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Role of spatial resolution in simulating hydrological processes using a physically-based hydrological model

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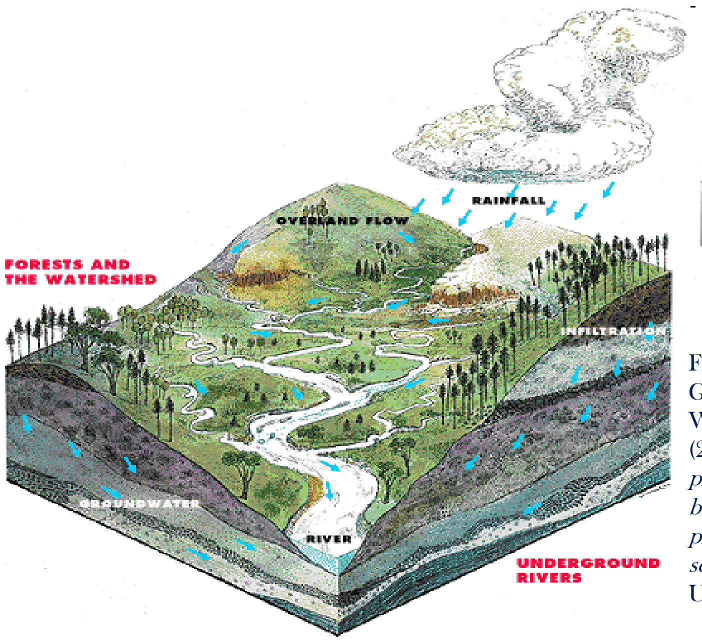


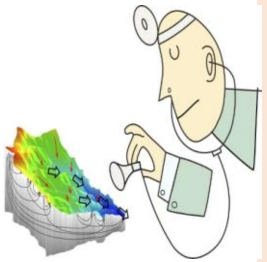


Figure source: Blöschl, G., Sivapalan, M., and Wagener, T. (Eds.). (2013). *Runoff prediction in ungauged basins: Synthesis across processes, places and scales*. Cambridge University Press

Catchments are complex, self-organizing systems, whose form, drainage network, ground, and channel slopes, channel hydraulic geometries, soils, and vegetation, are all a result of adaptive ecological, geomorphic, and land-forming processes (Sivapalan, 2005)

Introduction

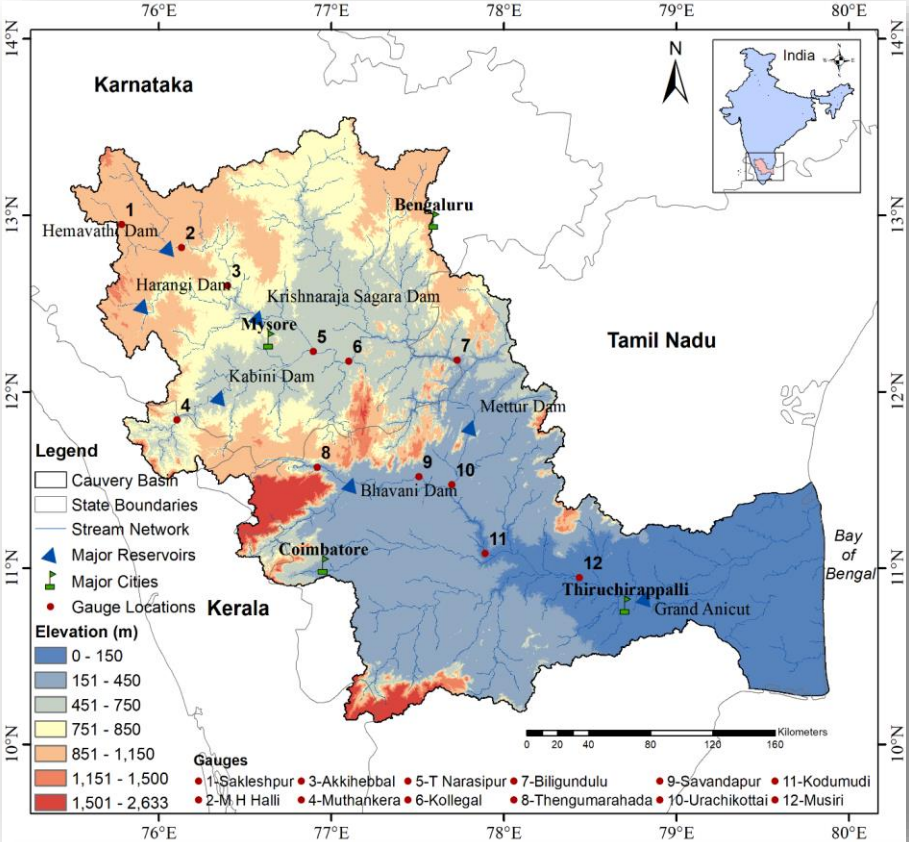
- Hydrological responses of a catchment are predominantly governed by complex interactions of processes
- Hydrological processes exhibit non-linear behaviour at all scales
- Hydrological modelling is a powerful tool in assimilating the complex behaviour of hydrological systems
- Adopted modelling strategies have significant impact on the adequate representation of processes
- Appropriate spatial resolution of the model becomes a critical factor in regionally complex catchments

Research Question

- How much spatial approximations are necessary for a model to adequately represent reality?

