CS 575

Paper Project

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- ✓ **What is the general theme of the paper you read? What does the title mean?**

  Due to the recent increase in formations of hurricanes, a much accurate prediction system is required. The paper "*PetaScale WRF simulation of Hurricane Sandy"*, has the great approach in validating the model when applied upon a giant set of data. WRF stands for Weather Research and Forecasting model and the significance of "Petascale" is due to the giant 4 billion points real date for the prediction and simulation of the landfall of Hurricane Sandy. The simulation was carried out on the world's most advanced supercomputer, Blue Water's "Cray XE6". The supercomputer is at the University of Illinois NCSA. 9120x9216x48 which is equivalent to 1.4Tb as input was taken into account. With the write rate of 2Gbytes/Second, 86 Gb of data was written after every 6 hours. This data was post processed and displayed at NCAR.

- ✓ **Who are the authors? Where are they from? What positions do they hold? Can you find out something about their backgrounds?**

  The authors of this paper are, Peter Johnsen, Melvyn Shapiro¸ Mark Straka, Thomas Galarneau, and Alan Norton. Apart from Peter Johnsen who is working in Cray. Inc, in a performance engineering group as a Meteorologist, the other 3 authors are working in the National Center for Atmospheric Research. The research was conducted with the help of a supercomputer named "Blue Water" which consists of 16-core 64-bit AMD Opteron 6276 series processor. This processor is named as "Cray XE6". This Supercomputer is presently situated in University of Illinois (Urbana-Champaign) at the National Center for Supercomputing Applications. According to them, there mission is to broaden the scientific and university's capabilities.

- ✓ **What experiments did the paper present?**

  The paper starts by discussing about the specifications and capabilities of the Supercomputer, "Blue Waters". The manufacturers of this system are Cray Inc., and is able to achieve 13 quadrillion calculations per second when performing at its peak performance. The supercomputer is having 237 Cray XE6 Cabinet & 32 Cray XK7 cabinets along with Nvidia Kepler GPU. The CrayXE6 processor is a 16-core 64-bit AMD Opteron 6276 series which has 8x64 KB of L1 instruction cache, 16x16 KB of L1 data cache, 8x2 MB of L2 cache per processor core, and 2x8 MB shared L3 cache. It is perfectly suitable for handling the parallel computing for the WRF model. WRF stands for Weather Research & Forecasting. It is given in the paper that the Hurricane SANDY had 9120 by 9216 points in horizontal grid and 48 in vertical grid. There is a Peta scale of data when it comes to predicting the hurricanes and weather phenomenon.

The methodology that the paper discussed has 3 available realms which are referred as: source code, run-time, and system level. In the 1st layer or source code, it focused on the limiting of the Runtime System Library output by modifying the version of WRF 3.3.1 from public distribution with concerns for I/O burden per MPI task. For the RunTime Layer, the WRF model being a Hybrid MPI/OpenMp code, decomposes the global grid while distributing the memory via patches which are rectangular sub-domains, to MPI ranks. When discussing about the system layer, a wide range of application-independent MPICH environment variables and Cray specific topology placement tools which make a significant change in all the applications that are run upon Blue Waters. In this project, the gamut from communication protocol and message sizes to rank reordering can be spanned by MPICH parameters which make a significant impact. This was followed by some preliminary experiments stated below and explained further:

Load Imbalance, Jitter analysis & Topology Effects for communication

- The load imbalance test is usually done to calculate the complex set of microphysics like the rain and graupel precipitation. Later the estimation of topology refinement challenges is done by doing This is done when the PAPI hardware makes the max/min values for corresponding process locations.
- At a scale of more than 10000 cores, they observed the increase of 50% in the periodic groups the cause of which wasn't the input model or code. Instead, they tried jitter through using core specialization which means, idling the core deliberately so that the non-user resources can be essentially allocated. This can also be done by -r1 option to aprun the commands while utilizing all the cores on the node. After this they assured that the dedicated partitions on the torus are being used. Moreover, the balanced injection was considered where they attempted to inject the bandwidth of the nodes along with network for communication patterns.

