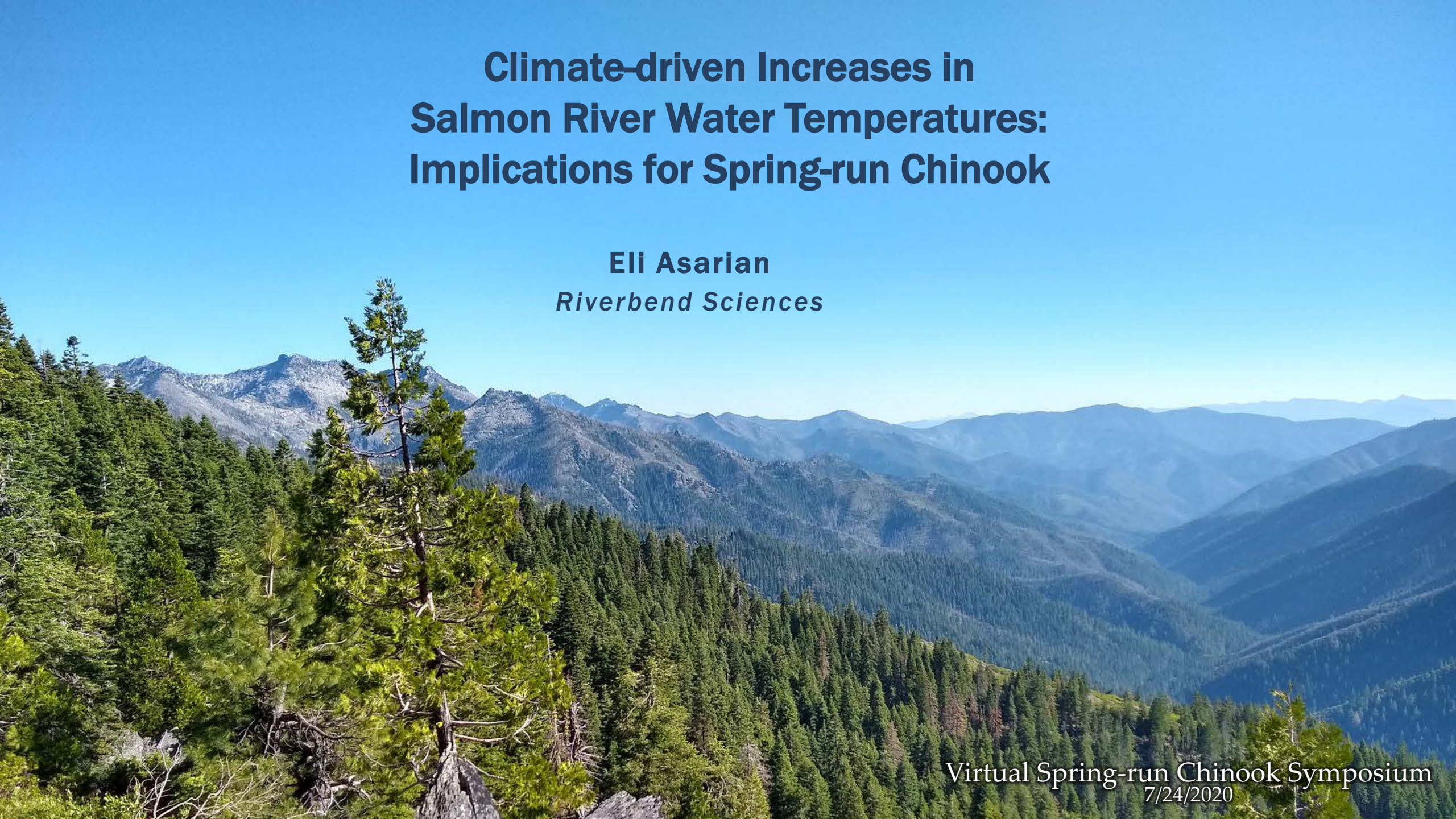
Climate-driven Increases in Salmon River Water Temperatures: Implications for Spring-run Chinook

Eli Asarian

Riverbend Sciences



Virtual Spring-run Chinook Symposium

7/24/2020

https://klamathwaterquality.com/documents.html

Influence of Snowpack, Streamflow, Air Temperature, and Wildfire Smoke on Klamath Basin Stream Temperatures Including Long-Term Trends, 1995-2017

Toz Soto
Karuk Tribe
Department of Natural Resources

J. Eli Asarian
Riverbend Sciences

Lyra Cressey and **Bonnie Bennett**
Salmon River Restoration Council

LeRoy Cyr
Six Rivers National Forest
Lower Trinity, Orleans and Ukonom
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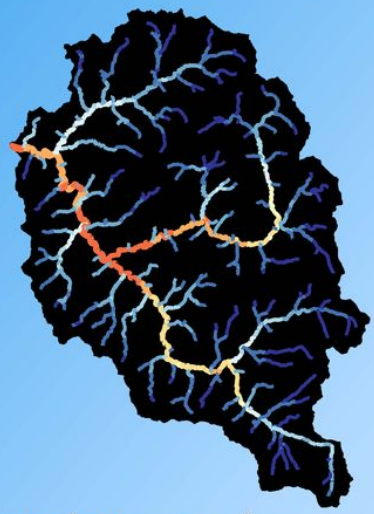
Crystal Robinson
Quartz Valley Indian Reservation

Jon Grunbaum
Klamath National Forest
Happy Camp Oak Knoll
Ranger District

Riverbend Sciences

Prepared for:
Klamath Tribal Water Quality Consortium
July 2020

https://srrc.org/publications/



Evidence of Climate-Driven Increases in Salmon River Water Temperatures

J. Eli Asarian
Riverbend Sciences

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November 2019

Riverbend Sciences

http://www.riverbendsci.com/reports-and-publications-1

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Leroy Cyr Six Rivers National Forest
Callie McConnell NRM CSO

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Toz Soto, Grant Johnson, Susan Fricke, Sophie Price, and **Emilio Tripp**
Karuk Department of Natural Resources

Nick Som, Dan Gale, Aaron David,Taylor Daley and **Christian Romberger**
US Fish and Wildlife Service

Lyra Cressey, Bonnie Bennett, Karuna Greenberg, Scott Harding, and **Melissa Van Scoyoc**
Salmon River Restoration Council

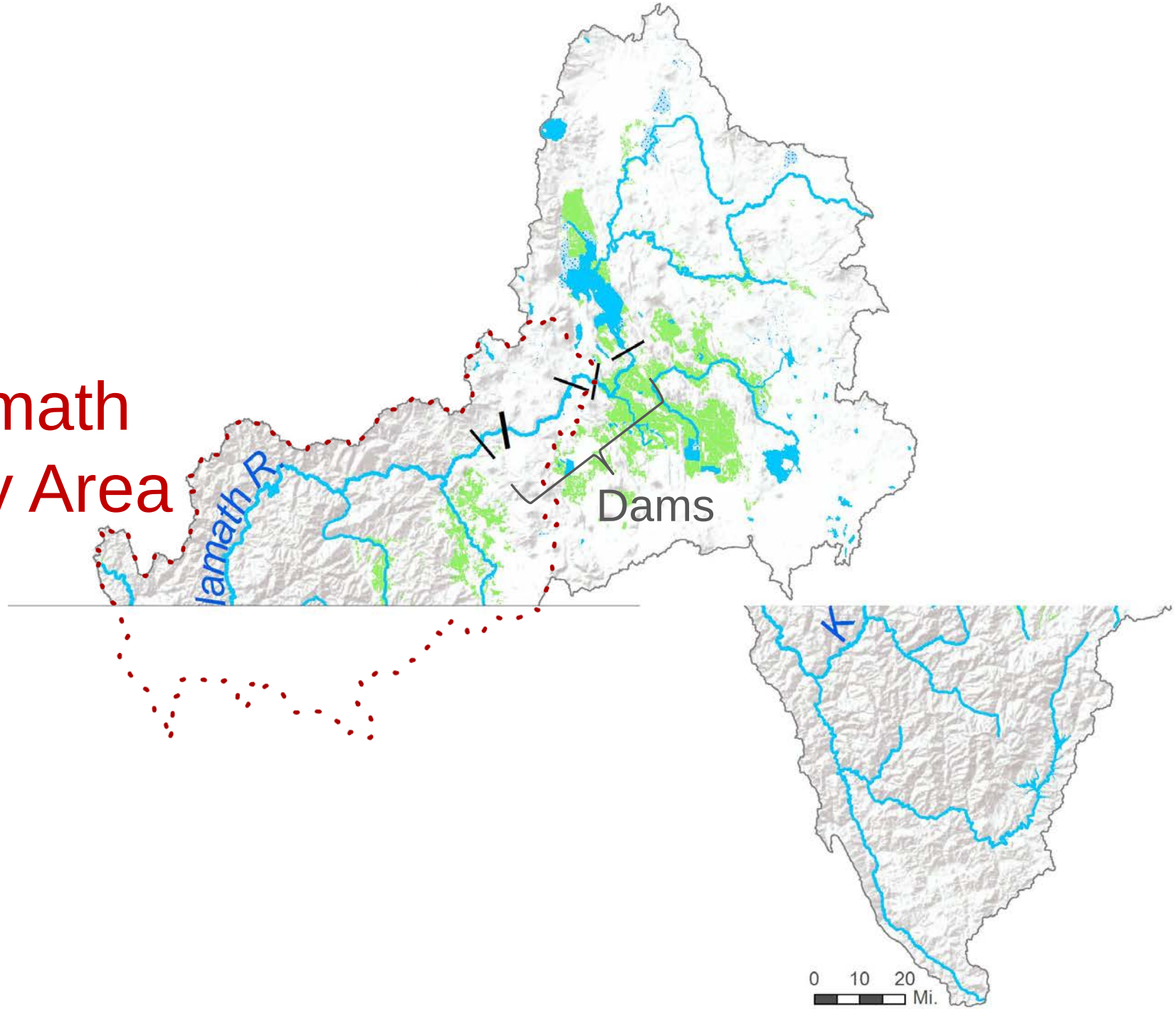
Crystal Robinson, Sarah Schaefer
Quartz Valley Indian Reservation

GIS: **Nick Cusick**

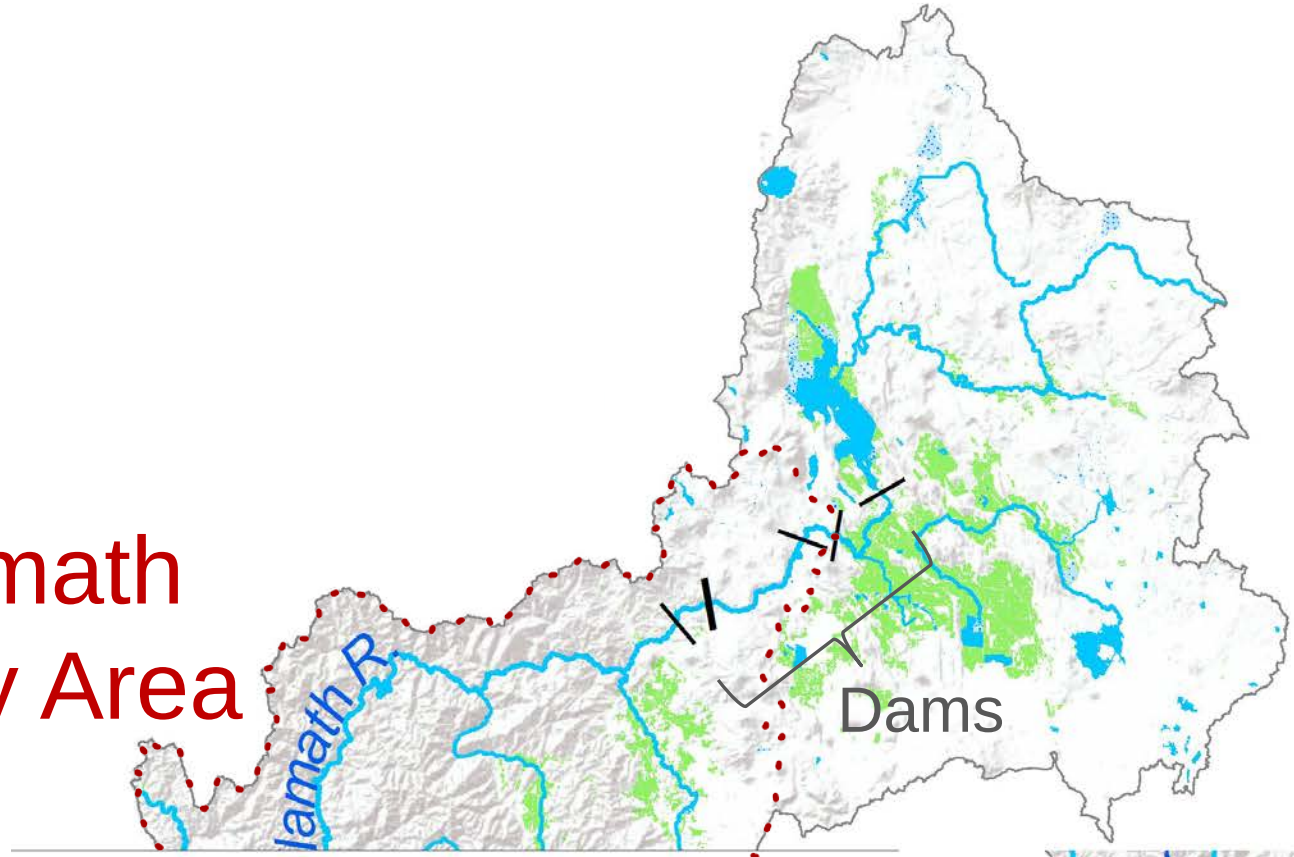
Tim Montfort, Chelsea Aquino
US Bureau of Land Management

