SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Globo Ensemble Reforecast 2023 – GLEREF23
Computer Project Account:	spitmast
Start Year - End Year :	2023-2024
Principal Investigator(s)	Daniele Mastrangelo
Affiliation/Address:	CNR-ISAC
Other Researchers (Name/Affiliation):	--

Summary of project objectives

This project aimed at creating a new dataset of subseasonal ensemble reforecast simulations with an updated version of the atmospheric general circulation model Globo developed at CNR-ISAC. Each ensemble is made up of 8 35-days reforecast members for a total of 11680 simulations.
The reforecast dataset is currently used to calibrate the real-time forecasts operationally issued by ISAC participating, for instance, into the S2S Prediction Project and its database. Therefore, GLEREF23 was a preliminary step necessary to update the CNR-ISAC S2S forecasting system.
Also, covering a climatologically significant period, this dataset is used to perform research studies on the model performance, its forecasting skill on the subseasonal scale, and as benchmark for new model upgrades.

Summary of problems encountered

No relevant issues were encountered.

Experience with the Special Project framework

The overall experience was very good both from the technical and the administrative point of view.

Summary of results

Producing a new reforecast dataset necessary to upgrade the CNR-ISAC S2S operational forecasting system was the main practical outcome of the project. After the simulating phase, and before upgrading the real-time forecasting system, reforecasts were evaluated and partially compared to the reforecast dataset used in the previous version of the forecasting system, which was running operationally up to September 2024. Some results are reported here. Beyond the operational consequences, the new reforecast dataset also gives the opportunity to have a solid benchmark to evaluate further improvements of the model.

a) Operational activity

The whole reforecast dataset was successfully completed with all the planned simulations: reforecasts are initialized on fixed dates, every 5 days from 1 Jan to 27 Dec, over the 2001-2020 reference period, with initial conditions based on the ERA5 reanalyses. Since every ensemble is made up of 8 members, a total of 8 members * 20 years * 73 calendar days = 11680 35-days simulations were run. For each reforecast, 2 output files were produced and converted into grib2 files: the S2S outputs, at 1.5 x 1.5° lat-lon resolution, and the original-resolution files where a subset of variables are stored on the 360 x 512 lat-lon points of the model regular grid. The S2S outputs passed the file check for the S2S database and were successfully uploaded on it, where are now publicly available (https://apps.ecmwf.int/datasets/data/s2s-reforecasts-daily-averaged-isac/levtype=sfc/type=cf/; model version 2023-10-16).

Following the completion of the database, the reforecasts have been used for testing the updated real-time S2S forecasting system based on the same Globo version (Globo23) used for the reforecasts. Subsequently, with the forecast of 5 September 2024, the new CNR-ISAC S2S system became fully operational (https://www.isac.cnr.it/dinamica/projects/forecasts/monthly/monthly.htm).

b) Reforecast assessment

The new reforecast runs have been verified against ERA5 reanalyses to evaluate model bias for various variables and lead times. An important step is to assess how the bias has changed compared to the reforecasts performed for the previous model (Globo17) and forecasting system cycle. This task can be partially accounted mainly because the new reference period covered by GLEREF23 reforecasts (2001-2020) is not the same of the old system reference period (1981-2010), overlapping for 10 years. However, by using many simulations the main features of the two forecasting systems can be drawn. To this end, and as an example, Figure 1 shows the daily evolution of the Northern extratropical hemisphere (lat > 20° N) area-averaged biases of 500-hPa geopotential height, and of 850-hPa temperature averaged over the Italian area (36°-48° N lat, 6°-19.5° E lon).

In both cases, daily curves are averaged over all reference years to provide a mean climatological assessment while, by preserving the dependence on the initialization date (i.e., the period of the year) we can evaluate how the bias changes throughout the year. Each curve is thus obtained by averaging over 30 (Globo17) and 20 years (Globo23) the daily biases calculated from the ensemble mean of each reforecast, with the resulting values therefore derived from 150 and 160 simulations, respectively.

