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Developing a new emergent constraint through network analysis

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Climate sensitivity expresses how average global temperature responds to an increase in greenhouse gas concentration. It is a key metric to assess climate change, and to formulate policy decisions, but its estimation from the Earth System Models (ESM) provides a wide range: between 2.5 and 4.0 K based on the sixth assessment report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). To narrow down this spread, a number of observable metrics, called “emergent constraints” have been proposed, but often are based on relatively few parameters from a simulation – thought to express the “essence” of the climate simulation and its relationship with climate sensitivity. Many of the constraints to date however are model-dependent, therefore questionable in terms of their robustness.

We postulate that methods based on “holistic” consideration of the simulations and observations may provide more robust constraints; we also focus on Sea Surface Temperature (SST) ensembles as SST is a major driver of climate variability. To extract the essential patterns of SST variability, we use a knowledge discovery and network inference method, δ-Maps (Fountalis et al., 2016, Falasca et al, 2019), expanded to include a causal discovery algorithm (PCMCI) that relies on conditional independence testing, to capture the essential dynamics of the climate simulation on a functional graph and explore the true causal effects of the underlying dynamical system (Runge et al., 2019). The resulting networks are then quantitatively compared using network “metrics” that capture different aspects, including the regions of uniform behavior, how they alternate over time and the strength of association. These metrics are then compared between simulations, and observations and used as emergent constraints, called Causal Model Evaluation (CME).

We apply δ-Maps and CME to CMIP6 model SST outputs and demonstrate how the networks and related metrics can be used to assess the historical performance of CMIP models, and climate sensitivity. We start by comparing the CMIP6 simulations against CMIP5 models, by using the reanalysis dataset HadISST (Met Office Hadley Centre) as a proxy for observations. Each field is reduced to a network and then how similar they are with reanalysis SST. The CMIP6 historical networks are then compared against CMIP6 projected networks, build from the Shared Socio-Economic Pathway ssp245 (“Middle of the road”) scenario. Comparing past and future SST

networks help us to evaluate the extent to which climate warming is encompassed in the change overlying dynamical system of our networks. A large distance from network build over the past period to network build over a future scenario could be tightly related to a large temperature response to an increase of greenhouse gas emission, that is the way we define climate sensitivity. We finally give a new estimation of the climate sensitivity with a weighting scheme approach, derived from a combination of its performance metrics.