using the data collected by the onboard meteorological measuring system and by human observations (supported by a photographic record). Two centres are indicated for the severe typhoon at the time of the observation. The estimated maximum 10m wind speed is generally consistent with the satellite estimation, although the estimated minimum MSLP appears to be higher. A special flight route was devised to provide an estimate of the gale-force wind radius of the severe typhoon, and this estimate is consistent with satellite estimations. Photographs were taken at the location of an outer rainband and near the typhoon centre. The meteorological observations from this investigation are valuable and will be used for further study of the structure of the severe typhoon, for example through numerical simulation by assimilating the flight data, with the results being reported in a future publication.

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UK Citizen Rainfall Network: a pilot study

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Introduction

Crowd sourcing as a potential method to collect large amounts of data in a relatively inexpensive manner while also educating the general public, has received much press recently in both the scientific and public domain. It was first defined by Jeff Howe (Brabham, 2008, and references therein) as *the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call* and, although this method has been used to great effect in a number of profitable cases by a variety of industries, its vast potential for scientific research has also recently begun to be exploited. From a scientific perspective, crowd-sourcing projects are often referred to as citizen science, which is defined by Wiggins and Crowston (2011) as *a form of research collaboration involving members of the public in scientific research projects to address real-world problems.*

With its history of public involvement, weather monitoring lends itself readily to citizen-science-style activities, with recent examples including: real-time temperature monitoring using smartphone battery temperatures (Overeem *et al.*, 2013), the use of social media broadcasts to obtain accurate snowfall data (e.g. http://snowcore.uwaterloo.ca/snowtweets/index.html; Muller, 2013), smartphone weather apps (e.g. MetWit: https://metwit.com/; Weather Signal: http://weathersignal.com/) and the uploading of amateur weather station data (e.g. Met Office WOW: http://wow.metoffice.gov.uk/). Such activities also build on the number of urban meteorological networks, with a range of research or operational objectives, that now exist within the UK (Muller *et al.*, 2013a).

Currently, there are over 200 automatic weather stations across the UK, as well as 4000 registered open rain gauges, which can provide hourly, daily and monthly measurements, thus making the British rainfall network one of the densest in the world. However, even with this extensive network there are still many areas across the UK that do not provide measurements of rainfall. There is also a historical tendency for the rainfall measurements to be somewhat intermittent: 12 100 rainfall-monitoring stations were reported at some point between 1961 and 2000, with only around 40% of these stations found to be active at any one time (Hollis and Perry, 2004).

Citizen science provides a feasible and low-cost solution to increasing the number of British rainfall-monitoring stations, with the potential coverage of these measurements extended to cover all areas of settlement across the British Isles. Such a voluntary rainfall network already exists in countries outside the UK, with the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) in the USA being a particularly effective example (Cifelli *et al.*, 2005; http://www.cocorahs.org/).

The CoCoRaHS is a unique, non-profit, community-based network of volunteers who work together to measure and map precipitation, using low-cost measurement tools and utilising an interactive website to provide daily and 'extreme event' precipitation measurements (Cifelli *et al.*, 2005). After being set up by the Colorado State University as an initial response to the 1997 Fort Collins floods, the CoCoRaHS network now includes thousands of volunteers nationwide, and has become the largest provider of daily precipitation observations in the USA.

As well as improving the coverage of the current network of rain gauges, and therefore the potential application to forecasting, nowcasting, satellite and radar verification, flood-warning systems and decision making, a community rainfall-collection scheme in the UK would have the additional benefit of encouraging citizens to become involved in meteorological science, thereby heightening their awareness of weather, and engaging the public by participating in actual scientific research.

Case study: the UK Citizen Rainfall Network

In order to assess the feasibility of employing a UK-wide community rainfall-collection scheme, and inspired by the US CoCoRaHS network, a short, unfunded proof-of-concept study – the UK Citizen Rainfall Network (UCRaiN) – was set up across three major UK cities: Birmingham, Manchester and Leicester. The goal of the UCRaiN study was to engage with primary schools from across the three regions and to involve the school children in 'real' science (Muller *et al.*, 2013b), as well as to demonstrate the potential for improving the spatial extent and coverage of current UK rainfall monitoring stations, with each participant collecting information about the daily rainfall at their school, which is then uploaded to a central database.