Geopotential height is evaluated over the entire extratropical Northern Hemisphere to gain a comprehensive view of the difference from ERA5 for this variable, which summarizes the model hemispheric circulation. Figure 1a clearly shows that Globo 2023 (Fig. 1b) has significantly better performance with a bias limited to ±20 m, a value reached beyond the first 3 weeks of simulation. The bias is symmetrically distributed with respect to the seasons, being cold in autumn and winter and warm in spring and summer, whereas in Globo 2017 (Fig. 1a), the bias was generally positive with values reaching 50 m towards the end of the reforecasts performed during the boreal warm semester.

Improvements are also evident for the 850-hPa temperature bias over the Italian territory. Three main differences can be identified: the bias of Globo23 (Fig. 1d) is systematically and markedly smaller, reaching a seasonally averaged value of about +1 °C (-1 °C) in summer (winter), compared to approximately +3 °C (-2 °C) for the old model (Fig. 1c); the bias saturates around the first 20 days, after which it does not worsen further, whereas the bias continued to increase until the end of the run, particularly in the summer months in the Globo17 reforecasts: the trend of the first 4-5 days of simulation is weaker, likely due also to a smaller error in the initialization (0 lead time).

Several works on S2S predictability and forecasting have discussed the relevance of the dynamics of the stratospheric polar vortex as a potential predictability source (e.g. Hitchcock et al., 2022). A reduced number of vertical levels and a low model top can lead to a poor performance in simulating the stratospheric dynamics and its interaction with the troposphere (e.g. Lawrence et al., 2022). The new version of Globo features more vertical levels (70) than globo17 (54) and reaches ~1.4 hPa, an improved height if compared to the Globo17 set up. The bias for the 10-hPa geopotential height over the northern polar cap (lat > 60° N) for both the model versions is therefore compared here (Fig. 2). A substantial improvement is shown for the Globo23 reforecasts (Fig 2b) that, above all, benefits from a better initialization. The bias gets bigger in the cold period, when the vortex is active, with values that continue to get negative as the lead time increases. A similar trend is evident in the Globo17 reforecasts but with stronger values mainly due to shift already evident at the beginning of the simulations.

