SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	IFS water cycle verification using river discharge observations
Computer Project Account:	spgbclok
Start Year - End Year :	2012 – 2014
Principal Investigator(s)	Prof Hannah Cloke
Affiliation/Address:	Department of Geography and Environmental Science / Department of Meteorology University of Reading Whiteknights Reading RG6 6DW United Kingdom (previously at King's College London)
Other Researchers (Name/Affiliation):	Florian Pappenberger, Emanuel Dutra, Gianpaolo Balsamo, Dick Dee, Antje Weisheimer (ECMWF)

The following should cover the entire project duration.

Summary of project objectives
(10 lines max)

This project focuses on evaluating the land surface hydrology and river routing predictions of the HTESSEL land surface scheme used in the IFS. The aim is also to provide an independent verification of ECMWF's reanalysis products as well as the implementation of river routing schemes in HTESSEL and the sensitivity of forecasts to the land surface parameterisation. It uses observations from the Global Runoff Data Centre (GRDC).

Summary of problems encountered
(If you encountered any problems of a more technical nature, please describe them here.)

None.

Experience with the Special Project framework
(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The administration was flawless.

Summary of results

Note on project computing resources: The IFS water cycle project originally commenced in 2012. This coincided with an invited visiting scientist position for Cloke at ECMWF to work on reanalysis and land surface hydrology, which meant that the special project computing resources were used at a much reduced rate, as internal resources were used instead as collaboration was direct at the centre. This has continued in the subsequent work and was unanticipated when writing the project. In 2013 Cloke was on maternity leave for 9 months and again special project computing resources were used at a much reduced rate.

Project results:

ERA-Interim/Land global land surface reanalysis (Balsamo et al, 2015)

This part of the work contributed to the ERA-Interim/Land global land surface reanalysis data set covering the period 1979–2010. The dataset describes the evolution of soil moisture, soil temperature and snowpack. ERA-Interim/Land is the result of a single 32-year simulation with the latest ECMWF (European Centre for Medium-Range Weather Forecasts) land surface model driven by meteorological forcing from the ERA-Interim atmospheric reanalysis and precipitation adjustments based on monthly GPCP v2.1 (Global Precipitation Climatology Project). The horizontal resolution is about 80 km and the time frequency is 3-hourly. ERA-Interim/Land includes a number of parameterization improvements in the land surface scheme with respect to the original ERA-Interim data set, which makes it more suitable for climate studies involving land water resources. The quality of ERA-Interim/Land is assessed by comparing with ground-based and remote sensing observations. In particular, estimates of soil moisture, snow depth, surface albedo, turbulent latent and sensible fluxes, and river discharges are verified against a large number of site measurements. ERA-Interim/Land provides a global integrated and coherent estimate of soil moisture and snow water equivalent, which can also be used for the initialization of numerical weather prediction and climate models.

One particular contribution of the IFS water cycle project was the river discharge analysis, which was used to provide an integrated quantity of the continental water cycle for verifying improvements in the representation of land hydrology. For each discharge station, ERA-Interim and ERA-Interim/Land runoff were averaged over the corresponding catchment area and correlated with the observed monthly values covering the entire reanalysis period. Then a PDF of the correlation coefficients was created by clustering over large areas. Figure 1 shows the cumulative distribution function of the correlations from ERA-Interim/Land (blue line) and ERA-Interm (red line). A general improvement is seen in ERA-Interm/Land, as the correlations are higher at all levels in nearly all cases (the blue line is nearly always to the right of the red line, indicating a higher frequence of high correlation).

