Thermal regime modeling

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Stream Temperature Data and Modeling Meeting II

USFWS Regional Office

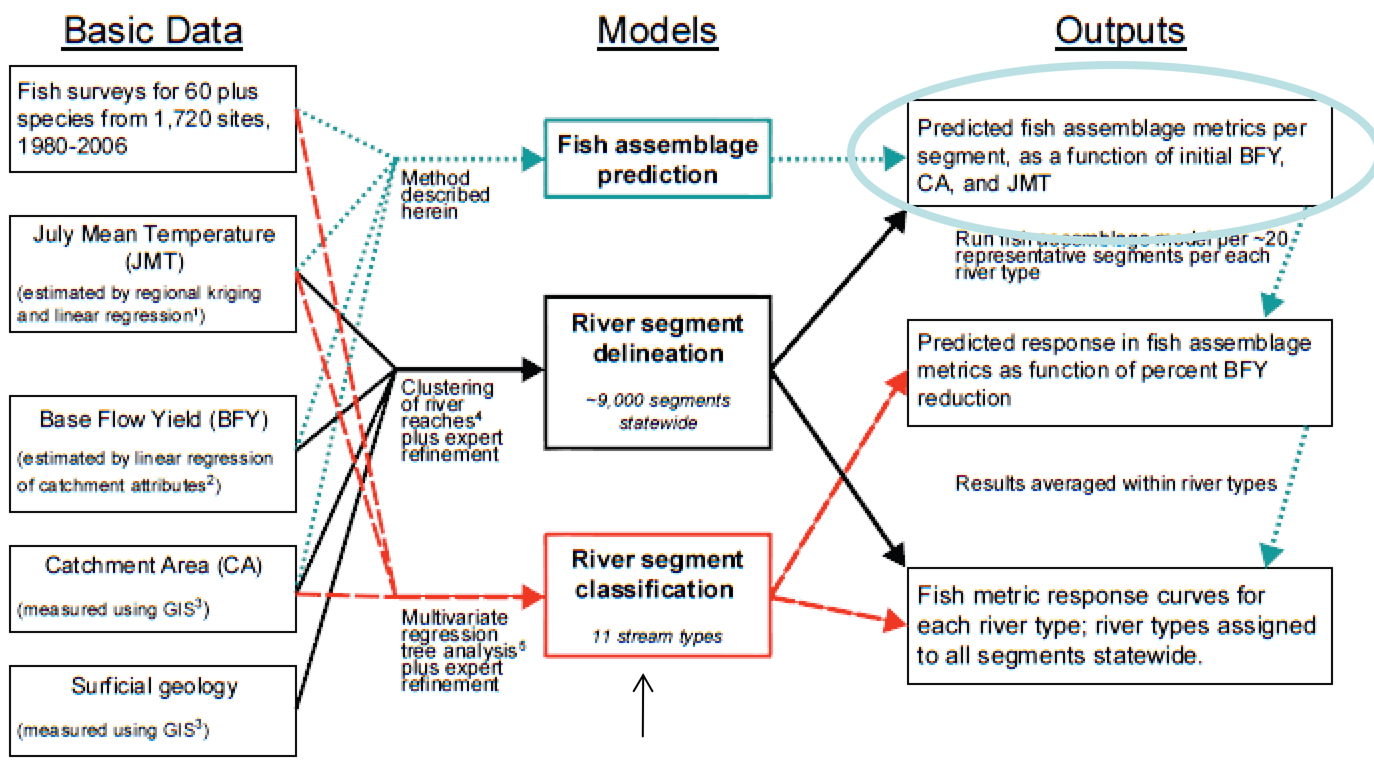
Hadley, MA

May 1, 2014

Fish community prediction

Alternate metrics (modelled)

7Q10 = f(winter/spring prec, ann avg temp, %coarse deposits, %wetlands)