All this led to the increase in the complexity of the program. Therefore, to increase the performance of the WRF model was to run it on the AMD Bulldozer core modules along with OpenMP/MPI in a hybrid setting environment so that for each MPI rank there are 2 OpenMP threads. This method made sure that there are 16 MPI ranks per XE6 node.

We can see how the performance increased after the optimizations were performed.

Placement Method	*Total Messages*	*Total Bytes Exchanged*	*On-node Messages*	*Off-node Messages*	*Off-node Bytes Exchanged*
Default Placement	3.6E07	1.5E12	1.8E07	1.8E07	1.1E12
Optimized MPI rank Ordering	3.6E07	1.5E12	2.4E07	1.2E07	2.8E11

The above results have concluded that the complex application programs which depict the real-world problems can be run at heretofore scale while maintaining a high level of performance. This proved that strong scaling led to great performance numbers but the overhead was relatively low considering the extreme scale. When weak scaling was compared to it, it was able to achieve efficiency. The simulation of the strong scaling of WRF Hurricane Sandy Simulation is shown below according to the paper:

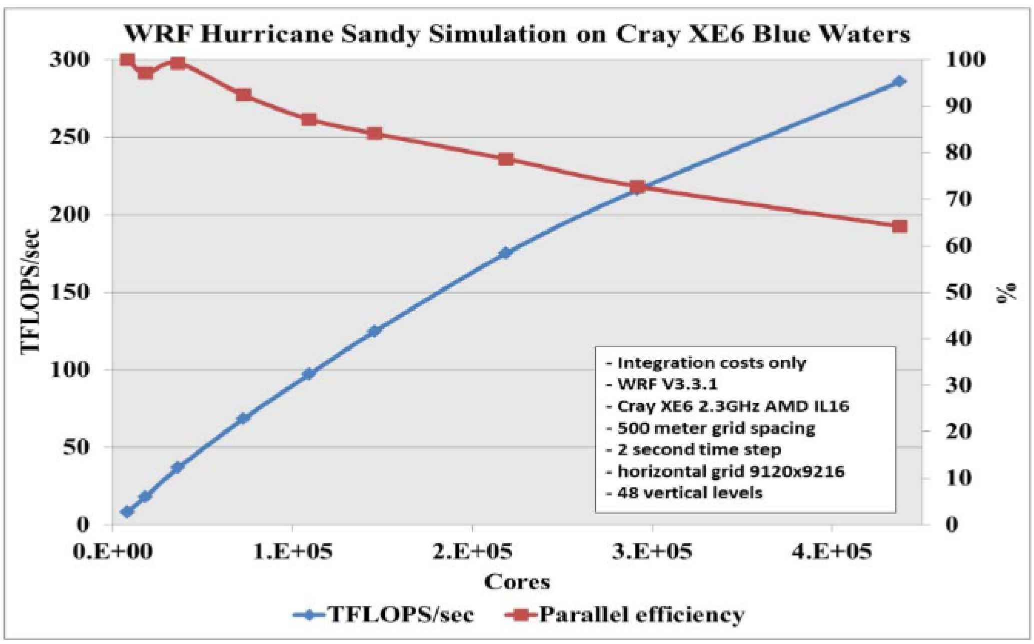

Figure 4. Strong scaling of Hurricane Sandy run. Sustained performance in Tflops/second (y-axis, left) and parallel efficiency over base run on 8,192 cores (y-axis, right) are shown.

- ✓ **What conclusions did the paper draw from them?**

There were two simulations performed, one generated on 500m in horizontal points and 150m in vertical points, spanning a surface of 26 km. The other simulation was generated at 3km. These simulations were then compared with the real time simulations of the hurricane SANDY which made landfall on the New Jersey shoreline at 2330 UTC 30 October 2012. The graphical representations of the simulations are shown and explained below:

