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Consistent representation of temporal variations of boundary forcings in reanalyses and seasonal forecasts

Experimental protocol for land and aerosol forcing re-forecasts

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Contents

1 Executive Summary

The aim of this document is to provide a description of the re-forecasts planned in WP3 to assess the impact of improved boundary forcings in an initialized climate prediction setting.

Several sets of experiments are planned. A first category of experiments relate to developments in WP1 on the representation of time-varying land use and vegetation in land surface models and reanalyses, which are key ingredients for seasonal forecasting systems and multi-annual forecasting systems operated in the framework of the Copernicus Climate Change Service (C3S). Another category of experiments will evaluate the impact of tropospheric and volcanic aerosol forcing on seasonal and multi-annual experiments.

This document details plans for each model / system as of Month 9 of the project. In some cases, which are specified, some details of the experimental setup are yet to be decided based on results from analyses in WP1 and WP2. However, this deliverable provides a first framework for WP3 activities and leaves room for future adjustments, to be agreed among partners, when needed.

2 Introduction

2.1 Background and scope of this deliverable

2.1.1 Objectives of this deliverable

CONFESS WP3 integrates developments and improvements from workpackages 1 and 2 to analyse the influence of these on the quality of seasonal and near-term predictions. To complete this main objective, several sets of experiments are planned. This deliverable presents details on the experiments planned for WP3 by each contributing partner. Experiment names, setup, model version and resolution are listed where relevant, as well as the scientific questions addressed.

2.1.2 Work performed in this deliverable

Partners first discussed the experimental protocol envisaged for the different tasks of WP3 during the CONFESS kick-off meeting breakout group discussion in November 2020. Following this first discussion, each partner contributed to a shared Confluence space to provide more details on plans, and a teleconference took place in June 2021 to finalize some choices. Since developments in CONFESS will (partly) be model-dependent, each contributing centre decided how best to assess improvements in their own model, with respect to work in WP1 and/or WP2.

2.1.3 Deviations and counter measures

Some details for experiments will depend on assessments in WP1 and WP2 which haven't yet been completed. These dependencies are therefore mentioned in the document.

The case studies for Task 3.1 (land-surface forcings) will be selected based on the analysis of the first set of seasonal re-forecast experiments which are yet to be run. These will consist mainly in extending the ensemble size and/or running additional start dates for a given heat wave or drought event.

2.2 Description of models used in WP3

2.2.1 ECMWF IFS-NEMO

Experiments run by ECMWF will be based on different cycles and model resolutions for IFS-NEMO, the model used for the ECMWF seasonal forecasting system (currently SEAS5, Johnson et al. 2019). One standard reference version will likely be IFS Cy48r1 at low-resolution (TCo199L37, approximately 50 km horizontal resolution) and NEMO ORCA1.

Some experiments could be run at higher resolution with a candidate configuration for the next operational seasonal forecasting system SEAS6, with IFS Cy49r1 (TCo319L137) and ocean resolution either ORCA1 or ORCA0.25 (to be consistent with the fully high resolution operational system). This is discussed further in section 4.3 on the volcanic aerosol case study experiments.

Data output from the seasonal re-forecasts for tasks 3.1 and 3.2 will follow specifications from the Copernicus Climate Change Services seasonal forecast database (https://confluence.ecmwf.int/display/CKB/Detailed+list+of+parameters), allowing for a lower frequency output when daily or sub-daily fields are not strictly necessary.

Additional variables requested by partners for the analysis of experiments relative to the land surface are listed in section 3.4.

2.2.2 CNRM-CM (Météo-France)

Most experiments in tasks 3.1 and 3.3 will be run at Météo-France using a version slightly updated from the CNRM-CM6-1 coupled climate model contributing to CMIP6 (Voldoire et al. 2019). The atmospheric component will likely be ARPEGE-Climat v6.4.1 (Roehrig et al. 2020) with the SURFEX v8 surface modeling platform encompassing the ISBA-CTRIP land surface and river routing model (Decharme et al. 2019). ARPEGE-Climat/SURFEX will be run at standard CMIP6 resolution (tl127l91r) and coupled to the NEMO v3.6 (ORCA1L75) and GELATO v6 sea ice model.

