Weather Research and Forecast Model: Progress, Applications, Lessons Learned

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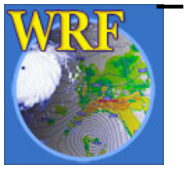
Computing in Atmospheric Science Workshop

Outline

- WRF Overview
- Applications and New Capabilities
- Lessons learned: shortcomings and successes

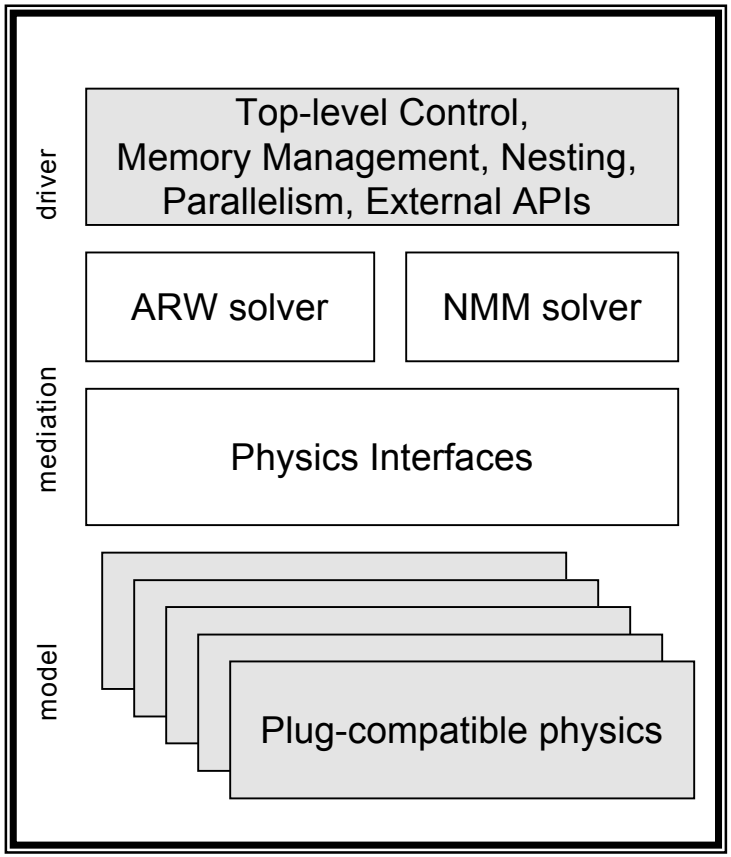
WRF Overview and Status

- Seven-year, multi-agency collaboration to develop advanced community mesoscale model and data assimilation system with direct path to operations
- Current release WRFV2.1, May 2005
  - Two dynamical cores, numerous physics, chemistry
  - Variational Data Assimilation (released) and Ensemble Kalman Filter (in development)
  - Rapid community growth
    - More than 3,000 registered users
    - June 2005 Users Workshop: 219 participants, 117 inst., 65 countries
    - 46 scientific papers: real-time NWP, atmos. chemistry, data assimilation, climate, wildfires, mesoscale processes
- Operational capabilities implemented or planned
  - Air Force Weather Agency
  - National Centers for Environmental Prediction
  - KMA (Korea), IMD (India), CWB (Taiwan), IAF (Israel), WSI (U.S.)



WRF Software Framework Overview

- Implementation of WRF Architecture
  - Hierarchical organization
  - Multiple dynamical cores
  - Plug compatible physics
  - Abstract interfaces (APIs) to external packages
  - Performance-portable

