IGS

SESSION 3

PHYSICAL SITE SPECIFICATIONS

Physical Site Specifications:

General Remarks

The Position paper about ***Physical Site Specifications*** tries to summarize the currently known facts and problems related with the setup of permanent GPS tracking stations as used in the IGS Global Network, and it will result in a number of recommendations for the improvement of the current and future tracking network.

It consists of the following individual contributions:

Site Naming and Identification	W. Gurtner
Geodetic Site Monumentation	L. Combrinck, M. Schmidt
GPS Antenna Calibrations	G.Mader
Special Equipment: Radomes and Met Sensors	J. Johansson

Physical Site Specifications:
Site Naming and Identification

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Before going into physical aspects of permanent tracking sites we will discuss a more administrative problem continuously being discussed at various meetings and workshops and by e-mail exchange between analysts, the Central Bureau, Data and Operational Centers, and Tracking Sites:

The proper and unique identification of the marker, the receiver, and the antenna with all necessary auxiliary information valid at the time when the tracking data to be processed have been collected.

Four-Character ID

The first identification an IGS user usually comes across is the 4-character Station ID.

This code was originally used for naming purposes of RINEX files only: The recommended RINEX filename contains 4 characters for the site identification (e.g. zimm1230.98o). The requirement for the code was to be as unique as necessary to not generate confusions between RINEX files of the same date within e.g. the same campaign or the same permanent network. IGS adopted this system. Consequently the requirement was uniqueness at least within the IGS network (plus some of the regional networks like EUREF, SCIGN, CORS, etc.).

IGS also set up a directory of station log files in the Central Bureau Information System. For their naming the same 4-character code was used. (See below).

The analysis centers also started to use this code for the identification of sites for the analysis and in resulting products (coordinate and velocity lists, etc).

This was simple as long as there was one marker, or rather one receiver operating on a specific site only. A soon as markers were replaced or new marker added, more than one receiver hooked on the same antenna, things became more complicated because the unique relation between this 4-character code and a specific receiver connected with a specific marker/antenna got lost. Many station managers tried to maintain the uniqueness of the 4-character codes by deliberately introducing new code, one for each new receiver or marker, such as RCM2, RCM3, etc.

This practice increased the probability of duplicate codes across the network, generated codes more difficult to memorize, and blocked codes still reserved for markers not used or existing anymore.

The DOMES Number

IERS has been using for marker identification purposes the so-called DOMES numbering scheme for years. The DOMES numbers (Directory Of MErit Sites) have been developed and maintained by the ITRF section of IERS at the Institut Geographique National (IGN) in Paris. As it was the only globally unique and suitable numbering system that was readily available, IGS decided in collaboration with IGN to also use this scheme for its purposes. The DOMES number is now a requested item to be assigned to all IGS-accepted sites.

There still remains the problem of identification of multiple receivers hooked to the same antenna, and of the identification of discontinuous solutions of the marker positions due to special events such as earth quakes or changes in the immediate environment of the marker or replacements of equipments (e.g., antennas, domes).

The RINEX Header Contents

The RINEX observation file headers contain various entries designed to allow for unambiguous processing of the related data:

MARKER NAME
MARKER NUMBER
RECEIVER TYPE
ANTENNA TYPE

IGS decided to have the stations store their DOMES number into the RINEX header MARKER NUMBER field which allows, together with the receiver type field, a proper identification of the data in the file.

Unclear is what has to be stored into the MARKER NAME record. It would make sense to include a somewhat descriptive name of the site including a marker identification such as

ZIMMERWALD L+T88

or

ZIMMERWALD GPS87

which are also found in the station log file (see below) or in site documentations of the owner agency.

The Station Log File

The standard site log file being requested by IGS for all IGS sites is rather a marker or more precisely an "active receiver" log file: Each log file treats one marker only and there is no provision in the log file to deal with more than one receiver simultaneously hooked to the same antenna.

Consequently for each active receiver an individual log file is requested (as it is true for the RINEX files, too, of course).

The naming convention used in the IGS CB Information System is:

ssssyymm.log with: mm = month,
yy = year of the creation/modification date

Each log file shows a fill history of the receiver/antenna/domes information from the creation date till the last modification date.

Modified files are always stored under a new name containing the modification date as discribed above. Obsolete log files are moved into an "oldlog" directory.

SINEX Files

The CODE (4 characters) of the SITE/ID field is rather a site and not a marker identifier. The PT identifier is used to distinguish different markers at the same site.

The combination of CODE and PT is a unique identifier for each marker in the SINEX file but is not (or doesn't have to be) globally unique across all existing SINEX files.

The primary and globally unique identifier in the SINEX files generated and used by the IGS Analysis and Associate Analysis Centers is the DOMES number.

If there are several receivers on the same antenna their solutions are kept apart by the SOLN parameter.

Some of the Analysis Centers would prefer to always keep the CODE (4 characters) for a certain site, even when markers are moved or added.

Much of the confusion comes from the fact that the 4-character codes used for RINEX file namings don't necessarily agree with the codes used in the SINEX files, as the example of two receivers hooked to the same antenna clearly demonstrates (same CODE in the SINEX file, different code for the RINEX file naming).

Site Versus Marker

It is understandable that the analysts prefer to "see" primarily the site and not the individual marker or receiver because

- markers and receivers tend to have limited life times whereas sites should last much longer
- all the markers on the same site (hopefully) show the same behaviour with respect to geokinematic interpretations

A proper identification of the individual markers, antennas and receivers, however, is absolutely mandatory.

Proposed Solution

Official IGS Site Code

For each site IGS decides, in collaboration with the station responsible, which marker and, if more than one receiver is hooked to this marker, which receiver is the official one,

- the data of which are to be included into the IGS data directories of the Data Centers
- the data of which are to be processed by the Analysis Centers to generate the official IGS products.

This marker/receiver pair is assigned a 4-character code which should not contain a digit in the fourth position.

This 4-character code is used to name the RINEX observation and navigation message file of this marker/receiver as well as the met data file, if any.

The same code is also used for the naming of the corresponding station log file.

The same code is also used in the SINEX file in the CODE field of all solutions pertaining to the site (i.e. for additional markers or receivers on the same site, too, see below).

Case: Multiple Receivers on the Same Antenna/Marker

In case of multiple receivers on the same antenna the RINEX and station log files of the additional receivers are named using a derivative of the official code by replacing the fourth character by a digit or a meaningful other character.

Care has to be taken to not assign a code used by an other IGS site or site of a Regional Network contributing to IGS.

The data of these additional receivers should be stored in a separate directory at the Data Centers.

- In case the additional receiver is again put out of operation the assigned code is free to be used for other markers/receivers by the same or different sites.

The intermediate log file (with the derivative name) is moved into the "old log" directory.

- In case the official receiver is put out of operation the assigned code is transferred to the new receiver and the site log file modified to reflect in fact a receiver change on the marker.

  The intermediate log file (with the derivative name) is moved into the "old log" directory. From now on the RINEX file of the new receiver will be named with the official site code.

- In case the official receiver is replaced by the new one but continues to operate, its RINEX and log file will have to be named using a derivative of the site code.

If the Analysis Centers process more than just the official data files the SINEX records all contain the same (official) CODE, the same PT and DOMES numbers but individual solution numbers.

Case: Multiple Markers on the Same Site

In case of multiple markers on the same site the RINEX and station log files of the additional receivers are named using a derivative of the official code by replacing the fourth character by a digit or a meaningful other character.

Care has to be taken to not assign a code used by an other IGS site or site of a Regional Network contributing to IGS.

A new DOMES number has to be defined by IERS for each additional marker.

The data collected at these additional markers should be stored in a separate directory at the Data Centers, unless important reasons ask for a different decision.

- In case the receiver on the additional marker is again put out of operation the assigned code is free to be used for other markers/receivers by the same or different sites.

The intermediate log file (with the derivative name) is moved into the "old log" directory.

- In case the official marker is put out of operation, the assigned code is transferred to the new official marker. The site log file of the old marker is modified to reflect the change of the marker (add new DOMES number, add new local ties, etc). A comment in the log file should also make it clear that the new marker replaces the old one.

(We have to slightly modify the site log file format to allow for marker descriptor and DOMES number modifications.)

The old and the intermediate log files are moved into the "old log" directory.

From now on the RINEX file of the receiver on the new marker will be named with the official site code.

- In case the official receiver on the old marker is replaced by the one of the new marker but continues to operate, its RINEX and log file will have to be named using a derivative of the site code.

- If the official marker is replaced by a new one without transition period the transfer of the code can be done immediately. The log file has to be modified to contain the new DOMES number, new marker description and local ties, etc. The original site log file is moved into the "oldlog" directory. No derivative code has to be defined.

If the Analysis Centers process more than just the data files of the official marker, the SINEX site records all contain the same (official) CODE but individual PTs and DOMES numbers. The solution numbers are set according to other specific needs.

We propose to use as PT the fourth character of the corresponding RINEX file code.

Advantages/Disadvantages

The **advantages** of the proposed solution are:

- Avoid generation of obsolete codes
- Avoid generation of code series like RCM1 RCM2 RCM3 etc
- Use of four characters (and not three plus one digit) for all official IGS sites
- Decrease probability of code conflicts
- Identity of the RINEX and SINEX codes to a large extent, the exceptions are clearly defined

The **disadvantages** of the proposed solution are:

- There is not necesserily a one-to-one relationship between the site code and a specific marker for all times (but at each instant!)
- One cannot necessarily derive the correct marker/receiver from the RINEX filename alone without consulting additional information (contents of the RINEX header and/or site log file), only the site.

Examples

New marker replaces old one, no parallel operation

```
---------------------------------------+--------------------------------------
            Official                   |               Additional
---------------------------------------+--------------------------------------
RINEX DOMES Recvr Logfile     SINEX    |RINEX DOMES Recvr Logfile     SINEX
Code                       CODE PT SOL |Code                       CODE PT SOL
---------------------------------------+--------------------------------------
ABCD   M001 4000i ABCD0397 ABCD  A  1  |
ABCD   M002 4000i ABCD0298 ABCD  B  1  |
---------------------------------------+--------------------------------------
```

Second marker in parallel, replaces later the original one

```
---------------------------------------+--------------------------------------
            Official                   |               Additional
RINEX DOMES Recvr Logfile     SINEX    |RINEX DOMES Recvr Logfile     SINEX
Code                       CODE PT SOL |Code                       CODE PT SOL
---------------------------------------+--------------------------------------
DEFG   M001 4000i DEFG0397 DEFG  A  1  |
DEFG   M001 4000i DEFG0397 DEFG  A  1  |DEF1   M002  TR   DEF10997 DEFG  B  1
DEFG   M002  TR   DEFG0298 DEFG  B  1  |
---------------------------------------+--------------------------------------
```

Second receiver on same antenna, replaces later the original one

```
---------------------------------------+--------------------------------------
            Official                   |               Additional
---------------------------------------+--------------------------------------
RINEX DOMES Recvr Logfile     SINEX    |RINEX DOMES Recvr Logfile     SINEX
Code                       CODE PT SOL |Code                       CODE PT SOL
---------------------------------------+--------------------------------------
HIJK   M001  TR   HIJK0397 HIJK  A  1  |
HIJK   M001  TR   HIJK0397 HIJK  A  1  |HIJ1   M001 4000i HIJ10997 HIJK  A  2
HIJK   M001 4000i HIJK0298 HIJK  A  1  |
---------------------------------------+--------------------------------------
```

Site Log File Modifications

Site Events

In order to especially help the users of the IGS tracking data and reference stations, the reconstruction of the complete history of the sites and markers has to be possible anytime.

The site log files (including the historical ones in the "oldlog" directory), together with the RINEX file header contents have to guarantee this, as there are not (and possible should not be) more sources of information available for the user.

The current format of the log file does not contain fields where (apart from receiver/antenna/radome changes) special events can be recorded that might influence the value of computed positions:

- earthquakes
- changes in horizon mask: buildings, removal of trees, ...
- changes in RF environment, e.g. metal fence around antenna
- timing receivers: Changing antenna cables or connectors,
  changing environmental conditions

The site log file as central source of site information would be the natural place where to store such events. Therefore we recommend to include into the site log file format a "special event" field:

12. Local Events Possibly Affecting Computed Position

```
12.x  Date                        : (dd-MMM-yyyy hh:mm UT)
      Event                       : (multiple lines)
```

Monument and Marker Description

In order to improve the informations about the monument and marker (can be important to interpret time series of computed positions) we propose to include into the

1. Site Identification of the GPS/GLONASS Monument

part the following two new lines:

```
  Monument Description     : (PILLAR/BRASS PLATE/STEEL MAST/FICTIVE/etc)
  Mark Description         : (CHISELLED CROSS/DIVOT/BRASS NAIL/etc)
```

The two modifications have already been introduced into the IGEX-98 site logs.

