CloudHarmony

transparency for the cloud

CenturyLink Hyperscale Testing

Final Engagement Report

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Version 1.11

Introduction

About this Report

This report summarizes testing of CenturyLink Cloud Hyperscale compute instances in April 2014. Compute instances from Amazon Elastic Compute Cloud (EC2), Rackspace Cloud, as well as non-Hyperscale CenturyLink Cloud instances were included in testing for comparison purposes. CenturyLink engaged CloudHarmony to conduct this testing and provide independent performance analysis and comparisons of these services. This report summarizes the results of this testing.

Test Methodology

To measure and analyze performance, we ran benchmark tests on multiple compute instances from each service. Multiple iterations of testing were performed on each compute instance. CenturyLink Hyperscale compute instances provide faster and more consistent disk input/output (IO) performance compared to non-Hyperscale instances through use of local solid state disks (SSD). This report emphasizes disk performance, but also covers CPU, memory and server performance.

Compute Instance Selection

Comparing cloud compute services requires first selection of comparable compute instances between the services. Each service offers slightly different compute instance configurations and options. Because of this, it is not always possible to precisely match compute instances between services for comparison. Typically, the best that can be done is to find the closest possible matches. Our primary criteria for instance type selection was matching the number of CPU cores because this typically has the greatest impact on benchmark results and application performance in general. We also sought to achieve a 2X ratio between the number of CPU cores and the amount of memory in gigabytes (GB).

CenturyLink Cloud

CenturyLink Cloud offers a single class of compute instances. Hyperscale is an option that determines the type of disk volumes a compute instance uses (although Hyperscale instances in our testing also deployed to hosts with newer processors). Hyperscale disks are located on the same physical host as the compute instance, as opposed to non-Hyperscale disks that reside on an separate external (networked) storage platform. The proximity of Hyperscale disks, and because they do not use the network, allow them to provide faster and more consistent performance. Our instance selections for CenturyLink Cloud include both Hyperscale and non-Hyperscale instances that were otherwise configured identically. Because CenturyLink Cloud allows for independent selection of CPU cores and memory, we chose 2, 4, 8 and 16 cores compute instances with 4, 8, 16 and 32 GB of memory.

Amazon EC2

Amazon EC2 offers nearly a dozen compute instance classes including legacy classes like m1 and c1, and more current generation like m3 and c3. Of these, the c3 class was the closest match because of its 1.9X CPU cores to memory ratio (m3 is closer to a 4X ratio), use of current generation Intel processors and local SSD storage.

Rackspace Cloud

Rackspace Cloud offers two compute instances classes. Their latest class is called Performance Cloud and uses current generation Intel processors and local SSD storage. However, the CPU cores to memory ratios for this class are either 1X (Performance 1) or 3.75X (Performance 2), so it was not possible to precisely obtain a 2X CPU cores to memory ratio. We opted to include Performance 1 instances for 2, 4 and 8 cores, and Performance 2 for the 16 core instance (Performance 1 is not available with 16 cores).

Compute Instance Comparison Matrix

The table below lists each of the compute instance configurations tested as well as the number of CPU cores and amount of memory included with each. Comparable compute instances are listed on the same line of the table.

CenturyLink Cloud - Hyperscale (NY1)	CenturyLink Cloud - Standard (NY1)	Amazon EC2 - c3 (us-east-1)	Rackspace Cloud - Performance Series (DFW)
2 cores / 4 GB	2 cores / 4 GB	c3.large - 2 cores / 3.75 GB	P1 - 2 cores / 2 GB
4 cores / 8 GB	4 cores / 8 GB	c3.xlarge - 4 cores / 7.5 GB	P1 - 4 cores / 4 GB
8 cores / 16 GB	8 cores / 16 GB	c3.2xlarge - 8 cores / 15 GB	P1 - 8 cores / 8 GB
16 cores / 30 GB	16 cores / 30 GB	c3.4xlarge - 16 cores / 30 GB	P2 - 16 cores / 60 GB

Storage Volumes

Compute service storage volumes are either local and external. Local storage volumes are located on the same physical hardware as a compute instance, while external volumes reside on an external storage system. This engagement covered testing of local SSD storage volumes for every compute instance except non-Hyperscale CenturyLink instances which uses external storage volumes.

Local vs. External Storage Volumes Pros and Cons

The following table summarizes the pros and cons of local and external storage.

Volume Type	Pros	Cons
Local	• Often faster and more consistent because it is not networked	• Less durable - hardware failure may result in loss of both compute instance and data • If you terminate the compute instance, storage volumes are lost • Often a fixed size depending on the compute instance type (the hardware can only have so many drives) • Usually doesn't support advanced features like volume backups/snapshots, copying or migration to another compute instance
External	• More scalable - size and quantity of volumes is flexible • Often supports advanced features like volume backups/snapshots, copying, volume sharing, or migration to another compute instance • Independent of the compute instance • More durable - failure of compute instance does not result in loss of a volume	• Often slower and less consistent due because it is network connected • Performance may be affected by changing network conditions • Although built to be more fault tolerant than a hard drive - failure may occur • Sometimes providers charge additional fees for input/ouput (IO) commands

Benchmark Selections

Benchmarks are used to quantify and compare performance. To compare performance of compute services, it is necessary to first determine which performance characteristics are relevant (based on actual workloads), and then to select benchmarks that accurately measure those characteristics. For our testing, we chose benchmarks that measure processing, disk, memory and server performance. Each benchmark was run three times on each compute instance. The table below lists each benchmark that was run and the associated benchmark run options. The proceeding comparisons present analysis from a subset of these benchmarks. The complete results have been provided to CenturyLink.

Benchmark	Description	Options	Characteristic
SPEC CPU 2006	SPEC's industry-standardized, CPU-intensive benchmark suite, stressing a system's processor, memory subsystem and compiler. This benchmark consists of 29 underlying sub-benchmarks that measure CPU integer and floating point performance characteristics.	• SPECint and SPECfp - base/rate tests performed • 1 copy per CPU core • 64-bit binaries • Compiled using Intel compiler suite"	CPU, Memory
SPECjbb 2005	SPEC's benchmark for evaluating the performance of server side Java by emulating a three-tier client/server system. It also measures the performance of CPUs, caches, memory hierarchy and the scalability of shared memory processors (SMPs).	Copies = CPU cores / 2	Application, CPU, Memory
HPCC	HPC Challenge is a suite of benchmarks that measure performance of processor, memory subsystem, and the interconnect.	HPL Process Grids (PxQ): P=floor(sqrt(# of CPUs)) Q=floor(# of CPUs/P)	CPU, Memory

Benchmark	Description	Options	Characteristic
Geekbench	Geekbench provides a set of benchmarks engineered to measure processor and memory performance.		CPU, Memory
fio	fio is used to simulate and measure IO load characteristics based a wide range of IO load options.	fio workloads included in analysis: • 4k random and sequential read • 16k random and sequential read • 32k random and sequential read • 64k random and sequential read • 128k random and sequential read • 1m random and sequential read Options: • ioengine: libaio • iodepth: optimal for IOPS • rampup time: 5 minutes • runtime: 10 minutes Notes: • Buffers randomized and volume filled prior to testing • Optimal iodepth for each workload calculated during runup • 3 test iterations performed	Disk IO
aio-stress	AIO-Stress is an a-synchronous I/O benchmark created by SuSE.	Random Write	Disk IO
apache	A test of ab, the Apache benchmark program against Apache. Measures requests/sec a given system can sustain when carrying out 700,000 requests with 100 requests carried out concurrently.		Application
bork	Bork is a small, cross-platform file encryption utility. This test measures the amount of time it takes to encrypt a sample file.		Application

Benchmark	Description	Options	Characteristic
build-imagemagick	This test times how long it takes to build ImageMagick		Application
build-linux-kernel	This test times how long it takes to build the Linux 3.1 kernel.		Application
build-mplayer	This test times how long it takes to build the MPlayer media player program.		Application
build-php	This test times how long it takes to build PHP 5 with the Zend engine.		Application
c-ray	C-Ray is a simple raytracer designed to test floating-point CPU performance. This test is multi-threaded (16 threads per core), shoots 8 rays per pixel for anti-aliasing, and generates a 1600 x 1200 image.		CPU
cachebench	CacheBench is designed to test the memory and cache bandwidth performance.	Read Cache Write Cache	Memory
compilebench	Compilebench tries to age a filesystem by simulating some of the disk IO common in creating, compiling, patching, stating and reading kernel trees. It indirectly measures how well filesystems can maintain directory locality as the disk fills up and directories age.	Tests: Compile, Initial Create, Read Compiled Tree	Disk IO
compress-7zip	This is a test of 7-Zip using p7zip with its integrated benchmark feature.		Application

Benchmark	Description	Options	Characteristic
compress-gzip	This test measures the time needed to compress a file using Gzip compression.		Application
compress-lzma	This test measures the time needed to compress a file using LZMA compression.		Application
compress-pzip2	This test measures the time needed to compress a file using PZIP2 compression.		Application
crafty	This is a performance test of Crafty, an advanced open-source chess engine.		CPU
dbench	Dbench contains file-system calls for testing disk performance.	Num clients: 1, 12, 48, 128	Disk IO
dcraw	This test times how long it takes to convert several high-resolution RAW NEF image files to PPM image format using dcraw.		CPU
encode-ape	This test times how long it takes to encode a sample WAV file to APE format.		Application
encode-flac	This test times how long it takes to encode a sample WAV file to FLAC format.		Application
encode-mp3	This test times how long it takes to encode a sample WAV file to MP3 format.		Application
encode-ogg	This test times how long it takes to encode a sample WAV file to OGG format.		Application

Benchmark	Description	Options	Characteristic
encode-wavpack	This test times how long it takes to encode a sample WAV file to WavPack format.		Application
espeak	This test times how long it takes the eSpeak speech synthesizer to read Project Gutenberg's The Outline of Science and output to a WAV file.		Application
ffmpeg	This test uses FFmpeg for testing the system's audio/video encoding performance.		Application
ffte	FFTE is a package by Daisuke Takahashi to compute Discrete Fourier Transforms of 1-, 2- and 3-dimensional sequences of length (2^p)*(3^q)*(5^r).		Application
fhourstones	This integer benchmark solves positions in the game of connect-4.		CPU
fs-mark	FS_Mark is designed to test a system's file-system performance.	1000 files, 1MB size	Disk IO
gcrypt	libgcrypt's integrated benchmark with the CAMELLIA256-ECB cipher and 100 repetitions.		CPU
gmpbench	GMPbench is a test of the GMP 5.0.3 math library.		CPU

Benchmark	Description	Options	Characteristic
graphics-magick	A test of GraphicsMagick with its OpenMP implementation that performs various imaging tests to stress the system's CPU.	Operation: HWB Color Space	CPU
himeno	The Himeno benchmark is a linear solver of pressure Poisson using a point-Jacobi method.		CPU
hmmer	Searches the Pfam database of profile hidden markov models. The search finds the domain structure of Drosophila Sevenless protein.		CPU
iozone	IOzone tests the hard disk drive / file-system performance.	8GB Read 8GB Write	Disk IO
java-scimark2	A Java version of SciMark 2.0, a benchmark for scientific and numerical computing developed by programmers at the National Institute of Standards and Technology.	Composite Performance FFT Performance Monte Carlo Performance SOR Performance	CPU
john-the-ripper	A benchmark of John The Ripper, a password cracker.	Blowfish	CPU
mafft	Performs an alignment of 100 pyruvate decarboxylase sequences.		CPU

Benchmark	Description	Options	Characteristic
mencoder	Uses mplayer's mencoder utility and libavcodec to test a system's audio/video encoding performance.		Application
minion	An open-source constraint solver designed to be very scalable.		CPU
nero2d	Nero2D is a two-dimensional TM/TE solver for Open FMM. This test times how long it takes to solve a 2D example.		Application
nginx	A test of ab, the Apache benchmark program against nginx. Measures requests/sec a given system can sustain when carrying out 500,000 requests with 100 requests carried out concurrently.		Application
openssl	An open-source toolkit that implements SSL and TLS protocols. This test measures RSA 4096-bit performance of OpenSSL.		Application
pgbench	A simple TPC-B like benchmark of PostgreSQL.		Application
phpbench	Performs a large number of simple tests in order to bench various aspects of the PHP interpreter.		Application
postmark	Simulates small-file testing similar to the tasks endured by web and mail servers.		Disk IO

Benchmark	Description	Options	Characteristic
povray	This is a test of POV-Ray used to create 3D graphics using ray-tracing.		CPU
ramspeed	This benchmark tests the system memory (RAM) performance.	Floating-Point Add Integer Add Integer Copy Integer Scale	Memory
scimark2	Runs the ANSI C version of SciMark 2.0, which is a benchmark for scientific and numerical computing developed by programmers at the National Institute of Standards and Technology.		CPU
sqlite	Measures the time to perform a pre-defined number of insertions on an indexed database.		Application
stream	This benchmark tests the system memory (RAM) performance.	Add, Copy, Scale, Triad	Memory
sudokut	A Sudoku puzzle solver written in Tcl. Measures how long it takes to solve 100 Sudoku puzzles.		CPU
tiobench	Benchmarks the hard disk drive / file-system performance.	64MB Random Read - 32 Threads	Disk IO
tscp	A performance test of TSCP, Tom Kerrigan's Simple Chess Program.		CPU
unpack-linux	This test measures how long it takes to extract the .tar.bz2 Linux kernel package.		Disk IO

Benchmark	Description	Options	Characteristic
vpxenc	A standard video encoding test using Google's libvpx library and the vpxenc command for the VP8/WebM format.		Application
x264	A simple test of the x264 H.264/AVC encoder.		Application

Summary Metrics

To simplify complex performance comparisons we use a method of combining multiple related benchmark metrics to a single comparable value called a summary metric. Because each benchmark metric is based on a different numeric scale, before combining we first convert them a common scale using a reference system as a normalizing constant. By dividing benchmark metrics of a compute instance by the same metrics of the reference system we create ratios that represent performance relative to the reference system. We then combine ratios from multiple benchmarks using a geometric mean to produce more generalized performance metrics and use those as the basis for comparisons. In order to simplify the numeric values, we multiple ratios by 100 so that a summary metric equal to 100 signifies performance that is nearly comparable to the reference system, less than 100 worse, and greater than 100 better

The reference system we used is a bare metal (non-virtualized) Dell M610 PowerEdge server. This server had two Intel X5650 2.66 GHz CPUs (12 cores total), 48 GB DDR3-10166 memory, and a Seagate SAS 2.0 10k RPM drive dedicated for testing.

The proceeding analysis provides comparisons using both benchmark metrics and summary metrics.

Performance Comparisons

This section summarizes and compares performance of the compute instances tested during this engagement. This analysis is presented using a subset of the benchmarks listed in the preceding section. The analysis is presented in 4 different generalize performance categories: CPU, Disk, Memory and Server performance. Each of these categories is analyzed and compared using both actual benchmarks and summary metrics.

CPU Performance

CPU performance is a commonly compared performance characteristic. To some extent, all workloads are affected by it. Workloads with intensive math, scientific, or geographic computations are more likely to be affected than those that primarily read and write files to disk or transfer data over the network.

Processing performance is usually bound by the number of CPU cores, clock speed, and type of hardware your compute instance runs on. A new CPU model will usually perform better than the model it proceeds, even with the same number of cores and clock speed.

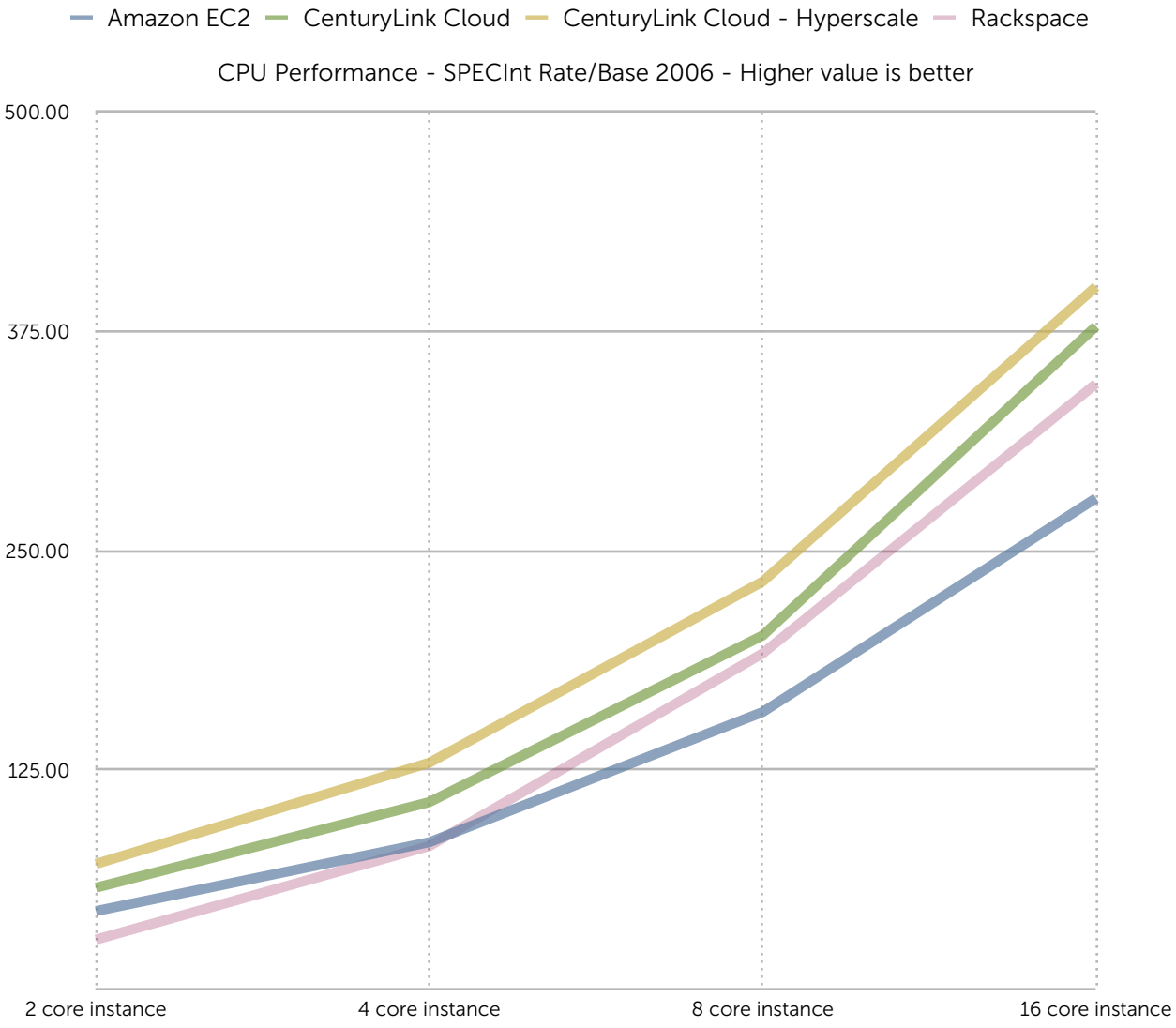
Our comparisons and analysis of CPU performance are based on the SPEC CPU 2006 benchmark suite. SPEC CPU 2006 consists of 29 underlying CPU benchmarks and produces two metrics, SPECint and SPECfp summarizing both the integer (12) and floating point (17) CPU performance. A higher value for these metrics represents better performance. Each are presented separately for every instance type in the analysis below.

CPU Model

In addition to number of CPU cores and clock speed, CPU model is also a significant factor in performance. Newer Intel E5 v2 processors, known as Ivy Bridge, are faster than their similarly named predecessors (Sandy Bridge) due in part to faster cache and memory buses. Amazon EC2 and CenturyLink Cloud Hyperscale both appear to be using Ivy Bridge, while Rackspace Cloud (Performance) and non-Hyperscale CenturyLink use Sandy Bridge. The table below lists the specific CPU models we observed for each service. Providers often do not disclose CPU model because it is subject to change over time.

