SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2021
Project Title:	Towards seamless development of land processes for Earth System prediction and projection
Computer Project Account:	spitales
Principal Investigator(s):	Andrea Alessandri
Affiliation:	Institute of Atmospheric Sciences and Climate, National Research Council of Italy, Bologna, Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	G. Balsamo, S. Boussetta, G. Arduini, T. Stockdale and M. Balmaseda
Start date of the project:	2019
Expected end date:	2021

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)	5500000	4992293.78	5500000	95154.84
Data storage capacity	(Gbytes)	31250	31000	47000	39000

Summary of project objectives (10 lines max)

The objectives of this special project are (i) to include the representation of the Earth System processes and feedbacks over land (from the latest Earth System Model developments in the frame of CMIP6 and beyond) that can suitably contribute to the short-term climate predictions performed using EC-Earth (Hazeleger et al., 2012; Doscher et al., 2021), (ii) to evaluate the impact of including Earth system processes over land on the skill of the retrospective seasonal forecasts, (iii) to progress towards new frontiers in the seamless development of Earth system predictions/projections across multiple time-scales.

Summary of problems encountered (10 lines max)

The delay in the set-up and simulation of control seasonal hindcasts (SEAS-CTRL) that were planned at BSC (in the framework of APPLICATE projects) gave us the opportunity to pursue a different strategy by performing the set of seasonal hindcasts using a low resolution (TCO199) version of ECMWF SEAS5 instead of EC-Earth as a follow-up of the H2020 project PROCEED. To this aim, the developments in the representation of land cover/vegetation dynamics previously done in EC-Earth has been included in SEAS5. This task has been accomplished thanks to the collaboration with colleagues at ECMWF [relevant people from the Research and Development department and the Earth System predictability department (G. Balsamo, S. Boussetta, G. Arduini, T. Stockdale and M. Balmaseda)]. The setup has been already tested as part of the EU H2020 project PROCEED and the hindcasts and analysis will be completed by 2021.

Summary of plans for the continuation of the project (10 lines max)

A set of retrospective seasonal forecasts (SEAS-EXP) with improved representation of land cover/vegetation processes over land is accomplished using the ECMWF SEAS5 at low resolution (TCO199, cubic octahedral reduced Gaussian grid equivalent to 800 x 400 longitude/latitude with a nominal resolution of 50 km at the equator, and 91 levels with the top level at 0.01 hPa) and compared with a control set of seasonal hindcasts (SEAS-CTRL).

The analysis of climate feedbacks in the climate projections together with the verification against new-generation satellite observations of (i) historical runs and (ii) seasonal forecasts will provide knowledge to better constrain the land processes for next developments in Earth system prediction.

List of publications/reports from the project with complete references

Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arneth, A., and Co-authors: The EC-Earth3 Earth System Model for the Climate Model Intercomparison Project 6, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2020-446, in review, 2021.

Alessandri et al, 2021: Improving the physical parameterizations of the land-surface model in EC-Earth. Under Submission.

Catalano et al, 2021: Land-surface feedbacks on temperature and precipitation in CMIP6-LS3MIP projections. In preparation.

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

To allow a consistent assessment of the impact of the long-term mean soil moisture changes between 1982–2014 and 2071–2100 on the late 21st century climate, an additional set of control projections (hereinafter PROJ-RMN) has been performed by prescribing a seasonal cycle of soil moisture as transient climatology (30 year running mean) obtained across the 1980-2100 period from the reference PROJ-EXP scenario. Same as PROJ-CTL, the climate projections for both SSP1-2.6 and SSP5-8.5 scenarios are performed with version 3.3 of EC-Earth, i.e. including all the latest Earth System Model developments over land in the frame of CMIP6.

The transient 30-year climatology of soil moisture was prescribed using the same technical interface implemented for PROJ-CTL by following the LS3MIP protocol (van den Hurk et al. 2016) that requires prescription of daily soil moisture values with the same relaxation time of 24 hours for all the four soil layers in HTESSEL.

