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Effect of extreme rainfall characteristics within differing monsoon synoptic systems on flood response in headwaters

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Prof Michael Bonell
7 Nov 1943 – 11 July 2014

long held view

Rainfall characteristics associated with particular synoptic types strongly affect runoff behaviour

e.g., Bonell M, Gilmour D A & Cassells DS (1986) *The storm runoff response to various rainfall systems on the wet tropical coast of northeast Queensland*. Working paper of East-West Environment and Policy Institute, Honolulu

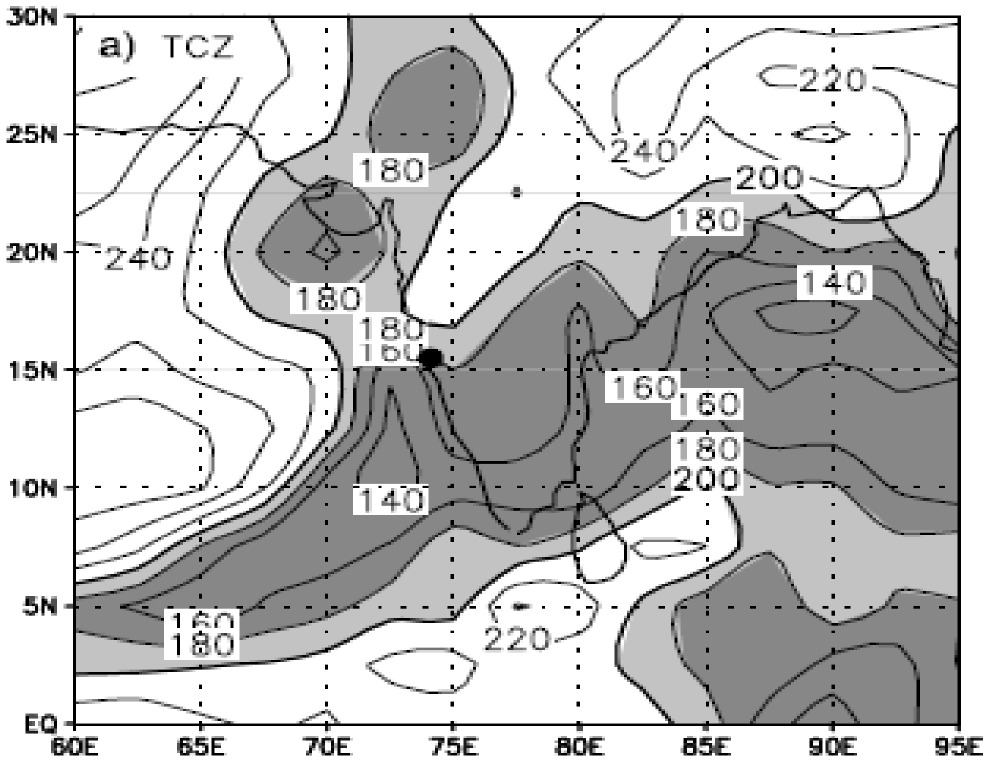
Rationale

Why important?

Floods during the Indian summer monsoon affect more than **30 million people**

Times of India, 20 June 2013

e.g., Uttarakhand, India, on June 18, 2013



11AUG1982, Max R.F 24.32 cm (Valpoi)

India good place to focus the research:

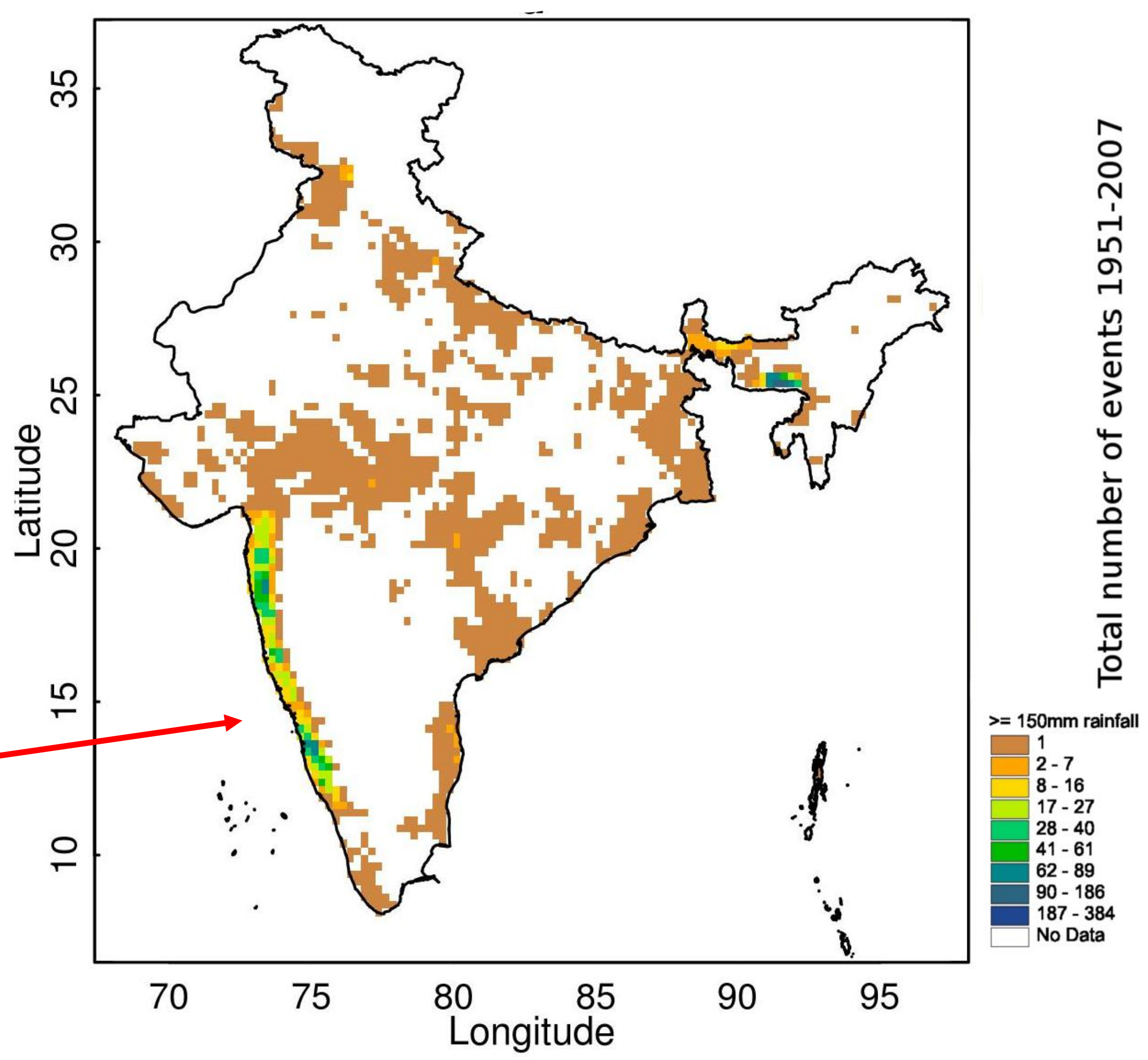
Range of synoptic conditions that generate extreme rainfalls hence floods

- 4 types in SW monsoon e.g., TCZ *(left)*
- Local convective activity
- Tropical cyclones

We focus on Western Ghats region of India

As it experiences the highest rainfall intensities in India

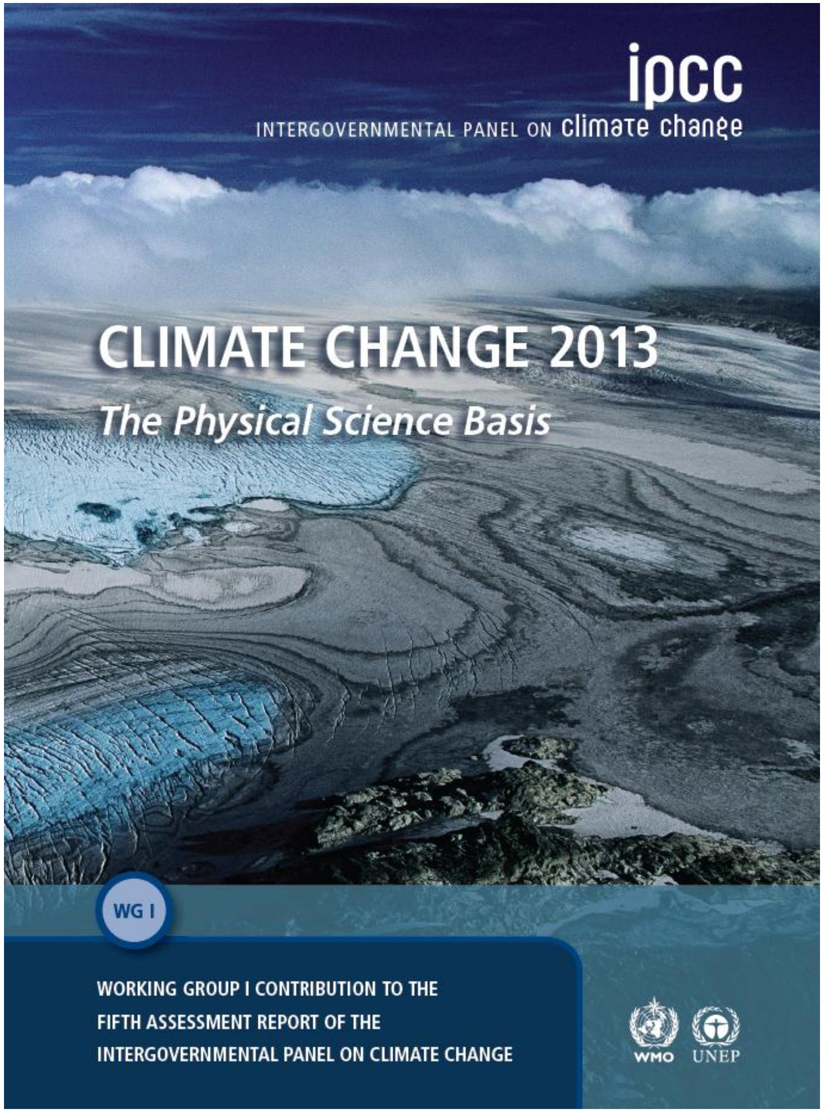
e.g., incidences of daily rainfall > 150 mm/d



