Parameter Estimation for Climate Modelling

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Research Proposal

Much research effort has been spent on the modelling side of climate simulations, with simulation models for climate, such as the Met Office' HadCM3, becoming increasingly highly complex software constructions. It remains a difficult issue, however, to tune the parameters of such models in other than a heuristic manner as experience has mostly been considered sufficient for making parameter choices. The absence of parameter estimation by some mathematically-supported optimization routine is also due to the high cost and time of running climate simulations, making function evaluations very expensive and noisy. Furthermore, by contrast to data assimilation problems, it is apparently impossible here to perform any adjoint method for Jacobian estimation, implying that the derivatives — a crucial input required by many optimization routines — are highly inaccurate and that only low accuracy in the optimization process can be obtained. However, if meaningful changes to the climate models are to be possible to implement, or even experiment with, it is crucial to understand how changes to the parameters affect the models. Thus for a more robust parameter estimation, we have been investigating applying a data fitting procedure for finding optimal values of relevant parameters that yield model predictions (of reflected shortwave radiation and outgoing longwave radiation) that are consistent with observations of these quantities; the computed parameter values could then be incorporated in any runs of the climate model.

We have adapted standard optimization techniques such as steepest descent and Gauss-Newton [1] to this context, namely, when we have noisy and expensive function values and no derivatives information. These approaches had to be embedded into a suitable software structure that communicates with the GeoScience-managed version of HadAM3 and allows the latter to run in parallel for obtaining the input model values required by the optimization subroutines. Such a software infrastructure is now in place and we can include in it optimization subroutines of our choosing. Our preliminary testing shows secant (implicit-filtering-like [1]) Gauss-Newton techniques to be efficiently reducing the discrepancy between model outputs and observations to be within the noise level, without excessive costs in terms of function evaluations and for arbitrary initial choices of parameters [2]. Our numerical results also revealed an area in the parameter space where optimal parameter values lie, allowing us to 'discard' climate models that have suboptimal parameter choices outside of this area as being inconsistent with observations. Most importantly, we have found that the resulting 'optimal climate models' have a sensitivity to doubling of CO_2 in the atmosphere that is within a smaller range than that reported in the most recent IPCC assessment; this also allows us to ascertain with a higher degree of confidence than previously that higher values of climate sensitivities can be ruled out [2]. These promising preliminary conclusions now need to be consolidated into a robust approach.

In order to rigorously infer that climate sensitivities indeed lie in a prescribed interval and that higher values are highly improbable, we must ensure that with high probability, we have found all parameter solutions that yield model outputs consistent with observations (independent of the regularization of the ill-posed inverse problem). The optimization techniques we are currently using are able to find one such solution at a time, and starting the optimization routine from different initial values of the parameters often leads to finding different solutions. However, to span the set of solutions, we need to employ *global* optimization techniques; of particular interest are those based on building emulators — simplified approximations of the models — and their global minimization, as such approaches can be efficient in terms of function evaluation counts. This requires a re-design of the software infrastructure we currently have in place, as well as adapting, and if needed developing new, global optimization techniques for this context. Also, though we have used most of the relevant parameters (`entcoef`, `vf1`, `ct` and `rhcrit`) in our tests, we intend to incorporate all of the HadAM3 parameters (raising the variable count to at most 10); hence an optimization routine that is efficient in terms of evaluation counts is essential.

References

[1] J. Nocedal and S. J. Wright. *Numerical Optimization.* Second Edition, Springer, New York, 2006.

[2] S. F. B. Tett, M. Mineter, C. Cartis, D. Rowlands, and P. Liu. Constraining climate sensitivity using top of atmosphere radiation measurements. 2011; 32 pages. Available upon request.