Eighth International Conference on Paleoceanography

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Every three years since 1983, the paleoceanographic community comes together to share new discoveries and celebrate their discipline at the International Conference on Paleoceanography (ICP). The host country and meeting location are different each time, and the next venue is selected by community vote at the end of each conference. In recognition of the internationally renowned efforts of the French community in both the Integrated Ocean Drilling Program (IODP) and International Marine Global Changes (IMAGES) coring programs, France was selected at the end of ICP-7 in Sapporo (Japan) to be the organizer of the 2004 ICP-8.

ICP-8 took place in Biarritz, France, from September 5 to September 10, 2004, in the conference center of the local landmark casino. The Environnments et Paléoenvironnement Océanique (EPOC) group of University Bordeaux I acted as the local organizing committee. A total of 700 scientists attended from 34 different countries—including 250 students. The overall conference theme was "An Ocean View of Global Change."

Scientific topics addressed during ICP-8 provided attendees with information about the latest discoveries and the current state of knowledge in paleoceanography. Meeting talks and discussions identified emerging new areas of knowledge and raised questions about unresolved scientific problems. The Scientific Committee selected five themes covering two time scales: (1) the Mesozoic (from 248 to 65 million years ago [Ma]) and Cenozoic (from 65 Ma to the present) oceans, but with an emphasis on (2) oceanographic questions concerning the more modern oceans of the Holocene (the last 10,000 years) and the most recent glacial. Two main scientific fields were considered: changes in the chemistry of the ocean (e.g., the carbonate and silica systems of the Pleistocene [1.8 Ma to 10,000 years ago] ocean and biogeochemical cycles) and changes in climate (e.g., high-frequency climate variability and interhemispheric ocean-continent-climate links).

The main highlights and outcomes that emerged from the thirty-five invited talks and the five hundred posters are summarized below. To obtain a copy of the detailed agenda, full abstracts, and a list of invited speakers and their reported results and hypotheses, go to the ICP-8 web site: www.icp8.cnrs.fr.

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CENOZOIC-MESOZOIC OCEANS

Data about the Cenozoic and Mesozoic oceans are provided by long sediment cores recovered by drillships devoted to oceanographic research, such as the D/V *JOIDES Resolution* (one of the drilling vessels of the IODP) (Figure 1) and its predecessor the D/V *Glomar Challenger* (the Deep Sea Drilling Project's drillship). These sediment records allow us to address various problems including: oceanic responses to tectonic changes; oceanic carbon cycle dynamics on tectonic and orbital scales; tropical oceans and orbital-scale climate and biogeochemical change; past and present greenhouse climates and ocean dynamics; extreme climates, evolution of the Asian Monsoon; and the evolution of major current systems (e.g., equatorial Pacific, eastern boundary currents). These longer-time-scale problems have to be solved if we want to better understand extreme environments, such as the extremely warm Cretaceous period.

A wealth of new results were presented on Cenozoic-Mesozoic climate change. New oxygen isotopic records clearly demonstrate that significant climate variability on short and long times scales can be documented from carefully selected, well-preserved foraminiferal tests despite diagenetic concerns associated with older, typically more deeply buried sequences. It was shown, for example, that thermal maxima events that occurred during the Eocene were marked by rapid warmings and by major carbon-cycle perturbations. Although the warmings at these events were not as dramatic as those associated with the Paleocene/Eocene Thermal Maximum, these events may have had similar triggers. To better understand the global carbon cycle, alkenone-based carbon isotope records were used to reconstruct atmospheric carbon dioxide levels dating back to the middle Eocene. This work

Figure 1. The well-known scientific drillship *JOIDES Resolution* (all the talks and posters presented during session #1 were focused on cores retrieved during *JOIDES Resolution* research cruises). Photo courtesy of the Integrated Ocean Drilling Program, U.S. Implementing Organization.

showed the importance of understanding the oceanographic setting of the sites used in such reconstructions. Similarly, the use of "molecular fossils"—indicative of cyanobacteria—led to the conclusion that times of black shale deposition during oceanic anoxic events were times dominated by nitrogen fixation by cyanobacteria (a major nutrient supply).

