Geological controls of discharge variability in the Thames Basin, UK from cross-spectral analysis: observations versus modelling

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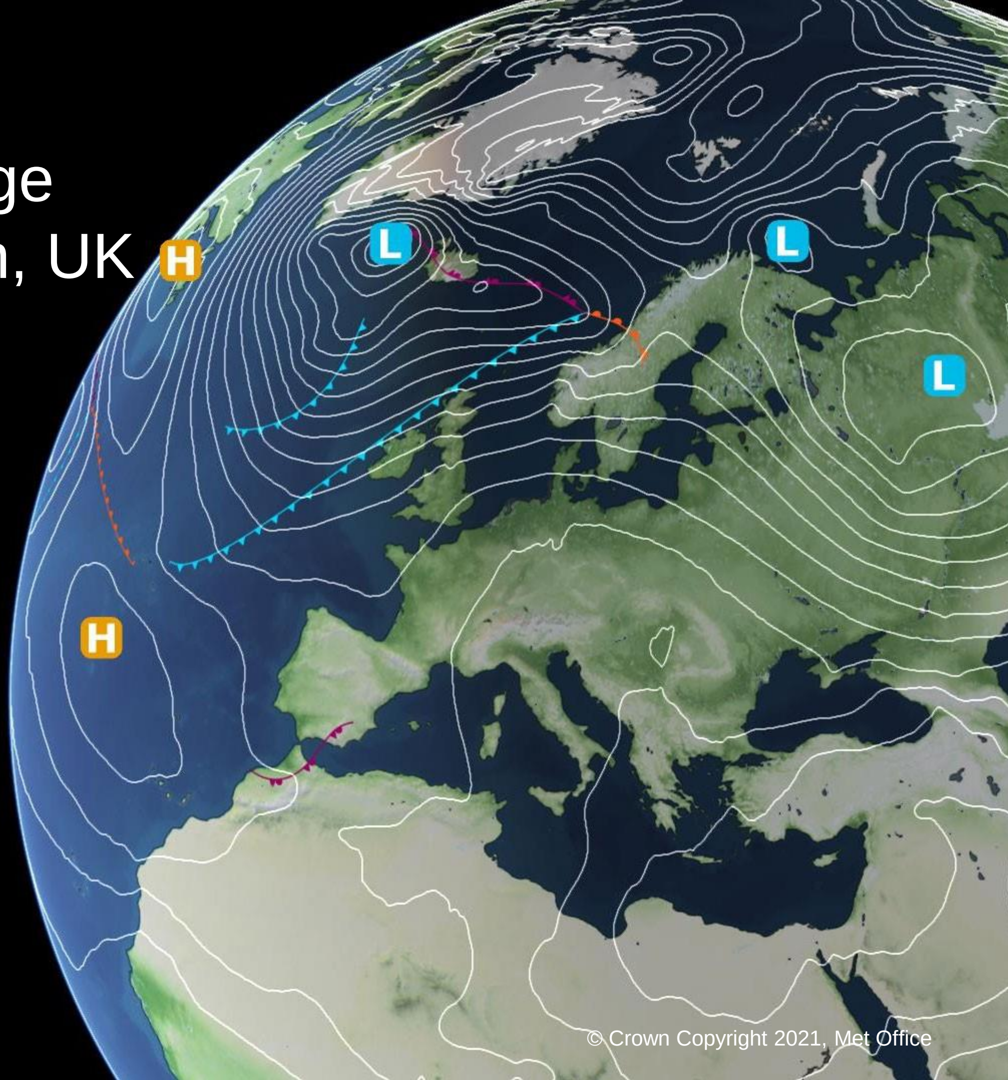
JULES Annual meeting, 15th Sept 2022



Methodological details

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Hypothesis: Discharge variability is controlled by the underlying rocks. Bloomfield et al (2009, *J. Hydrol.*, 373, 164-176, doi: 10.1016/j.hydrol.2009.04.025) showed that BFI is strongly influenced by geology – especially rock permeability within the Thames Basin.

Method: Spectral and cross-spectral analyses (Weedon et al., 2015, *JHM*, 16, 214-231, doi: 10.1175/JHM-D-14-0021.1).

Observations 1st Jan 1990 to 31st Dec 2014:

a) CEH-GEAR daily basinwide rainfall (converted to $m^3\ s^{-1}$).
b) NRFA daily discharge ($m^3\ s^{-1}$) for Thames at Kingston plus **48 gauges in sub-catchments that drain to the Thames or Thames estuary**.
c) Fractions of geological formations.

JULES runs:

a) vn6.2 standalone, RAL3 configuration (including TOPMODEL).
b) 1 km^2 grid plus 1 km^2 routing (Davies et al., 2022, NERC EDS Environmental Information Data Centre (Dataset) doi: 10.5285/6da95899-f3b8-4089-b621-560818aa78ba), hourly time step, soil ancils copied from ANTS-derived 2.2 km^2 grid.
c) Forcing daily CHESS data (Robinson et al., 2017, *HESS*, 21, 1189-1224, doi: 10.5194/hess-21-1189-2017) disaggregated to hourly – **except CEH-GEAR1hr hourly precipitation** (Lewis et al., 2018, *J. Hydrol.*, 564, 930-943, doi: 10.1016/j.hydrol.2018.07.034).