Physical Site Specifications: Geodetic Site Monumentation

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Abstract

Monumentation is one of the most important aspects of a geodetic installation, whether it be for VLBI, SLR or a GPS installation. Currently a large number of different monument types, with varying designs, construction, quality and suitability are used in the IGS network. This chapter gives an introduction to the current approach to monumentation, some of the aspects of site selection and monumentation, with special emphasis on safety from vandalism, stability and collocation as seen from the GPS technique viewpoint.

Introduction

Several different techniques are used in modern geodesy and currently there are several space geodetic techniques which are utilised at facilities all over the world. Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and Global Positioning System (GPS) are three of the main space geodetic techniques supported at fiducial sites. The monumentation for each technique may differ as the instrumentation that needs to be supported is quite different. For instance there is a large difference in mass between a GPS antenna and a geodetic VLBI antenna. However, one wishes to achieve the highest possible stability of the monument in each case. Apart from stability, one needs to assess the site for other prerequisites such as low horizon, possible multipathing and vandalism which will determine whether the site is suitable. The nature of the site determines to a large extent the type of monumentation required.

In order to determine the stability of each geodetic fiducial site on a local scale, small networks are measured which surrounds the geodetic sites. These footprint networks normally cover a radius of hundreds of metres to tens of kilometres. For instance Goddard Space Flight Centre's (GSFC) Crustal Dynamics Project and now its successor, the NASA Space Geodesy Program has been involved in the acquisition of GPS data at footprint networks located around primary VLBI and SLR sites since 1990. Footprints may cover geodetic sites which support not only GPS, but other techniques such as VLBI and SLR. In this case one would want to tie the reference points of each geodetic system and this can be done simultaneously using GPS.

GPS Monumentation

The IGS guidelines taken from their webpage has the following specifications for the geodetic monument and can be found under the section describing requirements for permanent stations:

Marker: *The marker should fulfil standard requirements for a first order geodetic monument with respect to stability, durability, long-term maintenance, documentation and access. The marker description should be fully documented in the IGS site log file.*

The log file requests a full description of the monument. Table describes the status of 44 IGS global stations (sampled alphabetically in sequence) log files as far as monumentation is concerned. More often than not it is not specified whether the monument is in fact founded on the underlying bedrock. Sometimes there is a GIF image which at least shows if the monument is located on a building, but the table reflects only the contents of the current log file as submitted. The GIF image, although adding useful information does not supply all the required information. It is obvious that the log file entries leave a lot to be desired and in many cases is totally useless in terms of describing monument, monument foundation, mounting plate and other relevant detail. This lack of detail needs to be addressed. It seems there are different interpretations of the terms monument, marker and mounting plate. The monument is a lasting, many times colossal, structure which serves as foundation for the marker. This monument can be in the form of a concrete pier, steel construction or rock outcrop, designed or selected to represent the earth's crust or as close as you can get to it. In the case of an antenna fixed to a roof of a building, the building is the monument and the pipe supporting the antenna is an extension of it. The reference marker is attached to the monument and serves as the geodetic reference point. This can be a brass or stainless steel pin or fitting with centred punch mark. Your antenna height is measured to the reference mark. The mounting plate supports the antenna, and could have as part of its construction a reference mark. The reference mark must however be fixed permanently to the monument. An adjustable reference mark is *not* a reference mark.

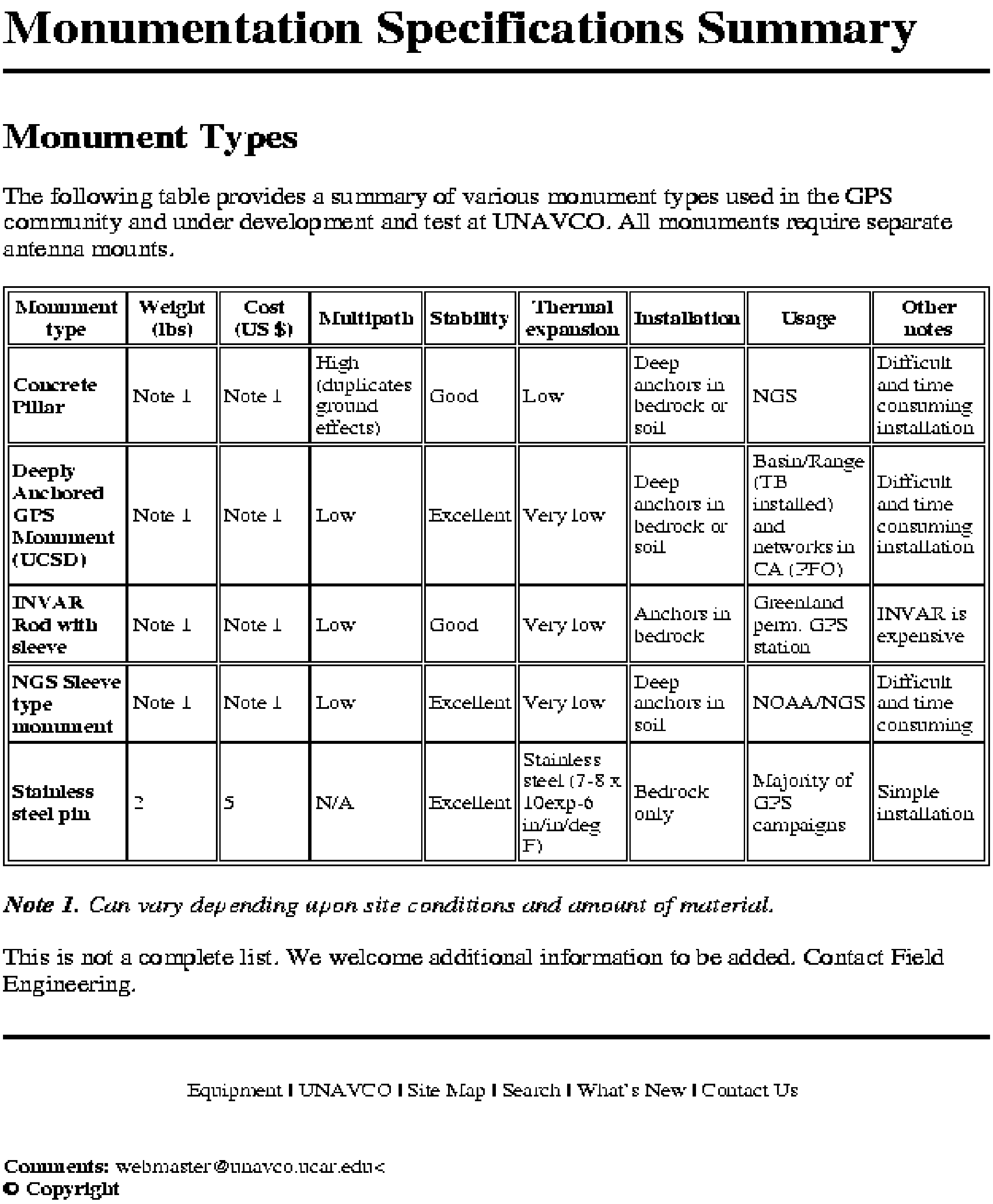
UNAVCO has an excellent website which contains a large amount of interesting and useful details on monumentation. They have invested a large amount of time on monument stability and is a 'must read' for the investigator who is planning to construct and install geodetic monumentation. UNAVCO's preferred monument according to their webpage is the deeply anchored/braced monument designed by Frank Wyatt, Hadley Johnson and Duncan Agnew, as described in *Improved stability of a deeply anchored geodetic monument for deformation monitoring*, Geophysical Research Letters, Vol. 22, No. 24, Pages 3533-3536, December 15,1995. UNAVCO supports requests for monument consultation and design with details of some of these to be found on their website, such as the design for a monument using an Invar rod to withstand the climatic extremes of Greenland. Details of the UNAVCO levelling mount, GPS geodetic quality benchmarks and recommendations on sleeve depths for expansive soils can also be obtained on the website.

Table 1: IGS Global stations

Station	Monument Type	Foundation Material	Monument Foundation Confirmed
ALBH	Concrete pier	Exposed bedrock	Specified
AIGO	Concrete pier	Exposed bedrock	Specified
ANKR	Pillar	Clay and Silt, Limestone	?
AREQ	?	Alluvium	?
ASC1	Building	?	Roof mount
AUCK	Concrete	Clayey soil, sandstone, mudstone	augered to refusal ?
BAHR	?	?	?
BARB	Building ?	?	?
BOGT	Buiding ?	?	?
BRMU	Building ?	?	?
CAS1	?	?	?
CHAT	Concrete pier	Clay,100 ft firm/waterlogged soil	Presumed ?
COCO	?	?	?
CRO1	Concrete pier	?	?
DAV1	?	?	?
DGAR	?	?	?
DRAO	Concrete pier	Exposed bedrock	Specified
EISL	Concrete pier	?	?
FAIR	?	Metamorphic rock	?
FORT	?	?	?
GALA	?	?	?
GOL2	25 M microwave tower	Alluvium	?
GUAM	Building	?	Roof of observatory
HARK	?	?	?
HOB2	Concrete pier	Jurassic Dolerite	?
HRAO	Interlocking steel rod	Andesite	Specified
IISC	?	?	?
IRKT	Rock	?	Installed on 'a rock'
KELY	?	?	?
KERG	Concrete pier	?	?
KIT3	?	?	?
KOKB	Satellite tracking base	Magma	?
KOSG	?	?	?
KOUR	Concrete pier	?	?
KSTU	Pillar	Bedrock	Specified
KWJL	Mast on building	Coral reef formation	?
LHAS	Pillar on building	?	?
LPGS	?	Conglomerate	?
MAC1	?	Sedimentary bedrock	?
MAD2	No monument ?	Granite/sandy soil	?
MAG0	Steel rod	Bedrock	Specified
MALI	Concrete monument	?	?
MAS1	?	?	?
MATE	Pillar on building	Sedimentary bedrock	?

Monument Types

A very informative monumentation specification table which characterizes various monuments in terms of approximate cost, multipath and physical attributes is on the website and is reproduced here for our benefit in Fig 1. One common attribute which is conspicuous in the UNAVCO table for most 'excellent' monuments is that these installations are difficult and time consuming. Even the stainless steel pin installed in bedrock, although listed as a simple installation, may require a thorough site investigation using geophysical techniques as 'bedrock' is sometimes not what it appears to be. The building type monument is not listed, but currently it is of a type that should be added to the list. If one attaches a geodetic monument to a building, the building in effect forms part of that monument.



Monumentation Specifications Summary

Monument Types

The following table provides a summary of various monument types used in the GPS community and under development and test at UNAVCO. All monuments require separate antenna mounts.

Monument type	Weight (lbs)	Cost (US $)	Multipath	Stability	Thermal expansion	Installation	Usage	Other notes
Concrete Pillar	Note 1	Note 1	High (duplicates ground effects)	Good	Low	Deep anchors in bedrock or soil	NGS	Difficult and time consuming installation
Deeply Anchored GPS Monument (UCSD)	Note 1	Note 1	Low	Excellent	Very low	Deep anchors in bedrock or soil	Basin/Range (TB installed) and networks in CA (PFO)	Difficult and time consuming installation
INVAR Rod with sleeve	Note 1	Note 1	Low	Good	Very low	Anchors in bedrock	Greenland perm. GPS station	INVAR is expensive
NGS Sleeve type monument	Note 1	Note 1	Low	Excellent	Very low	Deep anchors in soil	NOAA/NGS	Difficult and time consuming
Stainless steel pin	2	5	N/A	Excellent	Stainless steel (7-8 x 10exp-6 in/in/deg F)	Bedrock only	Majority of GPS campaigns	Simple installation

Note 1. *Can vary depending upon site conditions and amount of material.*

This is not a complete list. We welcome additional information to be added. Contact Field Engineering.

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Figure 1: UNAVCO monument specification table

Finding a Good Site

For a footprint, it would be difficult to build a monument for each reference point in the footprint network which would have comparable or better stability than a site's main geodetic GPS monument, unless unlimited funds were available. However, for the main geodetic monument, one must do your best to ensure that instabilities of any kind have been minimized. If we could build a monument and tie it to bedrock, or be fortunate enough to find exposed bedrock, monument instability would be minimized.

