Reliable and Accurate Weather and Climate Prediction: Why IBM® Resilient High Performance Computing (HPC) Solutions have an Overwhelming Lead

Sponsored by IBM
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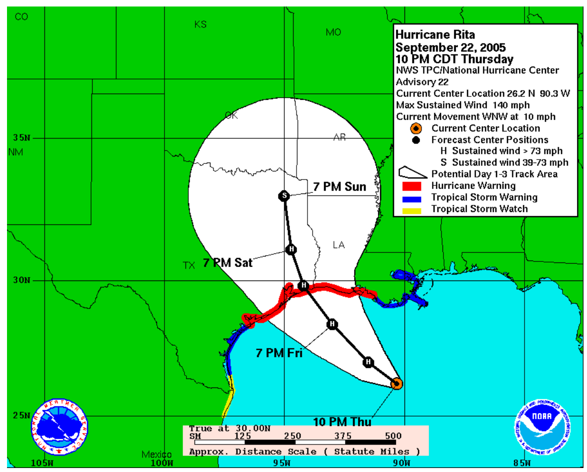
Introduction – Benefits of Weather and Climate Prediction Powered by IBM HPC Solutions

Many economic sectors routinely use weather[1] and climate predictions[2] to make critical business decisions. The agricultural sector uses these forecasts to determine when to plant, irrigate, and mitigate frost damages. The transportation industry makes routing decisions to avoid severe weather events. And the energy sector estimates peak demands geographically to balance load. Even households use weather forecasts to decide what to wear and when and where to go on vacations. Likewise, anticipated climatic changes – from rising sea levels to stronger and more frequent storms and extreme temperature events – will have real impacts on the natural environment as well as on human-made infrastructure and their ability to contribute to economic activity and quality of life. Governments, the private sector, and citizens face the full spectrum of direct and indirect costs accrued from increasing environmental damage and disruption. For instance, the economic cost estimates from hurricane Katrina range upward of $200 billion, or over 1% of US gross domestic product[3].

With a longer advance notice of a more intense hurricane season, public agencies can better prepare months in advance to minimize damage to buildings and save lives, as well as better optimize evacuation plans. With more accurate predictions of the intensity and landfall of individual hurricanes, emergency service personnel and resources can be better deployed, properties can be prepared for the wind and water impact, and the civilian population can be more accurately forewarned, facilitating effective evacuation procedures.[4] Conversely, an ill-advised or misdirected evacuation is not only costly in economic terms, but in terms of damaged credibility too.



Predictions made with such confidence benefit greatly from the use of supercomputers which have become the essential tool powering a wide variety of weather, ocean, and climate models. Current weather conditions are typically used as input into sophisticated mathematical models of the atmosphere and the earth system to predict the weather and model climate into the future. Manipulating the huge datasets and performing the complex calculations necessary to do this on a resolution fine enough to make the results useful and reliable requires the use of the most powerful resilient supercomputers. Typically, many forecast models, both global and regional in scale, are run to create forecasts for nations worldwide. Ensemble forecasts help define the forecast uncertainty and extend weather forecasting farther into the future.

Through in-depth research and interviews, this article highlights the substantial business value IBM's HPC portfolio delivers to the weather forecasting and climate modeling marketplace. Over the last decade, IBM HPC solutions have been used extensively to advance the reliability, accuracy, and length of weather, ocean, seasonal, and climatic predictions by permitting increased resolutions and more complex models. Globally,

[1] Laurie L. Houston, Richard M. Adams, and Rodney F. Weiher, "The Economic Benefits of Weather Forecasts: Implications for Investments in Rusohydromet Services", Report prepared for NOAA and World Bank, May, 2004.
[2] "Financial Risks of Climate Change", Summary Report, Association of British Insurers, June, 2005.
[3] Matthias Ruth, Dana Coelho, and Daria Karetnikov, "The US Economic Impacts of Climate Change and the Costs of Inaction", Center for Integrative Environmental Research (CIER) at the University of Maryland, October 2007.
[4] David Blaskovich, IBM, "Personal Communications", 2009.

some of the largest weather centers have relied on IBM HPC systems primarily based on the Power architecture to deliver the most accurate and up-to-date weather forecasts to their stakeholders. In the next five years, many of these centers expect to enhance their products and capabilities to further improve medium-to-long range forecasts through more accurate computational models, and focus on improving early warnings of severe adverse weather events. These centers are also expected to significantly increase climate prediction capabilities and deliver analyses and forecasts of atmospheric composition. Even in emerging geographies, weather centers are expected to significantly increase spending in technology for weather forecasting. For example, in India, the Ministry of Earth Sciences recently approved $620 million to upgrade and modernize weather technology[5] crucial to predict rainfall during the monsoon season.

All this would require next-generation petascale and even exascale systems to deliver orders of magnitude increases in computational and data management capability. Despite significant spending reductions on supercomputers in other HPC segments, supercomputer spend for weather and climate applications is expected to remain flat[6] for the short-term during the current economic downturn. We believe, IBM is well positioned to extend its current market leadership of about 60%. Equally as important as performance, these powerful supercomputers and related family of products must possess the reliability, resilience, and ease-of-use to significantly improve the productivity of those scientists who fuel the drive for better predictions. In the end (as depicted in the following figure), it is the economy and society which reaps the benefits in daily life, safety, and efficiency from reliable and accurate weather and climate prediction.