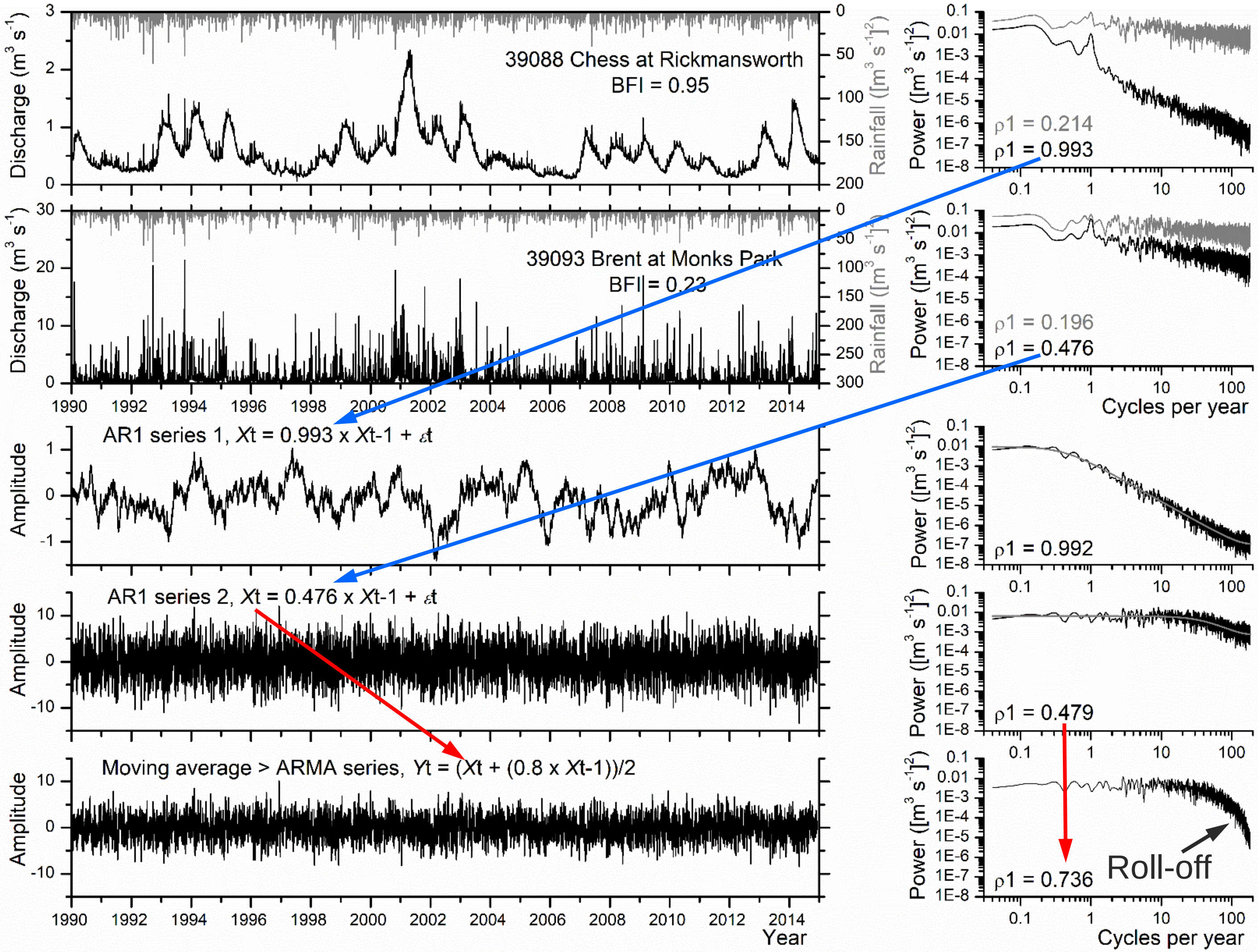
High BFI & ρ1

Low BFI & ρ1

Autoregression 1

Autoregression 2

ARMA series (from Moving Ave of AR1 series 2)



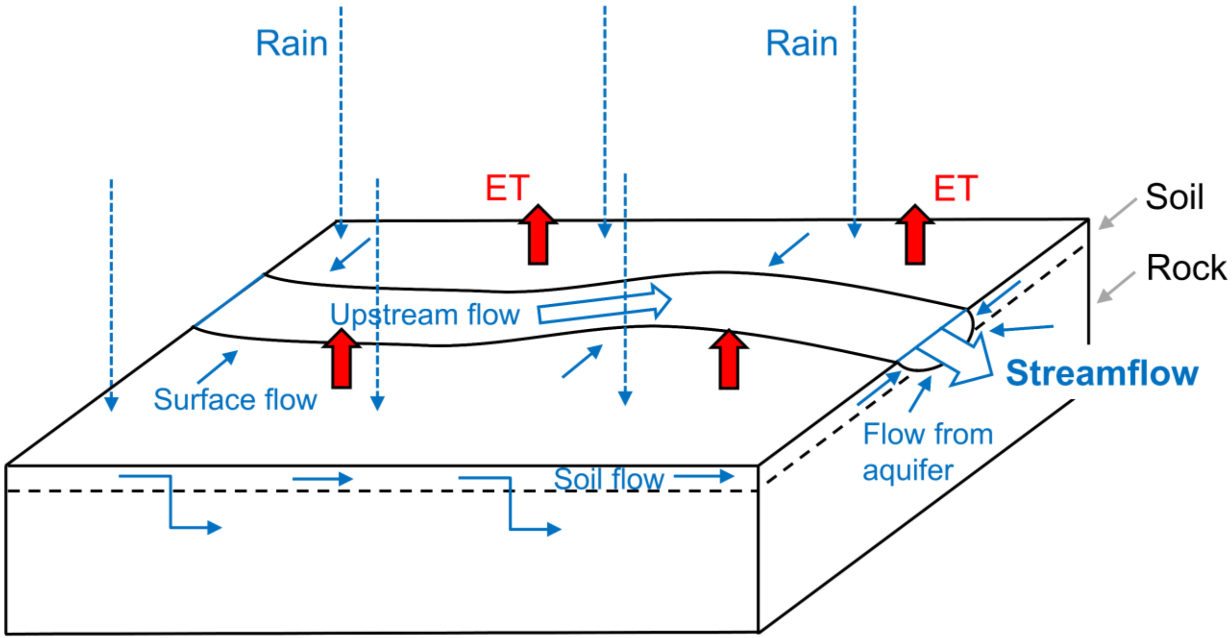
Overall concept

Streamflow is fed by: Surface flow
Flow from soils
Flow from aquifers (rocks)
Upstream flow

Increasing attenuation of precipitation variability (> increased serial correlation, higher $\rho 1$)