Some of the requirements for a good primary monument site are:

(1) shallow bedrock of high quality

(2) clear horizon

(3) safe from vandalism

(4) clear of reflecting surfaces (fences, metal poles etc.)

(5) not too far from receiver

(6) ease of access

(7) data accessibility

(8) electric power

(9) no local crustal instabilities

(10) controlled vegetation (growing horizon elevators)

Of course not all these site qualities are easily found, or are economical or practical to achieve.

The type of monument normally depends on the site characteristics, as well as on the investigators eagerness to obtain as stable and durable a monument as possible. Don't build a monument flush with the earth's surface, apart from antenna interaction with (varying) conductive soil, humans and growing vegetation shadowing satellite signals, the antenna is 'overexposed' to its environment. Bugs will crawl into it, ants will nest in it, it might get flooded, trampled on etc. The UNAVCO site has some examples of monument types. Some interesting monuments exist, such as the massive monolith used by the University of New Castle (Geoff Blewitt's group).

To find a good site, one starts out with an idea as to where the GPS monument should be located, with the above mentioned requirements in mind.

Horizon Mask

The horizon mask is defined as those areas of the horizon, when viewed from the antenna, that are obstructed so as to impede or block the satellite signal from reaching the antenna. Ideally there would be no obstruction above the horizon; however in a practical world it is rare that this optimum is achieved at the same time as meeting all other siting specifications. Significant blockage below certain elevations or in specific azimuthal quadrants can limit the usefulness of the data collected as well as constrain the user community to a select group rather than meeting the needs of a broader user group.

"Solid" objects such as mountains and buildings as well as trees and structures can cause the blocking of the satellite signal. In the former case the signal will be lost for the duration of time the satellite(s) is/are behind or below the obstructing object. For example in deep valleys or within the boundaries of large cities, this can amount to a considerable amount of lost data. In the case of vegetation and other less "solid" obstructions, the loss may be of a more intermittent nature depending on the transparency of the obstruction to the satellite signal. The obstruction may also vary with time. Deciduous trees, which have lost their leaves, will provide less obstruction compared to fully foliated trees. The type of tree cover (thick rain forest vs. sparse needle forest) is important as is the capability of the receiver / antenna that are to be used at the site. Some receivers / antenna combinations are designed to track under tree cover while others are not. Trees will obviously also grow and thus affect the horizon mask with time. In a similar fashion urban growth or development in the immediate area of the reference station installation may affect the horizon mask with time. Intermittent blockages and site changes may also cause multipath problems.

It is important to select a site with minimal blockage and to ensure that the horizon will not undergo significant change with time. It may be necessary to determine the extent of anticipated development from adjacent landowners. During the site reconnaissance stage, obstructions (current and planned), should be noted and prediction software used to determine the effect of the blockages on the data collection and thus the range of user applications of the data. Changes over time should be noted in the site log.

Multipathing

Multipath can cause errors in GPS measurements, the severity of which is dependent on the extent and type of multipath. As the expression indicates, multipath refers to signals that arrive at the antenna via multiple paths, in this case caused by reflective surfaces in the vicinity of the reference station. Multipath causes interference or distortion, and therefore error, primarily on the code pseudo-ranges but also on the phase pseudo-ranges.

Different types of reflective surfaces can cause a multipath effect on the received signal. Most obvious are highly reflective surfaces such as the sides of buildings, solar panels, vehicles, etc.. Fluctuations in multipath levels can be caused by surfaces such as water whose reflective properties will change with time. Similarly the accumulation of snow or ice on nearby structures or on the surrounding ground can effectively change the properties of the reflected radio signal as a function of time. A diffused scattering of the satellite signal can be expected from metallic structures such as large radio towers and chain link fences.

The siting of the antenna installation and the monitoring of any changes in the surrounding area is very important. Prior to establishing the site, data should be collected using the same type of instrumentation that is to be installed and as close as possible to the exact location of the proposed antenna site. A longer test data set, for example 72 hours, when analyzed should provide a good indication of the impact of the site's multipath environment. It may be necessary to test several different antenna heights in order to judge the optimal height for the reference station antenna. The addition of ground planes and use of RF absorbing material may have to be considered. It should also be noted that reflective waves from surfaces below the antenna, such as the ground and the top of a concrete pier can also cause problems and steps may be required to minimize this source of near-field multipath.

Buildings

If a building is being considered for your monument, installation is normally easier as there might be convenient access to power, clear horizon, security and other items on your wish list. Stability will to a large extent be dependent on the size of the building, its foundations, its age and nature of the site it has been constructed on. There might also be other RF equipment installed on the building, for instance VHF and UHF repeaters, with their accompanying RF harmonics radiating and causing intereference in the L band which will degrade your installation. Sometimes there are metal structures which should be taken into account such as airconditioning plants, guard rails, water tanks and antenna towers. A solidly constructed building, with foundations on bedrock can be a good monument/site, but one has to be aware of its stability limitations. Large structures increases the room for instability.

RF Environment

The radio frequency (RF) signal received by reference station satellite receivers can be detrimentally affected by the presence of interference from other RF sources. This interference can simply show up as additional noise in the data, cause intermittent or partial loss of lock or, in the more severe cases, render the reference station completely inoperable.

The close proximity of a transmitting facility (such as a TV station, microwave facility, etc.) can cause an overload in the front-end filters of the antenna / receiver. Other sources of RF include FM radio stations, cellular telephones, CB radios, radar, high voltage transmissions lines, etc. Some sources which are near-band w.r.t. the primary satellite signals are obvious sources of RF interference (RFI). However harmonics from other sources are not so obvious. It should also be noted that the close proximity of pseudolite ground transmitters can cause interference or jamming of the satellite signal in a reference station receiver.

It is therefore important to collect as much information about transmitters (current and planned) in the area as well as the use of any portable RF equipment prior to installing a site. The potential presence of RFI is another good reason to test a site thoroughly. In addition to collecting and analyzing a data set (72 hours if possible) a spectrum analyzer should be used to identify any RFI in the band allocated to the satellite signals. Ideally the spectrum analyzer would be connected to the satellite receiver's antenna via a splitter at the same time the test data set is collected.

Field Installation

Once you have decided on the geographical region for your installation and have studied available geological and geotechnical data, a field reconnaissance should be undertaken to gather information on the proposed site. Look for possible exposed bedrock, note the strike and dip of the rock, joint spacing and condition. You would want to draw a map of the site and its immediate surroundings, keeping in mind that you want a stable monument. Factors which might influence the stability of your monument on rock are:

(1) Presence of faults

(2) Joints, fractures, shear zones

(3) Varying ground water levels

(4) Rock slope instability

(5) Rock which could cause problems due to swelling, dissolving and shrinking

(6) Presence of cavities due to karstic formations, such as found in dolomitic regions

(7) Human engineering activity, gas,water and sewer pipes, drainage ditches.

(8) The type and condition of the rock

The effect of these factors are quite obvious. For instance joints, fractures and shear zones may be filled with compressible soils such as expansive clay. During drying and wetting cycles, expansive minerals, for instance montmorillonite and anhydrite, shrink and expand, leading to a seasonal signal in your time series. Cavities develop in soluble rocks, especially dolomite, limestone, rock salt and gypsum. This might not have an immediate effect on your monument, but an existing cavity may lead to your monument disappearing into a sinkhole when the cavity roof collapses. Flow of water dissolves gypsum and can cause tilting of your monument. Certain types of rock are less suitable for a stable site, as the density of the rock is normally a factor in the swelling characteristics of the rock. Shales for instance are affected by moisture content, density, weathering and mineral structure.

Boring

Sometimes one can find bedrock which is hidden below the soil by utilizing techniques of geophysics such as resistivity tests and gravimeter measurements. Once a point has been found that will be suitable, boring is the only viable tool which will directly reveal the condition of the subsurface conditions. At HartRAO for instance, during the installation of the SLR reference point, resistivity and gravimetry measurements showed large fluctuations in depth to bedrock. The mother material of the soil is andesite, which often weathers in such a way as to leave large boulders suspended in soil. This could lead to a monument bedded onto a suspended boulder instead of onto real bedrock. Core logging describes a permanent record of the rock mass conditions and is useful in estimating the depth to the weathered zone and fresh bedrock. After finding solid bedrock, one still has to drill through and clear off the weathered and fractured top section until fresh bedrock has been reached. This is the part to which you want to fix your monument. We eventually augered a 1 metre diameter 6 metre deep hole which was cut partially into the andesite to access fresh bedrock. The monument was isolated with foam from the soil and is a massive steel and concrete structure fixed to bedrock. Of course the number of borings and the depths would be limited if the rock mass conditions are of excellent quality and massive. Rock boring is expensive, so more time spent on locating an approximate position of the bedrock closest to the surface will be worth it. In the case of our IGS GPS station (HRAO) monument we drilled through exposed shale and then into bedrock and grouted a steel monument into the andesite by pressure pumping grouting down the steel tube. The tube had holes drilled in the bottom section, so that the grouting would be forced out into the joints and cracks of the rock, effectively like a tree sprouting roots. The steel was then isolated from the drilled hole via thick wall plastic tube and guided through a steel collar cemented onto a foundation installed on the slate. This allows the shale to breathe as it absorps and loses water, without affecting the stability of the monument.

Not Fixed to Bedrock?

Not all monuments can be tied to bedrock, you might have to install a monument on sand, on top of a building, deep soil or expansive clay. What should be realised at the outset is that there are instabilities introduced the further your monument moves away from the bedrock. Expansive clay is not a stable foundation and great care should be taken when designing your monument. There are many GPS monuments which are not tied to bedrock and they produce good results. We must however be sure that we are measuring what we were originally planning to do and not perhaps thermal expansion, short and long term building foundation settlement, slope movement, local subsidence due to groundwater extraction etc.

The 'Building Type' Monument

When a building is constructed, its foundations may or may not be fixed to bedrock. The load imposed by the structure at the foundation level will always be accompanied by strain which result in settlement of structures. This is true for your monument as well to a certain extent. The total settlement of the monument or building foundation in general is given by

$$S = S_e + S_c + S_s \qquad (1)$$

where S_e immediate settlement, S_c primary consolidation settlement and S_s secondary consolidation settlement. In granular soils the predominant part of the settling is during the immediate settlement phase. In areas where saturated inorganic silts and clays occur the primary consolidation settlement predominates. If your monument is located on highly organic soils or peats the secondary consolidation settlement forms the major part of the settlement.

Of course the expected settlement is not easy to calculate due to the many variables involved such as modulus of elasticity, shear modulus and Poissons ratio obtained from triaxial tests, but reasonable estimates are possible. One can find many different approaches in the literature. If you are installing a monument on a newly constructed building, mortar shrinkage will also produce some instabilities, these last about 6 months. Typical primary consolidation over a period of 10 years is on the several cm level. The settlement depends a lot on how close the foundation is to bedrock, the closer, the more stable your monument will be.

The coefficient of secondary consolidation for thick clay is defined as

$$C_\alpha = \frac{\Delta H_t / H_t}{\Delta \log t} \qquad (2)$$

where t is time and H_t is the thickness of the clay layer. C_ decreases logarithmically with time and is directly proportional to the total thickness of the clay layer once secondary consolidation has started. So, within reason, if you have to choose a building for your monument location, the building becomes part of the monument and in general older buildings will most likely be more stable.

Antenna Mounts

UNAVCO has done a considerable amount of work on suitable mounts and normally they attempt to address points such as:

(1) relocation of a replacement antenna
(2) ease of installation
(3) stability
(4) durability
(5) tampering
(6) levelling and orientation of antenna
(7) multipathing
(8) attachment to monument

UNAVCO has a summary of various antenna mounts on their web page. There are many different versions of the same type and it is often up to the ingenuity of your mechanical workshop as to how the mount is made. There are several good designs available. I recently saw a nice easy mount designed and built at SOPAC, which simplifies antenna installation and removal, making it very convenient for testing antennas. There is no ultimate mount, but there are some which you may want to throw out after some thought.

For all our installations, HRAO, HARK and our new HartRAO/JPL site for Namibia we use a similar design to UNAVCO's 'levelling mount'. These can be made up easily and are very stable, easy to align and durable. Mounts should use only marine grade stainless steel, marine grade aluminum or other stable and durable material. PVC and other material which do not withstand bushfire or intense solar radiation should be used with caution.

