Project Status Report

High End Computing Capability
Strategic Capabilities Assets Program

December 10, 2012

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HECC Experts Achieve 2000x Application Speed-up

- HECC experts recently identified the execution runs of the Cloud+Snow Reflectance code as the cause of a massive (5–10x) slowdown in both program compilation and I/O times to a single Pleiades Network File System (NFS).
- Analysis showed that the code, a serial program, was being run as an embarrassingly parallel, 2016-way job for 96 hours, with each serial task opening, reading, and closing the same file repeatedly throughout the run—causing the equivalent of a denial-of-service attack on the NFS server, which also hosted the compilers.
- The performance of the code was improved 2000-fold by moving the input and output files from NFS to /tmp and removing the repeated reads of the input files.
- The same job can now be run in under 1 hour with fewer serial tasks and no impact on the NFS server.

Mission Impact: Optimizing this climate code improved the overall performance and throughput of the HECC I/O system for all users, while potentially enabling more complex calculations with 3D effects of snow surface in the coupled surface-cloud simulations.

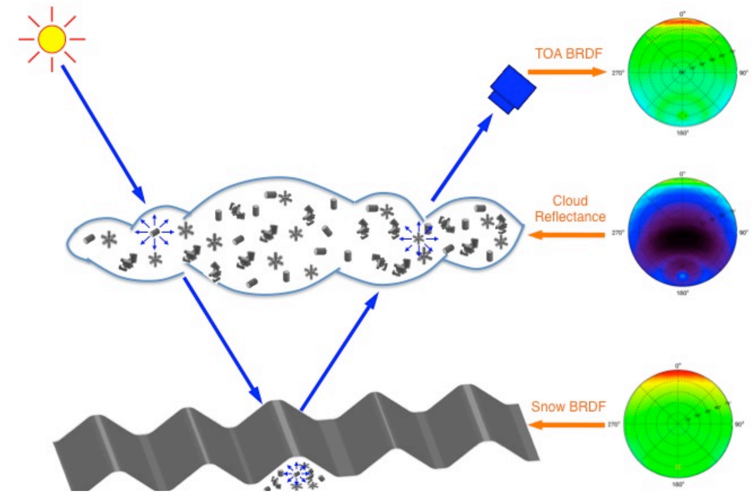


Illustration showing that reflectance from snow surfaces over polar regions is of the same magnitude as reflectance from clouds, and that coupling of the bidirectional reflectance distribution function from both snow and cloud surfaces must be considered to arrive at the reflectance at the top of the atmosphere, as seen by satellite imagers. *Gang Hong, NASA/Langley*

POCs: Johnny Chang, johnny.chang@nasa.gov, (650) 604-4356; Dale Talcott, dale.r.talcott@nasa.gov, (650) 604-0555, NASA Advanced Supercomputing Division, Computer Sciences Corporation

Networking, ESS Teams Complete Initial Phase of IPv6 Implementation

- The HECC Networking team, working with the Engineering Servers and Services team, established Internet Protocol version 6 (IPv6) peering, and completed the transition of public web servers to IPv6 in time to meet the September 30, 2012 federal mandate.
- As part of this work, the teams established IPv6 hardening guidelines for Linux kernel tuning on servers, switches, and routers, for maximum security.
- Network engineers also designed a new addressing scheme based on external IPv6 address space allocations provided by the NASA Integrated Communications Services team, and re-addressed servers, routers, and security scanners.
- Extensive testing prior to implementation ensured a seamless transition from IPv4 to IPv6, with no impact to users.

Mission Impact: By testing and implementing an IPv6 architecture for public-facing services, the HECC Project complies with federal mandates for IPv6 readiness, and moves one step closer to a complete transition to IPv6.

IPv6 is the latest revision of the Internet Protocol (IP), the primary communications protocol on which the entire Internet is built. It is intended to replace the older IPv4, which is still employed for the vast majority of Internet traffic as of 2012. IPv6 was developed by the Internet Engineering Task Force (IETF) to deal with the long-anticipated problem of IPv4 running out of addresses.

POC: Nichole Boscia, nichole.boscia@nasa.gov, (650) 604-0891, NASA Advanced Supercomputing Division, Computer Sciences Corporation

Four-Rack Intel Xeon Phi System (Maia) Delivers 212.9 TF in Early LINPACK Benchmark

- Looking toward the future of NASA's high-end computing capabilities, HECC ordered an SGI Pyramid System as part of the ongoing Space Act agreement between SGI, Intel, and NASA.
- The new system, named Maia, has 128 nodes, each containing 2 Intel Xeon E5-2670 (8-core) processors, 2.6 GHz; and 2 Intel Xeon Phi 5110P (60-core) processors as accelerators.
- Maia will be assessed as a candidate architecture for HECC, going forward; the dense computational capability promises performance not available with non-accelerated systems.
- Over the next several months, HECC will evaluate the effectiveness of the Intel Phi in meeting NASA's engineering and science requirements in a cost-effective manner.
- In early tests, Maia achieved over 70% efficiency on the LINPACK benchmark.
- The theoretical peak performance of Maia is 301.4 teraflops (TF); the November 2012 LINPACK results were 212.9 TF.

Mission Impact: By evaluating potential advances in hardware technology for full deployment, HECC decreases the risk of fielding an unsuitable system before increasing the computational capability available to NASA.

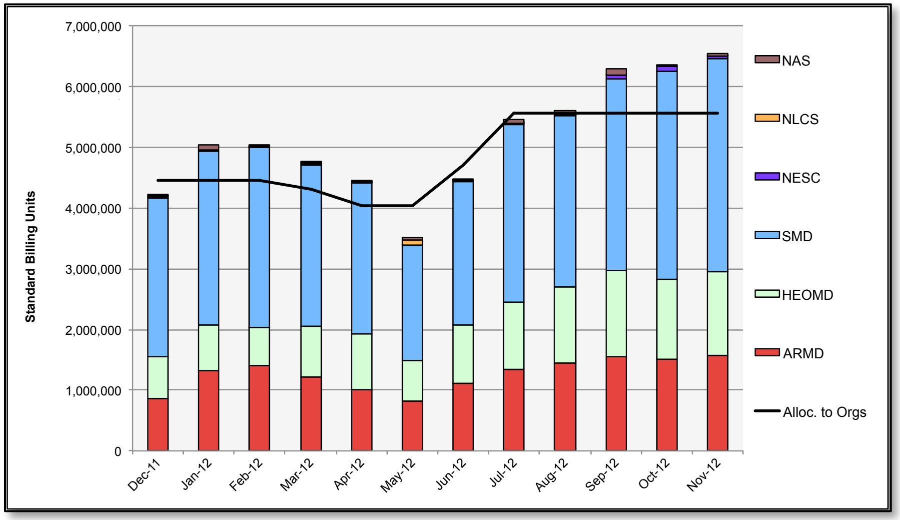
The Maia system is being assembled in Chippewa Falls, WI. This new technology has the potential to significantly increase the compute capability available to NASA's scientists and engineers.

POC: William Thigpen, william.w.thigpen@nasa.gov, (650) 604-1061, NASA Advanced Supercomputing Division

Record-High Usage on Pleiades Provides Maximum Resources for NASA Missions

- November showed record-high usage of HECC's Pleiades supercomputer, with over 6.5 million Standard Billing Units (SBUs) used by NASA's Mission Directorates and mission support organizations—exceeding the previous record (from September 2012) of 6.3 million SBUs.
- This increase of approximately 4% was enabled by efficient operations that delivered better than 99% availability and better than 89% system utilization (75% utilization is the target).
- Researchers in the Science Mission Directorate were the biggest users, consuming approximately 53% of all Pleiades SBUs.
- Computing resources continue to expand and are made available to users from all Mission Directorates to support their computing needs.

Mission Impact: Increasing Pleiades system utilization with efficient operations provides NASA Mission Directorates with more resources for the accomplishment of their goals and objectives.



Utilization of Pleiades by all mission directorates and support organizations. Data is shown in Standard Billing Units (SBUs), where one SBU is equivalent to one node hour of a 12-core Westmere node of Pleiades. Data is normalized to a 30-day month.

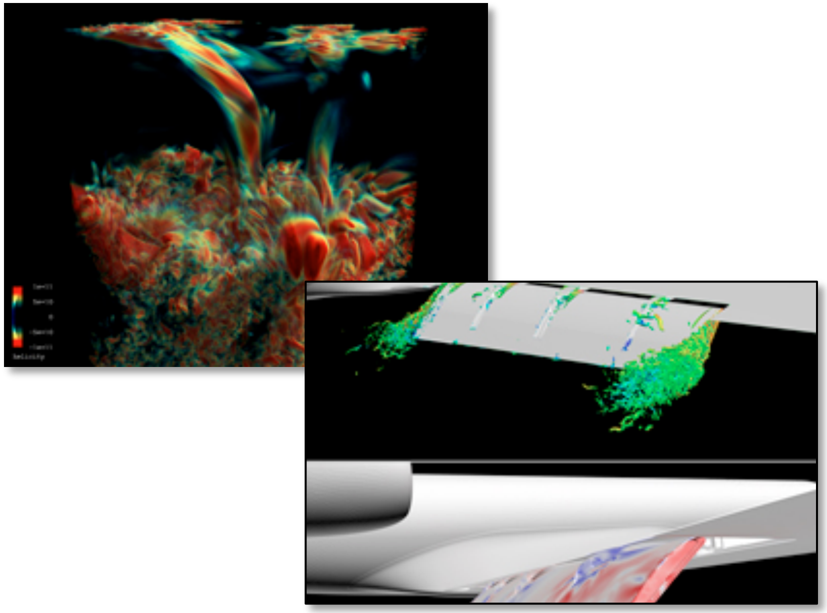
POC: Catherine Schulbach, catherine.h.schulbach@nasa.gov. (650) 604-3180, NASA Advanced Supercomputing Division

New Allocation Period Begins for ARMD and SMD

- November 1 marked the beginning of a new allocation period for the Aeronautics Research Mission Directorate (ARMD) and the Science Mission Directorate (SMD).
- These two organizations awarded new allocations on Columbia and Pleiades to over 260 computing projects that support their science and engineering activities.
- The combined awards, equally distributed between ARMD and SMD, exceeded 50 million Standard Billing Units (SBUs)* — double the awards for November 2011 (note that SMD allocates twice a year)
- Continued growth of Pleiades makes it possible for HECC to keep pace with these ever-expanding demands for resources.
- The new allocation period provides an opportunity for each organization to rebalance allocations to meet computing needs for the upcoming year.

*1 SBU equals 1 hour of a Pleiades Westmere 12-core node.

Mission Impact: NASA programs and projects periodically review the distribution of computing time to assure it is consistent with the achievement of mission-specific goals and objectives.



Top: Visualization of kinetic helicity above the subsurface, turbulent, convective layer of the Sun. Tim Sandstrom, NASA/Ames; Irina Kitiashvili, Stanford University. Bottom: The complex, unsteady flow features at flap tips of Gulfstream aircraft. Raymond Mineck, NASA/Langley; Patrick Moran, NASA/Ames.

POC: Catherine Schulbach, catherine.h.schulbach@nasa.gov. (650) 604-3180, NASA Advanced Supercomputing Division

HECC/NAS Staff Spearhead Successful Agency Exhibit at SC12 Conference

- Staff from the HECC Project and NAS Division coordinated the agency's highly successful presence at SC12, the International Conference for High-Performance Computing, Networking, Storage, and Analysis, Salt Lake City, November 10–16.
- Users from universities and 6 NASA centers, representing all Mission Directorates, explained their recent science and engineering projects, many enabled by Pleiades.
- At the conference, it was announced that Pleiades won the HPCwire People's Choice Award for Top Supercomputing Achievement "for the NASA Kepler Mission discovery of new planets in the Milky Way."
- Crowds at the NASA booth were frequently standing-room-only to see the eye-catching science and engineering images and videos shown on HECC's new traveling hyperwall.

Mission Impact: Participation in SC12 provided an important opportunity to exchange information with peers and HEC industry leaders from around the world, convey the importance of NASA missions, and meet with candidates for internship/job opportunities.

