ESEX commentary

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**More rain, less soil: long-term changes in rainfall intensity with climate change**

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Abstract:

This commentary discusses the role of long-term climate change in driving increases in soil erosion. Assuming that land use and management remain effectively constant, we discuss changes in the ability of rainfall to cause erosion (erosivity), using long daily rainfall data sets from south east England. An upward trend in mean rainfall per rain day is detected at the century-plus time scale. Implications for soil erosion and sediment delivery are discussed and evidence from other regions reviewed. We conclude that rates of soil erosion may well increase in a warmer, wetter world.

Commentary:

The erosive power of rainfall can be expected to change as climate changes (Nearing, 2001). The importance of a 'trend toward more precipitation occurring in more extreme events and shorter return periods for heavy precipitation' has been recognised in the U.S. climate record (Soil and Water Conservation Society, 2003) and similar observations have been made in the UK (Maraun et al., 2008). Whilst climate, vegetation, and soil can be coupled in a variety of complex ways, here we start to address the role of climate change on soil erosion by isolating changes in the ability of rainfall to cause erosion (erosivity), setting aside the impacts of other changes, in particular, land use and management. In the latter half of the 20$^{th}$ century, the most important influence on soil erosion in south-east England was the shift from grassland to arable, associated with mechanisation and the intensification of agricultural production (Boardman, 2013; Howden et al., 2013). Nowadays, an arable monoculture dominates, although some further changes, in particular the recent introduction of the highly erodible crop maize, may still be of significance in terms of changing erodibility. However, assuming constant land use and management, we are able to examine the influence of climate change on soil erosion. Are we able to detect significant changes in rainfall erosivity over the long term?

We examined a number of very long daily rainfall records for selected meteorological stations in south-east England (Figure 1). It is important to examine very long time series because, when viewed over shorter time periods, such records can show a variety of trends, increasing or decreasing, because of natural, long-term oscillations (Hirsch and Archfield, 2015). Using very long records allows us to detect subtle, underlying trends within noisy records (Burt, 1994). Where gaps were present, data from nearby stations (usually within a few kilometres) were inserted (Table 1); note that the Kew Gardens gauge closed in 1980 but fortunately there were many stations nearby in SW London recording daily rainfall totals. Petworth and Cambridge have the most complete records at a single site. No attempt was made to adjust infill data given the proximity of stations; correlations between adjacent site records is very high (e.g. for Falmer and House Dean Farm: $R^2 = 0.95$, $n = 3652$).

Records were compiled for total seasonal and annual rainfall (mm), numbers of rain days (daily total of at least 0.25 mm), mean rainfall per rain day, and the number of heavy falls of rain (2-day totals of at least 30mm, an index known to relate to incidences of soil erosion in the region: Boardman and Favis-Mortlock, 1993). Pearson correlation coefficients were calculated for each time series (Table 1). In all cases, there is a general decrease in the number of rain days and a consequent increase in the mean rainfall per rain day. There are fewer significant trends in total rainfall or for heavy falls of rain. Figure 2 shows annual results for Falmer, near Brighton, on the south coast. Whilst the long-term increase in annual rainfall total is only just statistically significant ($p = 0.011$), there are highly significant trends for number of rain days, for mean rainfall per rain day and for number of 2-day totals above 30mm. Although results do differ locally, there is a strong suggestion that, for these stations, which lie close to the European mainland, mean rainfall per rain day has increased over the last century. Why might this be significant in terms of Earth surface processes and might we expect to see similar results elsewhere?

The results for the Falmer gauge are of especial interest as it is at the centre of the eastern South Downs, an area intensively studied in terms of erosion and off-site effects (e.g. Boardman, 2003). Rainfall per rain day has been increasing for all seasons including autumn and winter when a very high proportion of the erosion occurs on winter cereal fields (Table 1). In the Petworth area, for example, severe erosion occurred in 2000 and 2006, associated with exceptionally high rainfall totals for autumn and early winter months (Boardman et al., 2009). Of course, intense rainfall can cause erosion at other times of the year, for example, convectional storms in early summer on recently cultivated maize fields (Boardman et al., 1996).

