**Fast Super-Parameterization via Neural Net Emulation**

**FAST VS ACCURATE:** Physical parameterizations have to be simple to be fast. But super-parameterization demonstrates more accurate parameterizations can significantly improve climate predictions [1]. With neural-network (NN) emulation [2] it is possible to achieve super-parameterization quality with no reduction in model throughput.

**A NONLINEAR MAP:** Physical parameterizations are nonlinear maps from state variables to forcing terms (sources/sinks) in a column. This is precisely the kind of things neural nets are designed to do. By generating thousands of state/forcing pairs, the neural net can be trained to accurately emulate the super-parameterization. At run time, the parameterization costs no more than a single evaluation of the NN. Neural Net emulation has been applied to the long-wave and short-wave radiation parameterizations in CCSM by Krasnopolsky and Rabinovitz, with good results.[3]

**SCALE AWARE:** By expanding the input vector to include length and time scales, and expanding the training data to cover the output of models at multiple scales, it may be possible to construct a single NN emulation valid across multiple scales.

**CHALLENGES:** Open questions remain in how to determine the optimal network structure and training data set needed to achieve adequate state-space coverage.

![U, V, T, P, Q](image)

![F_U, F_V, F_T, F_P, F_Q](image)

**Improved Topography with Immersed Boundaries**

**MESH DISTORTION:** Terrain following grids cause mesh distortion in vertical coordinate surfaces above steep orography. [4] Imperfect cancellation of geopotential-gradient and pressure-gradient forces produces numerical errors. This causes spontaneous generation of velocity fields and prevents steady state solutions in mountainous regions [5]. The problem gets worse as simulation resolution increases and resolved mountain slopes become steeper.

**THE IB TECHNIQUE:** Immersed boundaries (IB) offer a potential solution to this problem. The IB technique is commonly used in aerospace to represent complex geometries. Boundary conditions are enforced by setting field values beneath the surface. Field values at immersed points (black) are obtained by reflecting about the immersed boundary (yellow) and interpolating field values at matching fluid points (white). No mesh distortion is produced and the mesh need not be changed as resolution is increased. IB techniques can even handle topography that moves over time due to melting glaciers or shifting coastlines. This approach has been applied successfully in WRF [6].

**CHALLENGES:** Some physical parameterizations implicitly expect field values at terrain following coordinates, with the lowest point directly at the boundary. Thus fields must be projected onto the terrain following mesh, or those parameterizations need to be altered.

**Automated Discovery of Scale-Aware Parameterizations**

**BEFTER PARAMETERIZATIONS:** The automated discovery of equations of motion from data is another possible route to achieving improved physical parameterizations.

**SPARSE REGRESSION:** Brunton et al [7] demonstrated a fast technique for identifying analytic equations of motion from iterative sparse regression of time-sampled data including the chaotic Lorenz system. By applying this technique to data generated by DNS, large eddy simulations, and convection-permitting simulations, it should be possible to construct accurate phenomenological approximations directly from data.

**SCALE AWARE:** Sampling simulation data from simulations at multiple scales should enable extraction of scale aware approximations as well. It would be interesting to compare the trade-offs of this approach with the neural net emulation technique outlined above.

**CHALLENGES:** This approach works best with a small set of dynamic variables. This requires research into dimensional reduction techniques for generating low order basis functions from gridded data.

**References**


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