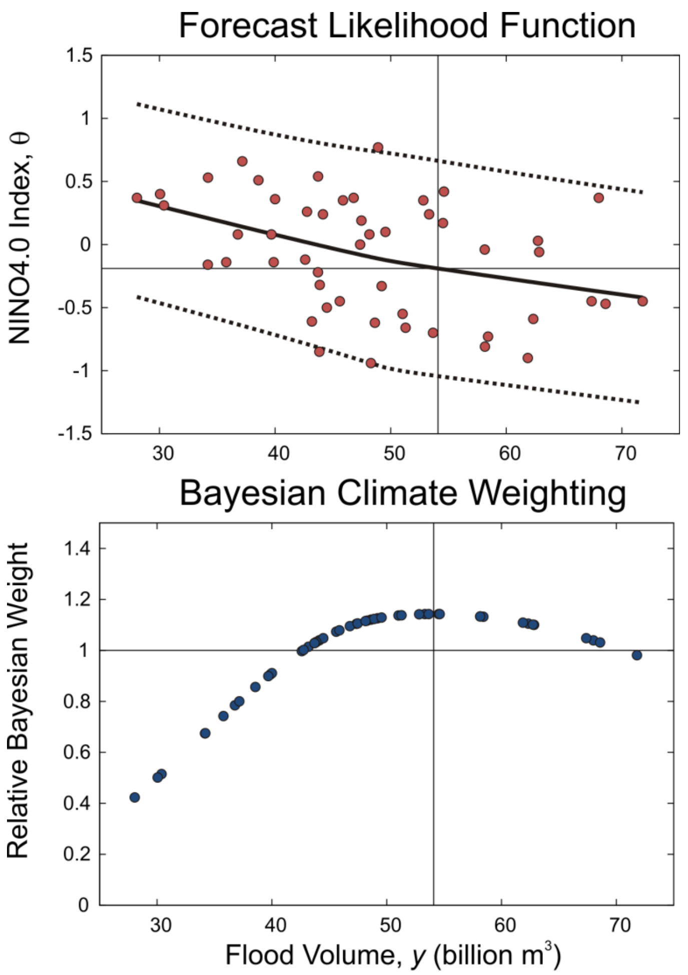
A Climate Index Weighting Method for Ensemble Forecasts Based on a Bayesian Resampling Approach



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IIHR Hydroscience & Engineering

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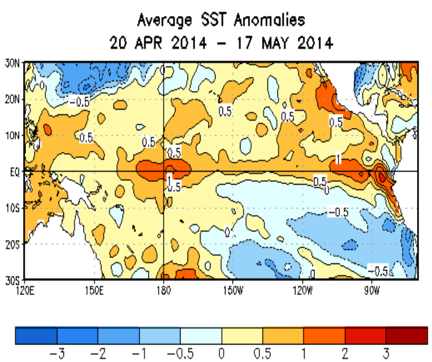
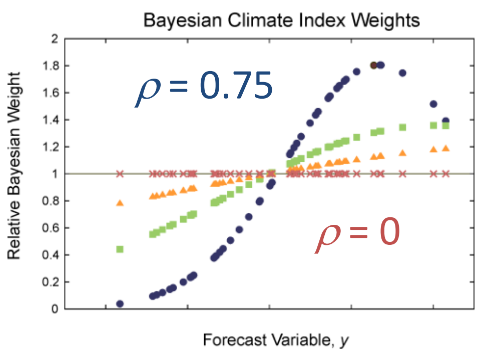
CENTER FOR URBAN ENVIRONMENTAL RESEARCH AND EDUCATION

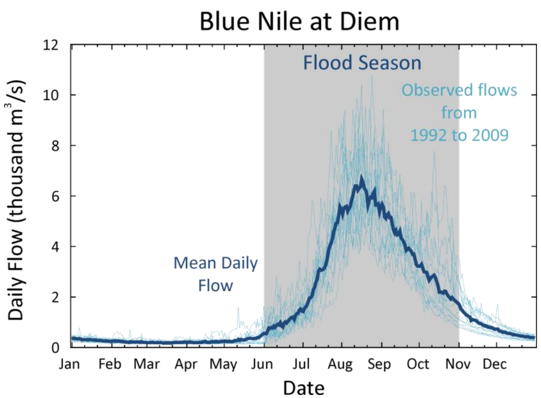
This presentation introduces a new climate index weighting method for ensembles



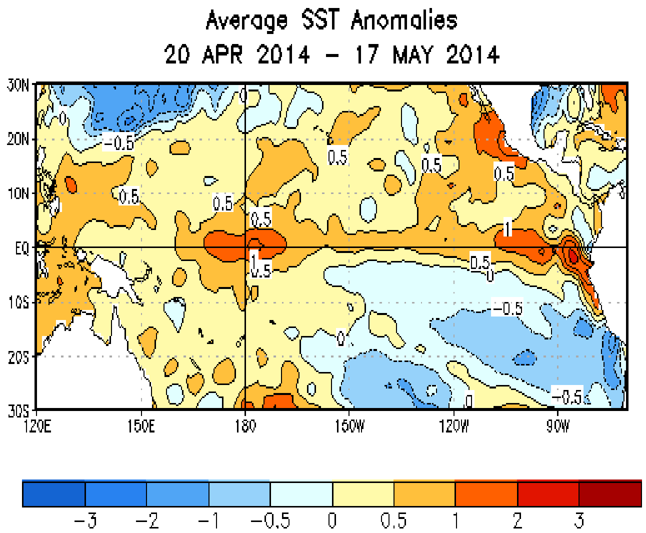
A Bayesian resampling method for climate index weighting



Some properties of the Bayesian climate index weighting method



An application of the method for Blue Nile ensemble forecasts

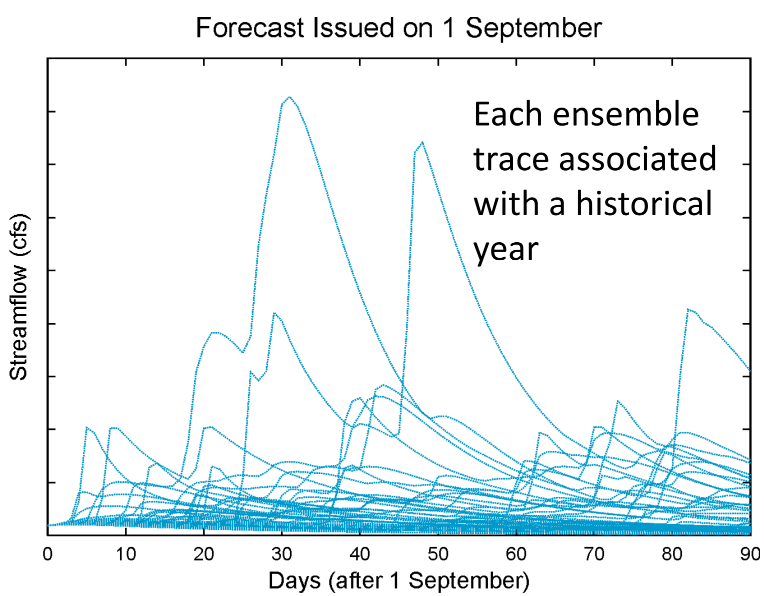


Climate Index Weighting Using a Bayesian Resampling Method

CLIMATE INDEX WEIGHTING IN ENSEMBLE FORECASTING

Historical weather or streamflow is often used to make seasonal ensemble forecasts

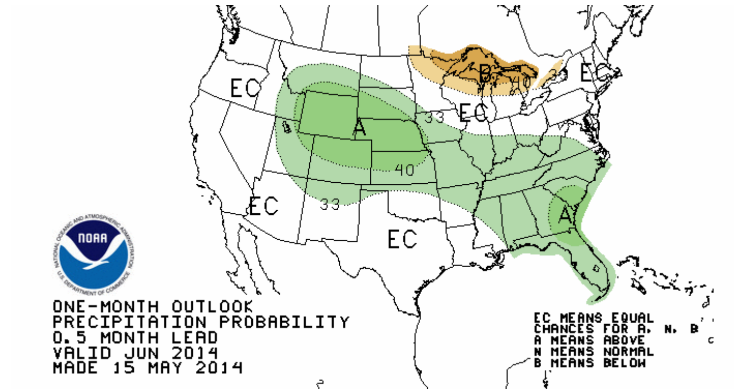
Seasonal Ensemble Forecast



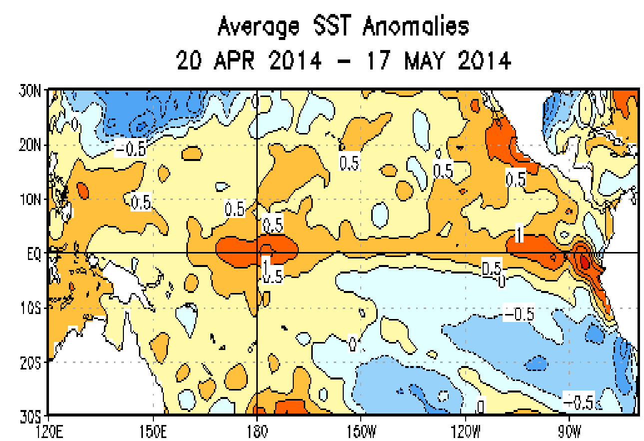
Climate Index Weighting

Each ensemble member is selectively weighted to reflect the climate conditions at the time of the forecast

Assign weights based on climate forecast



Assign weights based on climate state



Source: NWS Climate Prediction Center

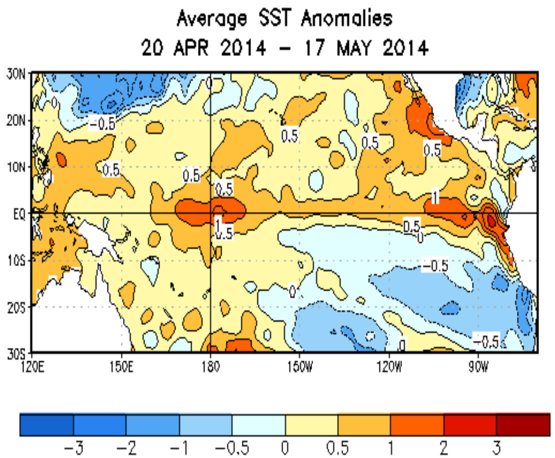
Bayes Theorem uses new information to update the prior ensemble distribution

