



Documentation of the METEO-FRANCE seasonal forecasting system 8

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Executive summary

Météo-France has been involved in real-time seasonal forecasting activities since the late 1990s, first as part of the Eurosip consortium, and now in the framework of Copernicus Climate Change Services (C3S). As part of the Eurosip consortium, the seasonal forecast system at Météo-France has evolved through the development of several consecutive versions, including the latest developments of the components of the coupled GCM as well as new ensemble initialization and generation techniques. In the framework of C3S contract C3S-433, Météo-France seasonal forecasting System 6 was developed. Météo-France System 7 was then introduced in autumn 2019.

The aim of this document is to present the forthcoming Météo-France System 8, which is planned to be operational in summer 2021. We will first present a brief overview of this new system and describe the main features of each individual component. The third section of this document presents the main novelty of System 8, the coupled initialization strategy. We then describe in detail the ensemble generation strategy (similar to Systems 6 and 7), and provide an overview of the workflow procedures, from initialization to post-processing (section 5). Technical details and the links to the scripts used on the Météo-France machines are listed in an Appendix to this documentation.

This document does not address the atmosphere and ocean data assimilation techniques which are carried out respectively by ECMWF and Mercator Ocean International, but describes the coupled relaxation experiment designed to derive the initial conditions for the coupled model from these separate reanalysis datasets.



1. Basic Facts

The table below gives the main features of Météo-France System 8.

Table 1 : basic facts

Météo-France System 8	
Ensemble version	
Ensemble version identifier code	CNRM-CM 6
Short description	Global ensemble system using a lagged-average and a stochastic scheme to take into account initial state and model uncertainties. Based on 51 members, run once a month up to 7 months.
Status	Operational
Data time of the first forecast run	01/06/2021
Configuration of the EPS	
Is the model coupled to an ocean model?	Yes from day 0
Short description of the ocean model	NEMO v3.6 , ORCA 0,25° grid, 75 model levels
Is the model is coupled to a sea ice model?	Yes
Short description of the sea ice model	GELATO v6 (Salas y Melia, 2002), embedded in the ocean model. GELATO includes multi-category ice and an elastic-viscous-plastic rheology.
Is the model coupled to a wave model?	No
Horizontal resolution of the atmospheric model	TL359
Number of atmospheric model levels	137
Top of the model	0.01 hPa
Type of model levels	Hybrid sigma-pressure
Forecast length	7 months
Run frequency	Once a month
Is there an unperturbed control forecast included	No



Number of perturbed ensemble members	51
Integration time step	Atmosphere/surface: 10' Ocean/sea-ice: 15' Coupling frequency: 1 hour
Initial conditions and perturbations	
Data assimilation method for analysis	Coupled initialization run nudged towards ERA5T in the atmosphere and Mercator Ocean International (MOI) operational analyses in the ocean. Sea ice initial conditions are provided by a separate NEMO-GELATO ORCA0.25 forced run nudged toward the same MOI analyses.
Resolution of the model used to generate Control Analysis	tl359l137r (atmosphere, surface) and ORCA0.25° (ocean, sea ice)
Ensemble initial perturbation strategy	Lagged-average and in-run atmospheric perturbations
Model uncertainties perturbations	
Is model physics perturbed?	No
Do all ensemble members use exactly the same model version?	Yes
Is model dynamics perturbed?	Yes (Batté and Déqué 2016)
Are the above perturbations applied to all forecast members?	Yes
Surface boundary perturbations	
Perturbation to sea surface temperature?	No
Perturbation to soil moisture?	No
Perturbation to surface stress or roughness?	No
Any other surface perturbation?	No
Other details of the models	
Description of the model grid	Reduced Gaussian Grid
List of model levels	From top to bottom (Pa) 1, 3, 4, 6, 8, 12, 16, 22, 29, 38, 49, 62, 78, 97, 119, 145, 175, 210, 249, 293, 343, 398, 460, 529, 604, 687, 777, 875, 982, 1097, 1221, 1355, 1498, 1651, 1813, 1987, 2171, 2366, 2572, 2789, 30178, 3258, 3511, 3776, 4053, 4343, 4645, 4960, 5286, 5626, 5977, 6342,



	6719, 7112, 7520, 7945, 8388, 8851, 9335, 9842, 10371, 10924, 11502, 12105, 12735, 13392, 14077, 14791, 15534, 16309, 17116, 17955, 18829, 19737, 20681, 21662, 22680, 23738, 24836, 25976, 27157, 28382, 29652, 30967, 32329, 33739, 35199, 36709, 38271, 39885, 41554, 43278, 45059, 46897, 48795, 50750, 52757, 54803, 56877, 58968, 61066, 63162, 65244, 67304, 69330, 71316, 73253, 75134, 76953, 78705, 80386, 81993, 83524, 84977, 86352, 87650, 88871, 90017, 91090, 92092, 93026, 93895, 94702, 95451, 96143, 96783, 97374, 97919, 98420, 98881, 99305, 99695, 100052, 100379, 100679, 100954, 101205
What kind of large scale dynamics is used ?	Spectral semi-lagrangian
What kind of boundary layer parametrization is used ?	Cuxart, Bougeault and Redelsperger (2000)
What kind of convective parametrization is used ?	Gueremy (2011), Piriou et al. (2007)
What kind of large scale precipitation scheme is used ?	Lopez (2002)
What cloud scheme is used ?	Sommeria and Deardorff (1977)
What kind of land-surface scheme is used ?	Explicit multilayer snow and soil scheme as described in Masson et al. (2013)
How is radiation parametrized ?	Long wave radiation : Mlawer et al. (1997) Short wave radiation : Morcrette (1990)
Re-forecast configuration	
Number of years covered	26 years (1993-2018)
Produced on the fly or fixed re-forecasts ?	fixed re-forecasts
Frequency	monthly
Ensemble size	25 members
Initial conditions	Coupled initialization run nudged towards ERA5 in the atmosphere and MOI reanalyses in the ocean. Sea ice initial conditions are provided by a separate NEMO-GELATO ORCA0.25 forced run nudged toward the same MOI reanalyses.



Is the model physics and resolution the same as for the real-time forecasts?	Yes
Is the ensemble generation the same as for the real-time forecasts?	Yes



2. Modeling components of the forecast system

2.1 Introduction

As any long-range forecast system, Météo-France system consists of an ensemble forecast operational production together with an ensemble re-forecast dataset, also called hindcast.

Both ensembles come from integrations of the global coupled atmosphere/ocean/sea ice/land surface model CNRM-CM illustrated in Figure 1.