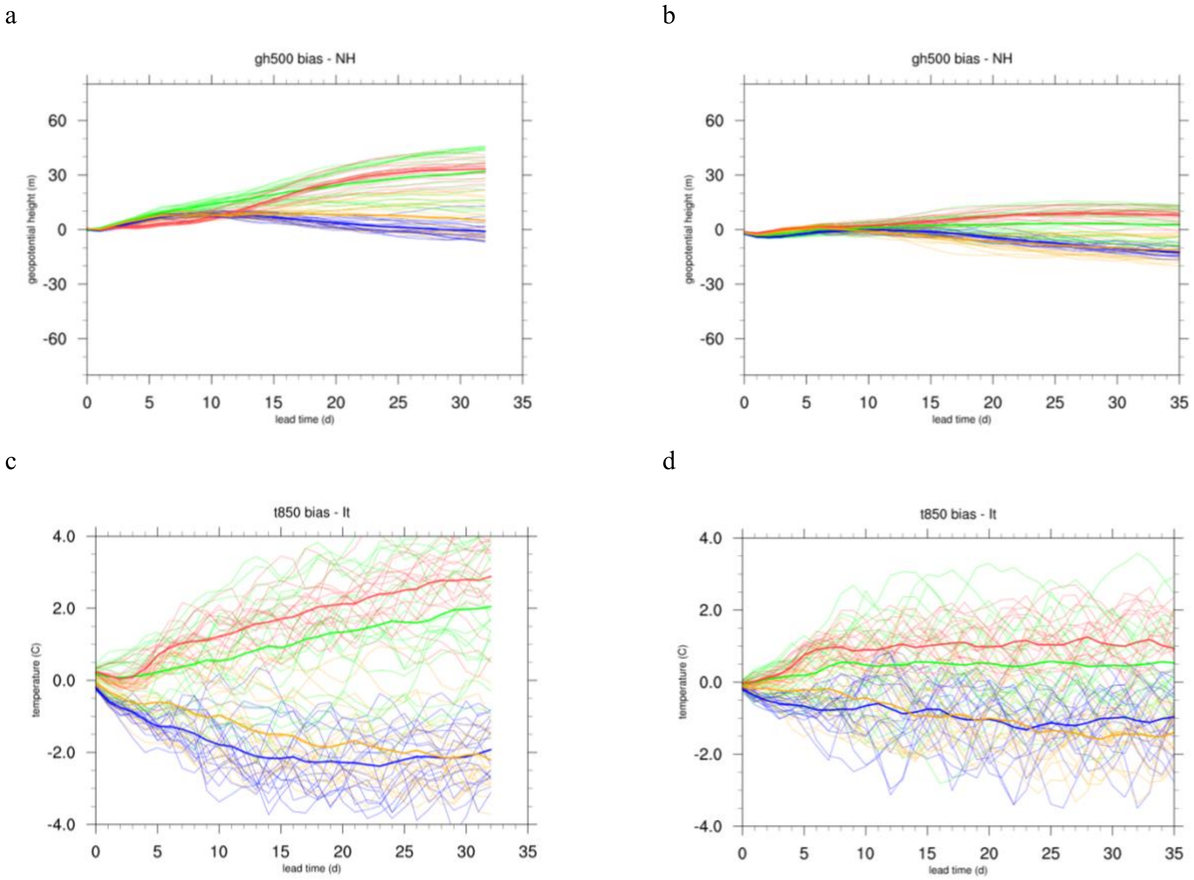

Figure 1: Time series of bias as a function of the initialization date and the forecast lead time (32 days for Globo17, left panels; 35 days for Globo23, right panels) for geopotential height at 500 hPa (a, b) and temperature at 850 hPa (c, d). The bias values are area-weighted averages using cos(lat) over the Northern Hemisphere extratropics (>20° N latitude) and over the Italian area for t850 temperature. Blue curves indicate initialization dates for DJF, green for MAM, red for JJA, and brown for SON. Thicker curves indicate the seasonal averages.

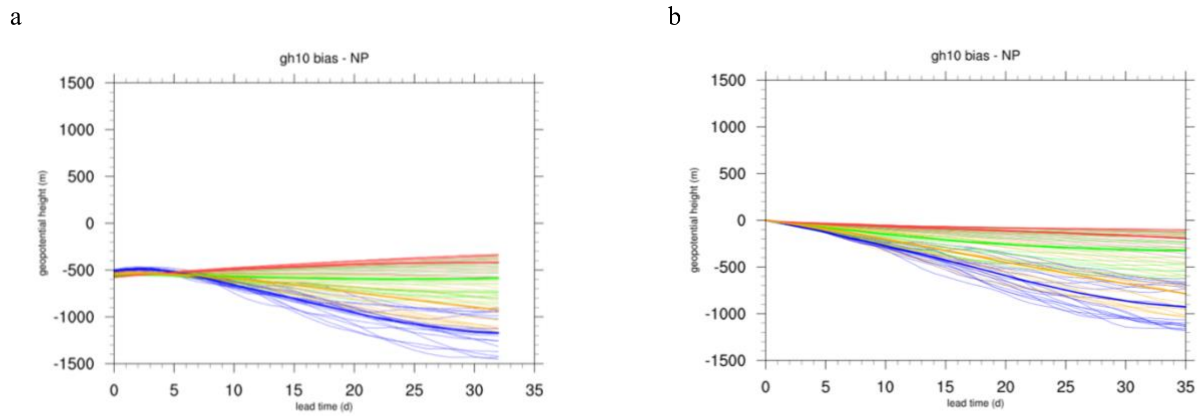

Figure 2: As in Figure 1 but for 10-hPa geopotential height averaged over the northern polar cap (lat >60° N)

