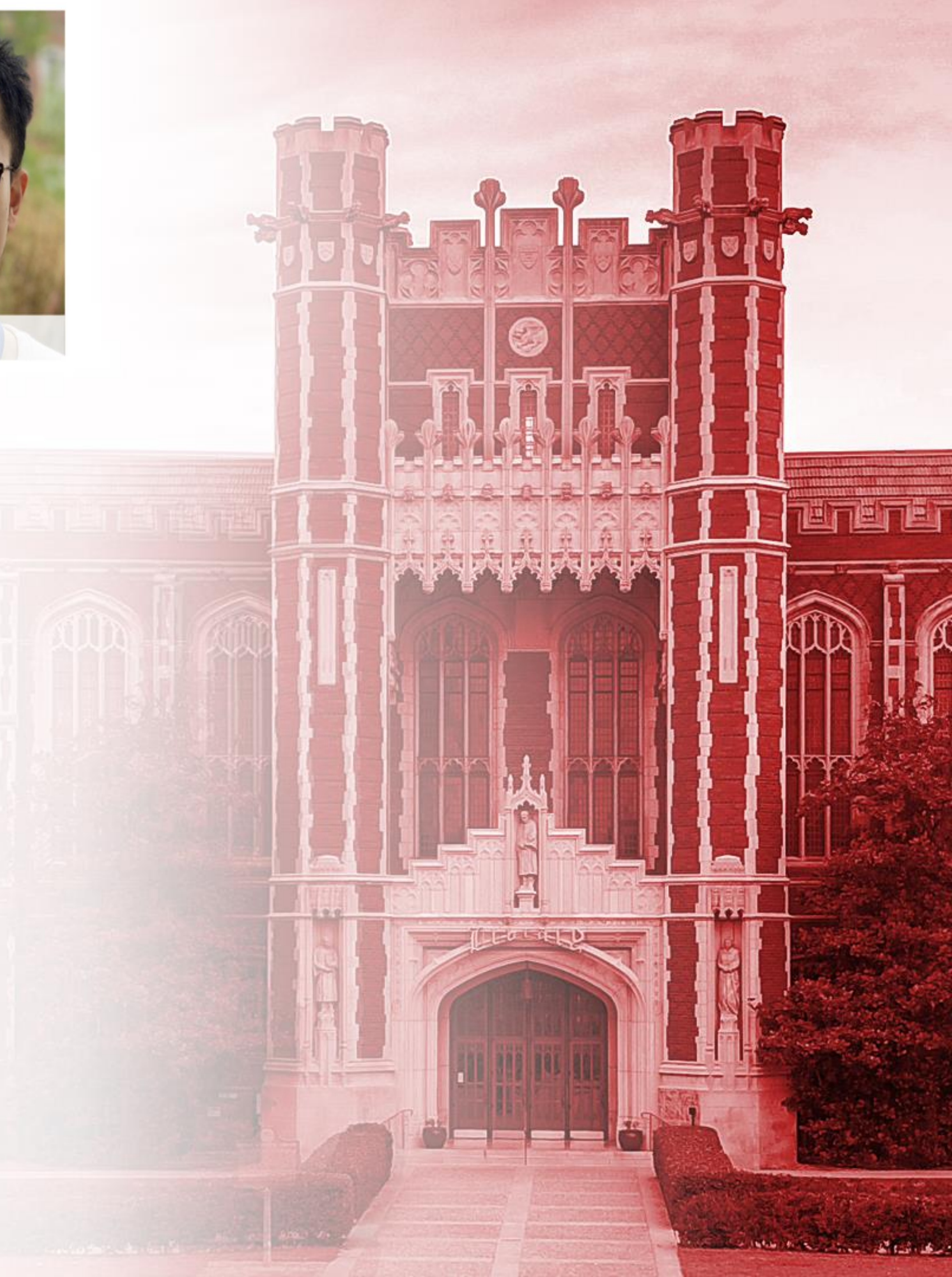
Introducing Flash-Intensity-Duration-Frequency (F-IDF) curve: A New Metric to Quantify Flash Flood Intensity



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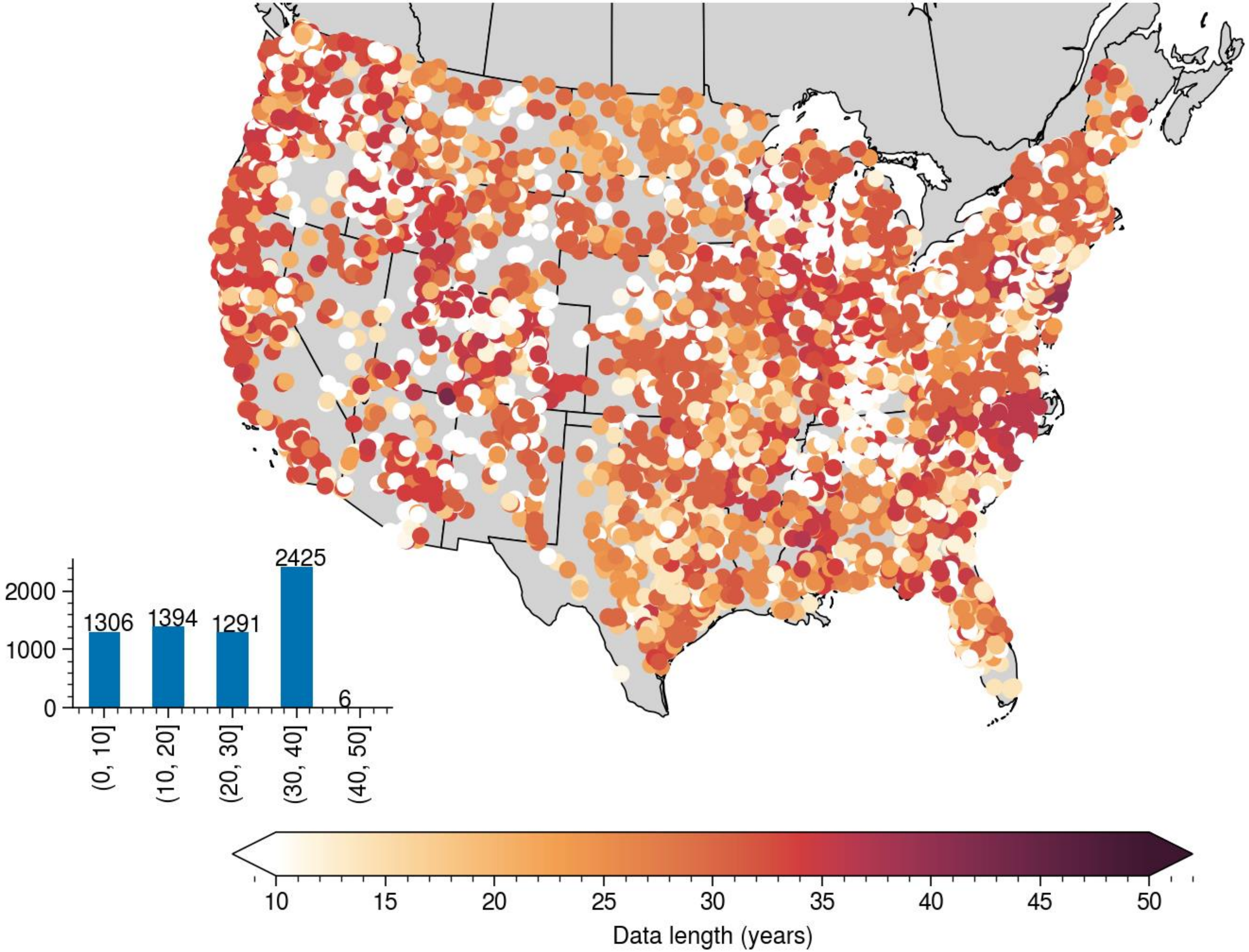
Context

- How to identify basins or parts or the country that are “flashy” and thus respond quickly to rainfall and with high magnitudes?
- If flashiness variables can be identified using observed discharge, can they be used in a forecasting context?
  - Proposal: Compute Flashiness-Intensity-Duration-Frequency Curves
  - Apply in 5,116 USGS gauges at 15-min resolution