CNRM-CM is run at Météo-France on the **belenos** and **taranis** supercomputers.

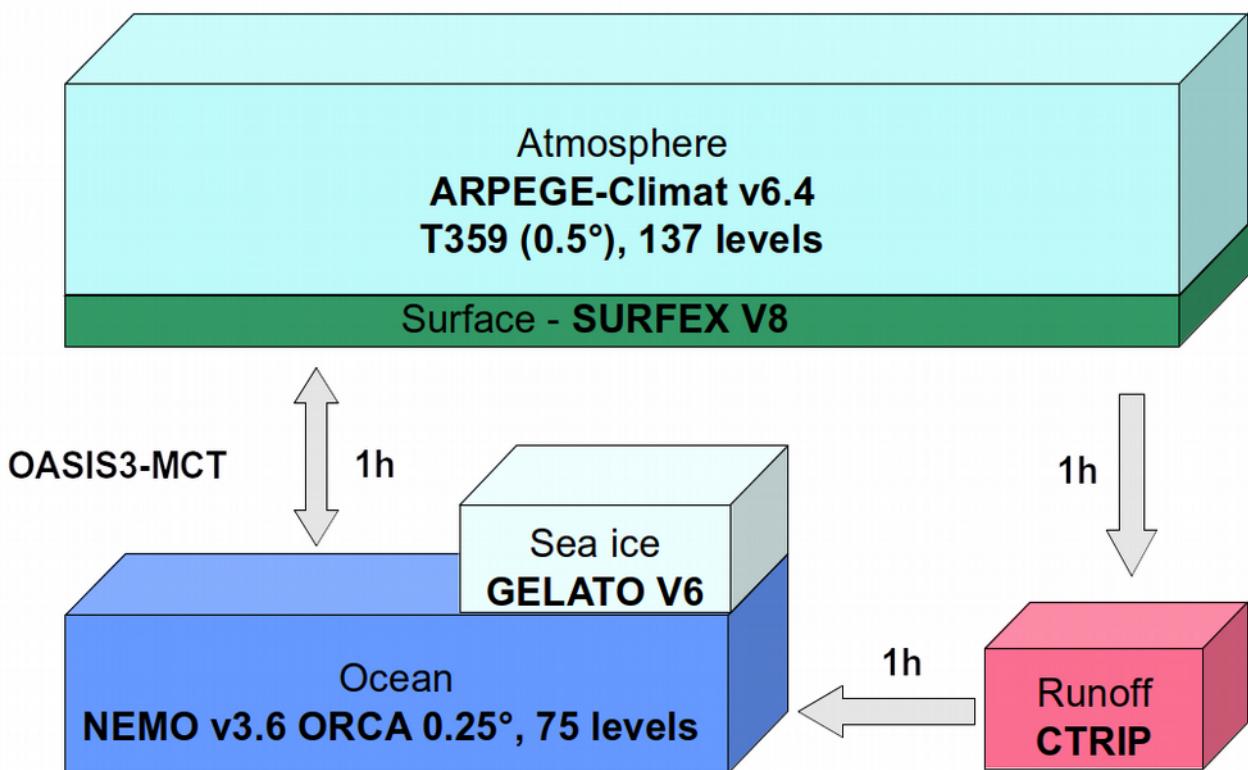


Figure 1 - CNRM-CM model components of the seasonal forecast system

2.2 The atmospheric model, ARPEGE V6.4



ARPEGE-IFS forecast model has been jointly developed by ECMWF and Météo-France for numerical weather prediction since the late 1980s (Courtier and Geleyn, 1988). A climate version of this model was especially designed for climate change and seasonal predictability experiments by Déqué et al. (1994). The weather and climate versions have evolved in parallel since this date, including major improvements like semi-lagrangian advection and high performance parallelization. ECMWF and Météo-France use different schemes for the physical parameterizations of the model. As for System 6 and 7, System 8 uses the physical parameterization schemes developed for the CMIP6 version of the CNRM-CM model (Volodire et al. 2019). The atmospheric component ARPEGE-Climat V6.3 is described in detail in Roehrig et al. (2020). With respect to the previous seasonal forecasting System 7, some changes have been implemented for System 8 which uses ARPEGE-Climat V6.4:

- Vertical resolution has been enhanced to 137 levels, using the same level definition strategy as for the IFS, described here: <https://www.ecmwf.int/en/forecasts/documentation-and-support/137-model-levels> ;
- Changes were made to the implementation of the surface momentum flux due to orography based on Beljaars (2004);
- Improvements to the code were included for better water conservation, subgrid-scale variability of surface fluxes, and turbulence in stable cases.

2.3 The ocean model NEMO V3.6 and sea-ice model GELATO V6

No changes with respect to the ocean and sea-ice models in System 7 were implemented for System 8.

The ocean engine of NEMO (Nucleus for European Modelling of the Ocean) is a primitive equation model adapted to regional and global ocean circulation problems. It is intended to be a flexible tool for studying the ocean and its interactions with the other components of the Earth climate system over a wide range of space and time scales. Prognostic variables are the three-dimensional velocity field, a non-linear sea surface height, the conservative temperature and the absolute salinity. In the horizontal direction, the model uses a curvilinear orthogonal grid and in the vertical direction, a full or partial step z -coordinate, or s -coordinate, or a mixture of the two. The distribution of variables is a three-dimensional Arakawa C-type grid. Various physical choices are available to describe ocean physics, including TKE, and GLS vertical physics. Within NEMO, the ocean is interfaced with a sea ice model (GELATO V6), and, via the OASIS coupler, with the atmospheric model ARPEGE V6.4.

A more detailed presentation of NEMO is available here:



<https://forge.ipsl.jussieu.fr/nemo/wiki/Users>

The reference paper for the current version of GELATO is Salas y Mélia (2002). Details on new developments in the GELATO model since this reference paper are provided in Volodire et al. (2019). A different tuning of the turbulent vertical diffusion is used, with increased coefficients for thermodynamic and TKE (through factors included in the namelist) versus the dynamic.

2.4 The Land Surface model Surfex V8.0 and river routing model CTRIP

The same version of Surfex than for System 7 is used for System 8.

Surfex (Surface Externalisée, in French) is a surface modeling platform developed by Météo-France in cooperation with the scientific community.

Surfex is composed of various physical models for natural land surface, urbanized areas, lakes and oceans. It also simulates chemistry and aerosols surface processes and can be used for assimilation of surface and near surface variables.

