Danmarks Meteorologiske Institut

DMI Report 22-28
Earth System Modelling and CMIP

Final scientific report of the 2021 National Centre for Climate Research Work Package 4.1

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1. Scientific summary

Short description

This work package aims at further developing our capability in global climate modelling, climate predictions and projections. We have closely collaborated with the EC-Earth consortium to develop the Earth System Model (ESM) EC-Earth. This includes evaluating and documenting the suite of EC-Earth3 which is the ESM applied for the Coupled Model Intercomparison Project phase 6 (CMIP6), and to adapt its high resolution configuration, EC-Earth3-HR, to DMI's High Performance Computer (HPC) system. We have assessed the CMIP6 and CMIP6 endorsed MIPs to extend our understanding on the climate response for various anthropogenic emission scenarios. We have also continued the development of the EC-Earth3 climate prediction system using anomaly initialization for the ocean and sea ice with focus on understanding the value of initialization for the improvement of climate predictions.

The capacity building also comprises establishing an Earth System Grid Federation (ESGF) data node at DMI for publication of the CMIP6 data that we have produced using the EC-Earth3 ESM. The ESGF system is a collaboration that develops, deploys and maintains software infrastructure for the management, dissemination and analysis of CMIP6 model output and observations. The CMIP6 model output published on the ESGF have to be reformatted following the CMIP6 standard and quality assurance compliance, and thus adhere the FAIR (finable, accessible, interoperable and reusable) data principle. We have worked extensively on our CMIP6 simulation data to ensure they follow the up-to-date guidelines from the CMIP6 data infrastructure panel.

Overall results

We have worked with the EC-Earth consortium in evaluating and documenting the EC-Earth3 (Döscher et al, 2021). The EC-Earth3 features with improved physical and dynamic features, new ESM components, community tools, and largely improved physical performance compared to the CMIP5 version. Its key performance metrics demonstrate physical behavior and biases well within the frame known from recent CMIP6 models. We have also started the work of configuring the EC-Earth3-HR on the DMI's HPC. A series of tests with individual component model and AOGCM (Atmosphere-Ocean General Circulation Model) at high resolution (at 0.25° for the ocean and ~39 km for the atmosphere) are performed to investigate the running efficiency and the load balance of the model. We are now working with the IT department to find a solution of most cost-effective implementing the EC-Earth3-HR on the current HPC.

The EC-Earth3 model has been used to contribute to a number of CMIP6 and CMIP6 endorsed MIPs. We have joined the international modelling teams in investigating these multi-model ensembles simulations for assessments of the climate responses to various anthropogenic emission scenarios. In an analysis of the CMIP6 ScenarioMIPs, we quantified the projected climate changes toward the end of the 21st century for a number of emission scenarios (Tebaldi et al, 2021). We found that the target of keeping global mean temperature under the 1.5°C will not be possible with any of the ScenarioMIP Tier 1 scenario (e.g., SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) and

the ssp1-1.9. But there is good chance to keep the 2°C target if follows the ssp1-1.9 scenario. All other scenarios will reach 2°C at around 2039 – 2064.

In a study of the CMIP6 CovidMIP that addresses the climate impact of the emission reduction due to the covid-19 pandemic lockdown in many nations during 2020, we found that aerosol amounts are reduced, especially over East Asia, during 2020-2024 (Jones et al, 2021). This leads to increases in solar radiation reaching the surface in this region. However, there are no detectable signals on temperature or rainfall that are associated to impact of the reduced emissions.

The EC-Earth3 climate prediction system is also used to investigate the impact of sea ice initialization on the annual to decadal climate prediction in the Arctic. By comparing the decadal prediction experiments with and without sea ice initialization, evidence of improved skill in the Arctic and in some atmospheric quantities are found (Tian et al, 2021). In particular, the persistence of multi-year ice thickness in the Central Arctic Ocean affects the interannual predictability of sea ice in its adjacent waters via advection process or wind. Thus the initialization of sea ice thickness is important for regional Arctic sea ice predictions at decadal time scale. In the evaluation and validation of the prediction system and simulations, we found a couple of bugs in the implementation of the initialization, implying that some observed anomalies were not fully incorporated into the initial conditions used to initiate the prediction simulations. We, together with the development team at SMHI (Swedish Meteorological and Hydrological Institute), have evaluated the impact of these errors. We conclude that the dynamical imbalance due to the bugs only influences the simulations in a limited time span, and does not change the overall results of the predictions on annual to decadal time scales. We are now working on a draft to document the problems found and the evaluation.

Next steps

Our work on model development, evaluation and analysis of the CMIP6 simulations have led to a number of peer review publications in scientific journals. We will continue to work on the development of the EC-Earth model. In particular we will contribute to the development of the next generation of the EC-Earth model, EC-Earth4, which uses component models with improved physics and dynamics. The targeted resolutions of the EC-Earth4 will be at 0.25° for the ocean and equivalent for the atmosphere, which allows better representation of many small scale processes. The model thus can better capture the interaction between different processes and components in the climate system. We will also continue to improve the current climate prediction system by introducing new methods such as nudging the sea surface temperature and surface wind, so that the system can better assimilate the climate state and the initial conditions. We have already prepared all our CMIP6 simulation data for publication on the ESGF data node. We will finalize the installation of the DMI ESGF data node with the help of the National Supercomputer Centre (NSC) at Linköping University who represents the CMIP6 data infrastructure panel on ESGF management, and make the final publication of our data.

