INTER-SERVICE DATA INTEGRATION FOR GEODETIC OPERATIONS

INDIGO

PROPOSAL SUBMITTED TO

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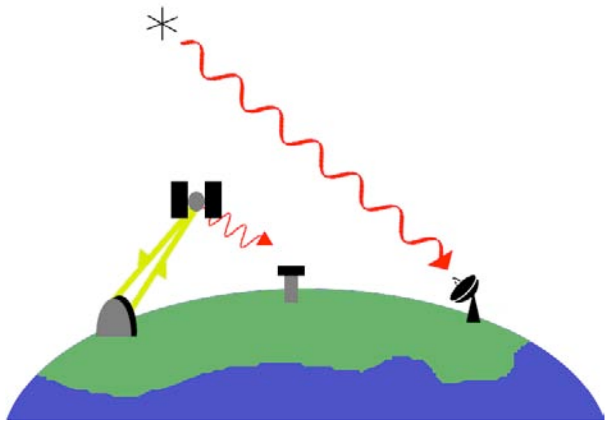

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1.0 ABSTRACT

We will enable improved performance, accuracy, and efficiency in support of NASA's Earth science and international user community by developing and providing uniform access to heterogeneous space geodetic data systems. This collective effort will be a project titled *Inter-Service Data Integration for Geodetic Operations*, "INDIGO", built upon data and information systems of space geodetic observations that have served users effectively over the last decade. Key observations come from the techniques of the Global Positioning System (GPS), Very Long Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR), which are fundamental for defining and maintaining the precise reference system of the Earth and the Cosmos. The unique history and success of the community-based international scientific services - the International GPS Service (IGS), International VLBI Service (IVS) and International Laser Ranging Service (ILRS) - stem from committed support to evolve data information systems well-suited to users' needs. These services fundamentally support the International Earth Rotation Service (IERS) and therein the generation and maintenance of the International Terrestrial Reference Frame (ITRF). Recognizing current scientific concepts and requirements as described in the National Geodetic Observatory (NGO) plan and the Integrated Global Geodetic Observing System (IGGOS) of the International Association of Geodesy (IAG), it is timely to unify these data systems. These systems will be integrated, upgraded and enhanced in response to user requirements, initiating first steps towards realizing NGO/IGGOS scientific objectives. User interface and access will be streamlined and seamless with state-of-the-art web-based services. Extensive user participation in the formulation of the new system is ensured, as this is the approach of the geodetic services. INDIGO will extend the GPS Seamless Archive (GSAC) philosophy to all data types. INDIGO is well aligned with the SEEDS philosophy and anticipates full engagement with SEEDS working groups.

(289 words)

2.0 PROJECT DESCRIPTION: INDIGO INTER-SERVICE DATA INTEGRATION FOR GEODETIC OPERATIONS

Space geodesy is fundamental to Earth sciences, creating the framework to which a broad class of observations and measurements are tied and inter-related. We will develop and provide uniform access to independent space geodetic data systems to enable improved performance, access, accuracy, and efficiency in support of NASA's Earth science user community. This project, titled Inter-Service Data Integration for Geodetic Operations or "INDIGO", is built upon data and information systems of space geodetic observations currently supported by NASA that have served users effectively over the last decade.

The space geodetic techniques of the Global Positioning System (GPS), Very Long Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR) are responsible contributors that define, evolve, and maintain the global reference frame of the International Terrestrial Reference System (ITRS)[1] and the International Celestial Reference System (ICRS)[2]. The user communities of each have successfully self-organized into thriving services, the International GPS Service (IGS)[3], International Laser Ranging Service (ILRS)[4] and the International VLBI Service(IVS)[5]. These three technique services provide direct data products to, and collaborate with, the International Earth Rotation Service (IERS),[6] where the rigorous combination of solutions is performed annually producing the ITRF and ICRS. Although data preservation, archival and accessibility have been addressed by the geodetic network operators of each observing technique, the critical value of the data and products from these space geodetic observations has become much more obvious in recent years.

In the recently released report Living on a Restless Planet[7], from NASA's Solid Earth Science Working Group (SESWG), one of seven recommendations for observational strategies is related to Space Geodetic Networks and the International Terrestrial Reference Frame:

> *"In cooperation with many international partners, NASA's Solid Earth Science Program plays a key role in establishing, maintaining, and operating global geodetic networks. Currently the networks include SLR, VLBI, and the GPS ground system. Relevant data products and valuable services are provided to the worldwide research community through the International Laser Ranging Service, the International VLBI Service, and the International GPS Service, respectively. Precise 3-D crustal motions are determined by all three networks, with dense GPS arrays particularly useful for regional tectonic and earthquake cycle studies. Beyond their scientific value, these data, together with precise determination of the 3-D geocenter motion by SLR and GPS, constitute the geodetic elements that define the International Terrestrial Reference Frame (ITRF), which is the basis for all geodetic measurements described in this report. The ITRF is geometrically connected to the Celestial Reference Frame via Earth Orientation Parameter (EOP) time series, which are determined primarily by the VLBI technique and contain a wealth of geophysical and climatic information. The ITRF and EOP, and hence the networks, should continue to be maintained and improved and their data routinely acquired at the best possible accuracy and temporal resolution."*

While the above recommendation addresses the end-to-end capabilities of the international services, this proposal focuses only on improving accessibility to data, data products and information systems to the broad NASA science community, and to improve the accuracy of the data and data products. This is in response to two current and related scientific concepts.

The first is the International Association of Geodesy's (IAG)[8] move towards integration by adopting the strategy of an Integrated Global Geodetic Observing System[9] (IGGOS), with "the ultimate goal to come up with one consistent, technique-independent set of coordinates and transformation parameters." IGGOS is in the early planning stages and it is evident that this novel and challenging concept of integration is shared by the international science community and is dependent on the services.

The second strategy driving INDIGO is contained in a research proposal titled "Integration of Space Geodesy: A National Geodetic Observatory"[10] (NGO), whose intent is to conduct a program of research into the technical issues of integrating SLR, VLBI and GPS to produce a unified set of global geodetic parameters. If approved, NGO will be an integral element of IGGOS working through the international services and under the official auspices of the IAG. NGO hopes to create an enduring unification of space geodesy within NASA and the US, and at the same time help to bring the international IGGOS effort to fruition.

Recognizing the scientific concepts and requirements of IGGOS and NGO, this proposal is structured as the implementation of the first steps to facilitate data access and enable the science investigations. It is timely to unify the geodetic data systems, by integrating, upgrading and enhancing the separate data systems, while maintaining independence of the systems for technique-specific users.

The project will leverage its existing depth in the science community in developing standards and formats, and in metadata and archival to apply principles from SEEDS (NASA's Strategic Evolution of ESE Data Systems). Specifications will be developed through existing cooperation with the following organizations: IERS, IGS, IVS, ILRS, IAG, IGGOS, NGO. In developing the system, the GPS Seamless Archive (GSAC) philosophy[11], where data at different systems is located and served to users transparently, will be extended to all data types. Given this expertise, this project will support ongoing SEEDS efforts through participation in the Standards and Interfaces Working Group. All products will be archived and made publicly available through a SEEDS-compliant data system and web interface. Increased understanding of the data and data product applications will be enabled throughout the system. To ensure that INDIGO is attuned to evolving science user requirements, a science advisory team (SAT), drawing on the NGO/IGGOS teams, will be established to provide direction and advice as the project develops. This will be augmented by an international Inter-Service Working Group to ensure that global perspectives are achieved and are in accordance with the services' data policies and decision processes.

Living on a Restless Planet summary notes that *"All of the recommendations for solid-Earth science are predicated on maintaining NASA's special capabilities in updating the terrestrial reference frame, monitoring Earth orientation parameters, and carrying out precise orbit determination."* Project INDIGO can ensure that NASA's space geodetic data and information services benefit and evolve these special capabilities in service to the user community and as NASA's significant contribution to the international activities.

We have brought together a project team that has the experience to insure a successful INDIGO. Each of the three services is represented on the team by individuals who have played integral roles in inaugurating, developing, and maturing the services and their data systems. Our team has the direct relevant experience with each service to bring the appropriate expertise to the project. Several team members have experience with information technology that will give us the ability to establish INDIGO. The project lead has the longest experience with services, having been involved in the establishment of the IGS and nurturing its data systems through ten years of existence and is committed to ensuring the collaborative success of INDIGO.