Surfex has its own initialization procedures and can be used in stand alone mode and coupled to an atmospheric model.

In Surfex, each model grid box is represented by four surface types : sea or ocean, water bodies (lakes, ...), urban areas and nature (soil and vegetation). Each surface type is modelled with a specific surface model and the total flux of the grid box results from the addition of the individual fluxes weighted by their respective fraction.

A more detailed presentation of Surfex is available here:

<http://www.umr-cnrm.fr/surfex/>

More details on the latest version of Surfex and the ISBA-CTRIP land surface and river routing models can be found in Volodire et al. (2017) and Decharme et al. (2019).

2.5 The coupler OASIS3-MCT

OASIS is the coupler that manages the exchange of information between the three aforementioned model groups.

In 1991, CERFACS started the development of a software interface to couple existing ocean and atmosphere numerical General Circulation Models. Today, different versions of the OASIS coupler are used by about 45 modelling groups all around the world on different computing platforms.



OASIS sustained development is ensured by a collaboration between CERFACS and the Centre National de la Recherche Scientifique (CNRS).

The current OASIS-MCT (Volodire et al. 2017) internally uses MCT, the Model Coupling Toolkit2 (Larson et al. 2005, Jacob et al. 2005), developed by the Argonne National Laboratory in the USA. MCT implements fully parallel regridding, as a parallel matrix vector multiplication, and parallel distributed exchanges of the coupling fields, based on pre-computed regridding weights and addresses. Its design philosophy, based on flexibility and minimal invasiveness, is close to the OASIS approach. MCT has proven parallel performance and is, most notably, the underlying coupling software used in National Center for Atmospheric Research Community Earth System Model (NCAR CESM).

OASIS-MCT is a portable set of Fortran 77, Fortran 90 and C routines. Low-intrusiveness, portability and flexibility are OASIS-MCT key design concepts. After compilation OASIS-MCT is a coupling library to be linked to the component models, and which main function is to interpolate and exchange the coupling fields between them to form a coupled system. OASIS-MCT supports coupling of 2D logically-rectangular fields but 3D fields and 1D fields expressed on unstructured grids are also supported using a one-dimension degeneration of the structures. Thanks to MCT, all transformations, including regridding, are performed in parallel on the set of source or target component processes and all coupling exchanges are now executed in parallel directly between the component processes via Message Passing Interface (MPI). OASIS-MCT also supports file I/O using netcdf.

The new version, OASIS3-MCT supports coupling exchanges between components deployed in much more diverse configurations than before. It is of course possible to implement coupling exchanges between two components corresponding to two different executables running concurrently on separate sets of tasks, as before, but also between two components running concurrently on separate sets of tasks within one same executable, or between different sub-components defined on separate or overlapping sets of tasks within one executable. It is also now possible to have some or all tasks of a component not participating to the coupling exchanges.

In spite of the significant changes in underlying implementation, usage of OASIS3-MCT in the codes has largely remained unchanged with respect to previous OASIS 3 versions. To communicate with another component, or to perform I/O actions, a component model needs to include few specific calls of the Application Programming Interface (API) OASIS MCT coupling library.

A more detailed presentation of OASIS is available here:

https://verc.enes.org/oasis/oasis3-mct_3-0-official-release



2.6 ECLIS

As for Systems 6 and 7, the ECLIS (Environment for CLImate Simulations) environment is used to define and run the seasonal forecast experiments. The different model components (coupler included) each have a namelist, almost all have a restart file, and most have their own output format. Several binaries related to each model group are used. This information is stored in a so-called param file used by ECLIS. The binaries are launched together using a MPI message passing software. A CNRM-CM run is made of an automated sequence of "macro-jobs", where each "macro-job" iterates on a number of months.

2.7 XIOS

As for System 7, System 8 uses the XIOS output manager for online processing of model component outputs (Meurdesoif, 2018). The XIOS software manages the output of each model on each process, and builds a single output file onto the disk. By means of xml files, many post-processing operations can be requested directly to XIOS (e.g. time sampling and/or averaging, regridding, vertical interpolation, ...). More details on the use of XIOS in System 8 are provided in section 5.3 and the Appendix.

2.8 Boundary forcings

Green house gas concentrations, ozone, solar forcing are defined as for the CNRM-CM6-1 model run for the CMIP6 experiments up to 2014, and then follow the ssp370 scenario.

A climatology of monthly aerosol optical depths is computed over the 1995-2014 period from a prior run using the interactive aerosols TACTIC_v2 scheme (Michou et al. 2020). Volcanic aerosols use a longer climatology (1850-2014) from CMIP6.

For full details on the boundary forcings for CNRM-CM6, please refer to section 3.2 in Voldoire et al. (2019).



3. Coupled initialization strategy

3.1 Overview

Arguably the most significant change with respect to System 7, Météo-France seasonal forecast System 8 is initialized from a coupled nudged initialization run using the same model version as for the numerical forecasts. The intent is to reduce initialization shock due to model inconsistencies between the ocean and atmosphere reanalyses and operational analyses and the coupled model itself, and also ensure an improved consistency between re-forecast and forecast initial conditions. However, a strong relaxation is used to benefit from the information provided by more elaborate assimilation techniques in the ECMWF and Mercator Ocean International reanalyses and analyses.

This section describes in detail the methodology to define initial conditions for all components of the re-forecast and forecast.

