Probabilistic wind forecasting using BMA

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Why probabilistic wind forecasting?

- Situations where certain ranges or thresholds are of interest
- Situations where knowing not just the most likely outcome, but possible extremes are important
- Situations involving a cost / loss analysis, where probabilities of different outcomes need to be known
- Examples:
  - Wind energy
  - Military
  - Sailing
  - Airports
  - Kite-flying

Bayesian Model Averaging

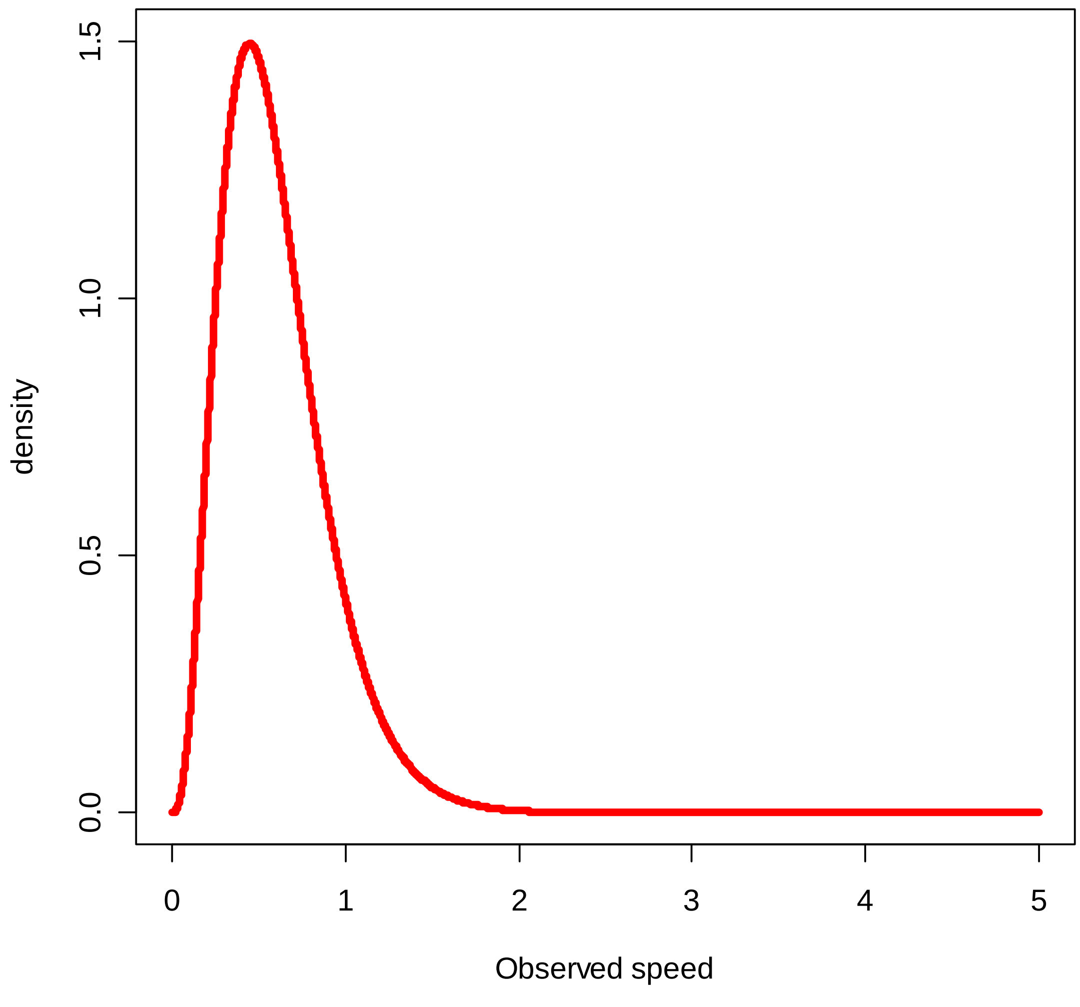
- Create a single forecast model by combining multiple forecasts
- Weigh the importance / value of individual forecasts relative to one another
- Create probabilistic forecasts – say something about uncertainty or error in forecasts as well as a "best" forecast

Bayesian Model Averaging

- Distribution of observed values relative to each forecast
- What sorts of observations to we tend to see when the forecast looks like this?
- Fit weights based on how well each forecast does
- Overall forecast distribution is weighted average of individual distributions

Example

- Suppose we had a set of five wind speed forecasts for tomorrow: 0.6 knots, 1.3 knots, 1.5 knots, 1.8 knots, and 2.1 knots
- Based on the observations we had seen over the past month, suppose we could say what our distribution of potential observed values was based on each of those
- We can plot each of these densities



