REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: United Kingdom

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Dr. Stephanie Johnson (ECMWF)
Dr. Antje Weisheimer (ECMWF)

Project Title:

Arctic sea-ice, ENSO and seasonal prediction skill in mid-latitude winter circulation

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2021	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2021-2023: (To make changes to an existing project please submit an amended version of the original form.)		**2021**	**2022**	**2023**
High Performance Computing Facility	(SBU)	14,000,000		
Accumulated data storage (total archive volume)[2]	(GB)	8000		

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.

[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.

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Extended abstract

Brief summary:

In recent years, evidence of a `signal-to-noise paradox' in seasonal forecasts of the wintertime Euro-Atlantic circulation has begun to emerge. In this paradox, initialised forecasts in November show robust levels of skill at predicting large-scale circulation anomalies, but simultaneously also very low signal-to-noise ratios, implying a strong degree of model under-confidence. A notable example of this phenomena is in the North Atlantic Oscillation (NAO): because the NAO heavily influences European winter weather, it is of great scientific and communal interest to understand both the sources of predictability in the system and also the features which drive this under-confidence.

The aim of this project is two-fold, with the primary aim being to understand the role of interannual Arctic sea-ice variability in driving the Euro-Atlantic circulation, and the secondary goal being to examine the role that interannual variability in the ENSO region plays in the same way. A large body of literature suggests anomalies in both sea-ice and ENSO may be adding predictability to the mid-latitude winter circulation, but as of yet there have been no extensive hindcast experiments to assess their roles robustly (particularly in the case of sea-ice), with existing studies primarily restricted to individual years.

The novelty of this project lies in the generation of long ensemble hindcast experiments (1980-2015) to examine their relative influence on seasonal prediction skill more robustly. In one experiment, Arctic sea-ice variability will be suppressed (and ENSO left alone), while in the other ENSO variability is suppressed (and the Arctic left alone). The most recent available IFS cycle (47r1) would be used. Technical details of the experiments are included below.

One very concrete objective in our analysis is to examine changes in both long-term correlations and signal-to-noise ratios, and hence study the relative role of the Arctic and ENSO on the signal-to-noise paradox: some of this analysis will be carried out in the context of weather regimes (details below). A second, more exploratory objective is to understand how Arctic sea-ice anomalies influence the mid-latitude circulation in the IFS more broadly, with a particular eye on the role of mean-state sea-ice biases.

Technical details and unit estimation

The technical experiment protocol will be created in assistance with Dr. Stephanie Johnson (ECMWF), an expert on seasonal prediction experiments with the IFS. In order to both make use of existing experiments and to align more closely with the goals of ECMWF, we will be running experiments using IFS cycle 47r1 in coupled mode. The resolution to be used is **Tco199Orca1**, with experiments covering 1980-2015 with November startdates. For each startdate, a 50-member ensemble will be run for 4 months to cover the full DJF season. Single precision mode will be used to save resources.

Dr. Johnson's estimate of SBU cost for such a single-precision simulation is 950 SBUs per forecast month. Therefore, a full hindcast experiment will cost 950*4*35*50 = 6650000 SBUs. The cost of two such experiments is therefore rounded to an even 14 million SBUs, to account for any testing required. Data volume estimates are based on a pragmatic choice of output on daily and monthly frequencies, which produce 4 Tb of data for each experiment.

The experimental protocols will be as follows. To suppress Arctic sea-ice variability, we will simply alter the November sea-ice initial conditions in the Arctic region, replacing them with a fixed, strongly positive sea-ice anomaly. The underlying sea-surface temperatures in the Arctic may also be similarly replaced for consistency. To suppress ENSO variability, we similarly simply alter the initial condition SST fields in the ENSO region, replacing it with a fixed, climatological pattern which is smoothly tapered back to the true SST field outside the region. Discussions with Dr. Johnson and Dr. O'Reilly (who has experience with similar IFS experiments in past Special Projects) suggests these protocols are technically feasible. Note that a control simulation (no tampering with variability) will be produced by Dr. Johnson as part of normal ECMWF work: this will be used for comparison.

