# CDDIS Global Data Center Technical Report 2015

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## 1 Introduction

The Crustal Dynamics Data Information System (CDDIS) is NASA's data archive and information service supporting the international space geodesy community. For over 35 years, the CDDIS has provided continuous, long term, public access to the data (mainly GNSS-Global Navigation Satellite System, SLR-Satellite Laser Ranging, VLBI-Very Long Baseline Interferometry, and DORIS-Doppler Orbitography and Radiopositioning Integrated by Satellite) and products derived from these data required for a variety of science observations, including the determination of a global terrestrial reference frame and geodetic studies in plate tectonics, earthquake displacements, volcano monitoring, Earth orientation, and atmospheric angular momentum, among others. The specialized nature of the CDDIS lends itself well to enhancement to accommodate diverse data sets and user requirements. The CDDIS is one of NASA's Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Centers (DAACs); EOSDIS data centers serve a diverse user community and are tasked to provide facilities to search and access science data and products. The CDDIS is also a regular member of the International Council for Science (ICSU) World Data System (WDS).

The CDDIS serves as one of the primary data centers and core components for the geometric services established under the International Association of Geodesy (IAG), an organization that promotes scientific cooperation and research in geodesy on a global scale. The system has supported the International GNSS Service (IGS) as a global data center since 1992. The CDDIS activities within the IGS during 2015 are summarized below; this report also includes any recent changes or enhancements made to the CDDIS.

## 2 System Description

The CDDIS archive of IGS data and products are accessible worldwide through anonymous ftp (*ftp:/cddis.gsfc.nasa.gov*). The CDDIS has also implemented web-based access to the archive (*http:/cddis.gsfc.nasa.gov/archive*). The CDDIS is located at NASA's Goddard Space Flight Center (GSFC) and is available to users 24 hours per day, seven days per week.

The CDDIS computer system is fully redundant with primary and secondary/failover systems. Each system utilizes a distributed functionality (incoming, outgoing, processing, database, and map servers) and is configured with a local backup system as well as a full backup system located in a third building at GSFC. The archive is equipped with a multi-Tbyte RAID storage system and is scaled to accommodate future growth. All ftp and web access is performed on the outgoing servers. Data centers, stations, and analysis centers push files to the CDDIS incoming servers. Processing of incoming files for the on-line archive is performed in a separate environment that also includes database servers for managing metadata extracted from incoming data.

## 3 Archive Content

As a global data center for the IGS, the CDDIS is responsible for archiving and providing access to GNSS data from the global IGS network as well as the products derived from the analyses of these data in support of both operational and working group/pilot project activities. The CDDIS archive is

approximately 15.1 Tbytes in size of which 14.5 Tbytes (95%) is devoted to GNSS data (13.5 Tbytes), products (1 Tbytes), and ancillary information. All data and products are accessible through subdirectories of *ftp:/cddis.gsfc.nasa.gov/gnss*.

## 3.1 GNSS Tracking Data

### 3.1.1 Operational Data Archive

The user community has access to GNSS data available through the on-line global data center archives of the IGS. Over 70 operational and regional IGS data centers and station operators make data (observation, navigation, and meteorological) available in RINEX format to the CDDIS from selected receivers on a daily, hourly, and sub-hourly basis. The CDDIS also accesses the archives of the other three IGS global data centers, Scripps Institution of Oceanography (SIO) in California, the Institut Géographique National (IGN) in France, and the Korea Astronomy and Space Science Institute (KASI) to retrieve (or receive) data holdings not routinely transmitted to the CDDIS by an operational or regional data center. Table 1 below summarizes the types of IGS operational GNSS data sets archived at the CDDIS.

