The CDDIS: Supporting Scientific Analysis for 25+ Years Using Space Geodesy Data and Products

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- History and background
- System development
- User community

CDDIS

- Crustal Dynamics Data Information System, NASA's active archive of space geodesy data, products, and information
- CDDIS began operations as the data system supporting NASA's Crustal Dynamics Project in 1982
- The CDP used space geodesy to monitor plate motion and the rotational dynamics of the Earth with unprecedented accuracy
- Authorized CDP investigators obtained data from the CDDIS (tapes!) and provided their scientific results to the CDDIS
- CDDIS has been actively serving the international user community since the CDP-era and expanded its data holdings and role within this community

CDDIS & Geodesy

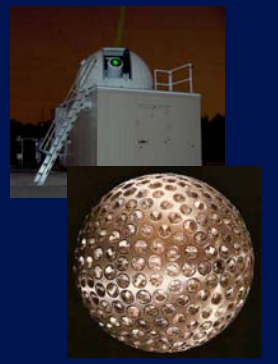
- Geodesy: Measuring the Earth's geometry, gravity field, and rotation; the size and shape of the Earth
- Space Geodesy: Making these measurements between ground-based instruments and objects in space:
  - GNSS
  - Laser ranging
  - VLBI
  - DORIS
- Space geodesy enables research in solid Earth physics, natural hazards, oceanographic, atmospheric, and environmental science
- Accomplished through the creation of a terrestrial reference frame: positions and velocities of a global network of observing stations

Space Geodesy 101

- Geodesy provides a foundation for all Earth observations
- Space geodesy is the use of precise measurements between space objects (e.g., orbiting satellites, quasars) to determine
  - Positions of points on the Earth
  - Position of the Earth's pole
  - Earth's gravity field and geoid

GNSS: Satellites (GPS-U.S., Russia-GLONASS, future EU-Galileo) equipped with precise clocks transmitting messages such as ephemeris, clock offsets, etc. to ground (and spaced-based) receivers to measure station to satellite pseudo-range, phase delay

SLR/LLR: Ground-based short-pulse laser transmitting to satellites (or planetary targets) equipped with corner cubes to measure round-trip pulse time-of-flight to satellite



VLBI: Radio telescopes equipped with X/S wideband receivers record signals from quasars to measure difference in signal arrival times

DORIS: Satellites equipped with DORIS receiver and uplink hardware transmit signals to ground beacons to measure Doppler shift on radiofrequency signals

