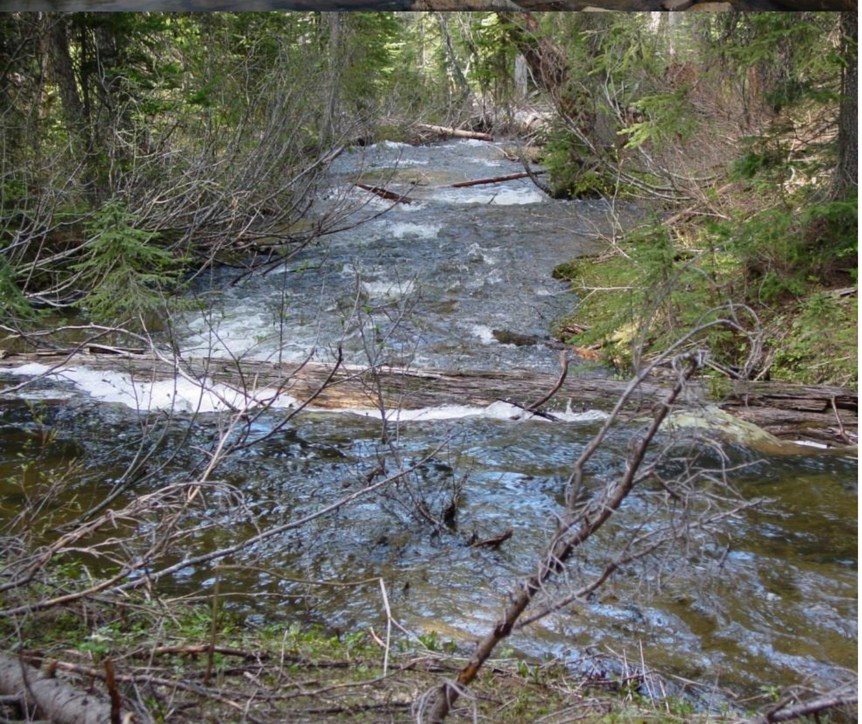


Sensitivity of Summer Stream Temperatures to Climate Variability in Pacific Northwest Forests

Charles Luce , US Forest Service
Brian Staab, US Forest Service
Marc Kramer, U. Florida
Seth Wenger, U. Georgia
Dan Isaak, US Forest Service
Callie McConnell, US Forest Service

A Rapidly Growing Sensitivity Literature (>2012)…

Kanno et al. (2014). Paired stream–air temperature measurements reveal fine-scale thermal heterogeneity within headwater brook trout stream networks. River research and applications, 30:745-755.

Kelleher et al. (2012) Investigating controls on the thermal sensitivity of Pennsylvania streams. Hydrol. Process. 26:771–785.

Kurylyk et al. (2015) Shallow groundwater thermal sensitivity to climate change and land cover disturbances: derivation of analytical expressions and implications for stream temperature modeling. Hydrol. Earth Syst. Sci 19: 2469-2489.

Leach & Moore (2014) Winter stream temperature in the rain-on-snow zone of the Pacific northwest: influences of hillslope runoff and transient snow cover. Hydrology and Earth System Sciences 18: 819-838.

Luce et al. (2014). Sensitivity of summer stream temperatures to climate variability in the Pacific Northwest. Water Resour. Res, 50, 2.

Mayer (2012). Controls of summer stream temperature in the Pacific Northwest. Journal of Hydrology, 475:323-335.

Null et al. (2013). Stream temperature sensitivity to climate warming in California's Sierra Nevada: impacts to coldwater habitat. Climatic Change, 116:149-170.

Snyder et al. (2015) Accounting for groundwater in stream fish thermal habitat responses to climate change. Ecological Applications 25:1397–1419.

Trumbo et al. (2014). Ranking site vulnerability to increasing temperatures in southern Appalachian Brook Trout streams in Virginia: an exposure-sensitivity approach. Transactions of the American Fisheries Society, 143:173-187.

Sensitivity defined as: Var_{S*T}

1) stream Δ˚C : air Δ˚C

2) stream Δ˚C : flow ΔSD(Q)

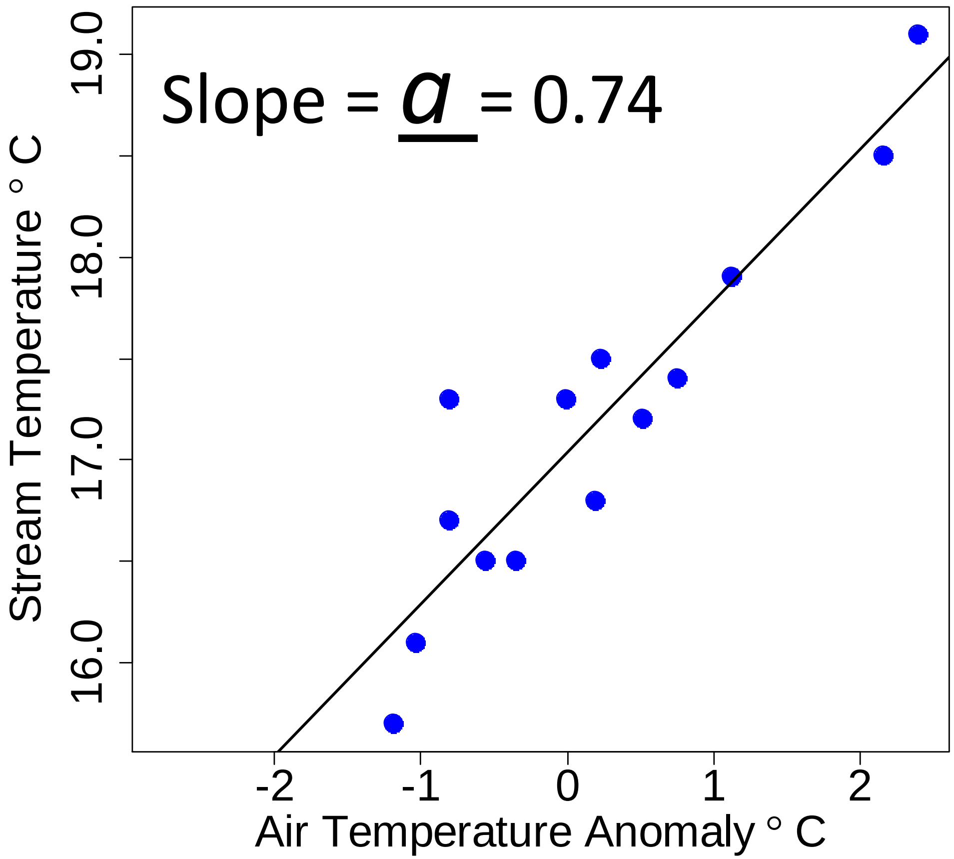
“Connectivity” Theory

Streams that are cold in summer months are poorly “connected” to the atmosphere via energy exchanges.

Prediction: cold streams should show less variation relative to climate forcing factors (air temperature and discharge).