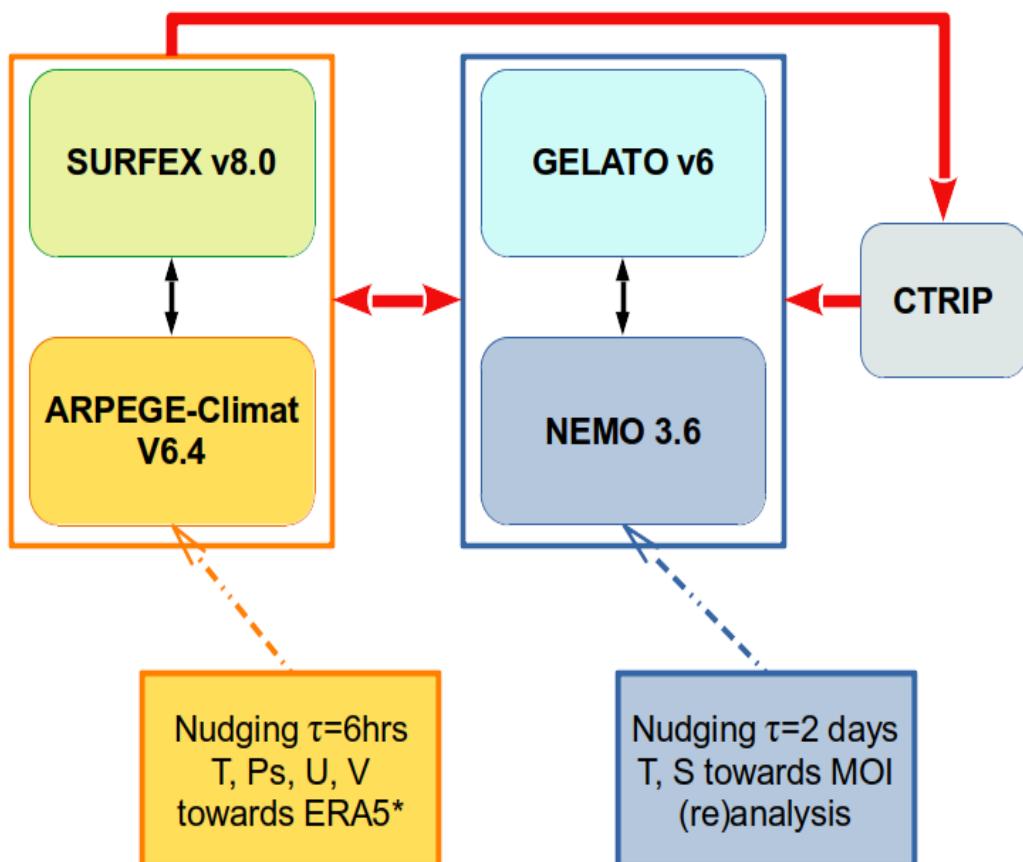


Figure 2: Schematic of the coupled nudged integration of CNRM-CM used to derive initial conditions for System 8.



The initialization run is a continuous integration of the CNRM-CM coupled climate model over the 1992-present period, with both atmospheric and ocean nudging towards reanalysis / analysis fields. Restart files for each coupled model component (except for GELATO, see later) are output during this coupled integration, to serve as initial conditions for the re-forecast and forecast for System 8.

Figure 2 illustrates the coupled initialization run methodology: from 1992 to 2018, the ARPEGE-Climat atmospheric component is strongly nudged (6 hours e-folding time) in spectral space for horizontal winds, temperature and surface pressure towards ERA5 reanalysis fields interpolated onto the ARPEGE t1359l137 geometry over the re-forecast period, and NEMO is strongly nudged (2 days e-folding time) towards temperature and salinity fields upscaled from the Mercator Ocean International GLORYS12V1 reanalysis.

In the atmosphere, a vertical profile of nudging strength is introduced so as to dial nudging down to zero in the atmospheric boundary layer, except for the first vertical level at 10m where a 24h nudging strength is applied for temperature and winds, in order to avoid a long term energy drift in the continental subsurface due the surface energy imbalance induced by the nudging. As a sponge layer in the mesosphere is implemented in ARPEGE, nudging is similarly reduced to zero in the uppermost levels of the atmosphere. No nudging of specific humidity to ERA5 was introduced, as this was found to have adverse effects on the evaporation and precipitation budget of the model.

In the ocean, we use a 2-day relaxation strength with the same settings as used at Mercator Ocean International to prepare initial conditions for System 7: temperature and salinity profiles are relaxed for the 75 model levels, and no relaxation is applied within 225 kilometers of coastlines, nor in the presence of sea ice.

Sea ice in the GELATO model adjusts to the atmosphere and ocean, as no constraint to sea ice concentration or thickness is applied. The resulting sea ice conditions are not used to initialize System 8 to avoid adverse effects. Instead, GELATO is initialized using a forced NEMO-GELATO run prepared by Mercator Ocean International as for System 7.

On the other hand, the land surface is initialized from the coupled integration SURFEX restart files. A correction of the precipitation fluxes in the SURFEX initial conditions is applied following the methodology described in Ardilouze et al. (2019), which uses a grid point multiplicative coefficient to correct the precipitation feeding the land surface model, based on the ratio of monthly mean precipitation in the MSWEP dataset (Beck et al., 2017) with the monthly mean precipitation in a preliminary nudged run with the coupled system. The coefficient values are limited to the [0.5; 2] interval to avoid instabilities.

So as to use a continuous run and possibly reduce spin-up effects, the coupled integration was run during a transition period covering 2019 and 2020, described in section 3.3.



3.2 Re-forecast period (1993-2018)

The nudging fields for ARPEGE come from ERA5 reanalyses, extracted at 6-hourly frequency from 1 December 1992 to the 1 January 2019. The files are extracted from the Climate Data Store and converted into ARPEGE format. The nudging fields for NEMO are provided by Mercator Ocean International from the GLORYS12V1 reanalysis.

3.3 Re-forecast to forecast transition (2019-2020)

The GLORYS12V1 ocean reanalysis ends in 2018. Starting from January 2019, GLORYS12V1 files to nudge NEMO are therefore replaced by upscaled PSY4V3R1 files from the operational analysis prepared by Mercator Ocean International. The files are also retrieved from hendrix and follow a similar structure to the GLORYS12V1 files listed in section 3.2.

For the atmosphere, ERA5 nudging files are used for the coupled integration over 2019-2020 as for the re-forecast period.

3.4 Forecast period (2021-present)

So as to provide initial conditions for the forecasts as close as possible to the re-forecasts, and avoid discrepancies, the same coupled initialization strategy is used.

The coupled nudged integration is therefore extended each month, using the following nudging fields:

- For the atmosphere, if available in due time, ARPEGE nudging files are derived from the near-real time reanalysis ERA5T, following the same procedure as for ERA5 in the re-forecast initialization.
- For the ocean, the NEMO nudging files are provided by Mercator Ocean International as daily upscaled temperature and salinity fields from the PSY4V3R1 operational analysis, prepared on the ORCA 0.25° grid.



4. Generation of stochastic perturbations

4.1 Introduction

Atmospheric stochastic perturbations were introduced in Météo-France System 5. A detailed description of the technique can be found in Batté and Déqué (2016). The role of stochastic perturbations in the forecast system is threefold:

1. to generate equi-probable ensemble members
2. to attempt to partly correct the model imperfections (in particular the systematic error)
3. to address rare spurious model simulation failures/crashes.

