Course title: Earth's climate and its past, present, and future changes

Modality: CFA- Advance Training

Orientation:

Ocean Observation and Global Change
Sustainable use of Marine Resources
Integral Management of the Sea
Technological progress. Engineering and Business Management

Dates: 3-9-10-16 December and 12-14-18-20-24-25-26 January

Timetable: 11:00-13:00h (3-9-10-16 D, 12-14-18 J), 11:00-14:00h (20J), 11:00-12:00 (24-25-26 J) (Spanish time)

Duration: 20 horas

Location: Universidade de Vigo, Campus Lagoas Marcosende.

Language: English

Academic coordinator:

Name	Institution	e-mail
Gianluca Marino	Universidade de Vigo	gianluca.marino@uvigo.es

Lecturers:

Name	Institution	e-mail
Alfio Alessandro Chiarenza	Universidade de Vigo	a.chiarenza15@gmail.com
Alvaro Fernandez Bremer	Instituto Andaluz de Ciencias de la Tierra (CSIC)	alvaro.bremer@csic.es
Elisabeth Losa Adams	Universidade de Vigo (external collaborator)	elosa@uvigo.es

General description:

Climate change is progressing at unprecedented pace, thereby posing major scientific, economic, and societal challenges. In summer 2021, the latest report of the Intergovernmental Panel on Climate Change (IPCC) was released. Consensus among based on the scientific evidence assessed therein that human activities and the associated greenhouse gas emissions are the ultimate cause of the ongoing global warming. In addition, the report signals that global temperature is likely cross the 1.5℃ threshold in the next few decades. The scientific community is therefore faced with a pressing demand for deciphering the impacts of a global temperature rise by 1.5℃ (or more) above pre-industrial levels.

Our ability to address this problem hinges on the knowledge of how: (*i*) the atmosphere, hydrosphere, cryosphere, land surface, and biosphere function as an integrated and synergistic system; (*ii*) the various forcing, feedback, and response mechanisms – each operating at a characteristic timescale – produce a continuum of global climate variability; and (*iii*) climate change and variability depend on the underlying climate state. Although there is substantial direct observation that documents recent and ongoing patterns of climate change and variability, the somewhat more fragmented and proxy-based evidence of past climate change – the so-called palaeoclimate record – has proven essential to provide a comprehensive view of the temporal and spatial scales of natural (pre-anthropogenic) climate fluctuations and their dependence on the underlying climate state.

This postgraduate course covers a broad spectrum of topics in climate science. It provides a comprehensive overview of the Earth's climate system based on the physical principles of planetary climate as well as on the evidence of climate change and variability from both instrumental and palaeoclimate records. The course shows how this wealth of information is central to hone the projections of future climate change and to effectively size climate mitigation strategies.

Contents:

Lectures:

Part I | Introduction to Climate Science

1. 1. Climate science: principles and methods;
2. 2. Climate change versus climate variability;
3. 3. The Earth's energy budget: forcing, feedback, and response mechanisms;
4. 4. The metrics of climate change: (*i*) transient climate response; (*ii*) equilibrium climate sensitivity; and (*iii*) Earth system sensitivity.

Part II | Tectonic-Scale Climate Change

1. 5. Plate tectonics, weathering, CO_2, and long-term climate;
2. 6. Greenhouse and icehouse climates;
3. 7. Examples of climate change at tectonic timescales.

Part IV | Orbital-Scale Climate Change

1. 8. Astronomical control of solar radiation;
2. 9. Insolation control of climate;
3. 10. Examples of orbitally paced cyclicities in climate change.

Part V | Millennial- and centennial-scale climate variability

1. 11. Patterns and mechanisms of sub-orbital climate variability;
2. 12. The roles of the Atlantic Meridional Overturning Circulation, Northern Hemisphere ice sheets; and solar output;
3. 13. Examples of centennial- to millennial-scale climate change.

Part VI | Historical Climate Change

1. 14. Humans and preindustrial climate;
2. 15. Climate of the Common Era.

Part VI | Future climate change

1. 16. The 1.5°C warming problem and the "climate thresholds";
2. 17. CO_2 emissions and ocean acidification;
3. 18. Mitigation strategies.

Seminars:

1. 1. Climate, water, and weathering from extra-terrestrial environments (Dr Elisabeth Losa Adams, external collaborator Universidade de Vigo, Spain);
2. 2. Stalagmite fluid inclusions and what they tell us about tropical temperature and hydrologic change across the last glacial termination (Dr Alvaro Fernandez Bremer, Juan de la Cierva Fellow, Instituto Andaluz de Ciencias de la Tierra (CSIC), Granada, Spain);

3. 3. How warm was the tropical ocean during the Cretaceous super-green house? (Dr Alvaro Fernandez Bremer, Juan de la Cierva Fellow, Instituto Andaluz de Ciencias de la Tierra (CSIC), Granada, Spain);
4. 4. Climatic drivers behind the Cretaceous–Paleogene mass extinction (Dr Alfio Alessandro Chiarenza, Juan de la Cierva Fellow, Universidade de Vigo, Spain).

Teaching methodologies:

The course contents are developed using topical lectures, discussion groups, flipped classrooms, practical exercises, and presentations.

Evaluation system:

A final presentation and/or a short report on a topic related to the course contents.