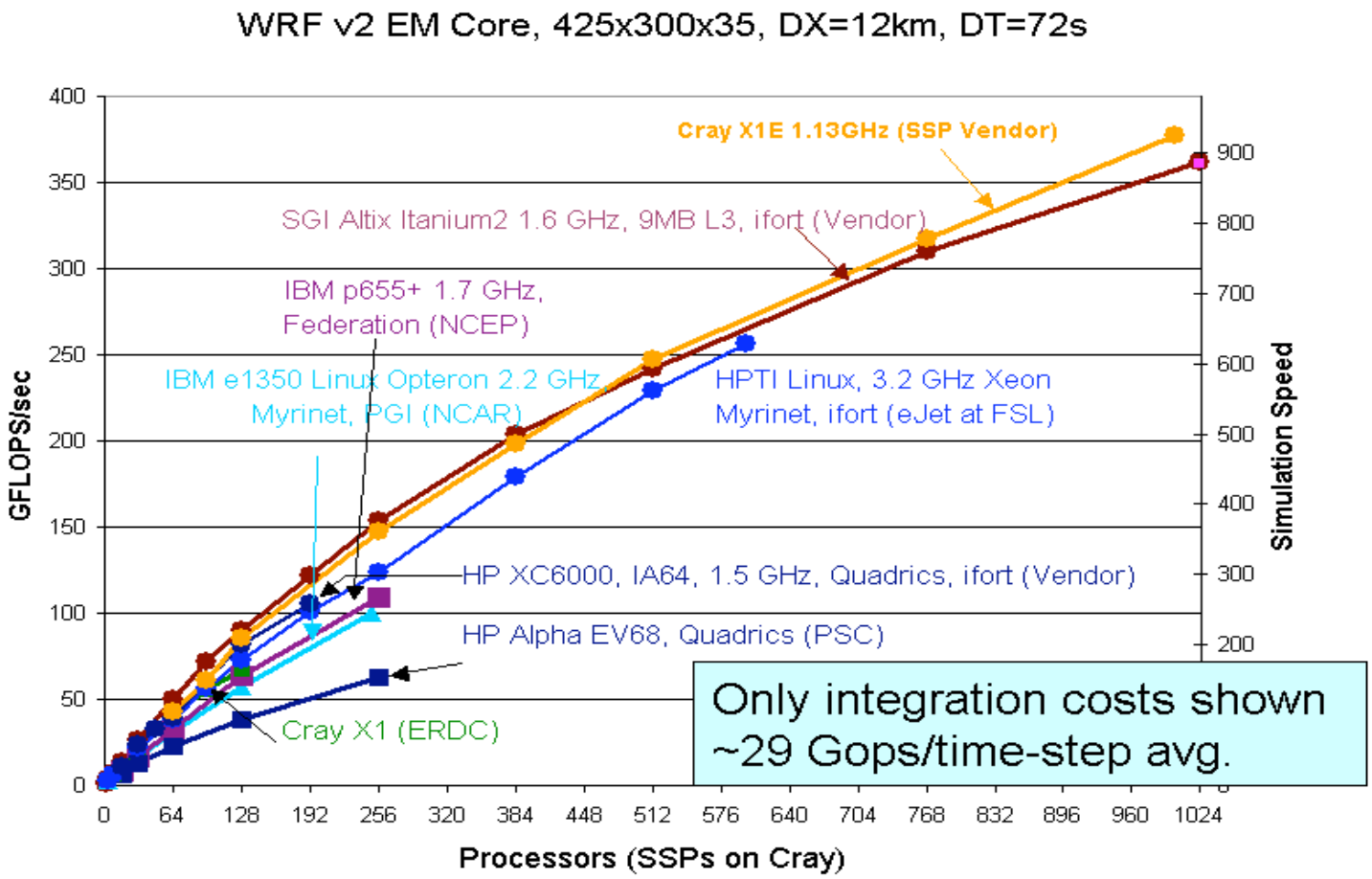


WRF Supported Platforms

Vendor	Hardware	OS	Compiler
Apple (*)	G5	MacOS	IBM
Cray Inc.	X1, X1e	UNICOS	Cray
	Opteron	Linux	PGI
HP/Compaq	Alpha	Tru64	Compaq
	Itanium-2	Linux	Intel
		HPUX	HP
IBM	Power-3/4/5; BG/L (**)	AIX	IBM
SGI	Itanium-2	Linux	Intel
	MIPS	IRIX	SGI
Sun (*)	UltraSPARC	Solaris	Sun
various	Xeon and Athlon	Linux	Intel, PGI
	Itanium-2 and Opteron		

(*) dm-parallel not supported yet; (**) Experimental, not released

Performance (v2.0.x)



- New v2.1 based standardized benchmark cases will be released in coming weeks, with release of WRF v2.1
- www.mmm.ucar.edu/wrf/WG2/bench/wrf_benchmark_page.htm