There is also concern…

"…globally, it is likely that the area encompassed by monsoon systems will increase over the 21st century. While monsoon winds are likely to weaken, **monsoon precipitation is likely to intensify** due to the increase in atmospheric moisture…"

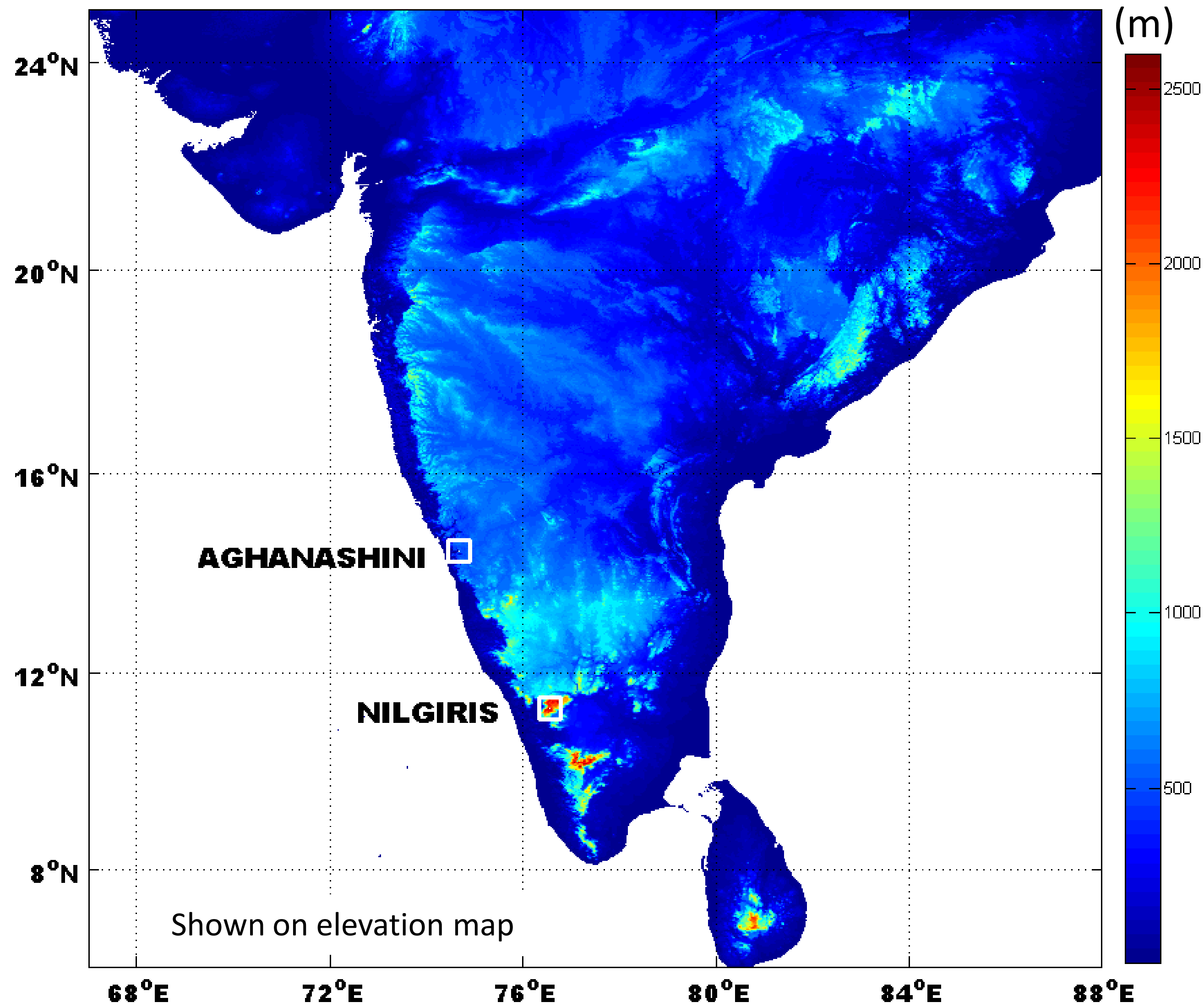
IPCC (2013) Fifth Assessment Report, p23



Project centred on **two groups of replicated headwater basins in Western Ghats**

e.g., Nilgiris in area with one of highest elevations outside of Himalayas

Highest raingauge on 2629 m Kolaribetta mountain



Floods initiated in headwater basins

As typically account for 70 – 80 % of worldwide river networks

e.g., Gomi *et al.* (2002) *BioScience* 52: 905–916

i.e., most flood-water entering rivers does so in low-order (headwater) streams

Rationale

Hypothesis

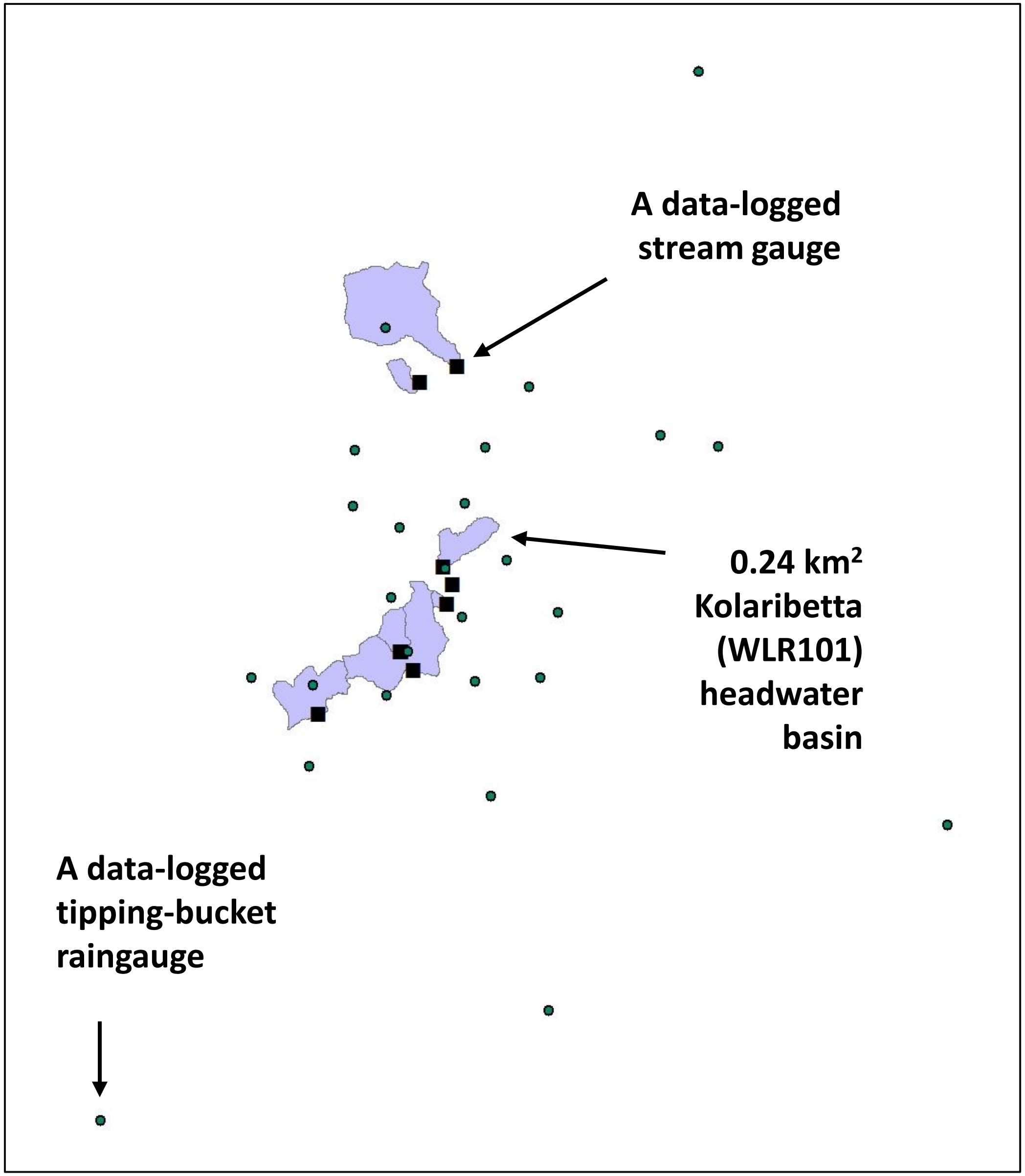
Storm-type affects rainfall-runoff response