Increasing BFI

Longer rivers > more moving average component



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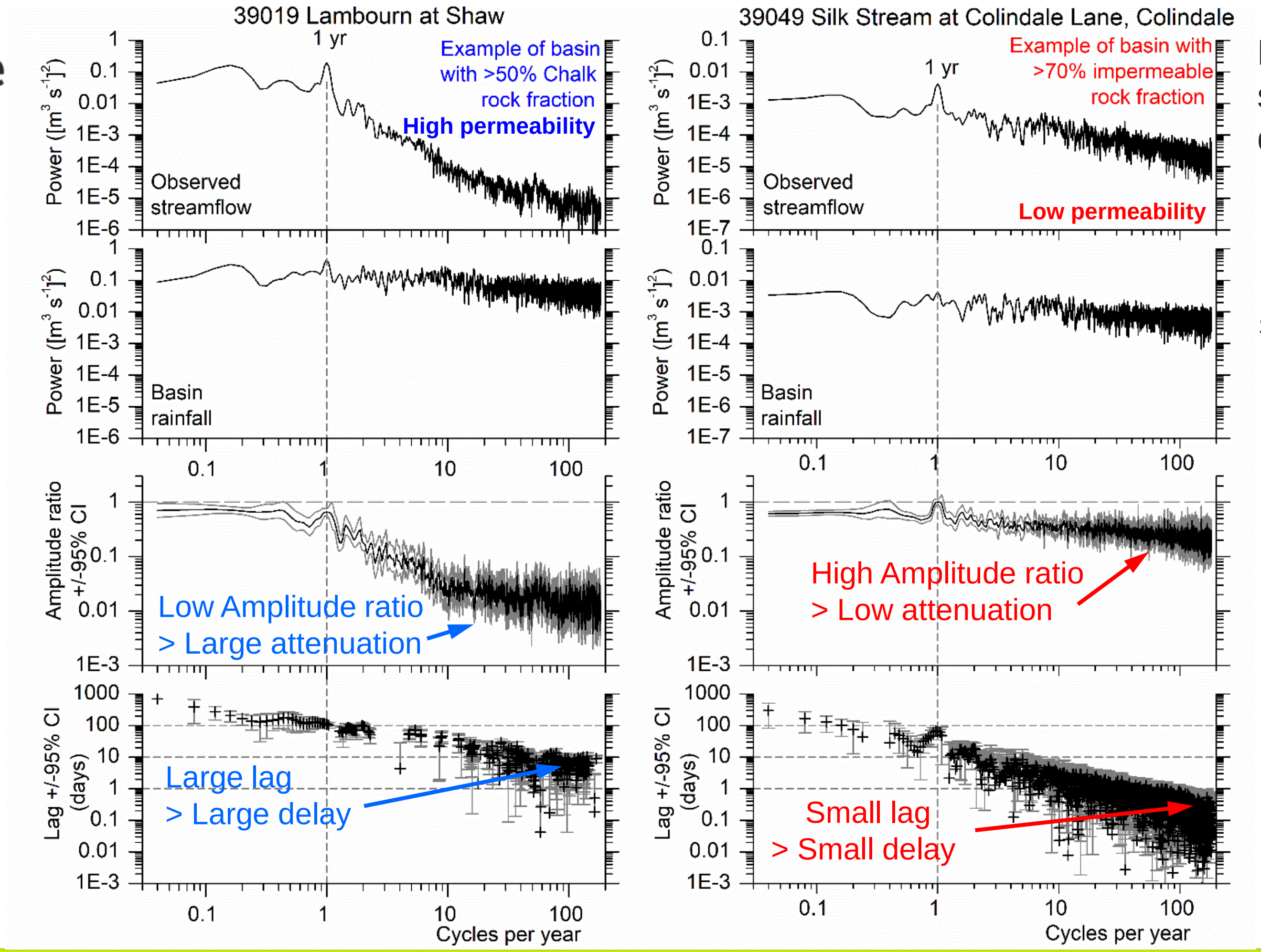
Cross spectral methods of Weedon et al. (2015) *JHM*