Data record length for USGS gauges



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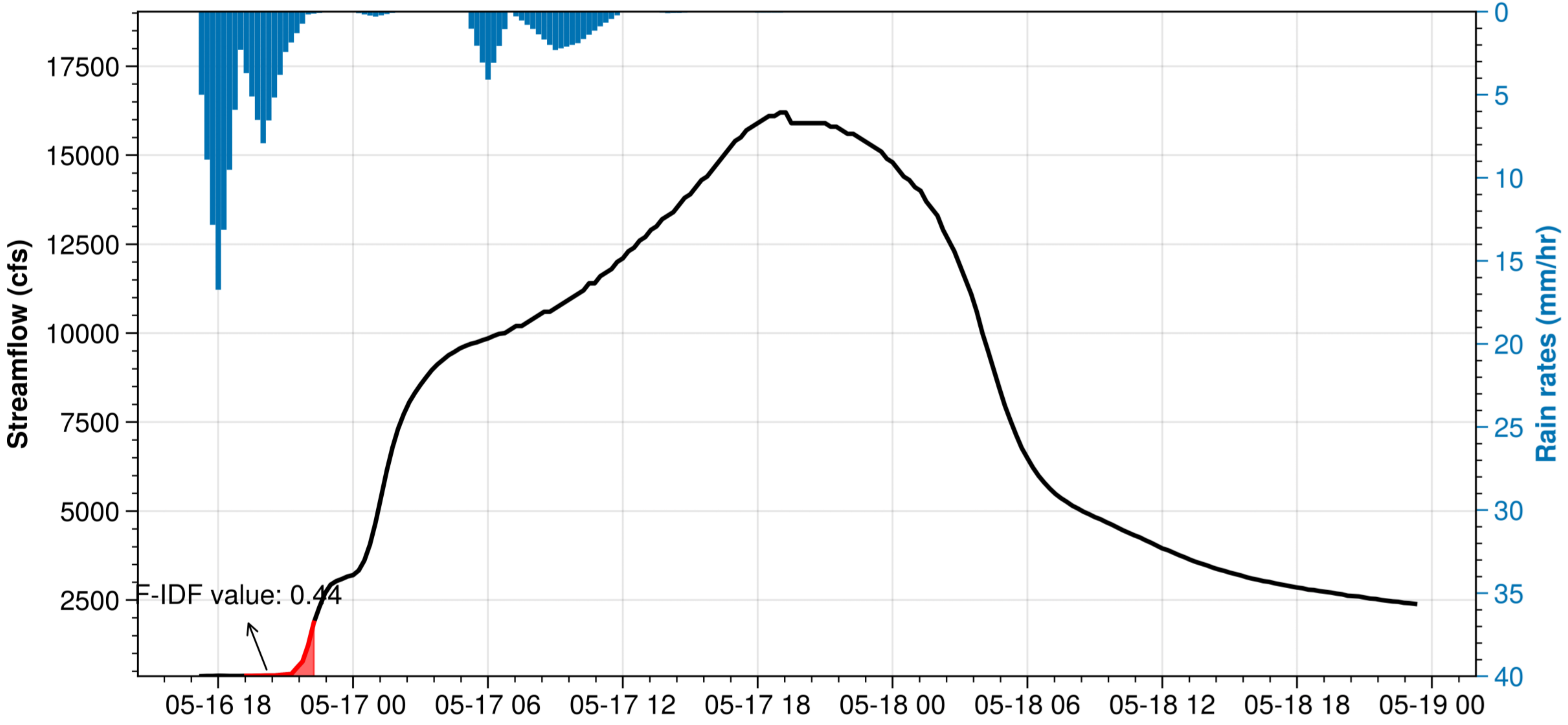
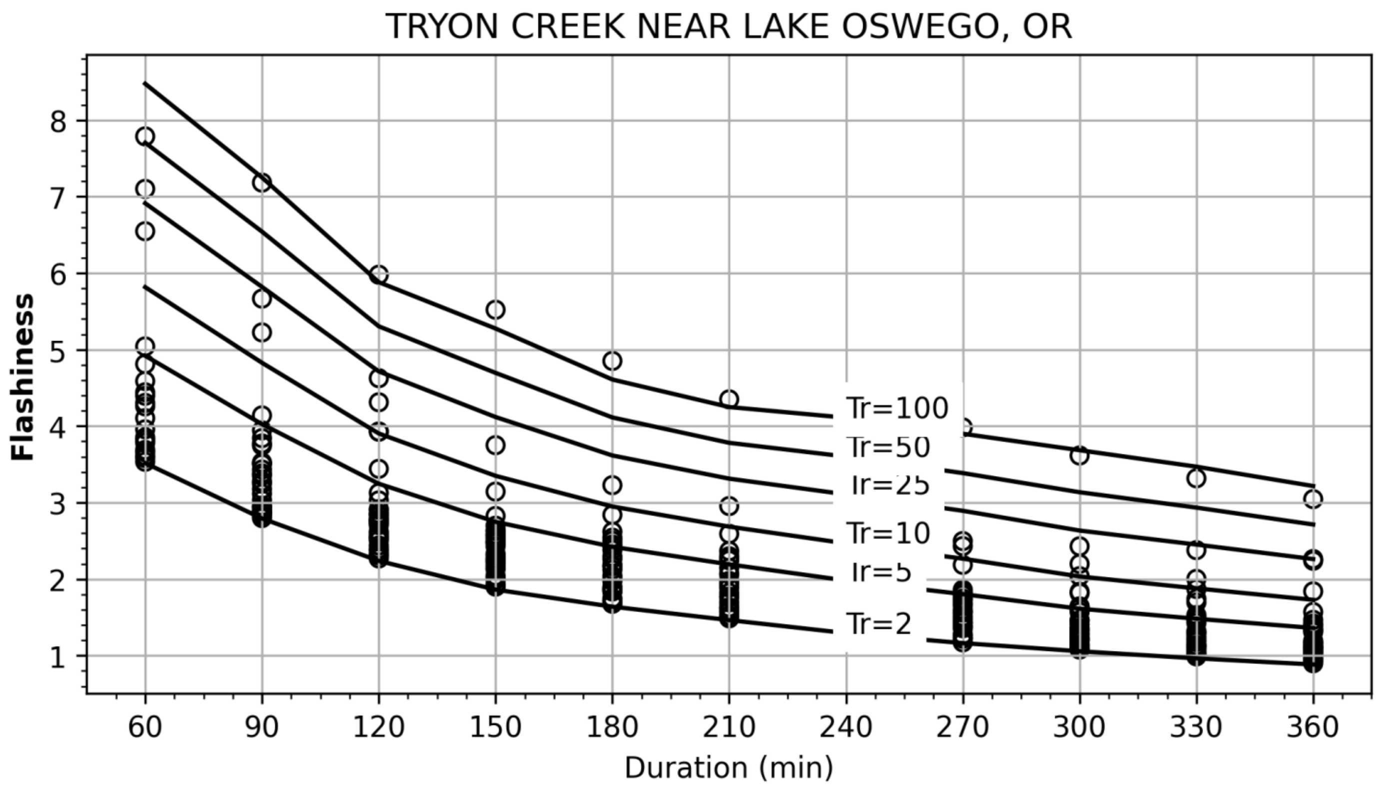
Fit extreme value distribution

- Find maximum slope of hydrograph over a moving time window (D=1hr, 2hr, 3hr, 4hr, 5hr, and 6hr)
- Extract the annual maximum
- Fit into general extreme value distribution and logPearson Type III distribution
- Find an optimal fit based on the BIC (Bayesian Information Criterion)
- Find flashiness values at different frequency 2-yrs, 5-yrs, 10-yrs, 25-yrs, 50-yrs, and 100-yrs

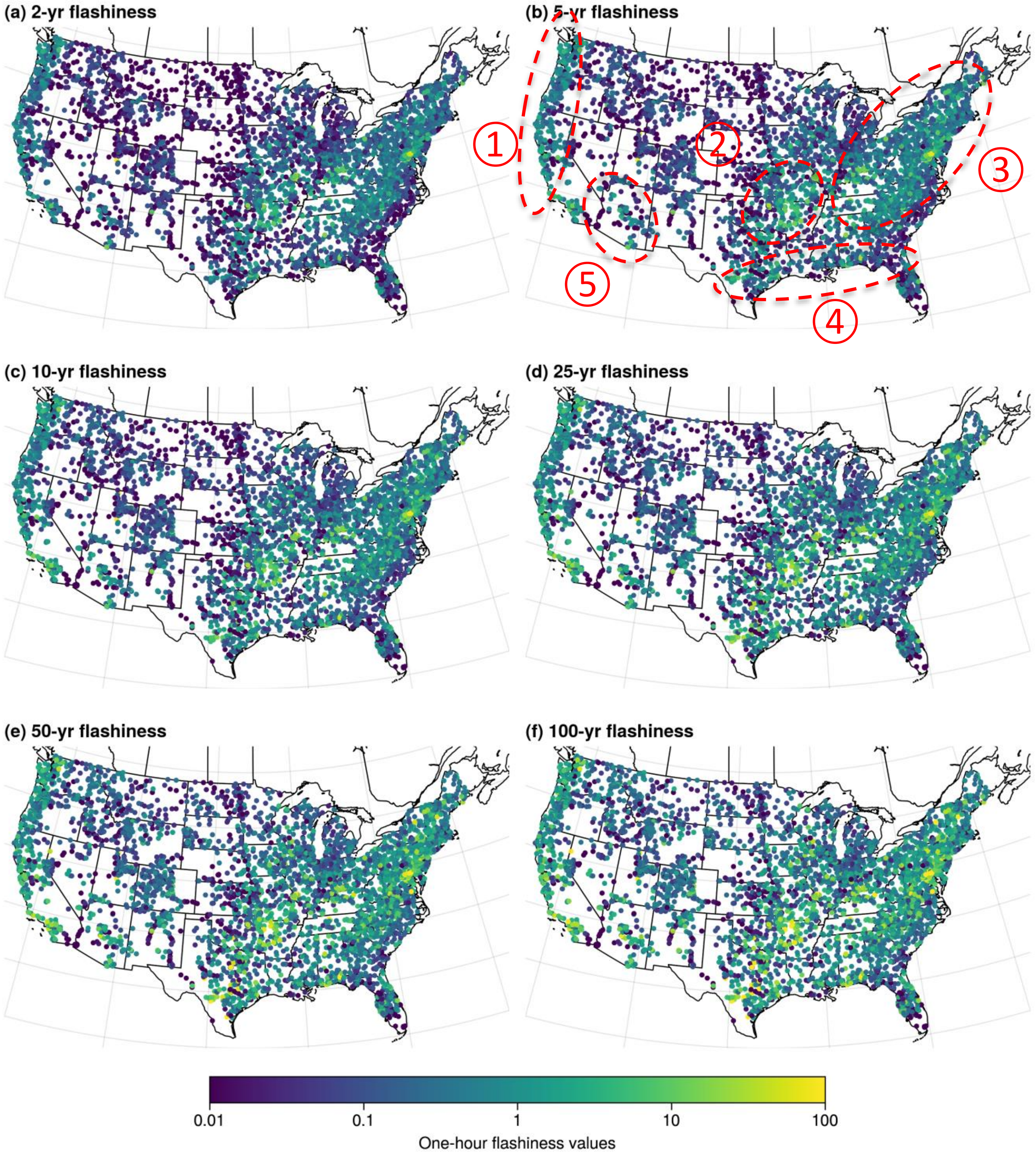
Illustration – 3hour FIDF



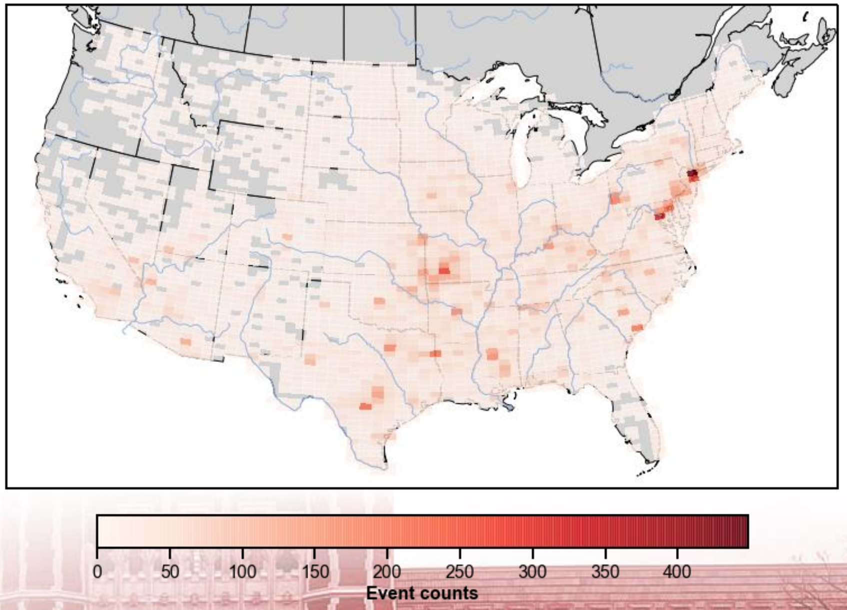
Flashiness-Intensity-Duration-Frequency (F-IDF) curve