Study Area - Cauvery River Basin, Peninsular India

- Origin : Talakaveri, Kodagu in Karnataka, India
- Basin area: approx. 85600 sq. kms.
- Total length of the river: 800 kms.
- Elevation at origin: 1341m
- Extends over the Indian states of Tamil Nadu, Karnataka, Kerala and Union Territory of Puducherry
- Covers nearly 2.7% of the total geographical area of India
- Major land use is agriculture; annual avg. rainfall varies from 500 to 3000 mm

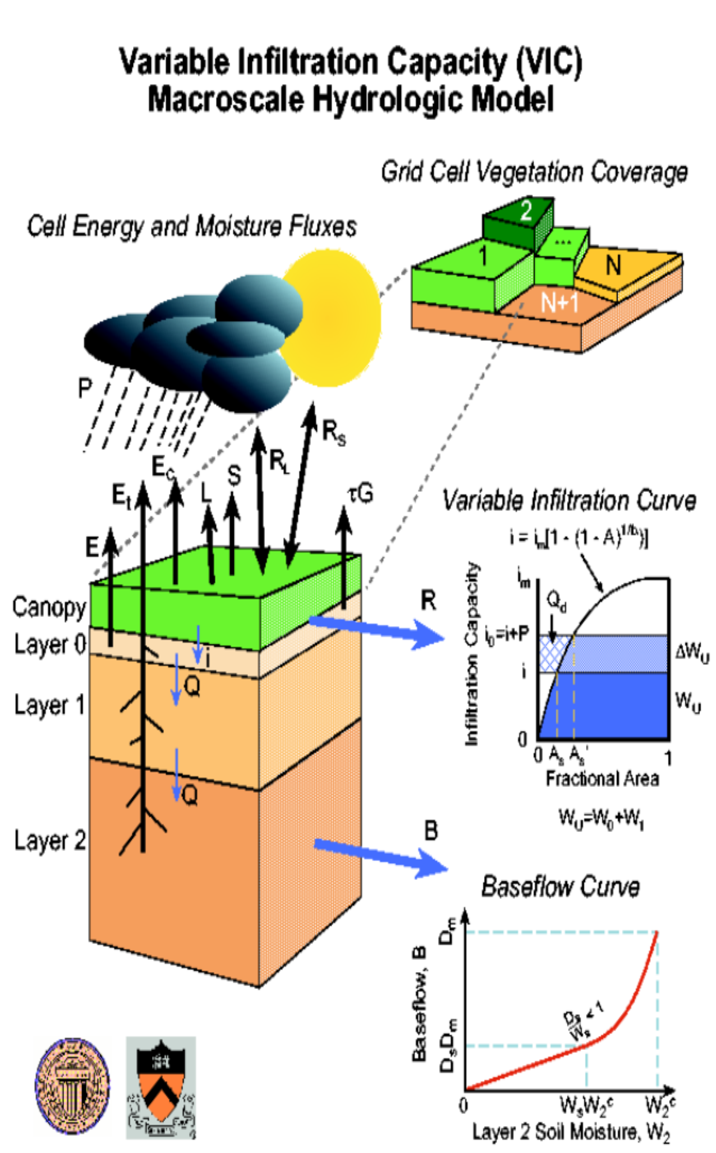


Major Challenges

- Water management challenges at the local, regional and basin scales
- Large number of small and large scale interventions
- High variability in water availability, both, temporally and spatially
- Large scale shift in land use and land cover over the past decades

Images: Google, Project UPSCAPE

Variable Infiltration Capacity (VIC) Model

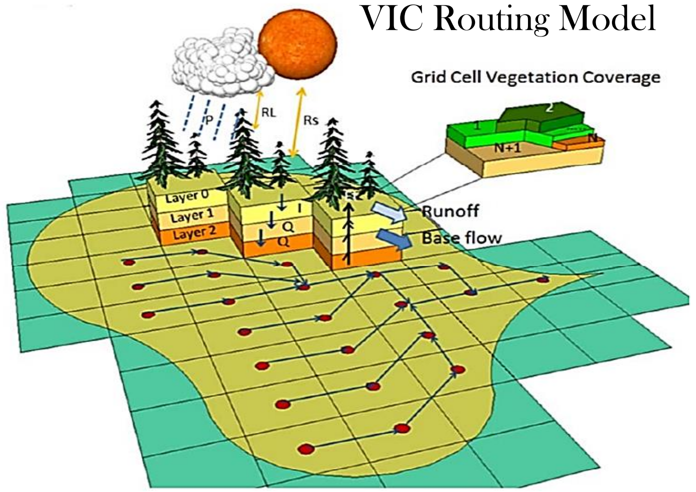


Source: University of Washington

Model Properties:

- Physically based hydrology model
- Solves energy and water balance equations for every grid cell
- Considers soil heterogeneity and non- linear base flow
- Can include multiple soil layers with variable infiltration