Data output from the seasonal re-forecasts for task 3.1 will follow specifications from the Copernicus Climate Change Services seasonal forecast database.

2.2.3 EC-Earth

The experiments to be performed with EC-Earth will be based on its version 3.3 (Döescher et al. 2021), based itself on the atmospheric component IFS (cycle 36R1), the ocean component NEMO3.6 (Madec et al 2015), the sea ice model LIM3 (Rousset et al. 2015), and the land surface model HTESSEL-LPJGuess (Alessandri et al., 2017, 2021; Miller et al., 2021). The standard resolution configuration of EC-Earth will be used in all envisaged experiments, which includes a T255L91 atmosphere, and an ORCA1L75 ocean and sea ice configuration.

Since the reference experiments for task 3.3 with EC-Earth will be based on the Decadal Climate Prediction Project (Boer et al. 2016) DCPP-A simulations, the variables and forcing data for these experiments will therefore follow the DCPP-A protocol.

3 Land surface re-forecasts

3.1 Rationale

The main objective of these experiments is to investigate the impact of evolving or prescribed vegetation (LAI) and Land Use / Land Cover (LULC) in seasonal re-forecasts with CNRM-CM and IFS-NEMO, building on work in WP1.

The experiments will help define appropriate strategies to account for time-evolving land surface forcings in forthcoming operational seasonal forecasting systems for Copernicus Climate Change Services at Météo-France and ECMWF.

Common characteristics of experiments have been agreed as follows:

- Re-forecast period is 1993-2016
- Re-forecast duration is 4 months for 1 May and 1 November starts
- Ensemble size should be large (at least 30 members, 50 members if possible)
- Additional start dates for the spring season will be considered for 2nd tier of experiments (shorter runs, 2 month lead, starting from 1 March and/or 1 April).

3.2 Météo-France experiments

Based on work in WP1, Météo-France plans the set of experiments listed in Table 1. A re-forecast with climatological LAI and LULC (climatologies from the ECOCLIMAP database) will serve as a benchmark. The impact of an interactive LAI, and the impact of prescribing an evolving LULC based on the LUH2 database will be assessed in two separate re-forecasts. Additionally, another set of re-forecasts with prescribed LAI (from the Copernicus Global Land Service database, CGLS hereafter) will be considered, as a means of evaluating the potential knowledge gain from perfect knowledge of the evolution of the LAI during the season. This last set is of lower priority and could be run for spring or summer start dates only, depending on preliminary assessments from WP1.

Table 1: Météo-France re-forecasts on land-surface conditions; LAI and LULC definition and purpose of each re-forecast set planned.

Experiment name	LAI	LULC	Purpose	Priority
STANDARD	ECOCLIMAP climatology	ECOCLIMAP climatology	Benchmark/control re-forecast set (current state-of-the-art)	High
LAI_INT	Interactive (1)	climatology	Impact of interactive LAI	High
LULC_EVOL	Interactive (2)	Evolving (LUH2)	Impact of prescribing LULC evolution	High
LAI_PERF	CGLS LAI	climatology	Evaluation of "perfect" evolution of LAI during model integration	Low

In experiment LAI_INT, two options are currently considered for LAI initialization: either using an offline ISBA-CTRIP run with interactive LAI, or an offline IBSA-CTRIP run constraining LAI towards the

CGLS LAI dataset. The choice will be based on the analysis of the LAI datasets currently in production in WP1 and preliminary tests with the CNRM-CM6-1 model in forecast mode.

For experiment LULC_EVOL, the choice of LAI still needs to be clarified, but at the moment an interactive LAI is the most likely option.

After analysis of results from the experiments listed in table 1, re-forecasts at the resolution of the Météo-France operational seasonal forecast system will be run with the configuration of LAI and LULC candidate for inclusion in the following operational system, for November and May nominal start dates.

