Decadal variability of the extratropical response to the Madden-Julian Oscillation: The North Atlantic

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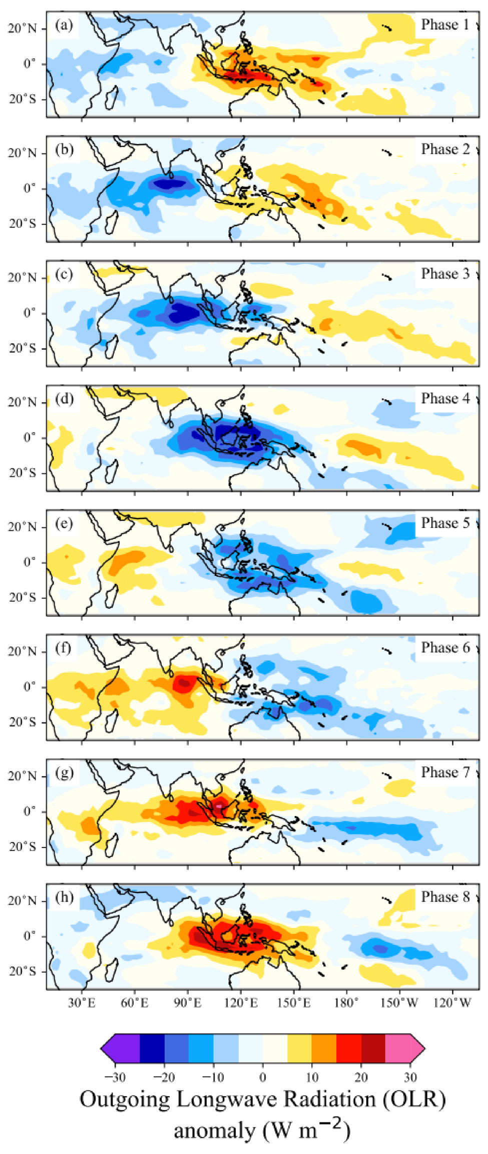

Figure 1: OLR anomaly composites over the eight phases of the MJO.

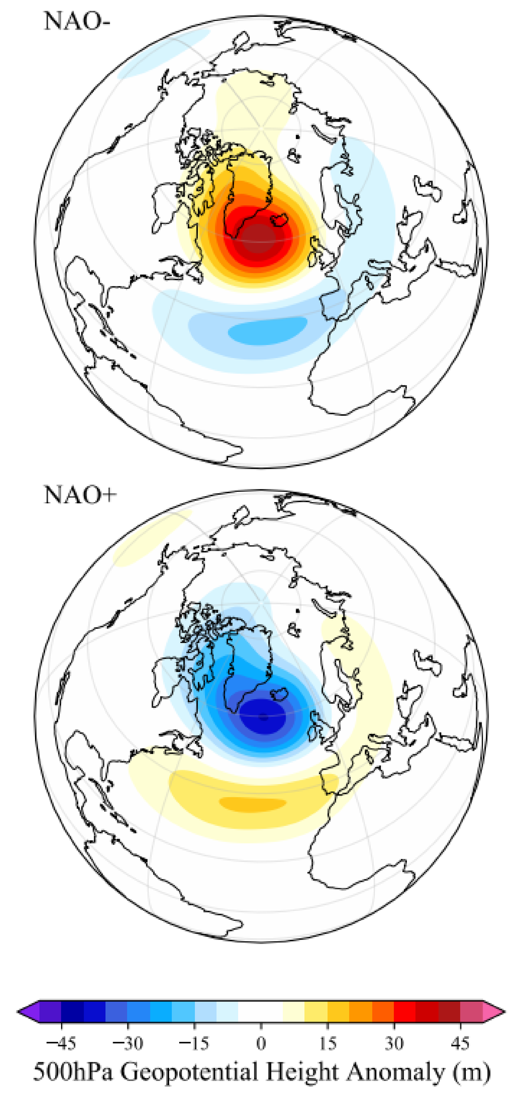

Figure 2: 500hPa geopotential height anomaly composites over the NAO- and NAO+

The Madden-Julian Oscillation and the North Atlantic Oscillation

The **Madden-Julian Oscillation (MJO)** and the **North Atlantic Oscillation (NAO)** are the leading modes of atmospheric variability on sub-seasonal time scales in the tropics and North Atlantic respectively.