VIC Routing Model



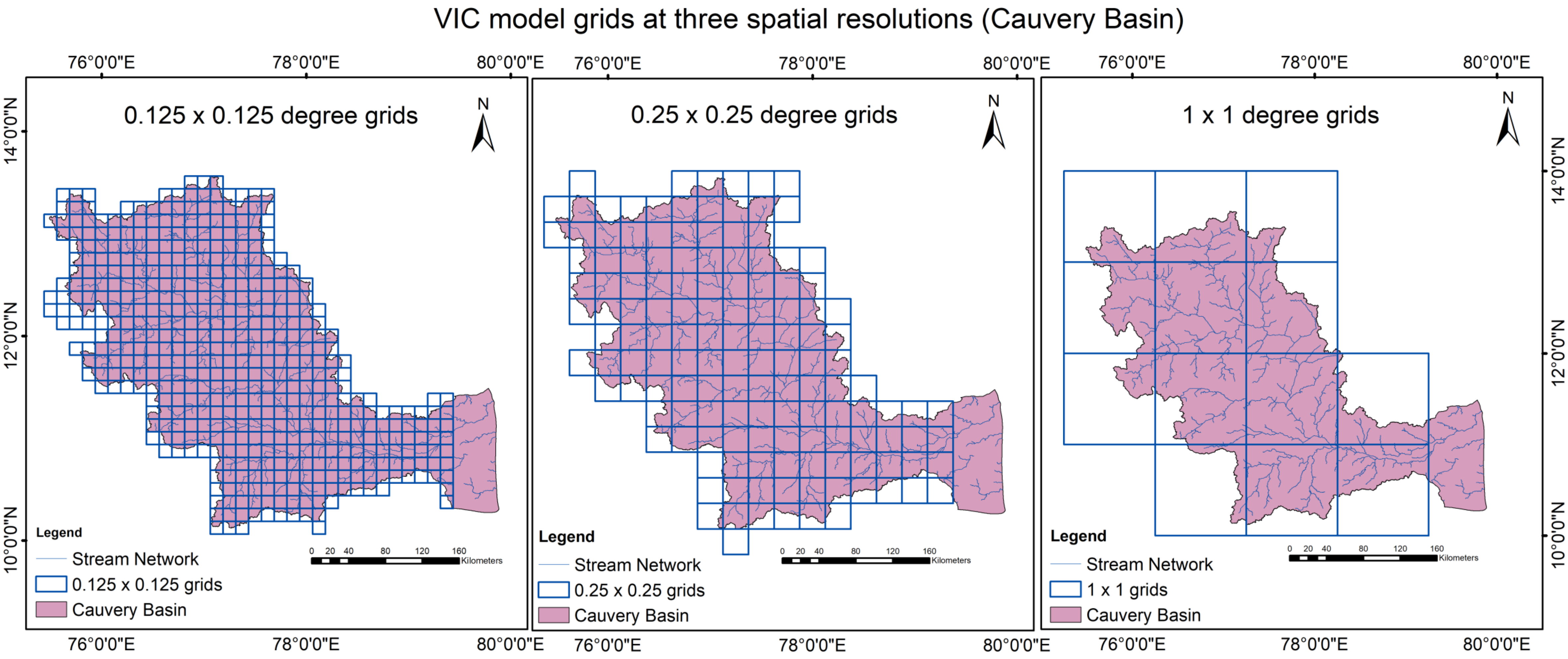
Source: Carrasco and Hamlet, Final Report for the Columbia Basin Climate Change Scenarios Project, Chapter 6, 2010.

Key components involved are land- atmospheric fluxes like precipitation, surface runoff, evapo-transpiration, baseflow and soil-moisture calculations

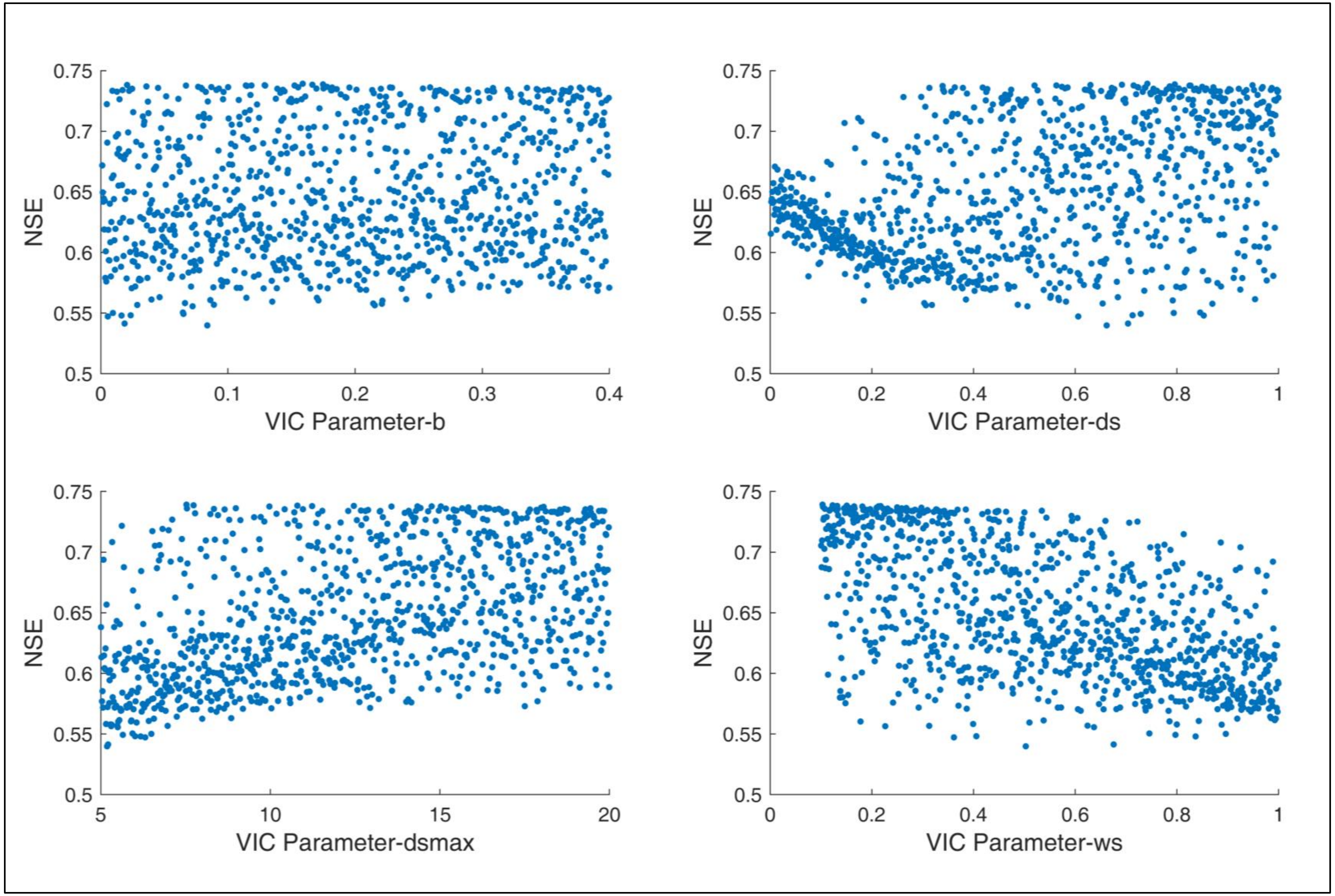
Methodology adapted in the study:

- VIC model coupled with a routing model is set up for Cauvery River Basin
- Model implemented at three spatial resolutions – $1^0 \times 1^0$, $0.25^0 \times 0.25^0$, $0.125^0 \times 0.125^0$ grid resolutions
- Simulations carried out in the water balance mode and a sensitivity analysis-based calibration approach is adopted
- Surface fluxes are computed at a daily time scale for the period 1951–2016

VIC grids set up at different spatial resolutions for Cauvery Basin, India



Results - Sensitivity Analysis of Model Parameters



Model Parameter Sensitivity – 0.25x0.25 degree grids

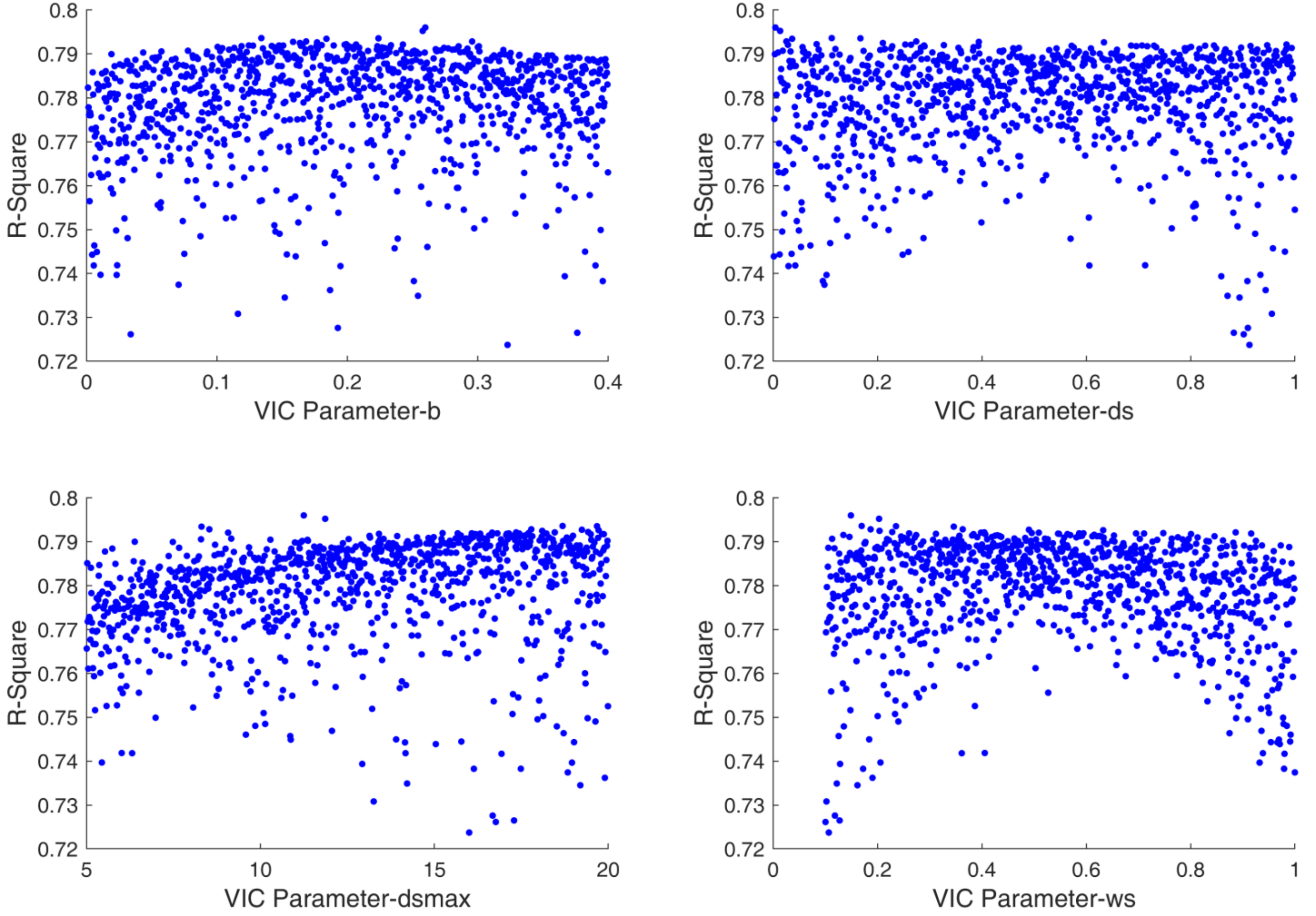
Results shown correspond to one of the sub-basins selected for calibration (Sakleshpur, approx. 587 sq.kms)

VIC parameters considered for calibration (units)	Description
b (N/A)	Variable Infiltration Curve parameter
Ds (fraction)	Fraction of maximum velocity of baseflow at which non-linear baseflow begins
Ws (fraction)	Fraction of soil moisture where non-linear flow begins
Dsmax (mm/day)	Maximum velocity of baseflow for each grid cell

Methodology

- Performance measures considered are:
  - NSE (Nash-Sutcliffe Coefficient) – Range: Inf to 1
  - R-square (Coefficient of Determination) – Range: 0 to 1
- Latin hypercube sampling of parameter space is adopted to obtain a fair distribution of parameters
- Optimized set of parameters are employed to simulate catchment water balance

