CliMathNet Conference 2016

University of Exeter
5^{th} – 8^{th} July 2016

Newman Collaborative Lecture Theatre
Peter Chalk Centre
University of Exeter
EX4 4QQ

www.climathnet.org/conference2016
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Version as of 7^{th} July 2016

UNIVERSITY OF EXETER

STREATHAM CAMPUS

ACADEMIC, ADMINISTRATION AND SOCIAL BUILDINGS

Alexander	47	10E
Amory	29	5H
Bill Douglas Cinema Museum	7	8G
Business School Building:One	84	6I
Byrne House	37	7K
Catholic Chaplaincy	74	3A
Clayden	54	8D
Clydesdale House	63	5D
Cornwall House	32	6I
Cornwall House Swimming Pool	80	7I
Devonshire House	2	6G
Exeter Northcott Theatre	13	5F
Family Centre	59	5E
Forum	3	6G
Geoffrey Pope	20	5F
Great Hall	1	6G
Harrison	23	4H
Hatherly	6	7G
Henry Wellcome Building for Biocatalysis	19	5F
Hope Hall	41	7K
Innovation Centre	25	4I
Institute of Arab and Islamic Studies	16	5E
INTO International Study Centre	83	6H
Kay Building	24	4H
Kay House Duryard	85	1A
Knightley	55	8E
Lafrowda House	33	6J
Laver	22	4G
Lazenby	38	7L
Library	4	6H
Living Systems (to be completed Summer 2016)	87	5F
Mary Harris Memorial Chapel	10	7F
Newman	18	5F
Northcote House	12	6F
Old Library	7	8G
Peter Chalk Centre	17	5F
Physics	21	4F
Queen's	11	7F
Redcot	56	7D
Reed Hall	14	6E
Reed Mews Wellbeing Centre	15	5E
Roborough	8	8F
Russell Seal Fitness Centre	88	4E
Sir Christopher Ondaatje Devon Cricket Centre	77	3E
Sir Henry Wellcome Building for Mood Disorders Research	82	8F
Sports Park	60	4E
St David's Retail Services	52	11B
Streatham Court	31	6H
Streatham Farm	5	6H
Student Health Centre	86	6E
Tennis Centre	61	4E
Thornlea	48	10D
University Reception	1	6G
Washington Singer	9	8E
XFI	30	5I

RESIDENCES

Birks Grange Village	66	5B
Bonhay House	53	11C
Clydesdale Court	64	5C
Clydesdale Rise	65	4C
Cook Mews	69	4A
Duryard	72	2B
Garden Hill House	27	3J
Holland Hall	62	4D
Holland Hall Studios	62	4D
King Edward Court	68	5A
King Edward Studios	67	5B
Lafrowda	43	7J
Lafrowda Cottage	44	8J
Llewellyn Mews	70	4A
Lopes Hall	34	6K
Mardon Hall	58	5E
Moberly	71	3B
Nash Grove	57	5D
Northfield	75	9C
Pennsylvania Court	36	6L
Ransom Pickard	35	6L
Rowe House	45	7J
St David's	51	12B
St German's	42	7K

Contents

CliMathNet Conference 2016

University of Exeter
5th – 8th July

Dear Colleague,

Welcome to the fourth annual meeting of the CliMathNet network!

This network was set up three years ago with the intention of linking mathematicians, climate scientists and policy makers. Since then it has run a wide range of activities, with the annual meetings as the centrepiece. We are happy to acknowledge funding from EPSRC, under the auspices of ReCoVER, for the continuation for this and next year. Note that several of the contributions are from projects that have been supported by ReCoVER.

We hope you find the plenary and contributed talks on these topics informative, as well as taking advantage of the opportunity to meet others and to learn from each other. We also hope that you will have a chance to explore the city on Wednesday and to join us for the conference dinner that evening.

The purpose of CliMathNet has always been to bring people together in this area, and we hope that you will all contribute to make this a success. We hope you enjoy the meeting and that it will spark collaborations, both new and old.

Yours sincerely,

Peter Ashwin and Tim Lenton.
On behalf of the scientific committee.

Scientific Programme

The themes of the conference will aim to provide a forum for mathematics and statistics applied to weather and climate science.

The Conference Programme is being organised by Prof Peter Ashwin and Prof Tim Lenton of ReCoVER and the University of Exeter, with the help of the scientific committee:

The Scientific Committee:
Peter Challenor, University of Exeter
Peter Cox, University of Exeter
Chris Budd, University of Bath
Paul Bates, University of Bristol

Also with thanks to:
Emily Paremain, ReCoVER
Emma Clarke, ReCoVER

And our CliMathNet Conference Volunteers.

Plenary Speakers

Xiaofeng Li, Newcastle University

Klaus Fraedrich, Universität Hamburg

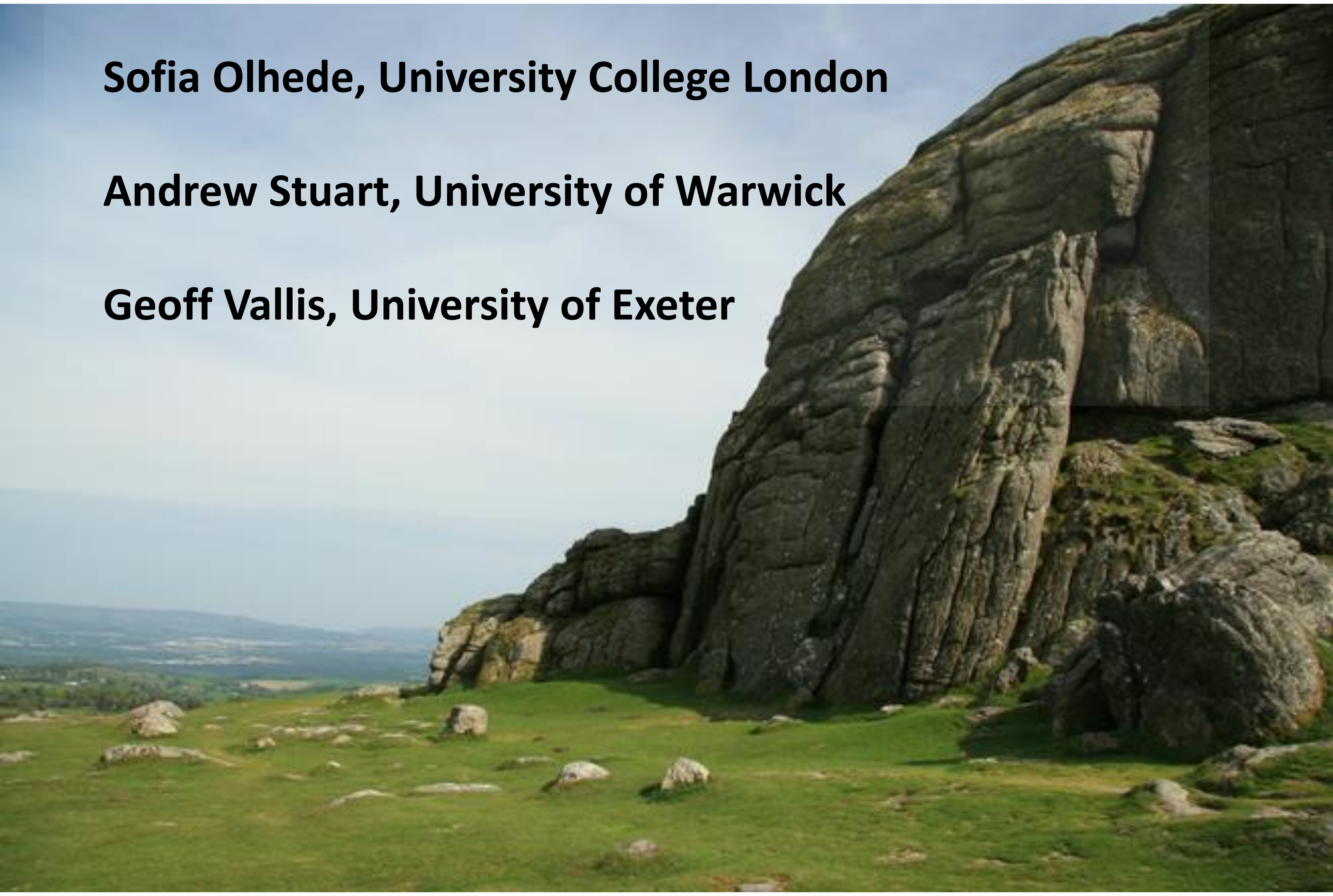
Rachel Kuske, University of British Columbia

Nathan Mayne, University of Exeter

Sofia Olhede, University College London

Andrew Stuart, University of Warwick

Geoff Vallis, University of Exeter



Programme

Tuesday 5th July

Time	
12.30	Registration and Lunch on arrival
13.30	Introduction / Welcome
13.40	Plenary: **Andrew Stuart**, University of Warwick Blending Mathematical Models and Data: Algorithms, Analysis and Applications
14.25	Oxygen Variability in the Last 500 Million Years: Implications for Climate and the Use of Earth System Models for Understanding Past Climates. **David C. Wade** Centre for Atmospheric Science, Department of Chemistry, University of Cambridge
14.45	Extension of a non-hydrostatic dynamical core into the thermosphere. **Daniel Griffin** College of Engineering, Mathematics and Physical Sciences, Mathematics, University of Exeter
15.05	Tea & Coffee
15.35	Plenary: **Xiaofeng Li**, Newcastle University ***(NB replaces Hayley Fowler)*** Explaining recent wetting and cooling over Northern Australia: the importance of oceans under a warming climate
16.20	Bayesian parameter estimation with weak data and when combining evidence: the case of climate sensitivity. **Nicholas Lewis** Independent Scientist
16.40	Can early warning signals be reliably detected in the Cenozoic palaeoclimate record? **David I. Armstrong McKay** Ocean and Earth Science, National Oceanography Centre Southampton, University of Southampton
17.00	End of Day

Wednesday 6th July

Time	
09.15	Plenary: **Klaus Fraedrich**, Max Planck Institute for Meteorology Experiments with an Earth-like climate: Abrupt, static, and transient changes
10.00	State-dependence of climate sensitivity: attractor constraints and palaeoclimate regimes. **Anna S. von der Heydt** Institute for Marine and Atmospheric research Utrecht and Center for Extreme Matter and Emergent Phenomena, Utrecht University
10.20	Emulation of climate uncertainties arising from uncertain parametrizations. **Kai-Lan Chang** Department of Statistical Science, University College London
10.40	Tea, Coffee and Posters
11.10	Plenary: **Geoff Vallis**, University of Exeter From theory to numerical simulation in understanding climate on Earth and other planets.
11.55	Spatial paleoclimate reconstructions using model simulations and proxy data. **Sophie Stolzenberger** Meteorological Institute, University of Bonn
12.15	Parametrization of stochastic effects in an advection-condensation model. **Yue-Kin Tsang** Centre for Geophysical and Astrophysical Fluid Dynamics Mathematics, University of Exeter
12.35	Lunch
13.30	Evaluating forecasts when the truth is uncertain. **Chris Ferro** College of Engineering, Mathematics and Physical Sciences, Statistics, University of Exeter

