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Integrating geological, geochemical and geophysical data and uncertainties into a coherent 3D model

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Geoneutrino measurements by particle physicists provide the opportunity for geoscientists to build interdisciplinary bridges to solve open questions about heat production in our planet. Geoneutrinos are electron antineutrinos emitted in beta minus decays, with some from the ^{238}U and ^{232}Th decay chains having sufficient energy to be detected. These particles, originating from the crust and the mantle, are able to pass through most matter without interacting, so they can bring to surface useful information about the planet's composition. Their detection establishes the planet's radioactive element budget. Experimental results from ongoing (KamLAND and Borexino) and future experiments (e.g., SNO+, JUNO, Jinping) broaden their value if supported by a priori geophysical and geochemical models based on an integrated understanding and quantification of uncertainties. The mantle contribution to the geoneutrino signal at an individual detector cannot be pursued without critically combining multi-source uncertainties affecting the modeling and evaluating their correlation.

Thanks to 2 km of rock overburden and $\sim$1 kiloton of ultrapure liquid scintillator, the SNO+ detector (Ontario, Canada) is strategically designed for detecting low energy anti-neutrinos, and aims to reach several fundamental physics goals, among them the study of geoneutrinos. The geoneutrino signal produced by U and Th distributed is dominated by the closest lithologies in the surrounding 50 $\times$ 50 km of upper crust near SNO+ whose contribution is comparable with that of the whole mantle of the Earth. We focused on this crucial portion of Canadian Shield, and characterized nine distinct units based on lithology, metamorphism, tectonic events, and evolutional history. We developed a 3D numerical model defined by multiple geological and geophysical inputs (e.g., geological map, digital elevation models, cross sections deriving from seismic and gravimetric inputs) and the estimation error was inferred on the base of probabilistic geostatistical methods. A sampling campaign that was proportionally biased to the surface area distribution of lithologies and a statistical study of the frequency distributions, allowed for probing the normal and lognormal tendencies of the U and Th distributions, providing for each unit the central value and the uncertainties of the abundances.

Uncertainties in the predicted geoneutrino signal were estimated considering the degree of correlation between values for U and Th abundances. Monte Carlo simulations were conducted in order to propagated uncertainties assuming a bivariate normal distribution for the Probability Density Function's (PDF) describing the joint logarithmic U and Th distribution. The mentioned geochemical PDFs combined with the geophysical uncertainties are the input for building the total geoneutrino signal distributions from which the median and 1σ values are derived.