Table 1a: GNSS Data Type Summary.

| Data Type | Sample Rate | Data Format | Available On-line |
|---|---|---|---|
| Daily GNSS | 30 sec. | RINEX and compact RINEX | Since 1992 |
| Hourly GNSS | 30 sec. | Compact RINEX | 10+ years |
| High-rate GNSS | 1 sec. | Compact RINEX | Since May 2001 |
| Satellite GPS | 10 sec. | Compact RINEX | Since 2002 |

Table 1b: GNSS Data Archive Summary for 2015.

| Data Type | Avg. No. Sites/Day | No. Unique Sites | Avg. Volume/Day | Total Volume/Year | No. Files | Directory Location |
|---|---|---|---|---|---|---|
| Daily GNSS | 485 | 566 | 1,300 Mb | 400 Gb | 735K | */gnss/data/daily* |
| Hourly GNSS | 325 | 384 | 485 Mb | 140 Gb | 6,705K | */gnss/data/hourly* |
| High-rate GNSS | 185 | 224 | 3,100 Mb | 765 Gb | 9,750K | */gnss/data/highrate* |

Data, in RINEX V2.10 or V2.11 format, from GPS and GPS+GLONASS receivers are archived within the main GNSS directory structure */gnss/data*.

The CDDIS archives four major types/formats of GNSS data, all in RINEX format, as described in Table 1a. Daily RINEX data are quality-checked, summarized, and archived to public disk areas in subdirectories by year, day, and file type; the summary and inventory information are also loaded into an on-line database. Over 177K daily station days from 566 distinct GNSS receivers were archived at the CDDIS during 2015. A complete list of daily, hourly, and high-rate sites archived in the CDDIS can be found in the yearly summary reports at URL *ftp:/cddis.gsfc.nasa.gov/reports/gnss/*.

Within minutes of receipt, the hourly GNSS files are archived to subdirectories by year, day, and hour. Although these data are retained on-line, the daily files delivered at the end of the UTC day contain all data from these hourly files and thus can be used in lieu of the individual hourly files. A total of 384 unique hourly sites (over 6.7 million files) were archived during 2015.

High-rate (typically 1-second sampling) GNSS data are archived in files containing fifteen minutes of data and in subdirectories by year, day, file type, and hour. Many of these data files are created from real-time streams. Data from 224 unique high-rate sites (nearly 10 million files) were also archived in the CDDIS in 2015.

The CDDIS generates global broadcast ephemeris files (for both GPS and GLONASS) on an hourly basis. These files are derived from the site-specific ephemeris data files for each day/hour. These files are appended to a single file that contains the orbit information for all GPS and GLONASS satellites for the day up through that hour. The merged ephemeris data files are then copied to the day's subdirectory within the hourly data file system. Within 1-2 hours after the end of the UTC day, after sufficient station-specific navigation files have been submitted, this concatenation procedure is repeated to create the daily

broadcast ephemeris files (both GPS and GLONASS), using daily site-specific navigation files as input. These daily broadcast files are then copied to the corresponding subdirectory under the daily file system. Users can thus download this single, daily (or hourly) file to obtain the unique navigation messages rather than downloading multiple broadcast ephemeris files from the individual stations.

The CDDIS generates and updates "status" files, (*/gnss/data/daily/YYYY/DDD/YYDD.status*) that summarize the holdings of daily GNSS data. These files include a list of stations. The archive status files of CDDIS GNSS data holdings reflect timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath. The user community can thus view a snapshot of data availability and quality by checking the contents of such a summary file.

### 3.1.2 RINEX V3 (MGEX) Archive

During 2015 the CDDIS continued the archiving of data in RINEX V3 format from multi-GNSS receivers participating in the Multi-GNSS Experiment (MGEX) as well as products derived from the analysis of these data. The data include all available multi-GNSS signals (e.g., Galileo, QZS, SBAS, and BeiDou) in addition to GPS and GLONASS. The data are currently archived in a campaign directory structure at CDDIS *(/gnss/campaign/mgex/data*). The summary of the MGEX data holdings at the CDDIS is shown in Table 2 below. Daily status files are also provided that summarize the MGEX data holdings; however, data quality information, generated for operational GNSS data holdings, is not available through the software used by CDDIS to summarize data in RINEX V3 format. CDDIS continues to investigate and evaluate software capable of providing data summary/QC information for RINEX V3 data. Products derived in support of MGEX by three to six ACs are also available through the CDDIS (*/gnss/products/mgex/WWWW*).

