SOUTHERN HEMISPHERE PALEO– AND NEOCLIMATES: KEY SITES, METHODS, DATA AND MODELS

[1]SMOLKA, P., VOLKHEIMER, W. [1]Geological Institute, University Muenster, Germany, [2]IANIGLA/CRICYT, Mendoza, Argentina

IGCP-341: Overview of the addressed Question

IGCP-341, Southern-Hemisphere Paleo- and Neoclimates integrates Neogene marine paleoclimatology / paleooceanography, high-resolution worldwide stratigrahy for the Neogene and Paleogene, climatic modeling, terrestrial paleoclimatology with emphasis on the Pleistocene and Holocene, the detection of present-day climate change and the development and application of new methods which range from transfer-algorithms (contributions from various fields) to the application of neural networks for monsoon prediction, meteorological early warning systems, predictive methods for the development of fluvial networks (the "natural" equilibrium in case of precipitation change, so maintenance of dams could be optimized).

The stratigraphic database of more than 80000 species with ageranges in million years following a worldwide uniform correlation scheme is a novelty that could bring paleontology considerably forward.

For the Neogene several worldwide quantitative paleotemperature maps have been established. These maps, that are also available in gridded form suitable for paleoclimate modeling how the existance of major parts of the present-day circulation system. Although intensities and extensions of ocean currents changed, it could be concluded that green-house situations of the Neogene did NOT cause a breakdown of the global circulation. The most important factor affecting the global circulation are orographic changes, such as the closing of the Isthmus of Panama. This was an event that affected indirectly even wells between Australia and New Zealand (most likely through the impact on the deep-water circulation).

Furthermore in many cases throughout the entire Neogene, paleotemperature fluctuations of the magnitude observed during the Quaternary have been detected (compared also to drillholes where the conditions have been remarkable stable). On any age and timescale however (contemporaneous, historic, quaternary, neogene) environmental change is of differential nature. That is: Areas of warming are neighboured by areas of cooling; areas of increased precipitation by areas of draught. Thus any environmental assesment of global change should not focus on detecting phenomena on a global average, but on many examples of regional scale.

Keeping the great natural magnitude in mind, mankind should be happy of the currently "comfortable" climatic conditions and avoid anything which might change them (such as triggering another natural change).

Another major goal of IGCP-341 was the enhancement of various powerful methods that permit the indirect assessment of paleoenvironmental parameters from other observations (transfer-algorithms). This includes methods from dendroclimatology as well as methods to assess paleotemperatures and moistsure availabilities, methods that asses ENSO and paleoenso indices, methods that focus on the quantitative assessment of atmospheric parameters from isotopes as well as methods that focus on the reconstruction of marine paleotemperatures from Neogene faunal communities. It could be shown by various contributors that these methods have a potential that is often overlooked.

In addition most of the data as well as the software are published on a CD of a summarizing book (Smolka and Volkheimer, 2000). Furthermore a state-of-the art version of an atmospheric general circulation model (ccm3.6 from NCAR) was transferred to Windows NT. As this needs less than 30 minutes for one day (compared to 9 minutes on a Cray) at T42 resolution such a tool permits state-of-ther art atmospheric and paleoclimate modeling also in low budget regions. Special emphasis was put on making all data AND methods (software) accessible to the public through the CD so not only the data but also the methods can be transferred easily to similar cases beyond the study area of IGCP-341.

Results:

1. Innovative Methods

1.1 The Change of River Networks

Different preciptation patterns change the equiibria of river networks. Jacovkis adopted and developed a series of methods, both theoretically and computationally to predict the changes of river networks depending on changing environmental parameters.

1.2. *Monsoonal Change / Time Series prediction*

Calvo et al. focused on the prediction of parameters (monsoonal rainfall) based on neural networks. It could be shown that these methods have, if applied carefully, a potential that has been overlooked in large parts of geology.

