EXTREME MULTI-BASIN FLOODING LINKED WITH EXTRA-TROPICAL CYCLONES[1]

De Luca P.*, Hillier J. K., Wilby R. L., Quinn W. N., Harrigan S.

*Dept. Geography, Loughborough University, UK

p.deluca@lboro.ac.uk @PaoloGeog87

1. ABSTRACT

Fluvial floods are typically investigated as 'events' at the single basin-scale, hence flood management authorities may underestimate the threat of flooding across multiple basins driven by large-scale and nearly concurrent atmospheric event(s). We pilot a national-scale statistical analysis of the spatio-temporal characteristics of extreme multi-basin flooding (MBF) episodes, using peak river flow data for 260 basins in Great Britain (1975-2014), a sentinel region for storms impacting northwest and central Europe. During the most widespread MBF episode, 108 basins (~46% of the study area) recorded Annual Maximum (AMAX) discharge within a 16-day window. Such episodes are associated with persistent cyclonic and westerly atmospheric circulations, atmospheric rivers, and precipitation falling onto previously saturated ground, leading to hydrological response times <40h and documented flood impacts. Furthermore, peak flows tend to occur after 0-13 days of very severe gales causing combined and spatially-distributed, yet differentially time-lagged, wind and flood damages. These findings have implications for emergency responders, insurers and contingency planners worldwide.

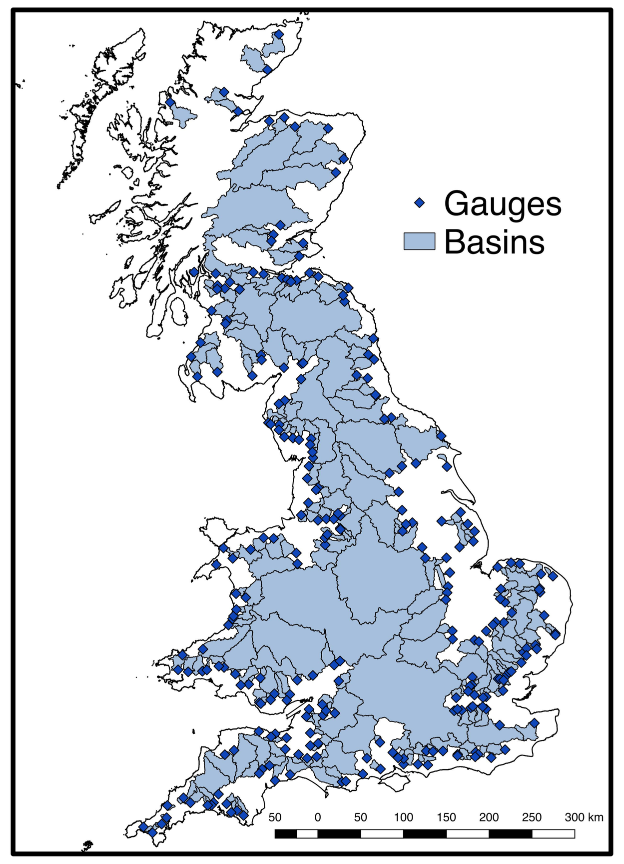

Fig. 1 – Network of 260 non-nested gauges.