The MJO[a] is a large area of **enhanced anomalous convection** (blue shading in Figure 1) moving eastwards over the Maritime Continent, followed by a similar area of depressed convection. The location of the enhanced convection is usually described by its phase given as a number from 1 to 8.

The NAO[b] can be considered as a semi-periodic oscillation in **anomalous atmospheric pressure** between Iceland and the Azores. These changes in pressure have considerable influence over the weather throughout Northern Europe, **particularly in the UK**.

It is known that the NAO shows a **response to the MJO**[c] at lead times of one to two weeks, however less well understood is how this response may change on **longer time scales**.

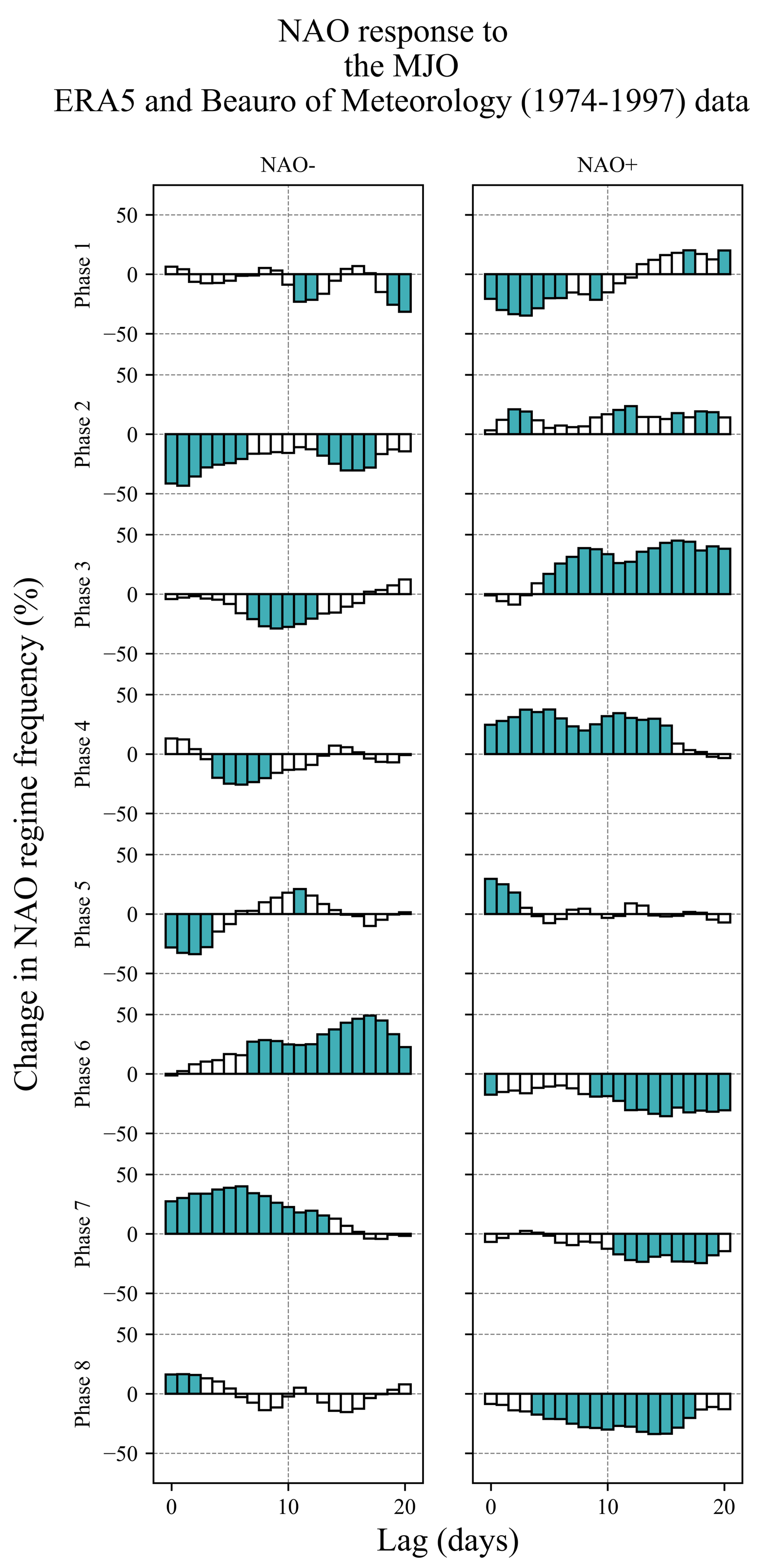

Figure 3: The observed NAO response to the MJO for 1974-1997[Note]. Bars represent the change in likelihood of seeing a given NAO regime, blue shading indicates that the change is significant at the 95% level.

The observed NAO response to the MJO

Most studies into the North Atlantic response to the MJO focus on **single time periods**. This has meant that most of our knowledge of these responses is **specific to recent** (in climatological terms!) history.

We compare two **non-overlapping time segments:** 1974-1997[Note] and 1997-2018. Data is taken from the ERA5 reanalysis dataset[d] (geopotential height) and the Bureau of Meteorology[e] (MJO RMM index).

In Figures 3 and 4 we can see a strong positive response from **NAO- to MJO phase 6** and a positive response (at roughly 1-2 weeks lag) from **NAO+ to phase 3** (two canonical MJO-NAO predictors). Note that the gradient of the response as a function of lag points towards **causality** in the response rather than simply correlation.

It is also clear that there are **qualitative differences** in the two time segments. The NAO response is generally **weaker** in the 1997-2018 time segment and has a **different temporal structure**. For context, this difference is similar in magnitude to what we see between observations and many models[f]. There is, however, enough of a change to **warrant further investigation**.