In earlier forecast systems item 1 was managed by introducing a perturbation in an initial atmospheric situation, or by lagging the initial situation by a few days. Item 2 was taken into account by considering forecast anomalies with respect to a model climatology (this is still the case in the new system). Item 3 was managed by slightly modifying the horizontal diffusion coefficient temporarily.

Three ingredients are necessary to activate the stochastic perturbation system in the re-forecast as well as in the forecast production:

1. the perturbation fields
2. the random calendars
3. the definition of the ensembles.

These 3 ingredients are then used in the model script.

4.2 Generating the perturbation fields

This is a hard and complex task. Each time the model or the ingredients (e.g. the initial situations) are changed, the perturbation fields need to be re-created. This model dependency is similar to the dependency between forecasts and re-forecasts. It is, however, not so crucial: a slight change like a change in computer should not make regeneration necessary.

The fundamental idea is that a model is not perfect, and its equations bear errors:

```
dX/dt=model_equations(X,t)  
=true_equations(X,t)+model_errors(X,t)
```



where X is the vector describing the prognostic variables (temperature, moisture, wind and surface pressure) and t is time. We have coded $\text{model_equations}(X,t)$ as we ignore $\text{true_equations}(X,t)$ or, equivalently, $\text{model_errors}(X,t)$.

If we can estimate $\text{model_errors}(X,t)$ for a set of re-forecasts, we cannot fully correct a forecast, but we can re-inject the past errors at random to take into account the uncertainty about our $\text{model_equations}(X,t)$.

A way to estimate this error is to carry out a set of preliminary single-member re-forecasts during which the model is linearly relaxed (or nudged) toward the true trajectory, here the ERA5 reanalysis. There is a big dilemma:

- if the relaxation is strong, the model will follow ERA5 closely, but the errors will be errors of a short-range forecast (model starting from an analysis)
- if the relaxation is weak, the model will be in a similar state as in a standard seasonal forecast, but the relaxation terms will correspond to a small fraction of the error.

The method depends on the frequency of the random drawings and the intensity of the perturbation, which is linked to the relaxation time. So as to generate ensemble spread, random drawings are done every day. The choice of the relaxation time is less obvious. In previous studies, we have tried values between 1 and 100 days. Using a 6 h relaxation time for both divergence and vorticity produces dynamical imbalances in the model, because the normal modes of the ARPEGE and ECMWF models are different. Values above 100 days are useless, as we want to account for model error during the first months of the forecasts. While System 6 used sequences of perturbations and random drawings every 5 days, and therefore a 10 day relaxation time, for System 8 a 40 day relaxation time was chosen since random perturbations are changed every day. This is slightly longer than for System 7 (30 days).

The nudged experiment is based on 12×26 7-month simulations. There are indeed 12 calendar months and 26 available re-forecast years (1993-2018). Note that a start date on 01 December 2018 implies that the model is nudged toward ERA5 till June 2019. The nudged simulations are as close as possible to members 001 of the re-forecasts, with four differences

1. the model does not include stochastic perturbations
2. the model is nudged toward 6-hourly ERA5 prognostic variables
3. the postprocessing is highly simplified
4. each day, the differences ERA5 minus model variables, times the relaxation factor, are saved in a file.



Note that because the surface schemes are based on different empirical approaches in ARPEGE and in ERA5, the relaxation is progressively damped down to zero in the lowest 31 vertical levels (the lowest 25 levels, from about 1600m, being not relaxed at all). A symmetrical treatment is applied to the highest 5 levels, since a specific relaxation is applied in the model in the mesospheric layer.

4.3 Random calendar and definition of ensembles

The random choice of a perturbation is done by selecting an arbitrary day and year (not calendar month). This means that the random choice of the perturbations for a given month during a forecast can be described by a random calendar, because each day we need a new perturbation. Random calendars are created once and for all and are valid whatever a re-forecast or a forecast, whatever the initial month or the year.

A random calendar is a monthly calendar: it allows to associate to each day of the month a random day with the constraint that:

- the same calendar month is used
- the year is taken at random among the years of the nudging phase (1993-2018); in the re-forecast phase this introduces a small (not significant) positive bias in the scores by the fact that nearly 4% of the perturbations use observed data from the month to be predicted.
- each day a new random perturbation is drawn.

A random calendar is a text file called `1nRANDOM$NN` where NN is the member number, including 32 lines assigning each day of the month to a random correction file. More details are provided in the Appendix at the end of this document.

Note that much more than 51 independent calendars can be generated without associating the same random date to a given date. Three groups of calendars (NUMR = a, b, c) with 51 members each are prepared. The model uses series “a”. When it crashes for a given member because of a numerical (reproducible) instability, it uses series “b” during that month, then goes back to series “a”. Just in case, a third series of calendars is available for a third attempt. This method of “butterfly effect” can fail if the numerical explosion occurs during the first day of the month. In this case, a recovery script restarts the model one month earlier and replaces series “a” by series “b”. The series number is automatically reset to “a” at the end of a successful month.

The case of the first partial month (members others than 001) needs a specific care. As there is a single member for the nudged simulations (see section 4.2 above), one has to use for the runs starting at the end of a given month, the perturbation of the month after.



Once the perturbations and the calendar exist, one has to decide which calendar is used for which ensemble member. To simplify the process the choice will be the same whatever the start date.

4.4 Model implementation

With the ingredients described above, the implementation in the model script (embedded in ECLIS) used for the re-forecasts as well as for the forecasts is straightforward:

At the beginning NUMR=a and NUMR is reset to “a” at the end of a successful run. If the run fails, NUMR is set to “b”, then to “c” using the ECLIS running environment (see section 5.2) when the model crashes. Then, the model is automatically re-launched by the script from the beginning of the current month.

In case of a computer system failure (MPI trouble, node failure, preemption ,...), this procedure (NUMR change) is useless, the model being automatically re-launched from the beginning of the current month without any change in the script. This type of failure occurs much more often than the numerical explosions.

The perturbation files are stored in a huge directory (about 1 TB for one calendar month). It is saved on a long-term storage machine (hendrix machine at Météo-France, ecfs at ECMWF), but is copied on the high performance computer disks before a forecast or a re-forecast starts.

The model script needs to know the current month MM and the true month MT to properly manage the random calendars (from the file rand_calendm\$MM_n51_\$NUMR.tar, see section 4.3). In case of a member different from the first one, there is a lagged start date; as explained in section 4.3, MT is the month after only for the lagging month, and equal to the current month MM thereafter.

