India-UK Water Security Exchange Initiative – February 2016 Visit

Hydrologic & carbon services in the Western Ghats: Response of forests & agro-ecosystems to extreme rainfall events

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Ian Ball, Nick A Chappell, Wlodek Tych, Srinivas Vaidyanathan, Mahesh Sankaran,
Susan Varghese, Naresh Vissa, Trevor Page, Tim Jones & Ciaran Broderick

CEH Wallingford 18 Feb 2016

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Original UK lead

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Lancaster lead

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Ciaran Broderick

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CWC Western Ghats India-UK research team

Objectives of India-UK inter-disciplinary project

NERC
SCIENCE OF THE ENVIRONMENT

Ministry of Earth Sciences

1/ To couple synoptic & mesoscale meteorology with spatial & temporal dimensions of Extreme Rainfall Events (ERE) in Western Ghats (Karnataka and Tamil Nadu States) & in turn, hydrologic responses linked with spatial patterns of land-cover & land-use

2/ To determine hydrologic & carbon dynamics consequences of existing land-cover & land-use including large scale forestation in Western Ghats & adjacent Deccan plateau

3/ To assess hydrologic & carbon vulnerability of ecosystems, natural, semi-natural & agro-ecosystems, to ERE at various spatial scales

4/ To prioritise sites in Western Ghats & adjacent Deccan plateau for restoration under *Green India Mission* (India is one of the global leaders in forestation of degraded land) & contribute towards water resources management & climate change mitigation policy

Hypotheses

Storm-type affects rainfall-runoff response

…larger affect than land-cover change

…impacts carbon loss (aquatic & atmospheric)

Magod Falls
(River Bedti, Karnataka)


Chennai floods
2nd Dec 2015

Storm-type affects rainfall-runoff response

1/ High frequency sampling of rainfall in time & space

2/ Separate storm periods

3/ Classify synoptic conditions associated with each storm

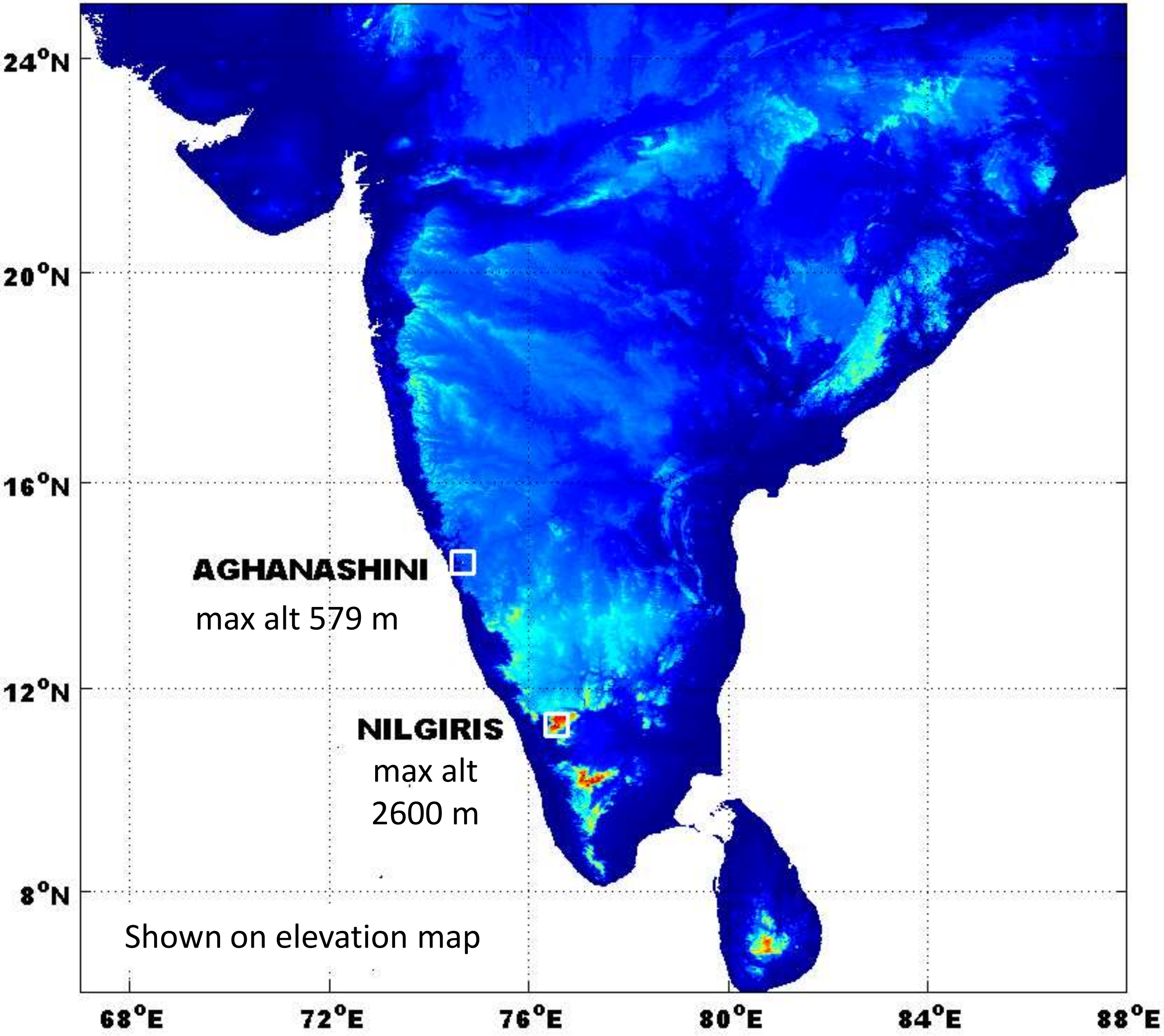
4/ Replicate runoff catchments in raingauge network

5/ Parsimonious modelling approach to see change in rainfall-runoff characteristics

How to answer?

1/ High frequency sampling of rainfall in time & space

Two raingauge networks installed in Western Ghats



Shown on elevation map

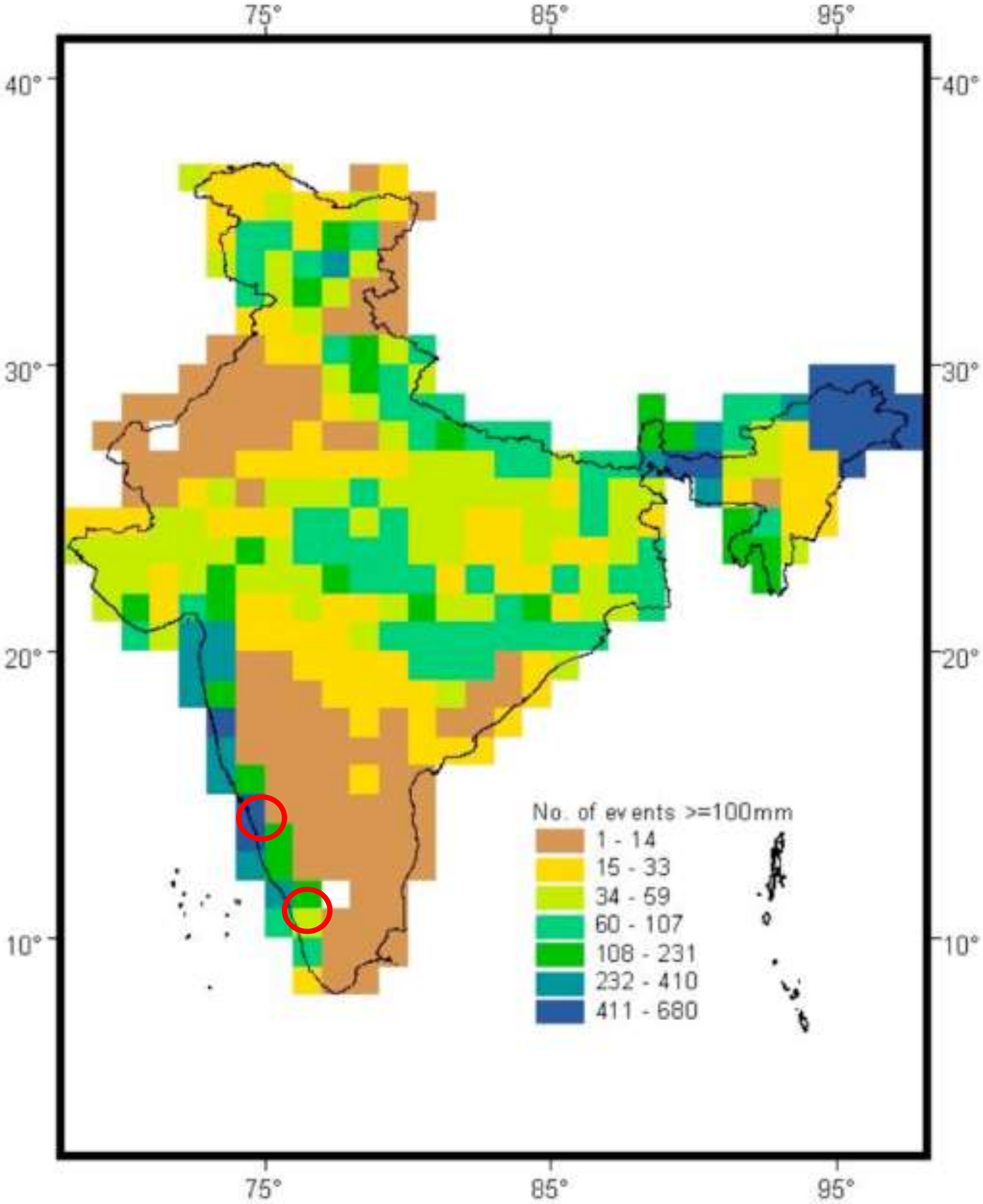
Storm-type affects rainfall-runoff response