Jay Stallman and Rafael Real de Asua
Stillwater Sciences

Klamath Study Area



Klamath Study Area



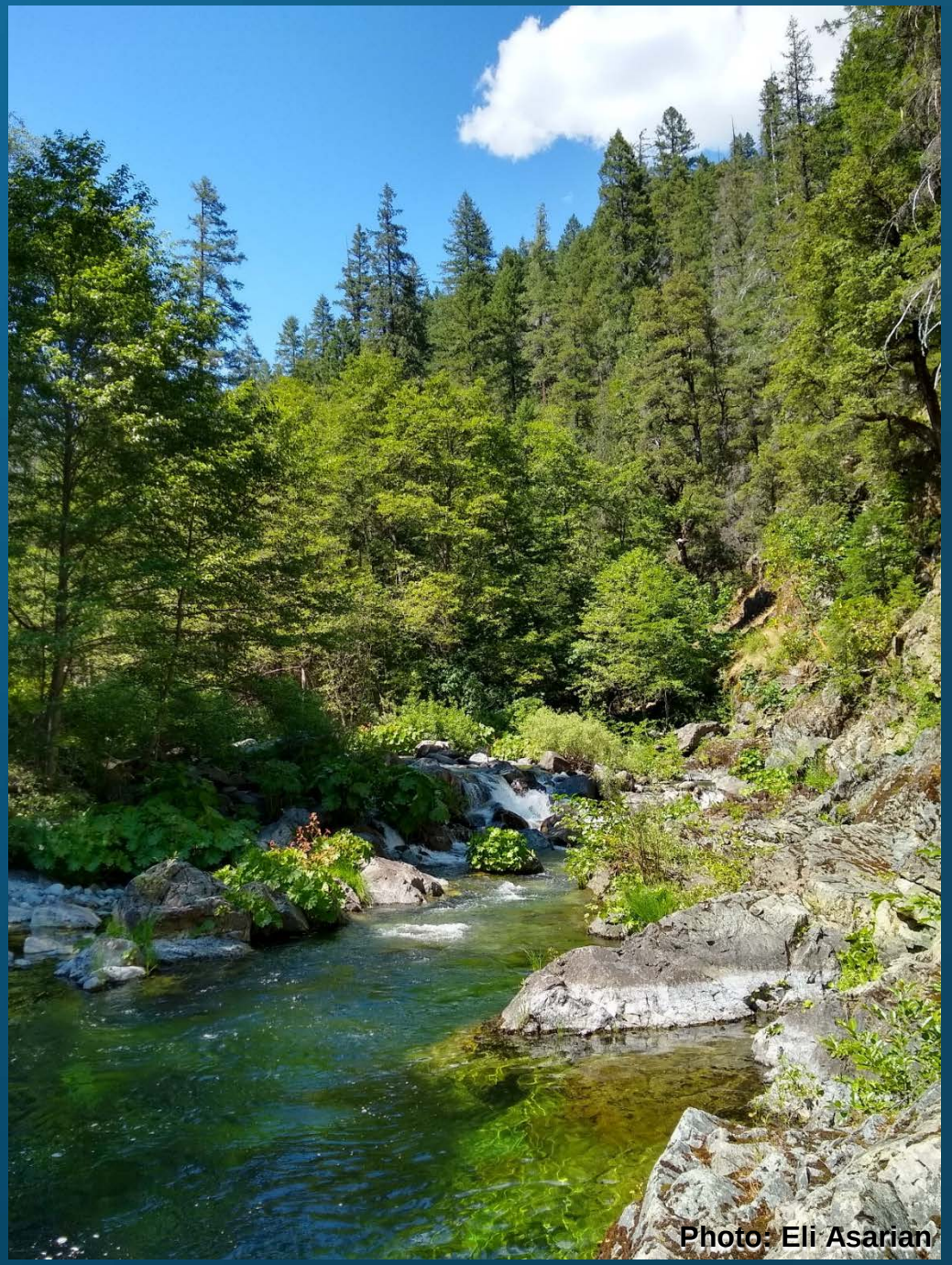
Salmon River

Questions

- Have stream temperatures changed over the study period?
  - If yes, why?

- What climate variables explain interannual variability in stream temperatures ?

- How will climate change affect future temperatures?



Value of long-term monitoring

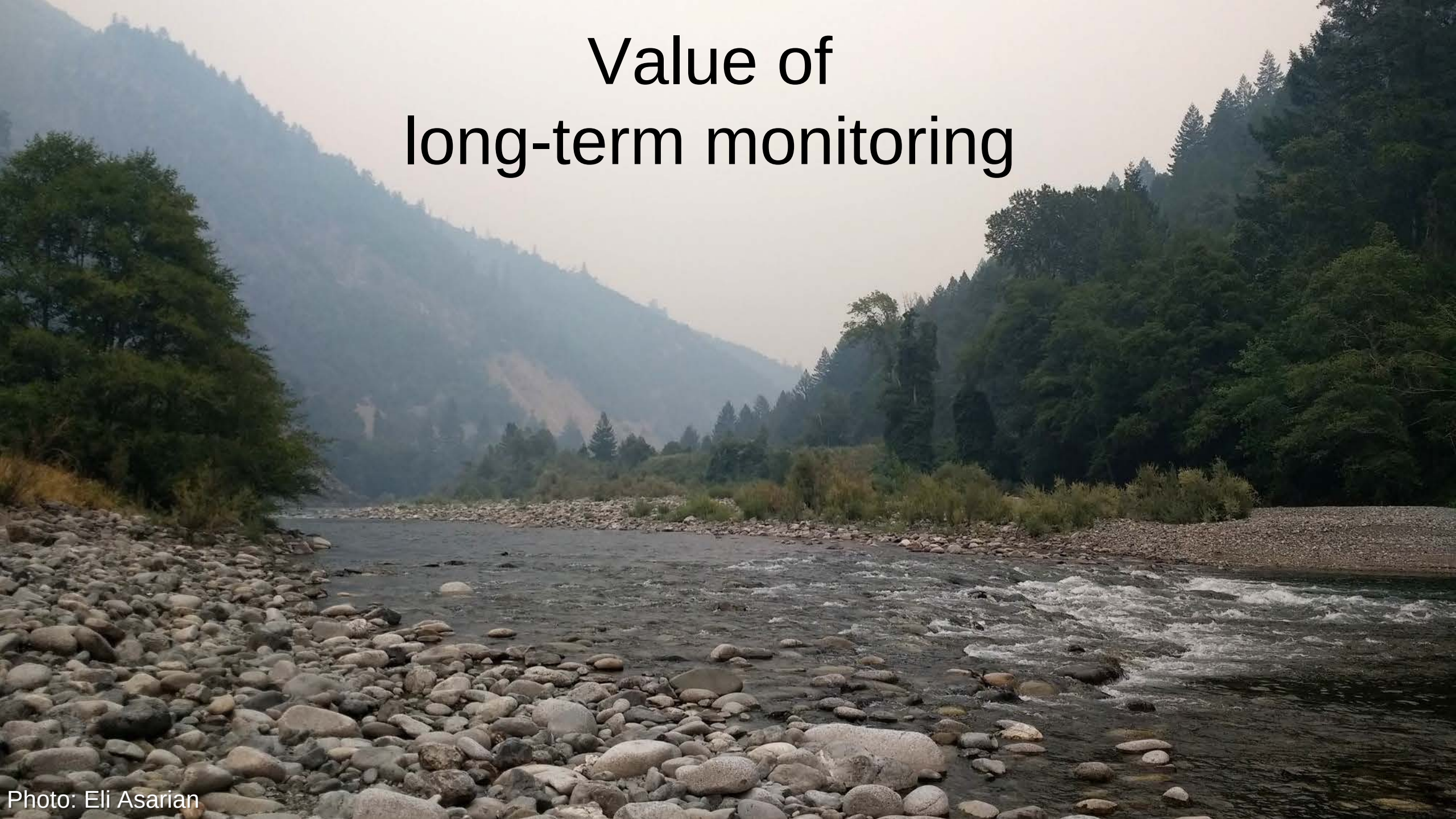
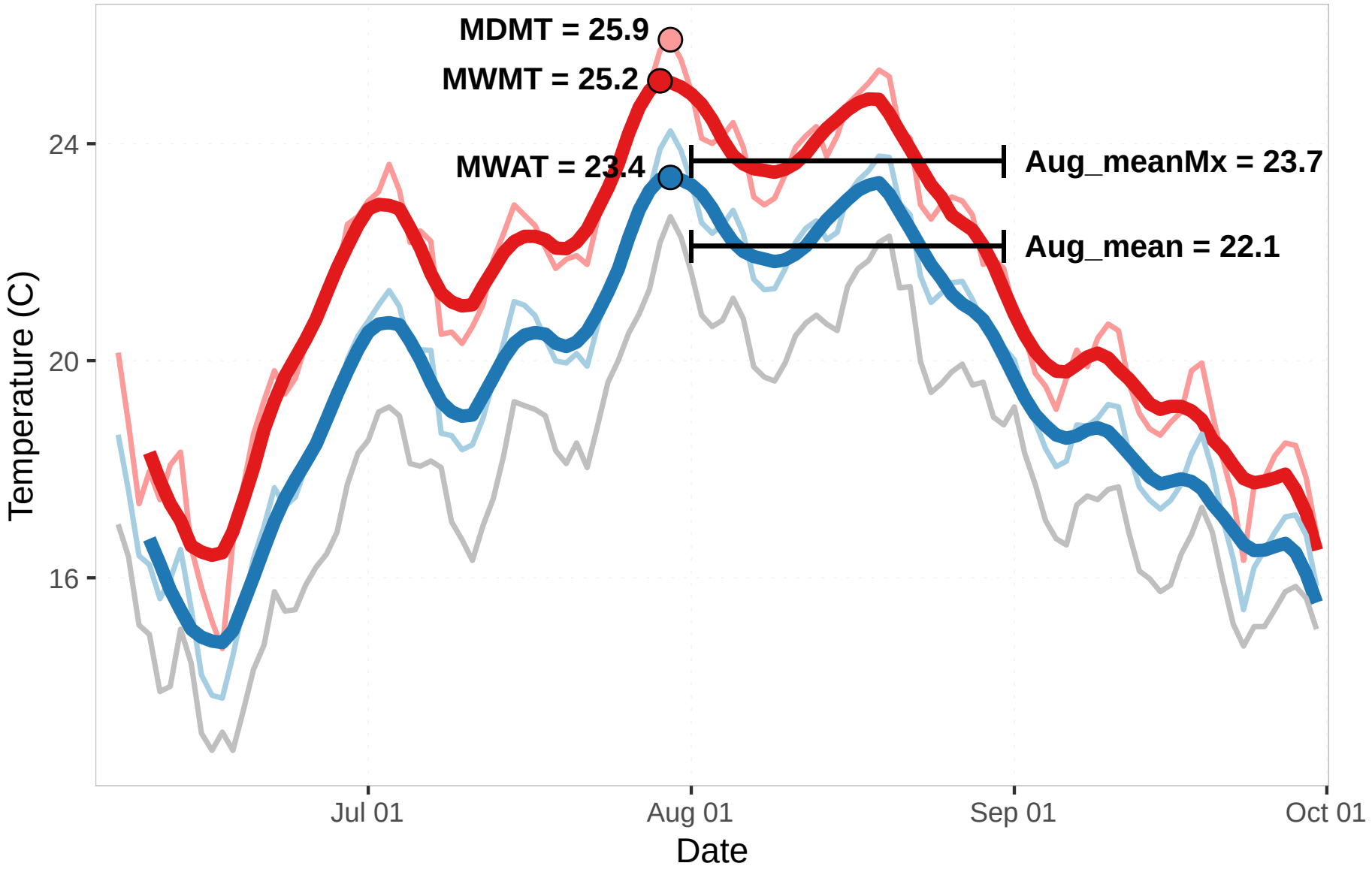


Photo: Eli Asarian

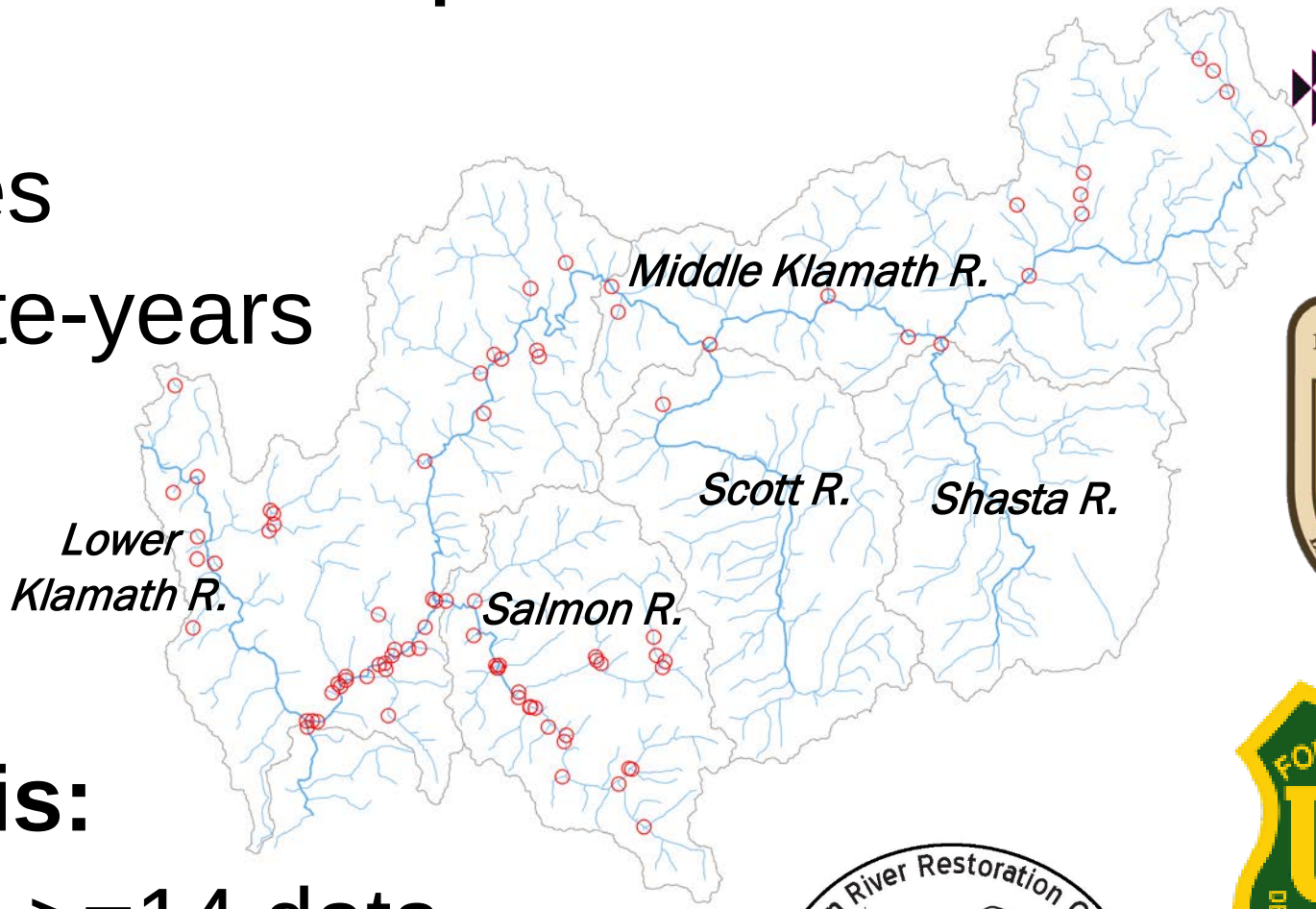

MDMT = 25.9
MWMT = 25.2
MWAT = 23.4
Aug_meanMx = 23.7
Aug_mean = 22.1
24
20
16
Temperature (C)
Jul 01
Aug 01
Sep 01
Oct 01
Date