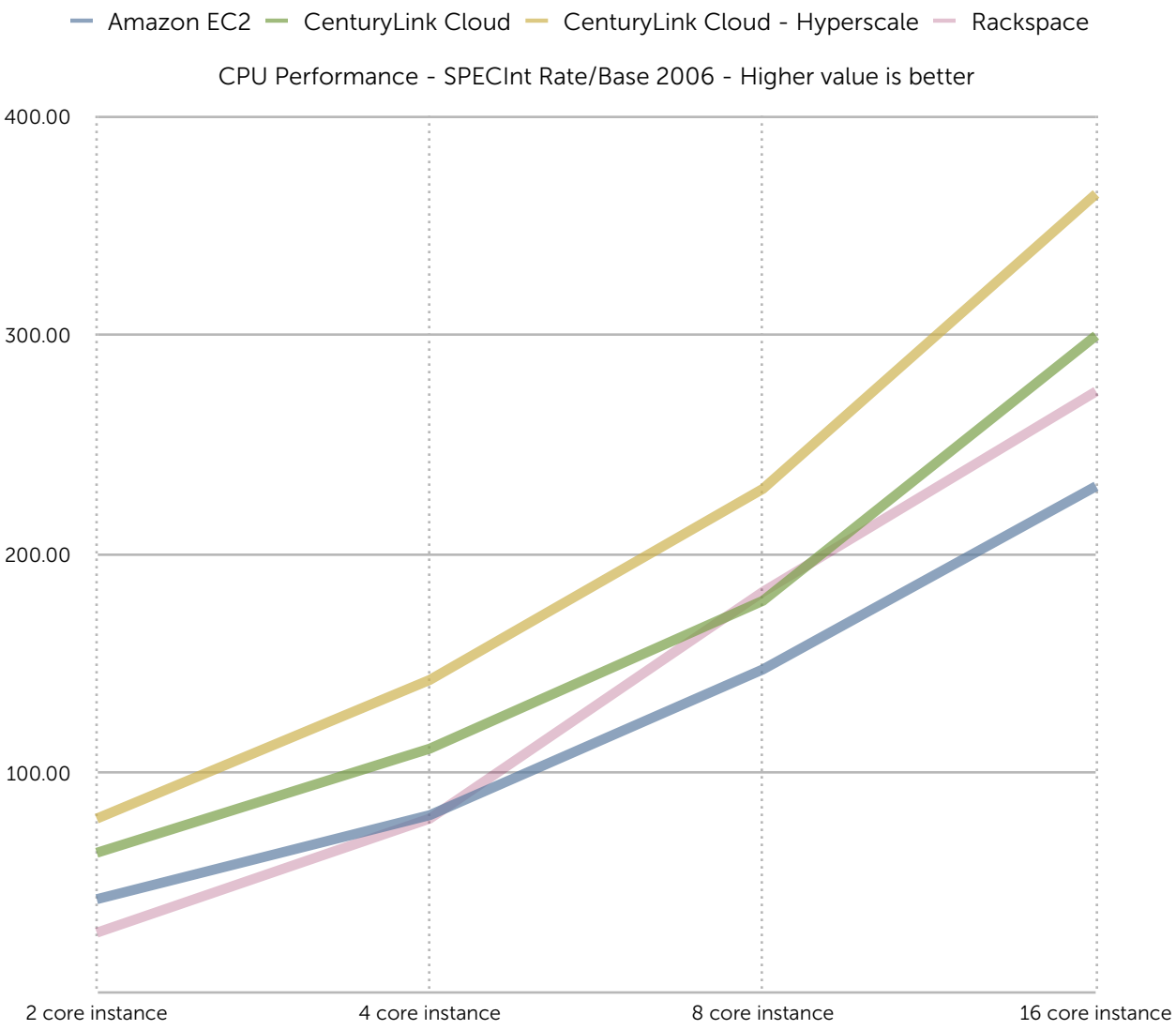
Service	CPU Architecture
Amazon EC2	Intel Xeon E5-2680 v2 2.80GHz
CenturyLink Cloud	Intel Xeon E5-2680 2.70GHz
CenturyLink Cloud - Hyperscale	Intel Xeon E5-2650 v2 2.60GHz
Rackspace	Intel Xeon E5-2670 2.60GHz

SPECint Rate/Base 2006 (estimate)



Instance Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
2 core instance	44.53	57.87	71.43	28.26
4 core instance	83.79	106.68	129.12	81.63
8 core instance	158.01	201.67	232.44	191.46
16 core instance	279.96	377.99	400.56	345.19

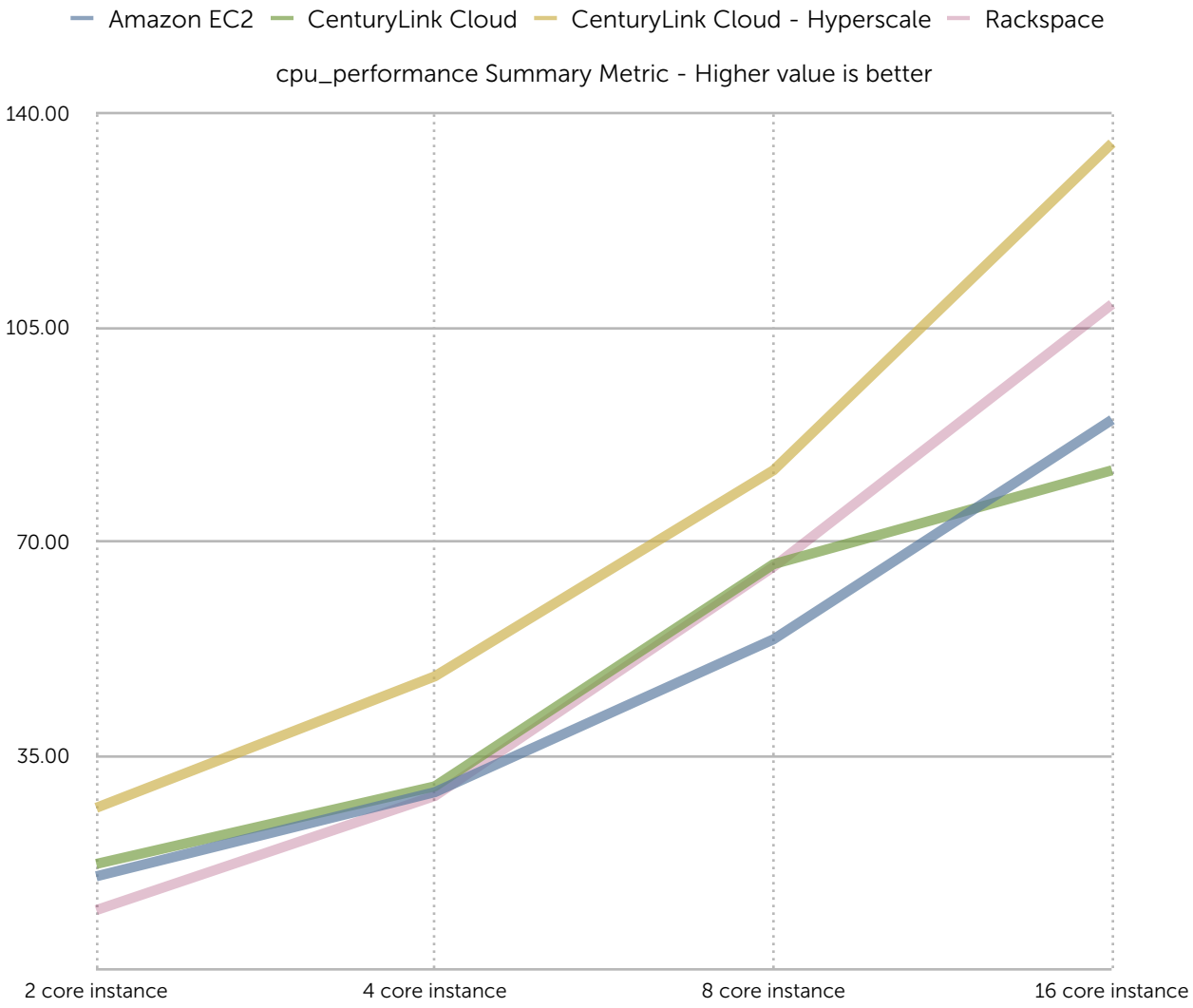
SPECfp Rate/Base 2006 (estimate)



Instance Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
2 core instance	42.65	63.83	79.42	27.36
4 core instance	81.02	111.38	142.75	79.45
8 core instance	147.53	178.86	229.95	182.94
16 core instance	231.12	299.87	364.53	274.39

CPU Performance Summary Metric

The *cpu_performance* summary metric is based on ratios from both SPECint and SPECfp Rate/Base 2006 metrics relative to the reference system. The reference system was a bare metal Dell M610 server with dual X5650 processors (total of 12 physical cores).



Instance Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
2 core instance	15.32	17.34	26.51	9.80
4 core instance	29.07	30.02	47.99	28.45
8 core instance	54.03	66.31	81.65	65.88
16 core instance	89.91	81.65	135.08	108.78

CPU Performance Comments

Lower results for the Rackspace 2 and 4 core instances were due to slightly different benchmark configurations that were necessary to work around memory limitations on those instances. The 8 and 16 cores Rackspace instances, however, are based on the same benchmark configuration as other services and the resulting metrics are more in line with comparable instances.

CenturyLink Cloud Hyperscale performed well in this phase of testing. Use of newer Ivy Bridge processors allowed it to outperform services based on older CPU models. The difference between Amazon EC2 and CenturyLink Cloud Hyperscale instances, despite both using Ivy Bridge, could be due to differences in virtualization or use/non-use of CPU hyper threading (hardware managed threading of CPU cores).

Disk Performance

Disk performance determines how quickly applications can read and write to disk volumes in order to interact with persistent data and files. Disk usage patterns vary by workload. A web server, for example, will likely perform many more read than write operations; while a database server will likely have a mix of read and write. A workload might also access data in small pieces located in different places on disk, or fewer large pieces in close proximity wherein block size and sequential or random access patterns come into play.

We used the industry standard *fio* benchmark to measure disk performance. In total, we ran three test iterations, each consisting of 36 workloads in addition to run-up testing on each compute instance. Total test duration was about 40 hours per compute instance. Testing was optimized for faster IO using the asynchronous Linux *libaio* engine and an optimized queue depth setting. Asynchronous IO allows applications to submit operations without waiting for a response. It is usually faster than synchronous IO because applications can submit non-blocking requests to an IO queue, and the system will work off that queue in the fastest way possible.

When using fio with asynchronous IO, one configurable parameter is queue depth. Queue depth defines the maximum number of requests to submit before waiting for some of them to be fulfilled. To maximize IO, it is best to set use a queue depth that submits enough requests so that the system is never idle, but not so many that queue management overhead consumes so many resources that is may actually reduce IO performance.

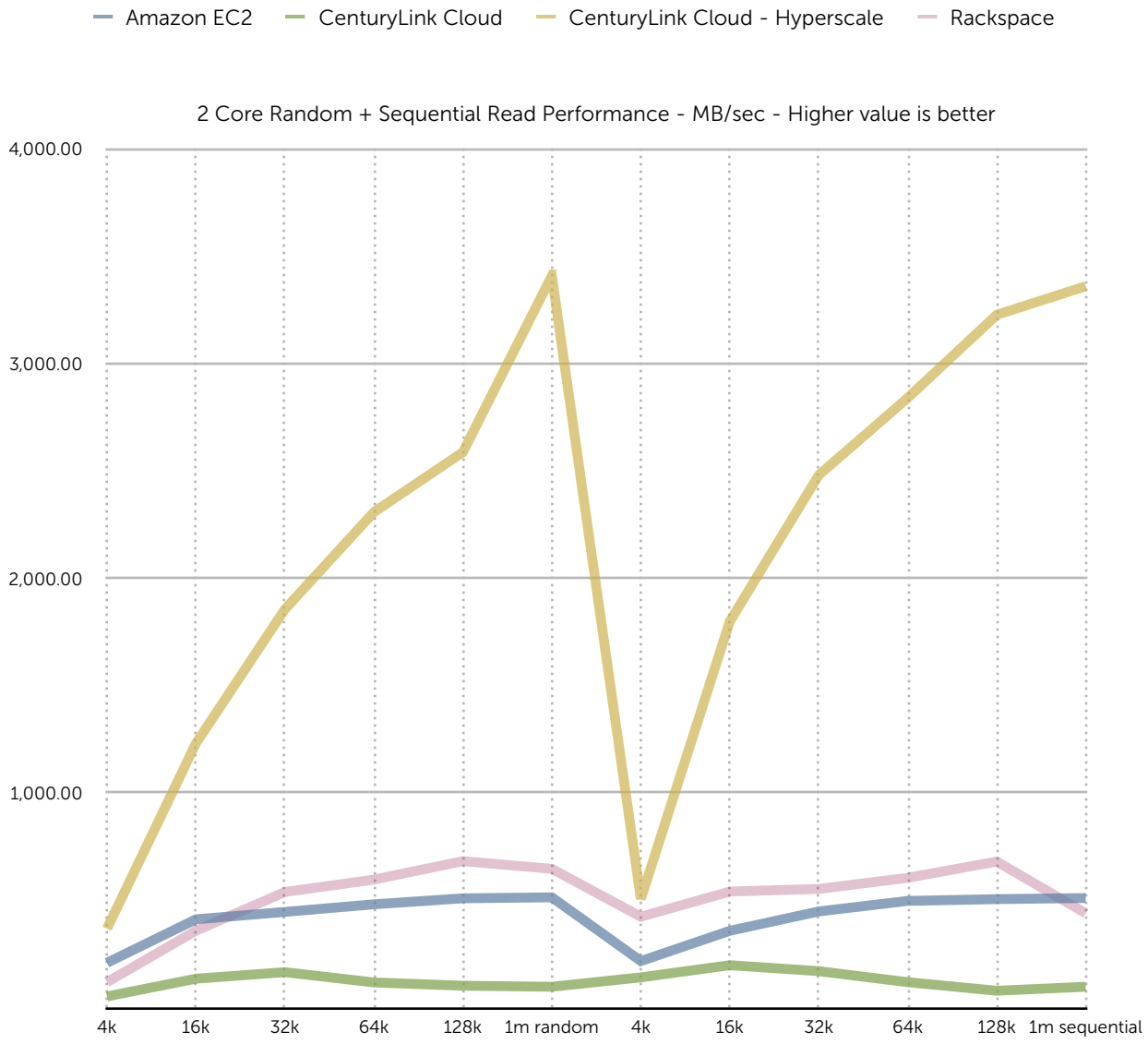
To optimize queue depth for our tests, we first used a pre-test phase to determine the best setting to use for each of the 36 workloads. To do this, we ran sets of three abbreviated tests using incrementing queue depths (1, 2, 4, 8, etc.) until IO did not increase by at least 3 percent over the preceding set of tests. These queue depths settings were then used for the actual testing.

The analysis below presents IO bandwidth in megabytes per second (MB/s) for each of 36 fio workloads that were tested. A higher value represents faster disk performance. IO consistency is also presented separately. It is based on the standard deviation of IOPS (represented as a relative percentage) for each workload. In the consistency analysis, a higher value represents less consistent performance. Inconsistent IO is often undesirable for production applications like database servers.

Disk Read Performance

The graphs and tables below present disk IO read throughput and consistency for both random and sequential workloads based on six block sizes. Each subsection presents a different instance type comparison: 2, 4, 8 and 16 cores as listed in the preceding comparison matrix. A higher throughput value signifies better performance. A lower IO standard deviation represents better performance consistency.

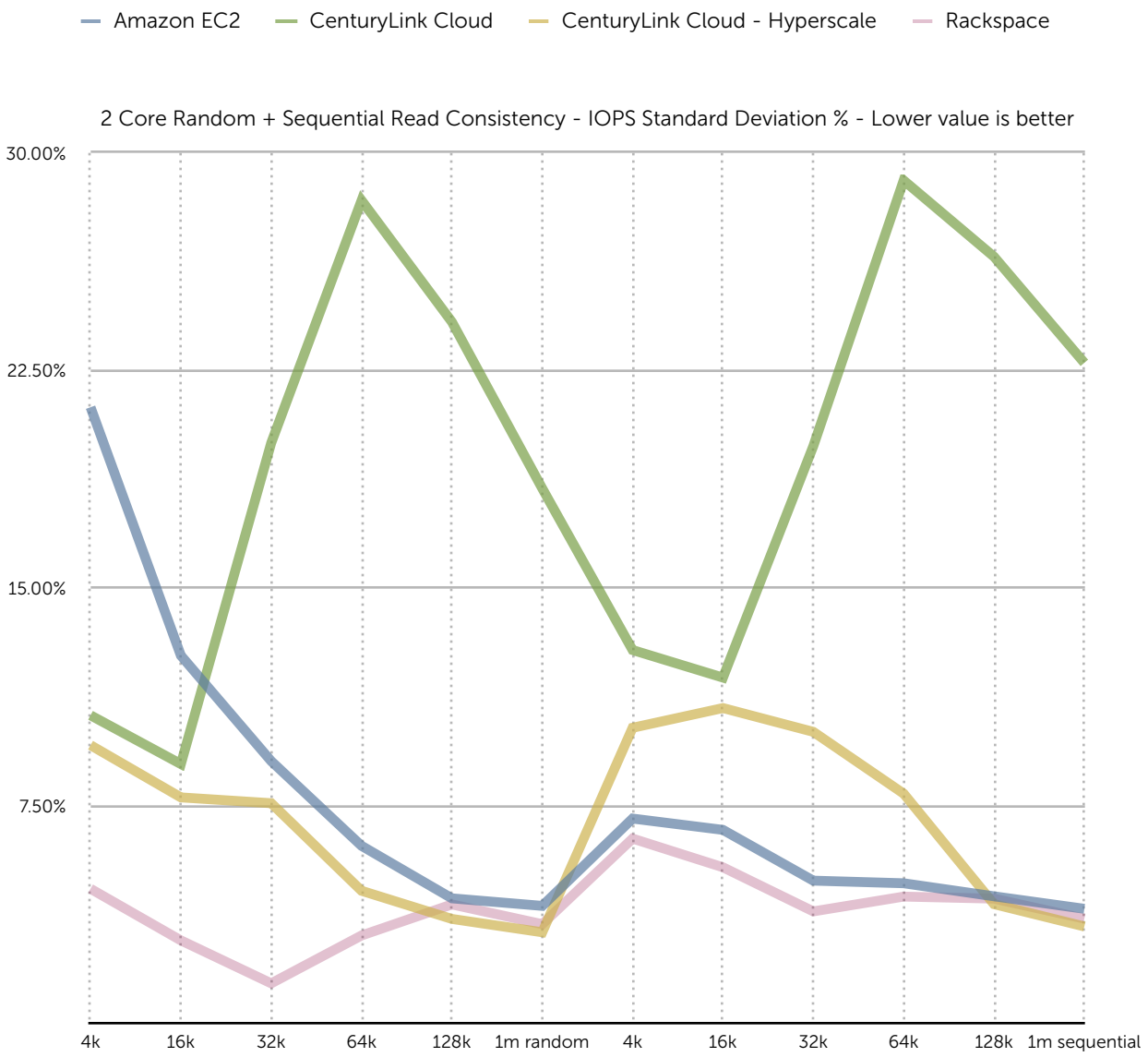
Disk Read Performance - 2 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	210.18	53.66	369.43	119.94

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
16k	412.80	136.24	1,232.40	359.69
32k	447.21	166.60	1,856.88	539.98
64k	482.66	118.75	2,309.04	597.68
128k	510.55	103.47	2,588.20	683.79
1m random	515.07	98.66	3,409.95	647.76
4k	218.32	142.38	507.73	424.99
16k	359.29	199.05	1,800.27	542.04
32k	449.50	171.35	2,481.74	554.20
64k	498.54	119.93	2,841.34	606.12
128k	506.70	80.08	3,228.00	681.65
1m sequential	511.83	98.66	3,361.13	440.75

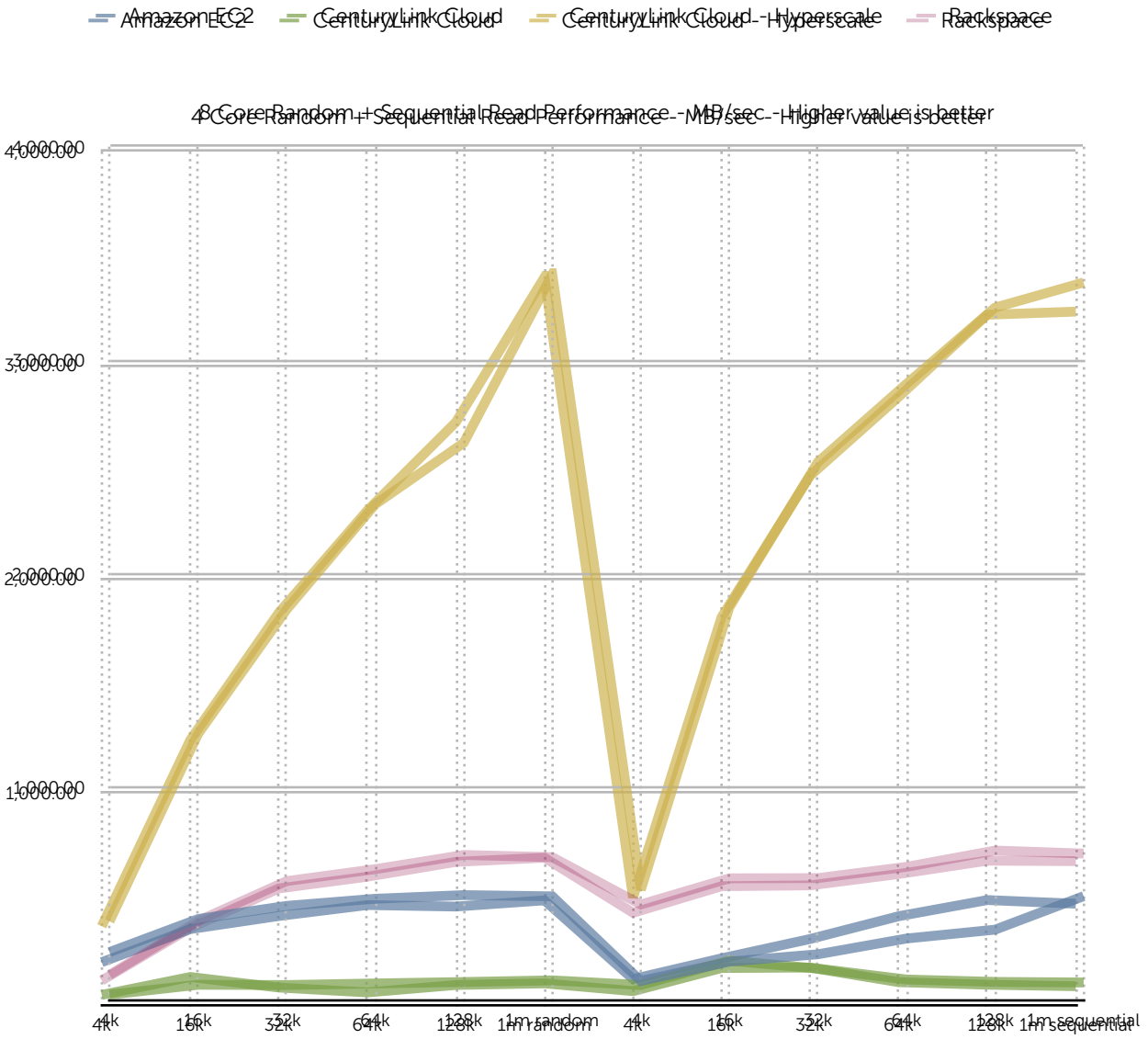
Disk Read Consistency - 2 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	21.23%	10.61%	9.58%	4.63%
16k	12.67%	8.93%	7.78%	2.85%
32k	9.03%	20.00%	7.58%	1.37%
64k	6.11%	28.36%	4.56%	3.02%
128k	4.30%	24.17%	3.59%	4.09%
1m random	4.04%	18.43%	3.13%	3.41%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	7.05%	12.86%	10.18%	6.36%
16k	6.66%	11.91%	10.86%	5.37%
32k	4.91%	19.89%	10.04%	3.85%
64k	4.82%	29.05%	7.91%	4.36%
128k	4.37%	26.42%	4.10%	4.29%
1m sequential	3.94%	22.76%	3.33%	3.60%