Two raingauge networks installed in Western Ghats

region experiences some of highest daily rainfall rates

e.g., # incidences of daily rainfall > 100 mm/d

Krishnaswamy *et al* 2014 *Clim Dyn* 10.1007/s00382-0.14-2288-0



Storm-type affects rainfall-runoff response

e.g., core Nilgiris network in Cauvery headwaters

Nilgiris

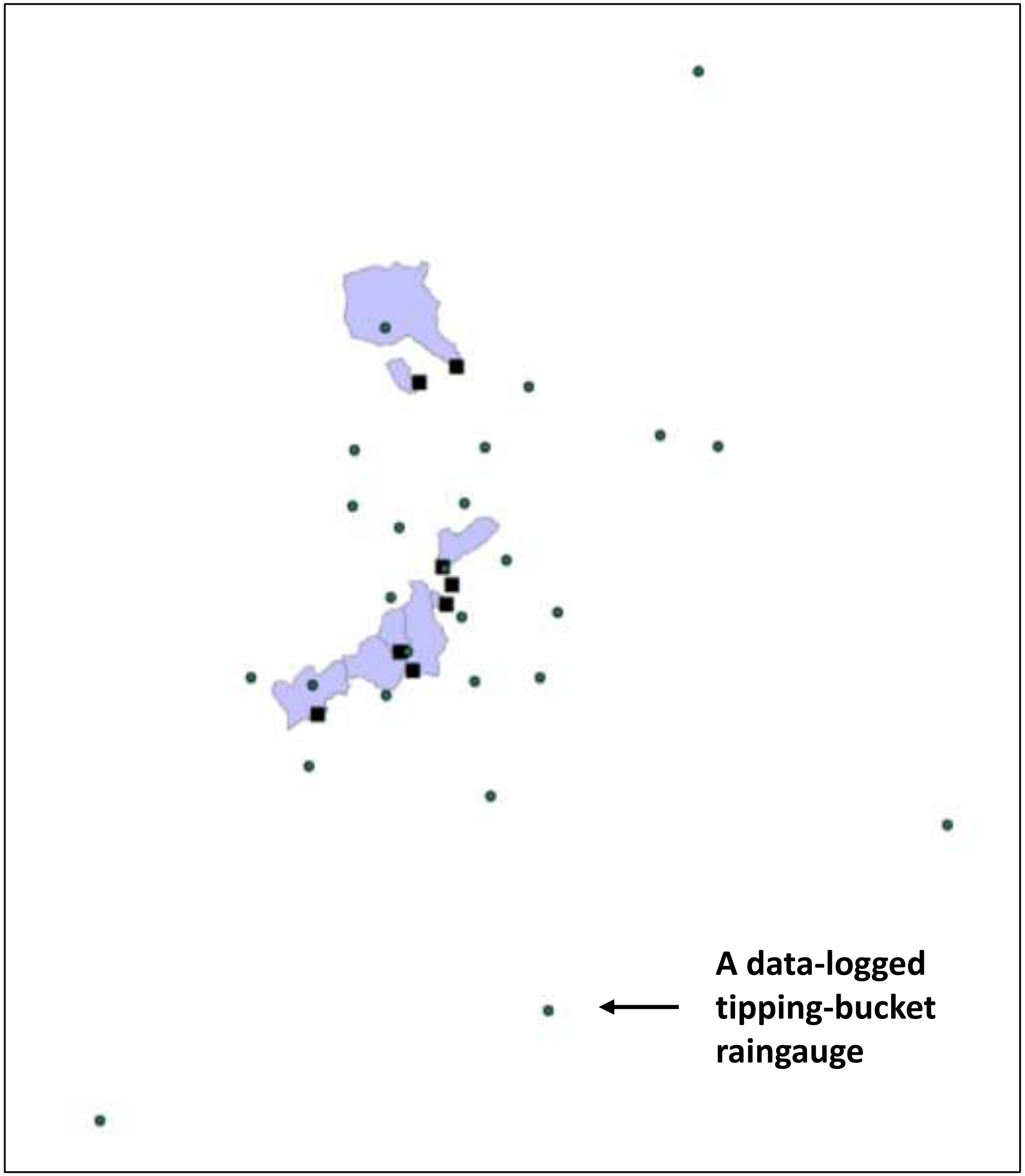
Core :
1 raingauge / 1.5 km^2

Whole 120 km^2:
1 raingauge / 4.6km^2

Aghanashini

Core :
1 raingauge / 1.5 km^2

Whole 80 km^2:
1 raingauge / 2.8 km^2



A data-logged tipping-bucket raingauge

Toughened raingauge installations to give reliable sub-hourly rainfall

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

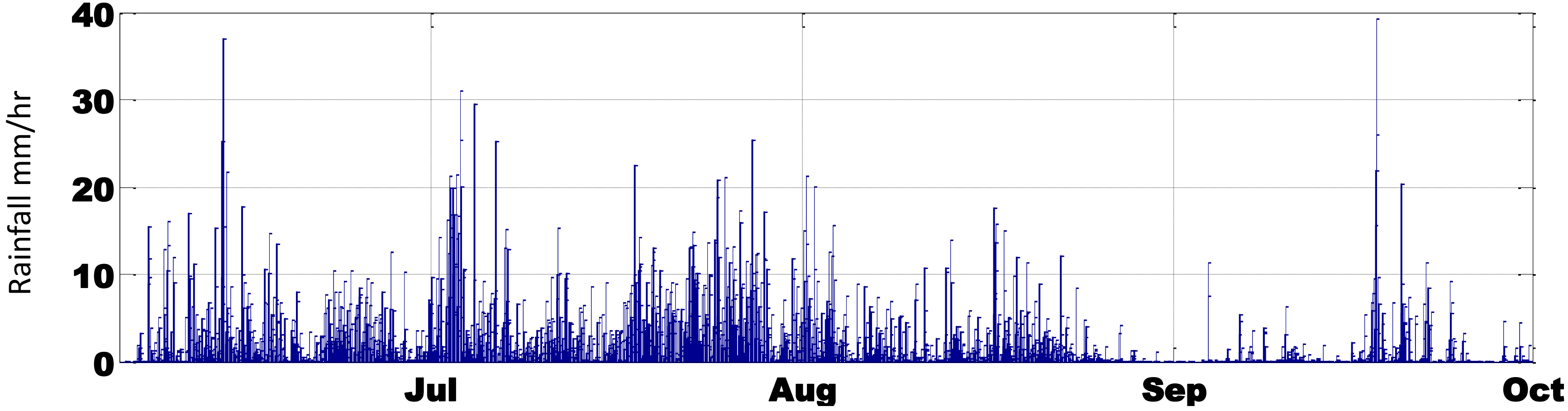
Storm-type affects rainfall-runoff response

2/ Separate storm periods

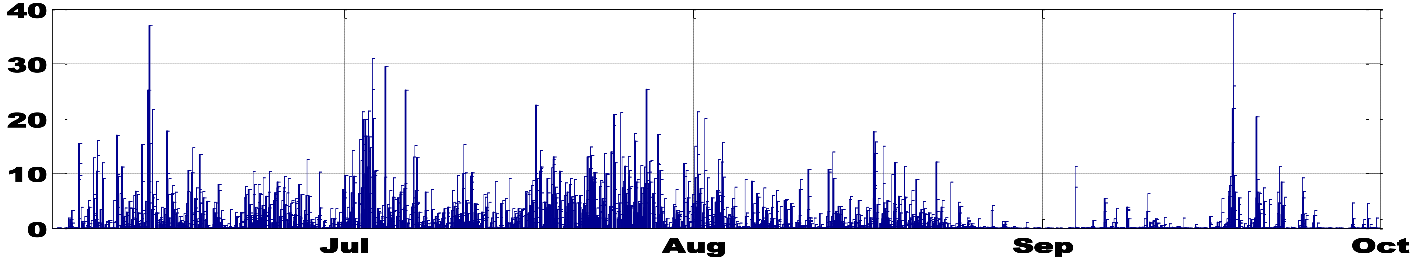
Using WAVELET.M in Matlab^{TM} based on

Torrence & Compo (1998). *B. Am. Meteorol. Soc.*79: 61-78

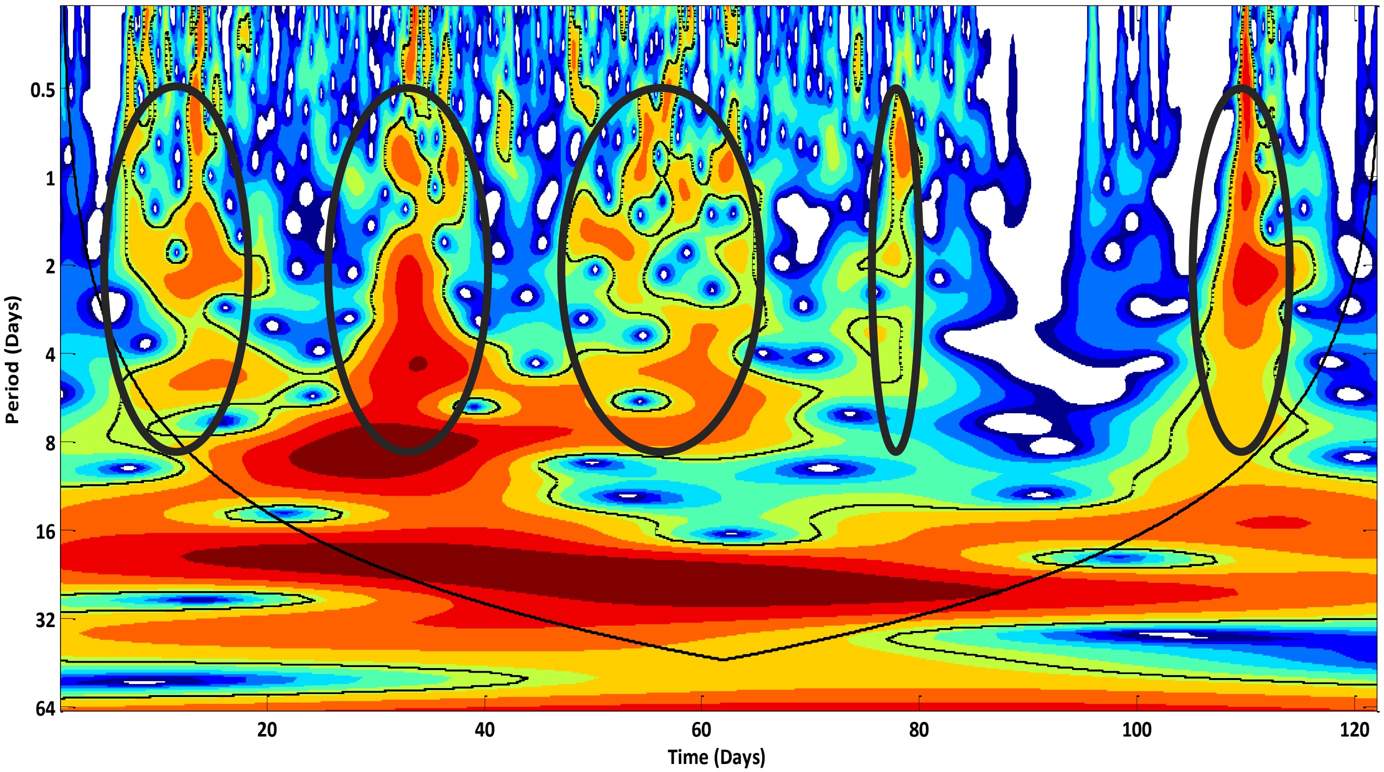
e.g., applied to hourly rainfall from arithmetic mean of 26 raingauges in Aghanashini area (2013 monsoon)