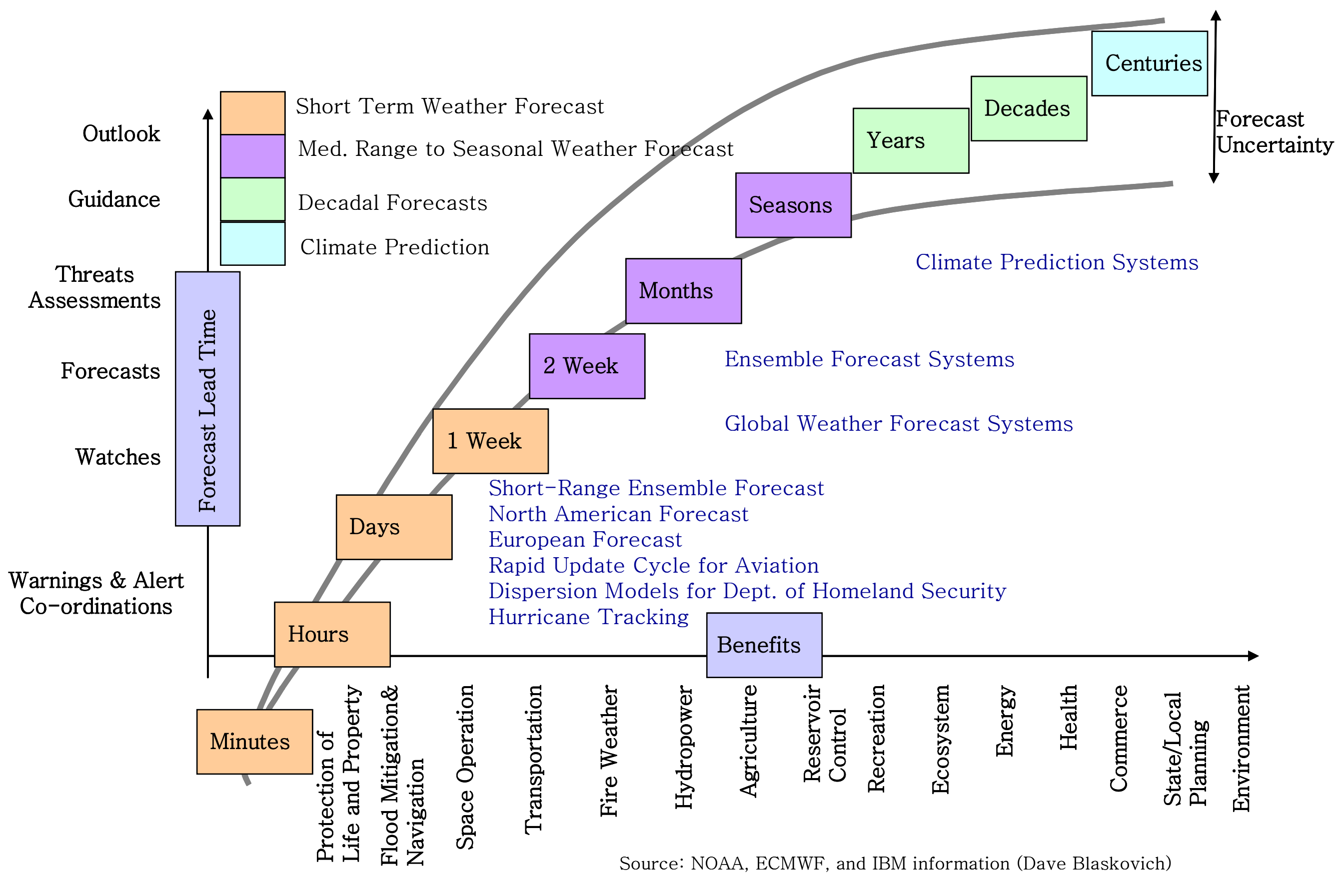
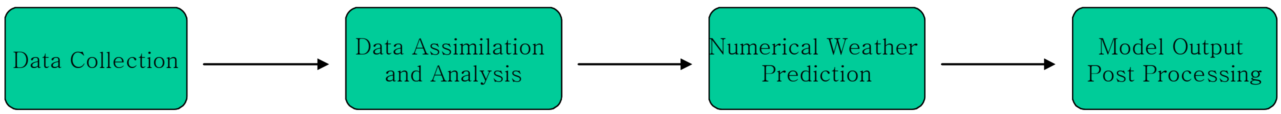


Figure 1: Business Value of Forecast Products Spanning Weather and Climate Modeling

[5] Sonya Misquitta and Geeta Anand, "India Hopes for Rain and an Accurate Forecast", the Wall Street Journal, August 13, 2009.
[6] http://www.hpcuserforum.com/presentations/April2009Roanoke/EarlandJieIDCMarketUpdateslides4.19.2009.ppt#1109,9,The New IT Budgets: Recovery in 2010

How is Weather and Climate Predicted? - Establishing the Need for Supercomputers.

Short Range Weather Forecasting (Hours to Days) is the best place to start because the forecasts are more familiar and the highly-successful methodology is similar to medium range weather forecasting and climate prediction in many ways. The process of short range weather forecasting is at the core of almost every weather/climate model and includes several steps to analyze and refine the raw weather observations, to make the numerical predictions, to generate useable forecast products, and to then distribute those forecasts to users across the nation.[7] Within this operational production process, several steps take place each with a somewhat different computational role: Data collection, Data assimilation and analysis, Numerical weather prediction, and Model output post processing.



