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Artificial Intelligence and Earth System Modeling - revisiting Research of the Past and Future

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Today's climate science is being driven by IT more than ever. Earth system models on high-performance computers (HPC) are common tools for researching the past and projecting it into the future. In addition to that, statistical modelling is reborn thanks to modern computer architectures equipped with artificial intelligence (from ensemble to deep learning). Future advances in machine learning will also shape climate research through analysis tools, prediction techniques, signal and event classification, post-processing, Model Output Statistics (MOS), evaluation and verification, etc. This presentation will look at nowadays research about the future (part one) and the past (part two) of our climate system using AI/ML ideas and technologies in combination with numerical climate models - from two publications accordingly. A special focus will be on the importance of climate science, where the needs are, and how to choose the AI/ML hammer wisely:

(1) FUTURE: Derived from machine (ensemble) learning and bagging, a new hybrid climate prediction technique called 'Ensemble Dispersion Filter' is developed. It exploits two important climate prediction paradigms: the ocean's heat capacity and the advantage of the ensemble mean. The Ensemble Dispersion Filter averages the ocean temperatures of the ensemble members every three months, uses this ensemble mean as a restart condition for each member, and further executes the prediction. The evaluation shows that the Ensemble Dispersion Filter results in a significant improvement in the predictive skill compared to the unfiltered reference system. Even in comparison with prediction systems of a larger ensemble size and higher resolution, the Ensemble Dispersion Filter system performs better. In particular, the prediction of the global average temperature of the forecast years 2 to 5 shows a significant skill improvement.

Kadow, C., Illing, S., Kröner, I., Ulbrich, U., and Cubasch, U. (2017), Decadal climate predictions improved by ocean ensemble dispersion filtering, *J. Adv. Model. Earth Syst.*, 9, 1138– 1149, doi:10.1002/2016MS000787.

(2) PAST: Nowadays climate change research relies on climate information of the past. Historic climate records of temperature observations form global gridded datasets like HadCRUT4, which is investigated e.g. in the IPCC reports. However, record combining data-sets are sparse in the past.

Even today they contain missing values. Here we show that artificial intelligence (AI) technology can be applied to reconstruct these missing climate values. We found that recently successful image inpainting technologies, using partial convolutions in a CUDA accelerated deep neural network, can be trained by 20CR reanalysis and CMIP5 experiments. The derived AI networks are capable to independently reconstruct artificially trimmed versions of 20CR and CMIP5 in grid space for every given month using the HadCRUT4 missing value mask. The evaluation reaches high temporal correlations and low errors for the global mean temperature.

Kadow, C., Hall, D.M. & Ulbrich, U. Artificial intelligence reconstructs missing climate information. *Nat. Geosci.* **13**, 408–413 (2020). <https://doi.org/10.1038/s41561-020-0582-5>