Changing Water Cycle

2010–2017

NERC SCIENCE OF THE ENVIRONMENT
Using Observational Evidence and Process Understanding to Improve Predictions of Extreme Rainfall Change (Convective Extremes: CONVEX)

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Climate change will increase the intensity and frequency of climatic and hydrological extremes. Standard resolution climate models can simulate large-scale frontal (UK winter) rainfall extremes reasonably well, but are poor at simulating summer convective extremes which fall in short but intense bursts. These were seen during the Boscastle flooding of 2004 and ’Toon Monsoon’ in Newcastle in 2012.

A key focus of CONVEX was to achieve a better understanding of short, intense rainfall events as they are important contributors to flooding, particularly in urban areas. To achieve this the project has produced a new, high quality dataset of historical hourly rainfall for the UK, providing usable products for the hydrological community. In collaboration with the Met Office, the project also ran the first climate change experiments with a very high resolution ‘convection permitting’ model. Results from this model have:

• identified potential benefits in the simulation of intense rainfall from high resolution modelling and led to other, similar experiments globally;
• provided evidence that intense summer rainfall indicative of serious flash flooding could become several times more frequent by 2100;
• provided better guidance on using information from climate models, and better information on future UK summer flood risk.

The project has recommended that guidance, for example for urban drainage design, must be revisited in the light of new understanding from CONVEX and has subsequently worked with UKWIR, DECC and DEFRA to enable the development of new guidance.

Hydrological Extremes and Feedbacks in the Changing Water Cycle (HydEF)

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Permeable catchments with complex geologies, where groundwater and surface water are major components of the water cycle, are under increasing hydrological pressures. These pressures are being exacerbated through climate change. Tools are needed to simulate how such catchments respond to extreme events (floods and droughts) and to evaluate what feedbacks can occur from these events.

HydEF developed new approaches to integrating geology, groundwater and surface water when simulating the catchment water cycle. These use tailored hydrogeological models that can be linked to the surface water network. Exchange fluxes and atmospheric feedbacks at the land surface are represented using a modified version of the Joint UK Land Environment Simulator (JULES). The project focused on the Thames and Eden catchments, which have been subject to recent major flooding events and a major drought.

The project has:

• identified important geological controls on groundwater response and how complex superficial deposits and underlying geology affect both runoff and groundwater processes,
• developed new methods to identify ‘atmospheric rivers’, conveyor belts of moisture, which can lead to extreme flooding events. These occurrences are likely to increase under projected climate change scenarios.
• developed a multisite, multivariate weather generator based on generalised linear models which can drive distributed catchment models for extended time periods using a variety of input variables, while preserving their inter-dependencies.

Through these outputs, HydEF has provided a suite of new tools for researchers, water companies and regulators to address climate change impacts on the water cycle in complex catchments.
Constraining the response of the hydrological cycle, land surface and regional weather to global change (HYDRA)

PI: Prof Myles Allen, University of Oxford, Myles.Allen@physics.ox.ac.uk

HYDRA’s overarching objective was to develop a ‘temperature scenario driven’ paradigm for climate change modelling, as opposed to the ‘emissions scenario driven’ approach that was then almost universal. The logic was that running our most complex climate models and comparing their results for a specific time in a specific emissions scenario must give much larger uncertainty in most impact-relevant variables than running atmosphere-only models for a specific warming; while estimating the impact at a specific warming may often be at least as useful as a totally scenario-dependent impact at a specific date in the future. Now that the Paris Agreement has transformed the policy context to focus on specific levels of warming, this approach is being widely adopted.

The largest ever ensemble of simulations of a dynamic climate model (134,354) used HYDRA’s high-resolution limited-area model. It was used to attribute the January 2014 southern England floods to anthropogenic greenhouse gases. The well-established thermodynamic effect on extreme rain (warmer air can contain more water) was seen, but also for the first time, a dynamic effect—the persistent Westerly flow over the North Atlantic, generating one cyclone after another, of that month was made more likely by the pattern of sea surface warming simulated by most state-of-the-art climate models.