Data collection: Each day, millions of observations of the atmosphere and oceans are made around the world with weather balloon, ships, ground stations, radars, and airplanes. Included are measurements of temperature, pressure, humidity, wind speed, and several other parameters. In the near future, more capable weather-observing satellites will significantly increase the quantity of observations, especially over the open oceans in areas where few ships travel.

Data assimilation and analysis: Because the weather observations are scattered irregularly over the surface of the planet, based on location of the observing platform, highly sophisticated numerical analysis programs interpolate the values of the observations to grid points on a three dimensional mesh data structure placed over the globe by the analysis program. In addition, the analysis program melds these data with a “first guess” of the current weather picture taken from a forecast made by the previous run of the operational forecast suite. These data sets on grids constitute the snapshot of the current state of the atmosphere.

Numerical weather prediction (NWP) models then advance that 3-D snapshot forward in time. These models use numerical algorithms to describe the behavior of the atmosphere and oceans as fluids, using mathematical formulas based on the physics of radiation, momentum, energy, heat, and the rotation of the earth. The formulas include Newton’s laws of motion, laws of conservation, and other equations to describe how temperature, wind, humidity, and other parameters will change at every grid point.

Model output post processing: The raw output is often modified before being presented as the forecast. This can be in the form of statistical techniques to remove known biases in the model, or of adjustment to take into account consensus among other numerical weather forecasts. MOS or model output statistics is a technique used to interpret numerical model output and produce site-specific guidance. This guidance is presented in coded numerical form, and can be obtained for nearly all National Weather Service reporting stations in the United States and elsewhere.

By international protocol, all nations in the United Nations openly and freely share weather data every day via networks and telecommunications. The U.S. National Centers for Environmental Prediction (NCEP), which is based in the Washington D.C. Area, but includes several additional facilities across the country, is responsible for all weather and environmental predictions and warning in the United States. Using the global data set of daily observations, NCEP can assemble a “snapshot” picture of the earth’s weather, and then advance that picture forward in time, making in effect a fast forward movie “forecast” of the weather into the future. The trick is to complete the formulation of this snapshot and make the forecast much faster than the weather changes. Every analysis and forecast run involves millions of data points and many trillions of calculations to produce a single forecast, and it is estimated the forecast model needs to run at

[7] “Personal Communications”, Dave Blaskovich, IBM, 2009.

least an order of magnitude faster than real-time weather in order to be useful. This "need for speed" establishes the fundamental requirement for supercomputers in weather forecast agencies around the world.

Medium Range and Seasonal Weather Forecasts (Weeks to Months) have an increasing element of uncertainty that scientists have devoted considerable effort to quantify and control. This uncertainty arises because of numerical truncation errors, scales of motion smaller than the grid resolution, and sensitivity to initial conditions - the so called butterfly effect due to non-linear chaotic effects.[8] Scientists have overcome this uncertainty by calculating a set of multiple forecasts (*an ensemble*) that differ very slightly in their initial conditions and parameterizations. Forecasts can now predict both the most likely future weather state and the probability of deviation from this state. Ensemble forecasts drive up the need for computational speed even further and benefit greatly from scalable parallel systems. Many seasonal models consider coupled ocean, land, and atmospheric effects, making the computational problem larger demanding even more performance and scale from supercomputers.

Decadal Forecasts (Years) go beyond seasonal forecasts and have to also consider coupled ocean, land, and atmospheric effects. In recent years, along with climate predictions, decadal forecasts have become crucial to global policy making and a topic of intense research at many weather and climate agencies around the world. Some decadal forecast models also include human induced effects such as greenhouse gas emissions.[9] These longer running models require even greater scientific skill and computing performance to generate timely and accurate forecasts.

Climate Prediction (Decades to Centuries), at first sight, seems to be an intractable problem as it attempts to predict the weather over time scales into decades or even centuries, greatly compounding the problem of uncertainty. But just as thermodynamics is used to predict the average behavior of gases without being able to deterministically predict the exact location, momentum, or temperature of an individual molecule over time, numerical climate prediction models developed in recent years require only the average and statistics of weather states not the precise sequence.[8] Climate is determined by factors such as incoming solar radiation, atmospheric composition, reflective and other properties of the atmosphere and the underlying surface. Over the last 40 years, primarily because of advances in supercomputing, climate models can now consider the interacting effects of both natural and human induced factors. In addition to the atmosphere, land, ocean, sea, ice, some of the most advanced climate models include the effects of aerosols, carbon, and other biogeochemical factors. Just as in medium range weather forecasts, climate ensemble models are used to predict the expected climate change and the deviation from this expected state. Currently computational limitations restrict climate models to be run with grid points significantly further apart than weather models thereby limiting accuracy. In the next ten years, with the expected growth in supercomputer performance into the exascale regime and greater model realism, numerical climate prediction could become just as credible and successful as short range weather forecasting is today.

While Supercomputer Performance is Key….Reliability and Availability are Crucial Too

All of the processing for short term operational weather forecasting must be completed within a very strict timetable (often within one hour) called the forecast operational suite of programs, which is repeated at least once every twelve hours at NCEP. For hurricane tracking, this is often repeated every six hours. This requires extremely fast and exceptionally reliable supercomputers to guarantee the operational production will run to completion. Winning HPC solutions must possess this combination of sustained high performance + reliability/availability + functionality.