Bayes Theorem

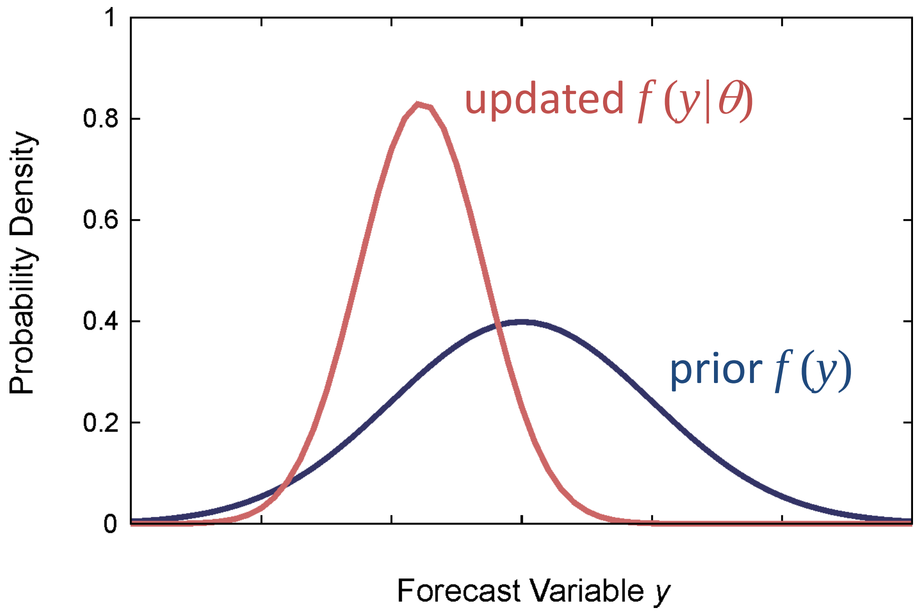
updated distribution — likelihood function — prior distribution

$$f(y\,|\,\theta) = \frac{f_\theta(\theta\,|\,y)\,f(y)}{f_\theta(\theta)}$$

Climate index θ at time of forecast



Bayesian Updating



Direct evaluation of the updated distribution can be very challenging

Bayesian updating is more easily done with a sample drawn from the prior distribution

Original Ensemble Forecast

$$y_i, i = 1, \ldots, N$$

$$w_i = \frac{1}{N}$$

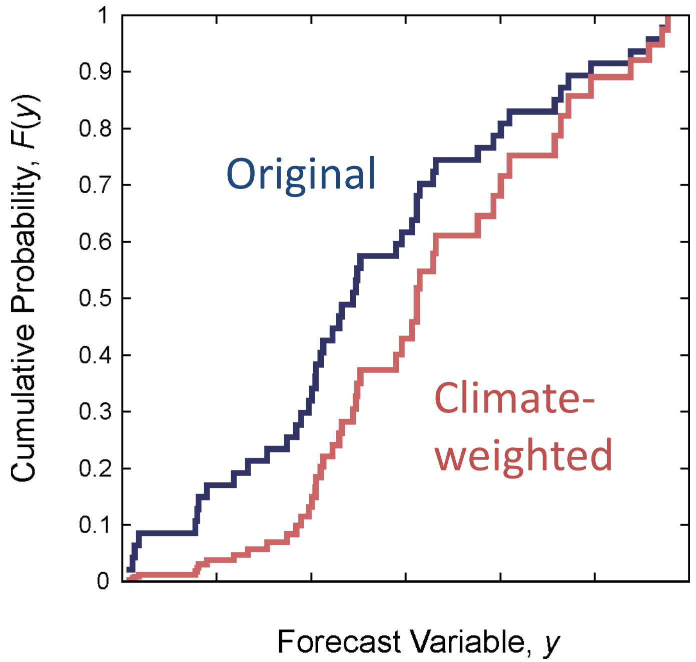
A sample from the prior distribution

Climate-Weighted Ensemble Forecast

$$y_i, i = 1, \ldots, N$$

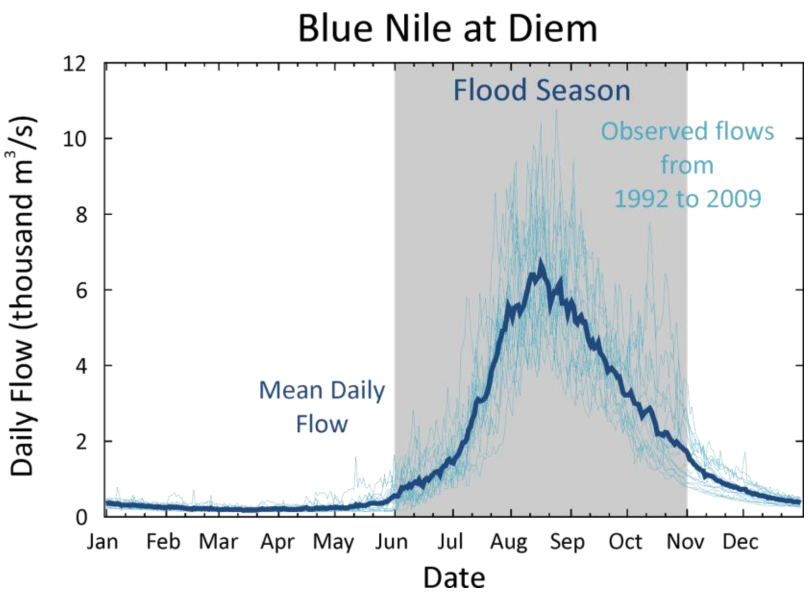
$$w_i = \frac{f_\theta(\theta \mid y_i)}{\sum_{i=1}^{N} f_\theta(\theta \mid y_i)}$$

A sample from the updated distribution



This resampling approach defines climate index weights that accomplish Bayesian updating

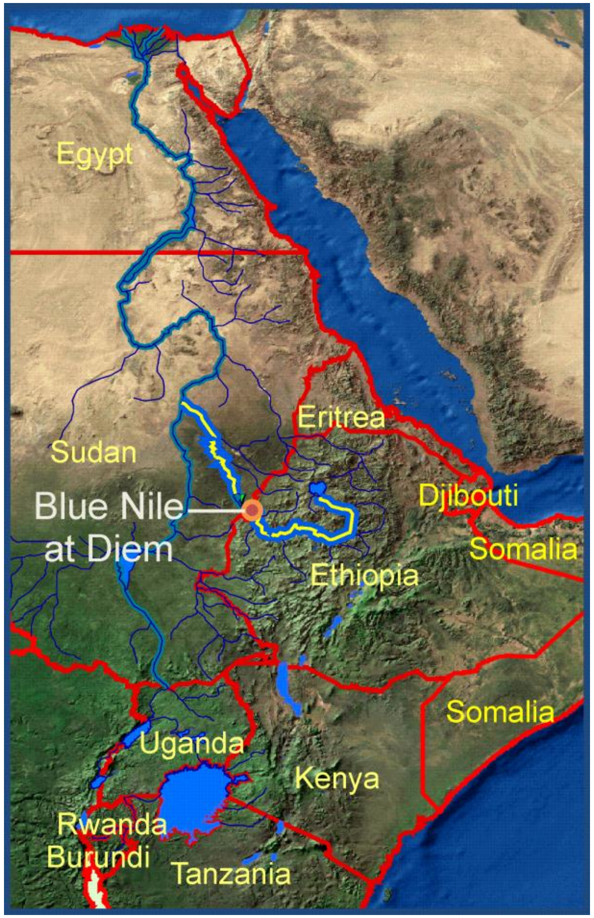
Reference: Smith and Gelfand (1992)