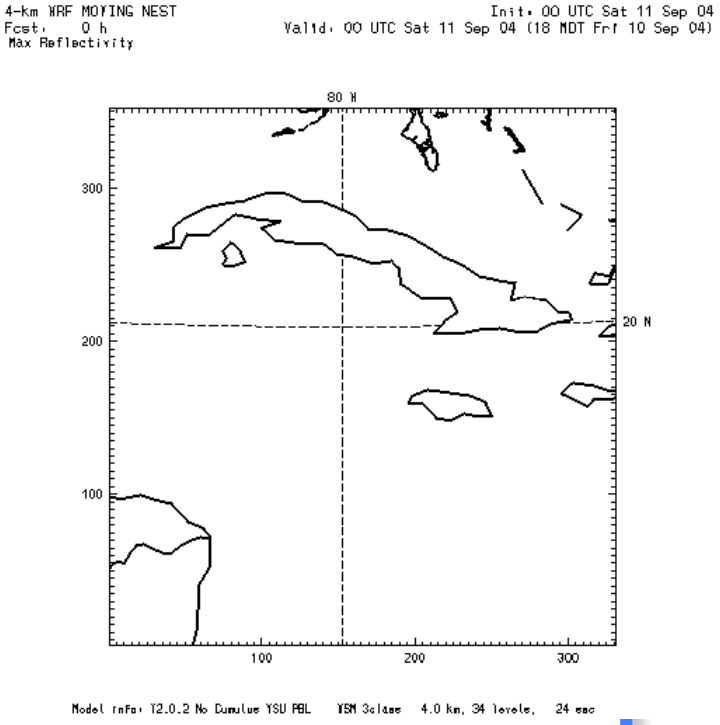
New Applications and Capabilities

- Applications
  - Air quality (WRF-Chem)
  - Regional Climate (RC-WRF)
  - TC-prediction (H-WRF)
  - Global WRF
- Data assimilation
- ESMF Integration

Hurricane WRF

- New hurricane & TC prediction capability based on WRF for research and prediction
  - U. Miami: Shuyi Chen
  - NCEP: Naomi Surgi, Bob Tuleya, et al.
  - NRL-Stennis: Alan Wallcraft
- Status
  - Automatic feature-following moving nests
    - Scalable and efficient (< 2% overhead)
    - Allows smaller high-resolution nests; overall 2x improvement over fixed-nest runs
  - Moving high resolution lower boundary conditions
  - Dynamic ocean coupling, HYCOM in progress
  - In use for RAINEX and real-time hurricane forecasting at NCAR

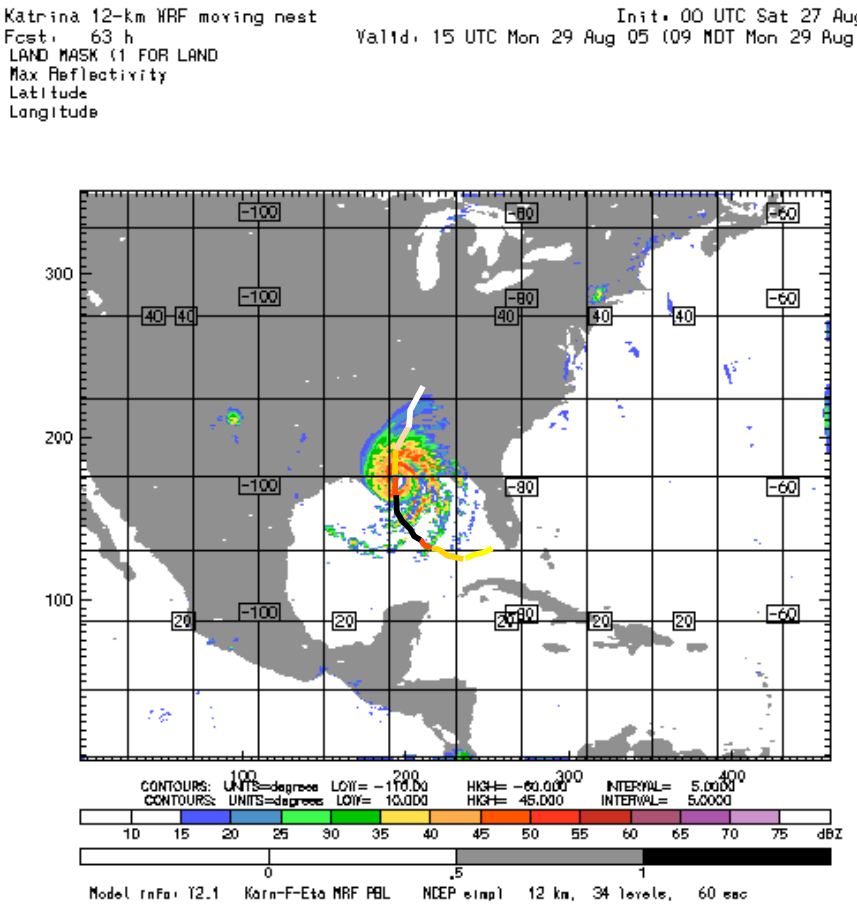
WRF 4km simulated reflectivity
Hurricane Ivan, September 2004
Moving nest (80 processors)