Brief CV of the lecturers:

Gianluca Marino (coordinator and lecturer) is a Distinguished Researcher and a Beatriz Galindo Fellow at the Universidade de Vigo and Honorary Senior Lecturer at the Research School of Earth Sciences, the Australian National University (Australia). Previously, he has worked at the Australian National University, Universitat Autònoma de Barcelona (Spain), and at Utrecht University (The Netherlands), where he obtained his PhD in 2008. He has been visiting scientist at several world-class academic institutions, such as the National Oceanography Centre Southampton (UK), University of Cambridge (UK), and the Lamont-Doherty Earth Observatory of the Columbia University (USA). Gianluca's research hinges on a wide portfolio of geochemical, micropaleontological, sedimentological, and statistical tools to quantitatively determine the timing, magnitude, and rates of (past) ocean and climate change. He has received funding from several national and international organizations, (co)authored 34 publications in the most prestigious general and specialised journals and presented his research at international congresses, topical workshops, and research institutions in the form of invited and keynote lectures. His involvement in supervision and teaching spans all levels of academic education, while his numerous outreach activities centre on promoting climate change topics within the popular science media and non-academic public.

Alfio Alessandro Chiarenza (lecturer) is a Postdoctoral Researcher and Juan de la Cierva Fellow at the Universidade de Vigo. He completed his PhD at the Imperial College London (UK) in 2019 and subsequently was awarded a post-doctoral fellowship at the Perot Museum of Nature and Science in Dallas (USA) prior to joining the MAPAS lab of the Universidade de Vigo as a European Research Council (ERC) postdoctoral fellow in 2021. Alessandro is a palaeontologist interested in dinosaur palaeobiology, macroecology, and extinction, using phylogenetic, biogeographic, statistical, and Earth System Modelling tools. Main research topics include: (*i*) deciphering the relationship between physical agents that shape the vertebrate fossil record and disentangling their role to detect genuine biodiversity signals in deep time; (*ii*) the interplay between changing climate, geography, biodiversity, and the macroevolution and macroecological patterns of dinosaurs and other Mesozoic vertebrates; and (*iii*) the physical drivers behind evolutionary adaptations and extinction of dinosaurs. He has received several awards and (co)authored 12 publications, which have appeared in specialised and high-profile, multidisciplinary journals.

Alvaro Fernandez Bremer (lecturer) is a Postdoctoral Researcher and Juan de la Cierva Fellow at the Instituto Andaluz de Ciencias de la Tierra, Consejo Superior de Investigaciones Científicas (CSIC) in Granada (Spain). Following his PhD obtained in 2015 at Tulane University, in New Orleans (USA) he moved to Zürich (Switzerland) for a postdoctoral position at the Eidgenössische Technische Hochschule (ETH) and subsequently to Bergen (Norway) for a postdoctoral position at the University of Bergen. Alvaro's research centres on the quantitative analysis of palaeoclimate change, using the sedimentary record and geochemical proxies to reconstruct Earth's climate. His broad expertise covers several geochemical techniques – such as radiocarbon dating and clumped isotope thermometry – and advanced statistical routines that are applied to address diverse palaeoclimate problems that range from the climate evolution of the Meso-Cenozoic, through climate sensitivity, to the Pleistocene glacial-interglacial cycles. Alvaro has (co)authored 24 publications that appeared in

specialised and multidisciplinary, high-profile journals. In addition, he is actively involved in supervision of PhD students, and served as examiner in several PhD and Master evaluation panels.

Elisabeth Losa Adams (lecturer) is a research collaborator of the Universidade de Vigo. She completed her PhD at the Universidade de Vigo in 2018 and subsequently stayed at that institution taking up several research positions, including a postdoctoral fellowship that terminated in September 2021. Her expertise in geochemistry and mineralogy is applied to both terrestrial and extra-terrestrial materials to decipher: (*i*) the nature of past environments on Mars and the planet's habitability; (*ii*) the biogenic *versus* detrital origin of carbonates in deep-sea sediments; (*iii*) the geochemical fingerprint of detrital sediments to decipher their source-to-sink pattern. Elisabeth has (co)authored 6 scientific publications that include a leading author publication in the high-profile journal *Nature Astronomy*, has presented her work at national and international conferences and topical workshops, and has contributed to several research projects both in the field of planetary science and palaeoclimatology.

Relevant references:

Archer, D.E., 2010. *The Global Carbon Cycle*. Princeton Primers in Climate.

Holland, H.D., Turekian, K.K., 2014, *Treatise on Geochemistry, Second Edition*. Oxford: Elsevier.

Manabe, S., Broccoli, A.J., 2020. *Beyond Global Warming: How Numerical Models Revealed the Secrets of Climate Change*. Princeton University Press

Maslin, M.A., 2021. *How to save our planet: the facts*. Penguin Life.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., Zhou, B., 2021. IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Pierrehumbert, R.T., 2010. *Principles of Planetary Climate*. Cambridge University Press.

Rohling, E.J., 2017. *The oceans: a deep history*. Princeton University Press.

Ruddiman, W. F., 2014. *Earth's Climate. Past and Future*. W. H. Freeman and Company.

Schmittner, A., Chiang, J., Hemmings, S., 2007. *Ocean Circulation: Mechanisms and Impacts*. Geophysical Monograph Series 173.