

SAMBa student projects

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Students starting in 2020

Exponentially small selection mechanisms in potential flows - **Cecilie Andersen**

Supervisor: Phil Trinh

This project considers the asymptotic analysis of differential equations in some singular limit, say $\varepsilon \rightarrow 0$, and where an eigenvalue, say λ , exhibits a selection mechanism. In some cases, this yields a countably infinite sequence, $\lambda_1 < \lambda_2 < \lambda_3 < \dots$. However, within a number of such open problems, the mechanism determining the sequence as $\varepsilon \rightarrow 0$ is governed by exponentially small terms beyond-all-orders.

This project will study open problems related to selection mechanisms in potential flow. First we are considering the open problem related to the selection mechanism determining the angle of separation in the falling jet/rising bubble problem. Later we hope to resolve such selection mechanisms for several other related open challenges in fluid and continuum mechanics.

Epidemiological dynamics in populations with spatial and demographic structure - **Abby Barlow**

Supervisor: Ben Adams, Sarah Penington

Abby's research lies in the field of epidemiology. In particular, she is concerned with further developing and applying the theory of spatially and demographically structured epidemiological models. In her thesis formulation report, she developed and analysed an age-structured model for COVID-19 epidemiology in Mongolia. The model incorporates age-related transmission rates to account for the country's specific demographic structure. In her future PhD research she plans to develop spatially-structured epidemiological models under metapopulation and household frameworks. Under these frameworks, the population is divided into subpopulations based on their spatial separation or designated households. This allows for a distinction between the stronger and more frequent contacts we expect between individuals who reside closer to each other and the weaker contacts between those further apart.

A priori bounds for fractional SPDEs - **Salvador Esquivel**

Supervisors: Hendrik Weber

Salvador's research is in the field of singular SPDEs, more particularly in the fractional ϕ^4 model which is an important model in Quantum Field Theory that arises as the natural Glauber dynamics in the Brydges-Mitter-Scoppola model. In recent years the theories of Regularity Structures and Paracontrolled Distributions have led to a lot of research for the non fractional ϕ^4 model. The aim of the project is to extend some of this work to the fractional case by constructing a solution theory and a priori bounds to extend local in time existence of solutions.

The symbiotic contact process on non-lattice structures - **Carmen van-de-l'Isle**

Supervisors: Marcel Ortgiere, Sarah Penington

The symbiotic contact process is a two particle type extension of the contact process. We can think of the process as two contact processes which help each other to survive, hence the symbiotic name. The process can be motivated by both disease modelling, where a patient is less likely to recover as quickly from two illnesses versus one, or modelling animal species which live longer in close contact. The process has been studied on lattices where a phase transition has been proved between survival and extinction given the infection rate of the process. We aim to extend on this work by providing results for the phase transitions and critical values for the infection parameter on non-lattice structures such as Galton-Watson trees and random graphs.

Excursions from Hyperplanes for Isotropic Stable Processes - **Sonny Medina Jimenez**

Supervisors: Andreas Kyprianou, Juan Carlos Pardo Millan

Breaking the paths of isotropic Lévy processes in $\mathbb{R}^d$ in radial excursions from the origin is a technique that has been used to understand the behaviour of processes when they approach the origin or the unit sphere $S = \{x \in \mathbb{R}^d : |x| = 1\}$. We aim to build on these ideas and techniques and consider related behaviour in relation to the hyperplane $H = \{x \in \mathbb{R}^d : \langle x, v \rangle = 0\}$, with $v \in S$, and use the associated path decomposition to address questions such as how to condition the process to stay on one side of the hyperplane, examining the point of closest reach to H , conditioning to never touch the hyperplane or the relationship between this and the spherical case via conformal transformations of Riemannian manifolds.

Multivariate Regression on High-Dimensional Networks - **Daniel Miles**

Supervisors: Sandipan Roy and Vangelis Evangelou

A crucial feature of many modern data sets is their inherent graphical (network) structure embedded in them. Gaussian Graphical Models, known by various other names, are commonly used in Statistics to encode a graphical conditional relationship onto a multivariate Gaussian distribution. Many scientific applications manifest a high dimensionality combined with a sparse graph structure, which can hinder inference and high-level interpretation when fitting graphical models onto relevant data. However, as exemplified through geospatial crime data, the implementation of a regression-based transformation through a penalty term in the log-likelihood function can efficiently and informatively infer a covariate relationship between a high number of connected nodes (crime rates for different regions) with a smaller number of secondary variables (socioeconomic factors). Daniel's project aims to establish tractability conditions for parameter estimation under a generalised expression of this new Gaussian graphical model, through an iterative algorithmic procedure. Where a graph structure is not known, a Lasso-like penalty must be employed in tandem with the regression penalty. Further considerations include the extension of the single graph case to that of an evolving graph, mainly in a temporal sense.

Problems for self-similar Markov processes - **Mehar Motala**

Supervisors: Andreas Kyprianou, Alex Cox

The interplay between stable Lévy processes and self-similar Markov processes has attracted much interest in recent decades, and is what continues to motivate research in the field of Lévy processes. In particular, the problem of characterising the laws of Markov processes via Doob h-transforms which arise from limiting procedures of conditioned processes has been considered. As part of this project, we aim to describe the Markov Additive Process conditioned to continuously hit the unit sphere in d dimensions, building upon existing work which involved conditioning the stable process to continuously approach the unit sphere.

Statistical learning methods for dimension reduction in multivariate extremes - **Matthew Pawley**

Supervisors: Christian Rohrbach, Evangelos Evangelou

In many application areas, such as climate science and finance, it is important to assess the risk of rare, extreme events. Mathematically, this involves modelling the tail behaviour of a multivariate random variable using techniques from a field of statistics called multivariate extreme value theory. However, the tail dependence between the components is characterised by a measure that must be estimated using only a small number of observations. Traditional methods for modelling this measure are limited to small or moderate dimensions. Recently, methods from unsupervised learning, such as clustering and principal components analysis, have been adapted to extreme; these methods are better-equipped to handle high-dimensional settings. Matthew's project aims to advance existing techniques and develop new methodology in this area.

Flow-based statistical-shape models - **Allen Paul**

Supervisor: Tony Shardlow

The project will develop flow-based methods for understanding and categorizing medical images, with a long-term goal of describing shape variation of bones in psoriatic arthritis. Two key areas to be explored are: i) large-deformation diffeomorphic metric mapping: deterministic techniques for warping two images via a diffeomorphism to identify areas of similarity and difference, and ii) statistical techniques for working with uncertain deformation fields and Bayesian techniques for describing shape variation.

Modelling of ice crystal icing in engines - **Timothy Peters**

Supervisors: Phil Trinh, Hui Tang

In 2006 a new phenomenon was recorded to have caused repeated reports of engine failure. This was coined ice crystal icing and occurred at altitudes previously thought benign. Ice crystals would be ingested into airplane engines where they would partially melt, leading to the accretion and breaking off of ice, causing engine damage. Timothy is exploring this accretion problem, with the aim to develop a full accretion model for an arbitrary engine geometry. This accretion problem lends itself to a few different long-term projects. The first is the development of the accretion models and a large-scale analysis of key physical quantities. The second involves studying the dynamics of ice break off in the engine.

Tumour and Treatment Modelling - **Jenny Power**

Supervisors: Tristan Pryer, Silvia Gazzola

This project is concerned with brachytherapy treatment for cancer patients. Brachytherapy is a type of radiation treatment that consists of placing sealed, radioactive sources directly into or next to the tumour to be treated. These sources emit radiation which kills the tumour. It has proven to be an efficient form of treatment as the radiation dose delivered can be focused on the tumour, and can be quite high, while limiting dose exposure of the surrounding normal tissue. However, a disadvantage of brachytherapy occurs when the tumour is close to a critical organ. In this instance, the radiation emitted from the sources may damage these critical organs, which could cause further health problems and complications. A challenge lies in positioning the sources such that the tumour is exposed to the required amount of radiation to kill it, but the critical organ is not exposed to excessive toxicity. The main question this project will address is “Where should these radioactive seeds be placed (and how many of them), such that the dose on the critical organs is minimised?”. This project spans the mathematical topics of partial differential equations, numerical analysis, inverse problems and PDE constrained optimisation, as well as the physical and biological processes behind radiation transport. The aim of this work is to develop a numerical model which will determine the optimal placements of these radioactive sources such that the damage on the critical organs and surrounding tissue is minimal, but the dose on the tumour is still high enough to eradicate it. This problem is formulated as a PDE constrained optimisation problem.

Once-reinforced random walks on tree-like graphs - **Pawel Rudnicki**

Supervisors: Daniel Kious and Hendrik Weber

Once reinforced random walk (ORRW) is an example of a self-interacting random walk, which is not Markovian, and hence, the study of it often proves to be rather nontrivial. It has been studied mainly on trees, and the existence of a phase transition for recurrence/transience has been established on those graphs. There have only been a few results obtained for ORRW on non-simple graphs, exclusively on ‘ladder graphs’, which are essentially one-dimensional. Pawel is investigating ORRW on tree-like graphs, that is, graphs with loops which additionally possess a useful tree structure. In particular, Pawel’s research concerns learning about the phase transition on that class of graphs.

Learning the Regulariser for Inverse Problems - **Seb Scott**

Supervisors: Matthias Ehrhardt, Silvia Gazzola

Solving inverse problems, such as those that arise in imaging applications, like computed tomography, is a challenging task due to their inherent ill-posedness and high dimensionality. Traditionally, one solves them using model-based methods, with variational regularisation models [2] being the most popular - where the choice of regulariser is usually a fixed, ad hoc decision. Recently, more data-driven approaches for determining regularisation operators and regularisation parameters have been considered [1]. This project is an exploratory study into these semi-data-driven methods for solving inverse problems, with a focus on the bi-level learning framework, and how one may use a neural network to learn, with mathematical guarantees, an appropriate regulariser.