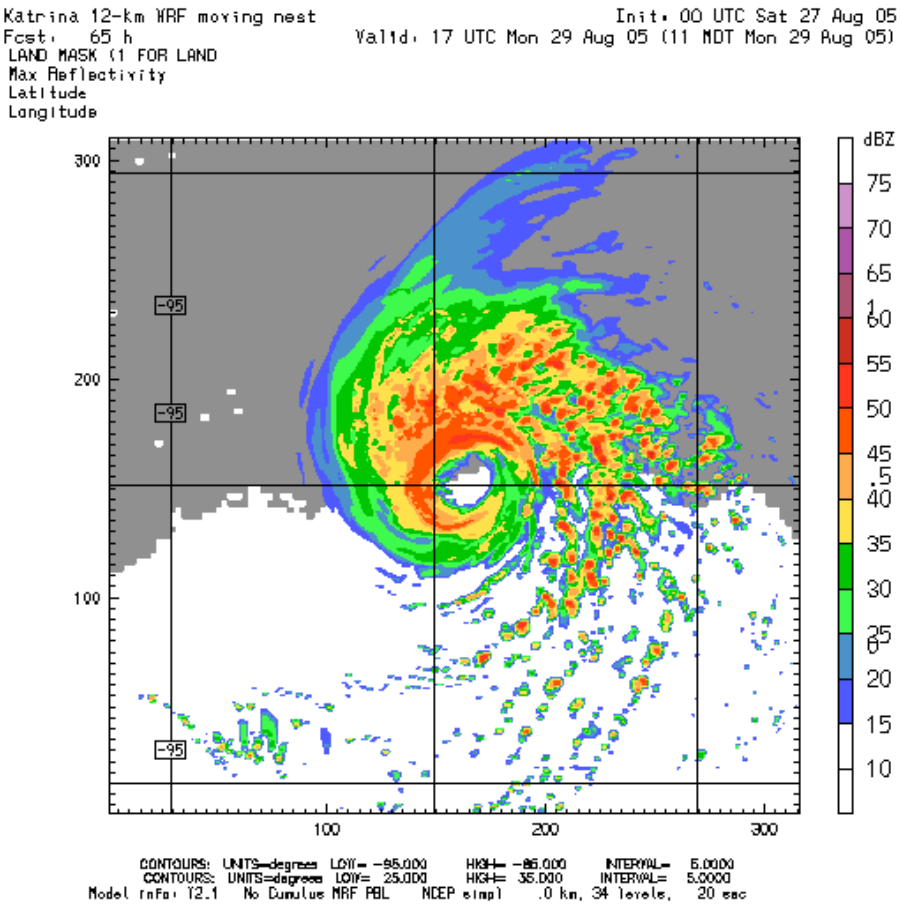
Hurricane Katrina

(For animation: http://www.mmm.ucar.edu/wrf/WG2/Katrina_20050827.gif)

