Space, Time, and Temperature in Streams:
Towards a General Framework for Understanding and Prediction of Thermal Regimes

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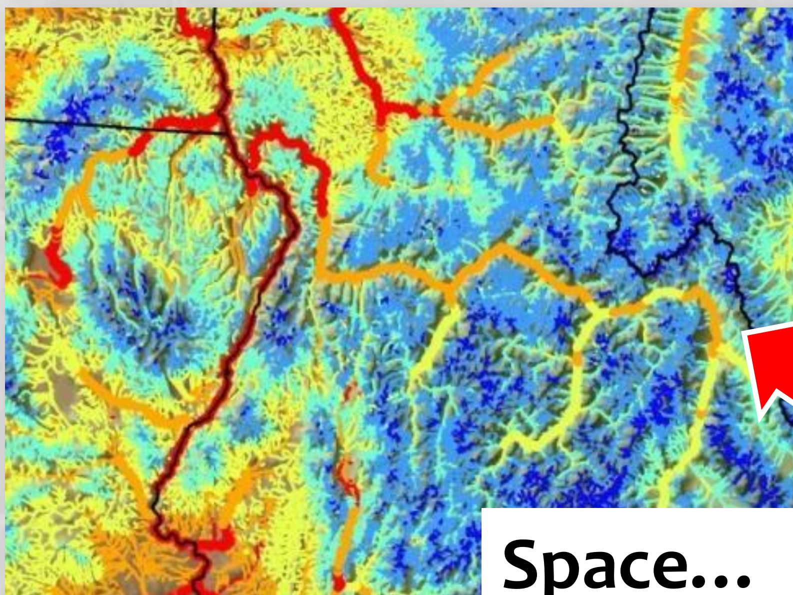
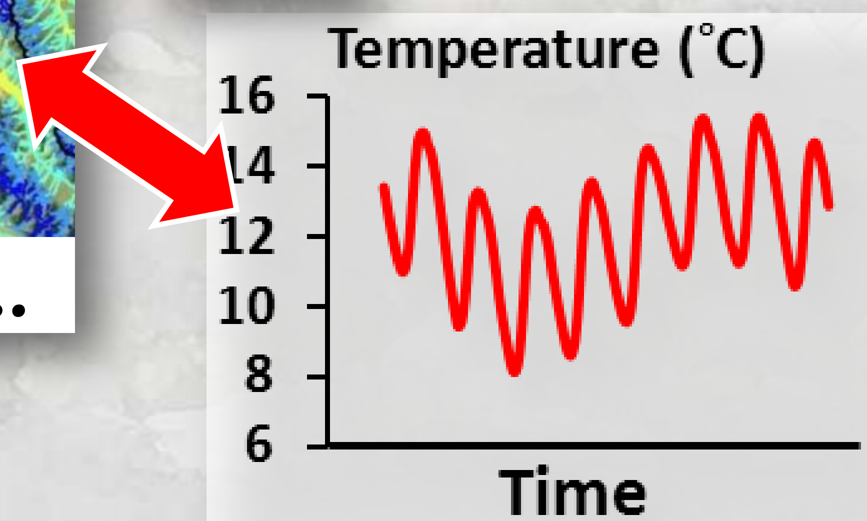
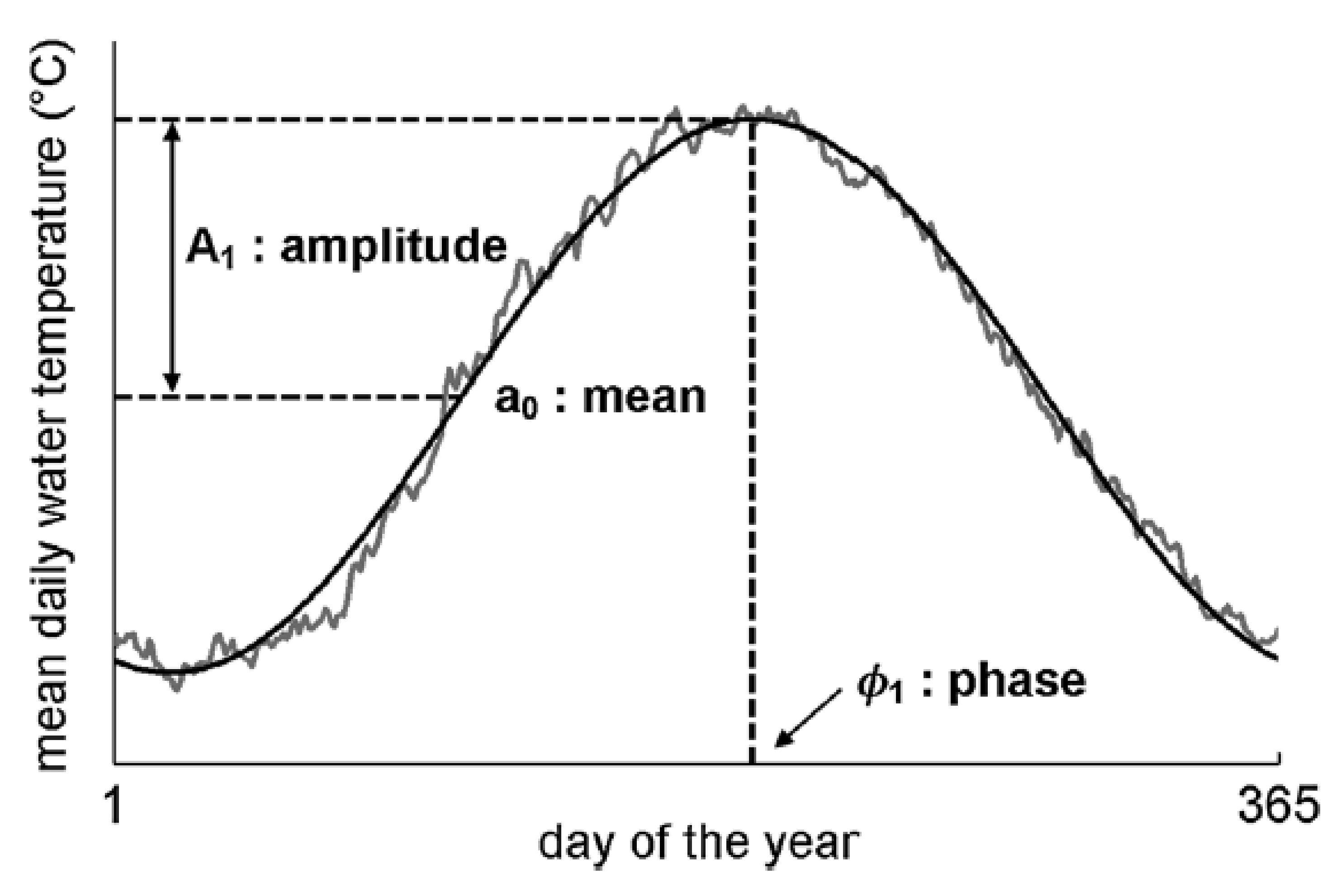




What is a Regime?

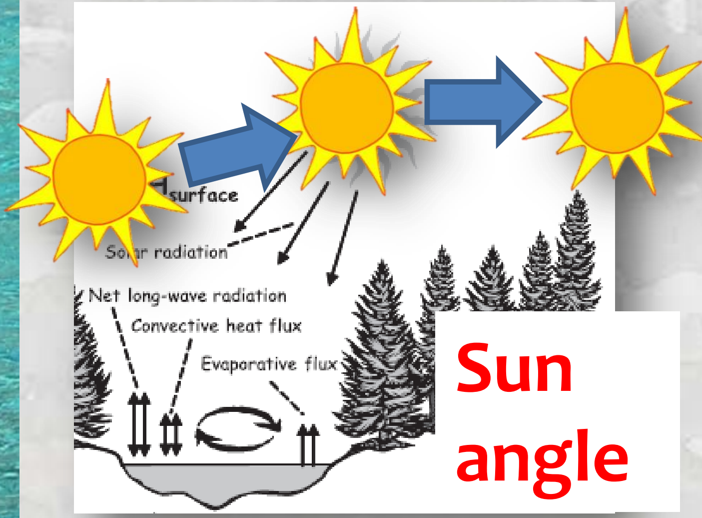
Temporal variation characteristic to a site

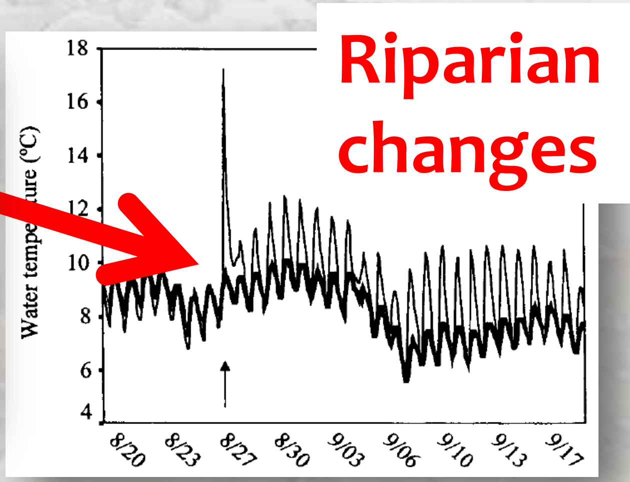


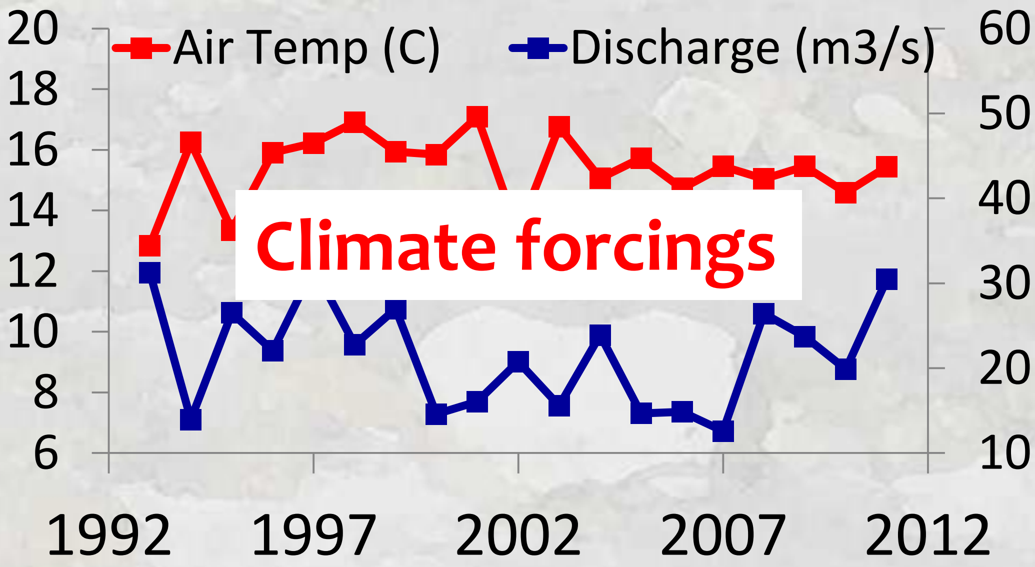
Maheu et al. 2015. A classification of stream water temperature regimes. *River Research & Applications*