[1] S. Arridge et al. “Solving inverse problems using data-driven models”. eng. In: Acta numerica 28 (2019), pp. 1–174. issn: 0962-4929.

[2] J. Chung, S. Knepper, and J. G. Nagy. "Large-Scale Inverse Problems in Imaging". eng. In: Handbook of Mathematical Methods in Imaging. New York, NY: Springer New York, pp. 43–86. isbn: 0387929193.

Exploring information spread and stochastic systems in biology - **Andrei Sontag**

Supervisors: Tim Rogers, Christian Yates

Mathematical modelling of biological systems has been of paramount importance in aiding policy-making aimed to curb the spread of diseases or rumours, save endangered species, and control plagues of locusts. This project will concern the exploration of intriguing and exciting topics in mathematical biology. Three research topics are of particular interest. First, the study of the complex dynamics arising from the feedback between the behavioural reactions of individuals to an ongoing epidemic. Second, the investigation of information and misinformation spread in populations, particularly on networks. And third, the study of the collective motion of locusts, focusing mainly on the extension of existing models to account for halting movement.

Robust Adaptive Dynamic Programming for the Newsvendor Problem - **Marcel Stożir**

Supervisor: Alex Cox, Clarice Poon

In data-driven stochastic optimisation problems that account for model uncertainty, the decision maker can either act myopically based on the knowledge that has been acquired so far or exploratory by choosing a sub-optimal action that may gather more information about the system to improve future decisions. This exploration-exploitation trade-off is most prominently encountered in the newsvendor problem where a retailer can only observe the number of products sold but not the excess demand, and is encouraged to learn about the unknown demand distribution to make more informed inventory decisions. Marcel's work focuses on approximating the optimal solution in this planning problem in such a way that the decision maker can learn the true characteristics of the demand robustly under model misspecifications. Based on concepts from optimal transport theory he plans to develop a method aimed at adaptively reducing the infinite space of attainable future models to a finite number of distinct forms; which allows for an effective computation of the intractable Bellman equation. He intends to extend this method to a broader range of uncertain stochastic optimisation problems which may also allow for a scenario reduction technique in algorithm planning for Reinforcement Learning applications.

Justification of kinetic equations using graph structures - **Theodora Syntaka**

Supervisor: Karsten Matthies

The derivation of continuum equations from a discrete deterministic system of particles is of major interest. This is an area of research in mathematical physics originating from Hilbert's Sixth Problem in 1900. This problem has been approached in two steps using the Boltzmann equation as a mesoscopic description. The first one is to derive kinetic equations, such as the Boltzmann equation, from a system of particles and the second is to derive continuum equations, such as Navier-Stokes and Euler equations, from the Boltzmann equation. Kinetic equations such as the Boltzmann equation are iconic because they illustrate the phenomenon that irreversible dynamics can be the result of reversible microscopic motion. My project focuses on developing a

novel approach which combines tools from Probability theory and Analysis to systematically approximate the particle dynamics with simpler evolutions.

Adaptive Undersampling in Spectromicroscopy - Oliver Townsend

Supervisors: Silvia Gazzola, Sergey Dolgov, Paul Quinn

My project is focussed on making the spectromicroscopy experiment more efficient through the use of undersampling. The spectromicroscopy experiment is a key tool used by material scientists to determine the chemical speciation of a specimen at the microscopic level; the issue is that even relatively small samples take a long time to complete, causing a bottleneck in services. By taking fewer measurements and recovering the missing data entries (one method is through the use of Low Rank Matrix Completion Algorithms), we can reduce the time each experiment takes, and allow a significant increase in the number and quality of scans taking place.

Stochastic Pattern Formation - Fraser Waters

Supervisors: Kit Yates, Jonathan Dawes

First proposed as an explanatory model for morphogenesis, the paradigm of a 'Turing pattern' has been used to analyse the spontaneous emergence of coherent spatio-temporal structures in reaction-diffusion systems across a wide range of applications, from mathematical biology to nonlinear optics. In continuous deterministic models, this instability mechanism is well understood, and typical analysis can predict the leading order spatial characteristics and growth rates of these emerging patterns, as well as the parameter regimes in which they may be observed. Stochastic models have been shown to exhibit such patterns far outside the parameter regimes predicted by their deterministic counterparts. Fraser is exploring the analysis of these 'Turing pattern'-like instabilities in lattice-based stochastic jump process reaction-diffusion models, in particular the effects of stochasticity on the susceptibility of the system to this spontaneous patterning, and the characteristics of the emergent structures.

Students starting in 2019

Mathematical and statistical analysis of time series data to quantify trends and events in ocean noise - Gianluca Audone

Supervisors: Matt Nunes, Philippe Blondel, Chris Budd, Peter Harris, Stephen Robinson

Variation in the ambient sound levels in the deep ocean has been the subject of recent studies, with particular interest in the identification of trends, features and events in the data. Many early studies demonstrated the effect of shipping on low frequency sound dynamics in the deep-ocean. However, it is now recognised that there is a variety of other sound sources, both natural and man-made, contributing to the soundscapes. In addition, climatic variations like warmer oceans or sea ice cover can influence sound propagation over large distances. Given the high-dimensional and complex nature of the dataset, Gianluca is developing a modelling framework to reveal intersource and intersensor dependencies in the data, i.e. to extract quantitative information about sound levels in the deep ocean from the data. The analysis methodology developed includes aspects of signal processing, statistical characterisation of dynamics and machine learning

techniques. Being able to separate and efficiently analyse sources of noise in this complex environment will lead to improved understanding of the local and global causes of fluctuations in ocean acoustics, and have potential impact in short- / long-term environmental planning and marine conservation. Gianluca is working in collaboration with the National Physical Laboratory (NPL).

Design principles for active solids – Guido Baardink

Supervisor: Anton Souslov

Metamaterials are designed materials whose microscopic geometry is carefully engineered to achieve macroscopic properties not readily found in nature. Guido's research focuses on mechanical metamaterials, modelled as large ball-spring networks, and aims to find general design principles for modifying the geometry and topology of the network to attain a variety of unusual mechanical responses. In particular, he is interested in how introducing active mechanical components (e.g., motors that inject energy) into the network can lead to novel materials for applications in such areas as shock absorption and mechanical actuation.

Limit Theorems for generalised urn schemes - Chris Dean

Supervisors: Cécile Mailler, Mathew Penrose

Generalised urn schemes are a classical discrete-time probabilistic model that describe the contents of an urn that contains balls of different colours. At each time step, a ball is chosen uniformly at random in the urn, and replaced into the urn together with a set of new balls whose number and colours depend on the colour of the selected ball and on a replacement rule, which is encoded in a matrix R . The cases of R being either the identity matrix or irreducible are well-studied in the literature and limiting theorems show how the composition of the urn behaves when time goes to infinity. In the case of the identity matrix, recent developments by Borovkov have been made on the convergence of the composition of the urn as the number of initial balls goes to infinity together with time; different behaviours have been observed, depending on the scaling of these two factors. Chris' project will begin by looking at Borovkov's results and see if similar results can be shown in the case when R is irreducible. Chris will generalise these results to infinitely-many-colour urns, which leads to the natural and interesting open problem of making the number of colours go to infinity together with time.

Change point detection in spatio-temporal data - Josh Inoue

Supervisors: Matt Nunes, Sandipan Roy

When analysing spatio-temporal data in applications such as in environmental, ecological, or epidemiological settings, detecting abrupt changes over space and or time gives insight into the underlying mechanics of a system and can have a significant impact in the interpretation of the evolution and future state of the process. The aims of the project include looking at methods that analyse spatio-temporal data and expand on these further, where gaps in the literature exist, developing a set of robust statistical tools to interpret these data sets. In particular, we will

consider how the space and time elements of the data interact, and when we are able to detect change points or anomalies how easily can we classify them.

Euler-Poincare equations for nonconservative action principles - **Rosa Kowaleski**

Supervisors: David Tsang, Karsten Matthies

The non-Hamiltonian action principle developed by Galley (2012), was developed to capture the dynamics of non-conservative systems by extremising an action with a doubling of the degrees of freedom. Such an action principle allows for the development of non-conservative classical field theories, including dissipative fluid dynamics. The Euler-Poincare equations are the analogue of the Lie-Poisson equations for a Lagrangian system. They are equivalent to the Euler-Lagrange equations for the action on the (infinite-dimensional) Lie group (and algebra) that describes the geodesic evolution of a system. Rosa's project focuses on developing the Euler-Poincare equations for the non-Hamiltonian action principle, in particular capturing the dissipative behaviour of a viscous fluid.

Localization of waves in random media with resonant inclusions - **Yi Sheng Lim**

Supervisors: Kirill Cherednichenko, Hendrik Weber

Consider waves travelling through a domain with two key features: (1) that it has numerous tiny regions of high contrast ("resonant inclusions"), and (2) a random landscape outside these microscopic inclusions. Physically, we may think of this media as a composite material with disorder; mathematically, a wave equation where the coefficients are very large at (1) and random at (2). The goal of Yi Sheng's project is then to show that waves are "caught" by the environment, with probability one. This is in contrast with the classical picture of waves travelling through a non-resonant and ordered environment (e.g. sound waves propagate through air over large distances). The fact that this is possible in a random environment is one of the most important discoveries of physics in the late fifties. However, a mathematically rigorous study of this "Anderson localisation" phenomena is only available for a few specific models, so work is far from complete. Considering the inclusions (1) and the disorder (2) separately, we also know that (1) has strikingly similar spectral properties to (2). Since the goal of proving that waves are localised may be formulated in terms of the spectrum, Yi Sheng asks if the resonant inclusions may "assist" in trapping waves. This will be made rigorous using multiscale analysis as the primary tool, accompanied by ideas from the theory of random operators.