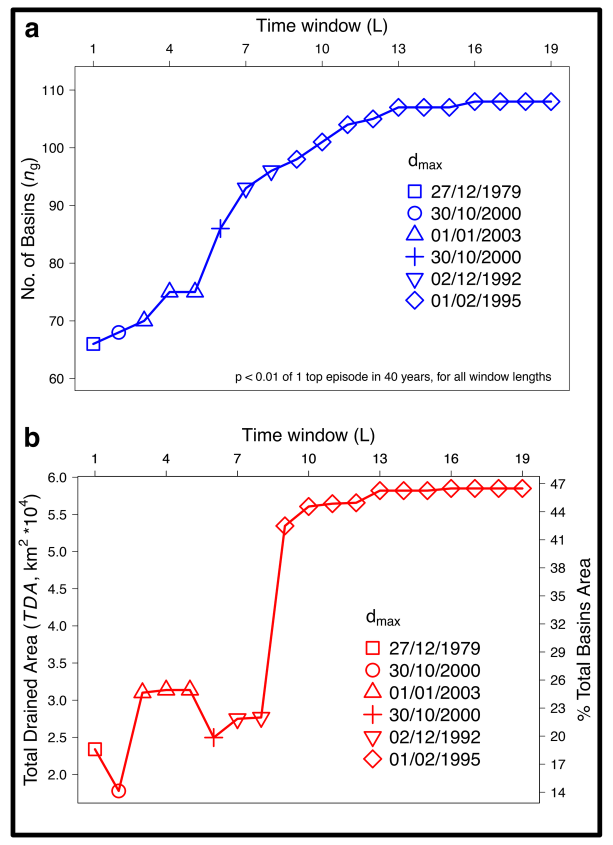

Fig. 2 – a) No. of concurrent basins (n_g) found in the extreme MBF episodes (event-set E); b) Total Drained Area (*TDA*, km^2) of study impacted by the episodes. X-axis shows time window length (*L*) in days and d_{max} is the day where the largest number of basins have been recorded.

2. DATA and METHOD

- **Peak Flow** (m^3/s) **Annual Maximum** (AMAX) **data**, for all GB during **1975-2014 time period** (water years), from NRFA and SEPA;
- A new **simple and pragmatic approach** based on the **count of concurrent basins reaching their AMAX within a given time window** has been developed;
- **Time window (L) = n days before d_{max}** (included), where d_{max} is the day where the largest number of basins reached their AMAX;
- **5 event-sets** used for the analysis based on different properties:

➢ **Event-set A**: single AMAX dates;
➢ **Event-set B**: extreme MBF episodes (based on no. of basins, n_g) + next 10 subsequent;
➢ **Event-set C**: extreme L = 13-days episodes per each water year based on multi-basin flood yield (*mFY*);
➢ **Event-set D**: extreme L = 13-days episodes per each water year based on total drained area (*TDA*);
➢ **Event-set E**: extreme MBF episodes based on n_g.

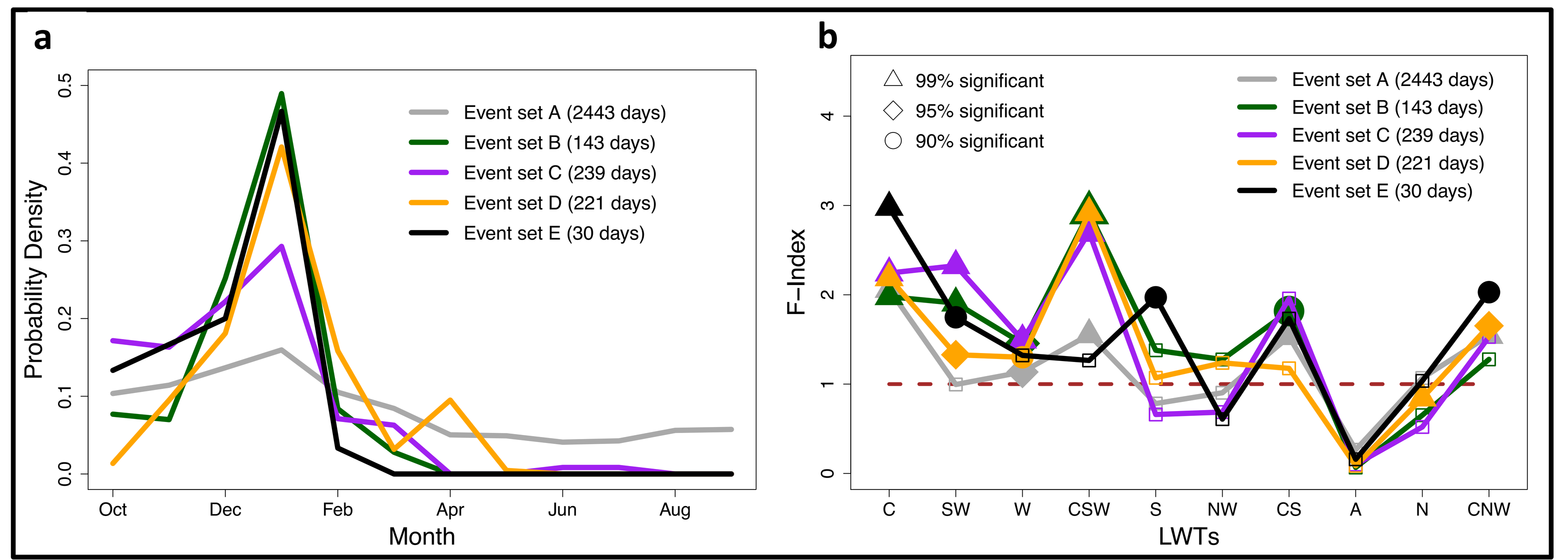

Fig. 3 - a) Temporal distribution of peak flow AMAX; b) Flood-Index [2] for the 10 most common LWTs [3] observed.

