

## CYCLIC FLUCTUATIONS, CLIMATIC CHANGES AND ROLE OF NOISE IN PLANKTONIC FORAMINIFERA IN THE MEDITERRANEAN SEA

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The study of Planktonic Foraminifera abundances permits to obtain climatic curves on the basis of percentage ratio between tropical and temperate/polar forms. Climatic changes were controlled by several phenomena as: (i) Milankovitch's cycles, produced by variations of astronomical parameters such as precession, obliquity and eccentricity; (ii) continental geodynamic evolution and orogenic belt; (iii) variations of atmospheric and oceanic currents; (iv) volcanic eruptions; (v) meteor impacts. But while astronomical parameters have a quasi-regular periodicity, the other phenomena can be considered as "noise signal" in natural systems. The interplay between cyclical astronomical variations, the "noise signal" and the intrinsic nonlinearity of the ecologic system produces strong glacial or interglacial period according to the stochastic resonance phenomenon.

*Keywords:* Planktonic foraminifera; climatic changes; stochastic resonance.

### 1. Introduction

Planktonic Foraminifera (PF) are unicellular organisms that commonly live in the sea surface and intermediate water rarely in the deepest part of water column. PF are very sensible to the seasonal temperature variations, and in particular some species prefer sea surface tropical water, while other species prefer temperate or polar water [1]. The study of dynamic population of PF permit to obtain climatic curves through two methods: (i) study of the percentage ratio between tropical and temperate/polar species; (ii) analysis of the oxygen isotope  $\delta^{18}O$  variations by car-

bonatic test of PF [2]. PF are in fact good markers for the reconstruction of Earth climate [3,4]. Moreover other methods are used to reconstruct the Earth's climate history, as that based on the analysis of variations of ( $\delta^{18}O$ ), present in the ice cores from Greenland and Antarctic [5]. According to Ref. [6], climatic fluctuations were essentially produced by cyclical variations of sun energy received by Earth, that periodically change its astronomical parameters (equinox precession, 21 ky ( $1ky = 10^3 years$ ); obliquity of Earth's axis, 41 ky; eccentricity of the orbit 100 ky). These astronomical cyclicities are known in earth sciences as Milankovitch's cycles, and they can be considered a quasi-deterministic signal that periodically produced drastic changes in Earth climate. The astronomical forcing is not the only reason for glacial/interglacial oscillations. In fact insolation variations produce changes in the atmospheric temperature, but the geographical distribution, and position, of continent and margin plates are extremely important. The presence of a barrier, as the continental marginal plate, indeed can influence the atmospheric and oceanic currents. In addition to these global events, other "randomic" events occur: (i) tectonic uplift of belt ridge; (ii) volcanic activity, in particular explosive eruptions; (iii) meteor impacts, that occasionally strike the Earth and that caused several catastrophic mass extinctions [7]. The Mediterranean Sea, because of its geographical position, between tropical and temperate area, is a good laboratory for the study of the climatic variations of Earth history [4]. High resolution studies carried out on marine sediments and ice cores from Greenland and Antarctic, have demonstrated that in the last 400 kyr, in addition to the classic Milankovitch cycles, other cyclic variations were present with a higher frequencies, known as sub-Milankovian cycles. In particular spectral analysis carried out on these sequences has permitted to recognize periodicities of 5000, 2500, 1600 and 200 years [8]. Recently geochemical isotopes of ice cores from Greenland have suggested that Earth's climate variations occur according to the model based on stochastic resonance phenomenon [8].

## 2. Experimental Data

In this work we analyze data from: (i) Mediterranean core sediments (Sites 963, Leg 160), taken during Ocean Drilling Program (ODP), and compared with upper Pleistocene ice cores (GRIP and GISP2), from Greenland [5]; (ii) landscape section outcropping in Southern Sicily, and compared with Pliocene-Pleistocene core sediments come from Atlantic Ocean Sites 659 [9]. For detailed description of experiments see Refs. [3,4,9].