Storm-type affects rainfall-runoff response



Hourly Rainfall Wavelet Power Spectrum



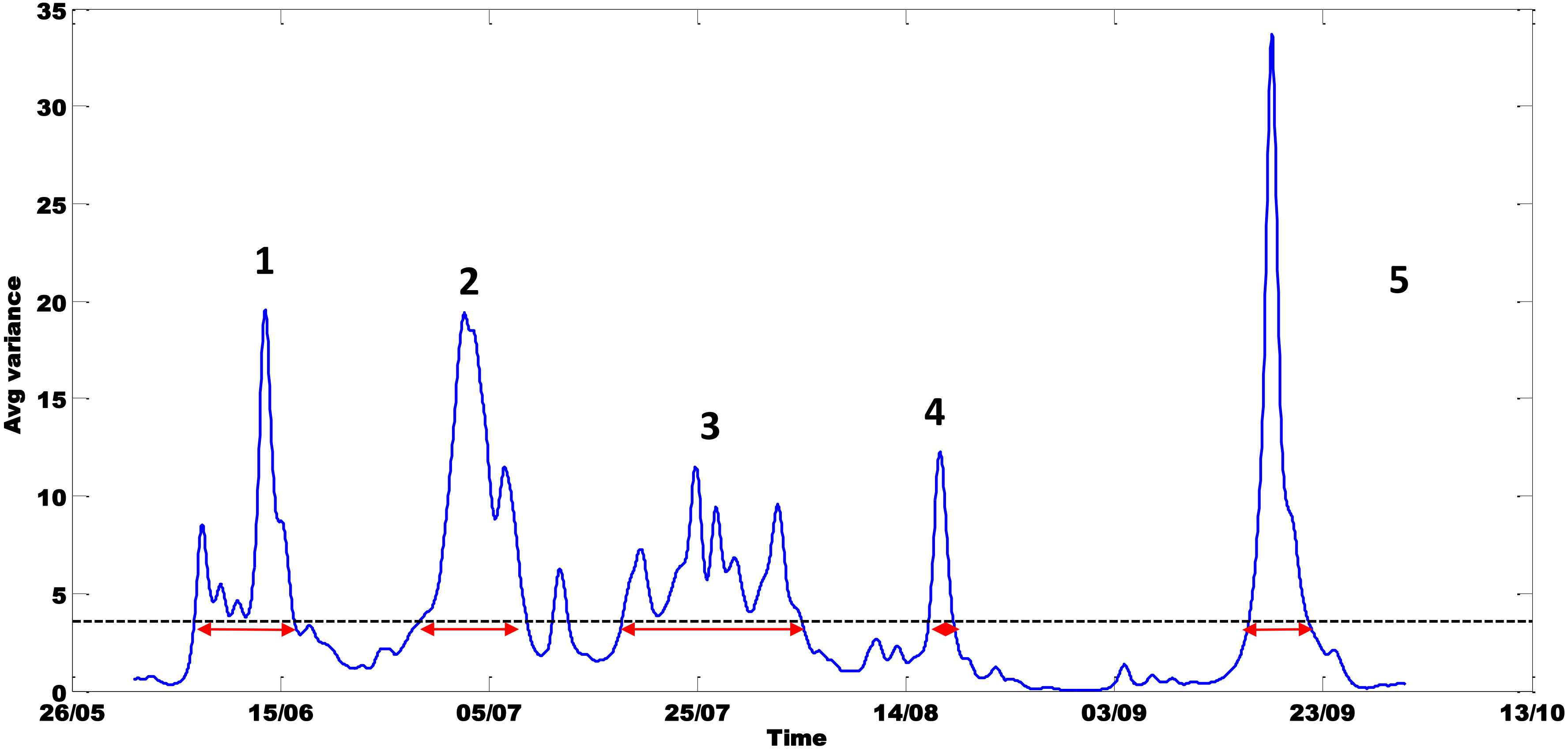
Periods with peaks in coefficients that are significantly higher (95% level)

then averaging coefficients from 0.5 to 8 days

Storm-type affects rainfall-runoff response

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

Broken black line is 95% confidence level



Storm-type affects rainfall-runoff response

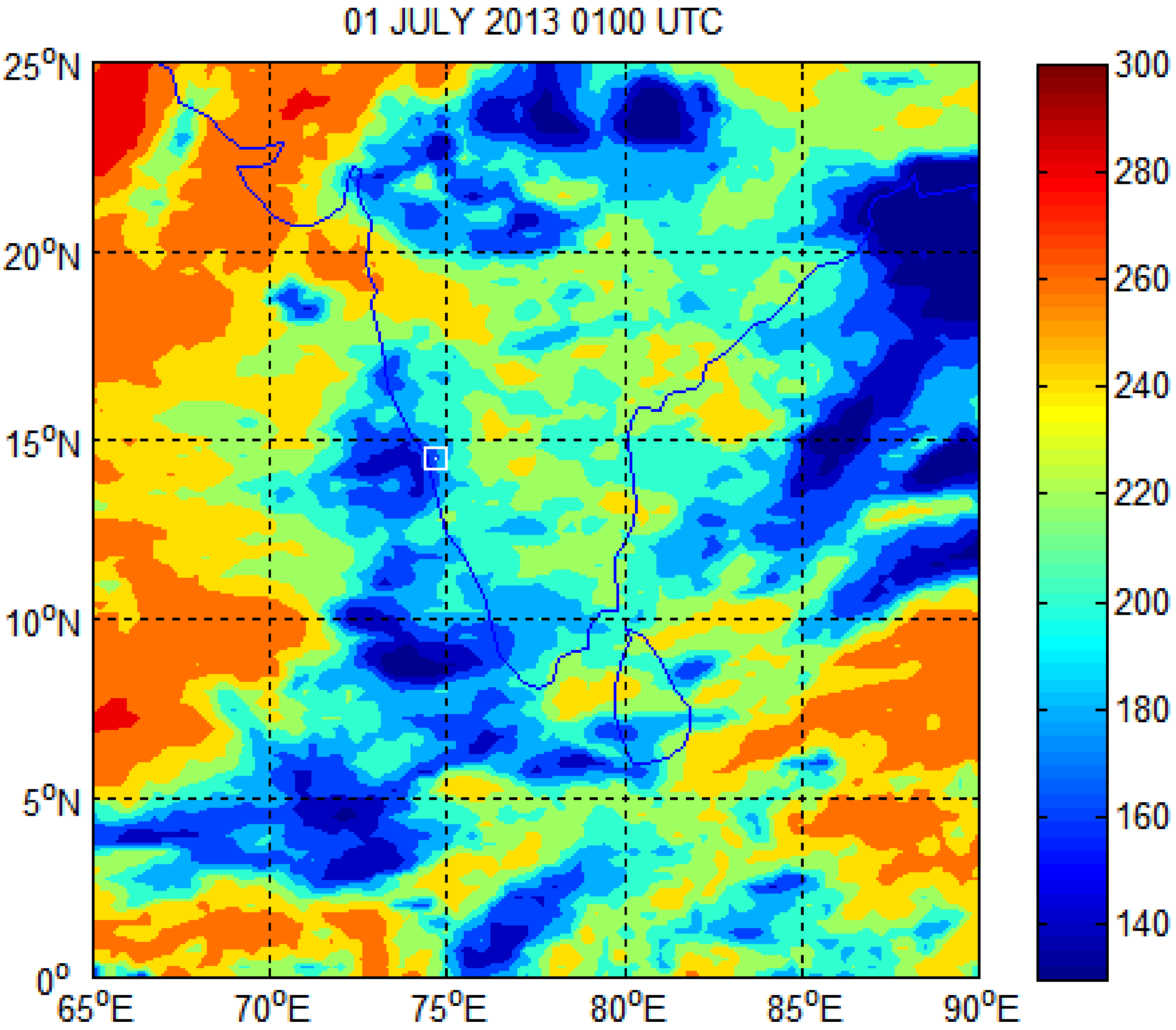
3/ Classify synoptic conditions associated with each storm

