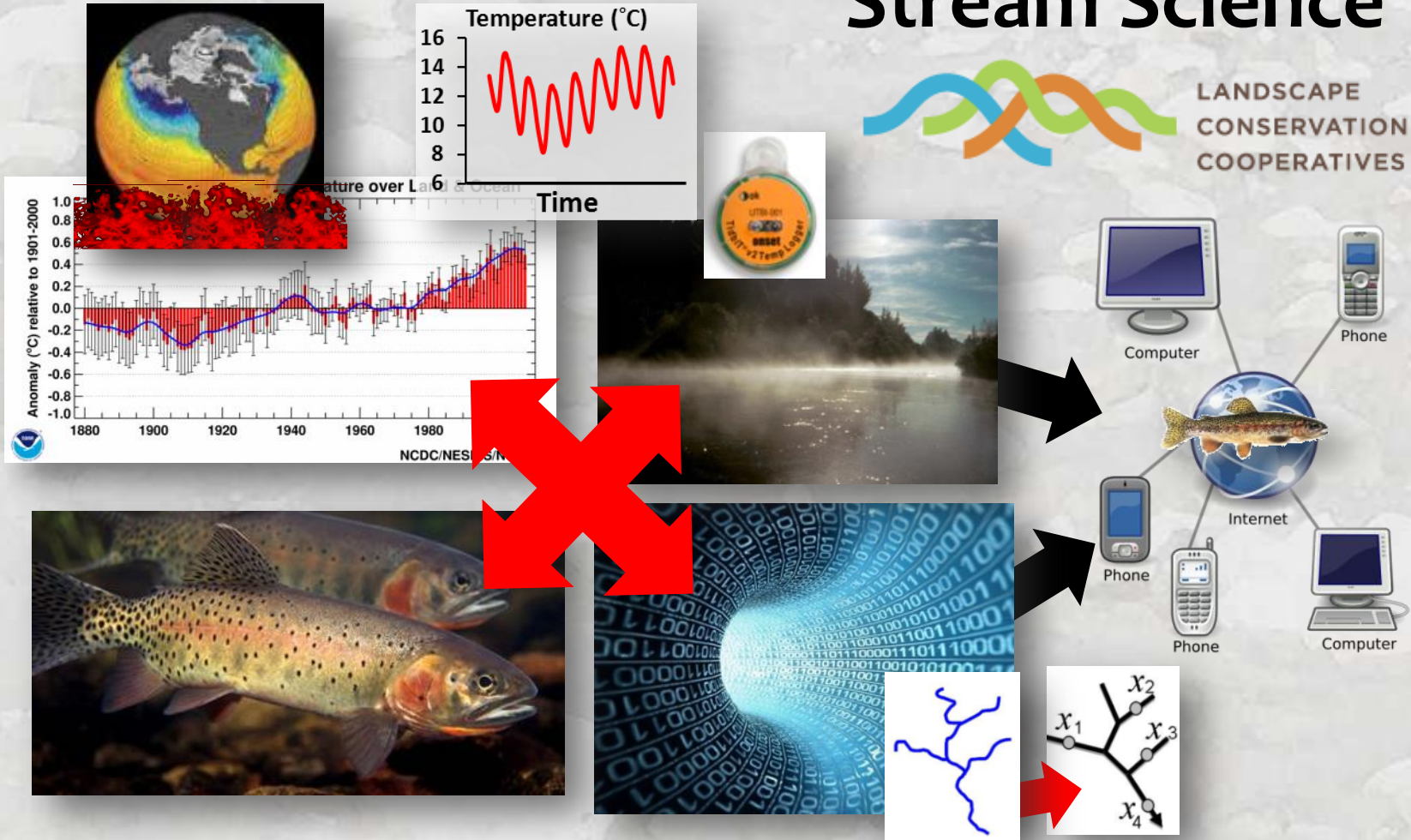
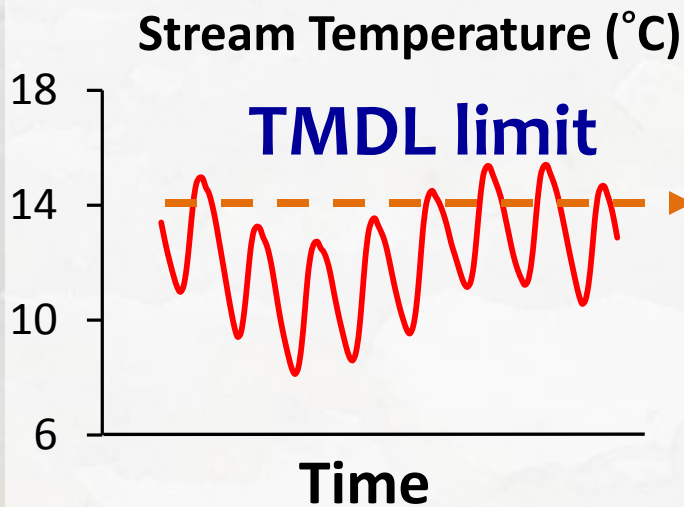
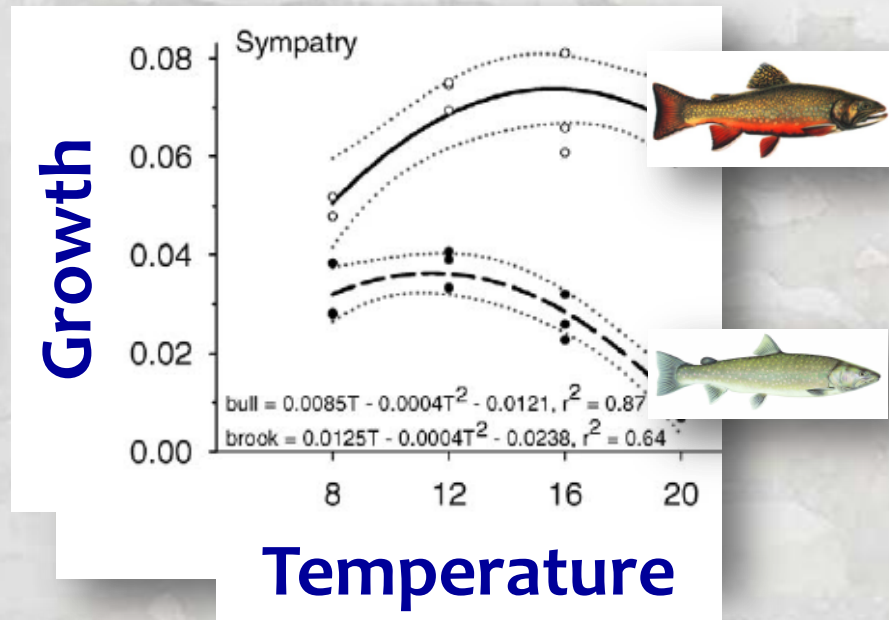


# Temperature Data & Climate Concerns as the “Gateway” to Hardcore Stream Science



## Part II: “Killer Apps” & The Stream Internet

# Concern About "Climate" Drove Temperature TMDL Standards



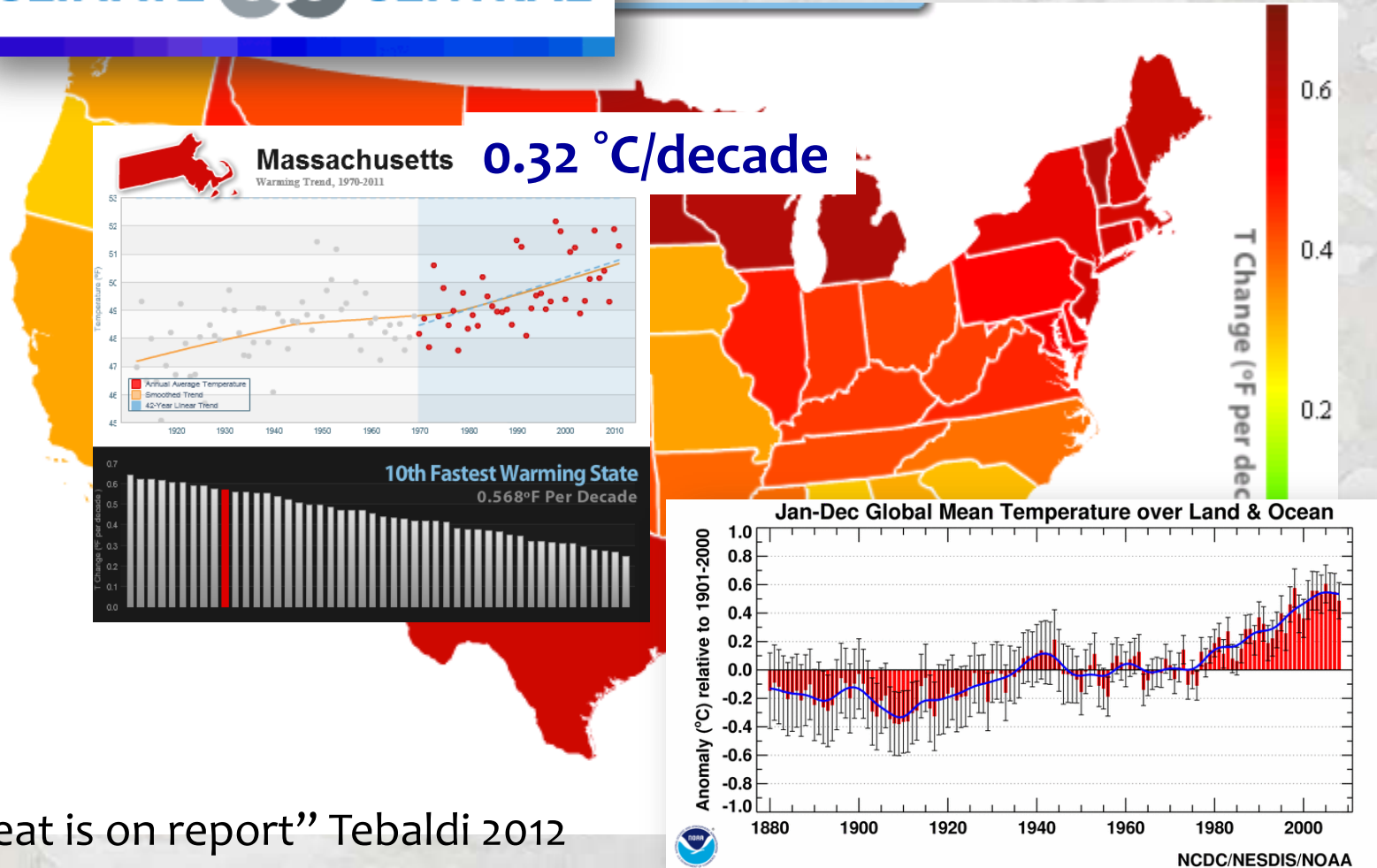
**Too Hot!**



# New Concerns About “Climate Change”

## Air Temperature Warming Rates (1970 – 2011)

CLIMATE CENTRAL



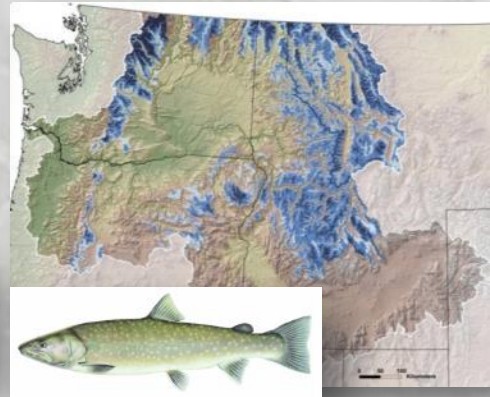
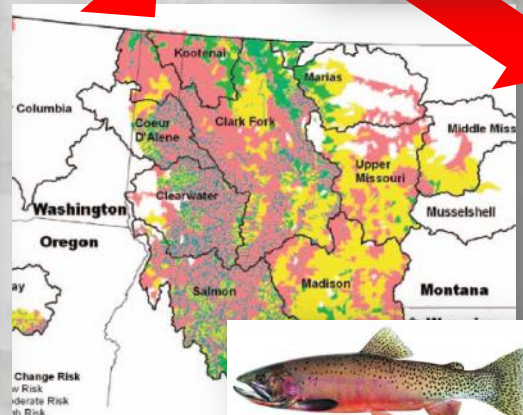
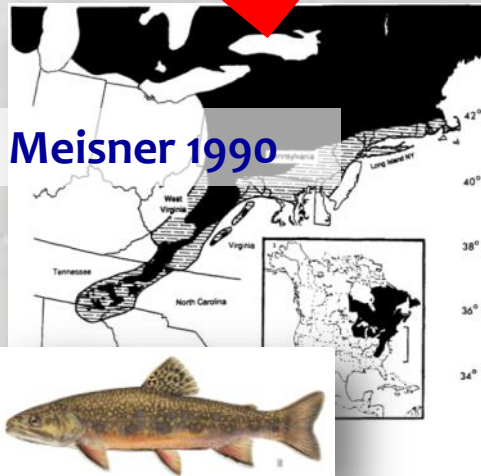
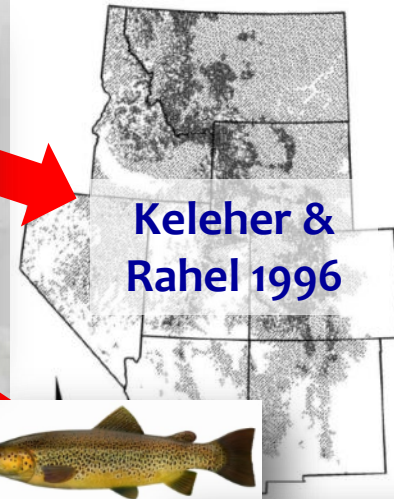
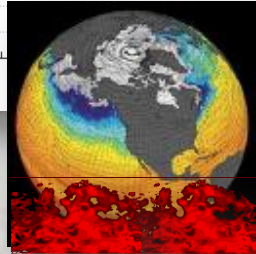
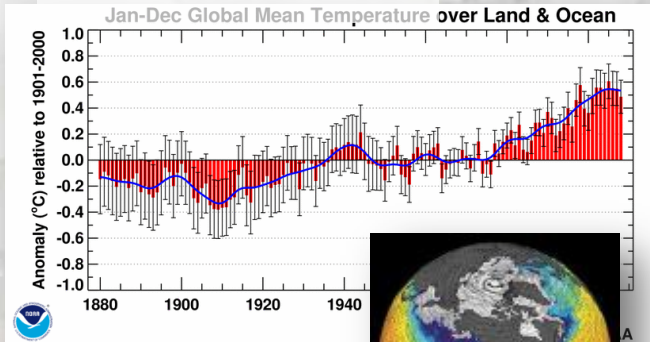
“Heat is on report” Tebaldi 2012

<http://www.climatecentral.org/news/the-heat-is-on/>

# New Concerns About “Climate Change”

## Drive Biological Vulnerability Assessments

### Air trends...

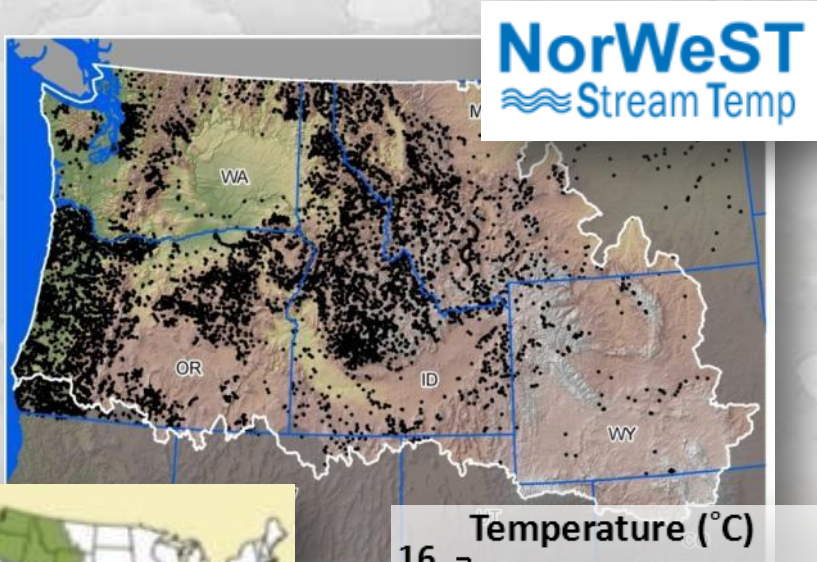


### Many Others...

- Isaak et al. 2010
- Eaton & Schaller 1996
- Reusch et al. 2012
- Rahel et al. 1996
- Mohseni et al. 2003
- Flebbe et al. 2006
- Rieman et al. 2007
- Kennedy et al. 2008
- Williams et al. 2009
- Wenger et al. 2011
- Almodovar et al. 2011
- Etc.



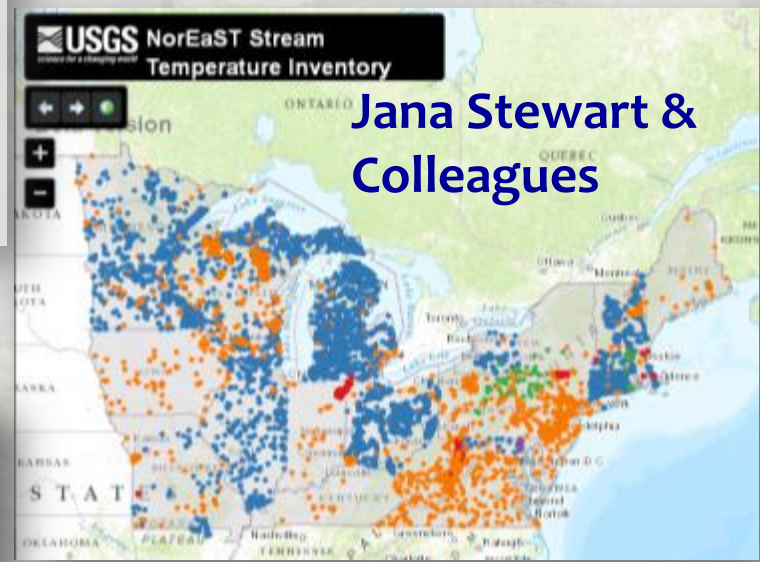
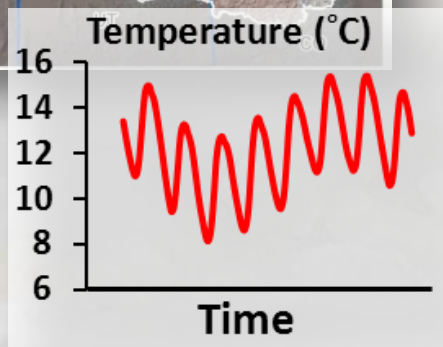
# So We've Collected a Lot of Temperature Data



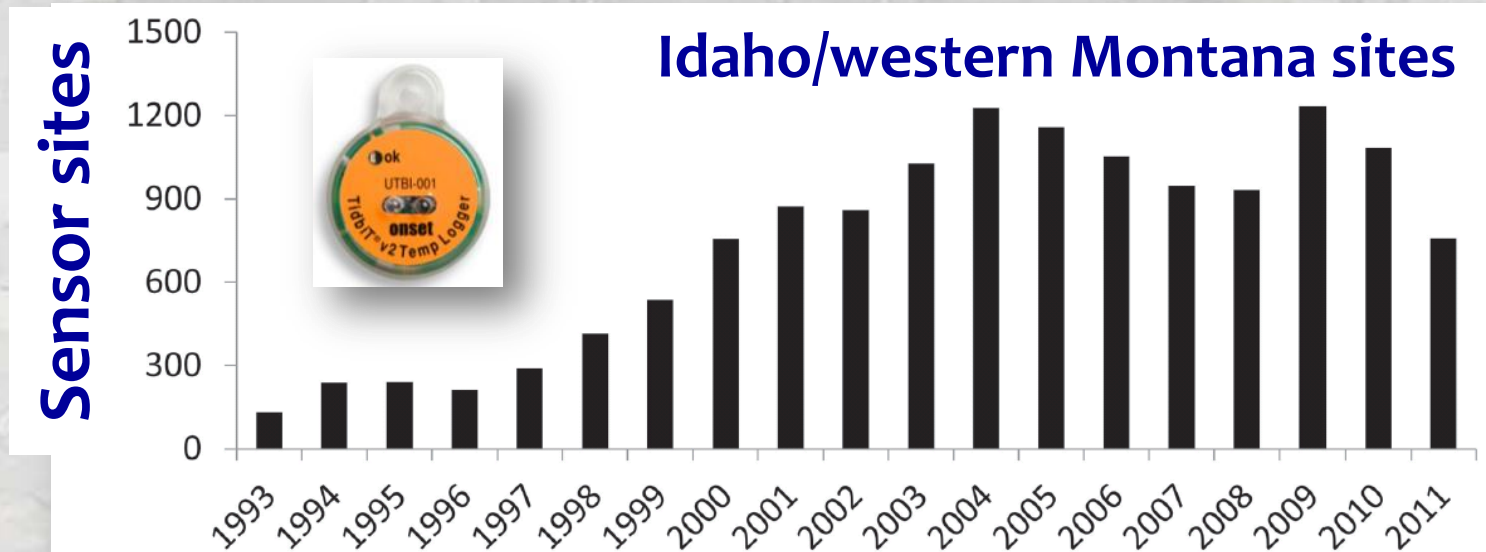
Free



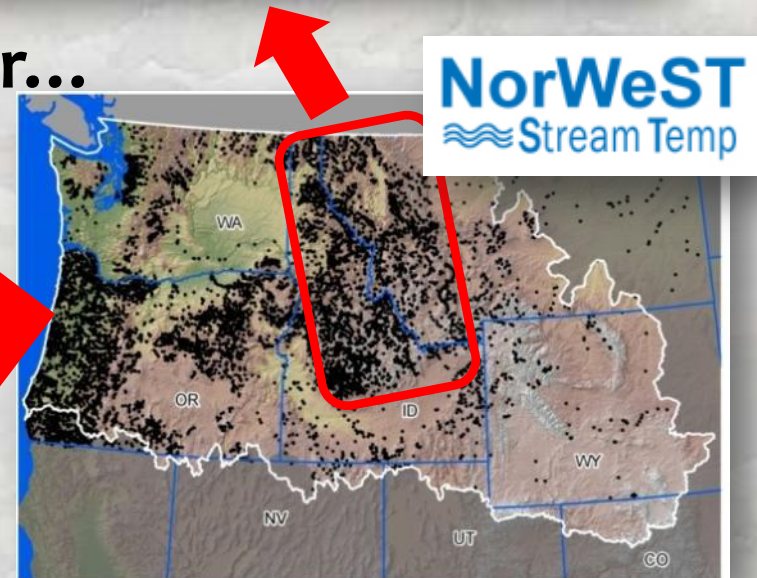
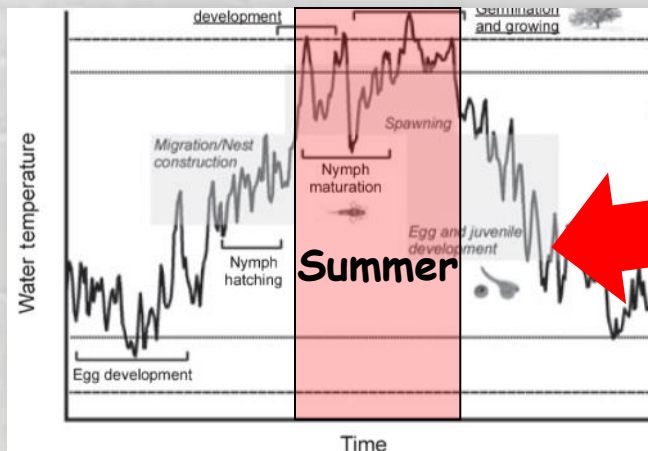
millions!



# How Have We Monitored? Many sites, but...

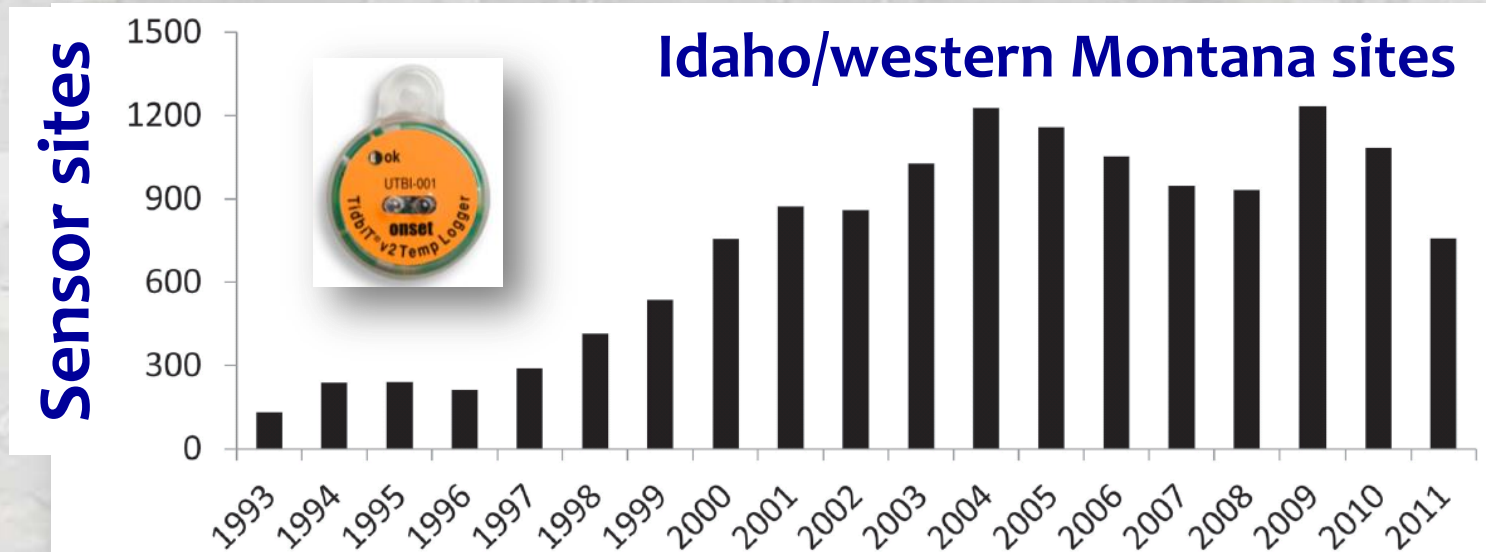


usually only in the summer...

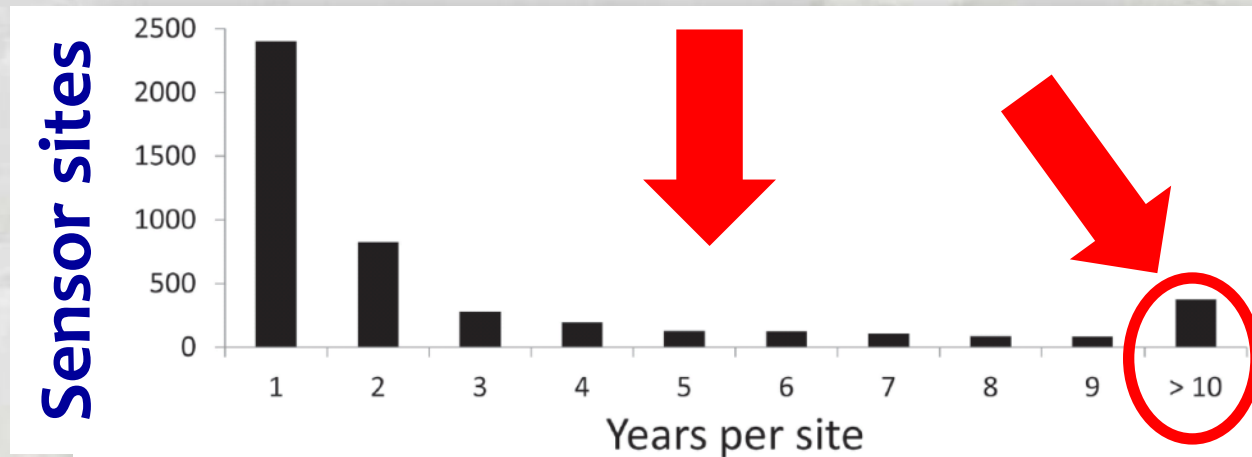


Isaak et al. 2013. [A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams.](#) USFS General Technical Report, 314.

# How Have We Monitored? Many sites, but...



**& not for very long**

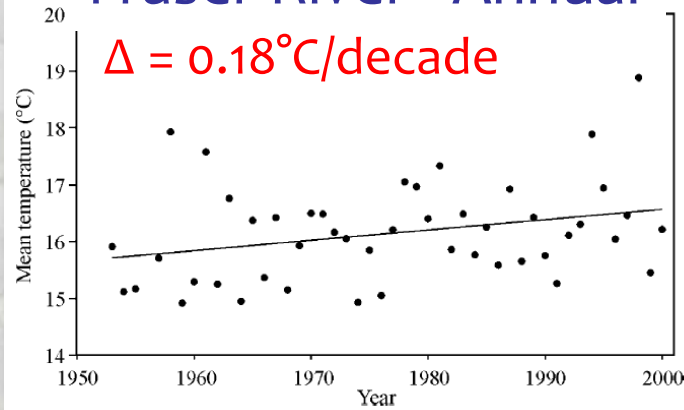


Isaak et al. 2013. [A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams](#). USFS General Technical Report, 314.

