A Framework for Inland Probabilistic Flood Hazard Assessments: Analysis of Extreme Snow Water Equivalent in Central New Hampshire

ERDC
Engineer Research and Development Center

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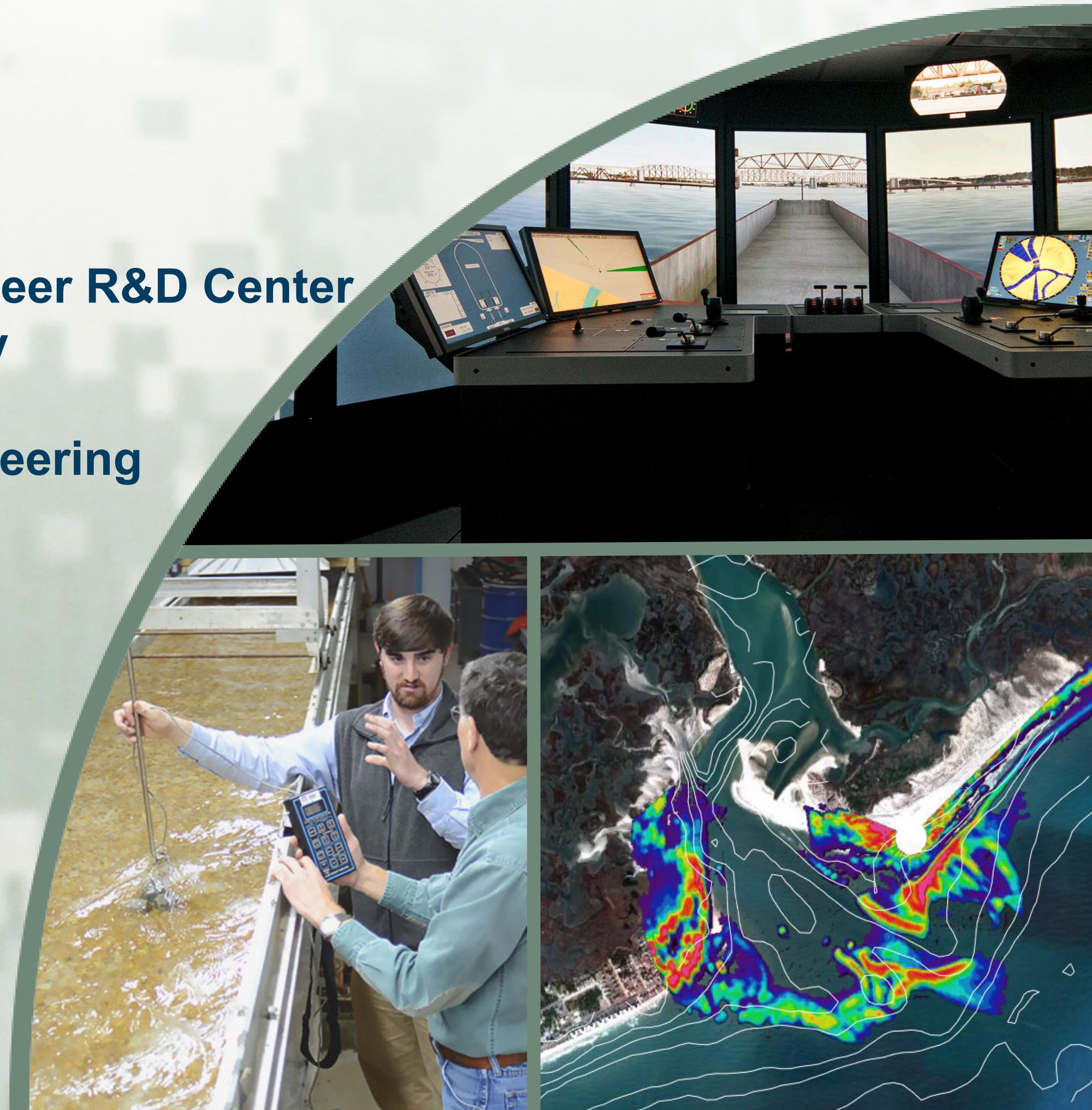
December 05, 2017



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Objective

Construct site-specific flood hazard curves for the full range of return periods of interest for nuclear power plants.

Must be able to incorporate probabilistic models, allow for characterization and quantification of aleatory and epistemic sources of uncertainty, and facilitate propagation of uncertainties and sensitivity analysis.

Build on recent advances in modeling extremes

Practical

Efficient

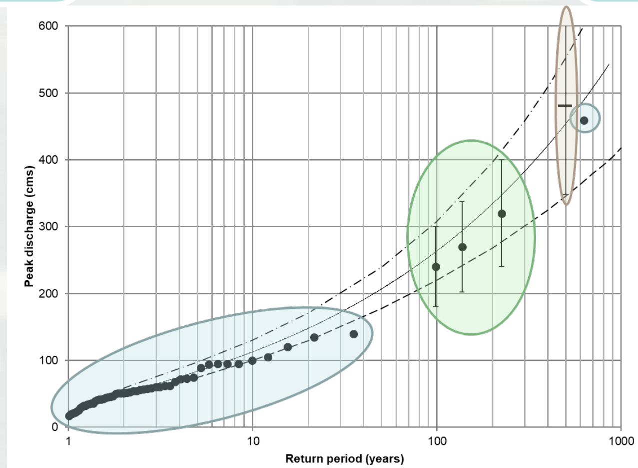
Flexible

Revisable

Adaptable

Usable

Credible extrapolation



Focus areas:

Literature review

Rainfall and Local Intense Precipitation

Cool Season Processes

Site-scale Flooding from Local Intense Precipitation

Riverine Flooding - Rainfall or Rainfall and Snowmelt

Riverine Flooding - Hydrologic Dam/Levee Failure

Knowledge transfer

Should be capable of modeling spatial and temporal correlation between and within events.

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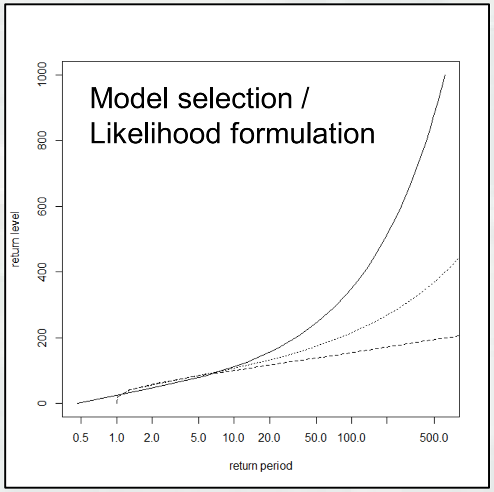
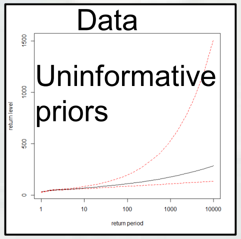
PFHA Framework

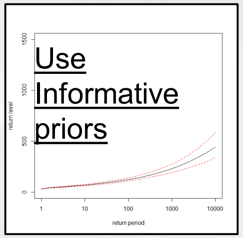
Step 1 (Repeat K times)

Data Analysis



Causal Information Expansion





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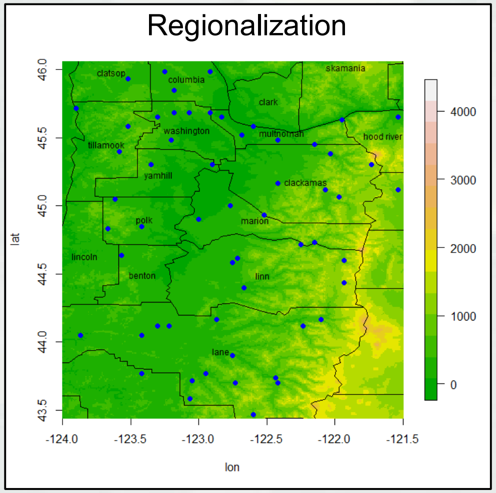
Spatial Information Expansion Data



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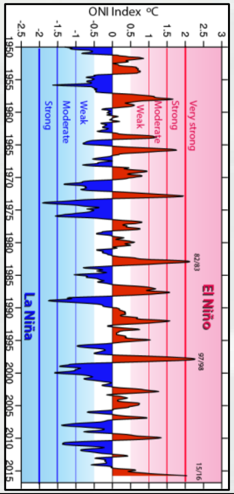
Temporal Information Expansion Data[1]



Climate Index

Historical / Paleoflood Data

Available tools: R packages SpatialExtremes

Spatio-temporal BHM / Spatial Extremes

Step 2 Apply a multi-model averaging technique

For example

Bayesian Model Averaging

$$p(\triangle \mid M_1, \ldots, M_k) = \sum_{k=1}^{K} w_k g_k(\triangle \mid M_k)$$

or

Information Criterion Averaging

$$\beta_k = \frac{\exp\left(-\frac{1}{2} I_k\right)}{\sum_{k=1}^{K} \exp\left(-\frac{1}{2} I_k\right)}$$

