Bernese GNSS Software Version 5.4

Tutorial

Processing Example
Introductory Course
Terminal Session

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1 Introduction to the Example Campaign

1.1 Stations in the Example Campaign

Data from 18 European stations of the International GNSS Service (IGS) network and from the EUREF Permanent Network (EPN) were selected for the example campaign. They are listed in Table 1.1. The locations of these stations are given in Figure 1.1.

The observations for these stations are available for four days. Two days in year 2023 (day of year 010 and 011) and two in 2024 (day of year 201 and 202). The observations are mostly contained in RINEX 3 files with long file names, with the exception of station MORP, where the data is in RINEX 2 format (with short file names). Within the campaign area we use a Bernese-specific naming convention for observation and navigation RINEX files that is neutral with respect to the original very different file naming. The observation files contain measurements from different GNSS, indicated in Table 1.1 by the RINEX system characters:

G	GPS	Global Positioning System
R	GLONASS	Russian Global Navigation Satellite System
E	Galileo	European Galileo Navigation Satellite System
C	BDS	BeiDou Navigation Satellite System
J	QZSS	Quasi-Zenith Satellite System
I	NAVIC	Navigation with Indian Constellation

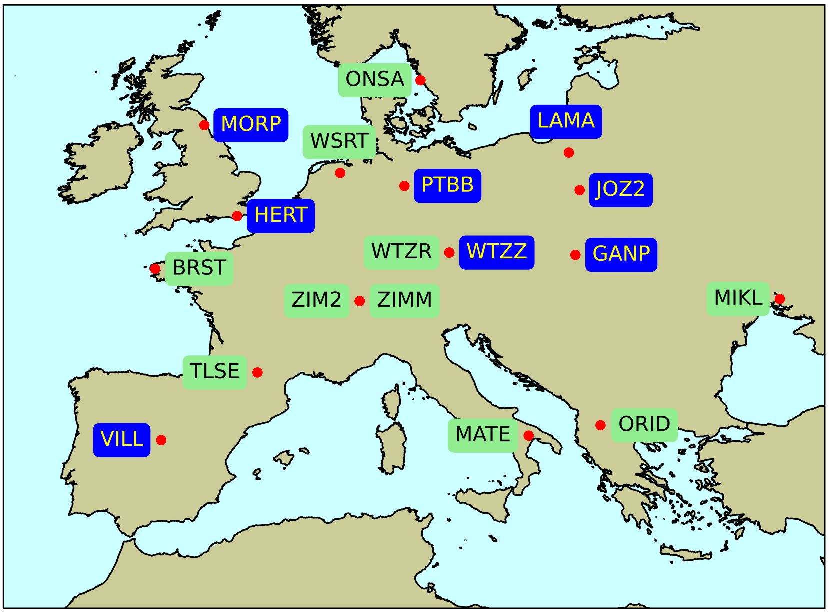


Figure 1.1: Stations used in example campaign (stations indicated by light boxes have coordinates given in the IGS 20 reference frame)

Table 1.1: List of stations used for the example campaign including receiver and antenna type as well as the antenna height.

Station name	Location		Receiver type Antenna type	Radome	Antenna height
BRST00FRA 10004M004	Brest, France		TRIMBLE ALLOY TRM57971.00	NONE	(GREC) 2.0431 m
GANP00SVK 11515M001	Ganovce, Slovakia		TRIMBLE ALLOY TRM59800.00	SCIS	(GRECJI) 0.3830 m
HERT00GBR 13212M010	Hailsham, United Kingdom		LEICA GRX1200GGPRO LEIAT504GG	NONE	(GR) 0.0000 m
JOZ200POL 12204M002	Jozefoslaw, Poland		TRIMBLE NETR9 TRM59800.00	NONE	(GRECJ) 0.0000 m
LAMA00POL 12209M001	Olsztyn, Poland		LEICA GR50 LEIAR20	LEIM	(GRECJ) 0.0600 m
MATE00ITA 12734M008	Matera, Italy		LEICA GR30 LEIAR20	NONE	(GREC) 0.1010 m
MIKL00UKR 12335M001	Mykolaiv, Ukraine		LEICA GR50 LEIAR20	LEIM	(GRECJ) 0.1008 m
MORP00GBR 13299S001	Morpeth, United Kingdom		TRIMBLE NETR8 AOAD/M_T	NONE	(G) 0.0330 m
ONSA00SWE 10402M004	Onsala, Sweden		SEPT POLARX5TR AOAD/M_B	OSOD	(GREC) 0.9950 m
ORID00MKD 15601M001	Ohrid, Republic of North Macedonia		LEICA GR30 LEIAR25.R4	LEIT	(GREC) 0.0310 m
PTBB00DEU 14234M001	Braunschweig, Germany		SEPT POLARX5TR LEIAR25.R4	LEIT	(GRECJI) 0.0590 m
TLSE00FRA 10003M009	Toulouse, France		TRIMBLE ALLOY TRM59800.00	NONE	(GRECI) 1.0530 m
VILL00ESP 13406M001	Villafranca, Spain		SEPT POLARX5 SEPCHOKE_B3E6	NONE	(GREC) 0.0937 m
WSRT00NLD 13506M005	Westerbork, The Netherlands	2023: 2024:	SEPT POLARX5 AOAD/M_T SEPT POLARX5 LEIAR25.R4	 DUTD LEIT	(GRECJI) 0.3888 m (GRECJI) 0.3754 m
WTZR00DEU 14201M010	Kötzting, Germany		LEICA GR50 LEIAR25.R3	LEIT	(GRECI) 0.0710 m
WTZZ00DEU 14201M014	Kötzting, Germany		JAVAD TRE_3 DELTA LEIAR25.R3	LEIT	(GREC) 0.2840 m
ZIM200CHE 14001M008	Zimmerwald, Switzerland		TRIMBLE NETR9 TRM59800.00	NONE	(GREC) 0.0000 m
ZIMM00CHE 14001M004	Zimmerwald, Switzerland		TRIMBLE NETR9 TRM29659.00	NONE	(G) 0.0000 m

In the terminal sessions you will analyze the data in order to obtain a velocity field based on GNSS products computed by Center for Orbit Determination in Europe (CODE) for the IGS. For ten of these stations, coordinates and velocities are given in the IGS 20 reference frame, an IGS–specific realization of the ITRF 2020 (see `https://itrf.ign.fr/en/solutions/ITRF2020`).

Between the selected days in 2023 and 2024 the antenna in WSRT was changed. The receiver types, the antenna types, and the antenna heights of all stations are provided in Table 1.1.

Ideally, consistent (`ROBOT`) calibrations for each GNSS should be used. However, those calibrations are not always available. The antenna calibrations available for the example network and related to the IGS 20 antenna model are shown in Table 1.2. For station ONSA we have the situation that for the antenna type/radome combination even no calibration is available. The values from the same antenna type without radome are used as a proxy.

The network has an extension of about 2000 km North to South and 3000 km East-West. The distances between occupied locations are ranging between 200 and 1000 km, resulting in baselines between 270 and 1700 km length. Two locations (Zimmerwald and Kötzting) are occupied by receiver/antenna pairs defining separate stations each: in Zimmerwald, the distance between ZIMM and ZIM2 is only 19 m. In Kötzting, WTZR and WTZZ are separated by less than 2 m — these are short baselines.

The receivers used at the stations MATE, ONSA, PTBB, WTZR and WTZZ are connected to H-Maser clocks, VILL to a Cesium clock. Both receivers in Kötzting (WTZR and WTZZ) are connected to the same H–Maser (EFOS 18).

Table 1.2: List of antenna/radome combinations used in the example campaign together with the available antenna calibration values in IGS20 model.

Antenna type		Type of calibration		used at stations
AOAD/M_B	OSOD	ADOPTED from NONE ADOPTED from GPS	for GPS for other systems	ONSA
AOAD/M_T	DUTD	ROBOT ADOPTED from GPS	for GPS and GLO for other systems	WSRT (2023)
AOAD/M_T	NONE	ROBOT ADOPTED from GPS	for GPS and GLO for other systems	MORP
LEIAR20	LEIM	ROBOT	for all systems	LAMA, MIKL
LEIAR20	NONE	ROBOT	for all systems	MATE
LEIAR25.R3	LEIT	ROBOT	for all systems	WTZR, WTZZ
LEIAR25.R4	LEIT	ROBOT	for all systems	ORID, PTBB, WSRT (2024)
LEIAT504GG	NONE	ROBOT	for all systems	HERT
SEPCHOKE_B3E6	NONE	ROBOT	for all systems	VILL
TRM29659.00	NONE	ROBOT	for all systems	ZIMM
TRM57971.00	NONE	ROBOT	for all systems	BRST
TRM59800.00	NONE	ROBOT	for all systems	JOZ2, TLSE, ZIM2
TRM59800.00	SCIS	ROBOT	for all systems	GANP

1.2 Directory Structure

The data belonging to this example campaign is included in the distribution of the *Bernese GNSS Software*. Therefore, you may also use this document to generate solutions from the example dataset to train yourself in the use of the *Bernese GNSS Software* outside the environment of the *Bernese Introductory Course*.

There are three areas relevant for the data processing (in the environment of the *Bernese Introductory Course* they are all located in the `${HOME}/GPSDATA` directory):

`${D}`: The `DATAPOOL` area is intended as an interface where all external files can be deposited after their download. It can be used by several processing campaigns.

`${P}`: The `CAMPAIGN54` directory contains all processing campaigns for the Version 5.4 of the *Bernese GNSS Software*. In the *Bernese Introductory Course* environment all groups use `${P}/INTRO` in their `${HOME}` directory.

`${S}`: The `SAVEDISK` area serves as a product database where the result files from different processes/projects can be collected and archived. Before you start processing, only reference files (`*.*_REF`) obtained with the example BPE from the distribution are available here.

1.2.1 The `DATAPOOL` Directory Structure (`${D}`)

Motivation for the DATAPOOL area

The idea of the `DATAPOOL` area is to place local copies of external files somewhere on your filesystem. It has several advantages compared to downloading the data each time when starting the processing:

- The files are downloaded only once, even if they are used for several campaigns.
- The data download can be organized with a set of scripts running independently from the *Bernese GNSS Software* environment, scheduled by the expected availability of the external files to download.
- The processing itself becomes independent from the availability of external data sources.

Structure and content of the DATAPOOL area

The `DATAPOOL` area contains several subdirectories taking into account the different potential sources of files and their formats:

GNSS observation data :

`RINEX`-directory :
The data of GNSS stations are provided in Receiver INdependent EXchange format (RINEX). The directory may contain observation (Hatanaka-compressed) and navigation files. The files in this area may be UNIX- or gzip-compressed. RINEX file versions 2, 3 or 4 are supported and may be introduced with the

related filenaming conventions. If several versions of RINEX files for the same station are available, the script (RNX_COP) decides on the priority.

These RINEX files are "originary" files that are not changed during the processing.

The RINEX files can be downloaded from international data centers. Project-specific files are copied into this area. If you mix the station lists from different projects, it is recommended to keep the four-character IDs of all stations in the RINEX file names unique (even if the remaining characters of the nine-character ID is different). The reason is that a mixture with four-character IDs from files using the RINEX 2 naming convention may lead to unpredictable effects.

HOURLY-**directory** :
The same as the RINEX directory but dedicated to hourly RINEX data used for near real–time applications.
Note: not all stations in this example provide hourly RINEX files.

GNSS products :
Orbits, Earth orientation parameters (EOP), satellite clock corrections and biases are basic external information for a GNSS analysis. We propose to use the ID of the source also to create related subdirectories:

COD – CODE operational final solution, containing GPS, GLONASS and Galileo. Short file names.

COD0OPSFIN – CODE operational final solution, containing GPS, GLONASS and Galileo. Long file names.

COD0MGXFIN – CODE experimental Multi-GNSS Extension (MGEX) solution, containing GPS, GLONASS, Galileo, BeiDou, and QZSS.

IGS0OPSFIN – combined IGS products from the final series, containing only GPS.

The files are provided at the download area from CODE (http://www.aiub.unibe.ch/download/CODE/). Instructions for downloading of combined IGS products as well as selected analysis center results are available at https://files.igs.org/pub/product/readme.txt
Note that not all analysis centers/solution series provide clock corrections and consistent bias products.

The files are either named with the GPS-week and the day of the week (apart from files containing information for the entire week, e.g., ERP, or the processing summaries). Alternatively also the new naming convention with long filenames indicating the beginning of the dataset with year, day of year, hour and minute together with the length of the dataset in the file is supported. Unix- or gzip-compressions may be applied to these files.

BSW54 :
In this directory we have placed files containing external input information in Bernese specific formats. The files are neutral with respect to the data you are going to process. Typically these are ionosphere maps. If the external GNSS product source does not provide biases also Bernese formatted bias files (OSB) may be placed here. Please take care on the consistency in this case. These files

can be downloaded from http://www.aiub.unibe.ch/download/CODE/ or http://www.aiub.unibe.ch/download/BSWUSER54/ areas.

REF54 :
Here we propose to collect files in Bernese format which are useful for several campaigns.

- At first these are the series of files related to the reference frame (e.g., IGB14 or IGS20) that may be updated via the download area http://www.aiub.unibe.ch/download/BSWUSER54/REF
- Typically, also the sets of files related to the project-specific station selection are prepared in this area. This allows the usage of these files in various campaigns for data processing. Such files are typically: station coordinates (CRD) and velocities (VEL), station information (STA) and equipment conflict (CRX) files, abbreviation (ABB), cluster (CLU) and tectonic plate (PLD) tables, as well as the ocean and atmosphere tidal loading correction tables (BLQ and ATL, respectively).
- The antenna phase center variation (PCV) are expanded according to the used antennas. The supported systems are extracted from the observation selection file (SEL). Both are sitting in the campaigns GEN directory for processing.
  If these files are prepared project-specific they can be taken from this REF54 directory, alternatively one file serving for all projects can be prepared and placed in the ${CONFIG} folder.
- The directory is also the source of the SINEX and IONEX skeleton files to be used to generate the various result files.

LEO-data (e.g., GRCC or GRCD):
These directories are intended to host files which are necessary for Low Earth Orbiter (LEO) data processing. For each LEO satellite a separate folder is foreseen.
RINEX observation files (version 2 or 3/4) are stored in the subdirectory RINEX (of the LEO directory). The corresponding attitude files are placed in the subdirectory ATTIT.
Both locations can be addressed with PCF variables "V_RNXDIR" and "V_ATTDIR". Also the names of the files in these directories are flexible and can be specified via the variables "V_RNXFIL" and "V_ATTFIL" respectively.

These files are needed to run the example BPE on LEO orbit determination (LEOPOD.PCF). They are not used in the example during the *Bernese Introductory Course*.

SLR_data :
The Satellite Laser Ranging (SLR) data is provided either in the traditional quicklook normal point or the current consolidated range data format. The directory contains the normal point files downloaded from the International Laser Ranging Service (ILRS) data centers.

These files are needed to run the example BPE on orbit validation using SLR observations (SLRVAL.PCF). They are not used during the *Bernese Introductory Course*.

Miscellaneous directories :
The files in these directories are not necessary for executing the example BPEs as they are provided with the software. They indicate additional files which might be useful when processing your own data with adjusted processing setups.

`StationLogs` :
This directory contains the site log files (e.g., from `https://files.igs.org/pub/station/log`) providing the information on the equipment history in order to be filled into the station information file to check the header of the RINEX observation files before processing.

`VMF3` :
The grids for the Vienna Mapping Function (VMF) (Version 3) are located in a separate directory.

`GFZloading` :
Grid files with crustal deformation corrections from the non-tidal loading models as provided by GFZ Potsdam for atmosphere, ocean and hydrology non-tidal loading effects.

All files and meta–information related to the 18 stations selected for the example campaign are already in this `DATAPOOL`–area (`${D}`) after installing the *Bernese GNSS Software*. GNSS orbit information is available from CODE (legacy and MGEX) and IGS (directories `${D}/COD`, `${D}/COD0OPSFIN`, `${D}/COD0MGXFIN` or `${D}/IGS0OPSFIN`, respectively).

1.2.2 The Campaign Directory Structure

Putting data from the DATAPOOL into the campaign

When running an automated processing using the BPE there is a script at the beginning of the process which copies the data from the `DATAPOOL`–area into the campaign. If you are going to process data manually you first have to copy the necessary files into the campaign and decompress them if necessary using standard utilities (`uncompress`, `gunzip`[1], or `CRZ2RNX` for RINEX–files).

Content of the campaign area to process the example

All files needed to process the data according to this tutorial are already copied into the campaign area. If you want to follow the example outside the *Bernese Introductory Course* environment you have to put the following files at the correct places in the campaign directory structure.

```
${P}/INTRO/ATM/    HOI_20230100.ION          HOI_20230110.ION
                   HOI_20242010.ION          HOI_20242020.ION

${P}/INTRO/BPE/

${P}/INTRO/GEN/    ANTENNA_I14.PCV    ANTENNA_I20.PCV    I14.ATX            I20.ATX
                   OBSERV.SEL         SESSIONS.SES       SINEX_INTRO.SKL

${P}/INTRO/GRD/    VMF3_20230100.GRD         VMF3_20230110.GRD
                   VMF3_20242010.GRD         VMF3_20242020.GRD

${P}/INTRO/OBS/

${P}/INTRO/ORB/    COD_20230100.PRE          COD_20230100.IEP          COD_20230100.BIA
                   COD_20230110.PRE          COD_20230110.IEP          COD_20230110.BIA
                   COD_20242010.PRE          COD_20242010.IEP          COD_20242010.BIA
                   COD_20242020.PRE          COD_20242020.IEP          COD_20242020.BIA
```

[1] These tools are also available for WINDOWS-platforms, see `www.gzip.org`. Note, that `gunzip` can also be used to uncompress UNIX–compressed files with the extension `.Z`.

```
                    IGS_20230100.PRE          IGS_20230100.IEP
                    IGS_20230110.PRE          IGS_20230110.IEP
                    IGS_20242010.PRE          IGS_20242010.IEP
                    IGS_20242020.PRE          IGS_20242020.IEP

${P}/INTRO/ORX/

${P}/INTRO/OUT/     COD_20230100.CLK          COD_20230110.CLK
                    COD_20242010.CLK          COD_20242020.CLK
                    IGS_20230100.CLK          IGS_20230110.CLK
                    IGS_20242010.CLK          IGS_20242020.CLK

${P}/INTRO/RAW/     BRST00FRA_20230100.RXO    BRST00FRA_20230110.RXO
                    BRST00FRA_20242010.RXO    BRST00FRA_20242020.RXO
                    GANP00SVK_20230100.RXO    GANP00SVK_20230110.RXO
                    GANP00SVK_20242010.RXO    GANP00SVK_20242020.RXO
                    HERT00GBR_20230100.RXO    HERT00GBR_20230110.RXO
                    HERT00GBR_20242010.RXO    HERT00GBR_20242020.RXO
                    JOZ200POL_20230100.RXO    JOZ200POL_20230110.RXO
                    JOZ200POL_20242010.RXO    JOZ200POL_20242020.RXO
                    LAMA00POL_20230100.RXO    LAMA00POL_20230110.RXO
                    LAMA00POL_20242010.RXO    LAMA00POL_20242020.RXO
                    MATE00ITA_20230100.RXO    MATE00ITA_20230110.RXO
                    MATE00ITA_20242010.RXO    MATE00ITA_20242020.RXO
                    MIKL00UKR_20230100.RXO    MIKL00UKR_20230110.RXO
                    MIKL00UKR_20242010.RXO    MIKL00UKR_20242020.RXO
                    MORP00XYZ_20230100.RXO    MORP00XYZ_20230110.RXO
                    MORP00XYZ_20242010.RXO    MORP00XYZ_20242020.RXO
                    ONSA00SWE_20230100.RXO    ONSA00SWE_20230110.RXO
                    ONSA00SWE_20242010.RXO    ONSA00SWE_20242020.RXO
                    ORID00MKD_20230100.RXO    ORID00MKD_20230110.RXO
                    ORID00MKD_20242010.RXO    ORID00MKD_20242020.RXO
                    PTBB00DEU_20230100.RXO    PTBB00DEU_20230110.RXO
                    PTBB00DEU_20242010.RXO    PTBB00DEU_20242020.RXO
                    TLSE00FRA_20230100.RXO    TLSE00FRA_20230110.RXO
                    TLSE00FRA_20242010.RXO    TLSE00FRA_20242020.RXO
                    VILL00ESP_20230100.RXO    VILL00ESP_20230110.RXO
                    VILL00ESP_20242010.RXO    VILL00ESP_20242020.RXO
                    WSRT00NLD_20230100.RXO    WSRT00NLD_20230110.RXO
                    WSRT00NLD_20242010.RXO    WSRT00NLD_20242020.RXO
                    WTZR00DEU_20230100.RXO    WTZR00DEU_20230110.RXO
                    WTZR00DEU_20242010.RXO    WTZR00DEU_20242020.RXO
                    WTZZ00DEU_20230100.RXO    WTZZ00DEU_20230110.RXO
                    WTZZ00DEU_20242010.RXO    WTZZ00DEU_20242020.RXO
                    ZIM200CHE_20230100.RXO    ZIM200CHE_20230110.RXO
                    ZIM200CHE_20242010.RXO    ZIM200CHE_20242020.RXO
                    ZIMM00CHE_20230100.RXO    ZIMM00CHE_20230110.RXO
                    ZIMM00CHE_20242010.RXO    ZIMM00CHE_20242020.RXO

${P}/INTRO/SOL/

${P}/INTRO/STA/     EXAMPLE.CRD         EXAMPLE.VEL         EXAMPLE.STA         EXAMPLE.ABB
                    EXAMPLE.BLQ         EXAMPLE.ATL         EXAMPLE.CLU         EXAMPLE.PLD
                    IGB14_R.CRD         IGB14_R.VEL         IGB14.PSD
                    IGB14.FIX           IGB14.SIG
                    IGS20_R.CRD         IGS20_R.VEL         IGS20.PSD
                    IGS20.FIX           IGS20.SIG
```

The directories `${P}/INTRO/MODEL/` and `${P}/INTRO/CONFIG/` contain copies of the files from the `${MODEL}`- and `${CONFIG}`-directories, which are used by the processing programs. If you want to view these files, please use those in your campaign and not the ones in the `${MODEL}`- and `${CONFIG}`-directory to prevent potential interferences with your colleagues.

```
${P}/INTRO/MDOEL/   CONST.BSW           EGM2008_SMALL.GRV   IAU2000R06.NUT      DESAI2016.SUB
                    OT_FES2004.TID      s1_s2_def_ce.dat    TIDE2000.TPO

${P}/INTRO/CONFIG/  BOXWING.MAC         DATUM.BSW           GPSUTC.BSW          POLOFF.POL
                    SAT_2023.CRX        SAT_2024.CRX
                    SATELLIT_I14.SAT    SATELLIT_I20.SAT
```

1.2.3 Input Files for the Processing Examples

Atmosphere files ATM

The input files in this directory are global ionosphere models in the Bernese format obtained from the IGS processing at CODE. They will be used to support the phase ambiguity resolution with the QIF strategy and to enable the higher order ionosphere (HOI) corrections.

General files GEN

In this directory campaign-specific configuration files are located:

- SESSIONS.SES: Session table
  Initial versions for daily and hourly processing are available in ${PAN}.
- OBSERV.SEL: Priority list for selecting the observation/signal types for processing
  Initial versions as they are used for the processing at CODE can be downloaded from BSW aftp.
- ANTENNA_I14.PCV or ANTENNA_I20.PCV: Phase center eccentricities and variations
  Updates are needed when introducing new antenna corrections or new antenna/radome combinations. An initial version can be downloaded from BSW aftp and updated with ATX2PCV.
- I14.ATX or I20.ATX: Antenna correction model in ANTenna correction EXchange format (ANTEX)
  The corrections are related to IGS 14 and IGS 20, respectively.
- SINEX header information
  The metadata in the SINEX header has to be adapted to your institution, it is applied to the general SINEX as well as troposphere and bias SINEX.
  The skeleton of this file is available at ${DOC}/EXAMPLE_SINEX.SKL; versions prepared for the distributed processing examples are copied from ${D}/REF54 into the campaign:

SINEX_PPP.SKL	for PPP example
SINEX_RNX2SNX.SKL	for RNX2SNX example
SINEX_IONDET.SKL	for IONDET example

- IONEX header information
  Adapt IONEX header for your institution
  The skeleton of this file is available at ${DOC}/EXAMPLE_IONEX.SKL; versions prepared for the distributed processing examples are copied from ${D}/REF54 into the campaign:

IONEX_IONDET.SKL	for IONDET example

Grid files GRD

In this directory the grid files *.GRD are collected. To apply, e.g., the VMF troposphere model (a priori information from European Centre for Medium-Range Weather Forecasts (ECMWF) and Vienna mapping function) you need a grid with the necessary coefficients.

Orbit files ORB

The precise orbits in the files *.PRE are usually the final products from CODE analysis center containing Global Positioning System (GPS), Russian Global Navigation Satellite System (GLONASS), and European Galileo Navigation Satellite System (Galileo) orbits from a rigorous multi–GNSS analysis. Alternatively also the combined final products from the IGS can be used. The corresponding EOP are given in files with the extension *.IEP (take care on full consistency with the orbit product).

Furthermore, the directory contains code and phase bias values either in the international Bias SINEX format with the extension BIA or the Bernese internal format for Observation-specific signal biasess (OSBs) (extension OSB).

Clock RINEX files OUT

The clock RINEX files are located in the OUT–directory. They are consistent with the GNSS orbits, EOP, and potentially the phase bias products in the ORB–directory. They contain station and satellite clock corrections with at least 5 minutes sampling — there are also files from the IGS or some of the analysis centers (ACs) providing satellite clock corrections with a sampling of 30 seconds.

RINEX files RAW

The raw data are given in RINEX format. In the Bernese internal naming scheme, we combine the nine character long station identifier with the four digit year and the session. The extension is RXO for observation and RXN for navigation RINEX files. In case of RINEX 2 files, the four characters are just extended by the default naming 00XYZ.

Station files STA

The coordinates and velocities of the stations given in the IGS realization of the reference frame ITRF 2020 are available in the files IGS20_R.CRD and IGS20_R.VEL. For some stations also corrections for Post Seismic Deformation (PSD) need to be applied that are provided in the file IGS20.PSD. The IGS core stations are listed in IGS20.FIX. This file will be used to define the geodetic datum when estimating station coordinates. The files for the previously published IGS realization (based on ITRF 2014) are available as well: IGB14_R.CRD, IGB14_R.VEL, IGB14.PSD and IGB14.FIX. You can browse all these files with a text editor or with the menu ("Menu>Campaign>Edit station files").

For all stations that have unknown coordinates in the IGS 20 reference frame a Precise Point Positioning (PPP) using the example BPE (PPP.PCF) for day 010 of year 2023 has been executed. For our EXAMPLE project a resulting coordinate file EXAMPLE.CRD has been generated. It contains all IGS core sites (copied from file IGS20_R.CRD) and the PPP results for the remaining stations. The epoch of the coordinates is January 01, 2015 . The corresponding velocity file EXAMPLE.VEL contains the velocities for the core sites (copied from file IGS20_R.VEL) completed by the NNR–NUVEL1A velocities for the other stations. The assignment of stations to tectonic plates is given in the file EXAMPLE.PLD.

To make sure that you process the data in the *Bernese GNSS Software* with correct station information (station name, receiver type, antenna type, antenna height, etc.) the file EXAMPLE.STA is used to verify the RINEX header information. The reason to use this file has to be seen in the context that some antenna heights or receiver/antenna types in the RINEX files may not be correct or may be measured to a different antenna reference point. Similarly, the marker (station) names in the RINEX files may differ from the names we want to use in the processing. The antenna types have to correspond to those in the file ${P}/INTRO/GEN/ANTENNA_I20.PCV to ensure that the correct phase center offsets and variations are used.

For each station name unique four– and two–character abbreviations to construct the names for the Bernese observation files need to be defined in the file EXAMPLE.ABB . It was automatically generated by the PPP example BPE. If you want to process big networks, the baselines need to be divided into clusters to speed up the processing. For that purpose each station has to be assigned to a region by a cluster number in the file EXAMPLE.CLU .

The last files to be mentioned in this directory are EXAMPLE.BLQ and EXAMPLE.ATL. They respectively provide the coefficients for the ocean and atmospheric tidal loading of the stations. They should at least be applied in the final run of GPSEST.

Global model and configuration files MODEL and CONFIG

These general model and configuration files contain information that is neither user– nor campaign–specific. They are accessed by all users, and changes in these files will affect processing for everyone. Consequently, these files have a central location in either ${C}/GLOBAL/MODEL or ${C}/GLOBAL/CONFIG directory. Table 1.3 shows the list of these files necessary for the processing example. It also shows which files need to be updated from time to time by downloading them from the anonymous ftp–server of AIUB (http://www.aiub.unibe.ch/download/BSWUSER54/).

The antenna corrections have to be applied consistently to the reference frame. Since we are going to use the IGS 20 coordinates and velocities to define the datum for our solution, the related antenna correction model has to be applied: IGS20.ATX .The related values are available in the SATELLIT_I20.SAT and ANTENNA_I20.PCV files. The first of these two files is located in the central CONFIG directory the latter one is contained in the campaign-specific GEN directory because it should contain only antenna/radome combinations that are processed in this campaign. Disregarding the two locations it is essential to *use these two files consistently*. For the ITRF 2014 related datum, the files are available as well: SATELLIT_I14.SAT and ANTENNA_I14.PCV .

Table 1.3: List of global model and configuration files to be used in the Bernese programs for the processing example.

Model files located in ${C}/GLOBAL/MODEL			
Filename	Content	Modification	Update from
CONST.BSW	All constants used in the *Bernese GNSS Software*	No	BSW aftp
IAU2000R06.NUT	Nutation model coefficients	No	—
DESAI2016.SUB	Subdaily pole model coefficients	No	—
OT_FES2004.TID	Ocean tides coefficients	No	—
TIDE2000.TPO	Solid Earth tides coefficients	No	—
EGM2008_SMALL.GRV	Earth potential coefficients (reduced version, sufficient for GNSS and LEO orbit determination)	No	—
s1_s2_def_ce.dat	S1/S2 atmospheric tidal loading coefficients	No	—
Configuration files located in ${C}/GLOBAL/CONFIG			
Filename	Content	Modification	Update from
DATUM.BSW	Definition of geodetic datum	Introducing new reference ellipsoid	BSW aftp
GPSUTC.BSW	Leap seconds	When a new leap second is announced by the IERS	BSW aftp
POLOFF.POL	Pole offset coefficients	Introducing new values from IERS annual report (until 1997)	—
SATELLIT_I14.SAT or SATELLIT_I20.SAT	Satellite information file	New launched satellites	BSW aftp
BOXWING.MAC	Definition of orbit model parameters	New launched satellites	BSW aftp
SAT_$Y+0.CRX	Satellite problems	Satellite maneuvers, bad data, ...	BSW aftp

Each Bernese processing program has its own panel for general files. Make sure that you use the correct files listed in Table 1.3 .

1.2.4 The SAVEDISK Directory Structure (${S})

Motivation for the SAVEDISK area

When processing GNSS data, a lot of files from various processing steps will populate your campaign directories. The main result files from the data analysis are collected in the SAVEDISK area. This area is intended as long-term archive for your result files.

Because the result files are stored in the SAVEDISK area, you can easily clean up your campaign area without loosing important files. Please keep in mind that the computing performance decreases if you have several thousands of files in a directory.

Structure and content of the SAVEDISK area

We propose to build subdirectories in the SAVEDISK area for each of your projects. If these projects collect data over several years, yearly subdirectories are recommended. It is also practical to use further subdirectories like ATM, ORB, OUT, SOL, STA to distribute the files and to get shorter listings if you are looking for a file. For reproducibility and documentation of the obtained results it might be a good idea to add the used configuration and model files to a GEN directory.

The SAVEDISK area contains after its installation a directory structure according to the description above. Each example BPE is assumed as a project. Therefore, you will find on the top level of the SAVEDISK the directories PPP, RNX2SNX, CLKDET, IONDET, LEOPOD, and SLRVAL (related to the different example BPEs).

In each of these directories you will find several files ending with _REF. They are generated by running the example BPEs on the system at Astronomical Institute of the University of Bern (AIUB). Even though this tutorial and of the RNX2SNX example BPE are both aiming on processing the same dataset from a regional network, the results will not be identical since there are some differences in the processing strategies and selected options.

1.2.5 Preparing the environment

For the *Bernese Introductory Course* the three data areas are prepared in such a way that the processing of the example data can immediately start. Some of the data are copied from the DATAPOOL-area into the CAMPAIGN-area and decompressed. An archive file containing the related files is made available that can be installed by

```
cd $D
cd ..
tar -xvzf _where_ever_it_is_/TUTORIAL.tgz
```

(_where_ever_it_is_ should be replaced by the location of this archive file on your system)

On Windows platforms you have to copy the three subdirectories of the archive to the related locations using the Windows File Explorer.

2 Terminal Session: Monday

Today's terminal session is to:

1. *become familiar with the UNIX environment, the menu of the* Bernese GNSS Software*, and the example campaign,*
2. *verify the campaign setup done for you (see sections 2.2 and 2.3, and also the handout for the terminal sessions),*
3. *generate the a priori coordinates for all 4 days using* COOVEL *(see Section 2.5), and*
4. *start to prepare pole and orbit information according to chapter 3.*

2.1 Start the Menu

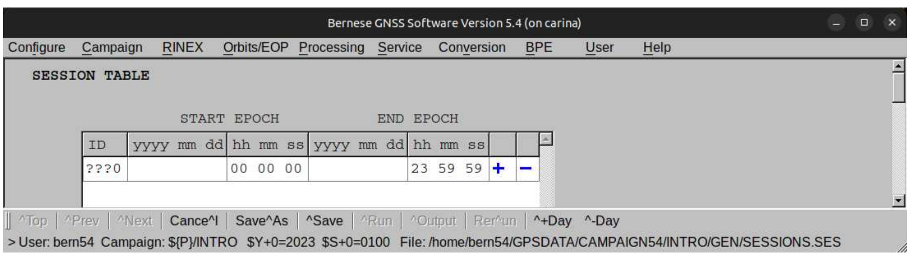
Start the menu program using the command `G`[1].

Navigate through the submenus to become familiar with the structure of the menu. Read the general help (available at "Menu>Help>General") to get an overview on the usage of the menu program of the *Bernese GNSS Software*.

For the terminal session in the *Bernese Introductory Course*, the campaign setup has already been done for each user. Please check that the campaign name in the status bar of the Bernese Menu is set correctly to your campaign (i.e., Campaign ${P}/INTRO) and that the current session is set to the first session (i.e., $Y+0=2023, $S+0=0100). If this is not the case, please contact the staff in the terminal room.

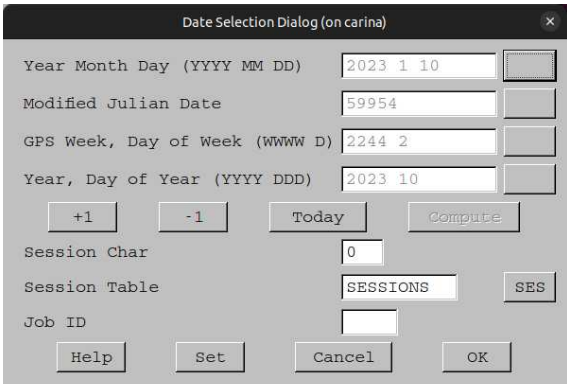
2.2 Select Current Session

Select "Menu>Campaign>Edit session table" to check the session table. It is recommended to use the wildcard string ???0 for the "List of sessions" in panel "SESSION TABLE". The panel below shows the session definition for a typical permanent campaign with 24-hours sessions. The setup of the session table is a very important task when you prepare a campaign. Please read the corresponding online help carefully.



[1] At the exercise terminals the Bernese environment is loaded automatically during login. At home you have to source the file `${C}/LOADGPS.setvar` on UNIX–platforms either manually or during login.

Save the session table (press the ^Save button) and open the "Date Selection Dialog" in the "Menu>Configure>Set session/compute date" in order to define the current session:



2.3 Campaign Setup

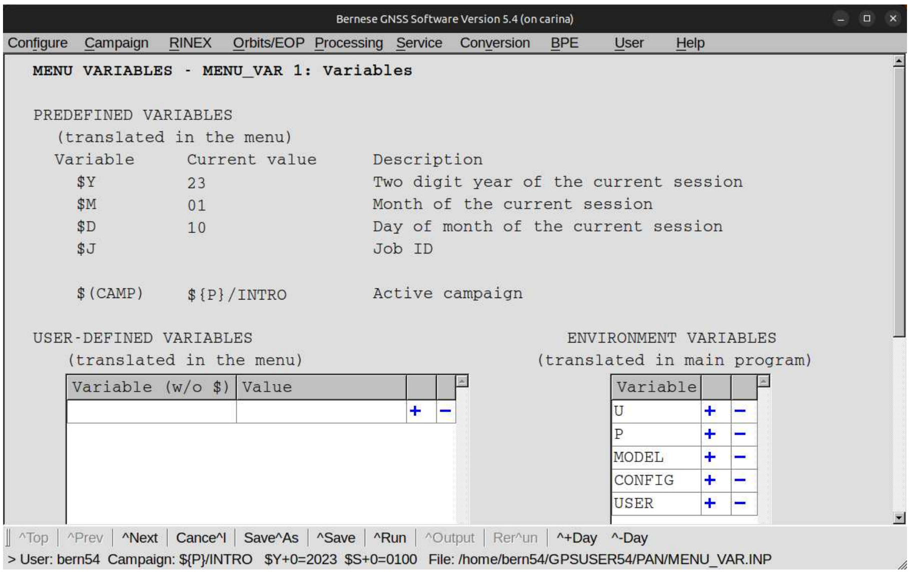
Usually, a new campaign must be added to the campaign list ("Menu>Campaign>Edit list of campaigns") first and select it as the active campaign ("Menu>Campaign>Select active campaign"), before the directory structure can be created ("Menu>Campaign>Create new campaign"). In the *Bernese Introductory Course* environment this should already have been done for your campaign, but please verify that.

In the *Bernese Introductory Course* environment the selected campaign should be `${P}/INTRO`. In order to become familiar with the campaign structure, you can inspect your campaign directory and inspect the contents using the command line (using *cd* for changing directories and *ls* to create directory listings) or using a filemanager (e.g., midnight commander *mc*).

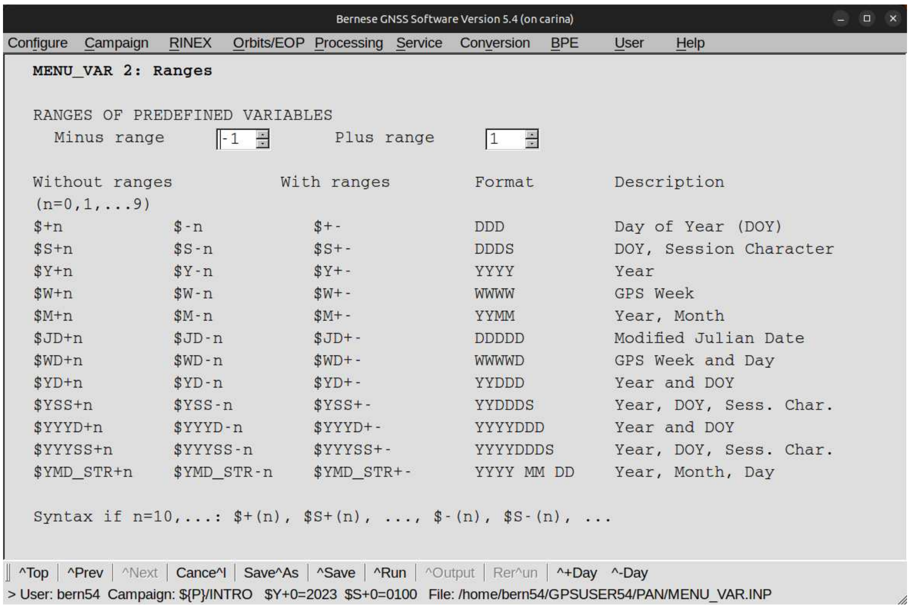
2.4 Menu Variables

When processing GNSS data, it is often necessary to repeat a program run several times with only slightly different option settings. A typical example would be the processing of several sessions of data. The names of observation files change from session to session because the session number is typically a part of the filename. It would be very cumbersome to repeat all the runs selecting the correct files manually every time. For the BPE an automation is mandatory. For such cases the Bernese menu system provides a powerful tool: the so–called menu variables. The menu variables are defined in the user–specific menu input file `${U}/PAN/MENU_VAR.INP` that is accessible through "Menu>Configure>Menu variables". Three kinds of menu variables are available: predefined variables (also called menu time variables), user–defined variables, and system environment variables.

The use of system environment variables is necessary to generate the complete path to the files used in the *Bernese GNSS Software*. The campaign data are located in the directory `${P}/INTRO=${HOME}/GPSDATA/CAMPAIGN54/INTRO`. The user–dependent files can be found at `${U}=${HOME}/GPSUSER54` — note that `${HOME}` may have been already translated into the name of your home–directory. The temporary user files are saved in `${T}=/scratch/local/bern54` (change bern54 to your user name). Finally, the campaign–independent model and configuration files reside in `${MODEL}=${C}/GLOBAL/MODEL` and `${CONFIG}=${C}/GLOBAL/CONFIG`, respectively.



The predefined variables provide a set of time strings assigned to the current session. From the second panel of the menu variables you get an overview on the available variables and their usage:



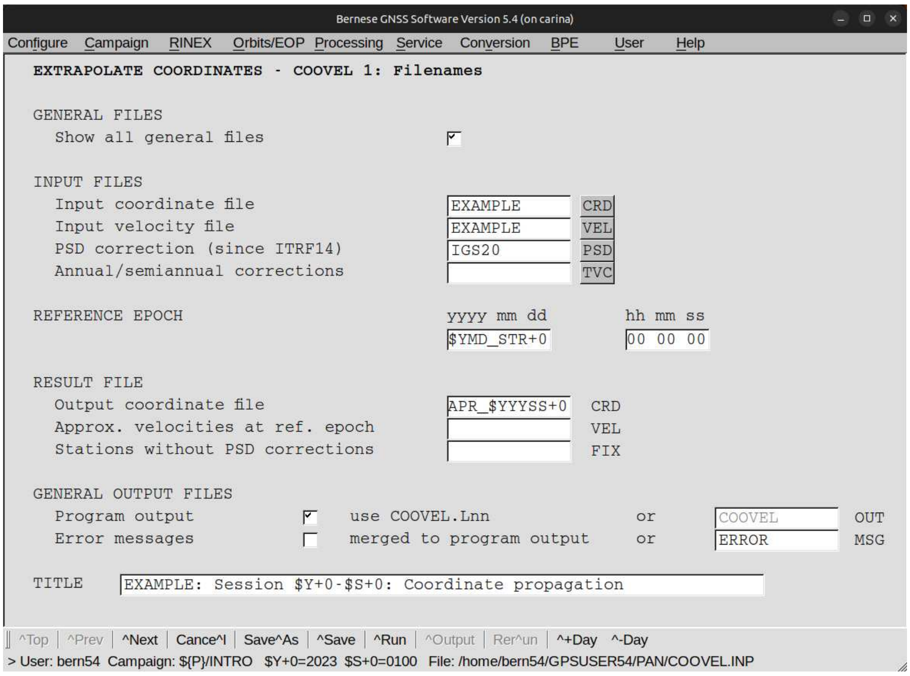
Be aware that the variable `$S+1` refers to the next *session*. Because we are using a session table for daily processing it also corresponds to the next day.

These variables are automatically translated by the menu upon saving the panel or running the program. We recommend to make use of them in the input panels (e.g. for filename specification).

2.5 Generate A Priori Coordinates

As stated before the a priori coordinates generated from the PPP processing example BPE refer to the epoch January 01, 2015 . The first step is to extrapolate the coordinates to the epoch that is currently processed. In the recent ITRF-solutions also Post Seismic Deformation (PSD) corrections have to be applied when the epoch of the coordinate sets are changed. They are provided in the input field "PSD corrections (since ITRF14)". Of course this feature is also included in the IGS 20 frame – the IGS-specific realization of the ITRF 2020 .

Coordinate extrapolation is the task of the program COOVEL. Open the program input panel in "Menu>Service>Coordinate tools>Extrapolate coordinates":



"Reference epoch: date"	$YMD_STR+0	→	2023 01 10
"Output coordinate file"	APR_$YYYSS+0	→	APR_20230100
"Title line"	Session $Y+0-$S+0:	→	Session 2023-0100:

Start the program with the ^Run–button. The program generates an output file COOVEL.L?? in the directory ${P}/INTRO/OUT. This file may be browsed using the ^Output–button or with "Menu>Service>Browse program output". It should look like

```
==========================================================================
Bernese GNSS Software, Version 5.4
--------------------------------------------------------------------------
Program        : COOVEL
Purpose        : Extrapolate coordinates
--------------------------------------------------------------------------
Campaign       : ${P}/INTRO
Default session: 0100 year 2023
Date           : 10-Jan-2025 13:29:39
User name      : bern54
==========================================================================
```

```
 EXAMPLE: Session 2023-0100: Coordinate propagation
 ------------------------------------------------------------------------------


 INPUT AND OUTPUT FILENAMES
 --------------------------

 ------------------------------------------------------------------------------
 Geodetic datum                  : ${CONFIG}/DATUM.BSW
 Input coordinate file           : ${P}/INTRO/STA/EXAMPLE.CRD
 Input velocity file             : ${P}/INTRO/STA/EXAMPLE.VEL
 Output coordinate file          : ${P}/INTRO/STA/APR_20230100.CRD
 Approx. velocities at ref. epoch:  ---
 PSD corrections (since ITRF14)  : ${P}/INTRO/STA/IGS20.PSD
 Annual/semiannual corrections (s:  ---
 Stations without PSD corrections:  ---
 Program output                  : ${P}/INTRO/OUT/COOVEL.L00
 Error message                   : ${U}/WORK/ERROR.MSG
 Session table                   : ${P}/INTRO/GEN/SESSIONS.SES
 ------------------------------------------------------------------------------


 REFERENCE EPOCH:         2015-01-01 00:00:00
 INTERPOLATION FACTOR:    -8.0246406570841895


-----------------------------------------------------------------
>>> CPU/Real time for pgm "COOVEL": 0:00:00.119 / 0:00:00.119
>>> Program finished successfully
```

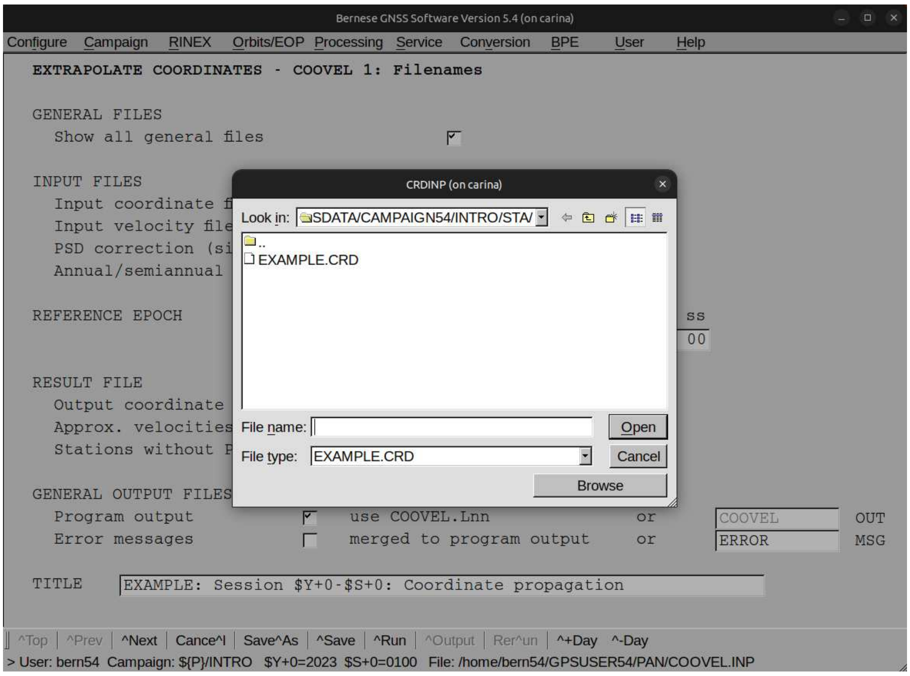
The header area of the program output is standardized for all programs of the *Bernese GNSS Software*, Version 5.4 . Furthermore each program has a title line that should characterize the program run. It is printed to the program output and to most of the result files. Many program output files furthermore provide a list of input and output files that have been used or generated.

The last two lines of the above example appear also in each program output of the *Bernese GNSS Software*, Version 5.4 . It reports the processing time and the status successful or with error.

The result of the COOVEL run is an a priori coordinate file (`${P}/INTRO/STA/APR_20230100.CRD`) containing the positions of the sites to be processed for the epoch of the current session (the lines for the other stations are ignored in the processing):

```
EXAMPLE: Session 2023-0100: Coordinate propagation
------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20             EPOCH: 2023-01-10 00:00:00

NUM  STATION NAME           X (M)          Y (M)          Z (M)     FLAG
SYSTEM

 39  BRST 10004M004    4231162.37190  -332746.35968  4745131.11148    IGS20
 95  GANP 11515M001    3929181.23080  1455237.01639  4793654.06899    PPP
108  HERT 13212M010    4033460.69084    23538.10355  4924318.44192    PPP
127  JOZ2 12204M002    3664880.24989  1409190.87367  5009618.62657    PPP
148  LAMA 12209M001    3524522.60337  1329693.89759  5129846.50454    PPP
165  MATE 12734M008    4641949.22470  1393045.76799  4133287.72420    IGS20
179  MIKL 12335M001    3698553.63394  2308676.29253  4639769.66327    IGS20
184  MORP 13299S001    3645667.61688  -107276.95605  5215053.70864    PPP
213  ONSA 10402M004    3370658.28373   711877.40047  5349787.13059    IGS20
214  ORID 15601M001    4498451.41849  1708267.34152  4173592.01967    IGS20
237  PTBB 14234M001    3844059.68188   709661.61050  5023129.72783    PPP
294  TLSE 10003M009    4627851.61562   119640.36363  4372993.76001    IGS20
316  VILL 13406M001    4849833.53054  -335048.67881  4116015.16448    PPP
325  WSRT 13506M005    3828735.59233   443305.24643  5064884.89279    IGS20
326  WTZR 14201M010    4075580.26234   931854.10652  4801568.31008    IGS20
327  WTZZ 14201M014    4075579.13158   931853.42100  4801569.22993    PPP
339  ZIM2 14001M008    4331299.63003   567537.64663  4633133.92568    IGS20
340  ZIMM 14001M004    4331296.81917   567556.20338  4633134.14534    IGS20
```

Have a look at the LOCAL GEODETIC DATUM: in the resulting coordinate file. It is set to IGS20 in this case. If you go back to your input file (e.g., pressing the `Rer^un` button) you may open the dialog to select the "Input coordinate file" by pressing on the button next to the input field. Select now the file `EXAMPLE.CRD` and press the button `Browse` in order to open a window where the selected file is displayed.



Here you can see the LOCAL GEODETIC DATUM: is set to IGS20_0. This difference is the indicator whether the PSD corrections have been applied or not. Coordinate files indicating that the PSD corrections have not been applied cannot be used for processing GNSS data. At the same time it is protecting you from applying the corrections twice. For that reason the execution of the program COOVEL for applying the PSD corrections is also essential even if none of the stations in your processing (as in our example) is affected by these corrections.

You can repeat all steps for the other sessions in the example campaign by changing the current session using the `^+Day` or `^-Day` to change a limited number of days (not sessions) or via "Menu>Configure>Set session/compute date". You can then use the `Rer^un` button to restart the program. No options need to be changed because of the consequent use of the menu time variables was made. Even if you are going to process only the first day (010, year 2023) of the example dataset during the terminal sessions, you will need prepared coordinate files for all days later on Thursday. That is why this step should be executed for all four days: 010 and 011 of year 2023 as well as 201 and 202 of year 2024.

2.6 Session Goals

At the end of this session, you should have created the following files:

1. *a priori coordinates in your campaign's STA directory: for four sessions* `APR_20230100.CRD`, `APR_20230110.CRD`, `APR_20242010.CRD`, *and* `APR_20242020.CRD`

Until the end of today's terminal session you should start with preparing the pole and orbit information, see Chapter 3.

3 Terminal Session: Pole and Orbit Preparation (Monday/Tuesday)

The terminal session on pole and orbit preparation is to:
1. *generate the pole information file in the Bernese format (POLUPD)*
2. *generate the Bernese standard orbit files from CODE precise orbit files (ORBGEN)*
3. *extract satellite clock corrections for receiver clock synchronization (SATCLK2)*
4. *convert biases from external to internal format (BIA2OSB)*

You should start with these tasks during Monday's terminal sessions and finish the processing during the terminal session on Tuesday.

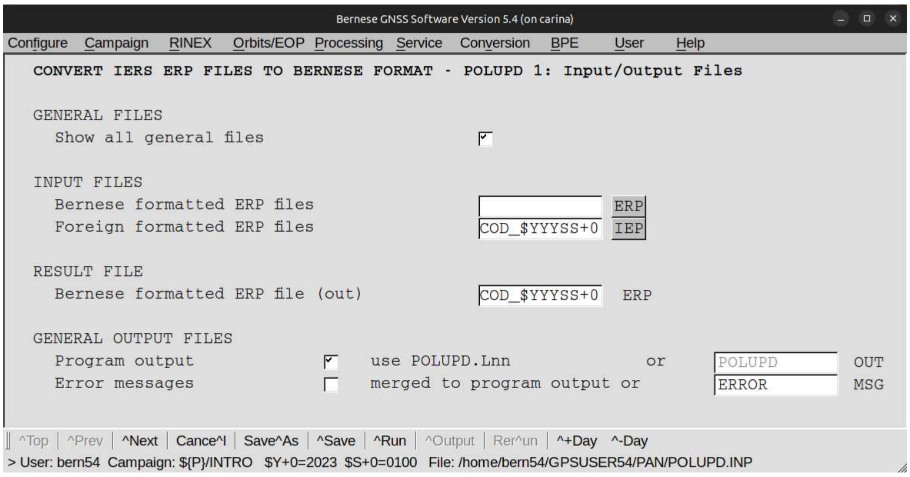
Introductory Remark

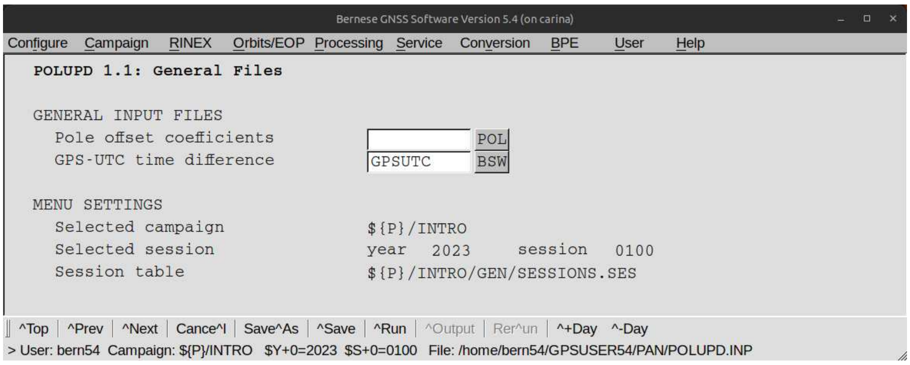
We recommend to use the final products from CODE because they contain consistent orbits for GPS, GLONASS, and Galileo. Alternatively, the CODE rapid series contains the orbits from these three systems since September 2019. All these series include all active GNSS satellites (even if they are unhealthy or during GPS satellite repositioning events) with the highest possible accuracy thanks to the three-day long-arc technology. Due to this choice you will get the best possible consistency between the external products and the software.

Products for other systems are available in the MGEX solutions provided by CODE and other ACs. Note, that these are experimental products used, e.g., to test various orbit models or antenna calibration sets.

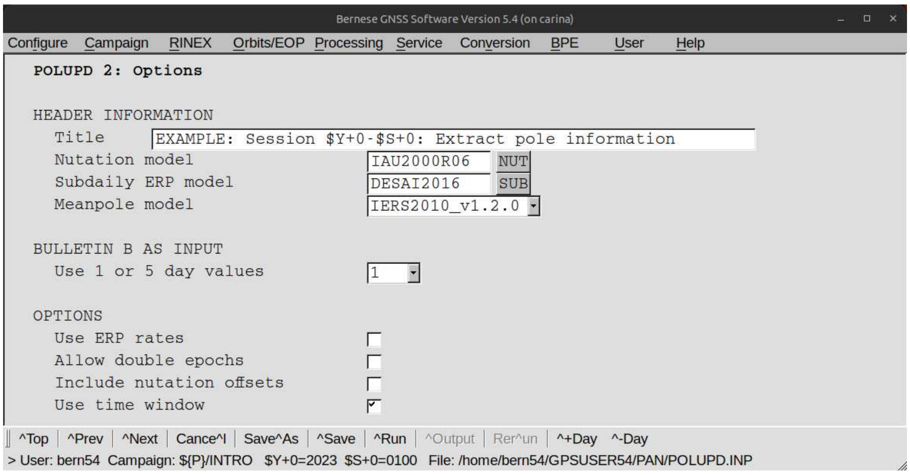
3.1 Prepare Pole Information

Together with the precise orbit files (`PRE`), a consistent set of Earth orientation parameters is provided in the `ORB` directory. Whereas the orbits are given in daily files the EOP may be available in weekly files for some product series. We have to convert the information from the International Earth Rotation and Reference Systems Service (IERS)/IGS standard format (file extension within the *Bernese GNSS Software* is `IEP`) into the internal Bernese EOP format (file extension within the *Bernese GNSS Software* is `ERP`). This is the task of the program POLUPD ("Menu>Orbits/EOP>Handle EOP files>Convert IERS to Bernese Format") which is also able to update the EOP records of an existing file.



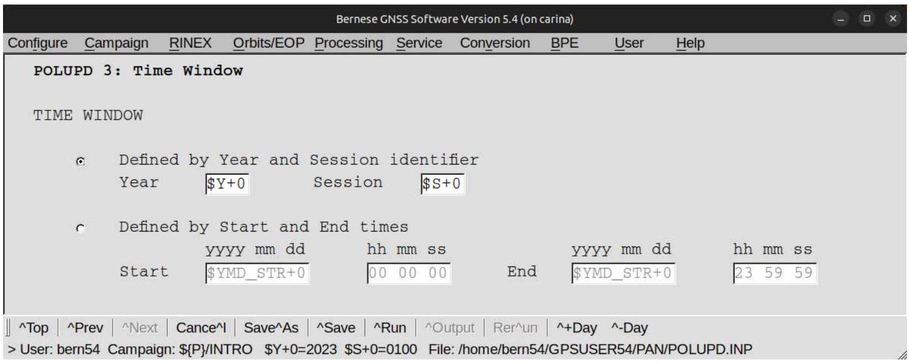


Together with the nutation and subdaily pole model also the meanpole model is specified in this panel. They are reported in the resulting Bernese formatted pole file in order to check the consistent use.



Take care on the option "Meanpole model". It has to be chosen consistently to the EOPs to be converted. The current CODE operational series use IERS2010_v1.2.0. For earlier operational products the IERS2010XY has to be used.

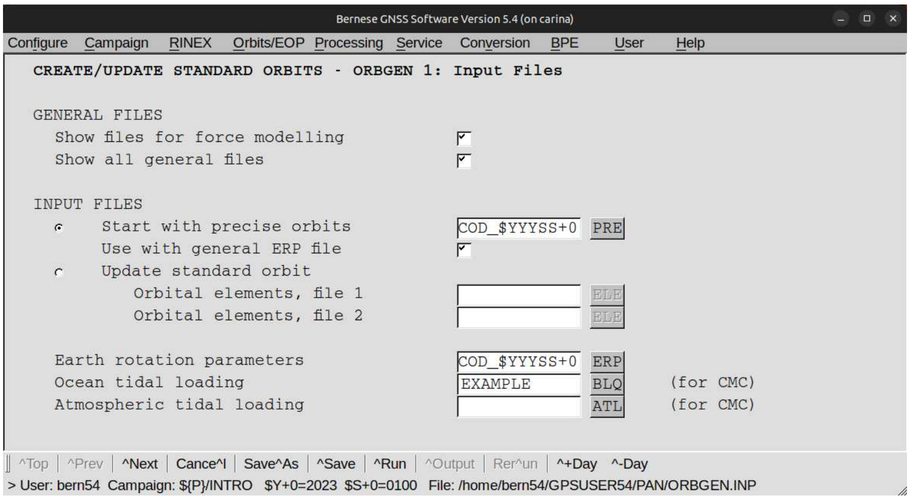
Another important remark is related to option "Use ERP rates": please check your input "Foreign formatted ERP files" whether they contain the midnight epochs requested to cover the entire period of the session (e.g., in the CODE products). In that case the checkbox should be deactivated. If you have only one record per day at noon in your input "Foreign formatted ERP files" (e.g., in IGS products) the rates from the file should be used, the option has to be activated.



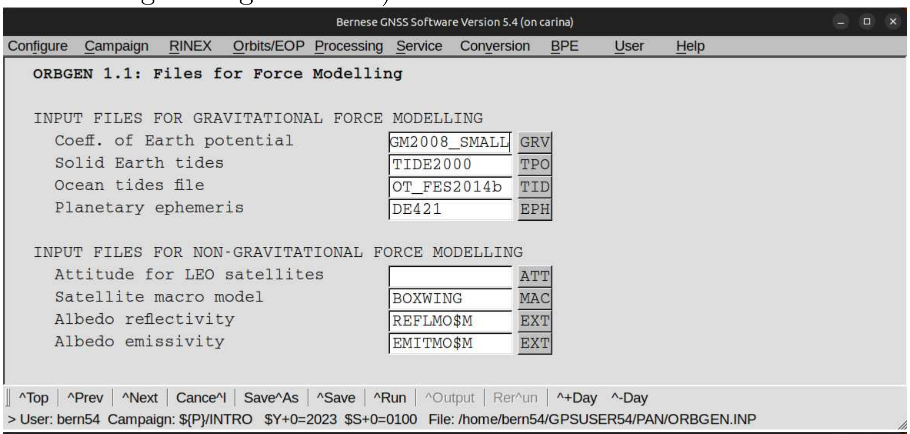
The last panel of the program POLUPD is an example for the specification of time windows in the *Bernese GNSS Software*, Version 5.4 . Time windows can be defined by sessions (a single session or a range of sessions). Alternatively, a time window may be specified by a start and an end epoch. By entering either a start or an end epoch you may define only the beginning or the end of the time interval. We refer to the online help for more details.