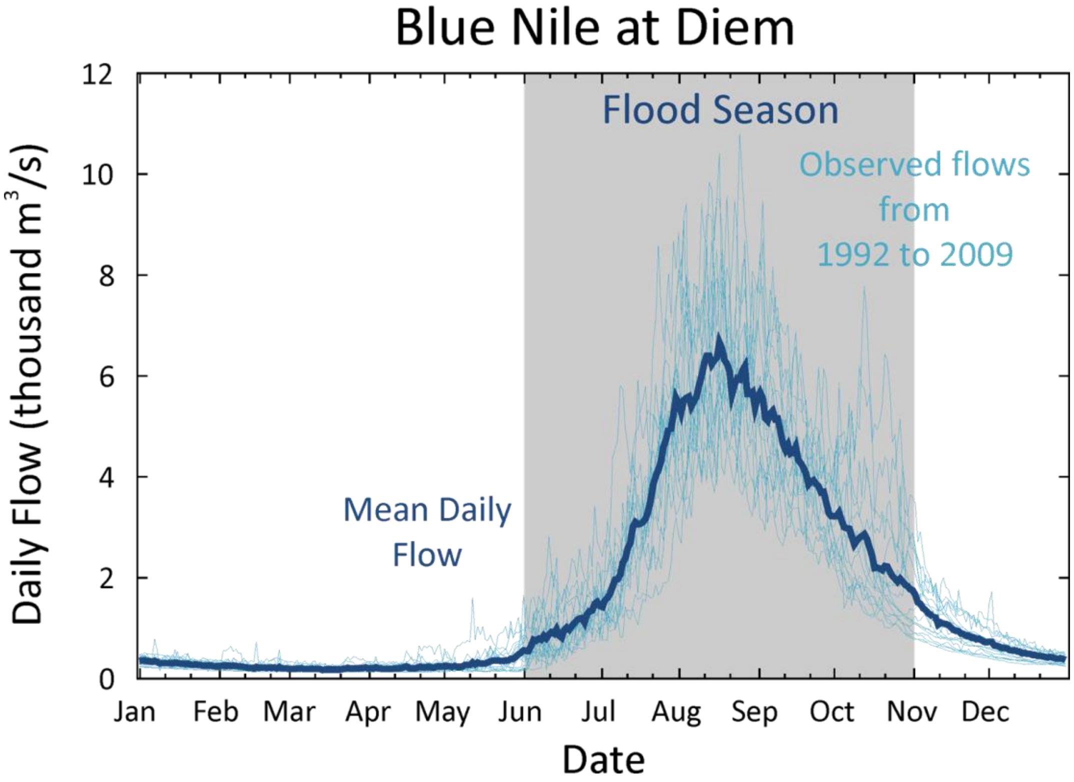


Climate Index Weighting Using a Bayesian Resampling Method

APPLICATION TO BLUE NILE ENSEMBLE FLOOD FORECASTS

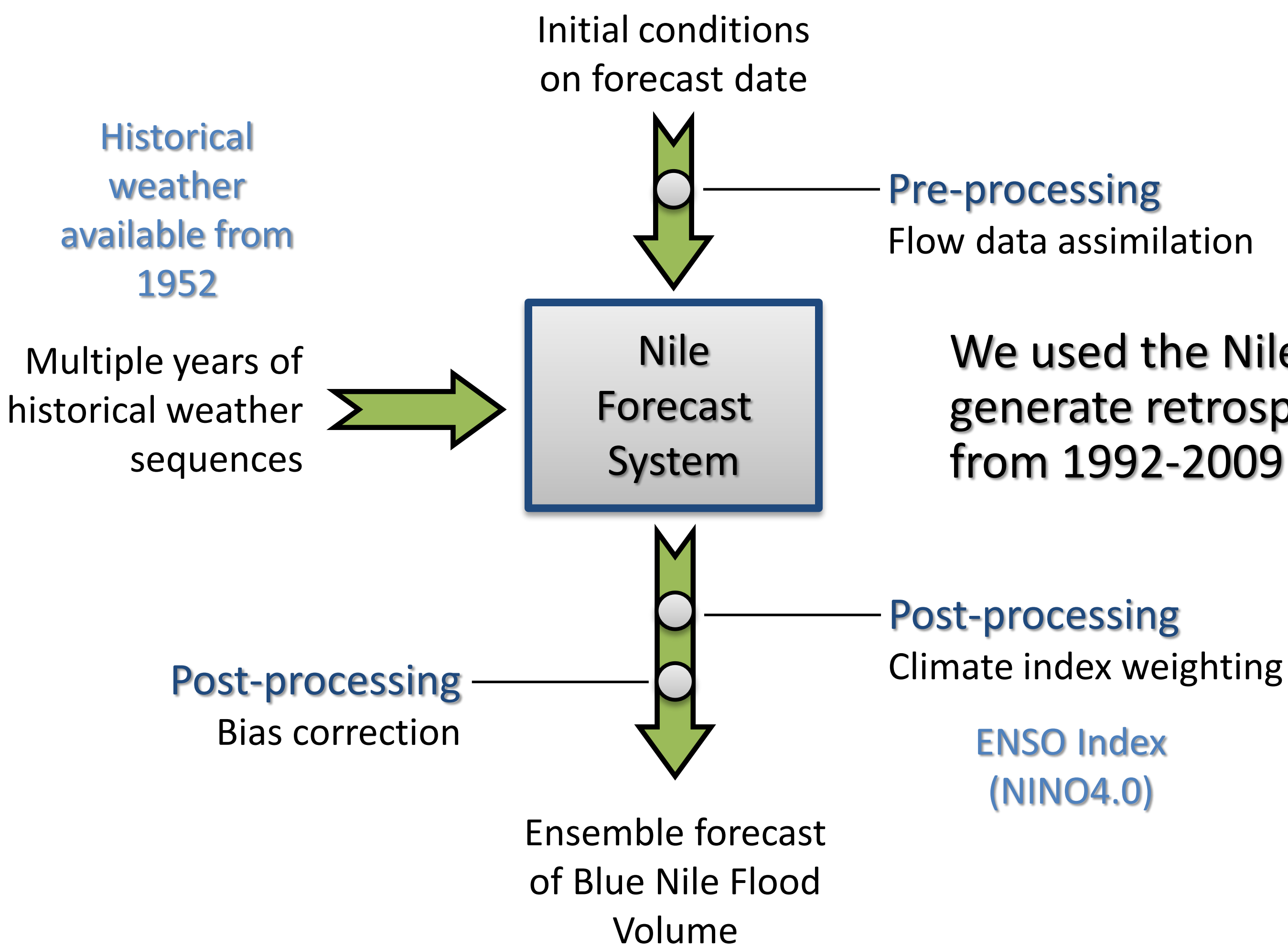
Blue Nile flood volume is correlated with the El Niño-Southern Oscillation (ENSO)





Interannual variability in the Blue Nile flood is related to ENSO. Floods tend to be larger (smaller) during La Niña (El Niño) years.

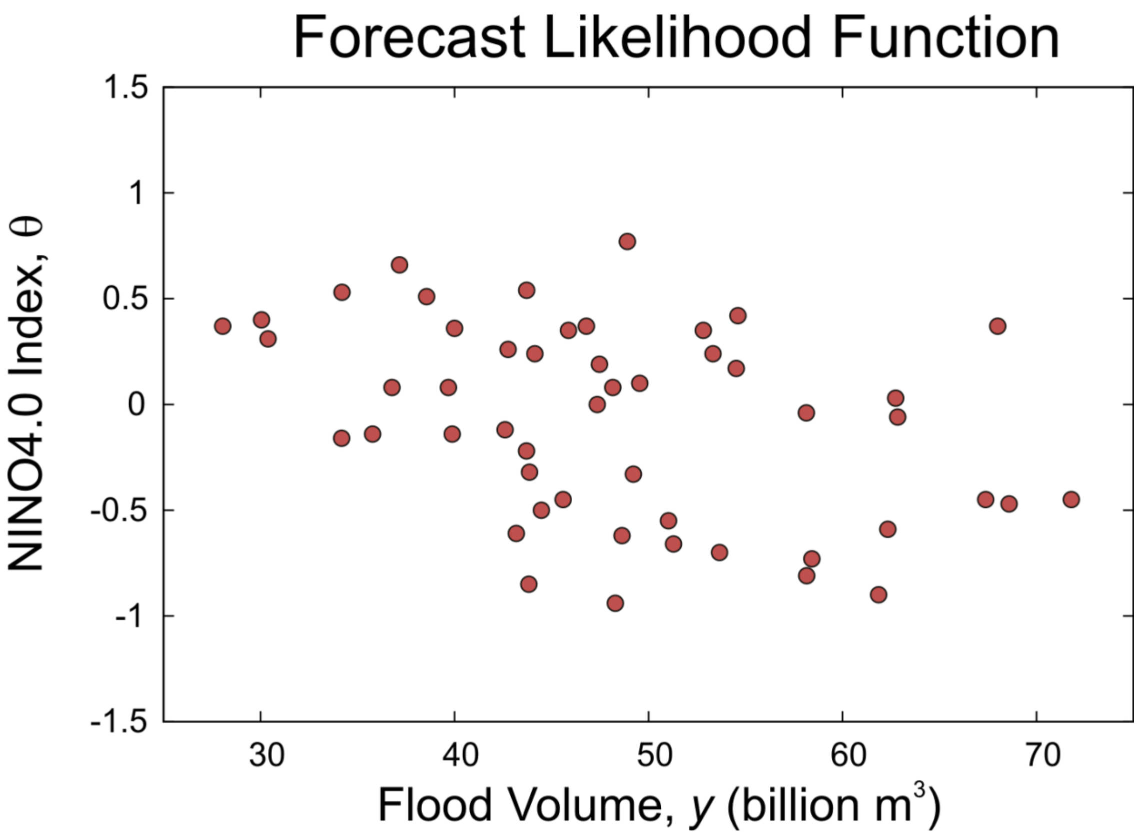
Nile Forecast System (NFS) flood volume forecasts issued in June will be examined



We used the Nile Forecast System to generate retrospective forecasts from 1992-2009

The ensemble forecast has the information needed to define the likelihood function

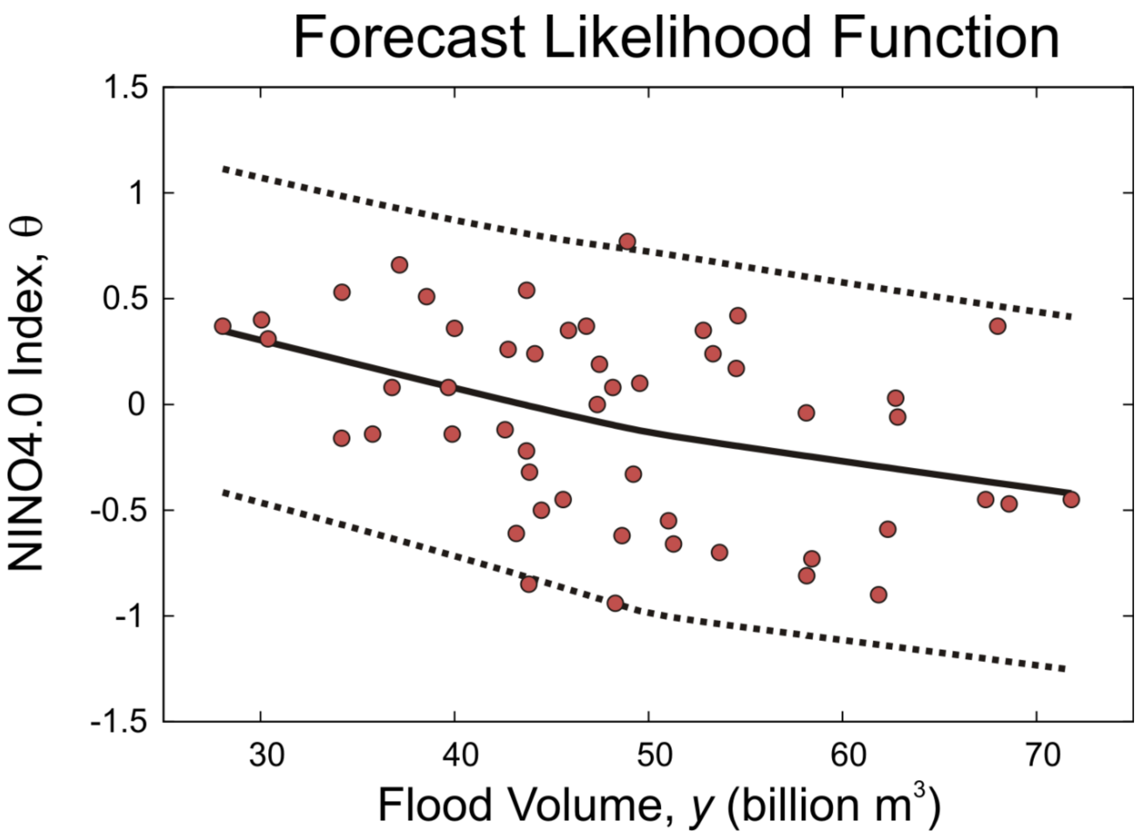
2001 Ensemble Forecast (Issued in June) for the Blue Nile Flood Volume



The ensemble forecast flood volume y_i is plotted along with the NINO4.0 Index θ_i for its historical year

The ensemble forecast has the information needed to define the likelihood function

