INTERNATIONAL GNSS SERVICE

GUIDELINES FOR CONTINUOUSLY OPERATING REFERENCE STATIONS IN THE IGS

Contact: cb@igs.org

International GNSS Service (IGS)
IGS Infrastructure Committee (IC)

Version 1.0
October 2023

Document History

These Guidelines replace the formerly known "IGS Site Guidelines" with its latest version from July 2015.

Date	Version	Amendments	Author(s)
2023-10-01	1.0	Document available	M. Bradke R. Ruddick P. Rebischung P. Steigenberger W. Söhne D. Maggert

Table of Contents

References

NGS. (2018, 08 01). *Guidelines for New and Existing Continuously Operating Reference Stations (CORS).* Retrieved from https://www.ngs.noaa.gov/PUBS_LIB/CORS_guidelines.pdf

IGS. (2021). *International GNSS Standards and Formats*. Retrieved from https://files.igs.org/pub/data/format/

IGS. (2021). *Naming Conventions for GNSS Equipment.* Retrieved from https://files.igs.org/pub/station/general/rcvr_ant.tab

IGS. (2018). *Instructions for Filling out IGS Site Logs.* Retrieved from https://files.igs.org/pub/station/general/sitelog_instr.txt

IGS. (2021). *IGS ANTEX 2020.* Retrieved from https://files.igs.org/pub/station/general/igs20.atx

IGS. (2021). *IGS Blank Site Log.* Retrieved from https://files.igs.org/pub/station/general/blank.log

ICSM. (2020, 12 07). *Guideline for Continuously Operating Reference Stations.* Retrieved from https://icsm.gov.au/sites/default/files/2020-12/Guideline-for-Continuously-Operating-Reference-Stations_v2.2.pdf

Gurtner, W. (2007, 12 10). *RINEX 2.11*. Retrieved from https://files.igs.org/pub/data/format/rinex211.txt

Romero, I., & Ruddick, R. (2020, 07 06). *RINEX 2.11: Compression Method Clarification Addendum.* Retrieved from https://files.igs.org/pub/data/format/Addendum-rinex211.pdf

IGS/RTCM Working Group. (2020, 12 01). *RINEX 3.05.* (I. Romero, Ed.) Retrieved from https://files.igs.org/pub/data/format/rinex305.pdf

IGS/RTCM RINEX Working Group. (2021, 12 01). *RINEX 4.00.* (I. Romero, Ed.) Retrieved from https://files.igs.org/pub/data/format/rinex_4.00.pdf

IGS Real-Time WG/IGS Infrastructure Committee. (2021, 10 01). *Guidelines for IGS Real-Time Broadcasters and Stations*

Retrieved from https://files.igs.org/pub/resource/pubs/Guidelines-for-IGS-Real-Time-Broadcasters-and-Stations_v1.0.pdf

Terms and Definitions

Acronym/Term	Definition
ADSL	Asymmetric Digital Subscriber Line
APC	Antenna Phase Centre: The point inside a GNSS antenna to which all GNSS signals are measured.
APREF	Asia-Pacific Reference Frame
ARP	Antenna Reference Point: the physically accessible point on a GNSS antenna to which all measurements related to the antenna refer to.
BDS	BeiDou System: GNSS of the People's Republic of China.
CORS	Continuously Operating Reference Station(s)
Cycle Slip	Discontinuities in the time series of carrier-phase measurements due to the receiver temporarily losing lock on the carrier of a GNSS signal.
DOMES number	Directory of MERIT Sites (DOMES): A unique geodetic marker identifier that is issued by IGN.
EPN	EUREF Permanent GNSS Network
EUREF	Reference Frame Sub Commission for Europe
Galileo	European Union GNSS
GLONASS	Globalnaja Nawigazionnaja Sputnikowaja Sistema: GNSS of the Russian Federation.

GNSS	Global Navigation Satellite System: Generic term for all satellite navigation systems.
GPS	Global Positioning System: GNSS of the United States
IGN	Institut national de l'information géographique et forestière
ITRF	International Terrestrial Reference Frame
Multipath	Errors in GNSS observations are caused by reflected GNSS signals interfering with the direct GNSS signal because of their common time origin but different path lengths.
NavIC/IRNSS	Navigation with Indian Constellation/Indian Regional Navigation Satellite System: RNSS of the Republic of India.
NRT	Near-Real-Time (file-based)
NTRIP	Networked Transport of RTCM via Internet Protocol: Application-level protocol for streaming GNSS data over the Internet.
ODC	Operational Data Centre
PCO/PCV	Phase Centre Offset/Phase Centre Variation
PDU	Power Distribution Unit: device used for controlling electrical power.
QZSS	Quasi-Zenith Satellite System: RNSS of Japan.
RFI	Radio Frequency Interference
RINEX	Receiver Independent Exchange Format: De-facto standard for the exchange of GNSS data independent from the vendor's

	binary format.
RNSS	Regional Navigation Satellite System
RT	Real-Time (stream-based)
RTCM	Radio Technical Commission for Maritime Services: Special Commission 104 defines international standards of radio communication and navigation using Differential GNSS.
SBAS	Satellite Based Augmentation System
SIRGAS	Sistema de Referencia Geodésico para las Américas
SNR	Signal-to-Noise Ratio
SOPAC	Scripps Orbit and Permanent Array Center
UPS	Uninterruptible Power Supply: Electrical device providing short term power in case of primary source power failures.
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network

1 Introduction

The IGS tracking network is a collection of Continuously Operating Reference Stations (CORS) maintained and operated by a variety of different organisations pooling their resources under the umbrella of the IGS for the common good. Strict rules are inconsistent with the voluntary nature of the IGS. However, participating stations should adhere to an agreed set of standards and conventions, which ensure the provision of consistent, fit-for-purpose data. Of particular importance to the IGS products is the stable, long-term operation of the tracking network. Therefore, any changes to station configuration or the surrounding environment should be carefully planned to minimise discontinuities in the station's position time series. Special consideration should be given to designated reference frame stations that contribute to the realisation of the International Terrestrial Reference Frame[1] (ITRF).