Unifying different approaches for flood estimation - **Piotr Morawiecki**

Supervisors: Philippe Trinh, Paul Milewski

The development of accurate models for flood prediction is a key challenge in the modern era. Piotr's research is motivated by the inability of current methods to predict flooding in small catchments or areas with limited data. Currently used methods include physical, conceptual, and statistical models; often, the underlying assumptions within these approaches are not assessed and the model limitations are unknown. The aim of the PhD is to deeply understand the limitations of these flood models and sources of their inaccuracy. As a part of this analysis, an asymptotic framework is developed to provide scaling laws and analytical predictions over a range of

scenarios. This analysis will allow a more direct comparison of the many disparate approaches used in industry. Finally, the project will seek the development of specific computational models that will better handle catchments for which the standard methods are inaccurate.

Stochastic Modelling of Migration and Proliferation of Melanoblast Neural Crest Cells in Mammals - Shahzeb Raja Noureen

Supervisors: Kit Yates, Tim Rogers

Piebaldism is a condition which occurs when an animal's fur, hair or skin lacks pigmentation in patches, typically at the ventral (front) side of the body, due to the absence of pigment-producing cells (melanocytes). The process responsible for this discolouration happens during the early stages of embryonic development. Early melanocyte precursors known as melanoblasts (one sub-type of a whole family of cells of developmental origin known as neural crest cells) which originate towards the dorsal (back) end of the embryo are responsible for giving the skin its colour. During the development of the embryo, these cells travel from the back towards the front of the body and as they do so, they divide to create daughter cells which themselves can migrate and divide. Research suggests that a piebald phenotype in mice is a result of the melanoblast neural crest cells failing to reach the dorsal epidermis (front region of the skin). It was originally assumed that this happens due to slow diffusion of melanoblasts but recent evidence suggests that in fact, the reason is the slower proliferation of these cells rather than the decreased rate of migration. The slow proliferation has been linked to mutations in the kit gene. Other types of neural crest cells are responsible for other essential developmental processes in mammals and erroneous proliferation or migration in these cells can result in developmental defects such as deafness, heart problems and even cancer. Shahzeb is exploring the proliferation and movement of the melanoblast neural crest cells using agent-based methods, both on- and off-lattice and on a uniformly growing domain. He aims to develop multistage models that can relate the cell-cycle stages to other migratory parameters and generate more realistic cell-cycle time distributions. The multistage models, developed on- and off-lattice, will allow him to examine the effects of relatedness between cells and build models where individual cell properties are inherited by daughter cells. He is investigating the importance of distinct melanoblast sub-populations during epidermal colonisation and develop methods of modelling clonal behaviour.

Fluid dynamical analysis of drops on fluid baths - Katie Phillips

Supervisors: Paul Milewski, Phil Trinh, Jonathan Evans

When a small droplet impacts on a bath of the same fluid it usually coalesces. In certain regimes, however, a thin layer of air remains between the droplet and the bath acting as a barrier, and as such it is possible for the droplet to be propelled upwards due to the restorative capillary force of the bath, before this air layer is depleted. If the bath is vibrated at a suitable vibration frequency, this rebounding mechanism can repeat periodically causing the droplet to bounce indefinitely off the surface of the bath. In addition, for a vibrating bath, Faraday waves are generated radiating outwards from the impact site on the surface of the bath. As the vibration amplitude is increased, the rebounds are higher and the resulting Faraday waves increase in amplitude, eventually destabilising the droplet causing it to 'walk' across the surface of the bath. These phenomena

provide motivation for the problem at hand, as the main topic of study will be the role of the lubrication air layer that allows for this droplet, and also similar solid-fluid impacts at the capillary scale, to exhibit rebound. Using a combination of theoretical and numerical methods we aim to elucidate the phenomena of such bouncing droplets.

Scaling Limits for Random Walks on Random Conductances - **Carlo Scali**

Supervisors: Daniel Kious, Alexandre Stauffer

Random walks on random conductances form a well-established class of motions in random environment, that has already been investigated in depth. In the case where the conductances are bounded away from zero and infinity, it is well-known that the re-scaled walk converges to a Brownian motion. Out of this regime, this model showcases “trapping phenomena”, that is, a slow down in the walk due to the presence of small areas in the environment that behave atypically. In this case, the usual invariance principle does not hold anymore. Although this mechanism is now well identified, it is challenging to obtain, in the trapped regimes, functional scaling limits and other fine results (e.g. aging, quenched convergence). Carlo’s project explores trapping phenomena for random walks in random environments and on random graphs. In particular, Carlo will investigate the relationship between the Bouchaud Trap Model and random walks on random conductances in the trapped regimes.

Computational Optimal Transport - **Fengpei Wang**

Supervisors: Clarice Poon, Tony Shardlow

Optimal transport seeks the best way of transforming one probability distribution into another. It provides a natural, elegant framework for comparing probability distributions while respecting the underlying geometry. Within machine learning and related fields, optimal transport distances (in particular the Wasserstein metric) have found successful application in things like image registration and interpolation and adversarial neural networks. However, computing optimal transport distances between arbitrary (i.e. not necessarily discrete) probability distributions remains a challenging problem. Fengpei is studying the use of the Sinkhorn algorithm for computing the optimal transport between continuous measures, given point samples. She is interested to explore how to combine optimal transport with several different methods. These include stochastic algorithms and acceleration techniques by screening out variables.

Hybrid numerical-asymptotic analysis of snaking bifurcations - **Edwin Watson-Miller**

Supervisors: Philippe Trinh, Jonathan Dawes

There is a great deal of interest in nonlinear differential and difference equations that exhibit homoclinic snaking, in which solution curves of localised patterns ‘snake’ back and forth across a bifurcation diagram in a narrow region of parameter space. These snaking bifurcations arise in many experimental and theoretical contexts, including optics, convection, ferrofluids, Couette flow, buckling problems, neuroscience, and so forth. In recent years, a methodology using beyond-all-orders asymptotics has been developed to describe snaking bifurcations. However, this approach has not yet enjoyed wide adoption on account of the significant technical theory and machinery required. Edwin is making this more accessible by using numerical methods to replace

certain analytical steps. This would also enable generalising this method to systems where we cannot solve these steps analytically, as opposed to basic 1D systems and Edwin is generalising the beyond-all-orders analysis to systems with non-smooth nonlinearities.

Stochastic active flows - **Jeremy Worsfold**

Supervisors: Tim Rogers, Kit Yates

Mathematical models of fluids have been used very successfully to explain the behaviour of a wide range of systems beyond the liquid flows that inspired their initial development. For example, they have been used to describe the formation of traffic jams and the collective behaviour of large animal groups. However, these models typically take a purely macroscopic approach to explain these phenomena. This class of PDE-based models does not capture the effects of noise-induced fluctuations arising from finite size effects in 'fluids' composed of discrete moving agents. Jeremy's research seeks to explicitly link microscopic simulation-based models of interacting agents with macroscopic fluid models, enabling an analysis of the effects of noise induced by finite size effects.

The role of precursors of active regions in space weather forecasting: reliably predicting CMEs and SEPs before their occurrence with the help of machine learning - **Tina Zhou**

Supervisors: Chris Budd, Apala Majumdar, Silvia Gazzola and Tom Fincham Haines

The Met Office produces real-time operational space weather forecasts: severe space weather has appeared on the UK National Risk Register since 2011. Space weather can have major impacts on UK and international critical infrastructure (e.g. the electricity grid, satellites, aviation, Global Navigation Satellite System (GNSS) positioning, navigation and timing, radio communications) and on human health. The Met Office is constantly striving to produce improved space weather forecasts to meet their customers' needs, but this can be very challenging. The difficulty of solar weather forecasting is due to the uncertainty of solar movement and speed of arrival of an observed event (a few minutes or up to a few days before arrival on Earth). The focus of this project is to develop improved solar weather modelling forecasts based on the analysis of solar and near-Earth space observation data. New data from the spacecraft Parker will be available for research and there is no doubt that Parker can introduce many new results. Part of the approach will use machine learning to train proper models for better forecasting results. Additionally there is the possibility of combining methodologies in applicable probability, statistics theories and methods (for example time series analysis, Markov process and Bayesian simulations) and maths modelling methods in areas of numerical PDEs or stochastic PDEs. Most of those aspects are new and based on several recent technology break-throughs. The output of this project is to establish new methods in tracking space weather forecasts and seek new conclusions from observations by those new technologies.

Students starting in 2018

Adaptive Semi-implicit Semi-Lagrangian (SISL) method for the Shallow Water System - **Simone Appella**

Supervisor: Chris Budd

Numerical Weather prediction is an essential component to weather forecasting and climate modelling. It is based on the design of accurate and efficient numerical schemes to simulate the motion of ocean and atmosphere. In such context, explicit numerical methods have to satisfy the CFL condition, which imposes a strict time step restriction, in order to be stable. To overcome this limit, the Met Office is currently adopting the Semi-Implicit, Semi-Lagrangian method (SISL), which permits the use of larger time steps without stability issues. However, many global meteorological phenomena of relevance (storms, tsunami) occur on a scale smaller than 25km, that cannot be efficiently resolved by SISL with an uniform grid. A natural way to fix this is to cluster the mesh points in proximity of small features evolving in time. Such adaptive methods, though, are inefficient to use because are either unstable or require small time steps. This issue can be avoided by coupling them with a SISL method. Simone will investigate the adaptive SISL scheme applied on the Shallow Water system, that models the shallow atmosphere. He will start to examine the accuracy and stability of this method in the 1D case. This will be then extended to 2/3 dimensions based on the optimal transport moving mesh strategy.