Jet Propulsion Laboratory's Timofey Ovcharenko wowed SC12 crowds with 3D movies of Curiosity's perfect landing on Mars, shown on the HECC's new traveling hyperwall. The talk included details on the agency's enabling technologies behind the mission. David Robertson, NASA/Ames

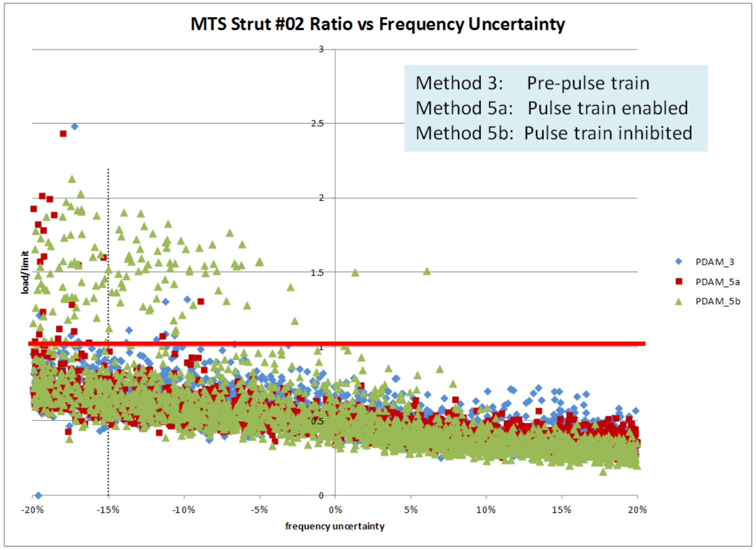
POC: Gina Morello, gina.f.morello@nasa.gov, (650) 604-4462, NASA Advanced Supercomputing Division

HECC Ensures Timely Software Updates for Upcoming ISS and ISS/SpaceX Missions

- The International Space Station (ISS) Loads & Dynamics team completed extensive analyses requiring more than 0.5 million SBUs on Pleiades over the past three months.
- Analyses included completion of a Pre-determined Debris Avoidance Maneuver (PDAM) screening that incorporated the latest ISS Motion Control System (MCS) pulse train.
  - Interface loads were verified for strength and approved by the ISS structures team, clearing the PDAM for on-orbit operation where it will enable quick response to required debris avoidance events;
  - Due to the ability to run on Pleiades, the work was completed early and delivered to the ISS Structural Integrity team in time to complete their analysis ahead of schedule.
- The team also completed the SpaceX-2 Verification Analysis Cycle (VAC) for ISS attitude control and reboost of orbital height.
  - Results showed that the new ISS MCS pulse train resulted in acceptable peak on-orbit loads for the ISS/SpaceX-2 mission configuration.
  - Results were delivered to the ISS Program as part of structural verification requirements for the upcoming SpaceX-2 mission.

** HECC provided resources and services in support of this work.*

Mission Impact: Enabled by HECC supercomputing resources, fast verification analyses ensure timely on-orbit implementation of critical ISS software updates and completion of structural verification requirements for upcoming scheduled missions.



Thousands of simulations were run to verify the Pre-determined Debris Avoidance Maneuver (PDAM) control method that minimizes loads on the ISS structure. Sensitivity of modal frequency uncertainty was studied and showed that acceptable loads were predicted for one of the methods using a verified frequency uncertainty.

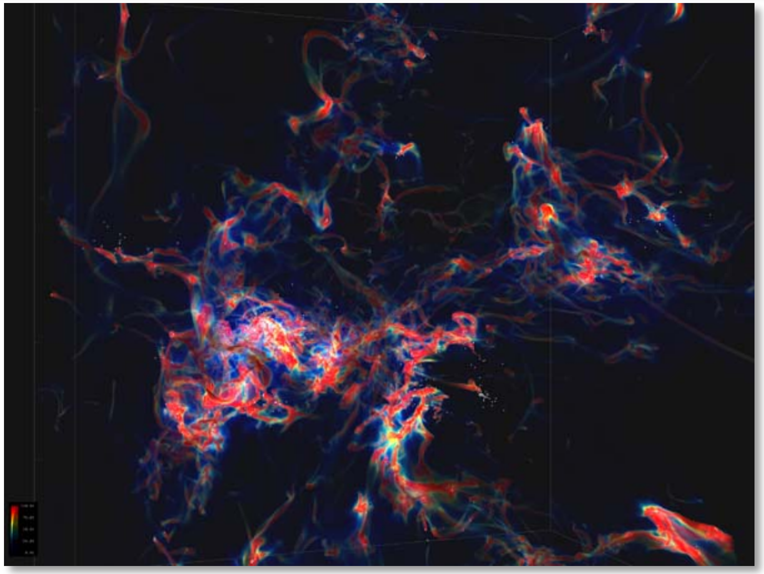
POC: Quyen T. Jones, quyen.t.jones@nasa.gov, (281) 483-0564, Loads and Structural Dynamics Branch, NASA Johnson Space Center

HECC Resources Help Unravel the Mysterious Origin of Stellar Masses

- Researchers supporting the Science Mission Directorate carried out the largest simulations to date of star-forming clouds, capturing the full range of stellar masses.
- Among the milestones achieved:
  - Generation of thousands of stars per simulation, covering the entire range of stellar masses, from brown dwarfs (a small percentage of a solar mass), to massive stars (tens of solar masses);
  - A probability distribution of simulated stellar masses that reproduces those found in stellar clusters;
  - A rate of star formation in the simulations comparable to that measured in star-forming regions.
- Users plan to simulate star formation within a 100x larger volume, including the explosion of supernovas that drive the turbulence in the interstellar gas.

** HECC provided resources and services in support of this work.*

Mission Impact: Simulations such as these allow researchers to test theoretical models of star formation that are necessary to understand the formation of galaxies. They explain the process that assembles the mass of stars and shed new light onto the early phases of star and planet formation.



Close-up from a simulation of a turbulent, star-forming cloud, showing complex gas density distribution, with a network of intersecting filaments where stars are formed. Bright spots show the position of stars approximately one million years after the beginning of star formation.

POC: Paolo Padoan, ppadoan@icc.ub.edu, Catalan Institution for Research and Advanced Studies, Institute of Cosmos Sciences, University of Barcelona

Pleiades Enables a Breakthrough in the Accuracy of Rotorcraft Prediction Methods

•Aeronautics Research Mission Directorate researchers have used NASA's OVERFLOW computational fluid dynamics (CFD) code and Pleiades to achieve a breakthrough in rotorcraft prediction accuracy.

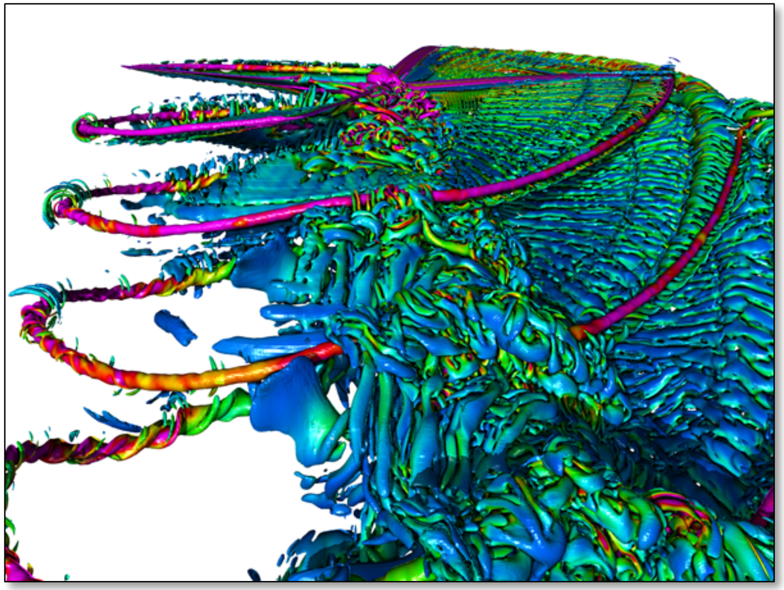
•CFD results include:

- For the first time, the rotor figure of merit (rotor blade efficiency) has been predicted within experimental error using high-order spatial accuracy and detached eddy simulation;
- An adaptive mesh refinement (AMR) method efficiently resolves the rotor wake, revealing remarkable blade vortex and turbulent flow physics details never before computed or observed;
- AMR now significantly improves prediction of vortex core size and growth rate with wake age; the error in vortex core growth rate is dramatically reduced—from 60% to 4%.

•These groundbreaking results will impact the next generation of rotorcraft analysis and design; future work will include using AMR on the rotor blades to better resolve strong blade vortex interaction and dynamic stall cases.

** HECC provided resources and services in support of this work.*

Mission Impact: The ability to accurately predict rotor blade efficiency, coupled with a dramatic reduction in vortex core growth rate error from 60% to 4% will lead to improved performance, safety, and environmental impact for the design of next-generation rotorcraft.

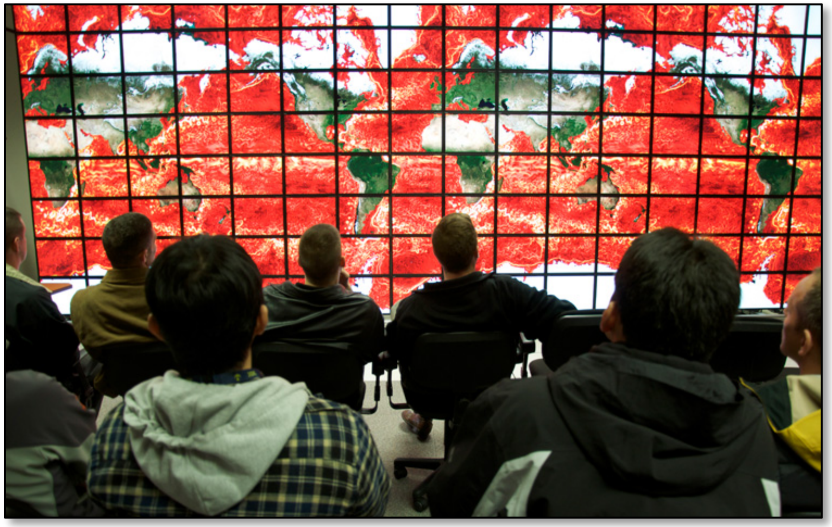


This aft view from a detached eddy simulation of a UH-60 Black Hawk helicopter rotor in forward flight shows the 3D nature of the vortex wake. Note the separated flow leaving the center-body in the middle of the image, and the uneven wake separation due to the blade motion. *Tim Sandstrom, NASA/Ames*

POC: Neal M. Chaderjian, neal.chaderjian@nasa.gov, (650) 604-4472, NASA Advanced Supercomputing Division

HECC Facility Hosts Several Visitors and Tours in November 2012

- HECC hosted five tour groups in November; guests learned about the agency-wide missions being supported by Pleiades, and viewed scientific results on the hyperwall system. Visitors this month included:
  - Seth Statler, Associate Administrator for the Office Legislative and Intergovernmental Affairs;
  - Carlos Nobre, who serves as the Director of the Center for Earth System Science and Senior Scientist at the National Institute for Space of Brazil, and as Scientific Director of Brazil's National Institute for Climate Change Research;
  - Juan Carlos Castilla-Rubio, CEO, and Teji Abraham, Chief Development Officer of Planetary Skin Institute, a global non-profit research and development organization;
  - A group from the United States Geological Survey office in Menlo Park, CA;
  - Members of the NASA Ames legal office team.



The hyperwall-2 at the NASA Advanced Supercomputing (NAS) facility is a favorite tour stop for groups visiting Ames Research Center. Global climate simulations such at that shown here generate interesting questions from a variety of audiences.