Wednesday 6th July - continued

Time	
13.50	Combining new statistical methods for post-processing ensemble weather forecasts. *(NB change of time)* **Robin M. Williams** College of Engineering, Mathematics and Physical Sciences, Mathematics, University of Exeter
14.10	Poster introduction session **All presenters of posters are asked to be available for questions about their posters!**
14.30	Tea, Coffee and Posters
15.00	Using a climate model ensemble to assess the present day climate risk to maize production. **Chris Kent** Met Office, Exeter
15.20	A dynamical systems framework for exploring resilience. **Mary Lou Zeeman** Mathematics Department, Bowdoin College, Brunswick, US.
15.40	When will it tip? Predicting when a bifurcation will occur from early warning signals **Chris Boulton** Geography, University of Exeter
16.00	Group Photo. Front of Peter Chalk Conference & Events Centre.
16.15	Free time to explore Exeter
18.30	Conference Dinner

Thursday 7th July

Time	
09.15	Plenary: **Rachel Kuske**, University of British Columbia New averaging results motivated by climate models: fat tails, oscillations, and tipping.
10.00	Implications of rebasing GCM generated global mean temperature output **Sandra Chapman** Physics Department, University of Warwick
10.20	ENSO-related tropical precipitation change under global warming. **Alexander Todd** College of Engineering, Mathematics and Physical Sciences, Exeter Climate Systems, University of Exeter
10.40	Tea, Coffee and Posters
11.10	Plenary: **Sofia Olhede**, University College London Big Oceanic Data in Time
11.55	Verification of Interval Probability Forecasts. **Keith Mitchell** College of Engineering, Mathematics and Physical Sciences, Mathematics, University of Exeter
12.15	Can the use of numerical precision be optimised in simulations of chaotic systems using Lyapunov covariant vectors or singular vectors? **Fenwick C. Cooper** Department of Physics, University of Oxford
12.35	Lunch

Thursday 7th July - continued

13.30	**ReCoVER/ Maths for LWEC Session**
13.50	Quantifying uncertainty in model projections of the Antarctic ice sheet. **Neil Edwards** Department of Physical Sciences, The Open University
14.10	Gauging Limitations of Imperfect Model Prediction with Sculpted Ensembles (GLIMPSE) **Ed Wheatcroft** Centre for the Analysis of Time Series, London School of Economics
14.30	Using social media to detect and locate natural hazards. **Hywel T P Williams** University of Exeter
14.50	Tea, Coffee and Posters
15.20	Modelling heterogeneous consumer behaviour and diverse policy levers in global IAMs: proof of concept. **Aileen Lam** University of Cambridge
15.40	Trialling a seasonal climate service for UK transport stakeholders. **Emilie Vanvyve** Met Office, Exeter
16.00	**Panel Discussion**
17.00	End of Day

Friday 8th July

Time	
09.15	Plenary: **Nathan Mayne,** University of Exeter Developing a unified framework for modelling (exo)planets
10.00	Influence of ENSO on Regional Indian Summer Monsoon Precipitation—Local Atmospheric Influences or Remote Influence from Pacific. **Indrani Roy** College of Engineering, Mathematics and Physical Sciences, University of Exeter
10.20	Title: to be confirmed. **Tim Lenton** Geography, University of Exeter
10.40	Tea, Coffee and Poster Competition winner announcement
11.10	**Panel Discussion: Challenges for Mathematics from Climate and Weather: learning from other planets?**
12.10	Lunch
13.30	Depart

Andrew Stuart, University of Warwick

Tuesday 5th July, 13.40

Blending Mathematical Models and Data: Algorithms, Analysis and Applications

Many problems in the sciences and engineering lead to the inverse problem of determining an unknown set of parameters, or field, which is input data for a mathematical model, from a finite set of indirect measurements of the system being modelled. Accurate estimation of these parameters is of crucial importance for the predictive capability of the models. Climate modelling provides a prime example of a field where this inverse problem is a key step. Other examples include oceanography, weather forecasting, personalized medicine and the modelling of human behaviour. In this talk we discuss the inverse problem of blending models with data, highlighting generic issues which arise, and showing the role of the mathematical sciences in developing a methodological approach to this problem. The aforementioned applications will be used to illustrate the ideas.

Xiaofeng Li, Newcastle University (replaces Hayley Fowler)

Tuesday 5th July, 15.35

Explaining recent wetting and cooling over Northern Australia: the importance of oceans under a warming climate

(with Jingjing Yu, National Meteorological Information Center, China Meteorological Administration, Beijing 100081, Chinaand Yun Li, CSIRO Mathematics, Informatics and Statistics, CSIRO Climate Adaptation Flagship, Floreat, Western Australia 6014, Australia)
Summer rainfall over northern Australia (NA) is the largest water source of Australia. This study reports a new dominant wetting and cooling pattern over NA in the post-1979 satellite era, contradicting the global mean warming trend. Further investigation reveals that sea surface temperature (SST) in the Tropical Western Pacific (TWP) is the controlling factor responsible for recent NA rainfall increase. We identify that direct thermal forcing by increasing SST in this region leads to anomalously high rainfall. As such, the increasing SST in the TWP induces over 50% of the observed rainfall wetting trend over NA. This increased rainfall in turn induces land surface cooling in NA. This mechanism can be confirmed with results obtained from sensitivity experiments of an atmospheric general circulation model. Thus, increasing SST in the TWP has contributed much of the recent summer rainfall increase, and consequently, the surface cooling over NA. Our results have implications for understanding regional climate change in the Tropics and highlight the importance of ocean processes.

Klaus Fraedrich, Max-Planck Institute for Meteorology, Hamburg

Wednesday 6th July, 09.15

Experiments with an Earth-like climate: Abrupt, static, and transient changes.

Experiments with an Earth-like climate are performed by inducing static, transient and abrupt changes in terms of a parameter variation of solar constant and atmospheric greenhouse gases. Focusing on static, dynamic, and memory hysteresis, a brief introduction to a new Intermediate Complexity AO-GCM (PLASIM-GENIE) is given before analyzing numerical experiments (PLASIM plus mixed layer ocean) under changing atmospheric radiative forcing jointly with the corresponding analytic results of a toy-model (EBM).
Static change experiments demonstrate that the solar constant varying by 20% reveals warm and snowball Earth regimes depending on the system's history. Thermodynamic analysis shows (i) both climates being characterized by global mean surface temperature and entropy growing with increasing solar constant; (ii) the climate system's efficiency decreases (increases) with increasing solar constant in present-day warm (snowball) climate conditions, and (iii) climate transitions near bifurcation points are characterized by high efficiency associated with the system's large distance from the stable regime.
Abrupt change experiments are performed by greenhouse effects being switched off. (i) CO-2 concentration is abruptly decreased from its actual value. Assessing model response as a bifurcation point, the steady solution shows a critical CO-2 threshold with the model ending up in a snowball Earth state. The transition to ice-covered Earth is favored removing Q-flux corrections (of ocean heat transports). Zero- and one-dimensional EBMs substantiate the results. (ii) Ozone (O-3) is abruptly decreased from its actual value. Although ozone appears in the Earth's atmosphere in a small abundance, it plays a key role in the energy balance of the planet through its involvement in radiative processes. The total removal of O-3 content in an Earth-like atmosphere leads to a new equilibrium suggesting the model to attain a colder state mainly because of the water vapor content decrease. Most of the cooling occurs in the Southern Hemisphere while in the northern ice cap melts consistently. This process is governed by northward cross-equatorial heat transports induced by general circulation change.
Transient change experiments demonstrate dynamic and memory hysteresis when changing the direct atmospheric radiative forcing associated with a well-mixed carbon dioxide (CO-2) concentration. Modifying the planetary thermodynamic state (surface temperature) the hysteresis is effected by different CO-2 change rates: (i) The response is due to infrared cooling (for constant temperature lapse-rate) which, in turn, is related to the surface temperature through the Stefan-Boltzmann law in a ratio proportional to the new infrared opacity. Subsequent indirect effects of water-vapor-greenhouse and ice-albedo feedbacks enhance the response. (ii) Different rates of CO-2 variation may lead to similar transient climates characterized by the same global mean surface temperature but different values of CO-2. (iii) Far from bifurcation points the model's climate depends on the history of the radiative forcing thus displaying a hysteresis cycle that is neither static nor dynamical, but is related to the memory response of the model determined by the ocean's mixed-layer depth. These results are supported by a zero-dimensional energy balance model.

Geoff Vallis, University of Exeter

Wednesday 6th July, 11.10

From theory to numerical simulation in understanding climate on Earth and other planets.

I will discuss two related topics in climate dynamics. First, what are some of the scientific problems? Second, how should we address these problems, and in particular what is the relation of 'theory' to numerical simulation?

After a brief overview of the main scientific problems, I will discuss the methodology. Often we use large and complicated numerical models to address the problems. Is this the best way? Does 'theory' in the conventional sense — elegant equations making testable predictions — still have a role? Perhaps numerical models are our modern-day theory? Throughout the talk I'll pose questions as much as answer them and I'll be giving my opinion on the matters, not necessarily the consensus of the community.

Rachel Kuske, University of British Columbia

Thursday 7th July, 09.15

New averaging results motivated by climate models: fat tails, oscillations, and tipping

We review recent results where new averaging approaches are developed and applied in the context of systems with multiple time scales and fat tails and in non-autonomous multiple scale systems with oscillatory forcing. These types of systems appear in a variety of higher dimensional climate models, as well as in other areas of application. The results open new research directions, with potential to better address questions like: which mechanisms contribute to fat-tail statistical properties appearing in climate data? What are reasonable approximations for multiple scale systems with non-Gaussian behaviour? How can these approximations provide insight into the dynamics of larger models, such as parameter ranges with large variability, tipping, or reversibility? Some areas for further research are discussed.

Sofia Olhede, University College London

Thursday 7th July, 11.10

Big Oceanic Data in Time

Observations relevant to our understanding of the global climate system are highly structured: taking the form either of temporal observations, or spatially structured data. Analysis is normally challenged by sheer volume of data, and so algorithmic choices become important. I will discuss stochastic modelling of global scale observations of ocean circulation, and what we can understand from such observations.

This is joint work with Jeffrey Early, Shane Elipot, Arthur Guillaumin, Jonathan Lilly & Adam Sykulski.

Nathan Mayne, University of Exeter

Friday 8th July, 09.15

Developing a unified framework for modelling (exo)planets.

The first detection of an exoplanet, or planet outside our solar system, was made over twenty years ago. The number of detected planets has rapidly increased over these two decades, and the field, driven by the huge diversity of planetary states, has transitioned to an era of characterisation. Observations have now provided, in some cases, glimpses of the atmospheric state of these atmospheres providing constraint on compositions, temperatures and even wind speeds.

At the University of Exeter, in collaboration with the UK Met Office, we are developing a theoretical framework with which to interpret current, and future observations of exoplanets and place them in context with our own planet.

I will present an overview of the observational constraints for exoplanets, outline the main puzzles and challenges and summarise attempts to interpret these observations. I will also detail our own work on this subject, and outline how we are embedding our research within the model framework of the UK Met Office. Finally I will look ahead and what to expect from the field of exoplanet research in the coming years.

Things to do & see in Exeter

Exeter

Exeter is an ancient city with a modern feel. Pre-dating the arrival of the Romans in AD 50, the city has a long and rich history. This is reflected in its unique visitor attractions including the:

- Underground Passages,
- Royal Albert Memorial Museum,
- Exeter Cathedral,
- Roman wall,
- Historic quayside.

Exeter also offers a diverse selection of shopping options, with the large High Street names mixing in with the smaller independent shops and boutiques in the city's distinct shopping quarters.