The evaluation of total precipitation is done by comparing the mean absolute error (MAE) of the two Globo fields and showing the areas where Globo23 (light grey areas) or Globo17 (dark grey areas) performed better: Figures 3 and 4 display the results as weekly averages for the boreal winter and summer quarters, respectively, for the first 4 lead weeks. For simplicity, these areas have also been assigned a value of ±1 so that, in the zonal averages reported alongside each panel, a value >0 indicates a latitudinal band where Globo23 outperforms Globo17. It should be emphasized that this method does not provide a quantitative measure of the MAE difference. Also, MAE is calculated against ERA5 data, which represents a proxy for observed precipitation, especially in certain areas (e.g., Lavers et al., 2022). However, by comparing the two model fields against the same reference field, we can still highlight the differences in the performance of the two versions of the model.

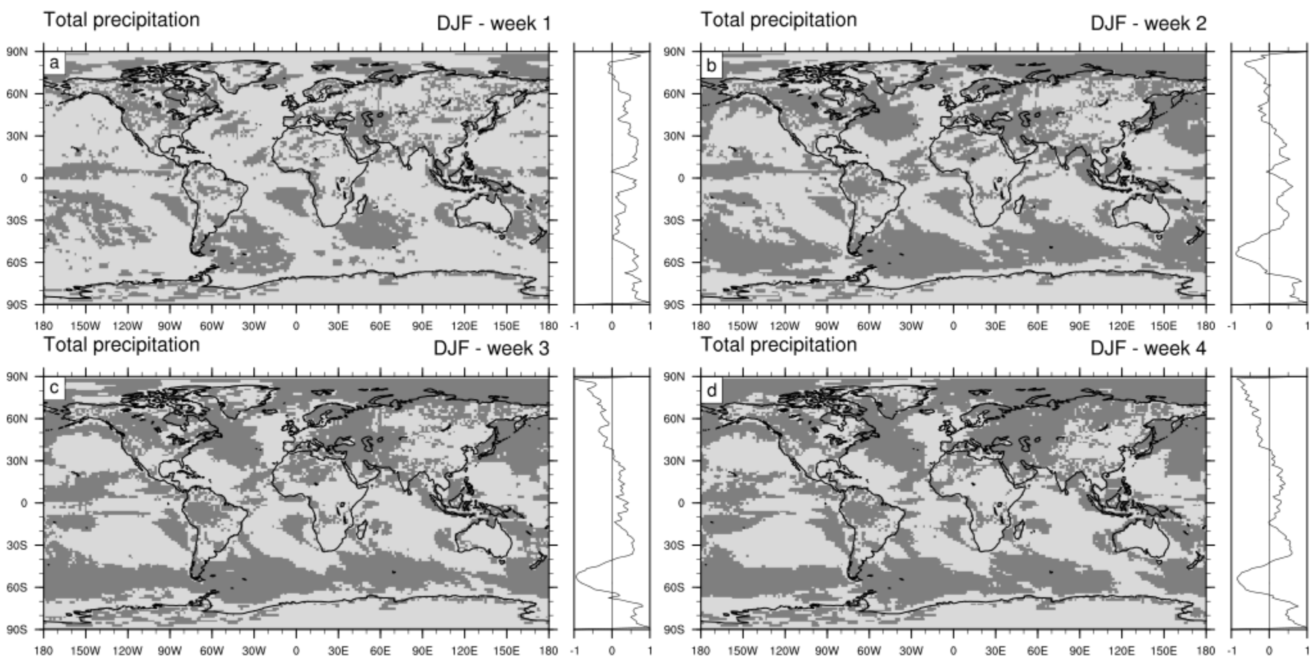

Figure 3: Representation of areas with lower/higher (light grey/dark grey) mean absolute error (MAE) of total precipitation for Globo23 compared to Globo17. Side plots show the zonal average: values >0 indicate a prevalence of areas where Globo23 produced a lower MAE, thus performing better. The maps display weekly average values obtained by averaging, for all the initialization dates within DJF, the multi-year climate average of the error calculated between the ensemble mean and the matching ERA5 precipitation.

