Geophysical Research Abstracts
Vol. 21, EGU2019-16901, 2019
EGU General Assembly 2019
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Quantification of information exchange in idealized and climate system applications

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Detection and quantification of interactions of subsystems or processes assist in understanding complex system dynamics. Often in climate system studies, linear or symmetric statistical measures like correlations are applied to quantify these interactions. The linearity assumption might be misguiding, and the assumed symmetry does not allow identification of the driving and responding subsystems. This study investigates two interaction measures from information theory: the axiomatically proposed transfer entropy (TE) and the first principle based information flow (IF). They are tested for idealized linear and non-linear systems and experimentally applied for two important climate phenomena. This study applies linear estimators (TE-linear, IF-linear) as well as non-linear, non-parametric estimators (TE-binning, TE-kernel, and TE-k nearest neighbor). As expected, the linear estimators fail for strongly non-linear systems. The non-parametric kernel and k-nearest neighbor estimators are reliable for both linear and non-linear systems. Nevertheless, the non-parametric methods are sensitive to the parameter selection in their implementations. Thus, this work proposes a complementing use of the kernel and k-nearest neighbor TE estimators with parameter testing for consistent results, and with TE-linear and IF-linear as robust additional methods for weakly non-linear systems. By applying this approach to the two climate systems, expected bi-directional information exchange between the Indian and Pacific SSTs was detected. However not only the NAO to European air temperature exchange was detected, but the estimators detected unexpected reversal information exchange too. The latter hints to a hidden process driving both the NAO and European temperatures. Hence, even though TE and IF are useful measures, their limitations and the system at hand must be carefully taken into account before drawing any conclusions from their estimations. Moreover, the limitations of the estimation of the transfer entropy are discussed in this study.