Consideration of OPeNDAP Server 3 with NetCDF files and Climate and Forecast Conventions for Transport of In-situ Observation Data

John Ulmer
Perot Systems Government Services at the National Oceanic and Atmospheric Administration, Coastal Services Center

Robert Cermak
Alaska Ocean Observing System

Vembu Subramanian
College of Marine Science, University of South Florida

James Potemra
University of Hawaii

December 2007

Table of Contents

Introduction to the Data Transport Laboratory (DTL)

The Integrated Ocean Observing System (IOOS) data providers operate in a highly heterogeneous computing environment and follow the Ocean.US Data Management and Communications (DMAC) strategy to enhance interoperability and deliver effective data transport. The "on-the-ground" possibilities for implementing the DMAC transport strategies are broad, and each provider may implement them differently. Consequently, in some cases there are redundant research and development efforts and in others an inability to test and deploy a candidate solution because it is new or different from the existing environment. Further, some candidate solutions are backed by political or cultural camps that advocate for their respective candidates from a narrow perspective. There is a risk that the political and cultural dynamics and resource limitations could cause the adoption of candidates that would not necessarily be the best solution from an information technology (IT) perspective. The DTL seeks to provide a persistent and objective development and testing facility in order to reduce the effects of the political or cultural dynamics and increase an objective community-wide approach to selecting data transport solutions.

To that end, the DTL surveys the community for candidate technologies, assesses their relevance to the Ocean.US DMAC and local and regional data providers, and picks relevant candidates to implement. The implementation of those candidates in the DTL will provide an objective basis for discussion and decision making in the Ocean.US DMAC community.

DTL Project Sequence

The DTL uses a “project” construct to examine technologies relevant to IOOS data transport. Each technology project follows a process that is intended to educate the DTL staff on the technology, produce a reference implementation of the technology, engage external partners to test and critique the technology, and produce a final report. The following is a listing of the general steps that are followed in DTL projects.

1. Select next appropriate project for the DTL according to the Technology Selection Plan.
2. Build the project on the DTL servers and document.
3. While implementing the technology in the DTL, recruit external partners to participate in the testing and critiquing of the project.
4. Also, while implementing the project in the DTL, design and implement a testing approach for the project. To the extent possible, the testing approach should be objective. However, many important dynamics associated with a given project may be quite subjective. For the subjective material, it will be the responsibility of the DTL staff to compile and organize contributions from external partners in an appropriate and productive manner.
5. Provide external partners with testing plan for review and modify as appropriate.
6. Initiate internal and external testing of the DTL project.

7. Coordinate testing and solicit results and commentary from the external partners.
8. Compile results and commentary.
9. Draft report.
10. Fully document the project on the DTL website (*www.csc.noaa.gov/DTL/*) with possible content for the Community Information Repository (*www.csc.noaa.gov/cir/*) and pass on to the IOOS DMAC as appropriate.

DTL Project 1 – OPeNDAP with NetCDF and CF

The first DTL project was the consideration of the OPeNDAP server, version 3, with NetCDF files using the Climate and Forecast (CF) conventions for use with in-situ data in the local and regional arenas. OPeNDAP, or the Open-source Project for a Network Data Access Protocol, has been a significant data-sharing technology in the oceanographic community. Several different implementations of the protocols exist, including the Live Access Server and the THREDDS server. This project used the latest version of the base OPeNDAP server, version three, that was available at the time of the project's start from the main OPeNDAP website (*www.opendap.org*). The data, which were in NetCDF files employing the CF conventions, were harvested from the National Data Buoy Center.

Project Selection

Suggestions for candidate technologies to be implemented in the DTL are accepted from the Integrated Ocean Observing System (IOOS) community. The primary sources for the identification of candidates are the local observatories, regional associations, Ocean.US Data Management and Communications (DMAC) team and its expert teams, and deliberate outreach efforts of the DTL staff, such as meetings and workshops.

Candidate technologies, identified through these mechanisms, are filtered through a set of criteria to assess their relevance and importance to the stakeholders. For more details, read about the DTL technology selection process (*www.csc.noaa.gov/DTL/dtltechselec.html*).

The selection of the OPeNDAP base server with network Common Data Form (NetCDF) data was based on the most recent "Concrete Guidance for Data Providers" (*June 2, 2006*) released by the Ocean.US DMAC. DMAC has not yet released any recommendations for "operational" standards. The strongest recommendation, to date, is for OPeNDAP as a "pre-operational" standard. Also, there is an existing install base of the servers among the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center's local and regional partners. The use of the NetCDF file format for the data repository was based on the widespread use of the format by the OPeNDAP servers in the IOOS community and the format's traditional combination with the OPeNDAP servers. The following table (Table 1) lists the scoring and rationale of that

scoring for the selection of this project. The scores range from a minimum of zero to a maximum of five.

Table 1 – DTL Project Selection Scoring

Criteria	Score	Rationale
Significance to Local Observatories	4	A number of local observatories already employ OPeNDAP servers. While the OPeNDAP servers were developed first for gridded data, they may have significant utility in serving in-situ data at the local level.
Significance to Regional Associations	5	Regional data-collecting facilities will be handling more and heavier data than the local observatories. They will need to be able to aggregate local feeds and then publish the aggregated data sets up to the next level, possibly to the federal backbone. With larger geographic extents and more dense data types, the regional facilities will need efficient services. The DAP2 data model and format may show significant utility in this context.
Relevance to DMAC Guidance	5	The DMAC Data Transport Expert Team categorizes its recommendations as research, pilot, pre-operational, and operational. To date, there are no recommended standards for "operational" technologies. The only recommendation for a pre-operational standard is the DAP2 protocol combined with the Climate and Forecast (CF) conventions. A common implementation of the DAP2 protocol is the OPeNDAP server with NetCDF files.
Relative Maturity of Candidate	4	The base Common Gateway Interface OPeNDAP servers are several years old and benefit from years of use and exercise. The required libraries and applications are available for a variety of common operating systems. Some question remains about the availability of the NetCDF libraries for the Windows operating systems.
Appropriate Level of Effort for DTL	5	The installation and testing of the OPeNDAP servers requires a reasonable and appropriate level of effort from the DTL.
Coincidence of other Center Efforts	0	While there are no active implementations of the OPeNDAP servers at the NOAA Coastal Services Center, there is some use of the NetCDF file format on several Center projects. Other projects are exploring their possible use.
Total Score	23	

Related Links

OPeNDAP Home:	*www.opendap.org*
OPeNDAP FAQs:	*www.opendap.org/faq/index.html*
OPeNDAP Quick Start:	*www.opendap.org/user/quick-html/quick.html*
OPeNDAP Server Installation Guide:	*www.opendap.org/server/install-html/install.html*
OPeNDAP User Guide:	*www.opendap.org/user/guide-html/guide.html*
OPeNDAP Client-Server Architecture:	*www.opendap.org/getStarted/architecture.html*
NetCDF Home:	*www.unidata.ucar.edu/software/netcdf/*
NetCDF FAQs:	*www.unidata.ucar.edu/software/netcdf/docs/faq.html*
NetCDF Installation and Porting Guide:	*www.unidata.ucar.edu/software/netcdf/docs/netcdf-install/*
NetCDF User's Guide:	*www.unidata.ucar.edu/software/netcdf/docs/netcdf/*

Use Case Description

The Ocean.US DMAC calls for a Service Oriented Architecture (SOA) based on open standards. This SOA should be manifested as a limited number of services that provide access to a contributor's data holdings. As the IOOS data exchange standards evolve, it is unlikely that a single unified data model and service description will be produced to handle all data types at the national, regional, and sub-regional layers of the IOOS IT infrastructure. Instead, it is more likely that the IOOS data exchange standards and infrastructure will be an incremental evolution of both competing and complementary standards and technologies. It is the intent of the DTL to foster convergence on a complementary set of standards and infrastructure. Consequently, it is critical that those standards and technologies selected for use in the evolving system present implementers with the greatest possible flexibility and the least risk associated with early adoption.

The DTL focuses on the regional and sub-regional arenas of the IOOS IT architecture. The DMAC asserts that the standards and technologies adopted should do no harm to the data provider or, at least, should do as little harm as possible. This strongly implies that selected solutions should be minimally invasive to the data provider's data management systems. Reviews of candidate standards and technologies should assess the extent to which a data provider's IT systems would have to be modified to implement the candidate and how easily the data provider would be able to respond to the evolving data model.

Specifically, in this project, we are considering the use of the OPeNDAP server with NetCDF data and the CF conventions for the transport of in-situ measured physical and chemical parameters in the local and regional arenas. A general architecture is shown below in Figure 1. This architecture does not preclude or prevent a local observatory or regional (or sub-regional) aggregation facility from making its data available in any other way it deems necessary to serve its mission needs. But, for the purposes of this project, those non-IOOS data users and services are not relevant. Further, the data transport is between machines where the client is a regional aggregation facility in the case of a local observatory or a federal assembly center in the case of a regional aggregation facility.

The regional aggregation facilities are expected to be creatures of the regional associations. This may tend to foster a regional approach to the aggregation behavior. But, beyond that general tendency, considerations of the relationship between a regional association and a regional aggregation facility are beyond the scope of this project.

The primary consumer of the local observatory data services will likely be a regional or sub-regional aggregation facility. The facility's primary function will be to aggregate the local data feeds into consistent temporal and spatial repositories from a regional perspective so that they can be efficiently provided to information product developers and national data centers. The primary consumer of data provided by the regional aggregation centers will be a data mart or some component of the federal backbone.

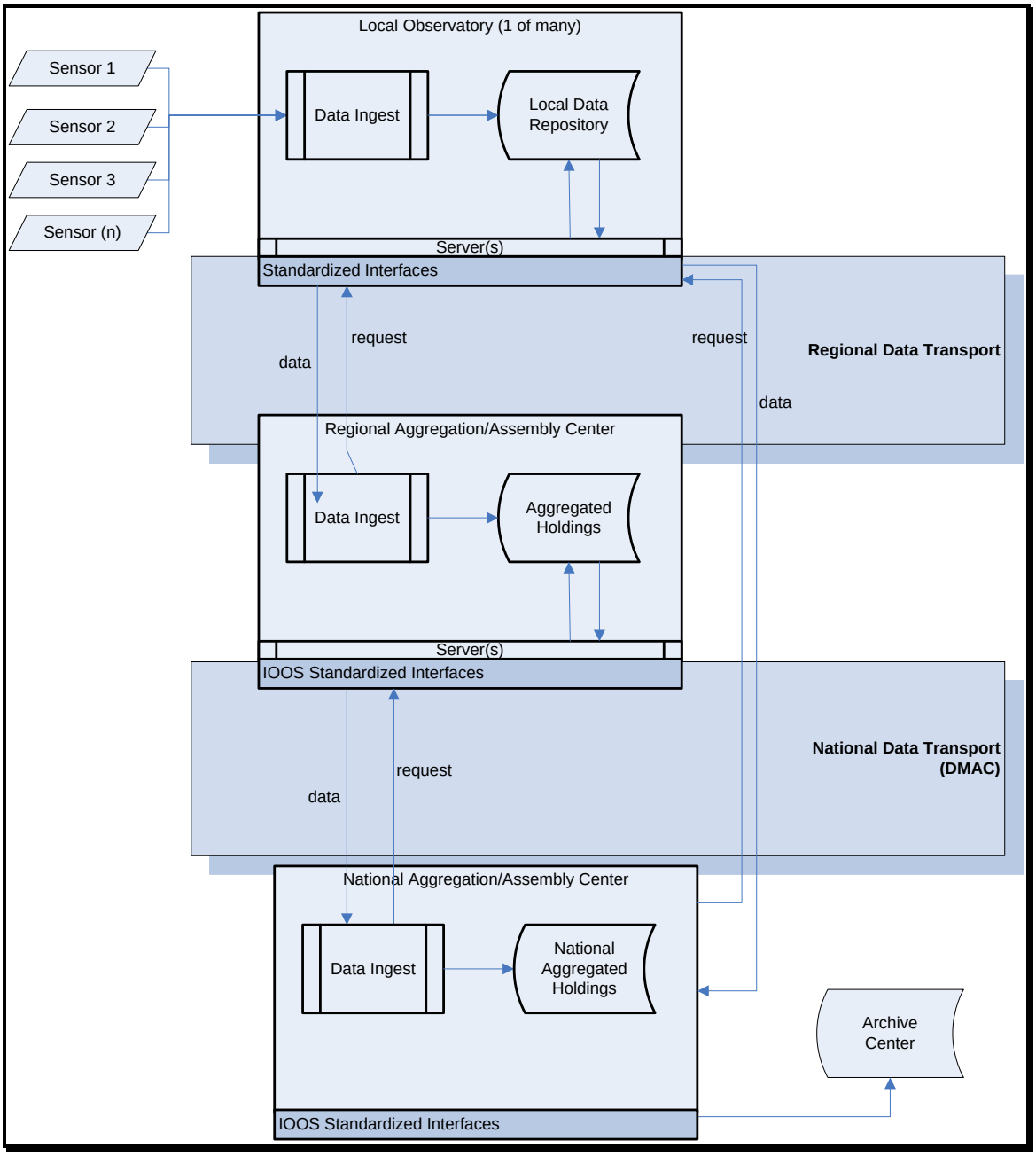


Figure 1 – General SOA for Regional or Sub-regional Data Transport

Reference Implementation

In the DTL, the OPeNDAP and NetCDF software was installed on a Dell PowerEdge 1850 machine with two 3.0 MHz Xeon CPUs, four gigabytes of RAM, 300 gigabytes of

10,000 RPM disks, and Gigabit network cards. The operating system is Red Hat Linux Enterprise 4, kernel 2.6.9-42.

External Partner Server Descriptions

Server Descriptions	Alaska Ocean Observing System (AOOS)	South Florida University (SFU)	University of Hawaii
No. of CPUs	1	2	2
CPU Speed (GHz)	3.2	3.2	3
RAM (GB)	2	4	2
Network Interface	Gigabit Ethernet	Gigabit Ethernet	Gigabit Ethernet
Operating System	Linux	Linux	Linux

Test and Critique Regimen

The DTL staff drafted a testing regimen that the team reviewed and adopted. The DTL coordinated periodic conference calls using WebEx to facilitate planning, scheduling, project execution, and team discussion. Each external partner installed the base OPeNDAP server 3 (the latest available at the start of this project) and configured it to serve NetCDF data. So that the performance testing for each installation would be more directly compared to the others, copies of a single identical NetCDF file were used at each installation and identical queries were issued to each server. As each external partner performed the testing regimen against the other server installations, they sent their performance results to the DTL and to the AOOS partner, who performed simple statistics on the result sets in parallel with the DTL. The DTL and AOOS results were compared to ensure accuracy. Subsequently, the external partners submitted written critiques in response to items 3-15 of the testing regimen (see appendix).

The Apache Project JMeter (*http://jakarta.apache.org/jmeter/*) tool was selected to execute items 1 and 2 of the test plan. JMeter is a graphical desktop Java application that supports a number of query types including HTTP GET and POST, SOAP/XML, JDBC, and others. JMeter facilitates scheduled loading of servers and measures server response time, throughput, and other basic statistics.

Two JMeter tests were designed, a light load plan and a full load plan. Both plans requested 5 days of salinity data from each target server along with time and position attributes. The light load plan was intended to demonstrate the best case performance for each server. It issued one thread that is analogous to a client request and looped on that request for 20 iterations. This allowed each request to complete before the next request was issued. The full load tests were intended to show system performance when multiple concurrent requests were received. The full load test used 100 threads (concurrent users) ramped up in 5 seconds. Each load scheme was run requesting ASCII data and again requesting DODS data objects. Each external partner ran the test plans against all other OPeNDAP servers in the project.

A typical query was:

http://csc-s-ial-p.csc.noaa.gov/cgi-bin/nph-dods.cgi/data/ndbc/netcdf/ocean/41030o9999.nc.ascii?salinity[0:1:54][0:1:0][0:1:0].

A typical ASCII response:

Dataset: 41030o9999.nc
salinity.longitude, -79.34
salinity.salinity[salinity.time=1098543600][salinity.latitude=32.52], 33.42
salinity.salinity[salinity.time=1098550800][salinity.latitude=32.52], 33.42
salinity.salinity[salinity.time=1098558000][salinity.latitude=32.52], 33.48
salinity.salinity[salinity.time=1098565200][salinity.latitude=32.52], 33.53
salinity.salinity[salinity.time=1098572400][salinity.latitude=32.52], 33.55
salinity.salinity[salinity.time=1098579600][salinity.latitude=32.52], 33.47
salinity.salinity[salinity.time=1098586800][salinity.latitude=32.52], 33.53
salinity.salinity[salinity.time=1098594000][salinity.latitude=32.52], 33.65
salinity.salinity[salinity.time=1098608400][salinity.latitude=32.52], 33.76
…… output truncated for brevity……

General Server Performance

Because of the variability in the server hardware and load, the objective server performance measures are intended as general indications of competent performance. They are not intended as benchmarks. All physical servers, both those that were dedicated to the OPeNDAP servers and those that hosted other applications, showed competent performance. Observation data for five days were transferred from the servers to the clients in times that would satisfy typical HTTP clients. The longest light- and full-load ASCII test results were 755 and 3216 milliseconds, respectively. The following tables (Tables 2 and 3) show the results of the light-load and full-load testing sequences.