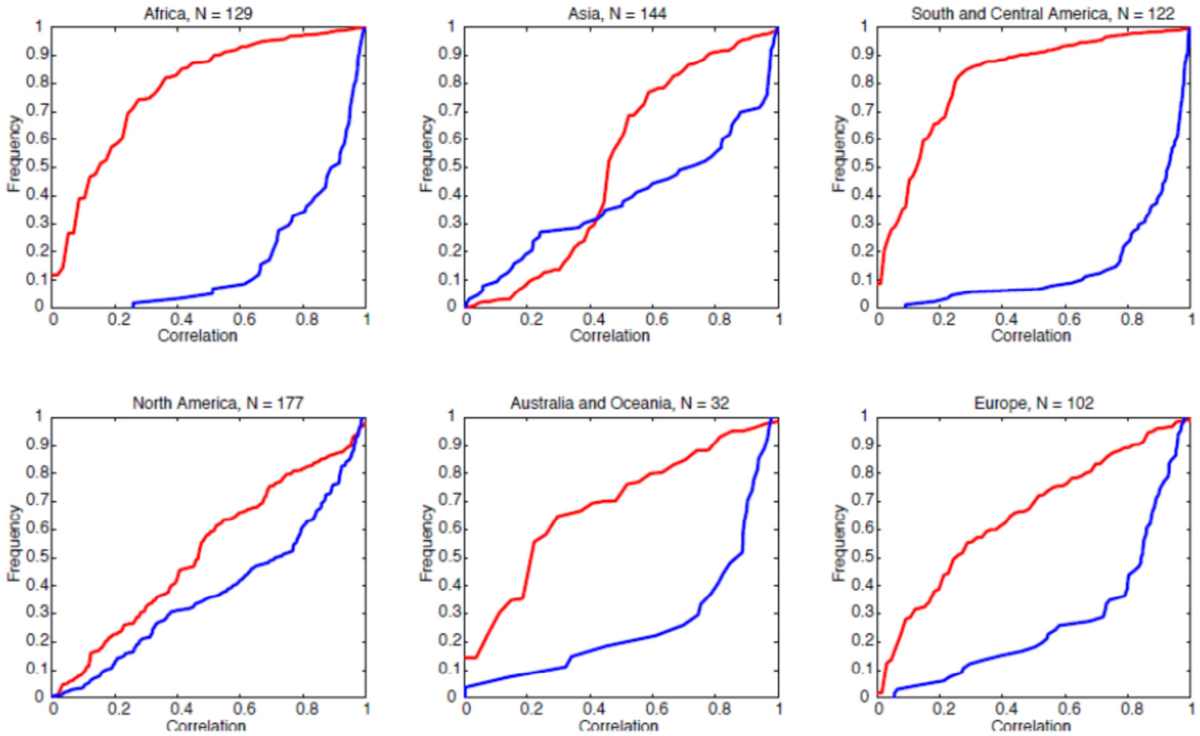

Figure 1. Cumulative distribution function of river discharge correlations of ERA-Interim (red) and ERA-Interim/Land (blue) with GRDC data clustered by continents.

The improvements in runoff are large for two reasons: (i) the revised hydrology, i.e. soil infiltration, soil properties and runoff formulation and (ii) the GPCP bias correction in the tropics and the Southern Hemisphere, consistent with what is known of ERA-Interim precipitation errors. Both effects can be seen in the figure. The improvements over Asia, North America and Europe are mainly the result of the model changes, whereas the impact over Africa, South and Central America and Australia are much larger as the result of the additional effect of GPCP bias correction.

Although there is still some way to go in effectively representing river discharge in large-scale land surface schemes, coupling such schemes to state-of-the-art river hydrology models can bring further improvement. In the current evaluation it is particularly encouraging that the average improvement of river discharge correlations of ERA-Interim/Land over ERA-Interim occurs on all continents, which encompass different rivers and different water balance regimes.

Representation of drought in ECMWF reanalysis and seasonal forecast products (Dutra et al, 2013).

This part of the work evaluated the use of ECMWF products in monitoring and forecasting drought conditions during the recent 2010–2011 drought in the Horn of Africa (HoA) supporting ECMWF researchers.