POC: Gina Morello, gina.f.morello@nasa.gov, (650) 604-4462, NASA Advanced Supercomputer Division

Presentations and Papers

- "**Kiloparsec-Scale Simulations of Magnetized Molecular Clouds in Disk Galaxies**," S. Van Loo, M. J. Butler, J. C. Tan, S. A. E. G. Falle, arXiv:1211.0508 [astro-ph.GA], November 2, 2012. *
  http://arxiv.org/abs/1211.0508

- "**Evaluation of Hydrometer Phase and Ice Properties in Cloud-Resolving Model Simulations of Tropical Deep Convection Using Radiance and Polarization Measurements,**" B. van Diedenhoven, A. M. Fridlind, A. S. Ackerman, B. Cairns, Journal of the Atmospheric Sciences, Volume 69, Issue 11, November 2012. *
  http://journals.amestsoc.org/doi/full/10.1175/JAS-D-11-0314.1

- "**Ice flow sensitivity to geothermal heat flux of Pine Island Glacier, Antarctica**," E. Larour, M. Morlighem, H. Seroussi, J. Schiemeier, E. Rignot, Journal of Geophysical Research, Volume 117, November 16, 2012. *
  http://www.agu.org/journals/jf/jf1204/2012JF002371/

- "**Effects of Turbulent Magnetic Fields on the Transport and Acceleration of Energetic Charged Particles: Numerical Simulations with Application to Heliospheric Physics**," F. Guo, arXiv:1211.3735 [astro-ph.HE], November 15, 2012. *
  http://arxiv.org/abs/1211.3735

- "**On the Process of Controlling the Seasonal Cycles of the Air-Sea Fluxes of O2 and N2O: A Modeling Study,**" M. Manizza, R. F. Keeling, C. D. Nevison, Tellus B 2012, 64, November 20, 2012. *
  http://www.tellusb.net/index.php/tellusb/article/view/18429.html

** HECC provided supercomputing resources and services in support of this work.*

Presentations and Papers (continued)

- "**Preindustrial to Present Day Change in Tropspheric Hydroxyl Radical and Methane Lifetime from the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP)**," V. Naik, et all, Atmospheric Chemistry and Physics Discussions, Vol 12, 3075 *
  http://www.atmos-chem-phys-discuss.net/12/30755/2012/acpd-12-30755-2012.pdf

- **2012 Supercomputing Conference,** November 12-15, 2012, Salt Lake City, Utah.
  - "Large-Scale Energy-Efficient Graph Traversal: A Path to Efficient Data-Intensive Supercomputing," N. Satish, C. Kim, J. Chhugani, P. Dubey.*
    http://conferences.computer.org/sc/2012/papers/1000a018.pdf
  - "Extending the BT NAS Parallel Benchmark to Exascale Computing," R. F. Van der Wijngaart, S. Sridharan, V. W. Lee. * *http://conferences.computer.org/sc/2012/papers/1000a094.pdf*
  - "A Breakthrough in Rotorcraft Prediction Accuracy Using Detached Eddy Simulation," N. Chaderjian (NASA ARC). * *http://www.nas.nasa.gov/SC12/demos/demo1.html*
  - "Simulating Planetary Entry Environments for Space Exploration Vehicles," Steven Yoon, Chun Tang, David Saunders (NASA ARC). * *http://www.nas.nasa.gov/SC12/demos/demo2.html*
  - "Adjoint-Based Design for Complex Aerospace Configurations," E. Nielsen (NASA LaRC). *
    http://www.nas.nasa.gov/SC12/demos/demo3.html
  - "Simulating Hypersonic Turbulent Combustion for Future Aircraft," J. Edwards (North Carolina State University), J. Fulton (North Carolina State University).*
    http://www.nas.nasa.gov/SC12/demos/demo4.html
  - "From a Roar to a Whisper: Making Modern Aircraft Quieter," M. Khorrami (NASA LaRC). *
    http://www.nas.nasa.gov/SC12/demos/demo5.html

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Presentations and Papers (continued)

- **2012 Supercomputing Conference** November 12-15, 2012, Salt Lake City, Utah (continued)
  - "Modeling Extended Formation Flight on High-Performance Computers," M. Aftosmis (NASA ARC). * *http://www.nas.nasa.gov/SC12/demos/demo6.html*
  - "Validating Water Spray Simulation Models for the SLS Launch Environment," G. Putnam (NASA MSFC. * *http://www.nas.nasa.gov/SC12/demos/demo8.html*
  - "Simulating Moving Valves for Space Launch System Liquid Engines," B. Richardson (NASA MSFC). * *http://www.nas.nasa.gov/SC12/demos/demo9.html*
  - "Innovative Simulations for Modeling the SLS Solid Rocket Booster Ignition," P. Davis (NASA MSFC). * *http://www.nas.nasa.gov/SC12/demos/demo10.html*
  - "Solid Rocket Booster Ignition Overpressure Simulations for the Space Launch System," B. Williams (NASA MSFC). * *http://www.nas.nasa.gov/SC12/demos/demo11.html*
  - "CFD Simulations to Support the Next Generation of Launch Pads," C. Kiris (NASA ARC), C. Brehm (NASA ARC). * *http://www.nas.nasa.gov/SC12/demos/demo12.html*
  - "Modeling and Simulation Support for NASA's Next-Generation Space Launch System," C. Kiris (NASA ARC). * *http://www.nas.nasa.gov/SC12/demos/demo13.html*
  - "Simulating Galaxies and the Universe," Joel Primack, University of California, Santa Cruz. * *http://www.nas.nasa.gov/SC12/demos/demo14.html*
  - "The Mysterious Origin of Stellar Masses," Paolo Padoan, Catalan Institution for Research and Advanced Studies, Institute of Cosmos Sciences, University of Barcelona. * *http://www.nas.nasa.gov/SC12/demos/demo15.html*
  - "Hot-Plasma Geysers on the Sun," Alan Wray (NASA ARC), Irina Kitiashvili, Stanford University. * *http://www.nas.nasa.gov/SC12/demos/demo26.html*

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Presentations and Papers (continued)

- **2012 Supercomputing Conference,** November 12-15, 2012, Salt Lake City, Utah (continued)
  - "Modeling Weather on the Sun," R. Stein, Michigan State University. * *http://www.nas.nasa.gov/SC12/demos/demo27.html*
  - "Causes and Consequences of Turbulence in the Earth's Protective Shield," H. Karimabadi (University of California, San Diego/SciberQuest, Inc.), A. Le (University of California, San Diego). * *http://www.nas.nasa.gov/SC12/demos/demo28.html*
  - "The Search Continues: Kepler's Quest for Habitable Earth-Sized Planets," S. Seader (NASA ARC) * *http://www.nas.nasa.gov/SC12/demos/demo31.html*
  - "NASA Earth Exchange: A Collaborative Supercomputing Platform," P. Votava (NASA ARC), R. Nemani (NASA ARC). * *http://www.nas.nasa.gov/SC12/demos/demo32.html*
  - "Turbulent Life of Kepler Stars," Nagi Mansour (NASA ARC), Alexander Kosovichev, Stanford University. * *http://www.nas.nasa.gov/SC12/demos/demo34.html*
  - "Continuous Enhancements to the Pleiades Supercomputer for Maximum Uptime," Davin Chan (NASA ARC).
  - "Enhancing Performance of NASA's High-End Computing Applications," Robert Hood (NASA ARC).
  - "Meeting NASA's High-End Computing Goals Through Innovation," William Thigpen (NASA ARC).

** HECC provided supercomputing resources and services in support of this work.*

News and Events

- **NASA Missions Featured at Supercomputing Conference,** *NASA Ames press release,* November 5, 2012 – NASA missions and projects from NASA centers and university and industry partners, enabled by the supercomputing resources at the NASA Advanced Supercomputing facility and the NASA Center for Climate Simulation, will be presented at SC12 in Salt Lake City, Utah November 12-15, 2012.
  http://www.nasa.gov/centers/ames/news/releases/2012/12-83AR.html

- **NASA Demonstrates Its Need for Speed with 100 Gb-Per-Second Network with cPacket**, *Satellite Spotlight/TMCnet,* November 12, 2012 – NASA booth demonstrates 100 Gb/sec network transfers at SC12 as part of the “Big Data” theme.
  http://satellite.tmcnet.com/topics/satellite/articles/2012/11/12/315665-nasa-demonstrates-its-need-speed-with-100-gb.htm

- **NASA, cPacket Demo 100-Gigabit Networking**, *HPCwire*, November 12, 2012 – HPCwire’s coverage of the 100 Gb/sec demonstration at the NASA SC12 booth in Salt Lake City.
  http://www.hcpwire.com/hpcwire/2012-11-12/nasa_cpacket_demo_100-gigabit_networking.html

- **HPCwire Announces 2012 Readers’ Choice Awards Winners,** *HPCwire,* November 12, 2012 – the Pleiades supercomputer wins Readers’ Choice for the Top Supercomputing Achievement for the work done with the Kepler Mission discovering new planets within the Milky Way galaxy.
  http://www.hpcwire.com/hpcwire/2012-11-12/hpcwire_announces_2012_readers_choice_awards_winners.html
  http://www.hpcwire.com/specialfeatures/2012_Annual_HPCwire_Readers_Choice_Awards.html

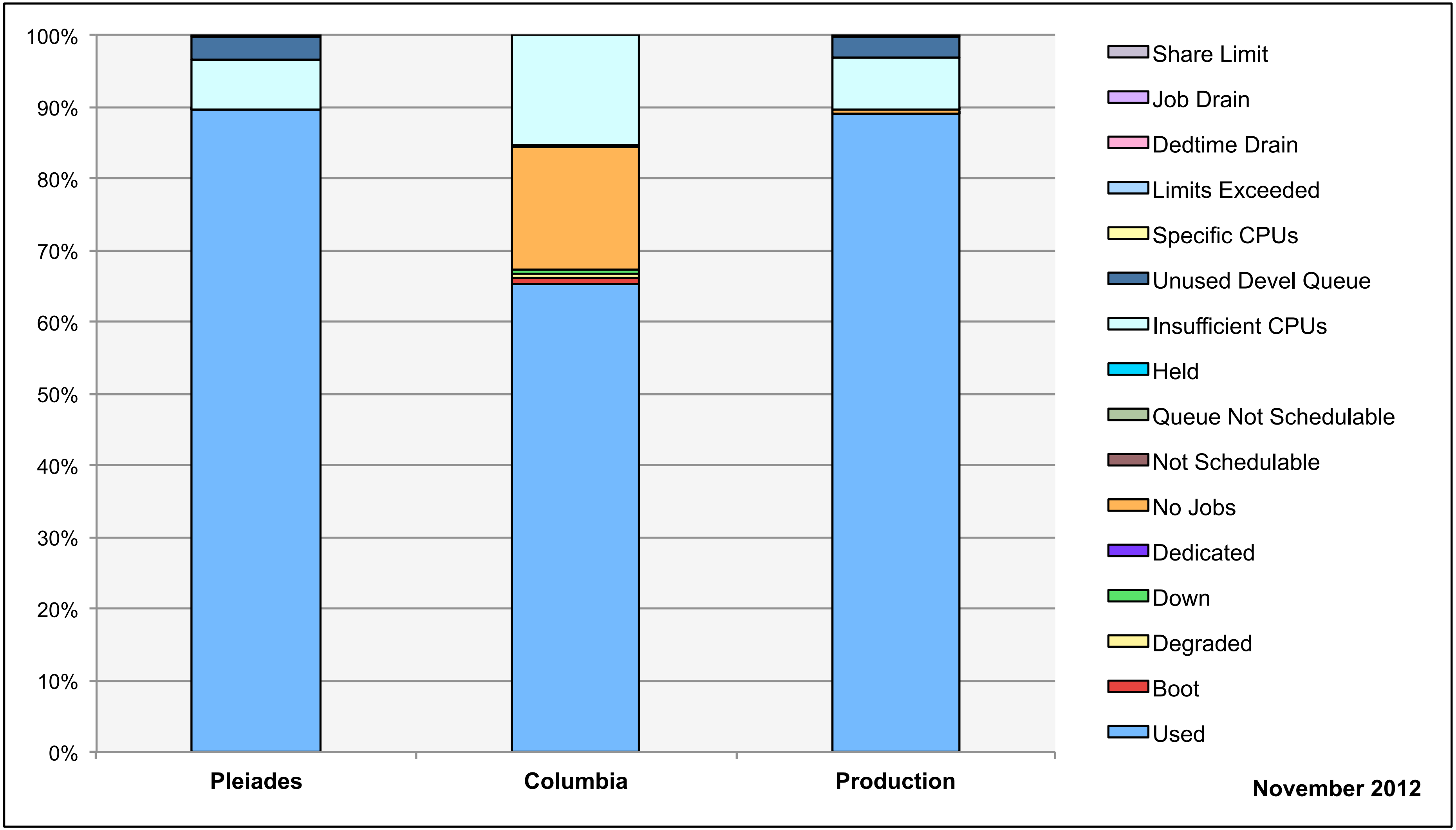
News and Events (continued)

- **Top500 List, November 2012,** *Top500.org,* November 12, 2012 – Pleiades supercomputer ranks at #14, Maia ranks at #117.
  http://www.top500.org/list/2012/11/

