Flow of Global GPS Data and Products From Station to User

Science Information Systems Interoperability Conference
Distributed Data Management Tools Session

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Abstract

The International GPS Service for Geodynamics (IGS) was formed by the International Association of Geodesy (IAG) to provide GPS data and highly accurate ephemerides in a timely fashion to the global science community to aid in geophysical research. This service has been operational since January, 1994. The GPS data flows from a global network of permanent GPS tracking sites through a hierarchy of data centers before they are available to the user at the global and regional data centers. A majority of these data flow from the receiver to global data centers within 24 hours of the end of the observation day. Common data formats and compression software are utilized throughout the data flow to facilitate efficient data transfer. IGS analysis centers retrieve these data daily to produce IGS products (e.g., orbits, clock corrections, Earth rotation parameters, and station positions). These products are then forwarded to the global data centers by the analysts for access by the IGS Analysis Coordinator, for generation of the rapid and final IGS orbit product, and for access by the user community in general. The IGS Central Bureau Information System (CBIS) provides information for the contributors to the IGS as well as the general user community. The CBIS, accessible through ftp and the WWW, provides up-to-date data holding summaries of the distributed data systems.

A discussion of the network data flow, from station to global data center to users, will be presented as well as a description of the IGS CBIS. Statistics on data quantity, volume, latency, and user access will be given.

INTRODUCTION

OVERVIEW OF GPS

The U.S. Department of Defense developed the Global Positioning System (GPS) as an all-weather, satellite-based navigation system for military and civilian applications. The current operational configuration of 24 satellites are in circular orbit at a height of approximately 20,200 km above the Earth and positioned so that at least four to six satellites are visible from any point on the Earth at one time. In addition to their military uses, GPS receivers are available to civilian applications; in fact, the system has become increasingly important to scientific and commercial applications. Some of the diverse civilian applications are vehicle location and navigation, marine and aircraft navigation, management of natural resources, including integration with geographic information systems (GIS), and geodetic studies of the Earth.

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GPS is a one-way ranging system where GPS satellites transmit ranging codes to receivers in two radio frequency carriers at L-band frequencies. The receiver measures the time required for the signal to travel from the satellite to the receiver. Through various internal calculations, the receiver determines the range to the satellite. Three-dimensional, geocentric coordinates can then be ascertained by combining the ranges to four satellites with the orbit positions of the satellites.

GPS receivers can be fixed, in mobile vehicles, on aircraft, or on spacecraft. Users can derive their position directly from the receiver at an accuracy of less than 10 meters; a relative position using corrections from another GPS receiver at a known position can yield the user's position to less than one meter. Postprocessing the data using dual-band carrier-phase measurements provide users with sub-centimeter accuracies. This precise positioning is utilized by scientists to study plate tectonics and Earth orientation and monitor deformation of the solid Earth, such as earthquake displacements.

THE INTERNATIONAL GPS SERVICE FOR GEODYNAMICS (IGS)

The International GPS Service for Geodynamics (IGS) was formed with the endorsement of the International Association of Geodesy (IAG) [Mueller, 1993]. The purpose of this international service is to provide GPS data from a global network of GPS tracking sites as well as derived products, such as highly accurate ephemerides, Earth rotation parameters, a global reference frame, to the international science community to further understanding in geodetic and geophysical research. In 1991, a call for participation was issued, seeking participation from groups and agencies to install GPS sites and serve as data centers and/or data analysis centers. The first IGS campaign was held mid-1992; a pilot service continued after this successful test period and the service became operational in January 1994. In general, the GPS tracking data are delivered, archived, and publicly available within 48 hours (often 24) after the end of observation day. The map in Figure 1 depicts the current global network of IGS sites. Derived products, including an official IGS orbit, are available within ten days.

During the IGS planning stages, it was realized that a distributed data management system was vital to the success of the service. A distributed system would provide for rapid turnaround of data from the global GPS network as well as ensure system backup and redundancy should a particular data center become unavailable for some period of time. Furthermore, establishment of standards in data formats and compression were necessary to ensure the efficient and timely flow of data and products. Finally, a centralized information system has been established to provide the user community with the current status of the receiver network as well as the data holdings at the distributed data centers.

