Non-stationarity in US extreme sea level records and the role of large scale climate variations

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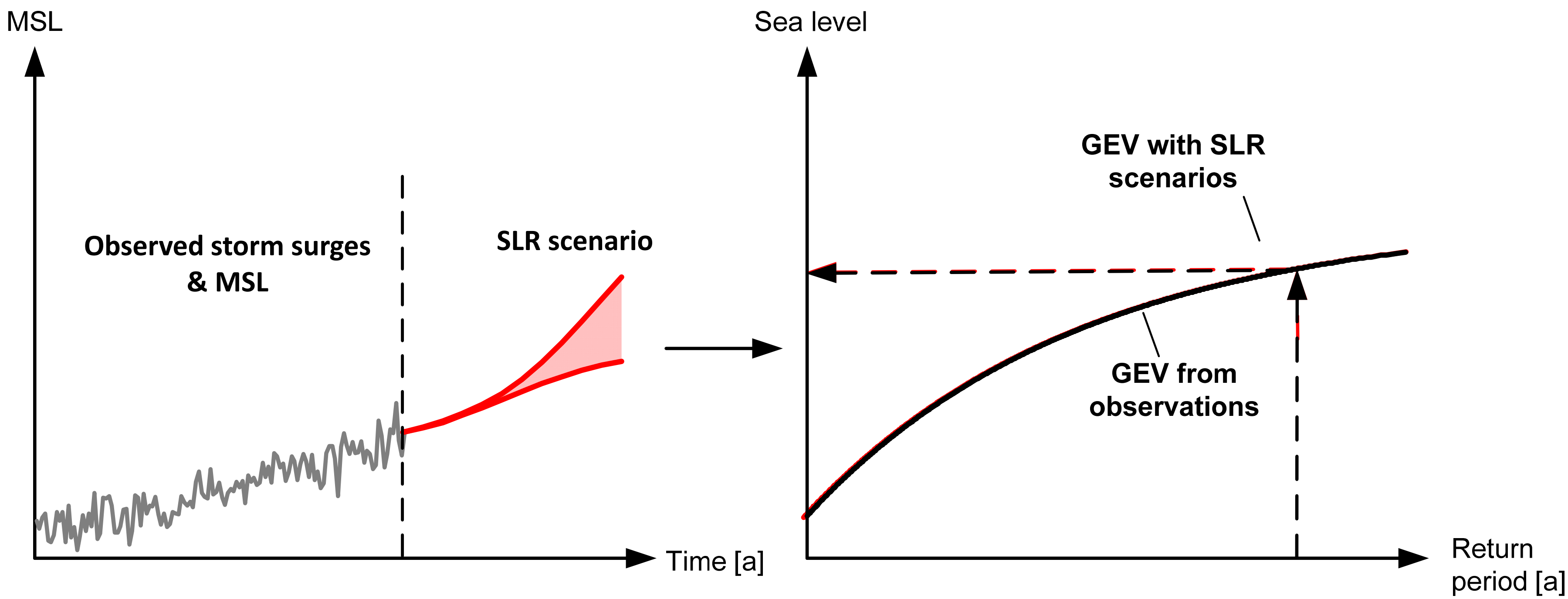
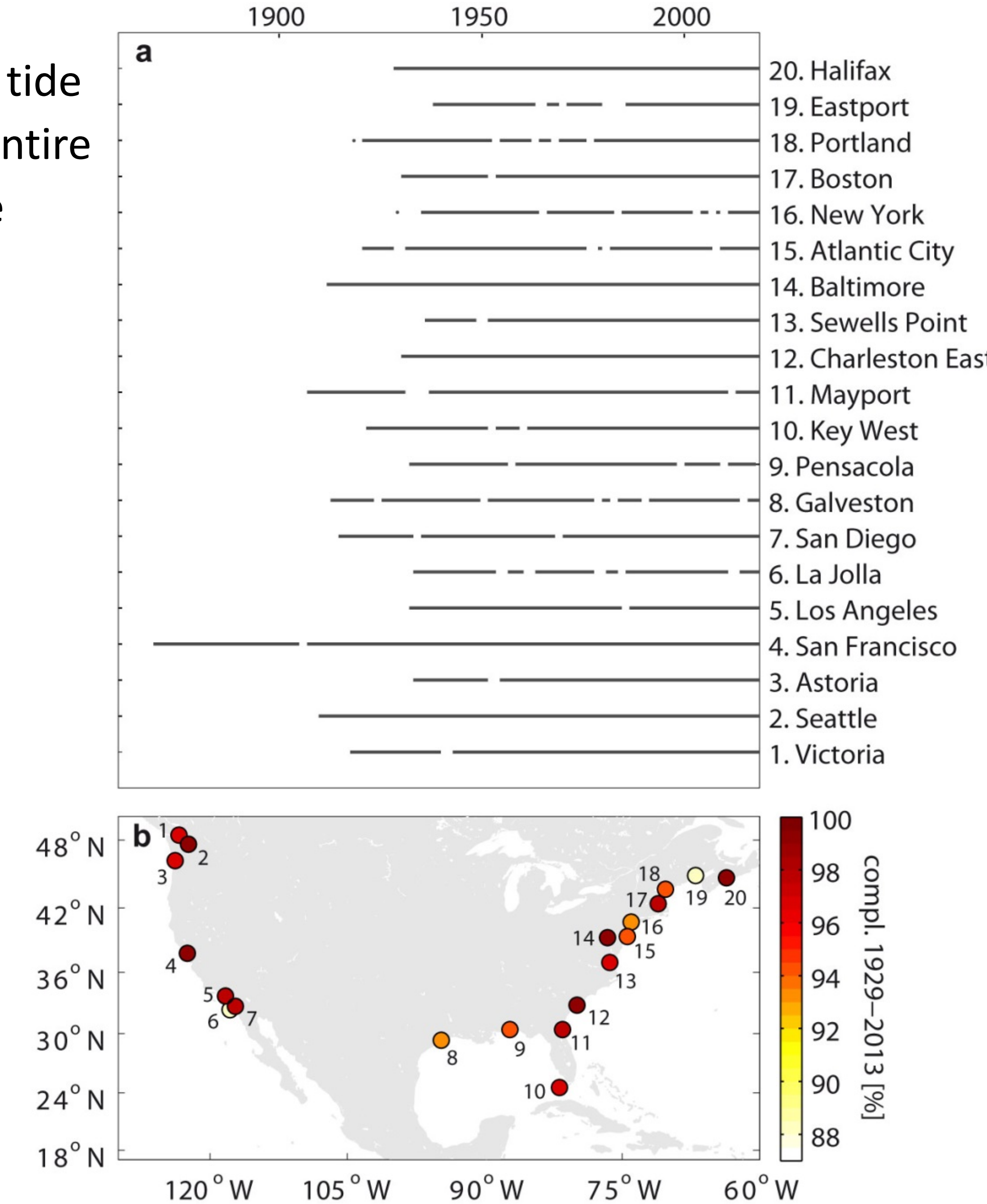
"Societal impacts of sea level change primarily occur via the extreme levels rather than as a direct consequence of mean sea level changes." (IPCC, 2007)

Mean sea level rise is nowadays routinely taken into account for coastal design and adaptation planning, usually by following the "MSL-offset method" (or allowances):

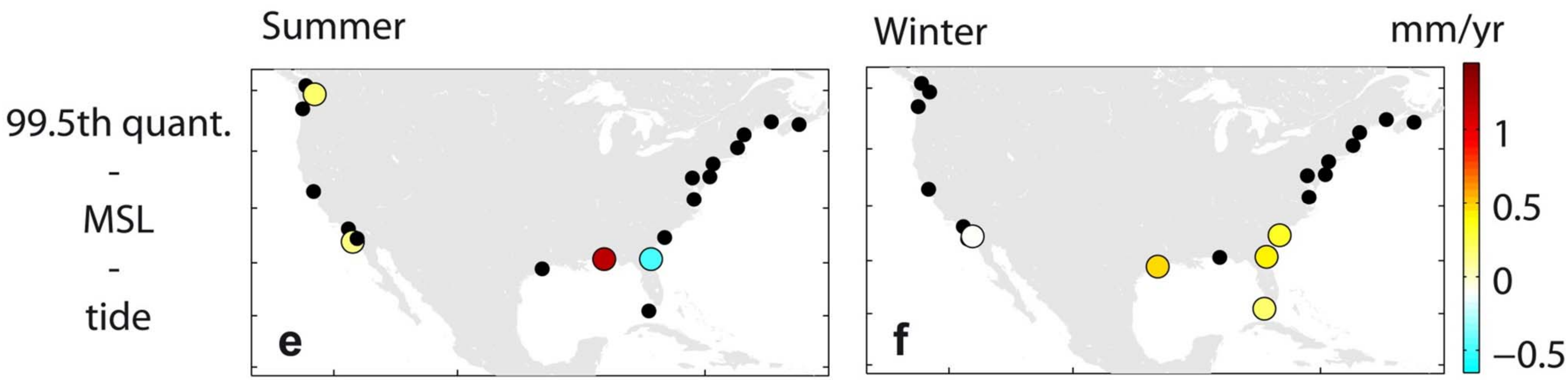


What about changes in the storm surge climate?

Hourly tide gauge records from 20 tide gauges are used which cover the entire U.S. coast and provide data for the common period 1929 to 2013.

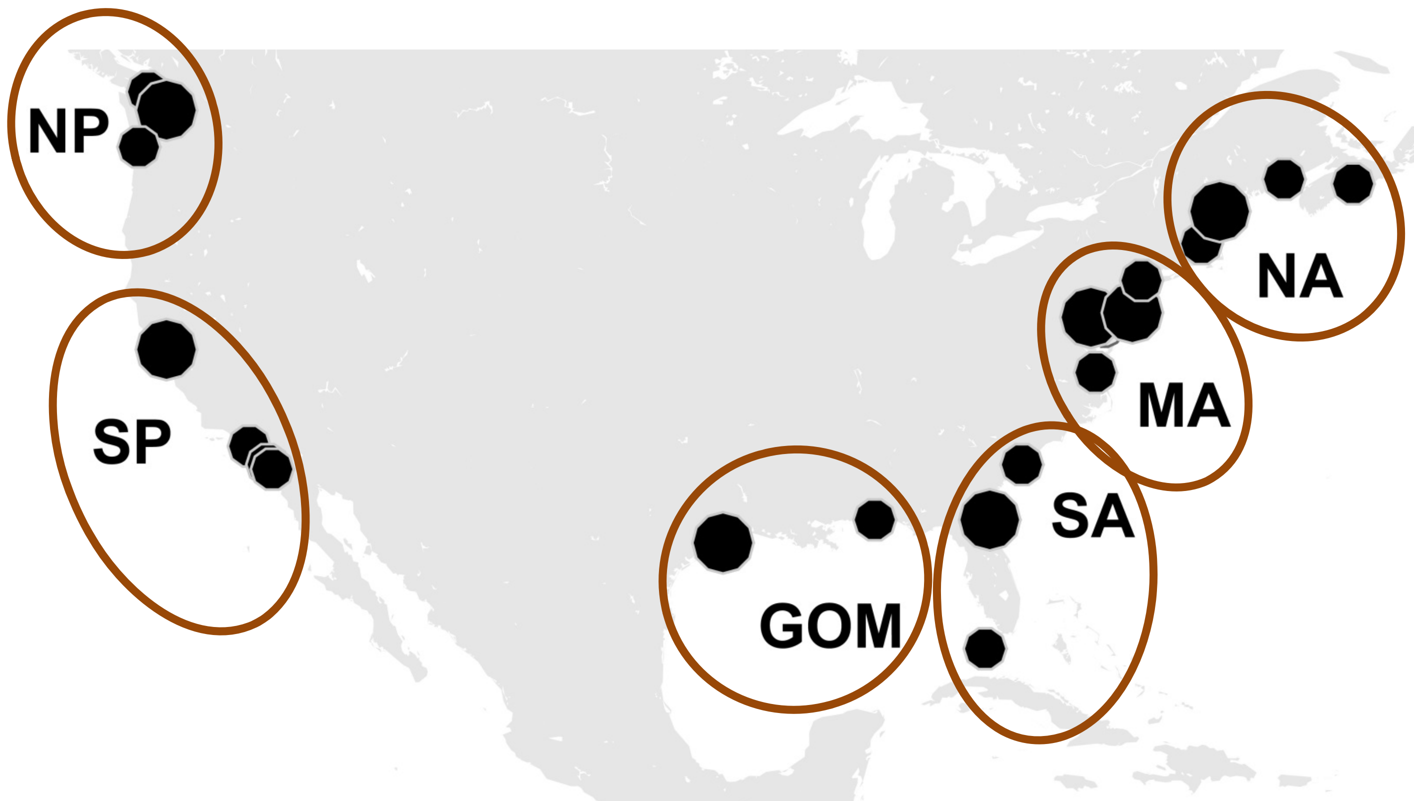


- We calculate trends from seasonal percentile time series obtained directly from the observations and after correcting for MSL and tidal influences.



- Results are broadly consistent with those from earlier assessments at the global scale that focused on shorter time periods and annual data.
- What about **multi-decadal changes** that cannot be captured by linear trends or other simple parametric functions?

1. Identify regions with coherent variability using different methods, e.g. quasi-non-stationary extreme value analysis (nEVA): GEV(μ(t),σ(t),k).