Stream Temperature Data

Total:

556 sites

4369 site-years

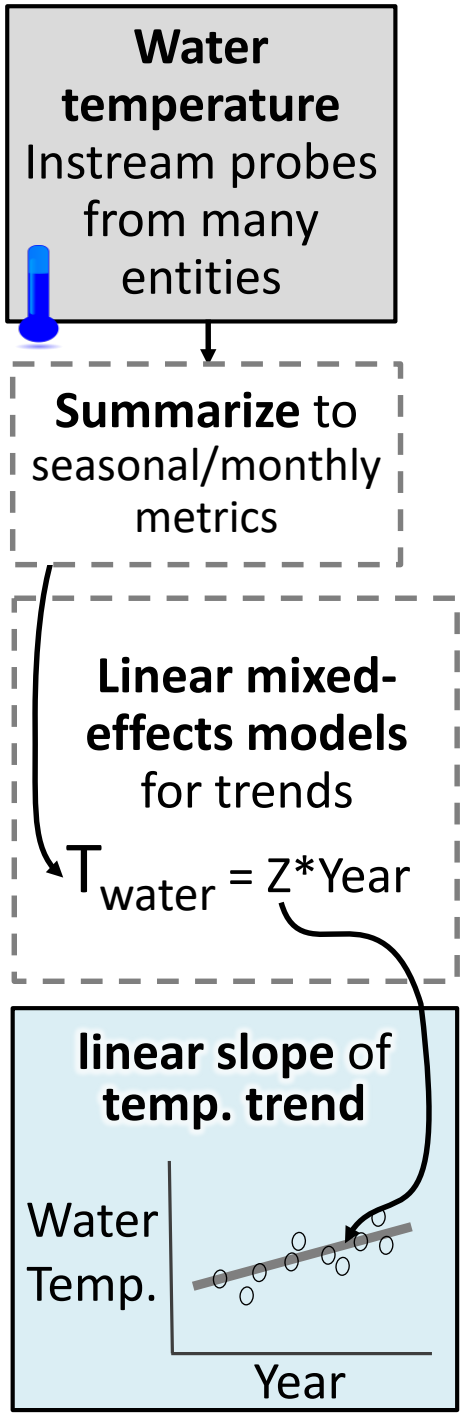


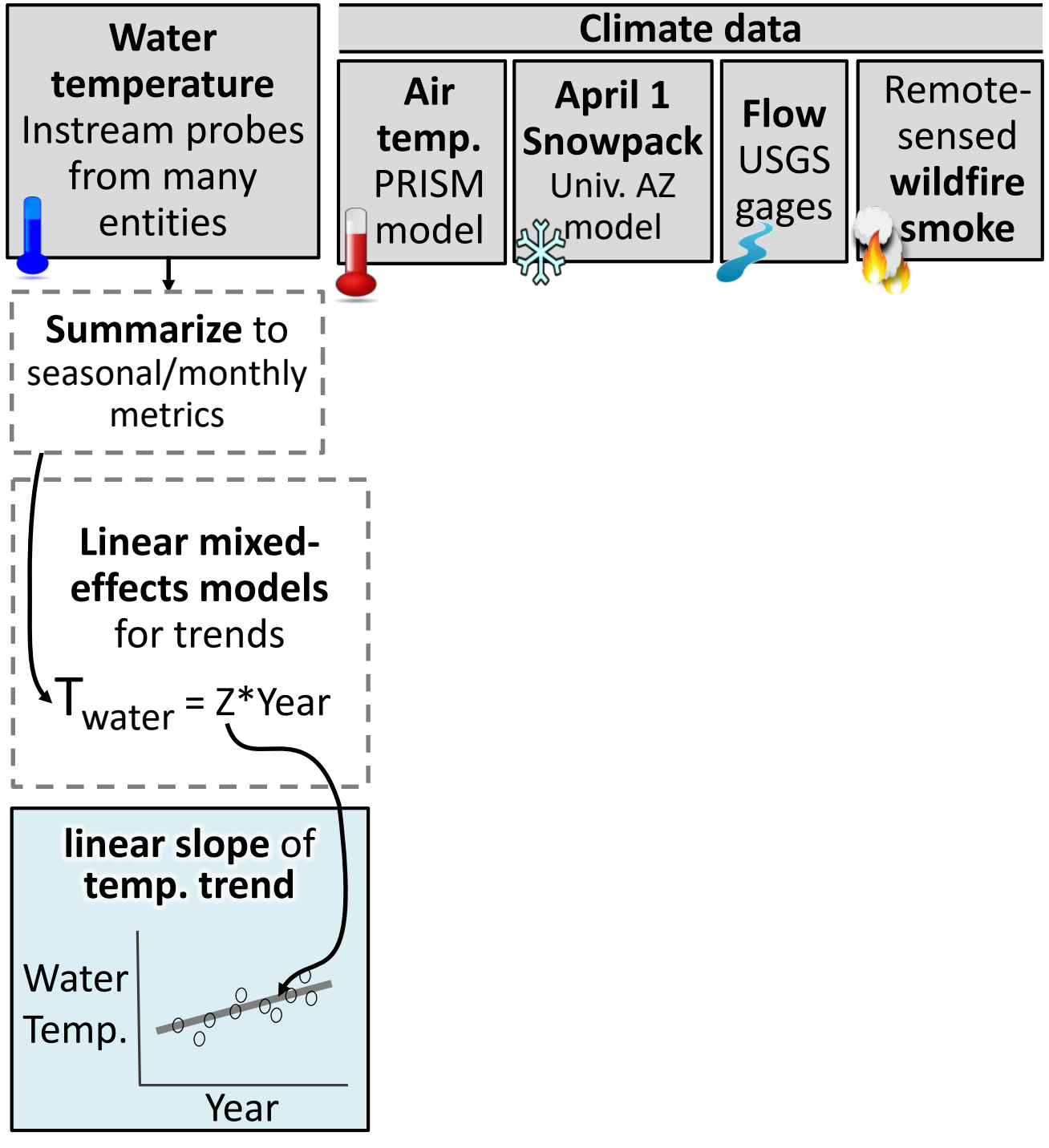
Analysis:

85 sites >=14 data

1995–2017

Logos for illustration only, does not imply endorsement


Water temperature
Instream probes from many entities
Summarize to seasonal/monthly metrics
Linear mixed-effects models for trends
$T_{water} = Z*Year$
linear slope of **temp. trend**
Water Temp.
Year