Impact of climate change on cocoa farming - Oluwatosin Babasola

Supervisor: Chris Budd and Ben Adams

Cocoa is a delicate and sensitive crop whose production has been hugely affected by several different factors including climate change. These lead to uncertainties in planning for the future both in the short term (seeding and harvesting) and in the long term (allocation of land use). The planning process can be helped by the construction of an appropriate mathematical model and linking these to data on climate variation. Tosin's project involves constructing such models and comparing them with data on both cocoa production and local climate variation. This model will be used to track the impact of time lags between the flowering and harvesting stage of the cocoa crop and further used to establish how cocoa trees will behave in the near future as atmospheric temperatures continue to rise due to climate change.

Accessibility percolation in dynamic fitness landscapes - Thomas Bartos

Supervisors: Marcel Ortgiere and Tiffany Taylor

The fitness landscape concept originates in evolutionary biology as a metaphor to describe adaptive pathways taken by populations, where fitness is thought of as a height above a multidimensional genotypic space. Such landscapes can be modelled by representing the genotype space as a finite graph and the fitness function as a random vector associated to the vertices of the graph. Researchers have recently made progress in understanding the statistical properties of the number of so-called 'accessible paths' - sequences of adjacent vertices of increasing fitness. Thomas is studying how the accessibility properties of a graph are affected by a time-varying fitness function. The first case is where the fitness values are re-sampled according to a Markov chain; to analyse this he is adapting methods from first-passage percolation and dynamic percolation theory. Other situations to be considered include continuously changing landscapes and pairs of interacting landscapes. The aim is also to use the theoretical results obtained to explain the observed patterns of evolution of flagella in a recent experimental study of particular bacterial strains under varying selective pressures.

On-line drill system parameter estimation and hazardous event detection - **Dan Burrows**

Supervisors: Kari Heine, Mark Opmeer and Inês Cecilio

Dan's research, in collaboration with Schlumberger, develops statistical methods for automatic detection of hazardous events in oil and gas drilling operations. Initially, only two particular hazardous events are considered. The first is called washout and it means the appearance of a hole in the drill pipe which may compromise the safety and efficiency of the operation as well as equipment integrity. The second event is called mud loss and it means the loss of drill fluid due to a leakage in the drill system to the surrounding rock formation. As the project progresses, more complex scenarios will be considered, involving multiphase flow, influx of gas from the formation, accumulation of rock cuttings around the drill pipe, wear of the drill bit, plugged bit nozzles, or the degradation of the motor. The initially one dimensional model could also be extended to two or three dimensions for increased accuracy.

Monte Carlo Methods for Particle Systems and the Neutron Transport Equation - **Tom Davis**

Supervisors: Alex Cox and Andreas Kyprianou

The flux of neutrons in a nuclear reactor has traditionally been modelled and understood using deterministic numerical methods. Recent probabilistic treatments have justified the use of stochastic processes to model neutron flux; Monte Carlo methods can then be used to simulate these processes. However, different Monte Carlo estimators suffer from various pitfalls: some techniques have a high per-iteration cost and are very difficult to parallelise, while other estimators have lower cost per individual simulation but an unacceptably high variance. Tom's research project will investigate ways in which the neutron particle system may be simulated, using Monte Carlo algorithms which are both efficient and amenable to parallelisation. He also hopes to establish convergence, and other theoretical properties, of the resulting algorithms.

Mathematical modelling of formulation composition trade-offs for pesticides - **Jenny Delos Reyes**

Supervisors: Jane White, Begona Delgado-Charro and Josh Fernandes

Creating validated mathematical models that can inform the process of risk assessment during pesticide product development is an industry-wide aspiration. It is particularly challenging given the wide range of formulations that may be used to produce new pesticides and the complexity of developing products that have good foliar uptake but poor dermal absorption. Working with Syngenta, Jenny is developing and analysing a series of spatially explicit mathematical models for membrane penetration parameterised using existing data sets. The impact of formulation products is explored in relation to their physicochemical properties in an attempt to categorise formulation impact across the two membranes. The models will subsequently be combined and analysed within a novel optimisation framework which should highlight the key parameter groupings responsible for good foliar uptake and poor dermal absorption based on existing data sets.

Generative Models Applied to Inverse Problems - **Margaret Duff**

Supervisors: Matthias Ehrhardt and Neill Campbell

An inverse problem is the process of calculating from a set of observations, the data, the causal factors that produced them, the model parameters. Inverse problems that are interesting are nearly always ill-posed, meaning that small errors in the data may lead to large errors in the model

parameter and there are several possible model parameter values that are consistent with the observations. Addressing this ill-posedness is critical in applications where decision making is based on the recovered model parameter, such as for medical imaging. Medical images remain the gold standard for diagnostics of many conditions. However, analysis of medical images raises fundamental issues with the standard “deep learning” approach of training a multi-layer neural network on hundreds of thousands of images. Such algorithms cannot accurately quantify their uncertainty, nor describe the reasoning that led to a given classification for an image. Generative models provide a promising avenue to solve the aforementioned problems. They implicitly model high-dimensional distributions of data from noisy indirect observations. From this, new samples from the distribution could be generated and estimators calculated. However, in pushing the boundaries of computer science, fundamental mathematics has somewhat been left behind and this threatens the ability to exploit the many applications of these methods. Margaret’s project aims to fill some of these mathematical gaps.

Bayesian inference for low-resolution Nuclear Magnetic Resonance in porous media - Michele Firmo
Supervisors: Silvia Gazzola, Tony Shardlow and Edmund Fordham

Nuclear Magnetic Resonance is used to infer properties of porous media, such as rocks, through which oil can be extracted. Michele’s research project aims to surpass the current standard inference methodology by providing uncertainty estimates alongside state estimates in an efficient manner and to develop the technique for shales. Working with Schlumberger, this will be achieved through reformulating the problem in a Bayesian framework and applying tools from numerical linear algebra.

Hybrid methods for modelling the cell-division cycle - Josh C. Kynaston
Supervisor: Kit Yates

Biological systems exhibit a tremendously wide variety of behaviours at many different spatial scales. While in theory, the behaviour of a system at any scale can be viewed as emergent from the behaviour of its smallest components, deriving these scale relationships is analytically intractable except in only very carefully constructed examples. Numerical methods based purely on a system’s microscopic behaviour can quickly become cost-prohibitive as the number of atomic components of a system increases. To achieve computational feasibility, different modelling regimes are used at different scales, though at the cost of information loss when using coarser representations. Josh’s work is concerned with hybrid methods, which combine multiple regimes to balance the advantages and disadvantages of each. In particular, he aims to construct a hybrid method based on a model of the cell-division cycle as a reaction-diffusion system, building upon previous hybrid methods such as the pseudo-compartment method.

Stochastic Optimal Control for problems arising in data science - Marco Murtinu
Supervisors: Alex Cox and Kari Heine

Stochastic optimal control is a sub field of control theory that deals with the existence of uncertainty either in observations or in the noise that drives the system. Its aim is to design the path of the controlled variables that performs the desired task with minimum cost. Marco is studying problems where there is a data collection process, and a decision based on this

information such as when to stop, or what information to collect. These problems are related to sequential detection problems and to uncertain stochastic control problems, where the law of the stochastic process driving the system is not known. Marco plans to investigate how these problems are related and to explore possible applications in data science, where it is fundamental to understand when, during a sampling procedure, enough samples have been collected to make a decision.

Hybrid physical-statistical models for air quality prediction from traffic data - **Laura Oporto**

Supervisors: Paul Milewski and Theresa Smith

Laura's project aims to combine deterministic and statistical modelling to forecast air pollution levels in a city with a focus on traffic impact. Her project is in collaboration with AVL. Local air quality management can be complex due to the different emission sources such as transport, buildings, industry and more. Weather conditions, local topography, and emissions from distant places may also influence pollutant transport and amplify pollution in certain locations. Her project has three main parts: a deterministic approach, where she's looking at a fluid and chemical modelling to predict pollutant concentrations; a statistical model to analyse data from pollution and traffic monitors; and methods combining these two to calibrate parameters, improve the accuracy of the model and extend prediction horizons.

Faraday wave-droplet dynamics: Stochastic analysis of the droplet trajectory - **Eileen Russell**

Supervisors: Paul Milewski and Tim Rogers

For a suitably vibrating bath of fluid, a small droplet of the same fluid will "walk" across the surface due to the propulsive interactions with the waves generated by the previous droplet-bath impacts. As the bath vertically vibrates at a sufficiently large (yet sub-critical) amplitude, the droplet will bounce periodically. The bouncing droplet does not make contact with the bath, it is instead propelled back into the air due to the cushioning effect of the lubrication layer of air trapped between the bath and droplet visible only on a microscopic scale. As the amplitude increases, the droplet will destabilise and receive a "kick" in the horizontal direction resulting in the drop walking along the surface. Increasing the forcing vibration will increase the Faraday wave's decay time yielding a longer path "memory" from previous drop impacts. In an infinite domain, the walking droplet will continue in a straight line at a constant speed. If we confine the droplet to a coral, a wavelike statistical pattern emerges from the complex trajectory. Eileen will derive and analyse this pattern using a combination of fluid mechanics and stochastics.

N-particle branching random walk - **Zsófia Talyigás**

Supervisors: Sarah Penington and Matt Roberts

Branching random walks are well-studied models in probability theory. In particular, the Nparticle branching random walk (N-BRW), a branching random walk with selection, was first studied in the physics literature as a stochastic model for front propagation. In the N-BRW, at each time step, N particles have locations on the real line. Each of the N particles has two offspring, which have a random displacement from the location of their parent according to some fixed jump distribution. Then among the $2N$ offspring particles, only the N rightmost particles survive to form the next

generation. The main purpose of Zsófia's project is to explore the long-term behaviour of this process with different jump distributions. There has been substantial recent progress in this area, but many interesting questions remain, including the behaviour of the system when the jump distribution has stretched exponential tails.