Factors Causing Temporal Variation

Environmental covariates

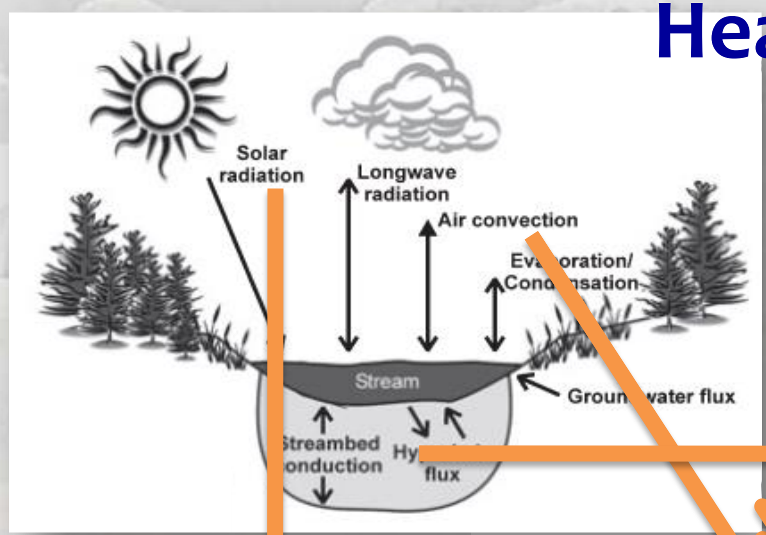






Factors Causing Temporal Variation

Heat budget mechanisms



Shortwave radiation

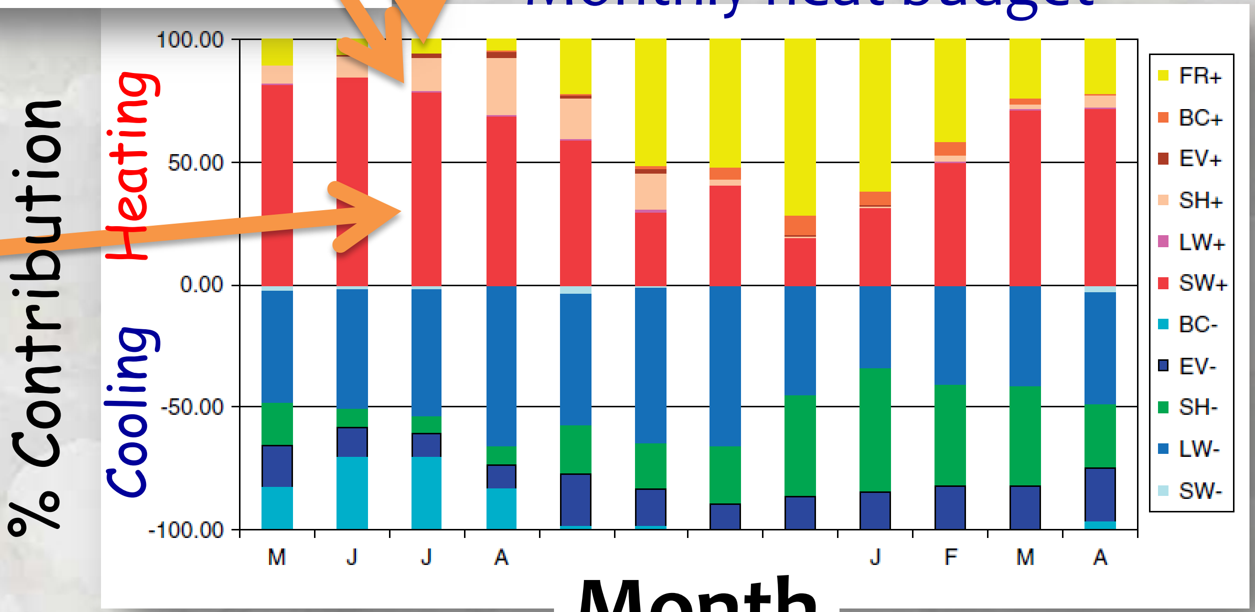
Sensible heat

Longwave radiation

Bed friction

Advection

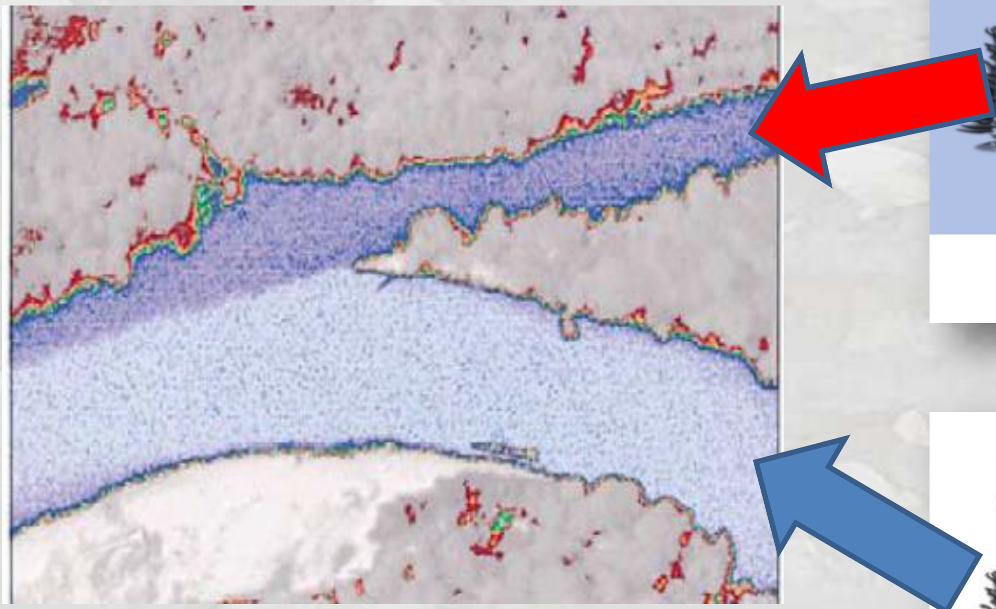
Monthly heat budget

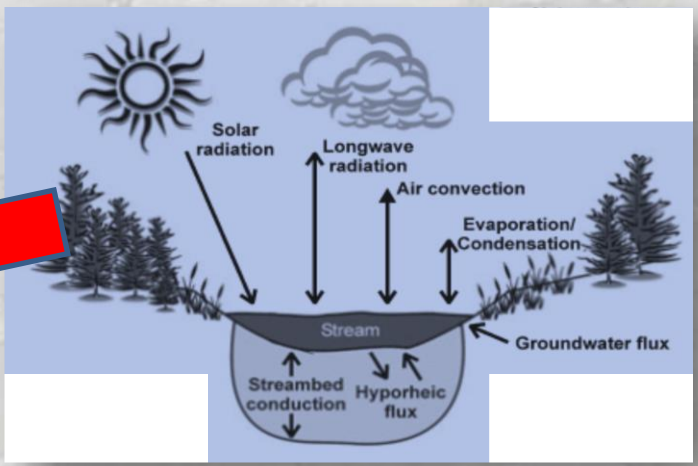


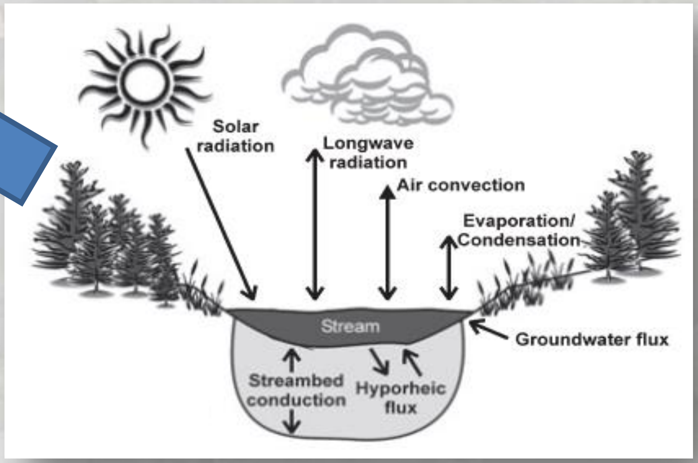
Webb et al. 2008. Recent advances in stream and river temperature research. *Hydrological Processes* **22**: 902-918.

