MedCLIVAR Exchange Grant 1459 Final Report

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1. Executive summary of the programme

A number of arguments supports the view that the recent warming of the climate system is real with a global mean surface temperature increase of 0.74±0.18°C over the last 100 years and a sea surface temperature rise strongly evident at all latitudes throughout the oceans, and very likely forced by human influence (IPCC, 2007).

Therefore, one of the major issues in climate studies is the understanding of the anthropogenic contribution to climate changes.

In particular, it is fundamental to understand how anthropogenic forcing and natural variability have interacted in the recent past and quantify the real anthropogenic contribution on natural climate. This implies a better understanding of natural climate variability from multiple locations and back in time. The development of numerical models has significantly contributed to the progress in the understanding of climate processes in the past and in the present, and has allowed previsions for the future. The General Circulation Models (GCMs) simulate climate variability and the interaction between atmosphere, oceans, lithosphere and biosphere and provide an important tool for understanding climate system dynamics. Although GCMs can simulate current climate fairly faithfully, they contain many approximations and uncertainties that are difficult to quantify and remove. Thus, in order to make GCMs more reliable and accurate in the simulation of climate variability and in the prediction of future changes, they need to be tested and evaluated experimentally against records of high-resolution climate changes in the past. The only possibility to extend our climate database far beyond the instrumental record is studying well-dated natural archives of climate variability, available from a variety of sources, e.g. tree rings, ice cores, sediment cores, fossil pollens, corals and speleothems. Corals and speleothems can provide the opportunity to evaluate model performance and can quantify precise correlation of the climatic conditions between oceanic and continental regions. One of the great advantages of corals and speleothems as paleoclimatic archives stems from the fact that they offer absolute dating possibilities with the ^{14}C method, the U/Th decay series and the band/lamina counting, thereby allowing the records of climate variability to be extended into the late Quaternary.

In addition, they systematically incorporate stable isotopes and trace elements into the carbonate material and this incorporation is directly driven by climate processes that can be quantified. Another important criterion for choosing corals and speleothems is the possibility to calibrate their information to instrumental climate data, which allow to obtain accurate calibration equations. This was the first result that we achieved during this exchange grant period.

By using coral and speleothem geochemical proxies we estimated different calibration equations for different sampling sites. Three coral samples were collected by scuba diving in Portofino, Miramare and Taranto, three sites located in the Mediterranean Sea, and the trace elements compositions were calibrated using instrumental SST data obtained with CTD probes. An active spelothem was collected from the calcareous promontory of Capo Caccia in the north-west part of Sardinia. Its geochemical composition (stable isotopes and trace elements) was calibrated against an instrumental 50-year long precipitation time series from Alghero (12 km from Capo Caccia) and a 500 year-long rainfall time series reconstructed by Andreas Pauling (Personal communication)

The subsequent step of the research will be devoted to the comparison between proxy reconstructions and CGM model data obtained through the collaboration with Dr. Cristoph Raible from the Physics Department (Bern University).

2. Programme scientific objectives

The first step of the proposed research was to study the time variability of the data using time series analysis and subsequently to compare and validate the climate model simulations with proxy records.

We applied a specific calibration method both to the coral and the speleothem data, following and improving the method developed by De Ridder et al. (2004).

Calibration method for the non tropical coral paleoclimatic data

A Fourier analysis has been used with the aim to obtain a calibration function comparing the high-resolution geochemical values and the instrumental SST data collected over the last five years in the Marine Reserve of Miramare, in the north-eastern Adriatic Sea.

The non-tropical coral investigated for geochemical analysis belongs to the species *Cladocora caespitosa* and it was previously demonstrated that it stops (or significantly reduces) the skeletogenesis process during ~ 5-6 months every year, when SST drops below 14 °C, (Montagna et. al 2007).

This represents a limitation in the application of the Fourier analysis since the observations need to be placed in a unit time interval.

Therefore, the focal point of our research was to adapt the spectral analysis to the non tropical coral data, which are affected by a time gap in the yearly cycle.

Here, we report, step by step, an example of our calibration method applied to B/Ca ratios of the Miramare specimen.

The first step was to estimate the exact time period in which the coral stops its growth. This period has been found to be about six months and was calculated through the best B/Ca vs. SST fitting model. Six months is the time when coral ceases to grow and SST drops below 14°C.