For these ancient times, it appears that it is also important to know whether simulations with atmospheric general circulation models (GCMs) could produce polar ice sheets. Indeed, a better knowledge of extreme climates (e.g., the Cretaceous greenhouse world) is critical for making improvements to GCMs. These modeling efforts can be constrained by reliable field data—such as the isotopic signal of glacio-eustasy—provided by the oceanic cores. For example (although from a more recent time scale, the early Miocene to the present), outstanding new oxygen isotope records from the South China Sea have allowed scientists to more clearly visualize the inception of Northern Hemisphere glaciation and glacial-interglacial variations, revealing unexpected long-distance hemispheric teleconnections.

THE CARBONATE AND SILICA SYSTEMS OF THE PLEISTOCENE OCEAN

The carbonate and silica systems in the ocean are very important because they play a major role in the oceanic/atmosphere CO_2 balance at Earth's surface. Numerous questions remain open in this field: Do we really understand the ocean carbonate and silica systems during the Pleistocene glacial-interglacial cycles? How can we measure CO_2 levels beyond the reach of the ice core record and what does it tell us? What can we learn from the study of oceanic fluxes? Which model types are "best"?

According to several speakers, it appears that we should give up trying to find a single explanation for the magnitude of glacial-interglacial pCO_2 change and devise instead a "CO_2 stew" involving changes in temperature, salinity of bottom waters, nutrient changes, and dust. Furthermore, ocean circulation is definitely a forcing parameter in the global CO_2 balance. The recent development of new deep circulation proxies provides new tools to increase our understanding of such circulation changes. A remarkable record of Nd isotopes (from a Cape Basin core) shows fluctuations in North Atlantic Deep Water (NADW) export to the Southern Ocean and, additionally, shows offsets between Nd and ^{13}C records that provide the potential to separate circulation effects from other factors affecting C isotopes in foraminifera.

Using multiple proxies on cores from the Pacific oxygen minimum zone (OMZ), it appears now that hypotheses on the El Niño-Southern Oscillation (ENSO) system behavior, on both orbital and millennial time scales, can be tested. OMZ weakening could have resulted from reduced productivity or increased southern ventilation, with proxy data pointing to the former.

Particle fluxes in the water column and to the sediments have long been studied with tracers such as Th and Pa. However, other tracers are providing exciting new insights into the complex chemistry of the ocean. For example, it was shown that Fe dramatically changes Si/N uptake ratios, an observation that may help reconcile outstanding issues over the compatibility of nutrient proxies in the glacial ocean. In addition, Si isotope measurements may become as routine as those of ^{18}O in carbonates, which would open up large areas of the ocean to future paleo-reconstructions.

BIOGEOCHEMICAL CYCLES IN THE PAST

During ICP-8, the problem of past biogeochemical cycles was also addressed. Although there is general understanding of the main biogeochemical cycles that have operated over geologic time, it is clear that interest is increasingly focused on the coupling between climate change and the cycling of materials on Earth. This interest in coupling leads to a number of key questions still waiting for an answer: How do changes in the physical environment affect biogeochemical cycles in marine environments? Are the palaeoproductivity and nutrient (C, N, P) cycles similar at various time scales (Holocene, last glacial rapid climatic cycles, Cenozoic, Mesozoic, Paleozoic)? What are the processes involved during rapid climate events and transitions?

Interesting progress has been made concerning nitrate utilization during the last glacial maximum (LGM). This progress is based on measurements of the isotopic composition of diatom-bound nitrogen—a sedimentary N fraction that is not compromised by diagenesis. Based on data from sediment cores in the Atlantic and Indian sectors of the Southern Ocean, previous estimates of enhanced nitrate utilization in the Antarctic have been revised downward. However, a newly recognized isotopic change in the Subantarctic Zone of the Southern Ocean may well indicate iron fertilization during glacial times. Fortunately, these data converge with numerical model experiments indicating that it would have been difficult for increased dust inputs to cause pervasive iron fertilization across the entire Southern Ocean during glacial times. The model experiments also suggest that any such iron fertilization would not have, by itself, had a major impact on atmospheric CO_2 content.

Another growing research field concerns the use of biomarkers as paleoceanographic proxies. It is now not only possible to use biomarkers for reconstructing sea-surface temperature (SST) changes, but also for reconstructing biological export production or sea-ice extent. For example, a major event has been identified that preceded the well-known Mid-Pleistocene Revolution (starting at 920 thousand years ago [ka] to 660 ka), when dominant cyclicities in marine records changed from obliquity to eccentricity periods. At 1140 ka, an irreversible drop of SST in the Pacific and Atlantic Oceans was accompanied by rising and sustained export production productivity. The reasons for that global temperature decrease are as yet unclear; ice volume expansion and the transition to an eccentricity-dominated climate system apparently lagged the drop of SST by 300,000 years.

