Fast and Accurate Approximation of the Long Wave Radiation Parameterization in a GCM Using Neural Networks: Evaluation of Computational Performance and Accuracy of Approximation in the NCAR Single Column Model

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A new approach using neural networks was applied to develop a fast and accurate approximation of atmospheric long wave radiation parameterization used in numerical climate and weather prediction models. The long wave radiation is usually the most time consuming part of model physics calculations.

NN approximations of model physics are based on the fact that any parameterization of physics can be considered as a continuous or almost continuous mapping (input vector vs. output vector dependence), and NNs are a generic tool for approximation of such mappings [*Krasnopolsky and Chevallie, 2003*] . NN is an analytical approximation that uses a family of functions like:

$$y_q = a_{q0} + \sum_{j=1}^{k} a_{qj} \cdot \phi(b_{j0} + \sum_{i=1}^{n} b_{ji} \cdot x_i); \quad q = 1, 2, \ldots, m \tag{1}$$

where x_i and y_q are components of the input and output vectors respectively, a and b are fitting parameters, and ϕ is a so called activation function (usually it is a hyperbolic tangent), n and m are the numbers of inputs and outputs respectively, and k is the number of neurons in the hidden layer (for more details see appendix in [*Krasnopolsky et al., 2002*]).

The function of the LW radiation parameterization in atmospheric GCMs is to calculate heat fluxes cased by LW radiation processes in the atmosphere. In the NCAR CAM LWR parameterization [*Collins et al., 2002*] used in this study, the calculations of cloudiness are completely separated from the calculations of radiation effects. Due to this structure convenient for NN approximation, we are able to approximate the entire LW radiation parameterization with only one NN, with cloudiness used just as one of the inputs of this NN.

The NN developed for approximation of the LW radiation parameterization has 101 inputs (n = 101 in eq. (1)), which include seven profiles (atmospheric temperature, humidity, ozone concentration, path length for CO_2, path length for H_2O, and cloudiness) and two relevant surface characteristics (surface pressure and the upward LW flux at the surface). This NN has 19 outputs (m = 19 in eq. (1)): a profile of the heat rates (HRs) $\{q_k\}_{k=1,\ldots,18}$ and downward LW flux to the surface. The NN has one hidden layer with 90 neurons (k = 90 in eq. (1)) that provide the sufficient accuracy of approximation.

For this initial experiment, a representative data set consisting of about 100,000 input/output combinations has been generated using the 19-level NCAR single column model with the physics identical to that of NCAR CAM-2. This model simulation data set covers the entire year of 2002. It was divided into three parts each containing about 33,000 input/output combinations. The first part was used for training, the second one was used for tests (control of overfitting, control of a NN architecture, etc.), and the third part was used for validations only.

Table 1 shows a bulk validation statistics for the accuracy of approximation and computational performance of our NN approximation and also the comparison with the accuracy and performance of the successful ECMWF NeuroFlux approximation [*Chevallier et al., 2000*]. NN approximations have been evaluated against the original parameterizations. For calculating the error statistics presented in Table 1, the original parameterization and its NN approximation have been applied to validation data. Two sets of the corresponding HR profiles and two sets of outgoing long wave radiations (OLRs) (for the original parameterization and its approximation) have been generated. Bias (or the mean error) and RMSE presented in Table 1 have been calculated as the mean differences between these two sets of HRs and OLRs. Mean values and standard deviations (σ) of HRs and OLRs are also presented for a better understanding of relative errors. The ECMWF results are also shown for comparison. Our NN approximation has very high accuracy with an almost negligible systematic error (bias). Most importantly, that in addition to that it performs 65 times faster than the original parameterization. This speed-up is achieved for NN approximation of the entire LW radiation scheme that includes calculations of optical properties (emissivity and absorptivity), and HRs and radiative fluxes.

Table 1. Accuracy and Computational Performance of LW NN Approximation for NCAR CAM-2 and the ECMWF Model vs. their Corresponding Original Parameterizations

Parameter	Model	Bias	RMSE	Mean	σ	Performance
HR (*K/d*)	ECMWF	0.2	0.45			8 times faster
	NCAR	0.00002	0.05	-1.43	1.76	65 times faster
OLR (*W/m*^{2})	ECMWF	0.8	1.9			
	NCAR	0.01	0.9	240.5	46.9	

The obtained results show that the NN approximation of the considered atmospheric LW radiation parameterization is highly accurate and provides a significantly improved computational efficiency. It opens the opportunity of a complete reexamination of computations for all model physics components in NCAR CAM. This in turn will potentially make an important positive impact on extensive experimentation with this kind of complex models needed for improving climate change assessments and weather prediction. The developed methodology can be applied to other LW radiation schemes used in the variety of applications.

Currently, we are working on development of NN approximation of the LW radiation for NCAR CAM and producing climate simulation results using this NN approximation. The preliminary results show that the parallel NCAR CAM climate simulations, performed with the original LW radiation parameterization and its NN approximation, are very close to each other [*Krasnopolsky et al., 2004*]. Results of this study will be submitted to the next issue of this report.

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