Hydrological extremes and feedbacks in the changing water cycle (HydEF)
PROGRESS REPORT
March 2012 – August 2012

Background

Guidance to support adaptation to the changing water cycle and development of mitigation strategies to combat climate change is urgently required, yet the ability of water cycle models to represent the hydrological impacts of climate change is limited in several important respects. Climate models are an essential tool in scenario development, but suffer from key limitations in accuracy and resolution and fundamental weaknesses in the simulation of hydrology. This project is producing the underlying science and models needed to address these current limitations, integrating climate and hydrological science to take impact modelling beyond current state of the art. Specifically, the project is:

a) exploiting current generation climate science and advanced statistical methods to improve and enhance projections of potential change in hydrologically-relevant variables and metrics over a time-scale of 10 to 60 years, in particular extremes of heavy precipitation and drought;

b) building on the analysis of historical meteorological and hydrological data, drawn from NERC and Defra/EA observational programmes, to improve scientific understanding and develop innovative methods for the modelling of the hydrological response to climate variability;

c) seeking to improve the representation of hydrological processes in land surface models, in particular, the enhanced modelling of unsaturated zone and groundwater processes and associated land-atmosphere feedbacks.

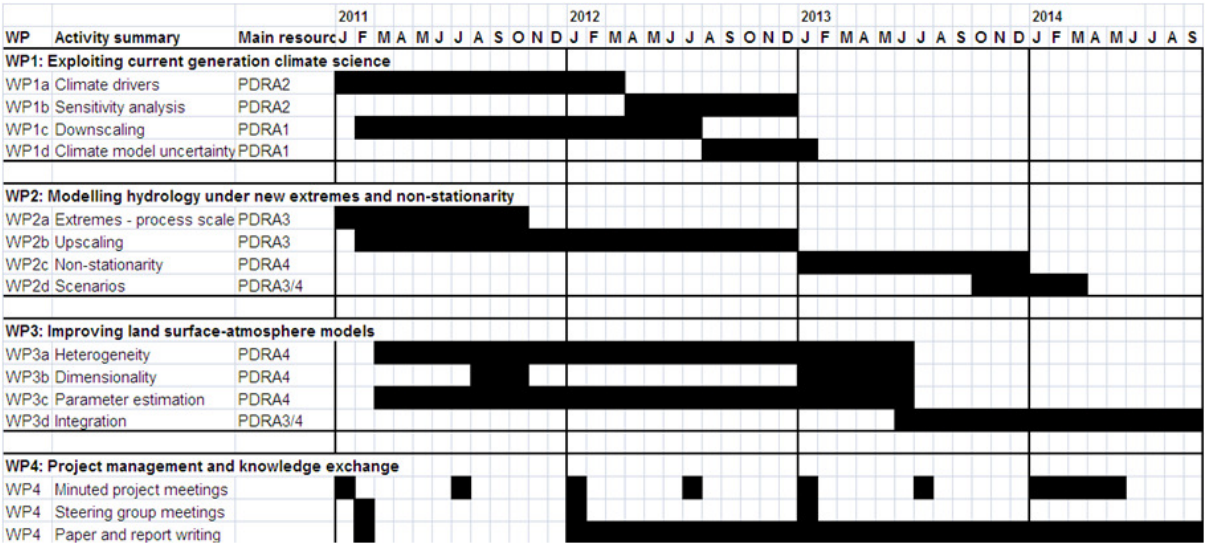
Summary of achievements in this period (more detail is in work package reports below)

Milestones reached in this period:

- JULES has been coupled with ZOOMQ3D to provide the basis for more process-based integrated water cycle modelling.
- Atmospheric Rivers (ARs) have been identified as an important cause of the largest floods in northern and western Britain.
- An algorithm has been developed for the identification of Atmospheric Rivers (ARs) in atmospheric reanalyses (and climate model output).

