A Probabilistic Method for the Estimation of Roughness Length and Displacement Height

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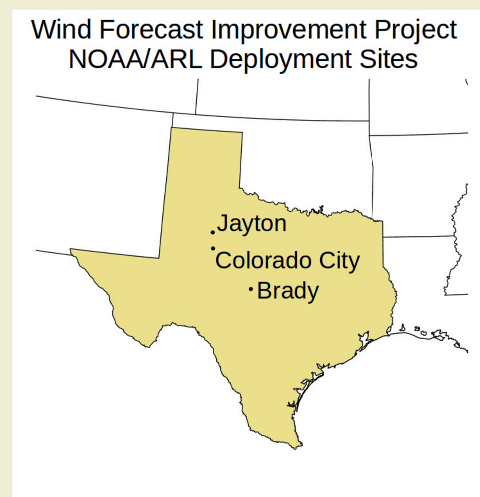
Background

As part of a wind-energy study called the Wind Forecast Improvement Project (WFIP), ARL installed meteorological towers, sodars, and a radar profiler at three sites in Texas. To evaluate wind forecasts at wind turbine hub height, we want to estimate the roughness length z_o and displacement height d at these sites, but there are significant uncertainties due to the site characteristics and issues with the observed wind profiles. Is there an objective way to determine the uncertainty of the z_o and d estimates?



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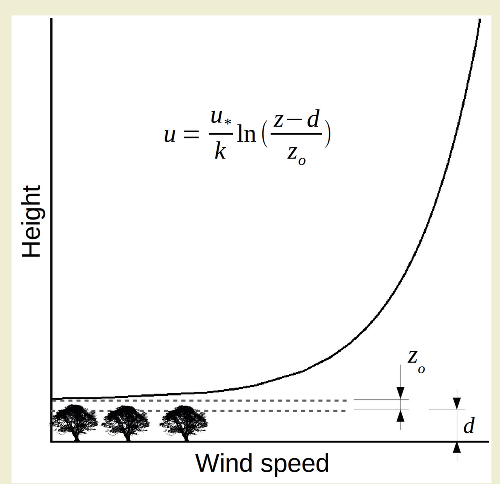
Research Objective

Develop probabilistic estimates of z_o and d using Bayesian data analysis

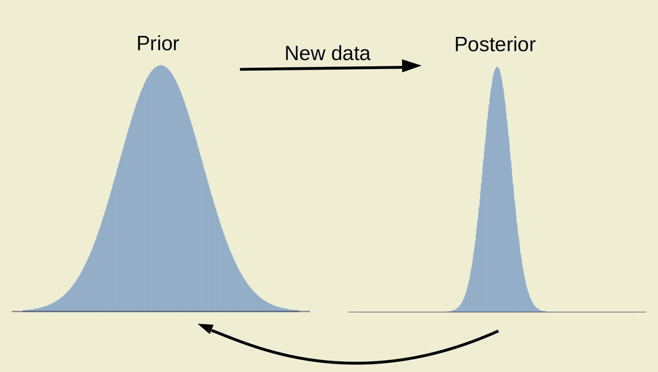


Bayesian Probability

Bayes' rule:

Posterior probability distribution $\propto$ Likelihood $\times$ Prior probability distribution

Prior distribution = Knowledge before collecting new data
Likelihood = Impact of new data
Posterior distribution = Knowledge after collecting new data



- Bayes' rule can potentially be repeated as additional data sets come in
- Noninformative (flat) priors can be used in cases where there is limited prior information
- In simple cases Bayesian probability gives the same results as conventional statistics; this often involves using noninformative priors
- Bayesian approach provides natural way to account for "nuisance parameters" that affect the results but are not of interest to the user

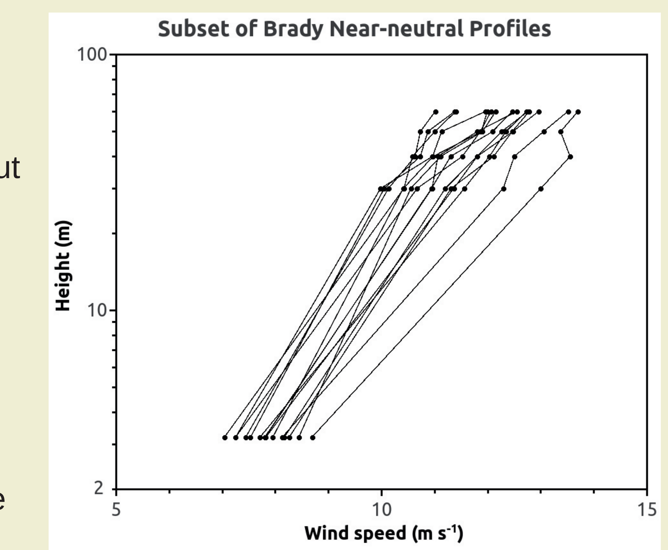
Method

In near-neutral conditions, the wind profile is assumed to follow a logarithmic law:

$$u = \frac{u_*}{k}\ln\left(\frac{z-d}{z_o}\right)$$

We develop a Bayesian regression model based on this equation in which the wind speed u is the response and the height z is the explanatory variable; the friction velocity u_*, roughness length z_o, and displacement height d are all unknown regression parameters. Observed winds are assumed to be normally distributed about the model with error variance σ^2.