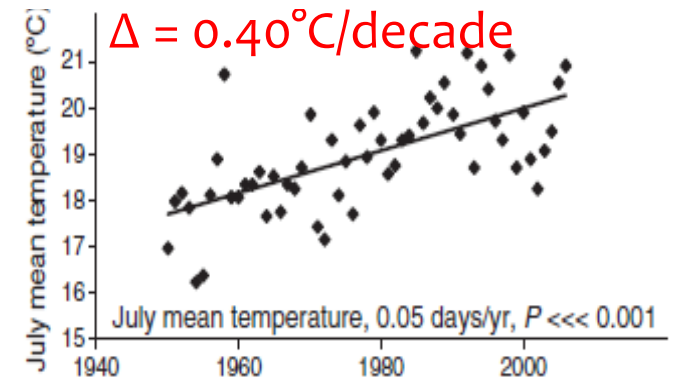
# Temperature Trends In Northwest Rivers



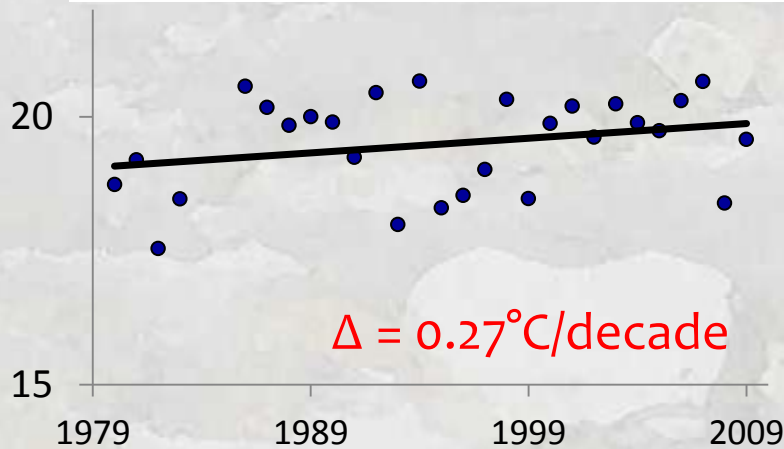
## Fraser River - Annual



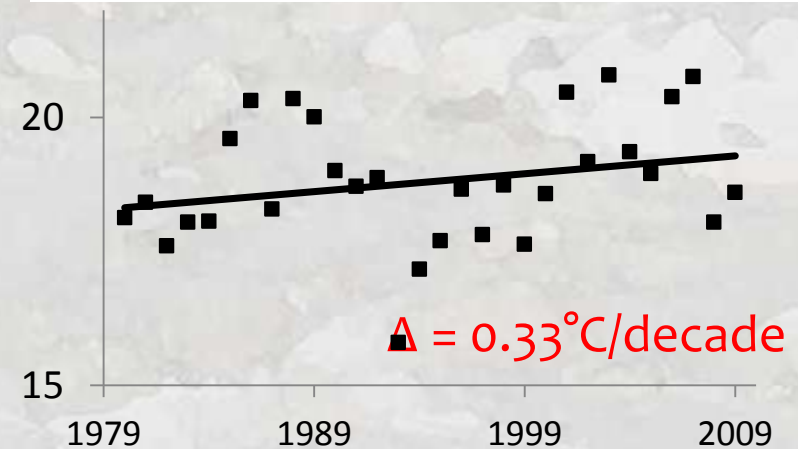
## Columbia River - Summer



## Snake River, ID - Summer

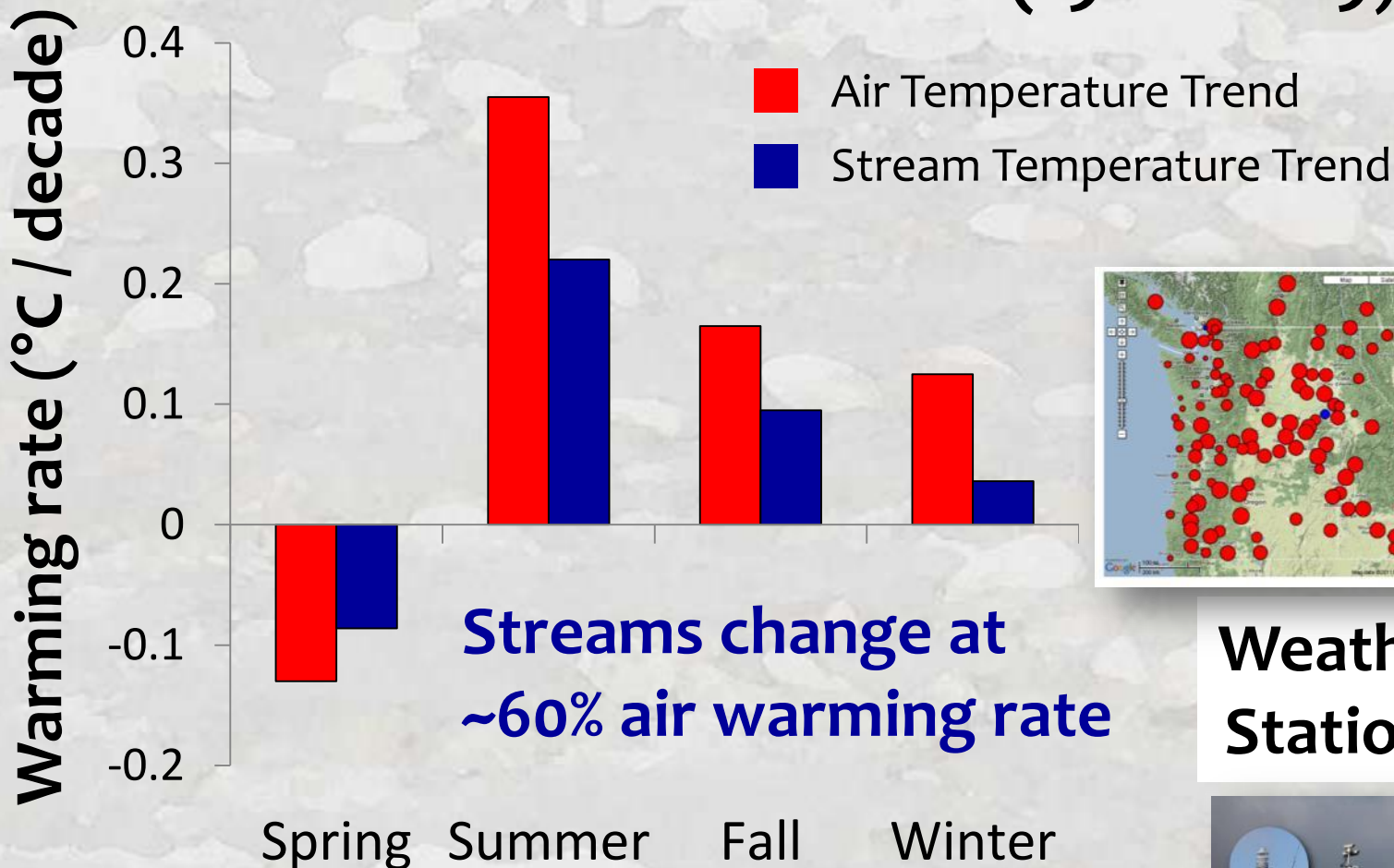


## Missouri River, MT - Summer

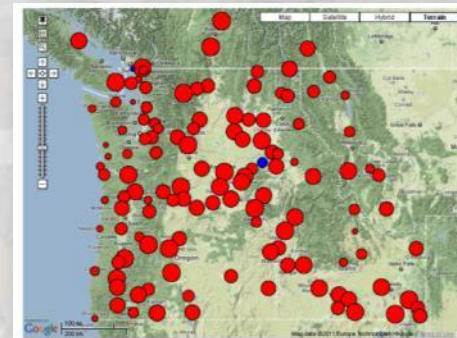




# Stream Temp Trends Track Air Trends at Local Weather Stations (1980-2009)



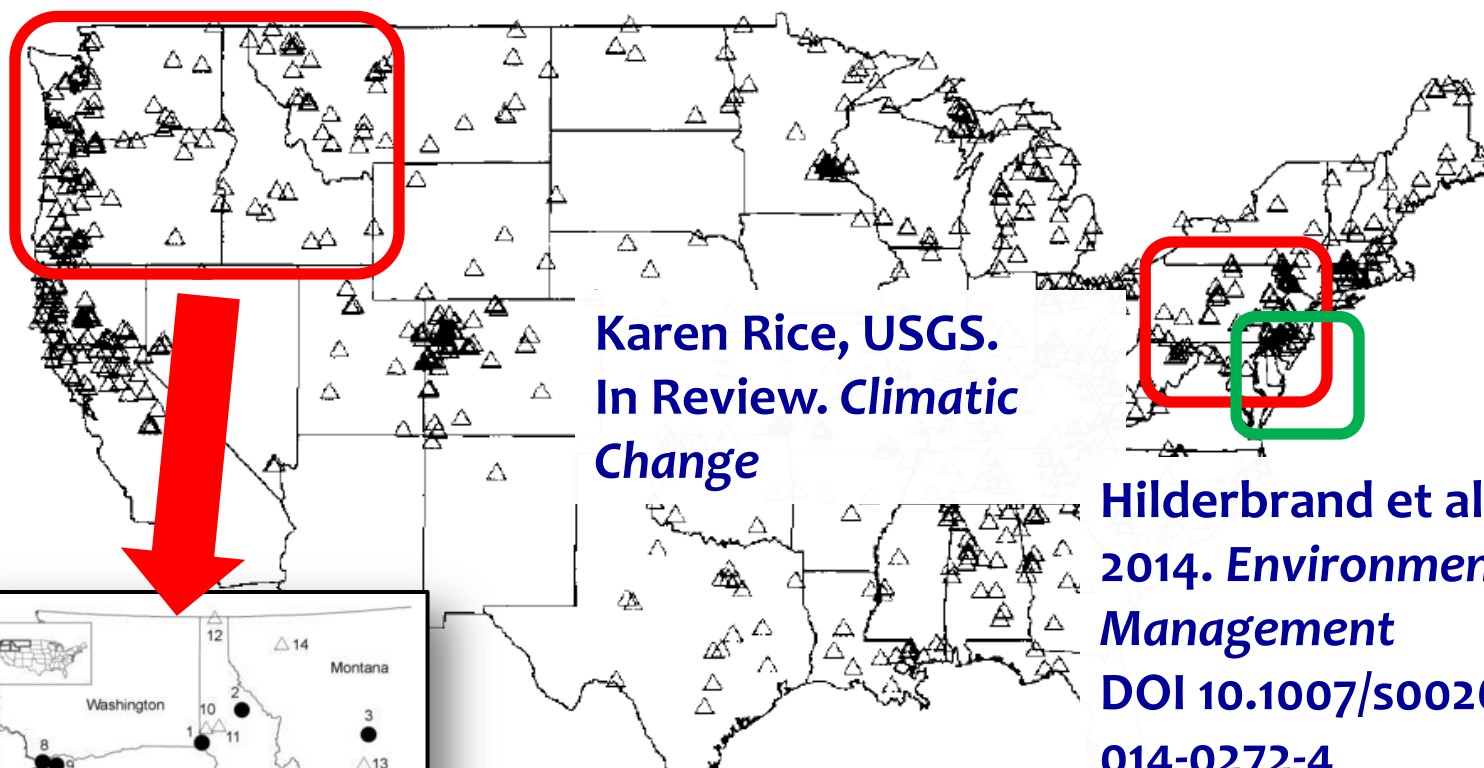
Isaak et al. 2012. Climate change effects on river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. *Climatic Change* **113**:499-524.



# Sites with Long-term Data are Rare

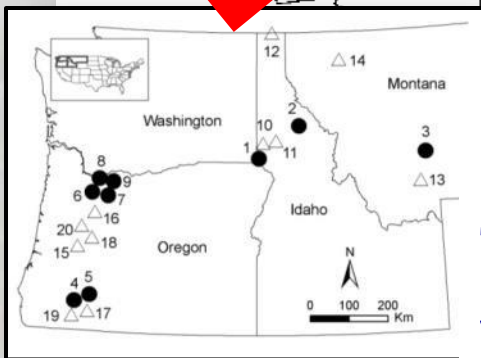
764 gage sites have some temperature data

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



Karen Rice, USGS.  
In Review. *Climatic Change*

Hilderbrand et al.  
2014. *Environmental Management*  
DOI 10.1007/s00267-014-0272-4



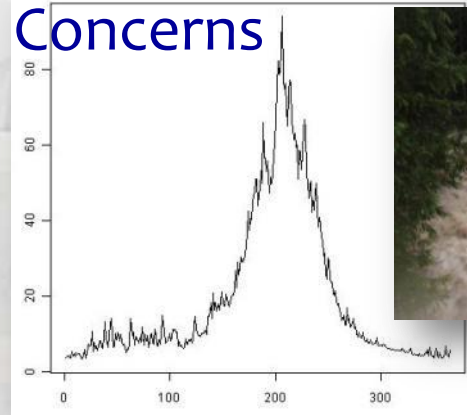
7 unregulated sites  
with >20 years



# More Longterm, Annual Monitoring Needed

## Inexpensive, reliable “epoxy protocol”

Annual Flooding



Underwater epoxy cement



**\$130 = 5 years of data**

Data retrieved  
from underwater

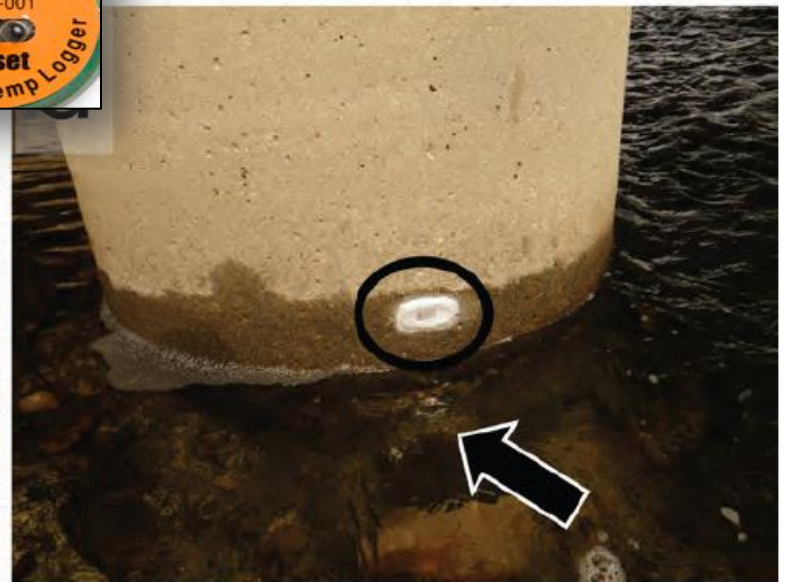
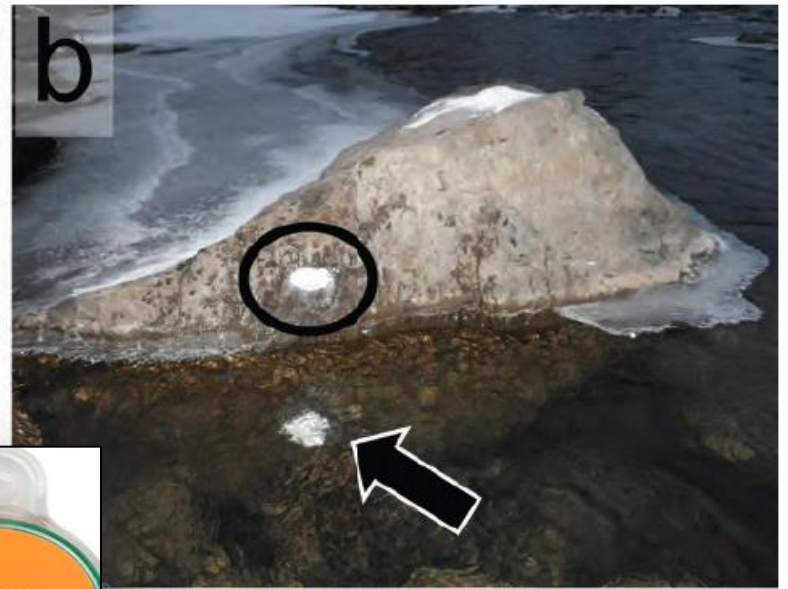


Sensors glued to large  
boulders & bridges



Isaak et al. 2013. USFS Report;  
Isaak & Horan 2011. *NAJFM* 31:134-137

# Small Sensors & Immobile Objects



# Small Sensors & Immobile Objects

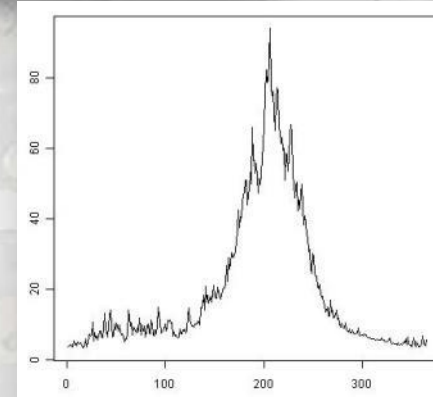
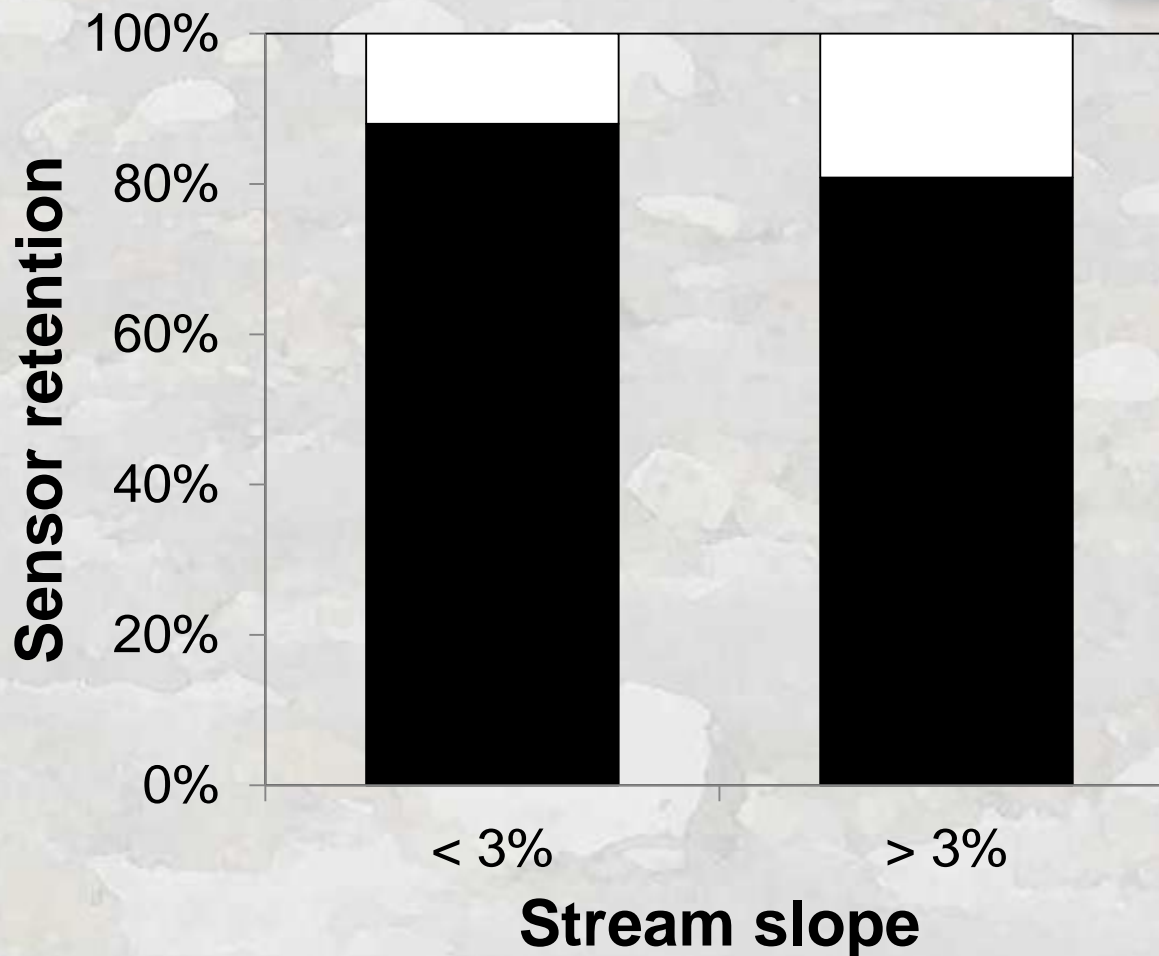


# Does it Work?

Retention success at...

1 Year (n=72)

■ Retained □ Lost

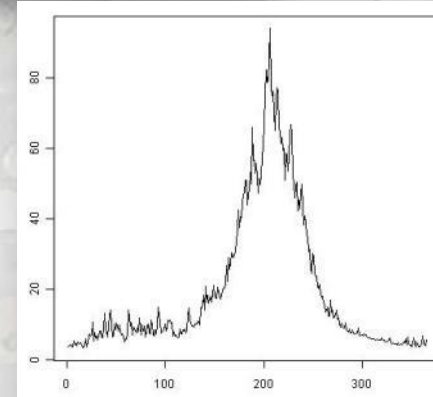
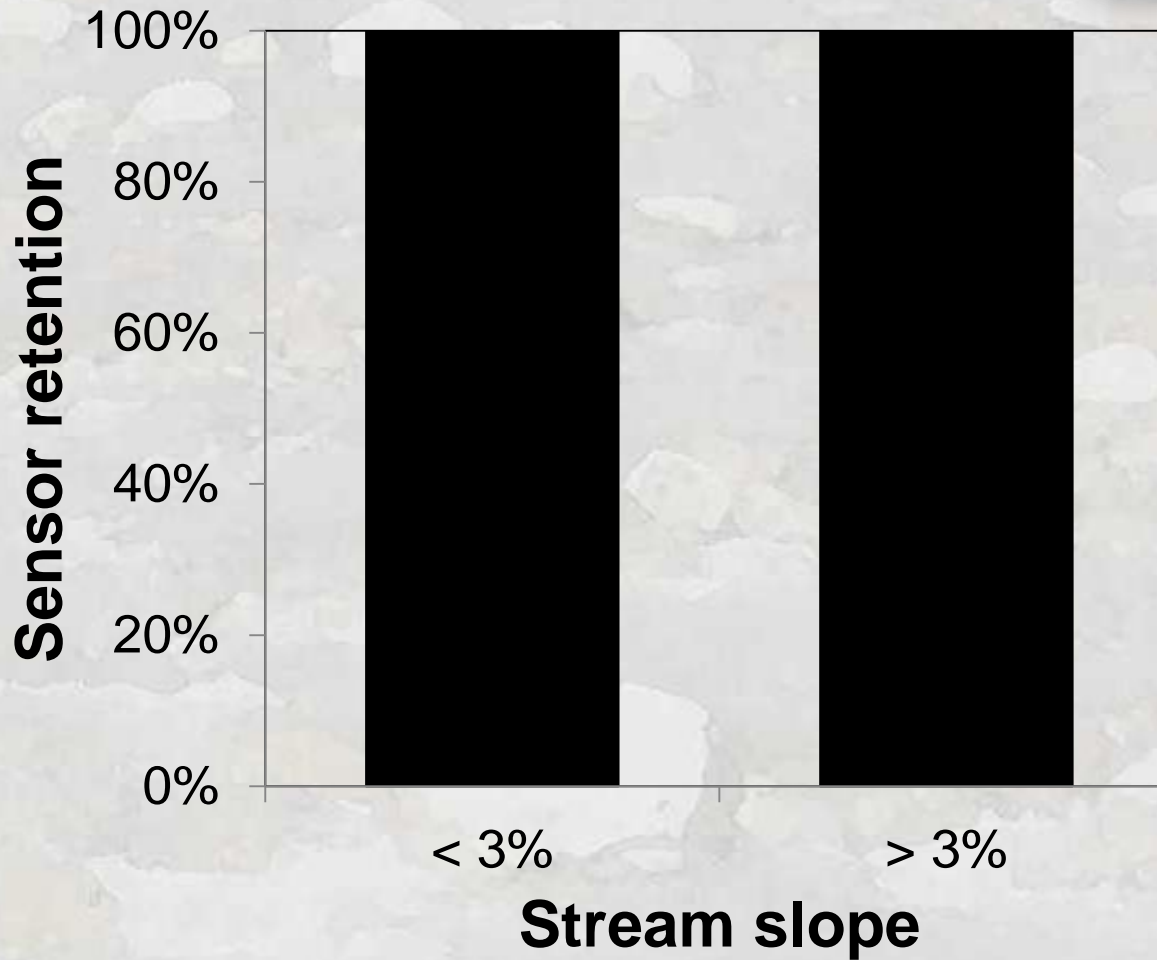


# Does it Work?

Retention success at...

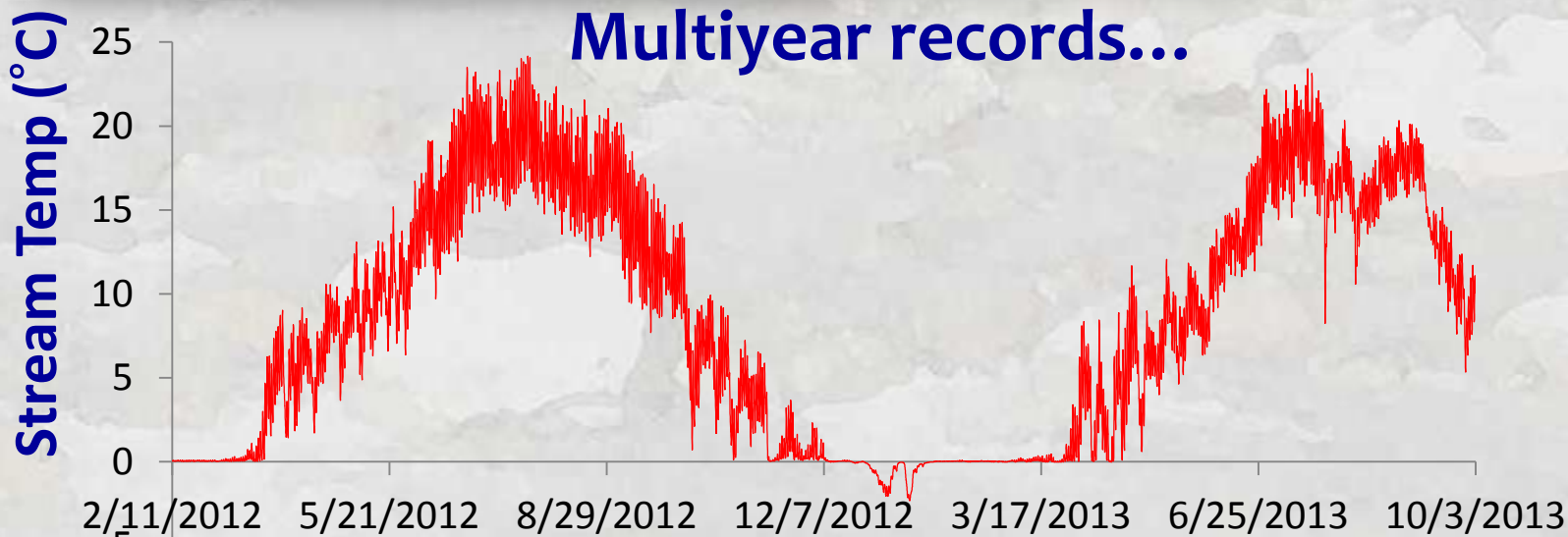
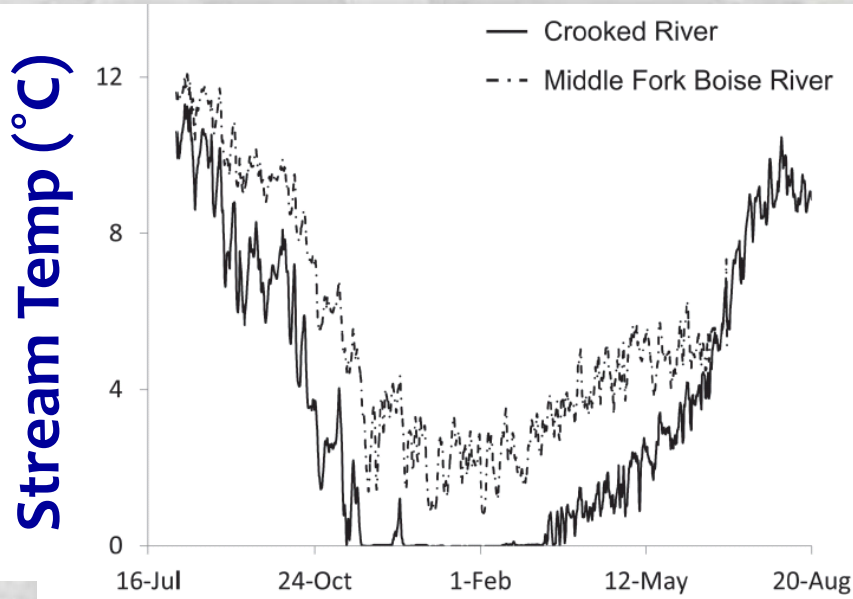
2 Year (n=35)

■ Retained □ Lost



# It's a Win-Win

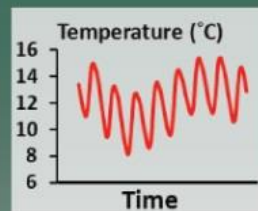
More data, more hunting!



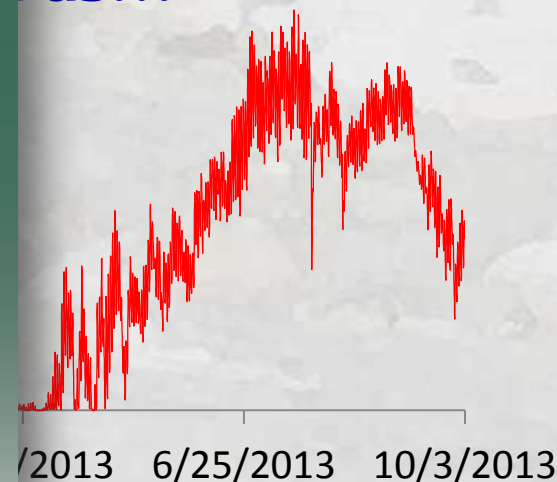


# A Simple Protocol Using Underwater Epoxy to Install Annual Temperature Monitoring Sites in Rivers and Streams

Daniel J. Isaak  
Dona L. Horan  
Sherry P. Wollrab



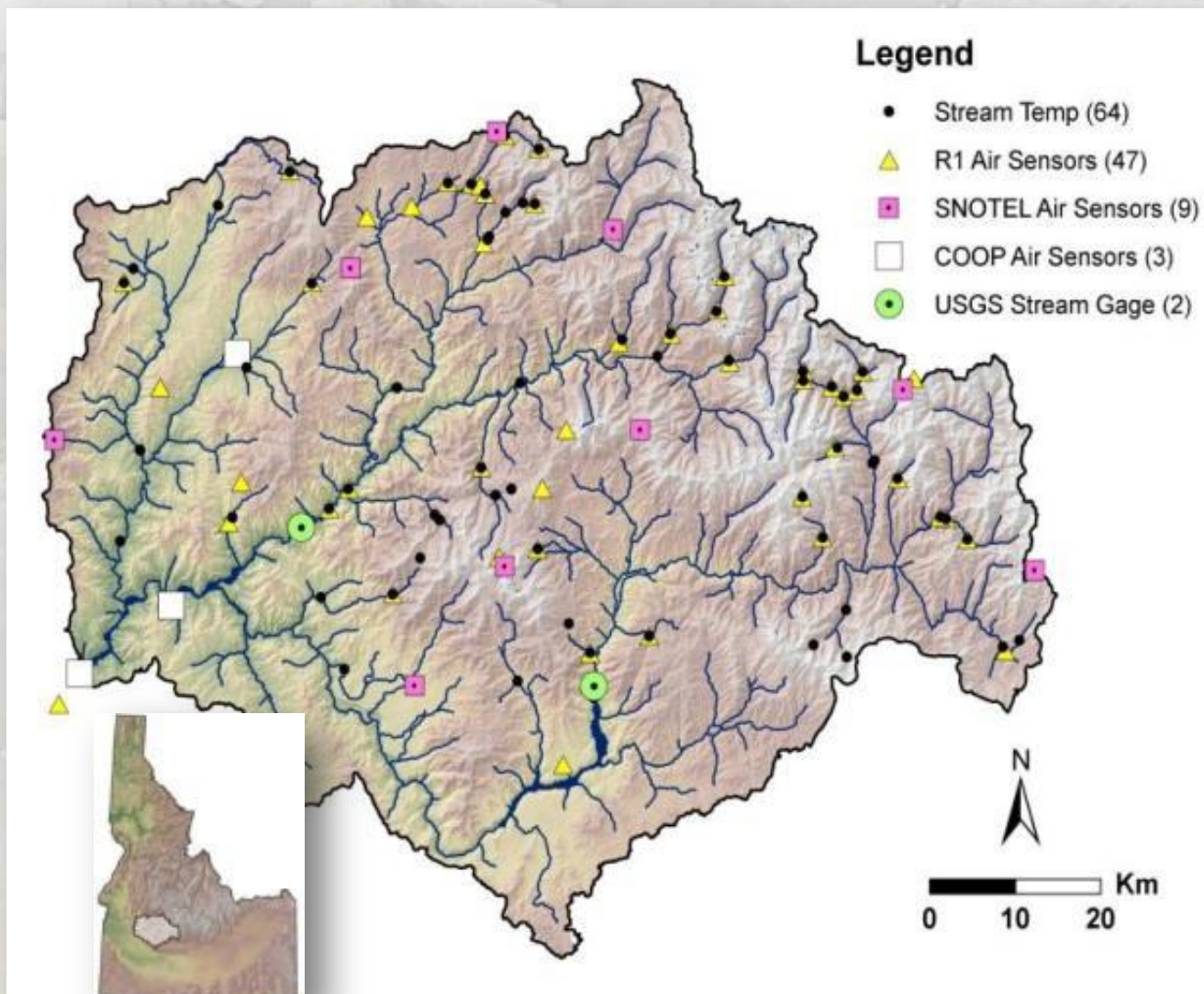
ards...