"The production of numerical predictions within the operational time windows required by field forecasters is one of the most computationally intensive undertakings ever attempted within an operational environment," said Dr. Louis Uccellini[7], Director of NCEP. "Precision in forecasting, both short-term and

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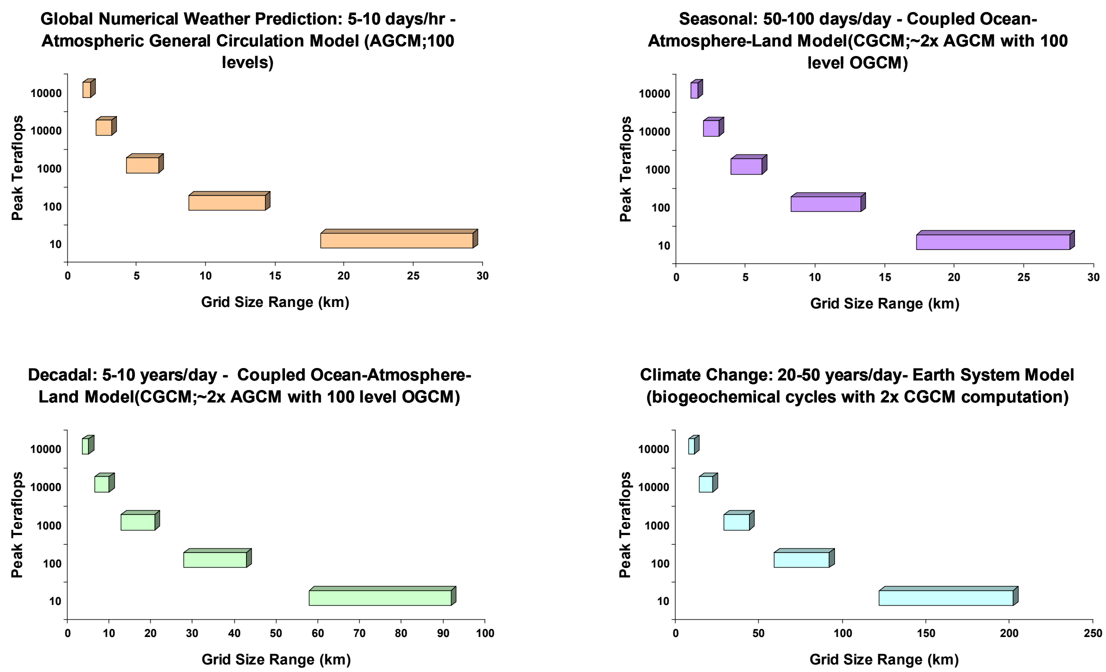
[8] Alan J. Thorpe, "Climate Change Prediction: A Challenging Scientific Problem", Institute of Physics, 2005.
[9] Sutton and Hodson, 2005: Atlantic Ocean Forcing of North American and European Summer Climate. Science 309, 5731.

long-term, is the goal we're trying to reach. Having advanced technology like the supercomputer gives meteorologists the information they need, on a consistent, reliable schedule."

The resolution or spacing of the grid points in one of the main factors which limits the accuracy of the weather forecast, and determines the performance requirements of a supercomputer in order to make the predictions faster than the weather changes. Currently grid point spacing is on the order of 25-50 kilometers with 91 levels with 50 ensemble forecasts for the suite of models.[10] More powerful computers such as the IBM Power Systems clusters at NCEP have permitted model resolution to improve to 10-20 kilometer spacing, significantly increasing the detail of forecasts. Because the grids are three-dimensional, a doubling of grid resolution and levels would increase the number of grid points by a factor of eight. For finite-difference models, this would again be doubled as the model time-stepping must be halved to guarantee numerical convergence and stability[11], leading to a sixteen-fold increase in the requirement for computing performance to double grid resolution in three dimensions.

Since an operational weather forecast is at the core of most weather/climate products, grid size ranges are limited by the sustained performance delivered by the fastest supercomputers available at any time. The following figure estimates the computing requirements and corresponding grid size ranges for increasingly complex and higher resolution weather and climate models. This indicates that several orders of magnitude increase in supercomputer power will be necessary to support the scientific quests to deliver the social and economic value required for informed decisions in the future.



Grid Size Range: Assumed efficiency of 10-40%
Applications are assumed to scale on scalable systems with scalar processors

Source: Jim Abeles (IBM)

Figure 2: Increased Computing Capability Enables More Realistic Models

Reliability, availability, and serviceability (RAS) of the supercomputer are equally critical for weather centers. Resource failures and downtimes have become a growing concern in large HPC installations as they tend to grow with the number of processors and have an adverse effect on productivity. Because of their

[10] Isabella Weger, "High Performance Computing for Numerical Weather Prediction", European Center for Medium-Range Weather Forecasts, IDC User Forum, London, 2008.
[11] "The Courant-Friedrichs-Lewy (CFL) Condition", http://en.wikipedia.org/wiki/Courant%E2%80%93Friedrichs%E2%80%93Lewy_condition

mission-critical nature, weather centers are particularly sensitive to these reliability concerns and often demand stringent availability and quality of service guarantees from the HPC solution provider as part of their procurement process.