Water temperature
Instream probes from many entities
Climate data
Air temp.
PRISM model
April 1 Snowpack
Univ. AZ model
Flow
USGS gages
Remote-sensed wildfire smoke
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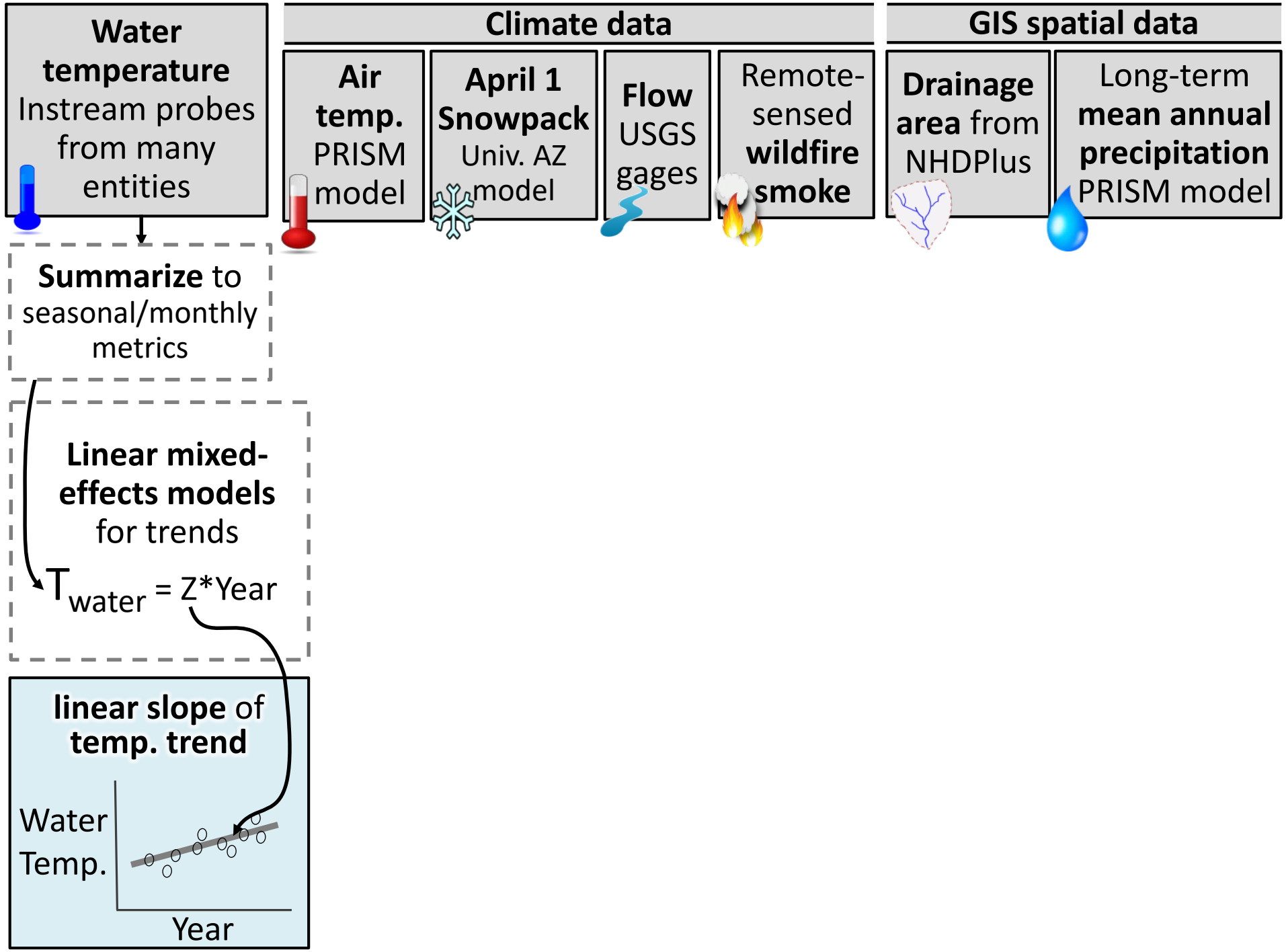
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GIS spatial data
Drainage area from NHDPlus
Long-term mean annual precipitation
PRISM model
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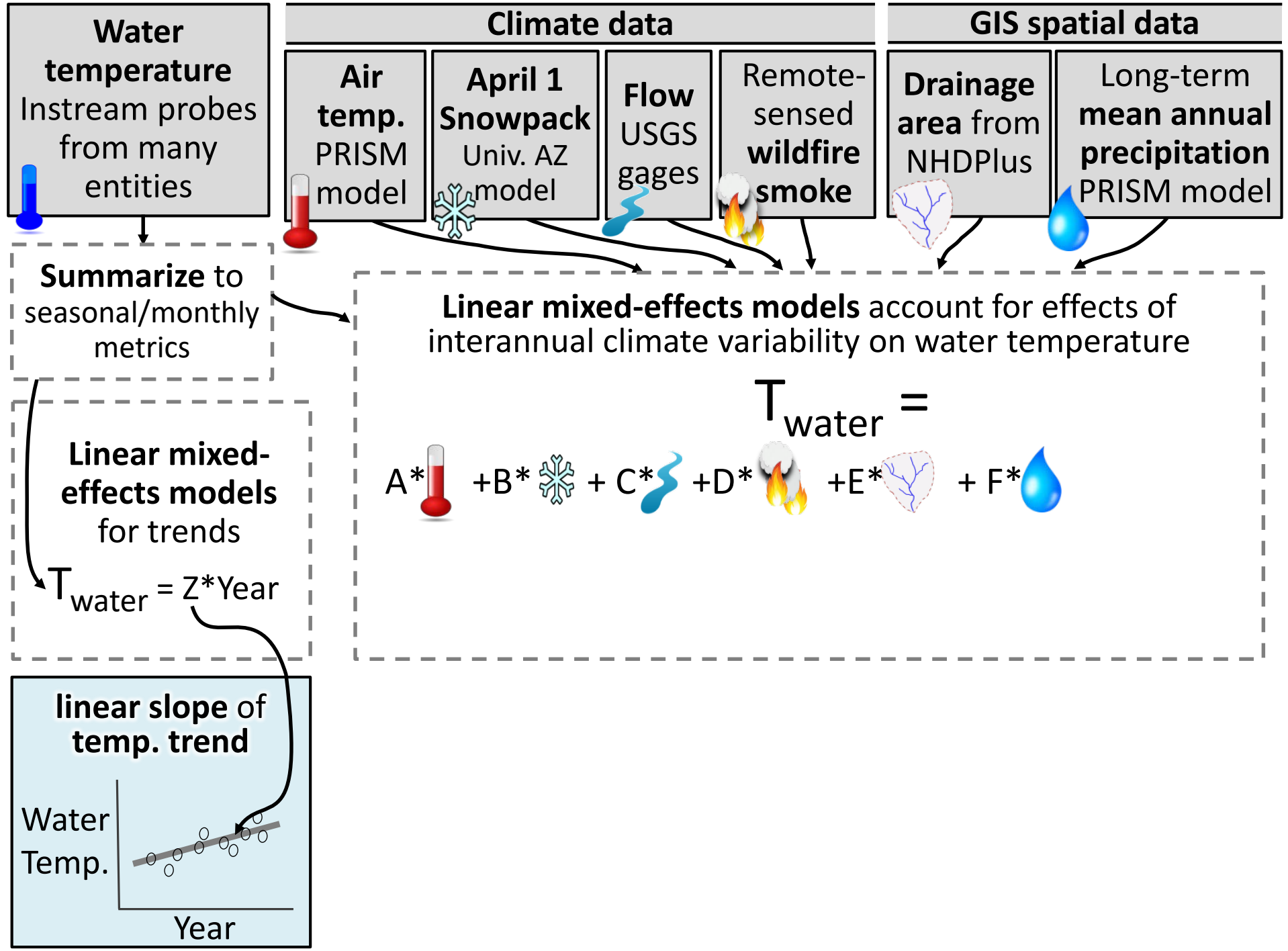
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T water =
A* +B* + C* +D* +E* + F*
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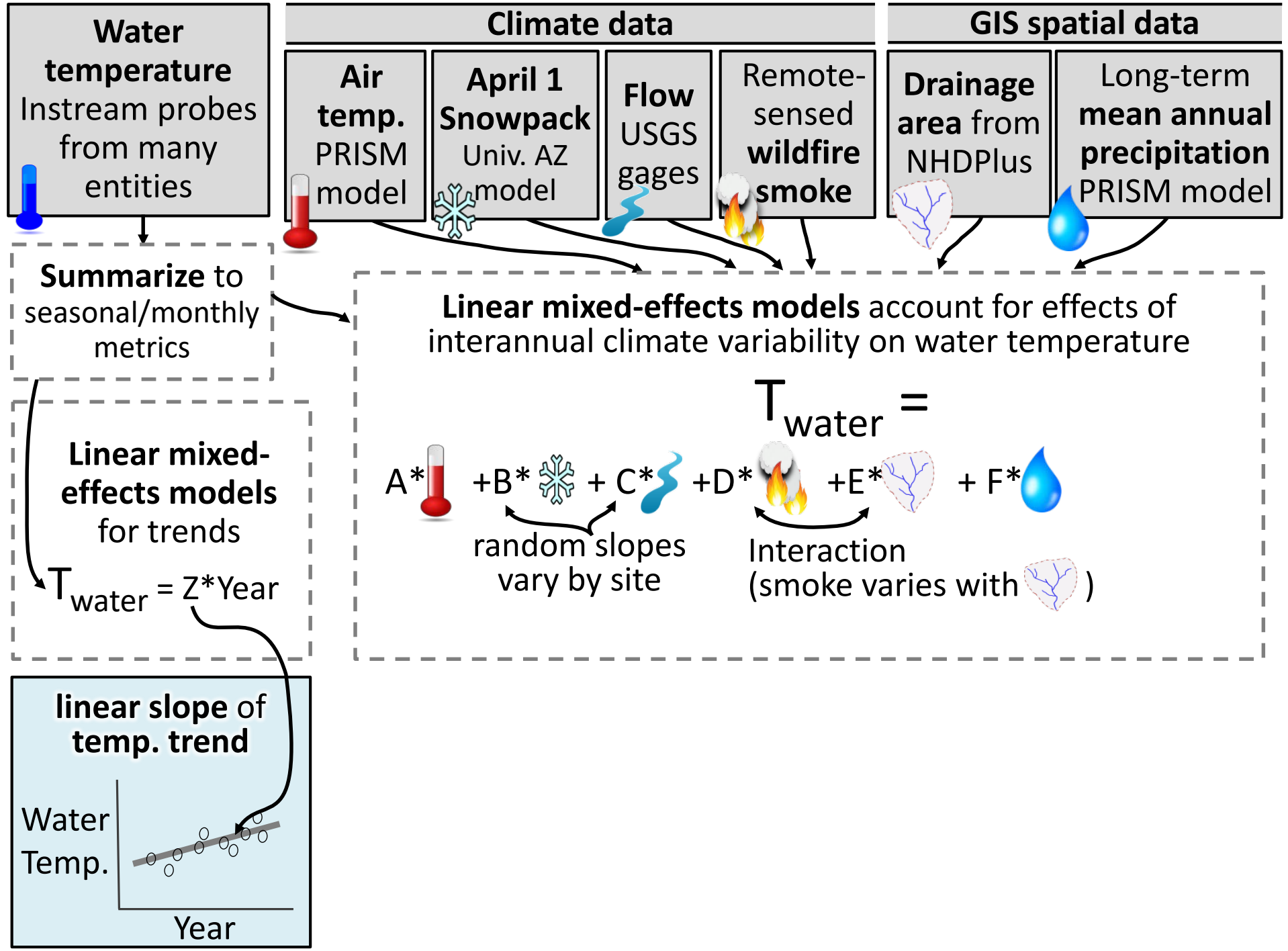
Water Temp.
Year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A*
+B*
+ C*
+D*
+E*
+ F*
random slopes vary by site
Interaction (smoke varies with)
Linear mixed-effects models for trends
T water = Z*Year
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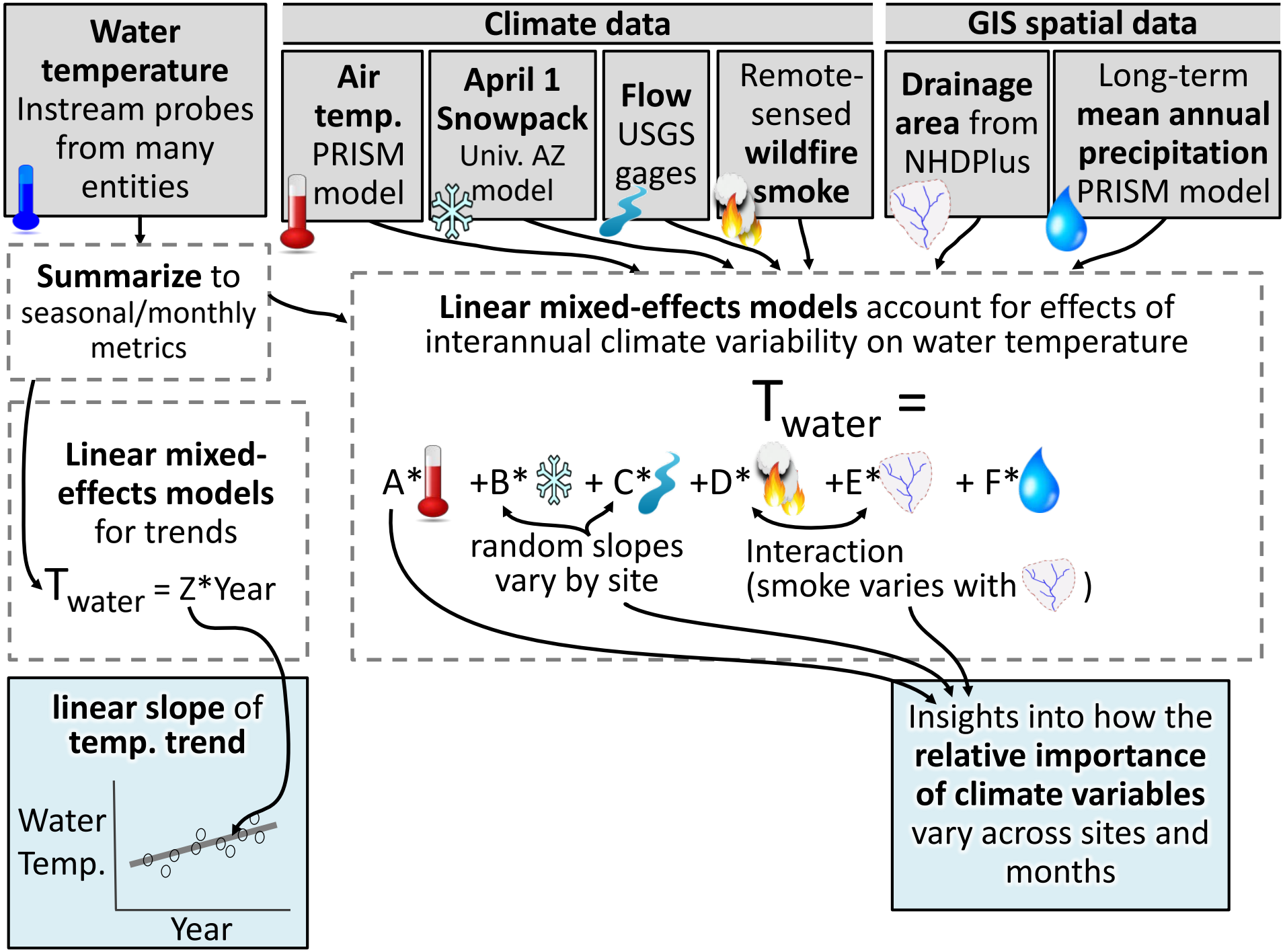
Water Temp.
Year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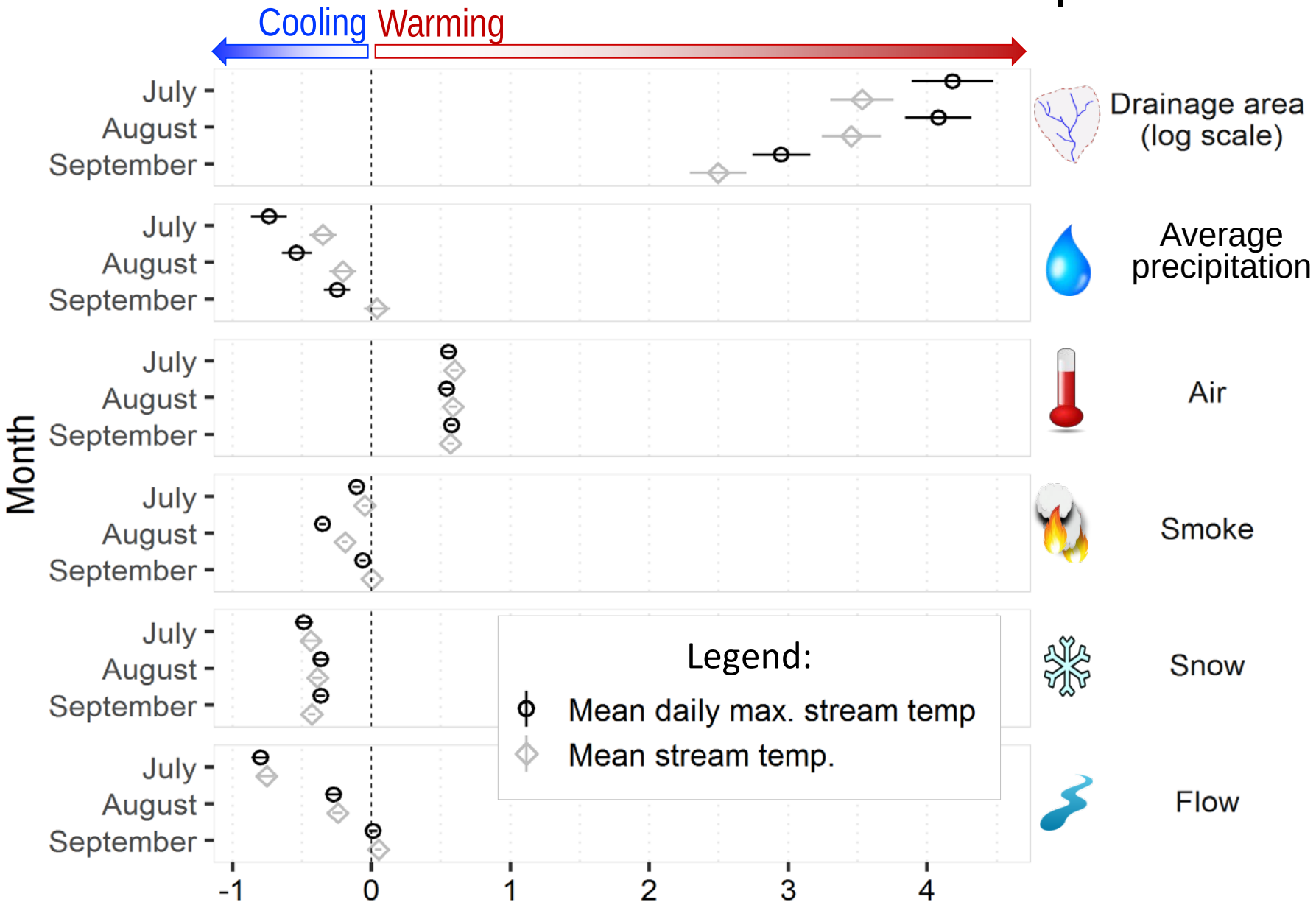
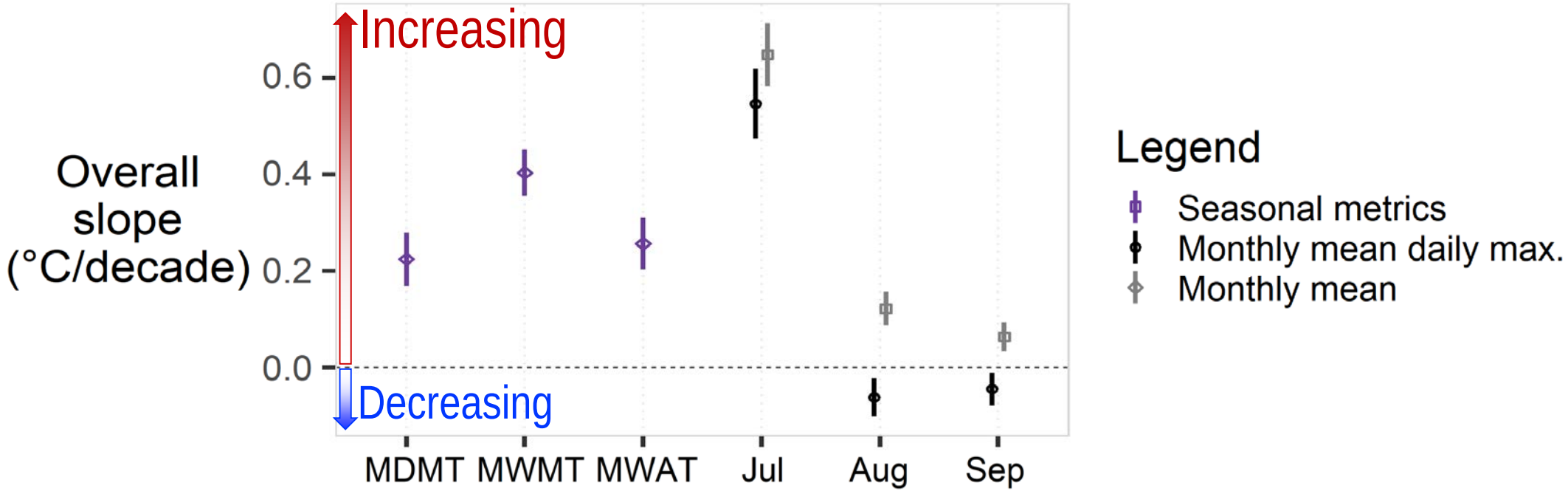
Water Temp.
Year
Insights into how the relative importance of climate variables vary across sites and months

