SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	……………………2016……………………………. ……
Project Title:	Sensitivity of multi-annual forecasts to model resolution ………………………………………………………..……
Computer Project Account:	………………SPITCORT………………………………
Principal Investigator(s):	…………Susanna Corti……………………………..…… ………………………………………………………..……
Affiliation:	Institute of Atmospheric Science and Climate (ISAC) of the Italian National Research Council (CNR)………
Name of ECMWF scientist(s) collaborating to the project (if applicable)	………………………………………………………..…… ………………………………………………………..……
Start date of the project:	………………01-01-2014………………………..……
Expected end date:	……………31-12-2016……………………………..……

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	28 millions	28 millions	19 millions	1411124
Data storage capacity	(Gbytes)	50000 Gb		50000 Gb	

Summary of project objectives

(10 lines max)

This is a three-year project, which aims to investigate the sensitivity of multi-year forecasts to model resolution. During the first project year it was planned to assess the sensitivity to the atmospheric model resolution. In the following project years, depending on the results of the experiments carried out during the first year, it was planned to assess the sensitivity to the ocean model resolution. Such sensitivity should have been assessed by a set of integrations with a suitable versions of the ECMWF coupled system (including the Sea-Ice interactive module LIM2) where ocean resolution is kept at the standard ~1˚ or increased to ~0.25˚, while atmospheric resolution is increased from T255 (~80 km) to T511 (~40km).

Summary of problems encountered (if any)

(20 lines max)

The set of experiments planned for the second project year was a set of three-year long integrations using a complete high-resolution coupled system (HRCTL 10-3-1: 10 starting dates, 3-year long, 1 ensemble member). The configuration chosen consists of IFS Cycle 40R1 integrated at T511L91 coupled with the ocean model NEMO ORCA025 (0.25˚). In this configuration we were supposed to repeat the same hindcasts as in the control (CTL 10-3-5; i.e. IFS at T255L91 coupled with NEMO ORCA1) and in the atmospheric high-resolution experiments (HRA 10-3-5; i.e. IFS at T511L91 coupled with NEMO ORCA1). These experiments were set to estimate how much the improvement of the key ocean processes, such as for example ocean convection and the representation of ocean currents, impacts the ability of the models to simulate important modes of variability (for example ENSO and the Atlantic Meridional Overturning Circulation), which in turn influence the extended range predictability over remote continental regions (via teleconnections).
However, due to serious problems in finding an acceptable configuration for NEMO ORCA025 coupled with T511L91, both in terms of computing time efficiency and in terms of stability of the configuration, we decided to change strategy and postpone/dismiss the HRCTL 10-3-1 experiments. The computer time allocated for year 2015 was used to carried out two different sets of experiments: 1) Multi-year SWAP experiments with three starting dates and 2) Atmospheric seasonal forecasts of the 20th Century starting from ERA20C reanalysis.

Summary of results of the current year (from July 2015 to June 2016)

During the current project year we carried out the following experiments:

1) The first experiment (Multi-year SWAP) is a specifically designed sensitivity experiment set up to assess the impact of initial conditions relative to external forcings in 3-year long integrations. It complements the control (and high resolution) series of hindcasts carried out during the first-year project. It consists, for each atmospheric resolution, of three sets of ensemble hindcasts for three initial dates in 1988, 1994 and 2002 (1st of November) using either the external forcings from the "correct" 3-year period or swapping the forcings between the 3-year periods. By comparing the three sets of integrations, the impact of external forcing versus initial conditions on the predictability over multi-annual time scales is estimated. In particular we estimate the sensitivity of the model to initial conditions in predicting the multi-year climate oscillations that modulate the global warming trend. As mentioned above, the Multi-year SWAP experiment has been carried out in the two model configurations used in the multi-year hindcasts performed during the first project year. That is at standard resolution with the atmospheric model integrated at T255 (~80km) with 91

levels in vertical, and at high horizontal resolution with the atmospheric component integrated at T511. The oceanic component resolution is the standard NEMO-ORCA1 (~1˚). We run 5 ensemble members for each starting dates.