Prediction of Biological Meta-Data using DNA Sequences - **Jordan Taylor**

Supervisors: Sandipan Roy, Matt Nunes and Lauren Cowley

A human base-paired DNA sequence is approximately 3 million letters in length and consists of the letters "G", "A", "T", and "C". With the multitude of different combinations, it is of interest to find whether, given a subset of much smaller sub-sequences, one can infer that an individual caught some bacteria from a particular country or any other associated meta-data. The bacteria of interest initially include Shiga Toxigenic Escherichia coli and Salmonella. Though machine learning methods have shown recently to provide state-of-the-art results in many domain areas in high dimensional space, many of the methods are seen as "black boxes" with little interpretability. Jordan is investigating explainable machine learning and statistical methods in context of both prediction and ranking of the significance of the sub-sequences.

Antagonistic coevolution in multi-species interactions - **Jason Wood**

Supervisors: Ben Ashby and Nick Priest

Jason's initial aim is to create models for the coevolutionary dynamics of hosts and parasites are changed by the addition of a hyperparasite. These are two subsets of host-parasite-hyperparasite systems, which are often found in nature (e.g. viruses which infect bacteria, hyperparasitic fungi) and which can have medical or industrial applications, for instance phage therapy. This work will then be extended to focus on vector-borne diseases.

Students starting in 2017

Systemic sclerosis: including prevalent and incident cases in order to evaluate the association with pulmonary hypertension - **Eleanor Barry**

Supervisors: Anita McGrogan and Jonathan Bartlett

Systemic sclerosis (SSc), or scleroderma, is a long-term condition that causes thickening and hardening of the skin due to a build-up of collagen. SSc can also affect internal organs such as the kidneys, heart, lungs and gastrointestinal tract. It is believed that there is a possible link between SSc and other serious health conditions, and Barry's Ph.D. explores the association between SSc and the occurrence of serious outcomes compared to people who do not have SSc. Working with the Department of Pharmacy and Pharmacology, she is focusing on statistical techniques used to minimise errors when estimating effects of SSc on occurrence of cancer.

Non-linear stochastic partial differential equations - **Stefano Bruno**

Supervisors: Hendrik Weber and Manuel Del Pino

Stefano's research is in the field of non-linear Stochastic Partial Differential Equations (Stochastic PDEs). This field has been very active over the last few years, due to two major developments: 1.) The theory of Regularity Structures (and related ideas) which permits a detailed small scale description of some Stochastic PDEs, such as semi-linear equations (relatively easy from a PDE point of view) driven by extremely irregular noise; 2.) The Kinetic Solution Theory for highly non-linear equations (such as quasilinear degenerate PDEs) perturbed by regular noise. The vision behind Stefano's project is to combine these two theories in order to treat non-linear equations driven by very irregular noise.

Spatial fragmentations - Alice Callegaro

Supervisors: Matt Roberts and Marcel Ortgiese

Fragmentation, the breaking up of large structures into smaller pieces, occurs naturally in many situations, from earthquakes to hard drives. The mathematical definition of a fragmentation process involves an object that breaks up at random into smaller pieces, which then break up themselves, and so on; but with the rule that the way in which a piece breaks up must depend only on its size. This condition is a huge simplification which allows rigorous study, but prevents traditional mathematical models from accurately representing the vast array of real-life possibilities. In her Ph.D., Alice focused on spatial fragmentations, in which the speed at which pieces fragment depends on their shape in a non-trivial way.

Mathematical and numerical problems in seismic imaging - Shaunagh Downing

Supervisors: Ivan Graham, Euan Spence and Evren Yarman

Shaunagh's project, in collaboration with industrial partner Schlumberger, concerns the numerical analysis of wave propagation problems and applications to marine seismic exploration. As part of the seismic exploration process, acoustic waves are emitted from a source into the earth. These waves are then reflected from the subsurface and measured by sensors. The relationship between the earth's subsurface and the measurements are mathematically modelled by partial differential equations (PDEs). Given the measurements, the properties of the subsurface can be inferred from the numerical solution of these PDEs to obtain a detailed image of the subsurface. This is then used to select and drill exploration and production wells. In seismic exploration, a problem of great practical interest is that of optimal sensor placement and this project explores how, if given prior information about the likely make-up of the subsurface (in the form of a class of generic models), the location of the sensors can be optimised to retrieve sufficient information about the subsurface.

Multi-particle diffusion limited aggregation - Tom Finn

Supervisor: Alexandre Stauffer

Multi-particle diffusion limited aggregation (MDLA) was formulated as a tractable model for dendritic growth. Unfortunately, geometric and dynamic properties of it have evaded a strong mathematical treatment for decades and understanding the behaviour of MDLA remains an open challenge. For example, under certain parameters MDLA may observe some limiting shape at macroscopic scales, but at the mesoscopic and microscopic scales will have complex and

fractal-like structure. A competition model called 'first passage percolation in a hostile environment' (FPPHE) has been successfully coupled with MDLA to show a phase of linear growth exists. Tom's project investigates these links further and attempts to prove stronger results for FPPHE, such as the existence of a 'co-existence' phase between the competing growth processes. The project also aims to understand variants of MDLA better, such as 24a Poissonized version of MDLA, whereby there is initially a Poisson cloud of particles, and each particle performs a random walk until aggregated. In one dimension the critical value for the initial density is 1 for linear growth, but in higher dimensions it is conjectured to be 0, and this project aims to prove this and related results.

Asymptotic and numerical analysis of wave propagation in photonic fibres with a thin-structure cladding - **Will Graham**

Supervisors: Kirill Cherednichenko and David Bird

Optical fibres are widely used in telecommunications systems across the world. Photonic crystal fibres are a relatively new development, as they have the potential to provide all of the same service (but better) and more uses than conventional optical fibres. This is because photonic crystal fibres have microstructure at the same length-scale as the wavelength of the light passed through it, which allows for the light to be controlled in more ways. Will is analysing periodic "thin-structure" problems that describe the propagation of light through photonic crystal fibres: understanding the spectrum of these problems and their effective "limit problems" can better inform the design or use of such fibres.

Echo State Networks and their application to dynamical systems - **Allen Hart**

Supervisor: Jonathan Dawes

Allen is studying how well a particular recurrent neural network architecture called the Echo State Network (ESN) can approximate dynamical systems, predicting their future behaviour as well as inferring their topological features. Allen hopes to use ideas from Takens' Embedding Theorem to prove that an ESN trained on a time series of low dimensional observations of a high dimensional dynamical system can learn the topology of the high dimensional system. Having learned the topology to some level of precision, the ideas from the Universal Approximation Theorem could be deployed to prove that a sufficiently large ESN trained on sufficiently many data can predict the future dynamics of a system arbitrarily well. Numerical experiments will also provide some intuition about how well practical ESNs perform on example dynamical systems like the Lorenz, or Mackey-Glass systems.

Numerical and analytical approaches using complex ray theory and exponential asymptotics in 3D wave-structure interactions - **Yyanis Johnson-Llambias**

Supervisors: Philippe Trinh and Paul Milewski

Despite significant advances in computational hardware and numerical algorithms, the simulation of fully nonlinear three-dimensional free-surface flows around blunt-bodied objects remains particularly limited. On account of the processing power required, most modern desktop (and in some cases high-performance) computations still require the use of simplifying geometrical assumptions and coarse meshes on the order of a hundred points per spatial dimension. In

contrast, numerical simulations of comparable two-dimensional flows can be routinely done with $O(1000)$ grid points in the spatial dimension. There continues to be a need for the analytical theories that can provide explicit asymptotic descriptions of the flow properties, particularly for the use of efficient hybrid numerical-analytical approaches. Recently, there has been success in developing new asymptotic techniques for studying linear wave-structure flows in three-dimensions. These techniques are based on the use of exponential asymptotics applied to low-speed hydrodynamical flows. Yyanis's research develops new analytical and numerical techniques related to the area of complex ray theory and asymptotic analysis, to extend these ideas to nonlinear problems.

Market microstructure, flash crashes and market manipulation - **Kevin Olding**

Supervisor: Alex Cox

The aim of market microstructure modelling is to construct models which capture the ecosphere of participants in financial markets involved in high-frequency trading, such as informed investors, market makers and uninformed or 'noise' traders. Such models should be internally consistent, in that all market participants act optimally to solve stochastic optimisation problems, but may also contain features which provide opportunities for a single large trader to manipulate the market. Automatic or algorithmic trades may also inadvertently converge on strategies which have a similar impact. Whilst generating short term profits, such a trader or algorithm could cause instability in the market, leading to a loss of liquidity or a 'mini-flash crash'. Kevin is looking to construct simple models which reflect accurately the ways in which liquidity is provided to, and prices are set in, financial markets and to understand the circumstances that might lead short term trading algorithms to disrupt ordinary market conditions.

Complexity-based selection of large-scale network models - **Lizhi Zhang**

Supervisor: Tiago Peixoto

The large-scale structure of real-world network systems cannot be directly obtained by inspection, and require instead robust methods of description and extraction. One common approach is to identify modules or "communities" via the statistical inference of generative models. Despite significant recent work in this direction, most existing methods rely on simplistic assumptions that disregard dynamical aspects of the network generation, and do not contain domain-specific information about the most likely mixing patterns. Lizhi is developing general tools applicable when the network grows over time (e.g. a citation network, or the world-wide-web), or when it contain heterogeneous assortative/disassortative mixing patterns (e.g. social networks).