Sensitivity Parameters from Regressions

$$T_s = b_0 + aT_a + bQ_s + \epsilon$$

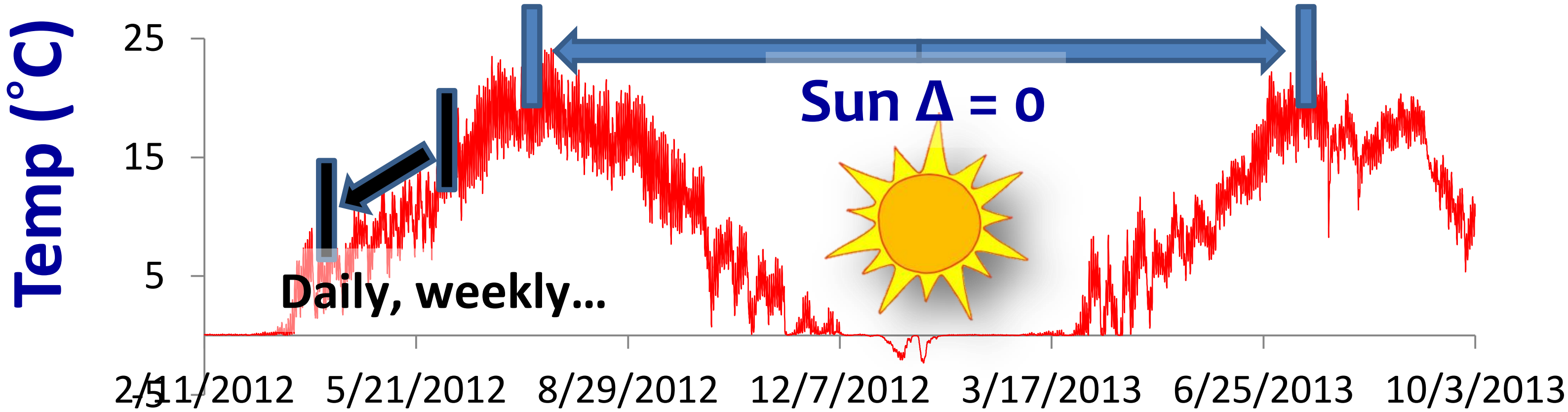


T_a: Air temperature anomaly

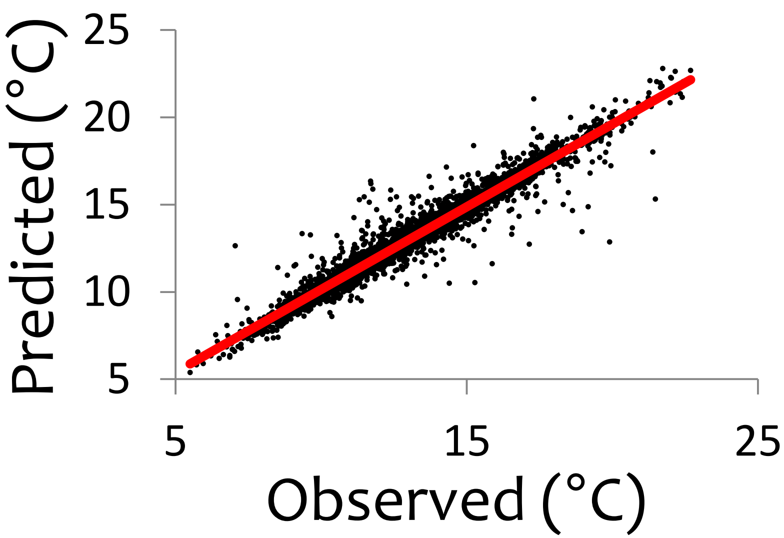
Q_s: Standardized streamflow

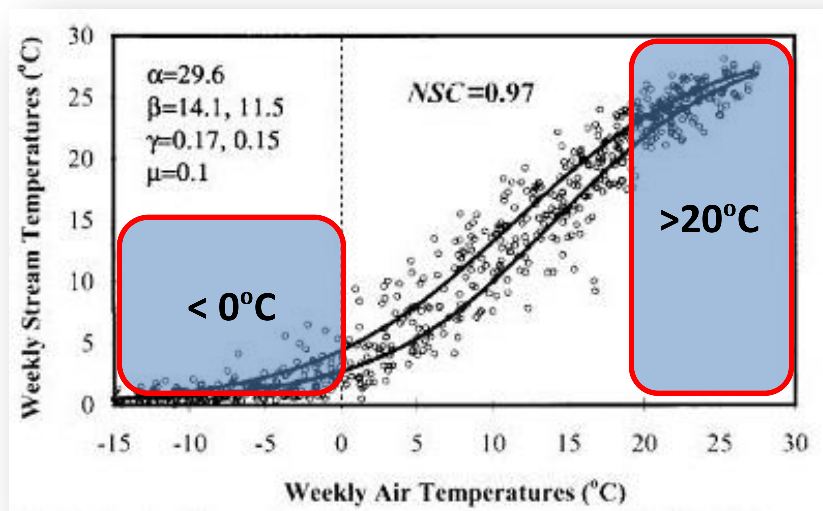
Model Timestep & Functional Form

Intra-annual vs. Inter-annual



Linear vs. Non-linear





Mohseni et al. 1998.

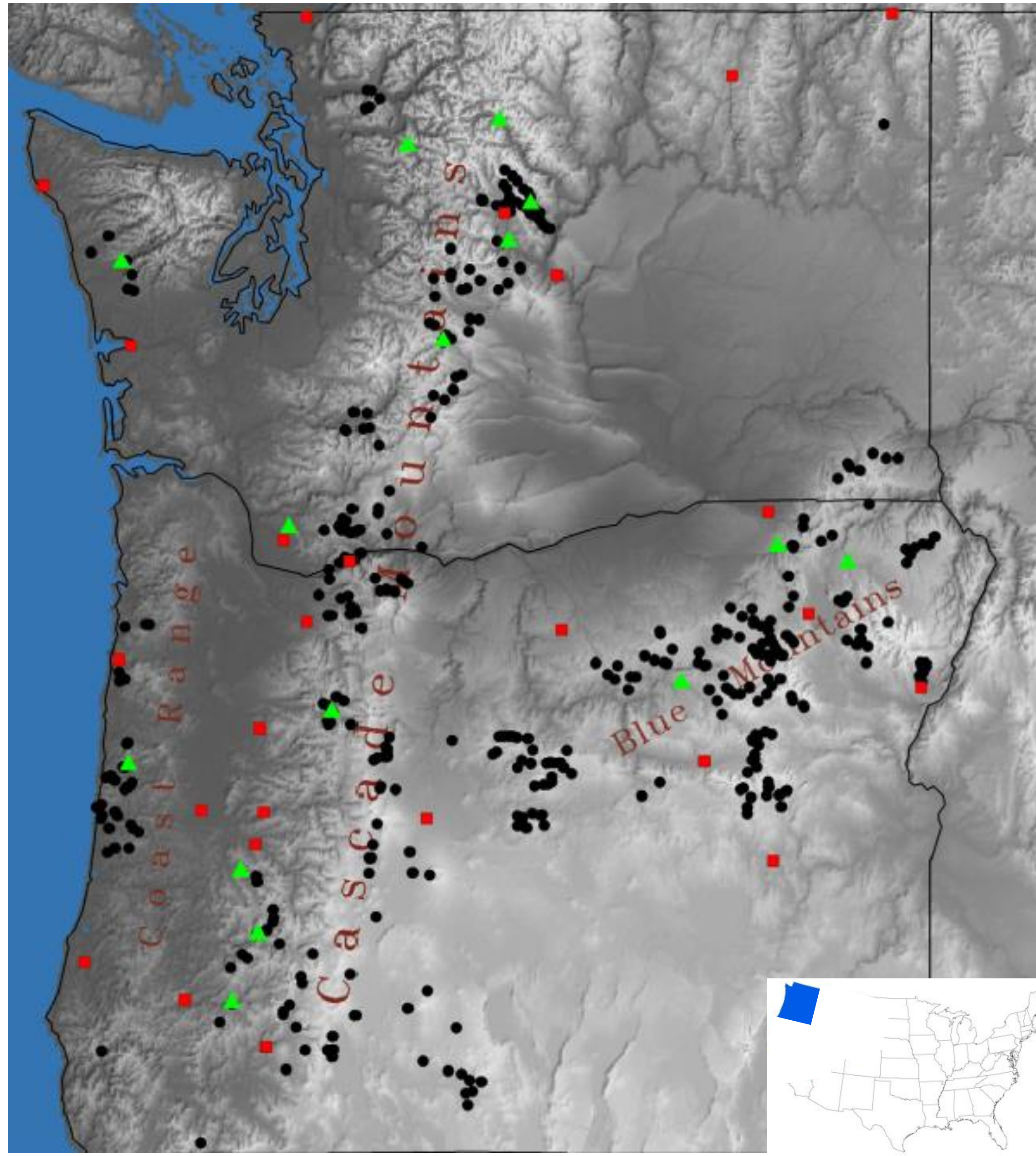
Dataset (Region 6 USFS)

Stream Temp Sites (n = 246; $\geq$7 summers of data)

USHCN Air Temp Red (n = 25)

Streamflow Blue (n = 15)

Small to medium size streams



Principal Component Reconstructions for:

