CURRICULUM VITAE

Edouard BARD
Born September 1, 1962 in Geneva,
French Citizenship. Married, two children (Antoine and Mathias).

CEREGE, UMR AMU, CNRS, IRD, CdF
Technopole de l'Arbois BP80, 13545 Aix-en-Provence cdx4, France;
Phone: +33 442507418, +33 442507416 (secr.), e-mail: bard@cerege.fr

also at Collège de France, Place Marcelin Berthelot, 75005 Paris

Home address: 1975 rue de la Baou, 13480 Cabriès, France, Phone: +33 442224277

web pages : https://www.cerege.fr/spip.php?rubrique37
http://www.college-de-france.fr/site/en-edouard-bard/index.htm
http://www.academie-sciences.fr/academie/membre/Bard_Edouard.htm

EDUCATION IN FRANCE

1985, M.S.#1 Geological Engineering, ENSG at Nancy,
1985, M.S.#2 Applied Geochemistry (DEA), University of Nancy
1987, Ph.D. defended Dec. 8, University of Paris 11-Orsay "Isotope analysis of carbon by accelerator mass spectrometry. Applications to marine geochemistry and geochronology";
1991, Habilitation defended Feb. 21, Univ. Aix-Marseille "Isotope analysis of uranium and thorium by thermal ionization mass spectrometry. Applications to geochronology and paleoclimatology"

EMPLOYMENT

1985-87, Doctoral Fellow of the Commissariat à l'Energie Atomique (CEA), France
1988, Postdoctoral Fellow at Lamont-Doherty Earth Observatory (LDEO) of Columbia University, New York USA
1989, Associate Research Scientist at LDEO
1990-1991, Physicist at CEA (tenured associate research scientist) working at Centre des Faibles Radioactivités (CNRS-CEA) in Gif-sur-Yvette
1991-2001, Professor at Aix-Marseille University
1999-2000, Visiting Professor at Harvard University (NATO Fellowship), Cambridge, USA
2008-2009, Visiting Professor at the University of Bern (Oeschger Center Fellowship), Switzerland
2001- present, Professor at the Collège de France, chair in Climate and Ocean Evolution
2007-present, Associate Director of the CEREGE in Aix-en-Provence.

INTERNATIONAL HONORS

1993, Outstanding Young Scientist Award of the European Union of Geosciences (EUG)
1993, invited speaker, Frontiers of Science Symposium, U.S. Nat. Acad. Sci. (Irvine CA)
1997, Donath Medal of the Geological Society of America (GSA) and Senior Fellow of GSA
1997, Macelwane Medal of the American Geophysical Union (AGU) and Fellow of AGU
1997, Paul Gast Award Lecture of the Geochemical Society and European Association of Geochemistry (Goldschmidt Annual Meeting, Tucson)
1999, NATO Senior Scientist Fellowship (sabbatical year at Harvard University)

2001, Challenger Lecture (W. Smith Meeting, Geological Society, London)
2001, Highly Cited Researcher in Geosciences (http://isihighlycited.com/)
2004, Mentorship Award of the Comer Science and Education Foundation (USA)
2005, A.G. Huntsman Award for excellence in marine sciences (Canada)
2005, Georges Lemaître Prize in geophysics and astronomy (Belgium)
2006, Flint Lectures, Yale University
2006, Dudley Wright Lecture, University of Geneva
2006, Sverdrup Award Lecture of the AGU Ocean Sciences section (Fall meeting, San Francisco)
2008, Wiley Lecture of the Quaternary Research Association (Royal Geographic. Soc., London)
2009, 'WMO/ICSU Certificate of Appreciation' for work linked to the International Polar Year,
2009, Oeschger Lectures, University of Bern (Oeschger Centre for Climate Change Research),
2009, elected Member of the *Academia Europaea*.
2011, elected foreign Member of the Royal Academy of Belgium, section of Sciences
2011, Plenary Lecture, Annual V.M. Goldschmidt Conference (Prague),
2012, Jaeger-Hales Lecture of the Australian National University (Canberra).
2013, Alfred Wegener Medal & Honorary Fellowship of the European Geosciences Union (EGU)
2013, Werner Petersen award of the Helmholtz Center for Ocean Research (GEOMAR Kiel, Germany).
2014, elected foreign Member of the US National Academy of Sciences.
2014, Thomson Reuters Highly Cited Researcher (http://highlycited.com/)
2014, Prince Albert I Medal of the Oceanographic Institute of Monaco

FRENCH HONORS

1991, Bronze Medal of the Centre National de la Recherche Scientifique (CNRS)
1994-99, Elected as a junior Member of the Institut Universitaire de France (IUF).
2001, French Citation Laureate 1981-98 of Institute for Scientific Information (ISI)
2006, Gérard Mégie Grand Prize, French Academy of Sciences and CNRS.
2007, Chevalier (Knight) dans l'Ordre National de la Légion d'Honneur,
2008, honorary Member of the French National Committee of INQUA,
2010, elected Member of the French Académie des Sciences (Institut de France)

INTERNATIONAL AND GOVERNMENTAL EXPERTISE

_ Member of the Board of reviewing Editors for *Science* (2000 & 2001),
_ Editor-in-chief for *Earth and Planetary Science Letters* (2001 to 2004),
_ Editor for *Quaternary Science Reviews* (2004 to 2007).
_ Associate Editor or member of Advisory Board for several scientific journals: *Radiocarbon* (since 1989), *The Holocene* (since 1999), *Terra Nova* (1997-2008), *Quaternary Science Reviews* (1994-2004), *Earth and Planetary Science Letters* (1997-2001), *G-cubed (Geochemistry, Geophysics, Geosystems)* (1999-2005),

_ Member, IntCal group for the radiocarbon calibration (1993-present).
_ Member, Scientific Council of European Association for Geochemistry (EAG, 1995-96 & 2001),
_ Member, Selection committee for EUG Young Scientist Award (1997-03, president in 2000-01),
_ Member, ODP Program Planning Group "Scientific drilling of shallow-water systems" (1997-01),
_ Member, Selection committee for fellows of the Geochemical Society and EAG (2000),
_ Member, Scientific Council of EUG (2001-03),
_ Member, Scientific Council of Centre National de la Recherche Scientifique (CNRS), (2001-03),
_ Member, Selection committee for the Urey Medal of EAG (2004-2006),

_ President, Scientific Council of the French Polar Institute (IPEV) (2002-2006),
_ Member, Council of the Agence d’évaluation de la recherche et de l'enseignement supérieur (AERES) (2007-2011),
_ Member, Advisory Board of the NOSAMS laboratory, Woods-Hole USA (2006-2008).
_ Vice-President, Governmental advisory panel « Grenelle de l’Environnement », Ministère de l’Ecologie du Développement et de l’Aménagement Durables (2007).
_ Member, Delegation accompanying State Minister J.-L. Borloo (Ilulissat Greenland, Sept. 2007).
_ Member, Delegation of the French government for the 2007 United Nations Climate Change Conference (UNFCCC COP13, Bali, Indonesia, Dec. 2007),
_ Participant, Round table on climate under the presidency of N. Sarkozy and H.S.H. Prince Albert II (Monaco, April 2008),
_ Testimony (« Audition ») at the French Senate (OPECST, Paris, June 26 2008),
_ Scientific expert, Conference and round table on The Arctic organized by the French Presidency of the Council of the European Union, in presence of State Minister, J.-L. Borloo, and Prince Albert II (Monaco, 9-10 novembre 2008),
_ Member, Governmental advisory panel «Commission du Grand Emprunt National» under the presidency of former Prime Ministers A. Juppé and M. Rocard (2009).
_ Member, Scientific Council of OPECST (French Senate & Chamber of Deputies, 2010-2013).
_ Keynote speaker for the 2010 workshop on sea-level rise and ice sheet instabilities of the Intergovernmental Panel on Climate Change (IPCC, Kuala Lumpur, June 2010).
_ Member, Steering Committee of the PALSEA working group (PALeo constraints on future SEA-level rise) in the frame of PAGES/IGBP/IMAGES (2010-present).
_ Member, Award Nomination Committee of the Geochemical Society (2011-2014).
_ President, Science Innovation Award Committee of the EAG (2012-2013).
_ Member of the GEOMAR (Kiel) Scientific Advisory Board (2013-)

ORGANISATION OF INTERNATIONAL SCIENTIFIC MEETINGS

_ 1990 May, Baltimore (MD), Spring AGU, Union Session U51B "Millenial changes in radiocarbon production" (with W. S. Broecker),
_ 1990 Dec., Erice (Italy) Director of the NATO Advanced Research Workshop "The last deglaciation: absolute and radiocarbon chronologies",
_ 1992 Sept., Kiel (FRG), 4th International Conference on Paleoceanography (ICP), convenor and chairman of the symposium: "Deglaciations and 100-year-scale events",
_ 1994 Apr., Grenoble (France), 19th EGS General Assembly, convenor and chairman of the session SE12/OA26 "Climatic and geophysical changes in the Late Quaternary. Dating and construction of time series",
_ 1998 Sept., Toulouse (France), 8th Goldschmidt Conference, convenor and chairman of the symposium "Proxies in paleoceanography",
_ 1999 May, Delmenhorst (FRG). 1st EPILOG Workshop sponsored by PAGES, IMAGES and HANSE Institute for Advanced Study (with A. Mix and R.R. Schneider),
_ 2000 Sept., Oxford (UK), 10th Goldschmidt Conference, convenor and chairman of the symposium "Rapid Climate Changes",
_ 2000 Oct., Mt Hood (Oregon), 2nd EPILOG Workshop of PAGES and IMAGES. "Global Ice Sheets and Sea Level During the Last Glacial Maximum" (with A. Mix and P.U. Clark),
_ 2009 May, Paris (French Senate and Collège de France), “Closing of the 4th International Polar Year” (with C. Gaudin),
_ 2009 June, Davos (Switzerland), 19th Goldschmidt Conference, convenor and chairman of the session "The sequence of events at glacial termination" (with V. Masson).

_2011 August, Prague, XXth Goldschmidt Conference, convenor and chairman of the session "Chronologies and Rates of Climate Change" (with D. Fleitmann).
_ 2012 July, Paris (Fondation Hugot du Collège de France), Workshop of the IntCal group, organisor of the workshop (with P. Reimer).
_ 2012 July, Paris (UNESCO), 21st International Radiocarbon Conference, convenor of the session on "Calibration" (with P. Reimer and J. van der Plicht).

Member of the scientific committees for the 11th EUG meeting (Strasbourg, Apr. 2001), 7th ICP (Sapporo, Sept. 2001), 27th EGS Assembly (Nice, Apr. 2003, jointly with EUG and AGU meetings), 3rd International Meeting on Karst (Montpellier, May 2003), 18th International Radiocarbon Conference (Wellington, Sept. 2003), the 8th ICP (Bordeaux, Sept. 2004), « Lucy 30 yrs later» (Aix-en-Provence, June 2006), « SealAix » (Giens, Sept. 2006), Goldschmidt Conference (Prague, 2011), 21st International Radiocarbon Conference (Paris 2012), International Partnerships in Ice Core Sciences (Giens, Oct. 2012), 13th Accelerator Mass Spectrometry Conference (Aix-en-Provence, Aug. 2014)

INVOLVEMENT IN THIRD PARTY FUNDED PROJECTS

Single Principal Investigator (PI) and co-PI of successful projects su)pported by the US NSF (ATM-89-12377 and ATM-90-01139) and the only French PI in the framework of an international pluri-annual collaboration (2004-2008) funded by the US Comer Science & Education Foundation.

Coordinator of the European project MilEClim (ENV4-CT97-0659) and French PI for several other European Commission projects (FMRX-CT-1996-0046, TEMPUS ENV4-CT97-0564, STOPFEN HPRN-CT-2002-00221) and a recently completed European Science Foundation Project (ESF EuroMARC CHECREEF 2007-2010). Involved as WP1.2 leader for the European Commission project "Past for Future" (FP7 FPT-ENV-2009-1, 2010-2015).

Since the early 90s, leader of numerous French projects supported by the CNRS. Presently, coordinator for the Agence Nationale de la Recherche (ANR) project VolSol (2009-2013) on the reconstruction of volcanic and solar forcings on climate over the past millennia based on Antarctica ice cores. Also partner or participant in other French projects supported by the ANR (VANISH, ECO-MIST).

Second PI for the ODP proposal 519 on « The Last Deglacial Sea-Level Rise in the South Pacific: Offshore Drilling in Tahiti (French Polynesia) and on the Australian Great Barrier Reef ». This proposal led ultimately to the IODP Leg 310 off Tahiti in 2005 and IODP Leg 325 in 2010 off the GBR.

PI for several proposals to purchase modern geochemical equipments for my laboratory in Aix-en-Provence (e.g. TIMS, ITRAX XRF, LCMS, GCMS, ICPMS, AMS facilities).

First PI (coordinator) of the French Agence Nationale de la Recherche (ANR) project VOLSOL (2009-2014) on the reconstruction of volcanic and solar forcings on climate over the past millennia based on Antarctica ice cores.

First PI (coordinator) for the ANR EQUIPEX Project ASTER-CEREGE (2011-2019). This grant allowed the purchase and installation of new equipements to upgrade the mass spectrometry facilities installed at CEREGE in Aix-en-Provence: a MICADAS compact accelerator for ^{14}C, a MC-ICPMS for U-series, and a new ion source for the 5 MV ASTER Accelerator used to measure ^{10}Be and other cosmogenic isotopes.

SCIENTIFIC ACTIVITIES

(keyed to the publication list)

My various studies are at the interface of climatology, oceanography and geology. The essential objective is to understand the natural functioning of the ocean-atmosphere system on time scales ranging from a few centuries to several million years. To document these changes more fully, to date them precisely, to understand the mechanisms and to model them are important tasks within the framework of projects aimed at predicting the future evolution of the climate.

For this research, I use techniques of analytical chemistry to determine the extent and the timing of climatic variations. New quantitative methods have enabled me to reconstruct past climates using varied archives such as oceanic sediments, lake sediments, corals, stalagmites and polar ice. The guiding principle is the wish to study the same climatic phenomena, for example the glaciations, using complementary and often innovative geochemical techniques. Another characteristic of this research is the to-and-fro of information between recent and older periods. Indeed, the variations of the climate involve mechanisms with very different time-constants. It is thus necessary to have a long-term perspective in order to distinguish the respective impacts of geological, astronomical and anthropogenic forcings. My principal scientific results are described below and linked with some references listed in annex.

1/ Diffusion-advection of carbon dioxide radiolabelled by thermonuclear ^{14}C: In the 1980s, I took an active part in the development of the accelerator mass spectrometry, which makes it possible to measure $^{14}C/^{12}C$ ratio directly on samples of very small size [7]. This technique truly revolutionized the application of radiocarbon in the Earth sciences, particularly in chemical oceanography. With this approach, I was thus able to quantify the penetration of ^{14}C of thermonuclear origin in the Indian Ocean. I published the first results of this type [4] in the same year (1987) as two other groups (collaborations Heidelberg-Zürich and Miami-Uppsala). This isotopic labeling allowed us to follow the fate of CO_2 of anthropogenic origin and test mathematical models of general circulation in the oceans (e.g. at the GFDL in Princeton [16]). These studies paved the way to the inclusion of a sampling program dedicated to AMS in the World Ocean Circulation Experiment (WOCE).