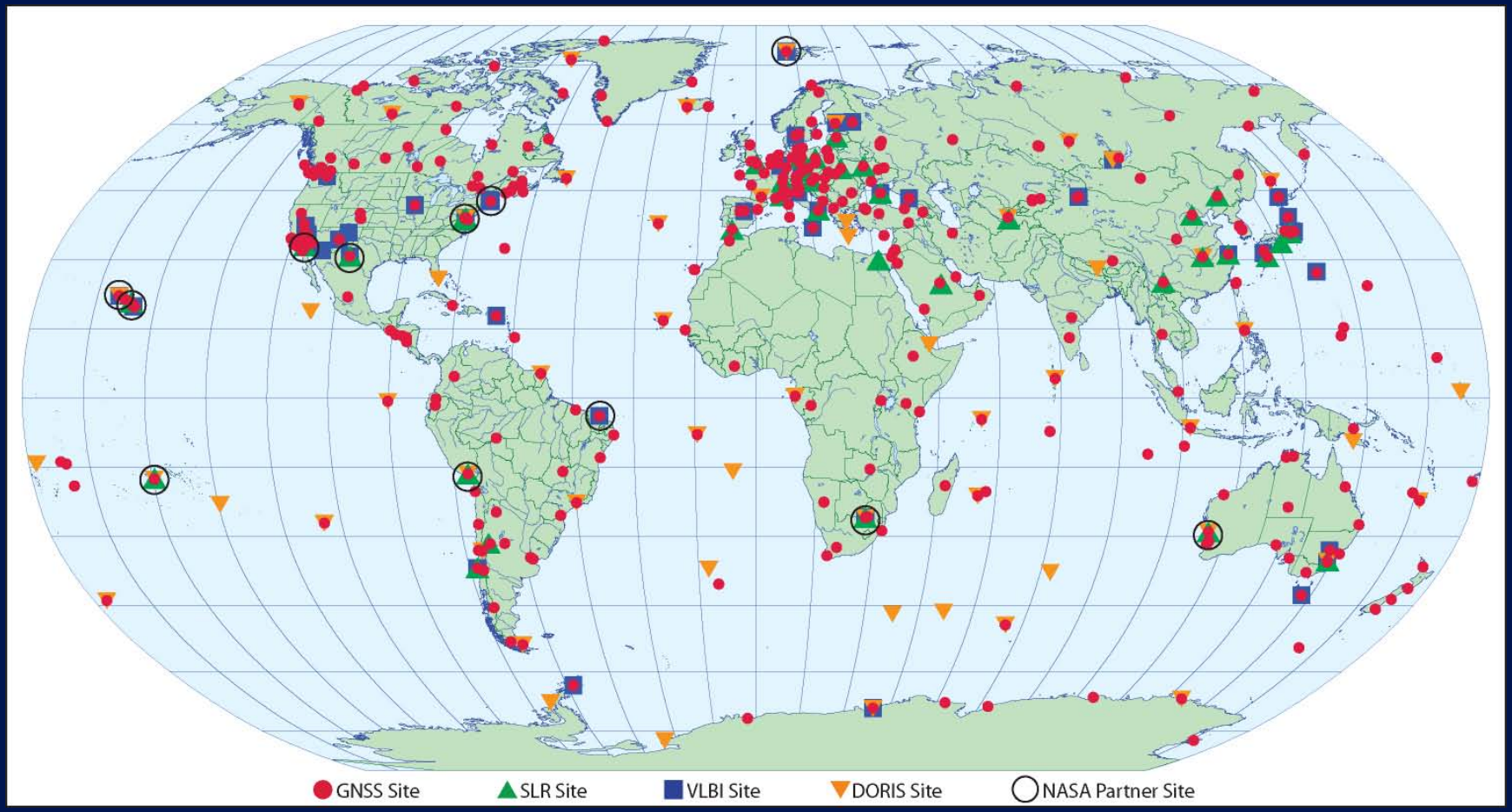
Historical Perspective

- The CDP paved the way for cooperative investigation using space geodesy
- Cost high, global coverage low (with SLR and VLBI)
- By late 1980's, government agencies, universities, etc. began deploying GPS receivers in permanent configurations for scientific study
- Goal: millimeter-level positioning
- Problem: No single government/agency/group could do the job on a global scale
- Solution: international, cooperative partnerships to facilitate research
- Multi-level cooperation: networks, data centers, analysis groups
- The International Association of Geodesy (IAG) began planning for the IGS – The International GPS Service
- Today, the International GNSS Service is a voluntary organization of over 200 agencies
- The IGS has provided precise GNSS observations and products for nearly 20 years

