the ensemble of the Feb 5 initialization (SSW already in the forecast) implying probabilistic predictability **> 20 days** before the extreme event
- Results from the nudging experiment (left of the first vertical line in Fig. 2): „correct“ stratosphere leads to a significant enhancement of predictability

Influence of the stratosphere on predictability

- With SSW: cold spell associated with NAO-
- Without SSW: cold spell associated with Ural blocking

→ <u>Hypothesis:</u> **the occurrence of SSW in the forecast is neither a necessary nor sufficient condition to predict cold spell**

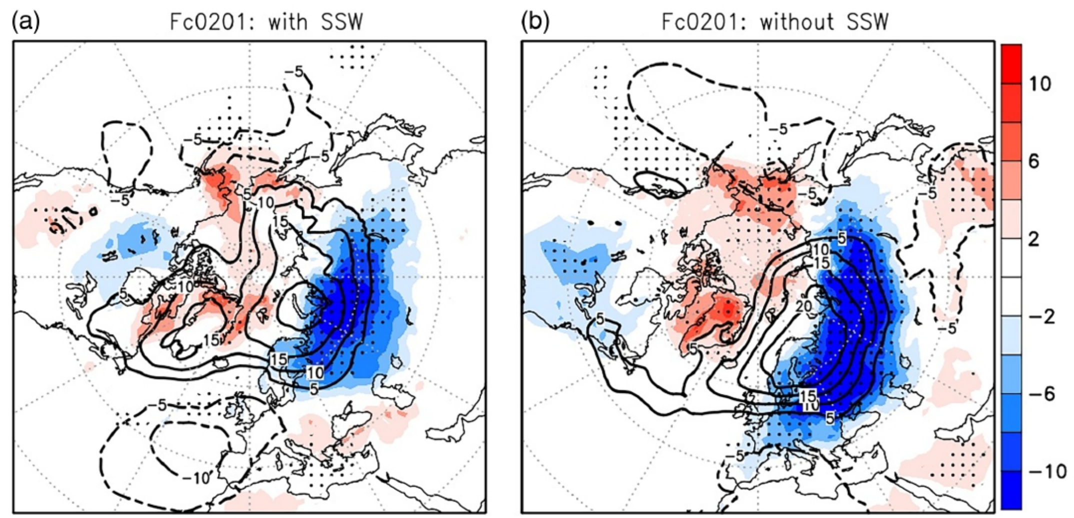

Figure 3. (a) MSLP and T2m differences between the mean of members with the coldest anomaly over Eurasia (below the 25th percentile, five members) and the mean of members with the warmest anomaly (above the 75th percentile, four members) averaged over a time period from February 25 to March 6 based on members with SSW from the forecast initialized on February 1. (b) The same as (a), but for members without SSW (the "warm" cluster consisting of five members and the "cold" cluster consisting of six members). Dotted areas indicate significant differences in the T2m field between the two clusters.

