REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE:	Spain
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Project Title:	Hindcast experiments using the IFS 49r1 to investigate the impact of stratospheric ozone on predictability for the Horizon Europe project SOCLIM

To make changes to an existing project please submit an amended version of the original form.)

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.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☐	NO X☐

Computer resources required for project year:		**2026**	**2027**	**2028**
High Performance Computing Facility	[SBU]	2,880,000	5,760,000	5,760,000
Accumulated data storage (total archive volume)[2]	[GB]	16,820	23,620	23,620

EWC resources required for project year:		**2026**	**2027**	**2028**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			

[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.
[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

Number of vGPUs[3] [#]			

Continue overleaf.

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Extended abstract

Stratospheric composition—primarily ozone and water vapour—plays a key but underexplored role in forcing atmospheric circulation. These components can significantly influence the predictability of weather and climate from sub-seasonal to multi-decadal scales. However, interactions between stratospheric composition, dynamics, transport, and radiative processes remain poorly understood. Most state-of-the-art weather models simplify these processes, leaving their implications for sub-seasonal to seasonal predictions unclear.

The Horizon Europe ERC-funded SOCLIM project (Stratospheric cOmposition in a changing CLIMate) addresses this critical gap by delivering a holistic assessment of the impact of stratospheric ozone and water vapour on predictability. SOCLIM will, for the first time, investigate the impact of incorporating interactive stratospheric chemistry in the operational IFS, the state-of-the-art numerical weather prediction model of ECMWF, explicitly resolving interactions between stratospheric and tropospheric composition and their impacts on weather and climate.

To achieve these goals, SOCLIM will:

1) Test the impact of stratospheric ozone within the operational IFS by coupling the IFS to a range of ozone schemes, ranging from simplified linearized ozone to full comprehensive interactive stratospheric chemistry modules.

2) Perform targeted hindcast experiments to quantify the influence of stratospheric composition extremes—such as Arctic ozone depletion events—on stratospheric and surface climate predictability.

3) Use independent Sub-seasonal to Seasonal (S2S) forecasting systems as part of coordinated inter-comparison studies to isolate and quantify the dynamic and radiative impacts of stratospheric composition on regional weather and climate projections.

4) Integrate in-situ observations, satellite and reanalysis data to constrain and the IFS validate model results.

Through these activities, SOCLIM will advance our understanding of chemistry-climate interactions, reducing uncertainty in weather and climate predictions. The project runs from June 2024 until May 2029, and is led by Dr. Gabriel Chiodo at IGEO-CSIC, and will significantly strengthen European leadership in climate science, supporting improved weather and seasonal forecasting for the benefit of society, fostering international collaboration between research institutions, including ECMWF itself, and the wider community involved in several activities coordinated by the World Climate Research Program (WCRP) - Atmospheric Processes And their Role in Climate (APARC - https://www.aparc-climate.org/), such as the Stratospheric Network for the Assessment of Predictability (SNAP).

Scientific Background and Motivation

Constraining the role of stratospheric ozone in sub-seasonal to seasonal (S2S) predictability remains a critical challenge for advancing weather and climate forecasting. In most operational forecasting systems, including all IFS cycles before cycle 48r1, stratospheric ozone was prescribed from climatology, due to the large computational cost of fully interactive chemistry. Recent studies have shown, for the first time, that Arctic ozone has a sizable impact on the atmospheric circulation in the aftermath of episodic Arctic ozone depletion events (Friedel et al., 2022a). More specifically, in these situations, ozone depletion extends the lifetime of the polar vortex, leading to an amplification of surface climate anomalies, including warming over Eurasia and drying over central Europe. It has also been shown that Arctic ozone also modulates the surface signature of Final Stratospheric Warmings (FSWs ; see Friedel et al., 2022b). These effects are not only limited to the Northern Hemisphere: incorporating interannual ozone variations in the Antarctic stratosphere leads to improved prediction of surface climate anomalies over Australia (Lim et al., 2024). However, these studies have mostly employed coarse resolution climate models which are not initialized with observations, or prediction systems forced with observed ozone anomalies. Hence, these studies do not allow robust and definitive conclusions concerning the role of ozone as a source of predictability and the added value for model skill.