Places to eat:

Exeter has established a reputation as one of the foodie capitals of the South West, from the weekly farmers' market selling field-fresh produce to the celebrated Exeter Street Food Market, cosy cafes to fine dining in award-winning restaurants.

In the evenings consider trying:

- The Rusty Bike (with an award winning kitchen serving up local produce and game)
- The Firehouse (with a reputation of excellence for its pizzas, served in the evenings only)
- Rendezvous Wine Bar & Restaurant (an ever changing menu of fresh west and country fare, with an extensive wine list to accompany)
- Herbies (Specialising in an all Vegetarian menu)
- Las Iguanas (flame grilled Latin American dishes)
- Mill on the Exe (A beautiful and tranquil place to visit for both food and drink set aside the Blackaller Weir and Millston Footrbidge)
- Typeyedong (a contemporary noodle bar serving Chinese and Japanese dishes)
- The Imperial (a Weatherspoon's set in beautiful grounds, very close to campus)
- The Fat Pig (sister pub to the Rusty Bike, it's all about locally sourced produce and boasts it's own experimental brewery on site!)

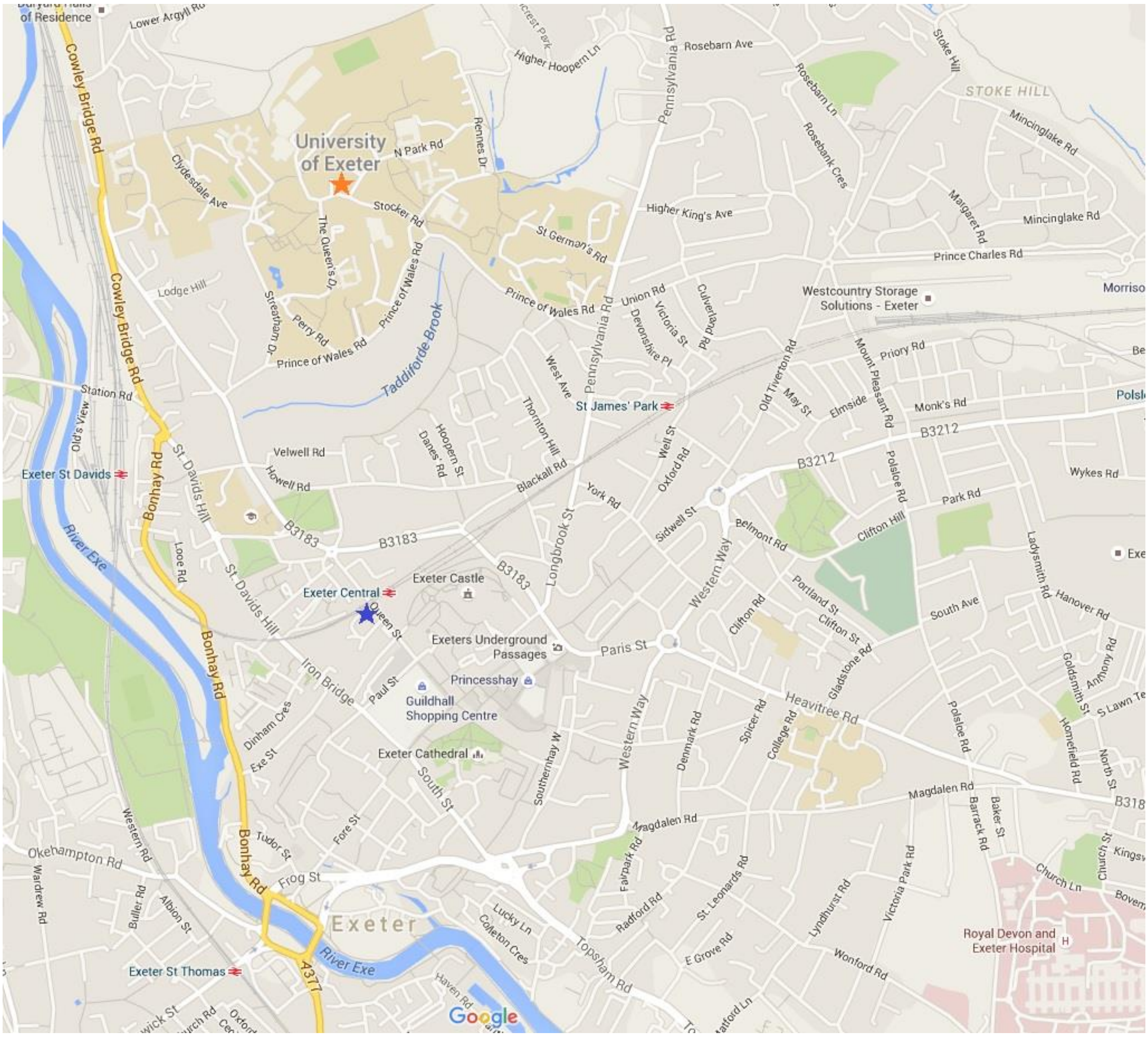
… among many other options …

What's nearby:

Just 10 miles from Exeter easily accessible by train you will reach the Jurassic Coast, more than thirty miles of stunning UNESCO World Heritage Coastline, part of the 95 miles charting 185 million years of the Earth's history.

Travel west by bus, car or train and you will reach Dartmoor Nation Park. 954km^2 of moorland, forests, rivers, wetlands and tors. A great place for all manner of outdoor pursuits and many opportunities for good dinning amidst an impressive landscape.

Exeter City Centre Map



Conference Dinner Venue

Mercure HOTELS

Mercure Exeter Rougemont Hotel

Queen Street
EX43SP EXETER
Tel : (+44) 8713 769 018

Mathematics for LWEC Networks

ReCoVER, Research on Changes of Variability and Environmental Risk
www.recoverlwec.org
Twitter: @CliMathNet

This research network aims to develop and apply new mathematical tools and methods to understand environmental variability and the connections with environmental risks. From April 2015 to March 2018 we are funded by the EPSRC grant EP/M008495/1 to promote research in this area via a number of mechanisms, including a £315k fund for feasibility studies. ReCoVER is affiliated to the research network CliMathNet and is directed by Peter Ashwin and Tim Lenton, supported by an Expert Panel and an Advisory Board. There are three scientific focus areas: (i) Computing complexity, (ii) extreme events, tipping points and quantifying uncertainty and (iii) modelling coupled social-environmental systems.

During its first year, the ReCoVER Network has:

- Organized 4 interdisciplinary workshops, and supported a further 2 workshops as organized by partner networks.
- Funded 14 feasibility studies so far, with a total value of £240k of various sizes across the scientific focus areas.
- Promoted Outreach Activities through a Virtual Outreach Conference in June 2016.
- Supported the CliMathNet annual meetings: after this one, the next one is planned for the University of Reading in July 2017.
- Supported other CliMathNet activities, notably the newsletter.

Membership

If you would like to become a member of CliMathNet and receive the newsletters, please see the website (www.climathnet.org/whoweare/members/) and fill out the online Membership Form. Membership is free, and we encourage interested non-UK scientists to sign up as associate members.

Statistics of Environmental Change, Resources and Ecosystems

EP/M008347/1 (February 2015 - February 2018)

The SECURE network, based at the University of Glasgow, is led by Marian Scott, with Co-I Susan Waldron and Gillian Brown as Project Administrator.

The SECURE network aims to bring together the environmental and statistical communities to provide fresh intelligence and new insights into environmental change and society's management of that change. In this way the network addresses some of the key challenge areas including ecosystems, resources (e.g. water), health, infrastructure, and climate change underpinned by environmental and Earth observation.
The network has now been operating for over a year and two calls for small (up to £25K) feasibility projects have been announced. Five projects were commissioned by SECURE in each of these calls. The projects from the first call are now coming to an end and presentations from these projects will be made at our Annual conference to be held on the 20th September at the Glasgow Science Centre. The network has also provided support to people giving presentations at both UK and international conferences, whose themes link in with those of SECURE. In additional the network has funded three workshops on different SECURE themes: "Environmental, Health and Wellbeing", "Use of 'low-cost' sensor technology to monitor air quality and engage citizens" and "Modelling uncertainty from multi-scale data streams in environmental sciences".

SECURE has also co-sponsored two joint events with the PURE network: "Computational and Data Challenges in Environmental Modelling" and "Regulatory challenges related to risk in the natural environment". At the International Environmetrics conference in July SECURE will be sponsoring a session on "Dynamic spatial temporal modeling of the impact of air pollution on adverse pregnancy outcomes".

The first year of the network has seen existing partnerships successful in feasibility applications and new partnerships being formed. A major aim going forward is to expand the base of the network by bringing new institutions on board. Allied to this aim it is important that the opportunity is given for the further development of new partnerships. The plan is to facilitate this through devoting funding resources to sandpit type meetings.

Our annual conference on the 20th September will provide another opportunity for interested parties to meet and exchange ideas. For further details of events and funding opportunities visit the SECURE website:

www.gla.ac.uk/research/az/SECURE

Maths Foresees

EPSRC Network Living with Environmental Change

http://www1.maths.leeds.ac.uk/mathsforesees/

Twitter: @MathsForesees

The Maths Foresees Network aims to rethink the approach to modelling extreme weather events and promote the mathematical modelling of environmental hazards among the wider UK community. Since its launch in May 2015, the network has successfully brought together academics working in the mathematical and environmental sciences with end-users of environmental research (including the Met Office, the Environment Agency, JBA Trust, HR Wallingford, Pennine Prospects, Leeds City Council, Fugro GEOS and Risk Management Solutions) to deliver the following activities:
(i) **General assembly** (University of Leeds, May 2015), which officially launched the network and brought together the initial membership. Mini-workshops were held on the themes of deep convection and rapid inundation modelling, which have since led to further collaborations. The next general assembly will be held at St Leonard's Hall, Edinburgh, in September 2016.
(ii) **Environmental Modelling in Industry study group** (Isaac Newton Institute, September 2015), which brought together over 40 academic experts and industry representatives to facilitate the development of innovative solutions relevant to industry. A second event will be held in April 2017.
(iii) Communicating the role of mathematics in flood prediction and mitigation at the '**Science of Floods**' public event led by Pennine Prospects (Hebden Bridge, May 2015).

The Maths Foresees network has also awarded a range of subprojects:

- **Feasibility studies** (maximum £25,000):
  - *A multiscale model of urban dispersion* (PI Jacques Vanneste, Edinburgh)
  - *Modelling the wave dynamics of jet currents in a flume* (PI Sergei Lukaschuk, Hull)
  - *Multilevel Monte Carlo methods for flood risk assessment* (PI Colin Cotter, Imperial)
  - *Effects of topographic uncertainty on flood and debris flow modelling* (PI Andrew Hogg, Bristol)
  - *A prototype vortex-in-cell algorithm for modelling moist convection* (PI David Dritschel, St Andrews)
- **Outreach projects** (maximum £10,000):
  - *A conceptual table-top demonstration of catchments, river floods and flood mitigation* (PI Onno Bokhove, Leeds)
- **Focused mathematics workshops** (maximum £3,750):
  - *Mathematics of dispersion in the environment* (PI Alexandra Tzella, Birmingham)
  - *Coupling convection and large-scale dynamics in numerical weather prediction models* (PI Ian Roulstone, Surrey)
  - *Volcanic ash forecasting* (PI Vera Hazelwood, Smith Institute)

Past Earth Network

Website: www.pastearth.net
Mailing List: www.jiscmail.ac.uk/pastearth
Twitter: @pastearth

The Past Earth Network (PEN) is an EPSRC funded network founded upon the idea that much can be learned about how our current climate models will perform in a changed climate, by studying past climate. To make this happen, the network will improve communication between Palaeo-climate scientists and statisticians. The network holds periodical conference events, working group meetings, workshops, research kitchens and talks in schools. The PEN explores how palaeo-climate data and models can be used, in conjunction with statistical methods, to assess and improve the quality of climate forecasts. Most work in the network is done in our four working groups:

- Quantification of error and uncertainty of *data*.
- Quantification of uncertainty in complex *models*.
- Methodologies which enable robust *data-model comparison*.
- *Forecasting* and future climate projections.