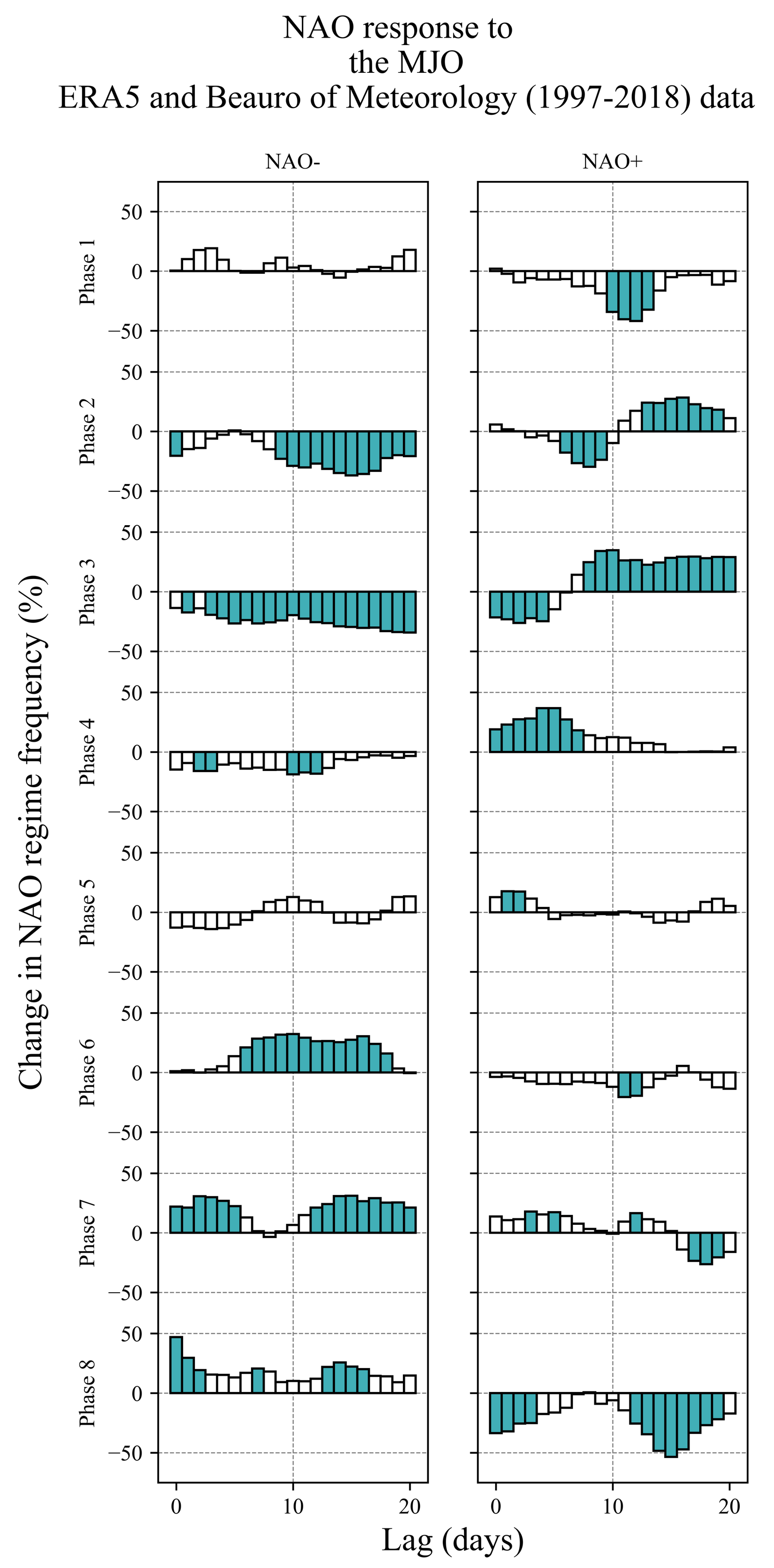

Figure 4: As in Figure 3 but for 1997-2018.

Variations in NAO response over an extended model run

Now consider the Met Office **UKESM-1-0-LL** model[g] pre-industrial control run. This model simulates the coupled climate system but with anthropogenic forcing held at **pre-industrial** levels.

This gives us access to **1100 years** of data.

We run our analysis **independently** on non-overlapping time segments of **different lengths** to assess the impact of sampling errors.

Segments have lengths of **10, 20, 30 and 40 years** and were all taken from the end of the 1100 year model run. We chose to use **27 segments** of each length to keep a consistent sample size.

The 27 segments of length 10 years cover a much shorter domain that those of length 40 years, allowing us to estimate the **time scale** of the variability.