(i) ***Mediterranean ODP sites*** — The core from Site 963 (central part of Mediterranean Sea, Sicily Channel), consisting of grey marls rich of PF, was sampled each 2 cm in order to have a continuous sequence from today to 25 ky before present (B.P.). The PF fluctuation abundances [3] are compared with oxygen isotope of Gisp2. There is a good correlation between the fluctuation percentage ratio of a particular warm species (*Globigerinoides ruber*) and  $\delta^{18}O$  variations. In particular while *G. ruber* is always present in the interval today-10 ky, even if small oscillations in percentage ratio have been observed, in some particular intervals, between 14.5 ky and 25 ky, *G. ruber* is absent or very rare (Fig. 2) due to the drastic decrease of global temperature during Younger Dryas and Last Glacial Maximum periods.

(ii) ***Southern Sicily*** — The Bonsignore section (near Ribera) is characterized

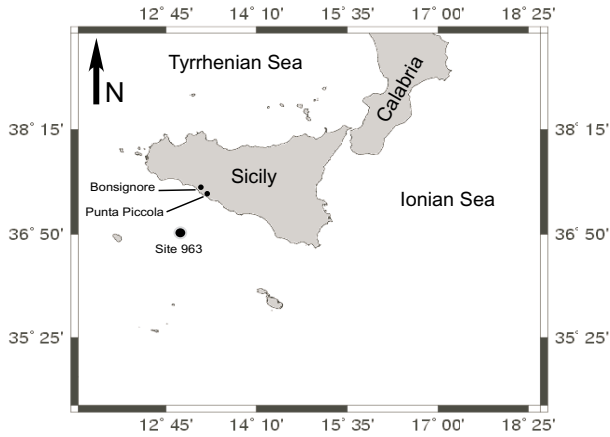


Fig. 1. Location map of studied sections in the Mediterranean area.

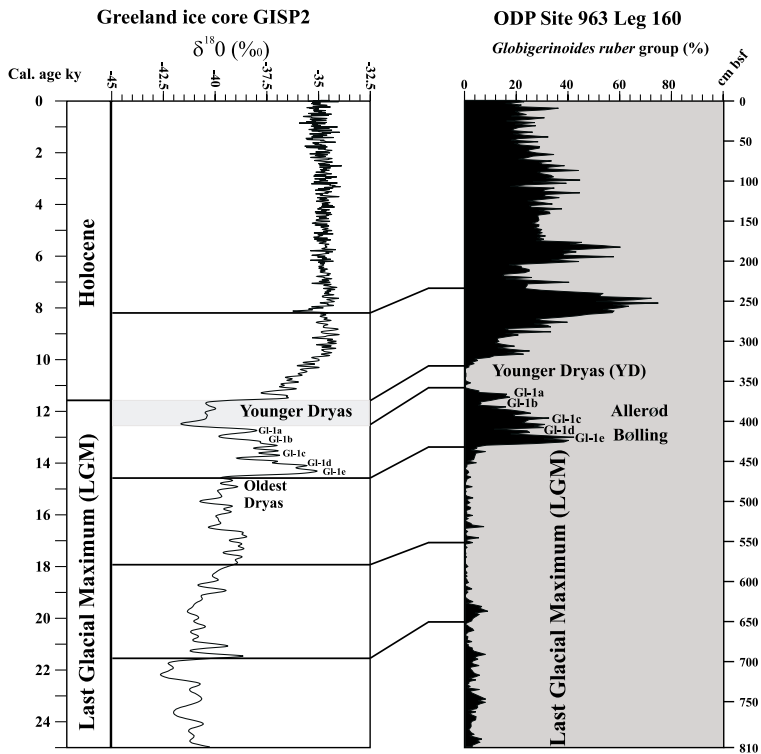


Fig. 2. Correlation between oxygen isotope  $\delta^{18}O$  (GISP2) and percentage fluctuations of *G. ruber* of Site 963. The Last Glacial Maximum (LGM) and Younger Dryas (YD) correspond to minima percentages of *G. ruber*. This tropical species is always present in the Mediterranean area from today until  $\approx 10$  ky (B.P.), but during glacial phases was absent or very rare.

