REQUEST FOR A SPECIAL PROJECT 2021–2023

MEMBER STATE: Finland

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Project Title:

Towards operational attribution of predicted signals in sub-seasonal forecasts

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 X	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)	10,900,000	X	X
Accumulated data storage (total archive volume)[2]	(GB)	21,715	X	X

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.

Principal Investigator: Dr. Alexey Karpechko

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Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific Advisory Committee. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, disciplinary relevance, and justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests asking for 1,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more might receive a detailed review by members of the Scientific Advisory Committee.

Motivation

This project aims to investigate sources of predicted signals in sub-seasonal forecasts for Europe. So far, attempts have been made to attribute predictable signals for some past cases on seasonal and sub-seasonal time scales by performing relaxation experiments in which parts of the atmosphere have been nudged towards observations. However, we argue that there are benefits of having information about sources of predicted signals available operationally at (nearly) the same time as the forecasts themselves because the knowledge of why models predict what they predict can help users in their applications. Such information would be especially helpful during cases when forecasts have a strong predicted signal for weeks 3-4 and beyond, i.e. at long lead times at which the skill of the forecasts is usually low. In such cases, distinguishing between signals associated with well understood sources (e.g. Madden-Julian Oscillation (MJO), stratospheric circulation anomalies) and cases when the signal has no clear origin, may make an impact on decision making by forecast users.

Obviously, observations would not be available for relaxation experiments during operational forecasting. Instead, relaxation should be performed towards selected operational forecast ensemble members, referred here as scenarios, that exhibit pronounced signals in regions where predictability is usually larger than that in the extratropical troposphere. Such regions are the stratosphere and/or the Tropics.

In this project we plan to test the feasibility of the approach outlined above by performing a set of experiments with operational ECMWF model for a number of past cases when there was an evidence for extended predictability during forecast weeks 3-4.

Sources of predictability

It is currently well established that predictability is larger in some parts of the atmosphere than in others. For example, tropical phenomena such as MJO can be skilfully predicted for up to four weeks (Vitart 2017) – a skill level that cannot be normally expected in the extratropics. Similarly, stratospheric anomalies in winter can be skilfully predicted beyond 15 days, partly due to longer timescales of the stratospheric variability (Karpechko 2018). It is also well established that these regions are dynamically coupled to the extratropical atmosphere, e.g. through so-called teleconnections. It is thus reasonable to expect that during certain periods of time a larger predictability can be achieved in the extratropical troposphere due to interactions with the tropics or/and the stratosphere. Examples of such cases include February-March 2018 when, following a Sudden Stratospheric Warming (SSW), a cold signal for Eurasia was skilfully predicted beyond two weeks, which at least partly was associated with stratosphere-troposphere coupling (Karpechko et al. 2018; Kautz et al. 2020).

Relaxation experiments have been successfully used in the past for understanding driving forces of specific anomalies. For example, Jung et al. (2010) nudged tropical atmosphere and extratropical stratosphere to understand their contributions to cold anomalies observed in the NH extratropics during winter 2005/06. They concluded that the extratropical extreme anomalies were driven by tropical variability, while the stratosphere played little role in driving the circulation. On sub-seasonal timescale, Kautz et al. (2020) used relaxation experiments to show that the Sudden Stratospheric Warming 2018 increased chances for a severe cold spell in Europe in February-March 2018 from 0.05 to 0.45, i.e. by factor 9. Vitart et al. (2014) showed that developing MJO in late winter 2013 produced a cold signal over Europe at lead time of 4 weeks.

These examples demonstrate usefulness of relaxation experiments in attributing observed anomalies to dynamical drivers as well as in clarifying the causes for extended predictability (e.g. the case studies by Kautz et al. (2020) and Vitart et al. (2014)).