Published HYDRA results have demonstrated:

- Detection of anthropogenic aerosol changes on regional scales
- Observed changes in the Earth’s radiative balance and how this controls the intensity of the hydrological cycle
- The effect of high resolution simulation on reproducing process-based changing water cycle fingerprints within the global atmosphere
- Successful simulation of the Sahel precipitation recovery since the mid-1980s
- How storm tracks have changed across the North Atlantic and how this impacts Europe in terms of water supply

PAGODA analyses and results have also been published in the IPCC Fifth Assessment Report (AR5).

HydRological cYcle Understanding via Process-based GiObal Detection, Attribution and prediction (Horyuji—PAGODA)

PI: Prof Pier Luigi Vidale, University of Reading, p.vidale@reading.ac.uk

Governments and society require actionable information on water availability and impacts for the next few years to decades, at the regional and, ideally, local scales. This is precisely where the current generation of climate models lack sufficient skill to make trustworthy predictions. PAGODA’s overarching aim was to make more reliable projections of the changing water cycle through process-based detection, attribution and prediction.

PAGODA has enabled substantial progress in the simulation of the key processes driving the transport of water in the climate system. PAGODA has also improved the understanding of the effects of aerosol interactions on regional precipitation. These advances have huge socio-political consequences, because they enable more advanced predictive capability at the regional scale.

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Soil water–climate feedbacks in Europe in the 21st Century (SWELTER-21)

PI: Dr Chris Taylor, Centre for Ecology and Hydrology, cmt@ceh.ac.uk

Computer projections of future climate agree that rising concentrations of greenhouse gases will warm the earth's surface over the 21st century. There is less consensus about how this will affect the climate in Europe, particularly changes in rainfall. SWELTER-21 has been using data from satellites, along with a state-of-the-art computer model of the land surface and atmosphere, to improve our understanding of how soil moisture influences rainfall. Specifically, the project addressed two key questions about the land-atmosphere system in Europe: how does soil moisture control evapotranspiration, and how does soil moisture influence atmospheric convection?

SWELTER-21 used satellite observations of surface and cloud-top temperature to show for the first time that spring and summer storm initiation in Europe is influenced by soil moisture. The project also established a novel method for characterising the strength of soil moisture limitation on evapotranspiration using satellite observations of land surface temperature during surface dry downs. This provides a new tool for testing the performance of climate models not only in Europe, but particularly in parts of the world where in situ observations are sparse. The results from SWELTER-21 will guide further improvement of weather forecasting models and climate models that are used for projections of future climate change.

Hydrologic and carbon services in the Western Ghats: Response of forests and agro-ecosystems to extreme rainfall events

PI (UK): Nick Chappell, Lancaster University, n.chappell@lancaster.ac.uk

River flood events have devastating consequences for health, livelihoods and economic development in India. This project focused on the role of extreme rainfall events in flood generation in the Western Ghats Mountains, the region of India with the most intense rainfall.

We combined parsimonious modelling with existing and new meteorological-hydrological time series to examine causes of extreme rainfall events, whether their particular characteristics are fully captured by flood models, whether the effects can be moderated by forests, and implications for rainfall-driven carbon transport. We discovered that:

- Rainfall extremes are more sensitive to the Indian Ocean Dipole than to the La Niña phenomenon,
- Data science models of flood response need parameters to change between storms of different intensity regimes, in addition to capturing basin wetness effects,
- The effects of land cover (forest proportion) and variations in groundwater contribution do not mask rainstorm intensity effects,
- Aquatic carbon is very sensitive to flood dynamics,
- Atmospheric influx of soil carbon is greatest during intermediate events rather than extreme events, while grassland conversion to tree plantation reduces these losses.

Integral to this, the India-UK team trained over 100 individuals from government departments, NGOs and academic institutions in our techniques.
Hydrometeorological feedbacks and changes in water storage and fluxes in Northern India (HYDROFLUX)

PI (UK): Wouter Buytaert, Imperial College London, w.buytaert@imperial.ac.uk

The Ganges Basin is one of the most intensely populated areas of the world, and plays a major role in India’s socio-economic wellbeing. The region has experienced significant land use change and water resource exploitation, creating important scientific research questions to understand, quantify and predict the availability of water resources under changing conditions.

