Attributing flood trends to atmospheric rivers in western Washington

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How are flood trends related to atmospheric rivers (ARs) in western Washington?

Case study of twelve river basins in the 2.5 x 2.5 degree cell centered at 47.5^{o} N, 122.5^{o} W without regulation and relatively complete streamflow records since 1951.

- *Test for rank trends in AR (magnitude and frequency) and annual peak streamflow using all possible start and end years from 1951 to 2015.*

- *Examine flood characteristics that could indicate other changes in ARs that generate floods.*

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Rationale

Atmospheric rivers (AR) generate most floods in western Washington state.

Annual peak streamflow has increased in some rivers since ~1980, which can be presumed to be a response to ARs.

Attribution of flood trends is necessary to permit adjustment of flood frequencies (Bulletin 17C).

The spatial resolution of historical ARs is a key limitation for flood-trend attribution, but coarse-resolution analysis may provide a framework for predicting flood impacts from projections of future ARs, which also have limited spatial resolution.

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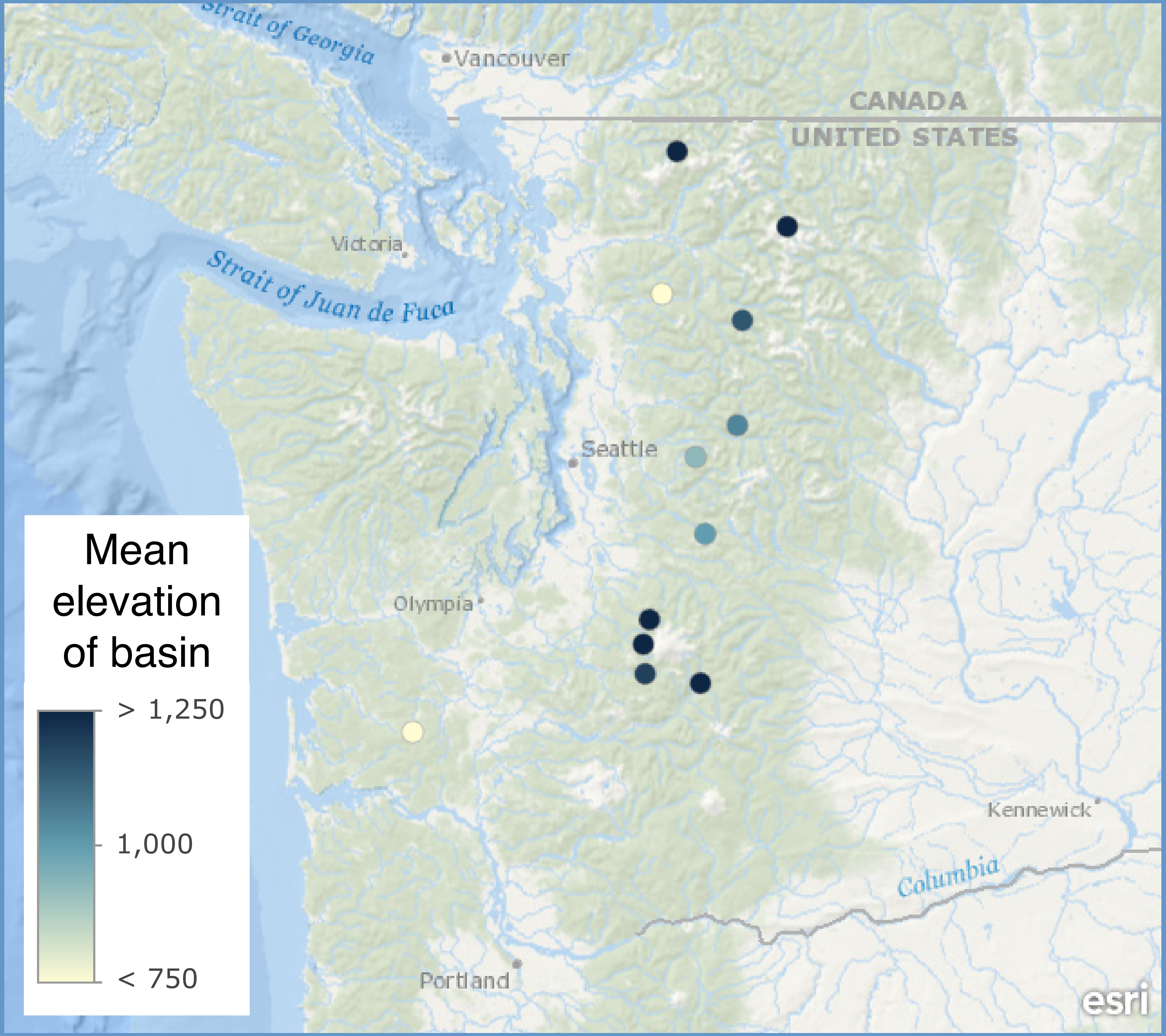
Location and Elevation of Basins

12 rivers basins - mostly on the west slope of the Cascade Range + Chehalis River

Drainage areas range from 100 to 1800 sq km.

Median annual maximum daily runoff ranges from 3 to 7 cm/ day.