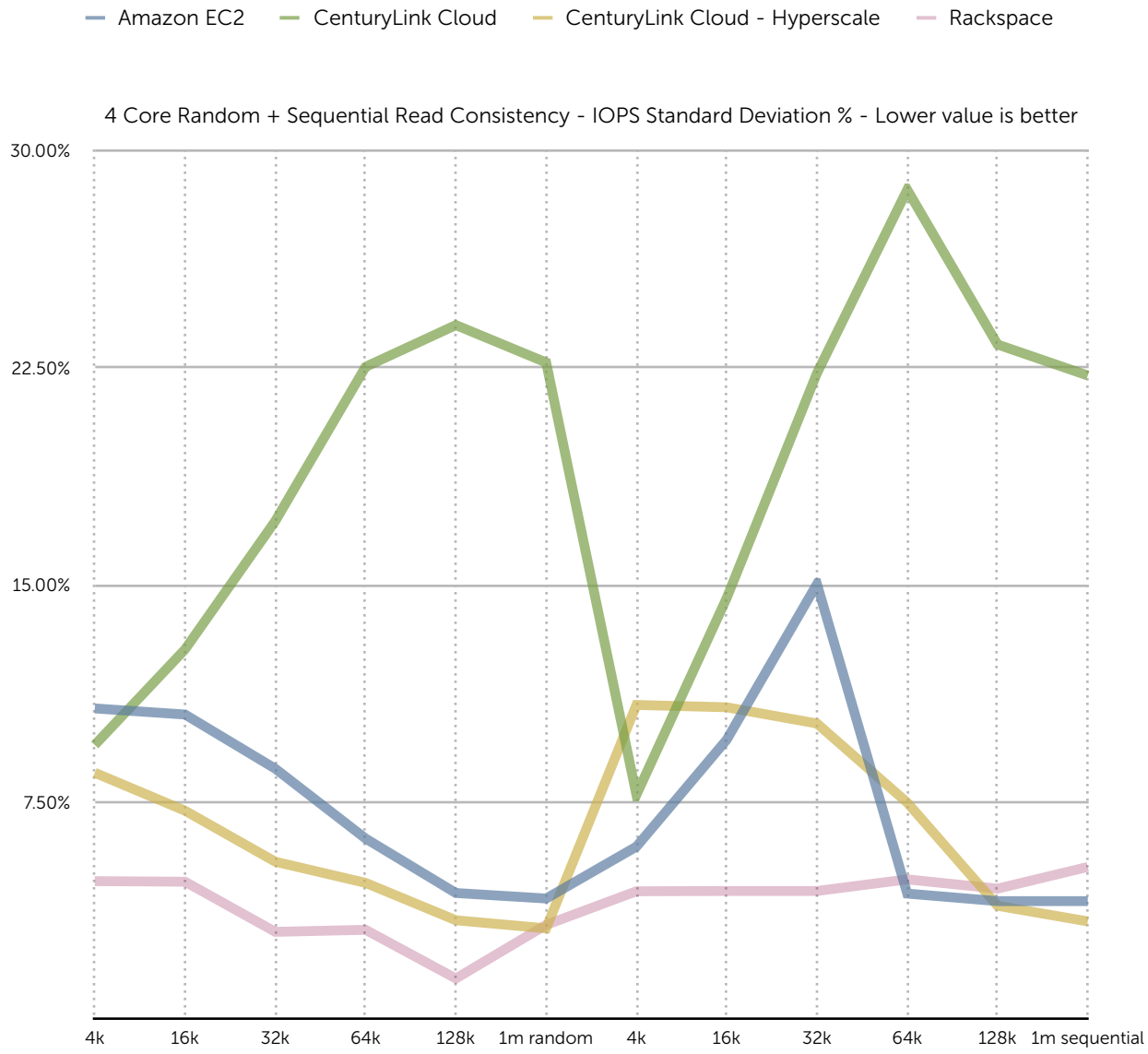
Disk Read Performance - 4 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	206.31	53.25	374.41	120.48
16k	361.14	137.08	1,245.96	366.06
32k	422.57	87.68	1,841.64	551.48
64k	473.74	64.97	2,320.20	606.34
128k	466.66	99.68	2,733.74	675.72
1m random	495.67	107.27	3,411.56	695.27

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	127.44	70.81	509.61	437.49
16k	224.49	179.06	1,821.13	561.92
32k	314.86	181.08	2,482.90	565.83
64k	421.42	112.88	2,851.79	618.91
128k	497.07	100.97	3,236.13	681.30
1m sequential	480.08	93.89	3,250.75	679.23

Disk Read Consistency - 4 Core Instance Type



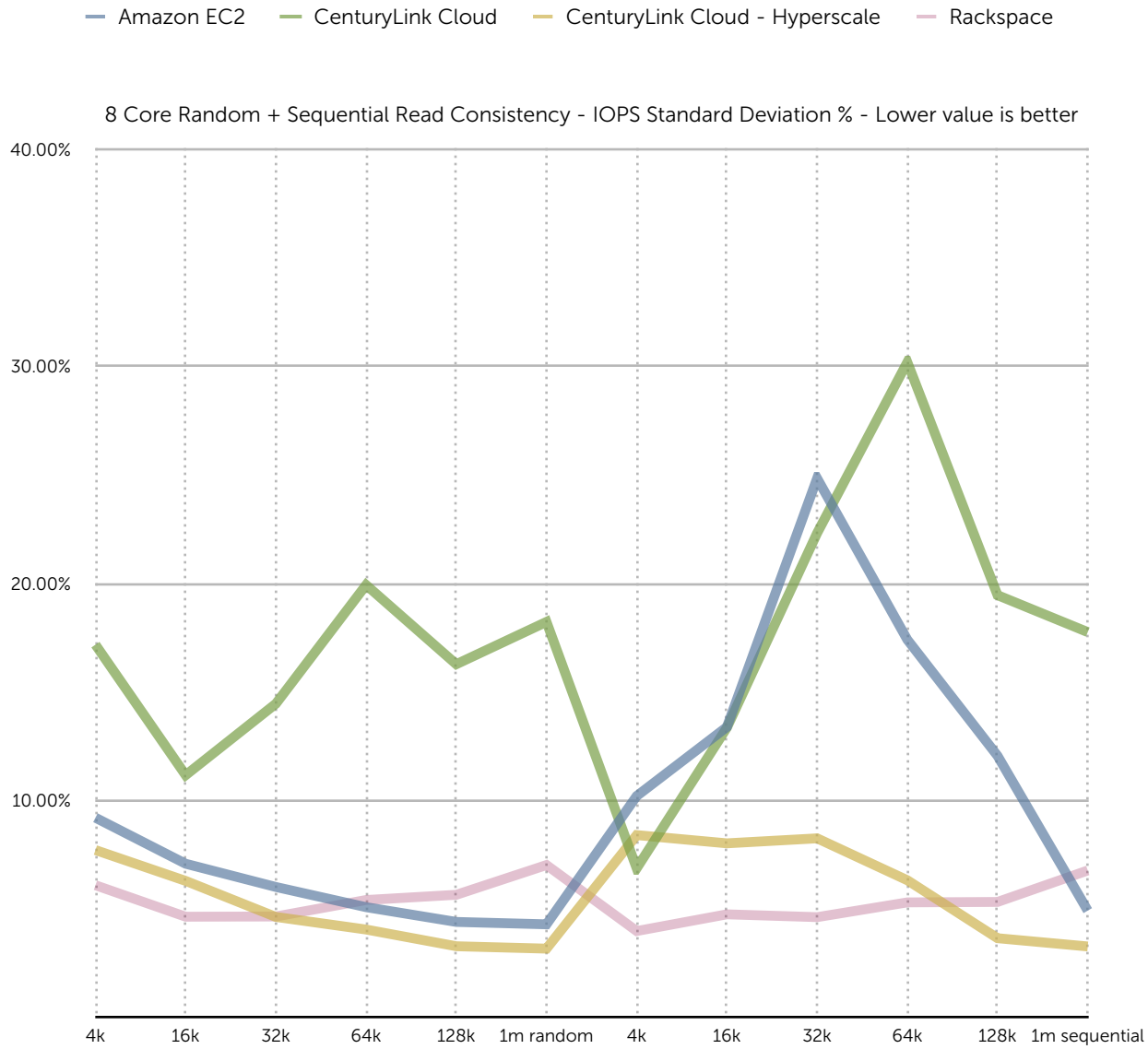
Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	10.74%	9.48%	8.52%	4.78%
16k	10.53%	12.78%	7.21%	4.76%
32k	8.66%	17.21%	5.45%	3.03%
64k	6.25%	22.53%	4.72%	3.10%
128k	4.37%	23.97%	3.43%	1.42%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	4.18%	22.68%	3.15%	3.27%
4k	5.97%	7.76%	10.86%	4.43%
16k	9.66%	14.55%	10.78%	4.44%
32k	15.03%	22.31%	10.22%	4.44%
64k	4.35%	28.64%	7.49%	4.84%
128k	4.09%	23.30%	3.93%	4.52%
1m sequential	4.09%	22.23%	3.39%	5.27%

Disk Read Performance - 8 Core Instance Type

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	230.65	31.63	374.50	124.02
16k	385.30	77.70	1,251.75	376.35
32k	446.94	76.49	1,833.83	562.88
64k	480.20	83.94	2,325.67	618.72
128k	497.39	90.68	2,613.66	685.22
1m random	491.60	98.43	3,401.57	674.79
4k	95.61	76.75	522.28	453.49
16k	186.18	190.31	1,844.05	575.90
32k	220.42	153.46	2,524.06	576.92
64k	294.19	102.29	2,889.49	629.63
128k	335.65	91.17	3,246.53	705.92
1m sequential	492.32	88.49	3,364.05	691.66

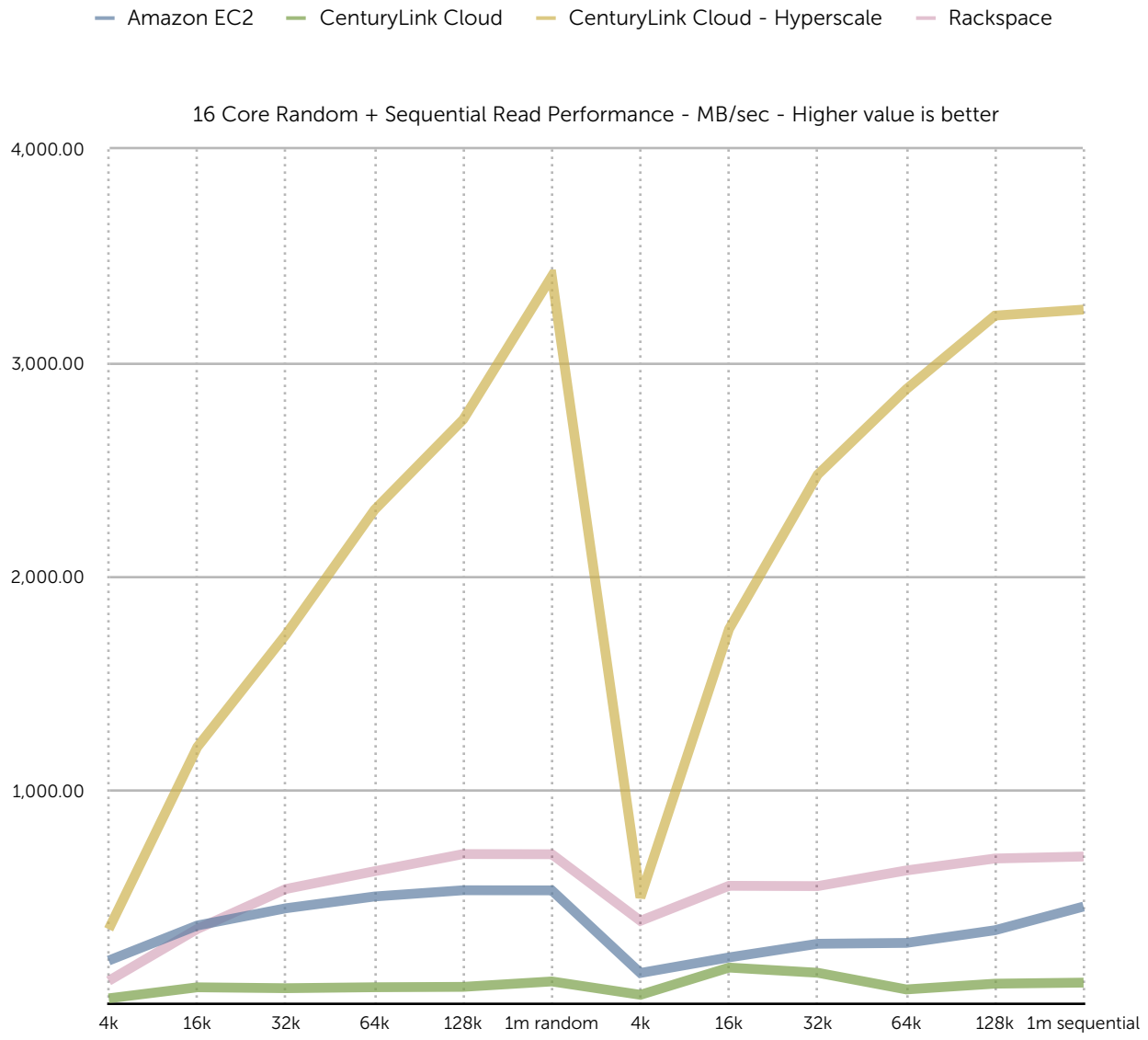
Disk Read Consistency - 8 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	9.20%	17.17%	7.71%	6.09%
16k	7.08%	11.16%	6.29%	4.64%
32k	6.01%	14.45%	4.63%	4.65%
64k	5.08%	19.92%	4.05%	5.41%
128k	4.40%	16.27%	3.28%	5.65%
1m random	4.29%	18.22%	3.17%	7.02%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	10.20%	6.87%	8.40%	3.98%
16k	13.38%	13.35%	8.02%	4.75%
32k	24.83%	22.31%	8.25%	4.62%
64k	17.40%	30.18%	6.32%	5.30%
128k	12.05%	19.45%	3.65%	5.32%
1m sequential	4.92%	17.75%	3.27%	6.77%

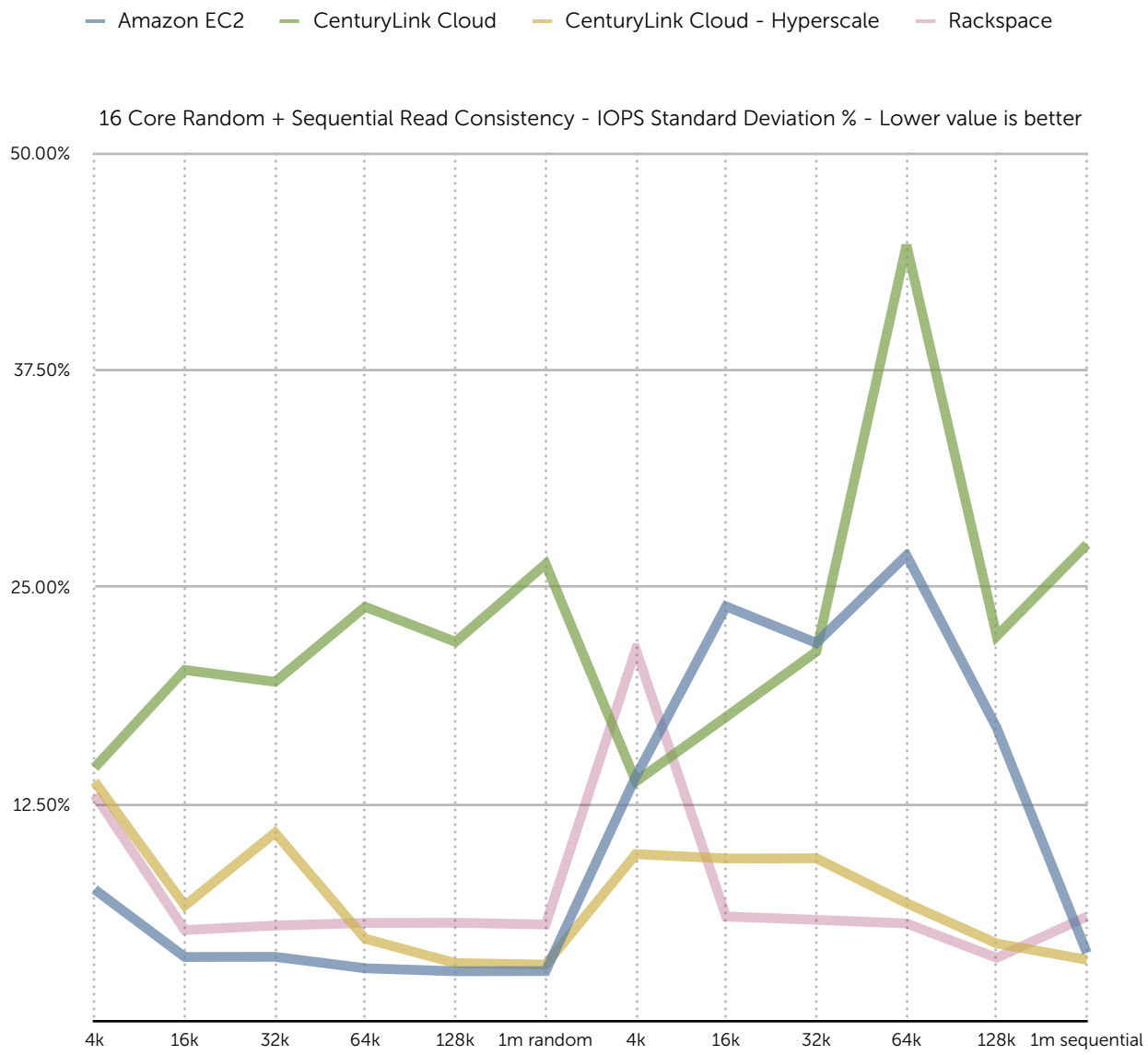
Disk Read Performance - 16 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	206.91	30.13	353.28	112.02
16k	370.69	81.78	1,205.11	354.40
32k	451.35	77.68	1,730.86	541.46
64k	506.35	82.10	2,314.15	624.44
128k	535.52	83.87	2,736.04	704.71

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	534.95	109.20	3,406.09	703.92
4k	148.80	46.70	501.06	392.57
16k	221.62	173.99	1,756.81	556.27
32k	285.33	149.79	2,478.56	554.90
64k	289.34	71.89	2,877.86	628.09
128k	348.60	98.76	3,221.98	683.89
1m sequential	459.36	103.70	3,250.20	693.19

Disk Read Consistency - 16 Core Instance Type



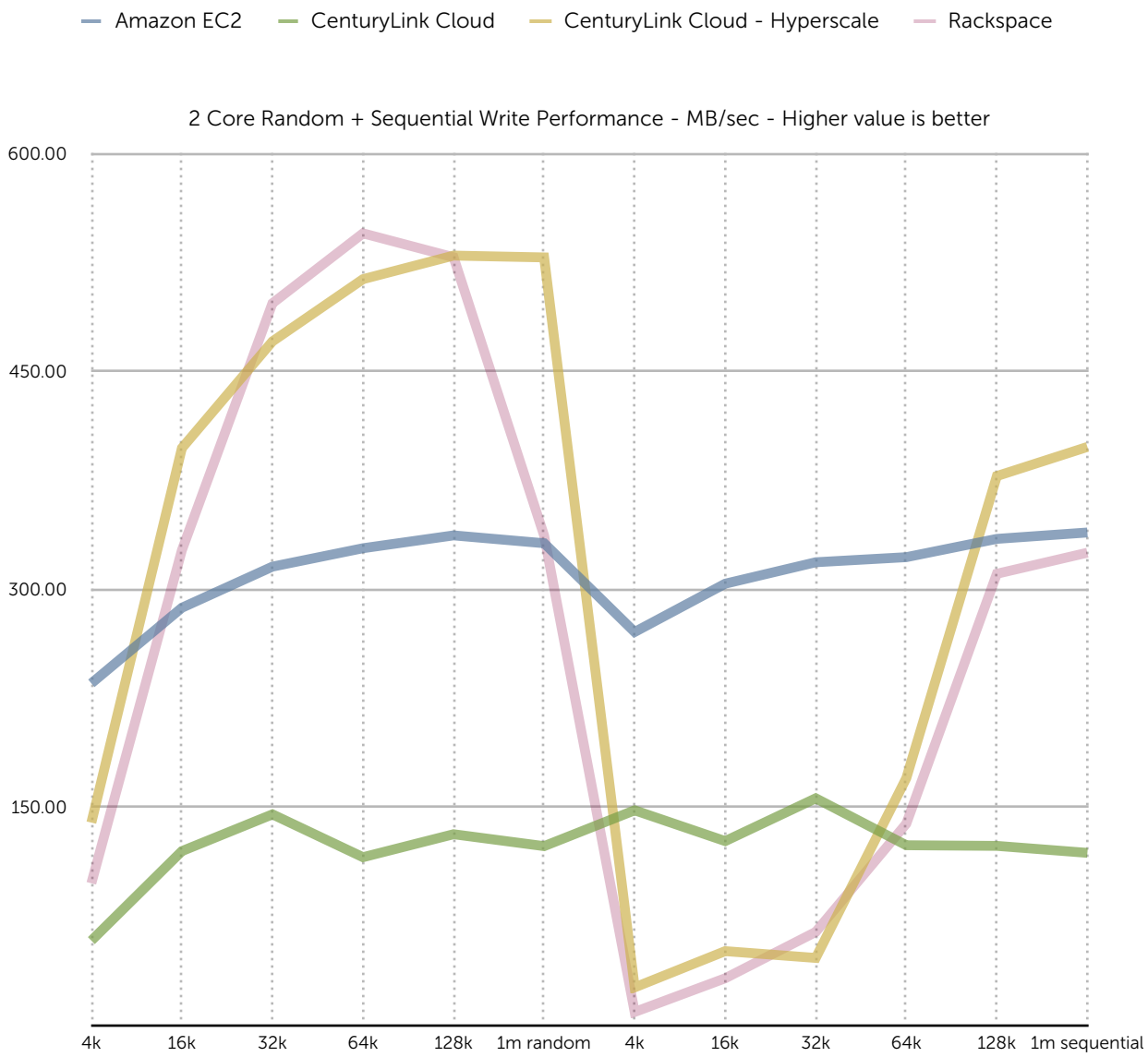
Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	7.60%	14.61%	13.80%	13.04%
16k	3.71%	20.23%	6.67%	5.26%
32k	3.72%	19.55%	10.86%	5.52%
64k	3.06%	23.87%	4.76%	5.67%
128k	2.89%	21.85%	3.36%	5.68%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	2.90%	26.33%	3.27%	5.58%
4k	14.10%	13.81%	9.63%	21.41%
16k	23.89%	17.53%	9.38%	6.04%
32k	21.79%	21.28%	9.39%	5.85%
64k	26.83%	44.69%	6.81%	5.64%
128k	16.90%	22.18%	4.49%	3.66%
1m sequential	3.94%	27.46%	3.55%	6.04%