United States Department of Agriculture / Forest Service  
Rocky Mountain Research Station  
General Technical Report RMRS-GTR-314  
September 2013

# Example Annual Monitoring Networks...

## Boise River Basin – dense sensor array



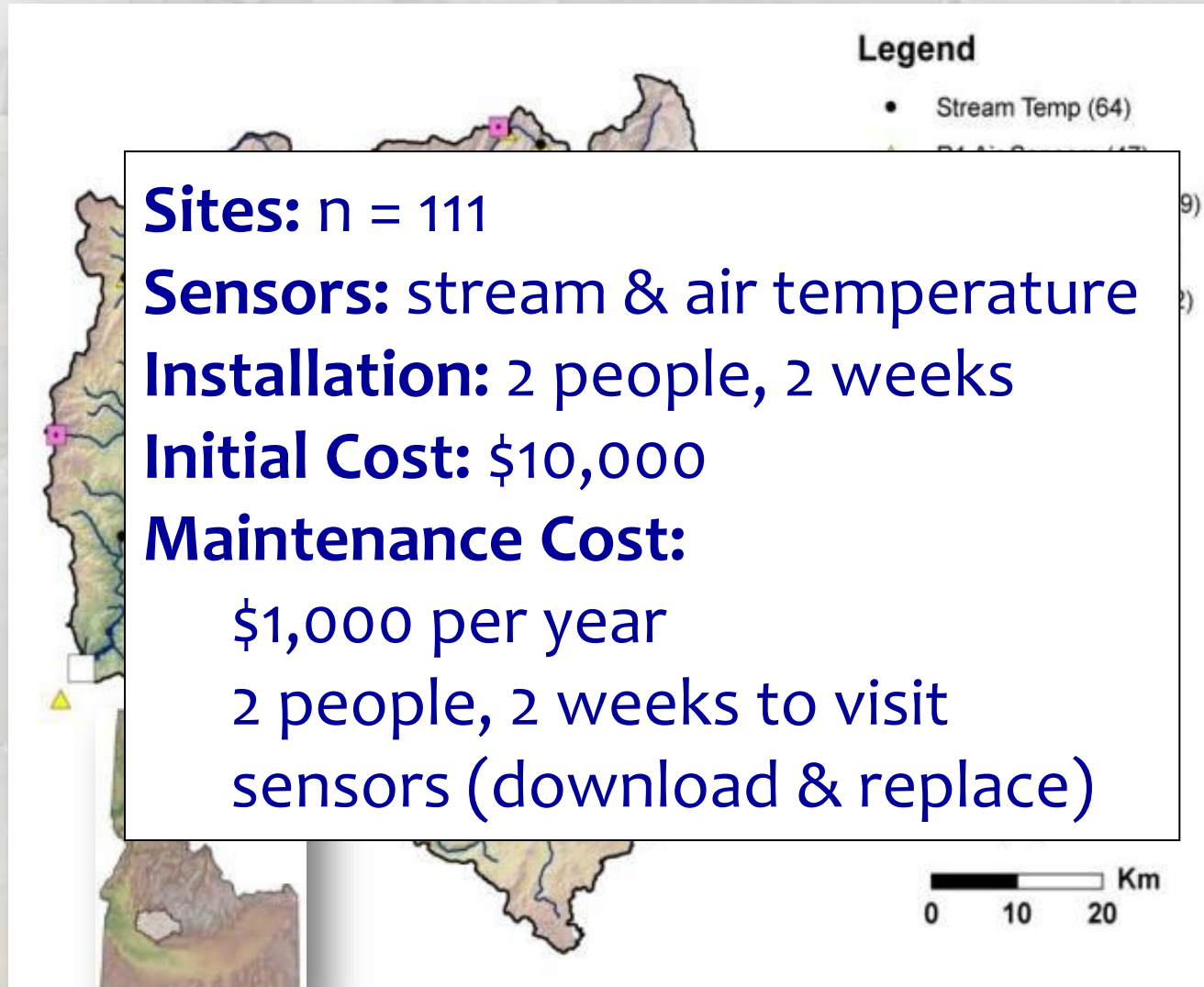
Stream sensors



Air sensors

# Example Annual Monitoring Networks...

## Boise River Basin – dense sensor array

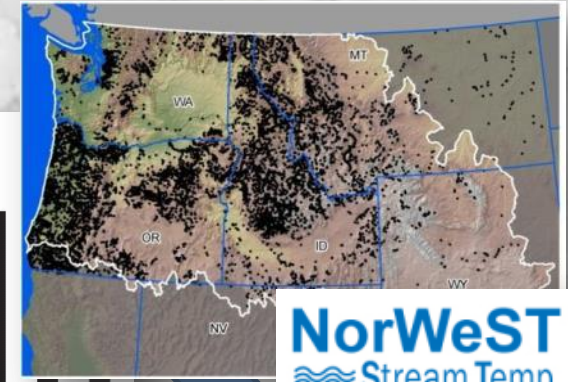
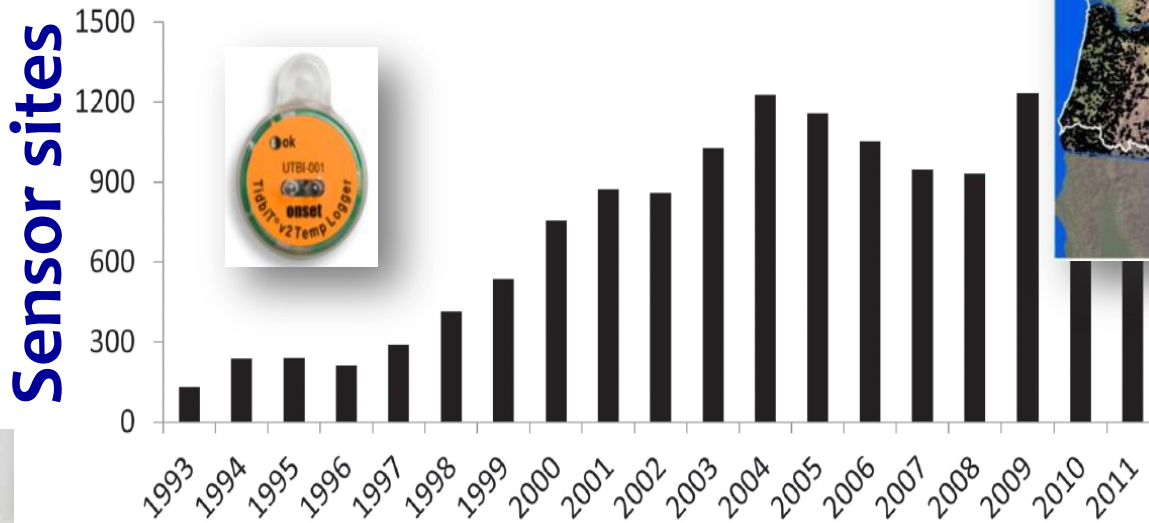


Stream sensors

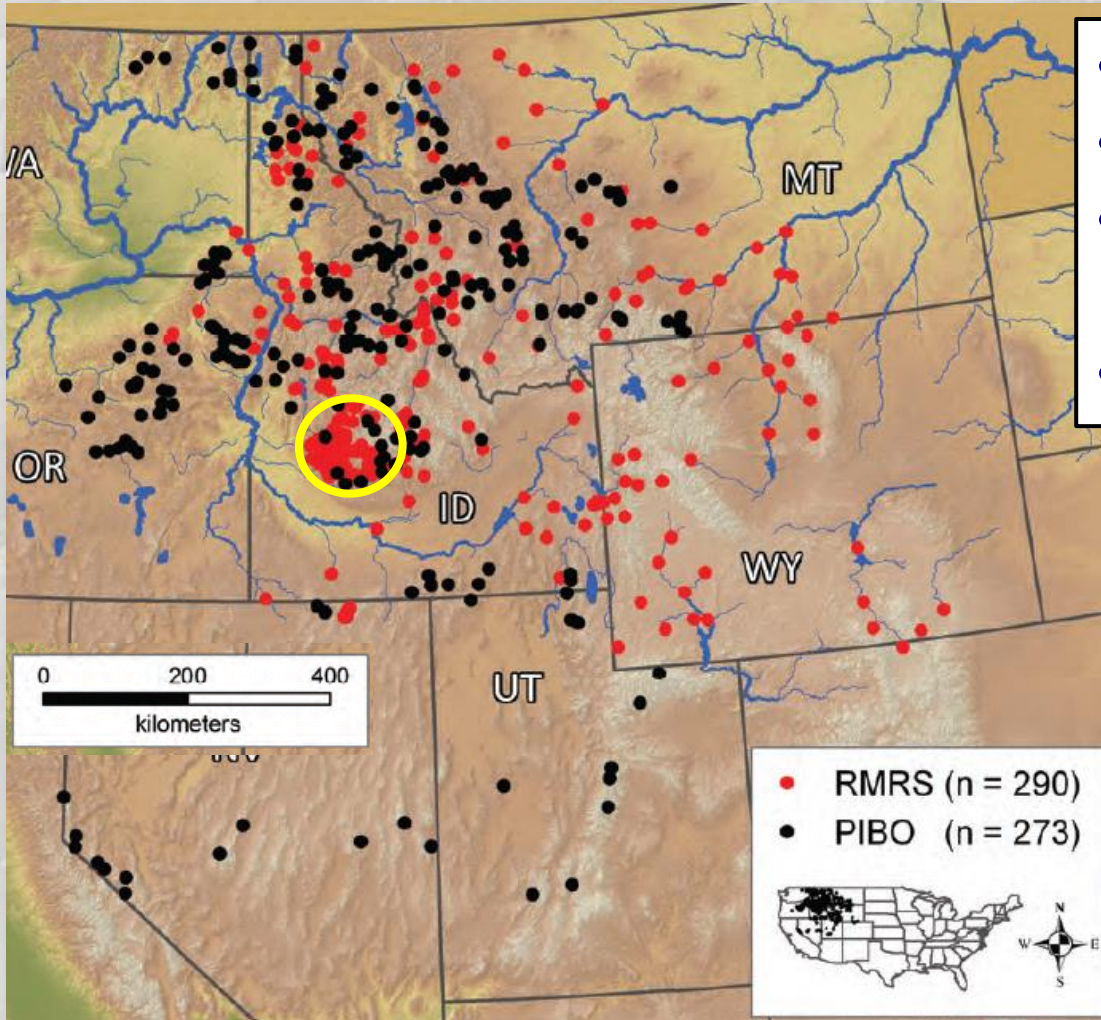


Air sensors

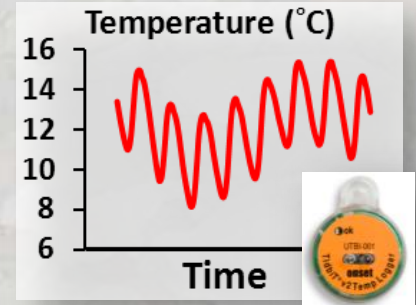
# Monitoring GAP = unregulated rivers with important fisheries



# NoRRTN: Northern Rockies River Temperature Network



- n = 563 sites;
- Cost = \$100,000;
- 3 months time for 2 technicians;
- 2,500 years data



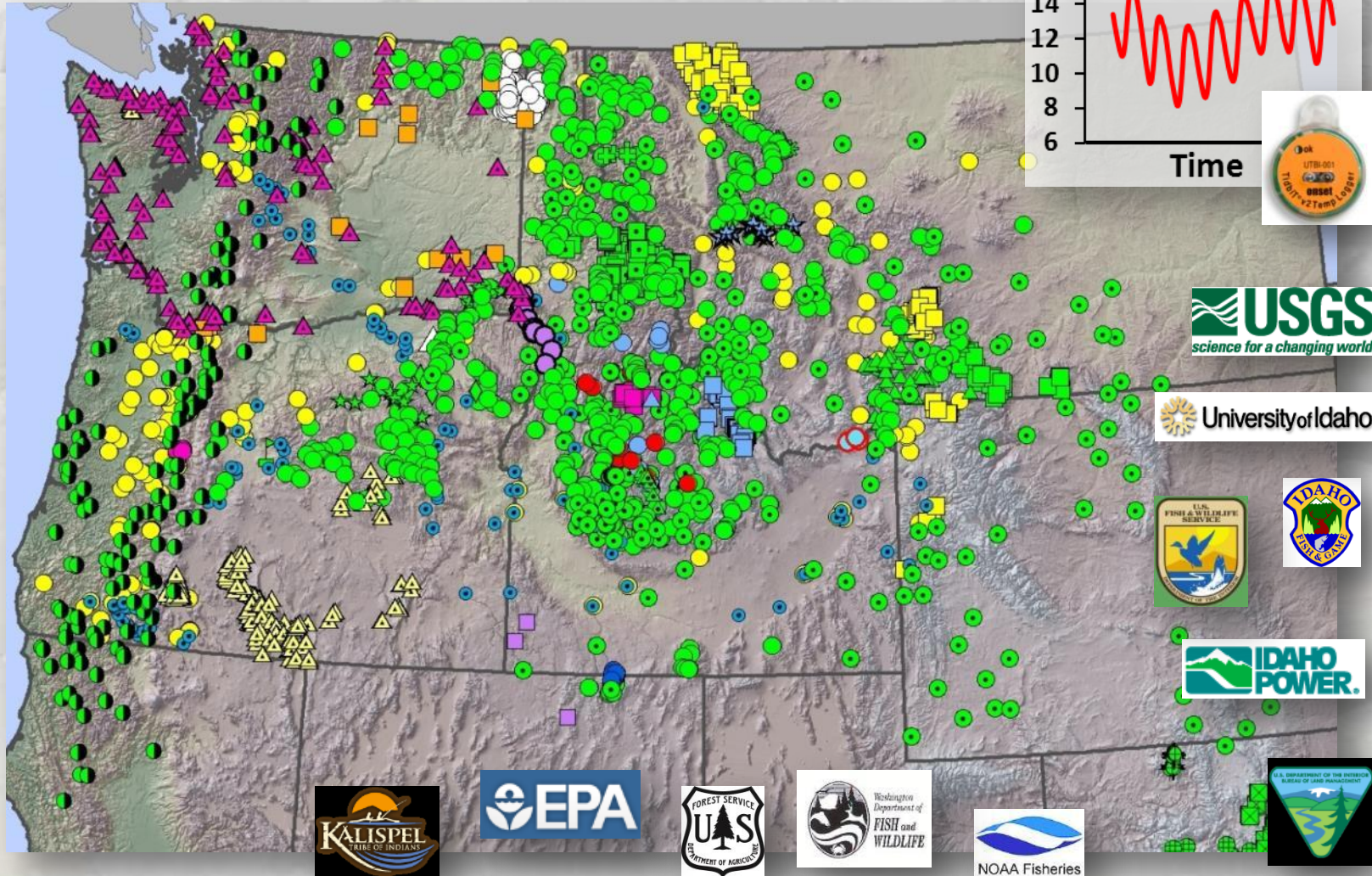
During today's meeting, NoRRTN recorded 3,378 stream temperatures (that's 3,698,910 annually...)



# Annual Temperature Monitoring is Increasing

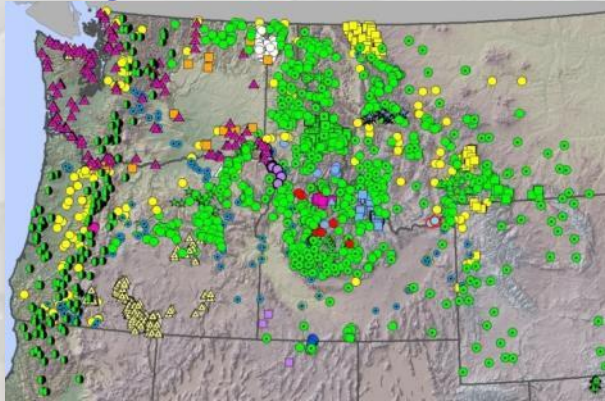
>3,000 sites in Pacific Northwest

>300 new sites last year



# A GoogleMap Tool for Dynamic Queries of Temperature Monitoring Sites

## Regional Sensor Network



### Site Information

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



### Query Individual Sites

Google maps Search Maps Show search options

Get Directions My Maps Save to My Maps

**Montana Annual Stream Temperature**  
Points available  
www.fs.fed.us/rm/boise/AWAE/projects/temperature.shtml  
Stream Temperature Points available by Agency  
2/02/2011  
62 views - Public  
Created on Feb 2 - Updated 13 hours ago  
By  
Rate this map - Write a comment

● **Adair Creek**  
Thermograph Location: Adair Creek Contact: Clint Muhlfeld - cmuhfeld@usgs.gov (406-888-7926)  
USGS, NOROCK

● **Agassiz Creek**  
Thermograph Location: Agassiz Creek Contact: Clint Muhlfeld - cmuhfeld@usgs.gov (406-888-7926)  
USGS, NOROCK

● **Akokala Creek**  
Thermograph Location: Akokala Creek Contact: Clint Muhlfeld - cmuhfeld@usgs.gov (406-888-7926)  
USGS, NOROCK

**Cottonwood-Clyde Park- Creek**  
Updated 2 days ago  
Thermograph Location: Cottonwood-Clyde Park- Creek  
Contact: Robert Al-Chokhachy - ral-chokhachy@usgs.gov (406-994-7842)  
USGS, NOROCK  
Directions Search nearby more

1 of 2 nearby results Next

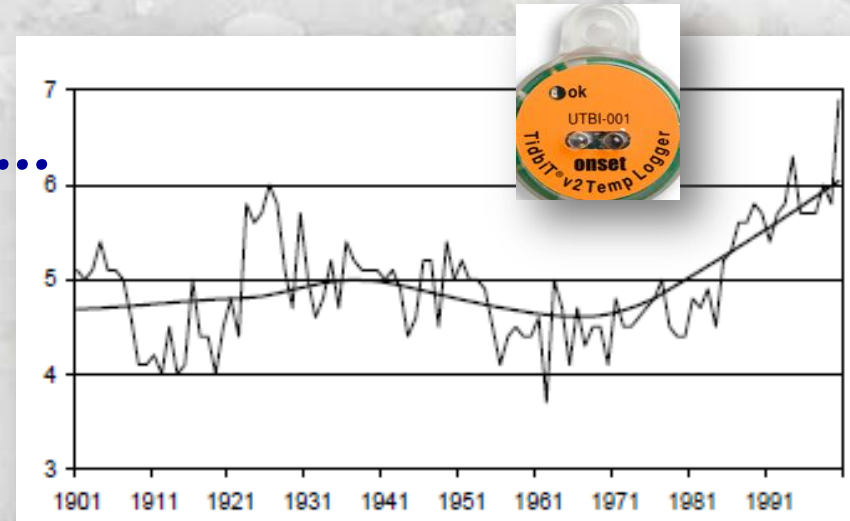
GoogleMap Tool at “Stream Temperature Monitoring and Modeling” website



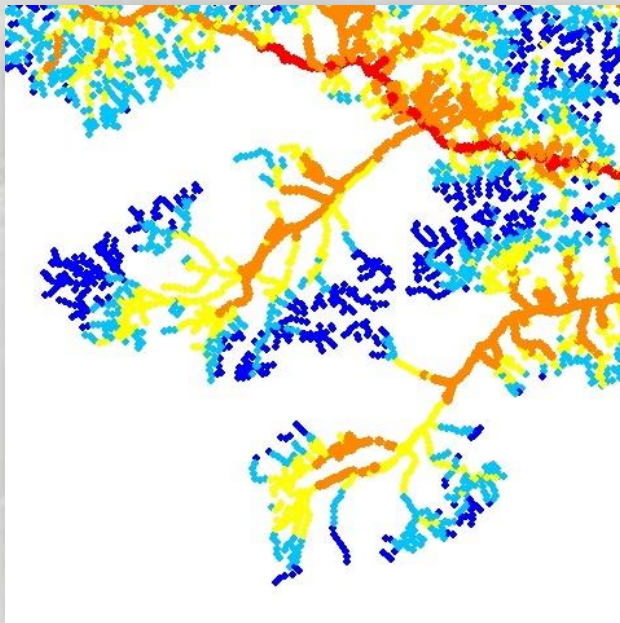
# How Long Should Temperatures be Monitored?

Long-term records are rare...

So some sites should be monitored indefinitely



Webb and Nobilus 2007



... but spatial variation among sites contains most “information” about thermal regimes

So some sites could be monitored for short periods (2 – 3 years) & sensors rotated to new sites





# Logistics & Efficient Data Collection



# Logistics & Efficient Data Collection

## Crews could deploy multi-sensor packages

Pressure transducers for stream discharge (\$299)



Air sensors (\$30 - \$50)



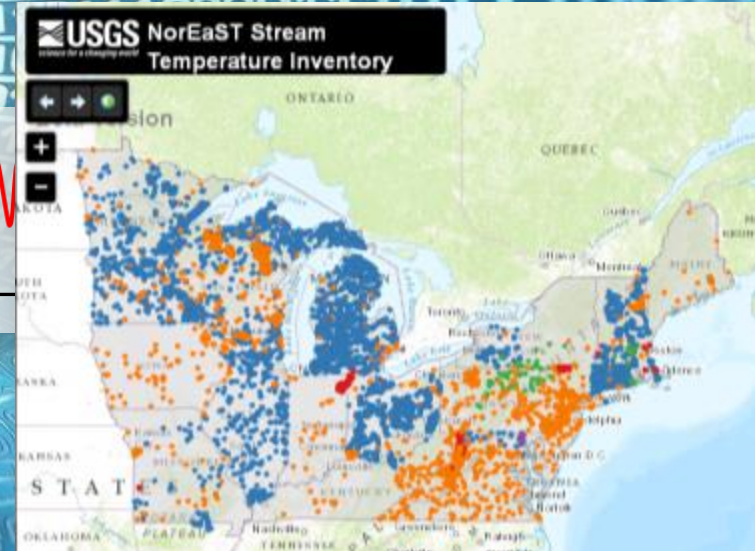
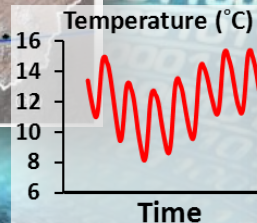
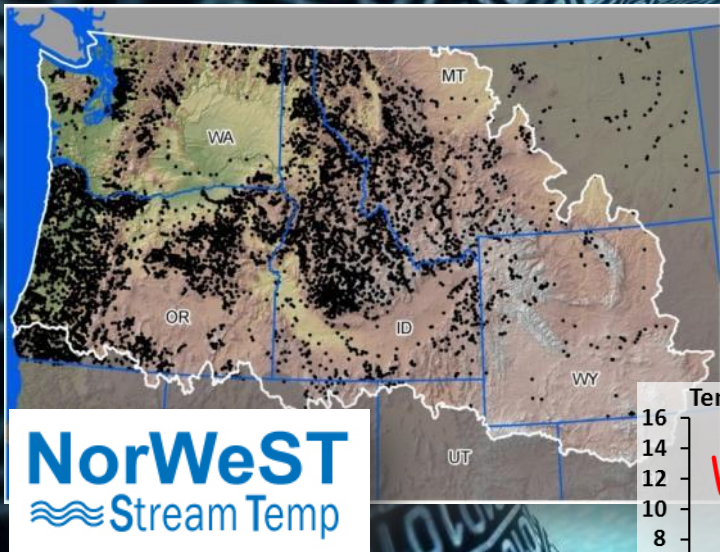
Holden et al. 2013. *Agricultural & Forest Met.* 180:281-286



Protocol Document...

U.S. EPA. In Review. Guidelines for Continuous Monitoring of Temperature and Flow in Wadeable Streams. Global Change Research Program. National Center for Environmental Assessment. Office of Research and Development. Washington, DC.

# So What About All That Summer Data?



**BIG DATA = BIG INFORMATION?**



It's the **MOTHER  
LODE!**



B

# The NorWeST Stream Temperature Database, Model, & Climate Scenarios

Dan Isaak, Seth Wenger<sup>1</sup>, Erin Peterson<sup>2</sup>, Jay Ver Hoef<sup>3</sup> Charlie Luce, Steve Hostetler<sup>4</sup>, Jason Dunham<sup>4</sup>, Jeff Kershner<sup>4</sup>, Brett Roper, Dave Nagel, Dona Horan, Gwynne Chandler, Sharon Parkes, Sherry Wollrab, Colete Bresheares, Neal Bernklau

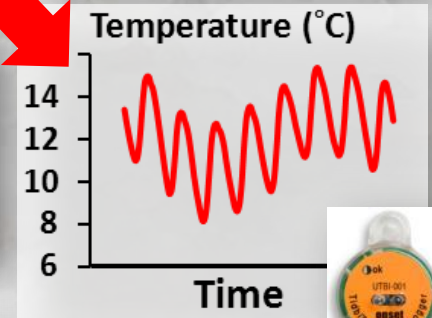
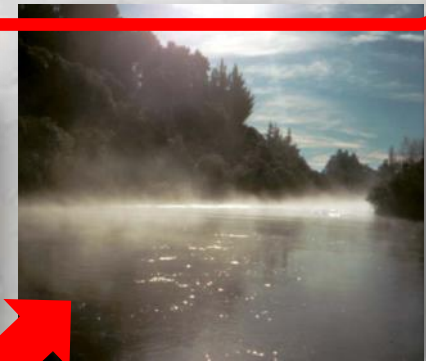
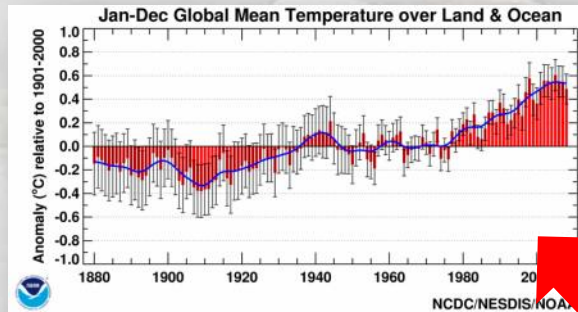
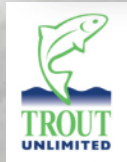
U.S. Forest Service

<sup>1</sup>Trout Unlimited

<sup>2</sup>CSIRO

<sup>3</sup>NOAA

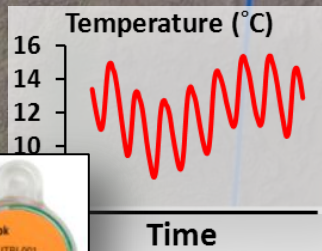
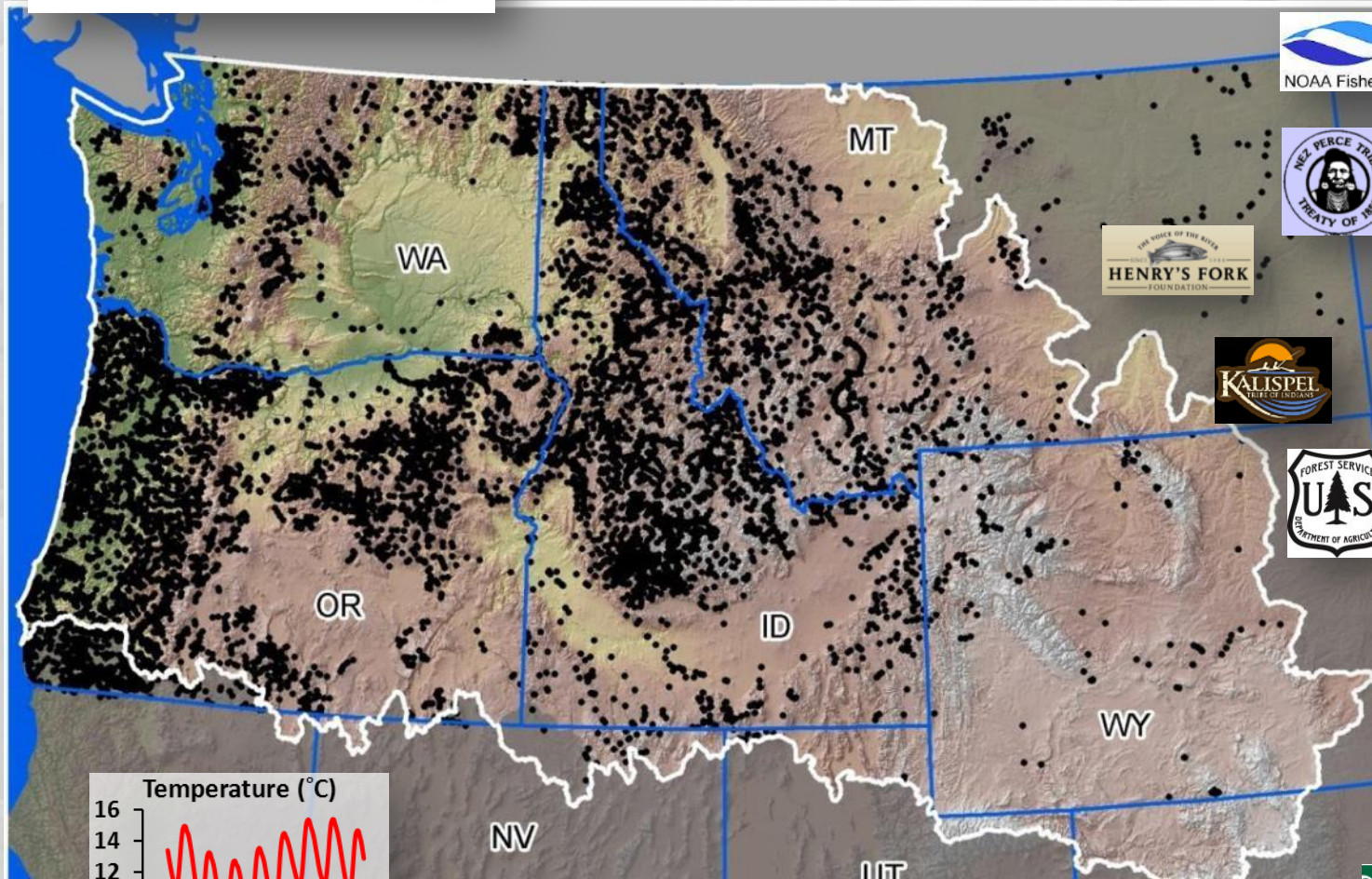
<sup>4</sup>USGS