1.3. *The microbiological impact of climate change*

All biological systems are aqueous systems. In these systems CO2 is soluble (contribution of Beckmann et al.). Since CO2 participates directly or indirectly in many important reactions in cells, the CO2-pressure in the cell is of prime importance. In systems that are characterized by low CO2 partial pressures, such as many microbiological systems, moderate changes of the atmospheric CO2 partial pressure causes a massive impact on chemical equilibria. Thus for many biological systems, the **change** (not necessarily the absolute value) of the CO2 partial pressure means a major environmental stress, caused by the close connection between atmospheric partial pressure and the interior of the cells. This environmental stress forces all species to adapt genetically. Microbiota and viruses can adapt much faster to the new situation due to their short life-span, resulting in a large number of new species. Statistically it has to be expected that among these new species there are at least some, that are incompatible with other hitherto existing biota (including "macrobiota"), i.e. threatening them as pests and diseases. This aspect of environmental change has not yet been paid sufficient attention.

1.4. *Detection of ongoing climate change*

In the last 20 years, the damages caused by the floods in Argentina have caused social and economic problems in several regions (contribution of Barros et al.). In the western part of the province of Buenos Aires and in the depressed basin of the Salado River the floods are becoming more frequent and intense. There are frequent reports of catastrophes of the same kind in the low lands along the Paraná river and its tributaries. On the other hand the more favorable social and economical manifestation of what seems to have the same cause is evidencing in silently but continuously: The *increase* in the rainfall in the semi-arid zone of the country has permitted the expansion of the agricultural frontier considerably westward. The economic benefits have been very important for the landowners of that zone and for the national economy although they have not yet been duly measured.

Despite these observations there are few studies focusing on the recent trends of the rainfall in Argentina. The authors show that during the last decades in the study area various important characteristics, also in the high atmosphere (such as pressure gradients, location of certail lows etc) have changed. This has amongst others the following consequences:

1) A warmer hemispheric temperature INCREASES the precipitation over most of eastern Argentina, probably due to the increase of water vapor.
2) In addition to the increase of precipitation over eastern Argentina, Uruguay and Southern Brazil a DECREASE in Northeastern Argentina and Paraguay should be expected.
3) In times of a strong meridional gradient however a higher precipitation is expected for Paraguay
4) Overall a poleward (southward) shift of the atmospheric circulation was observed. This causes also a change of the precipitation-fields.

It should be noted that these few lines simplify extremely the comprehensive results of the working-group of V. Barros (Meteorological Institute, Buenos Aires). On the other hand, BOTH increase AND decrease of precipitation as ONGOING phenomenon causing problems in Paraguay is shown. Also this contribution clearly highlights the differential nature of climate change producing both winners and loosers. In addition indications for a precipitation deficit in Southern Amazonia can be observed.

1.5. *Late Pleistocene and Holocene climate changes*

The group of M.R. Prieto contributed with a synoptic study on historical climatic variability in South America. This study which includes Argentina, Bolivia and Chiles covers the pre-instrumental period. It should be noted that THEIR findings are consistent with the esteimations of ENSO / PaleENSO from treering and isotope studies. In addition they noted severe droughts and floods in the 16th and 17th century that extend all present-day droughts and floods in the study area by far. Again it should be noted that while one area was affected by a draught other areas suffered from floods at the same time (differential nature of climate behaviour). In this context the work of the group of Villalba is important who studied synoptically on a hemisphere wide scale the *differential nature* of climate change.

As above data come from the 16th and 17th century, a time which is generally addressed as "little ice-age" (as historical term as it might have been "cold" in Europe and "normal" elsewhere) the climatic warming in the 18th and 19th century had obviously a favourable effect for land-use and economy. This however could not be projected into the future because the present-day equilibrium might be quite fragile. Studies of the climate of the 12th century, which have been initiated by above group of historians might provide insight into the nature of warmer equilibria.