Arguably, understanding of sources of predictability could be done by statistical analysis of excising forecast ensembles without additional experiments. For example, Karpechko et al. (2018) used ensemble correlation to show that the SSW 2018 forecasts by sub-seasonal models was closely linked to forecasts of the Ural high. Such statistical analysis is valuable because it can provide information about potential drivers of the events, and also provide guidance for scenario selection. However, statistical analysis would not provide physical arguments for attribution. Attribution becomes more straightforward in relaxation experiments with specified boundary conditions. Further, additional data available from the relaxation experiments proposed in this project would also improve statistical estimates of the teleconnection strengths, which is especially important in the case of low signal to noise ratio typical for sub-seasonal and seasonal forecasting.

Case studies, experiments and required resources:

In the project we plan to select 10 cases during the recent decade with significant anomalies in European weather, both during cold season (5 cases) and warm season (5 cases), when ECMWF model showed an enhanced predictability at lead times of 3-4 weeks. Preliminary analysis suggests that good candidates for the analysis are winter 2019-20 when ECMWF forecasts showed significant warm anomalies, at long lead times, consistent with observations. Also, the heat wave in July 2018 was skilfully predicted at lead time 19-25 days. The full set of case studies will be prepared during year 2020.

For each case study we will run a number of experiments to test for potential driving mechanisms and to test a null hypothesis that the driving candidate played no role in the anomalies. We will use the latest ECMWF operational model IFS cycle 47r1 at a horizontal resolution Tco199 with 137 levels in vertical and employ single precision calculations. The ocean component will have horizontal resolution of 1°x1° degree and 75 levels in vertical. (The experimental setup is recommended by Dr. F Vitart, ECWMF) The reduced horizontal resolution is a reasonable compromise between computational requirements and the skill. The number of vertical levels is the same as in ERA-5 reanalysis which will be used for initial conditions and relaxation experiments. Each experiment will consist of 50 ensemble members and will be run for a 4-weeks periods. The experiments are listed below.

1. Control experiment (CTRL). The purpose of CTRL is to provide base line for the analysis and also provide scenarios for testing the drivers of the signal. Scenarios will be selected among forecast ensemble members predicting anomalies in the stratosphere or in the tropics (see experiments 2-5). CTRL will be run in a coupled atmosphere-ocean mode initiated from ERA-5 and ORAS5 reanalyses.

2. STRAT: this experiment will test the hypothesis that the anomalies were driven by the extratropical stratosphere. The ensemble members will be nudged towards an CTRL ensemble member that exhibited an anomalous behaviour in the stratosphere: e.g. weakening or strengthening of the polar vortex. Zonal mean zonal winds at 60N and 10-hPa (U10) will be used as an index for the forecasted vortex evolution. The nudging area is 20N-90N and above 70 hPa. The experiment will be driven by SSTs from the selected CTRL ensemble member. STRAT experiment will only be run during cold season (5 cases).

3. NO-STRAT: This experiment will test for the alternative hypothesis to STRAT, that the extratropical stratosphere played no role in the anomalies. The ensemble members will be nudged towards a CTRL ensemble member that exhibited an opposite (or strongly different) behaviour in comparison to that in STRAT in terms of U10 index. The nudging area is 20N-90N and above 70 hPa. The experiment will be driven by SSTs from the selected CTRL ensemble member. NO-STRAT experiment will only be run during cold season (5 cases).

4. TROP: this experiment will test the hypothesis that the anomalies were driven by the Tropics. The ensemble members will be nudged towards an CTRL ensemble member that exhibited an anomalous behaviour in the Tropics. Rainfall anomalies in the tropical basins identified by Scaife et al. (2017) as Rossby wave sources responsible for teleconnections, will be used as an index. The nudging area is 20S-20N from the surface to the top of the atmosphere. The experiment will be driven by SSTs from the selected CTRL ensemble member.

5. NO-TROP: this experiment will test the alternative hypothesis that the anomalies were not driven by the Tropics. The ensemble members will be nudged towards an CTRL ensemble member that exhibited an opposite (or strongly different) behaviour in comparison to that in TROP in terms of rainfall anomalies. The nudging area is 20S-90S and from the surface to the top of the atmosphere. The experiment will be driven by SSTs from the selected CTRL ensemble members.