Scalable parallel clusters with thousands processors are the dominant platform for HPC now and into the near future. Research on the reliability and availability of HPC clusters is very recent and ongoing.[12] While *a priori* prediction and analysis of failures and reliability are just beginning to appear, *a posteriori* approaches based on log file information and end-user surveys indicate that HPC clusters have significantly less availability compared to other traditional monolithic systems such as mainframes.[13] Although, most parallel HPC applications, inherently long-running, have the capability to checkpoint and restart to recover from job failures, systems with lower availability may not only increase the true cost of ownership (TCO) but also may not satisfy the mission-critical requirements demanded by operational weather centers. What's crucial for weather centers and in fact for all production HPC parallel applications is the elapsed time between submission of a parallel job and its successful completion despite unplanned outages. So it's critical to have a holistic view of reliability and availability spanning the application, system (hardware and software), and even the administrative policies of the HPC data center. Recent studies based on exhaustive surveys have shown that large supercomputers have between 95% to almost 100% availability.[14] But even a 1% difference in availability has a substantial business impact especially for operational weather centers.

But sustained performance and reliability alone is not adequate to satisfy all the needs of weather and climate agencies. The process of research and prediction is a large and complex scientific production endeavor that requires a functional end-to-end IT solution. Beyond supercomputers, additional IT tools are required and used. Weather and climate applications produce large volumes of data which must be stored, analyzed, post-processed, disseminated, and visualized. Each of these national agencies has a requirement to support a broad set of end users, therefore the timely dissemination of information via telecommunications links, fax, and the World Wide Web is critical. Each has a cadre of scientists who monitor, control, and interact with the forecast process using workstations. A full set of IT capabilities is utilized to maximize productivity in research and operations, providing opportunities for companies such as IBM to deploy its entire family of IT infrastructure solutions as toolsets for these environments.

Over the last few decades, IBM has made sustained technology investments to enhance functionality, performance, and reliability across its portfolio of systems and technology offerings. Investments in semiconductor processor technology e.g. the Power architecture (www.power.org), RAS features in the System z mainframes[15] that have been systematically implemented across the IBM portfolio, next generation energy-efficient data centers[16], and deep HPC weather and climate domain skills, have positioned IBM well to extend its lead in the weather/climate marketplace.

The Key Elements of the IBM HPC Solutions Portfolio

IBM offers a wide array of HPC solutions through its multi-core processor systems, large storage systems, support for a broad range of operating systems, visualization, innovative applications, middleware and partner ISVs with proven expertise and deep industry presence. IBM has the leading portfolio[17] of HPC architectures, systems, and software ranging from the System x® Cluster 1350™, Blades,

[12] Raju Gottumukkala, et. al., "Reliability Analysis of HPC Clusters", http://xcr.cenit.latech.edu/hapcw2006/program/papers/hapcw_rel_analysis.pdf
[13] Stephen L. Scott and Christian Engelmann, "Advancing Reliability, Availability, and Serviceability for High Performance Computing", Oak Ridge National Laboratory, April, 2006.
[14] Alan Simpson, Mark Bull, and Jon Hill, "Identification and Categorization of Applications and Initial Benchmarks Suite", PRACE Consortium Partners, 2008.
[15] http://publib.boulder.ibm.com/infocenter/zos/basics/index.jsp?topic=/com.ibm.zos.zmainframe/zconc_RAS.htm
[16] The New Enterprise Data Center, http://www-03.ibm.com/systems/nedc/index.html
[17] The IBM Deep Computing Portfolio, http://www-03.ibm.com/systems/deepcomputing/index.html

iDataPlex®, Power based System p®, and Blue Gene® with support for a range of operating systems including Linux®, AIX®, and Windows® together with cluster management software, a high-performance shared-disk clustered file system - General Parallel File System (GPFS™), and optimized scientific and engineering libraries. In addition, IBM has a worldwide technical staff of domain experts to help weather and climate agencies migrate and optimize their applications on the IBM HPC portfolio to solve their largest and most challenging problems.

Why has IBM Established Leadership in the Weather and Climate Marketplace?

The weather services of the largest nations run global models and very detailed regional models, and therefore require the fastest supercomputers available to run models with the highest global resolution possible. The U.S. NCEP, the ECMWF (European Centre for Medium-Range Weather Forecasts), and most of the world's national weather centers use IBM Power-based supercomputers for their global forecasts. NCEP is currently on its fourth generation of IBM supercomputers. ECMWF has also been using IBM products for their data handling system, and ECMWF is also on its fourth of IBM HPC solutions. Many national weather centers and commercial firms can satisfy their forecast needs using regional or local models which can then utilize smaller IBM systems to make these local forecasts. The following table lists many of IBM customers worldwide for operational weather forecasting and earth systems research (climate, ocean, and the environment). IBM Power based systems are installed at over 90% of this list. In some cases, e.g. SciNet, both IBM Power based systems and the iDataPlex are installed and the National Center for Atmospheric Research (NCAR) has installed IBM Power, System x, and the Blue Gene supercomputers.