e.g.,

Kalpana-1 OLR

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

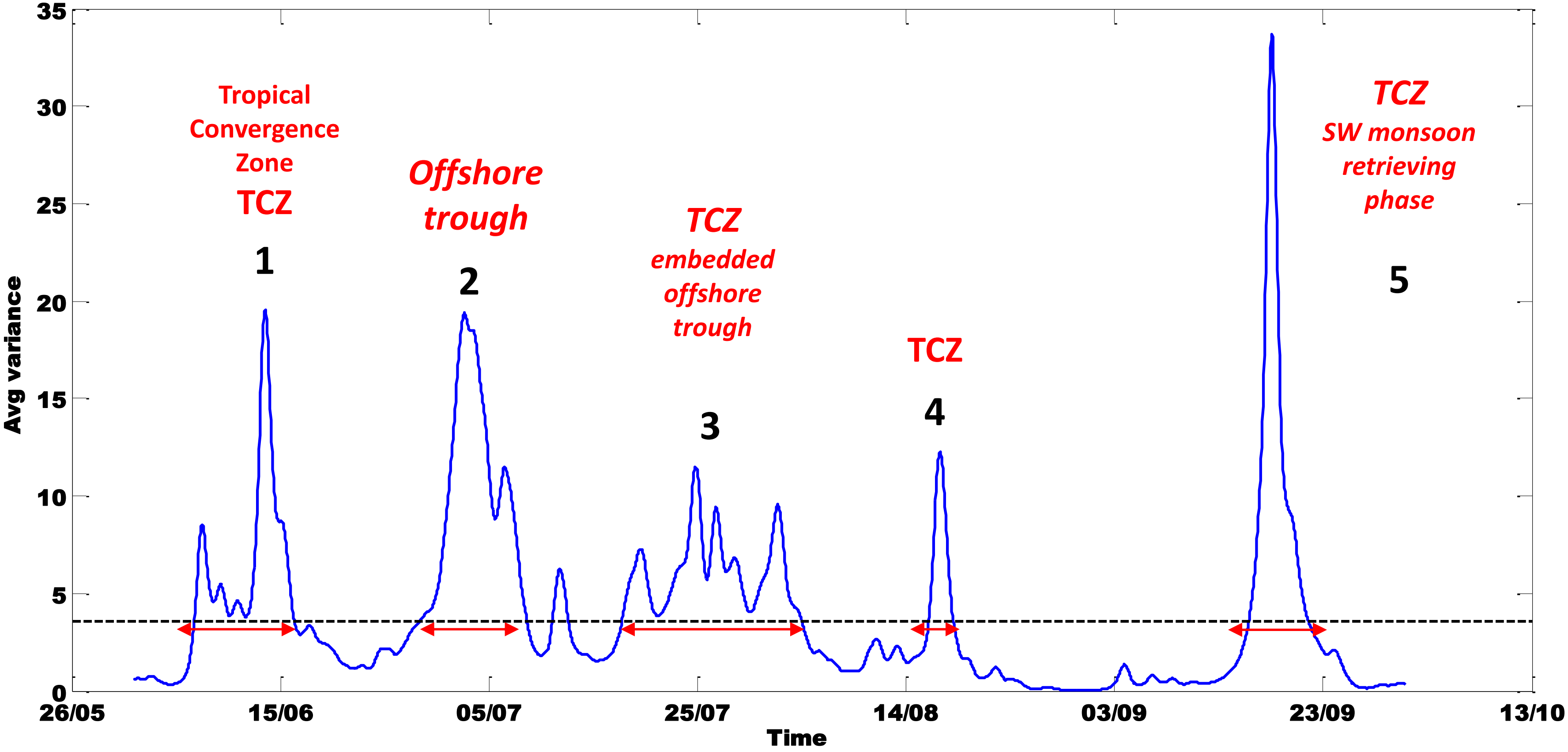
2013 Event 2 (offshore trough)



Storm-type affects rainfall-runoff response

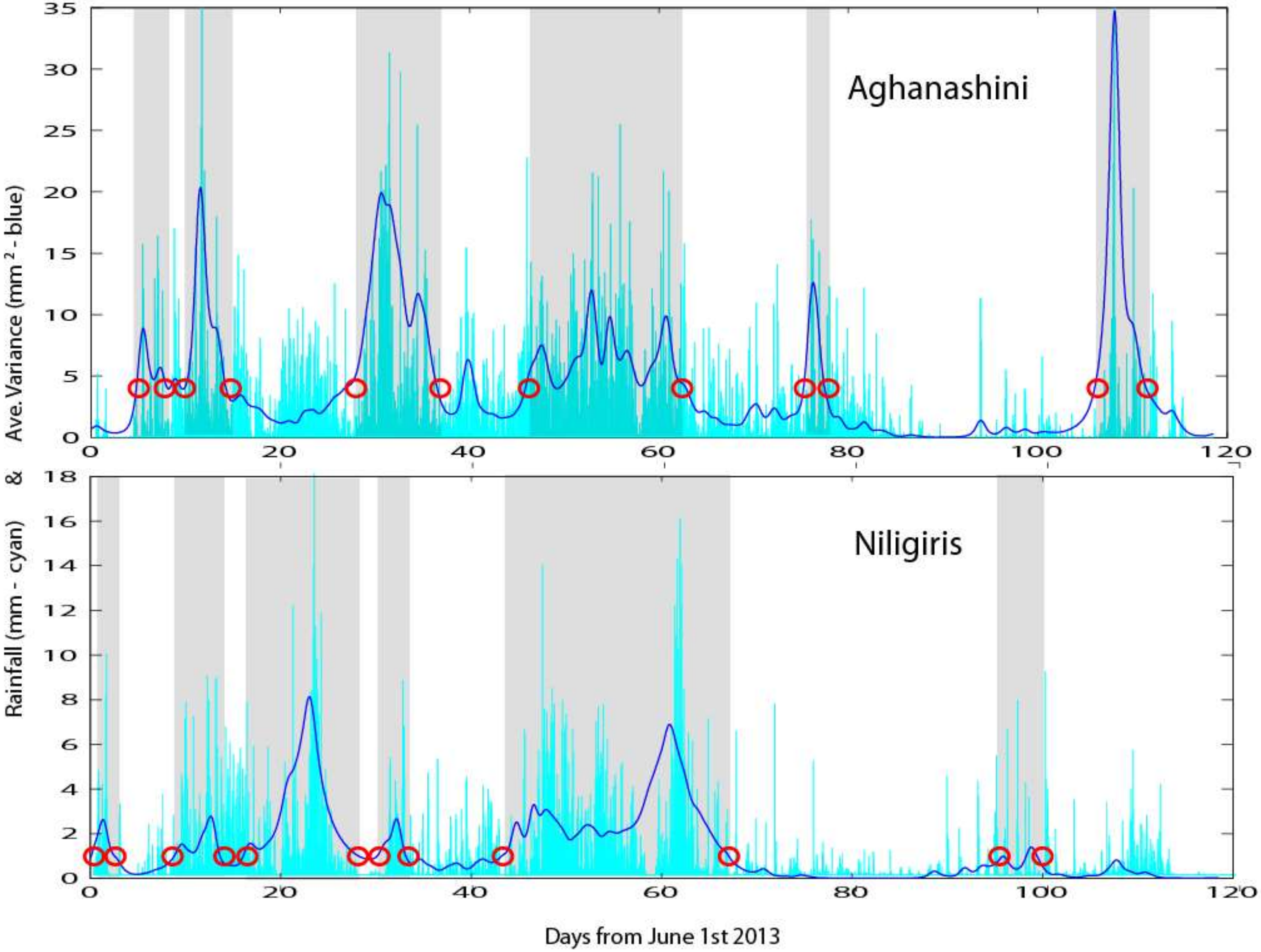
Using e.g., Francis & Gadgil (2006) *Meteorol Atmos Phys* 94: 27–42

classified storms & calculated rainfall intensity characteristics (e.g., I_{WET15})



Storm-type affects rainfall-runoff response

Different periods (& event types) identified for Nilgiris area 400 km SSE



Storm-type affects rainfall-runoff response

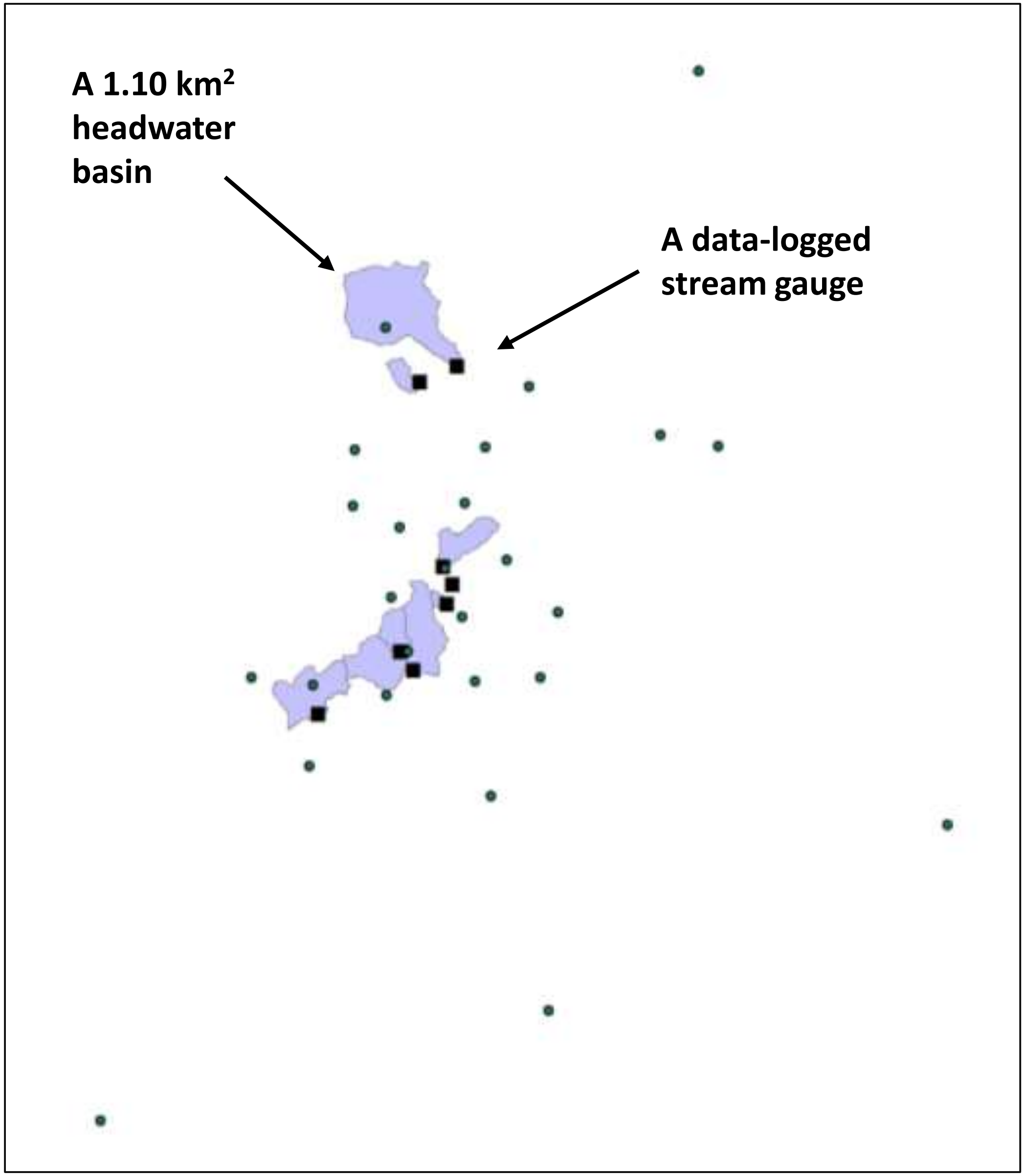
4/ Replicate runoff catchments in raingauge network