2.1 Relevance of Data and International Geodetic Services.

Developments in space-based geodetic techniques have revolutionized the science of geodesy and contribute to a much greater understanding of the dynamics of the Earth. International recognition of the value of observations made by VLBI, GPS, and SLR led to the establishment of the three scientific services during the last ten years. This is in response to the user community desires and recognition of the need to preserve long term geodetic data records over decades (and centuries). Space geodesy provides fundamental systematic measurements that support Earth science observations. NASA has been, and continues to be, one of the primary supporters and developers of these techniques as highlighted in the recent report Living with a Restless Planet.[12] NASA's support of the technique coordinating centers is of great value to its Earth science community and the broader international community. The three central offices of IGS, IVS and

ILRS develop and maintain independent information systems in support of and in response to users. The data system established by the Crustal Dynamics Project[13] (CDP), the Crustal Dynamics Data Information System (CDDIS)[14] is a repository for all space geodetic data types collected by NASA and its partners and is a critical element of this proposal. The existing, strong collaboration with the IERS is essential to the overall success of future INDIGO developments given the critical role that IERS plays as a primary user of the geodetic technique services.

Space geodetic techniques rely on precise measurements of the times of arrival of electromagnetic signals at receiving stations. When networks of receivers observe common signal sources, the spatial relationships of the sources and receivers can be solved for very accurately, yielding geodetic information.

Different space geodetic techniques exist because there are various sources of such signals, and each has particular strengths in making geodetic measurements. Use of different techniques is also important in providing mathematically independent measurements of similar quantities. The major geodetic techniques are summarized in Table 1.

Table 1. Space Geodetic Observations and Sources

	GPS/GLONASS	SLR	VLBI
Signal	Microwave (L-band)	Optical (laser)	Microwave
Source	GPS Satellites	Reflected by satellite or Moon reflector	Quasar
Observable	Time of arrival of time varying signal	Two-way travel time	Difference in time of arrival at two stations of time varying signal

All three technique services have observation networks that collect data (see Figure 1, Geodetic Service Network Maps). These data are deposited into various distributed data centers according to standards established within the services. Analysts access them accordingly and produce higher-level products which are used by scientists, project or working groups of the services leading to innovations, new products and applications.

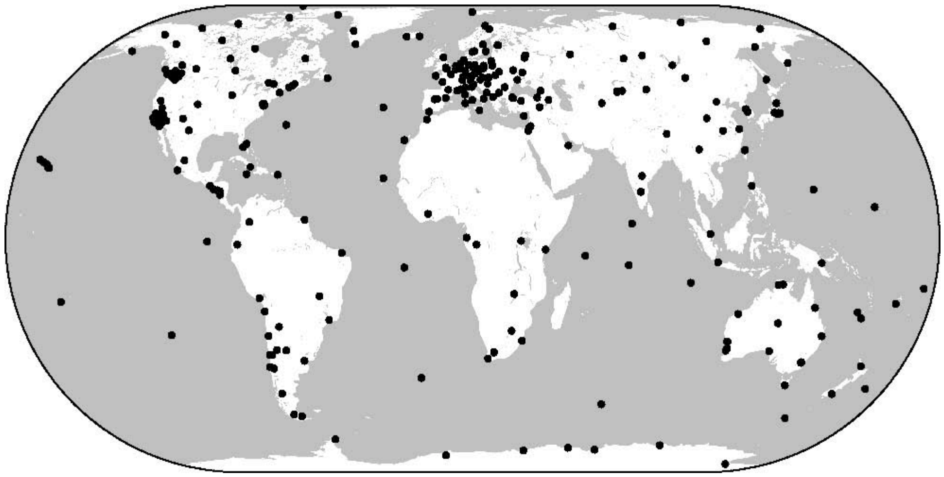
This proposal will implement a data system architecture that will lead to the unification of space geodesy – within the US and internationally – to improve both its performance and efficiency. The programs of joint research of IGGOS and NGO address the technical issues of integrating SLR, VLBI, and GPS geodesy to produce a unified set of advanced global geodetic products enabled by INDIGO. Principal benefits will be to reveal new research opportunities within both the Geodynamics and Surface Change themes of NASA ESE Strategic plan through greater integration of the geodetic data and data products.

Each service brings years of experience in developing global standards and specifications, and encouraging international adherence to conventions. Under INDIGO, the services will turn their attention to one another's standards and formats, identifying existing commonalities and opportunities for new ones. Users will find similar data types represented in equivalent formats, enabling ease in cross-technique data ingestion.

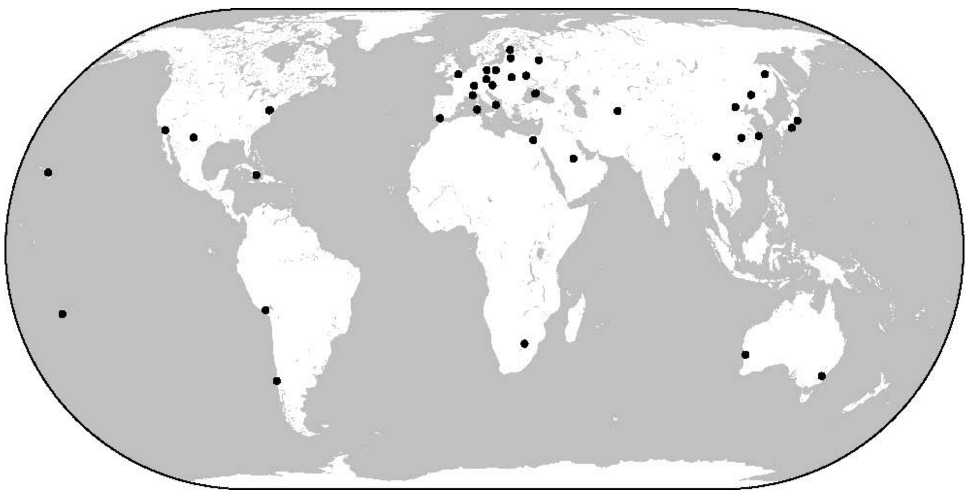
Space geodetic data archives successfully serve the community, to the tune of millions of files each month. However, the necessarily distributed, heterogeneous set of archives often requires data shopping expeditions to several dissimilar servers to satisfy a user's data needs. INDIGO will provide simplicity for the user in this complex scenario by providing Seamless Archive services which absolve the user of the need to know archive lists or details.

Important geodetic products, such as earth orientation parameters and terrestrial reference frame, are by each of the services based on analysis of their technique-specific data sets. INDIGO will encourage each technique to supply its products with maximum alacrity and present them side by side with uniform formatting, for the benefit of combination development and technique calibration. Additionally, the end user will be presented with the best single product set for his use, rather than a dizzying array of apparently similar yet unequal geodetic products.

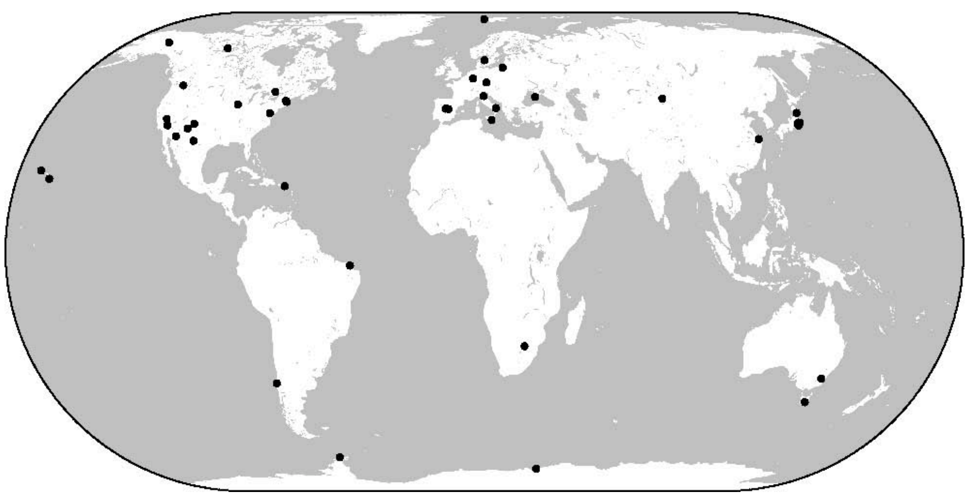
In short, INDIGO will build upon the successful independent histories of each service to provide an ensemble information service whose utility to geodetic science is greater than the sum of its



The International GPS Service network



The International Laser Ranging Service network



The International VLBI Service network

Figure 1. Geodetic Service Network Maps

parts. Table 2 lists the key goals and objectives of INDIGO which map into the task plan and scheduled milestones presented in Section 5.

