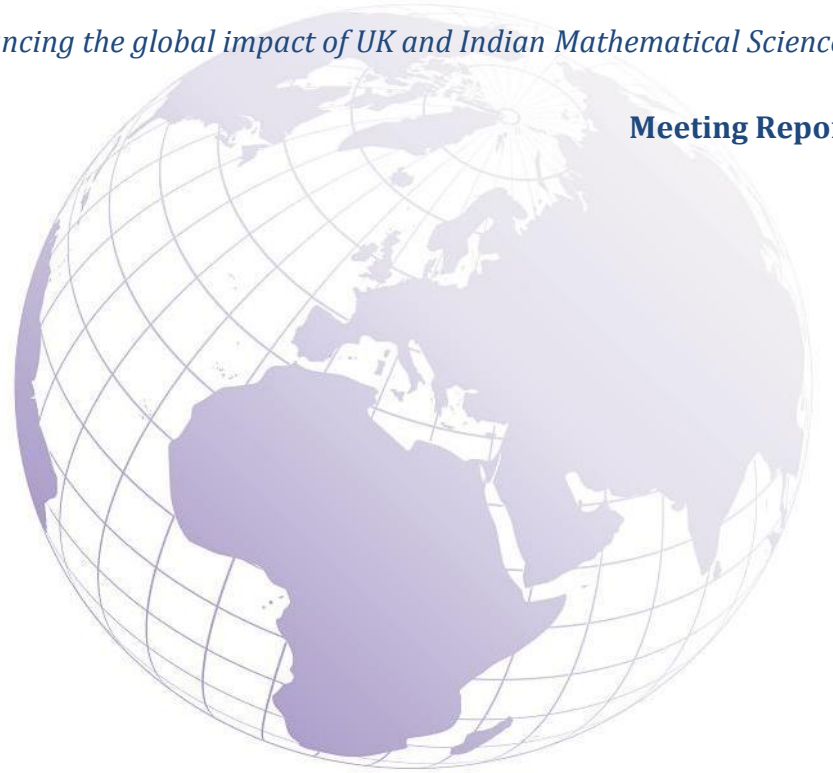
EPSRC/DST Interaction Meeting in

Applied Mathematical Sciences Research Challenges

Edinburgh, UK – July 2012

Creating and enhancing the global impact of UK and Indian Mathematical Sciences

Meeting Report



EPSRC
Engineering and Physical Sciences Research Council

RESEARCH COUNCILS UK
INDIA

Department of Science and Technology

Contents

Overview

The purpose of this Interaction Meeting was to explore possible links and commonalities between the UK and India in Applied Mathematics research. The meeting aimed to identify research gaps, which could yield opportunities for collaborations and cross-disciplinary research. The focus was on providing networking opportunities for researchers from both the UK and India, providing initial introductions which may lead to ongoing collaboration. There were also opportunities for discussion on specific areas of common interest, including Industrial Mathematics and the interface of Mathematics with Energy.

The meeting was co-hosted by the UK's Engineering and Physical Sciences Research Council (EPSRC) and India's Department for Science and Technology (DST). It was organised in partnership with RCUK India.

EPSRC would like to acknowledge and thank the International Centre for Mathematical Sciences (ICMS) for hosting the meeting and also for assisting with organisation of this event.

Format of the Interaction Meeting

The meeting was held in Edinburgh at the ICMS between 11th -13th July 2012 with 13 UK participants and 13 Indian participants. A full detail of the attendance list is available in Appendix 1.

The specific aims of the meeting were as follows:

- Explore links, commonalities and opportunities for collaboration between the UK and India within the mathematical sciences
- Stimulate new collaborations, opportunities and cross-disciplinary research
- Provide networking opportunities for researchers
- Shape and inform possible EPSRC/ DST collaboration, aimed at pump priming UK-India collaboration through small scale networks, feasibility studies, and similar activities.