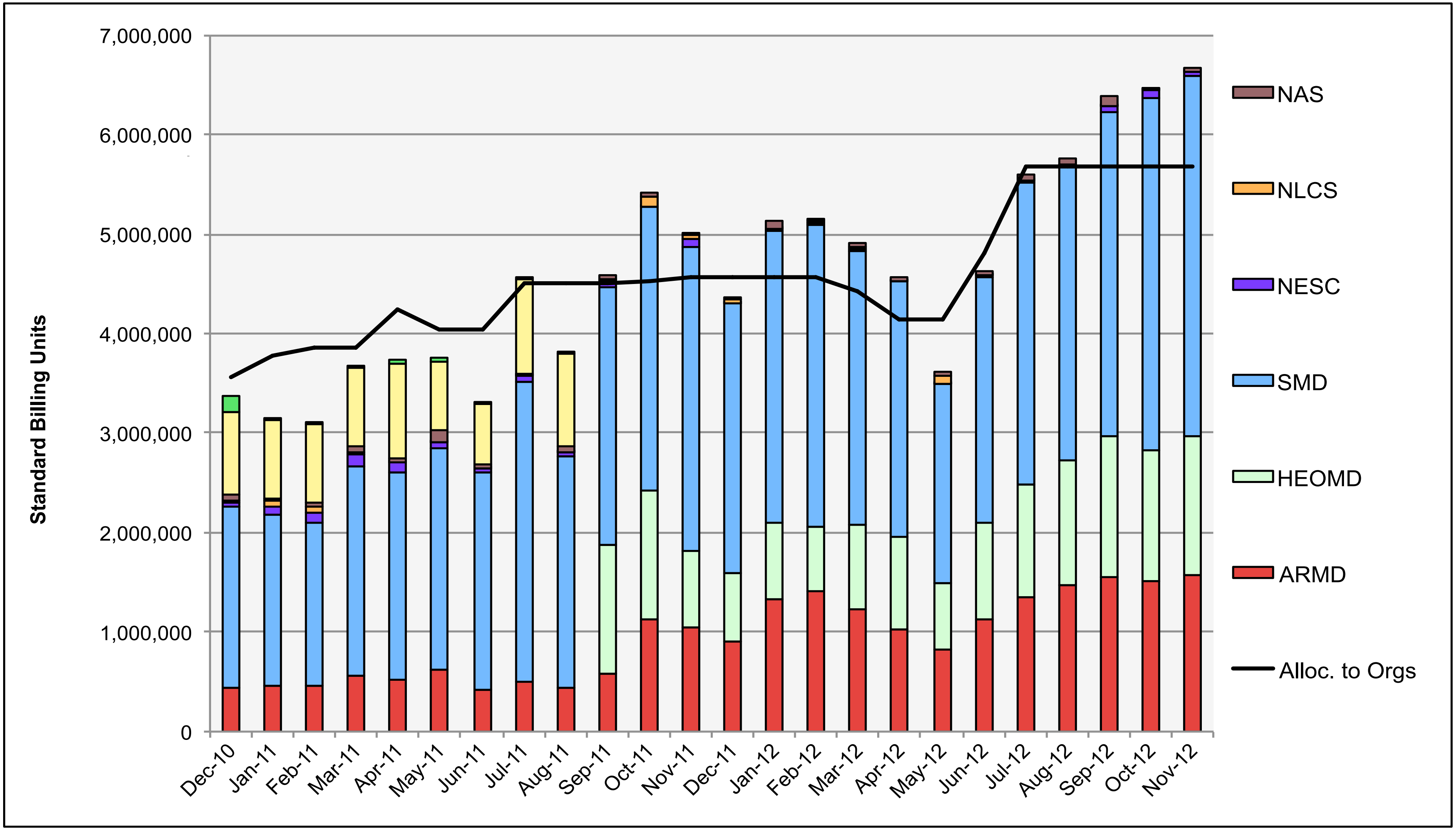
- **Green500 List, November 2012,** *Green500.org,* November 14, 2012 – Pleiades supercomputer ranks at #188, Maia at #33.
  http://www.green500.org/lists/green201211&green500from=1&green500to=100

- **Understanding Artic Sea Ice at MIT,** *MIT News Office,* November 21, 2012 – YouTube interview with MIT research scientist Patrick Heimbach, looking at ECCO2 model simulations run on Pleiades and visualized by the NAS visualization team.
  http://www.youtube.com/watch?v=Ce1INgtypWk

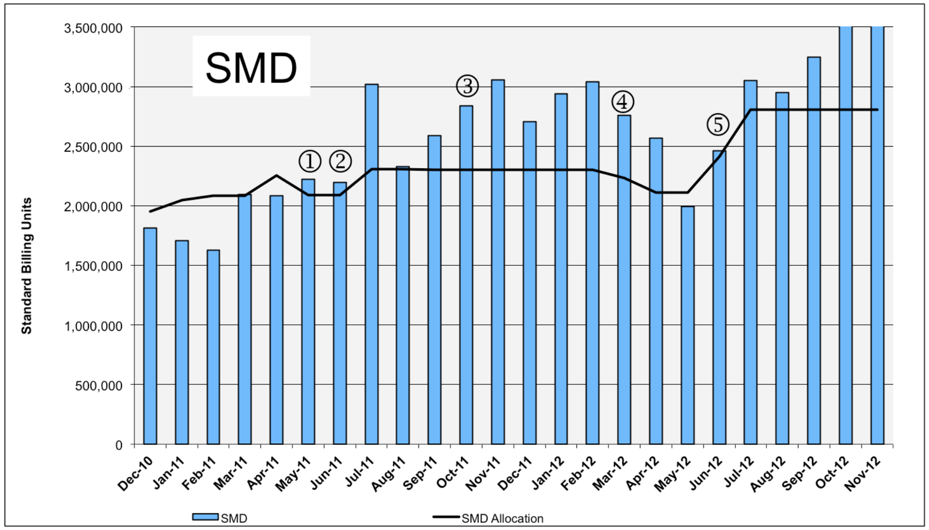
HECC Utilization

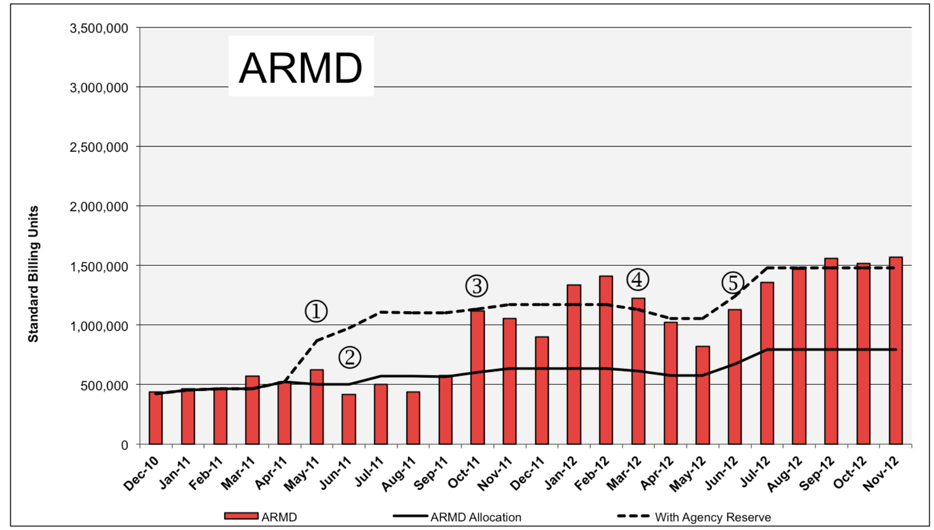


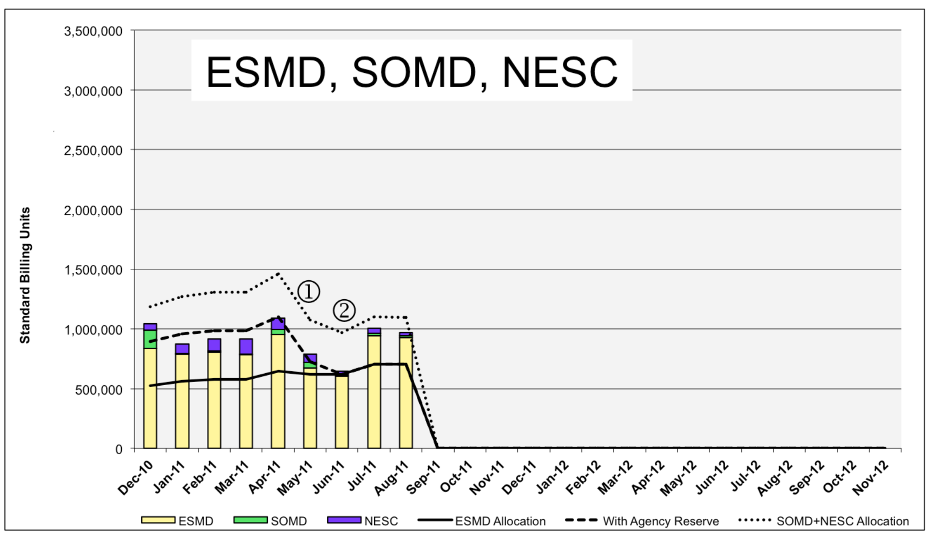
HECC Utilization Normalized to 30-Day Month

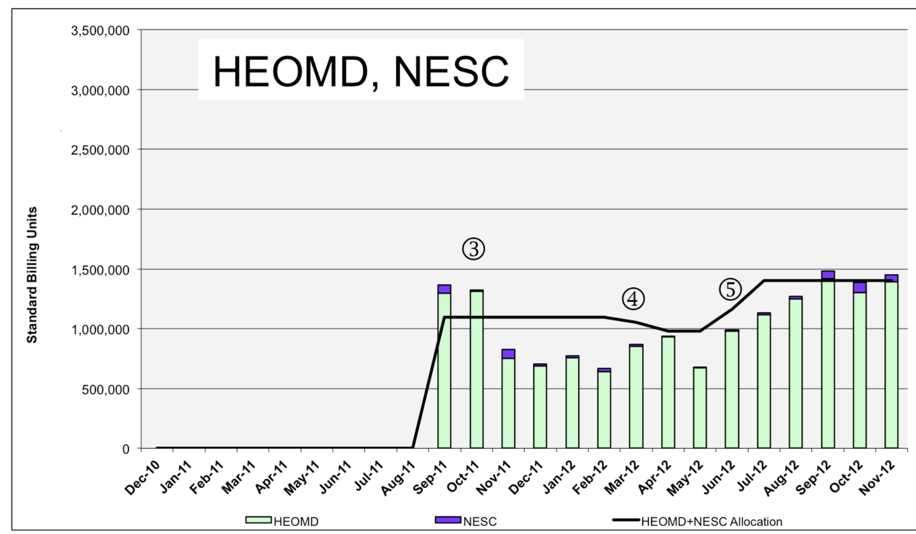


HECC Utilization Normalized to 30-Day Month



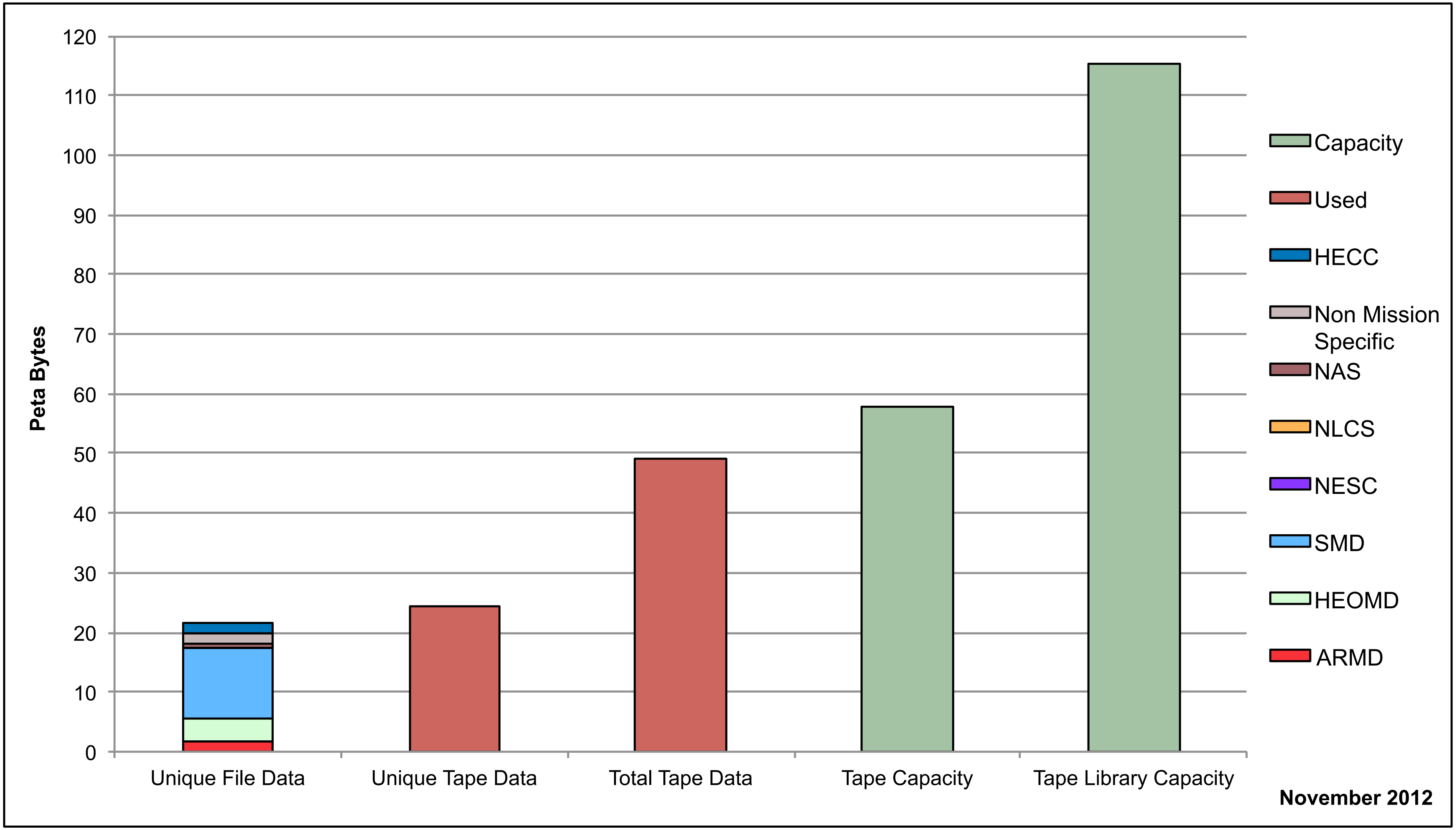






① Allocation to orgs. decreased to 75%, Agency reserve shifted to ARMD ② 14 Westmere racks added
③ 2 ARMD Westmere racks added ④ 28 Harpertown racks removed ⑤ 24 Sandy Bridge racks added

