EGU European Geosciences Union
GIFT – Geosciences Information For Teachers

GIFT WORKSHOP 2017

Atmosphere, Oceans and Earth's Magnetism

Cape Town, South Africa, 30 August-1 September 2017

ASSAf ACADEMY OF SCIENCE OF SOUTH AFRICA
IAPSO-IAMAS-IAGA 27 August – 1 September 2017 Cape Town, South Africa
EGU
iziko museums
University of Cape Town · iYunivesithi yaseKapa · Universiteit van Kaapstad

Welcome!

Dear Teachers,

Welcome to the Cape Town GIFT Workshop for Teachers sponsored by the European Geosciences Union. This is the second GIFT Workshop to be held in Cape Town, the 4th in Africa and the 25th worldwide. It unites around 60 teachers mostly from South Africa but also from Nigeria and Namibia.

It is organized on the occasion of the IAMAS-IAPSO-IAGA Joint Conference in Cape Town. These three host associations are all members of the International Union of Geodesy and Geophysics (IUGG) which, in turn, is one of the Unions of the International Council for Science (ICSU).

IAPSO - the International Association for the Physical Sciences of the Oceans - promotes the study of the physical sciences of the oceans and the interactions taking place at the sea floor, coastal, and atmospheric boundaries.

IAMAS - the International Association of Meteorology and Atmospheric Sciences - promotes research in all atmospheric sciences, especially programmes requiring international cooperation.

IAGA - the International Association of Geomagnetism and Aeronomy welcomes scientists to join in research of magnetism and Aeronomy of the Earth.

The Workshop is organized over three days, two at the CTICC and the third at the Slave Lodge of the Iziko Museum. Each day we'll explore some of the central themes of the three sponsoring organizations, starting with the Ocean.

First, after her welcoming address, Isabelle Ansorge, from the University of Cape Town, will take all of us with her on one of her oceanographic cruises. Then Tamaryn (Tammy) Morris, also from the University of Cape Town, will describe how Africa is entirely surrounded by Oceans and their currents.

Then, Sabrina Speich, from the Laboratoire de Méteorologie Dynamique, Ecole Normale Supérieure in Paris, will present the role of the Ocean as the key element of the global climate system.

Sabrina will be followed by André Berger and Qiushen Yin, of the Université Catholique de Louvain in Belgium. They will tell us how the knowledge of the climate in the past may help us to predict what the future has in store for us!

A study of how the climate has changed in the past, based on continental evidence rather than oceanic studies, will be presented by Thalassa Matthews from the Iziko Museum of South Africa.

As part of the oceanographic aspects of the Workshop, we will have the projection of a video on the actual state of the Ocean today "Ocean: the mystery of the missing plastic" directed by Vincent Pérazio, produced by Via Decouvertes Films & Arte France and distributed by Java Films, shedding some light on this huge worldwide environmental problem. As all the rivers flow to the Ocean, this professional video will be followed by an amateur video prepared by Kimberly (Kim) Pratt, a teacher at an elementary school in California, who will tell us how we can contribute to solving this problem on a personal basis.

Time permitting, we'll also show a video on an oceanographic cruise in the South China Sea, on board the French vessel "Marion Dufresne" prepared by Ana Sanchez Morante, a high school teacher from the neighbourhood of Madrid, Spain, and Carlo Laj of the EGU Committee on Education.

Edgar Bering, of the University of Houston in the USA, will take us up in the air by showing us how he uses balloons to introduce students to research in the upper atmosphere.

We will finally turn to the "magnetic" Earth, with Nicolas Gillet, of the University of Grenoble, in France, who will introduce us to the magnetic field of the Earth, and will be followed by Eduard Petrovski, from the Institute of Geophysics of the Czech Academy of Sciences in Prague, who will discuss the importance of the geomagnetic field for life on Earth. Then Angelo De Santis, from the Istituto Nazionale di Geofisica e Vulcanologia, in Roma, Italy, will show how the rapid growth of the South Atlantic Geomagnetic Anomaly (SAA) may indicate that the Earth's magnetic field is in the process of flipping its polarity. Finally, Carlo Laj and Catherine Kissel, respectively from the Ecole Normale Supérieure in Paris and from the Committee on Education of EGU, and the Laboratoire des Sciences du Climat et de l'Environnement, in Gif-sur-Yvette, will discuss this same argument, but basing their conclusions on the analysis of past history of the field.

As in all previous GIFT Workshops, the Cape Town workshop will include some hands-on activities, this time by Chris King, a specialist in classroom experiments and science education at Keele University in the UK and a member of the Committee on Education of EGU, and by Nicolas Gillet. Both Chris and Nicolas will use simple, inexpensive experiments which you will be able to show to your kids and have them participate.

We would like to continue to offer teachers the opportunity to attend GIFT and similar workshops in the future, but this depends upon us being able to show our sponsors that teachers have used what they have learnt at the GIFT workshops in their daily teaching, or as inspiration for new ways to teach science in their schools.

Therefore, **we ask you**:

1. To fill out the electronic evaluation form as soon as possible and send it back to us.
2. To make presentations of your experiences at GIFT to one or more groups of your teaching colleagues soon after you return.
3. To send us reports and photographs about how you have used the GIFT information in your classrooms.

We also encourage you to write reports on the GIFT workshop in publications specifically intended for geoscience teachers.

Information on past and future GIFT workshops is available on the EGU homepage (http://www.egu.eu/education/gift/workshops/). At this link it is possible to download brochures (.pdf) of the workshops and presentations given at the GIFT workshops for the past 13 years. Since 2009, web-TV presentations have also been included, which may be freely used in your classrooms.

We hope that you will all participate in the GIFT dinner on Thursday night and that you will greatly enjoy the whole GIFT Workshop experience in Cape Town!

The Organizing Committee
of the Cape Town GIFT Workshop

Organizing Committee

Carlo Laj

European Geosciences Union, Committee on Education, École Normale Supérieure, Paris, France

Chris King

Emeritus Professor Keele University, European Geosciences Union, Committee on Education, Keele, UK

Wendy Taylor

Honorary Research Associate, Dept. of Geological Sciences, University of Cape Town, Cape Town, South Africa

Friedrich Barnikel

European Geosciences Union, Committee on Education, Educational Coordinator for Geography, City of Munich, Germany

Daksha Naran

Education Manager, Natural History, Iziko South African Museum, Cape Town, South Africa

Andrew Petersen

Education Specialist, Schools Development Unit, University of Cape Town, Cape Town, South Africa

Thalassa Matthews

Curator, Quaternary Palaeontology Iziko South African Museum Cape Town, South Africa

Acknowledgements

The GIFT 2017 Workshop in Cape Town has been organized by the Committee on Education of the European Geosciences Union for the IAMAS-IAPSO-IAGA Joint Conference. EGU has supported the major share of the expenses, but the workshop has also benefited from the generous help of:

European Space Agency

Italian National Institute of Geophysics and Volcanology

IAPSO-IAMAS-IAGA

William S. Goree Award

Westermann Publishing House

And we thank all the speakers who have contributed to this educational workshop and their institutions!

European Geosciences Union
Geosciences Information for Teachers
Cape Town, 30 August – 1st September 2017-06-28

Oceans, Atmosphere and Earth Magnetism

Wednesday August 30, 2017 ROOM 1.64

08:30 – 08:40	WELCOME! Isabelle Ansorge & Carlo Laj
08:40 – 08:50	Practical Information for the 2017 GIFT Workshop The Organizing Committee
08:50 – 09:25	SEAmester – South Africa's Class Afloat Isabelle Ansorge
09:25 – 10:00	Bounded by the Oceans Tamaryn Morris
10:00 – 10:30	**Coffee Break**
10:30 – 11:15	The Ocean: a key component of the Global climate system Sabrina Speich
11:15 – 12:00	Using fossil micromammals and frogs for palaeoclimatic reconstruction Thalassa Matthews
12:00 – 13:30 Lunch Break	
13:30 – 14:15	Past Climate, a key to the future André Berger & Qiuzhen Yin
14:15 – 15:00	How can we best teach these ideas in the classroom? – led by EGU Committee members
15:00 – 15:30	**Coffee Break**
15:30 – 16:00	Fifteen years of Educational Activities at the European Geosciences Union (EGU) Carlo Laj
16:00 – 16:15	Pitfalls and drawbacks of engaging junior faculty in outreach activities Edgar Bering

16:15 – 16:30	Real-time geomagnetic data from a Rasberry Pi magnetometer network in the UK William Brown
16:30 – 16:45	Sparkling Geomagnetic Field: Geomagnetic observations with schools in Austria Rachel Bailey
16:45 – 17:00	A Brief History of the American Geophysical Union Space Physics and Aeronomy Section Education and Public Outreach Committee Edgar Bering

End of the day

Thursday August 31, 2017 ROOM: Terrace

10:30 – 11:15	Teaching Students How to Research the Upper Atmosphere Using High Altitude Balloons Edgar Bering
11:15 – 12:00	The geomagnetic field: behavior and origin Nicolas Gillet

12:00 - 13:30 Lunch Break

13:30 – 14:15	Importance of geomagnetic field for the life on Earth Eduard Petrovsky
14:15 – 15:00	The South Atlantic Magnetic Anomaly: a magnetic window from the Earth's core to space Angelo De Santis
15:00 – 15:30	**Coffee Break**
15:30 – 16:00	The original experiment of K. F. Gauss Nicolas Gillet
16:00 – 17:00	Classroom modelling activities to teach about the Earth and its magnetism Chris King

End of the day

Friday September 1, 2017 — Slave Lodge Iziko Museum

09:00 – 09:45	Is the Earth's magnetic field heading for a flip? Hints from the past Carlo Laj & Catherine Kissel
09:45 – 10:45	Oceans: The Mystery of the Missing Plastic Video directed by Vincent Pérazio, produced by Via Découvertes Films & Arte France, and distributed by Java Films.
10:45 – 11:15	**Coffee Break** and Alvarado Elementary School: B-Wet Video by Kim Pratt
11:10 – 12:00	How can we best teach these ideas in the classroom? – led by EGU committee members
12:00 – 13:30	**Buffet Lunch** and visit to the Iziko Museum Slave Lodge
13:30 – 14:30	Using demonstrations of the Earth, atmosphere and oceans to teach thinking and investigation skills Chris King
14:30 – 15:30	Visit to the Gardens and 'Earth science out of doors'
15:30 – 16:30	The GIFT workshop "Bring and Share"
16:30 – 17:00	Final considerations

End of the 2017 Cape Town GIFT Workshop!

Speakers

Isabelle **ANSORGE**

Professor

Department of Oceanography, University of Cape Town, RSA

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(Isabelle has a blue hat!)

Prof Isabelle Ansorge is the Head of the Oceanography Department at the University of Cape Town, South Africa. Isabelle's research interests focus on the impact changes in the Antarctic Circumpolar Current in the Southern Ocean have on Subantarctic Islands and the impact on their ecosystem functioning. She has been involved as the South African co-ordinator for the highly prestigious and privately funded Antarctic Circumpolar Expedition (ACE). In addition, Isabelle is responsible for the hands-on sea going training of all postgraduate students at the University of Cape Town and heads up the highly successful "SEAmester" Class Afloat programme, which enables students from all South African universities and technikons to gain experience working at sea. Isabelle is also the Principle Investigator of the SAMOC-SA (South Atlantic Meridional Overturning Circulation) programme and has a large cohort of postgraduate students and postdocs working on the ocean variability around South Africa. Finally, Isabelle is the Vice President of the International Association for Physical Oceanography (IAPSO) and an Executive Bureau member on the International Union of Geodesy and Geophysics (IUGG).

EDUCATION

1997-2000

University of Cape Town, South Africa. : PhD. in Physical Oceanography.

Dissertation: The hydrography and dynamics of the general ocean environment of the Prince Edward Islands (Southern Ocean).

1993-1996

University of Cape Town, South Africa. : MSc. in Physical Oceanography.

Dissertation: The structure and transport of the Agulhas Return Current.

1989-1992

University of Plymouth, United Kingdom. : BSc. Honours (2.1) in Ocean Science

CAREER

January 2016	:	Associate Professor and Head of Oceanography, UCT
January 2010	:	Senior Lecturer – Oceanography Department, UCT
January 2006 - 2009	:	Lecturer – Oceanography Department, UCT

PUBLICATIONS AND SERVICES

Ansorge IJ, Brundrit G, Brundrit J, Dorrington R, Fawcett S, Gammon D, ***[et al.]*** *(2016). SEAmester –South Africa's first class afloat. S Afr J Sci.,112(9/10): Art. #a0171, 4 pages.*

Braby L, Backeberg BC, Ansorge I, Roberts MJ, Krug M and Reason CJC (2016). Observed eddy dissipation in the Agulhas Current, Geophys. Res. Lett., 43:8143–8150, doi:10.1002/2016GL069480.

Hutchinson K, Swart S, Meijers A., Ansorge I and Speich S (2016).Decadal-scale thermohaline variability in the Atlantic sector of the Southern Ocean, J. Geophys. Res. Oceans, 121:3171-3189, doi:10.1002/2015JC011491.

Olsen et al., 1016 - Cytotoxic activity of marine sponge extracts from the sub-Antarctic Islands and the Southern Ocean. S.Afr. J.sci, vol. 112, n.11.12.

Massie P, McIntyre T, Ryan PG, Bester MN Bornemann H and Ansorge IJ (2016). The role of eddies in the diving behaviour of female southern elephant seals. Polar Biology, vol. 39, pp. 297-307.

SEAmester – South Africa's Class Afloat

Isabelle Ansorge
Department of Oceanography,
University of Cape Town,

South Africa's Department of Science and Technology's (DST's) 10-year Global Change Grand Challenge programme requires platforms to "attract young researchers to the region and retain them by exciting their interest in aspects of global change; while developing their capacity and professional skills in the relevant fields of investigation". In addition, in July 2014, President Zuma officially launched Operation Phakisa and announced that a key target of this Oceans Economy initiative would be 'for the Department of Higher Education and Training to drive alignment between theoretical and workplace learning.' SEAmester – South Africa's recently established Class Afloat – achieves just that. SEAmester introduces marine science as an applied and cross-disciplinary field to students who have shown an affinity for core science disciplines. It identifies with government's National Development Plan on education, training and innovation – critical to South Africa's long-term development and investment in this sector.

SEAmester has a long-term vision aimed at building capacity within the marine sciences by coordinating and fostering cross-disciplinary research projects and achieving this goal through a highly innovative programme. The strength of SEAmester is that postgraduate students combine theoretical classroom learning with the application of this knowledge through ship-based, and more importantly, hands-on research. The state-of-the-art research vessel, SA Agulhas II, provides an ideal teaching and research platform for this programme; its size, comfort and shipboard facilities allow large groups of students and lecturers to productively interact over a period of 10 days.

Tamaryn **Morris**

SAEON Egagasini Node, Cape Town, South Africa

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Tel: +27 (0)21 402 3118

EDUCATION

Secondary education was completed at Table View High School, Cape Town

National Diploma, Btech and Mtech degrees in Oceanography completed at the Cape Peninsula University of Technology (CPUT), Cape Town

Currently undertaking a PhD in Physical Oceanography at the University of Cape Town (UCT)

CAREER

I have worked for Bayworld Centre for Research and Education (BCRE) as an oceanography field team coordinator and research assistant for 13 years before moving to SAEON to coordinate the Agulhas System Climate Array (ASCA) large mooring array currently deployed off the east coast of South Africa and the focus of my talk. I have been involved with various physical oceanography data sets (and the in situ collections thereof), from coastal work to ship-based instrumentation and now large moored arrays collecting data in both delayed and real-time formats. I collaborate with a number of international projects including the SAMOC-SA team which facilitate the large mooring array currently deployed in the South Atlantic Ocean, the Argo program as the South African representative to the Argo Steering Team, and various research intiatives within the Western Indian Ocean. I have supervised interns and students and have worked with secondary education training programs to promote marine science at this level of education.

RESEARCH INTERESTS

My primary research interest is the Agulhas Current, the largest western boundary current in the Southern Hemisphere, and is the focus of my daily operations. My PhD looks at source water eddies to the Agulhas Current, most notably those stemming from the south-west coast of Madagascar and becoming entrained in the Agulhas Current off the east coast. These large rotating anomalies carry heat and salt towards the Agulhas Current and are of considerable interest to studies looking at changing climates and what role ocean dynamics play.

PUBLICATIONS AND SERVICES

Morris, T. et al. Large mooring arrays monitoring the Greater Agulhas Current and its inter-ocean exchanges. Submitted to South African Journal of Science.