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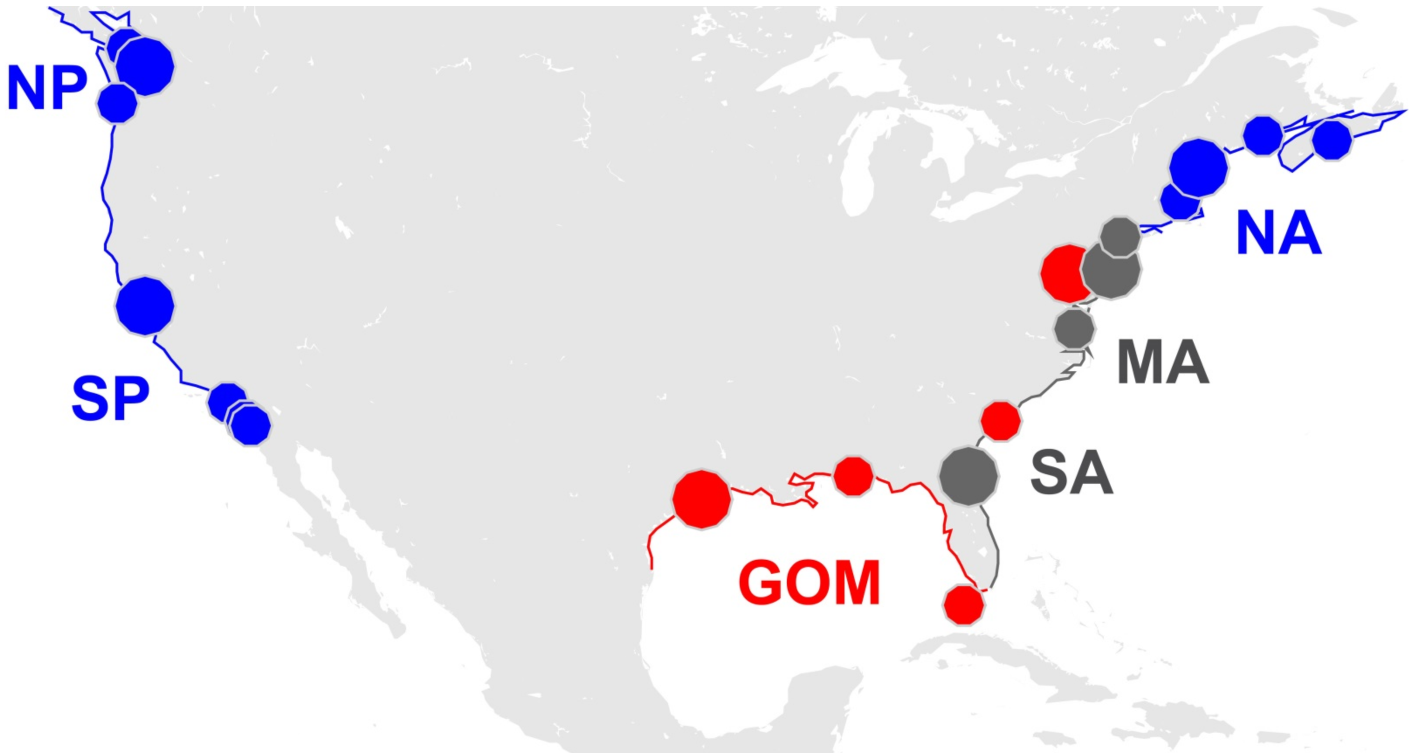
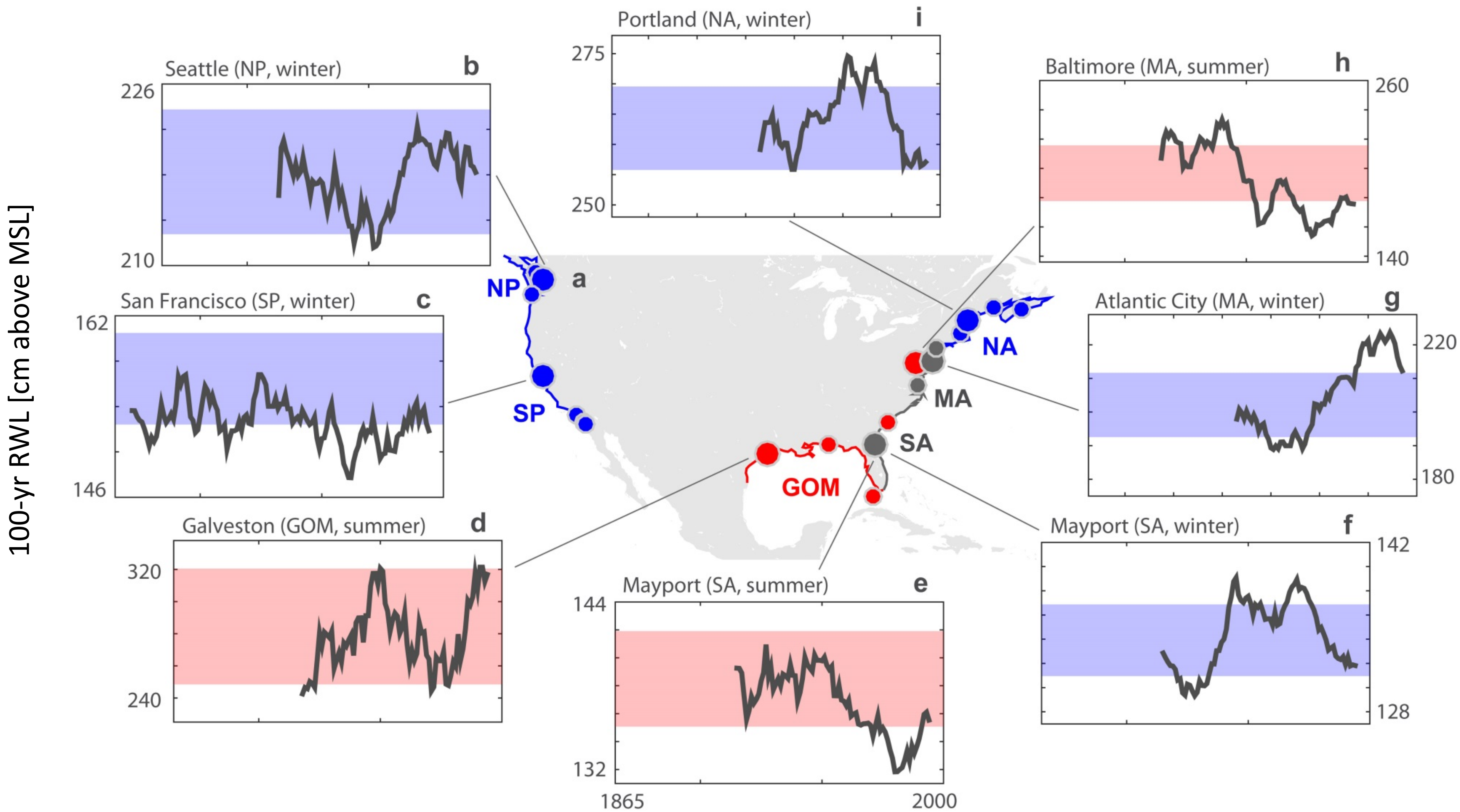
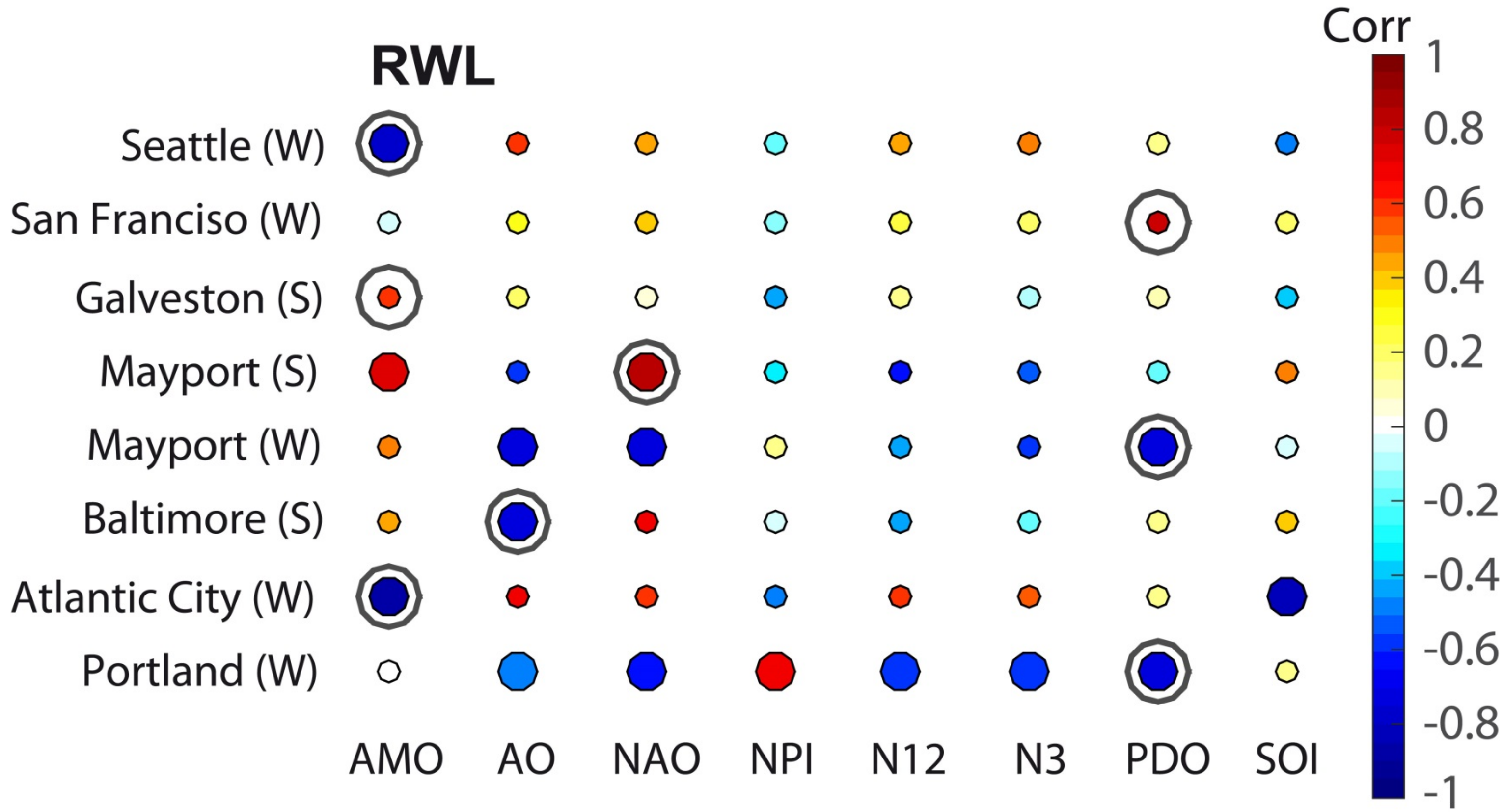
2. Identify relevant season where return water levels are higher and select representative tide gauge for each region and season.



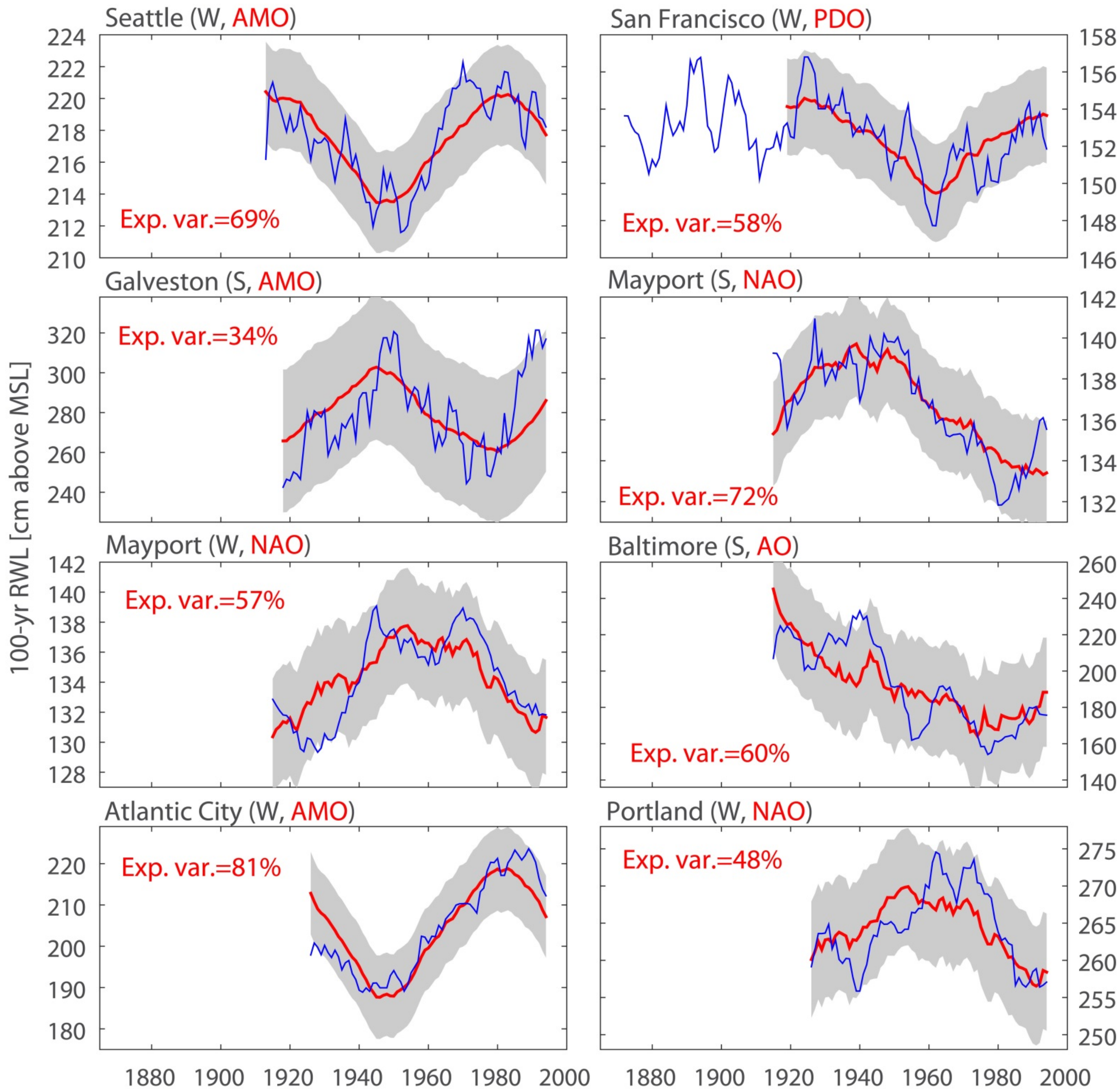
1. Identify regions with coherent variability using different methods, e.g. quasi-non-stationary extreme value analysis (nEVA).
2. Identify relevant season where return water levels are higher and select representative tide gauge for each region and season.
3. Compare results from nEVA and stationary extreme value analysis



- We find high correlation between changes in extreme sea levels (expressed as 100-year RWLs) and "traditional" climate indices.



- The indices with the strongest correlation are selected and used as predictors in simple linear regression models.


Seattle (W, AMO)
Exp. var.=69%
San Francisco (W, PDO)
Exp. var.=58%
Galveston (S, AMO)
Exp. var.=34%
Mayport (S, NAO)
Exp. var.=72%
Mayport (W, NAO)
Exp. var.=57%
Baltimore (S, AO)
Exp. var.=60%
Atlantic City (W, AMO)
Exp. var.=81%
Portland (W, NAO)
Exp. var.=48%
100-yr RWL [cm above MSL]
1880 1900 1920 1940 1960 1980 2000

- Climate indices have not been developed with the main purpose of explaining multi-decadal changes in US extreme sea levels and can be refined.

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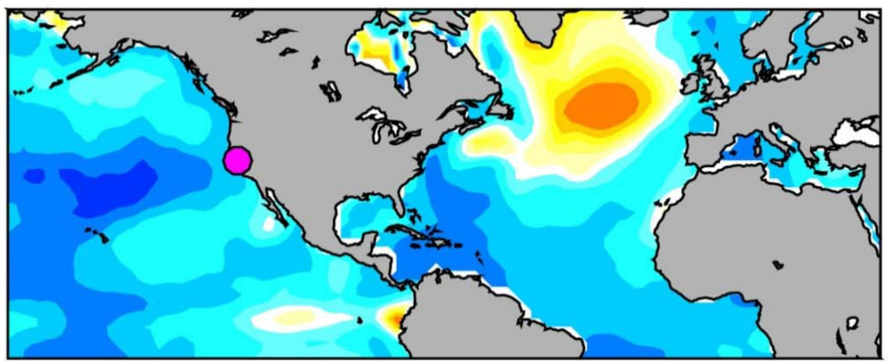
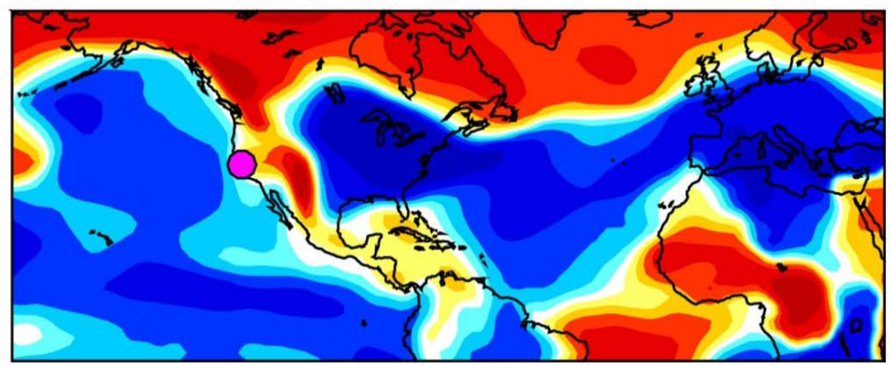
- For each site we plot the pointwise correlation between multi-decadal changes in extreme sea levels (100-yr RWLs) and smoothed SST and SLP.

San Francisco (W, SST)



San Francisco (W, SLP)



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- For each site we plot the pointwise correlation between multi-decadal changes in extreme sea levels (100-yr RWLs) and smoothed SST and SLP.
- We select regions with strong correlation that broadly resemble the spatial features of known climate indices.

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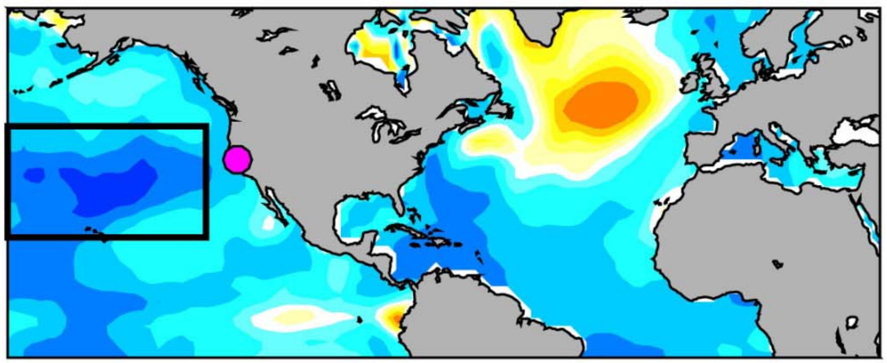

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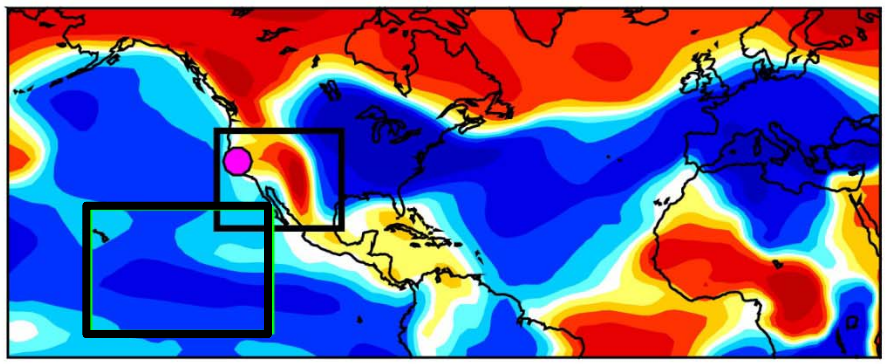

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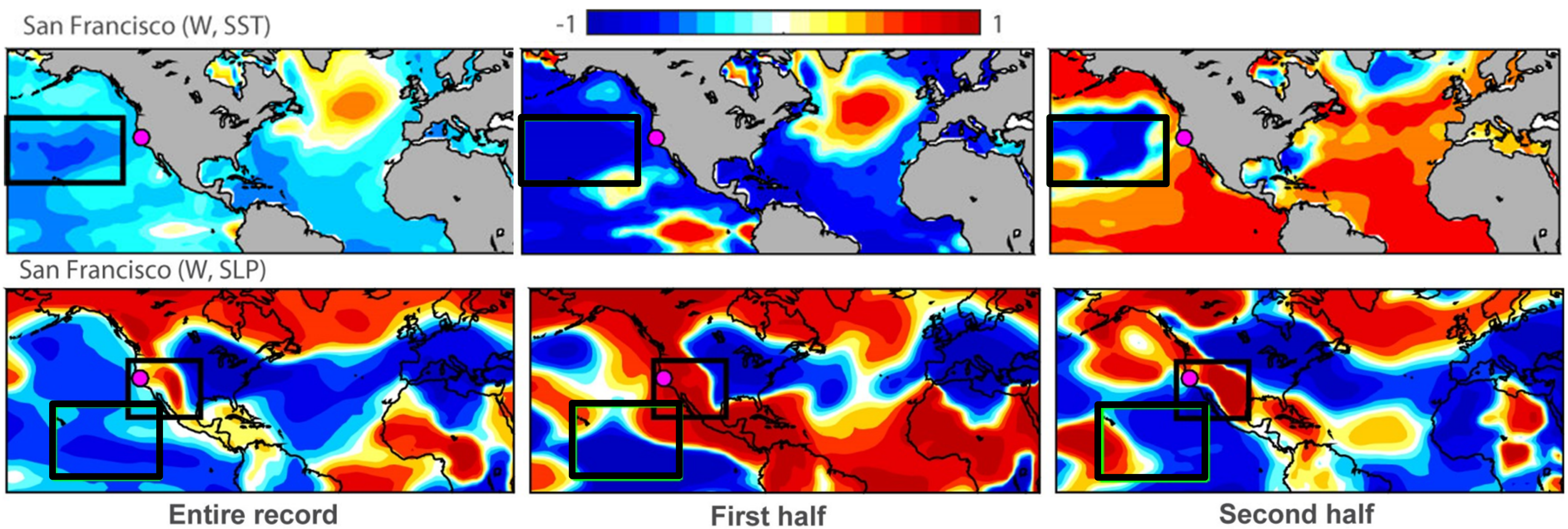
- We test the stability of the centers of action through time.



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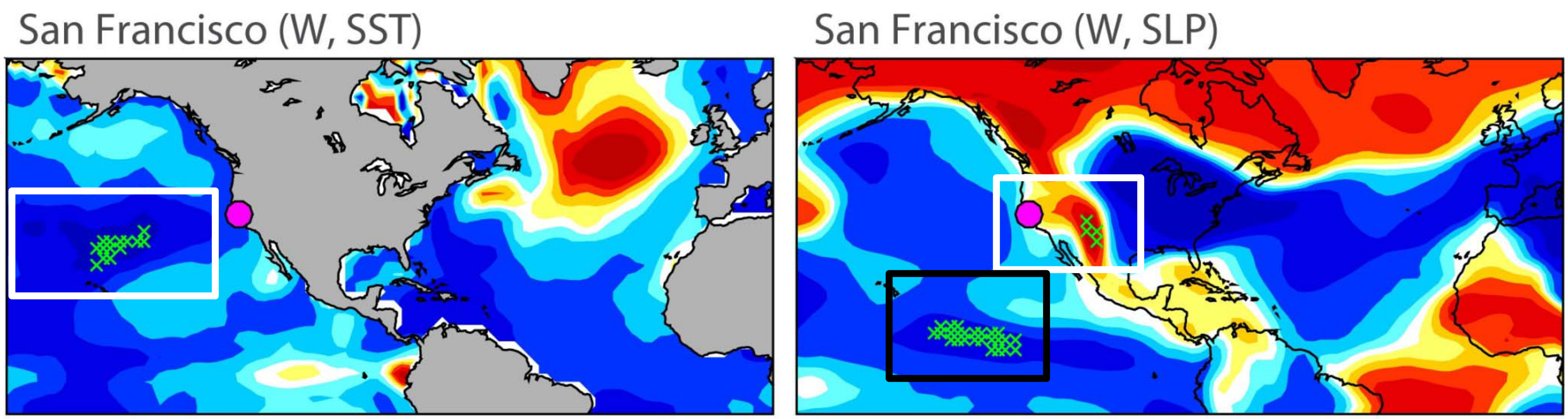
- Tailored indices are constructed from grid points with strongest correlations.



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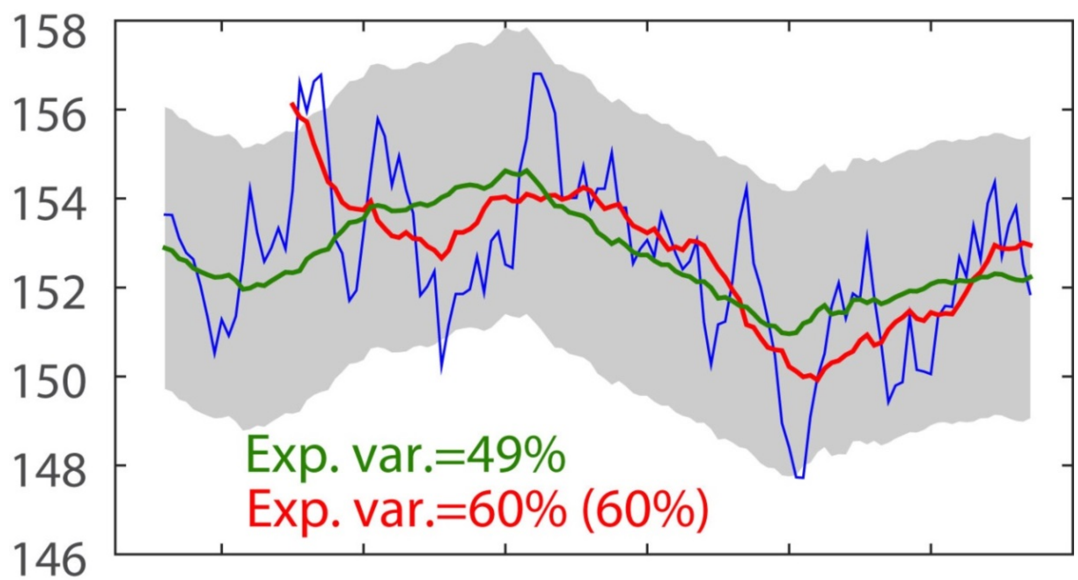
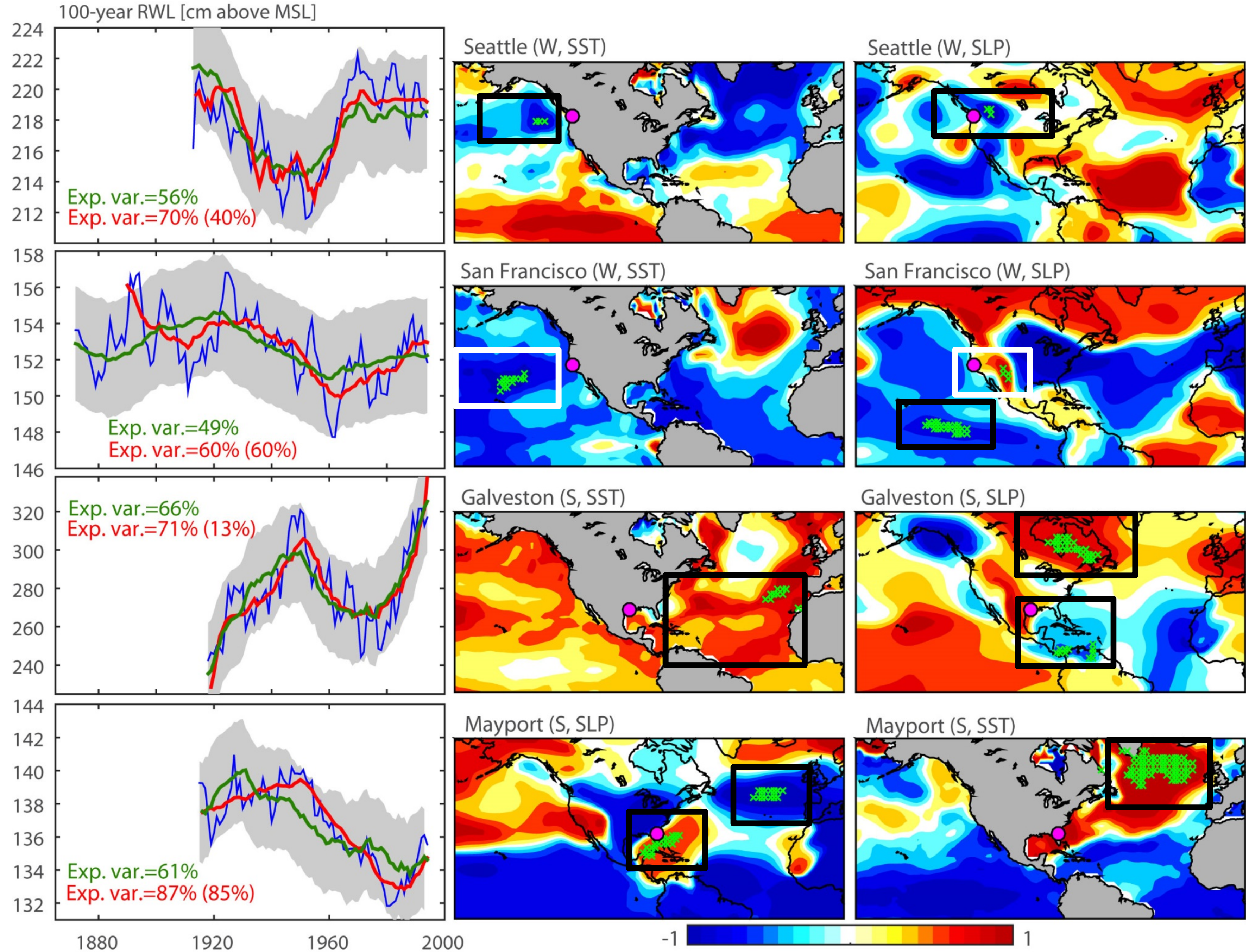
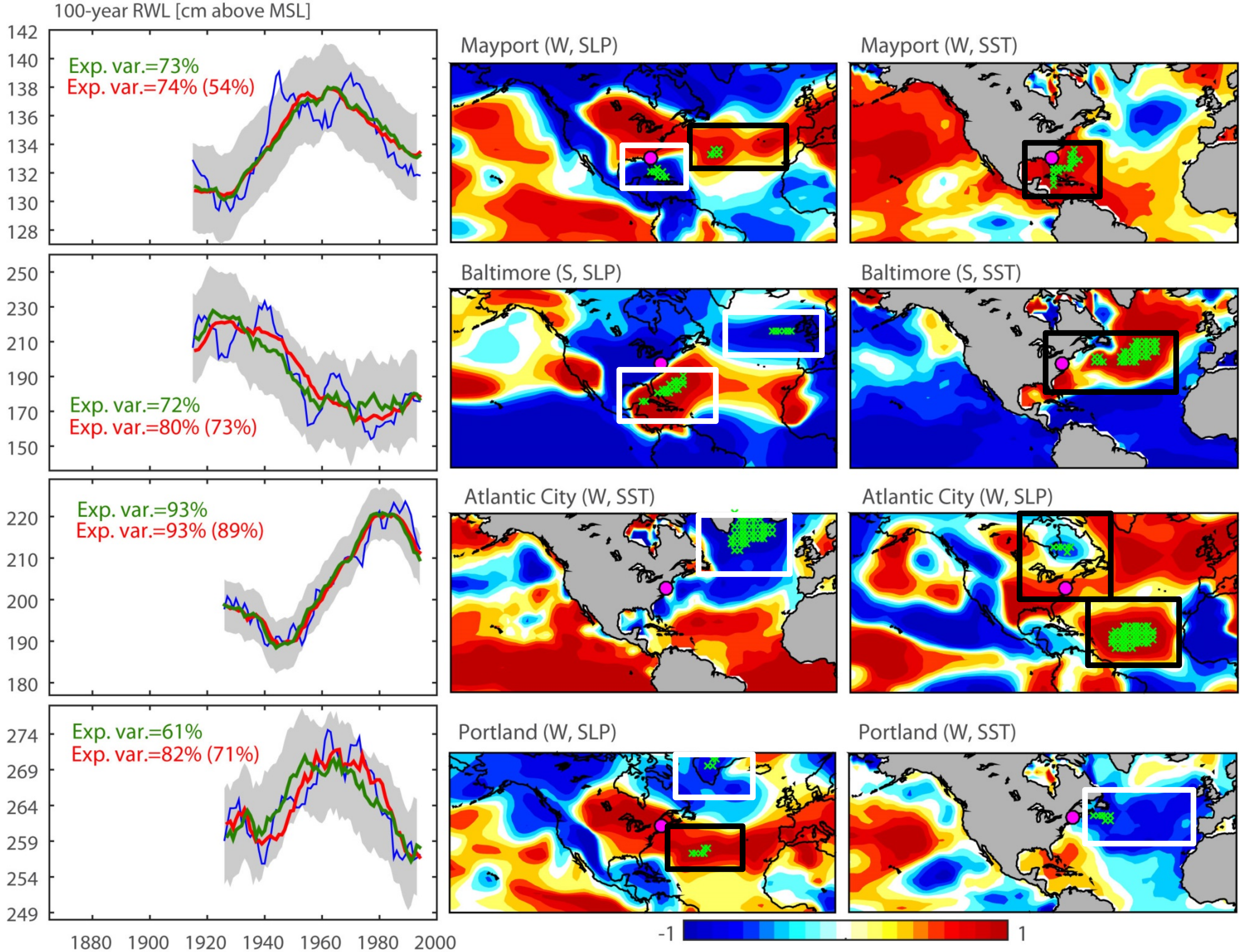
- We test the stability of the centers of action through time.
- Tailored indices are constructed from grid points with strongest correlations.
- The indices are used as predictors in simple and multiple regression models.