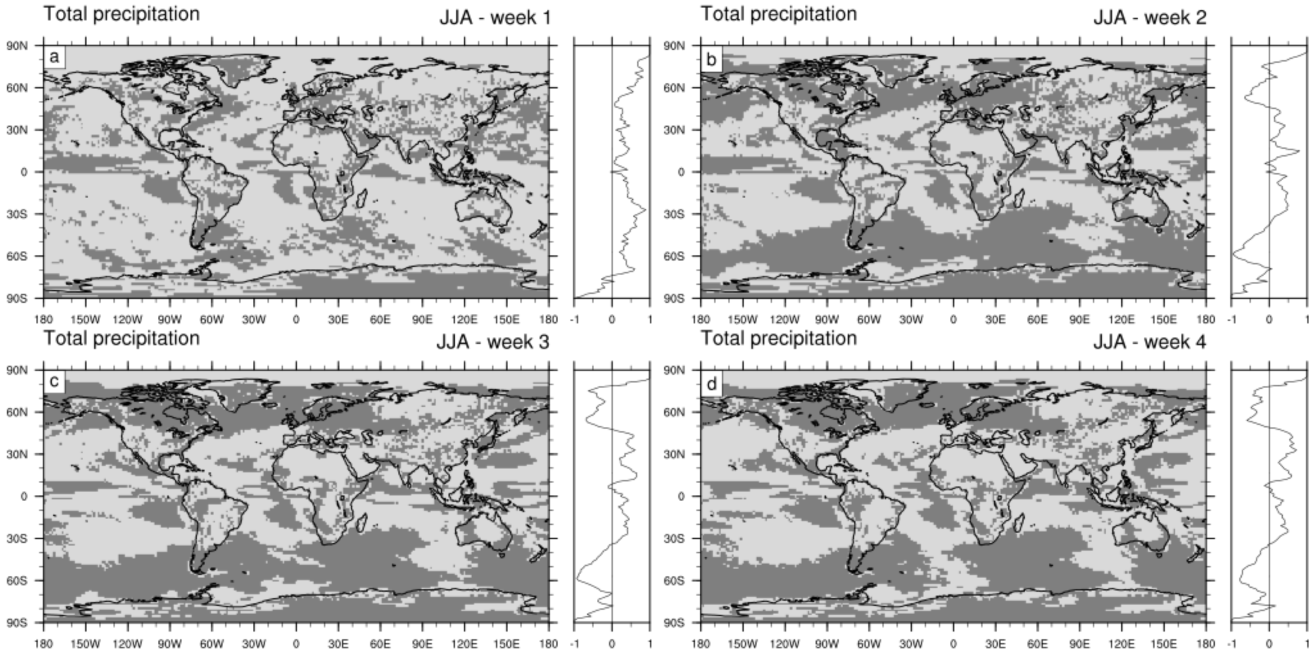

Figure 4: As Figure 3 but for JJA.

The main outcome of the MAE comparison is that Globo23 performs better across most of the global domain in the first week of both season (Fig. 3a and 4a). Beyond week 1, patterns remain overall consistent until the end of the forecasting range demonstrating that, for precipitation, the error saturates before other variables and confirming this as the most challenging variable in terms of predictive skill also on the S2S scale.

Also, during DJF (Fig. 3), Globo23 outperforms Globo17 over the tropical and subtropical regions (up to ~30° N/S lat), suggesting a possible improvement in deep convection precipitation, which is the primary source of rainfall at those latitudes. A marked deterioration is observed over the Southern Oceans. To the North, areas with greater error include Eurasia, the North Atlantic, and the purely polar region.

During JJA (Fig. 4) the Southern Ocean exhibits greater errors than in DJF. The lower MAE of Globo23 again affects the entire intertropical belt extending further North over some areas as, for instance, the westernmost portion of the Euro-Mediterranean region; a greater error in the Globo23 reforecast precipitation persists over the North Atlantic.