This document lists the minimum conventions that all IGS CORS must follow, as well as additional desirable characteristics, which enhance a station's value to the IGS. It is intended to be a useful reference to station owners and operators for planning and operating CORS. Suggestions for additions or changes to these Guidelines are welcomed at cb@igs.org.

1.1 Procedure for Becoming an IGS Station

The process for station owners or operators to follow in proposing a new IGS station is outlined in the document "Procedure for Becoming an IGS Station". In planning the new station proposal, the station operator should carefully review the guidelines contained within this document. The responsible agency must have an expectation that the station will operate perpetually, preferably as part of a national or regional reference network. Stations located within the footprint of a national or regional reference network should first coordinate with the relevant reference network coordinator[2]. Since most of the regional or national reference networks align with IGS standards, prior acceptance within such networks is considered favourable to the IGS. A sub-committee of the IGS Infrastructure Committee (Station Proposal Committee, SPC) will decide whether the proposed station should be accepted into the IGS tracking network based on location, instrumentation, operational characteristics, and whether it is relevant to any IGS Pilot Project or Working Group.

[1] The IGS20.snx contains a listing of stations that contribute to the IGS reference frame.

[2] The IGS actively coordinates station proposals with the regional networks of APREF, EPN, and SIRGAS.

The IGS Network Coordinator consults with the station operator through the application process and reviews compiled information for accuracy, completeness and compliance with these Guidelines.

1.2 Waivers for non-compliant Stations

On the occasion that a station does not comply with these Guidelines, but is still valuable to the IGS, a waiver may be granted to include the station within the IGS network, if agreed to by the SPC.

2 Summary of IGS CORS Guidelines

This section presents an overview of the mandatory and desirable recommendations that need to be fulfilled by a CORS to join the IGS network. They are intended to be applicable both to current active IGS stations and to proposed stations. Full compliance with these Guidelines is clearly desired by the IGS, however where guidelines cannot be complied with, station operators are asked to consult with the Infrastructure Committee. Detailed information about the shown recommendations can be found in subsequent chapters of these Guidelines.

Legend

Minimum	✳	Encouraged	▼
Not recommended	✖		

Table 1: Summary of Recommendations for IGS CORS

Recommendation	Classification
General	
Station belongs to a national/regional geodetic network[3]	▼
Station planned and installed for continuous and permanent operation	✳
Station's operating agency maintains full capability to repair, upgrade and maintain the station	✳
Foundation and Location (section 3.2.1)	

[3] Mandatory for regional CORS in the footprint of APREF, EPN, and SIRGAS.

Bedrock or massive concrete base	✳
Mounted on buildings or similar structures[4]	×
Clear sky view with limited obstructions above 10°	✳
Site is clear from signal obstructions or RFI	✳
Site is clear from reflective material	✳
Monumentation and Mounting (section 3.2)	
Concrete pillar or braced (tri-, quad-, …)pod monuments	✳
(Steel) mounts attached to building	×
The mount locks the antenna in place to maintain orientation and level	✳
The mount allows the antenna to be removed and returned within 0.5 mm and 1° of its original location and orientation	✳
Power and Communication (section 3.3)	
Ensure continuous operation of all communication devices	▼

[4] Waivers may be granted after revision by the SPC.

Ensure remotely controlled access to the receiver	✳
Receiver (section 4.1)	
Multi-frequency code and carrier phase tracking for all GNSS[5]	✳
Continuous logging of raw GNSS data	▼
Real-Time data streaming (RTCM)	▼
All-in-view satellite tracking (healthy and unhealthy) with a minimum of 5° elevation (0° is encouraged)	✳
Disabling pseudorange and phase smoothing	✳
Disabling multipath mitigation	✳
Ability to store a reasonable amount of raw data (depending on local circumstances)	✳
Antenna (section 4.2)	
Use of an antenna with an IGS calibrated absolute antenna phase centre (mean calibration) as included in the official IGS ANTEX[6]	✳

[5] New stations shall track all available frequency code and carrier phases.
[6] https://files.igs.org/pub/station/general/igs20.atx

Individually calibrated absolute antenna phase centre	▼
Antenna levelled and oriented within 5° to true North	✳
Antenna radome protection	×
Data (section 5)	
Data must be provided in RINEX format[7]	✳
If Real-Time stream is available[8]: RTCM 3 MSM5 stream for real-time applications[9]	✳
Data must be resubmitted to the data centres after communication outage	✳
RINEX data must be generated on-board the receiver or from native binary file	✳
File completeness target	99%
High-rate RINEX files (section 5.1)	
Provision	▼

[7] For new stations: RINEX 3.04 is the minimum accepted version. RINEX 2.11 is not accepted.
[8] New stations are highly encouraged to provide real-time streams.
[9] MSM7 is encouraged.