Available tools: R packages MSClaio2008, SpatialExtremes

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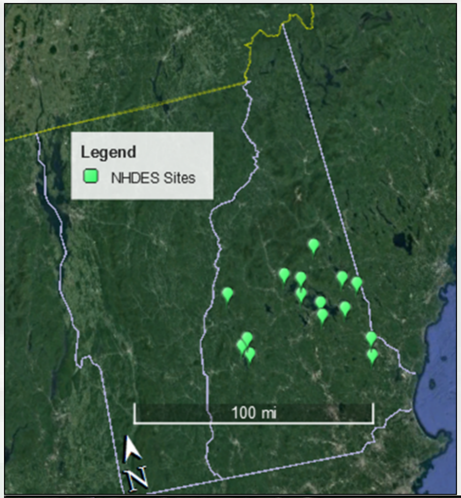
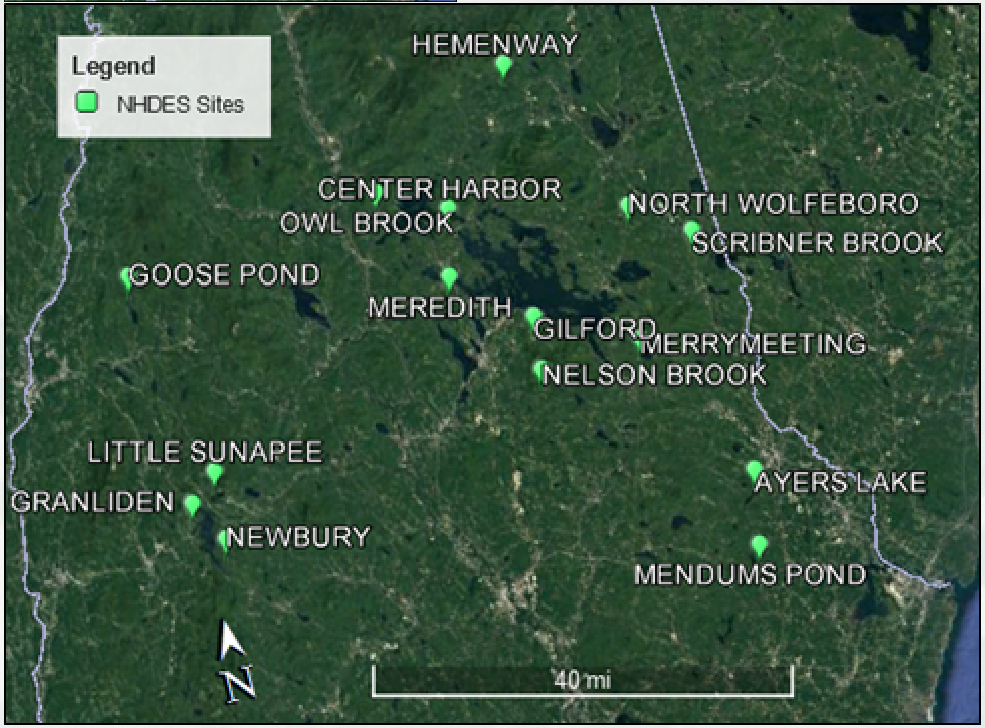
[1]Trenberth, Kevin & National Center for Atmospheric Research Staff (Eds). Last modified 02 Feb 2016. **"The Climate Data Guide: Nino SST Indices (Nino 1+2, 3, 3.4, 4; ONI and TNI)."** Retrieved from https://climatedataguide.ucar.edu/climate-data/nino-sst-indices-nino-12-3-34-4-oni-and-tni.

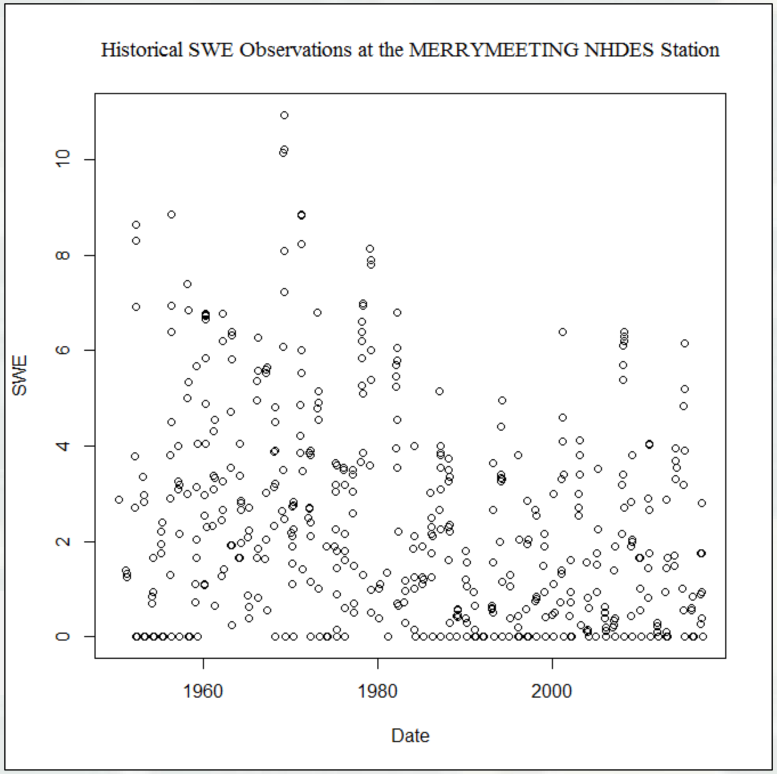
Demonstration Site & Data



New Hampshire Department of Environmental Services (NHDES) – The NHDES conducts bi-weekly snow surveys throughout the winter season in several basins in central New Hampshire where the agency manages reservoir water supply and releases.



Snow Survey, 3 Jan 2017, USACE New England District



Historical data is available for the period of record on their website: http://www4.des.state.nh.us/rti_home/snow_sampling_stations.asp

Causal Information Expansion Data

Livneh daily CONUS near-surface gridded meteorological and derived hydrometeorological data.

The VIC model is a large-scale, semi-distributed hydrologic model

Brief Description:

- This CONUS daily dataset from 1915 to 2011 is 1/16 resolution. The dataset variables have been generated using the Variable Infiltration Capacity **VIC** hydrologic model v.4.1.2.c which was driven with the companion meteorological data.

http://vic.readthedocs.io/en/master/

Temporal Coverage:

- Daily means from 1915/01 to 2011/12
- Monthly means from 1915/01 to 2011/12
- Daily long term means using 1981/01 to 2010/12
- Monthly long term means using 1981/01 to 2010/12

Spatial Coverage:

- .0625 degree latitude x .0625 degree longitude CONUS grid
- 21.21875-52.90625, 235.4688E-293.0312E

Levels:

- Surface

Update Schedule:

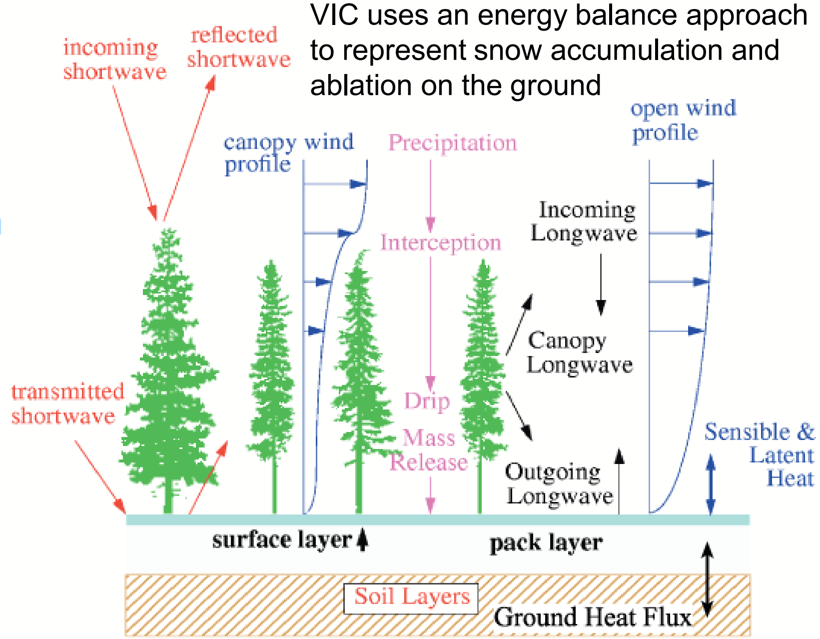
- None

Variables:

- Meteorological Variables(station variables input)
- Flux Variables(model generated)

VIC Snow Algorithm

VIC uses an energy balance approach to represent snow accumulation and ablation on the ground



The land surface is modeled as a grid of large (>>1km), flat, uniform cells

Sub-grid heterogeneity (e.g. elevation, land cover) is handled via statistical distributions

Inputs are time series of sub-daily meteorological drivers (e.g. precipitation, air temperature, wind speed, radiation, etc.)