400 x 301 x 35, dt = 72 sec



331 x 352 x 35, dt = 24 sec

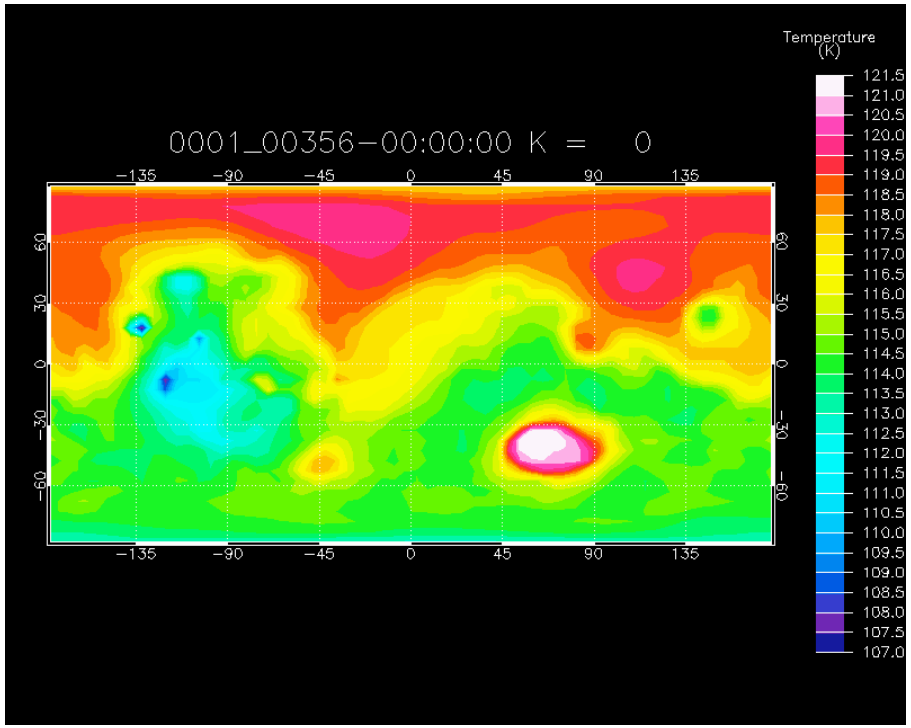


Run time: 5.5 hours on 128p IBM Power 4 (NCAR)

http://wrf-model.org/plots/realtime_main.php

Global WRF

- Mark Richardson, Cal Tech NASA/VPL et al. (*)
  - Allow non-conformal projections and user-specifiable planetary parameters
  - Separation of map scale factors into x and y directional components
  - Fourier polar filtering
  - Polar boundary conditions
  - Working with MMM
    - Parallelize, include as option in next community release of WRF
    - Adapt to terrestrial weather and climate for preliminary testing of high resolution global modeling

