Decadal Climate Simulations with NCAR CAM Using Accurate and Fast Neural Network Emulation of Full, Long- and Short Wave, Model Radiation

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The approach to calculation of model physics using neural network (NN) emulations, previously proposed and developed by the authors, has been implemented for decadal climate model simulations. NN emulations 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 et al. 2002*]. NN is an analytical approximation that uses a family of functions like:

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

where x_i and y_q are components of the input and output vectors respectively, a and b are fitting parameters, and hyperbolic tangent is a so called activation function, 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 long-wave and short-wave radiation (LWR and SWR) parameterizations or the *full model radiation* [*J. of Clim. 1998 and the references to W. Collins therein*], the most time consuming component of model physics, have been emulated with neural networks (NN) for the NCAR CAM-2. The developed highly accurate NN emulations for LWR and SWR are two orders and one order of magnitude faster than the original/control NCAR CAM LWR and SWR, respectively [*Krasnopolsky et al. 2005, 2006*]. The NN emulations using 50 neurons in the hidden layer provide, if run *separately* at every model physics time step (1 hour), the speed-up of ~ 150 times for LWR and of ~ 20 times for SWR as compared with the original LWR and SWR, respectively. Using NN emulations *simultaneously* for LWR and SWR or for the full model radiation, results in a significant, ~ 13 times, acceleration of calculations of the entire/full model radiation block. It is worth clarifying that for the control run, the original LWR (including time consuming optical properties calculations) is calculated less frequently, only every 12 hours or twice a day, and only computationally inexpensive heating rates and radiative fluxes are calculated every hour. For the model run using NN emulations, LWR (including both optical properties and heating rates and radiative fluxes) is calculated more frequently, every hour, that is more consistent with SWR and other model physics calculations.

The results of decadal climate simulations performed with NN emulations for both LWR and SWR, i. e., for the full model radiation, have been validated against the parallel control NCAR CAM simulation using the original LWR and SWR. The almost identical results have been obtained for these parallel 40-year climate simulations (Fig. 1). (Note that the first 10 years of simulations are not included in validation to avoid the impact of spin-up effects, so that years 11-50 are used for validation.)

The temperature distributions for the parallel runs are close to each other and their deviation or mean bias is practically zero, with minimum and maximal biases within ~ 2-2.5 K by magnitude, that is comparable with typical observation errors (as a reference). Close similarity has been also obtained for other model prognostic and diagnostic fields.

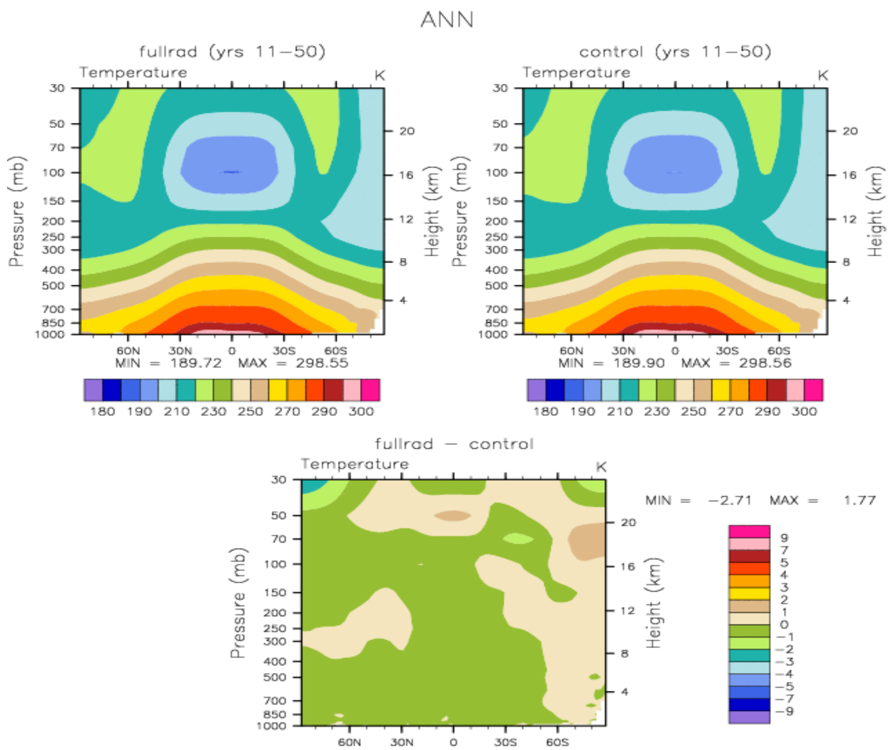

Fig. 1 Zonal mean vertical distribution of temperature, in K, for the 40-year period of NCAR CAM simulations with the NN emulations for the full model radiation (the upper left panel), the control (the upper right panel), and their difference or bias.

The obtained results open the opportunity of using efficient neural network emulations for full model radiation for decadal and longer climate simulations as well as for weather prediction models. The developed methodology can be applied to other LWR and SWR schemes used in the variety of models, process studies, and other applications.

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