NOTE: The PI is aware that Dr. Doug Smith is planning complementary 'PAMIP' experiments on a similar theme. I have been in touch with him and we have agreed there is no conflict.

Detailed scientific background/justification:

We now provide further detail on the scientific background and justification of the project.

There is an extensive literature on the role that Arctic sea-ice plays in modulating the Euro-Atlantic circulation, both on seasonal and climate timescales (e.g. Deser et al. 2007, Kim et al. 2014, Barnes and Screen 2015, Garcia-Serrano et al. 2015 and Wang et al. 2017). The main idea is the same in both, namely that a positive sea-ice anomaly forces a positive NAO signal. Part of the impact seems to follow a more direct tropospheric pathway, where the heat-flux anomaly induced by sea-ice anomalies generates a stationary Rossby wave which slowly grows into an equivalent barotropic structure resembling the NAO (Deser et al. 2007 and Strong and Magnusdottir 2010). There is also evidence that the waves generated in this process may reach the stratosphere in some cases, weakening the stratospheric polar vortex: this weakening then propagates back down in late winter, once again manifesting as an NAO pattern (e.g. Kim et al. 2014).

This NAO-like impact is typically strongest for anomalies in the Barents-Kara sea, especially when considering reanalysis and observational data, but other regions have been shown to have similar impacts. For models, which typically show sea-ice biases, the critical region in the Arctic is sometimes displaced compared to reanalysis. Indeed, while the principal EOF of reanalysis data picks out the Barents-Kara region, this is not always the case for models: an example for EC-Earthv3.2 (IFS cycle 36r4) is shown in Figure 1. However, model studies that impose sea-ice anomalies over the entire Arctic region also typically show an NAO signal (Screen et al. 2018), suggesting that while specific regions may be more or less crucial, the net Arctic sea-ice itself has a consistent signature on the circulation.

While a recurring theme in Arctic-midlatitude analysis is the noisiness of the signal (Screen et al. 2018), studies suggest that this signal may be important for long-term predictability. In Dunstone et al. (2016) it was shown that Barents-Kara anomalies are likely important for driving the high NAO skill seen in the GloSea5 system, even up to a year ahead. Wang et al. (2016) corroborated this with a statistical model (based on reanalysis data) demonstrating that observed NAO variability could be predicted to good accuracy a full year ahead, with Barents-Kara sea-ice being the dominant source of predictability. For the IFS, the papers Balmaseda et al. (2009) and Orsolini et al. (2012) showed that Arctic sea-ice anomalies were crucial in producing the strong circulation patterns of the 2007/2008 autumn and winter, while also highlighting the importance of the underlying sea-surface temperature anomalies.

A more comprehensive examination of the IFS skill at predicting the NAO[2] was undertaken in Parker et al. (2019), using the 20th century atmosphere-only hindcast experiments `ASF20C' (IFS cycle 40r1; Weisheimer et al. 2017). Since the NAO measures to first order variations in the position and speed of the eddy-driven jet, they justified a decomposition of the NAO into independent jet speed and jet latitude components. Linear regression techniques were used to conclude that the skill was coming entirely from the ability of the IFS to predict interannual variations in the jet latitude. A regime-based approach, inspired by this result and the underlying trimodality of the jet latitude on daily time-scales, was pursued in Strommen (2020), building on the hypothesis put forth in Strommen and Palmer (2019) that the paradox may be due to poor regime structure in models. It was shown that interannual variations in jet latitude regime persistence are predictable by the IFS, and these variations are sufficient to explain both the skill and the low signal-to-noise ratios, with the latter being linked to systematically weak persistence in the IFS.