‘Transfer Function’ Approach



Power spectra of discharge

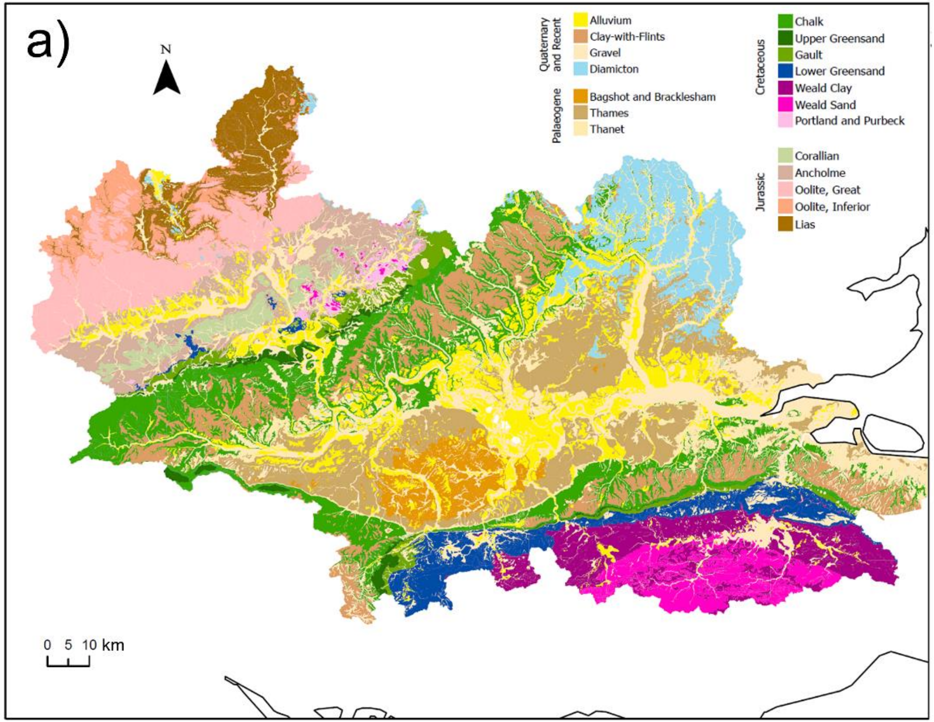
Power spectra of basin rainfall

Amplitude ratio spectra

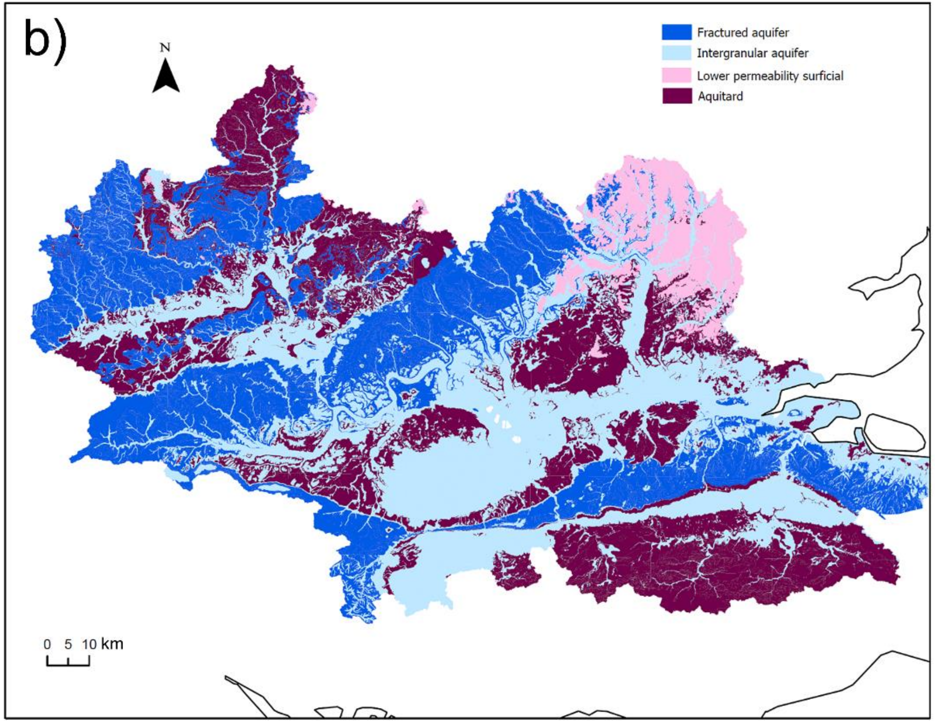
Phase difference spectra

Thames Basin

Geology



Permeability classes



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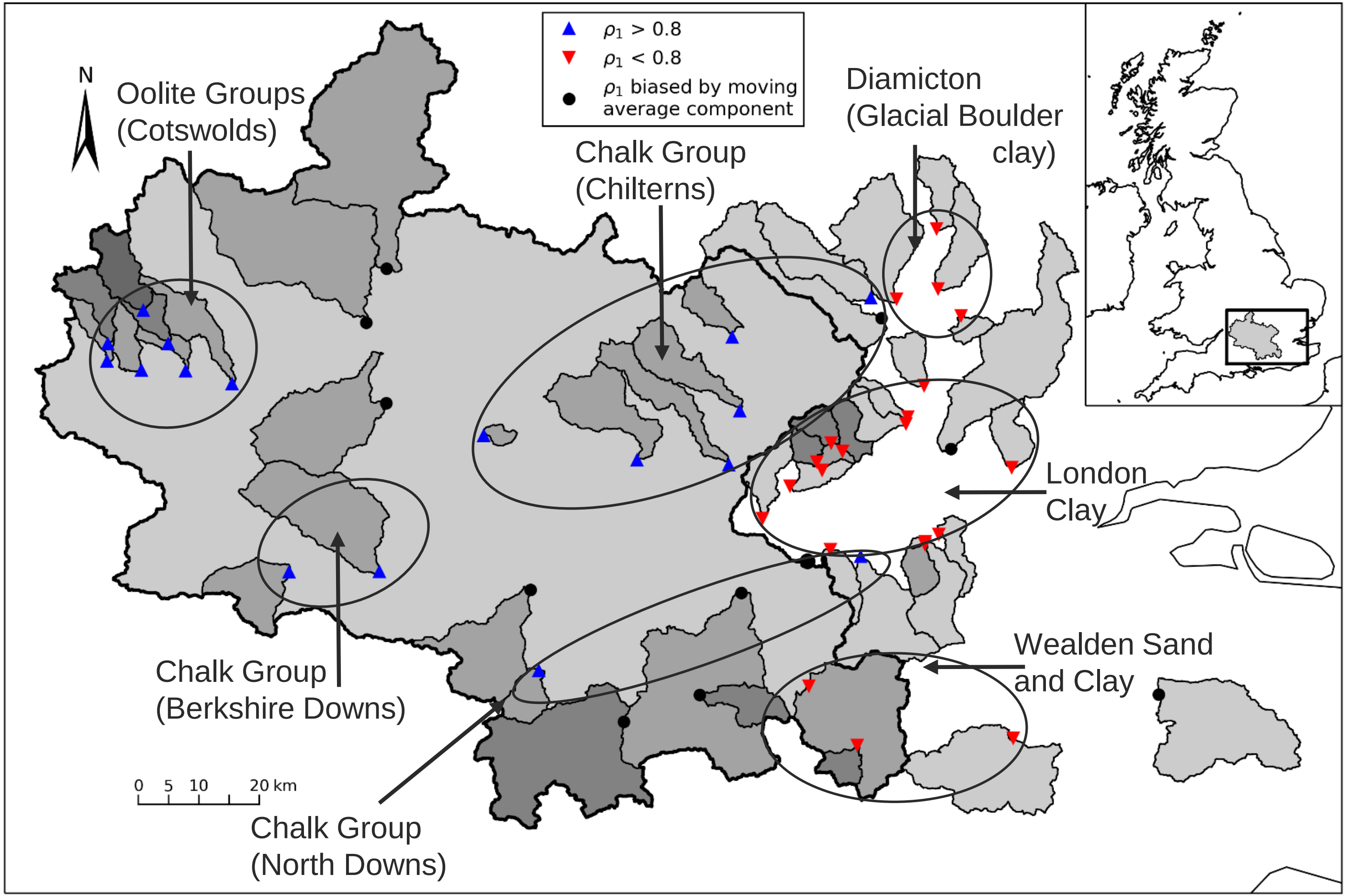
Black dots and triangles indicate NFRA gauge stations

High versus low ρ1 is dictated by the distribution of rock formations (excluding sub-catchments with a moving average component).



