SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Decadal climate predictions: exploit vegetation dynamics and improve fire risk assessment
Computer Project Account:	spnlales
Start Year - End Year :	2018-2019
Principal Investigator(s)	Andrea Alessandri
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Other Researchers (Name/Affiliation):	Etienne Tourigny (BSC), Franco Catalano (ENEA), Frank Selten (KNMI), Arthur Amaral (BSC), Rashed Mahmood (BSC), Roberto Bilbao (BSC), Pablo Ortega (BSC), Louis-Philippe Caron (BSC)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The objectives of this special project are (i) to verify the actual improvement of the decadal climate predictions due to improved land surface/vegetation and (ii) assess the related benefit for the prediction of fire risk. To this aim a set of sensitivity experiments will be performed with a modified version of EC-Earth that improves vegetation representation and variability by either prescribing or modeling the vegetation state and variability.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

The experiment planned in SPNLALES required the availability of the control Decadal Climate Prediction Project (DCPP) hindcasts (DCPP-ctl) that were originally scheduled to be completed by early 2018 as part of BSC's contribution to DCPP (Component A1; Boer et al., 2016). However, the production of DCPP-ctl was delayed by more than one year due to a late release of the 3.3 version of EC-Earth (the official CMIP6 one), requiring amendment to SPNLALES in 2018 to postpone the planned simulations to 2019. The simulation of DCPP-ctl was finally commenced in May 2019 and the sensitivity hindcasts (DCPP-vege) could be performed during the second half of 2019 using the same initial conditions prepared for DCPP-ctl. Even though delays of EC-Earth3 finalization affected significantly the realization of SPNLALES, we were able to finally accomplish the sensitivity hindcasts as planned in the amendment submitted in 2018.
The implementation of an improved wildfire model for LPJ-GUESS (SIMFIRE/BLAZE) suffered from long delays and has not yet been incorporated into the EC-Earth repository, which has impacted the assessment on wildfire risk predictions.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

No problems encountered and we got all information and help needed.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

Workflow manager configuration and setup

In collaboration with the colleagues at Barcelona Supercomputing Centre (BSC), the Autosubmit workflow manager has been employed in order to set-up a semi-automated procedure for the production of the improved set of decadal hindcasts (DCPP-vege).
The Autosubmit manager allows to run simulations on a number of HPCs, including Marenostrum4 at Barcellona Supercomputing Center and CCA/CCB at ECMWF.

The EC-Earth runtime scripts have been modified in order to perform parallel scheduling of the decadal predictions and post-processing and by setting up the required running environment including preparation and transfer in the working directory of the initial and boundary conditions required by the model.

System set-up and implementation of the sensitivity experiment (DCPP-vege)

In collaboration with the colleagues at BSC the initialization strategy has been implemented following the DCPP protocol. The initialization of DCPP-vege shares with DPCC-ctl the same initialization of all components but with an improved representation of the land cover/vegetation state.

Transient land cover/vegetation conditions for the DCPP-ctl are the same ones prepared for the DECK simulations. These were produced from one of the historical simulations performed with the EC-Earth-Veg version of the EC-Earth model, which includes the LPJ-GUESS dynamic vegetation model (Smith et al., 2014).

To evaluate the actual improvement of the decadal climate predictions due to enhanced land surface/vegetation, the DCPP-vege experiment was performed, in collaboration with colleagues at ENEA, by prescribing the better possible land cover/vegetation states that can be obtained from the available observational data. To this aim, the Leaf Area Index (LAI) of low and high vegetation for DCPP-vege has been obtained from available satellite derived LAI observations from the third generation GIMMS and MODIS satellite observations (Zhu et al. 2013). The LAI dataset has been pre-processed (monthly averaged, interpolated, gap-filled) in order to be used in HTESSEL. Following the approach in Alessandri et al. (2017), the observational LAI data has been further employed to derive effective vegetation cover (Ceff) of low (lveg) and high (hveg) vegetation in HTESSEL (i.e. the land surface model of EC-Earth3; Balsamo et al. 2009) according to the Lambert Beer (LB) law of extinction of light under a vegetation canopy:

$$Ceff_{lveg,hveg} = 1 - \exp(-0.5 \times LAI_{lveg,hveg})$$

To be consistent with DCPP-ctl, in DCPP-vege the Ceff computed from observational LAI has been corrected to have the same seasonal-cycle climatology of DCPP-ctl hindcast but preserving the observational variability.