Tape Archive Status



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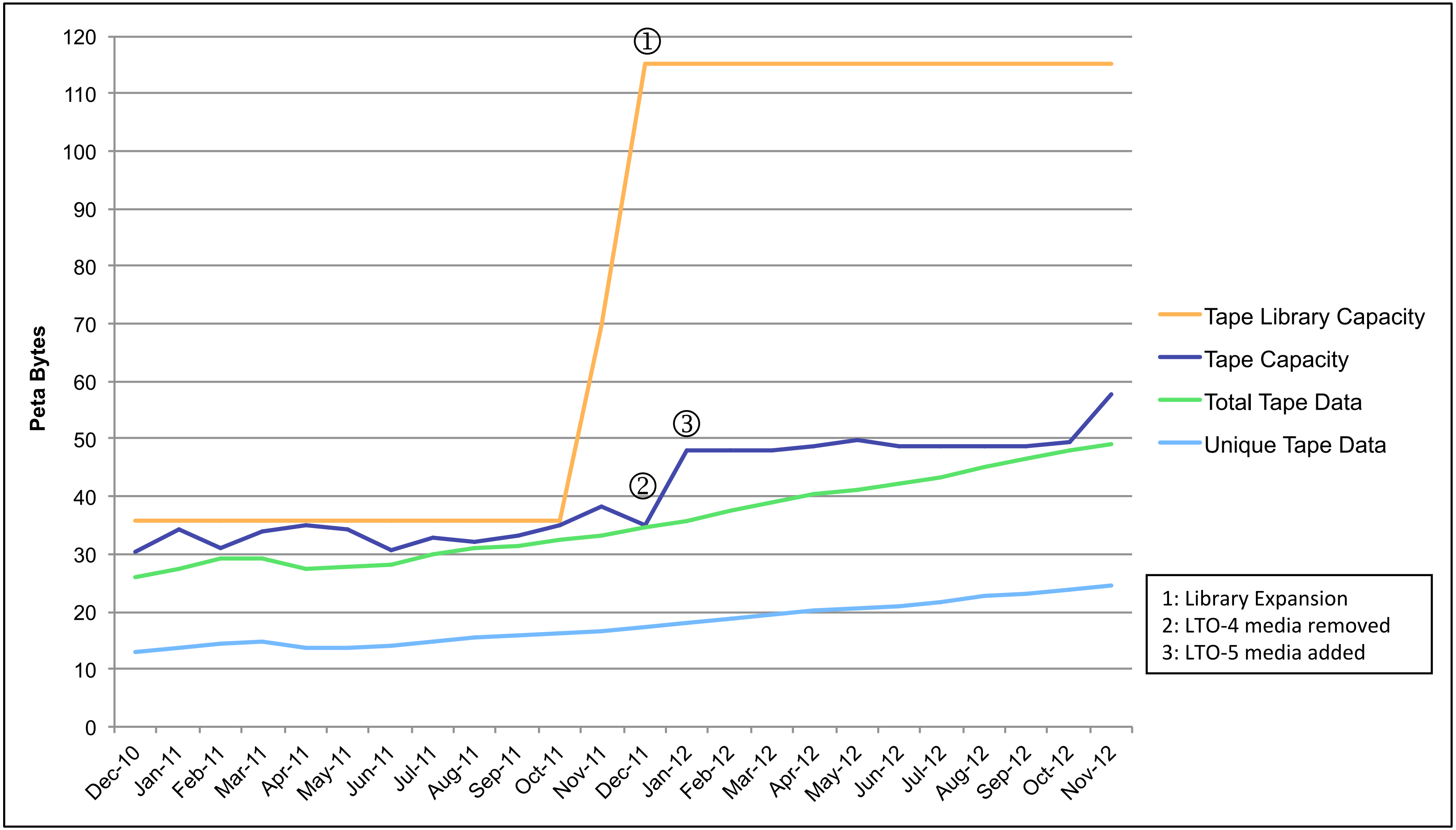
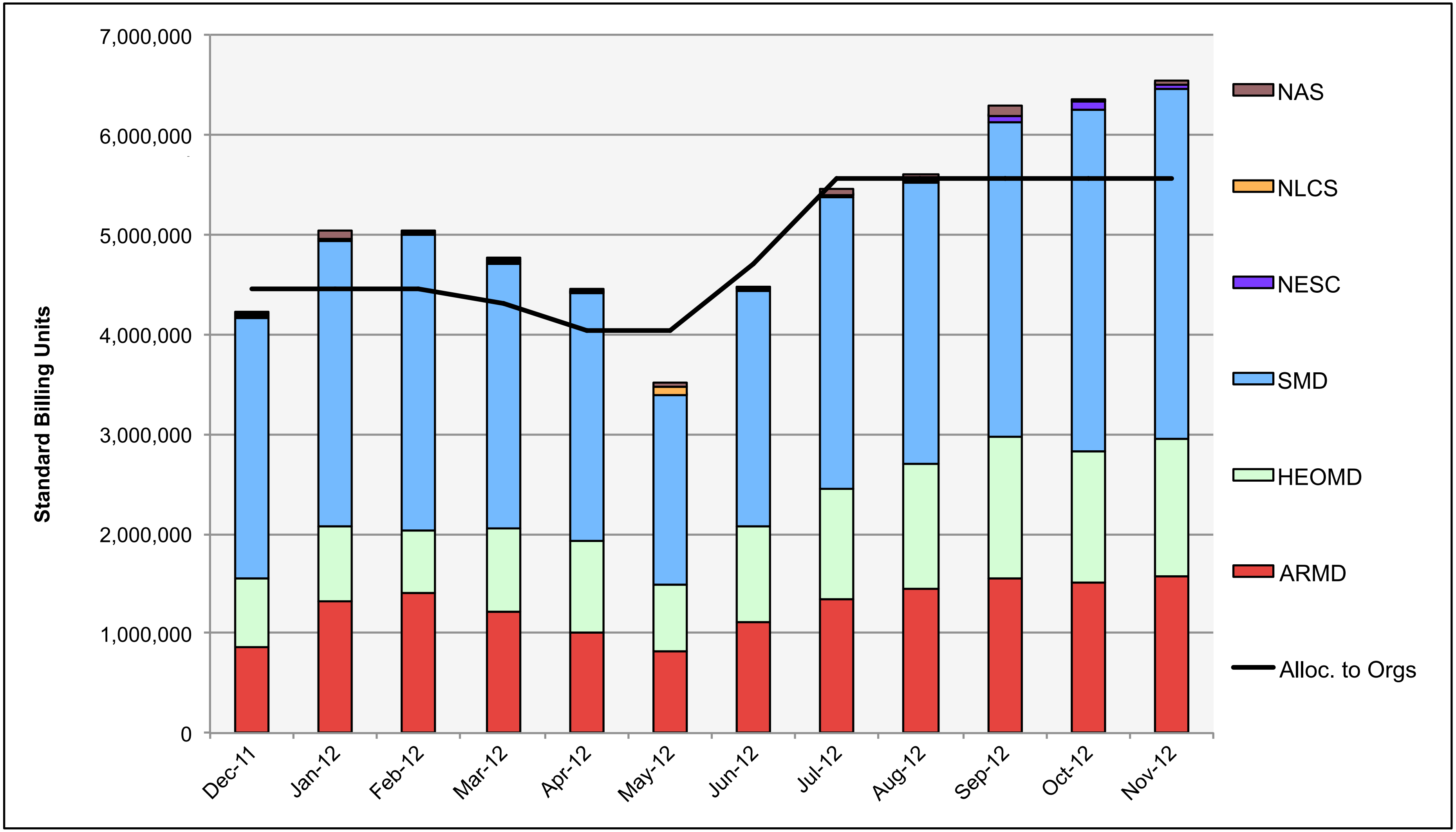
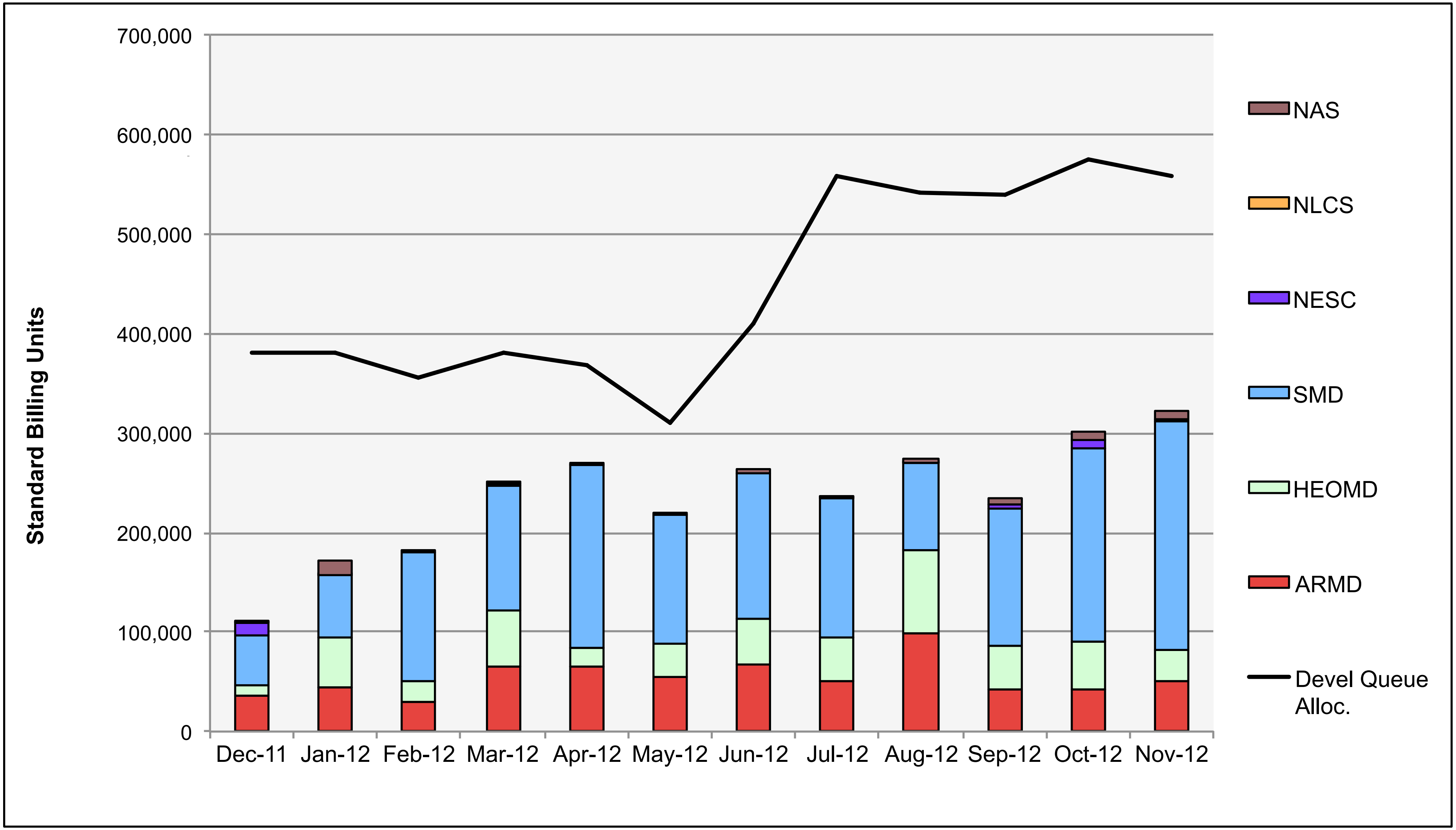