This project brought together researchers from the UK and India, incorporating cutting edge research in hydrology, climate and social sciences. The project aimed to investigate the extent to which extensive large scale land use change and groundwater depletion, which has taken place across the region, has fed back to hydrology and climate systems on a basin scale. It was the first study to combine both climate impacts on hydrological regime and hydrological feedbacks to climate. The study area also provides a unique case of a large scale river system dominated by groundwater resources.

Our researchers undertook field work, including interviews with over 200 farmers, and detailed modelling of climate, land surface and groundwater regimes. We produced an improved representation of the study environment, and the interactions between groundwater, land surface and climate, as well as incorporating the important roles provided by humans. The suite of modelling tools and developed data sets will allow for improved water resource management capabilities across the region.

Mitigating climate change impacts on India agriculture through improved irrigation water management (MICCI)

PI (UK): Dr Adebayo J. Adeloye, Heriot-Watt University, a.j.adeloye@hw.ac.uk

This project assessed the impacts and uncertainty of climate change and variability on irrigation water security in India and went on to evaluate the effectiveness of better irrigation water management strategies in reducing the impacts. The focus of MICCI’s activities was on the Himalayan, snow-dominated Beas River Basin and its Pong reservoir that serves irrigation, water supply, hydropower generation, and inter-basin water transfers. The main scientific findings include that:

- Most combinations of climate change situations will lead to significantly reduced flows and water availability in the long term, resulting in loss of performance for the Pong reservoir,
- Improved reservoir operation through managed water hedging proved highly successful in redressing the problem of the loss of reservoir performance,
- Simulated hydrological situations caused significant reductions in summer crop (e.g. corn), a major concern for future food security in India,
- Current irrigation practices are resulting in excessive deep percolation losses and low water use efficiency and productivity,
- On-farm reservoirs that harvest rainfall and runoff empower local farmers to control how they use water, and can result in significant reduction in groundwater abstractions for irrigation.

The measurable outcomes of the project include 11 journal papers, 18 conference papers, 7 theses/dissertations, 5 bi-lingual (English and Hindi) factsheets, and several workshops and stakeholder/public engagement activities, including the Indian stakeholders’ tour of commercial irrigation farms in East Anglia in June/July 2014.
South Asian precipitation: a seamless assessment (SAPRISE)

PI (UK): Prof Mat Collins, University of Exeter, M.Collins@exeter.ac.uk

The Indian summer monsoon provides about 80% of annual rainfall to around a billion people in South Asia. Even modest variations in its timing, intensity and duration can have a dramatic impact on lives and livelihoods. Yet predicting such variations — not only from season to season but in the much longer term too — continues to present a colossal challenge.

All kinds of factors, such as the El Niño phenomenon and particles from manmade sources including coal-fired power stations, vehicles and cooking fires, need to be taken into account. Evaluating their impact, how they interact and what this means for the monsoon requires sophisticated climate modelling capabilities combined with detailed observational data gathered by both satellite-borne and terrestrial instruments.

SAPRISE brought together UK and Indian scientists to make progress in understanding what affects the South Asian monsoon on different time scales. The outcomes include:

- Significant differences were found to exist between different rainfall data sets and this hampers model evaluation.
- Demonstrating the importance of sea-surface-temperatures in the Arabian Sea and land-surface processes in simulating the monsoon rainfall. Increasing model spatial resolution is not a panacea; representation of physical processes in models must be improved.
- Our research highlights an increasing frequency of extreme El Niño and La Niña under climate change, which will affect monsoon rainfall.
- We have shown that aerosol particles have contributed to a reduction in rainfall in the latter part of the 20th century. As aerosol emissions decline in the future, an increasing rainfall signal is projected to emerge.

The structure and dynamics of groundwater systems in northwestern India under past, present, and future climates

PI (UK): Prof Alexander Densmore, Durham University, a.l.densmore@duke.ac.uk

India, the largest agricultural user of groundwater in the world, has seen a revolutionary shift from surface water management to groundwater abstraction in the last 40 years, particularly in north-western India. As a result, the region has become one of the largest hotspots of groundwater depletion in the world. The unsustainable imbalance between demand and supply is further complicated by a burgeoning population and by potential, but poorly understood, effects of climate driven changes in the water cycle.