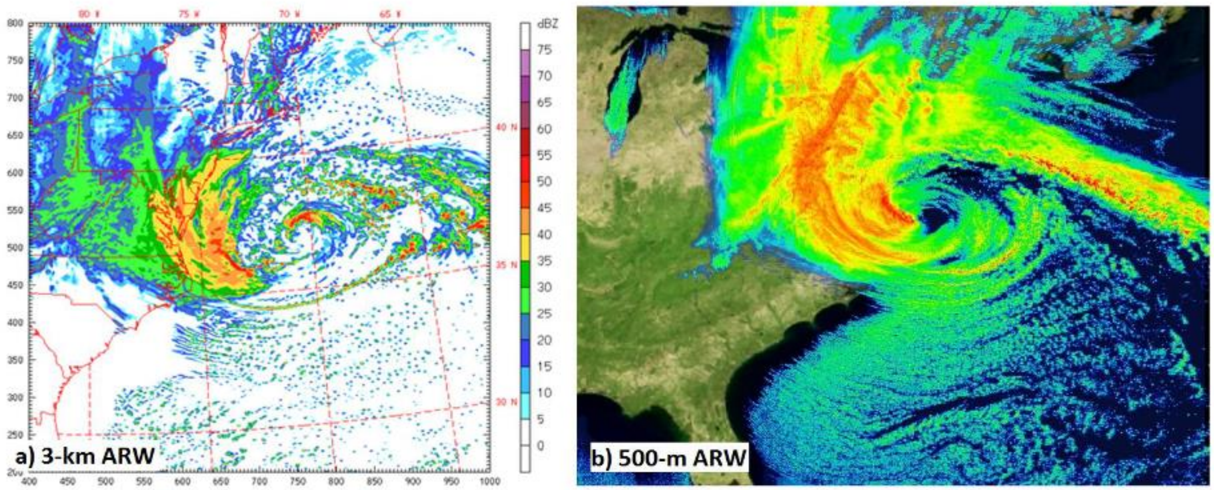

Figure 6. Comparison of (a) 3-km and (b) 500-m horizontal resolution ARW simulations of maximum radar reflectivity (shaded according to the color bar in dBZ) verifying at 1500 UTC 20 October 2012.

The figure above depicts that both the simulations confirmed the formation of high precipitations on the South-West side of the storm eye and according to the researcher's analysis, the precipitation take place around the area where the warm and moisture rich air from the north-east comes in contact with the cold-continental air.

These results greatly validated the investment the researcher's made in the WRF model and it also made new revelations in accordance with the further optimizations of the code, it's run time and moreover the operating system layers. Blue Waters machine made a bench mark in prediction models and all the future models will be now assessed in accordance with the Blue Waters system. This model was also validated by NCAR's model for Vapor software suite which compared the WRF model's rainfall, storm track, wind speeds and atmospheric pressures.

- ✓ **What insights did you get from the paper that you didn't already know?**

  The paper sheds importance on the need of parallelism and what are the advantages of it even for a machine that has humongous number of cores and tons of computing power. Moreover, it is really remarkable how much the parallelism can improve the performance of calculation on a peta-scale of data points. This also marks towards the further improvement of the system and more optimization in the algorithms so that even better performance is achieved which would ultimately contribute towards the better prediction of hurricanes and more time for the people and first responders on such a scenario.

- ✓ **Did you see any flaws or short-sightedness in the paper's methods or conclusions? (It's OK if you didn't.)**

  I wouldn't say that there were flaws but as the authors mentioned that there is always room for improvement in parallelism and the optimization of the code which will itself make a significant difference over the course of the technological advancements.

- ✓ **If you were these researchers, what would you do next in this line of research?**

  This will be a very uncommon decision but if I would have made the project OPEN-SOURCE. I know that this is a supercomputer-based simulation software which requires a ton of computing data, but making it open source would open it up for new advancements in the code optimization suggestions from many other researchers in the world. This kind of research can also contribute in predicting Tsunami and other natural calamities which are making havoc on the human civilization. This is purely hypothetical scenario and the number of people who will be able to utilize from it being open source will be very less due to the sheer computing power required for this scale of data.

Reference:

P. Johnsen, M. Straka, M. Shapiro, A. Norton and T. Galarneau, "Petascale WRF simulation of hurricane sandy: Deployment of NCSA's cray XE6 blue waters," SC '13: Proceedings of the International Conference on High Performance Computing, Networking, Storage and Analysis, 2013, pp. 1-7, doi: https://doi.org/10.1145/2503210.2503231