NorWeST Stream Temperature Model: Data Structure, Covariates, & Applications

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U.S. Forest Service
¹Trout Unlimited
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⁴USGS
Stream Temperature is “Climate” in Streams

Master variable for ectotherms

Stream Temperature (°C)

TMDL limit

Too Hot!

Growth

Temperature

Time

Sympathy

bull = 0.0085T - 0.0004T^2 - 0.0121, r^2 = 0.87
brook = 0.0125T - 0.0004T^2 - 0.0238, r^2 = 0.64
Temperature Trends In Northwest Rivers

Fraser River - Annual
\[ \Delta = 0.18^\circ C/\text{decade} \]

Morrison et al. 2001

Columbia River - Summer
\[ \Delta = 0.40^\circ C/\text{decade} \]

Crozier et al. 2008

Snake River, ID - Summer
\[ \Delta = 0.27^\circ C/\text{decade} \]


Missouri River, MT - Summer
\[ \Delta = 0.33^\circ C/\text{decade} \]
Pilot Study: Boise River Basin

Larger Scale Replication…

>50,000,000 hourly records
>15,000 unique stream sites
>80 resource agencies
Regional Temperature Model

Accurate temperature models

Cross-jurisdictional “maps” of stream temperatures

Consistent planning datum for 450,000 kilometers of stream
A Scale-able Approach

NHDPlus 1:100,000-Scale Streams

All 2,500,000 stream kilometers

A Scale-able Approach

NHDPlus 1:100,000-Scale Streams

Reach Descriptors:
- Elevation
- Slope
- %Landuse
- Precipitation
- 100’s more...


“Found” Data are often Autocorrelated
Spatial Statistical Network Models

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

Valid interpolation on networks

Let’s us connect the dots...

...& aggregate databases


Stream Models are Generalizable...

Response Metrics
- Gaussian
- Poisson
- Binomial

Distribution & abundance

Statistical stream models

Genetic Attributes

Water Quality Parameters

Stream Temperature
AutoCovariance Function Models Spatial Structure in Residual Errors

Autocovariance functions based on network structure

<table>
<thead>
<tr>
<th>Spatial relationship</th>
<th>Flow-connected</th>
<th>Flow-unconnected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tail-up</td>
<td>(a)</td>
<td>(c)</td>
</tr>
<tr>
<td>Tail-down</td>
<td>(b)</td>
<td>(d)</td>
</tr>
</tbody>
</table>

• Models deal with spatial autocorrelation among observations (non-independence)

Peterson et al. 2007. *Freshwater Biology* **52**:267-279;
Autocovariance Structure is “Black Box”

Spatial patterns in residual errors of MWMT model

Model Prediction Maps “Kriging”

Measurement sites provide local calibration
Temperature Dataset for Mid-Columbia

- Temperature site
- 9,521 August means
- 2,760 stream sites
- 19 summers (1993-2011)
- 60,099 stream kilometers
Temperature Dataset for Mid-Columbia

- 9,521 August means
- 2,760 stream sites
- 19 summers (1993-2011)
- 60,099 stream kilometers

• Temperature site
Mid-Columbia Temperature Model

\( n = 9,521 \)

**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**

- **Spatial Model**
  \( r^2 = 0.94; \text{RMSE} = 0.91°C \)

- **Non-spatial Model**
  \( r^2 = 0.60; \text{RMSE} = 2.26°C \)

More details: **NorWeST website**
## NorWeST Predictor Variable Sources

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stream slope</td>
<td>NHD+</td>
</tr>
<tr>
<td>2. %Glacier (ICE&amp;SNO)</td>
<td>NHD+ (NLCD)</td>
</tr>
<tr>
<td>3. %Lake (OPEN WATER)</td>
<td>NHD+ (NLCD)</td>
</tr>
<tr>
<td>4. Annual precipitation (AREAWTMAP)</td>
<td>NHD+</td>
</tr>
<tr>
<td>5. Stream width (CUMDRAINAG)</td>
<td>NHD+</td>
</tr>
<tr>
<td>6. Riparian Canopy %</td>
<td>NLCD 2001</td>
</tr>
<tr>
<td>7. Elevation</td>
<td>30 m DEM</td>
</tr>
<tr>
<td>8. Baseflow Index (BFI)</td>
<td>Santhi et al. 2008</td>
</tr>
<tr>
<td>9. Latitude</td>
<td>UTM coordinate</td>
</tr>
<tr>
<td>10. August Discharge Mean*</td>
<td>USGS gages</td>
</tr>
<tr>
<td>11. August Air Mean*</td>
<td>NCEP RegCM3 reanalysis</td>
</tr>
</tbody>
</table>

*Inter-annual climate variation*
Kriged Network Prediction Maps

Network-scale Status Maps

Which then facilitate trend assessments...
Models Enable Climate Scenario Maps

Many possibilities exist...