Table 2 – Light-Load Testing

20 iterations of 1 request

Target / Client	Alaska Ocean Ob. System (AOOS) ASCII	Alaska Ocean Ob. System (AOOS) DataObject	Coastal Services Center (CSC) ASCII	Coastal Services Center (CSC) DataObject	Pacific U of Hawaii Sea Level Center ASCII	Pacific U of Hawaii Sea Level Center DataObject	U of South Florida (USF) ASCII	U of South Florida (USF) DataObject
CSC Run Summary								
Average Request:	755	737	102	82	839	412	513	301
Min. Request:	484	343	93	78	578	406	296	172
Max. Request:	1280	3561	110	94	3782	438	1406	407
Total Time:	15119	14746	2050	1657	16780	8250	10263	6031
AOOS Run Summary								
Average Request:	156	80	647	459	372	264	552	326
Min. Request:	72	63	468	396	359	254	338	325
Max. Request:	887	213	3477	988	405	292	4590	329
Total Time:	3137	1615	12956	9181	7455	5286	11047	6534
Pacific Run Summary								
Average Request:	535	238	731	400	85	346	594	58
Min. Request:	256	237	576	398	79	341	363	55
Max. Request:	4188	253	3597	417	102	421	4956	70
Total Time: 20 requests	10711	4779	14636	8017	1712	6931	11899	1160
USF Run Summary								
Average Request:	443	520	237	188	546	339	96	84
Min. Request:	314	302	233	177	481	337	94	82
Max. Request:	593	4635	262	299	1732	343	100	86
Total Time:	8873	10411	4746	3774	10931	6781	1921	1691

Table 3 – Full-Load Testing

100 concurrent requests ramped up in 5 seconds.

Target / Client	Alaska Ocean Ob. System (AOOS)		Coastal Services Center (CSC)		Pacific University of Hawaii Sea Level Center		U of South Florida (USF)	
	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
CSC Run Summary								
Average Request:	2688	1231	107	78	609	414	600	288
Min. Request:	469	438	93	78	593	406	359	188
Max. Request:	6811	10966	125	94	797	469	3531	406
Total Time:	268856	123109	10743	7834	60966	41486	60075	28801
AOOS Summary								
Average Request:	3216	1820	489	707	371	264	342	329
Min. Request:	322	901	411	405	360	253	339	326
Max. Request:	5782	3015	907	2323	443	398	351	342
Total Time:	321622	182039	48980	70777	37100	26483	34283	32993
Pacific Summary								
Average Request:	1304	382	593	405	102	61	374	349
Min. Request:	357	238	580	397	81	56	364	341
Max. Request:	3221	1174	651	491	196	133	419	481
Total Time:	130468	38295	59376	40521	10299	6114	37470	34999
USF Summary								
Average Request:	1910	1239	362	192	492	343	224	122
Min. Request:	443	380	237	177	485	339	119	100
Max. Request:	8226	3558	490	275	518	352	1339	160
Total Time:	191076	123909	36246	19253	49260	34397	22438	12203

Findings

The following findings are a compilation of the DTL staff and external partner responses to items three through fifteen of the testing plan (see Appendix A). All references to OPeNDAP servers in these findings are relevant to server version 3 unless specifically noted.

Relative Ease or Difficulty of Installation of Server Software and Supporting Libraries

The project partners found the OPenDAP servers and NetCDF libraries easy to install, configure, and maintain. OPenDAP server 3 is a Common Gateway Interface (CGI) web Web application that operates, as any other CGI application would, within the context of an HTTP server configured to host such applications. The DTL staff was unable, at the start of this project, to identify a Windows port of the NetCDF libraries. Several references were found using Internet search engines to efforts to produce a Windows port, but no ports were found. Consequently, no Windows implementation of the OPeNDAP NetCDF server was possible.

Relative Ease or Difficulty of Modification in the Event of Evolving Data Models and Standards and Degree of Intrusiveness of the Transport Layer into the Data Storage Facility

As noted in the use case description above, the IOOS data transport is immature and evolving. A standards process has yet to be implemented to rigorously consider candidate technologies and data models for adoption and use in IOOS. Consequently, as development of IOOS progresses, there is potential for significant change in the nascent data models and conventions. Additionally, the local and regional contributors to the IOOS have primary local missions that are pursued with limited resources. The cost of participation in the Ocean.US DMAC development and implementation must be minimized. Further, the risks associated with early adoption of DMAC-related technologies must be minimized. It is the opinion of the DTL that these dynamics are best managed through the employment of a standards-based Service Oriented Architecture that specifies a service interface to local data holdings and, to the extent possible, refrains from forcing changes in a local observatory's data management infrastructure and processes. This approach requires that the service interface be flexible and extendible without requiring modification of the data provider's holdings.

The OPeNDAP servers are tightly coupled to the underlying data structure and semantics. While the employment of the NetCDF file format and the CF conventions facilitate some interoperability, the tight binding of the data service to the data storage restricts the server's ability to evolve with the expected changing data model and transport or application schema. As the data models evolve, the underlying data store will have to continuously evolve. The local data contributor is faced with the need to either modify or duplicate their holdings in order to serve data in a compliant manner. Since the DMAC

documents espouse a philosophy of doing no harm to the data provider, the recommended technologies should be minimally intrusive or invasive to the provider's IT architecture.

This contrasts with the employment of a Relational Database Management System (RDBMS) as the storage environment with an associated service layer. The tools available in modern RDBMS's, combined with the relative ease of producing different output forms or schemas via a Web service, allow for a very flexible service layer with minimal need to modify the underlying data. Figure 2 illustrates this contrast between services that are tightly bound to the underlying data storage mechanism and those that are more loosely bound.

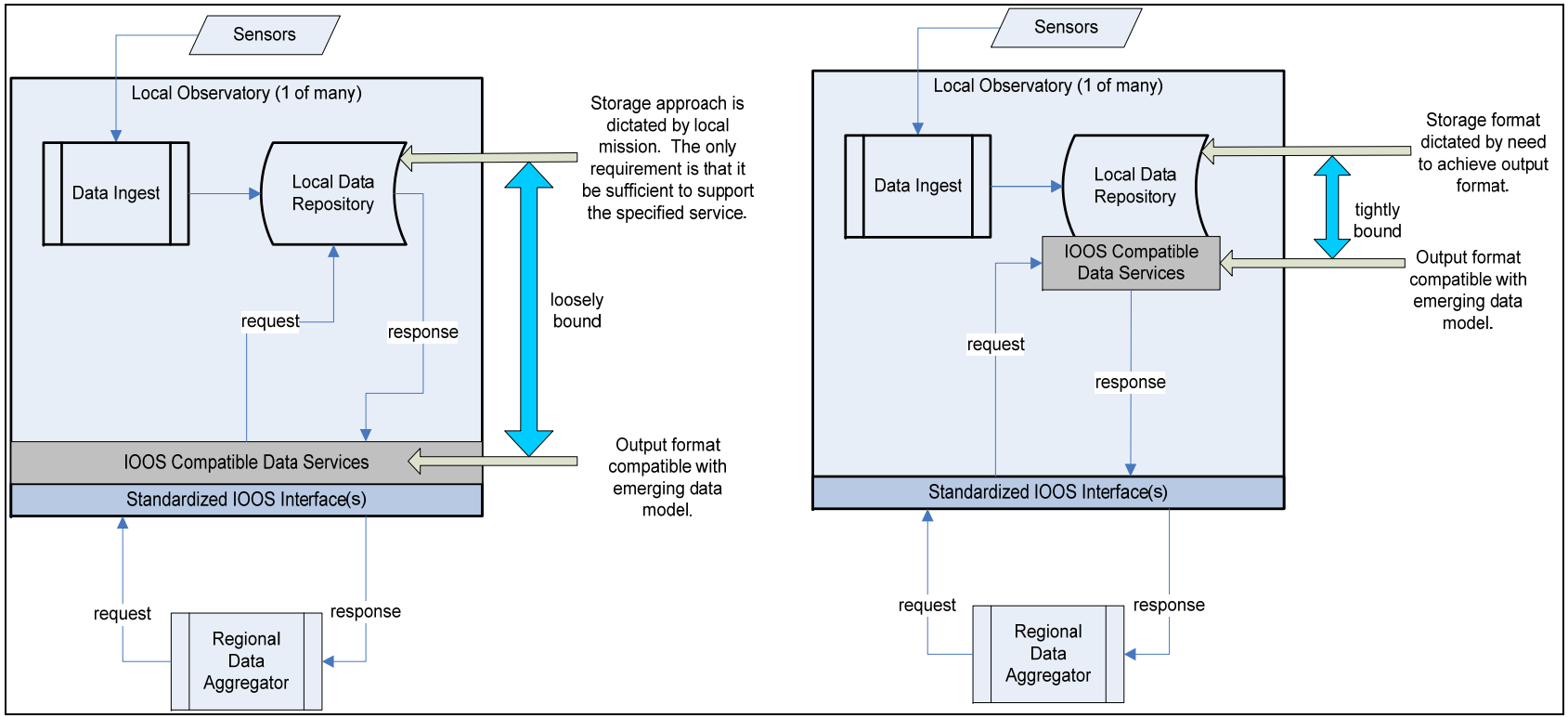


Figure 2 – Service Layers Tightly and Loosely Bound to Data Storage

Cost of Server Implementation

The cost of hosting the application was minimal where other CGI applications or the capacity to host them already existed. The NetCDF libraries were available in binary or source forms and were installed or built using typical tools and methods.

Cost of Client Implementations

Like previous OPeNDAP server versions, version 3 provides an HTML query interface that facilitates the construction of the client query. The HTML query interface supports the request of either an ASCII response or a DODS data object, a binary data bundle conforming to the Data Access Protocol specifications. The query URL created in the HTML interface can be used to make a data request from within any client that is capable of making an HTTP request (e.g., Microsoft Excel). Also, a number of client libraries are available for popular data-processing packages such as IDL and Matlab. These client libraries often provide a rich query capability from within the data-processing software package. A list of clients is available from the OPeNDAP project at *www.opendap.org/faq/whatClients.html*.

Support for Server Technology in the IOOS
Support for Server Technology in the Wider IT Community

The OPeNDAP project and protocol grew out of the oceanographic community. Consequently, the OPeNDAP project servers and protocols are common within the oceanographic community. However, outside that community there is far less knowledge or use of the protocol and servers. Within the oceanographic community are several active development efforts pursuing OPeNDAP server and client development. Also, the Ocean.US Data Management and Communications Expert Team has identified OPeNDAP as a preoperational technology for the emerging IOOS data transport infrastructure.

OPeNDAP servers and clients continue to be actively developed by several projects. Those projects include but are not limited to the OPeNDAP project (*www.opendap.org*), which has released version 4, the THREDDS server *www.unidata.ucar.edu/projects/THREDDS/*), the GrADS (*www.iges.org/grads/*), Ferret *(www.ferret.noaa.gov/Ferret/FDS/*), and the DAPPER project (*www.epic.noaa.gov/epic/software/dapper/*).

Availability of or Support for Development of Clients in the IOOS Community
Availability of or Support for Development of Clients in the IT Community

In its simplest use, the OPeNDAP server is an HTTP application. As noted previously, any application capable of issuing an HTTP request can access data served by OPeNDAP version 3 servers. Further, there is continued development of Application Programming Interfaces (APIs) and extensions to other data-processing software packages. See the OPeNDAP website for list of supported clients.

Relative Ease of Use with Conventional or Popular Client Package(s)

As the OPeNDAP protocol operates within an HTTP context, any application that can issue an HTTP request can make an OPeNDAP data request. Those clients that cannot parse the DODS data objects can request data in ASCII form. Those clients for which there are OPeNDAP client libraries available can request DODS data objects and easily integrate the data response into their work.

Degree to Which the Technology Supports IOOS Data Exchange Needs – Throughput

The OPeNDAP servers facilitate server-side sub-setting of the data sets. This is preferable over file-transfer-based options because it enables the client to request a smaller data bundle from within what might be a very large data set. Also, the OPeNDAP protocol bundles the data transfer in a binary form, unless ASCII data are requested, further minimizing the size of the data response. As shown in the server performance tests, the servers performed well in the HTTP environment.

Support IOOS Data Exchange Needs – Ease of Use

As noted previously, the OPeNDAP servers work well to deliver ASCII to any HTTP client and work within the normal user environment for those data-processing packages for which the client libraries are available. It should be noted that the construction of an OPeNDAP request string is not trivial. Since an OPeNDAP server presents the user with the structure and semantics of the underlying data, the user must either have some knowledge of those data or have the ability to research the structure and semantics of the data. The OPeNDAP servers present basic information about the structure and semantics via their .das and .dds responses. However, there remains substantial opportunity for the data, and consequently the server, to neglect the clear expression of the data model, making parsing and integrating the data difficult. The employment of the CF conventions ameliorates this problem somewhat. However, as noted above, this approach requires implementation of these conventions within the data storage facility instead of in the service layer.

Support IOOS Data Exchange Needs – Discovery

OPeNDAP servers are not intended as registries of services or data streams. They present the user with information about the content of the data served by a server. Consequently, “discovery” is not relevant. As is true in any Service Oriented Architecture, the widespread use of a service like OPeNDAP servers will require the implementation of a service registry containing metadata describing those services. That is beyond the intent or function of the OPeNDAP server 3.

Support IOOS Data Exchange Needs – Scalability and Extendibility

OPeNDAP server 3 (and likely 4) is scalable through the use of HTTP server management. It is extendible through the manipulation of the underlying data holdings. As described above, the requirement that the underlying data be modified to produce different output is problematic.

Support IOOS Data Exchange Needs – Security

There is concern about the provisioning of privately owned or otherwise controlled data in the IOOS infrastructure. It is expected that the use of Secure Socket Layer technology could be used to secure sensitive data. However, those concerns are beyond the scope of this project.

In April of 2007, a security vulnerability was identified in the OPeNDAP server 3 application, and several servers were compromised. The NOAA Computer Incident Response Team (CIRT) issued guidance recommending that all version 3 servers be taken off-line. The OPeNDAP project rapidly produced a patch and notified all known OPeNDAP server hosts. To date, the NOAA CIRT has not lifted the recommendation to remove or disable all version 3 servers. Also, in response to this incident, the OPeNDAP project created a formal team to address security issues in the software and has acquired training and certification for OPeNDAP project staff members. For more information, see the OPeNDAP webpages.

Support IOOS Data Exchange Needs – Metadata Access

Substantial ongoing efforts by the Federal Geographic Data Committee (FGDC) and the International Standards Organization (ISO) have produced specifications for the structure and semantics of metadata. The ability to determine whether a given data set is appropriate for use in a given context or product is critical. OPeNDAP server 3 presents the client with the content of the underlying NetCDF files. To the extent that those files contain or refer to their associated metadata, the OPeNDAP server makes that metadata available. To date, there is no widely adopted convention for the referencing of metadata from within a NetCDF file.

OPeNDAP servers provide two low-level descriptions (metadata) of their underlying data sets, which are the Data Attribute and Data Descriptor services. The Data Attribute service returns a text file describing the attributes of each data quantity in that data set. The Data Descriptor service returns a text file describing the structure of the variables in the data set. These services are useful in determining the variables and structure in data but are insufficient to identify the appropriate or inappropriate use of the data.

Support IOOS Data Exchange Needs – Mission Critical Reliability

Basic testing and use in the DTL and wide use of the OPeNDAP servers over years in the community have shown the servers to be dependable in accurately returning the requested data.

Recommendations

The issues identified in the OPeNDAP protocol and server version 3 were related to a lack of flexibility in supporting a changing data model and server and network security. To address these issues, the DTL makes the following recommendations:

1. Encourage OPeNDAP development efforts to incorporate in their designs the functionality to map the data structure(s) found in the source data to an output schema that will follow the evolving data model(s).

2. Continue to support the development and rigorous implementation of the formal approach to managing security in the design and development of OPeNDAP software.

3. Support the development of data models for in-situ observation data.

4. Support the exploration and development of Representational State Transfer (REST) and Simple Object Access Protocol (SOAP) XML-based services for the transport of physical and chemical in-situ observation data, specifically the Open Geospatial Consortium Web Feature Service and other more generic SOAP/XML approaches. The viability of these approaches is demonstrated in several projects, including the OOSTethys project (*www.oostethys.org*) and the NOAA Coastal Services Center DTL Project 4 – Transporting Time Series Observation Data with the Geography Markup Language and Its Simple Feature Profile via a Simple Web Feature Service (*www.csc.noaa.gov/DTL/dtl_proj4_gmlsfp_wfs.html*).