2001 Ensemble Forecast (Issued in June) for the Blue Nile Flood Volume

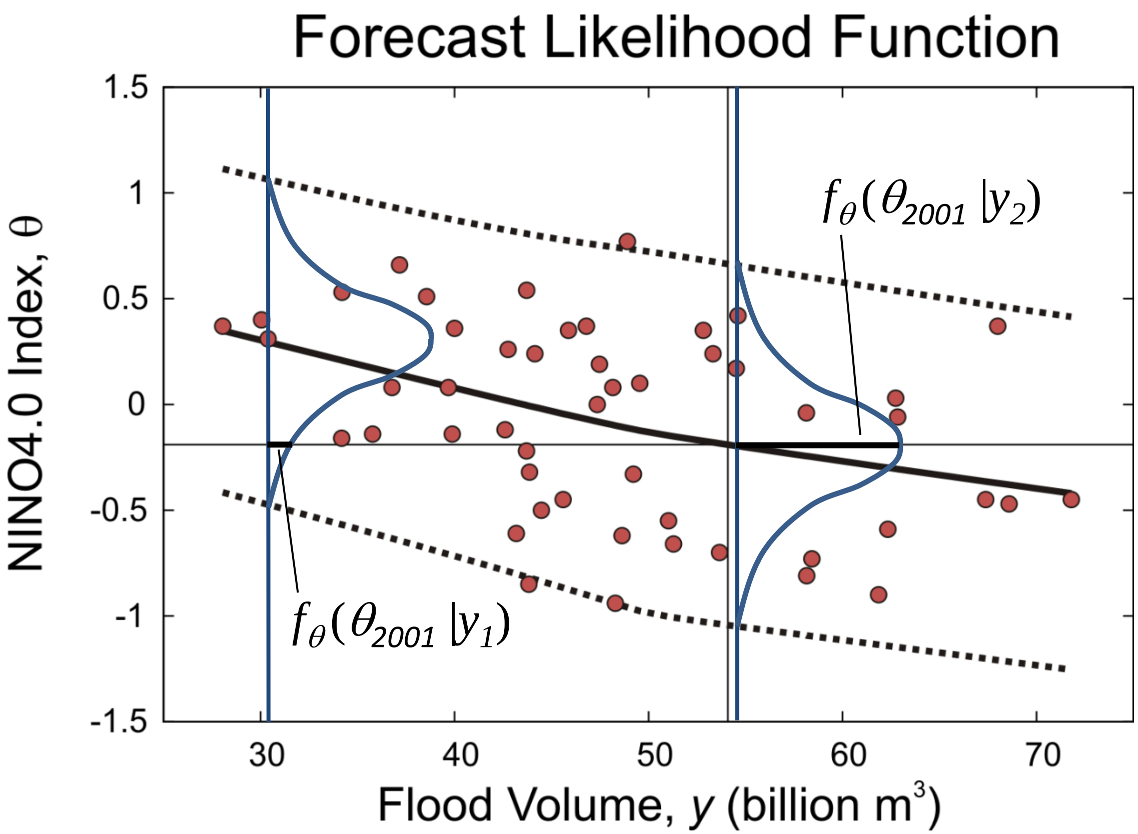


The ensemble forecast flood volume y_i is plotted along with the NINO4.0 Index θ_i for its historical year

The forecast likelihood function $f_\theta(\theta \mid y)$ is estimated directly by a regression model (LOWESS)

The ensemble forecast has the information needed to define the likelihood function

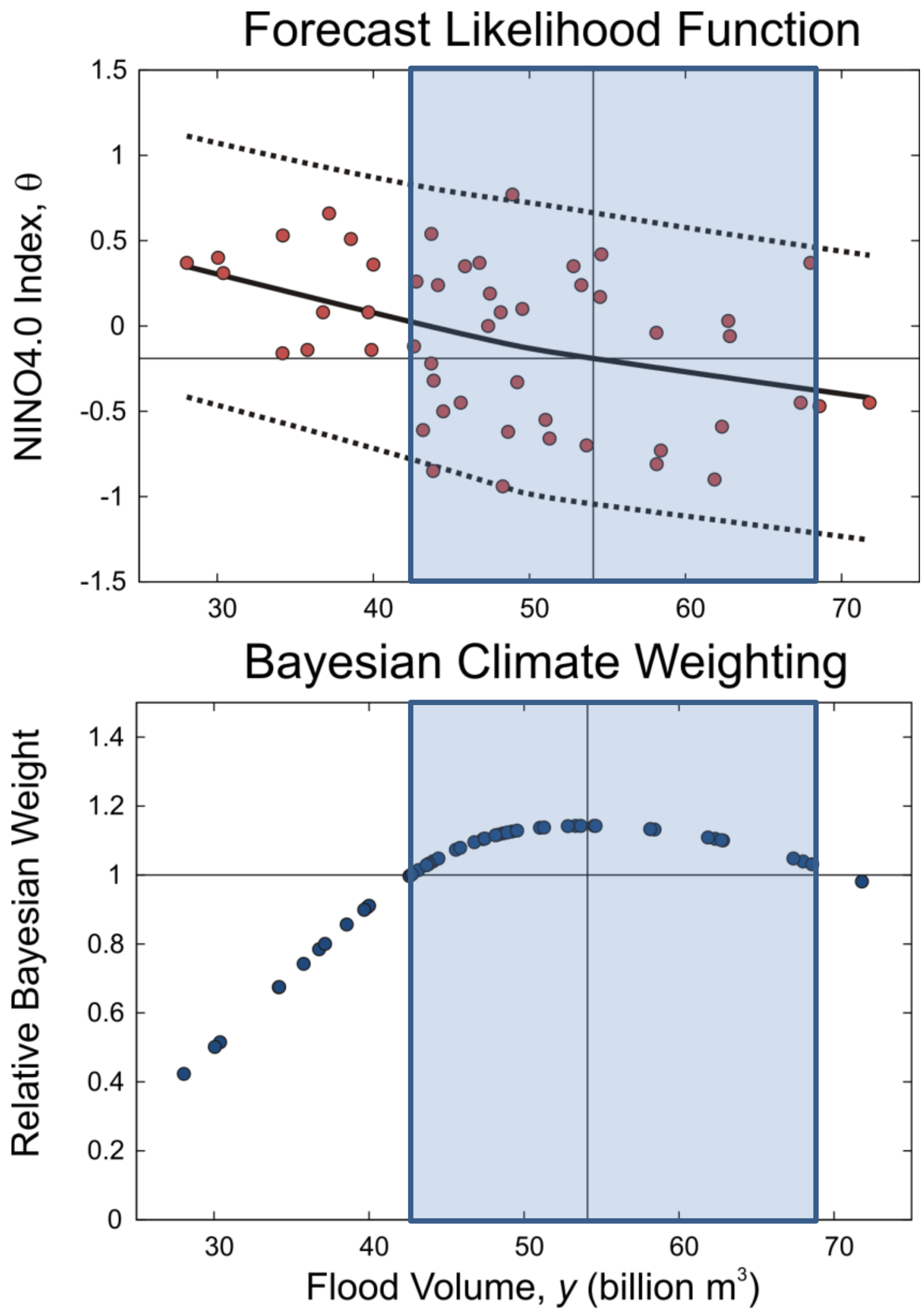
2001 Ensemble Forecast (Issued in June) for the Blue Nile Flood Volume



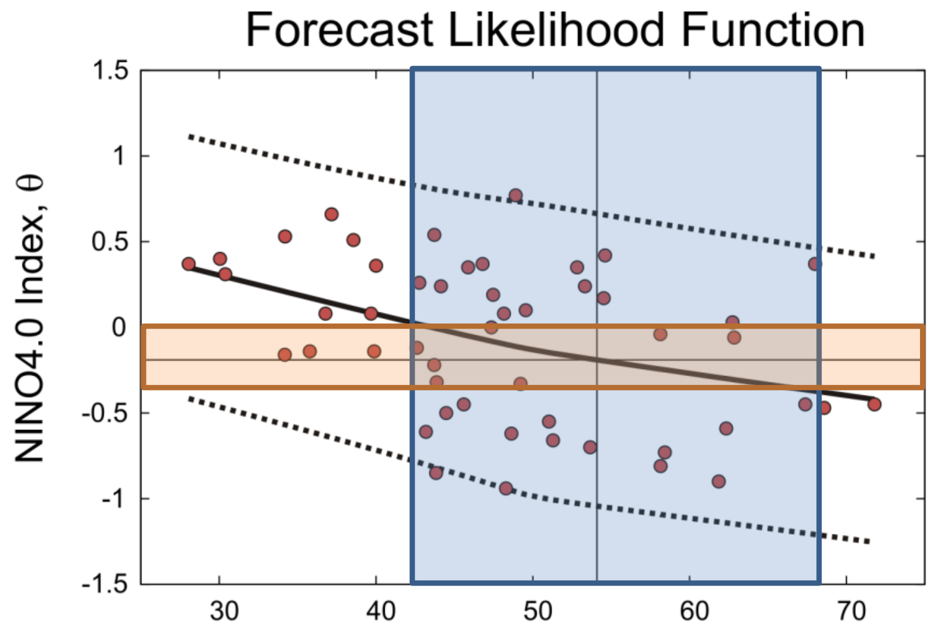
The ensemble forecast flood volume y_i is plotted along with the NINO4.0 Index θ_i for its historical year

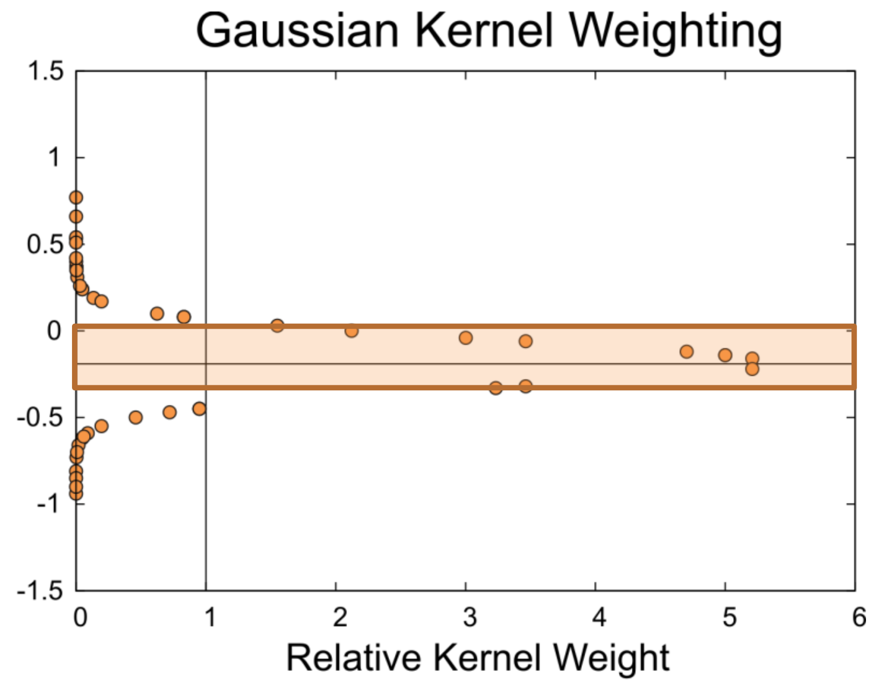
Climate Index θ_{2001}

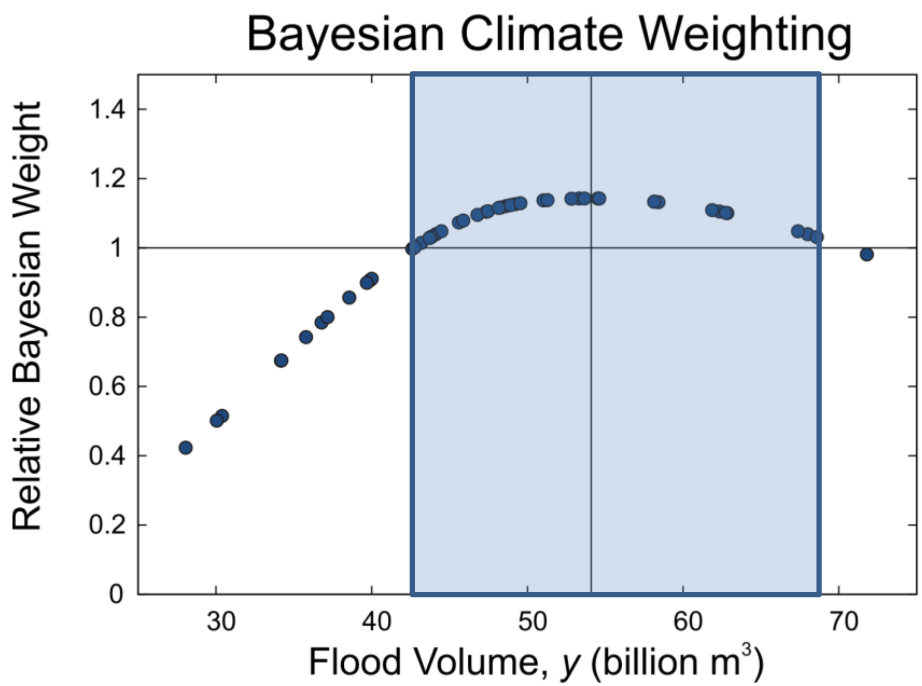
The forecast likelihood function $f_\theta(\theta|y)$ is estimated directly by a regression model (LOWESS)