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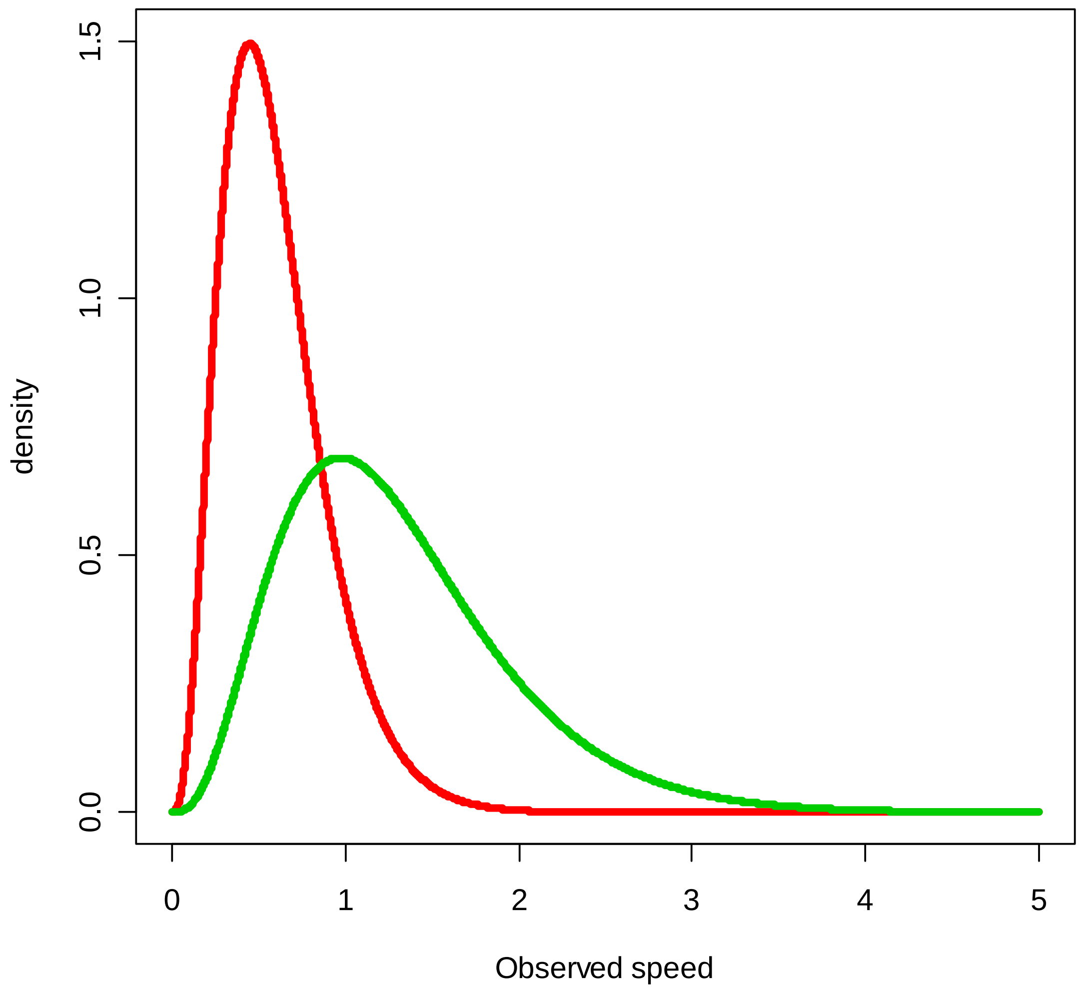
Observed speed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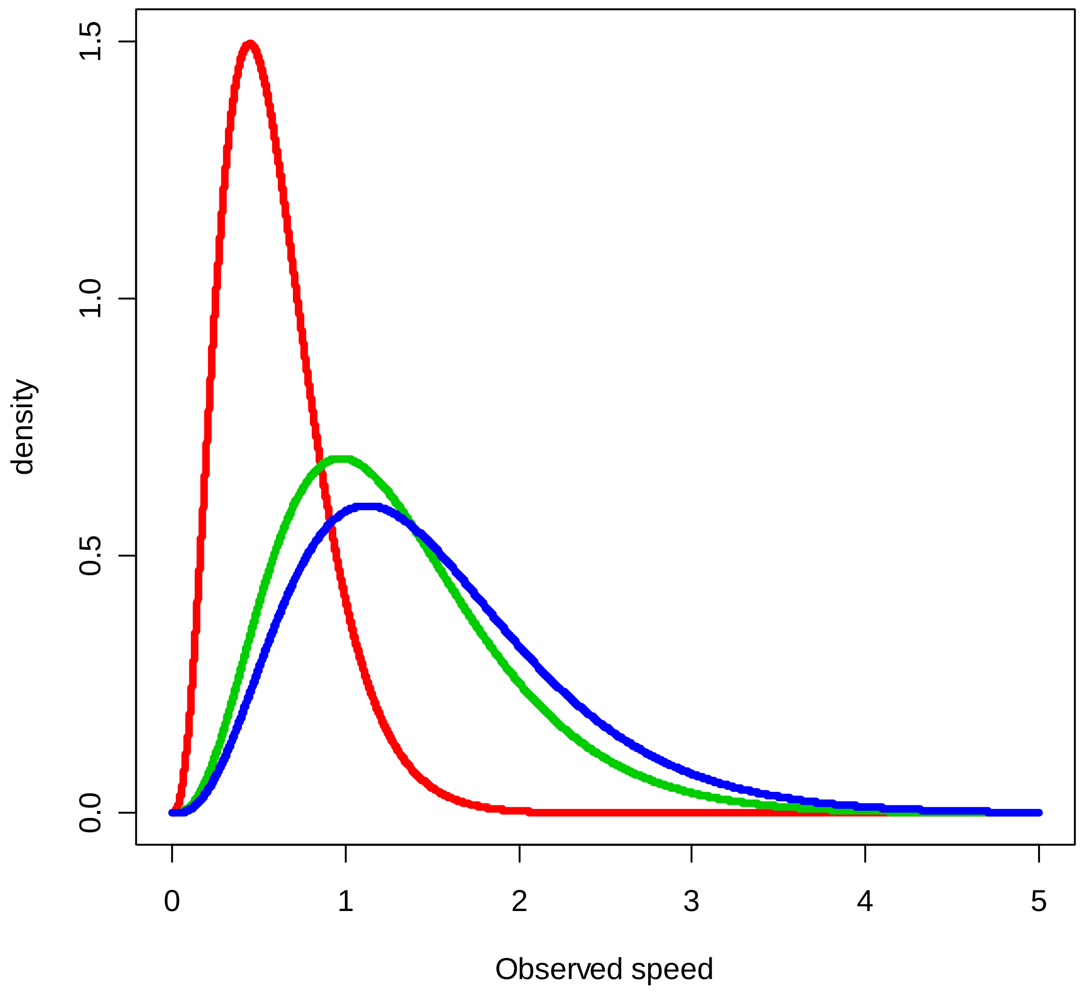