Morris, T., Lamont, T. and M.J. Roberts – 2013. Effects of deep-sea eddies on the northern KwaZulu-Natal shelf, South Africa. *African Journal of Marine Science.* Vol 35(3): 343-350

Bounded by oceans

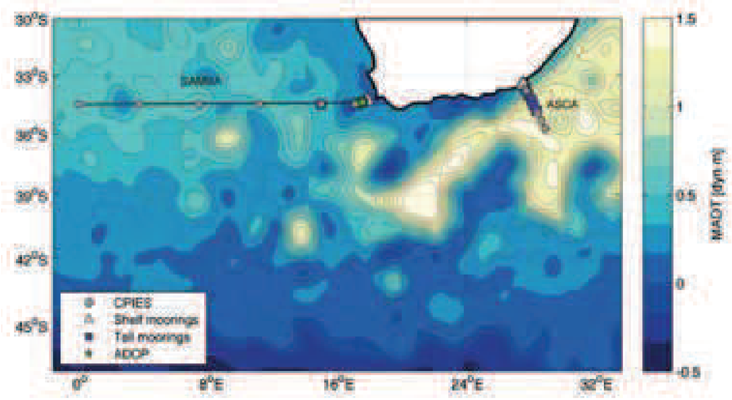
Tamaryn Morris, Juliet Hermes, Isabelle Ansorge, Marcel du Plessis and **Jethan d'Hotman** explain the ocean circulation around South Africa and how we study it using deep oceanic moorings.

The ocean currents around South Africa

South Africa is uniquely located within the global oceans. It is surrounded by three oceans and thus three large current systems: 1) the Indian Ocean and the powerful, warm Agulhas Current flowing from north to south along the east coast, 2) the Atlantic Ocean and the cold, sluggish Benguela Current flowing from south to north along the west coast, and 3) the Southern Ocean and the Antarctic Circumpolar Current flowing unhindered around the entire globe from west to east. This last current acts as a barrier in a wide and powerful series of fronts, between the cold Southern Ocean and the warmer Indian and Atlantic Oceans.

The Thermohaline Circulation, or oceanic conveyer belt, is a large inter-connected series of currents, which assists in driving and regulating global climate systems. The Agulhas System contributes warm and salty water to the south Atlantic Ocean in the form of rings and filaments, which is carried northwards to the north Atlantic on surface currents. Gradually the characteristics of this water change and when it reaches Iceland, it cools and sinks, having given off valuable heat to the Northern Hemisphere climate, and returns to the south Atlantic as a slow, deep, cold current. Thus changes within the Agulhas Current, and the leakage of this valuable water into the south Atlantic, need to be closely monitored to predict what will happen next in the story of our global climates.

The Greater Agulhas Current system around South Africa, showing the source waters in the form of mesoscale eddies from the Mozambique Channel and south of Madagascar, and the subgyre of the South Indian Ocean; the Agulhas Current, Retroflection and Return Current and the Agulhas Rings leaking into the south Atlantic Ocean. Image: Lutjeharms 2001



The ASCA and SAMBA mooring arrays overlaid on merged absolute dynamic topography (2015). Image: UCT

How do we measure the currents around South Africa?

The fundamentals of monitoring a current system are two-fold. Firstly, we need to ensure that the current in question is measured over a long period of time to make sure all the variations and anomalies are captured. Secondly, we need to measure the entire water column – from the surface to the seafloor. The best way to achieve both these goals is to deploy deep-ocean mooring systems along a pre-determined transect which is best placed to monitor the region of interest.

Deep-ocean moorings typically consist of sub-surface floatation buoys, a long length of steel wire rope and bottom weights, which will keep the entire system in one place without it 'walking away' in the strong currents. Along the steel wire rope, scientists bolt on different types of equipment, which will be used to collect different data on different factors to answer specific scientific questions. For example – How fast is the current moving and in which direction? How much water, in cubic meters, is being transported along with the currents? Does the temperature and salinity signature change across the continental shelf and with passing anomalies such as mesoscale eddies? One of the biggest questions posed for our current systems south of us, and in relation to the Thermohaline Circulation described above, is how much water from the Agulhas Current (the warm salty Indian Ocean waters) flows into the colder, slightly fresher, Atlantic Ocean, and is this increasing or decreasing with climate change? As mentioned above, this in turn affects the climate of the Northern Hemisphere and if this injection of warm salty water decreases, the Northern Hemisphere could get colder over time.

South African currently hosts two major deep-ocean moorings arrays to help answer these questions: 1) the Agulhas System Climate Array (ASCA), which crosses the Agulhas Current and measures water coming down the east coast and 2) the South Atlantic Meridional Overturning Circulation (SAMOC) Basin-Wide Array (SAMBA) located directly west of Cape Town and measures water propagating into the south Atlantic and northwards. This is complemented by two moorings arrays in the north Atlantic maintained by the United States, United Kingdom and other countries. These arrays then measure the overturning of water from the south Atlantic and the subsequent transfer of heat to climatic systems.

The instruments

The RD Instruments™ Acoustic Doppler Current Profiler (ADCP) uses sound waves pinged into the water column to collect data on the speed and direction the current is propagating. The sound waves bounce off particles suspended in the water column and using the Doppler principle (i.e. if the returned frequency is lower, the particle is travelling away

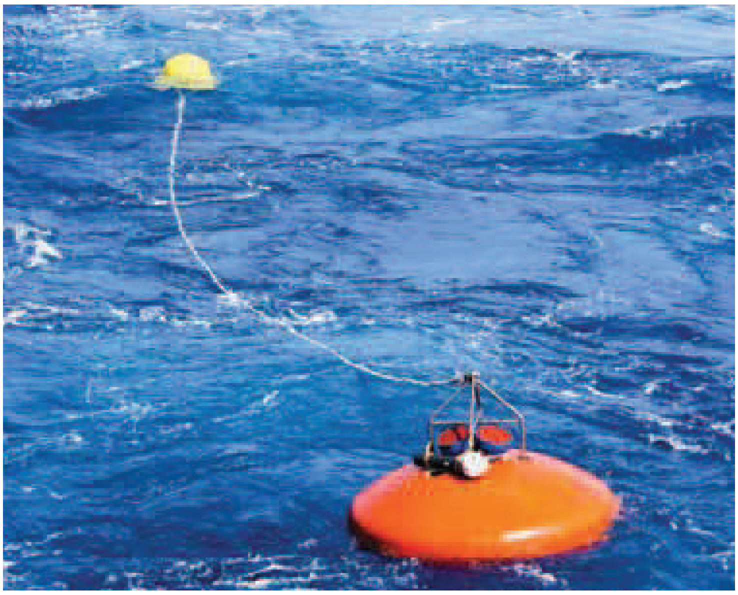
Mooring array readied for deployment from the ASCA transect. Note the ADCP within the orange float, with acoustic releases and counter-weight directly below the floatation package. Image: Jarred Voorneveld.

from the instrument and vice versa), the hourly current speed and direction every 8 m for a 500 m section of the water column (for the larger 75 kHz machines) can be calculated. Unfortunately, only one ADCP is available per mooring, so for the very deep moorings (> 600 m), smaller single-point current meters are used to collect additional current data. These work on the same principle as the ADCP, but will only collect data within 5 m of the instrument itself. A number of these instruments can be spaced along the mooring line to provide a more holistic picture of the deeper, slower currents.

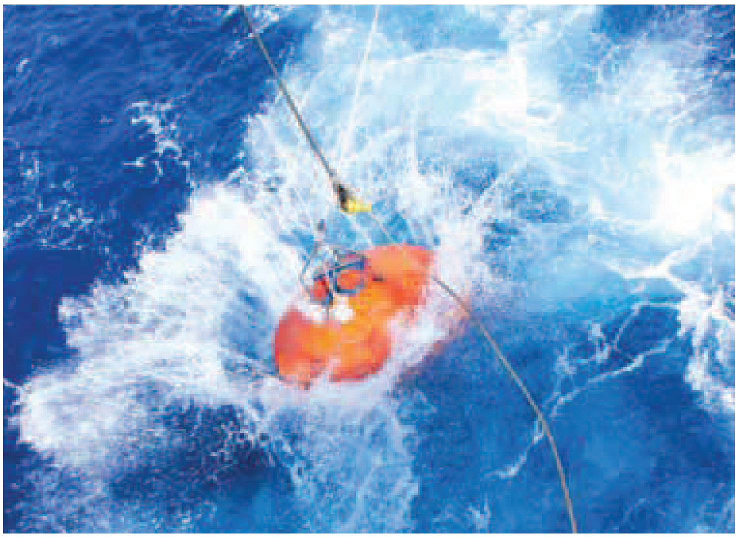
Sea-Bird Technologies™ manufactures a MicroCAT instrument, which can be attached to the steel wire rope mooring line, which collects hourly data on temperature, salinity and dissolved oxygen at its location. These data help build a picture of the physical changes over the entire water column for the study period.

Finally, acoustic releases, which are placed directly above the counter-weight keeping the mooring in place, are used to release the entire mooring to the surface. This is done every 12 to 18 months to service and calibrate the instruments, download their data and set the instruments up with new batteries and data storage capabilities.

The mooring arrays offer a wonderful opportunity for South African scientists, technicians and students to take part in and contribute significantly to international ocean programmes and assist in solving the big climate change problems. The necessary skills are being developed within our science community and this training is subsequently handed on to the next generation of scientists, engineers and policy makers to continue this work into the future. **Q**



Orange floatation buoy with ADCP and guide buoy floating on the sea surface. Image: Jarred Voorneveld.



Orange floatation package with ADCP being deployed. Image: Jarred Voorneveld.

Tamaryn Morris is the ASCA Coordinator at the Egagasini Node, SAEON, in Cape Town. She coordinates the ASCA project and is a part-time PhD student at UCT.

Juliet Hermes is the Node Manager for the Egagasini Node, SAEON, and is one of four co-Principal Investigators of the ASCA project. She is a collaborator on the SAMOC-SA project. She is also an HRA for both UCT and the Nelson Mandela Metropolitan University.

Isabelle Ansorge is the Head of the Oceanography Department at UCT and is the Principal Investigator for the SAMOC-SA project and a co-Principal Investigator for the SAMBA International group.

Marcel du Plessis is a PhD student at UCT and responsible for plotting The ASCA and SAMBA mooring arrays overlaid on merged absolute dynamic topography.

Jethan d'Hotman is the ASCA Officer and intern at the Egagasini Node, SAEON, in Cape Town.

References

Lutjeharms JRE. 2001. The Agulhas Current. In: Steele J, Thorpe S, Turekin K, editors. Encyclopedia of Ocean Science. London: Academic Press. p:104-113.

Sabrina **Speich**

Professor

Ecole normale supérieure (ENS), Paris

Laboratoire de Météorologie Dynamique – IPSL

EDUCATION

Sabrina Speich studied Physics in Italy at the University of Trieste and at CERN in Geneva (Switzerland). She received a PhD in Physical Oceanography from UPMC Paris VI (France) in 1992 and an *Habilitation à Diriger des Recherches* (HDR) from the University of Western Britanny (France) in 2008.

CAREER

Sabrina Speich is Professor of Ocean, Atmosphere and Climate Sciences at the Department of Geosciences of Ecole Normale Supérieure in Paris, France and at the *Laboratoire de Météorologie Dynamique* of the *Institut Pierre-Simon Laplace* (IPSL). She is also the Dean of Studies of the Department. Prior to this position, she was assistant researcher at the Department of Atmospheric Sciences at the University of California, Los Angeles (UCLA, USA) from 1992 to 1994 and at CNRS (Paris, France) in 1995. She then became Professor at the University of Brest (France) where she worked until 2013. She was invited Professor at the University of Cape Town (South Africa) in 2001 and 2003.

Prof. Speich is currently co-chairing and is chairing and has chaired some international programmes within the CLIVAR programme, The International Polar Year initiative and the European Research Projects framework and ANR. She has been serving on a number of national and international committees and review panels.

RESEARCH INTERESTS

Prof. Speich' research interests concern the uncovering and understanding of ocean dynamics and its role on climate variability and change. She is a world-recognized expert in ocean modelling as well as in organizing wide programs of in situ observations. She is recently focussing her research on scale-interactions in ocean dynamics, and how they affect the global ocean circulation, air-sea exchanges and ecosystems under a changing climate. She pioneered the use of Argo floats to observe the ocean.

PUBLICATIONS AND SERVICES

Speich, S., M. Arhan, E. Rusciano, V. Faure, M. Ollitrault, A. Prigent, S. Swart, 2012 : Use of ARGO floats to study the ocean dynamics south of Africa : What we have learned from the GoodHope project and what we plan within the SAMOC International Programme. Mercator Ocean—Coriolis Quarterly Newsletter - Special Issue, 45, 21-27.

The ocean: a key component of the global climate system

Sabrina Speich
Laboratoire de Météorologie Dynamique – IPSL
Ecole normale supérieure (ENS),
Département de Géosciences
Paris, France

The ocean is a key element of the global climate system. The numbers speak for themselves. The ocean covers 71% of the planet, holds 97% of the Earth's water, and has absorbed more than 90% of the excess heat and 25% of the additional CO_2 injected into the atmosphere by human activity. Additionally, it provides livelihoods for a substantial part of the world population. Thus, the ocean plays a crucial role in determining the climate of the planet. The global ocean is changing under the threat of global warming. We scientists need to continue to monitor the ocean and improve the observation of the system, knowing that observing the oceans is problematic even under the most favourable of conditions.

Our Earth is the only known planet where water exists in three forms (liquid, gas, solid), and in particular as liquid oceanic water. Due to its high heat capacity, radiative properties (gaseous) and phase changes, the presence of water is largely responsible both for our planet's mild climate as well as to the development of land life.

The oceans represent 71% of the surface of the planet. They are so vast that one can easily underestimate their role in the earth climate. The ocean is both a large reservoir, but at the same time continuously contributes to radiative, physical and gaseous exchanges with the atmosphere. These transfers and their impacts on the atmosphere and the ocean are at the core of the climate system.

The ocean receives heat from solar electromagnetic radiation, in particular in the tropics. It exchanges heat at its interface with the atmosphere at all latitudes, and with sea-ice in polar regions. The ocean is not a static environment: ocean currents are responsible for the redistribution of excess heat received at the equator towards the higher latitudes. At these latitudes transfers of water from the surface to the deep ocean take place as water losese buoyancy flowing poleward due to the effect of strong heat loss. The mechanism of this vertical dense water transfer related to an increase of sea-water density (caused by a lowering of the temperature or an increasing of salinity) is the starting point for the global ocean thermohaline circulation (derived from the Greek therme: heat; halos: sea salt). The ocean also reacts dynamically to changing climatic conditions (i.e. wind, solar radiation…). The time scale of these processes can vary from a seasonal or yearly scale in tropical areas to a decadal scale in surface waters, reaching several hundreds, even thousands of years in the deep ocean layers.

The atmosphere and ocean do not only exchange heat, but also water and chemical substances (Oxygen, CO_2, …). The latter, taken up at the surface of the ocean due to the high solubility of water are distributed by ocean currents across the globe and they are used to sustain the marine life in the ocean. These processes play a very important role in carbon cycling and the excess of CO_2 absorption as high latitude CO_2-enriched waters are drawn down towards the deep ocean where they remain for very long periods (hundreds of years).

The temperature of the ocean is rising

Recent warming caused by the emission of greenhouse gases related to human activity does not only affect the lower layers of the atmosphere and the surface of the continents. Measurements of sea temperature have been made during the past five to six decades over the 1000 to 2000 first meters of the ocean from ships, oceanographic buoys, moorings and more recently, autonomous profiling floats (the Argo project) that enable vertical sampling of the top 2000 m of the water column. They have allowed oceanographers to observe a significant increase in the temperature of the ocean over the studied period. This recent warming of the ocean affects the surface layers (the first 300 to 500 meters). However at high latitudes, the temperature increase has reached the deep layers of the ocean (Figure 1).

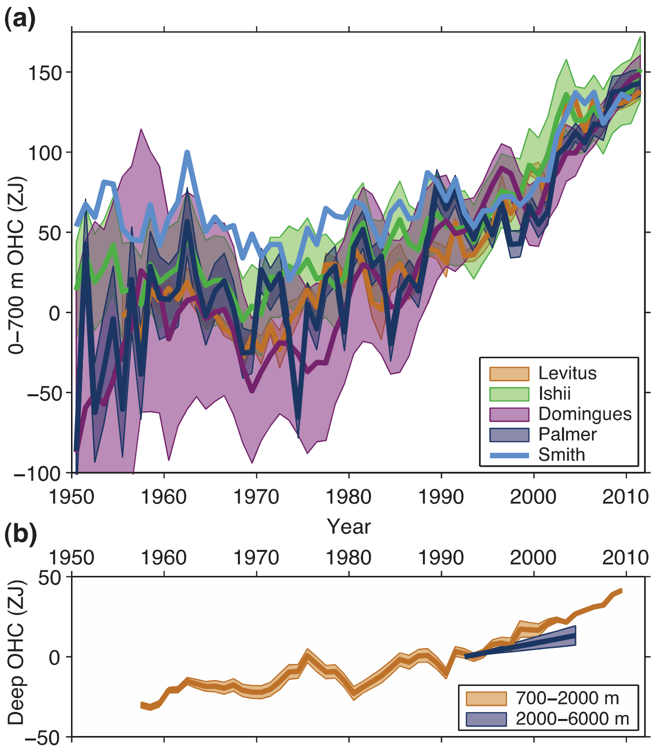


Figure 1 : (a) Evaluation of the yearly average of the heat content in ZJ (1 ZJ = 10^{21} Joules) calculated from observations in the surface layers of the ocean (between 0 and 700m depth). (b) Estimates of the moving average of the heat content in ZJ over 5 years for the 700 to 2000m layer and for the deep ocean (from 2000 to 6000m) during the 1992 to 2005 period. Figure adapted from Rhein *et al.*, 2013.

