J3.3 ACCURATE AND FAST NEURAL NETWORK EMULATION OF FULL, LONG- AND SHORT WAVE, MODEL RADIATION USED FOR DECADAL CLIMATE SIMULATIONS WITH NCAR CAM

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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 with the National Center for Atmospheric Research (NCAR) Community Atmospheric Model (CAM). 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*]).

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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.

Statistics	**LWR NN 50**	**SWR NN 55**
Bias (K/day)	$3. \cdot 10^{-4}$	$-4. \cdot 10^{-3}$
RMSE (K/day)	0.34	0.19
PRMSE (K/day)	0.28	0.15
$Bias_{26}$ (K/day)	0.20	$-5. \cdot 10^{-3}$
$RMSE_{26}$ (K/day)	0.86	0.43
Performance (times faster)	150	20

Table 1. Statistics estimating the accuracy of HRs (in K/day) calculations and computational performance for NCAR CAM-2 LWR and SWR using NN emulation vs. the original parameterization. $Bias_{26}$ and $RMSE_{26}$ (in K/day) correspond to the lowest layer.

Table 1 shows bulk validation statistics for the accuracy of approximation and computational performance for the best (in terms of accuracy and performance) developed NN emulations: NN 50 (k = 50 hidden neurons in eq.(1)) for the LWR emulation and NN 55 (k = 55 hidden neurons in eq.(1)) for the SWR emulation.

Field	**GCM with the original LWR and SWR Parameterizations**	**GCM with LWR and SWR NN Emulations**	**Difference in %**
Mean Sea Level Pressure (*hPa*)	1011.48	1011.50	0.002
Surface Temperature (°*K*)	289.02	288.92	0.03
Total Precipitation (*mm/day*)	2.86	2.89	1.04
Total Cloudiness (*fractions, %*)	60.71	61.12	0.6
Wind at 12 km *(m/s)*	16.21	16.29	0.5

Table 2. Time (40-years) and global means for model diagnostics from NCAR CAM-2 climate simulations with the original LWR and SWR, their NN emulations using NN 50 (LWR) and NN 55 (SWR), and their differences in %.

For definitions of the error statistics (Bias, RMSE, PRMSE, etc.) see [*Krasnopolsky et al., 2005*].

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, Krasnopolsky and Fox-Rabinovitz 2006a,b*]. The NN emulations using 50 neurons for the LWR NN emulation and 55 neurons for the SWR NN emulation 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.

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 (Table 2). (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 time and global mean mass or mean surface pressure are precisely preserved, which is the important property for climate simulations. There is a negligible difference in mean sea surface pressure between the NN and control runs. Other time global means, some of which are also presented in Table 2, show a profound similarity between the parallel simulations for these terms. It is noteworthy that the temporal variability, in terms of time series

for model prognostics and diagnostics, annual cycle and other characteristics, is also very close for the parallel runs.

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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