FLOW OF GPS DATA AND PRODUCTS FOR THE IGS

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INTRODUCTION TO THE IGS

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 designated 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 final IGS orbit product, and for access by the user community in general. To further aid users of IGS data and products, the IGS Central Bureau Information System (CBIS) was developed to provide information on IGS sites and participating data and analysis centers. The CBIS, accessible through ftp and the World Wide Web (WWW), provides up-to-date data holding summaries of the distributed data systems. The IGS, its data flow, and the archival and distribution at one of its data centers will be discussed.

IGS DATA AND PRODUCTS

In general, eighty percent of the GPS tracking data are delivered, archived, and publicly available within 24 hours after the end of observation day. Derived products, including an official IGS orbit, are available within ten days.

GPS Tracking Data

The network of IGS sites is composed of GPS receivers from a variety of manufacturers. 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, RINEX, Receiver INdependent EXchange format (Gurtner, 1994). GPS tracking data from the IGS network are recorded at a thirty second sampling rate[1]. The GPS data unit typically consists of two daily files, starting at 00:00:00 UTC and ending at 23:59:30 UTC; one file contains the

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[1] Selected sites sample data at higher rates (e.g., one second) in support of other programs; the data are dessimated at operational data centers prior to submission to the IGS data flow.

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 for archival and distribution. For selected sites, meteorological data from collocated weather stations are available and submitted in the data flow with the observation and navigation data; these data are also in RINEX format. Each site produces approximately 0.6 Mbytes of data per day in compressed RINEX format.

The daily GPS data in RINEX format from a single site are approximately 2.0 Mbytes in size; with a network of over 140 sites, this over 250 Mbytes per day. Thus, to lessen 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 70 Mbytes per day at a typical IGS global data center (GDC).

IGS Products

Seven IGS data analysis centers (ACs) retrieve the GPS tracking data daily from the global data centers to produce IGS products. These products consist of daily precise satellite ephemerides, clock corrections, Earth rotation parameters, and station positions. The files are sent to the IGS global data centers by these analysis centers in uncompressed ASCII (in general), using NGS SP3 format (Remondi, 1989) for the precise ephemerides and Software Independent Exchange Format, SINEX, (Blewitt et. al., 1995) for the station position solutions. The Analysis Coordinator for the IGS, located at NRCan, then accesses one of the global data centers on a regular basis to retrieve these products to derive the combined IGS orbits, clock corrections, and Earth rotation parameters as well as to generate reports on data quality and statistics on product comparisons (Beutler et. al., 1993). The time delay of the IGS final orbit products is dependent upon the timeliness of the individual IGS analysis centers; on average, the combined orbit is generated within two to three days of receipt of data from all analysis centers (typically within ten days). Furthermore, the IGS Analysis Coordinator produces a rapid orbit product, available within 24 hours and a predicted orbit, available within one hour UTC of the day for which this prediction was produced. The precise and rapid orbit products are available from the global data centers as well as the IGS Central Bureau.

Recently, associate analysis centers (AACs) have begun analyzing IGS data on a regional and global basis. To date, six groups regularly produce regionally-oriented analysis in SINEX format to global data centers. Three global network associate analysis centers (GNAACs) incorporate the weekly solutions provided by the analysis centers and the regional network associate analysis centers (RNAACs) to produce combined network solutions.

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 (Gurtner and Neilan, 1995) as shown in Figure 1:

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

The components of the IGS dealing with flow of data and products will be discussed in more detail below.