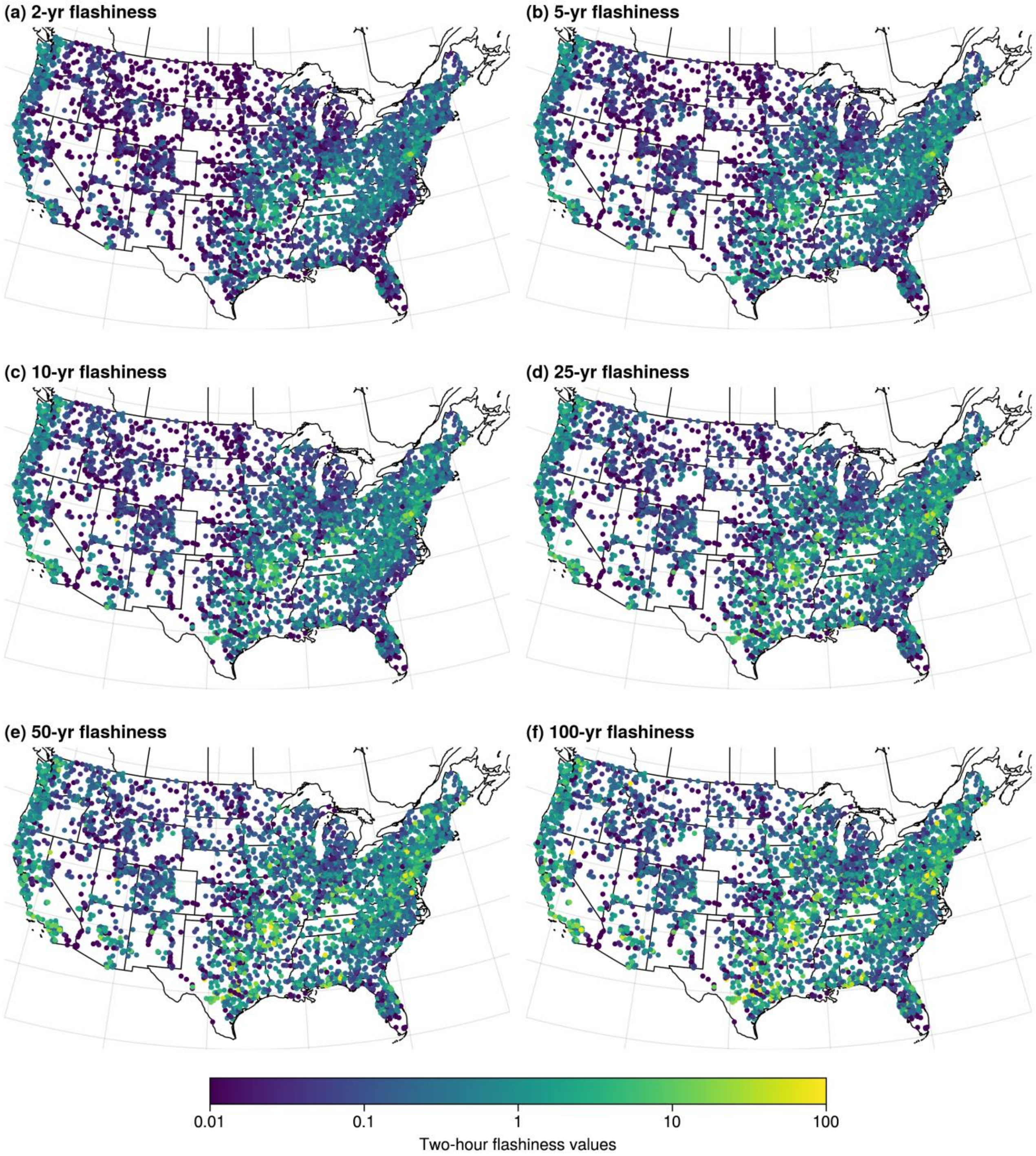


Flash flood frequency values at 1-hour duration

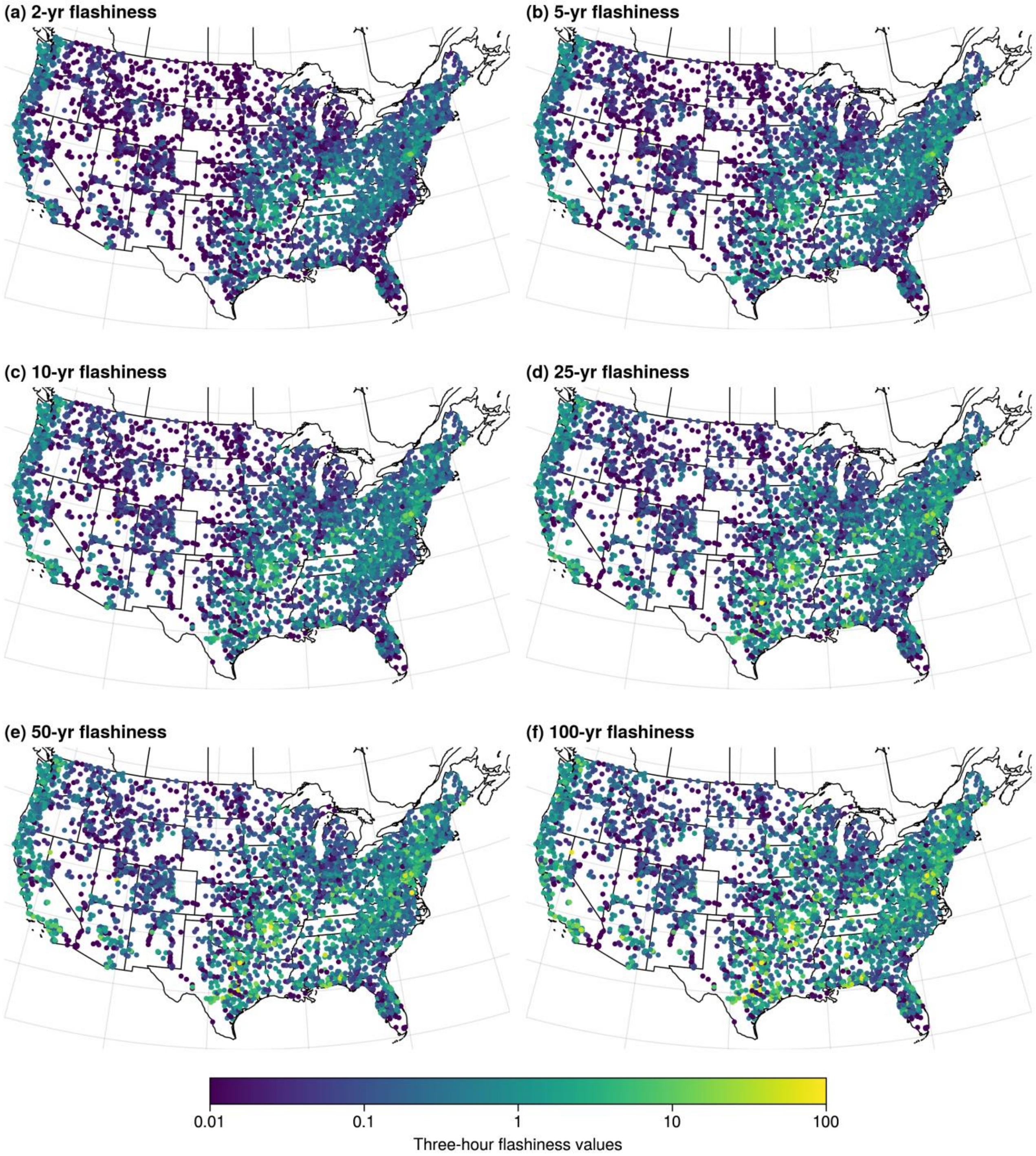


Flash flood occurrence density plot (based on Storm Events)