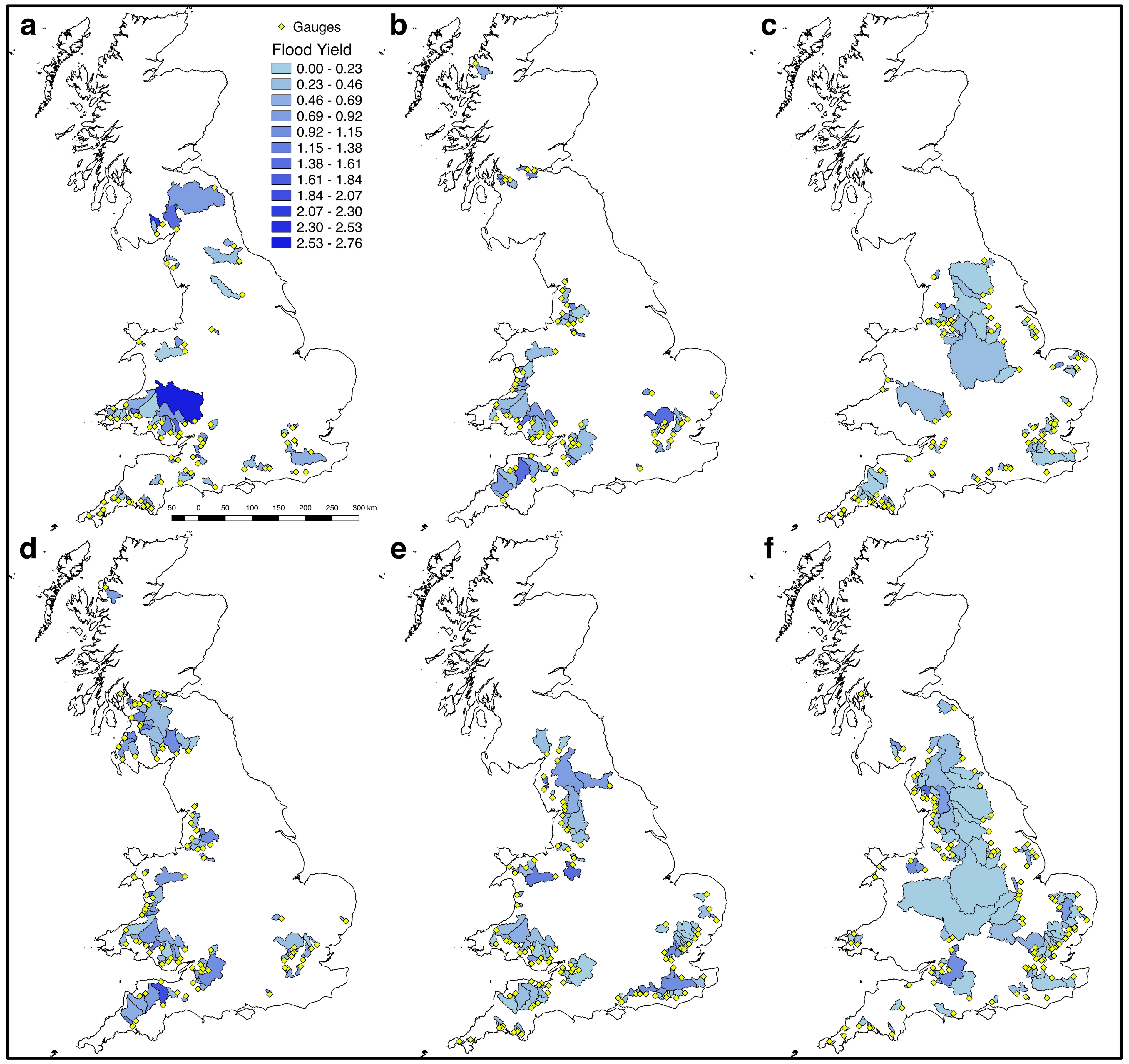

Fig. 4 - Distribution of basins contributing to the extreme MBF episodes in GB during 1975-2014 for six time window lengths (*L*) (event set E). The maps show respectively: (**a**) *L* = 1-day (d_{max} = 27/12/1979); (**b**) *L* = 2- days (d_{max} = 30/10/2000); (**c**) *L* = 4-days (d_{max} = 01/01/2003); (**d**) *L* = 6-days (d_{max} = 30/10/2000); (**e**) *L* = 8-days (d_{max} = 02/12/1992); and (**f**) *L* = 16-days (d_{max} = 01/02/1995). Flood Yield (*FY*) is a severity metric that represents each basin's peak flow AMAX normalized by the relative basin area.