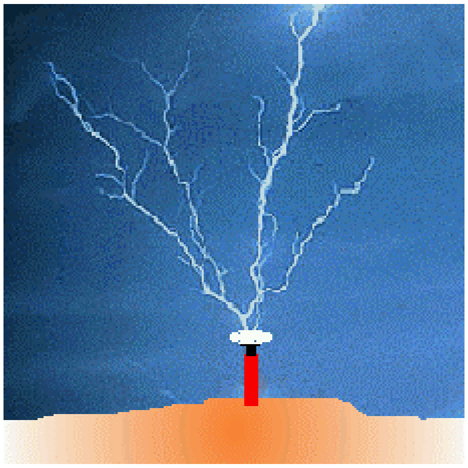

Figure 2: Your IGS station ?

Lightning and the Geodetic Monument

Many IGS and other GPS sites have been taken out by lightning, totally and partially, with damage occurring to the antennas, inline amplifiers, receivers and peripheral equipment. All sites should go to great lengths to ensure that their equipment is protected as best as possible as lightning damage is normally quite severe.

UNAVCO has done a lot of work on lightning protection for monumentation and the associated equipment attached to the monument and a large amount of useful information and technical details is given on their website. Direct lightning strikes of monuments are in the minority when compared to damage resulting from EMPs (electro-magnetic-pulses). The EMP induces high voltages in unprotected coaxial cables and antennas which allows massive voltage spikes to enter anything else attached to the cables. At HartRAO, we have had several outages of HRAO as a result of lightning, all of the EMP type. We might have a more severe problem in this regard as most other sites, as this area (Johannesburg) is reputed to have one of the highest counts of lightning strikes per year in the world. Proper grounding rods at the monument, and at the other side of the coax and data lines, inline EMP protectors (Huber+Suhner), surge protection in RS232 lines and power lines are all necessary to reduce the chances of damage. The use of optical fibre links for data communication should be used if possible. One should not use any form of lightning protection unless it has been properly tested and screened, so it would be prudent to check with UNAVCO if your proposed system is suitable. There is a large amount of totally inadequate devices on the market which will not produce the required results.

Surge Protecion Devices

Surge protection devices (SPDs) are also known as 'surge arrestors', 'lightning protection units' and 'lightning barriers'. The SPDs which you want to protect your equipment with should ideally operate instantaneously to divert a surge voltage and current to ground, resetting automatically to restore normal operation and be ready for the next surge. Tests done by the IEEE have shown that many cheap type of SPD functions only the first time, but still has an indicator that pretends all is well. Advanced SPDs however combine a number of different surge-supression components to utilize their different characteristics. Data line SPDs make use of high-current, high-voltage gas discharge tubes and low-voltage, low-current surge suppression diodes for rapid and accurate voltage control. UNAVCO is able to advise on suitable units.

Vandalism

Vandalism is probably of concern to us all and some locations may have serious problems in this regard. Vandalism comes in different forms and from different sources and in varying degrees of intensity. Certain electronics companies recognize this, for instance those who make public telephones will advertise their equipment to be well designed, durable and dependable. They will also offer a wide variety of models constructed of heavy gauge stainless steel, lexan armored cables and tamper-proof securities. Do we have the same approach for our GPS equipment? In South Africa I have yet to discover a survey beacon flag that is not riddled with large calibre bullet holes. How tough are these radomes?

Some IGS sites are particularly vulnerable in that they are easily accessible, with antenna and receiver a couple of metres apart. The receiver and small UPS may be enclosed in a metal box which is locked. Many times the box is fixed on a steel pipe, so that the casual vandal would not tamper with the equipment. The serious vandal however will saw off the pipe and remove the whole installation intact.

When a site selection and investigation is done, the vandal potential should be estimated amd minimized. Vandalism is normally of human origin (except in South Africa where I take baboons into account), but rodents and heavy hoofed animals may wreck havoc with wiring and coax if exposed, even fire should be considered. During the site selection and monument design phase consider some of these points:

(1) Is the site visible from public pathways and road?

(2) Is your color scheme for the monument and enclosures vandal yellow, or does it blend into the environment, making it less conspicuous?

(3) Is the monument constructed in such a way that the antenna is out of reach?

(4) Is the reference marker to be a nice, attractive, 2 Kg, beautifully machined and polished brass momento?

(5) If you are considering fencing, metal or (sometimes wet) wood, what about multipathing?

(6) The very casual vandal might be an innocent visitor, blocking off satellites because your antenna is below human height. Do you need loss of lock?

(7) Is your GPS site on the list of things all visitors must see?

(8) Are you incorporating some electronic alarm which will warn you if the equipment is being tampered with?

(9) Has the radome you are considering been checked for uniform thickness, rf transparency, does it retain these characteristics out in the sun?

(10) Should you consider additional insurance?

(11) Will the communication and rf cables be protected?

(12) Does the solar panel have reduced reflective surface?

(13) Are the equipment boxes really solid and can they be bolted from inside onto rock or buried stakes?

(14) Is the site plagued with bush fires?

There is of course no complete list of what should be taken into account, each investigator will have to carefully assess his options and requirements.

Other Issues

Other issues to be concerned about when siting a new reference station include future site development and change in ownership, power requirements and communications issues. Evidently any major changes in terms of construction and possible future interference of the site will be of concern. Use and ownership issues are perhaps best dealt with through comprehensive land use agreements and contracts. Power and communication to the site have to be reliable. Design issues may include long term (backup) power and data storage in the event of major disruption to the local power and communication infrastructure (e.g. major seismic event).

Overview of Footprint Studies

When one attempts to find footprint information on IGS sites, it is obvious that very little has been done at most of the IGS sites. It is clear that footprints are not regarded as being high on the list of IGS site priorities. Footprints do take a lot of effort and on some sites it is also a difficult practical problem. In order to give a general background on previous and current footprint studies conducted by NASA, a short overview is given based on and using extracts from an unpublished report by Bell et. al. (1994) and personal communication received from C Noll (CDDISA) and R Allenby. A GPS site footprint is similar in all respects except that it is easier to refer the footprint network to the main GPS reference, than say the reference point of a geodetic VLBI antenna.

At the time of their report, two epochs of GPS data had been taken by NASA at footprint networks at six different observing sites. Three of these are in California (Quincy, Pinyon Flat and Monument Peak), two in the continental U.S. (Fort Davis, Texas and the GGAO in Greenbelt, MD) and one in Alaska (Sourdough). Conventional geodetic surveys are usually performed to ascertain reference points of fixed observing instruments such as SLR and VLBI and the relative positions of reference monuments or other collocated geodetic instruments within the immediate site area. The classical and GPS surveys are used at the local reference and regional footprint scale to determine each site's stability.

The measurements are done in order to differentiate between local instability effects (local groundwater fluctuations, soil movement or monument instability) and geodetically measured motion from larger scale effects. The larger scale effects include coseismic displacement during an earthquake, subsidence or uplift due to glacial or fluvial loading or unloading, steady state slip resulting from plate motion, or displacement due to volcanic eruptions. A footprint measurement can provide crucial information when a site suddenly exhibits anomalous displacement. This is supported by the case of the Pinyon Flat Observatory in California, which had footprint measurements taken in 1992 and 1994, before and after the Landers earthquake. This earthquake sequence ruptured an area which is located about 40 to 50 kilometres from the Pinyon Flat Observatory, during June 1992.

NASA/GSFC Site Stability Program

The site stability program of NASA/GSFC was initiated in the late 1980s with the aim to ensure geodetic site integrity as outlined by a special committee of principle scientific investigators of the CDP. Through collaboration with local specialists basic guidelines were established for selecting, monumenting and surveying 'footprint' or site stability networks around primary geodetic sites. The footprint measurements then provided a basis for the analysis of both the tectonic and physical stability of these sites. As mentioned by Bell et.al. (1994) the objectives of the Site Stability Program are:

(1) Assuring the integrity of geodetic measurements taken at principal space geodetic observing sites (VLBI, SLR, and GPS)

(2) Implementing and measuring local GPS networks around the main observing monument that are representative of the local tectonic environment they encompass (5-30 km scale)

(3) Repeating conventional surveys of the reference markers relative to the main observing monument (less than 1 km) to assure monument stability

(4) Providing first and second epoch GPS footprint measurements at many of the essential fiducial geodetic sites used in the worldwide global networks, beginning with the U.S.

(5) Providing raw survey data and final geodetic results to NASA's CDDIS.

GPS Footprint Surveys

From 1990 to 1994, NASA's Site Stablity Program has implemented and measured local GPS networks (1-30 km scale) centred around main observing monuments with the aim to determine local stability of the area occupied by the main reference point. In comparison to the footprint survey, local GPS networks have been and are being measured by scientific teams in areas of tectonic interest to identify geological structures that are accommodating strain seen between and around geodetic fiducial sites. There is a basic difference between these two efforts however. The footprint encompasses a single tectonic feature which is occupied by the main site, the regional strain network encompasses an entire deformation field including all of its regional characteristics.

Concept of a Footprint System

At HartRAO we have been conducting a footprint study but on a slightly higher level. HartRAO has 3 primary reference points, and the stability of the footprint area is inferred from the measured stability of the footprint reference points, referred to the VLBI telescope, SLR pad, and IGS GPS receiver monument.

The footprint study is not a study concerned with only the baseline and relative position GPS measurements, in order to understand and correctly interpret small movements of the reference points one has to approach the footprint in a holistic way. Therefore, consideration needs to be given to the reference point as a system, and a combination of all these systems into the footprint system. During the formulation and slow process of setting up boundaries for a footprint study, it is clear that in order to solve this particular geodetic problem, use should be made of all relevant disciplines, in a multi-disciplinary approach. Free use should therefore be made of techniques and approaches used to solve problems in geodesy, geology, geophysics, electronics and other useful and sometimes seemingly unrelated sciences.

Collocation of Space Geodetic Techniques

An important part of the footprint is the determination of ties between the different geodetic reference points of each site. The IGS specifies that local ties to other markers on the site should be determined in the ITRF coordinate system to guarantee 1-mm precision in all three dimensions. Offsets should be given in delta-X, delta-Y, delta-Z, where X,Y,Z are the geocentric Cartesian coordinates (ITRF). This seems to be a reasonable request, but in practice may be difficult to achieve. This is particularly true when a geodetic VLBI antenna needs to be tied in. With such an antenna the reference point is the intersection of the axes, or when there is an axis offset, the projection of the declination axis onto the polar axis. At HartRAO we developed a technique to tie our VLBI antenna, SLR and GPS monuments simultaneously using GPS (Combrinck and Merry, 1997) with high accuracy. Due to possible errors being generated by the (mostly) elevation-dependent phase centre variations care has to be taken to use identical antennas on either end of GPS derived eccentricity vectors.

The advantage of using GPS for collocation and determining ties between the various reference points is that we need no intervisibility between the various instrument reference points. Not all sites have completed ties or footprints and many have yet to initiate such a project.

Summary and Conclusions

What then is the current position of IGS GPS monumentation, antenna mounts, footprints, collocation ties and protection against lightning and vandalism? The IGS does not specifically prescribe what should be used or how it should be done, nor does it give advanced information on designs and methods. Such a prescription would be impractical due to varying site characteristics, funds, access to engineering skills and different approaches. Heavy reliance is made on each site's ingenuity and interpretation of what a first order geodetic monument is and what sort of mounting plate is to be used.

Where to From Here?

Certainly no single station or installation has the final answer. There are nearly as many solutions (good and bad) as installations. UNAVCO seems to be the only site that offers solutions and informed help in an organised way to investigators aiming to set up an IGS station. Many sites have been set up using local expertise, approaches and designs. Some of these are documented but might not be readily available. Information on footprints is virtually nonexistent. Empty log files glare at us. Should we not forward more technical details, designs, footprint results, vandal and lightning protection measures and occurrences to a central point where it can be assimilated into an organised structure for the benefit of all ? Should we not have some sort of monument rating, however simple? Do we not rate stations already in some way based on their receivers, reference clocks, geographical positions, data quality and select these for networks? Should more emphasis be placed on higher quality monuments? Should there not be a couple of 'small' rules before a station becomes an accepted IGS station, such as a complete and detailed monument design and installation description?

References

Bell L., Bryant M., Nelson V. and Allenby R. *NASA's Space Geodesy Project: A Summary of GPS Footrpint Results*. Fall AGU, 1994.