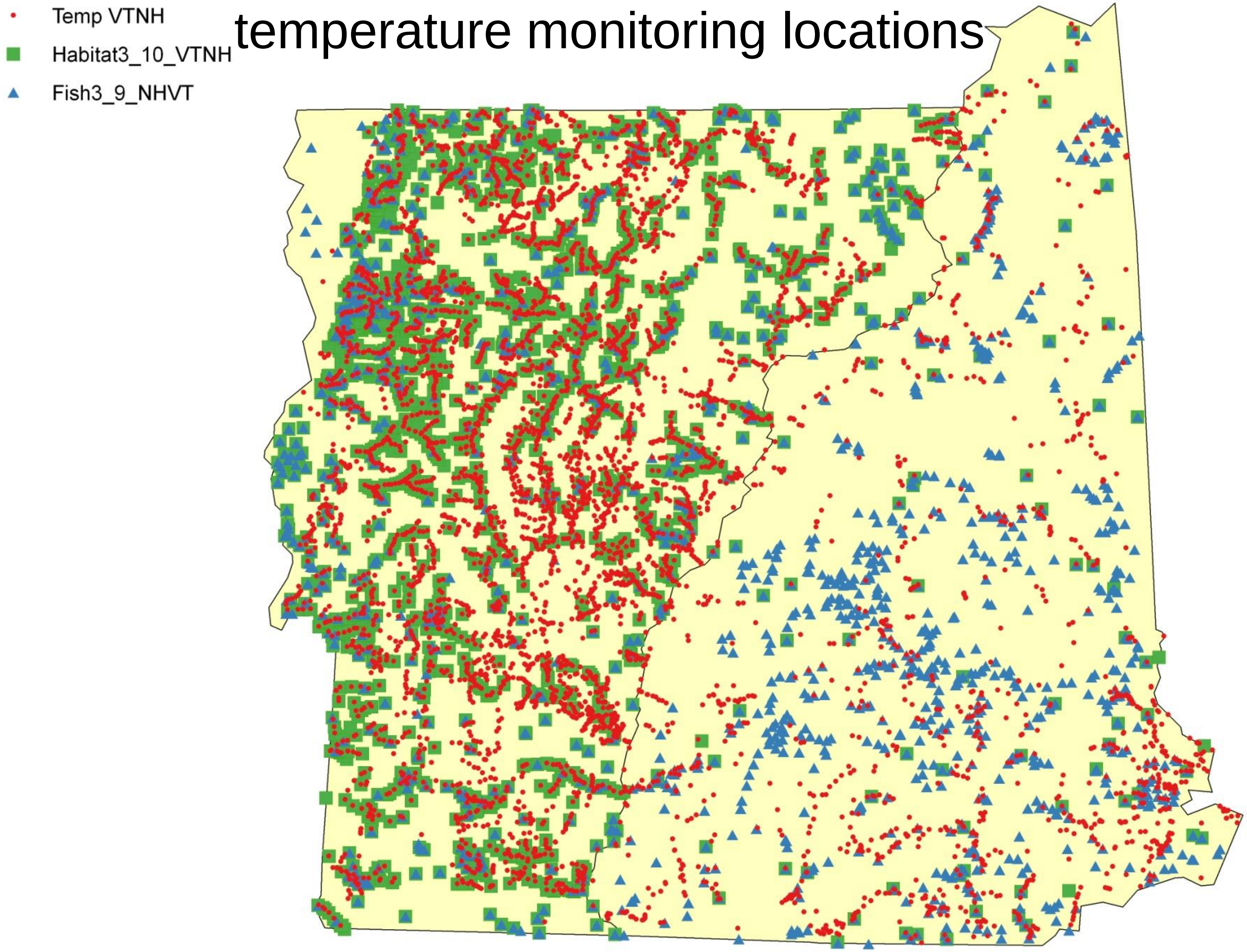


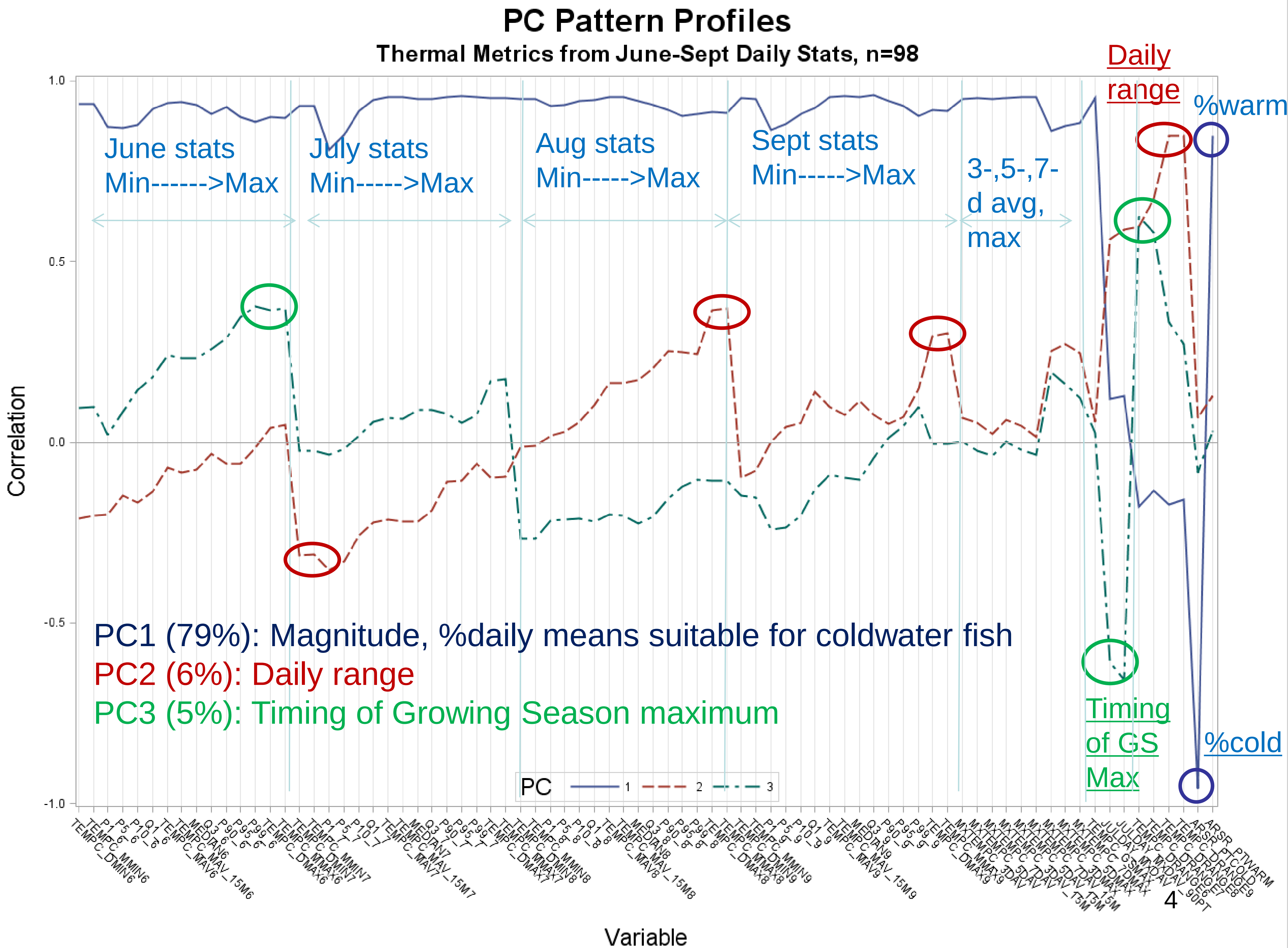
Test TNC Aquatic Habitat Classification as alternative