Experimental Design

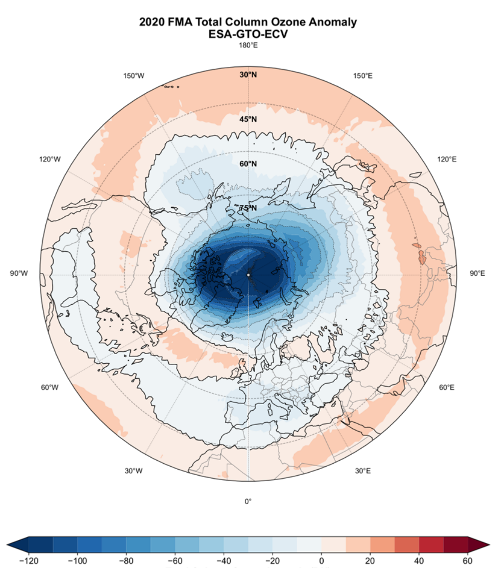
To address these limitations, SOCLIM will adopt a novel experimental strategy within the IFS framework, leveraging ECMWF's high-performance computing resources. We will use the existing chemistry-weather prediction system, and will employ different configurations of the IFS model. This will enable the explicit simulation of two-way interactions between stratospheric ozone and atmospheric dynamics, allowing us to unambiguously assess, for the first time, the impact of stratospheric ozone feedbacks on prediction skill.

Recently, the IFS Cycle 48r1 has adopted the integration of a radiatively interactive ozone in operational forecasting, through the Hybrid Linear Ozone (HLO – see Williams et al., 2021). This scheme has been shown to reduce certain biases in the IFS, such as the cold bias in the polar stratosphere and also an improvement in temperature and wind variability. It was concluded that HLO reduces temperature forecast bias in the middle to upper stratosphere leading up to and during an SSW onset. Including a similar ozone scheme leads to improvements in the Southern Hemispheric polar vortex and its variability (Monge-Sanz et al., 2021). It has also been recently shown that including a linearized ozone scheme increases the predictable signal of the FSW date in the Southern Hemisphere (Anil et al., 2025). However, the impact has only been evaluated for a few sudden stratospheric warmings (SSWs) with focus on the Southern Hemisphere. Moreover, linearized ozone schemes still represent a simplification of ozone-dynamics interactions, especially in non-linear regimes such as strong vortex situations in which ozone can undergo rapid chemical destruction. This calls for a more comprehensive evaluation of the HLO performance both in terms of representing ozone itself, as well in the impacts on prediction skill, particularly in the sub-seasonal to seasonal forecasting range, including non-SSW periods and springs with sizable Arctic ozone depletion.

A comprehensive atmospheric chemistry scheme is computationally much more expensive and has only been used in the production of chemical reanalysis. However, the focus has generally been on tropospheric chemistry (see e.g., Flemming et al., 2015). Recently, a more comprehensive stratospheric chemistry has been included (BASCOE) (Eskes et al. 2024; Chabrillat et al., 2025). In the short term (5-day), forecasts of stratospheric ozone with this configuration are improved compared to the simplified ozone parameterization from HLO (Eskes et al., 2024). However, the skill on S2S time-scales has not been evaluated yet. Most importantly, the effects on prediction skill are unclear, as winds are assimilated in these studies (e.g., Chabrillat et al., 2025). Dedicated experiments investigating the impact of two-way coupling between chemistry and the circulation are needed to conclusively assess the impact of ozone on model skill.

Proposed Experiments

Within this special project, we propose to assess the role of ozone as a source of predictability on S2S time-scales, by running hindcast experiments of springs with low and high Arctic ozone values. For Arctic ozone minima, we have identified the two strongest Arctic depletion events on records, 2011 and 2020. During these springs, the polar vortex was exceptionally strong and long-lived, leading to enhanced polar stratospheric cloud formation, and massive depletion of up to 20% in the ozone column (Figure 1 – see also Manney et al., 2011; 2020). During these springs, pronounced anomalies were also observed in tropospheric circulation: the Arctic Oscillation index (AO) was exceptionally high (Lawrence et al., 2020) and precipitation was below average for wide parts of Central Europe.