In regions where observational coverage is sufficient for assessment, the latest Intergovernmental Panel on Climate Change Report (IPCC 2014) concluded that there is *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century. It is *very likely* that global near-surface and tropospheric air specific humidity has increased since the 1970s. There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes, area-averaged long-term positive or negative trends have *low confidence*. Extreme precipitation events over most mid-latitude land masses will *very likely* become more intense and more frequent as global mean surface temperature increases. Not surprisingly, examples are accumulating from around the world, showing a long-term increase in rainfall erosivity. For example, in south-eastern Australia, the period since the late 1940s has been wetter than the first four decades of the 20$^{th}$ Century (Pittock, 1975). Examination of the annual rainfall erosivity values for Sydney showed that, for the period since 1949, both rainfall erosivity and rainfall amount were significantly higher compared to the period from 1922 to 1948 (Yu, 1995). In Belgium, Verstraeten et al (2006) showed that, whilst no significant monotonic trend in the annual R factor (of the Universal Soil Loss equation) could be observed over the entire study period (1898-2002), a standard normal homogeneity test showed significantly higher rainfall erosivity (+31%) for the period 1991–2002 compared to the rest of the record. In the central United States, records of daily rainfall accumulations from 447 rain gauge stations were used to assess past changes in the frequency of heavy rainfall, using a peaks-over-threshold approach (Villarini et al., 2013). The results point to increasing trends in heavy rainfall over the northern part of the region, the area with the largest increasing trends in temperature and, consequently, atmospheric water vapour. In the eastern Karoo, South Africa, average rain per rain day has steadily increased over the last 100 years to a value of 12 mm which is above the observed threshold for runoff on bare, badland areas (Boardman and Foster, 2008).

We agree that the first-order control on soil erosion is likely to be the way in which land is managed. However, in many regions, arable farming now dominates, meaning essentially no further change in soil erodibility therefore. This means that changes in the erosive effect of rainfall, in many ways a second-order effect, can assume greater relative importance, especially in relation to future climate change in a warmer world. The results presented here suggest that further work on rainfall regimes and in particular metrics such as rain per rain day would bear fruit in relation to predicting likely changes in soil erosion and sediment delivery. Previous work, which shows likely increases in erosion by water on arable land in south east England associated with modelled climate change, is based on the assumption of no change in climate variability (Boardman et al., 1990; Favis-Mortlock et al., 1991); current upward trends in rain per rain day suggest this may not be the case. It would also be interesting to examine sub-daily rainfall data; whilst such records (usually hourly totals) are relatively short, often with many short gaps, there may well be important information to be gleaned on changing patterns of rainfall intensity in the recent past (Blenkinsopp et al., submitted). Finally, we note that increases in the ability of rainfall to cause erosion (i.e. erosivity) are, of course, only one aspect of the way in which soils are responding to climate change; increasing temperature is probably very important too, for example, causing the decline of soil carbon content (Barraclough et al., 2015) and thereby increasing erodibility.