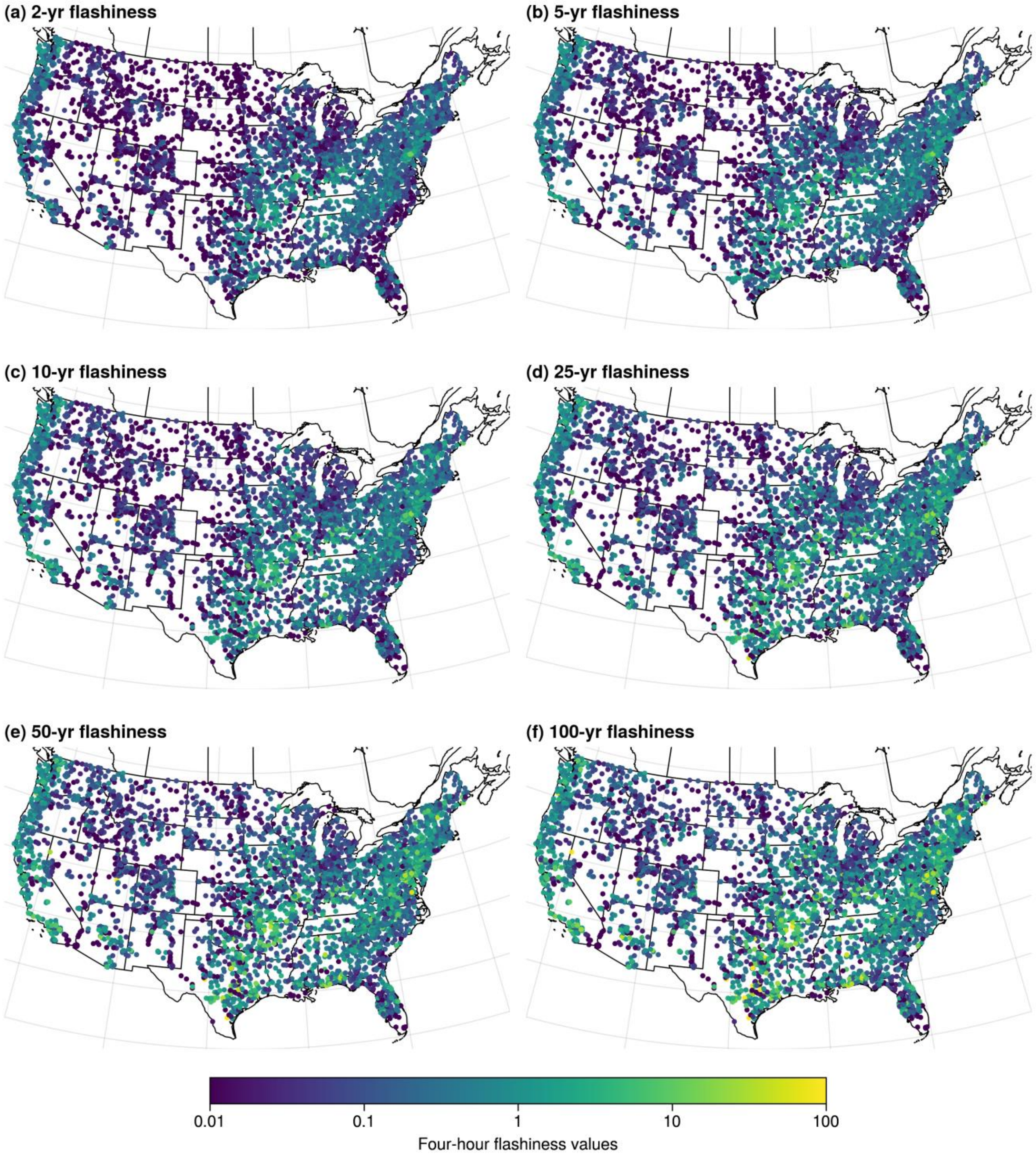


Flash flood frequency values at 2-hour duration

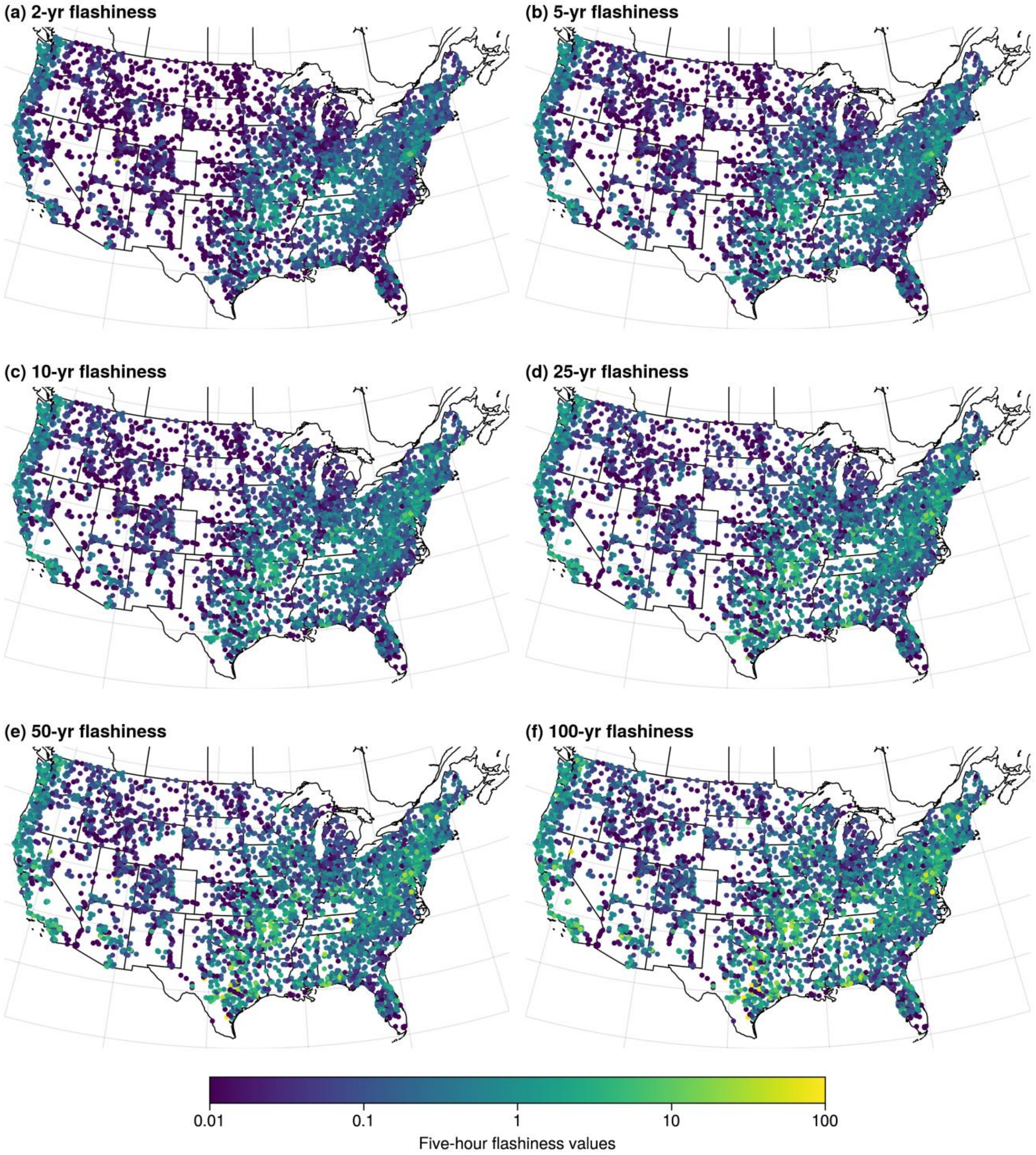


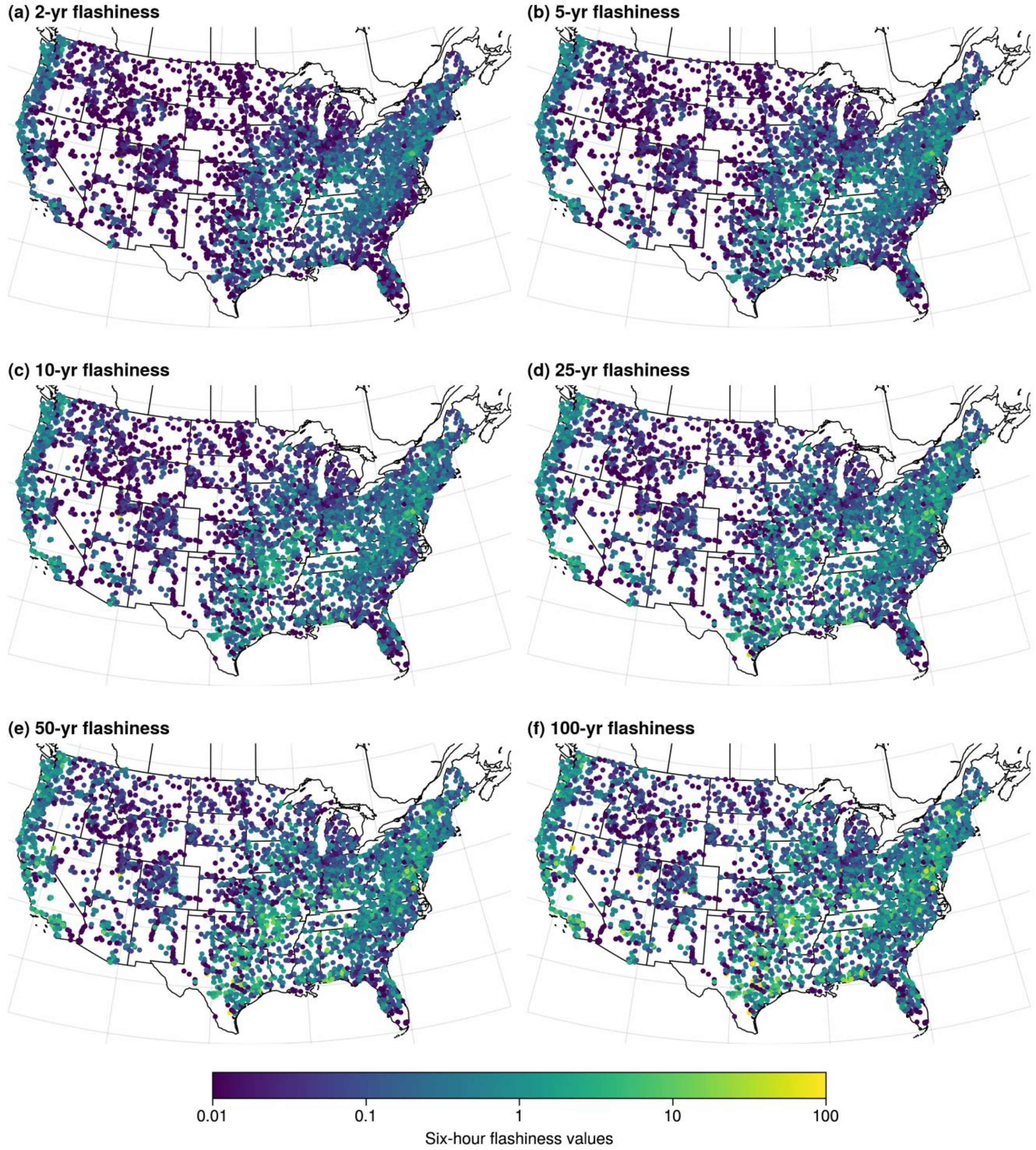
Flash flood frequency values at 3-hour duration

Flash flood frequency values at 4-hour duration



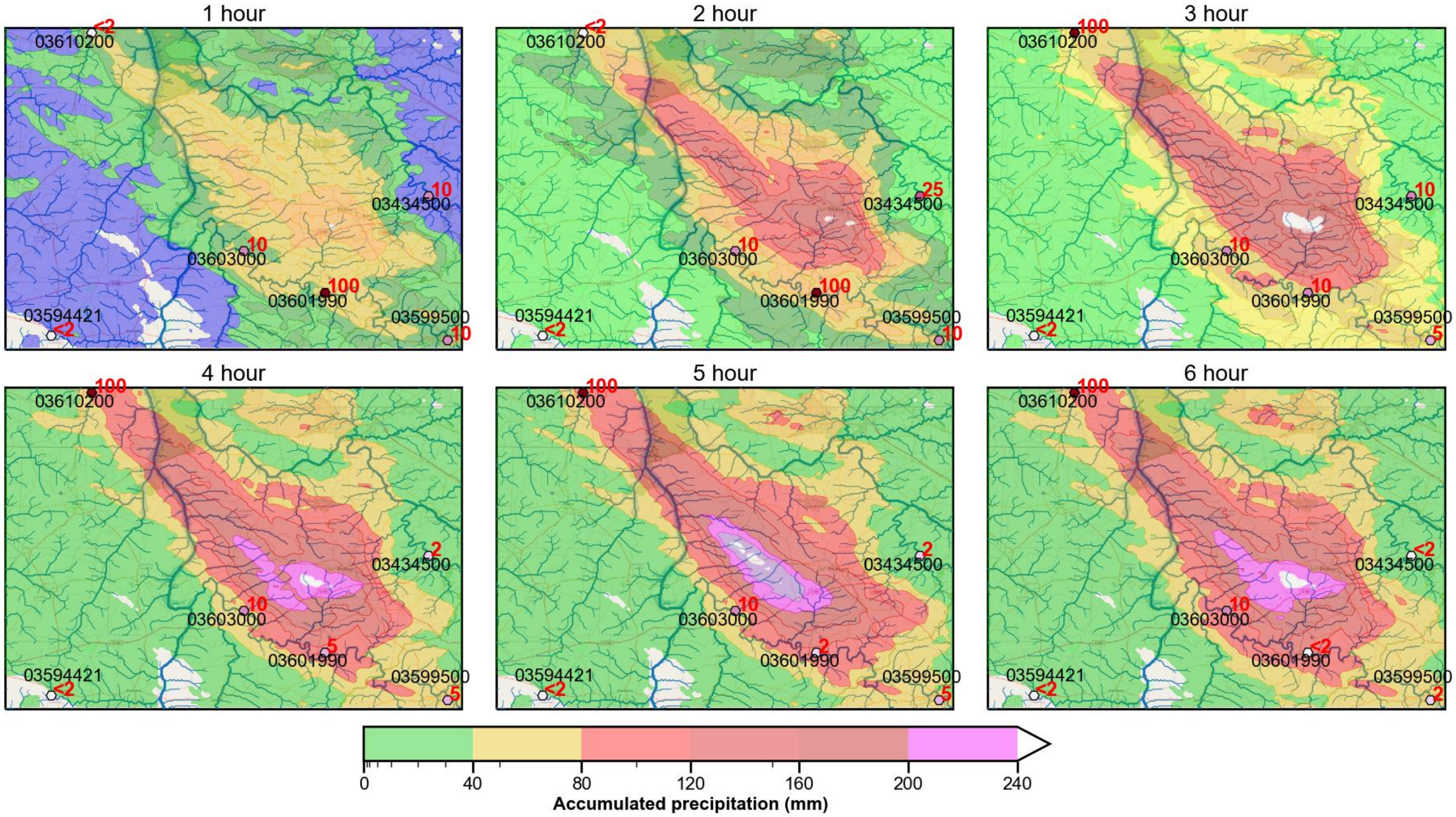
Flash flood frequency values at 5-hour duration





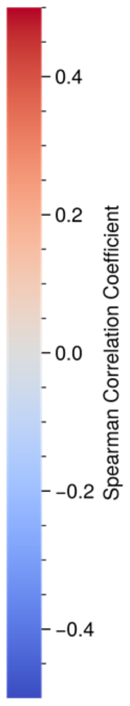
Flash flood frequency values at 6-hour duration

2021 Tennessee flash flooding



Group	Variable	Min CC	Mean CC	Max CC
Hydrology	Runoff	0.28	0.38	0.47
	Discharge	-0.22	-0.19	-0.13
	Inundation	-0.027	-0.0049	0.027
	GroundwaterTable	-0.073	-0.027	0.029
	Regulation	-0.28	-0.27	-0.24
	RiverVolume	-0.34	-0.31	-0.27
	RiverArea	-0.37	-0.35	-0.31
Physiography	ChannelSlope	0.056	0.088	0.13
	CatchmentSlope	0.012	0.029	0.065
	Elevation	-0.33	-0.28	-0.19
	DrainArea	-0.47	-0.42	-0.38
Climate	Precipitation	0.31	0.42	0.5
	ActualEvap	0.29	0.4	0.47
	Moisture	0.3	0.4	0.49
	Aridity	0.3	0.39	0.49
	AirTemperature	0.2	0.27	0.3
	PotentialEvap	0.099	0.14	0.16
	SnowCover	-0.29	-0.27	-0.19
Soils & Geology	SoilWaterContent	0.3	0.4	0.49
	ClayFract	0.12	0.18	0.21
	SiltFract	0.043	0.089	0.14
	Karst	-0.033	-0.029	-0.024
	Erosion	0.034	0.052	0.065
	SandFract	-0.19	-0.15	-0.094
Human	RoadDensity	0.24	0.32	0.37
	UrbanDensity	0.17	0.23	0.28
	Population	-0.064	-0.027	0.017