Afterwards, we applied the Johnson method (Johnson, 1949) in order to standardize the B/Ca ratios, and a 35-day low pass filter (Mann, 2004) to remove the high frequency from the data. The new time series was then converted in time unit using the Fourier analysis. Usually the conversion from a spatial scale to a time scale assumes a stepwise constant growth rate. The variation in growth rate can be defined as a distortion of the linear growth rate. In our analysis the growth rate is not estimated directly, as sometimes happen for tropical corals (e.g. using staining experiments on the carbonate skeleton). However, the distance between subsequent observations can be exactly quantified, based on the precise analytical technique used during the elemental analysis (i.e. high-resolution laser ablation inductively coupled plasma mass spectrometer system, Montagna et al., 2007). On the other hand, we need to know the time instances between these observations, and the ratio between the distance and the time determines the growth rate. To estimate the time instances, we use, as a starting point, an average constant growth rate, where the time instances between the observations are constant. It follows that the time instance at which the n^{th} observation was formed is given by:

$$tn = nTs \qquad (1)$$

where Ts is the sample period (dimension is time) and represents a measure for the average time instance between two subsequent observations. The dotted line in figure 1 is derived by this constant growth rate model. If the time instances are disturbed by a variation in growth or accretion rate, the Equation 1 will not be valid. We can model this distortion of the time base adding a distortion term, g(n), which is zero when the growth is equal to the average growth, negative when the average is slower than the average growth and positive when the growth is greater than the average growth. This leads to the following improved equation:

$$tn = nTs + g(n)Ts \qquad (2)$$

where the first term indicates the constant time step and g(n) represents the time base distortion (TBD) at observation position n (scalar quantity). The TBD consists in the difference between the dotted line and the full line in figure 1.

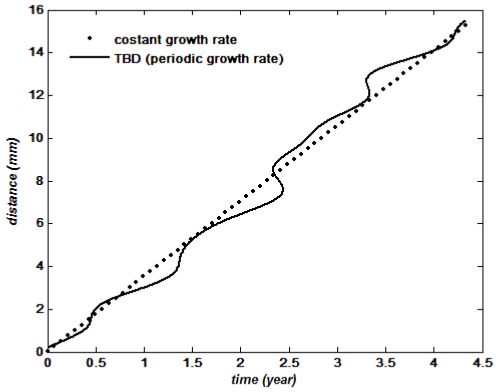

Figure 1 *Conceptual graph showing the transformation from a record along a distance grid to time series. The dotted line represents a constant growth rate, while the curved line along the diagonal represents the real growth rate.*

In order to estimate the TBD, g(n), we need to study our periodic record (i.e. the B/Ca ratios converted on a time scale through Equation 1), using a Fourier analysis.
By applying the Discrete Fourier Transform (DFT) we calculated the power spectrum for the B/Ca ratios and the instrumental SST, which show a peak at the frequency of 1.88 year^{-1} (Fig.2a), equal to a period of about six months and at 1.84 year^{-1} (Fig. 2b), respectively.

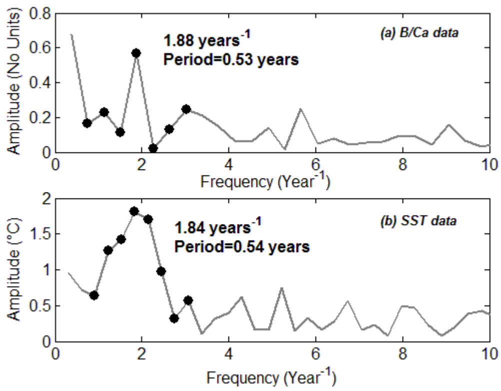

Figure 2. *Fourier spectrum of the B/Ca signal (a) and the instrumental SST data (b).*

The following step was to select a frequency window around the frequency of the major peak for the B/Ca ratios (1.88 year^{-1}) and build a function with the value one at the frequency of the selected window and zero in all the others points. We then applied the Inverse Discrete Fourier Transform (IDFT) to the new function and obtained the g(n) function using this formula:

$$g(n) = \frac{\varphi\left[\exp\left(-j(\omega_0/\omega_s)2\pi n\right) IDFT(G)\right]}{\omega_0}, \qquad (3)$$

With $\varphi(u)$ the phase of u, $j=\sqrt{-1}$, $\omega_0 = 2\pi / age(year^{-1})$, ω_s the radial sampling frequency, $G = c(\omega)S(\omega)$ with $c(\omega)=1$ if ω is in the frequency range of interest $c(\omega)=0$ elsewhere, $S(\omega)$ is the DFT of the signal.
The estimated g(n) function is the TBD function that will give us an approximation of the periodic growth rate of the coral sample and finally the time grid necessary for the B/Ca vs. instrumental SST calibration.
It is important to highlight that the calculated g(n) function has a period of six months and we had to add this period at the end of each arch of the curve in order to obtain the correct time grid (Fig. 3).
The improved time grid was then synchronized with the time grid for the SST data, obtaining theresults showed in figure 3.