The Bayesian method weights more heavily ensemble members with an *expected* climate index (regression line) close to the observed index θ

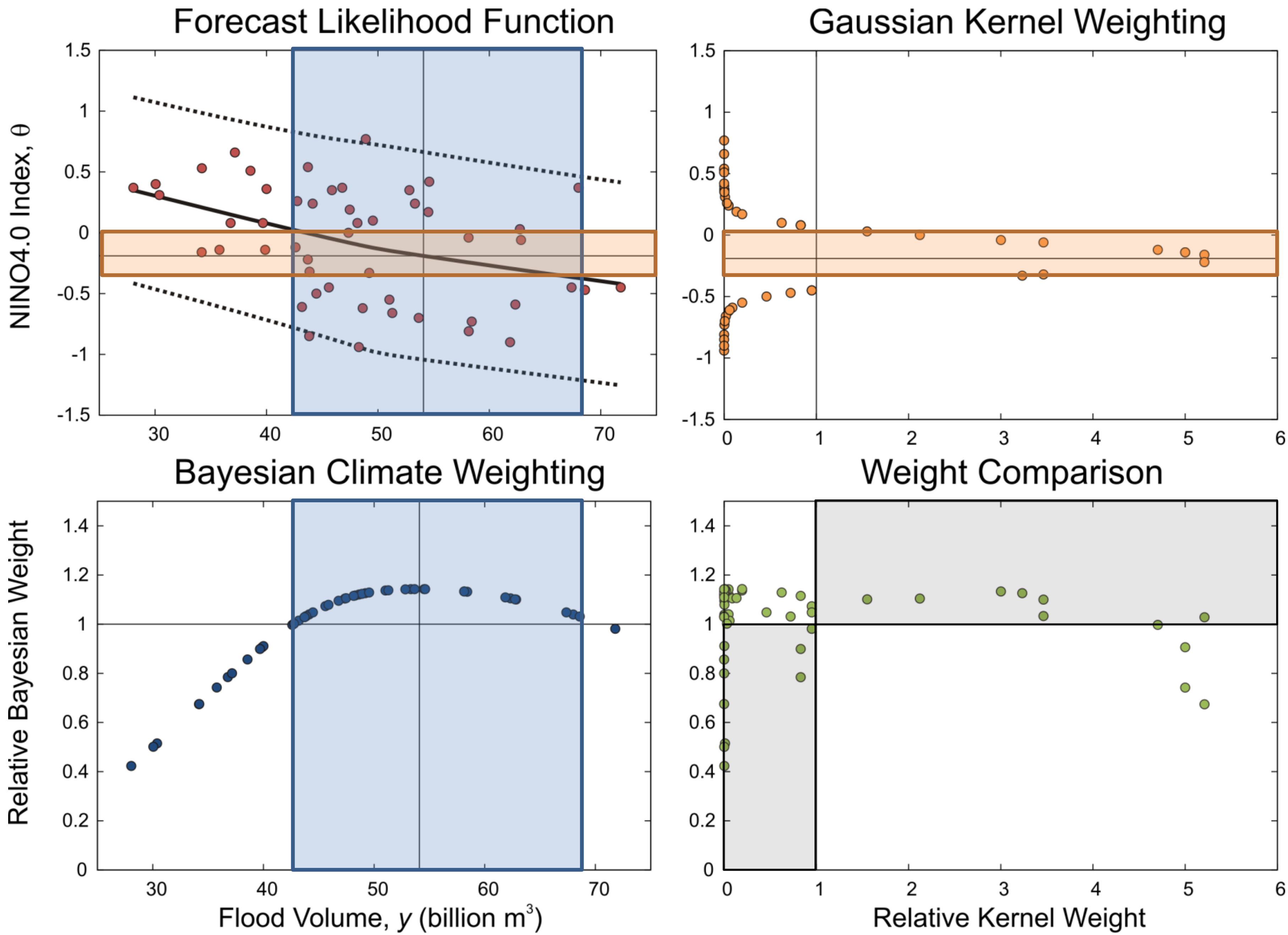






The kernel method weights more heavily ensemble members with a *historical* climate index close to the observed index θ

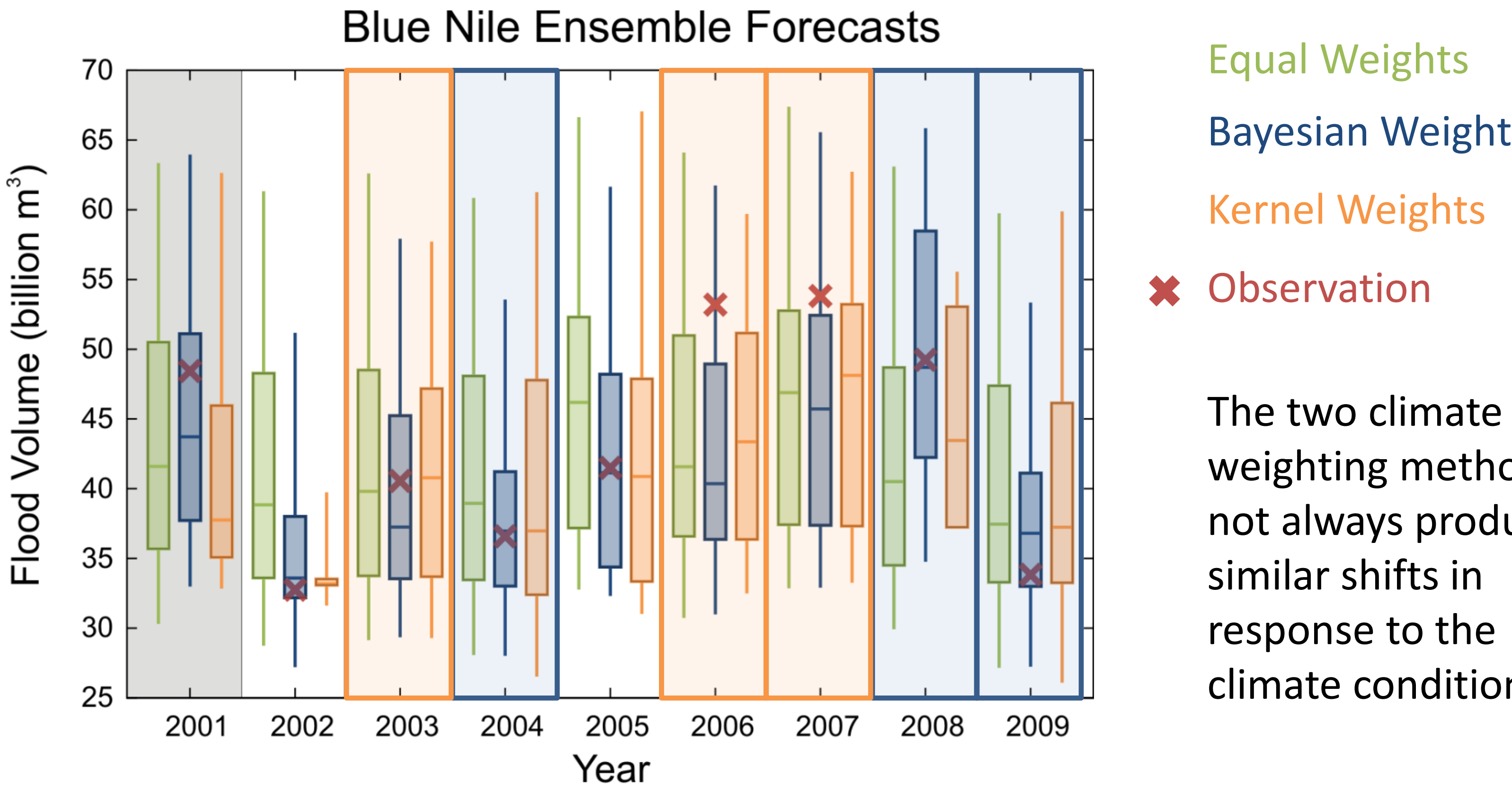
The Bayesian method weights more heavily ensemble members with an *expected* climate index (regression line) close to the observed index θ



Forecast Likelihood Function
Gaussian Kernel Weighting
Bayesian Climate Weighting
Weight Comparison
NINO4.0 Index, θ
Relative Bayesian Weight
Flood Volume, y (billion m³)
Relative Kernel Weight

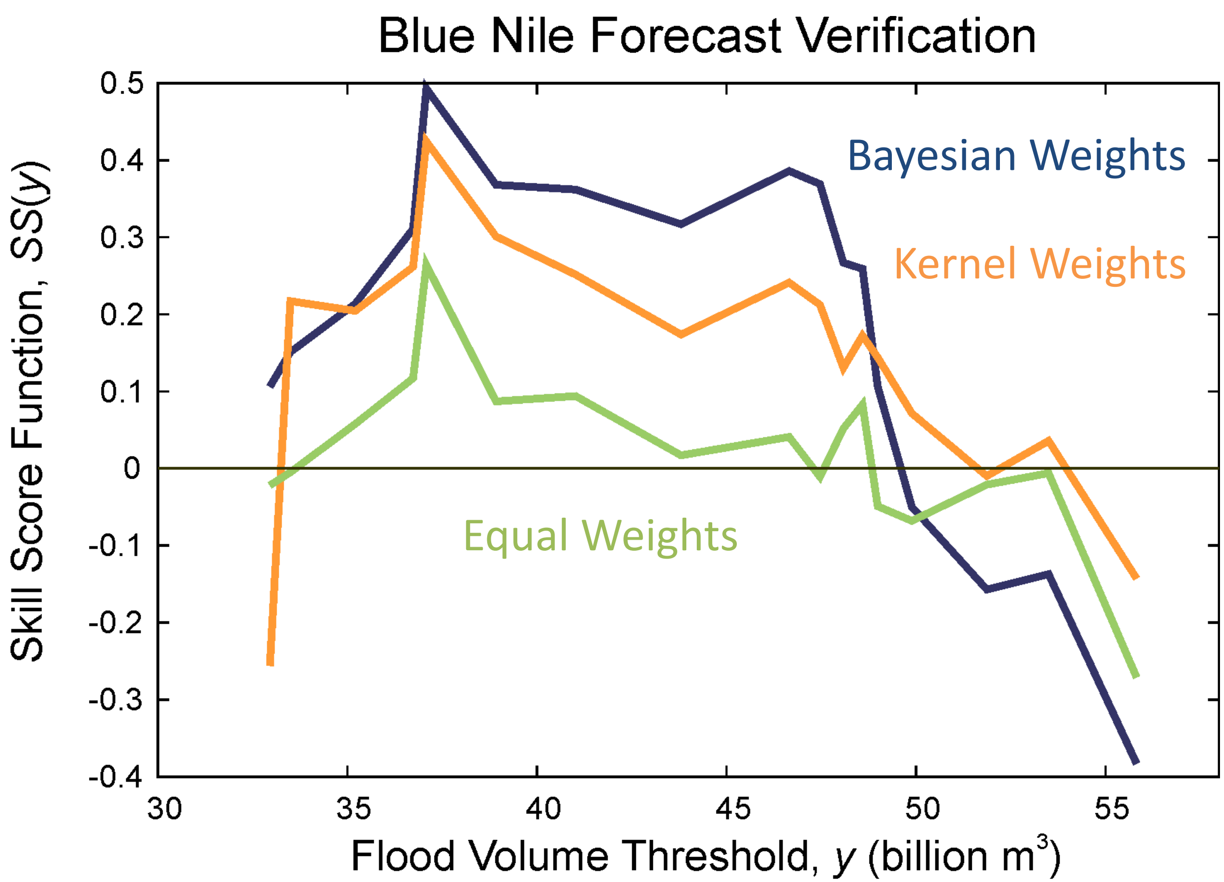
Bayesian and Kernel methods can assign very different weights