2) The second experiment consists of seasonal re-forecasts carried out with an atmosphere-only model using prescribed observed sea surface temperatures (SSTs) as lower boundary. Such a set-up can be seen as an experimental idealised version of the more complex coupled ocean-atmosphere seasonal forecasts. It assumes a perfect forcing of the atmosphere from the SSTs below and neglects any feedbacks from the atmosphere onto the SSTs. The hindcasts were performed using the European atmospheric re-analysis of the 20^{th} Century (ERA-20C, Poli et al., 2013; Poli et al., 2015) for initialisation and verification. ERA-20C assimilates only surface pressure and marine wind observations. An ensemble of SST realisations from the HadISST2.1.0.0 dataset (Reyner et al., 2003) was used to initialize and force the lower boundary, to create a total of 51 re-forecast ensemble members. Seasonal re- forecasts over 4 months were initialised for the spring and summer seasons (i.e. 1^{st} February, 1^{st} May) during the period 1900 to 2009. [Similar forecasts for the winter and autumn seasons were carried out under the special project "spgbawsf": Seasonal forecasts of the 20th Century: Reliability, attribution and the impact of stochastic perturbations]

The re-forecast experiments were set-up in a way to mimic the operational System 4 (except for the SST forcing and no singular vector perturbations at the initial state) as much as possible to enable a fair comparison with a forecasting system when only information before the initial date are available to use. In particular this means that time-varying greenhouse gas forcings were specified to improve the simulations of trends during the re-forecast period. The forcings also include a time-varying solar cycle and volcanic aerosols (Molteni et al., 2011).

Experiment 1) (i.e. Multi-year SWAP) uses IFS cycle 40R1 for the atmosphere, NEMO_V3.0 for the oceanic component (Medec 2008) and the LIM2 sea-ice dynamical component (Goosse and Fichefet 1999). All the simulations were initialized with a full initialization procedure (Magnusson et al. 2013) with NEMOVAR-ORAS4 ECMWF operational analysis (Mogensen et al. 2011). The atmosphere is initialised with ERA Interim (Dee et al. 2011). The sea ice initial conditions have been obtained forcing from a 5-member sea ice reconstruction described in Guemas et al. 2014. The external forcing is based on the CMIP5 recommended historical datasets (Taylor et al. 2012).

The atmospheric model used for experiment 2) (i.e. atmospheric-only seasonal re-forecasts) is the latest version (CY41R1) of the atmospheric component of ECMWF's Integrated Forecasting System model IFS. A slightly earlier version of the model (CY36R4) coupled to an ocean model is used for the production of ECMWF's operational seasonal forecasting System 4 (Molteni et al., 2011).

In this report we will show the first results from the Multi-year SWAP experiment. The analysis of the atmospheric-only seasonal re-forecasts is underway.

The Multi-year SWAP integrations extend to three starting dates the experimental setup described in Corti et al. 2015. In that study two sensitivity ensemble integrations were carried out: a decadal hindcast starting in November 1965 was integrated with the forcing from the 1995 decade; similarly a decadal hindcast starting in November 1995 was run with the forcing from the 1965 decade. By comparing the reference and the sensitivity integrations, the relative importance of initial conditions versus the external forcing was assessed. In particular, two estimates of the decadal predictability arising from initial conditions only and two estimates of the predictability driven by the external forcing were obtained.