By using networks that were already established between the three universities involved in this study (University of Birmingham, University of Manchester and University of Leicester), a total of 11 primary schools (six in the Birmingham catchment area, four for Manchester and one for Leicester) were signed up to the project, with additional interested parties (including parents not wishing to miss out on all of the fun!) taking the total number of measurement sites to 13. The locations of these sites are shown in Figure 1, and it can be seen that they cover a wide variety of urban and rural locations, with the different primary schools involved in this scheme also consisting of students that come from a wide range of socioeconomic backgrounds.

At the beginning of June, information packs detailing how to make a basic rain gauge by using ordinary household equipment (see Box 1 and Figure 2) were distributed to the participating primary schools. The schools were instructed to position the rain gauge at ground level and away from

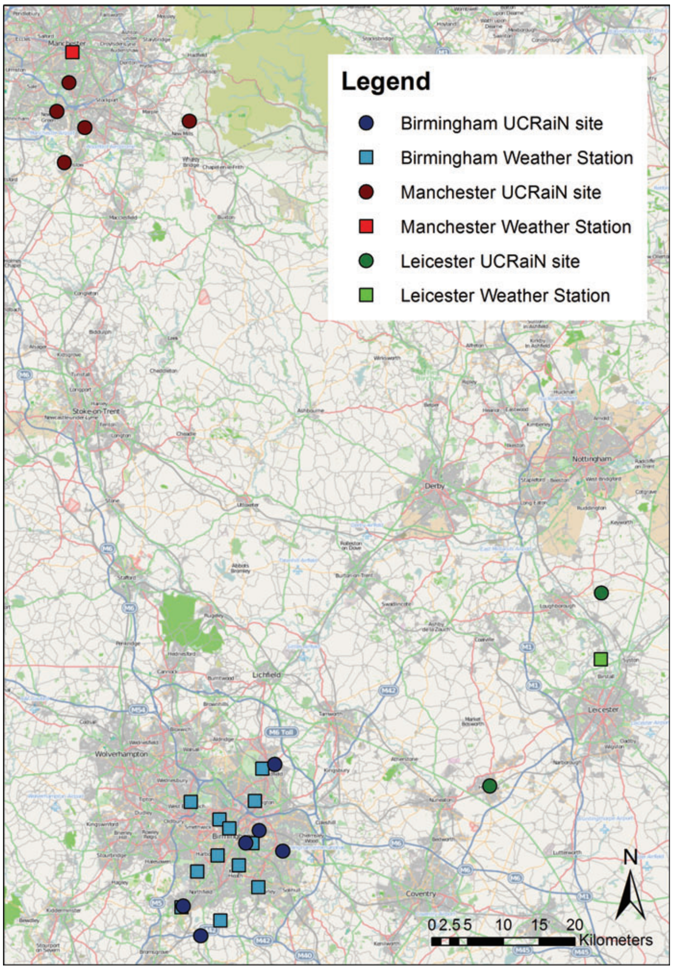

Figure 1. Map showing the locations of the participating UCRaiN sites (schools and individuals). The meteorological sites used for comparison are shown by the square symbols.

Box 1. Rain gauge equipment list that was distributed to the schools.

Equipment

- A standard, straight-sided, 2L, clear plastic drinks bottle
- Scissors
- Tape (e.g. duct tape, brown tape) or paperclip
- Jelly (three or four cubes made up as directed on the packet)
- Ruler
- Marker pen
- Sand or bricks

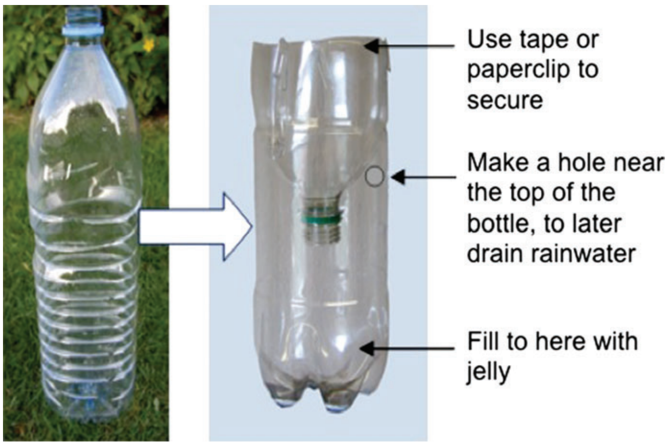

Figure 2. Diagrammatic instructions for making a rain gauge from the equipment listed in Box 1. (Modified after Wrage et al., 2006 and http://www.rmets.org/experiments.)