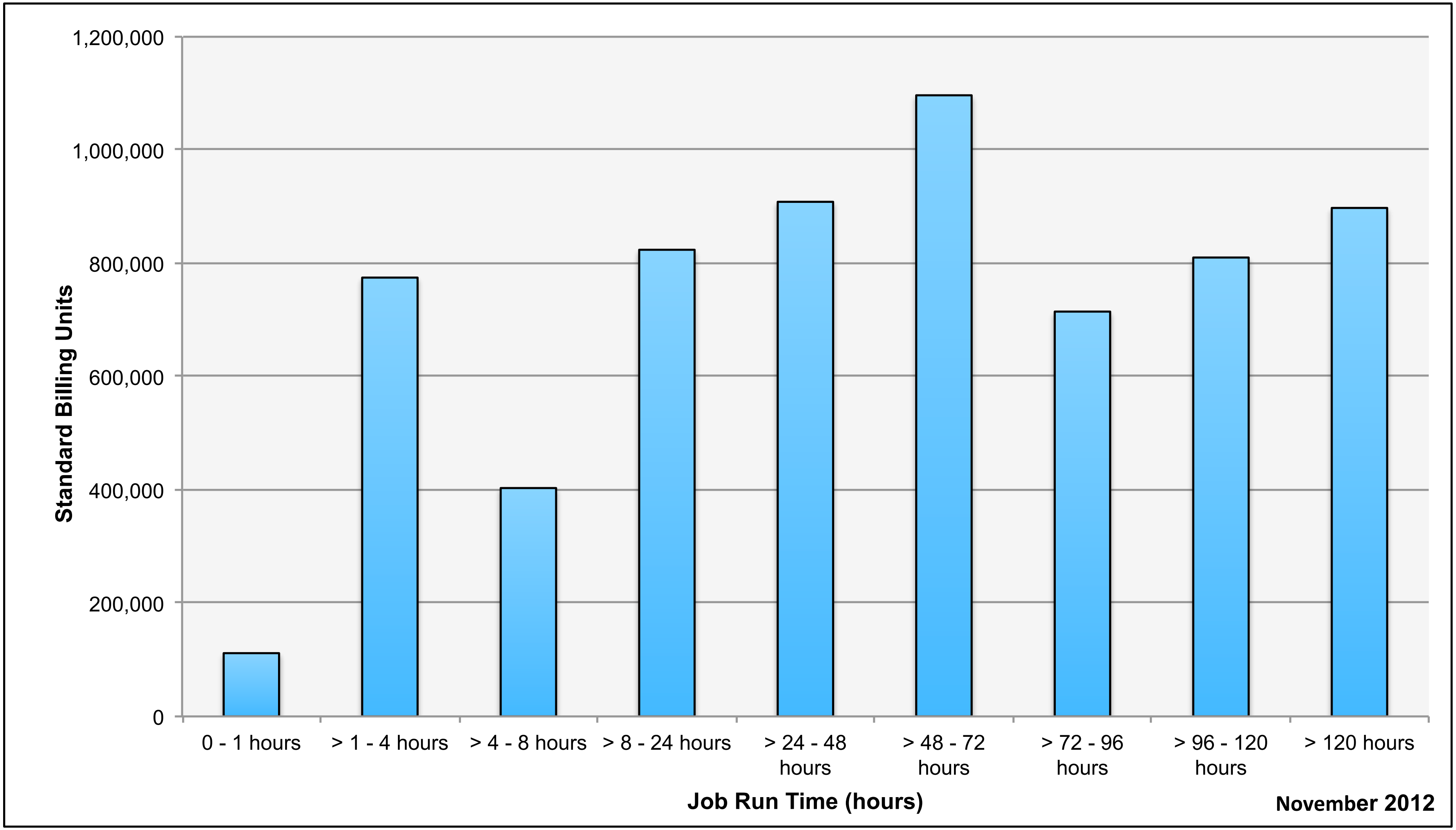
Pleiades:
SBUs Reported, Normalized to 30-Day Month



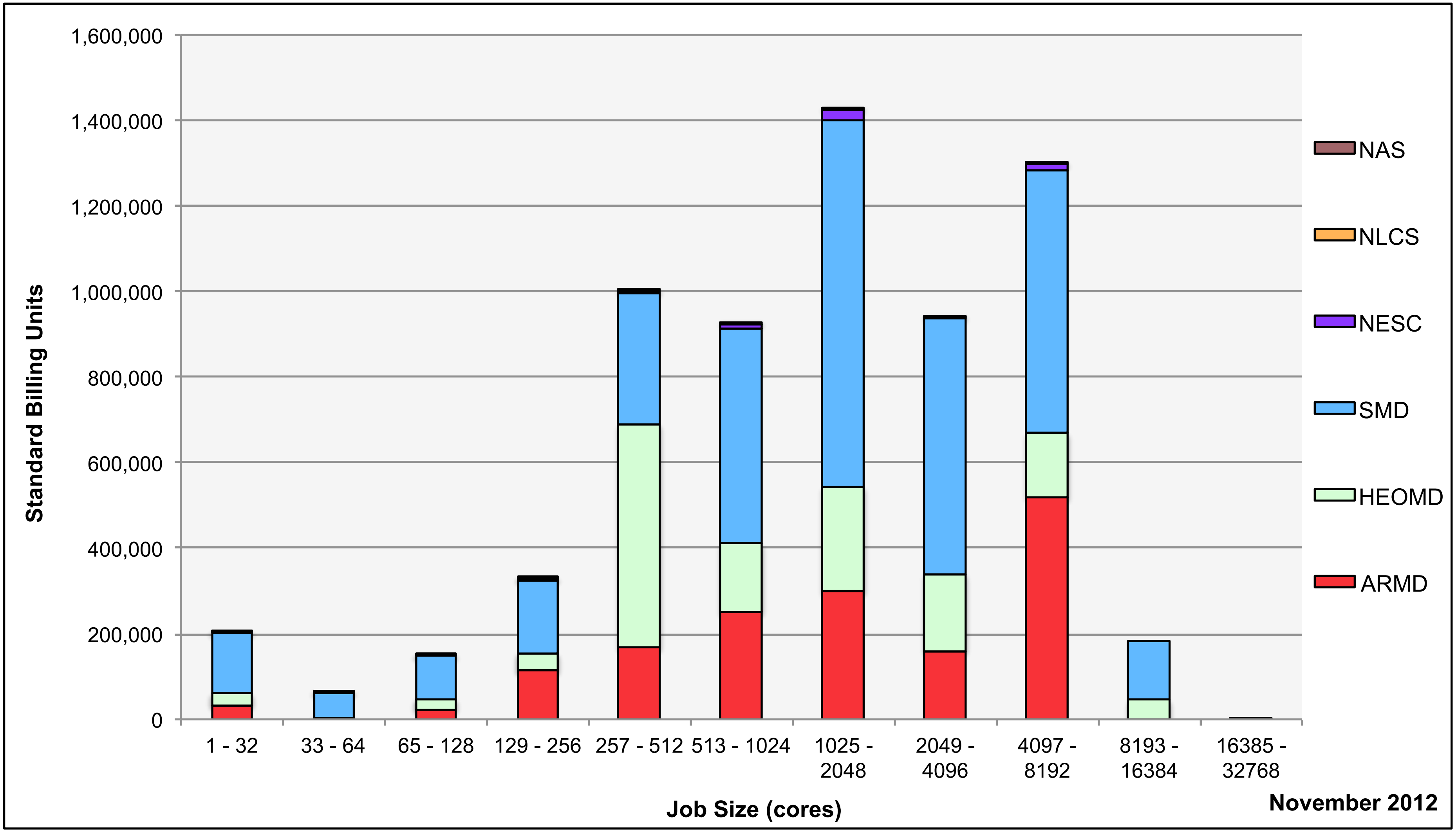
Pleiades:
Devel Queue Utilization



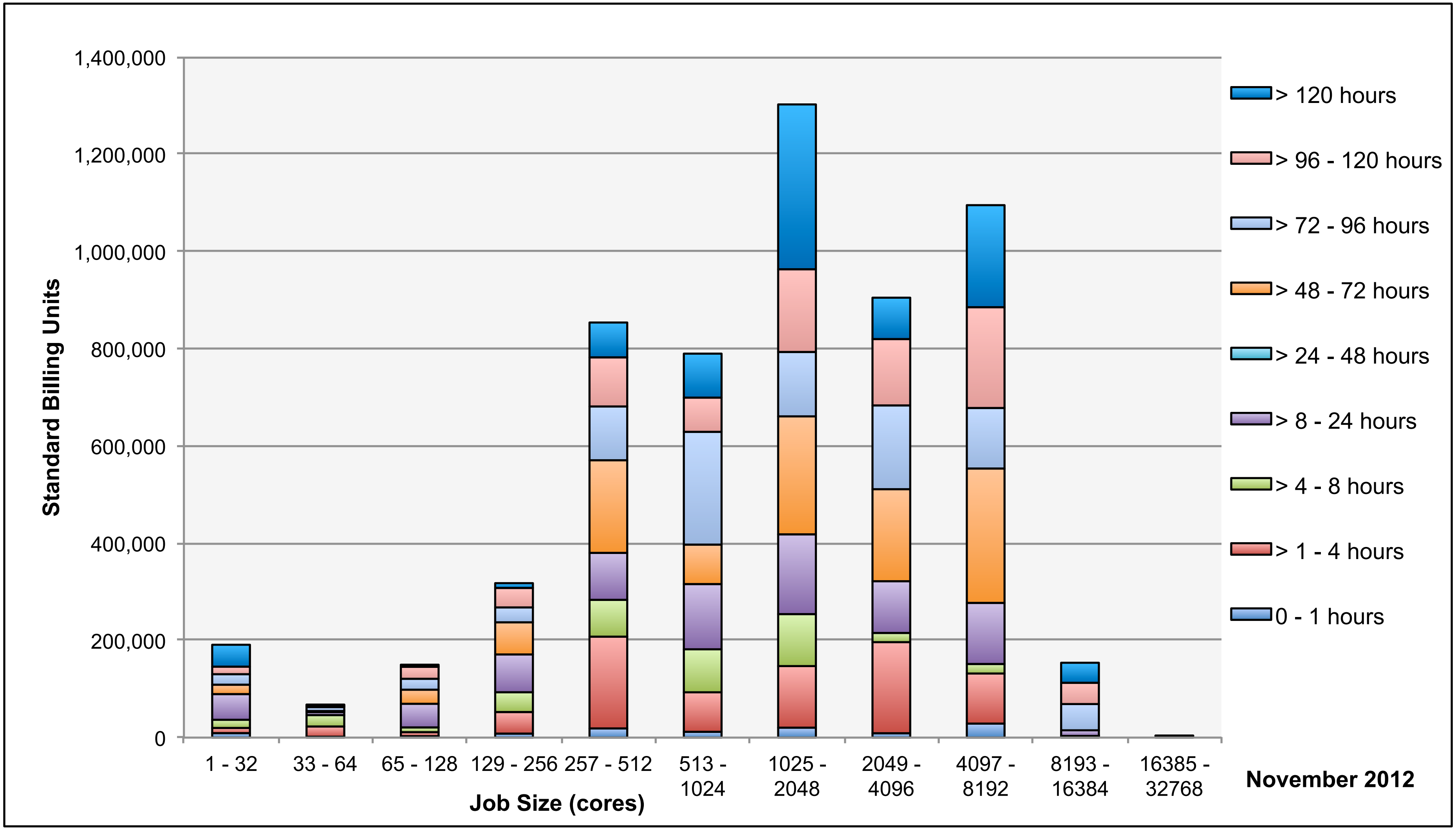
Pleiades: SBUs Reported, Normalized to 30-Day Month