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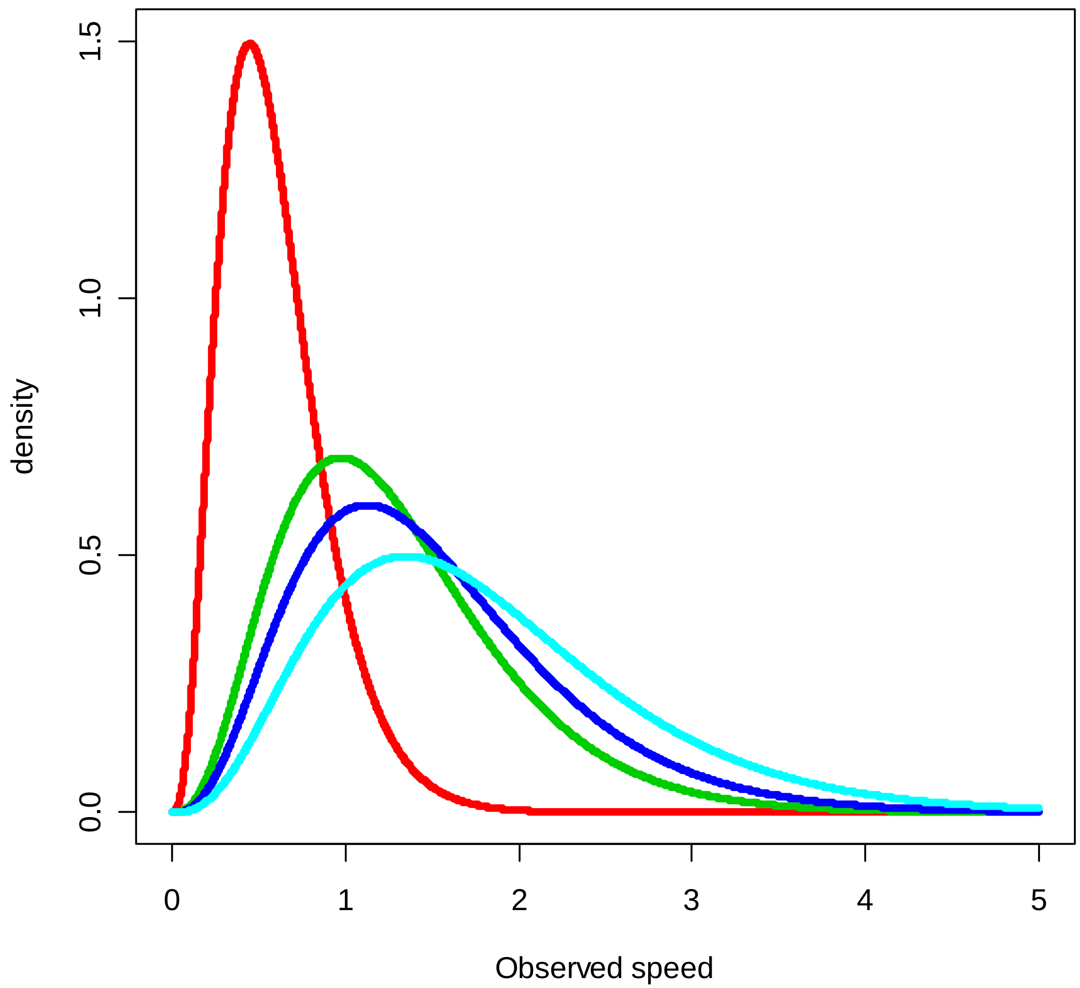
Observed speed