Disk Write Performance

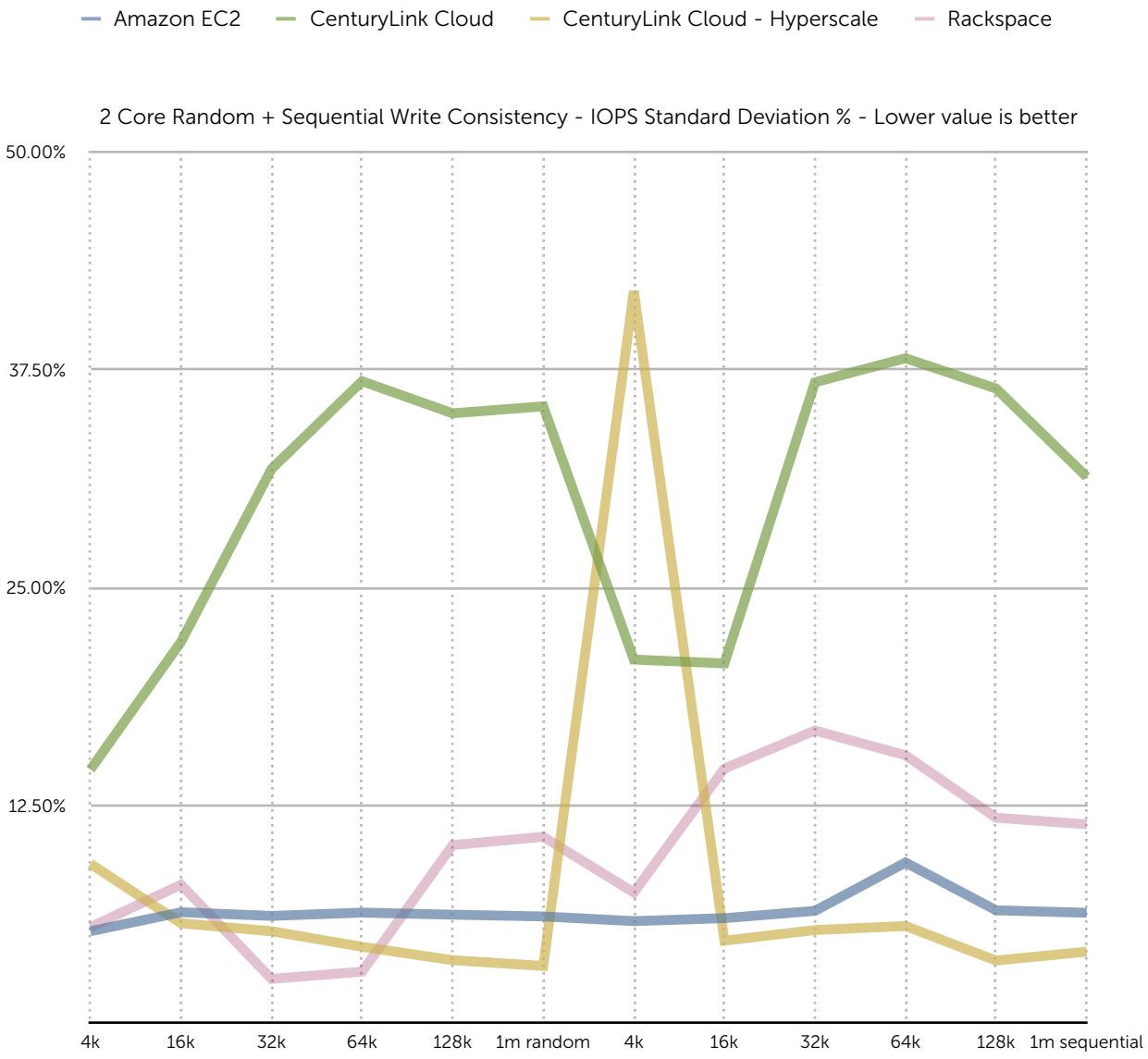
The graphs and tables below present disk IO write throughput and consistency for both random and sequential workloads based on six block sizes. Each subsection presents a different instance type comparison: 2, 4, 8 and 16 cores as listed in the preceding comparison matrix. A higher throughput value signifies better performance. A lower IO standard deviation represents better performance consistency.

Disk Write Performance - 2 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	234.94	57.77	139.03	97.24
16k	286.99	119.41	396.92	326.63
32k	315.30	144.72	470.41	496.66
64k	327.98	115.21	513.26	544.81
128k	336.81	131.03	529.49	528.36
1m random	331.41	122.83	528.24	336.70
4k	270.30	147.51	25.56	8.63
16k	303.55	126.30	50.53	31.84
32k	318.32	155.77	45.84	63.75
64k	321.82	123.45	169.66	138.30
128k	334.42	123.01	377.67	310.39
1m sequential	338.81	118.20	397.73	324.89

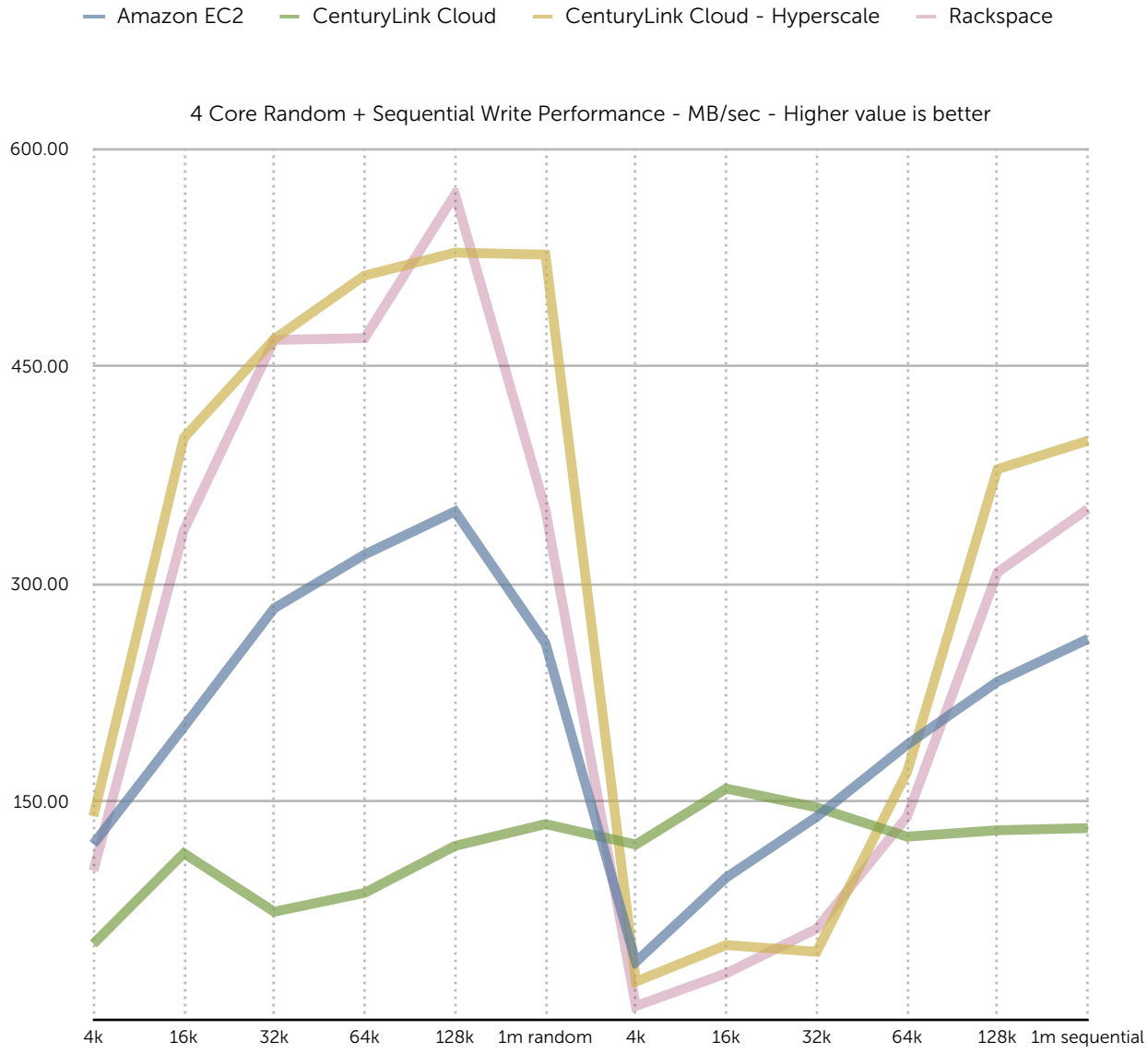
Disk Write Consistency - 2 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	5.30%	14.57%	9.17%	5.53%
16k	6.39%	21.89%	5.76%	7.97%
32k	6.18%	31.81%	5.30%	2.57%
64k	6.37%	36.84%	4.41%	2.98%
128k	6.25%	35.00%	3.64%	10.24%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	6.15%	35.40%	3.31%	10.72%
4k	5.88%	20.88%	42.01%	7.52%
16k	6.05%	20.66%	4.76%	14.63%
32k	6.47%	36.78%	5.37%	16.81%
64k	9.24%	38.16%	5.60%	15.39%
128k	6.50%	36.42%	3.62%	11.81%
1m sequential	6.36%	31.36%	4.13%	11.43%

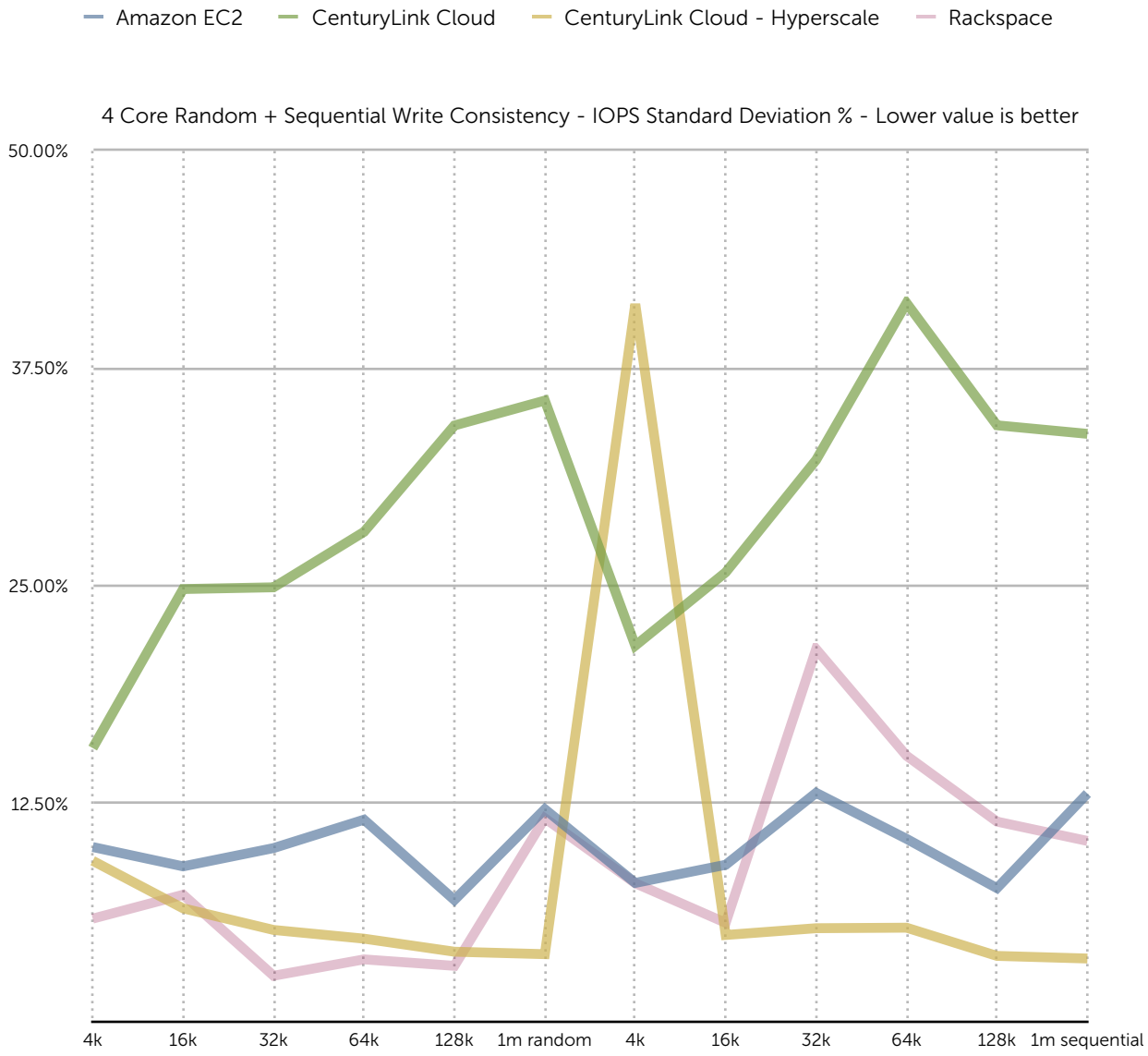
Disk Write Performance - 4 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	120.47	51.64	139.65	102.05
16k	201.23	114.08	400.47	336.79
32k	283.02	73.79	468.57	467.94
64k	320.02	86.80	512.35	469.25
128k	349.75	119.16	528.14	568.32

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	258.91	134.21	526.78	350.89
4k	39.19	120.11	25.60	8.78
16k	97.35	158.68	50.82	31.32
32k	139.23	145.73	46.17	62.08
64k	188.97	125.56	170.10	139.27
128k	232.41	129.95	378.85	307.77
1m sequential	261.84	131.45	398.52	351.47

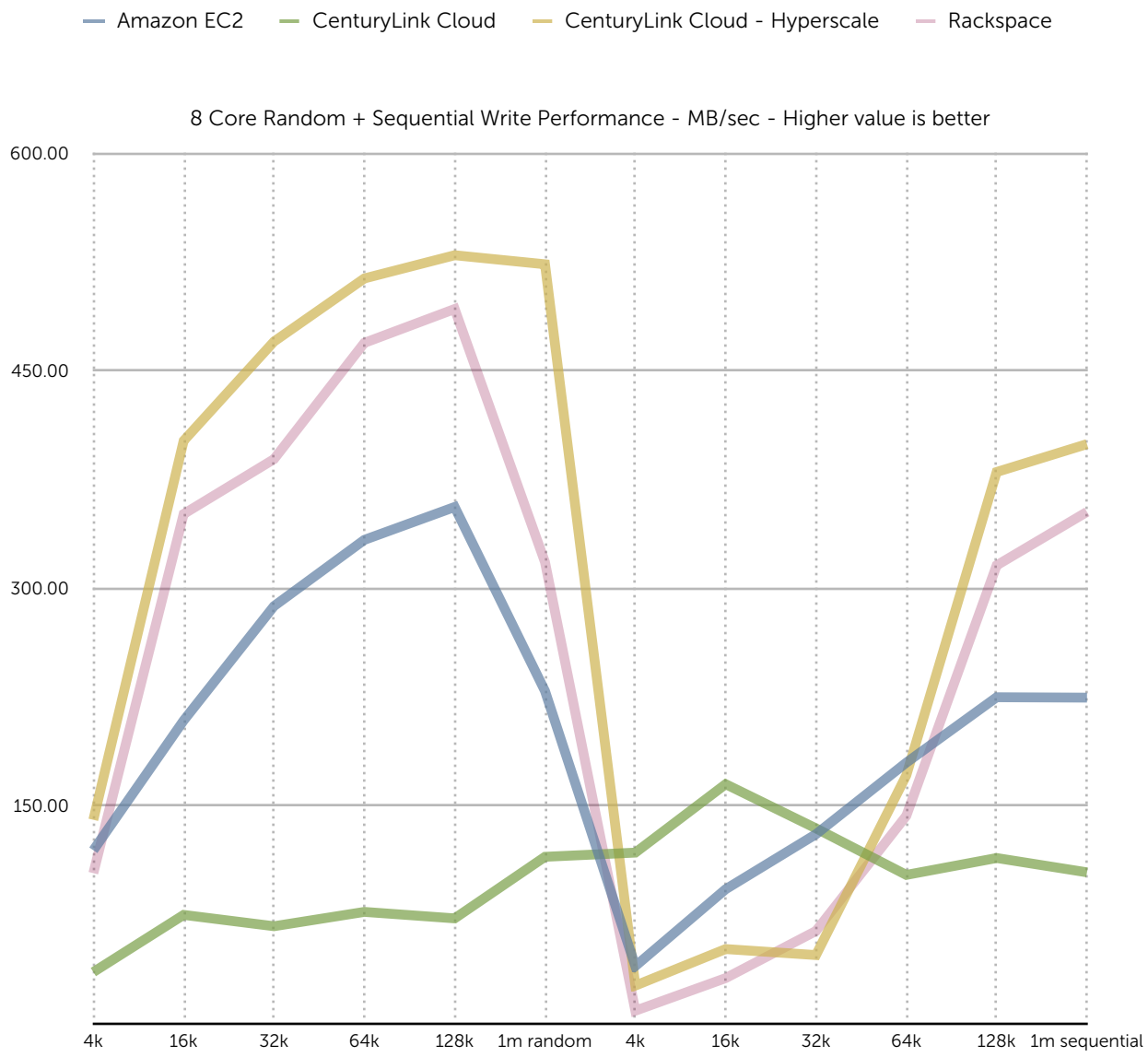
Disk Write Consistency - 4 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	10.00%	15.68%	9.21%	5.89%
16k	8.89%	24.81%	6.48%	7.26%
32k	9.94%	24.91%	5.24%	2.61%
64k	11.57%	28.09%	4.74%	3.55%
128k	6.96%	34.20%	3.99%	3.18%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	12.17%	35.63%	3.85%	11.65%
4k	7.94%	21.56%	41.17%	7.92%
16k	8.98%	25.77%	4.95%	5.65%
32k	13.11%	32.22%	5.34%	21.36%
64k	10.47%	41.23%	5.37%	15.24%
128k	7.64%	34.21%	3.75%	11.46%
1m sequential	13.07%	33.72%	3.60%	10.35%

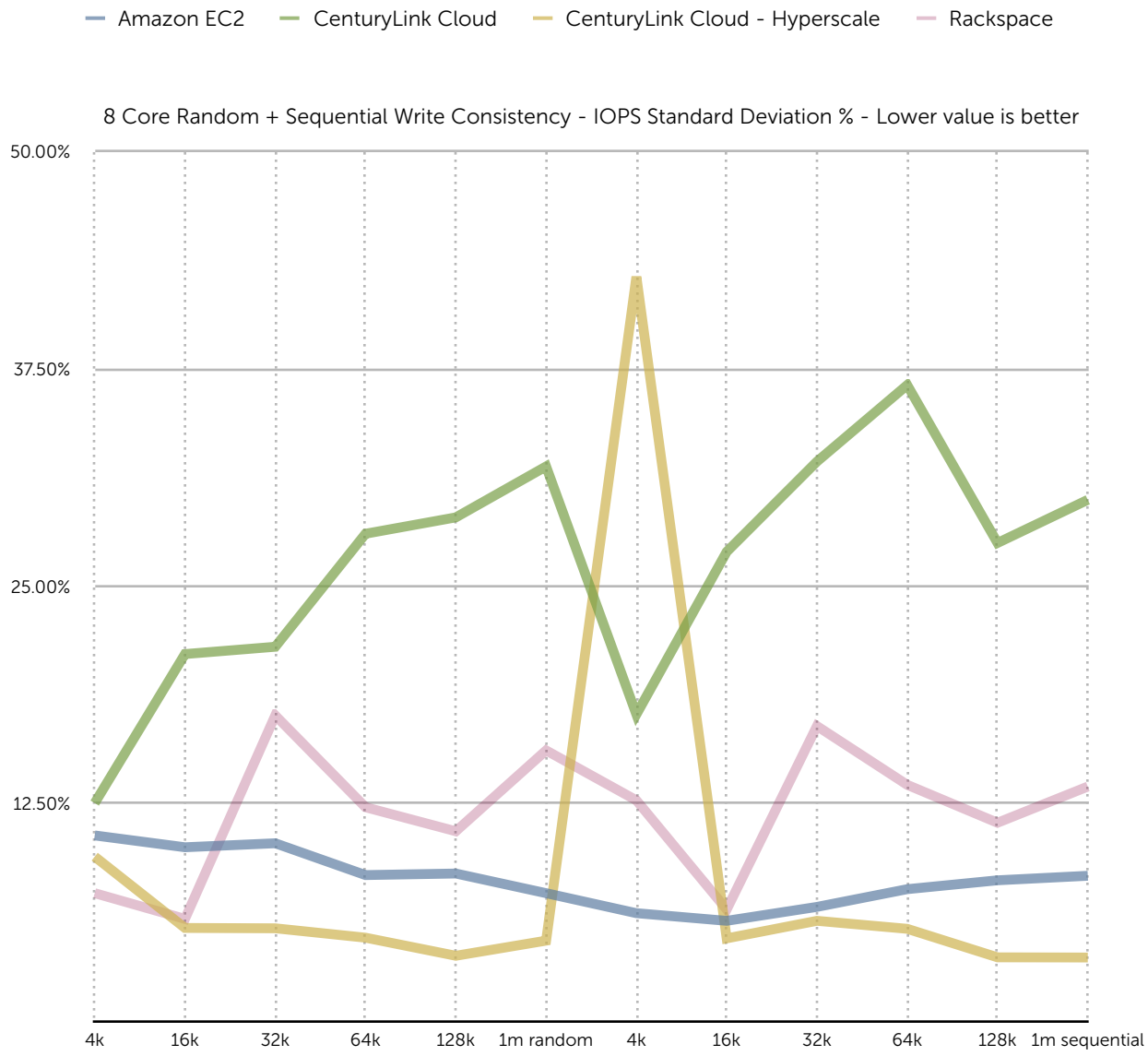
Disk Write Performance - 8 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	118.97	34.95	139.98	103.18
16k	208.50	74.38	401.45	350.94
32k	287.39	66.57	469.89	388.77
64k	333.07	76.45	513.41	468.97
128k	355.75	71.98	529.43	492.32