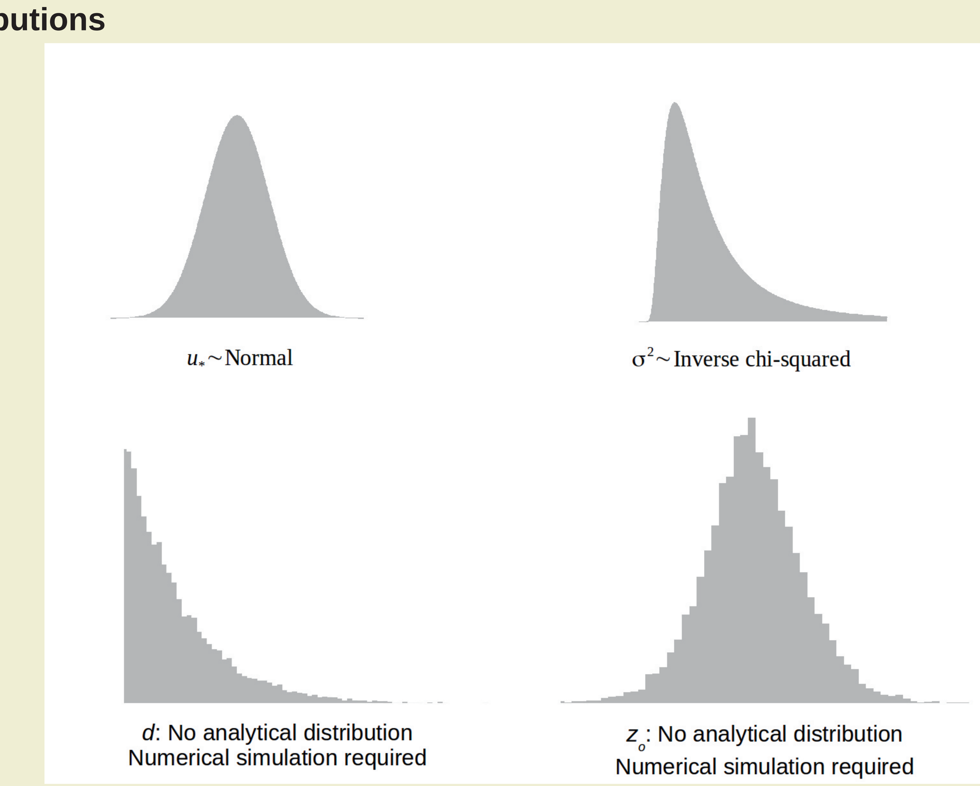
This regression model is not straightforward because each observed wind profile can have its own values of u_* and σ^2. If n near-neutral wind profiles are available for regression, we have $2n+2$ unknown parameters: n different u_* and σ^2 parameters together with z_o and d. The u_* and σ^2 values are "nuisance parameters" in that we are not particularly interested in their values, but they are still required for the regression computations.



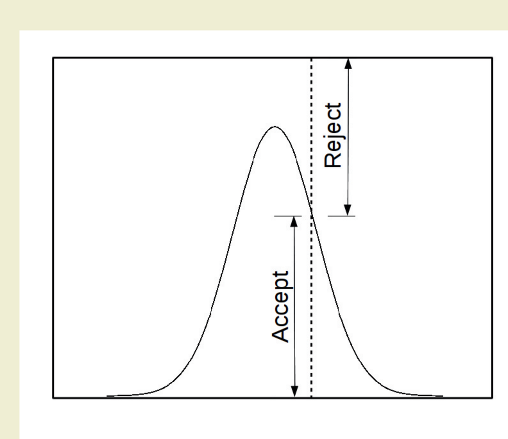
Bayesian Regression Assumptions

- Observed winds are normally distributed about the logarithmic wind profile with error variance σ^2. This specifies the likelihood as a normal distribution.
- All near-neutral wind profiles have the same values of z_o and d but possibly differing values of u_* and σ^2
- Noninformative prior distributions are used for all regression parameters. This could be changed in the future.

