Global long-term sub-daily reanalysis of fluvial floods through high-resolution modeling

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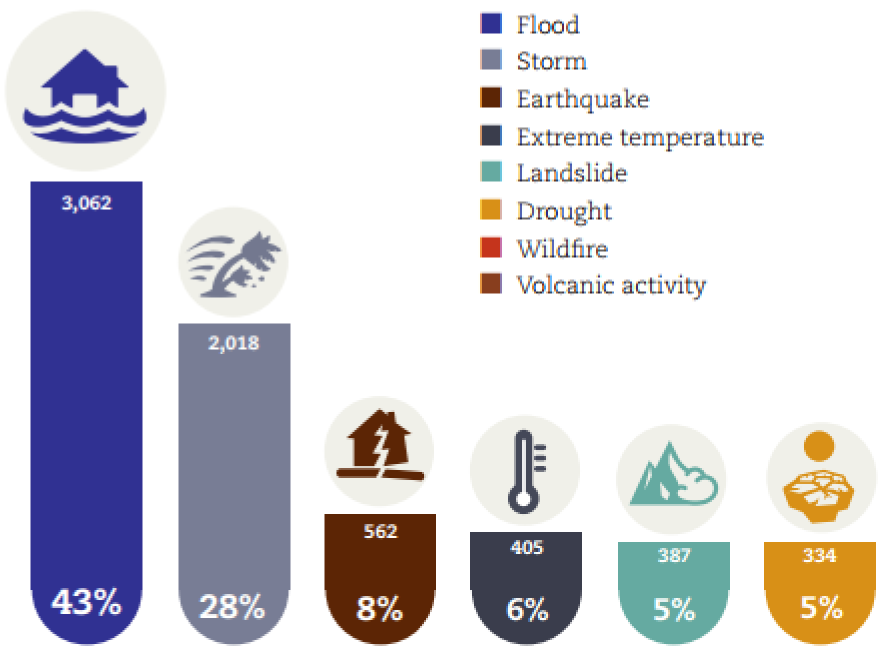
Motivation

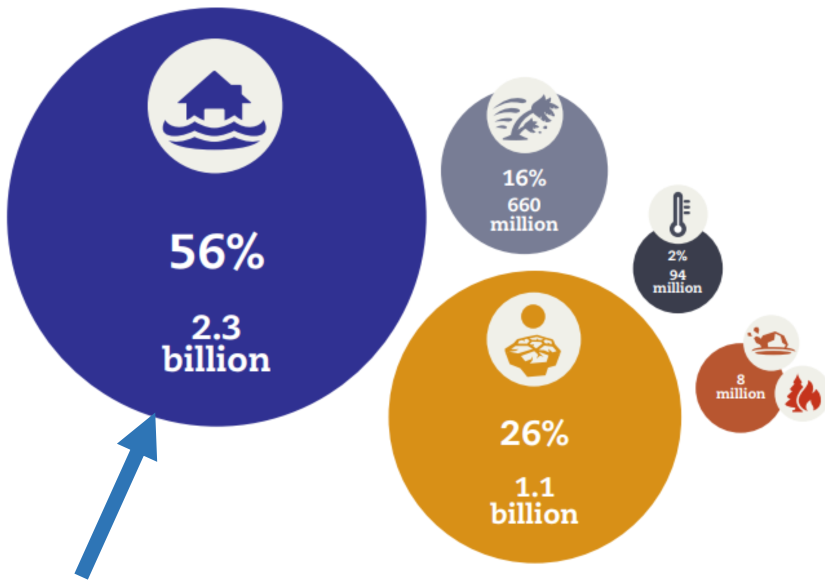
- Flood is one of the most devastating natural disasters of severe societal, economic, and environmental consequences.

Percentage of occurrences of natural disasters by disaster type (1995-2015)

Number of people affected by weather-related disasters (1995-2015)



Flood



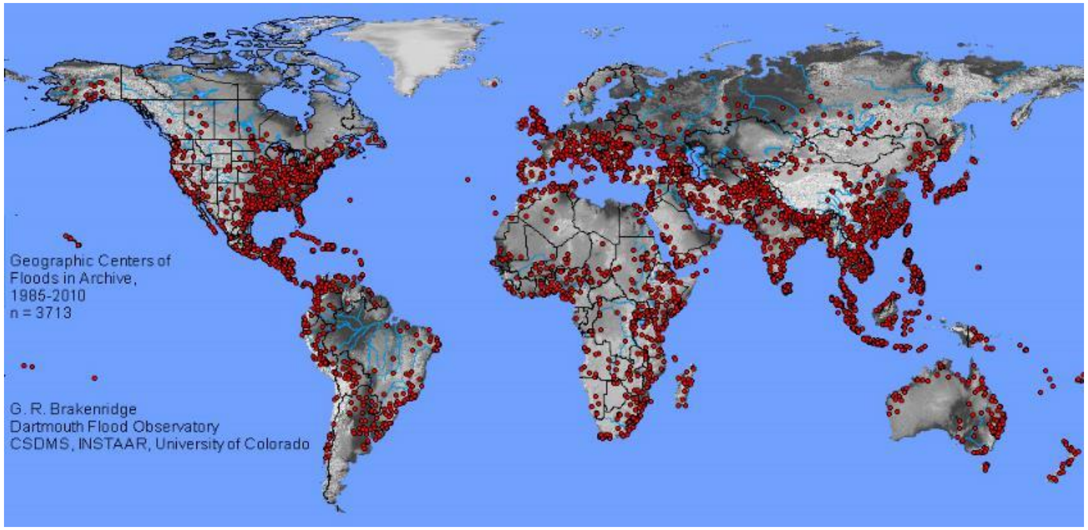
Flood

2015 *UN Report*

Motivation

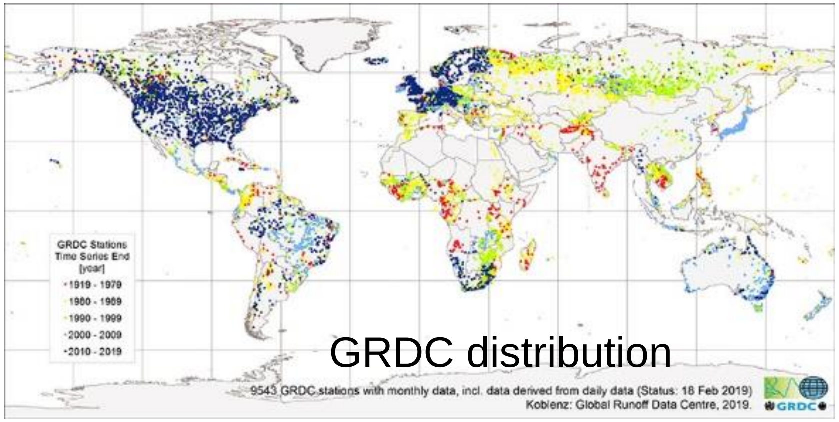
- The characteristics of floods:
  - Happen within a very short time: hours to days
  - Happen within a very small area: a few river reaches
  - Wide geographic distributions globally

Geographic centers of floods (1985-2010)
http://floodobservatory.colorado.edu/Archives/index.html

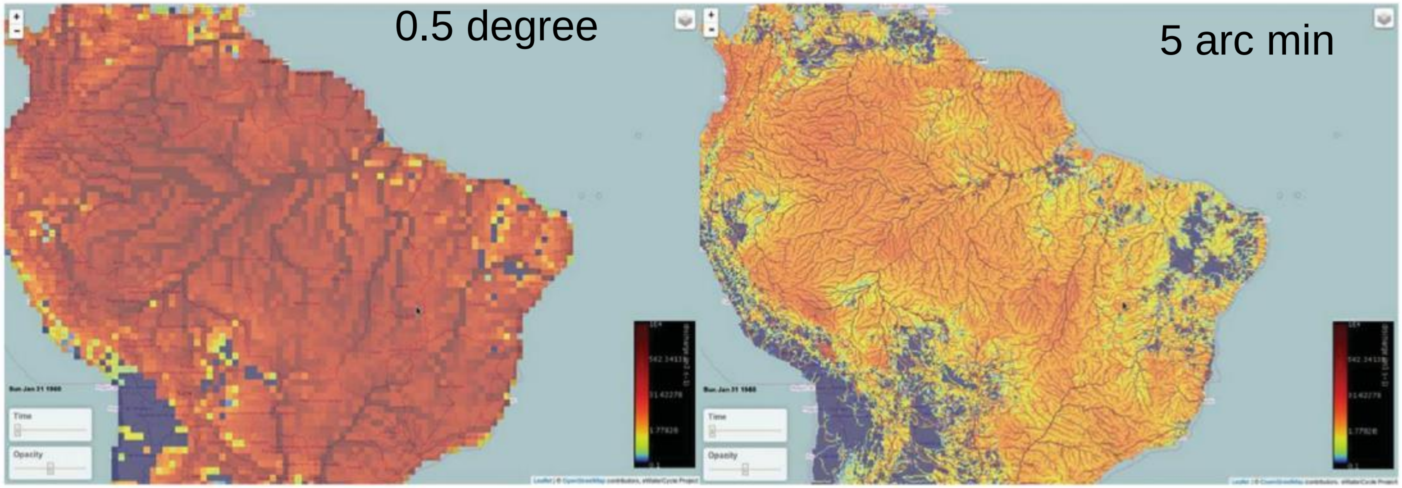


Grand challenges in global flood analysis

- In-situ observations: limited availability
  - Uneven distribution
  - Decreasing gauges
  - Daily & monthly records

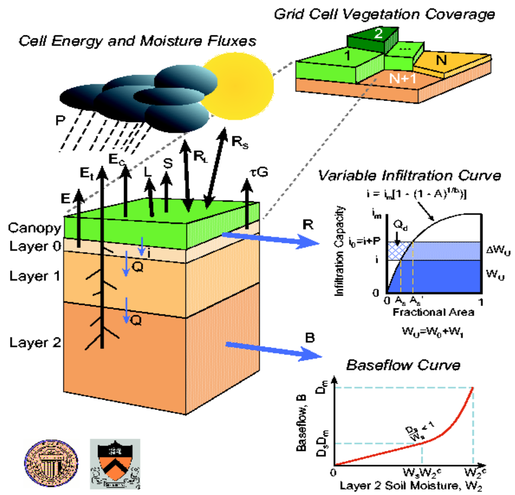


- Existing modeling efforts: lack the sufficiently high spatial /temporal resolutions

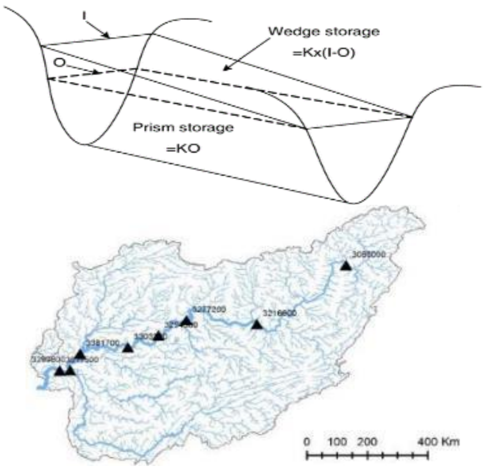


Bierkens et al., *WRR*, 2015

Global sub-daily modeling framework



VIC + RAPID

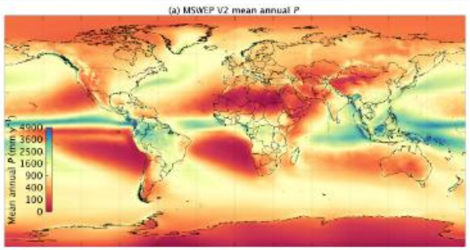


1. Capture local and "flashy" events: 0.05° 3-hourly + 90m DEM based rivers

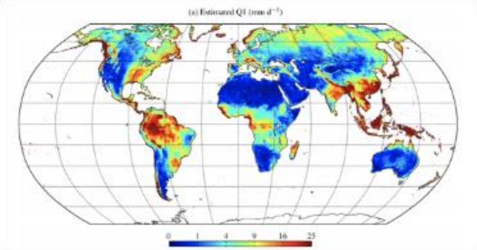
2. Long-term historical reanalysis: 1979 – 2019