Latency	< 5 minutes	✳
Sampling rate	1 Hz	✳
Duration	15 minutes	✳
Hourly RINEX files (section 5.1)		
Provision		▼
Latency	< 5 minutes	✳
Sampling rate	30 seconds	✳
Daily RINEX files (section 5.1)		
Provision		✳
Latency	< 30 minutes	✳
Sampling rate	30 seconds	✳
Metadata (section 5)		

Complete and up-to-date metadata in IGS site log/GeodesyML format	✳
Unique nine-character station identifier approved by IGS	✳
Assigned with unique IERS DOMES number	✳
Update of IGS site log within 24 hours of applied station change(s)	✳
RINEX header matches the information in the IGS metadata record	✳
Provision of pictures of the antenna installation in the 4 cardinal directions (N, E, S, W)	✳

3 IGS CORS Establishment and Operation

This section describes criteria to consider before installing new IGS CORS. They are compiled based on common practices determined by geodetic agencies in the last decades.

Every GNSS station will have site-specific issues to resolve. The general principles for the location and design of a CORS include:

- Stability of the Antenna Reference Point (ARP),
- Signal quality and data completeness,
- Continuous and reliable power supply,
- Reliable communication with minimum latency, (IGS Real-Time WG/IGS Infrastructure Committee, 2021)
- Infrastructure that resists the ambient environmental and security conditions.

It is recommended to identify the usability of a proposed GNSS station in advance by taking care of the following aspects:

- Significant signal obstructions,
- Potential multipath and Radio Frequency Interference (RFI) sources,
- Access restrictions,
- Access to available power and communications,
- Cable length requirements,
- Human, pest and environmental site security issues,
- Potential changes to sky visibility from tree growth and development at sites nearby,
- Site foundation suitability (this may require additional geophysical or structural analysis).

3.1 Signal Quality

The quality of a satellite signal arriving at a GNSS antenna has a crucial impact on the performance of a GNSS station. There are a variety of factors that can influence the signal quality that are outlined in the following sections.

3.1.1 Sky Visibility

GNSS stations should be located on sites with minimal obstructions above the local horizon. Above 10° elevation, the station should not show any obstructions. The receiver shall be set to track all satellites within an elevation mask of 0° (see also Section 4.1).

3.1.2 Multipath

The interference by multipath occurs when a GNSS satellite signal arrives at the antenna on different pathways. The signal arrives once directly from the satellite, and additionally by having reflected off other surfaces.

Multipath sources can be either natural or artificial. Table 2 lists possible sources known to generate strong multipath.

Table 2: List of Artificial and Natural Multipath Sources

Artificial Sources	Natural Sources
Metal panels and signs	Trees (especially wet ones)
Roofs	Water surfaces such as lakes, rivers, etc.
Walls of buildings	
Mesh fencing	
Solar panels	

Avoid these reflective bodies at GNSS sites at any time. Suspected sources of multipath should be a minimum of 20 metres away from the GNSS antenna and below 5° elevation.

3.1.3 Radio Interference Sources

Common sources of Radio Frequency Interference (RFI) include:

- Radio, television and mobile phone transmitters,
- Microwave data links,
- Power lines,
- Transformers.

Directional transmitters, particularly microwave data links pointing toward the CORS site, can cause significant RFI.

Among other parameters, the effect of RFI is a function of the frequency, radiated power, and distance to the source. The effect of RFI is significantly increased when the RFI is a harmonic of a GNSS signal frequency.

Therefore, it is difficult to define a safe operating distance from an RFI source. RFI can be difficult to confirm and specialist advice may be necessary if RFI is suspected. If RFI is confirmed, and cannot be mitigated at a proposed CORS site, an alternate CORS site should be considered.

Note: RFI sources do not only affect the GNSS signals received at the antenna, but also the wireless (radio or mobile phone network) transmission of site data. Where a CORS site is transmitting data via radio link, the radio transmission may itself be a source of RFI on the GNSS signals at the antenna.

Prior to the final installation of a monument, it is recommended to test the multipath environment and check whether RFI sources are present at the GNSS site. This could be done by installing the GNSS equipment on a temporary tripod and investigating the data quality.

3.2 Site Stability

The stability of a GNSS site is mainly dependent on the quality of the foundation, antenna monument and antenna mount.

3.2.1 Monument Foundation

Ideally, IGS CORS antenna monuments are structurally fixed to bedrock using drilled-braced tripod structures or tapered pillar type monuments. This is especially important for stations contributing to the realisation of the ITRF.

Roof or structure mounted antennas (e.g., attached to a wall) should be avoided unless environmental or economic circumstances don't allow a different approach. Those sites may be fixed to bedrock, a concrete foundation in stable soil, and on load bearing components of concrete, brick, or masonry structures, preferably near the intersection of two walls. Due to thermal expansion and wind loading, structures less than ten metres in height are preferred.

Structures with high thermal expansion and buildings undergoing post-construction settlement should be avoided. To reduce the effect of multipath from the building, avoid structures with metal cladding or roofs.

3.2.2 Antenna Monuments

The monument of a GNSS site should be designed to provide a stable and securely anchored structure to which the antenna is mounted. For all IGS CORS, the required characteristics of the monument include:

- Short-, medium-, and long-term stability,

- Long-term survivability,
- Minimal multipath,
- Sufficient height to minimise obstructions,
- Simple design for ease of manufacture, installation and maintenance,
- Low maintenance,
- Corrosion, erosion, and subsidence resistant,
- Capability of bearing the mass of the antenna,
- In reasonable distance to the receiver,
- Tamper-proof design.

If possible, it is recommended to attach the monument to solid bedrock to guarantee an extremely stable foundation. The depth of the monument anchor should be chosen in a way that is unaffected by frost action. The monument should be higher than snowfall levels.