T_a: **Air temperature anomaly** **&** Q_s: **Standardized streamflow**

$$X_{SY} = L_{Si} \text{ X } P_{iY}$$

P = Principal Component (time series)

i = which principal component (just using 1 & 2)

L= Loading (map)

S = Station

Y = Year

For a particular place, the time series is given by:

$$X_t = L_1 \text{X } P_{1t} + L_2 \text{X } P_{2t}$$

T_a: Air temperature anomaly

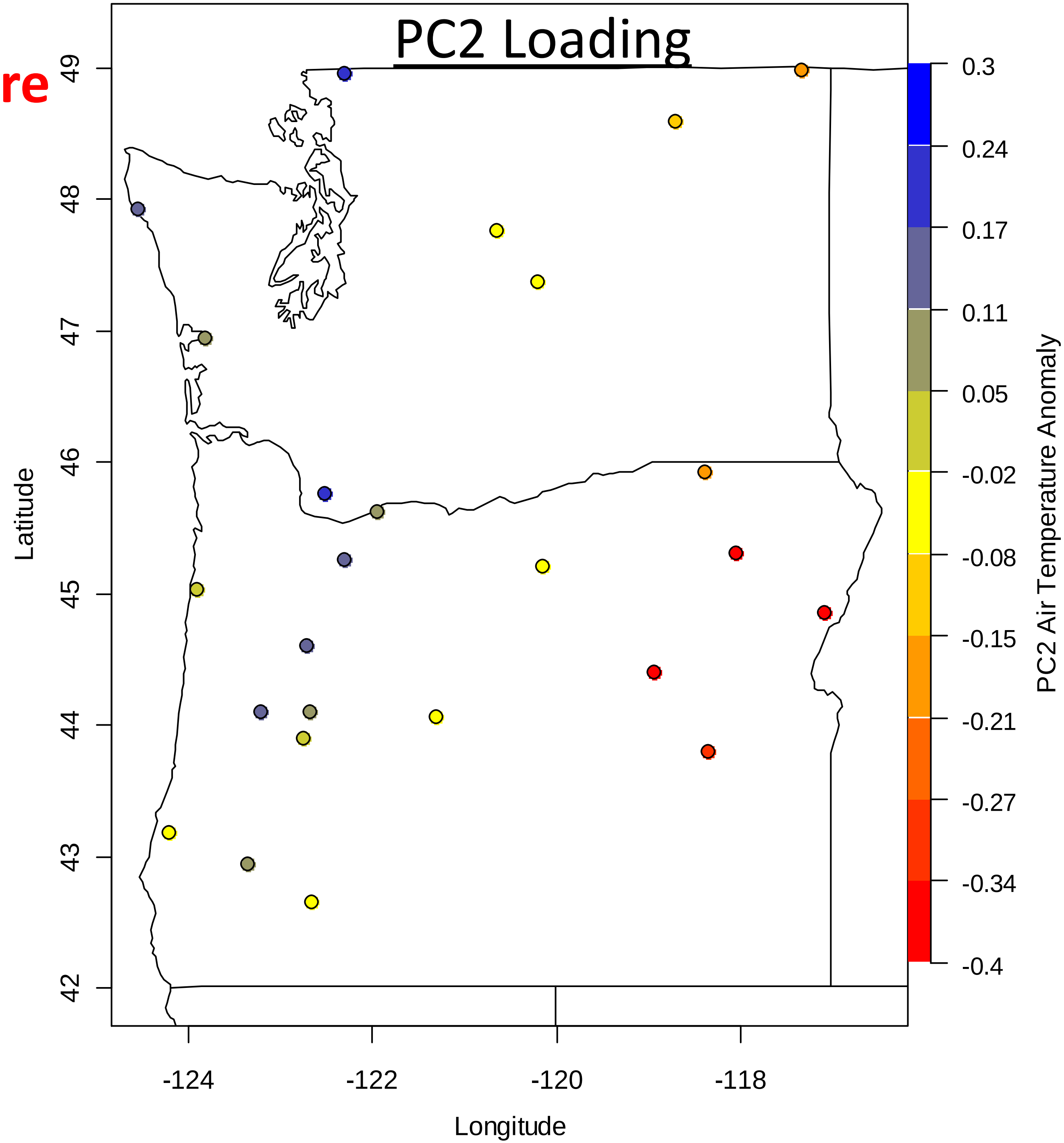
Air stations

2 PCs

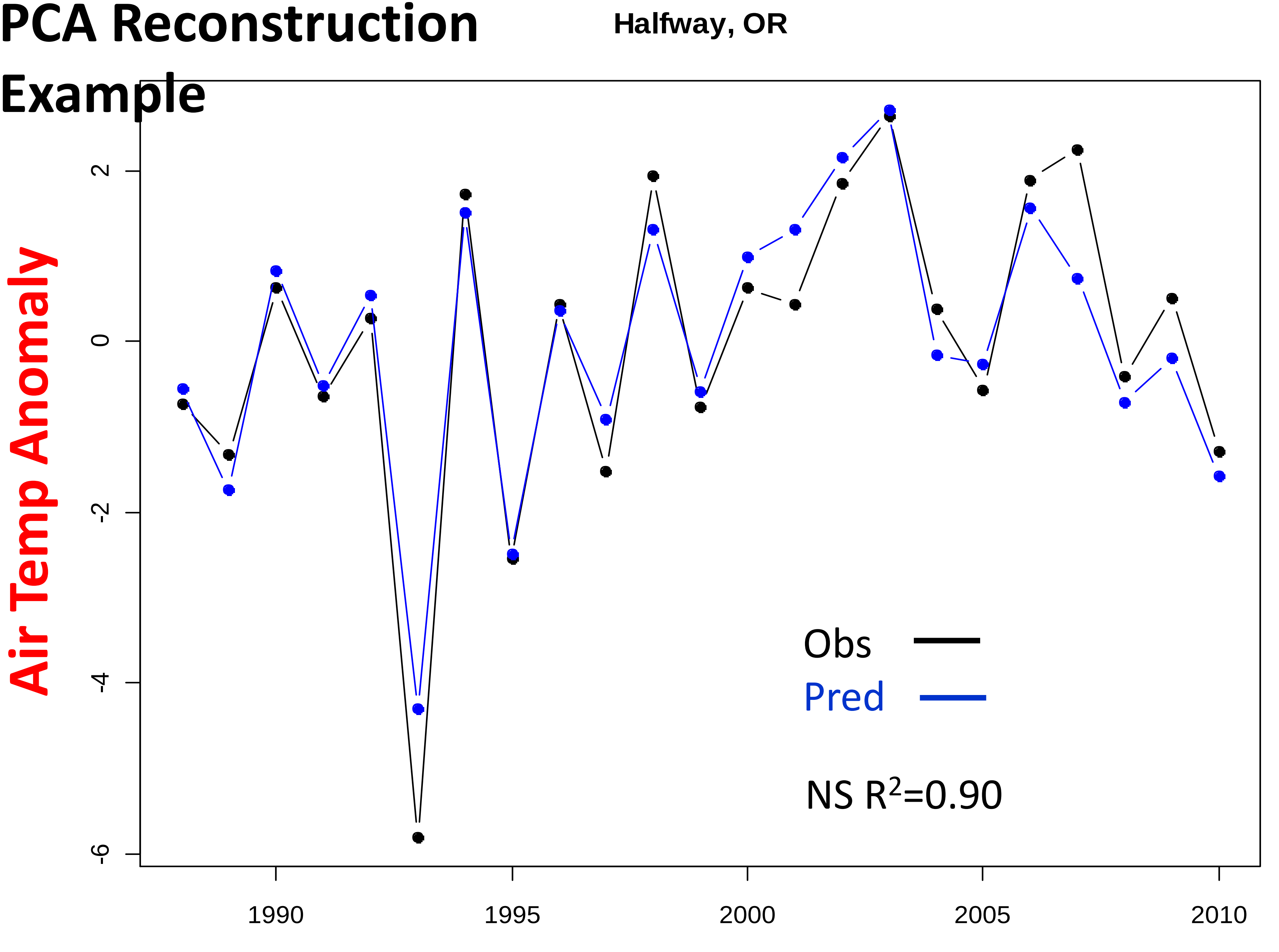
1st – Regional Mean

2nd – lat & lon

R^2=0.81



PCA Reconstruction Example



Q_s: Standardized streamflow

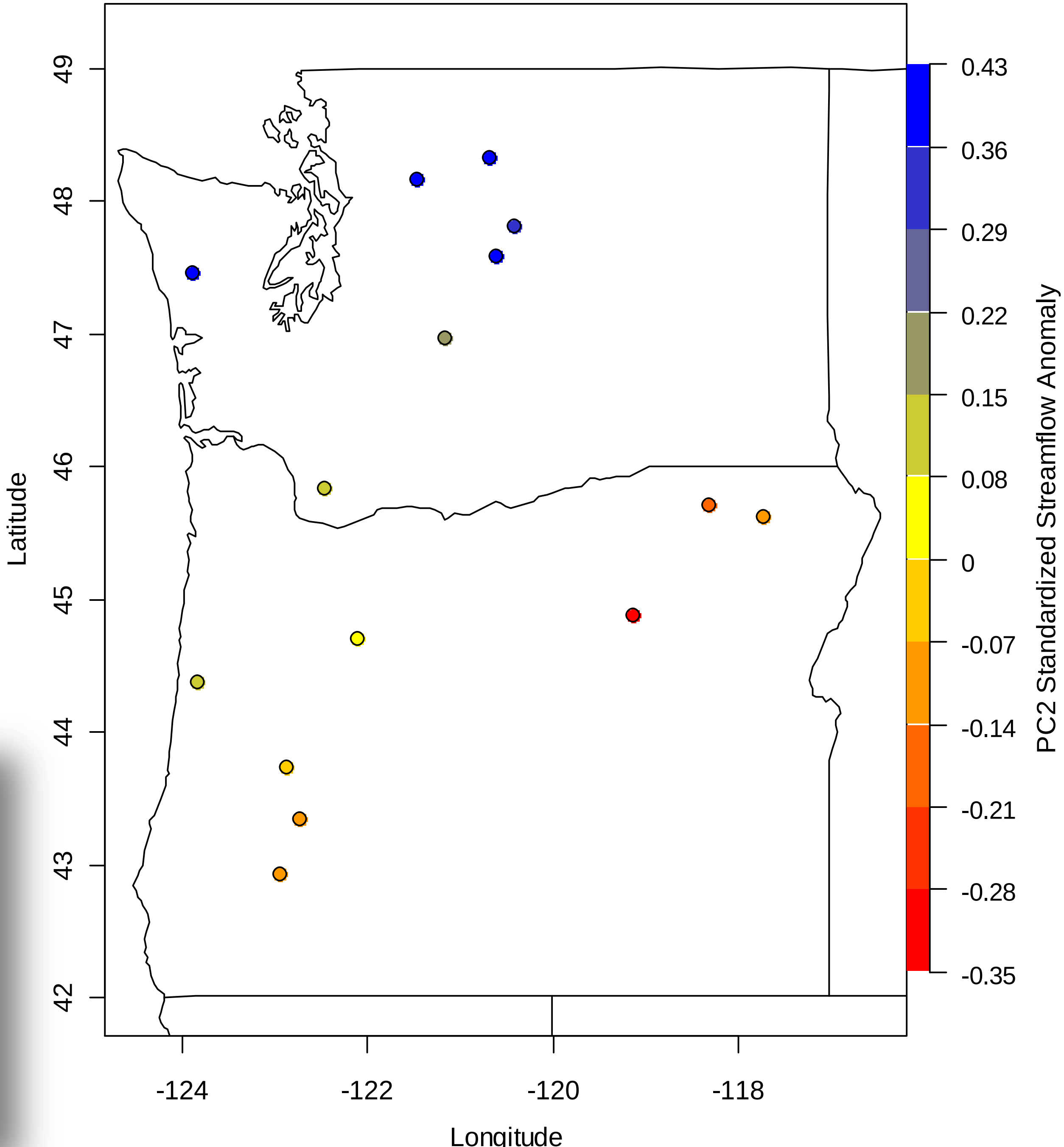
Streamflow Stations

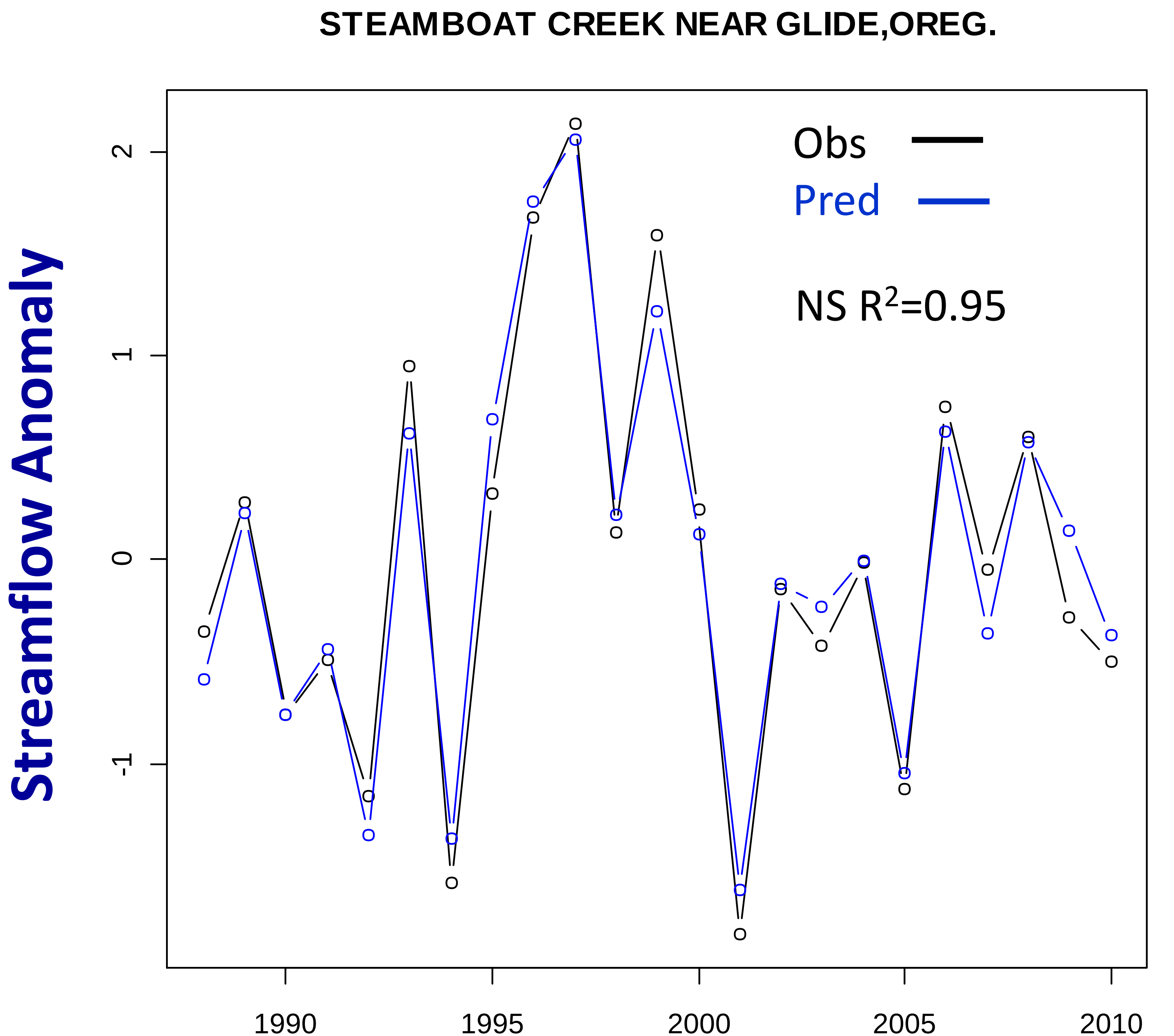
2 PCs

1st – Regional Mean