Recently announced events 2016 – 2017:

- AGU 2016 Session - Marrying palaeo data records and paleoclimate modelling within a statistical framework
- ICP 2016 Talk – Alice Marzocchi - The role of sea ice and buoyancy fluxes in shaping glacial and modern ocean circulation: an analysis of PMIP simulations
- XIV Palynological Congress Session – Understanding climate variability in a warmer than present Pliocene World
- PEN – ESS Workshop – 24-26 August 2016, Sidney Sussex College, Cambridge.
- Talks in schools – The network is now offering talks in schools from local academics, please visit the website for more information

Coming soon:

The PEN will be announcing the call for feasibility studies in the coming weeks. The network has four awards available, one per working group, to fund our members to perform studies that progress the address the aims of the network. For more information and to become a member of the network, please join the mailing list at the above link.

Contributed Talks - Abstracts

David C. Wade & Alexander T. Archibald

Oxygen Variability in the Last 500 Million Years: Implications for Climate and the Use of Earth System Models for Understanding Past Climates.

Tuesday 5th July, 14.25(pm)

Centre for Atmospheric Science, Department of Chemistry, University of Cambridge

The oxygen content of the atmosphere has varied considerably over the past 500 million years, however its role in the Earth system over this time is poorly understood. Palaeoclimate modelling studies have historically focused on the role of carbon dioxide and the position of the continents in explaining long-term climate change. However, there are a number of challenges reconciling the temperatures obtained by climate models and those reconstructed by proxy records. In particular, high-latitude temperatures during hothouse climates like the Eocene (35-50Mya) have been underestimated. A number of possible mechanisms have been proposed to explain this 'cold tropics paradox' including cloud feedbacks, ocean heat transport changes, Earth system feedbacks and many more. Oxygen content has recently been suggested as a contributing factor to reconciling this problem.

While our understanding of near-term climate change is informed by complex state-of-the-art Earth system models, often more simple conceptual models are used for understanding past climate. This is usually more practical as it requires less computational expense and doesn't rely on model parametrisations which might not hold under climate states very different to the present day. However it can mean that many feedbacks, such as cloud and ocean circulation changes are neglected with profound implications for our understanding of both past and future climates. The surface climate impacts of oxygen content variability have been investigated using models of varying complexity from a 1D photochemical model to a coupled atmosphere-ocean general circulation model with interactive atmospheric chemistry. The particular importance of a 3D representation of the ocean is demonstrated and highlights the value of complex climate models in tackling palaeoclimate problems. Possible implications for the biosphere, palaeoclimate proxy.

Daniel Griffin
Extension of a non-hydrostatic dynamical core into the thermosphere:
Tuesday 5th July, 14.45(pm)
University of Exeter
ENDGame is a semi-implicit, semi-Lagrangian, non-hydrostatic dynamical core, that is currently able to simulate the large scale fluid dynamics of the atmosphere and remain stable for altitudes of up to ~100km. However, the simulation does not currently remain stable if the top boundary is lifted higher than this. This seems to be because the model is not well equipped to deal with the exponential growth of vertically propagating waves in the thermosphere: the numerics may not be able to handle fast processes very well, there may be physics missing in the model which becomes more significant in the thermosphere, or the problem may be some combination of these two. The aim of this research is to find out whether the model can be developed so that the top boundary can be extended upwards to the top of the thermosphere at 600km altitude, so that it can model the whole atmosphere. I will present on my current progress towards this goal. I have developed a one-dimensional version of the ENDGame dynamical core for simulating vertical processes in a column of atmosphere. In this model, I have included the physical process of molecular viscosity which has a significant damping effect in the thermosphere. The viscosity has been combined with the dynamics in a fully coupled way and it can be demonstrated that the model damps fast acoustic waves in the thermosphere as expected from the theory, and the model's stability increases in the thermosphere as a result. I will also discuss my progress with examining the effects of resolution on wave propagation in the numerical model to determine whether this is responsible for the current excessive focussing of wave energy into the thermosphere.

Nicholas Lewis
Bayesian parameter estimation with weak data and when combining evidence: the case of climate sensitivity
Tuesday 5th July, 16.20(pm)
Independent Scientist
I take a critical look at Bayesian parameter estimation in situations where only weak data is available, focussing on climate sensitivity, and discuss and compare Subjective and Objective approaches. Most probabilistic climate sensitivity estimates have used Subjective Bayesian methods, which require a prior probability distribution representing existing knowledge about the values of the parameters being estimated. I highlight the serious biases in climate sensitivity estimation that this approach often results in, and explain the nature of 'noninformative' priors that can provide satisfactory results even with weak data. Standard Bayesian updating is shown to be an unreliable method for combining independent evidence. I set out a newly developed Objective Bayesian approach to doing so, well suited for estimating climate sensitivity and similar variables, and demonstrate its application to combining recent instrumental and palaeoclimate sensitivity estimates. A frequentist method that can produce densities for parameter estimates and combine evidence is also discussed.

David I. Armstrong M^c^Kay*[1,2], Toby Tyrrell[1], & Paul A. Wilson[1]

Can early warning signals be reliably detected in the Cenozoic palaeoclimate record?

Tuesday 5th July, 16.40(pm)

1. Ocean and Earth Science, National Oceanography Centre Southampton, University of Southampton, Waterfront Campus, Southampton
2. Geography and Environment, University of Southampton, University Road, Highfield Campus, Southampton

Several episodes of rapid climate change and perturbations to the carbon cycle in Earth's history are hypothesised to be the result of the Earth system reaching a tipping point beyond which an abrupt transition to a new state occurs. These critical transitions are common in other complex dynamical systems and are often preceded in datasets by indicators known as 'early warning signals' (EWS), such as critical slowing down and increasing variability, which suggest a tipping point may be about to be reached. Dakos et al. [2008] and subsequent studies analysed palaeorecords from across several past climate shifts and found that EWS can be detected prior to many of these events, suggesting that EWS can successfully be detected in the palaeoclimate record and that these events are examples of critical transitions in the Earth system. However, doubts have been raised about the reliability of EWS analysis on the palaeoclimate record, the degree to which parameter selection can affect the results, and the risk of committing the 'prosecutor's fallacy' when analysing suspected critical transitions.

Here we present preliminary EWS analysis of the highest-resolution carbon and oxygen isotope palaeorecords currently available across a number of perturbations to the Cenozoic carbon-climate system, including the Eocene-Oligocene Transition, mid-Miocene Climate Transition, and Palaeocene-Eocene Thermal Maximum. We find evidence that some but not all of the EWS indicators can be detected in the run-up to these events, but that some of the results are highly dependent on the parameter selection. Despite these problems our initial results appear to be relatively robust in most cases, and they reveal potentially useful information about the behaviour of the Earth system prior to Cenozoic carbon-climate system perturbations. As a result, this work indicates how EWS analysis can be a useful tool in palaeoclimatology when used with sufficient caution.

We hope to build on the preliminary analysis above through further work focusing on the most promising events, with additional sensitivity analyses and extended datasets where possible to improve resolution. The use of other EWS analysis methods such as detrended fluctuation analysis and model-based techniques will also be investigated in order to improve the reliability of our interpretations and explore the differences between the results of various EWS methodologies. An alternative approach of analysing longer records spanning across multiple events using a consistent EWS criteria in order to avoid the 'prosecutor's fallacy' of selecting only known events from the record for analysis will also be explored. Analysing longer records might also reveal the dynamics between events such as the hyperthermals in the late Palaeocene-early Eocene or during the Miocene Climatic Optimum.

Anna S. von der Heydt[1] and Peter Ashwin[2]
State-dependence of climate sensitivity: attractor constraints and palaeoclimate regimes
Wednesday 6th July, 10.00(am)
1. Institute for Marine and Atmospheric research Utrecht and Center for Extreme Matter and Emergent Phenomena, Utrecht University. 2. Centre for Systems, Dynamics and Control, Department of Mathematics, University of Exeter.
Equilibrium climate sensitivity is a frequently used measure to predict long-term climate change. However, both climate models and observational data suggest a rather large uncertainty on climate sensitivity (CS). The reasons for this include: the climate has a strong internal variability on many timescales, it is subject to a non-stationary forcing and it is, on many timescales, out of equilibrium with the changes in the radiative forcing. Palaeo records of past climate variations give insight into how the climate system responds to various forcings although care must be taken of the slow feedback processes before comparing palaeo CS estimates with model estimates. In addition, the fast feedback processes can change their relative strength and time scales over time. Consequently, another reason for the large uncertainty on palaeo climate sensitivity may be the fact that it is strongly state-dependent. Using a conceptual climate model, we explore how CS can be estimated from unperturbed and perturbed model time series. Even in this rather simple model we nd a wide range of estimates of the distribution of CS, depending on climate state and variability within the unperturbed attractor. For climate states perturbed by instantaneous doubling of CO2 , the sensitivity estimates agree with those for the unperturbed model after transient decay back the attractor. In this sense, climate sensitivity can be seen as a distribution that is a local property of the climate attractor. We also follow the classical climate model approach to sensitivity, where CO2 is prescribed and non-dynamic, leading to CS values consistently smaller than those derived from the experiments with dynamic CO2. This suggests that climate sensitivity estimates from climate models may depend significantly on future dynamics, and not just the level of CO2

Kai-Lan Chang and Serge Guillas
Emulation of climate uncertainties arising from uncertain parametrizations
Wednesday 6th July, 10.20(am)
Department of Statistical Science, University College London
The Whole Atmosphere Community Climate Model (WACCM) is a comprehensive numerical model. Many parameterizations of physical processes have to be set, resulting in potential concerns about error growth. To assess future climate uncertainties, we need to develop statistical models that can reproduce the outputs, and retrieve the uncertainties about the parameters and outputs in past and present climates. We employ the Bayesian emulation and calibration of complex computer models using Gaussian Processes (GPs), introduced by Kennedy and O'Hagan (2001), that has proven to be effective in a wide range of applications. However, the size of the outputs, such as climate models outputs, leads to computational challenges in implementing this framework. Covariance models for data distributed on the sphere also present additional challenges compared to covariance models for data distributed over an Euclidean space. To overcome these various challenges, we make use of the spherical harmonics (SHs) decomposition of the computer model output, and then apply a GP assumption to the coefficients in the decomposition. Furthermore, by using graphics processing unit (GPU) device, we further accelerate the Bayesian computation. Finally we perform uncertainty analysis and the emulation by calibrating the gravity waves parameters and accelerating the algorithm.

Sophie Stolzenberger and Andreas Hense
Spatial paleoclimate reconstructions using model simulations and proxy data
Wednesday 6th July, 11.55(am)
Meteorological Institute, University of Bonn, Germany

The German research programme “Our way to Europe“ (CRC 806) studies the history of the Modern Man in an interdisciplinary framework, by using geoscientific and archaeological methods. One aim of the climatological group is the spatial climate reconstruction for Europe by including all available proxy and model data.