The temperature of the 0-300m layer has increased by about 0.3°C since 1950. This value is approximately half the temperature increase at the surface of the ocean. Furthermore, although the average temperature of the ocean has increased less than that of the atmosphere, the ocean represents the greatest sink and reservoir of excess heat introduced into the climate system by human activities. This is due to its mass as well as its high thermal capacity. Indeed, over 90% of the excess heat due to anthropogenic warming accumulated in the climate system during the past 50 years has been absorbed by the ocean (15 to 20 times higher than observed in the lower atmosphere and on land; Figure 2). This represents an excess energy storage by the ocean that is greater than 200 zeta-joules (2 • J 1023 ; 1 ZJ = 1021 Joules) since the 1970s .

This excess heat in the ocean is caused by direct warming from solar energy (e.g., this is the case in the Arctic due to an increased reduction in the area of sea ice during summer) as well as thermal exchange enhanced by increasing infrared radiation due to rising concentrations of greenhouse gases in the atmosphere. Ocean temperature rises induce side effects that could be of consequence, if not catastrophic, but that are yet still poorly understood. Amongst these effects, there is its contribution to the rise of average sea level, currently estimated to be about 3 mm/year. The oceans and seas produce another direct effect on climate change: it is likely that rising temperatures are progressively leading to an intensification of the global water cycle (hence, there is more evaporation and more precipitation). Water vapor being a greenhouse gas, it has a role in accelerating global warming, and consequently water evaporation.

The ocean's heat rise also modifies the ocean dynamics, locally disrupting the surface exchanges of energy with the atmosphere. The global ocean circulation can also be disturbed and may affect the climate at a global scale by significantly reducing heat transfer towards the Polar regions and to the deep ocean.

Increasing ocean temperature also has a direct impact on the melting of the base of the platform reserves of the continental glaciers surrounding Greenland and Antarctica, the two major continental water. Hence, although it was known that global warming is enhancing glacial melt, it is now proven that the heating of the oceans is contributing primarily to the melting of ice shelves that extend the Antarctic ice cap over the ocean. For example, considering that Antarctica holds about 60% of the world's fresh water reserves, recent studies show that the melt of the base of the Antarctic ice caps has accounted for 55% of the total loss of their mass, representing a significantly large volume of water.

Ocean warming affects the biogeochemical mass-balance of the ocean and its biosphere. Although most of these aspects have been documented, it is noteworthy to mention that the warming of the oceans can also impact the extent of their oxygenation: the solubility of oxygen decreases with increasing water temperature: the warmer the water, the lower the dissolved oxygen content. The direct consequences involve losses of marine life and its biodiversity and restrictions to habitats.

Compared to the atmosphere, the ocean presents two characteristics that confer it an even more important role in the climate system:

1. Its thermal capacity is more than 1000 fold that of the atmosphere and allows the ocean to store most of the solar radiation flux and surplus energy generated by human activities.

2. Its dynamics are much slower than in the atmosphere, with a very strong thermal inertia; at time scales that are compatible with climate variability, the ocean therefore keeps a long-term memory of the disturbances (or anomalies) that have affected it.

However, the world ocean is still poorly known due to its great size and to the inherent technical difficulties encountered in oceanographic observation (e.g. the difficulty of high precision measurements at pressures exceeding 500 atmospheres; the need to collect *in situ* measurements everywhere in the ocean aboard research vessels that are operated at great cost). In addition, ocean dynamics can be very turbulent and subsequent interactions with the atmosphere, extremely complex. To unveil these unknowns and uncertainties will be an essential step in predicting the future evolution of climate in a more reliable manner. Observations and measurements are irreplaceable sources of knowledge. It is therefore necessary to improve the nature and quantity of ocean observations with the aim of establishing a long-lasting, internationally coordinated, large-scale ocean-observation system.

Observing the ocean provides the direct oceanographic data, such as temperature, salinity, currents, sea surface topography, waves, colour, turbulence and nutrients. Feeding data into integrative models could generate information products which portray the present state of the oceans, and help to forecast the future condition of the sea for socio-economic benefit. Such information is increasingly needed by nations to manage their ocean areas, exploit its resources, mitigate the impact of natural hazards and improve climate forecasting.

To describe the ocean more accurately and deliver useful management tools and products, more observational data are needed on weekly/monthly basis through many different platforms, such as satellites, research ships, drifting buoys, moorings.

Maintaining long-term, continuous, ocean-data records for understanding, monitoring changes in, and modeling climate changes are mandatory, if yet more challenging.

André **Berger** is Emeritus Professor and Senior Researcher at the Université catholique de Louvain. He is doctor honoris causa from the Universities of Aix-Marseille III, Toulouse, Mons and University of Massachusetts Amherst. His main scientific contributions are in the astronomical theory of paleoclimates and modelling past climatic variations. He has published 300 papers and edited 13 books on climate and climate changes. He has been chairman of the International Commission on Climate of IUGG, of the Paleoclimate Commission of INQUA, and of Climate Commissions of the European Union and of NATO. He was a member of the Scientific Committees of the European Environment Agency, of Gaz de France and of EDF. He was President of the European Geophysical Society and is Honorary President of the European Geo-Sciences Union, member of the Academia Europaea, of the Royal Academy of Belgium, and of the academies of Canada, Serbia, Paris and the Netherlands. He is presently Director of the Classe des Sciences of the Royal Academy of Belgium. He received the Quinquennal Prize from the National Fund for Scientific Research in Belgium in 1995, the European Latsis Prize from the European Science Foundation in 2001 and an Advanced Investigators Grant from the European Research Council in 2008.
He has been ennobled by His Majesty Albert II, King of the Belgians, with the title of Chevalier (Sir), received the title of Officier de la Légion d'Honneur from the President of France and is Grand Officier de l'Ordre de Leopold in Belgium.

Qiuzhen **Yin** is Research Associate of the Belgian National Fund for Research and Professor at Université catholique de Louvain since 2013. She obtained her doctoral degree from the Chinese Academy of Sciences in 2006 with a thesis on the loess-monsoon-climate relationship. Since 2006 she has been working at Université Catholique de Louvain focusing on paleoclimate modelling. Her main scientific contributions are about interglacial climates and paleo-monsoon dynamics. She has published 32 papers, and reviewed papers for 17 international journals. She has been invited to give seminars and lectures in 14 universities and institutes and to give presentations at 12 symposiums and conferences. She has organized 8 international scientific meetings. She is member of the International Commission on Climate and associate member of the Belgian National Committee of Geodesy and Geophysics. She is editorial members of Global and Planetary Change, Quaternary International and Quaternary Sciences. In 2016, she received the Charles Lagrange Award from the Royal Academy of Belgium.

Past climates, a key for the future

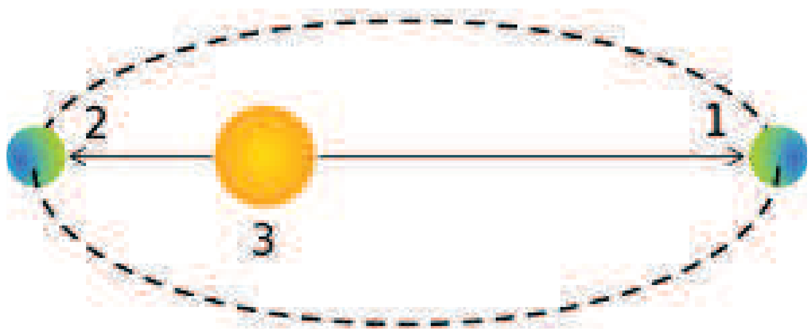
André Berger and Qiuzhen Yin

Georges Lemaître Center for Earth and Climate Research, Earth and Life Institute, Université catholique de Louvain, Louvain la Neuve, Belgium

The climate predicted to occur over the next centuries by the Intergovernmental Panel on Climate Change appears to be unprecedented over the past 150 years. There is a requirement, therefore to go back in the past history of the Earth looking for analogues. As we are presently in an interglacial (warm period, i.e. the Holocene), the interglacials of the late Pleistocene are particularly well suited. This is why we have investigated the response of the climate system to insolation and CO_2 at the peaks of the interglacials over the past 800,000 years using models of different complexity.

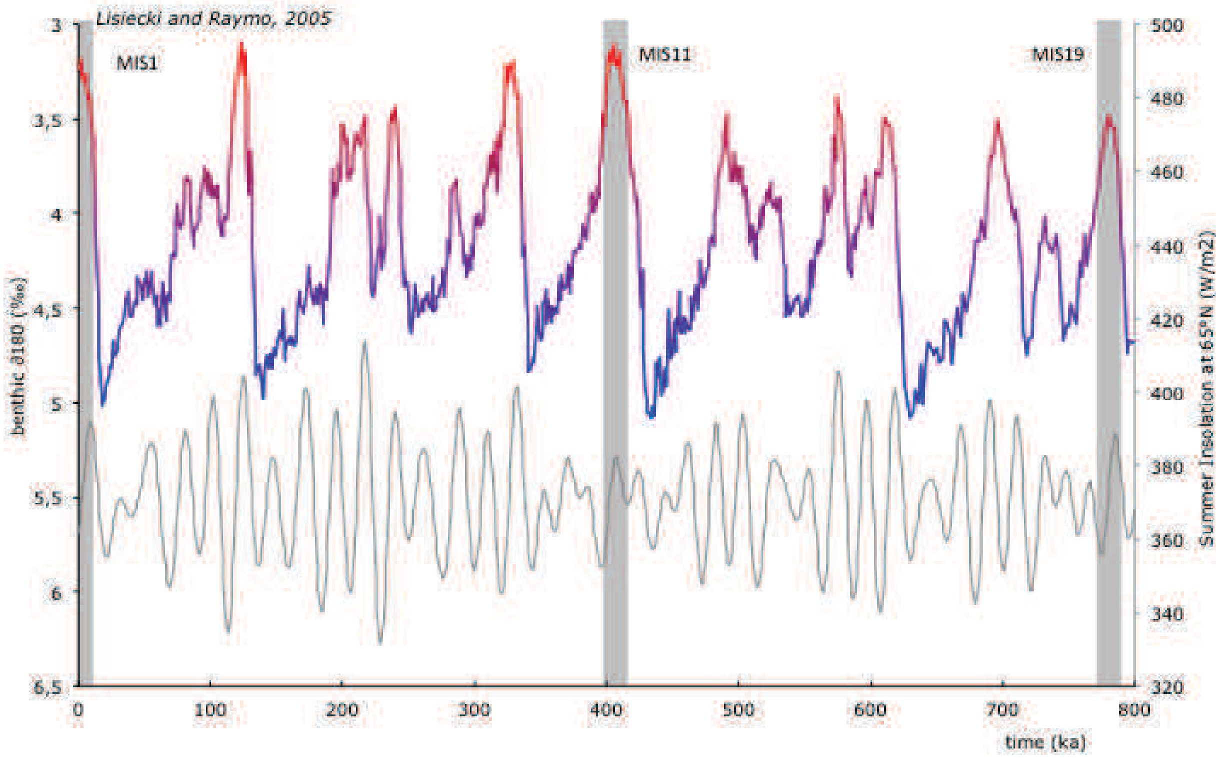
These simulations show that the relative contributions of insolation and CO_2 to the intensity and duration of each interglacial vary from one interglacial to another. They also show that CO_2 plays a dominant role in the variations of the global annual mean temperature and of the southern high latitude temperature and sea ice, whereas insolation plays a dominant role in the variation of monsoon precipitation, of vegetation and of the northern high latitude temperature and sea ice. In the explanation of the warmer climate during the interglacials after about 430,000 years ago, in contrast with those before, boreal winter is found to be a key season, a phenomenon similar to the warm winters occurring during the present-day global warming.

If we identify the peaks of the interglacials with Northern Hemisphere summers occurring at perihelion, MIS-1, MIS-11 and MIS-19 (respectively 12, 409 and 788 thousands of years ago - ka) show a pretty similar latitudinal and seasonal distribution of the incoming solar radiation (insolation).



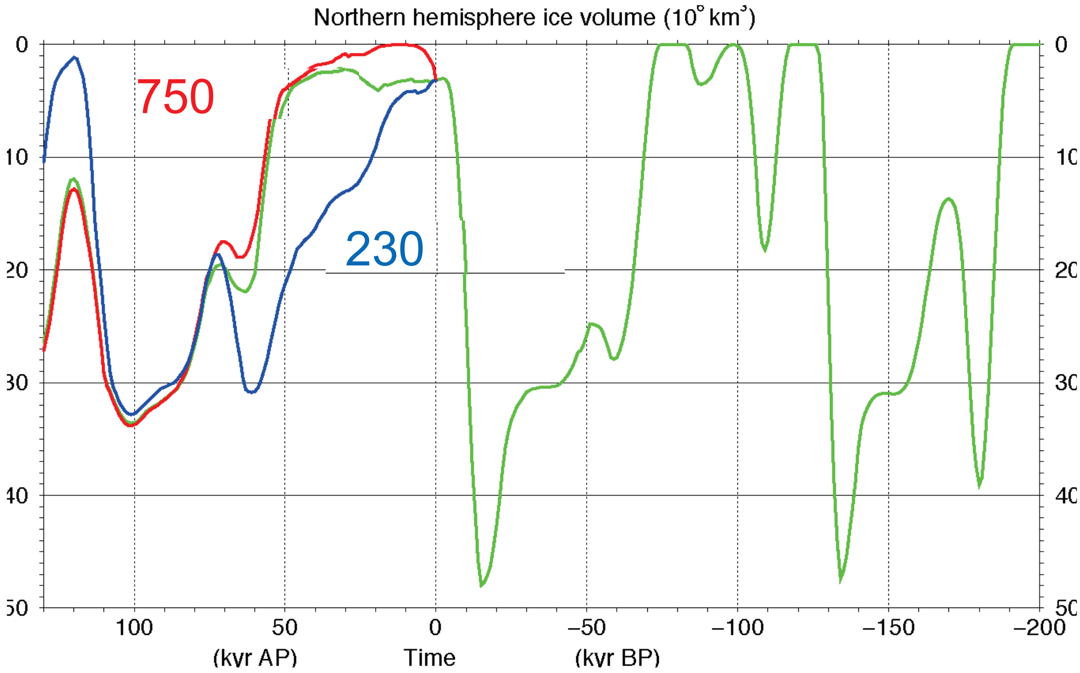
1. Earth at aphelion 2. Earth at perihelion 3. Sun

When compared to the average of the last 9 interglacials, they are under-insolated over the whole globe during boreal summer and are over-insolated during boreal winter with a maximum at the South Pole. This insolation distribution leads to a cooling over all the continents in boreal summer and to a warming over the whole Earth, except the Arctic, in boreal winter.



A warming over the Southern Ocean in austral winter occurs during MIS-1 and MIS-19 due to the summer remnant effect of insolation. However, this does not happen during MIS11 because the large global cooling during this season is dominating the remnant effect of the austral summer. This leads to MIS-11 being a cool insolation-induced interglacial and thus not as good an analogue of MIS-1 as MIS-19, at least as far as insolation is concerned. Its higher CO_2 concentration allows it however to be classified among the warm interglacials and as such to be compared to MIS-1.

Looking now for analogues of the whole Holocene and its future (the Anthropocene), it must be stressed that the shape of the Earth's orbit is approaching a circle. With this and a CO_2 concentration at the interglacial level, and even larger because of human influence, our interglacial was predicted to be exceptionally long as was MIS-11 in EPICA record. The interglacials MIS-9 and MIS-5 (respectively 334 and 127 ka ago) are the warmest interglacials and, as such, are considered as analogues for our CO_2-induced future warm interglacial, but their astronomical forcings are mostly different from MIS-1 and its future. The results also show that, compared to today, the past interglacials are warmer during boreal summer and cooler during boreal winter leading to a warmer annual mean with varying length for different interglacials. The best analogue to MIS-1 depends therefore upon the criteria used to select such an analogue.
If we compare the climate of these interglacials to the climate of a $2xCO_2$ atmospheric concentration simulated under Pre-Industrial conditions, both MIS-5 and MIS-9 during boreal winter are cooler over the whole Earth, especially over the continents.



Berger and Loutre,

Long term variations of the simulated ice volume in the Northern Hemisphere using the 2-D climate model of Louvain la Neuve forced by the astronomically generated insolation and the CO_2 concentration using the EPICA record for the past 200,000 years and 3 scenarios for the next 150,000 years.