Table 1

Standard Res & High Res	Boundary Conditions (Forcing)			
Initial Conditions		1988	1994	2002
	1988	IC88F88	IC88F94	IC88F02
	1994	IC94F88	IC94F94	IC94F02
	2002	IC02F88	IC02F94	IC02F02

Table 1 *Sensitivity experiments. Comparing experiments in the same row gives the impact of forcing. The comparison in the same column gives the impact of initialisation.*

In the experiment performed here three initial dates, namely, 1988 and 2002 (preceding years of pauses in global warming) and 1994 (preceding years of accelerate global warming), were chosen, and the following nine 3-year-long hindcasts were produced:

1 IC88F88 for 1988 initial conditions and correct observed forcing from 1988;
2 IC94F94 for 1994 initial conditions and correct observed forcing from 1994;
3 IC02F02 for 2002 initial conditions and correct observed forcing from 2002;
4 IC88F94 for 1988 initial conditions and swapped observed forcing from 1994;
5 IC88F02 for 1988 initial conditions and swapped observed forcing from 2002;
6 IC94F88 for 1994 initial conditions and swapped observed forcing from 1988;
7 IC94F02 for 1994 initial conditions and swapped observed forcing from 2002;
8 IC02F88 for 2002 initial conditions and swapped observed forcing from 1988;
9 IC02F94 for 2002 initial conditions and swapped observed forcing from 1994;

The same 9 experiments were repeated at high resolution. By comparing 1) with 6) and 8), 2) with 4) and 9) and 3) with 5) and 7) we have three estimates of the decadal predictability arising from having different initial conditions and the same forcing. By comparing 1) with 4) and 5), 2) with 6) and 7) and 3) with 8) and 9), we have three estimates of the impact of forcing (since initial conditions are identical) on the predictability of climate variables. A schematic of the nine experiments is given in Table 1.

In Corti et al. 2015, where two initial dates were swapped, namely November 1965 and November 1995, it was found that during the first year of integration, the predictability of surface temperature on a global scale arises mainly from the initial conditions. Here in Figure 1 and Figure 2 it is shown that, the previous statement might be not totally independent on the specific initial states (and corresponding forcings) chosen. When 1988 (or 1994) are swapped with 2002, the effect of the forcing in the global mean temperature from the first year of integration is apparent. In both cases (see Figure 1) the simulated global near-surface air temperature anomaly increases when the 2002 forcing is applied to 1988 and 1994 starting dates (and correspondently it decreases when 1988 or 1994 forcing is applied to 2002). On the other hand when 1988 and 1994 forcings are swapped, the simulation of the global mean temperature is almost unchanged (Figure 2).