Table 2. INDIGO GOALS & OBJECTIVES

Service System Unification and Integration
Develop a common catalog of existing services and products
Analyze interdependencies and identify synergies between current services
Develop and implement the structure to unify the services' data information systems via website INDIGO
Re-architect the independent services' data information systems
Develop and implement common interfaces for user access at each service where synergistic
Foster an international working group for the development and promotion of data and metadata standards
Present similar products side-by-side and uniformly formatted
Explore and implement 're-use' of GPS Seamless Archive philosophies/tools, extend to all techniques creating a Global Seamless Archive Center
Support and implement data processes for 'deep' inter-technique data integration
Enable combination of products in response to NGO/IGGOS
Provide reference frame data and products in support of IERS
Allow for data system inclusion of emerging technologies: altimetry, InSAR, space gravity, and magnetometry.
Conduct studies and experiments to address questions of proper data mix and locations of observing sites
INDIGO Support to the Earth Science User Community
Provide precise geospatial/temporal data search as well as word search of information
Implement a station coordinate/velocity plots for all sites in cooperation with the IERS
Create a new Site Ties catalog that is inter-technique and flexible to incorporate other techniques in the future
Prepare and publish the INDIGO Catalog of Observing Instruments and Stations (including GNSS constellation info)
Implement an auto-positioning service for investigators to submit/select data sets and return positions and information based on official inter-service products and IERS standards and conventions.
Investigate system and data integrity, with a forward-minded approach to GNSS (Galileo[15], GPS Modernization, GPS III) and Constellation civil integrity monitoring.
Develop INDIGO outreach and education activity to support users: displays, handout material attracting new users, on-line tutorials and material for user education and appropriate use of data & products
Combine and upgrade the web based directory of colleagues for the few thousand current users, enable expansion for many new users
INDIGO Responsiveness to Science Drivers
Establish a Science Advisory Team for direction on developments closely associated with developing scientific requirements of IGGOS/NGO; INDIGO directly supports these activities (of expert users) while continuing to serve broad Earth science users

The "face" of INDIGO, which will provide the initial interaction for most users, will be a web presence provided by the INDIGO information system. This will be designed to allow a single point of entry to the combined set of IGS, ILRS, and IVS information, as well as a route to the technique- specific information systems.

Each service will continue to maintain cognizance and management of its own information systems, as well as contributing to the INDIGO system, to allow best application of domain expertise, as well as convenience to single-technique users. Areas common across the services will be re-engineered to meet agreed-upon characteristics, including uniformity of presentation.

Similarities in the data types of each service are evident when summarized in Table 3. Likewise, many product types are realized by more than one service. Table 4 presents the services' products, also indicating the science requirements for each as noted in the NGO document.

In the following subsections, we introduce the particulars of each service, as well as the CDDIS archive and the role of the IERS. Although product development falls in the domain of in-kind support from the analysis sectors of the services, the INDIGO data services enable this development to take place. Progress toward meeting data and product latency prerequisites for the NGO science requirements will therefore be monitored by the INDIGO project. Each technique must meet the required timeline (subject to fundamental limits of each technique) to enable the NGO/IGGOS scientists to develop automatic combined multi-technique products.

Table. 3 Geodetic Observation Data Types

	GPS & GLONASS		SLR & LLR		VLBI	
	latency	**data type**	**latency**	**data type**	**latency**	**data type**
Primary Observations	1 day	signal range, phase, TOA, broadcast ephemerides	Varies	Full rate 2-way time of flight	15 days	TOA delay(24 hr session)
	1 hour					
	15 min		1 day	Normal Point 2-way time of flight	5 days	TOA delay (1 hr session)
	Near-real time		1 hour			
Auxilliary Data	1 day	Meteorological	1 day	Meteorological	1 hour	Meteorologcal, schedules, logs, cable calibrations
	1 hour		1 hour			
Configuration data	<1 day	station logs	1 day	Predicts, station logs, system configuration files	1 hour	Station configuration

Table 4. Approximate Current Space Geodetic Products Performance and Requirements

Product	VLBI	SLR	GPS	Science Req
TRF Global Components	*current*	*current*	*current*	*current - future*
Origin, 3D, Long-Term (mm)	n/a	1.0	tbd	1.0 - 0.3
Origin Rate, 3D, (mm/yr)	n/a	0.3	tbd	0.3 - 0.1
Geocenter, Monthly (x,y,z, mm)	n/a	3,3,10	3,3,10	n/a - 1,1,1
Scale, Long-Term (ppb)	0.2	0.3	1.0	0.2 - 0.1
Scale Rate (ppb/yr)	0.02	0.05	0.1	0.03 - 0.01
CRF				
Right ascension and declination (mas)	0.2	n/a	n/a	0.25, more sources
Station Location Components				
Coords, Long-Term (N,E,U, mm)	2, 2, 5	3, 3, 3	2, 2, 5	2, 2, 5 - 1, 1, 1
Linear Velocities (N,E,U, mm/yr)	1, 1, 2	2, 2, 2	1, 1, 3	1, 1, 3 - 1, 1, 1
Short-Term Motion (N,E,U, mm)	3,3,10, weekly	5,5,5, monthly	3,3,6, weekly	n/a - 1,1,3, daily
Earth Orientation Parameters				
Polar Motion (mas)	0.2, 3/wk	0.3, daily	0.1, daily	0.1 - 0.03, daily
Polar Motion Rate (mas/day)	0.4, 3/wk	0.6, daily	0.2, daily	0.2 - 0.03, daily
UT1 - UTC (μsec)	5, 3/wk	n/a	n/a	14 - 5, daily
Length of Day (μsec)	20, 3/wk	180, daily	20, daily	14 - 5, daily
Precession, Long-Term (mas/yr)	0.01	n/a	n/a	0.005
Nutation (mas)	0.2, 3/wk	n/a	n/a	0.05, daily
Satellite Parameters				
Satellite orbit ephemerides (cm)	n/a	2, varies	25, real time 5, 17 hours <5, 13 days	5, real-time 1, 13 days
Satellite and Station Clocks (ns)	n/a	n/a	5, real time 0.2, 17 hours 0.1, 13 days	0.2-0.5, real-time 0.03, 13 days
Atmospheric Parameters				
Tropospheric Delays (mm)	5, hourly	n/a	6, 3 hours 4, weekly	tbd
Precipitable Water Vapor (mm)	0.7, hourly	n/a	0.6, hourly	0.5 - tbd, hourly

2.1.1 Introduction to IGS

The IGS, a service established within the International Association of Geodesy (IAG), officially started its activities on January 1, 1994 after a successful pilot phase of more than one year. In 1999 the name was changed from the International GPS Service for Geodynamics to the International GPS Service due to a broadening range of scientific applications with GPS. The mission of the IGS is:

> '…to provide the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multi-disciplinary applications and education…'. [16]

IGS is based on over 300 globally distributed permanent GPS tracking sites (including 30 GLONASS[17]/GPS stations), three Global Data Centers, many Operational or Regional Data Centers, eight Analysis Centers, an Analysis Center Coordinator, an IGS Reference Frame Coordinator, and a Central Bureau. The IGS also includes projects dependent on the infrastructure afforded by the IGS. Working groups have been established to focus on the IGS Reference Frame (refining GPS contributions to the ITRF), Troposphere, Ionosphere, and Real time applications; projects include: Precise Time Transfer (joint with BIPM), Low Earth Orbiters (LEO), the International GLONASS Service, and TIGA Project for Sea Level studies. Over 200 organizations in more than 75 countries contribute to these activities. The IGS routinely provides high-quality orbits for all GPS satellites (estimated accuracy <5cm), and predicted orbits (accuracy~25cm) along with sub-nanosecond satellite and station clocks.

The tracking data and the individual Analysis Center orbits are available at the Global Data Centers, and the combined official IGS orbits are available at the Central Bureau and three Global Data Centers, of which CDDIS is one for GPS. The combined official IGS orbits are produced by the Analysis Center Coordinator currently supported by the Astronomical Institute, University of Bern, Switzerland. The Central Bureau, responsible for the day-to-day management of the IGS, maintains an IGS Information System (CBIS).

2.1.2 Introduction to IVS

The IVS was inaugurated in 1999, and has been approved as a service of the International Association of Geodesy (IAG) and of the International Astronomical Union (IAU). The IVS goals are 1) to provide a service to support geodetic and astrometric research and operational activities, 2) to promote research and development activities in all aspects of the geodetic and astrometric VLBI technique, and 3) to interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

VLBI is a geometric technique: it measures the time difference between the time of arrival (TOA) at two Earth-based antennas of a radio wavefront emitted by a distant quasar. Using large numbers of time difference measurements from many quasars observed with a global network of antennas, VLBI determines the inertial reference frame defined by the quasars and simultaneously the precise positions of the antennas. Because the time difference measurements are precise to a few picoseconds, VLBI determines the relative positions of the antennas to a few millimeters and the quasar positions to fractions of a milliarcsecond. Since the antennas are fixed to the Earth, their locations track the instantaneous orientation of the Earth in the inertial reference frame. Relative changes in the antenna locations from a series of measurements indicate tectonic plate motion, regional deformation, and local uplift or subsidence.