Observe & model all streamflows but focus on large flood events

Instrumentation, monitoring & calibration of rainfall & streamflow in headwaters

e.g.,

8x Nilgiris headwater basins & raingauge network in Western Ghats



Tough raingauge installations to give sub-hourly rainfall

e.g., TBGR1 in Saimane gauging station at Aghanashini

Similarly robust stream gauging stations to give 15-minute resolution streamflow

e.g., Hosagadde weir at Aghanashini

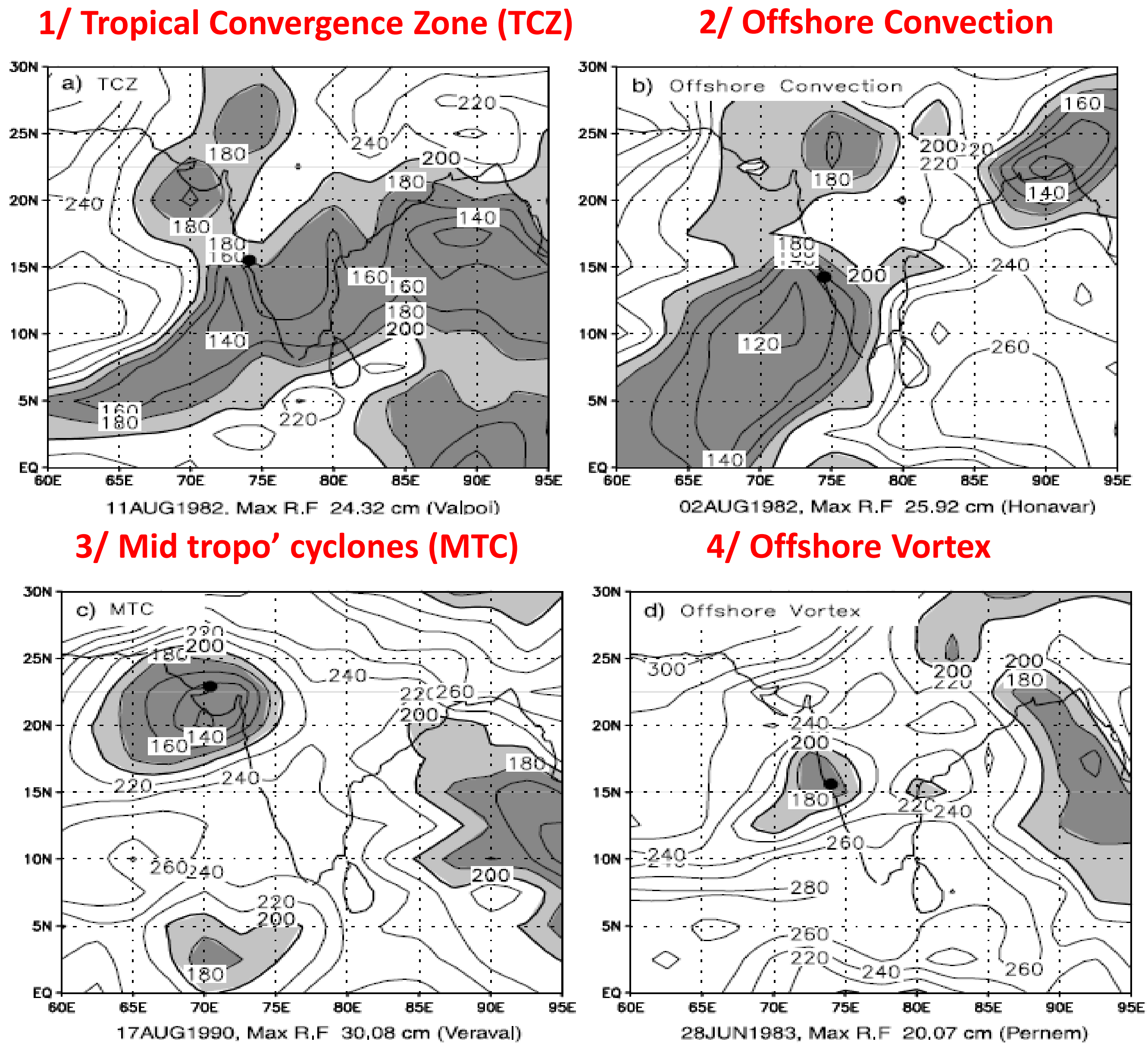
Each station being calibrated

e.g., current metering at lowflow
(high flow dilution gauging also used)

Classification of storm-types

rain-producing, synoptic-scale systems over Western Ghats

e.g., event typing during SW monsoon



Francis & Gadgil (2006) *Meteorol Atmos Phys* 94: 27–42

Classification of storm types

e.g.,

satellite outgoing long-wave radiation (OLR) at 0.25 degree & half hourly resolutions

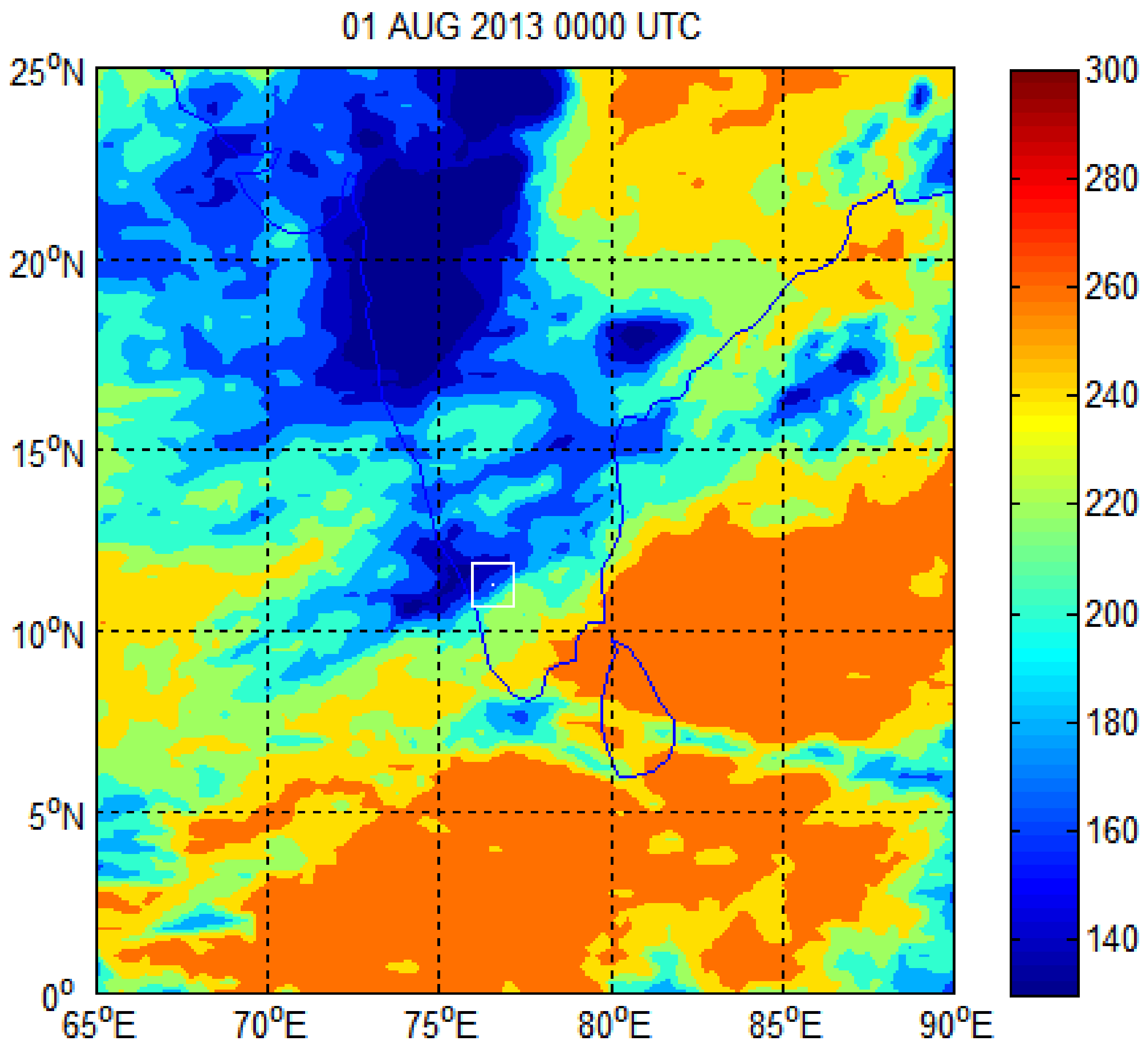
e.g.,

Kalpana-1 OLR

0.25° & ½ hrly resolution animation for one event affecting Nilgiris basins

Event 5

Type: offshore convection



Separation of periods of different storm-types

e.g.,

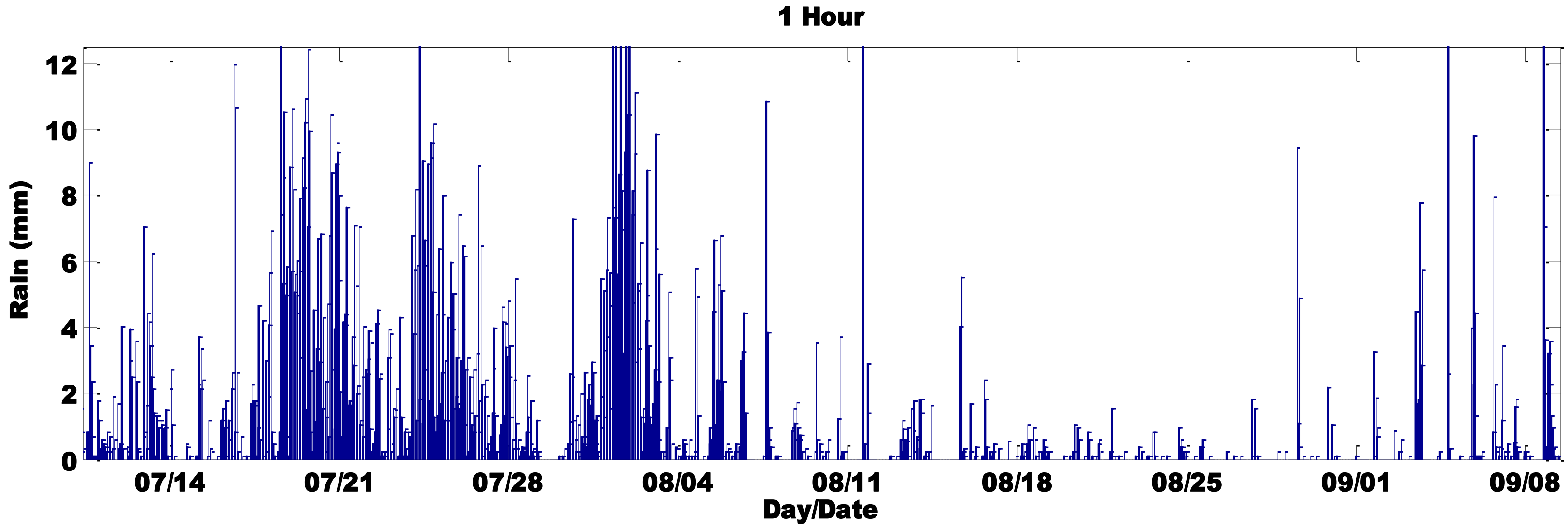
potentially first study to use *Time-Frequency Plots from Wavelet Analysis* to identify monsoon breakpoints