100-year RWL [cm above MSL]
Exp. var.=56%
Exp. var.=70% (40%)
Seattle (W, SST)
Seattle (W, SLP)
Exp. var.=49%
Exp. var.=60% (60%)
San Francisco (W, SST)
San Francisco (W, SLP)
Exp. var.=66%
Exp. var.=71% (13%)
Galveston (S, SST)
Galveston (S, SLP)
Exp. var.=61%
Exp. var.=87% (85%)
Mayport (S, SLP)
Mayport (S, SST)
1880
1920
1960
2000
-1
1


100-year RWL [cm above MSL]
Exp. var.=73%
Exp. var.=74% (54%)
Exp. var.=72%
Exp. var.=80% (73%)
Exp. var.=93%
Exp. var.=93% (89%)
Exp. var.=61%
Exp. var.=82% (71%)
142
140
138
136
134
132
130
128
250
230
210
190
170
150
220
210
200
190
180
274
269
264
259
254
249
1880 1900 1920 1940 1960 1980 2000
Mayport (W, SLP)
Mayport (W, SST)
Baltimore (S, SLP)
Baltimore (S, SST)
Atlantic City (W, SST)
Atlantic City (W, SLP)
Portland (W, SLP)
Portland (W, SST)
-1
1

Take-home message

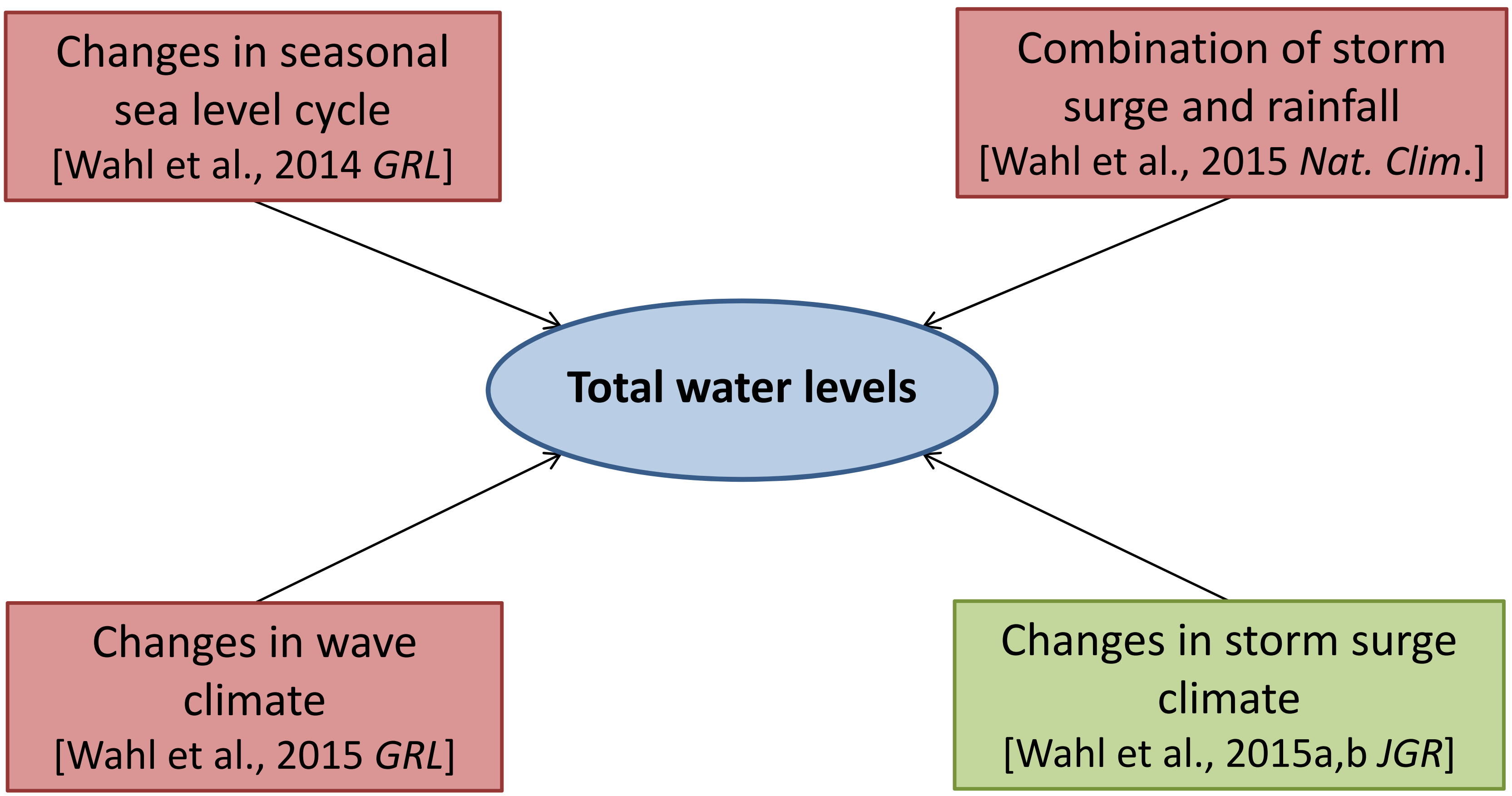
- Significant but small long-term trends in storm surge water levels exist at individual sites and in both seasons.
- Six regions exhibit coherent and strong multi-decadal variability affecting design relevant return water levels.
- The observed changes are related to well-known climate indices.
- Tailored indices have been developed allowing better and physically more consistent prediction of changes in return water levels throughout the last century.
- The results presented here suggest that we are, in principle, able to predict decadal changes in extreme sea levels (and RWLs) using global and regional climate models to support decision-making in the climate adaptation context.

References:

Wahl, T., Chambers, D.P. (2015). Evidence for multi-decadal variability in US extreme sea level records, *J. Geophys. Res. Oceans*, 120, 1527–1544.

Wahl, T., Chambers, D.P. (revised). Climate controls multi-decadal variability in U.S. extreme sea level records, *J. Geophys. Res. Oceans.*

Other effects acting on various time scales may affect total water levels regionally/locally and further increase or decrease the risk of coastal flooding and erosion but are often ignored.



Thank you for your attention!

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