Experiments and Results

The EC-Earth ESM with vegetation states prescribed as obtained from observational LAI has been used to perform a sensitivity experiment (hereinafter DCPP-vege) covering a subset of the tier-1 (Component A1) decadal hindcasts, which was performed by BSC in the framework of DCPP (Boer et al., 2016) and published on ESGF with doi:10.22033/ESGF/CMIP6.227. Overall, the improved set of decadal (5-years) hindcasts (DCPP-vege) cover 18 start dates in the recent 1982-2010 period, i.e. when reliable satellite-derived vegetation observations are available. The selection of the start dates followed from an in depth evaluation of the available satellite-derived vegetation observations. The years when vegetation is expected to have the strongest impact in terms of modulation of the climate response to external climate forcings (volcanic eruptions, ENSO) were identified according to the observational analysis outcomes in Catalano et al., 2016, leading to the following selection of start dates for 1st November: 1981-11, 1982-11, 1983-11, 1984-11, 1985-11, 1986-11, 1987-11, 1990-11, 1991-11, 1992-11, 1993-11, 1995-11, 1996-11, 1997-11, 1998-11, 2001-11, 2002-11, 2003-11, 2005-11.

For each start date, we performed 5-member ensemble hindcasts of 5-year forecast-length each, for a total of 450 years of production simulation. According to the plan, the simulations have been performed using version 3.3 of EC-Earth, i.e. including all the latest Earth System Model developments over land in the frame of CMIP6, at T255 horizontal resolution (corresponding to approximately 80 km lat x lon) and 91 vertical levels in the atmosphere, and ORCA1 grid in the ocean (irregular grid corresponding to nominally an average of 1 deg lat x lon) with 75 vertical levels.

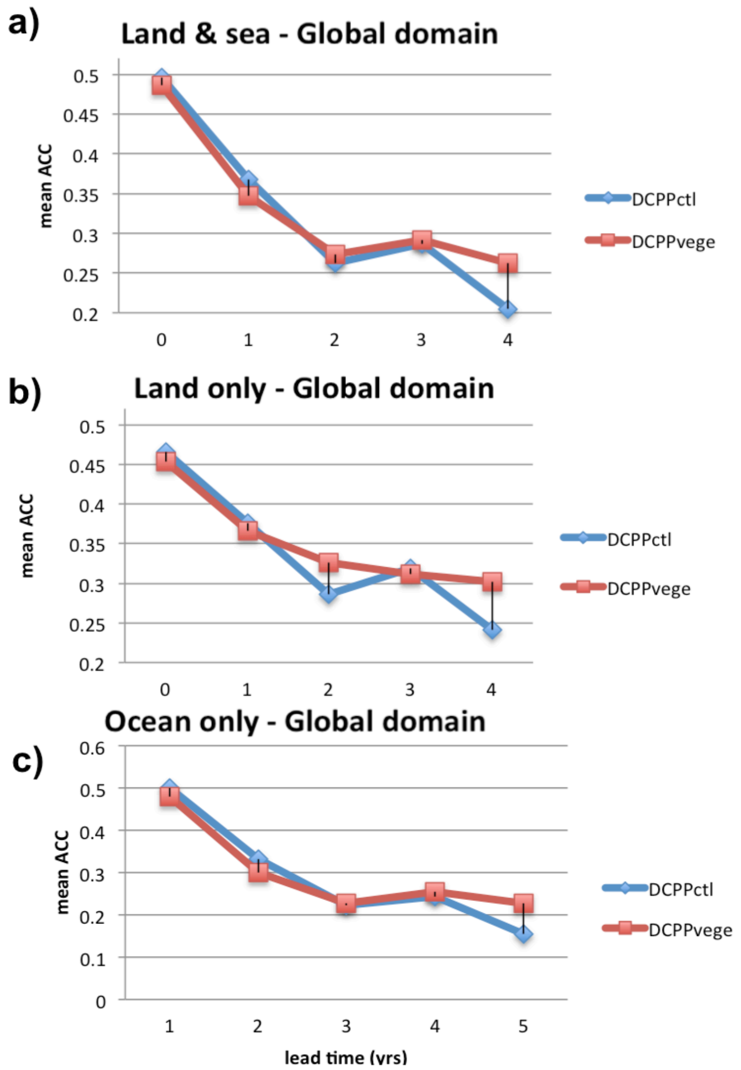

Figure 1: averaged anomaly correlations coefficient (ACC) over (a) global land & sea (b) global land-only and (c) global ocean-only domains for 1-year mean T2M as a function of lead time for DCPP-vege (red) and DCPP-ctl (blue). ACC are computed using GISTEMP data as reference observation.