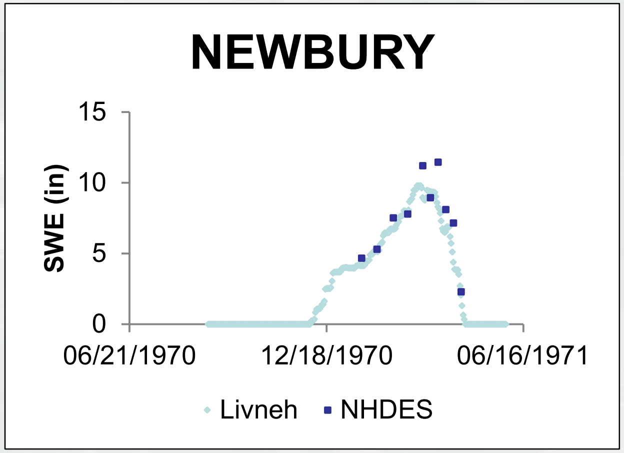
Land-atmosphere fluxes, and the water and energy balances at the land surface, are simulated at a daily or sub-daily time step

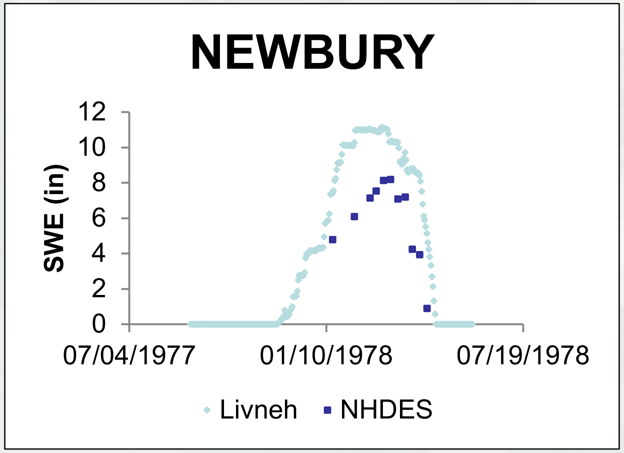
Water can only enter a grid cell via the atmosphere

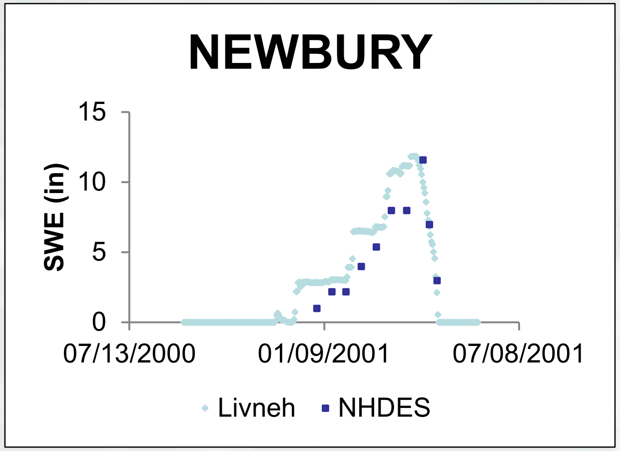
Livneh data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/

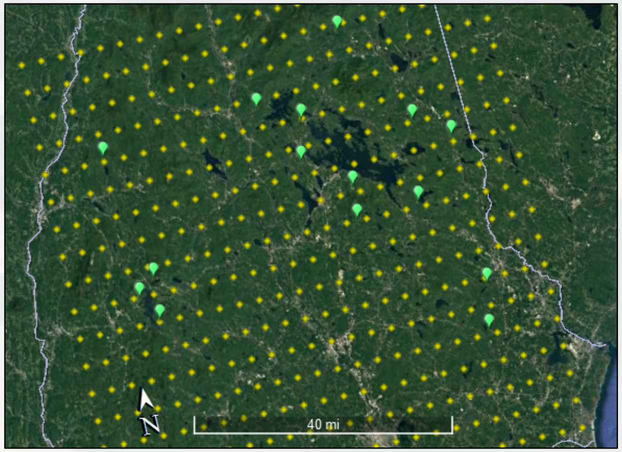
Livneh B., E.A. Rosenberg, C. Lin, B. Nijssen, V. Mishra, K.M. Andreadis, E.P. Maurer, and D.P. Lettenmaier, 2013: A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States: Update and Extensions, Journal of Climate, 26, 9384–9392.

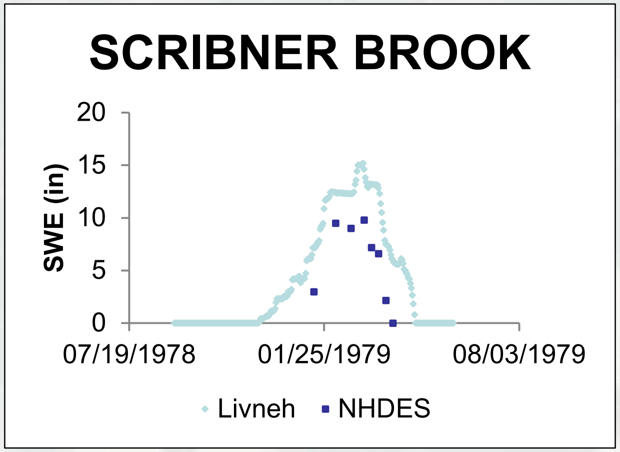
Causal Information Expansion Data

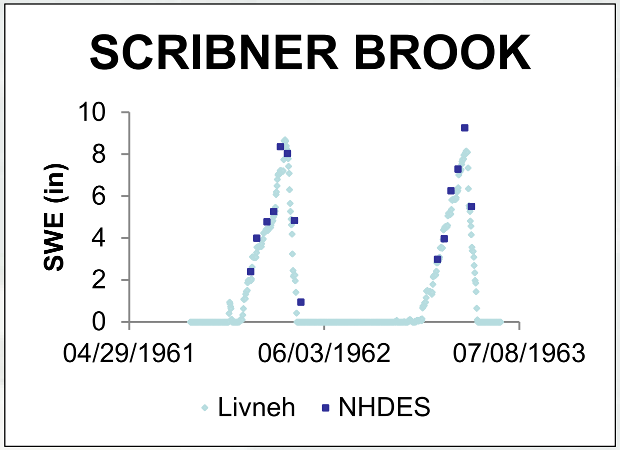






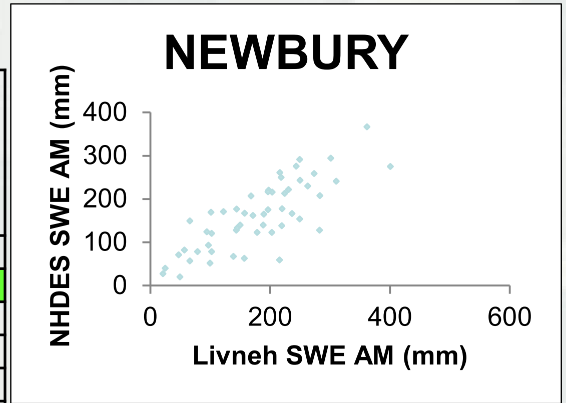


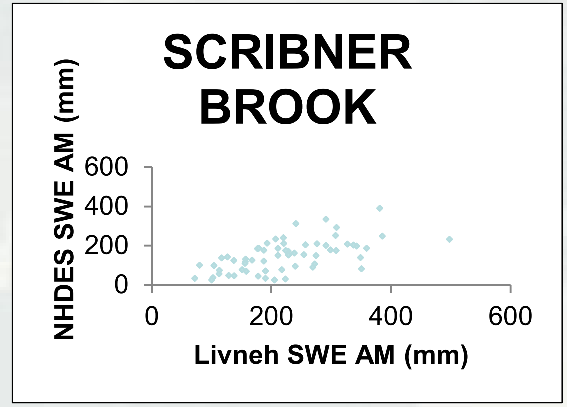


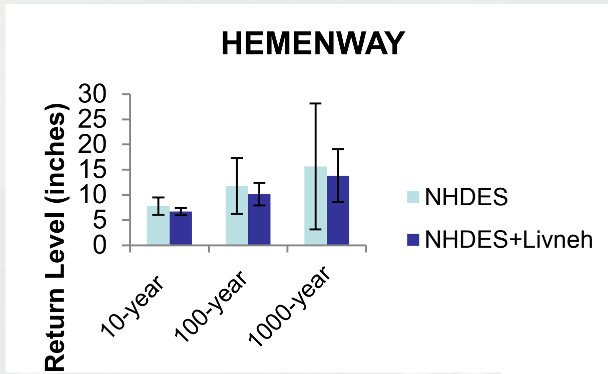


Causal Information Expansion Data

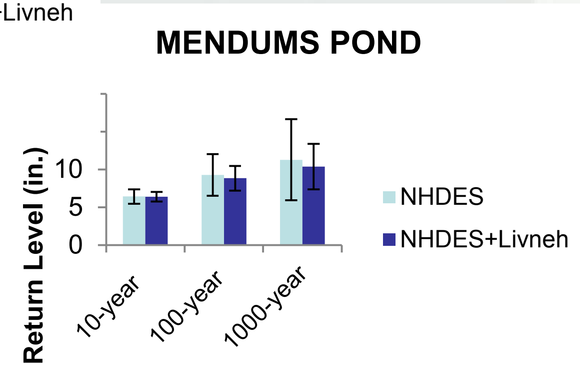
NHDES Site	Observed NHDES data record	Observed NHDES data record length	Remaining record using adjusted Livneh SWE data	Adjusted Livneh SWE data record length
GILFORD	1950 - 2017	68	1915 - 1949	35
GOOSE POND	1972 - 2017	46	1915 - 1971	57
MEREDITH	1950 - 2017	68	1915 - 1949	35
CENTER HARBOR	1950 - 2017	68	1915 - 1949	35
MERRYMEETING	1950 - 2017	68	1915 - 1949	35
OWL BROOK	1951 - 2017	67	1915 - 1950	36
HEMENWAY	1994 - 2017	24	1915 - 1993	79
LITTLE SUNAPEE	1960 - 2017	58	1915 - 1959	45
NORTH WOLFEBORO	1951 - 2017	67	1915 - 1950	36
GRANLIDEN	1960 - 2017	58	1915 - 1959	45
SCRIBNER BROOK	1950 - 1979 + 1981 - 2017	67	1915 - 1949 + 1980	36
NEWBURY	1960 - 2017	58	1915 - 1959	45
MENDUMS POND	1961 - 1979 + 1982 - 2017	55	1915 – 1960 + 1980 - 1981	48
AYERS LAKE	1961 - 1979 + 1982 - 2017	55	1915 – 1960 + 1980 - 1981	48
NELSON BROOK	1961 - 1979 + 1982 - 2017	55	1915 – 1960 + 1980 - 1981	48
	∑:	882	∑:	663