The region was affected by a precipitation deficit in both the October–December 2010 and March–May 2011 rainy seasons. These anomalies were captured by the ERA-Interim reanalysis (ERAI), despite its limitations in representing the March–May interannual variability. Soil moisture anomalies of ERAI also identified the onset of the drought condition in October 2010 with a persistent drought still present in September 2011. This signal was also evident in normalized difference vegetation index (NDVI) remote sensing data. The precipitation deficit in October–December 2010 was associated with a strong La Nina event. The ECMWF seasonal forecasts for the October–December 2010 season predicted the La Nina event from June 2010 onwards. The forecasts also predicted a below-average October–December rainfall, from July 2010 onwards. The subsequent March–May rainfall anomaly was only captured by the new ECWMF seasonal forecast system in the forecasts starting in March 2011. Our analysis shows that a recent (since 1999) drying in the region during the March–May season is captured by the new ECMWF seasonal forecast system and is consistent with recently published results. The HoA region and its population are highly vulnerable to future droughts, thus global monitoring and forecasting of drought, such as that presented here, will become increasingly important in the future.

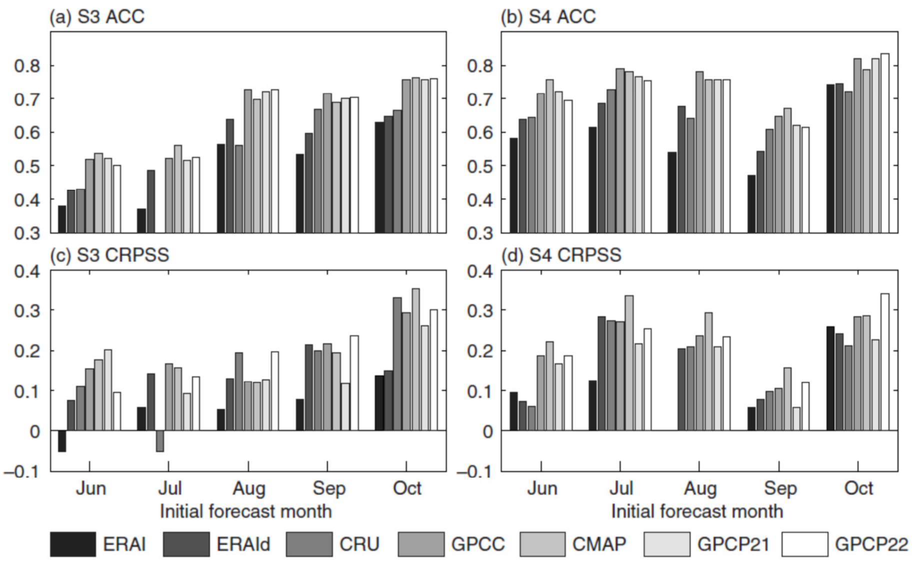

Figure 2. Skill of seasonal forecasts of precipitation for OND in the HoA for S3 (a and c) and S4 (b and d). The skill measures are the anomaly correlation coefficient (ACC; a and b) and the continuous rank probability skill score (CRPSS; c and d). The seasonal forecasts were verified against different datasets (bars in the panels): ERAI, ERAId, CRU, GPCC, CMAP, GPCP21 and GPCP22. Only significant (*P* <0.05) ACC are displayed and CPRSS values equal or lower than 0 are set to –0.05. The verification was performed over the entire length of each dataset.

Evaluation of ECMWF medium-range ensemble forecasts of precipitation for river basins (Ye et al, 2014).

This part of the work evaluated performance of raw medium-range ensemble forecasts and their potential values in forecasting extreme hydro-meteorological events. Ensemble forecasts of precipitation were evaluated over the period 1 January 2008 to 30 September 2012 on a selected midlatitude large-scale river basin, the Huai river basin (*ca*. 270 000 km^2) in central-east China. The evaluation unit is sub-basin in order to consider forecast performance in a hydrologically relevant way. The work finds that forecast performance varies with sub-basin properties, between flooding and non-flooding seasons, and with the forecast properties of aggregated time steps and lead times. Results have direct implications in hydrological forecasts when these ensemble precipitation forecasts are employed in hydrology.