# NorWeST

Stream Temp

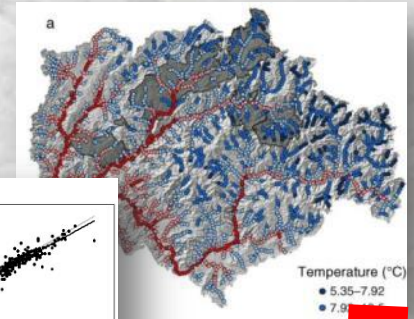
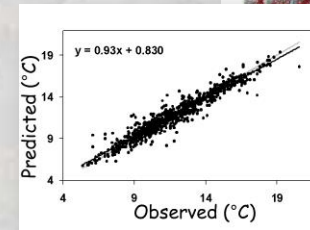
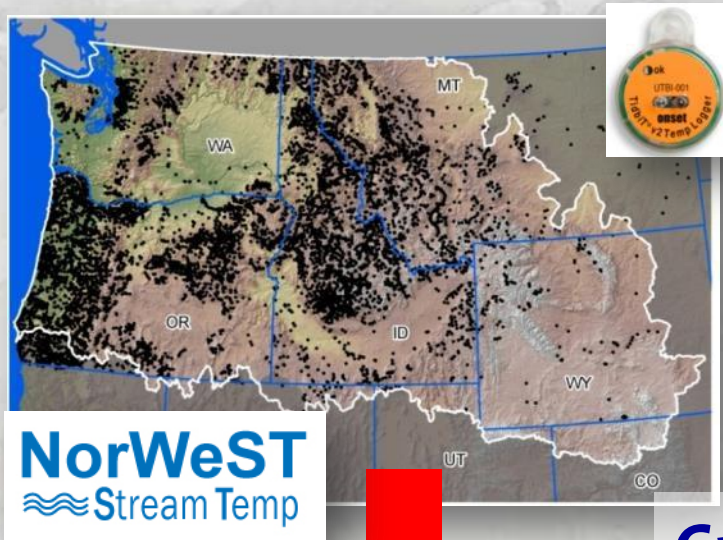
>70 agencies  
\$10,000,000 data value



>45,000,000 hourly records  
>15,000 unique stream sites

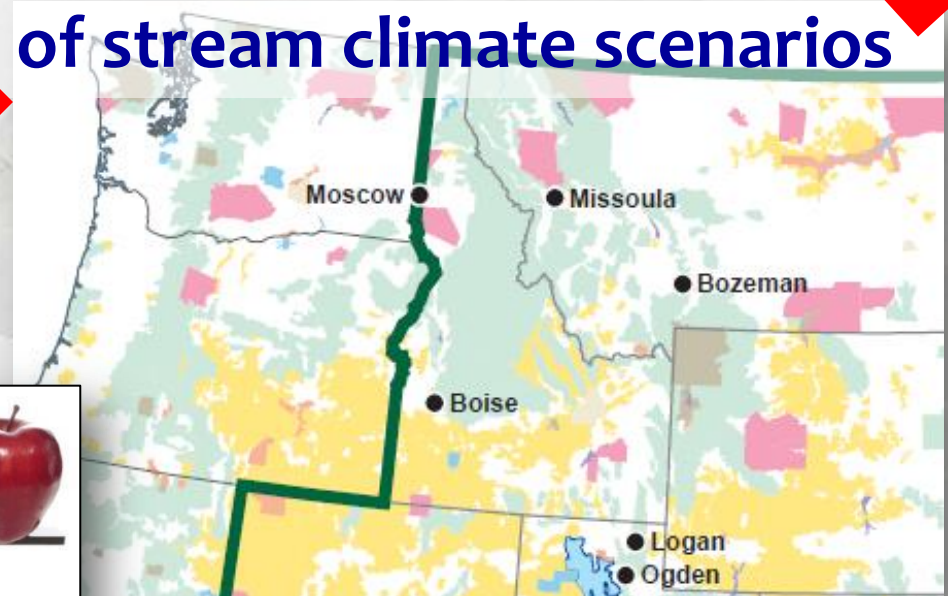
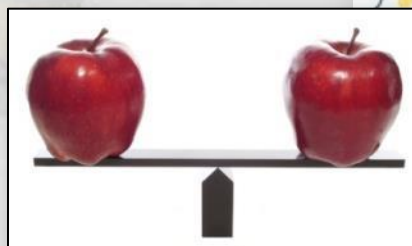
# Regional Temperature Model

Accurate stream temp model



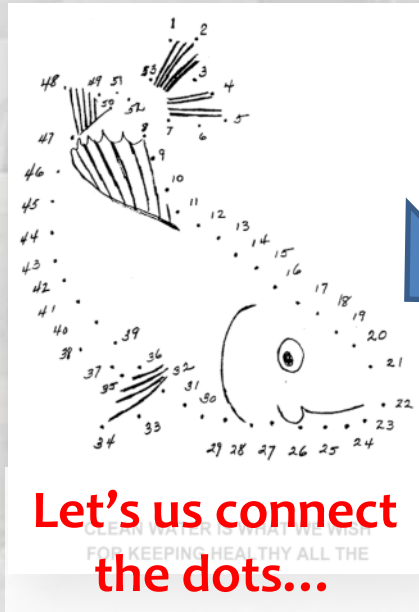
Cross-jurisdictional “maps” of stream climate scenarios

Consistent datum for strategic planning across 500,000 stream kilometers

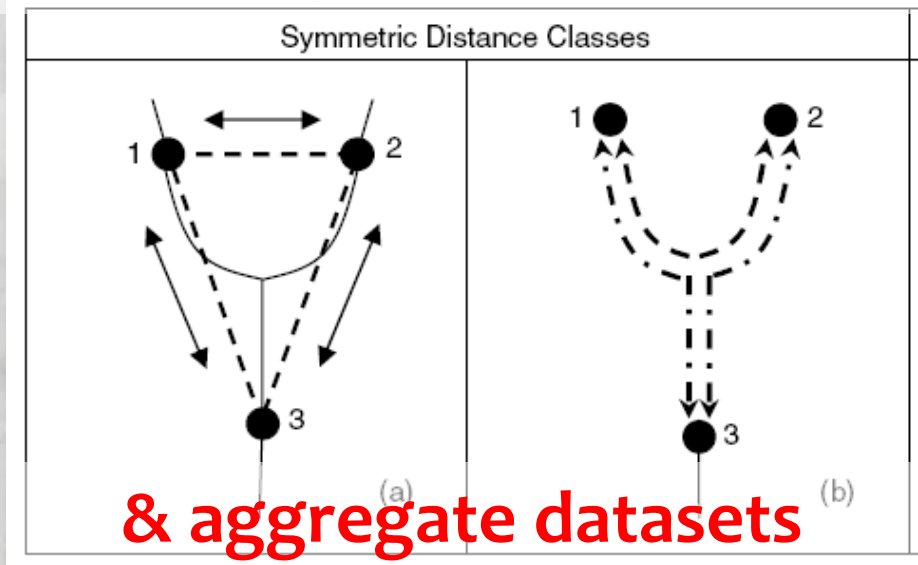


# BIG DATA are often Autocorrelated

## Spatial Statistical Network Models



Valid interpolation on networks

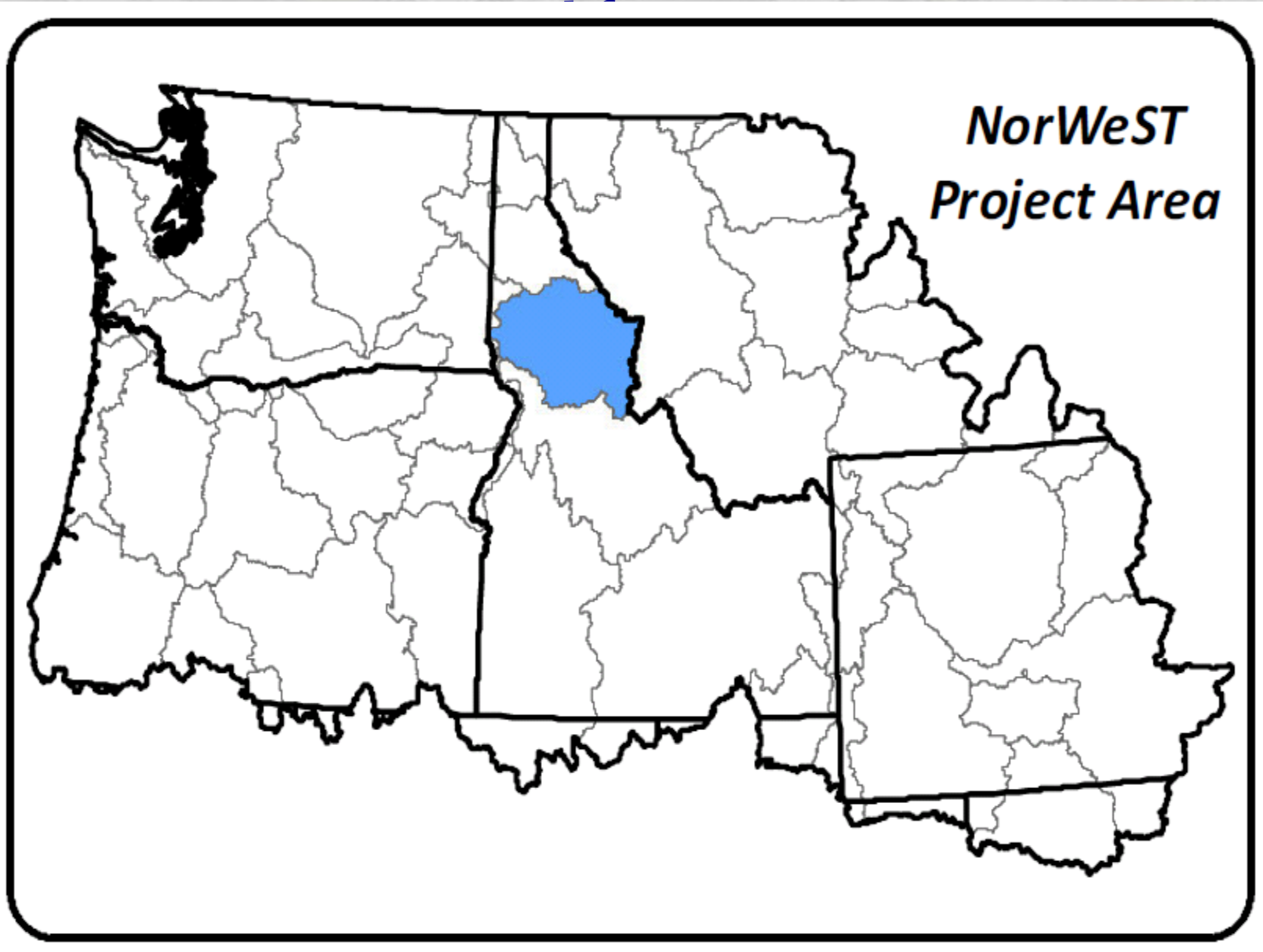


### Advantages:

- flexible & valid autocovariance structures that accommodate network topology & non-independence among observations
- improved predictive ability & parameter estimates relative to non-spatial models



# Example: Clearwater River Basin



# Clearwater River Temp Model

**n = 4,487**

## 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 (km<sup>2</sup>)

9. Discharge (m<sup>3</sup>/s)

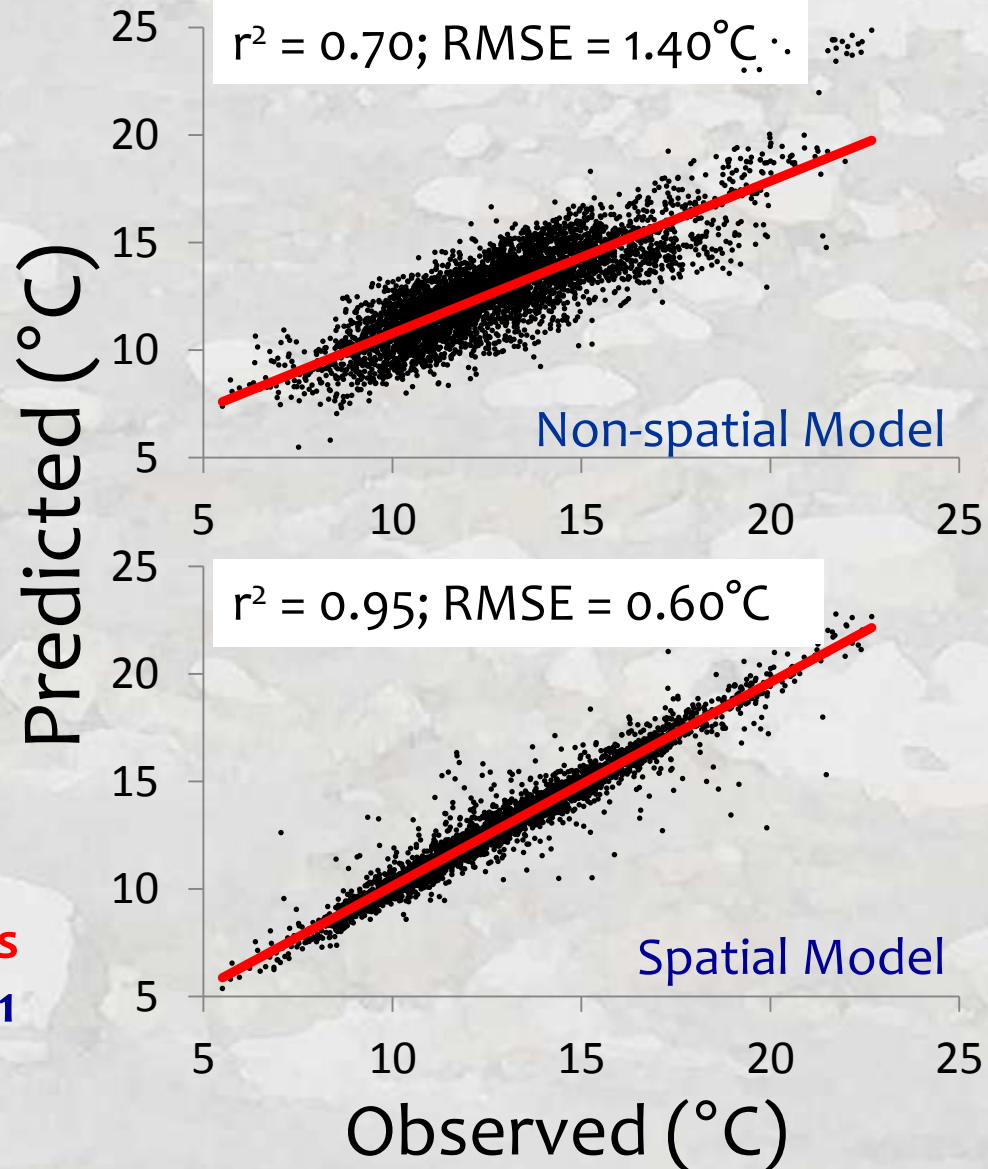
**USGS gage data**

10. Air Temperature (°C)

**RegCM3 NCEP reanalysis**

**Hostetler et al. 2011**

## Mean August Temperature



# Clearwater River Temp Model

**n = 4,487**

## 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 (km<sup>2</sup>)

9. Discharge (m<sup>3</sup>/s)

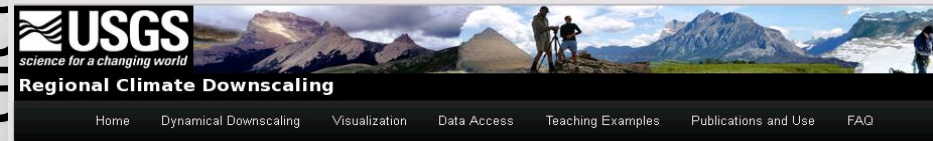
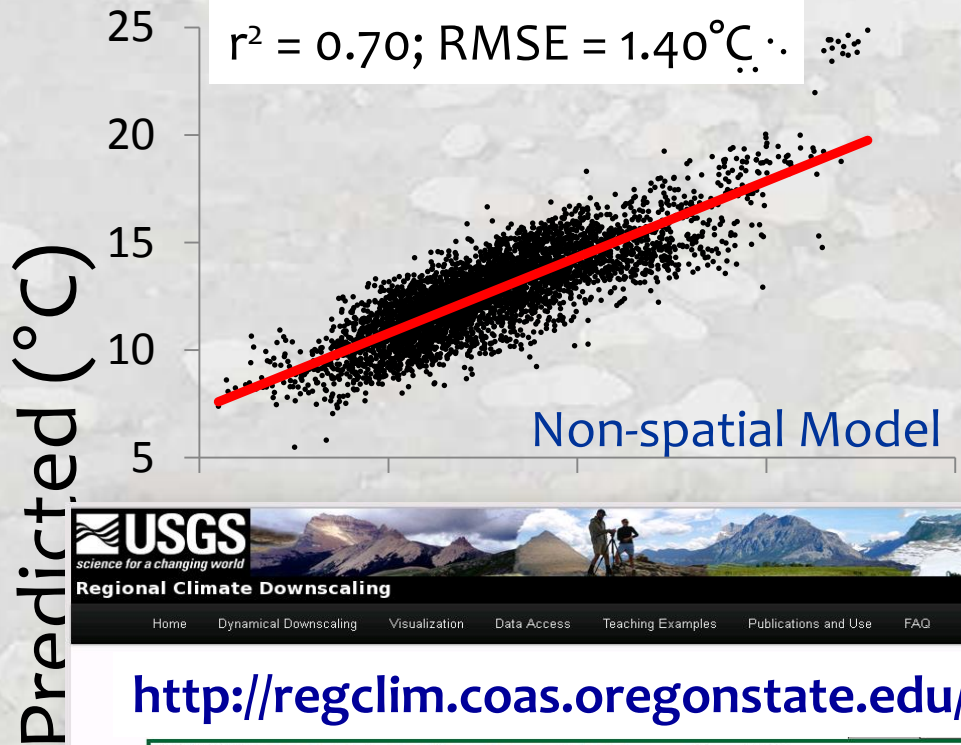
**USGS gage data**

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**Hostetler et al. 2011**

## Mean August Temperature

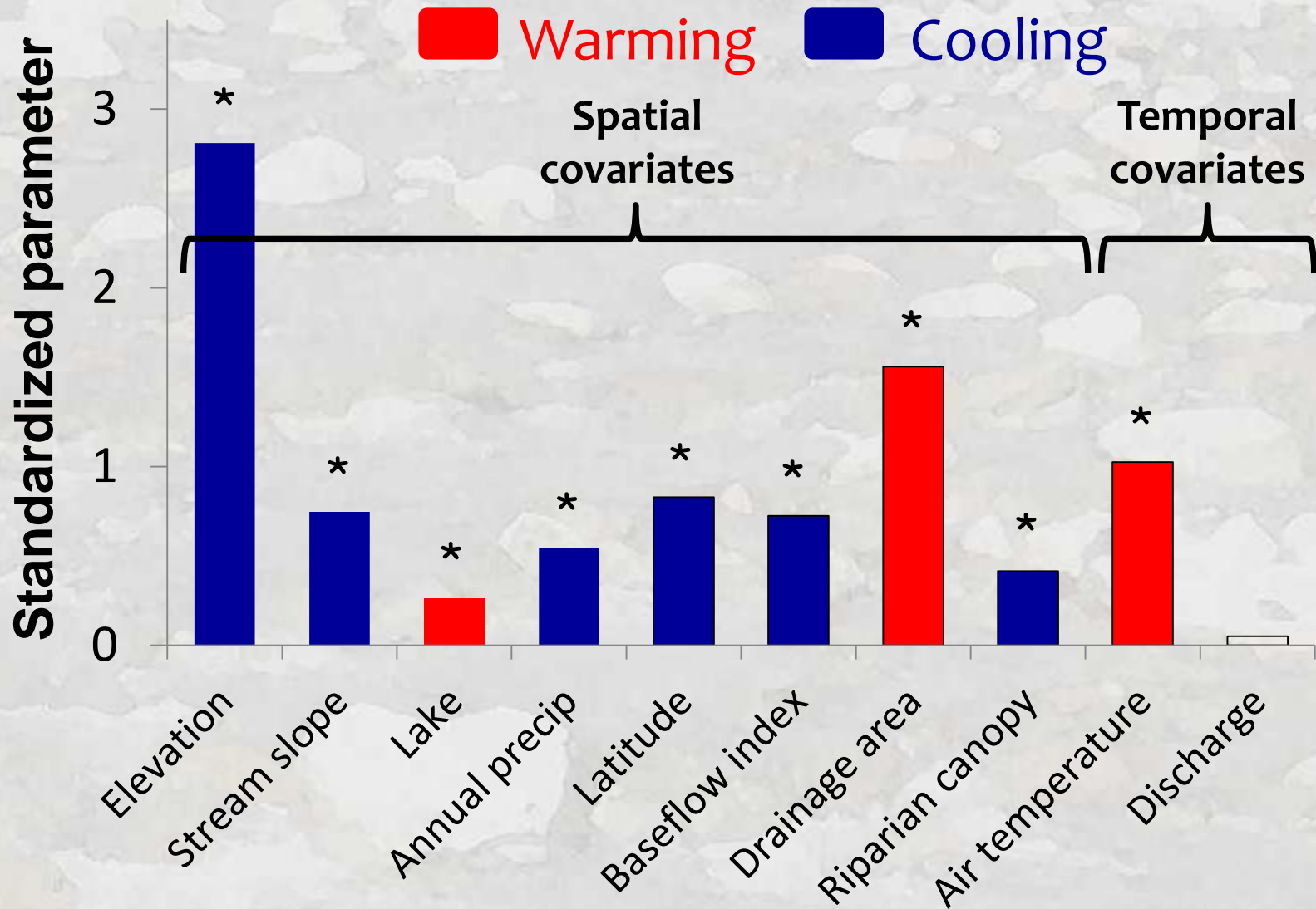


<http://regclim.coas.oregonstate.edu/>



# Relative Effects of Predictors

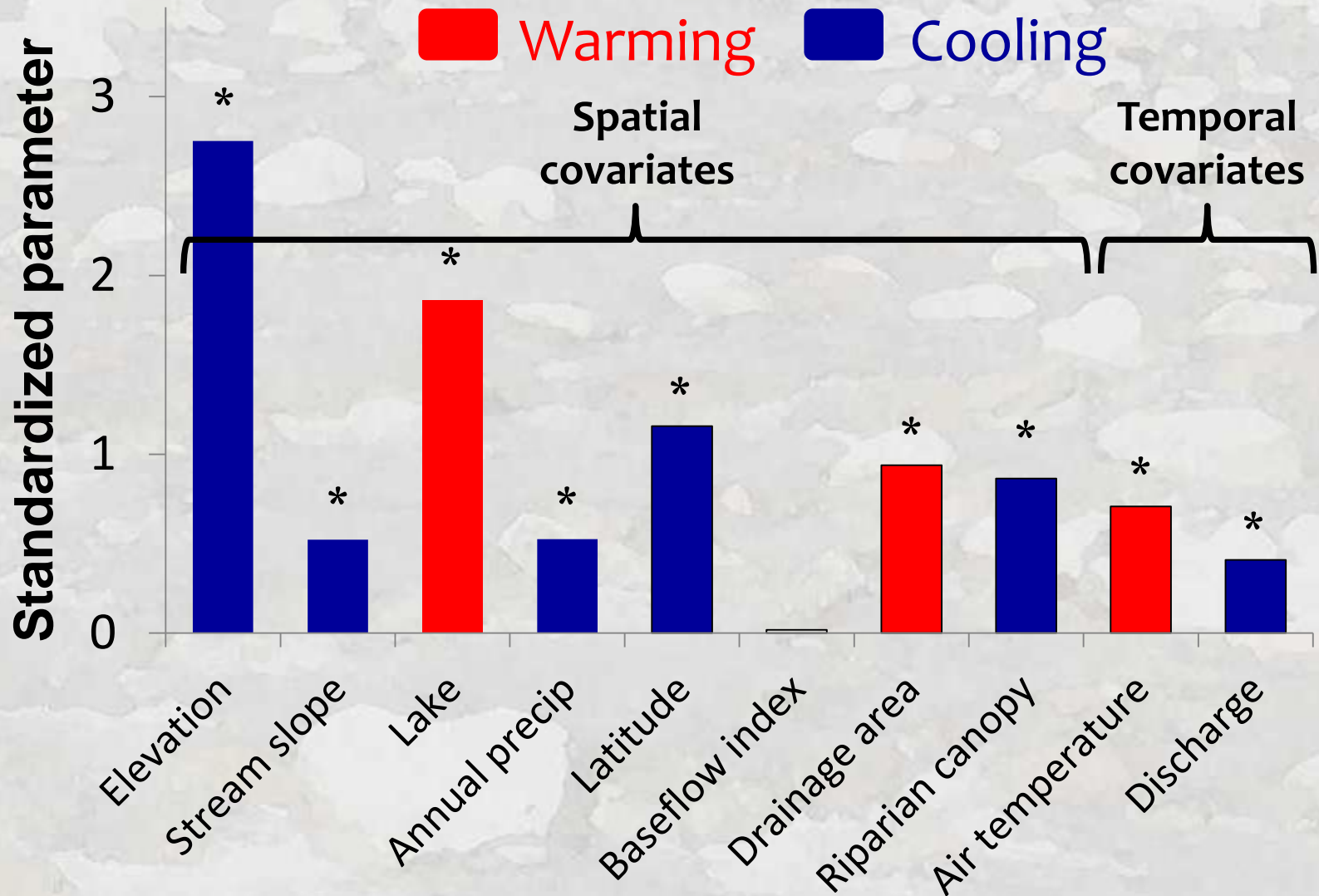
## Clearwater Temperature Model



\* = statistically significant at  $p < 0.01$

# Relative Effects of Predictors

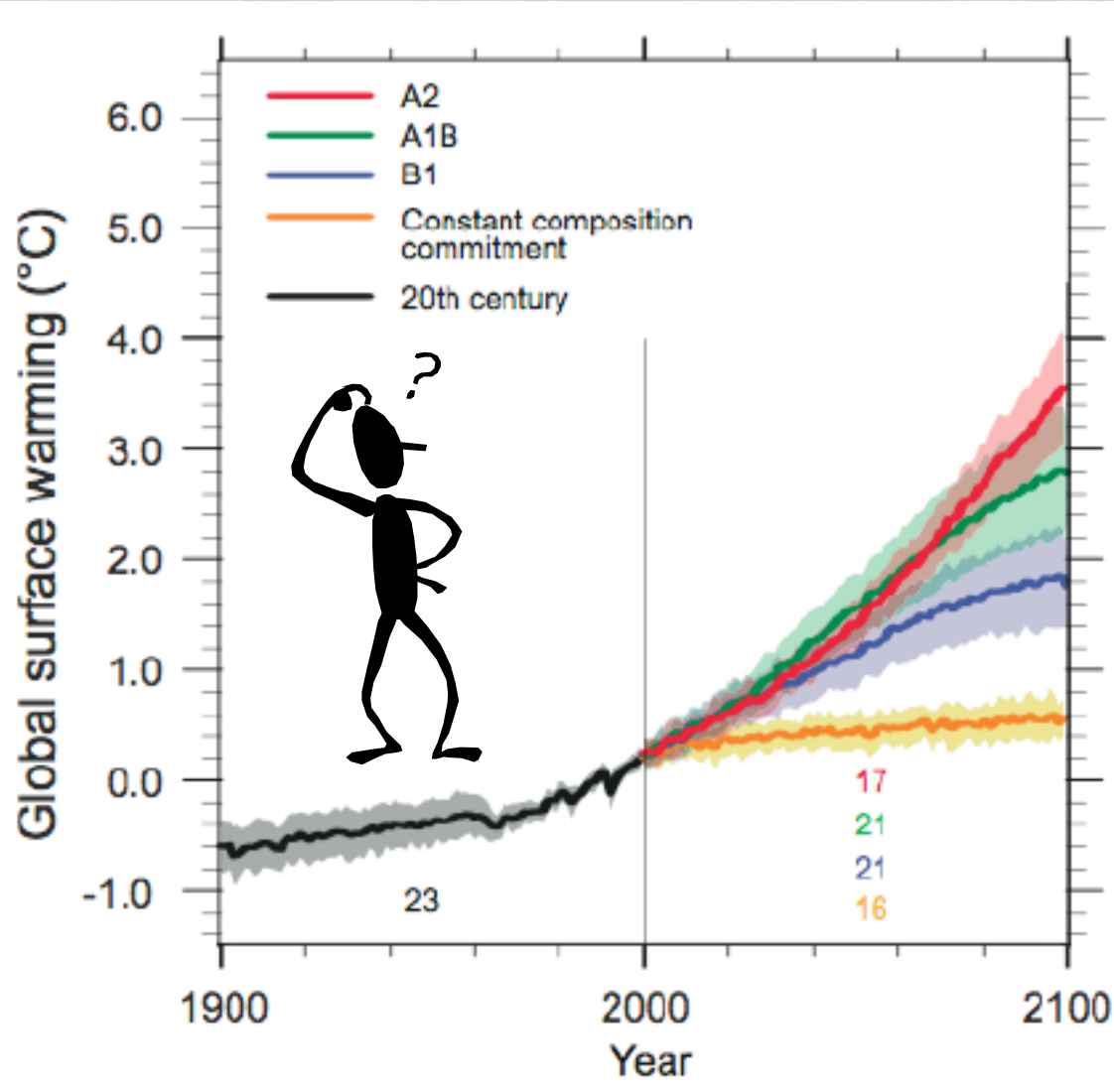
## SpoKoot Temperature Model



\* = statistically significant at  $p < 0.01$

# Models Enable Climate Scenario Maps

Many possibilities exist...



Adjust...