All of the river present flood hazards to developed lowland areas



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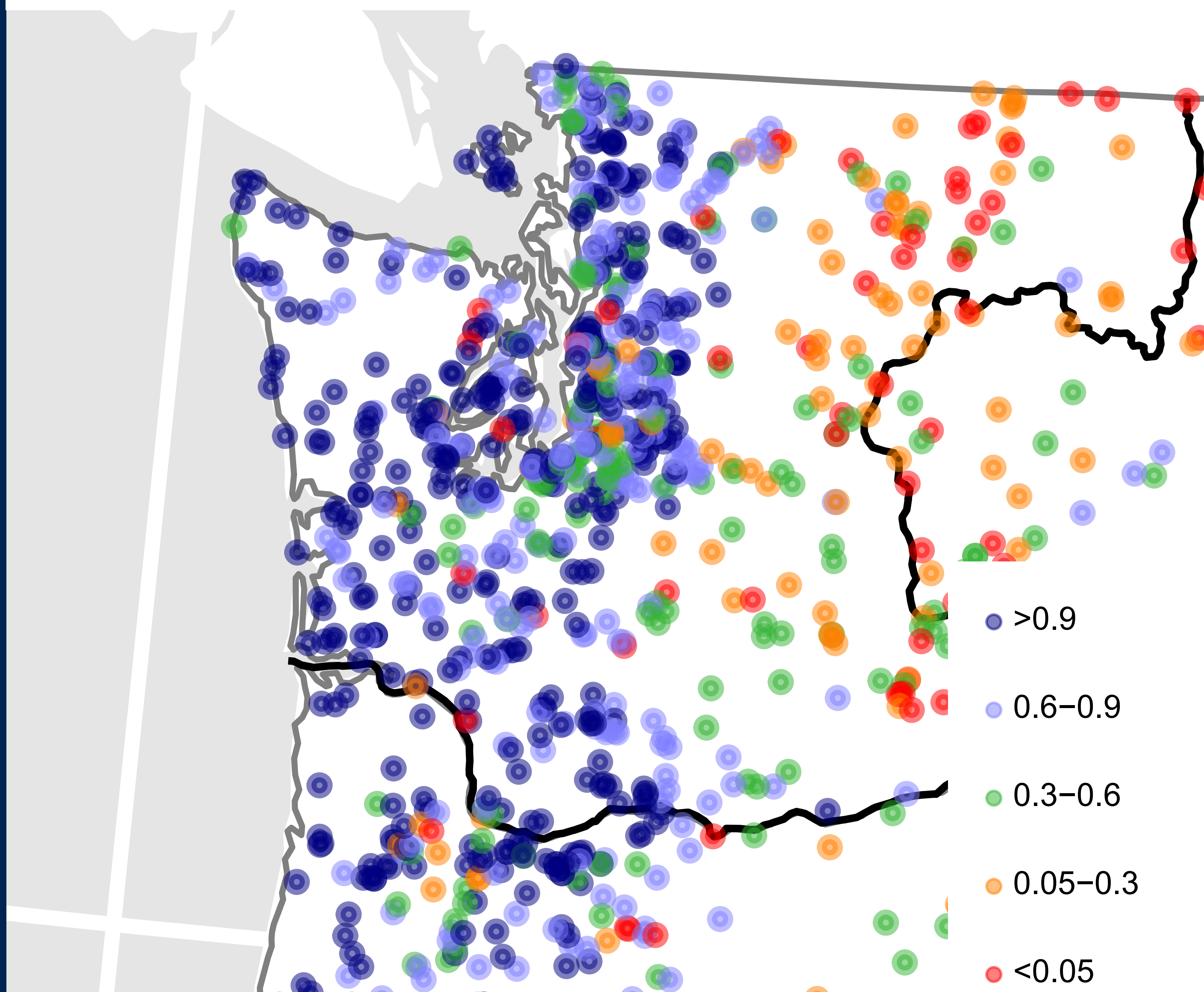
Floods and AR in Western Washington

Fraction of annual maximum daily streamflow that can be attributed to ARs



Konrad and Dettinger (2017)

Neiman et al. (2011) observed that annual peak streamflow in 4 western Washington (1980-2009) occur during landfalling ARs in the warm sector of extratropical cyclones.

Key characteristics contributing to floods including:

- strong, low level (<1 km) on-short water vapor flux;
- weakly stable, moisture saturated atmosphere below Cascade Crest; and
- high temperature in lower-troposphere.

These conditions produce heavy, orographically-forced precipitation as rain.