IVS has 75 Permanent Components, supported by agencies in 16 countries, which enable IVS to provide its data and products: 30 Network Stations that acquire high performance VLBI data; 3 Operation Centers that coordinate the observing; 6 Correlators that process the acquired data and submit it to 3 primary Data Centers plus 3 secondary Data Centers; 7 Analysis Centers and 14 Associate Analysis Centers that analyze data and produce results; 8 Technology Development Centers for new VLBI technology; a Coordinating Center that coordinates the daily and long term IVS activities. In addition IVS has Coordinators for Networks, Analysis, and Technology.

IVS products include the full set of Earth orientation parameters: UT1, polar motion, and nutation. These are provided for each 24-hour session. For the one-hour daily sessions only UT1 is produced. Also available for each 24-hour session is a SINEX format file with loose constraints and covariance information that allows more detailed analysis and combination. The celestial reference frame (CRF) is a unique VLBI product that contains the positions for several hundred celestial radio sources. The CRF produced by VLBI was adopted in 1998 by the International Astronomical Union as its standard system for celestial positioning, replacing the centuries old optical system.

2.1.3 Introduction to ILRS

In laser ranging, the time of flight of a laser pulse as it travels between a ground station and a retro-reflector-equipped satellite (or a reflector on the moon) is measured. Precise satellite orbits, positions of and distances between observing stations, and Earth rotation, orientation, and polar motion values can be derived from the laser ranging technique. Over the last thirty years, the global SLR network has evolved into a powerful source of data for studies of the solid Earth and its ocean and atmospheric systems. SLR is a proven geodetic technique and is the most accurate technique currently available to determine the geocentric position of an Earth satellite, allowing for the precise calibration of radar altimeters and separation of long-term instrumentation drift from secular changes in ocean topography. SLR data have also provided the standard, highly accurate, long wavelength gravity field and scale (GM). SLR provides a means for sub-nanosecond global time transfer, and a basis for special tests of the theory of General Relativity.

The International Laser Ranging Service (ILRS), operational since 1998, provides global satellite and lunar laser ranging (LLR) data and their related products to support geodetic and geophysical research activities as well as IERS products important to the maintenance of an accurate International Terrestrial Reference Frame (ITRF). The service develops the necessary global standards/specifications and encourages international adherence to its conventions. The ILRS collects, merges, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data sets of sufficient accuracy to satisfy the objectives of a wide range of scientific, engineering, and operational applications and experimentation. The ILRS currently includes more than forty SLR stations, routinely tracking over twenty retroreflector-equipped satellites and the Moon in support of user needs. The ILRS uses these data sets to generate a number of scientific and operational data products.

The ILRS works with new satellite missions in the design and building of retroreflector targets to maximize data quality and quantity and science programs to optimize scientific data yield. The ILRS Central Bureau maintains a comprehensive web site as the primary vehicle for the distribution of information within the ILRS community. The ILRS Governing Board has established standing and temporary working groups to carry out the activities of the ILRS. These working groups are intended to provide the expertise to make technical decisions and to plan programmatic courses of action; they are also responsible for reviewing and approving the content of technical and scientific databases maintained by the Central Bureau.

2.1.4 NASA's Data System & Archive for Geodetic Observations: CDDIS

The CDDIS is a dedicated data center supporting the international scientific community as NASA's space geodesy data archive since 1982. The CDDIS currently serves as one of several global data centers for each of the IGS, ILRS, IVS, and the future International DORIS Service (IDS).[18] It also serves as the NASA archive and distribution center for space geodesy data. The CDDIS provides easy and ready access to a variety of data sets, products, and information about these data. The specialized nature of the CDDIS lends itself well to enhancement to accommodate diverse data sets and user requirements. Most data sets are accessible to scientists through ftp and the web; general information about each data set is accessible via the web. The CDDIS website allows users to generate limited special and temporal queries to determine and access the on-line archive. The CDDIS staff and computer facility are located at NASA GSFC in Greenbelt, MD.

2.1.5 Role of the IERS

The IERS was created in 1987 by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG), replacing the Bureau International de l'Heure (BIH) and the International Polar Motion Service (IPMS), as a result of the ten-year international campaign. The IERS started its activities in January 1988. IERS was given the missions to define and maintain a terrestrial reference system based on the most precise space geodesy techniques at this time, to define and maintain a celestial reference system based on the directions of extragalactic radio sources and its tie to other celestial reference frames, and to monitor the Earth's orientation, i.e. the parameters that connect the terrestrial and the celestial reference systems as a function of time. The IERS is considered a key user of INDIGO since it is dependent on the services for data products. IERS will be involved in its development through an international Inter-Service Data Working Group to be established as a first step of the project.

2.2 Approaches for Data Production, Distribution, and User Support

The data flow for International Services is depicted in Figure 2, showing the common approach they have for organization, data collection, product generation and users support. This is an extremely effective approach for NASA and international partners and is truly an example of leveraged resources. The cost benefits of the services demonstrate that one gains much more from the collective activity than from any single organization.

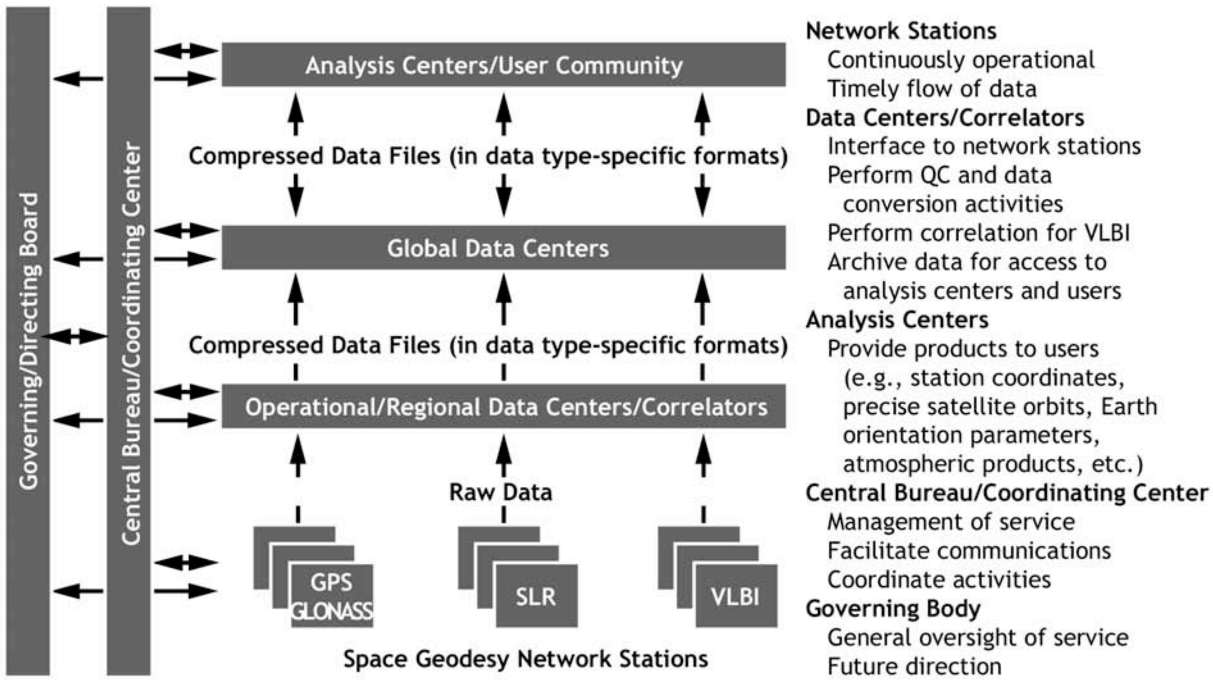


Figure 2. Data Flow for International Geodetic Services

2.2.1 GPS

The 300+ stations of IGS network generally produce data sampled at 30 seconds. The data is collected at a local, regional or global data archive depending on usage. Global stations are those analyzed by more than three of the 8 IGS Analysis Centers for the production of the classic suite of IGS products: orbits, station position and velocities, clocks, and so forth. Subsets of the network provide specialized data in support of an IGS project or activity, such as atmospheric zenith path delay for weather forecasting or ionospheric grid maps for space weather. A new project is TIGA, where GPS stations tied to tide gauge benchmarks at coastal sites over a long period of controlled observations provide systematic measurements contributing to the research of sea-level change. IGS data systems also support low Earth Orbiter (LEO) missions for atmospheric and gravitational studies, a role which is anticipated to expand.