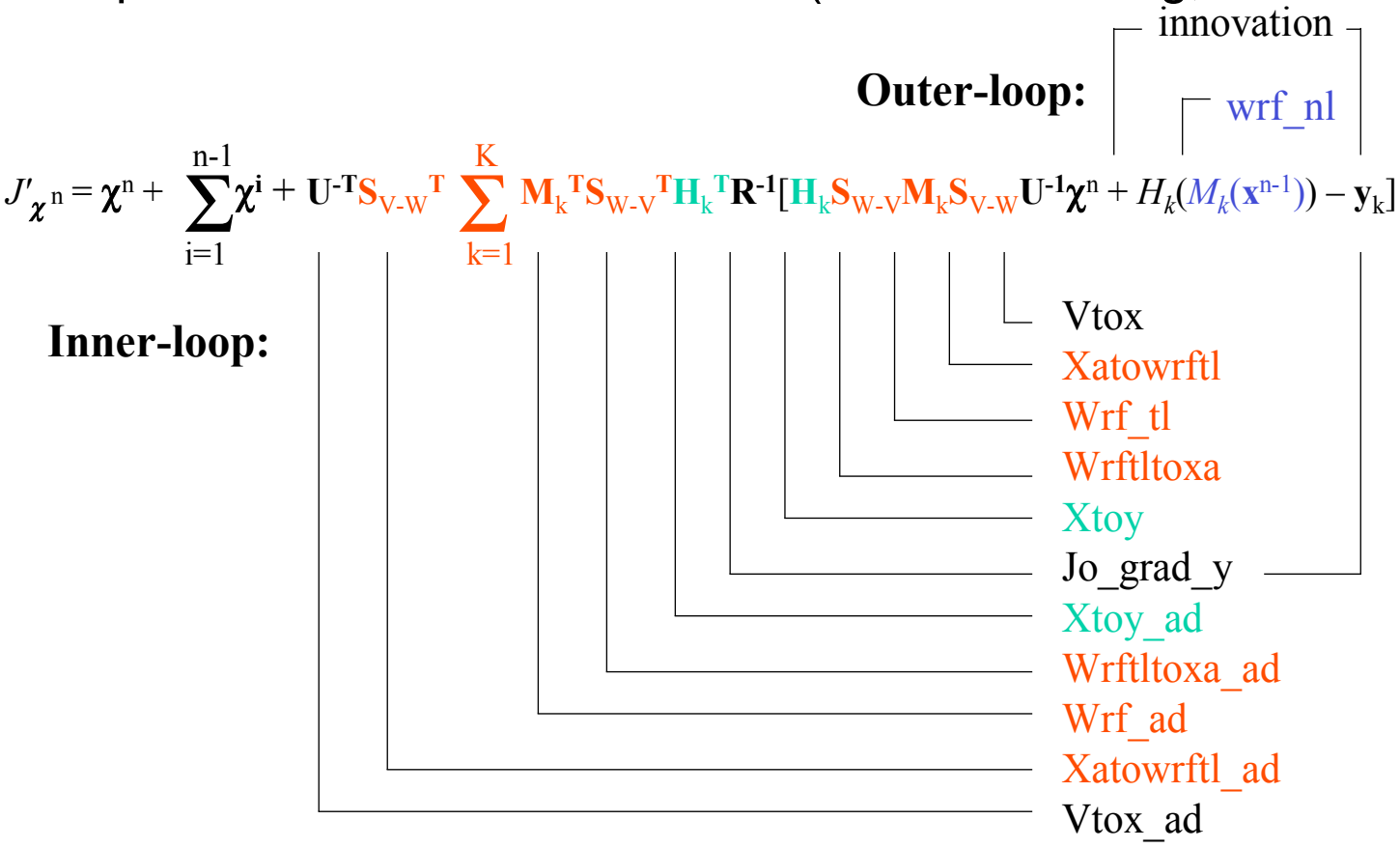


4-hour Martian surface temp;
Four MPI tasks, DEC Alpha

NON-CONFORMAL PROJECTION, GLOBAL, AND PLANETARY VERSIONS OF WRF. Mark I. Richardson,, and Claire E. Newman (Cal Tech), Anthony D. Toigo (Kobe University). Proceedings of 2005 WRF Users Workshop, Boulder, Colorado, June, 2005.
http://www.mmm.ucar.edu/wrf/users/workshops/WS2005/abstracts/Session7/1-Richardson.pdf

Data Assimilation

- WRF 3D and 4D Var systems being merged into a single conceptual and software framework (Barker & Huang, NCAR/MMM)