Adjust...
- Air
- Discharge
- %Canopy

...values to create scenarios
## NorWeST Historical Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1_93_11</td>
<td>Historical scenario representing 19 year average August mean stream temperatures for 1993-2011</td>
</tr>
<tr>
<td>S2_02_11</td>
<td>Historical scenario representing 10 year average August mean stream temperatures for 2002-2011</td>
</tr>
<tr>
<td>S3_1993</td>
<td>Historical scenario representing August mean stream temperatures for 1993</td>
</tr>
<tr>
<td>S4_1994</td>
<td>Historical scenario representing August mean stream temperatures for 1994</td>
</tr>
<tr>
<td>Etc…</td>
<td></td>
</tr>
<tr>
<td>S21_2013</td>
<td>Historical scenario representing August mean stream temperatures for 2013</td>
</tr>
</tbody>
</table>

*Extensive metadata on website*
High-Resolution Stream Temp Scenarios

R² = 0.91; RMSE = 1.0°C; 1-km resolution

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

- 46,674 summers of data swallowed
- 467,000 stream kilometers of thermal ooze
High-Resolution Stream Temp Scenarios

- $R^2 = 0.91$; RMSE = 1.0

- 46,674 summers of data swallowed
- 467,000 stream kilometers of thermal ooze

Solution

Baseline (93-11)

<table>
<thead>
<tr>
<th>Temp °C</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 8</td>
<td>blue</td>
</tr>
<tr>
<td>8 - 11</td>
<td>light blue</td>
</tr>
<tr>
<td>11 - 14</td>
<td>light green</td>
</tr>
<tr>
<td>14 - 17</td>
<td>yellow</td>
</tr>
<tr>
<td>17 - 20</td>
<td>red</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>brown</td>
</tr>
</tbody>
</table>

The BLOB…it just keeps growing…
Website Distributes Temperature Data & Scenarios for Convenient Use

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
Field-Based Temperature Standards using BIG FISH Databases

Stream temperature maps

Regional fish survey databases (n ~ 13,000)

NorWeST Stream Temp

Occurrence probability

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

Too warm... Too cold... Just right
Thermal Niches in Batch Mode...

NorWeST Stream Temperature ($S_1$)

~13,000 fish surveys

Wenger et al., In Preparation
More Accurate Species Distribution Models...

78% classification accuracy

85% classification accuracy

\[ p = \frac{\exp(a + bx \ldots ny)}{1 + \exp(a + bx \ldots ny)} \]
Better Climate Vulnerability Assessments & Precise Mapping of Refuge Streams

Relative Effects of Predictors

Mid-Columbia River Basin Model

Spatial covariates

Temporal covariates

Warming
Cooling

* = statistically significant at p < 0.01

0 1 2 3 4

Standardized parameter

Elevation, Stream slope, Lake, Annual precip, Latitude, Baseflow index, Drainage area, Riparian canopy, Air temperature, Discharge
Relative Effects of Predictors

Northwest Montana Model

- Elevation
- Stream slope
- Lake
- Annual precip
- Latitude
- Baseflow index
- Drainage area
- Riparian canopy
- Air temperature
- Discharge

* = statistically significant at p < 0.01

Standardized parameter

Warming

Cooling

Spatial covariates

Temporal covariates

Manage?
Riparian Canopy Predictor

%Canopy variable from 2001 NLCD

%Canopy adjusted by MTBS through 2008

1 km

Ways of teasing out 'management effects' "black box" of autocovariance

New covariates & refit model

Geostats block - kriging for treatment/ref conditions

Talk about at EPA webinar in few weeks
Natural vs Anthropogenic Effects

“Natural”

“Impaired”
1. Nesting Mechanistic & Statistical Models

NorWeST provides boundary conditions
2. Additional Covariate Predictors

NHDPlus 1:100,000-Scale Streams

Reach Descriptors:
- Elevation
- Slope
- %Landuse
- Precipitation
- 100’s more...

- Precise measures of local impairment
- Scale-able to other areas?
2. Additional Covariate Predictors

Best candidates...

Local stream radiation estimates (hemispherical photography/LiDAR surveys of current conditions... but site potential also needed)

Local flow estimates (current/potential under different climate/water use scenarios)

Local channel morphology estimates (current/potential conditions if fully restored)

...non-trivial tasks
2. Additional Covariate Predictors

An example...

NLCD Canopy% vs. Detailed hemispherical photos & radiation estimates

Radiation curves by vegetation class

3. Block-krige Estimates of Mean & Variance at User-Defined Scale

Temperature (˚C)
- 10.6 - 11.0
- 11.1 - 11.5
- 11.6 - 12.0
- 12.1 - 12.5
- 12.6 - 13.0
- 13.1 - 13.5
- 13.6 - 14.0
- 14.1 - 14.5
- 14.6 - 14.9

Precise & unbiased estimates

Bear Valley Creek Mean Temperature

Does this reach meet the TMDL standard?
Reference Site Comparison Approach

Pick “impaired” & “natural” streams to compare

How altered is this stream?
Block-Krige Estimates for Both Streams

~2°C difference

Stream

Simple random

Block krigeing

Summer temperature (°C)

1  2
Block-Krige Estimates for Both Streams

Do so anywhere within a river network
Reference Site Approach Requires Good Watershed/reach Classifications

Reference

Impaired

Watershed Condition Classification

- Functioning Properly
- Functioning at Risk
- Impaired Function

Map showing the classification of different areas based on their condition.
Block-Kriging & Reference Site Approach Broadly Applicable for Many Water Parameters...

- Sediment...
- Urban runoff...
- Nutrients...
- Mining...
Many Powerful New Tools & Datasets

SSN/STARS Website

- Software
- Example Datasets
- Documentation
The Grail is Within our Grasp...

Better information = better understanding & prediction