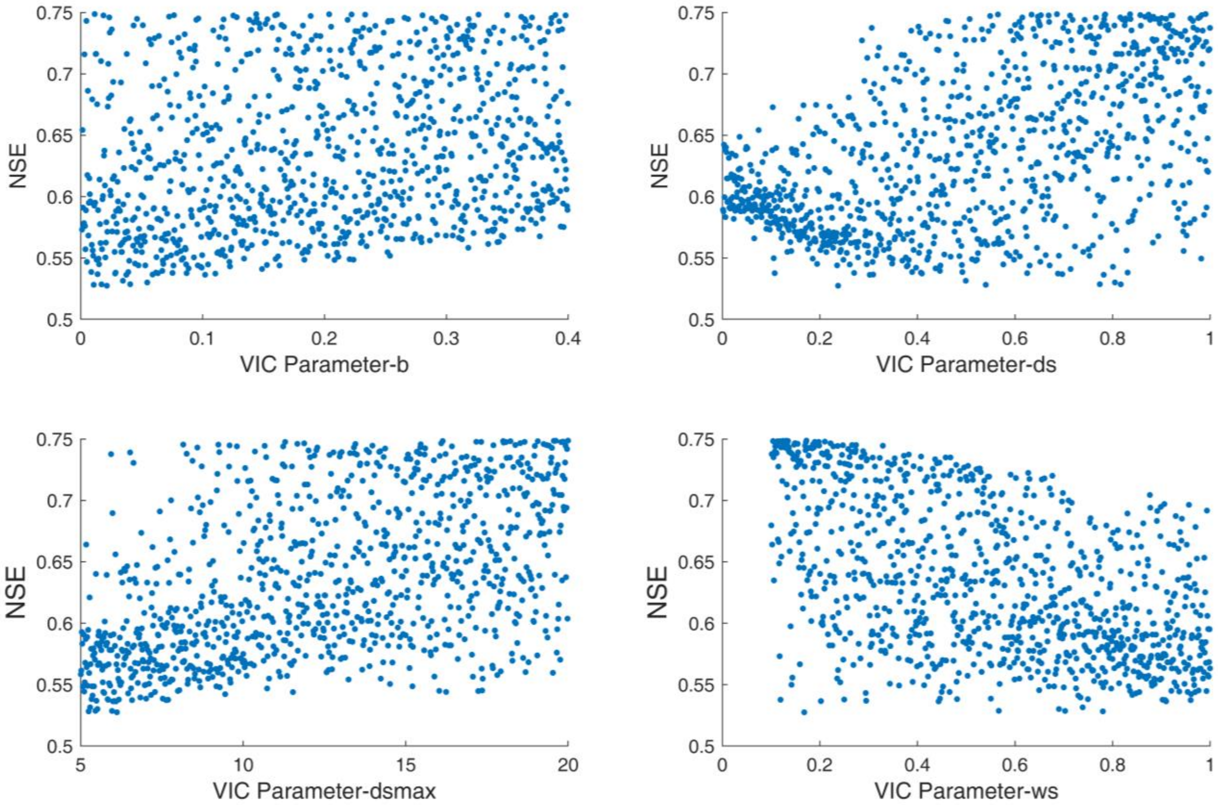
Model Parameter Sensitivity – 0.25x0.25 degree grids



Model Parameter Sensitivity – 0.25x0.25 degree grids

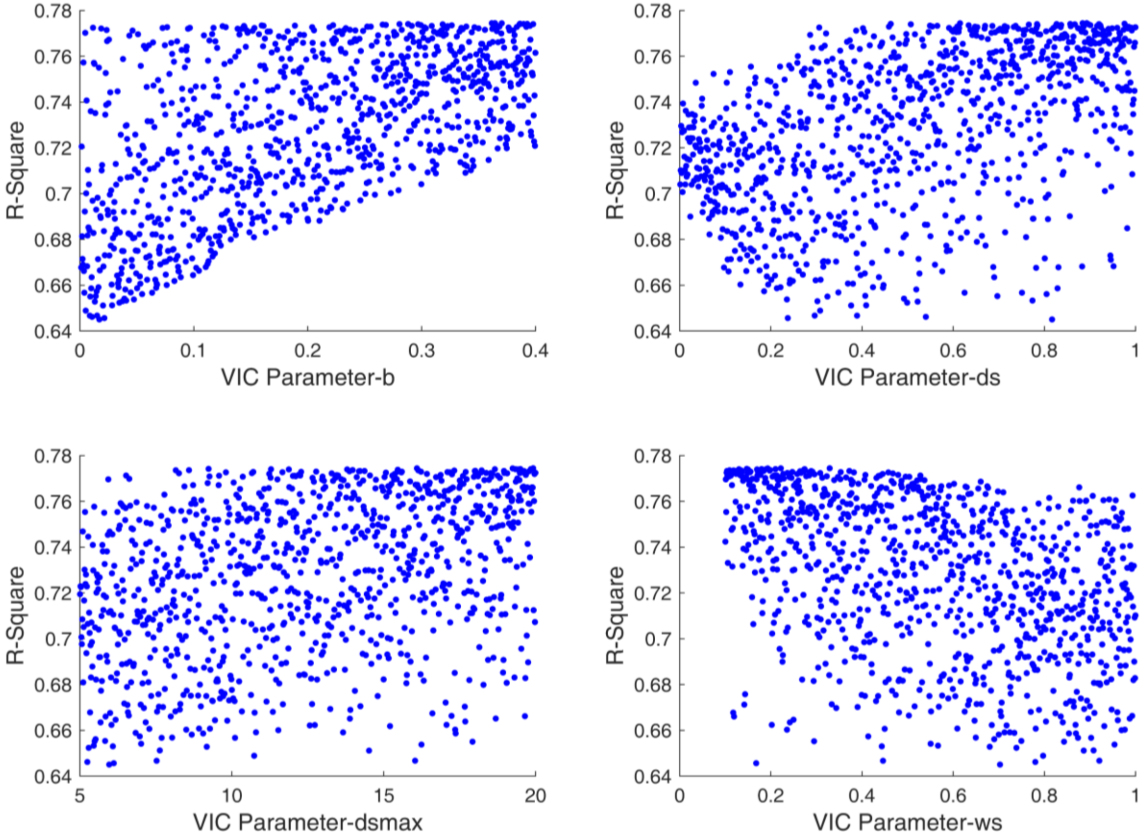
Results shown correspond to one of the sub-basins selected for calibration (Sakleshpur)