The width of the top of the monument should be less than the antenna diameter to minimise multipath from the monument edge and upper surface. It is recommended to avoid the amount of metal in close proximity to the antenna. In general, materials with low coefficients of thermal expansion should be used when high temperature variations are expected. If thermal expansion is a concern, insulation should be implemented. Aluminium monuments should be avoided due to the increased thermal expansion of aluminium. Roof monuments should place the antenna a minimum of 50 centimetres above the roof. Avoid structures with a metal roof where possible. If a structure with a metal roof or other reflective surface is used, avoid antenna heights that are multiples of GNSS carrier phase wavelengths (19 or 24 cm).

Use stainless steel bolts and fittings. Use through-bolts that penetrate the entire wall thickness for solid concrete walls unless the through bolt fitting will be exposed in an interior workspace such as an office or hallway. The use of stainless-steel backing plates will help distribute the force of through bolts. Avoid through bolts on cavity walls, as this may pull the skins together and weaken the foundation structure.

3.2.3 Antenna Mounts

The antenna mount (or adapter) connects the GNSS antenna to the monument. Once installed the antenna mount should lock the antenna in place so that it cannot be moved or rotated. When an antenna is removed and replaced, the mount should return the antenna reference point to within 0.5 mm and 1° of its original location and orientation. The antenna mount must maintain a level antenna, oriented to within 5° of true North for antenna calibrations to be effective.

3.3 Power and Communications

3.3.1 Power Supply

Every CORS needs to be powered by a continuous and reliable source. Mains and solar power are both suitable primary power sources. The choice between solar and mains primary power is a balance of cost, security, availability, and location. A distant connection to the power grid may make solar power with a battery array a more economical choice. Unreliable mains power, with significant power fluctuations, may make solar power preferable, particularly in regional areas.

Mains Power

Where mains power is used, a dedicated power circuit for the CORS equipment is recommended to reduce the risk that power loads from other equipment may trip a circuit breaker or residual current device and interrupt the power to the CORS equipment. Install mains power outlets in a manner that minimises inadvertent or wilful disconnection of power to the site equipment. It is recommended to install surge protection to prevent damage from power spikes.

Solar (Photovoltaic) Power

Available sunlight is the key factor for solar performance. This is a function of latitude and local climate conditions. One can check with the local weather agencies for average hours of available sunlight in the target area.

A battery system is required for solar powered sites, and is a common secondary power supply for sites with mains primary power. An Uninterruptible Power Supply (UPS) is a common short term power source, providing power during the switchover between the primary and long-term secondary power sources.

A Power Distribution Unit (PDU) is recommended for CORS sites. The PDU manages and conditions the power supply to the site, often with an automatic fall-over/fall-back mechanism to switch between primary and secondary power sources. A remotely managed PDU controls the power system within pre-set limitations and provides system tools, reports and alerts. Depending on the ambient conditions, a PDU may also switch less critical equipment off and back on again. A PDU with a communications link allows the CORS operator to control power to the equipment manually from a remote location.

3.3.2 Communications

A CORS site requires reliable communications for data transmission, either directly to users, or to an operational data centre (ODC). The design of this communication system is a core design issue affecting data transmission and remote control of the CORS equipment.

There are a range of communication options and service providers available. Common communication systems for data transmission between a CORS site and an ODC include:

- ADSL (Asymmetric Digital Subscriber Line),
- Mobile phone network,
- Corporate WAN (Wide Area Network) between offices,
- Very Small Aperture Terminal (VSAT) satellite link for remote locations.

The communication system design depends on the data bandwidth required, data protocols used, acceptable latency of data, and the services available in the target area.

A secondary independent communication system is recommended to improve site reliability. Secondary communications are important at sites offering real-time services, and at remote sites where the expense of a site visit exceeds the costs of the communication system.

The bandwidth required for CORS data transmission is affected by a number of factors including:

- Normal transmission operations (i.e., data streaming and regular data downloads),
- Irregular downloads such as retrieving data stored on the receiver after a communications outage,
- Uploads for receiver firmware upgrades,
- Additional bandwidth loads such as Graphical User Interface support for GNSS receivers, meteorological stations, and network or power management devices,
- Increased overall data volumes due to GNSS modernisation (i.e., additional signals, satellites, and satellite systems).

Irrespective of the communications method used, data latency from a CORS site to the user for real-time positioning services should not exceed two seconds.

4 GNSS Equipment

With the upcoming of new GNSS systems and signals and the recognised benefit for the society, GNSS technology is evolving at a rapid rate. Formats change and firmware versions are constantly adjusted and updated. Therefore, it is important to find a balance between technology, cost, efficiency and demand.

All IGS hardware components (receiver, antenna plus radome) must be listed in the *rcvr_ant.tab* (IGS, Naming Conventions for GNSS Equipment, 2021). This document contains naming conventions for GNSS equipment used to uniquely identify the equipment within various sources (e.g., ANTEX, IGS Site Log, RINEX headers).

4.1 GNSS Receiver

Table 3 gives an overview of recommended receiver characteristics at the date of issue of these Guidelines. Newly built GNSS stations proposed for the IGS shall fulfil all of the listed features. Station operators of established stations that cannot be upgraded at the moment, shall keep these recommendations in mind for future updates.

Table 3: Summary of Recommendations for GNSS Receivers

Component	Recommendation
Signal Tracking	• Tracking of all available carrier phase, pseudorange, signal-to-noise (SNR) per frequency. Doppler observations are optional. • No smoothing of pseudorange measurements. • Multipath mitigation must be disabled. • Newly proposed stations must track at least GPS, GLONASS, Galileo, and BeiDou[10]. • Capability to observe future signals is preferred. • Receiver set to track signals down to 0° elevation (5° is acceptable). • Receiver set to all-in-view tracking (including unhealthy satellites). • Receiver synchronises the actual instant of observation with GPS time to within 1 millisecond of the full second epoch.