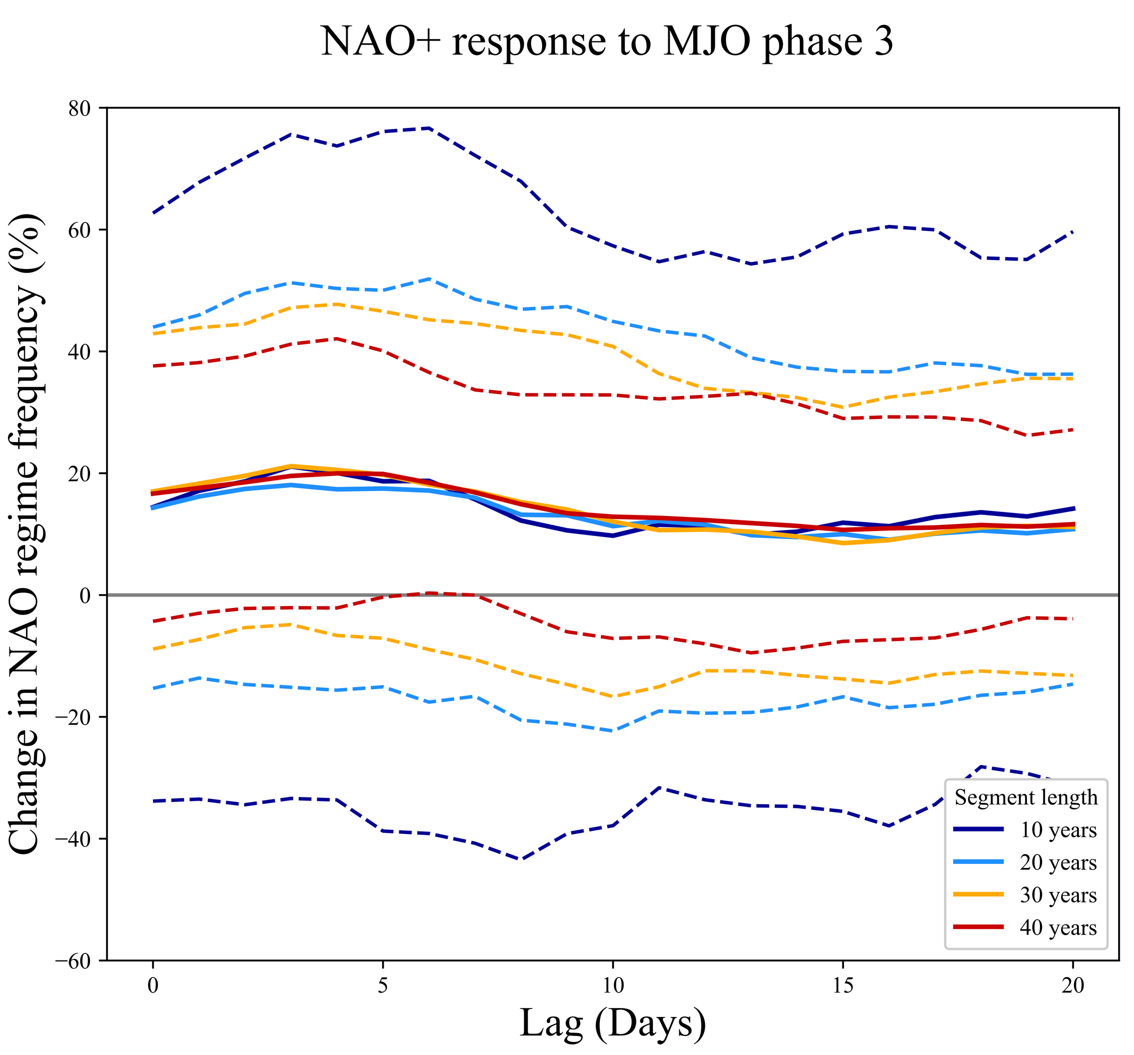

Figure 5: The model NAO+ response to MJO phase 3 over different segment lengths. Solid lines represent the mean response while dashed lines represent the mean plus/minus two standard deviations (~95% variance on a normal distribution).

NAO response to MJO over 1100 years

There is **considerable variability** in the NAO response to the MJO compared to the mean response.

The mean NAO+ response to MJO phase3 is consistently **positive**, pointing to the fact that the positive response is indeed a **robust** feature of the MJO-NAO interaction.

For the NAO- response to MJO phase 6 the mean signal is still positive but due to **high variability** we cannot predict this with confidence.

The general agreement in the means suggests that the variations we see occur on **decadal but not centennial** time scales.

The variability is large for the 10 year segments, suggesting that some of this variability is due to **sampling errors**, however by 30 years the standard deviation seems to converge.

The large variability means that the response is far **less predictable** than we may have expected.

These results motivate **further investigation** into the causes of this variability and a possible change to the way we use the MJO as a predictor in the extratropics.