with differing land-cover, hydrogeology etc e.g., Nilgiris headwater basins

account for 70–80% of worldwide river networks

Downing *et al* (2012)
10.5268/IW-2.4.502

Most flood-water entering rivers does so in low-order (headwater) streams



A 1.10 km^2 headwater basin

A data-logged stream gauge

Storm-type affects rainfall-runoff response

e.g., WLR101 gauging station (0.3 km^2), Cauvery headwaters

Storm-type affects rainfall-runoff response

5/ Parsimonious modelling approach to see change in rainfall-runoff characteristics

One such method developed at Lancaster

RIVC

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

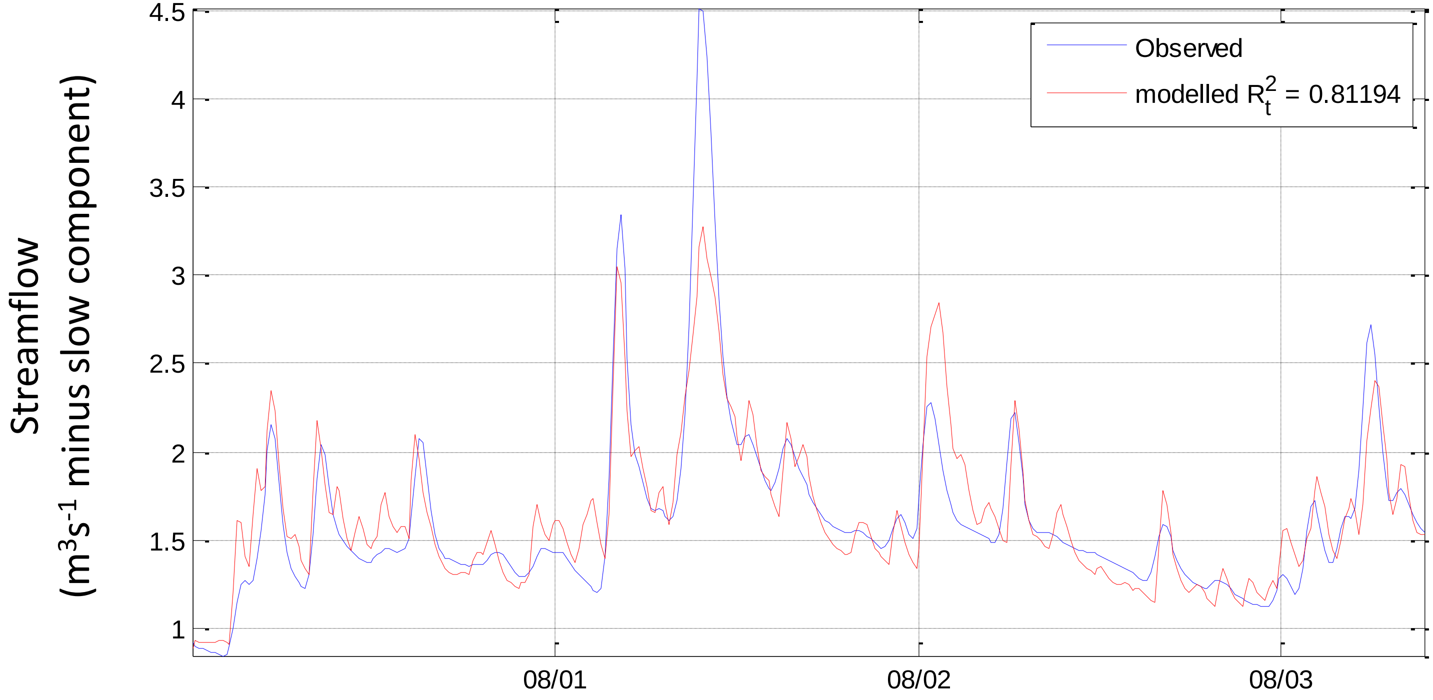
Young (2015) *Automatica* 52: 35-46

CAPTAIN
TOOLBOX

Lancaster
University

stems from Lancaster's seminal text:

Box & Jenkins (1970) *Time Series Analysis: Forecasting & Control*. Holden-Day e.g., for WLR001 basin (4.9 km^2 in Aghanashini area) for 2013 monsoon Event 4 rainfall-streamflow [2 2 0] model with $\boldsymbol{R_t^2 = 0.81}$ is optimal



15-min monitoring rate over Event 4 in 2013 monsoon

Storm-type affects rainfall-runoff response

nonlinear continuous-time transfer function model

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

with the terms for this period at WLR001 gives

$$q(t) = \frac{0.15126s + 0.011503}{s^2 + 0.47238s + 0.014417} r_{en}$$

e.g., just 4 well-defined parameter values (plus 1 nonlinearity term) capture dominant model of streamflow dynamics (peaks, lower flows)

After decomposition into two parallel 1st order pathways

$$q = \frac{0.15126}{s + 0.47238} r_{en} + \frac{0.011503}{s + 0.014417} r_{en}$$

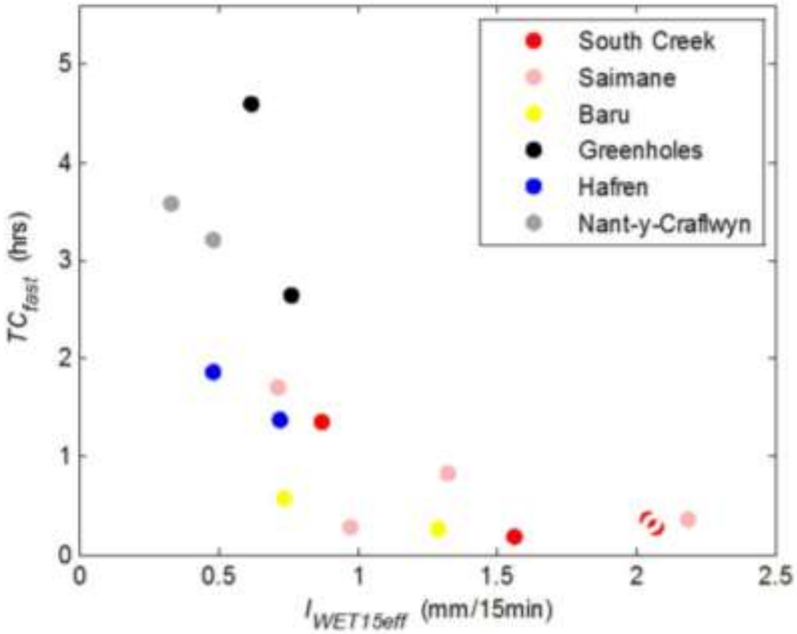
gives measure of flashiness of hydrograph during flood events, *TC* *fast*

Findings?