The tracking data and the individual Analysis Center orbits are available at the Global Data Centers, and the combined official IGS orbits are available at the Central Bureau and three Global Data Centers, of which CDDIS is one for GPS. The combined official IGS orbits are produced by the Analysis Center Coordinator currently supported by the Astronomical Institute, University of Bern, Switzerland. The Central Bureau, responsible for the day-to-day management of the IGS, maintains an IGS Information System (CBIS).

2.2.2 VLBI

During a 24-hour VLBI data session each station in an 8-station network typically acquires about 1200 Gbytes of data, recorded on magnetic instrumentation tapes or on hard disks. During data acquisition each station follows a detailed observing schedule which was prepared at least one week in advance by an IVS Operation Center and submitted via ftp to an IVS Data Center. Due to the lack of wide bandwidth fiber networks at the remote international locations of VLBI stations, the tapes or disks are shipped via express services to one of the IVS Correlators, arriving 3-4 days after data acquisition. Meanwhile, the stations submit their session log files via ftp to one of the IVS Data Centers within an hour of the end of the session.

The IVS Correlator processes the raw data, using the station log files for control information, and generates a VLBI data base which it submits via ftp to an IVS Data Center. The three IVS Data Centers mirror each other on a planned schedule several times daily.

IVS products are generated by 7 IVS Analysis Centers and the combined products are made by the IVS Analysis Coordinator. The complete set of basic Earth parameters (UT1, polar motion, and nutation) are produced for each 24-hour session. These values are appended to files that hold the EOP from every session since 1979. After the EOP analysis products from the IVS Analysis Centers are available, the Analysis Coordinator generates the combined product. Analysis Centers produce files with the CRF and TRF on a quarterly basis for submissions to the IERS. User access IVS products via the IVS web site, which links to ftp areas on each IVS Data Center.

2.2.3 LASER Ranging

ILRS tracking stations range to a constellation of satellites (including the Moon), compiled and approved by the Governing Board, with state-of-the-art laser ranging systems and transmit their data on a rapid basis (at least daily) to an ILRS data center. Stations are expected to meet ILRS data accuracy, quantity, and timeliness requirements, and their data must be regularly and continuously analyzed by at least one ILRS analysis center. ILRS operations centers collect and merge the data from the tracking sites, provide initial quality checks, reformat and compress the data if necessary, maintain a local archive of the tracking data, and relay the data to a data center. Global data centers receive and archive ranging data and supporting information from the operations centers, and provide this data on-line to the analysis centers. They also receive and archive ILRS scientific data products from the analysis centers and provide these products on-line to the users. Data are available at the global data centers in hourly and daily increments, typically within 24 hours of the observation time. Daily laser data files are typically 0.25 Mbytes in size.

At this time, the ILRS does not yet generate an “official” combined product from the individual ILRS analysis centers. The Analysis Working Group has issued a Call for Participation in a pilot project whose goal is to generate Earth orientation parameters and global station coordinates on a semi-real time basis (at least daily). Following a pilot phase, a combined product will be realized as is done within the IGS.

ILRS information, data, and products are accessible through the ILRS website. This facility provides links to data centers, thus allowing users to easily obtain access to these data sets and, in the future, official ILRS products.

2.2.4 CDDIS - The Role of a Global Data Center

GPS, laser, and VLBI experiment data flow from the network of tracking stations through various levels of data centers to ultimately reach the analysis centers and user community. The distributed data flow and archive scheme has been vital to the success of the services. Each of the services established a hierarchy of data centers to distribute data from the network of tracking stations. This scheme provides for efficient access and storage of GPS, laser, and VLBI data, thus reducing traffic on the Internet, as well as a level of redundancy allowing for security of the data holdings.

The “global” data centers, typically the final destination for data and products within the services, are ideally the principal data source for the analysis centers and the general user community. The on-line data are utilized by the analysis centers to create a range of products, which are then transmitted to the global data centers for public use. Use of several global data centers in each service avoids a single point of failure should a data center become unavailable; users can continue to reliably access data from one of the other global data centers. Furthermore, several centers reduce the network traffic that could occur to a single geographical location. The CDDIS serves as one of several global data centers for each of the IGS, ILRS, and IVS.

2.2.5 INDIGO Approaches for Data Production, Distribution, and User Support

INDIGO will build upon the services' successful data production, distribution, and user support approaches. The system will evolve to a unified web presence which automatically draws from the technique-specific information systems. Data production will continue in the distributed manner depicted in Figure 2. Data distribution will be augmented by geospatial search tools and GSAC capabilities which present data form the distributed sources as if from a single archive. User support will be strengthened with search capabilities, uniformity of presentation, and tutorial materials. Cost benefits are found in leveraging existing service structures and expertise, as well as by leveraging in-kind support from existing projects within the services. The GSAC effort has developed viable architectures and tools for GPS data, enabling cost-beneficial reuse in extending the concept to other data types.

2.3 Earth System Science User Support

Each service has a central coordination office hosting an information system to provide essential information to the community. These offices are responsible for the daily coordination and management of service activities. They facilitate communications and information transfer and promote compliance with network standards, monitor network operations, perform quality assurance of the data, maintain documentation and databases, organize meetings and workshops, and provide general user support. All data and products are freely available to the international science community with no restrictions. The three central information systems host similar information types: station metadata; signal source metadata; information about data and product types; pointers to data and product archives; publications; calendars; notices and communication vehicles (mailing lists); organizational information, international governance, terms of reference, charters, etc.; and invitations for feedback and questions. The central offices do not act as data archives, but depend upon the CDDIS and other data centers for this function.

The IGS Central Bureau has provided user support on the internet since 1993. Users acquire information regarding IGS via the WWW, and machine-readable product and configuration files in established formats via FTP. The IGS CB currently serves approximately 17.5 GB monthly to users at over 11,500 unique internet sites in more than 100 countries.

Users access IVS products via the IVS web site, which currently has links to the ftp areas on each IVS Data Center. All IVS data is available on a pre-planned schedule tied to the IVS Master Schedule which is published in December for the coming year and updated as needed throughout the year. User support is provided as needed by the IVS Coordinating Center.

The ILRS Central Bureau maintains a comprehensive web site as the primary vehicle for the distribution of information within the ILRS community. In order to strengthen the ILRS interface with the scientific community, a Science Coordinator and an Analysis Specialist within the CB take a proactive role to enhance dialogue, to promote SLR goals and capabilities, and to educate and advise the ILRS entities on current and future science requirements related to SLR.

The CDDIS supports the three major services (IGS, ILRS, and IVS) by providing on-line access to the data and products generated by the network and analysis centers. The CDDIS archives data from over 120 institutions in over sixty countries on a daily basis for distribution to an international user community. During 2001, on average, 2.2M files totaling over 250 Gbytes in size were downloaded from the CDDIS archive each month. Furthermore, over 150 users from nearly ninety countries accessed the CDDIS on a daily basis to download data. The system archives approximately 0.5 Gbytes of data per day in support of the IAG services.

Scientists interact with Earth science data archives in different modes, depending on the nature of the investigation. Owing to the successful operation of the services up to now, the three central offices of the services already have informative interactions with their respective user communities on a regular basis, revealing the habits and needs of the users. Activities in integrating and improving access to the data under discussion should be mindful of the various usage patterns.

Many users whose primary focus is one of the services obtain all or much of the regularly-produced data in an automated fashion, for their routine global processing. This group, while being largely focused on automation and in general comfortable with internet data file transfer, would still benefit from improved ease in familiarization when new data types or archives arise.

Other users focus on one type of data but perform more regional studies. This group would greatly benefit by the spatial search capabilities of the Seamless Archive approach.

Another class of users is those scientists who regularly utilize data from more than one of the services. This segment may also have either a regional or global focus, and in either case, would benefit from common approaches in metadata access and the ability to perform spatiotemporal data searches either independent of technique or specific to technique, as appropriate. The value of the proposed format and access unifications across all techniques to these users is clear. INDIGO enhancements are necessary enablers of the future integration of disparate measurement types planned under NGO and IGGOS.

Although these illustrations demonstrate that all users will benefit from the improvements to the existing suite of information services proposed under INDIGO, the users who perhaps stand to benefit the most from the improvements discussed here are new or infrequent users. The burden of needing to research and learn the inner workings of archives and stations would be lessened by the adoption of common metadata practices and a single instruction on searching for data with a GSAC client. The scientist will be able to extract the science signal from the data much more quickly, without paying the productivity cost to educate himself on how to locate data and information (up to 3 times over for multi-technique investigators).