The prescription of realistic vegetation states, as derived from observational LAI, leads to enhancements of skill over land in DCPP-vege compared with control experiment (DCPP-ctl). Overall, it is found a noticeable anomaly correlation coefficient (ACC) increase for DCPP-vege at the longer lead times (2 to 4 years; **Figure** 1). On the other hand, at lead-years 0 and 1 the difference is very small between the two experiments and with DCPP-ctl even displaying slightly larger ACC values. It is at lead 2-years that the contribution on the skill of a more realistic vegetation state/variability starts emerging and with the difference in the averaged ACC over land that maximizes in the last hindcast year (lead 4-years; **Figure** 1b). According to previous research, this can be related to vegetation contributing to provide memory of volcanic eruptions and ENSO, modulating at longer scales the effect of the land-surface forcing on climate (Alessandri and Navarra, 2008; Catalano et al., 2016). Interestingly, at lead 3-years the difference between DCPP-vege and DCPP-ctl almost vanishes as a consequence of an apparent rebound in performance of DCPP-ctl after declining sharply at lead 2 (**Figure** 1b).
Noteworthy, at 4-year lead time it is found a noticeable improvement of ACC averaged over ocean (**Figure** 1c), therefore indicating that the improved ACC over land due to the enhanced vegetation

representation can also extend in some respect the positive effects over the surrounding ocean domain.

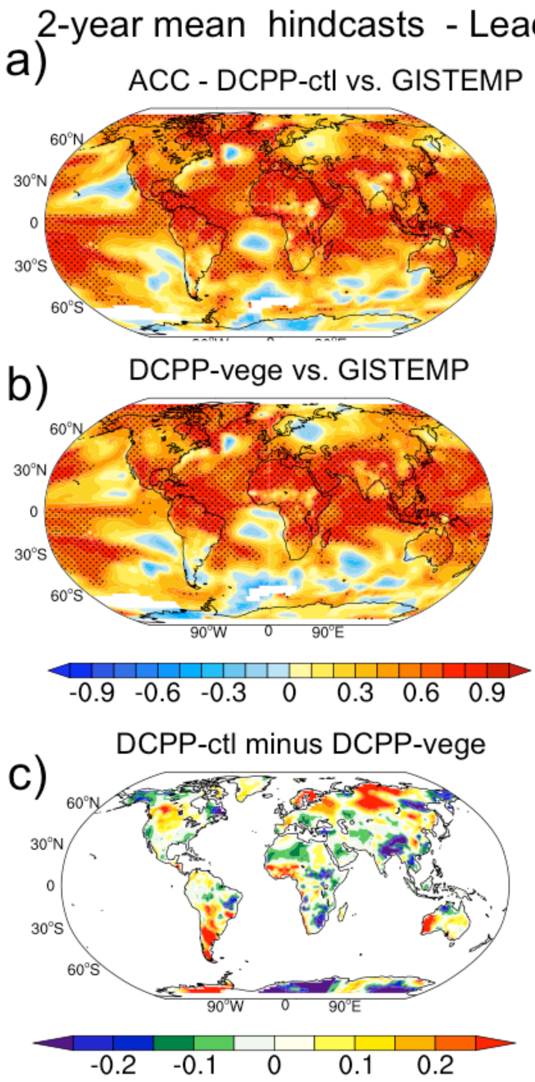

Figure 2: Anomaly Correlations of 2-years mean T2M predictions at 0-year lead time with the reference GISTEMP observation for (a) control experiment ($DCPP_{ctl}$); (b) $DCPP_{vege}$ and (c) $DCPP_{ctl}$ minus $DCPP_{vege}$ differences over land. Areas that did pass a significance test at 5% level are dotted in (a) and (b).

