SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Towards seamless development of land processes for Earth System prediction and projection
Computer Project Account:	Spitales
Start Year - End Year :	2019 - 2021
Principal Investigator(s)	Andrea Alessandri
Affiliation/Address:	Institute of Atmospheric Sciences and Climate, National Research Council of Italy (CNR-ISAC) Via Gobetti 101 I-40129 Bologna, Italy
Other Researchers (Name/Affiliation):	Franco Catalano (ENEA), Annalisa Cherchi (ISAC-CNR), Fransje van Oorschot (ISAC-CNR), Etienne Tourigny (BSC), Pablo Ortega (BSC), G. Balsamo (ECMWF), S. Boussetta (ECMWF), G. Arduini (ECMWF), T. Stockdale (ECMWF) and M. Balmaseda (ECMWF)

The following should cover the entire project duration.

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., 2022), (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

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

The set-up and configuration of the reference seasonal prediction system and associated set of control seasonal hindcasts (SEAS-CTRL) that were planned at BSC in 2019 (in the framework of APPLICATE H2020 project) was significantly postponed delaying the execution of the retrospective seasonal forecasts with improved representation of land cover/vegetation (SEAS-EXP). Still, the delays in producing the SEAS-CTRL experiment 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 previously accomplished in EC-Earth has been as well included in SEAS5. This task has been completed 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 LS3MIP interface for the climate-sensitivity projections caused a slight decrease of the model computational performance with a corresponding 15% SBU increase of computational costs for the sensitivity runs (PROJ-CTL and PROJ-RMN); this implied to request 1000000 SBU of additional resources that were granted to spitales in 2019.

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 with administrative aspects: 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.)

1. ***Land-surface feedback on climate change mediated by soil moisture***

A set of historical simulations and climate projections has been 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. These simulations (hereinafter PROJ-EXP) constitute the first member of the EC-Earth historical and scenario (ScenarioMIP; O'Neill et al., 2016) contribution to CMIP6 (Eyiring et al., 2016). The climate projections for this work are based on two different scenarios: SSP1-2.6 and SSP5-8.5.

Following Seneviratne et al. (2013), a set of climate-sensitivity projections has been carried out disabling the land feedbacks to climate change by prescribing the soil-moisture states from a climatology derived from "present climate conditions" (1980-2014). By comparing this sensitivity-experiment with standard projections with all feedbacks in place, we aim at diagnosing the role of land-atmosphere feedback on climate change. The climate-projection sensitivity experiments follow the LS3MIP protocol (van den Hurk et al. 2016) and constitute the EC-Earth contribution to the LFMIP-pdLC experiments. The two sensitivity simulations (hereinafter PROJ-CTL) span the period 1980-2100 with SST and sea-ice conditions prescribed from PROJ-EXP and soil moisture state prescribed from the 1980-2014 seasonal-climatology as well obtained from the historical PROJ-EXP. PROJ-CTL simulations have been run using CMIP6 version of EC-Earth (v3.3, same used for PROJ-EXP) but modified to include a new interface to prescribe soil moisture values.

To allow a consistent assessment of the impact of the long-term mean soil moisture changes between the present-day (1982–2014) and the late 21st century (2071-2100) climates, an additional set of climate-sensitivity 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. These new climate projections (both SSP1-2.6 and SSP5-8.5 scenarios) are performed using the version 3.3 of EC-Earth, same used for PROJ-CTL simulations. 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 defined in HTESSEL.

Results

Here we focus on the differences between PROJ-CTL and PROJ-RMN at the end of the 21st Century (2071–2100), which allows to effectively isolate the impact of only the long-term mean soil moisture changes on surface climate, while excluding the transient features and impacts of changes in the interannual soil moisture variability and coupling effects (please refer to the second-year report activity for the comparison between PROJ-EXP and PROJ-CTL).