Effect of GIS/Climate Predictors on Stream Temperature



Stream Temp. Long-Term Trends 1995-2017 (All Sites Combined)



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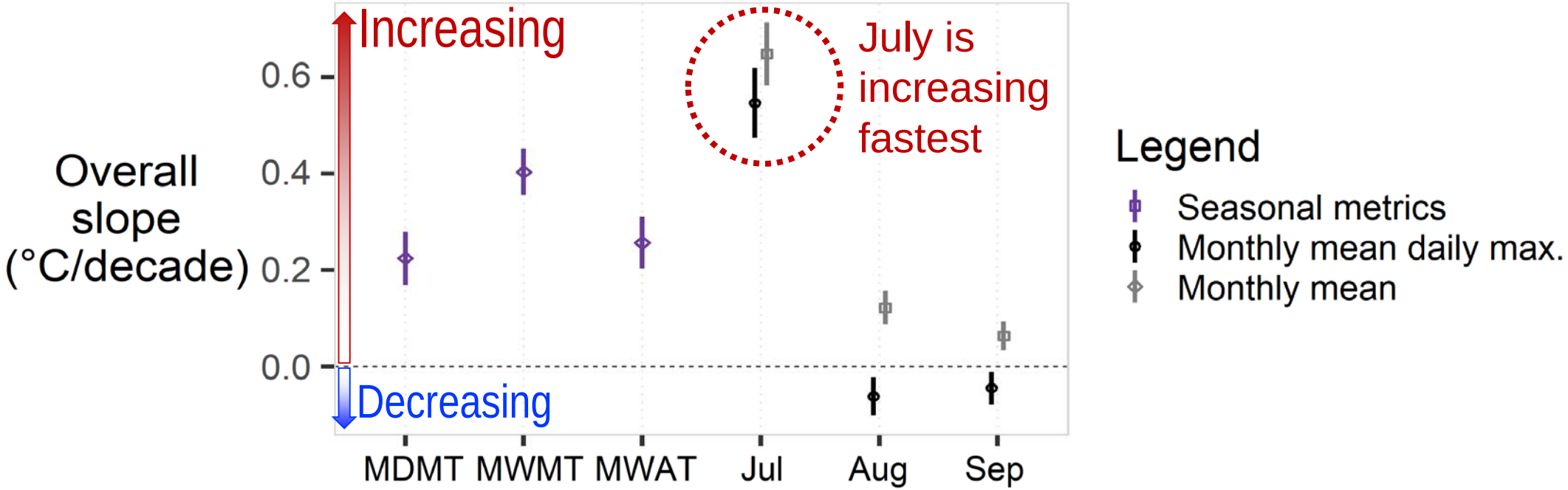

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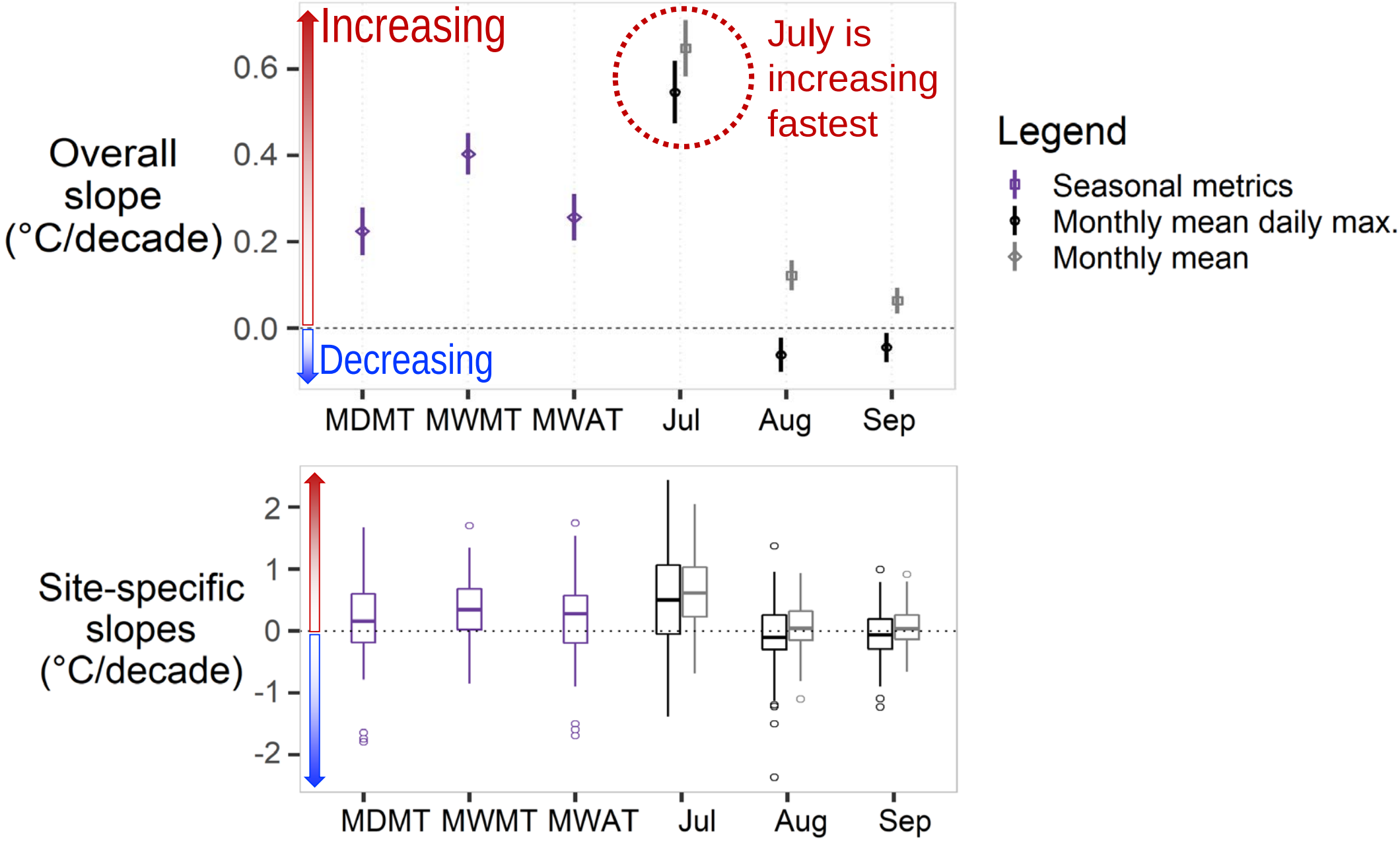