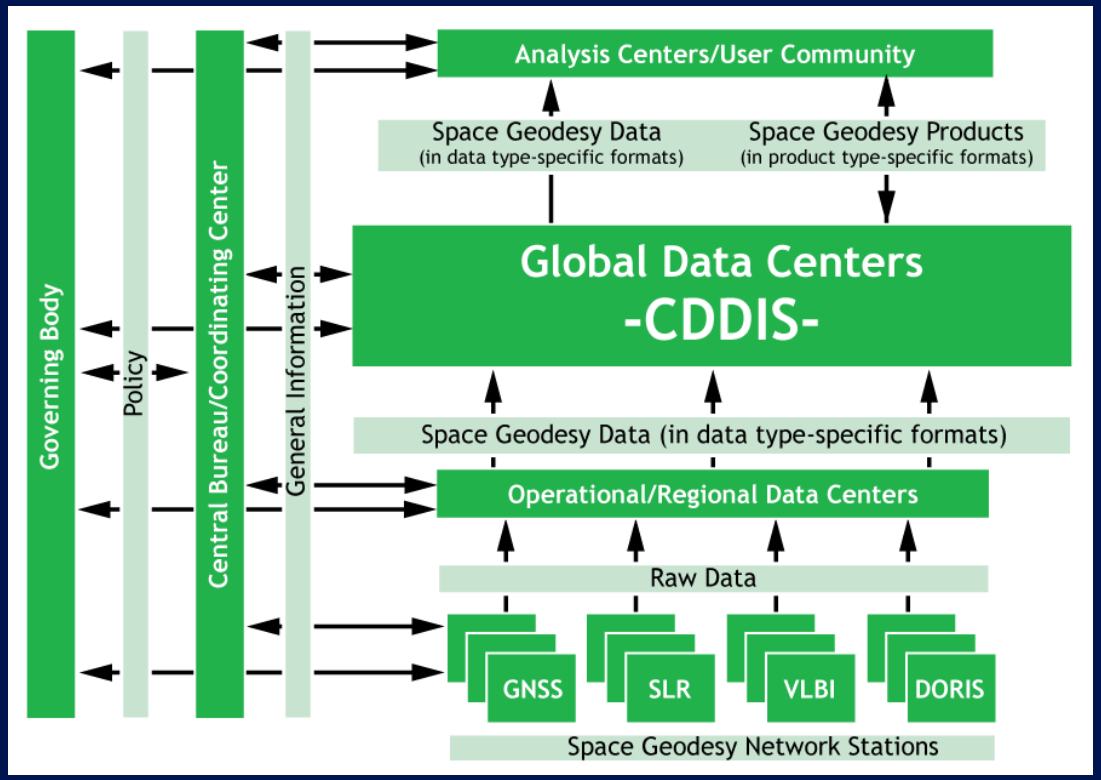
IAG Services

- The IGS served as a model for the creation of other services for space geodesy techniques
- Services function as cooperating federations dedicated to a particular type of data
- Provide data and products on an operational basis to geodesy analysts as well as a broader scientific community
- Examples of a successful model of community management:
  - develop standards
  - self-regulating
  - monitor performance
  - define and deliver products using pre-determined schedules
- Successful operation through cooperation of many international organizations who leverage their respective limited resources to all levels of service functionality

CDDIS Data: Global Networks



Flow of Files to/from CDDIS
(Information, Data, Products)



- Network Stations
  - Continuously operational
  - Timely flow of data
- Data Centers
  - Interface to network stations
  - Perform QC and data conversion activities
  - Archive data for access to analysis centers and users
- Analysis Centers and Coordinators
  - Provide products to users (e.g., station coordinates, precise satellite orbits, Earth orientation parameters, atmospheric products, etc.)
- Central Bureau
  - Management of service
  - Facilitate communications
  - Coordinate activities
- Governing Body
  - General oversight of service
  - Future direction

Space Geodesy Today

- Data from the CDDIS archive are utilized for direct science observations and geodetic studies, e.g., plate motion, gravity field, earthquake displacements, Earth orientation, atmospheric angular momentum, etc.
- Data also contribute to the determination of the Terrestrial Reference Frame, an accurate set of positions and velocities
  - TRF provides the essential stable coordinate system that allows measurements to be linked over space and time; independent of the technology used to define it
  - Space geodetic networks (GNSS, SLR, VLBI, DORIS) provide the critical infrastructure necessary to develop and maintain the TRF
- Data used for Precise Orbit Determination (POD)
  - CDDIS archive of SLR and DORIS data accessed to calculate and verify precise orbits for Earth observation missions (e.g., ERS-1/2, ALOS, Jason-1/2, Envisat, TOPEX, etc.)
  - CDDIS archive of SLR data and GPS flight receiver data also utilized for POD efforts for other geophysical missions (e.g., GFO-1, CHAMP, GRACE, ICESat, GOCE, etc.)
- Additional products include atmosphere measurements to aid in weather forecasting, etc.
- CDDIS providing support to the LRO-LR experiment through its laser ranging archive; also provides development support and hosting of LRO-LR real-time Web site for LOLA SOC

CDDIS Support of IAG Services

- CDDIS is the principle data center supporting services created under the International Association of Geodesy (IAG)
- Data center infrastructure designed for multiple data flow paths
- Redundant flow provides data security and network distribution
- Provides infrastructure for populating CDDIS archive
- Primary user community for CDDIS archive
- Simplicity is the key to success!

CDDIS Archive

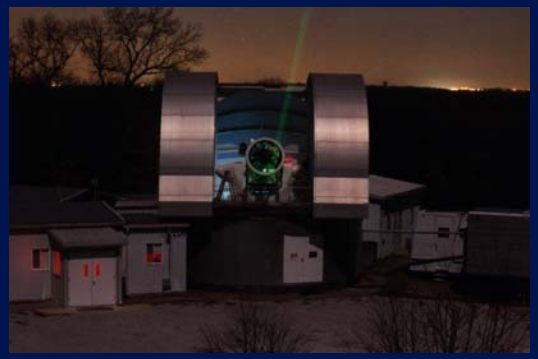
- Archive size: ~5Tb
- Ingest rate: ~60Gb/1 M files per month
- Distribution rate: ~5.5 Tb/40 M files per month
- File size is typically <2Mb/data “granule”, <10Mb/derived product “granule”
- Easy to add new data types/data sets
- Files:
  - Data, products derived from these data, and information about data and products
  - Multi-day, daily, hourly, sub-hourly
  - Varying latencies (minutes, hours, days)
- Metadata:
  - Non-standard, data type specific
  - Extracted from data (not all products) and loaded into relational database
  - Internal access to database