Model Parameter Sensitivity – 0.125x0.125 degree grids

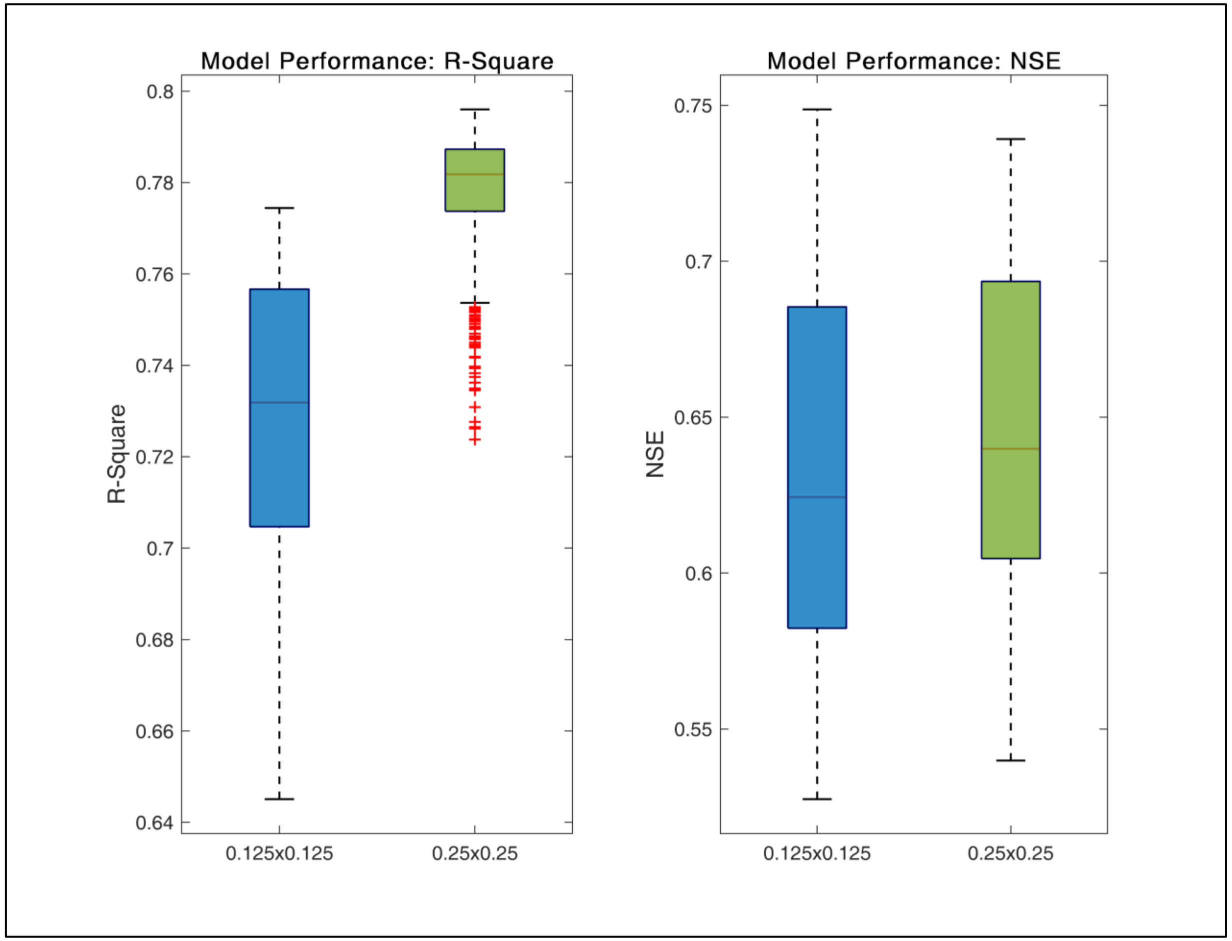


Model Parameter Sensitivity – 0.125x0.125 degree grids

Results shown correspond to one of the sub-basins selected for calibration (Sakleshpur)



Results - Sensitivity Analysis of Model Parameters



Box plots showing the variation of performance matrices for different spatial resolutions

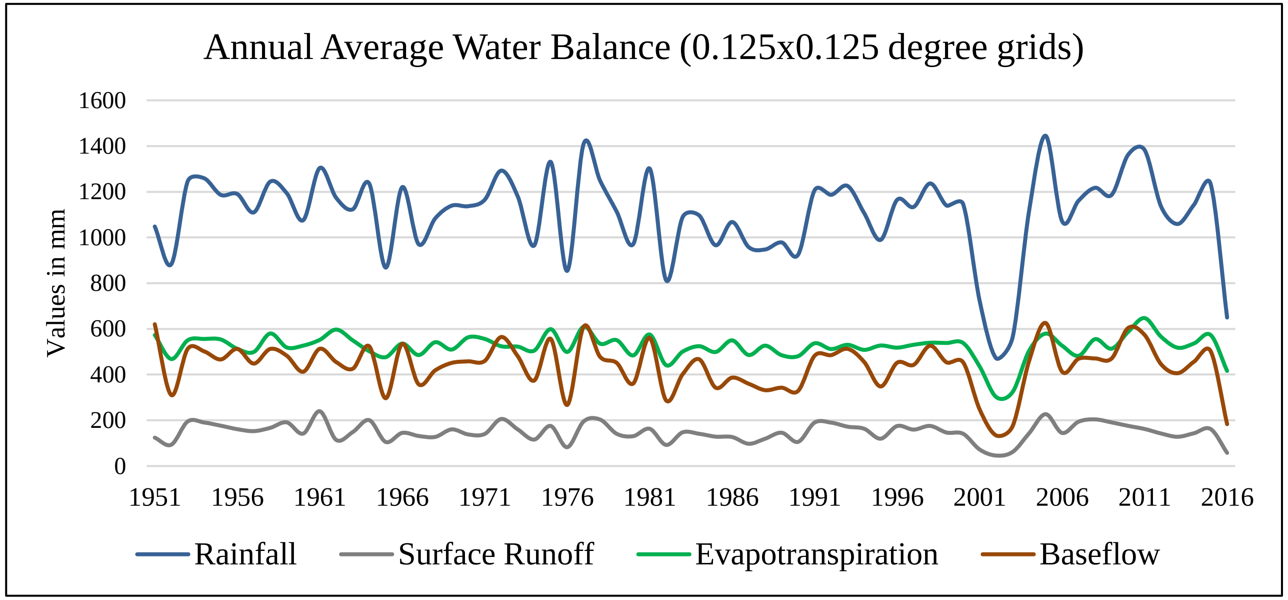
Results shown correspond to one of the sub-basins selected for calibration (Sakleshpur); 1x1 degree is excluded in the figure as the sub-basin size is smaller compared to the grid size

