

# Review of egusphere-2022-875: *Differentiable Programming for Earth System Modeling*

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Reviewer: Sam Hatfield, ECMWF

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Verdict: **Accept as is**

In this review the authors present a strong, comprehensive, yet succinct argument for developing differentiable Earth system models. The benefits of differentiability are discussed in the contexts of model parameter tuning, uncertainty quantification, and “hybrid” Earth system models, in which tools from machine learning are interfaced with a traditional model online. Some difficulties that may be encountered in practice are also outlined. Overall the manuscript serves as an excellent introduction to the ideas behind differentiability and would make for a useful reference in the literature as this idea gains traction. I would be happy to accept the manuscript as-is. Reading the manuscript, I did have some comments, but these are just left for the authors’ consideration and are not actionable:

- Speaking as someone who works with an operational weather prediction system that relies on a variational data assimilation algorithm, 4D-Var, I am most interested in the idea of differentiability in the context of tangent-linear and adjoint model generation. An inherently differentiable model could in principle obviate the need to hand-code tangent-linear and adjoint versions of the nonlinear forecasting model, and the authors briefly discuss this in Section 4. This was also the motivation behind my paper on neural network-based tangent-linear and adjoint models which the authors kindly cited. This idea could be expanded upon as a fourth benefit for differentiability in addition to those in Section 5. However I think in that case it would be wise to consult someone with direct experience with data assimilation development at ECMWF (Alan Geer would be the best person). There have been efforts to apply established automatic differentiation tools to the ECMWF model source code in the past, but as far as I know none of these amounted to anything useful, and ECMWF still relies on completely handwritten tangent-linear and adjoint code.
- Are the authors aware of the work of Stephan Hoyer, Peter Norgaard, Dmitrii Kochkov, and others at Google? If I understand both their work and this manuscript correctly, they are essentially attempting to do just what the authors propose. They have already published on direct numerical simulation of fluid flow, but they are currently developing a differentiable spectral general circulation model in JAX-CFD with learned physics. I don’t believe there is anything citable on this work yet, but it’s worth keeping an eye on it.