CDDIS User Community

- Expert Users (e.g., Science Teams)
  - Science Teams:
    - Analysis Centers supporting IAG services, tasked with providing standard products as per service specifications
    - U.S. and international groups who produce products for use in higher level products (e.g., orbits for GRACE, Jason, etc.; ionosphere/troposphere products for weather models)
    - Require continuous access to data for generation of products on pre-determined schedules
  - Production Users:
    - Retrieve files from CDDIS to equalize data holdings among other data centers supporting IAG services
  - Use scripts to automate retrieval of required files through ftp
- Novice/Occasional Users
  - Need to explore the contents of the archive by spatial, temporal, platform, or parameter specifications
  - Access archive through ftp to:
    - Pick and chose data or products
    - Grab large subsets of data on irregular basis

International Observe the Moon Night

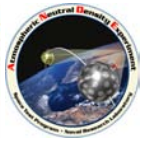
- *http://www.nasa.gov/centers/goddard/visitor/events/observe-the-moon.html*
- GSFC Visitor's Center, September 18th from 6:30-10:00
- Tour of the Goddard Geophysical and Astronomical Observatory (GGAO) laser ranging facilities
- GGAO is home to NASA's Satellite Laser Ranging (SLR) since its development in the early 1960s

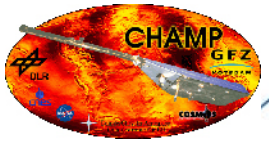


Supported Groups and Missions (a subset!)

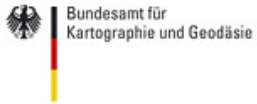
International Services

Missions



Agencies and Universities



Other

CDDIS Overview

- Crustal Dynamics Data Information System, NASA's active archive of space geodesy data, products, and information
- Established in 1982 as a dedicated data bank to archive and distribute all Crustal Dynamics Project-acquired data and information about these data
- Continues to serve as an archive and distribution center for space geodesy data, particularly GNSS, laser ranging, VLBI, and DORIS data
- Has extensive partnerships through the International Association of Geodesy (IAG) serving as one of the primary data centers for the IAG services and its observing system GGOS (Global Geodetic Observing System)
- Past CDDIS funding through NASA's Solid Earth Research Program; now funded through NASA Earth Science Data Systems Core Program

Scientific Contributions of Space Geodesy

- Terrestrial Reference Frame (TRF):
  - Station positions and velocities: GNSS, SLR, VLBI, DORIS
  - TRF scale and temporal variations: VLBI, SLR
  - Network densification: GNSS
  - Homogenous network distribution: DORIS
- Celestial Reference Frame: VLBI
- Precise Orbit Determination (POD):
  - Accurate satellite ephemerides: GNSS, SLR, DORIS
  - Calibration/validation for remote sensing missions, instruments: SLR, GNSS
  - Sea level monitoring: GNSS, SLR, DORIS
- Earth Orientation Parameters (EOP):
  - Polar motion and rates: VLBI, SLR, GNSS, DORIS
  - Length-of-day: GNSS, SLR, DORIS
  - UT1-UTC and long-term stability of nutation: VLBI
- Atmosphere:
  - Tropospheric zenith delays: GNSS, VLBI
  - Global maps of ionosphere mean electron content: GNSS, DORIS
  - Limb sounding for global profiles of water vapor: GNSS
- Gravity:
  - Static and time-varying coefficients of the Earth's gravity field: DORIS, SLR
  - Total Earth mass: SLR
  - Temporal variations of network origin with respect to Earth center of mass: SLR
- Timing:
  - Station and satellite clock solutions: GNSS
  - Time and frequency transfer between time laboratories: GNSS
- Fundamental Physics:
  - General relativity and alternative theories: SLR/LLR
  - Light bending, time dilation: VLBI