This contribution looks at the comparison between model simulations which are taken from the PMIP3 (Paleoclimate Modelling Intercomparison Project) database and statistical climate reconstructions based on pollen data. The aim is to optimise the model data by including the probabilistic information of the occuring taxa. This concept will be presented and discussed.

For the Mid-Holocene (6 ka BP), especially summer temperatures change clearly when assimilating the PMIP3 multimodel ensemble to the observed pollen data. In this case, the original PMIP3 simulated temperature data are increased through the inclusion of the paleo pollen data. This happens especially over land. The added value can be detected by the predominantly positive Brier skill scores.

Yue-Kin Tsang
Parametrization of stochastic effects in an advection-condensation model
Wednesday 6th July, 12.15(pm)
Centre for Geophysical and Astrophysical Fluid Dynamics Mathematics, University of Exeter

Water vapour is a potent greenhouse gas and its distribution in the atmosphere has a strong impact on climate. Large-scale atmospheric circulation, such as the Hadley cell, transports water vapour and plays a crucial role in controlling such distribution. The advection-condensation model, in which moist air parcels are advected and reacts through condensation, provides a theoretical framework for the investigation of atmospheric moisture distribution. In a stochastic formulation of the advection-condensation model, unresolved small-scale flow is represented as Brownian motion and the position and moisture content of each parcel are treated as random variables. Probability distribution of moisture can be obtained by Monte-Carlo simulations. Such stochastic model retains local fluctuation and hence is not overly prone to produce saturated air as in models where moisture is represented by a coarse-grained field evolving according to a partial differential equation. However, it is often not feasible to track a huge number of air parcels in weather and climate models. Here, we propose a condensation parametrization for use in coarse-grained moisture models that takes local fluctuation into account to some degree. We show examples that demonstrate the effectiveness of our parametrization scheme.

Chris Ferro

Evaluating forecasts when the truth is uncertain

Wednesday 6th July, 13.30(pm)

College of Engineering, Mathematics and Physical Sciences, Statistics, University of Exeter

Probability forecasts are a key part of risk-based decision support, and assessments of forecast performance help to guide both our responses to forecasts and our development of forecasting systems. The definitive measures of forecast performance are proper scoring rules. Scoring rules specify the score that will be awarded to a forecast once the actual value of the predicted quantity is known, and proper scoring rules are constructed in such a way that a forecaster optimises their expected score by issuing as their forecast the probability distribution that represents their beliefs about the predicted quantity. Thus, proper scoring rules encourage forecasters to be honest. This ignores the fact, however, that the actual value of the predicted quantity is typically measured with error, in which case proper scoring rules penalise good forecasts. This talk will define a new class of proper scoring rules whose assessment of forecast performance is insensitive to the presence of such observation error.

Maryam Ilyas and Serge Guillas, Chris Brierley

ENSO uncertainty quantification in spatial distribution of temperature using lattice kriging

Wednesday 6th July, 13.50(pm)

Department of Statistical Science, University College London
Department of Geography, University College London

Exploiting massive amounts of data generated over the large spatial regions in geophysical sciences is vital to monitor climate processes. The HadCRUT4 is one key large database of temperature anomalies. There are gaps in coverage, unlike other closely related data sets (e.g. GISS anomalies), which restricts regional analysis. The classical spatial statistical models for spatial data analysis necessitate calculations that become prohibitive in the framework of large data. The multi-resolution lattice kriging encapsulates nonstationary spatial dependence and ensures fast computations by modelling sparse precision (inverse covariance) matrices based on the coefficients of linear combination of basis functions. Sparsely observed HadCRUT4 global temperature anomalies are extended to cover the whole planet using the multi-resolution lattice kriging. The point wise prediction uncertainties of predicted smooth temperature anomalies are also computed. The lattice kriging ensembles are generated to present the distribution of these prediction uncertainties. The HadCRUT4 ensembles present sets of realizations accounting for the observational uncertainties arising from the non-climatic factors. These observational and prediction uncertainties associated with the El Niño Southern Oscillation (ENSO) is quantified using the HadCRUT4 and lattice kriging ensembles, respectively. This twofold uncertainty in the global average temperature propagates to the classification of El Niño states. The classification of El Niño events and temperature trend analysis of the grouped years exhibit that El Niño years are the warmest and La Niña years have the highest warming rate across the HadCRUT4 and lattice kriging ensembles. The sub classification of El Niño years reveals that the central Pacific El Niño years are the warmest having the highest rate of warming across ensembles presenting the distribution of observational uncertainties. However, the eastern Pacific El Niño years are the warmest having the highest rate of warming across ensembles sampling the prediction uncertainties.

Robin M. Williams, Christopher A. T. Ferro & Frank Kwasniok

Combining new statistical methods for post-processing ensemble weather forecasts

Wednesday 6th July, 14.10(pm)

College of Engineering, Mathematics and Physical Sciences, Mathematics, University of Exeter

This century has seen a change in focus from traditional, deterministic weather forecasts, to a framework that allows for the quantification of uncertainty in such forecasts, and so the use of ensemble forecasts to quantify the uncertainty in weather predictions is now commonplace in meteorological applications. Due to errors in numerical weather prediction models and uncertainty in the optimal conditions at which to initialise the ensemble member forecasts, operational ensemble forecasts are often biased and under dispersed. Statistical models, known as ensemble post-processing methods, have been successfully employed to correct for these errors, and can be used to produce either probability forecasts or recalibrated ensemble forecasts. In this work we combine several recent methodological advances to produce post processed ensemble forecasts, and assess their skill in forecasts of extreme events. Firstly, parameter uncertainty in the statistical post-processing models is accounted for using bootstrap resampling. Secondly, an approach that utilises the empirical copula of the ensemble forecasts is implemented, which has been shown to improve the skill of ensemble forecasts over spatial fields. The combined methodology is applied to ensemble forecasts of near-surface temperature and 10-metre wind speed, using the MOGREPS-UK ensemble
forecasting system of the UK Met Office, for 152 weather stations that cover the UK and Ireland. We find that the skill of temperature forecasts is strongly dependent on the diurnal cycle, and the skill of wind speed forecasts depends on topographical features. We also investigate the benefits of ensemble post-processing for spatial forecasts of cold temperatures and high windspeeds at airport locations, both of which are likely to impact on aviation.

Mary Lou Zeeman

A dynamical systems framework for exploring resilience

Wednesday 6th July, 15.20(pm)

Mathematics Department, Bowdoin College, Brunswick, US.

Resilience is a slippery concept, often described as the ability of a system to absorb change and disturbance while maintaining its basic structure and function. This has a variety of interpretations from a dynamical systems point of view, depending on the application and context. As a starting point, we subject the flow of an autonomous system of ODEs to regular "kicks" of constant size and direction, and study the interaction between the kick and the transient dynamics of the system. Natural questions to ask include: Does the resulting "flow-kick" system equilibrate? If so, where? Does that represent resilience? And what are the dynamics near the flow-kick equilibrium?

Chris Kent, Vikki Thompson, Edward Pope, Kirsty Lewis and Adam A. Scaife

Using a climate model ensemble to assess the present day climate risk to maize production

Wednesday 6th July, 15.00(pm)

Met Office, FitzRoy Road, Exeter

The relationship between climate and agricultural production is of considerable importance to global food security. However, while there is a considerable body of research investigating the links between climate change and average crop yields, there has been comparatively little exploration of climate-variability related yield shocks, which can have a significant impact on trade and food prices. The first step in understanding the properties and impacts of these shocks is to quantify the current climate risk to agriculture; for example, identifying important temporal and spatial patterns of natural variability, including the return period of multi-breadbasket failures. However, the relatively short observational record does not adequately sample the full range of natural variability meaning that, by themselves, empirical analyses and crop models cannot currently provide a complete understanding. Focusing on maize production in China and the USA, we present a new agroclimate indicator of severe water stress, specifically for use with gridded observational and climate model data. Combined, these two regions provide approximately 60% of the world's maize, and therefore, are crucial to food security from the global perspective. To probe a greater range of water stress associated with natural variability, the indicator has been applied to 700 realisations of the present day climate. Analysis suggests that even the present day climate is capable of producing unprecedented severe water stress conditions in these regions. There is also evidence for a higher risk of simultaneous low yield events in China and the United States, than occurs in the available observational record. Despite this, the larger sample of events produced no instances of the most severe water stress conditions occurring simultaneously in both regions. This approach provides a basis for beginning an assessment into the likelihood of compound crop failures around the world, through the analysis of multiple, physically-plausible climate simulations. In addition, short term risk analysis, through the use of seasonal and decadal ensemble predictions, has the potential to provide significant benefit to policy and decision makers.

Chris Boulton

When will it tip? Predicting when a bifurcation will occur from early warning signals

Wednesday 6th July, 15.40(pm)

Geography, University of Exeter

Research on early warning signals of tipping points focuses mainly on determining if a system is approaching a critical transition. Here we use a Bayesian framework to estimate when this tip may occur in the future by extrapolating early warning signals into the future and exploring the associated uncertainty. This framework is currently being added to an integrated assessment model to begin to determine the value of monitoring real world climate systems which may exhibit tipping point behaviour.

S. C. Chapman[1], D. A. Stainforth[2,1], N. W. Watkins[3,2,1]

Implications of rebasing GCM generated global mean temperature output

Thursday 7th July, 10.00(am)

1. Physics Department, University of Warwick
2. Grantham Institute and CATS, LSE, London
3. MCT, Open University, Milton Keynes

GCM generated time-series of global mean temperature (GMT) provide a simple means of benchmarking a broad ensemble of GCMs against each other and against past observed GMT. They also provide headline assessments of the consequences of possible future forcing scenarios. Ensembles of GCMs are often also used as the basis for statistical estimates of uncertainty in how GMT might change under a given future forcing scenario.

The slow variations of past *changes* in GMT seen in different GCMs track each other, and the observed GMT, reasonably closely [IPCC Chapter 9 P743 and fig 9.8, IPCC TS.14, IPCC SPM.6]. In this case "slow" is associated with "general features" and might be taken to mean changes on a timescale of roughly 30 years. However, the different GCMs tend to generate GMT time-series which have absolute values that are offset with respect to each other, typically by about 1 degree [see e.g. Mauritsen et al., Tuning the Climate of a Global Model, Journal of Advances in Modelling Earth Systems, 2012]. Subtracting these offsets, that is, 'rebasing' these model generated GMT time-series is an integral part of comparisons between ensembles of GCMs and observed past GMT.

We will discuss how linear rebasing constrains how the GCM are related to each other. The GMT of a given GCM is a macroscopic reduced variable that tracks a subset of the full information contained in the time evolving solution of that GCM. If the GMT slow timescale dynamics of different GCMs is to a good approximation the same subject to a linear translation, then the phenomenology captured by this dynamics is essentially linear; any feedback is to leading order linear in GMT. It then follows that a linear energy balance evolution equation for GMT is sufficient to reproduce the slow timescale GMT dynamics, provided that the appropriate effective heat capacity and feedback parameters are known. These will vary from one GCM to the next, as each GCM self-consistently evolves its own effective heat capacity and feedback parameters. Evolving linear GMT dynamics with the same time-dependent forcing but with different heat capacity and feedback parameters will lead to solutions that drift apart in time. We estimate this drift for the RCP45/RCP85 forcing time-series and a realistic range of heat capacity and feedback parameter values. The results are consistent with a scenario in which the slow timescale GMT obtained from different GCMs can be linearly rebased in the past, but spread out in the future. As a consequence GMT may not be a sensitive indicator of non-linear dynamics. Furthermore, to the extent that GCMs are tuned to achieve consistency with past GMT changes they may have limited possibilities of generating nonlinear responses related to fixed absolute temperatures. Thus they may underestimate the impact of, and uncertainty in, the outcomes of future forcing scenarios. Finally, the rebasing procedure identifies a slow time-scale dynamics in model generated GMT. Fluctuations on much faster timescales do not linearly rebase, that is they do not match up between the GCMs following rebasing. The GMT time-series can quite generally be decomposed into a slow and fast timescale and this may naturally lead to stochastic reduced energy balance models for GMT.