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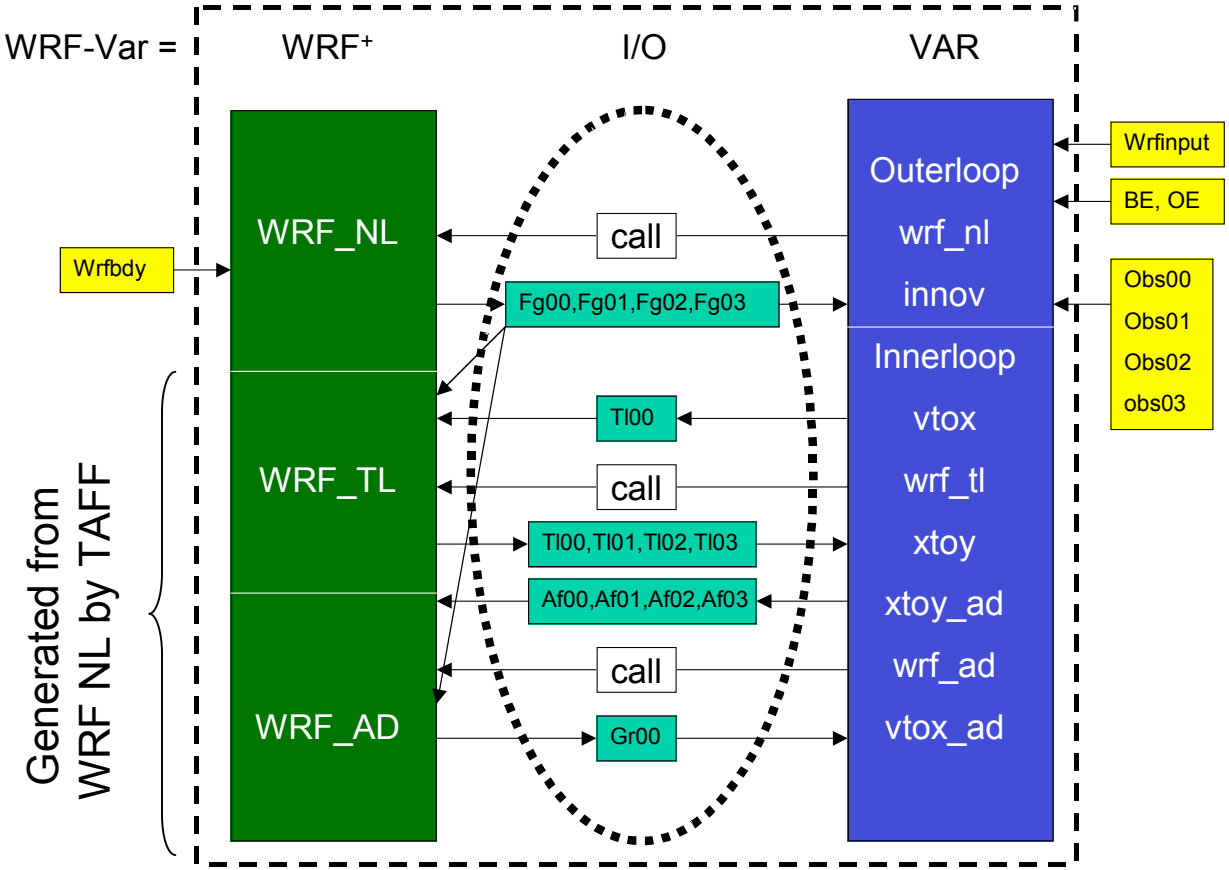


ESMF Integration

- WRF as an ESMF component model
  - WRF v2.1 can operate as an ESMF component (Tom Henderson, MMM)
  - Full coupling functionality through ESMF in-progress (initial target: HyCOM)
- Also:
  - ESMF Time Management Utility
  - ESMF Error Logging Utility
  - WRF I/O has been adopted in ESMF
  - Participating in CF metadata convention standardization

Lessons Learned: Problems

- Performance vs. Portability
- Generality vs. Simplicity
- Community Infrastructure vs. Total Control
- Research Community needs/contributions vs. Operational Centers needs/contributions

Performance vs. Portability

How much must I pay for WRF portability to systems I don't use?