It is interesting to note that the study of ancient sediments could also help to better understand present-day global warming. Whereas modern emissions of greenhouse gases are mostly attributed to continental and anthropogenic sources, growing evidence points to a potential oceanic source for methane, in the form of gas hydrates, that may have played an important role in climatic change during both the Mesozoic and Cenozoic. Interesting hypotheses are developing about triggers that could have led to large-scale destabilization of hydrates and on the masses of methane and CO_2 involved. The "clathrate hypothesis"—as a source for huge amounts of methane, as cause for intermittent hothouse conditions, and as a source for enhanced carbon burial—has found fertile ground in research on Mesozoic black shales. For example, high-resolution organic-geochemical and isotopic investigations have been conducted on environmental conditions that occurred during Oceanic Anoxic Event 2 (around 93.5 Ma). These have raised doubts about the veracity of stable carbon-isotope evidence from bulk organics for a postulated clathrate carbon source. Specifically, biomarker-specific carbon isotope data lack the depleted carbon-isotope signature of methane, and no molecular evidence for methane-oxidizing bacteria has been found. On the other hand, high abundances of molecular markers for nitrogen-fixing (diazotrophic) bacteria suggest them as a significant source for enhanced carbon burial during this black shale event. As one can see, the problem still needs further investigation!

Along with these experimental approaches, it is clear that numerical models have to be developed and improved in parallel. Over the past few years, many groups from different countries have generated paleoclimatic and paleocirculation models that provide simulations that agree quite well with data from archives of past climate and oceanography. This cross-fertilization between the data and modeling communities recently has led to the recent development of biogeochemical ocean GCMs that can produce synthetic sediment cores and isotope records. Not only can real sedimentary archives be used to check for consistency with these model-generated records, but this technique also holds promise for the direct assimilation of sediment core data into advanced Earth system models.

HIGH-FREQUENCY CLIMATE VARIABILITY

Over the two last decades, the discovery of abrupt climatic changes (e.g., Dansgaard-Oeschger events, Heinrich events) has triggered the interest of many paleoceanography groups studying high-frequency (sub-orbital) climate variability. Were abrupt climate changes a global or a regional phenomenon? Did they concern all reservoirs (ocean, atmosphere [ice], continents)? Were they restricted only to glacial periods, or interglacials (e.g., Holocene), too? Were the climate forcings external or internal? These questions have been addressed through study of a variety of archives, including long marine sediment cores recovered by ships such as the R/V *Marion Dufresne* (Figure 2), speleothems (mineral deposits formed from groundwater within underground caverns), and corals. The issue of high-frequency climate variability clearly motivates a large part of the community, as demonstrated by the large number of ICP-8 posters (more than 120 total) devoted to this subject. A few examples of the more striking new results are summarized in the remainder of this section.

A large number of new high-qual-

Figure 2. The French R/V *Marion Dufresne*, which since 1995 has been used by the international IMAGES community to recover giant CALYPSO cores, as much as 60 meters long. Approximately twenty-five percent of the results presented at ICP-8 were obtained from these cores. Photo courtesy of the French Polar Institute Paul Emile Victor (IPEV).

ity Holocene marine records from the North Atlantic were presented. An increasing emphasis on high deposition rate and, in some cases, laminated (Figure 3) sediment sequences has allowed many of these records to be sampled at subcentennial, and even subdecadal, time resolution. For example, results showing a close link between the strength of the Hadley circulation and the northward extent of the Intertropical Convergence Zone during the pronounced Holocene climate events demonstrated the importance of exploring the seasonal character of the proxies used. In the Pacific Ocean, ^{18}O results from more than a dozen fossil corals from Palmyra Island together preserve a record of interannual to centennial-scale tropical Pacific climate variability for the past millennium. The coral record suggests that ENSO characteristics varied significantly over this time interval, with the highest amplitude fluctuations during the peak of the "Little Ice Age." In contrast, the tropical Pacific was cool and dry, and conditions were more stable, during the so called "Medieval Warm Period," suggesting a possible role for the tropical Pacific in shaping the global expression of these centennial-scale climate variations.

A new paleocirculation reconstruction for the North Atlantic since the last glacial, based on paired benthic foraminiferal ^{13}C and bulk sediment ^{231}Pa/^{23}0Th measurements, showed large millennial-scale reductions in the meridional overturning circulation during the glacial accompanied by dramatic climate changes in the region. Furthermore, ^{13}C evidence suggests that similar swings occurred during the Holocene.

Results of a new Holocene reconstruction of the history of the density structure and of Gulf Stream transport through the Florida Straits were presented. These indicate that the density structure of the water column in the Straits did not undergo systematic changes between 2000 and 8000 years ago, suggesting that early Holocene warmth was not associated with a stronger meridional overturning circulation. However, high-resolution analyses of the last 1000 years indicate a modest increase in transport during the Medieval Warm period as compared to the Little Ice Age. These

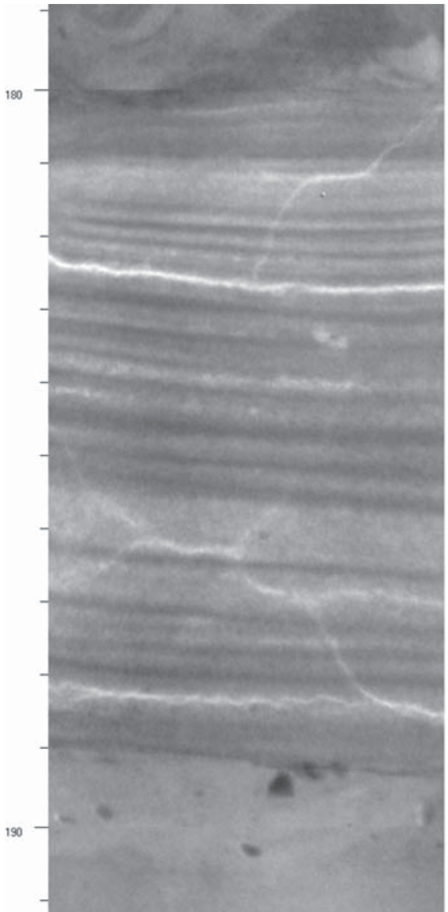

Figure 3. An x-ray photo of the internal structure of a sediment core displaying decadal-scale laminae. Such sediments afford the opportunity to gather paleoenvironmental data at unprecedented resolution. Photo courtesy EPOC, University of Bordeaux I.

reduced changes stand in marked contrast to the large changes observed over the deglacial period.

The need to consider the potential for substantial sea-level variations associated with high-frequency climate variations of the last glacial was highlighted. For example, new estimates of millennial-scale sea-level variations from the Red Sea imply that, in contrast to most models, enormous (30±5 m) individual sea-level shifts occurred during Marine Isotope Stage (MIS) 3. Surprisingly, these are not associated with Dansgaard/Oeschger-type variations, but instead appear to have occurred with an "Antarctic rhythm." Key questions clearly arise from this hypothesis: How precise are these reconstructions and their timing? And if correct, where does the meltwater responsible for these large sea-level excursions come from?

Finally, interesting results were presented from work on continental archives. A spectacular, well-dated new speleothem record from Israel, spanning the last 250,000 years, can be clearly related to eastern Mediterranean sea-surface conditions and closely matched with both the SPECMAP (orbitally tuned time scale based on marine oxygen isotope records) and Greenland ice-core records. The speleothem data indicate glacial-interglacial temperature variations ranging from 8 to 22 degrees C, with a Holocene average of 18 degrees C.

INTERHEMISPHERIC OCEAN-CONTINENT-CLIMATE LINKAGES

It was clear from presentations throughout ICP-8 that ocean-continent-climate linkages must be understood not only on a regional scale, but also on a global scale. These linkages encompass leads and lags (chronology), forcings imposed by gateway changes, and cross-latitudinal inter-hemispheric and inter-ocean links. They must be addressed in the framework of global thermohaline circulation variability, and their understanding requires ongoing comparisons among oceanic cores, ice cores, and continental records. Interhemispheric ocean-continent-climate linkages have become important topics in paleoclimate dynamics because they represent novel constraints and fingerprints for better understanding the mechanisms that underlie abrupt climate change. In particular, the Southern Ocean—undersampled and poorly understood—has become a major focus of these activities. Fortunately, recent data from the Southern Ocean presented at the conference corroborate evidence from the Antarctic ice cores: glacial periods were punctuated by interstadial events, which can be associated with changes in NADW registered by marine sediments. Such findings confirm the global occurrence of abrupt climatic changes. High-resolution paleoceanographic reconstruction has matured to the extent that SST changes can be constructed with sub-millennial resolution. For instance, during the Holocene, opposing trends in tropical and extratropical SST have been reported that could indicate a signature of Northern Hemisphere modes of variability superimposed on millennial trends. Interhemispheric linkages are mediated by the Atlantic Ocean's meridional overturning circulation, still physically the most viable process for explaining abrupt climate change.

Linkages also occur between the ocean and continents, though correlations between records representing one or the other can be a challenge. The reconstruction of pollen assemblages from marine cores provides one means of solving this problem. By linking pollen evidence for vegetation changes directly to marine indicators in the same core, the problem of synchronization is elegantly solved.

It is clear that the recent increase of multiproxy approaches conducted simultaneously in the different Earth reservoirs has permitted impressive advances in understanding ocean-content linkages. However, it is also clear that modelers have tremendously improved their models, allowing strong constraints to be placed on global concepts and theories. A series of new and interesting model approaches are worthy of mention. Below are three examples that pertain to global ocean circulation simulations (the so-called "conveyor belt"):

1. While mixing is the most important driving mechanism of global ocean circulation due to thermodynamic principles, some modelers argue that buoyancy forcing is responsible for the changes imprinted on this flow. Such changes are likely at the heart of the Dansgaard/Oeschger events, the series of abrupt warmings and millennial coolings during the last glacial found in the Greenland ice cores.
2. Whereas the traditional view is that perturbations of the surface freshwater balance are caused by massive ice sheet discharges, a few pioneers suggest that a global deep salt reservoir could be the engine of a "grand" salt oscillator.
3. Some models indicate that the global warming during the last Termination had two effects: (i) it kick started a sluggish glacial meridional overturning circulation in the Atlantic via a far-field effect, and (ii) it initiated widespread melting around the perimeter of the Northern Hemisphere ice sheets, which in turn perturbed the ocean circulation occasionally to create H1 and Younger Dryas cooling.

Although much remains to be done, it was clear from ICP-8 that our understanding of interhemispheric ocean-continent-climate linkages has vastly improved.

KEYNOTE LECTURES

Traditionally, ICP meetings adopt a classic format, including oral presentations reserved for invited speakers and poster sessions opened to all attendants. The main highlights and outcomes summarized above were developed during these sessions. Along with these presentations, keynote speakers are invited to deliver longer lectures. This year, keynote lectures were given by Sir Nick Shackleton, Robbie Toggweiler, André Berger, and Jean Jouzel. Sir Nick Shackleton reminded us that stratigraphy is really the backbone of paleoceanography. He emphasized the value of working directly with data, not just with its interpretation, and the importance of stratigraphy to all aspects of paleoceanography. He concluded by posing several challenges to the paleooceanography community present, one of which is the necessity of working at high temporal resolution regardless of where in the time scale the question is situated. The keynote lecture by Robbie Toggweiler returned to the theme of glacial-interglacial CO_2 cycles and outlined a "strawman" based on his 1999 seven-box model that generated its own 100,000-year cycle without ice sheets or sea-level variations. This lecture stimulated vigorous and penetrating discussion inside and outside the lecture hall. André Berger gave his keynote talk on the question: "How long will our interglacial last?" He addressed the nature of the 100- and 400-kyr orbital cycles and their significance to the posed question. He then focused on the importance of MIS 11, some 400 ka, as the best and closest analogue for our current interglacial. He concluded that we need to expect our present interglacial to last longer than previous ones, based on both orbital considerations and the ongoing rise of atmospheric CO_2 due to human activities. During the final talk of the meeting, Jean Jouzel displayed the very latest results obtained in 2004 on the famous EPICA ice-core from Antarctica: our ice colleagues have now reached ice deposited 740 ka, which is the world record for the oldest ice recovered so far. This fantastic new record will be instrumental for comparison with oceanic cores. Moreover, the study of greenhouse gases trapped during earlier interglacial periods will help modelers in their future global warming simulations.

WORKSHOPS

In addition to the primary agenda, five successful and well-attended workshops were organized to complement the ICP lecture program. These covered: (1) the Mg/Ca temperature proxy, (2) Southern Hemisphere Climate Modes, (3) Stable Isotope Laboratory Intercalibrations, (4) the Marine Isotopic Stage 11, and (5) LINKS, a SCOR-IMAGES Working Group. The general outcome of these workshops was the recognition by participants that major future advances in paleoceanography will require work of a more collaborative nature, using a more interdisciplinary approach, and with final results assembled for publication in dedicated special journal issues or in collaborative review papers.

The Mg/Ca Temperature Proxy Workshop. The Mg/Ca Workshop discussed improving the methodology and usage of the new Mg paleotemperature proxy—the Mg/Ca ratio in planktic and benthic foraminifera. In recent years, a number of studies have shown the great potential of this method for precise reconstructions of past surface- and deep-water temperature changes. However, problems exist that limit the accuracy of the reconstructions, including the need for interlaboratory calibrations and standardized cleaning procedures, dissolution during early diagenesis, and the lack of precise temperature calibrations. The aim of the workshop was to present the state of the art and discuss means for improving the accuracy and precision of this temperature proxy through international calibration. More than 120 scientists and students from over 40 different laboratories participated in this workshop. Leading specialists in the field reviewed results and problems, with the support of twelve posters. The two main outcomes of the discussion were: (1) the organization of a new laboratory intercalibration exercise, to be led by N. Caillon and M. Greaves, building on the earlier exercise by Y. Rosenthal and colleagues. To date, a total of 30 laboratories have expressed the wish to be associated. More laboratories are welcome. (2) The publication of a special theme volume in the electronic journal G-cubed (editors P. Martin and L. Labeyrie), which will include review papers, original contributions, and the results of the intercalibration. Participation in either exercise is welcome.

The Southern Hemisphere Climate Modes Workshop. This workshop had a strong focus on the ENSO and Indian Ocean Dipole modes. The outcome of this workshop was a summary of the current knowledge and knowledge gaps in understanding Southern Hemisphere climate modes. It was agreed that future research foci should include the frequencies of ENSO-like climate mean states over glacial cycles; the occurrence of the Younger Dryas in the Southern Hemisphere; the possibility of La Niña-like sea surface patterns, for example, during the Early Holocene; the theory of a suppressed ENSO system during the mid Holocene; the timing of the onset of the modern ENSO; and the interaction and teleconnection of ENSO and Indian Ocean Dipole modes over geologic time, especially recent time periods covered by paleoproxies such as corals. The participants also agreed that in the future special attention should be given to the use of and differentiation between terminology such as ENSO-like mean states and ENSO variability.

Analyzing the LINKS Between Present Oceanic Processes and Paleo-Records (LINKS) Working Group. LINKS, a Scientific Committee on Oceanic Research (SCOR)-IMAGES Working Group meeting focused on the export of material that links surface water processes with the sediment record. The central questions that this working group tackled included: How well do we understand the present-day ecosystem processes driving export production and how well can we make the link from proxies to past ecosystems? If proxies contradict each other, what is the cause and can we come to a mechanistic understanding? What are the major gaps in our understanding and can we suggest a strategy for the development of new proxies for specific processes? LINKS plans to publish a review paper structured according to the factors influencing export production and addressing the above questions. It will combine the expertise of present-day ecologists and oceanographers with paleoceanographers, and it will restrict its work to summarizing existing knowledge. Workshop participants' assessment of the current state of the art may help research projects to improve their sampling strategy or to promote new collaborations. In particular, workshop participants were encouraged to enhance their collaborations with GEOTRACES, CLIVAR, PAGES/IMAGES, LOICZ, SOLAS, GLOBEC, and IMBER.

SUPPORT AND FUTURE ICP

ICP-8 was a great success this year, thanks not only to the quality of the speakers, but also to the generous support and funding from a number of national and international agencies. These agencies include SCOR, IMAGES (IGBP Core-Program), the French Centre Nationale de la Recherche Scientifique (CNRS [SDU-INSU]), and the French Research Ministry. Support also came from local sources, including the Région Aquitaine, C.G. 64, and University Bordeaux I. Both IMAGES and SCOR provided travel grants to students and scientists from developing countries to help underwrite their participation at this meeting. The next ICP (ICP-9 in 2007) will be organized by our Chinese colleagues and held in Shanghai. The convener is Pinxian Wang of Tongji University.