In order to achieve these aims, participants from diverse backgrounds were invited. The attendees at the event worked in a variety of research areas, including:

- Mathematical Modelling and Numerical Simulation including Fluid Mechanics, Climate change, Ocean Modelling and Air-sea interactions
- Marine dynamics
- Dynamical systems, Nonlinear Dynamics and Time Series Analysis
- Smart / Intelligent Structures, including Computer Vision and Machine Learning
- Simulation of Dynamics of High Speed Mechanisms, including Stress and Vibration Analysis
- Image and Signal Processing, tomography e.g. medical
- Statistical Computing and probability
- Data Mining
- Mathematical finance
- Complex Networks
- Power systems
- Industrial Mathematics

Over the three days, the group were guided through a series of exercises focused on identifying areas of common interest. Details of the full agenda can be found in Appendix 2.

The first phase of the meeting was designed to allow each delegate to highlight their own background and existing research activity. This presented an opportunity to suggest areas in which they would like to collaborate.

As further stimulus to the attendees, presentations were delivered to provide an overview of activity in the UK and India.

- Professor Keith Ball (ICMS, UK) ‘Landscape in UK Mathematical Sciences’

- Professor Dinesh Singh (University of Delhi, India) 'Landscape in Indian Mathematical Sciences'.
- Professor Rangarajan (DST Centre for Mathematical Biology) 'Applied mathematics in India'
- Professor Ockendon (Oxford) 'Industrial Mathematics'

These presentations helped to give a broader background context to the delegates and acted as an introduction to facilitated discussion sessions, aimed at identifying possible areas for fruitful collaboration.

The Research Challenges

Following the introductory sessions, the participants were encouraged to identify & discuss areas of UK and India strength and potential complementarity.

Summary of Major Outputs

Appendix 3, 4 and 5 provide the full outputs of Group Discussion Session 1 and 2; however, the key outputs are shown in Appendix 6 which provides details of emerging themes for collaboration.

Nine themes were identified by the delegates and are summarised in the following list:

1) Statistical/ Signal Processing
2) Interconnections between Big Data, Networks and Cyber Security
3) Cyber Security
4) Climate/ Environment
5) Intersection between Applied Mathematical Sciences and Computer Science
6) Big Data
7) Networks (Non-Energy)/ Complex Systems- Methodology and Emerging Phenomena)
8) Risk/ Confidence
9) Energy

General Observations

In discussions, in addition to the nine themes listed above, the following points were noted:

1) There are already some UK-Indian collaboration and there is scope to increase this for mutual benefit to both countries.
2) The UK and Indian energy systems have both similarities and differences which provides both opportunities and barriers to mathematical collaboration in this area. For example, methods used by India to control their energy supply may be required by the UK in the future. In contrast, India is likely to benefit from UK mathematical research in renewable energy.
3) Big Data emerged as a strong theme on both the UK and Indian sides; having potential applications in a variety of applied areas.

4) The focus of the meeting delegates was relatively narrow due to the focus on Industrial Maths and Energy; however, it is clear that opportunities for collaboration are much broader and this should be considered in any potential future activities.

5) The meeting mainly concentrated on 'current' challenges; however, EPSRC and DST would like to look at longer term opportunities; this will enable a greater range of research disciplines within Mathematical Sciences to solve future problems and not just current issues.

6) Interaction between Indian and UK researchers within mathematical sciences is welcomed and should continue to be encouraged after the meeting.

7) In addition to collaborative opportunities within Applied Mathematics, it is clear that there is also significant scope to harness more areas of pure mathematics in addressing UK-Indian Mathematical Sciences problems. There is a role for industry to play collaborations between UK and India mathematicians.

Next Steps

The attendees were asked to discuss and identify possible next steps in building new collaborative links. The suggestions are summarised in appendix 7 and include:

- Visits
- Student exchange
- Study Groups
- Workshops

It was agreed that international collaboration is an important route for continued research excellence and that encouraging UK and Indian researchers to collaborate had potential for considerable mutual benefit. EPSRC and DST are working together to build upon the outcomes of this meeting, with a view to stimulate further collaboration between the UK and India.