Appendixes

Appendix A: Testing and Critique Plan

1. Light Load Request Response Time for a single request via Apache JMeter. Repeat 10 Iterations and record each. Calculate average, maximum, and minimum response times. The DTL designed a basic JMeter test plan that was refined and used by the DTL and the external partners to load each other's servers.
2. Heavy Load Request Response Time via Apache JMeter. The definition of heavy load will be case specific. In general, the test should load the server to the point that requests are queued at the server. Repeat 200 iterations and record each. Calc average, max, and min. NOAA Coastal Services Center will design a basic JMeter test plan that can be refined for each project and implemented.
3. Relative ease or difficulty of installation of server software
4. Relative ease or difficulty of installing and configuring any supporting software or libraries.
5. Relative ease or difficulty of modification in the event of evolving data models and standards.
6. Degree of intrusiveness of the transport layer into the data storage facility
7. Cost of server implementation (infrastructure and human resources)
8. Cost of client implementations (infrastructure and human resources)
9. Support for server technology in the IOOS community (e.g., continued development, documentation, and user support)
10. Support for server technology in the wider IT community(e.g., continued development, documentation, and user support)
11. Availability of or support for development of clients in the IOOS community
12. Availability of or support for development of clients in the IT community
13. Relative ease of use with conventional or popular client package(s).
14. Degree to which the technology supports IOOS data exchange needs for
    a. Throughput
    b. Ease of Use
    c. Discovery
    d. Scalability
    e. Extendibility
    f. Security – as related to the IT perspective on server security. There is concern about the provisioning of privately owned data in the IOOS infrastructure, but those concerns are beyond the scope of this project.
    g. Metadata Access to determine appropriate use contexts for a given data source. Can you determine via the available methods whether a given data stream provides data that are adequate for your needs? Is there any QC information or metadata? If not, does the technology lend itself to being extended to handle such information?
    h. Mission Critical Reliability
15. Data integrity (transactions, error checking missing/redundant/out of range data).

Appendix B: Server Performance Data

Summary of LIGHT-LOAD TESTS – *20 iterations of 1 request*

Target	Alaska Ocean Ob. System (AOOS)		Coastal Services Center (CSC)		Pacific University of Hawaii Sea Level Center		U of South Florida (USF)	
Client	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
CSC Run Summary								
Average Request:	755	737	102	82	839	412	513	301
Min. Request:	484	343	93	78	578	406	296	172
Max. Request:	1280	3561	110	94	3782	438	1406	407
Total Time:	15119	14746	2050	1657	16780	8250	10263	6031
AOOS Run Summary								
Average Request:	156	80	647	459	372	264	552	326
Min. Request:	72	63	468	396	359	254	338	325
Max. Request:	887	213	3477	988	405	292	4590	329
Total Time:	3137	1615	12956	9181	7455	5286	11047	6534
Pacific Run Summary								
Average Request:	535	238	731	400	85	346	594	58
Min. Request:	256	237	576	398	79	341	363	55
Max. Request:	4188	253	3597	417	102	421	4956	70
Total Time: 20 requests	10711	4779	14636	8017	1712	6931	11899	1160
USF Run Summary								
Average Request:	443	520	237	188	546	339	96	84
Min. Request:	314	302	233	177	481	337	94	82
Max. Request:	593	4635	262	299	1732	343	100	86
Total Time:	8873	10411	4746	3774	10931	6781	1921	1691

Summary of FULL-LOAD Results – *100 concurrent requests ramped up in 5 seconds*

Target / Client	Alaska Ocean Observing System (AOOS)		Coastal Services Center (CSC)		Pacific University of Hawaii Sea Level Center		U of South Florida (USF)	
	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
CSC Run Summary								
Average Request:	2688	1231	107	78	609	414	600	288
Min. Request:	469	438	93	78	593	406	359	188
Max. Request:	6811	10966	125	94	797	469	3531	406
Total Time:	268856	123109	10743	7834	60966	41486	60075	28801
AOOS Run Summary								
Average Request:	3216	1820	489	707	371	264	342	329
Min. Request:	322	901	411	405	360	253	339	326
Max. Request:	5782	3015	907	2323	443	398	351	342
Total Time:	321622	182039	48980	70777	37100	26483	34283	32993
Pacific Run Summary								
Average Request:	1304	382	593	405	102	61	374	349
Min. Request:	357	238	580	397	81	56	364	341
Max. Request:	3221	1174	651	491	196	133	419	481
Total Time:	130468	38295	59376	40521	10299	6114	37470	34999
USF Run Summary								
Average Request:	1910	1239	362	192	492	343	224	122
Min. Request:	443	380	237	177	485	339	119	100
Max. Request:	8226	3558	490	275	518	352	1339	160
Total Time:	191076	123909	36246	19253	49260	34397	22438	12203

Coastal Services Center (CSC) Light-Load Test (20 iterations of a single request)

All times reported in milliseconds

Average Request:	755	737	102	82	839	412	513	301
Min. Request:	484	343	93	78	578	406	296	172
Max. Request:	1280	3561	110	94	3782	438	1406	407
Total Time:	15119	14746	2050	1657	16780	8250	10263	6031

Target	AOOS		CSC		Pacific		USF	
Request Number	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
1	1280	547	109	79	1109	406	1406	250
2	859	594	94	93	656	406	640	265
3	860	609	94	79	3782	422	641	266
4	1156	1203	110	78	797	406	702	265
5	1218	3561	109	94	843	407	437	266
6	1000	688	110	78	672	422	344	281
7	1187	500	94	78	687	406	375	297
8	562	516	94	78	719	407	375	297
9	609	531	109	78	781	406	421	328
10	609	594	94	94	703	406	422	328
11	750	609	93	78	594	406	438	328
12	594	562	94	94	609	438	453	313
13	625	703	110	78	594	421	484	328
14	640	593	110	78	578	422	546	407
15	484	578	110	94	594	407	532	312
16	625	437	110	78	609	421	563	390
17	484	391	94	78	610	407	516	375
18	484	343	109	78	609	406	296	391
19	531	656	94	78	641	422	313	172
20	562	531	109	94	593	406	359	172

Coastal Services Center (CSC) Full-Load Test (100 requests, ramped to full load in 10 secs)

All times reported in milliseconds

Average Request:	2688	1231	107	78	609	414	600	288
Min. Request:	469	438	93	78	593	406	359	188
Max. Request:	6811	10966	125	94	797	469	3531	406
Total Time:	268856	123109	10743	7834	60966	41486	60075	28801

Target	AOOS		CSC		Pacific University of Hawaii Sea Level Center		USF	
Request Number	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
1	469	438	94	94	594	422	624	203
2	531	484	109	79	594	406	610	234
3	593	484	109	79	610	406	610	250
4	562	578	109	78	610	406	578	250
5	703	547	109	78	609	406	547	234
6	875	656	109	78	594	407	499	234
7	1187	532	110	78	594	453	516	219
8	1016	562	110	78	594	407	516	219
9	999	562	109	79	610	407	546	218
10	953	859	109	79	625	406	469	265
11	890	1312	109	78	609	406	656	282
12	1125	672	110	78	610	453	578	281
13	968	624	110	78	610	407	484	265
14	1266	578	110	78	625	407	375	234
15	1187	1234	110	78	609	422	468	218
16	1156	578	109	79	609	406	375	234
17	1094	844	94	78	625	406	359	249
18	1109	610	109	78	656	422	374	250
19	1124	609	109	78	609	422	421	235
20	1405	1249	109	78	609	406	406	234

(Table Continued)

Request Number	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
21	1266	1765	110	78	593	406	390	250
22	1327	719	94	78	641	437	359	235
23	1500	797	109	78	609	407	359	250
24	1266	999	109	78	594	438	360	250
25	1297	719	109	78	593	422	390	250
26	1156	641	109	78	593	422	375	250
27	1500	546	110	79	594	406	359	266
28	1531	968	110	79	609	407	390	266
29	1406	922	110	78	594	407	360	281
30	1609	969	109	78	593	422	406	266
31	2046	859	109	78	593	406	422	312
32	2156	953	110	78	609	406	421	297
33	2062	656	110	78	594	406	438	297
34	1671	765	110	78	594	453	391	328
35	1859	610	109	79	593	422	422	297
36	1844	968	94	79	625	406	453	281
37	1984	938	110	78	594	406	453	281
38	1843	890	110	78	610	406	453	266
39	1921	1983	110	78	766	406	438	265
40	2125	1859	125	78	610	406	422	281
41	2140	1547	109	78	609	406	453	265
42	2203	1391	125	78	797	406	453	281
43	2312	1046	110	78	593	406	438	266
44	4405	1093	110	78	625	406	406	266
45	2390	1016	110	78	594	406	421	281
46	4249	890	110	78	610	406	421	296
47	2608	1234	109	79	593	422	453	312
48	4264	1203	109	78	594	406	500	328
49	2515	2796	93	78	594	406	453	296

(Table Continued)

Request Number	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
50	2562	1672	110	78	610	407	469	297
51	2687	1031	94	78	765	454	453	297
52	2578	1000	109	78	593	406	484	281
53	2546	921	110	78	609	406	562	297
54	2671	828	110	78	594	406	531	281
55	2687	828	110	78	610	406	2906	298
56	2796	1390	110	78	610	454	563	266
57	2749	1374	109	79	593	406	516	297
58	2718	953	109	78	625	406	531	313
59	2843	969	109	78	594	406	453	312
60	2765	1093	109	78	610	406	515	312
61	2796	953	110	78	656	407	3531	297
62	4499	891	109	78	593	406	453	313
63	2890	859	94	79	593	422	625	328
64	3249	1921	125	79	594	422	625	313
65	2905	1016	110	79	609	406	609	328
66	2843	1077	93	78	640	407	484	328
67	2968	4046	94	78	610	406	625	313
68	3015	953	94	78	610	407	625	297
69	4874	921	110	78	609	407	453	328
70	4733	1078	110	78	594	406	937	328
71	2983	2124	110	79	594	406	562	328
72	3078	2187	94	78	610	406	515	360
73	3140	2031	109	78	594	454	921	344
74	3124	1719	109	78	609	407	671	328
75	3109	1703	110	78	609	406	546	375
76	3125	1234	94	78	609	406	563	328
77	5389	1203	109	78	594	406	594	344
78	3234	1203	109	78	594	469	562	376

(Table Continued)

Request Number	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
79	3531	1125	125	78	594	422	531	391
80	3296	1078	109	78	609	422	562	375
81	3312	1046	109	78	594	406	610	328
82	3406	1015	94	78	594	406	562	344
83	3390	984	109	78	609	422	656	345
84	3374	922	109	78	593	406	843	298
85	3483	2047	94	78	593	406	609	282
86	6811	1843	94	78	594	422	891	282
87	3905	1797	94	78	594	406	812	266
88	3437	1578	109	78	625	406	1015	297
89	3452	1343	109	78	609	422	781	297
90	3796	1296	109	78	609	422	938	312
91	3671	1249	109	78	610	422	1141	329
92	6452	1249	110	79	594	406	781	313
93	6092	1484	110	79	609	422	703	344
94	5858	1234	109	78	593	422	766	328
95	5764	1031	109	78	593	453	687	281
96	5576	1156	109	78	594	422	656	406
97	4905	1328	110	78	609	406	656	282
98	4733	1140	110	78	594	406	625	235
99	4702	1266	110	78	594	437	656	203
100	4687	10966	94	79	610	453	640	188

Alaska Ocean Observing System (AOOS) Light-Load Runs (20 iterations of 1 thread) (Iterations beyond #20 are ignored in calculated values)
All times reported in
milliseconds

Average Request:	156	80	647	459	372	264	552	326
Min. Request:	72	63	468	396	359	254	338	325
Max. Request:	887	213	3477	988	405	292	4590	329
Total Time:	3137	1615	12956	9181	7455	5286	11047	6534

Target	AOOS		CSC		Pacific University of Hawaii Sea Level Center		USF	
Request Number	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
1	887	67	679	549	375	280	4590	328
2	104	70	476	988	366	271	345	326
3	846	63	488	417	389	255	341	328
4	74	64	500	412	402	255	338	327
5	96	64	520	431	364	259	339	327
6	73	63	546	430	405	258	338	325
7	73	63	545	425	363	258	338	326
8	73	63	3477	405	365	269	339	326
9	74	63	485	396	369	274	342	329
10	82	63	482	421	365	261	338	327
11	73	63	470	411	366	272	344	325
12	77	63	480	419	366	257	340	327
13	77	63	471	428	370	259	340	327
14	74	64	474	412	378	261	340	327
15	73	84	479	415	373	258	338	327
16	89	74	473	421	359	266	338	325
17	72	65	477	418	366	292	341	327
18	74	199	485	434	381	257	339	326
19	73	84	481	438	364	270	341	328
20	73	213	468	511	369	254	338	326

Alaska Ocean Observing System (AOOS) Full-Load Test
(1 iterations of 100 threads) (Iterations beyond #100 are ignored in calculated values)
All times reported in milliseconds

Average								
Request:	3216	1820	489	707	371	264	342	329
Min. Request:	322	901	411	405	360	253	339	326
Max. Request:	5782	3015	907	2323	443	398	351	342
Total Time:	321622	182039	48980	70777	37100	26483	34283	32993

Target	AOOS		CSC		Pacific University of Hawaii Sea Level Center		USF	
Request No.	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
1	322	925	826	425	382	255	344	332
2	990	1184	733	418	370	255	346	331
3	1053	1319	706	410	362	258	342	329
4	1132	984	638	432	383	295	346	329
5	1104	901	706	452	443	263	342	329
6	1079	933	907	477	370	258	343	329
7	1087	1862	620	477	370	261	343	330
8	1576	1781	598	585	368	265	348	330
9	1336	1782	640	613	374	263	341	332
10	1301	1609	600	603	410	256	342	328
11	1310	1606	444	701	370	257	341	330
12	1789	1306	594	707	376	258	343	330
13	1131	1306	570	713	368	254	343	332
14	1692	1312	418	732	360	254	342	329
15	1723	1826	428	764	364	255	342	329
16	2151	2503	464	754	371	256	347	327
17	2037	2341	620	747	368	258	342	329
18	1567	1844	596	745	368	256	345	326
19	1599	1893	598	762	367	255	342	330
20	1617	1763	622	753	369	259	342	329

(Table Continued)

Request No.	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
21	1641	1803	592	732	366	255	342	330
22	1753	1320	720	772	373	257	340	329
23	3993	1321	652	716	374	258	344	329
24	2052	1960	730	710	365	264	347	329
25	3923	1355	570	755	373	262	343	328
26	3843	1356	666	726	371	263	342	328
27	3555	2123	571	718	366	258	343	337
28	3415	2124	550	755	372	256	344	329
29	3324	2039	547	714	371	258	342	331
30	3245	2191	500	742	367	255	345	328
31	2210	2124	462	723	370	258	343	331
32	3374	2097	452	715	369	257	346	333
33	3354	2849	476	718	363	259	342	329
34	3027	2096	434	722	363	256	343	329
35	3014	1954	440	710	372	255	341	329
36	2871	1804	440	680	378	258	345	332
37	2155	1825	432	674	370	257	340	331
38	4887	1873	434	710	373	266	344	328
39	3402	1912	436	703	365	266	347	329
40	3429	1248	418	732	365	259	345	330
41	2503	2008	422	710	367	263	341	330
42	2572	1278	422	687	373	266	342	331
43	3610	1278	418	765	370	276	339	327
44	3559	2077	430	753	368	261	342	331
45	3599	2093	464	788	373	262	340	342
46	2643	2077	443	762	367	277	343	330
47	2657	2076	425	767	373	263	341	330
48	3782	2061	425	824	367	264	345	327
49	2691	1965	472	797	367	262	343	330

(Table Continued)

Request No.	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
50	2714	1937	476	792	377	266	343	329
51	2726	1847	479	791	374	268	342	330
52	4035	1706	452	768	377	267	343	329
53	2770	1724	443	767	378	269	343	328
54	2780	1764	454	750	368	266	343	330
55	4131	1269	442	798	371	261	342	327
56	4141	1281	474	803	378	262	345	327
57	2810	1923	429	788	370	262	341	329
58	2831	1327	444	794	369	260	343	327
59	4316	1327	469	752	372	257	340	330
60	4319	2088	449	778	376	254	342	329
61	4319	2134	447	805	376	254	341	329
62	4231	2929	465	781	375	257	341	332
63	4238	2887	434	789	375	259	343	331
64	4484	2140	469	793	367	255	341	329
65	3282	2018	459	791	377	262	341	327
66	3288	1873	459	828	364	258	343	329
67	3300	1723	445	836	365	253	342	329
68	3315	1689	423	830	368	260	343	330
69	4822	1730	448	832	372	274	340	331
70	3432	1367	444	837	368	264	340	327
71	3442	1830	428	885	366	259	343	329
72	4996	1407	417	882	368	260	343	331
73	4985	1928	428	840	382	255	342	331
74	3487	1444	424	743	361	255	345	328
75	3557	1444	436	709	367	256	351	328
76	4850	2943	412	664	394	266	341	333
77	4706	2900	414	423	363	268	343	334
78	3507	2855	412	406	372	263	343	334

(Table Continued)	AOOS		CSC		Pacific University of Hawaii Sea Level Center		USF	
Request No.	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
79	4710	2121	412	419	366	265	343	331
80	3511	1231	416	406	372	398	342	331
81	3522	1343	432	405	371	340	345	332
82	3528	1339	416	406	367	280	343	331
83	4811	1376	423	416	367	256	346	330
84	3545	1388	411	429	362	259	341	328
85	3556	1328	411	472	369	337	343	329
86	4954	1328	413	492	364	347	342	328
87	3565	2543	414	499	364	300	343	328
88	3566	2452	415	537	370	282	346	331
89	5196	2367	429	544	362	261	341	331
90	3672	2221	422	561	364	257	342	330
91	3696	2231	414	581	368	255	342	330
92	5384	2222	437	562	373	255	342	331
93	3762	2203	416	565	365	262	345	328
94	3764	1856	445	2319	369	259	343	334
95	5576	1718	412	606	368	255	342	330
96	3810	3015	422	594	374	257	342	328
97	5782	2968	421	617	368	259	339	330
98	5667	1764	476	2323	369	254	344	334
99	4273	1158	436	597	369	257	343	331
100	4279	1166	441	622	365	256	341	333

Pacific Light-Load Test (20 iterations of 1 thread) (Iterations beyond #20 are ignored in calculated values)
All times reported in milliseconds

Average Request:	535	238	731	400	85	346	594	58
Min. Request:	256	237	576	398	79	341	363	55
Max. Request:	4188	253	3597	417	102	421	4956	70
Total Time: 20 requests	10711	4779	14636	8017	1712	6931	11899	1160

Target	AOOS		CSC		Pacific		USF	
Request Number	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
	4188	239	3597	401	100	342	4956	56
	400	237	580	400	83	344	365	57
	344	238	579	398	84	341	364	56
	345	238	593	400	89	341	365	55
	354	253	590	402	83	342	365	56
	345	240	577	403	82	342	365	57
	343	238	578	399	83	342	366	56
	345	237	578	401	79	344	366	57
	345	238	576	398	82	342	363	56
	344	239	579	399	82	344	367	56
	344	237	577	398	82	342	366	56
	344	237	582	401	82	343	363	56
	346	237	576	401	91	343	365	57
	344	238	578	398	90	343	364	55
	345	243	578	399	82	421	364	55
	344	238	578	402	82	343	365	70
	346	237	597	398	89	342	366	61
	345	239	578	398	83	343	373	60
	344	238	585	417	82	344	365	67
	256	238	580	404	102	343	366	61

Pacific Full-Load Test (1 iterations of 100 threads) (Iterations beyond #100 are ignored in calculated values)
All times reported in milliseconds

Average								
Request:	1304	382	593	405	102	61	374	349
Min. Request:	357	238	580	397	81	56	364	341
Max. Request:	3221	1174	651	491	196	133	419	481
Total Time:	130468	38295	59376	40521	10299	6114	37470	34999

Target	AOOS		CSC		Pacific University of Hawaii Sea Level Center		USF	
Request No.	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
1	357	243	651	403	187	59	373	343
2	544	297	625	403	130	57	366	342
3	468	486	607	403	109	57	368	343
4	563	291	597	406	108	58	368	343
5	502	269	624	419	98	56	376	342
6	496	266	620	399	106	57	369	342
7	627	561	603	403	97	57	372	343
8	616	240	622	399	102	56	371	343
9	634	517	595	402	94	57	366	343
10	680	333	590	405	91	57	371	343
11	694	248	595	491	87	58	380	343
12	865	240	592	432	89	57	368	345
13	518	563	585	406	99	57	368	342
14	578	513	580	417	100	57	366	343
15	690	465	585	402	98	56	364	342
16	658	263	587	489	107	57	377	345
17	701	288	592	401	102	133	376	354
18	724	266	583	425	97	57	404	370
19	830	382	591	422	179	57	397	356
20	719	348	589	399	163	57	414	342
21	783	313	597	404	162	63	386	343

(Table Continued)

Request No.	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
22	950	323	590	413	173	56	382	343
23	913	251	582	406	177	68	378	342
24	813	273	584	401	126	69	376	343
25	1069	306	590	399	196	61	370	341
26	1039	247	584	402	124	59	371	343
27	1029	301	590	405	96	57	371	343
28	1281	249	586	404	97	57	377	343
29	963	269	596	404	93	64	379	343
30	830	253	600	401	97	57	371	343
31	1205	305	601	399	90	62	373	344
32	1295	980	588	400	91	61	368	346
33	990	642	593	399	92	56	367	342
34	962	863	591	401	95	57	368	343
35	1132	498	603	400	92	56	368	343
36	817	276	587	401	86	57	379	481
37	1207	255	601	400	87	62	374	464
38	1225	261	599	402	92	67	369	427
39	1074	266	600	401	106	56	369	468
40	1399	327	593	401	104	58	375	447
41	1253	260	591	411	90	60	388	404
42	966	260	601	402	105	58	389	343
43	1287	425	599	397	105	59	372	343
44	2207	247	596	401	89	64	370	355
45	1792	437	587	397	90	57	366	343
46	1207	242	594	401	87	58	417	344
47	1194	240	583	404	95	57	374	343
48	1197	242	589	399	94	58	394	343
49	1127	255	605	400	101	57	419	342
50	1072	287	599	399	98	57	409	343

(Table Continued)

Request No.	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
51	1084	331	592	405	113	57	401	345
52	1067	282	593	402	100	58	379	344
53	1299	283	597	400	106	57	376	343
54	1645	285	589	399	105	60	376	344
55	1526	272	590	399	106	69	373	342
56	1335	651	585	400	125	60	370	343
57	1207	289	581	408	119	66	368	343
58	1223	453	582	412	103	68	371	343
59	2599	404	597	401	114	66	369	343
60	2563	1174	596	405	81	71	371	342
61	2333	1146	596	402	86	64	368	343
62	1360	255	591	397	88	65	371	342
63	1310	733	597	404	85	65	368	343
64	1231	484	589	398	89	64	366	342
65	1246	463	605	400	91	72	370	342
66	1465	420	593	407	87	79	370	342
67	1457	396	581	406	88	69	371	343
68	1465	241	590	402	98	75	367	342
69	1468	251	599	398	91	77	370	344
70	2125	285	599	404	83	76	373	346
71	1390	252	594	400	88	75	381	343
72	2050	368	584	404	89	73	369	344
73	1963	400	587	400	92	74	372	343
74	1632	417	580	401	95	66	372	342
75	2296	348	585	407	95	62	368	343
76	1558	312	595	402	88	57	369	344
77	1518	592	604	403	88	57	370	344
78	1700	411	590	400	88	57	368	342
79	1782	377	598	400	88	57	378	343

(Table Continued)

Request No.	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
80	1700	251	595	400	89	57	380	342
81	1712	258	607	400	88	56	375	345
82	1372	262	593	408	88	56	372	343
83	1300	250	585	405	88	57	373	343
84	1267	318	583	401	92	57	377	347
85	1284	324	595	414	94	57	373	343
86	1249	793	594	400	100	57	370	341
87	1356	697	587	406	113	57	366	342
88	1310	349	602	402	86	57	365	342
89	2291	1138	591	403	88	57	364	342
90	2353	262	582	413	81	57	372	342
91	2500	243	589	401	147	57	369	343
92	1869	512	582	398	96	56	373	342
93	1493	463	585	402	93	57	368	343
94	1713	366	591	400	89	57	367	343
95	1683	446	592	407	109	56	371	344
96	1594	238	586	398	107	57	370	342
97	2408	267	597	407	100	57	370	345
98	1560	303	585	406	111	56	373	343
99	1594	294	602	401	101	56	375	345
100	3221	254	582	403	97	59	369	344

U of South Florida (USF) Light-Load Test (20 iterations of 1 thread) (Iterations beyond No. 20 are ignored in calculated values)
All times reported in milliseconds

Average Request:	443	520	237	188	546	339	96	84
Min. Request:	314	302	233	177	481	337	94	82
Max. Request:	593	4635	262	299	1732	343	100	86
Total Time:	8873	10411	4746	3774	10931	6781	1921	1691

Target	AOOS		CSC		Pacific University of Hawaii Sea Level Center		USF	
Request Number	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
1	467	4635	237	299	1732	338	96	85
2	433	307	234	182	490	337	96	86
3	432	307	233	178	482	343	97	82
4	432	302	237	187	484	339	94	83
5	469	305	234	210	483	341	96	83
6	509	302	234	213	482	338	94	84
7	438	303	241	178	484	337	95	85
8	350	303	241	178	482	337	100	85
9	445	306	234	186	490	337	96	85
10	434	302	235	177	481	340	97	86
11	432	303	237	177	483	342	94	86
12	432	302	234	177	483	338	96	86
13	518	303	234	178	482	340	96	84
14	593	303	234	178	484	338	95	84
15	436	303	239	177	484	339	97	86
16	441	310	234	178	482	340	96	84
17	314	302	244	177	483	339	95	84
18	432	307	234	178	485	339	99	83
19	432	303	262	187	484	340	97	86
20	434	303	234	179	491	339	95	84

U of South Florida (USF) Full-Load Test (1 iteration of 100 threads) (Iterations beyond 100 are ignored in calculated values)

All times reported in milliseconds

Average								
Request:	1910	1239	362	192	492	343	224	122
Min. Request:	443	380	237	177	485	339	119	100
Max. Request:	8226	3558	490	275	518	352	1339	160
Total Time:	191076	123909	36246	19253	49260	34397	22438	12203

Target	AOOS		CSC		Pacific University of Hawaii Sea Level Center		USF	
Request No.	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
1	443	500	405	182	489	339	208	103
2	512	397	411	180	489	344	183	124
3	534	447	431	180	488	343	157	118
4	518	380	428	178	489	343	213	121
5	494	426	423	178	487	344	222	129
6	872	636	465	178	489	343	387	126
7	561	623	458	180	490	343	281	108
8	847	580	470	180	489	343	538	113
9	630	553	464	181	496	344	225	119
10	640	636	466	182	490	343	357	127
11	659	509	441	178	488	343	200	127
12	644	723	452	178	492	343	515	109
13	850	691	480	178	495	344	452	134
14	933	644	489	179	491	344	388	131
15	891	790	466	179	503	343	291	108
16	824	605	471	178	498	343	390	130
17	1903	571	466	177	502	343	268	132
18	1419	781	470	178	496	343	260	140
19	940	683	473	185	491	343	387	120
20	862	654	478	179	507	343	1339	120
21	1936	968	482	178	495	343	296	123

(Table Continued)

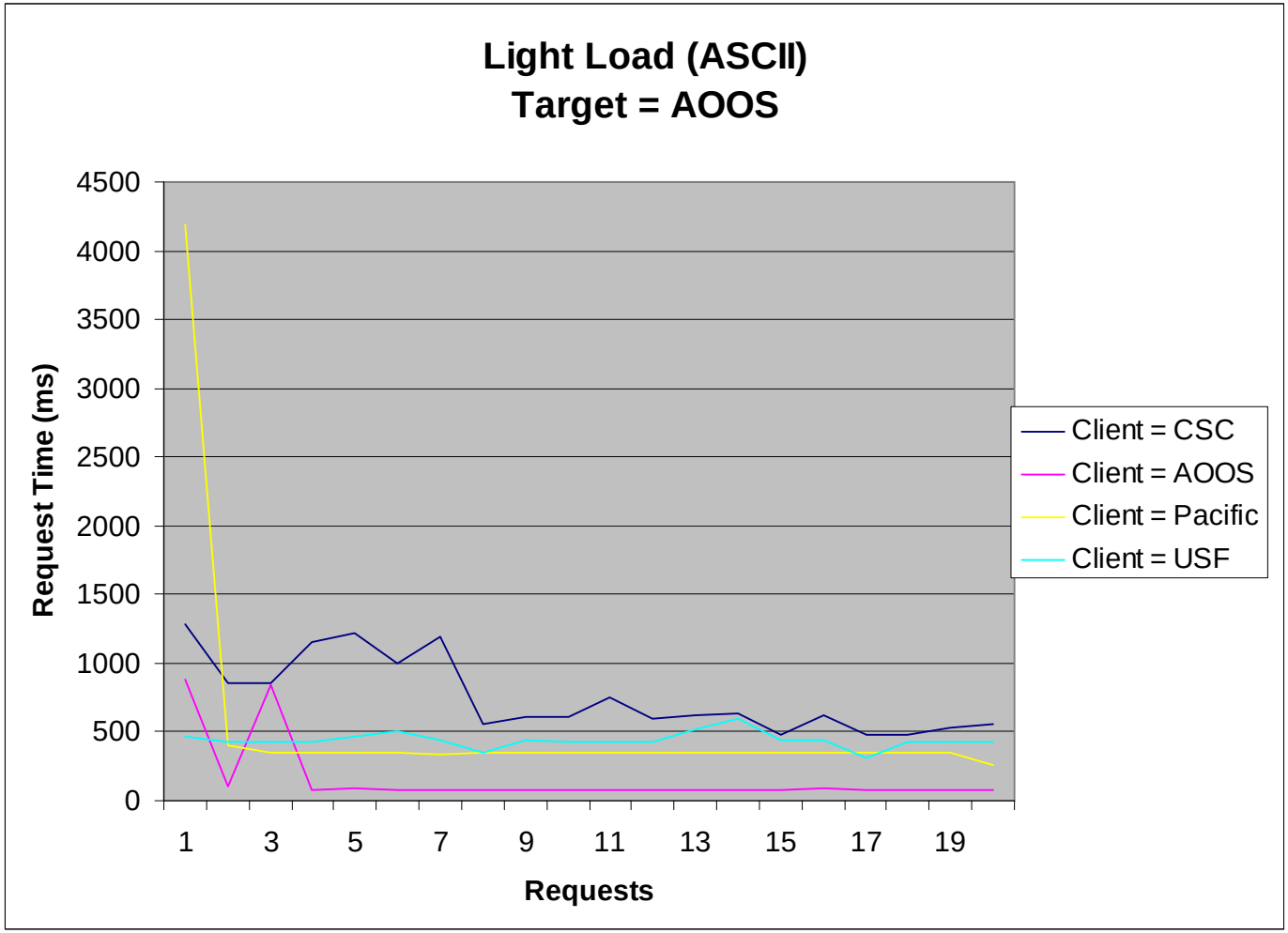
Request No.	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
22	1163	871	480	179	495	344	257	120
23	1164	1078	475	178	496	345	201	119
24	987	845	483	179	495	345	431	128
25	974	820	485	180	497	344	199	119
26	1010	821	482	179	505	344	340	123
27	2685	736	487	183	498	344	260	133
28	1439	1149	484	178	493	343	194	142
29	1442	1006	486	209	506	343	169	113
30	1253	815	483	187	498	343	147	121
31	1237	773	470	188	492	343	341	118
32	1486	1001	484	183	492	343	130	118
33	1332	912	489	179	491	343	207	109
34	1305	1125	488	179	488	344	287	111
35	1277	1087	482	178	499	343	187	121
36	1260	753	477	177	499	344	200	122
37	1464	728	489	181	496	343	179	109
38	2186	1070	485	179	509	342	181	110
39	2150	1069	459	179	497	351	177	119
40	2111	766	481	178	500	352	146	123
41	1878	905	487	180	493	351	139	130
42	1444	876	490	184	518	345	182	130
43	1693	836	471	179	507	343	181	109
44	1623	1368	464	178	498	342	171	116
45	1601	1375	480	179	505	343	158	118
46	1578	1056	451	186	497	345	178	107
47	1581	1029	416	180	496	343	178	109
48	1556	1018	395	180	493	343	149	102
49	1491	994	353	178	495	343	155	119
50	1899	967	327	181	489	344	184	114

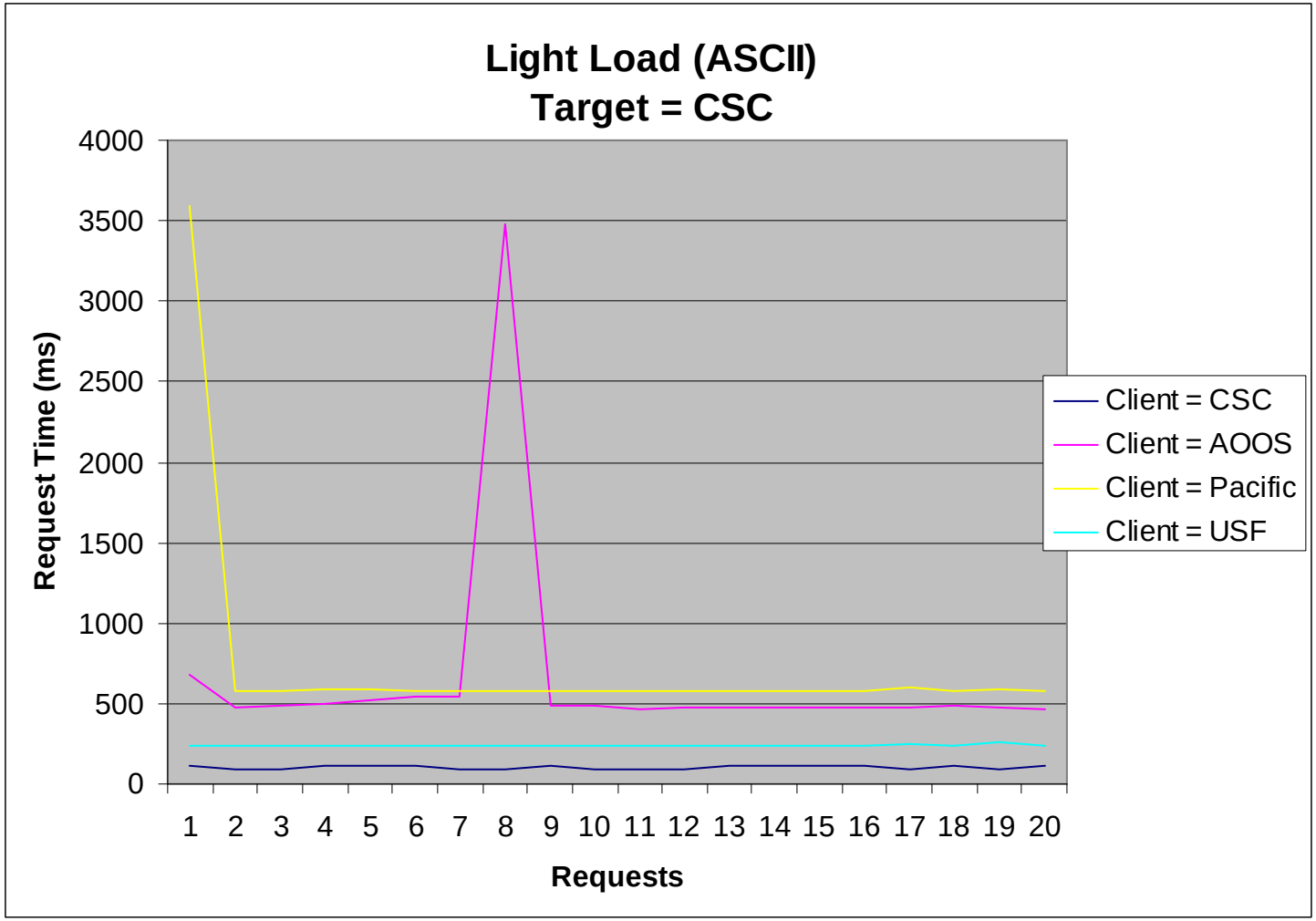
(Table Continued)

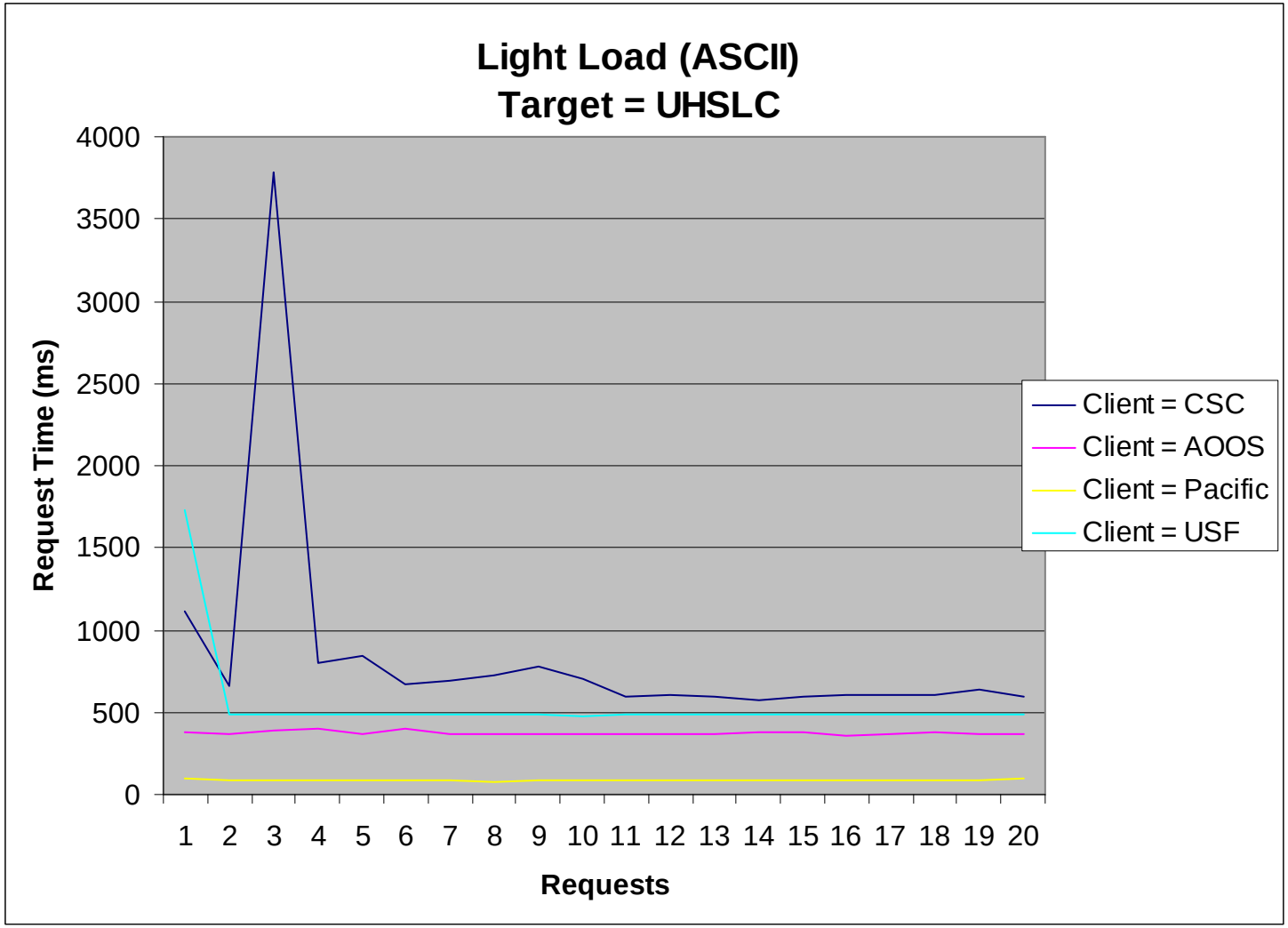
Request No.	AOOS ASCII	AOOS DataObject	CSC ASCII	CSC DataObject	Pacific University of Hawaii Sea Level Center ASCII	Pacific University of Hawaii Sea Level Center DataObject	USF ASCII	USF DataObject
51	2063	2087	348	180	490	345	157	136
52	1629	930	364	185	489	343	162	143
53	1650	794	347	178	493	343	130	127
54	1729	2415	316	179	488	344	174	132
55	1800	947	269	178	488	344	168	123
56	1813	928	328	179	490	344	239	114
57	1798	928	286	178	489	344	169	131
58	1728	1843	264	178	489	345	151	153
59	2755	1039	270	178	489	343	311	112
60	2853	1012	274	179	488	344	159	134
61	1803	1722	262	179	488	343	174	128
62	2169	1831	253	186	488	344	202	110
63	2090	1636	254	187	488	344	170	124
64	2058	1593	254	180	490	344	143	108
65	2026	1502	257	179	487	344	170	106
66	1898	2629	241	178	491	345	122	112
67	2063	1459	249	179	489	344	174	100
68	2836	1244	251	178	491	343	156	140
69	2046	1319	260	179	488	344	213	121
70	2466	976	248	178	507	343	161	126
71	2179	2858	249	195	489	342	238	132
72	2058	2812	249	179	490	351	119	119
73	1985	1603	258	200	490	349	207	118
74	1908	1441	257	185	488	344	167	116
75	2387	1301	270	183	488	344	167	142
76	2104	1311	255	180	489	344	178	123
77	2093	1234	254	179	489	341	173	121
78	2103	1198	263	194	488	345	140	112
79	2840	1164	244	242	492	343	147	111

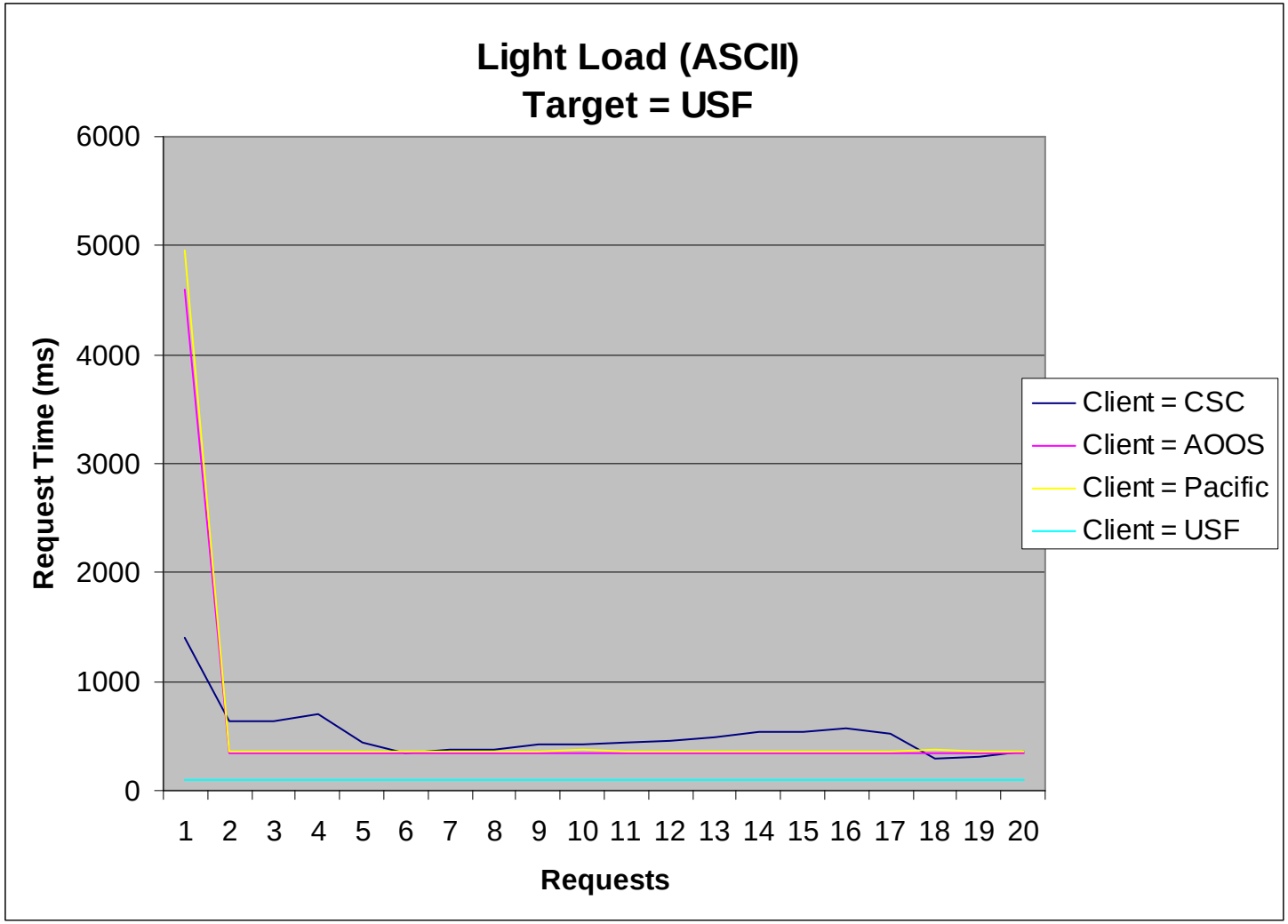
(Table Continued)	AOOS		CSC		Pacific University of Hawaii Sea Level Center		USF	
Request No.	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject	ASCII	DataObject
80	2407	1136	243	217	489	343	145	114
81	2776	1172	244	220	490	343	138	122
82	2739	1145	247	253	487	346	172	113
83	2321	1164	249	255	491	345	162	108
84	2295	1152	253	263	488	346	154	119
85	2462	2448	254	262	489	343	176	125
86	2438	1898	254	269	488	347	165	116
87	2413	1278	247	257	490	344	171	111
88	2929	2411	271	275	488	345	174	112
89	3194	2363	256	262	488	346	210	112
90	3105	1561	247	271	488	344	192	120
91	2732	2328	247	231	490	343	182	124
92	2479	1528	249	229	487	344	125	125
93	2447	1482	252	233	489	345	217	125
94	2469	2299	261	207	489	343	236	129
95	2553	1950	243	260	491	345	244	160
96	2538	1903	262	198	491	345	259	155
97	3084	1408	254	184	488	344	242	151
98	7395	1868	258	185	488	344	208	141
99	4963	3455	252	187	492	344	189	131
100	8226	3558	237	179	485	339	171	122

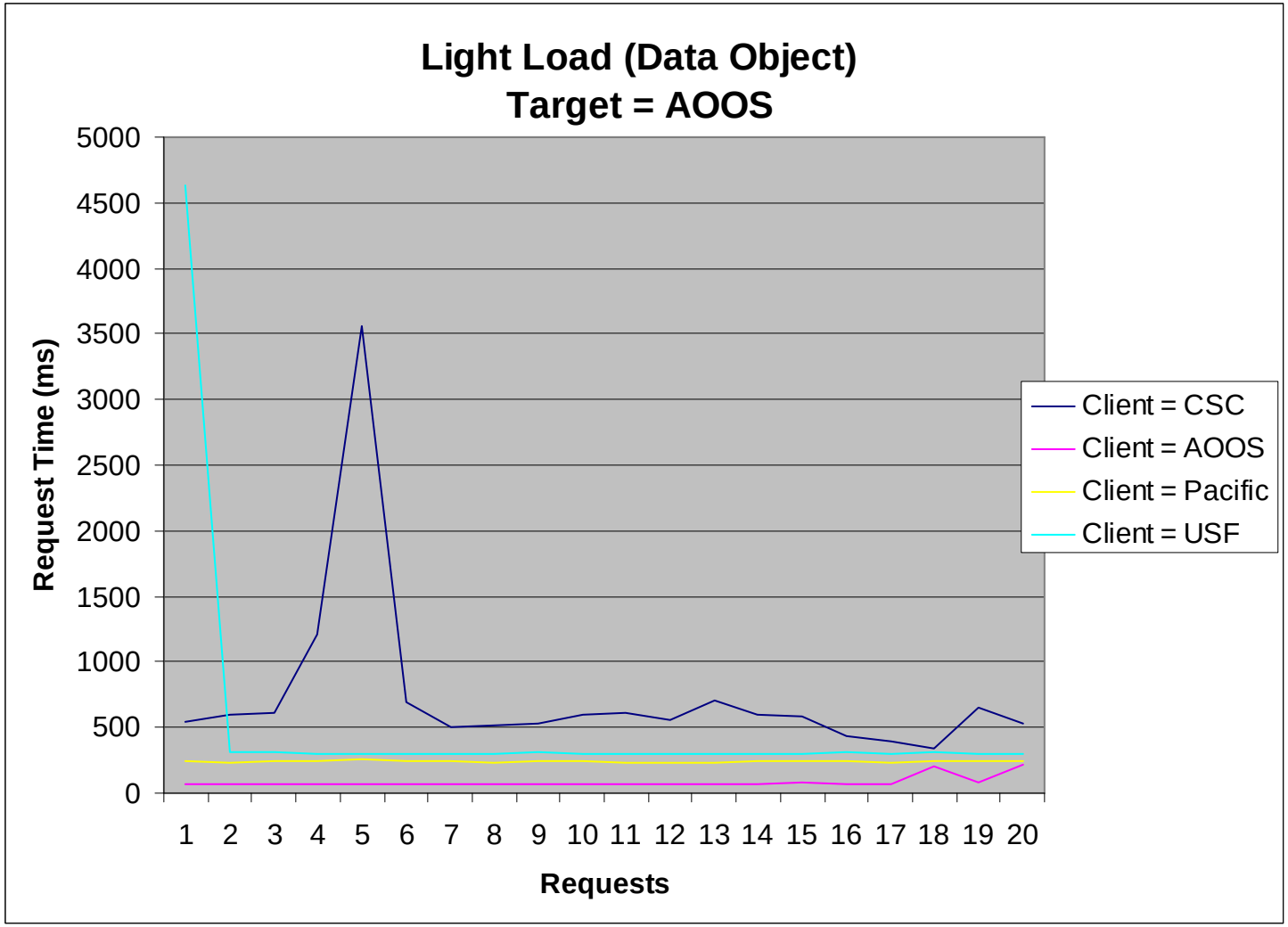
Appendix C: Server Performance Summary Charts

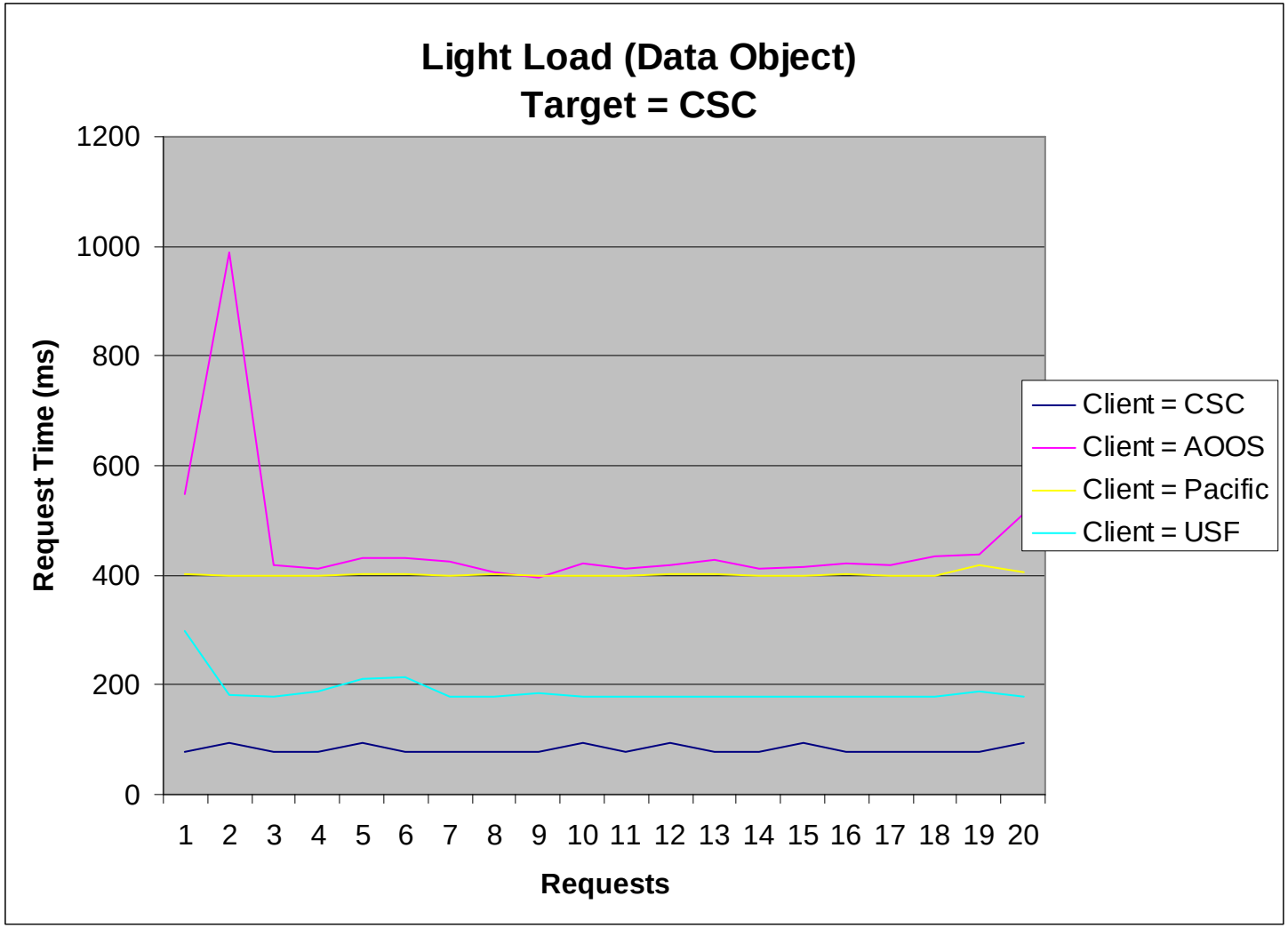


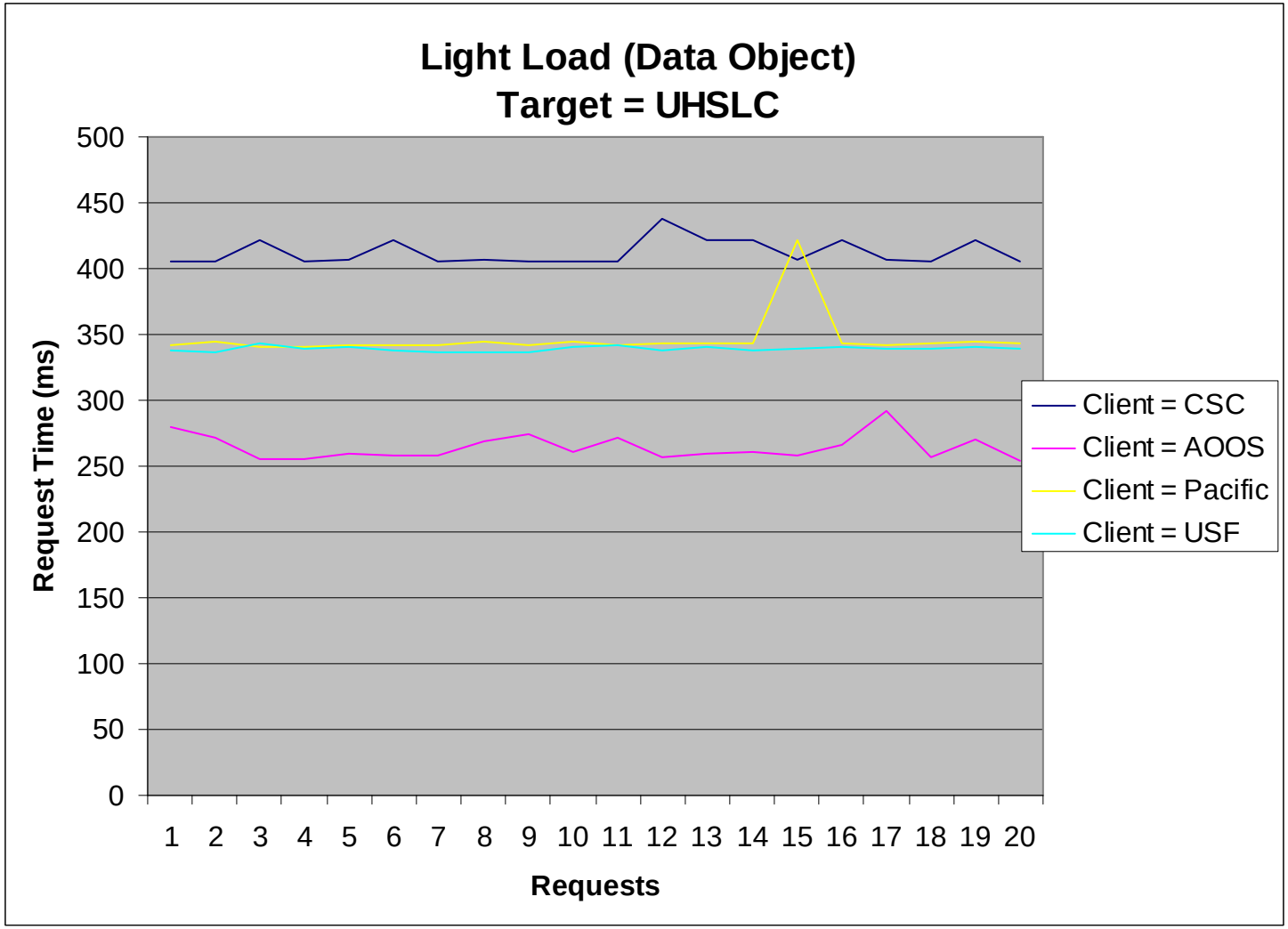

Light Load (ASCII)
Target = CSC
Request Time (ms)
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

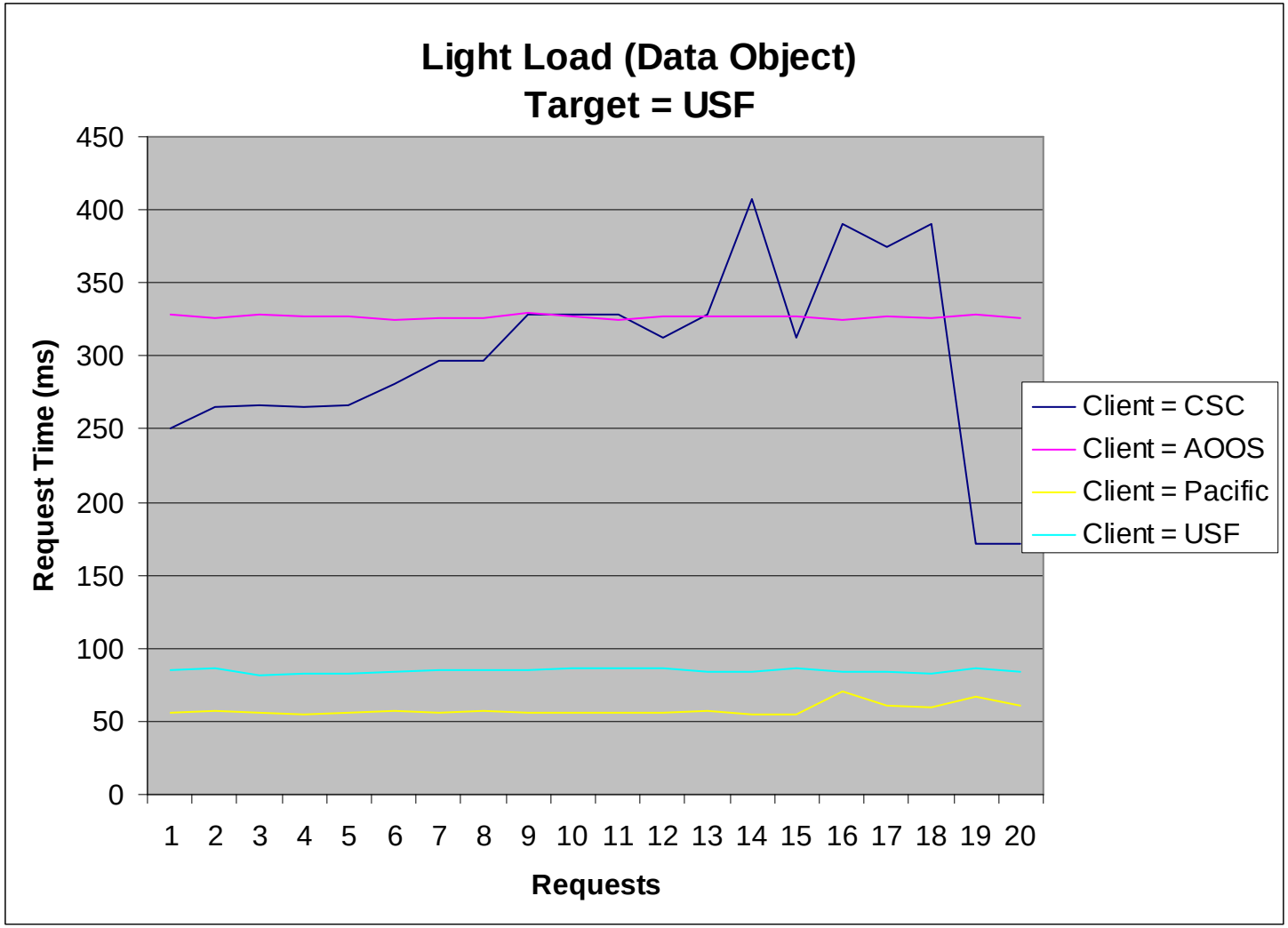

Light Load (ASCII)
Target = UHSLC
Request Time (ms)
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

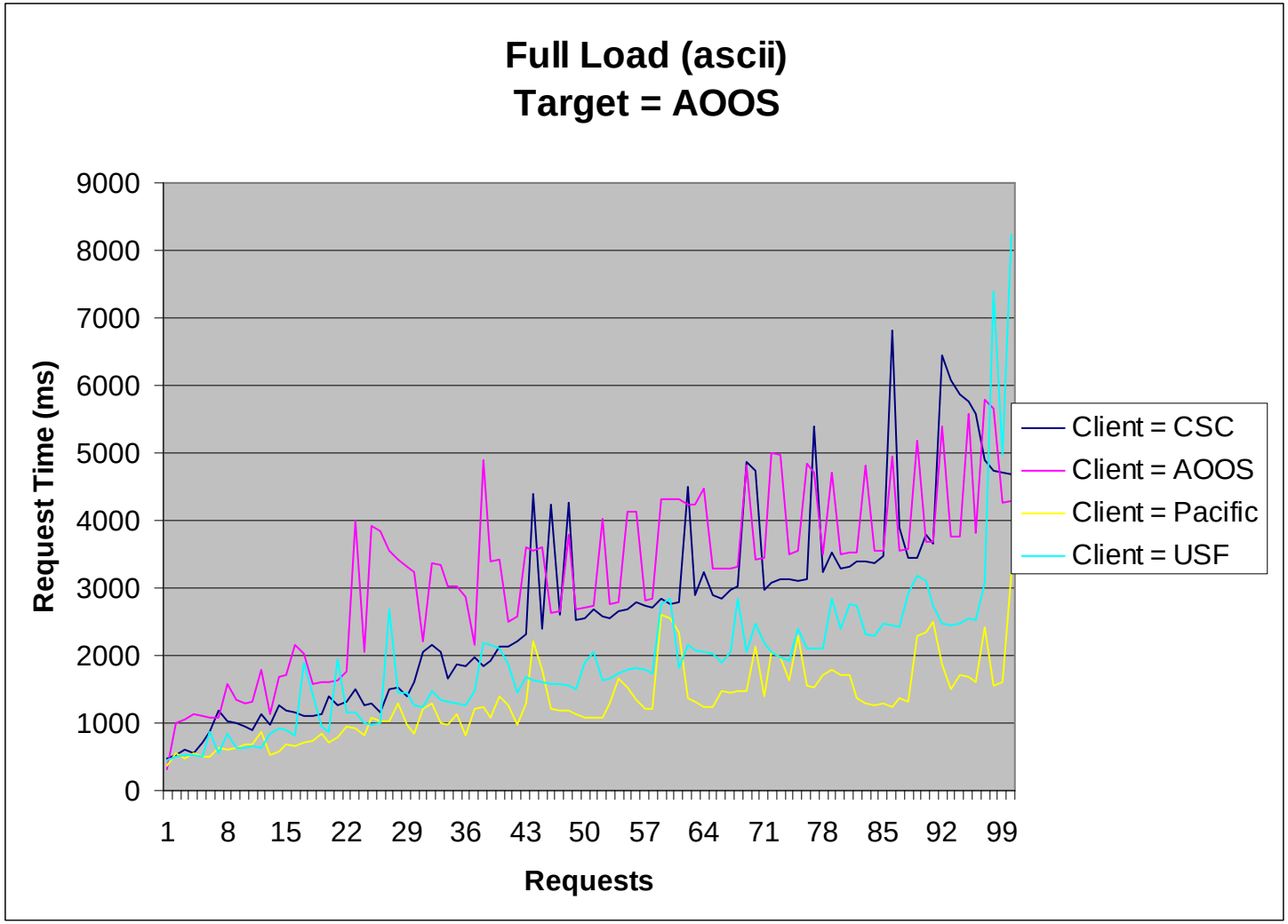

Light Load (ASCII)
Target = USF
Request Time (ms)
6000
5000
4000
3000
2000
1000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

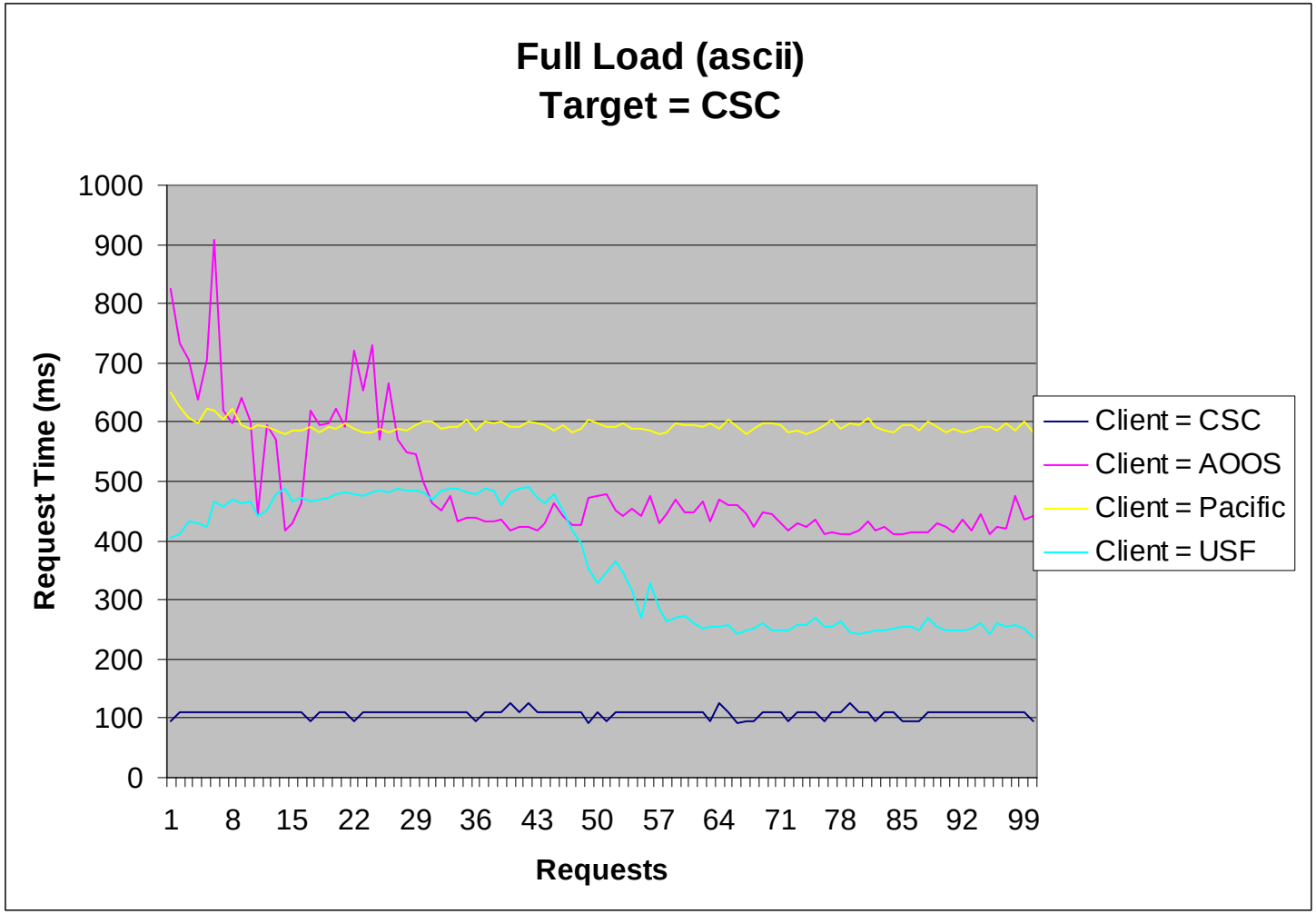

Light Load (Data Object)
Target = AOOS
Request Time (ms)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

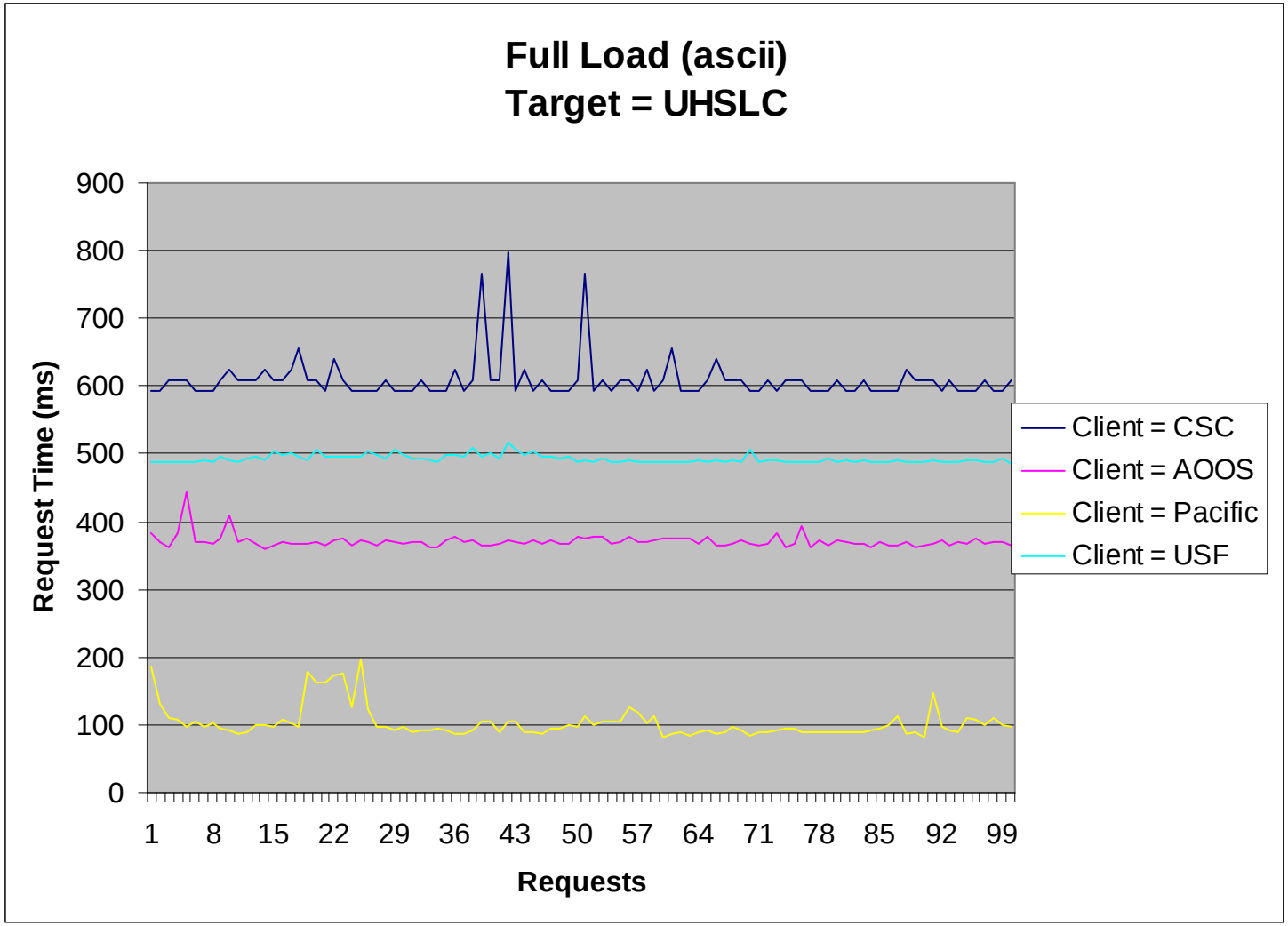

Light Load (Data Object)
Target = CSC
Request Time (ms)
0
200
400
600
800
1000
1200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

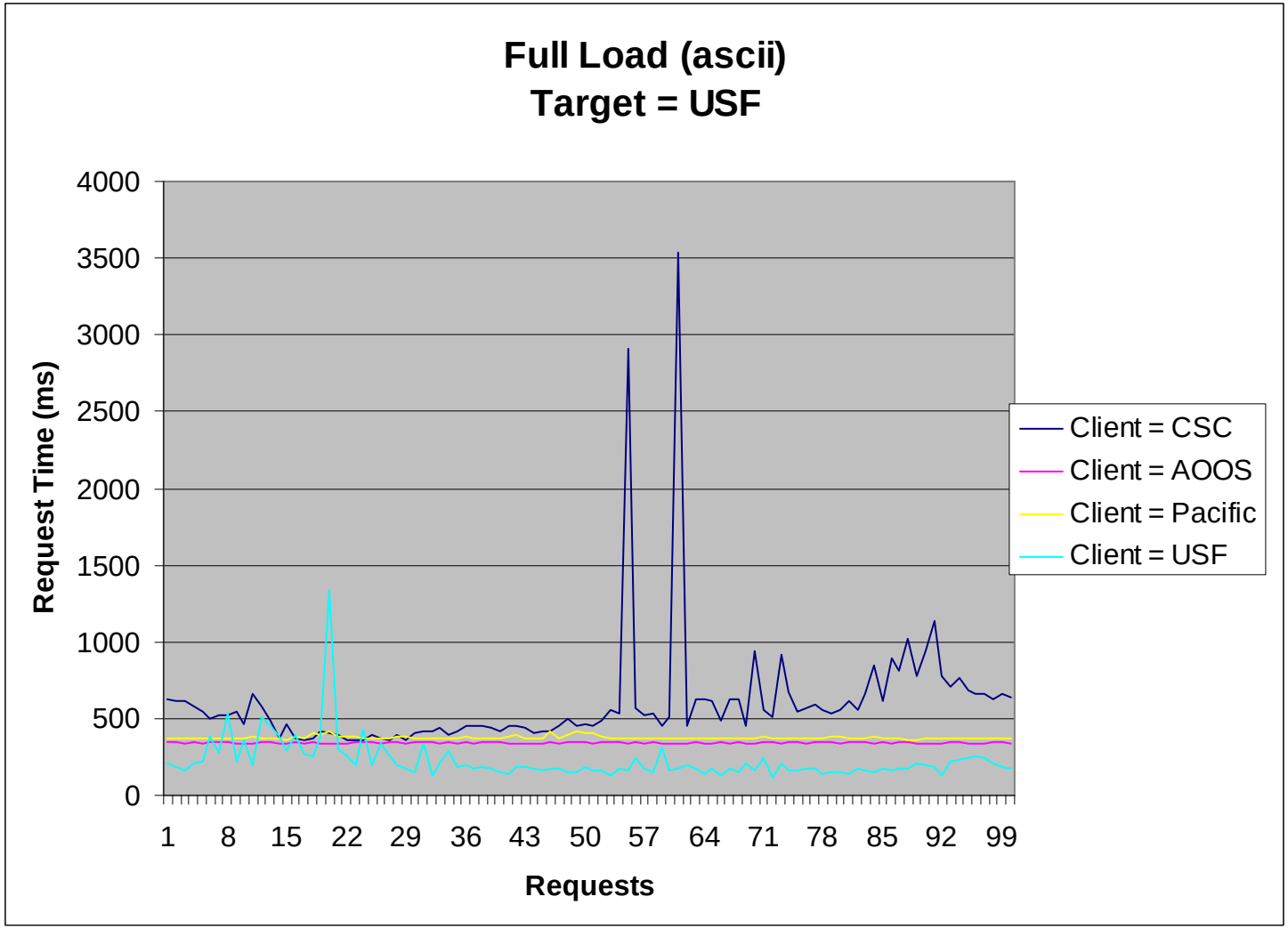

Light Load (Data Object)
Target = UHSLC
Request Time (ms)
500
450
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

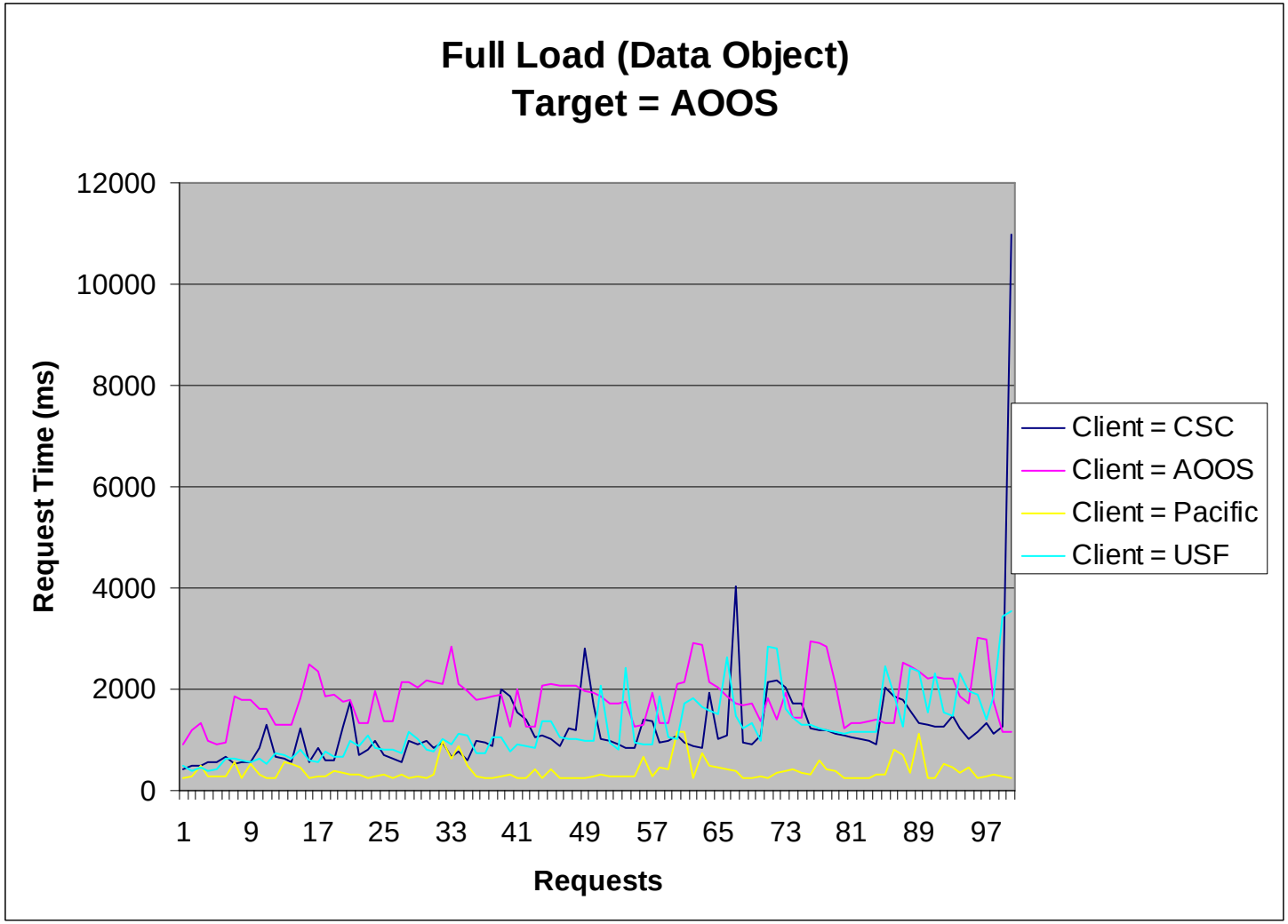

Light Load (Data Object)
Target = USF
Request Time (ms)
450
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

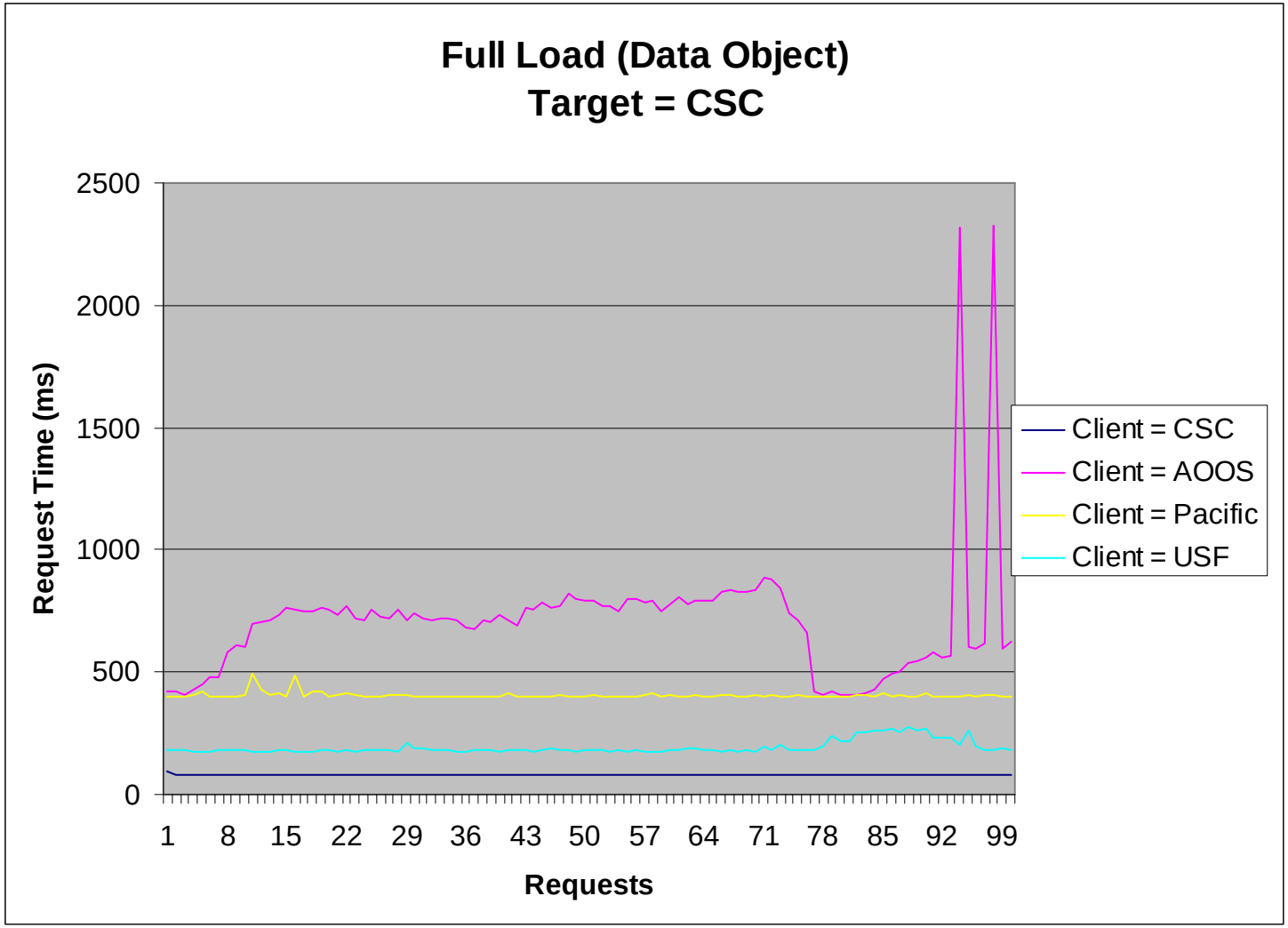

Full Load (ascii)
Target = AOOS
Request Time (ms)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

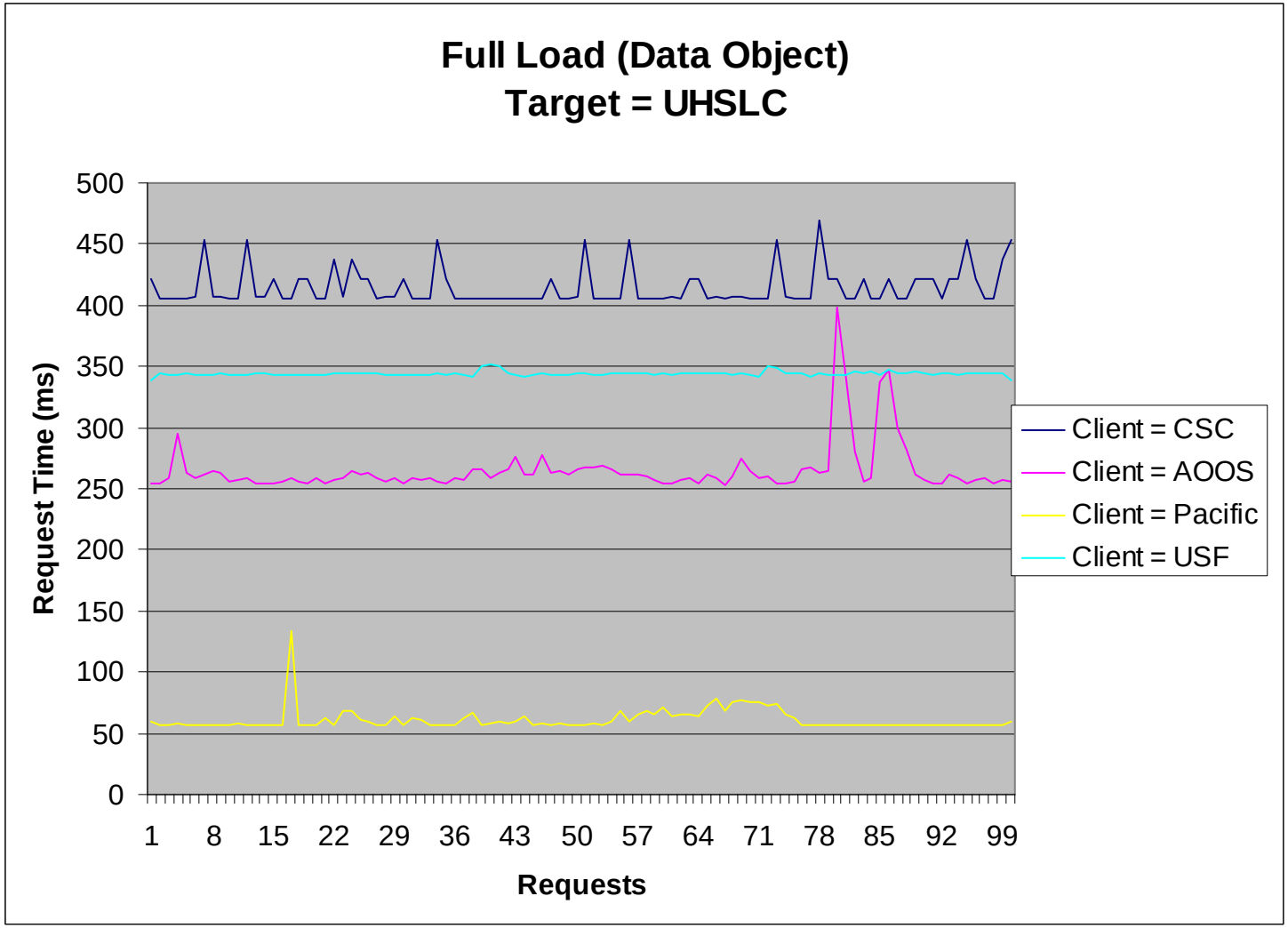

Full Load (ascii)
Target = CSC
Request Time (ms)
1000
900
800
700
600
500
400
300
200
100
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

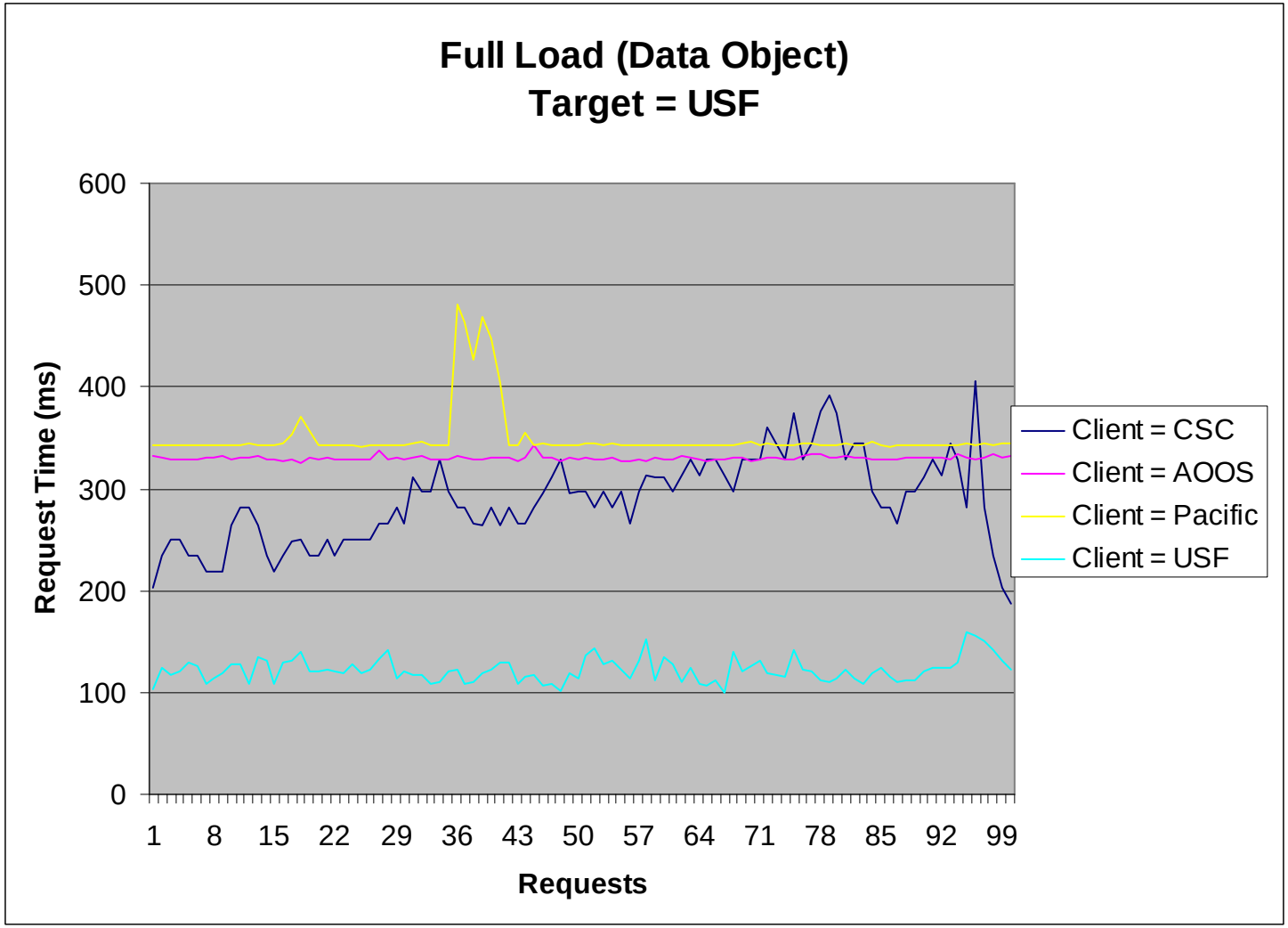

Full Load (ascii)
Target = UHSLC
Request Time (ms)
900
800
700
600
500
400
300
200
100
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF


Full Load (ascii)
Target = USF
Request Time (ms)
4000
3500
3000
2500
2000
1500
1000
500
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF


Full Load (Data Object)
Target = AOOS
Request Time (ms)
12000
10000
8000
6000
4000
2000
0
1
9
17
25
33
41
49
57
65
73
81
89
97
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF


Full Load (Data Object)
Target = CSC
Request Time (ms)
2500
2000
1500
1000
500
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF


Full Load (Data Object)
Target = UHSLC
Request Time (ms)
500
450
400
350
300
250
200
150
100
50
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF


Full Load (Data Object)
Target = USF
Request Time (ms)
600
500
400
300
200
100
0
1
8
15
22
29
36
43
50
57
64
71
78
85
92
99
Requests
Client = CSC
Client = AOOS
Client = Pacific
Client = USF

Appendix D: NOAA Coastal Services Center DTL Server Installation Notes

Package Downloads

OPeNDAP main download page: *www.opendap.org/download/index.html*
OPeNDAP CGI Server Base Software: *www.opendap.org/download/CGI_server.html*
NetCDF: *www.unidata.ucar.edu/downloads/netcdf/index.jsp*
NetCDF handler: *www.opendap.org/download/nc_server.html*

Windows builds: *www.opendap.org/winPort.html*
Builds for Microsoft Windows can also be found on the main download page.
However, there is no Windows build since OPeNDAP version 3.4.8.

OPeNDAP Installation under Linux

The installation of the OPeNDAP NetCDF server components was accomplished following the bundled installation instructions. There were no OPeNDAP RPM packages for RHL 4. The DTL staff attempted to install the RPM for RHL 3, which failed. The source was downloaded and compiled as described below.

The following commands created a new user account for compiling the source. You must have root privileges to use the "useradd" command. Compiling as the root user is considered unsafe.
[prompt]$ useradd username
[prompt]$ passwd userpassword

The following commands downloaded, compiled, and installed libdap 3.6.2, which is required by dap-server 3.6.1:
[prompt]$ su username (created in the previous step)
[prompt]$ cd ~/opendap
[prompt]$ tar zxvf libdap-3.6.2.tar.gz
[prompt]$ cd libdap-3.6.2
[prompt]$ ./configure
[prompt]$ make
[prompt]$ su root
[prompt]$ make install

The libraries installed in the default location, /usr/local/lib.

The following commands downloaded, compiled, and installed dap-server 3.6.1:
[prompt]$ su username
[prompt]$ cd ~/opendap
[prompt]$ wget ftp://ftp.unidata.ucar.edu/pub/opendap/source/dap-server-3.6.1.tar.gz
[prompt]$ tar zxvf dap-server-3.6.1.tar.gz
[prompt]$ cd dap-server-3.6.1
[prompt]$ ./configure
[prompt]$ make
[prompt]$ su root
[prompt]$ make install

The Perl modules installed in the default location, /usr/local/share/dap-server.
The CGI program "nph-dods" installed in the default location, /usr/local/share/dap-server-cgi.

To configure the OPeNDAP server to handle the NetCDF data, modify its configuration file. Open the configuration file for OPeNDAP and change the following items. (The default settings that haven't been changed are not listed here.)
maintainer you@yourmail.server
curl /usr/bin/curl
#handler .*\.(HDF|hdf|EOS|eos)(.Z|.gz|.bz2)?$ /usr/local/bin/dap_hdf4_handler
handler .*\.(NC|nc|cdf|CDF)(.Z|.gz|.bz2)?$ /usr/local/share/netcdf-handler/bin/dap_nc_handler
#handler .*\.(dat|bin)$ /usr/local/bin/dap_ff_handler
#handler .*\.(pvu)(.Z|.gz)?$ /usr/local/bin/dap_dsp_handler
#handler .*/test$ /usr/local/bin/jg_handler

Copy the OPeNDAP CGI program and configuration file into the cgi-bin directory:
[prompt]$ cp /usr/local/share/dap-server-cgi/* /var/www/cgi-bin/.

Initial attempts to test the server, produced an error, "...error while loading shared libraries: libdap.so.4...". In order to facilitate the server finding the required libdap files, the DTL staff created a link to the libdap library, which will be dynamically linked to dap_nc_handler and others.
[prompt]$ cd /usr/lib [prompt]$ ln /usr/local/lib/libdap.so.4.0.0 libdap.so.4

Note that the recommended method of setting the LD_LIBRARY_PATH environment variable did not work.

NetCDF Installation

The following commands downloaded, compiled, and installed netcdf-3.6.1:

```
[prompt]$ su username
[prompt]$ cd ~/opendap
[prompt]$ wget http://www.unidata.ucar.edu/downloads/netcdf/ftp/netcdf-3.6.1.tar.gz
[prompt]$ tar zxvf netcdf-3.6.1.tar.gz
[prompt]$ cd netcdf-3.6.1/src
[prompt]$ ./configure --prefix=/usr/local/share/netcdf
[prompt]$ make
[prompt]$ su root
[prompt]$ mkdir /usr/local/share/netcdf
[prompt]$ make install
```

NetCDF installed in the specified location, /usr/local/share/netcdf.

The following commands downloaded, compiled, and installed netcdf_handler-3.6.0. (NetCDF is required for configuring this NetCDF handler.)

```
[prompt]$ su username
[prompt]$ cd ~/opendap
[prompt]$ wget ftp://ftp.unidata.ucar.edu/pub/opendap/source/netcdf_handler-3.6.0.tar.gz
[prompt]$ tar zxvf netcdf_handler-3.6.0.tar.gz
[prompt]$ cd netcdf_handler-3.6.0
[prompt]$ ./configure --prefix=/usr/local/share/netcdf-handler --with-netcdf=/usr/local/share/netcdf
[prompt]$ make
[prompt]$ su root
[prompt]$ mkdir /usr/local/share/netcdf-handler
[prompt]$ make install
```

The NetCDF handler installed in the specified location, /usr/local/share/netcdf-handler.

Base Testing

To demonstrate the successful installation of the OPeNDAP NetCDF server, ask the server for its version information by adding the argument '/version' to the URL. This was done using the following link in a Web browser:
http://csc-s-ial-d/cgi-bin/nph-dods/version

This successfully generated the following output:
OPeNDAP server core software: DAP2/3.6.1

To access data stored on your machine or network, in a Web browser, add the path and name of the file of interest, relative to your Web server root, to the end of the OPeNDAP server URL. For instance, if you have a data file at "/var/www/html//data/ndbc/netcdf/ocean/15319o9999.nc" you can use the following links, except that you will need to change the server name and path to your OPeNDAP server installation.

The data descriptor structure (DDS):
http://csc-s-ial-d/cgi-bin/nph-dods/data/ndbc/netcdf/ocean/15319o9999.nc.dds

The data attribute structure (DAS):
http://csc-s-ial-d/cgi-bin/nph-dods/data/ndbc/netcdf/ocean/15319o9999.nc.das

The content of the file as plain ASCII text:
http://csc-s-ial-d/cgi-bin/nph-dods/data/ndbc/netcdf/ocean/15319o9999.nc.asc

The OPeNDAP Server Dataset Access Form for the file:
http://csc-s-ial-d/cgi-bin/nph-dods/data/ndbc/netcdf/ocean/15319o9999.nc.html

To test another data file, simply change the path and/or filename you append to the end of the OPeNDAP CGI URL. For instance, given a file at "/var/www/html/data/ndbc/netcdf/stdmet/31201h2005.nc", use the URL,
http://csc-s-ial-d/cgi-bin/nph-dods/data/ndbc/netcdf/stdmet/31201h2005.nc.html Project Sequence

The DTL staff harvested several years of National Data Buoy Center (NDBC) buoy data in NetCDF files and stored them in /var/www/html/data/.