Recognizing the wide range of users and usages, all over the globe and with all ranges of client software, INDIGO is committed to enabling platform-independent access, implemented by using open-source software where appropriate. INDIGO web service HTML will conform to w3c and US section 508 standards, to ensure browser and device independence to the user, and avoid reliance on any specific software packages by the participating INDIGO services. The INDIGO information system will in general automatically integrate information from the technique-specific systems. For example, the INDIGO publications area will consist of a presentation "shell" designed by the INDIGO team, but the listed publications will be dynamically updated based on the publications lists on each of the techniques' information systems. INDIGO participating services are in this way freed from making duplicate updates of the service-specific system as well as the INDIGO system, and the currency of information provided by the INDIGO system is ensured. The agreed-upon characteristics of each service's common web areas will allow for easy machine readability to enable this mode of operation.

2.4 User Community Involvement - SEEDS Guiding Principles

The space geodetic services are built upon the principle of a mutually beneficial pooling of global resources across agency and national boundaries. As such, community engagement can be identified as a strength of the services, even prior to official inception. The central offices of the services employ similar successful models for communication both within participants and externally to users. E-mail lists, web information systems, publication of annual reports consisting of submissions from participating organizations, service-specific workshops, and participation in major science meetings internationally are organized by the central offices and are the primary venues for broad community input and feedback. Under INDIGO these will be continued and improved, with an eye toward uniformity of presentation where appropriate, and extensions to support and nurture the growing field of multi-technique data usage.

2.5 Level of Participation in SEEDS Working Group

2.5.1 INDIGO Participation in SEEDS

Many of the characteristics described in the CAN as desired or required for evolving Earth science data systems are neatly demonstrated within the geodetic services today. The approach of the services is to respond to requirements and to 'serve' the scientific users to facilitate their work. Many of the formats, conventions and processes adopted by the services tend towards standards then followed by the international community as well. INDIGO will actively contribute to SEEDS.

2.5.2 Data Format and Content

Current core data and product file formats (such as RINEX, SINEX, SP3) are ASCII, which provides machine independence, and when compressed (where size warrants) for archival and transmission, are of quite manageable size. These formats and current product granularity are well-established and in wide use so these legacy formats will be retained. An important extension of existing formats is the explicit representation of product metadata using a standard format (e.g., XML, PVL, ODL) and standard geospatial metadata nomenclature with one metadata label per product. The project will investigate, with consultation from the community, including the INDIGO Science Advisors, SEEDS, the XML subgroup of GSAC, and the INDIGO International Standards Working Group, whether there is a need for this foundation to be extended to provide data and products in an alternative standard format (such as HDF or XML) more readily supported by third-party analysis tools such as Matlab. If deemed a worthwhile endeavor by the community, this will be carried out by either providing statically pre-produced alternate format products or generating the alternate format on demand, according to an evaluation of resource utilization of each option.

2.5.3 Interface Standards

Current practice relies on one central information site per service for general information, and ftp from one or more distributed archives. The system will evolve to a unified NGO/IGGOS web site augmented with catalog search and retrieval systems providing on-demand access to both core and intermediate products. This system will automatically draw from the technique-specific information systems, which will continue to exist to most effectively serve single-technique users, but will be redesigned to provide a uniform presentation in areas which are common across all techniques. The standardization of interfaces is enhanced by consistent use of FGDC-compliant metadata, common data formats (e.g. HDF), common metadata formats (e.g., XML), and an SQL-based query language.

2.5.4 Software Reuse

The GSAC project is developing new capabilities as a broker of raw GPS data. GSAC tools enable the user to perform geospatial and temporal searches and procure data transparently data from the appropriate archive(s) in the distributed system, an improvement over the present system wherein users must individually locate the archive and directory areas hosting the needed data. CDDIS participates as a GSAC data wholesaler and JPL is a GSAC Working Group member. The GSAC concepts and software will be extensively reused and leveraged as INDIGO works toward extending the GSAC model to support the SLR and VLBI techniques, and products from all 3 services.

The GPS Occultation GENESIS[19] System offers proven technology for web site organization, file repository management, metadata generation, product metadata labels, cataloging, metadata search, HDF product generation, a Web Mapping Viewer and others.

2.5.5 Evolution

While maintaining current successful processes for product production, formatting, and ftp distribution, new capabilities will be added as they become viable, rather than in a single large system delivery at the conclusion of the project. These incremental additional capabilities include explicit metadata, standard data formats, new intermediate products, catalog searches and specialized presentations. These can be safely added to existing capabilities without disruption of established and operationally-utilized usage patterns. The community will continue to be engaged at all stages, to address potential shifting requirements.

2.5.6 Technology Utilization

Through the engagement of the community, INDIGO will remain informed about current relevant technology throughout its life cycle, to ensure effective use of technology in delivering geodetic data and products. Presently, the capabilities of the GSAC effort provide one example of technology which can improve users' access to the types of data provided by the geodetic services. The GSAC concept overcomes the complexity of the pooled set of data from heterogeneous providers by using resources such as SQL, GIS, and Oracle to free users from needing to locate, learn, and download data from each of numerous archives.

2.5.7 Levels of Service

The primary "ordering" service is an internet-based direct demand system supported by a searchable catalog and retrievable online file products. The catalog will enable SQL-style search of FGDC-compliant metadata, yielding unique references to selected products. Alternative formats, if deemed desirable by the community, will be either pre-produced and available for direct retrieval for all available time periods or generated on demand, according to an evaluation of the effectiveness of each option based on resource utilization. The typical size of most of these products does not warrant the inconvenience and expense of subsetting techniques or offline ordering systems. Long time-series products such as earth orientation parameters may be an exception, and tools for requesting specified subsets of such series are envisioned. One auxiliary service will be available through the GSAC partnership, offering data selection and delivery services.

2.5.8 Metrics

INDIGO services will track usage statistics in an agreed-upon way individually as services; these statistics can be combined with the INDIGO server statistics to form aggregate numbers. Web services will track number of hits, number of visits, number of distinct sites visiting, and volume of information downloaded. Data services will track number of file downloads, number of distinct sites downloading, and volume of information downloaded. The fraction of users accessing data via the GSAC (for data available in the GSAC) will also be calculated.

Metrics for measuring INDIGO project progress, products, services and accomplishing objectives are identified in Table 5:

Table 5: Quality, Capability and Value Metrics

Measure	Metric
Quality	Products compliant to established and documented formats
	Similar products from multiple techniques side-by–side and uniformly formatted
Capability	Search tools available
	Global Seamless Archive tools available
Value	Download statistics of products from more than one technique rendered uniform under INDIGO
	Download statistics of cross-technique station meta-data

2.5.9 Participation of the Project Investigators and Staff on SEEDS Working Groups

The INDIGO team will supply a participant at 0.25 FTE to the Standards and Interface Activities group, due to the strong synergy between existing service activities and the proposed INDIGO improvements. Members of the project team are very familiar with developing standards now adhered to globally based on user inputs, and the user base continues to grow. As an alternative, the Architecture and Reuse group also has related goals.

2.6 Compliance with REASoN Project Requirements

2.6.1 INDIGO will meet the following requirements as a REASoN Project :

Maintain a public WWW-compliant presence. Each of the services currently maintain public websites, with data and information available publicly over the Internet. These will be enhanced and augmented with uniformity of access.

The data systems are included in the NASA GCMD. The products shall contain and be searchable via FGDC compliant metadata.

INDIGO will apply for membership to the existing Federation. The IGS and CDDIS are active participants in the ESIP Federation's GENESIS.[19]

2.7 Long Term Archiving, Distribution and Availability of Products

The services have adopted and championed open data policies for pooled global geodetic data and products and will continue to do so under INDIGO.

2.7.1 Archiving

Archiving of INDIGO will be provided by CDDIS, which has been a premier global data center for this community since 1982. The necessity of long term data storage and access is fundamental to Earth reference frame maintenance scientists who perform these analyses, especially the IERS. CDDIS plans to continue these archiving activities after the completion of this project.

2.7.2 Distribution of End Products

INDIGO is intended to be a long term activity as required by the nature and value of geodetic data sets and products. INDIGO will provide for the distribution of all end-products of space geodetic research activities, including complete documentation, applicable metadata, publications, ancillary information, and supporting peer-reviewed articles as well as a wealth of links. Messages are archived to trace the development of issues and solutions by user community in the mail service.