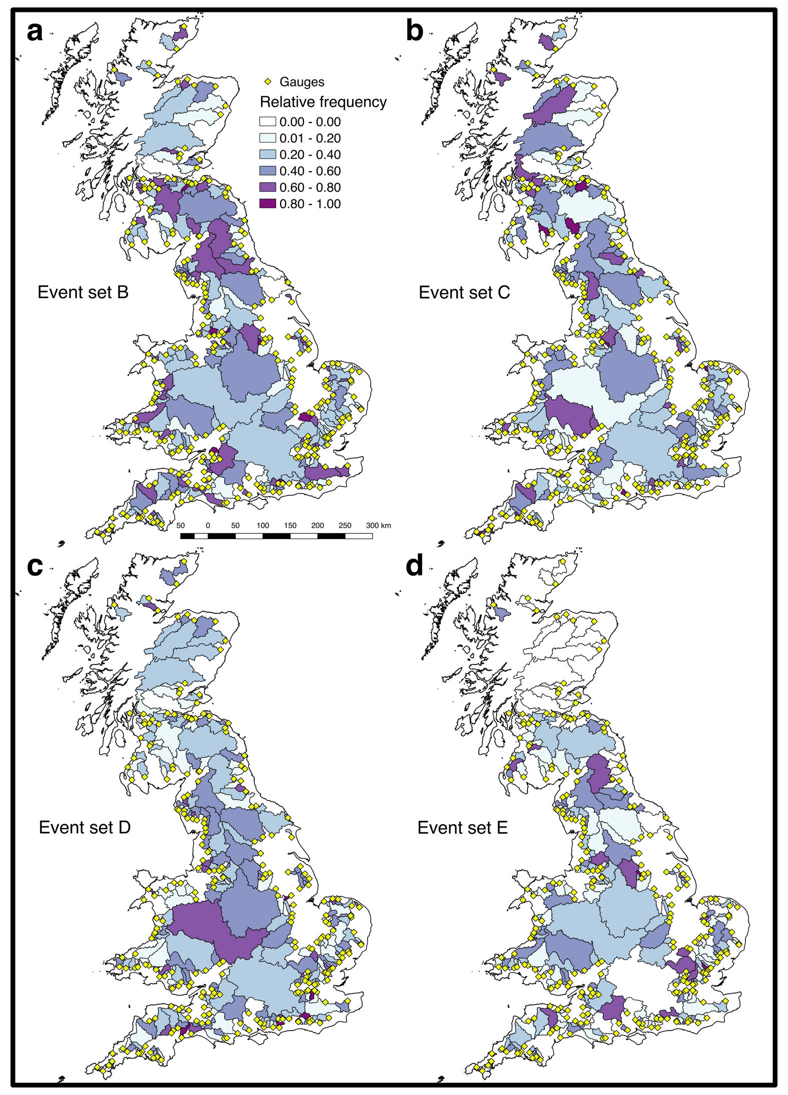

Fig. 5 - Distribution and relative frequency of occurrence of peak flow AMAX within event sets B, C, D and E. The colour scale is a ratio of AMAX occurrences in a given basin relative to the basin with the largest number in that panel, with dark colours indicating most occurrences.

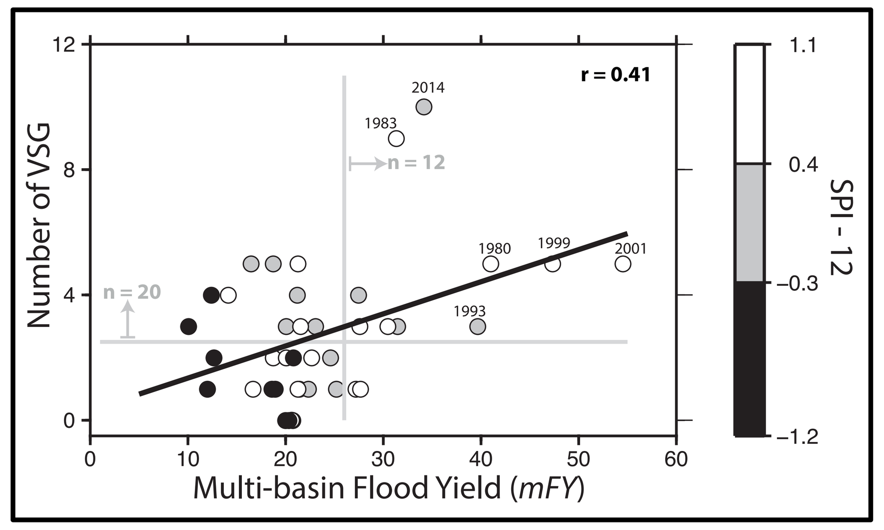

Fig. 6 - Number of Very Severe Gales (VSG) [3] versus extreme multi-basin Flood Yield (*mFY*) episodes belonging to event set C. *mFY* is the sum of single *FY* within a multi-basin episode.