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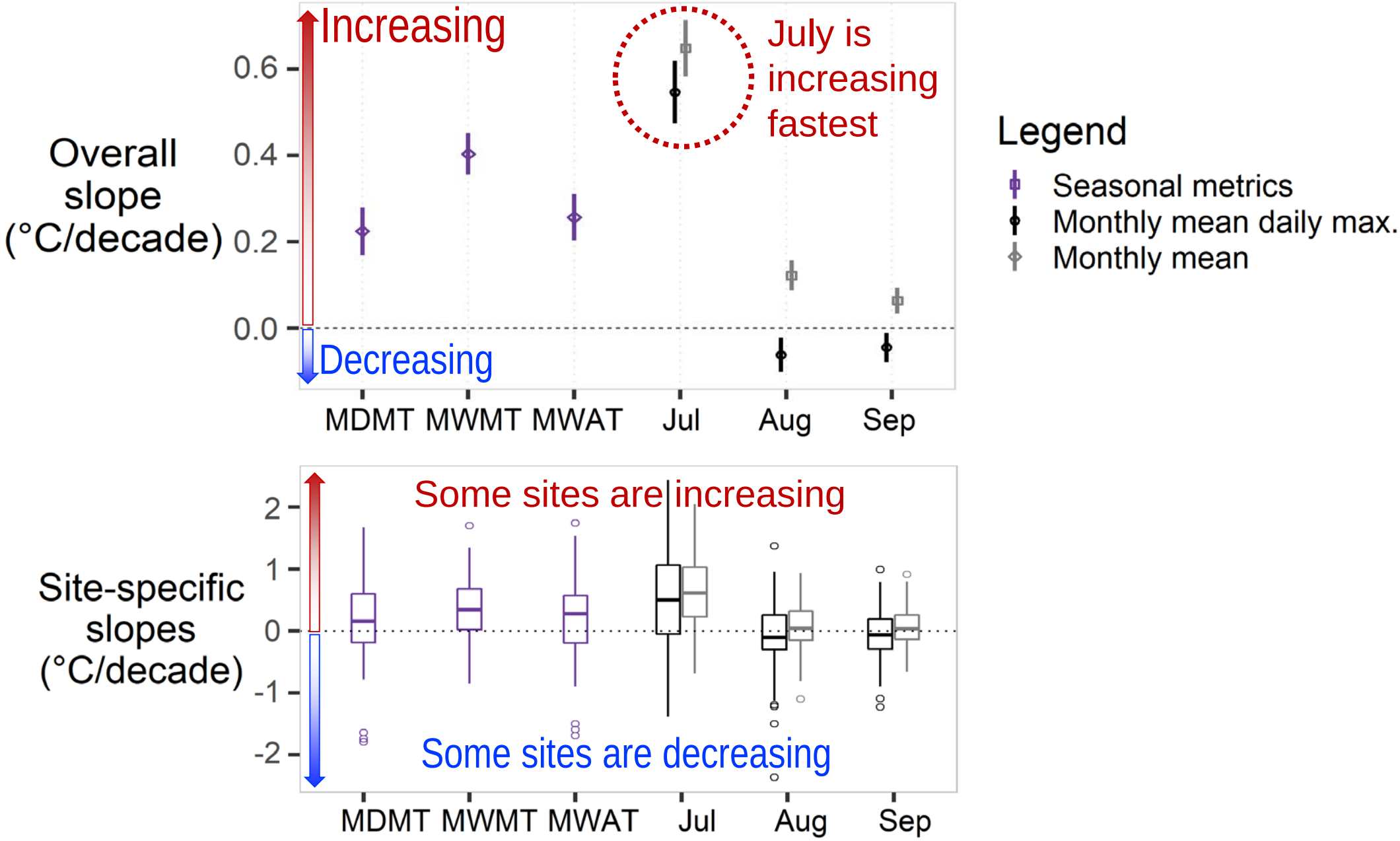
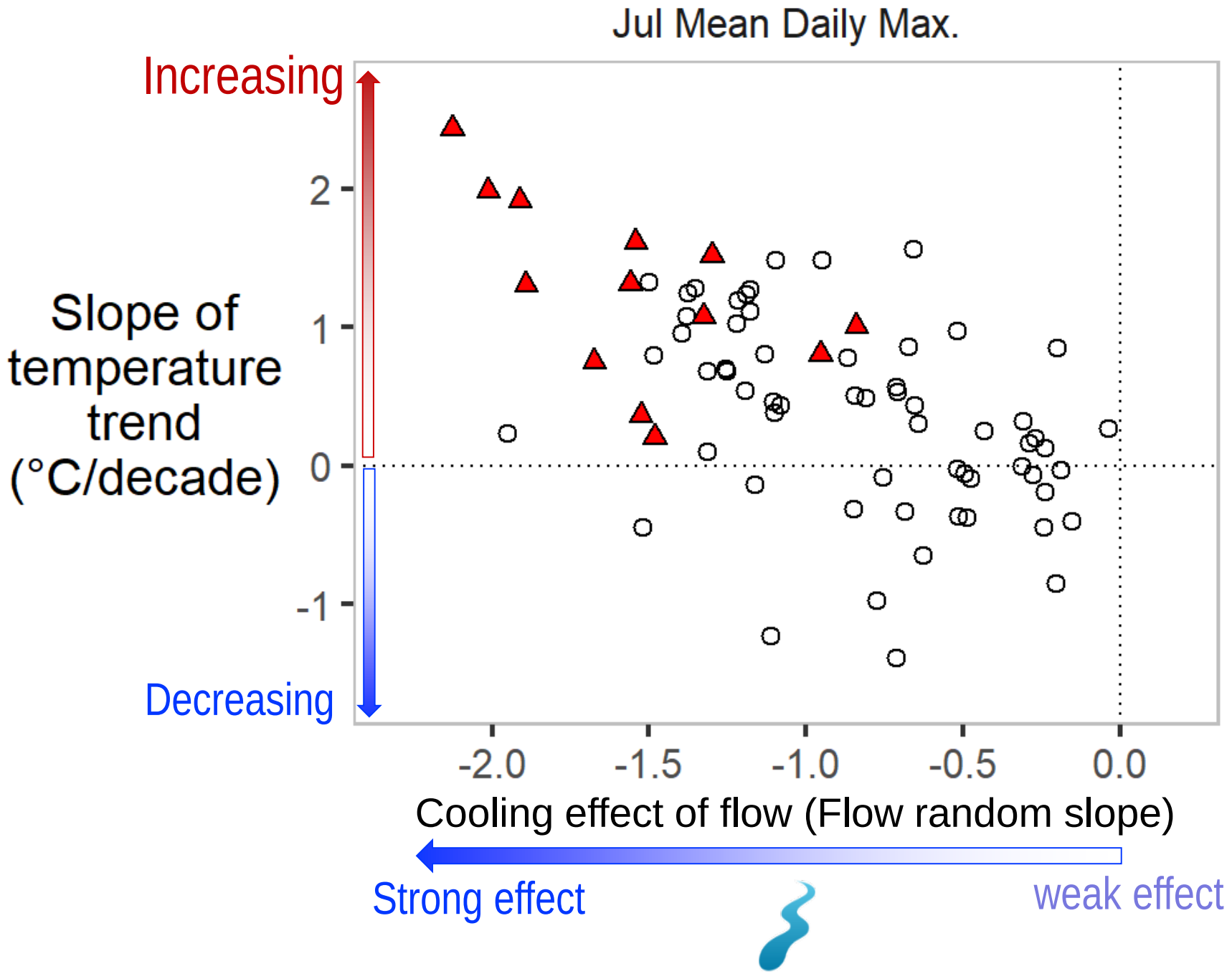
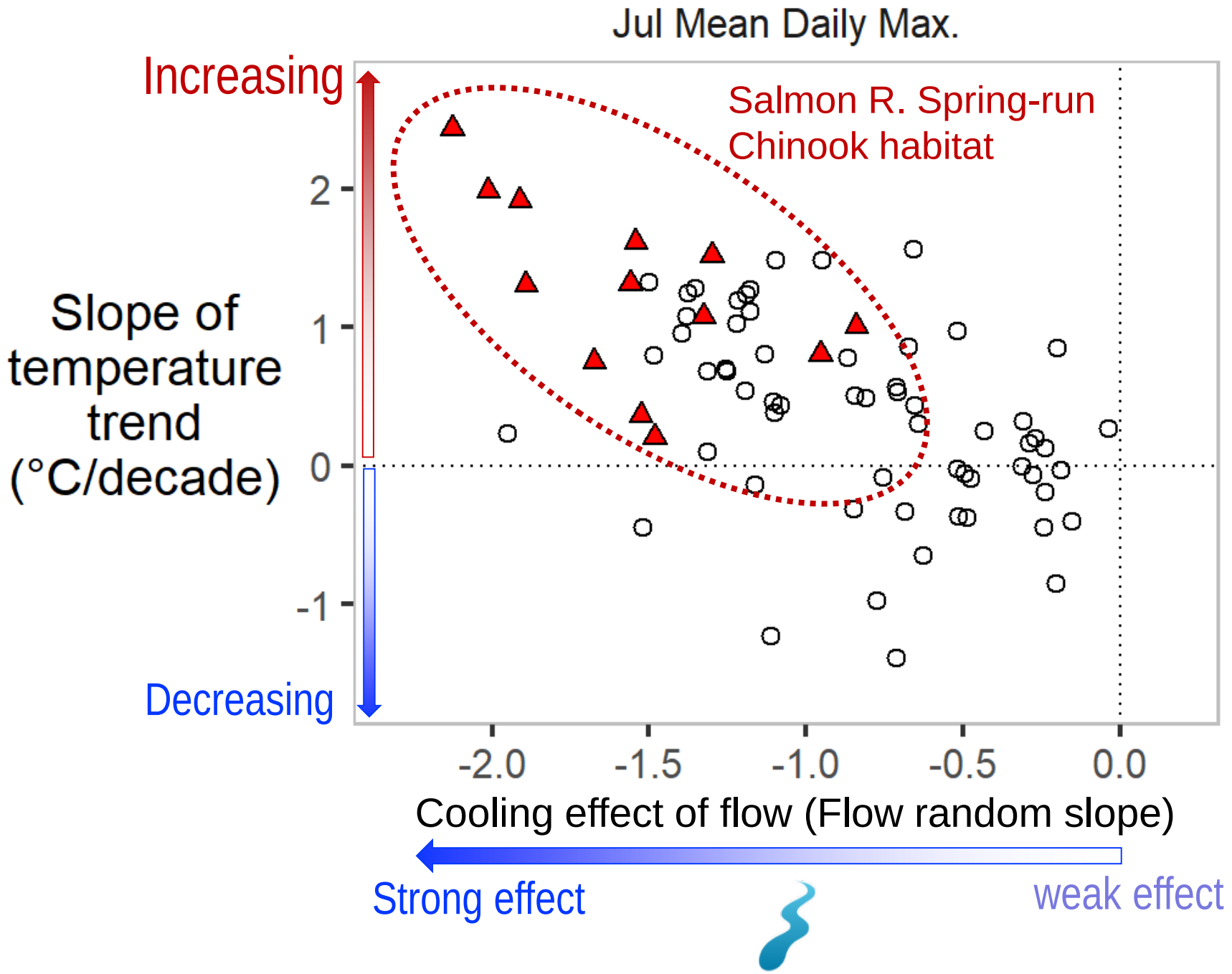
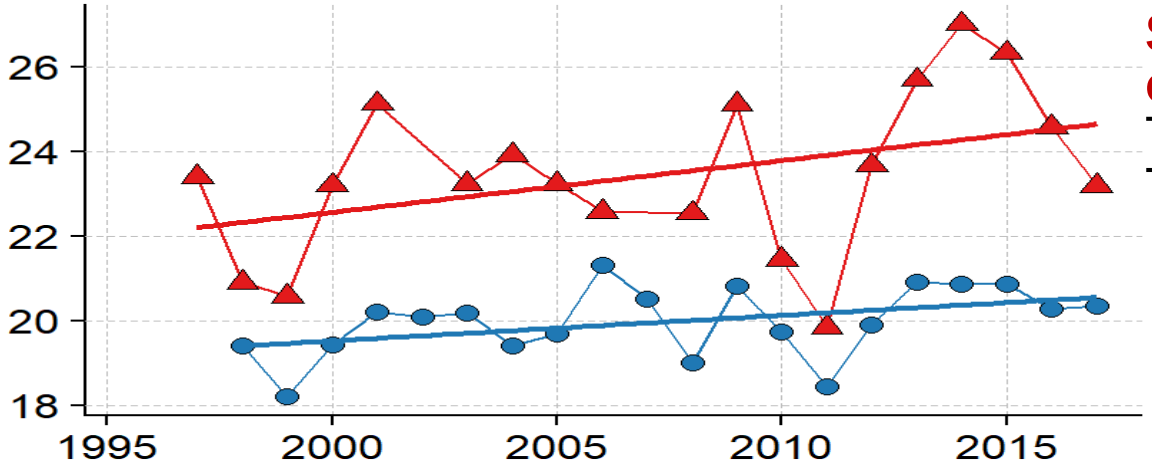



Jul Mean Daily Max.
Increasing
Slope of temperature trend (°C/decade)
2
1
0
-1
Decreasing
-2.0
-1.5
-1.0
-0.5
0.0
Cooling effect of flow (Flow random slope)
Strong effect
weak effect


Jul Mean Daily Max.
Increasing
Salmon R. Spring-run
Chinook habitat
Slope of
temperature
trend
(°C/decade)
2
1
0
-1
Decreasing
-2.0
-1.5
-1.0
-0.5
0.0
Cooling effect of flow (Flow random slope)
Strong effect
weak effect

Annual maximum stream temperature (°C)

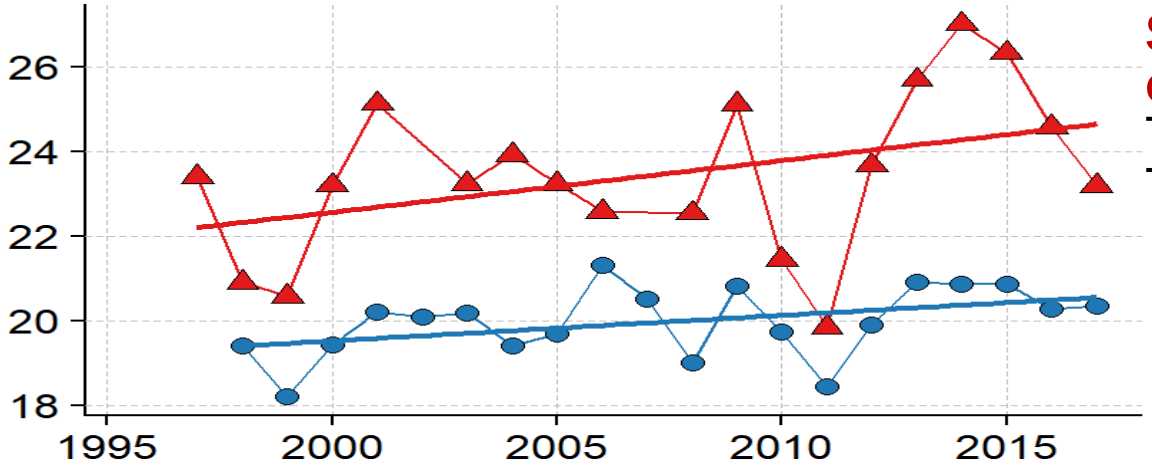


Average August Salmon R. flow (cubic ft/sec)

South Fork Salmon R. upstream of Black Bear Creek:
Temps highly sensitive to flow
Trends is steep increase

Little North Fork Salmon R:
Less sensitive to flow
Trend is increasing slower

Annual maximum stream temperature (°C)



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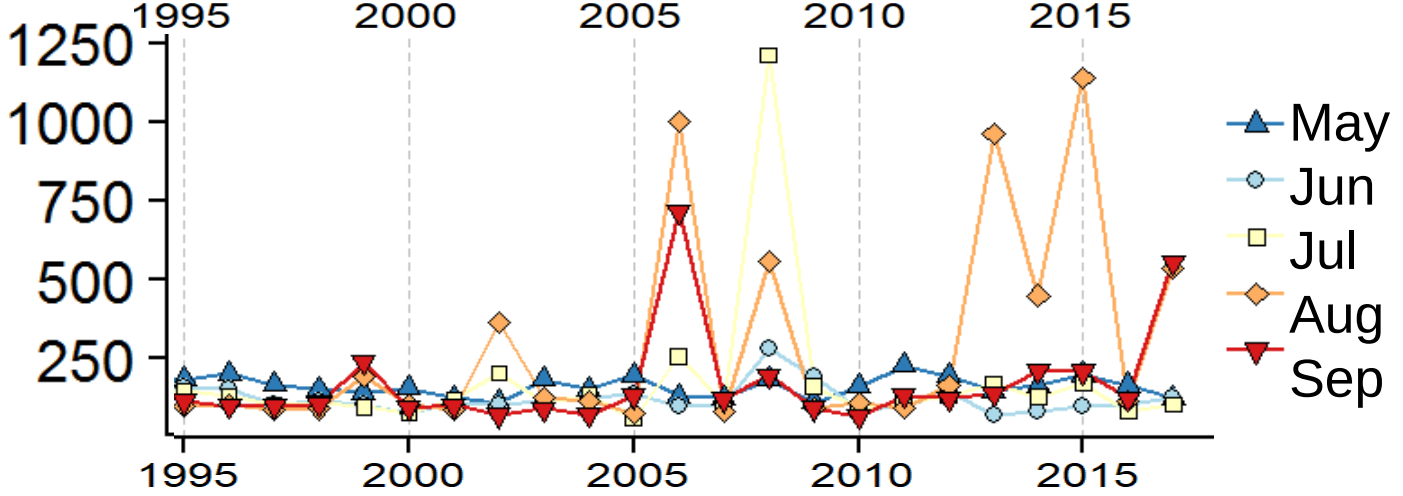
Average August Salmon R. flow (cubic ft/sec)

Smoke



Conclusions Part 1 (Trends)

- 🌡️❄️🔥🌬️ all useful predictors of inter-annual stream temp variation
  - 🔥effect greatest rivers and large streams.
- Trends:
  - Greatest increases in July
  - 🔥 limiting rises in August stream temps (and flow matters less)
  - Site-specific responses vary
    - Rising air temperature 🌡️
    - Flow-sensitive tribs warming faster 🌬️❄️ (bad news for spring Chinook)

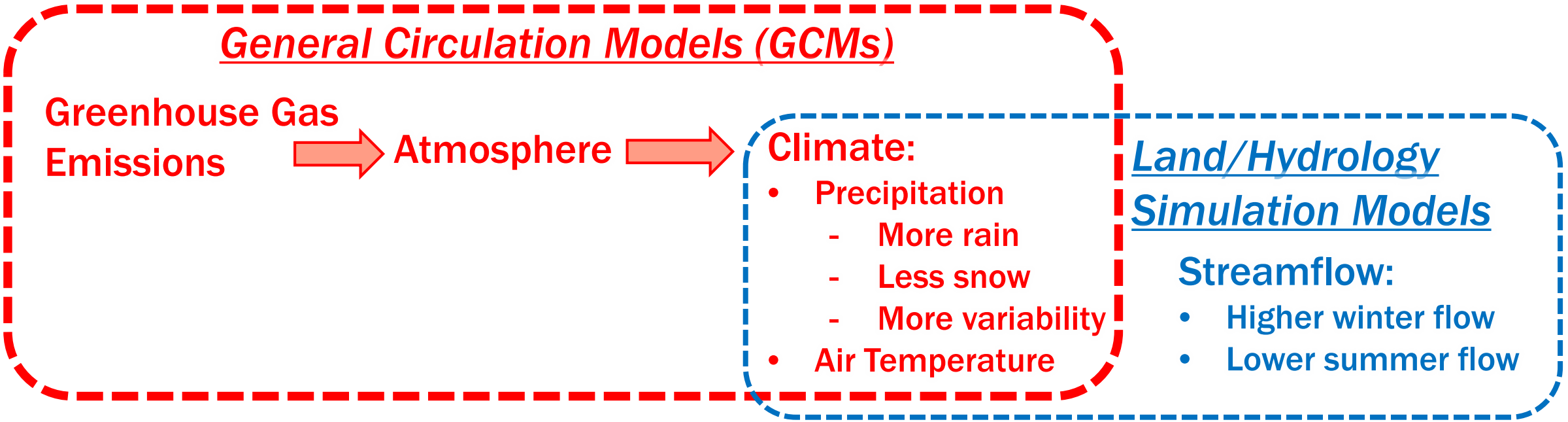
Tools and Conceptual Model for Climate Change Assessment