FLOW OF IGS DATA AND INFORMATION

The flow of IGS data (including both GPS data and derived products) as well as general information can be divided into several levels [IGS Colleague Directory, 1994] as shown in Figure 2:

- Tracking Stations
- Data Centers (operational, regional, and global)
- Analysis Centers
- Analysis Center Coordinator
- Central Bureau (including the Central Bureau Information System, CBIS)
- Governing Board

These components of the IGS will be discussed in more detail below.

Tracking Stations

The global network of GPS tracking stations are equipped with precision, dual-frequency, P-code receivers operating at a thirty-second sampling rate. The IGS currently supports nearly 100 globally distributed stations. These stations are continuously tracking and are accessible through phone lines, network, or satellite connections thus permitting rapid, automated download of data on a daily basis. Any station wishing to participate in the IGS must submit a completed station log to the IGS Central Bureau, detailing the receiver, site location, responsible agencies, and other general information. These station logs are accessible through the CBIS. The IGS has established a hierarchy of these 100 sites since not all sites are utilized by every analysis center [Gurtner, et. al., 1995]. A core set of approximately forty sites are analyzed on a daily basis by most centers; these sites are called global sites. Sites used by one or two analysis centers for densification on a regional basis are termed regional sites. Finally, sites part of highly dense networks, such as one established in southern California to monitor earthquake deformation, are termed local sites. This classification of IGS sites determines how far in the data center hierarchy the data are archived. For example, only global sites should flow to the global data center level, where regional sites would be archived at a regional data center only.

Data Centers

The IGS has also established a hierarchy of data centers to distribute data from the network of tracking stations: operational, regional, and global data centers. Operational data centers are responsible for the direct interface to the GPS receiver, connecting to the remote site daily and downloading and archiving the raw receiver data. The quality of these data are validated by checking the number of observations, number of observed satellites, date and time of the first and last record in the file. The data are then translated from raw receiver format to a common format and compressed. Both the observation and navigation files are then transmitted to a regional or global data center within 24 hours following the end of the observation day.

Regional data centers gather data from various operational data centers and maintain an archive for users interested in stations of a particular region. These data centers forward data from designated global sites to the global data centers within at most 24 hours of receipt. IGS regional data centers have been established in several areas, including Europe and Australia.

The IGS global data centers are ideally the principle GPS data source for the IGS analysis centers and the general user community. Global data centers are tasked to provide an on-line archive of at least 150 days of GPS data in the common data format, including, at a minimum, the data from all global IGS sites. The global data centers are also required to provide an on-line archive of derived products, generated by the seven IGS analysis centers. There are currently three IGS global data centers:

- Crustal Dynamics Data Information System (CDDIS), at NASA's Goddard Space Flight Center in Greenbelt, MD
- Institut Geographique National (IGN) in Paris, France
- Scripps Institution of Oceanography (SIO) in La Jolla, CA

These data centers equalize holdings of global sites and derived products on a daily basis. The three global data centers provide the IGS with a level of redundancy, thus preventing a single point of failure should a data center become unavailable. Users can continue to reliably access data on a daily basis from one of the other two data centers. Furthermore, three centers reduce the network traffic that could occur to a single geographical location.

Analysis Centers

The seven IGS analysis centers retrieve the IGS tracking data from the global data centers on a daily basis and produce daily orbit products and weekly Earth rotation parameters and station position solutions. These solutions, along with summary files detailing data processing techniques, station and satellite statistics, etc., are then submitted to the global data centers within one week of the end of the observation week.

Analysis Center Coordinator

The Analysis Center Coordinator, located at the National Resources Canada (NRCan), retrieves the derived products and produces a combined IGS orbit product based on a weighted average of the seven individual analysis center results. The combined orbit is then made available to the global data centers and the IGS CBIS within ten days following the end of the observation week.