Changes to work programme

The Imperial grant has been extended to September 2014 to allow for maternity leave of Dr Bulygina. The BGS post-doc (PDRA3) has been selected and will be appointed in September 2012.



Project Meetings

The project was represented by several members at the SRM-CWC programme meeting on 1-2 May 2012. A full project meeting was held at Wallingford on 27th June 2012, followed by a demonstration of the BGS 3D geological models in their new 3D visualisation laboratory. A field trip to the Cotswolds to gain insight into the water cycle of the upper Thames region was held on the 28th June. Additionally, various intra-project meetings and meetings with CEH staff and other partners have been held. The next full project meeting will be at UCL on 6th Nov 2012.

Presentations from all meetings are available from the project website
http://www3.imperial.ac.uk/ewre/research/currentresearch/hydrology/changingwatercycles

Knowledge exchange activities

The project will co-convene two sessions at the AGU Fall meeting in San Francisco in December 2012: (1) "Developing the Science for High Resolution Water-Energy-Biogeochemical Cycle Modeling" with Dr Bulygina (this project), Eric Wood of Princeton, James Famiglietti of UC Irvine, and Eleanor Blyth of CEH, and (2) "Hydrohazards: Processes, Diagnosis and Projection" with David Lavers (this project), Upmanu Lall (Columbia University), David Hannah (University of Birmingham) and Amir AghaKouchak (UC Irvine).

Presentations:
Dr Lavers gave an invited seminar at the Earth Systems Research Laboratory (ESRL) in Boulder, Colorado USA in May 2012 "Atmospheric Rivers and British Winter Floods".

Dr Allan contributed a solicited talk "Current and future changes in precipitation and its extremes" at the EGU session "Climate, Hydrology and Water Infrastructure" 26th April 2012

Dr Allan contributed to the knowledge exchange Climate KIC program talking on "Climate change and the global water cycle", Reading, July 2012

Dr Allan presented an invited talk "Current changes in precipitation and moisture" at the Changing Water Cycle Workshop on Quantifying Changes in the Water Cycle Reading, June 2012.

Dr Allan and Dr Lavers gave invited talks at the Convex workshop on 'Extreme Rainfall' at the University of Reading, 17-18 April 2012.

James Simpson presented a poster "Adaptation to changing water requirements in the UK" at the BHS Peter Wolf Symposium in April.

James Simpson presented a poster "Water Resource Impact and Adaptation under Climate Change for the Isle of Wight" at the Tyndall Centre Knowledge Gaps Conference. A poster of the same title was also presented at the CWC/SRM meeting in May.

C. Bakopoulou, N. Bulygina, A.P. Butler, and N.R. McIntyre. 2012. "Sensitivity Analysis and Parameter Identifiability of the Land Surface Model JULES at the point scale in permeable catchments" Poster presentation at EGU, Vienna, April 2012.

Dr McIntyre will give an invited talk at the IAHS symposium "Completion of the IAHS Decade on Prediction in Ungauged Basins and the Way Ahead" in Delft in October 2012, on the problem of estimating parameters under non-stationary conditions and in ungauged areas.

Dr McIntyre gave an invited presentation "The value of high resolution rainfall for hydrological modeling" at user-focussed meteorology workshop in South Korea on 29th August 2012. The project case studies were used as examples of developments in coupling high resolution rainfall and hydrological and hydrogeological models.

S.Bricker, M.Barron, K. Manamsa, K. James, C. Jackson, A. Hughes, D.Peach. Geological framework for hydrogeological understanding - modelling the limestone aquifers of the Cotswolds. Presented at IAH Groundwater in Fractured aquifers, Prague, May 20-24 2012.

Andrew Hughes, Denis Peach, Chris Jackson, Stephanie Bricker, Majdi Mansour, Jon Ford and Holger Kessler. Towards the understanding, simulation and management of multi-aquifer basins: The Thames Basin, UK. Poster presented at Planet Under Pressure, London, March 25-29, 2012.