Each member \$MEMBER is assigned a calendar number \$NN. This calendar is extracted from the right tar archive and the file 1nRANDOM\$NN is executed. This file creates symbolic links between existing perturbations (with random dates) and daily files which will be read each day by the atmospheric model during the run.



5. Overview of the workflow

This section provides an overview of the workflow for the forecast and re-forecast ensemble production. More details, including full links to the scripts used, are provided in the Appendix to this documentation.

5.1 Initialization and ensemble generation

A forecast ensemble is based on 51 individual model integrations. These 51 members of the forecast come from a combination of 3 batches of model integrations (called runs). The batches differ by the initial dates, which are on two Thursdays of the previous month and the 1st of the current month. Within a given batch, the forecast members differ by the application of random perturbations during the integration following the stochastic dynamics technique (see section 4), thus generating the ensemble spread.

Figure 3 shows an illustration of how the 51 members of the forecast are generated.

The start dates of month M forecasts, as stated above, correspond to:

- Two Thursdays from the second half of month M-1
- The 1st of month M

The initial conditions for ARPEGE, SURFEX, NEMO, CTRIP and OASIS are provided by the coupled nudged run described in section 3.4. GELATO is initialized using a forced NEMO-GELATO run prepared by Mercator Ocean International as for System 7. Prior to the operational forecast, the coupled integration is extended using T, S nudging fields for NEMO from Mercator Ocean International and atmospheric nudging fields for ARPEGE derived from the ERA5T reanalysis.

As soon as the ERA5T reanalysis files are available, the nudged initialization run is extended to cover the target start date. Typically two days after the first start date, 25 integrations of the model begin, each one with a distinct set of stochastic dynamics perturbations. Two days after the second one, 25 more integrations are initiated similarly. The last integration (starting on the 1st day of the month) is launched typically on the 3rd of the month at the latest. In case the ERA5T reanalysis is not available as expected for this last member, it will be replaced by the IFS operational analysis so as to deliver a forecast on time.

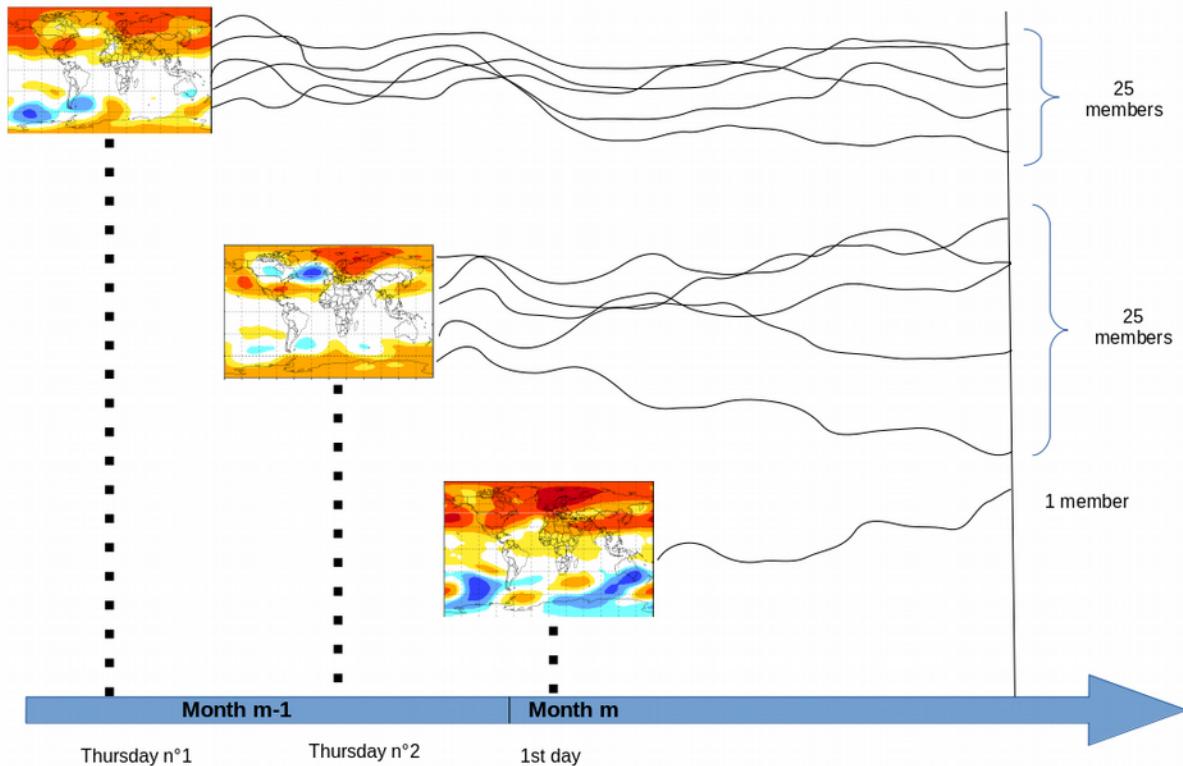


Figure 3 : Generation of the 51-member ensemble of the seasonal forecast

For each calendar month, a series of re-forecasts is produced at least two months before the forecast. It accounts for 25 members and spans 26 years from 1993 until 2018. The only differences with the forecast are the size of the ensembles and the preparation of the initial states, which is managed in advance because the initial conditions from the nudged integration are already available. In order to maintain the best homogeneity between the forecasts and the re-forecasts, 12 members start from the Thursday approximately two weeks before the end of the previous month, 12 more members start from the following Thursday (still in the previous month), and the last member starts from the 1st of the current month. Thus the diagram is very similar to Figure 3 (replacing 25 members with 12 members). As opposed to the 51 forecasts which are launched in three batches (according to the earliest availability of the initial states) the 25 re-forecasts are launched in a single batch with 3 initial dates for a given initial month and year.

As an example, the members of the re-forecast for the nominal start date of the 1st of January 1993 are launched as follows: 12 members on the 17th of December 1992, 12 on the 24th of December 1992, and one on the 1st of January 1993.



All re-forecast and forecast start dates have been predetermined (see Appendix for further details).

Note that during the re-forecast production phase (2021), the re-forecasts will be run on belenos and real-time forecasts on taranis. Following this phase, both machines can be used, allowing a flexibility to switch more runs onto a given machine depending on the availability of resources.

5.2 Environment for CLImate Simulation (ECLIS)

ECLIS (Environment for CLImate Simulation) is the set of scripts and tools necessary to run CNRM-CM. It does not include tools for preparing initial nor boundary conditions. Basically, the script `install` allows to prepare an experiment, and defines another script which will actually run the experiment.