IBM Operational Weather Forecast Customers	IBM Earth Systems Research Customers
U.S. NOAA National Centers for Environmental Prediction (NCEP) NCEP Back-up & Research Facility Fairmont U.S. Navy Fleet Numeric Meteor & Oceanography Center (FNMOC) U.S. Air Force Weather Agency (AFWA) Environment Canada (EC) Meteor. Services of Canada (MSC) European Centre for Medium-Range Weather Forecasts (ECMWF) Greek Hellenic National Meteorological Service (HNMS) Ireland Met Eireann Norway Meteorological (met.no) @ NTNU United Kingdom Meteorological Office (UK Met) Portugal Insituto de Meteorologia (IM) Morocco Direction de la Meteorologie Nationale (DMN) Slovakia Hydrometeorology New Zealand National Institute of Water and Atmospheric Research (NIWA) Taiwan Central Weather Bureau (CWB) Tunisia l'Institut National de la Météorologie (INM) China National Meteorological Centre (NMC) China Guandong Regional Weather Service China Shanghai Weather Bureau Tianjin Weather Bureau India Ministry of Environmental Sciences (MoES) - National Centre for Medium Range Weather Forecasts (NCMRWF)	U.S. NOAA NCEP R&D U.S. NOAA National Climatic Data Center (NCDC) U.S. National Center for Atmospheric Research (NCAR) U.S. Naval Oceanographic Office (NavO) U.S. Environmental Protection Agency (EPA) U.S. Scripps Institute of Oceanography (SIO) Canada University of Toronto Scinet Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC) German Potsdam Institute fur Klimate (PIK) German Deutsches Kimarechenzentrum (DKRZ/MPIMH) Proudman Oceanographic Lab. (POL), England Service Hydrographique et Oceanographique de la Marine (SHOM), France India Ministry of Environmental Sciences (MoES) China National Climate Centre (NCC) China State Ocean Bureau Beijing Ocean Bureau (BOB) Thailand Asia Disaster Prevention Center (ADPC) Raytheon NPOESS Atmospheric & Environmental Research, Inc. (AER) AirDat Weather Services International (WSI)

So why has IBM been so successful in the weather and climate marketplace? We believe that over the past decade, IBM, particularly with Power-based supercomputers, has been able to deliver supercomputers, associated HPC solutions, and other complementary IT infrastructure solutions with the best mix of sustained performance, and reliability/availability, and end-to-end functionality. We examine each of these attributes separately and altogether.

The WRF benchmark[18] results are one key indicator of achievable sustained performance on scalable parallel systems. These benchmarks are reported twice a year. The most recent results as of July, 2009 are shown in the following two figures for a grid size of 12 km and 2.5 km respectively.

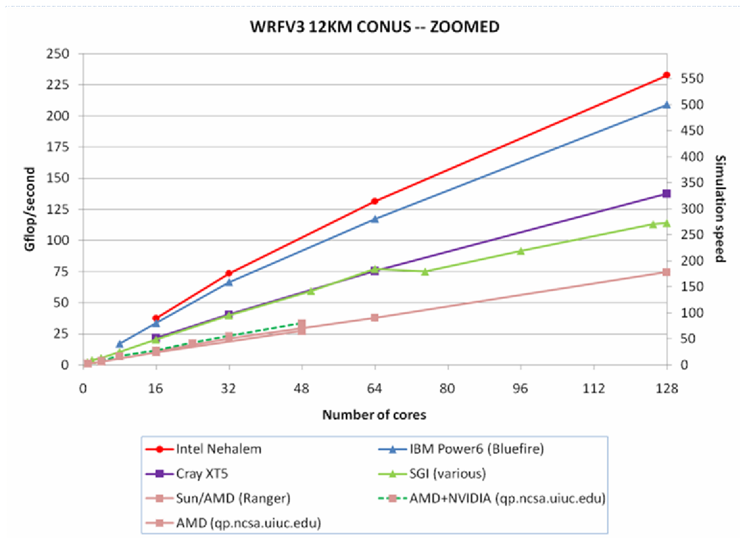


Figure 3: 12 km WRF CONUS Benchmark Results

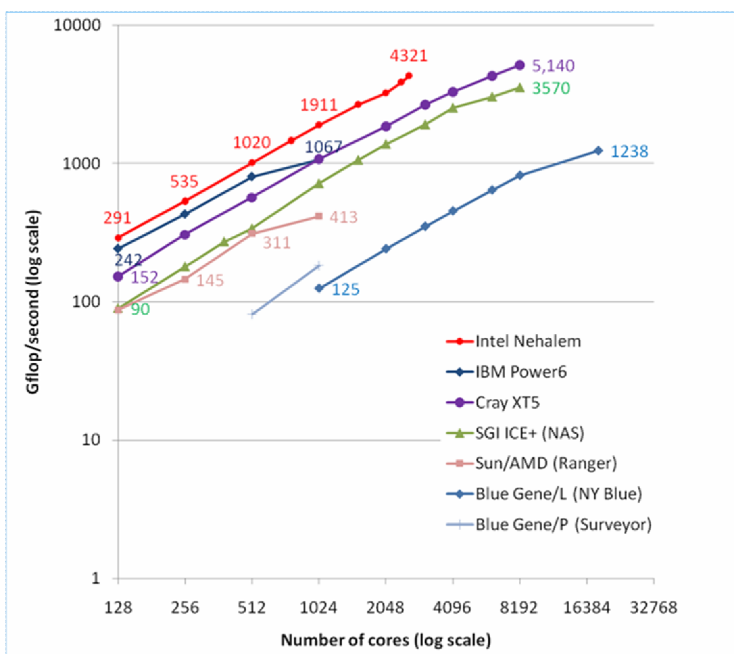


Figure 4: 2.5 km WRF CONUS Benchmark Results

[18] "The WRF V3 Parallel Benchmark", http://www.mmm.ucar.edu/wrf/WG2/bench/

Clusters based on Intel's Nehalem processor and IBM's Power 6 processors lead in sustained performance The Nehalem system has a small edge in these particular instances. Systems with the Nehalem processors – including a family of IBM System x clusters - were announced in March, 2009. IBM Power 6 clusters have been around at least 12-18 months longer. We expect HPC systems based on the recently announced Power 7 (www.power.org) clusters to be significantly faster without additional application tuning and optimization.