An abstract entitled "Complexity in the conceptualisation of groundwater systems at a basin scale integrated modelling: A case study using the Thames Basin, UK." has been accepted for IAH Niagara meeting (see http://www.iah2012.org/)

One abstract has been submitted to the AGU conference from WP1: "Linking variations in large-scale climatic circulation and groundwater level in southern England".

Three abstracts have been submitted to the AGU conference from WP2 and WP3:

"Improving coupling of surface and groundwater for high resolution water cycle models"; "Objective Assessment of Groundwater Resources for the Isle of Wight, UK"; "A stochastic framework for the assessment of agricultural water demand and adaptation to water scarcity".

Collaboration with other NERC programmes. The JULES applications are being run on a modelling framework developed at Imperial under NERC's Environmental Virtual Observatory programme.

Press articles:
Dr Butler published an article in the BBC news about the science behind the 2012 drought in England. http://m.bbc.co.uk/news/magazine-17875456 (accessed 14th Sept 2012)

Dr Allan appeared on BBC Newsnight talking about drought and climate projections (12th Match 2012)

An article on Atmospheric Rivers and flooding in Britain was published in New Scientist (12th November 2011) following the publication of Lavers et al., 2011.

Publications

Bakopoulou C., Bulygina N., Butler A.P., McIntyre N.R. 2012. Sensitivity Analysis and Parameter Identifiability of the Land Surface Model JULES at the point scale in permeable catchments. Proc. of British Hydrological Society National Symposium, Dundee, June 2012

Lavers, D. A., Villarini, G., Allan, R. P., Wood, E. F. and Wade, A. J. (Under Review). The detection of Atmospheric Rivers in Atmospheric Reanalyses and their links to British Winter Floods and the Large-Scale Climatic Circulation. Journal of Geophysical Research – Atmospheres.

Other outputs and achievements

N/A

Related funding

Dr Chandler and Dr McIntyre have been funded under NERC's PURE programme to investigate improved uncertainty and risk methods, including climate and hydrological applications relevant to CWC.

Work package reports

<u>Work package 1: Exploiting current generation climate science</u> (Reading University, University College London, Imperial College London)
Dr David A. Lavers, Prof Andrew J. Wade, Dr David Brayshaw, Dr Richard Allan, Prof Nigel Arnell
Dr Richard Chandler, Dr Chiara Ambrosino, Dr Christian Onof

The Reading team:
In our previous research, British winter floods were shown to be related to narrow bands of atmospheric moisture transport called Atmospheric Rivers (ARs). This was undertaken from a hydrological standpoint. In our latest research, we have investigated ARs from an atmospheric standpoint and produced an algorithm that identifies ARs in atmospheric reanalyses. The algorithm uses the spatial and temporal extent of the horizontal Integrated Water Vapour Transport (IVT) for the detection of persistent ARs (lasting 18 hours or longer) in five atmospheric reanalysis products. Reasonable agreement of AR occurrence (near Great Britain) between the products was found during the winter half-years of 1980–2010 (31 years). The relationship between persistent ARs and winter floods was shown using winter peaks-over-threshold (POT) floods (with on average one flood peak per winter). In the nine study basins, the number of winter POT-1 floods associated with persistent ARs ranged from approximately 40 to 80 % (**Figure 1**). Furthermore the winter occurrence of ARs was found to have a significant negative dependence with the Scandinavian Pattern. Given the strong link between the ARs identified in the algorithm and the British winter floods, the algorithm will now be applied to the latest climate projections to assess future AR activity near Great Britain and hence, their associated winter floods.