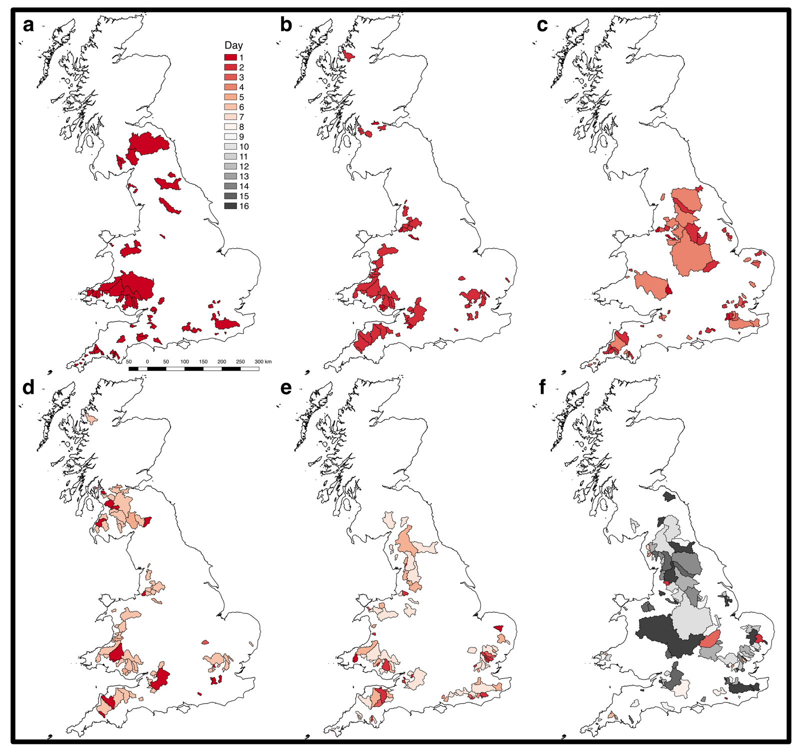

Fig. 7 - Joining times (*Jt*) of extreme MBF episodes (event set E, see Fig. 4 for episodes' dates). The *Jt* for a basin represents the day, within an MBF episode it contributes to, where it reached its AMAX. Days are ordered chronologically (e.g. Day = 16 represents dmax for L = 16-days).