During boreal summer, they are much warmer over the continents, but remain cooler over the oceans. This shows the importance of the insolation which is much larger at MIS-5 and MIS-9 (even at MIS-11 and MIS-19) with boreal summer occurring at perihelion than in the following future with boreal summer occurring at aphelion. This sensitivity of climate to the latitudinal and seasonal distribution of insolation must be kept in mind for climatic projection at the century-millennium time scales.

These results underline the diversity of the warm climates of the past one million years and therefore the potential but also the difficulty of finding exact analogs for our own interglacial and its future.

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YIN Q.Z. and A. BERGER, 2010. Insolation and CO2 contribution to the interglacials before and after the Mid-Brunhes Event. Nature Geoscience, 3(4), pp. 243-246. doi: 10.1038/ngeo771.

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YIN Q.Z. and BERGER A., 2015. Interglacials analogues of the Holocene and its near future. Quaternary Science Review, 120, 28-46.

This work was supported by the European Research Council Advanced Grant EMIS (2008-2013).

Dr. Thalassa **Matthews**

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EDUCATION

- PhD awarded in Dec. 2004 (University of Cape Town)
- Graduated June 1998 with Distinction *Masters* degree in Archaeology (University of Cape Town)
- Graduated Dec. 1992 *Honours* degree in Archaeology (University of Cape Town)
- Graduated Dec. 1991 *Diploma in African Studies* (University of Cape Town)
- Graduated Dec. 1989 *Bachelor of Arts* degree (University of Cape Town, Majors: Economics and English)

CAREER

Dr Matthews is currently based at the Iziko South African Museum in Cape Town. Her research specialisation includes fossil micromammals (e.g. mice, rats, shrews and mole rats) and frogs. She has been carrying out research on and off since the completion of her PhD in 2014, but other work experiences include working as a Project Manager and Research Director, Lecturer and Teacher at school and university level, Fundraiser and proposal writer, Desk-top publisher and Editor of research journals and newsletters, and as a curriculum-based resource developer for schools.

RESEARCH INTERESTS

Since completion of her Phd, Dr Matthews has worked on fossil small mammals and, more recently, frogs, from archaeological and palaeontological sites from the south and west coasts of South Africa, and the interior, dating to the Pleistocene and Holocene. One focus of research has been to elucidate Quaternary palaeoenvironments and ecologies, and investigate climatic change over time using fossil micromammal and frog assemblages as environmental proxies. Another is to research the evolution of micromammals and frogs during the Quaternary, and map changes in distribution, which has relevance to the development and use of climatic modelling.

PUBLICATIONS AND SERVICES

Matthews, T., Measey, G.J. Roberts, D. L. 2016. Implications of summer breeding frogs from Langebaanweg: regional climate evolution at 5.1 Mya. *South African Journal of Science*. Volume 112(9/10). DOI: http://dx.doi.org/10.17159/sajs.2016/20160070.

Matthews T. and du Plessis A. 2016. Using X-ray computed tomography analysis tools to compare the skeletal element morphology of fossil and modern frog (Anura) species. *Palaeontologia Electronica* 19.1.1T: 1-46.

AWARDS AND HONORS

Dr Matthews is a rated scientist and recieved a C2 rating from the National Research Foundation of South Africa in 2014.

Using fossil micromammals and frogs for palaeoclimatic reconstruction

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"Micromammal" is a term commonly used in archaeology and palaeontology which refers to the smaller mammals such as rats, mice, shrews and mole rats. Micromammals are frequently found in archaeological sites, particularly cave sites. They generally become associated with the site via the deposition of the pellets of owls, who roost in caves and rock shelters and regurgitate the undigested bones and teeth of their micromammalian prey (usually swallowed whole) at their roost sites. Owls may use the same roost site for a number or years and large accumulations of prey remains build up.

Figure 1: Disintegrating owl pellet composed of mouse fur and microfaunal bones (left) and owl pellet with mouse tail (caudal vertebrae) hanging out (right)

Over time these pellets disaggregate and leave pockets of bones and teeth in the soil. These are frequently recovered with, or in between, archaeological layers, which were accumulated when the cave was occupied by stone age people. Frogs may also be taken by owls and their bones deposited along with the micromammals. The teeth and bones of these animals are then used to identify them. The identification of the species present at the site in turn provides information on the environment in which they lived. Frogs and micromammals are particularly useful as they provide information on the immediate environment around the site as they have small home ranges, and many have precise habitat requirements. Changes over time in species abundance, and in the species represented, is used to inform on climatic change over time. The micromammal assemblages accumulated by owls may be considered broadly representative of what micromammals were living on the landscape at the time as the prey selection by owls is varied. In fact, owl pellets provide a better indication of the micromammals living in the area than routine trapping.

The paleoclimatic information obtained from fossil micromammal and frog studies places the archaeological studies within a palaeoenvironmental context and contributes to interpreting and understanding changes in various aspects of the archaeology, such as changes in diet, tool technologies, and so on.

Figure 2: Archaeologists excavating a South African south coast archaeological cave site

Frogs are very useful indicators of climatic change as they are highly sensitive to fluctuations in moisture levels and temperature, whereas micromammals respond more to changes in vegetation - thus used in tandem these under-utilised taxa are highly complementary.

Research includes studying patterns of frog and micromammalian evolution/migration through time over the Pliocene, Pleistocene and Holocene, and providing new palaeo-distributional and diversity data for taxa as little, or nothing, is known about these aspects of many micromammal, and most frog, taxa. Another research objective is to study the response of terrestrial ecosystems to glacial/interglacial cycles along the southern and eastern South African coast. This is turn provides information on biodiversity and climate change and contributes to understanding future impacts of global warming, and conservation planning for endangered frog and micromammal species.

Sites to be presented will include the 5.1 million year old palaeontological site of Langebaanweg, Coopers Cave from the Cradle of Humankind, and the archaeological sites from Pinnacle Point, Mossel Bay, and Knysna.

An ongoing project to build up a comparative database of Computed Tomography (CT) scans of modern frog skeletal material will be presented as this necessary for the identification of South African fossil frog assemblages – no such database currently exists.

Figure 3: Computed tomography scan of a frog. The various bones can be disarticulated and studied in 3D. The bones of modern frogs are used to identify fossil frog remains.

Edgar Andrew **Bering,** III

Professor of Physics and Electrical and Computer Engineering

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EDUCATION
Secondary school at Groton School, Groton, Mass., USA
University studies at Harvard and the University of California, Berkeley. Ph.D. in Space Physics

CAREER
Dr. Bering joined the University of Houston Physics Department in 1974, became an Assistant Professor in 1975, became a full professor in 1989 and received his dual appointment in 1998.

RESEARCH INTERESTS
Dr. Bering has participated in experiments to measure electron bremsstrahlung beneath auroras, electron bremsstrahlung accompanying both natural and triggered VLF events, auroral zone electric fields, plasmapause electric fields, electric fields at high altitude owing to thunderstorms, and the electromagnetic radiation spectrum of lightning at high altitude, VLF magnetic fields accompanying active experiments in the ionosphere, dc plasma properties in the ionosphere near pulsating aurora, electric fields near the magnetospheric cusp and atmospheric electric parameters at the South Pole. Dr. Bering is involved in the development of the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) at the Ad Astra Rocket Company. He is also working on the analysis and interpretation of the data from his recent Antarctic balloon campaigns, emphasizing studies of the role of ULF waves in the transport, energization and precipitation of radiation belt particles. He has published 134 Refereed papers, 77 Technical Reports, 96 Invited Talks, and 380 other Abstracts. He has supervised 3 PhD students and 7 Masters or Undergraduate Theses.

PUBLICATIONS AND SERVICES
The global circuit, E.A. Bering, III, A.Few and J. R. Benbrook, *Physics Today*, *51*(10), 24-30, 1998.

Dr. Bering created the annual Houston-wide UH Mars Rover model competition for budding engineers in grades 3-8 in 2002. From 2002 to 2005, this event experienced 40% per annum growth. As many as 720 students, 60+ teachers, 550 volunteers and 1000+ parents have attended these events. He has extensive experience conducting teacher training activities.
Dr. Bering has been active in several other youth oriented service activities, ranging from coaching baseball to tutoring neighborhood kids in physics. He was an Assistant Scoutmaster in BSA Troop 642. He has a son and a daughter, both now in their 20's, that majored in STEM subjects in college.

AWARDS AND HONORS
In 2000, Dr. Bering was a member of the VASIMR team that won the Rotary National Award for Space Achievement, Stellar Award, Team Category. In 2004, he received the AIAA Best Paper of the Year award in Plasmadynamics and Lasers. He has been involved in Education and Public

Outreach since 1990. In 2005, he received a Special Service Award from AIAA for his work on the Mars Rover Model Competition outreach program. He is an Associate Fellow of the AIAA. In 2017 he received the University of Houston Undergraduate Research Mentor Award.

Teaching Students How to Research the Upper Atmosphere Using High Altitude Balloons

This workshop will discuss the process of teaching how to use the new technology and instrumentation in balloon borne geospace investigations in the upper atmosphere. Motivation stems from advances in microelectronics and consumer electronic technology. Given the technological innovations over the past 20 years it is now possible to develop new instrumentation to study the upper atmosphere using ultralight balloon payloads. The workshop is based on my experience leading the University of Houston (UH) Undergraduate Student Instrument Project (USIP). My undergraduate teams have built 14 payloads for launch using1500-2000 gm latex weather balloons that were deployed in Houston and Fairbanks, AK as well as zero pressure balloons launched from northern Sweden. The latex balloon flights collected vertical profiles of wind speed, wind direction, temperature, electrical conductivity, ozone and odd nitrogen. The zero pressure balloons will obtain a suite of geophysical measurements including: ionospheric electron density effect on GPS signals via dual-channel GPS, X-ray detection, and VLF electromagnetic receivers. Students have flown payloads with different combinations of these instruments to determine which packages are successful. Teaching methodologies and best practices learned from this project will be discussed.

I. Introduction

This iteration of the University of Houston's USIP was initiated in January, 2016. About 25 new students were brought on to the project, and several students carried over from the previous iteration. The philosophy that was immediately instilled into this group by the project's faculty advisor, Dr. Edgar Bering, was that the students lead. This meant that students were responsible for organizing themselves, choosing research topics, creating a command structure, and leading the design process for their chosen instruments. The students were heavily encouraged to seek guidance from the faculty advisors, but for the most part we were on our own. For better or for worse, for the first months of the project the group set out to create this project structure, choose instruments to be designed, and divide into design teams to start the design process. Once team leaders and project managers were chosen from the group, guidelines were produced based on typical NASA project guidelines to guide the progress of each design. Each design team was required to produce a Gantt chart that detailed the different stages of their planned design and the critical path to a completed instrument.

At this point it is essential to make note of the level of design or project management experience that each student came into the project with: little to none. For this reason, the first months of the project consisted of the students struggling to find their footing with their projects and schedules. Initial Gantt chart schedules were optimistic and initial designs were ambitious, to put it lightly. Despite this, the group was eager to get to work.

II. Description of Instruments

The following sections are brief descriptions of the suite of instruments that this USIP group set out to design. Some instruments were new concepts developed by the USIP-II group, and others were initially developed by the USIP-I group and inherited by the USIP-II students.

Total Electron Content Detector

Total Electron Content is a measure of the total number of electrons contained in a profile of the Earth's atmosphere. The method used to measure TEC here is by using an accurate GPS receiver that measures the phase difference between dual frequency GPS signals from the orbiting GPS satellite network. When the signal is received, there is a small amount of phase shift caused by the electrons in the atmosphere. This phase shift can be used to determine how much the signal was delayed, and the electron content that causes such a delay.

Very Low Frequency Radio Receiver

Very Low Frequency radio waves are radio waves in the range of 3 kHz to 30 kHz. The VLF range can be used for communication, but the study of the range can also yield interesting scientific data. Natural phenomenon such as lightning strikes and electron precipitation can generate VLF waves that can propagate extremely far between the Earth and the Ionosphere. The instrument used to measure these waves consists of an air loop magnetic field antenna and a series of filtering amplifiers that captures and amplifies signals in the VLF range.

Digital to Analog IRIG-B Time Code Encoder

The IRIG-B encoder is an instrument that was designed to complement the VLF radio receiver. The purpose of the encoder is to provide a time stamped analog signal that is recorded alongside the VLF data. The device consists of a digital circuit controlled by an Arduino microcontroller connected to a GPS receiver chip. Accurate time data is parsed from the received GPS data and is outputted digitally and converted and outputted as an amplitude modulated analog signal formatted using the IRIG-B protocol.

Atmospheric Extremophile Organism Collection Device

The purpose of the Extremophile Collection Device is to attempt to recover a sample of the extremophile organisms that are theorized to reside in the Stratosphere. The difficulty of collecting these organisms is that it is difficult to design a pump that can perform well in the low pressure conditions of the stratosphere while taking a large enough sample to have a good possibility of capturing an organism for study. This is the problem the design sets out to solve. The design consists of a large folding bellows system with a valve controlled by an onboard Arduino microcontroller.

DC Electric Field Detector

This instrument sets out to measure atmospheric electric field and conductivity using the double probe method of electric field measurement. The goal of the instrument is to develop the classic two probe method further by creating a light weight and compact version of the instrument.

Auroral Imaging Spectroscope

The aurora phenomenon is caused by electrons precipitating from the Earth's magnetic field into the atmosphere that excite gas molecules that then release photons, generating the beautiful colors of the aurora. The colors generated by the excited gases are dependent on the temperature and concentration of the gas elements that are excited and the energies involved with the excitation. The goal of the imaging spectroscope instrument is to capture the color spectra outputted by the aurora, and to use the data to calculate energies involved with the auroral process.

Gaseous Compound Detector

This atmospheric gas detector uses several electrochemical transducers to measure O_3, NO, NO_2, and CO. The gases are pushed through the device using a small pump. The transducers are controlled by an Arduino microcontroller that reads, interprets, and stores the data. The instrument measures the gases in a profile of the atmosphere.

UV Ozone Detector

This instrument measures O_3 using a different method from the Gaseous Compounds detector. The UV Ozone detector uses UV spectroscopy to measure the ozone content being pushed through the device. Like the Gaseous Compounds instrument, the gas is being pushed through the device using a small pump.

Star Tracker

The Star Tracker instrument sets out to determine the attitude of the balloon payload using the star tracking method of attitude determination used by space craft. The instrument consists of a camera on a stabilized payload that captures images of the stars. In post analysis, the star arrangements in the images are compared and matched to star charts to determine the direction the camera is facing. A big challenge with this design is the stability of the payload during flight, as stability affects the quality of the captured images.

Airglow Imaging All-Sky Imaging Device

This is a ground based design with the purpose of capturing images of atmospheric airglow to detect gas waves in the upper atmosphere generated by the gravity of the Earth. The instrument consists of a high quality camera with a filtering lens setup that captures images of the full night sky. The instrument is ground based to ensure the stability of the device to ensure that high quality images are captured.

III. Project Organization

In the first months after the initiation of USIP-II, the students had to determine the best way to organize in to a coherent project structure with a chain of command and protocol in place to deal with issues that would inevitably crop up in the future. Because of the large number of students in the project and the large number of instruments that were chosen to be built, the project structure ended up being rather complex for an undergraduate project. Also, because the majority of the students had little to no project management experience at the start of the project, creating and maintaining this structure was difficult to say the least.

The structure that was decided upon by the student leadership under the guidance of Dr. Bering was a decentralized model where each design team was given a large amount of independence. The central leadership of the project was responsible for the greater logistics of the project, such as campaign planning, flight organization, and communication with the NASA USIP contacts. The project members were organized into instrument design teams and payload system teams, where each student had a role in both an instrument team and a system team.

This project structure will be elaborated upon further in the final manuscript of this report, along with an analysis of the issues that cropped up during the course of the project.

IV. Field Campaigns

Two field campaigns were conducted during the course of USIP-II; the Nasa/Dartmouth BARREL-4 Campaign and the USIP-II UH Fairbanks, Alaska, Campaign.

A. USIP-II Contributions to the BARREL-4 Campaign in Kiruna, Sweden

The Balloon Array for Radiation-belt Relativistic Electron Losses (BARREL) campaigns are put on by NASA and Dartmouth College in New Hampshire. The BARREL team is made up of researchers from various US universities, including Montana State University, UC Santa Cruz, and others. The goal of the campaigns are to measure X-Rays produced by electron microbursts during precipitation events from the Earth's radiation belts. The USIP-II team was extended the opportunity to fly a small number of student built instruments on board the BARREL payloads and to take part in launch operations during their fourth campaign at Esrange Space Center near Kiruna, Sweden in August, 2016.

The instruments that were chosen to fly with BARREL were the TEC and VLF/IRIG-B instruments. These projects were chosen because they were deemed to be relevant to the science BARREL was doing. In order to be ready for flight by August 2016, the TEC and VLF/IRIG-B teams were put on accelerated timelines to ensure that the instruments were completed before the campaign.