We recognise that the meeting concentrated on specifically identified areas and there are research opportunities exist beyond these themes.

EPSRC and DST will continue to explore future possibilities for other methods of engagement and welcome any further ideas which will help to strengthen the relationship between the two countries.

Appendix 1: Interaction Meeting Participants

UK Delegates	
Adesso, Gerardo	University of Nottingham
Arrowsmith, David	Queen Mary, University of London
Belmont, Michael	University of Exeter
Carvalho, Rui	Queen Mary, University of London
Cooker, Mark	University of East Anglia
Dent, Chris	Durham University
Eckley, Idris	Lancaster University
Moriarty, John	University of Manchester
Nelson, James	University College London
Ockendon, John	University of Oxford
Wieczorek, Sebastian	University of Exeter
Zachary, Stan	Heriot-Watt University
ICMS	
Ball, Keith	**ICMS**
Indian Delegates	
Bagai, Shobha	Cluster Innovation Centre
Dedania, Haresh V	Sardar Patel University
H. Kolekar, Mahesh Kumar	Indian Institute of Technology Patna
Janakiraman, S.K.	Bharathiar University
Kumar, Sanjeev	Indian Institute of Technology Roorkee
Kundu, Debasis	The Indian Institute of Technology Kanpur
Mitra, Amit	Indian Institute of Technology Kanpur
Ramesh, KV	CSIR Centre for Mathematical Modelling and Computer Simulation

Rangarajan, Govindan	DST Centre for Mathematical Biology
Seshu, P	CSIR Centre for Mathematical Modelling and Computer Simulation
Singh, Dinesh	University of Delhi
Srivastava, Tanuja	Indian Institute of Technology Roorkee
Varma, Manik	Microsoft Research
Engineering and Physical Sciences Research Council	
Cook, Nick	EPSRC
Hemmings, Philippa	EPSRC
Wong, Maisie	EPSRC
RCUK India	
Austin, Suzanne	RCUK India
Bailey, Helen	RCUK India
UK Science & Innovation Network	
Sharma, Rita	Science and Innovation Network
Department of Science and Technology	
Mukhopadhyay, Amalesh	DST Centre for Mathematical Biology
Vasishta, Naveen	DST Centre for Mathematical Biology

Appendix 2: Interaction Meeting Agenda

	Wednesday 11th July 2012 **Welcome and Scene Setting**	
19.00	**Welcome and introduction to the meeting**	EPSRC/DST
19.05	**Setting the Context:** Landscape in UK Mathematical Sciences	Prof Keith Ball, Scientific Director, ICMS
19.25	**Setting the Context:** Landscape in Indian Mathematical Sciences	Prof Dinesh Singh, University of Delhi
19.45	**Welcome Buffet at ICMS**	

	Thursday 12th July 2012 **Networking and General Mathematical Sciences**	
9.00	**Welcome and overview of the meeting**	EPSRC
9.15	**Overview presentations from all UK delegates covering:** - Existing work / research interests - Areas they would be interested in collaboration with India	All UK delegates, 1 slide max, plus 3 minutes maximum
10.15	**Tea and coffee**	
10.30	**Networking Session 1 – UK Marketplace**	All delegates
11.00	**Overview presentations from all Indian delegates covering** - Existing work / research interests - Areas they would be interested in collaboration with the UK	All Indian delegates, (3 minutes maximum and where slides being used, 1 slide maximum)
12.00	**Networking Session 2 – Indian Marketplace**	All delegates
12.30	Lunch Buffet	
13.30	**Group Discussion Session 1 – Common ground and Synergies**	All delegates
14.15	**Presentation on area of Indian Strength: Applied Mathematics**	Prof Rangarajan,
14.45	**Tea and coffee**	