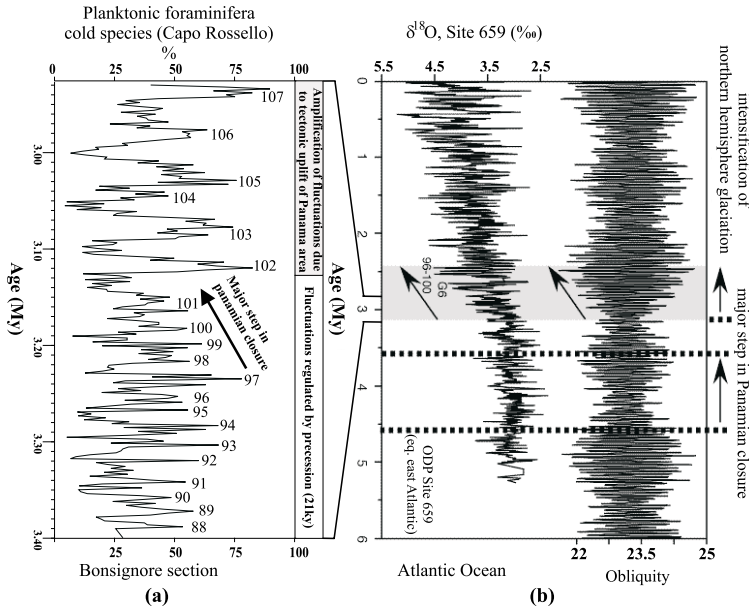


Fig. 3. (a) Cold species (*G. bulloides*) fluctuations between 3.4 My and 2.93 My (Bonsignore section) and (b) comparison with oxygen isotope ( $\delta^{18}O$ ) of Site 659 [9] between today and 6 My. The number of fluctuations 88–107 correspond to lithological cycles of Punta Piccola described by [6]. The increase of the amplitude of oscillations of cold species in (a) coincides with increase of tectonic uplift of Panama area in (b).

by a continuous sequence of marly-limestone and marls of Trubi and Monte Narbone Formations [4, 6], rich in PF. This sedimentary sequence is coeval with Punta Piccola section (Agrigento), where lithological cycles 88–107 were described [6]. Bonsignore section recover a time interval between 3.4 My (million years ago) and 2.93 My. From 3.4 to 3.2 My, lithological and foraminifera cyclicities are mostly controlled by precession forcing (Fig. 3(a)), while after 3.2 My the obliquity forcing becomes dominant [4, 6]. This change in climatic Earth system is connected with a casual event as the uplift of Panama area and, consequently, with the closure of Panamanian Isthmus. Figure 3(a) represents the time interval around the major step in Panama closure. This event produced a drastic change in oceanic and atmospheric circulation with the amplification of Gulf Current gyre and an increase of the formation of North Atlantic Deep Water (NADW) in consequence [4, 9]. In Fig. 3 it is possible to observe that the drastic increase of oscillation amplitude of cold species, recognized in the Mediterranean Sea, starts in coincidence with sharp increase of oxygen isotope (Atlantic Ocean). The Mediterranean Sea has perfectly recorded this important global climatic cooling that favored the formation of Polar Ice Sheet [4, 9].

### 3. The Model

The dynamics of the biological system described above appear rather complex due to the presence of periodicities which sometimes disappear. The main peculiarities

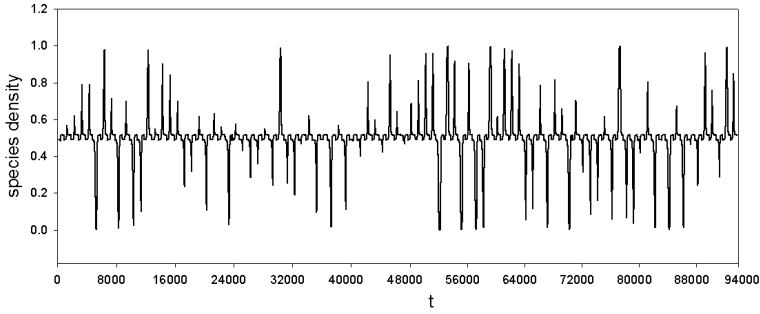


Fig. 4. Time evolution of both populations at different levels of the multiplicative noise, namely  $\sigma = 10^{-10}$  for  $0 < t < 48000$ , and  $\sigma = 10^{-9}$  for  $t > 48000$ . The values of the parameters are  $\gamma = 10^{-1}$ ,  $\omega_0/2\pi = 10^{-3}$ , and  $\sigma_\beta = 1.78 \cdot 10^{-3}$ . The initial values of the two species are  $x(0) = y(0) = 1$ .