The PROJ-RMN minus PROJ-CTL differences in climatological (2071-2100) annual mean soil moisture are shown in Figures 1a and 1b for SSP5-8.5 and SSP1-2.6, respectively. 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 Figures 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.

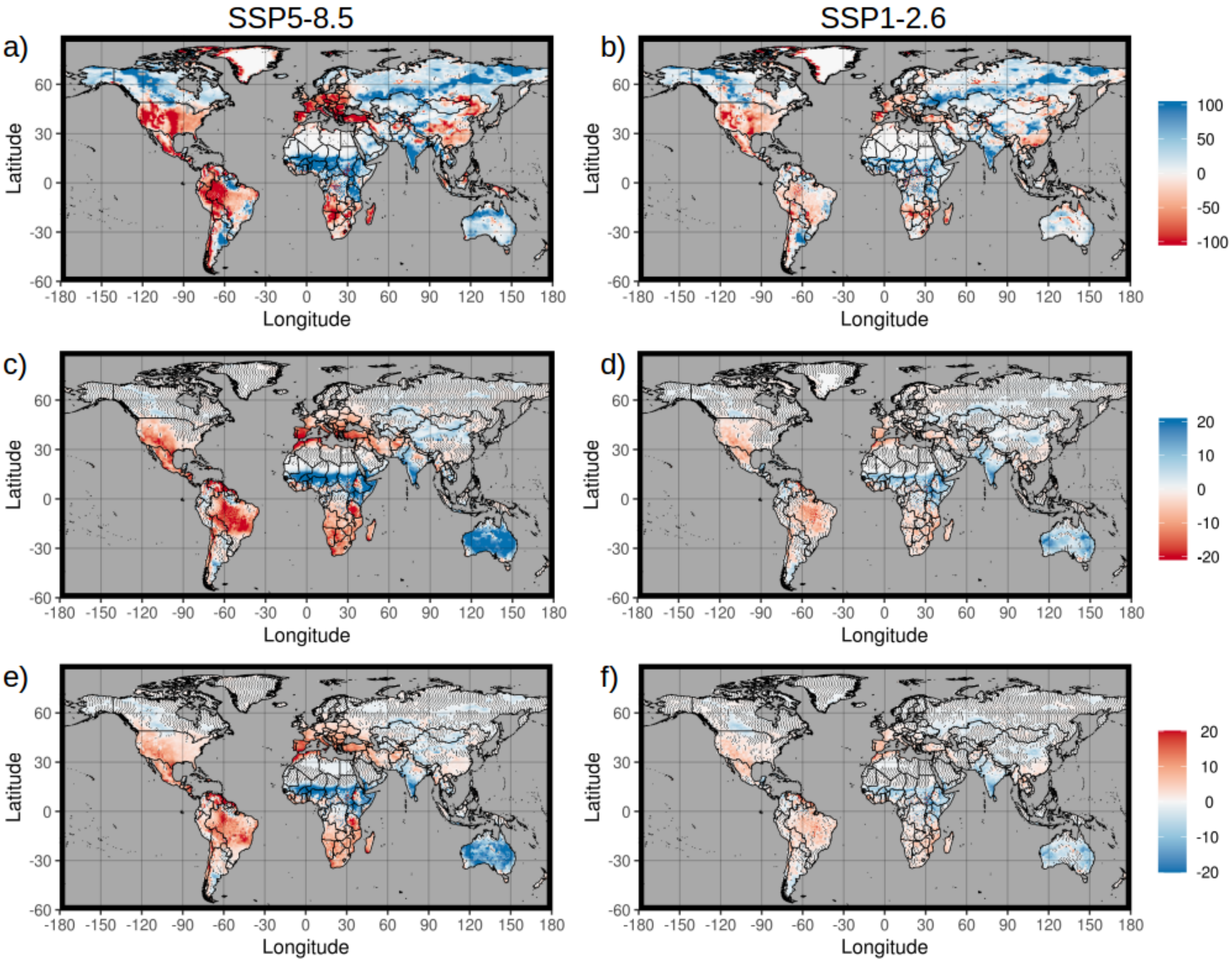

Figure 1: PROJ-RMN minus PROJ-CTL yearly mean difference over time period 2071-2100 for the two scenarios considered: SSP1-2.6 (left column) and SSP5-8.5 (right column), (a, b) soil moisture (mm), (c, d) latent heat flux (W m-2), (e, f) sensible heat flux (W m-2). Dotted grid points did not pass a Monte 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 Figure 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 (Figures 1a and 1b), the 2m-temperature increases significantly (Figures 2c and 2d); on the other hand, consistently with latent and sensible heat fluxes changes (Figure 1c-f), the colder temperature 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.