Combrinck W.L. and Merry, C.L. *Very long baseline interferometry antenna axis offset and intersection determination using GPS*. JGR, Vol.102, NO.B11, pages 24,741-24,743, 1997.

Physical Site Specifications:

GPS Antenna Calibrations

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GPS antenna calibrations are intended to provide 2 basic properties of GPS antennas:

- The location of the L1 and L2 phase centers (and hence the location of the ion-free phase center [L0]) with respect to a physical location on the antenna and,
- The variation of these phase centers with direction.

The horizontal locations of the L1 and L2 phase centers have been measured for several members of various antenna types. While average horizontal offsets of only a few millimeters from the symmetry axis of the antenna may occasionally appear, this author believes these horizontal offsets are too unreliable to be attributed to an entire antenna model series. The vertical offset of the most variable among antenna species and is generally measured from the bottommost surface of the integral antenna (i.e. the antenna without any removable mounting parts that may attach to the bottom).

Knowledge of these antenna calibrations is essential to allow the following:

- Separate solutions for L1, L2, and L0 for the same antenna should yield the same height.
- Different antennas may occupy the same mark and yield the same height.
- Elevation-dependent antenna phase variations may be separated from the tropospheric phase variations yielding consistent heights in mixed-antenna networks.

The phase center variation (PCV) of an antenna with direction to the satellite is inseparable from the offset for that antenna. The same antenna may have different vertical L1 and L2 offsets determined by different investigators or techniques but, provided that each offset is used with it's companion PCV's, the same heights should be obtained in each case. Therefore, it is good practice to always apply the PCV's even on short baseline where no tropospheric scale height may be adjusted or where the antennas are identical.

GPS antennas are calibrated under somewhat ideal conditions, i.e. for in situ measurements, antennas are generally calibrated at similar or identical sites, at a consistent height, and on flat terrain with no reflectors that may cause unwanted multipath reflections. It is important that the antenna environment during the test contribute no azimuthal asymmetry to the measurements. Currently popular GPS antennas generally are designed to be azimuthally symmetric. While some calibrations have detected small azimuthal variations for some antennas, it is unclear (at least to this author) if these variations aren't due to multipath (for in situ measurements). In any case, the azimuthal variations seen during a calibration are likely to be small compared to the azimuthal perturbations introduced at a real site and which cannot be accounted for. Reflectors in the vicinity of the antenna contribute to these azimuthal differences but should not have a significant effect on the dominant phase variation with elevation. Consequently, the phase calibrations in use today provide PCV's for elevation only. Users should always remember the conditions under which these calibrations were determined and that they are hopefully a reasonable approximation to the unique circumstances for the actual antenna to which they are applied. Under the best circumstances, every antenna would be individually calibrated at its own permanent site.

There are two classes of GPS antenna calibration in use today:

- Absolute calibrations done in an anechoic chamber or in a field measurement,
- Relative calibrations with respect to a standard antenna done at a field test site.

Anechoic Chamber Calibrations

Over the past few years Tom Clark and Bruce Schupler for GSFC and Chuck Meertens for UNAVCO have presented calibration results for several GPS antennas from their chamber measurements. These offsets and PCV's were used on field data to test their ability to yield consistent heights for different antennas placed over the same mark. The results (as this author recalls) were somewhat disappointing, and height discrepancies of several centimeters remained. In view of the great care exercised during these measurements, these results were puzzling. It was suggested that perhaps the frequencies synthesized in the chamber did not adequately represent the GPS signals or that the chamber environment is sufficiently different from the field that it's results do not transfer consistently to actual field measurements.

Clark has recently completed chamber tests on a series of choke ring antennas. These results should be resented as a poster paper at this meeting. Among other things, he as measured the phase slope with frequency across a wide spectrum that includes the GPS, GLONASS and proposed new GPS frequencies. In general, he finds his current choke ring results are within a few millimeters of his previous results and continue to show disagreement with the assumed choke ring model.

Anyone with results applying chamber measurements to field data is urged to bring these results for discussion.

Absolute Field Calibrations

A method for determining absolute antenna calibrations in field measurements has been reported (Wubbena, et al. and Menge, et al.). In this method, data taken over two days is aligned in sidereal time and differenced. The authors claim that multipath is thus eliminated or greatly reduced. By tilting and rotating the test antenna on the second day, the differences contain only the effect of the test antenna's PCV which can then be modeled by spherical harmonics. Results have been presented for different antenna types and show favorable reduction of height differences from mixed antennas. Results for the choke ring antenna have been determined and applied to a regional network (Europe) and a larger network (North Atlantic) using only choke ring antennas. As might be expected, significant (3-7cm) horizontal and vertical position differences are seen if these calibrations are used or not. However, at least to the knowledge of this author, no comparison of the scale was made with an alternate technique, such as VLBI, to evaluate the correctness of these calibrations.

The assumption by these authors that multipath geometrically repeats from day to day is valid, however, this author believes that tilting the antenna puts ground reflections on a different location in the antennas gain pattern, and therefore the multipath does not cancel out exactly due to different amplitudes. While the effect of this gain change on this technique has not been discussed, this technique remains very interesting.

Anyone with results using these antenna calibrations is also urged to brings those results for discussion.

Relative Field Calibrations

Determining the PCV and offsets of an antenna relative to a reference antenna is relatively easy to do with careful field measurements. Such relative measurements with respect to the standard choke ring antenna have been reported by Rothacher et al. and by Mader. In both cases, a short baseline is established between the reference and test antennas so that tropospheric and ionospheric effects may be neglected. The phase residuals contain the effects of the PCV, which may be estimated as a function of elevation (Mader) or elevation and azimuth (Rothacher). These techniques assume no horizontal offsets for the choke ring, and that the L1 and L2 vertical offsets of the choke ring antenna are 110mm and 128mm respectively above the bottom surface and that the PCV of the choke ring is 0.0 at all elevations and azimuths. These in situ measurements have shown good results in eliminating most of the effects of mixing antennas.

The early results of both these authors were combined in a weighted average to produce a file containing L1 and L2 offsets and PCV's in a standard format denoted igs_01.pcv. This file has been available from the IGS. Since this combination, numerous additional antennas have been calibrated with these techniques but these results have not been combined into a new IGS file. This author has established and maintained a web site (*http://www.grdl.noaa.gov/GRD/GPS/Projects/ANTCAL*) to present the results determined by the National Geodetic Survey antenna testing program. This site contains all the results of the NGS testing effort, which continues with frequent testing of new antenna models.

Some informal testing by the author and others at NGS showed that the exclusive NGS calibrations appeared to work slightly better than the IGS combination contained in igs_01.pcv. The reason for this is believed to be entirely due to small differences between the calibration techniques of Rothacher and Mader. Each technique and set of relative results is internally consistent and yields good results. However, combining measurements of identical antennas from the two techniques or using an antenna measured by one technique with a different antenna measured by the other technique appears to weaken the results compared to using one technique exclusively. For this reason, this author is inclined to discourage averaging results together, or including results from a variety of sources into a single set of calibrations.

Absolute vs. Relative Calibrations

It appears that the in situ relative antenna calibrations are in wide use. Commercial vendors (e.g. Trimble, Ashtech, Leica) have included, or plan to soon include, either the NGS calibrations or their own calibrations as a part of their baseline processing software. Any relative measurements can work well over small networks, but they become inadequate when satellite elevations as seen from either end of a baseline are substantially different. Large regional networks and global networks require absolute calibrations. The assumption that the PCV of the choke ring antenna is zero ignores the effect of the real PCV on troposphere estimates, and hence height and scale, over long baselines.

It is already known that inserting a non-zero PCV for the choke ring antennas into a global GPS solution will change all the station heights and the scale significantly. As far as this author knows, no choke ring PCV has been found which yields a change in GPS scale that is consistent with the expectations from comparisons with VLBI and SLR. These other space techniques appear to be the sole criterion by which the utility of absolute antenna calibrations will be judged.

Availability of Relative Calibrations

The initial set of calibrations by Rothacher and Mader are contained in the file igs_01.pcv and is available from the IGS web site. NGS also provides a web site for its antenna calibrations. The format for these results is nearly identical to that in igs_01.pcv. The sole difference is that a set of standard antenna names has been derived from the model number, which is almost always stamped on the antenna itself. These names are much more compact, more easily machine readable, and far less ambiguous than the names currently adopted by the IGS. The names are entered in the first 16 characters of the name-line of the antenna file. The NGS web site also includes the rms errors of the offset and PCV results along with photographs of the antennas. Recently, engineering drawings collected from the manufacturers have begun to be included. These drawings along with the photographs allow the antenna reference points (ARP) to be clearly identified. As these drawings become available, NGS will provide in the antenna file on the line containing the offset information, the radius and offset information needed to refer slant height measurements to the adopted ARP. NGS currently list calibrations for 46 GPS antenna models and is currently (Oct. 1998) testing the Novatel antenna models, new antennas from Ashtech and Trimble, and is trying to schedule the new Javad antennas.

New Developments

An effort is currently underway at Haystack Observatory (Jim Davis et al.) to develop a "GPS Calibration System". This system will include among other things development and construction of an in situ Multipath Calibration System (MCS). This MCS will consist of a "multipath-free" antenna used to create a short baseline to the test antenna thereby providing exact multipath and PCV data for that particular antenna in its own unique operating environment. The MCS will use a high-gain parabolic reflector with 3m diameter to achieve sub-mm multipath errors below 10 deg. elevation. This group is currently in the process of purchasing the parabolic reflector and positioner, and having the L-band feed manufactured. Following completion of the MCS, it will be transferred to UNAVCO who will coordinate site visits and maintenance.

Chuck Counselman has described an array GPS antenna which offer some promise of enhanced multipath suppression. A 3-element version of this array has been built and tested with favorable results. Counselman has been working with NGS on a 5-element design in order for NGS to build several prototypes for testing. This effort was originally motivated by NGS's need to find better antennas to operate in the multipath-intensive environment of ships. The first protypes of this antenna may be available for testing by Spring, 1999.

Physical Site Specifications:

Special Equipment: Radomes and Met Sensors

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Radomes - Protective Covers

A radome is a device commonly used to protect antennas from environmental forces at the same time as an electromagnetic wave transmitted or received by the antenna propagates through without any significant losses. Ideally, we would like to avoid the use of radomes since all material will interact with the propagating signal. The decision whether or not to use a radome to cover a GPS/GLONASS antenna can only be taken after station-dependent consideration for each station [Johansson et al., 1998].

The main reasons for using a cover for the antenna are:

- the protection of the antenna from environmental forces like snow, rain, sun, salty air etc.
- to keep the antenna in a temperature controlled environment.
- to hide the antenna from people or animals (some are really interested and cannot let go if they see an antenna.)

The drawback of using a protective cover is the introduction of yet another material which the signal has to propagate through on its way from the satellite to the GPS/GLONASS receivers.

Basically, the radomes belong to the same group of site-dependent effects as others associated with the receiver, antenna, and the signal [Johansson, 1998]. These are effects that will not, in general, change on a day-to-day basis. However, they might introduce biases in the solution. As long as nothing changes, the effect stays the same. If something changes, such as the satellite constellation (e.g., introduction of GLONASS) or the elevation cut-off angle, the results/products will be affected [Emardson et al, 1998b].

All materials have some effect on an electromagnetic wave. Radomes appear to delay and refract the GPS-signal in a similar way as snow [Jaldehag et al., 1996]. Several groups have been investigating effects due to the excess signal path delay through the radome.

In principle several parameters are of importance when choosing a radome:

- the shape of the radome (cone-shaped or hemispheric are most common),
- the material
- the thickness of the material

Different radomes have been tested in anechoic chambers [Clark et al., 1996; Meertens et al., 1996] as well as in field tests [Meertens et al., 1996; Johansson, 1998a]. All tests show that a conical cover may cause cm-level vertical errors when the tropospheric delay parameter is estimated. The influence is especially obvious looking at the estimates of Precipitable Water Vapor (PWV) and the estimates of the vertical position where bias terms can be introduced [Elosegui et al., 1995; Niell et al., 1994; Niell, 1996; Emardson et al., 1998a]. Such a bias could seriously affect the interpretation of the GPS data. From Baltex/Gewex (the Baltic Sea Experiment) [Elgered et al., 1997] in the World Climate Research Program (WCRP) and the Global Energy and Water Cycle Experiment (GEWEX) we note that the bias term in the estimates of PWV from GPS data may not exceed 1 mm in PWV (or equivalently about 6 mm in zenith wet delay) to be useful.