A Subset of Ensemble Forecasts for the Blue Nile Flood Volume



The two climate index weighting methods do not always produce similar shifts in response to the climate conditions

Forecast skill is higher for Bayesian climate weighting for most thresholds



Weighted Average Skill

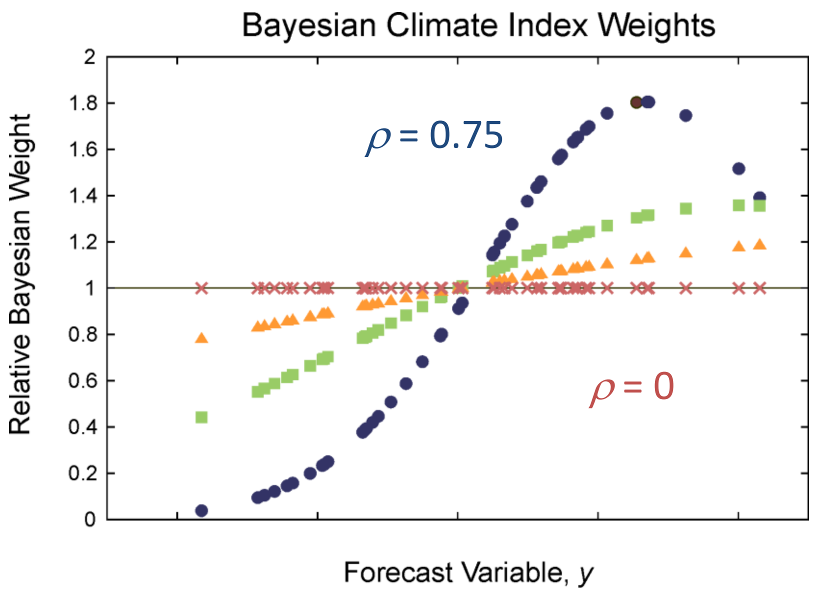
$\overline{SS}$ (Bayesian): 0.24

$\overline{SS}$ (Kernel): 0.19

$\overline{SS}$ (Equal): 0.04

The Kernel bandwidth parameter was found to maximizes $\overline{SS}$ for the hindcasts

Still, the average skill is higher for the Bayesian method (which requires no hindcast calibration)

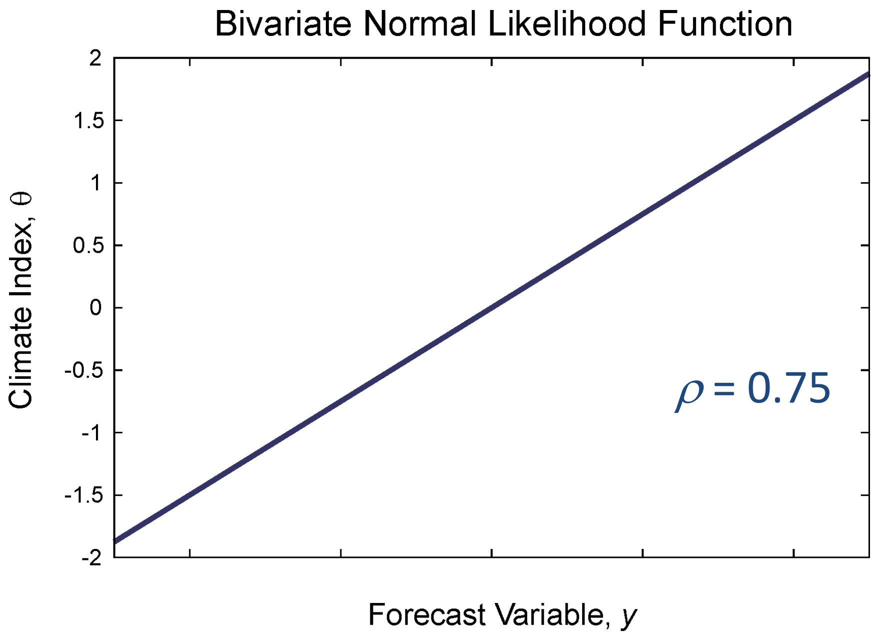


Climate Index Weighting Using a Bayesian Resampling Method

SOME PROPERTIES OF THE BAYESIAN CLIMATE WEIGHTING METHOD

Bayesian weights adapt to the strength of the relation with the climate index

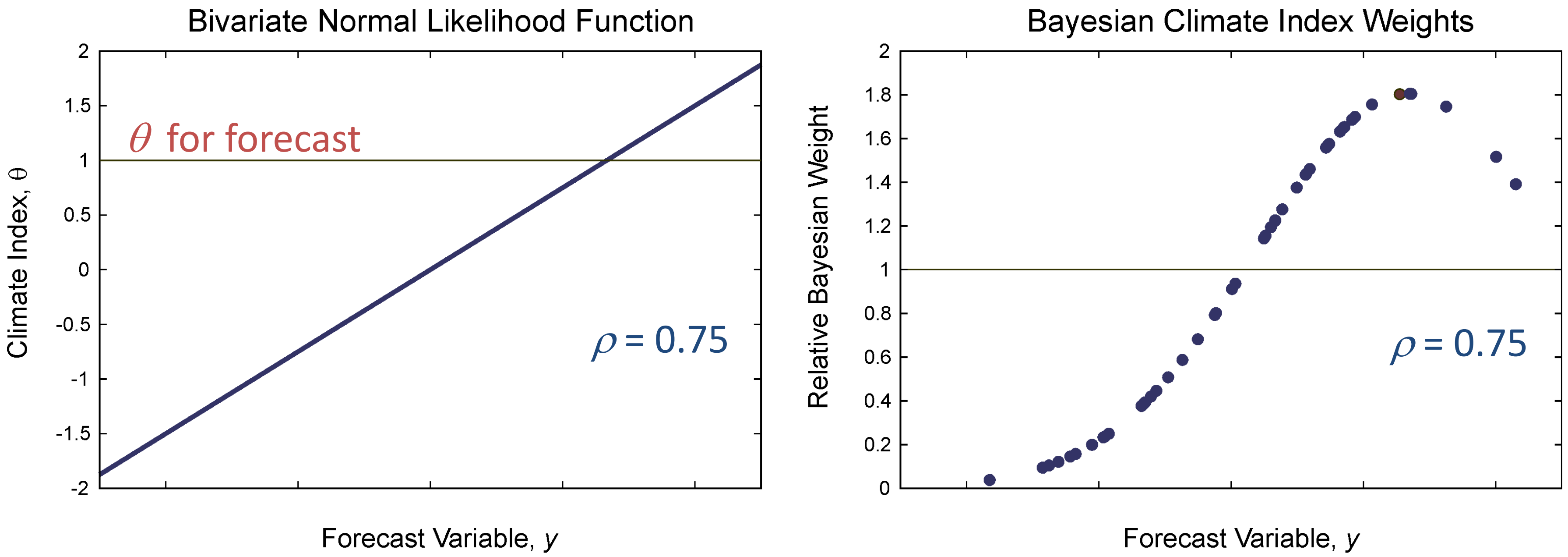
Hypothetical bivariate normal likelihood function



Bayesian weights depend on the strength of the relationship

Bayesian weights adapt to the strength of the relation with the climate index

Hypothetical bivariate normal likelihood function

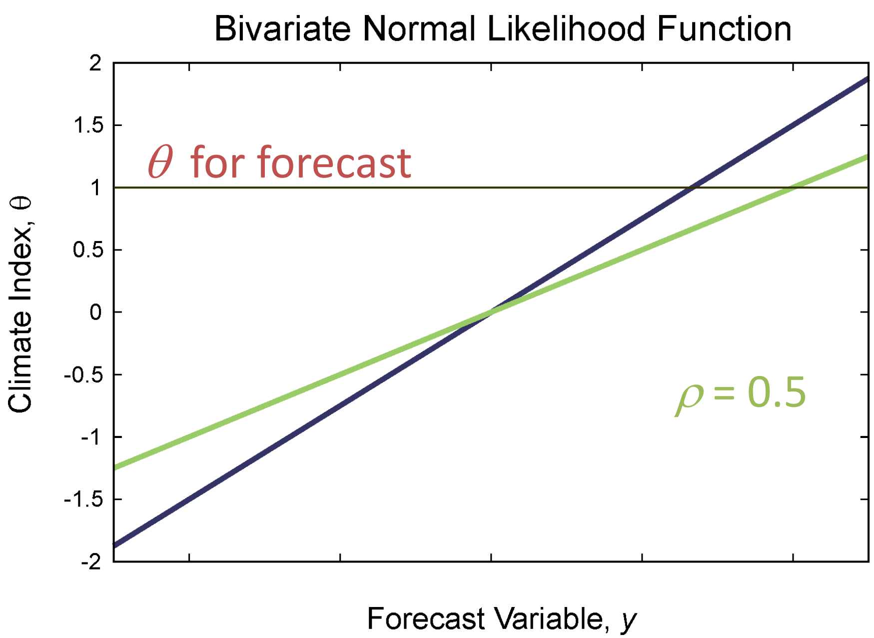


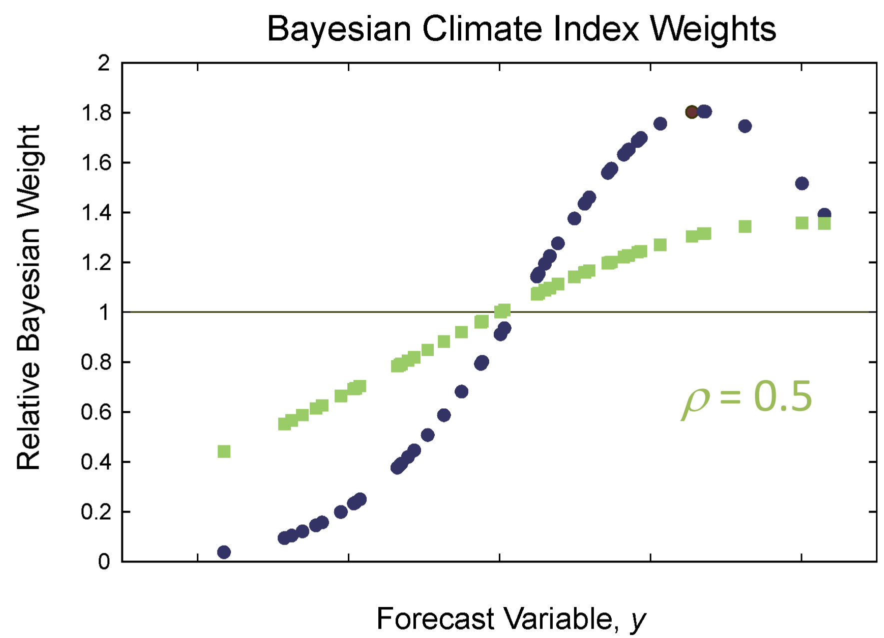
Bayesian weights depend on the strength of the relationship