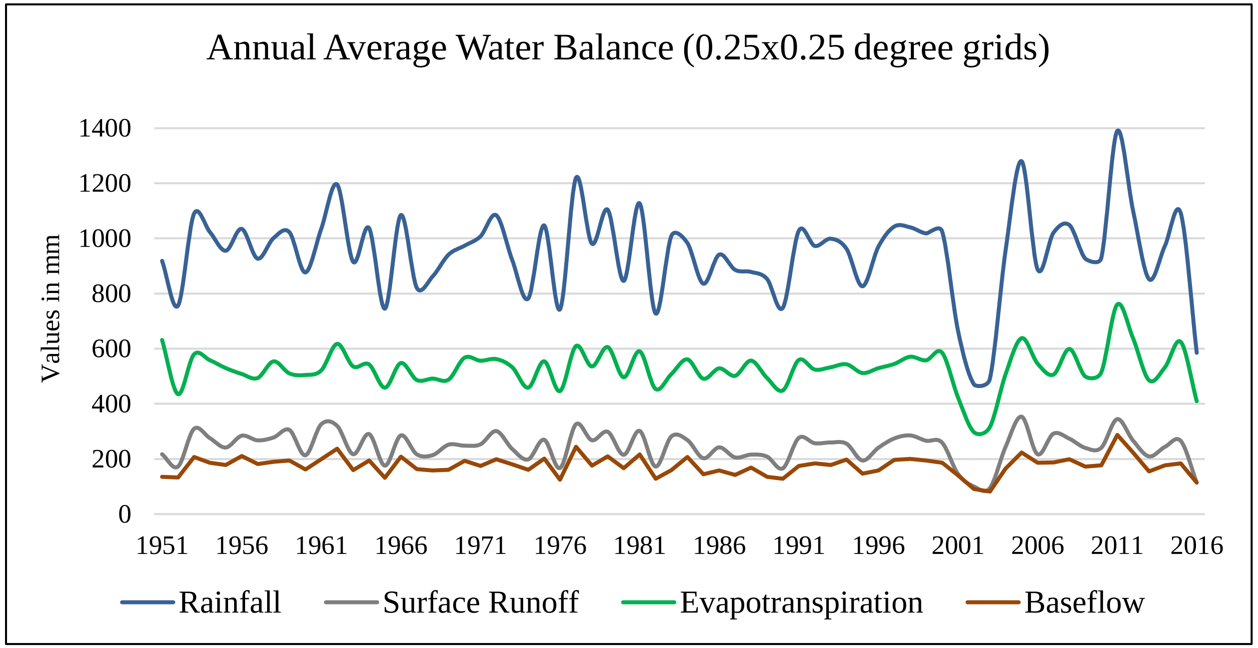
Observations

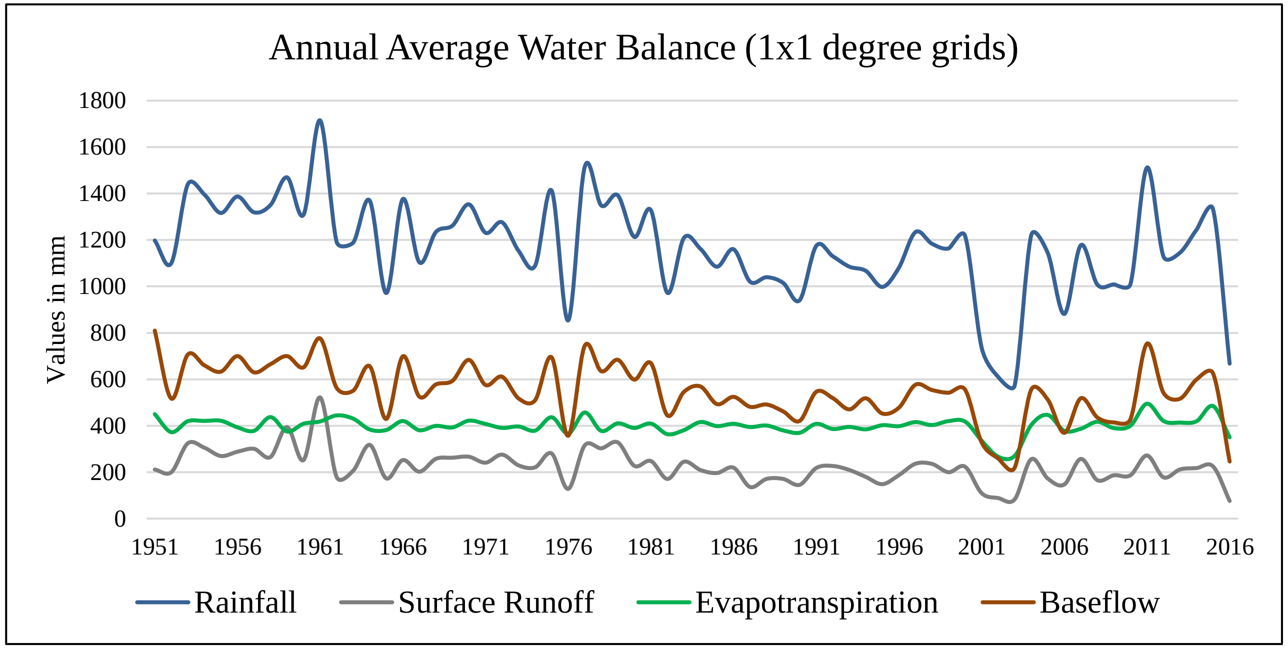
- Higher variability in performance matrices for finer resolutions
- Increasing the spatial resolution from 0.25 to 0.125 degree does not improve the performance metrices correspondingly
- Simulation and model-setup time required for the finer resolution is much higher, which necessarily may not signify model enhancement