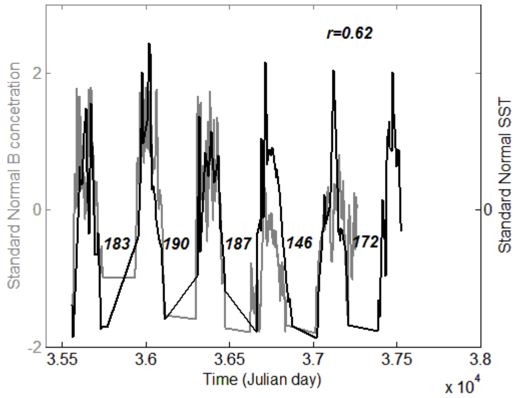

Figure 3 *B/C signal (grey line) plotted on the improved time grid compared with the SST values (black line).The integer numbers 183, 190, 187, 146 and 172 represent the number of days where SST was below 14 °C.*

By selecting both coral and SST data at one-day interval, a correlation coefficient of 0.62 has been calculated.
The final step was to average the data for the two records at two-week time resolution and apply a linear fit, obtaining the following calibration equation:

$$B/Ca=0.020(\pm 0.003)*SST+1.115(\pm 0.058) \quad (4)$$

Figure 4 shows the linear fit for the Miramare site. The same sequence of operational steps were followed for the other two Mediterranean sites (Taranto and Portofino) and results of the linear fits are reported in figures 5 and 6.

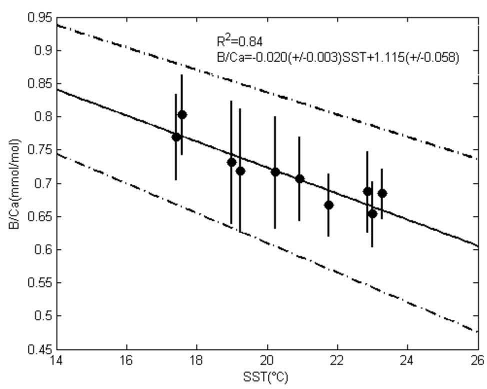

Figure 4 (Miramare) *Linear regression of B/Ca vs SST., For each year in the improved time grid the B/Ca data representing 15 days were averaged and compared with the corresponding averages for SST.*

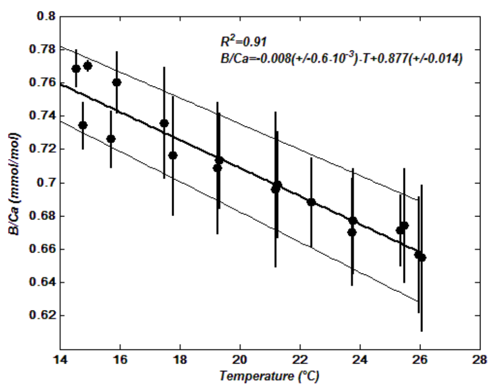

Figure 5 (Taranto) *Linear regression of B/Ca vs SST. For each year in the improved time grid the B/Ca data representing 15 days were averaged and compared with the corresponding averages for SST.*

The three calculated linear regression lines have been plotted together in figure 7. The calibrations for Taranto and Portofino show similar angular coefficients, whereas the calibration for Miramare show a steeper one, likely suggesting the influence of other environmental parameters, acting differently in the three Mediterranean sites (e.g. different nutrient concentrations, which might have an effect in the growth process). Further analysis will be carry out in the future.

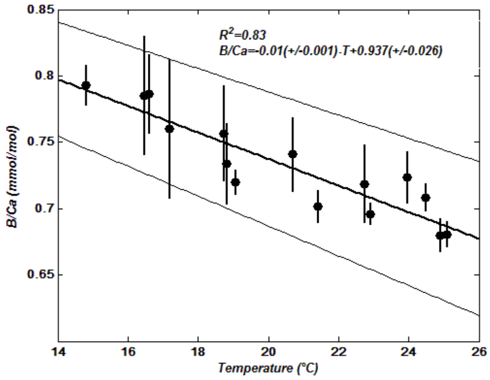

Figure 6 (Portofino) *Linear regression of B/Ca vs SST, 15th days averaged data taken out using the improved time grid.*

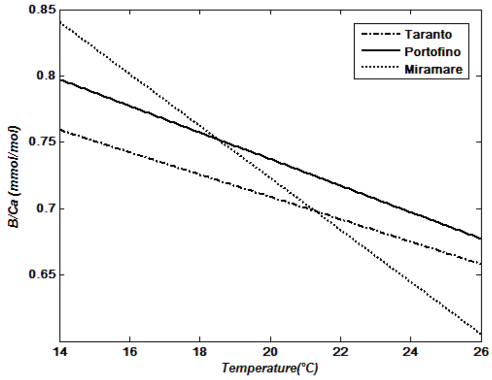

Figure 7 (Miramare, Taranto, Portofino). *Superimposed B/Ca vs .SST linear regressions.*

