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Forward Monte Carlo screening of model space to constrain a salt dome structure

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Statistical schemes for the constraint of earth systems, such as Markov Chain Monte Carlo (MCMC) methods, are increasingly being employed to help quantify uncertainty and risk. These techniques generally require running a large number of forward simulations in order to build up a posterior probability distribution over the model space. Where prohibitively expensive forward simulation are required, such as climate modelling and universe simulation, emulators are used in order to adequately sample the often large model space. An emulator is a fast stochastic representation of a system, similar to a neural network, which rapidly predicts the output of a complex simulator by using an uncertainty-calibrated function. This method is tried and tested for problems where a single emulation is suffice but are largely ignored in favour of search-based algorithms such as MCMC because of the task of sampling the entire possible model space. Here we develop a novel method for joint emulation of several different physical responses of the same system to screen a multi-parameter model space for plausibility in a straightforward Monte Carlo scheme. Being Bayesian in nature, the method allows for objective update and understanding of beliefs about the system concerned.

After designing emulators for seismic, gravity and magneto-telluric (MT) forward simulators, we then generate candidate joint models (coupled by an one of two empirical uncertain relationships; one pertaining to halite and the other to sediment) across the model space and screen them, using the emulators, for plausibility against the observed dataset (in this case from a salt-dome structure). Commonly plausible models are stored and after a sufficient number have been found, we build new, better predictive emulators with which to perform further screening. This is repeated in a cyclic fashion until the emulator uncertainty function can be reduced no further. The result of the process is an ensemble of model parameter-sets representing the plausible model space given the observed data, all system uncertainties, and the emulator parameterisation. Using this method, rather than simply discerning the structure of the region in question in each of the velocity, resistivity and density parameter spaces, we can provide a direct answer to the question of whether a salt body exists at the location in question, presenting the result as a probability map.