Alexander Todd
ENSO-related tropical precipitation change under global warming.
Thursday 7th July, 10.20(am)
University of Exeter
The El Niño-Southern Oscillation (ENSO) is a coupled ocean-atmosphere process and the leading cause of interannual climate variability on a global scale. ENSO events are associated with anomalous warming or cooling of sea surface temperatures (SST) in the eastern equatorial Pacific, causing large-scale circulation and precipitation pattern change. ENSO-related precipitation variability has a variety of social and economic impacts, locally in the tropics and remotely in the mid-latitudes. Recent studies have demonstrated changes in the spatial patterns of ENSO-related SST anomalies, and the frequency of extreme events, in CMIP5 model simulations of the twenty-first century under a range of global warming scenarios. We use AMIP experiments for an ensemble of atmosphere-only CMIP5 models to explore how ENSO-related precipitation changes in response to prescribed SST conditions. We identify and investigate a significant pattern change in precipitation under a spatially uniform SST increase. This adds to recent findings in the literature, suggesting that precipitation change can be driven by several factors in addition to SST pattern change. Precipitation change is decomposed into thermodynamical and dynamical contributions using a contemporary framework. A moisture budget analysis is also applied to examine mechanisms related to these precipitation changes. A key aim of this study is to improve mechanistic understanding of tropical precipitation change, in order to improve ENSO simulation in coupled climate models.

Keith Mitchell
Verification of Interval Probability Forecasts
Thursday 7th July, 10.55(am)
College of Engineering, Mathematics and Physical Sciences, Mathematics. University of Exeter
A forecast may be issued as the probability of a future dichotomous event (e.g. chance of rain tomorrow is 35\%). One approach to assessing, or verifying, such probability forecasts is to assign a score to each forecast-outcome pair; the method of calculating a score is called a scoring rule. Only proper scoring rules should be used, that is, scoring rules that do not allow a forecaster to improve their score by issuing a forecast that differs from their true belief. Existing studies of proper scoring rules have assumed that the forecast probability is a precise number. However, it may be preferable to give a forecast as an interval of probabilities (e.g. chance of rain tomorrow 25-40\%). Proper scoring rules for precise probability forecasts cannot be directly applied to the verification of interval probability forecasts, except in specific circumstances. New scoring rules that are proper for interval probability forecasts are required. We derive a general characterisation of scoring rules that are proper for interval probability forecasts. From this general characterisation we deduce particular scoring rules that may be considered analogues of the proper scoring rules commonly used for precise probability forecasts.

Fenwick C. Cooper, Peter D. Düben, Peter Ashwin

Can the use of numerical precision be optimised in simulations of chaotic systems using Lyapunov covariant vectors or singular vectors?

Thursday 7th July, 12.15(pm)

Department of Physics, University of Oxford

We test the impact of changing numerical precision upon forecasts using the chaotic Lorenz-95 system. Changing precision in the direction of eigenvectors of the growth and decay of forecast error is found to have only a small impact upon the forecast skill. On the other hand, in comparison with the calculated tendencies, errors due to the finite numerical precision representation of the system at an instant in time are dominant. In an average sense, these errors grow exponentially at a rate according to the leading Lyapunov exponent. This allows us to determine the maximum saving, in silicon, electricity and money, that can be obtained by reducing the numerical precision of forecast integrations.

Neil R. Edwards, Tamsin L. Edwards and Philip Holden

Quantifying uncertainty in model projections of the Antarctic ice sheet

Thursday 7th July, 13.50(pm)

Department of Physical Sciences. The Open University

Until recently, predictions of the Antarctic dynamic contribution to sea level rise - in particular the possibility of self-sustaining ice losses known as Marine Ice Sheet Instability (MISI) - have been widely different. Few had uncertainty estimates, so it was difficult to interpret their differences. Since the IPCC Fifth Assessment Report in 2013, a handful of studies have been published using ensembles of numerical model simulations and, in some cases, formal statistical inference such as Bayesian calibration with satellite data, to estimate uncertainties in projections.

We evaluate perturbed parameter ensembles from three different ice-sheet simulators (GRISLI and PISM, which are highly parameterised, and the high-resolution regional model BISICLES) to reconcile their apparent differences. We use emulation (statistical modelling of numerical simulators) to evaluate the sensitivity of sea-level contribution to model structure, ensemble design, calibration data and assumptions. BISICLES is well-described by emulation, indicating a promising way forward for quantifying and reducing uncertainty in predictions of the future of Antarctica.

Ed Wheatcroft
Gauging limitations of imperfect model prediction with sculpted ensembles (GLIMPSE)
Thursday 7th July, 14.10(pm)
Centre for the Analysis of Time Series, London School of Economics.
Many processes in nature, such as the Earth's atmosphere, are believed to be chaotic, that is they show sensitive dependence to initial condition error. Since, in practice, observations of natural variables and phenomena will almost certainly be obscured by measurement error, a single point forecast will always, in time, diverge from the Truth. Ensemble methods, in which multiple model simulations are run with slightly differing conditions, have therefore been developed. Occassionally, one or more ensemble members will feature some extreme event, such as, in weather forecasting, a large storm, a heat wave or a flood. Whilst it is useful to predict the likelihood of such an event, it is also of interest to determine how it may pan out. For example, if, a model simulation were to show a hurricane reaching the east coast of the USA, we may wish to try and determine its possible intensity or whether any model simulations show it hitting a major city.In theory, there is no limit to the number of model simulations that can be formed and, therefore, any number of different model scenarios can be examined. In practice, the size of the ensemble is usually severely limited by computational constraints. GLIMPSE uses data assimilation to attempt to find model simulations that lie close to one or more in which an event of interest occurs. Such model simulations are more likely to feature the event of interest and can thus give a better insight into how it may pan out. This talk will use dynamical systems to demonstrate GLIMPSE and discuss possible real world applications.

Hywel T P Williams, Chris Boulton and Humphrey Shotton,

Using social media to detect and locate natural hazards

Thursday 7th July, 14.30(pm)

University of Exeter

Methods for detecting and tracking natural hazards continue to increase in coverage, resolution and reliability. However, information on the social impacts of natural hazards is often lacking. Here we discuss the feasibility of using social media data (Twitter and Instagram) to detect and locate two important classes of natural hazard: wildfires and floods. If “social sensing” of these hazards can be shown to be reliable, then the potential exists to develop these data streams as a source of realtime information on social impacts of hazard events.

For wildfires in the USA, we analysed geotagged social media posts associated with wildfires over several time periods and compared them with wildfire occurrence data derived from satellite-based remote sensing and on-the-ground observations. For the whole of the contiguous United States, there were significant temporal correlations between wildfire-related social media activity and wildfire occurrence, but also substantial variation in the strength of this relationship at smaller spatial scales (states and counties). For flooding in the UK, we compared social media posts about flooding to historical archives of flood warnings and alerts by the Environment Agency. Again there were significant temporal and spatial correlations between social media and flood occurrence.

For both wildfires and floods, we then explored the utility of social media for location of hazard events. Application of several simple event-detection methods showed that social media data can locate wildfire and flood events with reasonable accuracy. For flooding in particular, social media data was able to identify events that were not logged by the Environment Agency, suggesting that this data may offer a useful expansion on existing observation methods. Results are improved by use of location inference algorithms to expand the set of geotagged social media data.

These encouraging preliminary findings suggest that social media data can be an effective resource for detection and location of natural hazard events. Since these datasets also contain rich information about how people are affected by these events, further investigation may yield useful quantitative insights into the social impacts of natural hazards.

Aileen Lam, Jean Francois Mercure, Charlie Wilson and Hazel Pettifor

Modelling heterogeneous consumer behaviour and diverse policy levers in global IAMs: proof of concept

Thursday 7th July, 15.20(pm)

University of Cambridge

Introduction

Transport predominantly relies on petroleum that supplies around 95% of the total energy used by world transport. With high rate of economic and population growth, transport energy use and related CO2 emissions are expected to increase more than 50% by 2030 compared to 2005 and more than double by 2050 with the fastest growth from LDV (IPCC 2014) and air vehicle.

Research question

While the average efficiency of passenger cars has improved significantly, existing studies have shown that energy efficiency improvements have been offset by a shift in purchasing patterns towards larger engine class (e.g. Gallachoir et al, 2009, Ajanovic et al, 2012, Van den Brink and Van Wee, 2001), partly as a result of income changes. This research examines the effect of income changes on future energy system transitions and emissions generated by passenger cars.

Method

To analyse the impact of income changes on the rate of technological transition, this paper uses a model of technology selection diffusion, called the FTT: transport, to simulate the impact of income rises on the rate of technological diffusion, energy use and emissions. The FTT: transport models socio-technical energy transitions by using Lokta-Volterra competition diffusion equations. It has the advantage of addressing innovation diffusion dynamics while capturing the heterogeneity of agents.

The paper first studies the relationship between income and car prices. To do this, we have collected national survey data from the USA, UK, Spain, Russia, Spain and China. In order to capture the relationships between income and willingness to pay for car, multivariate regression has been done to find the effect of changes in income on changes in car prices. Then, the income and price relationship is simulated in the FTT: transport model to explore the rate of technology diffusion and emissions.

Empirical results

Our results demonstrate that income effects on car engine class preference vary significantly across countries. For example, we found that countries such as the USA and Russia have a strong preference towards large engine cars compared to small engine cars when income rises. While in China and Korea, the preferences towards large engine sizes compared to middle size engine cars are less significant.

When simulated in the FTT model, we found that the technological diffusion pattern changes as a result of income changes. Luxury cars diffuse faster when income rises. Thus, the effect of emissions policies could be significantly counteracted, depending both on the levels of income rises and the cultural preference in individual countries. In certain countries (such as the USA), increase in income causes emissions to rise moderately, while in other countries (e.g. Russia), same level of increase in income resulted in a significant increase in emissions.

Emilie Vanvyve, Edward Pope, Helen Hanlon, Erika J. Palin, Adam A. Scaife, Margaret Gordon, Jeff Knight, Emily Wallace, Alberto Arribas and Anca Brookshaw

Trialling a seasonal climate service for UK transport stakeholders

Thursday 7th July, 15.40(pm)

Met Office, FitzRoy Road, Exeter

Major recent advances in the predictability of the winter North Atlantic Oscillation (NAO) index at seasonal timescales using the Met Office Global Seasonal Forecasting System (GloSea5) present opportunities for assessing the predictability of a variety of winter weather impacts on the UK. We have explored these in a current study, jointly supported by the UK Government Department for Transport (DfT) and the EU FP7 EUPORIAS project. Our earlier work in this study has shown that there is scope for using the NAO predictability to develop prototype risk-based seasonal forecasts of various winter impacts on the UK transport system (e.g. Scaife et al., 2014; Palin et al., 2015). We have now developed a methodology for providing examples of probabilistic impact forecasts, and have trialled these during winter 2015/16 as part of a service offered to UK transport stakeholders. These forecasts are produced using a statistical framework which combines the empirical relationship between the NAO and a number of transport-related impacts, with uncertainty in the seasonal NAO forecast. The approach yields statistically significant skill for a number of relevant impacts, demonstrating potential benefits the UK transport network.

