NCCR Summer School 2003, Workshop1.2

Module Bipolar Seesaw

Introduction

Abrupt climate change was abundant during the last ice age (Stocker, 2000; Alley *et al.*, 2003). Such events thus serve as an important testbed for theories and climate models about how large signals in the climate system are propagated. The best known events of abrupt change are the rapid warmings of up to 16°C that are inferred from the stable water isotopes measured on the Greenland ice cores from GRIP and GISP2. In total, 24 such events, so called Dansgaard/Oeschger events, have been found during the last ice age from 14 kyBP back to 110 kyrBP (Dansgaard *et al.*, 1993). Antarctic ice cores, on the other hand, do not show such rapid and large fluctuations, but they exhibit slow millennial-scale warmings and coolings during the last glacial (Jouzel *et al.*, 1987). Climate records derived from Antarctic ice cores thus have a very different temporal characteristic than those obtained from Greenland ice cores.

The most viable mechanism for the abrupt changes in the North Atlantic region is still associated with reorganisations of the ocean circulation. Broecker et al. (1985) suggested that ocean circulation changes are responsible for the abrupt climate shifts they found in the Greenland ice cores and other paleoclimatic archives. The thermohaline circulation in the Atlantic (THC) transports a substantial amount of heat northward which is responsible for a relatively mild climate in that region. A rapid shut-down of this circulation causes a cooling in ocean and atmosphere. This cooling has been simulated using the entire hierachy of models ranging from climate models of reduced complexity to fully coupled 3-dimensional AOGCMs (see reviews by Stocker *et al.*, 2001; and by Rahmstorf, 2002).

Based on these model simulations, a testable prediction about the climate response in regions outside the North Atlantic can be made: the South Atlantic is cooled by the THC. According to this hypothesis, a shut-off of the THC, which triggers a rapid cooling in the north, should produce a warming in the south, because heat is no longer exported northwards. This is the basic mechanism behind the bipolar seesaw and would argue for an antiphase relationship between north and south (Broecker, 1998; Stocker, 1998).

The simple seesaw concept was recently questioned because it does not account for the very different time characteristics, nor does it account for the apparent leads or lags that result from a lag-correlation analysis of the GRIP and the Byrd isotopic temperatures. Steig and Alley (2002) present a correlation analysis which shows two maxima, one for in-phase relation with a southern lead by about 1000 to 1600 years, or alternatively an anti-phase relation with a northern lead by 400 to 800 years. The absolute values of the correlations are smaller than 0.5, and the two possibilities are statistically indistinguishable. However, they are both inconsistent with the classical bipolar seesaw which postulates anti-phase relation with zero lag.

The simplest possible model is proposed to explain a large fraction of the millennial climate variability measured in the isotopic composition of Antarctic ice cores. The model results from the classic bipolar seesaw by coupling it to a heat reservoir. In this "thermal bipolar seesaw" the heat reservoir convolves northern time signals with a characteristic time scale (Stocker and Johnsen, 2003). Applying the model to the data of GRIP and Byrd we demonstrate that maximum correlation can be obtained using a time scale of about 1000-1500 years. Higher correlations are obtained by first filtering out the long-term variability which is due to astronomical and greenhouse gas forcing and not part of the thermal bipolar seesaw. The model resolves the apparent confusion whether northern and southern climate records are in or out-of-phase, synchronous, or time lagged.

Tasks:

1. Use the Matlab script **`plotdatamodel`** to view the filtered isotopic time series from the GRIP and Byrd ice cores. Choose **`0`** for the characteristic time scale.
2. Calculate the lag correlation of the two time series using the Matlab script **`lagcorr`**
3. Investigate how strongly the maximum absolute correlation depends upon the choice of data window.
4. Use the Matlab script **`plotdatamodel`** to view synthetic southern temperature time series generated using different characteristic time scales.
5. Use the Matlab script **`bipolar`** to calculate correlations between the synthetic southern temperature time series and the filtered Byrd time series for different characteristic time scales and different data windows.
6. Investigate the influence of data smoothing on the correlation.
7. Determine whether the characteristic time scales for short Dansgaard/Oeschger events is different from that of long D/O events.
8. Discuss potential problems with the bipolar seesaw hypothesis

Literature:

Alley, R.B., J. Marotzke, W.D. Nordhaus, J.T. Overpeck, D.M. Peteet, R.A. Pielke Jr., R.T. Pierrehumbert, P.B. Rhines, T.F. Stocker, L.D. Talley and J.M. Wallace, 2003: Abrupt climate change. *Science*, **299**, 2005-2010.

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