Central Bureau

The Central Bureau, located at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, sees to the day-to-day operations and management of the IGS. The Central Bureau facilitates communication within the IGS community through several electronic mail services. The Central Bureau also has created, operates, and maintains the Central Bureau Information System (CBIS) [Liu, et. al., 1995], designed to disseminate information about the IGS and its participants within the community as well as to other interested parties. The CBIS was developed to provide a central source for general information on the IGS as well as pointers to the distributed data centers, guiding users to the most efficient access to data and product holdings. In addition, the CBIS contains general information about the current status of the GPS constellation, the IGS global network, and the various data and analysis centers associated with the IGS. The CBIS contains information about:

- IGS organization and operation
- global network of GPS tracking sites
- general descriptions of GPS receivers and antennas
- access information and data holdings summaries for the IGS data centers
- descriptions of GPS data flow
- up-to-date data and product availability charts
- GPS system status
- IGS electronic mail archives
- software for general use (e.g., UNIX-compatible compress/decompress routines for various platforms)
- IGS combined orbit product archive

The CBIS server is accessible over the Internet, via anonymous ftp, and the World Wide Web (WWW).

Governing Board

The IGS Governing Board, consisting of fifteen elected members from the IGS participants, is responsible for the overall management of the IGS and recommending modifications to the organization of the service in order to improve its efficiency, reliability, etc.

OPTIMIZATION OF THE FLOW OF DATA AND INFORMATION

During the IGS design phases, it was realized that a distributed data flow/data archive scheme would be required. The network of fixed GPS receivers could easily grow to over 200. Therefore, the volume of data transmitted must be optimized in order to make efficient use of electronic networks in place around the world. Furthermore, a centralized data information system would be required to monitor the flow of data and provide general information on data holdings and status of the IGS in general.

The network of IGS sites is composed of a mix of GPS receivers. To facilitate the analysis of these data, raw receiver data are downloaded on a daily basis by operational data centers and converted into a standard format called RINEX, Receiver INdependent EXchange format. This format was developed within the GPS user community and has been adopted not only by users of GPS data but also by receiver manufacturers. The GPS data unit currently consists of two daily files, starting at 00:00:00 UTC and ending at 23:59:30 UTC; one file contains the range observations, a second file contains the GPS broadcast ephemerides for all satellites tracked. These two RINEX data files form the smallest unit of GPS data for the IGS and after format conversion, are forwarded to a regional or global data center. Data products generated by IGS analysis centers are also available in standard formats, developed by the GPS user community.

A second area of standards employed by the IGS is in data compression. The daily GPS data in RINEX format from a single site are approximately 2.0 Mbytes in size; with a network of nearly 100 sites, this totals 200 Mbytes per day. Thus, to lesson electronic network traffic as well as storage at the various data centers, a data compression scheme was promoted from the start of the IGS test campaign. It was realized that the chosen software must be executable on a variety of platforms (e.g., UNIX, VAX/VMS, and PC) and must be in the public domain. After testing several packages, UNIX compression was the software of choice and executables for VAX/VMS and PC platforms were obtained and distributed to data and analysis centers. This data compression algorithm reduces the size of the distributed files by approximately a factor of three; thus daily GPS files average 0.6 Mbytes per site, or a total of 60 Mbytes per day.

The Central Bureau Information System (CBIS), discussed earlier, is an electronic service accessible via INTERnet and WWW for distributing information to the IGS user community. Although the CBIS is a central data information system, the underlying data are updated via automated queries to the distributed data centers. These queries update the CBIS data holdings information as well as GPS status reports and IGS electronic mail archives several times per day. Other data, such as station configuration logs and the official IGS product archives, are deposited when new/updated information is generated.

STATISTICS ON DATA FLOW

The Crustal Dynamics Data Information System (CDDIS) serves as a global data center for the IGS. Automated routines are executed at scheduled times each day to receive/retrieve GPS data from regional and operational data centers, summarize and validate these data, archive these data to on-line disk areas for user access, and create upload status files on data holdings for the CBIS.

The CDDIS has been compiling statistics on system usage of GPS data and products since late 1992. Figure 3 shows that 75 percent of the data from IGS global sites are available at the global data center level within one day and 85 percent are available within two days. The IGS tracking stations and data centers hope to improve this statistic in the next few months. Procedures are currently under test to push data to the global data centers even faster. This already remarkable statistic would not have been possible, however, without the adoption of standards in data formatting and compression.