The *CRPSS* was used to evaluate the overall performance of ECMWF's ensemble forecasts in comparison with climatology. Figure 3 shows *CRPSS* calculated using 24 h accumulated precipitation and averaged over the five flooding and five non-flooding seasons respectively. Sub-plots are presented in ascending order of sub-basin size. All sub-basins, except nos. 5, 12, 13, 23, 24 and 25, in both flooding and non-flooding seasons show overall decreasing skill scores with increasing lead times for the forecasted precipitation. The six atypical sub-basins exhibit rising or fluctuating skill scores with increasing lead times. Sub-basins nos. 5, 23, 24 and 25 are located towards the north-west of the basin dominated by the Tongbai mountains, and sub-basins nos. 12 and 13 are located towards the north-east dominated by the Yimeng mountain ranges. The ensemble forecasts completely failed to show any skill in these six sub-basins all located between 34◦N and 36 ◦ N and characterised by high altitudes. This may suggest the need for local models in the areas dominated by high altitude to resolve rain-driven processes at small scales. The skill scores vary depending on the seasons and the sizes of the sub-basins. Flooding seasons (line with dots) showed higher skill scores than non-flooding seasons (line with circles). This may indicate it is easier to correctly forecast rain occurrence and magnitude in a wet season than in a dry season, and the forecasts tend to be more skilful in the wet season compared to the dry season. *CRPSS* for the flooding seasons never drops below 0, which means the forecasted precipitation for all 27 sub-basins was more skilful than their climatology. For sub-basins smaller than 2000 km2 (the first row of sub-basins in Figure 3) except nos. 23 and 25, the highest scores never exceeded 0.4 during flooding seasons. The scores are much lower during the non-flooding seasons and most of them show no skill at all (*CRPSS* < 0). For the sub-basins smaller than 10 000 km2 (the second row of subbasins in Figure 3) except nos. 12, 13 and 24, the scores appear to be better than the first row of sub-basins. The best scores were achieved by the sub-basins larger than 10 000 km2 (the last row of sub-basins in Figure 3) except no. 5. In general, the forecast skill improves as the sub-basin size increases, and forecasts in the flooding seasons outperform those in the non-flooding seasons. For midlatitude sub-basins like the ones in the Huai river basin, ECMWF’s ensemble forecasts can be used in forecasting floods with relatively low, medium and high confidence during flooding seasons for sub-basins with sizes <2000, 2000–10 000, >10 000 km2 respectively. The exception here is the sub-basin dominated by high elevations. During non-flooding seasons, ECMWF’s ensemble forecasts did not show satisfactory skills for sub-basins smaller than 2000 km2, but some reasonable skill for sub-basins larger than 2000 km2. Overall, the forecasts are more skilful in the flooding seasons than the non-flooding seasons over this midlatitude river basin.

