Entrapping hidden changes in nature

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The study of climate change is a very important field of science, since life is directly affected by these changes. Many proxies, i.e. data previously preserved within speleothems, sediments, tree rings, corals, etc., have been observed and many theoretical models have been developed in order to gain a comprehensive understanding of past and future climate. Investigating the past climate changes leads to the forecasts of future possibilities. Therefore, enlightening the past is a keystone to answer questions about climate as well as vegetation, life, evolution, and nature. Paleoclimatology, the understanding of changes in climate during the history of Earth, has become a popular area of research at the intersection of climatology, chemistry, physics and mathematics. In order to extract the proxy information, many observations and mathematical studies have been performed.

In this thesis, I focus on detecting dynamical regime transitions in nonlinear dynamical systems as well as in climate proxies where they mark previous critical climate changes. The Poincaré recurrence theorem, a fundamental theory in nonlinear dynamics proves that certain systems will revisit a state which is infinitesimally close to a previous state in finite time, is the backbone of the work. The thesis begins with a brief methodological background and brings the recurrence plot (RP) to forefront as the main tool for the further analyses. The thesis consists of three main studies: (i) The formation of RPs naturally depends on a free parameter in the analysis given by the distance threshold. I propose an alternative definition by using a weighted variant of the RP, called weighted recurrence plot (wRP), which removes dependence on this free parameter. Moreover, the entropy of RP for some cases leads to inconsistent results, and a new entropy definition of wRP overcome this problem. (ii) Furthermore, I suggest a novel way to select the threshold for a recurrence network (RN) for a specific time series. Selecting the optimization parameters for a specific time series is very important for the performance of the analysis. (iii) In the following theoretical work, I introduce a new preprocessing technique to deal with the heterogeneousness of time series, since the RP is not directly applicable on such data sets and the proxies from speleothems, in general, are irregularly sampled.

These theoretical approaches are performed on prototypical models in order to test their feasibility. The synthetic time series are created in regard of the possible difficulties which can arise from real-world applications. The success of the methods is represented and discussed in detail. Based upon the results of pragmatic applications, I have applied the methods on real data sets. The dynamical regime transitions are detected on an electrochemical experiment and several paleoclimate speleothem proxies. The most striking application of this thesis, the behaviour of the East Asian and Indonesian–Australian summer monsoons throughout the Holocene has been the focus, although no explanation of millennial-scale relationships between the two has yet been offered. An understanding of any such phasing relationships would provide insight into the long-term variability of the broader East Asian–Indonesian–Australian monsoon regime. Applying the new techniques to Holocene speleothem proxy records from northwestern Australia and southern China, I demonstrate the existence of a bipolar seesaw relationship between the two regional monsoon systems and show that this anti-phasing can be related to shifts in the ITCZ and related tropical precipitation in response to solar variability.

Among these presented approaches are suitable methods to investigate the dynamical transition and they can be used for different purposes in a large variety of time series analyses. For instance, these techniques can be used in several different disciplines which have heterogeneousness in their sources. Finally, after the relationship between the two proxies from northwestern Australia and southern China has been uncovered, in the future, it should be achievable to extend the study to create a large paleoclimate relationship network for the entire Earth by using the methods given in this Thesis.