Before considering detailed results for India

this is the **emerging global relation**

between $I_{WET15eff}$ (per storm period) & TC_{fast}



for diverse range of storm-types (temperate frontal – tropical cyclones)
but only shallow water pathways

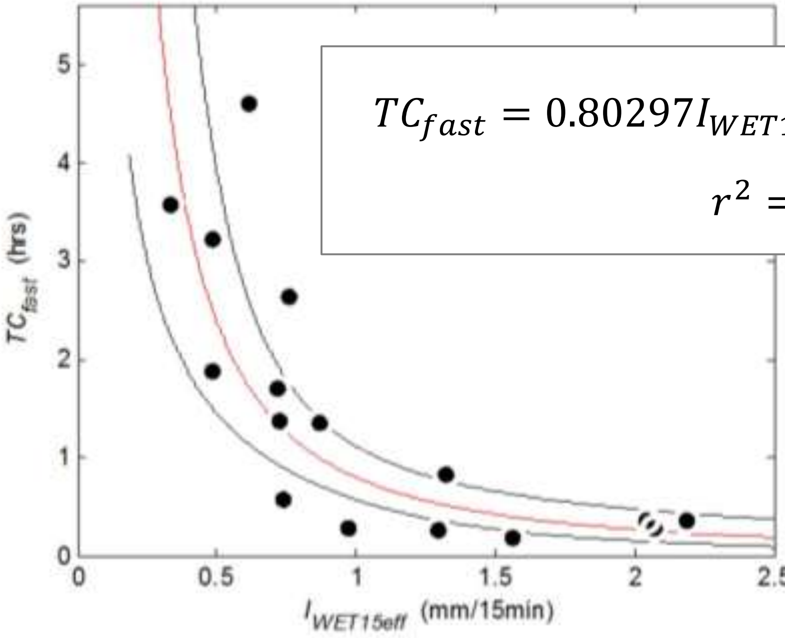
Chappell *et al. Geophysical Research Letters,* in submission

Storm-type affects rainfall-runoff response

Before considering detailed results for India

this is the **emerging global relation**

between $I_{WET15eff}$ (per storm period) & TC_{fast}



$$TC_{fast} = 0.80297 I_{WET15eff}{}^{-1.568}$$

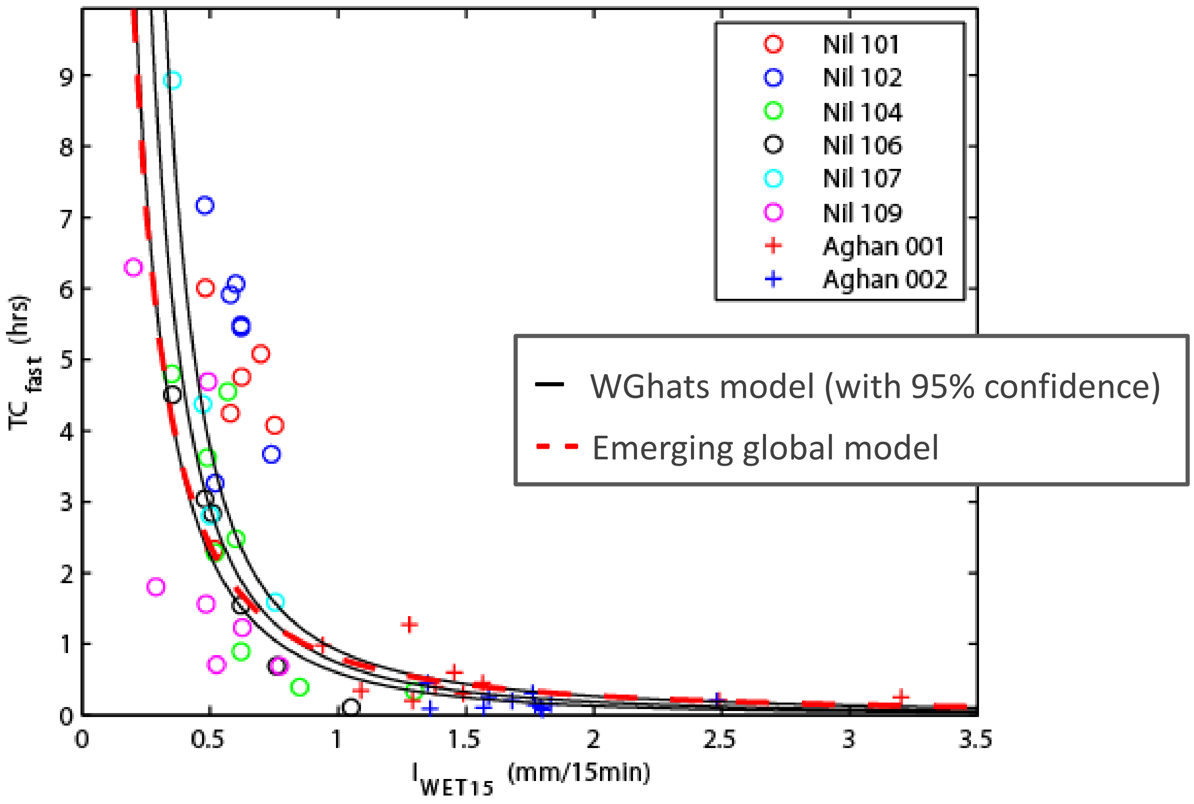
$$r^2 = 0.69$$

for diverse range of storm-types (temperate frontal – tropical cyclones)
but only shallow water pathways

Chappell *et al. Geophysical Research Letters,* in submission

Storm-type affects rainfall-runoff response

…and for basins in the two Western Ghats regions with contrasting storm intensities

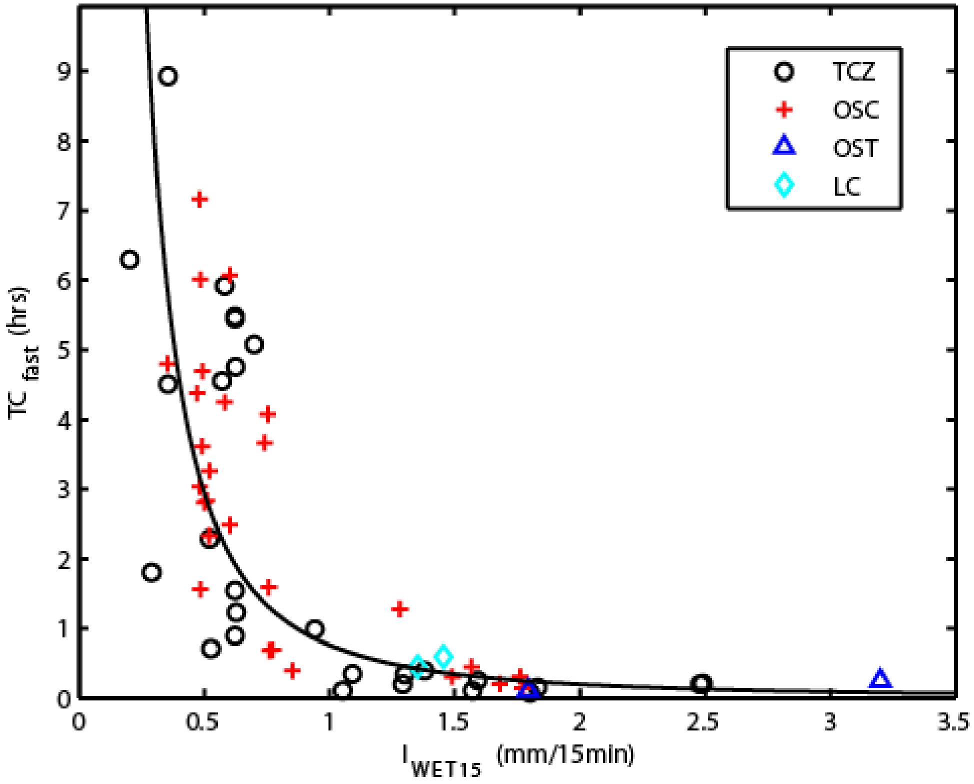


for a range of storm-types in 2013 & 2014 monsoon
but with systems having shallow & deep water pathways

Page *et al.,* in preparation

Storm-type affects rainfall-runoff response

…while *new* storm intensity affect apparent association with 'synoptic storm type' less clear

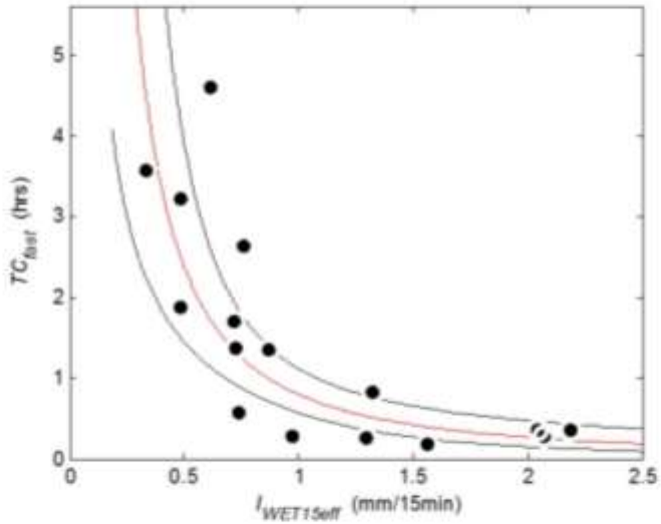


TCZ = tropical convergence zone; OSC = off shore convection;
OST = off shore trough; LC = local convection

Page *et al.,* in preparation

Storm-type affects rainfall-runoff response

Current watershed models do not vary values of model watershed parameters between periods of differing storm-averaged rainfall intensity; only separate effects of changing antecedent basin wetness are captured by current model parameterizations