3.3 ECMWF experiments

ECMWF will perform three sets of experiments with 51 members: a control experiment, an experiment where initial conditions include time-evolving LAI and LULC, and an experiment with interactive LAI. In the second set of experiments, the exact setup for the evolution of LAI still needs to be defined.

Further higher-resolution testing might be considered for a configuration candidate for SEAS6, but the cut-off for model changes for SEAS6 is around M18 of the project and it is not envisaged at this stage that interactive vegetation be included in Cy49r1. However, time-varying land cover might be feasible, with fixed LULC in real-time.

3.4 Additional variables needed for analysis

Beyond C3S seasonal forecast parameters, the additional variables requested for the analysis of these experiments are listed in table 2. Note that for runoff, C3S requires only total runoff, but not the decomposition into surface and sub-surface runoff.

Soil moisture should be provided so as to be comparable between land surface models (e.g. top 100 cm soil moisture or root-zone soil moisture).

Table 2: Additional variables for land surface forcing re-forecasts

Long name	Level(s)	Frequency
Vertical velocity	500 hPa	daily
Transpiration flux	surface	daily
Albedo	surface	daily
Runoff	surface	daily
Runoff	sub-surface	daily
Soil moisture	integrated	daily
Soil evaporation	surface	daily

4 Aerosol re-forecast experiments

4.1 Rationale

In WP2, work conducted by BSC and ECMWF will create a harmonized dataset for tropospheric aerosols, merging CMIP6 and CAMS data. Developments in IFS will enable an improved representation of the stratospheric and tropospheric aerosols, thus creating a capability to react to large volcanic events in a seasonal forecasting framework.

Experiments in WP3 task 3.2 will analyse the impact of decadal variability of volcanic and tropospheric aerosol in re-forecasts with the ECMWF system. The protocol for these experiments is detailed in section 4.2. Case studies will focus on the Pinatubo and El Chichon events (section 4.3).

4.2 Re-forecasts for tropospheric and volcanic aerosol impact

ECMWF will run 13 month re-forecasts using the low resolution version of IFS-NEMO, but covering a longer time period than for the land-surface experiments. The IFS will include radiatively interactive hybrid linear ozone. Ensembles of 10 members will be initialized for November starts over 1981-2020.

A possible extension to May starts but for shorter forecast times (when SST hasn't drifted as much) is suggested. However, in the case of volcanic aerosol, the Pinatubo eruption occurred in June 1991 and wouldn't be included in May starts, whereas the El Chichon eruption occurred end of March – beginning of April 1982 but sulphate aerosol particles probably wouldn't be well developed in an April monthly mean field for May 1st start. Table 3 lists the experiments planned for task 3.2.

Table 3: ECMWF re-forecasts on tropospheric and volcanic aerosols; each row details the specification of aerosols and purpose of the planned re-forecasts.

Experiment name	Tropospheric aerosol	Volcanic aerosol	Purpose	Priority
OLD	Old (SEAS5 style CMIP5)	SEAS5 style predicted	Standard control representing present state-of-the-art (will already exist)	
NEWTROP	New specification	FVF specified	Impact of new time-varying aerosol specification	High
FIXTROP	Fixed present-day CAMS aerosol	FVF specified	Control for NEWTROP	High
FCVOLC	New specification	EVA-H predicted forcing	Compare predicted forcing with actual forcing, impact on stratospheric temperature and SST Compare proposed new system against existing OLD treatment	High
NOVOLC	New specification	Fixed background (no volcanoes)	Allows overview of impact of volcanoes on temperatures, for one lead time profile	Low
OLDTROP	Old (SEAS5 style CMIP5)	FVF specified	Clean comparison of new vs old tropospheric aerosol	Medium

Experiment output variables in the atmosphere will be mostly monthly mean fields.