The Anomaly Correlation (AC) coefficient, a basic deterministic measure of the model predictive skill, was calculated for several variables and is shown, for both model versions, in Figure 5 and 6 for 2m temperature averaged on week 1 and week 4 of DJF and JJA. For each initialization date, the anomaly was generated by subtracting the mean reforecast climate of the remaining 19 (29) Globo23 (Globo17) reforecast years (leave-one-out approach) from the ensemble mean of the reforecast of the selected initialization date. This forecast anomaly was then compared with the matching anomaly from ERA5 reanalyses. Each figure, therefore, represents the seasonally averaged AC calculated from each individual ensemble reforecast initialized during the selected season.

Although the differences shown in Figure 5 are rather light, and the AC patterns are very similar especially in week 1, both weeks shows a generally better performance by Globo23 (also detectable through the zonal average to the right of each panel). In week 4, some areas stand out where the AC value has improved, including most of the European continent. Some zones still exhibit values close to 0 or slightly negative, such as parts of Africa and the Southern pole areas.

In JJA (Figure 6), the improvements in week1 cover larger areas although the Western Pacific is affected by lower skill. On week 4, the AC shows some better results for the Globo23 dataset over Europe again and on some African area; south of the Sahara the temperature skill improvement is related to a better modelled precipitation regime. Some lack of skill in instead observed over Australia and the central and eastern areas of Russia.