In ongoing follow-up work, the Principal Investigator has been examining the roles of both Arctic sea-ice and ENSO on jet latitude variability, both directly and in the jet regime context. It is found that correlations between the NAO and Arctic sea-ice in November are not detectable in ASF20C (unlike in ERA20C). By compositing mean DJF geopotential height fields at 500hPa (Z500) across years with positive/negative November Barents-Kara anomalies and taking the difference, one finds that the signature of Barents-Kara anomalies in ASF20C is large in magnitude but significantly displaced compared to ERA20C: see Figure 2. However, at the same time, statistically significant correlations between Arctic sea-ice and the jet latitude are found for both ERA20C and ASF20C, though the critical region is nearer the Laptev sea for the IFS: see Figure 3. This is consistent with the earlier discussion implying that only the jet latitude component of the NAO is predictable by IFS cycle 40r1. This influence of the Laptev sea is also felt by the jet persistence measures (not shown) considered in Strommen (2020).

The above preliminary results suggest that Arctic sea-ice is influencing the mid-latitude winter circulation in the IFS, in a way which projects positively onto the jet latitude, but which also suffers notable biases, especially when viewed in the more detailed Z500 field. At the same time, there is an equally comprehensive literature examining the role of ENSO in modulating the North Atlantic winter circulation, including the NAO. Once again, both a `direct' tropospheric pathway (involving a modulation of the Pacific jet) and a slower stratospheric pathway (involving a modulation of the polar vortex) appear to be present (e.g. Jimenez-Esteve and Domeisen (2018) and references therein). However, the exact strength and nature of the ENSO teleconnection is still unclear, owing to inherent

[2] Note that the ensemble mean correlation that the IFS DJF NAO has with the observed DJF NAO ranges between 0.4 and 0.5, which is statistically significant across multiple IFS cycles.

non-linearities, both related to the SST-precipitation relationship as well as, potentially, non-linear interactions between ENSO and the Madden Julian Oscillation (MJO). Indeed, reanalysis data show little to no linear correlation between ENSO indices and NAO indices. It is also possible that impacts via the stratosphere may not always be synchronised with any such coming from the Arctic, which may be a further source of non-linearities.

The decomposition of the jet latitude into Northern and Southern jet latitude components (and their associated levels of persistence) from Strommen (2020) allows for a direct way to measure potential non-linearities, as the net impact on the jet is a non-linear combination of the two components through an explicit formula. In Strommen (2020), this was used to show that ENSO seems to be important for setting the Southern jet persistence but not the Northern, which was influenced more by Barents-Kara sea-ice. Ongoing work strongly supports the role of ENSO in modulating jet persistence, vividly illustrated in Figure 4. This shows correlations between November gridpoint SSTs and a measure of the transient baroclinic eddy feedback on the Southern jet regime: a massive ENSO signal is clearly present, extending all the way out to the Indian Ocean. Because the eddy feedback is a key driver of jet persistence, this clearly points to the importance of ENSO in setting the preferred jet position. Crucially, and unlike when considering the NAO directly, significant linear correlations are present, allowing for *quantitative* assessments of its role in driving predictable signals in Euro-Atlantic winter circulation.

All this analysis, undertaken with the ASF20C ensemble (IFS cycle 40r1), along with the earlier and complementary studies referenced, clearly suggests that both Arctic sea-ice and ENSO are important sources of predictability in the IFS. However, since these phenomena are relatively independent of each other, and there is strong evidence of non-linearities, it is extremely hard to untangle the relative importance of each; for sea-ice, this is further exacerbated by the clear biases in the atmospheric response (Figure 2). The hindcast experiments proposed for this Special Project represent a pragmatic and transparent way to allow this untangling to begin to be addressed.

Finally, we emphasise that besides the more concrete analysis described above, we would be aiming to also undertake more exploratory analysis on how Arctic-midlatitude teleconnections are represented in the IFS more generally, including potential surface level impacts across both Europe and North America.