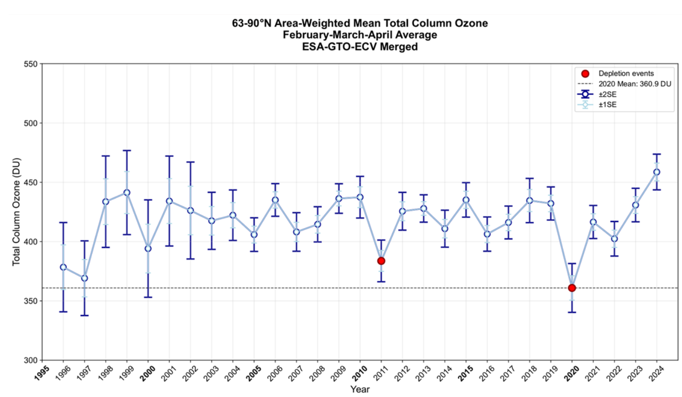


Figure 1: (left) Total column ozone anomaly of the February-April average total column in 2020 and (right) evolution over the last 30 years according to the ESA-GTO-ECV merged satellite data set. The two case studies of interest for this proposal are marked in red. Light blue and dark blue whiskers represent the ±1 and ±2 standard error (SE) deviations from the mean constituted by the uncertainty surrounding the merging of the different sensor ozone products in the ESA-GTO-ECV merged dataset.

For Arctic ozone maxima, two springs are of special interest: 2018 and 2023. During these springs, the vortex was exceptionally perturbed, with one of the strongest SSWs on record in February 2018 and two SSWs occurring one after the other in the winter-spring of 2023. A dynamically disturbed vortex led to mixing of ozone-rich air from the mid-latitudes into the polar stratosphere (De la Camara et al., 2018). If the enhanced ozone abundances persist until springtime, Arctic ozone can radiatively warm the polar stratosphere, modulating the magnitude of SSWs and downward coupling (Haase and Matthes, 2019; Oehrlein et al., 2020) and surface signature of FSWs (e.g. Friedel et al., 2022b). The key overarching question is then: did Arctic ozone drive the circulation anomalies observed during these years, and does the inclusion of ozone variations influence the model prediction skill?

To address these questions, we propose two sets of experiments using the IFS cycle 49r1 (137 vertical levels, Tco199 resolution, ~50 km), ocean at 0.25 deg. This is the current operational standard for extended-range and seasonal forecasting (SEAS6). In this cycle, the IFS has undergone several upgrades with respect to the first version in which a parameterized ozone was implemented (cycle48r1). Also, using dedicated experiments with the same exact IFS allows us to identify any skill changes that can be attributed solely to the ozone parameterisation.

Set A: Simplified ozone hindcasts (Year 1)

We will assess the impact of ozone anomalies during four key springs (2011, 2018, 2020, 2023) by running four 30-member ensembles, each 120 days long:

- ***IFS_noHLO*:** Control run with ozone prescribed as monthly-mean zonal mean (2D) climatology from SWOOSH, which is a merged satellite dataset (Davis et al., 2016).
- ***IFS_O3obs:*** Ozone prescribed from observed anomalies for each target spring, based on SWOOSH.
- ***IFS_HLO*:** Standard Hybrid Linear Ozone scheme
- ***IFS_HLO**** HLO with an added heterogeneous chemistry term, and updated linearization coefficients for improved interannual variability. Note that these coefficients will be derived from updated chemistry schemes compared to the old TOMCAT-based coefficients employed in Monge Sanz et al. (2022).

Model and resolution: IFS cycle 49r1 at Tco199 resolution (~50 km), 137 levels, ocean at 0.25 deg.