Figure 4 illustrates the monthly volume of data transferred to and archived at the CDDIS since 1994. Figure 5 shows the number of host accesses since 1994 as well as the number of distinct hosts accessing the CDDIS per month. As can be seen, the system usage continues to grow as GPS technology is utilized by an increasingly diverse user community.

CONCLUSIONS

The IGS has shown that near real-time availability of GPS data is a reality. The hierarchy that was established in both tracking stations and data centers has streamlined data flow, with the global data center serving as the main interface between the data and the user. Standards in data formats and compression software are essential to the successful operation of the IGS. Furthermore, automation in data archiving and retrieval is a necessity in order to provide near real-time access to data over an extended period of time. The IGS has found, however, that some data flow paths require optimization in order to prevent the flow of redundant data to data centers, as well as scheduling of data deliveries to avoid congestion over electronic networks.

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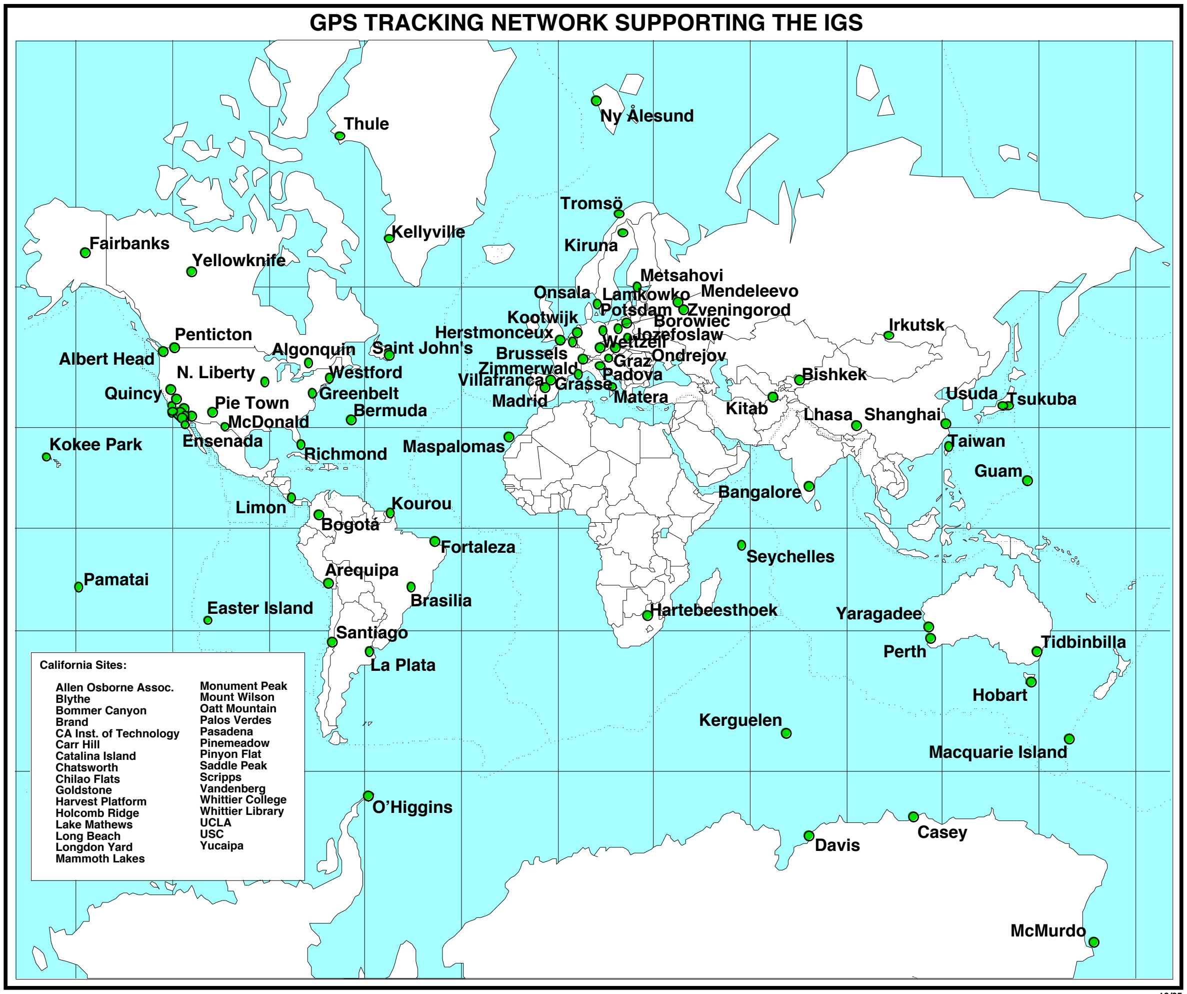