General Circulation Models (GCMs)

Greenhouse Gas Emissions → Atmosphere → Climate:

- Precipitation
  - More rain
  - Less snow
  - More variability
- Air Temperature

Tools and Conceptual Model for Climate Change Assessment



Tools and Conceptual Model for Climate Change Assessment

General Circulation Models (GCMs)

Greenhouse Gas Emissions → Atmosphere →

Climate:

- Precipitation
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- Air Temperature

Land/Hydrology Simulation Models

Streamflow:

- Higher winter flow
- Lower summer flow

Spatial Stream Network (SSN) Models

August stream temperature

Tools and Conceptual Model for Climate Change Assessment

General Circulation Models (GCMs)

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  - More variability
- Air Temperature

Land/Hydrology Simulation Models

Streamflow:

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Spatial Stream Network (SSN) Models

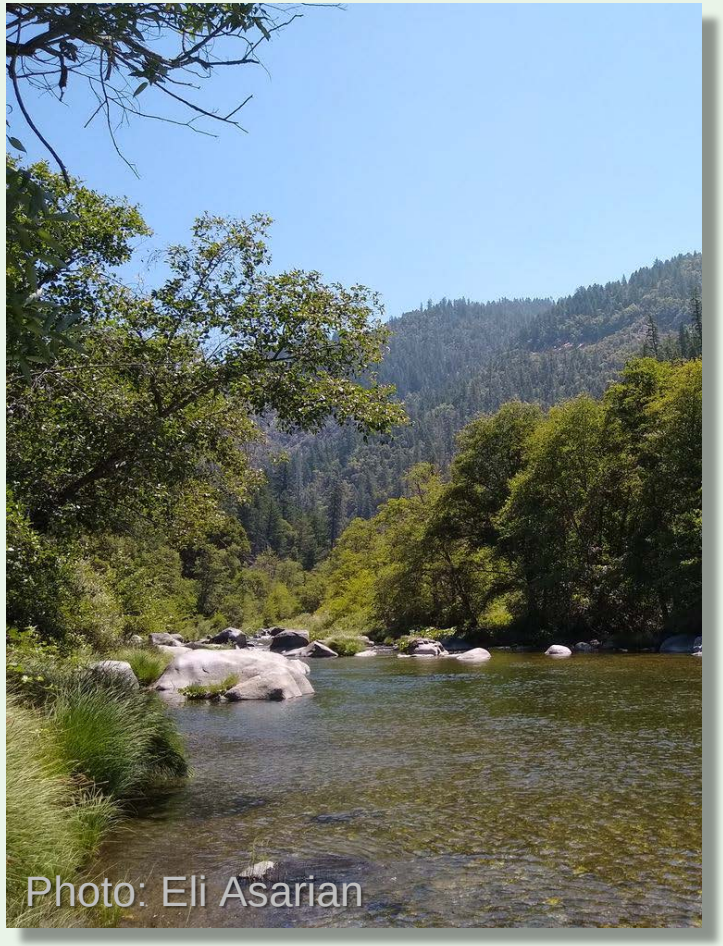
August stream temperature

Not included in analysis:

- Floods: channel & riparian veg
- Increasing groundwater temperatures
- Months except August

SPATIAL STREAM NETWORK (SSN) MODEL

- Adapted from NorWeST (Isaak et al. 2017)
- Statistical (empirical)
- SSN: Ver Hoef & Peterson
  - Spatial correlations
    - Network/tributary structure
  - Linear mixed effects (regression)
  - GIS-based reach attributes as predictors



Variable	Type	Warming or Cooling?	Interaction	Source
Drainage area	Spatial	+	Flow	GIS calc
Remote-sensed topo/veg shade		-		30m satellite USFS GNN veg & Shade-o-lator
Elevation		-		USGS
Water Yield (August)		-		Linear mixed effects model: USGS gage & SRRC/Karuk/USFS measurements
SF Salmon (Y/N)	Spatial/ categorical		Flow	GIS
Air Temperature (August)	Temporal	+		PRISM gridded climate data
Gage Flow (August)		-	Drainage area	USGS
Smoke		-	Drainage area	MERRA-2 re-analysis
Snowpack (April 1)	Spatio-temporal	-	Flow	Gridded model (Mote et al. 2014)

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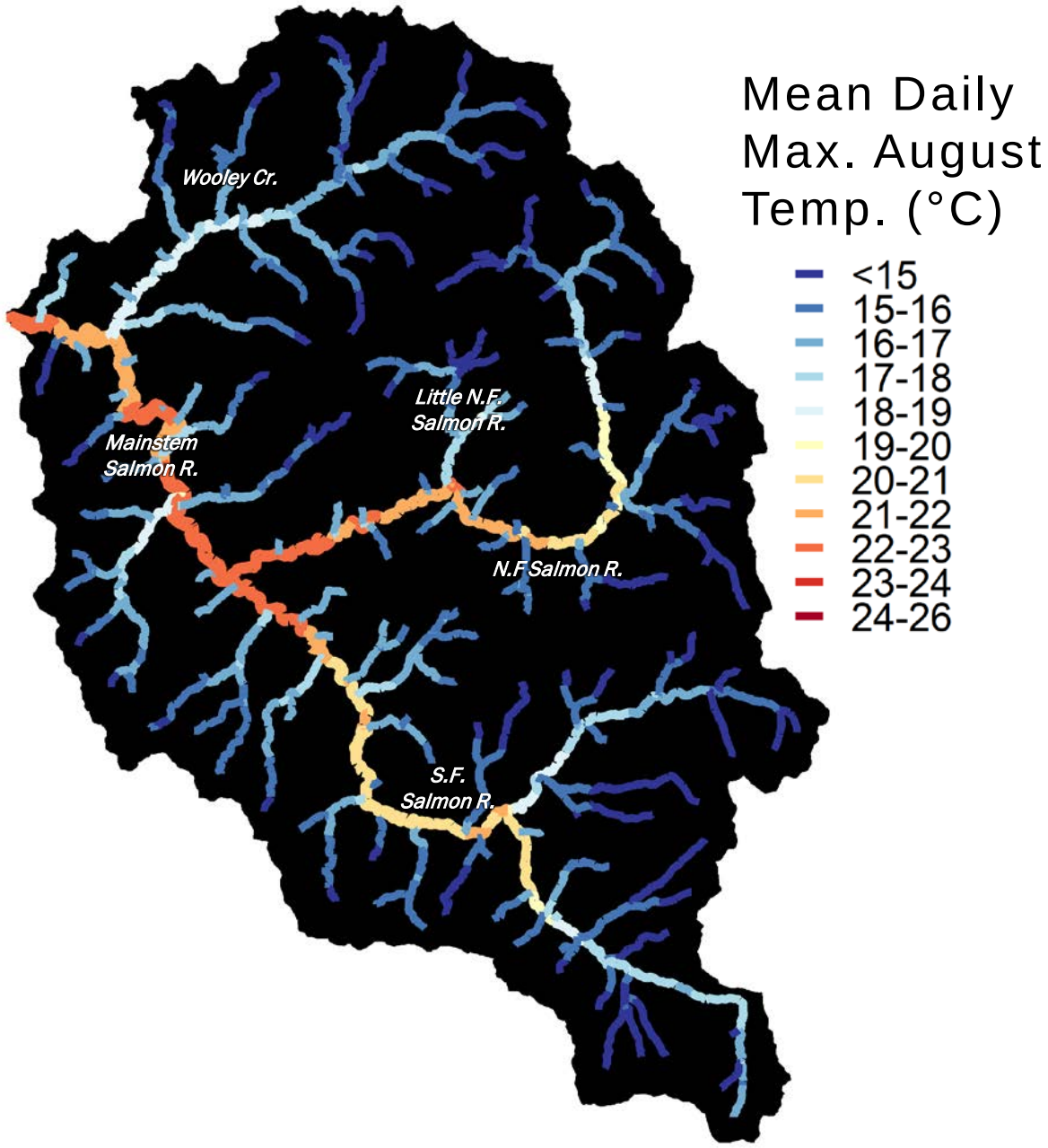
1990-2017 Baseline



SPATIAL STREAM NETWORK TEMPERATURE MODEL

Data:

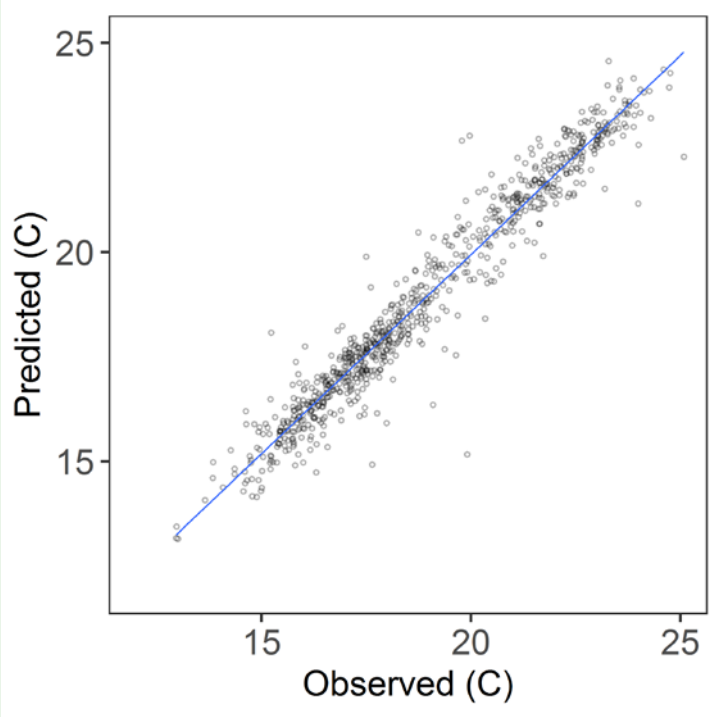
102 sites

n = 796 site years

LOOCV Performance:

RMSPE = 0.62 °C

R^2 = 0.95



CLIMATE SCENARIOS

Periods

- Baseline: 1990–2017 average
- Future: 2070–2099 average

August Air temperature

- Downscaled climate models

August Streamflow

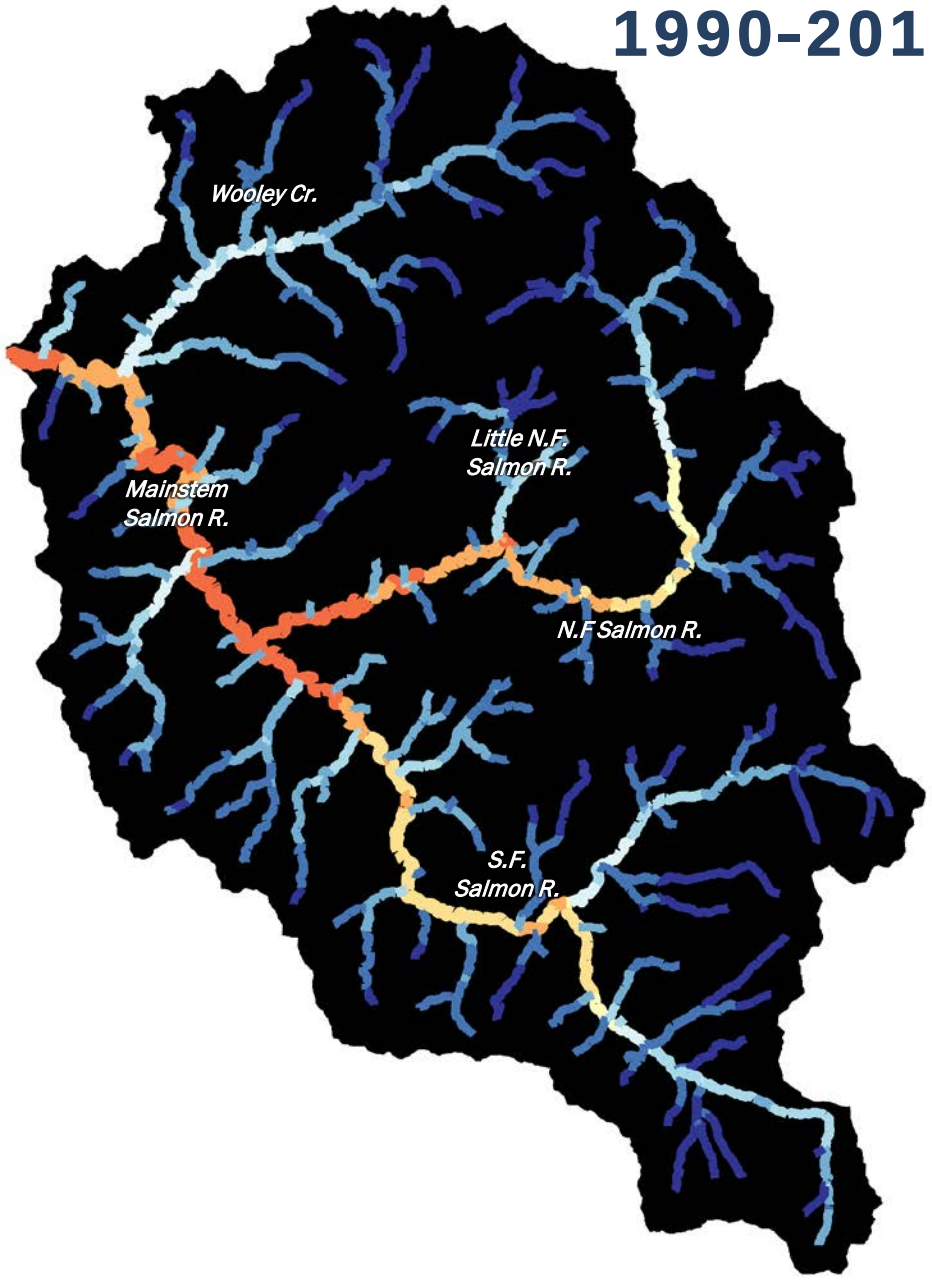
- Hydrologic simulations: Trinity, Feather, Yuba, American Rivers