3. Potential for real-time monitoring and forecast

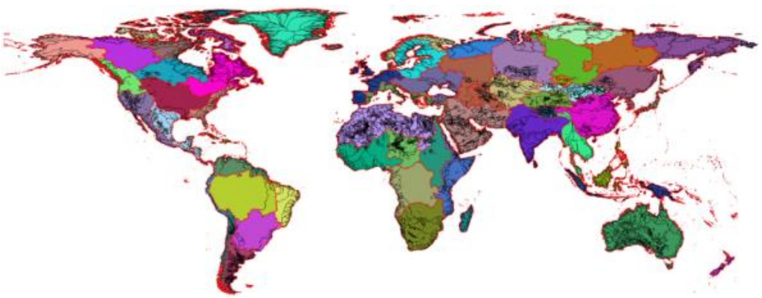
Global sub-daily modeling framework



Optimally merged
multi-source Precip
MSWEP



Global runoff
characteristics



90 m MERIT-derived Hydrography
（~2.94 million river reaches）

calibration

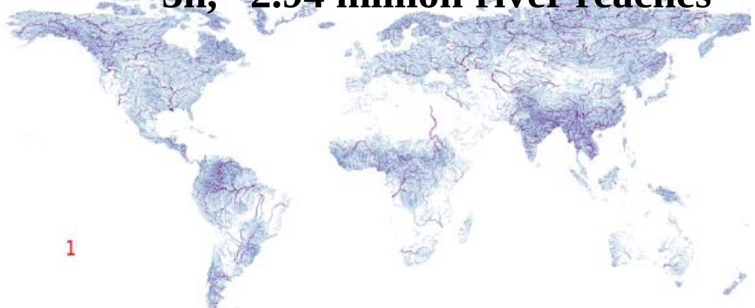
LSM
(VIC)

0.05°, 3h
runoff

Bias
correction

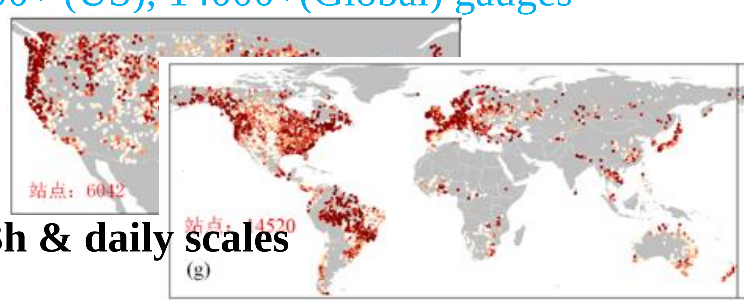
River routing
(RAPID)

Discharge（1979-present)
3h, ~2.94 million river reaches



Quality Assessment

6000+ (US), 14000+(Global) gauges

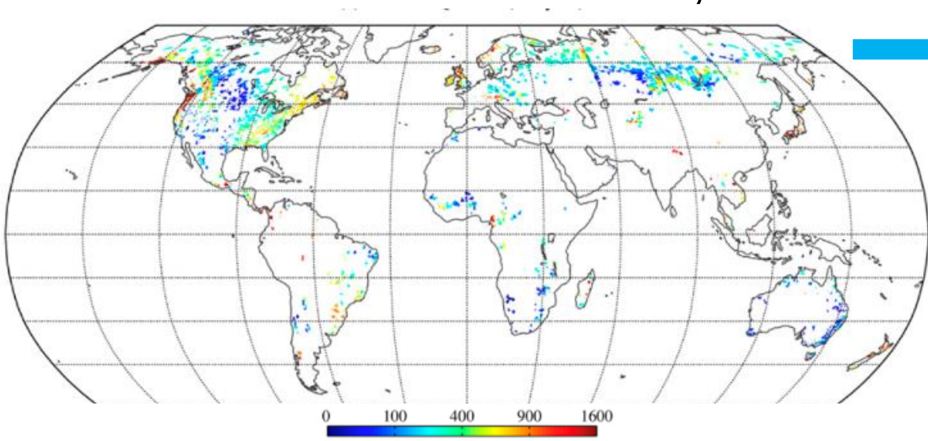


3h & daily scales

Runoff calibration/bias correction target

- Global runoff characteristics -- GSCD

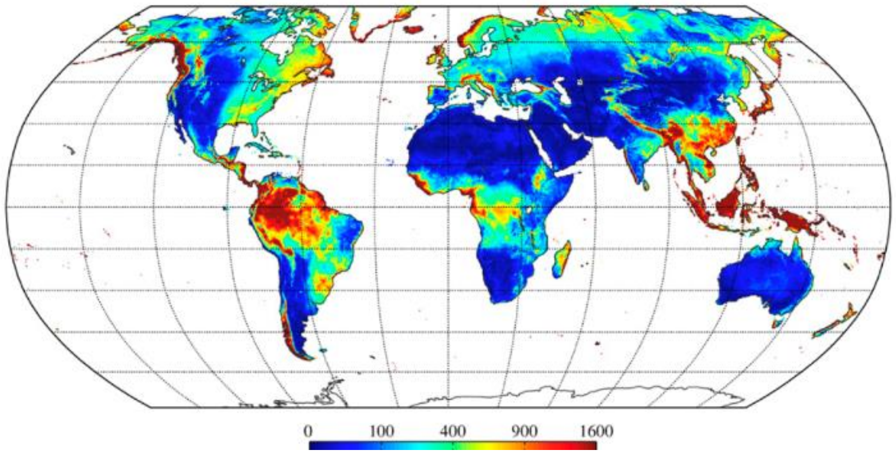
from >3,000 naturalized catchments



QMEAN (mm/yr)

<u>Regionalization via ML</u>: trained against 20 climate, topography, geology, land cover, soil factors

Similarly, Q_1, Q_5, Q_{10}, Q_{20}, Q_{50}, Q_{80}, Q_{90}, Q_{95}, Q_{99}, and BFI are derived globally (Testing R^2: 0.55 – 0.93)



QMEAN (mm/yr)

Beck et al. *JHM*, 2015

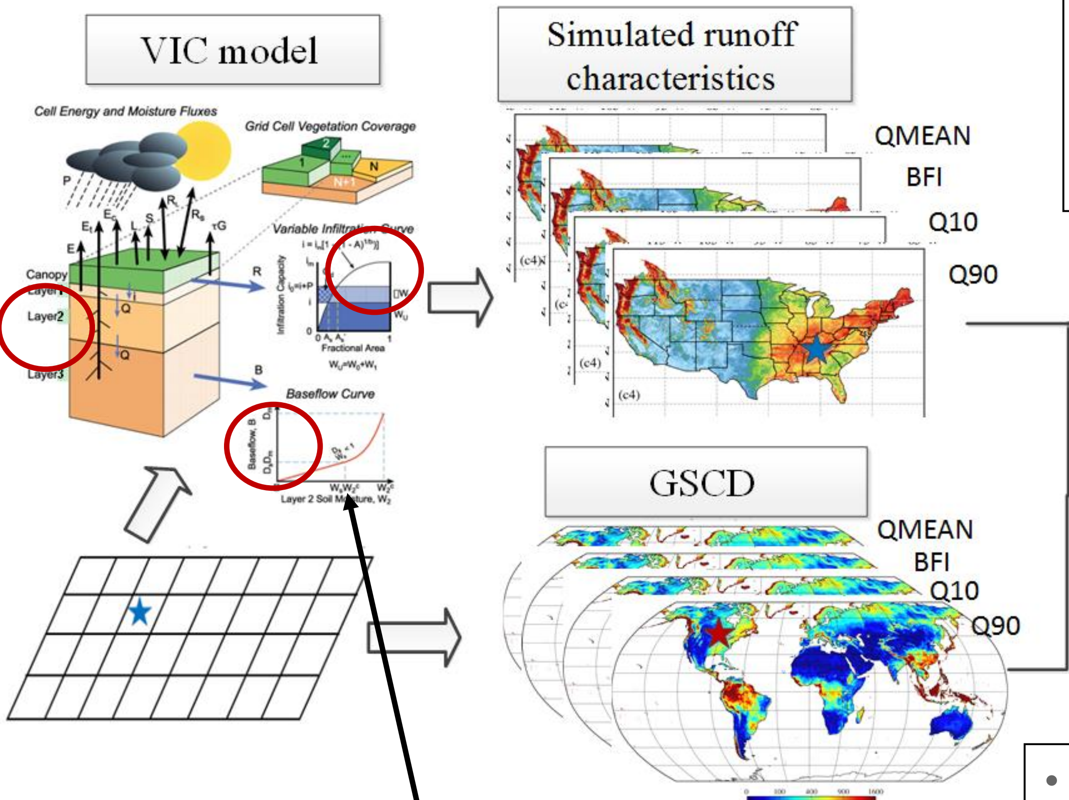
Pixel-level model calibration

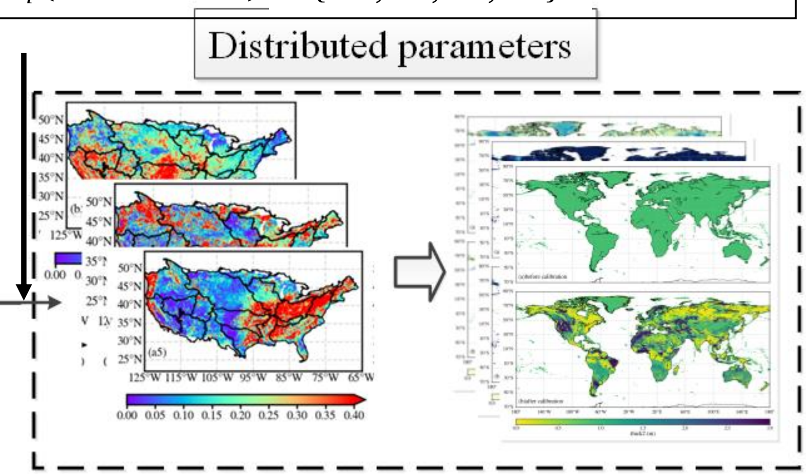
- Calibrate each pixel independently against runoff characteristics

Objective function

$$Obj = w_1 \left| \ln\left(\frac{QMEAN_m}{QMEAN_o}\right) \right| + w_2 \left| \ln\left(\frac{BFI_m}{BFI_o}\right) \right| + w_3 \left| \ln\left(\frac{Q_{10m}}{Q_{10o}}\right) \right| + w_4 \left| \ln\left(\frac{Q_{90m}}{Q_{90o}}\right) \right|$$

$$w_i\,(i = 1, 2, 3, 4) \quad = \{0.6, 0.2, 0.1, 0.1\}$$





- Variable infiltration curver parameter b_i
- Thickness of soil layer 2 $thick_2$
- Fraction of the maximum velocity of baseflow where nonlinear baseflow begins Ds