Results and experiences from the BARREL-4 campaign will be elaborated upon in the workshop presentation

B. USIP-II UH Campaign in Fairbanks, Alaska

The USIP-II Alaska Campaign took place from March 4th to March 26th, 2017. The campaign will consist of High Altitude Balloon launches with payloads constructed by USIP carrying the instruments designed and fabricated by the USIP-II students. During the three week campaign, there were 10 launch attempts and 9 flights. Six of the flights were recovered, with full data capture. Of the three flights that were not recovered, only one had full radio telemetry.

Results and experiences from this campaign will be talked about in detail in the workshop.

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EDUCATION

- 2004: PhD in geophysics with 1st class honors, University of Grenoble 1, France.
- 2000: M.Sc., Oceanography & Meteorology, University of Paris 6, France
- 1997-2000: École Nationale Supérieure des Techniques Avancées, Paris, France

CAREER

- co-PI since 2010 of annual proposals to the French National Space Center on rapid core dynamics from satellite observations.
- co-PI of the geomagnetic data assimilation project "*AVS-geomag*" (ANR funding 2011-2015, collaboration with IPG Paris, http://avsgeomag.ipgp.fr/).
- 2007-2009: Post-doc fellow at ISTerre in the "quasi-geostrophic secular variation " project (ANR grant).
- 2004-2007: Post-doc fellow at the Institute of Geophysics and Tectonics (Univ. of Leeds, UK) on the geomagnetic inverse problem (NERC grant).
- 2001-2004: PhD Thesis at ISTerre on "magnetoconvection in a rapidly rotating sphere: numerical and experimental models of convection in planetary cores".
- PhD supervision: G. Hellio (2015), F. Labbé (2015), O. Barrois (due in 2017);

RESEARCH INTERESTS

As a Researcher at ISTerre (Grenoble) since 2009, I work on the reconstruction and understanding of the dynamics within the Earth's outer core, from archeomagnetic (past millenia), historical (past centuries) and satellite (past decades) measurements of the geomagnetic field.

PUBLICATIONS AND SERVICES

I am (co-)author of 24 publications in peer-reviewed international journals.

- Head of the "geodynamo" team of ISTerre (since 2017)
- Convener at international meetings (AGU, IAGA)
  co-chair of IAGA division WG1.1
- Correspondent for communication at ISTerre (2012-2014)
- Organization of monthly seminars on the inverse problem (ISTerre, 2009-2012), of weekly seminars at the IGT (Leeds, 2006-2007)
- Teaching: Master (Lyon and Grenoble), Undergrad and PhD (Grenoble)

AWARDS AND HONORS

- 2012: Zatman memorial Lecture, SEDI meeting, Leeds, UK.
- 2008: Doornbos memorial prize, SEDI meeting, Kunming, China.

The geomagnetic field: behavior and origin

Nicolas Gillet,
ISTerre, University of Grenoble,
France.

The effects of the magnetic field of the Earth were discovered a long time ago (1st century in China, 12th century in Europe) and among its uses, magnetic compasses were used for geographic orientations, for example by sailors to cross oceans. In particular, the inclination (dip angle below the horizontal plane) and the declination (angle between the magnetic and geographic north) are crucial for knowing the geographic latitude and the azimuth direction to move towards. However, large length-scale magnetic anomalies to the dipole field have to be taken into account, such as the large South Atlantic anomaly. But geophysicists figured out that the Earth magnetic field is evolving over time (up to 10°per century). Consequently the magnetic field needs to be observed, and its time variations are not yet understood. Measurements have been made in magnetic observatories since the mid-XIXth century, such as the one in Hermanus, South Africa. Today, magnetic records from low-orbiting satellites (such as the Swarm constellation) are used to build magnetic maps, used in modern navigation. But the secular variation of the magnetic field is still unpredictable.

To make correct predictions, we need to understand how the magnetic field is generated and this is still poorly understood. The main magnetic field is self generated (dynamo effect) by the liquid motions inside the metallic core of the Earth. The core (about half the radius of the Earth) is made of two parts: a solid central part, the inner core (about 1200 km in radius) and a fluid outer core. Different sources of deep core motions are possible such as precession, tides, thermal or chemical convection. These motions are used as inputs to the dynamo equations, first written in 1946 by W. Elsasser, but the first complete numerical solution was computed only in 1995 (Glatzmaier and Roberts). In addition, two liquid sodium experiments, in 1999, tried to reproduce in laboratory the dynamo principle at work in the planetary cores. Much progress has been made since, in numerical simulations able to reproduce many geomagnetic features (dipolarity, reversals,…) and in laboratory experiments. But as the models become more and more realistic, the diversity of dynamo magnetic fields become larger and larger.

The quality and the versality of the dynamo models enable us to reproduce the magnetic situation of other planets in the solar system, to explain the fossil (Moon, Mars…) and the active (Mercury, Ganymede…) magnetic fields of terrestrial planets, but also the magnetic fields of the giant planets (Jupiter, Saturn…) and probably, very soon, the magnetic exoplanets…

Replicate of the absolute magnetometer by K. F. Gauss.

by Nicolas Gillet (nicolas.gillet@univ-grenoble-alpes.fr)

ISTerre, Grenoble, France

June 2017

1 Summary

The aim of the experiment I describe below is to reproduce one of the two absolute intensity magnetometer developed by K. F. Gauss in the 1830's – for more details, I refer to Becquerel (1846) and Kono (2007). At this epoch, it was already known that a magnetized needle would oscillate in the presence of a magnetic field, and that the oscillation period was related to the field intensity. However, this period was only a relative measure of the magnetic field intensity, since the notion of magnetic moment was lacking. The principle is the following:

- in a first step, one measures the oscillation period T of a magnet $\mathcal{A}$ in the horizontal plane. We will show below that T is linked to the product $M_{\mathcal{A}}H$, with $M_{\mathcal{A}}$ the magnetic moment of the magnet and H the intensity of the horizontal component of the Earth's magnetic field;
- in a second step, one measures the deviation angle α^* of the magnet $\mathcal{A}$ (with respect to the geomagnetic North) in presence of a secondary magnet $\mathcal{B}$ (similar to $\mathcal{A}$) placed at a distance d. Approximating the field of $\mathcal{B}$ by a dipole, we relate $\alpha^*(d)$ to the ratio $M_{\mathcal{A}}/H$.

Knowing $M_{\mathcal{A}}H$ and $M_{\mathcal{A}}/H$, we deduce H without a priori knowledge of the magnetic moment of the magnet. I give some details below.

2 Theoretical background

2.1 Oscillation period of a magnetized needle

I write $\mathbf{M}_{\mathcal{A}}$ the (vector) magnetic moment of the magnet $\mathcal{A}$ (positionned in the horizontal plane), in the presence of $\mathbf{B}$ the vector magnetic field of the Earth. The magnetic torque along the vertical unit vector $\mathbf{e}_z$ is

$$\Gamma = \mathbf{e}_z \cdot (\mathbf{M}_{\mathcal{A}} \times \mathbf{B}) = M_{\mathcal{A}} H \sin\alpha \,, \tag{1}$$

with H the horizontal component of the Earth's magnetic field and α the projection onto the horizontal plane of the angle between $\mathbf{M}_{\mathcal{A}}$ an $\mathbf{B}$. The conservation of angular momentum for the magnet $\mathcal{A}$ indicates, for small deviation angles ($\alpha \ll 1$),

$$I_{\mathcal{A}} \frac{d\omega}{dt} = I_{\mathcal{A}} \frac{d^2\alpha}{dt^2} \simeq M_{\mathcal{A}} H \alpha \,, \tag{2}$$

with $\omega = d\alpha/dt$ the angular velocity and $I_{\mathcal{A}}$ the moment of inertia of the magnet. Solutions to eq. (2) are sines and cosines of period

$$T = 2\pi\sqrt{I_{\mathcal{A}}/(M_{\mathcal{A}}H)}\,. \tag{3}$$

2.2 Deviation angle of a magnetized needle

I now approximate the magnetic field $\mathbf{B}_{\mathcal{B}}$ of a magnet $\mathcal{B}$ (of magnetic moment $M_{\mathcal{B}}$), positionned in the horizontal plane, by a dipole – Gauss gave the framework for the dipole formulae with the invention of spherical harmonics. The field intensity generated by the magnet $\mathcal{B}$, at a distance d of this magnet, is then

$$H_{\mathcal{B}}(d) \simeq \frac{\mu_0}{2\pi}\frac{M_{\mathcal{B}}}{d^3}\,, \tag{4}$$

where μ_0 is the magnetic permeability of free space. We consider the position of equilibrium for the magnet $\mathcal{A}$, sensitive too both $\mathbf{B}_{\mathcal{B}}$ and $\mathbf{B}$, with $H_{\mathcal{B}} \ll B$. It is such that $\mathbf{M}_{\mathcal{A}}$ is parrallel to $\mathbf{B}+\mathbf{B}_{\mathcal{B}}$. The magnet $\mathcal{A}$ is then deflected from the geomagnetic North by an angle $\alpha^* \ll 1$,

$$\alpha^* \simeq \sin\alpha^* = H_{\mathcal{B}}(d)/H\,, \tag{5}$$

where d is now the distance between the two magnets $\mathcal{A}$ and $\mathcal{B}$. Combining eq. (4) and (5) gives

$$\alpha^* \simeq \frac{\mu_0}{2\pi}\frac{M_{\mathcal{B}}}{H}d^{-3}\,. \tag{6}$$

If now we consider that the two magnets $\mathcal{A}$ and $\mathcal{B}$ are similar ($M_{\mathcal{B}} = M_{\mathcal{A}}$), we see that by measuring T and $\alpha^*(d)$, we can deduce H from eq. (3) and (6). Note that for the second step (estimation of the deflection angle α^*) one could replace $\mathcal{B}$ by $\mathcal{A}$, and take any magnet instead of $\mathcal{A}$.

Gauss performed this experiment in Göttingen in 1833. He estimated H by determining the two proportionality coefficients K_1 and K_2 for $\alpha^* = K_2 d^{-3}$ and $T^2 = K_1 I_{\mathcal{A}}$ (varying the moment of inertia $I_{\mathcal{A}}$ by moving little masses along the magnet $\mathcal{A}$). He found $H = 17.8\mu$T.

3 Replicating this instrument in practice

3.1 Dimensions for the experiment

moment of inertia

To get the dimensions of our system, we must first know the moment of inertia of the magnet. I will use to toy magnets 'geomag', that I consider as thin tall cylinders. I write ℓ their length, $S = \pi r^2$ their section (of radius $r = 3$ mm), and m their mass – implying a density $\rho = m/(\ell S)$. The moment of inertia is thus approximately

$$I_{\mathcal{A}} = \int_{-\ell/2}^{\ell/2} \rho S x^2 dx = \frac{m\ell^2}{12}\,. \tag{7}$$

With $m = 19.4$ g and $\ell = 11.6$ cm we find $I_{\mathcal{A}} \simeq 2.2\,10^{-5}$ kg.m^2.

magnetic moment

We also need its magnetic moment. We approximate it by that of a solenoid,

$$M_{\mathcal{A}} = \frac{B_{\mathcal{A}} S \ell}{\mu_0}\,, \tag{8}$$

with $B_{\mathcal{A}}$ the magnetic field inside the magnet. Taking $B_{\mathcal{A}} \simeq 0.5$ T, we find $M_{\mathcal{A}} \simeq 1.3$ A.m^2.

approximate period and deviation angle

We must check that the experiment can be run with a decent size, and a decent time... Given the values chosen above, I obtain $T \simeq 5$s – using $H = 2\,10^{-5}$ T in eq. (3), so that measuring T with O(10) periods lasts about 1 minute. For a distance between the two magnets of 50 cm (resp. 25 cm), the deviation angle is $\alpha \simeq 5°$ (resp. $\alpha \simeq 35°$): the experiment easily stands on a table.

3.2 Can we neglect the torsion torque of the wire?

Several precautions must be taken when running this experiment. First, the material for the frame should be nonmagnetic. The example shown below (Fig. 1) is built in duraluminium. Second, the torsional torque associated with the wire carying the magnet $\mathcal{A}$ should be negligeable, in comparison with the magnetic torque of eq. (1). For a full wire, it is given by

$$\Theta = G\theta I_0\,. \tag{9}$$

Here $\theta = \alpha/L$ is the torsion angle per unit length. The wire, of length L, will be in nylon (actually a fishing line).

$$G = \frac{E}{2(1+\nu)} \tag{10}$$

is the shear modulus, with E the Young modulus (between 2.6 and 3 GPa for a nylon wire), and ν the Poisson coefficient ($\simeq 0.39$ for nylon).

$$I_0 = \frac{\pi\delta^4}{32} \tag{11}$$

is the moment of inertia for the full wire. Using a fishing line of diameter $\delta = 0.16$ mm and length $L = 50$ cm, one finds $\Theta = O(10^{-7})$ N.m (for $\alpha = 1$ rad). This should be compared with the magnetic torque. With the above magnet of moment about 1 A.m^2 we have, in the presence of an ambient field $H = O(10^{-5})$ T, a magnetic torque $\Gamma \simeq 10^{-5}$ N.m (again for $\alpha = 1$ rad). We verify the hypothesis $\Gamma \gg \Theta$.

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- Kono M. (2007), *Geomagnetism in perspective*, in Treatise in Geophysics, Geomagnetism, vol 5, chap. 1, pp. 1-31, eds M. Kono & G. Schubert, Elsevier

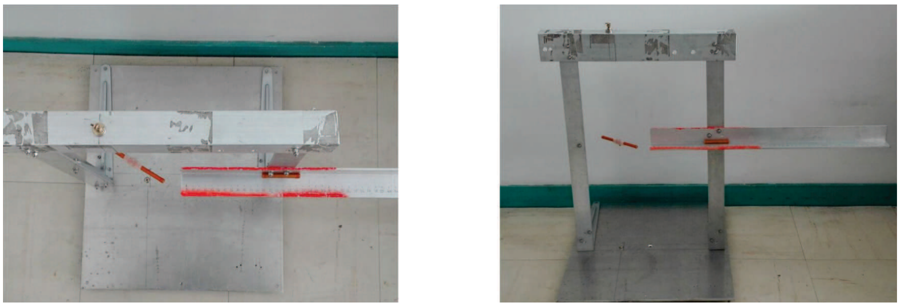


Figure 1: Photos of a prototype of the absolute intensity magnetometer, inspired by the experiment by K. F. Gauss.

Eduard **Petrovsky**

Prof. Dr.

Institute of Geophysics, Czech Academy of Sciences,
Prague

EDUCATION

- 1989-1995: Graduate study at Geophysical Institute, Acad. Sci. Czech Republic, for CSc. degree (equivalent to PhD.), thesis on *Magnetic stability of a system of fine hematite particles* defended in December 1995
- 1979-1984: University of P. J. Šafárik in Košice (East Slovakia) - 5 years study of solid state physics, namely magnetism. Final state exams in 1984, degree RNDr. (equivalent to M.Sc.)

CAREER

- Since 1985 in the Institute of Geophysics Acad. Sci. Czech Republic in Prague, Chair of Department of Geomagnetism, Chair of the Board of the Institute
- 2016: Docent in Solid Earth Geophysics, University of Helsinki, Finland

RESEARCH INTERESTS

- Experimental methods of rock magnetism, magnetic properties of rocks, minerals and synthetic samples, environmental magnetism, environmental geophysics, links to geochemistry, research of nano and microparticles for biomedical applications.

