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Modelling thickness variability in tephra deposition

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Analysis of tephra deposits is important for hazard and risk assessment of explosive eruptions due to its widespread impacts. Most studies describe tephra attenuation using numerical models based on advection-diffusion equations. We start from the Gonzalez-Mellado and De la Cruz-Reyna (2010) semi-empirical attenuation model. Here, the mean expected tephra thickness is estimated for a specific location as

$T(r,\xi) = \gamma \exp(-\beta U r\, [1-\cos(\xi-\phi)])\, r^{-\alpha}$

where T is the tephra thickness (cm) at distance from the vent r (km) in direction ξ. The effective volume γ, degree of wind dispersal βU, mean wind direction ϕ and attenuation rate α are parameters to be estimated.

Normally, isopachs are drawn to estimate the attenuation model, but this involves varying degrees of subjectivity. In a significant difference from common practice, our estimation uses actual individual tephra thickness measurements, rather than the derived isopachs. These thicknesses differ from an ideal (model) thickness due to randomness in the particle movements and to a lesser extent, landscape variability (which should be accounted for in the physical sampling process). This difference is termed the *sampling error* and can be explicitly incorporated in the estimation procedure. Since the thickness is strictly non-negative, and we expect a larger error for larger measurements, a multiplicative error structure is assumed. This suggests distributions such as the lognormal, Weibull and gamma to express this variability. The attenuation model is treated as a link function giving the expected thickness at a given location. The parameters in the model and the variance in the error distribution are estimated using maximum likelihood.

The 1973 Heimaey eruption was a typical small scale basaltic explosive eruption ideal for illustrating this method. While the Weibull and gamma fit the data well, the lognormal did not because of its tendency to require a number of greatly over-thickened measurements. Thus linear regression of the logarithm of thickness on distance is not an accurate means of predicting the expected tephra thickness. The estimated parameters from the other two error models were consistent with the observations made at the time of the eruption.

For multiple source eruptions, the model is implemented in a mixture framework to account for multiple lobes and/or vents. The source and direction of tephra deposits can then be identified from only the observed tephra thickness measurements. The Weibull distribution was used for the 1977 Ukinrek Maars eruption, which lasted for two weeks, producing two maars. The mixture attenuation model was able to identify lobes in the correct directions from each maar, matching the observed eruptive stages.