Weights strongly discriminate if the relationship is strong ($\rho = 0.75$)

Bayesian weights adapt to the strength of the relation with the climate index

Hypothetical bivariate normal likelihood function



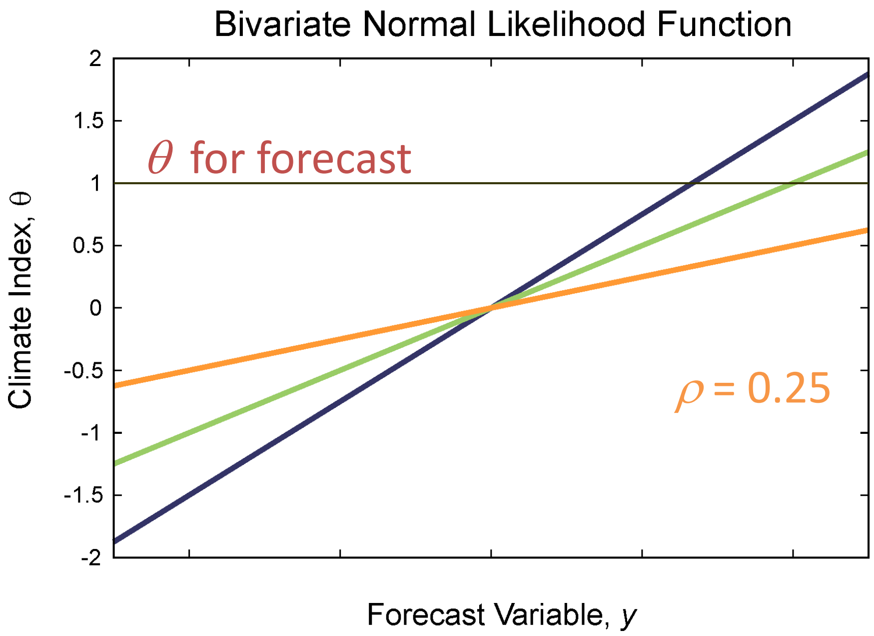


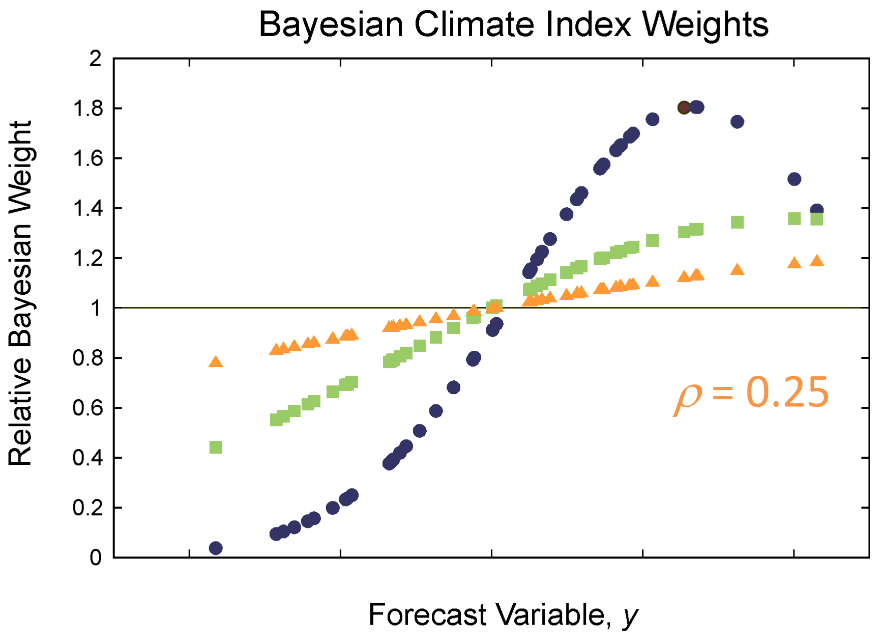
Bayesian weights depend on the strength of the relationship

Weights discriminate less as the strength of the relationship weakens ($\rho = 0.5$)

Bayesian weights adapt to the strength of the relation with the climate index

Hypothetical bivariate normal likelihood function



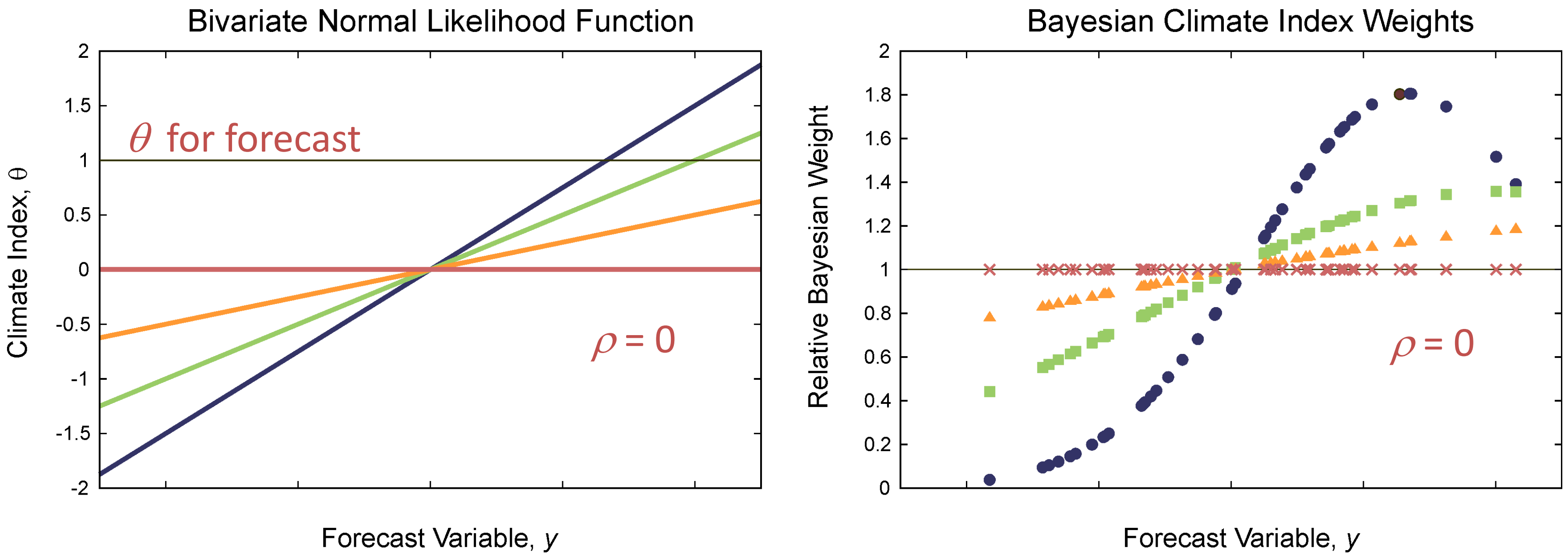


Bayesian weights depend on the strength of the relationship

Weights discriminate less as the strength of the relationship weakens (ρ = 0.25)

Bayesian weights adapt to the strength of the relation with the climate index

Hypothetical bivariate normal likelihood function



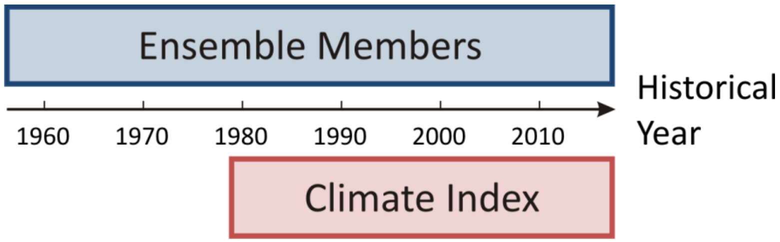
Bayesian weights depend on the strength of the relationship

Equal weights are applied if there is no relation with the climate index ($\rho = 0$)

Weights can be applied to ensemble traces that do not have a historical climate index

Mismatching Historical Periods

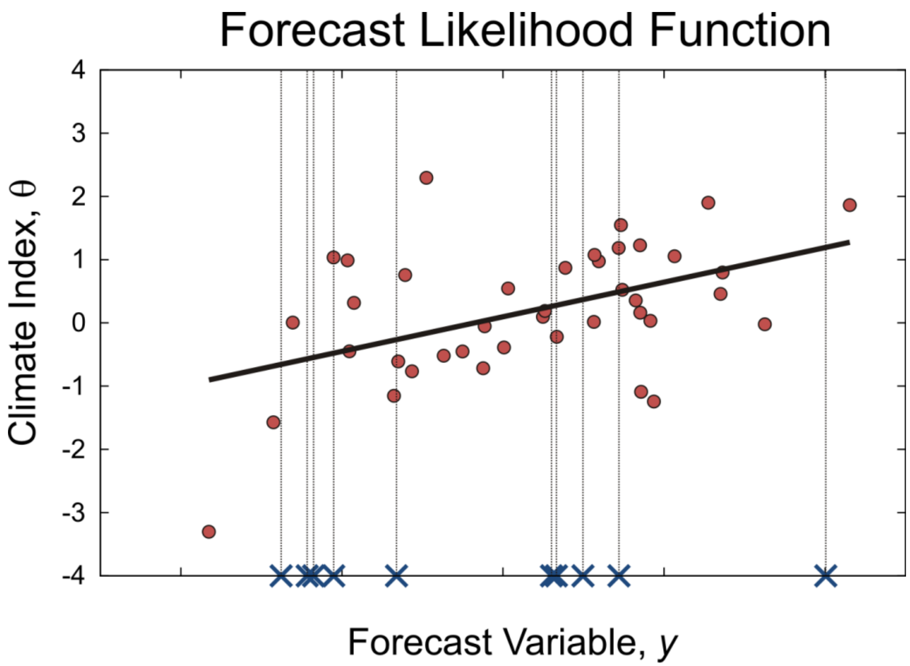
Ensemble forecast is created using a long historical record