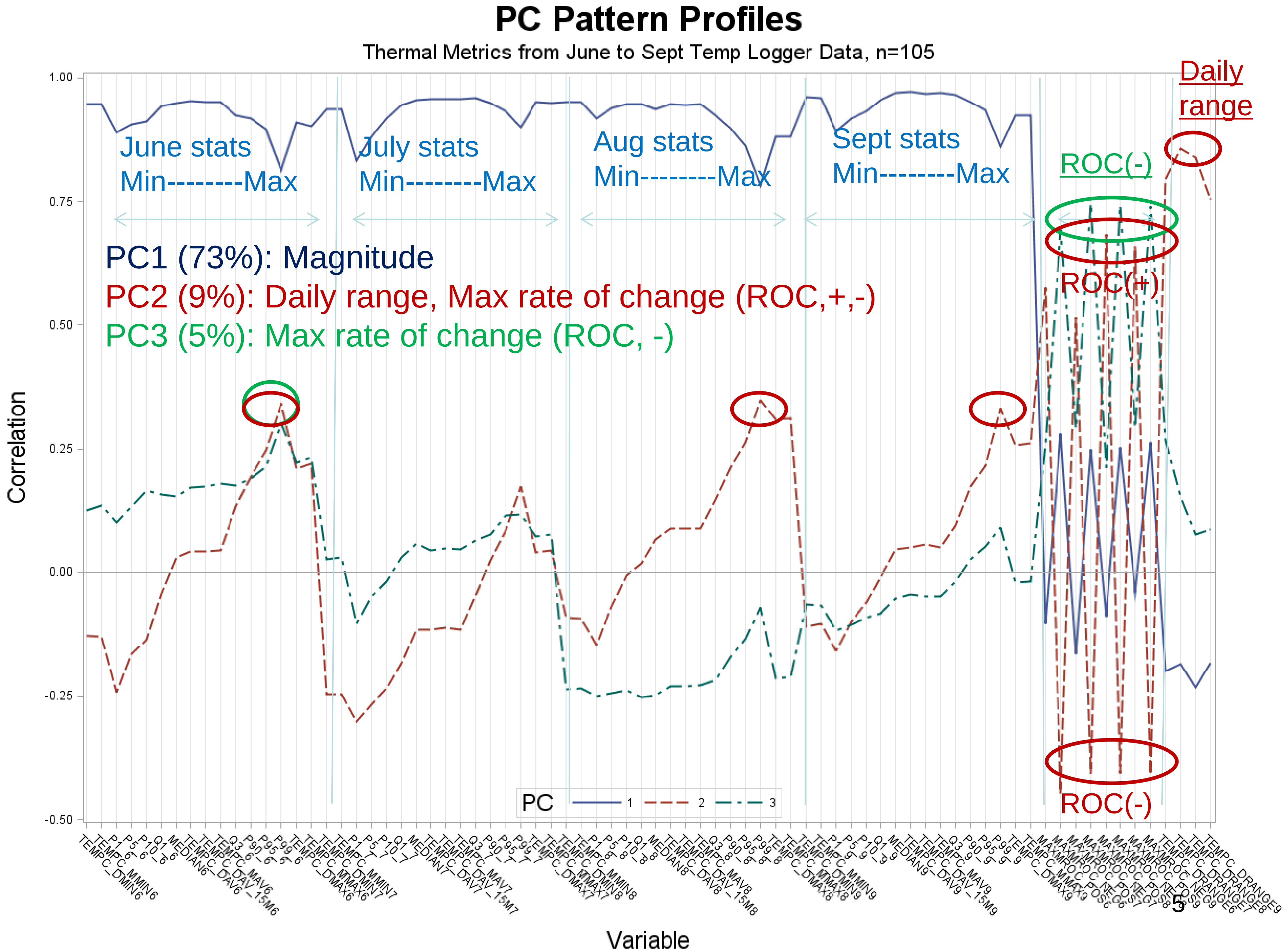
gure 1.–Flow chart of the flow-fish response assessment model showing major data, model, output components, and linkages.

From Zorn et al. 2008. A Regional-scale Habitat Suitability Model to Assess the Effects of Flow Reduction on Fish Assemblages in Michigan Streams. MI DNR, Ann Arbor, MI. Fisheries Div Res Report 2089.

The problem: Limited matches between fish and temperature monitoring locations




PC Pattern Profiles
Thermal Metrics from June-Sept Daily Stats, n=98
June stats Min------>Max
July stats Min----->Max
Aug stats Min----->Max
Sept stats Min----->Max
3-,5-,7-d avg, max
Daily range
%warm
%cold
Timing of GS Max
PC1 (79%): Magnitude, %daily means suitable for coldwater fish
PC2 (6%): Daily range
PC3 (5%): Timing of Growing Season maximum
PC 1 2 3
Correlation
Variable
1.0
0.5
0.0
-0.5
-1.0



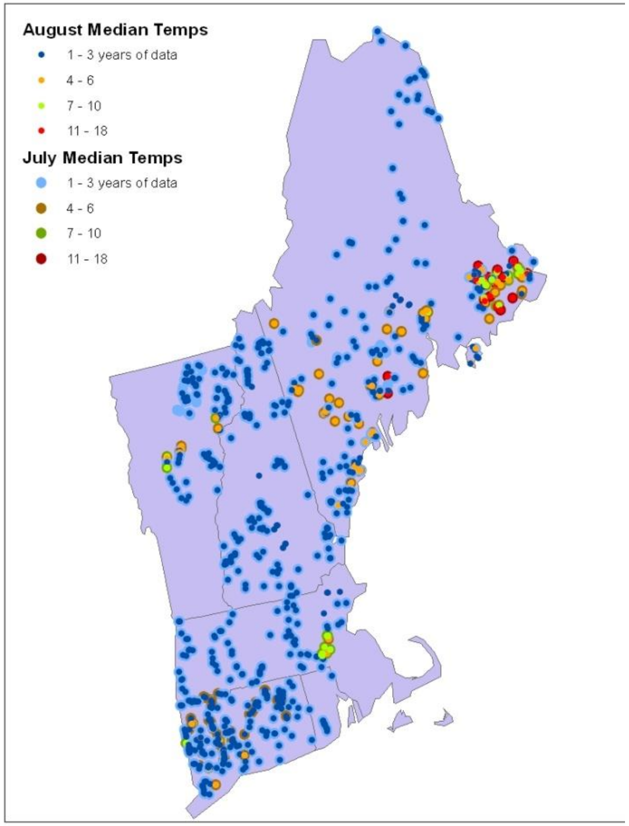
PC Pattern Profiles
Thermal Metrics from June to Sept Temp Logger Data, n=105
June stats
Min--------Max
July stats
Min--------Max
Aug stats
Min--------Max
Sept stats
Min--------Max
Daily range
ROC(-)
ROC(+)
ROC(-)
PC1 (73%): Magnitude
PC2 (9%): Daily range, Max rate of change (ROC,+,-)
PC3 (5%): Max rate of change (ROC, -)
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
Correlation
Variable
PC 1 2 3

Preliminary conclusions

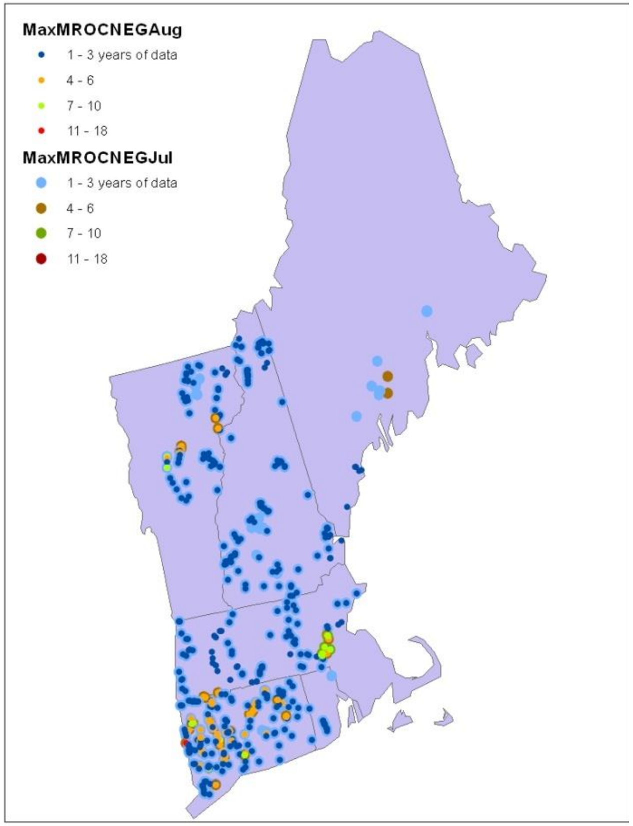
- Metrics to capture greatest variation across thermal regimes
  - Overall magnitude: July or August median
  - Daily range
  - Timing of growing season maximum
  - Max negative rate of change (recovery?)
- Observations limited by inconsistencies in sampling window and logger location but patterns consistent for larger data sets with shorter sampling windows