Regimes Vary in Space

Covariates & heat budgets differ in different places



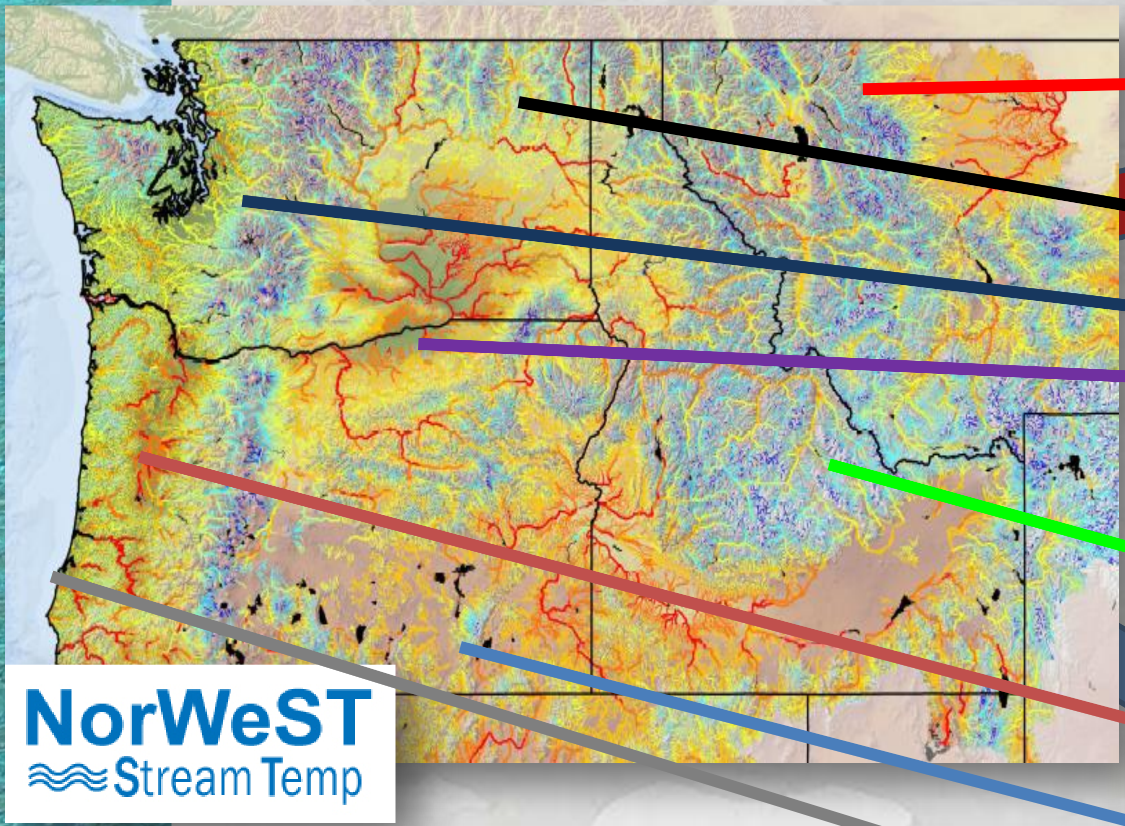


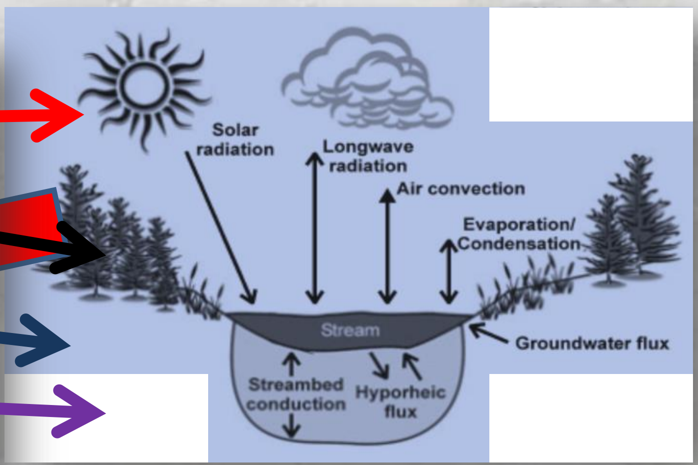


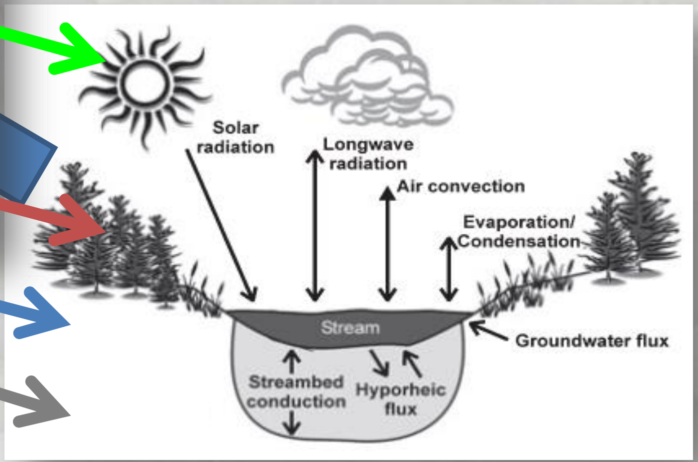
Regimes Vary in Space

Covariates & heat budgets differ in different places

~300,000 stream kilometers







Regimes Vary in Space

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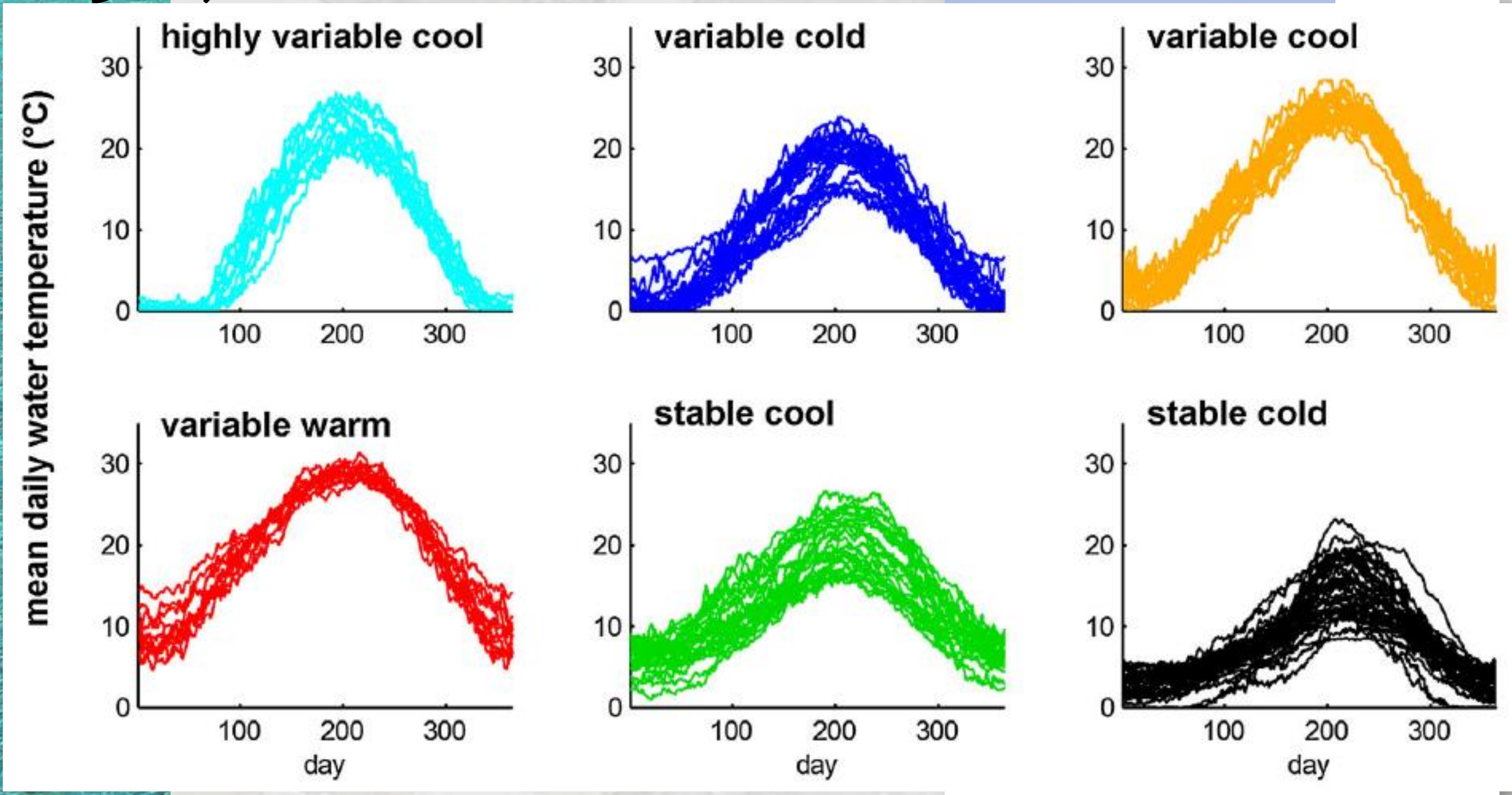
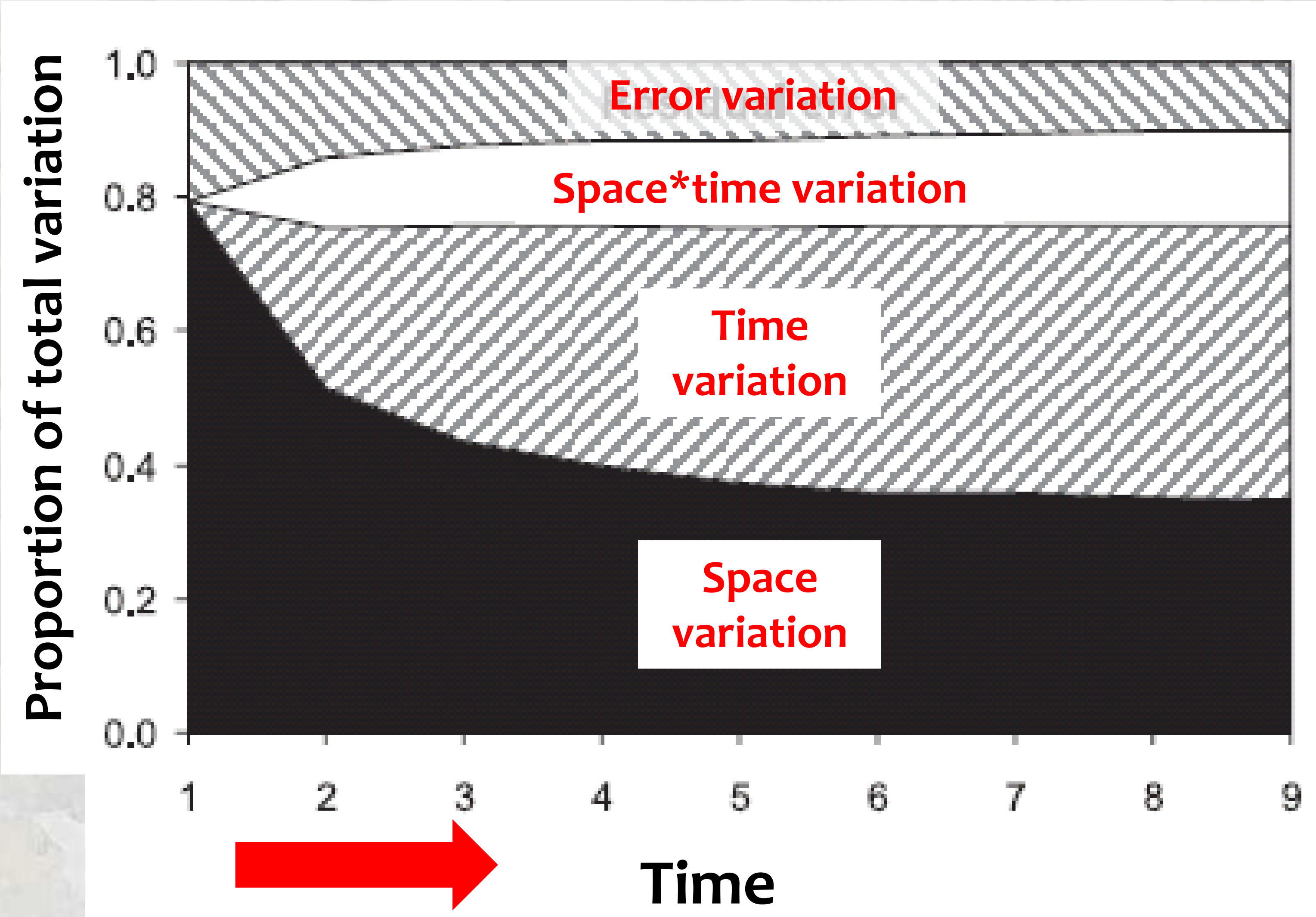


Maheu et al. 2015.