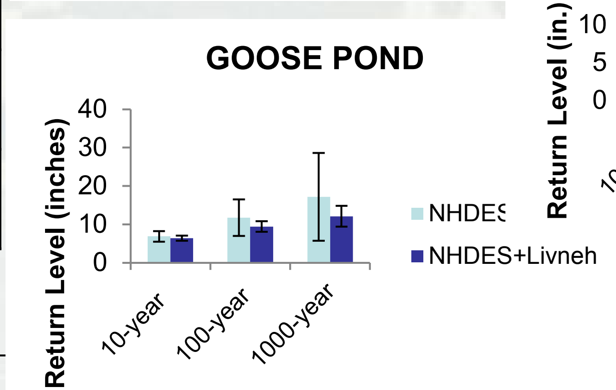






At-site analyses





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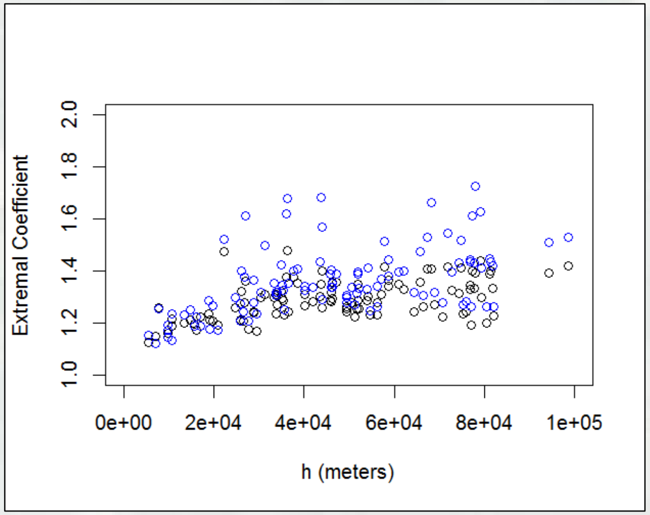
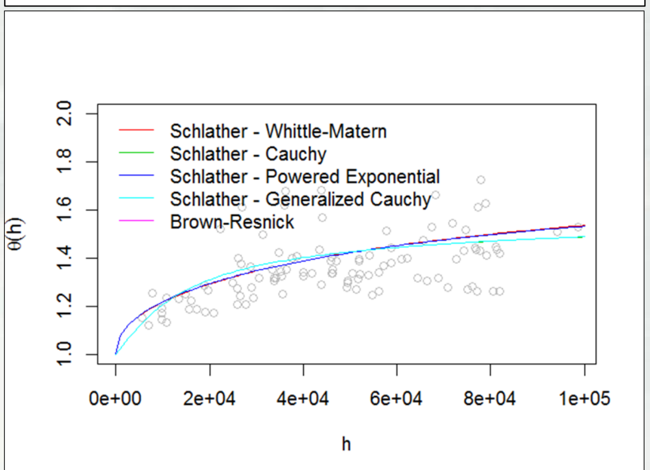
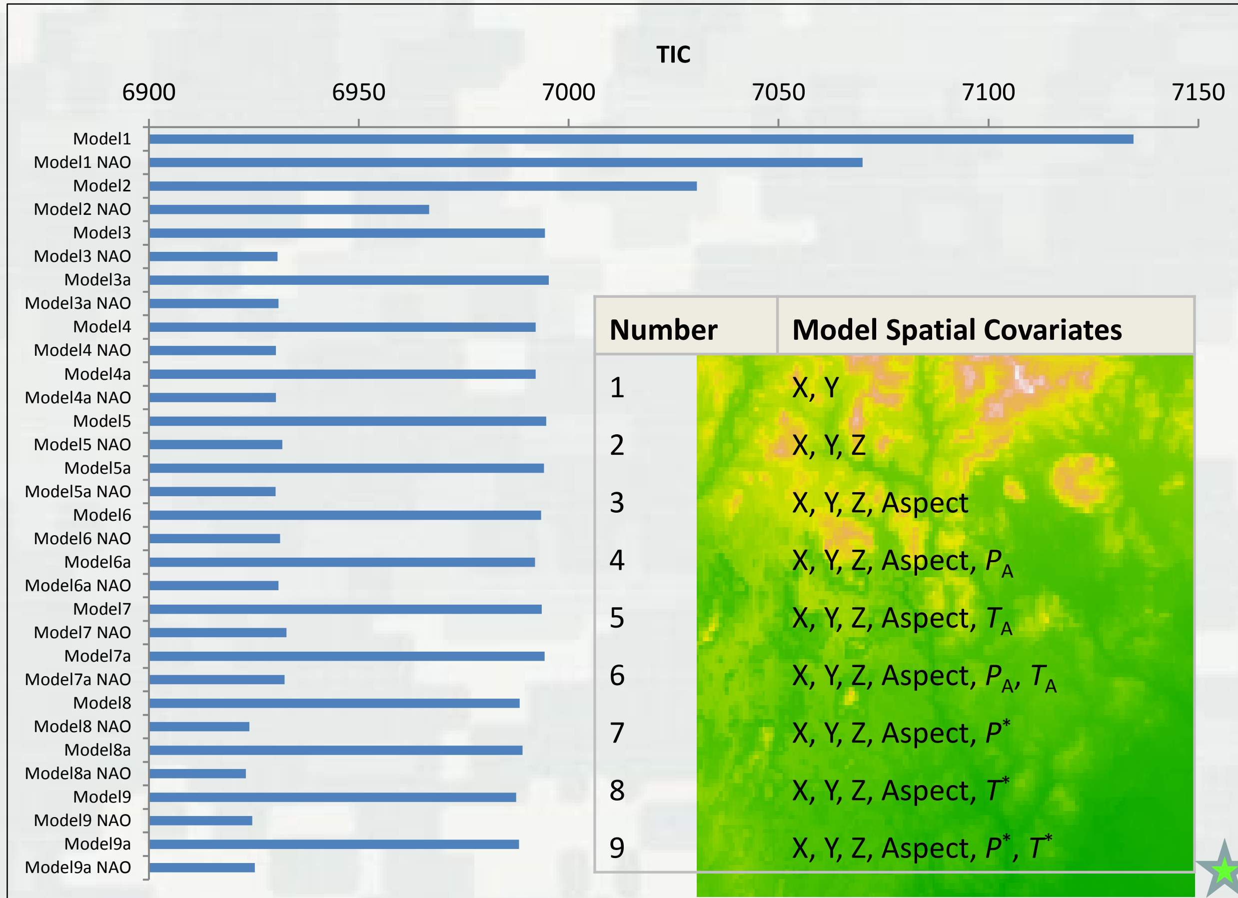
Model Dependence & Marginals







Number	Model Spatial Covariates
1	X, Y
2	X, Y, Z
3	X, Y, Z, Aspect
4	X, Y, Z, Aspect, P_A
5	X, Y, Z, Aspect, T_A
6	X, Y, Z, Aspect, P_A, T_A
7	X, Y, Z, Aspect, P^*
8	X, Y, Z, Aspect, T^*
9	X, Y, Z, Aspect, P^*, T^*

P_A= mean annual precipitation; T_A= mean annual temperature; P^*= mean winter precipitation; T^*= mean winter temperature; a = parsimonized version of model; NAO = use of North Atlantic Oscillation climate Index temporal covariate data