4.3 Case studies for volcanic aerosols

To better characterise the impact of changes in the treatment of volcanic aerosol, more detailed experiments will be carried out around specific volcanic events, focussing on the Pinatubo and El Chichon eruptions, and a recent smaller event (to be determined). Forecasts will cover a 3 year window, with 7 month forecasts, starting quarterly. Experiments will use FVF specified, EVA-H predicted, SEAS5 predicted and background (i.e. specified to be no eruption) volcanic aerosol. A first set will be carried out with the low resolution ECMWF model. Ensemble size will be 10 members to look at stratospheric response. For Pinatubo, ensemble size will be extended to 51 for the winter forecasts (August and November starts), to enable study of the tropospheric response.

The tropospheric aerosols will follow the "new specification", and the NEWTROP and/or FCVOLC experiments listed in table 3 above will be used to provide a 40-year climatology for the November starts to allow looking at anomalies. This will not be possible for the August starts, where comparisons will be made between the four experiments. Depending on results, some of the 51 member ensembles may be extended to 101 members. This is likely for the first winter in particular.

Some high resolution (TCo319L137, ocean resolution to be confirmed) experiments will also be carried out. These are proposed to be for November 1991 starts only, to be 4 months long, and to be either 51 or 101 members in size. The purpose is to assess whether there is any dependence of the dynamical response on resolution. Ocean resolution could be ORCA1 (so only the atmosphere resolution is different, and the cost is lower), or ORCA025 (to be consistent with the fully high resolution operational system). The ocean resolution affects both the mean bias in the equatorial Pacific (bias is colder in low resolution) and the anomalies (high resolution is a little warmer in the east, cooler in the west for the Nov 1991 forecast, both improvements). In terms of the full SST field, the low resolution is not warm enough in the east/central Pacific, while both resolutions are too warm in the west Pacific, the high resolution slightly more so. To understand the impact of the volcanic forcing on the Northern Hemisphere winter circulation in the context of the moderate El Niño of 1991/92 and the coupled model biases, it is unclear whether it is best to use a high resolution ocean, a low resolution ocean, or run the atmosphere model alone with observed SST. We could (1) use old-style tropospheric forcing and ORCA025 (so the SEAS5-style predicted experiment is identical to the standard cycle control, and we have a climatology available for this configuration); (ii) run all experiments with ORCA1 and new tropospheric aerosol, to halve the cost of the experiments and give better comparability to the low resolution experiments; or (iii) run all experiments with observed SST, which costs slightly less than the low resolution ocean, and avoids SST bias. The final decision may depend on details of model bias in Cycle 48r1, which is not yet known, and analysis of any additional coupled vs observed SST experiments available at the time.

5 Multi-year re-forecasts

As part of task 3.3, several sets of multi-year simulations are planned. At ISAC-CNR and BSC these simulations will follow Decadal Climate Prediction Project (DCPP) protocols (Boer et al., 2016) to benefit from simulations with EC-Earth3 already produced in this framework.

Météo-France also plans to run multi-year simulations, but rather in a historical multi-decadal framework to better quantify improvements in the representation of decadal variability due to varying land use / land cover and LAI. Specifics for these experiments depend on analyses from WP1 and have yet to be decided upon at this stage.

5.1 Vegetation and land use/land cover variability

EC-Earth with the improved vegetation representation accomplished in WP1 will be used at ISAC-CNR to perform a sensitivity experiment (hereinafter DCPP-veg) covering a subset of the tier-1 (Component A1) decadal hindcasts performed at BSC for the DCPP. The DCPP-veg set of decadal hindcasts will allow to assess the effect of the more realistic representation of vegetation by comparison with the control DCPP hindcasts.

The improved set of decadal (5-year) hindcasts (DCPP-veg) will cover a subset of start dates in the recent 1993-2015 period, i.e. when latest generation satellite-derived land cover and vegetation observations are available. Selection of the start dates will also follow from the analysis of the off-line simulations performed in WP1 and from an in depth evaluation of the available satellite land cover and vegetation observations, so that the years when vegetation is expected to have the strongest impact will be identified. For each start date, we will initially perform ensembles of 5-member hindcasts, of 5-year forecast-length each. Depending on the outcomes of preliminary analysis we'll decide to extend to an additional 5 members (10 members in total) and to additional 5 years of hindcast (10 years in total).