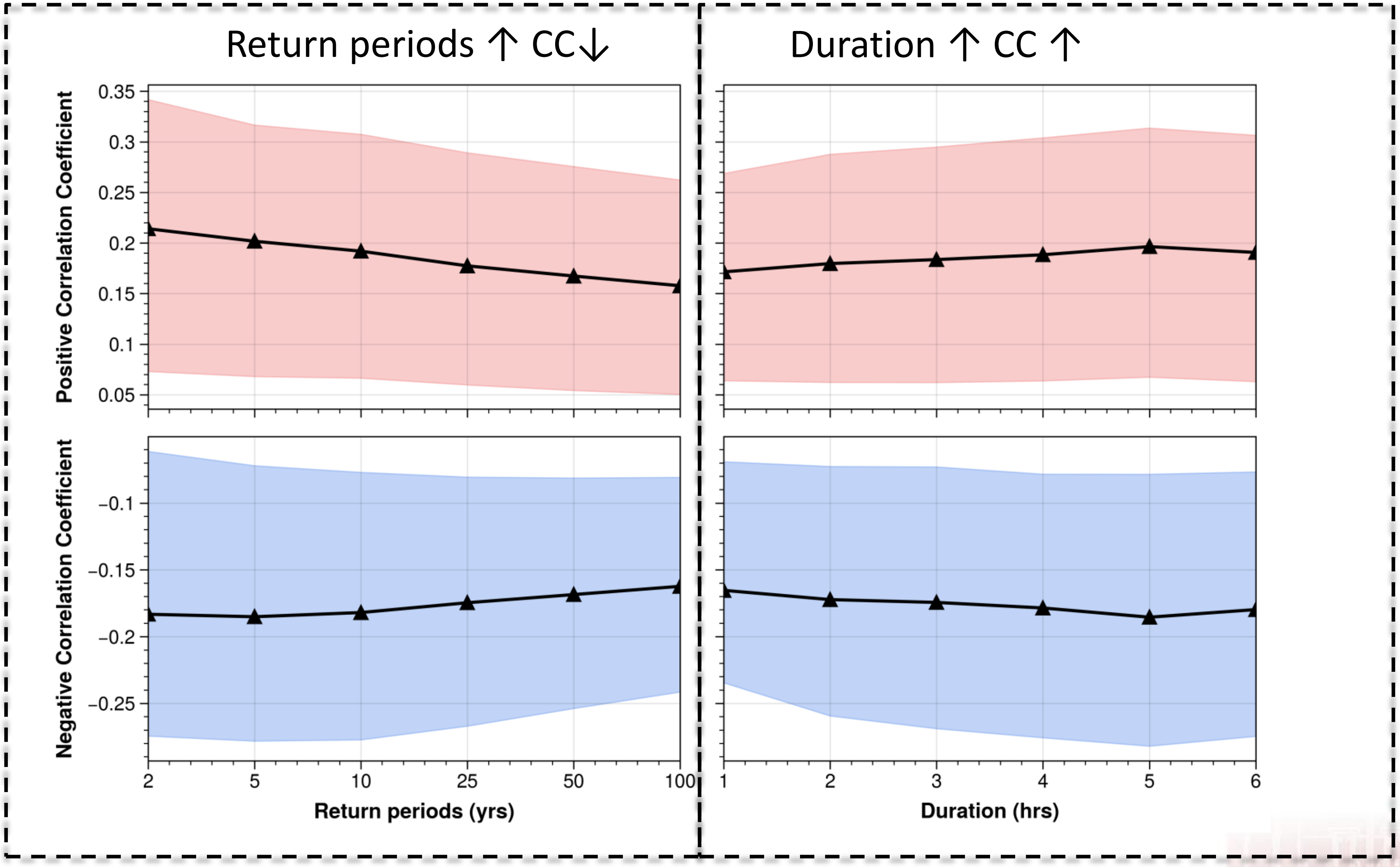
Group	Variable	Min CC	Mean CC	Max CC
Land Cover	Tree(broadleaved/evergreen)	0.12	0.13	0.13
	Tree(broadleaved/deciduous)	0.19	0.26	0.33
	Tree(needle-leaved/evergreen)	-0.22	-0.19	-0.14
	Tree(mixed leaf)	0.039	0.08	0.13
	Tree(mosaic)	-0.17	-0.15	-0.11
	Shrub (evergreen)	-0.24	-0.22	-0.2
	Shrub (deciduous)	-0.45	-0.37	-0.28
	Herbaceous	-0.31	-0.25	-0.2
	SparseHerbaceous	-0.2	-0.17	-0.14
	FloodedShrub	0.042	0.049	0.054
	Cultivated	-0.0017	0.046	0.095
	Mosaic	-0.11	-0.097	-0.083
	WaterBody	-0.13	-0.12	-0.089
	Snow	0.01	0.023	0.036
	Artificial	0.11	0.16	0.21
Natural Vegetation	TropicalEvergreen	0.12	0.13	0.14
	TropicalDeciduous	0.072	0.075	0.077
	TemperateDeciduous	0.19	0.24	0.3
	TemperateEvergreen	-0.16	-0.14	-0.11
	BorealEvergreen	-0.26	-0.24	-0.19
	BorealDeciduous	-0.24	-0.22	-0.19
	Evergreen	-0.075	-0.056	-0.03
	Savanna	-0.0091	0.014	0.029
	Grassland	-0.41	-0.34	-0.26
	DenseShrub	-0.25	-0.19	-0.12
	OpenShrub	-0.36	-0.31	-0.24
	Tundra	-0.045	-0.038	-0.03
	Desert	-0.021	-0.02	-0.019
Wetland	Lake	-0.093	-0.081	-0.05
	Reservoir	-0.097	-0.086	-0.071
	River	-0.019	-0.0069	0.0042
	Peatland	0.0097	0.013	0.016



Factors

1. ↑ Flashiness -> ↓ discharge, river area/volume: <u>small reaches tend to have higher flashiness values</u>
2. ↑ Flashiness -> ↓ regulation: <u>flood structures impede flash floods</u>
3. ↑ Flashiness -> ↑ land runoff, air temperature, aridity index, evaporation, climate moisture index: <u>flashiness is a weather-dependent variable not dependent on climate</u>
4. ↑ Flashiness -> ↓ snow cover extent: <u>flash floods are not typically snow-driven</u>
5. ↑ Flashiness -> ↑ clay, ↓ sand: <u>clay soils help generate flash floods</u>
6. ↑ Flashiness -> ↑ soil water content: <u>wet soils help generate flash floods</u>
7. ↑ Flashiness -> ↑ urban density, road density: <u>impervious surface area help generate flash floods</u>

Correlation changes regarding return periods and duration



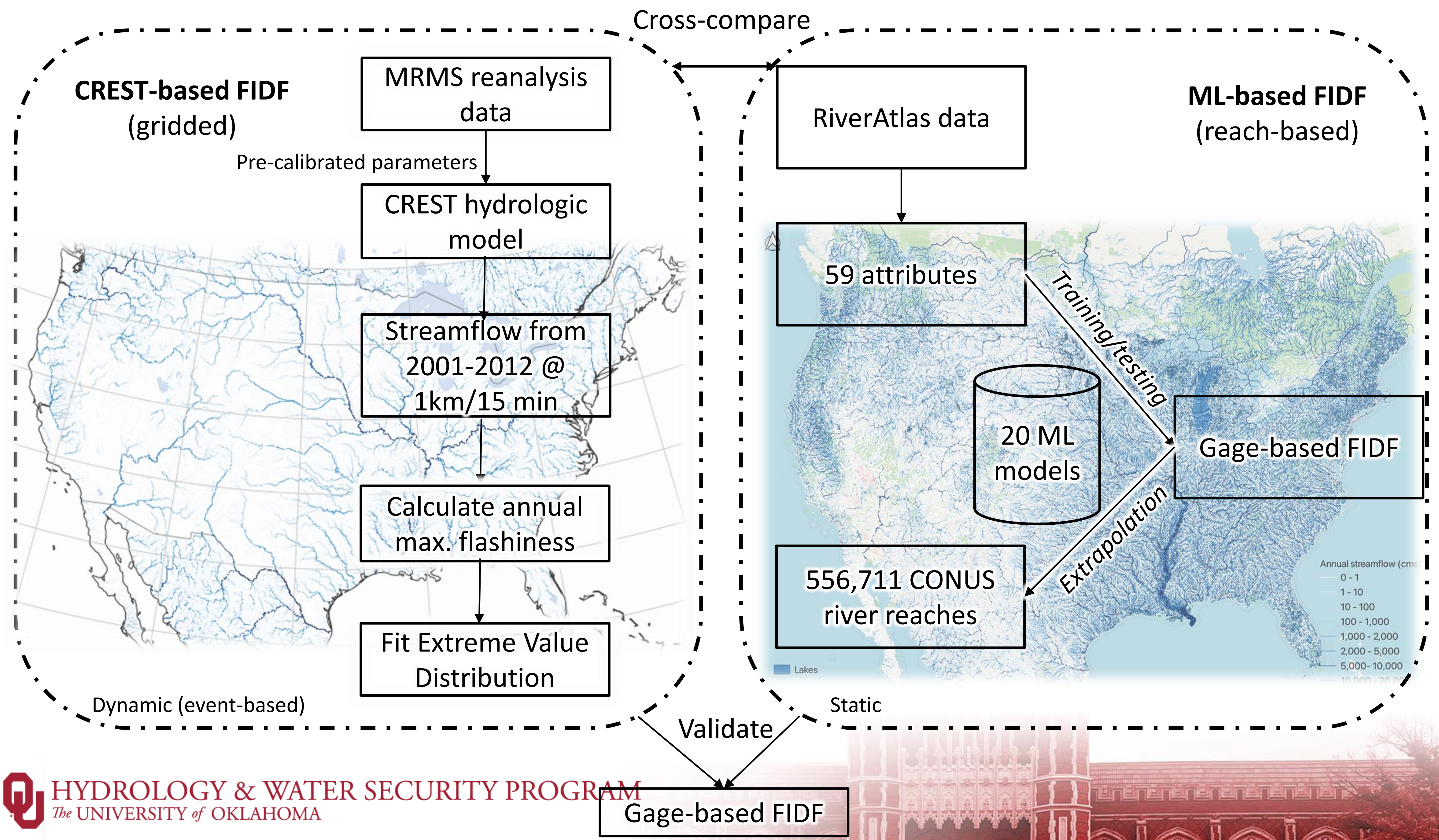
We reason:

1. When return period increases, flash flood event becomes less dependent on climate variables but rather on weather such as intense rainfall rates, etc.
2. When return period increases, the event is less dependent on a single factor (e.g., rain), but rather a joint factor (e.g., rain + wet antecedent soils + steep channels)

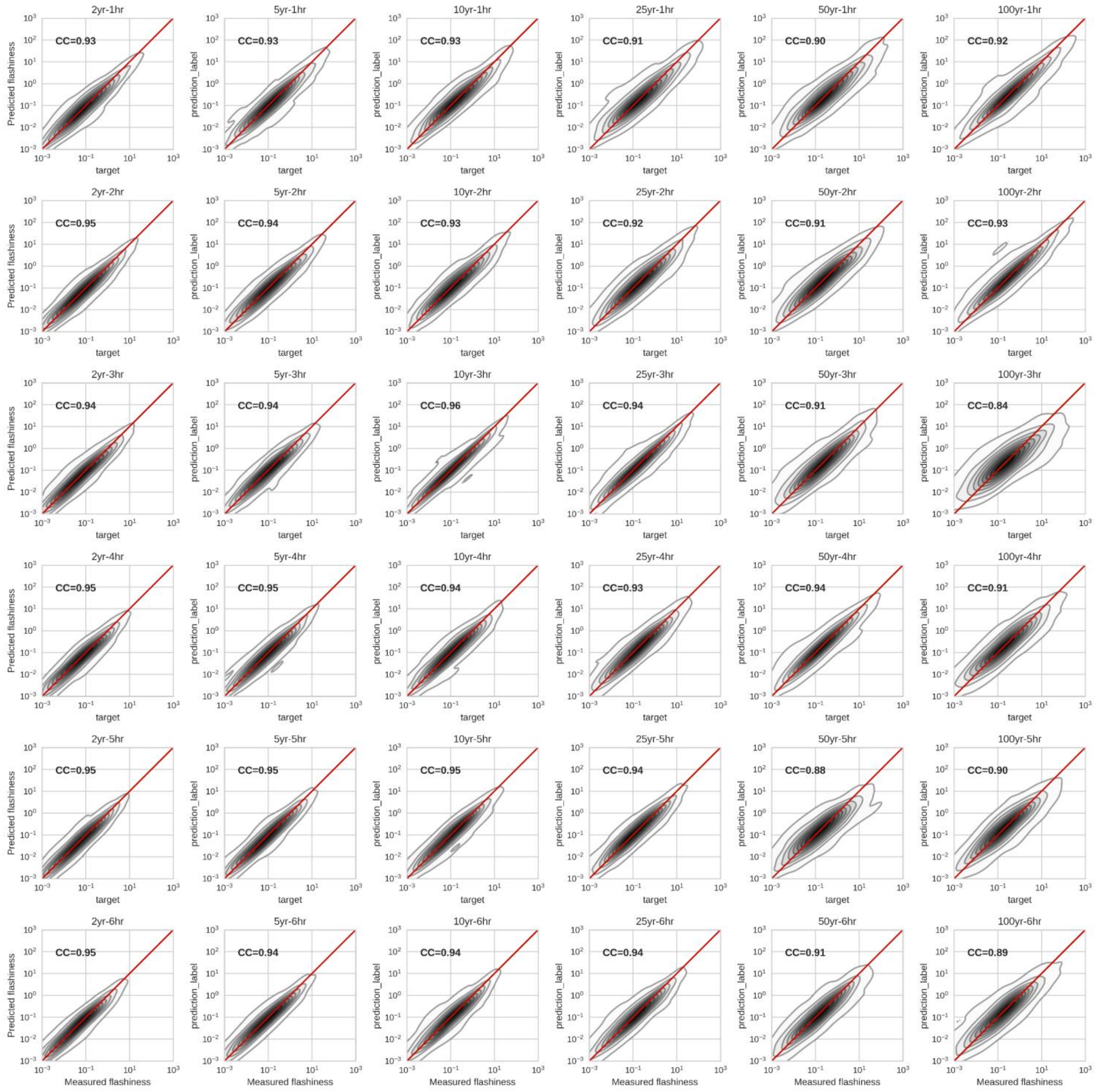
A distributed F-IDF curve over the CONUS

Research goals & Objectives

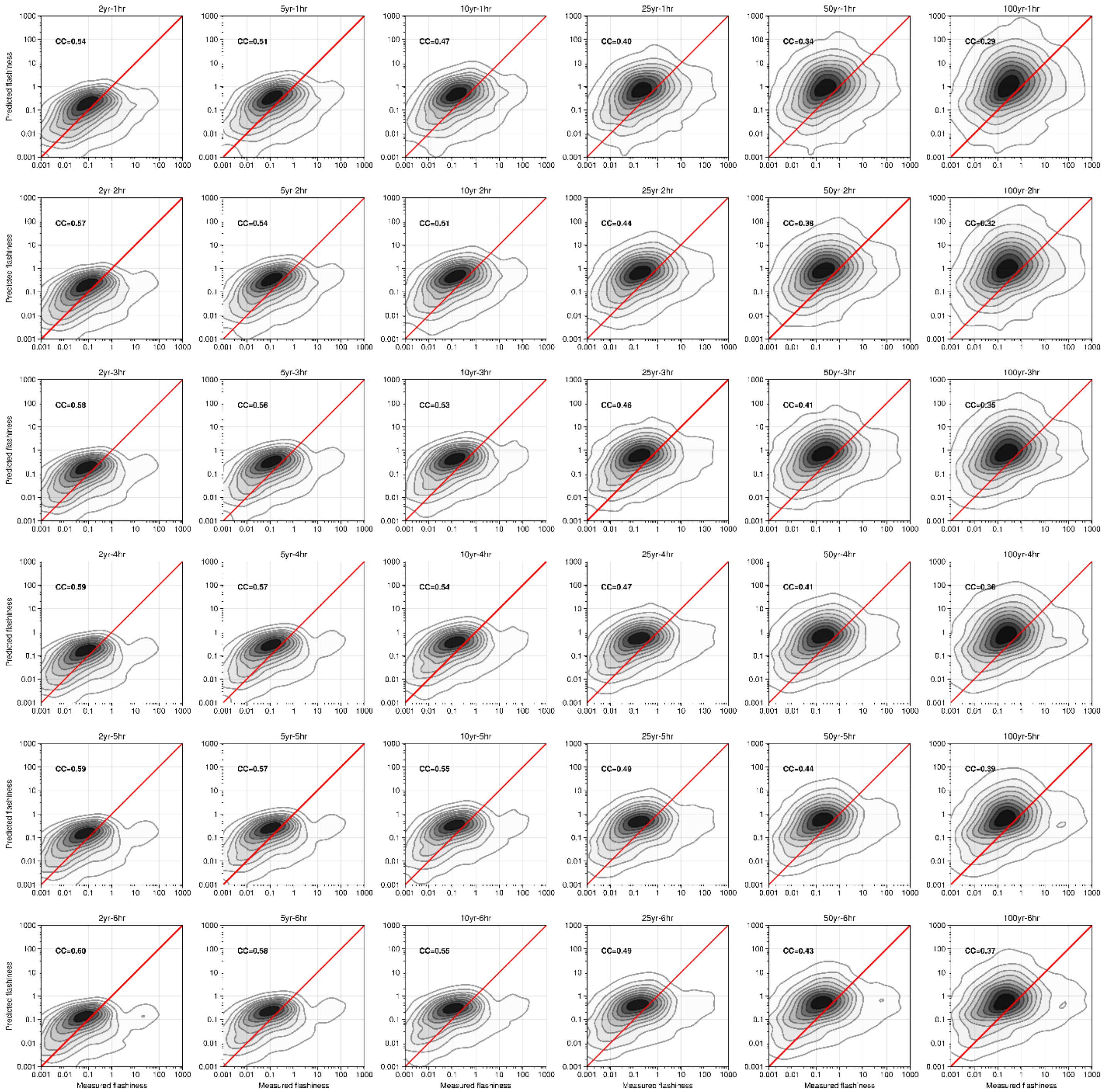
- Goal: offer a distributed F-IDF curve over the CONUS
- Objectives:
  - Produce CONUS-wide F-IDF curves based on (1) CREST (physical) and (2) AI (statistical)
  - Cross-compare the two approaches with regard to (1) flashiness representation, (2) limitations

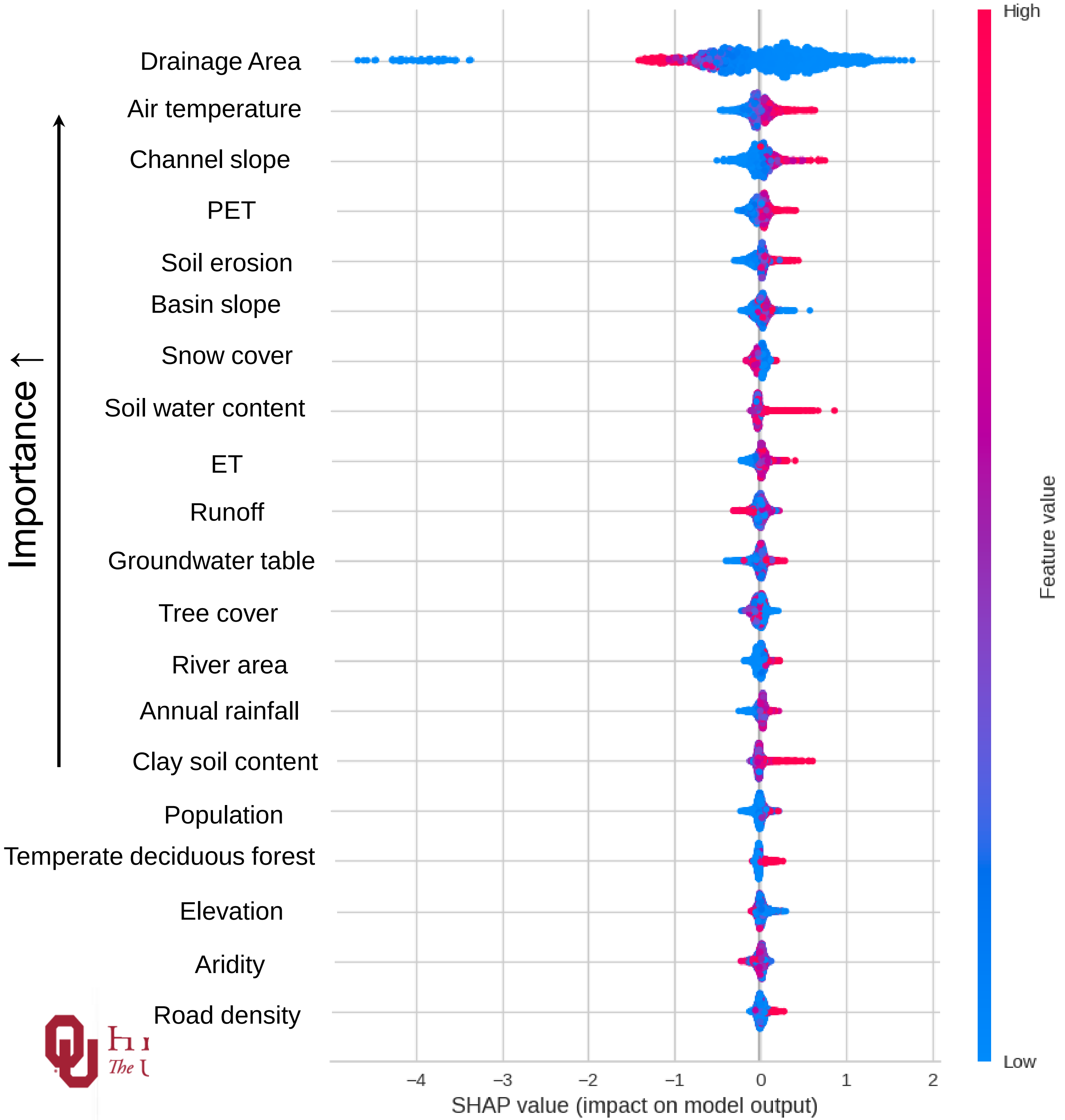

Cross-compare
CREST-based FIDF
(gridded)
MRMS reanalysis data
Pre-calibrated parameters
CREST hydrologic model
Streamflow from 2001-2012 @ 1km/15 min
Calculate annual max. flashiness
Fit Extreme Value Distribution
Dynamic (event-based)
ML-based FIDF
(reach-based)
RiverAtlas data
59 attributes
Training/testing
20 ML models
Gage-based FIDF
Extrapolation
556,711 CONUS river reaches
Annual streamflow (cms)
0 - 1
1 - 10
10 - 100
100 - 1,000
1,000 - 2,000
2,000 - 5,000
5,000- 10,000
Lakes
Static
Validate
Gage-based FIDF

ML-based testing (validated on gauges)



CREST-based testing

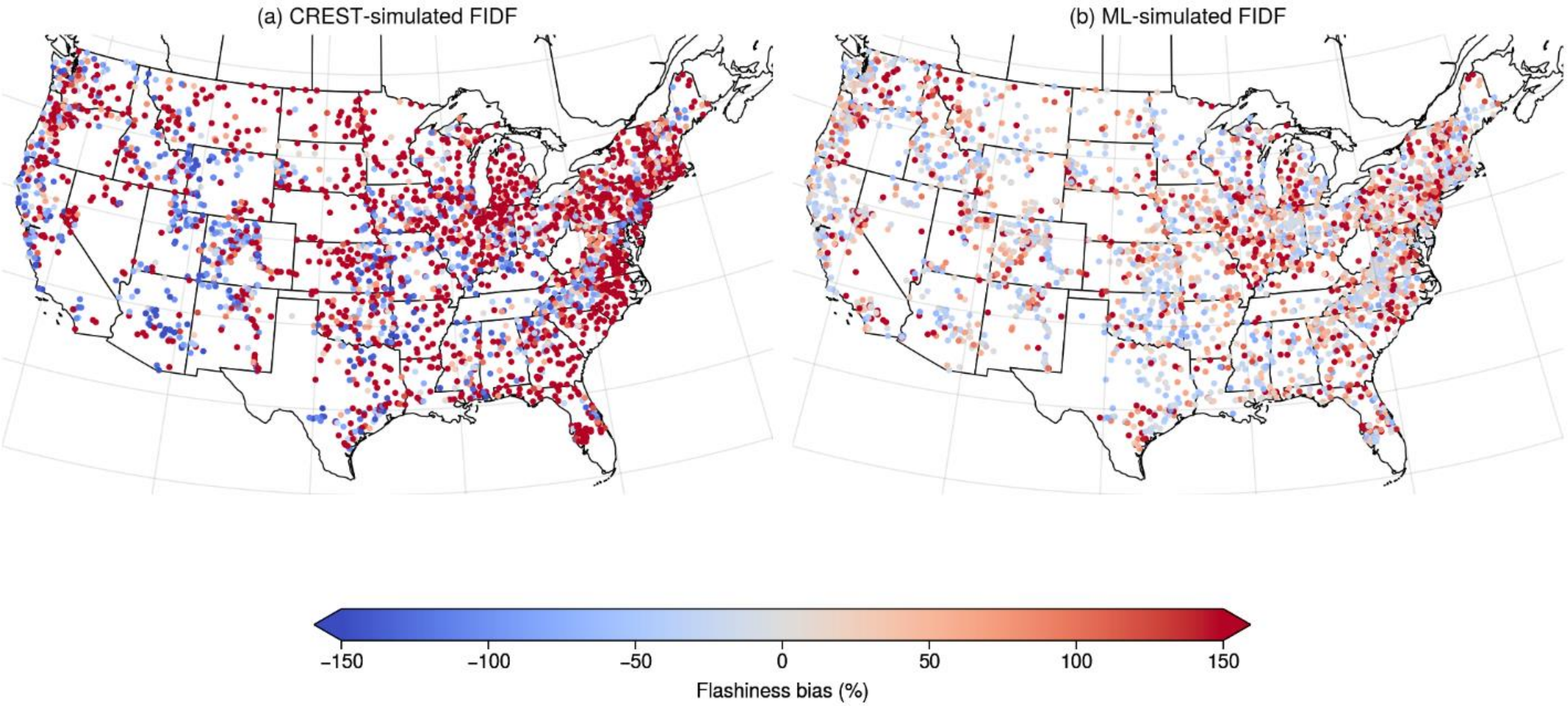


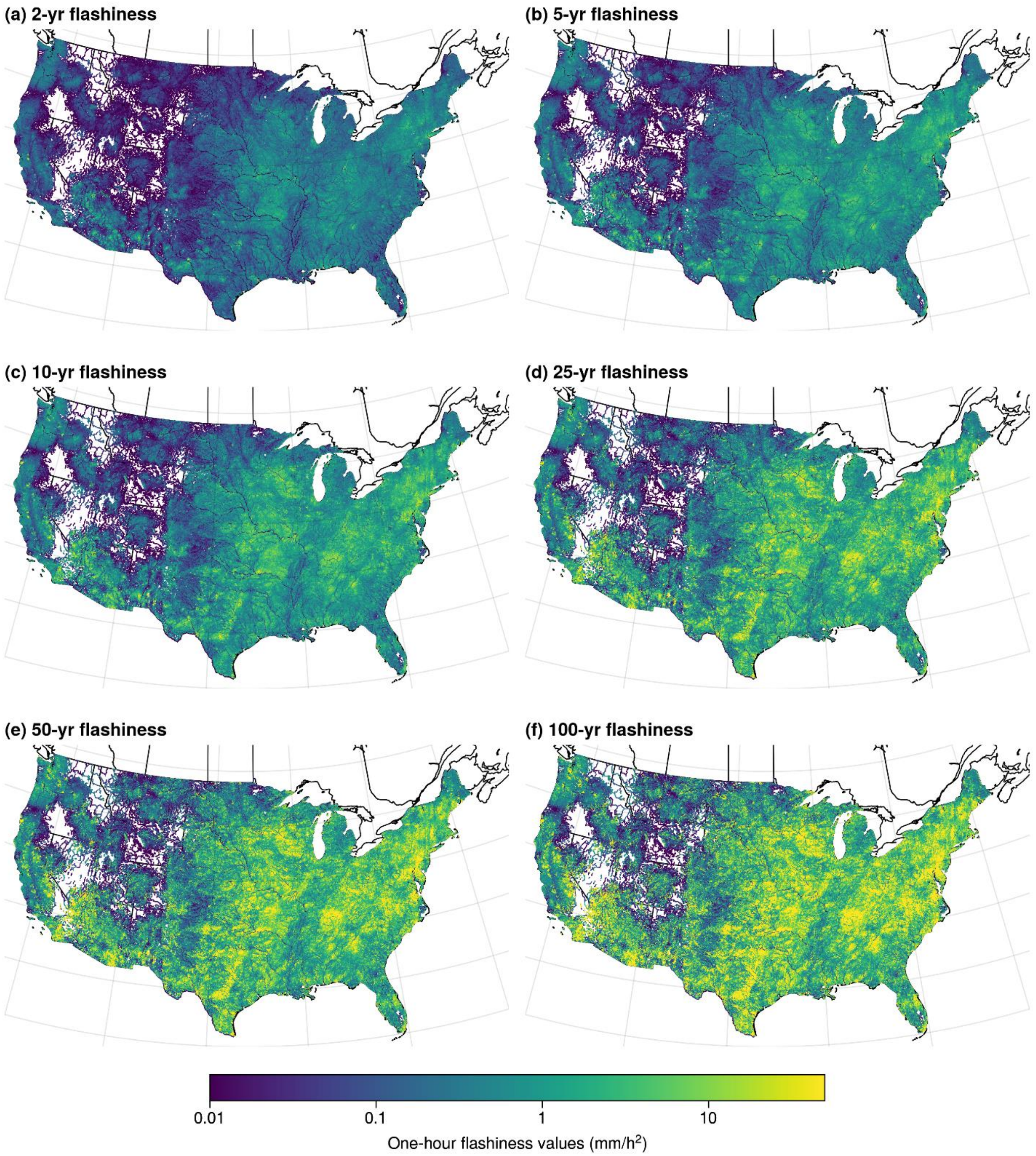


Variable importance ranking from ML-based model

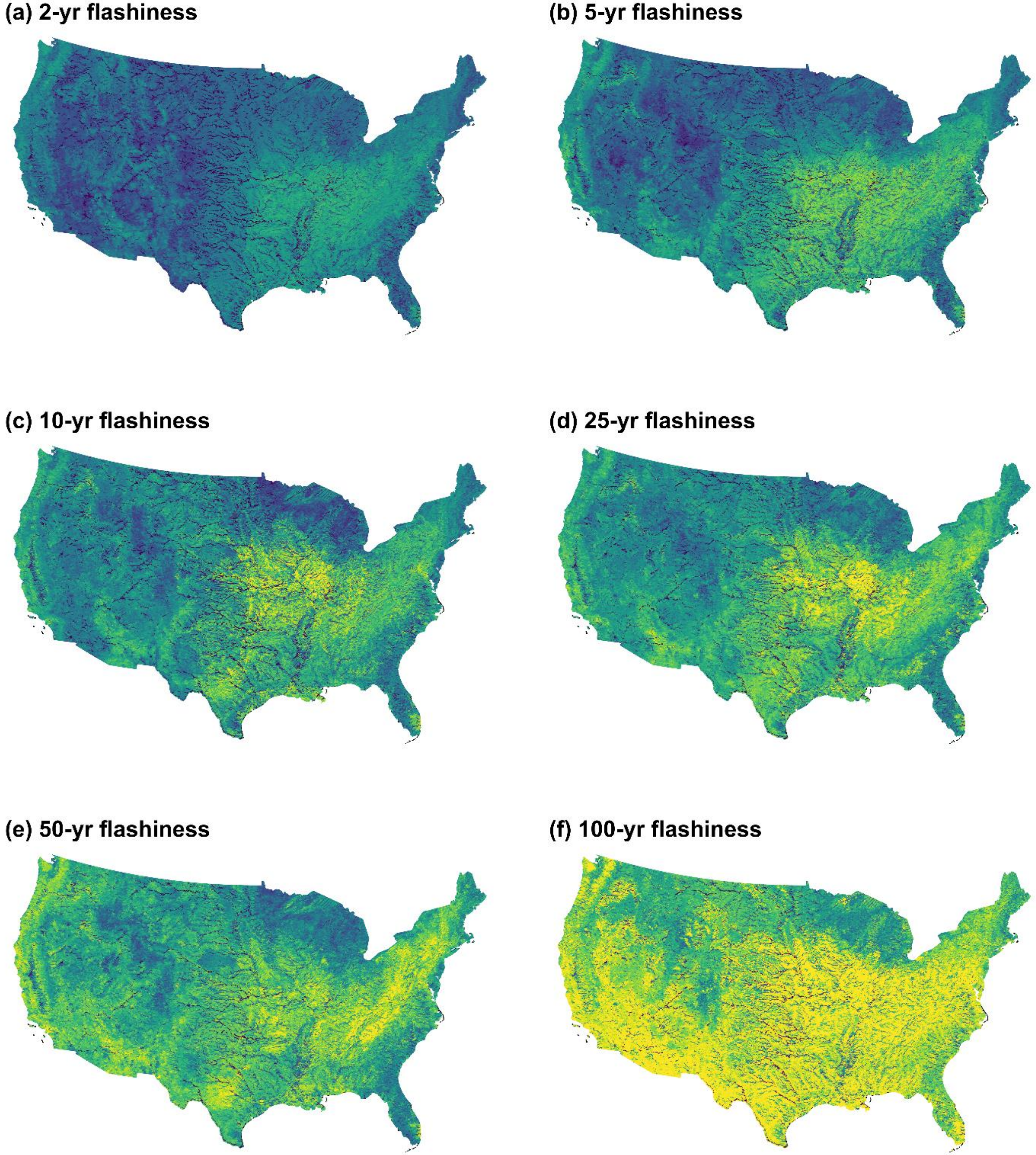
Drainage area has the greatest impact on the model prediction (lower values impact positively on the model prediction)