Figure 3. Alvechurch Church of England Middle School (near Birmingham) made sure that the rain gauge was secure!

Figure 4. A pupil at Lyndon Green Junior School, in Birmingham, studiously taking notes on the daily rainfall amount.

buildings, using sand or bricks to secure the gauge so that it would not be blown over (Figure 3). There was a requirement for the depth (in millimetres) of the water to be recorded every weekday at 0800 UTC (± 1 hour) (Figure 4), and for these measurements then to be sent, via email or twitter, to a representative at one of the participating universities. To act as an additional incentive to those involved in the UCRaiN project, it was advertised that there would be prizes (in the form of digital rain gauges and visits to the schools for further outreach activities) awarded to the schools that provided the most consistent sets of data.

Due to the nature of the project and the non-standard nature of the collectors used, conducting a thorough, scientific validation was beyond the scope of this experimental proof of concept. However, for the purposes of this study, and as a demonstration of a citizen-science experiment, these measurements and basic data-collection methods were found to be sufficient.

Once the rainfall measurements were received, they were uploaded to a central database, where they were then compared with local meteorological data available in each of the three cities. For Birmingham, the Elms Road Met Station was used, for Manchester it was the Whitworth Observatory and for Leicester the Mountsorrel Weather Station was utilised. The daily data were automatically plotted and at the beginning of each week the information and visualisations were sent to each of the participating schools, so that they could discuss their measurements, relative to the rest of the UK. Figure 5 shows the automatically generated Google graph of the daily mean rainfall measured in each city during the course of the UCRaiN project, as well as that recorded by the corresponding meteorological stations.

According to the Met Office, June 2013 was slightly drier than average across most of England, with most areas receiving around half to two-thirds of the normal amount of rainfall (based on an averaging period of 1981–2010). As can be seen from Figure 5, this (mostly) dry June was reflected in the data collected during this study.

Figure 6(a) shows the rainfall totals collected for each site across the whole trial period, classified according to whether it was a UCRaiN site or a measurement from an automatic weather station, and plotted using a system for working with maps and geographical information (ArcGIS). The variability in the data is clear, although there is a definite agreement at sites in the vicinity of meteorological stations. The variations could reflect either the true spatial variability in precipitation across each region, due to the wide area covered by the school sites (especially for convective precipitation), or the quality of the data collected and the measurement device used at each location.

If these data were to be used for operational or research purposes, verification would be required in order to assess its quality, and so some initial investigative work was conducted into the spatial variability across one of the cities. Birmingham

Figure 5. The GoogleChart that was automatically updated each day to show the daily mean rainfall measured in each city during the course of the study.

has recently implemented an Urban Meteorological Network (UMN; Muller *et al.*, 2013c) – the 'Birmingham Urban Climate Laboratory' (BUCL) – and at the time of this study the BUCL had 11 automatic weather stations in operation across Birmingham. When the precipitation recorded by this network was compared with the measurements that were made by the primary schools in that region, a correlation of 0.81 was observed. In addition to this agreement between the automated (and calibrated) weather stations and the UCRaiN measurements, there was also success in identifying the spatial variability of weather events across a single city, even during severe convective storms. Figure 6(b) shows the data for one particularly extreme thunderstorm event that occurred during the study, with the data from the four schools in that area agreeing with the data from the BUCL, thereby confirming that some parts of Birmingham did not receive as much precipitation during the storm compared to other parts of the city.

The UCRaiN study lasted for 6 weeks, from 3 June to 12 July 2013, and by the end of the study the majority of the schools had provided data on a daily basis, allowing for half term and teacher-training days that fell within this period. In fact the vast majority of the schools were so consistent in their reporting of the data that additional prizes were needed!