Using WAVELET.M in Matlab™ based on

Torrence and Compo (1998) A practical guide to wavelet analysis. *Bulletin of the American Meteorological Society* 79: 61-78

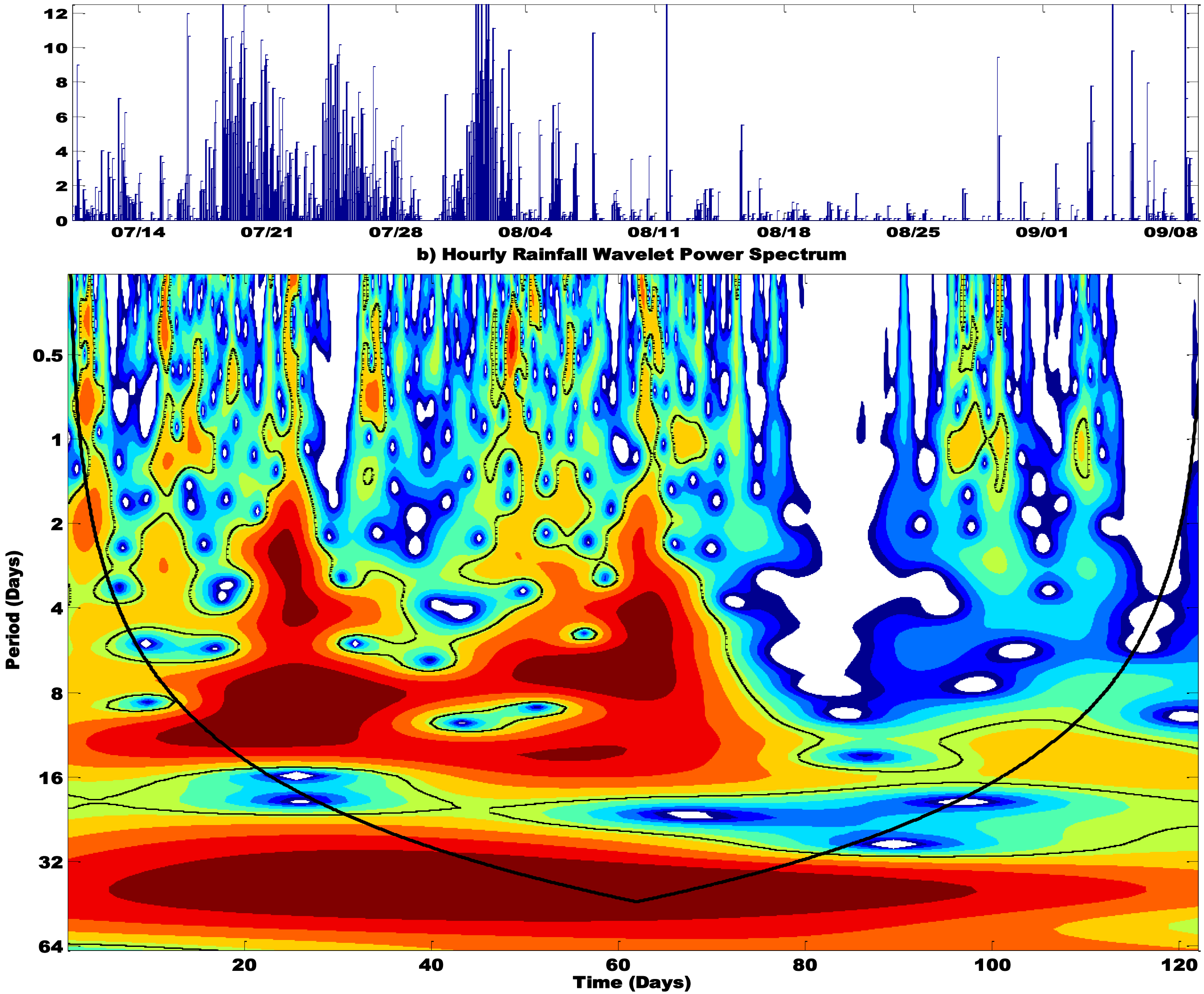
e.g., applied to rainfall from the Nilgiris basin (2013 monsoon)

Kolaribetta rain gauge (TBRG102) : 2013 monsoon hourly rainfall time series



Separation of periods of different storm types

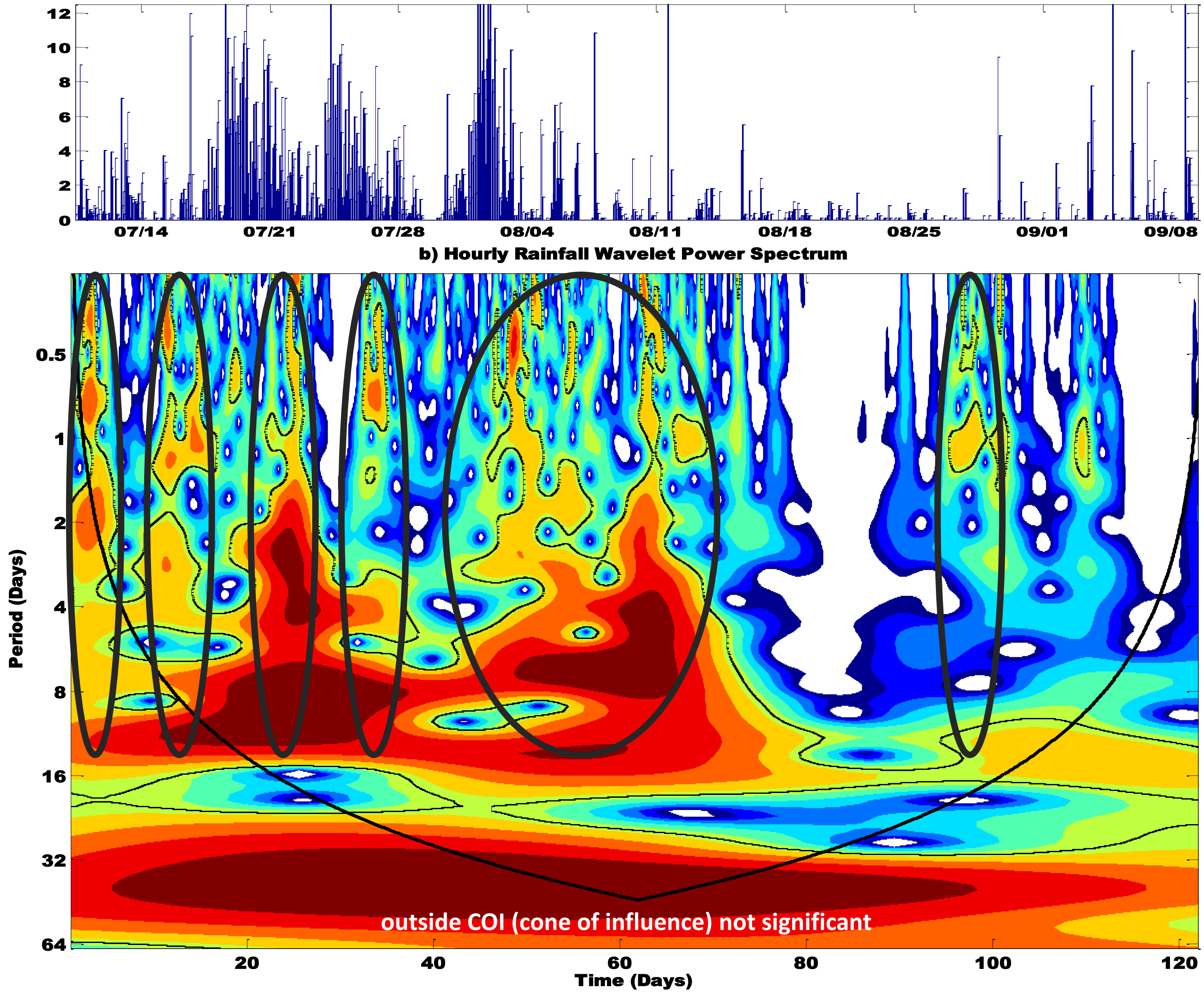
Scalogram produced by Morlet wavelet analysis



Separation of periods of different storm types

Periods with peaks in coefficients that are significantly higher (95% level)