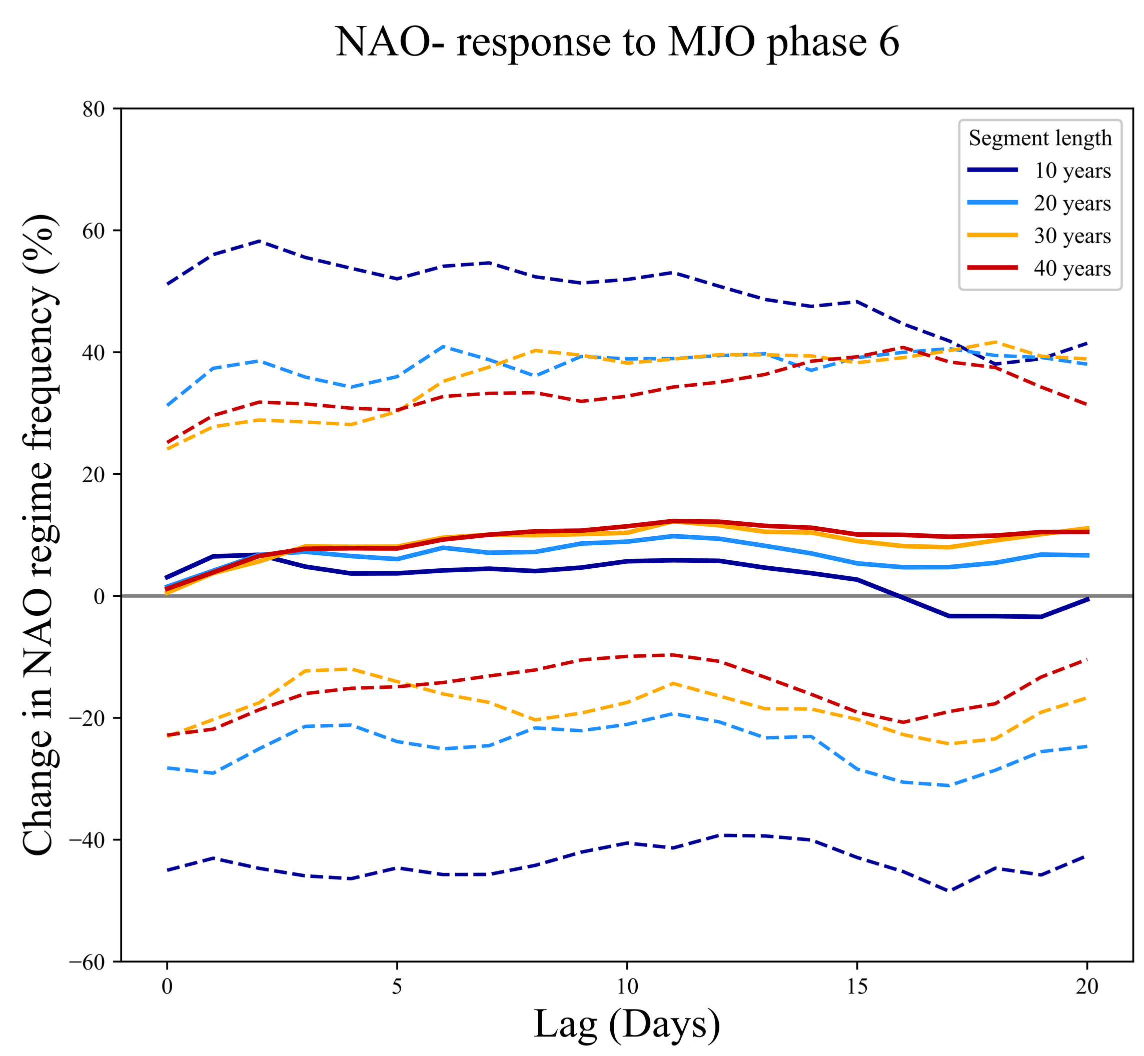

Figure 6: As in Figure 5 but for the NAO- response to MJO phase 6.

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Future questions

Which decadal climate variability modes are **modulating** the changes in the NAO response to the MJO?

How do responses in **other extratropical modes** vary over decadal time scales?

What are the **mechanistic** changes in the teleconnection patterns that correspond to variations in the responses in our statistical framework?

References and Notes

[a] Madden and Julian (1972) *J. Atmos. Sci.*, **29**(6), 1109-1123
[b] Walker and Bliss (1932) *Mem. R. Meteorol. Soc.*, **4**, 53-84
[c] Cassou (2008) *Nature*, **455**(7212), 523-527
[d] Hersbach et al. (2020) *Q. J. R. Meteorol. Soc.*, **146**(730), 1999-2049
[e] Bureau of Meteorology (2021) http://www.bom.gov.au/climate/mjo
[f] Skinner et al. (2022) *Weather*, (In review)
[g] Sellar et al. (2019) *J. Adv. Model. Earth Syst.*, **11**(12), 4513-4558

[Note] The 1977/78 and 1978/79 winter seasons are omitted due to a lack of OLR data.

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