2nd – lat & lon

R^2=0.90



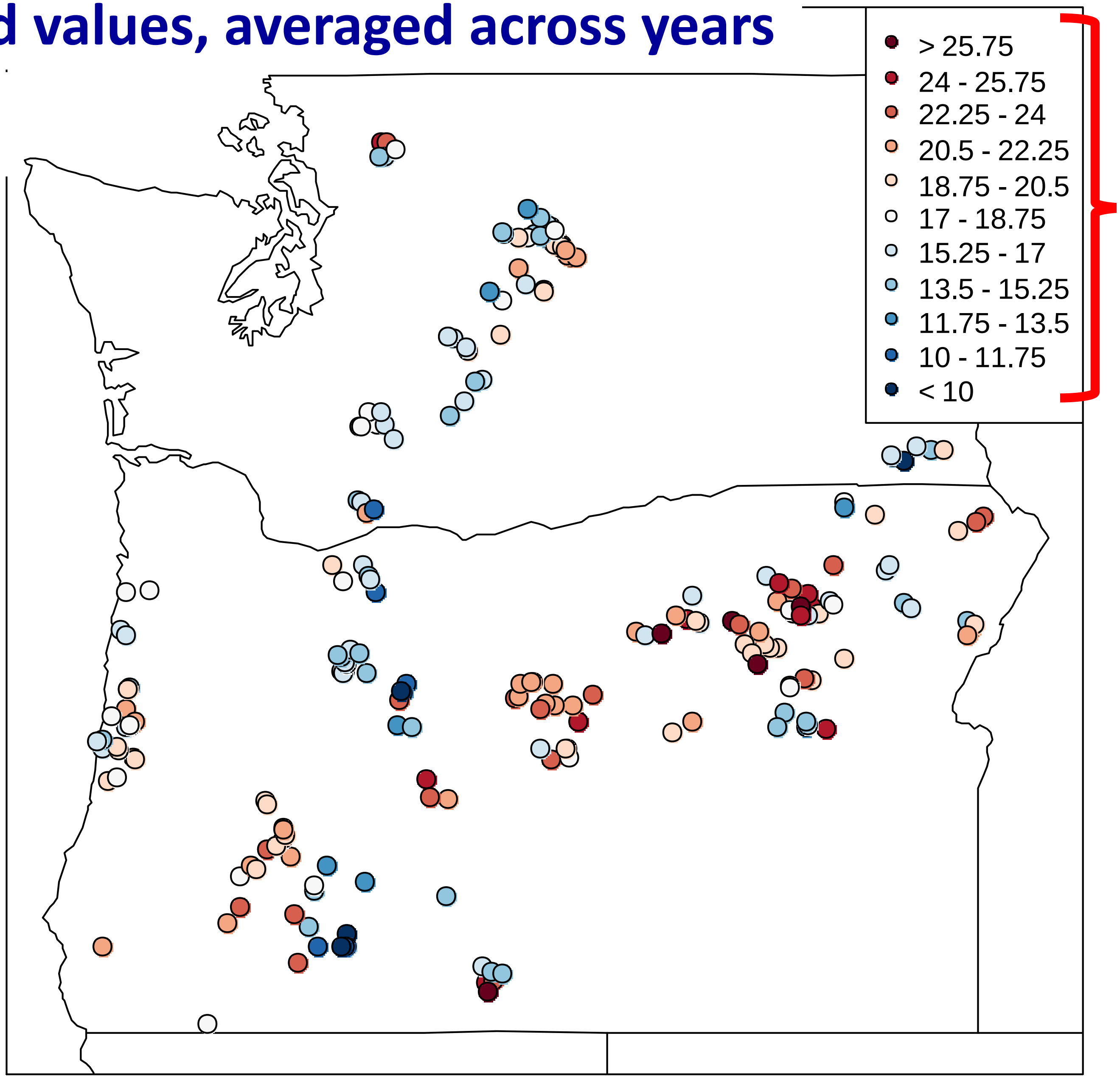


STEAMBOAT CREEK NEAR GLIDE,OREG.
Streamflow Anomaly
Obs
Pred
NS R2=0.95
2
1
0
-1
1990
1995
2000
2005
2010

Stream Maximum Weekly Maximum Temperature (MWMT; °C)

Observed values, averaged across years

★ **X-axis**

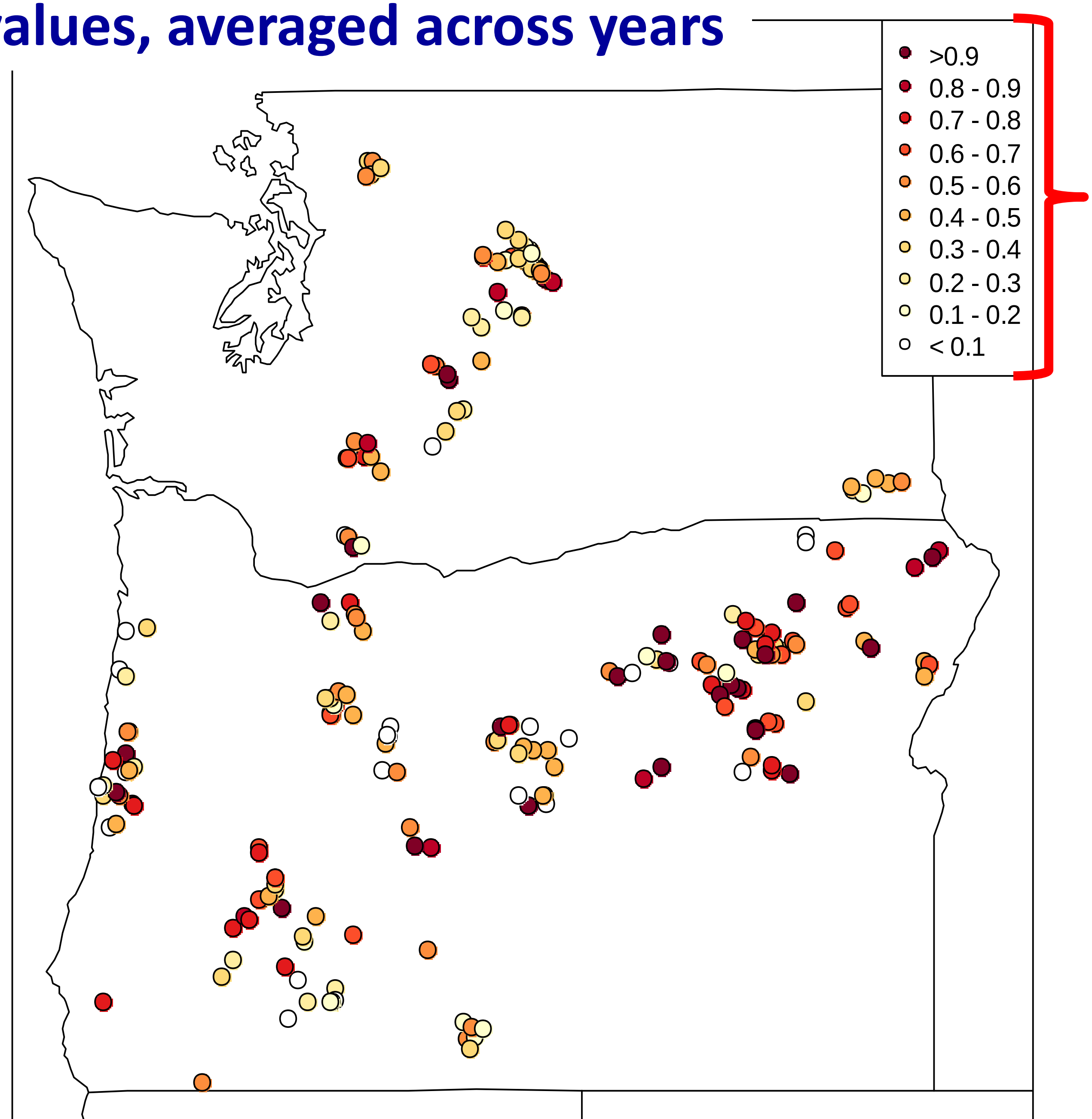


Wide range

Thermal Sensitivity (°C/°C)