15.00	**Presentation on area of UK Strength: Industrial Mathematics**	Prof John Ockendon, F.R.S
15.30	**Group Discussion Session 2 (Part 1)– Reviewing the areas of strength presented** **Group Discussion Session 2 (Part 2)– The challenges and opportunities**	All delegates
1630	**Plenary feedback**	All delegates
17.00	Day 1 Closes	

	Friday 13th July 2012 **Mathematics for Energy**	
8.30 – 8.50	New haven lecture theatre (level 4).	
8.50	**Brief Welcome and Introduction to Day 2**	EPSRC / DST
9.00	**Setting the Context:** UK Mathematical Sciences research landscape with Energy relevance	Prof. David K. Arrowsmith
9.25	Q&A	All delegates
9.40	**Setting the Context:** Indian Mathematical Sciences research landscape with Energy relevance	Prof Dinesh Singh, DST
10.05	Q&A	All delegates
10.20	**Tea and coffee**	
10.40	**Group Discussion Session 3: Building upon emerging themes**	All delegates
13.00	Lunch	
14.00	**Group Discussion Session 4: How can we build UK/ Indian collaborations in Mathematical Sciences?**	All delegates
15.00	**Plenary feedback session:**	All delegates
15.20	**Wrap-up and next steps**	

Appendix 3: Outputs

Group Discussion Session 1 – Common ground and Synergies

**CONSIDERING MATHEMATICAL SCIENCES IN ITS BROADEST SENSE:
DISCUSS, COMPARE AND CONTRAST**

Common Ground and Shared Interest

Group 1	
Where does the UK and India have common ground or shared interest	**What is/might be the added value of working together on this?**
• India very focused on using mathematics in the "real world" • Industrial needs as priority and build academia around it • India prefers applications lead process • Cyber security • Signal processing • Artificial intelligence • India very interested in imaging technology • Behind this - signal processing • Geosciences • Life sciences • Medical sciences • Quantum Information Theory is a shared interest • Statistics • Statistics - linking to imaging and climate • Extreme event statistics	• Study groups with industry which present a "concrete problem" – long term perspective • Shared workshops • Shared expertise

Group 2	
Where does the UK and India have common ground or shared interest	**What is/might be the added value of working together on this?**
• Renewables/climate change • Image/medical image processing • Energy/supply/demand • Cyber security (Pure maths) feeds cyber security • Industrial mathematics • HPC • Statistical analysis • BIG DATA	• Complimentary environments • UK medical/India image – compliment each other • On/off grids • Mutual interests • Industry applications – new techniques to solve real problems • Programming • New applications

	• How can we deal with (e.g. social/medical) future solutions

Group 3	
Where does the UK and India have common ground or shared interest	**What is/might be the added value of working together on this?**
• Mathematical biology for healthcare • Financial modeling, including in energy – expertise on both sides • Exchange of people • Themed workshops • Time series/signals and broad application areas	• Different perspectives on energy security – healthcare • Scale – UK to learn from India(challenges and solutions) e.g. health/energy • Idea generation from different and culture and perspective

Group 4	
Where does the UK and India have common ground or shared interest	**What is/might be the added value of working together on this?**
• Industrial mathematics • Algorithm development • Efficient programme for parallel computers • BIG DATA • Statistical filters, imaging • Maths Biology	• Better Information Systems and understanding of environment

Group 5	
Where does the UK and India have common ground or shared interest	**What is/might be the added value of working together on this?**
• Computer vision • Machine learning • Statistical modeling • Free boundary value problems • PDE • Developing researchers (PhD onwards)	• Undergraduate Summer programmes/ exchange programmes • Early academic fostering of students • Providing a second context/'use case' for applied research • Internship structures for undergraduate for student exchange • Trying out research ideas with opportunity for continued UK-India collaboration • Access to mutual data