3.0 PREFERENCES FOR PARTICIPATION IN THE FEDERATION AND SEEDS WORKING GROUP(S)

The project will leverage its existing depth in the science community in developing standards and formats, and in metadata and archival to apply principles of SEEDS. Members of the project team are very familiar with developing standards adhered to globally based on user inputs, and the user base continues to grow, lending credibility to our capabilities in this regard. Given this expertise, INDIGO will support ongoing SEEDS efforts through participation in the Standards and Interfaces Working Group with 0.25 FTE. As an alternative, the Architecture and Reuse group also has related goals.

4.0 METRICS

INDIGO services will track usage statistics in an agreed-upon way individually as services; these statistics can be combined with the INDIGO server statistics to form aggregate numbers. Web services will track number of hits, number of visits, number of distinct sites visiting, and volume of information downloaded. Data services will track number of file downloads, number of distinct sites downloading, and volume of information downloaded. The fraction of users accessing data via the GSAC (for data available in the GSAC) will also be calculated.

INDIGO is prepared to submit these metrics indicating the state of the project and the success in meeting project and NASA objectives, and as described in Section 2.5.8. We will contribute to the development and identification of meaningful metrics for SEEDS and abide by Federation adopted reporting schemes.

5.0 MANAGEMENT APPROACH

5.1 Management Approach

INDIGO project is a joint project of JPL and GSFC. The Project Lead is responsible for direct supervision of the work and the overall project performance. This project is a NASA initiative that contributes to the broader international activities of IGGOS/NGO and is viewed from the international perspective as a US contribution to this effort. As such, the team must be responsive to science directives to provide relevant unified data systems to the Earth science user community. In order to succeed, the INDIGO Team will establish a Science Advisory Team (SAT) to provide quality assessment of INDIGO based on science requirements that direct the evolution of the data system. The Project INDIGO Team and the SAT will meet on an annual basis for a status review, resulting in report card from the SAT. The INDIGO Team will initiate an International Inter-Service Data Information Systems Working Group to ensure full international engagement and participation in the promulgation of data system architecture, implementation and operation. This working group will be within the auspices of the International Association of Geodesy, as are each of the independent services. This is a proven method of the services, to address technical issues in international working groups of like-minded professionals, pool global expertise, and define the way forward in a collaborative and consensual manner. The Team will track tasks, budget, schedules and deliverables monthly to keep INDIGO on schedule and budget.

5.2 Coordination Between Participants

JPL and GSFC will continue to work closely to ensure INDIGO is realized -- this proposal is itself indicative of the significant level of cooperation that we now enjoy -- my how times have changed! The team will meet together specifically once per year for face-to-face working session, and generally two other times per year at opportune meeting or symposia venues. Every two weeks the team will meet via telecon for day-to-day details in developing and implementing INDIGO. The Team will also meet with the International Inter-Service Data Information System Working Group to gain participation from the our international colleagues and peers. Each team member will also bring the perspectives of their respective Governing Boards and user communities to INDIGO to gain international input, acceptance and propagation of the INDIGO standards where appropriate.

5.3 Statement of Work and Success Criteria

The following list describes the high-level elements of the milestone chart, and the associated success criteria for gauging progress.

1) **Funds on Contract, successful award of the REASON CAN to project INDIGO**: *Success criterion*: Funds available to initiate, develop and establish project INDIGO, key personnel authorized for work to proceed.
2) **Task plans finalized for the project, detailed schedules per instructions:** *Success criterion:* Task plans delivered to responsible officials
3) **Secure formal approvals of Service Governing Boards**: Present INDIGO concept to IGS, IVS, ILRS, and IERS Governing Boards. *Success criterion:* approval by each service and formal endorsement
4) **Establish international Inter-service Working Group on Data and Information Systems within IAG**: *Success criterion:* Formal establishment of Inter-service Working Group
5) **Establish a Science Advisory Team, annual reviews**: Secure agreement from Team members to participate and report annually. *Success criterion:* Availability of annual report card from SAT.
6) **Assess current services, prepare report on data & products, Assess inter-technique network architecture & mix of data**: Survey data and product types, interfaces, presentation styles, user support methods and prepare report. With SAT, NGO, & IGGOS, study and report optimum distribution and proportion of data from each technique to meet

science requirements. *Success criteria:* Availability of the current service report; availability of data mix report.

7) **Develop and implement website INDIGO**: Procure web server, develop initial project information. Develop INDIGO services including search functions, presentation of like metadata and products from multiple services, and tutorial material. *Success criteria:* Availability of initial website; availability of products and metadata from each service; availability of search functions; availability of tutorial.
8) **Re-architect service information systems, standardize**: Design common presentation look; update current service websites to provide cross-technique information uniformly. *Success criteria:* Web presentation design completed; service websites providing similar information types under the uniform structure.
9) **Develop & implement Global Seamless Archive Center services**: Work with GSAC group to generalize existing processes and tools to all geodetic data types. *Success criterion:* Availability of GSAC tools supporting all techniques.
10) **Implement auto-positioning service for GPS investigators**: Study existing services at JPL, NGS, AUSLIG, SIO; identify strengths and compliance to IERS standards. Implement IERS-compliant service via INDIGO. *Success criterion:* Availability of positioning service via INDIGO website.
11) **Implement integrity monitoring of GNSS constellations**: Study capability of IGS to monitor quality of the GPS (and other future) constellations and implement prototype. *Success criterion:* Availability of prototype GPS constellation integrity monitor via INDIGO website.
12) **Publish annual reports**: Solicit inputs from INDIGO participating agencies; edit and produce report detailing INDIGO activities in the preceding year. *Success criteria:* Availability of an annual report 6 months following the end of each calendar year.

5.4 Project Milestones

	INDIGO High Level Tasks and Milestone Chart	CY 03		CY 04		CY 05		CY 06		CY 07	
		Jun	Dec	Jun	Dec	Jun	Dec	Jun	Dec	Jun	Dec
1	Funds on contract										
2	Task plans finalized										
3	Secure formal approvals of Service Governing Boards										
4	Establish Inter-service WG on Data and Information Systems within IAG										
5	Establish a Science Advisory Team, annual reviews										
6	Assess current services, prepare report on data and products, Assess inter-technique network architecture & mix of data										
7	Develop and implement website INDIGO										
8	Re-architect service information systems, standardize										
9	Develop & implement Global Seamless Archive Center services										
10	Prepare and publish INDIGO Publications: Observation Catalog, Site ties, Directories, tutorial										
11	Implement GPS Auto-positioning Service										
12	Implement integrity monitoring for GNSS constellations										
13	Publish Annual Reports										
	Progressive task action - light grey										
	Deliverables, or task completion - dark grey										

5.5 Key Personnel

Ms. Ruth Neilan, manager of the IGS Central Bureau (CB), is the Principal Investigator (PI) with direct responsibility for the project. She will direct all aspects of INDIGO among the participating agencies. *Mr. Richard Borgen*, Task Leader for the JPL Distributed Object Manager Subsystem, will contribute valuable information technology knowledge and participate in a SEEDS Working Group. *Dr. Angelyn Moore*, the deputy manager of the IGS CB and IGS Network Coordinator, will coordinate INDIGO information system development between JPL and GSFC and lead IGS information system development. *Ms. Carey Noll*, who is Manager of CDDIS, Secretary of the ILRS Central Bureau, and Chair of the IGS Data Center Working Group, will lead development of the CDDIS archive for all data types and ILRS CC INDIGO activities. *Dr. Michael Pearlman*, Director of the ILRS Central Bureau, will provide requirements insight from the ILRS. *Mr. David Stowers*, manager of the NASA/JPL Global GPS Network and IGS' JPL Regional/Operational Data Center, will interface with the GSAC group. *Dr. Nancy Vandenberg*, Director of the IVS Coordinating Center, will lead IVS information system development. *Dr. Frank Webb*, Supervisor of JPL's Satellite Geodesy and Geodynamics Systems Group, will contribute to the automated positioning facilities. *Dr. Thomas Yunck*, NGO PI, will act as interface to NGO/IGGOS.

6.0 PERSONNEL

Attached are one page biographical sketches for each project team member.

7.0 PROPOSED COSTS

7.1 Budget Breakdown by Fiscal Year

Detailed budget sheets appear at the end of Section 7. The final budget is expected to be determined through task plan negotiation process of the REASON CAN. Funds will be split between the GSFC and JPL as indicated in the annual calendar year budget sheets. Full cost accounting is revealed for the civil servant salaries at GSFC.

7.2 Facilities and Equipment

Listed below is a brief description of the existing facilities and equipment available for this project.