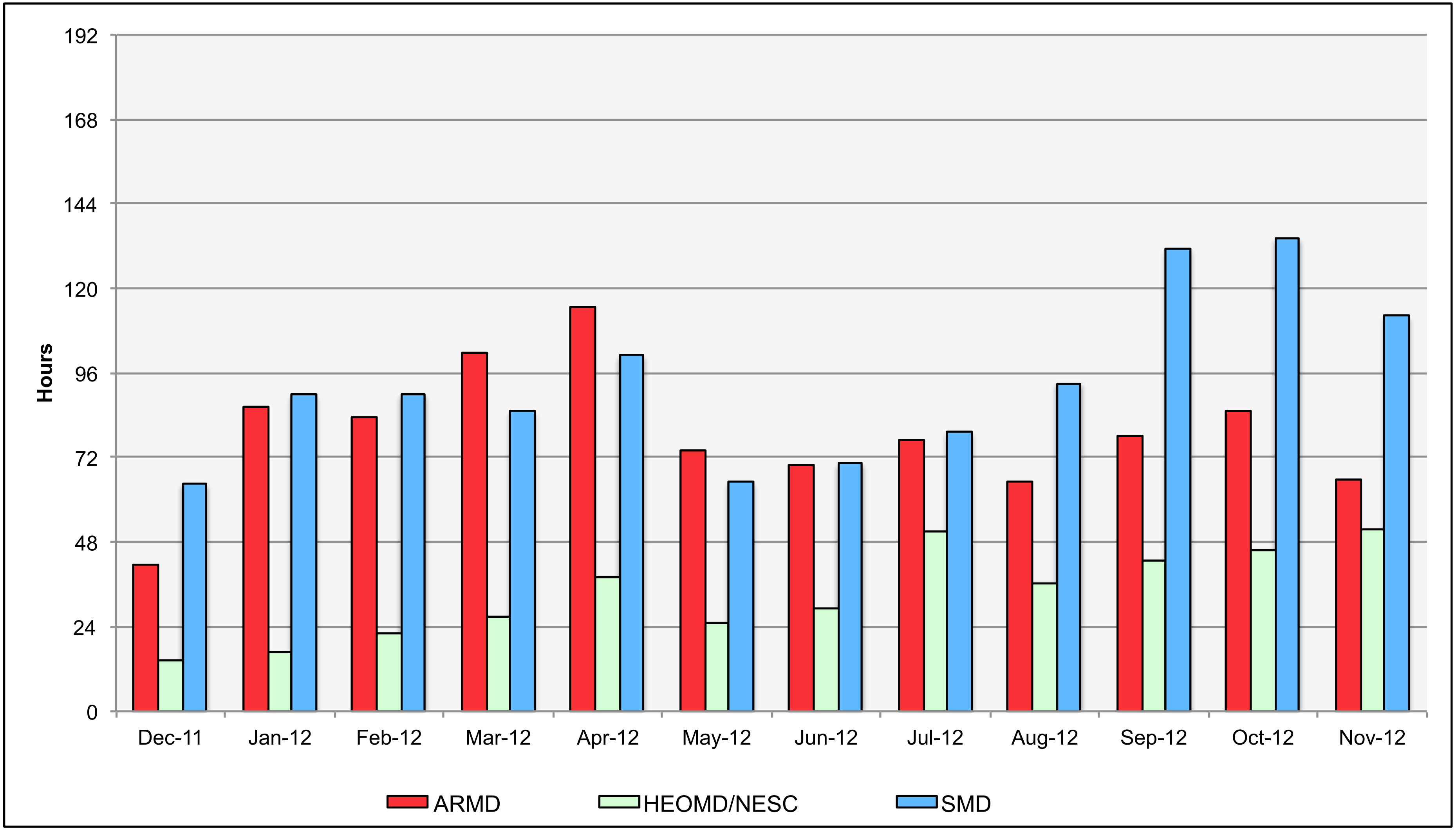
Pleiades: Monthly Utilization by Size and Mission



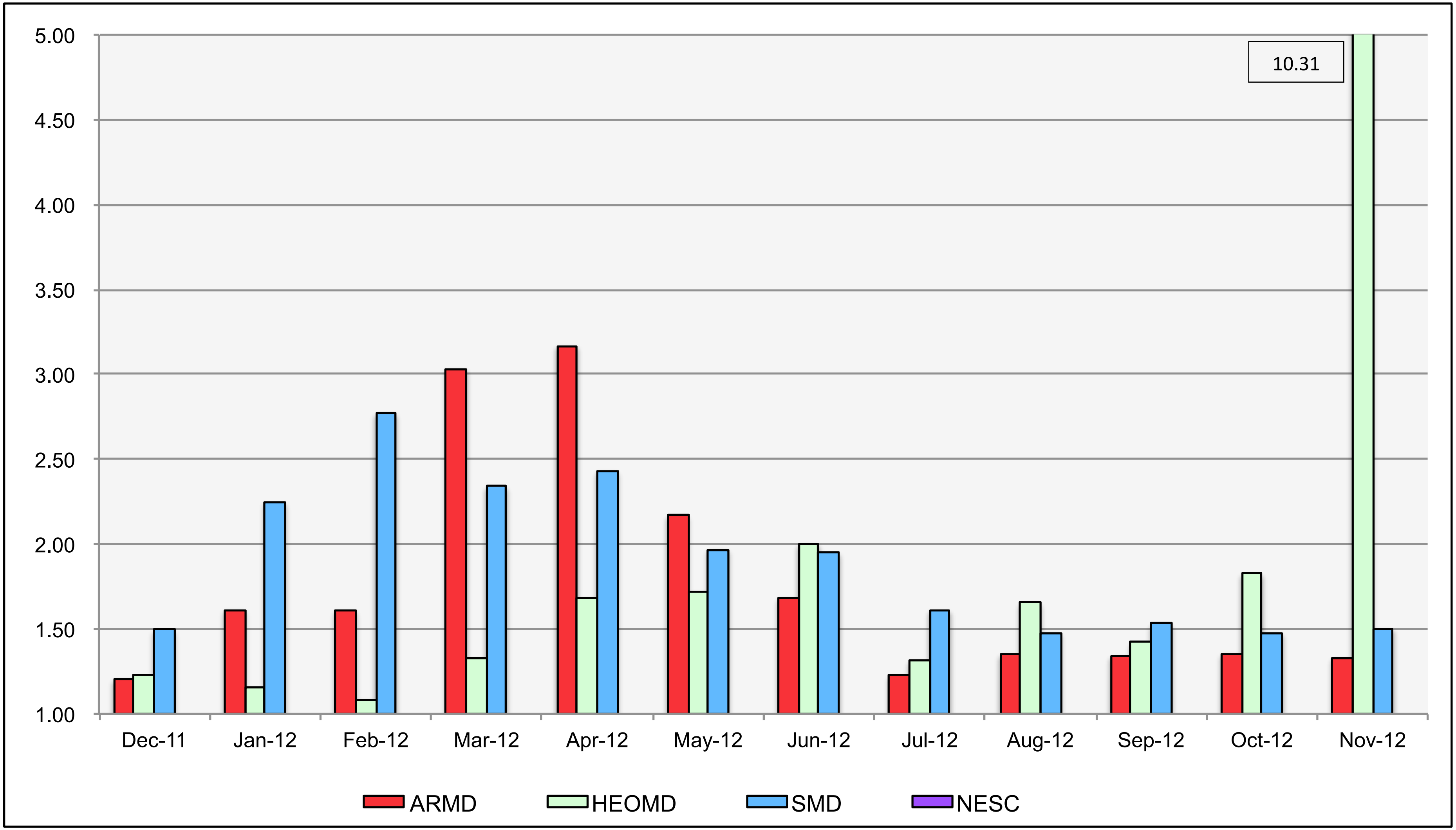
Pleiades:
Monthly Utilization by Size and Length



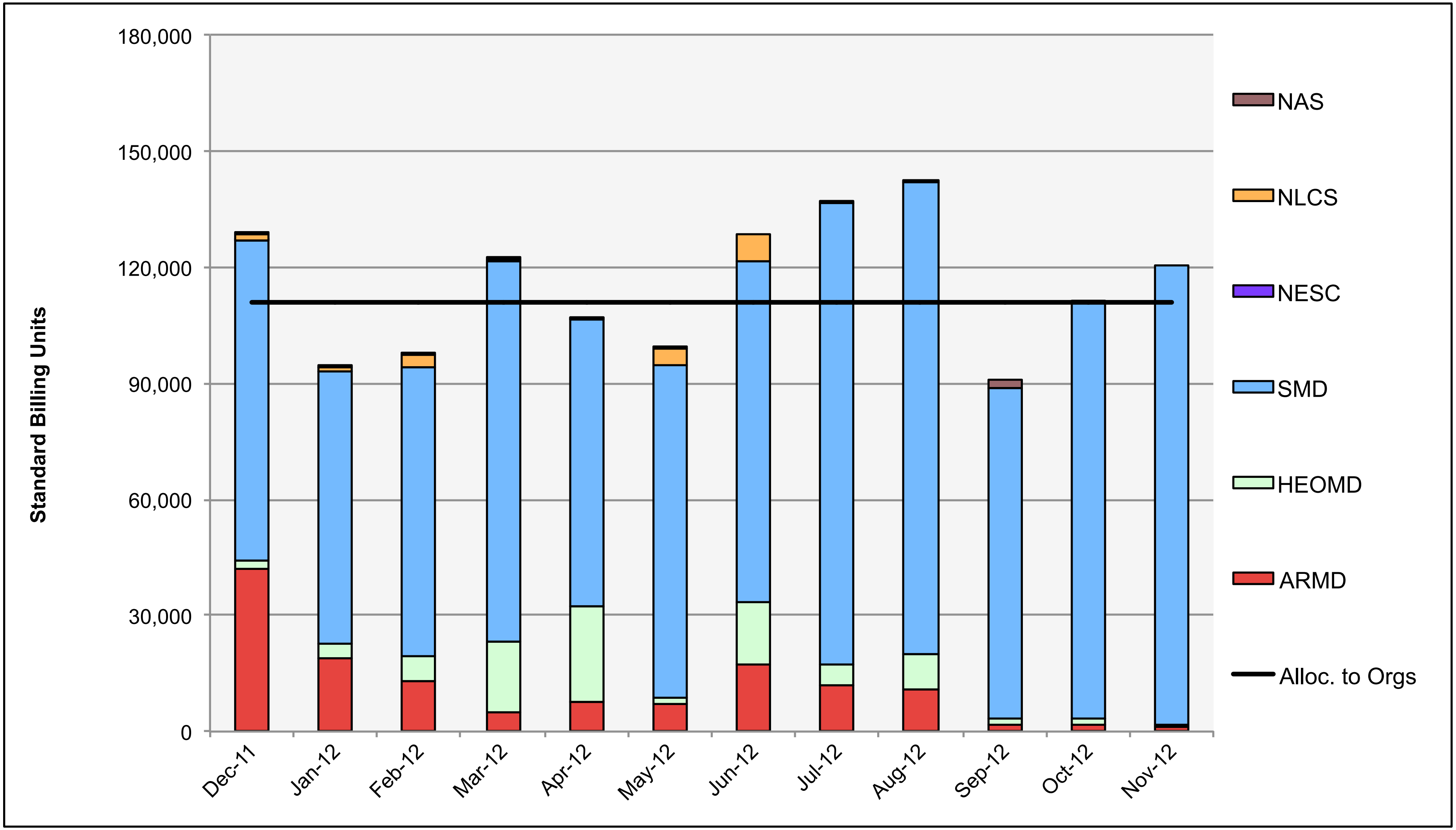
Pleiades: Average Time to Clear All Jobs