Figures

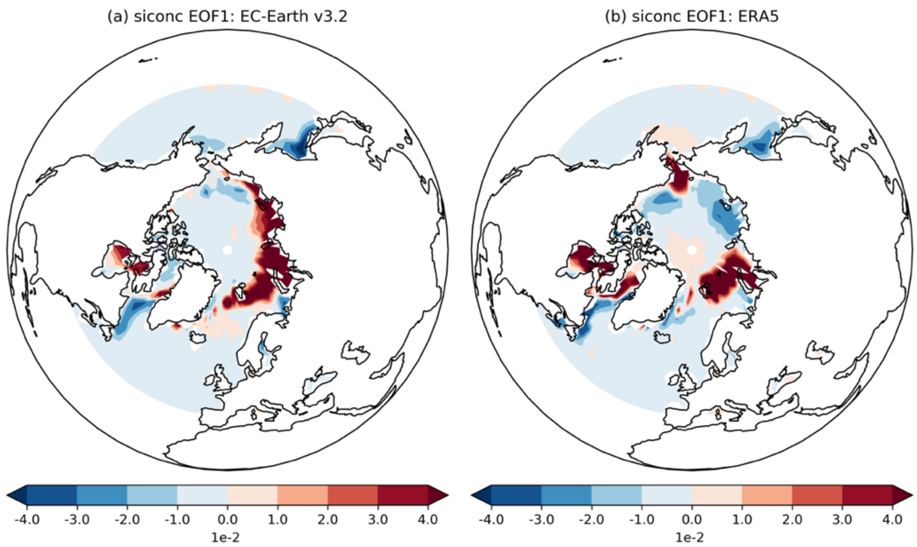

Figure 1: The leading EOF of monthly sea-ice concentration in (a) a fully coupled EC-Earth v3.2 (IFS cycle 36r4) and (b) ERA5 reanalysis data. Covering 1980-2015. Gridpoint timeseries are detrended prior to computing the EOFs.

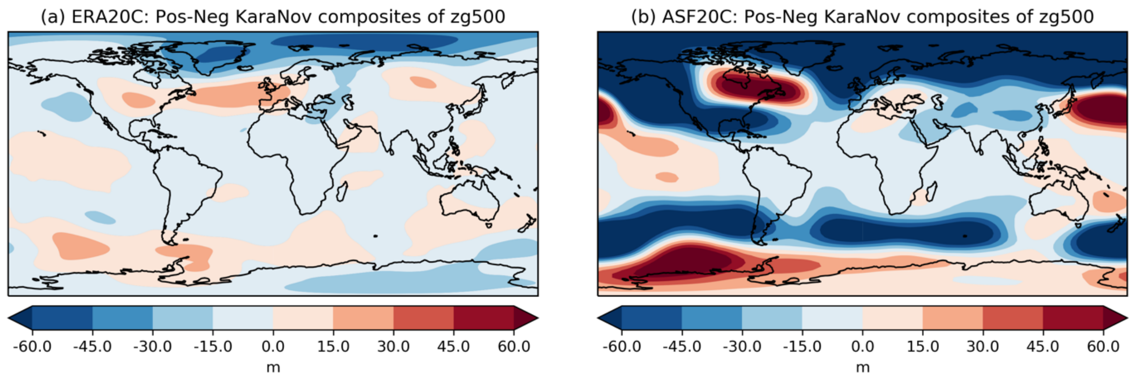

Figure 2: DJF Z500 composites across years (1980-2010) with a positive November Barents-Kara sea-ice anomaly minus composites across years with a negative November anomaly. In (a) for ERA20C and (b) for the ASF20C ensemble (IFS cycle 40r1). Note that ASF20C was initialised and forced by ERA20C data/boundary conditions. Covering 1980-2010.