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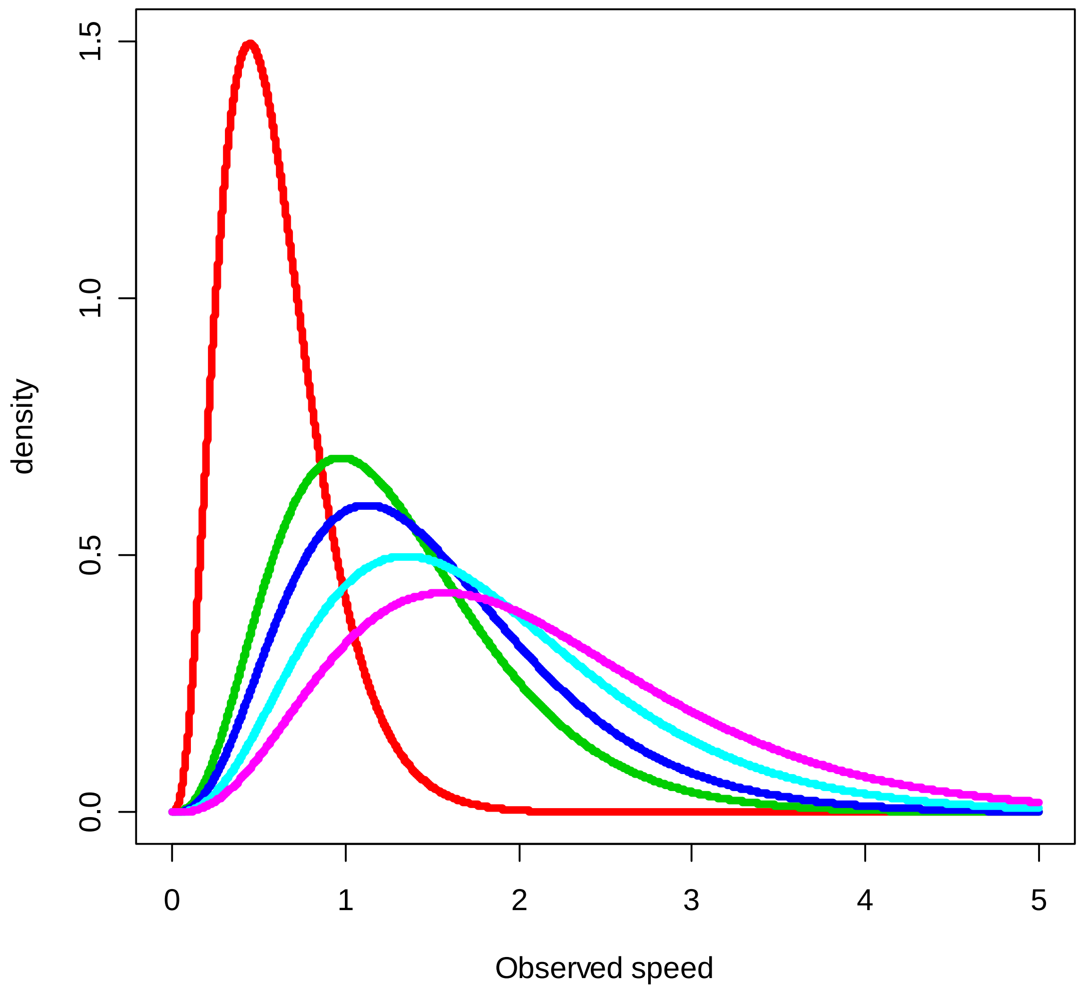