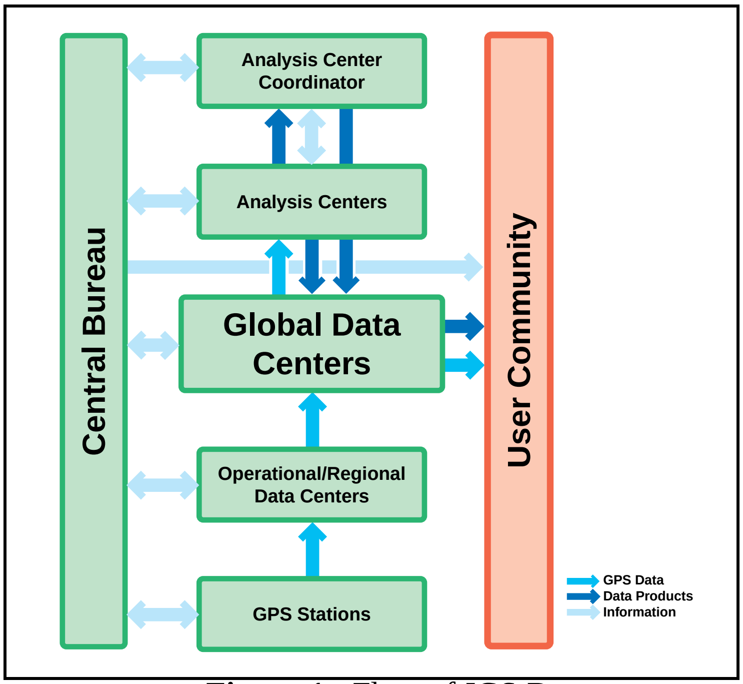

Figure 1. Flow of IGS Data

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 over 140 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 140 sites since not all sites are utilized by every analysis center (Gurtner and Neilan, 1995). A core set of nearly seventy 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, global sites should flow to the global data center level, where regional sites are typically archived at a regional data center only.

Procedures have been developed by the IGS CB for new stations wishing to participate in the IGS (Gurtner and Neilan, 1995). These procedures include recommendations for installation of the site, identification of data flow paths and contacts, and creation of proper site documentation.

Data Centers

During the IGS design phases, it was realized that a distributed data flow and archive scheme would be vital to the success of the service. Thus, the IGS has established a hierarchy of data centers to distribute data from the network of tracking stations: operational, regional, and global data centers. Operational data centers (ODCs) 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 (and sometimes meteorological data) are then transmitted to a regional or global data center within a few hours following the end of the observation day.

Regional data centers (RDCs) 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 ideally within one to two hours of receipt. IGS regional data centers have been established in several areas, including Europe and Australia.

The IGS global data centers (GDCs) are ideally the principle GPS data source for the IGS analysis centers and the general user community. GDCs are tasked to provide an on-line archive of at least 100 days of GPS data in the common data format, including, at a minimum, the data from all global IGS sites. The GDCs are also required to provide an on-line archive of derived products, generated by the IGS analysis centers and associate analysis centers; two of the three global data centers currently provide on-line access to IGS products generated since the start of the IGS test campaign (June 1992). These data centers equalize holdings of global sites and derived products on a daily basis (at minimum). The three GDCs 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. The flow of GPS data from the current network of IGS tracking stations to global data centers is shown in Figure 2; Table 1 presents this information by GPS station name. Table 2 lists the data centers currently supporting the IGS.

IGS data and products are freely available to the public. Interested users can access the IGS CBIS in order to determine a convenient source to access and follow the procedures for connecting to the selected data center.

Analysis Centers

The seven IGS data analysis centers (ACs) retrieve the GPS tracking data daily from the global data centers to produce daily orbit products and weekly Earth rotation parameters and station position solutions; the nine associate Analysis Centers (AACs) retrieve the data