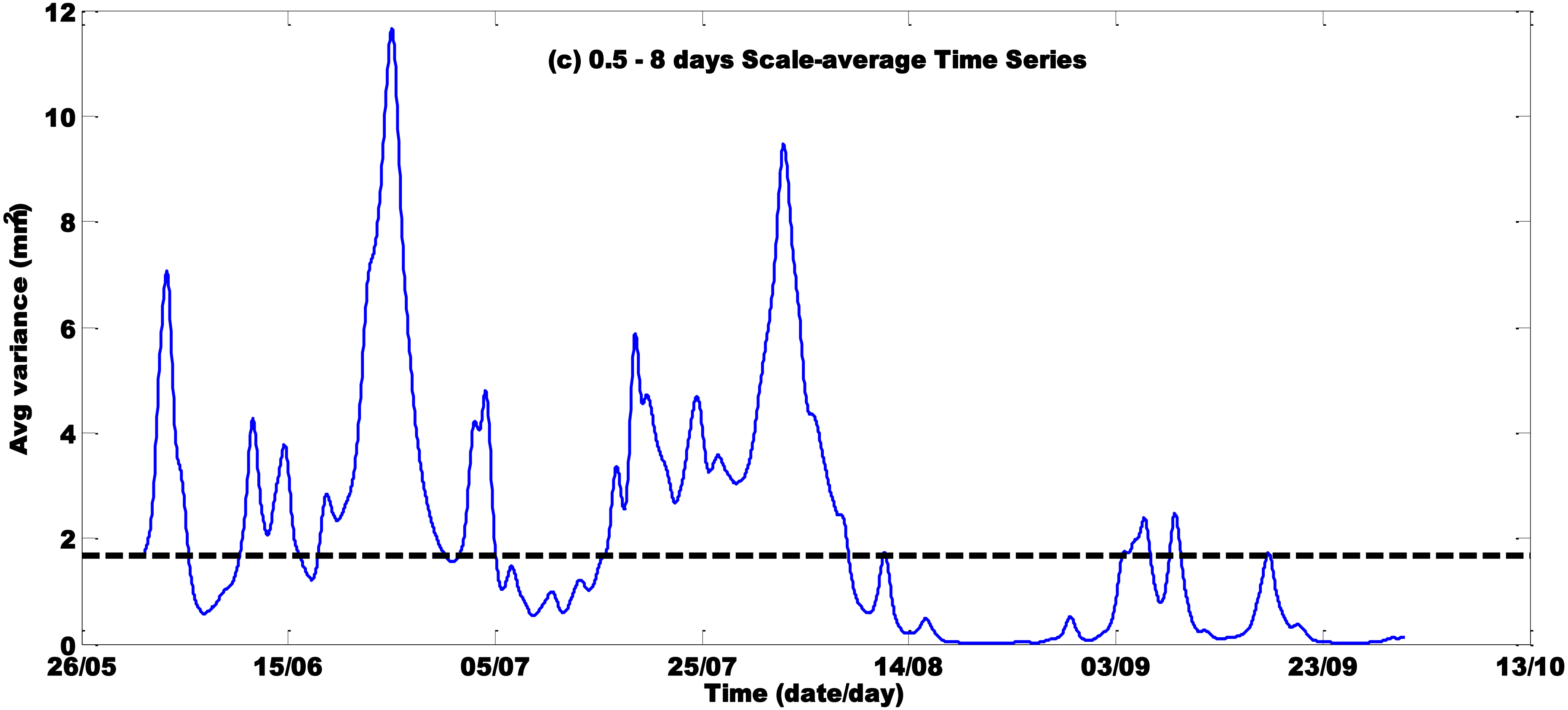
then averaging coefficients from 0.5 to 8 days



Separation of periods of different storm types

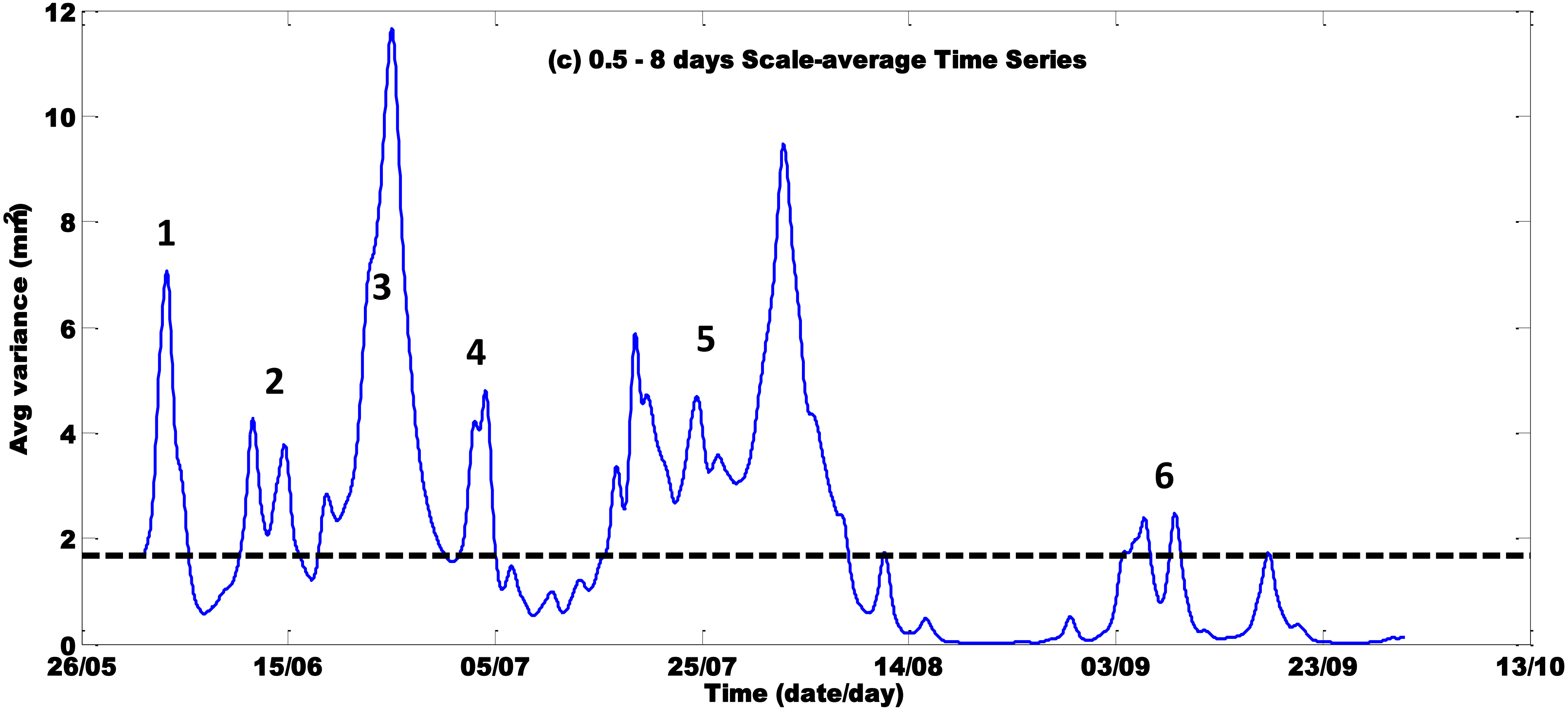
Mean modulus of wavelet coefficients for durations of **active periods 0.5 – 8 days**

Broken black line is 95% confidence level



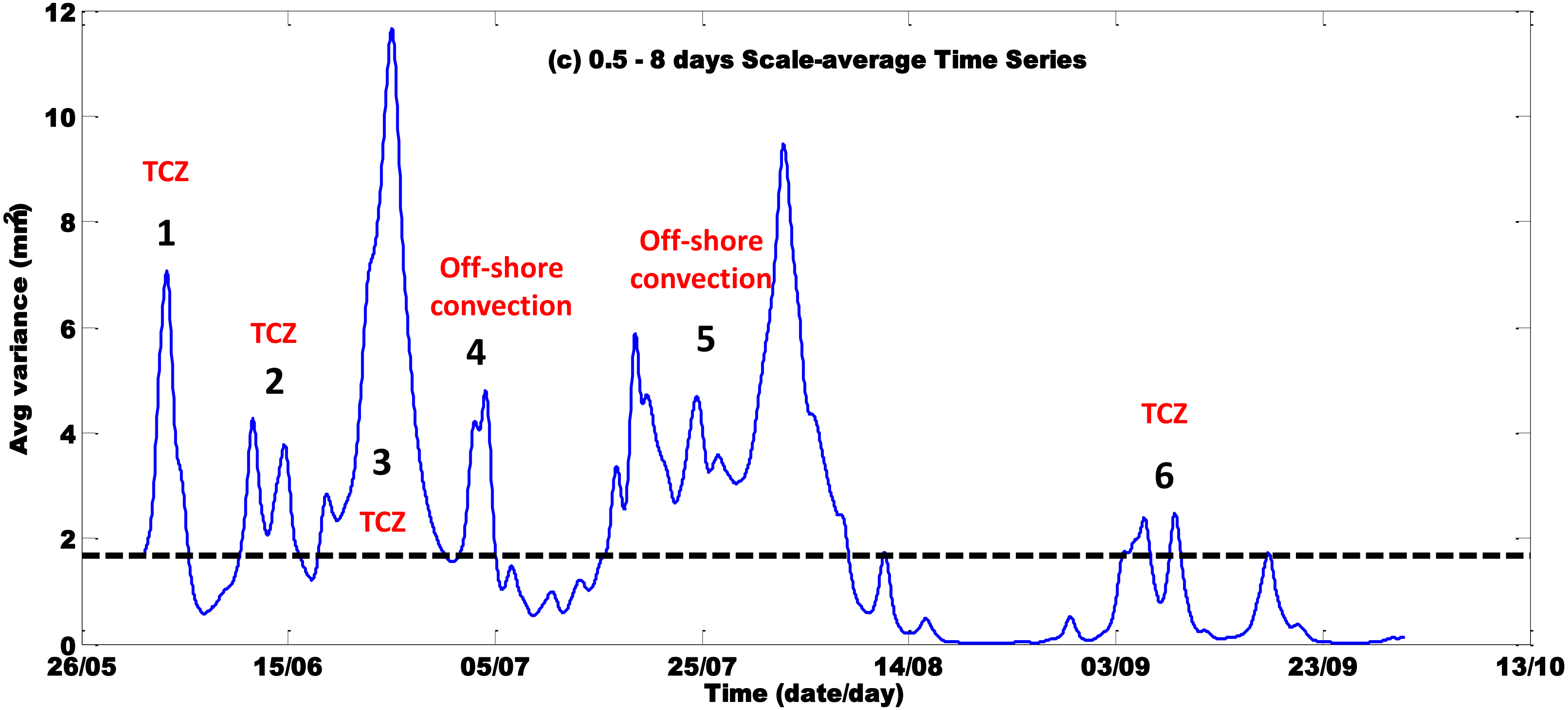
Separation of periods of different storm types