Table 2: GNSS MGEX Data Archive Summary for 2015.

| Data Type | Avg. No. Sites/Day | No. Unique Sites | No. Files | Avg. Volume/Day | Total Volume/Year | Directory Location |
|---|---|---|---|---|---|---|
| Daily GNSS | 110 | 137 | 35.1K | 710 Mb | | */gnss/data/campaign/mgex/daily* |
| Hourly GNSS | 50 | 58 | 17.1K | 190 Mb | | */gnss/campaign/mgex /data/hourly* |
| High-rate GNSS | 45 | 52 | 13.6K | 2,300 Mb | 740 Gb | */gnss/campaign/mgex /data/highrate* |

The CDDIS also added a merged, multi-GNSS broadcast ephemeris file containing GPS, GLONASS, Galileo, BeiDou, QZSS, and SBAS ephemerides from MGEX stations. This file, generate by colleagues at the Technical University in Munich (TUM) and Deutsches Zentrum f¨ur Luft- und Raumfahrt (DLR), is similar to the daily and hourly concatenated broadcast message files in RINEX V2 format provided by the CDDIS for the operational GPS+GLONASS data sets; it contains all the unique broadcast navigation messages for the day. The file is named brdmDDD0.YYp.Z and found in daily subdirectories within the MGEX campaign archive at CDDIS (*/gnss/data/campaign/mgex/daily/rinex3/YYYY/DDD/YYp*) and in a yearly top level subdirectory (*/gnss/data/campaign/mgex/daily/rinex3/YYYY/brdm)*.

In order to promote usage of RINEX V3 and allow users (and data centers) to become familiar with the format and file naming conventions, several data providers are now delivering data from MGEX stations using both RINEX V2 and V3 filename formats. The CDDIS established a daily subdirectory for the files containing observation or navigation data files using the RINEX V3 filename format within the daily MGEX directory structure (*/gnss/data/campaign/mgex/daily/rinex3/YYYY/DDD/crx*).

Colleagues at TUM and DLR are also providing GPS and QZSS CNAV (civilian navigation) data on an operational basis within MGEX. These messages are collected from a sub-network (ten stations) of MGEX stations and are provided in a merged daily file in a format similar to RINEX. These files are named *brdxDDD0.YYx.Z* and stored in a daily subdirectory within the MGEX archive at CDDIS (*/gnss/data/campaign/mgex/daily/rinex3/YYYY/cnav*).

Colleagues at DLR and the Chinese Academy of Sciences (CAS) provide differential code biases (DCBs) products for the MGEX campaign. This product was derived from GPS, GLONASS, Galileo, and BeiDou ionosphere-corrected pseudorange differences and is available in the bias SINEX format. DLR has

provided two files per year, daily satellite and daily satellite and station biases, for the 2013-2016 time period in CDDIS directory */gnss/products/mgex/dcb*; CAS provides daily files. Additional details on the DCB product are available in IGSMail message 6868 sent in February 2015 and message 7173 sent in October 2015. Both products use the new RINEX V3 file naming convention.

## 3.2 IGS Products

The CDDIS routinely archives IGS operational products (daily, rapid, and ultra-rapid orbits and clocks, ERP, and station positions) as well as products generated by IGS working groups and pilot projects (ionosphere, troposphere, real-time). Table 3 below summarizes the GNSS products available through the CDDIS. The CDDIS currently provides on-line access through anonymous ftp to all IGS products generated since the start of the IGS Test Campaign in June 1992 in the file system */gnss/products*; products from GPS+GLONASS products are available through this filesystem. Products derived from GLONASS data only continued to be archived at the CDDIS in a directory structure within the file system */glonass/products*.

Table 3: GNSS Product Summary.

| Product Type | Number of ACs/AACs | Volume | Directory |
|---|---|---|---|
| Orbits, clocks, ERP, positions | 14+Combinations | 1.2 Gb/week | */gnss/products/WWWW (GPS, GPS+GLONASS)*<br>*/glonass/products/WWWW (GLONASS only)* |
| Troposphere | Combination | 2.6 Mb/day, 940 Mb/year | */gnss/products/troposphere/YYYY* |
| Ionosphere | 5+Combination | 4 Mb/day, 1.5 Gb/year | */gnss/products/ionex/YYYY* |
| Real-time clocks | Combination | 6.0 Mb/week | */gnss/products/rtpp/YYYY* |
| Repro2 products | 9+Combination | 500 Mb/week | */gnss/products/WWWW/repro2* |

Note: *WWWW*=4-digit GPS week number; *YYYY*=4-digit year

The CDDIS also continues to archive combined troposphere estimates in directories by GPS week. Global ionosphere maps of total electron content (TEC) from the IONEX AACs are archived in subdirectories by year and day of year. Real-time clock comparison products have been archived at the CDDIS in support of the IGS Real-Time Pilot Project, and current IGS Real-Time Service, since 2009.