Stochastic differential equations and machine learning - **Teo Deveney**

Supervisors: Tony Shardlow and Eike Müller

Statistical machine learning and neural network methodologies have seen significant development in recent years with the advent of faster computation and the discovery of efficient optimisation algorithms. Methods based on such techniques have provided state-of-the-art results in many high dimensional data tasks, such as image and speech recognition, artificial intelligence, and more recently, in applied mathematics problems. This project is leveraging developments in machine learning to improve methodologies for stochastic differential equations, with particular attention

paid to applications in contaminant dispersal. Teo is investigating how deep learning and Bayesian methods can be used to solve a range of problems in this area, such as inferring appropriate PDE and SDE models from contaminant dispersal data, and efficiently approximating solutions to the high dimensional Fokker-Planck equations associated with current models.

Modern Statistical techniques for assessing and predicting herbicide performance - **Arron Gosnell** *Supervisors: Evangelos Evangelou and Kostas Papachristos*

Typically, thousands of potential herbicides will undergo a sequence of screening tests (assay tests) in the lab. Each time ineffective compounds will be discarded and those remaining are assessed against a more complex set of criteria, with the final few undergoing rigorous field trials. Evidently, the data from the early trials will exhibit high uncertainty and subjectivity. In most applications, a herbicide is assessed against a range of criteria. Therefore, a method to combine multiple criteria according to their significance for scoring each herbicide is required. Arron's research involves creating a model to predict the herbicide's performance on each test using information such as dosage, plant species, and the chemical's structure which can be presented as a graph. Modern regression methods such as support vector regression, neural networks, and Gaussian process regression are employed to exploit the relationships between plant species and families of chemicals in order to improve predictive performance.

Estimating the Frequency of Extreme Events in the Presence of Non-Systematic Records - **Tom Smith**

Supervisors: Ilaria Prosdocimi, Thomas Kjeldsen and Sean Longfield

Extreme flood events can be devastating, so having good estimates of how often floods of a given size might occur at a specified location is of clear importance. However, the systematically-collected river flow time series from which these estimates may be derived are short, being typically just 40-50 years long in the UK. Consequently, the flood frequency estimates have large uncertainties. The systematic record may be extended by utilising non-systematic records such as newspaper reports, photographs, and flood marks carved into buildings. Working with the Environment Agency, Tom is developing methodology to allow these non-systematic records to be routinely used in flood frequency analyses, with a particular focus on the importance of accounting for the many sources of uncertainty that such an analysis involves. He is also investigating the utility of non-systematic records in 'regional' flood frequency analysis, wherein river flow series from hydrologically similar catchments are combined in order to reduce uncertainty. The methodology developed during this research will be applicable to other natural hazards.

Phase 3 clinical trials statistics - **Abigail Burdon** *Supervisors: Chris Jennison and Lisa Hampson*

Clinical trials are composed of four stages, each of which has a different primary aim. This project focuses on Phase 3; the drug is already deemed safe, the dosage decided and the focus being efficacy and futility. The development of pharmaceuticals and medicines across all phases relies heavily on statistical methodology and accuracy, with Phase 3 summarised by a single hypothesis

test for the difference in size of treatment effects. Patient safety and well-being are central to the design process. Abigail's project considers group sequential trials, a mechanism introducing interim analyses and allowing for a trial to be stopped early for either efficacy or futility. The aspiration is that overall, less patients receive the less effective drug. For the analysis of clinical trials, a primary endpoint must be specified, this is the measurement of interest that is affected by the drug; for example this project focuses on survival or time-to-event as the primary endpoint. There has also been copious recent research on "biomarkers" which are underlying processes in the body that may be predictive or informative of the primary endpoint. Working with Novartis, Abigail is researching a joint model for the two processes and investigating the gain to be made when biomarkers are included in a group sequential trial due to the increase in information.

Students starting in 2016

Detection of underwater acoustic events in a large dataset with machine learning - Amélie Klein

Supervisors: Philippe Blondel and Kari Heine

Acoustic remote sensing listens to ambient noise underwater and uses it to recognise the sources of the sounds (e.g. marine life, human activities, weather). Passive sensors acquire data at very high rates (up to a million samples/second) for long periods (up to several years). In this project, Amélie is working on automating the processing and exploration of the large dataset using machine learning techniques and high-performance computing system. The project aims to detect long-term trends, like the increase in shipping or seasonal variations in marine life, and transient events, loud sounds associated to seismic prospection, vocalisations by animals (e.g. whales or dolphins), or small-scale weather observations. The key research questions are in the processing and analysing the vast amounts of continuous data and in deciding the best time scale to look at specific processes.

Monte Carlo methods for the neutron transport equation via branching processes - Emma Horton

Supervisors: Andreas Kyprianou, Alex Cox and Paul Smith

The neutron transport equation (NTE) is a balance equation that describes the flux of neutrons in inhomogeneous fissile mediums such as nuclear reactors. Working in collaboration with Wood plc, Emma modelled nuclear fission reactions via the probabilistic theory of Markov branching processes in order to both unify existing theory and develop new theoretical and numerical techniques that allowed her to study these processes in full generality. In particular, Emma worked to prove the existence of the leading eigenvalue and its corresponding eigenfunction, allowing her to study the limiting behaviour of the system of particles in different regimes. The methods developed allow for more efficient simulations of these processes, providing a greater depth of understanding of such systems for the purpose of safety and optimal reactor design.

Large scale differential geometric MCMC - Tom Pennington

Supervisors: Karim Anaya-Izquierdo and Rob Scheichl

Uncertainty Quantification (UQ) concerns both propagation of uncertainty through a physical model, known as the forward problem, and the inverse problem of inferring uncertain model

parameters from noisy measurements. Markov Chain Monte Carlo (MCMC) methods are the most widely used tools for computing expectations in UQ and large statistical models in general. Conventional approaches to MCMC are often inefficient and must compute many samples for a high accuracy. Geometric ideas can be used to improve the methods' statistical performance; two prominent algorithms in this line of thinking are Riemann Manifold Hamiltonian Monte Carlo (RMHMC) and Riemann Manifold Metropolis Adjusted Langevin Algorithm (RMMALA). Tom is interested in extending these ideas to exploit more general ideas from differential geometry, with a focus on developing methods that are suited to problems from UQ.

Raising the Roof: Extension of the Met Office's Unified Model into the Mesosphere and Lower Thermosphere - Matthew Griffith

Supervisors: Chris Budd, Nick Mitchell, David Jackson, John Thuburn

Forecasting weather in the lower thermosphere (85 – 120 km) is of particular interest due to its impact on spacecraft re-entry and radio communications. To this end, Matthew was extending the current 85 km upper boundary on the Met Office's Unified Model (UM) to a height of around 120 km. Thus, he was raising the roof on current numerical weather prediction and paving the way for the development of a coupled whole atmosphere model. In particular, the work focused on including the correct physical processes in the high atmosphere. This included accurately depicting the reversal of the mesospheric zonal jets, forced by gravity waves (GWs). In order to do this, tuning of the GW forcing schemes was required, which is performed by a comparison with radar and satellite data collected by the Department of Electronic & Electrical Engineering.

Bayesian inference for point processes - Nadeen Khaleel

Supervisor: Theresa Smith

Point patterns, specifically spatial point patterns, occur frequently in the environment sciences and epidemiology. These phenomena are possible to model using point processes from which it is possible to learn about any spatial relationships that cause the point pattern observed as well as stochastic dependence between points in the pattern. In particular, Cox processes (or "doubly stochastic" processes) are practical models when the point pattern is clustering due to environmental heterogeneity that is stochastic. Nadeen is working on computational methods for a particular type of Cox process, log-Gaussian Cox processes (LGCPs), where she builds upon the algorithms currently used for Bayesian inference for LGCPs in order to present an algorithm that can efficiently fit more complex spatial models by sharing data between disjoint regions.

Averaging for fast-slow systems - Matthias Klar

Supervisors: Johannes Zimmer and Karsten Matthies

Matthias studied systems with multiple time scales, so-called fast-slow systems. One aim was to derive effective large-scale descriptions of such systems, by 'averaging out' the fast scale. Thermodynamic systems are prototypical examples of systems with such a separation of time scales, and the aim of this project was to advance averaging methods for thermodynamic models.

Optimising First in Human trials - **Lizzi Pitt**

Supervisors: Chris Jennison and Chris Harbron

Lizzi's project involved developing the statistical methodology used to design and make decisions in Phase I/First in Human clinical trials and was in collaboration with Roche. This type of trial is the first stage in testing a potential new treatment in humans, after extensive laboratory testing. The primary aim is to establish the associated safety and tolerability in order to define the range of doses to be tested in phase II. Clinical trials are expensive and time consuming, thus research into optimising this process aims to reduce the number of people required, the duration and the cost. Lizzi's research addresses the topic of trial design from a different angle to most of the literature, putting the focus on clearly defining the aims of a specific trial up front and finding the design that is optimal with respect to those aims. This is achieved through exact and approximate dynamic programming. Lizzi investigated properties of trial designs through simulation to ensure a design was both statistically robust and fit for practical use, thus appealing to clinicians. She compared properties to those of existing model-based Bayesian dose finding methodology such as the Continual Reassessment Method. Traditionally, at this stage of the drug development process there is no evaluation of whether or not the treatment works. Lizzi's research therefore incorporated analysing an early signal of efficacy into the trial design.

Fast iterative regularisation methods - **Malena Sabate Landman**

Supervisor: Silvia Gazzola

Malena's project was based on the study of fast iterative regularisation methods, with a particular focus on Krylov subspace methods and novel ways for determining regularisation operators and regularisation parameters. These tools are widely used in solving inverse problems, which are challenging as they can be large scale and severely ill-posed. As an example, Malena explored different imaging applications, such as tomography or deblurring and denoising of images.

