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Conditional Mutual Information Functions for analyzing non-evenly spaced climatic time series:

The ITCZ (Intertropical Convergence Zone) is a zone of high cloudiness, deep atmospheric convection and precipitation. The ITCZ is a key component in the planetary thermal balance. The ITCZ position in the warmer hemisphere so it can transfer heat excess to the cooler hemisphere and therefore maintains the thermal balance of the planet. During the last glacial period (100 kyrs) the earth experienced temperatures oscillations recorded in ice-cores originating in the northern hemisphere. Paleo-precipitation reconstructions in the tropics show that these hemispheric thermal asymmetries displaced the position of the ITCZ (ITCZ displaced north/south will dry sites in the southern hemisphere). However, it is not clear if the Northern hemisphere temperatures were solely or the first cause of ITCZ migrations. Newly developed paleo-precipitation records from South America and china show that precipitation reconstructions during cool and stable periods of the last glacial period correlate better with high latitude temperatures of the southern hemisphere. In here, we compare set of paleoclimate time series to examine the similarity of a ITCZ paleo-precipitation (at 6°N) time series (X) to northern (Y) and southern hemisphere temperatures(Z) during the last glacial period. The condition mutual information (CMI) between Northern hemisphere temperatures and tropical precipitation given the southern hemisphere temperatures (X:Y/Z) is expected to be high during periods in which the northern hemisphere trigger changes in the thermal balance of the planet, thus displacing the ITCZ position towards the northern hemisphere and increasing/decreasing precipitation at our study site, emulating the temperature oscillation recorded in the plaeorecord of the northern hemisphere. Conversely, the CMI between X:Z/Y is expected to be high in periods where the southern hemisphere trigger changes in the planetary thermal balance and forced ITCZ migrations. Therefore, the primary goal of this project is to construct similarity estimators for non-evenly spaced paleo-climatic time series using CMI.

Non-linear and time depended system: Climate is considered a non-linear dynamical system. The climate response to perturbations can include feedback mechanisms that affect the linearity of the climatic response. For example, climatic regimen shifts (e.g glacial vs interglacial periods) that are triggered by changes in solar insolation will cause a decrease in global temperatures. However, the temperature response not only depends on the reduced amount of solar insolation, but on other climatic variables such as the amount of ice in the planet. As temperature drops glacier buildup takes place which in turns increase the planetary albedo decreasing even more global temperatures. The system is also time dependent example, the amount of solar radiation varies periodically and depending on the position of the earth against the sun. Given the non-linearity of the system analysis techniques such as MI are better suited to capture the dependence between climatic variables instead of linear estimates such as Pearson correlation coefficients.

State Space: In paleoclimate studies, it is common to describe the glacial-interglacial cycles as shifts between different climate states. Glacial period is commonly treated as a two-state system (cold stadial, warm interstadial).

Dynamic Mechanism: The Causes of stadials and interstadials is still matter of debate. It has been hypothesized that during stadials (cold periods) the strength of the Atlantic meridional overturning circulation (An oceanic current that transfer heat in the Atlantic from south to north) is reduced. Warm waters from tropical locations that usually get into the northern hemisphere are reduced, therefore cooling the north Atlantic. As a result, cold conditions are developed in the northern hemisphere. At the same time, the reduced AMOC caused buildup of warm waters in the southern hemisphere warming it up. The mechanism is known as the Bipolar seesaw. The mechanism is observable is paleo precipitation records that show the position of the ITCZ in response to these temperatures oscillations.

Why the system is interesting? The system is interesting because not all stadials and interstadials are the same. How symmetrical changes in solar insolation result in asymmetrical ice ages? is still one of the long-standing questions in climate dynamics. Stadials and interstadials vary in length and intensity. What makes the system stay in a long stadial(e.g last glacial maximum) or trigger a deglaciation is still unknown. Examining ITCZ paleo records that tracks changes in the thermal balance of the planet can tell us much about the directionality of the climate signal (e.g what climate component reacts first), tipping points(e.g what is the threshold temperature to change between a northern hemisphere controlled climate and southern hemisphere controlled climate) among others.

Dynamical Properties: This projects aim to investigate the controls from past temperature oscillations from both hemispheres over the position of the ITCZ. Conditional Mutual information indicates the amount of information shared between X(t) and Y(t), given the effect of the series Z(t) over Y(t). Therefore, high values of MI between northern hemisphere temperatures and Tropical precipitation given Antarctic temperatures will indicate coeval changes in Northern hemisphere temperatures and tropical precipitation and independency from southern hemisphere temperatures.

Intrinsic computation properties Methods:

Gaussian kernel estimates of unevenly spaced time series to form evenly spaced observations.

To translate unevenly spaced observations into equidistant measurements I plan to use Gaussian kernel functions. Weights those products higher whose time lag lies closer the selected lag index (selected time interval base on the proxy resolution)

Windowing functions

To calculate a certain quantity or measure at a certain point in time and compare it with previous or later values of this quantity I plan to use a windowing approach. Most of the quantities need a larger number of values to be calculated, i.e., time series will be divided into short pieces or time windows of length *w*. Such a time window is then moved over the entire time series. The window has a starting point t_1, an endpoint t_2, and a center point $(t_2 - t_1)/2$. The quantity calculated within this window is then assigned to this center point and, thus, provides a new time series of this quantity.

Conditional Mutual Information

Conditional Mutual information indicates the amount of information shared between X(t) and Y(t), given the effect of the series Z(t) over Y(t).

Hypothesis:

I hypothesize that during the last glacial period when there are regimens shits towards long and stable cold periods (e.g last glacial maximum) the northern hemisphere stays in a stable state while the southern hemisphere temperatures are the ones triggering changes in the thermal balance of the planet. While during the other parts of the last glacial period the northern hemisphere climate dominate over the earth climatic response. In terms of the time series analysis, given that X= ITCZ tropical rainfall, Y: Northern hemisphere temperatures and Z= Southern hemisphere temperatures, The MI(X:Z/Y)during cold and long stadials will be high while during the rest of the last glacial period MI(X:Y/Z)will be high.

Steps

1. Creating evenly spaced observations:
2. Windowing the data
3. Write the code for the CMI time series analysis
4. Write report

Time: Steps 1 and 2: 2 weeks

Step 3: 1 week

Step 4: 1 week