April 1 Snowpack

- Xiao et al. 2013 gridded model

Scenario Name	Relative to 1990-2017 Baseline		
	August Air Temperature	August Streamflow	April 1 Snowpack
Moderate Emissions (RCP 4.5)	+2.4 °C	-31%	-63%
High Emissions (RCP 8.5)	+4.4 °C	-46%	-83%

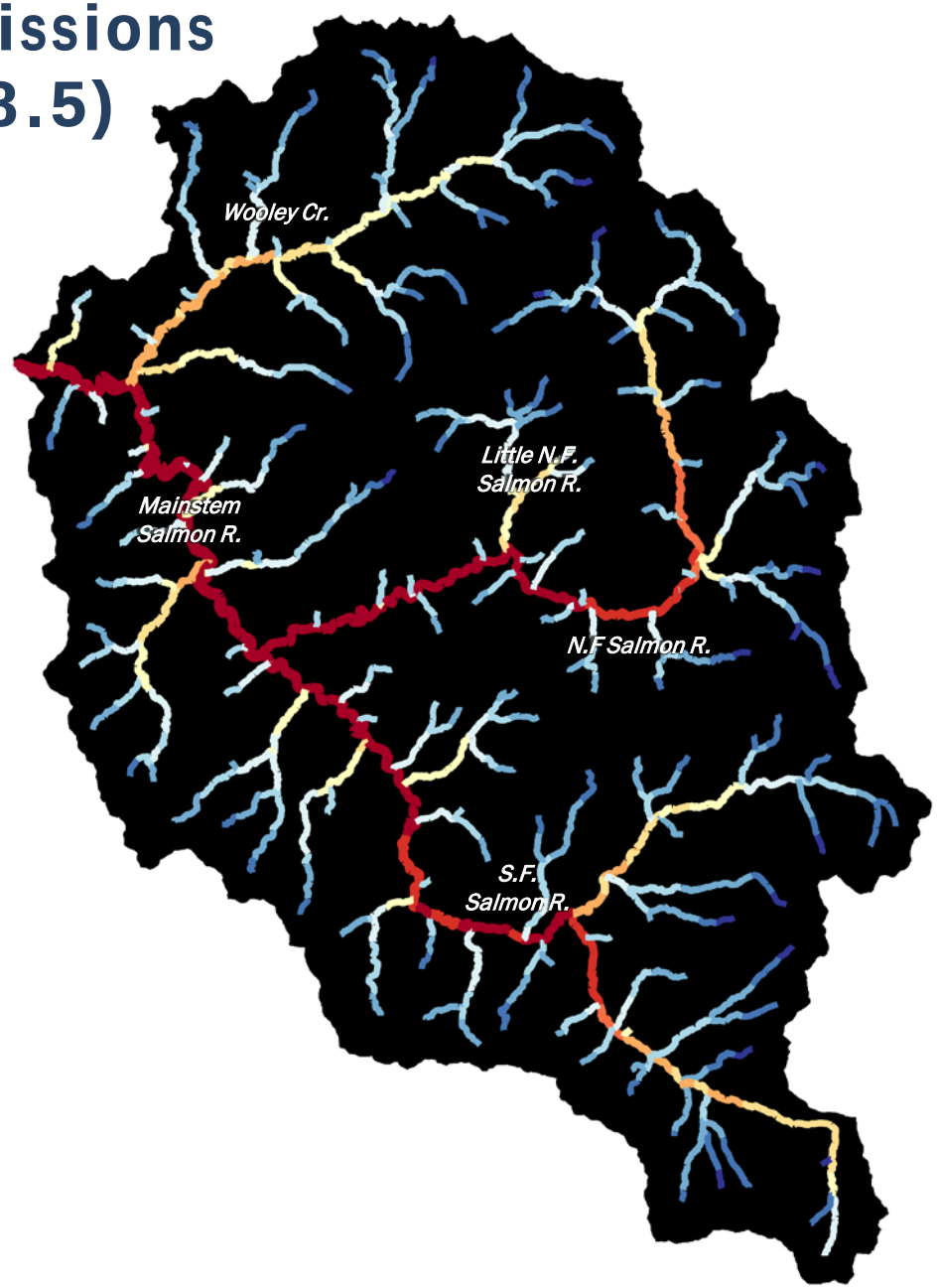
Baseline 1990–2017



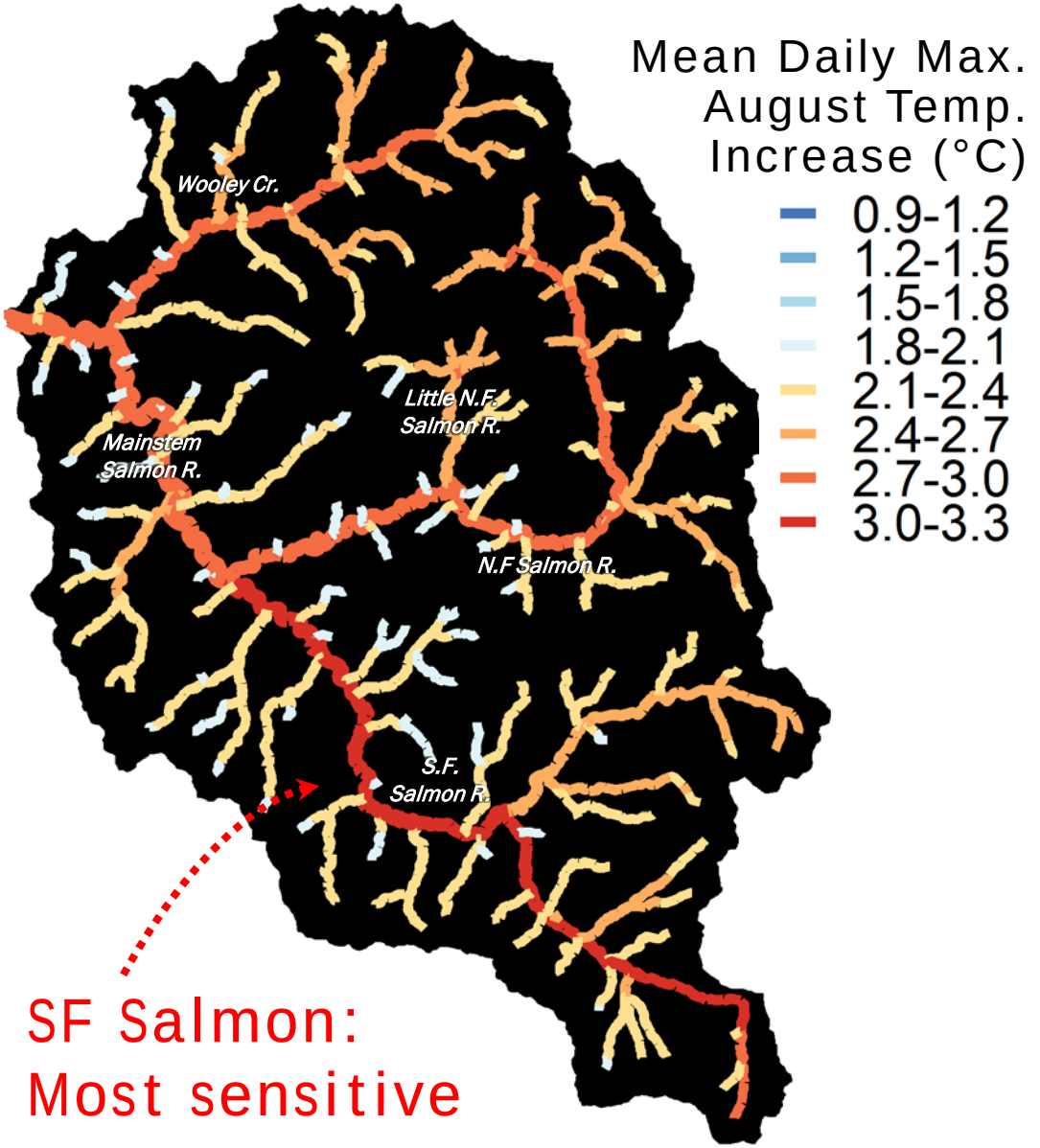
Mean Daily Max. August Temp. (°C)

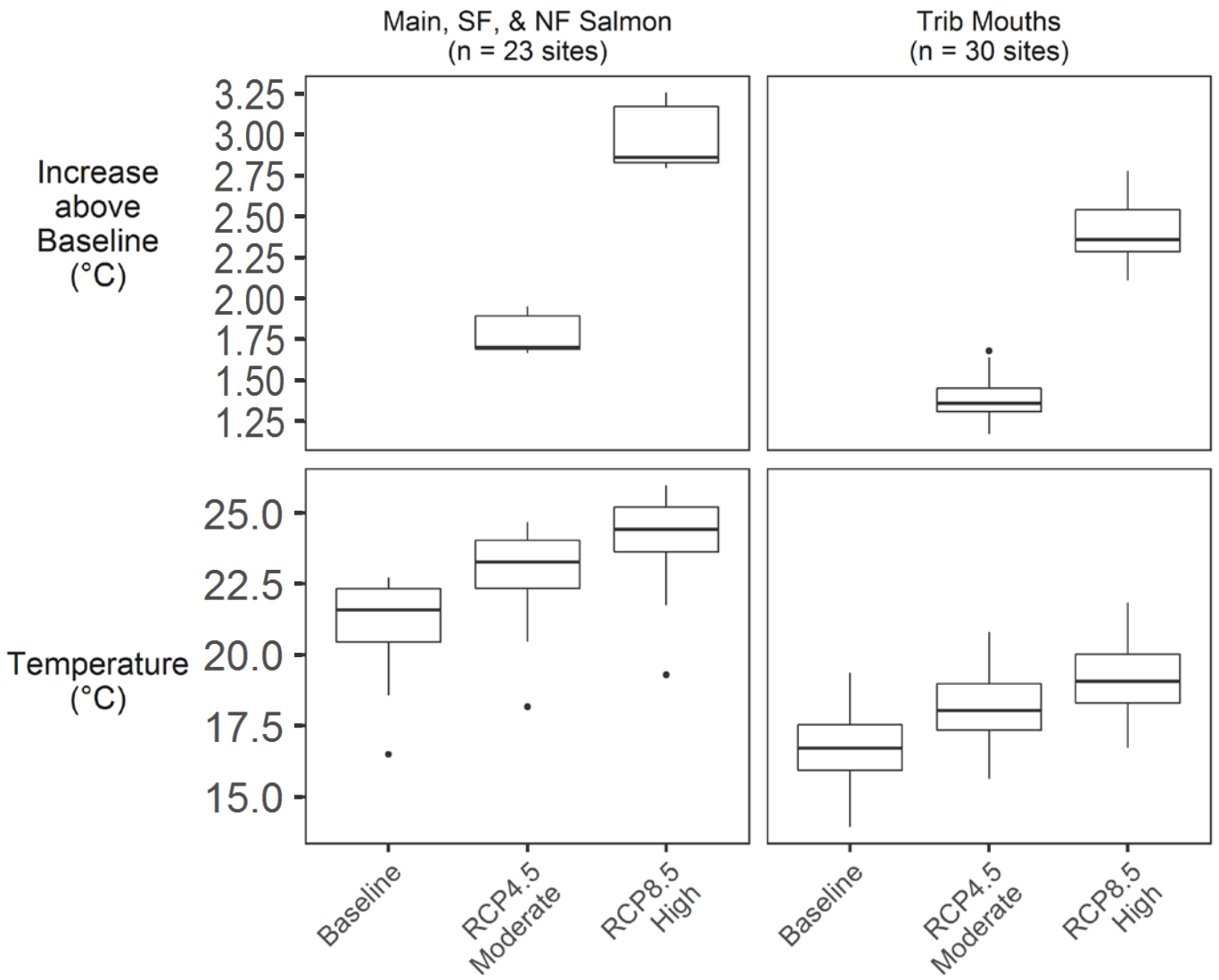
- <15
- 15-16
- 16-17
- 17-18
- 18-19
- 19-20
- 20-21
- 21-22
- 22-23
- 23-24
- 24-26

Future 2070–2099 High Emissions (RCP8.5)



Baseline vs 2070-2099 High Emissions (RCP8.5)





Conclusions Part 2 (Climate Change)

- Water temps warm 1.7–3.3 °C (3.1–5.9 °F) by 2070-2099) if emissions not reduced… 0.9–2.0 °C with reduced emissions
- Cold water contracts upstream
- Large rivers warm more than small streams
  - Trib mouth refugia become increasingly important
  - Need to protect/increase cold water
- Floodplains restoration for thermal diversity

Photo: Eli Asarian

https://klamathwaterquality.com/documents.html

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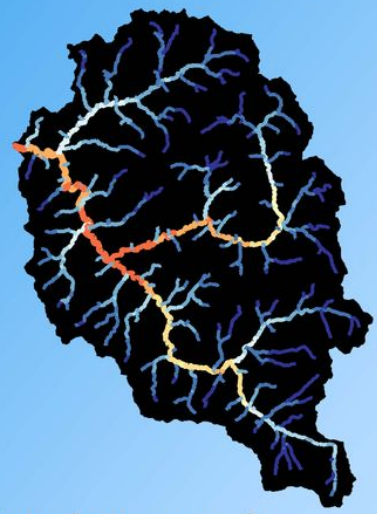
https://srrc.org/publications/



Evidence of Climate-Driven Increases in Salmon River Water Temperatures

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November 2019

Riverbend Sciences

http://www.riverbendsci.com/reports-and-publications-1

Photo by Thomas B. Dunklin

Smoke effect greatest in rivers and large streams

Mainstem Klamath and Trinity rivers

All other tributaries

34,575 km² (Klamath R at Klamath)

7,691 km² (Trinity R nr mouth)

1,946 km² (Salmon R nr mouth)

270 km² (Beaver Cr nr mouth)

10 km² (Aikens Cr nr mouth)

Mean Daily Max. August Stream Temperature

25.0
22.5
20.0
17.5
15.0

0 0.3 0.6 0.8 1.1 1.4

0 0.3 0.6 0.8 1.1 1.4

Smoke (AOT, original units)