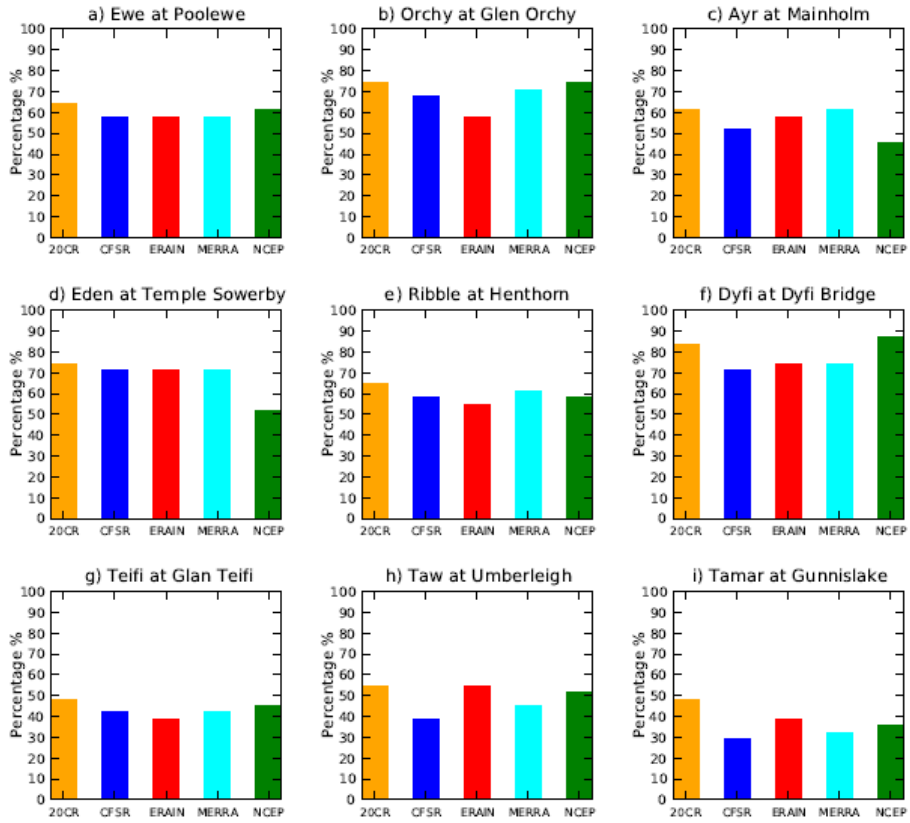


Figure 1: Percentage of the 31 POT-1 floods in each basin that are related to the persistent ARs identified in the five reanalyses.

The UCL team:
(i) The Rglimclim software package has been extended to allow the fitting of joint mean-variance models for use in multivariate downscaling applications. This allows the modelling (and, ultimately, simulation) of variables whose distribution is close to Gaussian but where both the mean and the variance change systematically in response to other factors such as time of year. Analyses carried out earlier in the project revealed this type of behaviour in many of the variables that are to be generated as part of Work Package 1. Further extensions to Rglimclim include work to allow the modelling of multiple variables simultaneously (this is almost complete); and the addition of routines to allow for easy plotting, checking and comparison of models.
(ii) Work has been done to identify the climate controls on daily pressure and rainfall above the Thames catchment.
(iii) A simple method to disaggregate daily air pressure, short wave radiation, air and wet bulb temperature and wind speed to hourly values has been developed: this will be applied to the daily series generated by Rglimclim, to generate the hourly inputs required by JULES. For a given day, Rglimclim will produce a mean or total for each variable, along with a range for the hourly values: these will then be used to disaggregate to an hourly pattern using a deterministic diurnal cycle as appropriate to the month of the year (see Figure 2 for short wave radiation as an example). Software to calibrate these cycles has been written, and it has been established that the amount of residual variation is negligible so that the assumption of a deterministic cycle is unlikely to detract from performance.