Water temperature metric locations

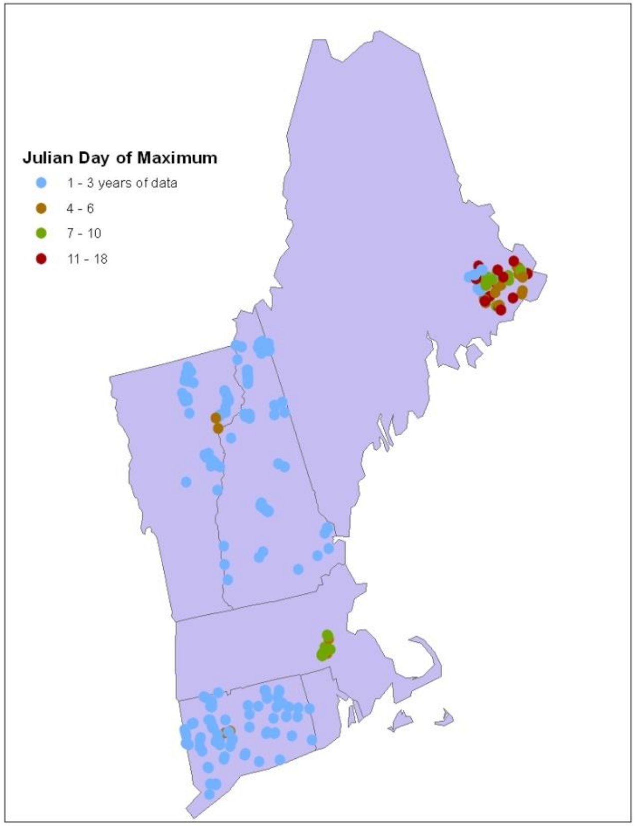
Medians



Max Rate of Change

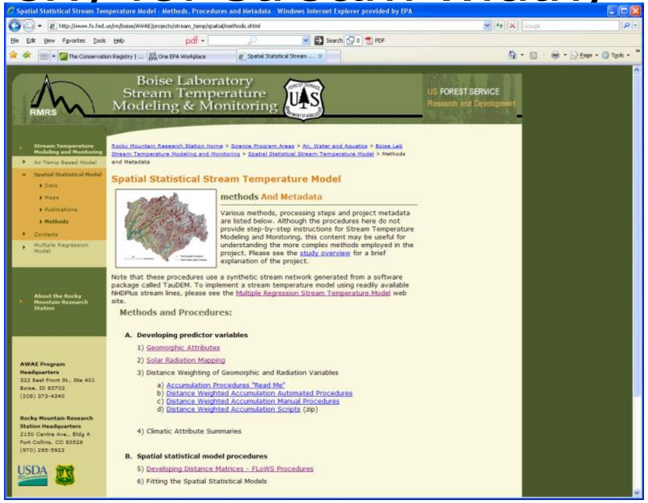


Timing of maximum



Temperature metric prediction model approach

- Flow-weighted spatial autocorrelation model using stream distance (ver Hoef et al. 2006)
- Potential predictors
  - Watershed area (proxy for stream width)
  - Drainage density
  - Elevation
  - Coarse deposits
  - Channel slope
  - % impervious area
  - Elevation-corrected air temperature
  - Solar radiation proxy (=f(average solar radiation, riparian vegetation type/density, stream width))
  - Stream flow (estimated)



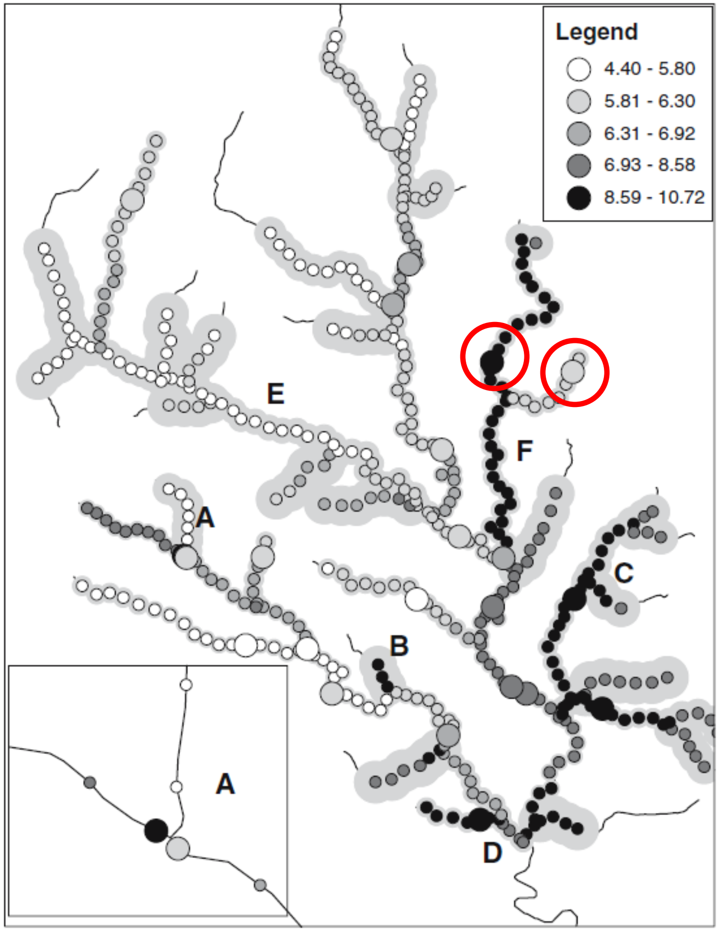


Fig. 6 Predictions for the example data in Fig. 2. The Observed locations are shown with large circles and predicted locations are shown with smaller circles; both are shaded according to their observed or predicted values. The width of the gray shading behind the circles is proportional to the prediction standard errors. Thus, areas with wider shading have less precision