Figure 1. Global IGS Network

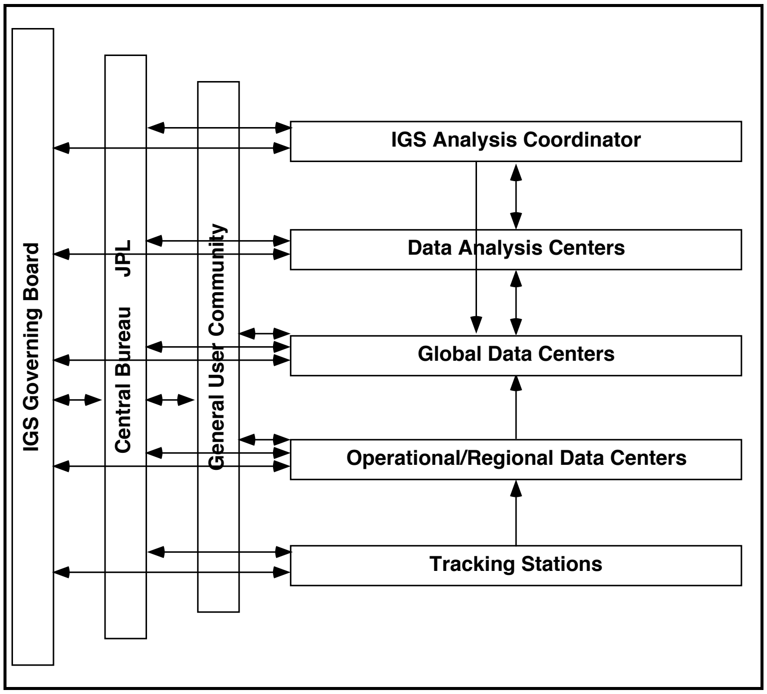

Figure 2. Flow of IGS Data and Information

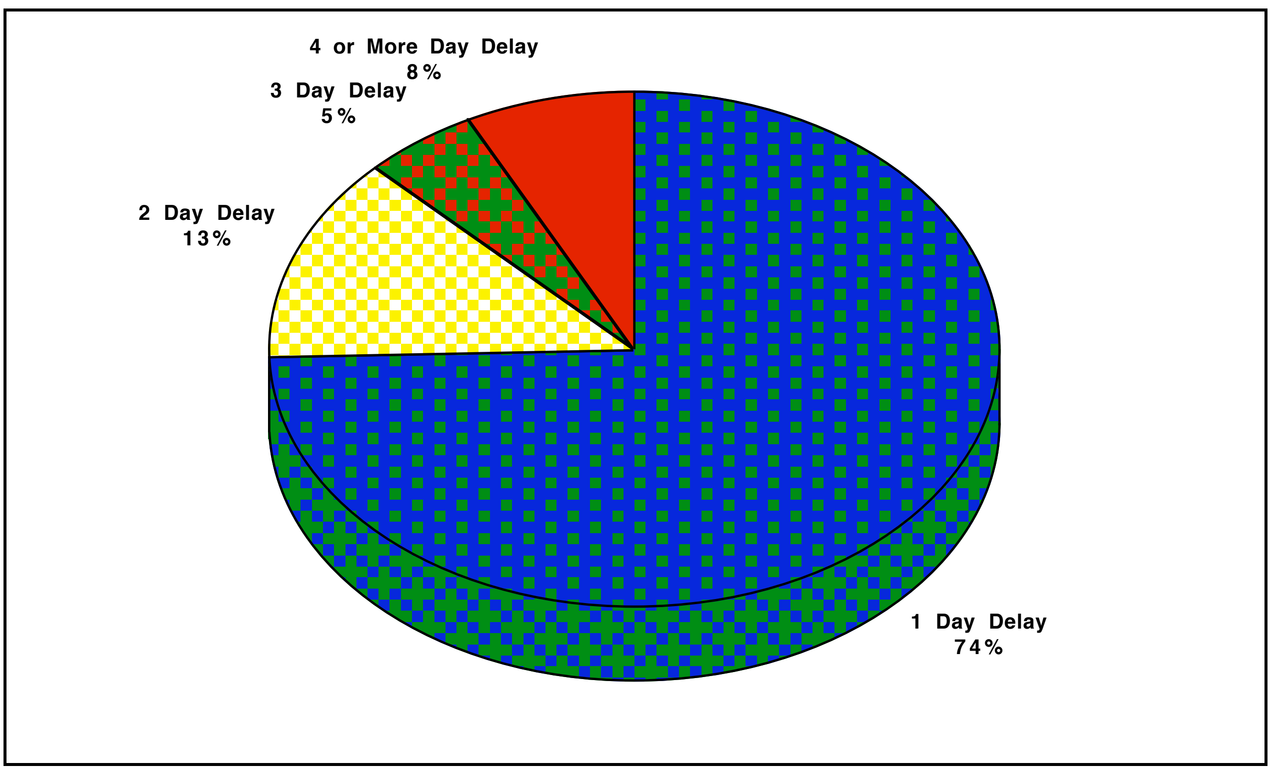