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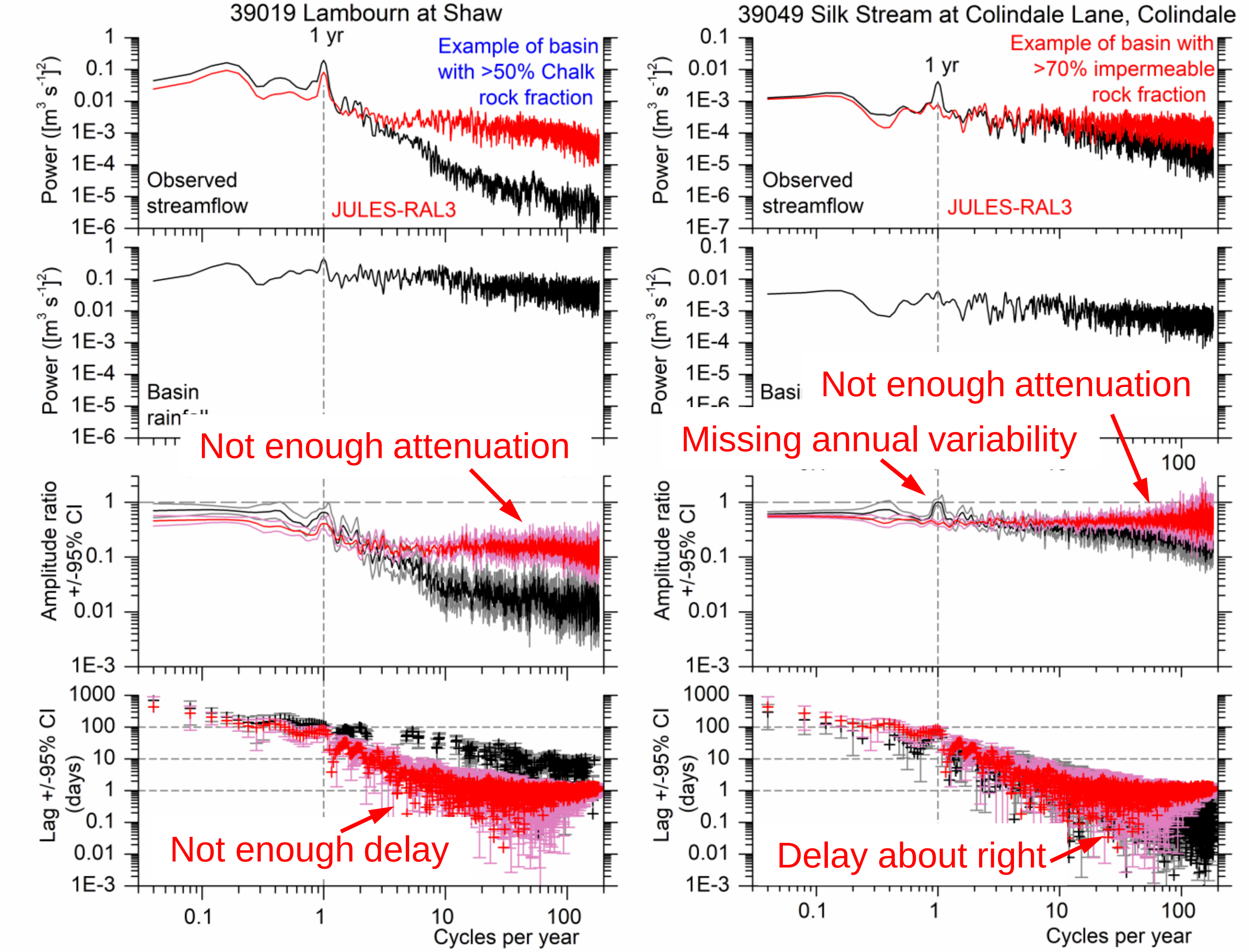
Observations