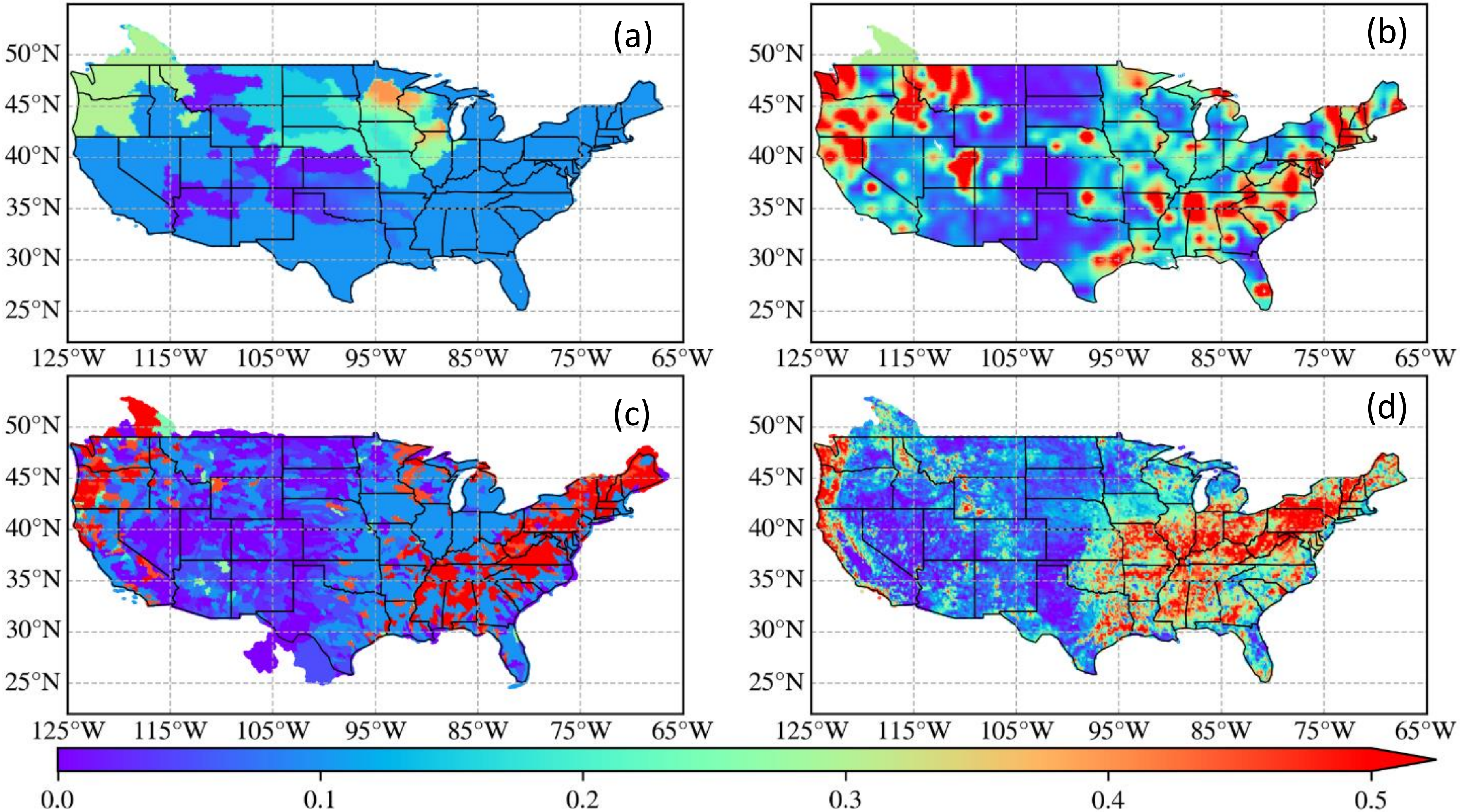
- Four runoff characteristics

  Q_{MEAN}: mean annual runoff per unit area (mm/yr)
  BFI: baseflow index
  Q_{10}: high runoff (mm/d)
  Q_{90}: low runoff (mm/d)

Yang et al. *WRR*, 2019

Pixel-level model calibration

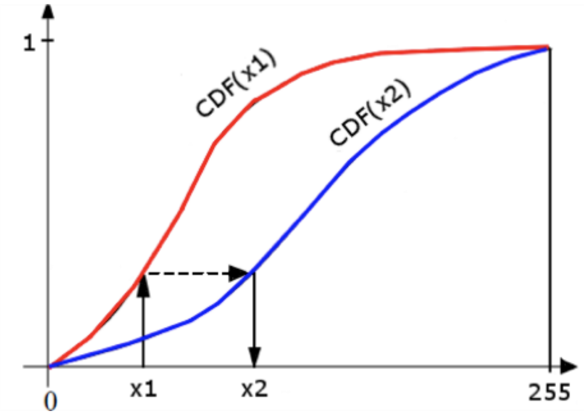
- Infiltration Curve Parameter in VIC model



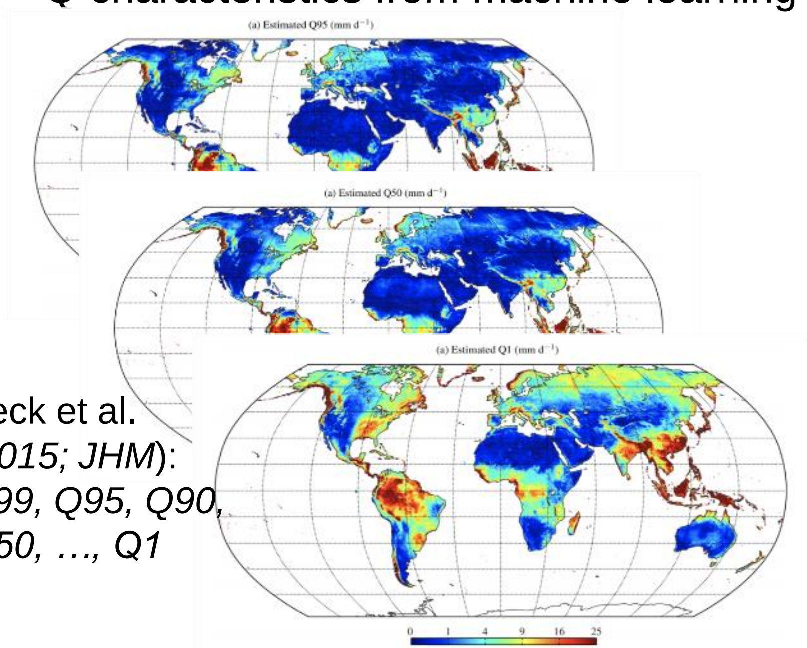
(a) Pre-calibration (NLDAS-2); (b) Troy et al., 2008; (c) Oubeidillah et al, 2014; (d) After calibration

Sparse CDF-matching for bias correction

- Traditional bias-correction: CDF matching

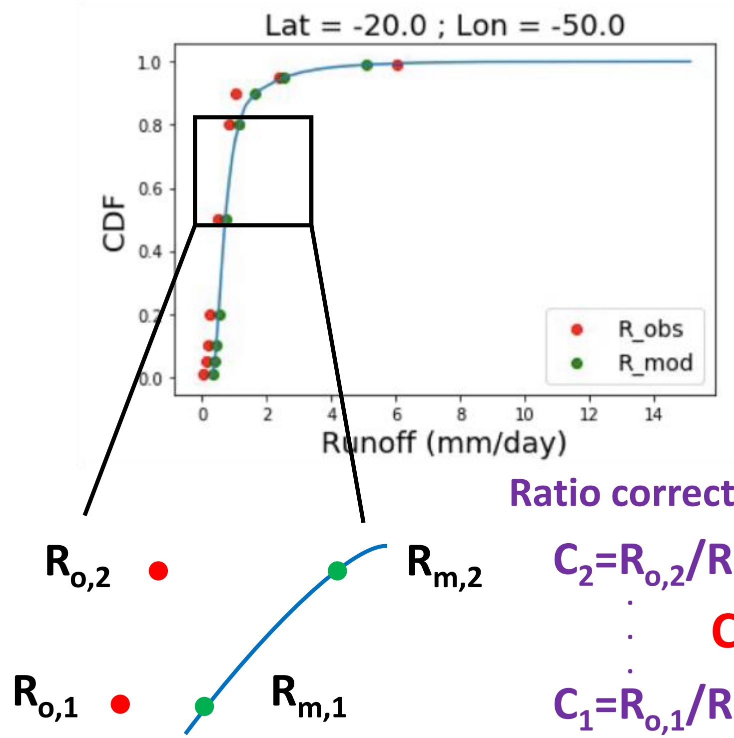


- Q characteristics from machine learning



Beck et al. (*2015; JHM*): *Q99, Q95, Q90, Q50, …, Q1*

- What if no full CDF of the reference data?



Ratio correction factor:

$C_2 = R_{o,2}/R_{m,2}$

C_j?

$C_1 = R_{o,1}/R_{m,1}$

Assume error is log-linear:

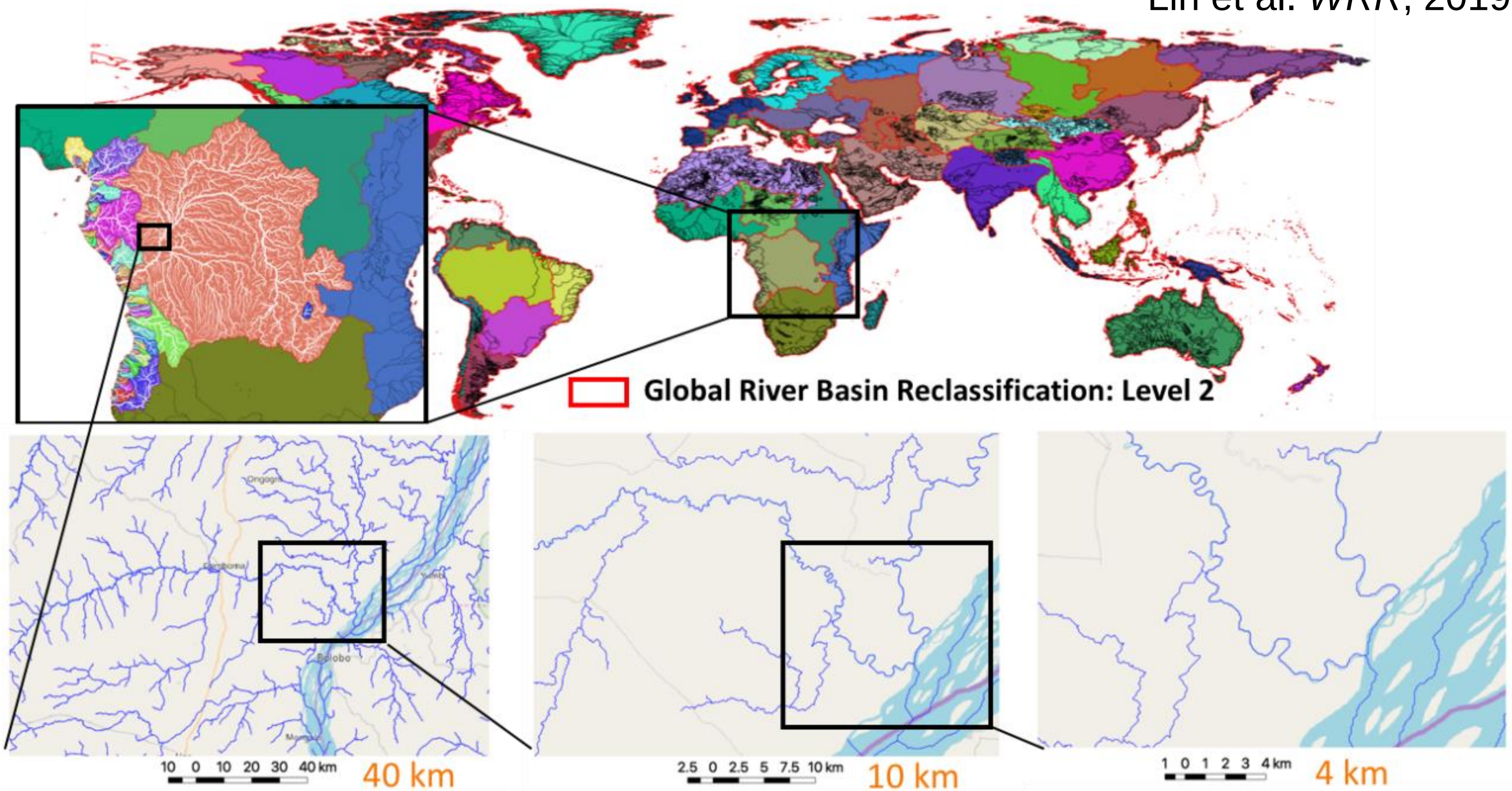
- $C_j = C_1^{\,1-j/N} \cdot C_2^{\,j/N}$
- j and N are the j-th element and total number of element between C_1 and C_2

Lin et al. *WRR*, 2019

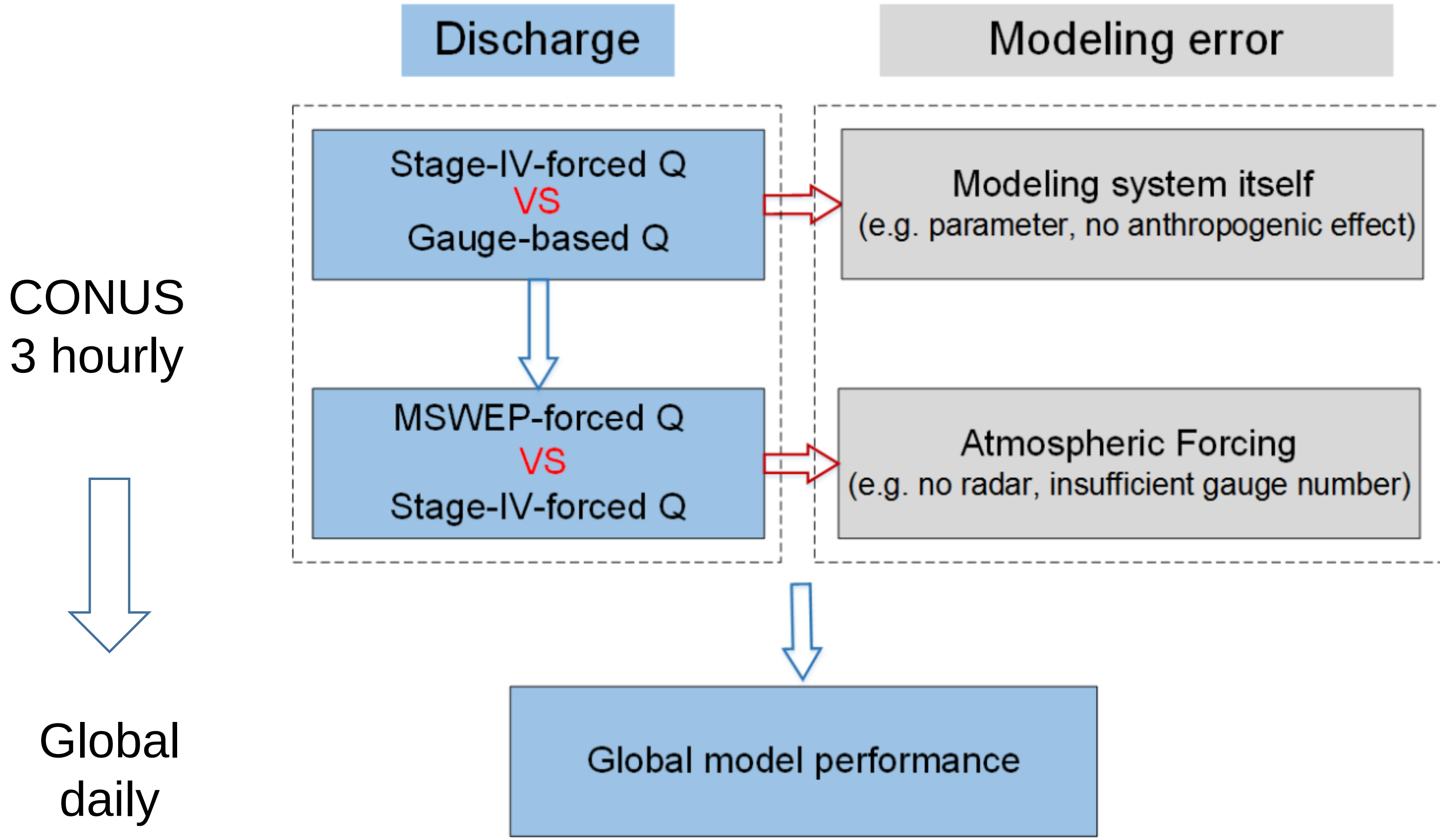
Global river network from 90m MERIT DEM

- MERIT Basins
  - 2.94 million reaches & catchments + properties (e.g. COMID, slope, connectivity) organized at Level 1 (9 regions) and Level 2 (61 basins)
  - Median = 6.8 km; Mean = 9.2 km; Total length= 2.6×10^{7} km

Lin et al. *WRR*, 2019

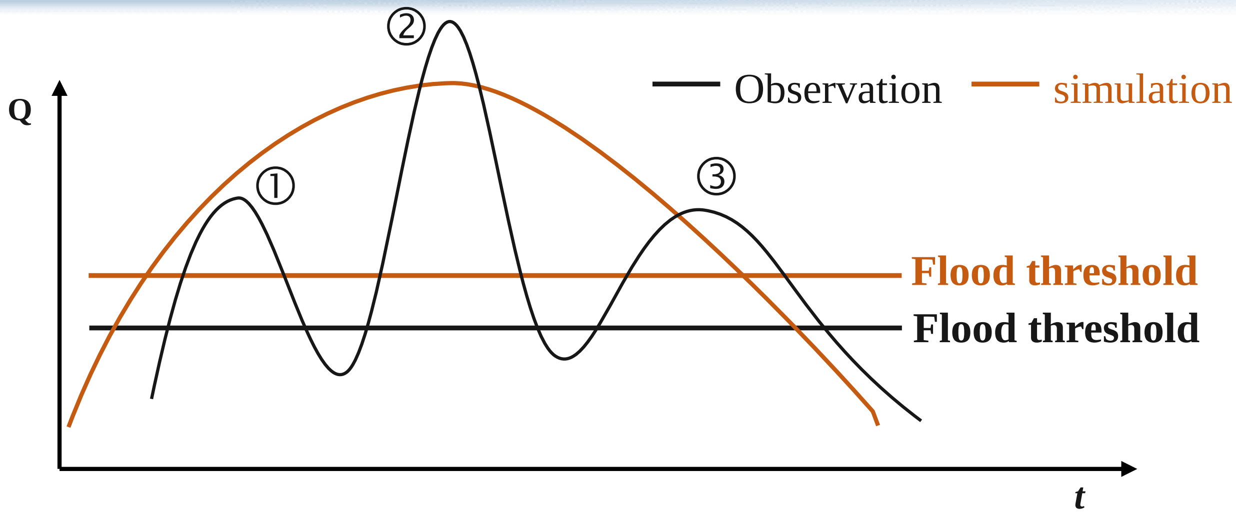


Discharge skill assessment

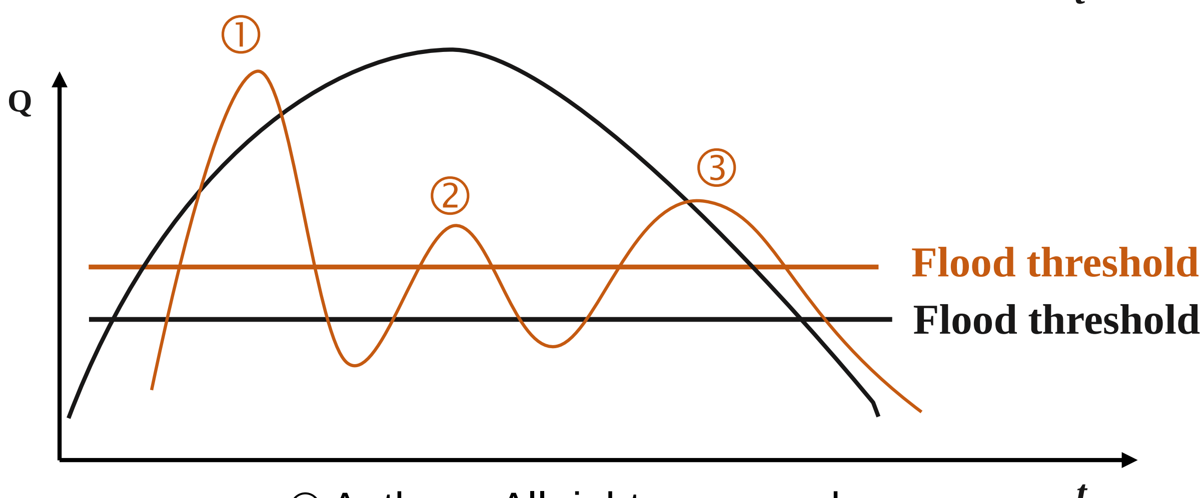


Metrics:
KGE and its 3 components: CC (Correlation Coefficient), RB (Relative Bias), RV (Relative Variability)

Flood-specific skill assessment



Event #② (the largest one) is treated as a hit event
Event #① & #③ are treated as missing events

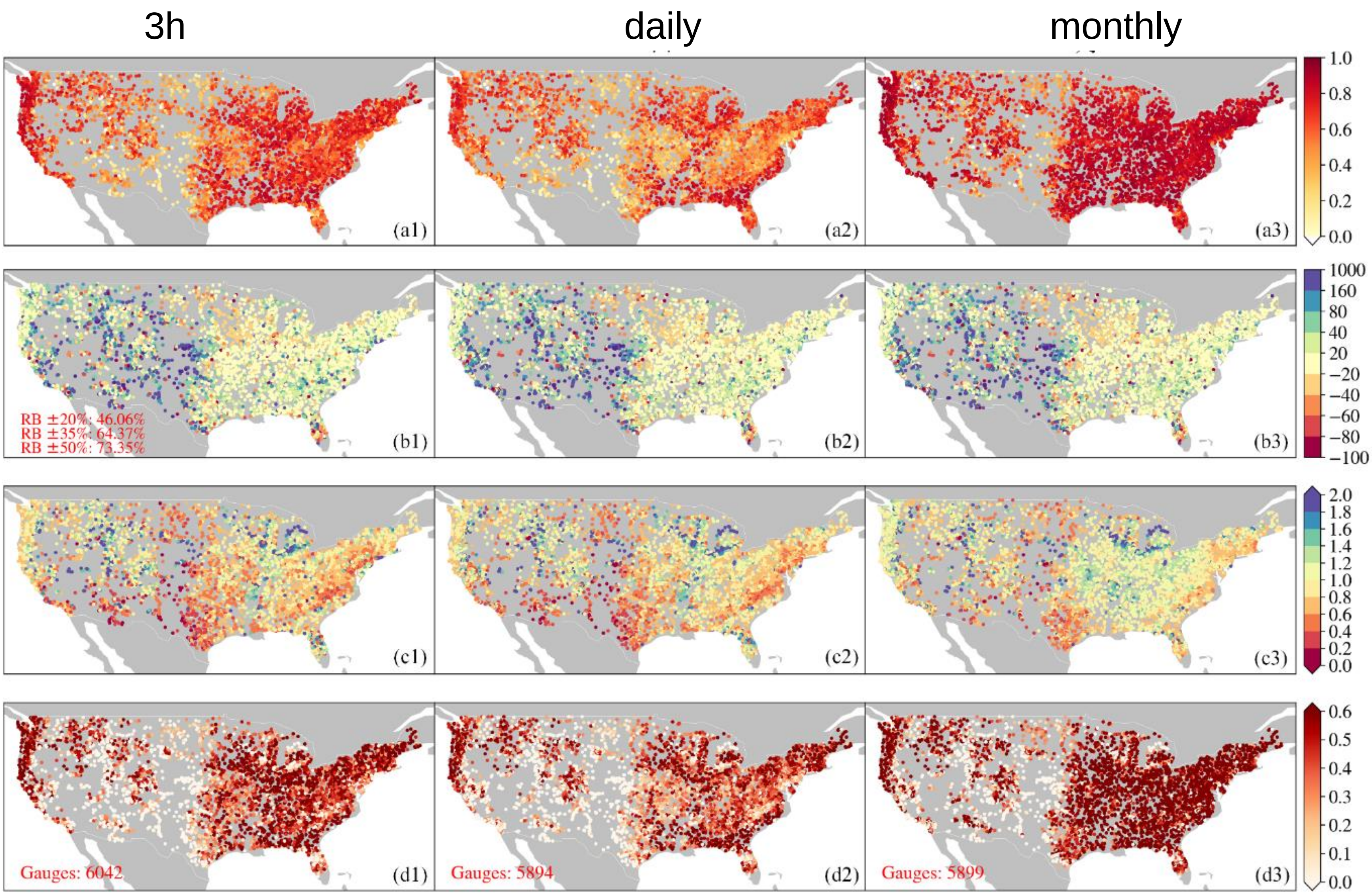


Event #① (the largest one) is treated as a hit event
Event #② &#③ are treated as false events

Metrics:
Flood detection capability: POD, FAR, CSI
Flood simulation statistics: flood volume/peak/timing errors

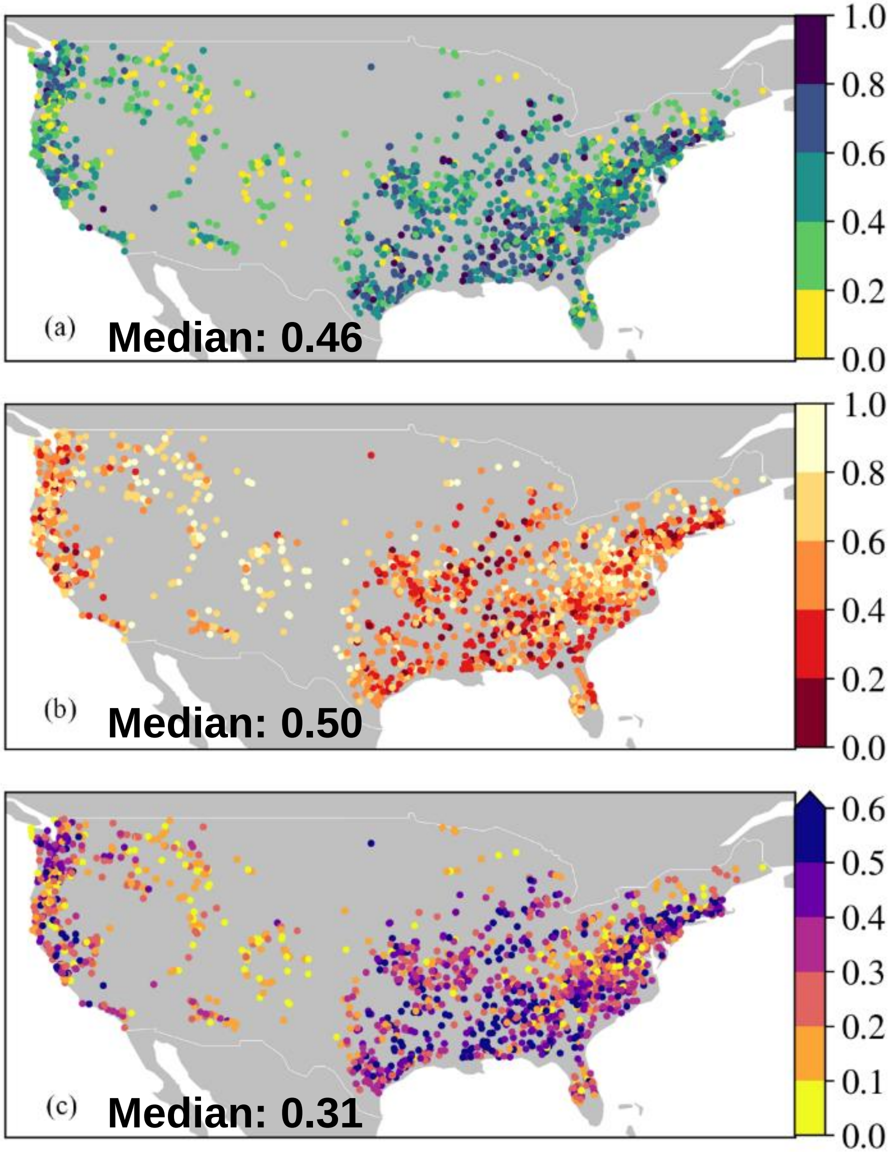
CONUS: Stage-IV vs Gauges

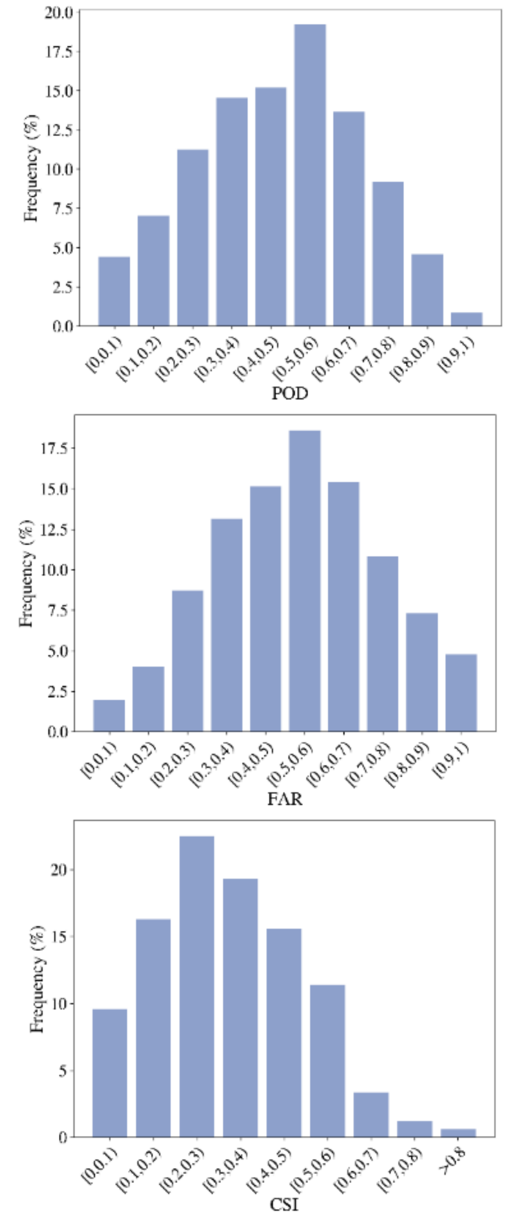
- Discharge skill assessment



CONUS: Stage-IV vs Gauges

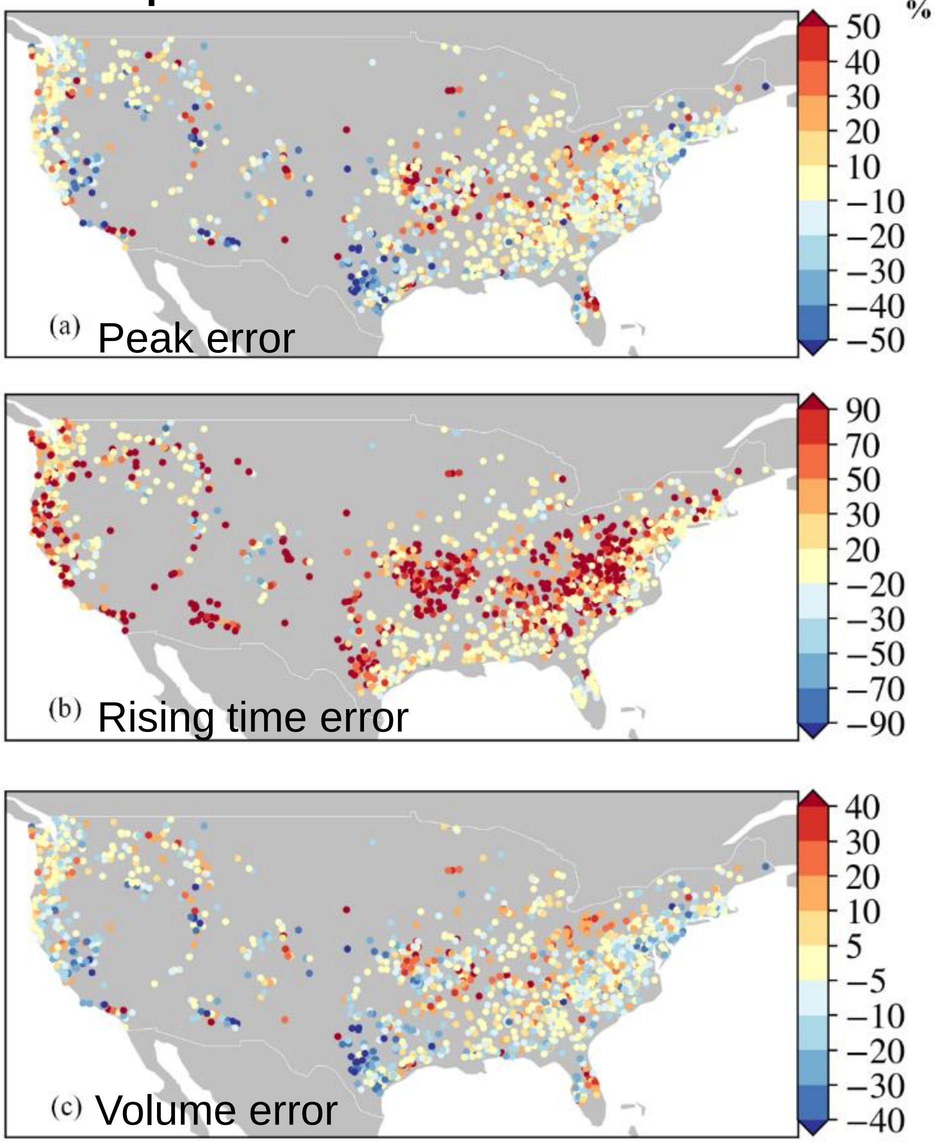
- Flood-specific skill assessment

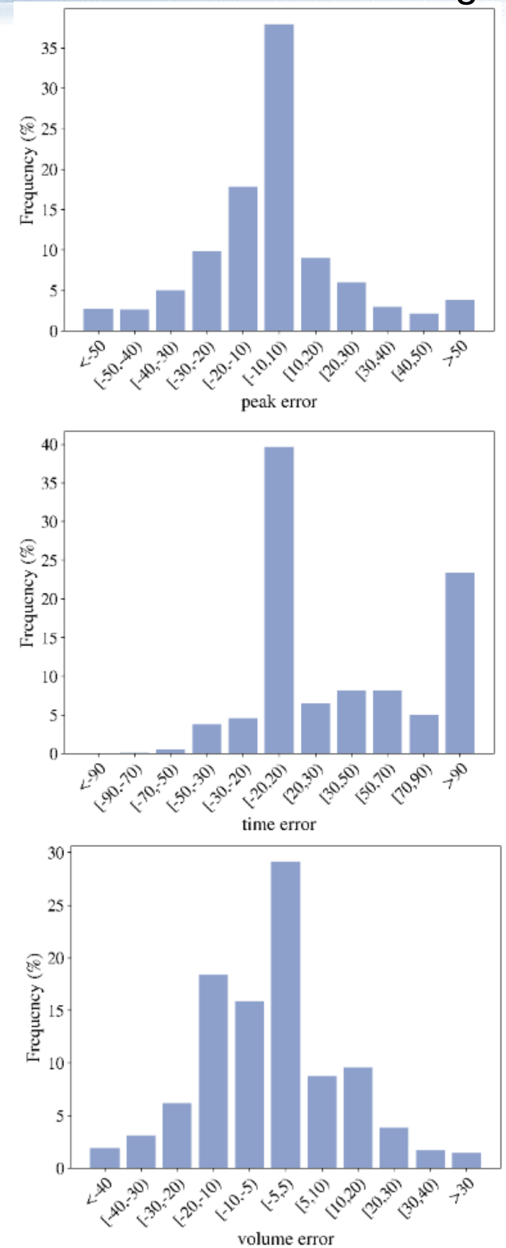




CONUS: Stage-IV vs Gauges

- Flood-specific skill assessment

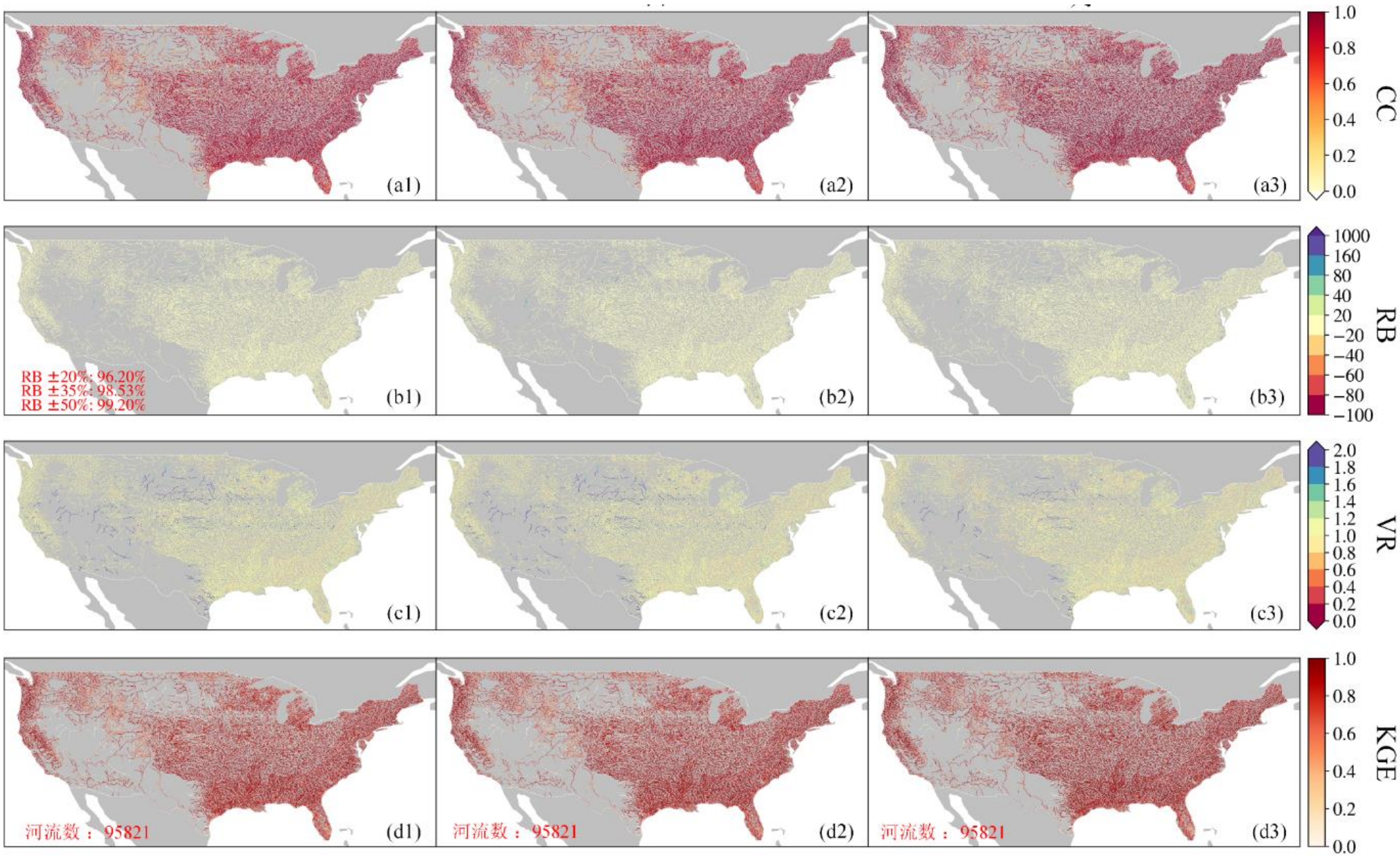




CONUS: MSWEP vs Stage-IV

- Discharge skill assessment

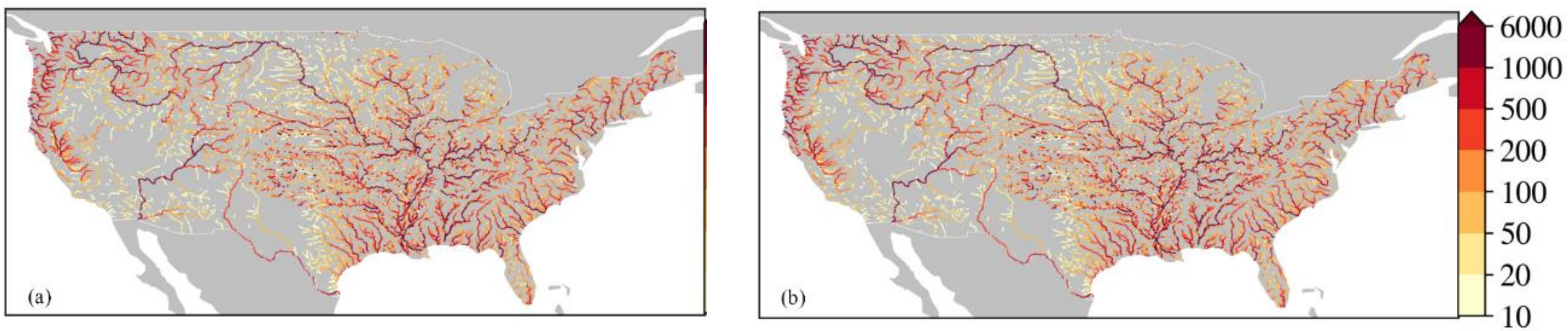
3h daily monthly

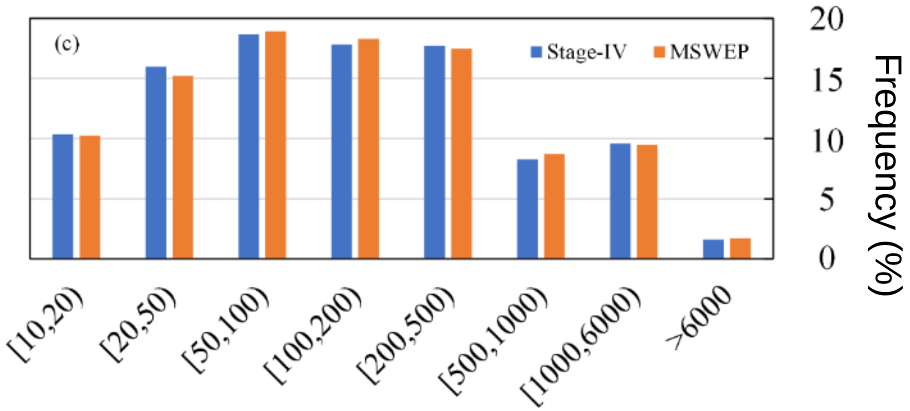


CONUS: MSWEP vs Stage-IV

- Flood-specific skill assessment

Stage-IV flood threshold MSWEP flood threshold

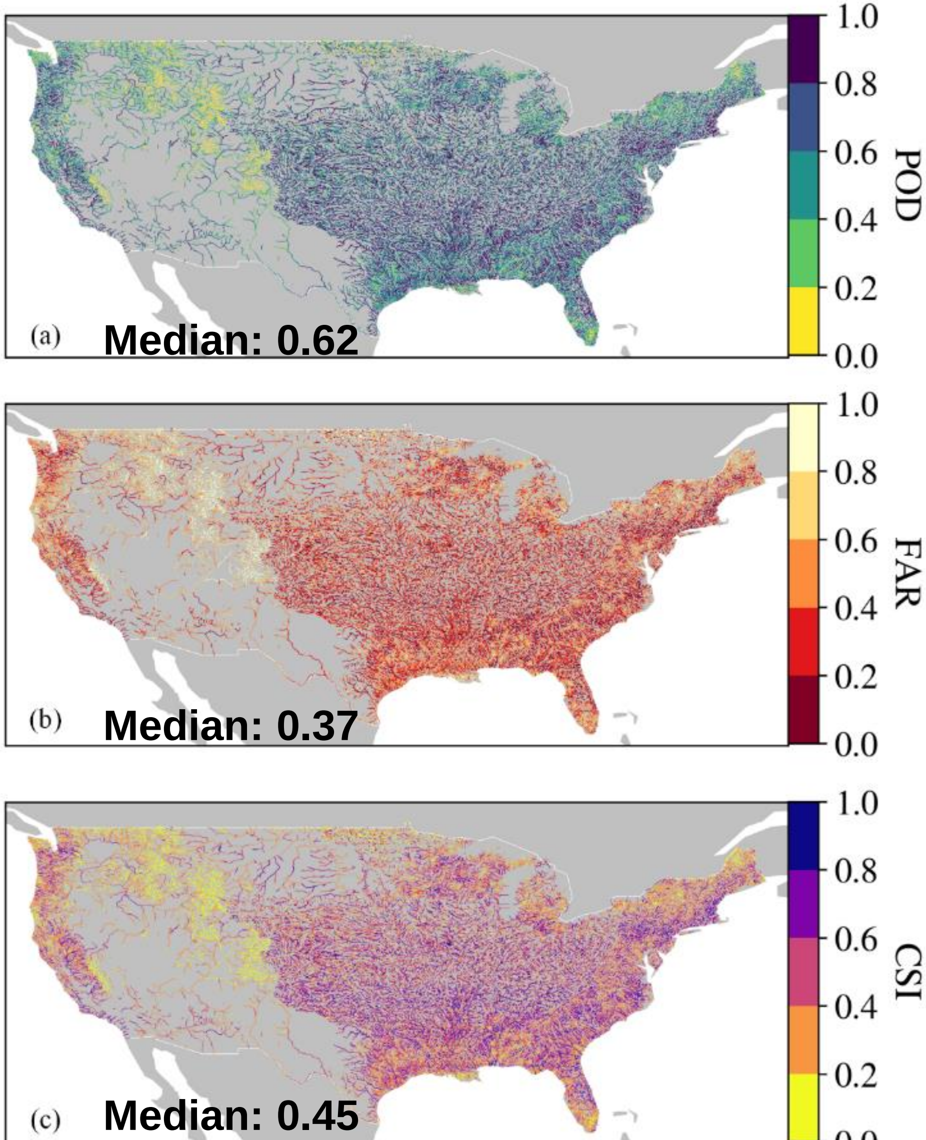


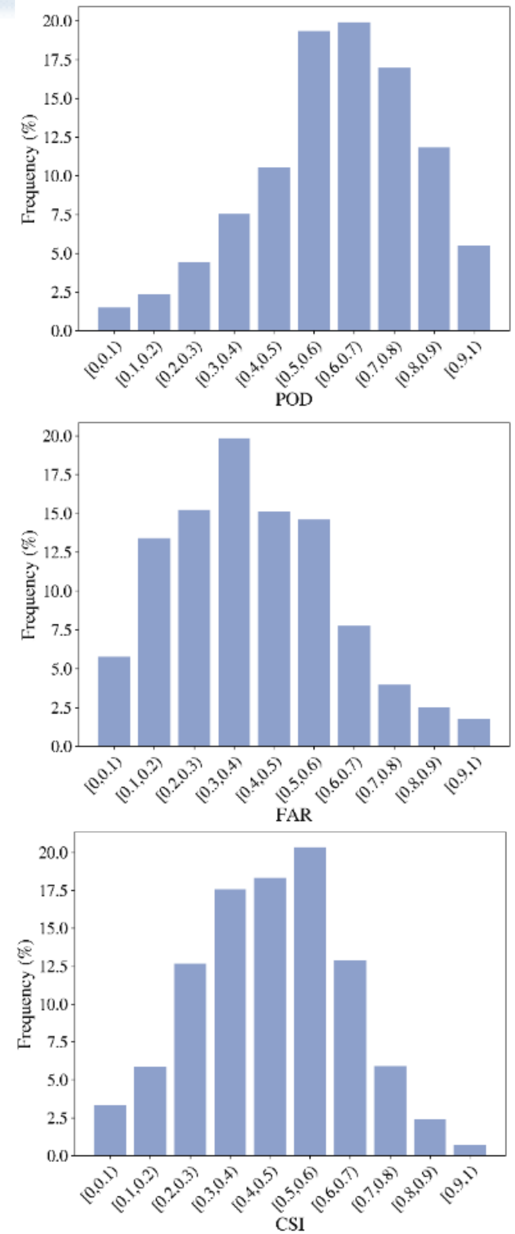


River reaches with stream order ≥3

CONUS: MSWEP vs Stage-IV

- Flood-specific skill assessment





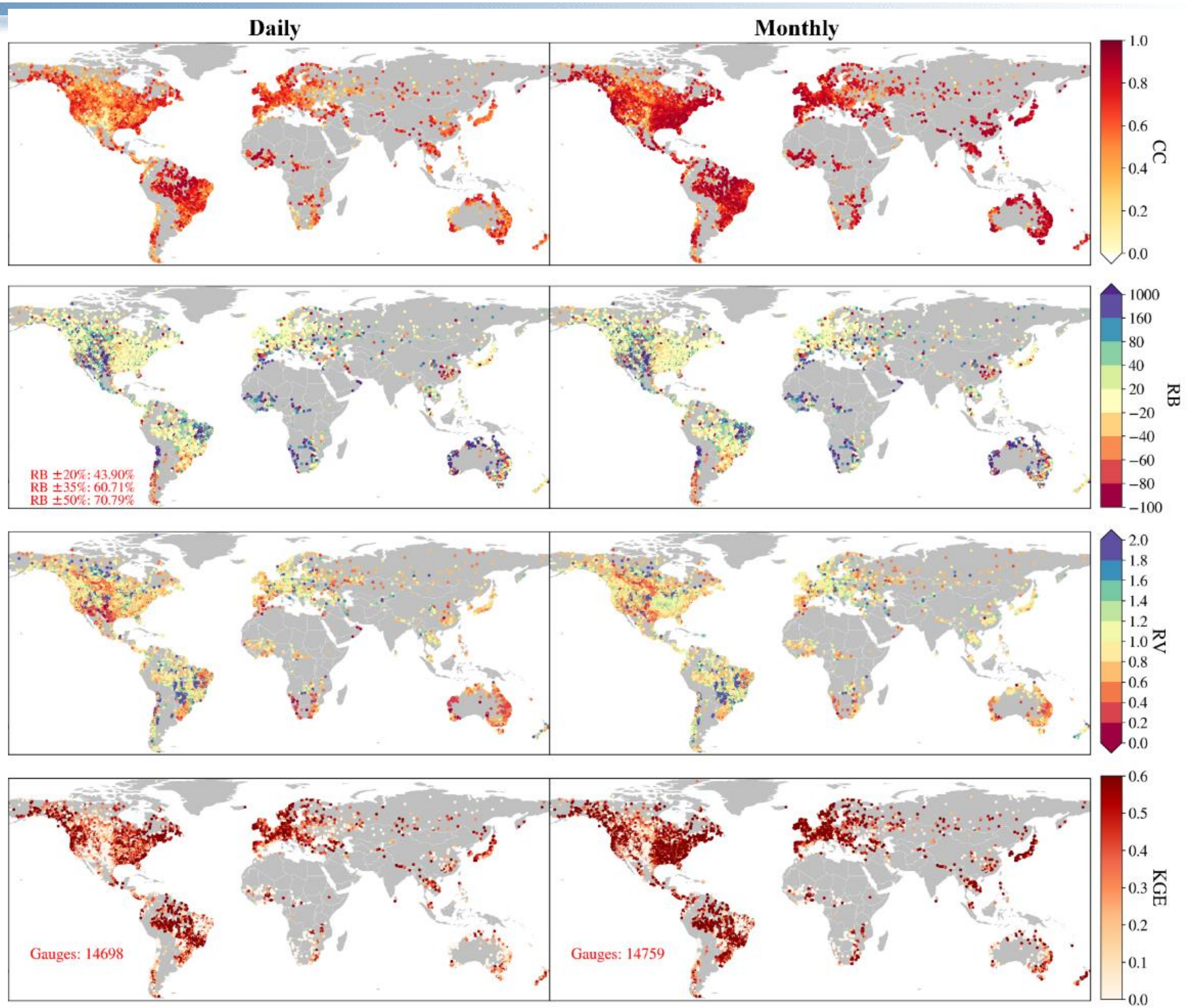
Global: daily/monthly skills

Correlation Coefficient

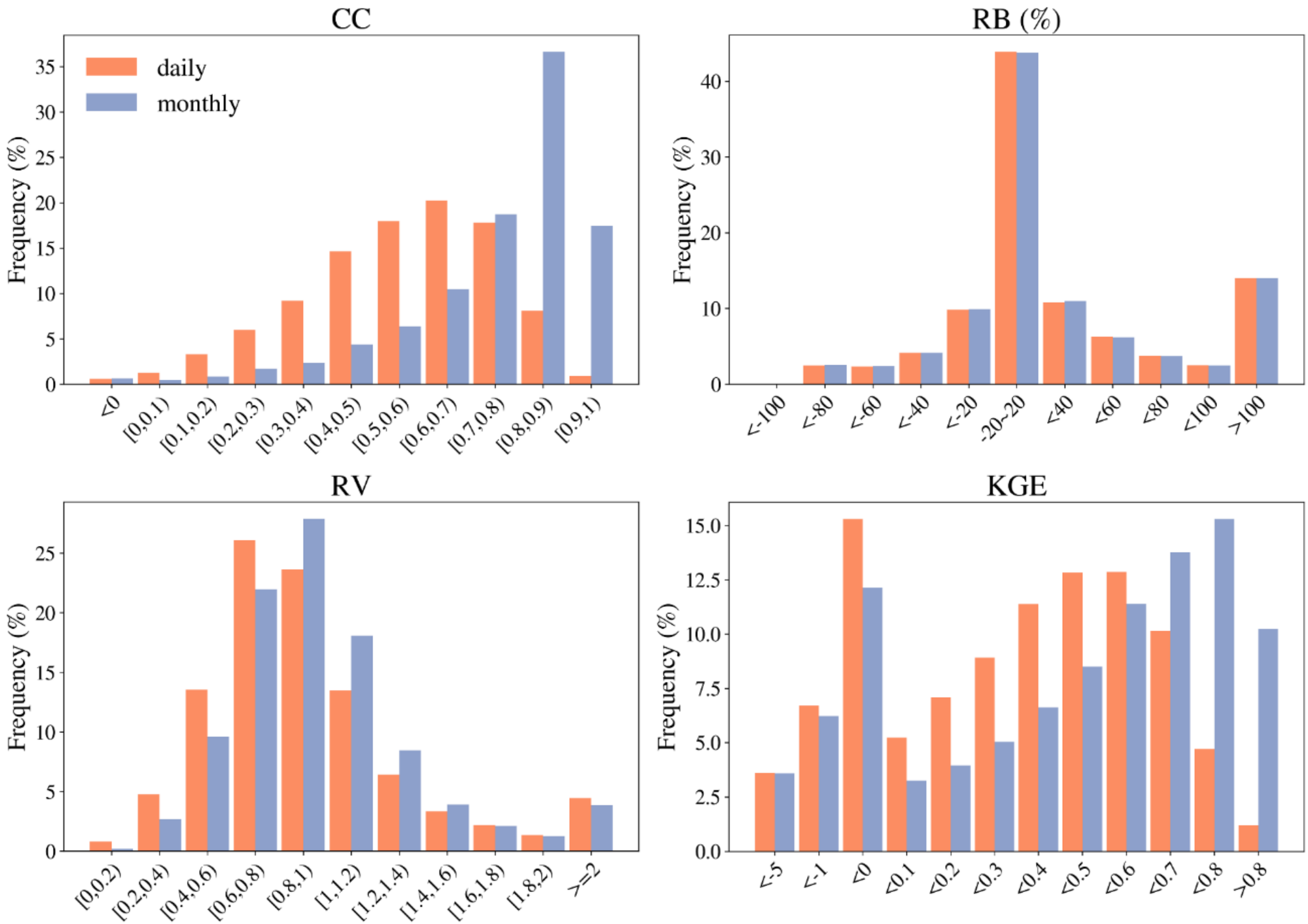
Relative Bias

Relative Variability

KGE

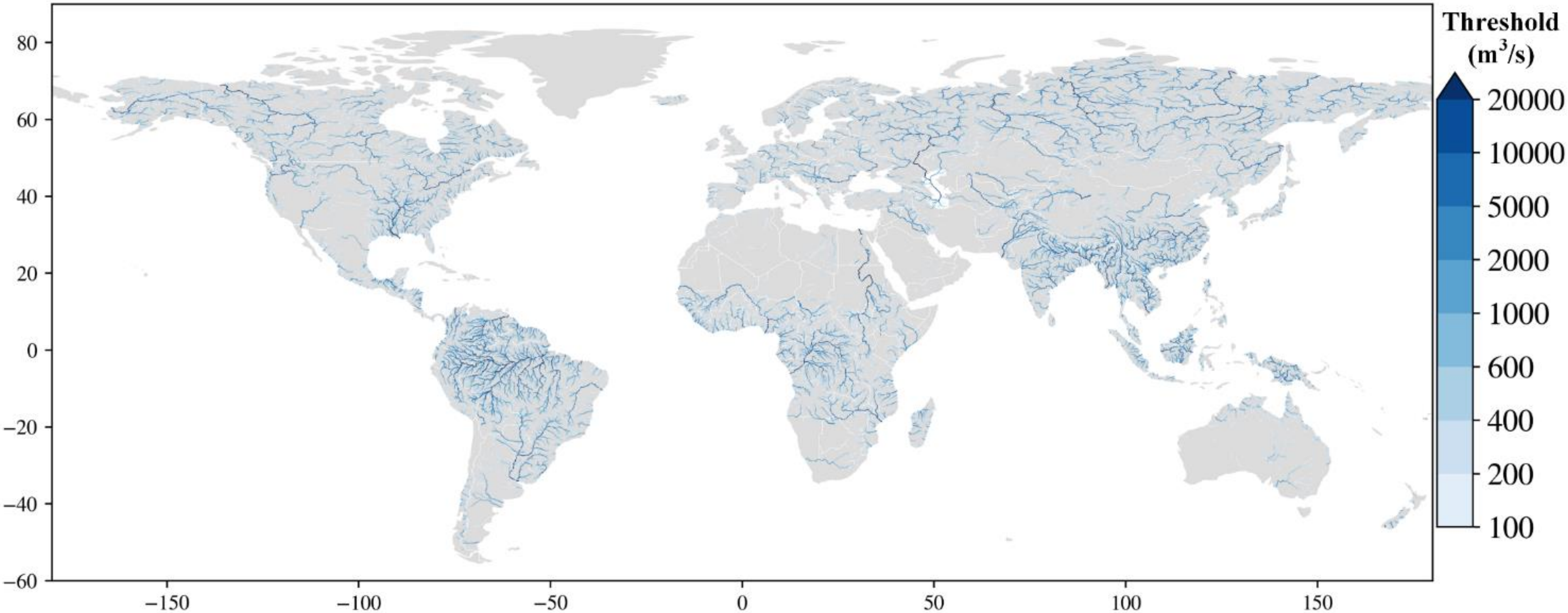


Global: daily/monthly skills



Global: flood analysis

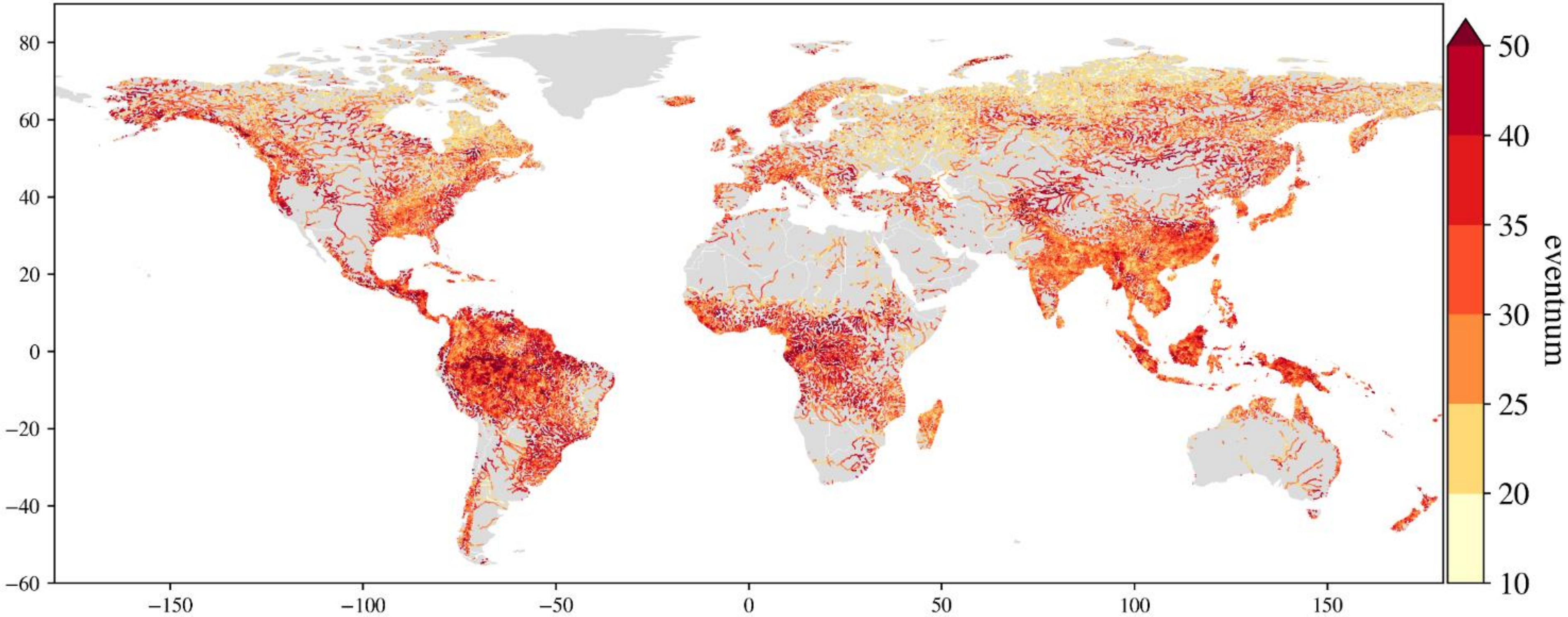
Global 3-hourly flood threshold (2-year return period)



River reaches with stream order ≥4 & threshold ≥ 100 m^3/s

Global: flood analysis

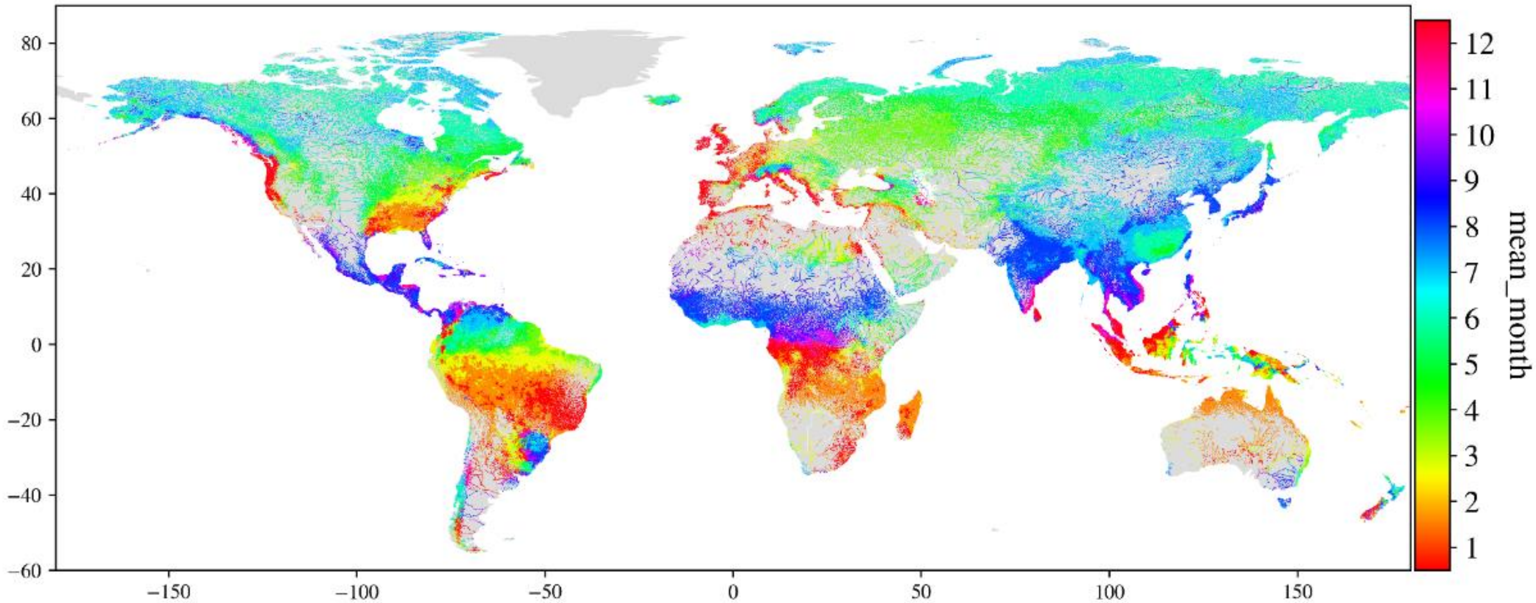
Number of flood events during 1980-2019



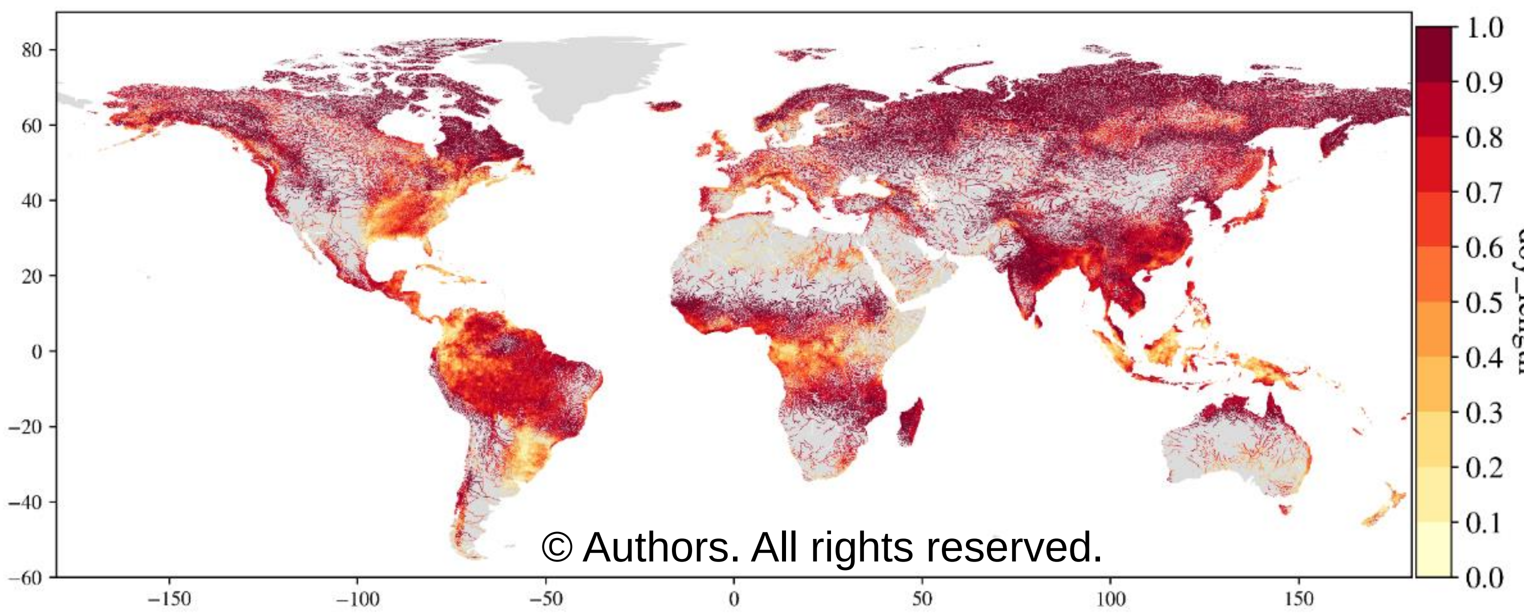
River reaches with threshold ≥ 100m^3/s

Global: flood analysis

Flood Seasonality



Seasonal Concentration



Conclusions and Outlook

- A carefully-designed modeling framework is implemented to generate 3-hourly river discharge record globally for 2.94 million river reaches derived from 90-m topography during 1980-2019.

- The model can reproduce the discharge time series well at both 3-hourly and daily scales.

- A set of global reach-level 3-hourly flood events (above 2-year return period) for the period of 1980-2019 is generated.

- On going steps: further analysis on characteristics & physical mechanisms of global flood events.

Thanks to:

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- The members of the Terrestrial Hydrology Group and the Princeton CEE department for their support in completing this research.

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