Results: Annual Water Balance for Cauvery Basin (1951-2016)

Annual average water balance fluxes (Rainfall, Total Surface Runoff, Actual Evapotranspiration (AET) and Baseflow) are estimated for the entire basin using the VIC model simulations at three spatial resolutions



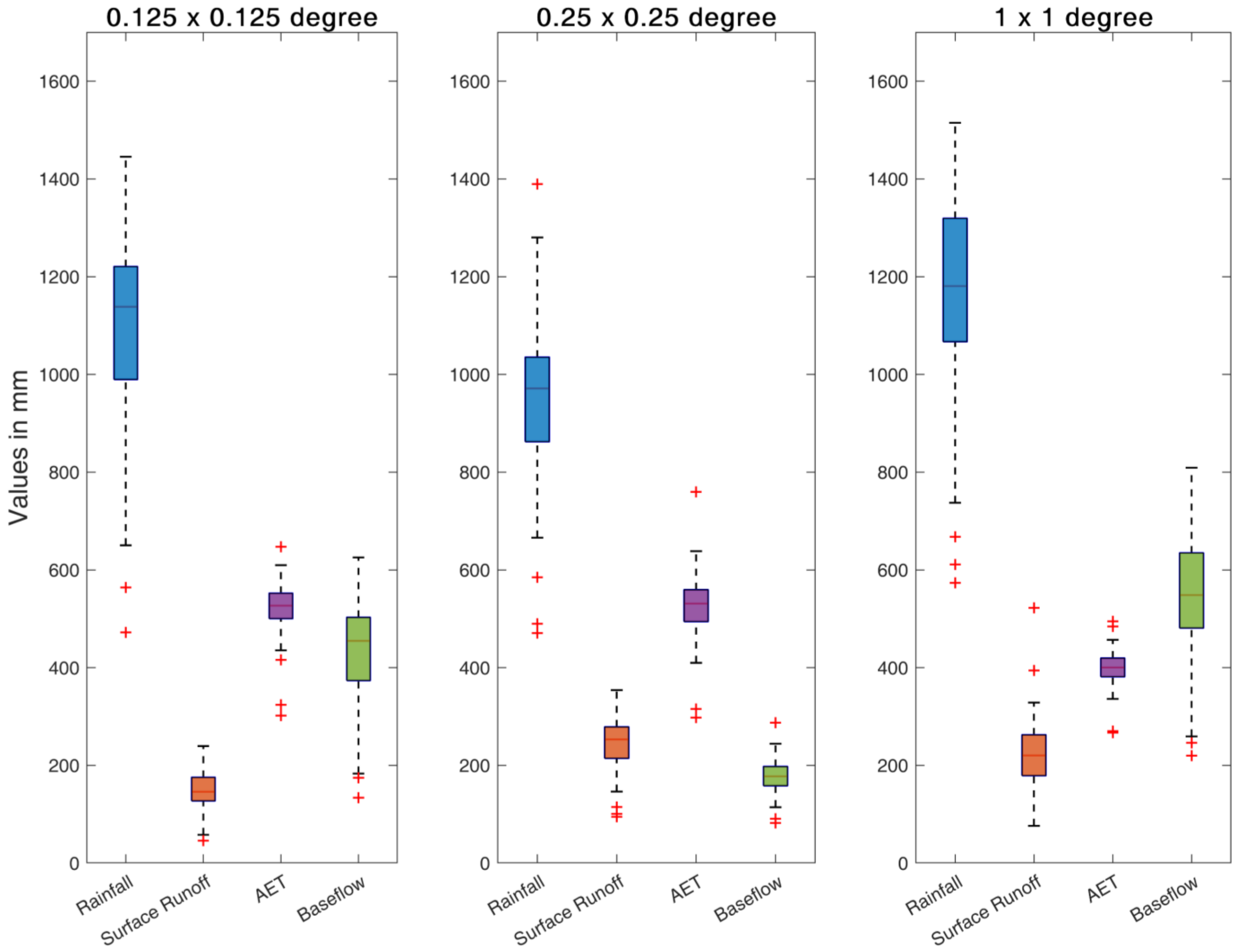




Results: Annual Water Balance for Cauvery Basin(1951-2016)

Observations

- Noticeable variability observed in the partitioning of water balance
- Rainfall-runoff partitioning remains almost constant irrespective of the spatial resolution which may be the effect of the calibration procedure
- Impact of spatial interpolation can be observed in the precipitation patterns (original data is available at 0.25x0.25 degree resolution)
- Model calibration parameters have a direct influence on the baseflow contributions



Water balance partitioning for different spatial resolutions

Conclusions

- Significant variations in the partitioning of water balance at different spatial resolutions are observed which signify the necessity of multi-objective calibration for VIC model in the selected basin

- The model's sensitivity to spatial scale decreases from 0.25 to 0.125 degree
- All the parameters considered show unidentifiable characteristics at both the spatial scales – Parsimonious model
- Such models have higher chance of success in regionalization to ungauged basins

- At different resolutions the meteorological, topographical, and land cover data are averaged spatially depending on data availability which may have a significant influence on the model results

Take home messages:

- ✓ Adopting finer resolution simulations which are computationally intensive may not necessarily lead to better model performance
- ✓ Water balance partitioning is greatly dependent on the model parameters chosen for calibration and hence site-specific modelling techniques have to be adopted
- ✓ This study provides significant insights towards adopting effective modelling strategies to ensure the adequate representation of hydrological processes in regionally complex catchments

Image Courtesy: Project UPSCAPE (CEH, IISc)

"All models are approximations.
Assumptions, whether implied or clearly stated, are never exactly true.
All models are wrong, but some models are useful."

- George E. P. Box (1919-2013)

Thank you for your attention

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