Appendix 4: Outputs

Group Discussion Session 2 (part 1) – Reviewing the areas of strength presented

Group 1	
UK Strengths • System and control theory – stochastic and deterministic • Catastrophe theory – tipping points etc • Fluid mechanics • Flows in joints, e.g. elbows, knees (healthcare apps) • Computational Fluid Dynamics • Meshing processes • Information theory and quantum information theory • Stochastic networks, e.g. fragility, blackouts etc • Climate System	**Indian Strengths** • Operator: Algebras • Differential geometry • Healthcare and imaging • Differential geometry • No theory • Algebraic geometry • Non-stationary processes • Functional analysis • Stochastic modelling • Signal processing • PDEs and mathematical modelling • Probability theory • Image analysis for medical applications
UK gaps and associated UK opportunities • E anach spaces • S olid mechanics • F unctional analysis • F inite geometries	**Indian gaps and associated Indian opportunities** • E ncryption • Q uantum information theory • C yber security • I maging techniques • I maging techniques in the life sciences and geosciences

Group 2	
UK Strengths • Cyber security • Climate change (met office/links with industry) • Fluid dynamics • Analysis – pure • Renewable energy (wind/tidal) – not	**Indian Strengths** • Astronomy/image processing (visualisation) • Cyber security • Analysis – pure • Signal processing • ICT – programming • HPC

necessarily mathematics • Industrial mathematics (localised in some areas) • HPC	• Statistical analysis
UK gaps and associated UK opportunities • Changes in energy supply – energy gap – learn from others • Energy demand/consumption • Medicine in mathematics/sciences • More mathematics into renewable energy • Increasing gap of statistical sciences an probability • BIG DATA	**Indian gaps and associated Indian opportunities** • Aspects of cyber security • Statistical analysis • Image processing in medical fields • Video surveillance and efficient storage • Renewable energy • BIG DATA (how do we deal with it?)

Group 3	
UK Strengths • Heritage of working with industry – collaborative • Capacity of mathematicians working in Energy research • Statistics – especially data intensive and computational statistics • Complexity and energy becoming well connected • Operational research	**Indian Strengths** • PD • Fluid dynamics • Probability statistics • Stochastic processing • Mathematical biology • Statistical signal processing
UK gaps and associated UK opportunities • Mathematical biology • Statistical signal processing • Financial modelling , e.g. in energy • Exchange of people • Students (PhD) • Staff and postdoc • Workshops on focussed themes	**Indian gaps and associated Indian opportunities** • Numerical analysis • Big data • Financial modelling , e.g. in energy • Exchange of people • Students (PhD) • Staff and postdoc • Workshops on focussed themes

Group 4	
UK Strengths • Number theory • Information security • KTN and industrial mathematics	**Indian Strengths** • Aspiring students • Enthusiasm for maths • Good national attitude

• Finance modelling • Defense • Radio Spectrum allocation • Machine learning	for mathematics • Combinatorics and algorithm development

UK gaps and associated UK opportunities	Indian gaps and associated Indian opportunities
• Mathematical computer science • Science administration • Lack of mid-career mathematicians	• Industrial mathematics • Knowledge transfer • Finance modeling • Data security and data compression

Group 5	
UK strengths	**Indian Strengths**
• Industrial collaboration and strength • Energy research in renewables	• Theoretical and applied statistics • Undergraduate teaching • Computing expertise
UK gaps and associated opportunities	**Indian gaps and associated Indian opportunities**
• Industry problems • No incentive • Industry tight lipped and not open to academics • Student Exchange Programme • 'Energy barrier' to crossing disciplines • Facilitating industrial sabbaticals (academia to industry)	• Postgraduate recruitment • Facilitating industrial sabbaticals (academia to industry) • Industry not getting their problems to academia] • Internship but no meaningful interaction • Academics working in windowless rooms

Appendix 5: Group discussion Session 2 (Part 2)