Recently, the National Institute of Water & Atmospheric (NIWA) Research in New Zealand announced plans to purchase an IBM Power 575 supercomputer with 100 times the performance of their existing CRAY T3E - allowing more complex and comprehensive weather and climate prediction models to be developed. According to NIWA chief executive John Morgan[19], "The United Kingdom Met Office estimated the benefit to cost ratio of their similar supercomputer was nine times that of the total cost of ownership, based solely on its capability to improve flood forecast lead times. This IBM system will also allow NIWA to improve early warning of the effects of severe events, such as flooding and storm surges". The IBM Power 575[20], also known as the Hydro-Cluster, is designed for organizations that require a highly scalable system with extreme parallel processing performance and dense, modular packaging. Densely packing up to 448 POWER6 processor cores per frame, each one running at 4.7 GHz with innovative cooling features, and the 32-core Power 575 supercomputing node is designed for speed and tuned for performance.

The Potsdam Institute for Climate Impact Research (PIK) has deployed a new IBM supercomputer that will increase its computing capacity more than thirty-fold. Potsdam researchers use IBM's high-performance iDataPlex servers to more precisely predict weather events that have so far proven to be incalculable – extreme, short-term phenomena such as torrential rain or drought. The iDataPlex[21] is a half-depth server solution, optimized both mechanically and component-wise for maximum power and cooling efficiency. It is a x86 industry-standards based server platform supporting Intel's Nehalem processors and designed to minimize utilization of data center floor space, and power and cooling infrastructure. An easily maintainable solution with individually serviceable servers, front access hard drives/cabling, and common tools for management at the node, rack, or data center level, it is configurable for client-specific compute, storage, or I/O needs and delivered pre-configured for rapid deployment.

Recent 2009 results contained in the ITIC Global Server Hardware & Server OS Reliability Survey indicate that Power systems with AIX deliver the best RAS of UNIX, Linux, Windows choices with the least amount of downtime (15 minutes per year), the fewest unscheduled outages (less than one outage per year), and the fastest patch time (11 minutes to apply a patch).[22] The survey did not include mainframes, which probably would have taken the top spot. Also, not included are IBM Blue Gene systems which, in our opinion, would have also come up high especially in the context of HPC reliability.[23]

In addition to sustained performance and reliability delivered by IBM supercomputers, weather and climate agencies have also benefited from IBM's unique capability to deliver and deploy end-to-end functional IT solutions leveraging its broader product portfolio of systems and software. For instance, in addition to a large Power p575 supercomputer, the UK Meteorological Office also has two other major subsystems that also run on IBM systems. The first is the MASS system - Meteorological Office Archive Storage System which holds all the scientific data on IBM storage products, including observations, model run outputs and scientific experiments. The other system is GPCS - General Purpose Computing System, which runs on an

[19] http://www.nbr.co.nz/article/niwa-12-million-supercomputer-will-trim-insurance-bills-109496
[20] "The IBM Power 575 supercomputing node", http://www-03.ibm.com/systems/power/hardware/575/index.html
[21] "The IBM iDataPlex", http://www-03.ibm.com/systems/info/x/idataplex/index.html
[22] "IBM Power servers most reliable in recent survey", Network World, July, 2009, http://www.networkworld.com/news/2009/071409-ibm-power-servers.html
[23] Srini Chari, "Reliability in HPC", Cabot Partners, Working Paper, 2009.

IBM mainframe. This provides pre-processing functionality to assimilate and prepare all observational data ready for ingestion into the supercomputer. Once the supercomputer system has done its modeling work, the mainframe then executes post-processing applications to turn model data into weather forecast products to disseminate to the Meteorological Office's customers - Radio/TV, other Government departments such as the Ministry of Defense, and other commercial customers. All three systems, including the p575, combine to provide the "National Weather Service", which is the Meteorological Office's prime public responsibility.

In another example, IBM was awarded three contracts a few years ago by the European Centre for Medium-Range Weather Forecasts (ECMWF) to not only install a very large IBM Power-based HPC system, but to also upgrade its entire data handling system (DHS). DHS uses another IBM Power-based cluster and IBM's High Performance Storage System (HPSS) – an IBM solution specifically designed to support large HPC parallel systems - to manage all ECMWF data. As of 2008, this system delivered about 4 teraflops of sustained performance. ECMWF strategic plans[10] call for a capability of 20 teraflops sustained performance in 2009 and between 150-200 teraflops sustained in 2011. ECMWF plans to continue to achieve these business objectives using future generations of IBM Power-based supercomputers with high performance InfiniBand networks.

Beyond functionality, scalable parallel supercomputers for weather and climate applications must meet the two simultaneous yet somewhat conflicting objectives (failures and downtimes typically grow with the number of processors) of sustained performance and excellent RAS. So it's important to examine availability normalized with respect to performance. We examine recent survey[14] data obtained from the largest European supercomputers, which we believe to be the most comprehensive recently published study of HPC application workload performance, system utilization, and system availability. The following figure plots the Linpack[24] peak performance (RMax on log scale) of these systems versus reported availability which vary from 95% to 100%. The bubble sizes are indicative of utilization levels which vary from 20% (Galera) to 95% (Neolith).