Indrani Roy, Renata G. Tedeschi and Mat Collins

Influence of ENSO on Regional Indian Summer Monsoon Precipitation—Local Atmospheric Influences or Remote Influence from Pacific

Friday 8th July, 10.00(am)

College of Engineering, Mathematics and Physical Sciences, University of Exeter

Using CMIP5 model outputs in different El Niño-Southern Oscillation (ENSO) phases, this work investigates the indicator that could be used as an Index to characterise regional Indian Summer Monsoon (ISM) precipitation. Dividing the Indian subcontinent into five arbitrarily chosen regions, viz. Central North East (CNE) (18°N–31°N, 86°E–75°E), Hilly (H) (28°N–38°N, 85°E–70°E), North West (NW) (21°N–31°N, 79°E–67°E), North East (NE) (21°N–31°N, 86°E–97°E) and Southern India (S) (18°N–7°N, 73°E–85°E), local wind field and remote influences from the tropical Pacific are considered to improve understanding of regional monsoon rainfall. Results are also compared with observations/reanalysis data to pinpoint areas of shortcomings and agreements. Model results suggest that regional wind velocity, viz. meridional wind component (V) at 850 mb level (V850) and zonal component at 200 mb (U200) and 850 mb (U850) can yield better estimation of local precipitation in regions CNE, H and NW, agreeing well with earlier proposed monsoon Indices. Such observations are independent of different subcategories of ENSO phases and models show good correspondence with observations. Analyses with V at 200 mb (V200) indicate circulation of the upper branch of Hadley cells in regions CNE and S, though suggest the best agreement among models in comparison with other fields, but there are some deviations from observations, indicating a missing mechanism in the models. Using models, this study identified the best parameter in different regions that could be used for the regional monsoon Index, irrespective of various ENSO subcategories; for CNE it is the U200, for H it is U200 and U850, and for NW it is U850. The current analysis, however, fails to indicate anything clearly about the NE region. When focusing on the remote influence from the eastern Pacific region, it is found that atmospheric contribution to regional ISM precipitation fails to indicate consistent roles among models, but sea surface temperature suggests strong connection. However, remote influence from the Central Pacific is captured uniformly in models via zonal components of wind in the H and NW regions.

David I. Armstrong McKay*[1], John A. Dearing[1], James G. Dyke[1], Guy Poppy[2], & Les Firbank[3]

The evolution of agricultural intensification and environmental degradation in the UK: a data-driven systems dynamics approach

Friday 8th July, 10.20(am)

[1] *Geography and Environment, University of Southampton, Southampton*
[2] *Centre for Biological Sciences, University of Southampton, Southampton*
[3] *School of Biology, University of Leeds, Leeds*

The world's population continues to grow rapidly, yet the current demand for food is already resulting in environmental degradation in many regions. As a result, an emerging challenge of the 21st century is how agriculture can simultaneously undergo sustainable intensification and be made more resilient to accelerating climate change. Key to this challenge is: a) finding the "safe and just operating space" for the global agri-ecosystem that both provides sufficient food for humanity and avoids crossing dangerous planetary boundaries, and b) downscaling this framework from a planetary to a regional scale in order to better inform decision making and incorporate regional dynamics within the planetary boundaries framework. Regional safe operating spaces can be defined and explored using a combination of metrics that indicate the changing status of ecosystem services (both provisioning and regulating), statistical techniques that reveal early warning signals and breakpoints, and dynamical system models of the regional agri-environment system. Initial attempts to apply this methodology have been made in developing countries (e.g. China (Dearing et al., 2014, 2012; Zhang et al., 2015)), but have not yet been attempted in more developed countries, for example the UK.

In this study we assess the changes in ecosystem services in England and two contrasting agricultural sub-regions, arable-dominated East England and pastoral-dominated South-West England, since the middle of the 20th Century. We identify and establish proxies and indices of various provisioning and regulating services in these two regions and use statistical analysis (primarily correlation analysis and principal component analysis) to explore how these are related and have changed over this time. We find that significant degradation of regulating services occurred in England in the early 1980s, reflecting a period of rapid intensification and escalating fertiliser usage, but that regulating services have begun to recover since 2000 mainly as a result of fertiliser usage decoupling from increasing wheat yield. Soil erosion / suspended sediment transport and atmospheric pollution have also declined in most regions, but biodiversity degradation metrics continue to rise. Environmental degradation resulting from agriculture appears to have followed the trajectory of an Environmental Kuznets Curve, with recent years showing that regional GDP growth has begun to decouple from ecological deterioration. The history of South-West England is complicated by the significant drop in livestock density as a result of the 2001 foot-and-mouth disease outbreak and highly variable erosion data, but in general a similar pattern of increasing degradation in the 1980s and a gradual recovery since ~2000 is observed. Data with higher spatial and temporal resolution is required in order to further investigate the differing behaviour of the agri-ecosystem in each region. Based on this analysis a prototype dynamical systems model of the English agri-ecosystem was developed, the preliminary results of which indicate the broad trends in the data can be recreated. Further development of this model will enhance our ability to identify regional social-ecological system boundaries and to detect the potential presence of tipping points within them.

Posters - Abstracts

Hassan Alkhayuon *and* Peter Ashwin

Pullback attractors and rate-induced tipping in parameter shift non-autonomous systems with nontrivial limit dynamics.

University of Exeter

Ashwin *et al* [1] have suggested a definition of R-tipping appropriate for parameter shift non-autonomous systems by using pullback attractors which limit to equilibrium points backward in time. This study aims to generalize that definition in order to cover wide range of invariant sets. We considered the pullback attractors that can limit to any invariant set, backward in time, and we used the concept of upper limit of sets to come up with more general definition. The new definition will allow us to study the phenomena of R-tipping that may occur when an invariant set, such as periodic orbit, is moved as an effect of the parameter shift.

[1] P. Ashwin, C. Perryman and S. Wieczorek. Parameter shift for nonautonomous systems in low dimension: bifurcation- and rate- induced tipping. arXiv:1506.07734.

Gabor Drotos

The framework of snapshot attractors in the characterization of teleconnections during climate changes.

MTA-ELTE Theoretical Physics Research Group Budapest

Separating the response of the climate dynamics to an external forcing from internal fluctuations is a long-standing problem. We claim that the latter, i.e., the internal variability, reflected in the variety of the possible weather patterns permitted within a given climate, is described by the natural probability measure of the dynamics' snapshot attractor in any instant of time, while the forced response is given by the time evolution of this probability measure. In the presence of an arbitrary and possibly non-periodic forcing, the snapshot attractor and its natural measure are traced out in any time instant by an ensemble of trajectories that differ solely in their initial conditions. In practice, these initial conditions should be prescribed in the past such that their convergence to the attractor takes place before the time instant of observation. This convergence, i.e., the process of forgetting the initial conditions, has a well-defined characteristic time scale (it is ``fast'') so that obtaining the snapshot attractor of a system is practically both feasible and relevant.

In the climate dynamics, teleconnections appear as statistically well-correlated weather patterns between remote geographical regions of the globe. In a changing climate, however, the strengths of the teleconnections might change, and an appropriate characterization of these correlations and their change is lacking in the literature. We claim that the snapshot attractor framework, by describing the probabilities of all possible weather patterns in any instant of time, provides a natural tool for characterizing teleconnections. In particular, the instantaneous strengths of the teleconnection patterns, even in a changing climate, are quantified by the correlation coefficients taken with respect to the natural measure which is, nevertheless, continually evolving in time.

As a particular example, we consider the teleconnection pattern of the North Atlantic Oscillation (NAO). In an intermediate-complexity general circulation model, the Planet Simulator of the University of Hamburg, we demonstrate that the snapshot attractor framework provides the only statistically appropriate characterization of the NAO teleconnection pattern, in contrast to the traditional approach which evaluates the correlations over time, along the evolution of single time series. In our setup, the NAO teleconnection pattern is found to persist during climate changes, but its strength is observed to be time-dependent.

Dominik Huelse

Studying Earth's recovery from greenhouse climates: Using a new, numerically efficient sediment model for the coupling to Earth System Models

University of Bristol

The ocean-sediment system, as the biggest carbon reservoir in the Earth's carbon cycle, plays a crucial role in regulating atmospheric carbon dioxide concentrations and climate. Therefore, it is essential to constrain the importance of marine and sedimentary carbon cycle feedbacks on global warming. I am interested in the development and application of mathematical models in order to enhance our understanding of global biogeochemical dynamics and its influence on the carbon cycle and climate. Despite its fundamental importance, an appropriate Earth System model of the coupled atmosphere-ocean-sediment system which is able to model all relevant processes and feedbacks over geological time-scales currently does not exist. The major problem is the high computational cost of simulating the essential redox reactions in marine sediments which are important to calculate burial of organic carbon and benthic recycling fluxes of chemical compounds. The goal of my research is to reconstruct the recovery dynamics of the Earth system from a greenhouse climate, using a newly developed analytical diagenetic model that includes a mechanistic description of organic carbon preservation in marine sediments (Hülse et al., in prep., GMD). By coupling it to a three-dimensional Earth system model of Intermediate Complexity (cGENIE, which currently does not represent the burial of organic carbon) we will create the first Earth system model accounting for all important modes of Earth system recovery from a condition of elevated atmospheric CO_2 concentrations and global warming. Our analytic model is based on a one-dimensional advection-diffusion reaction equation for solid and dissolved species in a porous media. It describes organic carbon mineralization/burial, the resulting C, O_2, N, S, and P diagenetic processes and the sediment-water interface exchange fluxes for nutrients as a function of bottom water concentrations, temperature and sediment characteristics (e.g. bioturbation). The model is based on a three layer approach, distinguishing between the oxic-zone, the nitrate reduction zone and the sulfate reduction-zone. This presentation provides an overview of the new sediment model, compares results with a well-established, state-of-the-art early diagenetic model (Biogeochemical Reaction Network Simulator, BRNS) and discusses research plans to apply the new cGENIE configuration for understanding Earth's recovery dynamics from a greenhouse climate.

Maryam Ilyas, Serge Guillas and Chris Brierley

ENSO uncertainty quantification in spatial distribution of temperature using lattice kriging

Department of Statistical Science, University College London. Department of Geography, University College London

Exploiting massive amounts of data generated over the large spatial regions in geophysical sciences is vital to monitor climate processes. The HadCRUT4 is one key large database of temperature anomalies. There are gaps in coverage, unlike other closely related data sets (e.g. GISS anomalies), which restricts regional analysis. The classical spatial statistical models for spatial data analysis necessitate calculations that become prohibitive in the framework of large data. The multi-resolution lattice kriging encapsulates nonstationary spatial dependence and ensures fast computations by modeling sparse precision (inverse covariance) matrices based on the coefficients of linear combination of basis functions. Sparsely observed HadCRUT4 global temperature anomalies are extended to cover the whole planet using the multi-resolution lattice kriging. The point wise prediction uncertainties of predicted smooth temperature anomalies are also computed. The lattice kriging ensembles are generated to present the distribution of these prediction uncertainties. The HadCRUT4 ensembles present sets of realizations accounting for the observational uncertainties arising from the non-climatic factors. These observational and prediction uncertainties associated with the El Niño Southern Oscillation (ENSO) is quantified using the HadCRUT4 and lattice kriging ensembles, respectively. This twofold uncertainty in the global average temperature propagates to the classification of El Niño states. The classification of El Niño events and temperature trend analysis of the grouped years exhibit that El Niño years are the warmest and La Niña years have the highest warming rate across the HadCRUT4 and lattice kriging ensembles. The sub classification of El Niño years reveals that the central Pacific El Niño years are the warmest having the highest rate of warming across ensembles presenting the distribution of observational uncertainties. However, the eastern Pacific El Niño years are the warmest having the highest rate of warming across ensembles sampling the prediction uncertainties.