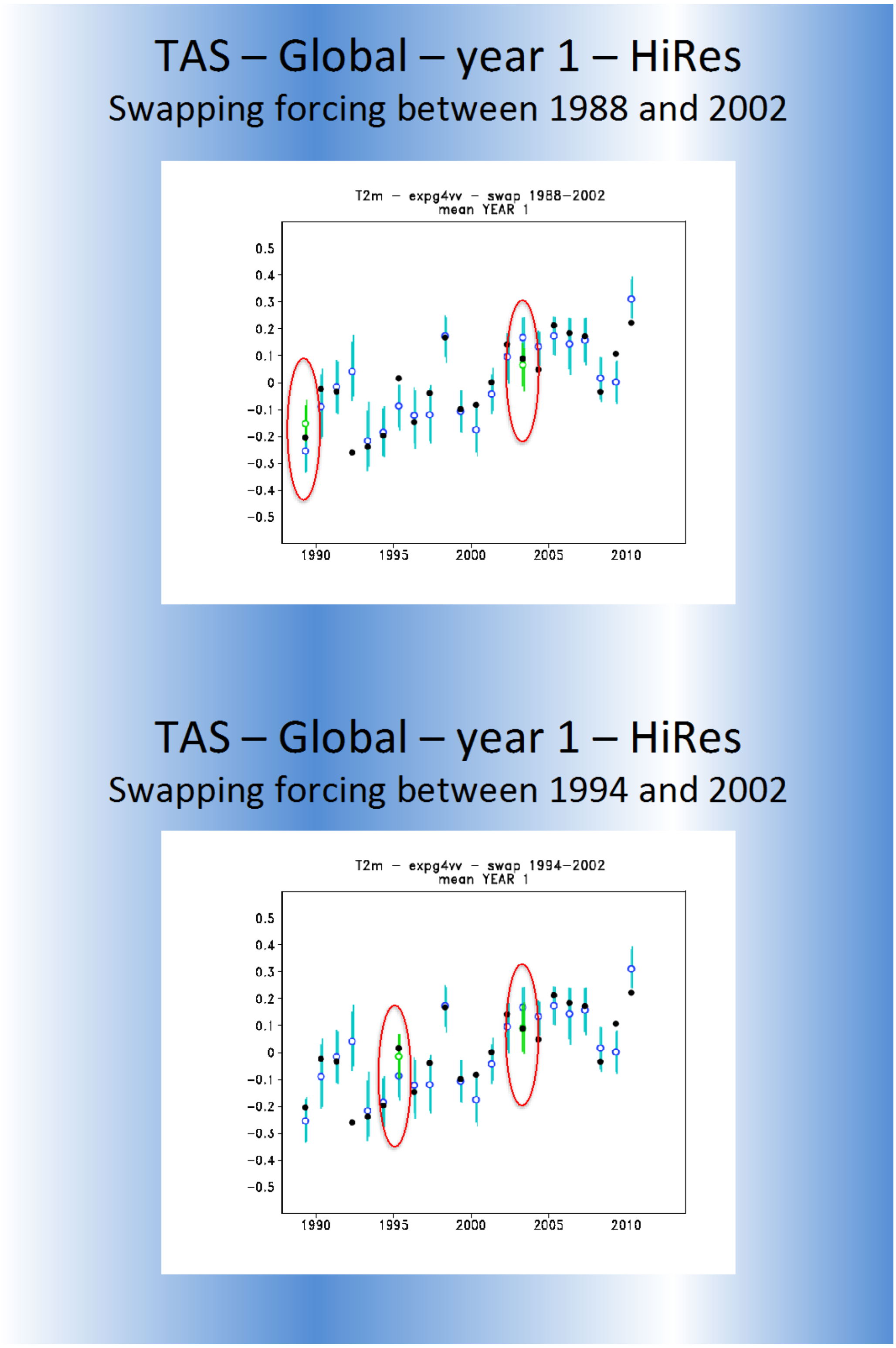

Figure 1. Time series of the near-surface air temperature (K) global mean anomalies observed (black dots) and simulated ensemble means (blue/green dots). Shown are annual means (observations) and the means of the first year of the high-resolution integrations (year-1 means). Bars represent the spread (standard deviation over the 5 ensemble members). Green dots and bars refer to integrations in which the forcing is swapped. Top panel: swapping between 1988 and 2002 forcing. Bottom panel: swapping between 1994 and 2002.