The challenges and opportunities

Group 1		
Describe the Challenge	**What are our gaps on knowledge**	**What are the opportunities**
• How to build techniques/mathematical techniques. How you build world views? • How this links to Artificial Intelligence • Image Analysis/image identification • Good algorithms to identify where the boundary is • Fuzzy boundaries • Geometry and tracking • How to identify where a boundary is so you can differentiate materials/properties • Free boundary problem • Pollution/terrorism (attack) – and where will the pollution go? • Sensitivity and 'nearness' of things to each other • Understanding an ensemble of techniques and identifying the cost/benefit of each and how they might work in different contexts • Getting useful information from large data sets – may also relate to boundaries • Vehicle tracking – the challenge is how to follow it when the object is moving	• Barrier: its an open problem • The field is not formalised • Identifying the mathematical techniques we can't do and why we can't do it • Knowledge transfer • How to take experience in one area and then translate into another. E.g. techniques which can be translated to other applications • Communication beyond research papers • Boundary recognition in medical imaging	Marvelous!

Group 2		
Describe the Challenge	**What are our gaps on knowledge**	**What are the opportunities**
• Transporting social mathematics and economical • Framework to formulate problems • Telimedicine • Mathematics in climate control • Medical image processing • Video surveillance	• How do we model people? Techno-social • What mechanisms are there? • Sensor analysis/deployment • Internet bandwidth • Need rigorous results/greater analysis (statistical) • Data collection/sharing	• Develop applications/analytic/approaches to current problems, e.g. traffic warnings • Helps to improve/inform policy makers • More collaborations less mistakes • New medical equipments • Second opinions to doctors • Good security

	• Data handling (large)	

General Notes:

- Logistical
- Networking
- How do mathematical scientists and social scientists interact?
- Academic acceptance of industrial involvement
- How do you reward industrial researchers?
- Workshops – how to get chemistry, organise, click together?
- Improving engagement/environment for Industrial Maths?

Group 3		
Describe the Challenge	**What are our gaps on knowledge**	**What are the opportunities**
• How to use remodelling to study complex systems, inc Energy, Climate impact, Finance, Biological systems, Healthcare, Food, Water • Big data	• Mathematicians and other experts not currently working closely • Access to some required data e.g. climate data national records	• Bring researchers together to tackle challenges. Benefit of adding maths expertise. New challenges stimulates new maths research. Benefits either research communities • Novel analysis methods and computational efficient methods. Interdisciplinarity can lead to surprising results. Different data sets can help refine models

Group 4		
Describe the Challenge	**What are our gaps on knowledge**	**What are the opportunities**
• Rapid response (for decision makers) • Profile of academic maths • More access to real world problems • Attracting more students to maths Cross fertilisation ⟨ Mathematics, Statistics, Computer Science		

Group 5		
Describe the Challenge	**What are our gaps on knowledge**	**What are the opportunities**
Big data – internet, data mining Managing complex energy systems –	Lack of sharing data (expensive) Relevant mathematics, especially probability theory	UK-India collaboration – requires mathematicians, statisticians and computer scientists Sharing intellectual resources/skills Complementarities – probability theory

including fair allocation of resources	and stats and optimisation	and stats Strategic ads

Appendix 6: Outputs

Group Discussion Session 3: Building upon emerging themes

STATISTICAL
Signal Processing

What is the research challenge ? What are the knowledge gaps?

- Robust parameter estimation
- Integration of signal processing with computational statistics and machine learning
- High dimensionality
- Processing of big data
- Stochastic modelling of images
- Signal processing tools as part of an artificial intelligence core. Making the world view bigger.

Why is it important? How might this impact on mathematical sciences or the Energy landscape? What does success look like?