Influence of the stratosphere on predictability

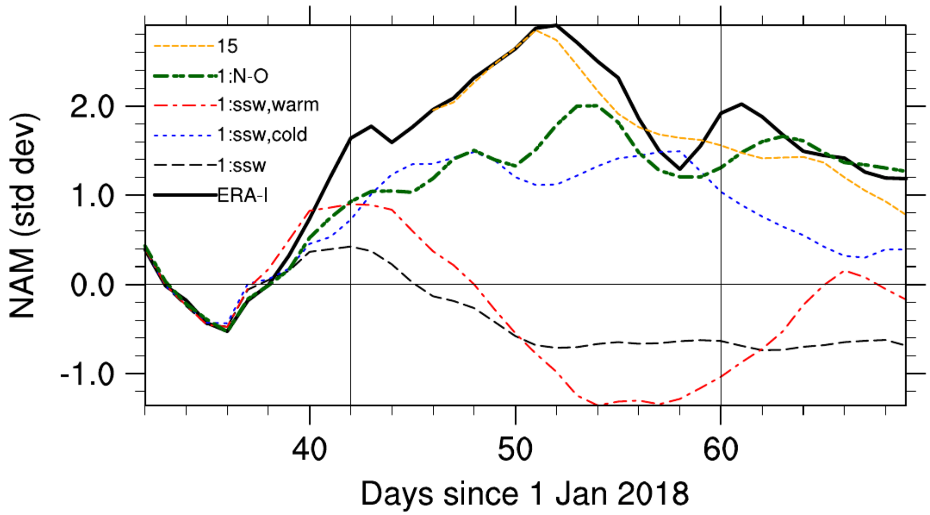

Figure 4. Time series of the 100-hPa NAM index (in standard deviation) for ERA-Interim (thick solid black line), the mean of the 18 “SSW” members in the February 1 forecasts (dashed black line), the mean of the “SSW” members in February 1 forecasts with the coldest anomaly over Eurasia between February 25 and March 6 (below the 25th percentile, five members, dotted blue line), the mean of the “SSW” members in the February 1 forecasts with the warmest anomaly over Eurasia between February 25 and March 6 (above the 75th percentile, four members, dot-dashed red line), the ensemble mean for the forecasts with the stratosphere above 70 hPa nudged to ERA-Interim (dot-dot-dashed green line) and the ensemble mean for the forecast initialized on February 15 (short-dashed orange line). The two vertical lines indicate the central date of the SSW and March 1, respectively.

- **ERA-Interim vs. “SSW” cluster:** persistence of the positive NAM index is too short and the amplitude too weak in the “SSW” members
- **coldest Eurasian anomaly “SSW” sub-cluster vs. warmest Eurasian anomaly “SSW” sub-cluster:** the better agreement of the NAM index for the coldest “SSW” sub-cluster with ERA-Interim suggests that the lower-stratospheric signal is important for the surface response
- **Nudging run (observed state):** the lower-stratospheric NAM index in the nudged ensemble is close to the observed

Variability of the tropospheric circulation

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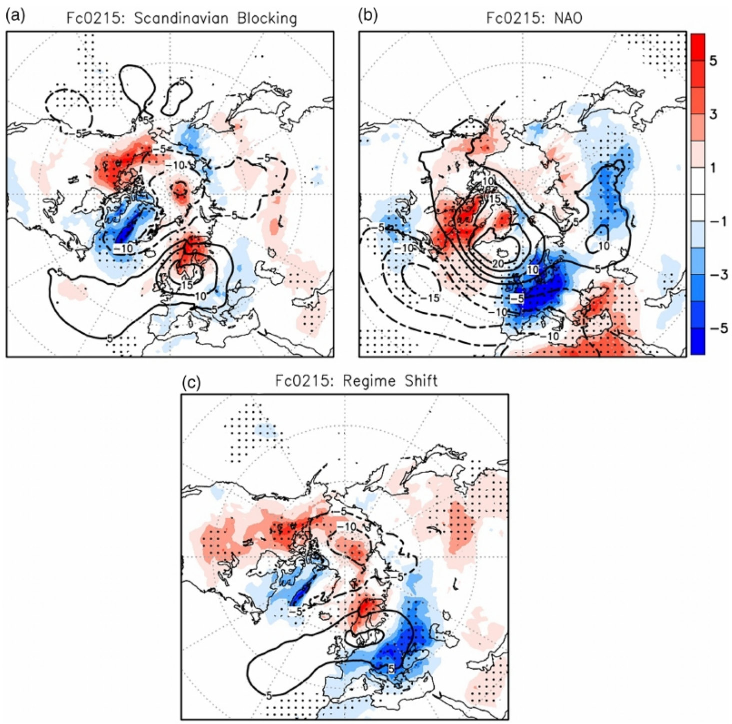