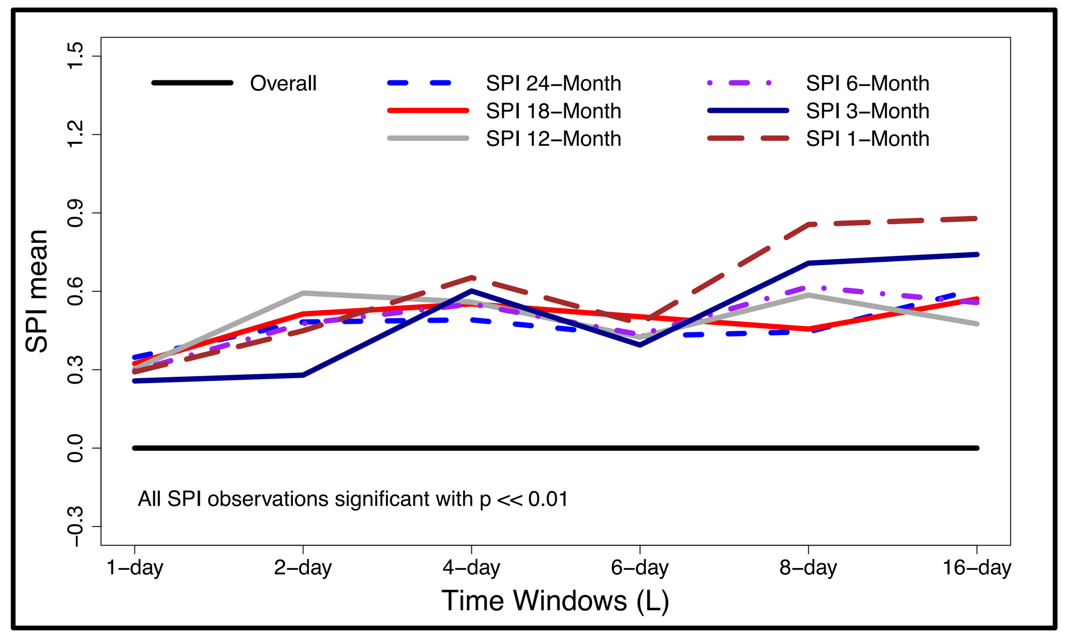

Fig. 8 – Mean of Standardized Precipitation Index (SPI) for episodes within event set B for each window length (*L*) and SPI time scale (24-1 Months) [5]. Coloured/dashed lines are episode SPI averages and the black line represents the overall (40-year, 1975-2014) SPI average, i.e. zero by definition.

3. RESULTS

- **5 temporally distinct extreme MBF episodes** have been identified (event-set E). **Number of basins** concurrently **involved from 66** (L = 1) **to 108** (L = 16) and **% total basins area drained** from **14.1%** (L = 2) to **46.5%** (L = 16);
- The episodes tend **to occur mostly during the DJF winter**, with a clear peak in **January** for all event-sets;
- **10 LWTs identified within event-set E**. C- (Cyclonic), SW- (Southwesterly), W- (Westerly), CSW-, CS- and NW-type more frequent than expected for all event-sets with **C-type ~3 times more frequent** (event-set E);
- **Event set C** episodes **correlate** with the no. of days with **VSGs** in that particular year (p-value <0.01) and **co-occurrence of extremes is 67% more likely than expected by chance** (10 co-occurrences, p-value <0.05). For **5 of 10 co-occurrences**, the **extreme multi-basin flows** occurred **on the same day of VSG** and **4 of 10** within **1-13 days after** a VSG (p-value << 0.001);
- The **distribution of AMAX peak flows occurrences is homogeneous** within the study area for event sets B, C, D and E;
- **Larger** (A ≥ 1,000km^2) **basins join the episodes essentially the same time as small** (A <1,000km^2) **ones** (Joining times *Jt* analysis). Larger basins have **a time to peak <40h**;
- **4 out of 5** temporally distinct **extreme MBF episodes occurred on the same day as an** **Atmospheric River** (AR) [4] impacting the Great Britain (p <0.01);
- **SPI 24-1 Month is significantly above the overall mean**, increasing with time window length, during the event-set B episodes.

4. CONCLUSIONS

- A **new pragmatic method with different metrics** for identify multi-basin flooding episodes has been introduced and due to its simplicity and few data required it is easily **applicable also beyond the study area**;
- A **national-scale return period** of widespread flooding can be estimated independently of the metric used;
- **Multi-basin flooding have similar physical drivers as single-basin floods** but duration for the former is larger (i.e. ~13 days), indicating that a memory in the physical system is required (e.g. wet soil or persistent LWTs);
- **ETCs are linked with multi-basin episodes, through C-type LWTs, VSGs and ARs**, bringing **combined flood-wind** impacts that could exceed the £0.3 billion of insurance losses reported for UK domestic properties [6];
- **Emergency managers and related resources** may be put under **high stress** during extreme MBF episodes concurrently impacting large areas.

References: **[1]** De Luca et al. (2017) Extreme multi-basin flooding linked with extra-tropical cyclones, *Environ. Res. Lett.* (in press) **[2]** Wilby & Quinn (2013) Reconstructing multi-decadal variations in fluvial flood risk using atmospheric circulation patterns, *J. Hydrol.*, 487, 109-121; **[3]** Jones et al. (2013) Lamb Weather Types derived from Reanalysis Products. *Int. J. Climatol.* 33, 1129-1139; **[4]** Brands et al. (2017) Twentieth-century atmospheric river activity along the west coasts of Europe and North America: algorithm formulation, reanalysis uncertainty and links to atmospheric circulation patterns. *Clim. Dyn.* 48: 2771; **[5]** Tanguy et al. (2015) Standardised Precipitation Index time series for Integrated Hydrological Units Hydrometric Areas (1961-2012). *NERC Environmental Information Data Centre*; **[6]** Hillier et al. (2015) Interactions between apparently 'primary' weather-driven hazards and their cost. *Environ. Res. Lett.* 10, 104003.

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