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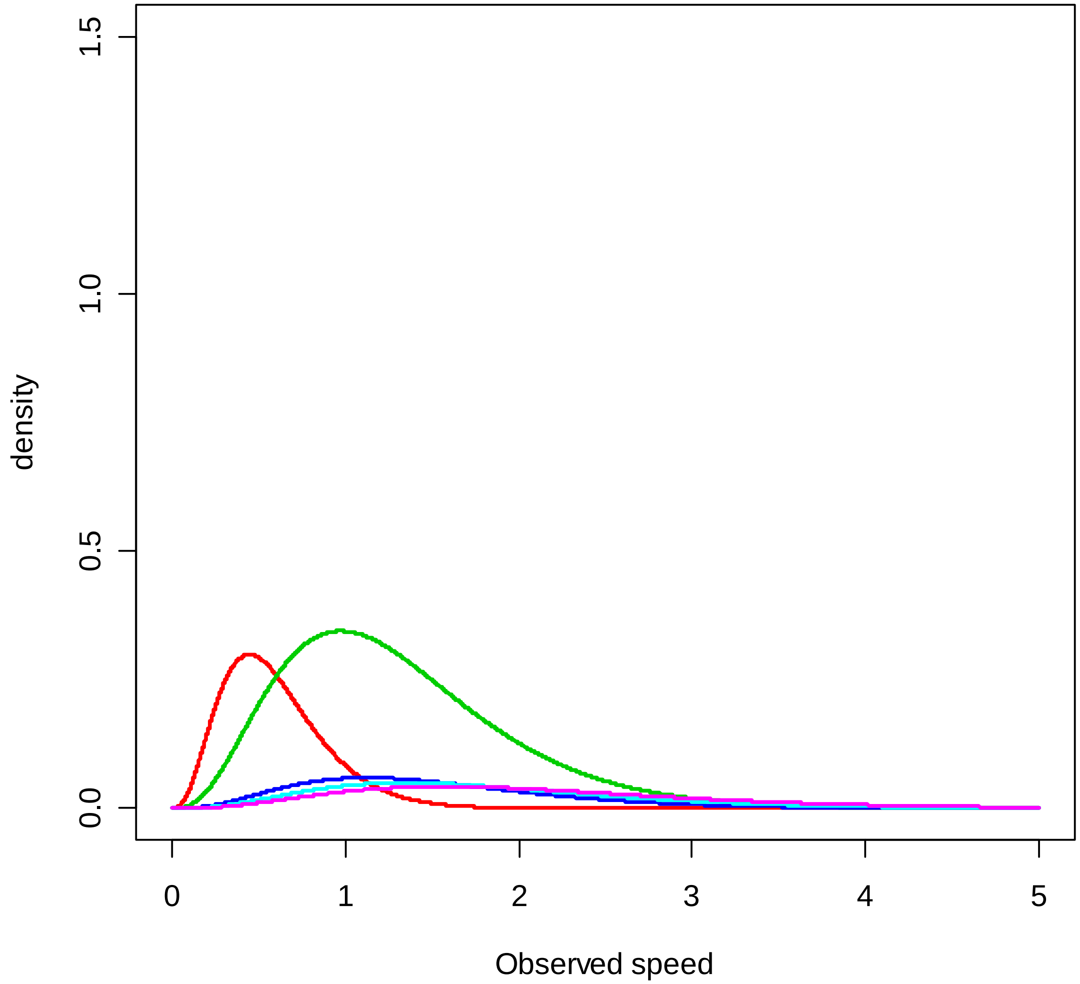
Observed speed