Consideration for speleothem paleoclimatic data

The speleothem was previously analyzed at high-resolution for stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) and trace elements (Sr, U, Mg, Ba, and P, normalized to Ca) (Montagna, 2005). In particular, the resolution is 0.2 mm and 0.02 mm for the stable isotopes and the trace elements, respectively.
Applying the Fourier analysis to the trace element values, an annual cycle has been recognized and used to build the time grid. The validity of this time scale has been verified with four additional ^{230}Th-^{234}U ages.
At this stage of the research, only the Fourier spectrum of the $\delta^{18}O$ values was calculated, since we are still working on an improved calibration method and we aim to achieve the final results during the next months .

3. Assessment and results achieved

The outcomes achieved during the first part of the research activity carried out at the University of Bern, under the supervision of Dr. Juerg Luterbacher and in collaboration with Christoph Raible and Dominique Fleitmann from the University of Bern and Sergio Silenzi and Paolo Montagna from ICRAM, are the result of a fruitful exchange of ideas on the climate system and the different calibration methods applied to the paleoclimatic data. The calibration method developed here, following the example by De Ridder et al. (2004), represents a more objective way to derive a calibration equation. The degree of subjectivity inherent in the anchor-point method, usually applied for paleoclimate reconstructions, is replaced by a more rigorous method, based on the Fourier analysis. The Department of Physical Geography of the University of Bern is an exciting place with weekly seminars and talks and visiting scientists. This gave me the opportunity to discuss about scientific problems with other researchers and also to establish the base for future long-term collaboration.

4. European "added value" and visibility of the program

The importance and the impact of this research is not just for the scientific community but also for the entire society that is facing the problem of the climate change. This research activity will help to address one of the major European research action (Environment, including Climate Change), highlighted in the European Research Council Work Programme FP7 and in other European Programmes, specifically developed for the Mediterranean Region (e.g. Circle-Med).
The precise calibrations of the geochemical signals for the non-tropical coral species and the speleothems in the Mediterranean Sea will give us the possibility to obtain accurate information on the climate changes back in time, through the analysis of fossil samples. These data will be used to carry out modelling exercises, allowing us to collocate the past climate variations in the context of the 20th century climate change.

5. Program finances and management

The expenses during my stay in Bern can be quantified as follow:

a) Rent (25 August 2007 – 20 December 2007): 2600 €
b) Living expenses: 2400 €
c) Flight ticket (Rome-Bern--Bern-Rome): 250.88 €

6. Publicity

The results achieved during my stay at the University of Bern will be submitted for publication in international journals and presented in national and international congresses. Moreover, some of the major results achieved during the grant will be make available to the public at large by producing one scientific documentary in collaboration with the Scientific Documentary Service at ICRAM, targeted to different educational levels, from high schools to Universities and Research Institutes.
In all the publications/congresses/scientific documentaries related with the present research activity, the ESF MedCLIVAR Exchange Grant will be acknowledged for the financial support.
In addition, the most significant results will be published in the ICRAM website (www.icram.org).

7. Future perspectives

We have very recently submitted a join Italy-China project, combining documentary proxy information with geochemical and morphological data from high-resolution natural archives (cave stalagmites, calcareous tufa and tree rings) from distant regions (Italy, China and Australia), with the aim to address the essential task of reconstructing the history of climate and environmental variability in the past, focusing in the last 2000 years and in climatically important time-windows (MIS 5 and 11). This research will offer an opportunity to study global remote influences, the mechanisms that might trigger similar/different behaviours in the patterns among the Mediterranean area, the eastern Asia and the Australasia, the underlying dynamics and forcing. In particular, we aim to assess whether those teleconnections are stable through time into past centuries and millennia, and during previous Interglacial periods.
Within the frame of the this future project, we want to apply the recently developed calibration methods with the aim to achieve the most accurate paleoclimate reconstructions, quantifying the errors and the limits of the reconstructions.

8. Appendices

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- Complete list of the Programme Steering Committee members and Programme Collaboration;

Juerg Luterbaker, Cristoph Raible, Paolo Montagna, Sergio Silenzi, Dominik Fleitemann

- List of the supporting ESF Member Organisations (and any others);

- Expenditure of funds broken down by budget heading;

- List of programme activities undertaken (workshops, scientific exchange visits, etc);