Six periods are identified for **storm or event typing** in this example from the 2013 monsoon in the Nilgiris area



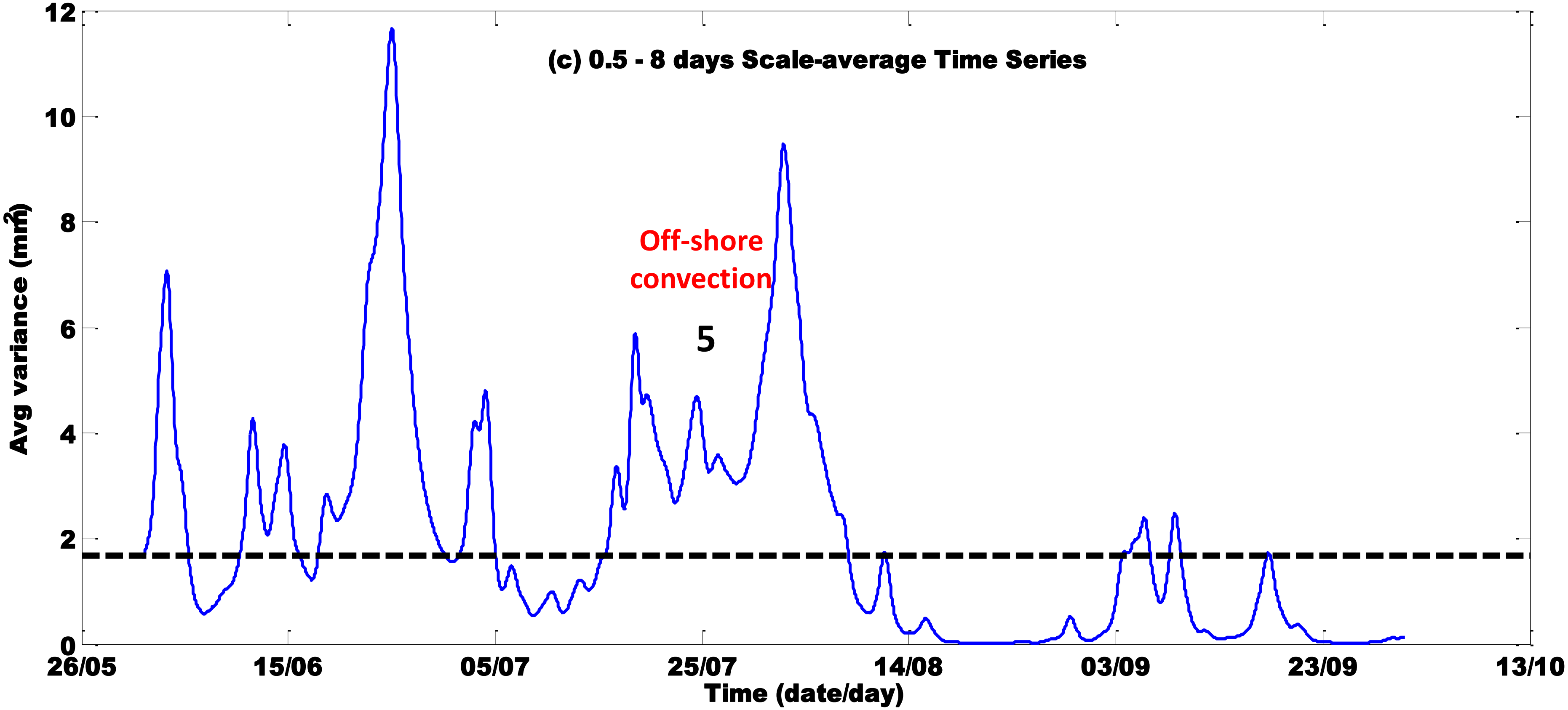
Separation of periods of different storm types

Using OLR maps **storm-type**
& **period duration** were defined



Separation of periods of different storm types

Select Event 5 (Offshore convection) to illustrate the rainfall-runoff modelling



Separation of periods of different storm types

Rainfall-Runoff modelling

Requirement

Characteristics of rainfall-runoff behaviour that have the least amount of uncertainty – to permit identification of differences between periods of different storm-types

Parsimonious approach
(few parameters but high simulation efficiency)

One such method developed at Lancaster

RIVC

Refined **I**nstrumental **V**ariable **C**ontinuous-time Box-Jenkins identification algorithm