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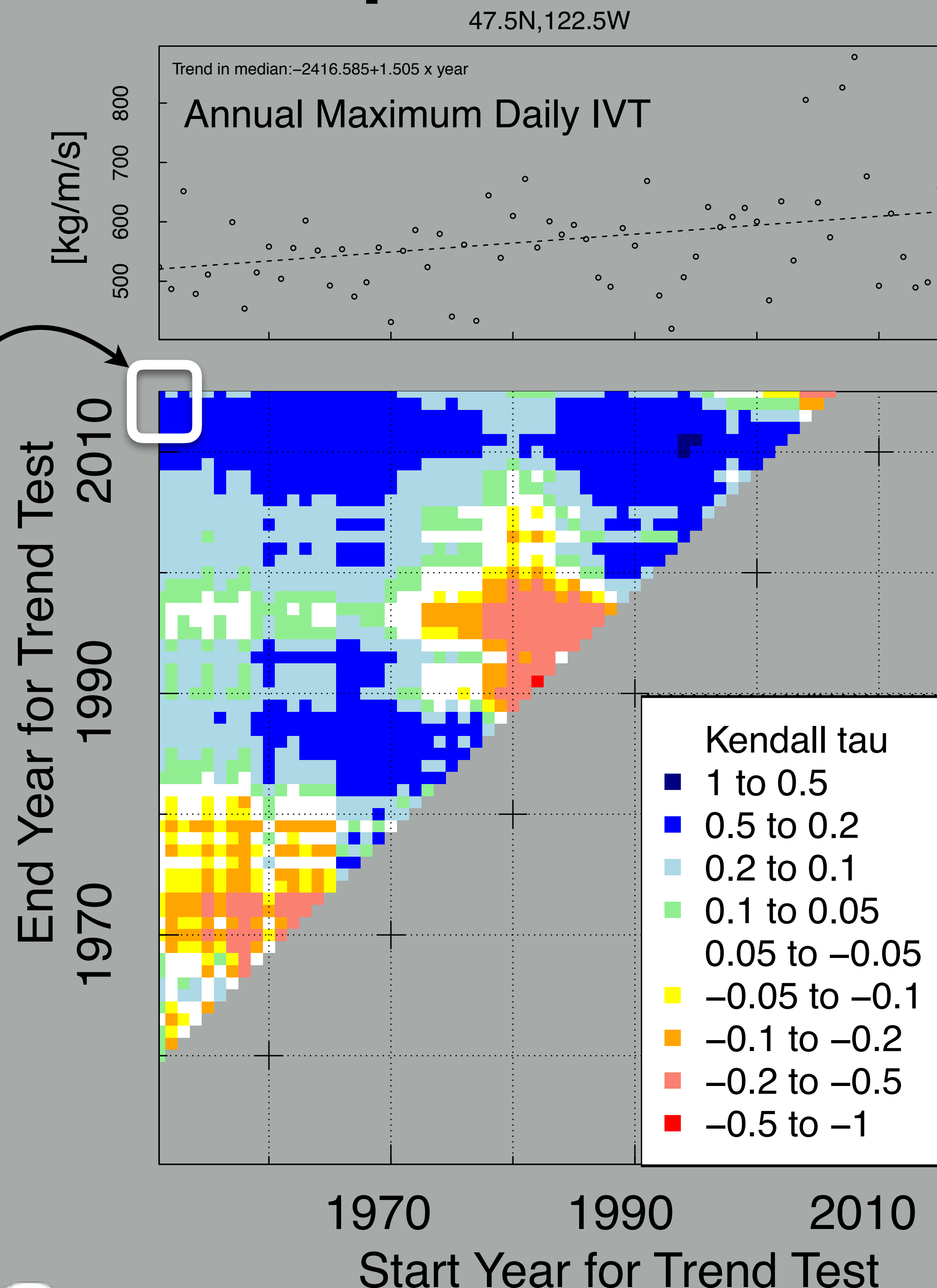
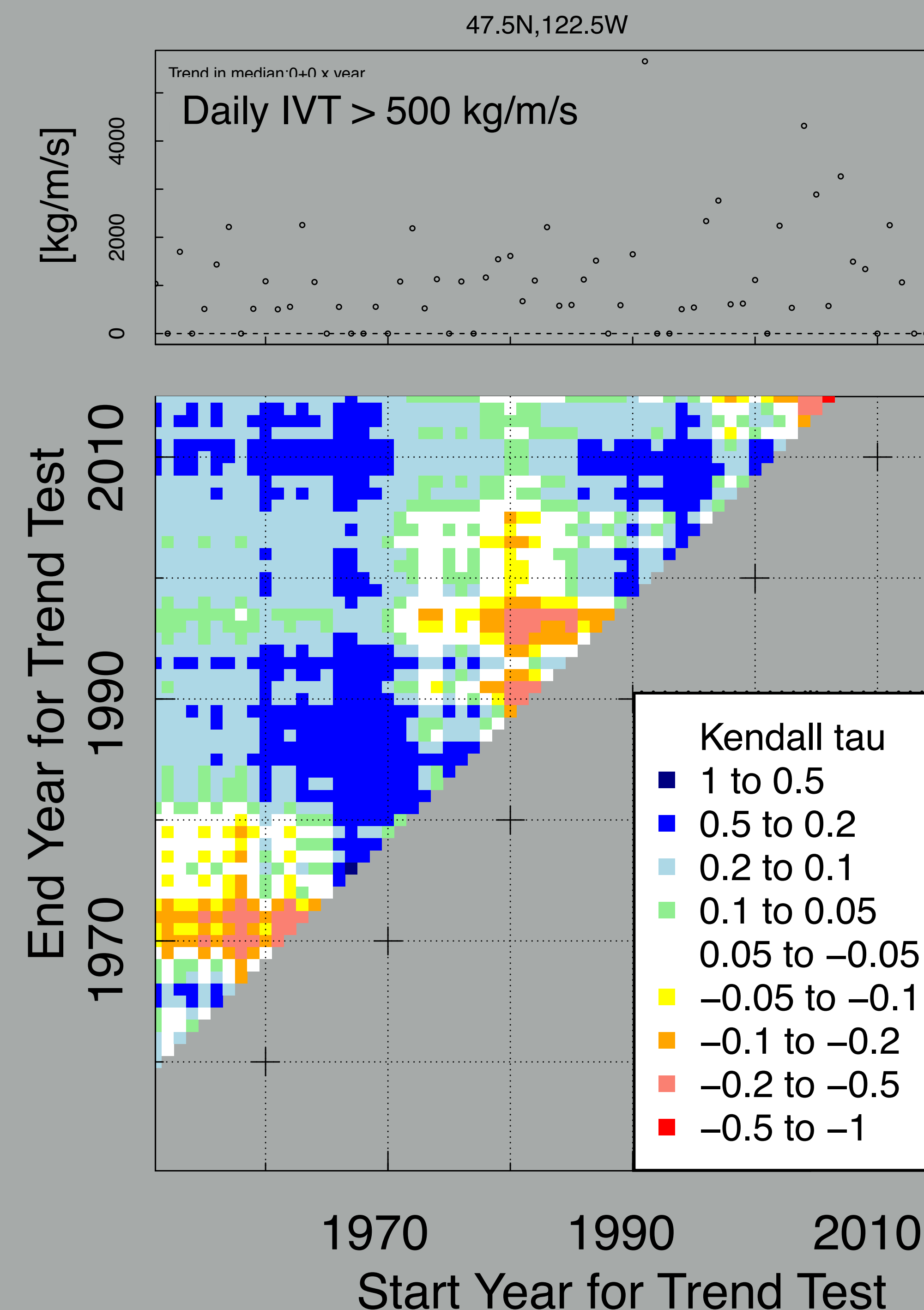
Trends in Daily Vertically Integrated Water-Vapor Transport (IVT) at 47.5^{0}N, 122.5^{0}W