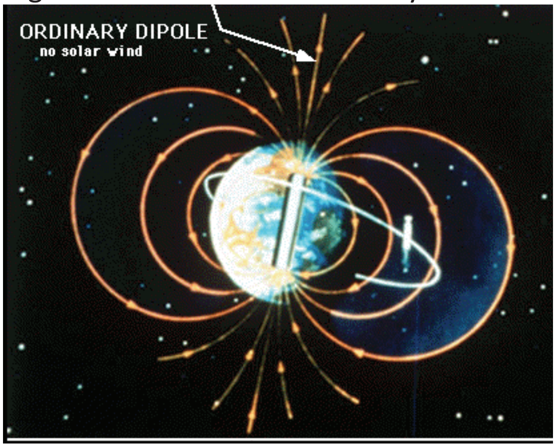
PUBLICATIONS AND SERVICES

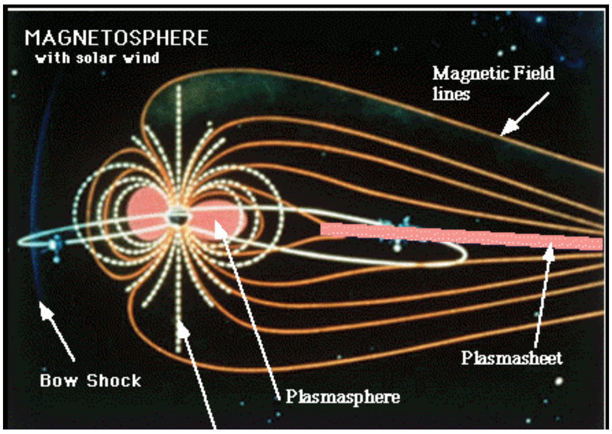
Petrovský E., Herrero-Bervera E., Harinarayana T., Ivers D. (Eds), The Earth's Magnetic Interior. Springer-Verlag, Heidelberg, Germany, ISBN: 978-94-007-0323-0

- Editorial Boards: Associate Editor of Geophysical Journal International, Technical Editor of Studia Geophysica et Geodaetica
- Guest editor of 11 special issues of international journals in 2001-2014 (Physics and Chemistry of the Earth, Journal of Applied Geophysics, Studia Geophysica et Geodaetica).
- Organization of Conferences: Since 2000 main organizer of biennial international meetings on Paleo, Rock and Environmental Magnetism (1990, 1992, 1994, 1996, 1998, 2000, 2002, 2004, 2006, 2008, 2010, 2012, 2014)
- Session Convenership: European Geophysical Society - EGS (1998, 1999, 2000, 2001, 2002, 2003); International Association for Geomagnetism and Aeronomy – IAGA (2001, 2003, 2007); Asia-Oceania Geophysical Society (2004); American Geophysical Union (2010); European Union of Geosciences (2012)
- 2011-2015: Vice-President of IAGA
- Since 2015 – President of IAGA

The importance of the geomagnetic field for life on Earth

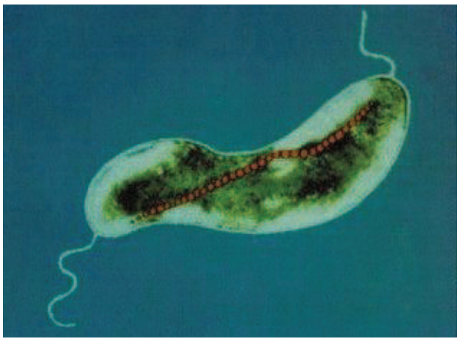
The Earth acts like a large spherical magnet: it is surrounded by a magnetic field that changes with time and location. The Earth's magnetic field, or geomagnetic field, is a field that extends from the Earth's interior out into space. It is a result of several magnetic fields generated by various sources. These fields are superimposed on and interact with each other. This field may be depicted by lines of force and it acts as a force on any substance that is able of response to it. As in physics, it acts by a torque on permanent magnet (turns the needle of a compass into the direction parallel to the lines of force) or it deflects moving charged particles from their trajectory (interaction with solar wind in the outer space). The main part of the field is generated by a geodynamo, but it is similar to that of a dipole magnet (i.e. a straight magnet with a north and south pole) located at the center of the Earth. The axis of the dipole is offset from the axis of the Earth's rotation by approximately 11 degrees. This means that the north and south geographic poles and the north and south magnetic poles are not located in the same place. At any point and time, the Earth's magnetic field is characterized by a direction and intensity which can be measured.

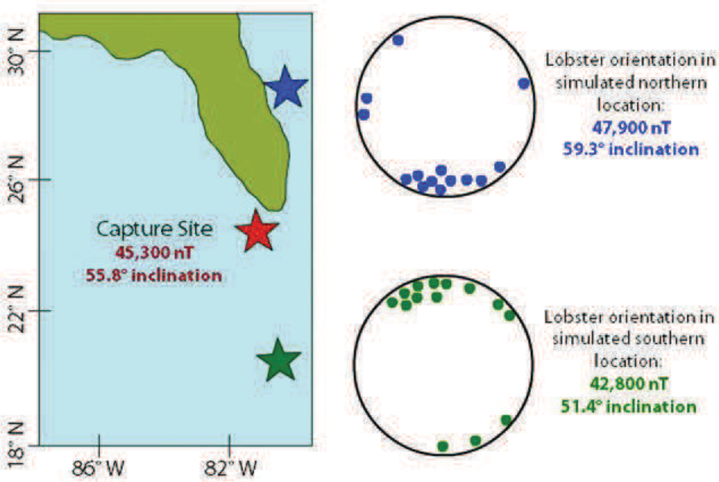




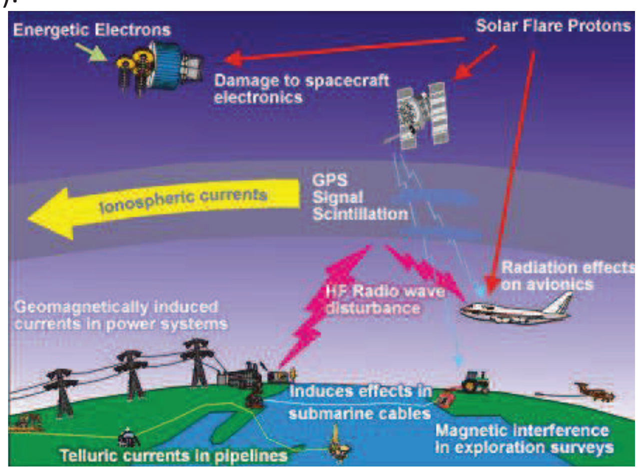
The geomagnetic field is one of the necessary prerequisites for the life on the Earth. It is not only humans who use compasses for orientation. Lines of force of the Earth's magnetic field are used for orientation by various livings as well, e.g. single-cell bacteria (magnetotactic bacteria), migratory birds, turtles, mammals, etc. However, orientation is not the only use of the geomagnetic field. The Earth's magnetic field is vital for keeping our atmosphere in place. It interacts with the solar wind – the flow of high-energetic charged particles emitted by solar eruptions, and protects the Earth's atmosphere and surface from being "burned" out. It was found that although the same stream of solar wind, hitting Mars and Earth, increased the pressure of the solar wind at both planets by similar amounts, the increase in the rate of loss of Martian oxygen was ten times that of Earth's increase. Such a difference would have a dramatic impact over billions of years, leading to large losses of the Martian atmosphere, perhaps explaining or at least contributing to its current tenuous state. After looking at the first six months of data collected by NASA's MAVEN spacecraft, sent to Mars in November 2013 to monitor its upper atmosphere, ionosphere and interaction with the solar wind, scientists say the solar wind has stripped away most of the its carbon dioxide and oxygen. Mars once had a strong magnetic field—like Earth does now—produced by a dynamo effect from its interior heat. But as the smaller planet cooled, Mars lost its magnetic field some time around 4.2 billion years ago, scientists say. During the next several hundred million years, the Sun's powerful solar wind stripped particles away from the unprotected Martian atmosphere at a rate 100 to 1,000 times greater than that of today. At that time Mars would have lost about the same amount of atmosphere that Earth has today, with its surface pressure of about 1,000 millibars. During that relatively short epoch the lakes and rivers on Mars, of which geologic evidence remains today, would have frozen and evaporated. The consequences for any life that might have existed almost certainly would have been disastrous. Today, billions of years later, the dry, red world has a surface pressure of only about 6 millibars. It is very probable that without a geomagnetic field the Earth would meet the same fate.

Thus, geomagnetic field is our umbrella protecting the life on Earth from the harmful particles heading from space. One should keep this in mind while admiring the colorful effect of the interaction of charged particles with our atmosphere in polar regions, called aurora borealis or aurora australis.





In this contribution we will present some examples of the use of magnetic orientation by living things by the Earth's magnetic field as well as the harmful effect of cosmic charged particles on both our technological systems (energetic lines, satellites) and humans (e.g., during long-distance flights over polar regions).



Prof. Angelo **de Santis**
Director of Research, Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy
Prof. University of Chieti Italy

Education

Doctor's degree in physics at La Sapienza Rome University 1984.
Full Professor Habilitation in 2012.

Research Interests

Interested in all aspects of geomagnetic field evolution, he developed original 2D and 3D techniques for regional geomagnetic field and ionospheric modelling. He has studied in depth chaos and fractal properties in the geomagnetic field and the possibility for an imminent change of its polarity.

He has been a member of the Phase A Mission Advisory Group of SWARM ESA satellite mission for the study of the Earth magnetic field, and is presently responsible of SAFE (SwArm For Earthquake study) project funded by ESA (2015-2016) and supervisor of another ESA funded Project, TEMPO

He has interest in seismology, contributing to the understanding of the possible lithosphere-atmosphere-ionosphere coupling before large earthquakes.

He has also participated to 5 expeditions in Antarctica and he was the scientific coordinator of all Italian scientific activities in Antarctica during the 1995 campaign.

Publications and Services

He has published 210 scientific/technical articles (164 international including 109 ISI papers and contributions to 22 books) and presented around 180 communications (70% international) several of which by invitation, and has tutored many (46 so far) students for graduate and PhD theses

He is Editor of three scientific Journals, and has been the reviewer for about 140 international papers (*Top Reviewer* for Tectonophysics in 2008) and Organiser/Convener in many International Conferences and Congresses

Overall scientific Activities and honors

President of EMRP (Earth Magnetism and Rock Physics) Division of European Geoscience Union (2015 to 2017).

Member of the Joint Committee INFN (National Institute of Nuclear Physics)-INGV and of the Interdivisional IAGA Working Group Education and Outreach.

Member of the International Scientific Committee of the Chinese satellite CSES Mission and of the EO Satellite Committee by ASI.

Responsible of many National and International projects funded by NATO, European Commission, ESA, Foreign Office, PNRA, Italian Ministry of Research and University and has been leader of SAGA-4-EPR Italian-Chinese project on Earthquake Recognition Anomalies, and of the WP8 "Infrastructure and Synergies" of the EC Project DS3F.

He has been a frequent visitor of the most important Academy and Research Institutions and Laboratories in Earth Science around the world (for instance in Europe: BGS (UK), IPGP (France), GFZ (Germany), ESA-ESTEC (Netherland), the University of Barcelona (Spain), Munich (Germany), Newcastle Upon Tyne (UK), Lviv Centre of Institute for Space Research (Ukraine)

The South Atlantic Magnetic Anomaly: a magnetic window from the Earth's core to space

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Istituto Nazionale di Geofisica e Vulcanologia
Roma, Italy

Abstract

At first order, the geomagnetic field resembles an inclined centered dipole. However there is a particular region, i.e. the South Atlantic Anomaly (SAA), where the field intensity is dramatically lower than expected (Fig.1). It is a very large feature at the Earth's surface, comprising the South Atlantic from Africa to South America (East-West) and from equator to Antarctica (North-South). With the field being much lower than in the rest of the world, it is a region where most charged particles coming from the Sun enter into the high atmosphere during magnetic storms.
This feature is not only characteristic of the present geomagnetic field but it has been present almost during the geomagnetic historical-instrumental era, i.e. the last 400 years. A very recent study analyses the antiquity of this anomaly by means of paleomagnetic data (from 1000 to 1600 AD) inferring the persistence of the anomaly also during those old epochs.

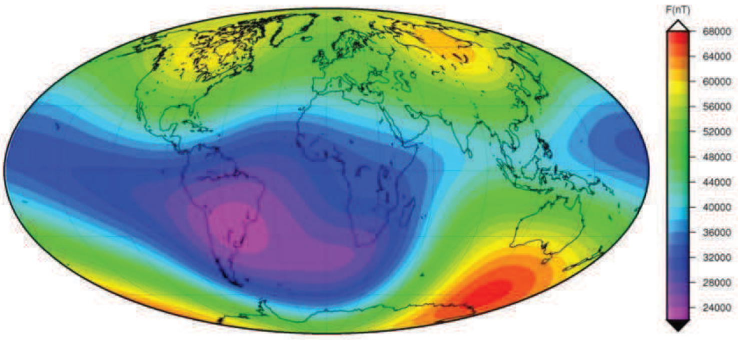

Fig.1 The present state of the geomagnetic field. The South Atlantic Anomaly is the largest feature at the Earth's surface, that could be precursor of a geomagnetic transition (reversal or excursion).

The region over the SAA (e.g. that confined by 32000 nT isoline; Fig.1) is characterized by a high radiation close to the Earth's surface due to the very weak local geomagnetic field and, consequently, it represents the favorite entrance for high-energy particles in the magnetosphere, together with the polar regions. This effect is not only problematic at high altitude, where the satellites or other objects orbiting around the Earth are affected by a high density of cosmic ray particles, but also at surface level, where the communications can be disturbed due to the induced currents in transmission lines during geomagnetic storms. As examples, the International Space Station requires extra shielding to deal with this problem and the Hubble Space Telescope interrupts data acquisition while passing through the SAA. Moreover, astronaut health is also affected by the augmented radiation in this region that is thought to be responsible for the peculiar 'shooting stars' happening in their visual field. Most of Low Earth Observation Satellites can have electronic failures particularly over the SAA (Fig.2).

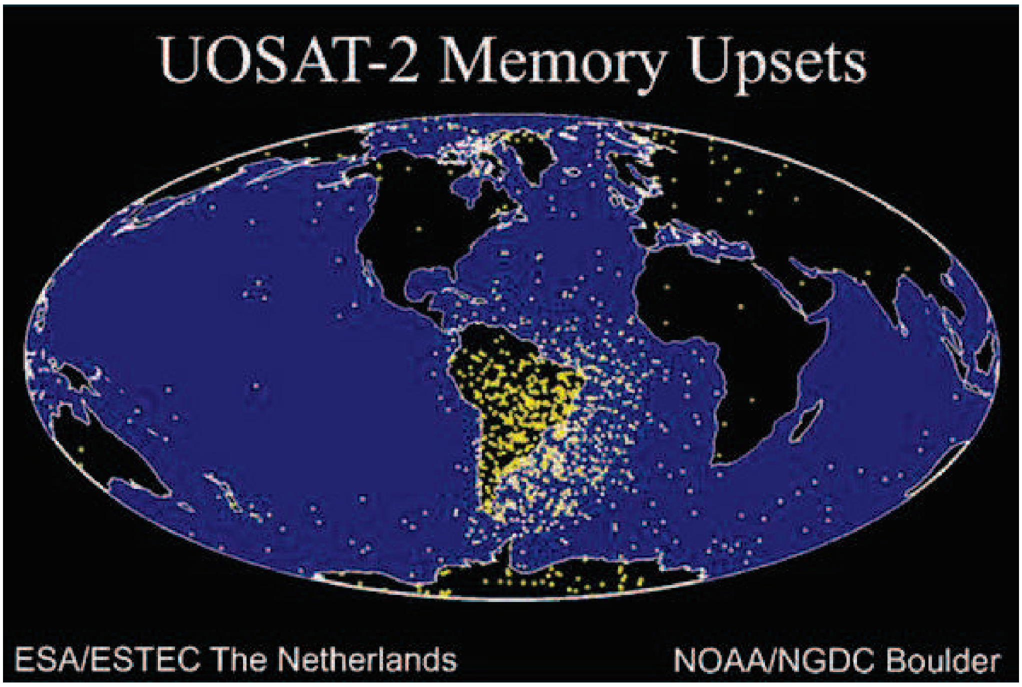

Fig.2 Memory failures of UOSAT2 satellite: most of them occur over the South Atlantic Anomaly.

Thanks to the present high resolution geomagnetic models, we know the inner origin of the SAA. The SAA at the Earth's surface is the response of an inverse flux path at the Core Mantle Boundary (CMB) of the radial component of the geomagnetic field located approximately under the South Atlantic Ocean, generating the hemisphere asymmetry of the geomagnetic field. The SAA behavior seems to indicate that this asymmetry could be connected to the general decrease of the dipolar field and to the significant increase of the non-dipolar field in the Southern Atlantic region.

Many aspects of the SAA are intriguing and worth studying.

It can be simply represented by a magnetic pole moving at the CMB depth in a circular fashion with periodicity of around 800 years, contributing to the most important feature of the secular variation, i.e. the western drift of the geomagnetic field.
Finally, what has been recently found is that the SAA area has increased significantly during the last few hundreds of years, as a possible indication of a potential change of polarity in the close future.

How the present field will continue to decrease and possibly to reverse can be understood by studying the SAA with great attention, especially from observatories and satellites. The present three-satellite mission Swarm by ESA will greatly contribute to this study by providing clear answers to questions related to the next geomagnetic field evolution.

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at Tinos (Greece) with a taphon

Education:
Secondary school in Italy and the USA (American Field Service Exchange Student).
University studies at the University of Paris, PhD in Solid State Physics.

Career
All my scientific career has been spent as an employee of the French Atomic Energy Commission, first as a researcher in the Physics Department then in the field of geophysics. In 1985, I was appointed as Deputy Director of the Centre des Faibles Radioactivités and Head of the Department of Earth Sciences. I created and was first director of the Laboratoire de Modélisation du Climatet de l'Environnement, which was later united with the Centre des Faibles Radioactivités to form the present Laboratoire des Sciences du Climat et de l'Environnement (LSCE).After 3 terms as Head of Department (12 years) I stepped down to a researcher position again, until I retired. I have been an "emeritus" researcher since then, and gradually reoriented my activities towards education.