2/ Fluctuations of the temperature of the oceans: In order to quantify oceanic paleotemperatures, I developed and used several geochemical methods based on the analysis of organic molecules, trace metals and stable isotopes. With my team at the CEREGE, I studied a large number of sediment cores taken at low latitudes in the three oceans. We proposed [50,57,64] a new evaluation of the glacial-related cooling of these zones (approximately 2-3°C, an average value subsequently confirmed by other groups [94,125]). Tropical cooling is a crucial parameter now used for testing climatic models [64,126] and determine the so-called "climate sensitivity" parameter.

Another aspect of my research on paleotemperatures relates to the rapid fluctuations on the scale of the century to the millenium [71,89]. Accelerator mass spectrometry proved essential for measuring precise ^{14}C ages and evaluating the rate of the climatic variations. Oceanic cores with high resolution enabled me to find evidence for numerous warming and cooling episodes, in agreement with the atmospheric changes analyzed in the polar icecaps. Our work published in 1987 [8] was actually the first showing the existence of abrupt changes of sea-surface temperature on the order of several °C per century, i.e. the same order of magnitude as the average warming predicted for the coming century. For the North Atlantic Ocean, intense cooling episodes are clearly related to periods of iceberg release, called Heinrich events following the pioneer article published in 1988 by this German geologist. Moreover, in 1987 [8], we had already described the most recent Heinrich event centered around 16,500 years B.P. (before present). In this 1987 paper, we even proposed a correct explanation for the phenomenon, with « a pulse like injection of large volume of ice or meltwater into the Atlantic ».

Since ten years, I also study these rapid climatic changes in the tropical oceans, away from the main source of the phenomenon, the North Atlantic. With my team, I study new sediment cores from the Pacific and Indian Oceans, applying robust paleothermometers (alkenones and foraminiferal Mg/Ca) [50,114,115,123,133,135,136,137]. We also tested the new paleothermometric method based on the TEX86 index. After intensive analytical development in Aix-en-Provence, we are now able to quantify accurately tetraether lipids by liquid chromatography coupled to mass spectrometry. Precision and accuracy of our paleothermometric data (alkenones, Mg/Ca and TEX86) have been tested in the frame of international intercomparisons [81,96,128].

3/ <u>Variations of sea level:</u> By applying a new technique of mass spectrometry to the measurement of uranium and thorium isotopes (U-Th, [21]), I carried out a detailed study of the variations in sea level during the last glacial cycles, using samples from coral reefs in the three oceans. The last deglaciation, between 21,000 years and 6,000 years B.P., led to a tremendous rise in the world sea level by approximately 120 meters. We reconstructed the precise chronology of this troubled period by studying drillings into reef formations on the islands of Barbados [22] and Tahiti [48,147]. During this period, many other climatic and oceanographic parameters underwent first-order variations: global warming of about 5 °C, approximately 40 % increase in the atmospheric contents of greenhouse gases (carbon dioxide and methane), reduction in wind speeds, reorganization of oceanic circulation, etc. One of the major results is the discovery of abrupt variations of the sea level (meltwater pulses MWP) at rates of several meters per century, therefore even faster than the rise predicted for the coming century. The two sea-level curves, from Barbados and Tahiti, now form the benchmark records that are used to model the geophysical response to the eustatic changes [67] (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-6-8.html ; or p. 458 of the IPCC AR4-WG1 2007). In order to complement our studies on cores drilled on shore Tahiti [48, 147], we succeeded in convincing scientists, technicians and administrators of the international Integrated Ocean Drilling Program to carry out offshore drillings (IODP proposal # 519 submitted in 1999 by Camoin, Bard, Hamelin and Davies). The coring operations carried out during IODP Leg 310 in November 2005, recovered more than 400 m of post-glacial reef material, ranging from 122 to 40 m below modern sea level. The new U-Th and ^{14}C results allow studying the last two deglaciations [132,165,166,167], notably the timing and amplitude of MWP-1A and the identification of ice sheets responsible for this major event.

Over longer time scales, the sea-level data can be compared with simulations carried out within the framework of the astronomical theory of paleoclimate [22,49,82,84,132]. Exceptional stalagmites sampled in a cave submerged by the Mediterranean Sea, enabled us to evaluate the duration of the sea-level highstands during the penultimate interglacial period [84,87,97,131].

An additional result of the coral project is a systematic survey of the oceanic $^{234}U/^{238}U$ ratio and its past variations through time linked to the global geochemical cycle of uranium. We were first to propose that genuine changes of the sea water $^{234}U/^{238}U$ could be linked to long term changes of chemical weathering [25,27,88]. We also introduced the use of this marker as a sensitive tool to detect diagenesis in old samples [22,25,49].

4/ <u>Changes in the global carbon cycle:</u> By measuring the ^{14}C in various compartments of the carbon cycle and by using geochronometers that are independent of ^{14}C, it is possible to use this isotope as a tracer of variations in the carbon cycle. Basing my approach on this principle, I showed in 1988 [11] that the $^{14}C/^{12}C$ ratio at the sea surface is sensitive to several physical phenomena (e.g. circulation of the water masses, extension of the sea ice, speed of the wind, atmospheric pCO_2 etc.). In this way, I demonstrated that this isotopic ratio can be used as a paleoceanographic tracer. The first application of this new proxy [41] was a study of the ocean-atmosphere exchanges during the Younger Dryas climatic event (13,000 to 11,500 years B.P.). From ^{14}C measurements and a chronological calibration provided by a layer of volcanic ash in lake and oceanic sediments as well as in Greenland ice cores [47], we were able to show that the North Atlantic deep circulation system had slowed down during this period of cooling. Since publication of this study in 1994 [41], several teams have used this new tracer by applying it to other periods and other geographical areas.

Longer paleoceanographic time series were also generated to investigate the climatic control on the marine biological productivity and in particular the importance of insolation cycles linked to orbital variations. My essential objective is to better understand the causes of long-term changes of the burial in marine sediments of organic matter, carbonates and trace metals [56,65,68,83, 86,91,99]. By means of molecular and isotopic markers, we evaluate the variations of the accumulation and preservation of organic carbon of marine and continental origins. Our recent developments involve the use of new markers like the $^{15}N/^{14}N$ isotopic ratio [120], biomarkers such as the diploptene, diplopterol [146], lycopane abundances and the branched isoprenoïd tetraether (BIT) index [111], and also ultra-high resolution elemental analyses by means of XRF microscopy [116]. The scientific outcomes concern the relations between the Asian monsoon and the presence at intermediate water depth of a zone depleted in oxygen, leading to mid-depth acidification [140] denitrification and diffusion of nitrous oxide into the atmosphere [120]. Other results concern the terrigenous organic matter fluxes transported by European rivers during the last ice age [111] and the thermal destabilization of methane hydrates during the last deglaciation [146].

5/ Calibration of the radiocarbon dating method: Corals allow a direct comparison of ^{14}C dating with the U-Th disequilibrium method, since the latter yields ages that are both accurate and precise. Specialists in ^{14}C dating had already pointed out some small chronological discrepancies in comparison with dendrochronology, i.e. by measuring the ^{14}C composition of fossil wood samples whose exact age is given independently by counting the annual growth rings on trees. Working from one tree trunk to another, it has been possible to extend this calibration back to 10,000 years B.P. However, these variations in initial ^{14}C composition remained entirely unknown between 10,000 and approximately 40,000 years B.P., the limit of application of this radiometric clock. This gap in information was filled by dating the corals from Barbados, Mururoa and Tahiti using ^{14}C and U-Th on the same samples [20,39,58]. Our results show that the two geochronometers gradually diverge, with ^{14}C giving ages that become systematically too young by several thousands of years. We have been able to correct several "fundamental dates": the last glacial maximum (LGM) is 21,000 years B.P. (instead of 18,000 years B.P. formerly) and the duration of the Holocene Period is now of 11,500 years (instead of 10,000 years).

Since 1993, our ^{14}C and U-Th results on corals are the backbone of the "official" database of the computer program for calibration distributed to all users of radiocarbon dating [60,101,102,103,143, 183]. This is an international collaboration (IntCal group, to which I belong) leading to the regular publication of a calibration curve marking the consensus of the time. After several specialized meetings and compilation works [80,90,93,108], we released the "official" curves (IntCal93, 98, 04, 09, 13 see [60,101,102,103,143, 183] and http://www.radiocarbon.org/). Over the last few years, we generated data on IODP Tahiti corals and sediments from the Iberian and Pakistan Margins [93,95,104,179,184). This radiocarbon calibration effort is crucial for scientific fields such as paleoclimatology and prehistoric archeology.

6/ Solar activity and variations of the geo- and heliomagnetic fields: The interest of revealing the bias of radiocarbon age dating also lies in the physical interpretation of the phenomenon itself. The inherent inaccuracy of the ^{14}C method implies that the atmospheric content of this isotope fluctuates in the course of time. The rapid variations in ^{14}C composition, of the order of the century to a millennium, are related to changes in the production rate of ^{14}C in response to magnetic fluctuations of the Sun, which modulate the arrival on Earth of protons from the cosmic rays. Our studies on this subject are based on the comparison of completely independent records: the ^{14}C measured in tree-rings and beryllium 10 analyzed in Antarctic ice cores (^{14}C and ^{10}Be are two cosmogenic nuclides formed in the upper atmosphere). In one respect, these series of analyses made it possible to pick out the periods of weak solar activity already known to astronomers from the counting of sunspots and direct observations of aurora borealis. Moreover, we were able to detect some even older solar minima [55,69,109,118,150]. Our solar variability reconstruction over 1000 years is used by climate modelers to study the link between the Sun and climate over the last millennium (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-6-14.html or p. 479 of the 2007 IPCC AR4-WG1; see also [154,159] used for the 2013 IPCC AR5-WG1 report). ^{10}Be measurements are now performed by means of the brand new 5MV AMS facility (ASTER) recently been installed at CEREGE. I lead French programs on cosmogenic isotopes in Antarctic ice cores, starting with the Talos Dome ice core drilled in 2006.

On the longer term, ^{14}C ages generally underestimate true ages, in particular during the last glaciation. Our data indicate that the atmospheric content of ^{14}C reached an excess of 50-70 % around 40.000 years B.P. By carrying out numerical simulations, I showed [20,28,54,59] that the dominant factor is the regular reduction in the terrestrial magnetic field, which is also recorded in volcanic and sedimentary rocks. Indeed, any reduction in this field allows penetration of more cosmic rays into the atmosphere, thus enhancing the formation of cosmogenic nuclides. The maximum of ^{14}C production corresponds to the Laschamp magnetic excursion, during which the geomagnetic field fell very sharply. These variations were correlated with those visible in the ^{10}Be records of marine sediments and polar ice cores.

PUBLICATIONS

I have published about 200 papers in the peer-reviewed scientific literature. These papers are well cited as illustrated by my distinction in 2001 as French Citation Laureate 1981-1998 of the Institute for Scientific Information (ISI), and my inclusions in 2001 and 2014 in the list of Highly Cited Researchers (http://highlycited.com/). According to Google Scholar my papers have been cited about 28,400 times translating to a H-index of 67 (> 2000 citations per year over the last 5 years). Among these papers, 18 are cited more than 300 times (11 as first author), and 48 are cited about 100 times or more (21 as first author).

I also made significant efforts to popularize climate science at various levels, ranging from the general public to students and scientists outside my field. For this purpose, I published and edited 5 books and wrote about 30 articles or chapters in French.

Volumes (only those in English):

Bard E, Broecker WS editors. (1992) The Last Deglaciation: Absolute and Radiocarbon Chronologies. NATO ASI serie I, vol 2, Springer-Verlag, 344 pp

Full list of articles published in the international scientific literature:

202- Bard E, Tuna T, Fagault Y, Bonvalot L, Wacker L, Fahrni S, Synal H-A. AixMICADAS, the accelerator mass spectrometer dedicated to ^{14}C recently installed in Aix-en-Provence, France. *Nuclear Instruments and Methods B*.

201- Tachikawa K, Vidal L, Cornuault M, Garcia M, Pothin A, Sonzogni C, Bard E, Menot G, Revel M. Eastern Mediterranean Sea circulation inferred from the conditions of S1 sapropel Deposition. *Climate of the Past Discussion*

200- Gasse F, Vidal L, Van Campo E, Demory F, Develle AL, Tachikawa K, Elias A, Bard E, Garcia M, Sonzogni C, Thouveny N. Hydroclimatic changes in northern Levant over the past 400,000 years. *Quaternary Science Reviews*

199- Aloisi G, Soulet G, Henry P, Wallmann K, Sauvestre R, Vallet-Coulomb C, Lécuyer C, Bard E. Freshening of the Marmara Sea prior to its post-glacial reconnection to the Mediterranean Sea. *Earth and Planetary Science Letters*

198- Sanchi L, Ménot G, Bard E. Environmental controls on paleo pH at mid-latitudes: a case study from Central and Eastern Europe. *Palaeogeography, Palaeoclimatology and Palaeoecology,* DOI : 10.1016/j.palaeo.2014.10.007 (2014).

197- Köhler P, Knorr G, Bard E. Permafrost thawing as source of abrupt carbon release at the onset of the Bølling/Allerød. *Nature Communications* 5, 1-10, + 20 p. suppl., DOI: 10.1038/ncomms6520 (2014).

196- Cauquoin A, Landais A, Raisbeck GM, Jouzel J, Bazin L, Kageyama M, Peterschmitt JY, Werner M, Bard E, ASTER Team. Using beryllium-10 to test the validity of past accumulation rate reconstruction from water isotopes records in East Antarctic ice cores. *Climate of the Past Discussion* 10, 3421–3447, DOI : 10.5194/cpd-10-3421-2014 (2014).

195- Wegwerth A, Dellwig O, Kaiser J, Ménot G, Bard E, Shumilovskikh L, Schnetger B, Kleinhanns IC, Wille M, Arz HW. Meltwater events and the Mediterranean reconnection at the Saalian–Eemian transition in the Black Sea. *Earth and Planetary Science Letters* 404, 124-135, DOI: 10.1016/j.epsl.2014.07.030 (2014).

194- Barlyaeva T, Bard E, Abarca-del-Rio R. Rotation of the Earth, solar activity and cosmic ray intensity. *Annales Geophysicae* 32, 1-11, DOI: 10.5194/angeo-32-1-2014 (2014).

193- Sanchi L, Ménot G, Bard E. Insights into continental temperatures in the northwestern Black Sea area during the last glacial period using branched tetraether lipids. *Quaternary Science Reviews* 84, 98-108, DOI: 10.1016/j.quascirev.2013.11.013, (2014).