Preliminary results of different hemispheric radomes show smaller, 2 mm vertical offsets. Tests have been carried out within regional GPS networks where some stations were equipped with hemispheric radomes while other stations used different types of cone-shaped covers [Johansson et al., 1998]. Clear elevation-dependent effects were seen for the cone-shaped radomes while sites with hemispheric radomes show much less systematic behavior. Furthermore, it is important to try to keep the radome thin and to only use material with very low influence on the GPS-signal.

Hemispheric, thin plexi-glass radomes have been used by several groups with fairly good results. Please be careful when using paint on the radome. Depending on the type of paint it could very well have a drastic effect on the GPS-signal and also on the aging of the radome material. Check with expertise (the manufacturer of both paint and radome) before applying paint on the radome.

We can conclude that all radomes influence the GPS signal at some level and appear as an excess signal path delay which will map into other parameters in the GPS software. The effect of the protective covers can most likely be misinterpreted as a tropospheric effect. The effect is more or less constant and may be calibrated or modeled. The recently employed hemispheric radomes seem to show much less elevation dependence. In the case of hemispheric radomes, the influence on the tropospheric wet delay estimates and subsequently, the vertical component of position will only be on the few mm level. We also assume that differential effects due to the excess signal path delay through the radome are canceled out as identical radomes are employed in the local or regional type of network but this may not be enough in large-area networks.

The majority of IGS stations do not have a radome, although some sites within the core and global network have conical radomes. The effects of those stations presently equipped with protective covers is dependent on the type of radome used and the elevation cut-off used by the IGS Analysis Centers. Any changes at the station like addition/removal/change of radome will affect the time series for that site and possibly also others through e.g. the orbit parameters. The changing of radomes should be carefully logged and information must be available well in advance.

Meteorological Sensors

The rapid development of the IGS network and the major improvements in GPS-data analysis have made possible new applications and raised the level of requirements of each individual station. The new IGS initiative supporting accurate time-transfer will require detailed documentation and station calibration of the contributing stations. Parameters such as the instrumental bias and the temporal variations the instrumental delay will be significant error sources when the GPS data is used to perform accurate clock determinations and estimation of the total electric content in the ionosphere. Logging the temperature at several places within and close to the GPS station may contribute to the understanding and modeling of these problems.

Over the last years GPS/GLONASS data has been recognized as an important tool used to estimate the amount of precipitable water vapor above each station. This can be used in climate research since water vapor is perhaps the most important indicator of climate changes. A possible "green-house" effect with improved global mean temperature would be "sensed" by an increased amount of tropospheric water vapor. The IGS network has already started to contribute to this important research. Furthermore, estimates of water vapor could also be of importance in weather forecasting applications. Meteorological institutes world-wide have recently shown much interest in the GPS technique and the products supplied by permanent GPS networks and GPS-data analysis. Several research groups have shown the potential of this technique and the possibility to have rapid turn-around of these products to be assimilated in to numerical weather prediction models [see e.g. Bar-server and Kroger, 1996; Duan et al., 1996; Emardson et al., 1998a; Rocken et al., 1993; Rocken et al., 1995; Yang et al., 1998].

The propagation delay of the neutral atmosphere is often considered to be the sum of a "dry" component caused by induced dipoles in the molecules, and a "wet" component caused by the permanent dipole moment of water vapor. The dry term is normally about 2.3 m in the zenith direction at sea level. It can be accurately estimated in the zenith direction using surface measurements of the pressure at the ground. An uncertainty of 1 mbar in the ground pressure implies an uncertainty of approximately 2 mm in the dry zenith delay. In order to model its elevation dependence other surface measurements, such as the ground temperature, are often used. The dry delay is directly proportional to the barometric pressure at the antenna height. With a good pressure sensor one can accurately determine the dry zenith delay. A measurement error of about 0.5 mbar measurement error, give rise to a 1 millimeter error in the zenith propagation delay. The use of a priori knowledge of ground pressure will help in the GPS-data analysis since the appropriate mapping function can be applied separately for the dry delay and the wet delay separately. However, performing a correction in post-processing is also possible.

The wet term is smaller and range from less than 1 cm to 40 cm or more in the zenith direction depending on the climate. The problem with the wet contribution is that them distribution of water vapor cannot be accurately predicted and that it is highly variable. The zenith wet delay is only weakly related surface conditions. It is a fact that the water vapor in the troposphere is poorly mixed. Furthermore, taking accurate surface measurements of relative humidity and temperature is difficult task.

Besides for diagnostic reasons and for use in some mapping functions, having accurate temperature readings at the site also provides the possibility to convert from wet delay to precipitable water vapor. However it is important to note that this conversion should utilize an effective temperature of the air mass above the station rather than the ground temperature at the site [Emardson and Derks, 1998]. Especially, if the temperature sensor is placed in a bad location at the site we could face severe problems.

Some meteorological institute prefer to include the total tropospheric delay rather than the precipitable water vapor or the wet delay in their models. In this case, we do not need to include either pressure nor temperature data in the GPS-data analysis except for perhaps applying the appropriate mapping function.

In the numerical weather prediction software where the GPS derived total delay are assimilated also accurate pressure and temperature data obtained from the fairly dense global meteorological network are used. In principle this procedure is similar to the philosophy that the actual pressure and temperature readings at a specific GPS station can be obtained by performing interpolation between the well calibrated observational stations operated and maintained by the meteorological institutes.

For the above mentioned projects the use of meteorological sensors at the IGS stations have again become a burning question. A general statement is that it is always good to have meteorological sensors available at the site at least for diagnostic reasons. To simply monitor the outdoor temperature within some degrees C can assist in detecting problems at a site. For the meteorological sensors to contribute in applications associated with climate change and weather forecasting more requirements have to be taken in to consideration.

Poor quality meteorological data caused by uncalibrated/poor sensors or choosing wrong locations for the sensors basically could ruin some of the applications mentioned above. Please consult expertise before deploying meteorological sensors [WMO, 1996]. Some general advice can be given:

- The pressure sensor should have an accuracy of 0.5 mbar and a resolution 0.1 mbar. It is important to accurately determine (dm-level) the separation in height between the

GPS/GLONASS antenna and the pressure sensor in order to apply appropriate corrections to the dry delay. Furthermore the pressure sensor needs to be calibrated once per year. A good collaboration with the national or local meteorological institute may provide assistance in calibration and the availability of values interpolated from their observation network. The data they can provide may even be accurate enough for our applications and the pressure sensor the GPS station avoided.

- Temperature data may be important in both climate and meteorological applications as well as in the monitoring and calibration of instrumental effects at a GPS/GLONASS station. Similarly as in the case of pressure sensors advice from the meteorological institutes should be used when deciding on the sensor and the exact location. The location of the temperature sensor must be chosen with care otherwise wrong temperature readings may occur. The accuracy should be around 1 deg. C. Again it is possible to either compare or use temperature logging and interpolated values from the meteorological observational network.

- In the case of calibration and modeling of instrumental delays it is perhaps essential to have several temperature sensors e.g. at the antenna, antenna cable, near the GPS/GLONASS instrument. The delay variations in a typical antenna cable caused by temperature variation may be about 1 ps/meter/deg.

- It is hard to give any advice regarding humidity sensors. It may be of interest for the monitoring of a station. However, relative humidity sensor will not significantly contribute to the meteorological applications due to the fact that the humidity data at ground say very little about the humidity at higher altitude. The problem of poor accuracy of humidity sensors and often strong degradation due to aging are other negative factors.

Ground-based Microwave Radiometry

Improved accuracy for estimates of the wet delay can be achieved by the use of remote sensing techniques. An instrument which has almost all weather capability, is a microwave radiometer measuring the emission from the atmosphere on and off the water vapor spectral line centered near 22 GHz. This type of radiometer is normally referred to as a water-vapor radiometer (WVR). A variety of different WVRs have been built (see e.g., Elgered and Lundh, [1983]). Since a WVR uses directional antennas, the measurements are taken along the line-of-sight. The accuracy in terms of the wet propagation delay is normally better than 1 centimeter. Also the presence of liquid water in clouds can be determined.

The sky is scanned by means of pointing maneuvers. Thus, the sky can be mapped by laying out a regular angular pattern. Alternatively, the instrument can be pointed at GPS satellites. Operating a WVR, however, implies also a substantial amount of data processing and experience with the technique. To consider WVR as a regular ancillary device at geodetic observation sites at present appears not really feasible. Size and delicacy of the instrument also argue against that prospect. Instead, a few of these instruments at fundamental stations, where they can run in parallel with several geodetic techniques has been and will probably also in the future be a more successful route. Problems persist, however, during rain; the radiometer data will typically overestimate the delay, however with a very high variance.

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Communications and Data Links

A. Moore, F. Boler, D. Stowers, L. Estey, and S. Fisher

An effort is underway to understand the data flow paths between IGS tracking stations and their respective Operational Centers the formation of the RINEX product, and the path of this product to a Data Center. This discussion will concern itself with these first steps in the data's journey, since the further data flow upward toward Global Data Centers is fairly well understood (see "Flow of Global GPS Data and Products from Station to User" under Documentation at http://cddisa.gsfc.nasa.gov).

Increased insight into these aspects of each site's data flow is desired for many reasons, including

- spirit of "freedom of information" regarding origins of IGS data
- an aid in troubleshooting the absence or unusual latency of data from any site
- identification of potential improvements
- understanding of station capabilities, in particular when forming application-oriented subnetworks with specific requirements (see Figure 1).

The IGS Central Bureau and Infrastructure Committee are tasked within the IGS to coordinate these activities.

The IGS data flow up to the point of a Regional or Global data center includes the following organizational components as defined in the Terms of Reference:

- **Tracking Stations (TS)**
  Approximately 196 Tracking Stations operate high precision, dual frequency GPS receivers and make tracking data available to the Operational Data Centers via Internet, telephone, satellite, or other means.

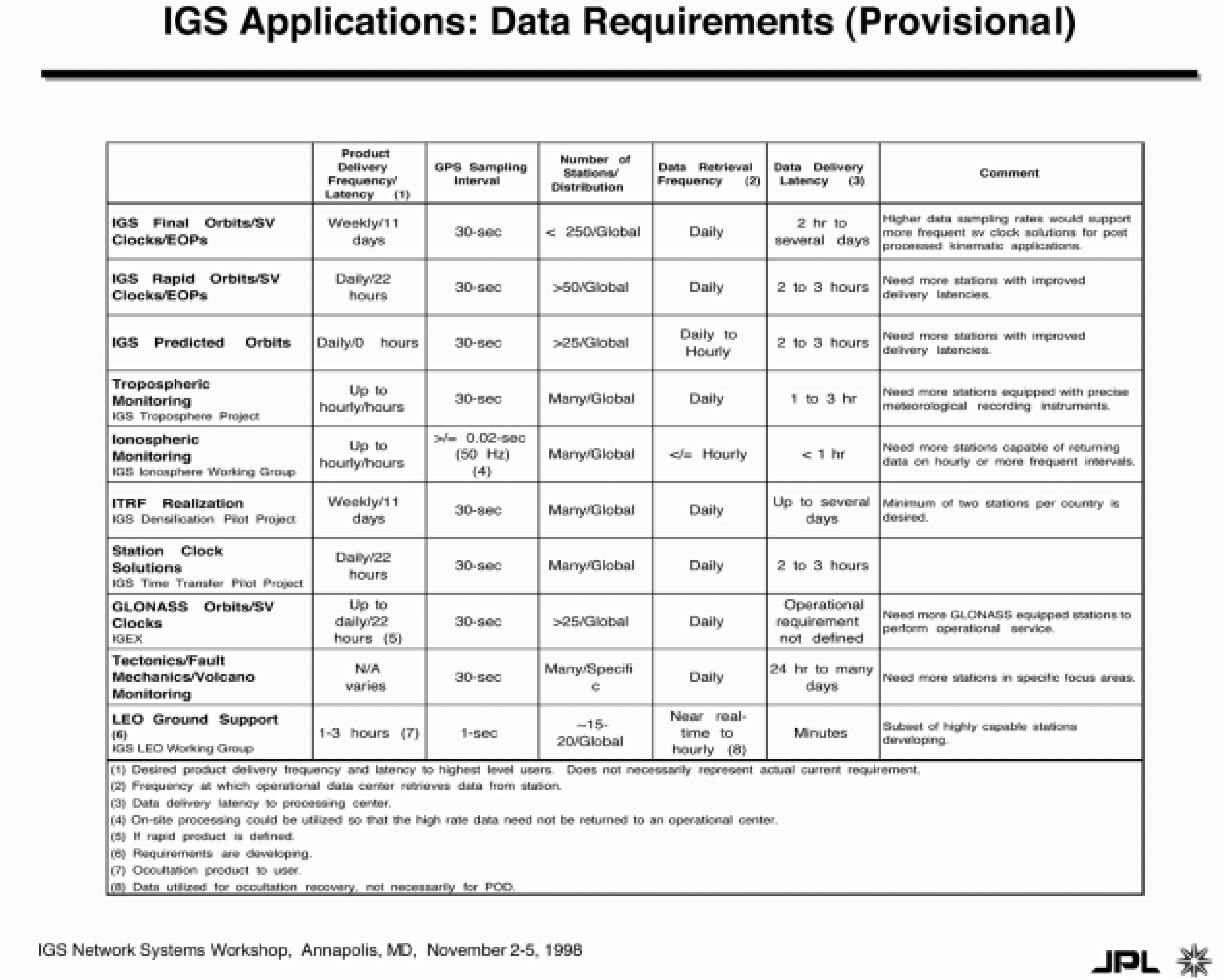
- **Operational Data Centers (ODC)**
  16 ODCs are in direct contact with the tracking sites. Their tasks include suitable data reformatting into a uniform format, compression of data files, maintenance of a local archive of the tracking data in its original receiver and in its reformatted format, and the electronic transmission of data to a Regional or Global Data Center. The Operational Data Center must download data from the receivers located at the Core sites on a timely (e.g., daily) basis, without interruption.

