Quantifying Satellite Precipitation Error Propagation Using a Hydrologic Analytical Framework

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Introduction

This study introduces the use of a hydrologic analytical framework to investigate the error propagation of satellite precipitation products in hydrologic simulations. Specifically, the analytical framework allows the decomposition of error in catchment flood response into components representing the space and time characteristics of precipitation, runoff generation and routing. The aim of this study is to quantify the contributions to error in flood event properties from different error sources in catchment flood response.

Hydrologic Analytical Framework

Catchment-average storm rainfall excess (mm/h):

$[R]_{at} = R1 + R2 + R3 + R4$

R1: Product between catchment- and storm-average rainfall and runoff coefficient

R2: Temporal covariance between the catchment-average rainfall and runoff coefficient

R3: Spatial covariance between storm-average rainfall and runoff coefficient

R4: Temporal correlation between spatial variation of precipitation and runoff coefficient

Expectation of catchment response time (h):

$E(\Phi) = \underbrace{E1 + E2}_{E(T_r)} + \underbrace{E3}_{E(T_h)} + \underbrace{E4 + E5}_{E(T_n)}$

E1: Half-length of the rainfall event

E2: Time distance from the event midpoint to the temporal mass center of catchment-average rainfall excess

E3: Mean of hillslope routing time

E4: Spatial mean of channel routing time

E5: Spatial covariance between storm-average rainfall excess and channel routing time

Variance of catchment response time (h^2):

$var(\Phi) = \underbrace{v1 + v2}_{var(T_r)} + \underbrace{v3}_{var(T_h)} + \underbrace{v4 + v5}_{var(T_n)} + \underbrace{2c}_{cov(T_r, T_n)}$

v1: Variance of runoff generation time generated by an invariant catchment-average rainfall excess

v2: Additional variance cause by the temporal variation in catchment-average rainfall excess

v3: Variance of hillslope routing time generated by an invariant storm-average rainfall excess

v4: Variance of channel routing time generated by an invariant storm-average rainfall excess

v5: Additional variance cause by the spatial variation in storm-average rainfall excess with respect to the channel routing time

c: Movement of runoff generation over the catchment channel network

Cumulative Volume (mm):

$V = \int_{T_F} Qdt$

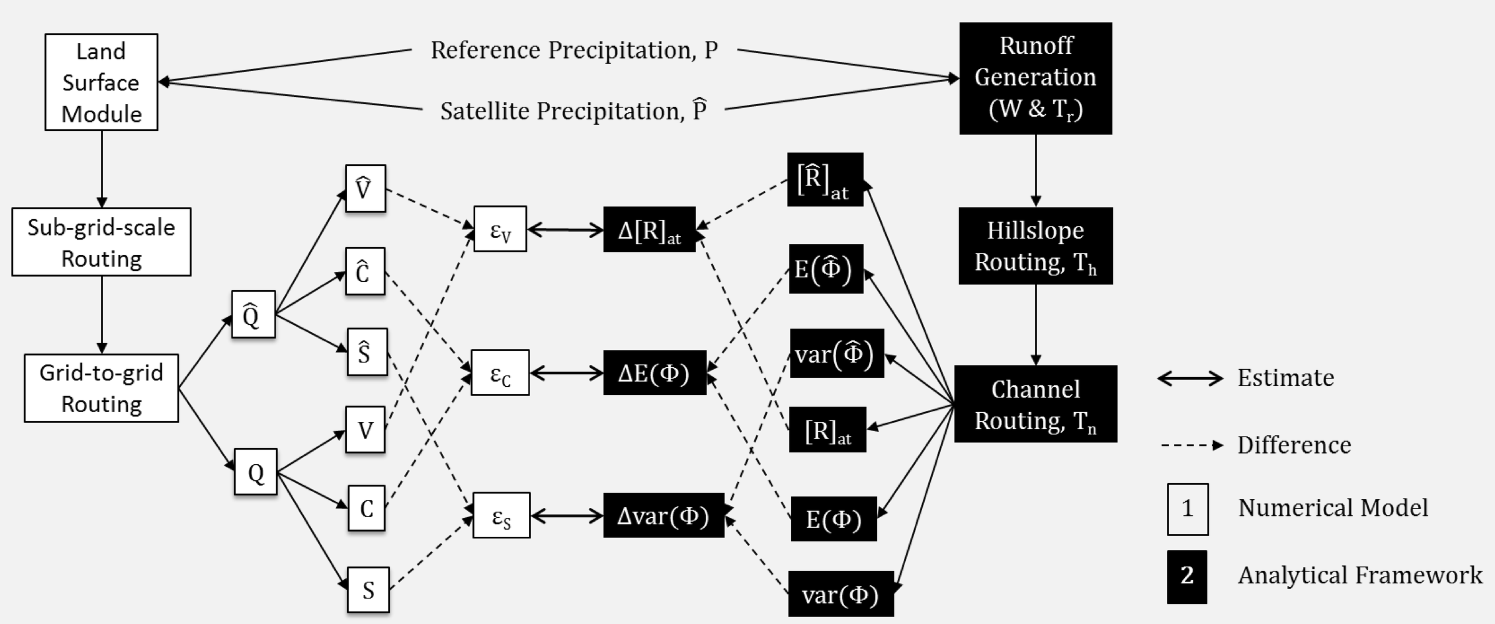
Mass Center (h):