Conditioned Stable Lévy Processes - **Tsogzolmaa Saizmaa**

Supervisor: Andreas Kyprianou

Tsoogii's project looks at ways to characterise the notion of path conditioning of a d -dimensional isotropic stable Lévy process. In an attempt to understand their behaviour, she also considered their time-reversed paths. In her analysis, she uses both a classical potential theory approach and recently developed methods around the theory of self-similar Markov processes. In doing so, she has the opportunity to consider the role of certain harmonic/excessive functions which have not been previously studied.

Spatial hybrid models in biology - **Cameron Smith**

Supervisor: Kit Yates

Spatial hybrid models are emerging methods used to simulate biological, chemical and physical phenomena on multiple scale levels. These methods take different models of the same system and at varying spatial resolutions, and employ them concurrently in different regions of the spatial domain. The main purpose of such hybrid models is to utilise the efficiency of coarser methods,

whilst maintaining accuracy by using the finer methods where necessary. Cameron developed various spatial hybrid models for biological processes in order to gain insight into how the underlying systems behave. Focusing initially on reaction-diffusion systems, which can be used to model many biological systems, from cell migration to the intracellular calcium dynamics, he incorporated biological realism into such methods.

Discordant voting on evolving scale-free networks - **John Fernley**

Supervisors: Marcel Ortgiere and Peter Mörters

Similarly to the Contact Process, voting models describe competing spread of two 'opinions' on a graph of interacting 'voters'. Cooper et al. in their 2016 paper 'discordant voting processes on finite graphs', explored the expected consensus time for a variety of voting models on extremal graphs. These discordant voting models could be seen as a bridge between the classical voter model and the Graph Fission evolving voter model of Durrett. John was interested in finding a universal description of the model's lifetime on scale-free heterogeneous networks, in particular with Chung-Lu type edge models. These models can then be made to evolve in time by vertex updating, and his next objective would be to show that this speeds consensus.

Methods for preferentially sampled spatial data - **Elizabeth Gray**

Supervisor: Evangelos Evangelou

In general, geostatistical methods deal with data under the assumption that the quantity being measured is independent of the locations at which measurements are being taken. However, this is often not the case. Preferential sampling refers to the situation in which there is some stochastic dependence between the quantity being measured and the process used to select the sampling locations, involving an investigator's 'design utility'. Ignoring such a dependence can lead to biased and inaccurate estimates. Elizabeth's Ph.D. involved investigating and developing methods for modelling such data.

Optimisation of wireless router location - **Hayley Wragg**

Supervisors: Chris Budd, Robert Watson and Keith Briggs

Recent developments in high frequency antennas for wireless communication could enable users to have stronger connections. However, these high frequencies within new technologies do not travel through objects as well as the lower frequencies do. In the past, propagation models for indoor wireless communications have not been needed and when used often rely on measurements that are specific to one environment. Hayley developed a mathematical model from Maxwell's equations to predict the strength of propagation that can be used to optimise the source location. The model accounted for variation in the environment and is therefore relevant outside of one specific location, unlike most of the current models.

Students starting in 2015

Higher-order DG Methods for atmospheric modelling - **Jack Betteridge**

Supervisors: Eike Müller and Ivan Graham

One technique for solving partial differential equations numerically is by using the Discontinuous Galerkin (DG) method. This method has high spatial locality, which improves the parallel scalability and can take greater advantage of modern (many core) high performance computing architectures. A hybrid multigrid approach has already been successfully used for elliptic PDEs arising from subsurface flow. Similar methods can also be applied to atmospheric modelling problems, for instance solving the Navier-Stokes equations in a thin spherical shell. Over the course of the project, Jack looked at the computational and algorithmic aspects of implementing a solver for these atmospheric models and the various different pre-conditioners to speed up the solution.

Modelling and optimised control of macro-parasitic diseases - **Quinn Boulton**

Supervisor: Jane White

Macro-parasites cause a variety of diseases throughout the world, including many neglected tropical diseases. When considering mathematical models of macro-parasitic diseases, the SIS models so often used when modelling the spread of bacterial or viral diseases do not capture some of the crucial ways in which macro-parasitic diseases differ. By considering a combination of ODE models, probabilistic and, hybrid models, Quinn attempted to formulate mathematical models which captured the dynamics of host-parasite relationships and macroparasitic infections and then used these to research how best to optimise the treatment of macro-parasitic infections in both people and animals.

Attribution of large scale drivers for environmental change - **Aoibheann Brady**

Supervisors: Ilaria Prosdocimi and Julian Faraway

Several large flood events have hit the UK in recent years, and there is a growing concern among the public opinion and policy makers on whether the current level of protection of cities and infrastructure is appropriate. In particular, there is a concern that climate change and its impacts might result in increased flood risks: climate change projections seem to indicate that flooding risk might increase, but this is not fully validated by the observed river flow data, for which there is no strong evidence of increasing trends. Further, due to the short period of river flow record, the testing methods routinely used to assess whether change can be detected in observed data are typically not very powerful (in a statistical sense) and cannot fully differentiate between possible confounders. Aoibheann developed methods to detect and attribute changes in flooding and other environmental variables. This resulted in methods for the detection of spatially coherent trends in environmental data. The project also investigated methods to make an assessment on the main drivers of higher river flows and flooding at a regional or national scale.

Analysis of transition rates for the Dean-Kawasaki model - **Federico Cornalba**

Supervisors: Johannes Zimmer and Tony Shardlow

Nucleation is a physical process, important in fields as diverse as physics, chemistry and biology. Nucleation is, broadly speaking, the process with which a material undergoes the formation of new

thermodynamic phases via self-assembly. The mathematical description of this process is comprised of several different relevant features. In his Ph.D., Federico focused on some aspects of the Dean-Kawasaki stochastic model, arising from the fluctuating hydrodynamics theory. Of this model, Federico he was primarily investigating the underlying mathematical geometry, the transition rates analysis in the context of metastability, sought a description of the nucleation pathways.

Accelerating Bayesian sampling - Gianluca Detommaso

Supervisor: Rob Scheichl

Gianluca's research brought together techniques from statistics, numerical analysis and applied mathematics to accelerate Bayesian sampling. In particular, he dealt with computationally expensive high-dimensional problems, trying to beat down the cost per iteration and performing algorithms that scale well in high-dimension. Gianluca developed interactions among different research fields, bringing together knowledge and experimenting with new ideas. He also tried out new potential sampling accelerations. His research involved multilevel methods, MCMC algorithms, transport maps and Bayesian inverse problems.

Spatial confounding - Emiko Dupont

Supervisor: Nicole Augustin

Spatial confounding is a problem that often occurs in environmental, ecological and epidemiological applications of spatial statistics. Models for spatial data usually include a fixed effect for the explanatory variable of interest as well as a random effect capturing spatial correlation in the data. Although the inclusion of a spatial random effect generally improves the goodness of fit of the model, it can also introduce bias in the estimated fixed effect due to co-linearity of the fixed and random effects, which could lead to incorrect statistical inference. This is called spatial confounding and is a general problem that is not restricted to any specific type of statistical model. Emiko's project was about gaining a better understanding of spatial confounding, using both real and simulated data to investigate when the problem occurs and what can be done to avoid it. She considered both parametric and non-parametric spatial models.

Mixing times and general behaviour of random walks on changing environments - Andrea Lelli

Supervisor: Alexandre Stauffer

Random walks in random environments have become a classical model for random motion in random media, and this model has been the source of many mathematical investigations over the years. More recently, people started to look at random walks in an environment which changes at the same time that the particle is moving. It is believed that when the environment is 'well behaved' (e.g. uniformly elliptic) and changes quickly enough, the random walk will behave in a way that is similar to a random walk on the underlying (non-changing) graph. This has been quantified, especially in the case of the d-dimensional infinite lattice, by the derivation of a law of large numbers and central limit theorems under some conditions related to the mixing time of the environment. Andrea was interested in understanding the effect of a slowly changing environment on the behaviour of simple random walks, e.g. the impact of the environment on the

recurrence/transience property of the random walk and the mixing time of the random walk inside a finite, but changing graph.

Distributed optimisation of LTE systems - Amy Middleton

Supervisors: Antal Járjai, Jon Dawes and Keith Briggs

Amy's project looked more fundamentally at the mathematics of self-optimising networks; in particular setting up and analysing precise dynamical models in order to gain information about fundamental limits of what can be achieved when system optimisation has to be performed with incomplete information. Working in collaboration with BT, Amy's project developed ways in which existing theory in diverse fields such as information theory, discrete-time dynamical systems, stochastic processes, optimisation, and others could be brought together to solve complex mathematical problems.

Seamless and overarching approaches for optimising over the phases of drug development - Robbie Peck

Supervisors: Chris Jennison and Alun Bedding

This project, in collaboration with Roche, concerned the optimisation of the drug development process at a program level. This involved considering multiple phases of treatment refinement and dose selection together. While individual phases of drug development had been studied in depth, there was relatively little work that looked at two or more phases jointly. Robbie's project used numerical computations and simulations to model different designs which involved computational challenges including (i) trial designs which used a form of gain function, or 'net present value', in order to optimise decision making throughout phases, (ii) use of Seamless Phase II/III designs that used data from Phase II in the final analysis, possibly through use of a combination test, and (iii) the realistic incorporation of beliefs about drug safety and tolerability into the program level decision making process.