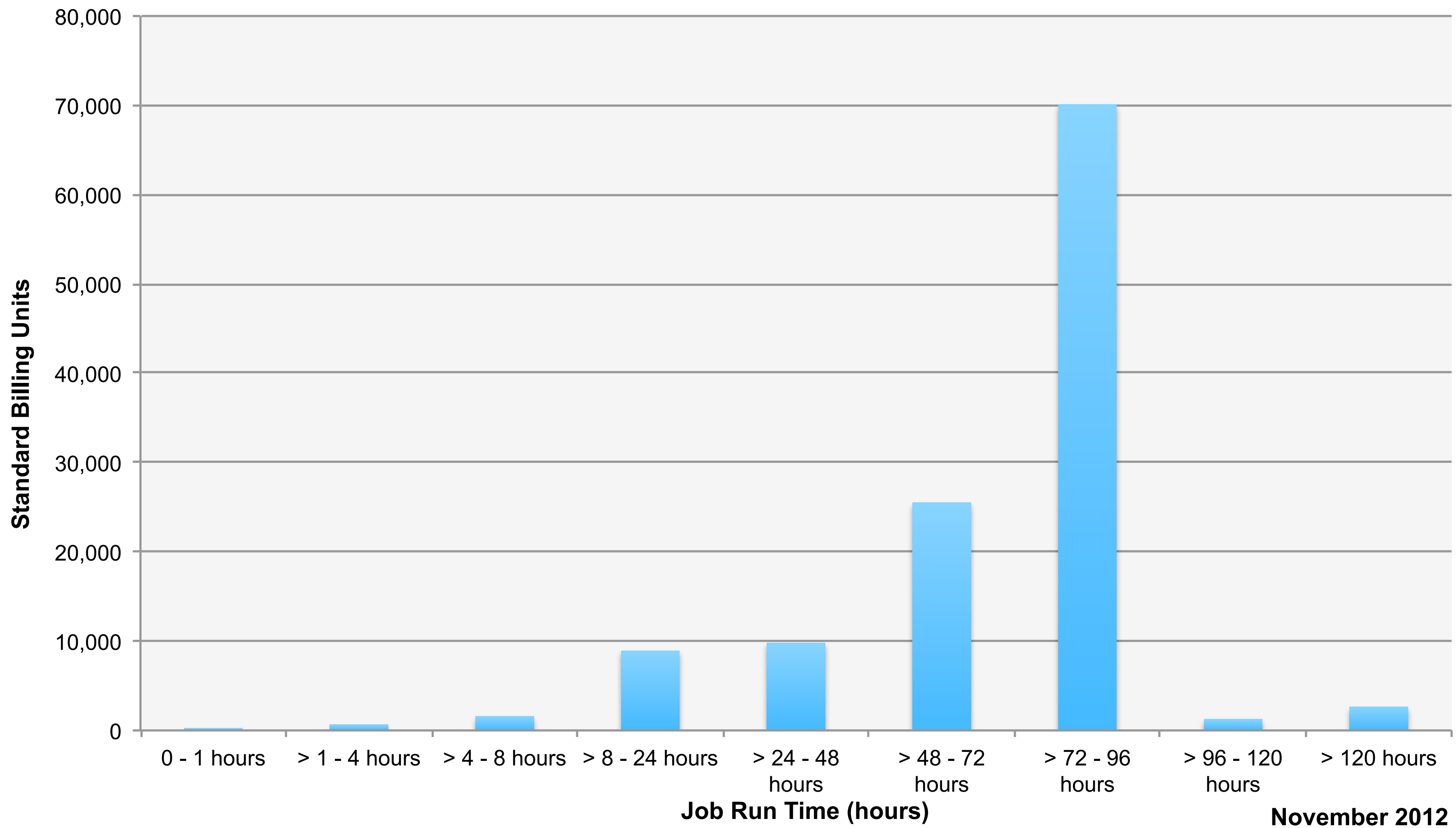
Pleiades: Average Expansion Factor



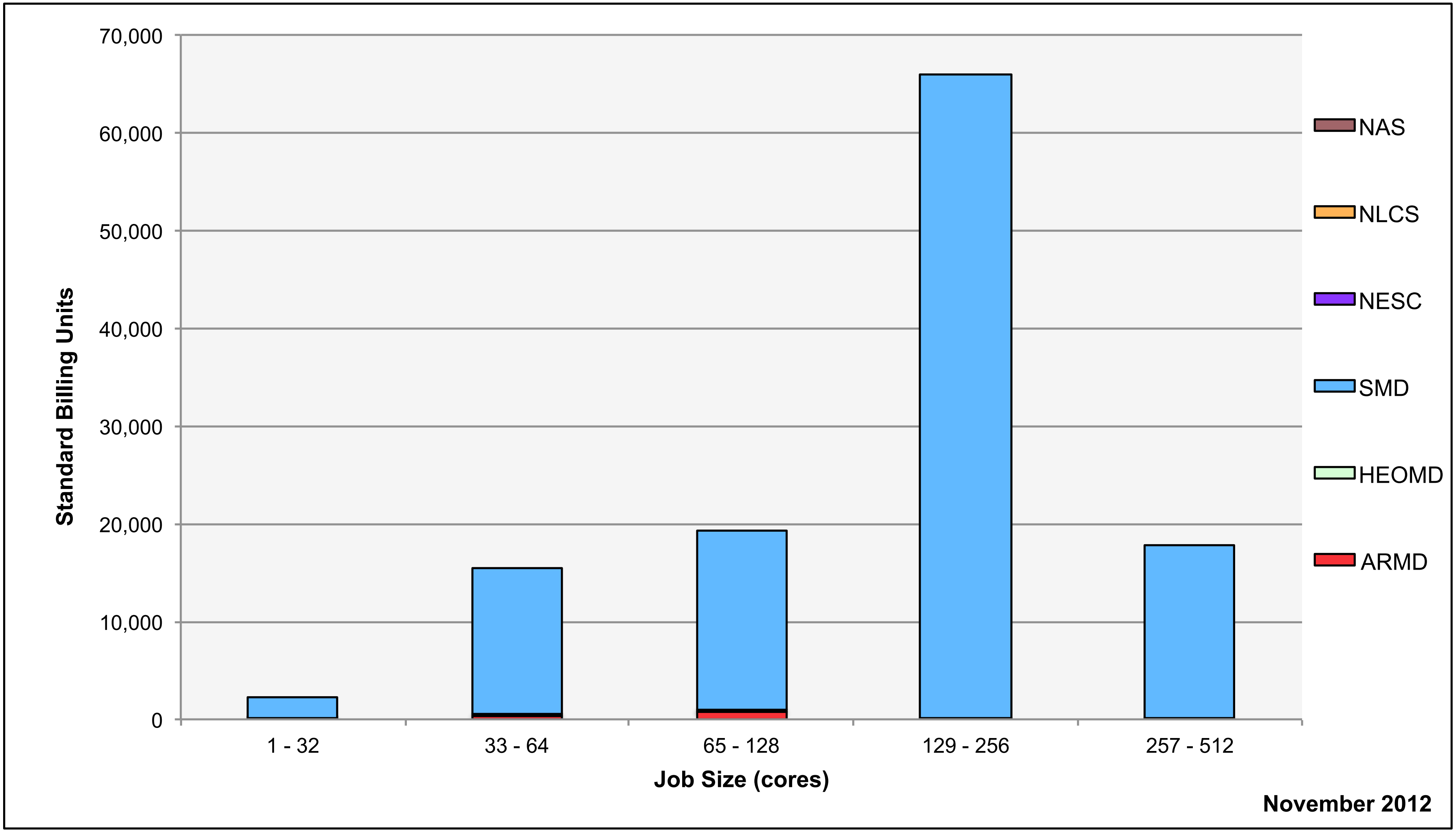
Columbia:
SBUs Reported, Normalized to 30-Day Month



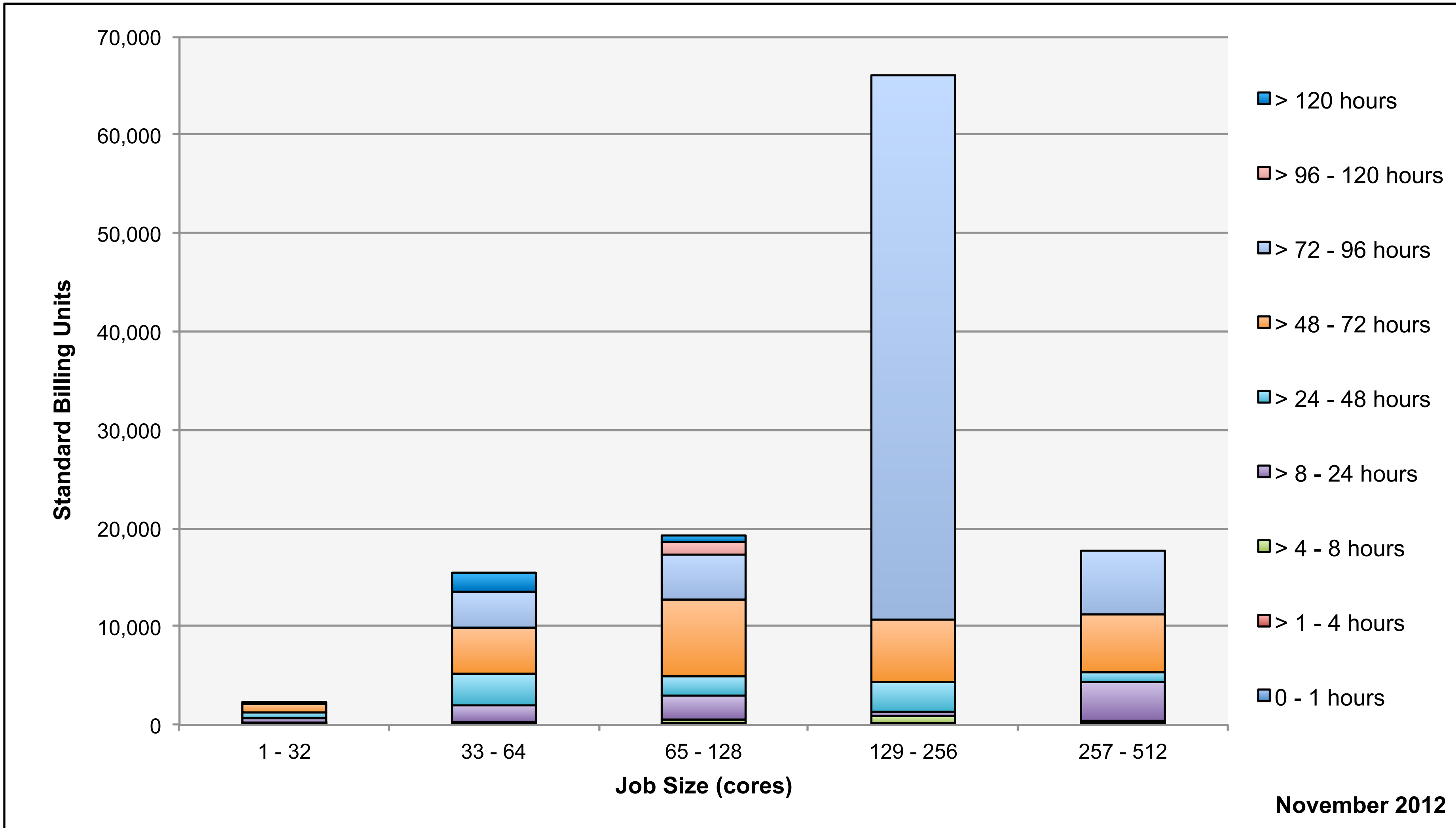
Columbia: SBUs Reported, Normalized to 30-Day Month



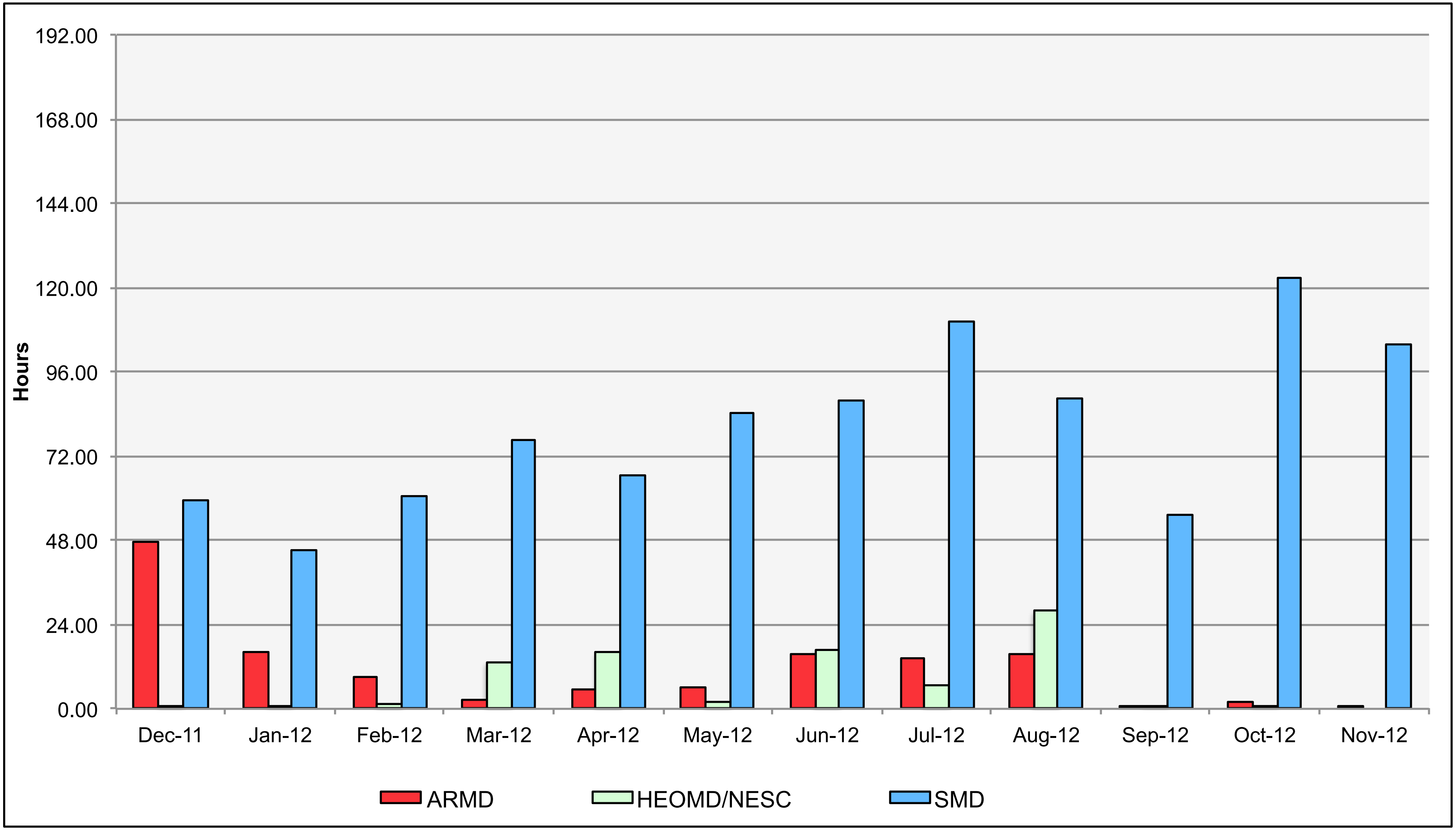
Columbia: Monthly Utilization by Size and Mission



Columbia: Monthly Utilization by Size and Length



Columbia: Average Time to Clear All Jobs



Columbia: Average Expansion Factor