It's Complex, but 100% Variance Covers It

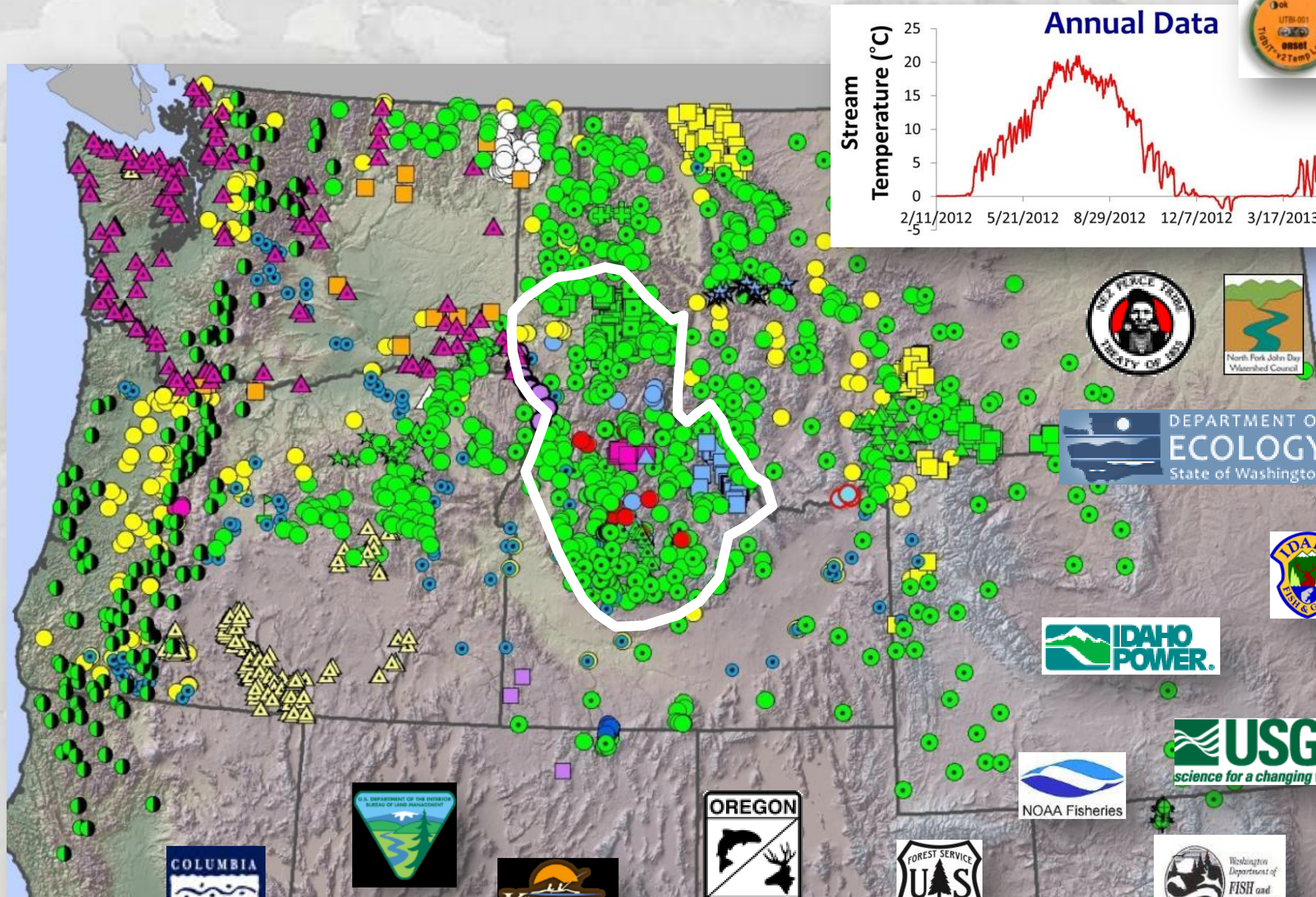
Space-Time ANOVA Variance Decomposition

$$Var_{total} = Var_{space} + Var_{time} + Var_{S*T} + error$$

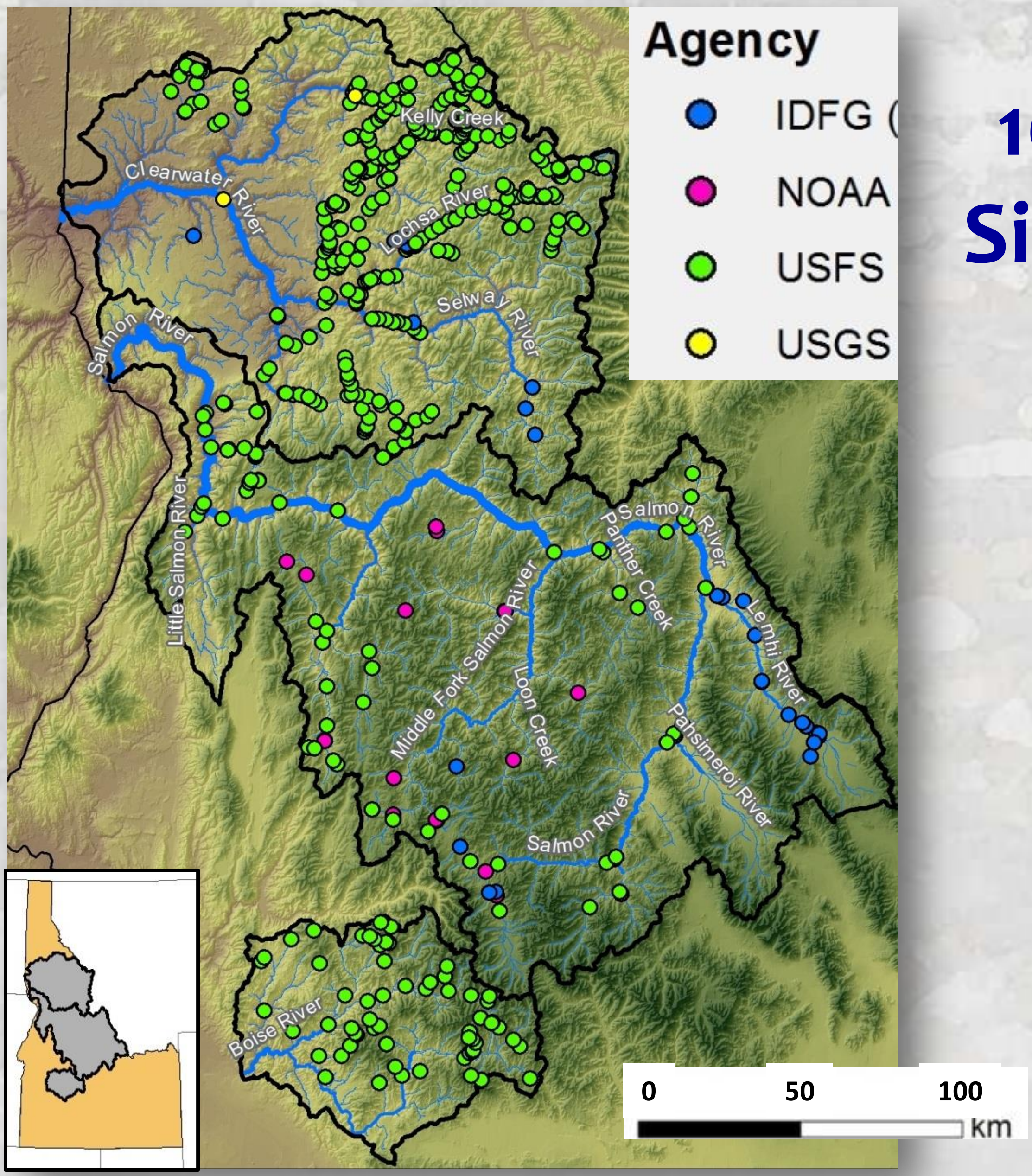


An Example with Real Data

~4,000 annual monitoring sites in PNW



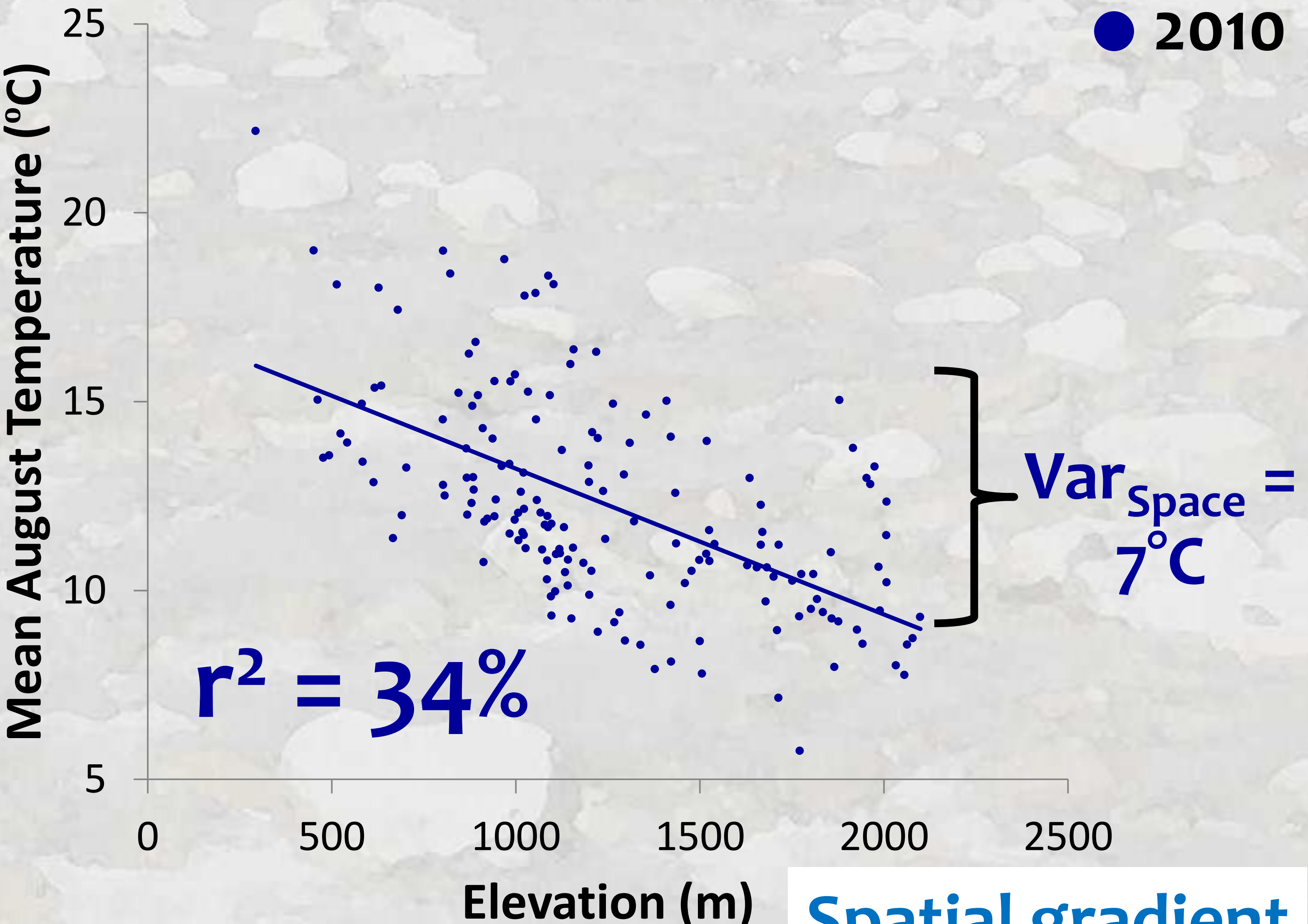
Central Idaho Temperature Network



167 Sites
Since 2010

Space-Time Variance Decomposition

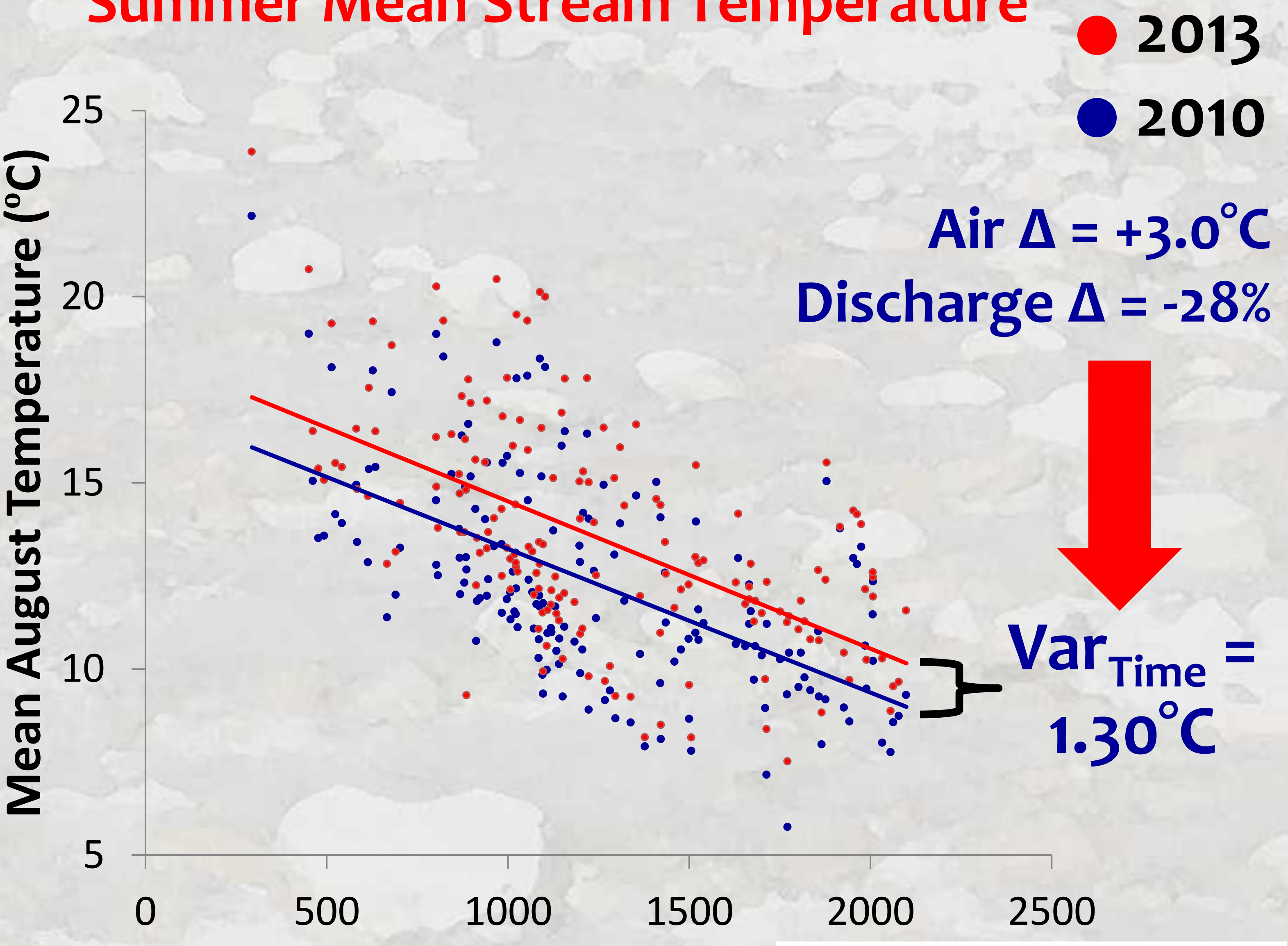
Summer Mean Stream Temperature



Spatial gradient

Space-Time Variance Decomposition

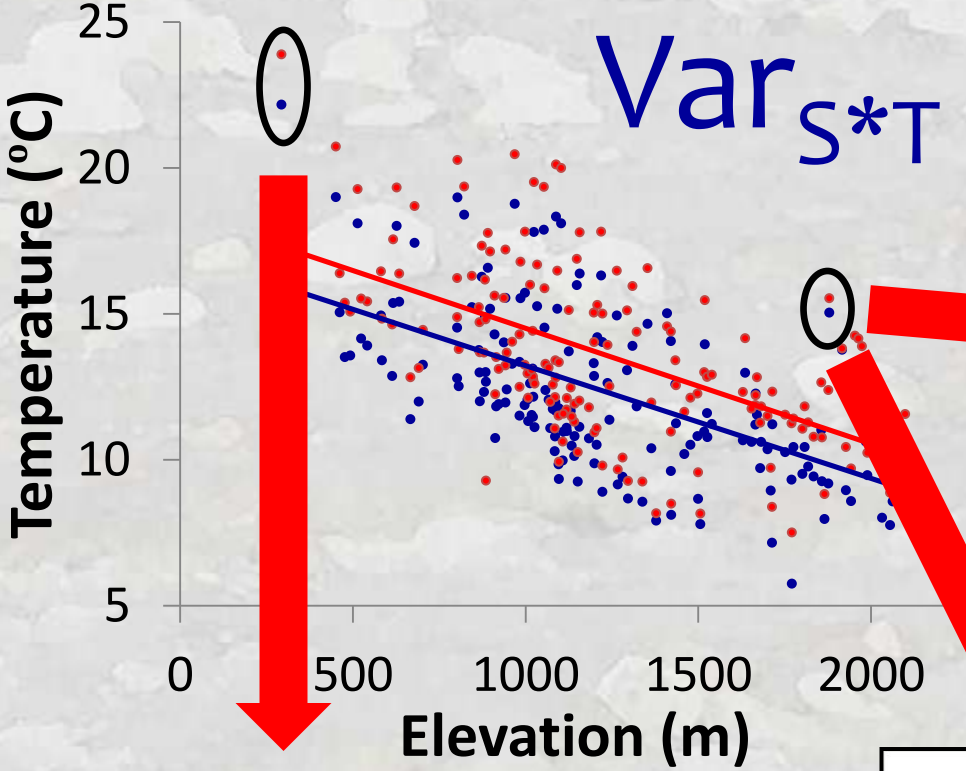