★ = gridded covariate dataset of mean annual temperature

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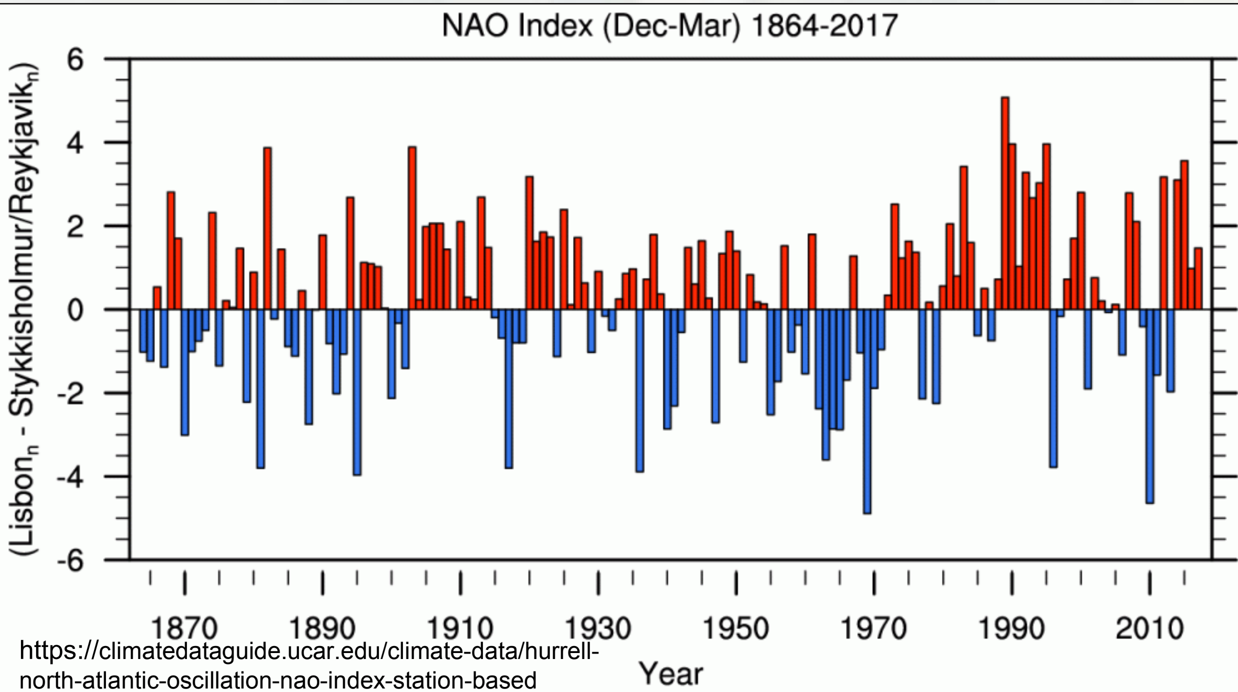
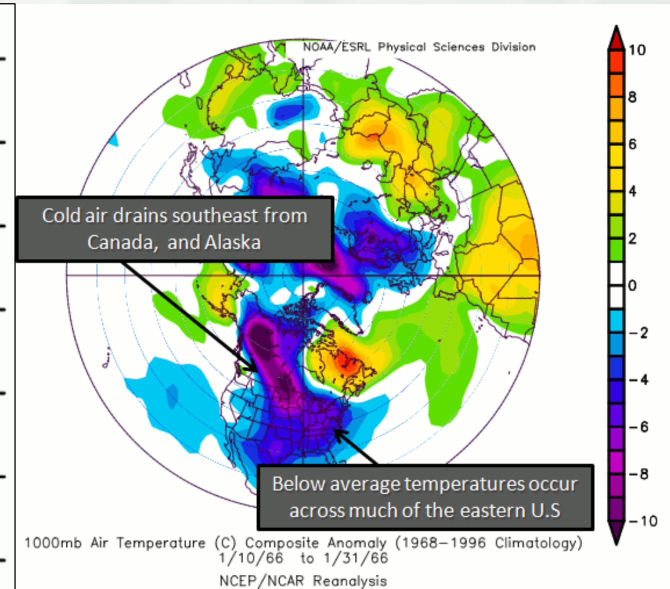
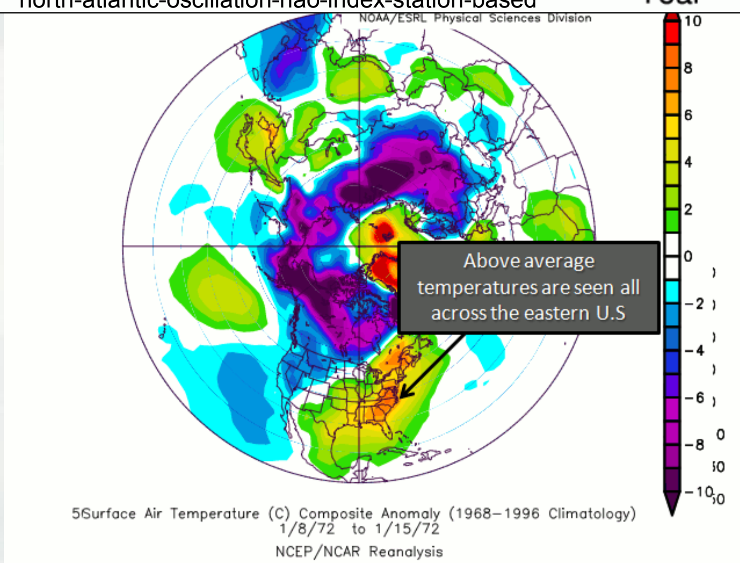
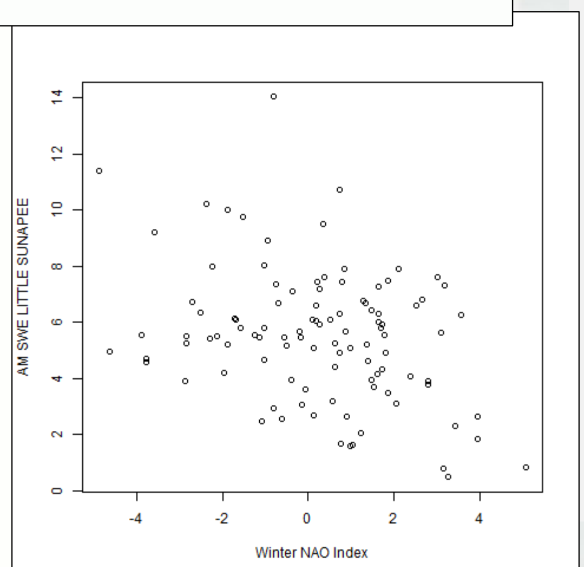
Temporal Information Expansion Data



https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based

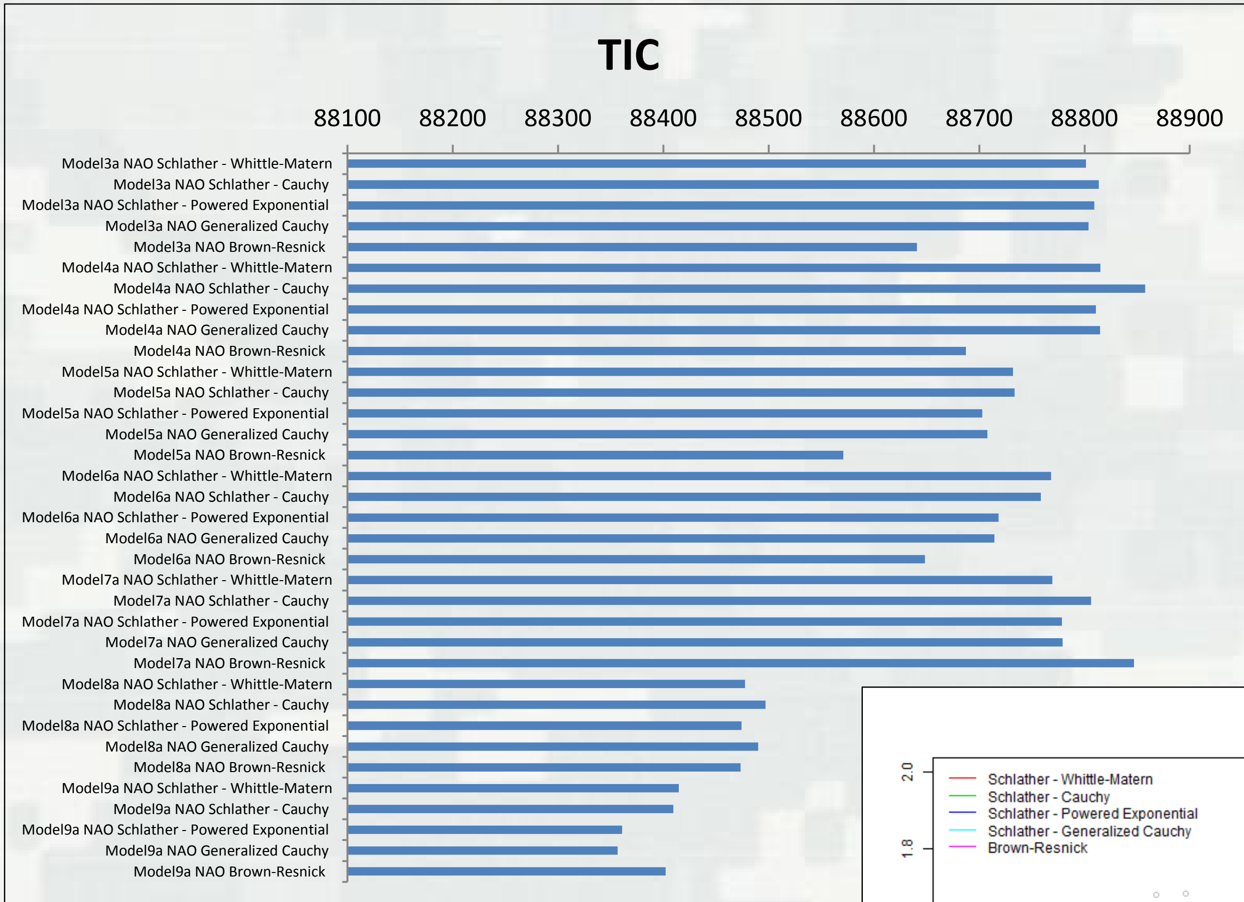


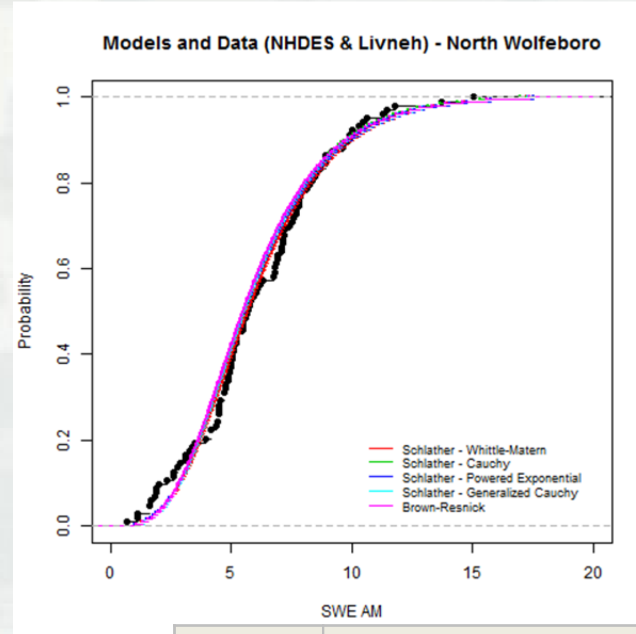




Roughly speaking, the NAO is an atmospheric process with two different phases, positive and negative, which relate to how the atmospheric mass is distributed. The gradient between two large scale pressure cells over the Atlantic Ocean, a low located near Iceland and a high over the Azores, affects the strength of westerlies and storm track direction.