All ensembles will be initialized 15 days before the target events (1 March for 2011/2020, 1 February for 2018/2023), using ERA5 for the atmosphere and CAMS reanalysis for chemical tracers. Only initial conditions will be perturbed, ensuring robust statistical analysis of model skill. All runs will span 120 days to cover the S2S time scale.

Estimated resources: 200 SBU/day × 120 days × 4 cases × 30 members = 2,880,000 SBU
Storage needs: 0.9 Tb per 30-member ensemble (storing 3-D fields as follows: 6 variables as daily averages on 40 pressure levels, 4 variables at 6-h resolution on 40 pressure levels, 30 2-D fields at the surface at TOA). This amounts to exactly 4,200 GB for all 4 ensembles x 4 cases = 16,820 GB in total.

Set B: Full ozone hindcasts (Year 2 and 3)

In 2027–2028, we will test the impact of a more realistic stratospheric chemistry representation using the IFS "COMPO" configuration, which includes comprehensive atmospheric chemistry with 123 tracers (BASCOE). This setup allows ozone to be subject to advection, chemistry, and radiative interactions, capturing full coupling between ozone and circulation. Due to computational cost, we will only focus on ozone minima (2011 and 2020):

- ***IFS_CHEM*:** BASCOE chemistry, 20 members, 120 days each, same model and resolution as Set A.

Estimated resources: ~2,400 SBU/day × 120 days × 2 cases × 20 members = 11,520,000 SBU
Storage needs: 0.6 Tb per 20-member ensemble (storing 3-D fields as follows: 6 variables as daily averages on 40 pressure levels, 4 variables at 6-h resolution on 40 pressure levels, 30 2-D fields at the surface at TOA). For these experiments, we also need to store chemical fields for detailed analysis, adding another 1,200 GB per 20-member ensemble. This amounts to exactly 3,600 GB for all ensembles x 2 cases = 6,800 GB in total.

The key difference with respect to Set A is that we now use a configuration with comprehensive atmospheric chemistry, with 123 chemical tracers. In the stratosphere, this model employs the BASCOE chemistry and should more accurately represent ozone variability than in HLO. We will attempt a 20% reduction in complexity from the standard 3,000 SBU/day configuration, by reducing the number of tracers and by simplifying the chemical mechanism.

Evaluation and Community Relevance

We will use ERA5 as a dataset to evaluate the model skill both in the stratosphere and troposphere/surface. First, we will evaluate the model skill in representing ozone variability in these years, both for the IFS_HLO and IFS_CHEM. By differentiating both ***IFS_CHEM***, ***IFS_HLO*** and ***IFS_HLO**** against ***IFS_noHLO***, we can assess the impact of the complexity in the ozone parameterization on the re-forecasts. Also, the use of a new ozone forcing dataset (SWOOSH) for ***IFS_noHLO*** and ***IFS_O3obs*** represents an update over the current standard use of CAMS ozone. Moreover, the use of new coefficients for the HLO linearization represents a major update over the standard configuration of Williams et al. (2021) and Monge Sanz et al., (2022). Last but not least, the use of the same exact IFS version across all ensembles allows us to unambiguously evaluate the impact of ozone feedback processes alone, something which is presently not possible with the existing IFS data stored in the S2S and SEAS data-sets.

These experiments will directly inform and coordinate with international community activities. Within APARC's SNAP phase 2, a dedicated protocol will investigate ozone's role in model skill, and will be led by G. Chiodo. Some experiments (e.g., ***IFS_O3obs***) will be very influential in the formulation of the SNAPSI-O3 protocol, which will serve to coordinate S2S modelling centres worldwide in 2026. The results from this project will also feed into other coordinated community projects and activities within APARC focused on ozone and water vapour, such as the QUasibiennial oscillation and Ozone Chemistry interactions in the Atmosphere (see Orbe et al., 2025) and the ISSI team on Stratospheric Water Vapour led by Felix Ploeger. Thus, this project will serve as a starting point for many international activities, advancing our understanding of the role of stratospheric composition in the climate system.

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