ECLIS manages an environment to run CNRM-CM simulations on supercomputers like belenos and taranis. It also manages the storage of the results.

5.2.1 ECLIS organization

An ECLIS version directory includes a version of tools `relan` and `mtool` which are consistent with the need of the main scripts. The `relan` utility allows to iterate several times a script, whereas the `mtool` utility allows to split a script at time of submission. This directory also contains the following directories:

- **param** which provides useful examples of experiment parameter files; for details on parameters see section 5.2.3 (Design a '`param_`' file)
- **testing** including parameter files for a very wide variety of experiment configurations; they are provided as a reference of the possible technical settings, but not as scientifically meaningful settings
- **scripts** where there is usually one single, non-numbered, version of the experiment installation script and of each script needed for running a coupled experiment; when a bug is fixed for a script, this appears in the git history of the release directory
- **plugins** which includes the code of the available plugins.

The file `cm_setup` sets up the environment used by ECLIS. It should be sourced from the user's configuration file `.profile`. It is automatically launched by the scripts when needed.

5.2.2 Use of ECLIS



ECLIS consists in designing an experiment parameter file that ends with source \$INSTALLER \$* and to execute this file with arguments :

- **noask** for avoiding being asked if a previous install should be erased
- **go** for launching the experiment at the end of the (successful) install phase. This is a way to create and launch an experiment at the end of a first one, when there is a logical dependency (e.g. the first experiment creates the restarts that are necessary for installing the second one).

5.2.3 Design a param_ file

Defining a CNRM-CM experiment is as simple as designing a so-called `param_` file, which filename must be of the form `param_EXPID`, where EXPID is the name given to the experiment. This file, in bash syntax, sets values for ECLIS parameters and then sources the ECLIS install script.

5.2.4 Standard plugins

Plugins are sets of shell-script commands that ECLIS can take into account during CNRM-CM experiment runs, in order to perform actions atop of the strict running of the coupled or atmosphere-only or ocean-only scripts. Special plugins have been developed for the specificities of seasonal forecast.



5.3 Post processing

The XIOS output software (Meurdesoif, 2018) now manages most of the post-processing of the model files to the requested format for C3S. The inputs to XIOS are sets of xml files for each model component type (Arpege/Surfex, Nemo/Gelato, Ctrip).

The different fields available, their long names, reference grid and diagnostic operations are listed in separate xml files for each model component (e.g. `surfex_fields.xml` `nemo_fields.xml` and `atmo_fields.xml`). XIOS can manage operations on model outputs such as time averaging, time slicing, or horizontal and vertical interpolation and statistics.

For each requested variable, all global attributes as well as output frequency, vertical levels and horizontal resolution, are defined in a set of files such as `arpsfx_files.xml` in the case of Arpege/Surfex outputs and `nemo_files.xml` for Nemo/Gelato.

XIOS thus generates directly the fields for the atmosphere, surface and ocean on the required $1^\circ \times 1^\circ$ grid with 180 latitudes and 360 longitudes starting at 89.5°S , 0.5°W and extending northwards and eastwards. The data (one file per field and per month) are stored both locally on the HPC machine and transferred to ECMWF using the ectrans utility.

Tables 2.1 and 2.2 list the variables produced. In addition, land-sea mask and surface orography are available.

Table 2.1: list of atmosphere / land variables archived

Every 6 hours	Every 24 hours	Every 24 hours, accumulated
2 metre temperature	moisture content of soil layer (for each of the 14 soil levels)	total precipitation
2 metre dewpoint temperature	snow depth (water equivalent)	convective precipitation
10 metre u wind	snow density	snow fall
10 metre v wind	Tmax at 2 m (over previous 24 h)	surface sensible heat flux
mean sea level pressure	Tmin at 2 m (over previous 24 h)	surface latent heat flux
total cloud cover	wind speed of gust (max over previous 24h)	surface solar radiation
land skin temperature	water vapor path	downwards
Every 12 hours		
geopotential	liquid water path	surface thermal radiation
temperature	solid water path	downwards
specific humidity		surface solar radiation
u/v wind components		surface thermal radiation
At the following 12 pressure levels:		surface runoff
1000, 925, 850, 700, 500, 400,		sub-surface runoff
		top incoming solar radiation
		top net solar radiation



300, 200, 100, 50, 30, 10 hPa	top thermal radiation east-west surface stress north-south surface stress evaporation
-------------------------------	--

Table 2.2: list of ocean / sea ice variables archived**Every 6 hours**

sea ice temperature

sea surface temperature

Every 24 hours

sea ice concentration

Every month

depth of 14C isotherm

depth of 17C isotherm

depth of 20C isotherm

depth of 26C isotherm

depth of 28C isotherm

depth average potential temperature of upper 300m

depth average salinity of upper 300m

sea surface height above geoid

sea ice thickness

ocean mixed layer thickness defined by sigma theta 0.01 kg/m³ocean mixed layer thickness defined by sigma theta 0.03 kg/m³



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Appendix : Detail of scripts for the System 8 workflow

This appendix goes into the detail of the workflow for System 8 on the Météo-France belenos or taranis machines and the hendrix storage system.

Coupled initialization

Over the re-forecast period, the ERA5 files for the nudging of ARPEGE in the coupled initialization run are converted to ARPEGE format using the following script on the ECMWF supercomputer:

```
cca:/home/ms/fr/top/arpege/grib_to_fa_auto
```

The ERA5 files are on the tl399l137R grid and are tarred by 10-day periods. They are converted to the model geometry tl359l91r and tarred by months by

```
cca:/home/ms/fr/top/arpege/arp2arp_ERA5_step1.cca
```

```
cca:/home/ms/fr/top/arpege/arp2arp_ERA5_step2.cca
```

Then the files are sent to Météo-France by the ectrans utility

```
ecgate:/home/ms/fr/top/SCRIPTS/transfer_restart_GRE_era5
```

```
to belenos:/scratch/work/dorell/era5/restart/
```

They are retrieved from the hendrix storage system in the following repository:

```
/home/duboisc/GLORYS12V1/Ocean_Ice_gene_states_ORCA025/out/
```

Files for the preceding, current, and following months of the re-forecast are needed for temperature and salinity fields:

```
GLORYS12V1_ORCA025_temp_V2_${YYYY}${MM}*.*.nc
```

```
GLORYS12V1_ORCA025_salt_V2_${YYYY}${MM}*.*.nc
```

These are daily NetCDF files upscaled on the ORCA 0.25° grid and directly read by NEMO during the coupled run integration.