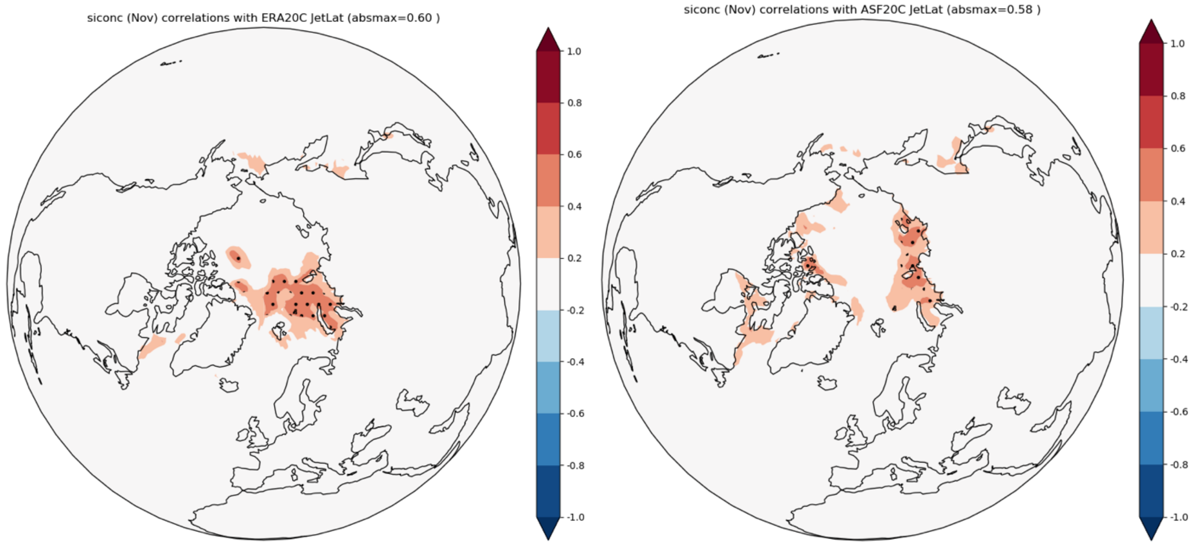

Figure 3: Correlations between November sea-ice gridpoint anomalies and the subsequent DJF mean jet latitude. Left: ERA20C, Right: the ASF20C ensemble (IFS cycle 40r1). Covering 1980-2010. Gridpoint timeseries are detrended prior to computing correlations. Black dots indicate statistical significance ($p<0.05$).

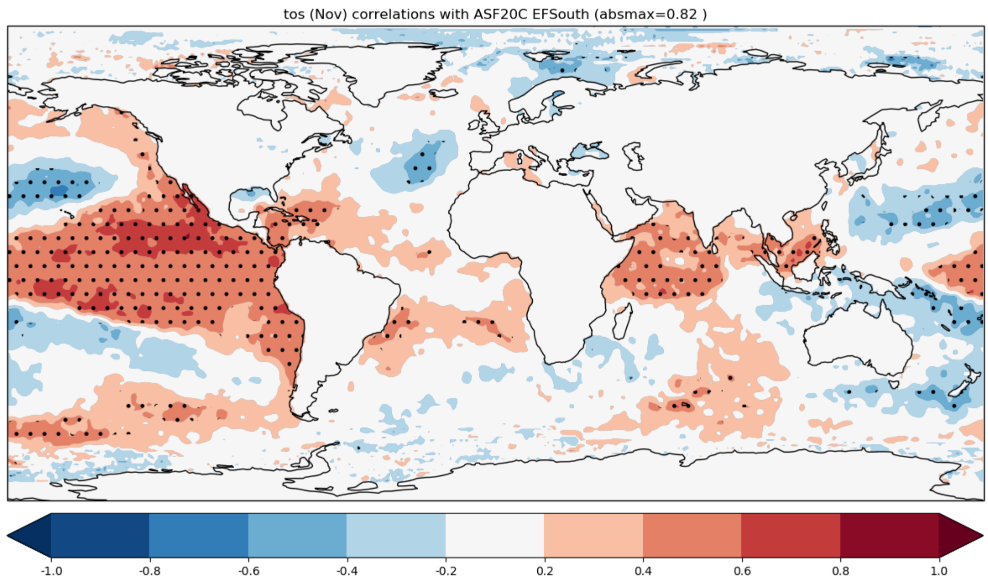

Figure 4: Correlations between November SST gridpoint anomalies and the strength of the subsequent DJF baroclinic eddy-forcing on the North Atlantic jet (as defined in Strommen 2020), using the ASF20C ensemble (IFS cycle 40r1). Covering 1980-2010. Gridpoint timeseries are detrended prior to computing correlations. Black dots indicate statistical significance ($p<0.05$).

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