James Kent

Dynamical Core Model Intercomparison Project 2016

University of South Wales

The Dynamical Core Model Intercomparison Project (DCMIP) is a workshop aimed at evaluating operational and newly developed dynamical cores. A suite of test cases have been developed (the moist baroclinic wave test, the simplified tropical cyclone test, and the supercell storm test), and a variety of modelling groups used DCMIP to test their dynamical cores in the key areas of physics-dynamics coupling and variable resolution modelling. The workshop also plays host to approximately 50 students, who attend specialist lectures and gain hands on experience of running dynamical core models. This poster describes the test cases, shows the model results, and provides an intercomparison between these models.

Louise Kimpton

Can our models reproduce the biogeochemistry of Ancient Oceans?

University of Exeter

A lot of our knowledge of palaeoclimate comes from models. Models of the physical environment are based on Newton's laws so we can be confident they will work as well in the past as in the present day. This is not the case for models of the biological system. We would expect the ecology of the ocean to be very different in the colder conditions of the last glacial maximum. Can our models, based on present day data, be used to simulate past conditions?

In this paper we see whether a model of present day biogeochemical cycles in the ocean (HadOCC), can successfully reproduce data from the last glacial maximum (LGM). In fact we test whether we can show that it cannot. We build a statistical representation of HadOCC, using emulators. This is computationally efficient requiring an initial set of training runs and allows us to estimate the model response across the whole of input space. We use a Gaussian process emulator; fully specified by its mean and covariance functions. Gaussian processes are similar to the familiar Normal distribution but over the space of functions. We use data from a version of the HadOCC model to build an emulator for the mean of the carbon content in the oceans over 50 years at the end of a long run. This emulator models the relationship between 8 inputs (parameters) and a single output, using a linear mean function and a Gaussian (squared exponential) covariance function.

Once we have built our emulator we can 'calibrate' the model with present day data. Rather than try to find an optimal set of parameters, we use a method known as history matching. History matching is a process to reduce the input space of a simulator. It involves using an implausibility measure to discount any regions of input space that could not produce acceptable matches between the simulator output and the observed data. We compare HadOCC to present day estimates of the total carbon content of the ocean. This comparison yields a set of HadOCC parameters which we cannot say are incompatible with the data. We then see whether the estimates of total carbon content from the LGM is within this set. If it is not, we can say that the models we use for the present day cannot be used to simulate ocean bio-geochemistry at the LGM; if it is, we cannot rule out that the models will give good simulations.

The HadOCC model is chaotic. The numbers it produces vary in an unpredictable way. An emulator of the variance shows that it cannot be considered constant. We model this by emulating both the mean and variance of the signal. This involves extending the concept of emulators, applying a multi-variate process to the HadOCC output. The covariance function for a multivariate Gaussian Process specifies an rxr covariance matrix between the r outputs of the simulator. For this example, we jointly emulate the mean and variance, to see if the emulator uncertainty is improved by considering the covariance between the mean and variance. Non-separable covariance structures are considered, in particular based on convolution methods. The convolution of a Gaussian white noise process with a smoothing kernel is used, where the smoothing kernels determine the input space correlation function for each output. In a similar way to the univariate problem described above, we use a modified version of history matching to see whether we can rule out being able to simulate the LGM.

Stephen Thomson & Geoffrey Vallis

The effect of reducing Rayleigh drag on the jets in a Jupiter GCM

University of Exeter

One of the significant problems with General Circulation Models (GCMs) of giant planets is the uncertainty over the boundary condition at the model's solid-lower boundary. In reality, giant planets such as Jupiter do not have such a boundary. Their vertical structure instead consists of a stably-stratified outer layer known as the 'weather-layer', which extends down to several bars in pressure, and a much deeper neutrally-stratified interior beneath. Solid-lower boundaries are, however, a practical necessity in GCMs.

A common feature of weather-layer-only GCMs is to include a frictional force, in the form of a Rayleigh drag, at the lower boundary. On terrestrial planets a drag at the lower boundary is well motivated, given the presence of a solid-lower boundary and the frictional 'boundary-layer' above. However, on a giant planet, no such boundary or boundary-layer exists, especially at the relatively shallow weather-layer depths used in most GCMs.

Given the uncertainty surrounding the use of Rayleigh drag at the model's lower boundary, we investigate the impact of reducing the magnitude of the Rayleigh drag in a weather-layer-only Jupiter GCM.

To investigate the effects of Rayleigh drag on the flow, we steadily reduce the magnitude of the Rayleigh drag to see how the atmosphere responds. We focus on the effects of the reduction on the morphology of the zonal jets. Early results indicate that reducing the drag has a significant impact on the jet morphology. Implications for future giant-planet GCMs will be discussed.

Philip Townsend, Mehmet Ersoy and Omar Lakkis

Numerical simulation of flood inundation for the shallow water equations with bulk recharge and discharge

University of Sussex

The flow of water in rivers and oceans can, under general assumptions, be efficiently modeled using the shallow water equations (SWEs), a hyperbolic system of conservation laws which can be derived from a starting point of incompressible Navier-Stokes. A common difficulty in the numerical simulation of such laws is the conservation of physical entropy. Work by Audusse, Bristeau, Perthame (2000) and Perthame, Simeoni (2001) proposed numerical shallow water solvers known as kinetic schemes, which can be shown to have desirable entropy-consistency properties, and are thus called well-balanced schemes.

In flood risk assessment models, the SWEs must be coupled with other equations describing the interaction with meteorological and hydrogeological phenomena such as rain and groundwater flows. The SWEs must therefore be appropriately modified to accommodate source and sink terms, and thus standard kinetic schemes are no longer valid. While modifications of the SWEs in this direction have been recently proposed (e.g. Delestre (2010)), we depart from the extant literature by proposing a novel model that is entropy-consistent and naturally extends the SWEs by respecting its kinetic formulation connections.

In doing so, we derive a system of partial differential equations modeling the ow of a one-dimensional river with both a precipitation term and a groundwater ow model to account for potential infiltration and recharge. We exhibit numerical simulations of the corresponding kinetic schemes, utilizing stochastically derived, data-driven precipitation terms. We consider these simulations in terms of their application to both
real world flood prediction and the tackling of wider issues on how climate and societal change are affecting flood risk.

Nick Watkins

Fact versus formula in the power spectra of complex systems

London School of Economics and Political Sciences, Centre for the Analysis of Time Series, London, United Kingdom. CFSA, University of Warwick, Coventry, United Kingdom. MCT, Open University, Milton Keynes,

More than 100 years ago, Thomson and Tait’s classic "Treatise on Natural Philosophy" cautioned its readers against "considering the formula and not the fact as physical reality". Deciding what the facts actually were, however, was left as an exercise for the reader. Complex systems offer many examples [1] of the ambiguity Thomson and Tait were trying to point out. This presentation will be about a formula-the "1/f" spectral shape seen in many areas of physics including climate science; and an empirical fact-the growth of rescaled range originally seen in river time series and now known as the Hurst effect.

It is well known that Mandelbrot kicked off the study of long range dependence (LRD) in the mid 1960s [2] with a stationary model for 1/f noise and the Hurst effect. This fractional Gaussian model is now so well known that it is often seen as synonymous with both 1/f noise and the Hurst effect. However Mandelbrot himself was aware that there were other models that produced 1/f noise, including a family [3-6] which he called "conditionally stationary", with power law distributions of times between switching of states. Late in his life he re-emphasised the clear contrasts between their behaviour and that of fGn. I will explain why these other models are also physically interesting, and will show why real systems including climate examples may potentially map more closely to one or the other, or may in fact combine both aspects. I will also discuss his proposals for distinguishing between the models and how they may be implemented.

[1] Watkins, Bunched Black Swans, Geophys Res. Lett, 2013
[2] Graves et al, A Brief History of Long Memory, arXiv:1406.6018 [stat.OT]
[3] Berger and Mandelbrot, "A New Model for Error Clustering in Telephone Circuits", IBM Technical Journal, July 1963.
[4] Mandelbrot, “Self-similar error clusters in communications systems, and the concept of conditional stationarity”, IEEE Trans. on Communications Technology, COM-13, 71-90, 1965.
[5] Mandelbrot, “Time varying Channels, 1/f noises, and the Infrared Catastrophe: Or why does the low frequency energy sometimes seem infinite ?”, IEEE Communication Convention, Boulder, Colorado, 1965.
[6] Mandelbrot, "Some Noises With 1/f Spectrum, a Bridge Between Direct Current and White Noise", IEEE Trans. Inf. Theory, 13(2), 289, 1967.

Andrew Wheadon

Subgrid interactions in a shallow water model

University of Exeter

Limitations to the resolution of production models result in processes falling below the resolvable scales. As the subgrid scale processes are able to interact with larger scales it is necessary to simulate these scales e.g. through a subgrid model or parametrisation. By using a high resolution shallow water model and truncating the energy spectra at a given wavenumber we may investigate the effect of the truncated scales on the rest of the energy spectrum. Further to this, given appropriate scaling the total energy spectrum may be formulated in terms of different quadratic components such as the divergent, rotational or potential energy. Thus interactions between these components may also be investigated to give a finer picture of the processes at work.

Useful Information

Internet Access:

Unlimited WiFi is provided free of charge in all of our accommodation. Access passwords will be provided to you on request when you check in.

Instructions for WiFi access at the Conference Venue will be provided at the Conference.

Parking:

Residential delegates will be issued a free of charge Residential Car Parking Permit on key collection.
Please display your permit, marked with your car registration number, clearly in your vehicle.
Subject to availability, you may use any of the Residential campus car parks. If you are unable to find a residential car parking space, then you would be required to purchase a standard car parking ticket.

Day Delegates must purchase a car parking ticket from the machines located near to the car parks on campus. Full information including charges, accessibility and location of car parks can be found on the website www.exeter.ac.uk/visit/directions/carparks/

Travel Advice:

Taxi's: Apple Central Taxis, 3-4 Isambard Parade, Exeter EX4 4BX, Tel: 01392 66 66 66

Sat Nav: use postcode **EX4 4QR.**

Campus Amenities:

The University has a range of cafés and restaurants on campus including:

- Reed Hall Restaurant and Café
- Costa Coffee, upstairs at the Forum
- La Touche Café, in Building: One, The Business School
- Northcott Theatre Bar, upstairs at Northcott Theatre

Useful shops located around the campus include the Market Place, located in both the Forum and Cornwall House providing take away food including sandwiches and snacks, groceries, confectionery, alcohol, newspapers , stationery and toiletries.

There are 2 banks on Campus, both with ATM machines.

- Natwest Bank: located on the ground floor of the Forum.
- Santander: located on the first floor of Devonshire House.

Notes

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