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	228.82	114.46	523.19	317.71
4k	39.06	117.34	25.62	8.29
16k	92.09	164.56	50.82	30.77
32k	130.05	134.07	46.67	63.28
64k	179.42	101.97	170.69	142.73
128k	224.52	113.62	379.90	315.51
1m sequential	224.25	103.74	399.14	352.38

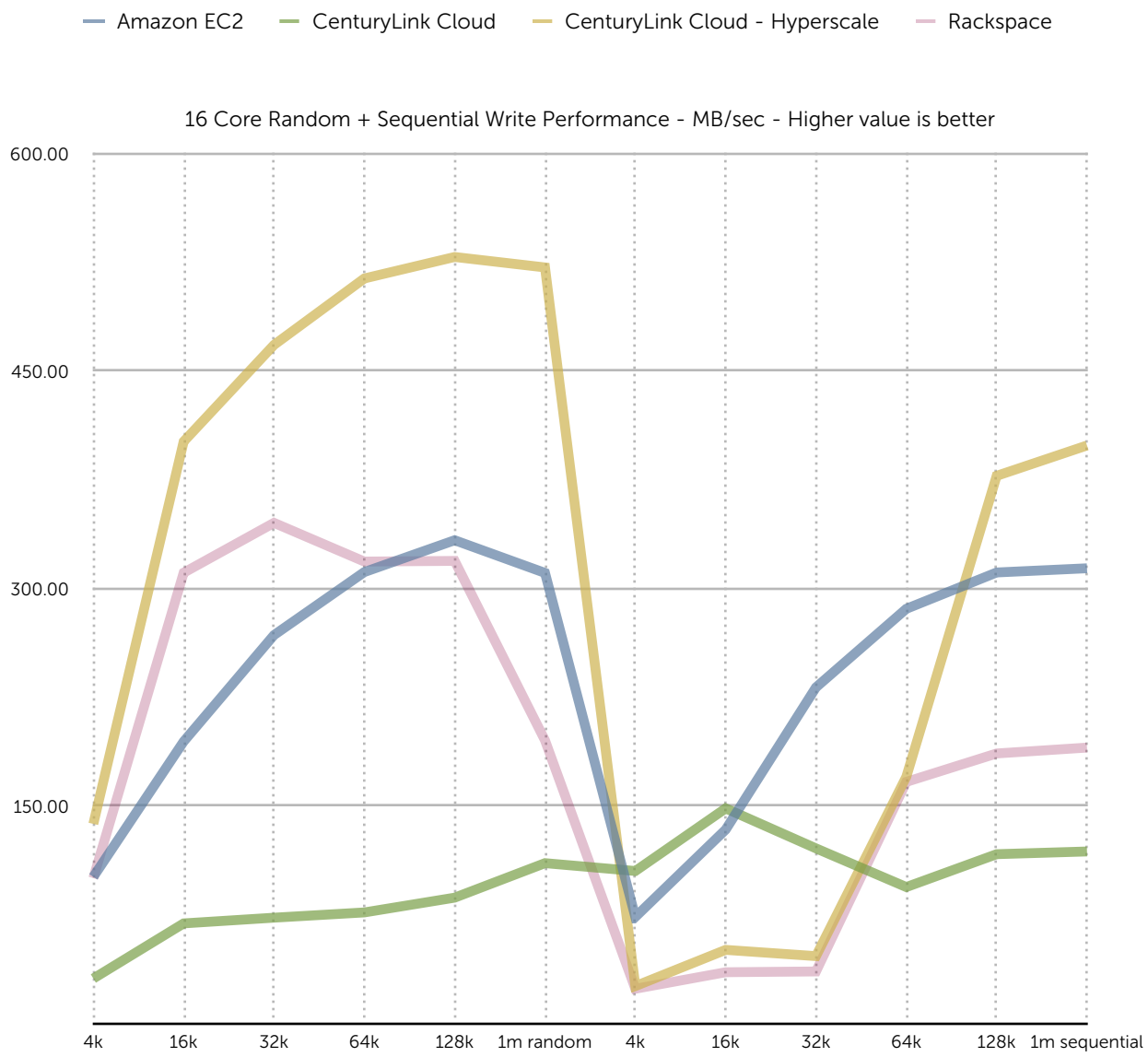
Disk Write Consistency - 8 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	10.67%	12.53%	9.45%	7.35%
16k	9.99%	21.10%	5.35%	5.87%
32k	10.22%	21.52%	5.33%	17.57%
64k	8.39%	28.02%	4.79%	12.29%
128k	8.48%	28.96%	3.75%	10.91%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	7.35%	31.89%	4.62%	15.56%
4k	6.20%	17.63%	42.80%	12.69%
16k	5.76%	26.98%	4.75%	6.41%
32k	6.56%	32.17%	5.76%	16.96%
64k	7.58%	36.57%	5.30%	13.58%
128k	8.09%	27.49%	3.66%	11.40%
1m sequential	8.35%	29.97%	3.65%	13.48%

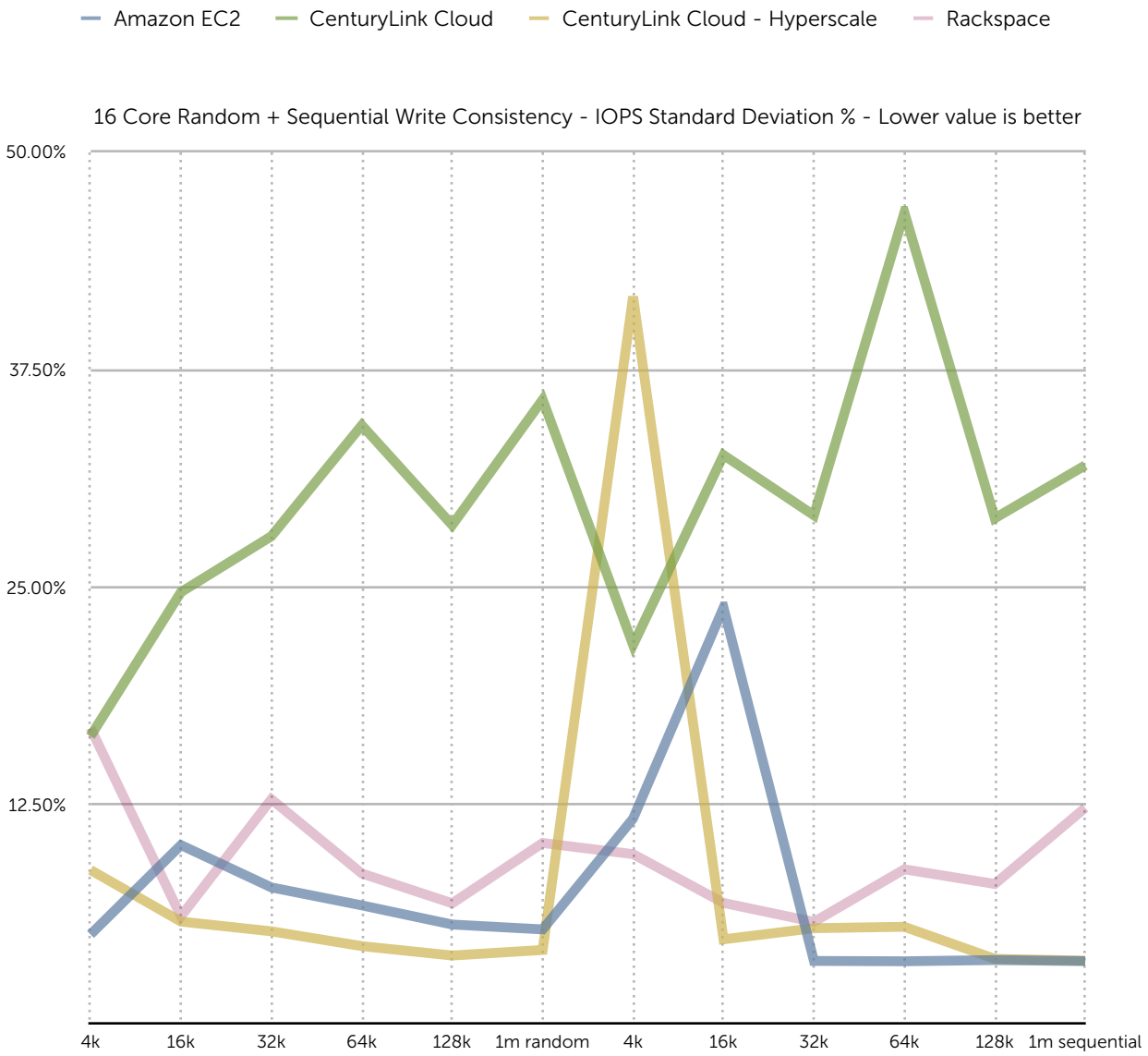
Disk Write Performance - 16 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	101.19	31.06	137.73	100.32
16k	194.55	69.08	401.48	310.99
32k	267.97	73.03	468.14	345.38
64k	311.44	76.65	513.97	318.69
128k	333.40	86.84	528.79	319.13

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	310.85	110.64	521.58	195.35
4k	73.53	105.22	25.83	23.98
16k	133.76	148.42	50.82	35.40
32k	231.91	120.83	46.50	35.93
64k	286.10	94.15	170.24	166.70
128k	311.16	116.83	377.82	186.30
1m sequential	314.05	118.70	398.76	190.36

Disk Write Consistency - 16 Core Instance Type



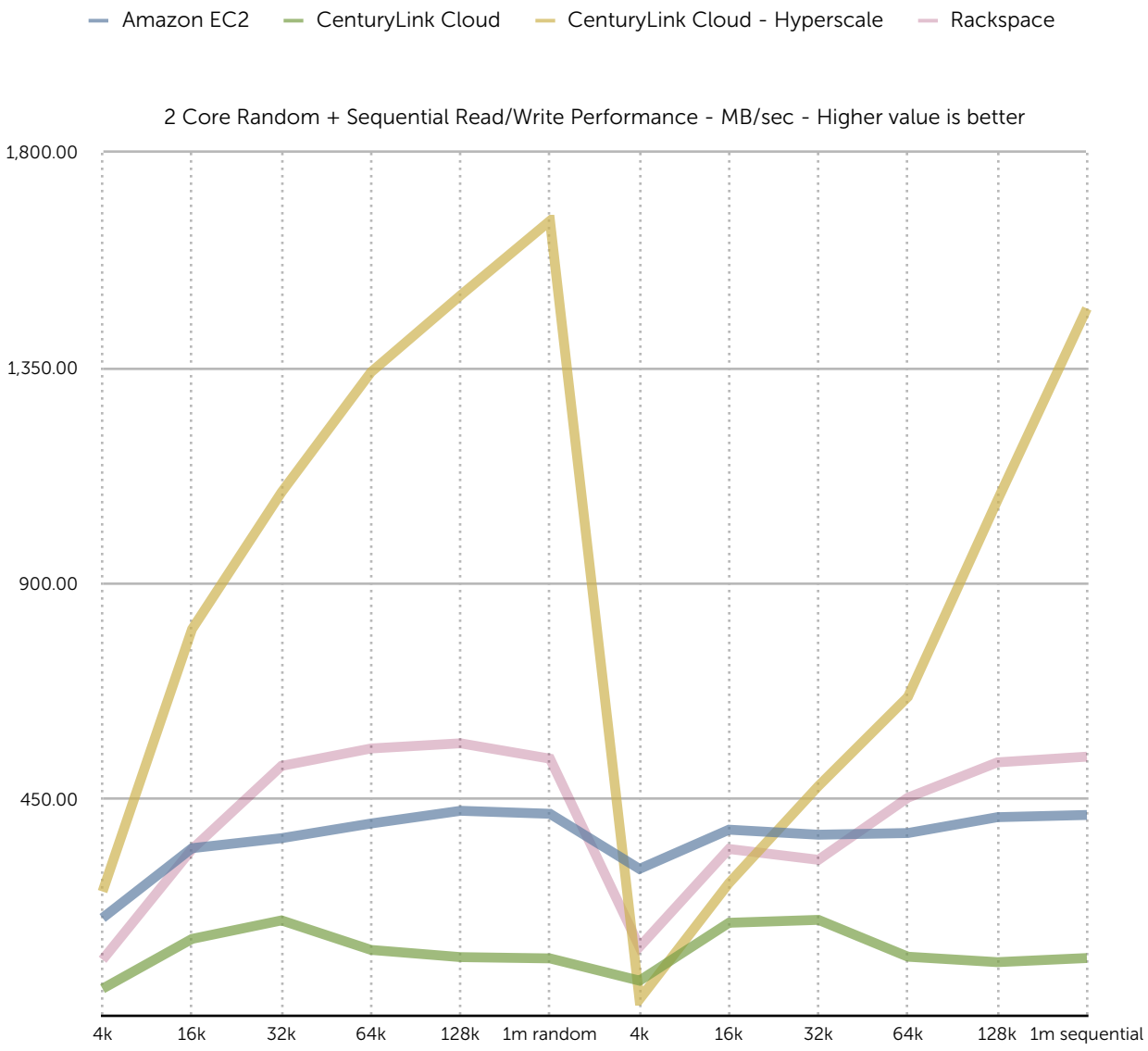
Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	5.07%	16.45%	8.77%	16.92%
16k	10.20%	24.72%	5.81%	6.11%
32k	7.77%	27.93%	5.25%	12.83%
64k	6.74%	34.30%	4.40%	8.57%
128k	5.64%	28.57%	3.86%	6.86%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	5.36%	35.77%	4.18%	10.32%
4k	11.72%	21.69%	41.69%	9.68%
16k	23.83%	32.59%	4.79%	6.88%
32k	3.55%	29.13%	5.43%	5.79%
64k	3.53%	46.51%	5.51%	8.81%
128k	3.60%	28.96%	3.67%	7.97%
1m sequential	3.54%	32.00%	3.56%	12.34%

Disk Read/Write Performance

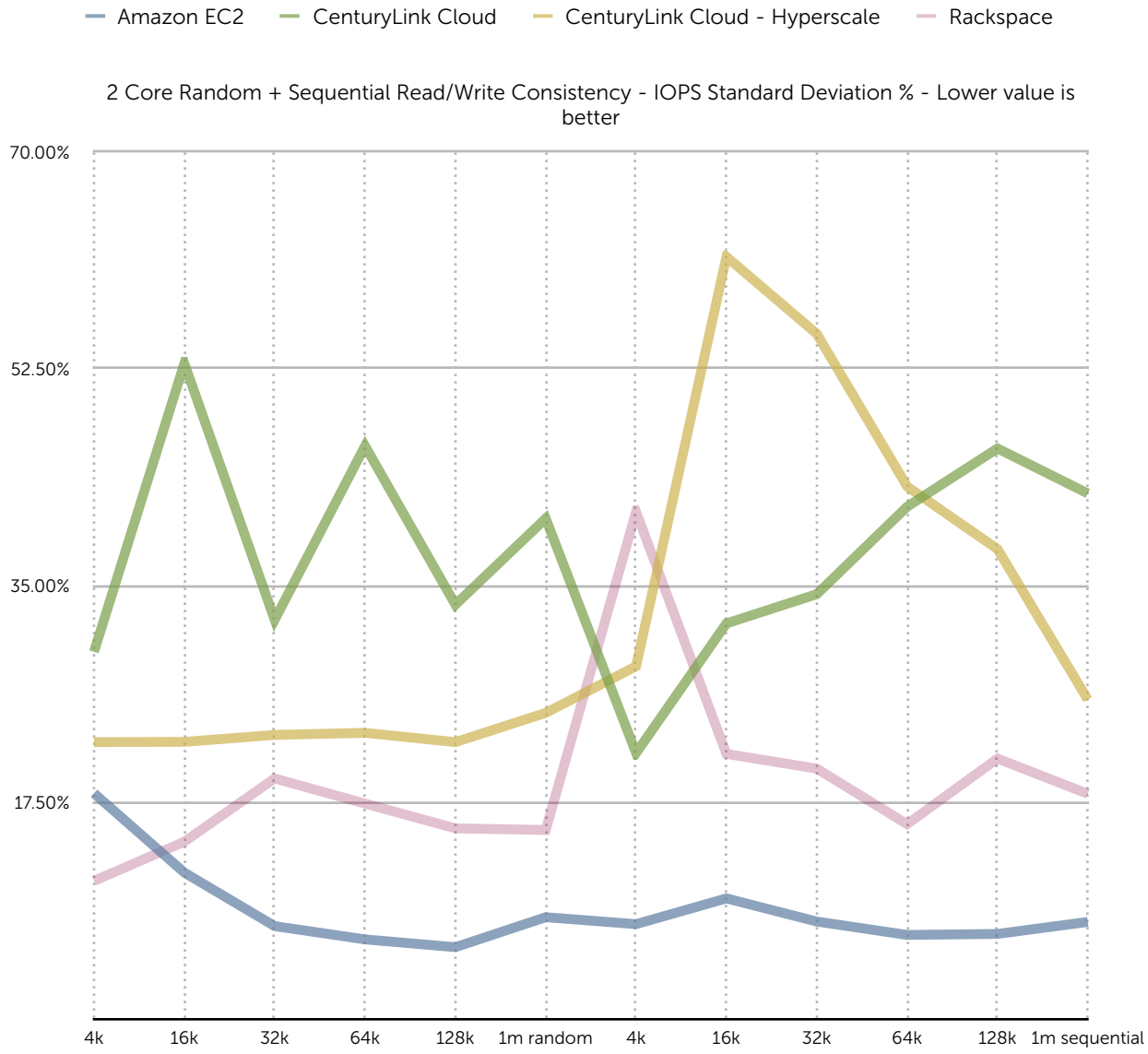
The graphs and tables below present disk IO read/write throughput and consistency for both random and sequential workloads based on six block sizes. These workloads used a combination of simultaneous read and write operations using a ratio of 80/20. Each subsection presents a different instance type comparison: 2, 4, 8 and 16 cores as listed in the preceding comparison matrix. A higher throughput value signifies better performance. A lower IO standard deviation represents better performance consistency.

Disk Read/Write Performance - 2 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	203.19	55.80	258.31	116.09
16k	348.72	159.61	805.32	346.65
32k	369.58	198.15	1,090.70	520.22
64k	400.18	136.64	1,341.14	556.60
128k	426.67	121.59	1,501.12	567.34
1m random	420.41	118.94	1,656.63	535.28
4k	305.53	72.53	33.58	142.92
16k	387.26	193.17	275.77	347.08
32k	376.78	199.25	478.35	324.45
64k	380.29	122.42	664.21	454.08
128k	413.32	111.11	1,073.82	527.66
1m sequential	417.94	119.69	1,473.87	539.50

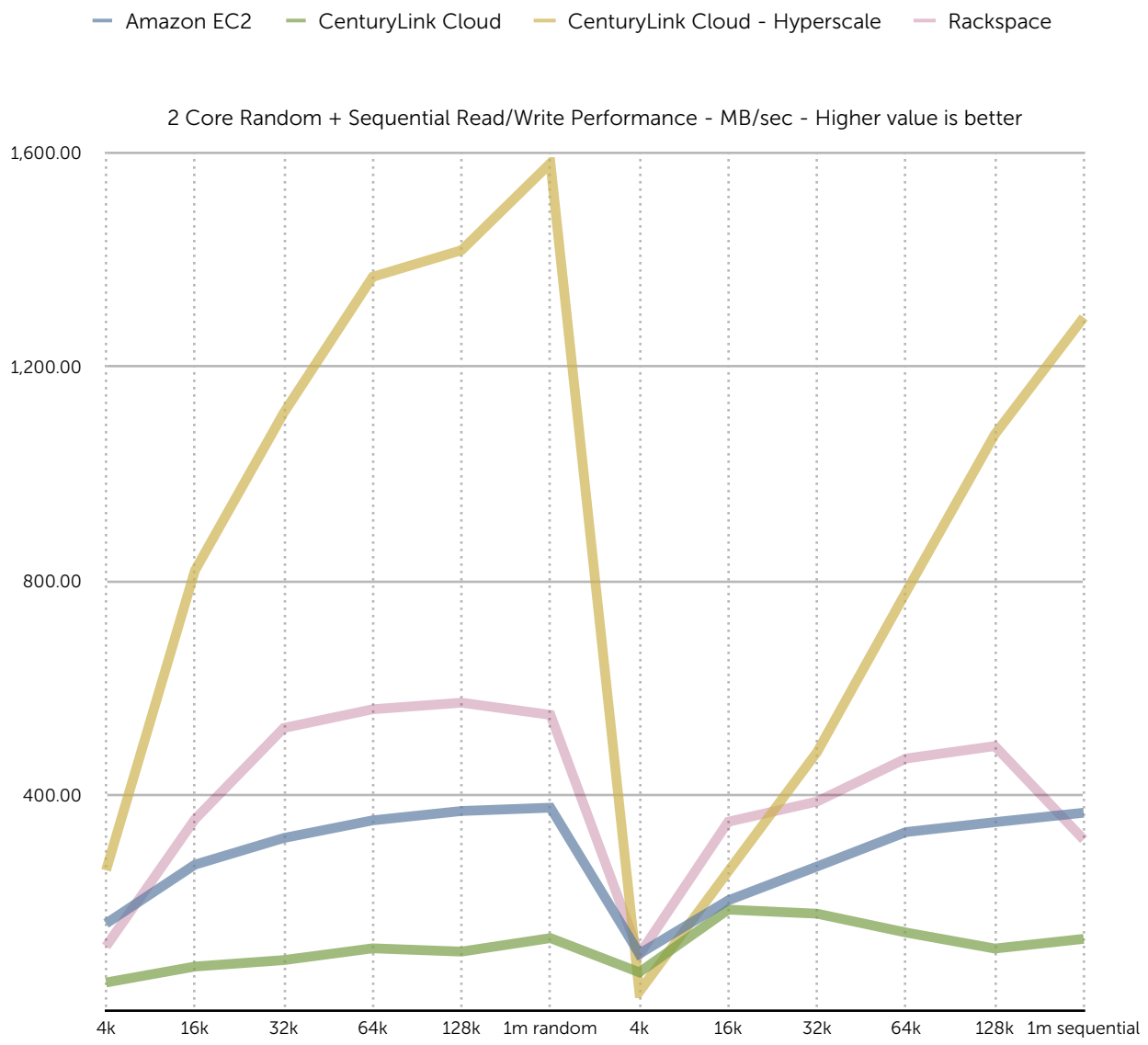
Disk Read/Write Consistency - 2 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	18.24%	29.66%	22.37%	11.17%
16k	11.84%	52.93%	22.39%	14.33%
32k	7.52%	32.24%	22.95%	19.44%
64k	6.45%	46.27%	23.12%	17.41%
128k	5.82%	33.46%	22.37%	15.41%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	8.24%	40.42%	24.73%	15.28%
4k	7.68%	21.49%	28.49%	40.95%
16k	9.76%	31.95%	61.54%	21.42%
32k	7.89%	34.31%	55.32%	20.23%
64k	6.81%	41.37%	43.00%	15.75%
128k	6.89%	46.07%	37.95%	21.04%
1m sequential	7.86%	42.44%	25.80%	18.20%