- Air
- Discharge
- %Canopy

... values to create scenarios



# NorWeST Scenario Descriptions

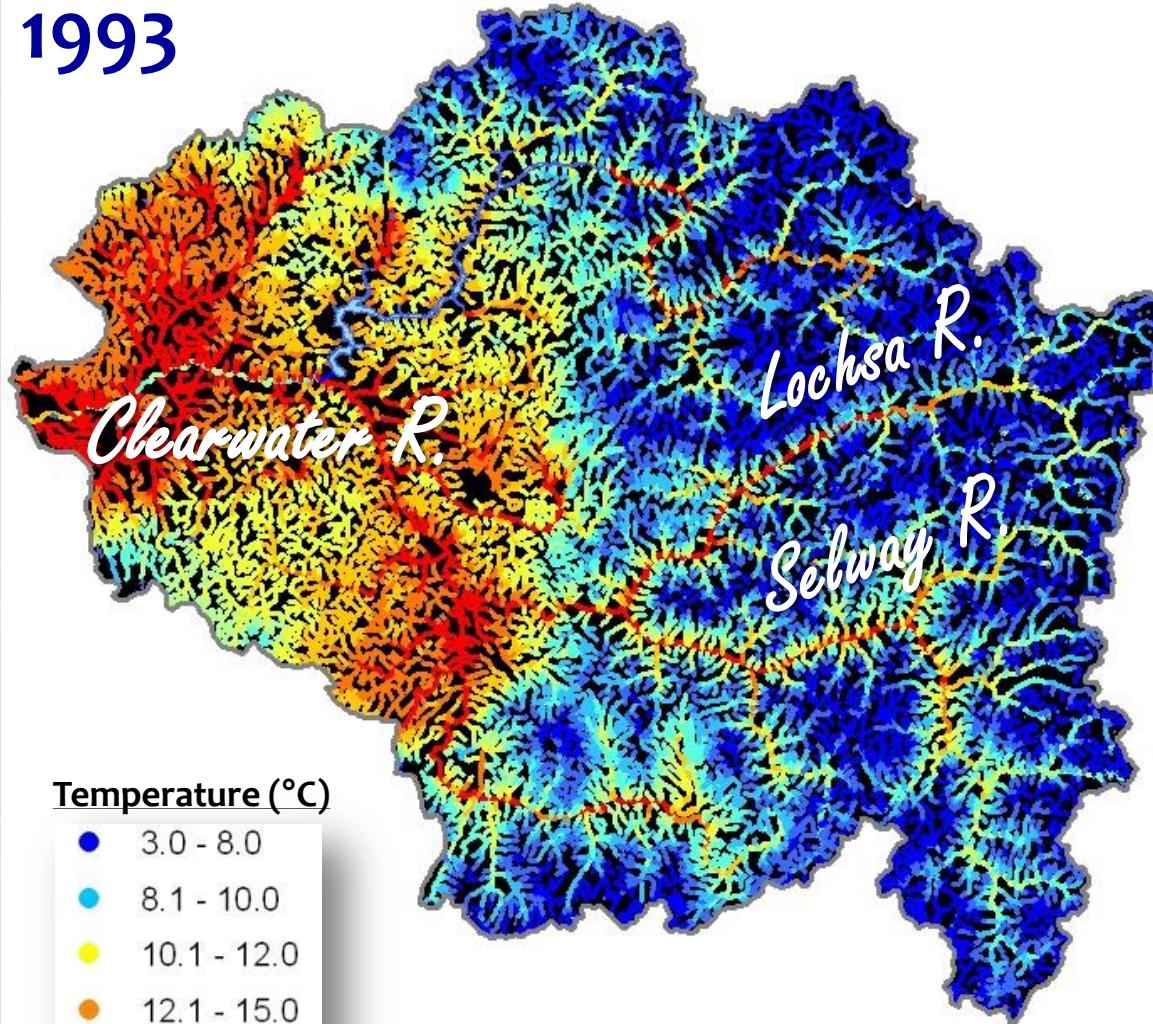
Scenario	Description
S1_93_11	Historical scenario representing 19 year average August mean stream temperatures for 1993-2011
S2_02_11	Historical scenario representing 10 year average August mean stream temperatures for 2002-2011
S3_1993	Historical scenario representing August mean stream temperatures for 1993
S4_1994	Historical scenario representing August mean stream temperatures for 1994
Etc...	
S22+...	Futures: 1) A1B scenarios for 2040s and 2080s; 2) “scenario free (e.g., +1°C, +2C, etc.)



# Historical Scenarios (1993-2011)

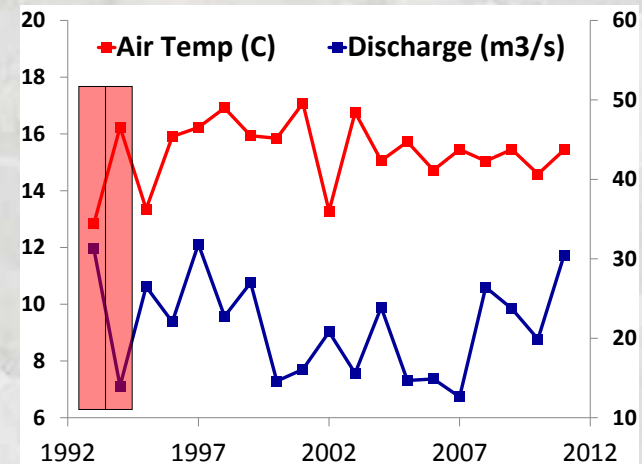
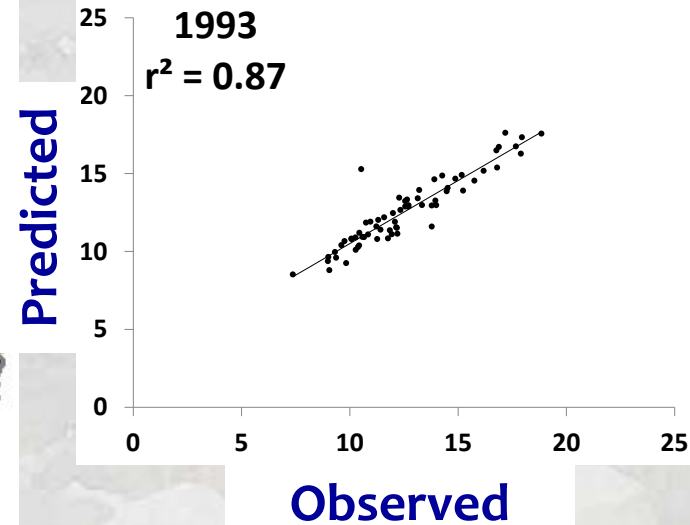
## Mean August Temperature - Clearwater Basin

1993



Temperature (°C)

- 3.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.0
- 12.1 - 15.0
- 15.1 - 27.0

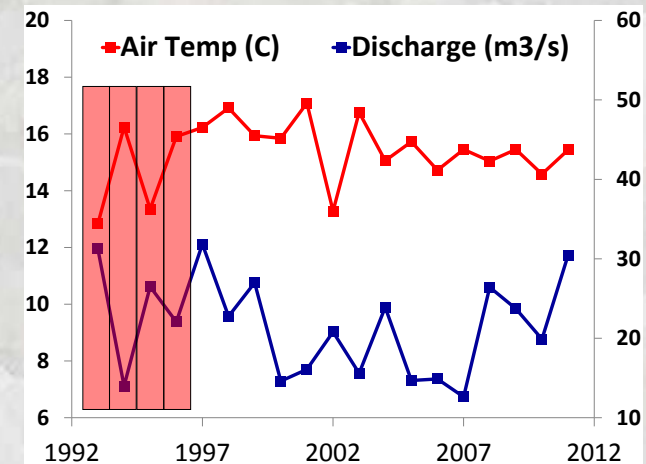
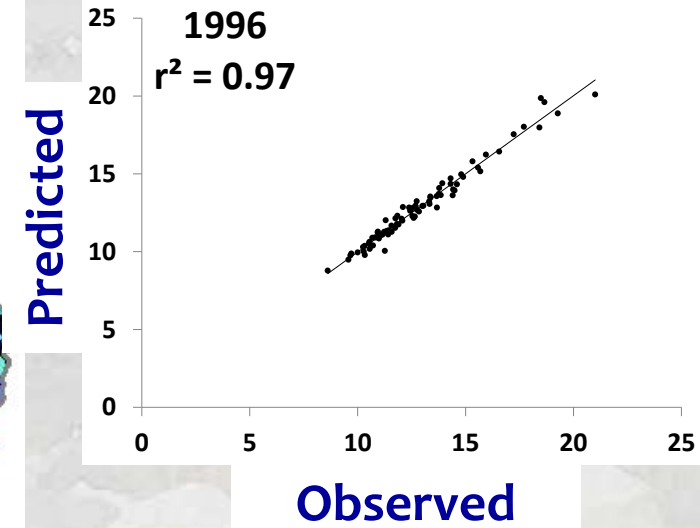
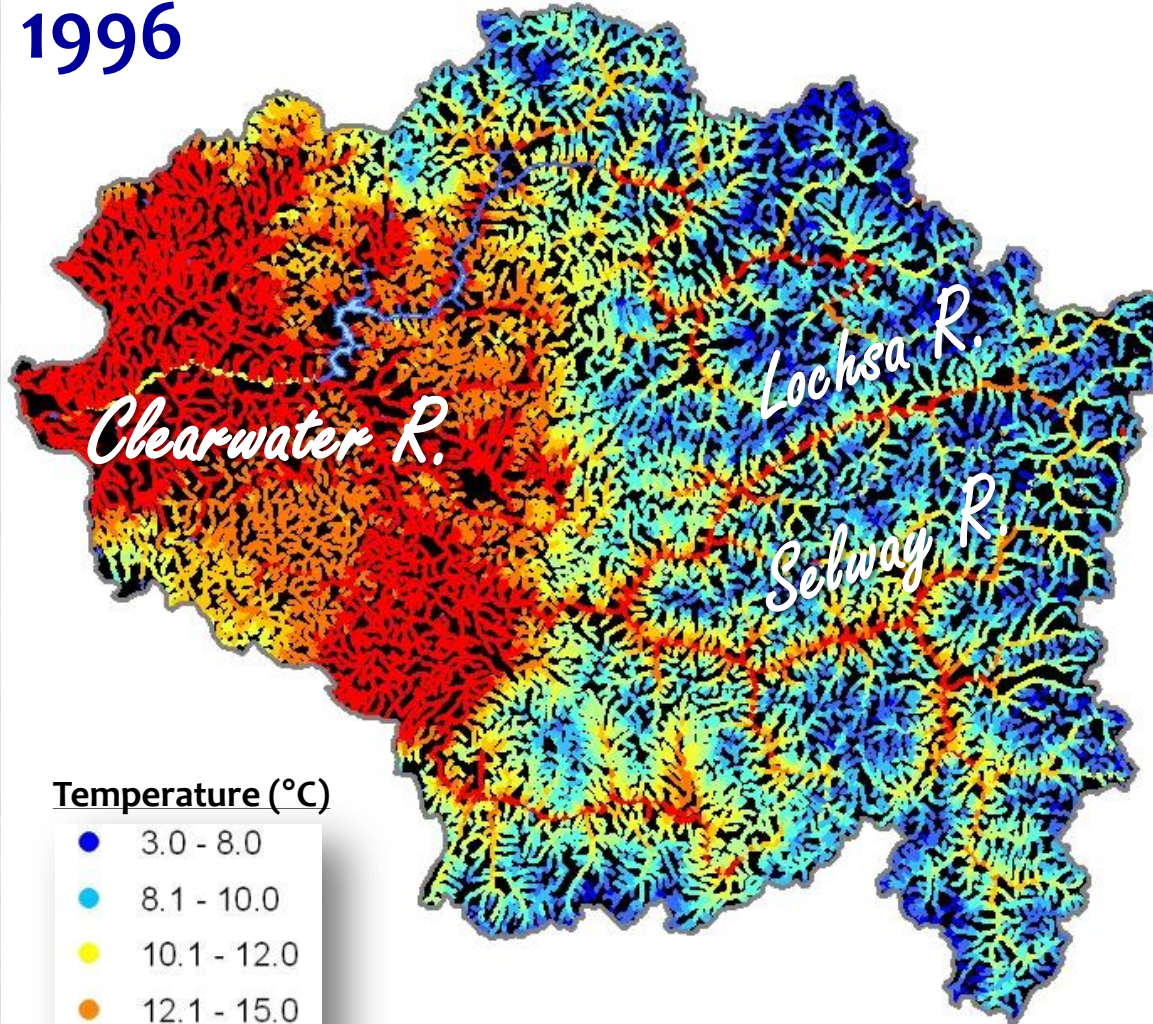




# Historical Scenarios (1993-2011)

## Mean August Temperature - Clearwater Basin

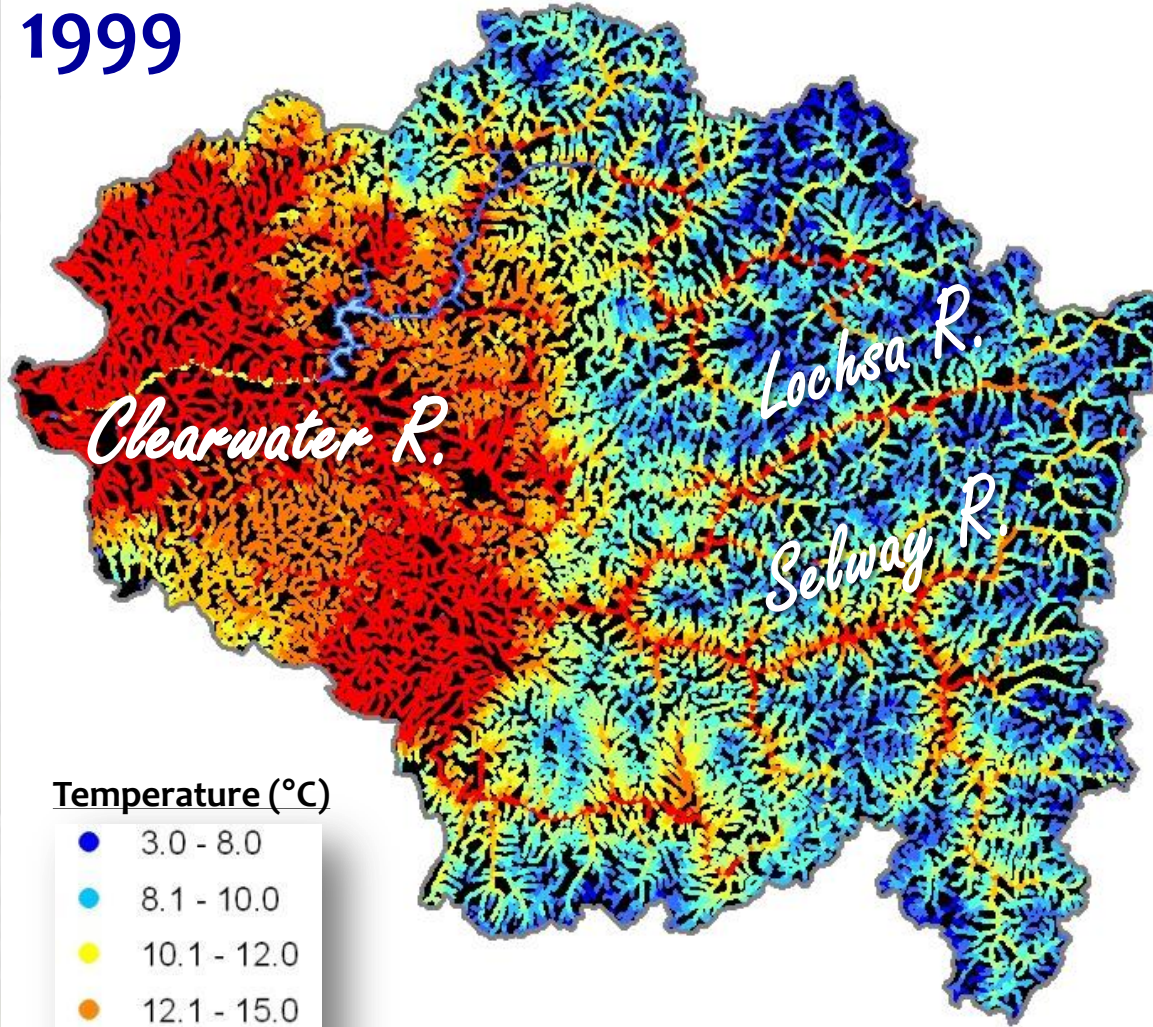
1996



# Historical Scenarios (1993-2011)

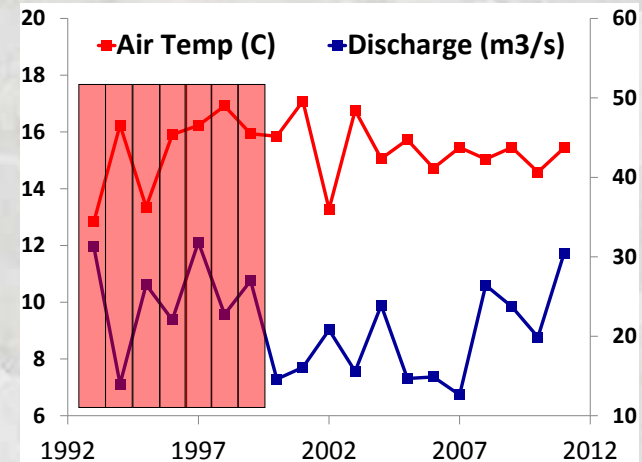
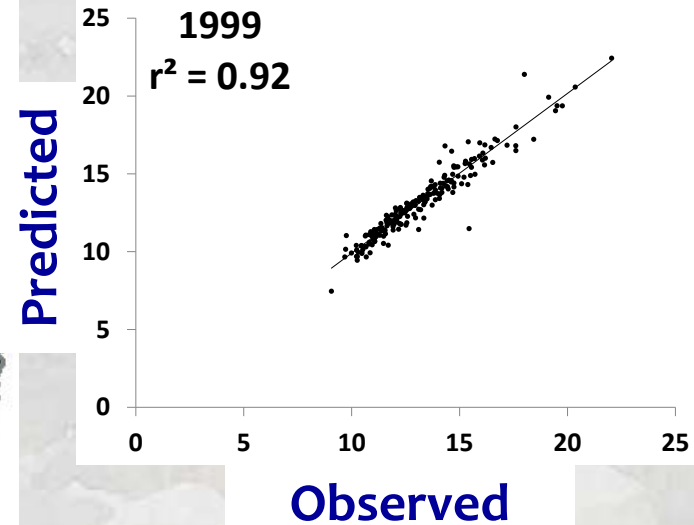
## Mean August Temperature - Clearwater Basin

1999



Temperature (°C)

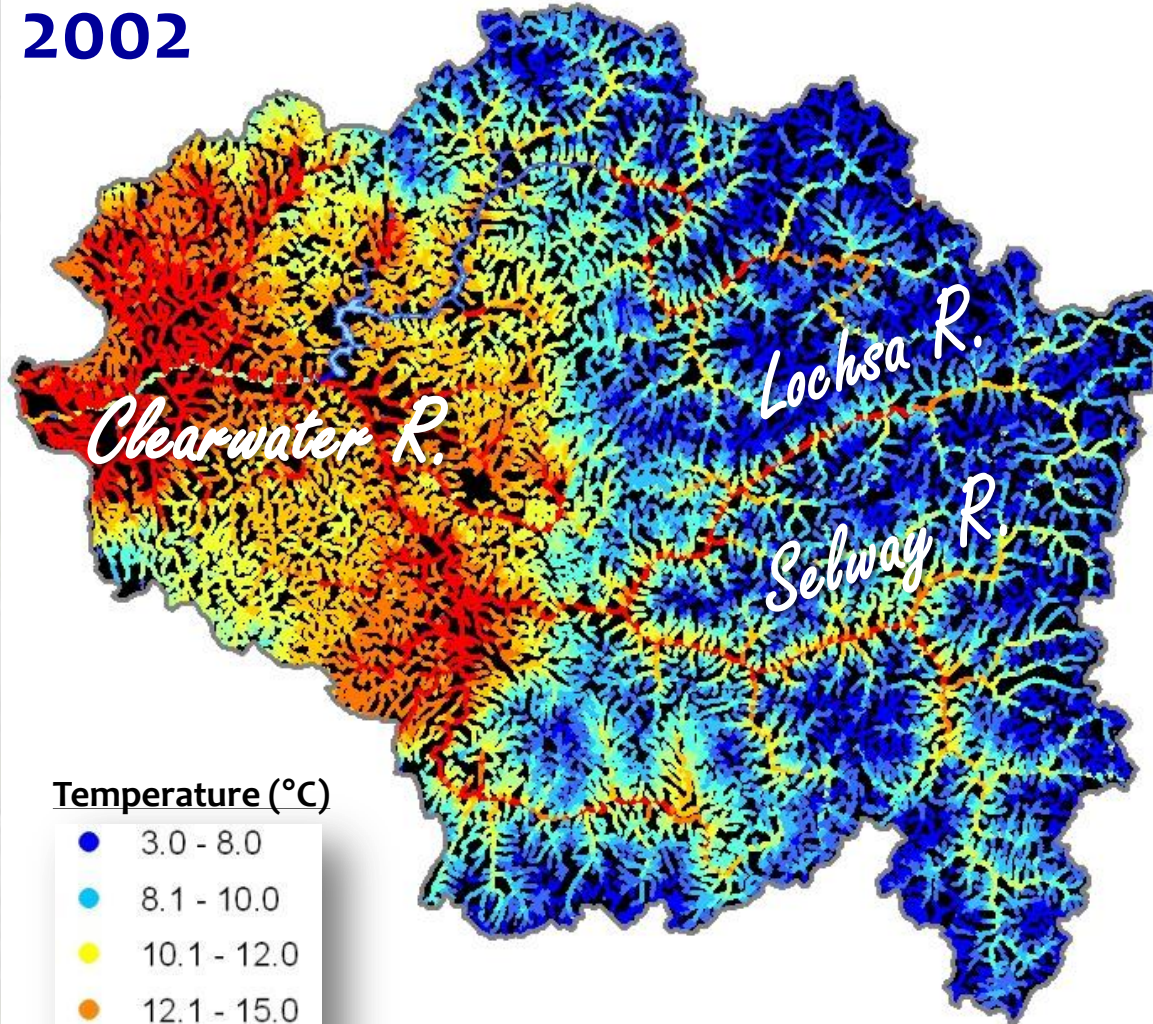
- 3.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.0
- 12.1 - 15.0
- 15.1 - 27.0



# Historical Scenarios (1993-2011)

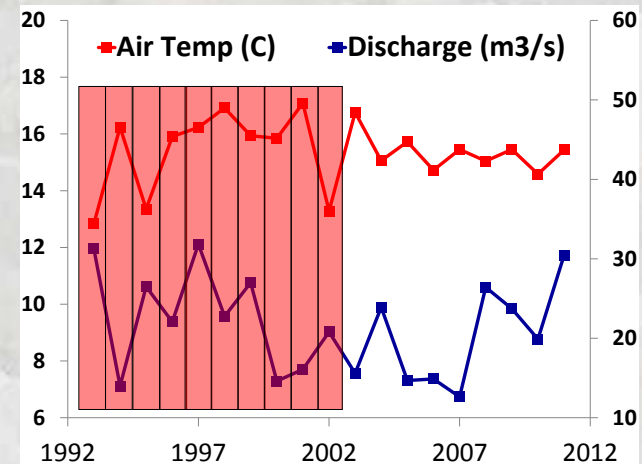
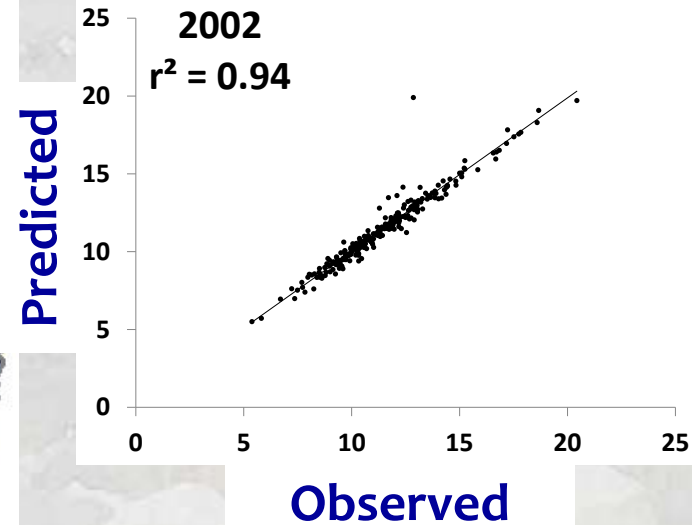
## Mean August Temperature - Clearwater Basin

2002



Temperature (°C)

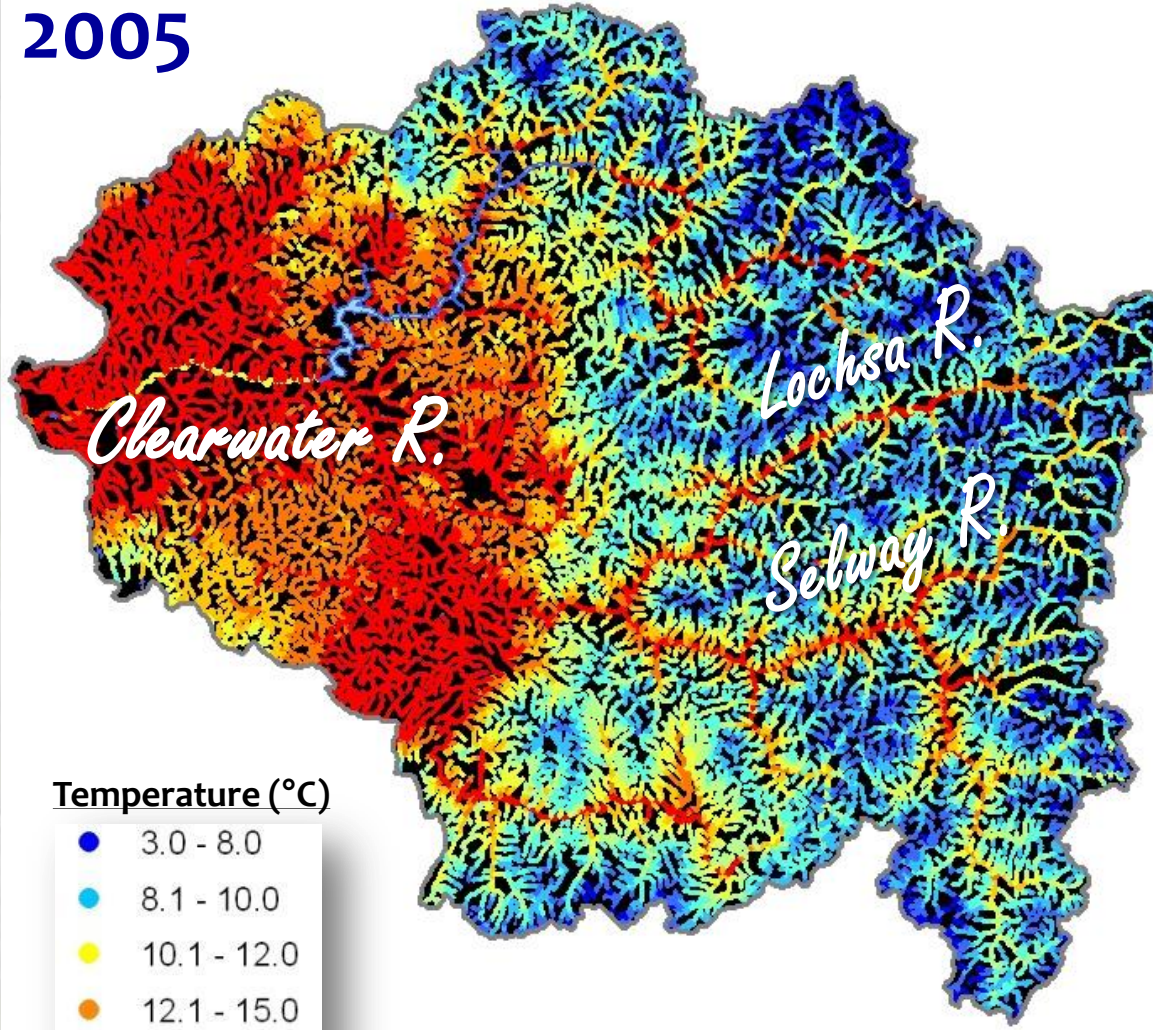
- 3.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.0
- 12.1 - 15.0
- 15.1 - 27.0



# Historical Scenarios (1993-2011)

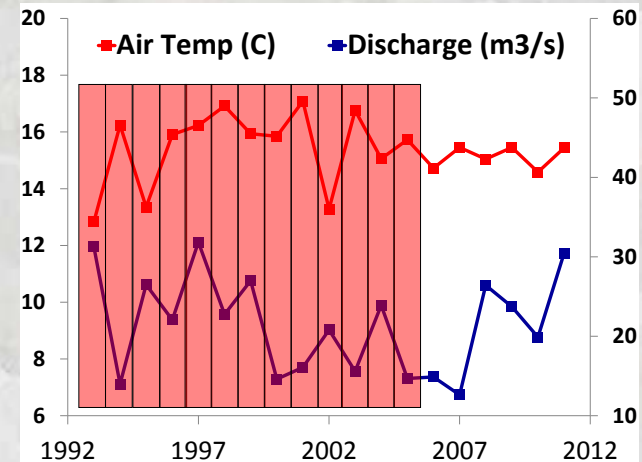
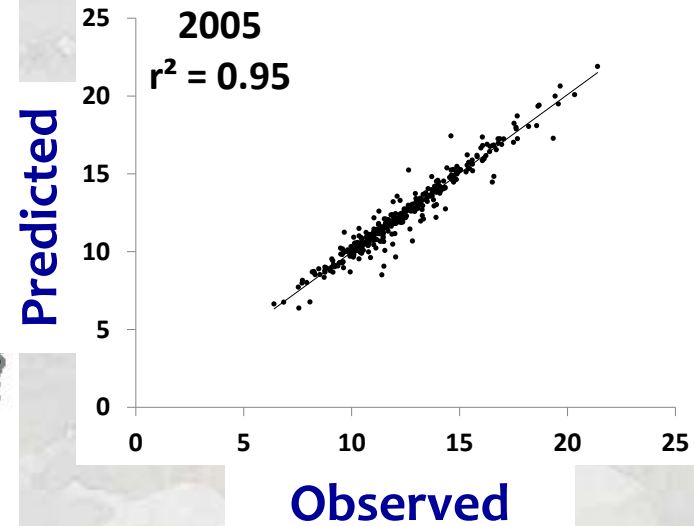
## Mean August Temperature - Clearwater Basin

2005



Temperature (°C)