Taylor, Pedregal, Young & Tych (2007) *Environ. Model. Software* 22: 797–814

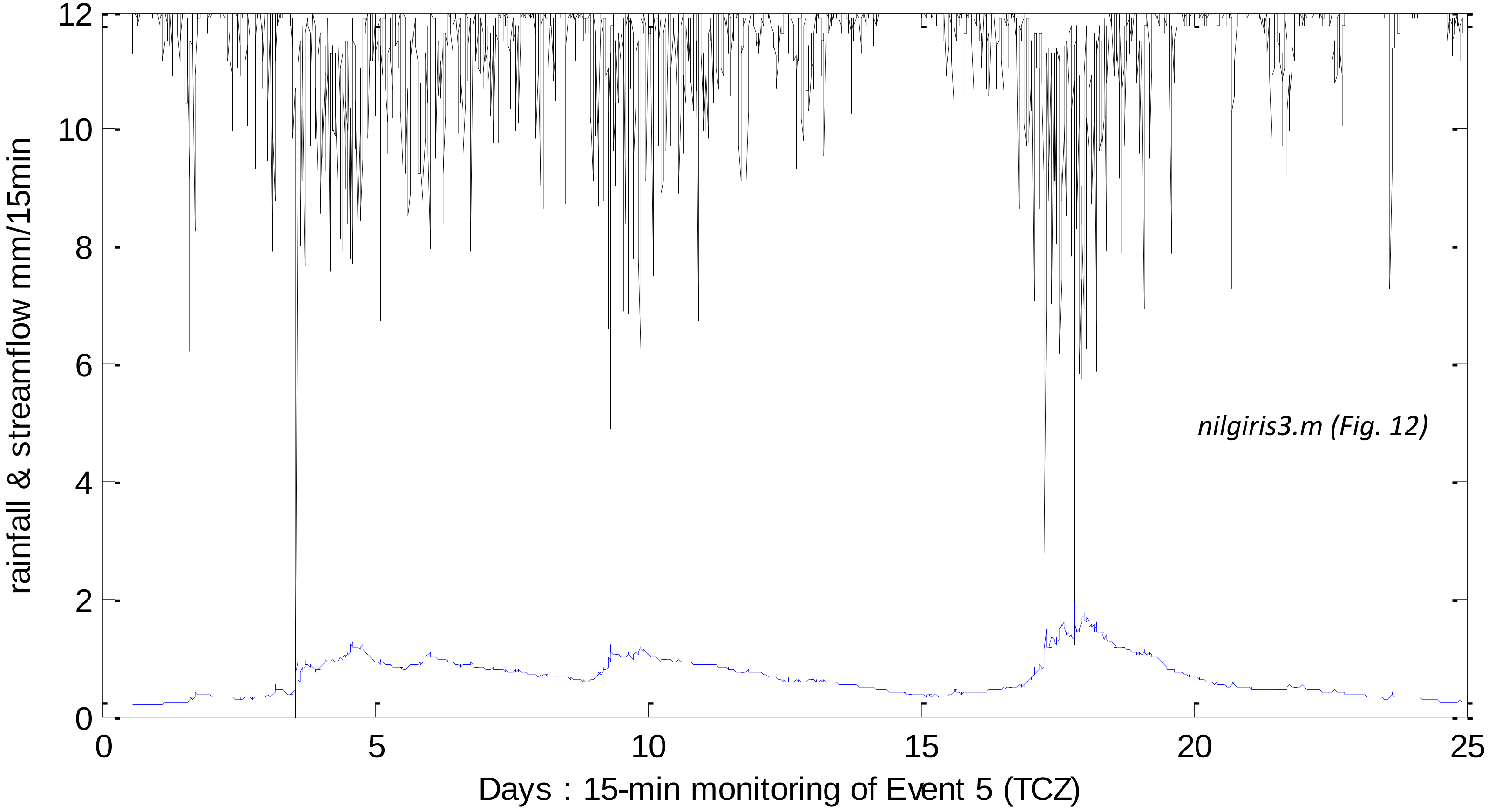
CAPTAIN TOOLBOX

LANCASTER UNIVERSITY

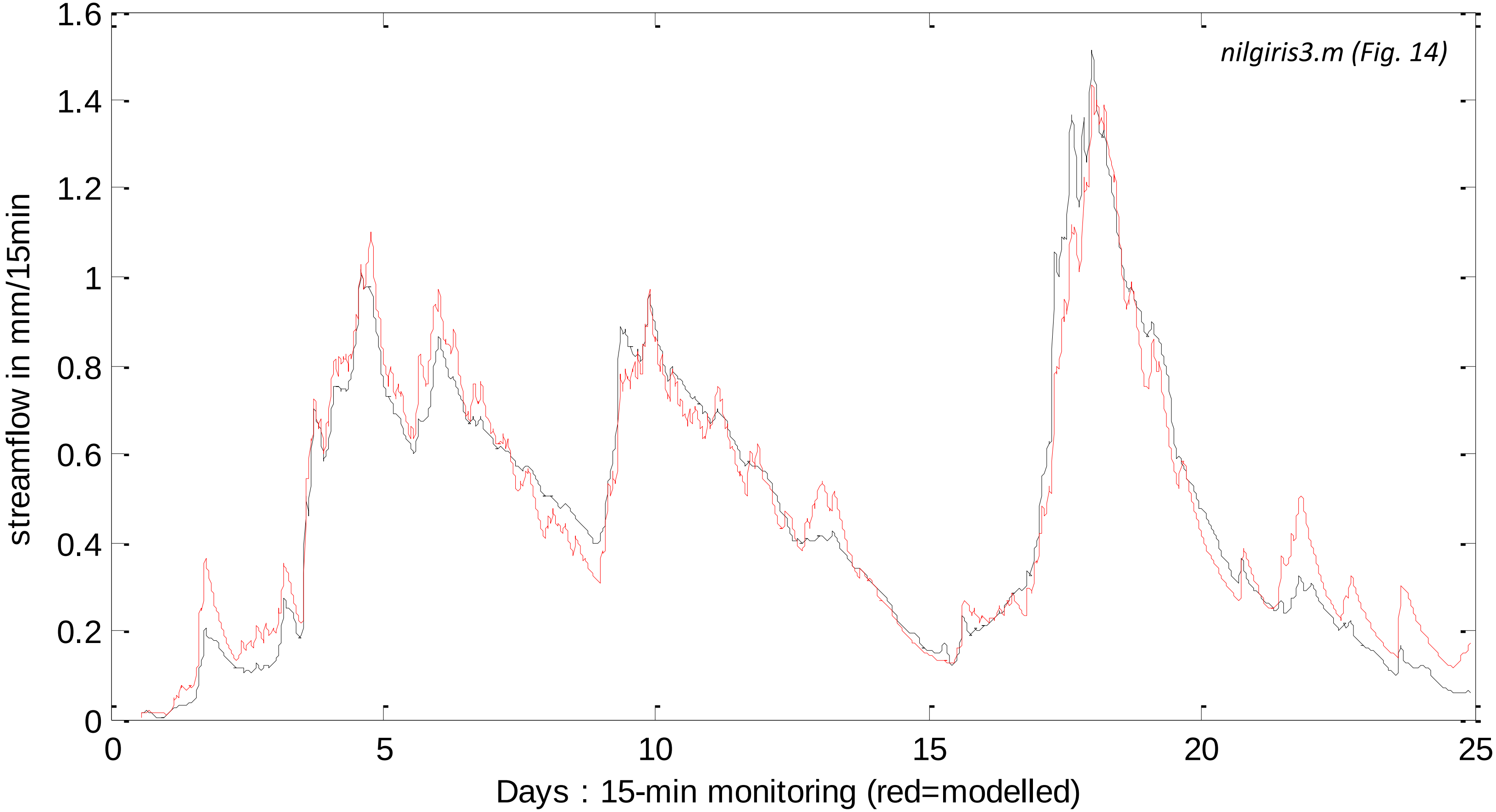
these models are parsimonious in part because they are <u>built directly from the information contained with the rainfall and runoff observations</u>

Illustration of model identification for rainfall to stream stage (stream discharge or runoff only just available)

e.g., for a 0.24 km^2 Kolaribetta basin (WLR101) & mean of two raingauges (r_{en})
for Synoptic Event 5 (Offshore convection-type)



e.g., for a 0.24 km^2 Kolaribetta basin (WLR101) over Event 5
a [2 2 0] model with $\boldsymbol{R_t^2}$ **= 0.95** is optimal



This model expressed as a continuous-time transfer function

$$q = \left(\frac{b_0 s + b_1}{s^2 + a_1 s + a_2}\right) e^{-s\tau} r_{en} \quad ; \quad s = \frac{d}{dt}$$

or in ordinary differential equation terms (ignoring initial conditions)

$$\frac{d^2 q(t)}{dt^2} + a_1 \frac{dq(t)}{dt} + a_2 q(t) = b_0 \frac{dr_{en}(t-\tau)}{dt} + b_1 r_{en}(t-\tau)$$

$$q = \left(\frac{b_0 s + b_1}{s^2 + a_1 s + a_2}\right) e^{-s\tau} r_{en} \quad ; \quad s = \frac{d}{dt}$$

with the terms for this period in Kolaribetta gives

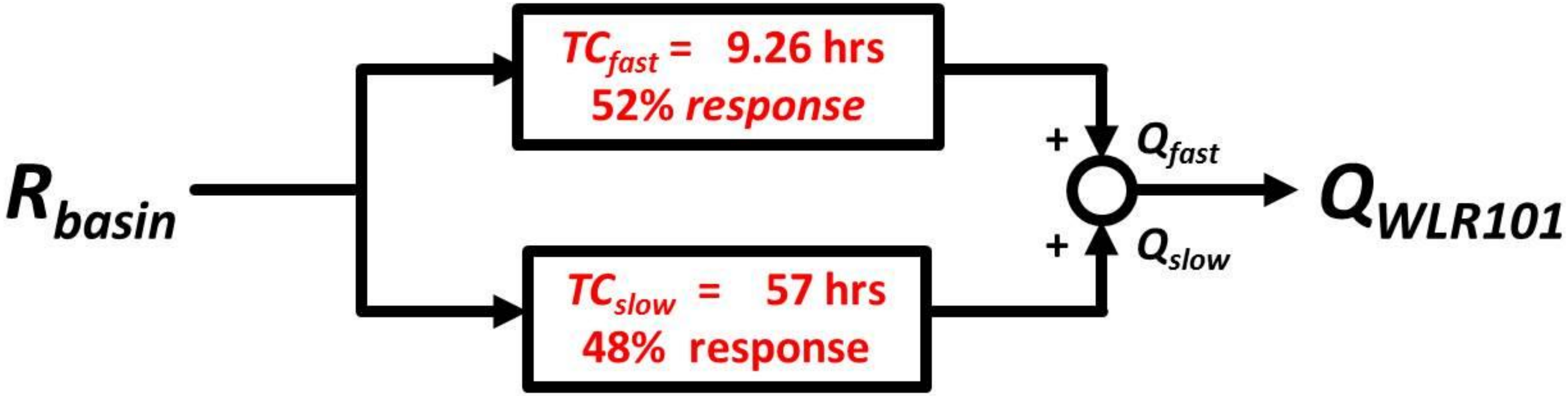
$$q(t) = \frac{0.01290s + 0.00009474}{s^2 + 0.0314s + 0.0001187} r_{en}$$

e.g., just 4 parameter values capture all aspects of streamflow dynamics (peaks, lower flows)

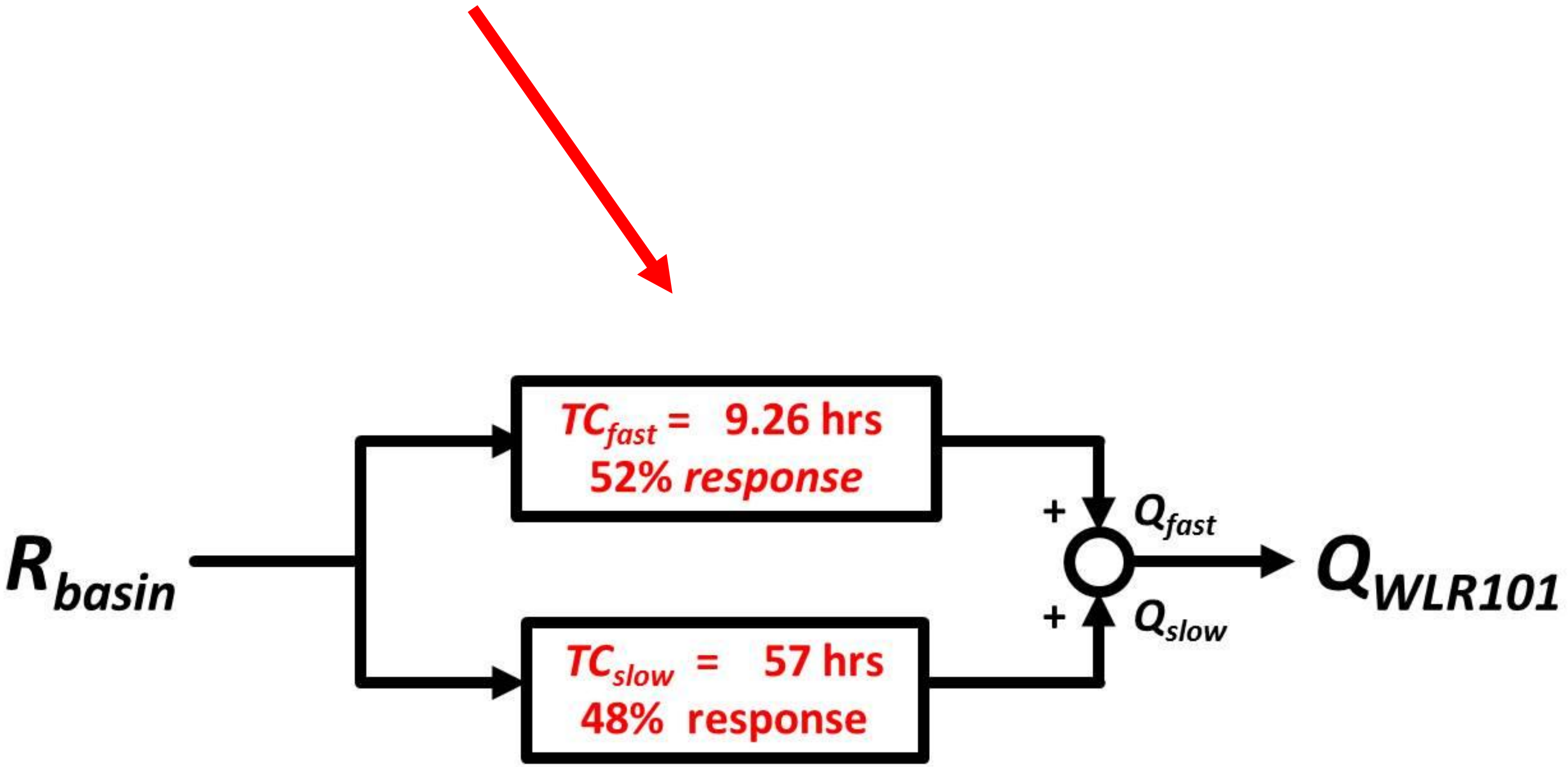
Decomposition of a 2nd-order rainfall-streamflow model into **two parallel first order pathways**