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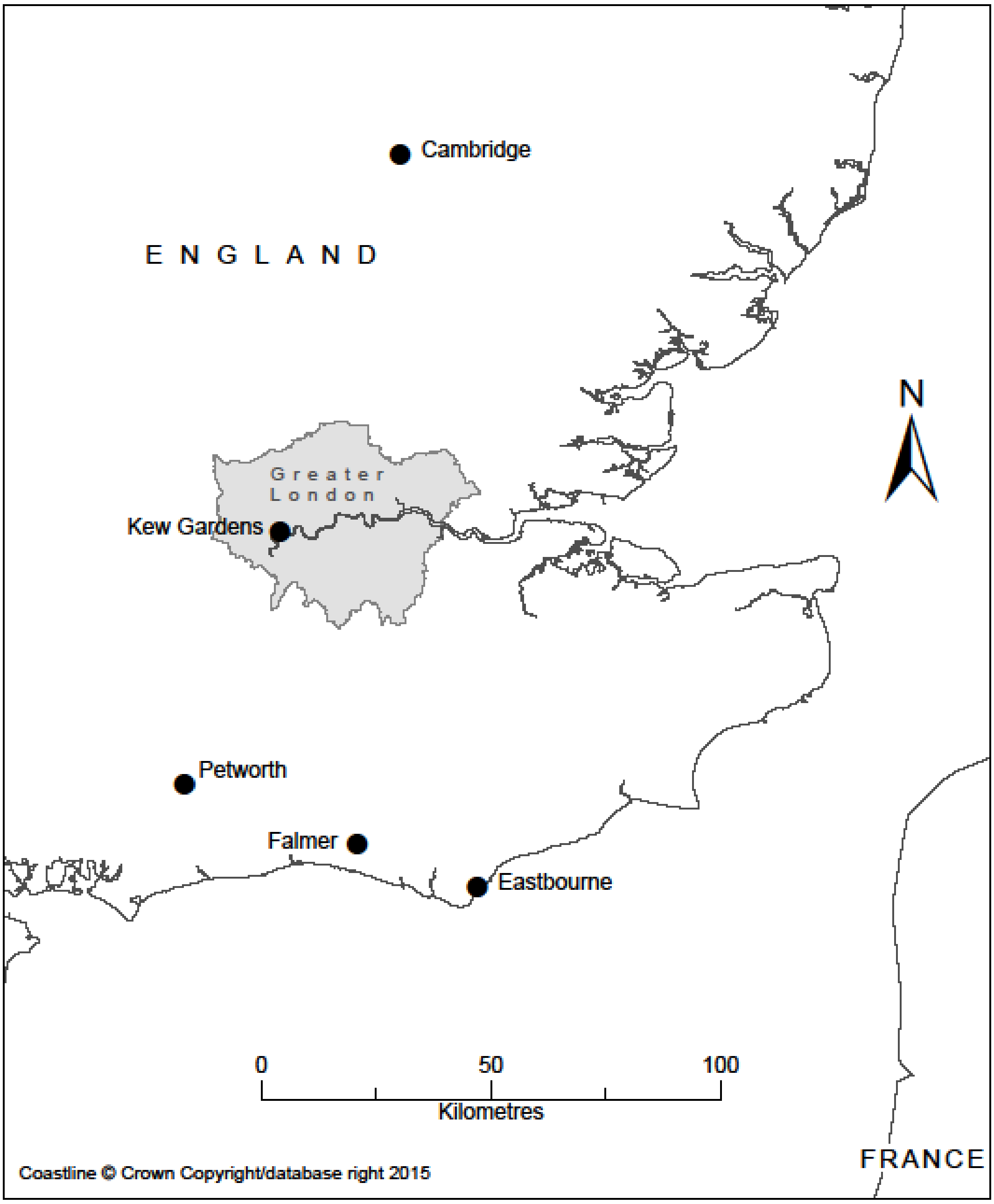
| Station | | Falmer | Petworth | Eastbourne | Cambridge | Kew |
|---|---|---|---|---|---|---|
| Start of record | | 1904 | 1907 | 1888 | 1900 | 1871 |
| Data infill (%) | | 8.7 | 0.1 | 3.4 | 0.3 | 16.0 |
| Total | Winter | | | | | |
| | Spring | | | | | |
| | Summer | | **-0.463** | | | -0.194 |
| | Autumn | | | | | |
| | Year | 0.240 | | | | |
| RD | Winter | **-0.397** | | -0.199 | | **-0.296** |
| | Spring | **-0.370** | | -0.185 | | *-0.283* |
| | Summer | **-0.342** | -0.195 | *-0.248* | | **-0.365** |
| | Autumn | *-0.289* | | | | **-0.408** |
| | Year | **-0.603** | -0.190 | **-0.385** | -0.242 | **-0.602** |
| R/ RD | Winter | **0.556** | | **0.317** | 0.221 | **0.356** |
| | Spring | **0.433** | | *0.293* | | **0.295** |
| | Summer | **0.422** | | | | |
| | Autumn | **0.424** | 0.192 | | 0.242 | **0.284** |
| | Year | **0.711** | | **0.404** | **0.317** | **0.442** |
| 2-day total >30 mm | Winter | *0.267* | | 0.236 | | |
| | Spring | | | | | |
| | Summer | 0.204 | | | | |
| | Autumn | | | | | |
| | Year | **0.325** | | | | |

Table 1. Seasonal and annual correlations over time for various rainfall metrics for five locations in south east England. Only significant results are shown: $p < 0.05$ for results in standard font; *p < 0.01 in italics*; **p < 0.001 in bold**. All records finish at the end of 2014 except Eastbourne (2012).

**Figure captions**

1. Map showing locations of the selected meteorological stations.



2. Long-term trends in annual rainfall metrics at Falmer, Sussex, England. (a) total rainfall; (b) number of rain days; (c) mean rainfall per rain day; (d) number of days with 2-day totals of at least 30 mm.