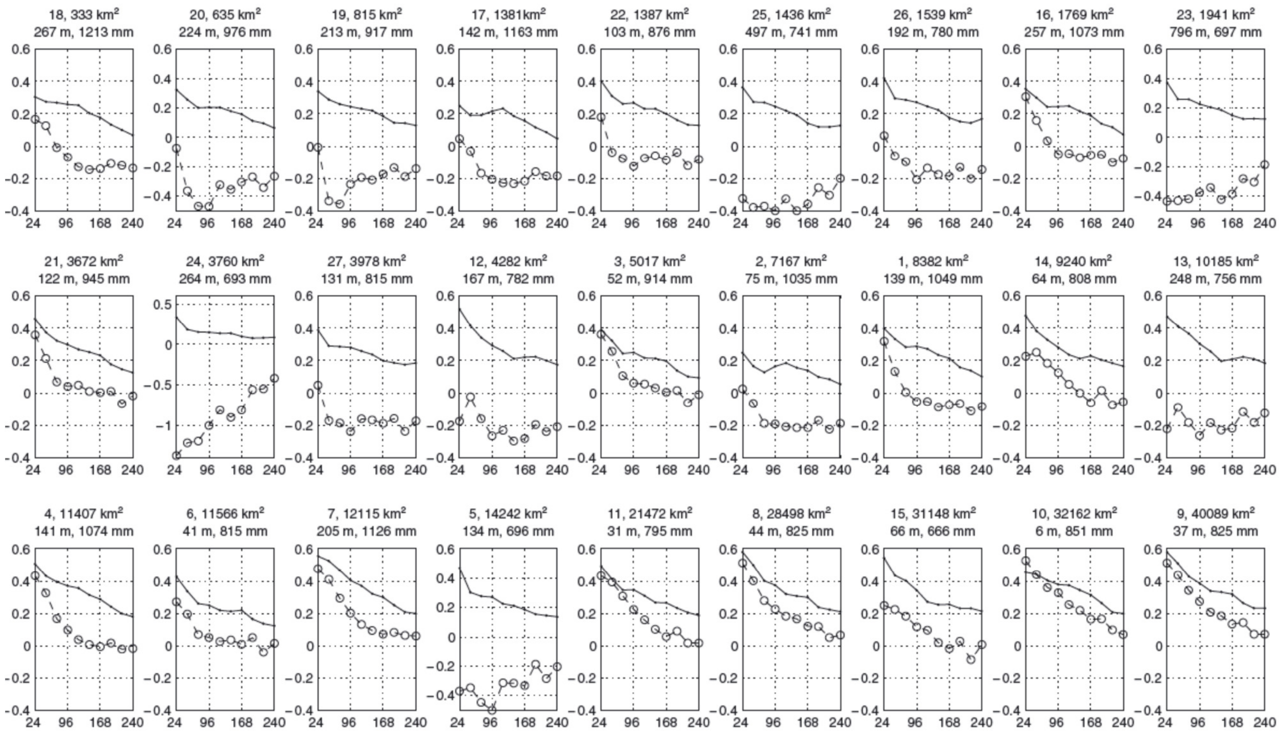

Figure 3 The mean CRPSS versus lead times for each sub-basin in flooding seasons (line with dots) and non-flooding seasons (line with circles). The score is calculated using 24h accumulated precipitation. Sub-plots are presented in ascending order of the sub-basin size. The numbers above each sub-plot are the sub-basin no., size, mean elevation and mean annual precipitation respectively.

List of publications/reports from the project with complete references

Balsamo, G. , Albergel, C., Beljaars, A., Boussetta, S., Brun, E., Cloke, H., Dee, D., Dutra, E., Muñoz-Sabater, J., Pappenberger, F., de Rosnay, P., Stockdale, T. and Vitart, F. (2015) ERA-Interim/Land: a global land surface reanalysis data set. Hydrology and Earth System Sciences, 19 (1). pp. 389-407. ISSN 1027-5606 doi: 10.5194/hess-19-389-2015

Dutra , E., Magnusson, L., Wetterhall, F., Cloke, H. L., Balsamo, G., Boussetta, S. and Pappenberger, F. (2013) The 2010-2011 drought in the Horn of Africa in ECMWF reanalysis and seasonal forecast products. International Journal of Climatology. ISSN 0899-8418 doi: 10.1002/joc.3545

Ye, J., He, Y., Pappenberger, F., Cloke, H. L., Manful, D. Y. and Li, Z. (2014) Evaluation of ECMWF medium-range ensemble forecasts of precipitation for river basins. Quarterly Journal of the Royal Meteorological Society, 140 (682). pp. 1615-1628. ISSN 1477-870X doi: 10.1002/qj.2243

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

We anticipate continuing our work in a future special project on water budgets and land surface uncertainty.