[10] Stations located in the footprint of the regional satellite systems QZSS and IRNSS shall additionally track those. SBAS tracking capability is encouraged.

Output	● Current RTCM SC-104 at 1 Hz on multiple ports. ● Proprietary raw data streaming. ● Capable of streaming data to multiple locations.
Logging	● Continuous logging of raw unsmoothed data. ● Logging of RINEX data (minimum: 30 sec sampling, if not generated outside the receiver). ● Logging of input sensor data.

The firmware of a GNSS receiver is a computer software that controls the tracking of the device. As with any other software, a firmware might be updated to either fix bugs or to improve the tracking capabilities of the receiver. Before upgrading, a new firmware should be thoroughly tested and only be considered on stations where it benefits from the change. In general, the receiver should be operated with the latest stable firmware within 6 months of its release.

4.2 GNSS Antenna

The station's GNSS absolute antenna calibration must be available in the current IGS ANTEX (IGS, IGS ANTEX 2020, 2021) format. This file contains model specific antenna calibrations. Although using type-mean calibrations is the current standard in the IGS analysis, it is preferred to also calibrate each GNSS used in the IGS network individually. It is recommended that new antennas are either calibrated by a robot or in the chamber. For antenna calibrations to be valid, the GNSS antenna must be oriented to True North with an accuracy of ±5°. Relative antenna calibration models should not be used.

The GNSS antenna must be rigidly and securely attached to the top of the station monument as described in section 3.2.

Eccentricities between the marker and the Antenna Reference Point (ARP) must be surveyed and reported in the IGS site logs and RINEX headers to ≤1 mm accuracy; a horizontal eccentricity of 0 m is preferred.

The use of choke-ring antennas is recommended. They have very stable and well understood properties, with high multipath mitigation.

The use of radomes is discouraged. Although they provide some level of protection from the elements, radomes alter the location of the Antenna Phase Centre (APC). Even worse, as ultraviolet light affects the properties of the radome material, its impact on the APC's location varies. However, environmental conditions such as snowfall, sea spray or the likelihood that the antenna may be used as a perch for birds may require the use of a radome. In this case, the antenna/radome combination must have a valid antenna calibration. Conical radomes should not be used. Do not remove radomes from existing GNSS antennas.

Experience shows that when a GNSS antenna is removed and replaced there is a change in the computed position of the site, even when the ARP is replaced precisely. Therefore, do not remove the antenna for any reason other than hardware failure or to perform necessary local tie surveys. For the latter reason it is mandatory to reflect this in the station metadata. If you need to change the antenna, users and analysis centres shall be forewarned (see section 5.5 Announcements).

Choose antennas that are capable of tracking as many planned GNSS signals as possible at the time of purchase to reduce the need to remove an antenna to track newly available GNSS signals. To avoid confusion, the IGS standard naming convention for antenna models (IGS, Naming Conventions for GNSS Equipment, 2021) must be used in the RINEX headers and metadata (see section 5.4).

Table 4 provides recommendations for a geodetic quality GNSS antenna at the date of issue of these Guidelines.

Table 4: Summary of Recommendations for GNSS Antennas

Component	Recommendation
Antenna Type	• Use of unique ("unknown") antennas is not permitted. • Preferably use of choke-ring antenna with Dorne-Margolin elements. • Antenna's satellite signal tracking capabilities should match or exceed the capability of the GNSS receiver. For new stations this requirement is mandatory.
Calibrations	• All IGS antennas shall have a valid IGS absolute antenna calibration. If an antenna is individually calibrated, the corresponding ANTEX file should be made available to the IGS. • Antennas should be either robot or chamber calibrated.
ARP and Eccentricities	• All antenna-offset measurements shall refer to the ARP. • Eccentricities (East, North, Up) from the permanent position marker to the ARP must be surveyed and reported

	in the metadata and RINEX headers with an accuracy of ≤ 1 mm.
Radome	● The use of a radome is strongly discouraged. ● If the use of a radome is absolutely necessary, the use of a hemispherical radome with a valid absolute antenna calibration is recommended. ● Do not use conical radomes.
Antenna Orientation	● The antenna has to be oriented to True North with an accuracy of ±5°. ● If the deviation is greater than 5°, the actual alignment has to be noted in the metadata.
Environment	● The antenna and antenna connectors must be weatherproof and corrosion resistant.

4.3 Antenna Cable

All GNSS station cabling is vulnerable to vandalism, weather, pests and fire. Externally running cables can be protected by using buried or secured conduits. Dedicated cableways are recommended within buildings. Cable connectors are potential points of failure when stressed, corroded, or infiltrated by water, dust and pests. The use of a self-amalgamating ultra-violet stabilised tape to protect cable connections is recommended.

Tension in the cable at the receiver and antenna connection may place stress on the connection causing failure or intermittent connection. At the antenna this tension may also cause the antenna to rotate. A short loop of excess cable at the antenna and receiver connections is recommended.

The quality of antenna cables is categorised by its rated signal loss per metre. Higher grade cables have less signal loss per linear metre at the expense of increased cost and decreased cable flexibility. Each connection along a cable increases the signal loss and adds a potential point of failure. Where inflexible high-grade cables are used for the main cable run, a short flexible lead of lower grade cable may reduce stress on the antenna or receiver connection. An unstressed cable of minimum length with minimal connectors provides an optimal solution.

An in-line amplifier reduces signal loss to the receiver, but adds another point of failure. Use higher rated low-loss cable in preference to lower rated cables with in-line amplifiers. Antenna splitters should only be used when the GNSS site includes multiple GNSS receivers, or for test purposes. Table 5 provides recommendations for antenna cables used at all GNSS sites.

