Accurate and Fast Neural Network Full Radiation for the NCEP Climate Forecast System Model

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The approach to calculation of model physics, using accurate and fast neural network (NN) emulations, has been previously proposed, developed and thoroughly tested by the authors for NCAR CAM [*Krasnopolsky et al. 2005, 2008*]. In this study the NN approach has been introduced and tested in the NCEP climate forecast system (CFS) model which is a coupled atmosphere–ocean model with significantly higher resolution, namely for T126 spectral horizontal and high vertical (L = 64 layers) resolutions. Because full model radiation is composed of two, long wave (LW) and short wave (SW), radiation parameterizations which are mappings between their inputs and outputs, NNs can be used to emulate both of these mappings. NNs learn the mappings during the NN training utilizing a training data set which was simulated using the NCEP CFS model run with the original radiation parameterizations.

The model radiation is the most time consuming component of model physics in CFS [e. g. Morcrette et al. 2008]. In this study, the NN emulations have been developed and tested for the original RRTM long-wave radiation (LWR) and short wave radiation parameterizations for the CFS model [*Mlawer et al.* 1997].

Table 1. Statistics estimating the accuracy of heating rates (HRs) (in K/day) calculations and computational performance for NCEP LWR and SWR using NN emulations vs. the original parameterization. Also, layer statistics for the top ($bias_H$ and $RMSE_H$ in K/day) and the bottom ($bias_L$ and $RMSE_L$ in K/day) atmospheric layers are included to illustrate the accuracy of NN emulations in the areas of the increased non-linearity [Morcrette et al. 2008].

NN	Bias (K/day)	RMSE (K/day)	PRMSE (K/day)	$\mathbf{Bias_L}$ (K/day)	$\mathbf{RMSE_L}$ (K/day)	$\mathbf{Bias_H}$ (K/day)	$\mathbf{RMSE_H}$ (K/day)	Times Faster
LWR	$2 \cdot 10^{-3}$	0.49	0.39	$6. \cdot 10^{-3}$	0.64	$-9. \cdot 10^{-3}$	0.18	12
SWR	$5. \cdot 10^{-3}$	0.20	0.16	$9. \cdot 10^{-3}$	0.22	$1. \cdot 10^{-2}$	0.21	45

Table 1 shows bulk validation statistics for the accuracy of approximation and computational performance for the developed LWR and SWR NNs emulations. The accuracy of NN emulations is estimated against the original CFS LWR and SWR. For definitions of the error statistics (Bias, RMSE, PRMSE, etc.) see [*Krasnopolsky et al., 2005*]. PRMSE shown in the Table is the RMSE for the entire profile. For these NN emulations, bias is negligible and RMSE is limited. Obtaining very small NN emulation biases is important for providing non-accumulating errors in the course of model integrations using NN emulations. There is no significant increase in the errors in the areas of the increased non-linearity [Morcrette et al. 2008] (the top the bottom layers). The developed highly accurate NN emulations for LWR and SWR, in terms of code-by-code comparison at each model time step when radiation is calculated, are about 12 and 45 times faster than the original/control NCEP CFS LWR and SWR respectively.

The LWR and SWR NN emulations have been validated in 17-year (1990-2007) CFS run. The comparison of time averaged (for the first four seasons and for 17 years) of model prognostic and diagnostic fields shows a close similarity for the parallel runs performed with LWR and SWR NN emulations and with the original LWR and SWR (the control run). The difference between 17-year mean SST fields (NN – control runs) is presented in Fig. 1 (left panel). The difference is close to zero and does not exceed ± 0.5 K. The difference between 17-year mean precipitation rate fields (NN – control runs) is presented in Fig. 1 (right panel). The difference is small and does not exceed ± 1 mm/day except for a few spots in the tropics where it is within ± 3 mm/day . Similar results are obtained for other prognostic and diagnostics fields [Krasnopolsky et al. 2009].

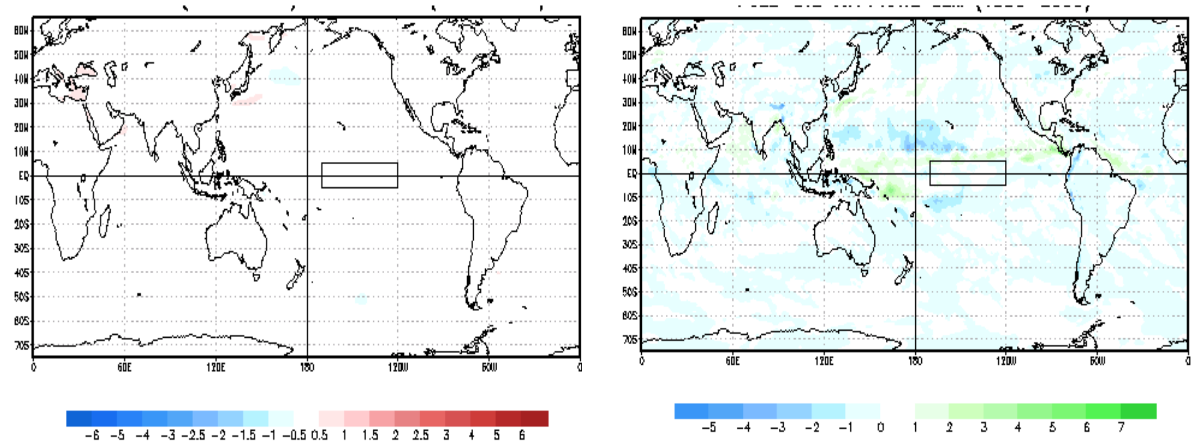

Fig. 1 The time mean (1990-2006) statistics for winter for the difference between the full radiation NN run and the control. The left panels: the SST statistics in K. The right panels: the precipitation rate statistics in mm/day.

In this study we demonstrated that our NN emulation approach provides a sufficient accuracy and speed of radiation calculations to be used in high resolution state-of-the-art coupled models like NCEP CFS and that it is significantly less dependent (in terms of both the accuracy and speed) on the increase of the vertical resolution than “NeuroFlux” for which at vertical resolution of 60 layers and more, both accuracy and rapidity could not be kept at once [Morcrette et al. 2008]. The further steps will include refinement of NN emulations for the CFS model, introduction of the concept of a compound parameterization including a quality control procedure**,** and the NN ensemble approach.

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