It is evident that climatic phenomena that show up as draughts and floods must also have shown up in the palynological, geomorphological and historical (satellite images) record of glaciers. This is especially important because the glacier line is an equilibrium of various factors. Especially it should be noted that not all rapid glacier advances are indications of decay (surges). They might reflect older times of high snowfall. Furthermore moisture availability (for vegetation) and glacier advances/retreats are indipendent phenomena as a time characterized by a glacier advance may be characterized by reduced river runoff and thus reduced moisture availability. It could be demonstrated clearly that moisture availability and/or glacier shrinkage may or may not be coupled. That is: In many case a glacier growth followed a wet and warm period, in other about 15 case a wet and cold period and so forth. This means that simplifying conclusions about global warming and glacier shrinkage should be abandoned and be replaced by detailed differential analyses, clearly budgeting precipitation, storage and runoff and not only for one case which is then erroneaoulsy extrapolated, but for each glacier considered.

Contributions from: Prieto, Leiva, Llorens, Wingenroth: IANIGLA (Argentine Institute for Nivology, Glaciology and Environmental Sciences at the CRICYT research center), Mendoza/Argentina

2. Reconstructions of changes of the tropical rainforests

This topic was addressed by the following authors (and members of their working groups): Latrubesse (Amazonia), Runge (Zaire), Anhuf (Central Africa 10 N to 10S).

It was demonstrated that during and around the last glacial maximum the tropical rainforests shrank considerably and have even been replaced with desert-like conditions (dunes). In Central Africa the increased aridity did not cause a disappearance of the rainforest but a reduction of ist area. On the one hand this shows that the Amazon rainforest is able to reestablish after a nearly complete disappearance. This means: There was not a global, irreversible "catastrophe" after the Last Glacial Maximum. On the other hand the question arises which economical effects such a natural disappearance would have had IF at that time human populations in the present-day sense would have had existed. As (see above) Southern Amazonia is even today an area of decreasing precipitation. A subsequent coupling of the reconstructed environments with an atmospheric general circulation model(with coupled land surface model such as ccm3.6 from NCAR) could show up how in the long range such envirnments may look like.

3. Reconstruction of "Greenhouse Climates"

(contributions mainly from Smolka)

From very young and Quaternary times considerable magnitudes of climate change at short timescales are known. Thus the assessment of greenhouse climates consists of two steps:

(a) the reconstuction of worldwide paleotemperature time-series well back into the Miocene and
(b) the synopsis of these time-series to maps.

The synchronization to maps however requires a worldwide uniform high resolution dating scheme.

3.1. A worldwide high-resolution Biostratigraphy for the Neogene and Paleogene

(contribution from Smolka)

For understanding dynamics of a process observations have to be hanged into a framework that is independent of the observations. Such a framework is called time. In order to study hemisphere- or worldwide processes, such as climate change, a worldwide uniform dating scheme (stratigraphy) is needed.

On the one hand evolution provides such a worldwide uniform "background clock". On the other hand newly formed species need time to spread. Classical paleontological assays utilze the evolution by assigning regionally the same age to beds where certain species occur for the first time (expressed here in a simplified manner). This assay containes the background assumption that for certain kinds of species the time to spread is small compared to the time (time-interval) that is dated.

Therefore within IGCP-341 a new concept was introduced: The evolutionary stratigraphy: Conceptually there is NO difference between a small basin with limited extension and the world ocean. EACH fossil has an evolutionary first appearance datum (wherever it is, eFAD) and each fossil has an evolutionary last appeareance datum, including "still living" (wherever it is, eLAD).

These datums can be found by establishing a relative order of all fossils observed. These have been in the context of IGCP-341 all planktonic foraminifera, coccolithes, diatoms and radiolaria of the Deep Sea Drilling Project / Ocean Drilling Program (after some screening, excluding disturbed wells etc).

This showed very clearly that by considering the whole ocean the life-spans of most fossils are much greater than previously thought.

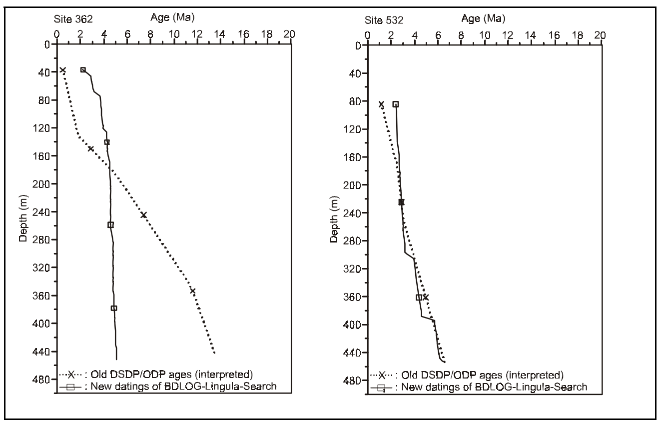

Fig. 3.1. DSDP Site 362 (left) and 532 (right) are drilled on nearly the same position. For the old site 362 the curve of the DSDP-workers and that of BDLOG differ considerably. For the new site 532 they coincide. In addition the age-depth-plot elaborated by BDLOG for the old DSDP-Site 362 coincides well with BOTH the BDLOG-curve for 532 AND the new age-depth-plot of the DSDP-workers for DSDP-Site 532. As the program gets only depths and samples (no regional information) the stability and reliability of both paleontology and BDLOG is demonstrated.

Once such an evolutionary sequence, also expressed in million years has been established (the data are available in Smolka and Volkheimer 2000) in the DATING step new thinking was introduced:

(1) Concepts like: Globorotalia truncatulinoids appears for the first time, there the observed bed is xxx.x million years old have been abandoned completely.
(2) They have been replaced by the concept: Globototalia truncatulinoids occurres. Therefore the observed bed is xxx.x million years old OR younger.
(3) By including ALL fossils of a well the time-span of a sample reduces considerably. Thus EACH fossil is an index fossil. NO fossil can be called unidagnostic.

Therefore we have now a database of life-spans of about 80 000 fossils, expressed in million years on a worldwide uniform basis. In addition we have now worldwide uniform age-models (age-depth curves) for about 700 drillsites from the DSDP and ODP.

For Neogene and Paleogene studies this is regarded as a major breakthrough.

3.2. Tertiary Climate Change

The Neogene is a time with increased CO2 contents. As the orography does in many aspects not differ fundamentally from present-day situations (exceptions see below), the Neogene is a key-time to understand the impact of increased CO2 contents on climate, ocean currents and ecosystems in general.

Major questions studies focusing on the Neogene can answer are:

1) Do the sometimes tremendeous climate changes that are observed during the Quaternary also occur in warmer Neogene times?
2) The ocean currents, especially the "global conveyor belt" (the deep water circulation) depends highly on subtle equilibria in the key areas for deep-water formation such as the area south of Iceland and the Weddell polynya (off Antarctica). As these subtle equilibria are dominated mainly by density (temperature dependent) and salinity of the waters, at least in principle a break-down of the global conveor belt could not be ruled out in times of higher atmospheric temperatures. This would of course show up (mass balances) in the global circulation pattern, including the patterns of the surface currents.
3) Are there patterns of climate change? And if yes: How to they look like.

Above tasks require a global coverage of data. This means that temperature algorithms have been developed that permit the quantitative assessment of sea surface temperatures from faunal communities. These are NOT transfer functions. This task has been performed successfully as a database of some 600-800 time-series of paleotemperatures exist now. Many samples however have not been processible due to evolutive phenomena.

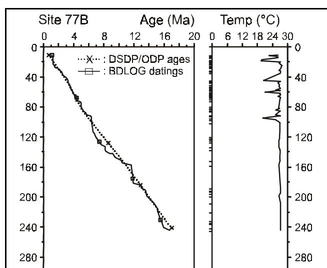

Fig. 3.2a. Site 77B shows for the central tropical Pacific between 16 and 1 Ma temperatures of about 26°C that are interrupted by some minor incursions of slightly colder waters between 6 and 0 Ma.

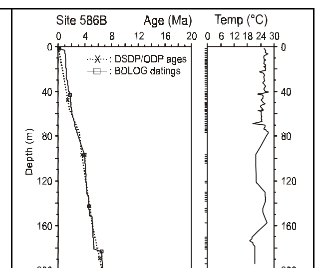

Fig. 3.2b. Site 586B documents for the tropical west Pacific east of New Guinea from about 6 to 1 Ma values around 26°C (between about 2.6 and 0 Ma some slightly colderintervals).

These time-series show the following major features:

There are areas that have been throughout the entire Neogene fairly stable. In such sites only minor temperature fluctuations, such as a baseline-shift around 4 my occur.

Sites that are located near water-mass boundaries, such as between Australia and New Zealand show considerable temperature fluctuations that are regarding their magnitude comparable to Quaternary temperature fluctuations.

The present day current system existed, with some modifications, throught the entire Neogene.

The Oyashio-Kuroshio system was in times prior to about 4 my either very weak or did not exist. This means that those watermasses that move today northward off Japan move in times prior to about 4 my northward further in the east (= in the central Pacific). This means that the Pacific gyre was "smaller".

This means that the Pacific gyre was "smaller".

The clousure of the Isthmus of Panama affected the global circulation drastically. A baseline shift of temperature fluctuations as well as a general shift of temperatures towards higher values could be observed practically throughout the world: The Carribean, the eastern coast of North America and even between Australia and New Zealand. The area immediately west of Panama experienced a minor decrease of temperatures.

This means that the closure of the Isthmus of Panama affected also indirectly (through deep water currents) the global circulation.

Above lines clearly show that throughout the entire Neogene marine ocean currents in the present-day sense existed. In other words: Even in times with generally warmer conditions ("greenhouse scenarios") a breakdown of the global circulation could NOT be observed.

4. Modeling

4.1. Global atmospheric modeling (ccm3.6)

In order to understand climate dynamics past, reconstructed oceans have to be linked with atmospheric general circulation models. This was up to now a problem because accessing models and computer-capacity for paleo-simulations is not always easy.

Therefore the atmospheric general circulation model (ccm3.6) from NCAR (National Center for Atmospheric Research) was transferred from Cray environment to Windows NT 4.0. On one of the Crays of NCAR in T42 resolution (!) one day needs about 9 minutes (single processor operation). In the PC version developed during IGCP-341 it needs less than 30 minutes (Pentium II/300, 256 MB RAM). Thus large-scale atmospheric modeling including teaching applications are now factually possible also in low budget regions.

To permit paleoclimate modeling the above mentioned time-series have been synchronized to maps and processed further to gridded datasets at 128 by 64 points resolution. These datasets exist for the following eleven time inervals: 2-3, 3-4, 4-5 etc. To 9-10, 10-12, 12-15 and 15-20 m.y. They can be found on the mentioned CD.

4.2. The Eximag System

Finally a suite of tools was developed that permits the detection and simulation linear, periodic and chaotic components in time-series (such as sedimentary time-series and ice core data (The Eximag System).

Studies have shown that the processes governing the formation of isotopic 18O time-series (which integrate ice-volume, temperature, salinity and other effects) change fundamentally at distinct intervals. Firthermore this method permits the analysis of the "behaviour of time-series" also in times immediately preceding and during qualitative environmental changes.

Reference:

Smolka, P., Volkheimer, W. 2000. Southern Hemisphere Paleo- and Neoclimates: Key Sites, Methods, Data and Models. Springer Science Publishers (with CD ROM).