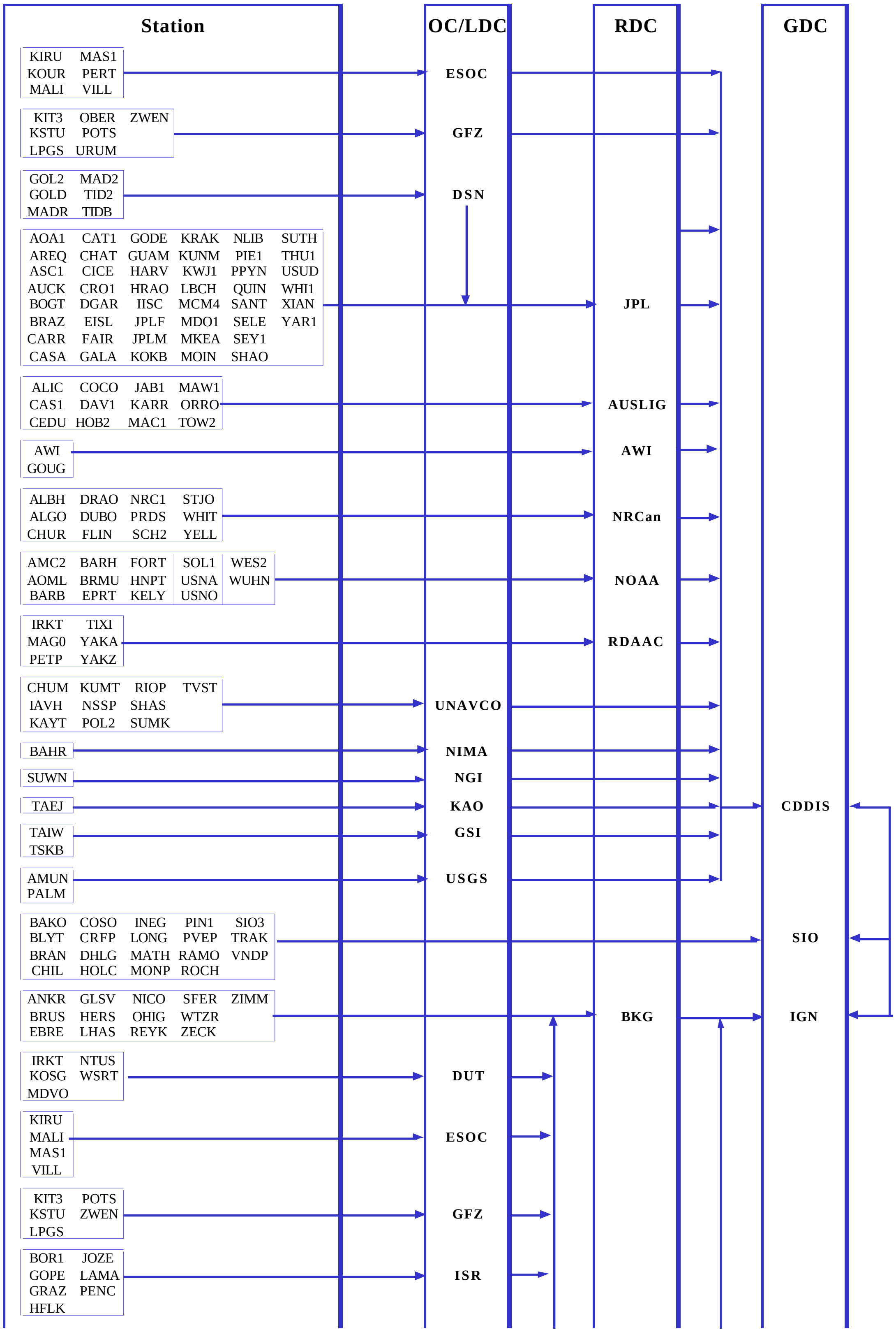

Figure 2. IGS Data Flow (by Data Center)

Table 1. IGS Data Flow (by Station)