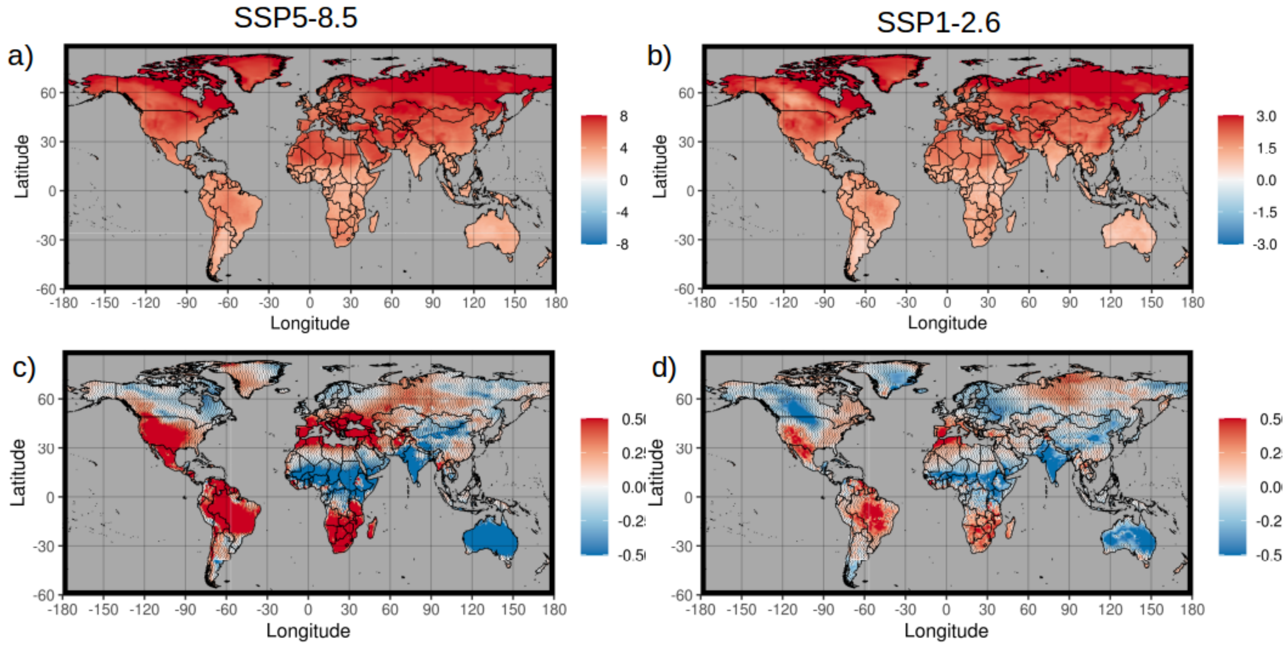

Figure 2: Sensitivity of 2m-temperature to soil moisture changes for the two scenarios considered: SSP1-2.6 (left column) and SSP5-8.5 (right column); (a, b) yearly mean difference of 2m-temperature over time period 2071-2100 with respect to present day conditions (1985-2014); (c, d) PROJ-RMN minus PROJ-CTL 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 (Figure 3a,b) increases in most part of the Northern Hemisphere continents and of Australia, 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 drier soil moisture conditions everywhere, except over Africa 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 related, at least in part, to the modified land-sea contrast in PROJ-CTL compared to PROJ-RMN (Figure 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.