In 2015, the IGS analysis centers completed the upload of products for the second IGS reprocessing campaign (repro2). The CDDIS provided support through upload of files from the ACs and online archive of these products (*/gnss/products/WWWW/repro2*).

## 3.3 Real-Time Activities

In 2013, the CDDIS staff configured a server and began testing a real-time caster to provide a real-time streaming capability at GSFC and support the IGS Real-Time Service (IGS RTS). The CDDIS successfully tested obtaining product streams from the BKG and IGS casters and providing access to these streams to authorized users; additional streams from NRCan and GA were later added to the caster. Work was completed in spring 2015 and the CDDIS caster became fully operational, broadcasting nearly 40 product and 165+ data streams in real-time. The caster runs the NTRIP (Network Transport of RTCM via internet Protocol) format. Figure 1 shows the distribution of stations providing real-time streams to the CDDIS caster.

As stated previously, the CDDIS is one of NASA's EOSDIS DAACs and through EOSDIS, has access to a world-class user registration process, the EOSDIS User Registration System (URS), with over 140K users in its system. Since the NTRIP-native registration/access software was not compatible with NASA policies, the CDDIS developed software to interface the caster and the URS within a generic Lightweight Directory Access Protocol (LDAP) framework. The module was specifically developed to easily interface with multiple user verification systems and was given back to the NTRIP community for possible inclusion in future releases. The user registration form is available on the CDDIS website; once completed, the data are passed to the URS, which generates an email to the user with a validation link. The user accesses the link and the URS validates the form's data; this process is accomplished within a

minute or less. The user's validated access request is submitted to CDDIS staff for access authorization to the CDDIS caster. This second step is not yet automated and can take several hours to configure depending on the time of day. In addition, users registering in this system have access to the entire suite of EOSDIS products across all 12 EOSDIS DAACs.

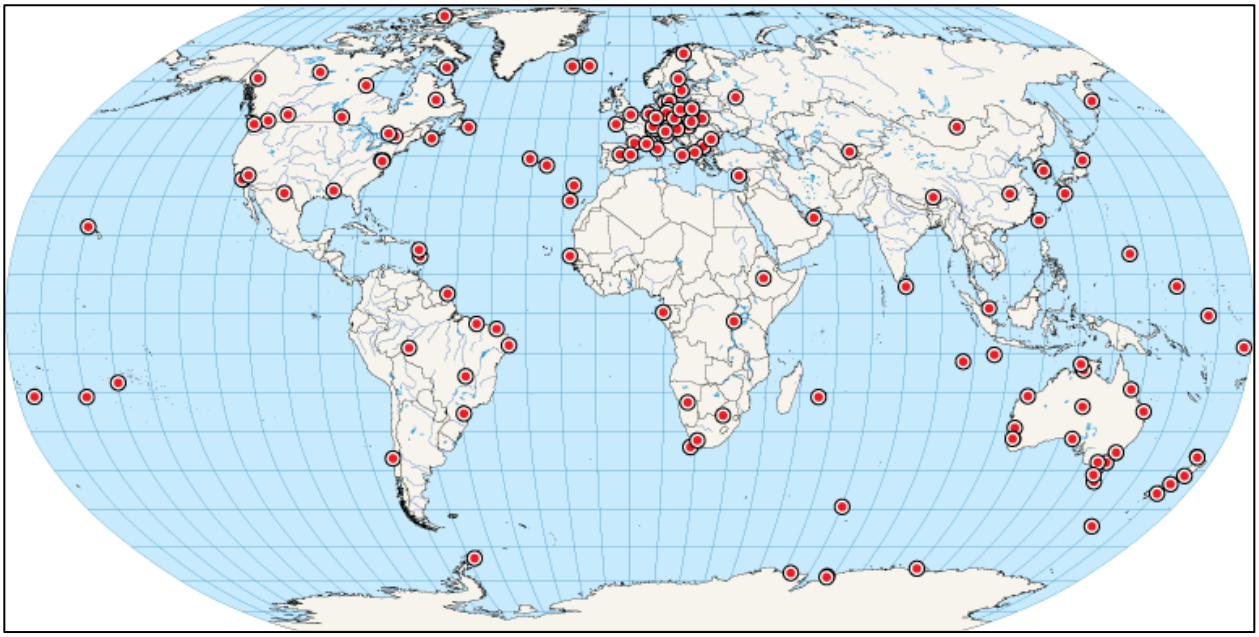

**Figure 1**. CDDIS is operationally supporting the dissemination of data from over 160 real-time GNSS sites as well as near real-time products derived from these data.

