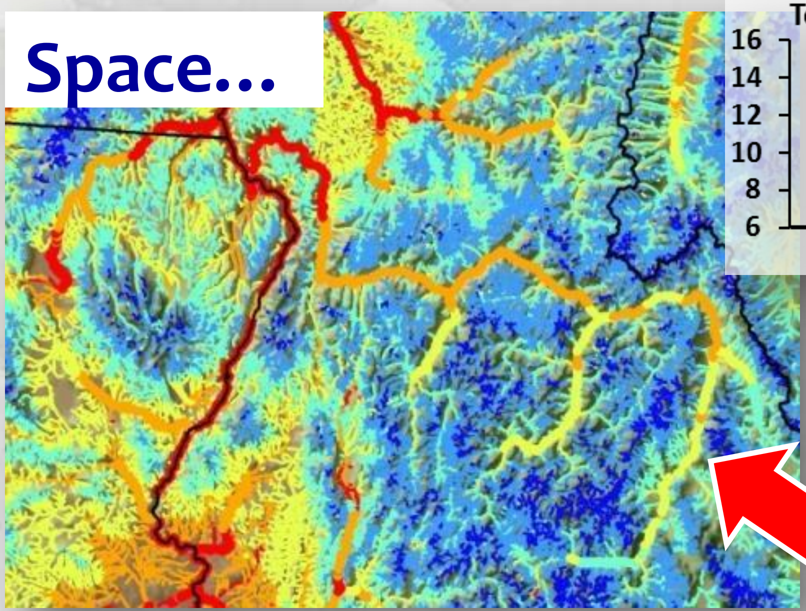
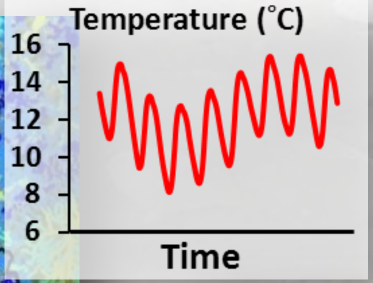
Spatial & Temporal Climate Patterns in PNW Rivers & Streams:

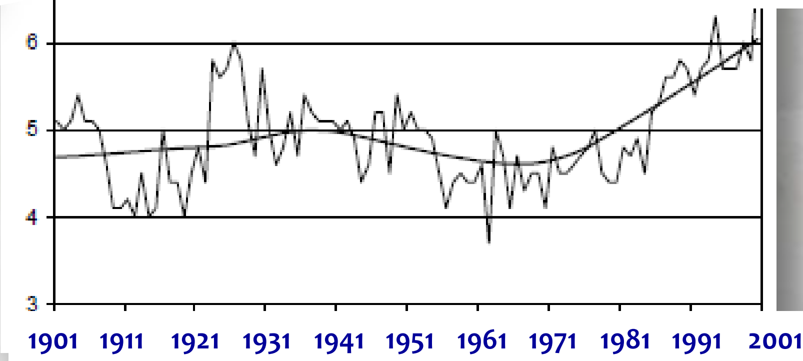
A Variance Decomposition Approach





Time…

Danube River, Austria (1901 – 2000)



Webb and Nobilus 2007

Dan Isaak, US Forest Service

Rocky Mountain Research Station

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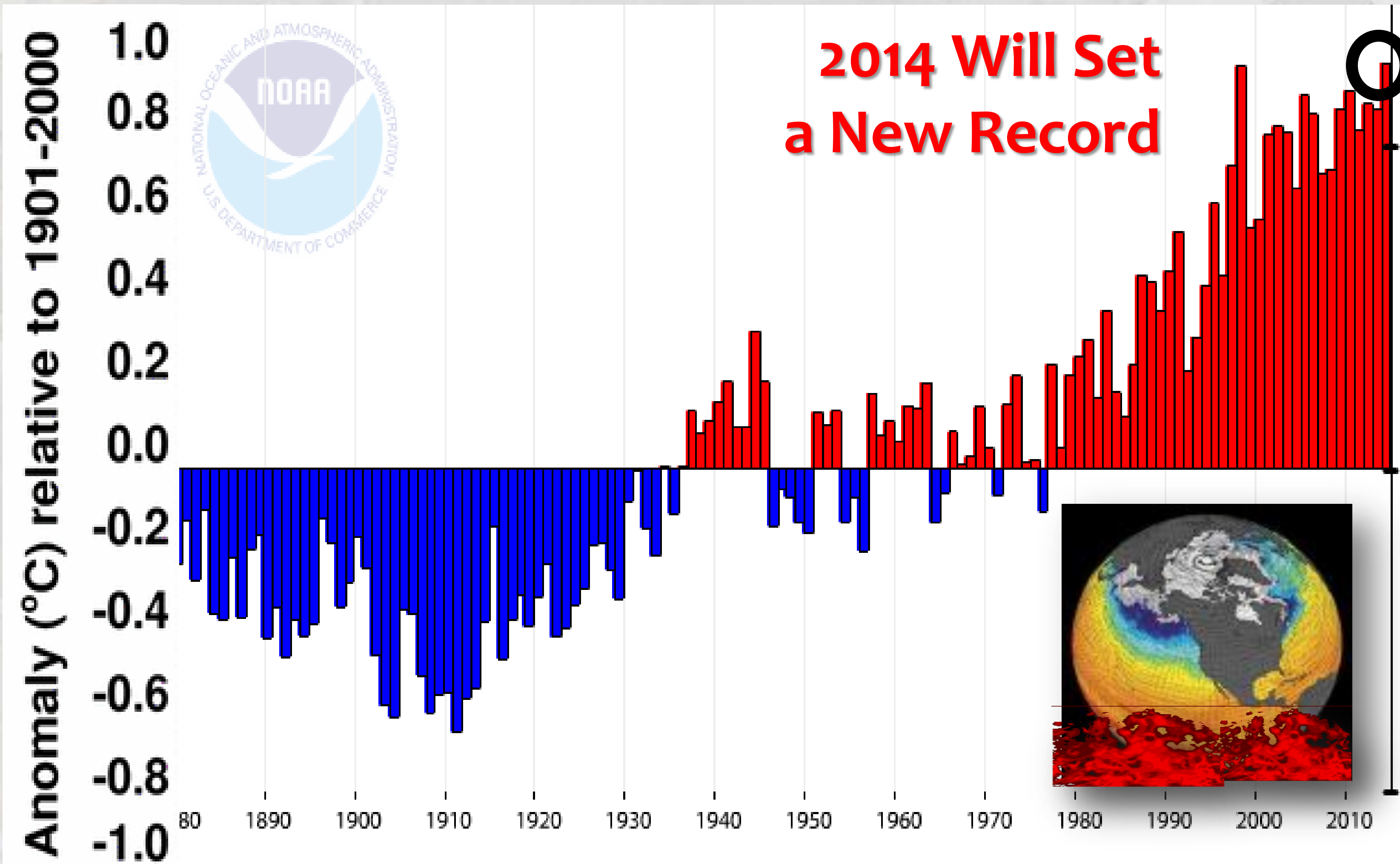


General outline:

1) Empirical patterns described from dense ***annual*** sensor arrays

2) Temporal trends & attribution

3) Spatial patterns & attribution (NorWeST)

4) Biological uses of NorWeST scenarios

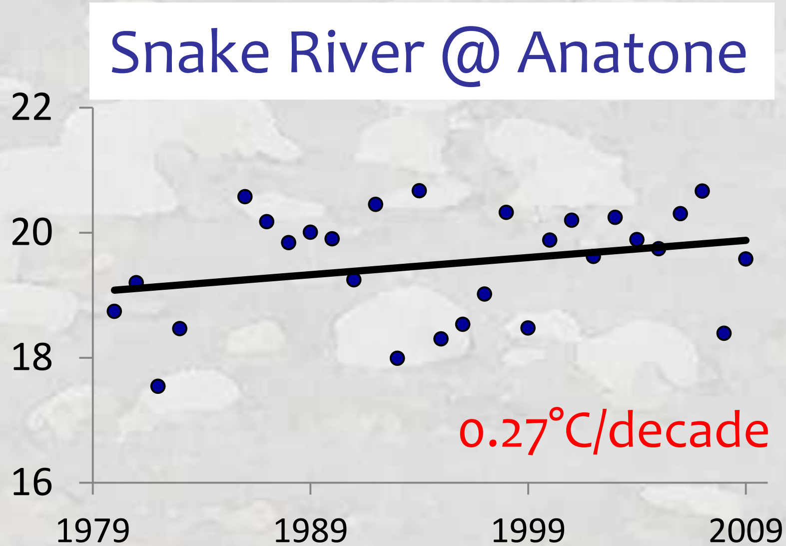
Part 1

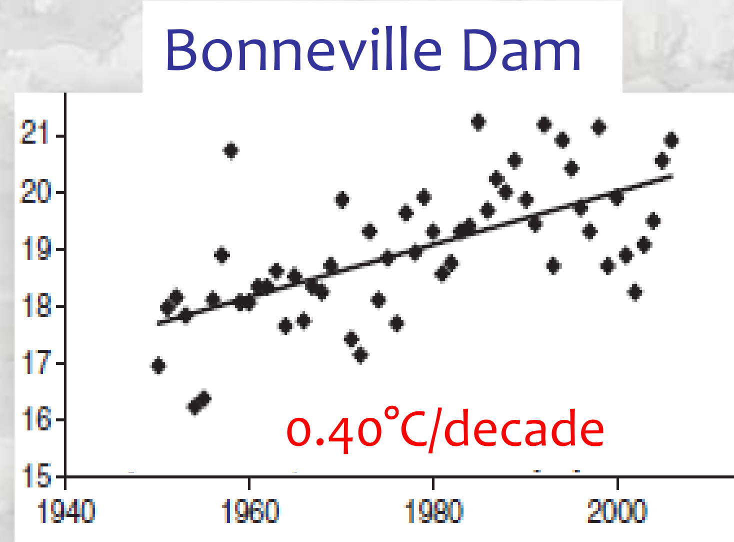
Part 2

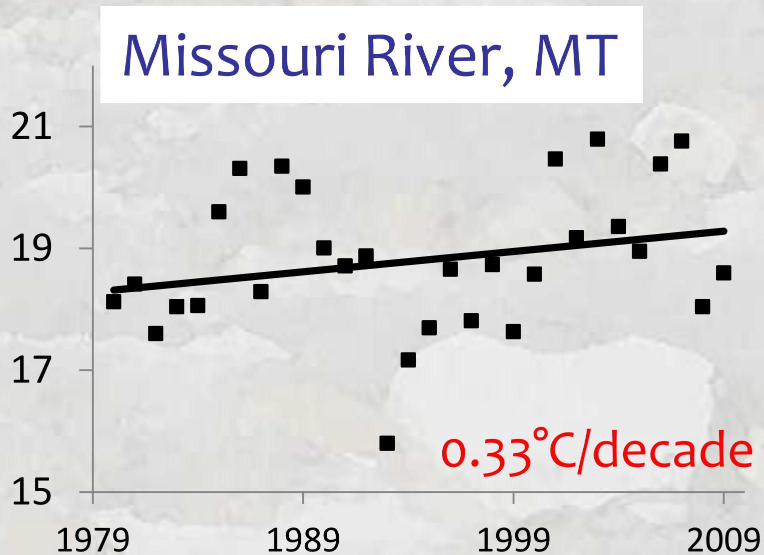
5) Future NorWeST scenarios

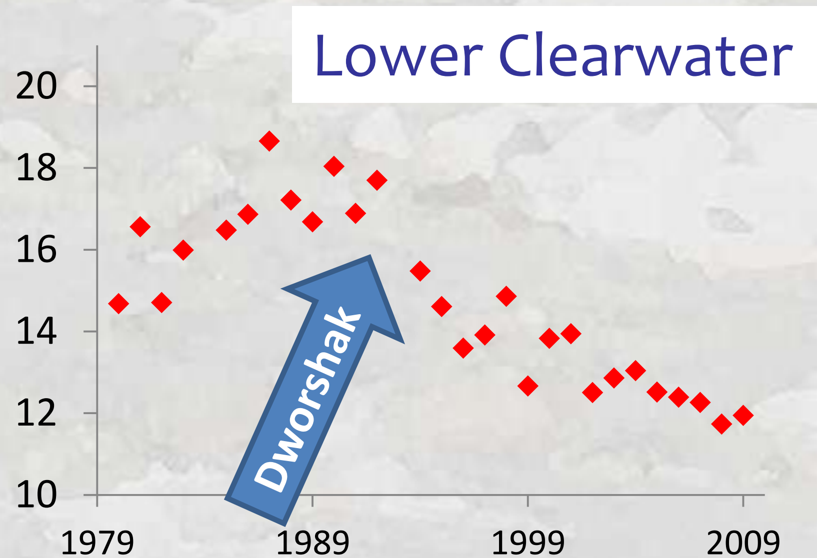
6) Interagency monitoring networks for reducing uncertainties

Summer Trends In Northwest Rivers



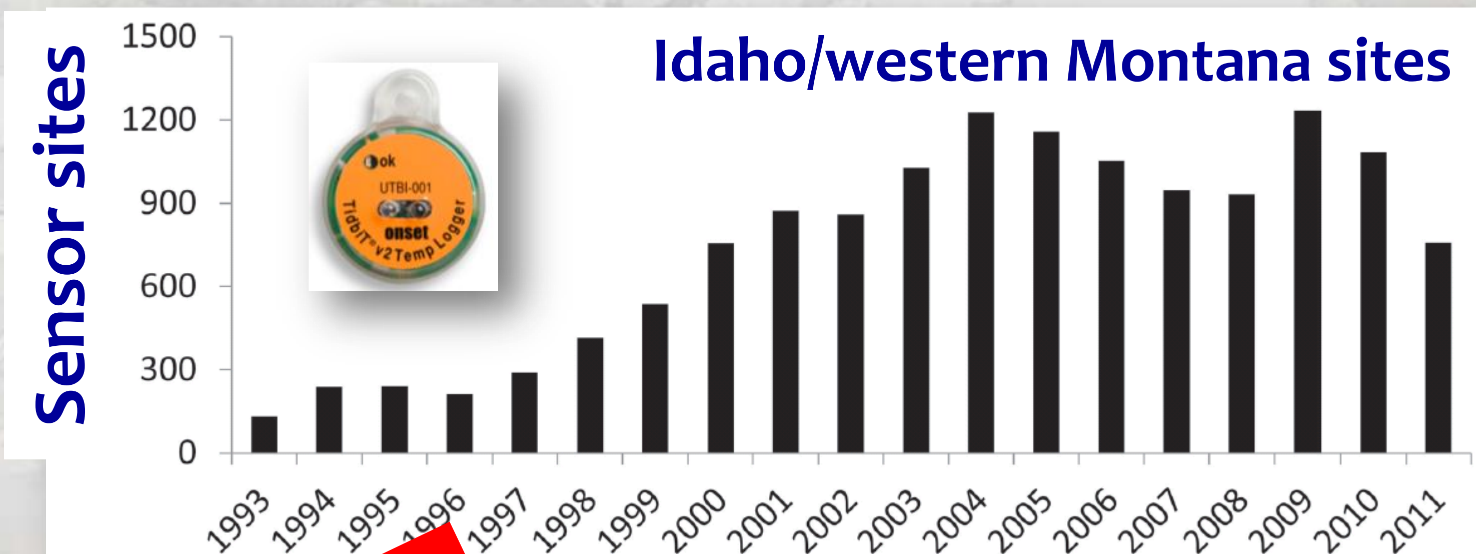




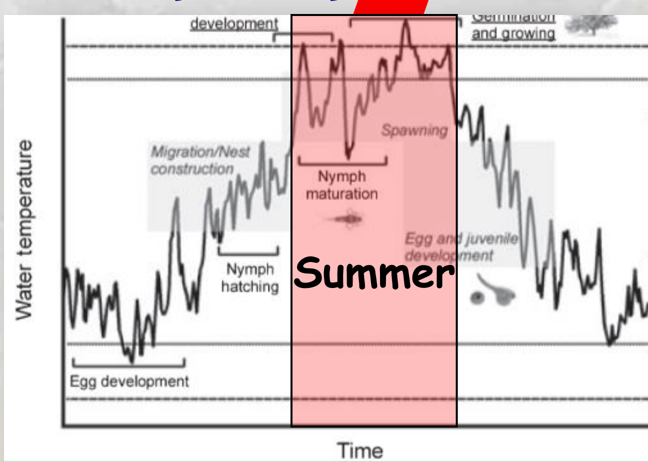


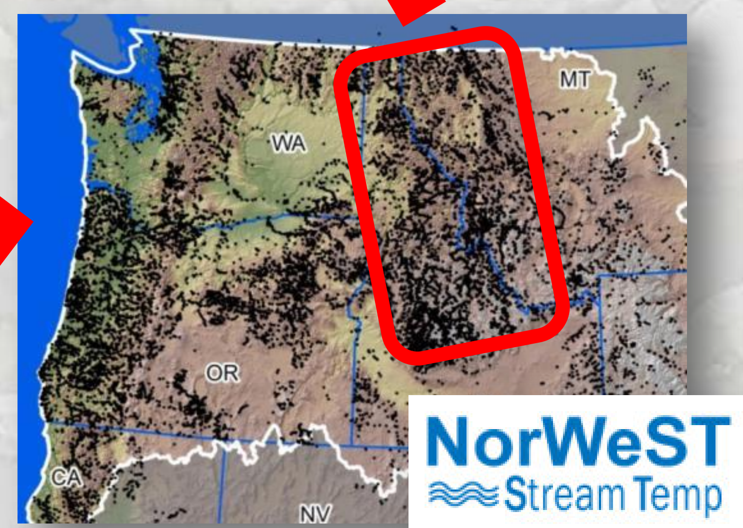
GAPS in existing Monitoring Networks

Many Sites, but…



Usually only in the summer…





GAPS in existing Monitoring Networks

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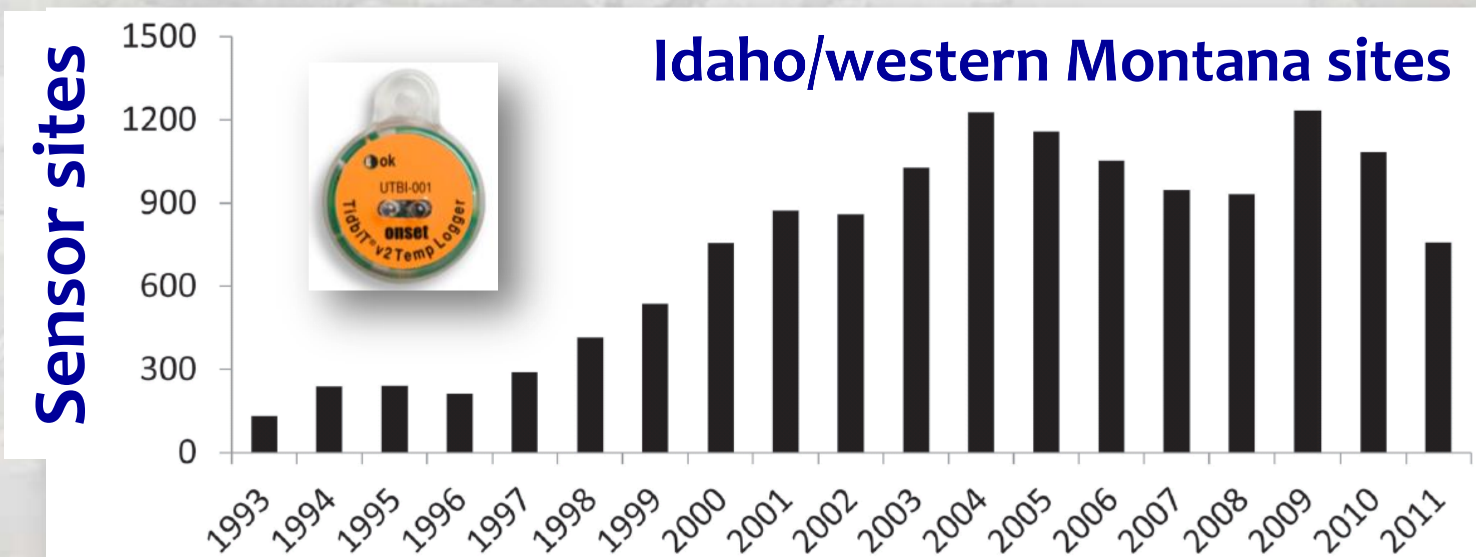
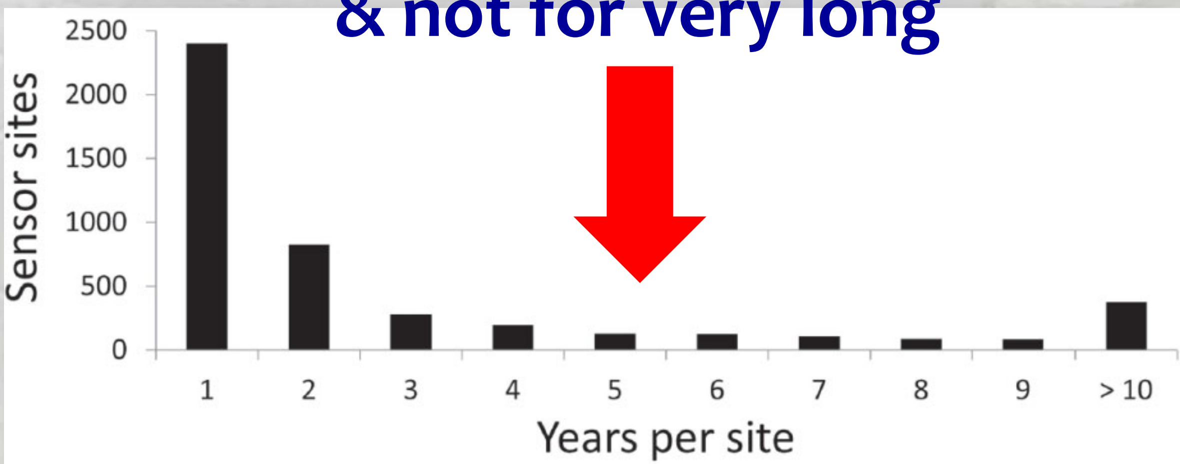
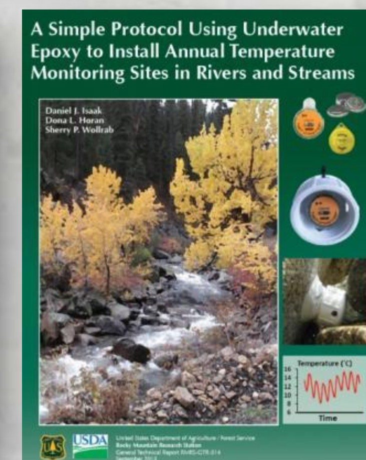


& not for very long

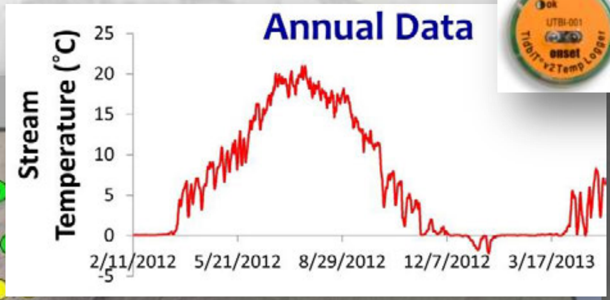


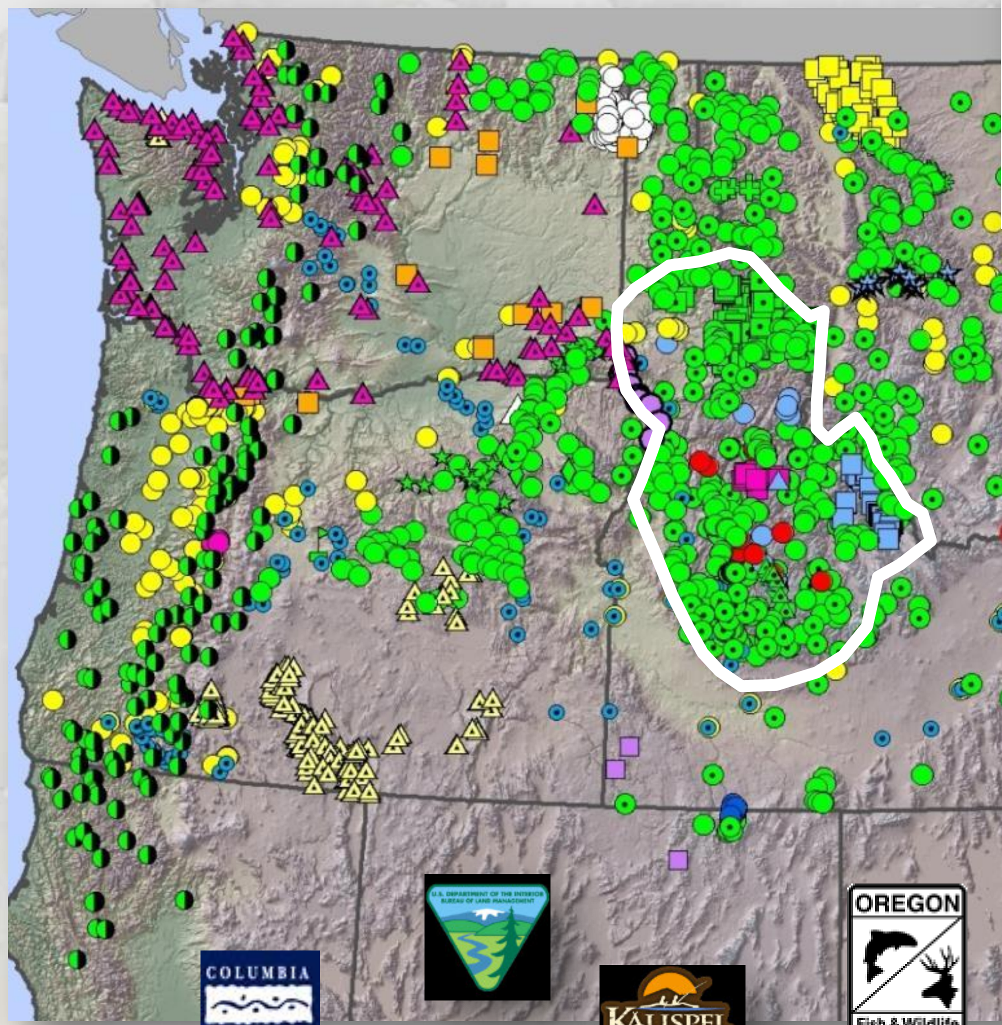


Isaak et al. 2013. A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams. USFS General Technical Report, 314.

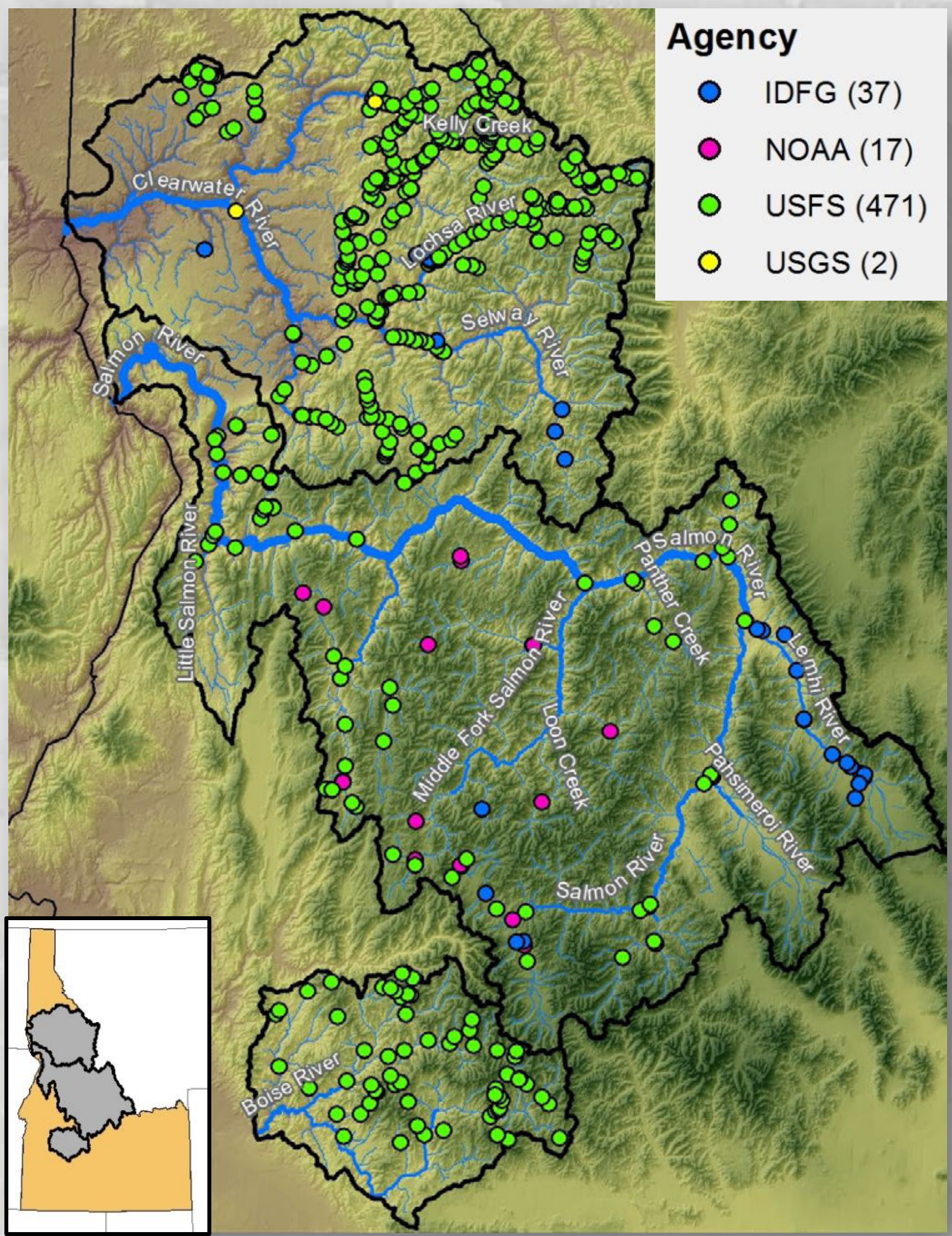
Annual Temperature Monitoring Sites

>3,000 sites in Pacific Northwest





Central Idaho Annual Temperature Dataset

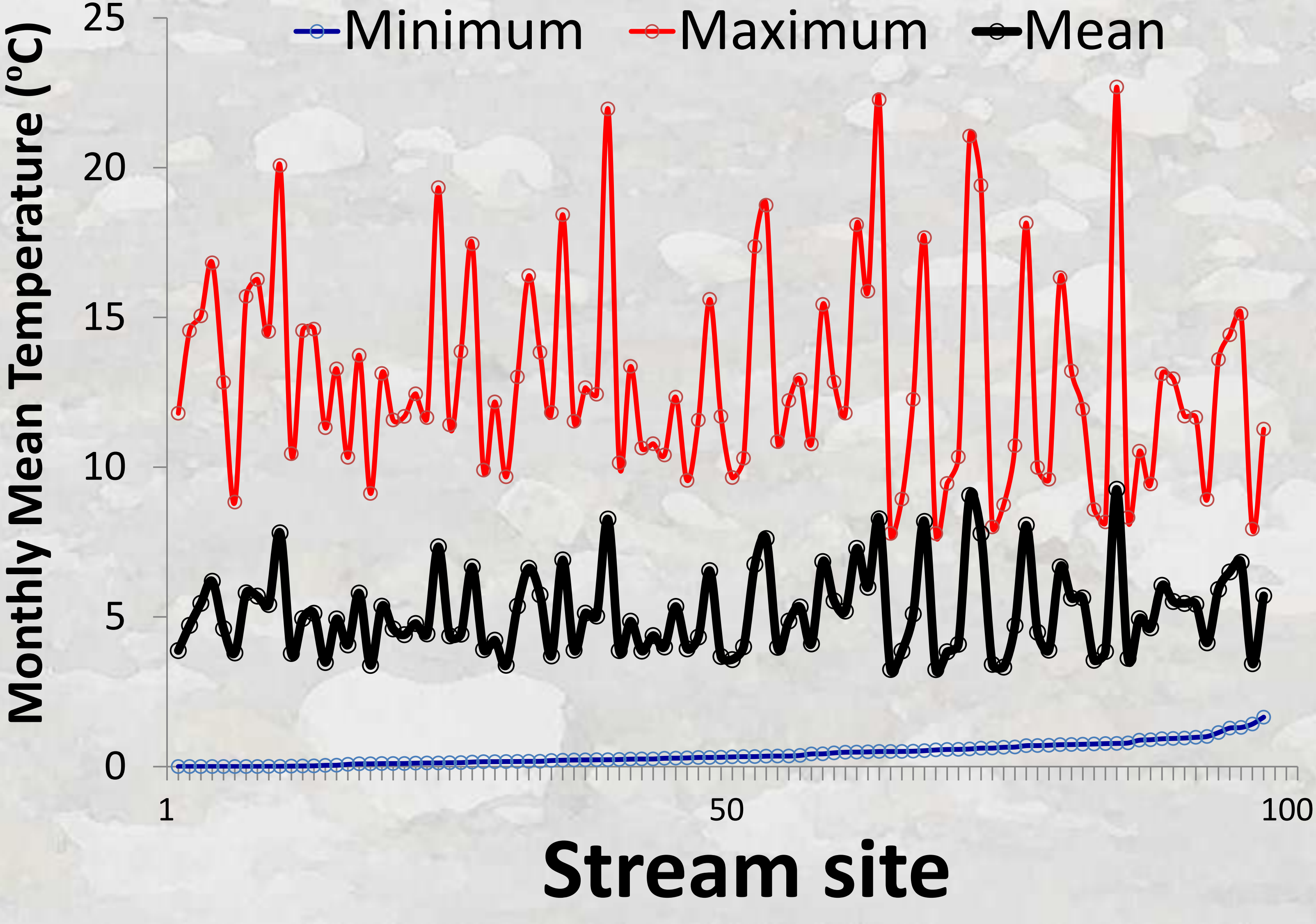


527 sites (2010-2013)

>1,000 years of data

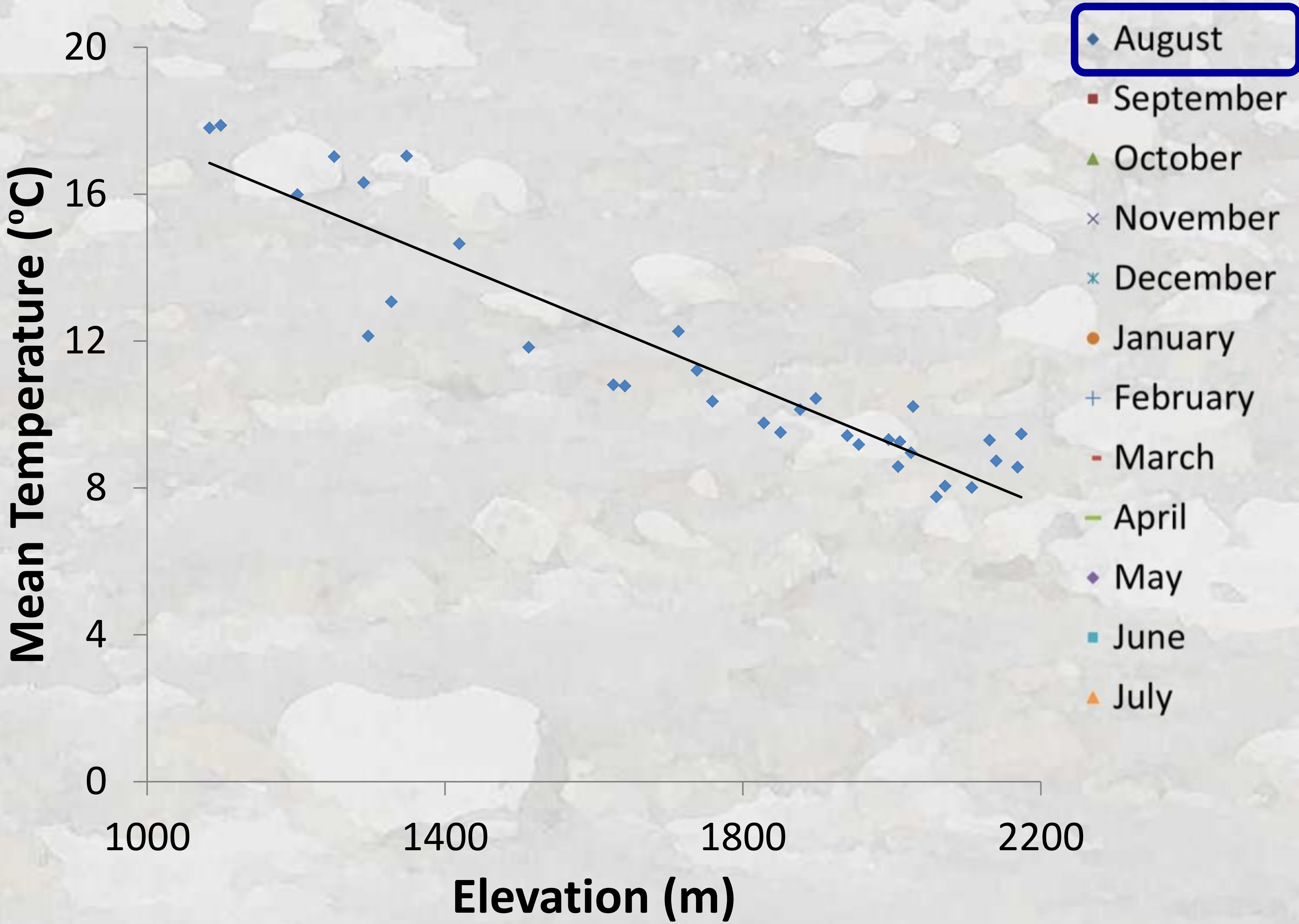
Observed Empirical Patterns

Monthly Averages (Min/Max/Mean - 2012)



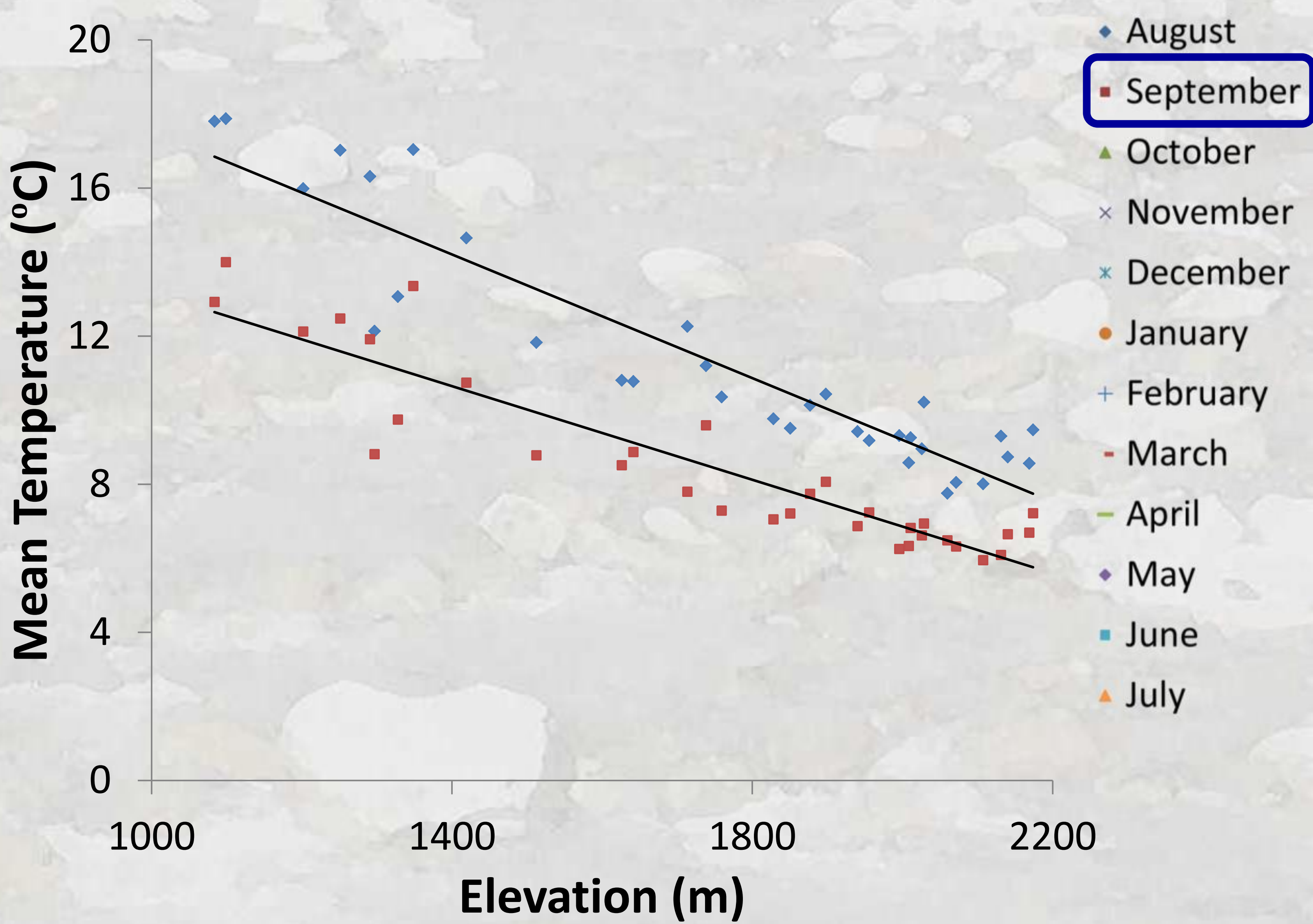
Observed Empirical Patterns

Temporal Variation Within Year & Basin



Observed Empirical Patterns

Temporal Variation Within Year & Basin



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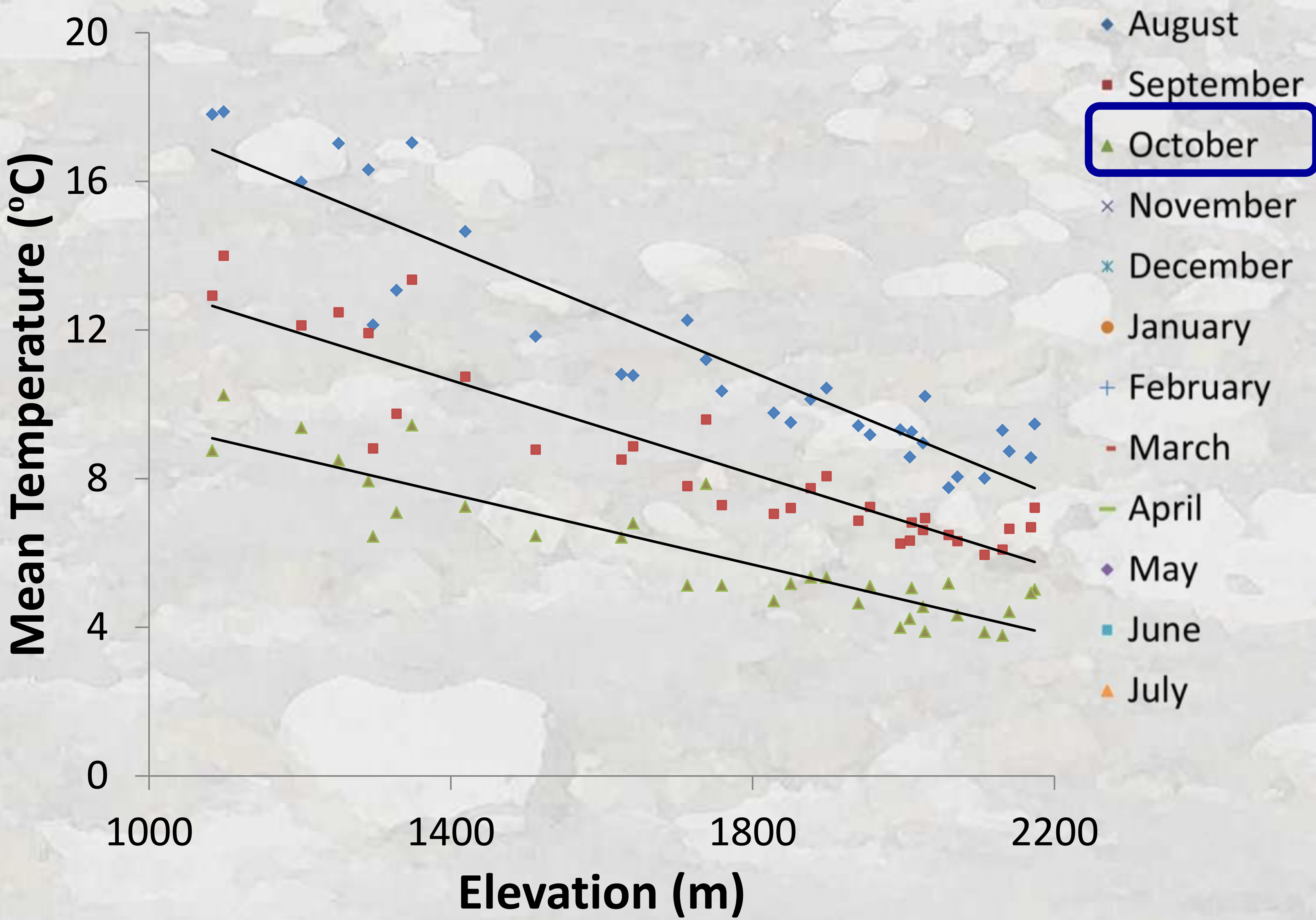

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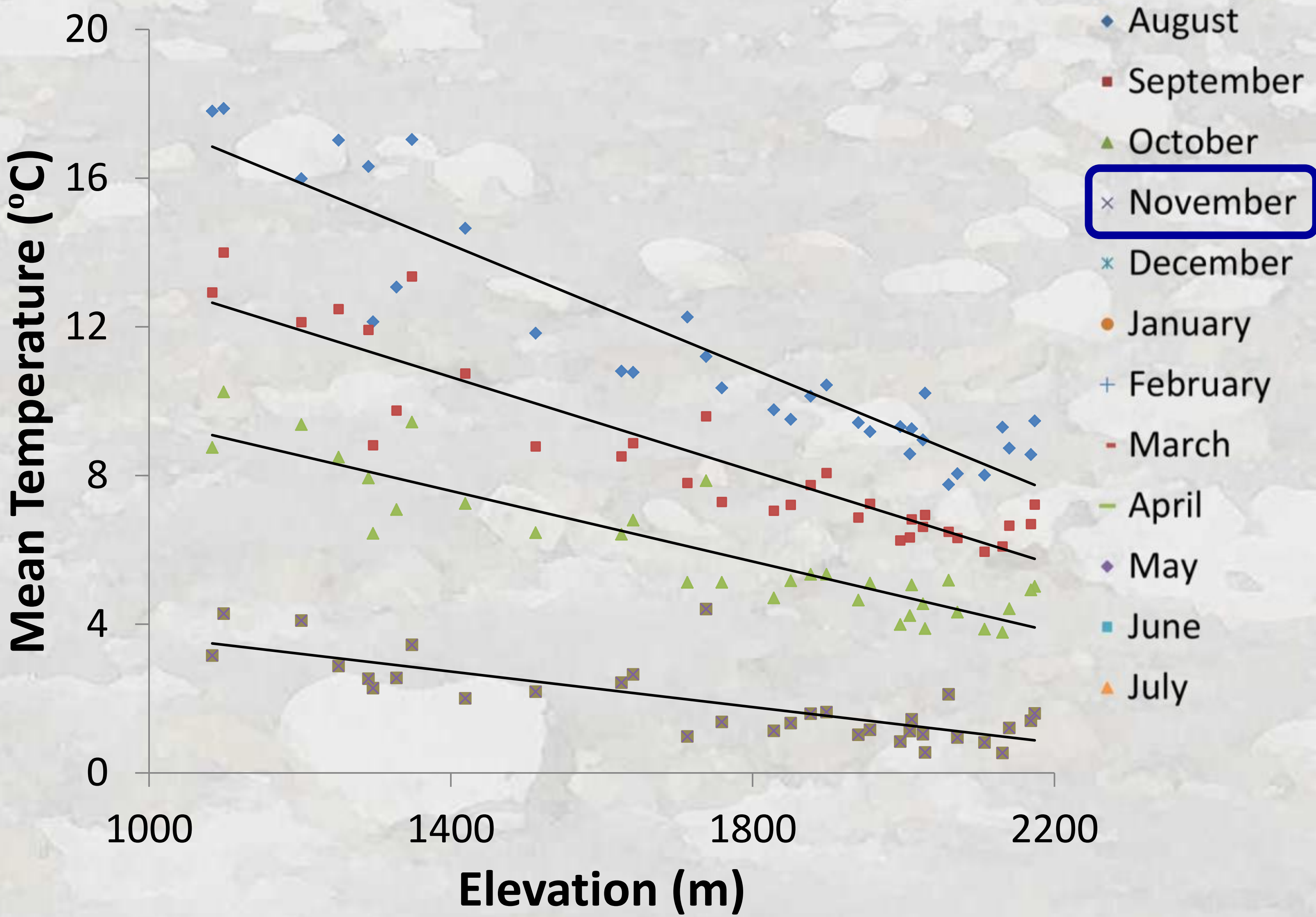

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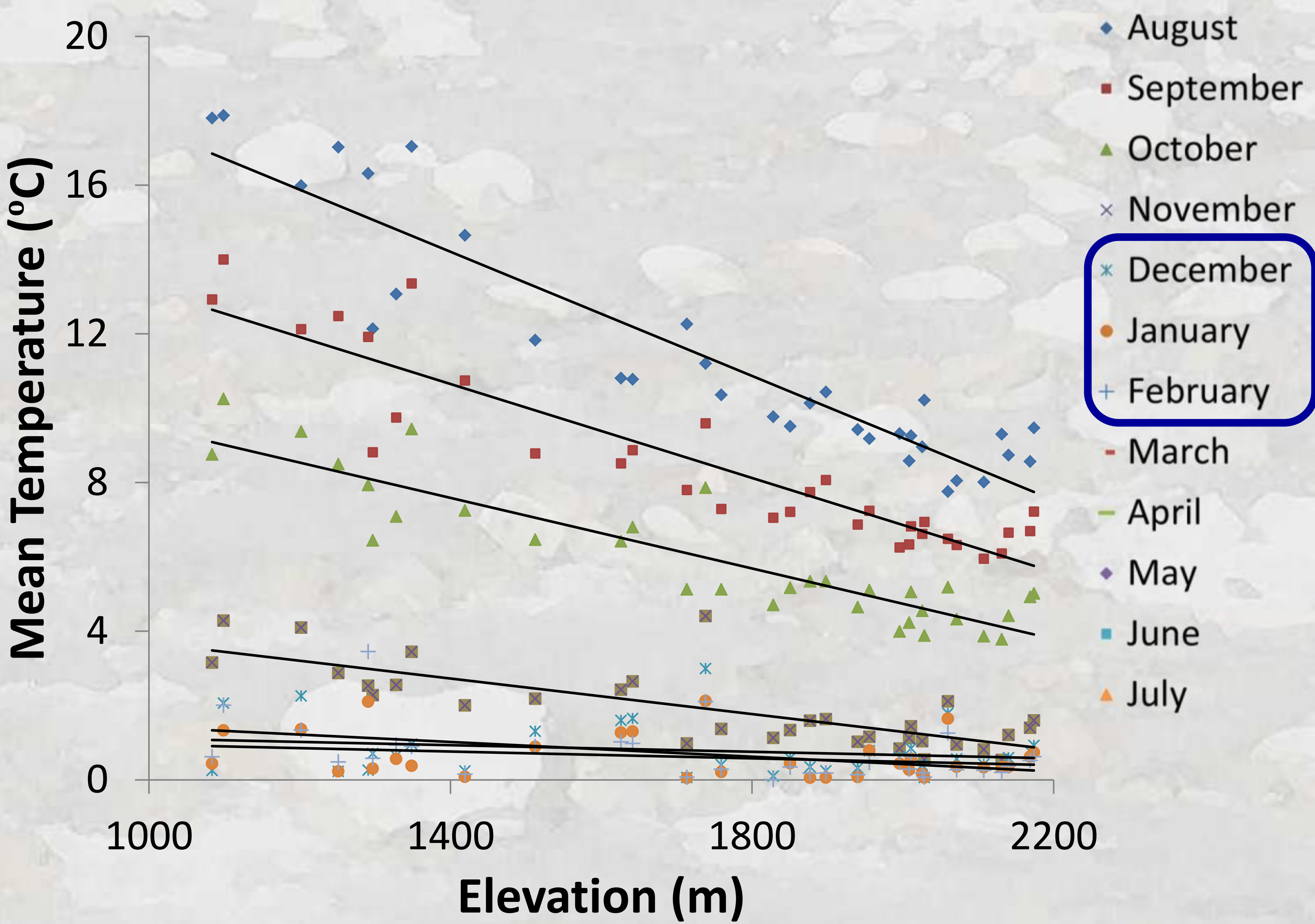

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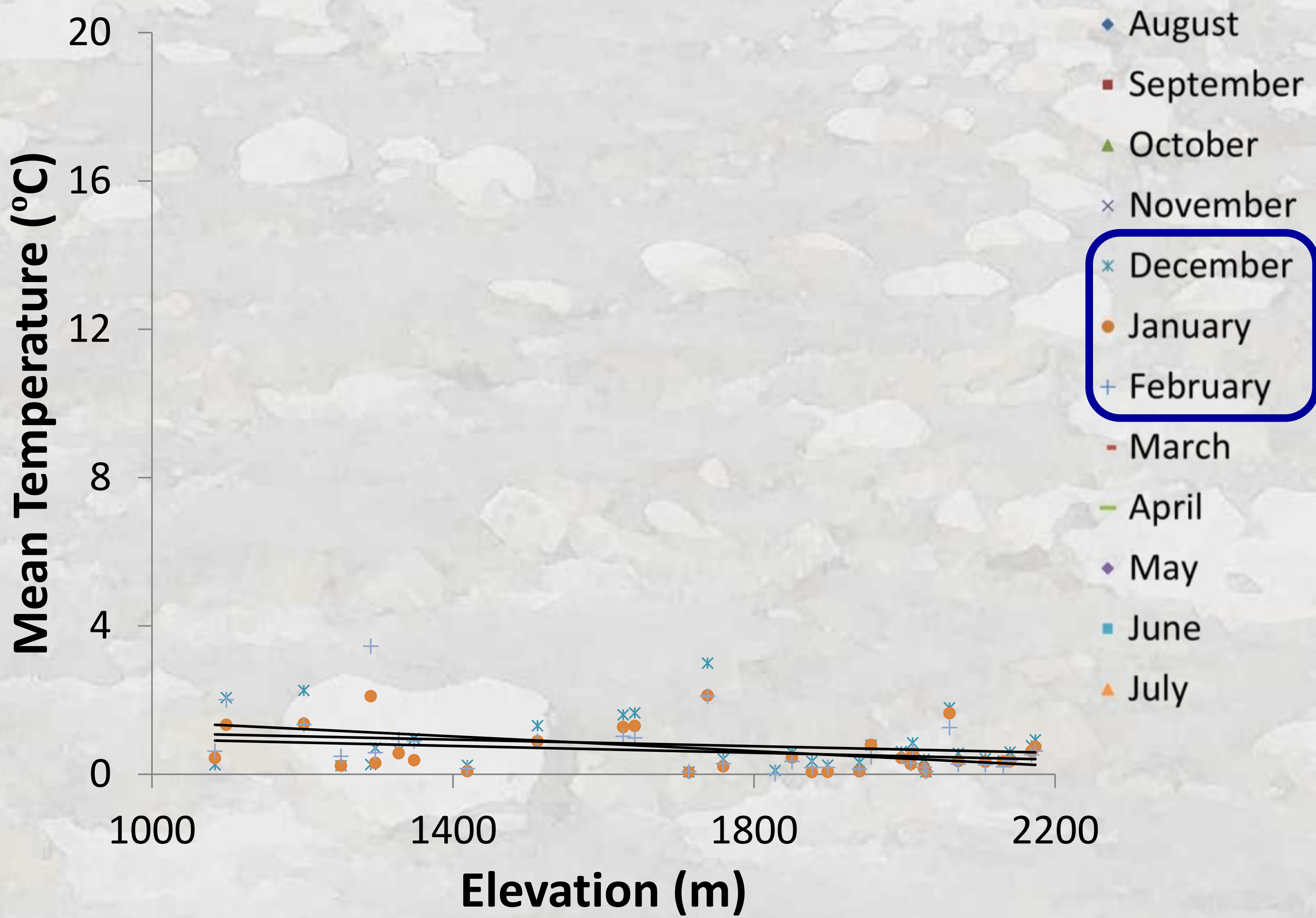

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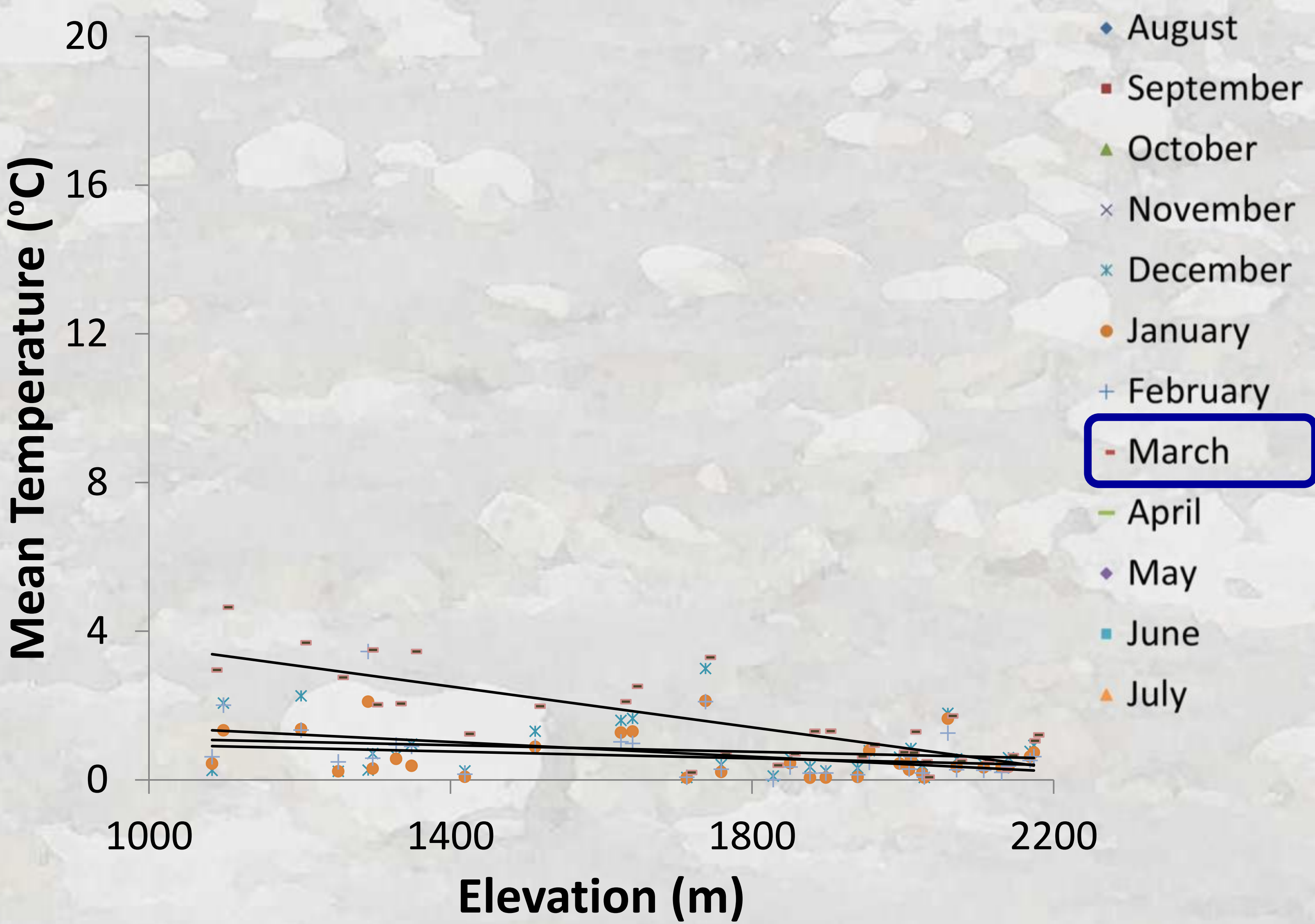

Observed Empirical Patterns

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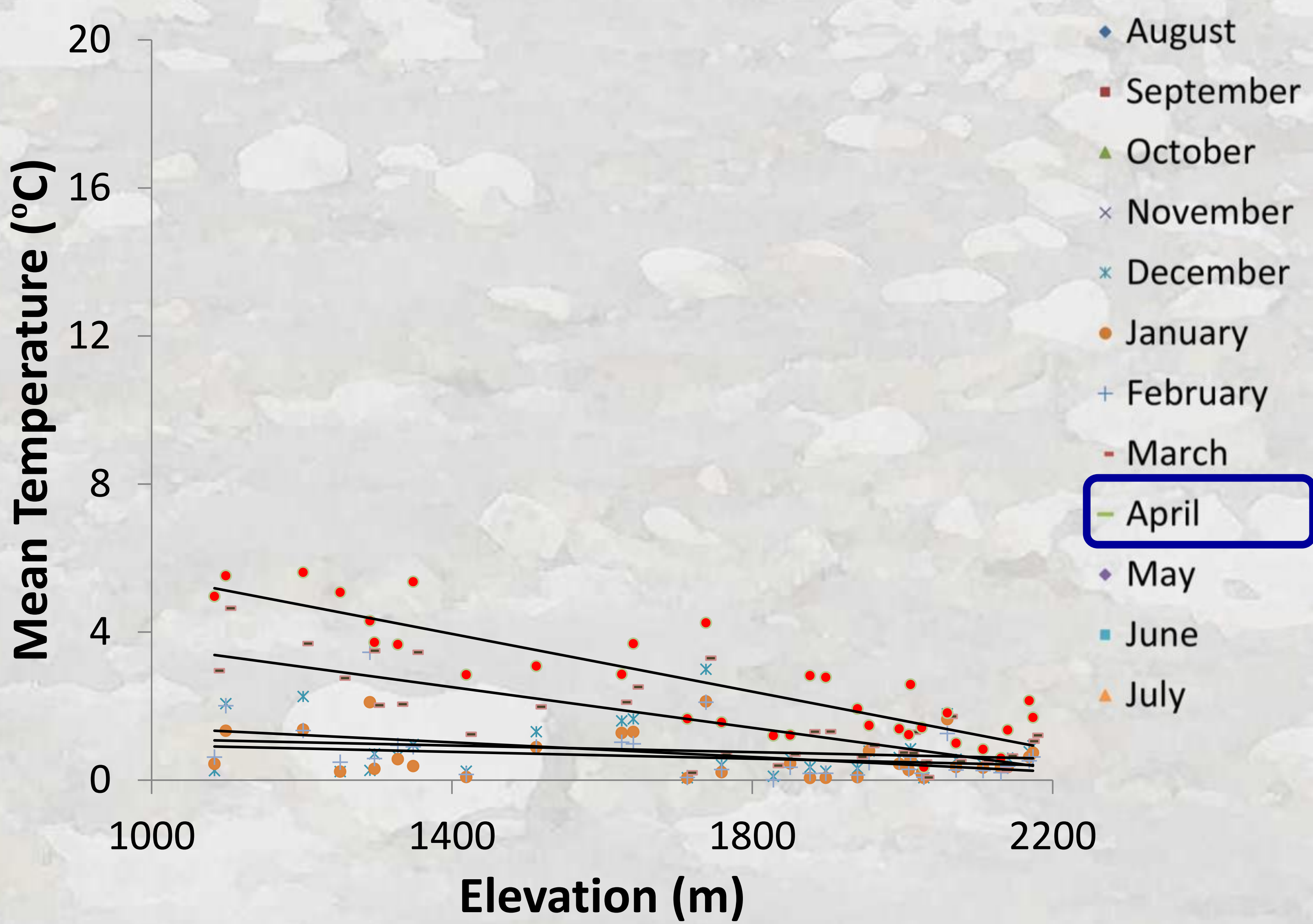

Observed Empirical Patterns

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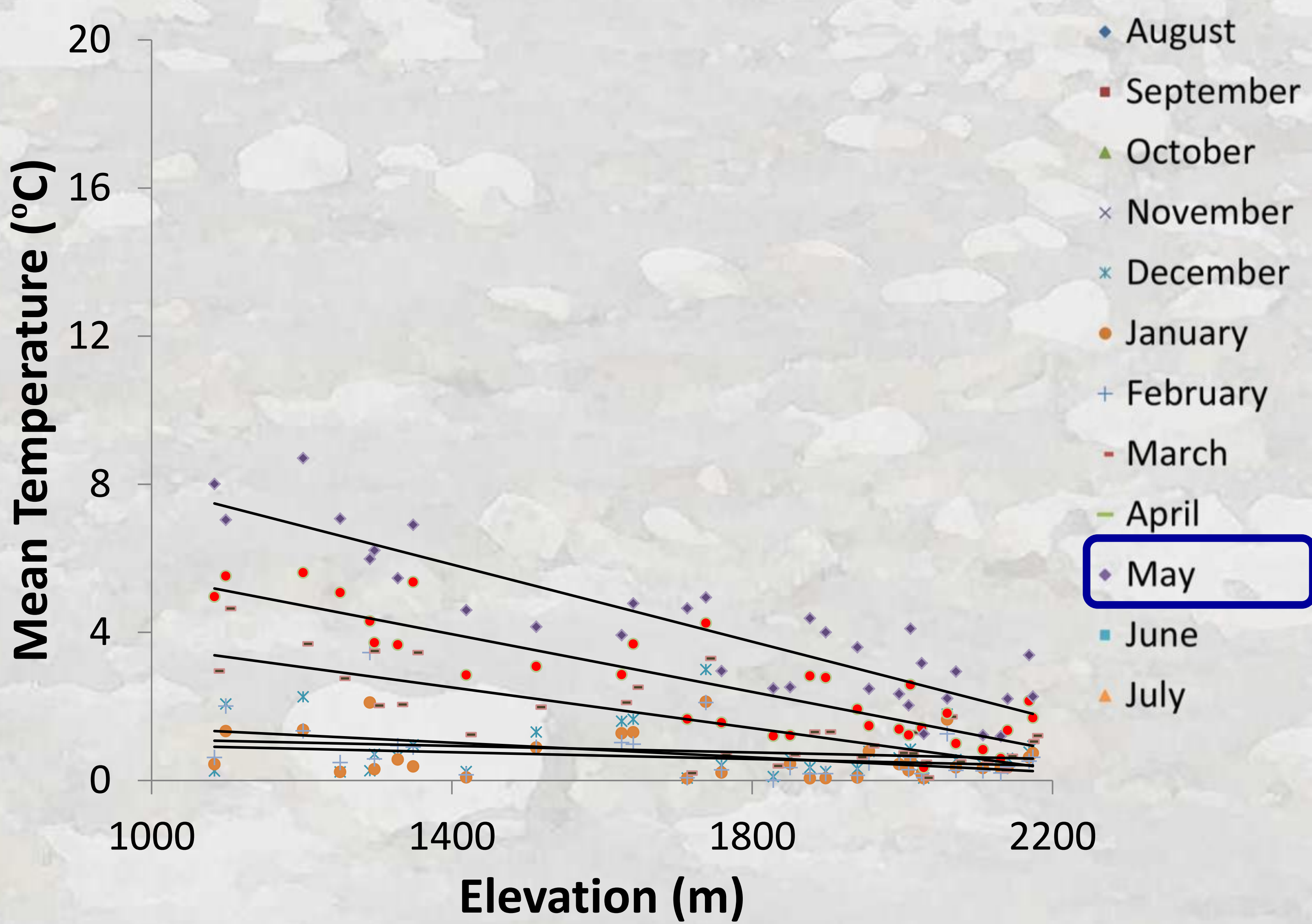

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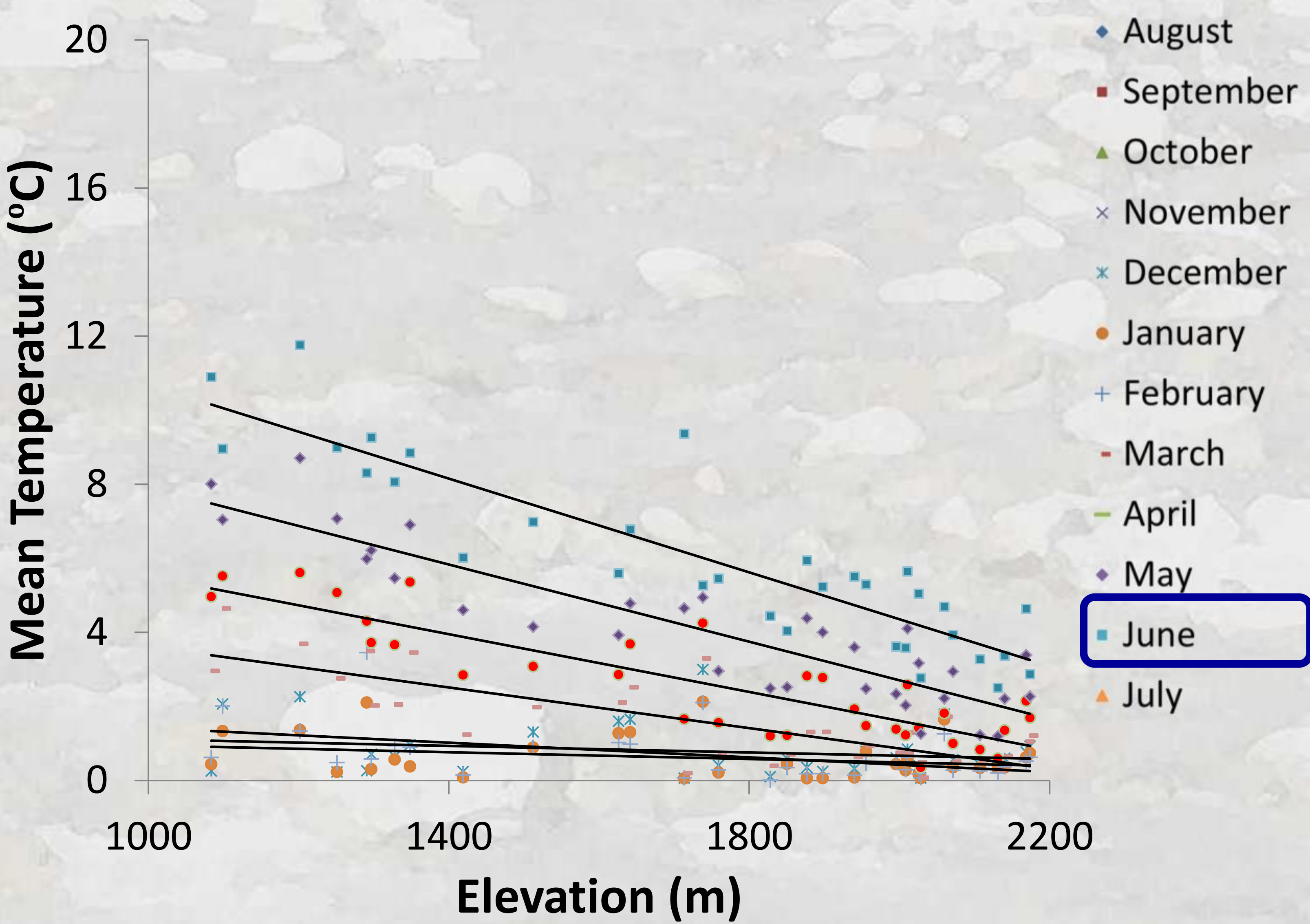

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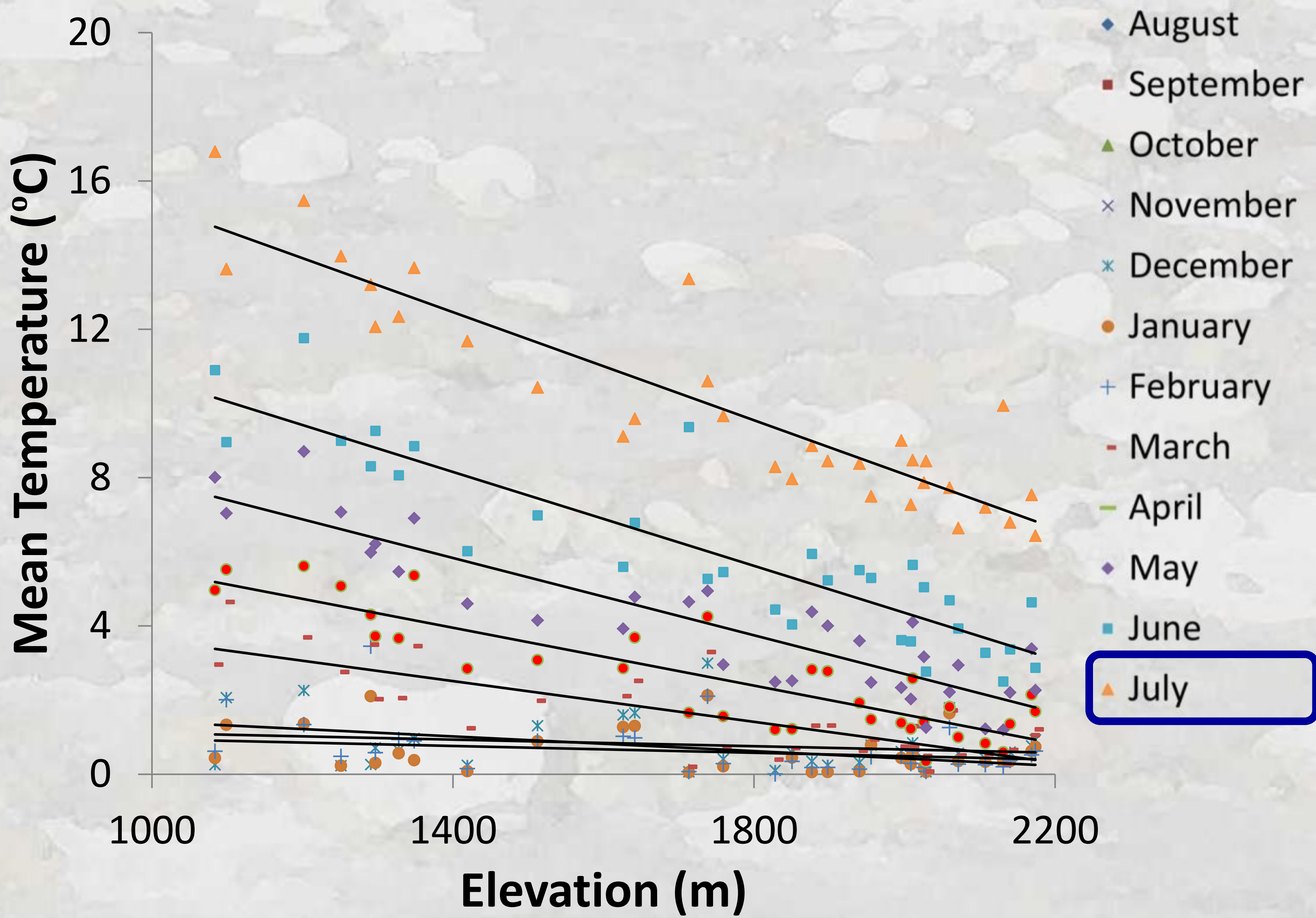

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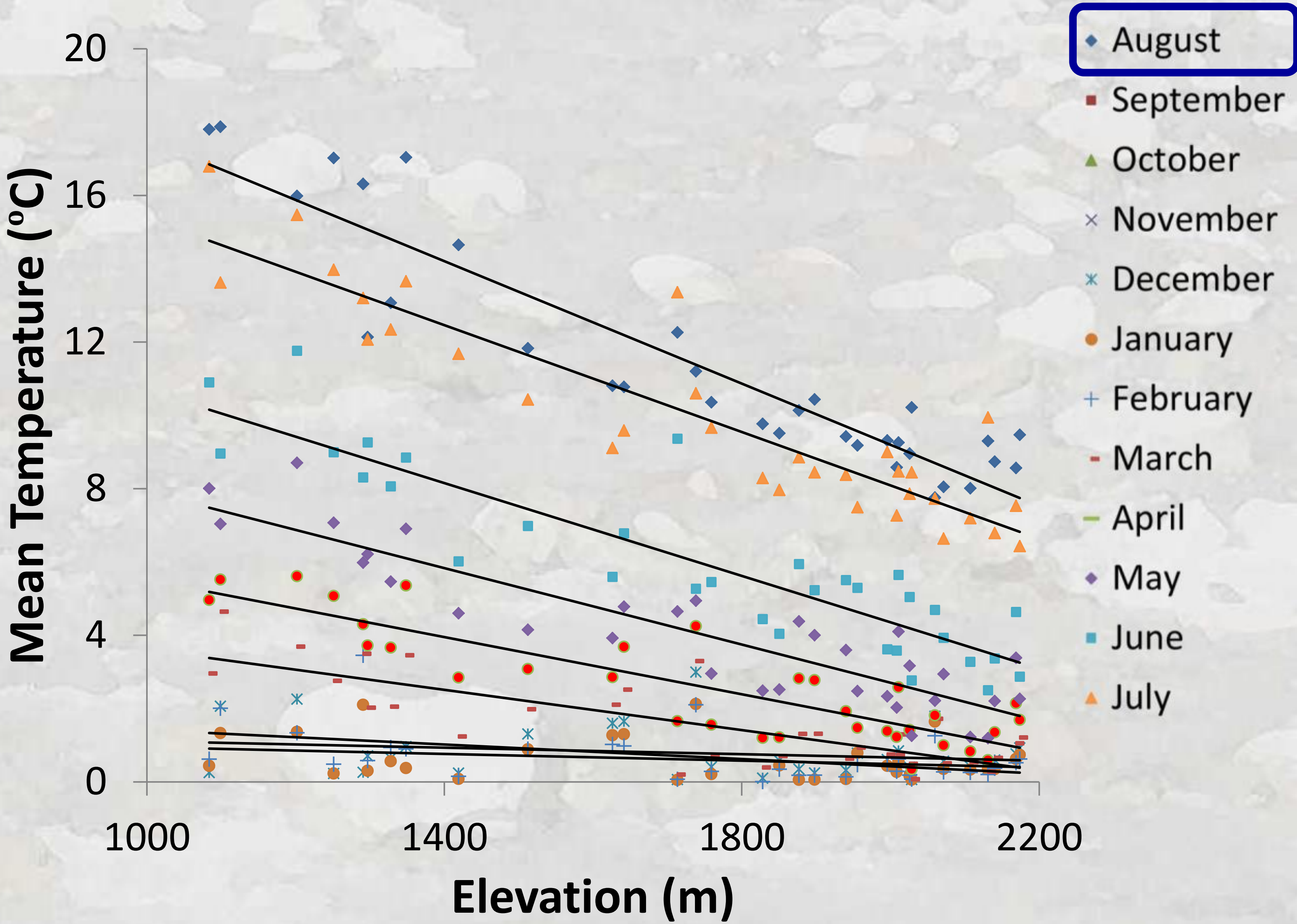

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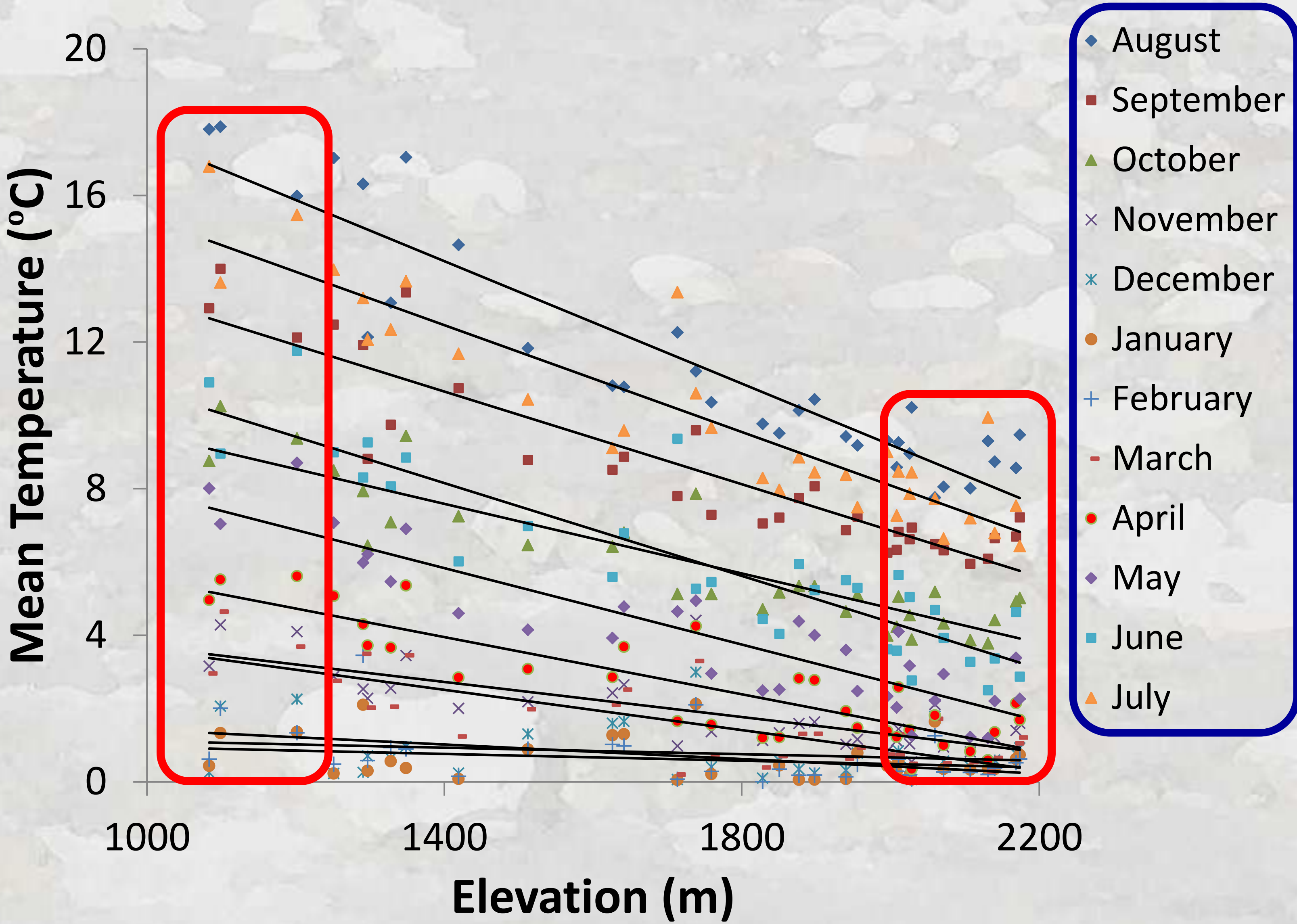


Correlations Among Monthly Means

Strong Correlations Except for Winter

	Sept	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*March*	*April*	*May*	*June*	*July*
Oct	0.97										
Nov	0.85	0.94									
Dec	0.29	0.48	0.71								
Jan	0.34	0.47	0.63	0.79							
Feb	0.56	0.62	0.68	0.57	0.90						
March	0.89	0.94	0.96	0.62	0.67	0.78					
April	0.93	0.96	0.93	0.47	0.45	0.60	0.95				
May	0.90	0.92	0.83	0.31	0.29	0.47	0.84	0.95			
June	0.82	0.83	0.71	0.21	0.23	0.39	0.72	0.85	0.95		
July	0.87	0.84	0.75	0.15	0.21	0.42	0.72	0.82	0.88	0.91	
Aug	0.98	0.92	0.75	0.14	0.23	0.48	0.79	0.87	0.88	0.84	0.93

Non-winter months **r = 0.87**

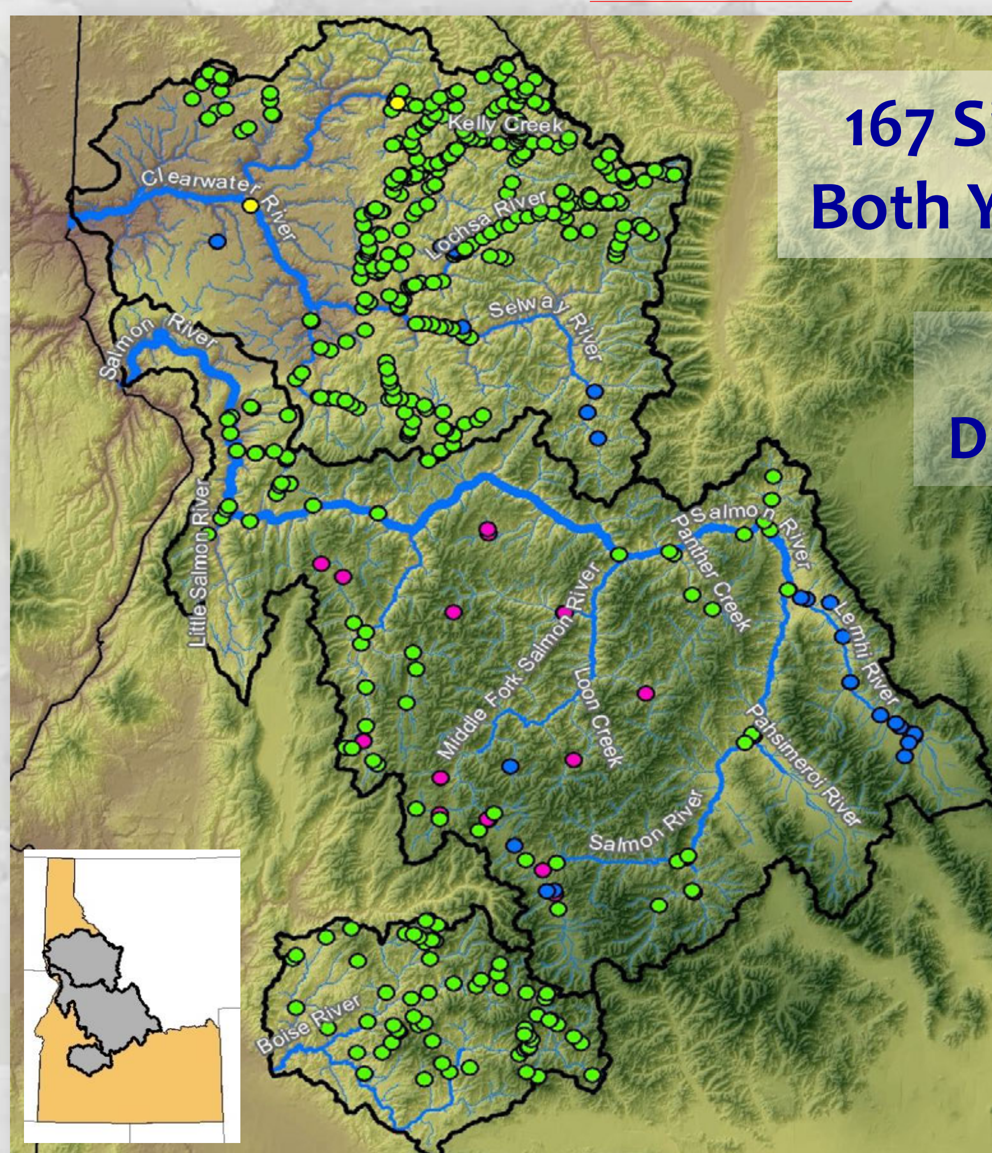
Winter months (DJF) **r = 0.47**

Observed Empirical Patterns

Variation Across Years

Mean August Temperature (°C)

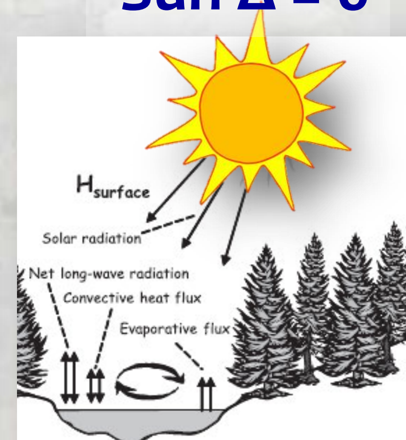
25
20
15
10
5



167 Sites Both Years

● 2013
● 2010

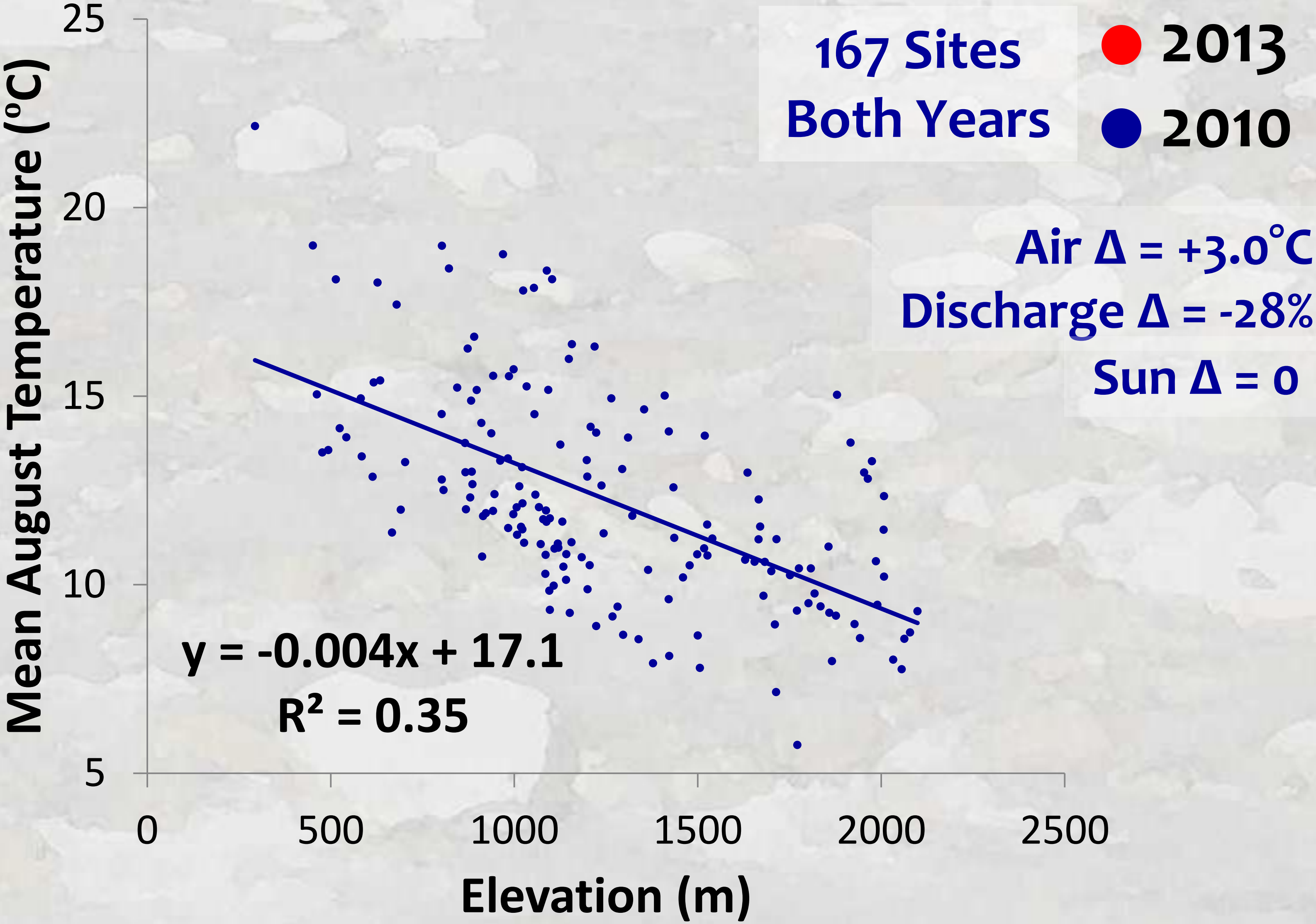
Air Δ = +3.0°C
Discharge Δ = -28%
Sun Δ = 0



2500

Observed Empirical Patterns

Variation Across Years



Observed Empirical Patterns

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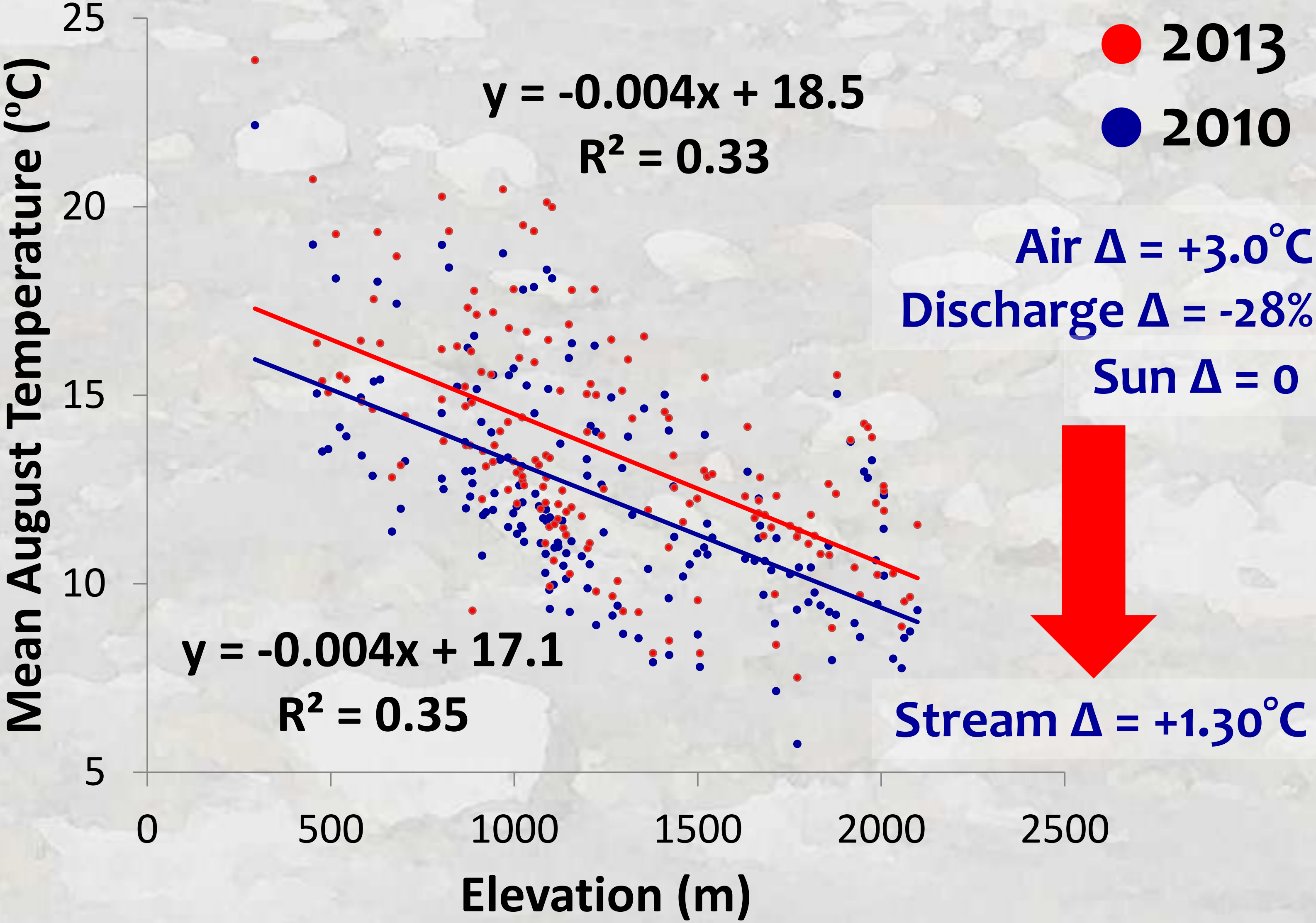
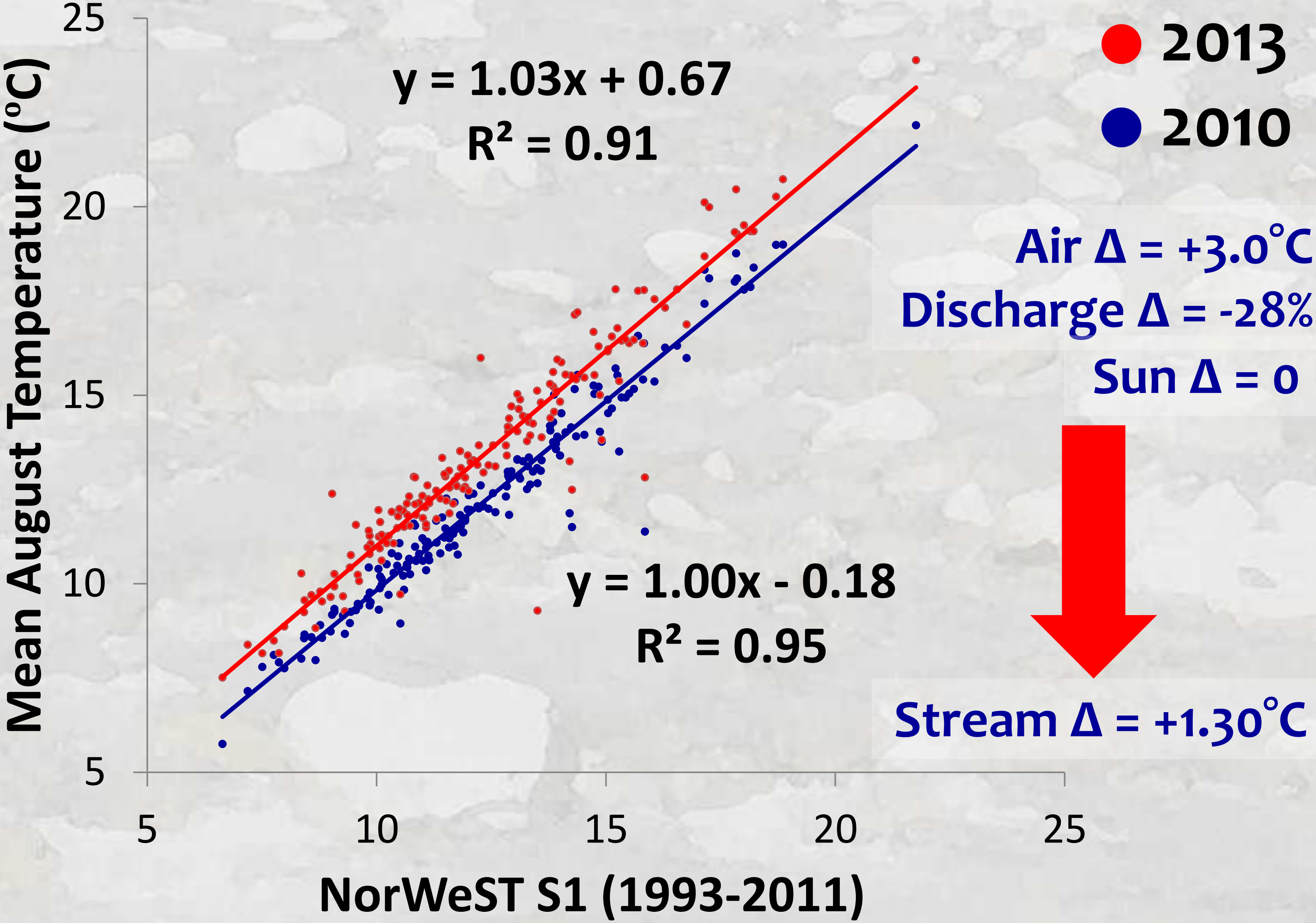


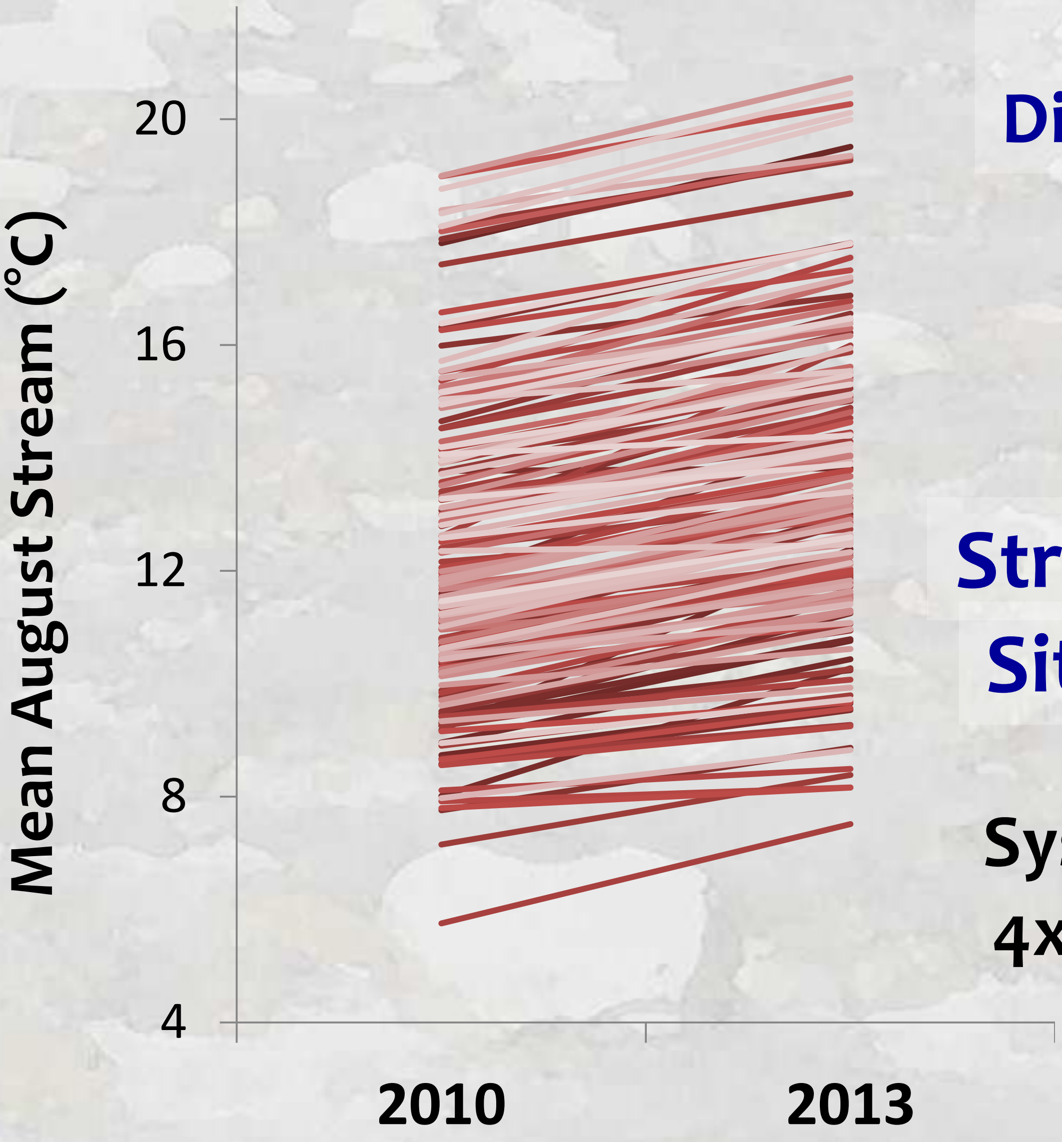
Observed Empirical Patterns

Variation Across Years



Systemic vs Site-Level Changes

What's Their Relative Importance?



Air Δ = +3.0°C
Discharge Δ = -28%

Stream Δ = +1.30°C
Site Δ = +/-0.37°C

Systemic changes ~ 4x larger than site-level changes

“Means” vs Short-Term Maxima…

- Short-term metrics are difficult to model
  - More variable/less stable than means
  - Occur @ different times each year (GCM linkage)
- Summer metrics are strongly correlated

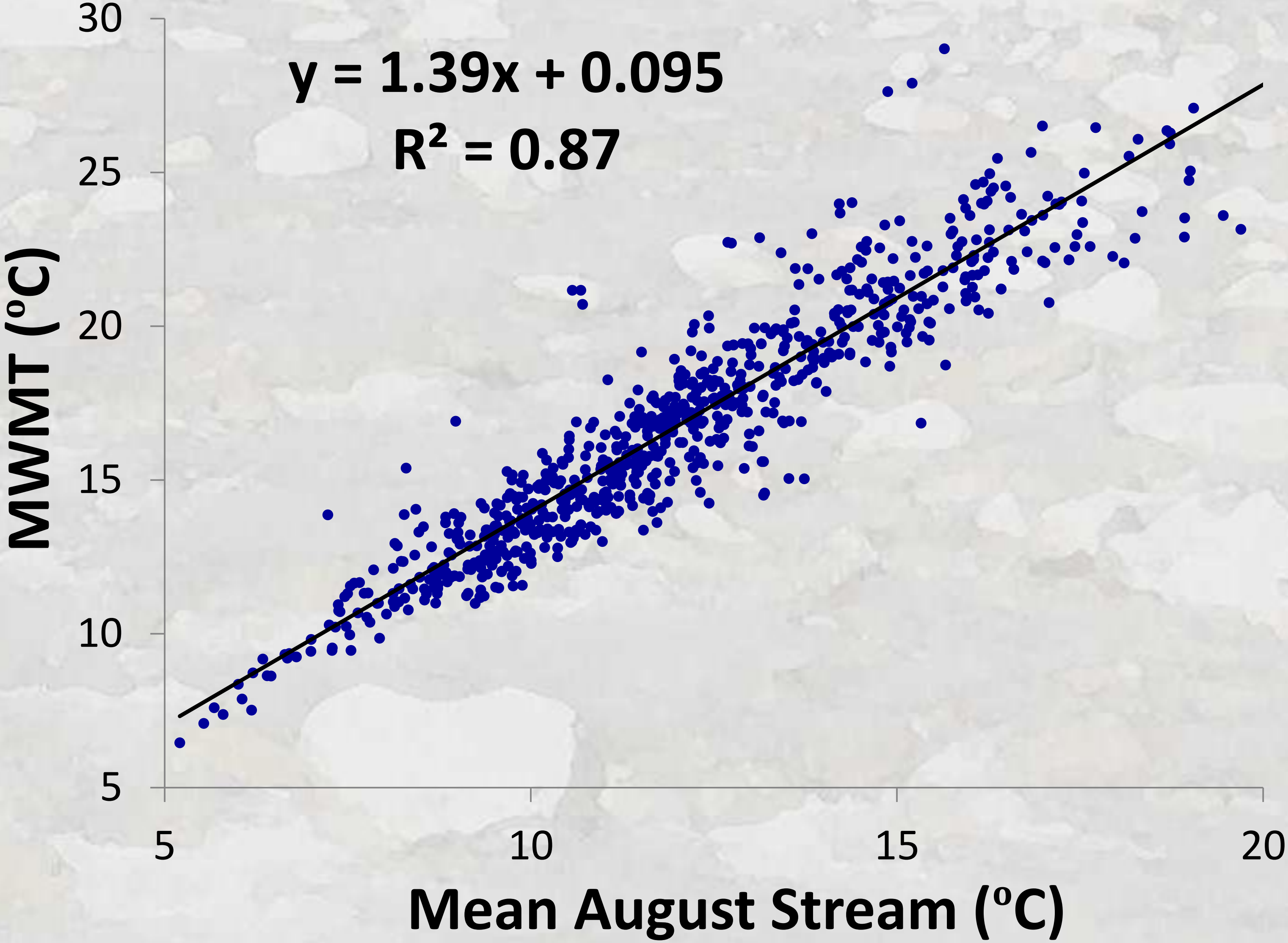
MWAT ~ **Maximum** ~ **Minimum**

MDAT ~ **AWAT** ~ **Degree-days** ~ Mean

	Summer_mn	*Mwmt*	*Mwat*	*awat_mn*	*awmt_mn*	***August Mean***
Summer_mn						
Mwmt	0.93					
Mwat	0.98	0.94				
awat_mn	1.00	0.93	0.97			
awmt_mn	0.96	0.98	0.94	0.96		
August Mean	**0.99**	**0.92**	**0.96**	**0.99**	**0.95**	
August MWMT	0.92	0.99	0.92	0.92	0.98	**0.92**

It's the Same "Information"

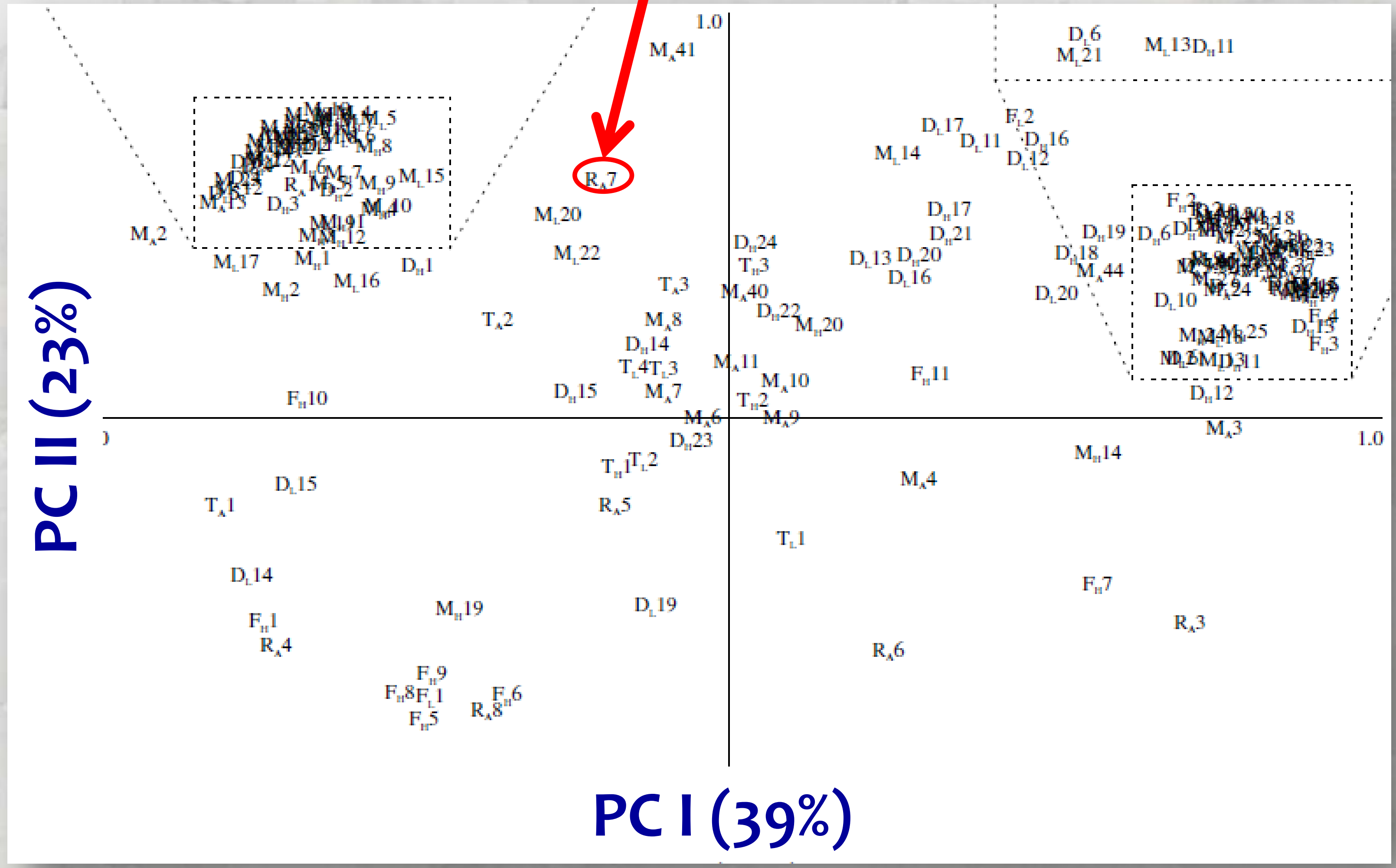
So Metric Conversions are Easy…



A Consistent Lexicon is Needed

Hydrology Community Improved Communication

Letters represent 171 different flow metrics

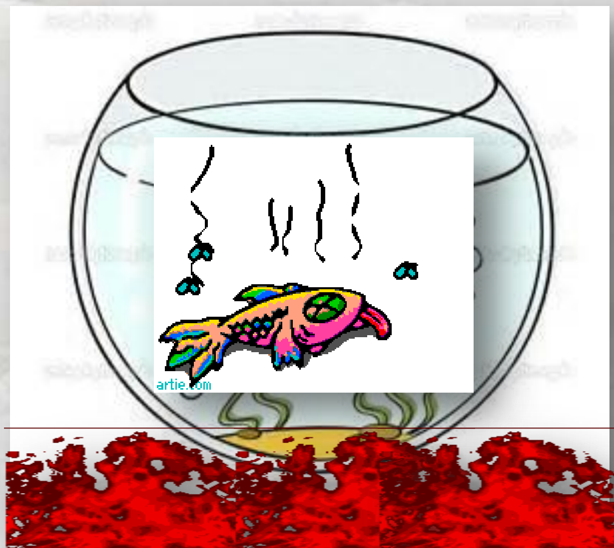


Olden, J.D., and N.L. Poff. 2003. Redundancy & the choice of hydrologic indices for characterizing streamflow regimes. *River Res. & Applications* **19**:101-121.

What’s BioClimatically Relevant?

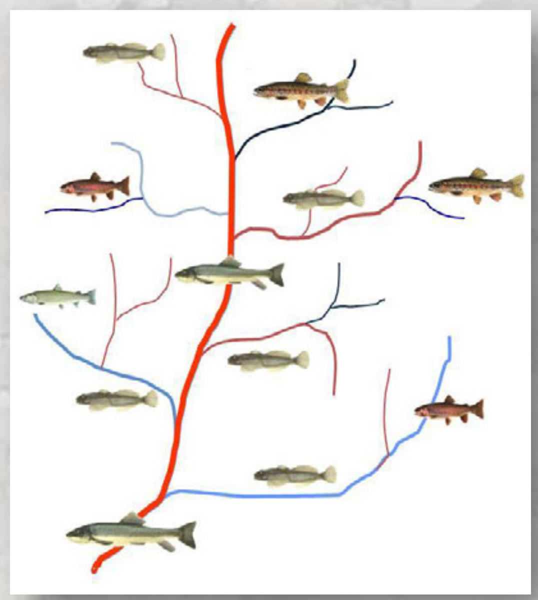
Stream “Weather” OR “Climate”?

Short-term Maxima in Lab



- Survival of individuals
- Local spatial scale
- Fundamental niche

Average Field Conditions

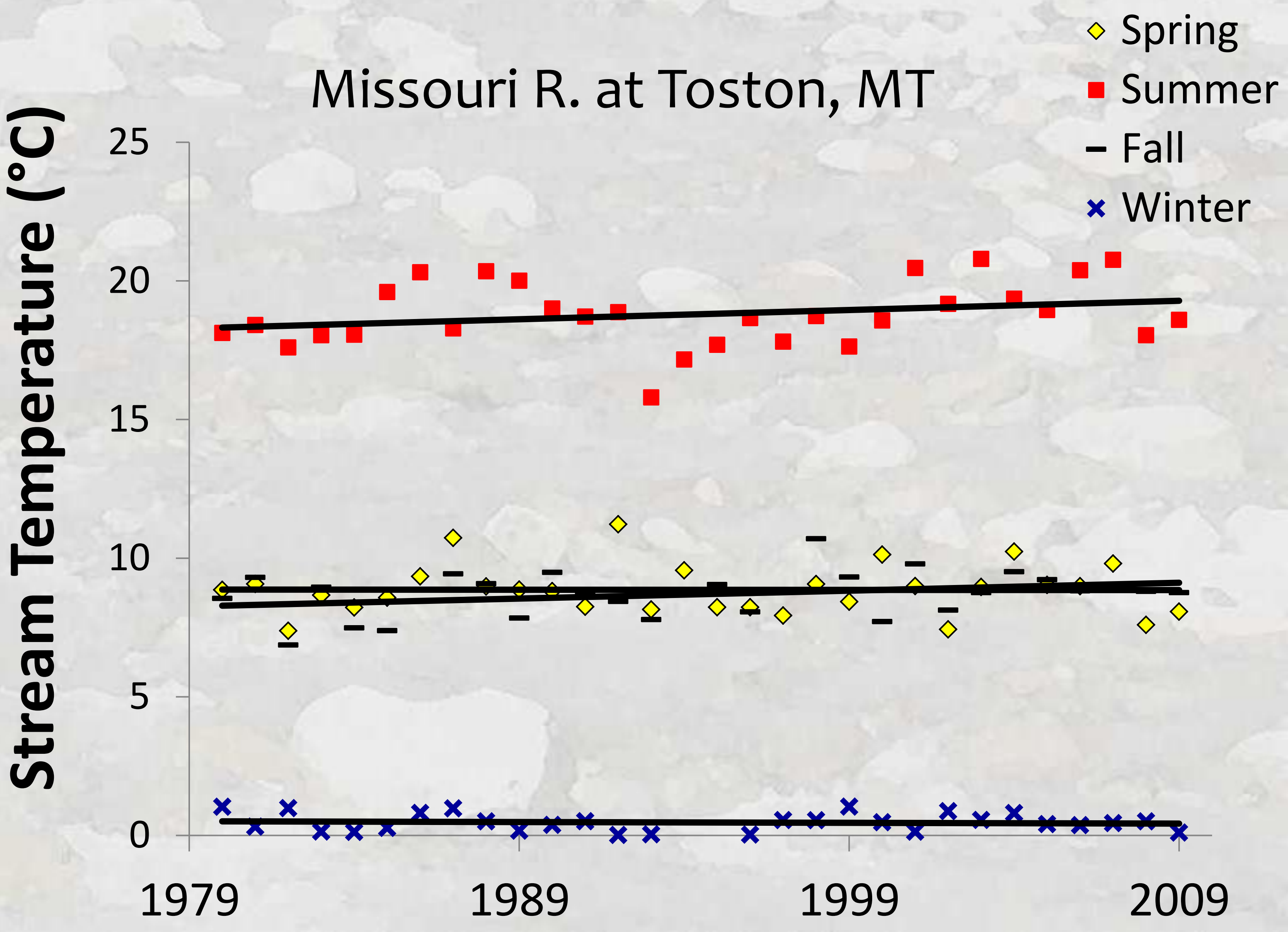


- Population survival (lambda)
- Broader spatial scales
- Realized niche

TMDLs

Climatic Change Analysis, Part 1

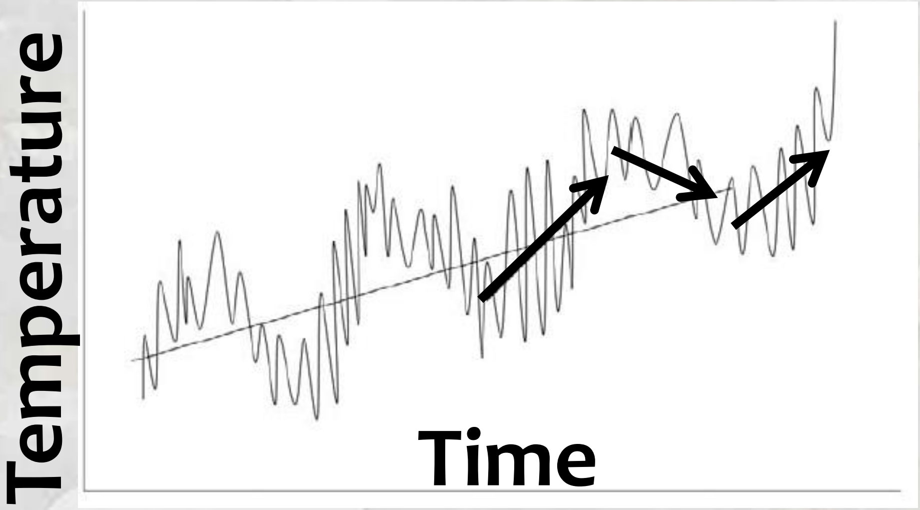
Temporal trends & attribution



Factors Complicating Climate Change Assessments with Temperature Time-Series…

1) Most long-term records were collected downstream of dams & are affected by river regulation/reservoirs

2) Regional climate ***cycles*** like PDO/ENSO mask/exacerbate climate ***trends*** (detrending required)



Factors Complicating Climate Change Assessments with Temperature Time-Series…

1) Most long-term records were collected downstream of dams & are affected by river regulation/reservoirs

2) Regional climate ***cycles*** like PDO/ENSO mask/exacerbate climate ***trends*** (detrending required)

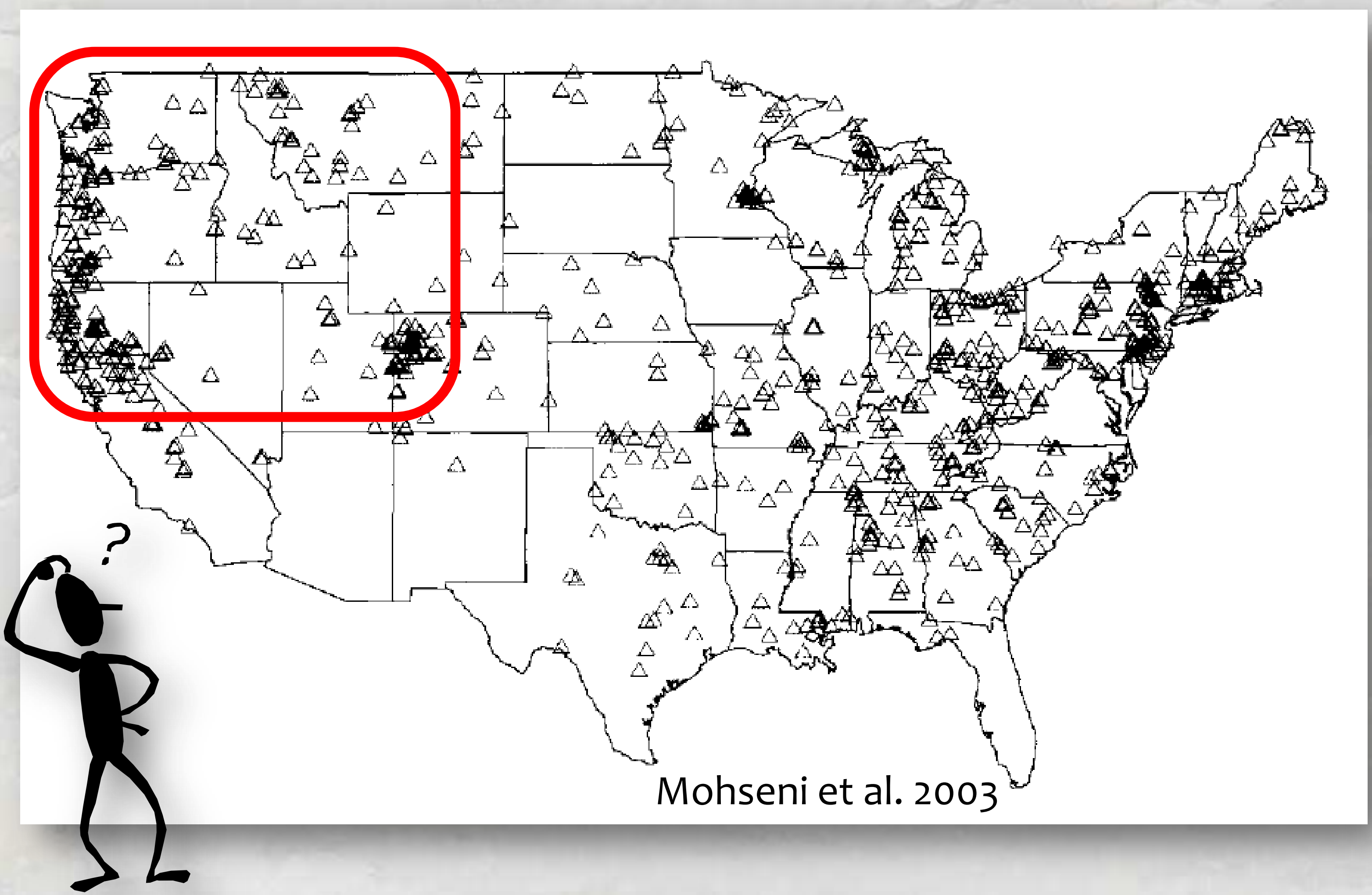
3) Inconsistent start/stop dates for monitoring records (standardized time period necessary)

4) Missing data in short monitoring record can bias trend or parameter estimates

Long-term Data from Unregulated Sites?

764 USGS gages have some temperature data

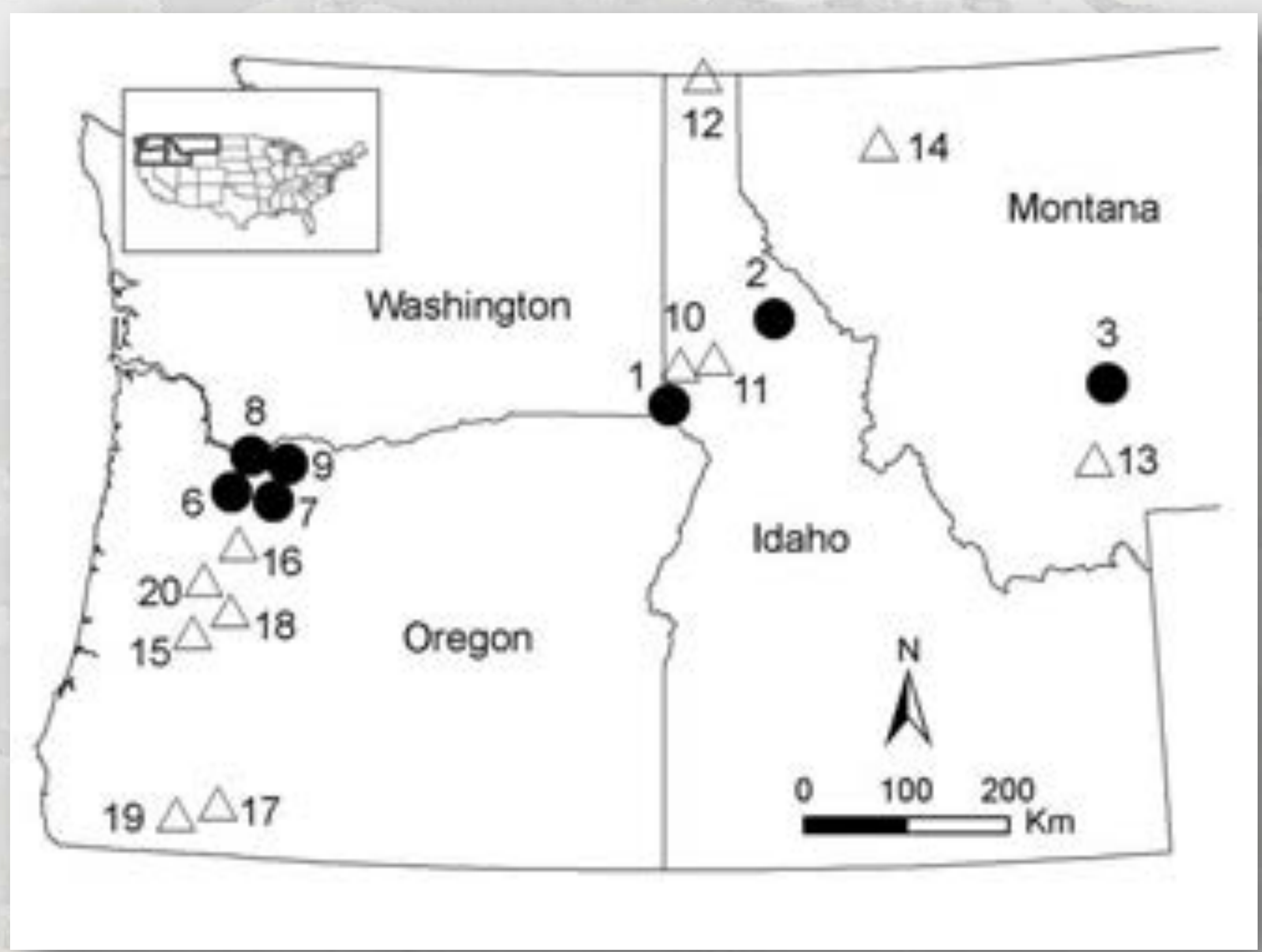
USGS NWIS Database (http://waterdata.usgs.gov/nwis)



Mohseni et al. 2003

Sites With >20 Years Stream Temperature Data

△ = regulated (11) ● = unregulated (7)



Methods

- Multiple regression models predict stream temperature at a site from discharge (co-located USGS gage) & air temperature (3 nearest COOP weather stations).

Stream temperature (Y) = $b_0 + b_1$(air) + b_2(discharge)

- Inter-annual changes modeled to negate sun angle

- **<u>Advantages:</u>** 1) parameter estimates for attribution & significance testing

  2) predictive equations for description of temperature trends under various climate scenarios (historic or future)

  3) overcome missing observations & detrend climate cycles (PDO/ENSO)

Multiple Regression Results

Spring season (March & April & May) & { Summer, Fall, Winter, Annual }

Stream site	Multiple regression equation (Air / Discharge)	R^2	RMSE (°C)	Significant Interaction?
Spring period				
1. Snake River Near Anatone, WA	$y=3.43+0.588^{a}(\text{air °C})-0.00013(m^3/s)$	0.68	0.37	No
2. North Fork Clearwater River, ID	$y=1.48+0.548^{a}(\text{air °C})-0.00373(m^3/s)$	0.79	0.32	No
3. Missouri River, MT	$y=7.05+0.583^{a}(\text{air °C})-0.00499^{a}(m^3/s)$	0.85	0.35	Yes
6. South Fork Bull Run River, OR	$y=1.01+0.716^{a}(\text{air °C})-0.183^{a}(m^3/s)$	0.85	0.32	No
7. Fir Creek, OR	$y=0.0139+0.701^{a}(\text{air °C}) - 0.313(m^3/s)$	0.89	0.26	No
8. North Fork Bull Run River, OR	$y=0.768+0.710^{a}(\text{air °C}) - 0.307^{a}(m^3/s)$	0.84	0.33	No
9. Bull Run River, OR	$y=-0.276+0.810^{a}(\text{air °C}) - 0.0392(m^3/s)$	0.83	0.32	No

- 35 of 35 air significant
- 17 of 35 discharge significant

Good Accuracy

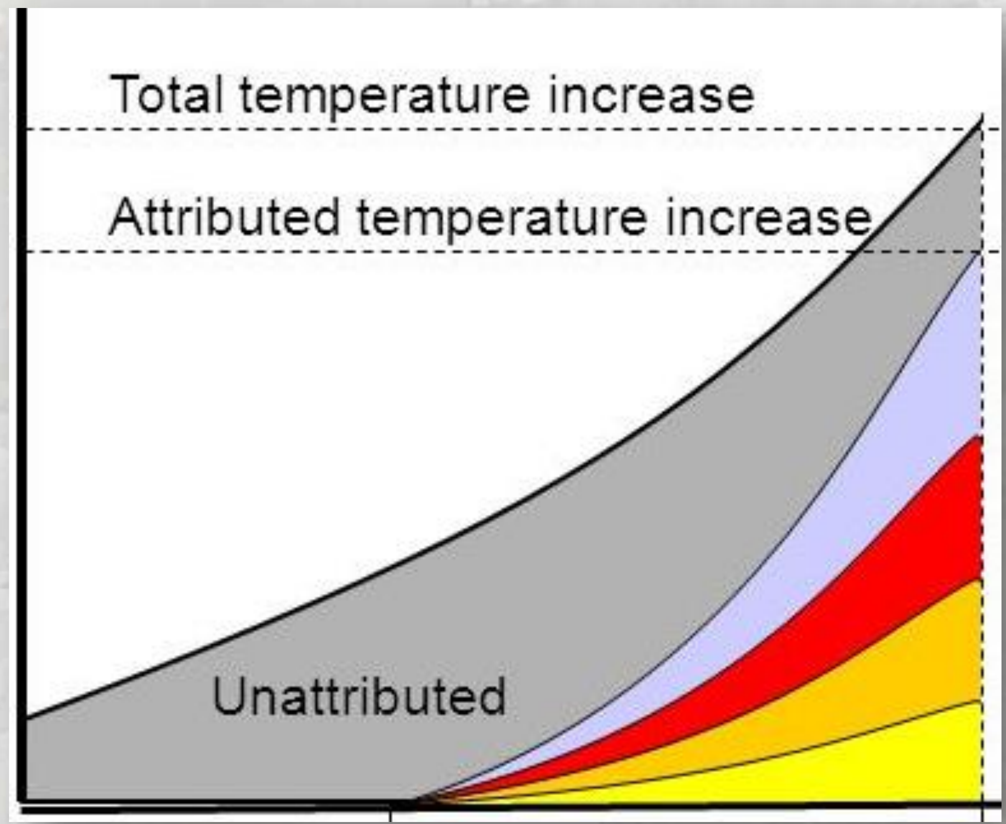
Rare

- 2 of 35 significant

Isaak et al. 2012. *Climatic Change* **113**:499-524.

Additive Air & Discharge Effects Make Attribution Straightforward

Temperature Increase



Time…

X% Increase Due to Variation in…

Air

Discharge

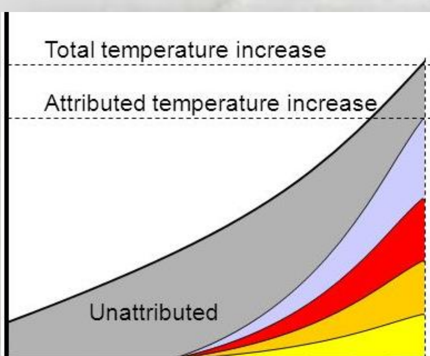
Must Also Incorporate Magnitude of Local Trends in Air & Discharge

Climate variable	Thermal category	Summer	Fall
30 year air temperature trend (°C/decade)	Unregulated	0.36 (0.10)	0.17 (0.10)
	Regulated	0.35 (0.082)	0.16 (0.086)
56 year discharge trend (% change/decade)	Unregulated	−3.5% (1.2%)	−0.8% (3.4%)
	Regulated	−1.7% (6.7%)	−0.22% (5.1%)

Isaak et al. 2012. *Climatic Change* **113**:499-524.

Multiply total change in air & discharge by regression parameters…

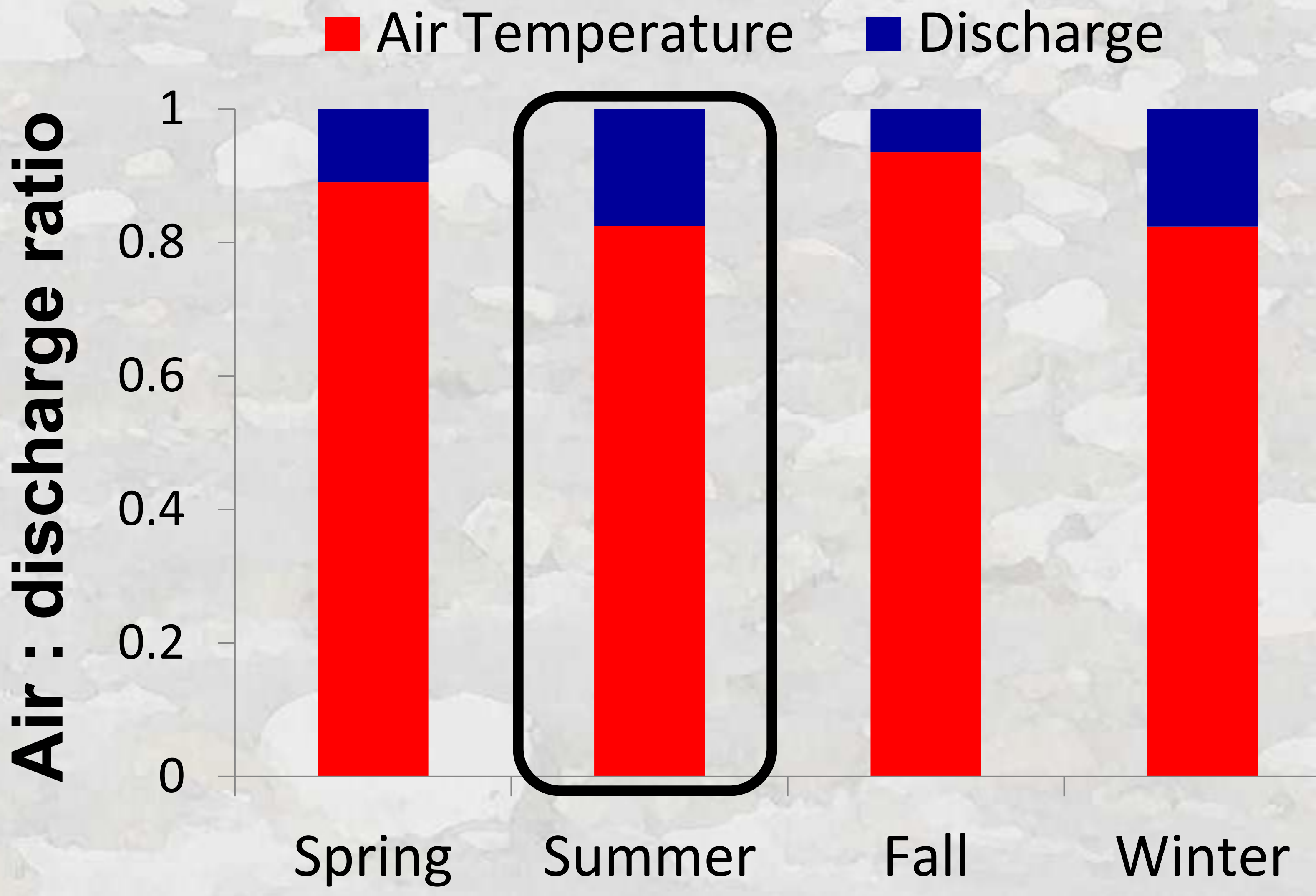
Stream temp (Y) = b_1(air) + b_2(discharge)



…which then yields amount of stream temp change & attribution

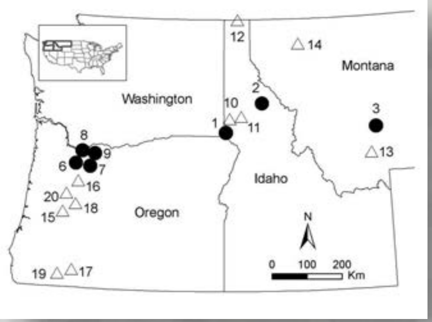
Attribution of Stream Temp Trends?

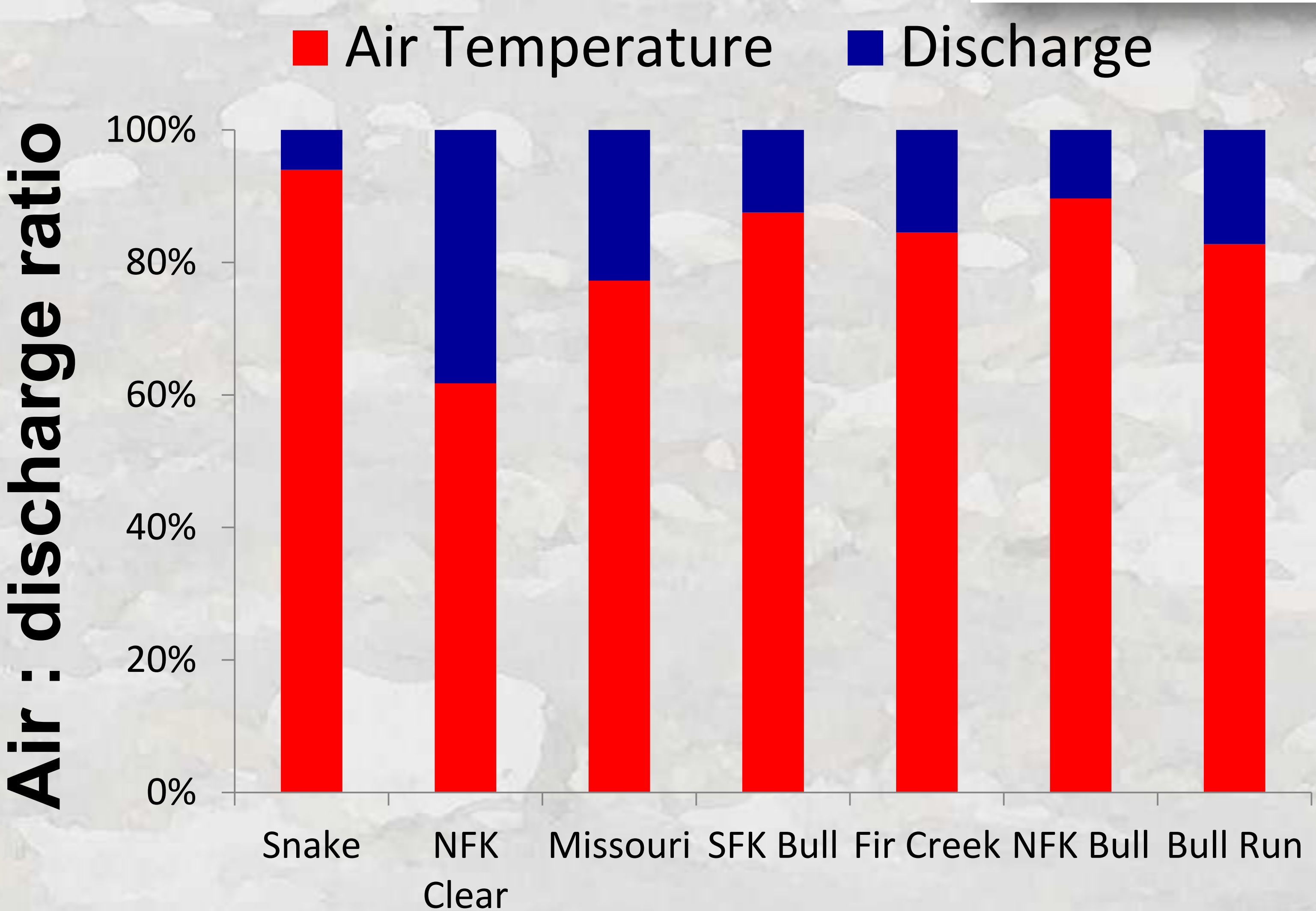
By Season (1980-2009)



Attribution? – Site Level

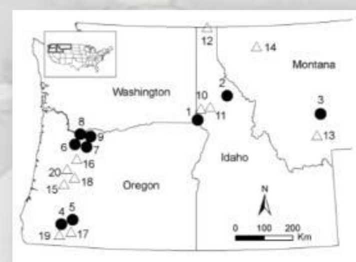
7 Unregulated Sites - Summer Period

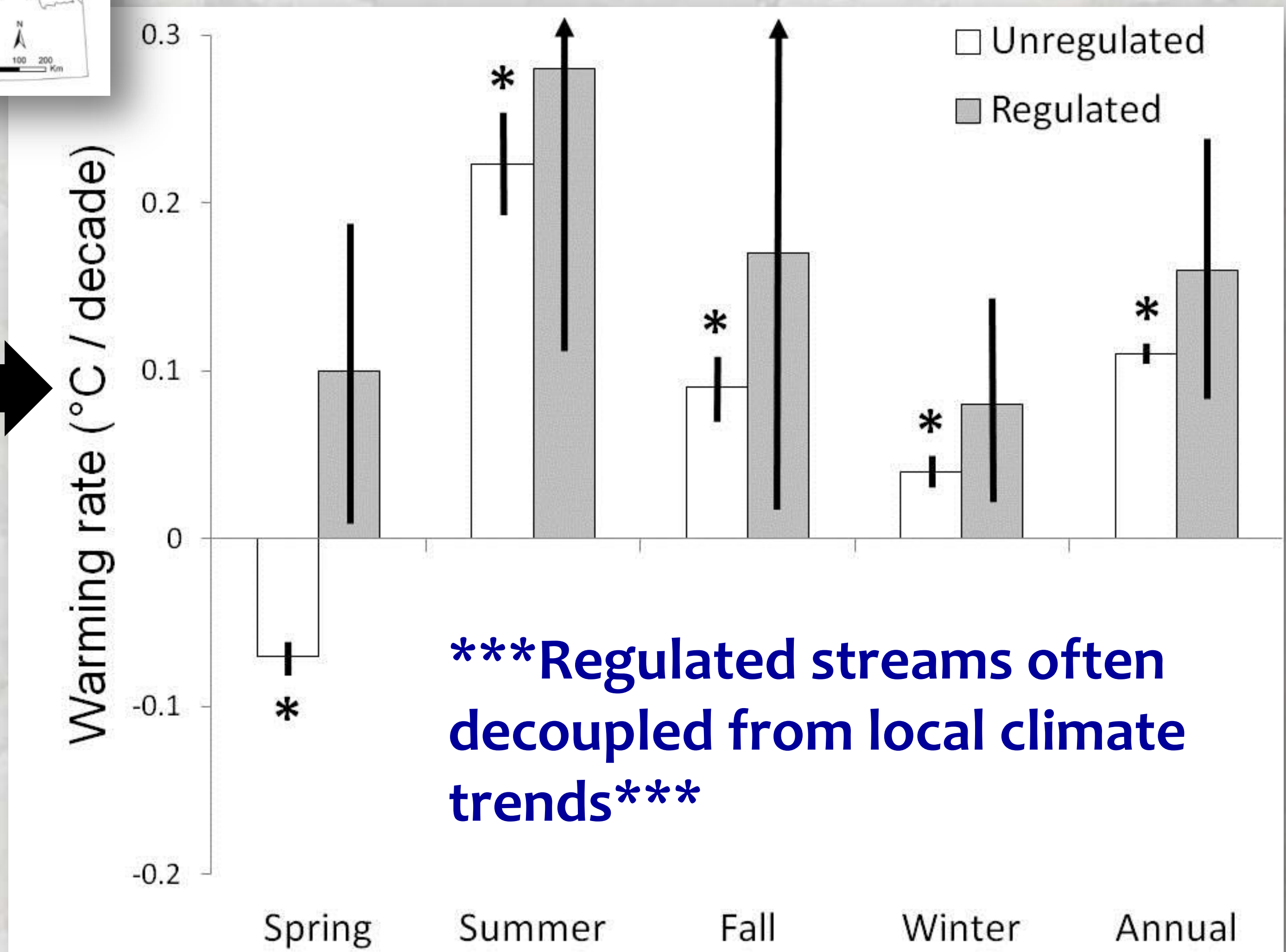




What are Long-Term Trends?

PNW Stream Temperatures (1980-2009)

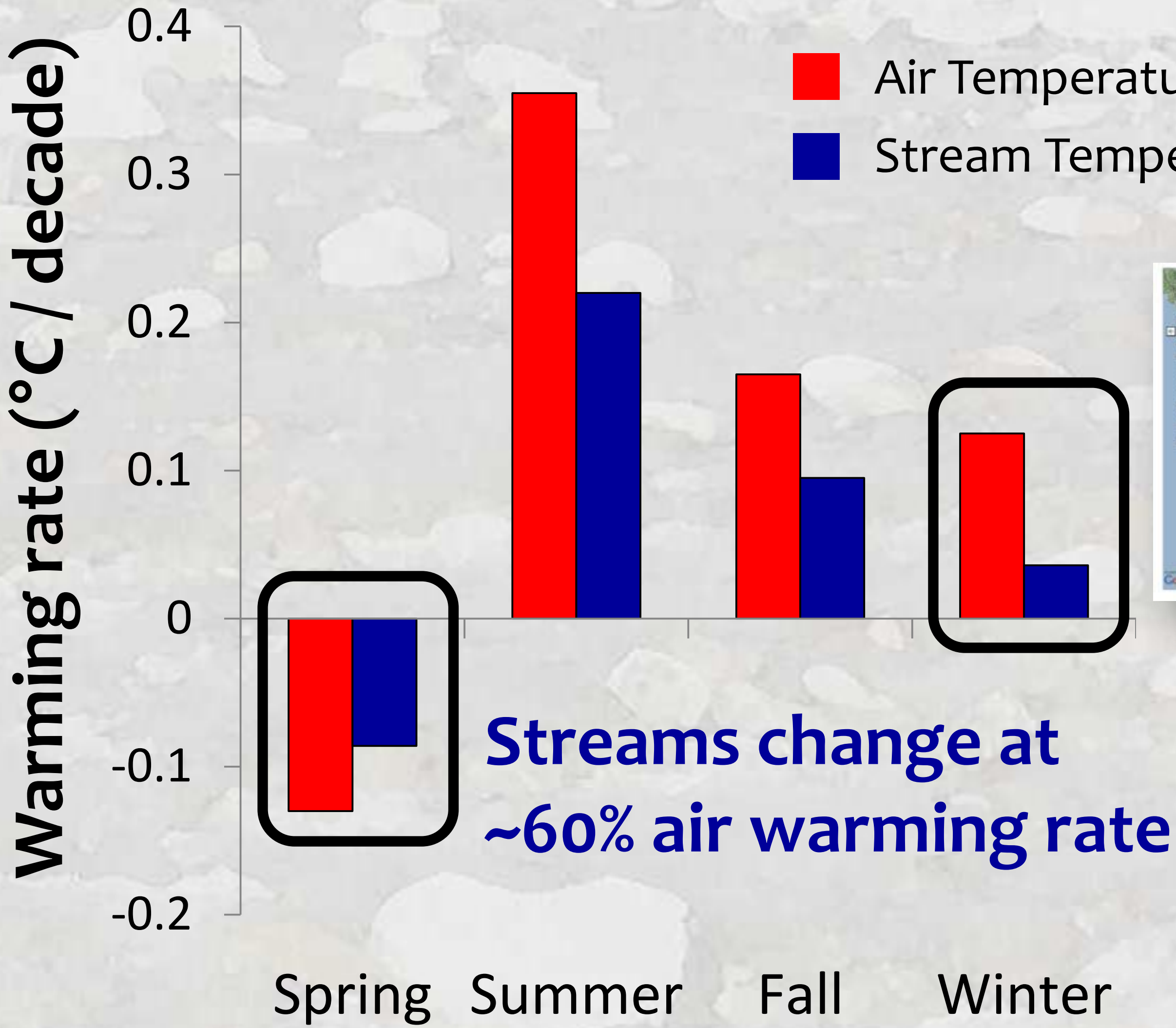




*****Regulated streams often decoupled from local climate trends*****

Isaak et al. 2012. *Climatic Change* **113**:499-524.

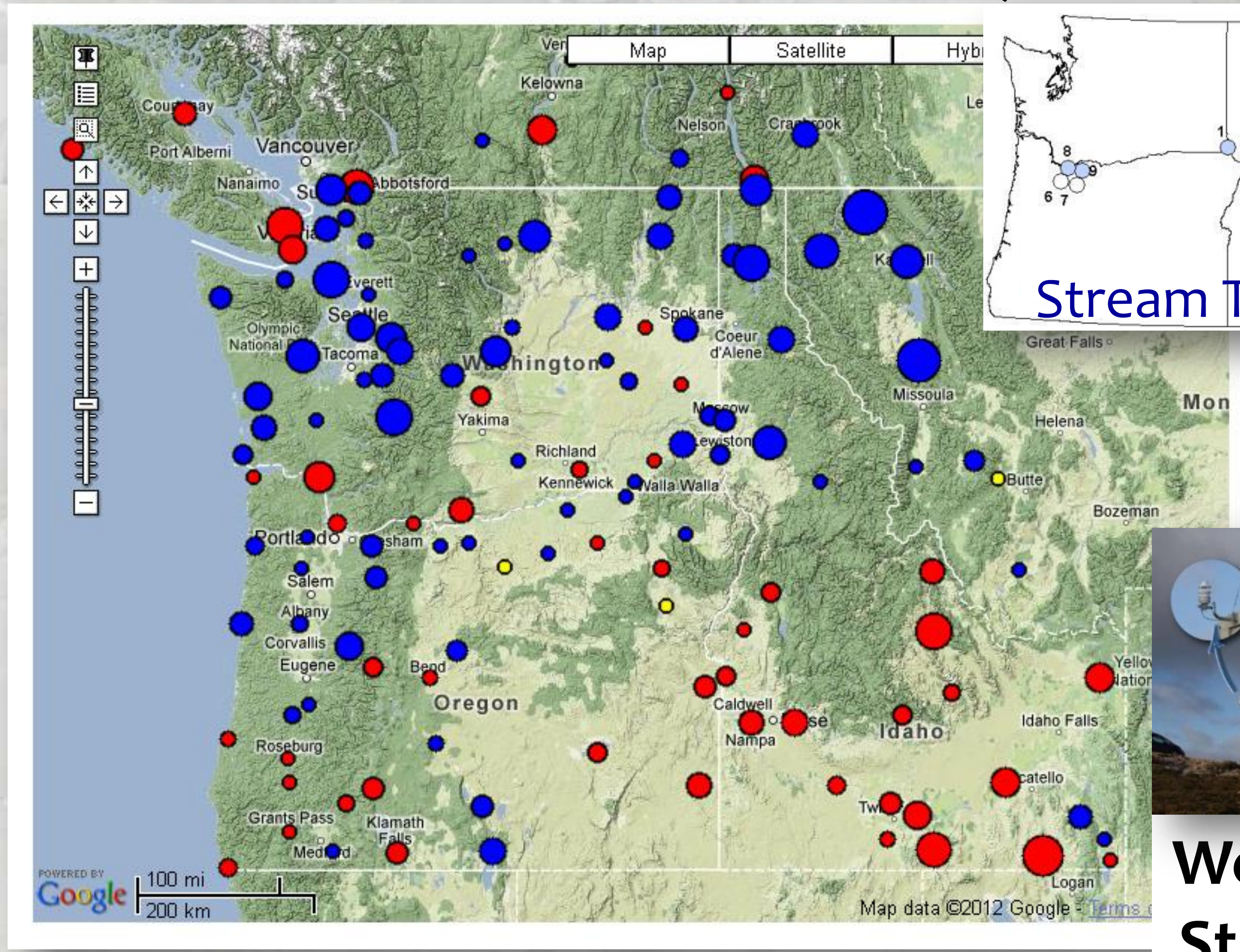
Stream Temperatures Track Air Trends at Local Weather Stations



Weather Stations

Spring Air Temperature Trends

(1980 – 2009)



Weather Stations

OWSC Climate Tool map

http://www.climate.washington.edu/trendanalysis/

Climatic Change Analysis, Part 2

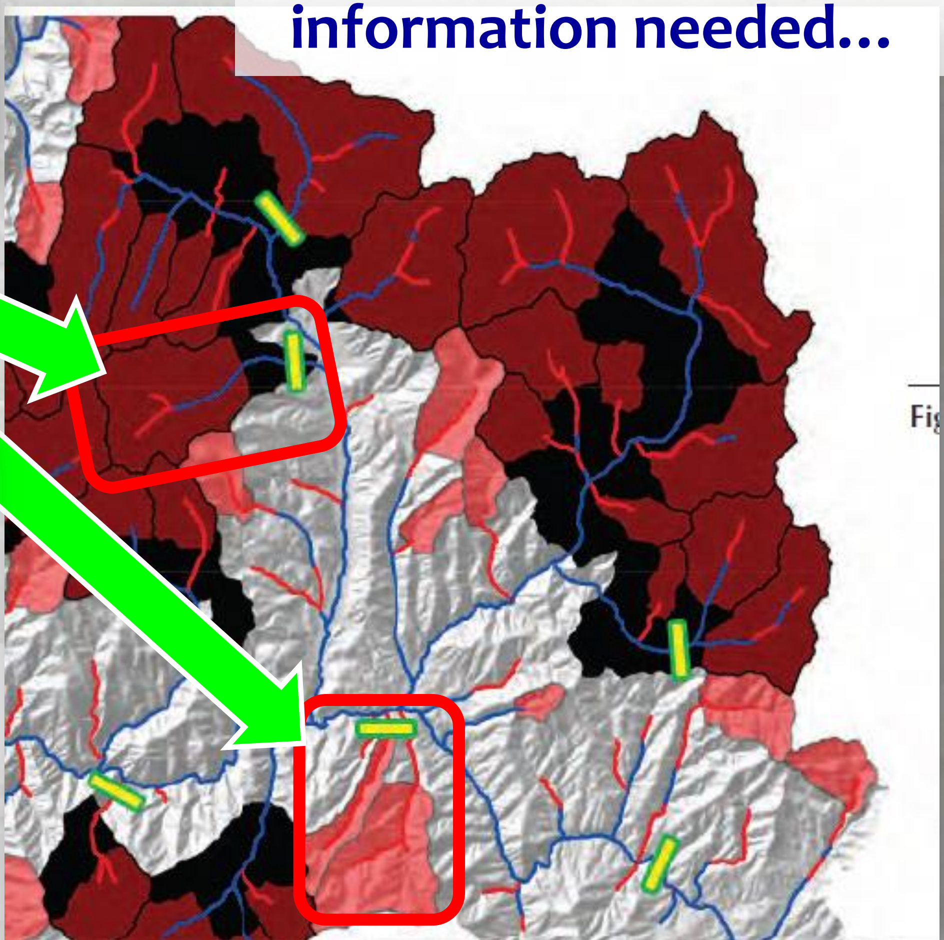
Time + *spatial patterns & attribution*

Space Travel is Much Harder

High-resolution climate information needed…

I'm going to invest here…

… instead of here



Good News: Lots of Things we Can do to Improve Stream Habitat Resilience

- •Maintaining/restoring flow…
- •Maintaining/restoring riparian…
- •Restoring channel form/function…
- •Prescribed burns limit wildfire risks…
- •Non-native species control…
- •Improve/impede fish passage…

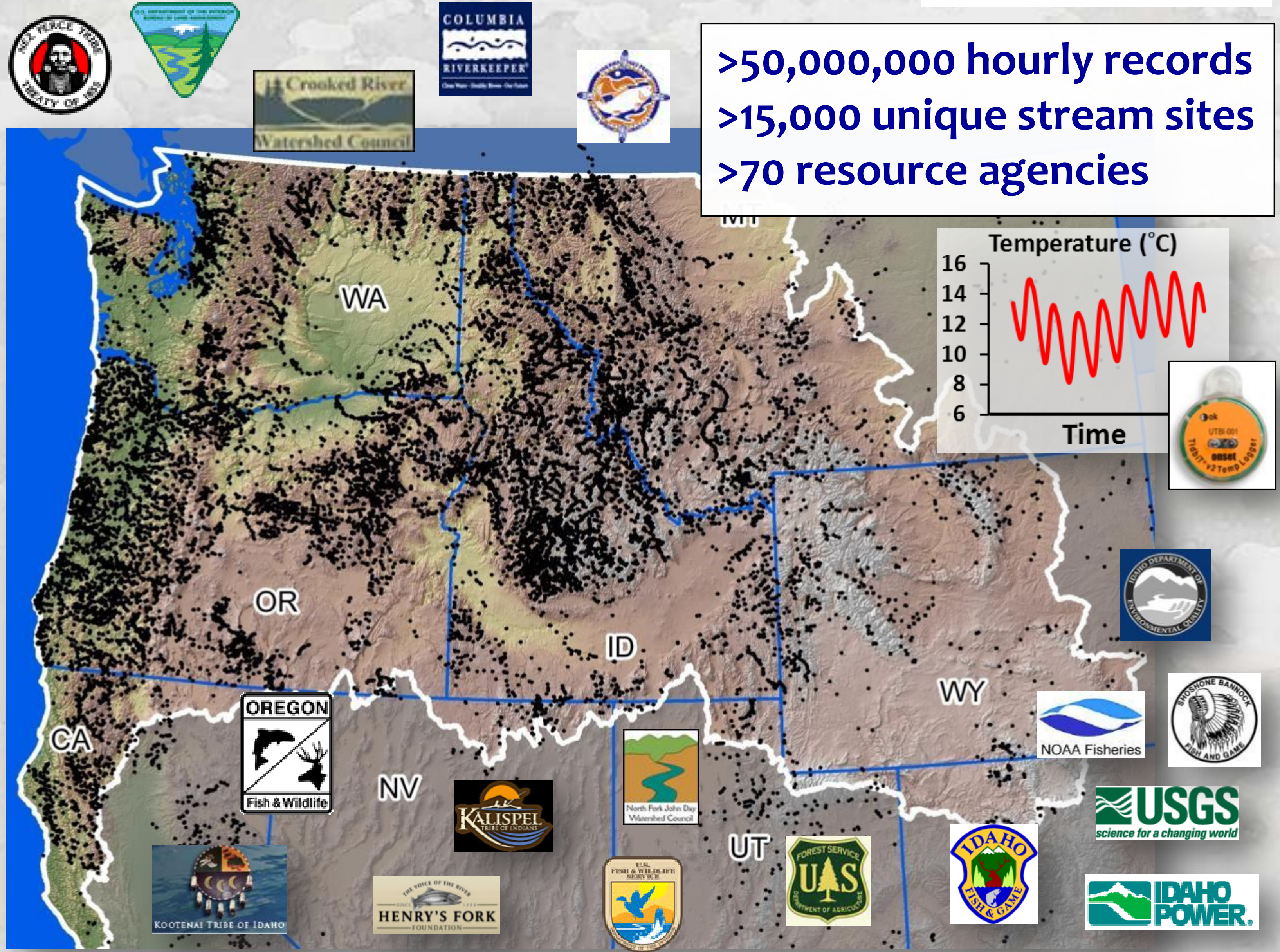
Where to do them?

Is there a grand strategy?

Aiding us in Space Travel is…

NorWeST Stream Temp

>50,000,000 hourly records
>15,000 unique stream sites
>70 resource agencies

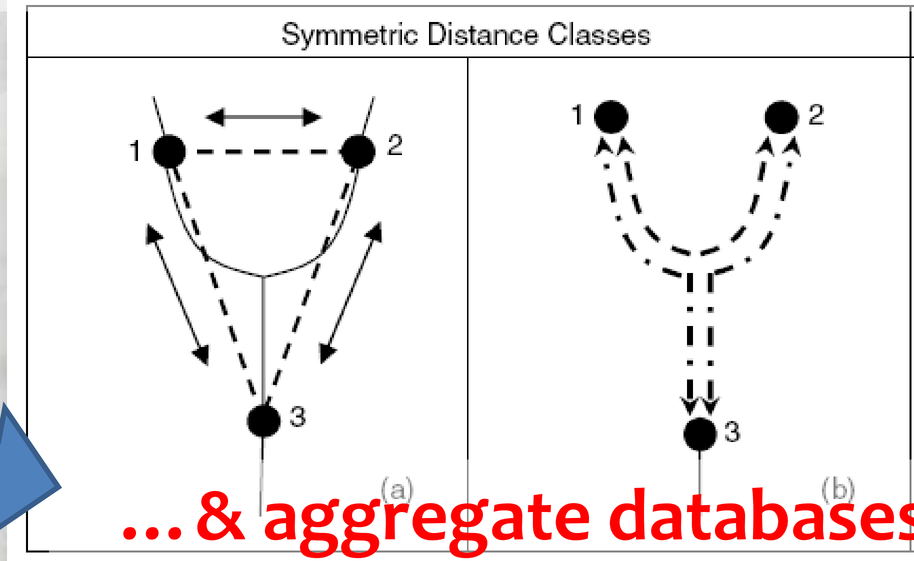


BIG DATA are often Autocorrelated

Spatial Statistical Network Models

Let's us connect the dots…

Valid interpolation on networks



… & aggregate databases

Advantages:

-flexible & valid autocovariance structures that accommodate network topology & non-independence among observations

-improved predictive ability & parameter estimates relative to non-spatial models

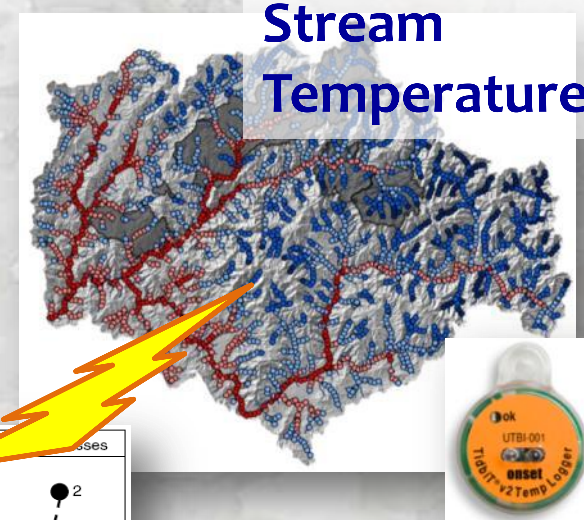
Ver Hoef et al. 2006; Ver Hoef & Peterson 2010; Peterson & Ver Hoef 2013

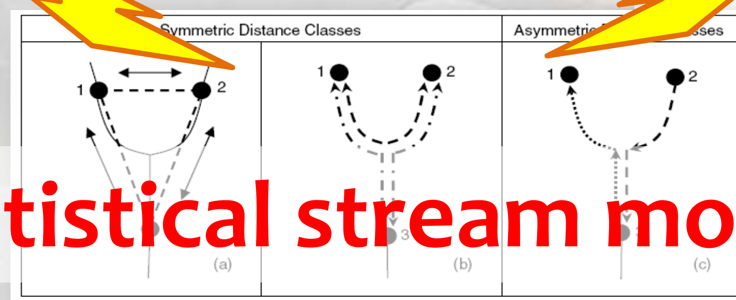
Stream Models are Generalizable…

Distribution & abundance

Response Metrics
- Gaussian
- Poissan
- Binomial

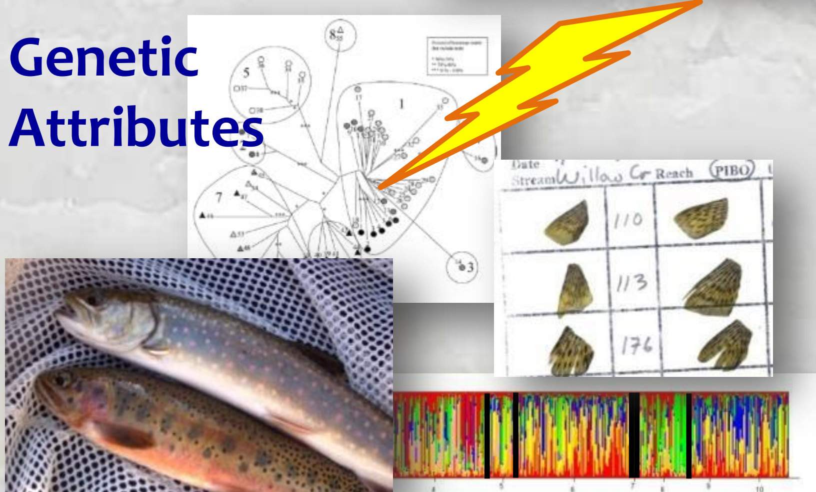
Stream Temperature





Statistical stream models

Genetic Attributes



Water Quality Parameters

Spatial Stream Statistics Working Group

NCEAS

National Center for Ecological Analysis and Synthesis

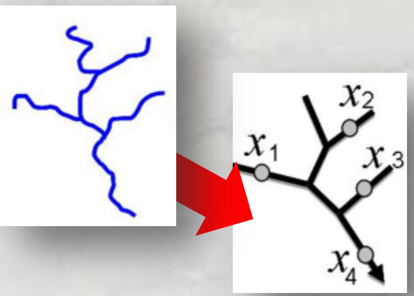
Isaak, D.J., E. Peterson, J. V. Hoef, S. Wenger, J. Falke, C. Torgersen, C. Sowder, A. Steel, M.J. Fortin, C. Jordan, A. Reusch, N. Som, P. Monestiez. 2014. Applications of spatial statistical network models to stream data. ***WIREs - Water*** ***1***:27-294.

Peterson E.E. & Ver Hoef J.M. 2014. STARS: An ArcGIS toolset used to calculate the spatial information needed to fit spatial statistical models to stream network data. ***Journal of Statistical Software*** 56(2):1-17.

Peterson E.E., Ver Hoef J.M., Isaak D.J., Falke J.A., Fortin M.J., Jordan C., McNyset K., Monestiez P., Ruesch A.S., Sengupta A., Som N., Steel A., Theobald D.M., Torgersen C.T. & Wenger S.J. 2013. Modeling dendritic ecological networks in space: an integrated network perspective. ***Ecology Letters*** 16:707-719.

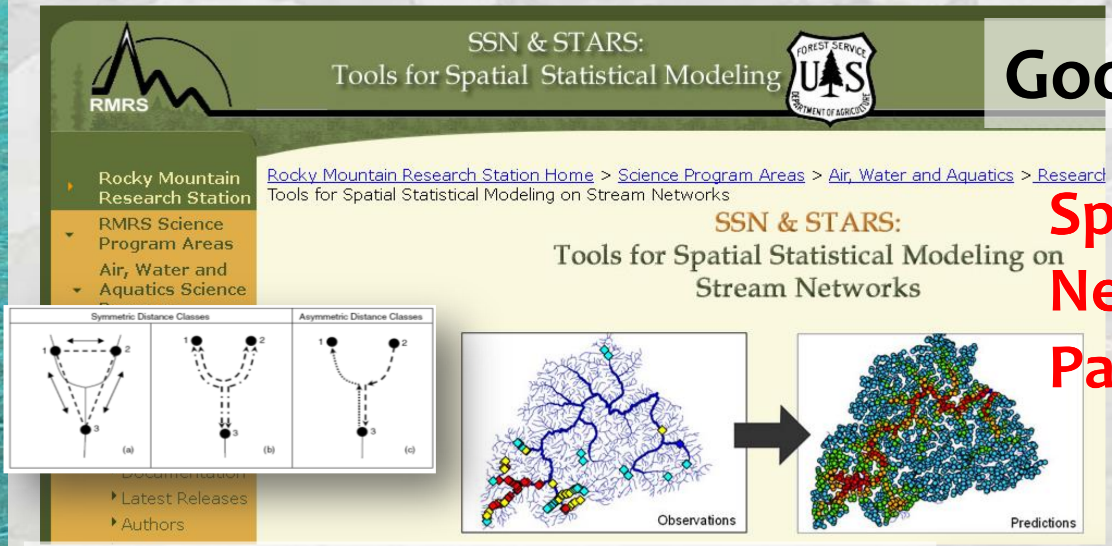
Som N.A., Monestiez P., Zimmerman D.L., Ver Hoef J.M. & Peterson E.E. In Press. Spatial sampling on streams: Principles for inference on aquatic networks. ***Environmetrics*** x:xxx.

Ver Hoef J.M., Peterson E.E., Clifford D. & Shah R. 2014. SSN: An R package for spatial statistical modeling on stream networks. ***Journal of Statistical Software*** 56(3):1-45.



SSN/STARS Website

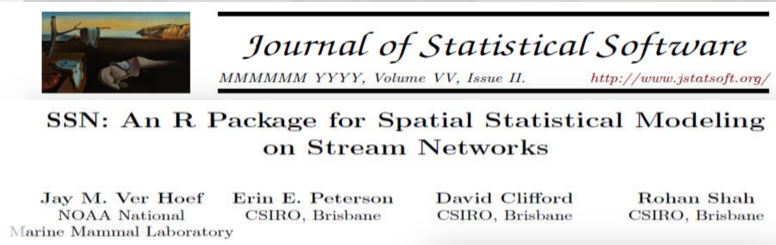
Tools For Statistical Analysis of Data on Stream Networks



Google "SSN/STARS"

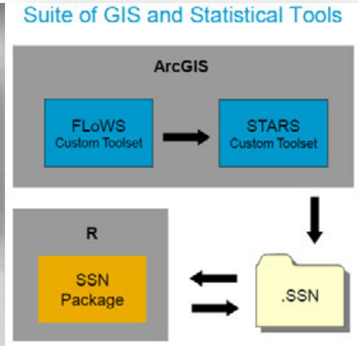
Spatial Stream Networks (SSN) Package for R

Open Source Statistical Stream Software, Example Datasets, & Applications


Journal of Statistical Software
MMMMMM YYYY, Volume VV, Issue II. http://www.jstatsoft.org/

SSN: An R Package for Spatial Statistical Modeling on Stream Networks

Jay M. Ver Hoef, NOAA National Marine Mammal Laboratory
Erin E. Peterson, CSIRO, Brisbane
David Clifford, CSIRO, Brisbane
Rohan Shah, CSIRO, Brisbane

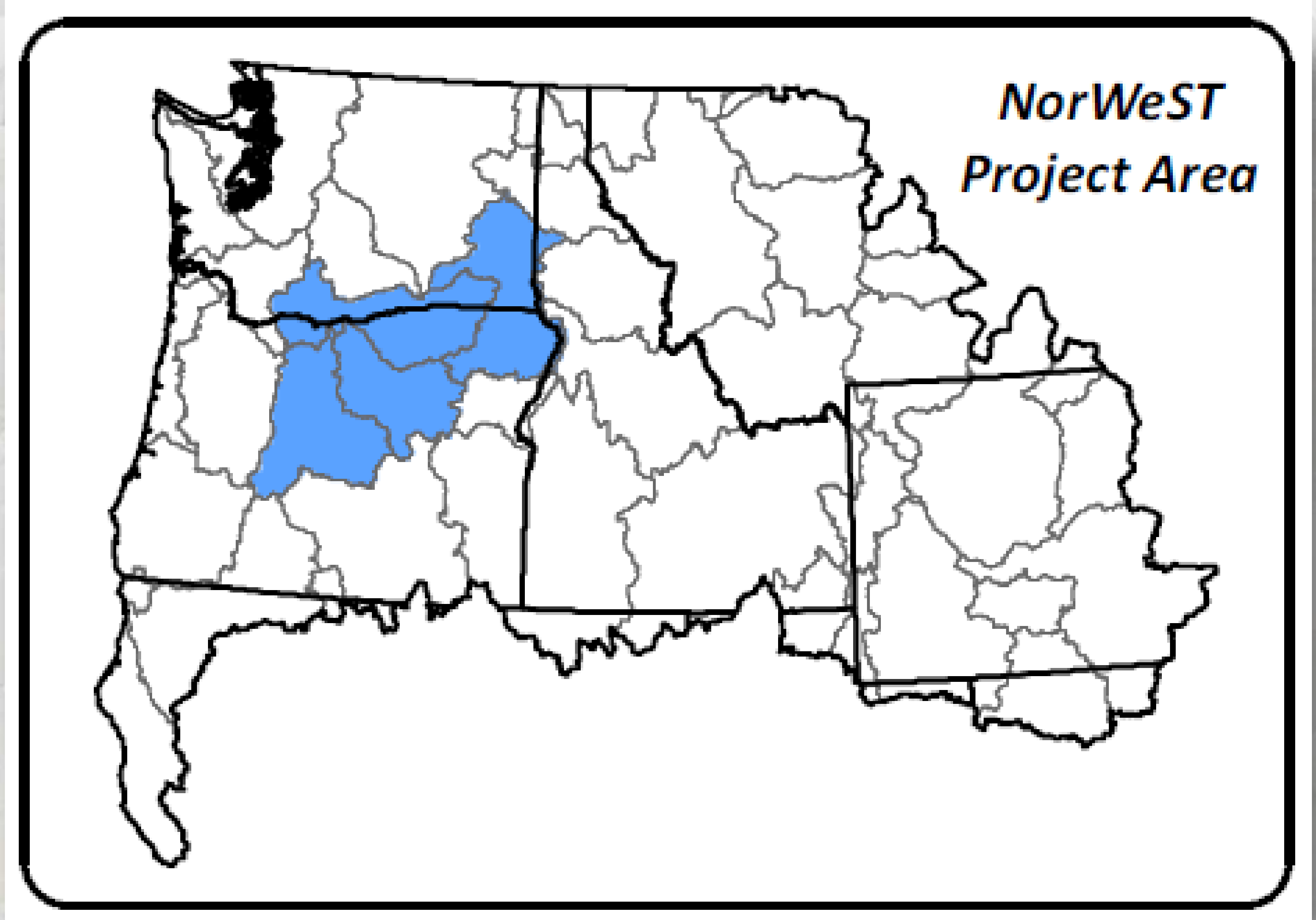


A Moving Average Approach for Spatial Statistical Models of Stream Networks

Jay M. Ver Hoef and Erin E. Peterson

STARS: An ArcGIS toolset used to calculate the spatial data needed to fit spatial statistical models to stream network data

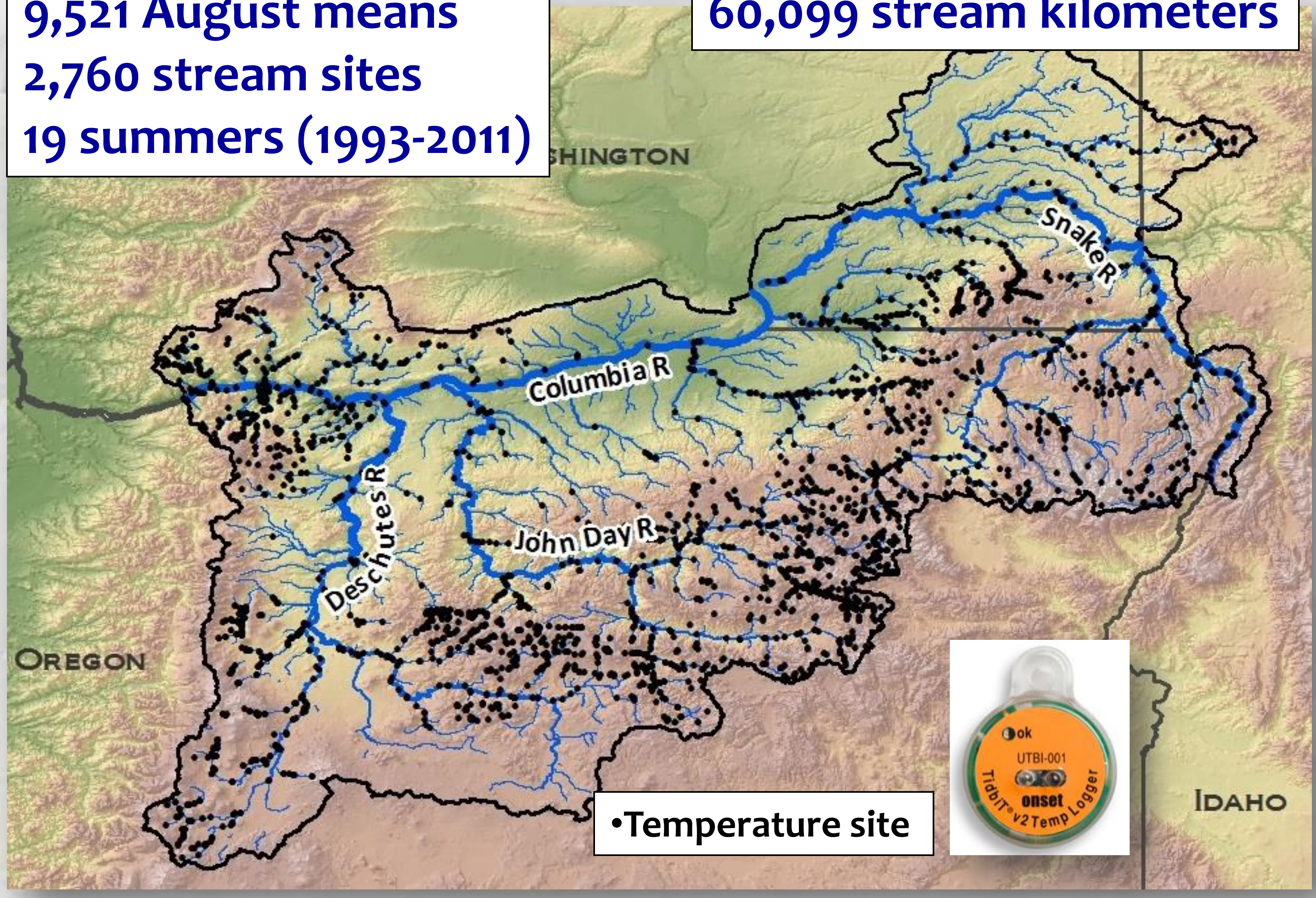
NorWeST Temperature Model for the Mid-Columbia



NorWeST Temperature Model for the Mid-Columbia

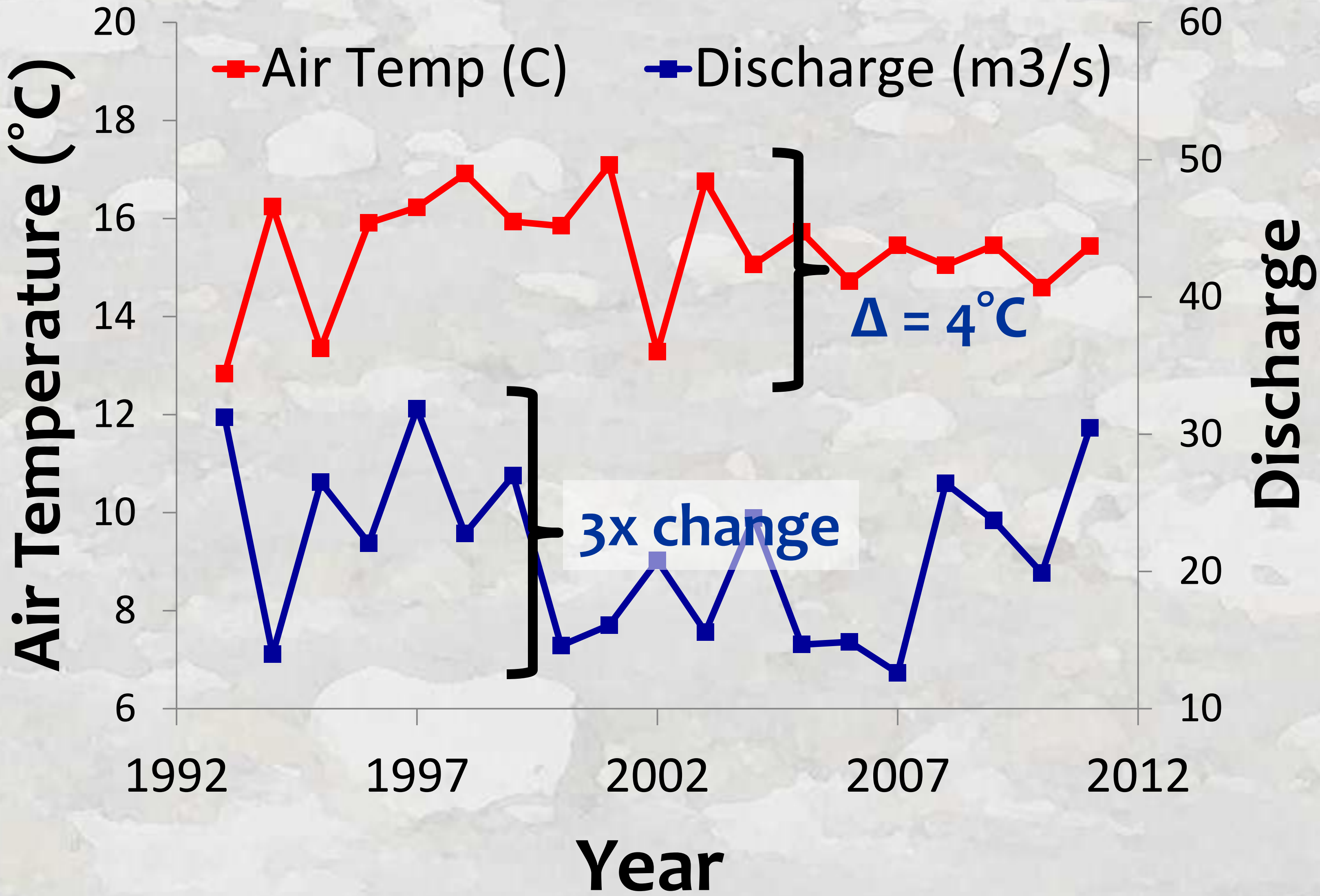
9,521 August means
2,760 stream sites
19 summers (1993-2011)

60,099 stream kilometers



Climatic Variability in Historical Record

Extreme years encompass mid-Century averages



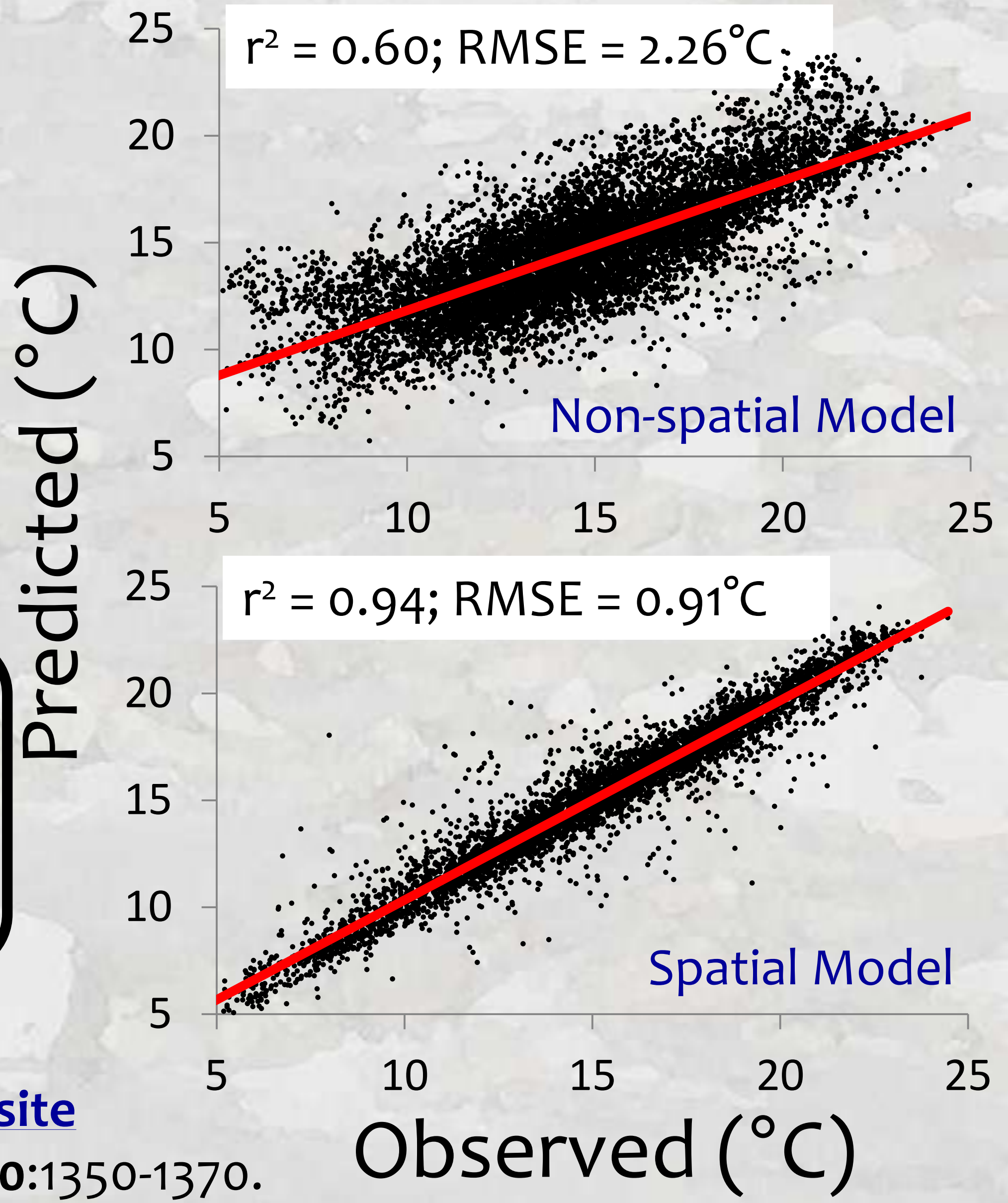
Mid-Columbia Temperature Model

Covariate Predictors

1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km²)
9. Glacier (%)

10. Discharge (m³/s)
    USGS gage data
11. Air Temperature (˚C)
    RegCM3 NCEP reanalysis
    Hostetler et al. 2011

Mean August Temperature

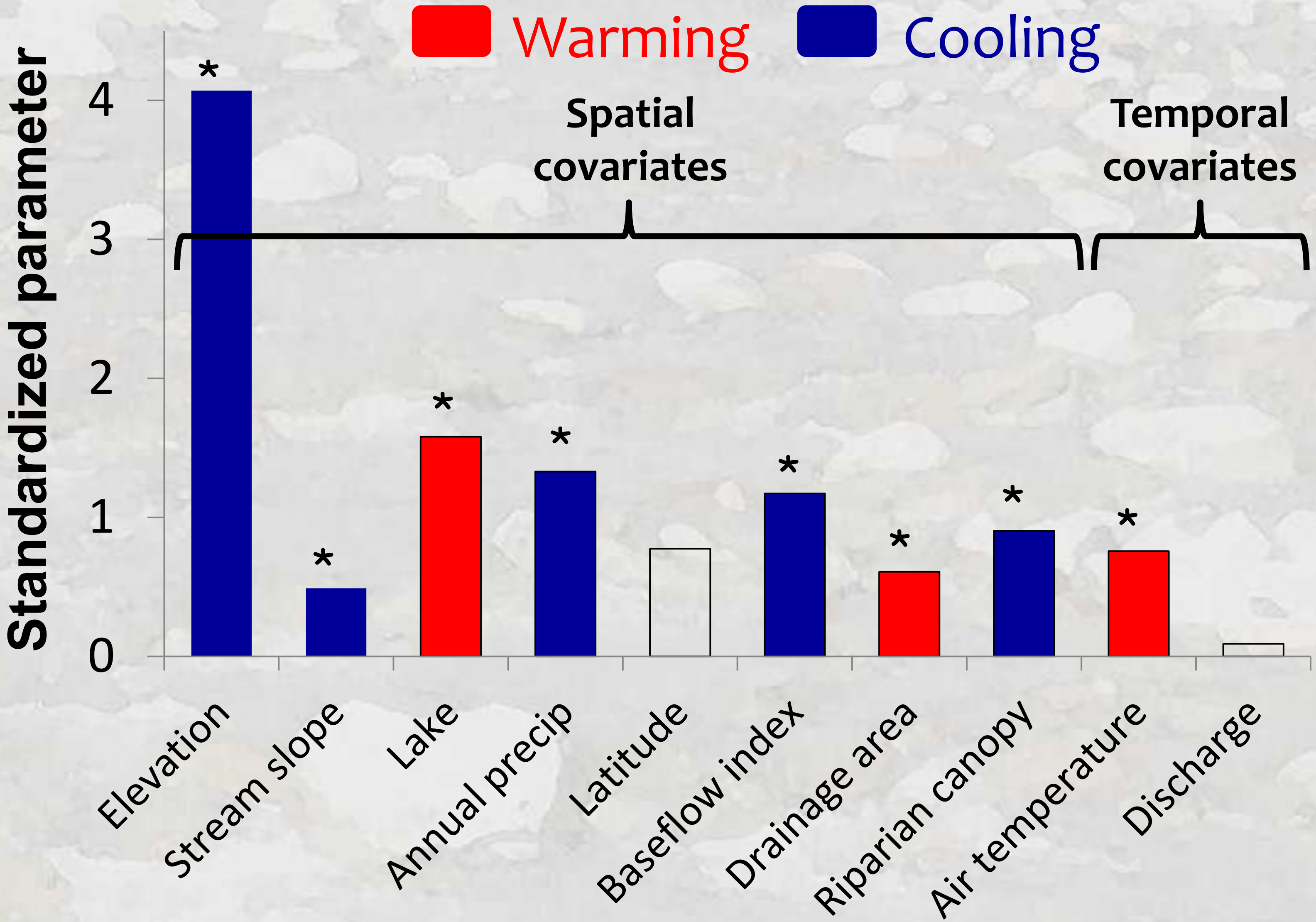


More details: NorWeST website

Isaak et al. 2010. *Ecol. Apps* **20**:1350-1370.

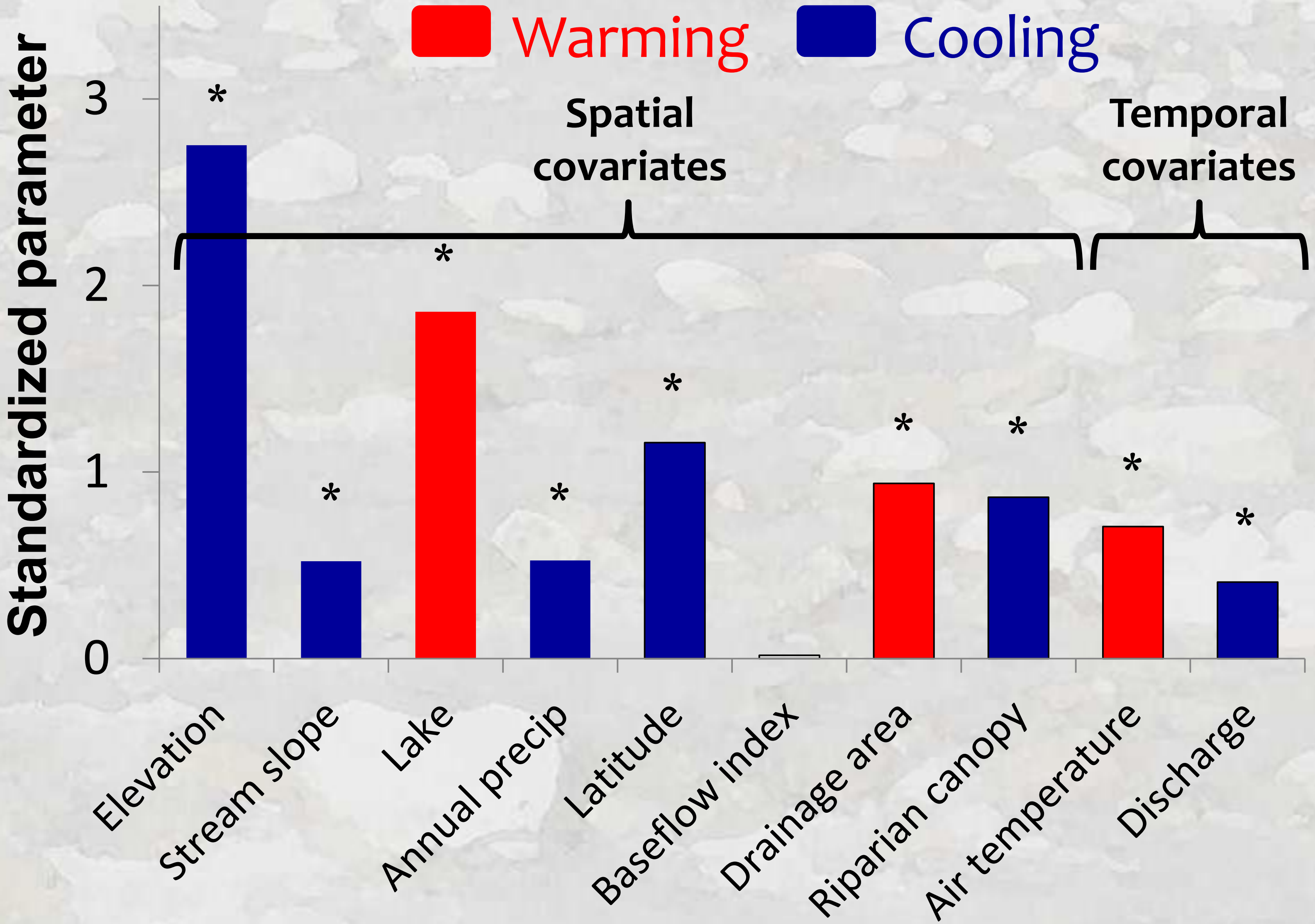
Relative Effects of Predictors

Mid-Columbia River Basin Model



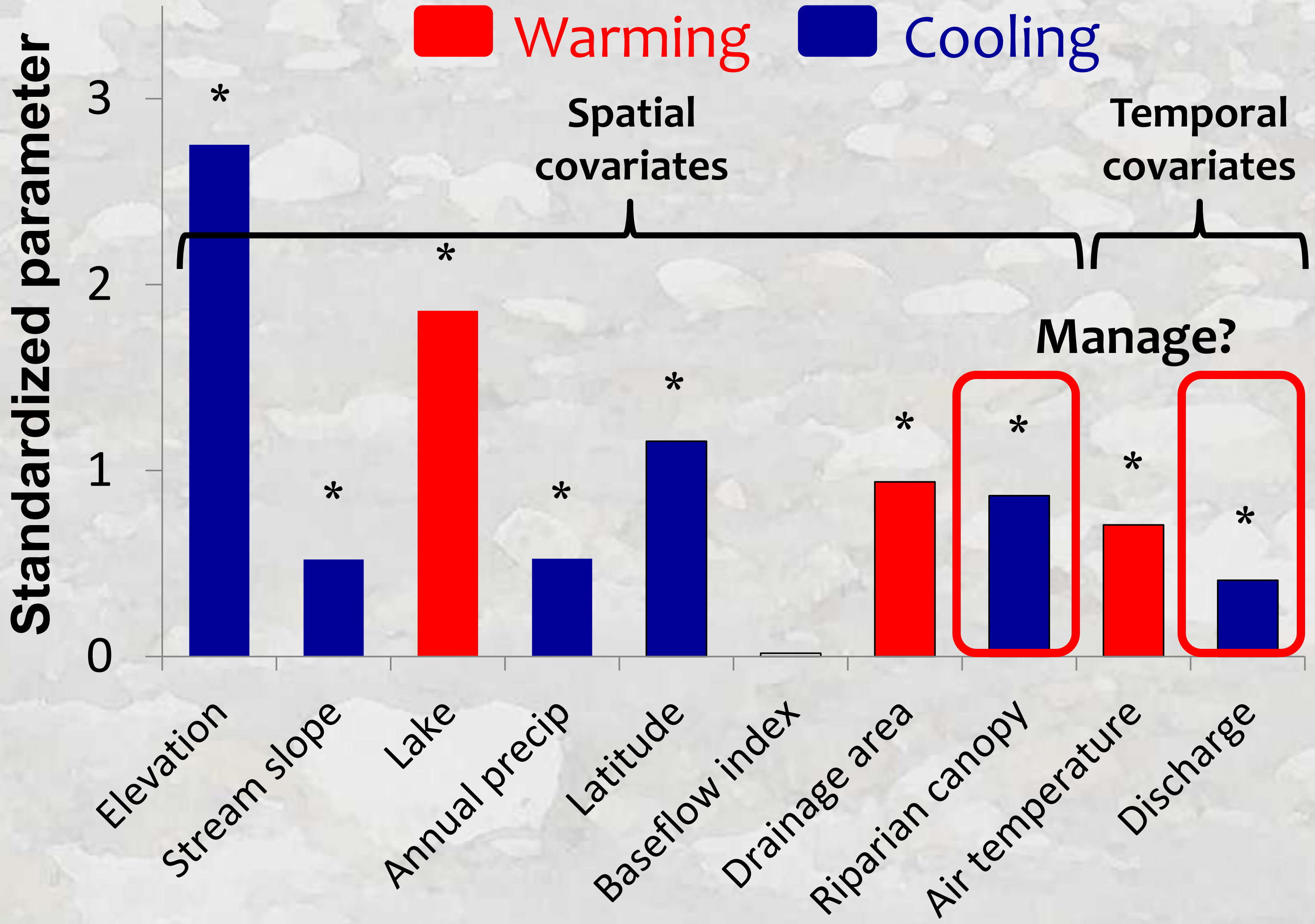
Relative Effects of Predictors

Northwest Montana Model



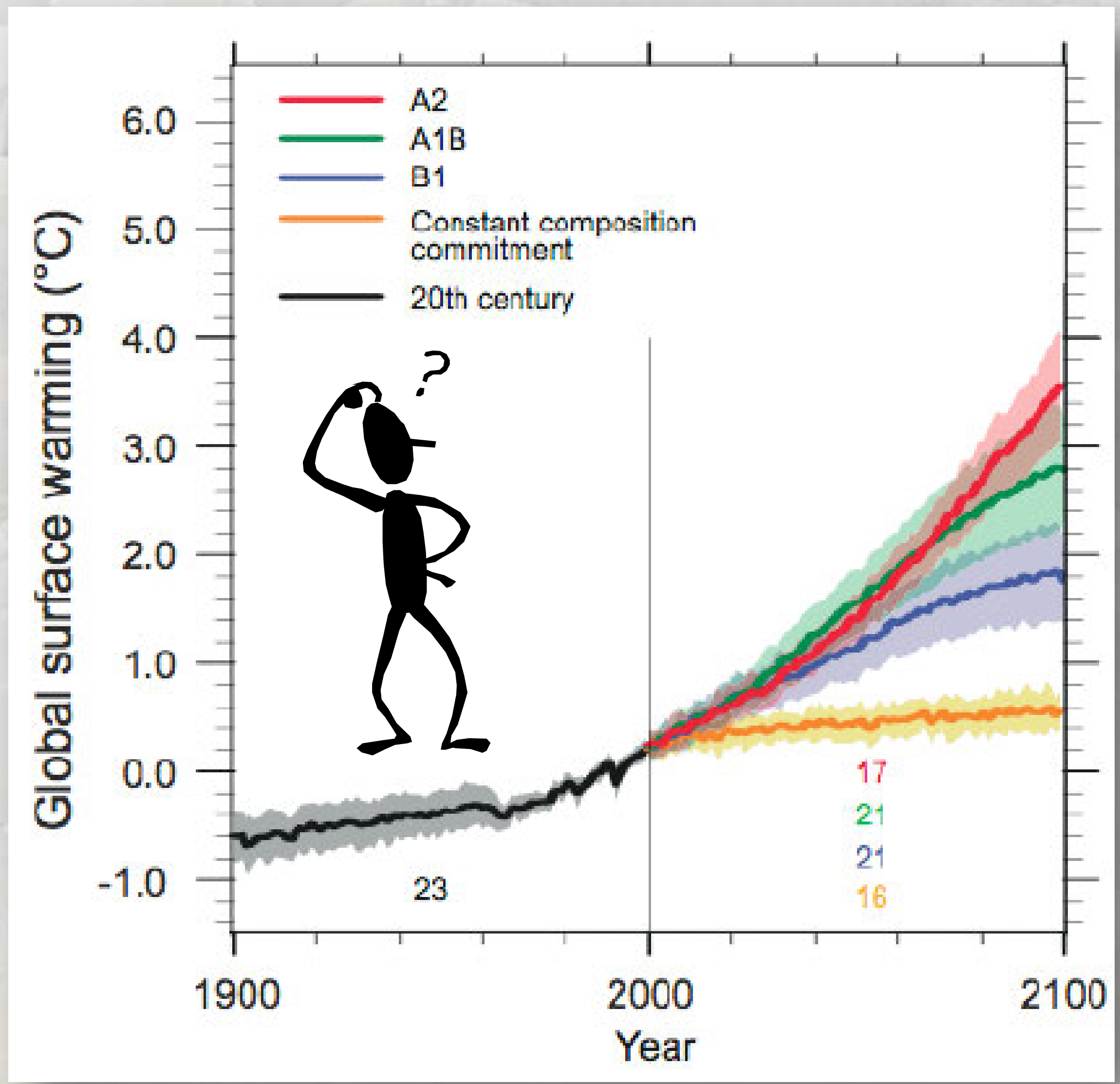
Relative Effects of Predictors

Northwest Montana Model



Models Enable Climate Scenario Maps

Many possibilities exist…



Adjust…

- Air
- Discharge
- %Canopy

…values to create scenarios

NorWeST Historical Scenarios

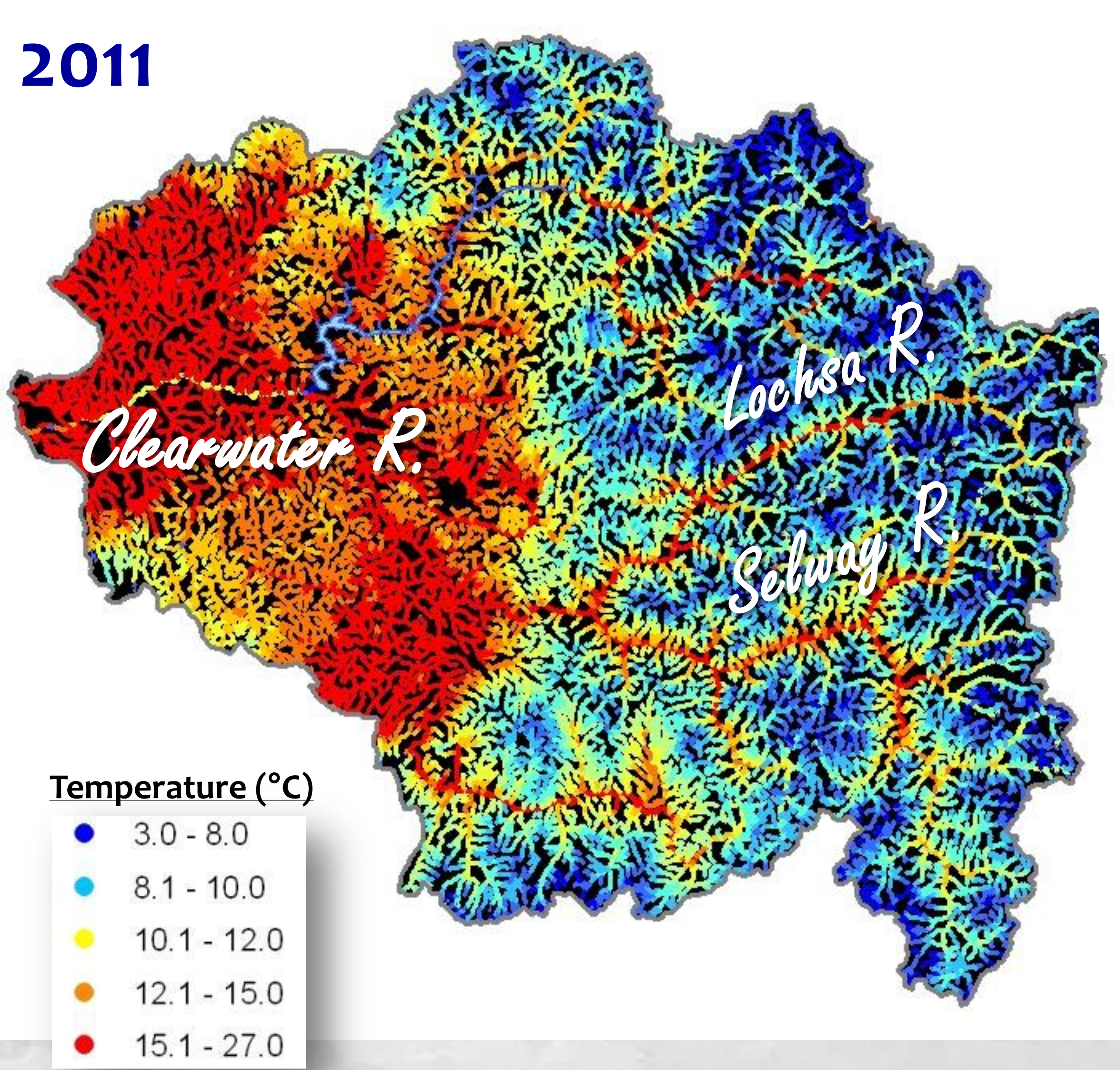
Scenario	Description
S1_93_11	Historical scenario representing 19 year average August mean stream temperatures for 1993-2011
S2_02_11	Historical scenario representing 10 year average August mean stream temperatures for 2002-2011
S3_1993	Historical scenario representing August mean stream temperatures for 1993
S4_1994	Historical scenario representing August mean stream temperatures for 1994
Etc…	
S21_2011	Historical scenario representing August mean stream temperatures for 2011

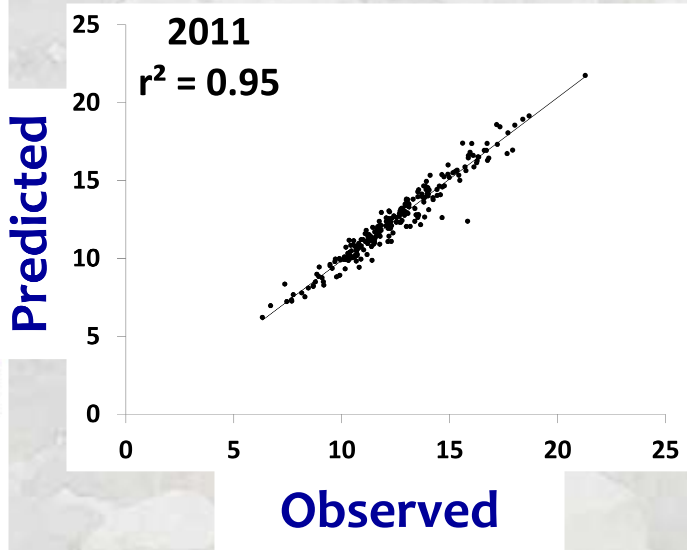
***2012 & 2013 starting with Washington**

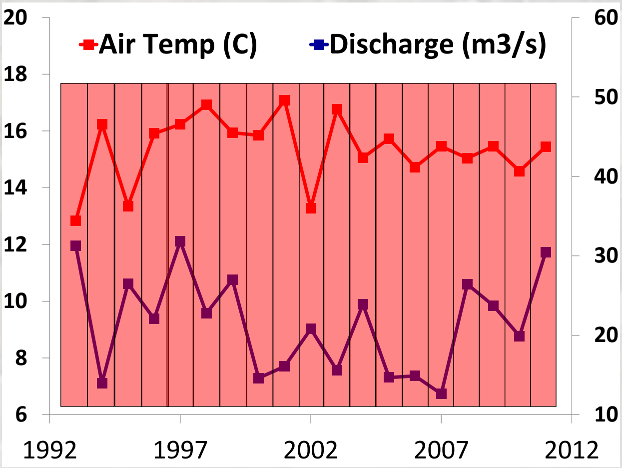
***Extensive metadata on website**

Historical Year Sequence (1993-2011)

Mean August Temperature - Clearwater Basin



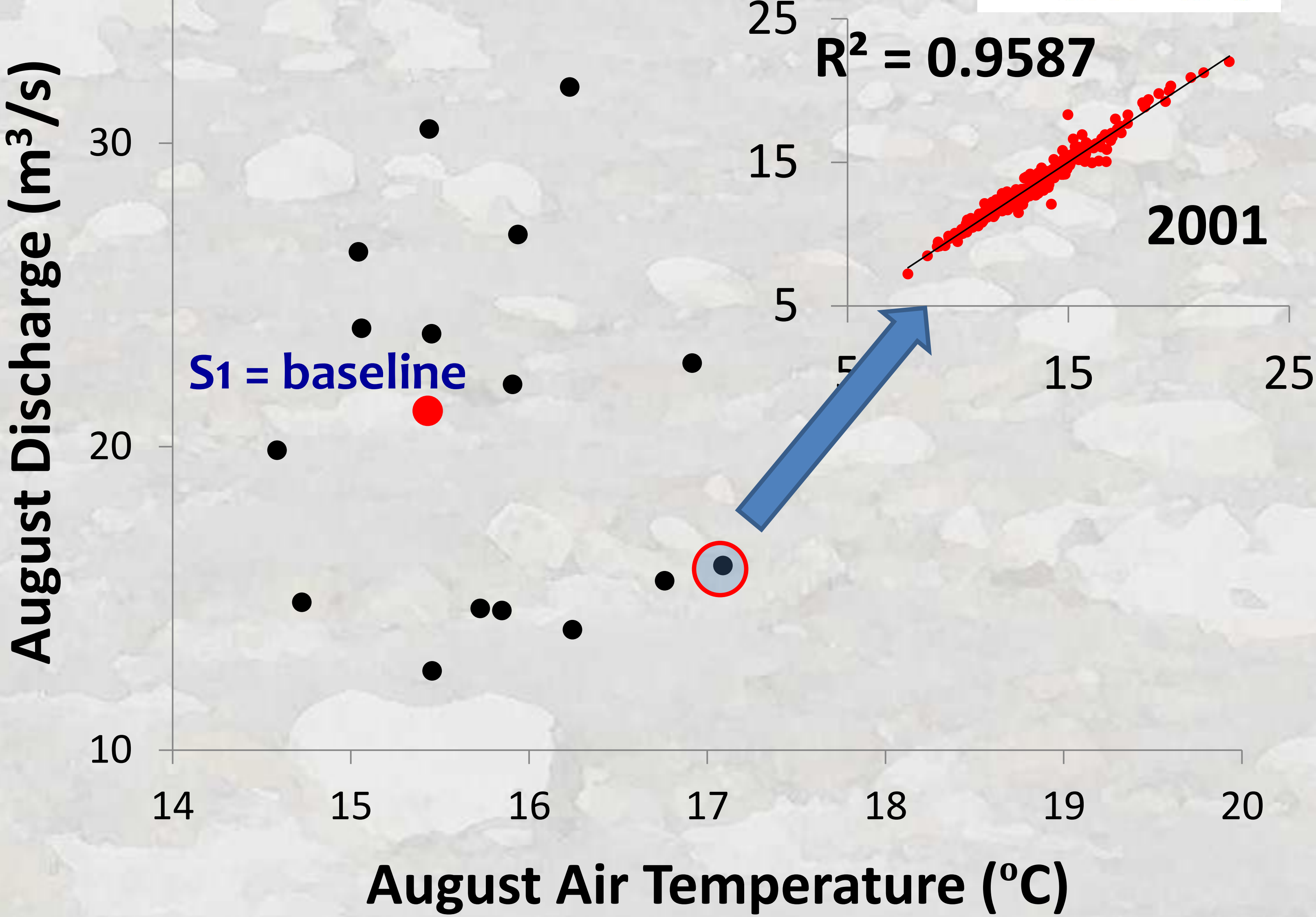




Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

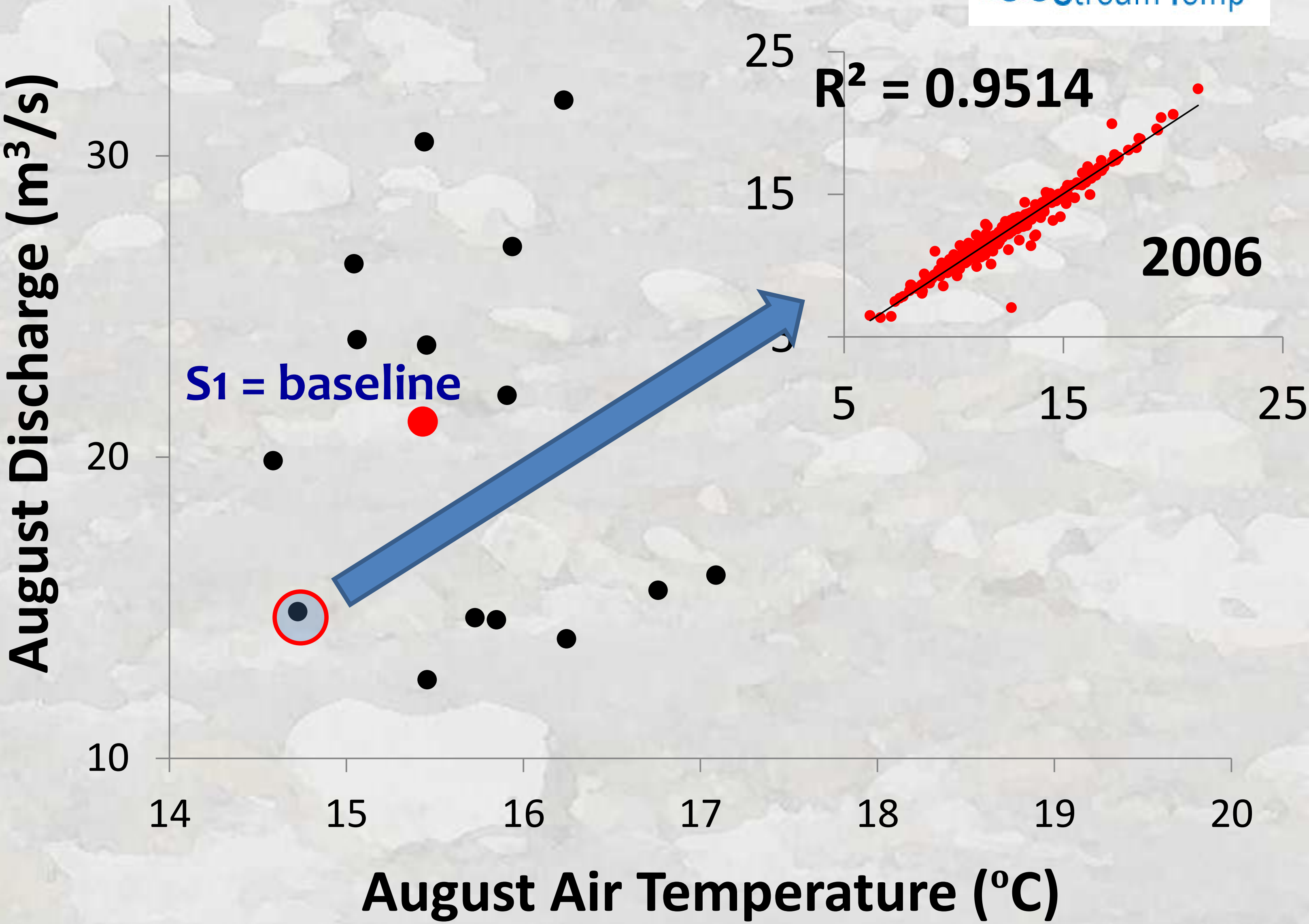
NorWeST Stream Temp



Climate Envelope Model Assessment

NorWeST Stream Temp

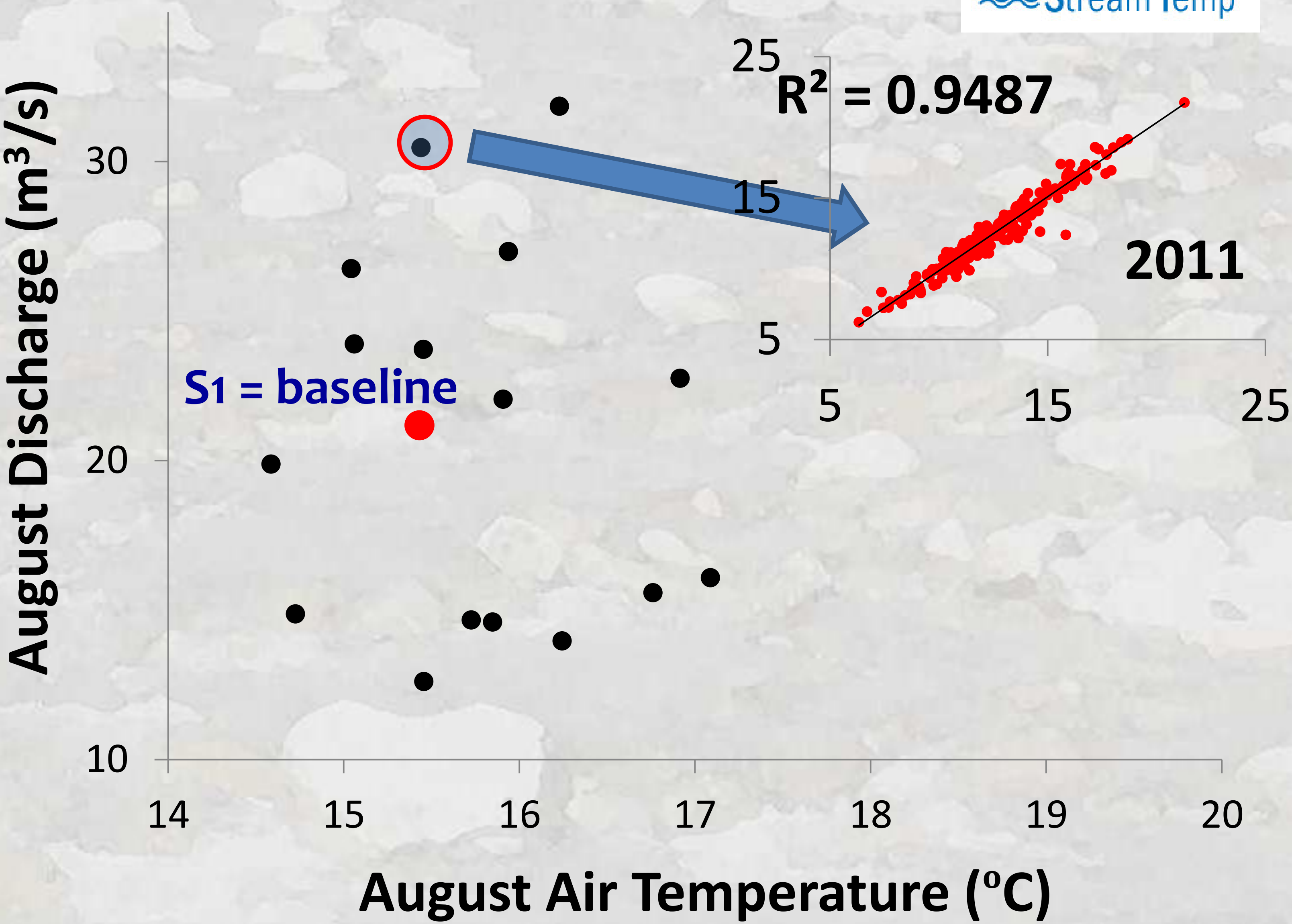
Clearwater Basin (1993-2011)



Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

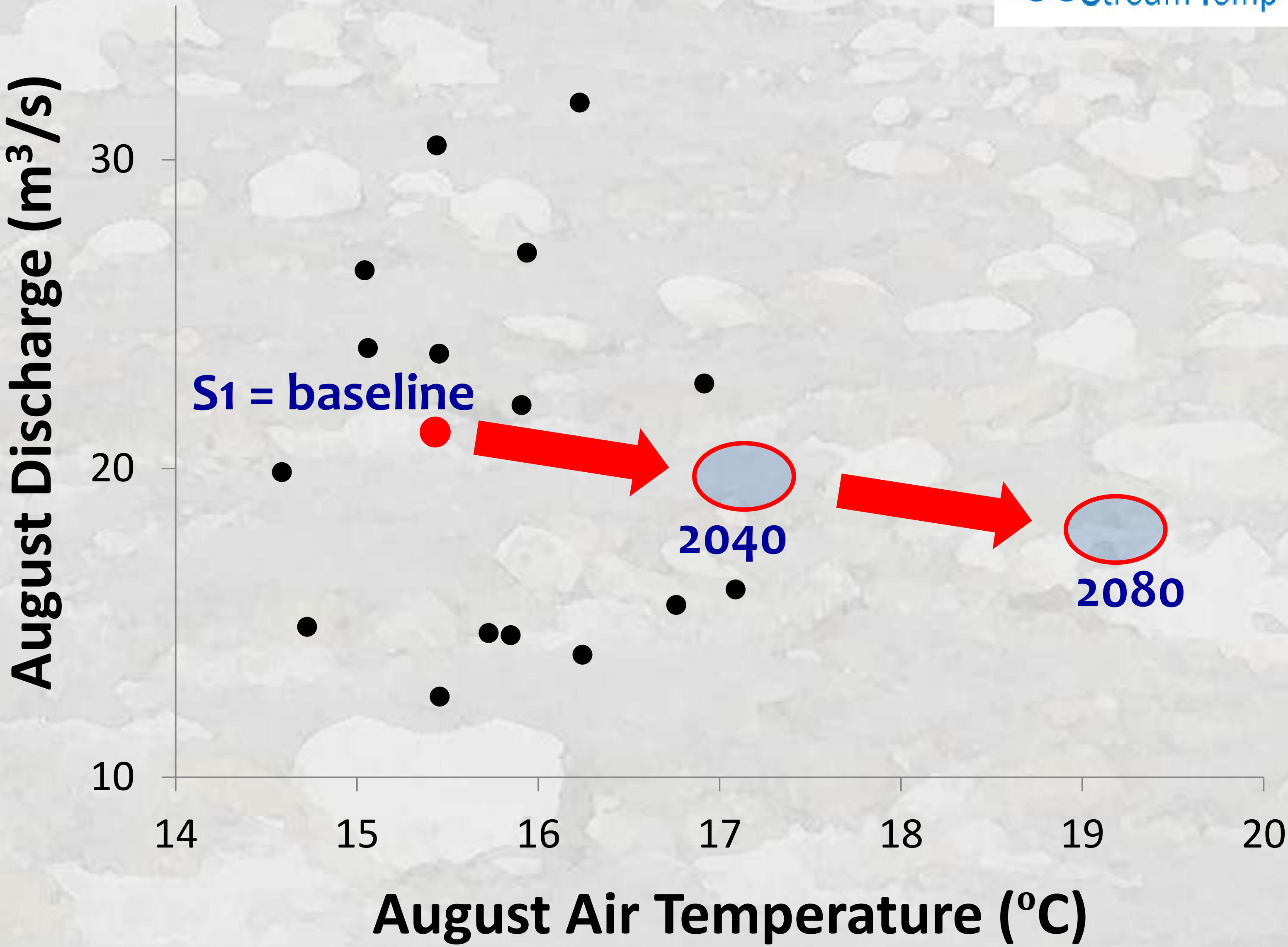
NorWeST Stream Temp



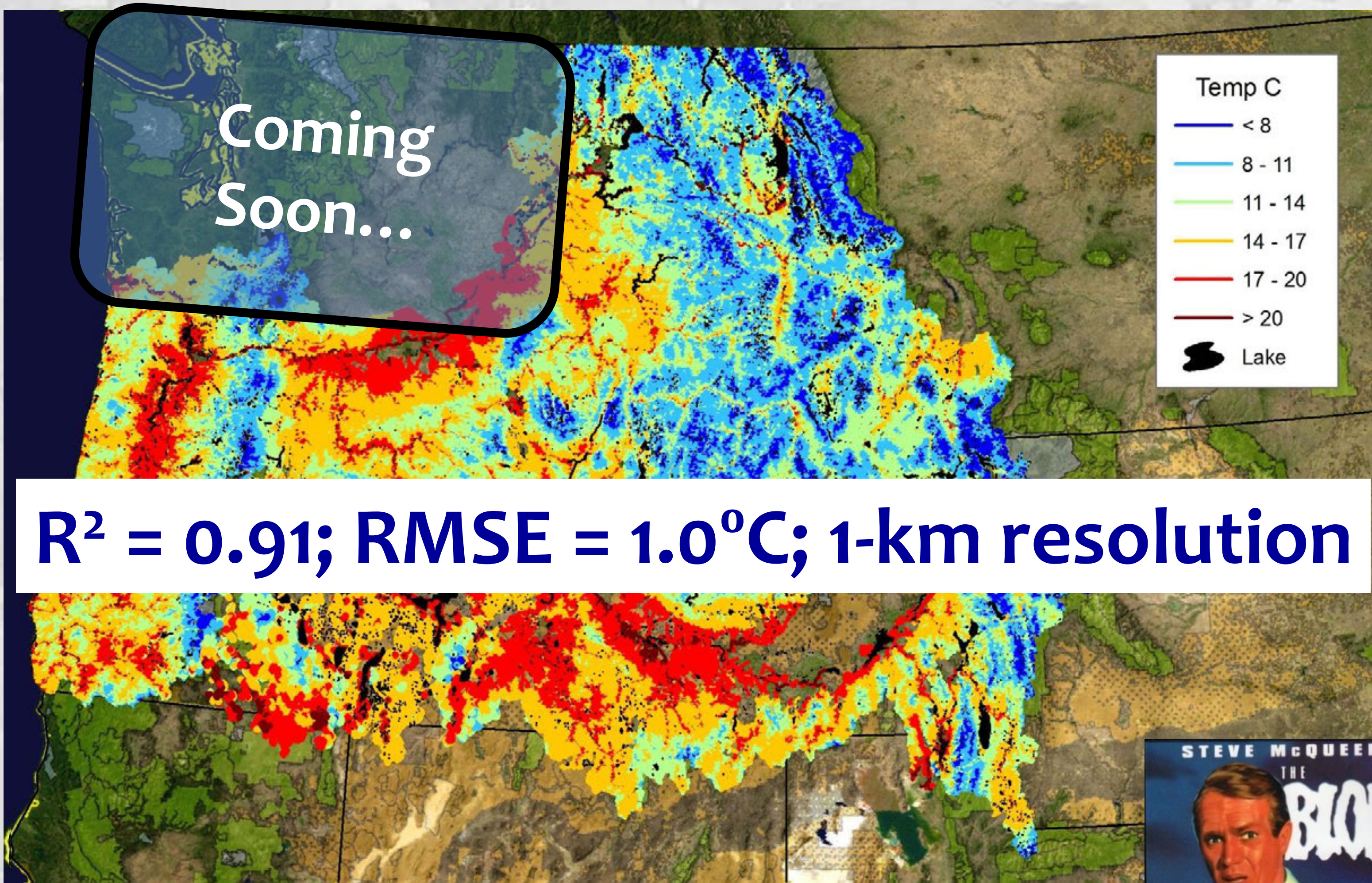
Climate Envelope Model Assessment

Clearwater Basin (1993-2011)

NorWeST Stream Temp



S1 Historical Stream Temperature Map



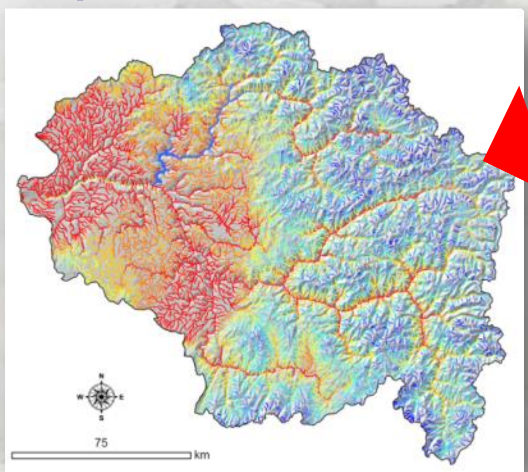
R^2 = 0.91; RMSE = 1.0°C; 1-km resolution

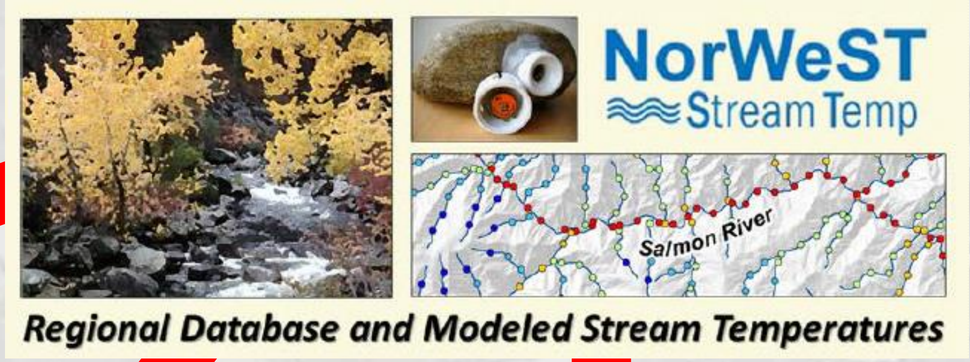
The BLOB… it just keeps growing…

- 40,397 summers of data swallowed
- 380,000 stream kilometers of thermal ooze

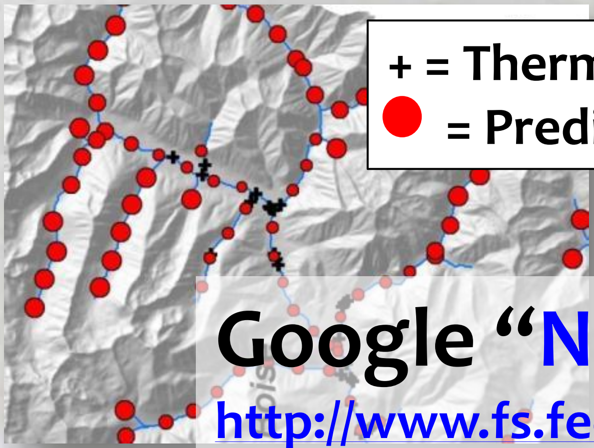
Website Distributes BLOB Scenarios & Temperature Data as GIS Layers

1) GIS shapefiles of stream temperature scenarios





2) GIS shapefiles of stream temperature model prediction precision



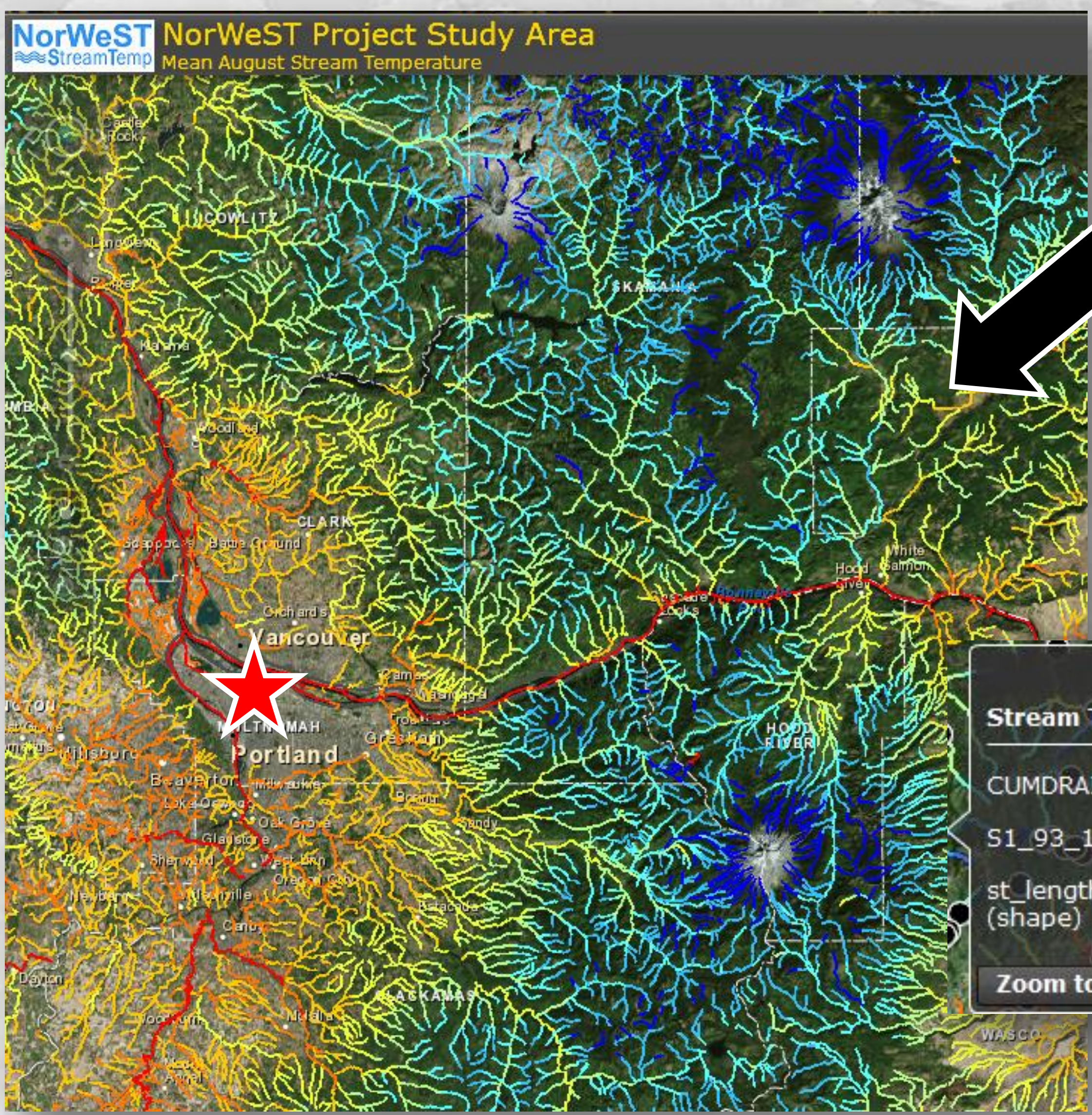
3) Temperature data summaries

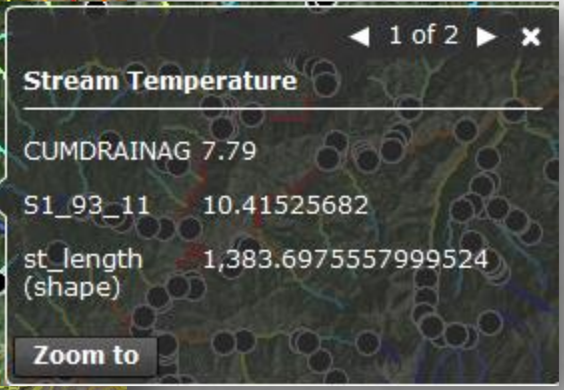
Google "NorWeST" or go here…

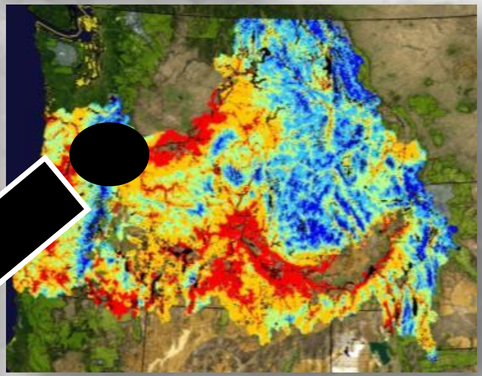
http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.shtml

Websurf the BLOB on…

Dynamic Online Map Viewer

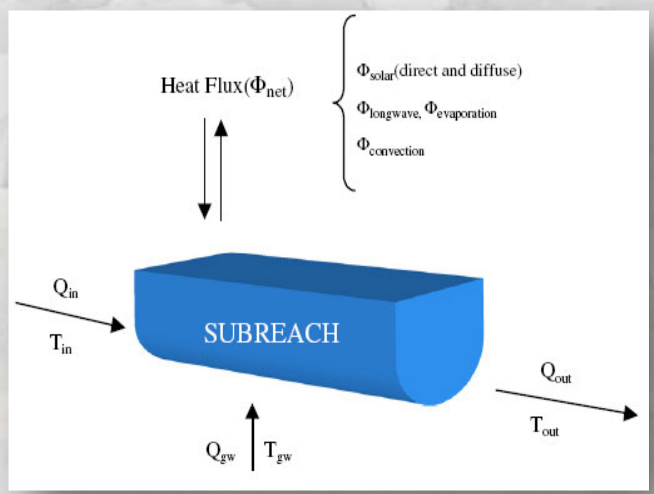


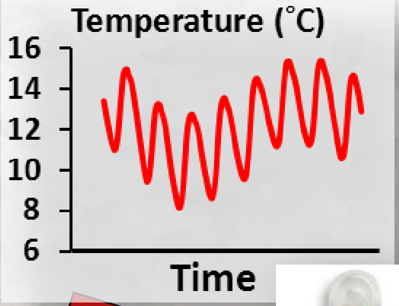




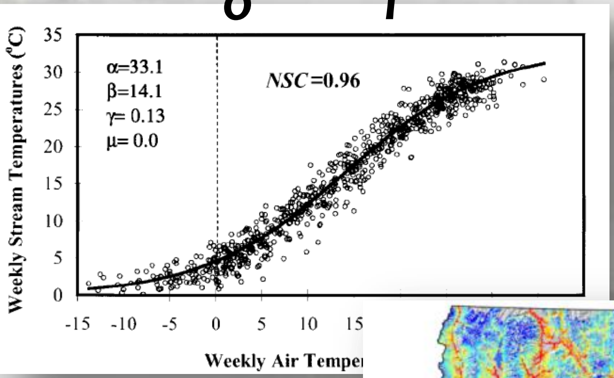
Data feeds All Models…

Mechanistic & Statistical





$$Y = b_o + b_1x$$

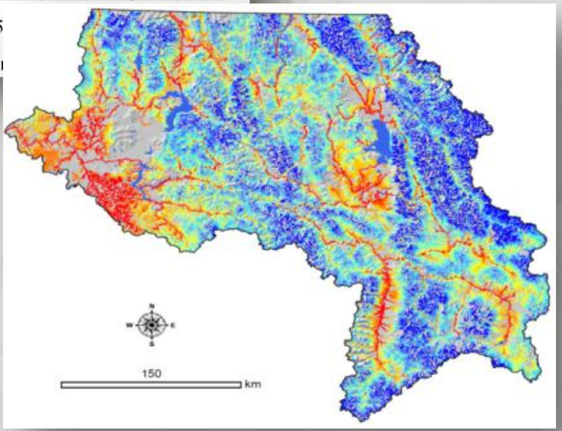


Site

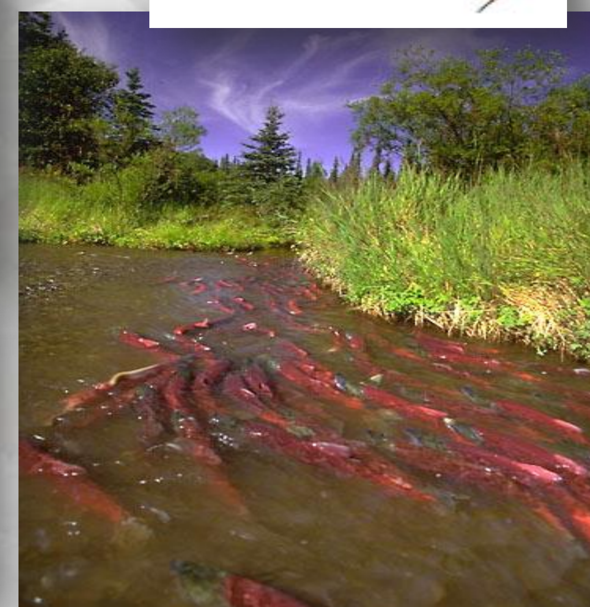
Examples…

- QUAL2Kw
- SSTEMP/SNTEMP
- BasinTemp
- Heat Source
- WET-Temp

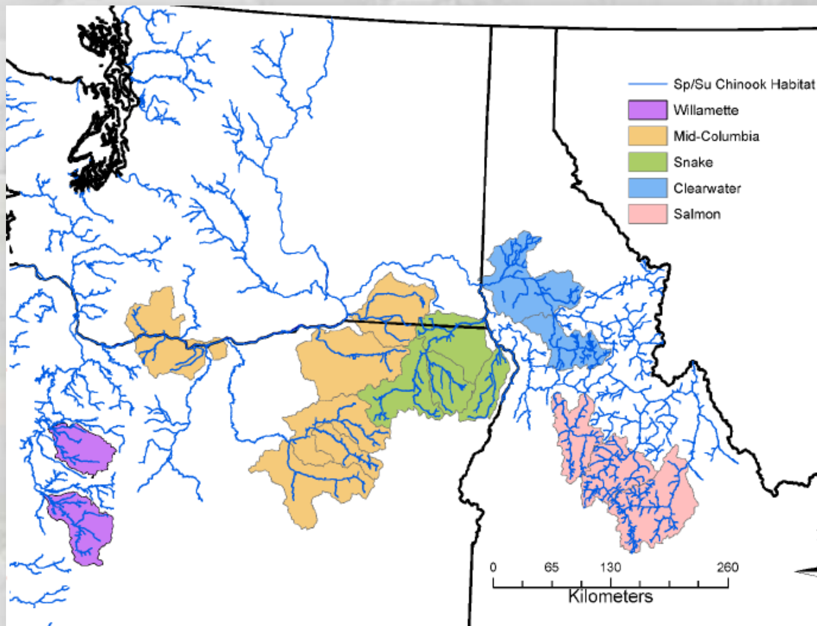
Network



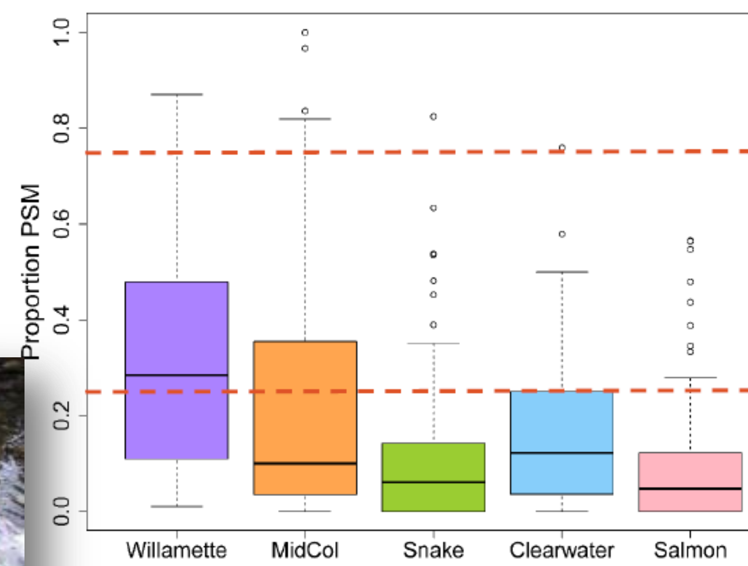
The Reasons Temperature Matters…



NorWeST Temperature & Prespawn Mortality in Salmon

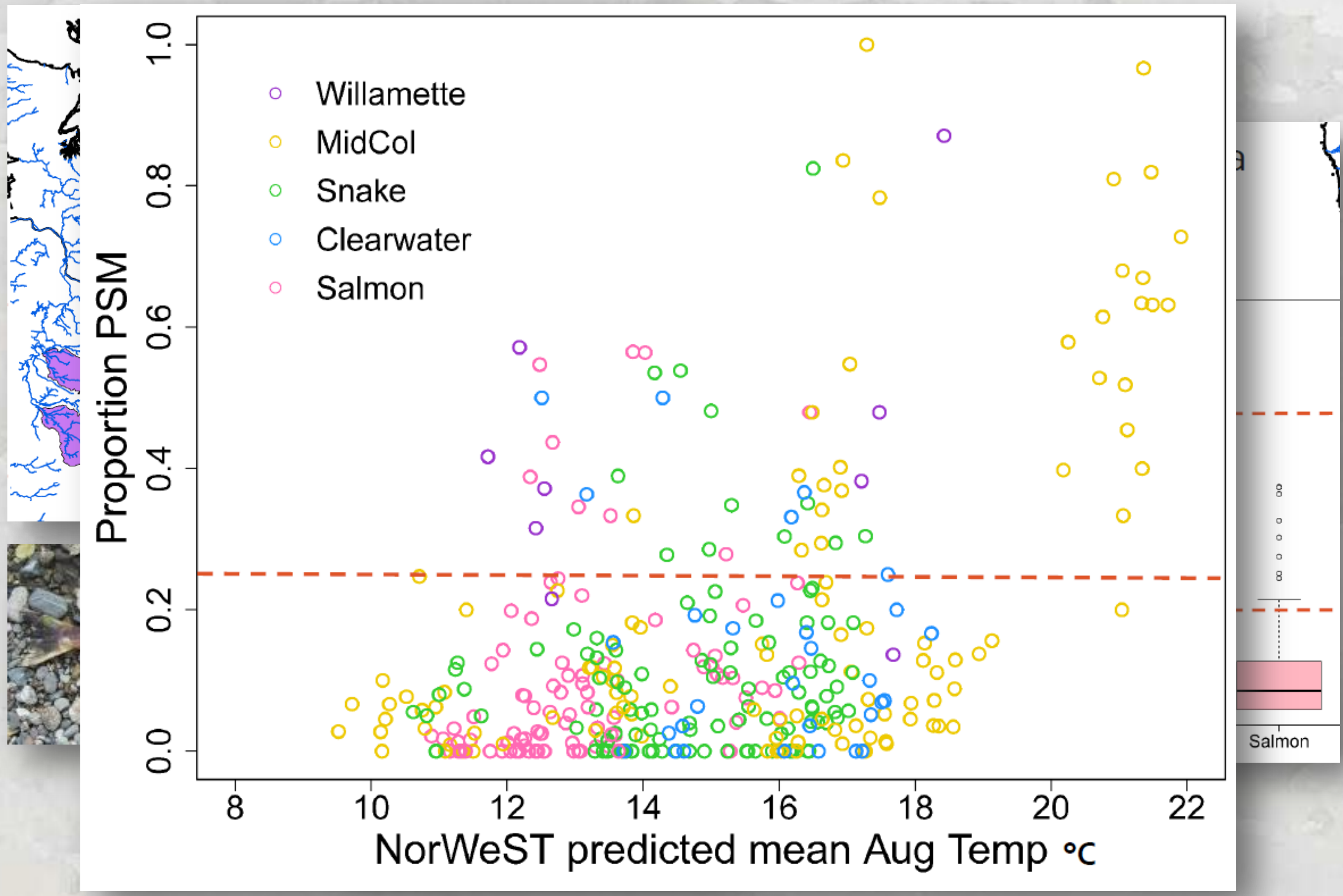


450 site years of PSM data
8 different agencies
3 ESUs



Bowerman, Keefer, & Caudill – U. Idaho

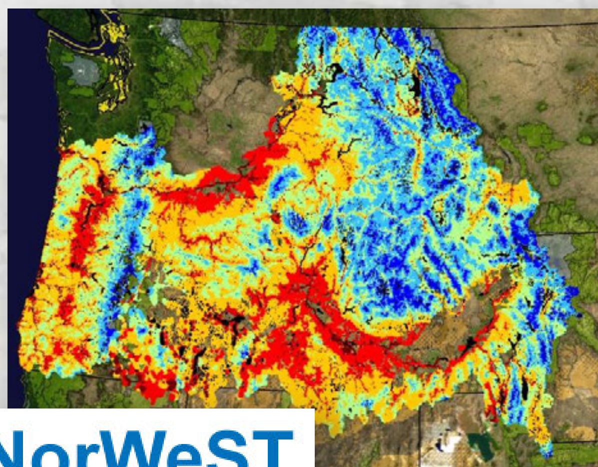
NorWeST Temperature & Prespawn Mortality in Salmon



Bowerman, Keefer, & Caudill – U. Idaho

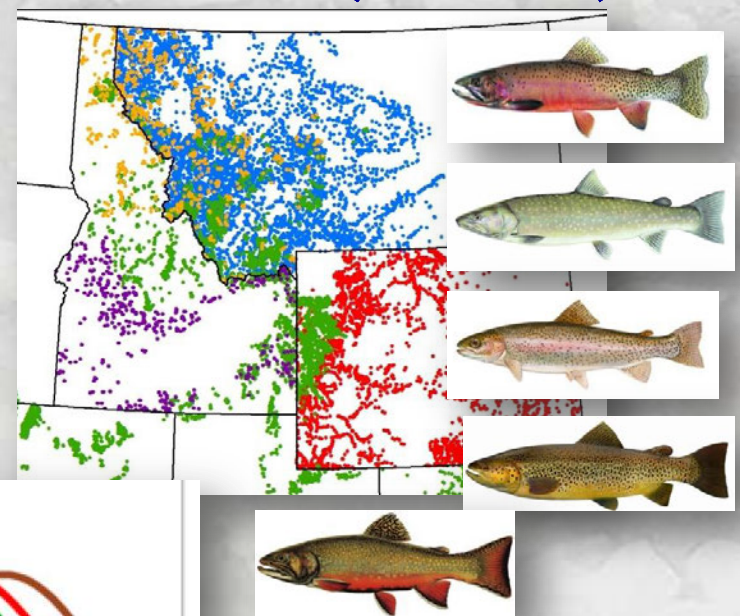
Field-Based Temperature Standards using BIG FISH Databases

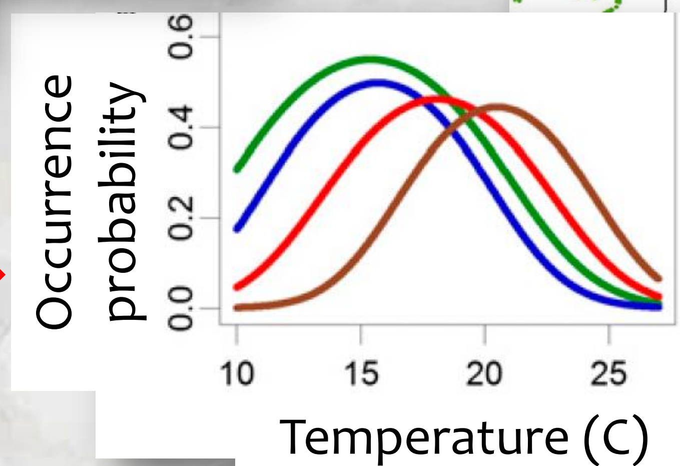
Stream temperature maps



NorWeST Stream Temp

Regional fish survey databases (n ~ 20,000)



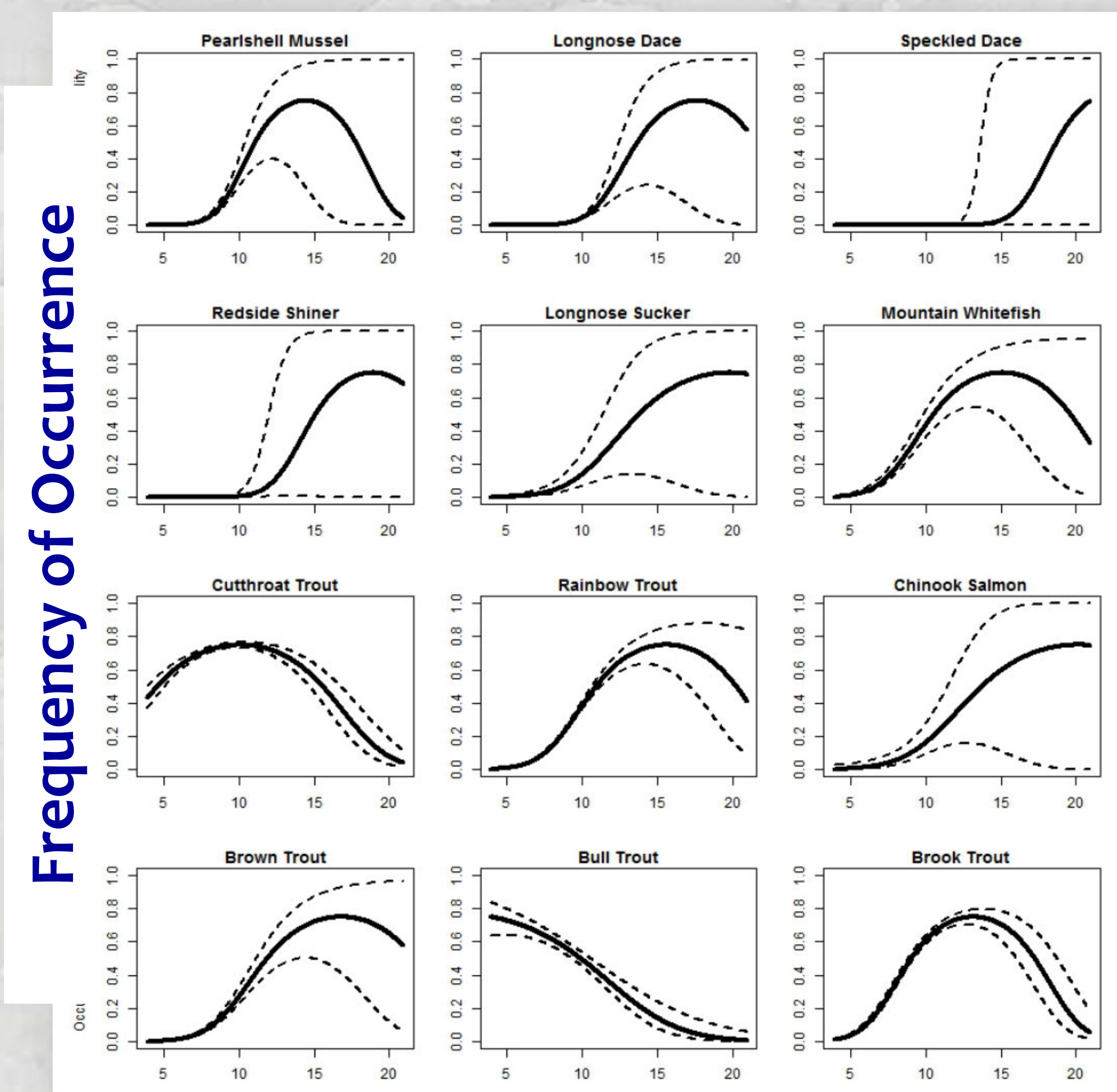


Wenger et al. 2011a. *PNAS* **108:**14175-14180
Wenger et al. 2011b. *CJFAS* **68**:988-1008; Wenger et al., *In Preparation*

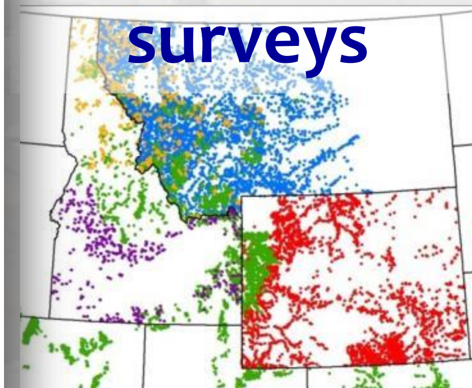
A Generalizable Approach…

Just need georeferenced biological survey data

Thermal Niches in Batch Mode…



~20,000 fish surveys



Wenger et al., *In Preparation*

Good Stream Temperature Information Creates Synergies…

Monitoring & Temperature Standards

- Interagency coordination & less redundancy
- Annual, long-term data instead of summer, short-term
- Oregon DEQ macroinvertebrate habitat indices & riparian conditions
- Total Maximum Daily Loads & site potential

Salmon & Resident Fish Research

- Hatchery stray rates (Westerley & Dittman, U Washington)
- Pre-spawn mortality rates in Chinook salmon (Bowerman, Keefer, & Caudill, U Idaho)
- Descriptions of historical species distribution shifts (Lemoine Ph.D., U Montana)

Climate Vulnerability Assessments & Land Management Planning

- Blue Mountains Adaptation Partnership, Northern Rockies Adaptation Partnership, Clearwater – EcoAdapt, etc.
- Forest Plan revisions (30 - 50 national forests) in Regions 1, 2, 4, & 6
- Southwest Crown of the Continent initiative

NorWeST Community of Users…

Website launched 2.5 Years Ago

- 13,046 visits
- 946 downloads last 6 months

NorWeST Community of Users…

Website launched 2.5 Years Ago

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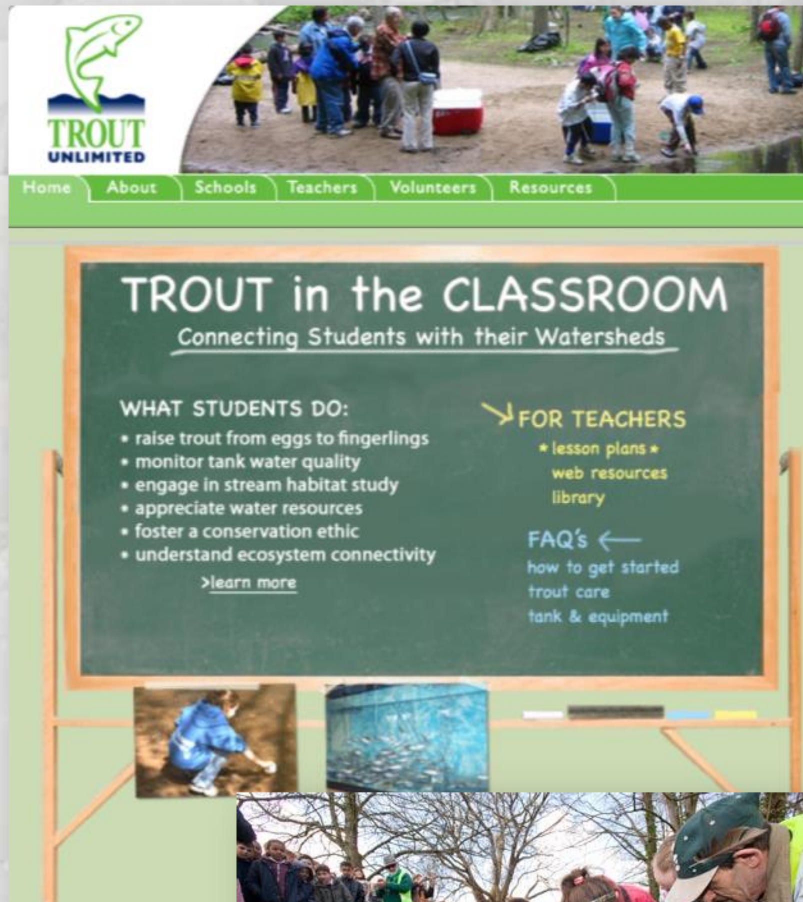
- 946 downloads last 6 months

Inspiring the Next Generation of Stream Climatologists…



Some school kids in 4,500 classrooms may be monitoring stream temperatures soon…

Part 2, future norwest scenarios

Future NorWeST Scenarios

Similar to Before…

Climate variable	Thermal category	Summer	Fall
30 year air temperature trend (°C/decade)	Unregulated	0.36 (0.10)	0.17 (0.10)
	Regulated	0.35 (0.082)	0.16 (0.086)
56 year discharge trend (% change/decade)	Unregulated	−3.5% (1.2%)	−0.8% (3.4%)
	Regulated	−1.7% (6.7%)	−0.22% (5.1%)

Multiply change in August air & discharge by NorWeST regression parameters…

NorWeST Stream Temp

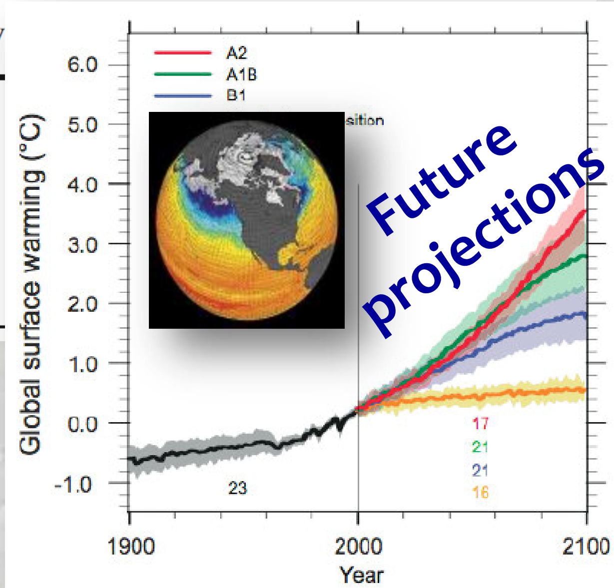
Stream temp (Y) = b_1(air) + b_2(discharge)

…which then yields amount of future stream temp change

Future NorWeST Scenarios

Similar to Before…

Climate variable	Thermal category
30 year air temperature trend (°C/decade)	Unregulated
	Regulated
56 year discharge trend (% change/decade)	Unregulated
	Regulated



Multiply change in August air & discharge by NorWeST regression parameters…

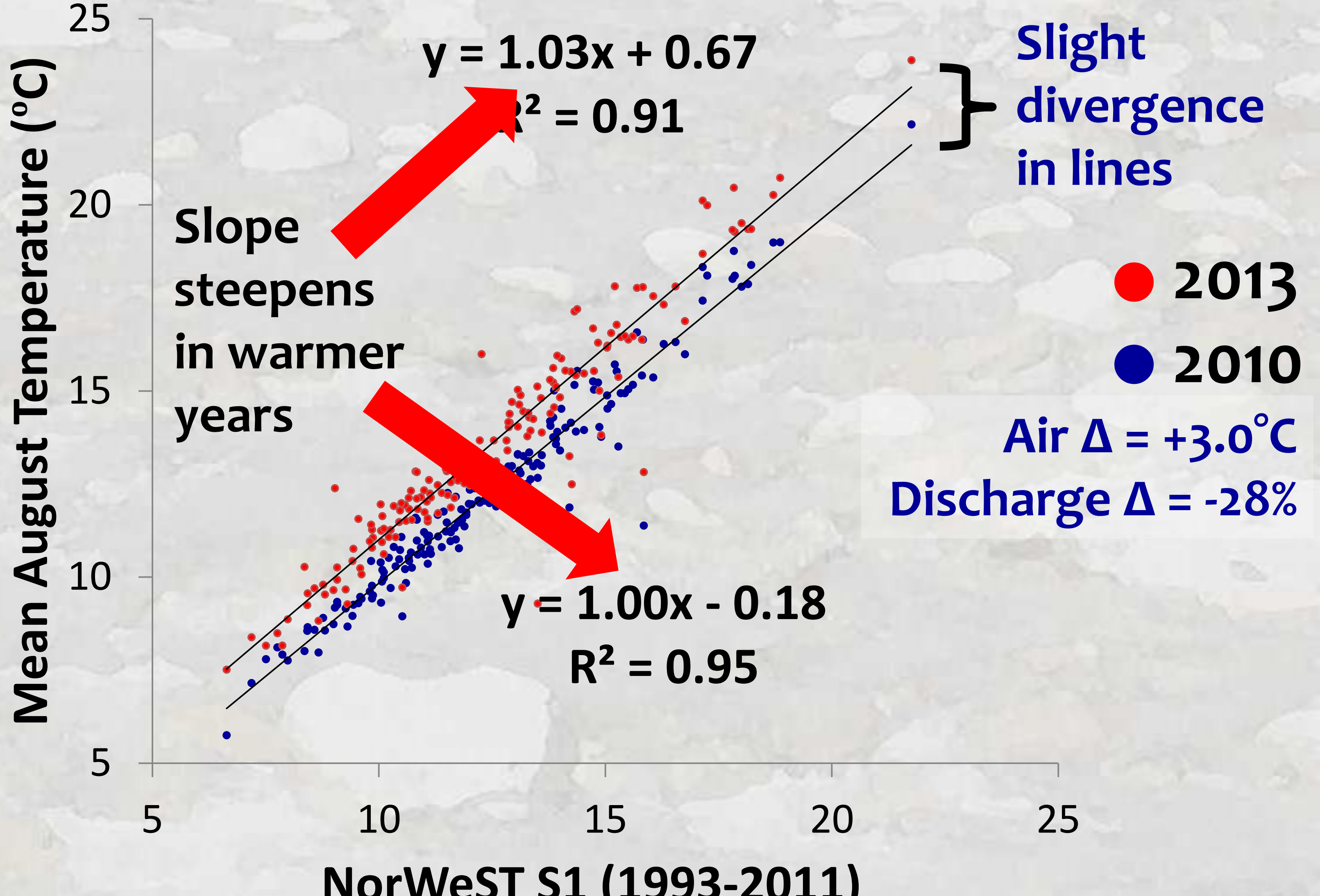
NorWeST Stream Temp

Stream temp (Y) = b_1 (air) + b_2 (discharge)

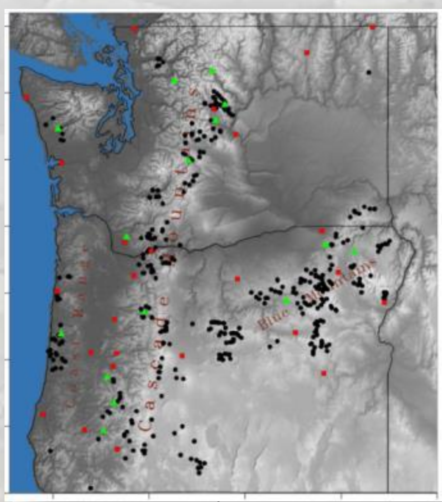
…which then yields amount of future stream temp change

But Some Streams Warm Faster

Variation Across Years

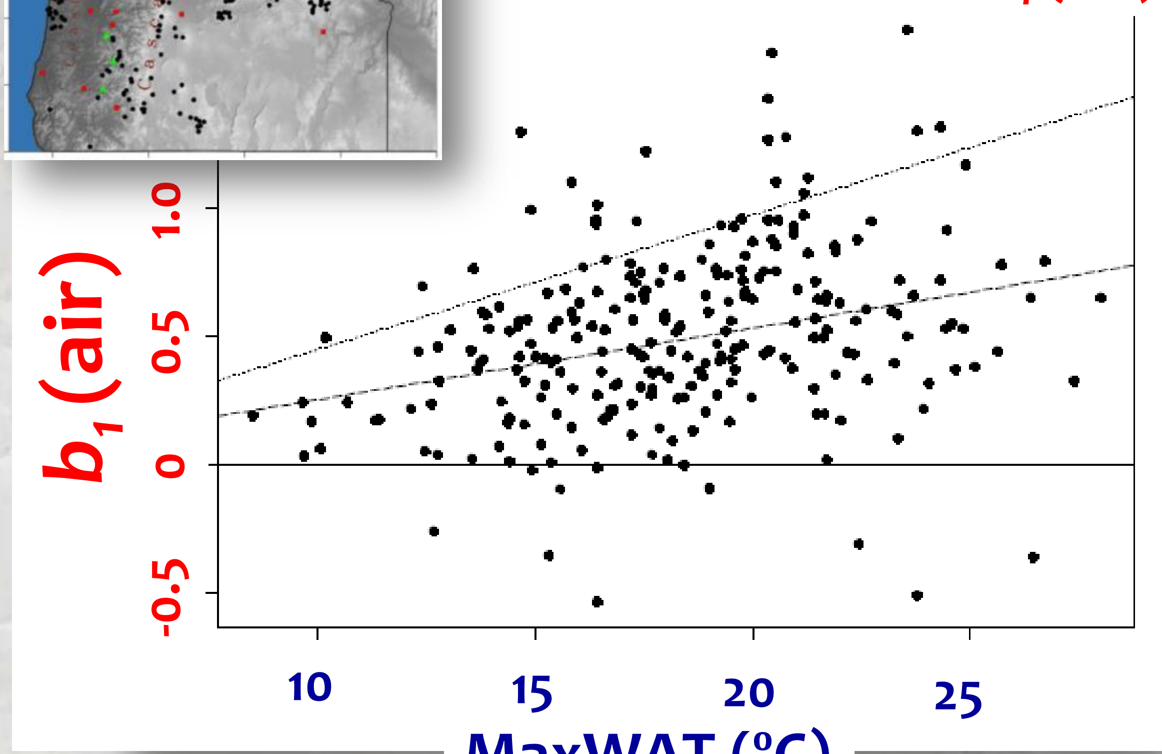


Cold Streams Less Sensitive to Climate Forcing



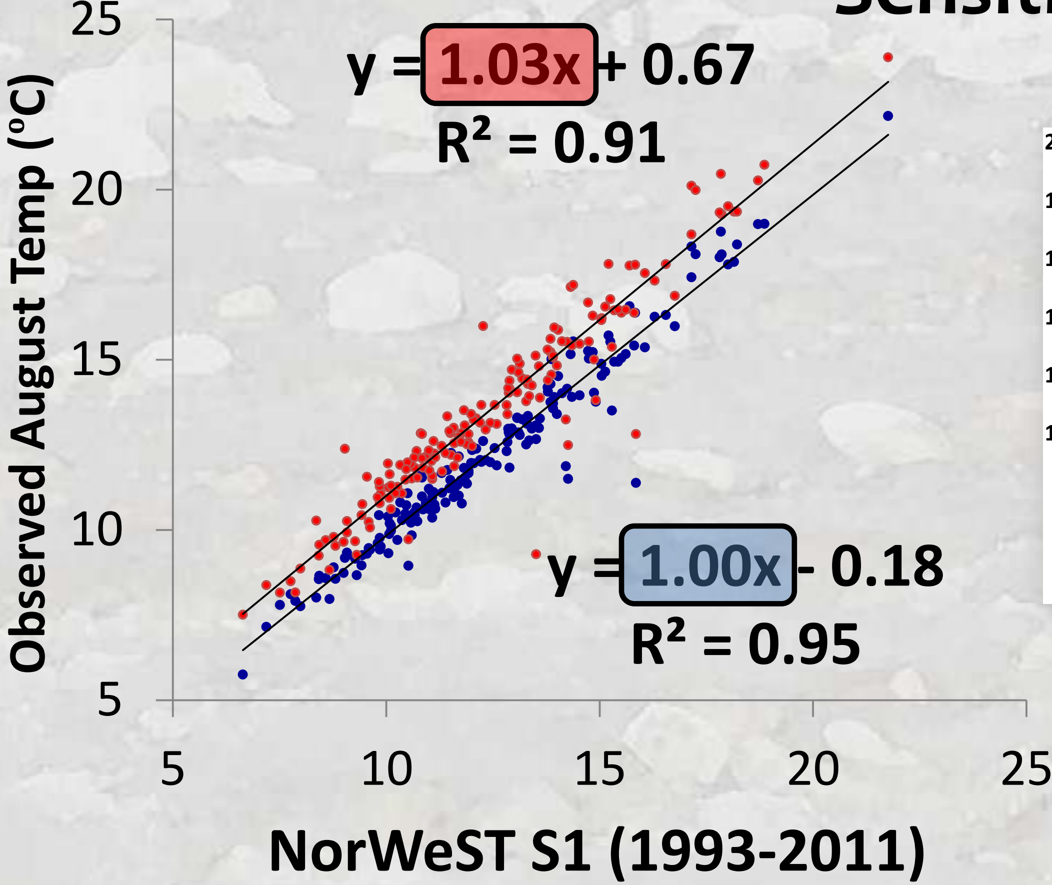
246 stream sites with >7 summers of data

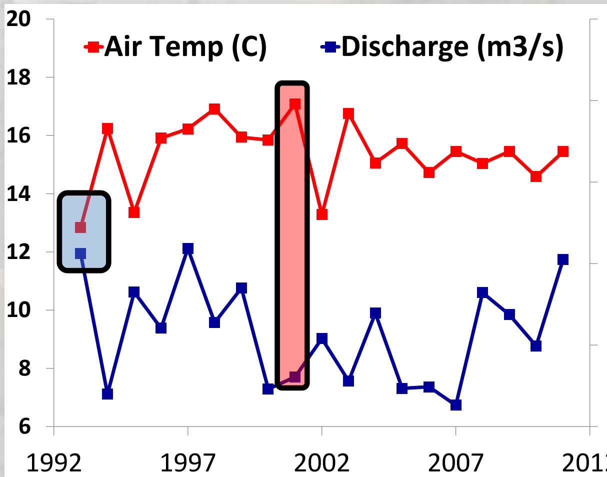
MaxWAT = b_1(air) + b_2(discharge)



Luce et al. 2014. Sensitivity of summer stream temperatures to climate variability in the Pacific Northwest. Water Resources Research 50: 1-16.

Estimation of NorWeST Basin-Specific Sensitivity Parameter





1) Regress each year's slope (1993-2011) against basin-average NorWeST temperature to estimate sensitivity parameter
2) Apply sensitivity adjustment with future air & flow deltas to correct for differential stream warming

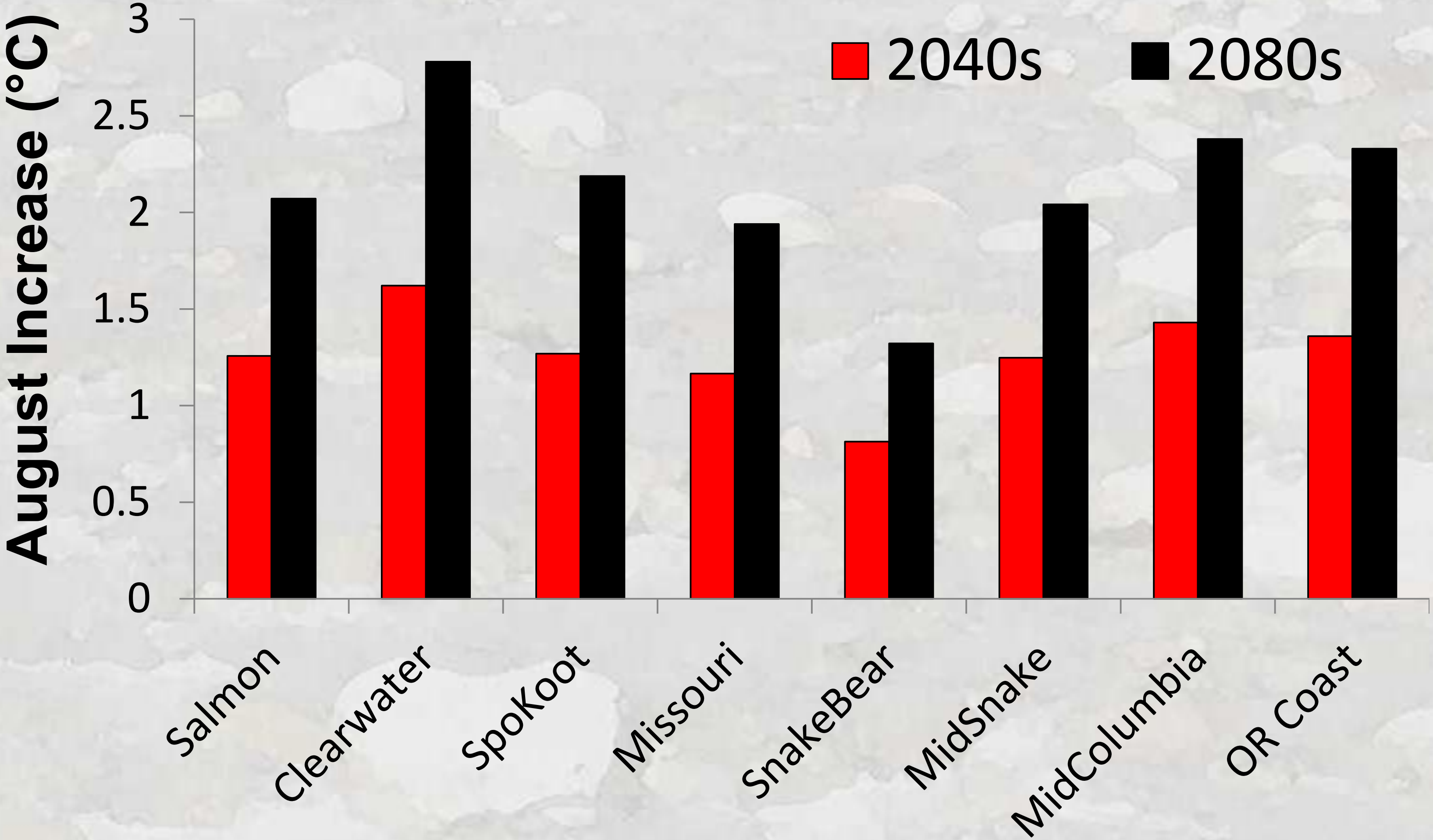
10 NorWeST Future Scenarios

Scenario	Description
S23_1C	Future scenario adds 1ºC to S1_93-11
S24_1C_D	Future scenario adds 1ºC to S1_93-11 & incorporates differential stream sensitivity
Etc…	For +2ºC & +3ºC
S29_2040	Future scenario based on August air and VIC flow deltas at 2040s from A1B GCM ensemble.
S30_2040_D	Future scenario based on August air and VIC flow deltas at 2040s from A1B GCM ensemble. Adjustment applied for differential sensitivity.
S31_2080	Etc…

***Extensive metadata on website**

Future Stream Temperature Increases Relative to 1980s (1970-1999) Baseline

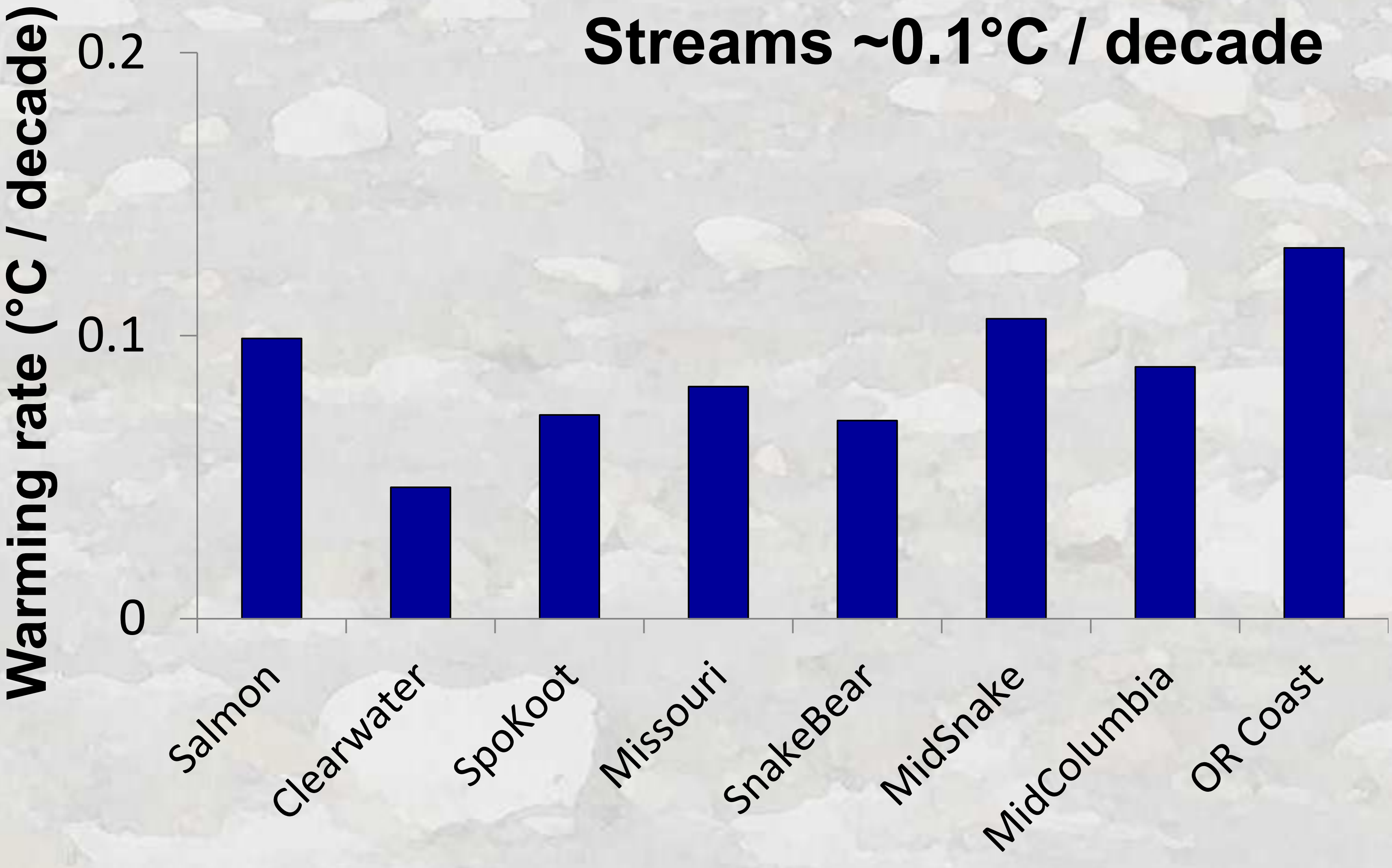
Scenarios Based on CIG 10 GCM ensemble for A1B trajectory



***Variation within basins +/-50% from sensitivity adjustment**

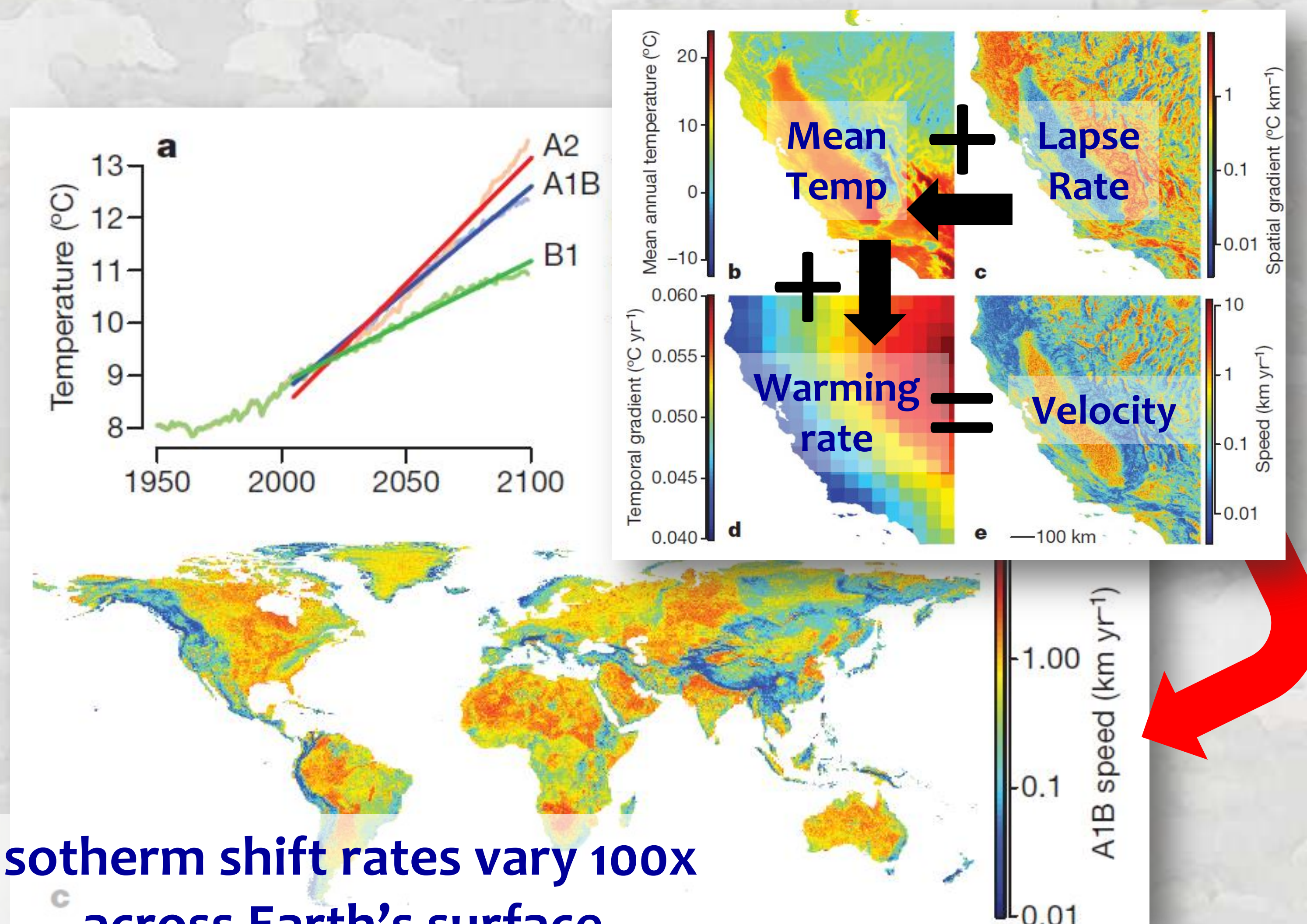
Reality Check: Past August Warming Rates

Reconstructions for Last 44 Years (1968 – 2011)



Implications for Thermal Habitat Distributions?

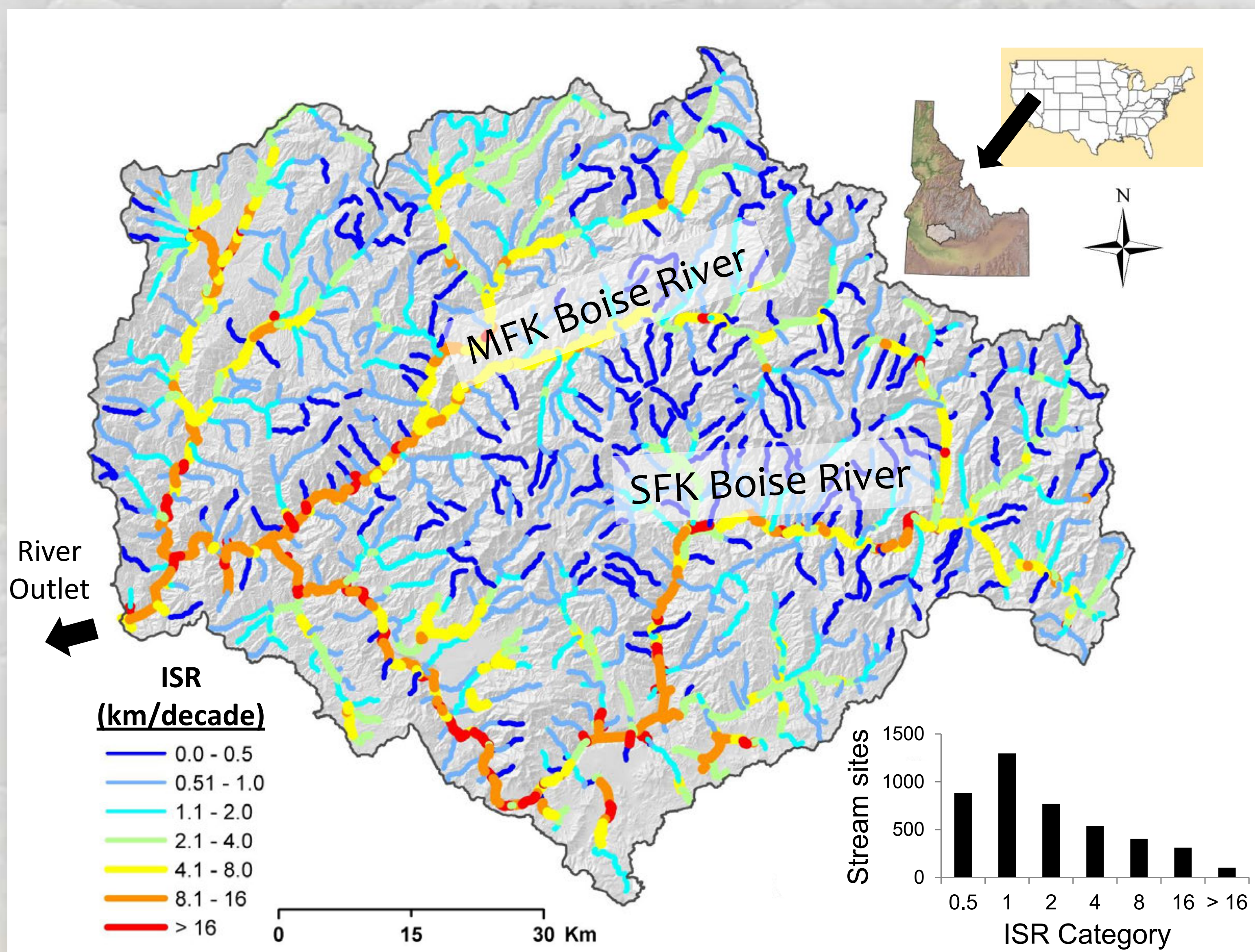
Climate Velocity is Strongly Mediated by Topography…



Isotherm shift rates vary 100x across Earth's surface

Loarie et al. 2009. The Velocity of Climate Change. *Nature* **462:**1052-1055.

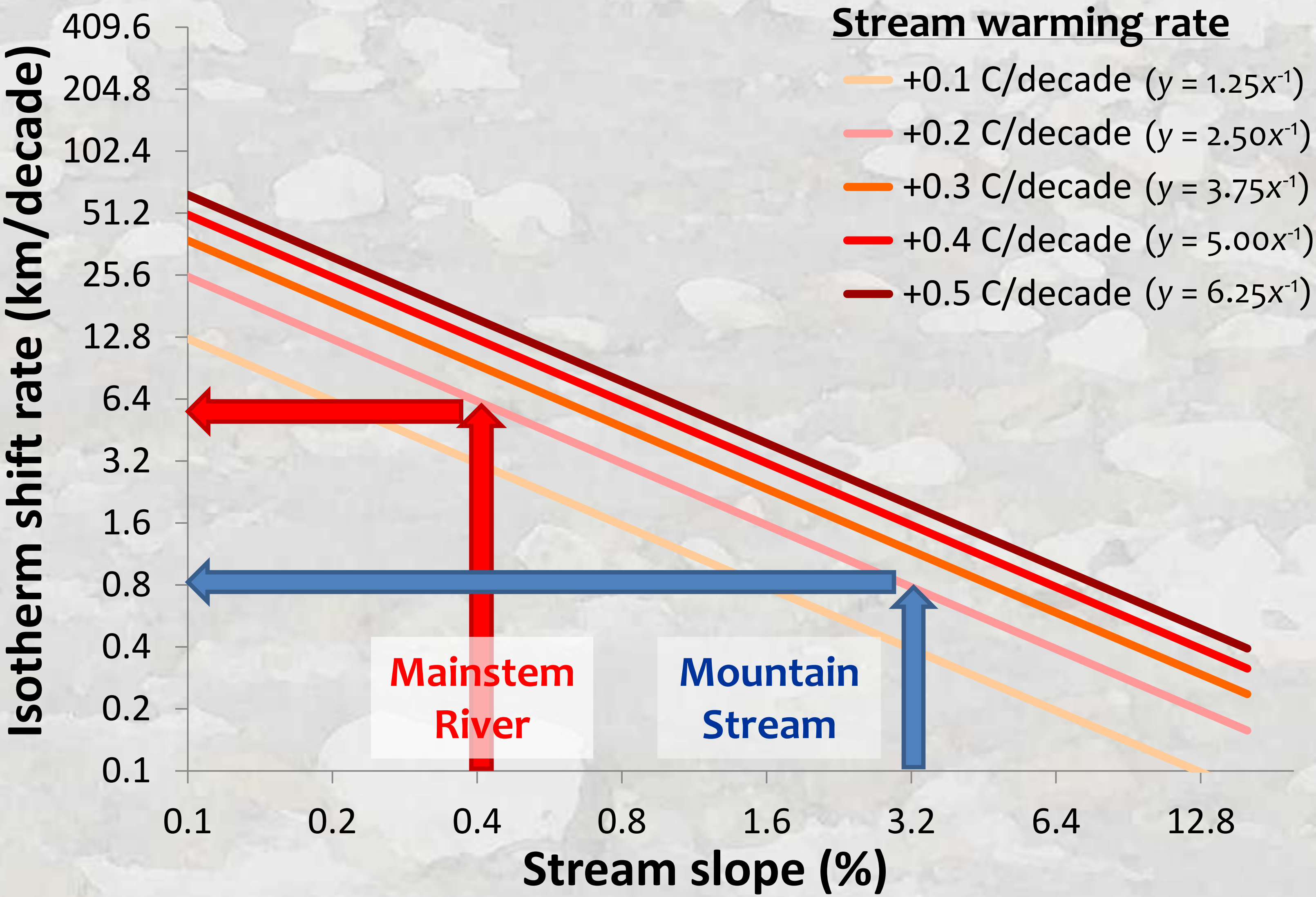
Climate Velocity Map for River Network



Isaak & Rieman. 2013. *Global Change Biology* **19**:742-751.

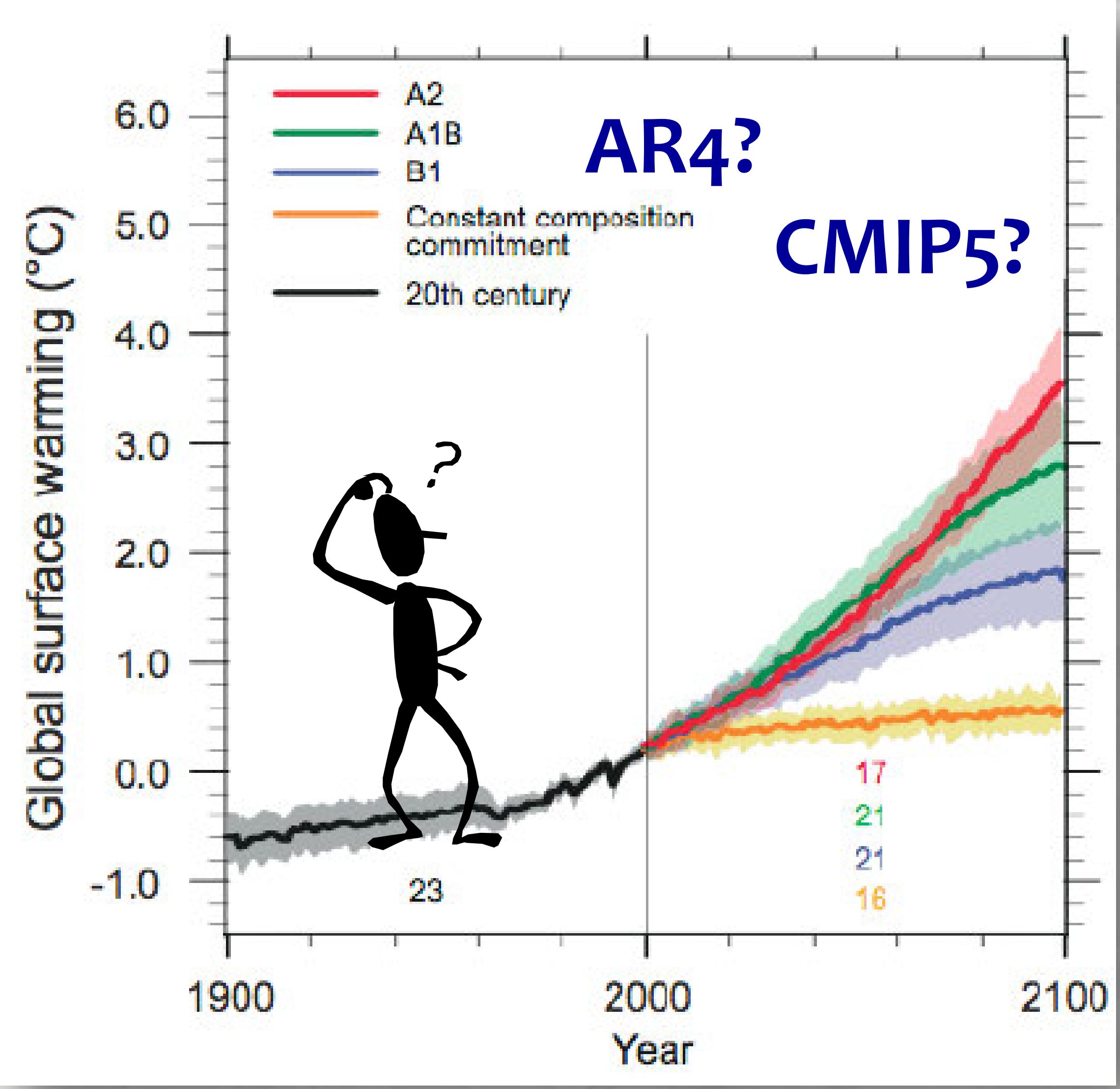
Isotherm Shift Rate Curves

Stream lapse rate = 0.8 °C / 100 m



Isaak & Rieman. 2013. *Global Change Biology* **19:**742-751.

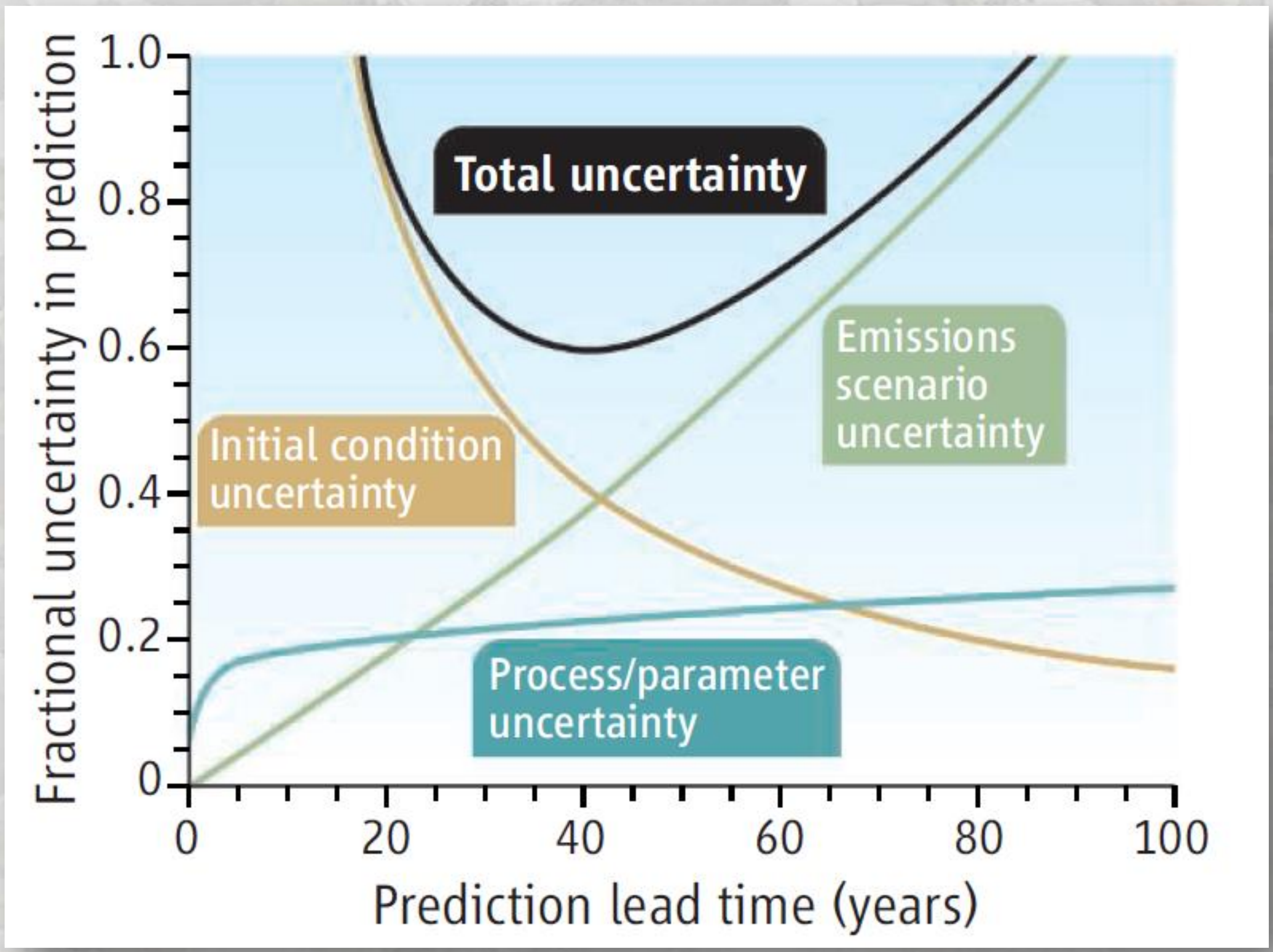
Which Emissions Scenario to Choose?



The Specifics are an "Unknowable Unknown"

Just plan on it gradually getting warmer…

Biggest Uncertainty is Future GHG Emissions

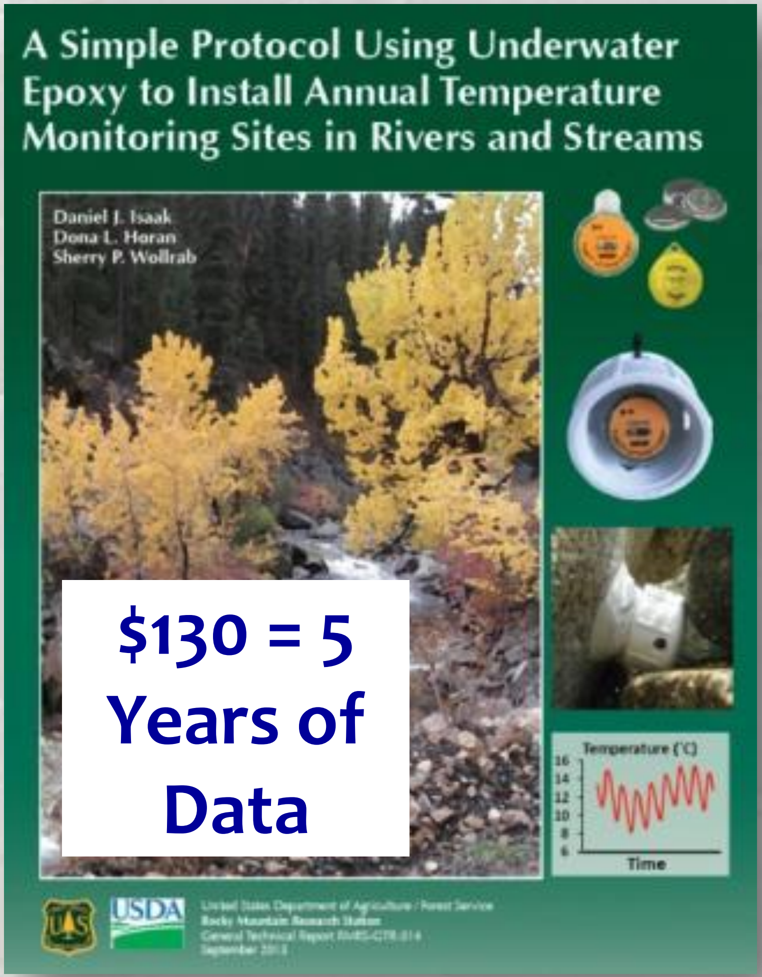


Cox & Stephenson 2007. A changing climate for predictions. *Science* **317**:207-208

Worry About What We Can Control

Good Monitoring Significantly Reduces Uncertainty

New Protocols & Sensors Make It Easy & Inexpensive



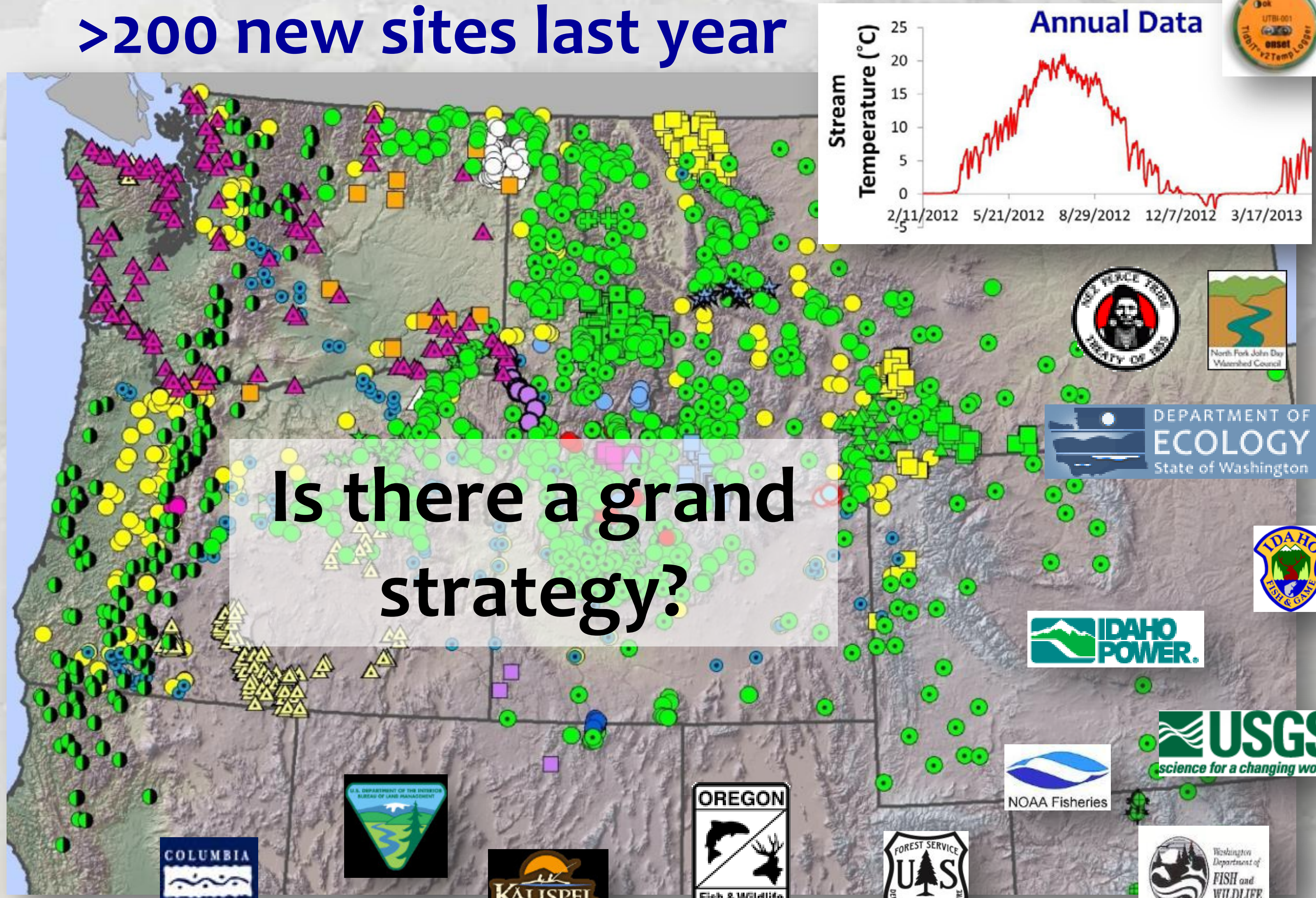
$130 = 5 Years of Data

FLOW too!

Annual Temperature Monitoring is Increasing

>3,000 sites in Pacific Northwest

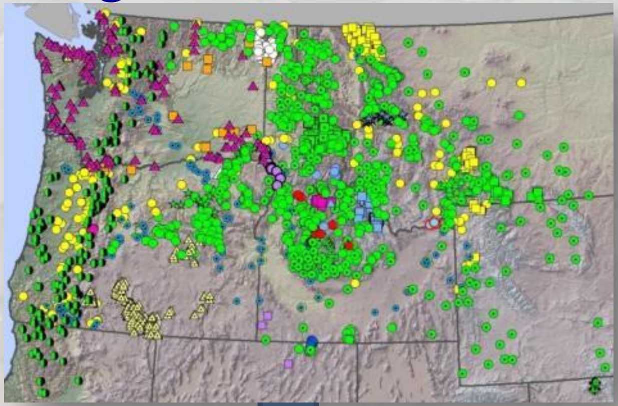
>200 new sites last year



Is there a grand strategy?

A GoogleMap Tool for InterAgency Coordination of Annual Monitoring Sites

Regional Sensor Network



Site Information

- Stream name
- Data steward contact information
- Agency
- Site Initiation Date

Query Individual Sites

GoogleMap Tool at "**Stream Temperature Monitoring and Modeling**" website

Don’t Miss Obvious by Looking too Far Ahead

Thermal Constraints on Salmon are Here Now…

1) Migration delays & clustering
near coldwater refuges

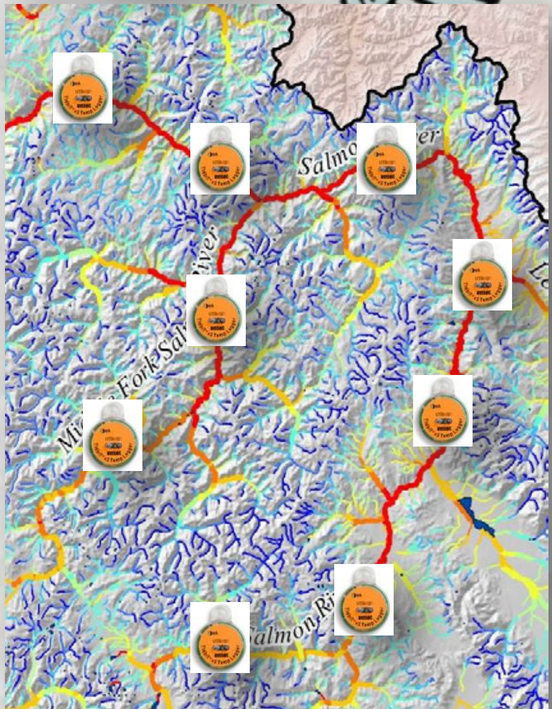
2) Fishing season closures

3) Selective gradients based
on run timing

4) Mass mortality events:
   a) upriver stocks of Fraser
   river sockeye “disappear”
   b) spawning ground fish kills

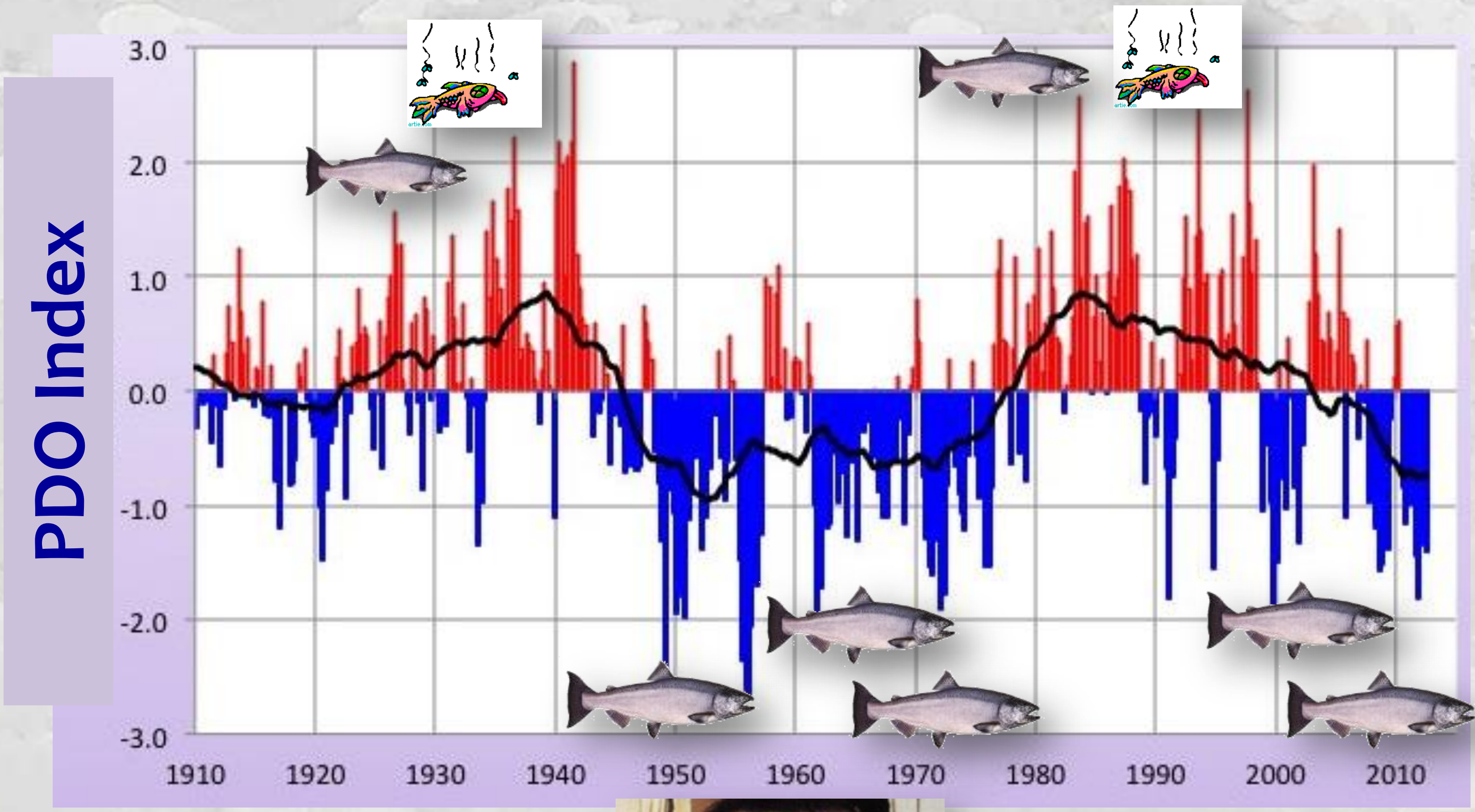
Real-Time River Temperature Networks

Short-term Forecasts Critical for Salmon

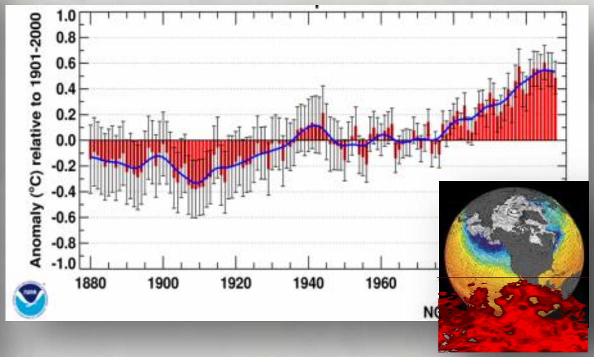


We need
fish weather
forecasts by…

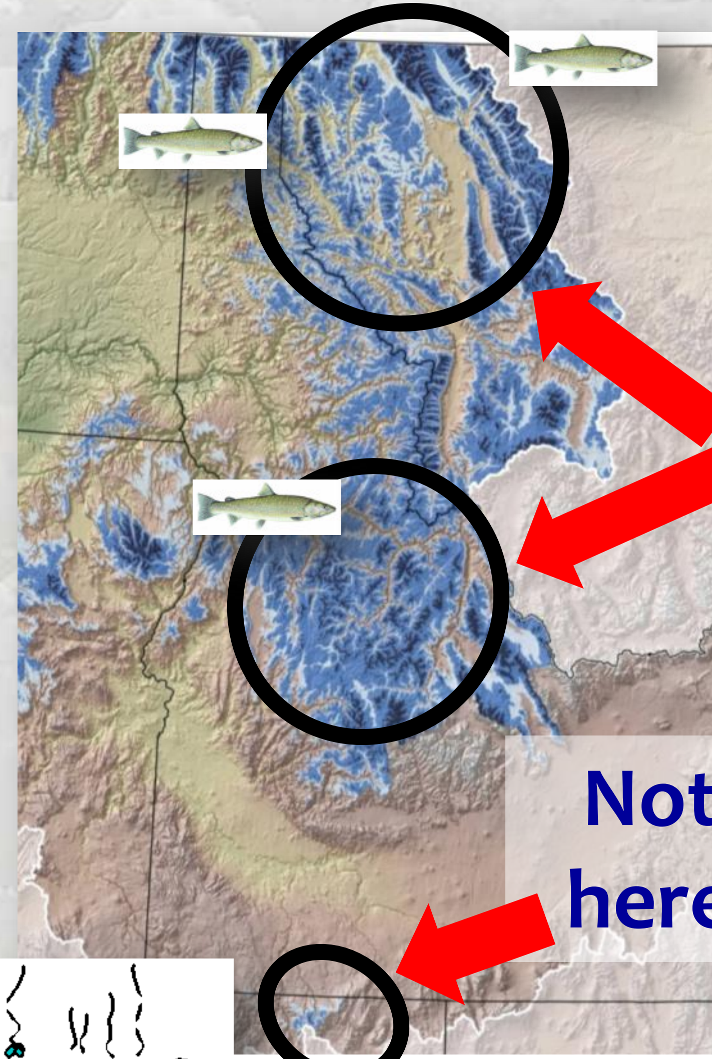
PDO Is Buying us Time…



“but I’ll be Back…”



Developing Good Scientific Information is the Easy Part, butt…



Invest Here

Not here

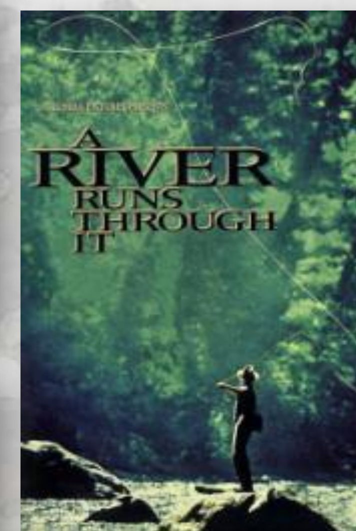
Sorry Charlie

Developing Good Scientific Information is the Easy Part, butt…

Sorry Charlie

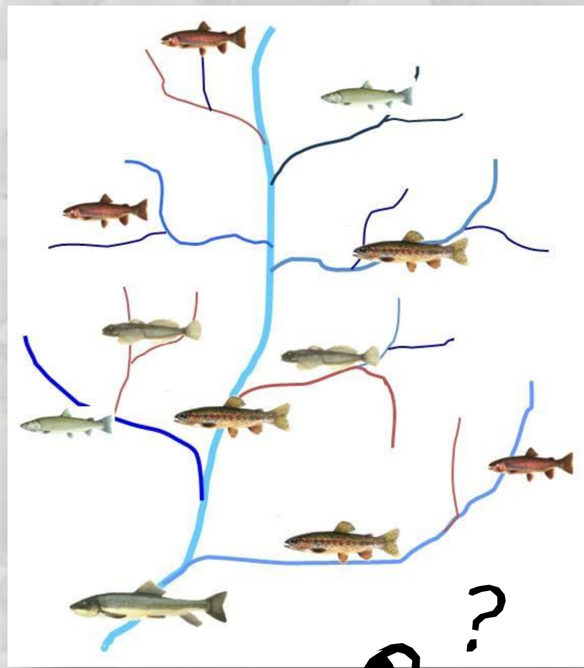
… we're not dealing with rational creatures here

People Love These Fish & Landscapes



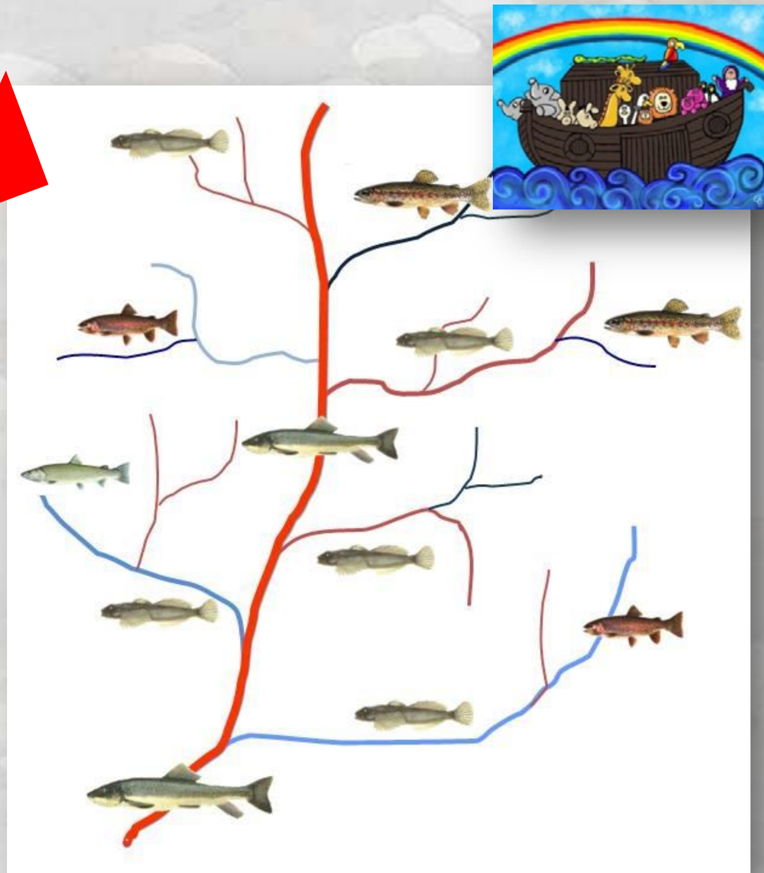
The 21st-Century will Be a Transitional One

Current Status

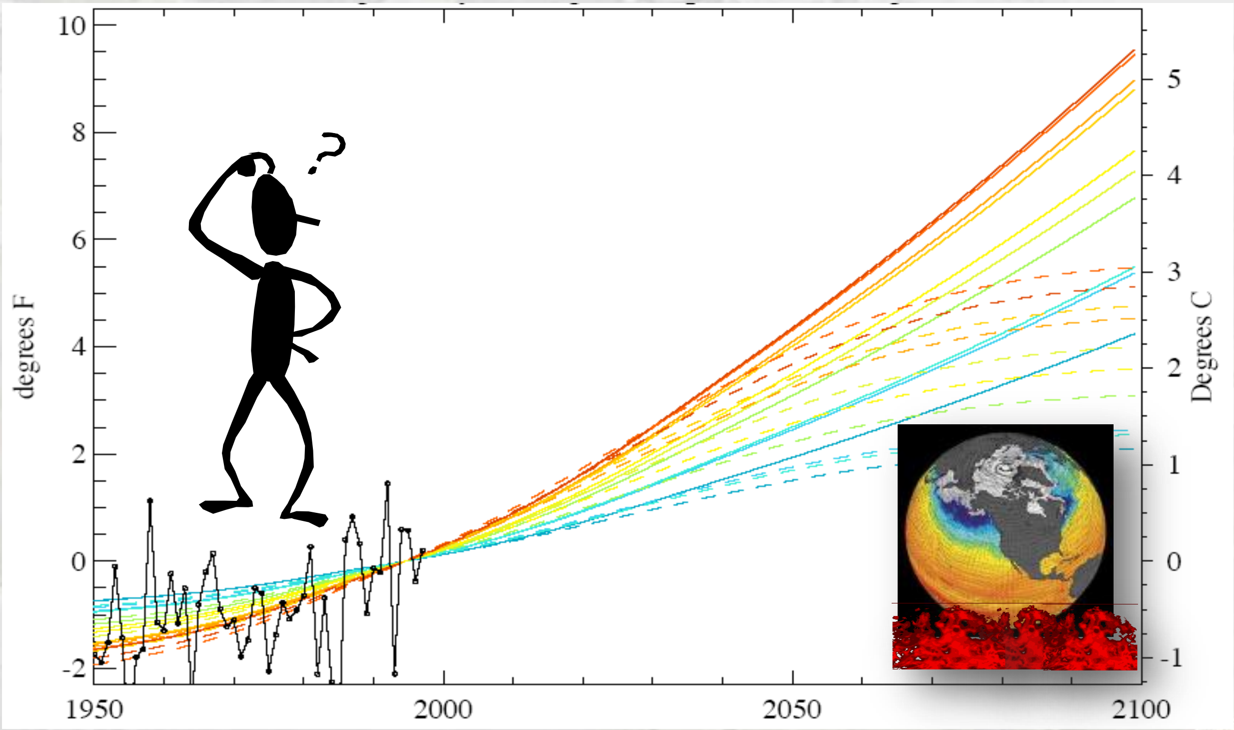


We'll Have to Make Choices About Where to Invest

Desired Future Status



The Sooner (& Smarter) We Act,
The Bigger the Long-term Impact…

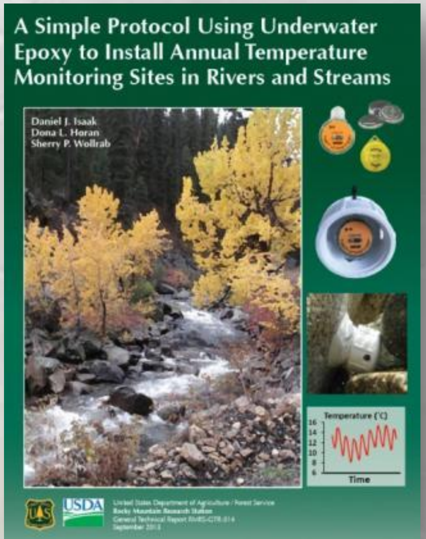


Stream Temperature Resources…

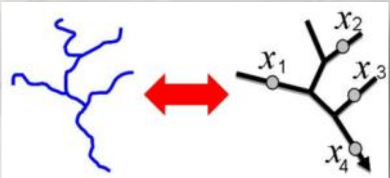
Websites (Google Search On…)

1) ***SSN/STARS*** – statistical modeling of data on networks
2) ***NorWeST*** – regional stream temperature database & climate scenarios
3) **Stream Temperature Modeling & Monitoring**

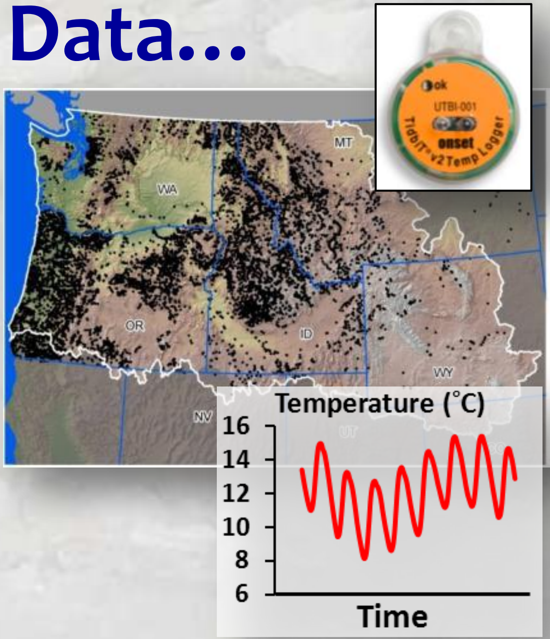
Publications…



Software…



Data…



The End