Climate index is unavailable for a portion of the ensemble members

Bayesian climate index weights can still be applied to all ensemble members

Example Ensemble Forecast

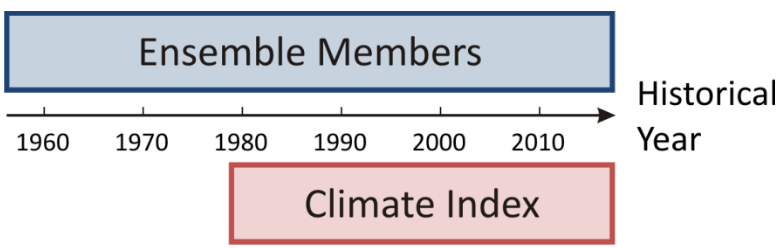


The forecast likelihood function $f_\theta(\theta|y)$ can be estimated for the overlapping historical period

Weights can be applied to ensemble traces that do not have a historical climate index

Mismatching Historical Periods

Ensemble forecast is created using a long historical record



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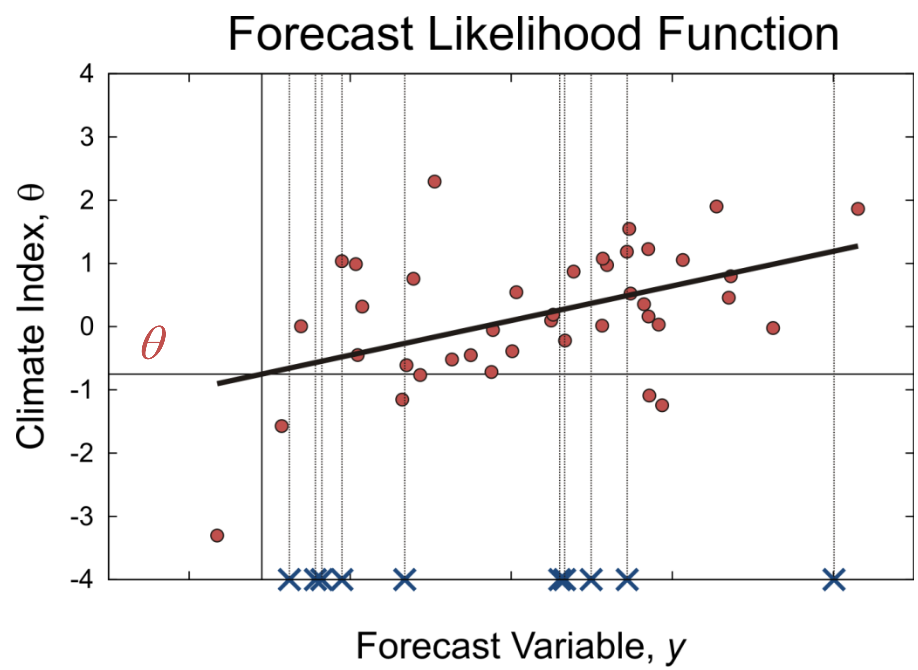

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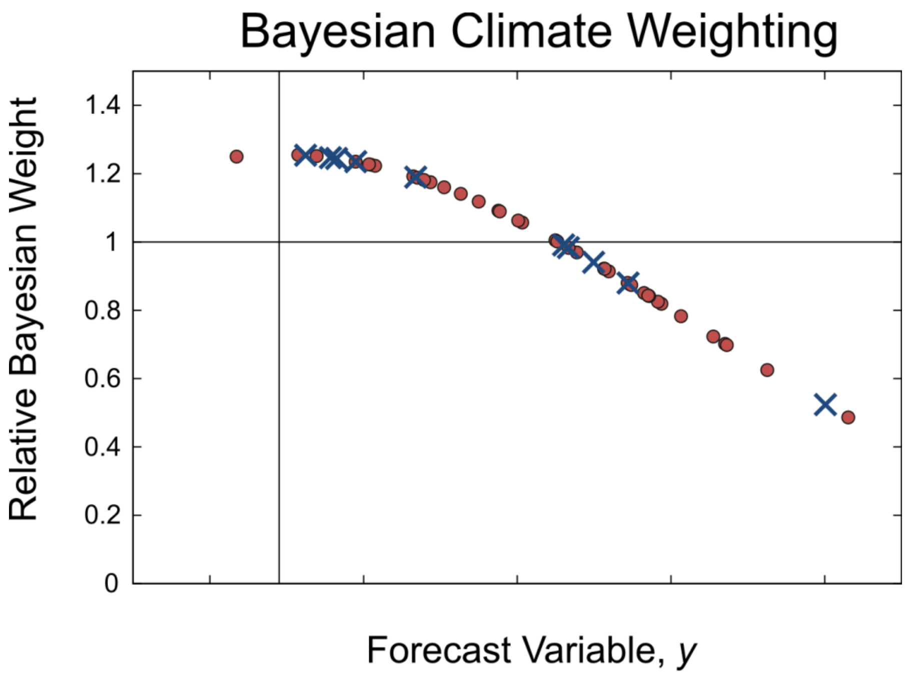
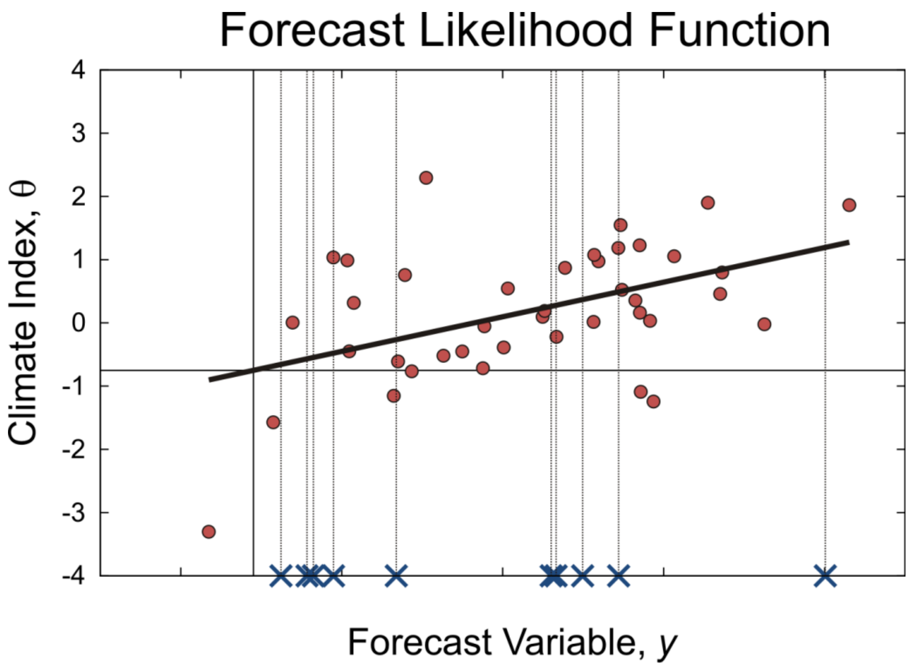
Mismatching Historical Periods

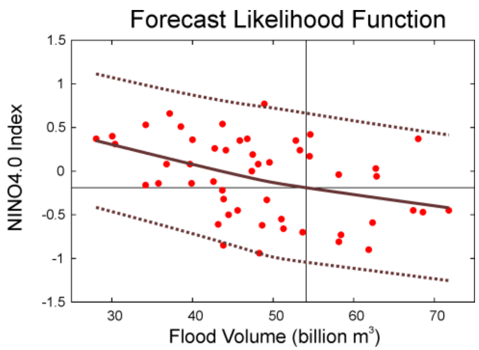


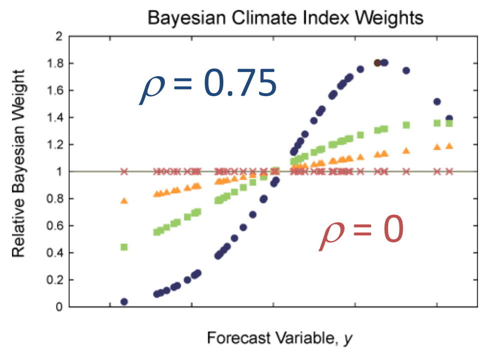
Weights can be assigned for the non-overlapping period because $f_\theta(\theta|y_i)$ is defined for all ensemble members

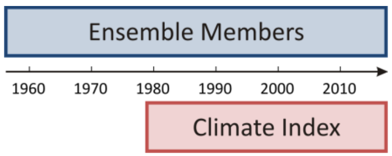
Example Ensemble Forecast



The forecast likelihood function $f_\theta(\theta|y)$ can be estimated for the overlapping historical period



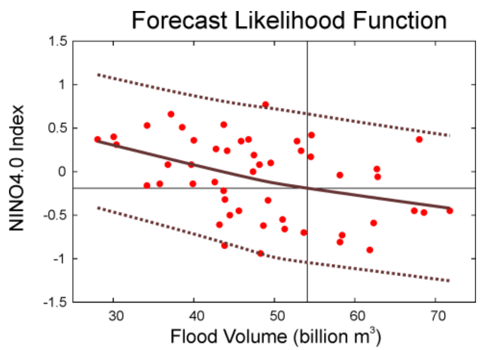




Climate Index Weighting Using a Bayesian Resampling Method

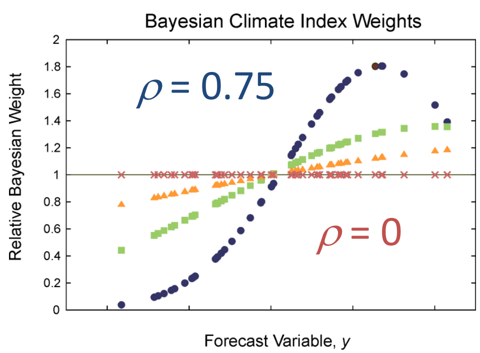
SUMMARY AND CONCLUSIONS

Bayesian climate index weighting is a simple, self-calibrating, self-adjusting method



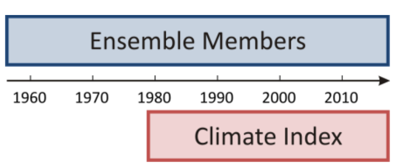
The method only uses the ensemble members from the forecast to estimate of climate index weights

The method can be applied to any ensemble forecast directly (no hindcasts are needed for calibration)



The weighting adjusts to the strength of the relationship with the climate index

If no relationship exists, the method defaults to equal weighting



Applications are not limited to ensemble traces that have historical climate index values

The likelihood function defines how all available traces are weighted