Initially, the CDDIS caster is providing access to product streams from several regional real-time casters. Data streams have also been tested, provided through JPL for receivers in NASA's Global GPS Network. In the near future, an additional set of stations from JPL's Global Differential GPS (GDGPS) network will be added to the CDDIS caster. This network of globally distributed, geodetic quality, dual frequency receivers, will provide additional 1 Hz data streams to those current available from the IGS RTS.

Now that the CDDIS caster is operational, the system serves as the third primary caster for the IGS RTS, thus providing a more robust topology with redundancy and increased reliability for the service. User registration, however, for all three casters is unique; therefore current users of the casters located at the IGS and BKG will be required to register through the CDDIS registration process in order to use the CDDIS caster. By the end of 2015, over 50 users from 16 countries have registered to use the CDDIS caster. More information about the CDDIS caster is available at *https://cddis-casterreg.gsfc.nasa.gov/index.html*.

The CDDIS has also developed software to capture real-time data streams into fifteen-minute high-rate files. This capability requires further testing and coordination with the IGS Central Bureau and Infrastructure Committee.

## 3.4 Supporting Information

Daily status files of GNSS data holdings, reflecting timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath, continue to be generated by the CDDIS for RINEX V2 data. By accessing these files, the user community can receive a quick look at a day's data availability and quality by viewing a single file. The daily status files are available through the web at URL *ftp:/cddis.gsfc.nasa.gov/reports/gnss/status*. The daily status files are also archived in the daily GNSS data directories.

In preparation for the analysis center's second reprocessing campaign, the CDDIS developed site-specific reports detailing missing data. Station operators and operational data centers can consult these lists (*ftp:/cddis.gsfc.nasa.gov/gnss/data/daily/reports/missing*) and if available, supply missing files to the CDDIS for inclusion in the global data center archives.

Ancillary information to aid in the use of GNSS data and products are also accessible through the CDDIS. Daily, weekly, and yearly summaries of IGS tracking data (daily, hourly, and high-rate) archived at the CDDIS are generated on a routine basis. These summaries are accessible through the web at URL *ftp:/cddis.gsfc.nasa.gov/reports/gnss.* The CDDIS also maintains an archive of and indices to IGS Mail, Report, Station, and other IGS-related messages.

# 4 System Usage

Figure 2 summarizes the usage of the CDDIS for the retrieval of GNSS data and products in 2015. This figure illustrates the number and volume of GNSS files retrieved by the user community during 2015, categorized by type (daily, hourly, high-rate, MGEX data, products). Nearly 930 million files (nearly 100 Tbytes), excluding robot downloads, were transferred in 2015, with an average of nearly 80 million files per month. Figure 3 illustrates the profile of users accessing the CDDIS IGS archive during 2015. The majority of CDDIS users were once again from hosts in North America, Asia, and Europe.

# 5 Recent Developments

## 5.1 CDDIS Website

The CDDIS developed two applications for querying site information or archive contents. The Site Log Viewer (*http://cddis.gsfc.nasa.gov/SLV2/network/QuerySiteLogs.action*) is an application for the enhanced display and comparison of the contents IAG service site logs; currently the IGS, ILRS, and IDS site logs are viewable through this application. Through the Site Log Viewer application, users can display a complete site log, section by section, display contents of one section for all site logs, and search the contents of one section of a site log for a specified parameter value. Thus, users can survey the entire collection of site logs for systems having particular equipment or characteristics.