Summer Mean Stream Temperature

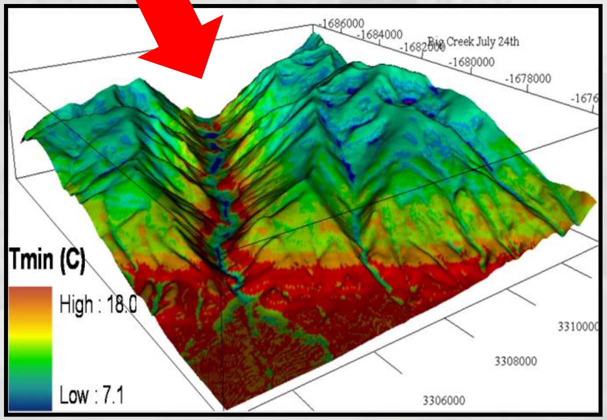


Spatial gradient

Space-Time Variance Decomposition

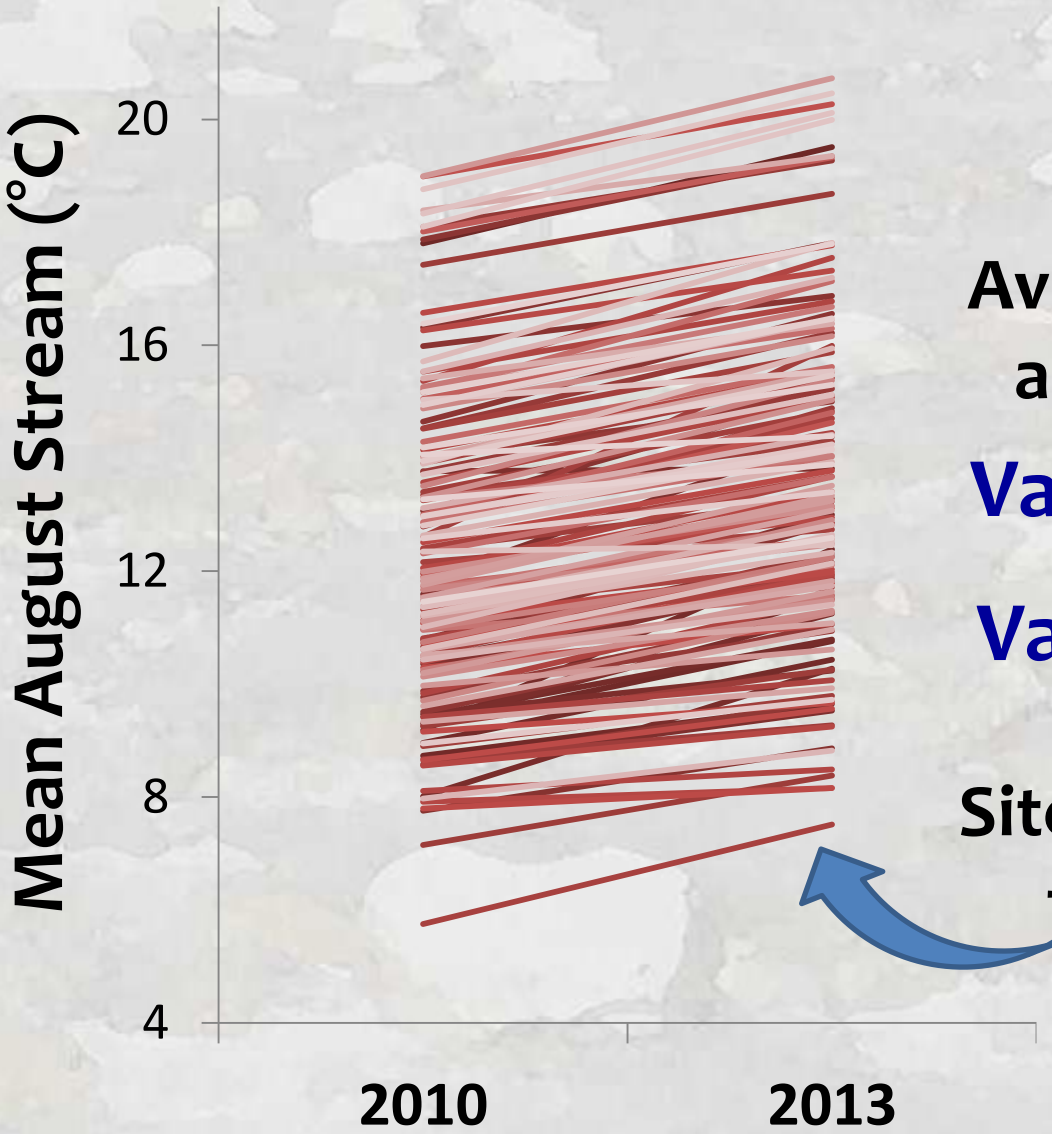
Summer Mean Stream Temperature





Space-Time Variance Decomposition

Summer Mean Stream Temperature



Average change across sites =

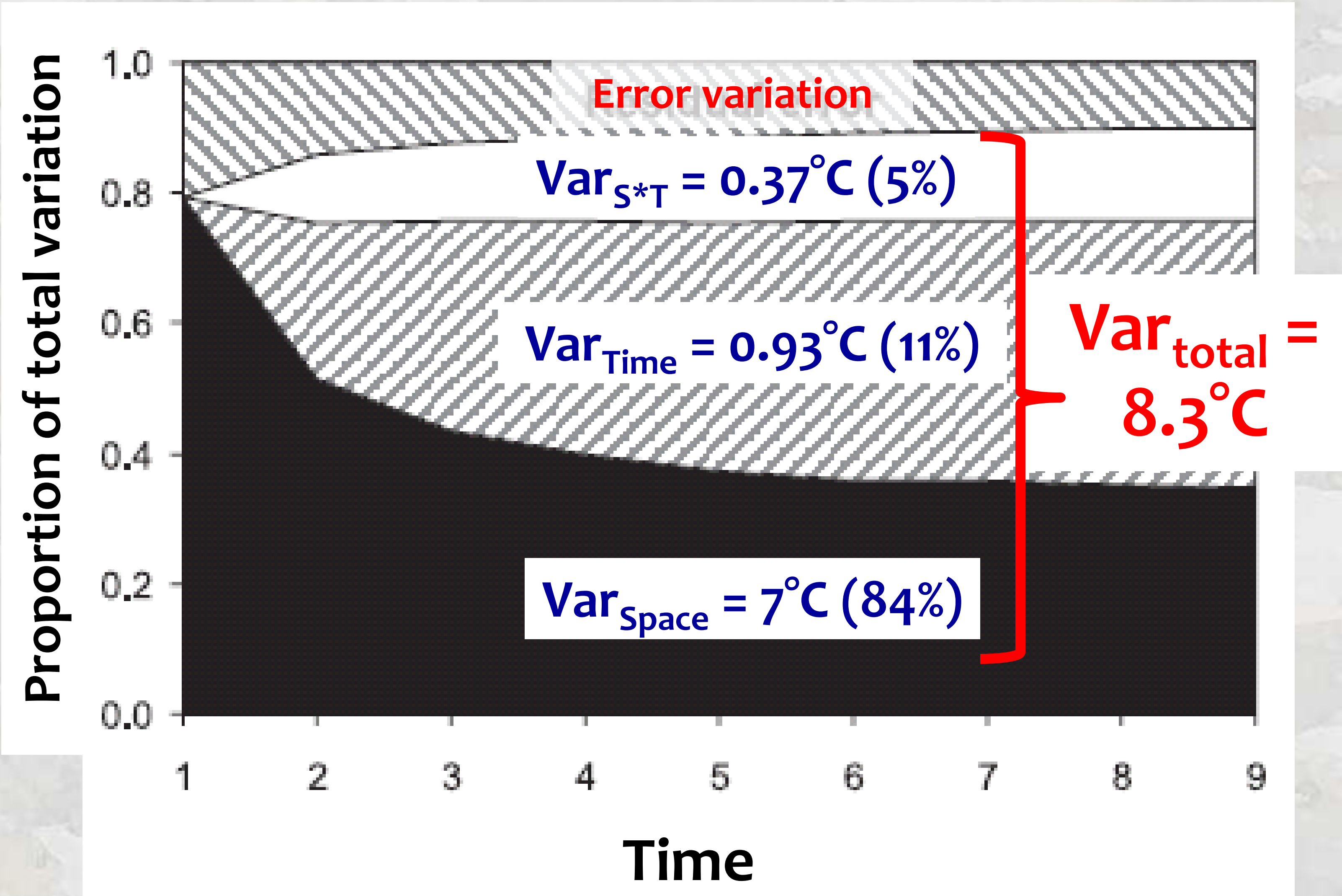
Var_{Time} = 1.30°C

Var_{S*T} = 0.37°C

Site level deviation from average change

Space-Time ANOVA Variance Decomposition

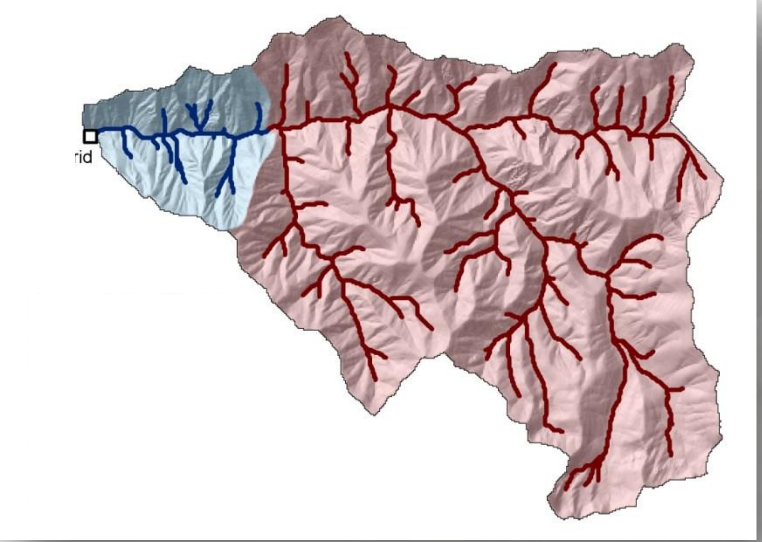
$$Var_{total} = Var_{space} + Var_{time} + Var_{S*T} + error$$