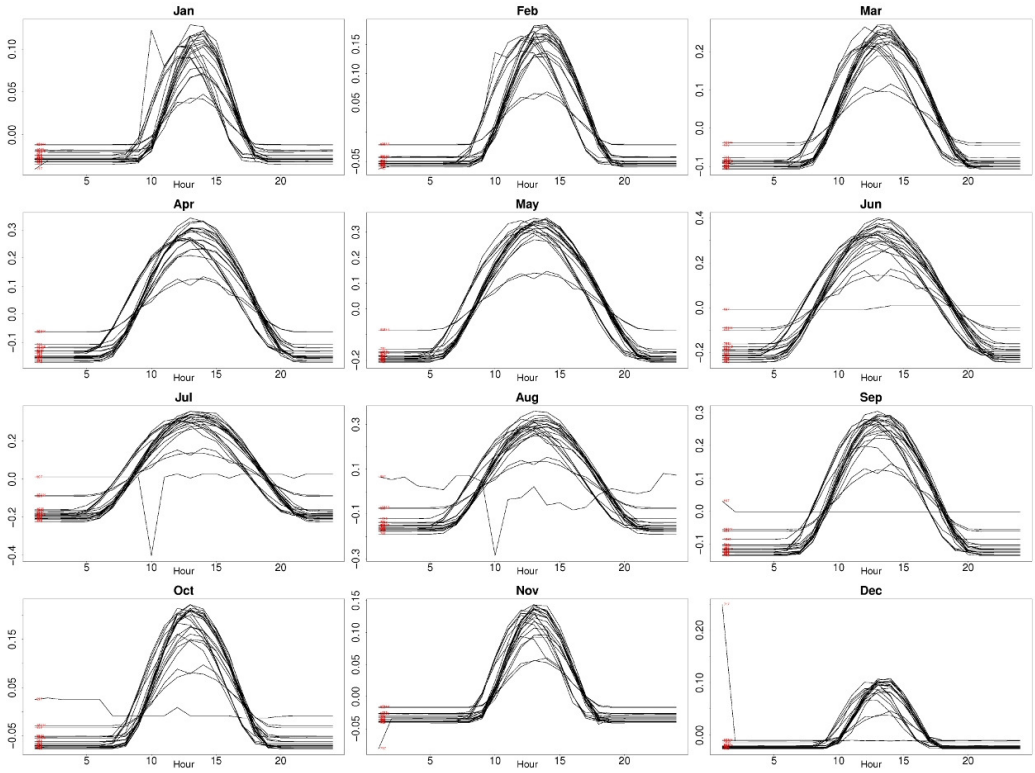


Figure 2: Deterministic diurnal cycles estimated for short wave radiation at 23 stations in the Thames catchment, separately for each month of the year. Each line represents the diurnal variation for a single station.

Work package 2: Prediction under new extremes and non-stationarity (British Geological Survey and Imperial College London)
Prof Denis Peach, Dr Andrew Hughes, Dr Chris Jackson, Mr David Macdonald, Ms Stephanie Bricker
Dr Neil McIntyre, Dr Adrian Butler, Dr Nataliya Bulygina, Mr James (Mike) Simpson, Ms Christina Bakopoulou, Prof Howard Wheater, Ms Kirsty Upton

The BGS tem:
The main thrusts of the BGS work have been as follows: improving conceptualisation of groundwater flow in the Cotswolds groundwater system, understanding flows to the Blue Pool Springs and developing a holistic model of the Thames Basin. Project staff, in conjunction with two MSc students, have been developing a conceptual understanding of and numerically testing river-aquifer interaction in the Cotswolds Jurassic limestone aquifers as well as developing an understanding of the Thames gravels and their role in supporting flow in the River Thames. Two boreholes were drilled and completed in the River Pang catchment, funded internally by BGS. These boreholes have improved geological and hydrogeological understanding around the Blue Pool Springs. Data are being collected and will be analysed once a sufficient period of time has elapsed. To allow a holistic understanding and simulation of the groundwater systems, a novel groundwater model of the Thames is being developed, again funded internally by BGS. This has made significant progress and currently the models are being joined together using the model linkage standard OpenMI. Alongside this work, an Imperial MEng student undertook a project on the Eden catchment examining the relationship between the superficial geology and recharge processes. His work enabled a preliminary recharge model to be developed and calibrated.