6. STRAT-OBS: this experiment is needed to estimate the role of "perfect" stratospheric boundary conditions and determine *potential* predictive signal associated with the stratosphere. It will allow estimating errors arising from the use of imperfect boundary conditions provided by the CTRL forecast member used in STRAT. The experiment will be similar to STRAT except that the nudging will be towards the observed extratropical stratosphere. The observations will be taken from ERA-5 and SST will be taken from ORAS5 reanalysis. STRAT-OBS experiment will only be run during cold season (5 cases).

7. TROP-OBS: this experiment is needed to estimate the role of "perfect" tropical boundary conditions and determine *potential* predictive signal associated with the Tropics. The experiment will be similar to TROP except that the nudging will be towards the observed tropical atmosphere. The atmospheric observations will be taken from ERA-5. SSTs will be taken from ORAS5 reanalysis.

Additionally, for each case study, a set of hindcasts will be run following excising practice at ECMWF. Namely, 11-ensemble member historical forecasts will be initiated at the same calendar date as the case study but during each of the preceding 20 years and run for the 4-week periods.

We estimate that each four-week run will require 2000 SBU. In all experiments, except CTRL, a four-week run will require 2,7 Gb of data storage in MARS (12-hourly output at the surface and at 8 pressure levels). CTRL experiments will additionally require storage of divergence, vorticity and air temperature at 6-hour time steps and at all model levels for using in nudging experiments. This will amount to 16,7 Gb of data storage in total for each CTRL runs. To reduce the storage requirements for CTRL we plan to only save model level outputs for a few ensemble members per each experiment. The exact number of members with saved model levels will be determined in test runs. The test runs will also be used to test various nudging configurations before running full nudging experiments.

Table 1: Summary of proposed experiments. For each experiment, each initial date and each scenario, 50 ensemble members will be run for 4-weeks periods

Experiment	Forecast month	SPU	Storage (Gb)
Tests	500	1,000,000	1,350
CTRL	10x50=500	1,000,000	8,350
STRAT	5x50=250	500,000	675
No-STRAT	5x50=250	500,000	675
TROP	10x50=500	1,000,000	1,350
No-TROP	10x50=500	1,000,000	1,350
Stratosphere-obs	5x50=250	500,000	675
Tropics-obs	10x50=500	1,000,000	1,350
Hindcasts	10x220=2200	4,400,000	5,940
Total	**5450**	**10,900,000**	**21,715**

References:

Jung, T., T. N. Palmer, M. J. Rodwell, and S. Serrar (2010), Understanding the anomalously cold European winter 2005/06 using relaxation experiments, Mon. Weather Rev., 138, 3157–3174.
Karpechko, A. Y. (2018), Predictability of sudden stratospheric warmings in the ECMWF extended-range forecast system, Mon. Weather Rev., 146(4), 1063–1075, doi:10.1175/MWR-D-17-0317.1, 5002018.
Karpechko, A. Y., Charlton-Perez, A., Balmaseda, M., Tyrrell, N. and Vitart, F. (2018), Predicting Sudden Stratospheric Warming 2018 and Its Climate Impacts With a Multimodel Ensemble, Geophys. Res. Lett., 45(24), 13,538-13,546, doi:10.1029/2018GL081091,2018.
Kautz, L. A., Polichtchouk, I., Birner, T., Garny, H. and Pinto, J. G., (2019), Enhanced extended-range predictability of the 2018 late-winter Eurasian cold spell due to the stratosphere, Q. J. R. Meteorol. Soc., 146, 1040–1055, doi:10.1002/qj.3724, 2019.
Scaife, A. A., Comer, R. E., Dunstone, N. J., Knight, J. R., Smith, D. M., MacLachlan, C.,...Slingo, J. (2017). Tropical rainfall, Rossby waves andregional climate prediction.Quarterly Journal of the Royal Meteorological Society,143,1–11. https://doi.org/10.1002/qj.2910
Vitart, F., (2017) Madden–Julian oscillation prediction and teleconnections in the S2S database. *Quart. J. Roy. Meteor. Soc.*, **143**, 2210–2220, https://doi.org/10.1002/qj.3079
Vitart et al. (2014), The March 2013 cold wave over Europe, Meteoworld May.