5.2 Volcanic aerosols

Multi-year forecasts with EC-Earth (BSC) will focus on the impact of volcanic eruptions of the Mount Agung (1963), El Chichon (1981) and Mount Pinatubo (1991) on decadal predictions. To do so, we will base our analysis in a comparison of the DCPP experiments following the protocols A and C (Boer et al., 2016) with EC-Earth3. DCPP-A consists of 10-member ensembles of 10-year-long predictions initialized every year in November from 1960 to 2018 with prescribed CMIP6 radiative forcing estimates, including the volcanic forcing (DCPP-A-hindcast in table 4). The different components (atmosphere, land, ocean and sea ice) have been initialized using full-field initialization, for further details see Bilbao et al. (2021). The DCPP-C protocol consists in repeating the hindcasts initialized in 1962, 1981 and 1990, removing the volcanic forcing and setting it to a background level (DCPP-C-noAgung, DCPP-C-noElChichon and DCPP-C-noPinatubo in table 4). Therefore the difference between the two experiments will allow us to estimate the volcanic impacts. Furthermore, the full hindcast of DCPP-A is available to compute anomalies including forecast drift corrections.

To evaluate the volcanic forcing generated with EVA-H, additional experiments will be performed. For these we will repeat the hindcasts initialized in 1962, 1981 and 1990, but with the volcanic forcings estimated with EVA-H (DCPP-C-noAgung_EVA-H, DCPP-C-noElChichon_EVA-H and DCPP-C-noPinatubo_EVA-H in table 4). These experiments will allow us to compare the climatic impacts of the volcanic forcings estimated with EVA-H and will indicate the expected uncertainty in the climate response when used in the case of a future volcanic eruption.

Table 4: Decadal re-forecasts planned (or available) at BSC with EC-Earth3 to evaluate the impact of volcanic forcing.

Experiment name	Description
DCPP-A	10 member ensembles of 10-year hindcasts initialised every year in November (1960-2018) Prescribed CMIP6 historical values of atmospheric composition and/or emissions (and other conditions, including volcanic aerosols)
DCPP-C-noPinatubo	Repeat 1990 hindcasts without Pinatubo forcing. - 10 forecast years - 10 ensemble members - Specify "background" volcanic aerosol to be the same as that used in the 2015 forecast
DCPP-C-noElChichon	Same as above but for 1981 hindcasts without El Chichon forcing.
DCPP-C-noAgung	Same as above but for 1962 hindcasts without Agung forcing.
DCPP-C-Pinatubo_EVA_H	Repeat 1990 hindcasts with the Pinatubo forcing generated with EVA_H. - 10 forecast years - 10 ensemble members
DCPP-C-ElChichon_EVA_H	Same as above but with El Chichon forcing generated with EVA_H for 1981 hindcasts.
DCPP-C-Agung_EVA_H	Same as above but with Agung forcing generated with EVA_H for 1962 hindcasts.

6 Conclusion

This document provides an overview of the different sets of experiments planned for WP3, to assess the impact of improved land cover and vegetation and aerosol forcings on seasonal and near-term predictions. These experiments will be run in the forthcoming months (once initial conditions in WP1 and model developments from WP2 are ready) and address key scientific questions tackled in the CONFESS project. They will enable partners to further understand the impact of improvements on forecast quality, and derive recommendations for implementation in future operational systems for Copernicus Climate Change Services.

As some specific details for these experiments are not yet known at this stage of the project, and different priorities have been set, this document provides a baseline for further discussions. Deviations from the plans listed here will be discussed among partners and reported. More specifically, the case studies for the impact of land surface forcings will be defined at a later stage, depending on preliminary analysis of the first sets of re-forecasts made available within the course of the project.

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