Table 5: Summary of Recommendations for GNSS Antenna Cables

Component	Recommendation
Cable Type	● The cable type must be sufficient for the intended length of the cable run. ● It is recommended to use high-quality low-loss cables with a loss < 0.2 dB/m at the L1 frequency. ● The usage of cable connectors as well as total cable length should be minimised.
Cable Protection	● Protect cables from weather, pests and other factors that could damage the cable. ● Use a suitable conduit. ● Seal antenna cable connectors with self-amalgamating ultraviolet stable tape for protection against water infiltration and ultraviolet radiation.
Cable Tension	● Minimise tension in the antenna cable, particularly at the receiver and antenna interface.
In-Line Amplifiers	● Avoid the use of in-line amplifiers where possible. ● If in use, details must be stated in the station metadata.
Cable Splitters	● Only use antenna splitters if other receivers are connected to the antenna. ● If in use, details must be stated in the station metadata.
Lightning Protection	● Include a grounded lightning protector to the antenna cable. ● In lightning prone areas, reduce the horizontal cable-run length to minimise the risk of signal induction from nearby lightning strikes.

4.4 Meteorological Sensors

It is recommended to install additional meteorological equipment at an IGS CORS. Meteorological data aids understanding the GNSS ambient environment and assists GNSS processing and the development of improved weather models[11].

Meteorological sensors need to be installed separately from the site's monument to minimise any increase in the multipath environment. RINEX shall be used to record and distribute meteorological data. The recommended data sampling interval shall be less than 60 minutes and it is recommended to be 5 or 10 minutes. The position of all auxiliary sensors needs to be surveyed and included in the relevant metadata.

Meteorological sensors at IGS CORS should have the following requirements:

- At a minimum, temperature and pressure should be measured,
- The pressure measurement accuracy shall be better than ± 0.5 hPa,
- The temperature measurement accuracy shall be better than ± 1° K,
- The height difference between the pressure measurement reference mark of the meteorological sensor and the antenna reference point should be determined to better than 10 cm,
- Make sure to calibrate the instruments periodically according to the manufacturer’s recommendations.

[11] https://igs.org/wg/troposphere/

5 Data and Metadata

This section gives recommendations about the reliability, latency and quality for the data recorded by an IGS CORS. Furthermore, it describes the handling of equipment changes in the corresponding station metadata.

5.1 Signal Tracking and Data Recording

The bare minimum that an IGS CORS needs to provide is daily RINEX observation files with a sampling rate of 30 seconds. A sampling rate of 15 seconds is acceptable but not encouraged. Furthermore, station operators are asked to provide RINEX navigation files[12].

It is recommended to provide hourly RINEX files with a sampling rate of 30 seconds. Newly proposed IGS stations are encouraged to provide hourly RINEX files with a sampling rate of 30 seconds and high-rate (1Hz) RINEX files with a duration of 15 minutes if feasible (see section 5.1.1).

Each RINEX data file has to be sent to at least two of the global IGS data centres[13]. If the station is already included in a regional network (e.g., APREF, EPN, SIRGAS) and data is publicly available, the transmission to one of the global data centres is sufficient. Data transmission will be coordinated through the IGS Network Coordinator.

After a communication outage, missing data files need to be submitted to the data centre(s). An announcement explaining details about the outage shall be sent to the community (see section 5.5 for more information).

Table 6 highlights key figures for the signal tracking, data recording and data transmission that should be aimed by each IGS CORS.

---

[12] To reduce the number of files, it recommended to send mixed navigation files that contain all navigation data in a single file.

[13] A list of IGS global data centres can be found on the IGS website:
https://igs.org/data-access/#data-centers

Table 6: Recommendations for IGS CORS Data

Criterion	Recommendations
Signal Tracking and Data Archival	● 99% of the available epochs in a day are fully observed, recorded and archived (<15 minutes of outage per day). ● 99% of the available epochs in a year are fully observed, recorded and archived (<91 hours of total outage per year).
Data Transmission	● The latency of an hourly data file for archival should be <5 minutes after the end of each hour. ● The latency of a daily data file for archival should be <30 minutes after the end of the day.
Resubmission after Outage	● All missing daily files need to be resubmitted as soon as possible. ● Missing hourly files need to be resubmitted at the minimum for the last complete three days.

5.1.1 High-Rate Data

In support of Near-Real-Time (NRT) applications, station operators are encouraged to provide 15-minute RINEX observation and navigation files with a data frequency of 1 Hz (if applicable). They could be either generated from real-time streams or recorded by the receiver.

The stations participating in the high-rate data provision are encouraged to provide the files with a delay of 5 minutes or less from the last recorded observation epoch.

5.1.2 Real-Time Data

In addition to meeting the standards of a conventional IGS station, Real-Time stations are required to stream GNSS observation data with a minimum data interval of 1 Hz. All newly proposed IGS stations must be able to stream data in real-time unless they are considered to be of value to contribute to the reference frame (e.g., by being co-located to a SLR or VLBI station) or are located in a region of geographical need.

The recommendations that need to be fulfilled by an IGS Real-Time station are described in section 2 of the "Guidelines for IGS Real-Time Broadcasters and Stations" (IGS Real-Time WG/IGS Infrastructure Committee, 2021).

5.1.3 Meteorological Data

It is recommended to install precise meteorological equipment on an IGS CORS. Sensor specific guidelines are described in Section 4.4. As a minimum, the data must include pressure and temperature measurements and shall be distributed in RINEX format. The RINEX files should be transmitted on the same schedule as the RINEX observation files (hourly and/or daily).