Numerics and analysis of waves in random media - Owen Pembrey

Supervisors: Euan Spence and Ivan Graham

Wave propagation problems arise in applications such as seismic imaging, radar and ultrasound scanning. The Helmholtz equation is the simplest model of acoustic wave propagation - solutions of the Helmholtz equation correspond to acoustic waves with a single frequency. Researchers have been studying the Helmholtz equation, and developing numerical methods to solve it, for many years. However, most of the research effort until now has been concerned with sound waves propagating through a homogeneous medium where the speed of sound is constant. Owen studied the Helmholtz equation where the medium is heterogeneous or random. He developed numerical methods for uncertainty quantification for it and proved rigorous mathematical results about solutions. These results allowed him to study the convergence behaviour of these numerical methods, and suggested new numerical methods.

Modelling the surge phenomenon within turbomachinery - **Kate Powers**

Supervisors: Chris Budd, Chris Brace, Colin Copeland and Paul Milewski

Turbochargers are used in internal combustion engines in order to get a better power output for smaller engines and to get better fuel efficiency. Turbochargers work by compressing air. In order to get the most out of a turbocharger the air before and after the compressor needs a high pressure ratio for a relatively low massflow. If the massflow is too low, the air flow can reverse direction and cause surge. Surge is a difficult phenomenon to model because it exhibits chaotic behaviour. Kate worked jointly with the Mechanical Engineering department with the aim of finding a model that could (i) give a better prediction of the onset of surge and (ii) describe what happens to the air flow during surge. This involved analysis of experimental data as well as a combination of theory from compressible fluid dynamics, rotating flows, dynamical systems and bifurcations.

Automatic diagnosis of psoriasis arthritis (xAPAD) - **Adwaye Rambojun**

Supervisors: Neill Campbell, Tony Shardlow, Gavin Shaddick and Will Tillett

Patients with Psoriasis Arthritis are graded according to the extent of damage by scoring Xrays. In collaboration with the Bath Royal National Hospital of Rheumatic Diseases, Adwaye worked on automating this scoring process by exploring machine learning techniques from the computer vision community. He worked towards building a statistical model of a healthy hand to be compared to a diseased hand enabling the scoring process to be automated. This will enable scoring to be performed on a large scale basis that will ultimately increase the understanding of how the disease progresses within patients.

Topics in optimal stopping and optimal transport - **Ben Robinson**

Supervisor: Alex Cox

Ben studied various stochastic optimisation problems and the connections between them. Recent work on optimal stopping problems has investigated imposing a constraint on the expected value of the stopping time in these problems to obtain so-called constrained optimal stopping problems. Ben built on this work, making use of a connection to stochastic optimal control problems. This approach required developing an understanding of the modern theory of stochastic optimal control, including the theory of weak solutions to partial differential equations in the viscosity sense. Certain problems of this type can be represented in terms of Monge-Ampère equations, a highly non-linear class of PDEs, which arise in the classical Monge-Kantorovich optimal transport problem. Ben was interested in this problem, as well as the variation, martingale optimal transport, in which additional constraints are imposed. Methods of martingale optimal transport have also been used in the Skorokhod embedding problem, a classical problem in probability theory. Each of these classes of problems has a financial motivation. Ben was particularly interested in how these problems are related.

Condensation in reinforced branching processes with fitness - **Anna Senkevich**

Supervisors: Peter Mörters and Cécile Mailler

Anna studied a stochastic model for evolution of a structured population of particles equipped with fitness values. Each particle reproduces independently, with rate given by its fitness, and its offspring either inherits the fitness with some probability, or gets a new fitness value drawn from some probability distribution, independent of everything else. The particles of the same fitness are referred to as families. This is a stochastic version of Kingman's model for population undergoing selection and mutation. However this framework also covers a dynamic random graph model, preferential attachment tree with fitness of Bianconi and Barabási, which is suitable for describing growth characteristics of real-life networks, such as social networks. There are two growth scenarios of the system: growth driven by bulk behaviour and growth driven by extremal behaviour (condensation case). Furthermore, there are two types of condensation: non-extensive, when no individual family makes an asymptotically positive contribution to the population, and macroscopic, when proportion of individuals in the largest family is asymptotically positive. Behaviour of the system is largely determined by properties of the chosen probability distribution. In this project, Anna focused on asymptotic behaviour of maximal families for bounded fitness distributions with a faster decay at the maximal fitness value. She established which of the above scenarios prevailed by drawing links with extreme value theory.

Inverse problems for brain imaging - Shaerdan Shataer

Supervisor: Chris Budd

Imaging is a fast growing area driven by its importance in real life application as well as its mathematical challenge. In the field of brain research, imaging brain activity serves as part of the ambition to understand some fundamental questions about cognition and perception. Mathematically, the problem could be perceived as two levels of the inverse problem: first to solve the source intensity image from the scalp measurement, second to infer the cause of source activity from source intensity image solved from the first part. Shaerdan worked to locate the active sources of brainwaves, given measurements of EEG on the surface of the scalp.

Bayesian statistical modelling for quantitative risk analysis - Sebastian Stolze

Supervisors: Finn Lindgren, Evangelos Evangelou and David Worthington

Sebastian studied extensions and innovative uses of Bayesian Networks (BNs) as a tool for Quantitative Risk Analysis (QRA). QRA is especially relevant for the oil and gas industry, where analysis is usually carried out probabilistically in order to assess likelihood and impact of safety issues. A common framework to represent results from such analyses are Event Trees (ETs) which lack many properties for dynamic risk assessment. Working in collaboration with DNV GL, the focus of this project was to study how ETs can be cast into BNs in a practical way using information measures that allow for simplifications of BNs. Furthermore, particular time-continuous extensions for BN modelling were considered that allow examination of time-to-event variables in more detail.

Students starting in 2014

Faraday wave-droplet dynamics: a hydrodynamic quantum analogue - **Matt Durey**

Supervisor: Paul Milewski

It has been observed on a microscopic scale that when a small fluid droplet is dropped onto a vertically vibrating fluid surface, it will 'walk' across the surface of the bath. The droplet-Faraday pilot wave pair's behaviour is now reminiscent of quantum physics; there is a particle-wave duality where the fluid droplet can undergo similar processes to a particle in the quantum world. On an unbounded domain, pairs of droplets can interact, deflect or capture each other, depending on various parameters. The quantum single-particle double-slit experiment can be reproduced for fluid droplets, with the interactions between wave field and slits causing a diffraction probability distribution for droplet positions to be produced. This phenomenon was the basis for two lines of research that was explored by Matt: (i) The fluid dynamics of droplet-Faraday pilot wave reflection properties at planar boundaries. (ii) The long time stationary behaviour of models for droplet-Faraday pilot wave dynamics in confined domains.

SDEs for embedded successful genealogies - **Dorka Fekete**

Supervisor: Andreas Kyprianou

Dorka used the mathematical medium of stochastic differential equations (SDEs) to describe the fitness of certain sub-populations in an asexual high-density stochastic population model known as a continuous-state branching process. In particular, she looked at ways to describe genealogies that propagate prolific traits in surviving populations, where 'survival' can be interpreted in different ways. For example, it can mean survival beyond a certain time horizon, but it can also mean survival according to some spatial criteria.

Topics in the geometric description of zero-range processes - **Marcus Kaiser**

Supervisors: Johannes Zimmer and Rob Jack

Marcus studied the geometric properties of interacting particle systems and their hydrodynamic scaling limits described by non-linear partial differential equations, such as drift diffusive systems. He looked at processes that can serve as prototypes for non-equilibrium behaviour, having underlying descriptions as irreversible Markov chains. A better understanding of the geometric behaviour and the links between the microscopic and macroscopic models yields new insights, such as the way processes converge to equilibrium.

Two-species contact processes - **Sam Moore**

Supervisors: Tim Rogers and Peter Mörters

Recent work in the physics literature has explored the 'two-species contact process' as a model of staged infections. The work has a biological interpretation in terms of host-parasite invasions, for example, when a growing colony of bacteria is under threat from a developing bacteriophage infection. Past studies have focused mainly on simulations on $\mathbb{Z}^2$. Sam was interested in exploring the possibility of obtaining mathematically rigorous results for models of this type but evolving on random graphs. He further made use of existing branching methods as a novel approach to the problem.

Uncertainty Quantification for neutron transport problems - **Matt Parkinson**

Supervisors: Ivan Graham, Rob Scheichl and Paul Smith

Working in collaboration with Wood plc., Matt's Ph.D. developed computation of uncertainty in flux and fundamental eigenvalue of a simplified 1D monoenergetic neutron transport problem with cross sections modelled by lognormal fields using KL sampling and Monte Carlo method. The methods started with situations where the transport equation could be solved analytically and went on to consider numerical solutions by discrete ordinates and then by analogue MC simulation. He analysed how the MC error and KL truncation affected the results and associated numerical experiments and applied MLMC methods to the problem while assessing the possibility of applying multilevel techniques to the analogue MC solver for the simplified neutron transport problem.

Modelling air pollution using data assimilation - **Matt Thomas**

Supervisors: Gavin Shaddick and Melina Freitag

In order to assess the burden of disease which may be attributable to air pollution, accurate estimates of exposure are required globally. There is a need for comprehensive integration of information from remote sensing, atmospheric models and surface monitoring to facilitate estimation of concentrations in areas throughout the world. Data assimilation is a method of combining model forecast data with observational data in order to more accurately understand the state of a system. Methods vary greatly in complexity and Matt explored different methods from both a statistical and numerical analysis standpoint. Elements of a suitable method included flexibility, modularity, the ability to incorporate multiple levels of uncertainty and techniques that allowed relationships between surface monitoring, remote sensing and atmospheric models that vary spatially and allow information to be 'borrowed' where monitoring data may be sparse. Throughout the project, the efficacy of different methods in this setting was examined by applying them to data from the Global Burden of Disease project. Of particular interest was their scalability with regards to use with high-dimensional data.