As well as the successful demonstration of the potential for a UK-wide community rainfall collection scheme, the UCRaiN project proved to be an excellent example of an outreach activity that caught the interest and imagination of those involved. An example of this was the novel way in which the participating schools adapted their rain gauges to face the difficulties presented by the jelly: the original purpose of the jelly was to act as a 'levelling agent', to provide a flatter base from which the scale could be read, thereby improving the accuracy of the measurements. Many of the schools observed that although sugar-free jelly kept the flies and midges at bay, it quickly became too viscous in the high temperatures, making the measurements very difficult to read (Figure 7). Some of the schools suggested (and implemented) the use of a more robust levelling agent such as gypsum plaster (plaster of Paris) or melted candle paraffin wax, whereas others preferred using a flat-bottomed bottle, which circumvented the need for a levelling agent entirely. Other schools were so caught up with the need to provide accurate and reliable data that they even purchased their own higher-quality apparatus, entirely of their own accord (e.g. Lyndon Green Junior school in Birmingham, Figure 8), with Thornsett Primary School in Manchester using six different rain gauges (at the same time) during the course of the UCRaiN project!

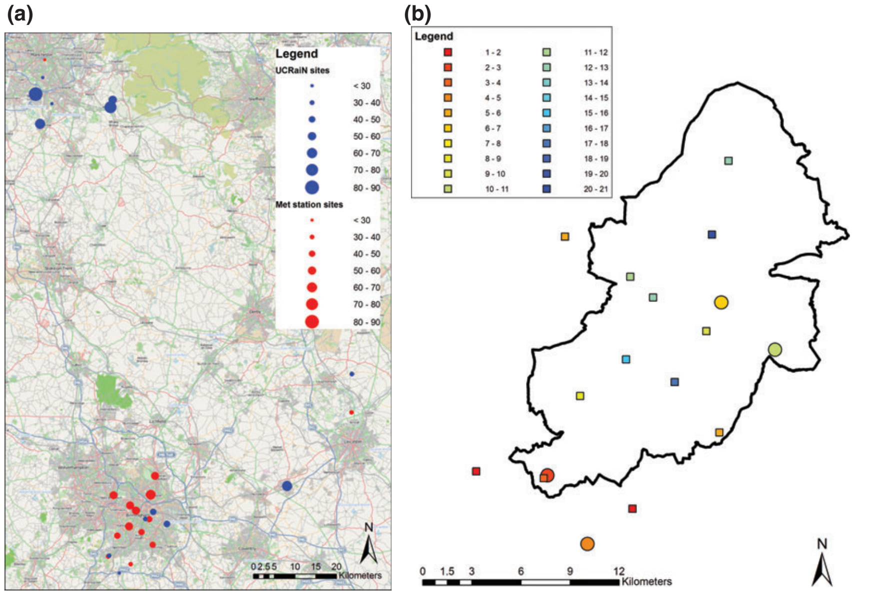

Figure 6. Example ArcGIS map showing (a) the total precipitation for each site over the whole trial period, classified by type of measurement (citizen-science measurement or weather station) and (b) daily variability across Birmingham from the BUCL sites (squares) and school measurements (circles) during a major thunderstorm that occurred on 20/21 June 2013: legend colours apply to both types of symbol; Birmingham conurbation outline shown in black.

Figure 7. The effect that the high temperatures had on the jelly initially led to some difficulties in making measurements.

Figure 8. A pupil at Lyndon Green Junior School makes use of a purpose-bought, and slightly more hi-tech, rain gauge.

The enthusiasm shown by the schools in overcoming some of the flaws in the basic rain gauges was symptomatic of the overall response received throughout this project, with one school – Lyndon Green Junior School in Birmingham – even going on to create their own blog (Figure 9), which can be found at: http://lgjseco.blogspot.co.uk/. All of the feedback from the schools was positive, and included the following testimonials:

> *We would like to be involved in any extended project in the future*

> *We will be carrying on with this as the children are so enthusiastic*

> *The kids really liked it especially as they knew someone else had asked for their data*

> *So sorry if the children continue to tweet data through to you!*

A similar theme throughout the feedback received from the schools was that they would happily be involved in any future projects, and that the students felt a real sense of achievement in the work they were doing. Using a range of different graphs to visualise the data helped to keep the project engaging for the students by demonstrating what could be achieved with their measurements. The UCRaiN project therefore can be seen as a great success in terms of operating as an appealing outreach activity that engaged with a large number of participants and encouraged them to become more involved in meteorological science and its applications.

