ROADMAP: The Role of ocean dynamics and Ocean-Atmosphere interactions in Driving cliMAte variations and future Projections of impact-relevant extreme events

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The goal of the JPI-Oceans / JPI-Climate ROADMAP project was to strengthen our understanding of the ocean role in shaping Northern Hemisphere climate and associated extreme events, on seasonal to climate change time scales. The ROADMAP consortium encompassed leading climate research institutions from seven European countries, including universities as well as institutions providing (national) meteorological and climate services. The project was structured into five different work packages, and RMI contributed to three of these work packages.

RMI has provided important input to the project, mainly through the application of a relatively novel causal method, called the Liang-Kleeman information flow (LKIF) method, to climate models and both in-situ and satellite observations. The LKIF method allows to identify true causal relationships between variables, and thus goes beyond classical correlation analyses.

In collaboration with different partners from or outside the ROADMAP consortium, we found that:

1. there is a two-way influence between Arctic sea ice on the one hand, and surface air temperature and ocean heat transport on the other hand (Docquier et al., 2022);
2. the Arctic Oscillation plays a key role at monthly time scales on the dynamics of the North Pacific and North Atlantic Oceans (Vannitsem & Liang, 2022);
3. the ocean influence on the atmosphere is larger than the reverse in many regions of the world at monthly time scales (Docquier et al., 2023);
4. LKIF performs better than another widely-used causal method with a smaller number of variables, while the other method is best with a larger number of variables (Docquier et al., 2024);
5. $\delta^{18}O$ measured in two different coastal ice cores in Antarctica shares several drivers, but also shows local specificity potentially linked to ocean proximity and air mass trajectories (Vannitsem et al., 2024b);
6. a nonlinear extension of LKIF allows to accurately capture nonlinear causal relationships between variables based on results from two artificial models (Pires et al., 2024);
7. the use of the nonlinear extension of LKIF to a reduced-order atmospheric model (Charney-Straus model) allows to disentangle the different contributions of the physical processes to the production of information uncertainty (Vannitsem et al., 2024).

Based on these results, our main recommendation is to systematically use a proper causal method as a complement to any correlation analysis in order to identify true causal links between climate variables. Additionally, in the case of a highly nonlinear problem, we recommend the use of the nonlinear extension of LKIF, which has been developed in the context of the ROADMAP project.

Keywords: Ocean-atmosphere-sea ice interactions, Causality, Information transfer, Nonlinearities