Comparing both CREST-based and ML-based FIDF on all the stream gages

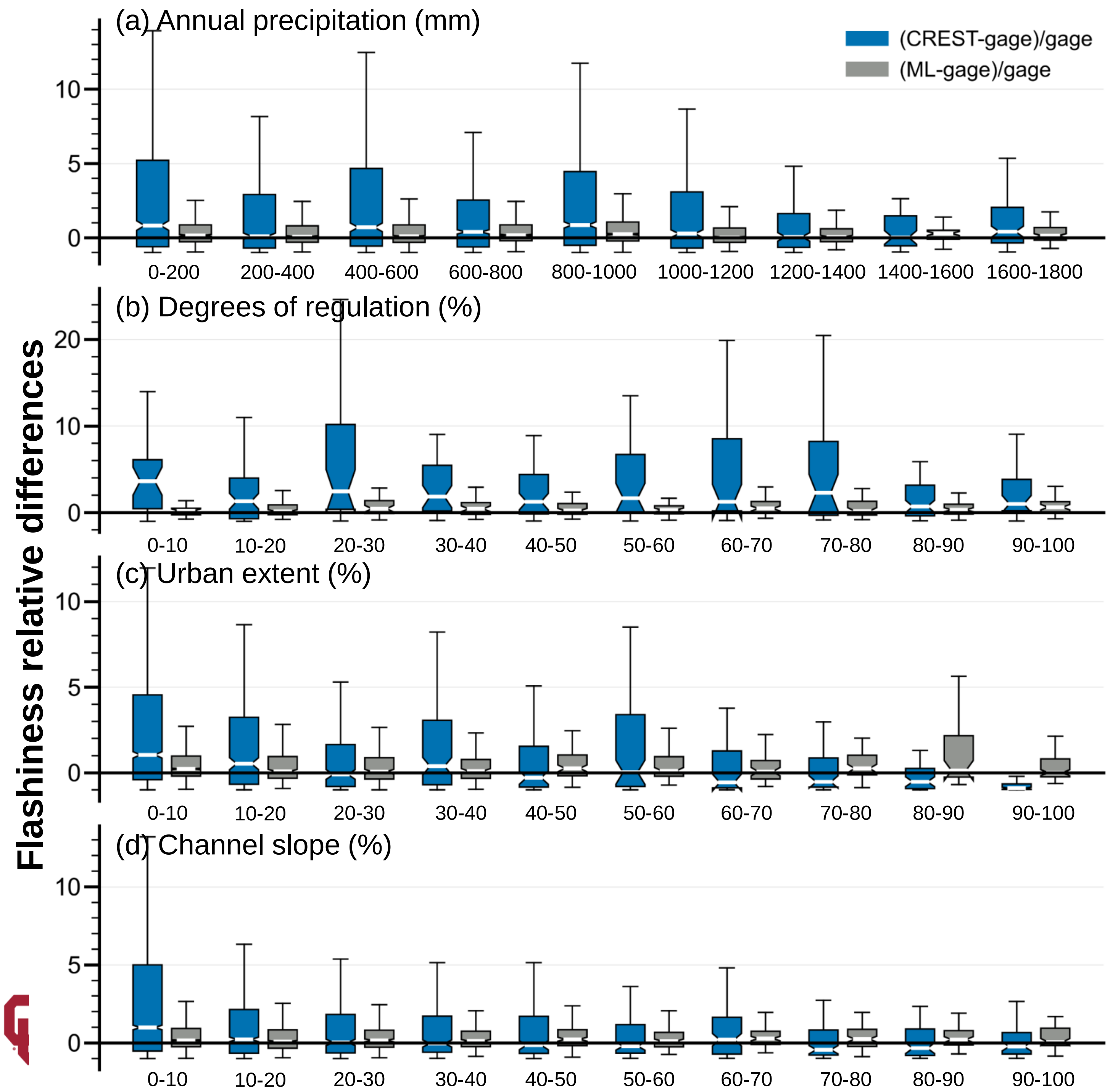




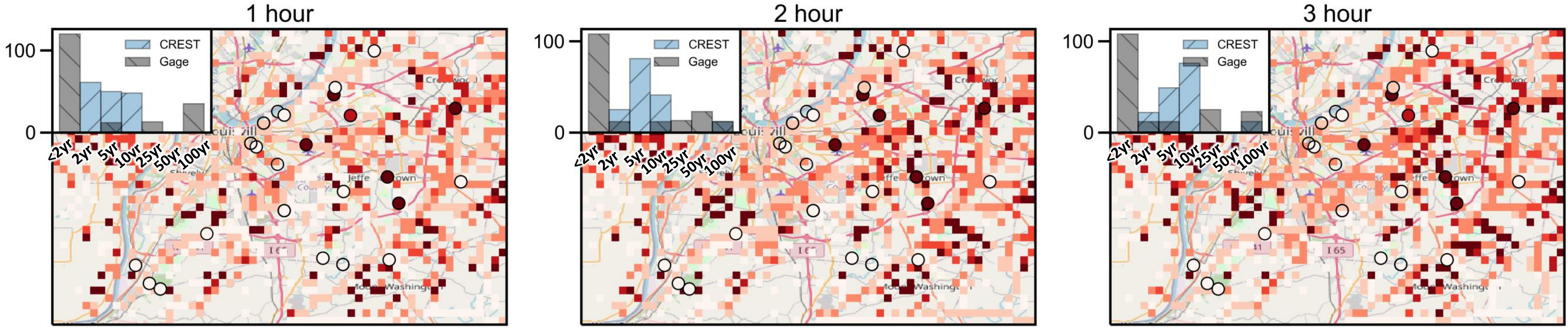
CREST-based distributed FIDF



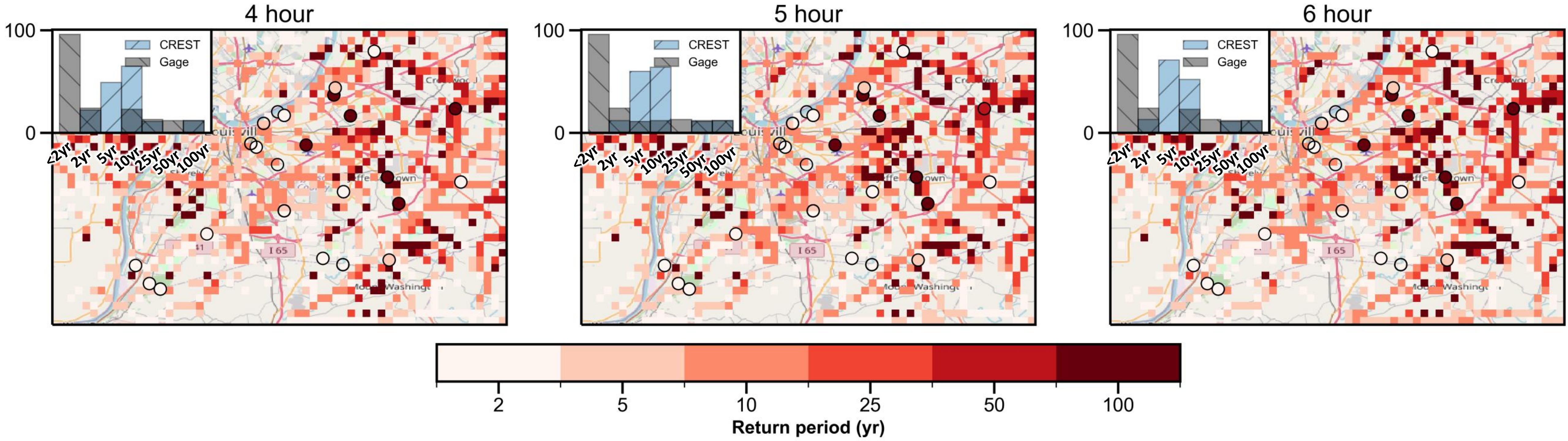
ML-based distributed FIDF

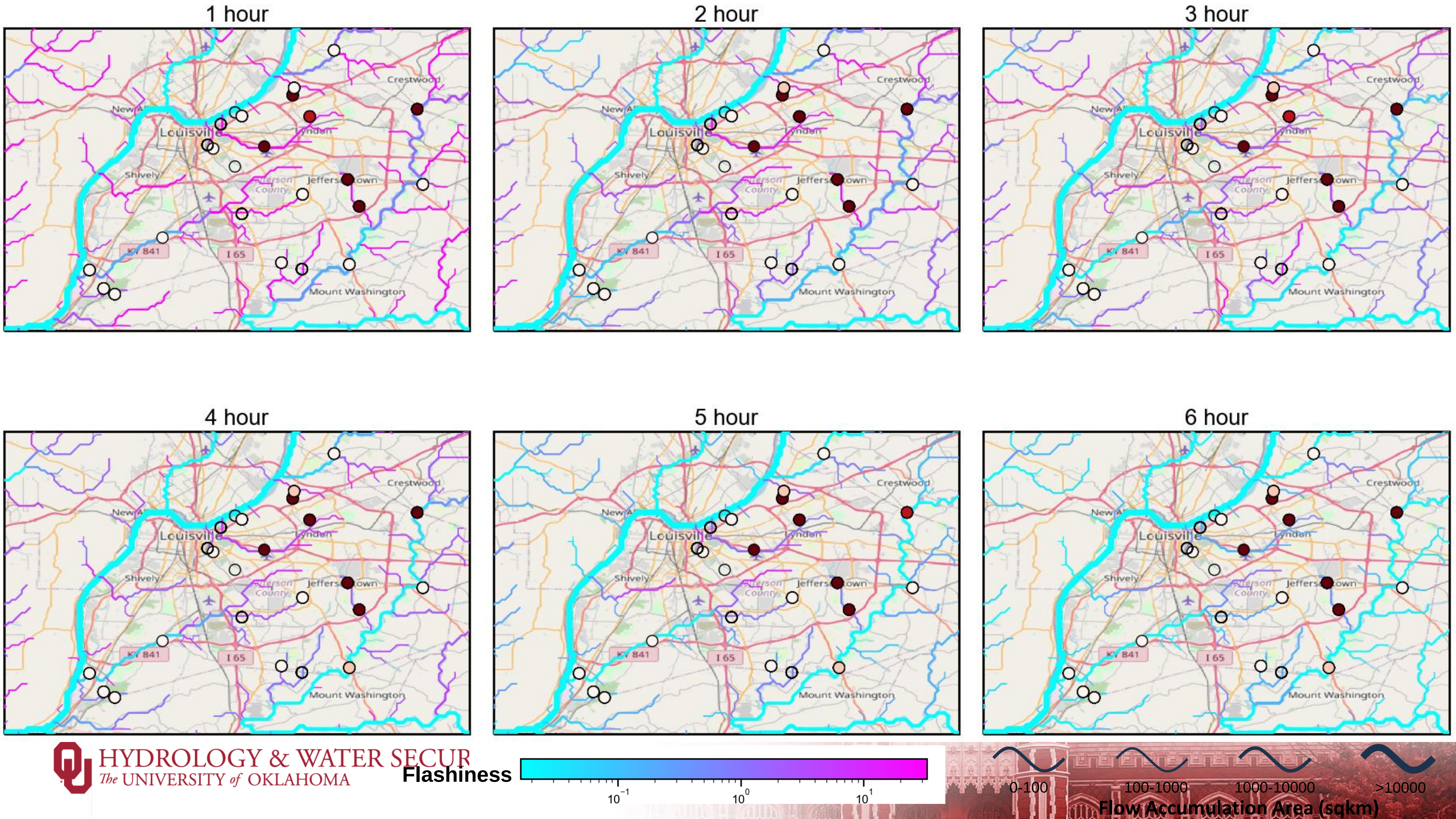


Conditional bias on different influential factors



2009 Louisville Flash flooding





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