Development of a second application, the CDDIS Archive Explorer, was completed in 2015; this application allows users to discover what data are available through the CDDIS. The application (accessible at *http://cddis.gsfc.nasa.gov/Data_and_Derived_Products/CddisArchiveExplorer.html*) allows users, particularly those new to the CDDIS, the ability to specify search criteria based on temporal, spatial, target, site designation, and/or observation parameter in order to identify data and products of interest for download. Results of these queries include a listing of sites and additional metadata satisfying the user input specifications. Such a user interface also aids CDDIS staff in managing the contents of the archive. Future plans for the application include adding a list of data holdings/URLs satisfying the search criteria.

## 5.2 Next Generation Hardware

The current CDDIS server configuration consists of multiple incoming and outgoing servers dedicated to specific functions; the system is equipped with 32 Tbytes of online RAID storage. A new virtual-machine based system was installed within the EOSDIS computer facility and network infrastructure and is currently under testing with expected operations in spring 2016. This new system configuration will provide a more reliable/redundant environment (power, HVAC, 24-hour on-site emergency personnel, etc.) and network connectivity; a disaster recovery system will be installed in a different location on the GSFC campus. The new system location will address the number one operational issue CDDIS has experienced over the past several years, namely, the lack of consistent and redundant power and cooling in its existing computer facility. Multiple redundant 40G network switches will also be utilized to take full advantage of a high-performance network infrastructure by utilizing fully redundant network paths for all outgoing and incoming streams along with dedicated 10G network connections between its primary

operations and its backup operations. The CDDIS will also transition approximately 85% of its operation services over to virtual machine (VM) technology for both multiple instance services in a load balancing configuration which will allow additional instances to be increased or decreased due to demand and will allow maintenance (patching, upgrades, etc.) to proceed without interruption to the user or any downtime. CDDIS will be utilizing a unified storage system (100 Tbytes in size) to easily accommodate future growth of the archive and facilitate near real-time replication between its production and disaster recovery sites.

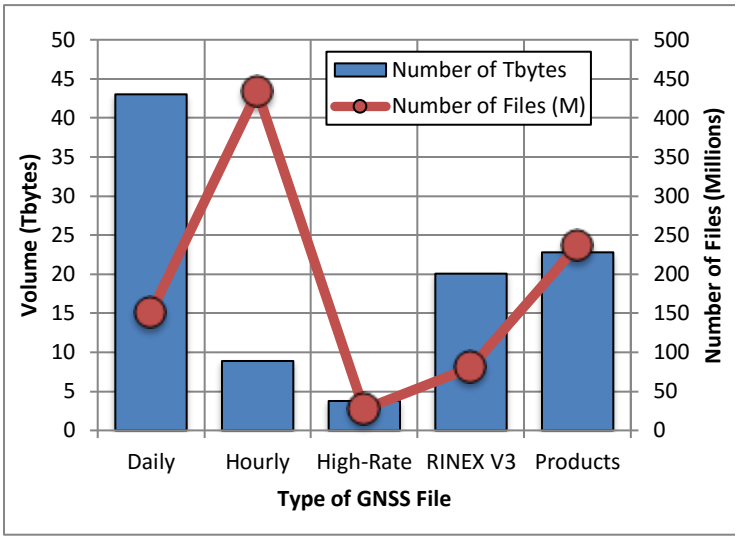


**Figure 2**: Number and volume of GNSS files transferred from the CDDIS in 2015.

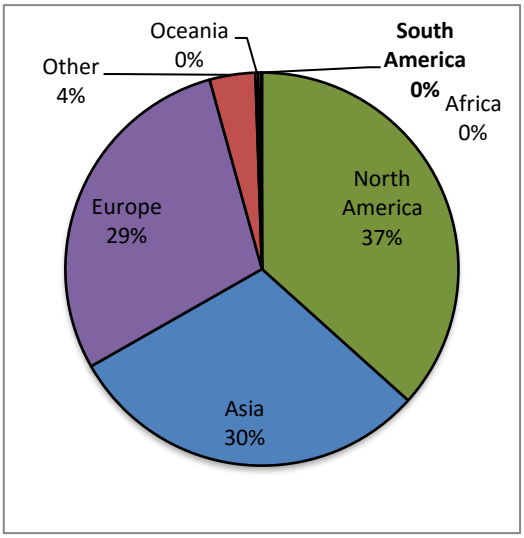


**Figure 3**: Geographic distribution of IGS users of the CDDIS in 2015.

### 5.3 Metadata Developments

The CDDIS continues to make modifications to the metadata extracted from incoming data and product files pushed to its archive. These enhancements have facilitated cross discipline data discovery by providing information about CDDIS archive holdings to other data portals such as Earth Observing System search client and future integration into the Global Geodetic Observing System (GGOS) portal. The staff has begun a metadata evolution effort, re-designing the metadata extracted from incoming data and adding information that will better support EOSDIS applications such as its search client and the metrics collection effort. The CDDIS is also participating in GGOS metadata efforts within the Bureau of Networks and Communications.