Different Extent & Grain = Different Variance Structure (spatial dimension)

Big network = great spatial heterogeneity

Small network = little spatial heterogeneity



Kotlier and Wiens 1990

Same Extent & Different Grain = Different Variance Structure

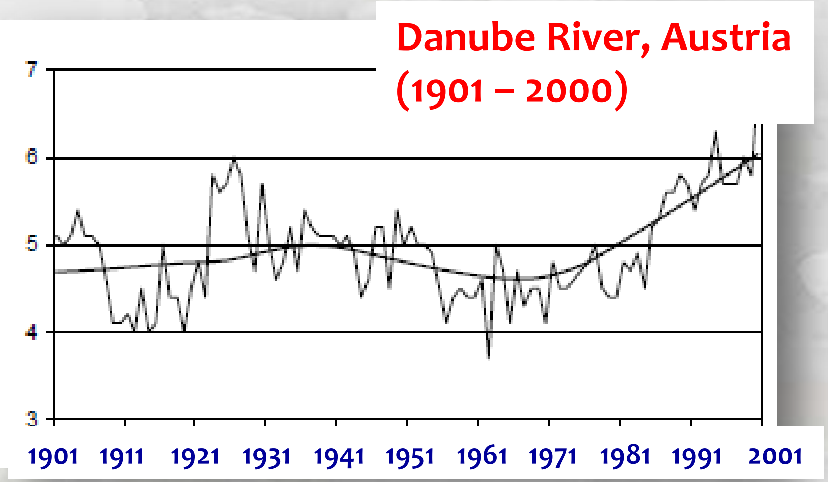
Big network = sparsely sampled

Big network = densely sampled

Kotlier and Wiens 1990

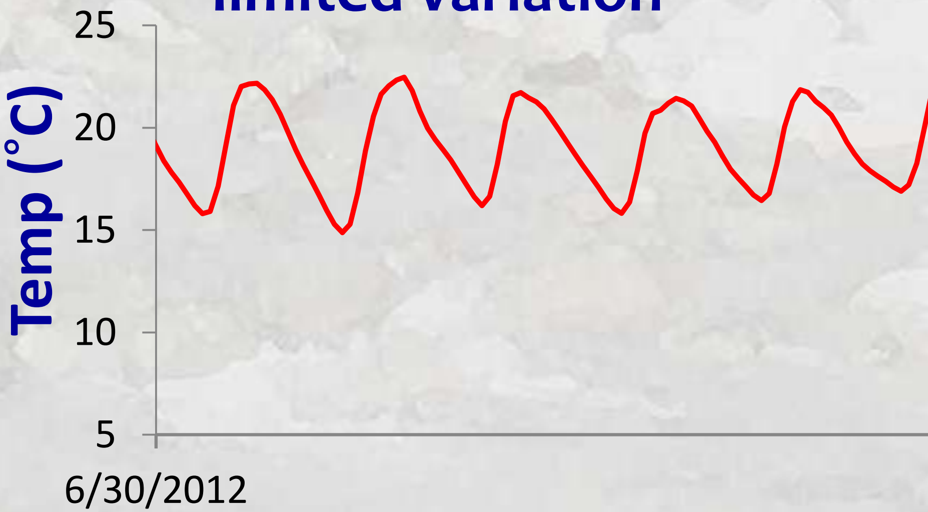
Different **Extent** & Grain = Different Variance Structure (temporal dimension)

Long duration (100 years) = much variation



Webb and Nobilus 2007

Short duration (1 week) = limited variation



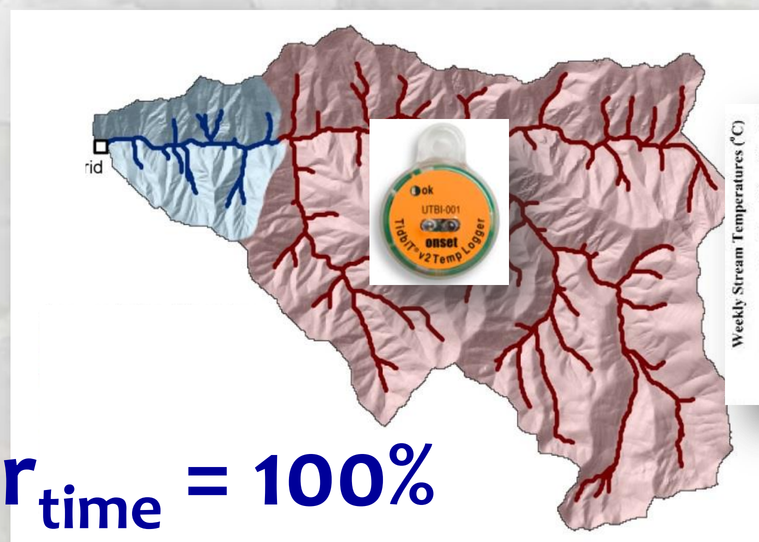
Kotlier and Wiens 1990

Different Extent & Grain = Different Variance Structure

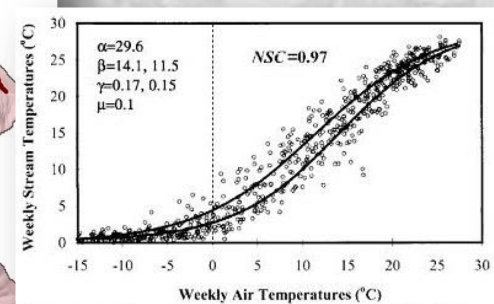
Short duration, densely sampled

Short duration, sparsely sampled

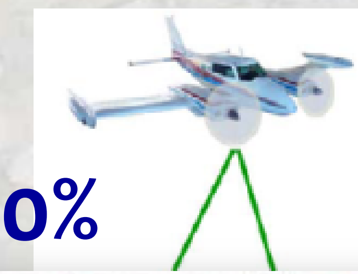
How We Model Also Affects Interpretation of Variance Structure