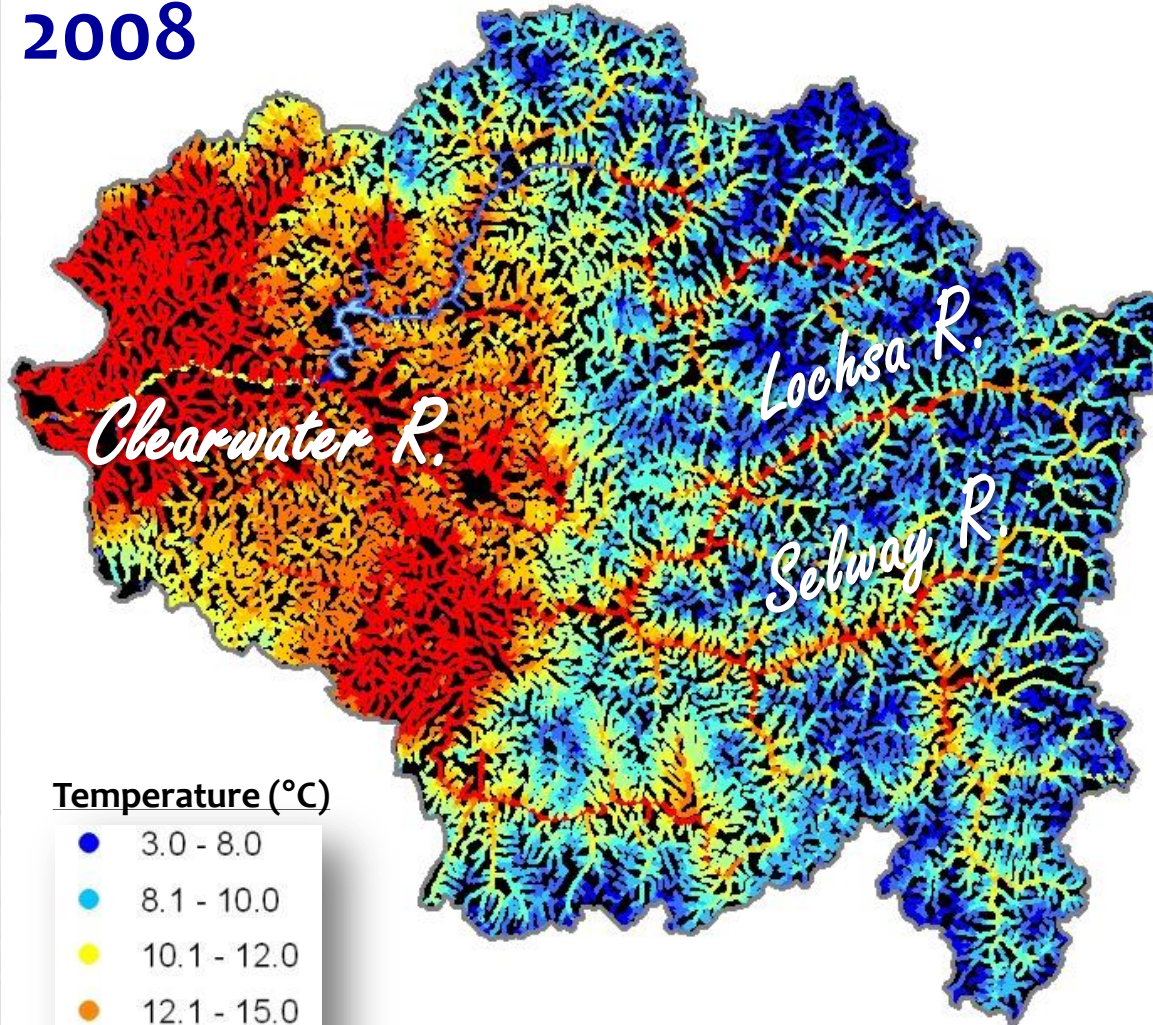
- 3.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.0
- 12.1 - 15.0
- 15.1 - 27.0



# Historical Scenarios (1993-2011)

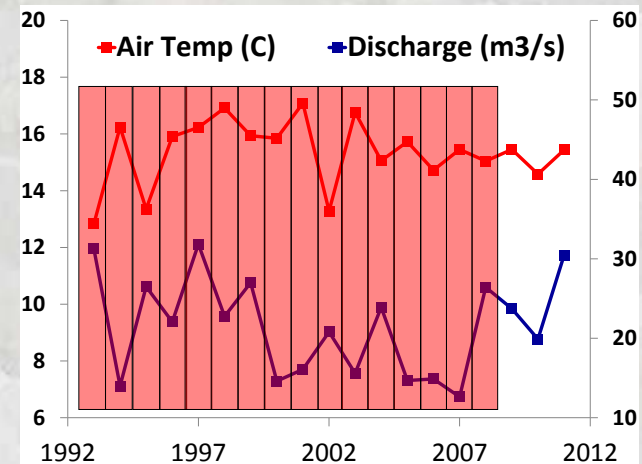
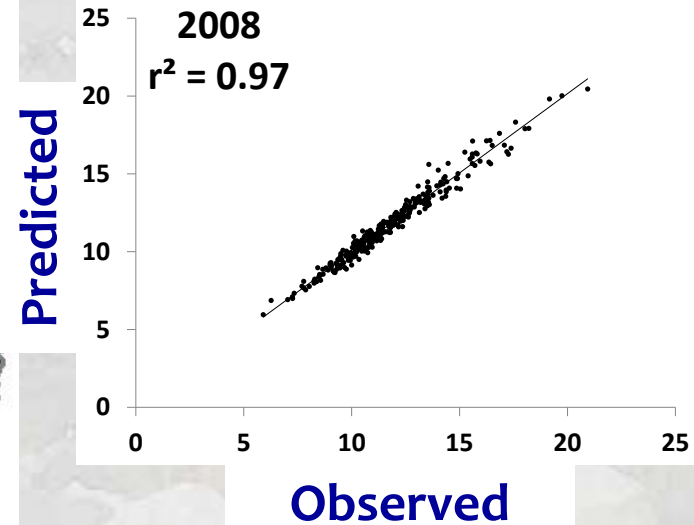
## Mean August Temperature - Clearwater Basin

2008



Temperature (°C)

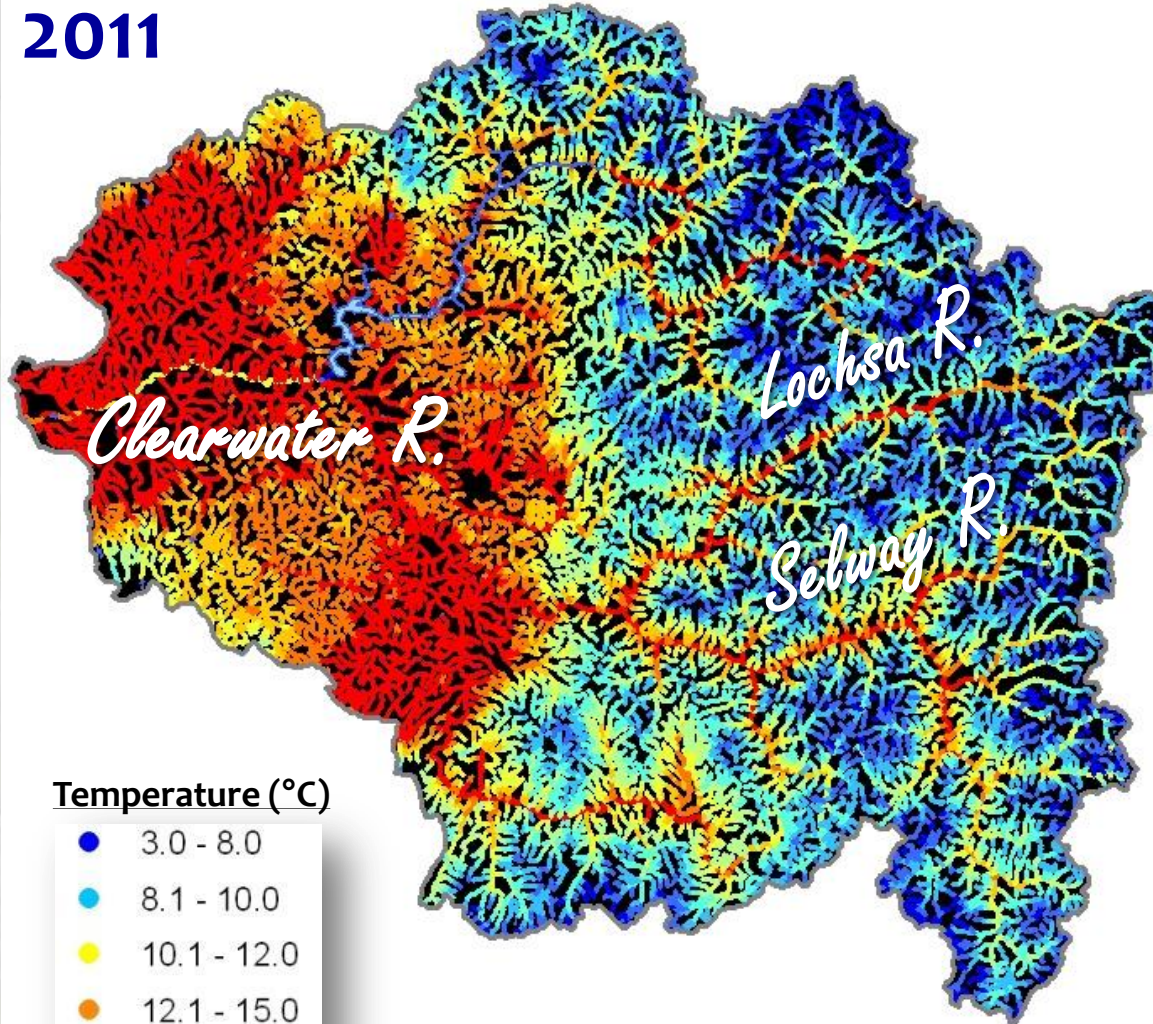
- 3.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.0
- 12.1 - 15.0
- 15.1 - 27.0



# Historical Scenarios (1993-2011)

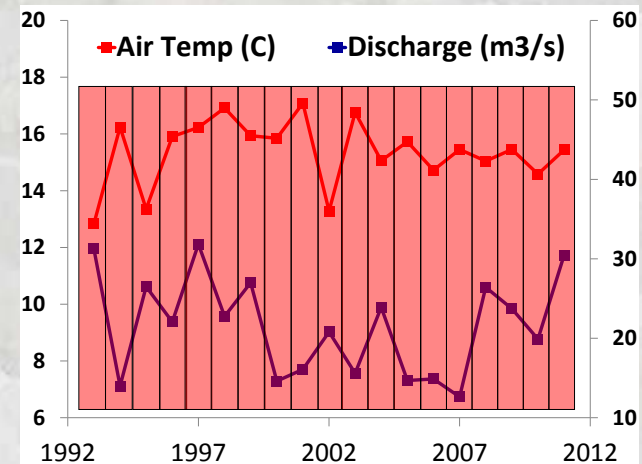
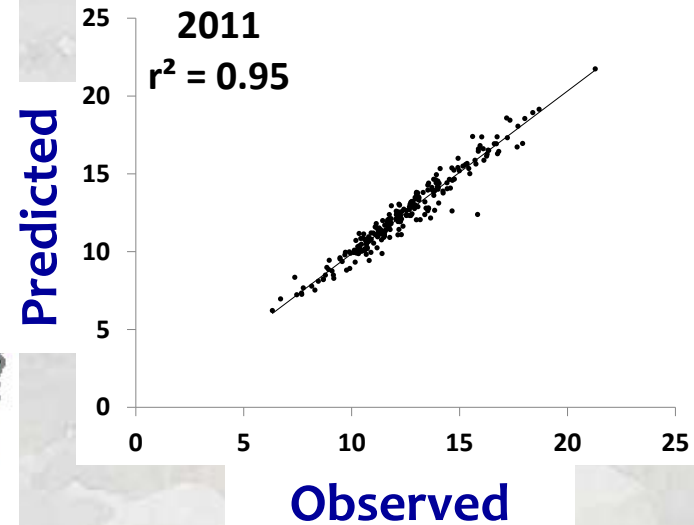
## Mean August Temperature - Clearwater Basin

2011



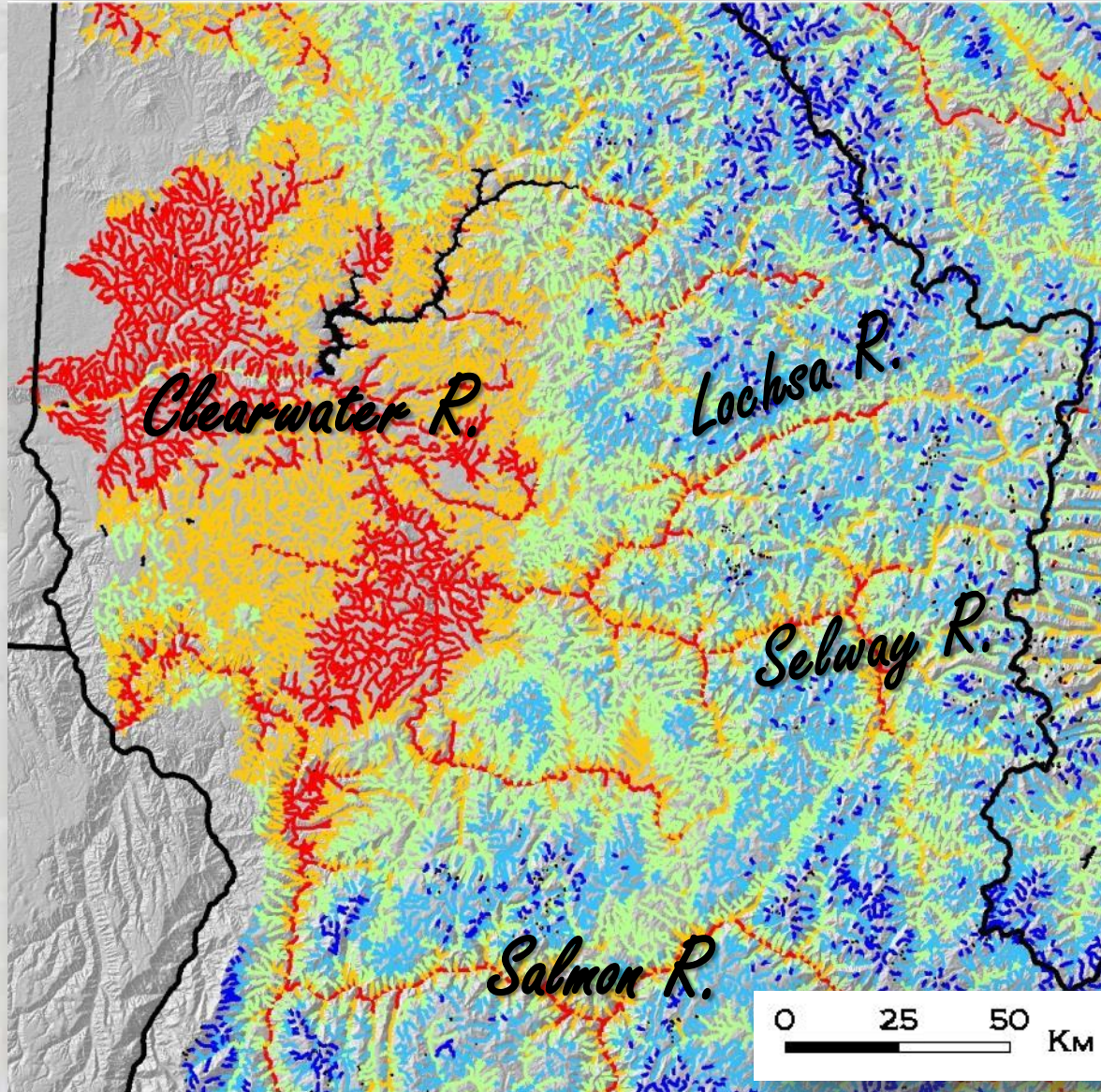
Temperature (°C)

- 3.0 - 8.0
- 8.1 - 10.0
- 10.1 - 12.0
- 12.1 - 15.0
- 15.1 - 27.0



# Clearwater Stream Temperature Scenario

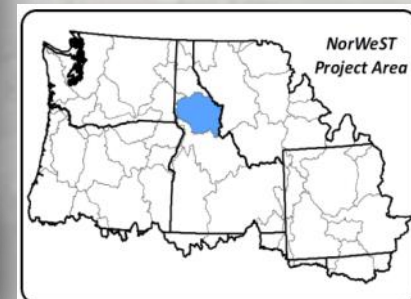
## Historic (1993-2011 Average August)



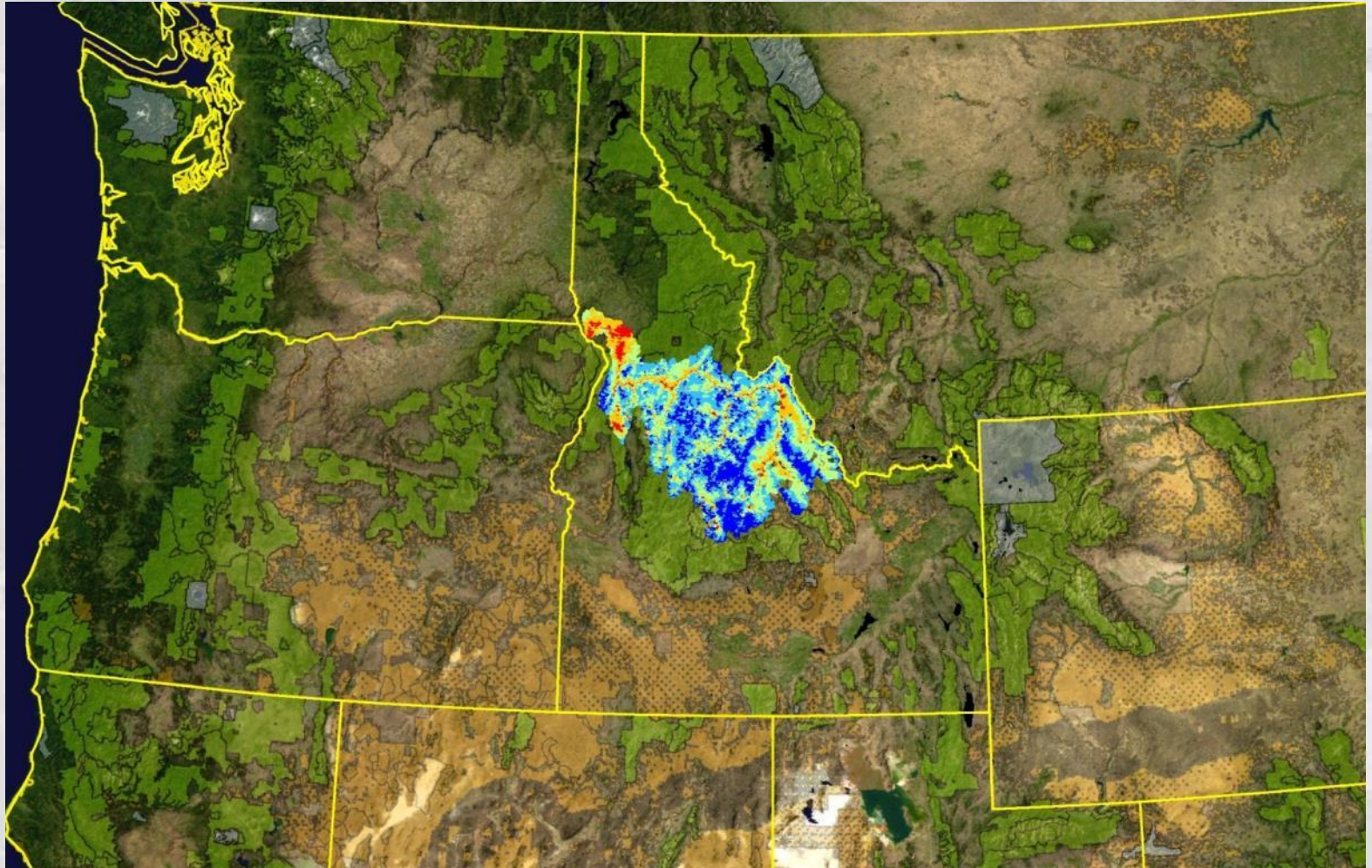
Temperature (°C)



**1 kilometer  
resolution**

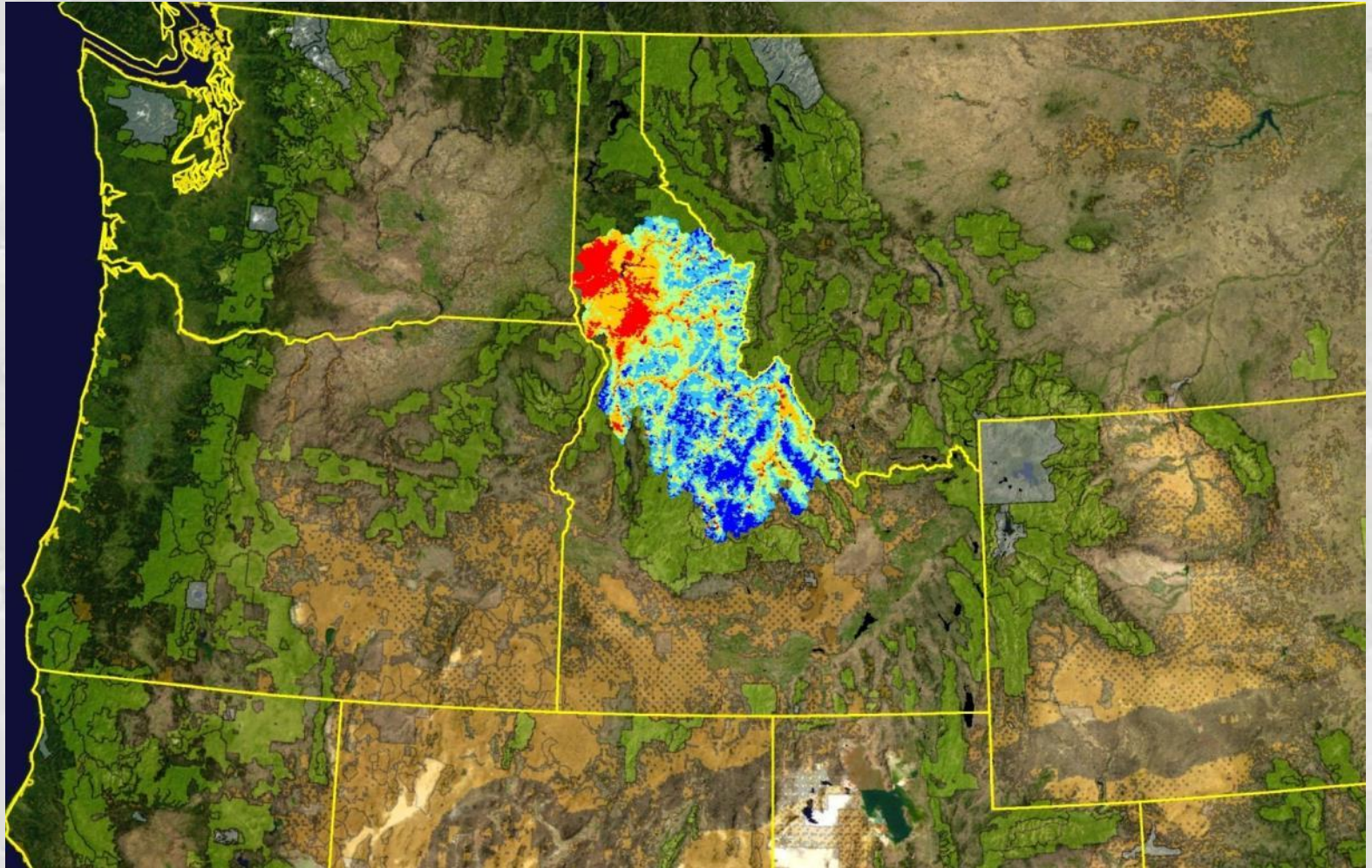


# Stream Thermalscape so Far...

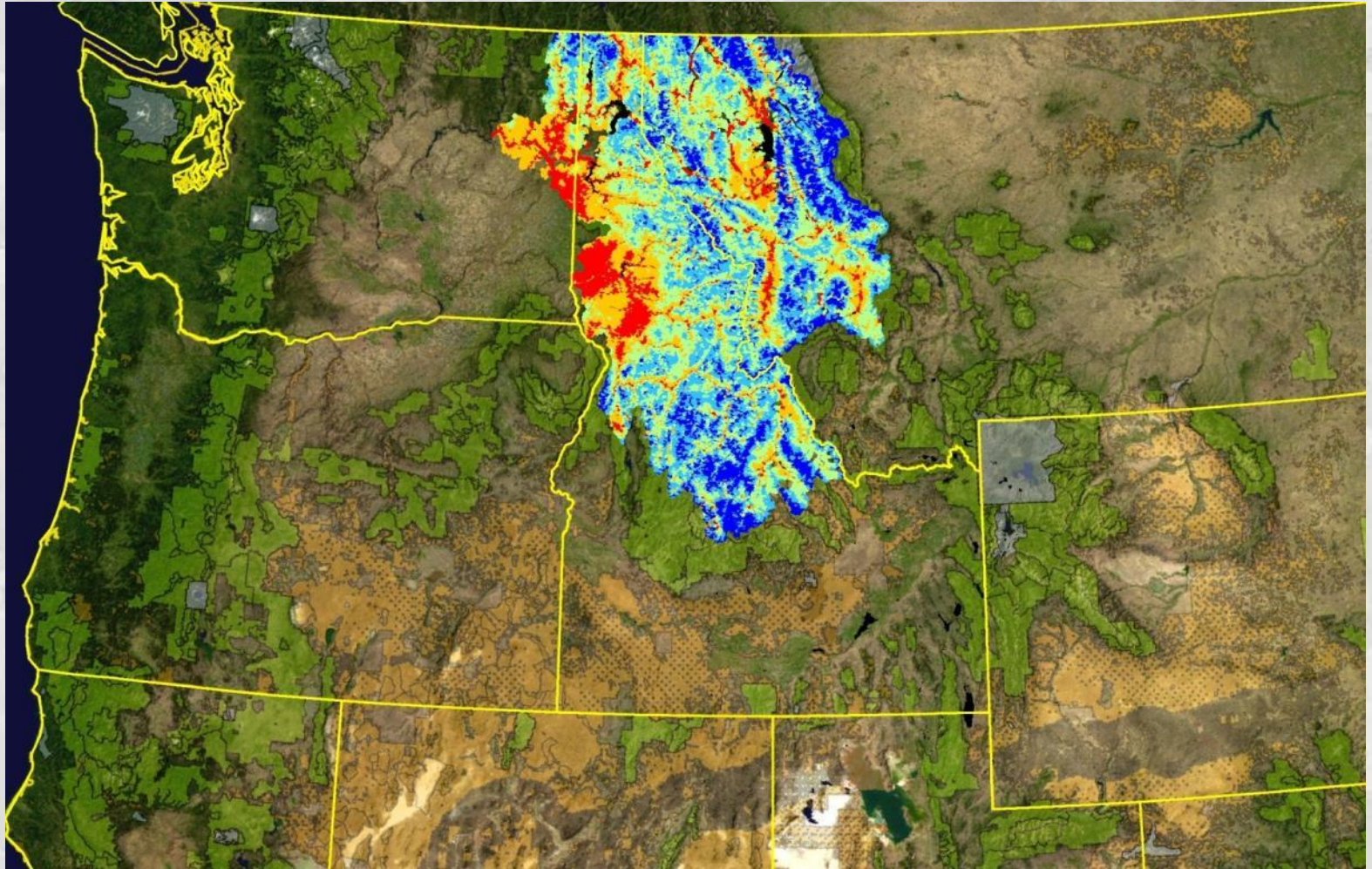




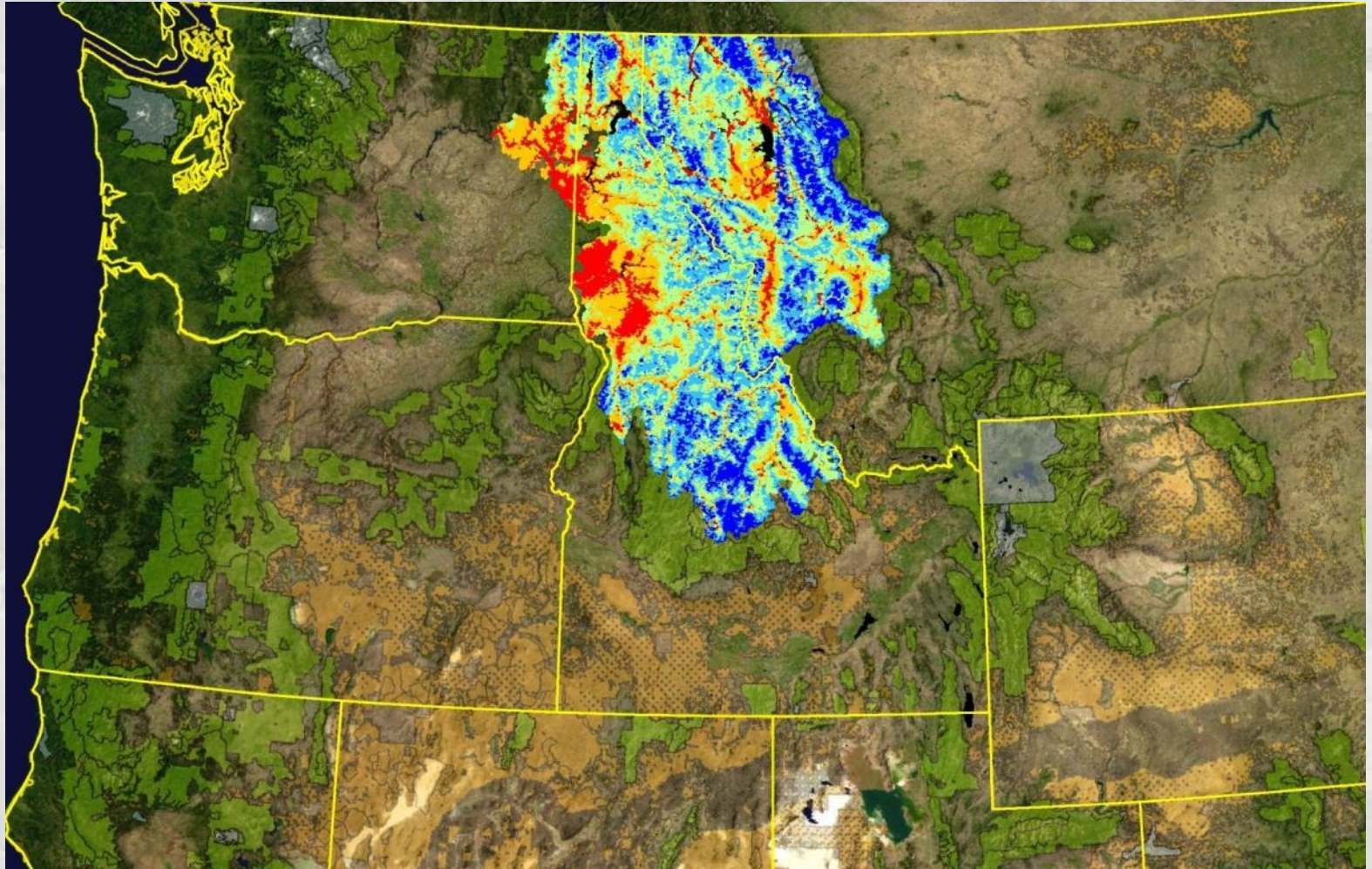
# Stream Thermalscape so Far...