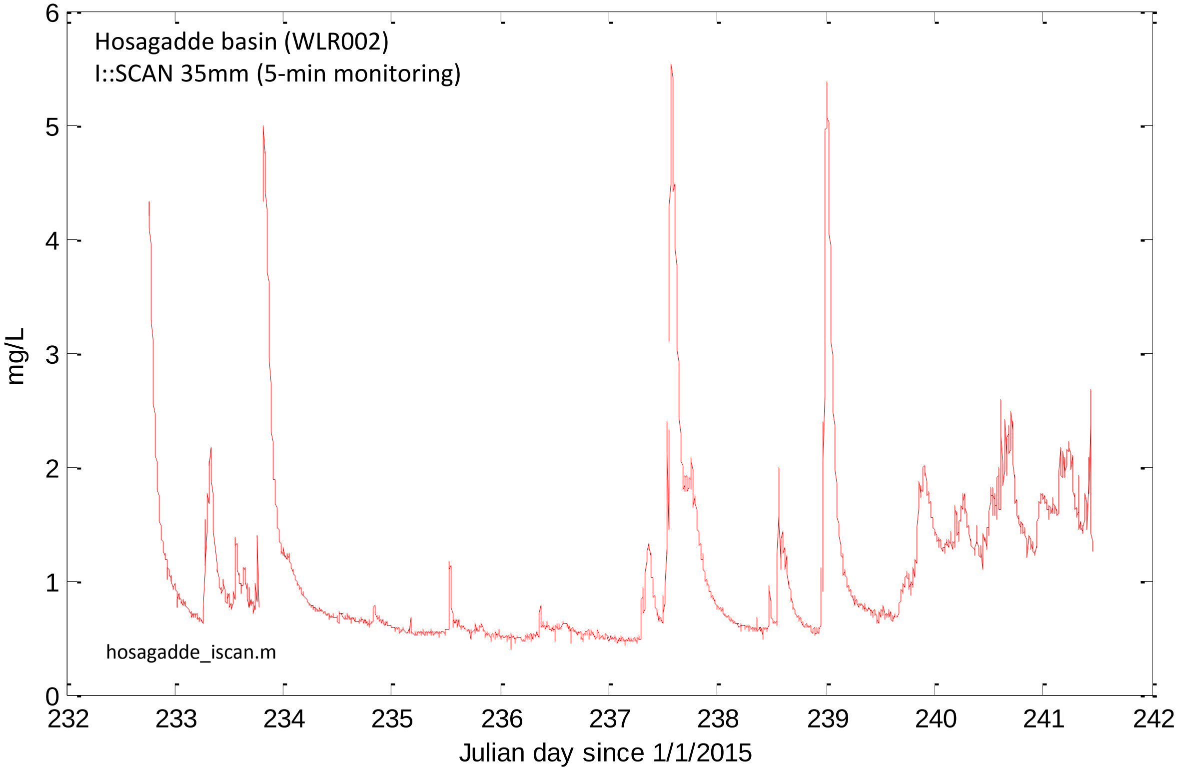
Models that do not vary watershed model parameters between periods of differing storm-averaged intensity will **underestimate fast residence times in periods of higher than average storm intensity**

Simulations or forecasts of flood events caused by particularly intense storm systems in a long record will be smaller than observed

Chappell *et al. Geophysical Research Letters,* in submission
Page *et al.,* in preparation

Storm impacts on carbon losses?

e.g., aquatic carbon losses from headwaters where labile carbon enters channels

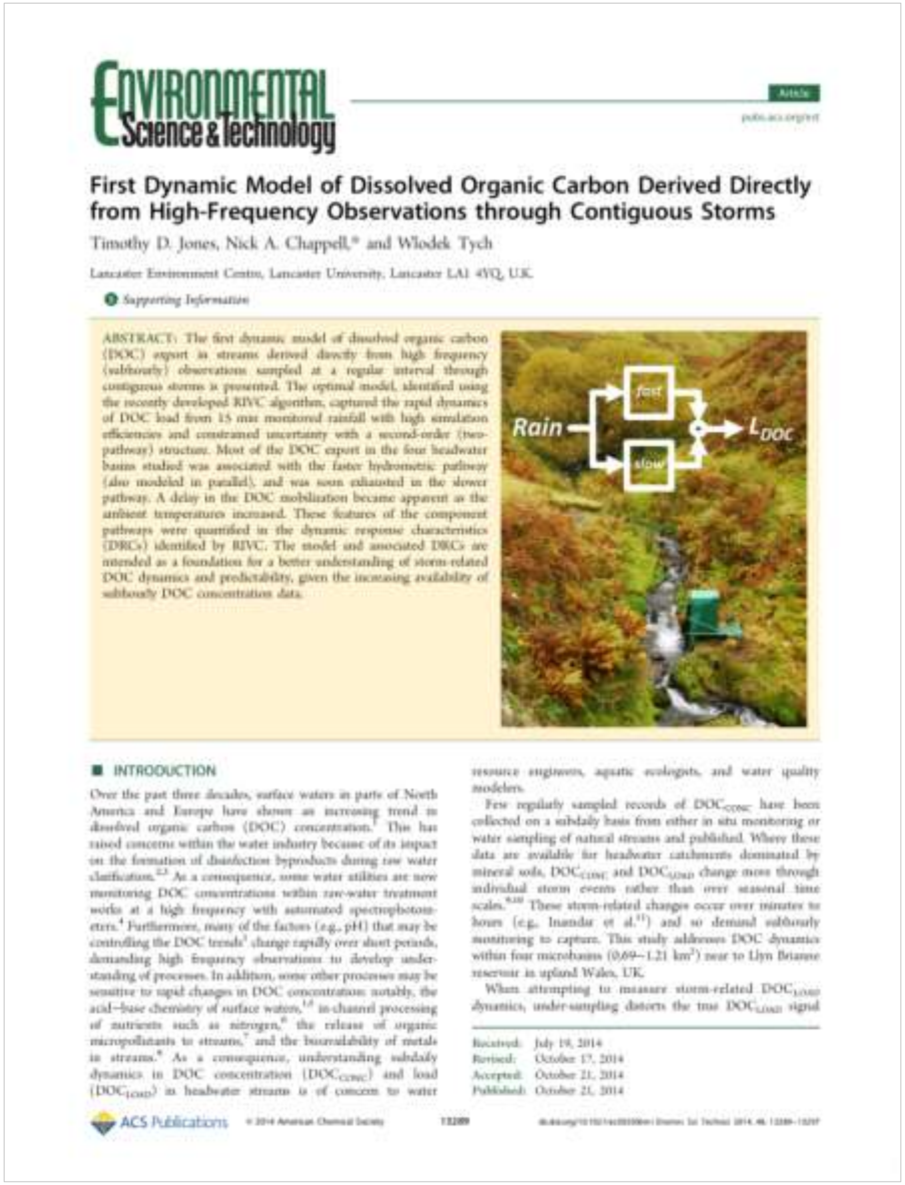


as sensitive to storm rainfall dynamics as streamflow

but out of phase (cannot interpolate infrequent samples using streamflow)

Jones *et al.* 2014. *Environ. Sci. Technol.*, 48: 13289-13297

Storm-type impacts on carbon losses



Environmental Science & Technology
Article
pubs.acs.org/est

First Dynamic Model of Dissolved Organic Carbon Derived Directly from High-Frequency Observations through Contiguous Storms

Timothy D. Jones, Nick A. Chappell,* and Wlodek Tych

Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, U.K.

Supporting Information

ABSTRACT: The first dynamic model of dissolved organic carbon (DOC) export in streams derived directly from high frequency (subhourly) observations sampled at a regular interval through contiguous storms is presented. The optimal model, identified using the recently developed RIVC algorithm, captured the rapid dynamics of DOC load from 15 min monitored rainfall with high simulation efficiencies and constrained uncertainty with a second-order (two-pathway) structure. Most of the DOC export in the four headwater basins studied was associated with the faster hydrometric pathway (also modeled in parallel), and was soon exhausted in the slower pathway. A delay in the DOC mobilization became apparent as the ambient temperatures increased. These features of the component pathways were quantified in the dynamic response characteristics (DRCs) identified by RIVC. The model and associated DRCs are intended as a foundation for a better understanding of storm-related DOC dynamics and predictability, given the increasing availability of subhourly DOC concentration data.

INTRODUCTION

Over the past three decades, surface waters in parts of North America and Europe have shown an increasing trend in dissolved organic carbon (DOC) concentration.[1] This has raised concerns within the water industry because of its impact on the formation of disinfection byproducts during raw water clarification.[2,3] As a consequence, some water utilities are now monitoring DOC concentrations within raw-water treatment works at a high frequency with automated spectrophotometers.[4] Furthermore, many of the factors (e.g., pH) that may be controlling the DOC trends[1] change rapidly over short periods, demanding high frequency observations to develop understanding of processes. In addition, some other processes may be sensitive to rapid changes in DOC concentration: notably, the acid–base chemistry of surface waters,[1,5] in-channel processing of nutrients such as nitrogen,[6] the release of organic micropollutants to streams,[7] and the bioavailability of metals in streams.[8] As a consequence, understanding subdaily dynamics in DOC concentration (DOC_{CONC}) and load (DOC_{LOAD}) in headwater streams is of concern to water resource engineers, aquatic ecologists, and water quality modelers.

Few regularly sampled records of DOC_{CONC} have been collected on a subdaily basis from either in situ monitoring or water sampling of natural streams and published. Where these data are available for headwater catchments dominated by mineral soils, DOC_{CONC} and DOC_{LOAD} change more through individual storm events rather than over seasonal time scales.[9,10] These storm-related changes occur over minutes to hours (e.g., Inamdar et al.[11]) and so demand subhourly monitoring to capture. This study addresses DOC dynamics within four microbasins (0.69–1.21 km^2) near to Llyn Brianne reservoir in upland Wales, UK.

When attempting to measure storm-related DOC_{LOAD} dynamics, under-sampling distorts the true DOC_{LOAD} signal

Received: July 19, 2014
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Accepted: October 21, 2014
Published: October 21, 2014

ACS Publications © 2014 American Chemical Society 13289 dx.doi.org/10.1021/[illegible] | Environ. Sci. Technol. 2014, 48, 13289−13297

Fortunately RIVC approach can be used to model carbon dynamics through storms (see left)

Provided DOC concentration monitored continuously at a fast rate (see below)

Chappell, N.A., Jones, T., Young, P., and Krishnaswamy, J. 2015. *Demonstrating value of fine-resolution optical data for minimising aliasing impacts on biogeochemical models of surface waters*. Presentation in session B14D of the American Geophysical Union meeting AGU Fall Meeting 2015 in San Francisco 14-18 December 2015

Storm-type impacts on carbon losses

Messages
for Indian Government Scientists?

from India-UK CWC-WGhats collaboration

1/ Mean 15-min intensity characteristics per periods of similar storms could be used to **identify floods that will be larger than forecast by existing models**

e.g., tipping-bucket raingauge in WGhats networks

1/ Mean 15-min intensity characteristics per periods of similar storms could be used to **identify floods that will be larger than forecast by existing models**


particularly if connected via phone telemetry

becoming much cheaper

e.g., Hosagadde (WLR002) basin, India


e.g., CEH Upper Hafren basin, UK

2/ Monitoring & modelling **unregulated headwaters** (i.e., no dams) essential for quantifying climate-related processes & changes in river resources

e.g., CWC Santeguli gauging station, Aghanashini basin

3/ Tropical rivers are very flashy (as is water quality) during storms

without sub-daily monitoring *the* most important information not collected

Insufficient information to constrain uncertainty
during calibration of possible sets of model parameters
capturing fundamental storm-based runoff dynamics

simulation of past conditions or future scenarios of

river behaviour during floods more uncertain than needs to be

3/ Tropical rivers are very flashy (as is water quality) during storms
without sub-daily monitoring *the* most important information not collected

RIVC

can identify model structures & parameters
even if observations very under-sampled ('aliased')

e.g., riverflow measurement at a specific time once per day

4/ Model structures should be no more complex than warranted by information content of observations (to minimise uncertainty)

Vol. 3, No. 2 Technometrics May, 1961

Discussion, Emphasizing the Connection Between Analysis of Variance and Spectrum Analysis*

John W. Tukey
Princeton University
and
Bell Telephone Laboratories

Introduction

1961 at Princetown

TIME SERIES
ANALYSIS
forecasting
and
control

GEORGE E. P. BOX
University of Wisconsin, U.S.A.

and

GWILYM M. JENKINS
University of Lancaster, U.K.