A predictive model accounting for spatial autocorrelation using Euclidean (straight-line) distance would assume these points are similar

observed

predicted

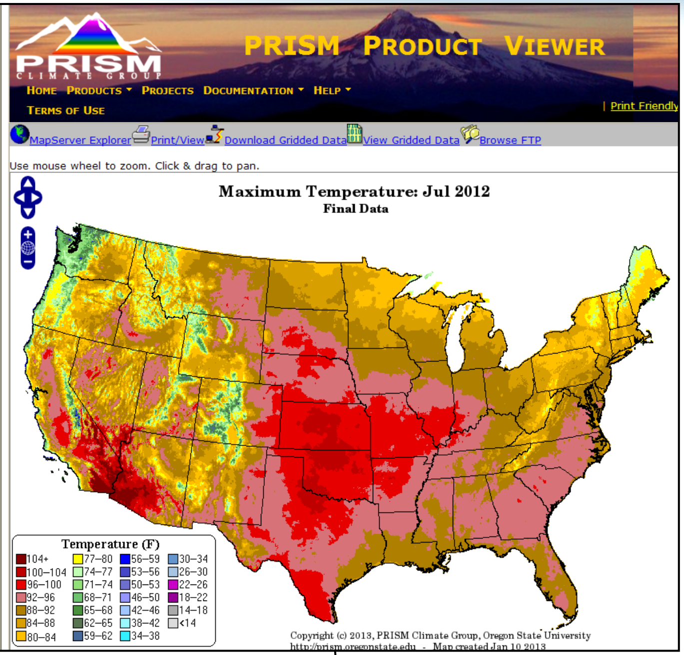
Environ Ecol Stat (2006) 13:449–464
DOI 10.1007/s10651-006-0022-8

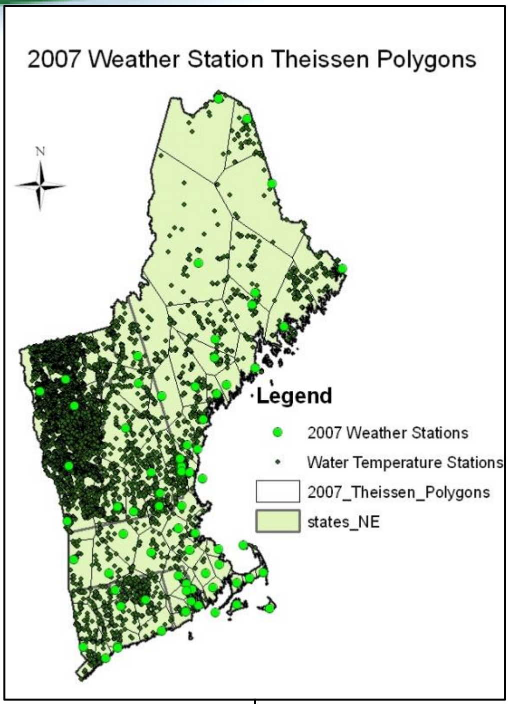
ORIGINAL ARTICLE

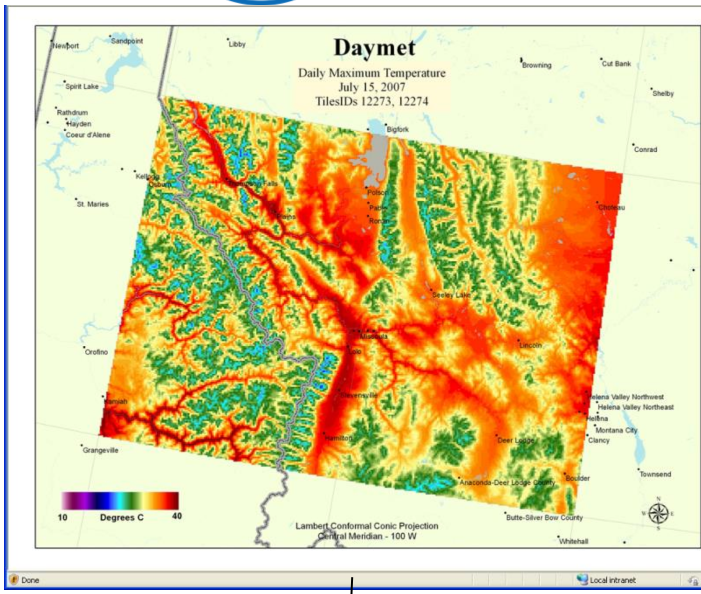
Spatial statistical models that use flow and stream distance

Jay M. Ver Hoef · Erin Peterson · David Theobald

Air Temperature Metrics





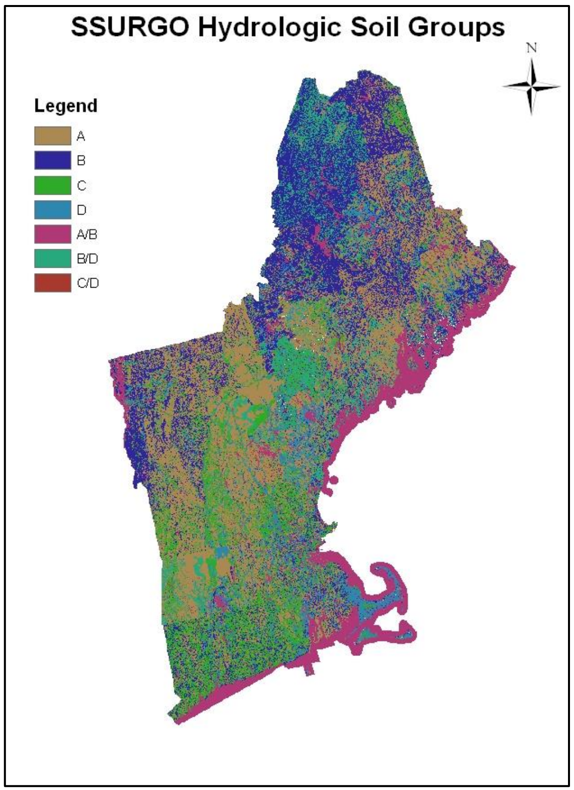


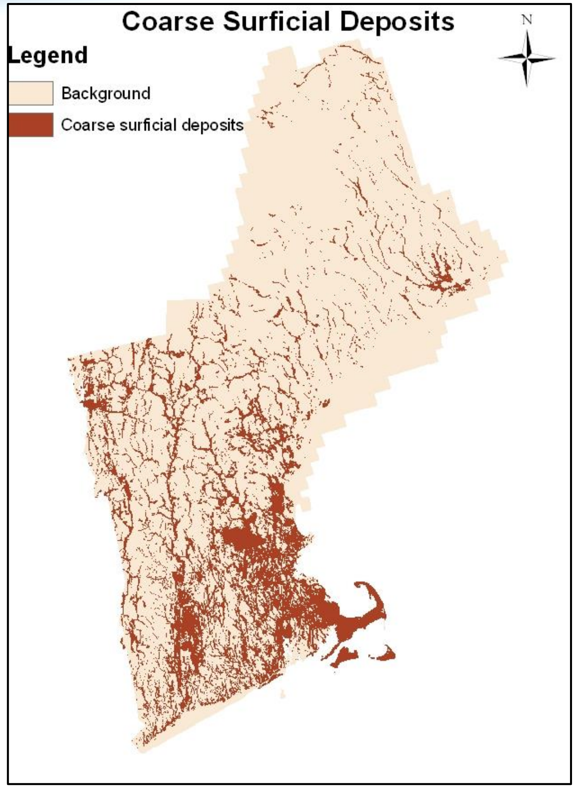
-Extract min/max monthly temperatures
- Weather stations
- Water temperature monitoring stations
- Calculate transfer function to translate minimum and maximum temperatures from nearest weather station record to water temperature monitoring station