Figure 2 compares the DCPP-ctl (panel a) and DCPP-vege (panel b) predictions of 2 m temperature at 0-year lead time, valid for the 1–2 year forecast period, by computing the correlations of the respective ensemble-mean forecasts with the reference GISTEMP observation (GISTEMP, 2020; Lenssen et al., 2019). The DCPP-ctl minus DCPP-vege difference of correlations over land shows quite a patchy pattern at lead-0 (Figure 2c) with the DCPP-vege improvements over Siberia, South-East Asia and Africa being compensated by a better performance of DCPP-ctl over Euro-Asian boreal area and South America. On the other hand at lead 2-years (Figure 3), a more consistent pattern of improvement in ACC emerges for DCPP-vege, when considering 3-year averages valid for the 3–5 year forecast period (Figure 3c). In particular, a large scale ACC enhancement is found over Asian boreal forests and surrounding areas indicating that indeed the improved representation of vegetation state/variability is playing an effective role there (Figure 3c). This is consistent with the results in Alessandri et al. (2017) reporting of a significant potential effect of vegetation on the prediction of air temperature at decadal time-scale over boreal winter middle-to-high latitudes in Eastern Europe, Russia and Siberia; this was found to be primarily due to the shadowing effect by tree-vegetation on snow surfaces that vary according with the interannual changes in the effective

cover of vegetation (Alessandri et al., 2017).
We plan to publish the outcomes of this analysis in a peer-reviewed paper for the scientific community that is currently in preparation:
A. Alessandri, and co-authors: Potential contribution of realistic vegetation-state variability on climate predictions at decadal time scale, In preparation.

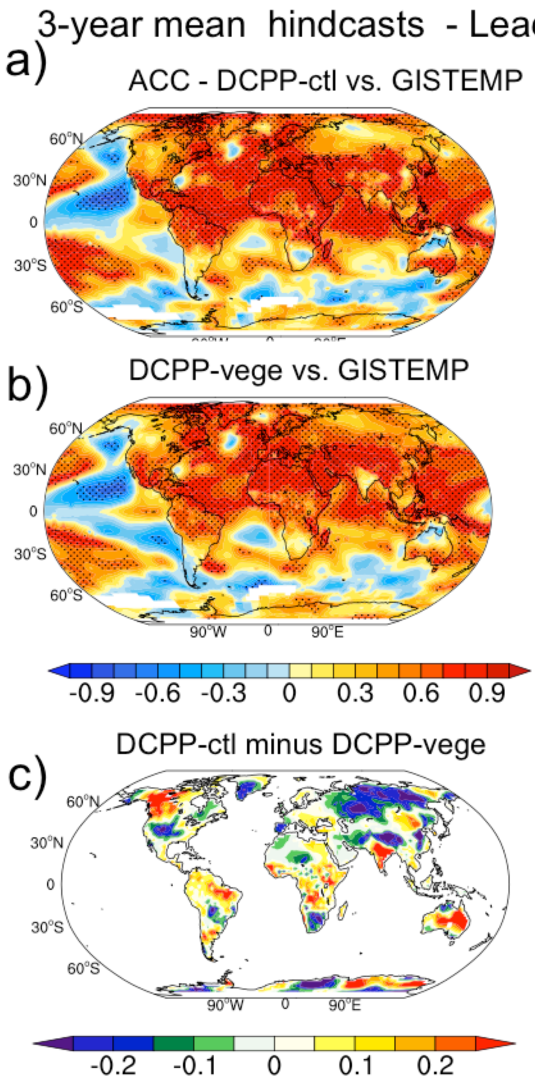

Figure 3: Same as but for 3-year mean hindcasts at 2 years lead time.

Fire models and enhanced fire danger forecasting

As part of this Special Project, it is expected that better Earth system predictions coming from improved land surface-vegetation representation will allow for better fire prediction. The strategy is to use the offline version of the LPJ-Guess model used in EC-Earth, forced by the output of the DCPP runs (that are accomplished with LPJ-Guess turned off, i.e. without simulation of an interactive dynamic vegetation). The LPJ-Guess dynamic vegetation model has been configured to be used off-line from EC-Earth to conduct seasonal-to-decadal predictions of fire danger. This setup will allow to calibrate, test and refine the fire model that is included in LPJ-Guess. Currently the fire model within LPJ-Guess is the GlobFIRM model. Preliminary results of the offline LPJGUESS model, forced by the first results of BSC's DCPP hindcasts are illustrated in **Figure 4**, displaying a bias of around 1 PgC. The improved wildfire model of LPJ-GUESS (SIMFIRE/BLAZE) suffered from long delays and has not yet been incorporated into the EC-Earth repository. Therefore the evaluation on the improved wildfire predictions will be done in the future.