Huge potential in many fields

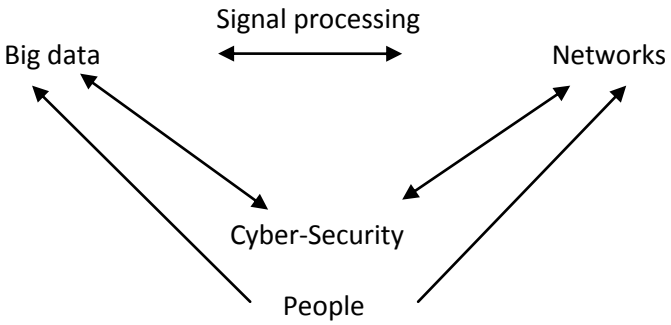
- Biomedical, speech, security, comms, energy, defence
- Novel theory and methods; meeting skills gap

What expertise/skills/equipment do we need to tackle this?

- People (PhDs, postdocs) – resource needed
- Computing resources
- Probability and stochastic processes and statistical inferences

INTERCONNECTIONS

What is the research challenge? What are the knowledge gaps?



Others:
Water supplies

Gas
Electricity

Why is it important? How might this impact on mathematical sciences or the Energy landscape?
What does success look like?

Modelling:

- Equations
- Constraints
- Boundary conditions
- Connectivities
- Topology dynamics

Recognition!

What expertise/skills/equipment do we need to tackle this?

Owners of the real-world problems ⟶ links to sets of mathematicians
Willing (open-minded) mathematicians to work with

Recognition!

CYBER SECURITY

What is the research challenge? What are the knowledge gaps?

- Voice data – usually 2 dimensional
- Images have 2 or 3 dimensional signals – harder to protect
- Encryption (images/image encryption) and speech data – (hacking prevention)
- Secure and efficient transmission of data
- Number of dimensions: application specific
- Practical implementation of efficient algorithms in real world by mathematicians
- Transfer of knowledge

Why is it important? How might this impact on mathematical sciences or the Energy landscape?
What does success look like?

Better utilisation, proper implementation, better research in terms of complexity moving from classroom to application

What expertise/skills/equipment do we need to tackle this?

- Interaction between industry and mathematicians (meetings and workshops)
- Impact on industry within 20 years – Industrial BUT ACADEMIC challenges

- Expertise in applied mathematics (number theory, integral transforms statistical and machine learning techniques
- Access to data to validate

CLIMATE/ENVIRONMENTAL

What is the research challenge? What are the knowledge gaps?

- Pollution modelling , mathematics and statistics and consequences of climate change
- Planning, modelling behaviours change… food, water, power, violent weather,
  - health sector, financial forecasting
- Gaps: between modelling, simulations and understanding challenge
- Monsoon modelling (not just India/UK)

Why is it important? How might this impact on mathematical sciences or the Energy landscape? What does success look like?

- Models stimulating new mathematics
- Influence: policy-making, decision making, Nobel prize, product, risk understanding, good reporting, mathematical papers, and status of maths

What expertise/skills/equipment do we need to tackle this?

- Mathematical study groups with scientists/engineers/)
- other experts) Funding to do
- Modelling camps) all this
- Stochastic processes and statistics)
- Mathematical modelling)
- Study groups with scientists)

INTERSECTION BETWEEN APPLIED MATHEMATICAL SCIENCES AND COMPUTER SCIENCE
Large Scale Numerical Scientific Computing

What is the research challenge? What are the knowledge gaps?

- Parallelisation of existing algorithms/codes
- Development of new algorithms for parallel computing
- Mathematical analysis of algorithms (e.g. convergence, rate of convergence)
- Stochastic optimisation and analysis

Why is it important? How might this impact on mathematical sciences or the Energy landscape? What does success look like?

- Enables tackling of climate simulation, CFD, ocean modelling, geophysical, big data problems

What expertise/skills/equipment do we need to tackle this?

- Close collaboration between mathematicians, computer scientists (distributed/parallel computing domain experts)

BIG DATA

What is the research challenge? What are the knowledge gaps?