The IGS data flow pattern depicted in Figure 2 indicates that data flow between a Tracking Station and its Operational Center may entail usage of computers, software, and any number of styles of communication (satellite, Internet, telephone, radio, media, etc). Also, there are in reality multiple data routing possibilities from IGS stations to users (including non-IGS users), which may result in inconsistencies between data sets used by different processing centers due to differences in file conversions and data handling along the way. Figure 3, a real-life example of the variability of station architectures, provide a clear demonstration of the complexities involved in describing a station's data communication path.

The UNAVCO Boulder Facility has designed a database structure expressly for the purpose of defining permanent stations' data flow.This site data flow database is part of a larger database currently being developed to support configuration control and management for permanent stations which the UNAVCO facility helps operate, including the NASA GPS Global Network. The database will ultimately accommodate all the information contained in the IGS station logs, as well as more detailed information related to specific station configurations and equipment being utilized. It is hoped that parts of this database will eventually be made available for Web-based queries, and for (moderated) third-party editing via Web-based forms. This will allow users to query for existing data flow paths or alternate paths,to aid in data flow problem resolution.

The UNAVCO Facility has requested Operators to complete a questionnaire available on the IGS Central Bureau Information System (http://igscb.jpl.nasa.gov). The purpose of the questionnaire is to begin the process of populating the database with local station configuration and local communication information, as well as detail on where the data flows from a station, and what the route to the IGS is for the data. The questionnaire emphasizes contact information, which will be kept confidential (if requested), and which will be used to obtain additional information as needed. Figure 4 lists the data flow characteristics which the questionnaire addresses, and Figure 5 details the function of the database.

A set of 18 sites has been selected for initially populating the database, and development of tools to produce text output suitable for inclusion in a web document is proceeding. The IGSCB and the JPL GGN will provide feedback to the UNAVCO facility as the Benchmarking project continues to mature.



IGS Applications: Data Requirements (Provisional)

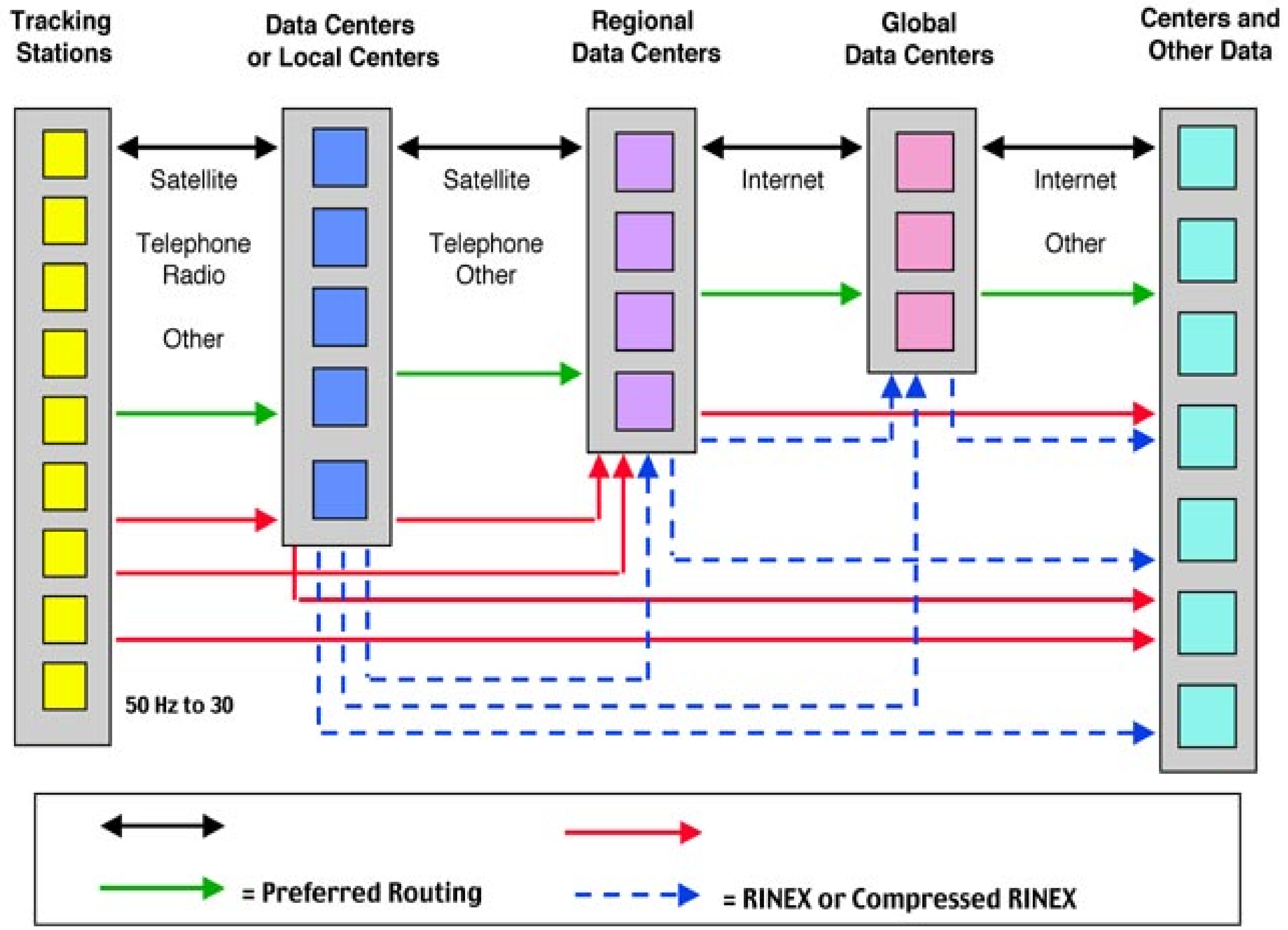
	Product Delivery Frequency/ Latency (1)	GPS Sampling Interval	Number of Stations/ Distribution	Data Retrieval Frequency (2)	Data Delivery Latency (3)	Comment
IGS Final Orbits/SV Clocks/EOPs	Weekly/11 days	30-sec	< 250/Global	Daily	2 hr to several days	Higher data sampling rates would support more frequent sv clock solutions for post processed kinematic applications.
IGS Rapid Orbits/SV Clocks/EOPs	Daily/22 hours	30-sec	>50/Global	Daily	2 to 3 hours	Need more stations with improved delivery latencies.
IGS Predicted Orbits	Daily/0 hours	30-sec	>25/Global	Daily to Hourly	2 to 3 hours	Need more stations with improved delivery latencies.
Tropospheric Monitoring IGS Troposphere Project	Up to hourly/hours	30-sec	Many/Global	Daily	1 to 3 hr	Need more stations equipped with precise meteorological recording instruments.
Ionospheric Monitoring IGS Ionosphere Working Group	Up to hourly/hours	>/= 0.02-sec (50 Hz) (4)	Many/Global	</= Hourly	< 1 hr	Need more stations capable of returning data on hourly or more frequent intervals.
ITRF Realization IGS Densification Pilot Project	Weekly/11 days	30-sec	Many/Global	Daily	Up to several days	Minimum of two stations per country is desired.
Station Clock Solutions IGS Time Transfer Pilot Project	Daily/22 hours	30-sec	Many/Global	Daily	2 to 3 hours	
GLONASS Orbits/SV Clocks IGEX	Up to daily/22 hours (5)	30-sec	>25/Global	Daily	Operational requirement not defined	Need more GLONASS equipped stations to perform operational service.
Tectonics/Fault Mechanics/Volcano Monitoring	N/A varies	30-sec	Many/Specific	Daily	24 hr to many days	Need more stations in specific focus areas.
LEO Ground Support (6) IGS LEO Working Group	1-3 hours (7)	1-sec	~15-20/Global	Near real-time to hourly (8)	Minutes	Subset of highly capable stations developing.

(1) Desired product delivery frequency and latency to highest level users. Does not necessarily represent actual current requirement.
(2) Frequency at which operational data center retrieves data from station.
(3) Data delivery latency to processing center.
(4) On-site processing could be utilized so that the high rate data need not be returned to an operational center.
(5) If rapid product is defined.
(6) Requirements are developing.
(7) Occultation product to user.
(8) Data utilized for occultation recovery, not necessarily for POD.