Research Interests:
After my PhD I spent a few years working with critical phenomena (scattering of laser light by critical fluids) then moved into the field of geophysics.
My main interests in this new field has always been linked to the magnetic properties of sediments and igneous rocks (paleomagnetism), used with several objectives: geodynamical reconstructions (particularly in the Eastern Mediterranean and the Andean Cordillera), reconstruction of the history of the Earth's magnetic field (including the morphology of field reversals) and more recently reconstructions of environmental and climatic changes on a global scale.
I have published over 200 articles in international scientific journals and a few general popular articles in different journals.
Supervisor of 12 PhD students, and 8 Masters of Science

Educational activities and Honors:
Founder and Chairman, Education Committee of the European Geosciences Union
Participant to different National and International Education Committees
Union Service Award for creating the Committee on Education of EGU
Excellence in Geophysical Education Award of the American Geophysical Union
Fellow of the American Geophysical Union (AGU).
F. Holweck prize of the French Academy of Science
Holmes Medalist of the European Geosciences Union

KISSEL Catherine

Dr.

Laboratoire des Sciences du Climat et de l'Environnement,
Université Paris-Saclay

EDUCATION

Dec. 1986: Thèse d'Etat. "Apport du paléomagnétisme à la compréhension de l'évolution géodynamique tertiaire du domaine égéen de l'Epire à l'Anatolie occidentale"

May 1984 : McS. "Evolution Géodynamique de la Grèce nord-occidentale depuis l'Oligocène: apport du paléomagnétisme". Univ. Pari-Sud.

CAREER

1987- Research Scientist, French Atomic Energy Commission
2015- Head of the CliMag team at LSCE
2011-2015 deputy responsible for the Theme « Climate archives » of LSCE
2008-2011 Head of the ChronoMag group (Environmental Magnetism and Chronology) at LSCE
1997-2007 Head of the Environmental Magnetism group at LSCE
1987-1997 Head of the Paleomagnetic group of the Centre des Faibles radiocativités.

RESEARCH INTERESTS

Paleomagnetism, Earth magnetic field, Environmental Magnetism, Rock Magnetism, Paleoceanography

PUBLICATIONS AND SERVICES

Laj C., and Kissel, C., An Impending geomagnetic transition? Hints from the past *Frontiers in Earth Science, 3:61.* doi: 10.3389/feart.2015.00061 (2015).

Kissel, C., Rodriguez-Gonzalez A., Laj C., Perez-Torrado F., Carracedo J. C., Wandres C., Guillou, H. Paleosecular variation of the earth magnetic field at the Canary Islands over the last 15 ka. *Earth Planet. Sci. Lett. 412, 52-60 (2015).*

Kissel, C., Van Toer, A., Laj, C., Cortijo, E., Michel, E. Variations in the Strength of the North Atlantic Bottom water during Holocene. *Earth Planet. Sci. Lett*. 369-370, 248-259, 2013.

Participation to the scientific documentary: "La terre perd le Nord"
(https://www.youtube.com/watch?v=CnW6sR5FXBY)

Is the Earth's magnetic field heading for a flip?
Hints from the past

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Since the pioneering work of Carl Friedrich Gauss in 1838, we know that the magnetic field of the Earth originates from its interior, and modern studies have proved that its source lies in the liquid part (mostly iron) of the core, some 3000 km below its surface. The flow in the liquid iron in this core creates electric currents, which in turn create the magnetic field. This is referred to as the Earth's Dynamo, or geodynamo.

The core is much too deep within the Earth for any direct measurement to be made. But fortunately the mathematical description of the magnetic field at the surface may be extended downwards so that by observing changes in the geomagnetic field, it is possible to infer fluid flows in the core.

This mathematical extension demands some assumptions and complicated mathematical processes and therefore still has some uncertainties, despite the use of powerful computers. However, we know with some accuracy, at least one of its main characteristic, namely that if we could magically, stop the engine which drives the flows in the liquid core, they would then progressively stop, eventually losing their orderly pattern, causing the magnetic field of the Earth to progressively disappear over about 20,000 years. The intensity of the present-day field is of the order of 40,000 nT (nano Tesla), so the field would decrease in intensity at an average rate of 2 nT per year. Geophysicists call this kind of decrease, decay by diffusion.

Which are the main characteristics of the present day geomagnetic field?

As we may have been taught in High School, the Earth's magnetic field closely resembles that which would be created by a giant bar magnet, placed at the centre of the Earth and tilted by about 11,5° from its axis of rotation (Figure 1).

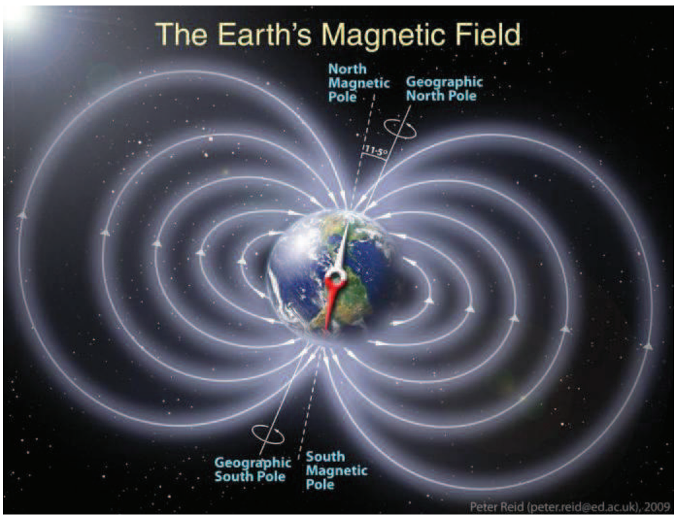


Fig. 1: (*Figure courtesy of Peter Reid, University of Edinburgh*)

This kind of field is called a “dipolar field”, as it has two poles, North and South. This is only a first order approximation, as the geomagnetic field is not stable, as would be the case if it were created by a static bar magnet. On the contrary, fluctuations and instabilities exist in the flow of molten iron in the fluid core, that in turn create fluctuations in both the direction and intensity of the geomagnetic field.

On a human time scale, these fluctuations are relatively small, and have been termed “the secular variation” of the geomagnetic field. Measurements by the first magnetic observatories, in London and Paris, have shown that in the last 200 years, declination and inclination (Figure 2) have changed by about 35° and 15° respectively, with large loops.

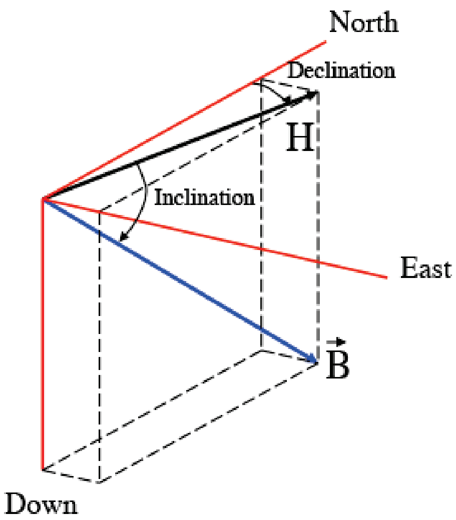


Fig. 2: Definition of magnetic declination and inclination. Declination is the angle between the geographic north and the projection onto the horizontal plane of the magnetic vector. Inclination is the angle in the vertical plane of the magnetic vector with the horizontal. By convention, inclination is positive (negative) when the vector points downwards (upwards).

We also know from many measurements, that the field at the Earth Surface is not as regular as that which would be expected if created by a bar magnet. On the contrary, there are many geographical zones where the field intensity is larger, and other zones where it is smaller than the average (one of these zones is called the South Atlantic Anomaly (SAA) which is rapidly evolving and will be discussed below). Figure 3 shows (in blue) the geographical extend of the SAA) as detected by the ESA Swarm satellite.

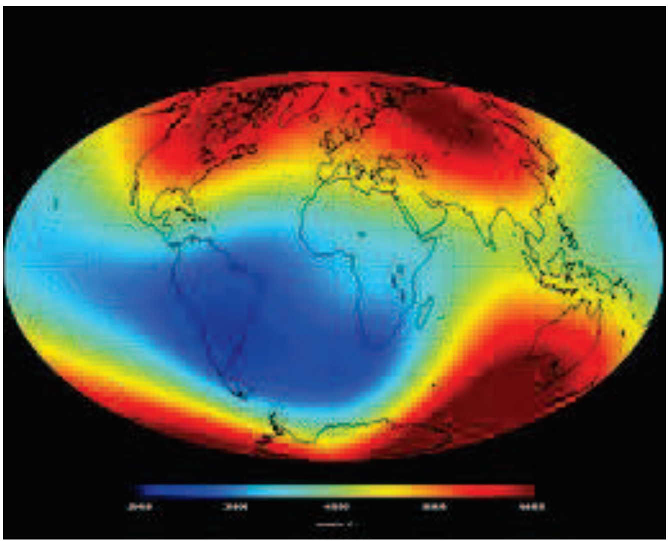


Fig.3 The South Atlantic Anomaly (Credit: European Space Agency)

Furthermore, and most importantly, since the first measurements made by the observatories, the Earth's magnetic field intensity has been diminishing at an average rate of 5% per century, i.e. an order of magnitude faster than the rate expected for simple decay by diffusion. This decrease has been documented at this same alarming rate for at least the past 400 years, and numerical simulations show that it is most likely to continue for at least the next century (no prediction is possible beyond that, from the present state of knowledge).

A famous British geophysicist, David Gubbins, noted (Gubbins, 1987) that a patch of flux (magnetic change) below the South Atlantic Anomaly (which extends from Zimbabwe to Chile, and is particularly significant beneath southern Africa) had an opposite sign to that expected for a dipole field in the Southern Hemisphere, when extrapolated to the core mantle boundary . This means that if we were able (again by some magic) to put a compass 3000 km deep under the southern tip of Africa we would see that it actually points South!. Gubbins suggested that "the present fall of the dipole field is directly related to the intensification and southward migration of this and other similar patches and that the fall may occasionally lead to polarity reversal". The presence of the SAA has been confirmed by many recent geomagnetic results, including the latest results from the ESA magnetic satellite Swarm (2015) (Figure 3, which shows, in blue, the extension of the zone where the geomagnetic field intensity is significantly lower than the average).

What is a polarity reversal and how do we know about the past?

One may imagine that apart from these fluctuations, the field is stable. But this is only true on a human time scale. On the geologic time scale the geomagnetic field is on the contrary very unstable! If you had been alive about 800.000 years ago, a magnetic compass in your hands would have indicated the South not the North as today: the Earth's Magnetic field has actually flipped in the past 800.000 years!

The evidence for these flips is not direct, and arises from the study of the magnetic properties of rocks, in both volcanic and sedimentary sequences (the science studying these properties is called paleomagnetism). The geomagnetic field determines the direction and the intensity of the magnetization of lavas when they cool down after being erupted, because the magnetic moments of tiny magnetic particles contained in the lavas align themselves along the geomagnetic field, much like a magnetic compass. When the lava solidifies at a definite temperature the magnetization is "frozen-in" and preserves a record of the orientation of the past geomagnetic field. When sediments settle down, the tiny magnetic particles deposit with their magnetic moment aligned with the geomagnetic field and they preserve this direction with an intensity proportional to the field strength when the sediment consolidates or changes into a solid sedimentary rock.

So we know today that every so often - of the order of a few hundred thousands years or so - the field has flipped over many times. Sometimes it stayed in the new orientation and this is called a reversal, sometimes it flipped back immediately (on a geological time scale!) and this is called a geomagnetic excursion. The last reversal, called the Matuyama-Brunhes reversal after the names of two very famous geophysicists in Japan and France, occurred 780,000 years ago, the last two excursions occurred about 41,000 and 34,000 years ago, and have been named the Laschamp and Mono Lake excursions, after the names of the localities where they were first discovered.

Geophysicists have identified hundreds of reversals and excursions over the past 3 billion years, so that on the geological time scale, reversals and excursions are the rule, not an exception of the geomagnetic field. Yet, we still don't know much about how these instabilities actually take place, because it is very difficult to find suitable outcrops having registered the phenomenon.

We have some more-or-less-precise ideas on how long a reversal or excursion lasts, usually of the order of a thousand years, with possible differences for different reversals. We don't know whether the field retains its dipolar nature during the reversal itself; most geophysicists believe it changes into a multipolar field, but evidence also exists for a simpler geometry of transitional fields during the reversal or excursion.

What we do know with certainty is that the overall intensity of the field decreases strongly during a reversal or an excursion, and that this may be the most important characteristic of these field instabilities. The rate at which the intensity of the field decreases is very difficult to establish and it has been well documented only as far back as the Laschamp excursion and with less accuracy to the Brunhes-Matuyama reversal.

Also, we know from numerical simulations that immediately prior to and during geomagnetic reversals, there are patches of reverse polarity which form near the equator and migrate towards the polar regions.

This is exactly what is observed for the South Atlantic Anomaly (SAA) today! This reverse patch carries the main responsibility for the decrease in the global geomagnetic field, and this is similar to scenarios appearing in numerical simulations immediately prior to geomagnetic reversals.

Moreover, it has been noted that the field has reversed every 200,000-300,000 thousand years on average, over the past 5 million years, but that the last reversal occurred 780,000 years. So, the next reversal seems to be very overdue!

In summary: we currently observe an extremely rapid decrease in geomagnetic field intensity coupled with at least one patch of reverse flux (the SAA) that is migrating southward, whilst an unusually long period of time has elapsed since the last geomagnetic reversal.

So, are we heading towards a geomagnetic flip?

We may examine this hypothesis by comparing the present rate of change with what can be observed from the past. We base our observations on a paleomagnetic stacked record of geomagnetic field intensity that extends over the past 75 kyr (GLOPIS-75) (Laj et al, 2004) combined with records of the ^{10}Be (Muscheler et al., 2004) and ^{36}Cl (Wagner et al., 2000a) concentrations in the Greenland ice cores. ^{10}Be and ^{36}Cl measurements enable us to reconstruct the evolution of the geomagnetic field intensity in an indirect, but totally independent way.

Figure 4 shows the GLOPIS-75 record of the changes of the geomagnetic dipolar field intensity over the past 75 kyr, together with a zoom over the interval 20-50 kyrs (the time axis in this figure is that of the GICC05 age model, which is the most accurate age model available for this time interval). In the zoom, we also show the geomagnetic field intensity as derived from ^{10}Be and ^{36}Cl studies.

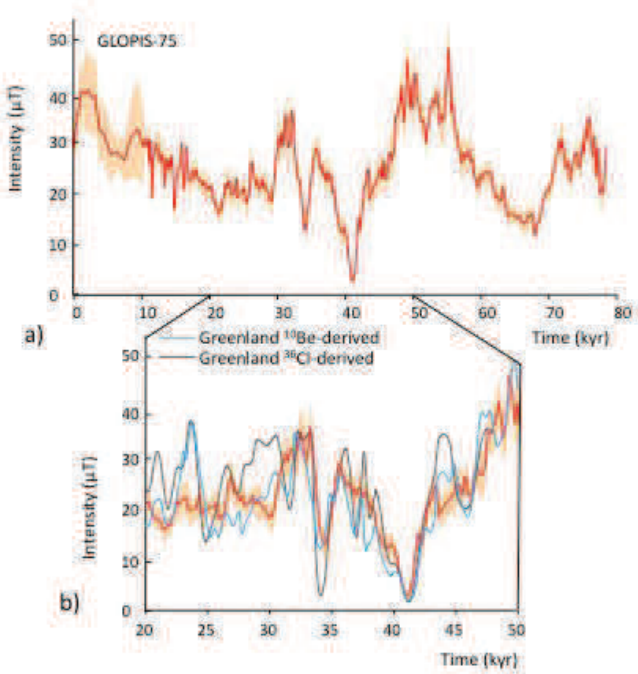


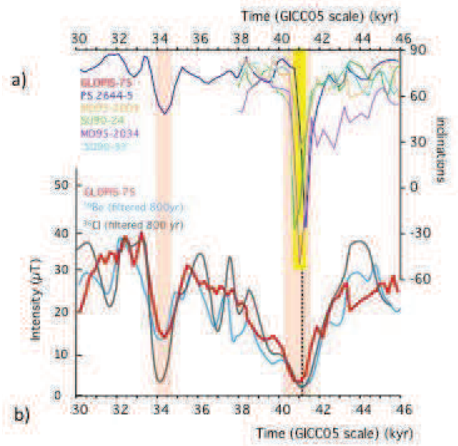
Fig. 4: a) GLOPIS-75 record for the 0-80 kyr time interval reported versus the Greenland ice GICC05 age model. b) comparison for the 20-50 kyr time interval of GLOPIS-75 record (in red) with the two curves derived from ^{10}Be (turquoise) (Muscheler et al., 2004) and ^{36}Cl (grey) (Wagner et al., 2000a) from Greenland.

There is an impressive agreement between the long-term features of the three records, which is a strong evidence that they robustly reflect variations in the dipolar field intensity.