- How does big data feedback into mathematical modelling?
- Large scale numerical computing
- Accept that data collection and analysis is a part of the project . Data costs money.

Why is it important? How might this impact on mathematical sciences or the Energy landscape? What does success look like?

- Observations/insight
- Ensuring privacy
- Machine learning (input)
- Mine data to inform policy or energy efficiency

What expertise/skills/equipment do we need to tackle this?

- Optimisation/probability and statistics
- Game theory/networks/data mining
- Statistical signal processing
- Machine learning – all data allows to profile in machine learning

(NON-ENERGY) NETWORKS
Complex Systems – Methodology and Emergent Phenomena

What is the research challenge? What are the knowledge gaps?

- To bring together the methodology of OR and observed emergent phenomena and hierarchy
- Coarse graining

Why is it important? How might this impact on mathematical sciences or the Energy landscape? What does success look like?

- Brings together two different approaches to complex systems

What expertise/skills/equipment do we need to tackle this?

- OR
- Graph theory,
- Opt techniques
- Network modelling
- Dynamical system (random)
- Social networks – biologists
- Communications
- Human responses – methods of social
- Intersection between applied maths and ICT

RISK/CONFIDENCE
Title: How to Mitigate Risk

What is the research challenge? What are the knowledge gaps?

- Understanding what the problems are
- Always a partial process
- Modelled versus unmodelled

Why is it important? How might this impact on mathematical sciences or the Energy landscape? What does success look like?

- Stochastic processes
- Transfers risk management from industry to academia

ENERGY

What is the research challenge? What are the knowledge gaps?

- New area
- Stats/optimisation/control/complex coupled
- Modelling hydropower energy network
- Modelling?
- Understanding controlling hierarchical networks

Why is it important? How might this impact on mathematical sciences or the Energy landscape? What does success look like?

- Releasing investment
- De-risking
- Reducing cost of renewables
- Confidence in maths releases funds to research

What expertise/skills/equipment do we need to tackle this?

- Systems mathematics
- Control mathematics
- How to use the UK Maths/Energy links to seed similar links in

India?

- Don't be precious
- Inference on operations (intermittent, non-stationary and messy)
- Monitoring
- Forecasting
- Fundamental constraints
- What can you do?
- Problem too big?
- New area of where mathematics is needed
- UK-India and vice-versa

Appendix 7: Outputs

Group Discussion Session 4: How can we build UK/ Indian collaborations in Mathematical Sciences?

- Visits
- Study groups
- Modelling camp
  - Training to allow people to become better at study groups (early career mainly)
- Doctoral training centres in India
  - UK visit India and teach for a short term and then this may release money for a postdoc to work in the UK – Prof Rangarajan and Michael Belmont
  - UK academics do 'master classes'
  - Would involve releasing funds to an existing and agreed project not at 50/50 funding
- Student Exchange Programme
  - Graduate – postdoc exchanges
  - Summer schemes for undergraduates
  - Internships
  - Formal exchange programme (2 way transfer) – through organised call not through informal relationships between researchers
- How can we encourage take up of Energy issues on the Indian sites
  - Invite Nottingham Grid or similar to give talks to India
- Encourage take up of CCS, due to India having huge coal reserves
  - Broad CCS research/Energy
  - Maths – modelling?
- Searchable database of academics/expertise so that UK and India could find each other
- Re Energy – how might we compare and contrast usage/distribution etc

- Identifying who to speak to on India site

- Summer Schools between UK/India

- Can we have/use virtual connections
  - For example, TCC/online courses
  - how might we share journals/publications – open access
  - Joint research through calls
  - UK /India Research Initiative
    - Offers pump priming opportunities (UKIERI)
    - Can EPSRC/DST support similar

- Bridging the gaps

- Industrial involvement in projects
  - Includeinvolvement Government of India (for access to data), Companies, e.g. power sector. Oil and Natural Gas Company

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