- Now, suppose further that we have assigned weights to each of these forecasts based on their performance over the past month
- Weights are 0.2, 0.5, 0.1, 0.1, and 0.1
- This tells us that the second forecast has been doing the best, the first has been the second best, and the third through fifth have been performing equally
- Scale each distribution by its weight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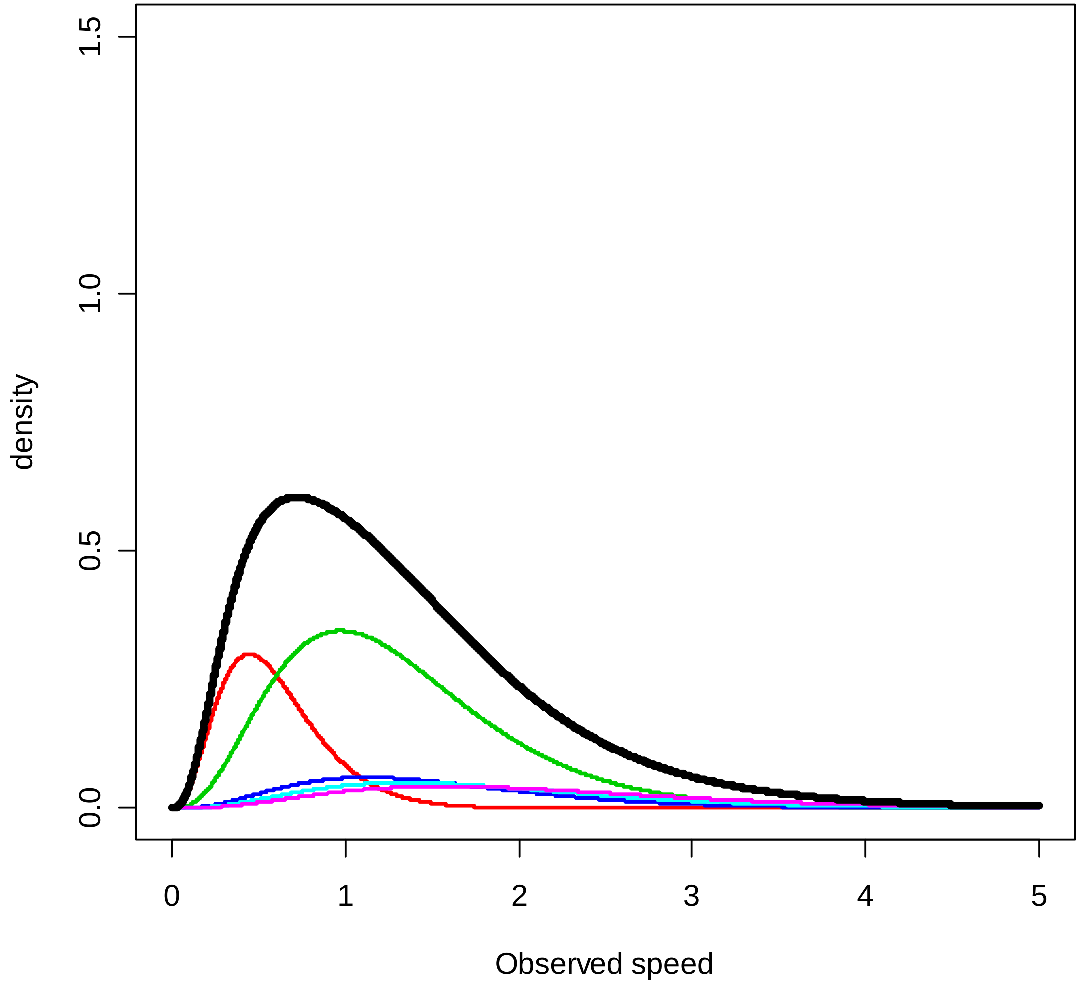
Observed speed