Results

In this analysis, we focus on the differences between PROJ-CTL and PROJ-RMN at the end of the 21st Century (2071–2100). Differently from the comparison between PROJ-EXP and PROJ-CTL described in the report for the previous-year project activity, this new comparison allows to isolate the impact of only the long-term mean soil moisture changes alone on surface climate, while excluding the transient features and impacts of changes in the interannual soil moisture variability and coupling effects.
The PROJ-RMN minus PROJ-CTL differences in climatological (2071-2100) yearly-mean soil moisture are shown in Figs. 1a and 1b for SSP5-8.5 and SSP1-2.6. Both the scenarios display drier conditions over Europe, United States, Central America, Amazon basin, South Africa, East China; on the other hand, wetter conditions are over Canada and Euro-Asian boreal forests, India, Sahel and Australia. The corresponding latent and sensible heat flux changes are displayed in Figs. 1c,d and 1e,f, respectively. It is shown that all the regions with soil moisture reduction display a corresponding decrease in latent heat flux but an increase in sensible heat flux, indicating a transition of the surface-energy partitioning towards drier climate conditions, in agreement with Seneviratne et al. (2013). On the other hand, when soil moisture increases, the opposite flux response, is found only over Sahel, Australia and India. This is consistent with the fact that evapotranspiration tends to be water-limited over Sahel, Australia and India (Koster et al 2000; Seneviratne et al. 2010), while in regions such as the boreal forests the energy availability is mostly limiting evapotranspiration (Seneviratne et al. 2010). The land-surface feedbacks appear consistent in the two scenarios considered but become more evident in the SSP5-8.5 scenario, indicating an intensification of the land-surface feedbacks as the anthropogenic radiative-forcing increases.