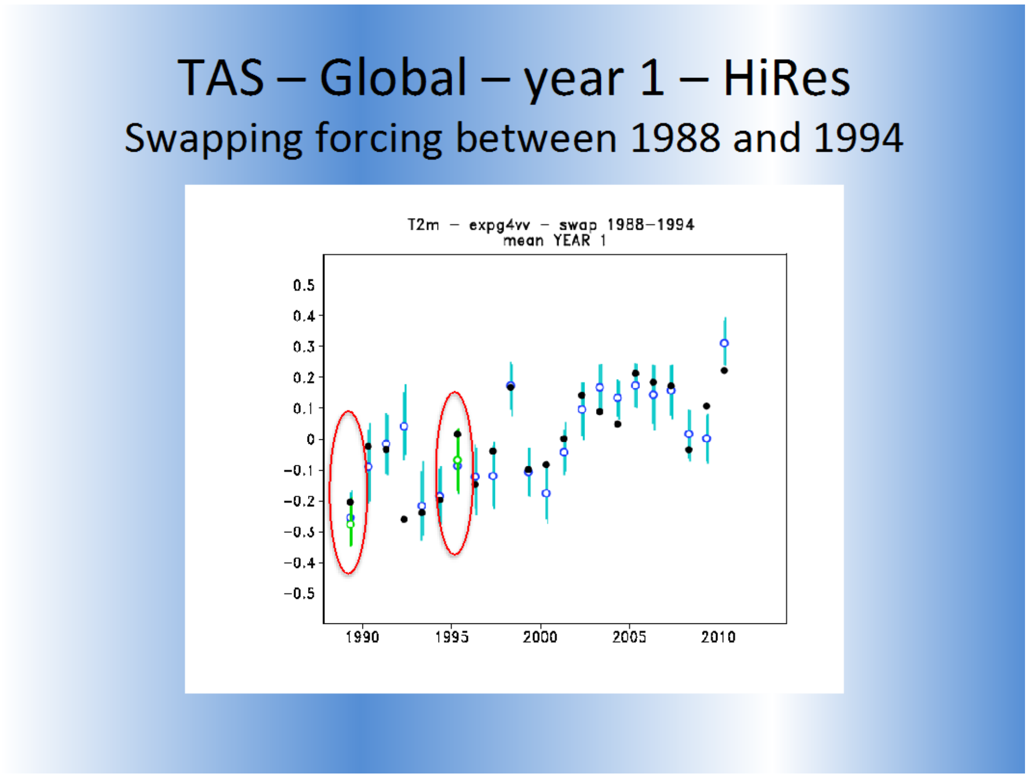

Figure 2. As in Figure 1 for the swapping between 1988 and 1994.

A similar behaviour, i.e. a dependency of the major driver of predictability on the specific chosen dates for the swap, can be found on regional anomalies (not shown). For example over the North Atlantic it was found a high sensitivity to changes in the forcing since the first year of integration for the forecasts initiated in Nov1994 (when the forcing is swapped with Nov1988). On the other hand the swap of forcings between 1988 and 2002 doesn't affect the model simulations for the all length of the integrations. Over the north-western Pacific, consistently with the global case, the forecast sensitivity to the forcing is more pronounced when 1988 (or 1994) are swapped with 2002. Further analyses are necessary to understand what causes this year-sensitive sensitivity of the forcing with respect to initial conditions in different portion of the phase space of the climate attractor. Further analyses of these experiments are under way.

Increased atmospheric model horizontal resolution doesn't affect the results of the Multi-year SWAP experiment.

References

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List of publications/reports from the project with complete references

The first results of the second-year project have been presented at UNESCo Conference "Our common future under Climate Change" held in Paris the 6-10 July 2015.
http://cfcc.event.y-congress.com/ScientificProcess/Schedule/index.html?setLng=en
A publication based on that presentation is in preparation.

Summary of plans for the continuation of the project

We have been discussing with ECMWF staff in the Predictability Division how to proceed with the experiments planned for the third project year. In principle it was planned to perform a new set of experiments (HRO 22-3-5) in which we use the same set up as in CTL 22-3-5, but the horizontal resolution of the ocean model will be increased to ~0.25" (ORCA025). The HRO experiments aim to estimate how much the improvement of the key ocean processes, such as for example ocean convection and the representation of ocean currents, impacts the ability of the models to simulate important modes of variability (for example ENSO and the Atlantic Meridional Overturning Circulation), which in turns influence the extended range predictability over remote continental regions (via teleconnections). However it seems now clear that there are still difficulties in setting up these experiments. Therefore it has been decided to use the computer time to perform a different kind of simulations with the EC-Earth coupled model at standard and high resolution. These experiments should be part of the H2020 project PRIMAVERA and have been planned in these months. They should be performed by the end of the current year. Similar experiments should be performed with the ECMWF coupled system by ECMWF staff in the framework of the same H2020 EU-project. A close collaboration in the preparation of these integrations with ECMWF scientists is envisaged.