Fit Models





Number	Model Spatial Covariates
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4	X, Y, Z, Aspect, P_A
5	X, Y, Z, Aspect, T_A
6	X, Y, Z, Aspect, P_A, T_A
7	X, Y, Z, Aspect, P^*
8	X, Y, Z, Aspect, T^*
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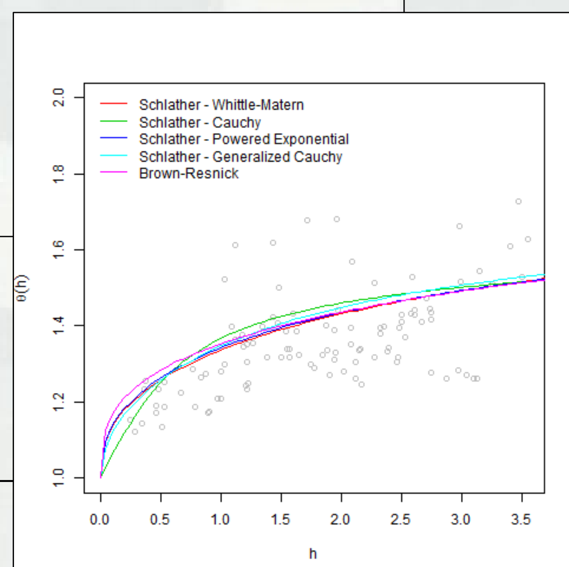
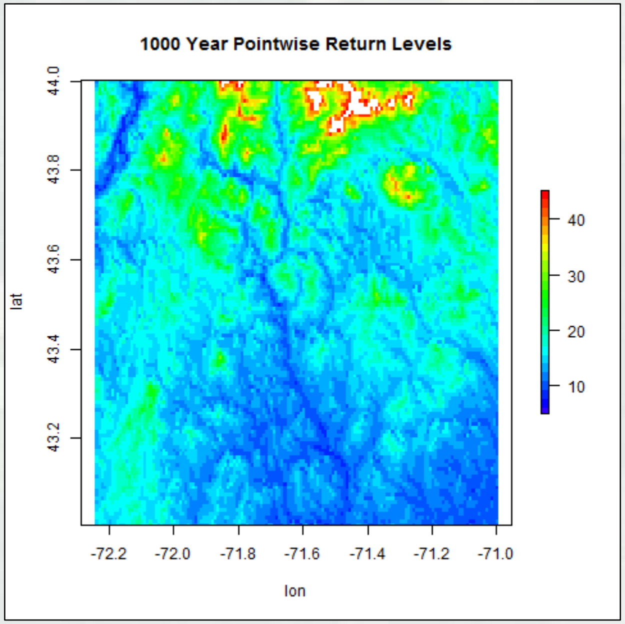
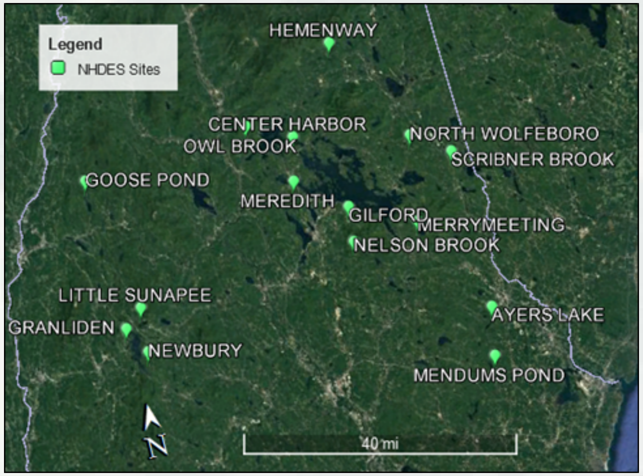
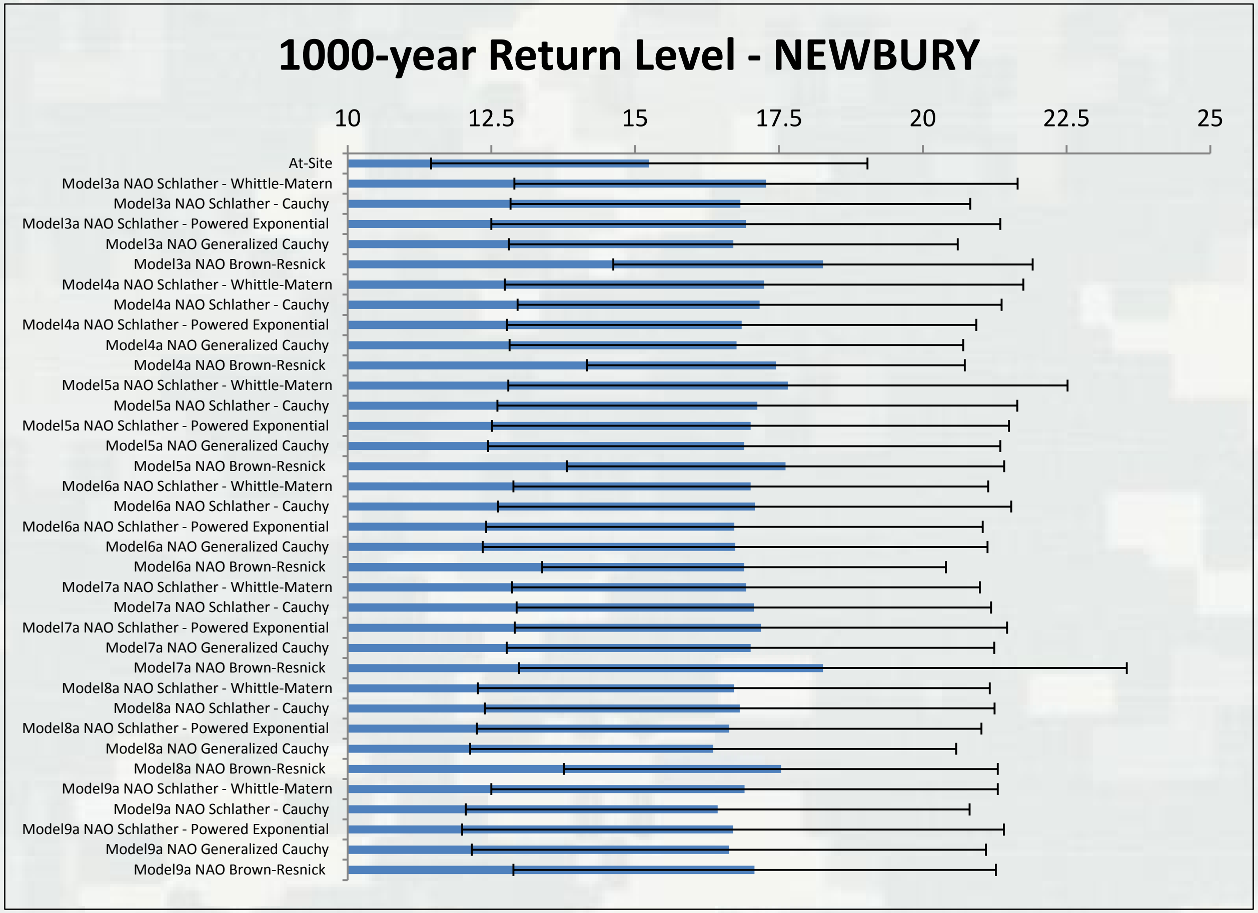


35 models considered; viz., 3a – 9a, all including use of NAO, and 5 max-stable model configurations