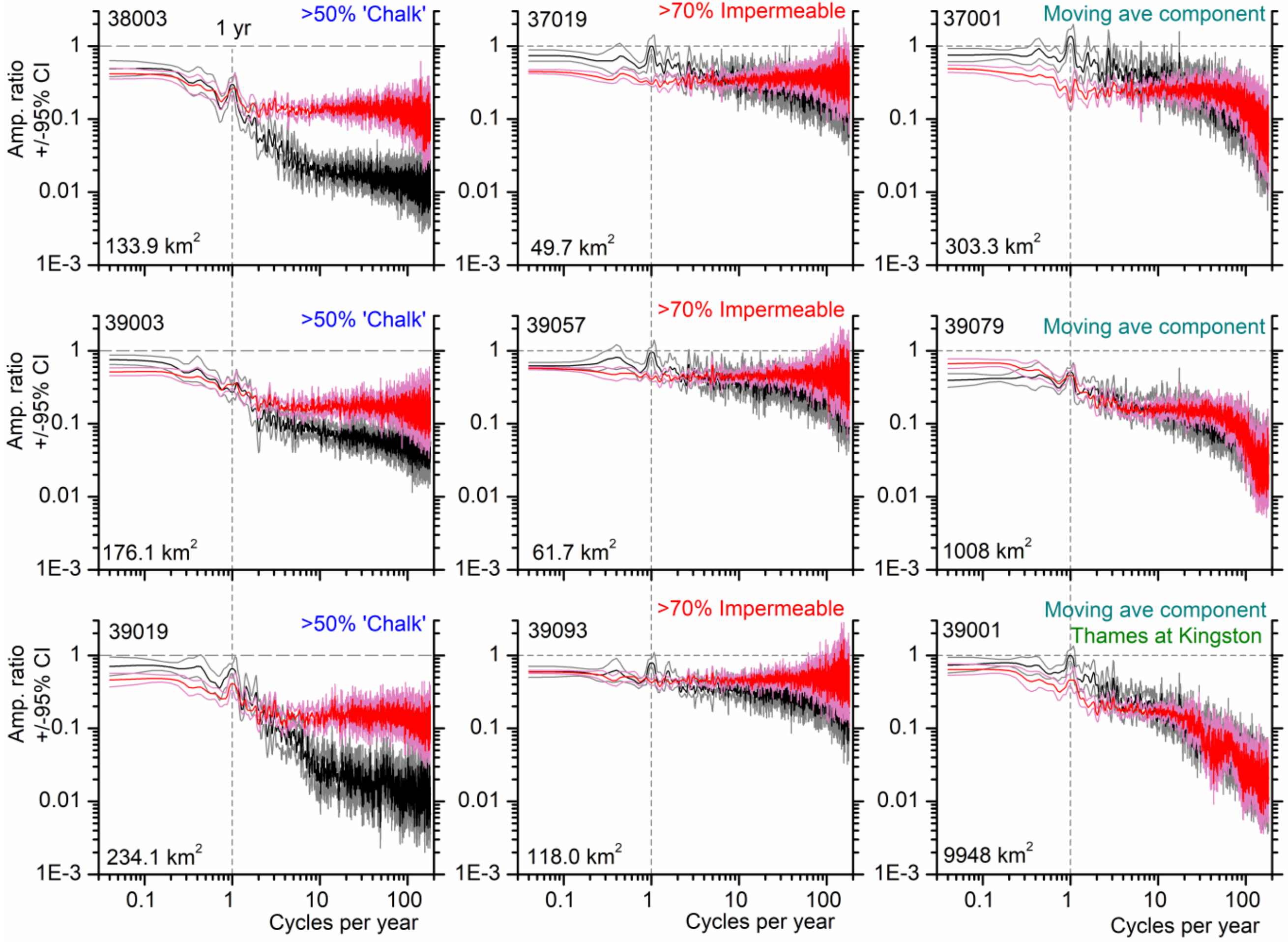
JULES RAL3



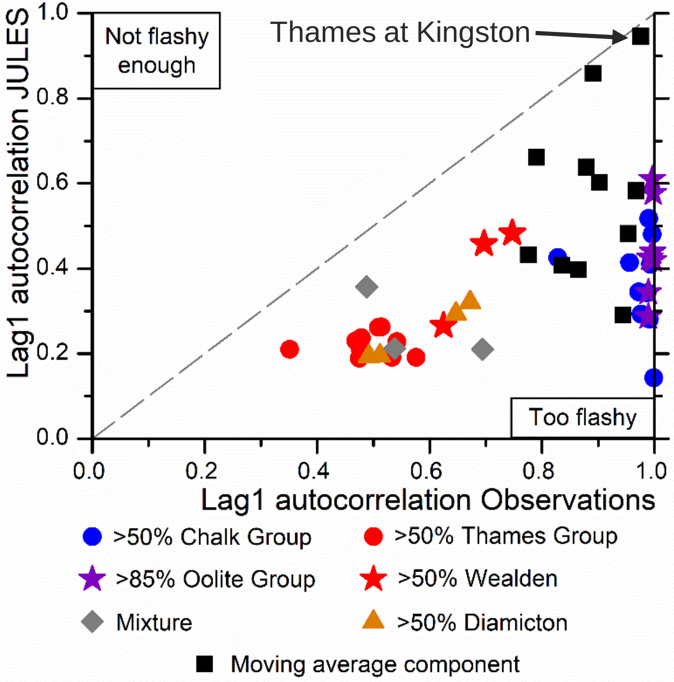
Observations

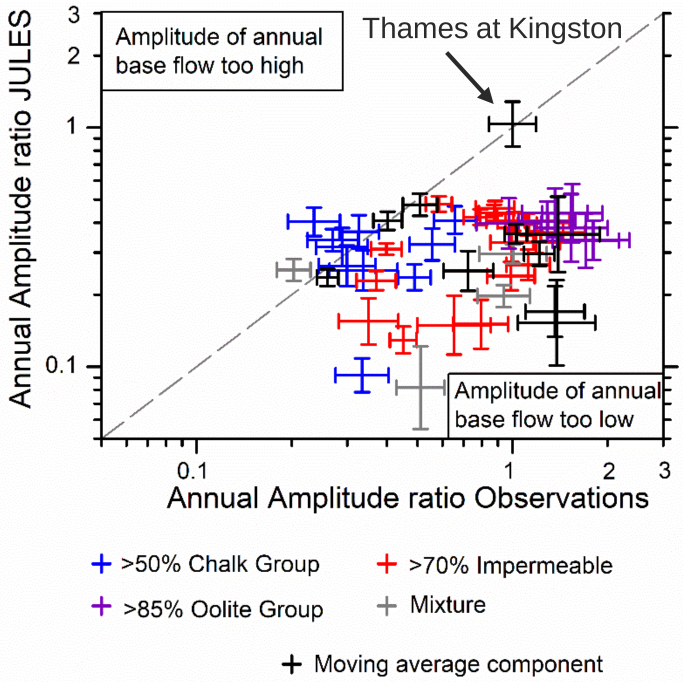
JULES RAL3

Larger catchments



Summary of spectral metrics





Assessment of JULES-RAL3:

Too flashy ($\rho 1JULES < \rho 1Obs$)

Often not enough base flow variability (Annual AR often < Obs)

In sub-catchments over chalk the delay is too small at all Frequencies (Lag-JULES shorter than Lag-Obs)

} Too little infiltration ➡ Sub-surface permeability Is too low

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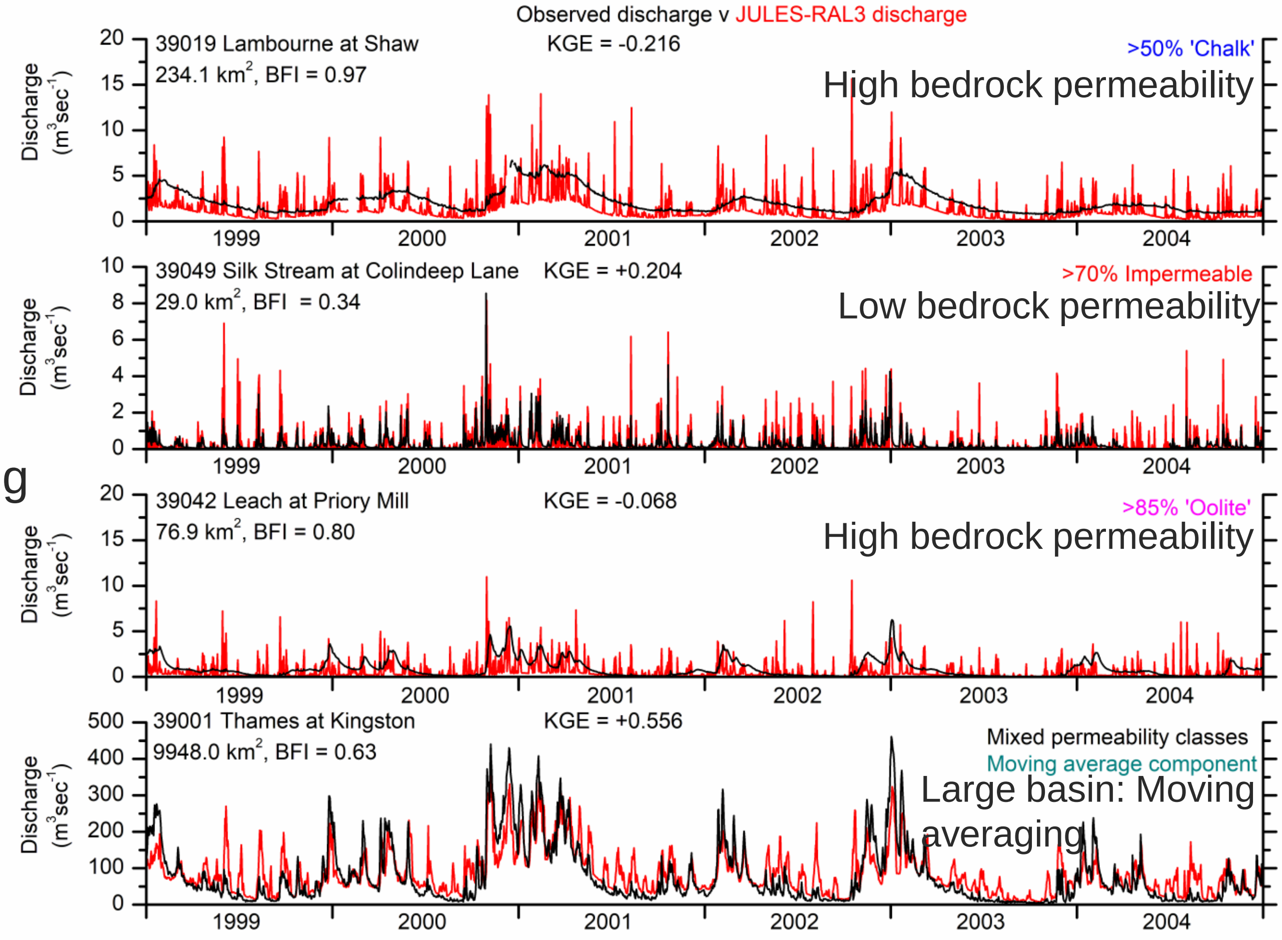
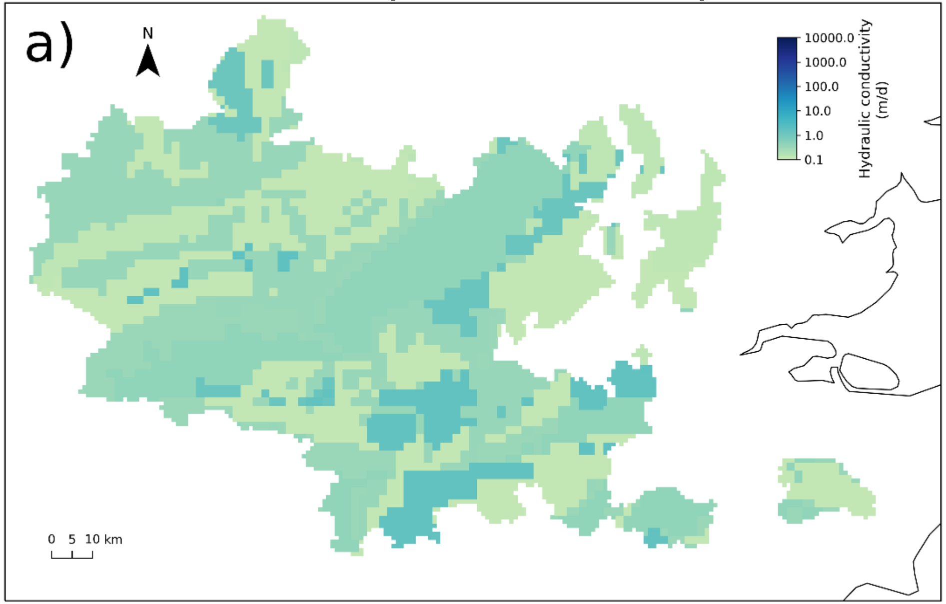
Discharge variability is linked to bedrock permeability, but in large basins (>300 km²) moving averaging dominates