In the reporting period, interviews were held for a PDRA and an appointment has been made. Dr Antoine Lafare joins BGS on 17th September and will work on the Eden catchment as well as aiding the application and calibration of the Thames model.

The Imperial team:
Isle of Wight case study. Following previous work on the conceptual modelling of groundwater-surface water processes, a methodology to incorporate abstraction data into the groundwater time series has been developed. Groundwater abstraction on the Isle of Wight has previously been shown to have a significant and localised effect on borehole records, so removing a constant value for abstractions across each aquifer unit is rejected in favour of a more physically representative model. Despite more than 150 years of study, understanding of the geological structure of the Isle of Wight at group level remains incomplete and attempts to translate knowledge of aquifer media to a realistic subsurface hydrology model have not succeeded. Objective assessment of the borehole time series through cluster analysis has been used to identify coherent groundwater units. Anomalous borehole records will then be identified though cross-validated interpolation, allowing the effects of known groundwater abstraction locations to be measured and a perceptual model of each groundwater unit to be implemented.

Work package 3: Improving land surface-atmosphere models (Imperial College London and British Geological Survey)
Dr Neil McIntyre, Dr Adrian Butler, Dr Nataliya Bulygina, Mr James (Mike) Simpson, Ms Christina Bakopoulou, Prof Howard Wheater

Prof Denis Peach, Dr Andrew Hughes, Dr Chris Jackson, Mr David Macdonald, Ms Stephanie Bricker

Catchment scale applications and development of JULES:
Imperial and BGS:
Work in this period has focussed on setting up a high resolution (1 km grid) of the Kennet catchment; and linking the JULES land surface model with the ZOOM3QD MABSWEC groundwater model; and investigating improved groundwater representation in JULES. JULES is being run within a remote server system developed under NERC's Environmental Virtual Observatory programme. The main items of progress and associated issues have been:

1) Data was obtained for soil hydraulics (NSRI), LCM2000, HOST, and CHESS climate data (the latter for use as an input to JULES pending outputs of Work Package 1). Data problems have arisen due to lack of soil properties below 1.5 m for groundwater and deep unsaturated zone modelling; and lack of high resolution observations of soil and groundwater to constrain such properties. It is therefore envisaged that a suitably simplified deep unsaturated zone model will be appropriate.
2) JULES was set up using the 1km NSRI multi-layer soil database: Using dominant soil type; Using the 12 largest soil types, and the 1 km CHESS data;
3) Assessment of JULES performance in terms of soil moisture and river flows. As an example, Figure 1 gives an example flow output without groundwater, using the NSRI and CHESS 1 km2 data, illustrating lack of groundwater storage. Unrealistic soil moisture patterns, specifically lack of vertical variability in moisture, were obtained because the hydraulic conductivity parameter, sathh, was mis-specified in the NSRI support information, which led to some delay, but is now resolved.
4) 1-way coupling with ZOOMQ3D (groundwater routing). Dr Simon Parker was funded by Imperial to develop code to translate the format of JULES' drainage output into the format required for ZOOM's recharge input.
5) Results have indicated that the principal limitation of JULES in terms of modelling flow outputs and soil moisture is the shallow, free drainage lower boundary condition used in the default model. Work in this period has investigated new lower boundary conditions using the TOPMODEL groundwater representation.