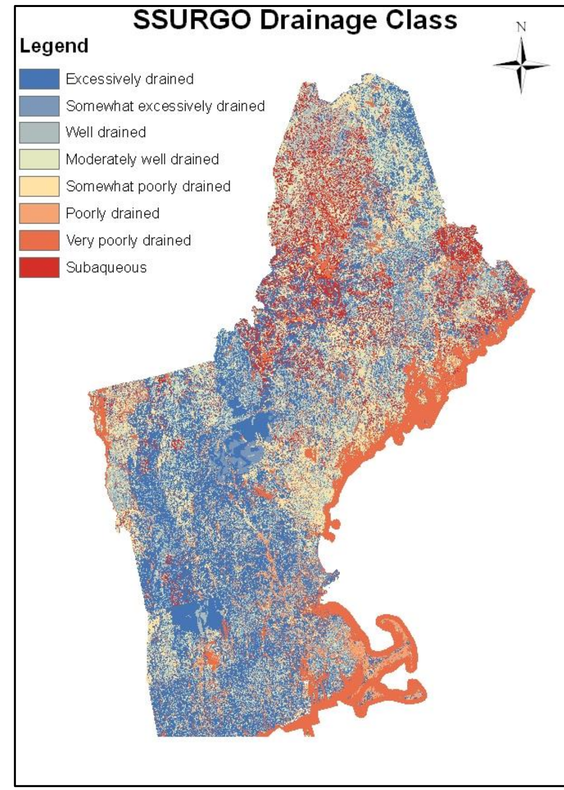
- Create Theissen polygons to define nearest weather station for each water temperature monitoring station
- Calculate air temperature metrics for high quality weather stations
- Apply transfer function

-Extract daily minimum and maximum temperature for each weather station over growing season
- Calculate daily range
-Use transfer functions to translate minimum and maximum temperatures from nearest weather station pixel to water temperature monitoring pixel
- Calculate timing of growing season maximum
- Fill in gaps for weather station metrics

Infiltration (groundwater supply) indicators





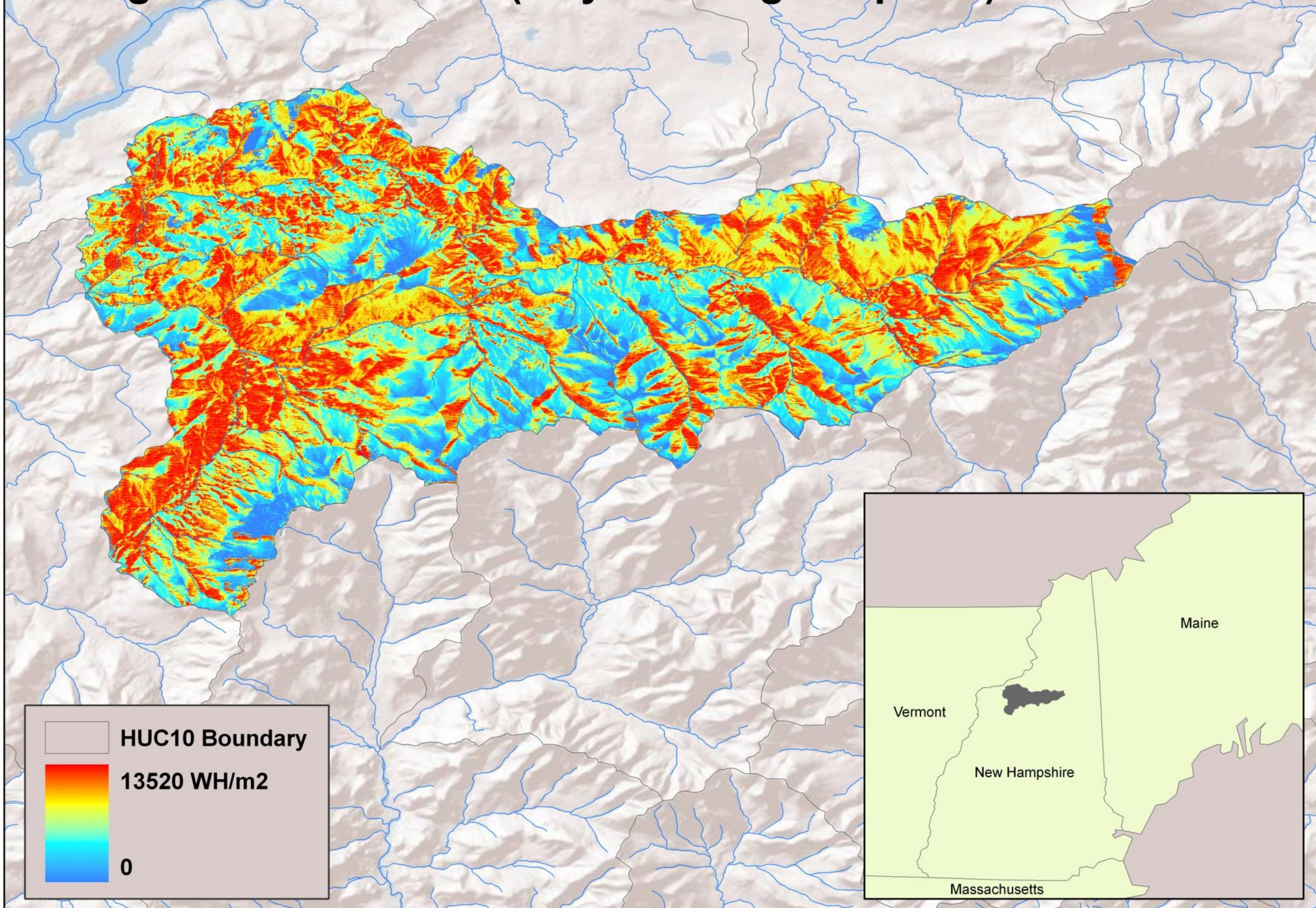


Shaded Solar Input Prediction Model

- Monthly solar radiation
  - Topographic shading predicted by ArcGIS solar radiation tool
- Local shading from vegetation
  - Nonlinear statistical model developed with densiometer readings from habitat surveys
  - Function of NLCD % canopy cover (75 m radius) and bankfull width
    - % canopy cover ==➔ bankfull width