Cyclic pattern:
1960 - 1970 (–)
1970 - 1980 (+)
1980 - 1990 (–)
1990 - 2010 (+)

Annual maximum IVT increased around 1980 and has a significant trend from 1951 to 2015

Total transport > 500 kg/m/s appears greater after 1980, but trend from 1951 to 2015 is not significant





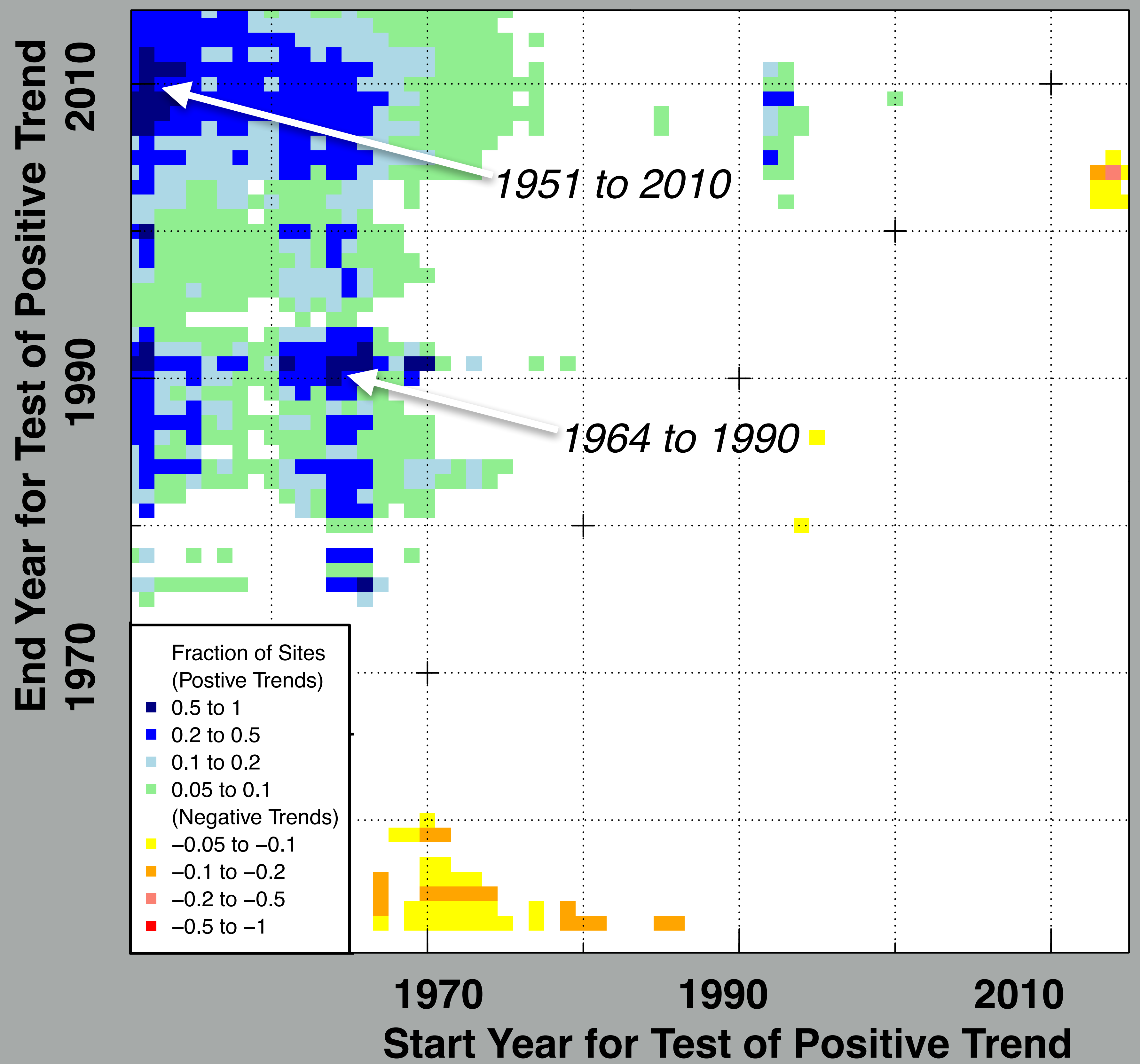
IVT data from Jonathan Rutz
http://www.inscc.utah.edu/~rutz/ar_catalogs/ncep_2.5/timeseries/

Trends in Annual Peak Streamflow

Five rivers had significant positive trends from 1951 to 2010, but nearly all rivers show increasing peaks.

Positive trends general began after 1980 matching the trends in IVT, but annual maximum streamflow occurs within 3 days of annual maximum IVT in only 13 to 42% of years (27% for median basin).

Negative trends were uncommon and short-lived.



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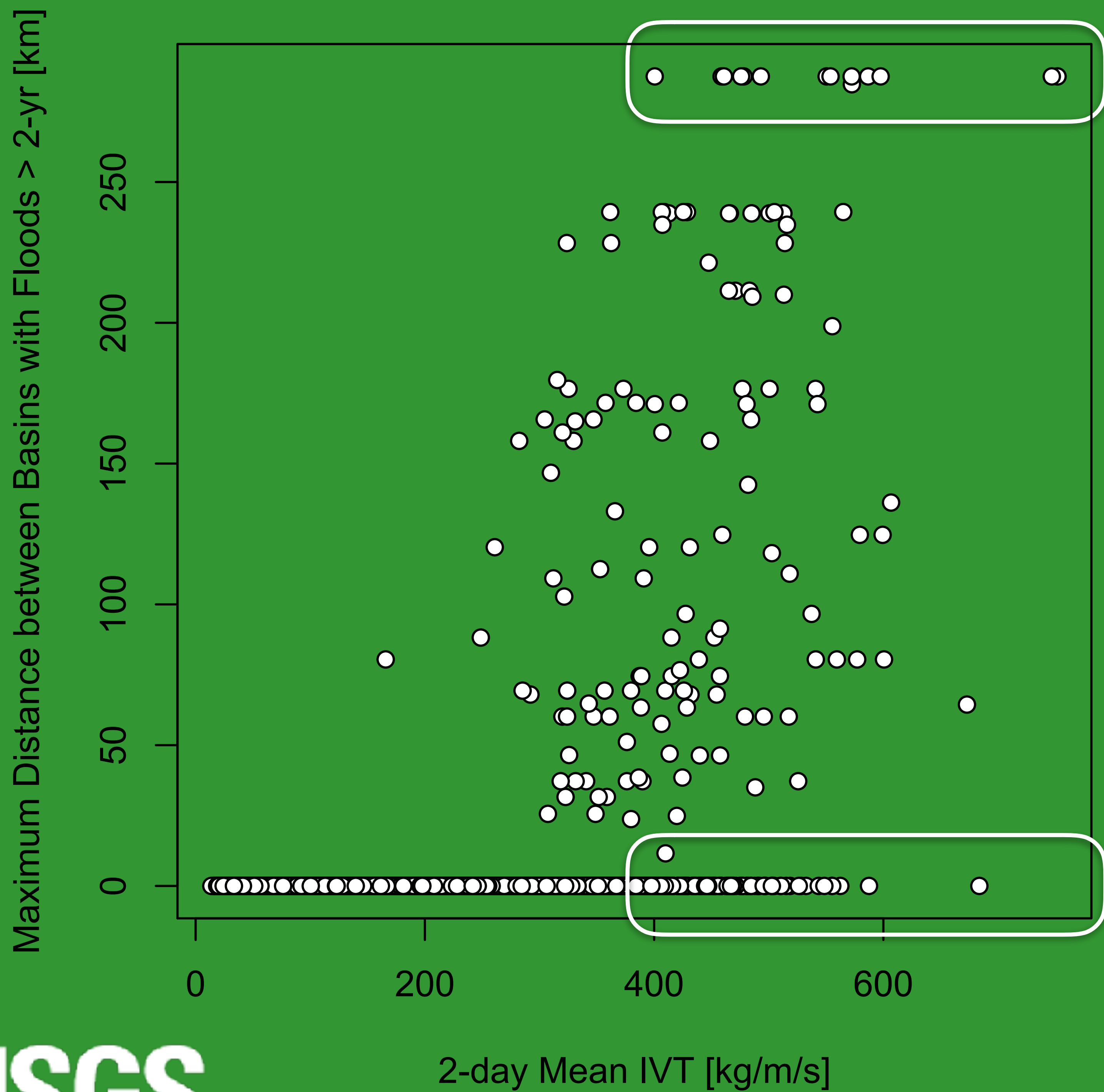
Strong and long ARs generate largest spatial extent of flooding



All 12 rivers had floods > 2-yr return period

Some moderate-intensity ARs do not generate floods

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Increased Extent of Large Floods Since 1980

Most basins had floods > 2-year return interval during these events.

Median (cross-basin) runoff for the largest regional floods is higher since 1980.

Dashed Line represents half of the period of analysis.

DATE	2-DAY MEAN IVT [kg/m/s]	SPATIAL EXTENT FLOODS > 2-YR [km]	MEDIAN 3-DAY RUNOFF [m]
1951-02-09	482	142	0.14
1959-11-22	471	211	0.12
1974-01-14	565	239	0.13
1975-12-02	478	288	0.19
1977-12-01	501	177	0.14
1980-12-25	550	288	0.15
1990-11-09	543	171	0.14
1990-11-23	587	288	0.18
1995-11-28	598	288	0.20
1996-02-07	407	239	0.20
2006-11-06	752	288	0.21
2009-01-07	505	239	0.17
2011-01-16	465	239	0.12

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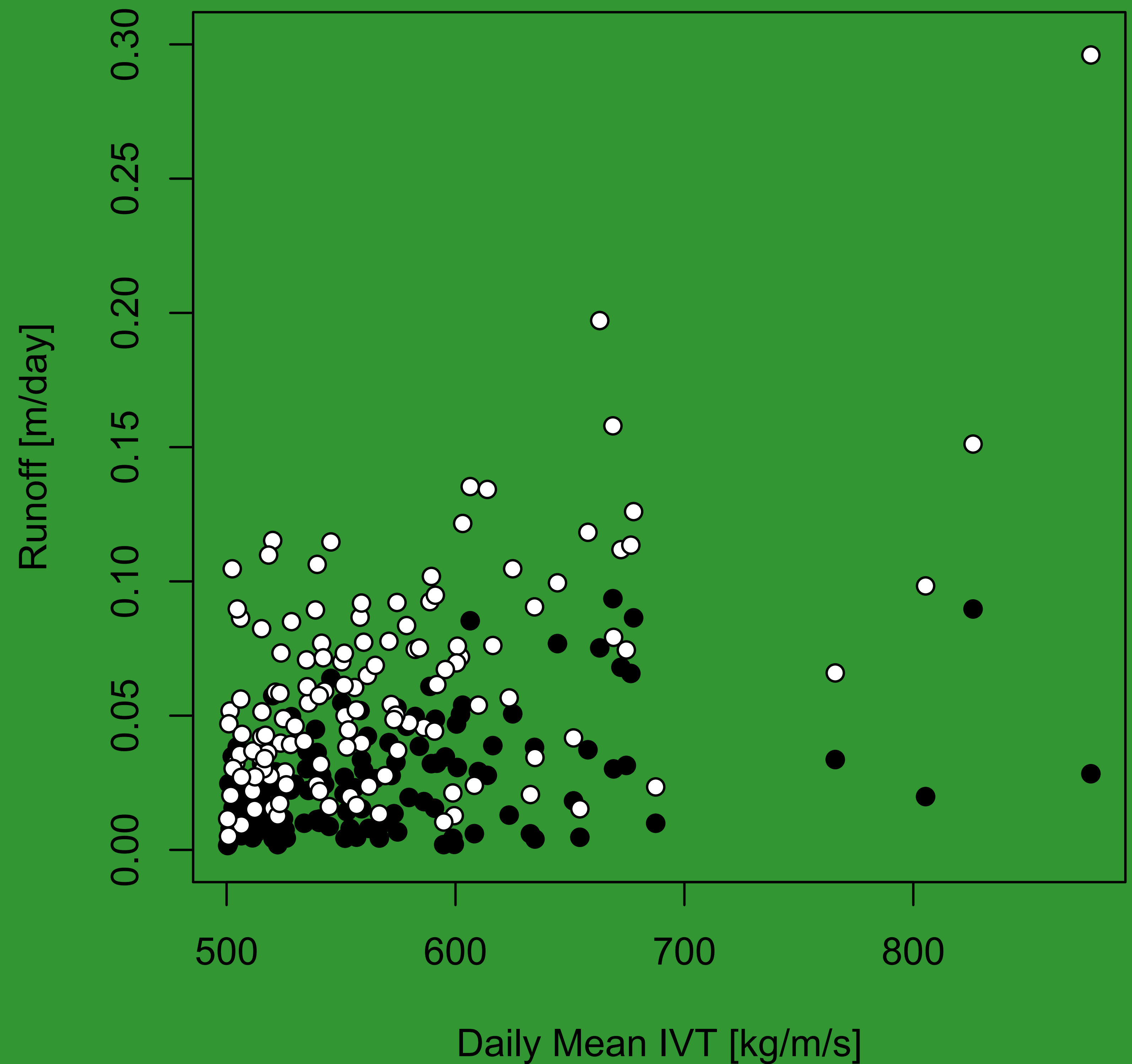
Runoff when Daily Mean IVT > 500 kg/m/s

Uncertainty in relation between runoff and IVT limits inference of flood trends from IVT trends.

White points: maximum runoff of the 12 rivers

Black points: median runoff of the 12 basins



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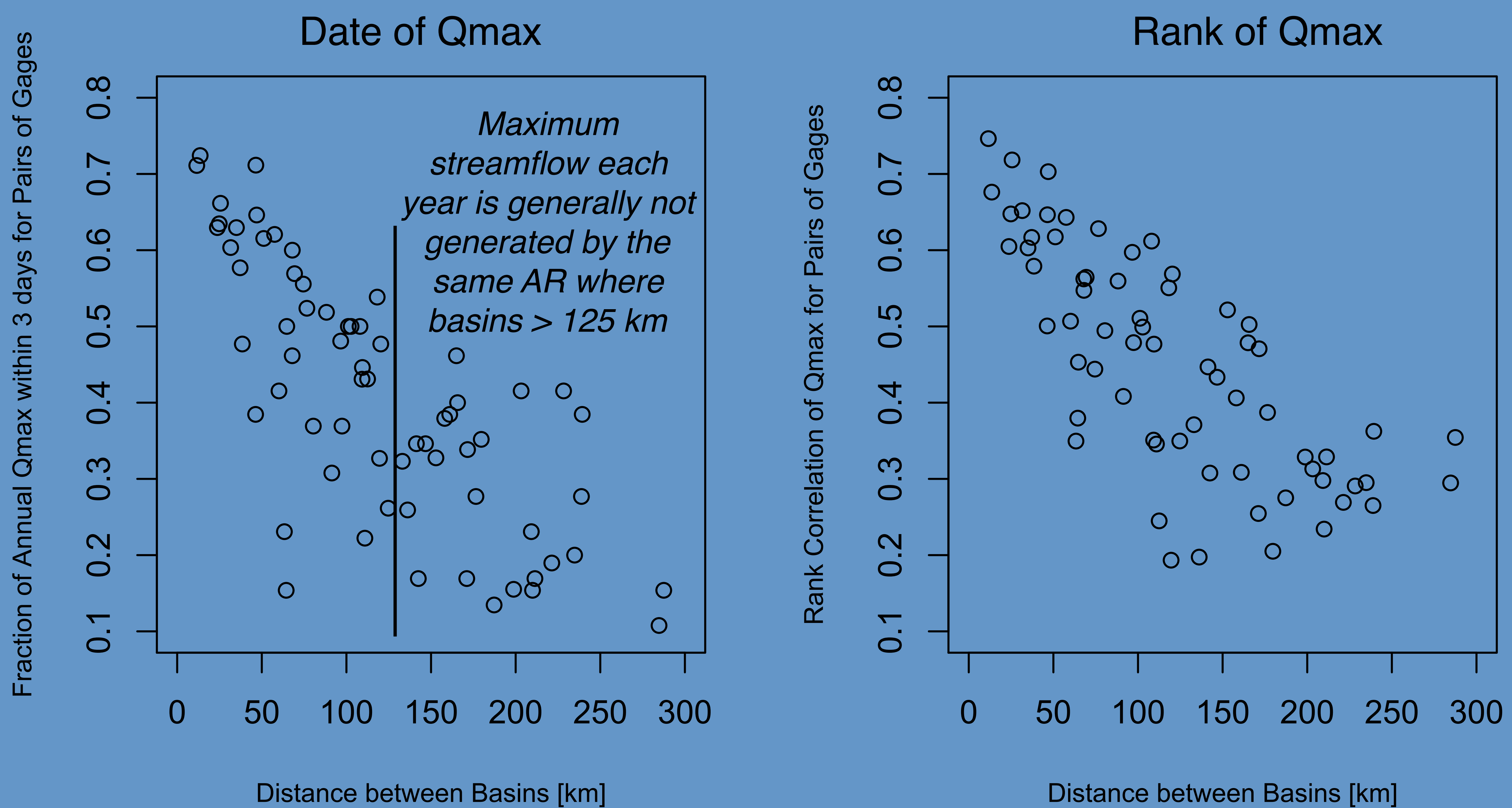
A Suite of ARs Contribute to Floods Each Year

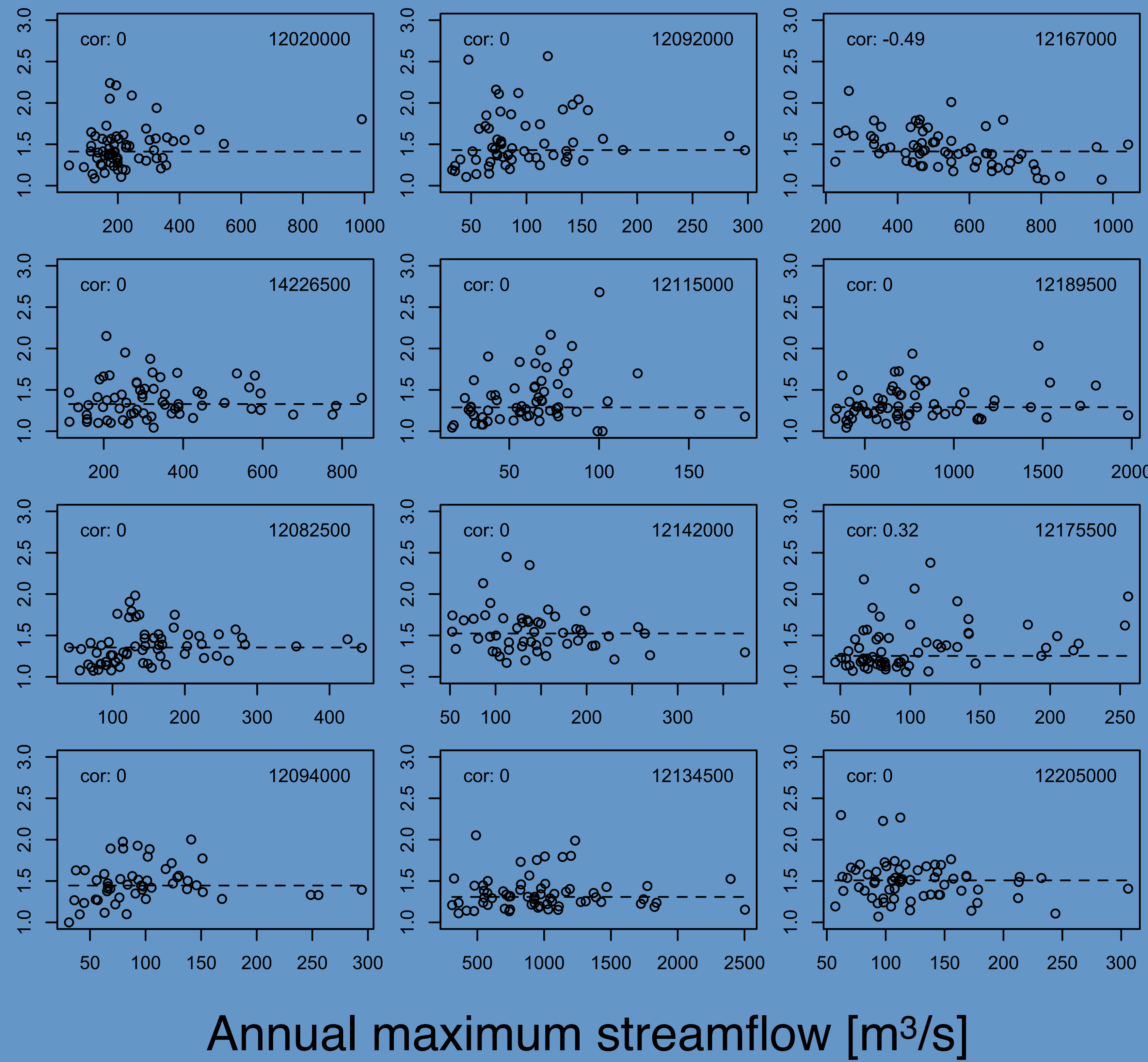


Corollary: AR location is not well-resolved at 2.5º for river-specific flood frequency analysis

Ratio of Peak to Daily Streamflow

Qpeak ~ 1.4 x Qday

- Ratio is not consistently correlated with flood magnitude
- No significant trends in the ratio for any river from 1951 to 2015
- No evidence for systematic shifts flood impacts in response to short-term AR dynamics

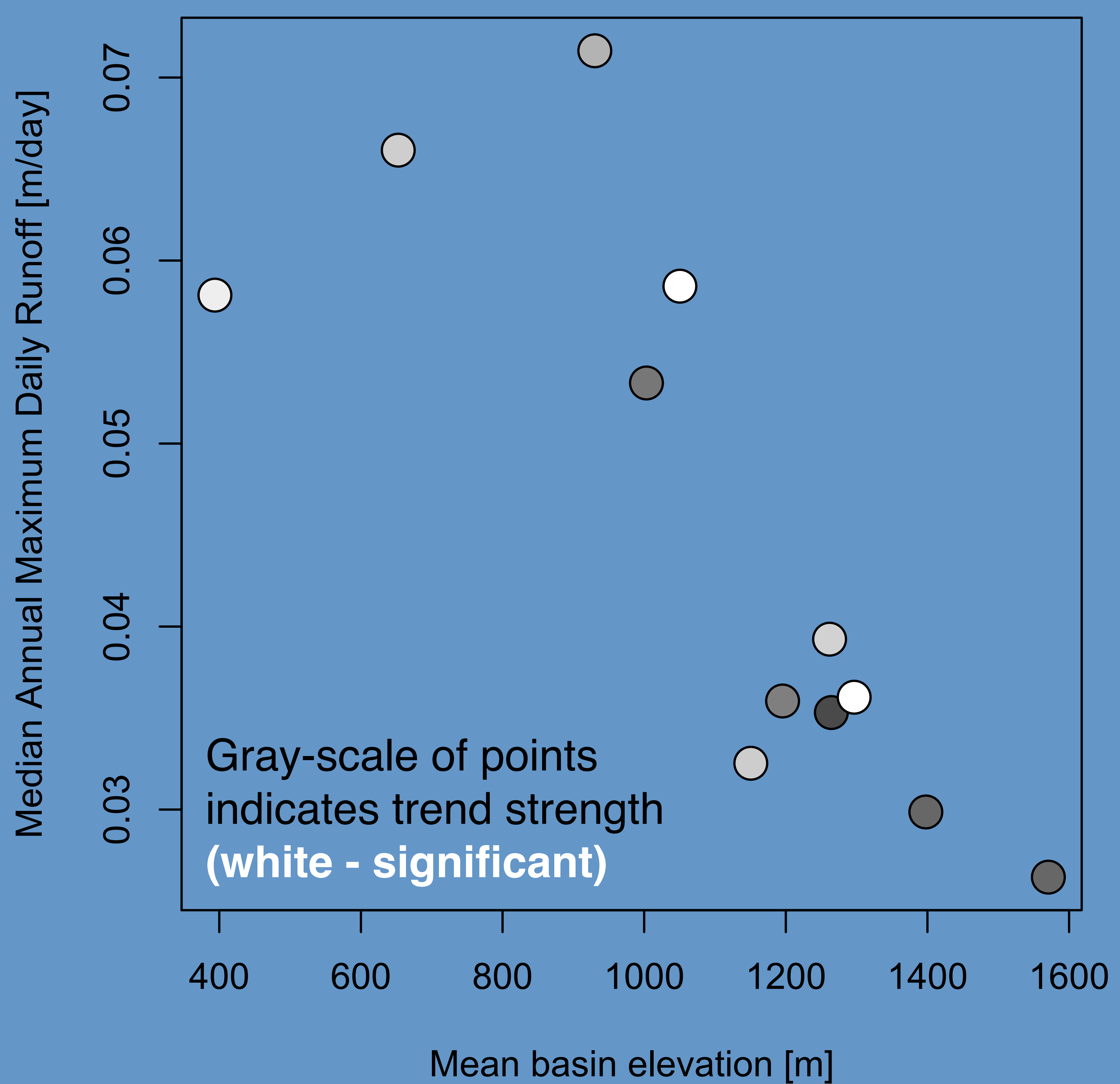


Annual Maximum Daily Streamflow

Median annual maximum daily runoff ranges from 3 to 7 cm/day with highest runoff from basins with mean elevation ~ 1000 m above sea level.

Strength of trends from 1962 to 2010 does not vary with consistently elevation.

Correlation of annual maximum streamflow with IVT ~ 0.6 but this does not account for ARs on “non-maximum” days.



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Summary

The frequency/magnitude of a suite of flood-generating ARs - *not the most intense AR each year* - account for observed trends in annual maximum floods in western Washington.

Flood impacts as a result of changing ARs dynamics are not indicated by the ratio of peak to daily streamflow or by differences in flood trends related basin elevation.

Median (cross-basin) runoff during large floods has been higher since 1980, but there may be geographic bias related to basin locations and AR trajectories.

Moving Forward

Flood impacts from ARs in western Washington result from the combination of a large on-shore flux of water vapor persisting for more than a day.

- *Flood frequency analysis in individual river basins requires resolution of AR magnitude, duration, and location, which are not easily represented by a single index.*

- *The joint probability of AR intensity (magnitude and duration), and location could be used with coarse-spatial resolution observations or predictions.*

- *Are there AR equivalents to the lateral migration rate of a river channel or the translation speed of tropical cyclones (e.g., Kossin 2018) that would indicate the duration of intense precipitation from an AR over a river basin?*

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