Pointwise Return Levels







Estimate including lower and upper 95% uncertainty bounds

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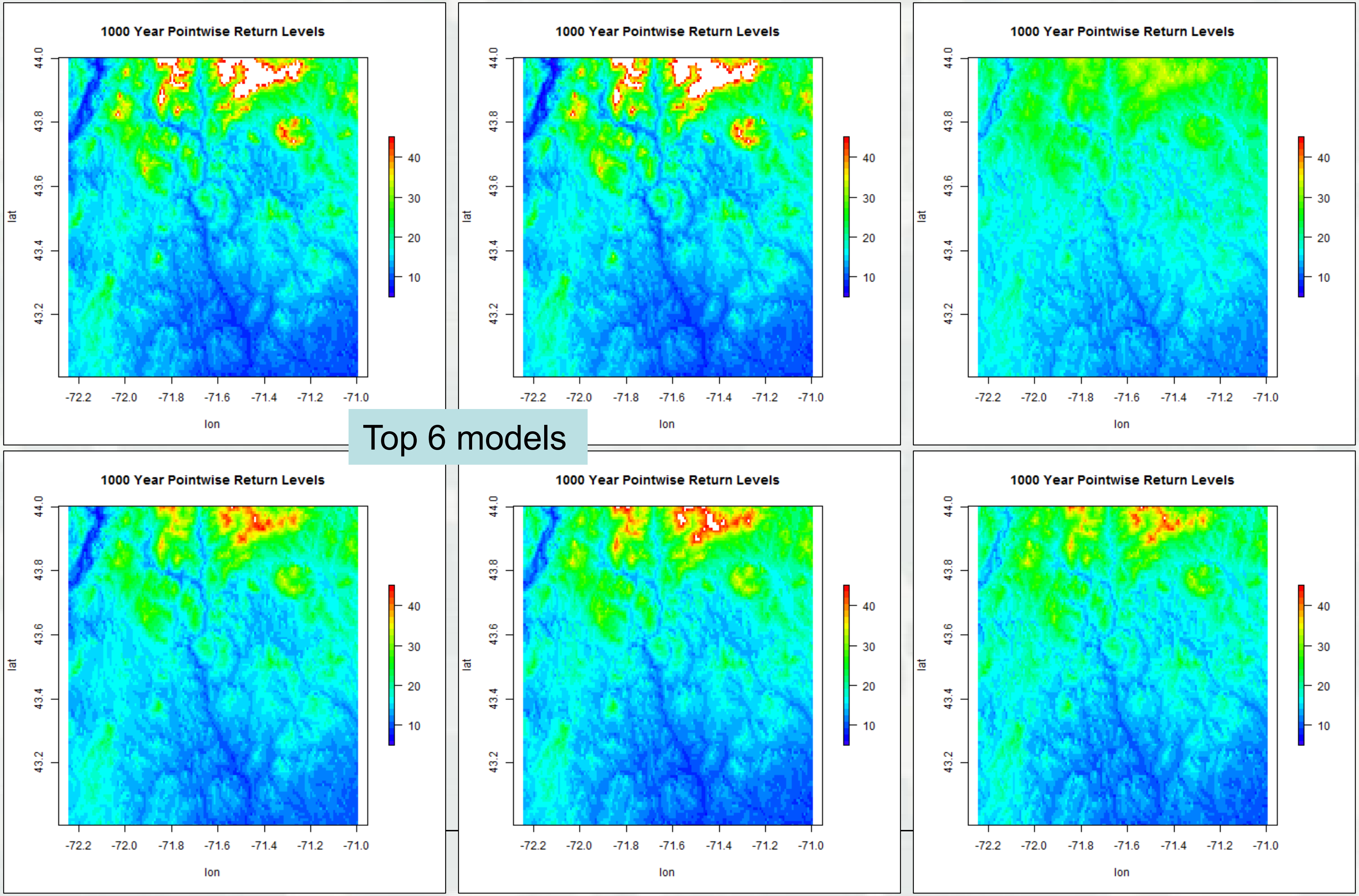
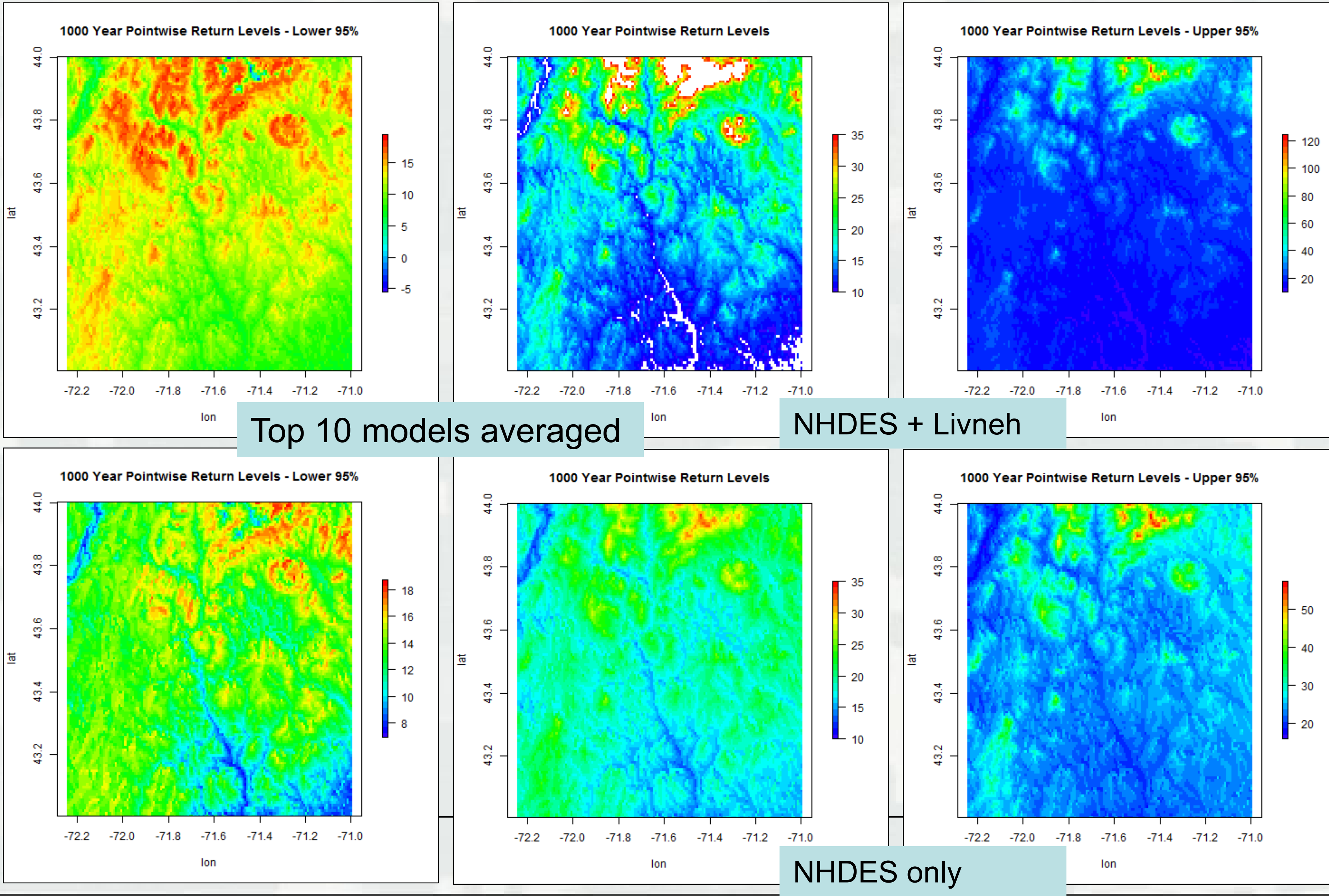
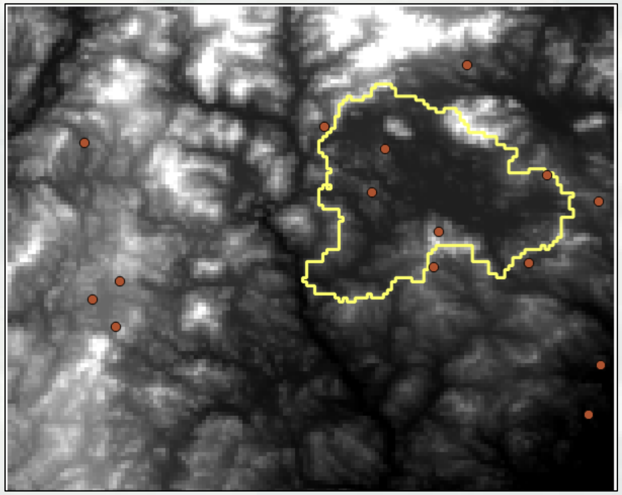
Model Choice



Generalize Model Selection

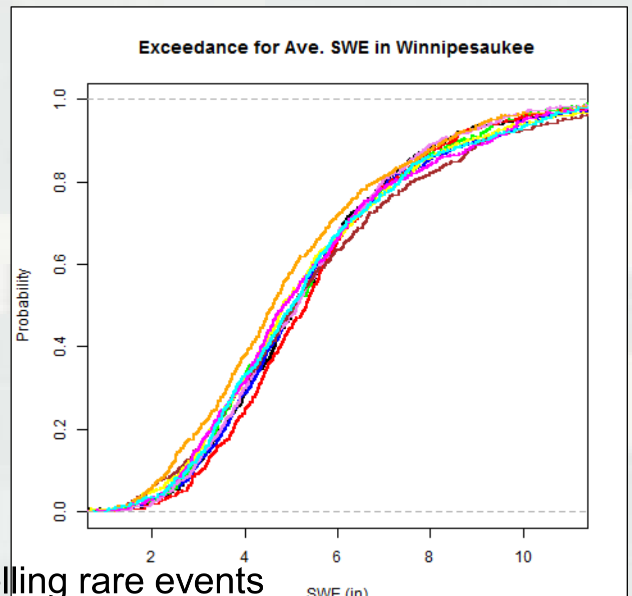


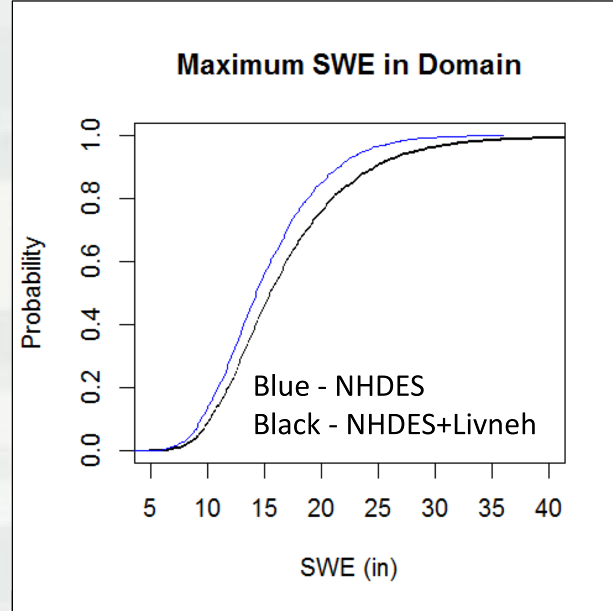
Areal-based Exceedances

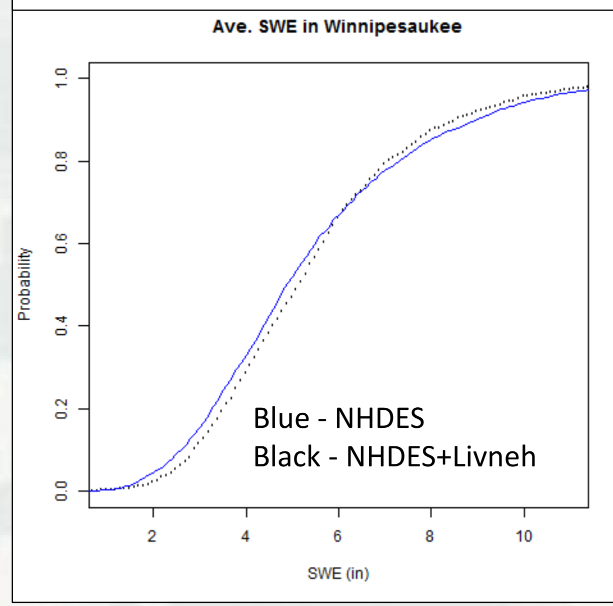


With max-stable process applications, additional more complex assessments of risk can also be evaluated. For example, the joint spatial modeling of observations (e.g., precipitation, snow water equivalent (SWE), snowmelt rate, or temperature), denoted for generality by $\Upsilon(x)$, over a basin $\mathcal{B}$, supports the capacity to compute, via simulation, an integral such as

