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Pleistocene/Pliocene climatic variations driven by the deep ocean and the Milankovitch orbital cycles

N.N. Ivashchenko (1), D.M. Sonechkin (2), N.V. Vakulenko (2)

(1) Hydrometeorological Research Centre of Russia, Moscow, Russia, (2) P.P. Shirshov Oceanology Institute RAS, Moscow, Russia (nnivach@mecom.ru / Fax: +7 495 2551582)

It is well known that the Pleistocene/Pliocene climatic variations look to be of very complex shapes. They are multiscale, apparently chaotic, and integrally nonstationary in the scale of the overall length of almost all of the proxy record being considered. The shorter-term (of the 100 – 1000 year periods) climatic variations reveal themselves as essentially nonlinear and apparently chaotic responses of the global climate system to the Sun-induced annual periodic heating, the Luni-Solar tides, the Sun activity cycles, the topographic torque etc. The climatic variations of the longer-term scales (of the 10000 – 1000000 year periods) seem to be more or less direct responses to the slowly varying external forces like the Milankovitch orbital cycles. Besides, a trend-like behavior is seen within the largest scales of many Millions years from the Early Pliocene to the present time. One can suppose this behavior is induced by monotonous decrease of the deep ocean heat contents. A new technique of the wavelet and cross-wavelet analysis has been developed in order to clear up the essence and origin of all of these variations and trends. This technique has been applied to proxy (ice cores and oceanic bottom drill) records covering the Pleistocene/Pliocene time period, and many evidences of nonlinearity and heterogeneous external force effects were recognized.

The well-known 100-kyr problem can be undertaken as a result of coupled actions of two main factors. The deep ocean heat contents can be indicated as the main governing parameter of the global climate system. During the Pleistocene/Pliocene the heat contents of the deep ocean decreased monotonously, and climatic cycles were of relatively small amplitude during the Early Pliocene. It was so especially before the

Panama passage closure when the continuous El-Nino-like conditions existed. After the Panama passage closure an El-Nino/La-Nino-like alternation has been started. But it seems there was no definite cycle length in this alternation firstly. Only after some further decrease of the deep ocean heat contents polar ice caps began to rise, firstly in Antarctic and then in Arctic, and some later a bifurcation took place connected with the establishment of a certain $\sim$40kyr long climatic cycle period during the Early Pleistocene.

Even if no explicit fingerprints of the 100-kyr glacial cycle can be seen in paleoclimatic records covering this time of the Late Pliocene/Early Pleistocene, our special wavelet analysis, intended to extract coherent structures from time series, reveals that the 100-kyr signal still can be seen as a hidden phenomenon during these times. This signal became to be seen explicitly after some further decrease of the deep ocean heat contents (near the time of the 800 kyr BP) when the next bifurcation of the glacial cycle length perhaps took place. However it must be stressed the estimation of the Late Pleistocene glacial cycle length as 100-kyr is true in mean only. Really, this length varied between 80 and 120 kyr, and so the bifurcations of the cycle length doubling and tripling probably took place during the Late Pleistocene.

Of course, these bifurcations were much more complex than any simple length doubling or tripling because the Milankovitch orbital cycles started to play an important role as the second governing parameter. Indeed, wavelet analyses of the Dome C (EPICA) ice core and some oceanic bottom drill records reveal the excitation of a frequency modulation of the glacial cycle length as a result of almost linear response of the climate system to the insolation variations within the eccentricity range of time scales. These variation effects are clearly seen in tropics only. As a result of the common action of both mentioned governing parameters a central symmetry of the Late Pleistocene glacial cycle lengths as well as the inversion of the saw-tooth shape of these cycles in respect of the time moment (about 400 kyr BP) of the Marine Isotope Stage 11 were established.