IGS Network Systems Workshop, Annapolis, MD, November 2-5, 1998

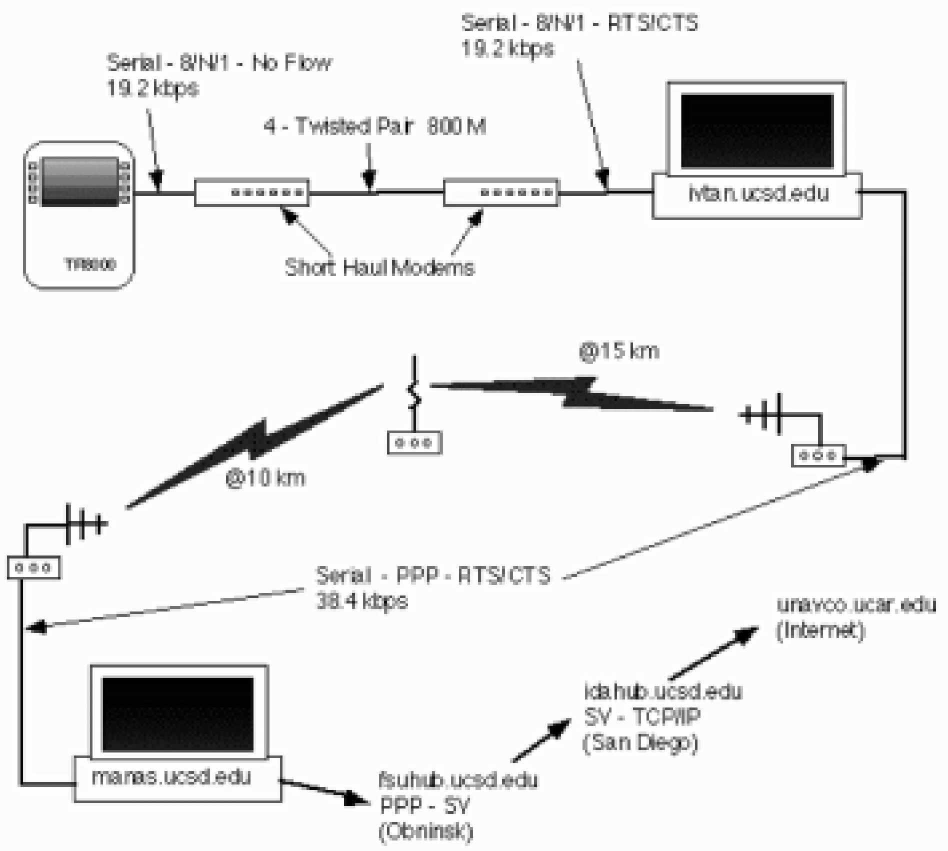
JPL

Actual IGS Data Flow



Example GPS Station Configuration

POL2 - IVTAN Communication Flow Diagram



Serial - 8/N/1 - No Flow
19.2 kbps

4 - Twisted Pair 800 M

Serial - 8/N/1 - RTS/CTS
19.2 kbps

TR8000

Short Haul Modems

ivtan.ucsd.edu

@15 km

@10 km

Serial - PPP - RTS/CTS
38.4 kbps

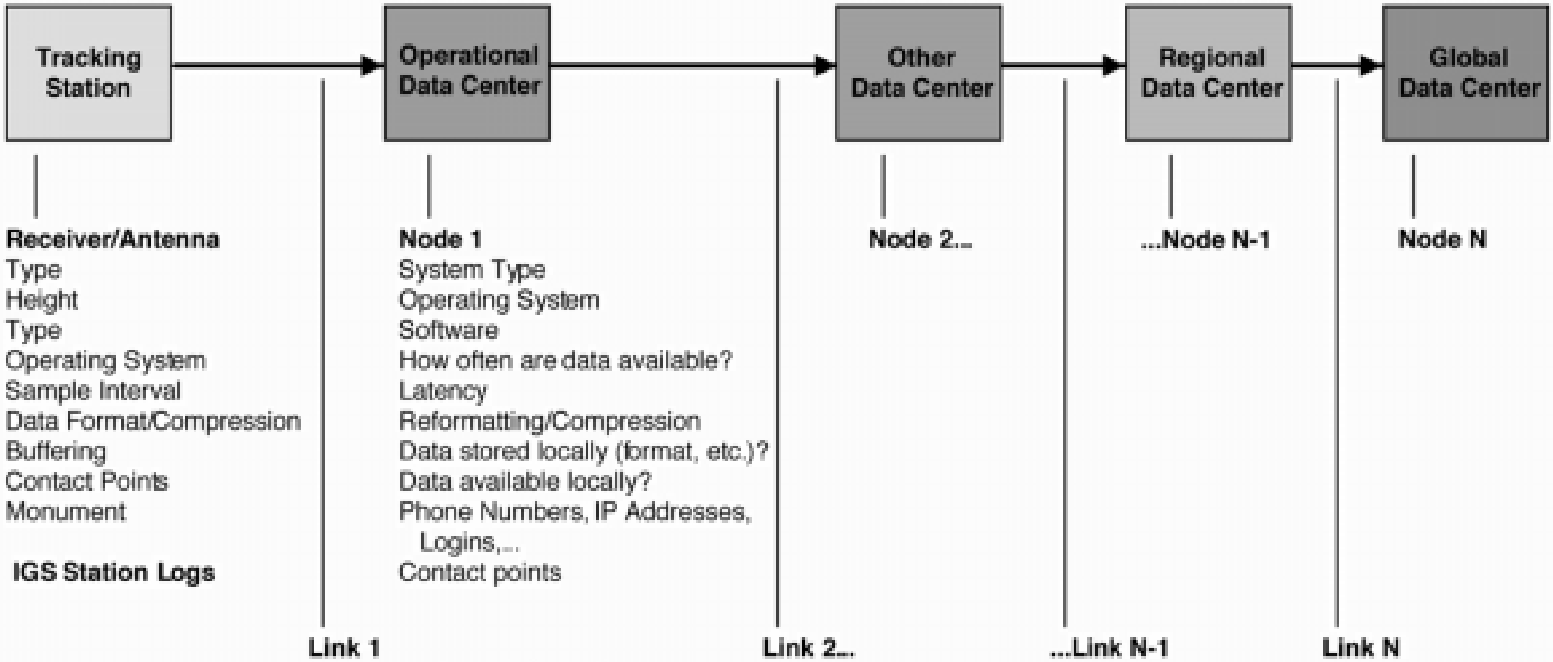
maras.ucsd.edu

fsuhub.ucsd.edu
PPP - SV
(Obninsk)

ida.hub.ucsd.edu
SV - TCP/IP
(San Diego)

unavco.ucar.edu
(Internet)

Identification of Important Network Data Flow Characteristics



Tracking Station → Operational Data Center → Other Data Center → Regional Data Center → Global Data Center

Receiver/Antenna
Type
Height
Type
Operating System
Sample Interval
Data Format/Compression
Buffering
Contact Points
Monument

IGS Station Logs

Node 1
System Type
Operating System
Software
How often are data available?
Latency
Reformatting/Compression
Data stored locally (format, etc.)?
Data available locally?
Phone Numbers, IP Addresses, Logins,...
Contact points

Node 2...

...Node N-1

Node N

Link 1
Link Type (Serial, Phone, Radio, Internet, Satellite,...)
Data Link Protocol (SLIP, PPP, ATM, X.25,...)
Data Transfer Protocol (XMODEM, FTP, SMTP, LDM, Streaming, Media, Push, Pull,...)
Data Format
Link Speed
Link Reliability

Link 2...

...Link N-1

Link N

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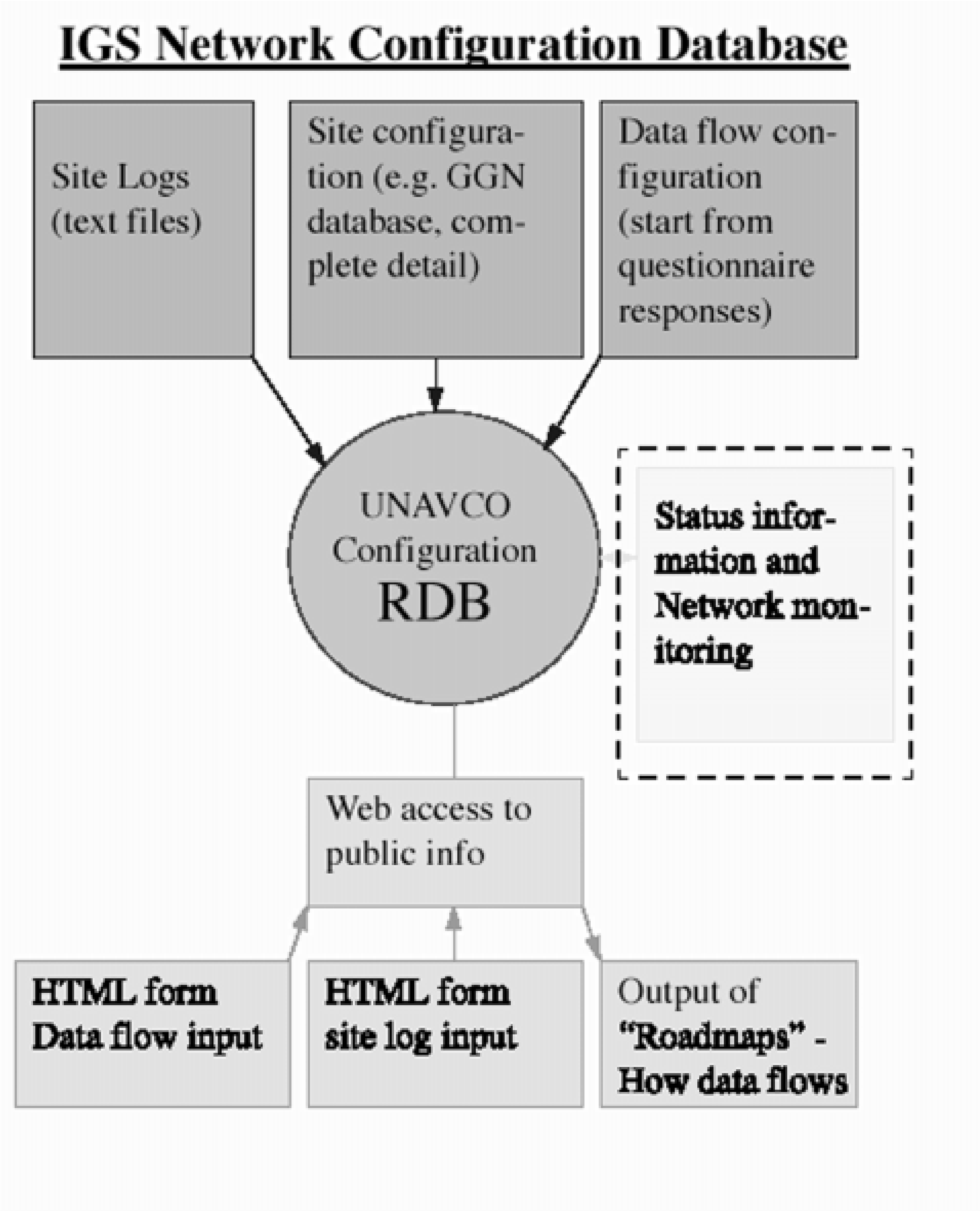

IGS Network Configuration Database

Site Logs (text files)

Site configuration (e.g. GGN database, complete detail)

Data flow configuration (start from questionnaire responses)

UNAVCO Configuration RDB

Status information and Network monitoring

Web access to public info

HTML form Data flow input

HTML form site log input

Output of **"Roadmaps" - How data flows**

IGS Site Logs and RINEX File Headers

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Accuracy and consistency of IGS station metadata is crucial for the integrity of IGS products. Metadata for a given site can be found in at least two places. The current IGS site log, maintained by the CBIS, and the current RINEX file for the site, available from global data centers. Metadata such as receiver model, antenna model, antenna height, and monument may be inconsistent between these two places. Discrepancies stemming from inaccuracies in the IGS site log arise when, for example, the site configuration changes and the log is not immediately updated. For RINEX files, the metadata may come from entries into the receiver configuration that are then incorporated into raw data files. Additional metadata may be provided at the time of translation of the raw file to RINEX. Errors or omissions in the receiver configuration or the translation configuration file will result in inaccurate RINEX header metadata.

UNAVCO, in cooperation with JPL/CBIS, has been pursuing efforts to ensure that current, accurate information is maintained in the IGS site logs held at CBIS, and to resolve discrepancies between IGS site logs and the daily RINEX header for four pieces of metadata: receiver, antenna, antenna height, and monument.

UNAVCO personnel prepare IGS site logs for new stations. Information is gathered as early as possible through communication with the installing engineer. As soon as the required information is available, a DOMES number application is made to the IERS. In the fall of 1997, UNAVCO began a systematic effort to verify and correct inaccuracies in the CBIS site logs. As Phase I of this work, UNAVCO contacted site operators for the 51 NASA GGN and DSN sites. Responses to date have allowed verification of 92 % of these sites. Complete information is lacking for four sites. Phase II of this effort began in the fall of 1998. The remaining 144 IGS sites are currently undergoing the verification process.

Summaries of RINEX metadata are produced at CDDIS. CDDIS “yydoy.status” files are generated daily and are available via anonymous ftp (ftp://cddisa.gsfc.nasa.gov/pub/reports/ gpsstatus/<yyyy>/<yy><doy>.status. These files contain one line for each station. The information in a line comes from parsing the output of UNAVCO QC on the current day’s RINEX file. Stations for which no RINEX exists for a given day have only the four-character ID as entries in the file. CDDIS updates earlier yydoy.status files as additional RINEX files become available for a given day.

Summaries of IGS site log information are produced at CBIS. CBIS “logsum.txt” files (ftp://igscb.jpl.nasa.gov/igscb/station/general/logsum.txt) are generated from the current set of IGS site logs, maintained at CBIS (ftp://igscb.jpl.nasa.gov/igscb/station/log/*.log). The logsum.txt file contains one line for each IGS log file (195 as of October, 1998), and is generated once per day.

CBIS runs a Perl program (provided by UNAVCO in March, 1998) to compare a one-week old (so that late arriving RINEX files are accounted for) yydoy.status file with the current logsum.txt file, reporting discrepancies in the four fields. Receiver or antenna designations that do not match the IGS table of receiver/antenna names are also flagged. This file is posted by CBIS (ftp://igscb.jpl.nasa.gov/igscb/station/general/rinex.err).

Through monitoring the rinex.err file and making corrections, some progress has been made in resolving discrepancies. However, because the number of IGS sites has increased by nearly 30% during the time period from March to October, the absolute number of discrepancies has also increased. Table 1 shows discrepancies by type for March 1998 and October 1998.

Table 1. Discrepancies

	March 1998	October, 1998
Total number of sites	144	195
No log at CBIS	1	17
No RINEX file at CDDIS	14	9
Total sites compared	129	169
Monument	19	30
Receiver	25	36
Antenna	13	20
Antenna height	30	31
RINEX: non-IGS receiver	12	17
IGS log: non-IGS receiver	19	33

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