$C = \frac{\int_{T_F} t \cdot Qdt}{\int_{T_F} Qdt}$

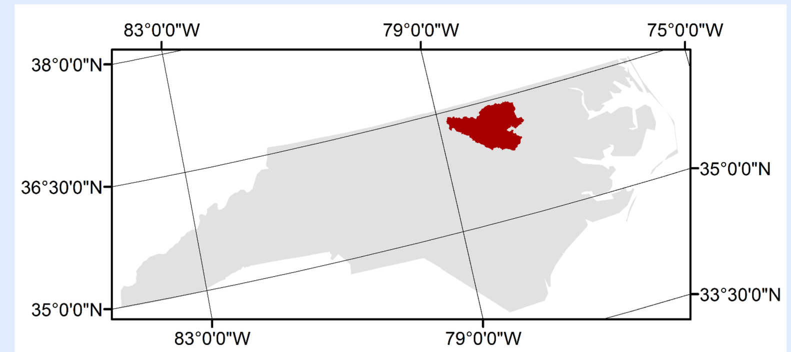
Dispersion (h):

$S = \sqrt{\frac{\int_{T_F} (t-C)^2 Qdt}{\int_{T_F} Qdt}}$

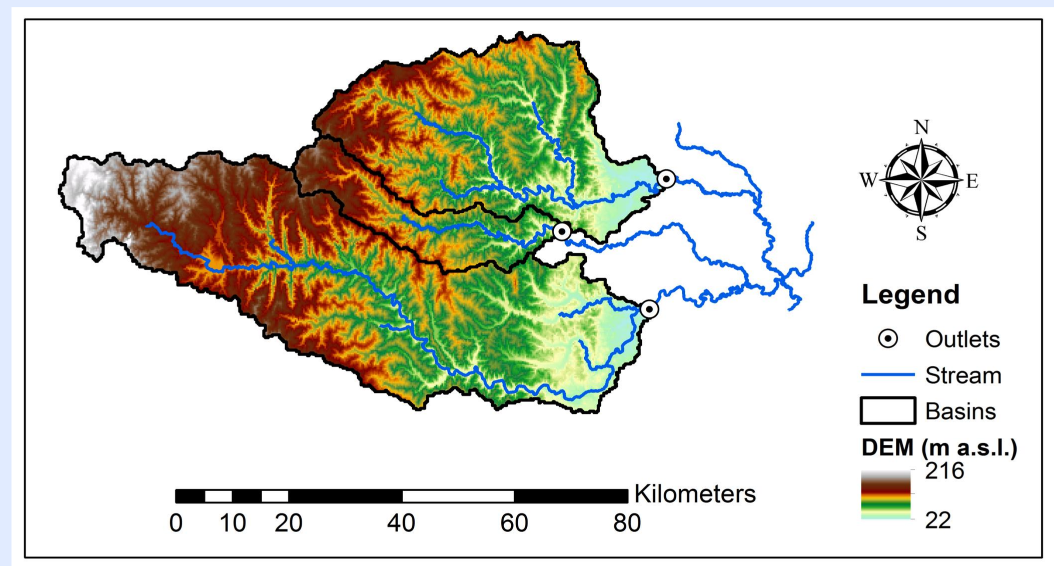
Decomposition of Error



Study Area & Datasets

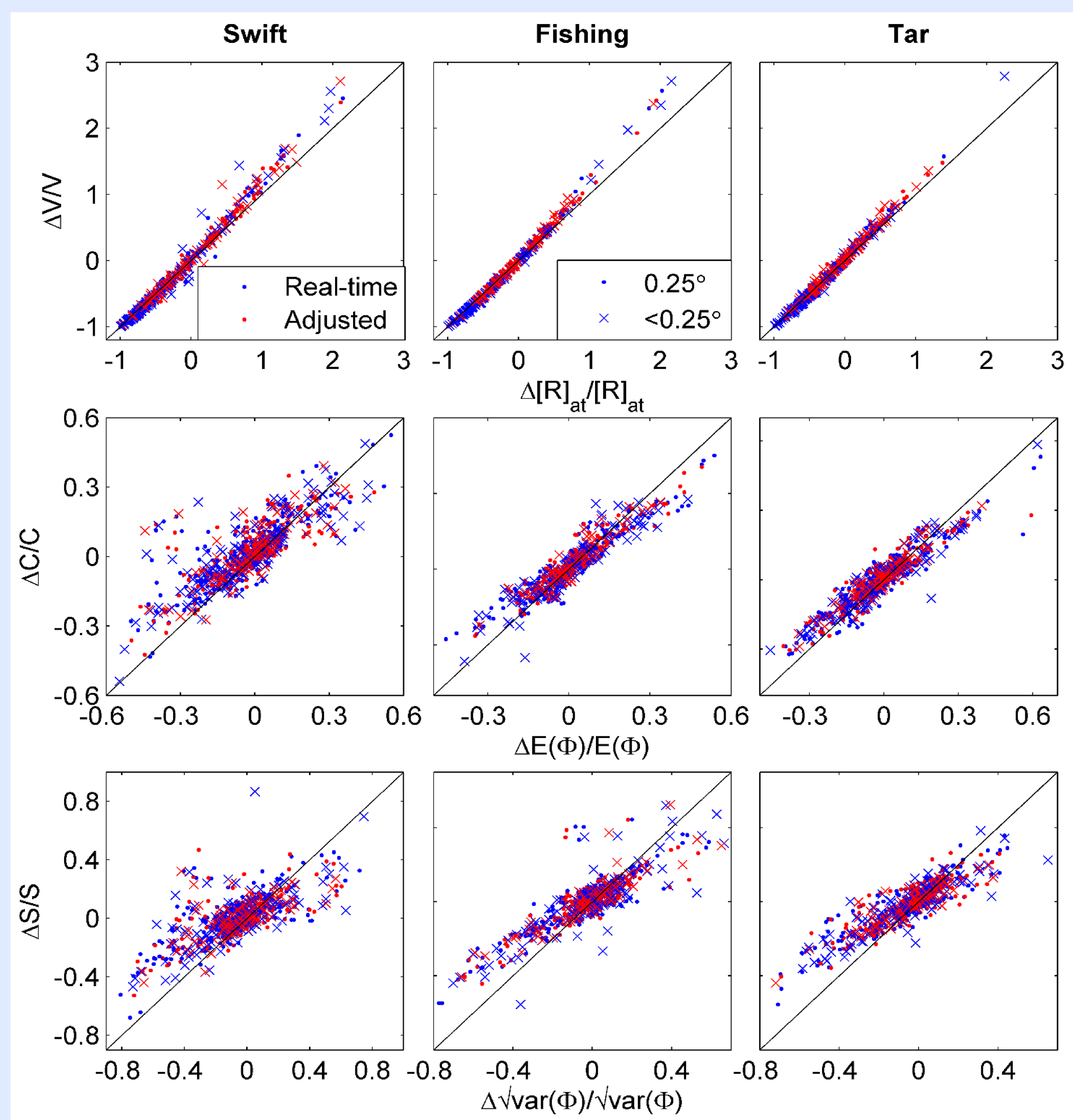


Basin Name	Area (km²)	Num. of Event
Swift	426	55
Fishing	1374	50
Tar	2406	55



T: 3B42-RT	C: CMORPH	P: PERSIANN
T_{cca}: 3B42-CCA	C_g: adjusted-CMORPH	P_g: adjusted-PERSIANN
T_g: 3B42-V7	HC: high resolution CMORPH	P_{ccs}: PERSIANN-CCS
G: GSMaP-MVK	HC_g: adjusted-high resolution CMORPH	Ref: Stage IV radar/gauge product
G_g: adjusted-GSMaP-MVK		

Sensitivity Tests

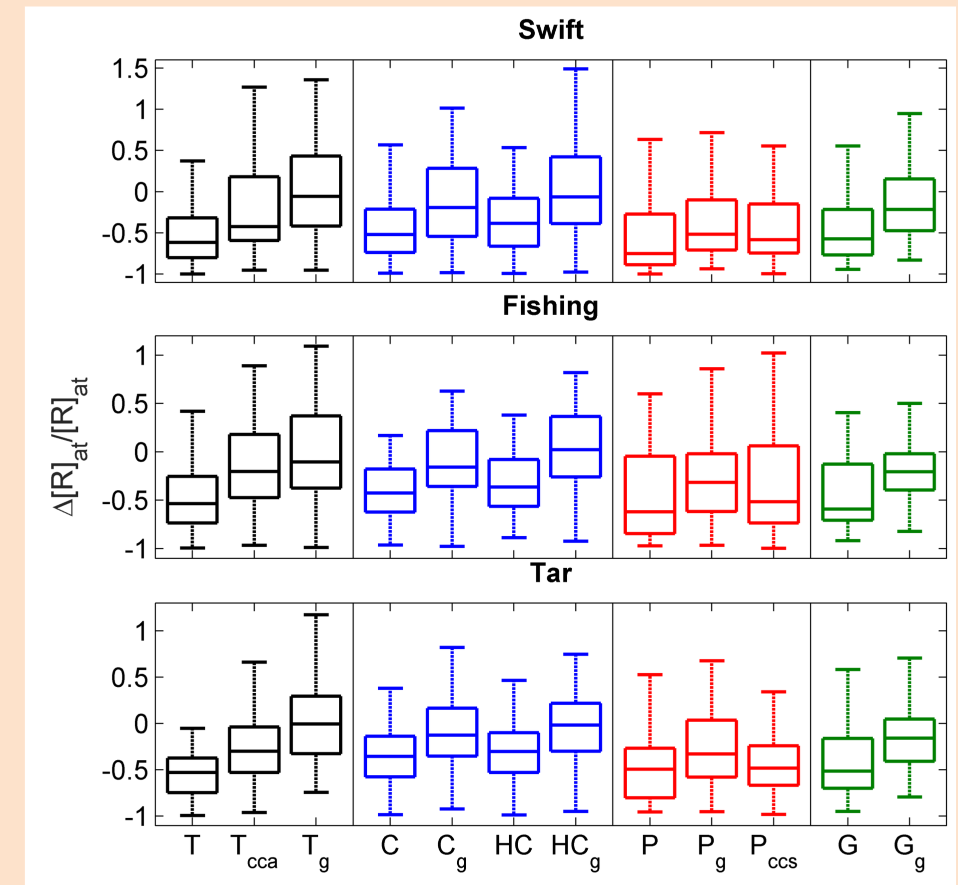


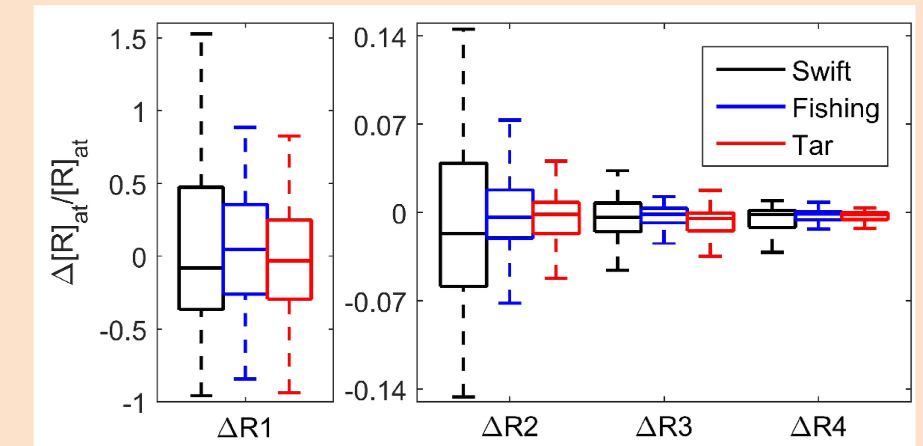
- Clear linear relationship;
- Greater magnitudes of the random error;
- Higher consistency in ΔV (ΔC and ΔS) estimation from the real-time/0.25° (adjusted/<0.25°) products

Magnitudes of Error Quantities

Error in catchment-average storm rainfall excess:

$\Delta[R]_{at} = \underbrace{\hat{R}1 - R1}_{\Delta R1} + \underbrace{\hat{R}2 - R2}_{\Delta R2} + \underbrace{\hat{R}3 - R3}_{\Delta R3} + \underbrace{\hat{R}4 - R4}_{\Delta R4}$

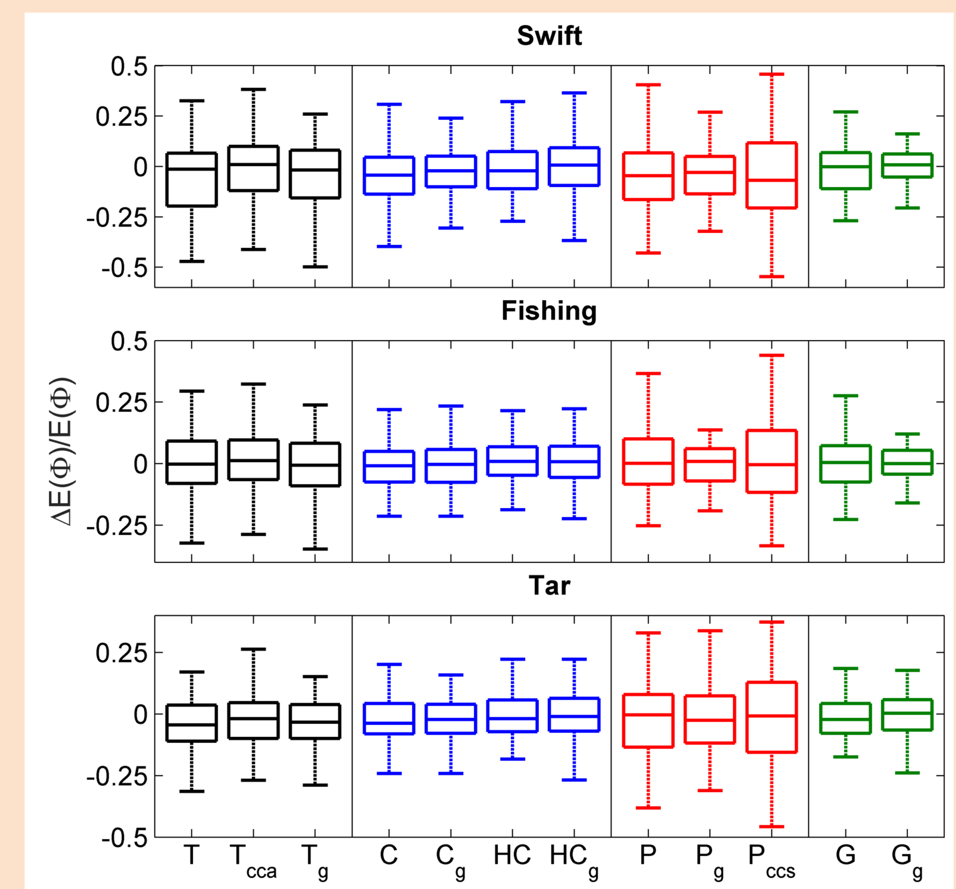


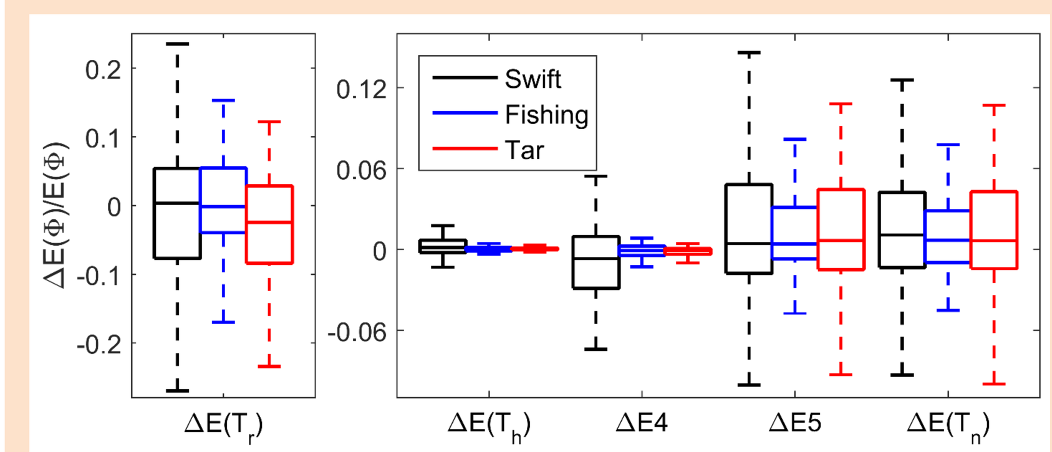


- $\Delta R1$, $\Delta R2$, $\Delta R3$ and $\Delta R4$ decrease with increases in basin scale;
- $\Delta R1$ is the main contributor to $\Delta[R]_{at}$;
- Relative importance of the time and space terms are higher for smaller basin;

Error in expectation of catchment response time:

$\Delta E(\Phi) = \underbrace{\hat{E}1 - E1}_{\Delta E1} + \underbrace{\hat{E}2 - E2}_{\Delta E2} + \underbrace{\hat{E}3 - E3}_{\Delta E3} + \underbrace{\hat{E}4 - E4}_{\Delta E4} + \underbrace{\hat{E}5 - E5}_{\Delta E5}$

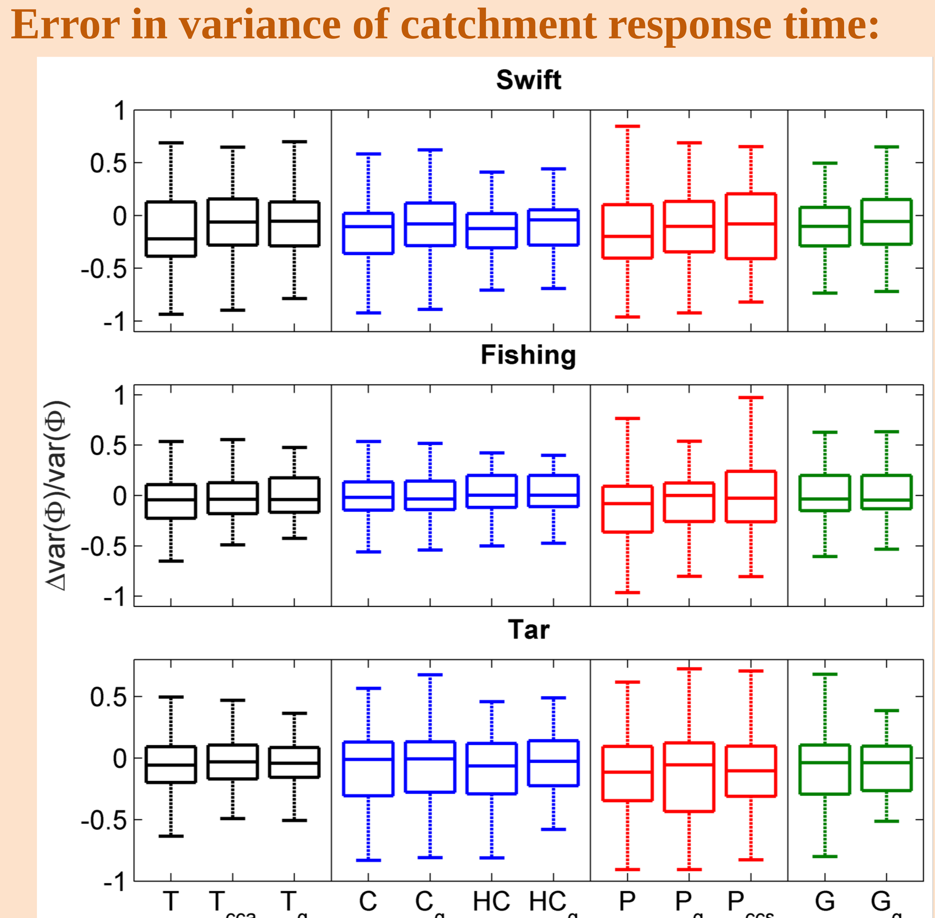


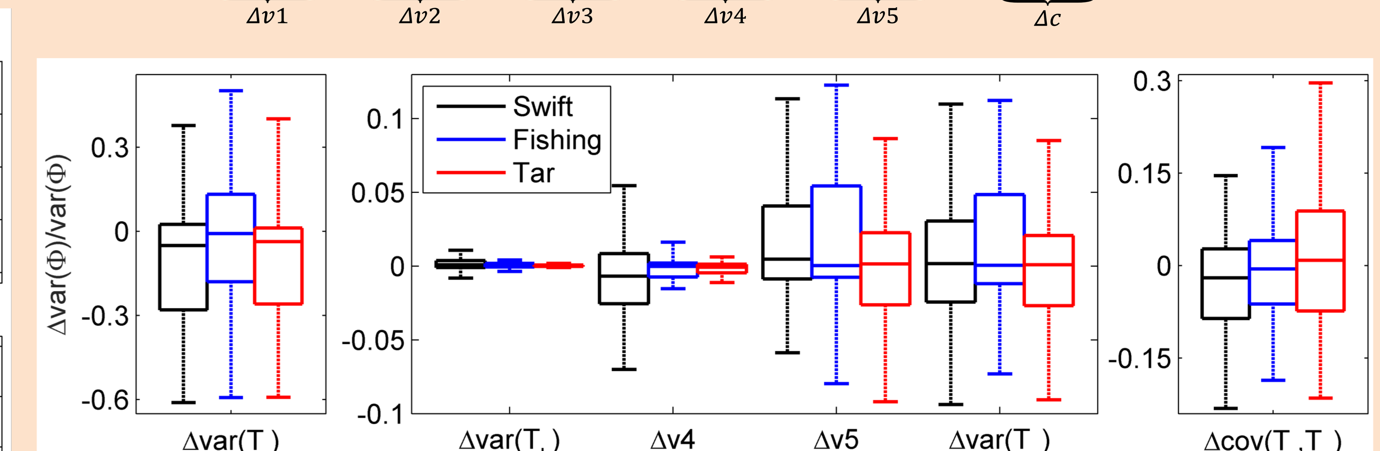


- The contributions to $\Delta E(\Phi)$ from the runoff generation stage and routing stage are comparable;
- Higher consistency for gauge-adjusted and high resolution products;

Error in variance of catchment response time:

$\Delta var(\Phi) = \underbrace{\hat{v}1 - v1}_{\Delta v1} + \underbrace{\hat{v}2 - v2}_{\Delta v2} + \underbrace{\hat{v}3 - v3}_{\Delta v3} + \underbrace{\hat{v}4 - v4}_{\Delta v4} + \underbrace{\hat{v}5 - v5}_{\Delta v5} + 2\underbrace{(\hat{c} - c)}_{\Delta c}$





- Main contributions to $\Delta var(\Phi)$ are from the runoff generation stage;
- Underestimation of runoff generation and dispersion;
- Temporal information outweighs the spatial one in contributing to the error of flood properties.

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