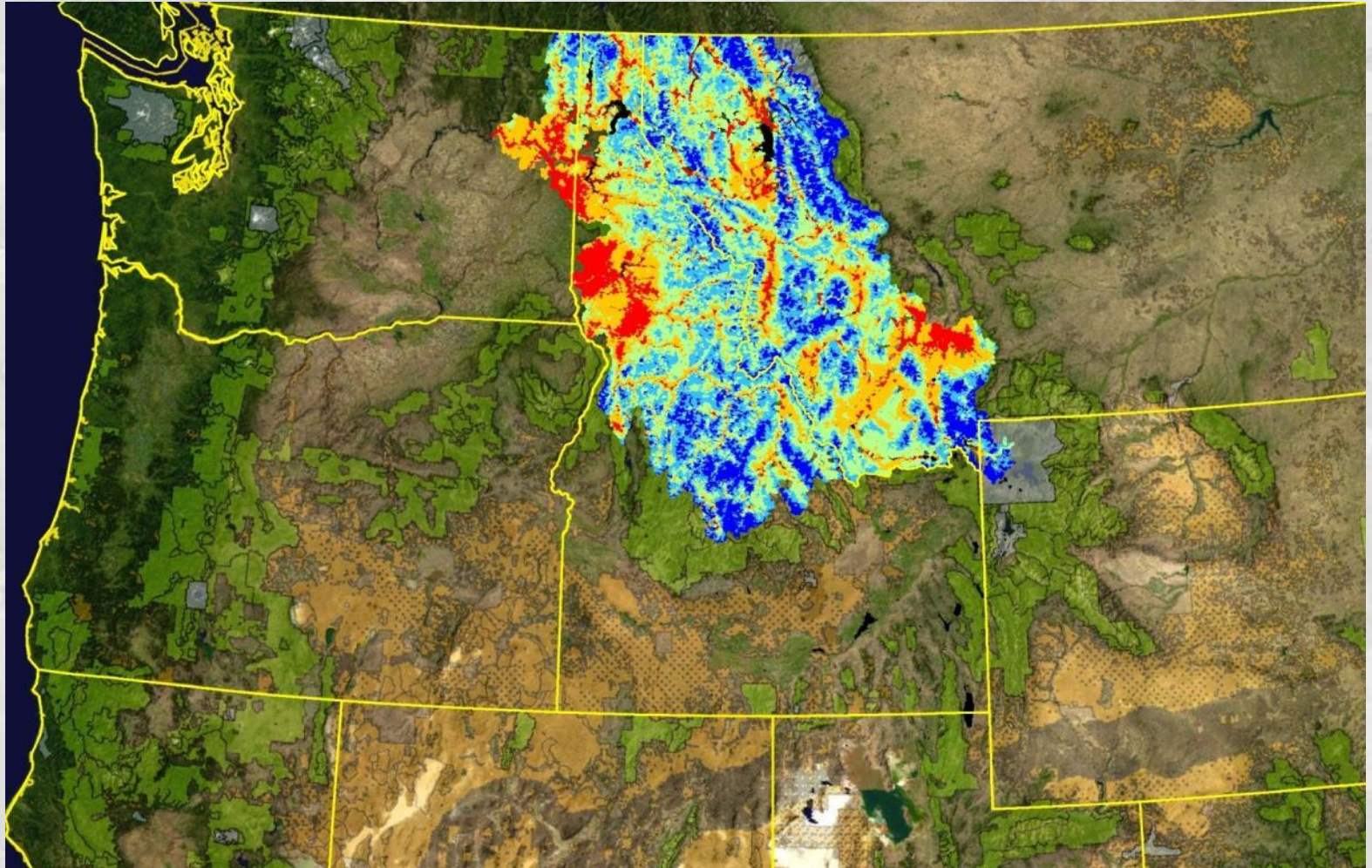
# Stream Thermalscape so Far...



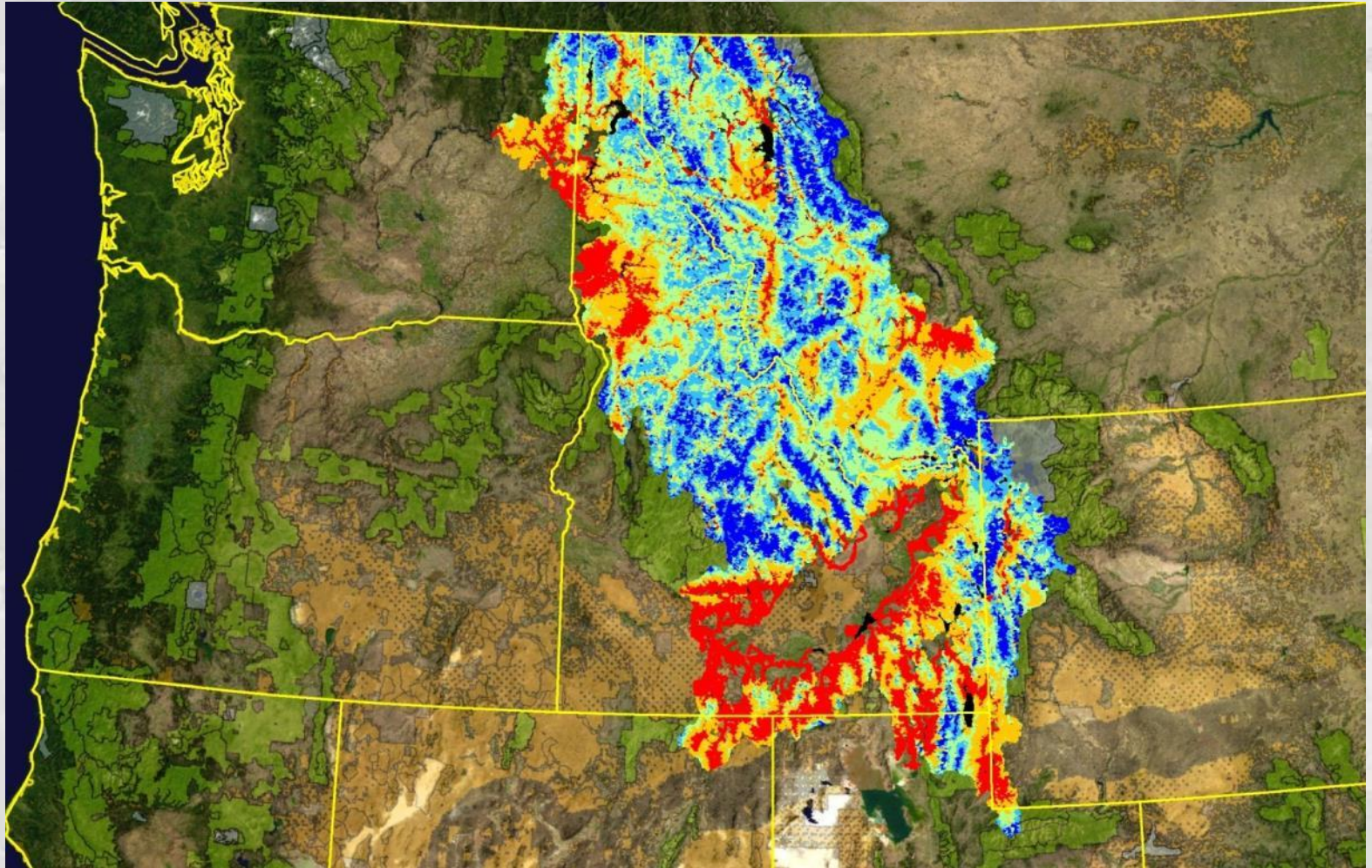
# Stream Thermalscape so Far...



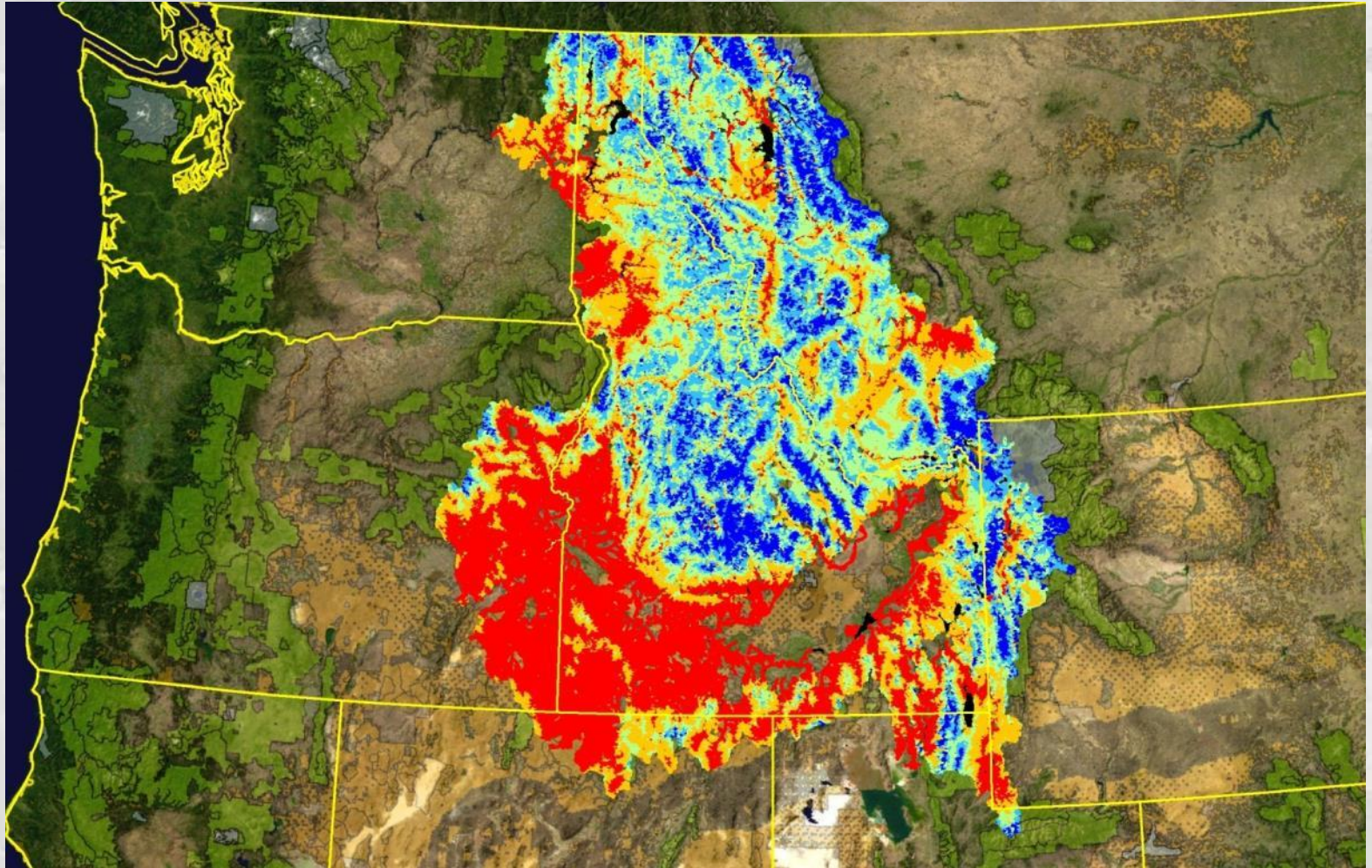
# Stream Thermalscape so Far...



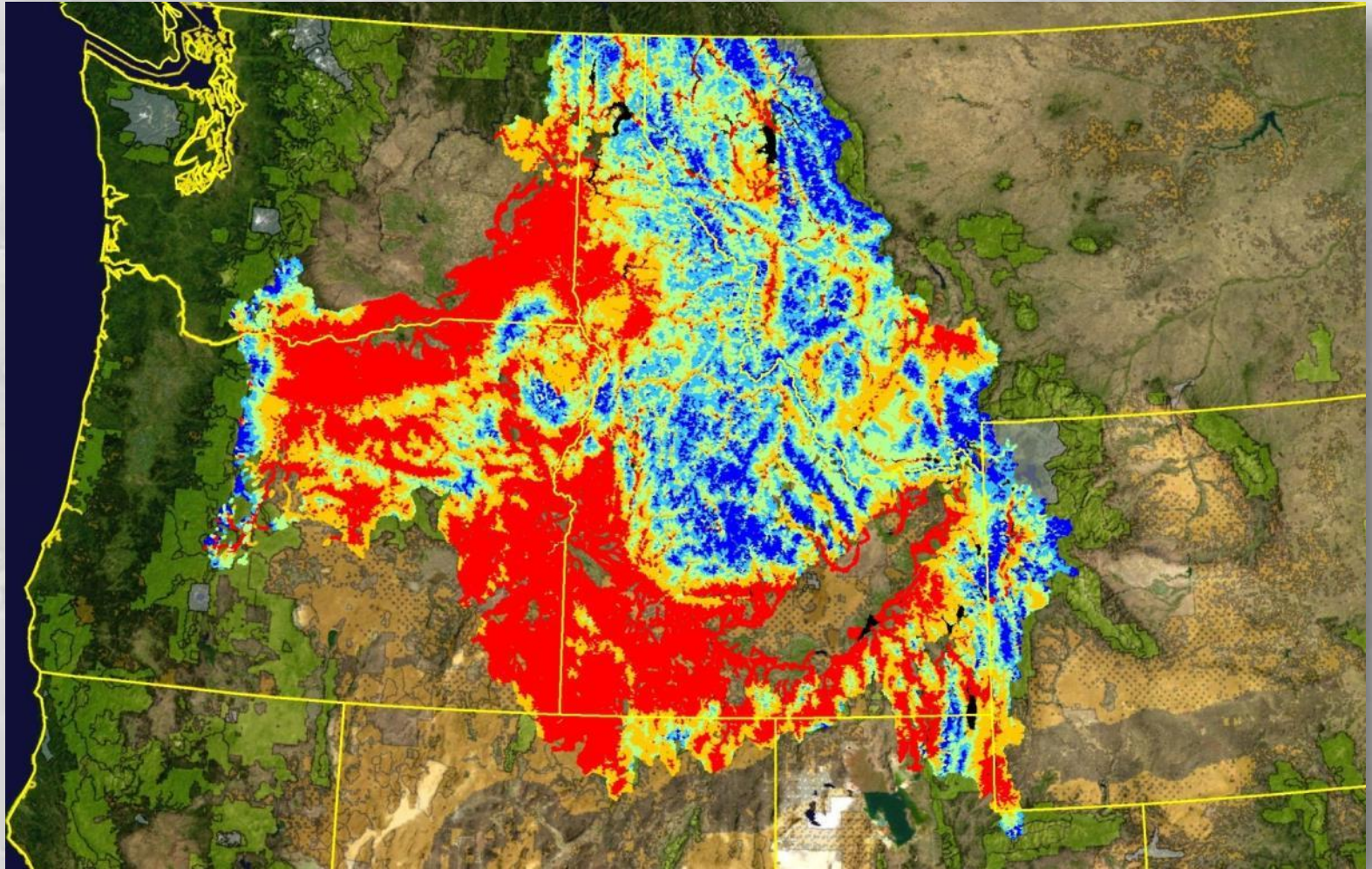
# Stream Thermalscape so Far...



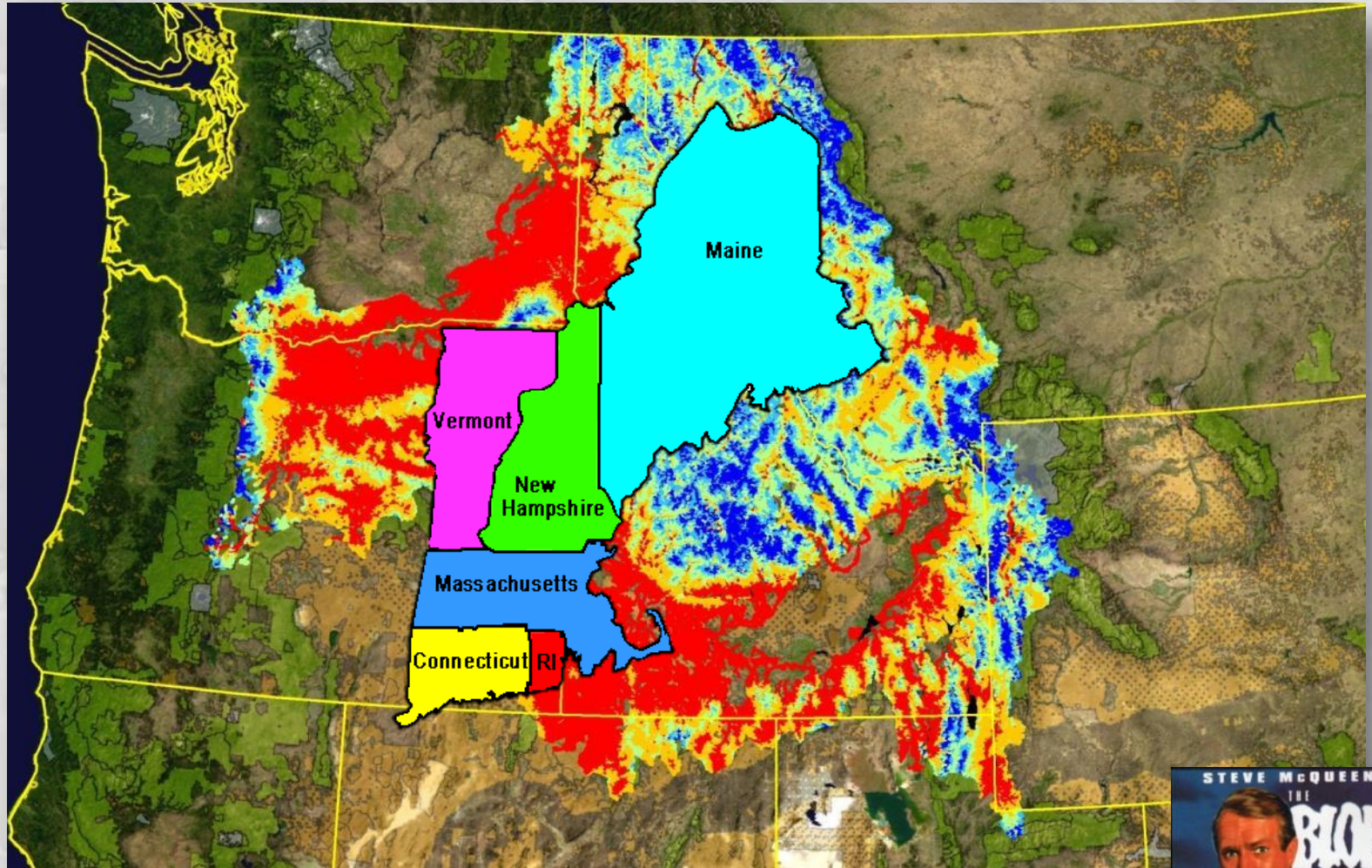
# Stream Thermalscape so Far...



# Stream Thermalscape so Far...

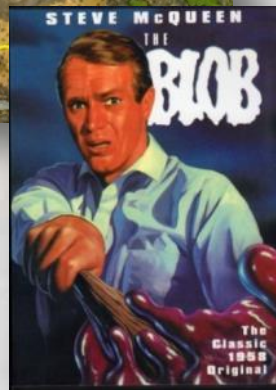


# Stream Thermalscape so Far...



**The BLOB... it just keeps growing...**

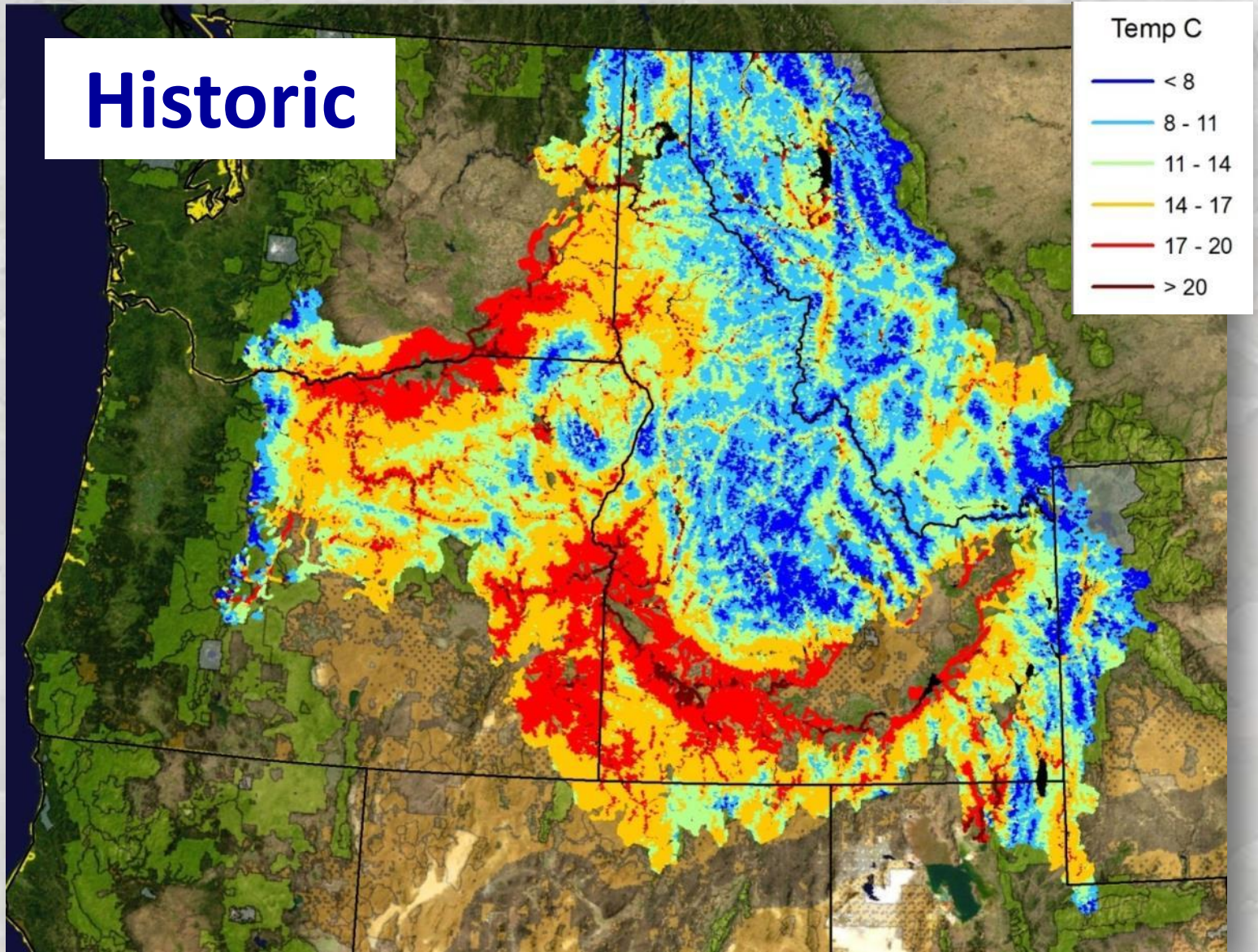
- 29,593 summers of data swallowed
- 296,000 stream kilometers of thermal ooze





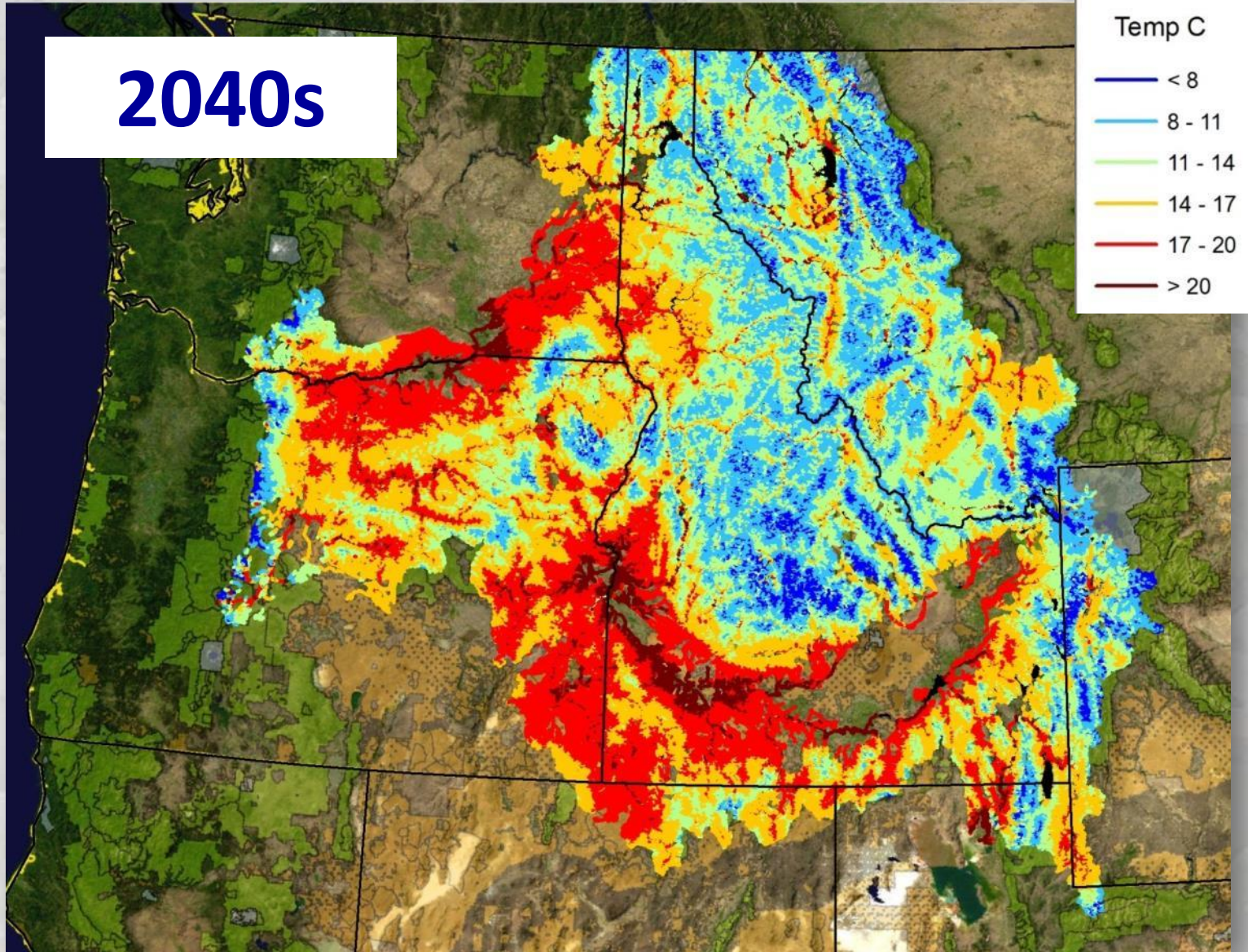
# BLOB Space, but BLOB time too...

**Historic**



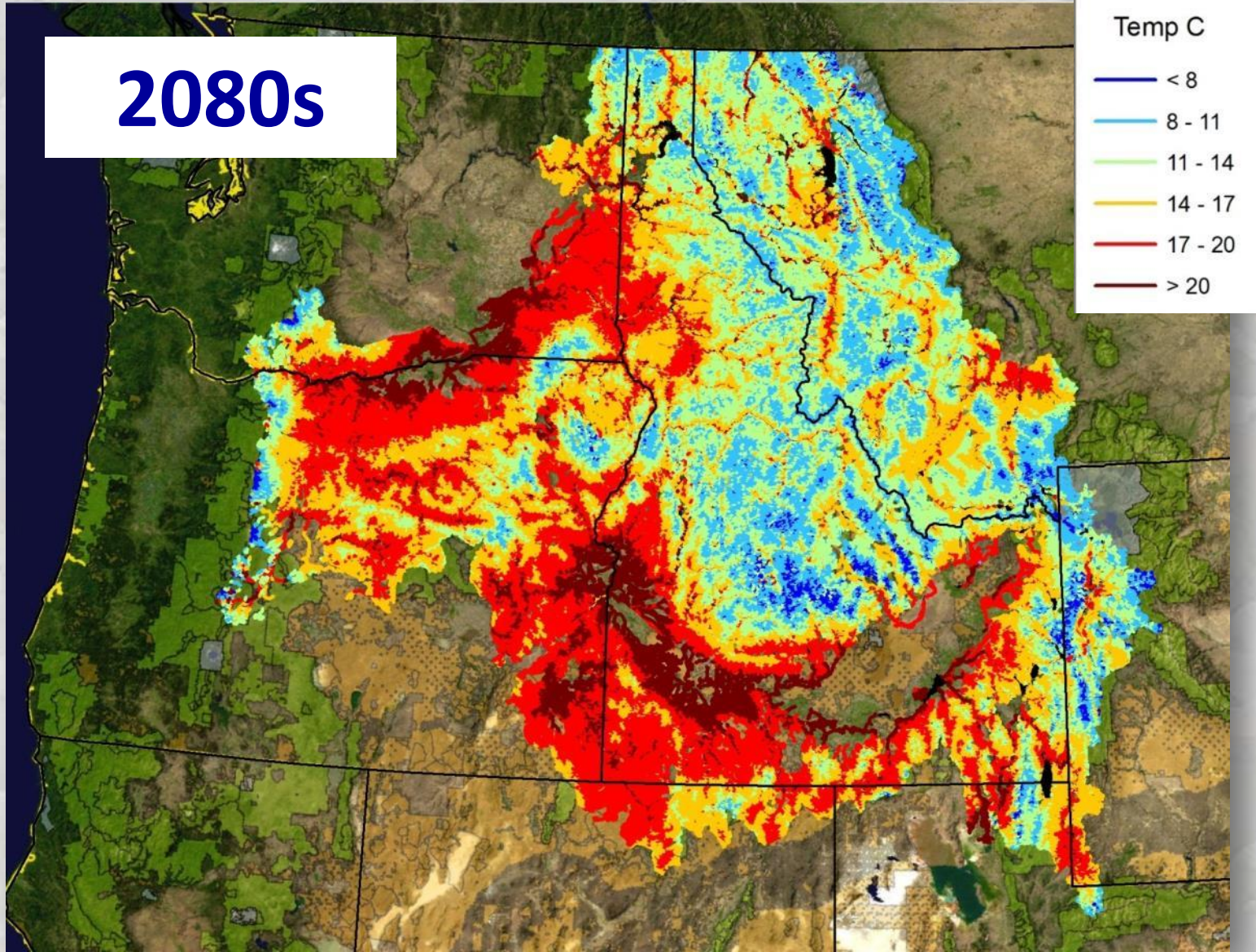
# BLOB Space, but BLOB time too...

**2040s**



# BLOB Space, but BLOB time too...

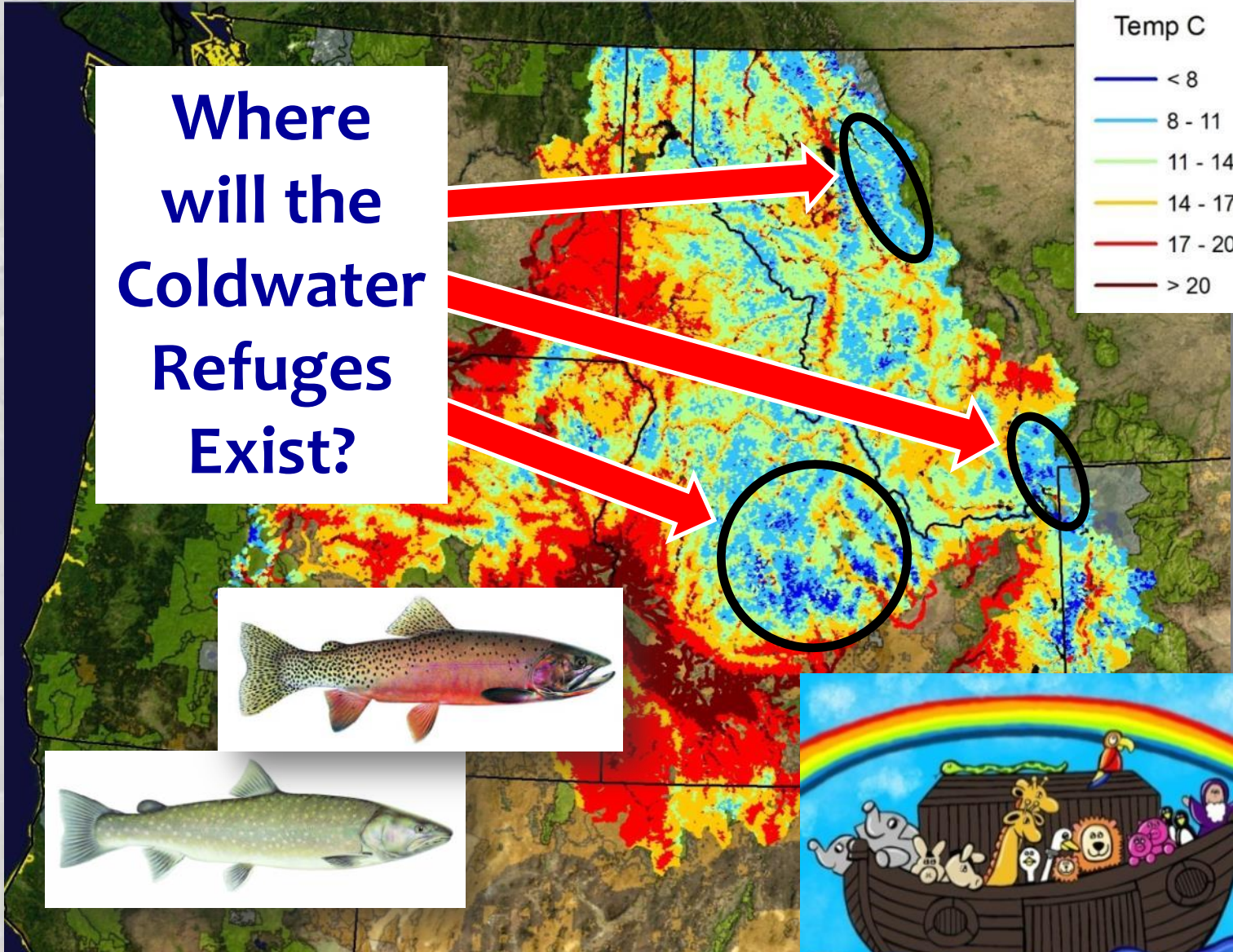
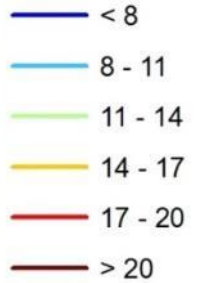
**2080s**



# BLOB Space, but BLOB time too...

Where  
will the  
Coldwater  
Refuges  
Exist?

Temp C



# The BLOB is User-Friendly

## Dynamic Online Scenario Map Viewer

Stream Temperature

CUMDRAINAG 7.79

S1\_93\_11 10.41525682

st\_length (shape) 1,383.6975557999524

Zoom to

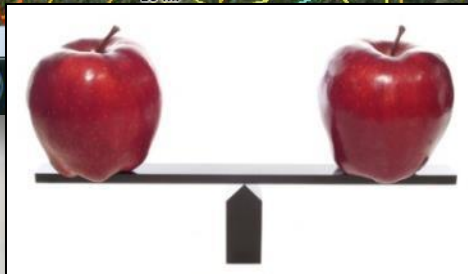
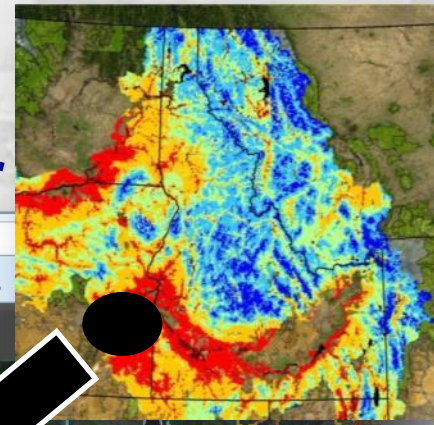
1 of 2

20 km

10 mi

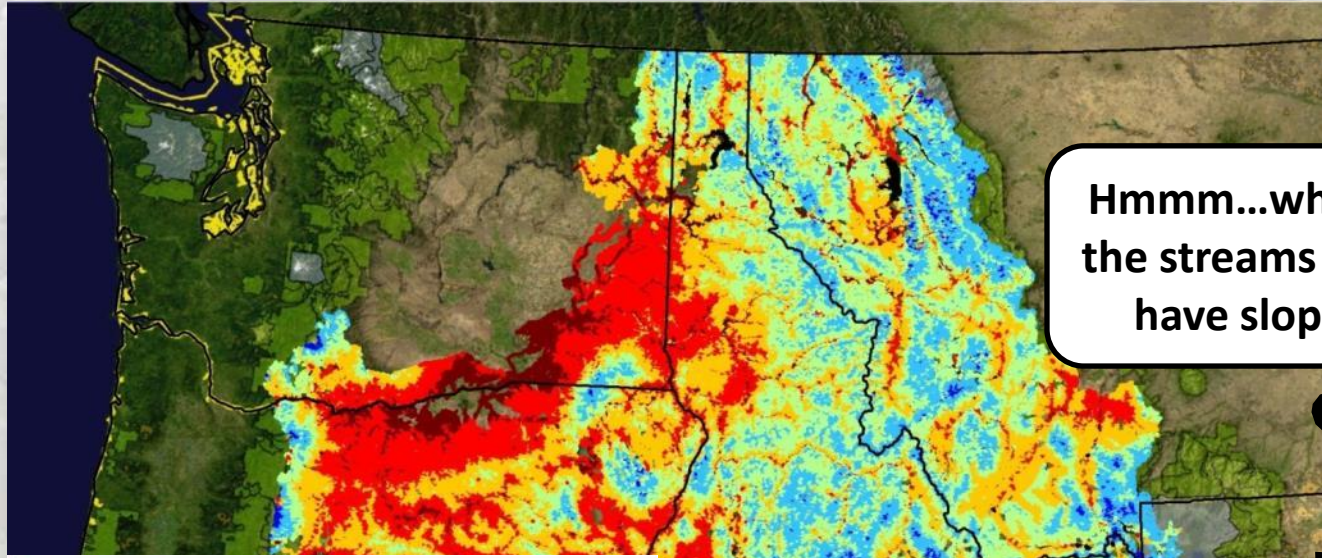
Now: 52°F Sat: 60°F Sun: 67°F

Inbox - disaa... W X P fish gra

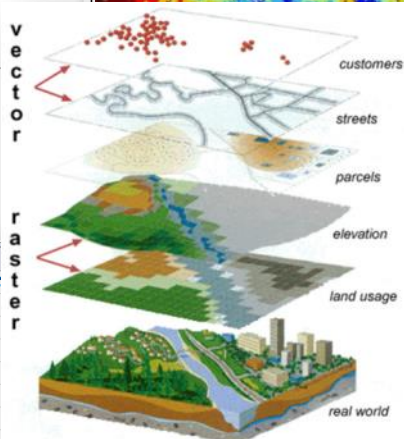
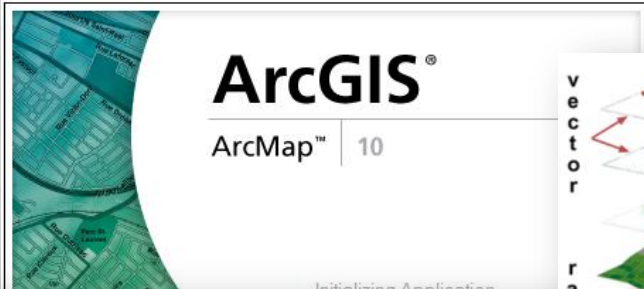


... comparisons from computer desktop

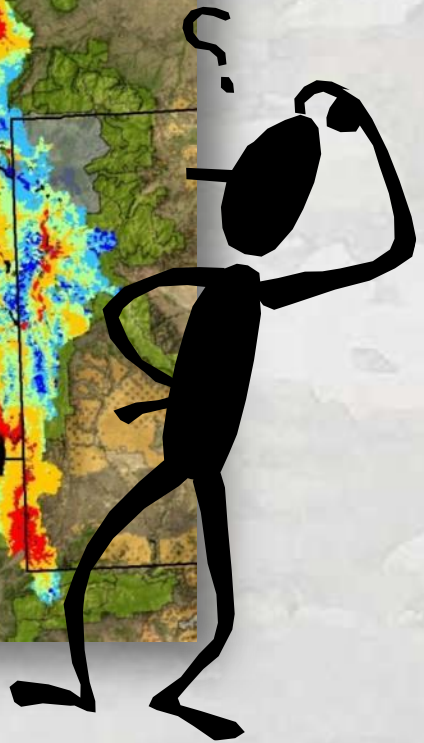
# More Detailed Queries are Possible Using Temperature Geodatabase



Hmmm...where are all the streams  $<10^{\circ}\text{C}$  that have slopes  $<3\%$ ?

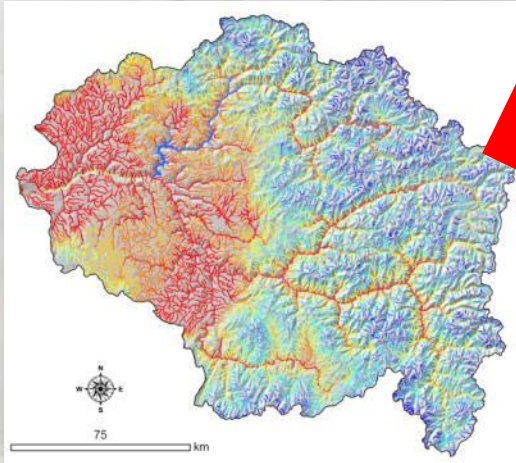


C	D	E	F	G	H	I	J	K	L	M	N
CANOPY	SLOPE	PRECIP	CUMDRAINAGE	Y_COORD	NLCD11PC	NLCD	...	...	...	...	...
2.82	0.08857	299.6256	19.833	1623663.32	0	...	...	...	...	...	...
2.82	0.08857	299.6256	19.833	1623663.32	0	...	...	...	...	...	...
2.82	0.08857	299.6256	19.833	1623663.32	0	...	...	...	...	...	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	...	...	...	...	...	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	...	...	...	...	...	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	...	...	...	...	...	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	...	...	...	...	...	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	0	80	13.14	29.44	10.9931936	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	0	80	14.54	22.19	11.3862545	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	0	80	14.02	35.71	11.4452903	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	0	80	13.20	40.52	11.5266484	...
12.23	0.03514	242.42	69.271	1620504.73	0.012	0	80	13.00	38.99	10.7834677	...

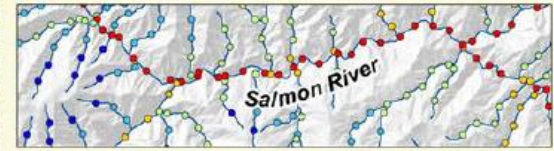


# Website Distributes BLOB Scenarios & Temperature Data as GIS Layers

1) GIS shapefiles of stream temperature scenarios

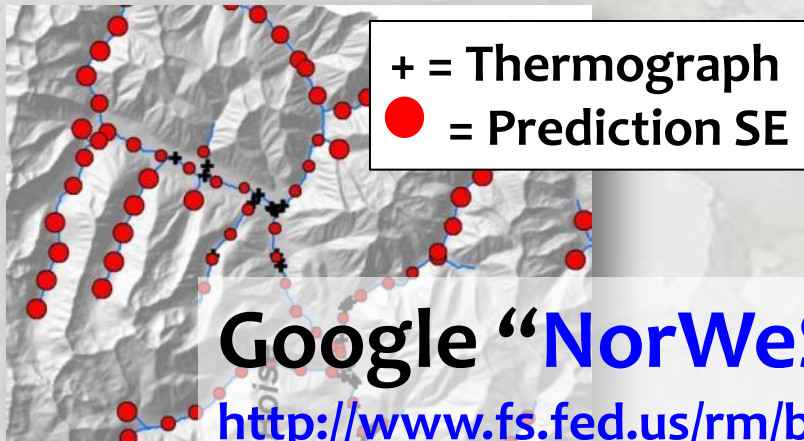


**NorWeST**  
Stream Temp



*Regional Database and Modeled Stream Temperatures*

2) GIS shapefiles of stream temperature model prediction precision



3) Temperature data summaries



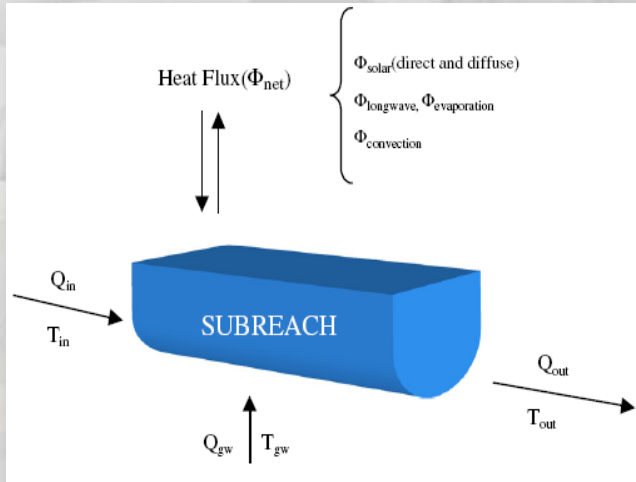
Google **NorWeST** or go here...

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



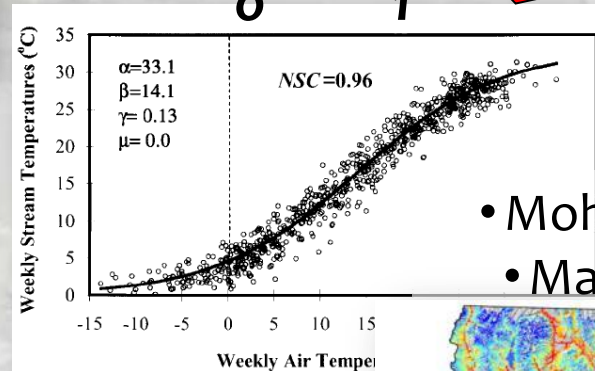
# Empirical Data feeds All Models...

## Mechanistic & Statistical



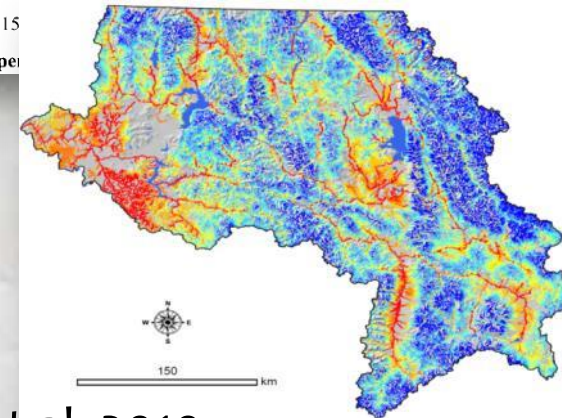
**NorWeST**  
Stream Temp

$$Y = b_0 + b_1 X$$



**Site**

- Mohseni et al. 1998
- Mantua et al. 2010



**Network**

Isaak et al. 2010

For example...

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

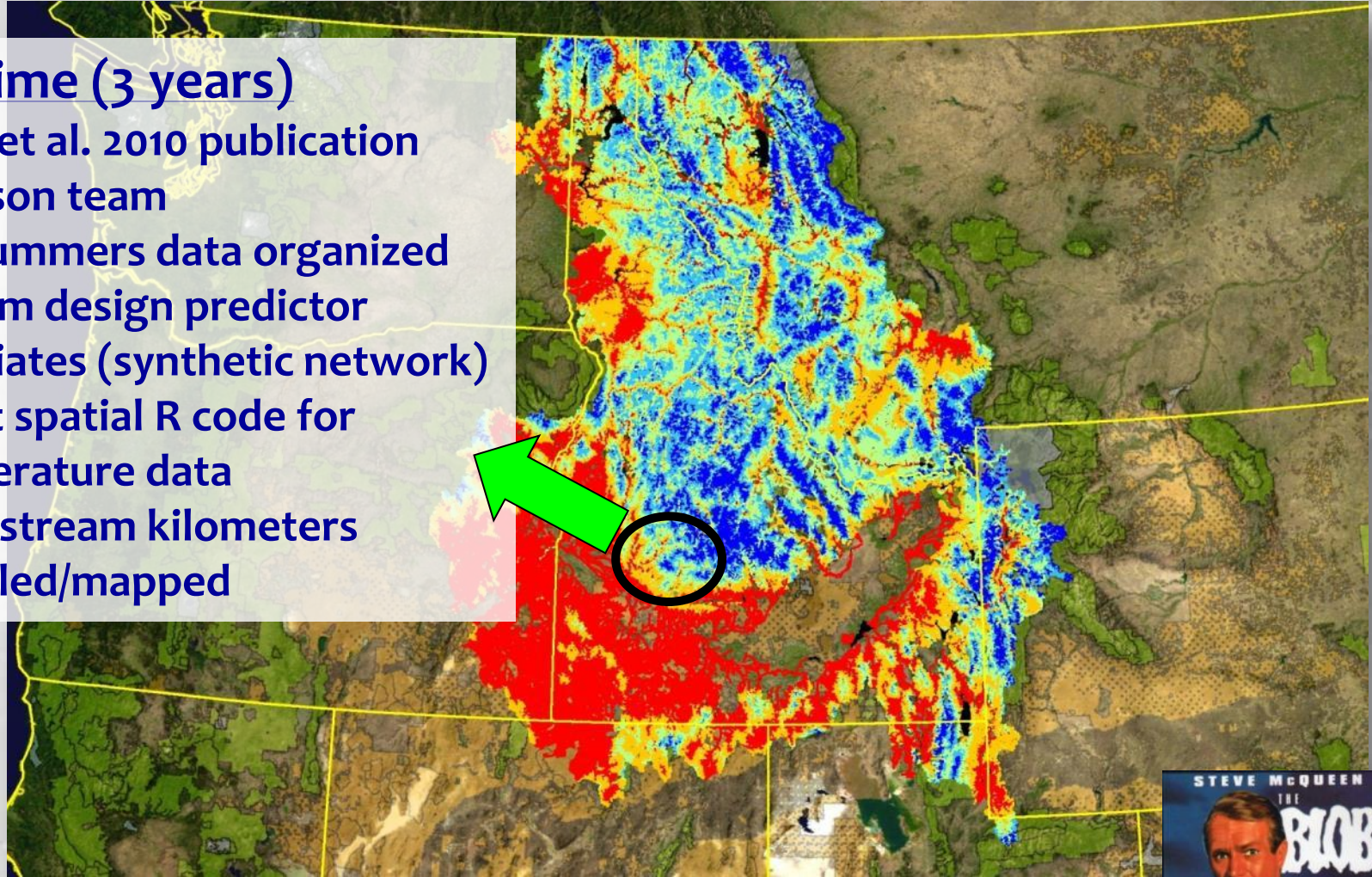




# The BLOB learns & grows faster...

## First time (3 years)

- Isaak et al. 2010 publication
- 8 person team
- 780 summers data organized
- Custom design predictor covariates (synthetic network)
- Adapt spatial R code for temperature data
- 2,500 stream kilometers modeled/mapped



The BLOB... it just keeps growing...

- 29,593 summers of data swallowed
- 296,000 stream kilometers of thermal ooze



# The BLOB learns & grows faster...

## First time (3 years)

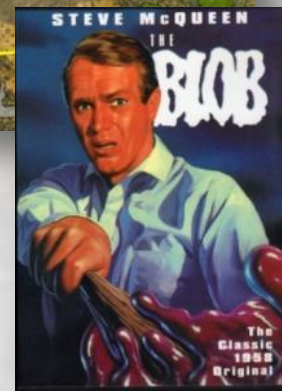
- Isaak et al. 2010 publication
- 8 person team
- 780 summers data organized
- Custom design predictor covariates (synthetic network)
- Adapt spatial R code for temperature data
- 2,500 stream kilometers modeled/mapped

## Second time (3 years)

- NorWeST
- 8 person team
- 29,593 summers data organized
- Use existing covariates (NHDPlus, NLCD, DEM, RCM)
- Adapt spatial R code to work with large databases
- 296,000 stream kilometers modeled/mapped
- Website designed
- Geospatial data distributed
- Dozens of agencies engaged

**The BLOB... it just keeps growing...**

- 29,593 summers of data swallowed
- 296,000 stream kilometers of thermal ooze



# Potato Baking Time...

3 Months Per Processing  
Unit (3<sup>rd</sup> code HUCs)



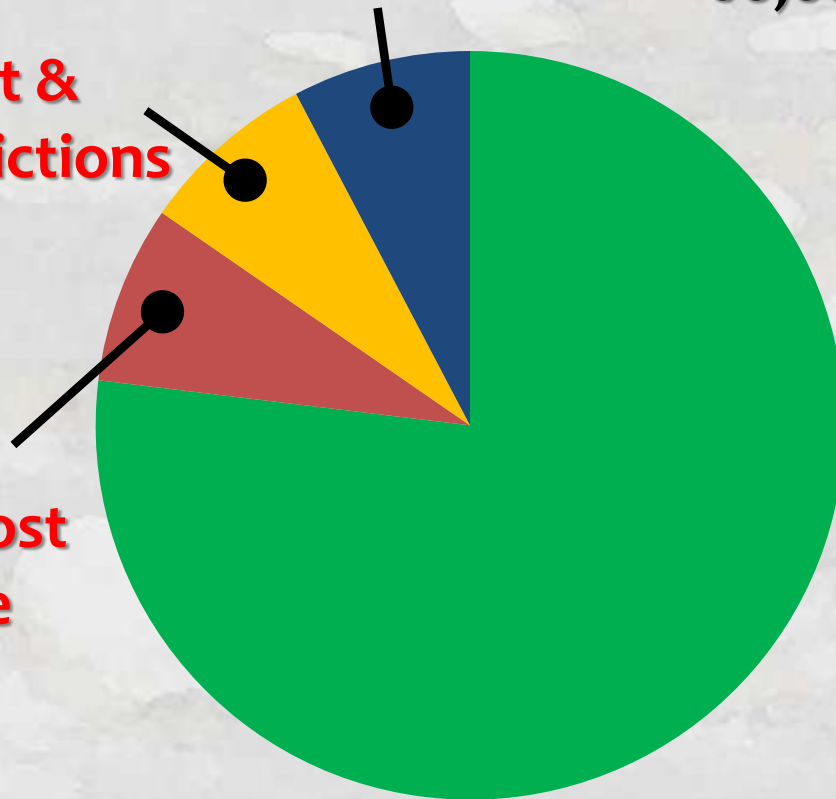
~3,500 data summers  
~60,000 stream  
kilometers

2. Covariate predictors  
(spatial & climate)

3. Model fit &  
scenario predictions

4. Create  
geospatial  
products & post  
to webpage

1. Temperature  
database (2.5  
months)



# What Has NorWeST Cost?

**NorWeST Budget (2011 – 2013)**

**Total: \$880,000**



USGS \$30,000

USFS-R1 \$30,000

NPLCC

\$72,000



GNLCC

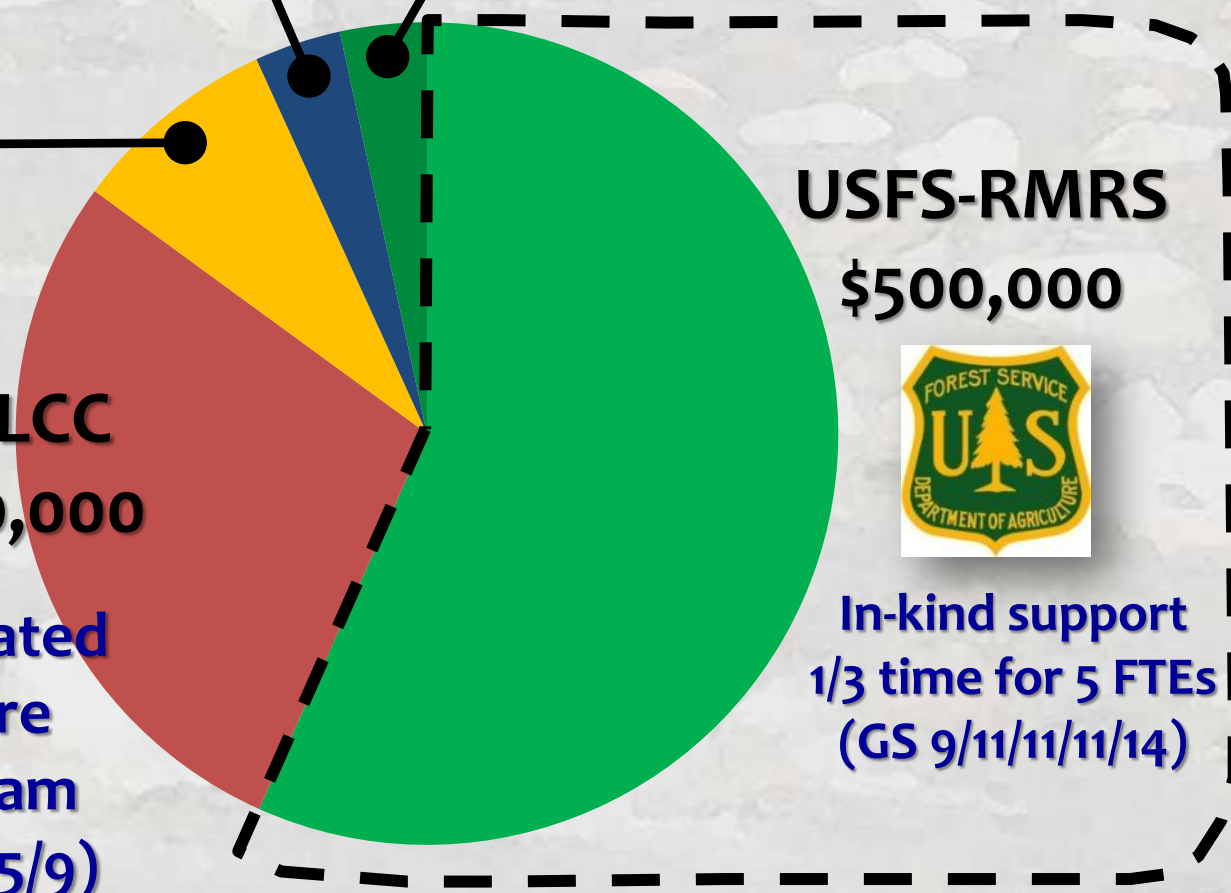
\$250,000

Create dedicated  
temperature  
database team  
3 FTEs (GS 5/5/9)

USFS-RMRS  
\$500,000

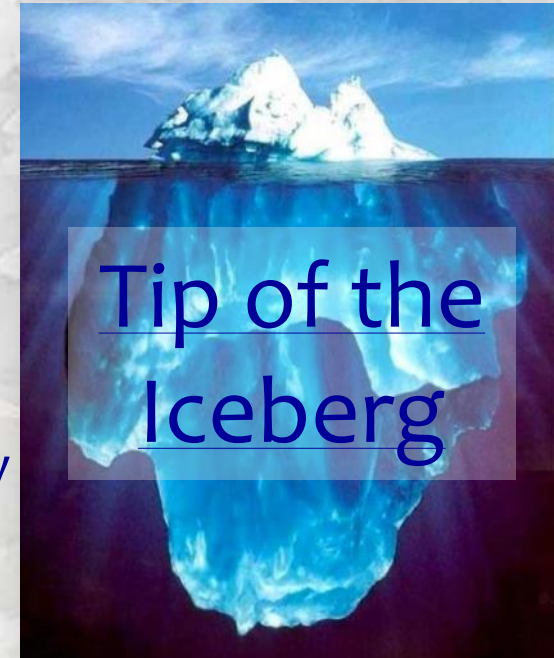


In-kind support  
1/3 time for 5 FTEs  
(GS 9/11/11/14)

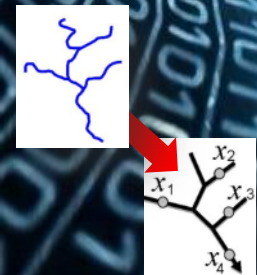
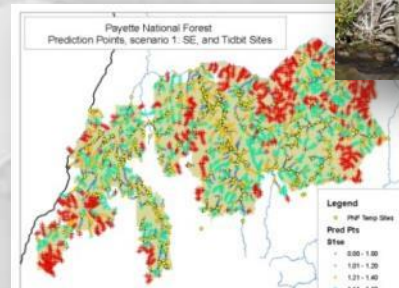
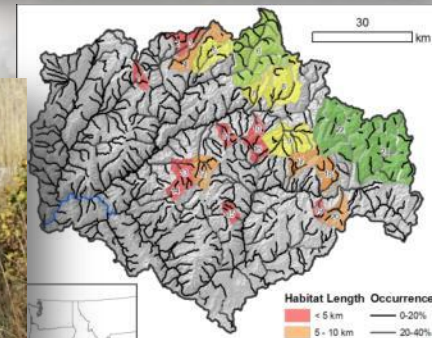


# “Killer Apps” & The Stream Internet

- Block-kriging for reference site comparisons & fish population estimates
- Regionally consistent thermal niche criteria using BIG FISH data
- Precise bioclimatic models & vulnerability assessments
- Consistent river basin application of decision support tools
- Efficient temperature & biological monitoring designs



Tip of the  
Iceberg



# “Killer Apps” & The Stream Internet

Consistent temperature information & stream analytical infrastructure creates huge synergies...



applicatio

biolog