Figure 3. Data Latency Statistics for IGS Global Sites at the CDDIS

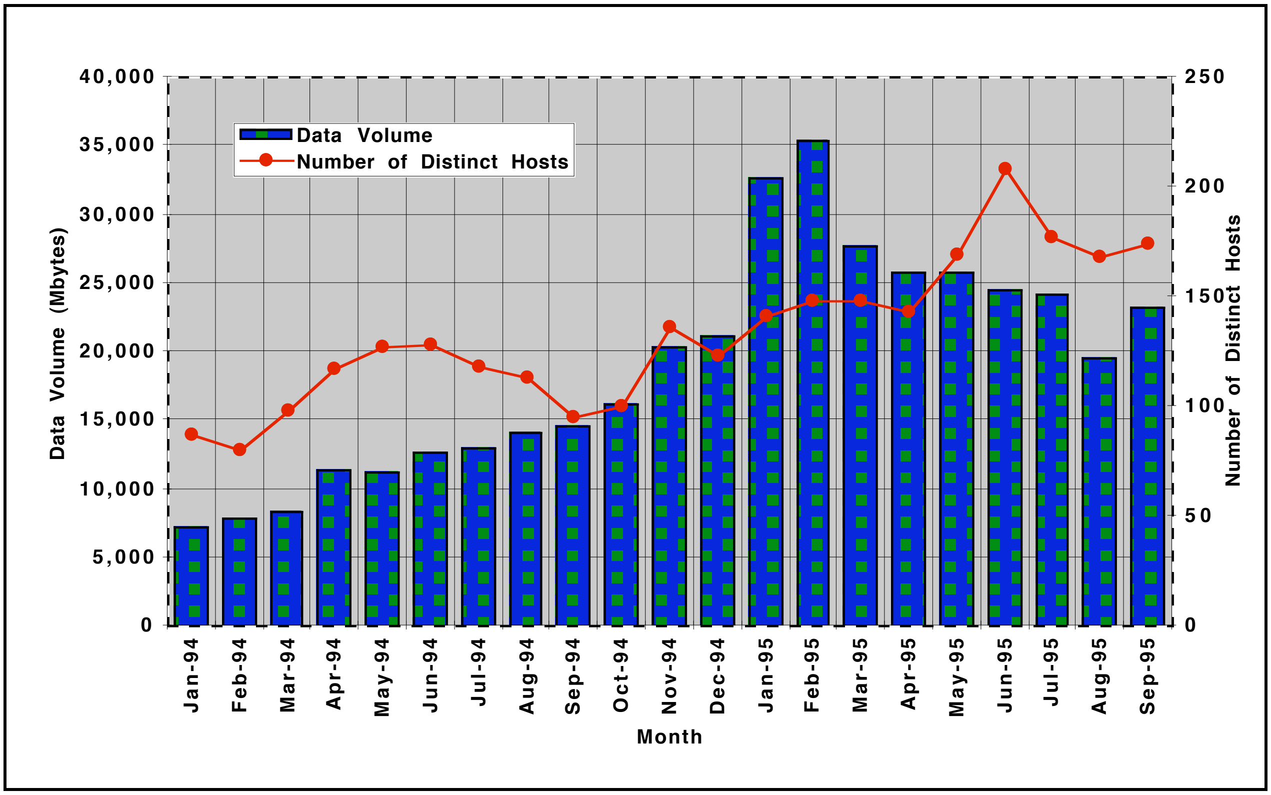