Conditional Posterior Distributions



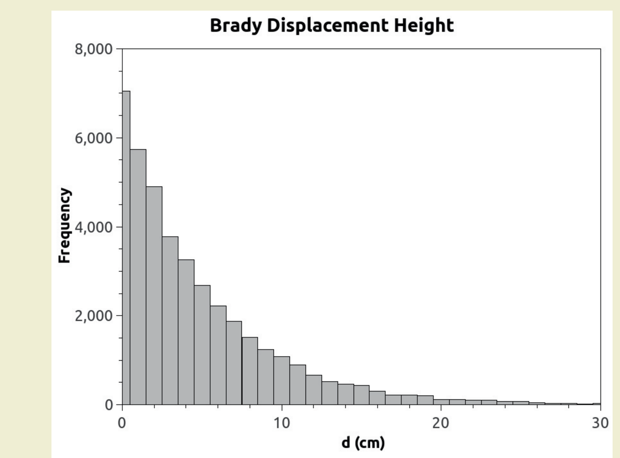
Numerical Simulation of Marginal Posterior Distributions

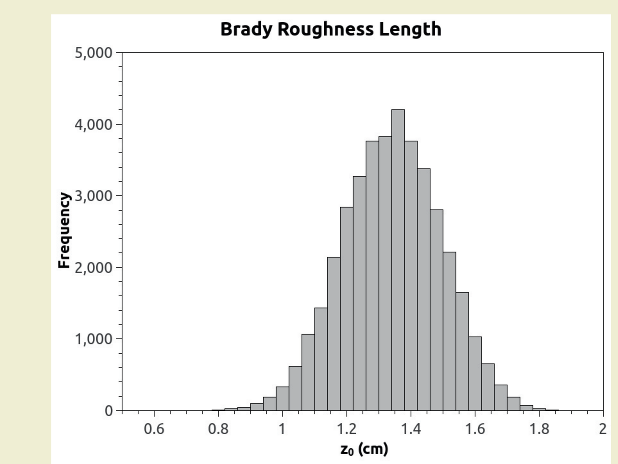


- Neither z_o nor d have simple analytical posterior distributions.
- Gibbs sampling algorithm used for u_* and σ^2.
- A Metropolis-Hastings algorithm is used to sample from the z_o and d posterior distributions. This is a form of rejection sampling.

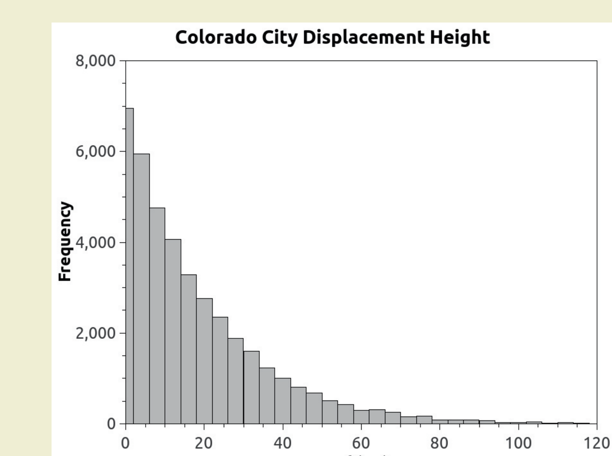
Results

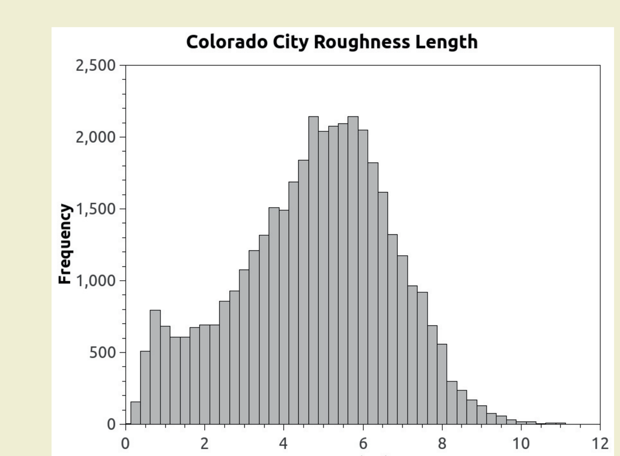
Brady (simple, smooth fetch)





Colorado City (more complicated fetch)





Summary

- Bayesian method provides full marginal probability distribution for z_o and d, not just point estimates
- Method can account for uncertainties related to fetch, limited data, or instrument mismatches
- Point estimates can be derived from median or mean values of distributions
- Results were used to evaluate wind profiles in Texas up to turbine hub heights in nonneutral conditions

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