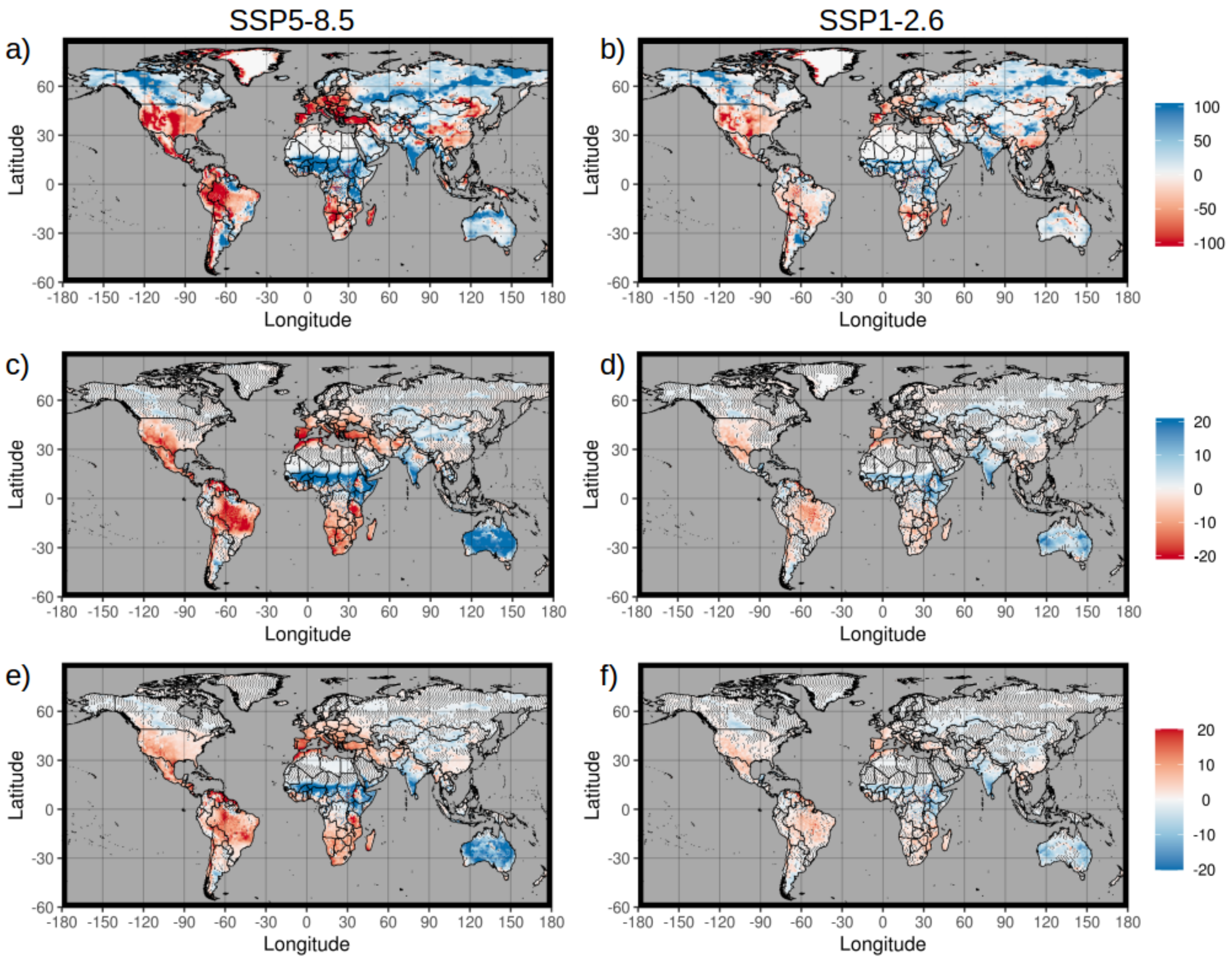

Fig. 1: PROJ-RMN minus PROJ-CTL yearly mean difference over time period 2071-2100 for the two scenarios considered: SSP1-2.6 (left column) and SSP5-8.5 (right column), (a, b) soil moisture (mm), (c, d) latent heat flux (W m-2), (e, f) sensible heat flux (W m-2). Dotted grid points did not pass a Monte Carlo bootstrap significance test at 10% level.

The (2071-2100) minus (1985-2014) difference of yearly-mean 2m-temperature for SSP5-8.5 and SSP1-2.6 are displayed in Fig. 2a and 2b, respectively. The temperature change over the 21st century is positive everywhere over land with values ranging from 0.2 K up to more than 3 K in SSP1-2.6 and from 1 K to more than 8 K in SSP5-8.5. Over the regions with negative soil moisture change (Figs 1a and 1b), the 2m-temperature increases significantly (Figs 2c and 2d); on the other hand, consistently with latent and sensible heat fluxes patterns (Fig. 1c-f), the cooling signal over regions getting wetter is significant only over Sahel, India and Australia. Again, the sensitivity of 2m-temperature to soil moisture is much stronger in the SSP5-8.5 scenario.

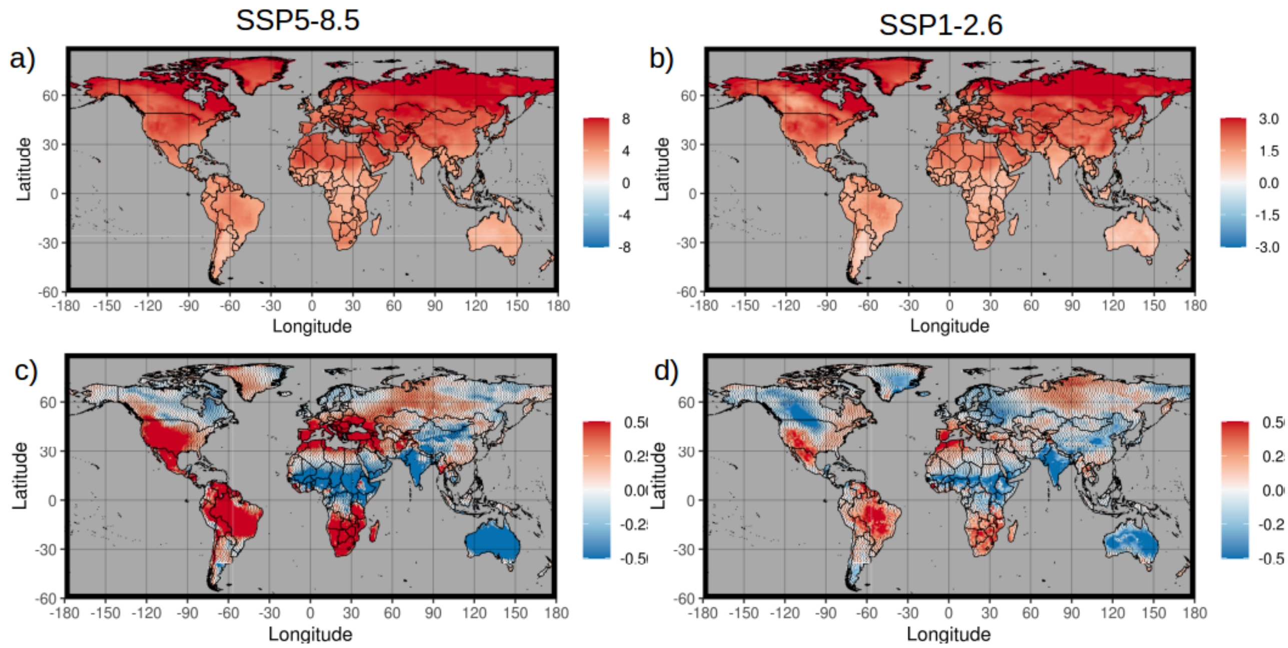

Fig. 2: Sensitivity of 2m-temperature to soil moisture changes for the two scenarios considered: SSP1-2.6 (left column) and SSP5-8.5 (right column); (a, b) yearly mean difference of 2m-temperature over time period 2071-2100 with respect to present day conditions (1985-2014); (c, d) PROJ-RMN minus PROJ-CTL yearly mean difference over time period 2071-2100. Values in K. Dotted grid points did not pass a Monte Carlo bootstrap significance test at 10% level.

Precipitation (Fig. 3 a, b) increases in the Northern Hemisphere, especially in SSP5-8.5 scenario. The larger effects on precipitation driven by the soil moisture occur over the US, Brazil, La Plata Basin, Sahel, Euro-Mediterranean domain and southern Asia, in agreement with observational analysis by Catalano et al. (2016). As expected, precipitation reduction is associated to drying soil moisture conditions almost everywhere, except for the African area north of the Gulf of Guinea where precipitation reduces but soil moisture increases. This may be due to changes in the dynamics of the West African monsoon, possibly partially related to the modified land-sea contrast in PROJ-CTL compared to PROJ-RMN (Fig 2c). This is consistent with Cherchi et al. (2011) where it has been shown that the West African monsoon can have a different behaviour compared to other monsoon systems because of a non-linear dynamical response to anthropogenic forcing that could lead to negative precipitation changes.