      Small streams =====➔ Large rivers
  - Stratified by predominant land-use/land-cover class (deciduous forest, conifer forest, open)

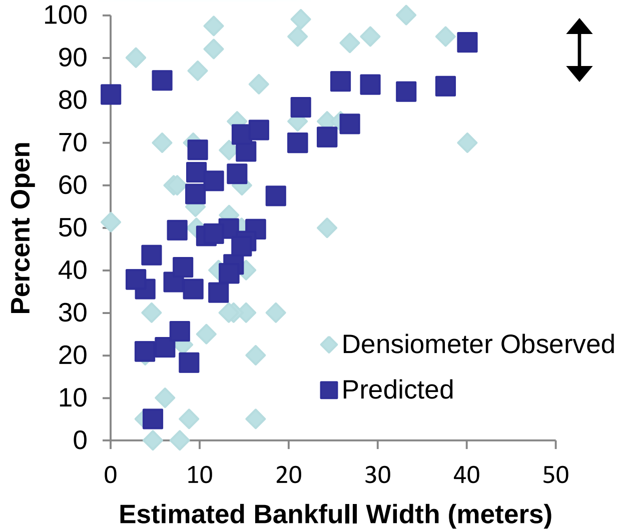
Average Solar Radiation (May 1 through Sept. 30)



Shade Model – Conifer Cover

Low canopy cover

High canopy cover



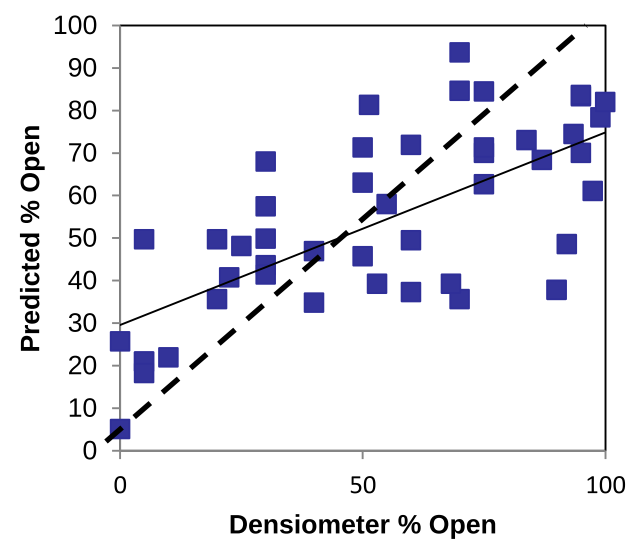
<u>Fitted model</u>

Highly significant : $p < 0.001$

Reproduces expected pattern – wide variation at low stream widths, converging to 100% open at large river widths

Bias: overestimate at low end, underestimate at high end

Potential for improvement: Recalculate NLCD % canopy and refit after snapping densiometer sampling points to high resolution NHD instead of NHDPlus and/or use hi resolution image analysis



<u>Nonlinear model fit</u>

Fitted parameters: proportionality constant, canopy diameter, maximum % open, half-saturation constant

If Bankfull Width < Canopy Diameter, assumed %open is proportional to NLCD_% canopy

If Bankfull Width > Canopy Diameter, assumed % open follows a Michaelis-Menten curve, approaching 100% at large river widths

Setting up spatial network for statistical analysis

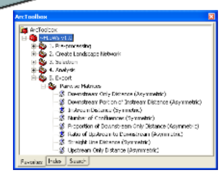
NHDPlus Stream Network

FLoWs toolbox

-Check network topology
- Simplify braided channels
- Simplify complex confluences

Landscape Network
- edges (stream reaches)
- nodes (junctions)
- reach contributing areas (RCAs, optional)
- points (observations, predictions)
- relationship tables (e.g., flow direction)