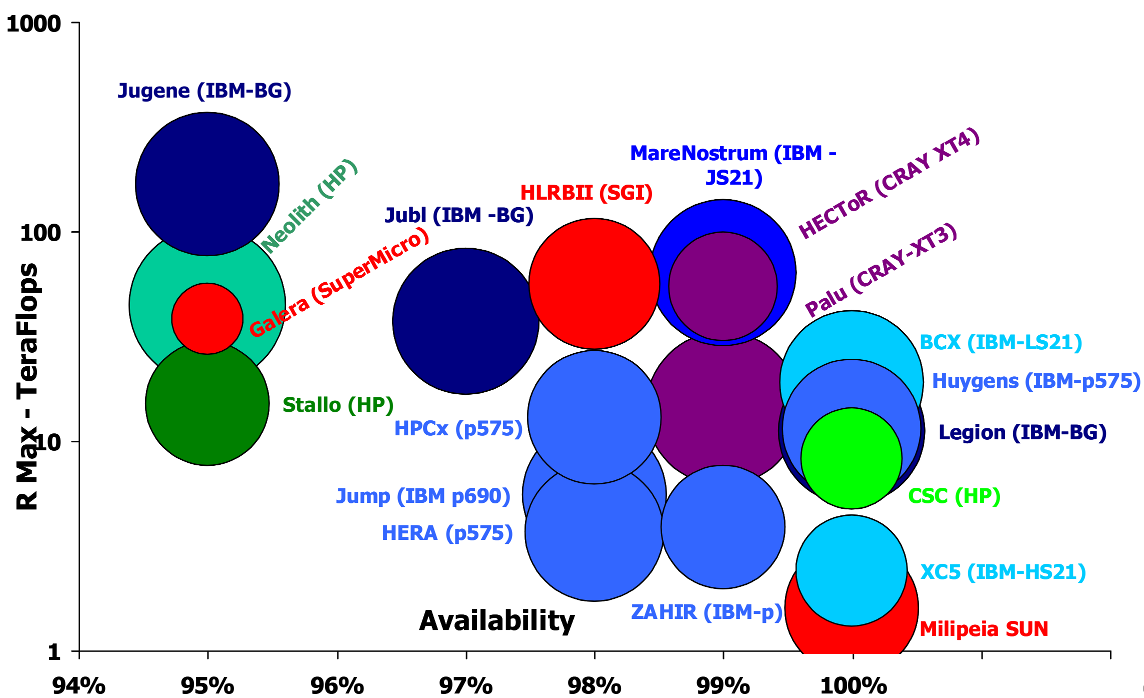


Figure 5: Linpack Performance (log-scale) vs. Availability for Various European Supercomputers - Larger Bubble Sizes Imply Greater System Utilization

24 www.top500.org

The IBM supercomputers are colored in shades of blue with the Blue Gene (darkest), Power based (medium), and x86 based clusters (lightest). Likewise, HP systems are colored in shades of green, the CRAY systems in purple and other systems (SGI, SUN, and Supermicro) are in red. The IBM portfolio of supercomputers leads in this metric. This, we believe, is a key reason why IBM with its Power-based supercomputers – many of them with GPFS and AIX - overwhelmingly leads the install base of supercomputers at weather and climate agencies.

Why is IBM Well-Positioned to extend its Leadership in the Weather and Climate Market?

While IBM is clearly the incumbent leader in the weather and climate market and may have some market power with its large install base and customer relationships, customers in the HPC marketplace traditionally have had low switching costs and vendor loyalty compared with the rest of the IT industry. This is probably truer in the weather and climate market where agencies have developed their own application software that could be easily ported to other platforms. Despite this we believe that IBM is uniquely well-positioned to extend its leadership in this market for the following reasons:

1. IBM has the broadest portfolio of HPC solutions with the flexibility to offer the best mix of functionality, sustained performance, and reliability,
2. Although today the performance gap between the Nehalem and Power 6 systems has narrowed, with the Power 7 and associated enhancements in the operating system, IBM will probably significantly enhance its performance leadership on the Power 7 in the near future,
3. Power 7 systems and the companion operating systems will have RAS and energy-efficiency enhancements that should further increase the reliability of these systems,
4. IBM's Programmable Easy-to-use Reliable Computing System (PERCS)[25] was selected by the Defense Advanced Research Projects Agency (DARPA) to provide systems designs and associated software that must support the eventual scaling of sustained computation to 10 petaflops. This system will be based on the Power architecture and will enable IBM to leverage this large government investment to satisfy expected future needs of weather and climate agencies,
5. For customers who may prefer x86 based systems, IBM System x clusters, particularly the iDataPlex, will continue to offer unique differentiation in compute density, scale, unique HPC software functionality such as GPFS, and reliability,
6. The Blue Gene is expected to have substantial enhancements to support large volume data management and visualization[26] and scaling into the tens of petaflops.[27] Recently, IBM even announced an exascale initiative[28],
7. And finally, and probably most strategic, IBM recently announced a business and predictive analytics initiative[29] with several billion dollars of investment to build integrated (hardware, software, and services) solutions. The operational weather forecasting process is in many ways an extreme example of business analytics workload. Systems designs are driven by and optimized for workloads. Many of IBM's future investments in its systems portfolio for business analytics should also help weather and climate agencies.

[25] "PERCS", IBM Almaden Research Center, http://www.almaden.ibm.com/StorageSystems/projects/percs/
[26] "Graphics processing installation to boost Argonne's Blue Gene/P visualization capabilities", http://www.physorg.com/news136041545.html
[27] "IBM Sequoia", http://en.wikipedia.org/wiki/IBM_Sequoia
[28] http://www.ibm.com/ibm/ahead/supercomputers/index3.shtml
[29] IBM to Acquire SPSS Inc. to Provide Clients Predictive Analytics Capabilities, http://www-03.ibm.com/press/us/en/pressrelease/27936.wss