7.2.1 Computing equipment

IGS Central Bureau Information System

The IGS CB WWW and FTP server is a dual Pentium II computer running the Linux operating system. It is managed according to an approved security plan on file with JPL's Network and Computer Security Group, which meets JPL IT security requirement D-7155 Rev 3. Presently this computer has 27GB of storage in on-board hard disk drives for storage of information and products.

IVS Coordinating Center Information System

The IVS CC web and ftp server is an HPUX workstation, networked to other VLBI workstations at Goddard Space Flight Center. It is maintained in accordance with existing GSFC security policies and practices, including regular internal security scans and updates. The IVSCC web site itself provides publications, organizational and meetings information. All data holdings are maintained at three primary IVS Data Centers.

Crustal Dynamics Data Information System

The CDDIS is operational on a Compaq Alphaserver 4000 running the UNIX operating system. The system is equipped with 540 Gbytes of on-line disk storage (470 Gbytes of RAID). The system is managed by staff of the Laboratory of Terrestrial Physics computing facility according to GSFC security mandates.

The ILRS website is operational on this same CDDIS computer.

7.2.2 Software

IGS CB

Open-source or freely available software is chosen whenever appropriate. The HTTP server is Apache and the FTP server is WU-FTPD. Majordomo and MhonArc provide mailing list and WWW list archive functions. Generic Mapping Tools (GMT) is utilized for automatically producing downloadable site maps. Webalizer produces regular usage statistic reports. Perl modules Net::FTP and Statistics::Descriptive are used for gathering data and file availability statistics from IGS data centers. UNAVCO's teqc software (reference A) is used for quality monitoring of the IGS dataset; Gnuplot provides graphs of station performance figures vs. time.

IVS CC

The web server for IVSCC is Apache; the FTP server is WU-FTPD. Mail archives are maintained using MhonArc software, while mail lists are handled with existing Perl scripts. Usage statistics for the web site are maintained by the NedStat service. Session and station statistics are automatically monitored with custom Perl scripts.

CDDIS

The Oracle RDBMS is utilized for metadata management. The Apache webserver is used for the CDDIS and supporting websites as well as the ILRS website. NcFTP is used for ftp access and OpenSSH is used for secure shell access. UNAVCO's teqc software [reference A] is used for quality monitoring of GPS and GLONASS data. Other software written in house by CDDIS staff in FORTRAN and C are utilized for quality monitoring of SLR and DORIS data and interface to Oracle database. Perl modules have been coded for interface to the database through the web. Analog [reference B] is used for website statistics. Thunderstone's Webinator [reference C] is the website search engine for both the CDDIS and ILRS websites.

GSAC

Current clients and servers utilize PostgreSQL, PostGIS, Oracle, Apache, Perl, and Mozilla XUL [reference D].

Software References

A) http://www.unavco.ucar.edu/data_support/software/teqc/teqc.html
B) http://www.analog.cx
C) http://www.thunderstone.com/texi
D) http://gsac.ucsd.edu/

8.0 COOPERATIVE AGREEMENT PAYMENT SCHEDULE

Below is INDIGO's schedule of performance-based payment milestones for each period. These correspond to the milestone chart in Section 5.4 and INDIGO goals and objectives of Table 2..

Within this schedule INDIGO team participation in the SEEDS Working Group is implicit.

Period	Date	Milestone Completed
1	Feb-Dec '03	Funds on contract authorizing work
		Final negotiated CAN task plans submitted
		International Inter-Service Data Inf. Sys Working Group established, charter & membership documented
		Science Advisory Team 1st meeting, report card for CY03 presented
2	Jan–Jun '04	Assessment report on multi-technique data and products published
		INDIGO Annual Report for CY03 available
3	Jul-Dec '04	SAT 2nd meeting, report card for CY04 activities presented
4	Jan-Jun '05	Auto-positioning service announced
		INDIGO Annual Report CY04 available
5	Jul-Dec '05	Observation catalog, Site-ties (inter-technique relational measurements), Directory completed
		SAT 3rd meeting, report card for CY05 activities presented
6	Jan-Jun '06	Report on Inter-technique network architecture and data observation mix complete
		GNSS constellation integrity monitoring service implemented
		INDIGO Annual Report CY05 available
7	Jul-Dec '06	Website INDIGO structure functional
		Service data system re-architecting and standardization complete
		Update of INDIGO catalogs available
		SAT 4th meeting, report card for CY06 activities presented
8	Jan-Jun '07	Global Seamless Archive Center serviced operational
		INDIGO Annual Report CY06 available
9	Jul-Dec '07	GNSS integrity monitoring incorporates Galileo constellation
		INDIGO web-based tutorials for users complete
		SAT 5th Final meeting, report card for CY07 presented
		Project completion

9.0 CURRENT AND PENDING SUPPORT

This table summarizes current and pending funding for each of the project team members requesting salary support under this proposal.

Person	Source of Support	Project Title/Grant #	Full Cost Accounting Addition	Award by Fiscal Year	Total Award	Award Period	Level of Effort/ mo/yr	Location of Work
Rick Borgen	NASA	AMMOS TTC & DM 100714		500K	500K	10/02-9/03	12	JPL
Angelyn Moore	NASA	GPS Global Network, 622.71.62		540K	540K	10/02-9/03	12	JPL
Ruth Neilan	NASA	GPS Global Network, 622.71.62		540K	540K		12	JPL
Carey Noll	NASA	CDDIS Support 622.71.91	*150K	350K	350K	10/02-9/03	9	GSFC
	NASA	ILRS Central Bureau	*50K	330K	330K	10/02-9/03	3	GSFC
Mike Pearlman	NASA	Development and Implementation of Joint Programs for Laser Measurement NAS5-01113		200K	1.1M	4/01-3/06	8	GSFC
Dave Stowers	NASA	GPS Base, 622.71.64		800K	800K	10/02-9/03	12	JPL
Nancy Vandenberg	NASA	Research and Development Services for Very Long Baseline Interferometry in support of Code 926, contract # NAS5-01127		1.2M	6M	8/01-7/06	12	GSFC
Frank Webb	NASA	GPS Analysis System Dev 622.71.66		420K	420K	10/02-9/03	10	JPL
	NASA	GIPSY 622.71.68		80K	80K	10/02-9/03	2	JPL
Tom Yunck	NASA	GENESIS GPS Data Information System		560K	2.8M	9/98-9/03	2	JPL
		National Geodetic Observatory [pending]		330K	1.0M	3/03-3/06	2	JPL

*FCA starts FY'04 but these figures reflect civil service level of effort in FY'03

10.0 SPECIAL MATTERS

No special matters apply to this proposal for INDIGO.

11.0 LETTERS OF ENDORSEMENT FOR PROJECT INDIGO

12.0 REFERENCES

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[2] ICRS Information http://www.iers.org/iers/earth/icrs/icrs.html
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[4] ILRS Central Bureau website http://ilrs.gsfc.nasa.gov
[5] International VLBI Coordinating Center website http://ivscc.gsfc.nasa.gov
[6] IERS Central Bureau website http://www.iers.org
[7] Living on a Restless Planet, Solid Earth Science Working Group Report October 2002; http://solidearth.jpl.nasa.gov
[8] IAG website: http://www.gfy.ku.dk/~iag
[9] Rummel, R., Drewes, H., Bosch, W., and Hornik, H. (eds.) "Towards an Integrated Global Geodetic Observing System (IGGOS)," International Association of Geodesy Symposia, Vol. 120, 2000.
[10] Yunck, T., "Integration of Space Geodesy: A National Geodetic Observatory," submitted in response to NASA Research Announcement NRA 01-OES-05
[11] GPS Seamless Archive Centers Information http://www.unavco.ucar.edu/data_support/data/gsac/gsac.html and http://gsac.ucsd.edu
[12] Living on a Restless Planet, Solid Earth Science Working Group Report October 2002; http://solidearth.jpl.nasa.gov
[13] Bosworth, J.M., R.J. Coates, and T.L. Fischetti, "The Development of NASA's Crustal Dynamics Project. Contributions of Space Geodesy to Geodynamics: Technology." AGU Geodynamics Series, Vol. 25. 1993.
[14] CDDIS website: http://cddisa.gsfc.nasa.gov
[15] A proposed European GNSS: http://europa.eu.int/comm/dgs/energy-transport/galileo
[16] IGS Strategic Plan (JPL 400-1000)
[17] GLONASS is GLObal NAvigation Satellite System, a Russian GNSS; http://www.rssi.ru/SFCIC/english.html
[18] DORIS information: http://ids.cls.fr
[19] GENESIS website http://genesis.jpl.nasa.gov