Groundwater in north-western India is largely present within buried, sandy channels deposited by rivers which flowed through the region in the geological past. A few of these palaeochannels have clear manifestations at the surface, but most are buried, and their existence (as well as their suitability as aquifer bodies) must be inferred. Information on the subsurface geology of these alluvial plains is fragmentary, thus it is very challenging to assess the aquifer system, estimation the water resource and its evolution through time, and manage the scarce groundwater resource.

This project has provided the first conceptual framework for understanding, assessing, and managing this uncertain resource, and has developed new ways of using existing data to:

- visualise the pattern and rate of groundwater decline, and
- predict aquifer body locations and characteristics in the subsurface.

We have trained scientists from the Central Groundwater Board and state boards in these techniques, and have developed a set of policy recommendations for groundwater resource assessment.
Changes in urbanisation and its effects on water quantity and quality from local to regional scale (POLLCURB)

PI: Dr Michael Hutchins, Centre for Ecology and Hydrology, mihu@ceh.ac.uk

Existing model-derived estimates suggested warmer and drier summers expected by 2050 will trigger more frequent incidence of undesirable water quality: for example, up to two weeks more per year when the River Thames has low dissolved oxygen, which currently only occurs very occasionally. The project pinpointed additional impacts of population growth on estimates of these and other water resources changes in the Thames. Measuring land cover, river flow and quality in urbanising case studies (centred on Swindon and Bracknell) improved our understanding of how urban areas affect water resources, which can better inform future developments.

The project revealed that urban expansion is unlikely to continue progressing at recent rates, with increased population largely being accommodated through densification. Consequently, hydrological changes due to climatic stressors are likely to swamp any signals of a more extreme flow regime resulting from urbanisation. Short-lived water quality problems downstream of urban areas resulted from flushing of accumulated sediment. This occurred following extreme weather conditions (e.g. flooding following dry periods in winter 2013–14). Chronic impacts resulting from wastewater overspills, though also apparent, were no more severe than summer low flow conditions when water quality is most vulnerable. Simple meta-models of flow and water quality (sediment, oxygen) have been developed for assessing water resources responses to combinations of stressors; it is feasible to refine these for use in other basins both in UK and beyond.

Hydrology-phosphorus interactions under changing climate and land-use: overcoming uncertainties and challenges for prediction to 2050 (NUTCAT 2050)

PI: Prof Philip Haygarth, Lancaster University, p.haygarth@lancaster.ac.uk

Climate change and intensification of agriculture for food production both pose threats to water quality and stream ecological health. Fluxes of phosphorus and other nutrients from land to water will be altered by changes in seasonal climate variability and changes in land use and management, thus affecting downstream eutrophication.

This collaborative project has brought together climate scientists, hydrologists, engineers, soil scientists, farmers and catchment stakeholders to improve understanding of the complex interactions between phosphorus and hydrology. Using a novel combination of the latest high spatial resolution climate models, phosphorus transfer models, high frequency phosphorus flux data from three representative catchments across the UK and stakeholder information on potential intensification of agriculture, estimations of future phosphorus transfers to 2050 and beyond were made. Uncertainties in both the climate projections and the phosphorus models were included by using an ensemble of future climate simulations, two phosphorus transfer models and a number of acceptable parameter sets.

Because of the large proportion of phosphorus transferred during storm events, the likely effect of the projected warmer, wetter winters is to increase phosphorus transfers. Large reductions in phosphorus inputs from agriculture would be required to offset the increase in transfers resulting from climate change. This understanding will help land managers, water resource managers and policy makers to plan appropriate measures to ensure resilience within agriculture without increasing the threats to future water quality.
The NERC Changing Water Cycle research programme has provided new understanding of the changes taking place in the components of the water cycle, in the UK, India, Europe and across the globe.

NERC has invested £10 million in this research programme, involving 12 projects, with teams based in more than 30 institutions.

Other collaborators have also supported the programme, including matched resources for the five South Asia focused projects funded by the Ministry of Earth Sciences of India.

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