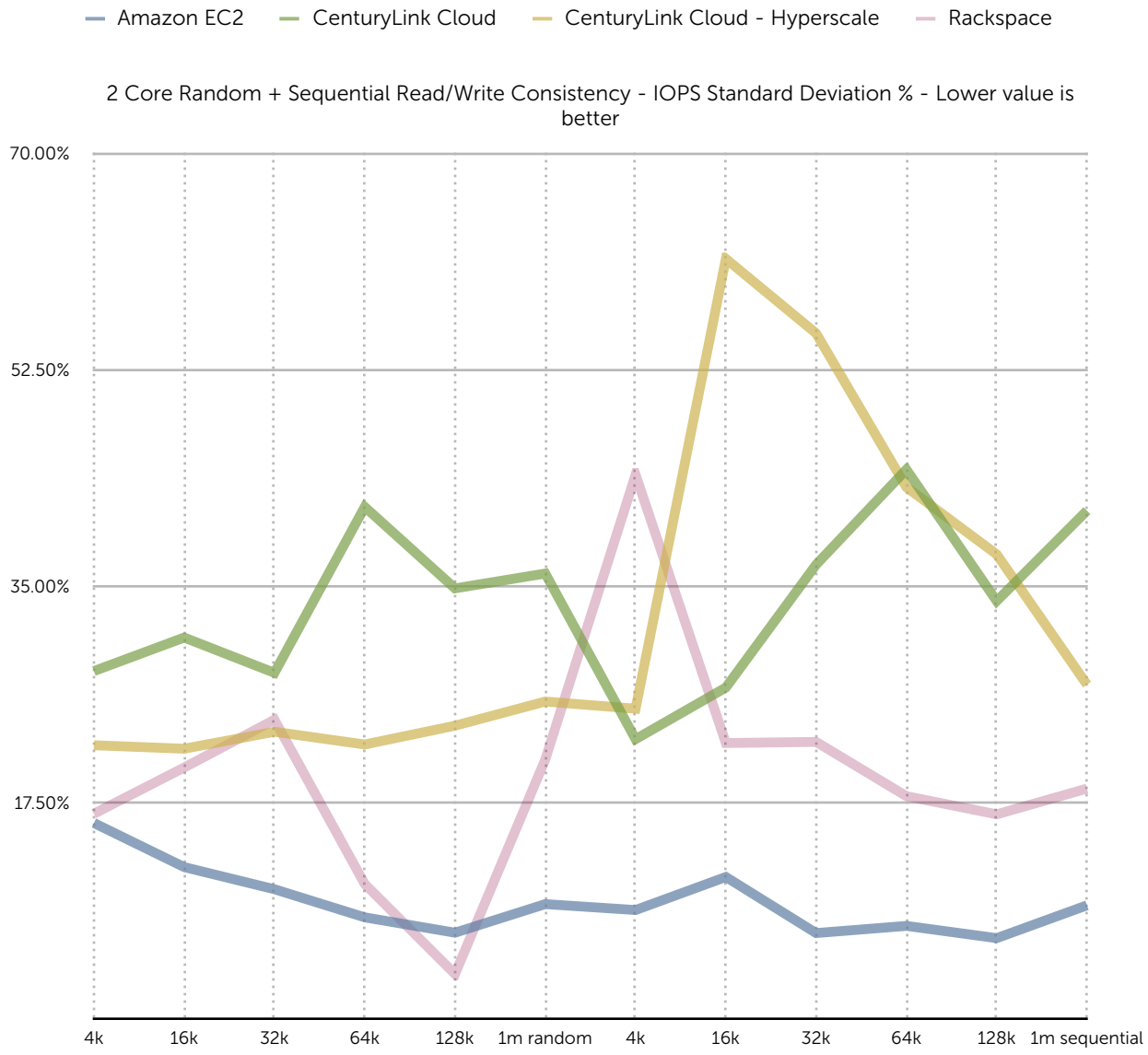
Disk Read/Write Performance - 4 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	161.08	50.98	260.41	118.41
16k	270.93	80.76	819.86	355.67
32k	320.70	92.81	1,114.44	526.05
64k	353.61	114.77	1,368.02	560.97
128k	371.06	108.66	1,417.79	573.21

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	377.25	133.89	1,580.24	550.53
4k	104.50	70.02	33.74	103.18
16k	204.21	187.02	258.33	350.94
32k	267.45	179.45	481.01	388.77
64k	331.78	144.29	779.47	468.97
128k	350.26	114.32	1,073.99	492.32
1m sequential	367.82	132.45	1,292.20	317.71

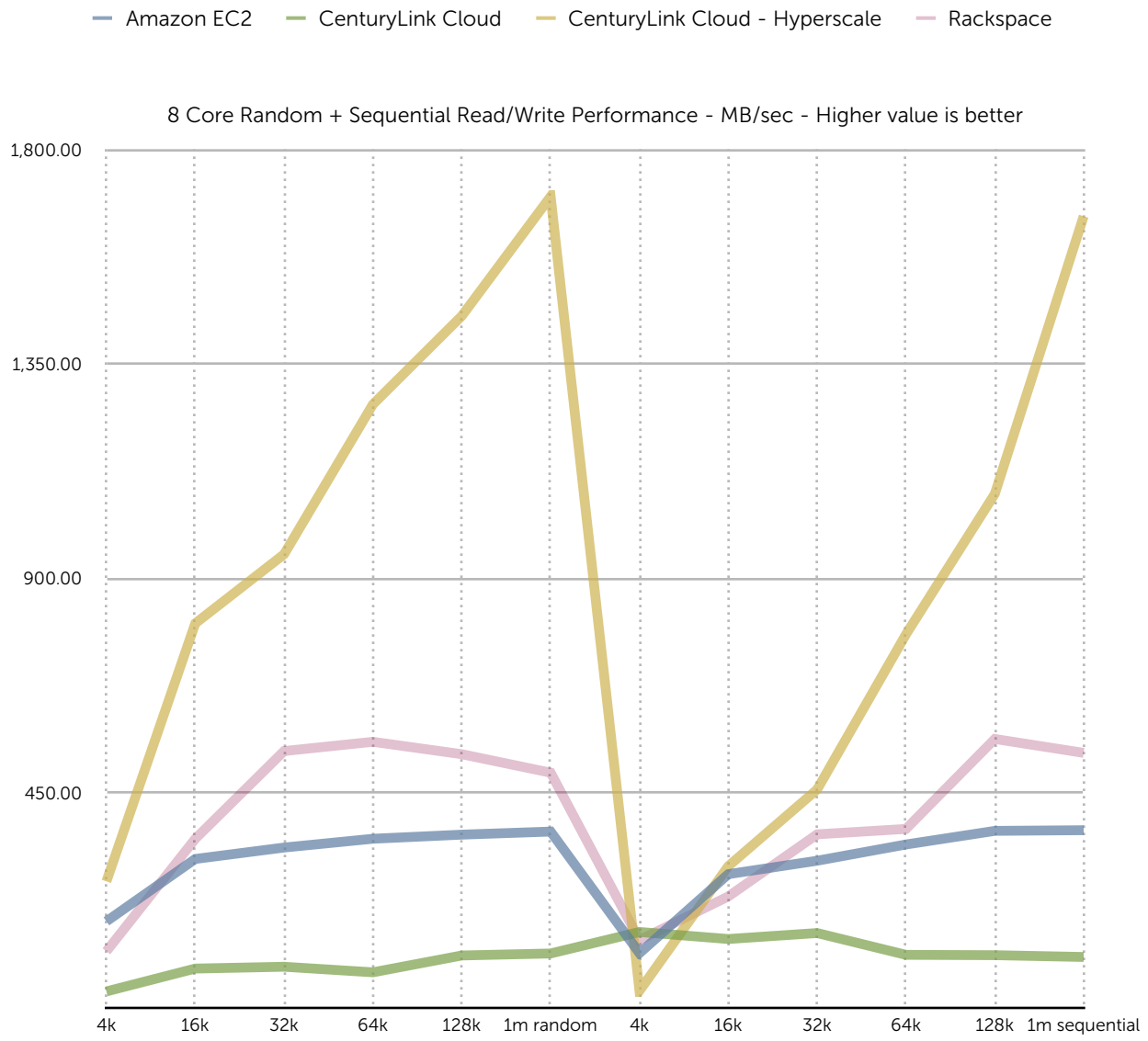
Disk Read/Write Consistency - 4 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	15.88%	28.15%	22.16%	16.63%
16k	12.32%	30.86%	21.88%	20.36%
32k	10.53%	28.01%	23.25%	24.22%
64k	8.26%	41.41%	22.22%	10.95%
128k	7.02%	34.83%	23.74%	3.68%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	9.33%	36.03%	25.69%	21.01%
4k	8.85%	22.65%	25.11%	44.01%
16k	11.52%	26.82%	61.45%	22.34%
32k	6.99%	36.75%	55.43%	22.43%
64k	7.57%	44.43%	43.00%	18.05%
128k	6.58%	33.81%	37.58%	16.58%
1m sequential	9.23%	41.11%	27.06%	18.66%

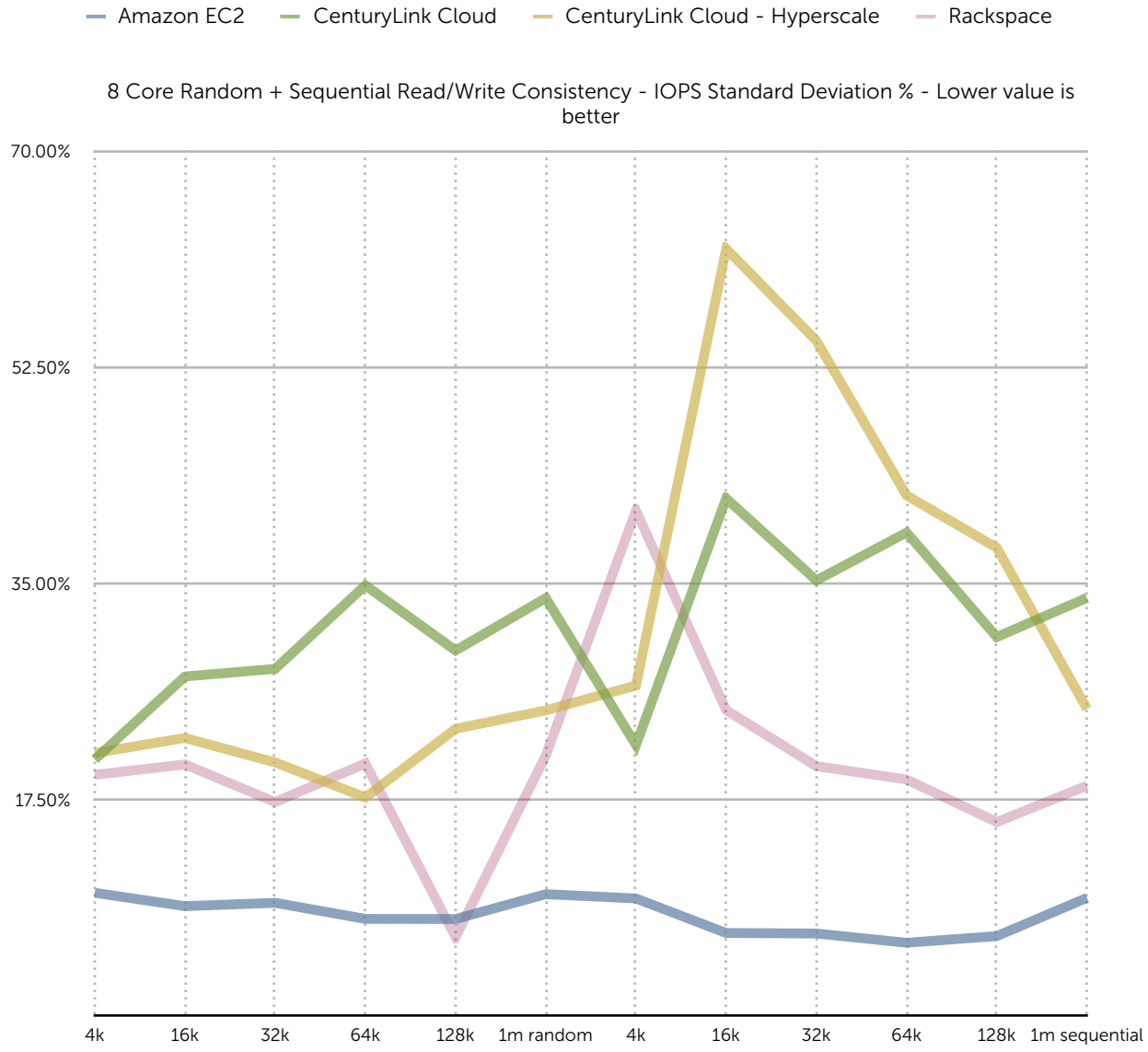
Disk Read/Write Performance - 8 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	179.46	32.19	263.46	116.49
16k	310.52	80.22	805.39	352.82
32k	334.50	84.03	950.78	537.20
64k	352.98	72.34	1,265.76	556.66
128k	361.59	107.72	1,451.42	530.65

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	368.06	111.92	1,702.41	491.79
4k	112.61	157.09	33.57	140.20
16k	278.58	142.31	295.38	231.73
32k	306.80	154.86	456.53	362.27
64k	340.93	109.05	782.55	373.62
128k	369.53	108.34	1,077.69	562.62
1m sequential	370.95	104.56	1,660.91	533.42

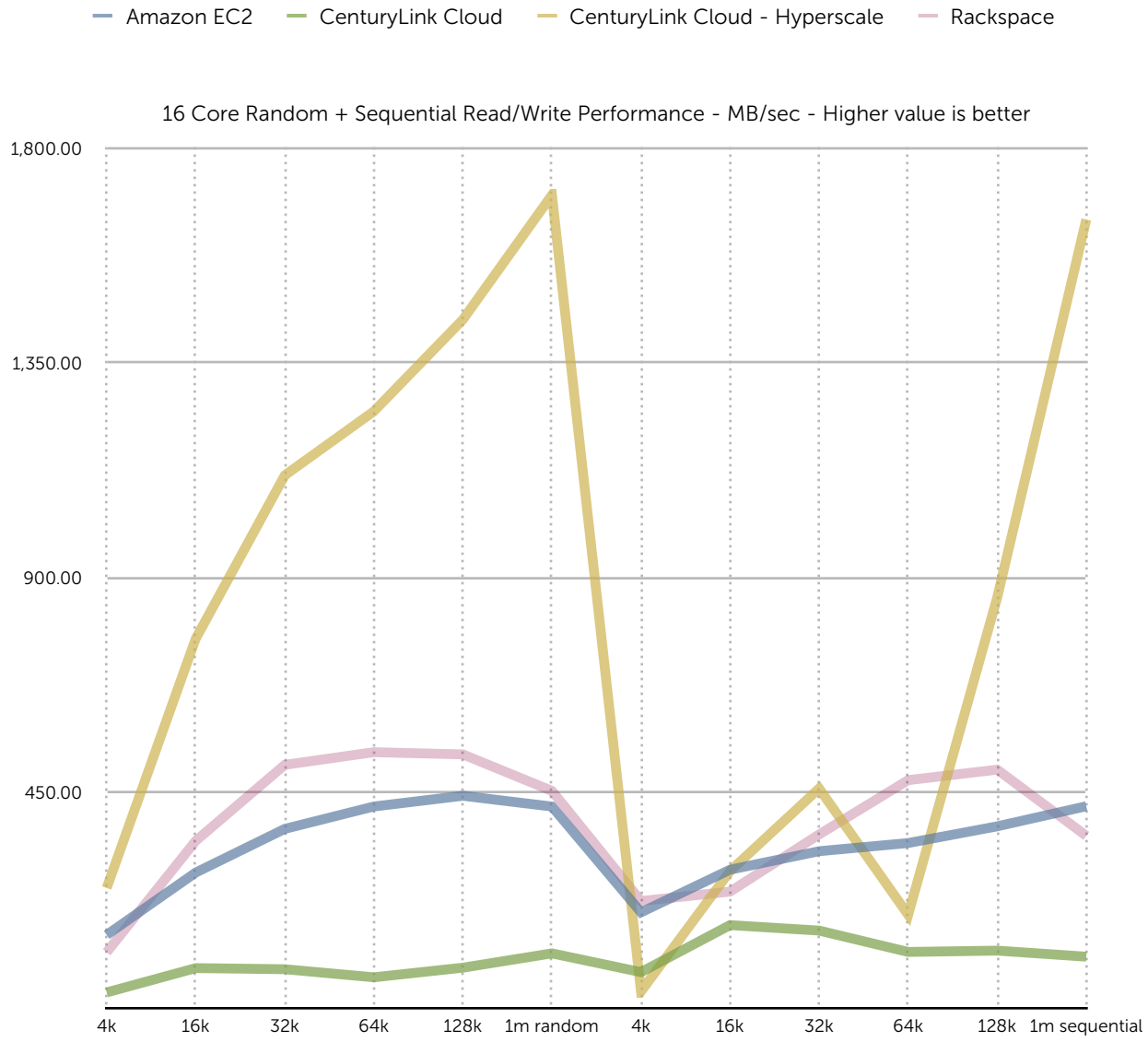
Disk Read/Write Consistency - 8 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	9.99%	20.77%	21.29%	19.53%
16k	8.91%	27.48%	22.51%	20.37%
32k	9.18%	28.10%	20.53%	17.32%
64k	7.88%	34.85%	17.70%	20.45%
128k	7.87%	29.58%	23.25%	6.41%

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	9.88%	33.82%	24.74%	21.09%
4k	9.53%	21.94%	26.75%	40.89%
16k	6.74%	41.88%	62.06%	24.76%
32k	6.70%	35.25%	54.63%	20.23%
64k	5.95%	39.12%	42.12%	19.15%
128k	6.49%	30.67%	37.89%	15.71%
1m sequential	9.58%	33.84%	24.86%	18.65%

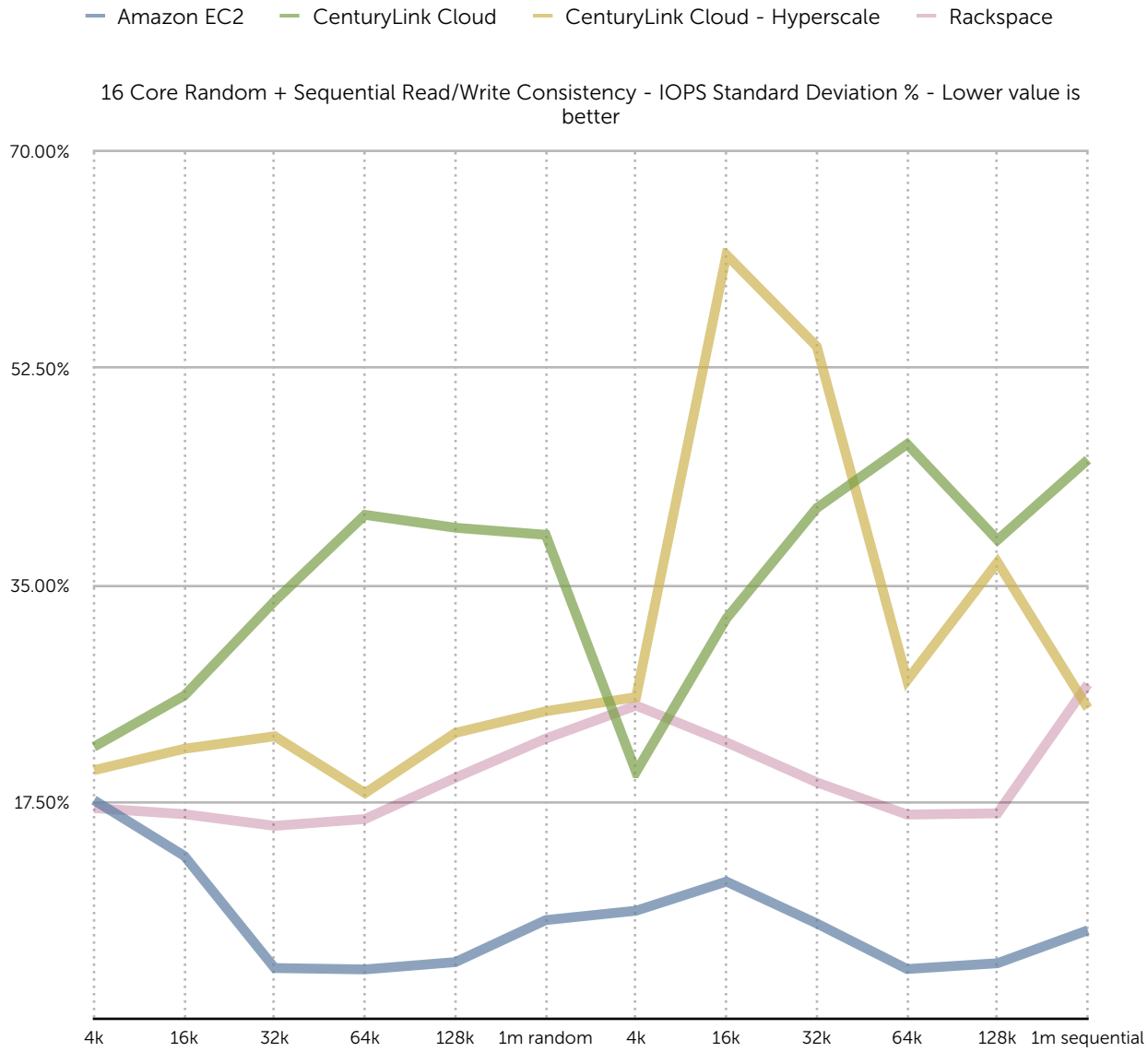
Disk Read/Write Performance - 16 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	151.16	30.63	249.44	114.83
16k	281.75	81.56	771.89	348.19
32k	373.29	79.24	1,114.16	507.48
64k	420.18	62.30	1,248.21	534.02
128k	442.67	82.45	1,440.49	529.35

Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	420.10	112.46	1,701.49	452.98
4k	198.44	73.12	32.73	222.08
16k	287.78	171.68	285.00	241.86
32k	326.52	160.21	457.95	361.58
64k	343.63	115.43	193.22	475.46
128k	378.63	118.20	858.20	497.41
1m sequential	420.73	105.51	1,650.22	358.74

Disk Read/Write Consistency - 16 Core Instance Type



Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
4k	17.65%	21.96%	20.07%	17.01%
16k	13.15%	26.09%	21.80%	16.52%
32k	4.10%	33.72%	22.81%	15.58%
64k	3.99%	40.68%	18.22%	16.13%
128k	4.58%	39.64%	23.08%	19.46%

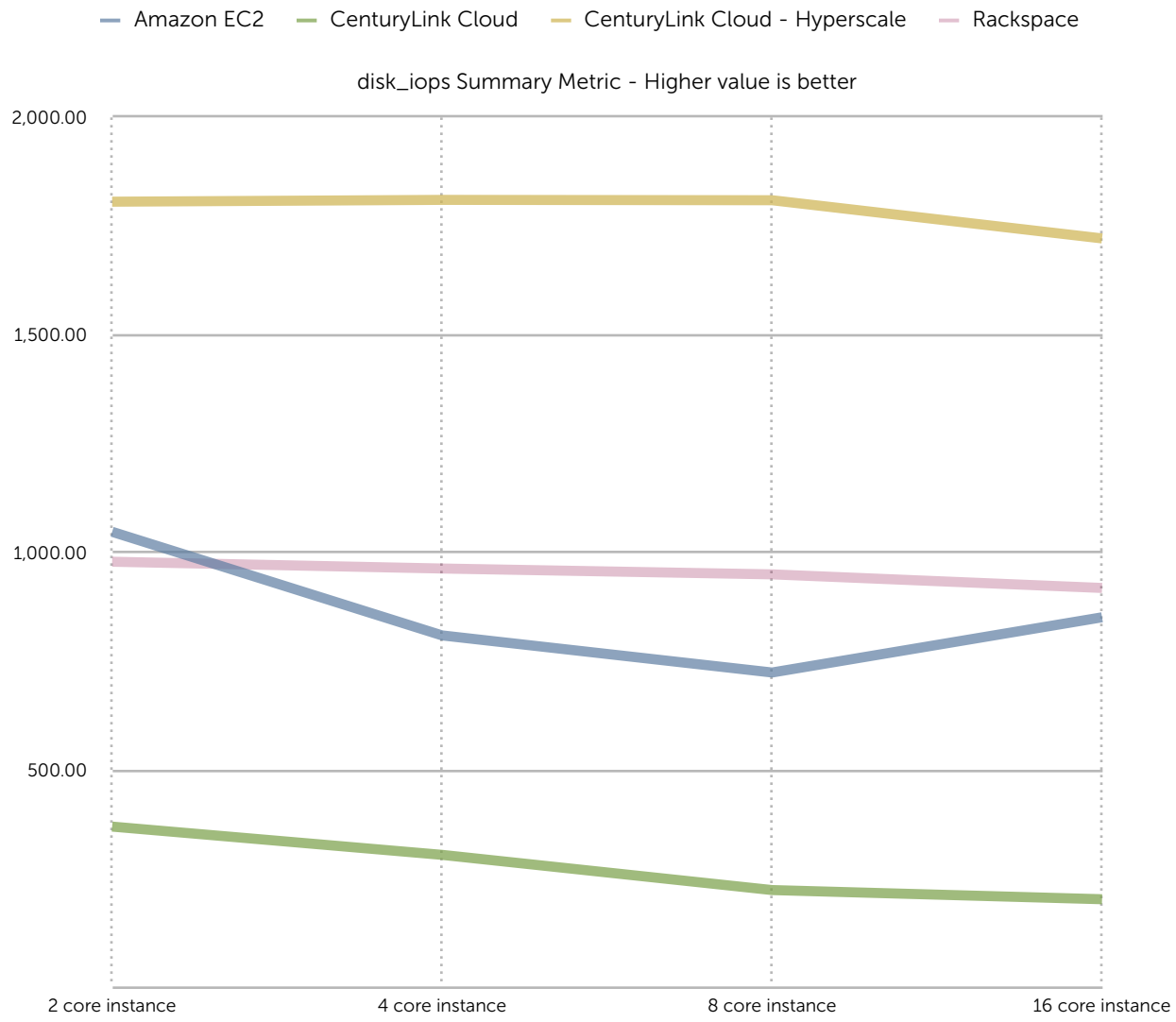
Block Size	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
1m random	7.97%	39.07%	24.83%	22.62%
4k	8.73%	19.93%	25.97%	25.29%
16k	11.08%	32.32%	61.67%	22.32%
32k	7.70%	41.23%	54.27%	19.09%
64k	4.02%	46.39%	27.33%	16.49%
128k	4.49%	38.65%	36.86%	16.59%
1m sequential	7.15%	45.13%	25.08%	27.01%

Disk Performance Summary Metrics

We created 3 summary metrics to represent disk performance. Each of these is derived from the preceding benchmark results convert to ratios relative to the reference system. A total of 36 IO test workloads are included in these metrics including both random and sequential access; read, write and read/write (80/20) workloads; and 4k, 16k, 32k, 64k, 128k and 1m block sizes. The reference system was a bare metal Dell M610 server with a Seagate SAS 2.0 6Gb/s 10K hard drive (model ST9146803SS) dedicated for testing.

Disk IOPS Summary Metric

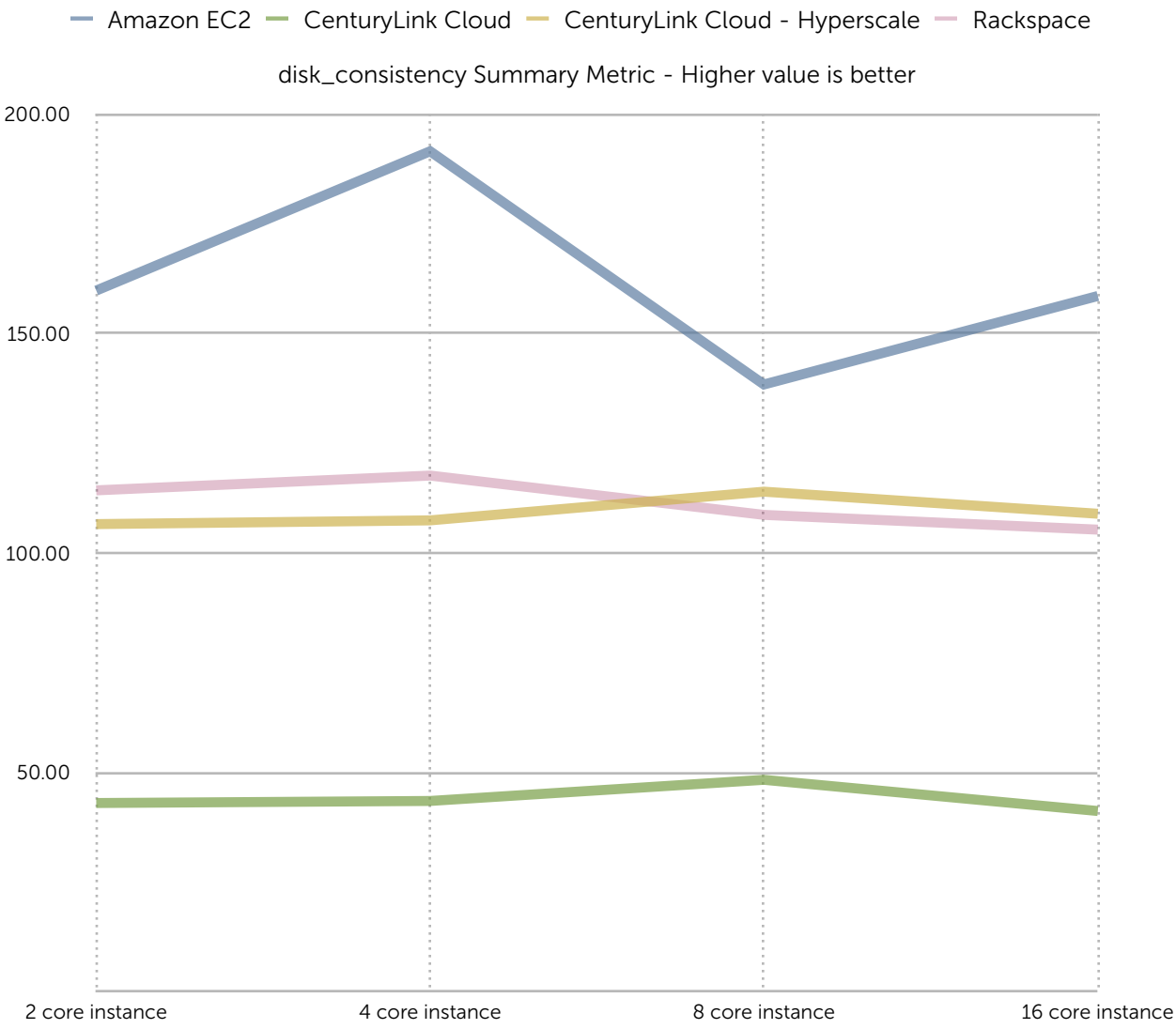
The *disk_iops* summary metric combines disk throughput metrics for 36 IO test workloads. It is derived from the ratio of these metrics relative to the reference system. A value of 100 signifies performance that is nearly comparable to the reference system, greater than 100 better and less than 100 worse.



Instance Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
2 core instance	1,047.30	369.80	1,805.95	978.54
4 core instance	809.18	304.83	1,810.11	962.94
8 core instance	723.93	223.95	1,809.31	949.48
16 core instance	850.82	202.86	1,721.54	918.23

Disk Consistency Summary Metric

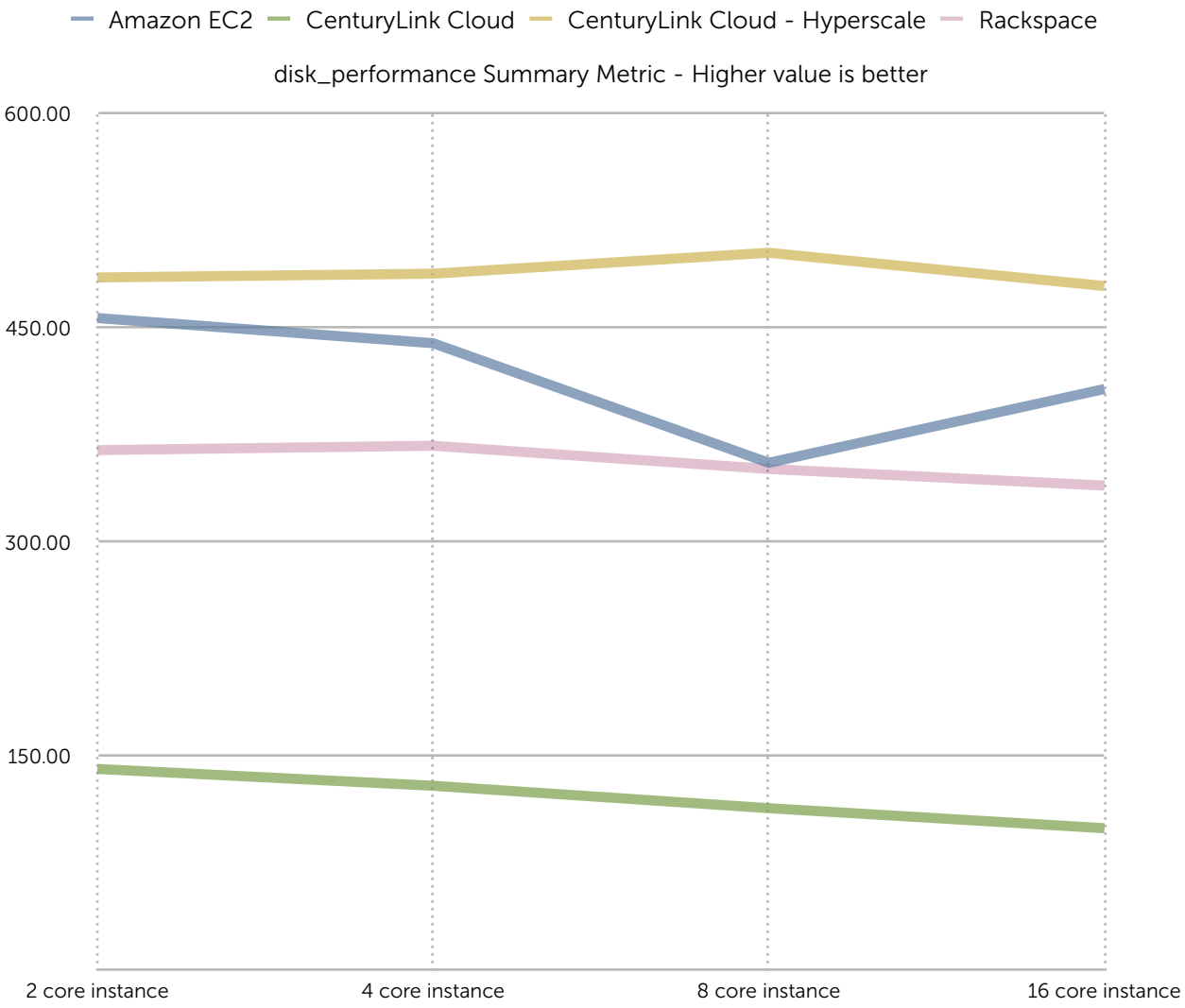
The *disk_consistency* summary metric combines IOPS standard deviation metrics for 36 IO test workloads. It is derived from the ratio of these metrics relative to the reference system. A value of 100 signifies performance that is nearly comparable to the reference system, greater than 100 better and less than 100 worse.



Instance Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
2 core instance	159.80	43.02	106.58	114.27
4 core instance	191.54	43.49	107.43	117.64
8 core instance	138.40	48.31	113.97	108.68
16 core instance	158.56	41.20	108.94	105.32

Disk Performance Summary Metric

The *disk_performance* summary metric combines both throughput and IOPS standard deviation metrics for 36 IO test workloads (a total of 72 ratios). It is derived from the ratio of these metrics relative to the reference system. A value of 100 signifies performance that is nearly comparable to the reference system, greater than 100 better and less than 100 worse.



Instance Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
2 core instance	456.80	141.23	485.16	364.34
4 core instance	439.18	129.44	487.81	367.41
8 core instance	355.48	113.76	502.46	351.15
16 core instance	407.12	99.73	479.19	339.49

Disk Performance Comments

In these test results each compute service demonstrated strengths and weaknesses. Amazon EC2 was the most consistent, but not the fastest. This might be attributed to possible non-use of a Raid controller which can increase IO latencies. Additionally, EC2 disk throughput could likely be improved through operating system managed Raid on the 2 SSD local drives assigned to each c3 instance. CenturyLink Cloud Hyperscale provided significantly faster read throughput compared to the other services due in no small part to its use of Raid using many physical disks. Write throughput was also a top performer but more similar to the other services. IO consistency was consistently lower than Amazon EC2 likely due to Raid overhead. Non-Hyperscale CenturyLink performance performed slower and less predictably than any of the other services. This may be attributed to it being a external, networked storage platform as opposed to local SSD. Rackspace Cloud performance was mixed with read throughput falling slightly above Amazon EC2 while consistency lagged behind.

Memory Performance

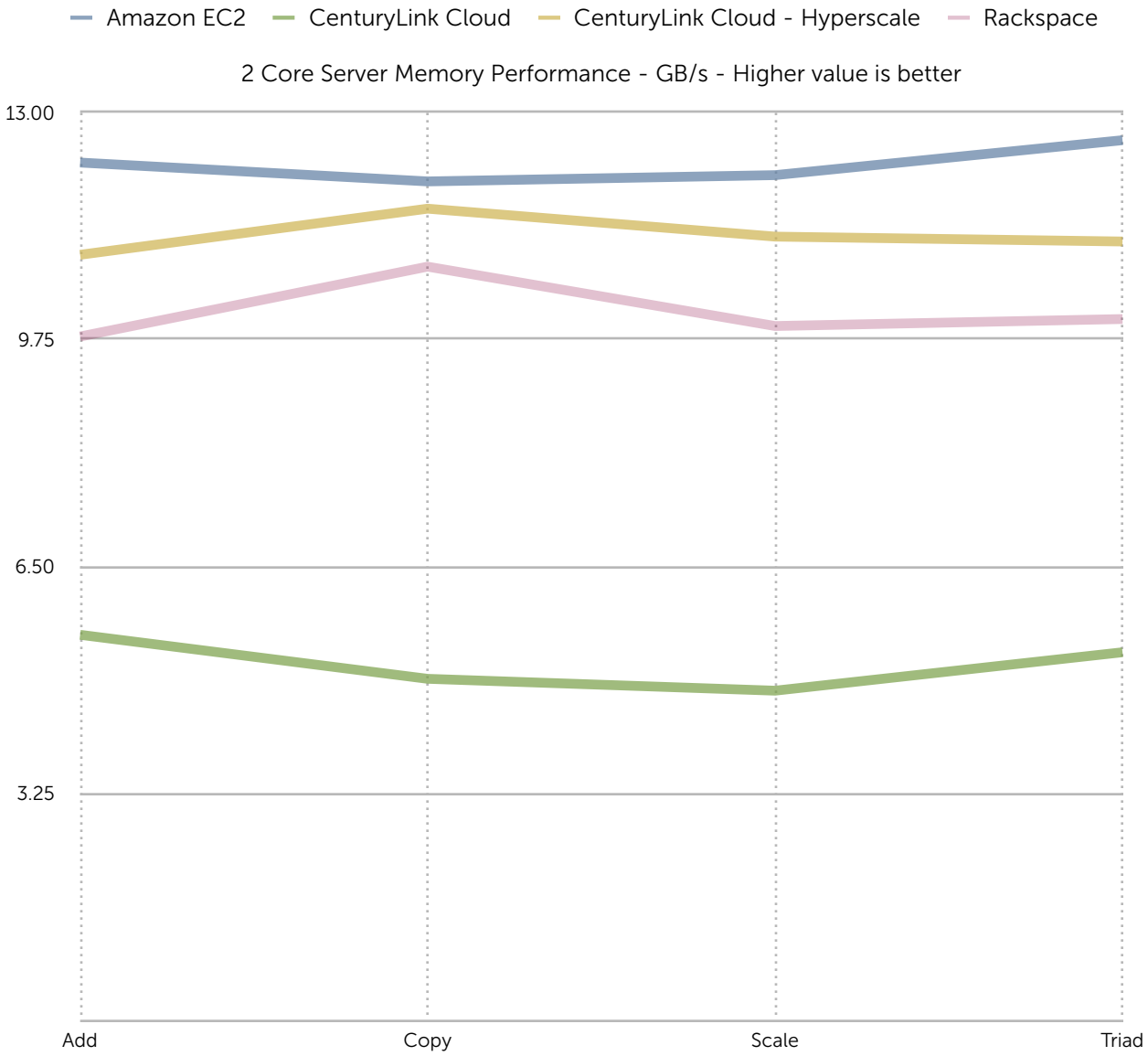
Memory holds data that can be very quickly accessed and updated. Every running application uses and lives in memory, so memory performance affects the performance of all workloads to some extent. It is faster to access data stored in memory than data stored on disk, so memory is often used to optimize disk operations. For example, database servers sometimes use memory to cache queries, or to buffer writes. Newer CPU models often have better memory performance due to faster chipsets and buses.