STARS toolbox



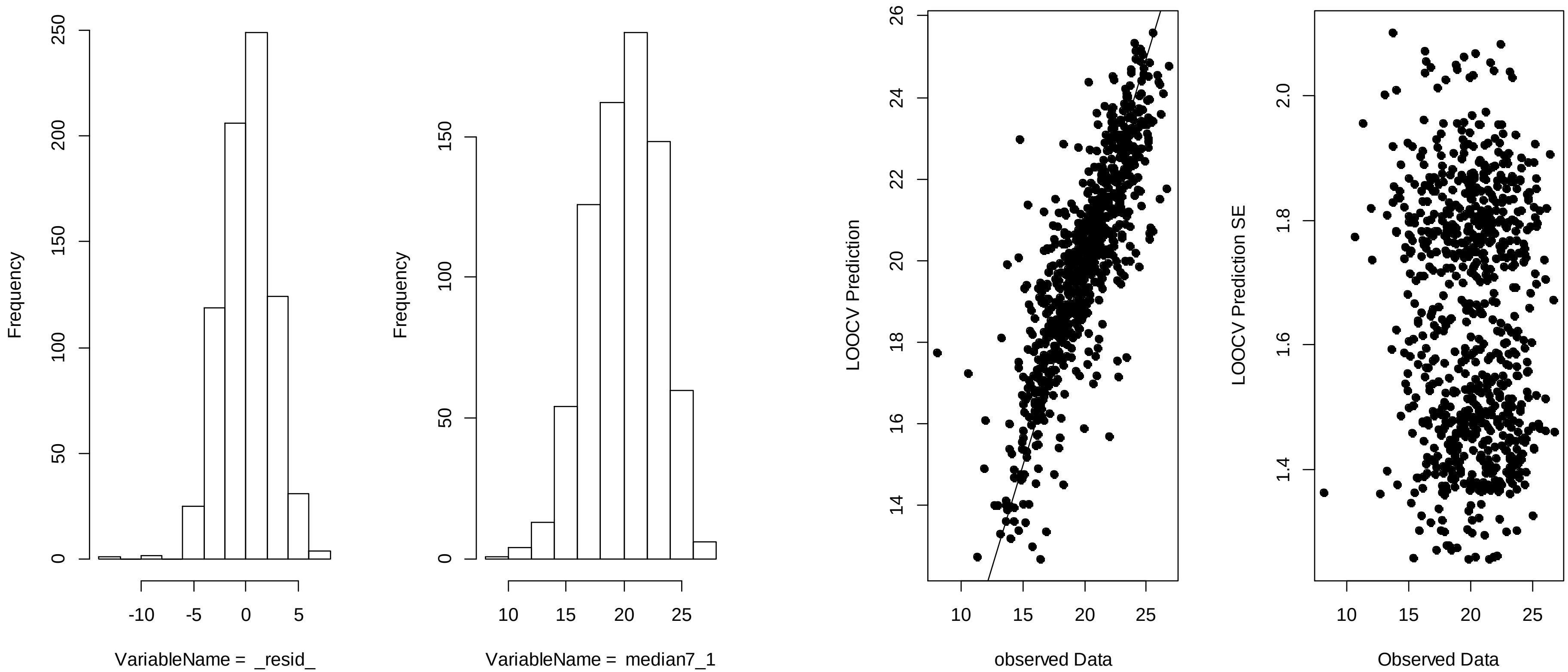
.ssn R object

SSN R package
Or FLoWs

Matrices of interpoint distances
- Linear (Euclidean distance)
- Upstream/downstream along flow path
- Upstream/downstream (not flow-connected)
- Weights (e.g. watershed area as proxy for flow volume)

Predictive model with spatial autocorrelation

Preliminary model performance: Median July temperature



Outlier analysis

- ~~Tidal reaches (tidal influence)~~
- ~~Upstream NPDES discharges (one~~ major or multiple minor) or discharge noted in station description
- ~~Questionable station locations~~
  - Snapped to wrong stream
  - Too close to confluence to determine relative location
  - On finer-scale reach than NHDPlus
- Upstream lakes or ~~reservoirs~~ not found in dams database
- Adjacent to gravel mining operations in/near floodplain (pumping?)

Predicting lake epilimnion temperature

Limnol. Oceanogr., 49(1), 2004, 271–282

Empirical modeling of summer lake surface temperatures in southwest Greenland

Helen Kettle[1] *and Roy Thompson*
Department of Geology and Geophysics, The University of Edinburgh, Grant Institute, West Mains Road, Edinburgh EH9 3JW, UK

N. John Anderson[2]
Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, DK-1350 Copenhagen K, Denmark

David M. Livingstone
Water Resources Department, Swiss Federal Institute of Environmental Science and Technology (EAWAG), Überla

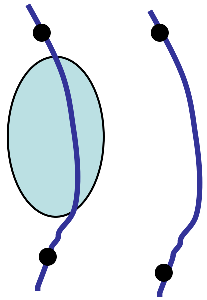
"The smoothed air temperatures and clear-sky solar radiation are linearly combined to estimate the daily mean lake surface temperatures. The smoothing parameters and the three linear coefficients of the model, obtained individually for each of 15 lakes, are found to relate to lake area and maximum depth, leading to the development of a general model."

Lake epilimnion temperature = f(maximum lake depth, solar radiation x maximum lake depth, ln(max lake depth x smoothed air temperature)

Cross-validation of the general model at each lake in turn indicated a 90% forecast skill and average standard error of prediction of 1.0°C. Examination of the daily prediction errors over time suggests a relation to strong wind events.

Alternative distance metric: Retention and travel time estimates

- 1/NHDPlus reach-scale velocity estimates
- Lake volume/∑(outlet discharge)
  - NHDPlus reach-scale discharge
  - Lake volume
    - Measured volume (where available)
    - Measured depth (preferable) or estimated depth from adjacent slope per Hollister et al. (2011) modified to assume 1 meter min Z
    - Assume conical shape for calculations



Alternative model tests: July median stream temperature

Network distance metric	Upstream Lake Effect Model Variables	AIC	RMS Prediction Error (deg C)	r^2	n parameters
None (nonspatial)	None	3736		0.119	2
	None	3057.7	1.641	0.333	9
	Separate*	3114.6	1.674	0.279	13
Length (km)	**Hybrid****	**3045.8**	**1.627**	**0.340**	**13**
	None	3125.4	1.704	0.289	13
Retention time + travel time along network (days)	Hybrid **	3099.7	1.683	0.284	13

* Separate = separate lake effect and watershed effect variables; reaches with upstream lakes have watershed variables set to zero; other reaches have lake variables set to zero

** Hybrid = both lake effect and watershed effects included for reaches with upstream lakes; other reaches have lake variables set to zero

Final Spatial Statistical Network Models

	Independent variables													
		Landscape metrics							Channel dimensions			Covariance components*		
Dependent variable (stream temp metric)	**Air temp metric**	**Water-shed area**	**Slope**	**Shaded Solar radiation**	**Infiltra-tion**	**Imper-vious-ness**	**Lake + Wetland Storage**	**Mean dis-charge**	**Width to Depth**	**WtoD x Temp**	**Upstream Lake**	**Tail-up**	**Tail-down**	**Eucli-dean**
July median	July median		Main channel	Mean July			X				Ln(Zmax)	LS	LS	G
August median	August median		Main channel	Mean Aug	Coarse surficial sediment		X				Ln(Zmax)	LS		C
July daily range	July daily range	X	Main channel		Extremely well-drained soils	X	X	Discharge	X	WtoD x July Daily Range		S	LS	S
Aug daily range	Aug daily range	X	Main channel	Mean Aug			X	Discharge				LS		S
Growing season max	Max daily median	X	Local channel	Mean Aug		X	X					LS	S	G

* LS = linear sill, G = Gaussian, C = Cauchy, S = Spherical

Final Spatial Statistical Network Models

	Independent variables												
		Landscape metrics									Covariance components*		
Dependent variable (stream temp metric)	**Air temp metric**	**Water-shed area**	**Slope**	**Shaded Solar radia-tion**	**Infiltration**	**Imper-viousness**	**Drain-age density**	**Lake + Wetland Storage**	**Mean discharge**	**Mean annual air temp**	**Tail-up**	**Tail-down**	**Eucli-dean**
Julian day of GS max	Julian Day of GS max	X			Extr. well-drained soils		X		Discharge				G
July max rate of change (+)	July MROC+		Main channel				X			X			G
Aug max rate of change (+)	Aug MROC+		Main channel				X			X			G
July max rate of change (-)	July MROC-		Main channel				X			X			G
Aug max rate of change (-)						X							

* LS = linear sill, G = Gaussian, C = Cauchy, S = Spherical

Next Steps

- Calculate predicted temperature metrics throughout New England stream network
- Publish and post data (EDM application)
- Version 2
  - More limited spatial coverage
  - Fine resolution (hydrography, canopy, IA)
  - Incorporate anthropogenic water withdrawals and discharges
  - Incorporate IC effect on infiltration

www.epa.gov/edm