2. Scientific publications

(1) This paper documents the detailed of the configuration suite and performance of the EC-Earth3, an Earth System Model contributed to CMIP6:

Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arneth, A., Arsouze, T., Bergmann, T., Bernadello, R., Bousetta, S., Caron, L.-P., Carver, G., Castrillo, M., Catalano, F., Cvijanovic, I., Davini, P., Dekker, E., Doblas-Reyes, F. J., Docquier, D., Echevarria, P., Fladrich, U., Fuentes-Franco, R., Gröger, M., v. Hardenberg, J., Hieronymus, J., Karami, M. P., Keskinen, J.-P., Koenigk, T., Makkonen, R., Massonnet, F., Ménégoz, M., Miller, P. A., Moreno-Chamarro, E., Nieradzik, L., van Noije, T., Nolan, P., O'Donnell, D., Ollinaho, P., van den Oord, G., Ortega, P., Prims, O. T., Ramos, A., Reerink, T., Rousset, C., Ruprich-Robert, Y., Le Sager, P., Schmith, T., Schrödner, R., Serva, F., Sicardi, V., Sloth Madsen, M., Smith, B., Tian, T., Tourigny, E., Uotila, P., Vancoppenolle, M., Wang, S., Wårlind, D., Willén, U., Wyser, K., Yang, S., Yepes-Arbós, X., and Zhang, Q.: The EC-Earth3 Earth System Model for the Climate Model Intercomparison Project 6, published on *Geosci. Model Dev*. [preprint], https://doi.org/10.5194/gmd-2020-446.

(2) A multi-model multi-member ensemble study addresses the climate response to the emission reductions due to the Covid-19 pandemic lockdown in 2020:

Jones, C. D., Hickman, J. E., Rumbold, S. T., Walton, J., Lamboll, R. D., Skeie, R. B., Jonathan E. Hickman, Steven T. Rumbold, Jeremy Walton, Robin D. Lamboll, Ragnhild B. Skeie, Stephanie Fiedler, Piers M. Forster, Joeri Rogelj, Manabu Abe, Michael Botzet, Katherine Calvin, Christophe Cassou, Jason N.S. Cole, Paolo Davini, Makoto Deushi, Martin Dix, John C. Fyfe, Nathan P. Gillett, Tatiana Ilyina, Michio Kawamiya, Maxwell Kelley, Slava Kharin, Tsuyoshi Koshiro, Hongmei Li, Chloe Mackallah, Wolfgang A. Müller, Pierre Nabat, Twan van Noije, Paul Nolan, Rumi Ohgaito, Dirk Olivié, Naga Oshima, Jose Parodi, Thomas J. Reerink, Lili Ren, Anastasia Romanou, Roland Séférian, Yongming Tang, Claudia Timmreck. Jerry Tjiputra, Etienne Tourigny, Kostas Tsigaridis. Hailong Wang. Mingxuan Wu. Klaus Wyser, Shuting Yang, Yang Yang, Tilo Ziehn, 2021: The Climate Response to Emissions Reductions due to COVID-19: Initial Results from CovidMIP. *Geophysical Research Letters*, 48, e2020GL091883. https://doi.org/10.1029/2020GL091883

(3) Assessment of the future climate changes under different anthropogenic emission scenarios as projected by the CMIP6 ScenarioMIP experiments:

Tebaldi, C., Debeire, K., Eyring, V., Fischer, E., Fyfe, J., Friedlingstein, P., Knutti, R., Lowe, J., O'Neill, B., Sanderson, B., van Vuuren, D., Riahi, K., Meinshausen, M., Nicholls, Z., Tokarska, K. B., Hurtt, G., Kriegler, E., Lamarque, J.-F., Meehl, G., Moss, R., Bauer, S. E., Boucher, O., Brovkin, V., Byun, Y.-H., Dix, M., Gualdi, S., Guo, H., John, J. G., Kharin, S., Kim, Y., Koshiro, T., Ma, L., Olivié, D., Panickal, S., Qiao, F., Rong, X., Rosenbloom, N., Schupfner, M., Séférian, R., Sellar, A., Semmler, T., Shi, X., Song, Z., Steger, C., Stouffer, R., Swart, N., Tachiiri, K., Tang, Q., Tatebe, H., Voldoire, A., Volodin, E., Wyser, K., Xin, X., Yang, S., Yu, Y., and Ziehn, T.: Climate model projections from the Scenario Model Intercomparison Project (ScenarioMIP) of CMIP6, *Earth Syst. Dynam*., 12, 253–293, https://doi.org/10.5194/esd-12-253-2021, 2021.

(4) Investigations on the role of sea ice initialization for the climate prediction in the Arctic on annual to decadal time-scales:

Tian, T., Yang, S., Karami, M. P., Massonnet, F., Kruschke, T., and Koenigk, T.: Benefits of sea ice initialization for the interannual-to-decadal climate prediction skill in the Arctic in EC-Earth3, *Geosci. Model Dev.*, 14, 4283–4305, https://doi.org/10.5194/gmd-14-4283-2021, 2021.