# WRF模式的软件架构与并行化

J. Michalakes et al. 2014. The Weather Research And Forecast Model: Software Architecture And Performance.

## 1前言

WRF项目是开发下一代的中尺度天气预报模式和同化系统。WRF2.0在2004年5月发布，被全世界科学家广泛使用。

WRF的业务化运行在NOAA National Centers for Environmental Prediction (NCEP) and at the U.S. Air Force Weather Agency。联合组织了NOAA/NCAR/DoD Developmental Testbed Center单位便于测试、评估和来自研究社区的新开发代码的转移。

## 2 WRF先进的软件框架

WRF由一系列单独的层组成，支持组件：Driver Layer, Model Layer, Registry和API接口到外部软件用于处理器间通信、数据格式和IO。

## 3嵌套网格和移动嵌套



## 4 IO和模型耦合

实施了API接口：netCDF, parallel HDF5, 原始二进制和GRIB1 I/O

与ESMF和OASIS3的接口。



## 5并行化

采用MPI+OpenMP混合并行化HWRF系统，可降低52%的飓风预报执行时间。

大部分工作重点研究区域分解和单线程下并行尺度化以及分布式内存环境，子程序层的计算效率优化通过优化函数和缓存效率优化实现(Barros)

J. Drake, I. Foster, J. Michalakes, B. Toonen, and P. Worley, Design and Performance of a Scalable Parallel Community Climate Model, J. Parallel Computing, vol. 21, issue 10, pp. 1571-1591, 1995.

S.R.M. Barros, D. Dent, L. Isaksen, G. Robinson, G. Mozdzynski, F. Wollenweber, The IFS model: A parallel production weather code, J. Parallel Computing, vol. 21, issue 10, pp. 1621-1638, 1995.

或者使用新的处理技术，如GPU

T. Henderson, J. Middlecoff, J. Rosinski, M. Govett, P. Madden, Experience Applying Fortran GPU Compilers to Numerical Weather Prediction, 2011 Symposium on Application Accelerators in High-Performance Computing (SAAHPC), pp. 34,41, July 2011.

J. Michalakes and M. Vachharajani, GPU Acceleration of Numerical Weather Prediction, Parallel Processing Letters*,* vol. 18, issue 4, World Scientific, pp. 531-548, Dec. 2008.

建议新的软件架构用于ESMF(Hill)

C. Hill, C. DeLuca, V. Balaji, M. Suarez, and A. da Silva, Architecture of the Earth System Modeling Framework, Computing in Science and Engineering, vol. 6, issue 1, pp. 18-28, 2004.

Quirino et al. 2014采用MPI+pthreads混合并行加速多个嵌套网格的WRF模式，并行化积分多个嵌套网格，利用多核架构：分配独立设置的风暴跟踪网格到不同的线程，在MVAPICH2 (ver. 1,8)下评估threaded MPI的效率。

Thiago Santos Quirino et al. (2014) Improving the Scalability of a Hurricane Forecast System in Mixed-Parallel Environments Advancing the WRF framework toward faster and more accurate forecasts. 2014 IEEE International Conference on High Performance Computing and Communications (HPCC), 2014 IEEE 6th International Symposium on Cyberspace Safety and Security (CSS) and 2014 IEEE 11th International Conference on Embedded Software and Systems (ICESS)

在很早的MPI分布下探讨了线程安全的MPI实施，但线程调用MPI进程的效率方面仍然是怀疑的，因为在MPICH-2为了线程安全，使用了全局锁或"brief global"锁，而MVAPICH-2是基于MPICH-2的。

W. Gropp and R. Thakur, Issues in developing a thread-safe MPI implementation, Proc. 13th European PVM/MPI User's Group conference on Recent advances in parallel virtual machine and message passing interface (EuroPVM/MPI'06), pp. 12-21, 2006.

P. Balaji, D. Buntinas, D. Goodell, W.D. Gropp, R. Thakur, Fine- Grained Multithreading Support for Hybrid Threaded MPI Programming, Int. J. High Perform. Comput. Appl, vol. 24, issue 1, pp. 49-57, 2010.

优化前后的HWRF代码结构：



使用标准的POSIX线程库(Pthreads)实施所有的线程化代码。因为OpenMP是针对循环层细粒度并行化，会导致过过多的开销(overhead)。因此基于Pthread库的函数创建自己的线程接口。