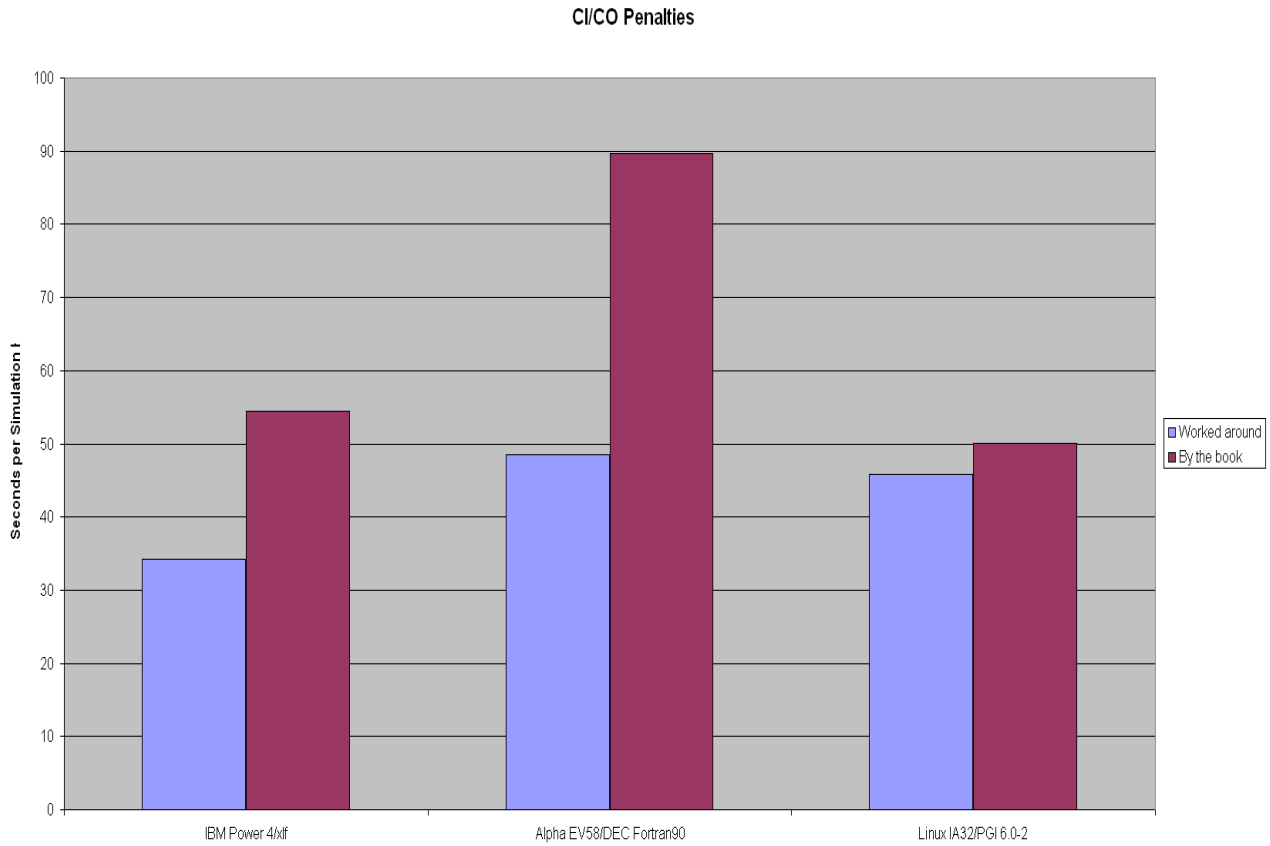
- Question should to consider time too: maybe, instead, "*systems I will never use*."
- Difficult to measure without a control
  - There is no NCAR-WRF outside the WRF framework
  - NCEP claims 20% penalty for NMM in vs. out of WRF
  - No analysis or attempt to improve WRF-NMM performance
  - Not clear the codes are identical
- Regardless, we know there is some overhead, primarily computational rather than parallel

Performance vs. Portability

- Dynamic memory allocation and argument adjustable arrays facilitate:
  - Run-time domain configuration, decomposition
  - Plug compatible, tile-callable model layer interface
  - Adaptive moving nesting
- Do not optimize as well as code where the array dimensions are known at compile time
- Pragmas/directives such as “IBM’s ASSERT” and “!DEC$ loop count” show promise

Fortran-Induced Code Complexity

- Fortran copy-in/copy-out issues warped the original object-oriented design for WRF



Fortran-induced Code Complexity

- Fortran copy-in/copy-out issues warped the original object-oriented design for WRF
  - Forced to dereference objects higher in call-tree
  - Compiler-specific tricks and over reliance on automatic code generation to force pass-by-reference
  - WRF software is seen as too complex, arcane.
- Situation has improved since 1999
  - Compilers are smarter about not doing CICO when they do not have to
  - WRF redesign and simplification underway

Lessons Learned: Problems

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Lessons Learned: Successes

- Rapid development from blank sheet to full-function community weather model in fewer than 7 years
  - 3000+ registered users including international
  - Many institutions, applications, computer platforms; real work getting done
- Adaptable to new applications, configurations, capabilities, increasingly user-contributed
  - Contributed physics
  - Extensions for atmospheric chemistry
  - Global WRF
  - GriB and GriB2 I/O

Additional Information

- www.wrf-model.org

  Users: www.mmm.ucar.edu/wrf/users

  Software:

  www.mmm.ucar.edu/wrf/WG2/software_v2
- wrfhelp@ucar.edu
- michalak@ucar.edu