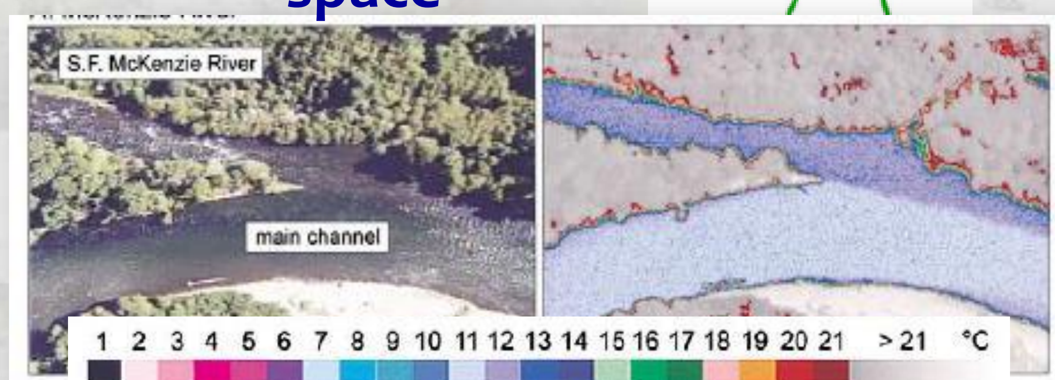
Mohseni curve



$\text{Var}_{time} = 100\%$

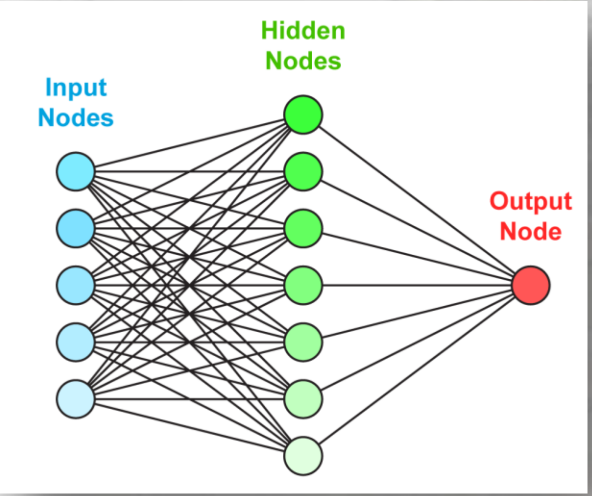


$\text{Var}_{space} = 100\%$

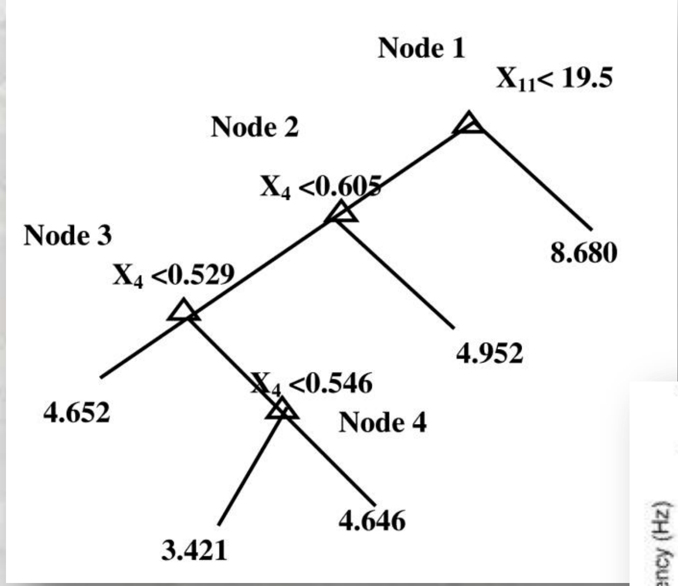


Many Accurate Predictive Tools…

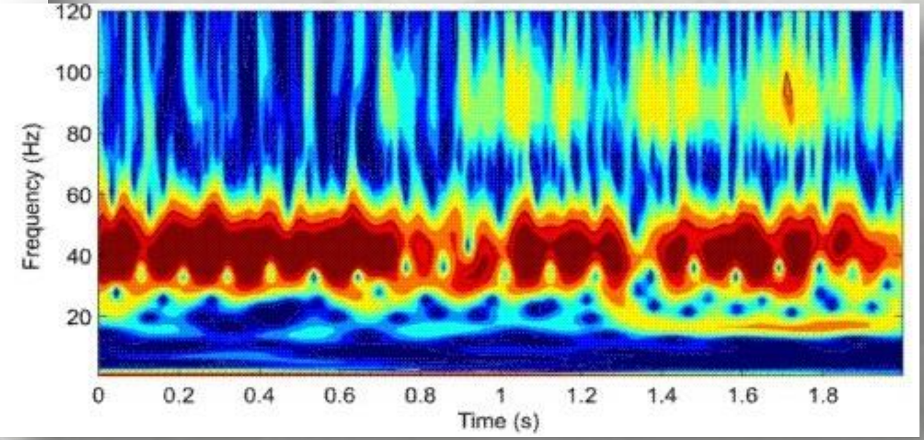
Neural networks



Regression trees



Wavelets

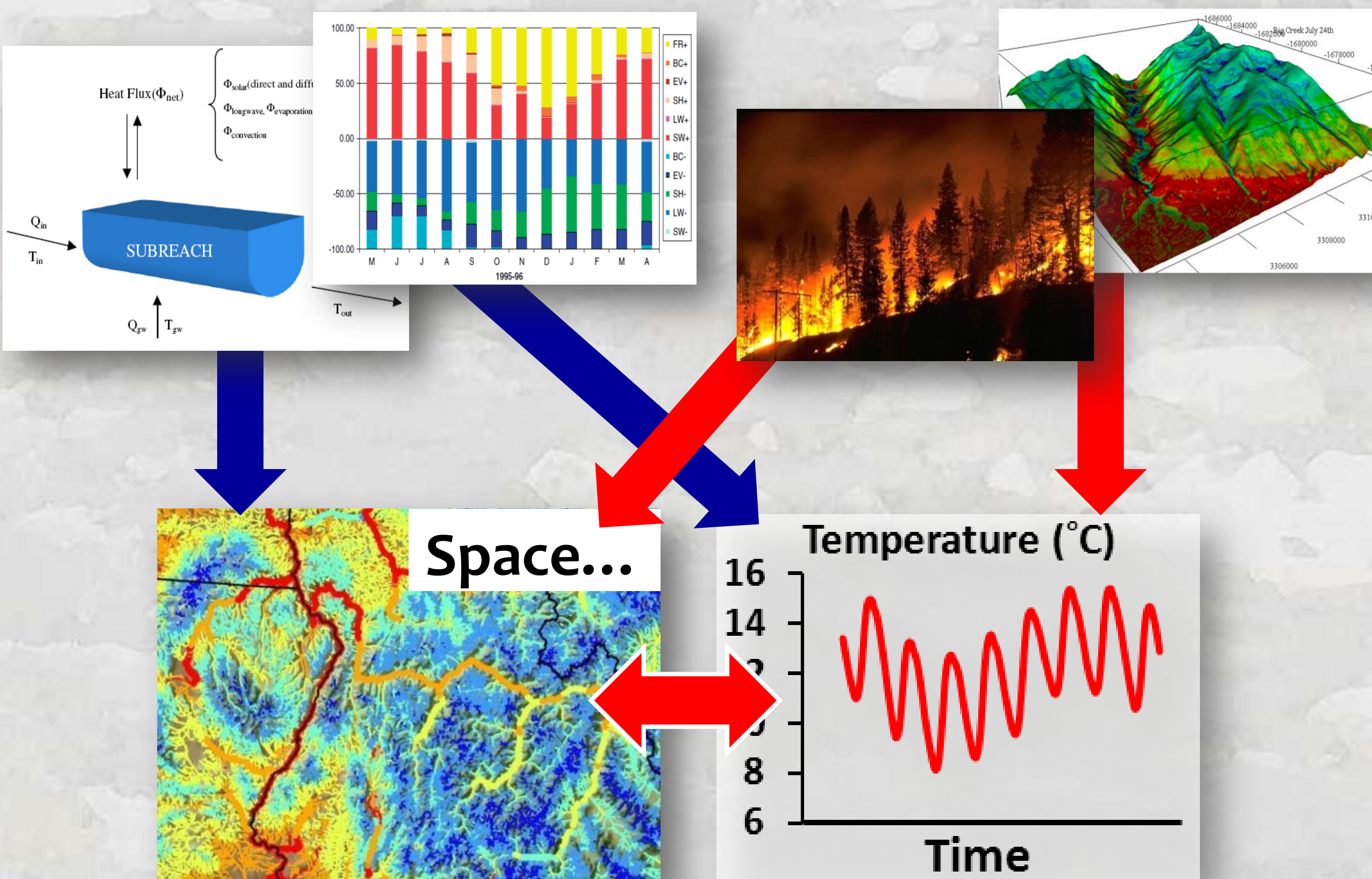


But Prediction ≠ Understanding

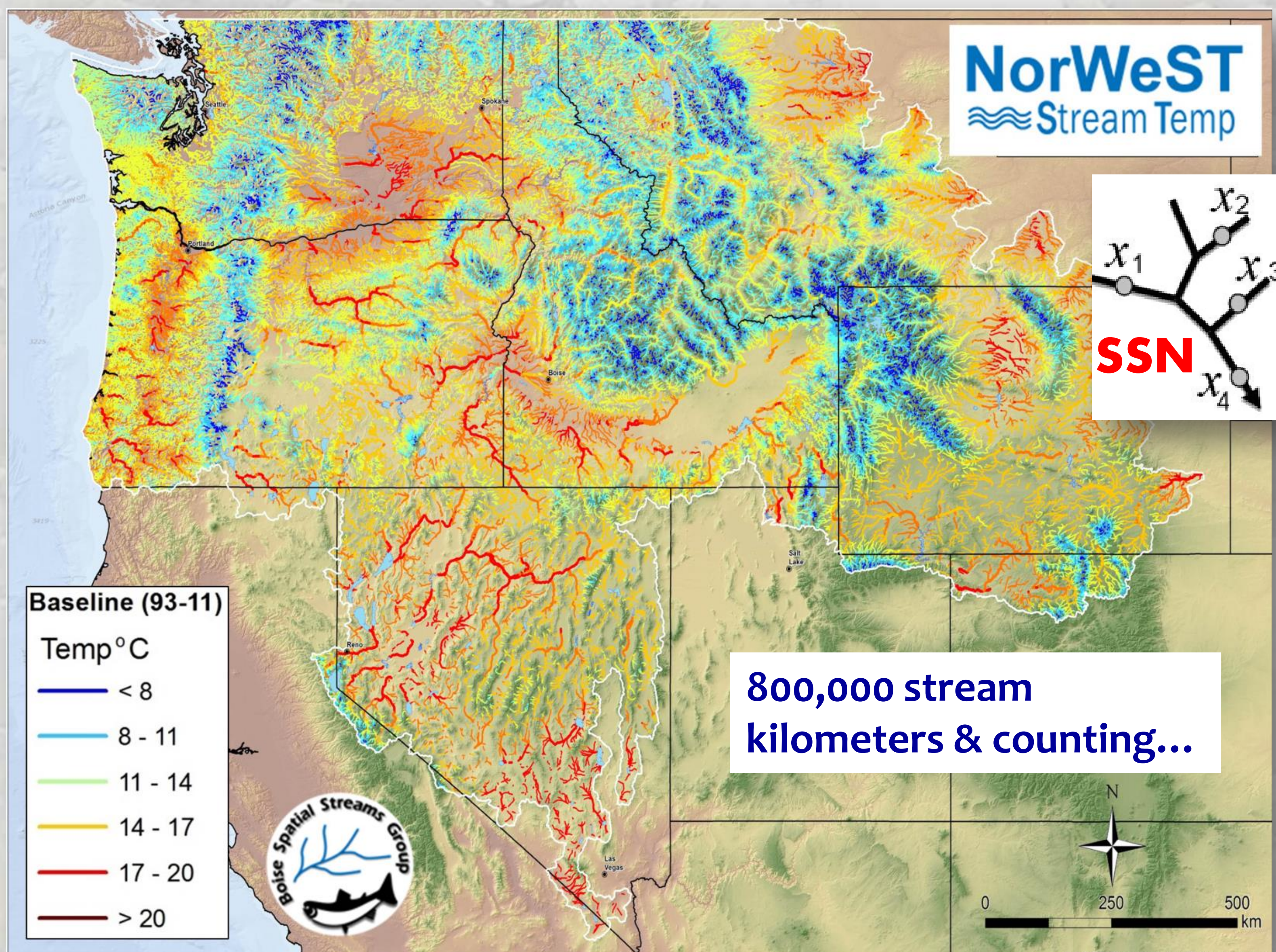
Understanding = Attribution of Variance

"Why" do temps change through space & time?

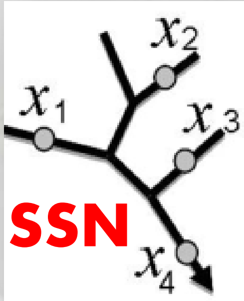
Mechanistic **Correlative**



An Attempt at Best of Both Worlds:
Understanding and Prediction



Accurate Prediction & Attribution of Variance to Covariates



n = 48,000 summers of data

21 years (1993-2013)

R^2 = 0.90

RMRS = 1.0°C

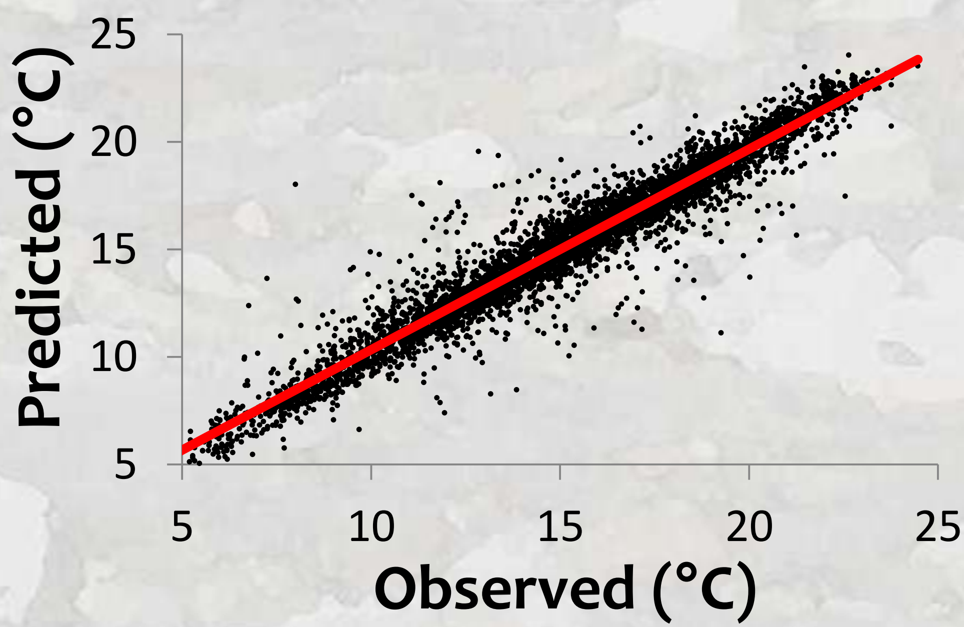
Covariate Predictors

Var_{space}

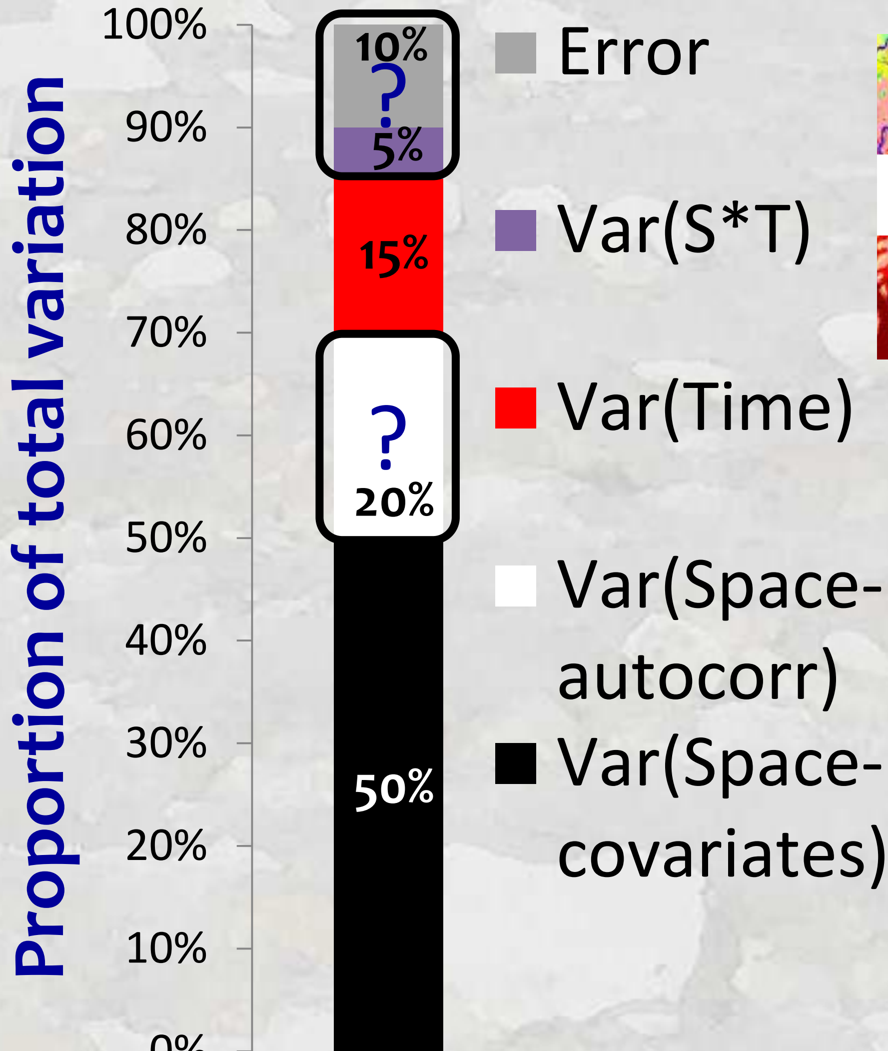
1. Elevation (m)
2. Canopy (%)
3. Stream slope (%)
4. Ave Precipitation (mm)
5. Latitude (km)
6. Lakes upstream (%)
7. Baseflow Index
8. Watershed size (km^2)
9. Glacier (%)

Var_{time}

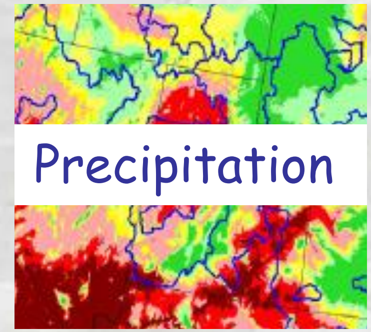
10. Discharge (m^3/s)
11. Air Temperature (°C)

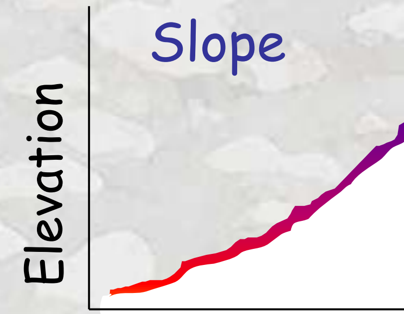


Measuring Covariates & Heat Budgets are Big Challenges

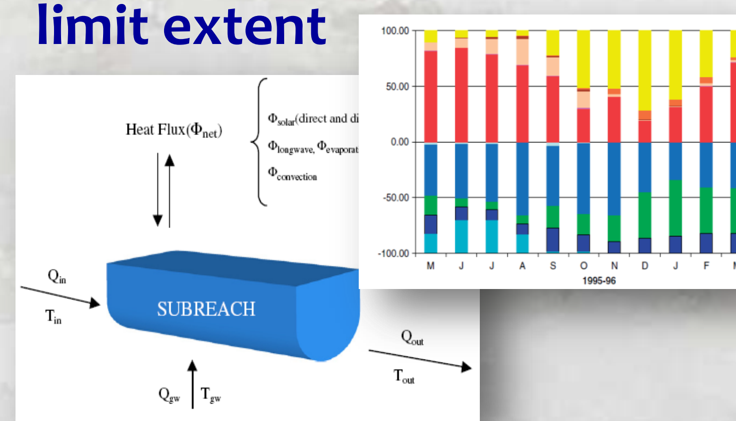


Correlative models = crude covariates limit understanding



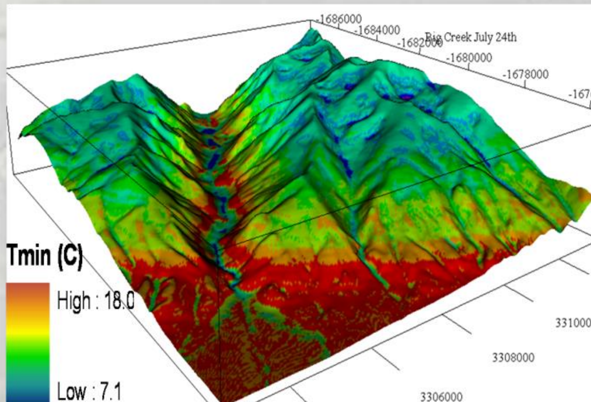


Mechanistic models = intensive measurements limit extent



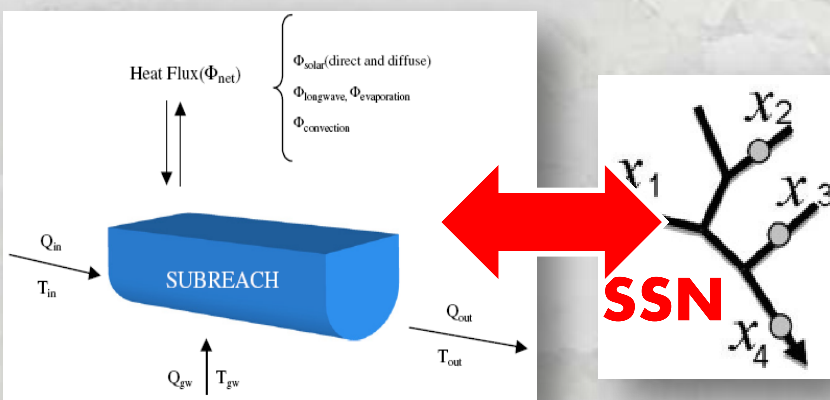
Measuring Covariates & Heat Budgets are Big Opportunities

High resolution air temperature models

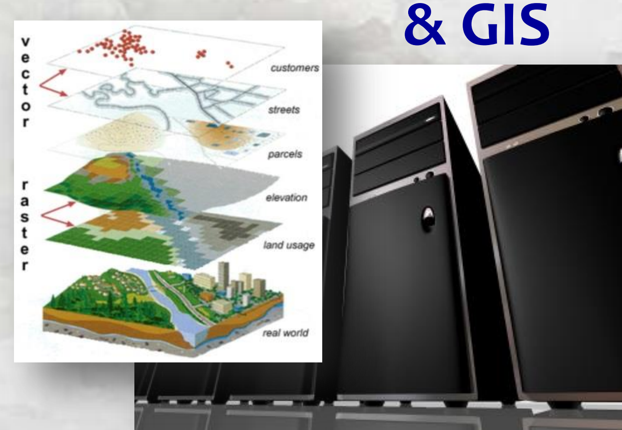


Satellite & drone sensors

Hybrid model approaches?



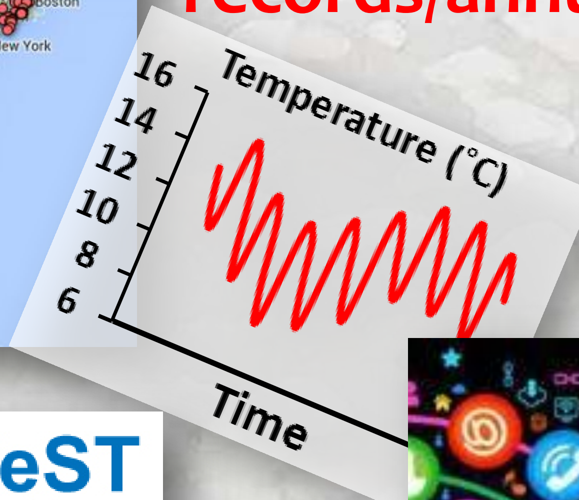
Bigger/faster computers & GIS

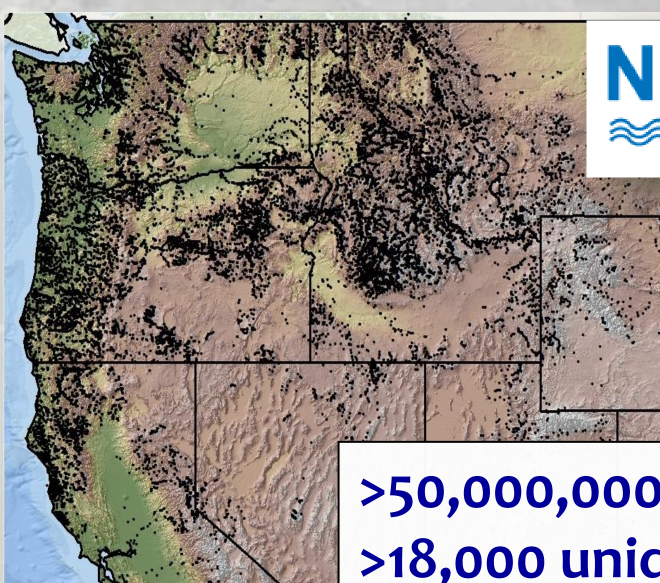


Data are not limiting

(>5,800 annual monitoring sites & growing)

~50,000,000 hourly records/annually!



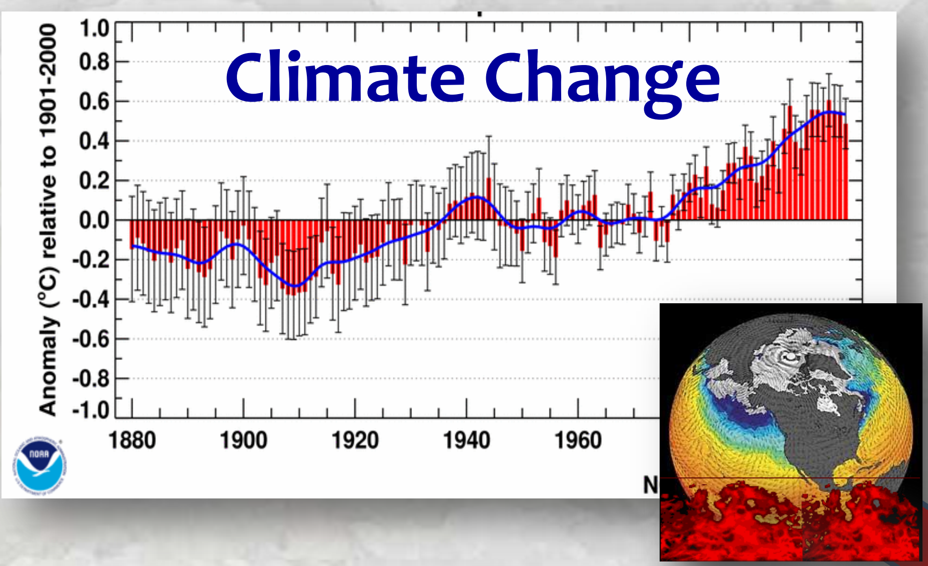


NorWeST Stream Temp

>50,000,000 hourly records
>18,000 unique stream sites

Challenges are Not Limiting

Need for better prediction & understanding will intensify



Urbanization &
Population Growth

Shrinking
Budgets

Need to do more
with less