Station	OC/LDC	RDC	GDC
ALBH*		NRCan	CDDIS
ALGO*		NRCan	CDDIS
ANKR*		IfAG	IGN
AOA1		JPL	CDDIS
AREQ*		JPL	CDDIS
ASC1*		JPL	CDDIS
AUCK*		JPL	CDDIS
AZU1		JPL	CDDIS
BAHR*	NIMA		CDDIS
BLYT			SIO
BOGT		JPL	CDDIS
BOR1	ISR	IfAG	IGN
BRAN			SIO
BRAZ*		JPL	CDDIS
BRMU*		NOAA	CDDIS
BRUS		IfAG	IGN
CAGL	ASI	IfAG	IGN
CARR		JPL	CDDIS
CAS1*		AUSLIG	CDDIS
CASA		JPL	CDDIS
CAT1		JPL	CDDIS
CHAT*		JPL	CDDIS
CHIL			SIO
CHUR		NRCan	CDDIS
CICE		JPL	CDDIS
CIT1		JPL	CDDIS
COCO*		AUSLIG	CDDIS
COSO			SIO
CRFP			SIO
CRO1*		JPL	CDDIS
CSN1		JPL	CDDIS
DAV1*		AUSLIG	CDDIS
DGAR*		JPL	CDDIS
DHLG			SIO
DRAO*		NRCan	CDDIS
DUBO		NRCan	CDDIS
EBRE		IfAG	IGN
EISL*		JPL	CDDIS
FAIR*		JPL	CDDIS
FLIN		NRCan	CDDIS
FORT*		NOAA	CDDIS
GALA		JPL	CDDIS
GODE		JPL	CDDIS
GOL2	DSN	JPL	CDDIS
GOLD*	DSN	JPL	CDDIS
GOPE	ISR	IfAG	IGN
GRAS	CNES		IGN
GRAZ	ISR	IfAG	IGN
GUAM*		JPL	CDDIS
HART	CNES		IGN
HARV		JPL	CDDIS
HERS		IfAG	IGN
HFLK	ISR	IfAG	IGN
HNPT		NOAA	CDDIS
HOB2*		AUSLIG	CDDIS
HOLC			SIO
HRAO		JPL	CDDIS
IISC*		JPL	CDDIS
IRKT*	DUT	IfAG	IGN
JOZE	ISR	IfAG	IGN
JPLM		JPL	CDDIS
KELY*		NOAA	CDDIS
KERG*	CNES		IGN
KIRU	ESOC	(none) | IfAG	CDDIS | IGN
KIT3*	GFZ	(none) | IfAG	CDDIS | IGN
KOKB*		JPL	CDDIS
KOSG*	DUT	IfAG	IGN
KOUR*	ESOC		CDDIS
KRAK		JPL	CDDIS
KWJ1*		JPL	CDDIS
LAMA	ISR	IfAG	IGN
LBCH		JPL	CDDIS
LHAS*		IfAG	IGN
LONG			SIO
LPGS*	GFZ		CDDIS | IGN
MAC1		AUSLIG	CDDIS
MADR*	DSN	JPL	CDDIS
MALI*	ESOC	(none) | IfAG	CDDIS | IGN
MAS1*	ESOC	(none) | IfAG	CDDIS | IGN
MATE*	ASI	IfAG	IGN
MATH			SIO
MCM4*		JPL	CDDIS
MDO1*		JPL	CDDIS
MDVO*	DUT	IfAG	IGN
MEDI	ASI	IfAG	IGN
METS*	NMA	IfAG	IGN
MKEA*		JPL	CDDIS
MOIN		JPL	CDDIS
MONP			SIO
NLIB*		JPL	CDDIS
NOTO	ASI	IfAG	IGN
NYAL*	NMA	IfAG	IGN
OAT2		JPL	CDDIS
OBER	GFZ	(none) | IfAG	CDDIS | IGN
OHIG*		IfAG	IGN
ONSA*	NMA	IfAG	IGN
PAMA*	CNES		IGN
PENC	ISR	IfAG	IGN
PERT*	ESOC		CDDIS
PIE1		JPL	CDDIS
PIN1			SIO
POL2*	UNAVCO		CDDIS
POTS	GFZ	(none) | IfAG	CDDIS | IGN
PVEP			SIO
QUIN		JPL	CDDIS
RCM6*		NOAA	CDDIS
REYK*		IfAG	IGN
ROCH			SIO
SANT*		JPL	CDDIS
SEY1		JPL	CDDIS
SFER		IfAG	IGN
SHAO*		JPL	CDDIS
SIO3			SIO
SNI1		JPL	CDDIS
SOL1		NOAA	CDDIS
SPK1		JPL	CDDIS
STJO*		NRCan	CDDIS
TAEJ*	KAO		CDDIS
TAIW*	GSI		CDDIS
THU1*		JPL	CDDIS
TID2	DSN	JPL	CDDIS
TIDB*	DSN	JPL	CDDIS
TOUL	CNES		IGN
TRAK			SIO
TROM*	NMA	IfAG	IGN
TSKB*	GSI		CDDIS
UCLP		JPL	CDDIS
UPAD	ASI	IfAG	IGN
USC1		JPL	CDDIS
USNA		GODC	CDDIS
USUD*		JPL	CDDIS
VILL	ESOC	(none) | IfAG	CDDIS | IGN
VNDP			SIO
WES2*		NOAA	CDDIS
WHC1		JPL	CDDIS
WHI1		JPL	CDDIS
WHIT*		NRCan	CDDIS
WLSN		JPL	CDDIS
WTZR*		IfAG	IGN
WUHN*		NOAA	CDDIS
XIAN		JPL	CDDIS
YAR1*		JPL	CDDIS
YELL*		NRCan	CDDIS
ZIMM		IfAG	IGN
ZWEN*	GFZ	(none) | IfAG	CDDIS | IGN