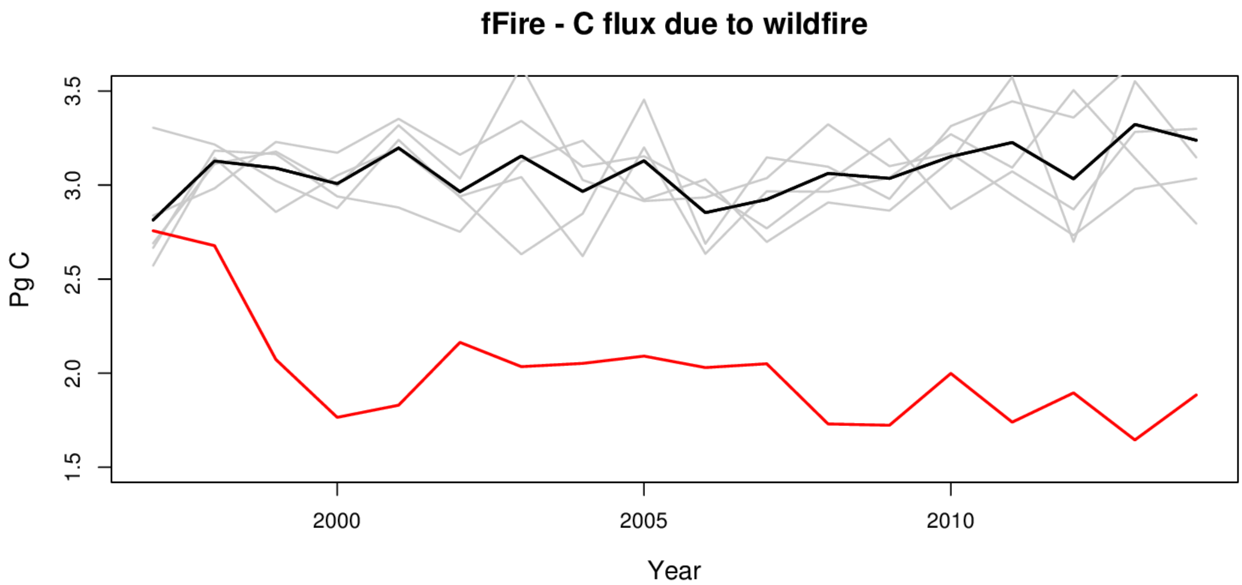

Figure 4: Carbon flux due to wildfire : estimations from GFED4s, compared to first year forecasts from the offline version of LPJG (with the GlobFIRM model) forced by 5 members of the DCPP forecasts done by BSC.

References

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Zhu Z, Bi J, Pan Y, Ganguly S, Anav A, Xu L, Samanta A, Piao S, Nemani RR, Myneni RB, 2013: Global data sets of vegetation leaf area index (LAI) 3g and fraction of photosynthetically active radiation (FPAR)3g derived from global inventory modeling and mapping studies (GIMMS) normalized difference vegetation index (NDVI3g) for the period 1981 to 2011. Remote Sens 5:927–948

List of publications/reports from the project with complete references

Alessandri et al., 2020: Potential contribution of realistic vegetation-state variability on climate predictions at decadal time scale, In preparation

Alessandri et al, 2020: Improving the physical parameterizations of the land-surface model in EC-Earth, In preparation

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

The limited HPC resources requested in SPNLALES special project allowed only a limited number of start dates of the decadal predictions. Given the encouraging beneficial effect of realistic vegetation in the evaluation performed so far in SPNLALES, we are currently considering to extend the simulations to additional start dates (and possibly ensemble members) to obtain enlarged sampling of the outcomes. To this aim, attempts will be made to obtain additional resources at ECMWF from follow-up special project or member state accounts and/or from HPC resources available at BSC, ISAC-CNR or ENEA in-house HPC systems.
By showing potential positive contribution of including realistic representation of biosphere processes on decadal climate predictions, this effort asks for continued activity in this field of research towards the development of integrated Earth system predictions.
Evaluation of the impact of the improvements on wildfire predictability will be done once the improved wildfire model (SIMFIRE/BLAZE) is incorporated into the EC-Earth version of LPJ-GUESS. Once the new version is available, we will produce some offline LPJ-GUESS simulation using the output of the simulations using the improved LAI dataset, which has been stored accordingly.