We used the STREAM benchmark to measure memory performance. STREAM is a simple synthetic benchmark program that measures sustainable memory bandwidth. The STREAM benchmark consists of four tests:

- *Copy* - measures transfer rates in the absence of arithmetic
- *Scale* - adds a simple arithmetic operation
- *Add* - adds a third operand to allow multiple load/store ports on vector machines to be tested
- *Triad* - allows chained/overlapped/fused multiply/add operations

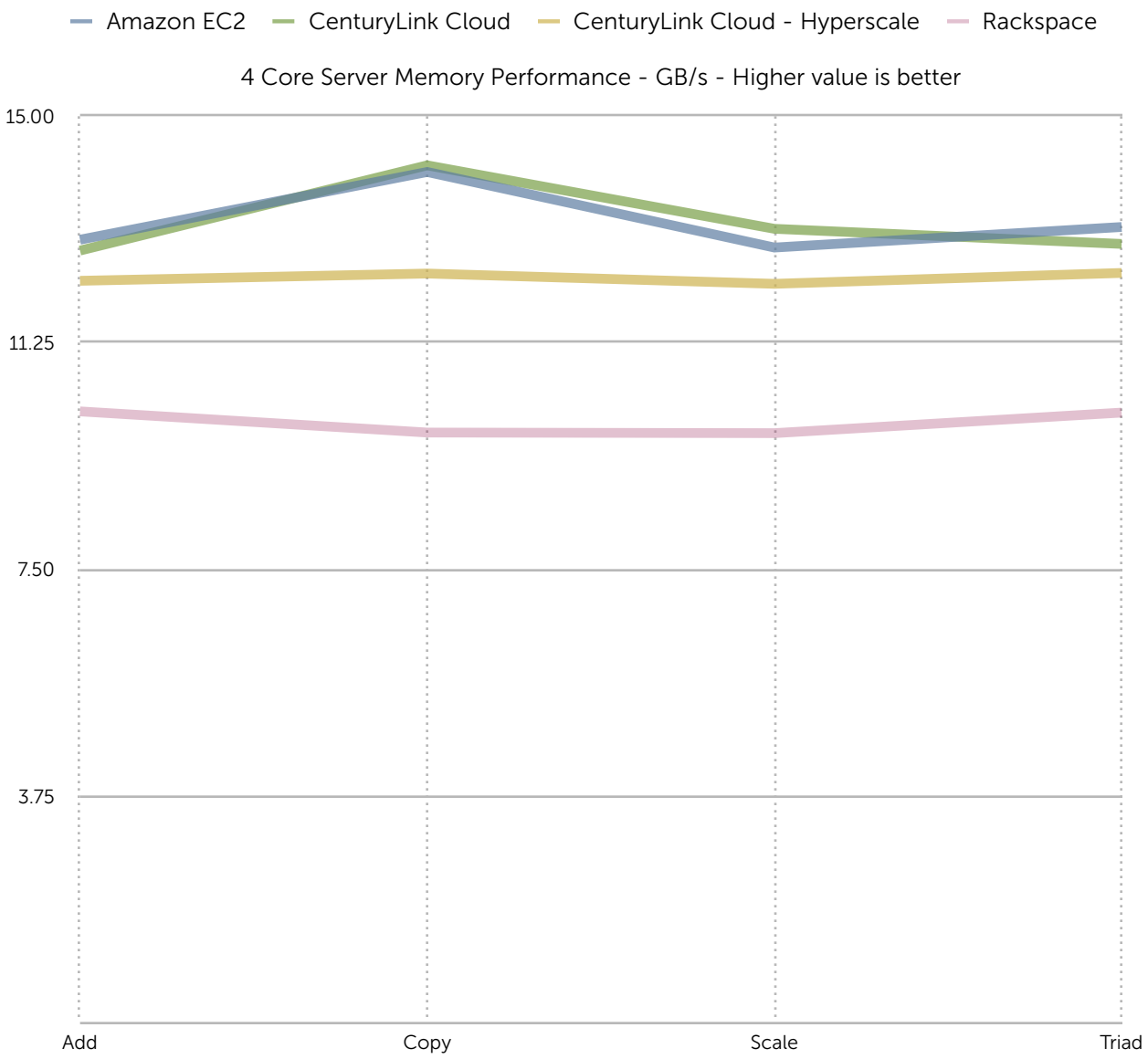
The proceeding results represent sustainable bandwidth for each of these tests in gigabytes per second (GB/s). A higher value represents better performance.

Memory Performance - 2 Core Instance Type



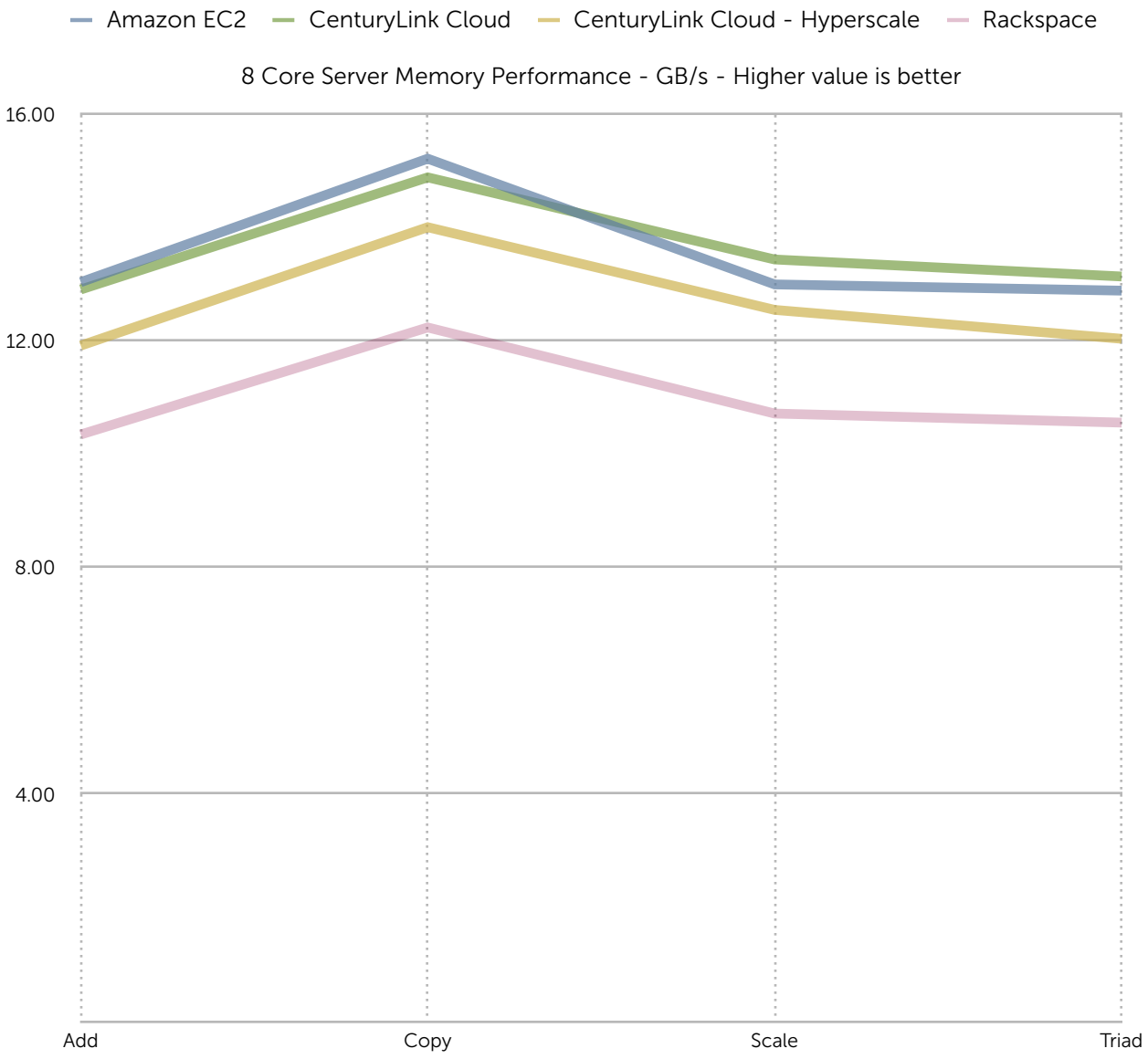
Server Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
Add	12.28	5.52	10.96	9.79
Copy	12.01	4.89	11.62	10.79
Scale	12.10	4.72	11.22	9.94
Triad	12.60	5.27	11.15	10.04

Memory Performance - 4 Core Instance Type



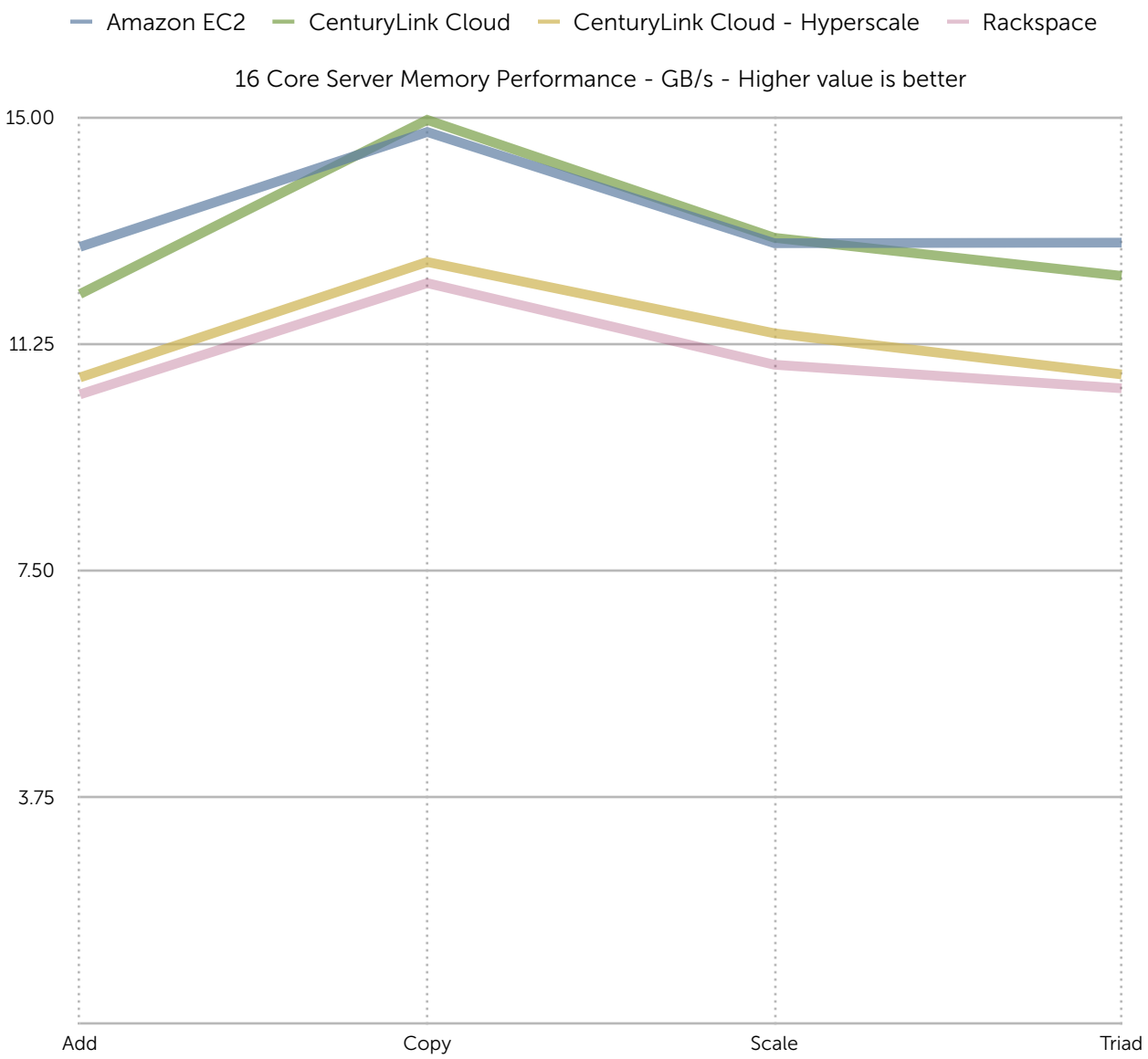
Server Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
Add	12.95	12.77	12.27	10.11
Copy	14.07	14.18	12.39	9.76
Scale	12.82	13.13	12.22	9.75
Triad	13.16	12.88	12.40	10.09

Memory Performance - 8 Core Instance Type



Server Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
Add	13.04	12.91	11.92	10.35
Copy	15.22	14.89	14.01	12.24
Scale	13.00	13.44	12.55	10.72
Triad	12.89	13.14	12.04	10.56

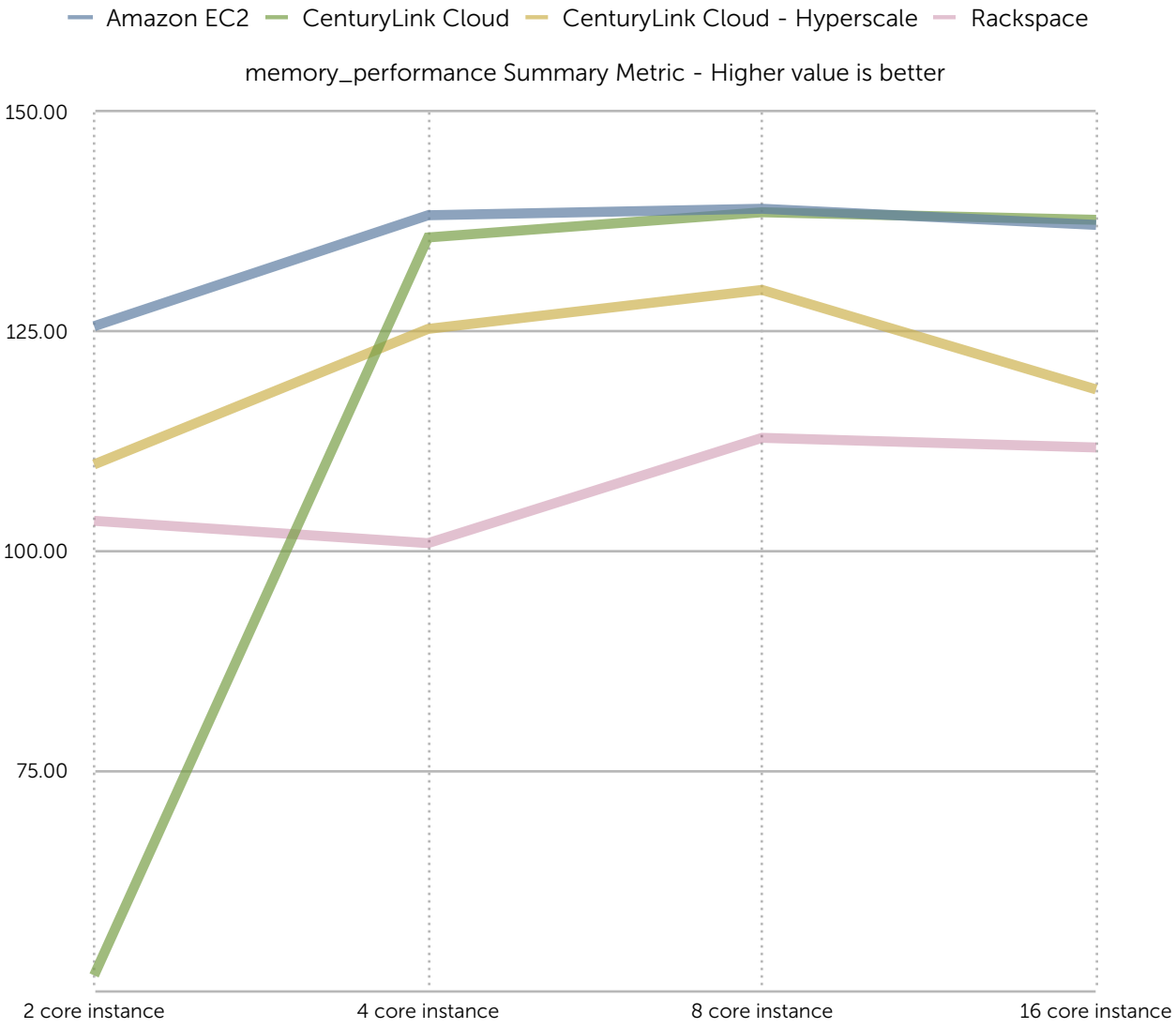
Memory Performance - 16 Core Instance Type



Server Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
Add	12.85	12.07	10.69	10.41
Copy	14.75	14.95	12.60	12.25
Scale	12.91	13.00	11.42	10.90
Triad	12.92	12.37	10.74	10.51

Memory Performance Summary Metric

The *memory_performance* summary metric is based on ratios from all 4 STREAM metrics relative to the reference system. The reference system was a bare metal Dell M610 server with dual X5650 processors and 48GB DDR3-1066 Ram.



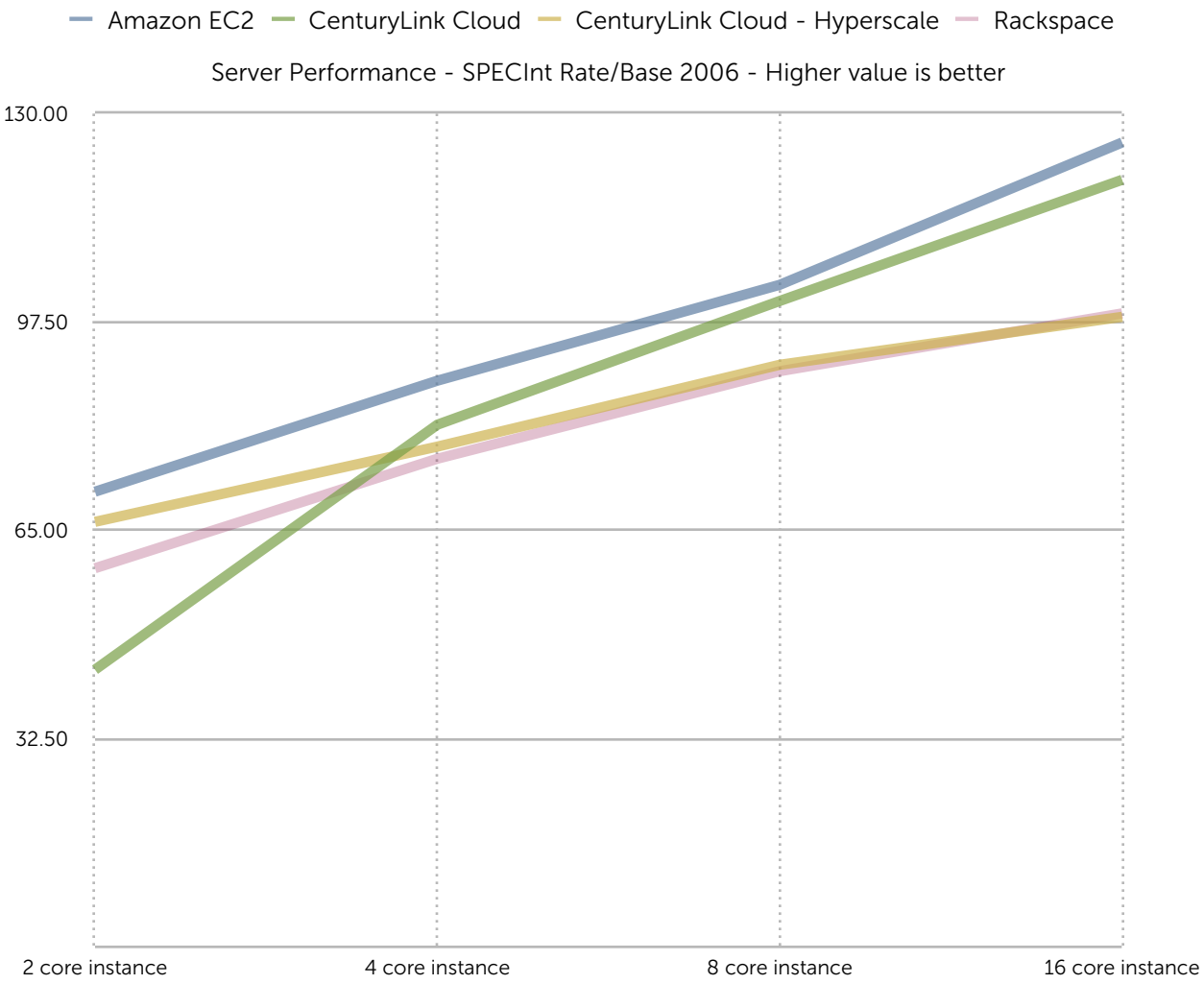
Instance Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
2 core instance	125.62	51.71	109.88	103.46
4 core instance	138.25	135.72	125.31	100.92
8 core instance	138.99	138.59	129.75	112.91
16 core instance	137.15	137.73	118.42	111.81

Memory Performance Comments

All 4 services performed well in this testing. Performance for all was consistently above that of the summary metric reference system. Amazon EC2's use of newer and faster 2.8 GHz Ivy Bridge processors gave it a slight edge over other services, while Rackspace Cloud's use of prior generation Sandy Bridge 2.6 GHz processors caused it to lag slightly behind. CenturyLink Cloud Hyperscale based on newer 2.6 GHz Ivy Bridge processors fell in the middle.

Server Performance Summary Metric

The *server_performance* summary metric is based on ratios from 8 server related benchmarks including SPECjbb 2005, apache, nginx, openssl, pgbench, phpbench, postmark and sqlite. The reference system was a bare metal Dell M610 server with dual X5650 processors and 48GB DDR3-1066 Ram.



Instance Type	Amazon EC2	CenturyLink Cloud	CenturyLink Cloud - Hyperscale	Rackspace
2 core instance	70.97	43.22	66.27	59.04
4 core instance	88.28	81.42	78.00	76.11
8 core instance	103.23	100.71	90.76	89.76
16 core instance	125.42	119.60	98.23	98.77

Server Performance Comments

Because the server performance benchmarks were primarily bound to CPU clock speed and memory throughput, the results generally paralleled those of the *memory_performance* summary metric.

Conclusion

Use of local SSD storage from Amazon EC2, CenturyLink Cloud (Hyperscale) or Rackspace provides the fastest and generally most consistent IO performance available with those services. However, before choosing this option, one should consider some trade offs including provisioning limits (fixed or capped volume sizes), tight coupling to compute instances, fewer features, and often lower durability. Choosing local SSD storage may still be ideal for read only workloads like a web server, or multi-node, fault tolerant applications. Write heavy, single node and mission critical applications like a relational database may not be the best fit for local storage.

Because the infrastructure behind each service is different, performance is likewise varied. The testing conducted during this engagement and analysis presented in this report identifies some of these variances. For example, CenturyLink Hyperscale provided the fastest disk read performance by a notable margin, while Amazon EC2 performed the most consistently in most phases of storage testing. Differences in CPU and memory performance were more subtle and often predictable based on the underlying hardware used by each service.

When choosing a cloud service, there are other factors to consider besides performance. Some of these include price, service ecosystem (other cloud services offered by the same provider), regional presence, support options, advanced features, and provisioning limits to name a few. It is important for users evaluating cloud services to include all relevant factors in the decision making process.