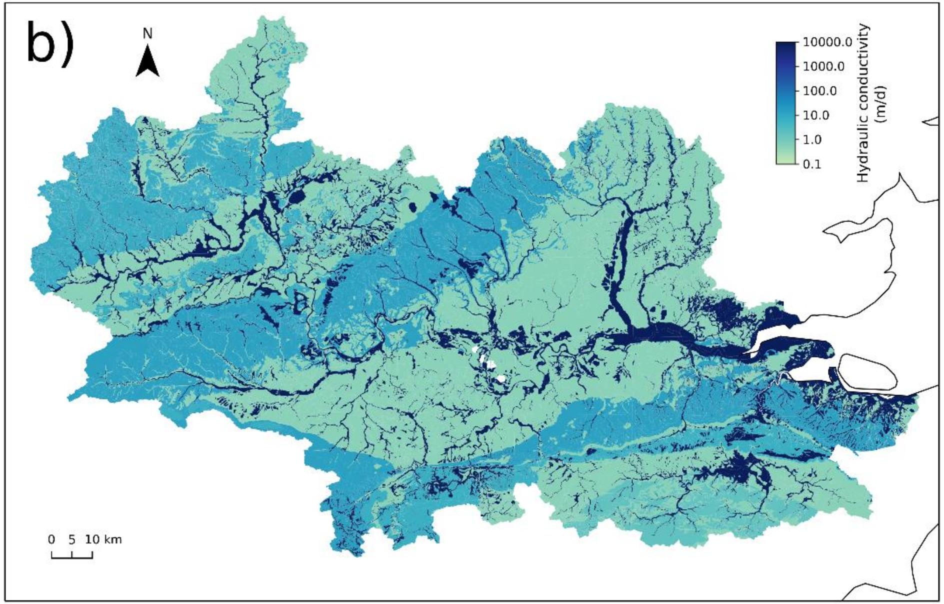


Saturated Hydraulic conductivity

Soils (JULES *satcon*)



Bedrock and alluvium



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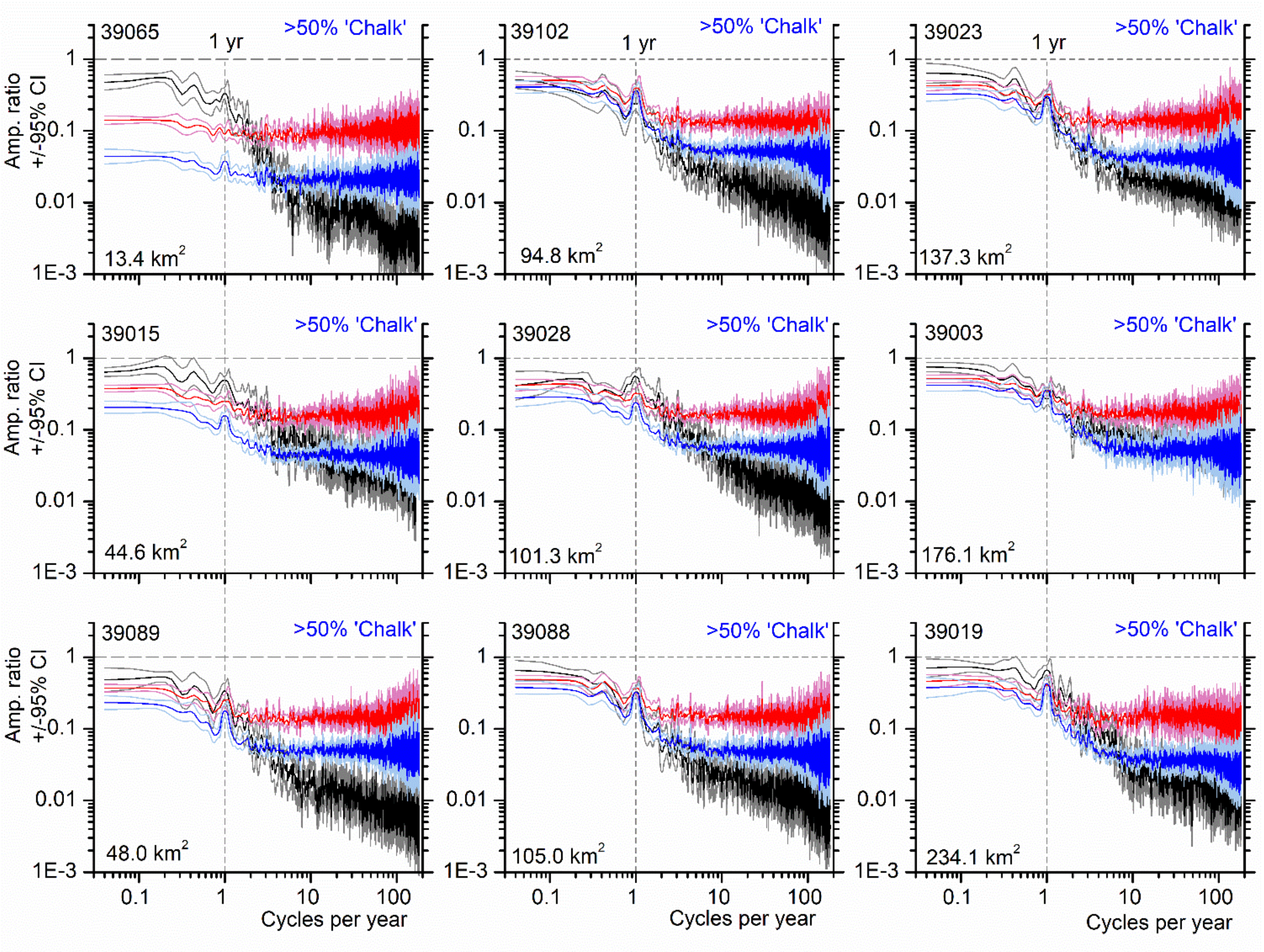
JULES is often run with 3 m of soils, but e.g. over Chalk the soil is often much thinner and/or macropores connect the surface to the bedrock