Figure 4. Monthly Data Volume Statistics for the CDDIS

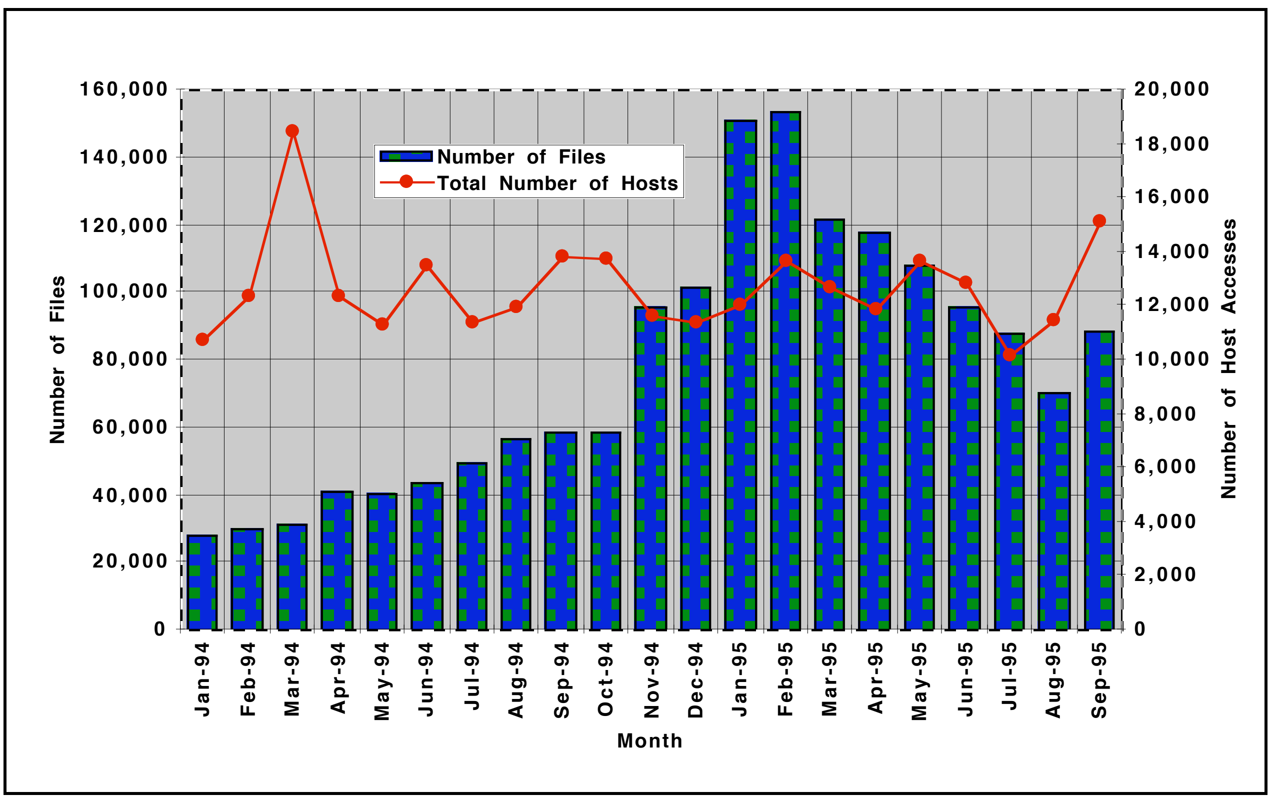

Figure 5. Monthly Host Access Statistics for the CDDIS