- Now add these together to get the overall forecast distribution


density
Observed speed
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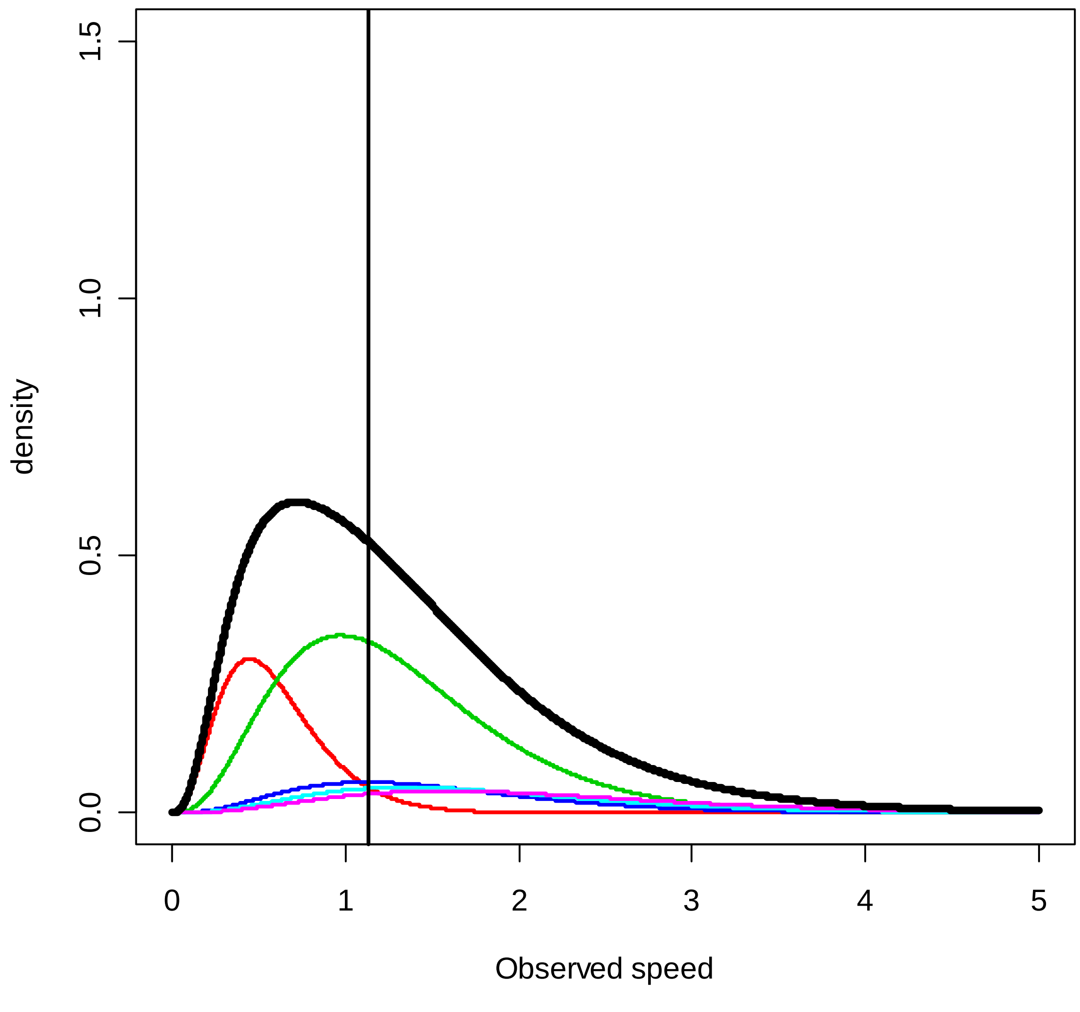
- The median of this distribution can serve as a deterministic forecast
- 1.14 knots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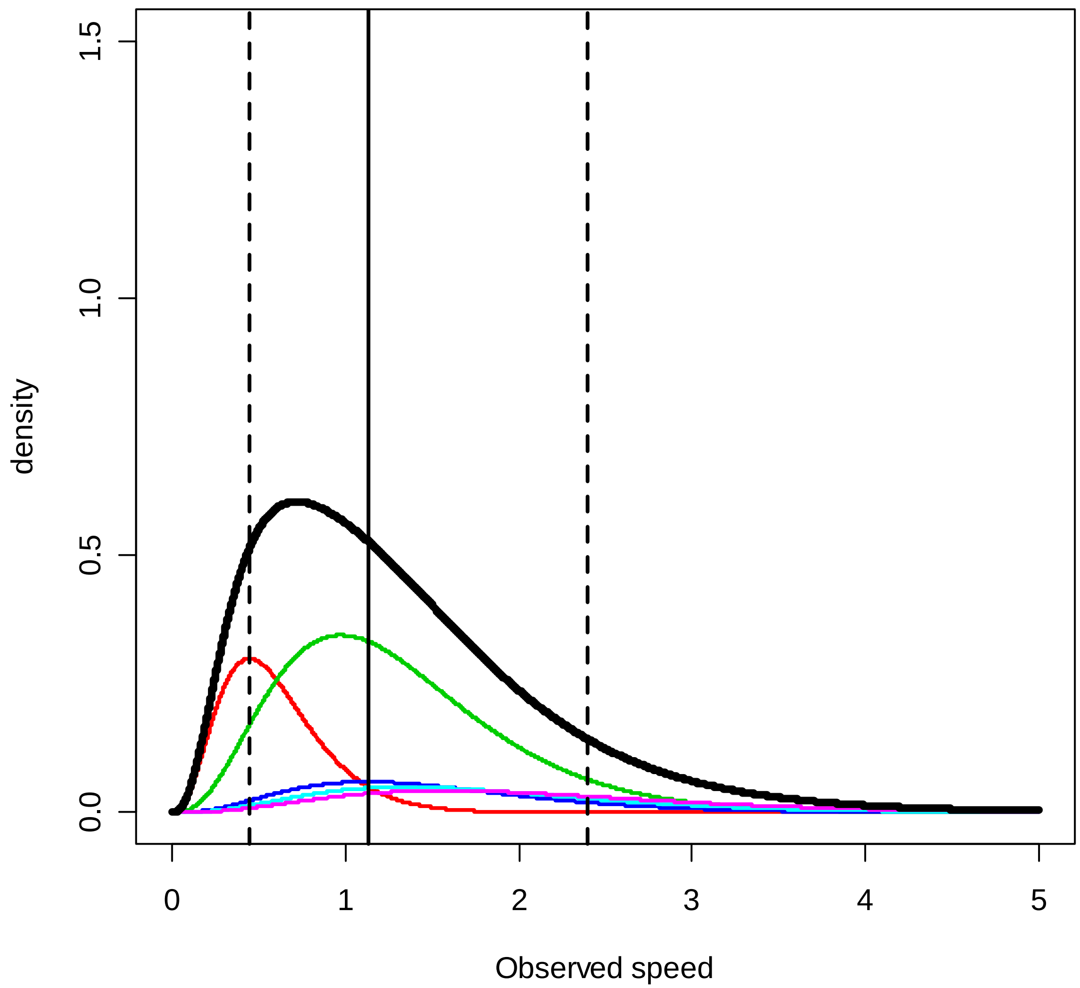
Observed speed