$$\Pr\left\{\int_{\mathcal{B}} \Upsilon(x)dx > z_{crit}\right\}$$

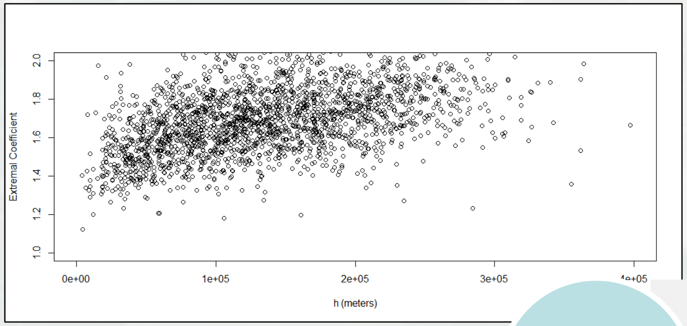






"By spatially modelling rare events one can simulate unusual episodes rather than merely produce pointwise maps of high quantiles, and thus allowing a more powerful risk analysis."

A. C. Davison, M. M. Gholamrezaee, 2012. Geostatistics of extremes. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science. DOI: 10.1098/rspa.2011.0412.



Summary

Recent advances in the modeling of extreme events

BHM

Assume independence among extremes

Bayesian inference

Max-stable models

Account for dependence

Credible extrapolation (conforms with EVT)

Areal based exceedance calculations

Spatial Information

Regionalization

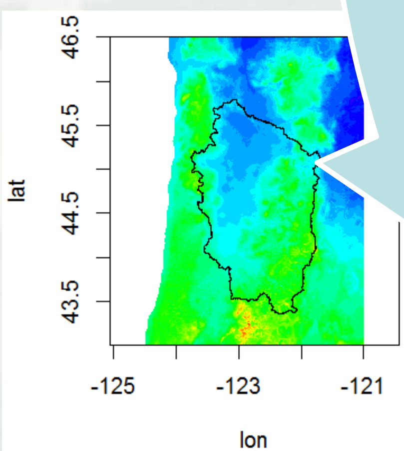
Casual Information

Livneh Data

Process Layer

Temporal Information

NAO Climate Index

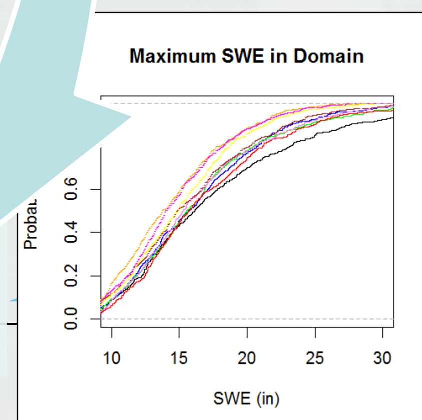


Multiple distributions

Generalize Model Choice

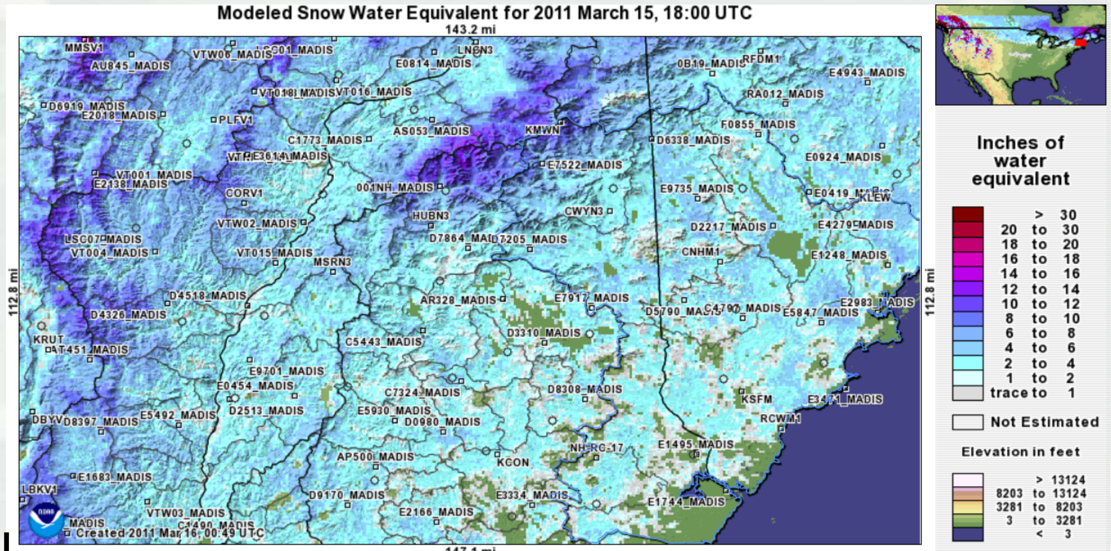
Process layer

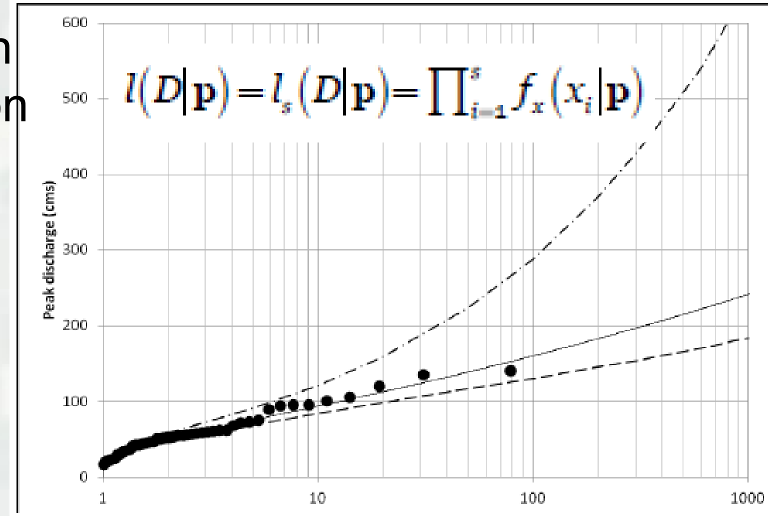
Multiple max-stable model permutations

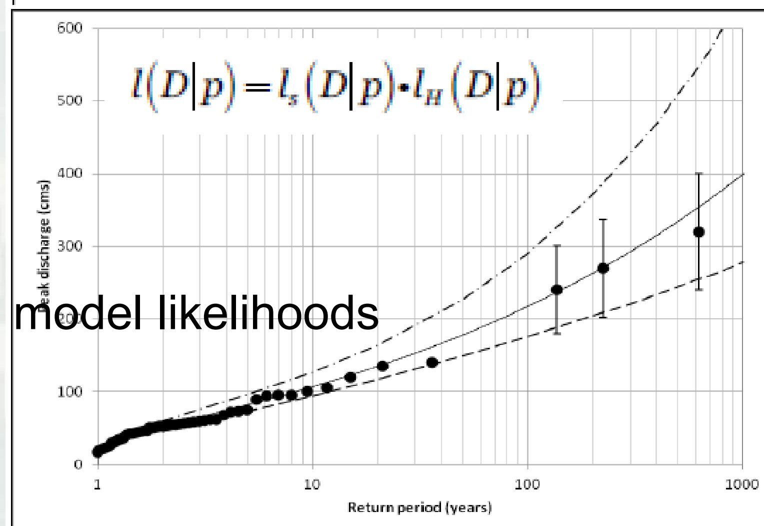


Future Related Work

Further develop and demonstrate cool season design scenarios via max-stable areal exceedance simulation and comparison with years with high SWE AM







Adapt Spatial/Spatio-temporal BHM and max-stable model likelihoods

$$p(\mathbf{y}|\{\mu_s, \kappa_s, \xi_s\}_{s\in\mathcal{S}}) = \prod_{s\in\mathcal{S}_o} \prod_{t=1}^{T_s} p(y_{ts}|\mu_s, \kappa_s, \xi_s)$$

Skahill, B. E., A. Viglione, and A. R. Byrd. 2016. *A Bayesian analysis of the flood frequency hydrology concept*. ERDC/CHL CHETN-X-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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https://www.nohrsc.noaa.gov

Probabilistic Flood Hazard Assessment Framework Development

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Watershed Systems Group
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