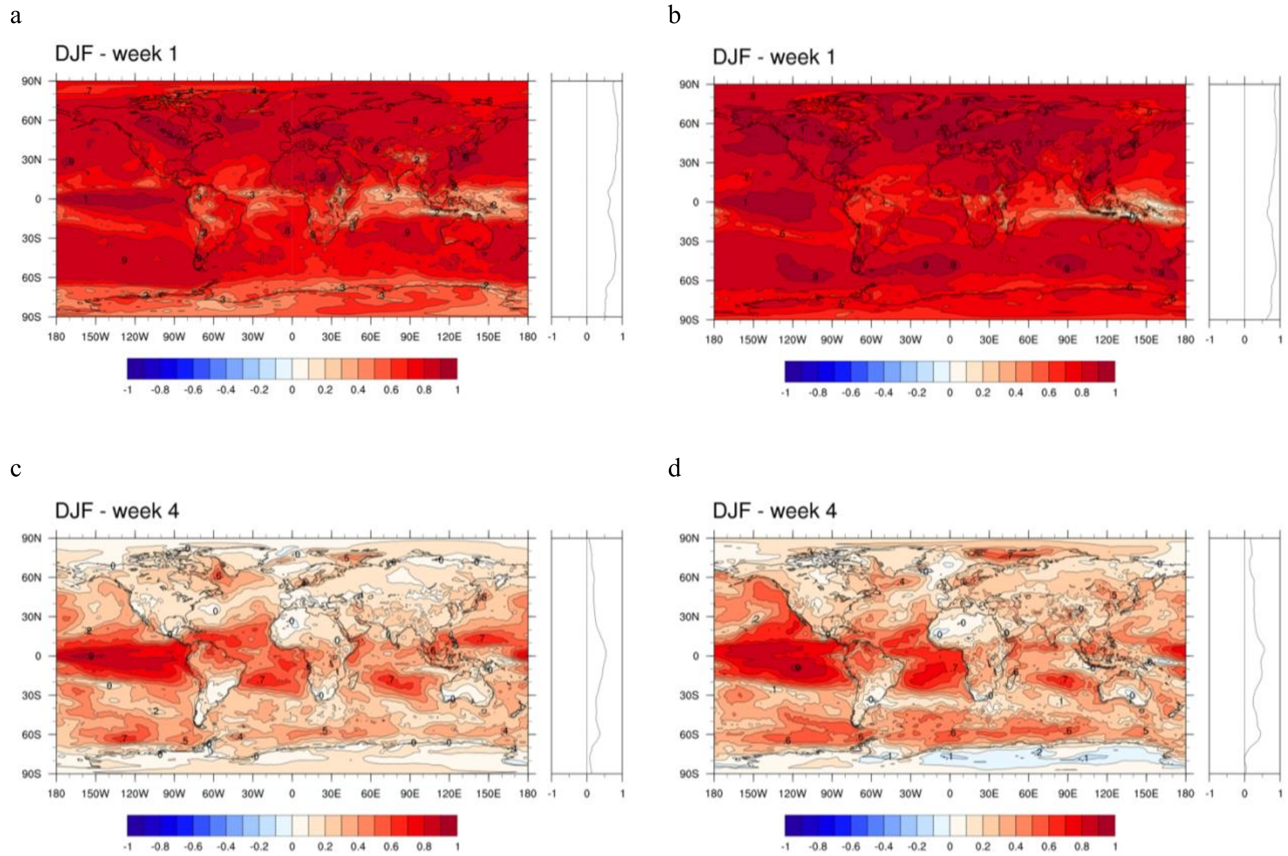

Figure 5: Week 1 (a, b) and 4 (c, d) averages of Anomaly Correlation (AC) of 2-m temperature for the winter months (DJF) from the reforecasts performed with Globo17 (a, c) and Globo23 (b, d)