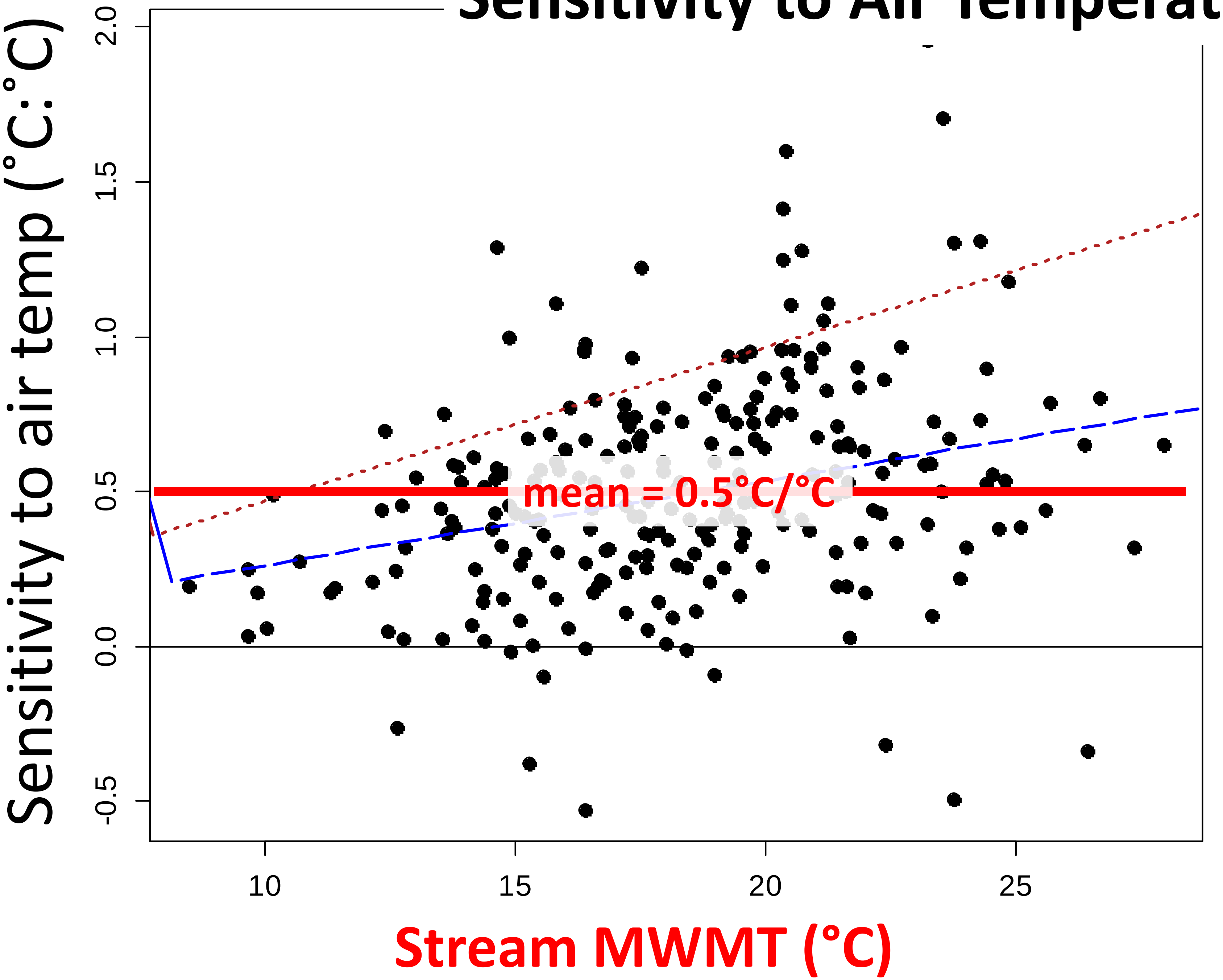
Observed values, averaged across years

Y-axis

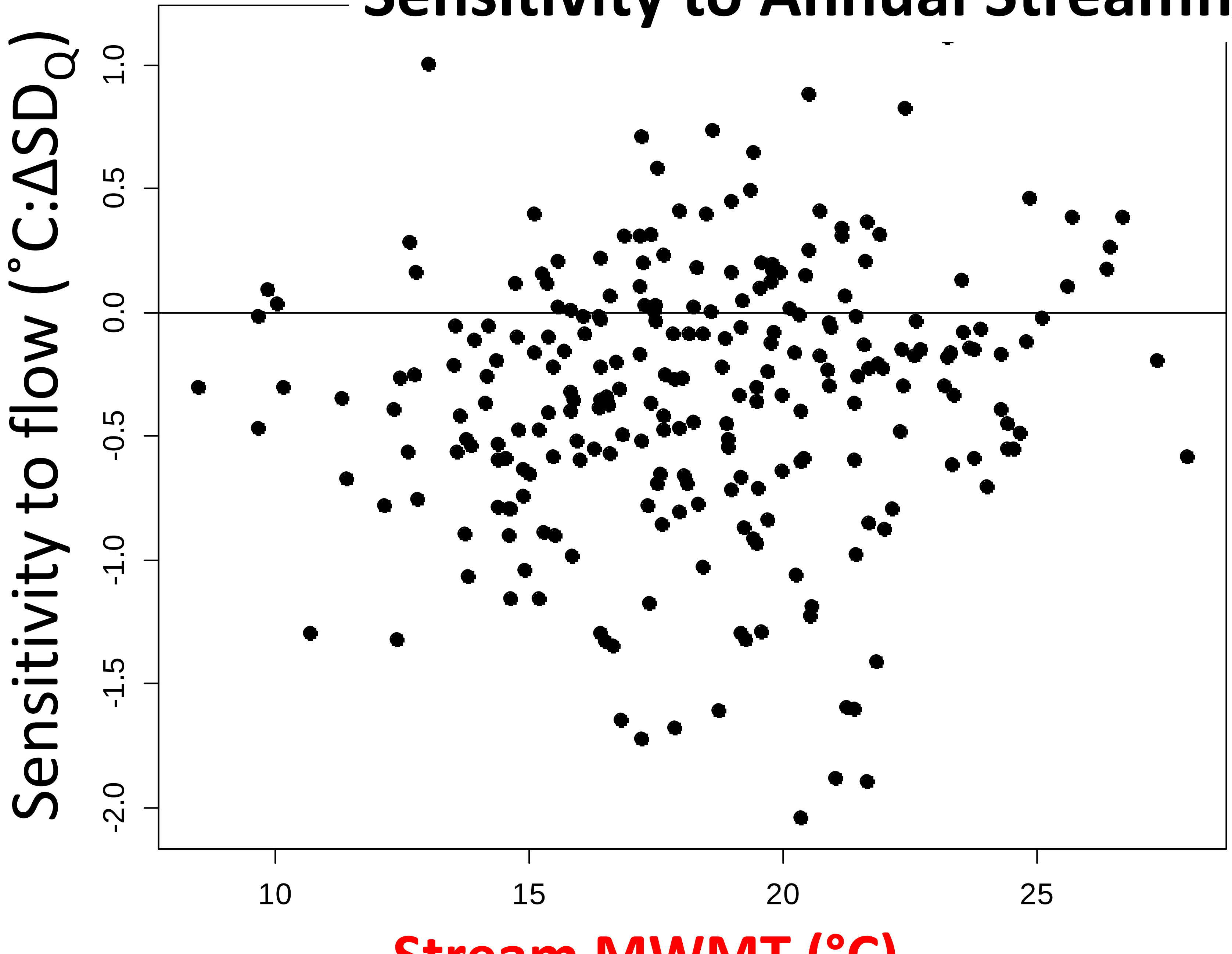


Wide range

Sensitivity to Air Temperature

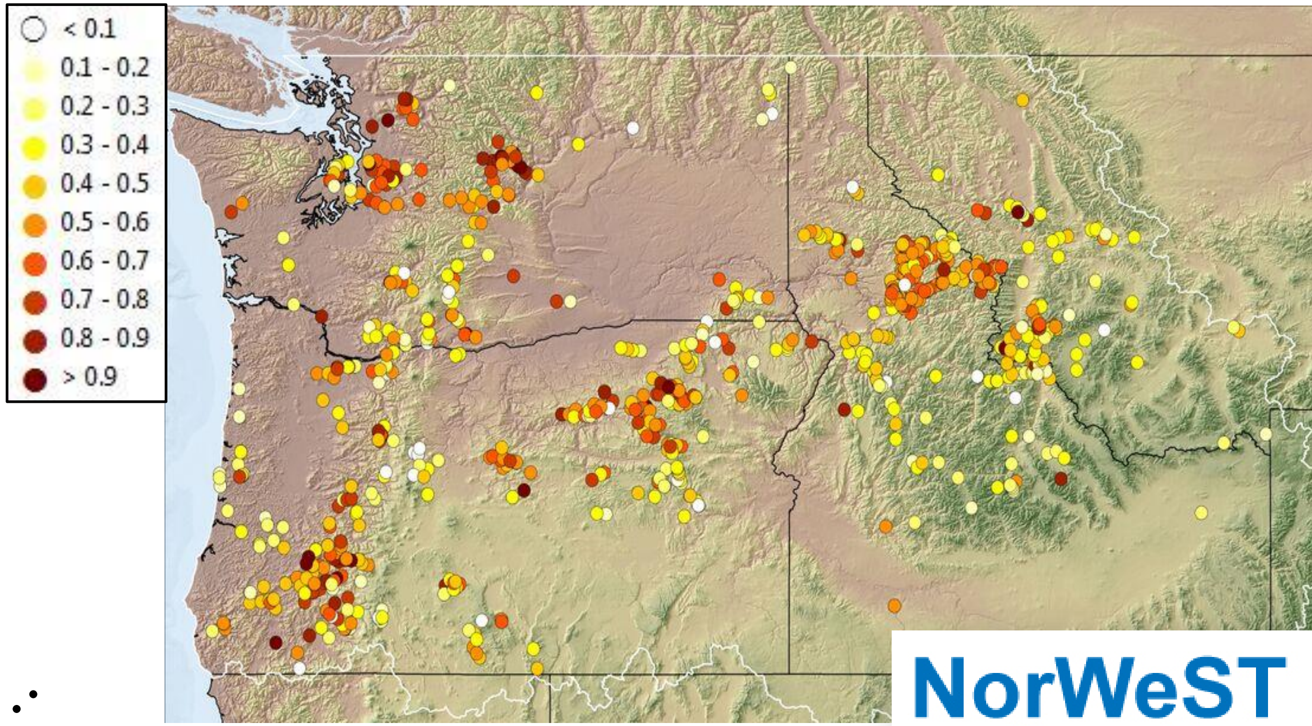


Sensitivity to Annual Streamflow

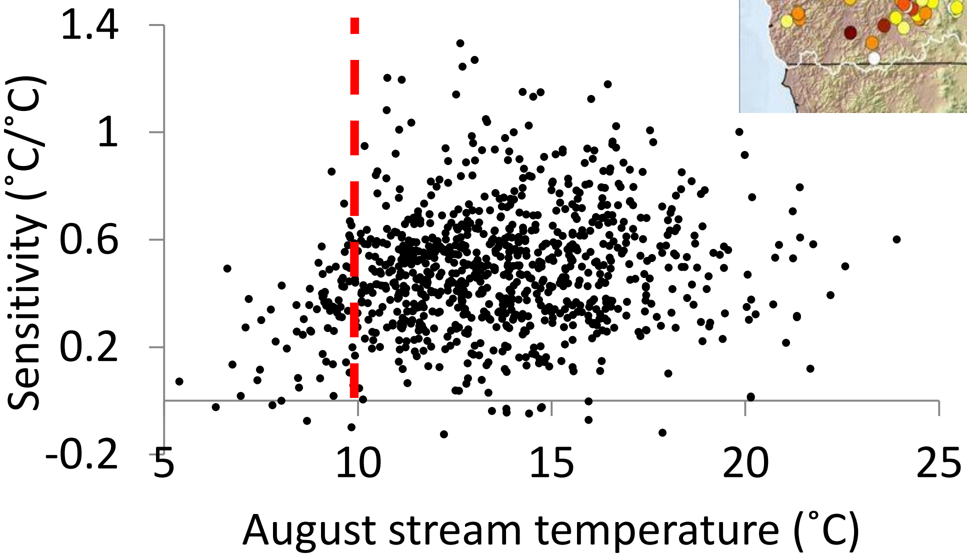


Bigger Data, Same Result…

(923 sites, 10-20 year monitoring records)



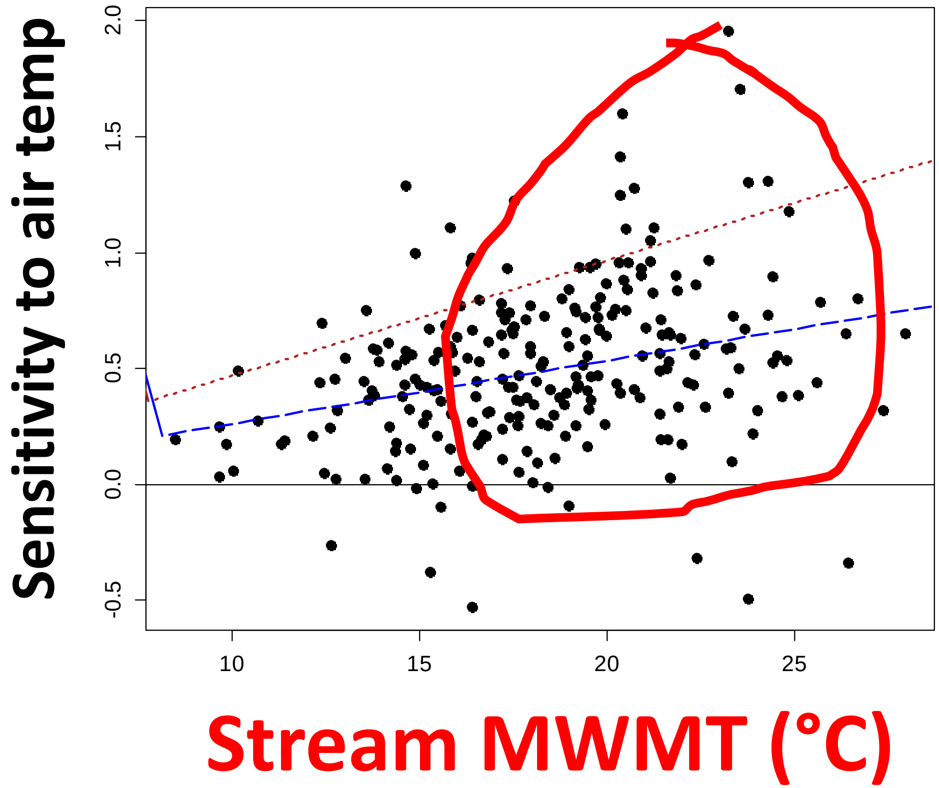
NorWeST Stream Temp



Isaak et al. In Preparation

Why? What explains low sensitivity of cold streams

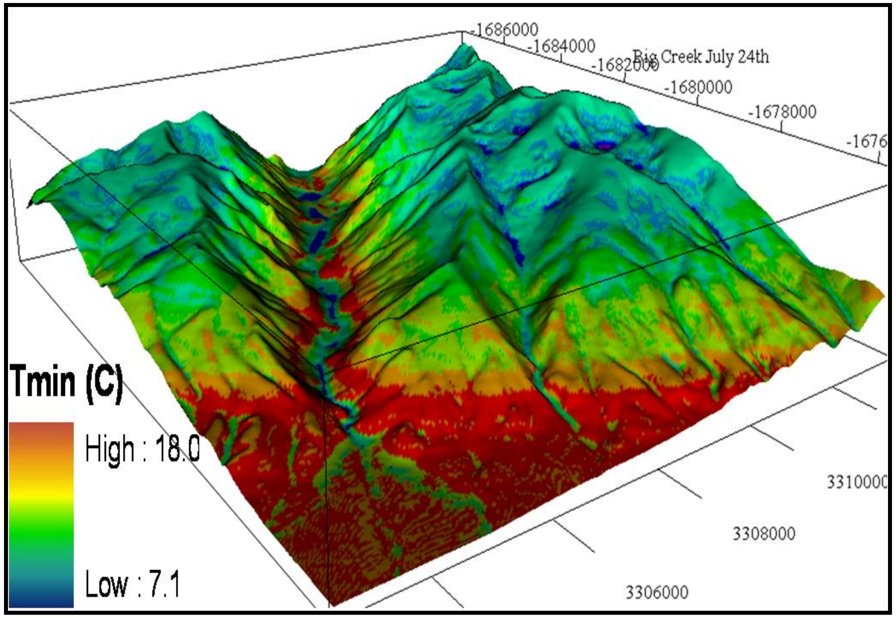
What about sensitivity of warmer streams?



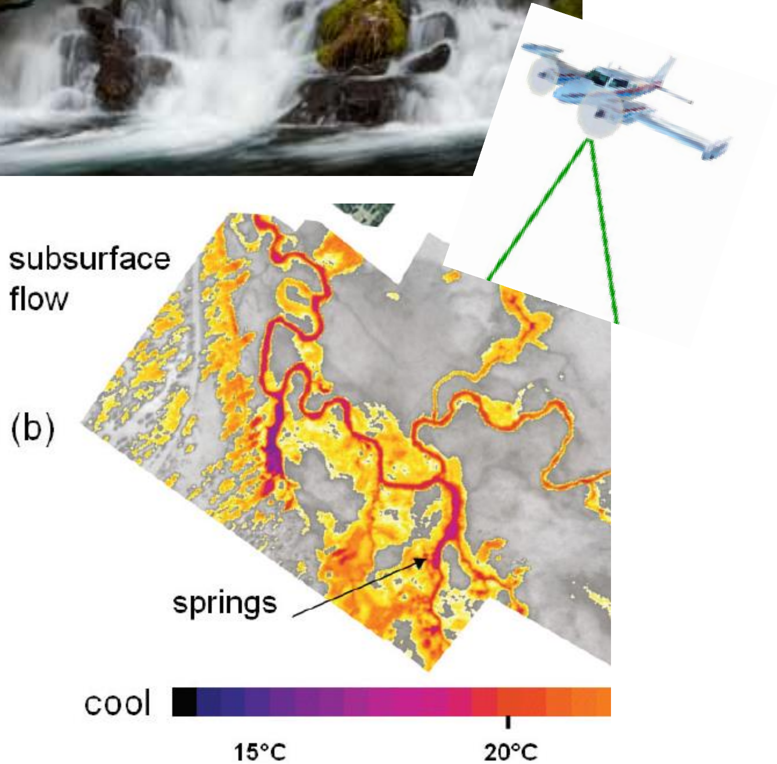
	°C/°C
Elevation	-0.07
BFI	0.02
Watershed size	-0.08
Annual Precip	0.05
Canopy %	0.07
Reach slope	0.04

Two Possibilities: Local Climate Forcing &/or Buffering

Air microclimates in complex valley morphologies



Groundwater influxes downstream of headwaters

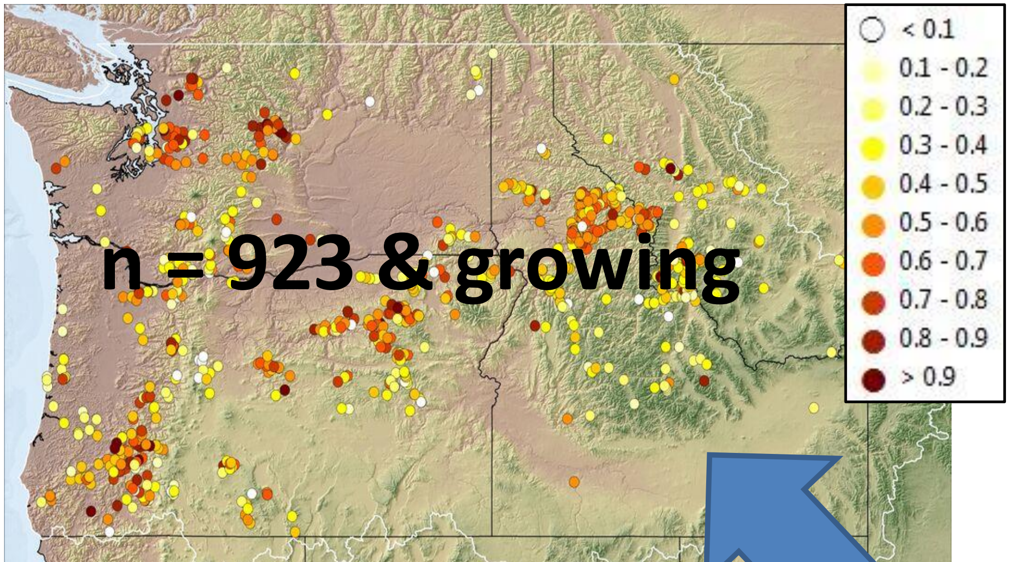


Torgersen et al. 2012

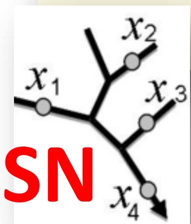
★ This information needed at high resolution across 100,000s stream kilometers

Brute Force, Empirical Approach

SSN models to geostatistically krige sensitivity

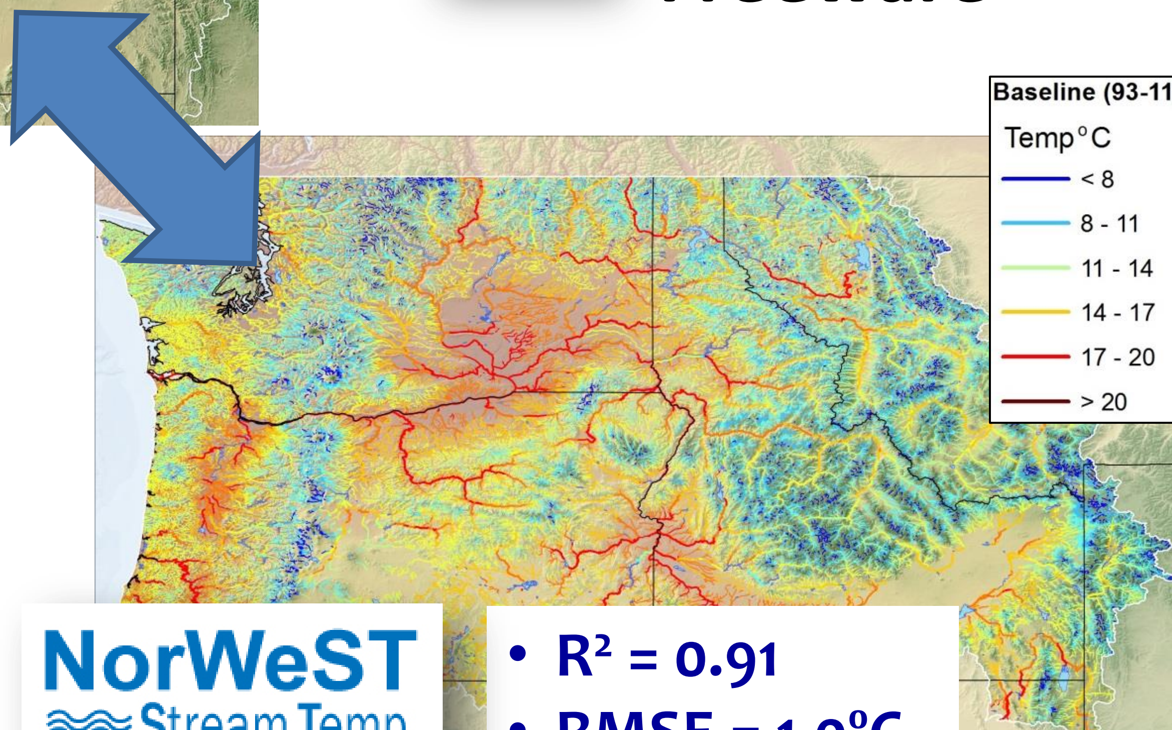


n = 923 & growing



SSN

Website & Freeware



NorWeST Stream Temp

- R^2 = 0.91
- RMSE = 1.0°C

Summary

- Streams exhibit a wide range of correlations with air temperature & discharge (sensitivity)

- Colder streams are less responsive to climate forcing across years
  - Groundwater, late snowpack
  - Indirect sensitivity to climate change could be large (e.g., wildfires alter riparian vegetation & limit site regrowth)

- Better understanding & prediction of sensitivities (especially in warmer streams) would enable better climate change forecasts