Figure 5. (a) MSLP and T2m differences between the mean of members with the strongest Scandinavian blocking (SB) between 15°E and 40°E (above the 75th percentile, 12 members) and the mean of members with the lowest SB (below the 25th percentile, 13 members) averaged over a time period from February 25 to March 1 from the forecast initialized on February 15. (b) The same as (a), but for the difference between the mean of members with strong NAO− (12 members) and the mean of members with NAO+ or weak NAO− (12 members) averaged over a time period from February 25 to March 6. (c) The same as (b) but for differences between the mean of members with the strongest SB between 15°E and 40°E (above the 75th percentile, 10 members) and the mean of members with the lowest SB (below the 25th percentile, 11 members) based on a time period from February 25 to March 1, conditioned on members with NAO− below −0.5 between March 2 and 6. Dotted areas indicate significant differences in the T2m field between the two clusters.

- **With/without Scandinavian block** (Feb 25 – Mar 1): members with strong Scandinavian blocking have lower temperatures over Eurasia; however, this cold anomaly is quite weak and not significant → no significant influence of the Scandinavian block on the cold spell over Eurasia
- **NAO-/NAO+** (Feb 25 – Mar 6): members with strong NAO− predict a stronger cold spell over western and central Europe → significant influence of NAO-
- **With/without regime change** (Feb 25 – Mar 6): members with Scandinavian blocking at the end of February have lower temperatures over Eurasia than members without the blocking → the Scandinavian block acted as a precursor to the cold spell as it favoured the flow of continental cold air from the northeast

Key findings

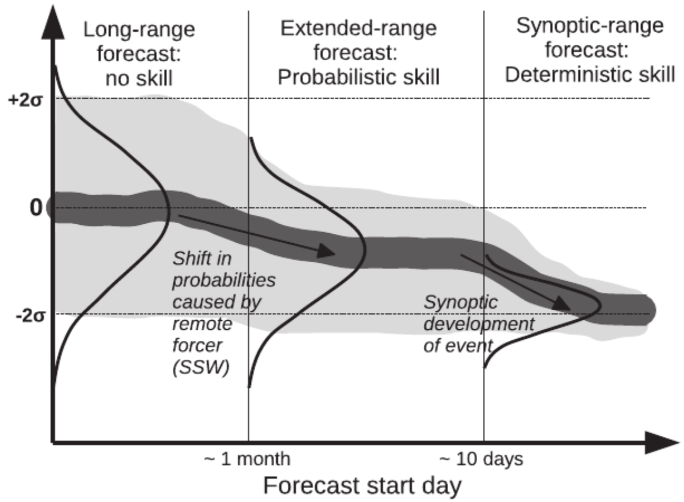

Figure 6. Schematic showing the predictability of a surface extreme event for different forecast ranges (from long-range forecasts with lead times of 1 month to synoptic-range forecasts with lead times of only a few days) under the influence of remote forcing (e.g., SSW) occurring during the extended range. Light grey shading indicates the ensemble spread (5th to 95th percentile), while dark grey shading indicates the ensemble mean.

Did the cold spell in Northern Eurasia develop independently from the NAO− phase?

- regime shift from the Scandinavian block to NAO− occurred at the beginning of March 2018 and favoured the westward advection of cold air leading to an intensification of the cold spell over western and central Europe
- cold spell did not develop independently of the NAO− phase

What role did the stratosphere play in triggering the NAO event?

- the occurrence of the NAO− phase appears to be favoured by the stratospheric evolution associated with the SSW
- However, the NAO− phase in early March 2018 exceeded the expected strength based on the SSW and may have occurred even without the SSW
- based on the nudged experiment, we were able to quantify that the probability of an extreme NAO− phase was severely enhanced (to 25%) by the stratospheric evolution, compared to 5% in the climatology
- the subsequent evolution throughout the lower stratosphere following the SSW, rather than the occurrence of the SSW itself, that is crucial in coupling to large-scale flow patterns in the troposphere

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