Space Geodesy Data Records In the CDDIS

Data Record	Data Set	Processing Level	Granule	Time Span
SLR/LLR	Round trip time of flight (full-rate)	1A	Daily, sub-daily	1975-date
	Round trip time of flight (normal point)	1A	Daily, sub-daily	1991-date
	Station positions	2	Weekly	1992-date
	EOP (polar motion, length of day)	2	Weekly	1992-date
GNSS	Pseudorange and phase observations (RINEX)	1A	Daily, sub-daily	1992-date
	Station positions	2	Weekly	1992-date
	Clocks	2	Weekly, daily, sub-daily	1992-date
	Orbits	2	Weekly, daily, sub-daily	1992-date
	EOP (polar motion and rates, length of day)	2	Weekly, daily, sub-daily	1992-date
	Zenith tropospheric path delay estimates	2	Weekly, daily	1997-date
	Global ionosphere maps	2	Weekly, daily	1998-date
VLBI	Correlated measurement experiment data bases	1A	Daily	1979-date
	Baselines	2	Daily	1979-date
	EOP	2	Daily	1979-date
	Station positions	2	Daily	1979-date
	Source positions	2	Daily	1979-date
	Zenith tropospheric path delay estimates	2	Weekly	2002-date
DORIS	Time-tagged station to satellite range	1A	10-day cycle, daily	1990-date
	Station positions	2	Daily	1993-date
	Derived vertical total electron content (VTEC)	2	Daily	2002-date
	EOP (polar motion, length of day)	2	Daily	2002-date

Space Geodesy Today (2/2)

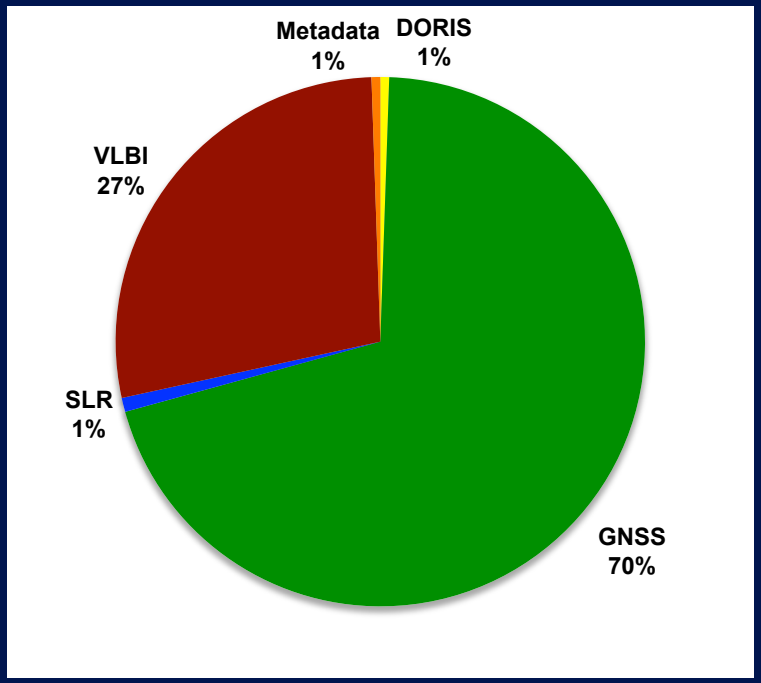
- Data
  - GNSS: 421 sites tracking GPS, GLONASS
  - Laser Ranging (SLR and LLR): 42 sites tracking 35+ satellites (including the Moon)
  - VLBI: 39 sites
  - DORIS: 57 sites tracking 6 satellites
  - Stations in the GNSS, SLR/LLR, VLBI, and DORIS networks generate point data on a multi-day, daily, hourly, and/or sub-hourly basis
- Products
  - Precise network station positions (for ITRF)
  - Satellite orbits (for POD)
  - Station and satellite clocks (for timing)
  - Earth rotation parameters
  - Positions of celestial objects (for CRF)
  - Atmospheric parameters (Ionosphere TEC, Troposphere ZPD)
  - …
  - Products provided weekly, daily basis

Future Developments: Enhancing CDDIS Data Discovery

- Plan to develop a search/metadata interface tool for CDDIS to:
  - Aid users in discovery of CDDIS data, products, and information
  - Aid staff in archive management
  - Promote CDDIS data holdings to a larger community (e.g., through metadata standards)
- Specify (any/all):
  - Temporal: Year, date/time, range
  - Spatial: Region, lat/lon, range
  - Target: Satellite (SLR, DORIS)
  - Designation: Station name/number/code
  - Parameter: Receiver type (GNSS), event timer (SLR), antenna type (GNSS, VLBI), …
- Results:
  - List of sites satisfying specifications
  - List of data holdings satisfying specifications
  - Metadata relevant to selection
  - …

CDDIS Archive Statistics

Archive contents by data type:



User distribution profile: