NOAA Technical Memorandum NOS NGS 92

Classifications, Standards and Specifications for GNSS Geodetic Control Surveys using OPUS Projects

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Silver Spring, MD
October 23, 2024

NOAA Technical Memorandum NOS NGS 92

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Preface

This publication supplements *Standards and Specifications for Geodetic Control Networks* issued September 1984 (Bossler 1984).

This publication replaces NOAA Technical Memorandum NOS NGS 58 *Guidelines for Establishing GPS-Derived Ellipsoid Heights, (Standards: 2 cm and 5 cm), Version 4.3* (Zilkoski et al. 1997) and also replaces NOAA Technical Memorandum NOS NGS 59 *Guidelines for Establishing GPS-Derived Orthometric Heights* (Zilkoski et al. 2008).

This publication provides classification, standards, and specifications for GNSS geodetic control surveys that use Global Navigation Satellite Systems (GNSS) and that will be submitted to NGS using OPUS Projects for review and publication. These types of surveys were not well-established by the dates of the 1984, 1997, and 2008 publications, nor did OPUS Projects exist. In addition, since 2008 GNSS technology has improved and considerable research has been done into the best practices regarding these surveys and the analyses of achievable results (e.g., Allahyari et al. 2018; El Shouny and Miky 2019; Gillins and Eddy 2015, 2017; Gillins et al. 2019a; Gillins et al. 2019b; Jamieson and Gillins 2018; Park et al. 2018; Schenewerk et al. 2016; Soler and Wang 2016; Wang and Soler 2013; Wang et al. 2017; Weaver et al. 2018). This publication is supported by that research.

This publication is specifically limited to supporting OPUS Projects (version 5.x), the current North American Datum of 1983 (NAD 83), the North American Vertical Datum of 1988 (NAVD 88) and other current vertical datums that are officially recognized by NGS. Future versions of OPUS Projects and future datums will require revision of this publication.

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Introduction

These Classifications, Standards, and Specifications are *intended* for GNSS geodetic control surveys that will be submitted to NGS for review and publication using the OPUS Projects software suite. These Classifications, Standards, and Specifications are *recommended* for all other GNSS control surveys that use the OPUS Projects software suite.

The OPUS Projects software suite is available via a web browser and is the means of analyzing and submitting GNSS geodetic control surveys to NGS for review and publication.
OPUS Projects organizes the field observation logs, observation files, photos, baseline computations, and adjustments, then produces the output files that enable NGS personnel to review and accept the project for publication or provide advice for necessary changes.

OPUS Projects supports GNSS static observations submitted via OPUS Static, and it also accepts uploaded GNSS vectors derived from third-party software via the GNSS Vector Exchange File Format (GVX) (Gillins and Sellars 2021).

NGS has discontinued the use of the former classifications for GNSS surveys by Order and Class and has replaced them with explicit numerical characterizations known as Network Accuracy and Local Accuracy (FGDC 1998; Milbert 2008 pp. 54-55; Dennis 2020 pp. 167–168). Network accuracy and local accuracy by themselves do not adequately characterize the survey's overall quality. They are estimates of uncertainty based on formal error propagation theory and least squares adjustment of a network. While that is an important measure of quality, it is not an adequate means of assessing the adherence of a survey to a set of defined standards. It is important to note that these Classifications, Standards, and Specifications require good surveying practices that are tailored to achieve the intended verifiable accuracy and precision. In other words, this document aims to account for factors that affect the quality of a GNSS control survey using OPUS Projects, beyond just network and local accuracies. Surveyors should continue to rely on existing NGS documents to guide leveling procedures.

Selected Terms and Definitions (also see Glossary)

This document introduces several new terms for convenience to shorten the wording of certain types of data processing techniques. The definitions of these terms are provided below because they are new and frequently used herein. See the Glossary for a fuller listing of definitions.

GVX — denotes the GNSS Vector Exchange File Format developed by NGS (Gillins and Sellars 2021). GVX is a standard file format for exchanging GNSS vectors from varying GNSS surveying methods and equipment manufacturers. GNSS vectors that are in the GVX file format can be uploaded directly to OPUS Projects. The GVX file format supports the uploading of 3 GNSS vector types: (1) Post-Processed (PP), (2) Network Real-Time Kinematic positioning (NRTK), and (3) Single Base Real-Time Kinematic positioning (SRTK). This document will use the generalized term "GVX vectors" in reference to them. Where it is appropriate to refer more narrowly to a specific GVX vector type, the terms GVX PP vector, GVX NRTK vector, or GVX SRTK vector will be used.

GVX PP — denotes GNSS vectors derived from post-processing static or rapid static data using external software (i.e., other than OPUS Projects). These vectors are uploaded into OPUS Projects via the GVX file format. GVX PP supports vectors from 2 styles of baseline post processing: (1) Sequential processing: vectors derived individually without any consideration of their possible cross-correlations. These vectors do not have a session record in the GVX file format. (2) Simultaneous processing: vectors derived from a session of simultaneous observations, with cross-correlations defined in a session record. In this document, GVX PP refers specifically to vectors where the information needed to resolve the integer ambiguities is collected during the mark occupation itself, with a minimum static occupation time of 15 minutes. The integer ambiguities are resolved later during a post-processing step in the user's software.

For post-processed kinematic (PPK) vectors, the integer ambiguities are resolved *prior* to mark occupation (usually while the rover is moving) and are thus essentially identical to real-time kinematic (RTK) vectors. The GVX PP category therefore does not include post-processed kinematic (PPK) vectors. PPK vectors are treated in exactly the same way as RTK vectors in this document.

GVX NRTK — denotes GNSS vectors collected with RTK methods using a full network corrector of a real-time GNSS network. Examples of full network correctors include using the Virtual Reference Station (VRS) method, Master Auxiliary Concept (MAC), etc. These vectors are uploaded into OPUS Projects via the GVX file format. GVX NRTK includes PPK vectors determined using network correctors during post-processing.

GVX SRTK — denotes GNSS vectors collected with RTK methods from a single base station. The single base station can be a temporary base, or it can be a permanent base that is part of a real-time network. These vectors are uploaded into OPUS Projects via the GVX file format. GVX SRTK includes PPK vectors that are post-processed with data from a single base.

OPUS PP vectors — refers to a baseline solution (vector) derived from post-processing static GNSS observations in OPUS Projects. The baseline processor in OPUS Projects (PAGES) uses simultaneous processing techniques; therefore, all OPUS PP vectors have cross-correlations with the other vectors measured simultaneously in a session solution.

Classifications of Intended Network and Local Accuracies

NGS defines the following **Classifications of Intended Network and Local Accuracy** for GNSS geodetic control surveys that will be submitted to NGS for review and publication (see Table 1 — Classifications of Intended Network and Local Accuracy). By following the requirements of Tables 2 through 10 the surveyor should expect to achieve the intended accuracies shown in Table 1. Since actual surveys sometimes do not achieve the intended accuracies, NGS will review any submitted survey that at least meets the requirements of the LOCAL Classification. In keeping with current practice, the NGS Datasheet will not designate a Classification on the datasheet.

Table 1 — Classifications of Intended Network and Local Accuracy

	Description	PRIMARY	SECONDARY	LOCAL
1.1	**Ellipsoid Height (cm) ***	2 cm	3 cm	5 cm
1.2	**Horizontal (cm) ***	1 cm	1.5 cm	2.5 cm
1.3	**Orthometric Height (cm) ***	3 cm	4 cm	6 cm

** Network and Local Accuracies are stated at the 95% confidence level.*

Standards

The Classifications of Intended Network and Local Accuracy are supported by the Standards in Table 2 through Table 10. The Specifications explain each Standard and/or describe how to meet the Standard. The Specifications section is arranged by Table and then each Standard is discussed separately in the order found in the Table.

There are 3 types of marks in a project in OPUS Projects: NCN CORS, GVX base marks, and passive marks (see Table 2 — Description of Mark Types and Anticipated Usage).

Each mark type must be positioned by an Observation Method (see Table 3 — Observation Method Requirements for Mark Types).

Each Observation Method must conform to a set of Observation Requirements (see Table 4 — Standards for Observation Requirements by Method).

The network design and selection of observation methods should ensure that error sources are minimized to the greatest extent possible. It is not possible in any document to consider every possible problem in network design. However, many situations can be considered and some limiting standards for Network Design can be set (see Table 5 — Standards for Network Design).

The best network designs use permanent, stable, publicly accessible, identifiable monuments (see Table 6 — Standards for Monumentation).

The Standards set objective measures by which error propagation can be assessed (see Table 7 — Standards for Session Processing and Adjustment Results).

Achieving good quality orthometric heights using GNSS surveys requires some additional network design considerations (see Table 8 — Standards for Achieving Valid Orthometric Heights).

No network design, however well planned, will produce acceptable results if the survey is not carried out with due attention to equipment, observational metadata, and office organization procedures (see Table 9 — Standards for Equipment Used in Field Observations and Office Procedures).

Documentation and supporting files are required for all projects submitted to NGS (see Table 10 — Standards for Required Documentation*)*.

Table 2 — Description of Mark Types and Anticipated Usage

	Mark Type	Description and Anticipated Usage
2.1	**NCN CORS**	A continuous GNSS station in the NOAA CORS Network (NCN). Each NCN CORS is well-known and monitored by the NGS.
2.2	**GVX Base mark**	A **GVX base** is an inclusive term for a mark **that will be used** as the origin of a vector in the GVX format. Since GVX vectors can be derived by 3 methods, the specific terms — GVX PP Base, GVX NRTK Base, and GVX SRTK Base may sometimes be used for clarity. **GVX PP base** A GVX PP base can be a NCN CORS, or a continuous GNSS station that is not in the NCN (a non-NCN CORS), or a mark **that will be used** as a base station for GVX PP vectors. A non-NCN CORS is not well-known or monitored by NGS. **GVX NRTK base** A GVX NRTK base can be an NCN CORS, or a non-NCN CORS **that will be used** as a base station for GVX NRTK vectors. A non-NCN CORS is not well-known or monitored by NGS. **GVX SRTK base** A GVX SRTK base can be an NCN CORS, or a non-NCN CORS, or a mark **that will be used** as a GVX SRTK base station. A non-NCN CORS is not well-known or monitored by NGS.
2.3	**Passive mark**	A passive mark is a mark **that will not be used** as a GVX PP base, as a GVX NRTK base, or as a GVX SRTK base.

Table 3 — Observation Method Requirements for Mark Types

	Mark Type	Observation Method Requirements for Mark Type
3.1	**NCN CORS**	NONE. OPUS Projects will automatically gather all needed information.
3.2	**GVX Base mark** **GVX PP** **GVX NRTK** **GVX STRK**	 Follow Requirements for OPUS PP in Table 4.2 Follow Requirements for OPUS PP in Table 4.2 Follow Requirements for OPUS PP in Table 4.2
3.3	**Passive mark**	Follow Requirements for OPUS PP in Table 4.2 - or- Follow Requirements for GVX PP in Table 4.3 - or - Follow Requirements for GVX NRTK in Table 4.4 - or - Follow Requirements for GVX SRTK in Table 4.5

Table 4 — Standards for Observation Requirements by Method

	Requirement	PRIMARY	SECONDARY	LOCAL
4.1	**Requirements for ALL METHODS — Repeat occupations and offset time**	Offset sessions/occupations by 3 to 21 hours.		
4.2	**Requirements for OPUS PP — Required TOTAL Static GNSS Observation Time (T) and Recommended GNSS sessions**	T = 20 hours (for 0 to 200 km) (2) 10 hour sessions or (3) 7 hour sessions or (4) 5 hour sessions Requires at least 2 sessions, with at least 1 session on a different day	T = 8 hours (for 0 to 200 km) (2) 4 hour sessions T = 6 hours (for 0 to 150 km) (2) 3 hour sessions T = 4 hours (for 0 to 100 km) (2) 2 hour sessions Requires at least 2 sessions.	T = 4 hours (for 0 to 200 km) (2) 2 hour sessions Requires at least 2 sessions.
4.3	**Requirements for GVX PP — Number and duration of sessions**	3 sessions 60 minutes each (for 0 to 25 km) 90 minutes each (for 25 to 50 km) Requires at least 1 session on a different day.	3 sessions 30 minutes each (for 0 to 25 km) 60 minutes each (for 25 to 50 km)	3 sessions 15 minutes each (for 0 to 25 km) 30 minutes each (for 25 to 50 km)
4.4	**Requirements for GVX NRTK — Number and duration of occupations**	(6) 5 minutes Requires at least 3 occupations on a different day.	(3) 5 minutes	(3) 5 minutes
4.5	**Requirements for GVX SRTK — Number and duration of occupations**	Not allowed	(5) 5 minutes Requires at least 2 occupation on a different day.	(4) 5 minutes Requires at least 1 occupation on a different day.

Table 5 — Standards for Network Design

	Requirement	PRIMARY	SECONDARY	LOCAL
5.1	**All Hubs are NCN CORS**	Yes.		
5.2	**Distance between Hubs**	100 km minimum, 400 km maximum.		
5.3	**Project includes 3 or more NCN CORS**	1 local NCN CORS used as hub (< 100 to 200 km) plus 1 or more nearby NCN CORS (< 300 km) plus 1 or more distant NCN CORS (400 to 800 km)		
5.4	**Project includes checkpoints (GVX Validation Stations)**	Yes, if GVX vectors are uploaded to the Project.		
5.5	**Longest OPUS PP Vector from Hub to mark** *(excluding from Hub to NCN CORS)*	200 km (for T = 20 hrs)	200 km (for T = 8 hrs) 150 km (for T = 6 hrs) 100 km (for T = 4 hrs)	200 km (for T = 4 hr)
5.6	**Longest *GVX* Vector** **— GVX PP** **— GVX NRTK** **— GVX SRTK**	 50 km 40 km Not allowed	 50 km 40 km 10 km	 50 km 40 km 20 km
5.7	**Maximum Number of Vector Steps in a Vector Chain**	2 vector steps, consisting of: 1 OPUS PP vector, plus 1 GVX vector.		
5.8	**Minimum Spacing Distance Between Adjacent Marks**	1000 meters	500 meters	100 meters
5.9	**Timeliness of Projects**	Start to end of observations = 12 months End of observations to date of submission = 6 months		

Table 6 — Standards for Monumentation

	Requirement	PRIMARY	SECONDARY	LOCAL
6.1	**General Requirement**	Stable, publicly accessible, identifiable, and permanent monuments.		
6.2	**Stamping/Designation**	Prefer unique stampings (see NGS 2023a: Annex D).		
6.3	**Vertical Stability Code**	A or B (See NGS 2023b: Annex P)	A, B, or C (See NGS 2023b:Annex P)	A, B, C, or D (See NGS 2023b: Annex P)

Table 7 — Standards for Session Processing and Adjustment Results

	Requirement	PRIMARY	SECONDARY	LOCAL
7.1	**Achieved Network Accuracy, less than or equal to** **HORIZ (cm)** **UP (cm)** **ORTHO (cm)**	 1.0 2.0 3.0	 1.5 3.0 4.0	 2.5 5.0 6.0
7.2	**Achieved Local Accuracy, less than or equal to** **HORIZ (cm)** **UP (cm)** **ORTHO (cm)**	 1.0 2.0 3.0	 1.5 3.0 4.0	 2.5 5.0 6.0
7.3	**Peak-to-peak Coordinate Comparison, less than or equal to** **NORTH (cm)** **EAST (cm)** **UP (cm)**	 3.0 3.0 6.0	 4.0 4.0 8.0	 5.0 5.0 10.0
7.4	**Maximum Residuals per Vector, less than or equal to, (in any adjustment)** **DN (cm)** **DE (cm)** **DU (cm)**	1.5 absolute value 1.5 absolute value 3.0 absolute value	2.0 absolute value 2.0 absolute value 4.0 absolute value	2.5 absolute value 2.5 absolute value 5.0 absolute value
7.5	**Statistical Checks from Constrained Adjustment** **- Horizontal Constrained Adjustment.txt file** **F-Statistic Test** **Maximum Allowable Mark Constraint Ratio** **N:** **E:** **U:** **- Vertical Constrained Adjustment.txt file** **F-Statistic Test** **Maximum Allowable Mark Constraint Ratio** **N:** **E:** **U:**	 PASS 3.0 3.0 3.0 PASS n/a n/a 3.0		

Table 8 — Standards for Achieving Valid Orthometric Heights

	Requirement	PRIMARY	SECONDARY	LOCAL
8.1	**Minimum Number of Existing Valid Orthometric Height Control Marks**	2		
8.2	**Method of Existing Valid Orthometric Height Control Marks**	Adjusted Leveling (3rd Order or better), and GPS-derived Height Modernization. See Specification 8.2 for detail.		
8.3	**Maximum Allowable Distance from Newly Established Control Mark to 2 Existing Valid Orthometric Height Control Marks**	Up to 50 km.		

Table 9 — Standards for Field Equipment and Office Procedures

	Requirement	PRIMARY	SECONDARY	LOCAL
9.1	**Tripod Type**	Fixed height or collapsible fixed height	Fixed height or collapsible fixed height	Fixed height, collapsible fixed height, or adjustable height
9.2	**Antenna Calibration**	Listed on NGS Antenna Calibration page		
9.3	**RINEX Version**	2.11 or newer		
9.4	**Ephemeris** **OPUS PP** **GVX PP** **GVX NRTK** **GVX SRTK**	 Final Precise Final Precise Broadcast Not allowed	 Rapid Rapid Broadcast Broadcast	 Rapid Rapid Broadcast Broadcast

Table 10 — Standards for Required Documentation

	Requirement	PRIMARY	SECONDARY	LOCAL
10.1	Project Proposal	See: OPUS Projects User Guide (NGS 2023c)		
10.2	Field Observation Logs	See: OPUS Projects User Guide (NGS 2023c)		
10.3	Windesc	See: OPUS Projects User Guide (NGS 2023c)		
10.4	Photographs	See: OPUS Projects User Guide (NGS 2023c)		
10.5	Project Report	See: OPUS Projects User Guide (NGS 2023c)		

Specifications

These Specifications support the Standards in Tables 2 through 10 above. These Specifications explain each Standard, describe how to meet the Standard, and provide guidance in surveying methodology. The Specifications section is arranged by Table and then each Standard is discussed separately in the order found in the Table.

Each survey that is submitted to NGS for review and publication must have a statement as to its intended classification. NGS will then review the survey, determine whether the survey has at least met the Standards for the LOCAL classification, and if so accept the survey for inclusion in the NGS Integrated Database.

In this context, a “survey” or “project” is a single adjusted network. A survey or project cannot contain disconnected sub-networks. All marks must be connected by vectors within a single network.

Table 1 — Classifications of Intended Network and Local Accuracy

Each Classification may be considered as being appropriate for an intended use. The Standards make it clear that significant differences in requirements exist between the Classifications. Surveyors should carefully consider what Classification is most appropriate for the intended final use of the proposed survey.

The surveyor can determine whether the intended Classification has been achieved by comparing the results of the survey to the Standards in Tables 2 through 10.

Achievement of an intended Classification is merely confirmative of a survey’s outcome. NGS does not assign a Classification to submitted surveys.

NGS will review any submitted survey that at least meets the requirements of the LOCAL Classification, therefore surveyors may choose to observe a survey using a variety of survey methods, occupation repetitions, durations, baseline lengths, etc.

1.1 — Ellipsoid Height (cm)
Each Classification has an intended ellipsoid height network and local accuracy expressed in centimeters (cm) at the 95% confidence level.

1.2 — Horizontal (cm)
Each Classification has an intended horizontal network and local accuracy expressed in centimeters (cm) at the 95% confidence level.

1.3 — Orthometric Height (cm)
Each Classification has an intended orthometric height network and local accuracy expressed in centimeters (cm) at the 95% confidence level.

Table 2 — Description of Mark Types and Anticipated Usage

The Standards define 3 mark types based on their anticipated usage in a project.

2.1 — NCN CORS
The NOAA CORS Network (NCN) consists of many Continuously Operating Reference Stations (CORS) located within and outside of the United States. Each CORS in the NCN sends daily raw data to the NGS for current performance analysis and future computations. The NCN CORS are owned by NOAA or by other cooperating entities. The NCN CORS function as the foundational geodetic control marks in a project and are usually constrained in the least squares adjustments. One or more NCN CORS can serve as hubs in the session processing.

There are many CORS that are not included in the NCN. NGS does not have direct knowledge of their condition, performance, or data availability. They do not send their daily raw data to NGS. These stations are referred to as non-NCN CORS.

2.2 — GVX Base Mark
The GVX format (Gillins and Sellars 2021) defines 3 GVX vector types, specifically GVX PP, GVX NRTK and GVX SRTK. Regardless of the GVX vector type, the vector's origin is at a GVX base.

2.3 — Passive Mark
Marks that will not be used as a GVX PP base, a GVX NRTK base, nor as a GVX SRTK base are passive marks. In this context, a permanent (or long-term) GNSS antenna mount that is not an NCN CORS nor a GVX base would be considered a passive mark.

Table 3 — Observation Method Requirements for Mark Type

Each mark type plays a role in a project. The NCN must be the foundational geodetic control for all surveys submitted under these Classifications, Standards, and Specifications. Each GVX base serves as a central point from which nearby passive marks are positioned. Accordingly, the need for accuracy and precision is highest for the NCN and GVX bases. The supporting Standards set forth observational method requirements for each mark type.

3.1 — NCN CORS

There are no observational requirements for NCN CORS. These CORS are well-known and monitored by NGS. All needed raw data files and metadata are managed as part of the daily operations of the NCN.

3.2 — GVX Base Mark

Because a GVX Base will be the origin of a vector that positions a passive mark, the position of the GVX Base must be of high quality. Accordingly, the standards require that all GVX Bases be observed using OPUS PP methods.

3.3 — Passive Mark

The accuracy and precision of the position of a passive mark need only be of sufficient quality to meet the requirements of the intended Classification of the project. Since passive marks are likely to be numerous and not likely to have constrainable existing positions, the observation method requirements are more flexible, allowing the surveyor to choose the most efficient method for the project.

Table 4 — Standards for Observation Requirements by Method

The National Geodetic Survey's NOAA CORS Network (NCN) must be the foundational geodetic control for all surveys submitted under these Classifications, Standards, and Specifications. As each vector is added from the NCN to the next mark, error accumulates, and if additional vectors are added from mark to following mark, the resulting chains of vectors may result in excessive error accumulation.

Observation methods vary in their underlying design to satisfy differing needs.

OPUS PP was designed by NGS to be able to successfully compute vectors ranging from a few kilometers to several hundreds of kilometers in length. To do so reliably, significant observation time is required to provide adequate raw data for the calculations. Marks that will be used as the base from which other marks will depend must be observed via OPUS PP methods.

The NGS has produced a standardized file type, the GNSS Vector Exchange File Format (GVX) (Gillins and Sellars 2021), to allow vectors that have been computed using external software and converted to GVX format, to be uploaded into OPUS Projects.

Using OPUS Projects, surveyors can limit error accumulation and simplify their network design. By collecting longer-duration static occupation data files and uploading them via OPUS Static, reliable direct ties are made to the NCN CORS. In many cases, this technique will be the simplest and most preferred. In other cases, it may be useful and efficient to employ other methods to extend or densify the local network. These include post-processed static methods (GVX PP) and real-time kinematic methods, known as Network RTK (GVX NRTK) and Single Base RTK (GVX SRTK). The vectors computed by these methods are uploaded to OPUS Projects using the GVX file format.

The supporting standards in Table 4 set observation requirements by method for OPUS PP, GVX PP, GVX NRTK, and GVX SRTK. Research indicates that the overall performance of NRTK is more robust than SRTK (Allahyari et al. 2018). Accordingly, there are separate standards for each method.

4.1 — Observation Requirements for ALL METHODS

Repeat Occupations and Offset Time
The listed requirements in Table 4 for occupation durations, session durations, and offset times are required. The required offset times are particularly important for achieving accurate heights.

Regardless of the method, the Standards require repeat occupations for all non-NCN mark types. It is good surveying practice to make each occupation independently so that potential systematic errors and blunders are avoided. The surveyor must also ensure that diversity of satellite geometry and mitigation of multipath are accomplished by having 3- to 21-hour offset as required, and ensure that weather diversity is accomplished by observing on different days. In some of the examples shown, the subsequent day could be a duplicate schedule of the first day.

The term “offset” refers to the difference in the starting times of successive occupations. Since satellite geometries at a given location on Earth repeat approximately every 24 hours, offset times of 3 to 21 hours are logical. In the case of repeat sessions/occupations whose durations are between 5 hours and 24 hours, no specific offset is required since these durations already provide adequate satellite diversity and multipath mitigation.

The 2 General Rules for acceptable offset start times are:

1) If occupations are 5 hours or more, then no specific offset is required.
2) If occupations are less than 5 hours, then 3- to 21-hour offsets are required.
    a) If only 2 occupations are required, they must be offset by at least 3 hours.
        i) Within the day, the repeat occupations must be offset by at least 3 hours.
        ii) If the collection of repeat occupations is conducted over two or more days, there must be at least one 3-hour offset among the collection.
    b) If 3 or more occupations are required, then:
        i) Within the day, the repeat occupations must be offset by at least 3 hours.
        ii) If the collection of repeat occupations is conducted over two or more days, there must be at least two 3-hour offsets among the collection.

Occupation Duration Time — Individual Occupations
In many places throughout this document, there are references to the duration of an **occupation**. For simplicity of language, those references are in whole minutes or whole hours. In practice it is difficult to achieve exactly the stated durations. The following minimum occupation durations will be allowed. Surveyors should note in their Project Report if significant

departures from these minimum occupation duration ranges occur during the execution of the survey project.

Stated Occupation Duration	***Minimum Occupation Duration (approximate % of stated)***
5 minutes	*4 minutes 45 seconds (95%)*
15 minutes	*14 minutes 45 seconds (98%)*
30 minutes	*29 minutes (97%)*
60 minutes	*58 minutes (97%)*
90 minutes	*88 minutes (98%)*
2 hours	*1 hour 58 minutes (98%)*
3 hours	*2 hour 58 minutes (99%)*
4 hours	*3 hour 58 minutes (99%)*
5 hours	*4 hour 58 minutes (99%)*
7 hours	*6 hour 58 minutes (99.5%)*
8 hours	*7 hour 58 minutes (99.5%)*
10 hours	*9 hour 58 minutes (99.5%)*

Table 11 - Minimum Occupation Durations

Session Duration Time — Minimum Overlap of Data Files in a Session
In many places throughout this document, there are references to the duration of a **session**. For simplicity of language, those references are in whole minutes or whole hours. In practice it is difficult to achieve exactly the stated durations. Overlap time is computed from latest start to earliest end of the data files making up the session. The following minimum session durations will be allowed. Surveyors should note in their Project Report if significant departures from these minimum session durations occur during the execution of the survey project.

Table 12 — Minimum Session Durations

Stated Session Duration	***Minimum Session Duration (approximate % of stated)***
15 minutes	14 minutes *(93%)*
30 minutes	28 minutes *(93%)*
60 minutes	57 minutes (95%)
90 minutes	85 minutes *(94%)*
2 hours	1 hour 55 minutes *(95%)*
3 hours	2 hours 50 minutes *(94%)*

4 hours	3 hours 45 minutes *(94%)*
5 hours	4 hours 45 minutes *(95%)*
6 hours	5 hours 40 minutes *(94%)*
7 hours	6 hours 40 minutes *(95%)*
8 hours	7 hours 35 minutes *(95%)*
10 hours	9 hours 30 minutes *(95%)*
24 hours	23 hours *(95%)*

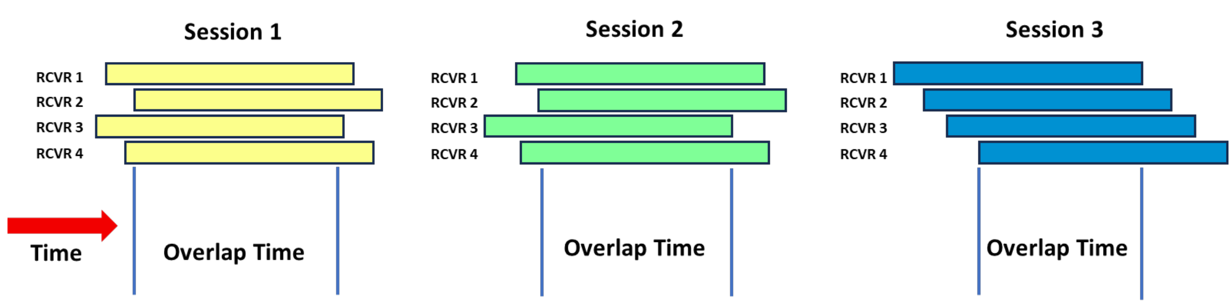


Figure 1 — Showing that session duration is determined by the minimum simultaneous overlap time among a group of receivers.

Offset Time — Minimum Separation between Sessions or Occupations
In many places throughout this document, there are references to the duration of an **offset**. For simplicity of language, those references are in whole hours. In practice it is difficult to achieve exactly the stated durations. The following duration range will be allowed. Surveyors should note in their Project Report if significant departures from this duration range occurs during the execution of the survey project. Figure 2, Figure 3, Figure 4, and Figure 5 show some acceptable observation scenarios for the various methods.

Table 13 — Minimum Offset Durations

Stated Offset Duration	***Duration Range***	
3 to 21 hours	*2 hours 50 minutes*	*21 hours 10 minutes*

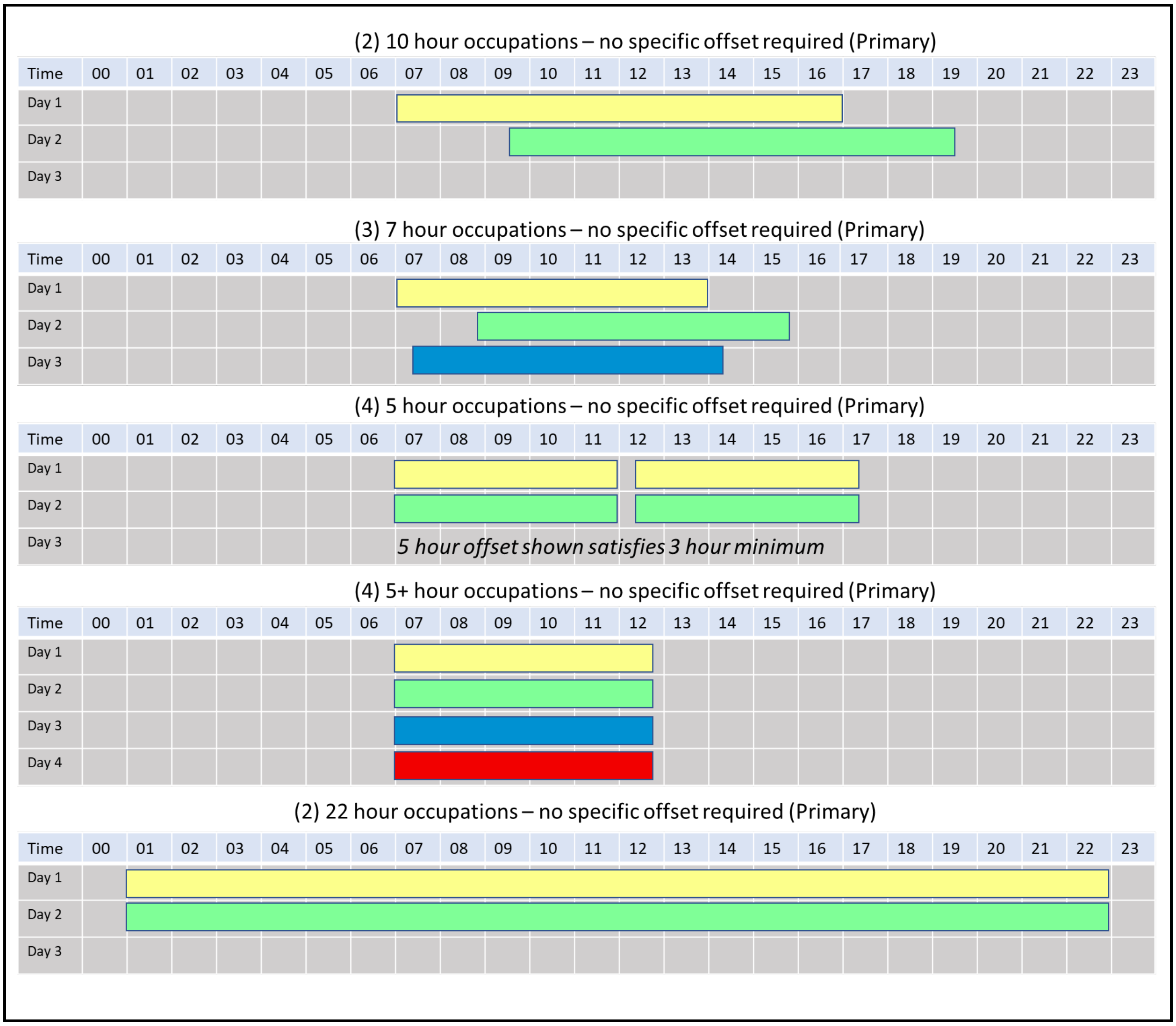
4.2 — Observation Requirements by Method — Requirements for OPUS PP

Required TOTAL Static GNSS Observation Time (T)

Research (Park et al. 2018) has shown that the *total static GNSS observation time (T)* is a reliable predictor of the expected uncertainty of vectors of varying length. Accordingly, the standards for OPUS PP sets limits for *T* based on the intended Classification and vector lengths.

Recommended GNSS Session Durations

Research (Eckl et al. 2001; Soler et al. 2006; Gillins and Eddy 2015, 2017; Gillins et al. 2019a; Jamieson and Gillins 2018) indicates that longer-duration static observation data files deliver more accurate baseline solutions than those of shorter duration, even if the total observation times (T) are similar. Accordingly, the standards for OPUS PP *recommend* a few logical combinations of number of occupations and session durations that will satisfy the required value of *T* and offset times. For Primary Classification, one or more occupations will be required on a different day.



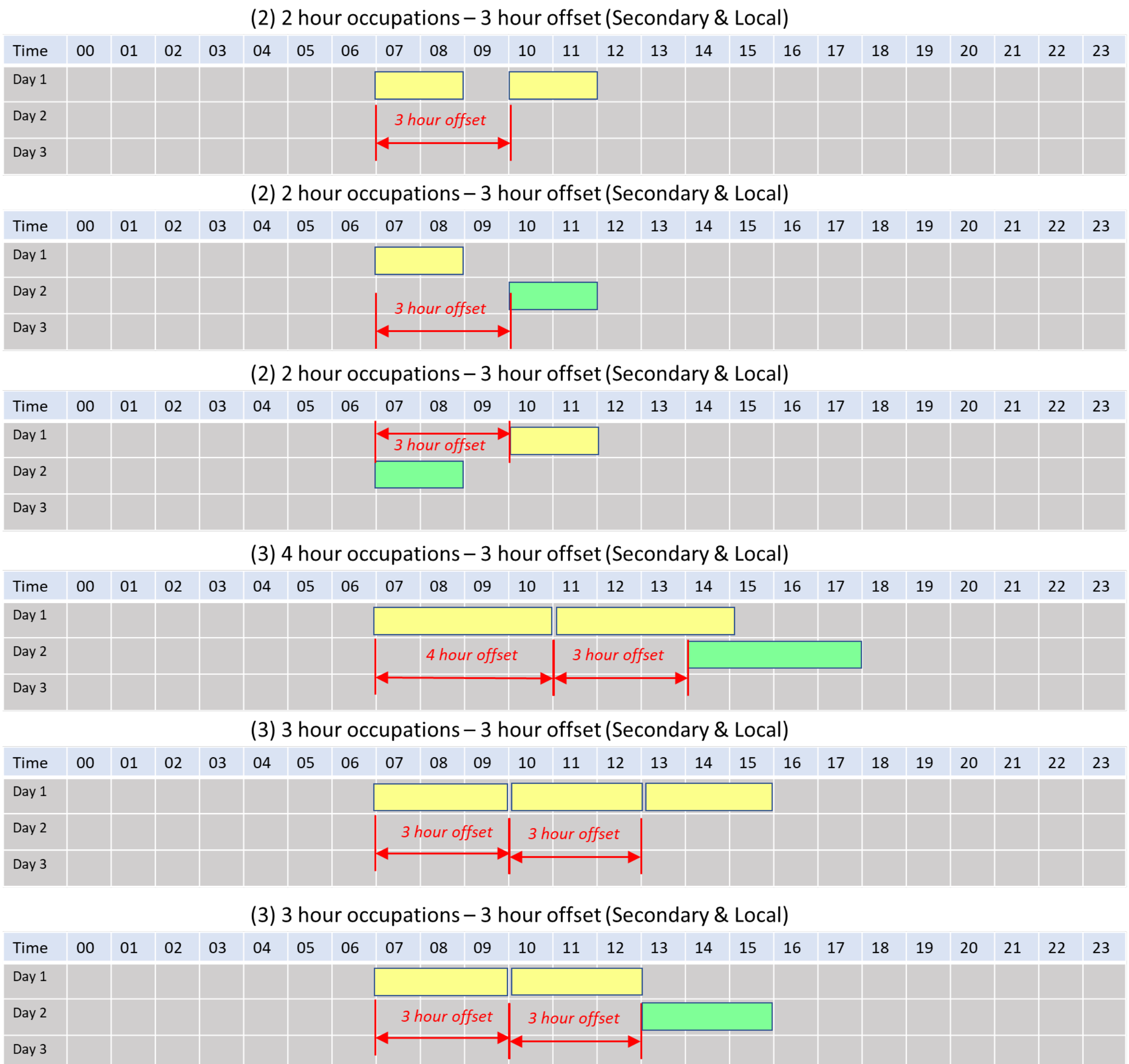


Figure 2 — Example observation scenarios for meeting the OPUS PP Offset Requirement, if individual observations exceed 5 hours, then no specific offset is required.

4.3 — Observation Requirements by Method — Requirements for GVX PP

The baseline processor inside OPUS (known as PAGES) must be able to incorporate continental effects like earth tides, ocean loading, etc., so that long baselines can be computed. The PAGES software needs longer data durations to do this. Vectors in GVX files are assumed to be created by external software other than PAGES. Hence, the standards limit GVX PP to baseline lengths of 50 km.

Number and Duration of Sessions

Vectors that are post-processed using external software can be submitted via the GVX file format. Standard 4.3 sets minimums for the number of occupations and session duration based on the intended Classification and length of the vector. For Primary Classification, one or more occupations will be required on a different day.

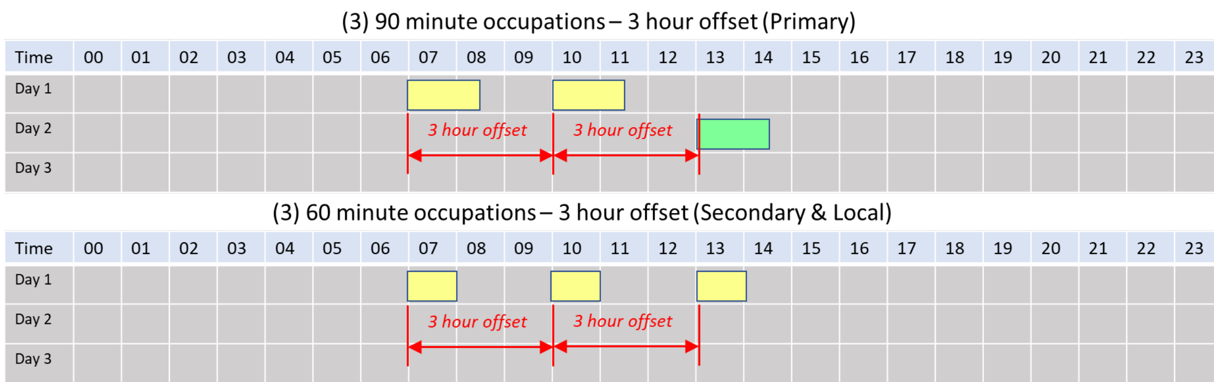


Figure 3 — Example observation scenarios for meeting the GVX PP Offset Requirement.

4.4 — Observation Requirements by Method — Requirements for GVX NRTK

Research (Gillins et al. 2019b; Weaver et al. 2018) has shown that GVX NRTK can achieve the intended network and local accuracy if adequate repetitions are made.

Number and duration of occupations

Vectors that are produced by GVX NRTK methods can be submitted via the GVX file format. Standard 4.4 sets minimums for the number and duration of occupations based on the intended Classification. For Primary Classification, some of the occupations will be required on a different day.

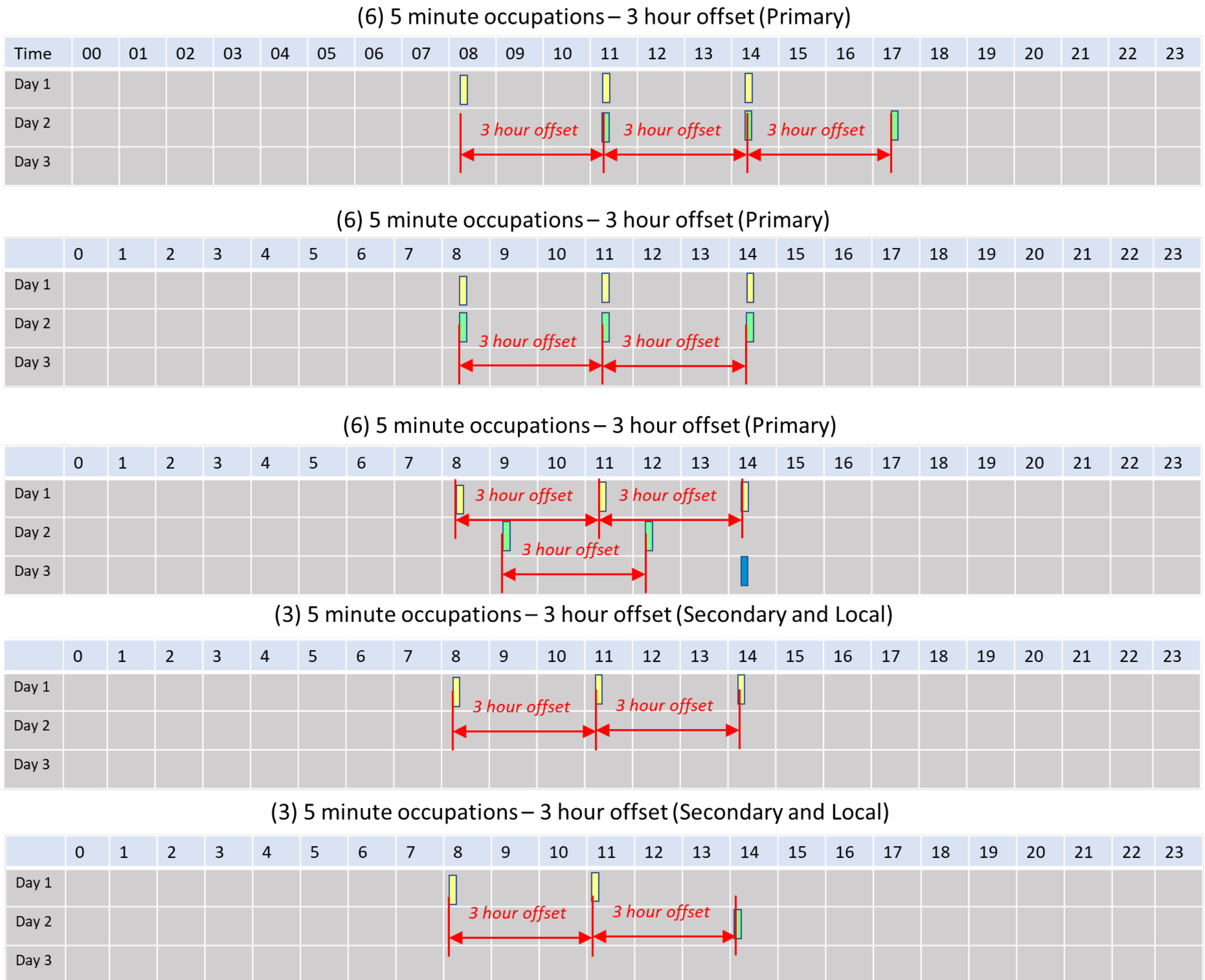


Figure 4 — Example observation scenarios for meeting the GVX NRTK Offset Requirement.

4.5 — Observation Requirements by Method — Requirements for GVX SRTK

Research (Weaver et al. 2018) has shown that SRTK can achieve the intended network and local accuracy if adequate repetitions are made.

Number and Duration of Occupations

Vectors that are produced by SRTK methods can be submitted via the GVX file format. Standard 4.5 sets minimums for the number and duration of occupations based on the intended Classification. The SRTK method is not allowed for Primary Classification. Due to the larger number of SRTK occupations required to achieve the intended Classification, it is required that one or more occupations be on a different day.

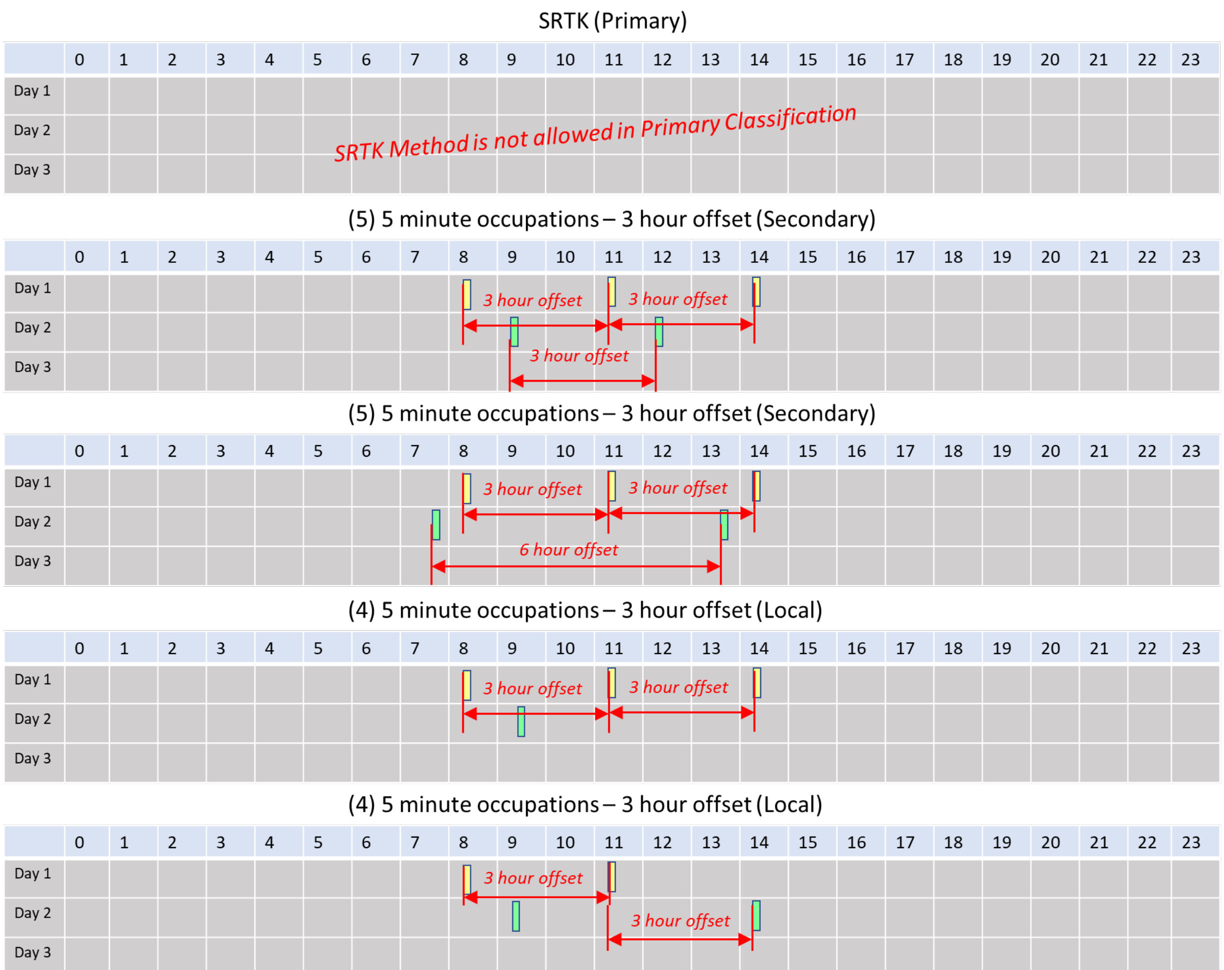


Figure 5 — Example observation scenarios for meeting the GVX SRTK Offset Requirement.

Table 5 — Standards for Network Design

General Explanation and Examples of Key Specification Elements in Table 5

Networks meeting these standards are intended to be reliable densifications of the National Spatial Reference System (NSRS).

The Standards for Network Design in Table 5 are intended to ensure that error accumulation is limited by maximizing the direct connections to the NCN and limiting the step-wise chaining of GVX vectors. The use of GVX vectors is limited to the last link in a vector chain.

Since error accumulation increases with each incremental step away from the NCN, the achievable accuracy is degraded by the number of observation vectors required to trace back to the NCN. So, the *achievable* network accuracy should be in line with the *intended* network accuracy. This network design philosophy is similar to the hierarchical classical network designs used in the former Order and Class standards (FGCC 1976, Table 1).

In Figure 6, the NCN CORS is the local hub from which a passive mark (green circle) is positioned by OPUS PP derived vectors (solid blue) and then used as a GVX SRTK base from which a series of additional GVX derived marks (green diamonds) are positioned by GVX vectors (dashed magenta) and in turn used as GVX SRTK bases. At each step, the accumulated error increases and the achievable network accuracy is degraded.

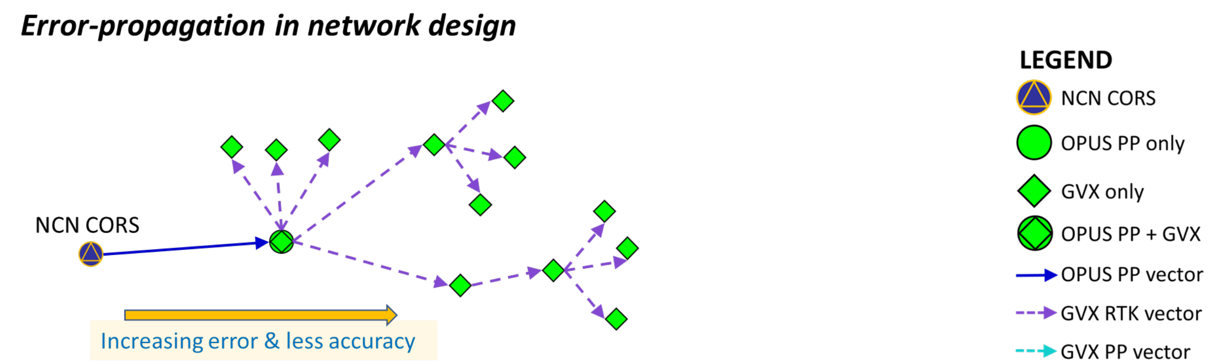


Figure 6 — Showing unacceptable error accumulation.

In Figure 7, the NCN CORS is the local hub from which a series of passive marks (green circles) are positioned by OPUS PP derived vectors (solid blue) and then they are used as GVX SRTK bases from which as series of additional GVX derived marks (green diamonds) are positioned by GVX vectors (dashed magenta). Since there are less vector steps, the accumulated error decreases and the achievable network accuracy is enhanced.

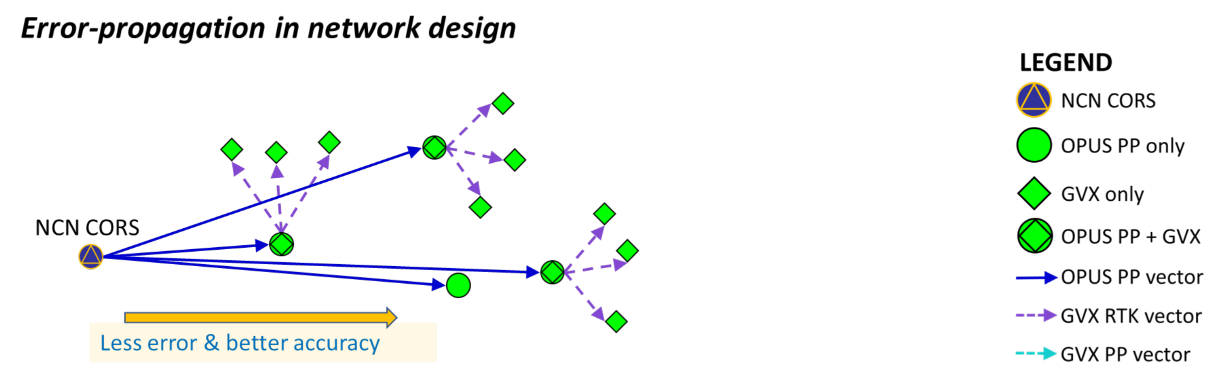


Figure 7 — Showing acceptable error accumulation.

Error accumulation can be controlled by adding more occupations of longer duration, hence Table 5 gives minimum standards for the several Classifications, thus allowing surveyors to use the most efficient method to achieve the intended Classification.

Users of OPUS Projects should keep in mind that many network designs, processing choices, and adjustments are possible within the capabilities of OPUS Projects. But, not all such designs or choices can be submitted to NGS for review and publication.

5.1 — All Hubs Are NCN CORS

The National Geodetic Survey's NOAA CORS Network (NCN) must be the foundational geodetic control for all surveys submitted under these Classifications, Standards, and Specifications. Using an NCN CORS as the hub provides the most direct connection to the NSRS. Each additional step (vector) away from the NCN results in the accumulation of additional error.

Non-NCN Mark Used as a Hub

There are situations where the nearest NCN CORS is far away (more than 200 km) from the survey site. A non-NCN mark can then be located very near the survey site and be used as a hub to shorten the local vector ties to the local marks. The surveyor may also be planning to use such a mark as a GVX base.

An NCN CORS has 24-hour data files making baseline processing reliable and successful. A non-NCN mark when used as a hub must serve the same purposes — as the tie to the local marks, as the tie to the nearby NCN CORS, and as the tie to the distant NCN CORS. Accordingly, non-NCN marks used as hubs must be operated on a mark for extended daily periods (timed to include all the other daily observations) or, more preferably, continuously for the duration of the project. *A non-NCN mark used as a hub must follow the Requirements for OPUS PP in Table 4.*

Because a non-NCN mark must be positioned *from* the NCN, and other marks will be positioned from there, *it adds an extra vector step of error accumulation*.

The use of non-NCN marks as hubs should be avoided when possible and used only when necessary.

5.2 — Distance between Hubs

Standard 5.2 sets 100 km as the closest spacing and 400 km as the furthest spacing between multiple hubs in a project. Given the non-uniform distribution of NCN CORS, project mark locations, and other considerations, this is not always possible. Refer to OPUS Projects User Guide (NGS 2023c), Section 8.2.2.

OPUS Projects can successfully process baselines of significant length depending on the session duration. For the 2-hour minimum duration, that length is about 100 km. If the session duration exceeds 2 hours, then longer-distance baselines are possible (see Table 5.5). So, if a mark lies over 100 km from the hub, then a 2 hour session duration may be insufficient and one has 2 choices — choose longer sessions or add a hub (Schenewerk 2018a). Choosing the second hub should follow the 100 km minimum spacing if possible.

In Figure 8 one can see that the green circle mark is beyond 100 km from hub 1. Surveyor chooses to use shorter session durations, so a closer hub is needed. The surveyor might have the choice of a nearby hub 2 or an alternative hub 2. NGS recommends 100 km as the closest spacing between hubs. Since the nearby hub 2 is less than 100 km from hub 1, the alternative hub 2 is the preferred design choice.

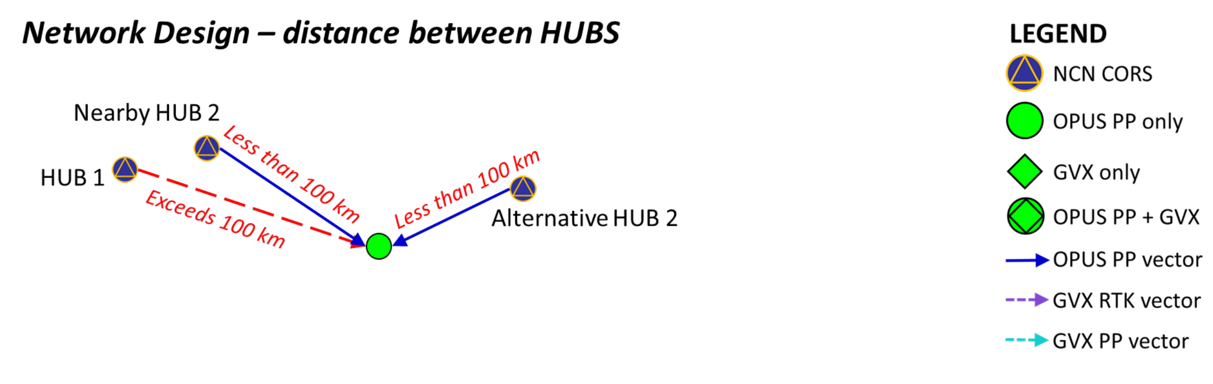


Figure 8 — Showing example of hub spacing choices.

5.3 — Project includes 3 or More NCN CORS

The NOAA CORS Network (NCN) must be the foundational geodetic control for all surveys submitted under these Classifications, Standards, and Specifications. The Standards require 3 or more CORS arranged within specific distances from the center-most hub in the project. Refer to OPUS Projects User Guide (NGS 2023c), Section 8.2.2.

Given the non-uniform distribution of NCN CORS, project mark locations, and other considerations, adherence to this Standard can best be judged by selecting a local CORS to use as a hub, then selecting the needed surrounding CORS (some call these Project CORS), and finally selecting a distant CORS (some call this a Tropo CORS, since it is used to determine tropospheric delays).

After these selections are made, one can measure:

- from the proposed local hub to the project marks (should be less than 100 km to 200 km, depending on occupation duration)
- from the proposed local hub to the nearby NCN CORS (should be less than 300 km)
- from the proposed local hub to the distant NCN CORS (should be 400 km to 800 km; Schenewerk 2018b)

If the project encompasses a larger geographic extent, then the project surveyor should add additional CORS to use as hubs, and possibly additional surrounding CORS as well. Very large projects can include additional distant CORS. Distant (Tropo) CORS are not needed if there are baselines in the session which exceed 400 km (Schenewerk 2018b).

These design selections in the form of a project diagram (see Figure 9) and an accompanying discussion should be included in the Project Proposal.

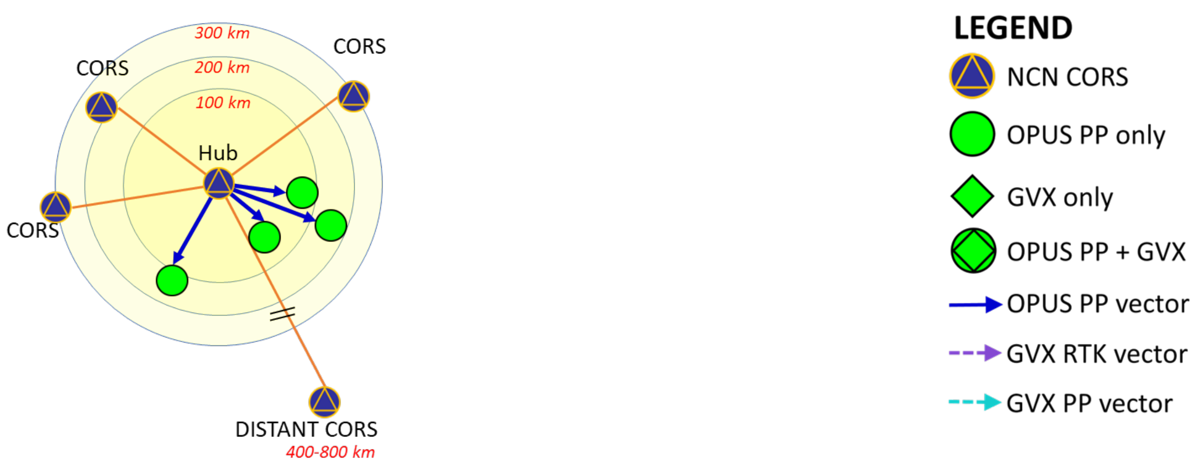


Figure 9 — Diagram of a proposed network showing proposed CORS selections and locations of marks within targeted distance ranges.

5.4 — Project includes Checkpoints (GVX Validation Stations)

There are many error sources in GVX PP, GVX NRTK, and GVX SRTK field and office operations that might lead to incorrect positions or heights. To guard against such errors, checkpoints are required if GVX vectors are uploaded to the Project.

A checkpoint (or GVX Validation Station) is a passive mark whose position is determined by OPUS PP methods within the network of the proposed OPUS Project and that is also included as a part of the GVX observations.

These marks must therefore meet the observation requirements by method for OPUS PP <u>and also</u> for the GVX method in use.

A valid checkpoint has the following characteristics:

- As a passive mark, it must be as stable, accessible, identifiable, and permanent as other passive marks in the intended Classification (see Table 6).
- It must be located in close proximity to the marks being observed by the various GVX methods (see Table 5.6)
- It must be observed by both the OPUS PP Method and by the GVX Method as required for the Classification (see Table 4).
    - As an example, an OPUS PP verified checkpoint in a Primary Classification survey would have:
        - 20 hours or more of OPUS Static observation time AND ALSO
        - (6) 5-min. GVX NRTK observations - *or* - 3 GVX PP sessions.

NGS recommends that at least one checkpoint be provided for each survey method or baseline processor used in a project, and to check each rover.

NGS recommends that a checkpoint be in close geographic proximity to the marks that were observed using the GVX PP, GVX NRTK and/or GVX SRTK methods, and that sufficient checkpoints be included so that they can be routinely included during field observations.

Standard 5.4 requires the inclusion of 1 or more OPUS PP verified passive marks as checkpoints (GVX Validation Stations) if GVX vectors are uploaded to the project.

But given the variability of survey conditions, terrain, accessibility, and other factors, it is not possible to set absolute requirements for quantity or proximity.

The Project Proposal should include a brief description of how the surveyor plans to implement checkpoints in the proposed project. The Project Diagram must include the checkpoints.

5.5 — Longest OPUS PP Vector from Hub to Mark

The Standard requires that OPUS PP vectors as measured from hub to mark (excluding from hub to NCN CORS) be less than the stated distance based on the intended Classification and the chosen session duration.

Given the non-uniform distribution of NCN CORS, project mark locations, and other considerations, the adherence to this Standard can best be judged by the project surveyor. If the design cannot be brought into compliance with the Standard, the design in the form of a project diagram (see Figure 9) and accompanying discussion that addresses significant departures from the Standard should be included in the Project Proposal.

OPUS Projects can successfully process baselines of significant length depending on the session duration. For the 2-hour minimum session duration, the maximum baseline length would be about 100 km. If the duration is exceeding 8 hours, then the maximum would be about 200 km.

5.6 — Longest GVX Vector

The longer the vector, the greater the error. Standard 5.6 sets limits for the maximum distance from base to rover based on the GVX Method.

5.7 — Maximum Number of Vector Steps in a Vector Chain

An error accumulation chain follows the vector path from a remote mark back to a station in the NCN. A vector chain may consist of 1 vector (either an OPUS PP vector or a GVX vector), or a maximum of 2 vectors (only 1 OPUS PP vector and only 1 GVX vector).

Using a non-NCN mark as a hub (see Specification 5.1) will increase the number of vector steps to 3; therefore, use of a non-NCN mark as a hub should be avoided when possible and used only when necessary.

A detailed project diagram showing the planned vector steps must be included in the Project Proposal.

5.8 — Minimum Spacing Distance between Adjacent Marks
The purpose of submitting projects to NGS for review and publication is to provide primary, secondary, or local geodetic control. Once that purpose is accomplished there is no gain by closer spacing. The Standard limits the spacing of adjacent control marks to a reasonable spacing within which local surveying practices can reliably be followed.

5.9 — Timeliness of Projects
Since all parts of the surface of the Earth are moving, it is a reasonable expectation that surveys should be completed in the shortest time frame. The rate of motion varies from place-to-place, so no absolute limits can be established. However, for uniformity, the Standard sets limits on the duration of the survey and how soon it should be submitted to NGS for review and publication.

Table 6 — Standards for Monumentation

6.1 — General Requirement
NGS requires stable, identifiable, and permanent monuments for all surveys. Such marks should be generally and routinely accessible to the public. As a matter of practicality, local conditions will dictate the design and accessibility of such marks.

6.2 — Stamping/Designation
Designations of marks and their stampings should be unique. Annex D (NGS 2023a) and the OPUS Projects User Guide,Section A.4.2 (NGS 2023c) give examples of designations and stampings as a guide for surveyors. Local practice and existing designations vary.

6.3 — Vertical Stability Code
The stability of a mark is of utmost importance in geodetic surveys. The OPUS Projects User Guide (NGS 2023c) Section A.4.1 Table A-1 and Annex P (NGS 2023b), Section A.29 Setting Class Code, lists presumed vertical stability codes for many types of marks based on their settings.

Table 7 — Standards for Session Processing and Adjustment Results

7.1 — Achieved Network Accuracy
Network accuracy represents the uncertainty of a mark's position relative to a geodetic reference frame (datum) at the 95% confidence level. Refer to OPUS Projects User Guide (NGS 2023c), Section 12.7.3.2 and Section 12.7.5.1.

The achieved **horizontal and ellipsoid height** network accuracy can be found in the **horizontal-constrained.sum** file, see Figure 10. The network accuracy summary has two columns, HORIZ (for horizontal in a local geodetic horizon) and UP (for the up component in a local geodetic horizon).

- The maximum HORIZ network accuracy must be less than or equal to the allowed value in Table 7.1. If any values exceed the allowed value, the survey has not met the intended horizontal network accuracy classification.
- The maximum UP network accuracy must be less than or equal to the allowed value in Table 7.1. If any values exceed the allowed value, the survey has not met the intended ellipsoid height network accuracy classification.

The achieved **orthometric height** network accuracy can be found in the **vertical-constrained.sum** file, see Figure 10. The network accuracy summary has two columns HORIZ and UP. Only the UP column is relevant for ORTHO.

- The maximum UP network accuracy must be less than or equal to the allowed value in Table 7.1. If any values exceed the allowed value, the survey has not met the intended orthometric height network accuracy classification.

```
NETWORK & LOCAL ACCURACIES (95% CONFIDENCE LEVEL)
COMPUTED USING A POSTERIORI STANDARD DEVIATION OF UNIT WEIGHT


 NETWORK ACCURACIES (CENTIMETERS)

  ISN  SSN   STATION DESIGNATION                         HORIZ    UP
    1    2 E 115                                       0.34    1.45 CM
    2    3 ULM A                                       0.29    1.29 CM
    3   13 ULM B                                       0.39    1.71 CM
    4    4 5208 K                                      0.35    1.48 CM
    5   14 ULM C                                       0.39    1.73 CM
    6    5 5202 G                                      0.37    1.60 CM
    7    6 ALTERNATE MASTER CORS ARP                   0.35    1.18 CM
    8    7 BLUE EARTH CORS ARP                         0.24    0.98 CM
    9    8 JEFFERS CORS ARP                            0.23    1.11 CM
   10   10 LAKEFIELD CORS ARP                          0.22    1.12 CM
   11    1 LESUEUR CORS ARP                            0.22    1.12 CM
   12   11 MORTON CORS ARP                             0.23    1.11 CM
```

(Note: Search for and locate Maximum in both HORIZ and UP columns. Tabulate in Project Report.)

Figure 10 — Network Accuracy Summary showing a sample from horizontal-constrained.sum; a sample vertical-constrained.sum is similar. See OPUS Projects User Guide (NGS 2023c), Section 12.7.3.2 Section 12.7.5.1

7.2 — Achieved Local Accuracy

Local accuracy represents the uncertainty of a mark's position relative to other control points that are connected by observations (whether direct vector connections or correlated observations in simultaneously processed sessions) at the 95% confidence level. Refer to OPUS Projects User Guide (NGS 2023c), Section 12.7.3.2 and Section 12.7.5.1.

The achieved **horizontal and ellipsoid height** local accuracy can be found in the **horizontal-constrained.sum** file, see Figure 11. The local accuracy summary has two columns, HORIZ and UP.

- The maximum HORIZ local accuracy must be less than or equal to the allowed value in Table 7.2. If any values exceed the allowed value, the survey has not met the intended horizontal local accuracy classification.
- The maximum UP local accuracy must be less than or equal to the allowed value in Table 7.2. If any values exceed the allowed value, the survey has not met the intended ellipsoid height local accuracy classification.

The achieved **orthometric height** local accuracy can be found in the **vertical-constrained.sum** file, see Figure 11. The local accuracy summary has two columns, HORIZ and UP. Only the UP column is relevant for ORTHO.

- The maximum UP local accuracy must be less than or equal to the allowed value in Table 7.2. If any values exceed the allowed value, the survey has not met the intended orthometric height local accuracy classification.

```
LOCAL ACCURACIES (CENTIMETERS) AND DISTANCE (KILOMETERS)

          ISN  SSN   STATION DESIGNATION
FROM        1    2 E 115                                 HORIZ    UP       DISTANCE
  TO        6    5 5202 G                                0.39    1.53 CM    2.17 KM
  TO        2    3 ULM A                                 0.33    1.26 CM    7.09 KM
  TO        4    4 5208 K                                0.37    1.40 CM   19.58 KM
  TO       12   11 MORTON CORS ARP                       0.30    1.14 CM   54.03 KM
  TO        9    8 JEFFERS CORS ARP                      0.30    1.14 CM   59.85 KM
  TO        8    7 BLUE EARTH CORS ARP                   0.30    1.14 CM   72.99 KM
  TO       10   10 LAKEFIELD CORS ARP                    0.30    1.14 CM   90.67 KM
  TO        7    6 ALTERNATE MASTER CORS ARP             0.40    1.20 CM 1037.29 KM

FROM        2    3 ULM A                                 HORIZ    UP       DISTANCE
  TO        5   14 ULM C                                 0.38    1.57 CM    0.62 KM
  TO        3   13 ULM B                                 0.38    1.56 CM    0.94 KM
  TO        6    5 5202 G                                0.36    1.43 CM    6.16 KM
  TO        4    4 5208 K                                0.33    1.29 CM   24.67 KM
  TO       12   11 MORTON CORS ARP                       0.24    0.94 CM   46.94 KM
  TO        9    8 JEFFERS CORS ARP                      0.24    0.94 CM   56.06 KM
  TO        8    7 BLUE EARTH CORS ARP                   0.24    0.94 CM   78.74 KM
  TO       10   10 LAKEFIELD CORS ARP                    0.24    0.94 CM   90.34 KM
  TO        7    6 ALTERNATE MASTER CORS ARP             0.36    1.00 CM 1034.40 KM
MORE
```

(Note: Search for and locate Maximum in both HORIZ and UP columns. Tabulate in Project Report.)

Figure 11 — Local Accuracy Summary showing a sample from horizontal-constrained.sum; a sample vertical-constrained.sum is similar. See OPUS Projects User Guide (NGS 2023c), Section 12.7.3.2 Section 12.7.5.1

7.3 — Peak-to-Peak Coordinate Comparison

The peak-to-peak coordinate comparison table in OPUS Projects shows the range in the repeat session solutions for each mark and CORS in the project. Refer to the OPUS Projects User Guide (NGS 2023c), Section 7.1.5 Figure 7-39, Section 7.4 Figure 7-76, and Section 11.7

Figure 11-19. If any values exceed the allowed value, the survey has not met the intended classification.

A large peak-to-peak table entry indicates poor repeat vector comparability or a blunder (such as a tripod height error). The COMPVECS output helps find which vector(s) may be the outlier(s). The COMPVECS file compares the vectors before they have been adjusted. The COMPVECS output is discussed extensively in the OPUS Projects User Guide (NGS 2023c) Section 12.6.3 and Section 12.7.2.2.

7.4 — Maximum Residuals per Vector

If the maximum residuals per vector are within the limits of Table 7.4, it indicates that the repeat vectors and the constrained coordinates are in agreement with each other. If any residual components (DN, DE, DU) in the PREPLT2 output file exceed the allowed value in Table 7.4, the survey has not met the intended classification.

The maximum residuals per vector are tabulated in the PREPLT2 output. The PREPLT2 output is summarized from the vector residuals that are available in detail in the Processing Log (.sum) file. Each adjustment will result in differing residuals due to the application of differing sets of constraints. Hence the surveyor will need to analyze PREPLT2 files after each adjustment for a given project in OPUS Projects.

A vector with large residuals in an adjustment may have two causes:

- inconsistent repeat vectors
- constrained coordinates that do not agree with the vectors or among themselves

Surveyors should refer to the OPUS Projects User Guide (NGS 2023c) for analysis suggestions. The COMPVECS output will be useful as well.

The PREPLT2 output is discussed extensively in the OPUS Projects User Guide (NGS 2023c) Section 12.6.4 Figure 12.14, and Section 12.7.2.2.

7.5 — Statistical Checks from Constrained Adjustment

OPUS Projects produces a .TXT output file for each adjustment. The F-Statistic Test and the Mark Constraint Ratios are listed in the Horizontal Constrained Adjustment.txt file and in the Vertical Constrained Adjustment.txt file.

When analyzing the Mark Constraint Ratios in the Horizontal Constrained Adjustment.txt file, the surveyor should examine the N (north), E (east), and U (up) columns. The 2D and 3D columns need not be examined for compliance.

When analyzing the Mark Constraint Ratios in the Vertical Constrained Adjustment.txt file, the surveyor should examine only the U column.

Refer to the OPUS Projects User Guide (NGS 2023c), Section 12.7.3.2 and Section 12.7.5.2

for analysis suggestions regarding the F-Statistic Test and the Mark Constraint Ratios.

Table 8 — Standards for Achieving Valid Orthometric Heights

The requirements of Table 8 are applicable only to surveys that seek to establish valid orthometric heights via GNSS Geodetic Control Surveys using OPUS Projects. Therefore, the Project Proposal must state whether the project proposes to establish valid orthometric heights and the Project Report must state the surveyor's intent regarding the orthometric heights in the project.

For surveys that do not propose to establish orthometric heights, OPUS Projects still requires that surveyors must perform all four adjustments (Horizontal Free, Horizontal Constrained, Vertical Free, and Vertical Constrained). The Project Report should explain which heights (or approximated heights) were constrained in the vertical adjustments, even though the results of these adjustments will not be published.

8.1 — Minimum Number of Existing Valid Orthometric Height Control Marks

Surveys that propose to establish valid orthometric heights via GNSS Geodetic Control Surveys using OPUS Projects must include at least 2 existing valid bench marks within the proximity requirements of Standard 8.3 (see detailed Specification 8.3 and Figure 14).

8.2 — Method of Existing Valid Orthometric Height Control Marks

NGS considers the first 4 of the 5 types of vertical marks defined below as valid candidates for use as orthometric height control. The fifth type might be allowed in unusual circumstances, as discussed below. Refer to the OPUS Projects User Guide Section 12.7.5.1.

Orthometric Height Type & Description

1) FGCS LEVELING IN NGS IDB
Leveled heights that have been adjusted by NGS and are included in the datum network.

2) GPS HEIGHTS: 2CM/5CM STANDARDS
GPS-derived orthometric heights that meet height modernization standards.

3) FGCS LEVELING POSTED
Orthometric heights established using FGCS leveling specifications and procedures, adjusted height is POSTED (pre-1991 precise leveling forced to fit the NAVD 88 data; excluded for various reasons from the NAVD 88 general adjustment).

4) LEVELING RESET
OP uses this term to describe two similar height sources:

a) LEVELING RESET: heights determined by differential leveling for classical horizontal observation reduction; reset procedures were used to establish the elevation, or

b) RESET: Third Order reset heights following reset specifications and procedures.

5) GPS HEIGHTS: DECIMETER ACCURACY
GPS-derived heights that do not meet height modernization standards. They should not be used as vertical control except in unusual circumstances where there is a lack of vertical control. Such circumstances require pre-approval.

8.3 — Maximum Allowable Distance from Newly Established Control Mark to 2 Existing Valid Orthometric Height Control Marks

Practice has shown that valid orthometric heights can be achieved on new control marks if at least 2 existing valid bench marks are located within a maximum allowable distance of the new control mark. The existing valid bench marks must be in good condition, stable in position, and observable using GNSS equipment. In addition, the existing valid bench marks must have an acceptable orthometric height type. Recognizing the uneven distribution of leveling lines, surveyors should locate and use the best available bench marks for their project.

The maximum allowable distance from a newly established control mark to 2 existing valid bench marks is limited to the amount shown in Figure 14. The limiting distances in Figure 14 represent a best practice based on several considerations.

- Uniformity for survey planning across all Classifications.
- General proximity of existing bench marks on a nationwide basis.
- The vertical datum is locally defined by the published heights on the existing bench marks in the vicinity of the project.
- The expected accuracy and precision of the allowable surveying methods.

The Project Proposal must include a Bench Mark Location and Spacing Diagram (see Figure 12) and a Bench Mark Distance Tabulation (see Figure 13). The format of the diagram and tabulation may vary to suit the project.

Figure 14 shows that for GVX SRTK and GVX NRTK methods (see symbol R1) the occupation time is short thus limiting the maximum distance from new marks to vertical control to 30 km or less.

Figure 14 also shows that for GVX PP methods (see symbol P1) and for OPUS PP Methods (see symbols O1, O2, and O3) the occupation times are longer, thus allowing the maximum distance from new marks to vertical control to extend up to 50 km.

In some circumstances the existing valid bench marks will not lie within the maximum allowable distance of the proposed new marks. If the Project Proposal cannot comply with Standard 8.3 it should include an explanation of the circumstances and a request for pre-approval of the proposed distances beyond the allowable distances in Figure 14.

Surveyors can choose the most efficient Method (see Table 4) and the proper number and duration of vectors for the chosen Method (see Table 5). Note that Table 5.7 limits vector chains to 2 steps from remote mark to NCN CORS hub.

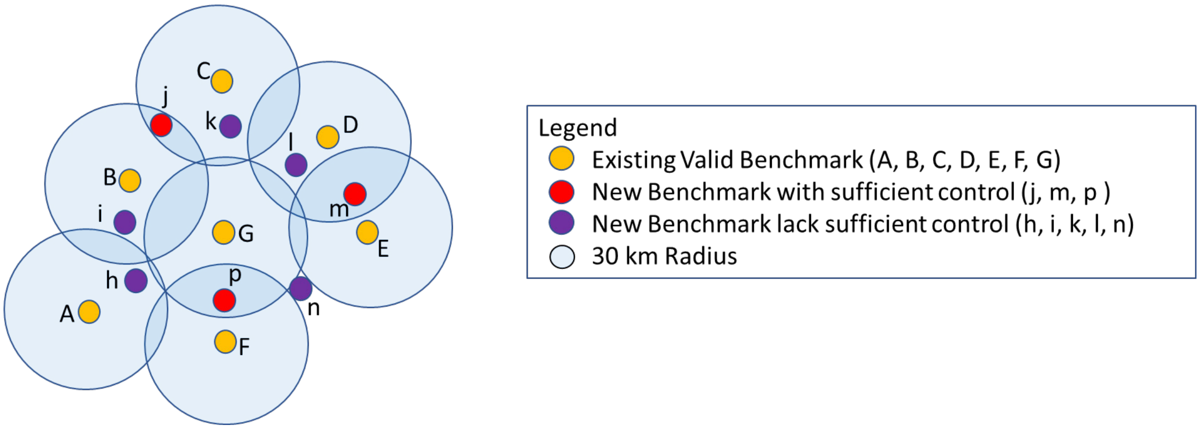


Figure 12 — Bench Mark Location and Spacing Diagram

Existing Valid Bench Mark List	New Control Mark List							
	h	i	j	k	l	m	n	p
A	**20**	34	44	46	47	52	48	40
B	50	**20**	**25**	37	40	53	40	37
C	46	38	**23**	**19**	35	43	52	49
D	49	46	47	35	**18**	**25**	44	51
E	45	44	43	39	32	**14**	32	40
F	37	42	47	46	44	40	34	**21**
G	34	35	39	34	35	38	32	**25**

Note: all distances are tabulated in units of kilometers (km).

Color Code: 0 to 30 km = bold font w/green color, 30 km or more = normal font w/pink color.

Figure 13 — Bench Mark Distance Tabulation. A column with 2 or more bold font w/green color is within 30 km of 2 or more existing valid bench marks.

Tips on Using Figure 14

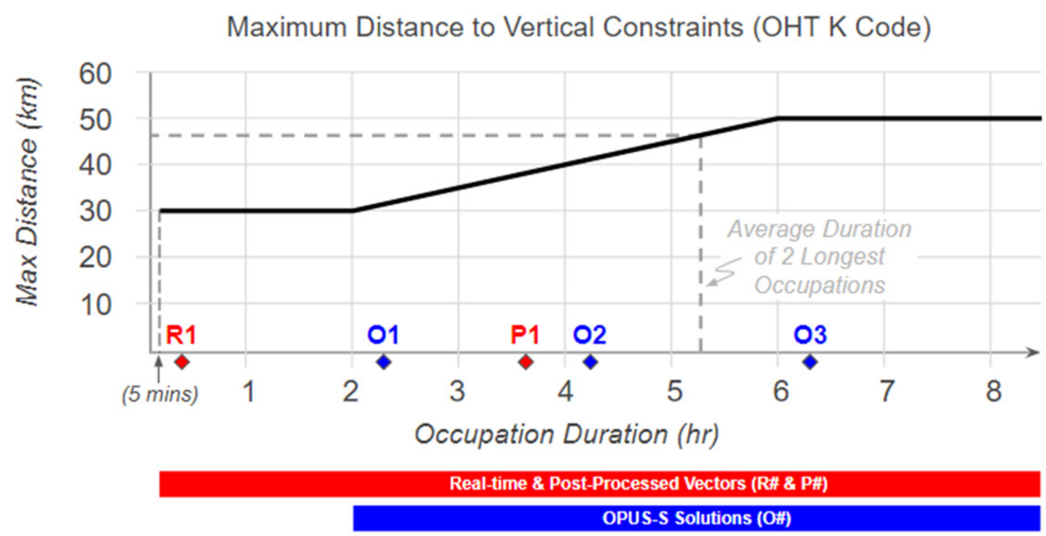
The chart in Figure 14 will help you plan how long to occupy new marks in order to determine high accuracy orthometric heights with GNSS . The session duration on such new control marks is dependent on the distance to two nearby existing valid bench marks. For a given control mark, you would look at your project map, find the two nearest existing valid bench marks, and plot their distances on this chart.

Say one is at 30 km, and the other is at 50 km. The more distant bench mark is further so select 50 km. The chart indicates to occupy the new mark for 6 hours.

Since the Standard requires a minimum of 2 or 3 sessions depending on Classification, then the surveyor should occupy the new mark for an average of 6 hours for the 2 or 3 sessions to meet the Specification.

Existing valid bench marks already have published orthometric heights. In that case, Figure 14 does not apply (orthometric heights are not being determined). Instead, marks should be occupied according to the desired Standard for ellipsoid heights.

The general rule for Figure 14: Occupation Duration times apply to the new control marks where you want to derive its orthometric height with GNSS.



$$distance_{max}(t_{avg}) = \begin{cases} 30 & , 5\ min <= t_{avg} < 2hr \\ 5t_{avg} + 20 & , 2\ hr <= t_{avg} < 6\ hr \\ 50 & , 6\ hr <= t_{avg} \end{cases}$$

Figure 14 — Allowable Distance to Vertical Constraints to Achieve Publishable GPS-Derived Orthometric Height (K-Code).

The occupation durations in Figure 14 apply to the proposed control marks as limiting standards even if the surveyor uses other occupation durations and distances in the other aspects of their project.

Table 9 — Standards for Field Equipment and Office Procedures

9.1 — Tripod Type

A fixed height tripod is one in which the distance from the center pole tip to the antenna reference point (ARP) cannot be adjusted or modified. For fixed height tripods, the pole tip to the ARP must be measured before and after a campaign.

A collapsible fixed height tripod is one in which the distance from the center pole tip to the antenna reference point (ARP) can be adjusted or modified, but only in an incremental and repeatable manner, such as by insertable pin locks or detents. For collapsible fixed height tripods, the pole tip to the ARP must be measured before and after a campaign.

An adjustable height tripod is one in which the distance from the pole tip to the ARP can be freely adjusted or modified using slip legs. For adjustable height tripods, the vertical distance from the mark to the ARP must be carefully measured for each occupation.

Fixed-height one-piece range poles, or collapsible fixed-height range poles with insertable pin locks or detents, when equipped with 2-legged or 3-legged stabilizers are allowed in any Classification. The pole tip to the ARP must be measured before and after a campaign.

Adjustable height range poles without insertable pin locks or detents, but which are equipped with 2-legged or 3-legged stabilizers are allowed only in Local Classification. For adjustable height range poles, the pole tip to the ARP must be carefully measured for each occupation.

NGS recommends that all tripods, tribrachs, and range poles should have level vials with a sensitivity of 8 arcminutes per 2 mm division (equivalent to 2.3 mm/m) or better. This will control horizontal centering above a mark to within approximately 5 mm using a 2 meter tripod height.

Sandbags on the support legs are strongly recommended. All tripods must be sturdy and in good repair. Level vials and tribrachs must be in good adjustment.

Because there are many designs of fixed-height, collapsible fixed-height, and adjustable height tripods available, the Project Proposal requires a typical photo, a description of the proposed tripods, and a description of the height measurement procedures.

9.2 — Antenna Calibration
The NGS Antenna Calibration Page has a list of calibrated GNSS antennas. Antennas which are not on this list are not allowed by the Standard. Refer to:
https://geodesy.noaa.gov/ANTCAL/

9.3 — RINEX version
GNSS raw data in RINEX version 2.11 or newer is acceptable for OPUS PP methods.
GVX methods may use whatever raw data file the external software requires.

9.4 — Ephemeris
Projects submitted to the NGS for review and publication may use the ephemeris version as listed by method in Table 9 to achieve the intended Classification. These versions are considered minimal to meet the Standard; of course, higher-accuracy ephemerides are acceptable. For example, the final precise ephemeris version is acceptable in all methods and classifications.

Table 10 — Standards for Required Documentation

Surveyors who are planning to submit a project to NGS for review and publication must carefully plan their surveys, create a Project Proposal, obtain a project tracking ID number, analyze the survey project carefully to verify adherence to the Standards, and write a Project Report. The Standards require documentation and supporting files to be submitted to NGS.

10.1 — Project Proposal

A Project Proposal is required. Refer to OPUS Projects User Guide (NGS 2023c) Section 2 NGS Survey Proposal.

10.2 — Field Observation Logs

Each occupation of a mark (excluding NCN CORS and non-NCN CORS) must have a field observation log to document the critical metadata for each occupation. Refer to OPUS Projects User Guide (NGS 2023c) Section 5.4 and Section 7.1.4.9.

10.3 — Windesc

A complete and error-free set of WinDesc files are required for submission to NGS. Refer to OPUS Projects User Guide (NGS 2023c) Appendix A.

10.4 — Photographs

For successful submission of the project to NGS, three (3) photos in *.JPG format must be uploaded for each passive mark observed. If your project contains data from a Non-NCN CORS station and you are the owner or manager of the station, it is suggested that three (3) photos be uploaded in *.JPG format. Photographs of NCN CORS are not required. Refer to OPUS Projects User Guide (NGS 2023c) Section 5.3.

10.5 — Project Report

A Project Report is required. Refer to OPUS Projects User Guide (NGS 2023c) Section 12.7.6.1 Final Project Report and Section 12.7.6.2 Project Submission Checklist.

Glossary

- Accuracy — A measure of the closeness of a measured or computed value to a standard or accepted value of a particular quantity. See also: precision.
- Baseline — A baseline is an idealized line between 2 marks. There can only be one baseline between two marks. The baseline exists even before any measurements are made of it. There can be multiple measurements (vectors) of that baseline. Indeed, over time, the same baseline may be independently measured by several surveyors in separate projects.
- Beidou — A set of global navigational satellites launched by China.
- Checkpoint — A passive mark whose position is determined by OPUS PP methods and also by GVX methods within the network of the proposed survey project. The checkpoint is routinely and frequently included as a part of the GVX observations. See also GVX Validation Station.
- Galileo — A set of global navigational satellites launched by the European Space Agency.
- GLONASS — A set of navigational satellites launched and operated by Russia.
- GNSS — Global Navigation Satellite Systems; a general term that includes GPS, GLONASS,Galileo, Beidou, QZSS, IRNSS, and other navigation satellite systems.
- GNSS geodetic control surveys — surveys using GNSS that establish latitude, longitude, and ellipsoid heights (and possibly orthometric heights.)
- GPS — Global Positioning System; a set of global navigational satellites launched by the United States.
- IRNSS — Indian Regional Navigation Satellite System; a set of navigational satellites launched by India
- Local Accuracy — A value that represents the uncertainty of a mark's coordinates at 95% confidence relative to another mark it is connected to by an observation (the observation can be a direct vector tie or a correlated observation from simultaneous baseline processing) (Dennis 2020, p. 168).
- Network Accuracy — A value that represents the uncertainty of a mark's coordinates at 95% confidence with respect to the geodetic datum. Network accuracy is computed from the post-adjustment covariance matrix for the mark (Dennis 2020, p. 168).
- NRTK — Network Real-Time Kinematic refers to a reference positioning technique wherein a rover GNSS receiver is connected to a network of permanent base stations for receiving full network correctors in real-time for high-accuracy positioning.
- PPK — Post-Processed Kinematic refers to a reference positioning technique where the high-accuracy position of a GNSS rover is determined by post-processing (after the rover data is collected in the field). PPK positions can be determined using network correctors (like NRTK) or by using data from a single base (like SRTK).
- Precision — an expression of the repeatability or internal agreement among a set of measurements of the same quantity. Often quantified using the standard deviation (which can be scaled to other confidence levels).
- QZSS — Quasi-Zenith Satellite System; a set of navigational satellites launched by Japan

- GVX Validation Station — See checkpoint.
- RTK, Real-Time Kinematic — (See NRTK and SRTK)
- Session — A group of observations treated as a coordinated, organized set collected over an overlapping period of time. See also: observation, occupation.
- Occupation — Refers to the physical act of setting a surveying instrument, such as a GNSS antenna, in position to take measurements. See also: observation, session.
- Observation — Refers to a survey measurement that is corrected for systematic errors. Observations are ready for input in a network least squares adjustment. See also: occupation, session.
- Length — Refers to a distance, as in the length of a vector. Does not refer to time. See also: duration.
- Duration — Refers to a span of time, such as a 3 hour duration. Does not refer to distance. The duration of a GNSS session refers to the span of time during which all receivers are simultaneously taking measurements. See also: length.
- Sequential Processing — Refers to the computation of vectors derived individually without any consideration of their possible cross-correlations. This is done as a single vector between two marks, so multiple vectors are computed individually one at a time. A simultaneously processed vector between only two marks in a session is equivalent with a sequentially processed vector.
- Simultaneous Processing — Refers to the computation of vectors derived from a session of simultaneous observations, with cross-correlations computed between all vectors in the session. This can be done on multiple marks where all vectors in a session are computed at the same time. A simultaneously processed vector between two marks is the same as a sequentially processed vector.
- Standards — A set of objective characteristics which a survey project must exhibit in order to be deemed acceptable.
- Specification — A method or process by which a particular standard will be achieved.
- SRTK — Single base Real-Time Kinematic refers to a reference positioning technique wherein a rover GNSS receiver is used with a single permanent or temporary base station for determining real-time high accuracy positions.
- Vector — A vector is an observation of a baseline between two marks, often expressed in delta Cartesian Coordinates (i.e., dX, dY, dZ). Such an observation may be made several times in a project and even in other projects. Each such observation is a vector. The several vectors can be combined in a least squares adjustment to produce an adjusted vector.
- Vector, adjusted — A best-fit vector from a least squares adjustment, computed from the available observations and constraints.
- Vector, independent — A vector whose characteristics are computed directly from the GNSS observations on two marks (or more marks for simultaneous baseline processing).
- Vector, trivial — A vector whose characteristics can be computed (in whole or in part) by mathematical operations on independent vectors. They are called “trivial” because they contain little or no unique information about a GNSS session. Such vectors are also

called "dependent" because they can be constructed from independent vectors. Trivial vectors can only occur in sequential baseline processing.

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