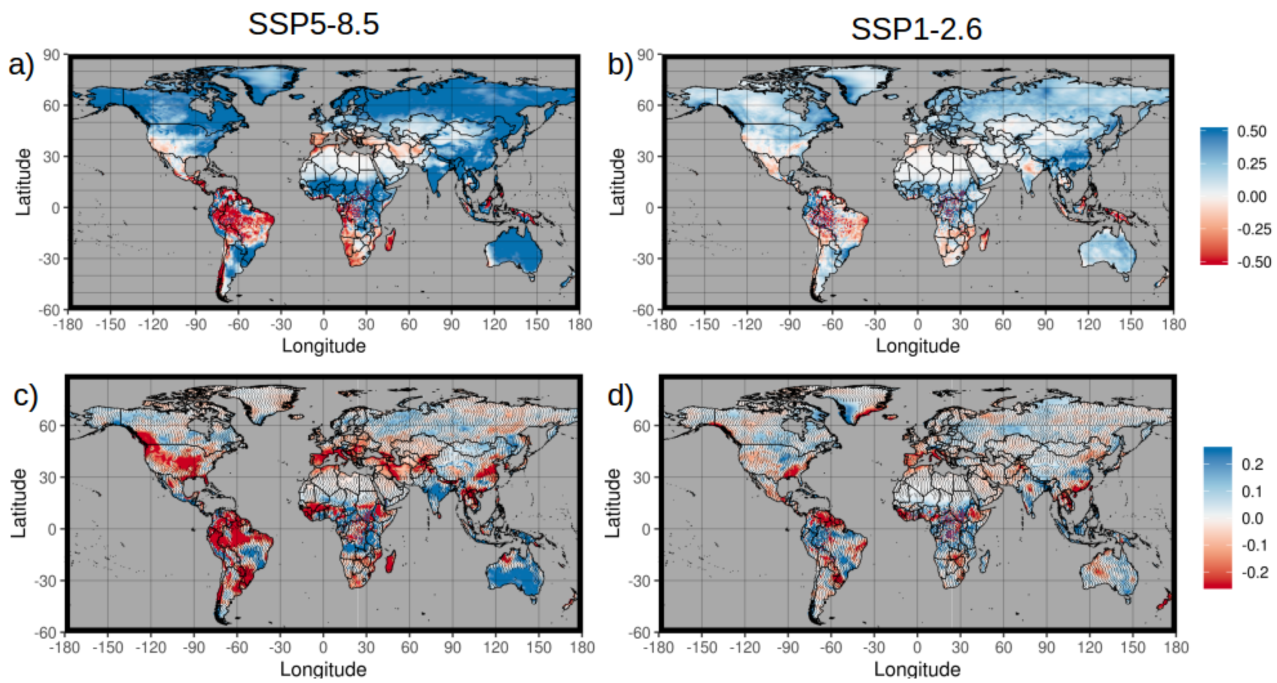

Figure 3: As Figure 2 but for precipitation.

The outcomes of this analysis will contribute to the multi-model intercomparison that will be discussed in a peer-reviewed paper for the scientific community that is currently in preparation:

F. Catalano, and co-authors: Land-surface feedbacks on temperature and precipitation in CMIP6-LS3MIP projections. Under submission, 2022.

2. ***Effect of improved representation of vegetation on ECMWF SEAS5 seasonal predictions***

The models that are developed for the short time-scales (Weather, seasonal to decadal climate predictions) include only that part of the surface and near-surface variability for which observations are available and that can be suitably modelled/initialized to positively contribute to the forecasts (verification-based approach). Therefore, to limit prediction errors, short time-scale models do not include those processes related to vegetation and their seasonal, interannual and sub-grid variability. Even the world leading weather and seasonal prediction system developed at ECMWF appears ill-equipped for this task. In this respect, the land surface model developed at ECMWF (HTESSEL; Balsamo et al. 2009), assumes land cover and vegetation characteristics to be constant in time (as obtained from the Global Land Cover Characteristics data; Loveland et al., 2000) and so the related biophysical parameters are likewise not varying in time. So far, only a climatological seasonal cycle of monthly-mean Leaf Area Index (LAI; defined as the green leaf area per unit ground surface area covered by vegetation) is prescribed in the HTESSEL model. This can only affect climate by modifying the seasonal march of the vegetation physiological resistance to evapotranspiration in HTESSEL, while albedo, surface roughness length, and soil water exploitable by roots for evapotranspiration do not vary in time. Even surface albedo of snow in vegetation-covered areas does not depend on LAI values in the model (Weiss et al., 2012; 2014).

To amend above limitations, here a parameterization of the vegetation cover variability has been introduced in HTESSEL that allows for a realistic coupling with the overlying atmosphere. The parameterization is suitably obtained from what previously tested/developed in the frame of EC-Earth (Alessandri et al., 2017)

Experiments and data

We use version 5 of ECMWF seasonal prediction system (SEAS5; Johnson et al 2019) at low-resolution configuration (Tco199Orca1_Z75; hereinafter lowres). Two 25-member ensembles of retrospective predictions are performed using (i) standard (CTRL) and (ii) modified (SENS) versions of the SEAS5 lowres for the period 1982-2014 (1st November start dates). The same configuration, resolution and initial conditions of SEAS5-lowres have been used in both CTRL and SENS but land surface. The difference over land is that the SENS version allows vegetation fractional coverage to change as a function of Leaf Area Index (LAI) for both low and high vegetation following the approach described in Alessandri et al. (2017). To initialize land, two distinguished ERA-Land off-line simulations have been performed with the same atmospheric forcing (ERA-Interim; Dee et al. 2011) and configuration but the effective vegetation-cover implementation in SENS. This is needed to make sure the initialized SENS is also in equilibrium with land initial conditions to avoid any possibility of artificial drifts that could affect the comparison. For SENS, both off-line simulation and hindcasts has been driven with observed LAI from 1982-2014 LAI3g data (Zhu et al., 2013).

The satellite observations of surface albedo (GLASS-GLCF; Liu et al., 2013) are used for the verification; ERA5 reanalysis (Hersbach et al. 2018) is the reference dataset for all the other surface climate variables considered in the evaluation (2m Temperature; Mean Sea Level pressure, snow depth, and surface fluxes of sensible and latent heat).

Results

Figure 4a shows the difference of the correlations with observed 2m-temperature between SENS and CTRL in the ensemble-mean seasonal forecasts at 1-month lead-time for the 2-4 month forecast period valid in DJF. For each grid point, we tested the null hypothesis of getting as high or higher correlation differences simply by chance through a Monte Carlo bootstrap method (1000 repetitions). Overall, the performance of SENS is better than CTRL, especially in the Northern Hemisphere. The SENS experiment displays increased correlations over Siberia and further west matching the distribution of Euro-Asian Boreal forests (e.g. see Settele et al., 2014). It is not found ACC improvement over North America boreal forests though, probably also due to the higher vegetation-LAI there that is in the part of the Lambert-beer curve that displays smaller slope and towards saturation to 1. As a consequence, there is less vegetation variability introduced that can affect albedo prediction in this domain when compared with GLASS-GLCF satellite data.

To investigate the coupling and the possible predictability sources, the relationships between the improvement of the correlation for the target variables (e.g. 2 m-temperature) is analyzed with respect to the improvements in the possible surface drivers for the areas of interest (e.g. surface snow depth, surface albedo, soil moisture). For this purpose, the correlation coefficient is decomposed in its components measuring the covariance between each predicted (x) and observed (y) yearly (i) anomalies [hereinafter normalized yearly covariance, $r(x,y)_i$] following the approach in Alessandri et al (2017). The SENS minus CTRL difference in the normalized yearly covariance [$\Delta r(x,y)_i$] is analyzed to identify the possible surface contributor to the enhanced predictability of the target variables due to the improved land surface conditions. To this aim, the linear relation between $\Delta r(x,y)_i$ of the target and driver fields is assessed using a least square method and the significance of the slope of linear relationship is evaluated using a Fisher parametric test. The positive linear relationship between target and driver in terms of the SENS-minus-CTRL $\Delta r(x,y)_i$ indicates the change of predictability of the target as mediated by the driver, which is directly affected by the difference in the land surface. Only the linear coefficients of the regression that passed significance test at 10 % level are considered. The analysis reveals a strong local coupling of the improved skill in 2m temperature, over Euro-Asian boreal forest coming from the surface albedo (Figure 4b). In fact, SENS displays a significant improvement in surface albedo compared with CTRL over Siberia (Not shown). Interestingly, the orange years (indicating when both target and driver lying in the lower/upper terciles of their respective distribution) on the upper-right quadrant of Figure 4b indicate that the positive effect of the surface-albedo coupling occurs in years of strong NAO activity (except for 2005). On the other hand, the orange years on the lower-left quadrant of Figure 4b occur in relatively neutral NAO years. This result suggests that the coupling from the land surface albedo might operate by amplifying the signal originating from the North Atlantic sector therefore producing improved T2m skill locally when NAO teleconnection is active.

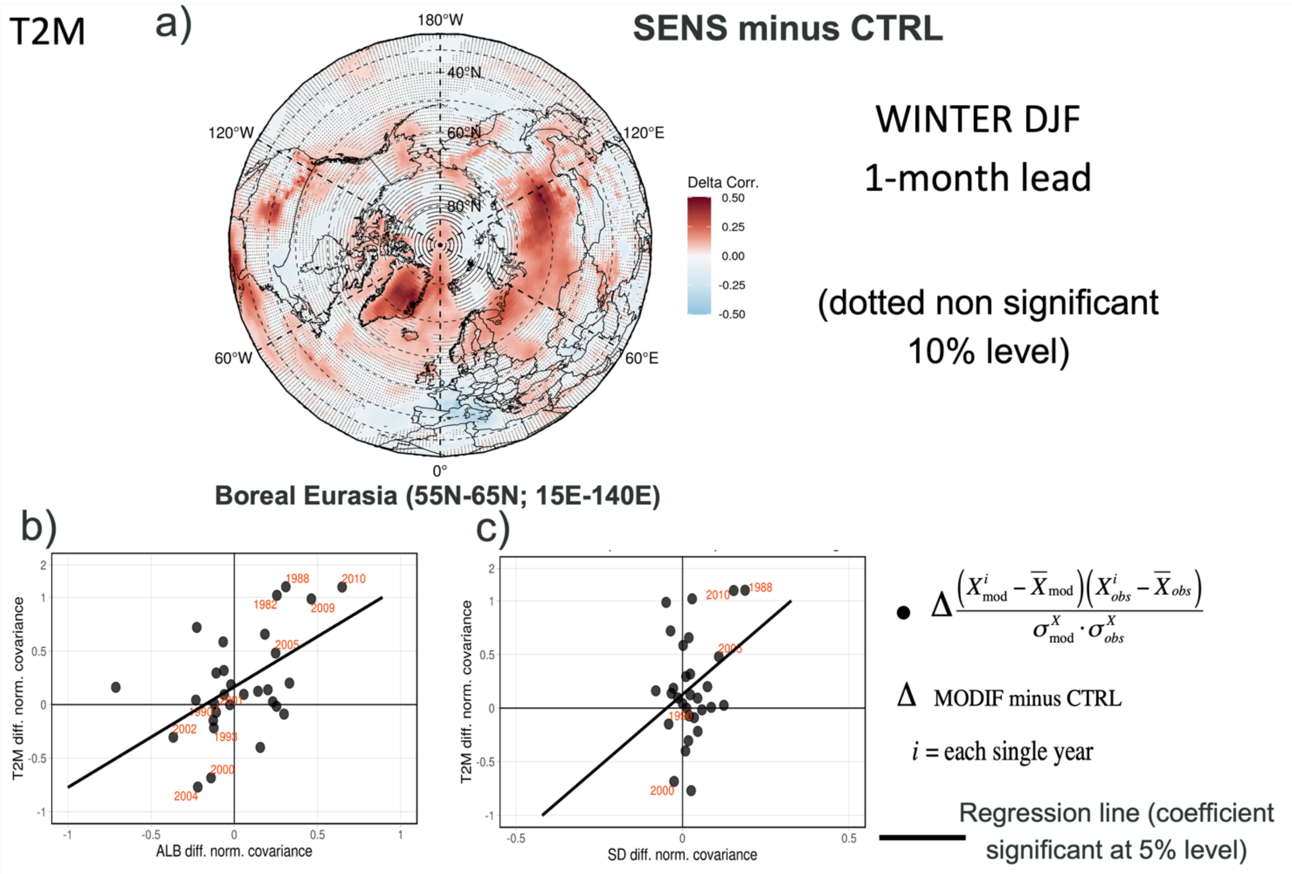

Figure 4: *a*) 1-month-lead boreal winter (DJF) 2 m temperature SENS minus *CTRL* correlation difference vs. ERA-5. Dotted grid points did not pass a significance test at 10 % level. b,c) Scatterplot of the normalized yearly covariance differences between SENS and *CTRL* [$\Delta r(x,y)ki$] for the predictions averaged over the Eurasia boreal forest domain (15E–140E; 55N–65N) of b) T2m versus albedo and c) T2m versus snow-depth. *Black filled circles* are the normalized yearly covariance differences for each start date (i = 1, 2, ...,33). Regression line indicate significant (10 % level) relationship between improved prediction of T2m and enhanced b) albedo and c) snow depth. Orange years indicate when normalized yearly covariance difference change in the same direction (i.e. both target and driver lying in the lower/upper terciles of their respective distribution).

From the regions with the largest 2m temperature improvements over Siberia originates a large-scale circulation effect encompassing Northern Hemisphere mid-to-high latitudes from Siberia to North Atlantic as displayed from the ACC difference in mean sea level pressure (MSLP; not shown). It corresponds to a significant MSLP ACC-enhancement over Siberia that extends further towards northwest also affecting, to some extent, the North Atlantic and Arctic domains. The Leading mode (EOF1) of DJF MSLP interannual variability over North Atlantic sector [20N-80N; 90W-40E] appears to be slightly better represented in SENS compared to CTRL (Not shown). Importantly, the correlation between the NAO index computed from the corresponding First Principal Component (PC1) against ERA5 show a significant improvement in SENS. In fact, the correlation coefficient increases from 0.18 (not statistically significant at 5% significance level) in CTRL to 0.38 (statistically significant 5% significance level) in SENS (see Table 1).

Correlation vs. ERA5	NAO
Sens	0.34 **
Control	0.18

Table 1: Correlation between the predicted NAO index [computed as the PC1 of leading mode (EOF1) of DJF MSLP interannual variability over North Atlantic sector; 20N-80N; 90W-40E] for SENS (1st row) and CTRL (2nd row) experiments against ERA5).

The outcomes of this analysis will be further discussed in a peer-reviewed paper for the scientific community that is currently under submission:

A. Alessandri, and co-authors: Enhancement of seasonal climate prediction in ECMWF SEAS5 by representing realistic vegetation-cover variability. Under submission, 2022.

Referenes:

Alessandri, A., Catalano, F., De Felice, M. et al., 2017: Multi-scale enhancement of climate prediction over land by increasing the model sensitivity to vegetation variability in EC-Earth. Clim Dyn 49, 1215–1237. https://doi.org/10.1007/s00382-016-3372-4

Balsamo, G., A. Beljaars, K. Scipal, P. Viterbo, B. van den Hurk, M. Hirschi, and A. K. Betts, 2009: A revised hydrology for the ECMWF model: Verification from field site to terrestrial water storage and impact in the integrated forecast system. J. Hydrometeor. , 10, 623–643, doi:10.1175/2008JHM1068.1.

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

Dee, D., and Coauthors, 2011: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. Quart. J. Roy. Meteor. Soc., 137, 553–597, doi:10.1002/qj.828.

Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arneth, A., and co-authors., 2022: The EC-Earth3 Earth System Model for the Climate Model Intercomparison Project 6, Geosci. Model Dev., 15, 2973–3020, https://doi.org/10.5194/gmd-15-2973-2022.

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

Hersbach et al (2018) Operational global reanalysis: progress, future directions and synergies with NWP. ERA Report series, ECMWF, 65 pp.

Hurk van den, 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

Johnson, S. J., Stockdale, T. N., Ferranti, L., Balmaseda, M. A., Molteni, F., Magnusson, L., Tietsche, S., Decremer, D., Weisheimer, A., Balsamo, G., Keeley, S. P. E., Mogensen, K., Zuo, H., and Monge-Sanz, B. M.: SEAS5, 2019: the new ECMWF seasonal forecast system, Geosci. Model Dev., 12, 1087-1117, https://doi.org/10.5194/gmd-12-1087-2019

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.

Liu, Q., L. Wang, Y. Qu, N. Liu, S. Liu, H. Tang, and S. Liang, 2013: Preliminary evaluation of the long-term glass albedo product. International Journal of Digital Earth, 6 (sup1), 69–95, doi:10.1080/17538947.2013.804601.

Loveland, T. R., B. C. Reed, J. F. Brown, D. O. Ohlen, Z. Zhu, L. Youing, and J. W. Merchant, 2000: Development of a global land cover characteristics database and IGBP DISCover from the 1km AVHRR data. Int. J. Remote Sensing, 21, 1303–1330.

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

Settele, J., R. Scholes, R. Betts, S. Bunn, P. Leadley, D. Nepstad, J.T. Overpeck, and M.A. Taboada, 2014: Terrestrial and inland water systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 271-359.

Weiss, M., van den Hurk, B., Haarsma, R., and Hazeleger, W., 2012: Impact of vegetation variability on potential predictability and skill of EC-Earth simulations; Clim. Dyn., 39, 2733–2746.

Weiss, M., Miller, P., van den Hurk, B., van Noije, T., Stefanescu, S., Haarsma, R., van Ulft, L. H., Hazeleger, W., Le Sager, P., Smith, B., and Schurges, G., 2014: Contribution of dynamic vegetation phenology to decadal climate predictability; J. Clim., doi:10.1175/JCLI-D-13-00684.1.

Zhu, Z., Bi, J., Pan, Y., Ganguly, S., Anav, A., Xu, L., Samanta, A., Piao, S., Nemani, R. R., and Myneni, R. B., 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

Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arneth, A., and Co-authors, 2022: The EC-Earth3 Earth system model for the Coupled Model Intercomparison Project 6, Geosci. Model Dev., 15, 2973–3020, https://doi.org/10.5194/gmd-15-2973-2022.

Alessandri, A., et al, 2022: Enhancement of seasonal climate prediction in ECMWF SEAS5 by representing realistic vegetation-cover variability. Under submission.

Catalano, F., et al, 2022: Land-surface feedbacks on temperature and precipitation in CMIP6-LS3MIP projections. Under Submission.

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 beneficial effects of a more realistic process-based vegetation modelling shown in this special project motivates a new special project [SPITALES - 2022-2023] aimed at exploiting observations to constrain land cover, vegetation and hydrology processes for improved near-term climate predictions over land.