5.2 File Naming Conventions

The IGS currently supports three major versions of the RINEX standard, RINEX v.2, RINEX v.3, and RINEX v.4. Every station operator is encouraged to transmit the latest available major/minor version. Newly proposed IGS CORS must submit their data in RINEX 3.04 at a minimum.

5.2.1 RINEX v.4/v.3

RINEX v.3 (IGS/RTCM Working Group, 2020) and RINEX v.4 (IGS/RTCM RINEX Working Group, 2021) data must be transmitted in the following file naming convention:

Observation and Meteorological Files

`SSSSMRCCC_S_YYYYDDDHHMM_DDU_FRU_DT.fff.cmp`

Navigation Files

`SSSSMRCCC_S_YYYYDDDHHMM_DDU_DT.fff.cmp`

All elements of the main body of the file name must contain capitalised ASCII letters or numbers and all elements are of a fixed length and separated by an underscore "_". The file type and compression fields (extension) use a period "." as a separator and must be lowercase ASCII characters. Fields must be padded with zeros to fill the field width (see Table 7).

In order to further reduce the size of observation files, the Hatanaka compression toolkit should be used. More information on the Hatanaka compression scheme can be found in: https://terras.gsi.go.jp/ja/crx2rnx.html.

5.2.2 RINEX v.2

RINEX v.2 (Gurtner, 2007) data must be transmitted in the following file naming convention:

`ssssdddf.yyt`

Table 8 describes each element of this file naming convention. Stations transmitting RINEX v.2 files are encouraged to provide gzip compressed files. Even if files are sent in Z-compression, IGS data centres will recompress them and make them publicly available using gzip (Romero & Ruddick, IGS, 2020).

Table 7: RINEX v.3/v.4 File Name Description as used in the IGS

Element	Description	Example	Comment
Station Name SSSSMRCCC	• SSSS: 4-character (existing) IGS station name • M: monument or marker number (0-9) • R: receiver number (0-9) • CCC: ISO-3166 country or region code (alpha-3)	POTS00DEU	To align with the SINEX format, marker and monument numbers other than 0 are currently not supported
Data Source S	• Data Source • Supported are R (from receiver using vendor or other software) and S (RTCM or another stream format)	R	
Start Time YYYYDDDHHMM	• YYYY: Gregorian year • DDD: Day of the year • HHMM: Hours and minutes of the day	2021 260 1000	It is preferred to use the nominal start time of the file. However, using the actual start time of a file is acceptable.
File Period DDU	• DD: File period • U: Unit of the file period • Accepted are 15M, 01H, 01D	01D	

Data Frequency FRU	• FR: Data frequency • U: Unit of the data frequency • Accepted are `01S` for high-rate data and `30S` or `15S` for hourly/daily data	30S	Not required for RINEX navigation files
Data Type DT	• Two characters represent the type • D: Satellite System (allowed are `G`, `R`, `E`, `C`, `J`, `S`, `I` and `M`(ixed)) • T: RINEX file type (allowed are `O`, `N`, `M`)	MO	
Format fff	• Format of the file • Supported are `rnx` (RINEX) and `crx` (compressed RINEX)	rnx	
Compression cmp	• Compression format • Supported is gzip (`gz`)	gz	

Table 8: RINEX v.2 File Name Description as used in the IGS

Element	Description	Example
Station Name ssss	• The 4-character IGS station name.	pots
Day of year ddd	• Day of the year of the first record.	260
File Period	• File sequence number/character within day	0

f	• Daily files (30 seconds): f=0 • Hourly files (30 seconds): – f=a (00:00:00 to 00:59:30), – f=b (01:00:00 to 01:59:30), – … – f=x (23:00:00 to 23:59:30) • High-rate files (15M, 1 Hz): – f=a00 (00:00:00 to 00:14:59) – f=a15 (00:15:00 to 00:29:59) … – f=m30 (12:30:00 to 12:44:59) … – f=x45 (23:45:00 to 23:59:59)	
Year yy	• Two-digit year	21
File Type t	• Allowed file types are: – O: Observation file – D: Hatanaka compressed observation file – N: GPS navigation file – G: GLONASS navigation file – M: Meteorological file	o

5.3 Data Quality

Each IGS CORS is expected to have high-quality data. Table 9 describes the parameters and metrics that should be fulfilled.

Table 9: Quality Parameters for CORS Data

Criterion	Recommendations
Tracking	• All (available) satellite systems are tracked. • All-in-view tracking is activated. • All (available) frequencies and signals are tracked.
Multipath	• The station ideally has a multipath below 30 cm for each satellite constellation.

Observations	• The number of observations should be above 95% (observed vs. expected) for an elevation of 5°.
Cycle Slips	• The station has a low number of cycle slips (<1 per 1000 observations).
Analysis (Post-Processing)	• Phase convergence in PPP analysis < 15 mm.

5.4 Metadata

GNSS metadata is the information about the site, including site ownership, contact details, monument information, the site coordinates and a history of the installed equipment. Reliable and current metadata is central to the management and use of a GNSS station, and is the responsibility of the station operator.

5.4.1 IGS Site Log/GeodesyML

The IGS requires that CORS record and maintain their metadata in an IGS site log (ASCII) or GeodesyML, and that the metadata is made available to the IGS and to all users. The IGS uses a web application[14] to maintain the station metadata.

It is mandatory that the metadata is completed and published for all CORS to provide a consistent method of distributing relevant site information to analysis centres and users. A CORS operator may need to keep additional metadata for the site to aid internal management and operation.