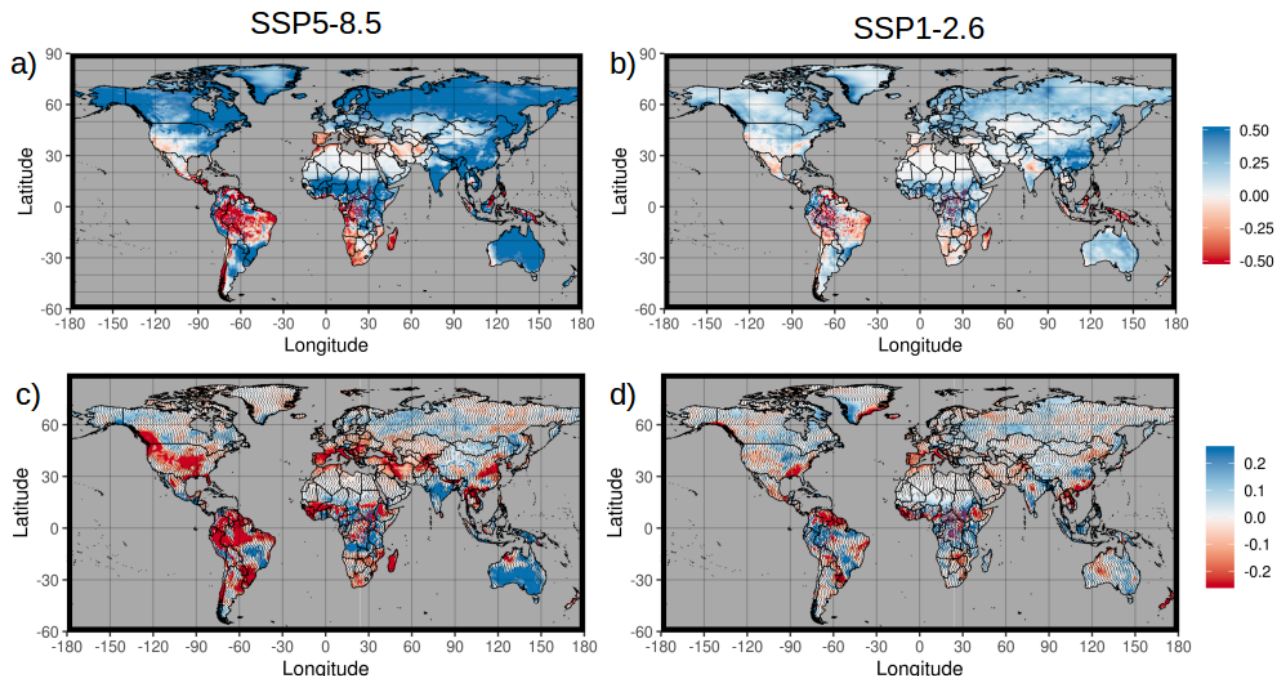

Fig. 3: As Fig. 2 but for precipitation.

References

Catalano F., Alessandri A., De Felice M., Zhu Z., Myneni R. B., 2016: Observationally based analysis of land-atmosphere coupling. Earth Syst. Dynam., 7, 251-266, doi:10.5194/esd-7-251-2016

Cherchi, A., Alessandri, A., Masina, S. *et al., 2011:* Effects of increased CO_2 levels on monsoons. *Clim Dyn* **37,** 83–101. https://doi.org/10.1007/s00382-010-0801-7

Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arneth, A., and co-authors.: The EC-Earth3 Earth System Model for the Climate Model Intercomparison Project 6, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2020-446, in review, 2021.

van den Hurk, B., Kim, H., Krinner, G., Seneviratne, S. I., Derksen, C., Oki, T., Douville, H., Colin, J., Ducharne, A., Cheruy, F., Viovy, N., Puma, M. J., Wada, Y., Li, W., Jia, B., Alessandri, A., Lawrence, D. M., Weedon, G. P., Ellis, R., Hagemann, S., Mao, J., Flanner, M. G., Zampieri, M., Materia, S., Law, R. M., and Sheffield, J., 2016: LS3MIP (v1.0) contribution to CMIP6: the Land Surface, Snow and Soil moisture Model Intercomparison Project – aims, setup and expected outcome, Geosci. Model Dev., 9, 2809–2832, https://doi.org/10.5194/gmd-9-2809-2016

Hazeleger W., Wang, X., Severijns, C. and Coauthors, 2012: EC-Earth v2.2: Description and validation of a new seamless Earth system prediction model. Climate Dyn., 39, 2611–2629, doi:10.1007/s00382-011-1228-5

Koster, R. D., Suarez, M. J., and Heiser, M., 2000: Variance and predictability of precipitation at seasonal-to-interannual timescales, J. Hydrometeorol., 1, 26–46.

Seneviratne, S. I., Corti, T., Davin, E. L., Hirschi, M, Jaeger, E. B., Lehner, I., Orlowsky, B., and Teuling, A. J., 2010: Investigating soil moisture–climate interactions in a changing climate: A review, Earth Sci. Rev., 99, 125–161.

Seneviratne, S. I., Wilhelm, M., Stanelle, T., van den Hurk, B., Hagemann, S., Berg, A., Cheruy, F., Higgins, M. E., Meier, A., Brovkin, V., Claussen, M., Ducharne, A., Dufresne, J.-L., Findell, K. L. Ghattas, J., Lawrence, D. M., Malyshev, S., Rummukainen, M., and Smith, B.: Impact of soil moisture-climate feedbacks on CMIP5 projections, 2013: First results from the GLACE-CMIP5 experiment, Geophys. Res. Lett., 40, 5212–5217, doi:10.1002/grl.50956