100% Sand experiment:
Soil parameters revised using ‘100% sand’ for Chalk-dominated catchments

— **Observations**

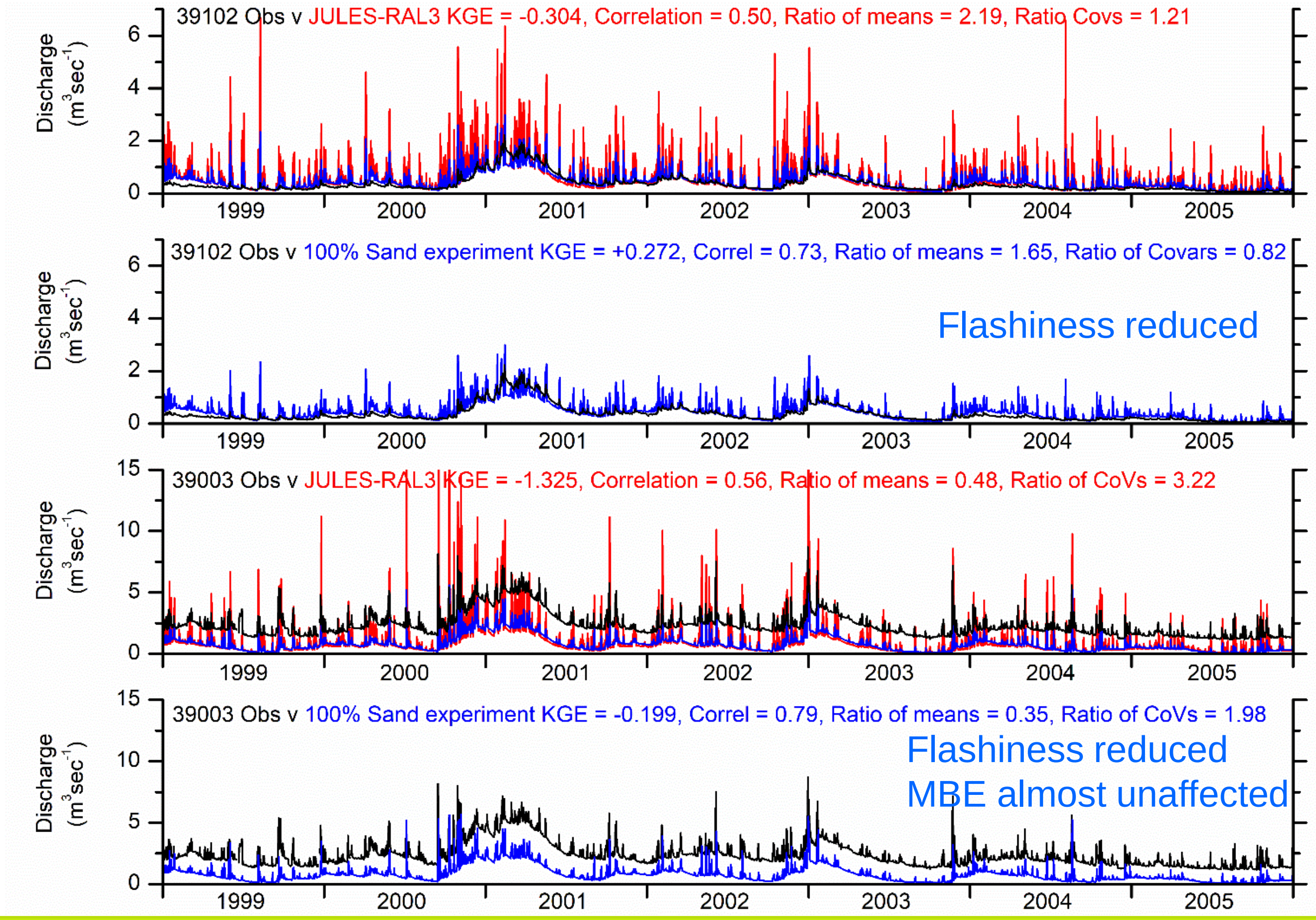
— **JULES-RAL3**

— **100% Sand JULES-RAL3**



100% sand experiment: Example discharge time series

Increased *satcon* using ‘100% sand’ soil parameters improves discharge variability in Chalk-dominated catchments



Conclusions for the Thames Basin

1) **JULES performance (modelled v observed discharge) in smaller catchments depends on the geology**. In smaller catchments the lag1 autocorrelation (serial correlation) is generally too low (BFI too low). Performance is worst where there is high permeability bedrock (high hydraulic conductivity). Performance is ok in larger catchments with moving averaging (due to routing) though there is often too much flashiness.

2) In JULES hydraulic conductivity is currently determined solely by *satcon* in soils. Experimentally increasing *satcon* (e.g. 100% sand experiment) consistent with soil pedotransfer functions leads to improved discharge variability in chalk-dominated catchments. This has little effect on mean bias error (linked to evapotranspiration). However, a far higher range of satcon will be required to match bedrock characteristics.

3) Potentially future modelling of groundwater in JULES will also improve discharge variability, but when modelling soils as 3 m thick *satcon* also needs attention/revision.

4) Paper submitted August 2022 to *Journal of Hydrology*.