67 global stations; 146 total stations

Notes: * indicates global stations
| notation indicates duplicate flow of data

Table 2. Data Centers Supporting the IGS

Operational Data Centers	
ASI	Italian Space Agency
AUSLIG	Australian Land Information Group
CNES	Centre National d'Etudes Spatiales, France
DSN	Deep Space Network, USA
DUT	Delft University of Technology, The Netherlands
ESOC	European Space Agency (ESA) Space Operations Center, Germany
GFZ	GeoForschungsZentrum Germany
GSI	Geographical Survey Institute, Japan
ISR	Institute for Space Research, Austria
JPL	Jet Propulsion Laboratory, USA
KAO	Korean Astronomical Observatory
NIMA	National Image and Mapping Agency (formerly DMA), USA
NMA	Norwegian Mapping Authority
NOAA	National Oceanic and Atmospheric Administration, USA
NRCan	Natural Resources Canada
SIO	Scripps Institution of Oceanography, USA
UNAVCO	University NAVSTAR Consortium, USA
Regional Data Centers	
AUSLIG	Australian Land Information Group
IfAG	Institut für Angewadte Geodäsie, Germany
JPL	Jet Propulsion Laboratory, USA
NOAA/GODC	National Oceanic and Atmospheric Administration, USA
NRCan	Natural Resources Canada
Global Data Centers	
CDDIS	Crustal Dynamics Data Information System, NASA GSFC, USA
IGN	Institut Géographique National, France
SIO	Scripps Institution of Oceanography, USA

and products to produce station position solutions. These AC 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; AAC solutions typically are submitted two to three weeks later.

Analysis Center Coordinator

The Analysis Center Coordinator, located at 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 GDCs and the IGS CBIS within ten days following the end of the observation week. Rapid and predicted orbits are also generated at NRCan; rapid orbits are available within 24 hours while the predicted orbits are available within one hour UTC of the day for which this prediction was generated.

Central Bureau

The Central Bureau, located at JPL, 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. 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 or updated information is generated.

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. The IGS would also like to encourage the stations and operational data centers to upload the data to regional and global data centers even faster than the current 24 hour average. This schedule would permit the analysis centers to produce more rapid orbit products.

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