The nudged coupled initialization run is implemented on the Météo-France belenos HPC. The full script is available here, and points to the relevant namelists and executables used for this run:

```
belenos:/home/gmgec/mrga/copernicusps/arpege/mccV6.42.tl3591137r_cp
_gel_4_reloa_xios_8n_1m_EA7_cp
```



Generation of atmospheric perturbations (nudged pre-hindcasts)

The scripts to derive the perturbations described in section 4.2 are run on the Météo-France HPCs.

A script (`mitrail_corrections.sh`) launches 26 simulations for a given starting month. In fact this script simply updates another script (`traite_nudging_sys8`) which prepares the environment for the model runs. The model script (`mccV6.42.tl359l137r_nud`) produces a one-month run. Details on the nudging for the computation of the corrections can be found in the NAMNUD section of the ARPEGE namelist.

Ahead of running System 8, the daily correction files (special FA ARPEGE format files) are named `CR$YYYY$MM$DD` and placed on

`belenos:/scratch/work/copernicusps/corrections/corr_N$S` and
`taranis:/scratch/work/dorell/corrections/corr_N$S`

where `$S` is a letter indicating the starting month (A=January, B=February, ... L=December).

Copies of these files are also stored on the `hendrix` storage system.

There are $4*137+1$ records in each file (4 variables in 137 vertical levels + mean sea level pressure). The fields are in spectral coefficients (T359 truncation).

Random calendars for perturbations

The random calendar text file `lnRANDOM$NN` (see section 4.3) is organized as follows:

```
ln -sf $CORR/CR1994${MT}08 RX$YYYY${MM}0100
```

...

```
ln -sf $CORR/CR1999${MT}22 RX$YYYY${MM}3100
```

```
ln -sf $CORR/CR2003${MT}05 RX$YYYYN${MN}0100
```

The year and the first day in each line come from a random generation process. The second day in each line corresponds to a sequence from 01 to 31. The last line corresponds to the first day of the next month. It is necessary for the linear time interpolation at each time step in the model.

The reason for having 31 days is to cover the entire month whatever the month. Of course, only the actual days are used by the model (e.g. 31 in January, 28 or 29 in February ...).

The variable `$CORR` indicates the temporary path to the perturbation files specified in the previous section.



The 51 calendars (for 51 ensemble members) for each forecast month \$MN are generated by the script `belenos:~copernicups/fic_cal_rand_c3s_5_18.sh` and gathered in three files:

```
belenos:~copernicups/cal_18/rand_calendm$MN_n51_$NUMR.tar and  
taranis:~copernicups/cal_18/rand_calendm$MN_n51_$NUMR.tar
```

where NUMR is “a”, “b” or “c”.

Fetching initial conditions

The re-forecast and forecast startdates have been predetermined and are stored in text files on the Météo-France supercomputer:

```
belenos:~copernicups/SAVE/opers8/startdate_199301_202212.txt  
belenos:~copernicups/SAVE/opers8/startdate_202101_202412.txt
```

For each re-forecast initial date, the initial conditions for ARPEGE, SURFEX, NEMO, CTRIP and OASIS are provided by the coupled nudged run described in section 3.2. These files are available in the following repository:

```
/scratch/work/copernicups/restart/EA7/
```

The files can also be retrieved from `hendrix` if needed.

For GELATO, the initial conditions for the re-forecasts have been prepared by Mercator Ocean International using the same approach as for System 7, and saved on a daily basis on the `hendrix` storage system:

```
hendrix:/home/duboisc/PSY2_G2V3/RUN025/RESTARTICE/
```

ECLIS retrieves the GELATO restart file directly on `hendrix`. Prior to launching the re-forecast, the restart files are “pre-staged” from the tape archive onto disk to avoid long queues in data retrieval.

Similarly, for each forecast initial date, the coupled nudged run is extended as soon as the nudging fields for NEMO (provided by Mercator Ocean International) and ARPEGE (provided by ECMWF ERA5T) are available. The initial conditions for ARPEGE, SURFEX, NEMO, CTRIP and OASIS are retrieved as described above.

For GELATO, Mercator Ocean International prepares restarts in a dedicated forced run and provides the fields in the following repository:

```
taranis:/scratch/work/mercator/PSY2G4R2/op/RESTART
```



Running the model with ECLIS

As stated in section 5, the seasonal ensemble forecast is launched 3 times per month. Two days after each start date (so that ERA5T files are available and the coupled initialization run has been successfully extended), a cron job-scheduler executes the scripts `lance_param_F_bln.sh` and `lance_param_F_trn.sh` on belenos and taranis machines.

This first script generates one `param_F?????????` file for each member of the ensemble forecast. It contains the initial date and the end date of the forecast. It also sources the generic `param_F` file which is the main file to launch a forecast with ECLIS (see section 5.2). At the end of `lance_param_F_???.sh`, the current script `param_F?????????` is executed. So, it sets values for ECLIS parameters and then sources the ECLIS install script.

Similarly, the generic `param_H` file is the main file to launch a re-forecast with ECLIS. These generic files include the complete links to the executables and namelists, as well as plugins, used for System 8.

Post-processing (XIOS) and transfer to ECMWF

The post-processing step relies on the XIOS output manager (see sections 2.7 and 5.3). All xml files used as input to XIOS for System 8 are stored on the belenos and taranis computers in the following path:

```
/home/gmgec/mrga/copernicups/SAVE/opers8/XIOS
```

XIOS thus generates directly the fields for the atmosphere, surface and ocean on the required $1^\circ \times 1^\circ$ grid with 180 latitudes and 360 longitudes starting at 89.5°S , 0.5°W and extending northwards and eastwards. The data (one file per field and per month) are stored both locally on the HPC machine:

```
belenos:/scratch/work/copernicups/outputs/HINDCAST/$EXPID/ and  
taranis:/scratch/work/copernicups/outputs/HINDCAST/$EXPID/
```

and uploaded on the Météo-France storage capacity:

```
hendrix:/home/copernicups/SYS8/HINDCAST
```

The data format is netcdf (with compression). The files are transferred by the ectrans utility to ECMWF on:

```
cca:/sc1/tcwork/zac/lb/copernicus/s8
```

For each starting month and member, a directory is created with a name containing the date and the member number. For example directory `199303_001` contains the files created for member 1 of the



March 1993 re-forecasts. Note that the start dates are in this case two starts end of February as well as 01 Mar. There is one tar file in each directory containing 55 netcdf files (one for each variable).



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