All IGS stations are identified using a unique **Nine-Character abbreviation**. The first four characters should be globally unique, and the name is usually chosen to represent the suburb, town or locality of the site. The GNSS operator should check with the IGS Network Coordinator that the proposed four-character identifier for a new CORS is not already in use. A non-exhaustive list of current and past four-character identifiers for CORS sites can be obtained from SOPAC[15] (Scripps Orbit and Permanent Array Center). Furthermore, each IGS CORS needs to apply for an IERS DOMES number[16]. Make sure that the intended four-character code has not

[14] Site Log Manager (SLM), available at: https://slm.igs.org

[15] http://sopac-old.ucsd.edu/checkSiteID.shtml

[16] https://itrf.ign.fr/en/network/domes/request

already been used for other geodetic techniques by checking the IERS DOMES number list (https://itrf.ign.fr/en/network/list).

5.4.2 RINEX Headers

RINEX headers must match the metadata recorded in the IGS site log. RINEX files shall be resubmitted in case of metadata discrepancies. All information in the RINEX header must be ASCII encoded. The usage of characters from other encoding standards (e.g., UTF-8) can lead to a shift of the header elements while decoding, e.g., by using diacritics. Table 10 lists the mandatory RINEX header elements provided for each RINEX file.

Table 10: Recommendations for RINEX headers

RINEX Header Element	Recommendations	Example
`MARKER NAME`	• It is recommended to use the nine-character station code. • Alternatively, the 4-character station code can be used. • All letters must be provided in uppercase.	OUS200NZL OUS2
`MARKER NUMBER`	• IERS Domes number. • All letters must be provided in uppercase.	50212M002
`MARKER TYPE`	• Must be set to `GEODETIC`.	
`OBSERVER`	• It is recommended to provide a generic email address. • Maximum number of characters is 20.	gnss@agency.org
`AGENCY`	• It is recommended to provide the agency abbreviations as stated in the IGS site log sections 11 and 12. • If multiple agencies are listed, they should be separated by a slash (“/”).	OUSD/GFZ

	• Maximum number of characters is 60.	
`REC # / TYPE / VERS`	• All receiver information must be identical to the metadata stated in the IGS site log. – Col 1: receiver serial number – Col 2: receiver model – Col 3: receiver firmware version	
`ANT # / TYPE`	• All antenna information must be identical to the metadata stated in the IGS site log. – Col 1: antenna serial number – Col 2: antenna model	
`APPROX POSITION XYZ`	• The approximate coordinates shall agree to 1 m accuracy to the ones stated in the IGS site log.	
`ANTENNA: DELTA H/E/N`	• The antenna eccentricities must match the ones stated in the IGS site log.	

5.4.3 Digital Photographs

Every CORS must provide pictures of the antenna installation in the four cardinal directions (preferably 8 pictures every 45°), the monument and its vicinity. They need to be updated after each event or hardware change on the site.

The pictures must be labelled and named in the following file naming convention:

`SSSSMRCCC_YYYYMMDD_D[D].fff`

Table 11 describes the elements of this convention. All elements are separated by an underscore ("_").

Table 11: Elements of a Station Picture File Name

Component	Description	Example
SSSSMRCCC	• The nine-character station code.	NYA200NOR
YYYYMMDD	• Date of admission (year, month, day) without separation and zero-padded.	20210131
D[D]	• Cardinal direction: N, E, S, W and a two-way combination of them • Antenna serial number: AS • Antenna mount: AM • Receiver: R • Monument: M	N (North) SE (South-East)
fff	• The format of the graphic file. • Supported are JPEG and PNG.	.jpg

Alternatively, pictures can be made available to a website hosted by the station operator or the parent organisation.

5.4.4 Individual Antenna Calibrations

Although not mandatory, it is recommended to provide individual antenna calibrations. They are useful for activities and investigations for different IGS working groups (e.g., Antenna Working Group). The corresponding ANTEX file should be made available to the IGS Network Coordinator.

5.4.5 Data Protection Compliance

The European Union and other countries implemented regulations on the protection of personal data. Since the IGS is a voluntary federation without a strong legal representation, it is not in the interest of the IGS to deal with the subtleties that each of the regulations bring with them.

We therefore ask, that all personal information in the metadata (IGS site logs/GeodesyML) and RINEX header (full names and email addresses) get replaced by generic names and email lists, e.g.:

- IGS Site Log/GeodesyML:
    - Contact Name: “Agency” Network operator

  - E-Mail: gnss@agency.org
- RINEX Header:
  - Observer: gnss@agency.org
  - Comments with disclaimer information

Stations proposed to the IGS will need to follow these rules prior to their acceptance. Station operators who are updating the metadata of their stations will also be asked to use data protection compliant contact information.

5.5 Announcements

The IGS uses an email distribution system to inform the community about events related to the network. A complete list of IGS mailing lists can be found on the IGS website[17]. Station operators are requested to subscribe and track the following lists to remain informed about the activities in the IGS:

- IGS Mail
- IGS Station

An advisory to the IGS *Station* list must be sent in the following cases:

- Station status message that could affect position solutions or require an IGS metadata update, e.g., changes in antenna, radome, receiver and receiver settings, cabling, frequency standard or environment (tree clearing, building constructions, etc.),
- Planned changes to the station (e.g., antenna or receiver change) should be announced at least one day prior to the change,
- Expected data outage for more than one week,
- Corrected IGS metadata,
- Resubmission of data due to corruption or incorrect metadata.

Briefly describe in the message what has changed. The subject of the email must start with the nine-character station code so that the email can be archived automatically.

[17] https://igs.org/mail