- We can take quantiles (say the 10^{th} and 90^{th} percentiles) of this distribution to create upper and lower bounds on our forecast
- 0.44 and 2.39 knots



density
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Observed speed

Wind Speed Modeling

- We fit the distributions as gamma distributions
- Mean and standard deviation are fit to be linear functions of the forecast amount
- Parameters for those functions, as well as the weights, are estimated using the EM algorithm (see Sloughter et al., 2007, Monthly Weather Review, for details on a similar model)

Results

- Fit model over all of 2003
- Using UW MM5 48-hour ahead forecasts of maximum wind speed over the Pacific Northwest

Results

- Using the ensemble median as a deterministic forecast gives an MAE of 4.25 knots
- Using the BMA median as a deterministic forecast gives an MAE of 3.59 knots

Results

- The Continuous Ranked Probability Score (CRPS) is an analogue of the MAE that takes into account probabilistic information
- The raw ensemble has a CRPS of 3.63
- The BMA forecast has a CRPS of 2.54

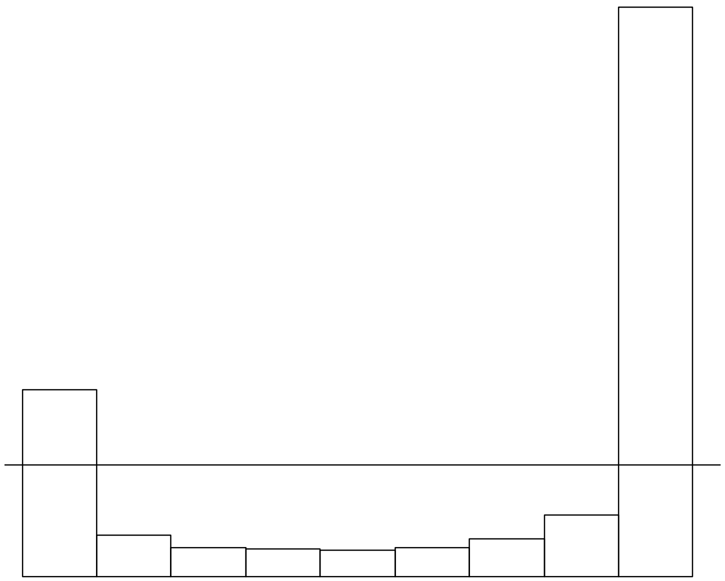
Results

- We can assess coverage and width of predictive intervals
- 78% predictive intervals from the raw ensemble averaged a width of 3.79 knots, but only included the observed value 25% of the time
- 78% predictive intervals from BMA averaged a width of 11.00 knots, and included the observed value 78% of the time

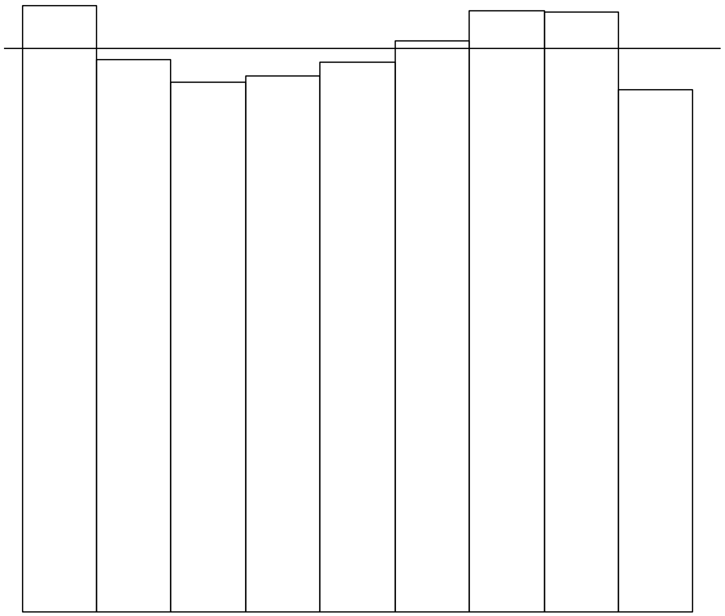
Results

- Calibration of the ensemble can be assessed by a verification rank histogram
- The analogue for a forecasted probability distribution is the probability integral transform histogram
- In both cases, the flatter the histogram, the better-calibrated the forecast

Results



Raw ensemble verification rank histogram



BMA probability integral transform histogram

Conclusions

- BMA can be used to combine information from multiple wind speed forecasts
- This combination provides a deterministic forecast which outperforms the original deterministic forecast
- BMA additionally provides calibrated probabilistic information, which can provide additional value to forecasts in a number of situations