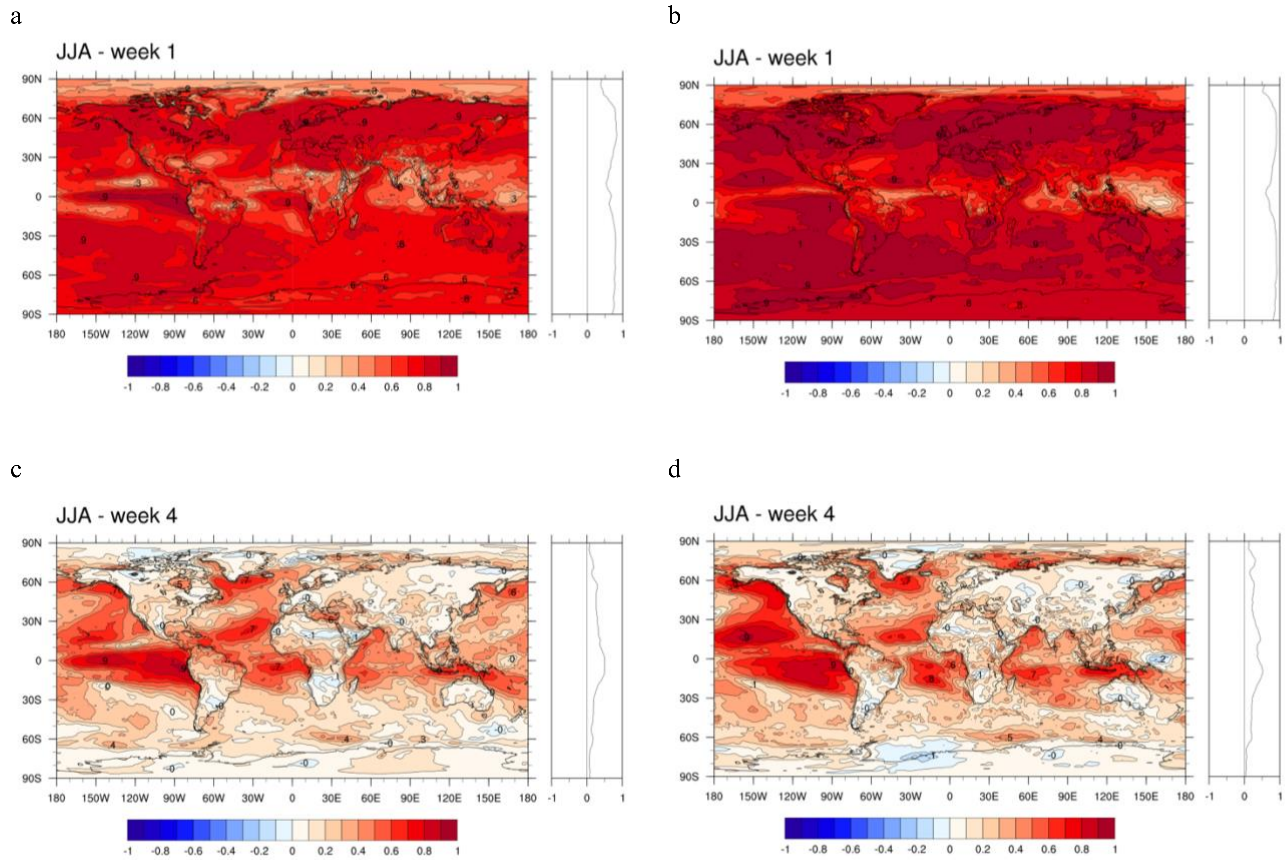

Figure 6: As Figure 5 but for JJA.

c) Model development
Several tests are currently being performed to both fixing some minor issue detected in the reforecasts and to further develop the model. In this test/development activity, the reforecasts produced in the framework of GLEREF23 are the reference simulations which new test simulations are compared with. For instance, a recent improvement in the orographic parameterization drag is being tested on Globo. Similarly, for a technical development activity which aimed at improving the model efficiency. Both these works were presented at the EGU25 conference and are referenced in the next section.

References

Hitchcock, P., Butler, A., Charlton-Perez, A., Garfinkel, C. I., Stockdale, T., Anstey, J., Mitchell, D., Domeisen, D. I. V., Wu, T., Lu, Y., Mastrangelo, D., Malguzzi, P., Lin, H., Muncaster, R., Merryfield, B., Sigmond, M., Xiang, B., Jia, L., Hyun, Y.-K., Oh, J., Specq, D., Simpson, I. R., Richter, J. H., Barton, C., Knight, J., Lim, E.-P., and Hendon, H.: Stratospheric Nudging And Predictable Surface Impacts (SNAPSI): a protocol for investigating the role of stratospheric polar vortex disturbances in subseasonal to seasonal forecasts, Geosci. Model Dev., 15, 5073–5092, https://doi.org/10.5194/gmd-15-5073-2022, 2022.

Lavers, D.A., Simmons, A., Vamborg, F. & Rodwell, M.J.(2022) An evaluation of ERA5 precipitation for climate monitoring. Quarterly Journal of the Royal Meteorological Society, 148(748) 3124–3137. Available from: https://doi.org/10.1002/qj.4351

Lawrence, Z. D., Abalos, M., AyarzagÃ¼ena, B., Barriopedro, D., Butler, A. H., Calvo, N., de la CÃ¡mara, A., Charlton-Perez, A., Domeisen, D. I. V., Dunn-Sigouin, E., GarcÃ-a-Serrano, J., Garfinkel, C. I., Hindley, N. P., Jia, L., Jucker, M., Karpechko, A. Y., Kim, H., Lang, A. L., Lee, S. H., Lin, P., Osman, M., Palmeiro, F. M., Perlwitz, J., Polichtchouk, I., Richter, J. H., Schwartz, C., Son, S.-W., Statnaia, I., Taguchi, M., Tyrrell, N. L., Wright, C. J., and Wu, R. W.-Y.: Quantifying stratospheric biases and identifying their potential sources in subseasonal forecast systems, Weather Clim. Dynam., 3, 977-1001, https://doi.org/10.5194/wcd-3-977-2022, 2022.

List of publications/reports from the project with complete references

- Davoli, G., Mastrangelo, D., Cherchi, A., and Alessandri, A.: A new orographic drag parameterization package for the GLOBO model: implementation and evaluation, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-872, https://doi.org/10.5194/egusphere-egu25-872, 2025.

- Guibert, D., Lucido, L., Raffin, E., Bellucci, A., Davini, P., Fabiano, F., Galizia, A., Lembo, V., and Mastrangelo, D.: Technical improvements with the GLOBO atmospheric model, through collaboration with ESiWACE3, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-17712, https://doi.org/10.5194/egusphere-egu25-17712, 2025.

Future plans

There is no Special Project linked to GLEREF23 currently running.