Future applications and potential

The UCRaiN project has demonstrated the potential for a citizen-science project in the UK to improve the spatial coverage of precipitation measurements, especially if low-cost purpose-built rain gauges are

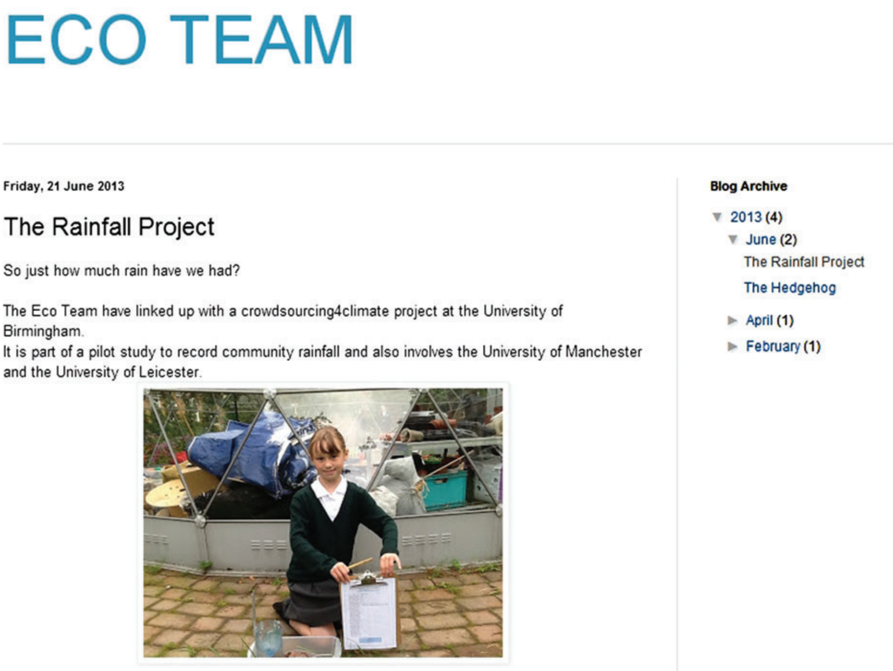

Figure 9. 'The Rainfall Project' blog, set up by Lyndon Green School (http://lgjseco.blogspot.co.uk/).

used. In this study the participants were mostly primary school children, but there is no reason why such a scheme could not be implemented in secondary schools, or indeed away from the education sector (e.g. at home or in residential care homes).

Obviously, if this type of public involvement project were to be rolled-out on a larger scale, and to be of serious scientific use for either operational or research purposes, there would need to be greater emphasis given at the outset to the quality and consistency of the measuring equipment used and to quality verification of the data obtained. Before any of the data collected in such a scheme could be fully incorporated as a regulated form of measurement, there would be a need to thoroughly validate the data, as was done for the CoCoRaHS programme in the USA (Cifelli *et al.*, 2005; Noah Newman, pers. comm., 2013), because this sort of measurement is particularly prone to human error and interpretation. Part of this error could be reduced by the implementation of more accurate and precise rain gauges, although this would mean that funds would need to be made available for the purchase of these rain gauges, so that schools unable to afford this additional outlay are not excluded from the scheme. As a result of the UCRaiN project, the authors are now seeking funding to extend it across the UK in force, and in doing so to explore the possibility of becoming affiliated with the CoCoRaHS. There is also the possibility of expanding this project into other areas, such as air-quality measurements, with the testing of affordable sensors for measuring air pollution having already begun. Expanding the scope of this project beyond meteorological data will allow for further integration with school curricula, and will also help to highlight other key environmental issues.

As with the CoCoRaHS network, if the quality of the measurements was known to be reliable, the data potentially could be incorporated into a number of meteorological and societal applications (e.g. flood-warning systems, radar verification etc.), especially if the data were sent via a dedicated website and/or smart device application, where it could be quality checked automatically and then visualised. This sort of initiative complements the current 'Internet of Things' school initiatives (e.g. the UK DISTANCE project: http://www.iotschool.org/; Curtis, 2013), which are encouraging the use of the Internet, technology and sensors for the measurment and sharing of data in schools, to help make learning fun and informative – and weather is certainly a topic that lends itself to these sorts of 'Big Data' endeavours.

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