The long-term pattern starts with a plateau around the present-day value between 70 and 72 kyr, followed by a decrease toward an intensity minimum (15 µT) between 69 and 65 kyr and then, a broad maximum reached (43-46 µT) between 56 and 48 kyr. The following period up to ~ 33 kyr is punctuated by two pronounced and distinct intensity lows corresponding to the Laschamp and the Mono Lake excursions. After a new short increase to ~ 35 µT at 32-31 kyr and a plateau at ~ 23 µT between 29 and 21 kyr, the intensity increases continuously to about 43 µT (in the last millennia the data comes from volcanic studies). The low intensity value at around 65 kyr does not correspond to any directional change.

The orange bars in Figure 5 indicate the time interval of the geomagnetic intensity lows, and the bright yellow bar, those characterized by negative inclinations (changes in inclinations are obtained only for the Laschamp excursion and they are indicated in detail for 5 records obtained from North Atlantic cores).

Figure 5: Inclination records of cores from North Atlantic used for NAPIS-75 and also included in GLOPIS-75 stack (upper panel). Only one of the core (PS2644-5) shows a slight shift in inclination around the Mono Lake excursion. Lower panel: paleointensity records from GLOPIS-75 (in red), ^{10}Be (in turquoise) and ^{36}Cl (in grey) - derived paleointensity curves from Greenland ice, both filtered at 800 years. The orange bars indicate the time interval characterized by geomagnetic dipole lows and the bright yellow bar is for the time interval with negative inclinations during the Laschamp excursion (centered at the vertical dashed line).



With this precise age model we can begin to evaluate the duration of the two excursions, using the duration of the intensity low and in the case of the Laschamp excursion, also the duration of the directional changes (Laj and Kissel, 2015).

In Figure 6 we estimate these durations calculated as the width at mid-height for the Laschamp and Mono Lake excursions. It can be seen that small discrepancies among the paleomagnetic and cosmogenic isotopes records lead to an estimation of about 1100 years for the Mono Lake and 1500 to 3000 years for the duration of the intensity low, while the duration of the directional change for the Laschamp excursion is more precise and it is of 640 years for the entire N-R-N cycle.

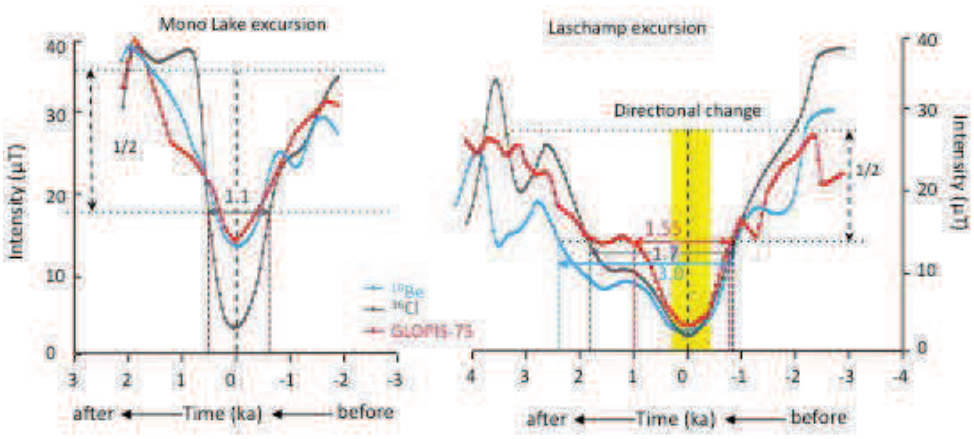


Fig. 6: Mono Lake (left) and Laschamp (right) excursions recorded in GLOPIS-75 (Laj et al., 2004) and in ice via the ^{10}Be (Muscheler et al., 2004) and ^{36}Cl (Wagner et al., 2000a) concentrations in Greenland ice reported versus a time scale where 0 is the occurrence of the geomagnetic dipole minimum. Negative (positive) numbers are for the time before (after) the excursions. The yellow bar indicates, accordingly to Figure 4, the duration of the inclination change during the Laschamp excursion. The duration of the geomagnetic dipole lows are evaluated as the width at mid-height (indicated by the two dashed lines and "1/2"). This duration during the Laschamp excursion is reported for each record (with the same color as the records themselves). For the Mono Lake excursion it is reported for the ^{36}Cl record because it is the most detailed one.

Finally, we can calculate the rate of change of the field intensity during the different stages of the two excursions (Figure 7):
First for the Laschamp excursion, from 52 to 44 kyr, we observe a rate of change of 4nT/yr, which progressively increases to 7.7 nT until 42 kyr and in the final phase attains 16.4 nT/yr. This is roughly the value of the rate of decrease of the field intensity today! And, in parallel, the extension of the SAA also increases!
The recovery phase of the Laschamp is much slower, but the rate of decrease for the Mono Lake excursion is even higher: 24.2 nT/yr!

However, during the intensity low at around 65 kyr (that does not correspond to any directional change) the maximum recorded rate of change was 5.6 nT/yr (Figure 4).

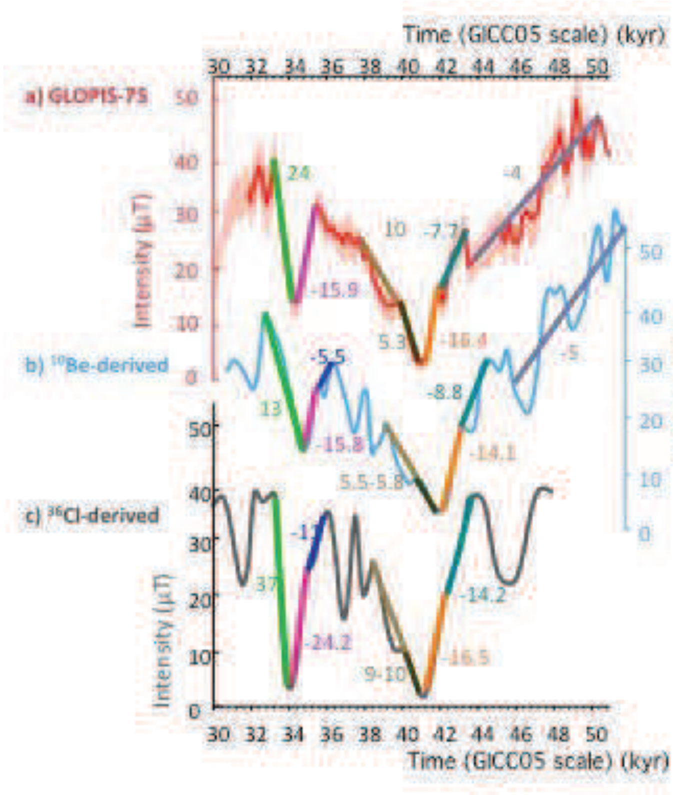


Fig. 7: GLOPIS-75 (a), Greenland ^{10}Be (b) and ^{36}Cl (c) derived curves on which the decay and growth rates of the geomagnetic dipole intensity are illustrated as colored lines. The numbers reported with the same colors as the lines are for the corresponding rates of change (in nT/yr) of the dipole field intensity (negative for decay and positive for growth).

Conclusions

We have shown that some of the characteristics of the present day geomagnetic field are similar to those observed for the Laschamp geomagnetic excursion.

Firstly, the very high rate of change of the field intensity today is similar to what happened some 42,000 year ago.

Moreover, an independent reconstruction of the global morphology of the field during the Laschamp excursion using a statistical Bayesian inversion of several paleomagnetic records used in GLOPIS 75 (Leonhardt et al., 2009), has given a scenario in which reverse magnetic field patches at the core-mantle boundary, first formed near the equator and then moved pole-ward. This is the same scenario as that described by David Gubbins for the present geomagnetic field! It is thus tempting to interpret the changes in the present field as an indication that at least an attempt towards a geomagnetic transition may have begun!

So, what if the present day field behaves exactly as during the Laschamp excursion?

This is a hypothesis of course, a reasonable one, but a hypothesis nevertheless! Let's examine it in more detail. (Laj and Kissel, 2015) The directional changes, which are centered on the minimum of intensity, only last 640 years, and begin when the intensity of the field is about half its non-transitional value. Assuming that the field will continue to decrease at the present rate, it would take about 1000 years to reach half its present value, or less if an acceleration takes place, as suggested by the increase in the rate of expansion of the SAA (Pavon-Carrasco and De Santis, 2016). Even assuming an increase of the rate of decrease of a factor of 2, it would take some 500 years for the directional change to start to be significant. The directional change would then last about 600 years. So we should have no worries for us, our children or grand-children!

But this is not a purely geologic phenomenon, there is a human perspective involved! If such a phenomenon had occurred in 1492, i.e. about 600 years ago, in the middle of a chaotic geomagnetic field, would the Italian navigator, Cristoforo Colombo (Christopher Columbus) have discovered America?

Acknowledgements: We wish to thank Prof. Chris King for his careful and constructive reading of the manuscript.

Suggested readings:

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EDUCATION

- BSc Honours in Geology, 2(2); University of Bristol, 1968 - 1971.
- MSc ‘Sedimentology’, (Distinction); University of Reading, 1976 - 1977.
- Postgraduate Certificate in Education; University of Keele, 1977 - 1978.

CAREER

APPOINTMENTS HELD

- Oct 1971 - July 1976 Geologist, De Beers Consolidated Mines Ltd., Kimberley, South Africa.
- Sept 1978 - July 1996 School Teacher, Altrincham Grammar School for Boys,
- Sept 1996 – Aug 2002 Science Education Lecturer: Earth sciences, Keele University
- Sept 2006 – Dec 2015 Professor of Earth Science Education
- Jan 2016 – today Emeritus Professor of Earth Science Education
- Sept 1999 – Dec 2015 Director of the Earth Science Education Unit at Keele University

MEMBERSHIP OF LEARNED BODIES AND PROFESSIONAL ASSOCIATIONS

- Chair of the International Union of Geological Sciences (IUGS) Commission on Geoscience Education
- Adviser (past-Chair and instigator) of the Council of the International Geoscience Education Organisation
- Chair of the Earth Science Education Forum (England and Wales) (ESEF (E & W)).
- Chair of Examiners, Welsh Joint Education Committee (WJEC) Geology ‘A’ level Examination Committee.
- Fellow of the Geological Society.

OTHER DETAILS OF CAREER

- Leader of the Earthlearningidea team, publishing Earth science activities for the Earthlearningidea website
- Educational Consultant to the ‘Building Earth Science Education Resilience’ group

RESEARCH INTERESTS

- the development of Earth science teaching.
- monitoring a national programme of Earth science INSET.
- misconceptions in Earth science understanding.
- the international development of Earth science teaching

PUBLICATIONS AND SERVICES

224 publicatons including: 8 authored books, 5 edited collections, 8 chapters in books, 32 publications in peer-reviewed journals, 128 other journal articles and 43 articles in edited collections.

AWARDS AND HONORS

- 2003 – winner of the Geological Society’s ‘Distinguished Service Award’

- 2012 – winner of the Geologists' Association's 'Halstead Medal'

SUGGESTED READINGS (Chapters in books)

- King, C. (2017) *Fostering deep understanding through the use of geoscience investigations, models and thought experiments – the Earth Science Education Unit and Earthlearningidea*. In Vasconcelos, C. (ed) *Geoscience education: trends and approaches*. Dordrecht: Springer.
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- King, C. (2013). *Using Research to Promote Action in Earth Science: Professional Development for Teachers.* In, Vincent Tong (ed) *Geoscience Research and Education*. 311-334. Dordrecht: Springer. ISBN 978-94-007-6942-7

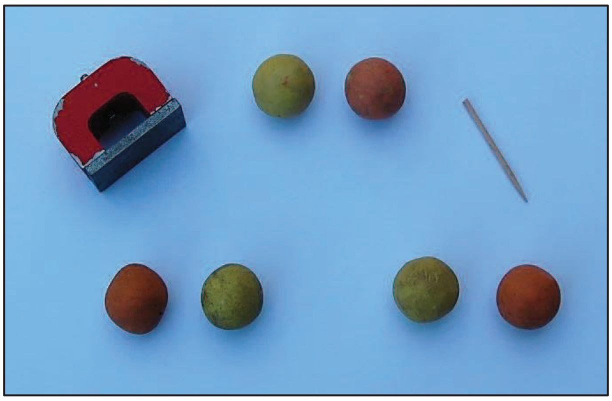
Classroom modelling activities to teach about the Earth and its magnetism

Chris King,
Keele University, UK

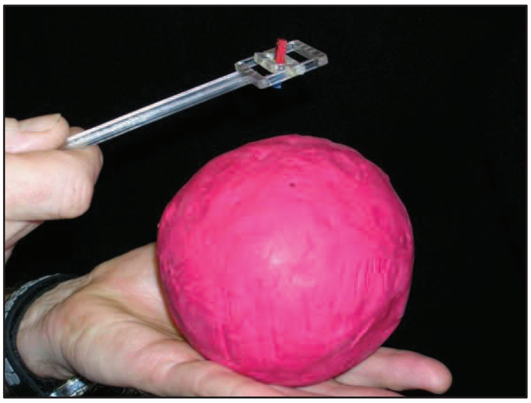
One hour

How can we teach that the Earth has a core and that the core has magnetic effects? We can begin with clay balls to encourage scientific discussions in our pupils, building up into a model 'magnetic Earth' that you can take away with you for testing and teaching. It is the Earth's magnetism which has produced the magnetic stripes we can find on the ocean floor – so how can we demonstrate to our pupils how the stripes form and can be detected? Even more, how can we show that the stripes provide key evidence for our understanding of how oceans grow and how the Earth's plates move? These activities and many more can be found on the Earthlearningidea website free to download and easy to use.

Join us for the discussions about how to use classroom modelling of the Earth's magnetism most effectively and take away your souvenir 'Magnetic Earth' to help you and your pupils to remember about the Earth's magnetism for ever more.

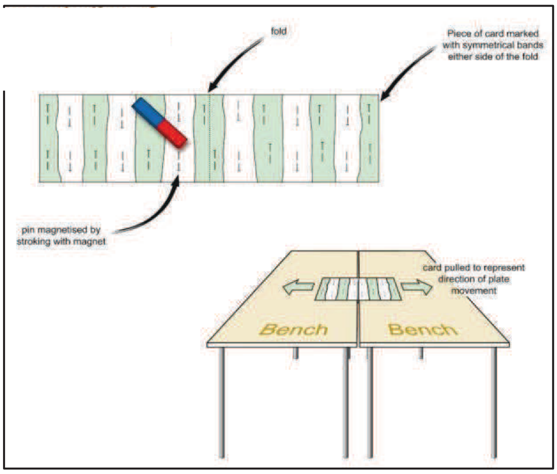


Clay balls



Magnetic Earth

Frozen magnetism



Magnetic stripes

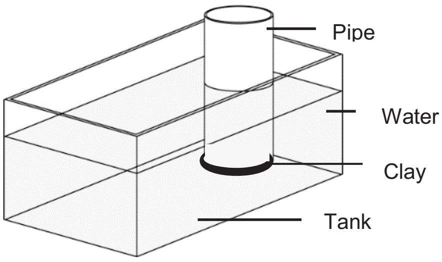
Using demonstrations of the Earth, atmosphere and oceans to teach thinking and investigation skills

Chris King,
Keele University, UK

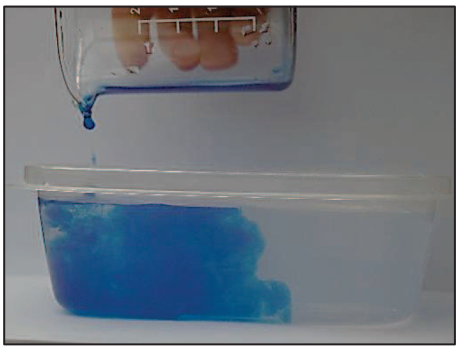
One hour

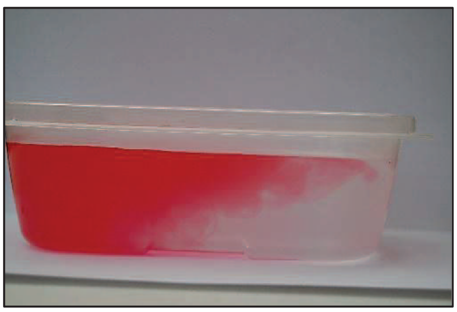
Join in the discussions about how we can model Earth, atmosphere and ocean activities in the classroom and test some of the activities yourself. Classroom modelling activities can be used to engage pupils, to develop their thinking skills and to investigate the dynamic Earth in the same way as geoscientists, if we use the right questions to promote the best kinds of discussion. The activities used today, and many more, can be found on the Earthlearningidea website – free to download and easy to use.

So do join us for this interactive session where your own participation is a key factor in the presentations. You will be able to take the activities and use them with your pupils in class as soon as you return to school – and run the activities in ways that your pupils will probably never forget.



Atmosphere and ocean set up





Atmosphere and ocean in a lunch box

Modelling interactions between the atmosphere, hydrosphere, lithosphere and biosphere