observed from experimental time series of PF are: (i) geological events produce “time windows” characterized by quasi-periodic fluctuations with almost constant intensity, which can be ascribed to different “noise levels”; (ii) some periodicities appear in one of this “time window”, while are absent in all the other ones; (iii) the two species *G. ruber* and *Globigerina bulloides* coexist in a competing dynamical regime. As a first approximation we try to describe the behavior of our ecosystem by a stochastic model of two competing species by using the following generalized Lotka–Volterra (LV) equations [10, 11]

$$\dot{x} = x(1 - x - \beta(t)y) + x\xi_x(t) \tag{1}$$

$$\dot{y} = y(1 - y - \beta(t)x) + y\xi_y(t), \tag{2}$$

where  $\xi_x(t)$  and  $\xi_y(t)$  are statistically independent  $\delta$ -correlated Gaussian white noises with zero mean. The multiplicative noise models the interaction between the environment and the species. The interaction parameter  $\beta$  is characterized by a critical value corresponding to  $\beta_c = 1$ . For  $\beta < \beta_c$  a coexistence regime of the two species is established, while for  $\beta > \beta_c$  an exclusion regime takes place, i.e. in a finite time one of the two species extinguishes. It is then interesting to investigate the time evolution of the ecosystem for  $\beta$  varying around the critical value  $\beta_c$  in the presence of fluctuations, due to the significant interaction with the environment. This behavior can be obtained assuming  $\beta$  subjected to a bistable potential and a periodic driving according to the following stochastic differential equation [11]

$$\frac{d\beta(t)}{dt} = -\frac{dU(\beta)}{d\beta} + \gamma\cos(\omega_0t) + \xi_\beta(t), \tag{3}$$

where  $\gamma = 10^{-1}$ ,  $\omega_0/(2\pi) = 10^{-3}$ , and  $U(\beta)$  is a generalized bistable potential  $U(\beta) = h(\beta - (1 + \rho))^4/\eta^4 - 2h(\beta - (1 + \rho))^2/\eta^2$ . The stable states correspond to the two regimes of the deterministic LV model. In Eq. (3)  $\xi_\beta(t)$  is a  $\delta$ -correlated Gaussian white noise with zero mean. To analyze the dynamics of the two species we fix the additive noise intensity at the value  $\sigma_\beta = 1.78 \cdot 10^{-3}$  [11]. The time series of the two species are obtained for two different values of the multiplicative noise intensity  $\sigma = 10^{-10}, 10^{-9}$  (see Fig. 4). For  $\sigma = 10^{-10}$  the two species coexist and

quasi-periodic oscillations appear with random periodical inversions of populations (Fig. 4). An increase of the noise ( $\sigma = 10^{-9}$ ) produces an enhancement of the amplitude of these quasi-periodical oscillation as observed in experimental data (see Fig. 3). The appearance of some periodicities, previously “hidden”, are due to the stochastic resonance phenomenon. The periodical signal of small amplitude, that is the obliquity in Fig. 3, is enhanced by the presence of the noise [11, 12]. We note finally that the theoretical model, based on the stochastic resonance phenomenon, predicts a time behavior of the two species abundances, which cannot be obtained by using models which are simply periodic or stochastic [10, 11, 13].

#### 4. Conclusions

The main peculiarities observed by analyzing our experimental data of PF in Sicily Channel can be explained within the proposed model of SR in population dynamics [11]. The nonlinearity of the natural system together with a periodical forcing and a “noise signal” produces a coherent response of the ecosystem, by enhancing the effect of the geological causes.

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