192- Cauquoin A, Raisbeck GM, Jouzel J, Bard E, ASTER Team. No evidence for planetary influence on solar activity 330 ka ago. *Astronomy & Astrophysics* 561, A132, 1-5, DOI: 10.1051/0004-6361/201322879, (2014).

191- Cartapanis O, Tachikawa K, Romero OE, Bard E. Persistent millennial-scale link between Greenland climate and northern Pacific Oxygen Minimum Zone under interglacial conditions. *Climate of the Past* 10, 405-418, DOI: 10.5194/cp-10-405-2014, (2014).

190- Schouten S, Hopmans EC, Rosell-Melé A, Pearson A, Adam P, Bauersachs T, Bard E, Bernasconi SM, Bianchi TS, Brocks JJ, Truxal Carlson L, Castañeda IS, Derenne S, Doğrul Selver A, Dutta K, Eglinton T, Fosse C, Galy V, Grice K, Hinrichs KU, Huang Y, Huguet A, Huguet C, Hurley S, Ingalls A, Jia G, Keely B, Knappy C, Kondo M, Krishnan S, Lincoln S, Lipp J, Mangelsdorf K, Martínez-García A, Ménot G, Mets A, Mollenhauer G, Ohkouchi N, Ossebaar J, Pagani M, Pancost RD, Pearson EJ, Peterse F, Reichart G-J, Schaeffer P, Schmitt G, Schwark L, Shah SR, Smith RW, Smittenberg RH, Summons RE, Takano Y, Talbot HM, Taylor KWR, Tarozo R, Uchida M, van Dongen BE, Van Mooy BAS, Wang J, Warren C, Weijers JWH, Werne JP, Woltering M, Xie S, Yamamoto M, Yang H, Zhang CL, Zhang Y, Zhao M, Sinninghe Damsté JS. An interlaboratory study of TEX86 and BIT analysis of sediments, extracts and standard mixtures. *Geochemistry Geophysics Geosystems (G-cubed*) 14 (12), 5263-5285, DOI: 10.1002/2013GC004904, (2013).

189- Brisset E, Miramont C, Guiter F, Anthony EJ, Tachikawa K, Poulenard J, Arnaud F, Delhon C, Meunier J-D, Bard E, Suméra F. Non-reversible geosystem destabilisation at 4200 cal. BP: Sedimentological, geochemical and botanical markers of soil erosion recorded in a Mediterranean alpine lake. *The Holocene* 23, 1863-1874, DOI: 10.1177/0959683613508158, (2013).

188- Simonneau A, Chapron E, Courp T, Tachikawa K, Le Roux G, Baron S, Galop D, Garcia M, Di Giovanni C, Motellica-Heino M, Mazier F, Foucher A, Houet T, Desmet M, Bard E. Recent climatic and anthropogenic imprints on lacustrine systems in the Pyrenean Mountains inferred from minerogenic and organic clastic supply (Vicdessos valley, Pyrenees, France). *The Holocene* 23, 1764-1777, DOI: 10.1177/0959683613505340, (2013).

187- Bard E. Out of the African Humid Period. *Science* 342, 808-809, DOI : 10.1126/science.1246519, (2013).

186- Heaton TJ, Bard E, Hughen K. Transferring chronologies between record via a Gaussian process. *Radiocarbon* 55 (4): 1975-1997, DOI: 10.2458/azu_js_rc.55.17777, (2013).

185- Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE, Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Haflidason H, Hajdas I, Hatté C, Heaton TJ, Hoffmann DL, Hogg AG, Hughen KA, Kaiser KF, Kromer B, Manning SW, Niu M, Reimer RW, Richards DA, Scott EM, Southon JR, Staff RA, Turney CSM, van der Plicht J. Selection and treatment of data for radiocarbon calibration: An update to the international calibration (IntCal) criteria. *Radiocarbon* 55 (4): 1923-1945, DOI: 10.2458/azu_js_rc.55.16955, (2013).

184- Bard E, Ménot G, Rostek F, Licari L, Böning P, Edwards RL, Cheng H, Wang YJ, Heaton TJ. Radiocarbon calibration/comparison records based on marine sediments from the Pakistan and Iberian Margins. *Radiocarbon* 55(4): 1999-2019, DOI: 10.2458/azu_js_rc.55.17114, (2013).

183- Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE, Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Haflidason H, Hajdas I, Hatté C, Heaton TJ, Hoffmann DL, Hogg AG, Hughen KA, Kaiser KF, Kromer B, Manning SW, Niu M, Reimer RW, Richards DA, Scott EM, Southon JR, Staff RA, Turney CSM, van der Plicht J. IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years Cal BP. *Radiocarbon* 55 (4): 1869-1887, DOI: 10.2458/azu_js_rc.55.16947, (2013).

182- Rostek F, Bard E. Hydrological changes in Eastern Europe during the last 40,000 years inferred from biomarkers in Black Sea sediments. *Quaternary Research* 80, 502-509 DOI: 10.1016/j.yqres.2013.07.003, (2013).

181- Sanchez-Goni MF, Bard E, Landais A, Rossignol L, d'Errico F. Air–sea temperature decoupling in western Europe during the last interglacial–glacial transition. *Nature Geoscience* 6, 837-841, + 8 p. suppl., DOI: 10.1038/NGEO1924, (2013).

180- Jenny JP, Arnaud F, Dorioz JM, Giguet Covex C, Frossard V, Sabatier P, Millet L, Reyss JL, Tachikawa K, Bard E, Pignol C, PSoufi F, Romeyer O, Perga ME. A spatiotemporal sediment investigation highlights the dynamics of hypolimnetic hypoxia in a large hard-water lake over the last 150 years. *Limnology & Oceanography* 58, 1395-1408, DOI: 10.4319/lo.2013.58.4.1395, (2013).

179- Durand N, Deschamps P, Bard E, Hamelin B, Camoin G, Thomas AL, Henderson GM, Yokoyama Y, Matsuzaki H. Comparison of ^{14}C and U-Th in corals from IODP #310 cores offshore Tahiti. *Radiocarbon* 55 (4), 1947-1974, DOI: 10.2458/azu_js_rc.v55i2.16134, (2013).

178- Soulet G, Ménot G, Bayon G, Rostek F, Ponzevera, Toucanne S, Lericolais G, Bard E. Abrupt drainage cycles of the Fennoscandian Ice sheet. *Proceedings of the National Academy of Science* 110 (17), 6682-6687, + 4 p. suppl. & 4 Tables, DOI: 10.1073/pnas.1214676110, (2013). (E. Bard co-corresponding author).

177- Doyen E, Vannière B, Berger JF, Arnaud F, Tachikawa K, Bard E. Land-use changes and environmental dynamics in the upper Rhone valley since Neolithic times inferred from sediments in Lac Moras. *The Holocene* 23, 961-973, DOI: 10.1177/0959683612475142, (2013).

176- Michel M, Delanghe-Sabatier D, Bard E, Barroso-Ruiz C. U/Th, ESR and 14C studies of the fossil remains from the Mousterian levels of Zafarraya Cave (Spain): a revised chronology of Neandertal presence. *Quaternary Geochronology* 15, 20-33, DOI: 10.1016/j.quageo.2012.12.008, (2013).

175- Wilhelm B, Arnaud F, Sabatier P, Magand O, Chapron E, Courp T, Tachikawa K, Fanget B, Malet E., Pignol C, Bard E, Delannoy J-J. Paleoflood activity and climate change over the last 1400 years recorded by lake sediments in the North-West European Alps. *Journal of Quaternary Science* 28, 189-199, DOI: 10.1002/jqs.2609, (2013).

174- Simonneau A, Doyen E, Chapron E, Millet L, Vannière B, Di Giovanni C, Bossard N, Tachikawa K, Bard E, Albéric P, Desmet M, Roux G, Lajeunesse P, Berger J-F, Arnaud F. Holocene land-use evolution and associated soil erosion in the French Prealps inferred from Lake Paladru sediments and archaeological evidences. *Journal of Archaeological Science* 40, 1636-1645, DOI: 10.1016/j.jas.2012.12.002, (2013).

173- Sanchi L, Ménot G, Bard E. An automated purification method for archaeal and bacterial tetraethers in soils and sediments. *Organic Geochemistry* 54, 83-90, DOI: 10.1016/j.orggeochem.2012.10.005, (2013).

172- Cartapanis O, Tachikawa K, Bard E. Latitudinal variations in intermediate depth ventilation and biological production over northeastern Pacific Oxygen Minimum Zones during the last glacial period. *Quaternary Science Reviews* 53, 24-38, DOI: 10.1016/j.quascirev.2012.08.009, (2012).

171- Felis T, Merkel U, Asami R, Deschamps P, Hathorne EC, Kölling M, Bard E, Cabioch G, Durand N, Prangue M, Schulz M, Cahyarini SY, Pfeiffer M. Pronounced interannual variability in tropical South Pacific temperatures during Heinrich stadial 1. *Nature Communications* 3 : 965, 1-7, + 17 p. suppl., DOI: 10.1038/ncomms1973, (2012).

170- Ménot G, Bard E. A precise search for drastic temperature shifts of the past 40,000 years in southeastern Europe. *Paleoceanography* 27, PA2210, 1-13, DOI:10.1029/2012PA002291, (2012).

169- Camoin GF, Seard C, Deschamps P, Webster JM, Abbey E, Braga JC, Iryu Y, Durand N, Bard E, Hamelin B, Yokoyama Y, Thomas AL, Henderson GM, Dussouillez P. Reef response to sea-level and environmental changes during the last deglaciation: Integrated Ocean Drilling Program Expedition 310, Tahiti Sea Level. *Geology* 40, 643-646, DOI:10.1130/G32057.1, (2012).

168- Shakun JD, Clark PU, He F, Liu Z, Otto-Bliesner B, Marcott SA, Mix AC, Schmittner A, Bard E. Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. *Nature* 484, 49-54, + 52 p. suppl., DOI: 10.1038/nature10915, (2012).

167- Wilhelm B, Arnaud F, Sabatier P, Crouzet C, Brisset E, Chaumillon E, Disnar JR, Guiter F, Malet E, Reyss JL, Tachikawa K, Bard E, Delannoy J-J. 1400yr of extreme precipitation patterns over the Mediterranean French Alps and possible forcing mechanisms. *Quaternary Research* 78, 1-12, DOI: 10.1016/j.yqres.2012.03.003, (2012).

166- Deschamps P, Durand N, Bard E, Hamelin B, Camoin G, Thomas AL, Henderson GM, Okuno J, Yokoyama Y. Ice sheet collapse and sea-level rise at the Bølling warming 14,600 yr ago. *Nature* 483, 559-564, + 35 p. suppl., DOI: 10.1038/nature10902, (2012).

165- Thomas AL, Fujitab K, Iryu Y, Bard E, Cabioch G, Camoin G, Cole JE, Deschamps P, Durand N, Hamelin B, Heindel K, Henderson GM, Masona AJ, Matsuda H, Ménabréaz L, Omori A, Quinn T, Sakai S, Sato T, Sugihara K, Takahashi Y, Thouveny N, Tudhope AW, Webster J, Westphal H, Yokoyama Y. Assessing uplift rates and paleo water depths for Tahiti reefs using U-Th chronology of altered corals. *Marine Geology* 295-298, 86-94, DOI:

10.1016/j.margeo.2011.12.006, (2012).

164- Schmidt GA, Jungclaus JH, Ammann CM, Bard E, Braconnot P, Crowley TJ, Delaygue G, Joos F, Krivova NA, Muscheler R, Otto-Bliesner BL, Pongratz J, Shindell DT, Solanki SK, Steinhilber F, Vieira LEA. Climate forcing reconstructions for use in PMIP simulations of the Last Millennium (v1.1). *Geoscientific Model Development* 5, 185-191, DOI: 10.5194/gmd-5-185-2012, (2012).

163- Tachikawa K, Cartapanis O, Vidal L, Beaufort L, Bard E. The precession phase of hydrological variability in the Western Pacific Warm Pool during the past 400 ka. *Quaternary Science Reviews* 30, 3716-3727, DOI:10.1016/j.quascirev.2011.09.016, (2011).

162- Baroni M, Bard E, Petit JR, Magand O, Bourlès D. Volcanic, solar activity, and atmospheric circulation influences on cosmogenic ^{10}Be fallout at Vostok and Concordia (Antarctica) over the last 60 years. *Geochimica et Cosmochimica Acta* 71, 7132-7145, DOI: doi:10.1016/j.gca.2011.09.002, (2011).

161- Cartapanis O, Tachikawa K, Bard E. North-Eastern Pacific oxygen minimum zone variability over the past 70 kyr: Impact of primary production and oceanic circulation. *Paleoceanography* 26, PA4208, 1-17, DOI:10.1029/2011PA002126, (2011).

160- Soulet G, Ménot G, Garreta V, Rostek F, Lericolais G, Zaragosi S, Bard E. Black Sea "Lake" reservoir age evolution since the Late Glacial hydrologic and climatic implications. *Earth and Planetary Science Letters* 308, 245-258, DOI: 10.1016/j.epsl.2011.06.002 (2011).

159- Schmidt GA, Jungclaus JH, Ammann CM, Bard E, Braconnot P, Crowley TJ, Delaygue G, Joos F, Krivova NA, Muscheler R, Otto-Bliesner BL, Pongratz J, Shindell DT, Solanki SK, Steinhilber F, Vieira LEA. Climate forcing reconstructions for use in PMIP simulations of the Last Millennium (v1.0). *Geoscientific Model Development* 4, 33-45, DOI: 10.5194/gmd-4-33-2011, (2011).

158- Soulet G, Ménot G, Lericolais G, Bard E. A revised calendar age for the last reconnection of the Black Sea to the global ocean. *Quaternary Science Reviews*, 30, 1019-1026, DOI: 10.1016/j.quascirev.2011.03.001, (2011).

157- Sepulcre S, Vidal L, Tachikawa K, Rostek F, Bard E. Sea-surface salinity variations in the Northern Caribbean Sea across the mid-Pleistocene transition. *Climate of the Past* 7, 75-90, DOI: 10.5194/cp-7-75-2011, (2011).

156- Seard C, Camoin G, Yokoyama Y, Matsuzaki H, Durand N, Bard E, Sepulcre S, Deschamps P. Microbialite development patterns in the last deglacial reefs from Tahiti (French Polynesia; IODP Expedition #310): implications on reef framework architecture. *Marine Geology* 279, 63-86 DOI: 10.1016/j.margeo.2010.10.013, (2011).

155- Stenni B, Buiron D, Frezzotti M, Albani S, Barbante C, Bard E, Barnola JM, Baroni M, Baumgartner M, Bonazza M, Capron E, Castellano E, Chappellaz J, Delmonte B, Falourd S, Genoni L, Iacumin P, Jouzel J, Kipfstuhl S, Landais A, Lemieux-Dudon B, Maggi V, Masson-Delmotte V, Mazzola C, Minster B, Montagnat M, Mulvaney R, Narcisi B, Oerter H, Parrenin F, Petit JR, Ritz C, Scarchilli C, Schilt A, Schüpbach S, Schwander J, Selmo E, Severi M, Stocker TF, Udisti U. Unified Antarctic and Greenland climate seesaw during the last deglaciation. *Nature*

Geoscience 4, 46-49 + 32 p. suppl., DOI: 10.1038/NGEO1026, (2011).

154- Delaygue G, Bard E. An Antarctic view of beryllium-10 and solar activity for the past millennium. *Climate Dynamics* 36, 2201-2218, DOI:10.1007/s00382-010-0795-1, (2011).

153- Leduc G, Vidal L, Tachikawa K, Bard E. Evidences for Glacial North Pacific Intermediate Water formation during the last glacial period. *Earth and Planetary Science Letters* 298, 217-228, DOI:10.1016/j.epsl.2010.08.002, (2010).

152- Legras B, Mestre O, Bard E, Yiou P. A critical look at solar-climate relationships from long temperature series. *Climate of the Past* 6, 745-758, DOI:10.5194/cp-6-745-2010, (2010).

151- Soulet G, Delaygue G, Vallet-Coulomb C, Böttcher ME, Sonzogni C, Lericolais G, Bard E. Glacial hydrologic conditions of the Black Sea reconstructed by means of geochemical pore water profiles. *Earth and Planetary Science Letters* 296, 57-66, DOI:10.1016/j.epsl.2010.04.045, (2010).

150- Yiou P, Bard E, Dandin P, Legras B, Naveau P, Rust HW, Terray L, Vrac M. Statistical issues about solar-climate relations. *Climate of the Past* 6, 565-573, DOI:10.5194/cp-6-565-2010, (2010).

149- Rincon-Martinez D, Lamy F, Contreras S, Leduc G, Bard E, Saukel C, Blanz T, Mackensen A, Tiedemann R. Wetter interglacials in Ecuador during the past 500 kyr and its relation to latitudinal shifts of the Equatorial Front in the eastern tropical Pacific. *Paleoceanography* 25, PA2210, 1-15, DOI:10.1029/2009PA001868, (2010).

148- Thevenon F, Williamson D, Bard E, Anselmetti FS, Beaufort L, Cachier H. Combining charcoal and elemental black carbon analysis in sedimentary archives: Implications for past fire regimes, the pyrogenic carbon cycle, and the human-climate interactions. *Global and Planetary Change* 72, 381-389, DOI:10.1016/j.gloplacha.2010.01.014, (2010).

147- Bard E, Hamelin B, Delanghe-Sabatier D. Deglacial melt water pulse 1B and Younger Dryas sea-levels revisited with new onshore boreholes at Tahiti. *Science* 327, 1235-1237 + 15 p. suppl., (2010).

146- Ménot G, Bard E. Geochemical evidence for a large methane release during the last deglaciation from Marmara Sea sediments. *Geochimica et Cosmochimica Acta* 74, 1537-1550, DOI : 10.1016/j.gca.2009.11.022, (2010).

145- Siddall M, Abe-Ouchi A, Andersen M, Antonioli F, Bamber J, Bard E, Clark J, Clark P, Deschamps P, Dutton A, Elliot M, Gallup C, Gomez N, Gregory J, Huybers P, Kawamura K, Kelly M, Lambeck K, Lowell T, Mitrovica J, Otto-Bliesner B, Richards D, Stanford J, Stirling C, Stocker T, Thomas A, Thompson B, Törnqvist T, Vazquez Riveiros N, Waelbroeck C, Yokoyama Y. The sea-level conundrum: case studies from palaeo-archives. *Journal of Quaternary Science* 25, 19-25, DOI: 10.1002/jqs.1270, (2010).

144- Vidal L, Ménot G, Joly C, Bruneton H, Rostek F, Cagatay N, Major C, Bard E. Marmara Sea hydrology over the last 23000 years : implications for the connection with the Black Sea and the sapropel deposition. *Paleoceanography* 25, PA1205, 1-16, DOI: 10.1029/2009PA001735, (2010).

143- Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, Buck CE, Burr GS, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Hajdas I, Heaton TJ, Hogg

AG, Hughen KA, Kaiser KF, Kromer B, McCormac FG, Manning SW, Reimer RW, Richards DA, Southon JR, Talamo S, Turney CSM, van der Plicht J, Weyhenmeyer CE. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal BP. *Radiocarbon* 51 (4), 1111–1150, (2009).

142- Sepulcre S, Tachikawa K, Vidal L, Thouveny N, Bard E. Preservation state of metastable magnesian calcite in periplatform sediments from the Walton Basin over the last million years. *Geochemistry Geophysics Geosystems (G-cubed)* 10, 1-15, DOI: 10.1029/2009GC002779, (2009).

141- Asami R, Felis T, Deschamps P, Hanawa K, Iryu Y, Bard E, Durand N, Murayama M. Evidence for tropical/subtropical South Pacific climate changes during the Younger Dryas and the Bølling–Allerød from geochemical records of fossil Tahiti corals. *Earth and Planetary Science Letters* 288, 96-107, (2009).

140- Böning P, Bard E. Millennial/centennial-scale thermocline ventilation changes in the Indian Ocean as reflected by aragonite preservation and geochemical variations in Arabian Sea sediments. *Geochimica et Cosmochimica Acta* 73, 6771-6788, (2009).

139- Leduc G, Vidal L, Cartapanis O, Bard E. Modes of Eastern Equatorial Pacific thermocline variability: implications for ENSO dynamics over the last glacial period. *Paleoceanography* 24, PA3204, 1-14, DOI : 10.1029/2008PA001701, (2009).

138- Cagatay N, Eris K, Ryan WBF, Sancar U, Polonia A, Akçer S, Biltekin D, Gasperini L, Görür N, Lericolais G, Bard E. Late Pleistocene-Holocene evolution of the northern shelf of the Sea of Marmara. *Marine Geology* 265, 87-100, (2009).

137- Bard E, Rickaby R. Migration of the Subtropical Front as a modulator of glacial climate. *Nature* 406, 380-383 + 10 p. suppl., (2009).

136- Naughton F, Sanchez Goni M-F, Kageyama M, Bard E, Duprat J, Cortijo E, Malaizé B, Joly C, Rostek F, Turon J-L. Wet to dry climatic trend in northwestern Iberia within Heinrich events. *Earth and Planetary Science Letters* 284, 329-342, (2009).

135- Saher MH, Rostek F, Jung SJA, Bard E, Schneider RR, Greaves M, Ganssen GM, Elderfield H, Kroon D. Western Arabian Sea SST in the penultimate and last interglacial: a comparison of Uk'37 and Mg/Ca palaeothermometry. *Paleoceanography* 24, PA2212, 1-12, DOI : 10.1029/2007PA001557, (2009).

134- Leduc G, Vidal L, Tachikawa K, Bard E. ITCZ rather than ENSO signature for abrupt climatic changes across the tropical Pacific? *Quaternary Research* 72, 123-131, (2009).

133- Tachikawa K, Vidal C, Sonzogni C, Bard E. Glacial/interglacial sea surface temperature changes in the Southwest Pacific ocean over the past 360 Kyears. *Quaternary Science Reviews* 28, 1160-1170, (2009).

132- Thomas AL, Henderson GM, Deschamps P, Yokoyama Y, Mason AJ, Bard E, Hamelin B, Durand N, Camoin G. Sea-level timing across the penultimate deglaciation: U/Th dating of corals from Tahiti. *Science* 324, 1186-1189, + 11 p. suppl., (2009).

131- Dutton A, Bard E, Antonioli F, Esat TM, Lambeck K, McCulloch MT. Phasing and amplitude of sea level and climate change during the penultimate interglacial. *Nature Geoscience* 2, 355-359,

+ 18 p. suppl., DOI :10.1038/NGEO470, (2009).

130- Usoskin IG, Horiuchi K, Solanki S, Kovaltsov GA, Bard E. On the common solar signal in different cosmogenic isotope data sets. *Journal of Geophysical Research* 114, 1-14, DOI:10.1029/2008JA013888, (2009).

129- Kölling M, Webster JM, Camoin G, Iryu Y, Bard E, Seard C. SEALEX – Internal reef chronology and virtual drill logs from a spreadsheet-based reef growth model. *Global and Planetary Change* 66, 149-159, DOI: 10.1016/j.gloplacha.2008.07.011, (2009).

128- Schouten S, Hopmans H, van der Meer J, Mets A, Bard E, Bianchi T, Diefendorf A, Escala M, Freeman KH, Huguet C, Ingalls A, Ménot G, Nederbragt AJ, Oba M, Pearson A, Pearson E, Rosell-Melé A, Schaeffer P, Smittenberg R, Talbot HM, Uchida M, van Moy B, Yamamoto M, Zhang Z, Sinninghe Damsté JS. An interlaboratory study of TEX86 and BIT analysis using high performance liquid chromatography/mass spectrometry. *Geochemistry Geophysics Geosystems (G-cubed) 10,* 1-13, DOI:10.1029/2008GC002221, (2009).

127- Sepulcre S, Durand N, Bard E. Mineralogical determination of reef and periplatform carbonates: calibration and implications for paleoceanography and radiochronology. *Global and Planetary Change* 66, 1-9, DOI: 10.1016/j.gloplacha.2008.07.008, (2009).

126- Otto-Bliesner B, Schneider R, Brady EC, Kucera M, Abe-Ouchi A, Bard E, Braconnot P, Crucifix M, Hewitt C, Kageyama M, Marti O, Paul A, Rosell-Mele A, Waelbroeck C, Weber SL, Weinelt M, Yu Y. A comparison of PMIP2 model simulations and the MARGO proxy reconstruction for tropical sea surface temperatures at last glacial maximum. *Climate Dynamics* 32, 799-815, DOI : 10.1007/s00382-008-0509-0, (2009).

125- Waelbroeck C, Paul A, Kucera M, Rosell-Melé A, Weinelt M, Schneider R, Mix AC, Abelmann A, Armand L, Bard E, Barker S, Barrows TT, Benway H, Cacho I, Chen M-T, Cortijo E, Crosta X, de Vernal A, Dokken T, Duprat J, Elderfield H, Eynaud F, Gersonde R, Hayes A, Henry M, Hillaire-Marcel C, Huang C-C, Jansen E, Juggins S, Kallel N, Kiefer T, Kienast M, Labeyrie L, Leclaire H, Londeix L, Mangin S, Matthiessen J, Marret F, Meland M, Morey AE, Mulitza S, Pflaumann U, Pisias NG, Radi T, Rochon A, Rohling EJ, Sbaffi L, Schäfer-Neth C, Solignac S, Spero H, Tachikawa K, Turon JL. Constraints on the magnitude and patterns of ocean cooling at the Last Glacial Maximum. *Nature Geoscience* 2, 127-132, + 138 p. suppl., DOI: 10.1038/NGEO411, (2009).

124- Eris KK, Ryan WBF, Cagatay MN, Lericolais G, Sancar U, Menot G, Bard E. Reply to Comment on « the timing and evolution of the post-glacial transgression across the Sea of Marmara shelf, south of Istanbul » by Hiscott et al., *Marine Geology* 254, 230-236, (2008).

123- Tachikawa K, Sépulcre S, Toyofuku T, Bard E. Assessing influence of diagenetic carbonate dissolution on planktonic foraminiferal Mg/Ca in the South-eastern Arabian Sea over the past 450 k years: Comparison between *Globigerinoides ruber* and *Globigerinoides sacculifer*. *Geochemistry Geophysics Geosystems (G-cubed)* 9 (4), Q04037, 1-16, DOI :10.1029/2007GC001904, (2008).

122- Bard E, Delaygue G. Comment on « Are there connections between the Earth's magnetic field and climate? » by Courtillot et al. (2007), *Earth and Planetary Science Letters* 265, 302-307, (2008).

121- Blanchet CL, Thouveny N, Vidal L, Leduc G, Tachikawa K, Bard E, Beaufort L. Terrigenous input response to glacial/interglacial climatic over southern Baja California: a rock magnetic approach. *Quaternary Science Reviews* 26, 3118-3133, (2007).

120- Pichevin L, Bard E, Martinez P, Billy I. Evidence of ventilation changes in the Arabian Sea during the Late Quaternary: implication for denitrification and nitrous oxide emission. *Global and Biogeochemical Cycles* 21, GB4008, 1-12, DOI :10.1029/2006GB002852, (2007).

119- Buck C, Bard E. A calendar chronology for mammoth and horse extinction in North America based on Bayesian radiocarbon calibration. *Quaternary Science Reviews* 26, 2031-2035, (2007).

118- Bard E, Raisbeck G, Yiou F, Jouzel J. Comment on « Solar activity during the last 1000 yr inferred from radionuclide records » by Muscheler et al. (2007). *Quaternary Science Reviews* 26, 2301-2308, (2007).

117- Eris KK, Ryan WBF, Cagatay MN, Sancar U, Lericolais G, Menot G, Bard E, The timing and evolution of the post-glacial transgression across the Sea of Marmara shelf, south of Istanbul, *Marine Geology* 243, 57-76, (2007).

116- Böning P, Bard E, Rose E. Towards direct micron-scale XRF elemental maps and quantitative profiles of wet marine sediments. *Geochemistry Geophysics Geosystems (G-cubed)* 8 (5), 1-14, DOI : 10.1029/2006GC001480, (2007).

115- de Garidel-Thoron T, Rosenthal Y, Beaufort L, Bard E, Sonzogni C, Mix A, A multiproxy assessment of the equatorial Pacific hydrography during the last 30 ky. *Paleoceanography* 22, PA3204, 1-18, DOI :10.1029/2006PA001269, (2007).

114- Leduc G, Vidal L, Tachikawa K, Rostek F, Sonzogni C, Beaufort L, Bard E. Moisture transport across Central America as a positive feedback on abrupt climatic changes. *Nature* 445, 908-911 + 25 p. suppl. (2007). (E. Bard co-corresponding author).

113- Rickaby REM, Bard E, Sonzogni C, Rostek F, Beaufort L, Barker S, Rees G, Schrag D. Coccolith chemistry reveals secular variations in the global ocean carbon cycle ? *Earth and Planetary Science Letters* 253, 83-95, (2007).

112- Stanford JD, Rohling EJ, Hunter, S, Roberts AP, Rasmussen SO, Bard E, McManus J, Fairbanks RG. Meltwater injections and deep circulation in the North Atlantic. *Paleoceanography* 21, PA4103, 1-9, DOI:10.1029/2006PA001340, (2006).

111- Ménot G, Bard E, Rostek F, Weijers JWH, Hopmans EC, Schouten S, Sinninghe Damsté JS. Early reactivation of European rivers during the last deglaciation. *Science* 313, 1623-1625 + 6 p. suppl. (2006). (E. Bard co-corresponding author).

110- Siddall M, Bard E, Rohling EJ, Hemleben C. Sea-level reversal during Termination II. *Geology* 34, 817-820 (2006).

109- Bard E, Frank M. Climate change and solar variability: what's new under the Sun. *Earth and Planetary Science Letters* 248, 1-14, (2006).

108- Reimer PJ, Baillie MGL, Bard E, Beck JW, Blackwell PG, Buck CE, Burr GS, Edwards RL, Friedrich M, Guilderson TP, Hogg AG, Hughen KA, Kromer B, McCormac G, Manning S, Reimer RW, Southon JR, Stuiver M, van der Plicht J, Weyhenmeyer CE. Comment on "Radiocarbon Calibration Curve Spanning 0 to 50,000 Years B.P. Based on Paired ^{230}Th/^{234}U/^{238}U and ^{14}C Dates on Pristine Corals" by R.G. Fairbanks et al. and "Extending The Radiocarbon Calibration Beyond 26,000 Years Before Present Using Fossil Corals" by T.-C. Chiu et al. *Quaternary Science Reviews* 25, 855-862, (2006).

107- Bard E, Rostek F, Ménot-Combes G. Chronologie des variations climatiques rapides pendant la dernière période glaciaire. *Comptes Rendus de l'Académie des Sciences (C.R. Palevol)* 5, 13-19, (2006).

106- Siddall M, Stocker TF, Blunier T, Spahni R, McManus J, Bard E. Using a maximum simplicity paleoclimate model to simulate millennial variability during the last four glacial periods. *Quaternary Science Reviews* 25, 3185-3197, (2006).

105- Silenzi S, Bard E, Montagna P, Antonioli F. Isotopic and elemental records in a non-tropical coral (*Cladocora caespitosa*): Discovery of a new high-resolution climate archive for the Mediterranean Sea. *Global and Planetary Change* 49, 94-120, (2005).

104- Bard E, Ménot-Combes G, Rostek F. Present status of radiocarbon calibration and comparison records based on polynesian corals and Iberian Margin sediments. *Radiocarbon* 46, 1189-1203, (2004).

103- van der Plicht J, Beck JW, Bard E, Baillie MGL, Blackwell PG, Buck CE, Friedrich M, Guilderson TP, Hughen KA, Kromer B, McCormac FG, Bronk Ramsey C, Reimer PJ, Reimer RW, Remmele S, Richards DA, Southon JR, Stuiver M, Weyhenmeyer CE. NOTCAL04 comparison-calibration ^{14}C records 26–50 cal kyr BP. *Radiocarbon* 46, 1225-1238, (2004).

102- Hughen KA, Baillie MGL, Bard E, Beck JW, Bertrand C, Blackwell PG, Buck CE, Burr G, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Kromer B, McCormac G, Manning S, Bronk Ramsey C, Reimer PJ, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J, Weyhenmeyer CE. MARINE04 marine radiocarbon age calibration 26-0 ka BP. *Radiocarbon* 46, 1059-1086, (2004).

101- Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand C, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Hog AG, Hughen KA, Kromer B, McCormac G, Manning S, Bronk Ramsey C, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J, Weyhenmeyer CE. INTCAL04 terrestrial radiocarbon age calibration. *Radiocarbon* 46, 1029-1058, (2004).

100- Bard E, Greenhouse effect and ice ages: historical perspective. *Comptes Rendus de l'Académie des Sciences (C.R. Geosciences)* 336, 603-638, (2004).

99- Thévenon F, Bard E, Williamson D, Beaufort L. Biomass burning records from the West Equatorial Pacific over the last 360 kyr: Methodological, climatic and anthropic implications. *Palaeogeography, Palaeoclimatology and Palaeoecology* 213, 83-99, (2004).

98- Paterne M, Ayliffe LK, Arnold M, Cabioch G, Tisnérat-Laborde N, Hatté C, Douville E, Bard E. Paired ^{14}C and $^{230}Th/U$ datings on surface corals from Marquesas and Vanuatu (sub-equatorial Pacific) in the 3000 to 15,000 cal yr range. *Radiocarbon* 46, 551-566, (2004).

97- Antonioli F, Bard E, Silenzi S, Potter E-K, Improta S. 215-kyr sea-level oscillations from marine and continental layers in Argentarola cave speleothems (Italy). *Global and Planetary Changes* 43, 57-78, (2004).

96- Rosenthal Y, Perron-Cashman S, Lear CH, Bard E, Barker S, Billups K, Bryan M, Delaney ML, deMenocal PB, Dwyer GS, Elderfield H, German CR, Greaves M, Lea DW, Marchitto Jr. TM, Pak DK, Ravelo AC, Paradis GL, Russell AD, Schneider R, Scheindrich K, Stott L, Tachikawa K, Tappa E, Thunell R, Wara M, Weldeab S, Wilson P. Inter-laboratory comparison study of Mg/Ca and Sr/Ca measurements in planktonic foraminifera for paleoceanographic research. *Geochemistry Geophysics Geosystems (G-cubed)* 5 (4), 1-29, DOI:10.1029/2003GC000650, (2004).

95- Bard E, Rostek F, Ménot-Combes G. Radiocarbon calibration beyond 20,000 B.P. by means of planktonic foraminifera of the Iberian Margin. *Quaternary Research* 61 (2), 204-214, (2004).

94- Rosell-Melé A, Bard E, Emeis KC, Grieger B, Hewitt C, Müller PJ, Schneider RR. Sea surface temperature glacial anomalies in the global ocean estimated from the alkenone UK37' index: comparison with GCMs. *Geophysical Research Letters* 31, L03208, 1-4, (2004).

93- Bard E, Rostek F, Ménot-Combes G. A better radiocarbon clock. *Science* 303, 178-179, (2004).

92- Bard E, Kromer B. Absolute and radiocarbon chronologies of the Younger Dryas cold period. *in* Widemann F, Taborin Y eds. Geophysical and archaeological chronologies for the Upper Palaeolithic, Bari Edipulgia, 375-379, (2003).

91- Schulte S, Bard E. Past changes of biologically mediated dissolution of calcite above the chemical lysocline documented in Indian Ocean sediments. *Quaternary Science Reviews* 22, 1757-1770, (2003).

90- Reimer PJ, Hughen KA, Guilderson TP, McCormac Baillie MGL, Bard E, Barratt P, Beck JW, Buck CE, Damon PE, Friedrich M, Kromer B, Bronk-Ramsey C, Reimer RW, Remmele S, Southon JR, Stuiver M, van der Plicht J. Preliminary report of the first workshop of the INTCAL04 radiocarbon calibration/comparison working group. *Radiocarbon* 44, 653-661, (2002).

89- Bard E. Climate shock: Abrupt changes over millennial time scales. *Physics Today* 55 (12), 32-38, (2002).

88- Delanghe D, Bard E, Hamelin B. New TIMS constraints on the uranium-238 and uranium-234 in seawaters from the main ocean basins and the Mediterranean Sea. *Marine Chemistry* 80, 79-93, (2002).

87- Bard E, Delaygue G, Rostek F, Antonioli F, Silenzi S, Schrag DP. Hydrological conditions over the western Mediterranean basin during the deposition of the cold sapropel 6 event. *Earth and Planetary Science Letters* 202, 481-494 (2002).

86- Pailler D, Bard E. High frequency paleoceanographic changes during the past 140,000 years recorded by the organic matter in sediments off the Iberian Margin. *Palaeogeography, Palaeoclimatology and Palaeoecology* 181, 431-452, (2002).

85- Sicre M-A, Bard E, Ezat U, Rostek F. Alkenones distributions in the North Atlantic and Nordic sea surface waters. *Geochemistry, Geophysics and Geosystems (G-cubed)* 3 (2), 2001GC000159, 1-13, DOI: 10.1029/2001GC000159 (2002).

84- Bard E, Antonioli F, Silenzi S. Sea-level during the penultimate interglacial period based on a submerged stalagmite from Argentarola Cave (Italy). *Earth and Planetary Science Letters* 196, 135-146, (2002).

83- Pailler D, Bard E, Rostek F, Zheng Y, Mortlock R, Van Geen A. Burial of redox-sensitive metals and organic matter in the equatorial Indian Ocean linked to precession. *Geochimica et Cosmochimica Acta* 66, 849-865, (2002).

82- Camoin G, Ebren P, Eisenhauer A, Bard E, Faure G. A 300,000 years coral reef record of sea level changes, Mururoa Atoll (French Polynesia). *Palaeogeography, Palaeoclimatology and Palaeoecology* 175, 325-341, (2001).

81- Rosell-Melé A, Bard E, Emeis K-C, Grimalt JO, Müller P, Schneider RR, Blanz T, Bouloubassi I, Epstein B, Fahl K, Fluegge A, Freeman K, Goni M, Güntner U, Hartz D, Hellebust S, Herbert T, Ikehara M, Ishiwatari R, Kawamura K, Kenig F, de Leeuw J, Lehman S, Mejanelle L, Ohkouchi N, Pancost RD, Pelejero C, Prahl F, Quinn J, Rontani J-F, Rostek F, Rullkötter J, Sachs J, Sawada K, Schulz-Bull D, Sikes E, Sonzogni C, Ternois Y, Versteegh G, Volkman J and Wakeham S. Precision of the current methods to measure the alkenone proxy UK37' and absolute abundance in sediments: results of an interlaboratory comparison study. *Geochemistry, Geophysics and Geosystems (G-cubed)* 2, 2000GC000141, 1-28, (2001).

80- Bard E. Extending the calibrated radiocarbon record. *Science* 292, 2443-2444, (2001).

79- Clark PU, Mix A, Bard E. Ice sheets and sea-level of the Last Glacial Maximum. *Eos Trans. of AGU* 82 (22), 241-246-247, (2001).

78- Bard E. Paleoceanographic implications of the difference in deep-sea sediment mixing between large and fine particles. *Paleoceanography* 16, 235-239, (2001).

77- Cardinal D, Hamelin B, Bard E, Pätzold J. Sr/Ca, U/Ca and $\delta^{18}O$ records in massive corals from Bermuda: Relationships with sea surface temperatures. *Chemical Geology* 176, 215-235, (2001).

76- Delaygue G, Bard E, Rollion C, Jouzel J, Stiévenard M, Duplessy J-C, Ganssen G. Oxygen isotope/salinity relationship in the northern Indian Ocean. *Journal of Geophysical Research* 106 (C3), 4565-4574, (2001).

75- Bard E. Comparison of alkenone estimates with other temperature proxies. *Geochemistry, Geophysics and Geosystems (G-cubed)* 2, 2000GC000050, 1-12, (2001).

74- Mix AC, Bard E, Schneider RR. Environmental Processes of the Ice age: Land, Oceans, Glaciers (EPILOG). *Quaternary Science Reviews* 20, 627-657, (2001).

73- Siani G, Paterne M, Arnold M, Bard E, Métivier B, Tisnerat N, Bassinot F. Radiocarbon reservoir ages in the Mediterranean sea and Black Sea. *Radiocarbon* 42, 271-280, (2000).

72- Mix AC, Bard E, Eglinton G, Keigwin LD, Ravelo AC, Rosenthal Y. Alkenones and multi-proxy strategies in paleoceanographic studies. *Geochemistry, Geophysics and Geosystems (G-cubed)* 1, 2000GC000056, 1-22, (2000).

71- Bard E, Rostek F, Turon J-L, Gendreau S. Hydrological impact of Heinrich events in the subtropical northeast Atlantic. *Science* 289, 1321-1324 + 2 p. suppl. (2000).

70- Delaygue G, Jouzel J, Masson V, Koster R, Bard E. Validity of the isotopic thermometer in central Antarctica: limited impact of glacial precipitation seasonality and moisture origin. *Geophysical Research Letters* 27 (17), 2677-2680, (2000).

69- Bard E, Raisbeck G, Yiou F, Jouzel J Solar irradiance during the last 1200 yr based on cosmogenic nuclides. *Tellus B* 52, 985-992, (2000).

68- Budziak D, Schneider R, Rostek F, Müller PJ, Bard E, Wefer G. Late Quaternary insolation forcing on total organic carbon and C37 alkenone variations in the Arabian Sea. *Paleoceanography* 15, 307-321, (2000).

67- Lambeck K, Bard E. Sea-level change along the French Mediterranean coast since the time of the Last Glacial Maximum. *Earth and Planetary Science Letters* 175, 202-222 (2000).

66- Cayre O, Bard E. The last deglaciation in the Eastern Arabian Sea: Planktonic foraminiferal and alkenone records. *Quaternary Research* 52, 337-342, (1999).

65- Schulte S, Rostek F, Bard E, Rullkötter J, Marchal O. Variations of oxygen-minimum and primary productivity recorded in sediments of the Arabian Sea. *Earth and Planetary Science Letters* 173, 205-221, (1999).

64- Bard E. Ice age temperatures and geochemistry. *Science* 284, 1133-1134, (1999).

63- Rosell-Melé A, Bard E, Emeis KC, Farrimond P, Grimalt J, Müller PJ, Schneider RR. Project takes a new look at past sea surface temperatures. *Eos Trans. of AGU* 79 (33) 393-394, (1998).

62- Duplessy J-C, Arnold M, Bard E, Cortijo E, Labeyrie L, Laj C, Lehman B, Mazaud A, Paterne M, Tisnerat N, Vidal L. Le carbone 14: progrès récents et limitations de la méthode de datation. *In* Causse C, Gasse F eds. Hydrogéologie et Géochimie Isotopique. Paris ORSTOM, 229-250, (1998).

61- Montaggioni L, Bard E. Continuous record of reef growth over the past 14 ky on the mid-Pacific island of Tahiti. Comment and Reply. *Geology* 26, 479-480, (1998).

60- Stuiver M, Reimer PJ, Bard E, Beck JW, Burr GS, Hughen KA, Kromer B, McCormac G, van der Plicht J, Spurk M. INTCAL98 radiocarbon age calibration, 24,000-0 cal BP. *Radiocarbon* 40, 1041-1083, (1998).

59- Bard E. Geochemical and geophysical implications of the radiocarbon calibration. *Geochimica et Cosmochimica Acta* 62, 2025-2038, (1998).

58- Bard E, Arnold M, Hamelin B, Tisnerat-Laborde N, Cabioch G. Radiocarbon calibration by means of mass spectrometric ^{230}Th/^{234}U and ^{14}C ages of corals. An updated data base including samples from Barbados, Mururoa and Tahiti. *Radiocarbon* 40, 1085-1092, (1998).

57- Sonzogni C, Bard E, Rostek F. Tropical sea surface temperature during the last glacial period: a view based on alkenones in Indian Ocean. *Quaternary Science Reviews* 17, 1185-1201, (1998).

56- Rostek F, Bard E, Beaufort L, Sonzogni C, Ganssen G. Sea surface temperature and productivity records for the past 240 kyr in the Arabian Sea. *Deep Sea Research II* 44, 1461-1480, (1997).

55- Bard E, Raisbeck G, Yiou F, Jouzel J Solar modulation of cosmogenic nuclide production over the last millennium: comparison between ^{14}C and ^{10}Be records. *Earth and Planetary Science Letters* 150, 453-462, (1997).

54- Bard E. Nuclide production by cosmic rays during the Last Ice Age. *Science* 277, 532-533, (1997)

53- Sonzogni C, Bard E, Rostek F, Dollfus D, Rosell-Melé A, Eglinton G. Temperature and salinity effects on alkenones ratios measured in sediments from the Indian Ocean. *Quaternary Research* 47, 344-355, (1997).

52- Montaggioni L, Cabioch G, Camoin G, Bard E, Ribaud-Laurenti A, Faure G, Déjardin P, Récy J. Continuous record of reef growth over the past 14 ky on the mid-Pacific island of Tahiti. *Geology* 25, 555-558, (1997).

51- Sonzogni C, Bard E, Rostek F, Lafont R, Rosell-Melé A, Eglinton G. Core-top calibration of the alkenone index versus sea surface temperature in the Indian Ocean. *Deep Sea Research II* 44, 1445-1460, (1997).

50- Bard E, Rostek F, Sonzogni C. Interhemispheric synchrony of the last deglaciation inferred from alkenone palaeothermometry. *Nature* 385, 707-710, (1997).

49- Bard E, Jouannic C, Hamelin B, Pirazzoli P, Arnold M, Faure G, Sumosusastro PA, Syaefudin. Pleistocene sea levels and tectonic uplift based on radiometric dating of coral terraces at Sumba Island, Indonesia. *Geophysical Research Letters* 23, 12, 1473-1476, (1996).

48- Bard E, Hamelin B, Arnold M, Montaggioni L, Cabioch G, Faure G, Rougerie F. Sea level record from Tahiti corals and the timing of deglacial meltwater discharge. *Nature* 382, 241-244, + 2 p. suppl. (1996).

47- Grönvold K, Oskarsson N, Johnsen SJ, Clausen HB, Hammer CU, Bond G, Bard E. Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land sediments. *Earth and Planetary Science Letters* 135, 149-155, (1995).

46- Bard E, Kromer B. The Younger Dryas: absolute and radiocarbon chronologies. *Proceedings of the Royal Dutch Academy of Science* 44, 161-167, (1995).

45- Goslar T, Arnold M, Bard E, Kuc T, Pazdur MF, Ralska-Jasiewiczowa M, Rozanski K, Tisnerat N, Walanus A , Wicik B, Wieckowski K. High concentration of atmospheric ^{14}C during the Younger Dryas cold episode. *Nature* 377, 414-417, (1995)

44- Austin WEN, Bard E, Hunt JB, Kroon D, Peacock JD. The ^{14}C age of the Icelandic Vedde Ash: implications for Younger Dryas marine reservoir age corrections. *Radiocarbon* 37, 53-62, (1995).

43- Rostek F, Ruhland G, Bassinot F, Beaufort L, Müller PJ, Bard E. Fluctuations of the Indian monsoon regime during the last 170,000 years: evidence from sea surface temperature, salinity and organic carbon records. in Global Precipitations and Climate Change. M. Desbois & F. Désalmand (eds). NATO ASI Serie I, 26, 27-51, (1994).

42- Bard E, Cornu S, Pätzold J. Paleotemperature of the last interglacial based on $\delta^{18}O$ of mollusks. *in* Duplessy JC & Spyridakis M (eds): Long Term Climatic Variations - Data and Modeling. Springer-Verlag. NATO ASI Serie I, vol 22 , 259-266, (1994).

41- Bard E, Arnold M, Mangerud M, Paterne M, Labeyrie L, Duprat J, Mélières MA, Sonstegaard E, Duplessy JC. The North Atlantic atmosphere-sea surface ^{14}C gradient during the Younger Dryas climatic event. *Earth and Planetary Science Letters* 126, 275-287, (1994).

40- Duplessy JC, Bard E, Labeyrie L, Duprat J, Moyes J. Oxygen isotope records and salinity changes in the Northeastern Atlantic during the last 18000 yrs. *Paleoceanography* 8, 341-350, (1993).

39- Bard E, Arnold M, Fairbanks RG, Hamelin B. $^{230}Th/^{234}U$ and ^{14}C ages obtained by mass spectrometry on corals. *Radiocarbon* 35, 191-199, (1993).

38- Cornu S, Pätzold J, Bard E, Meco J, Cuerda-Barcelo J. Paleotemperature of the last interglacial period based on $\delta^{18}O$ of *Strombus bubonius* from the western Mediterranean Sea. *Palaeogeography, Palaeoclimatology and Palaeoecology* 103, 1-20, (1993).

37- Rostek F, Ruhland G, Bassinot F, Müller PJ, Labeyrie L, Lancelot Y, Bard E. Reconstructing sea surface temperature and salinity using $\delta^{18}O$ and alkenone records. *Nature* 364, 319-321, (1993).

36- Bradley R, Bard E, Farqhar G, Joussaume S, Lautenschlager M, Molfino B, Raschke E, Shackleton N, Sirocko F, Stauffer B, White J. Evaluating strategies for reconstructing past global changes - what and where are the gaps. *In* Eddy JA, Oeschger H eds: Global Changes in the Perspective of the Past, J. Wiley Ltd, 103-120, (1993).

35- Goslar T, Kuc T, Ralska-Jasiewiczowa M, Rozanski K, Arnold M, Bard E, van Geel B, Pazdur M, Szeroczynska K, Wicik B, Wieckowski K, Walanus A. High-resolution lacustrine record of the Late glacial/Holocene transition in central Europe. *Quaternary Science Reviews* 12, 287-294, (1993).

34- Bard E, Stuiver M, Shackleton NJ. How accurate are our chronologies of the past ? *In* Eddy JA, Oeschger H eds: Global Changes in the Perspective of the Past, J. Wiley Ltd, 103-120, (1993).

33- Duplessy JC, Arnold M, Bard E, Labeyrie L, Duprat J, Moyes J. Glacial to interglacial changes in ocean circulation. *In* Taylor RE, Long A, Kra RS eds : Radiocarbon After Four Decades - An Interdisciplinary Perspective, Springer-Verlag, New-York, 62-74, (1992).

32- Goslar T, Kuc T, Pazdur M, Ralska-Jasiewiczowa M, Rozanski K, Szeroczynska K, Walanus A, Wicik B, Wieckowski K, Arnold M, Bard E. Possibilities of reconstruction of radiocarbon level changes during the Late Glacial by laminated sequence of the Gosciaz Lake. *Radiocarbon* 34, 826-832, (1992).

31- Bard E, Fairbanks RG, Hamelin B. How accurate are the U-Th ages obtained by mass spectrometry on coral terraces. *In* Kukla G & Went E eds: Start of a Glacial, NATO ASI serie I, vol. 3., Springer-Verlag, 15-21, (1992).

30- Bard E, Fairbanks RG, Arnold M, Hamelin B. $^{230}Th/^{234}U$ and ^{14}C ages obtained by mass spectrometry on corals from Barbados (West Indies), Isabela (Galapagos) and Mururoa (French Polynesia). *In* Bard E, Broecker WS eds: The Last Deglaciation: Absolute and Radiocarbon Chronologies, *NATO ASI series*, serie I, vol 2. Springer Verlag, 103-112, (1992).

29- Mazaud A, Laj C, Bard E, Arnold M, Tric E. A geomagnetic calibration of the radiocarbon time-scale. *In* Bard E & Broecker WS eds: The Last Deglaciation: Absolute and Radiocarbon Chronologies, NATO ASI series, serie I, vol 2. Springer Verlag, 163-169, (1992).

28- Raisbeck GM, Yiou F, Jouzel J, Petit JR, Barkov NI, Bard E. ^{10}Be deposition at Vostok, Antarctica, during the last 50,000 years and its relationship to possible cosmogenic production variations during this period. *In* Bard E & Broecker WS eds: The Last Deglaciation: Absolute and Radiocarbon Chronologies, NATO ASI series, I vol 2. Springer Verlag, 127-140, (1992).

27- Bard E, Fairbanks RG, Hamelin B, Zindler A, Hoang CT. Uranium-234 anomalies in corals older than 150,000 yr. *Geochimica et Cosmochimica Acta* 55, 2385-2390, (1991).

26- Mazaud A, Laj C, Bard E, Arnold M, Tric E. Geomagnetic field control of ^{14}C production over the last 80 ky: Implications for the radiocarbon time-scale. *Geophysical Research Letters* 18, 1885-1888, (1991).

25- Hamelin B, Bard E, Zindler A, Fairbanks RG. $^{234}U/^{238}U$ mass spectrometry of corals: How accurate is the U-Th age of the last interglacial period. *Earth and Planetary Science Letters* 106, 169-180, (1991).

24- Duplessy JC, Bard E, Arnold M, Shackleton NJ, Duprat J, Labeyrie LD. How fast did the ocean-atmosphere system run during the last deglaciation. *Earth and Planetary Science Letters* 103, 27-40, (1991).

23- Bard E, Arnold M, Duplessy JC. Reconciling the sea level record of the last deglaciation with the $\delta^{18}O$ spectra from deep sea cores. *Quaternary Proceedings* 1, 67-73, (1991).

22- Bard E, Hamelin B, Fairbanks RG. U/Th ages obtained by mass spectrometry in corals from Barbados : sea level during the past 130,000 years. *Nature* 346, 456-458, (1990).

21- Bard E, Hamelin B, Fairbanks RG, Zindler A, Arnold M., Mathieu G. U/Th and ^{14}C ages of corals from Barbados and their use for calibrating the ^{14}C timescale beyond 9000 years BP. *Nuclear Instruments and Methods B* 52, 461-468, (1990).

20- Bard E, Hamelin B, Fairbanks RG, Zindler A. Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals. *Nature* 345, 405-410, (1990).

19- Bard E, Labeyrie L, Pichon JJ, Labracherie M, Arnold M, Duprat J, Moyes J, Duplessy JC. The last deglaciation in the Southern and Northern Hemispheres: a comparison based on $\delta^{18}O$, sea surface temperature estimates and accelerator ^{14}C dating from deep sea sediments. *in* Bleil U. Thiede J. eds: Geological History of the Polar Oceans, NATO ASI series, serie C. Kluwer Academic, Dordrecht, 405-415, (1990).

18- Bard E, Fairbanks R, Arnold M, Duprat J, Moyes J, Duplessy JC. Sea-level estimates during the last deglaciation based on $\delta^{18}O$ and accelerator mass spectrometry ^{14}C-ages measured in *Globigerina bulloides*. *Quaternary Research* 31, 381-391, (1989).

17- Arnold M, Bard E, Maurice P, Valladas H, Duplessy JC. ^{14}C dating with the Gif-sur-Yvette Tandetron accelerator: status report and study of isotopic fractionation in the sputter ion source. *Radiocarbon* 31, 284-290, (1989).

16- Bard E, Arnold M, Toggweiler R, Maurice P, Duplessy JC. Bomb C-14 in the Indian Ocean measured by accelerator mass spectrometry. Oceanographic implications. *Radiocarbon* 31, 510-522, (1989).

15- Labracherie M, Labeyrie L, Duprat J, Bard E, Arnold M, Pichon JJ, Duplessy JC. The last deglaciation in the Southern Ocean. *Paleoceanography* 4, 629-638, (1989).

14- Bard E, Labeyrie L, Arnold M, Labracherie M, Pichon JJ, Duprat J, Duplessy JC. AMS-^{14}C ages measured in deep sea cores from the southern ocean: implications for sedimentation rates during isotope stage 2. *Quaternary Research* 31, 309-317, (1989).

13- Mazaud A, Laj C, Bard E. A phenomenological model for reversals of the geomagnetic field. *In* Lowes FJ *et al*. eds: Geomagnetism and Paleomagnetism, NATO ASI series, Kluwer Academic, Dordrecht, 205-214, (1989).

12- Duplessy JC, Arnold M, Bard E, Juillet-Leclerc A, Kallel N, Labeyrie L. AMS^{14}C study of transient events and of the ventilation rate of the Pacific intermediate water during the last deglaciation. *Radiocarbon* 31, 493-502, (1989).

11- Bard E. Correction of accelerator mass spectrometry ^{14}C ages measured in planktonic foraminifera: Paleoceanographic implications. *Paleoceanography* 3, 635-645, (1988).

10- Duplessy JC, Bard E, Arnold M, Maurice P. Determination of carbon-14 by accelerator mass spectrometry: oceanographic implications. *In* Guary JC, GueguenIat P, Pentreath RJ eds: Radionuclides: A Tool for Oceanography, Elsevier Sci. Pub. 64-73, (1988).

9- Bard E, Arnold M, Östlund HG, Maurice P, Monfray P, Duplessy JC. Penetration of bomb radiocarbon in the tropical Indian ocean by means of accelerator mass spectrometry. *Earth and Planetary Science Letters* 87, 379-389, (1988).

8- Bard E, Arnold M, Maurice P, Duprat J, Moyes J, Duplessy JC. Retreat velocity of the North-Atlantic polar front during the last deglaciation determined by ^{14}C accelerator mass spectrometry. *Nature* 328, 791-794, (1987).

7- Arnold M, Bard E, Maurice P, Duplessy JC. C-14 dating with the Gif sur Yvette Tandetron accelerator: status report. *Nuclear Instruments and Methods B* 29, 120-123, (1987).

6- Bard E, Arnold M, Duprat J, Moyes J, Duplessy JC. Reconstruction of the last deglaciation: deconvolved records of $\delta^{18}O$ profiles, micropaleontological variations and accelerator mass spectrometric ^{14}C dating. *Climate Dynamics* 1, 101-112, (1987).

5- Duplessy JC, Bard E, Arnold M, Maurice P. A.M.S. ^{14}C-chronology of the deglacial warming of the north Atlantic ocean. *Nuclear Instruments and Methods B* 29, 223-227, (1987).

4- Bard E, Arnold M, Maurice P, Duplessy JC. Bomb radiocarbon in the ocean by means of accelerator mass spectrometry: technical aspect. *Nuclear Instruments and Methods B* 29, 297-301, (1987).

3- Lapicque G, Livingston HD, Lambert CE, Bard E, Labeyrie LD. Interpretation of $^{239,240}Pu$ in Atlantic sediments with a non-steady state input model. *Deep Sea Research* 34, 1841-1850, (1987).

2- Bard E, Arnold M, Duprat J, Moyes J, Duplessy JC. Bioturbation effects on abrupt climatic changes recorded in deep sea sediments. Correlation between $\delta^{18}O$ profiles and accelerator ^{14}C dating. *in* Berger WH, Labeyrie LD eds: Abrupt Climatic Change. Evidence and Implications, NATO ASI series, Reidel Publishing Co. 263-278, (1987).

1- Duplessy JC, Arnold M, Maurice P, Bard E, Duprat J, Moyes J. Direct dating of the oxygen-isotope record of the last deglaciation by ^{14}C accelerator mass spectrometry. *Nature* 320 (6060), 350-352, (1986).

OCEAN AND CLIMATE EVOLUTION

Edouard Bard
Professor at the Collège de France,
Associate Director of CEREGE in Aix-en-Provence, France

A brief introduction on ocean and climate changes

The climate system comprises numerous compartments such as the atmosphere, the oceans, marine and continental ice, and even the Earth's crust. These various compartments exchange heat, mechanical energy and matter, in particular water and carbon dioxide. The complexity of the climatic system arises from the fact that all its compartments are undergoing perpetual change. The atmosphere, in particular, is driven by rapid and ceaseless movements that are studied by the meteorologist. The atmosphere is also coupled to the ocean that evolves over much longer periods, from times spans of a year for surface waters up to several centuries for the deep ocean. The continental ice sheets are evolving even more slowly with time reactions ranging from the century to several millennia. The climate system is also coupled to the biogeochemical cycles of carbon and water.

Figure 1: Ocean, atmosphere, biosphere (Maré, Loyalties Islands, New Caledonia) Photo: E. Bard

The global ocean is a huge carbon sink that is currently absorbing about a third of the carbon dioxide emissions associated with anthropogenic combustion (fossil fuels and deforestation). Since the beginning of the industrial period the ocean has been the main carbon reservoir to curb rising atmospheric CO_2, a trend which has inevitably been accompanied by a slow acidification of surface waters. The ocean also plays an important role in absorbing the bulk of the excess heat attributed to global warming, heat which is spreading from the surface into the great depths. Sea level has also increased over the past century, in particular through the input of fresh water from glaciers and continental ice sheets such as Greenland and Antarctica. Two-thirds of the current rise is due to melting ice and one third to thermal expansion caused by heat uptake.

To better evaluate and understand the evolution of today's environments, it is necessary to study natural variations, including the exchange of heat, water and carbon between ocean, atmosphere and ice, on long time scales. Because variations of the climate system involve mechanisms operating at very different time constants, it is crucial to have this long-term perspective in order to distinguish the effects of climatic disturbances according to their geological, astronomical and anthropogenic origins.

This type of study at the interface of climatology, oceanography and geology, has given rise to the field of paleoclimatology, and more specifically, to palaeoceanography which focuses on changes in the oceans on time scales ranging from centuries to millions of years. To document these changes more fully, to date them precisely, to understand and to model the mechanisms correctly are all important tasks within the framework of projects aimed at predicting the future evolution of the climate.

For this type of research, I have used techniques of analytical chemistry to determine the extent and the timing of climatic variations. Over the last three decades, new quantitative methods have enabled me to reconstruct past climates using varied archives such as oceanic sediments, lake sediments, corals, stalagmites and polar ice. My guiding principle has been the wish to study the same climatic phenomena, for example the glaciations, using complementary and often innovative geochemical techniques. Another characteristic of this research is the back-and-forth nature of the information gleaned from recent and older periods. In order to go back into the past, I have employed "time machines" - i.e. complex mass spectrometers with which I have been able to measure radioactive isotopes and thus date the climatic variations imprinted in the various archives.

In the following pages, I describe my main scientific results focusing first on the various roles of the global ocean as an enormous reservoir of carbon, heat and water, and then on the implications of cosmogenic isotopes to study the Earth and its environment.

The Ocean as a compartment of the carbon cycle, today and in the past:

Figure 2: Tandetron accelerator mass spectrometer (Gif-sur-Yvette)
Photo: Ph. Plailly CNRS

In the 1980s, I took an active part in the development of the accelerator mass spectrometry (AMS), which makes it possible to measure radiocarbon (^{14}C) directly on samples of very small size. This technique truly revolutionized the application of ^{14}C in the Earth sciences, particularly in chemical oceanography

With this approach, my team and I were able to quantify the penetration of ^{14}C of thermonuclear origin in the Indian Ocean. Indeed, large amounts of ^{14}C atoms were released directly into the atmosphere in the early 60s after the atomic bomb tests. We published the first AMS measurements of oceanic samples in 1987, the same year as two other international groups (Heidelberg-Zürich and Miami-Uppsala). This isotopic labeling by bomb ^{14}C allowed us to follow the fate of CO_2 of anthropogenic origin and to test mathematical models of general circulation in the oceans. These studies paved the way toward the inclusion of a sampling program dedicated to AMS in the World Ocean Circulation Experiment (WOCE) and subsequent programs.

By measuring the ^{14}C in various compartments of the carbon cycle and by using geochronometers that are independent of ^{14}C, it is also possible to use this isotope as a tracer of past variations in the carbon cycle. Basing my approach on this principle, I showed in 1988 that the $^{14}C/^{12}C$ ratio at the sea surface (so-called surface reservoir age) is sensitive to several physical phenomena such as the circulation of water masses, the extension of the sea ice, the speed of the wind, atmospheric pCO_2 etc. In this way, I demonstrated that this isotopic ratio can be used as a paleoceanographic tracer.

The first application of this new proxy was our study of the ocean-atmosphere exchanges during the Younger Dryas climatic event, which occurred between 13,000 and 11,500 years before present (yr B.P.). From ^{14}C measurements and a chronological marker provided by a layer of volcanic ash in both lake and oceanic sediments as well as in Greenland ice cores, we were able to show that the North Atlantic deep circulation system had

slowed down during this period of cooling. Since the publication of this study in 1994, many other authors from various institutions have used this new tracer, applying it to other periods and other ocean basins.
Another aspect of my research on the carbon cycle has been to investigate the climatic control on the marine biological productivity and in particular the importance of insolation cycles as linked to orbital variations. The principal objective of my team has been to study marine sediments in order to better understand the causes of long-term changes observed in the organic matter, carbonates and trace metals buried therein.
By means of molecular and isotopic markers, we evaluate the variations of the accumulation and preservation of organic carbon of marine and continental origins. Our work involves the use of geochemical markers (e.g. 15N/14N isotopic ratio, biomarkers such as the diploptene, diplopterol, lycopane and the tetraethers), and also ultra-high resolution elemental analyses by means of XRF scanning. The scientific outcomes concern, among others, the relationships between the Asian monsoon and the presence at intermediate water depth of an oxygen-depleted zone, leading to mid-depth acidification, denitrification and diffusion of nitrous oxide into the atmosphere. Other results deal with the terrigenous organic matter fluxes transported by European rivers during the last ice age and the thermal destabilization of methane hydrates during the last deglaciation.

Marine paleothermometry and Ocean-atmosphere heat exchange

In order to quantify oceanic paleotemperatures, we have developed and used several geochemical methods based on the analysis of organic molecules, trace metals and stable isotopes. My team and I have studied a large number of sediment cores taken at low latitudes in the three oceans. In 1997, we proposed a new evaluation of the glacial-related cooling within these zones of approximately 2 to 3°C, an average value subsequently which has been confirmed by other groups. Tropical cooling is a crucial parameter now used for testing climatic models and determining the so-called "climate sensitivity" parameter.

Another aspect of my research on paleotemperatures relates to rapid fluctuations on the scale of the century to the millennium. Here again, accelerator mass spectrometry (AMS) has proved essential for measuring precise ^{14}C ages and evaluating the rate of the climatic variations. Oceanic cores with high resolution have enabled us to find evidence for numerous warming and cooling episodes, in agreement with the atmospheric changes analyzed in the polar icecaps. Our initial work published in 1987 was actually the first to show the existence of abrupt changes of sea-surface temperature on the order of several °C per century, i.e. the same order of magnitude as the average warming predicted for the coming century.

For the North Atlantic Ocean, intense cooling episodes are clearly related to periods of iceberg release, called Heinrich events following the pioneering article published in 1988 by the German geologist of the same name. In 1987, we had already described the most recent Heinrich event centered around 16,500 years B.P. (before present). In that 1987 paper, I had gone so far as to propose an accurate explanation for the phenomenon, describing « a pulse like injection of a large volume of ice or meltwater into the Atlantic ».

Figure 3: Icebergs calving from an ice sheet (Ilulisat, Greenland) Photo: E. Bard

After this early contribution, I went on to study these rapid climatic changes in the tropical oceans, far from the main source of the phenomenon, the North Atlantic. With my team, we analyzed many sediment cores from the Atlantic, the Pacific and the Indian oceans, applying geochemical paleothermometers based on various molecules (alkenones or tetraethers) or trace elements (Mg, Sr, U) preserved in deep sea sediments or coral reefs.

At the same time, we compared the records of the Pacific, Indian and Atlantic, which allowed us to identify new amplifications of climate change. These different feedbacks involving the atmosphere and ocean are due to regional aspects such as the topography and the river systems of Central America, the flow of warm and salty water from the Indian to the Atlantic around the Cape of Good Hope, and to the thermal contrasts between the North Atlantic and the European continent. Modelers of the ocean and the atmosphere also study these feedbacks independently.

Our reconstructions of past variations of the oceans have since been complemented by many other records from polar ice, lacustrine sediments and cave stalagmites. The last deglaciation included several phases of intense cooling, of precipitation changes - notably at low latitudes and in the Asian monsoon area, of retreat and decay of glacial ice-sheets - as evidenced in sediments collected in river mouths, and of sea level change as recorded in corals from tropical islands (see more below). Various isotopic proxies of deep-sea ventilation have been used to identify the Meridional Overturning Circulation (MOC), indicating that ocean heat transport was involved in the observed climate fluctuations.

The various records documenting different climate parameters at many locations over the Earth are also used in meaningful comparisons with numerical model simulations performed in a transient mode. Collectively, these studies permit estimates of the phase relationships between the causes (insolation and the greenhouse effect) and the often-abrupt responses of the various components of the climate system, namely the atmosphere, oceans and ice sheets.

Sea level variations and water exchange between ice sheets and the ocean

Figure 4: Colony of coral in a fossil reef (Sumba, Indonesia) Photo: E. Bard

Figure 5: Fossil reef terraces (Maré, Loyalties Islands, New Caledonia) Photo: E. Bard

Starting in the late 80s, I became interested in sea-level changes over the last deglaciation, and I started to reconstruct them using oxygen isotopes measured in foraminifera. Recognizing the severe limitations of this method, I began using the then-new technique of mass spectrometry to measure uranium and thorium isotopes, in collaboration with colleagues at Columbia University in New York and later at Aix-Marseille University. This approach enabled us to date fossil corals and other coastal materials in order to study sea level changes

Concerning longer time scales, our sea level data have been compared with simulations carried out within the framework of the astronomical theory of paleoclimate. Measurements of exceptional stalagmites sampled in a cave submerged in the Mediterranean Sea enabled us to evaluate the duration of the sea level highstands during the penultimate interglacial periods in very good agreement with the orbital theory.
An additional result of our coral analyses is the systematic survey of the isotopic composition of uranium dis-

solved in seawater and its past variations through time, as linked to the global geochemical cycles. In 1991, we were first to propose that genuine changes of seawater uranium could be linked to long-term changes of chemical weathering. We also introduced the use of the isotopic composition of uranium as a sensitive tool to detect diagenesis in old fossil corals.

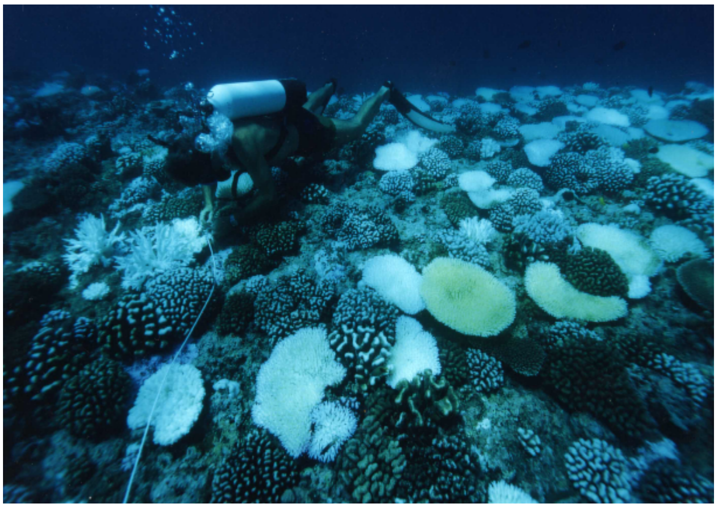

Figure 6: Modern barrier reef (Tahiti, French Polynesia)
Photo: J. Orempüller IRD

By using U-Th dating by mass spectrometry, I conducted detailed studies of the last deglaciation, using samples from coral reefs in the three oceans. The climatic transition between 21,000 years and 6,000 years B.P., led to a tremendous rise of approximately 130 meters in the world sea level. We reconstructed the precise chronology of this unsettled period by studying cores drilled from reef formations on the islands of Barbados in the Caribbean and Tahiti in French Polynesia. During that period, many other climatic and oceanographic parameters underwent first-order variations: global warming rose by 4 to 5 °C, there was about a 40 % increase in the atmospheric contents of greenhouse gases (carbon dioxide and methane), a reduction in wind speeds occurred, oceanic circulation was reorganized etc. One of our major results was the discovery of abrupt variations of the sea level (meltwater pulses MWP) at rates of several meters per century, which is even faster than the rise predicted for the coming century.

Figure 7: Integrated Ocean Drilling Program #310 (Tahiti, French Polynesia)
Photo: IODP

Our two sea level curves from Barbados and Tahiti now form the benchmark records that are used to model the geophysical response to the eustatic changes. In order to complement our studies on cores drilled onshore Tahiti, we succeeded in convincing the international Integrated Ocean Drilling Program's scientists, technicians and administrators to carry out offshore drillings. The coring operations undertaken during IODP Leg 310 in November 2005, recovered more than 400 m of post-glacial reef material, ranging from 122 to 40 m below modern sea level. The new U-Th and ^{14}C results allowed us to study the last two deglaciations, notably the timing and amplitude of MWP-1A and to identify the ice sheets which contributed to this major event.

Over the same periods, continental river systems underwent major changes due to the melting of continental ice caps, the emptying of proglacial lakes and because of geomorphological changes of river mouths. We measured geochemical indicators in sediments from the Bay of Biscay, in the Northeastern Atlantic, in order to study the activity of the then-Channel River (La Manche) which collected waters from a huge watershed across Western Europe during the last glacial period. Over the deglaciation, this gigantic river also drained meltwaters from the decaying Scandinavian and British ice sheets.

Around the same period in Central Europe, the Black Sea formed a large freshwater lake that drained the meltwater from mountain glaciers and the eastern part of the Fennoscandian ice cap via the Danube and the Dnieper. We were able to reconstruct the activity of rivers feeding the Black Sea and to reveal the source of sediment they carried during the last deglaciation. Our study demonstrates that the disappearance of an ice cap is not a simple linear phenomenon, due only to surface melting of the cap. We showed that the ice sheet collapsed during several century-long transient phases, shedding huge amounts of ice and spilling meltwater that drastically accelerated ice sheet decay and sea level rise.

Radiocarbon and other cosmogenic isotopes as tools in geochemistry, geophysics and astrophysics

Figure 8: Subfossil oak (Hanover, Germany)
Photo: E. Bard

Corals allow a direct comparison of ^{14}C dating with the U-Th disequilibrium method, the latter yielding ages that are both precise and accurate. As early as the 60s, specialists in ^{14}C dating were already highlighting chronological discrepancies when comparing with dendrochronology, i.e. when comparing the ^{14}C measurements of fossil wood samples whose exact age could be determined independently by counting the annual growth rings on the trees. Working from one tree trunk to another, it was possible to construct a calibration curve going back to 10,000 years B.P. However, these ^{14}C variations lacked entirely for the period between 10,000 and approximately 50,000 years B.P., the limit of application of this radiometric clock.

We filled this information gap by dating the corals from Barbados, Mururoa and Tahiti using ^{14}C and U-Th on the same samples. Our results, published in 1990 and after, demonstrate that the two geochronometers gradually diverge, with ^{14}C giving ages that become systematically too young by several thousands of years. We were able to correct several fundamental dates: the last glacial maximum (LGM) dates to 21,000 years B.P., and not 18,000 years B.P. as was formerly thought, and the duration of the Holocene period is about 11,500 years, rather than the earlier estimation of 10,000 years.

The radiocarbon calibration effort is crucial for scientific fields such as paleoclimatology and prehistoric archeology. Since the early 90s, I have been part of the international collaborative group preparing and updating the radiocarbon calibration curve as necessary to reflect advancing consensus. Our ^{14}C and U-Th results on corals constitute the backbone of this "official" database of the computerized calibration program which is distributed to all users of radiocarbon dating. Following specialized meetings and compilation works, we have released "official" curves every 4-5 years since 1993 (the last one is the so-called IntCal13 curve).

The interest of revealing the bias of radiocarbon age dating also lies in the physical interpretation of the phenomenon itself. The inherent inaccuracy of the ^{14}C method implies that the atmospheric content of this isotope fluctuates over the course of time. The high frequency variations in ^{14}C composition, on the order of centuries to a millennium, are related to changes in the production rate of ^{14}C in response to magnetic fluctuations of the Sun, which modulate the arrival on Earth of protons from the cosmic rays.

Our studies on this subject are based on the comparison of completely independent records: the ^{14}C as measured in tree-rings and beryllium 10 as analyzed in Antarctic ice cores (^{14}C and 10Be are two cosmogenic nuclides formed in the upper atmosphere). These series of analyses have also made it possible to accurately pick out the periods of weak solar activity already known to astronomers from the counting of sunspots and direct observations of aurora borealis. Moreover, we have been able to detect some even older solar minima.

Figure 9: ASTER accelerator mass spectrometer installed in 2007 in Aix-en-Provence. Photo: G. Aumaitre, CNRS

Our solar variability reconstruction over 1000 years has been used by climate modelers to study the link between the Sun and climate over the last millennium. We are now busy extending this work by comparing the past 10,000 years of the IntCal ^{14}C curve with 10Be data measured in new ice cores from Antarctica. 10Be measurements are performed by means of the 5MV AMS facility operating in Aix-en-Provence since 2007.

Over the longer term, ^{14}C ages generally underestimate true ages by several millennia, in particular over the last glaciation. Our data indicate that the atmospheric ^{14}C content reached an excess of 50-70 % between 30,000 and 40,000 years B.P. By carrying out numerical simulations, I showed that the dominant factor is the regular reduction in the terrestrial magnetic field, which is also recorded in volcanic and sedimentary rocks. Indeed, any reduction in this field allows penetration of more cosmic rays into the atmosphere, thus enhancing the formation of cosmogenic nuclides. The maximum of ^{14}C production corresponds to the Laschamp magnetic excursion, during which period the geomagnetic field weakened very sharply. These variations were correlated with those visible in the 10Be records of marine sediments and polar ice cores.

Figure 10: AixMICADAS accelerator mass spectrometer installed in 2014 in Aix-en-Provence. Photo: E. Bard

A second contribution of the shift between ^{14}C ages and true ages is linked to changes in the exchange rates and reservoir sizes of the global carbon cycle, which occurred during the last glacial period. I quantified this contribution by means of numerical box models representing the exchange between the atmosphere, biosphere and soils, and surface and deep oceans. The ^{14}C calibration provides key information about the origin of atmospheric CO_2 fluctuations accompanying, and partly responsible for, large climatic changes over the last 50,000 years.

Past environments as a useful perspective to communicate our science:

Although most of my studies concern naturally-occurring environmental changes that took place over long time periods in the past, useful parallels can be drawn with the evolution of modern climate. In fact, the phase relationships between forcings (such as greenhouse gases and solar input) and changes in regional and global temperatures are also at the heart of modern global climate change. As for deglaciations, the ocean can modulate warming regionally, thereby delaying, or even temporarily masking, long-term changes. The study of past sea level changes also provides a useful perspective on the future evolution of continental ice sheets such as Greenland and Antarctica, notably the western part of Antarctica, whose base is located below present sea level and may be sensitive to future climate change.

Fluctuations over the last century have been smaller in magnitude than those of the last deglaciation. Fortunately for us, there has been no recent collapse of gigantic ice masses such as the Laurentian and Fennoscandian ice sheets leading to changes of the ocean circulation. However, most climate models predict a reduction of the Meridional Overturning Circulation during the 21st century. Even if this change exerts only a minor influence on the projected magnitude of global warming, models indicate that such a slowdown in ocean circulation change would, in general, be sufficient to reduce the simulated warming over the North Atlantic with a resulting impact on adjacent continents, including Europe.

The relevance of this type of academic research for the future of our society also highlights the responsibility borne by scientists working on the evolution of ocean and climate. Our knowledge on this subject is still limited by numerous sources of uncertainty and by insufficient temporal and spatial coverage. The enormity of the task at hand requires that researchers from the world's leading institutions collaborate on these issues. Another reason for collaboration is that all developed countries are contributing to fossil fuel combustion and we are all breathing the same air. This places additional responsibility on climate scientists who must communicate with colleagues from other fields, inform politicians and educate today's youth and the general public.

Figure 11: Collège de France & CEREGE (Aix-en-Provence) Photo: E. Bard

I thus felt extremely honored and pleased to receive the 2013 Werner Petersen Award. I enjoyed the week I spent in Kiel, lecturing and discussing with students and fellow scientists from the GEOMAR Helmholtz Center for Ocean Research and the Christian Albrecht University. This opportunity strengthened my links with colleagues from Kiel and reinforced my ambition to collaborate with them on projects focused on climate and ocean sciences using isotopic geochemistry. This distinction also incited me to propose combining our strengths in order to improve the university teaching on these subjects at the European scale.

Selected publications on the four main topics of research

Topic #1 : The ocean as a compartment of the carbon cycle, today and in the past

Bard E, Arnold M, Maurice P, Duplessy JC. Bomb radiocarbon in the ocean by means of accelerator mass spectrometry: technical aspect. ***Nuclear Instruments and Methods*** *B* 29, 297-301 (1987).

Bard E, Arnold M, Östlund HG, Maurice P, Monfray P, Duplessy JC. Penetration of bomb radiocarbon in the tropical Indian ocean by means of accelerator mass spectrometry. ***Earth and Planetary Science Letters*** 87, 379-389 (1988).

Bard E. Correction of accelerator mass spectrometry ^{14}C ages measured in planktonic foraminifera: Paleoceanographic implications. ***Paleoceanography*** 3, 635-645 (1988).

Bard E, Arnold M, Toggweiler R, Maurice P, Duplessy JC. Bomb ^{14}C in the Indian Ocean measured by accelerator mass spectrometry. Oceanographic implications. ***Radiocarbon*** 31, 510-522 (1989).

Bard E, Arnold M, Mangerud M, Paterne M, Labeyrie L, Duprat J, Mélières MA, Sonstegaard E, Duplessy JC. The North Atlantic atmosphere-sea surface ^{14}C gradient during the Younger Dryas climatic event. ***Earth and Planetary Science Letters*** 126, 275-287 (1994).

Topic #2 : Marine paleothermometry and ocean-atmosphere heat exchange

Bard E, Arnold M, Maurice P, Duprat J, Moyes J, Duplessy JC. Retreat velocity of the North-Atlantic polar front during the last deglaciation determined by ^{14}C accelerator mass spectrometry. ***Nature*** 328, 791-794 (1987).

Rostek F, Ruhland G, Bassinot F, Müller PJ, Labeyrie L, Lancelot Y, Bard E. Reconstructing sea surface temperature and salinity using δ^{18}O and alkenone records. ***Nature*** 364, 319-321 (1993).

Bard E, Rostek F, Sonzogni C. Interhemispheric synchrony of the last deglaciation inferred from alkenone palaeothermometry. ***Nature*** 385, 707-710 (1997).

Bard E, Rostek F, Turon J-L, Gendreau S. Hydrological impact of Heinrich events in the subtropical northeast Atlantic. ***Science*** 289, 1321-1324 (2000).

Leduc G, Vidal L, Tachikawa K, Rostek F, Sonzogni C, Beaufort L, Bard E. Moisture transport across Central America as a positive feedback on abrupt climatic changes. ***Nature*** 445, 908-911 + 25 p. suppl. (2007).

Bard E, Rickaby R. Migration of the Subtropical Front as a modulator of glacial climate. ***Nature*** 406, 380-383 + 10 p. suppl. (2009).

Shakun JD, Clark PU, He F, Liu Z, Otto-Bliesner B, Marcott SA, Mix AC, Schmittner A, Bard E. Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. ***Nature*** 484, 49-54, + 52 p. suppl. (2012).

Sanchez-Goni MF, Bard E, Landais A, Rossignol L, d'Errico F. Air–sea temperature decoupling in western Europe during the last interglacial–glacial transition. ***Nature Geoscience*** 6, 837-841, + 8 p. suppl. (2013).

Topic #3 : Sea level variations and water exchange between ice sheets and the ocean

Bard E, Fairbanks R, Arnold M, Duprat J, Moyes J, Duplessy JC. Sea-level estimates during the last deglaciation based on δ^{18}O and accelerator mass spectrometry ^{14}C-ages measured in *Globigerina bulloides*. ***Quaternary Research*** 31, 381-391 (1989).

Bard E, Hamelin B, Fairbanks RG. U/Th ages obtained by mass spectrometry in corals from Barbados. Sea level during the past 130,000 years. ***Nature*** 346, 456-458 (1990).

Bard E, Fairbanks RG, Hamelin B, Zindler A, Hoang CT. Uranium-234 anomalies in corals older than 150,000 yr. ***Geochimica et Cosmochimica Acta*** 55, 2385-2390 (1991).

Bard E, Jouannic C, Hamelin B, Pirazzoli P, Arnold M, Faure G, Sumosusastro PA, Syaefudin. Pleistocene sea levels and tectonic uplift based on radiometric dating of coral terraces at Sumba Island, Indonesia. ***Geophysical Research Letters*** 23, 12, 1473-1476 (1996).

Bard E, Hamelin B, Arnold M, Montaggioni L, Cabioch G, Faure G, Rougerie F. Deglacial sea level record from Tahiti corals and the timing of meltwater discharge. ***Nature*** 382, 241-244 (1996).

Lambeck K, Bard E. Sea-level change along the French Mediterranean coast since the time of the Last Glacial Maximum. ***Earth and Planetary Science Letters*** 175, 202-222 (2000).

Bard E, Antonioli F, Silenzi S. Sea-level during the penultimate interglacial period based on a submerged stalagmite from Argentarola Cave (Italy). ***Earth and Planetary Science Letters*** 196, 135-146 (2002).

Ménot G, Bard E, Rostek F, Weijers JWH, Hopmans EC, Schouten S, Sinninghe Damsté JS. Early reactivation of European rivers during the last deglaciation. ***Science*** 313, 1623-1625 + 6 p. suppl. (2006).

Dutton A, Bard E, Antonioli F, Esat TM, Lambeck K, McCulloch MT. Phasing and amplitude of sea level and climate change during the penultimate interglacial. ***Nature Geoscience*** 2, 355-359, + 18 p. suppl. (2009).

Thomas AL, Henderson GM, Deschamps P, Yokoyama Y, Mason AJ, Bard E, Hamelin B, Durand N, Camoin G. Sea-level timing across the penultimate deglaciation: U/Th dating of corals from Tahiti. ***Science*** 324, 1186-1189 (2009).

Bard E, Hamelin B, Delanghe-Sabatier D. Deglacial melt water pulse 1B and Younger Dryas sea-levels revisited with new onshore boreholes at Tahiti. ***Science*** 327, 1235-1237 + 15 p. suppl. (2010)

Deschamps P, Durand N, Bard E, Hamelin B, Camoin G, Thomas AL, Henderson GM, Okuno J, Yokoyama Y. Ice sheet collapse and sea-level rise at the Bølling warming 14,600 yr ago. ***Nature*** 483, 559-564, + 35 p. suppl. (2012).

Soulet G, Ménot G, Bayon G, Rostek F, Ponzevera, Toucanne S, Lericolais G, Bard E. Abrupt drainage cycles of the Fennoscandian Ice sheet. ***Proceedings of the National Academy of Science*** 110 (17), 6682-6687, + 4 p. suppl. & 4 Tables (2013).

<u>Topic #4 : Radiocarbon and other cosmogenic isotopes as tools in geochemistry, geophysics and astrophysics</u>

Bard E, Hamelin B, Fairbanks RG, Zindler A. Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals. ***Nature*** 345, 405-410 (1990).

Bard E, Raisbeck G, Yiou F, Jouzel J Solar modulation of cosmogenic nuclide production over the last millennium: comparison between ^{14}C and ^{10}Be records. ***Earth and Planetary Science Letters*** 150, 453-462 (1997).

Bard E. Geochemical and geophysical implications of the radiocarbon calibration. ***Geochimica et Cosmochimica Acta*** 62, 2025-2038 (1998).

Bard E, Raisbeck G, Yiou F, Jouzel J Solar irradiance during the last 1200 yr based on cosmogenic nuclides. ***Tellus B*** 52, 985-992 (2000).

Bard E, Frank M. Climate change and solar variability: what's new under the Sun. ***Earth and Planetary Science Letters*** 248, 1-14 (2006).

Delaygue G, Bard E. An Antarctic view of beryllium-10 and solar activity for the past millennium. ***Climate Dynamics*** 36, 2201-2218 (2011).

Baroni M, Bard E, Petit JR, Magand O, Bourlès D. Volcanic, solar activity, and atmospheric circulation influences on cosmogenic ^{10}Be fallout at Vostok and Concordia (Antarctica) over the last 60 years. ***Geochimica et Cosmochimica Acta*** 71, 7132-7145 (2011).

Köhler P, Knorr G, Bard E. Permafrost thawing as source of abrupt carbon release at the onset of the Bølling/Allerød. ***Nature Communications*** 5, 5520, 1-10, + 22 p. suppl., DOI: 10.1038/ncomms6520 (2014).