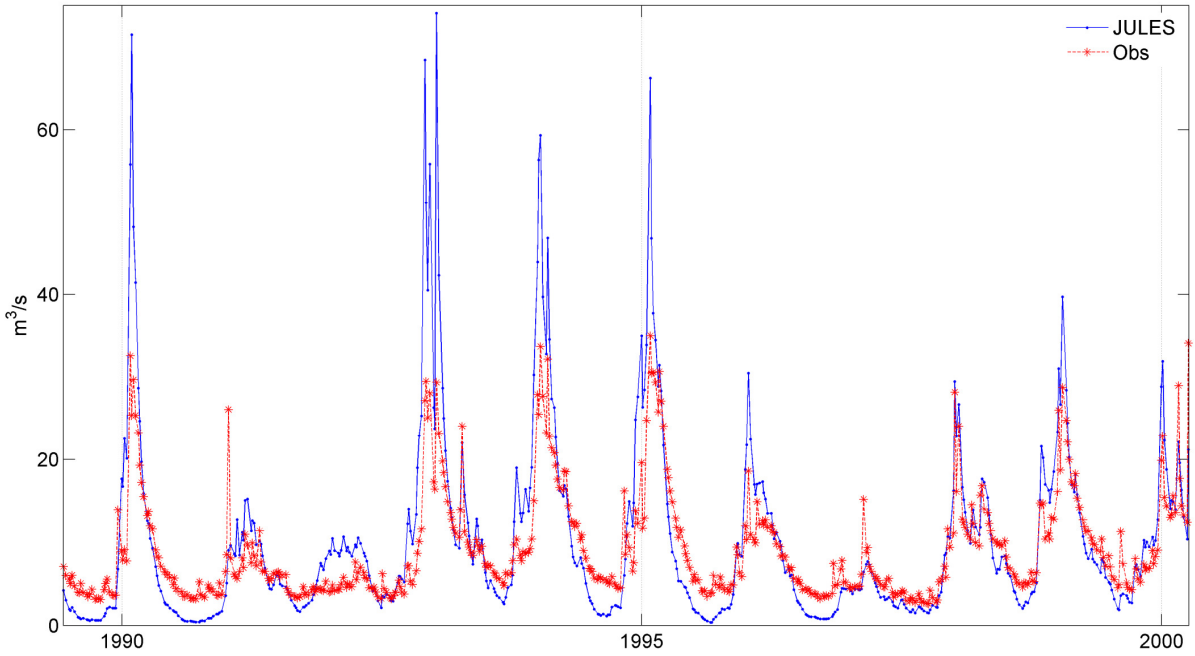


Figure 2 Kennet at Theale flows simulated using NSRI soils and CHESS meteorological inputs.

Current and proposed research directions are:

1) Compare the proposed lower boundary condition (when coupled to TOPMODEL) to a detailed chalk hillslope representation (Ireson et al, 2009);
2) Extension to a dynamic TOPMODEL to represent groundwater movement;
3) Comparison of the later to the groundwater model of Ireson et al, 2009.

Point scale testing of JULES (Imperial):

The work was focused on sensitivity analysis and parameter calibration in JULES at the point scale. The case study area was the Warren Farm site in the Pang catchment, and the examined dataset started on October 2002 and finished on December 2008. Eight soil parameters were selected for the analysis and the Regional Sensitivity Analysis was implemented to decide which parameters needed to be calibrated. The sensitivities of three JULES output fluxes (mean and standard deviation of evapotranspiration and drainage and the mean surface runoff coefficient) were investigated. It was found that evapotranspiration and drainage were mostly affected by parameters ‘b′ and ′θc′, while surface runoff coefficient was more sensitive to parameter ′b′. Then, the sensitivity of soil moisture to model parameters was examined, where it was indicated that soil moisture was visibly sensitive mainly to parameter ′b′ and less sensitive to the rest of the parameters, exhibiting almost no sensitivity to the heat related parameters. Also, the sampled minimum of RMSE for every soil layer gave an approximation of the optimum parameter set, and, thus, the sensitivity analysis acted as a preliminary calibration. Finally, it was found that when the optimised parameters were applied into each of the soil layers, the model performance for both the calibration and validation periods was generally enhanced, but still indicated that performance should be improved in the lowest layers. Current work is refining the analysis by individual analysis of soils and vegetation parameters and more intensive sampling of the parameter space.

Appendix A: project contacts and websites

NERC's CWC programme: http://www.nerc.ac.uk/research/programmes/cwc/facts.asp
HYDEF site:
http://www3.imperial.ac.uk/ewre/research/currentresearch/hydrology/changingwatercycles

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