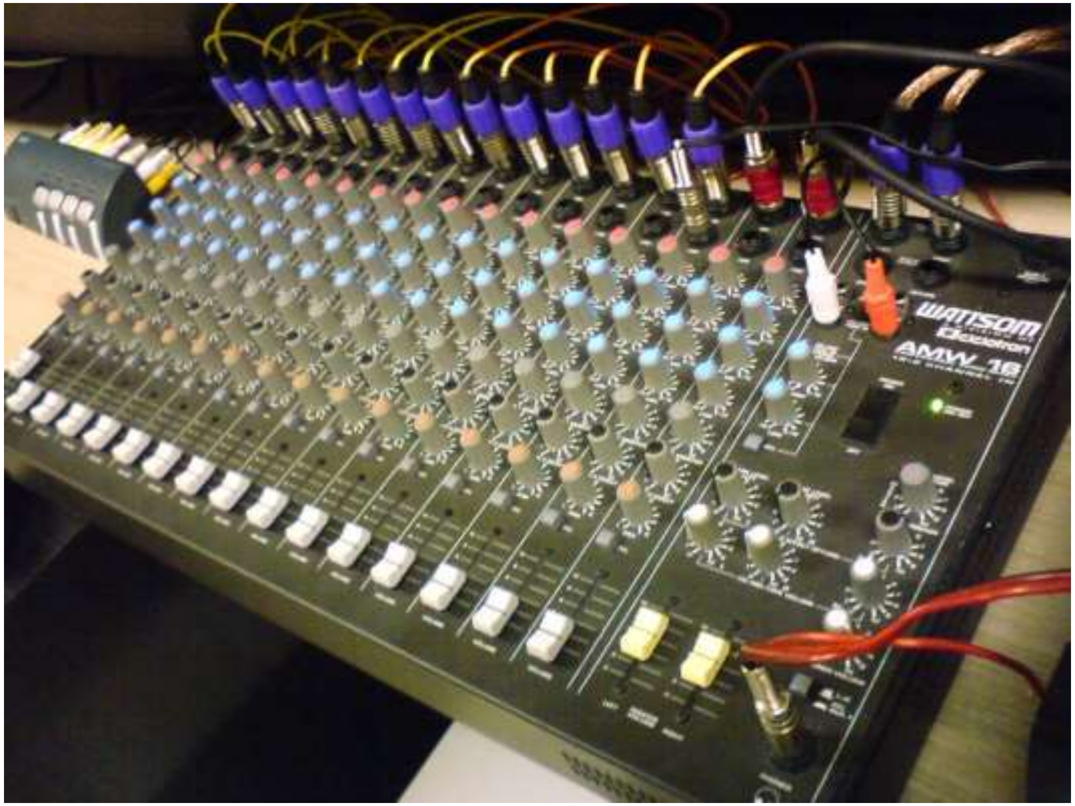
HOLDEN-DAY
San Francisco, Cambridge, London, Amsterdam

1970 at Wisconsin & Lancaster

Principle of Parsimony

simple physics-based, conceptual or time-series models not necessarily parsimonious

4/ Model structures should be no more complex than warranted by information content of observations (to minimise uncertainty)



complex models cannot be justified mathematically
with typically sparse catchment data-sets

4/ Model structures should be no more complex than warranted by information content of observations (to minimise uncertainty)

RIVC

model structure (e.g., rainfall-runoff) identified *directly* from observations
capture dominant modes of behaviour with fewest Nº parameters
optimal constraint on uncertainty – permitting interpretation of change

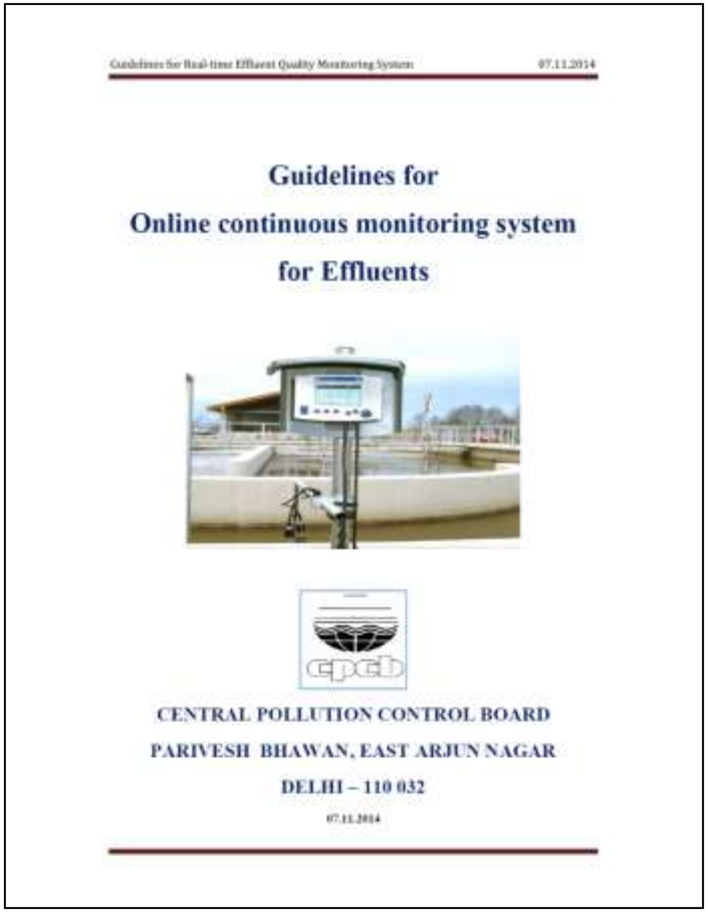
Additionally:

i/ not affected by problem of defining effective hydraulic conductivity at unmeasurable large-scales that besets models underpinned by Darcian assumptions

ii/ value of existing hydrological observations highlighted (e.g., those collected by Indian authorities)

iii/ gives explicit uncertainty estimates based directly on covariance matrix of parameters identified

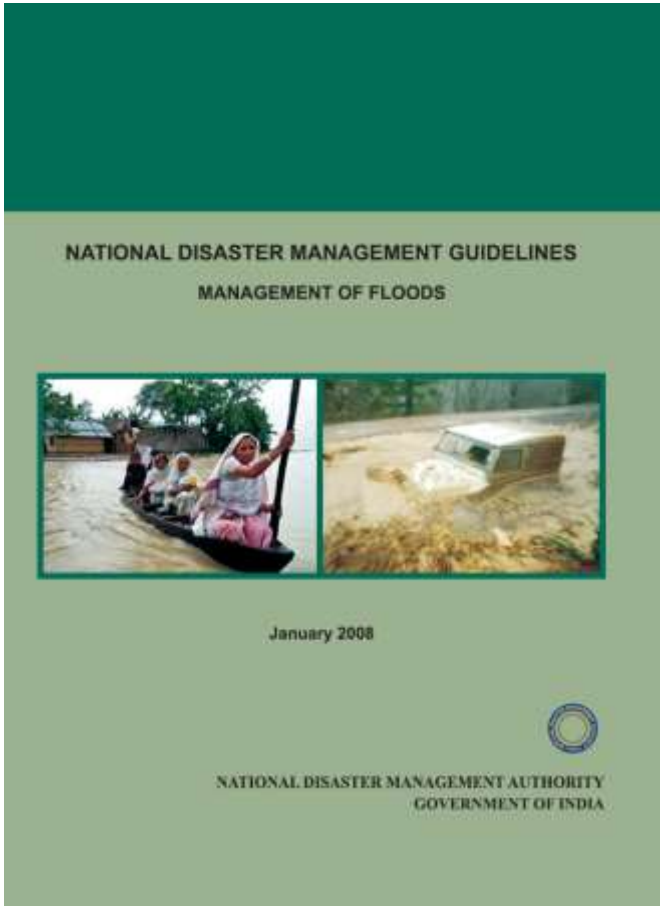
…consistent with recent **recommendations by Indian government** regarding approaches to water (including water quality) observation & modelling



Guidelines for Real-time Effluent Quality Monitoring System 07.11.2014

Guidelines for
Online continuous monitoring system
for Effluents

CENTRAL POLLUTION CONTROL BOARD
PARIVESH BHAWAN, EAST ARJUN NAGAR
DELHI – 110 032
07.11.2014



NATIONAL DISASTER MANAGEMENT GUIDELINES
MANAGEMENT OF FLOODS

January 2008

NATIONAL DISASTER MANAGEMENT AUTHORITY
GOVERNMENT OF INDIA

Messages

ATREE
Ashoka Trust for Research in Ecology and the Environment

Environment Centre

Lancaster University

University of Dundee

FERAL

ncbs

Thank you!