The CDDIS continues to implement Digital Object Identifiers (DOIs) to select IGS data sets (GNSS data and products). DOIs can provide easier access to CDDIS data holdings and allow researchers to cite these data holdings in publications. Landing pages are available for each of the DOIs created for CDDIS data products and linked to description pages on the CDDIS website; an example of a typical DOI description (or landing) page, for daily Hatanaka-compressed GNSS data files, can be viewed at: *http:/cddis.gsfc.nasa.gov/Data_and_Derived_Products/GNSS/daily_gnss_d.html*. DOIs will be assigned to additional GNSS data and product sets in the near future.

## 6 Publications

The CDDIS staff attended several conferences during 2015 and presented papers on or conducted demos of their activities within the IGS, including:

P. Michael, C. Noll, J. Roark. "CDDIS Near Real-Time Data for Geodesy Based Applications", Abstract IN43C-3709 presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 15-19 Dec.

M. Pearlman, C. Ma, C. Noll, E. Pavlis, H. Schuh, T. Schoene, R. Barzaghi, S. Kenyon, "The GGOS Bureau of Networks and Observations and an Update on the Space Geodesy Networks", Abstract EGU2015-7420 presented at EGU 2015, April 13-17, 2015, Vienna, Austria, April 12-17, 2015.

C. Noll, P. Michael, L. Tyahla, "Distributing Real-Time GNSS Data and Derived Products at the CDDIS", NASA Earthdata Webinar Series, July 22, 2015.

C. Noll, P. Michael, N. Pollack, "Recent Developments at the CDDIS in Support of GGOS", Abstract No. G43A-1023 presented at 2015 Fall AGU meeting, San Francisco, CA USA, December 14-18, 2015.

Electronic versions of these and other publications can be accessed through the CDDIS on-line documentation page on the web at URL *http:/cddis.gsfc.nasa.gov/Publications/Presentations.html*.

# 7 Future Plans

The CDDIS will continue to coordinate with the Infrastructure Committee, the Data Center Working Group, and other IGS data centers to implement steps outlined in the RINEX V3 transition plan to complete the incorporation of RINEX V3 data into the operational GNSS data directory structure. The CDDIS has begun this process with multi-GNSS, RINEX V3 data from January 2016 onwards; the CDDIS will continue these efforts by integrating RINEX V3 multi-GNSS data from years prior to 2016 into the IGS operational archives. MGEX campaign directories will continue to be maintained during this transition to the operational directory archive. Furthermore, the CDDIS staff will continue to test software to copy RINEX V3 data into files with RINEX V3 filenames as well as QC RINEX V3 data and files and incorporate the software into operational procedures.

The CDDIS will continue to add real-time data and product streams to its operational caster in support of the IGS Real-Time Service. Future activities in the real-time area include capturing the streams for generation of 15-minute high-rate files for archive. This capability requires further testing as the CDDIS caster becomes operational and data streams from real-time stations are added and coordination with the IC. The staff will also investigation automating the process of adding users to the CDDIS caster configuration files.

CDDIS has traditionally used ftp for delivery of data for the archive from both data centers and analysis centers. While this has worked well over the years, transition to the new system provides an opportune time time to look at updating this method to a web-based approach that can utilize the EOSDIS URS infrastructure. CDDIS will further pursue incorporating a web-based approach that will continue to allow suppliers to use existing scripts without significant modification but also tie authentication into the URS.

# 8 Contact Information

To obtain more information about the CDDIS IGS archive of data and products, contact:


| | | |
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C. Noll, Y. Bock, H. Habrich and A. Moore, "Development of data infrastructure to support scientific analysis for the International GNSS Service", Journal of Geodesy, Feb 2009, pages 309-325, DOI 10.1007/s00190-008-0245-6.