# Accurate and Fast Neural Network Emulations of Long Wave Radiation for the NCEP Climate Forecast System Model: Preliminary Results

V.M. Krasnopolsky[1,2], E-mail: Vladimir.Krasnopolsky@noaa.gov,
M. S. Fox-Rabinovitz[2], S. J. Lord[1], Y.-T. Hou[1], and A. A. Belochitski[2]
[1]Environmental Modeling Center, NCEP/NOAA,
[2]Earth System Science Interdisciplinary Center, University of Maryland, USA

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. NN emulations of model physics approximate the functional dependence between inputs and outputs of a parameterization. They learn this functional dependence during the NN training utilizing a training data set which was simulated using the original parameterization.

The model radiation is the most time consuming component of modelphysics in CFS. This study is the first step in developing the NN emulations of the full CFS model radiation. Namely, the NN emulations have been developed and tested for the original long-wave radiation (LWR) parameterization 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 using NN emulation vs. the original parameterization. $Bias_0$ and $RMSE_0$ (in K/day) correspond to the lowest layer. NN60, NN75, and NN85 denote NN emulations with k = 60, 75, and 85 in eq. (1), respectively.*

| NN | Bias (K/day) | RMSE (K/day) | PRMSE (K/day) | $Bias_0$ (K/day) | $RMSE_0$ (K/day) |
|---|---|---|---|---|---|
| NN 60 | $6. \cdot 10^{-3}$ | 0.44 | 0.35 | $1. \cdot 10^{-3}$ | 0.68 |
| NN 75 | $1. \cdot 10^{-3}$ | 0.40 | 0.30 | $-1. \cdot 10^{-2}$ | 0.57 |
| NN 85 | $3. \cdot 10^{-3}$ | 0.39 | 0.30 | $2. \cdot 10^{-2}$ | 0.57 |

Table 1 shows bulk validation statistics for the accuracy of approximation and computational performance for the some developed NNs emulations. The accuracy of NN emulations is estimated against the original CFS LWR. 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. The developed highly accurate NN emulations for LWR, in terms of code-by-code comparison at each model time step when LWR is calculated, are about two orders of magnitude faster than the original/control NCEP CFS LWR.

The next step is validation of LWR NN emulation in the CFS model integrations. The LWR emulation NN75 was selected for such an initial validation in the CSF model runs because it seems to be acceptable in terms of both its accuracy and minimal complexity. The results of the 2-year (2005-2006) CFS model integration performed with NN75 emulation have been validated against the parallel control NCEP CFS model integration using the original LWR. The comparison of instantaneous model prognostic and diagnostic fields produced for the first week of model integrations shows that the differences are comparable with observational errors or uncertainties of data analysis. The comparison of time averaged (for the first four seasons and for two years) model prognostic and diagnostic fields shows a close similarity for the parallel runs. The 2-year mean

upward LWR flux at the top of the atmosphere presented in Fig. 1 shows similar distributions for the parallel runs (the left and center panels), with small differences or bias (the right panel). Bias for the extratropics is close to 0 and does not exceed by magnitude 5 W/m² within just a few spots. Bias in the tropics is also limited to the ±5 W/m² range and does not exceed by magnitude10 – 15 W/m².

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 [Krasnopolsky et al. 2008], and the NN ensemble approach [Fox-Rabinovitz et al. 2006]. The developed methodology will be applied to short wave radiation to obtain NN emulations for the full/entire radiation block of the CFS model. The NN emulations will be also applied and validated for the GFS 10-day forecasts.

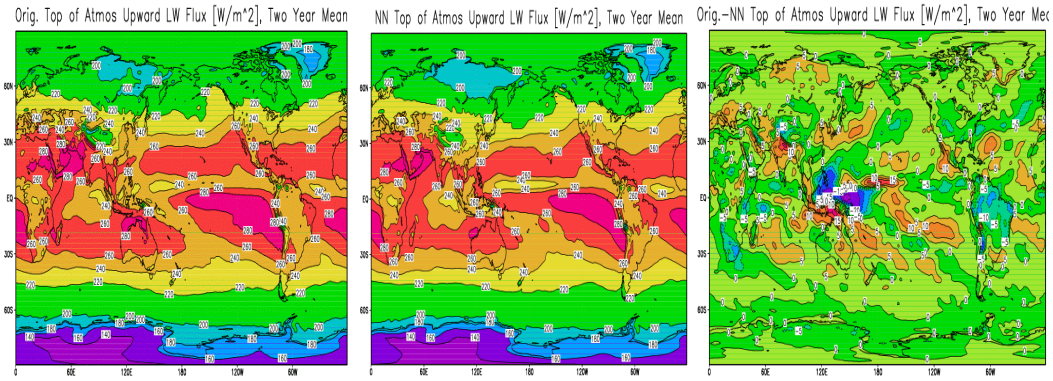


Fig. 1 2-year mean upward LWR flux at the top of the atmosphere, in W/m², for the CFS model integrations with: the original LWR (the left panel), the LWR NN75 emulation (the center panel), and their difference or bias (the right panel). The contour interval for the left and center panels is 20 W/m², and for the right panel is 5 W/m².

**Acknowledgments** The authors would like to thank Drs. H.-L. Pan, S. Saha, S. Moorthi, and M. Iredell for their useful consultations and discussions. The research is supported by the NOAA CPO CDEP CTB (Climate Test Bed) grant NA06OAR4310047.

## References

Fox-Rabinovitz M. S., V. Krasnopolsky, and A. Belochitski, 2006: "Ensemble of Neural Network Emulations for Climate Model Physics: The Impact on Climate Simulations", Proc., 2006 International Joint Conference on Neural Networks, Vancouver, BC, Canada, July 16-21, 2006, pp. 9321-9326, CD-ROM

Krasnopolsky, V.M., M.S. Fox-Rabinovitz, and D.V. Chalikov, 2005: "Fast and Accurate Neural Network Approximation of Long Wave Radiation in a Climate Model", *Monthly Weather Review*, vol. 133, No. 5, pp. 1370-1383.

Krasnopolsky, V. M., M.S. Fox-Rabinovitz, and A. A. Belochitski, 2008: "Decadal Climate Simulations Using Accurate and Fast Neural Network Emulation of Full, Long- and Short Wave, Radiation, *Monthly Weather Review,* in press.

Krasnopolsky, V.M., M.S. Fox-Rabinovitz, H.L. Tolman, and A. A. Belochitski, 2008: "Neural Network Approach for Robust and Fast Calculation of Physical Processes in Numerical Environmental Models: Compound Parameterization with a Quality Control of Larger Errors", *Neural Networks*, *doi:10.1016/j.neunet.2007.12.019* .

Mlawer, E.J., S.J. Taubman, P.D. Brown, M.J. Iacono, and S.A. Clough, 1997: "Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave, *J. Geophys. Res.*, 102, D14, 16,663-16,682