$$q = \frac{0.0112}{s + 0.0270} r_{en} + \frac{0.00168}{s + 0.00439} r_{en}$$

and expressed as a box diagram

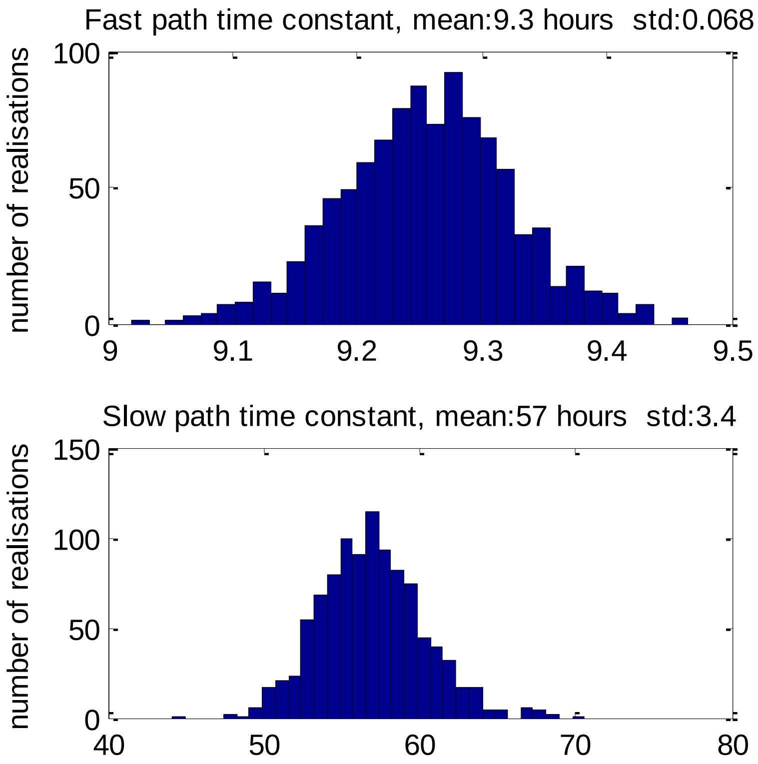


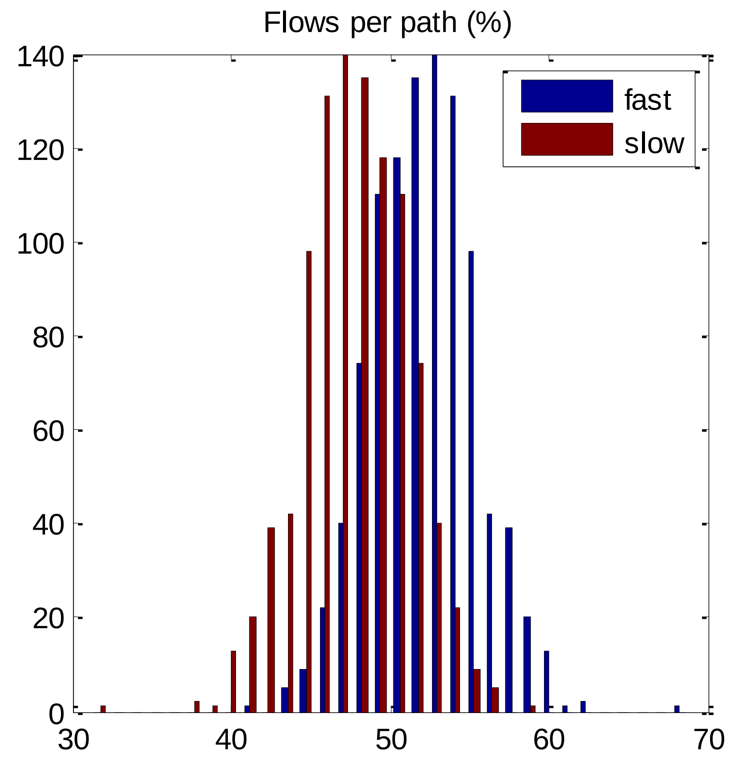
Primary interest in characteristics of
<u>fastest component generating floods</u>



Further RIVC advantage – **explicit uncertainty estimates**

e.g., apply to TC & proportion along fast path (1000 Monte Carlo realisations)





nilgiris3.m (Fig. 18 & 20)

…quantify if flood responses are significantly different between storms of different synoptic type

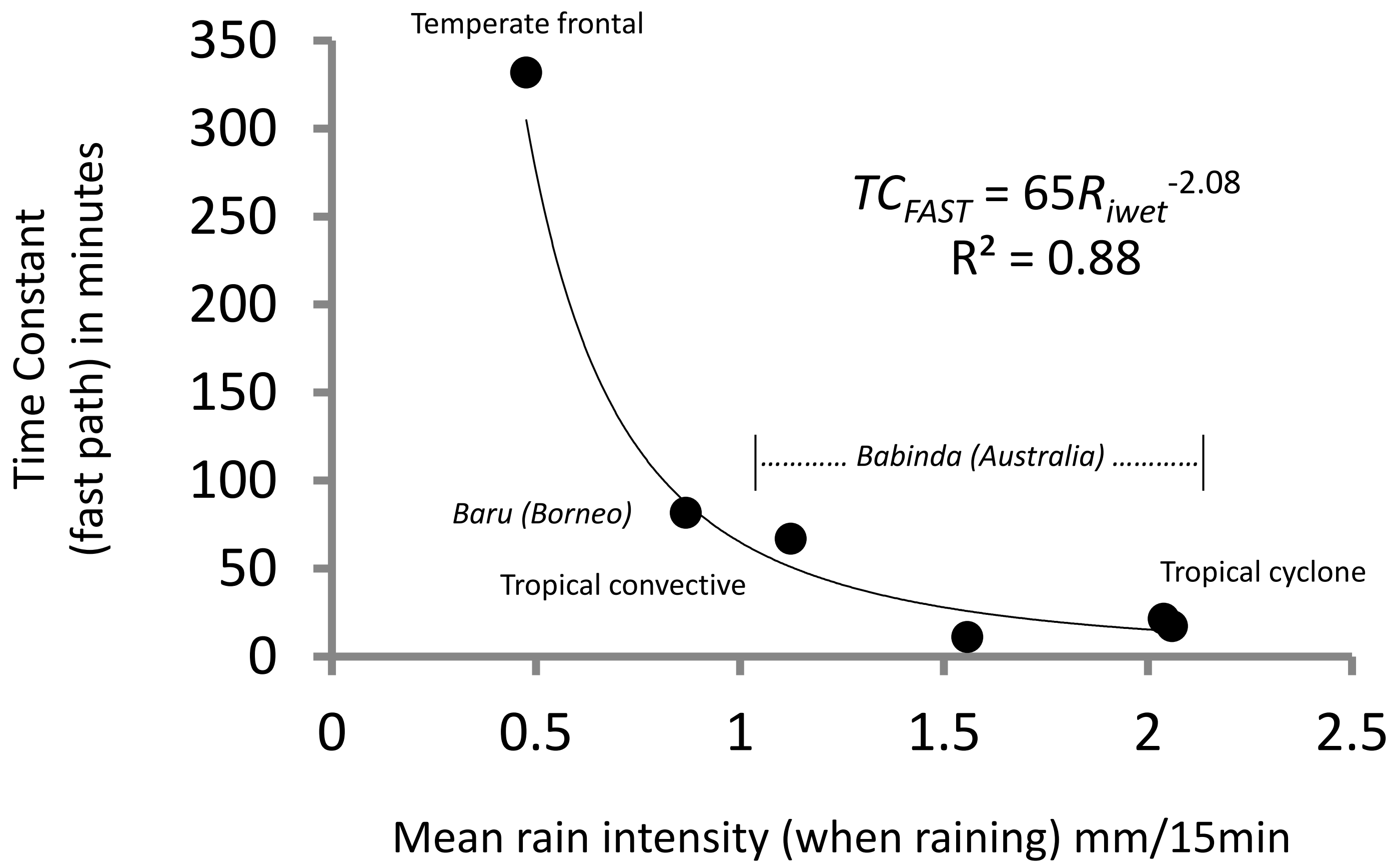
(given uncertainty)

And if so…

can knowledge of synoptic type (relative to catchment characteristics e.g., porous media depth etc) improve prediction of flood events in headwaters?

that then give over-bank flows downstream

Early indications from headwaters with floods from soil-water pathways elsewhere in the globe that this may be likely



Thank you!