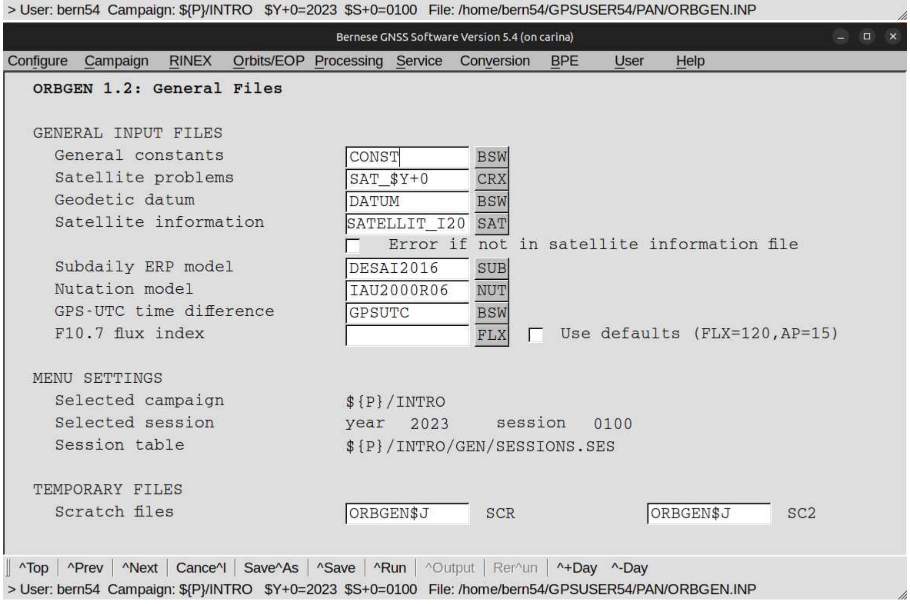
3.2 Generate Orbit Files

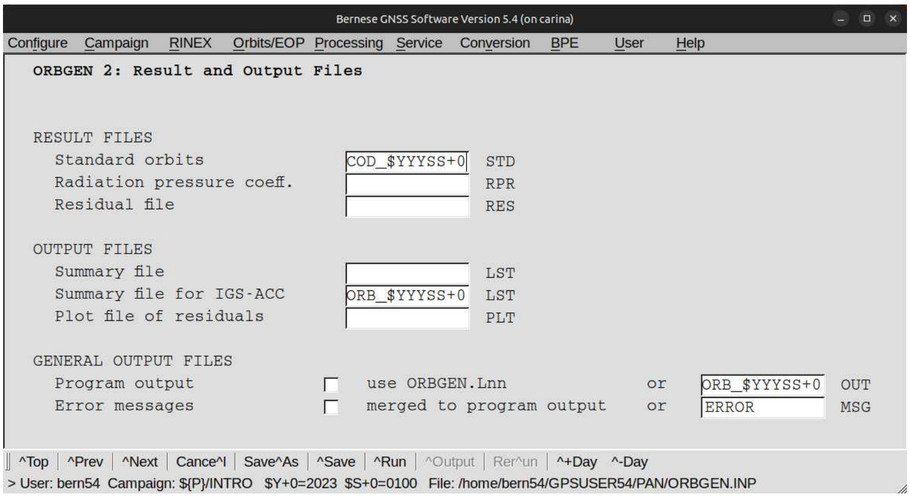
In this processing example we use only one program of the orbit part of the *Bernese GNSS Software*, namely ORBGEN ("Menu>Orbits/EOP>Create/update standard orbits"). It prepares the so-called standard orbits using the satellite positions in the precise orbit files as pseudo–observations for a least-squares adjustment.

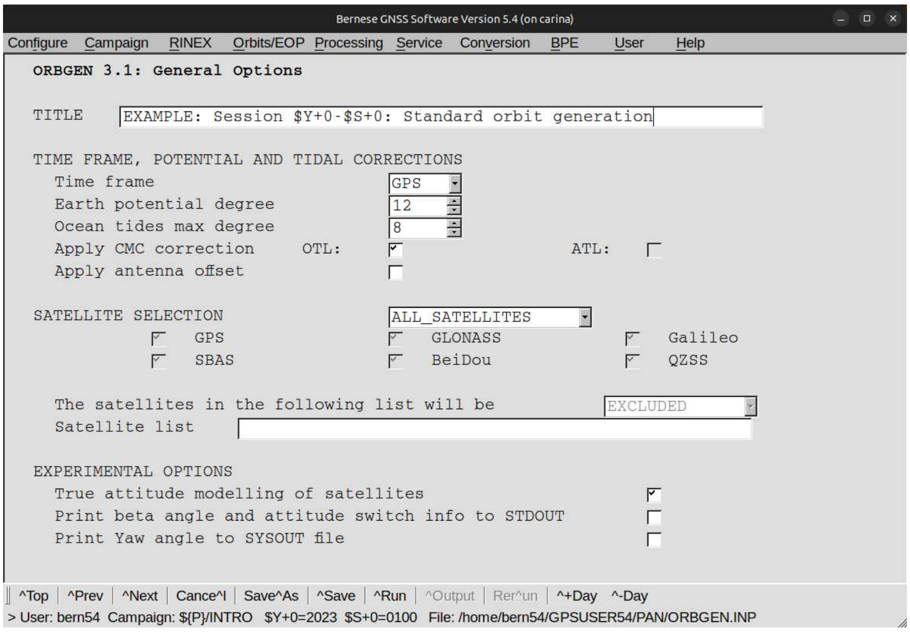


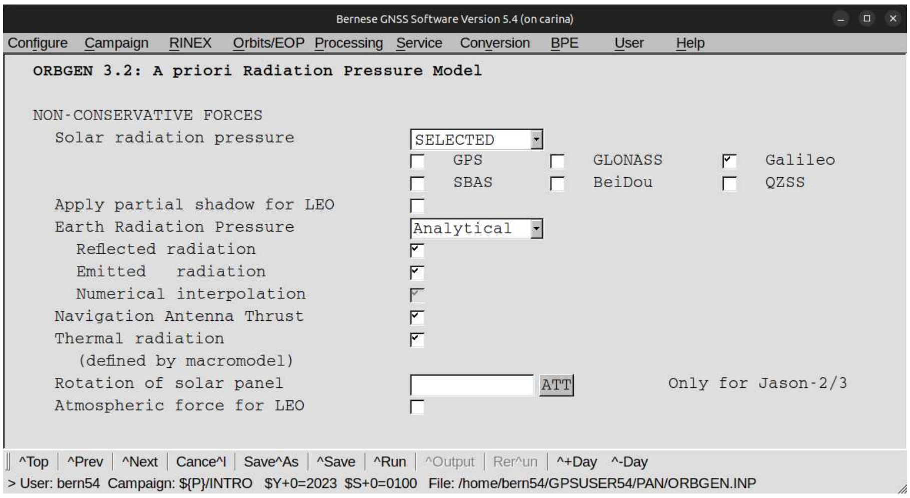
It is mandatory to consistently use the ERP file, the nutation, and the subdaily pole model together with the generated standard orbits in all subsequent processing steps/programs (otherwise a warning message is issued).



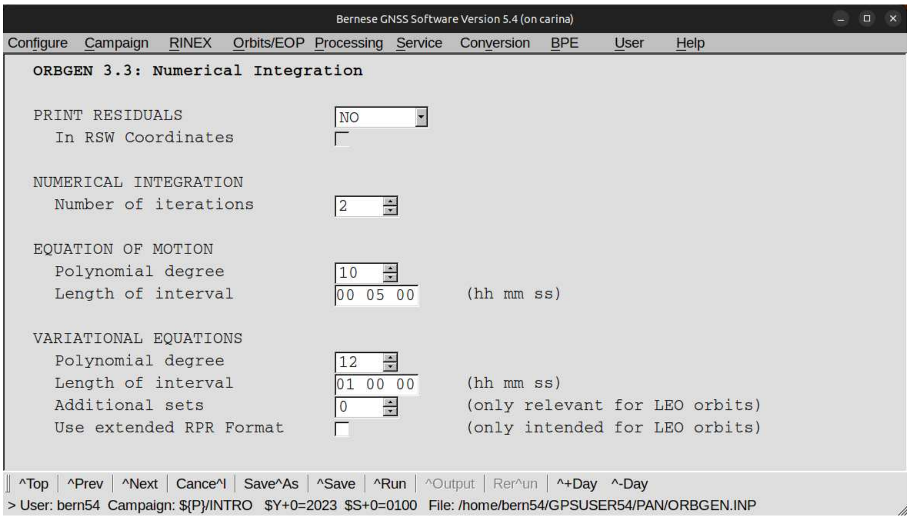



Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
ORBGEN 2: Result and Output Files
RESULT FILES
Standard orbits
COD_$YYYSS+0
STD
Radiation pressure coeff.
RPR
Residual file
RES
OUTPUT FILES
Summary file
LST
Summary file for IGS-ACC
ORB_$YYYSS+0
LST
Plot file of residuals
PLT
GENERAL OUTPUT FILES
Program output
use ORBGEN.Lnn
or
ORB_$YYYSS+0
OUT
Error messages
merged to program output
or
ERROR
MSG
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/ORBGEN.INP

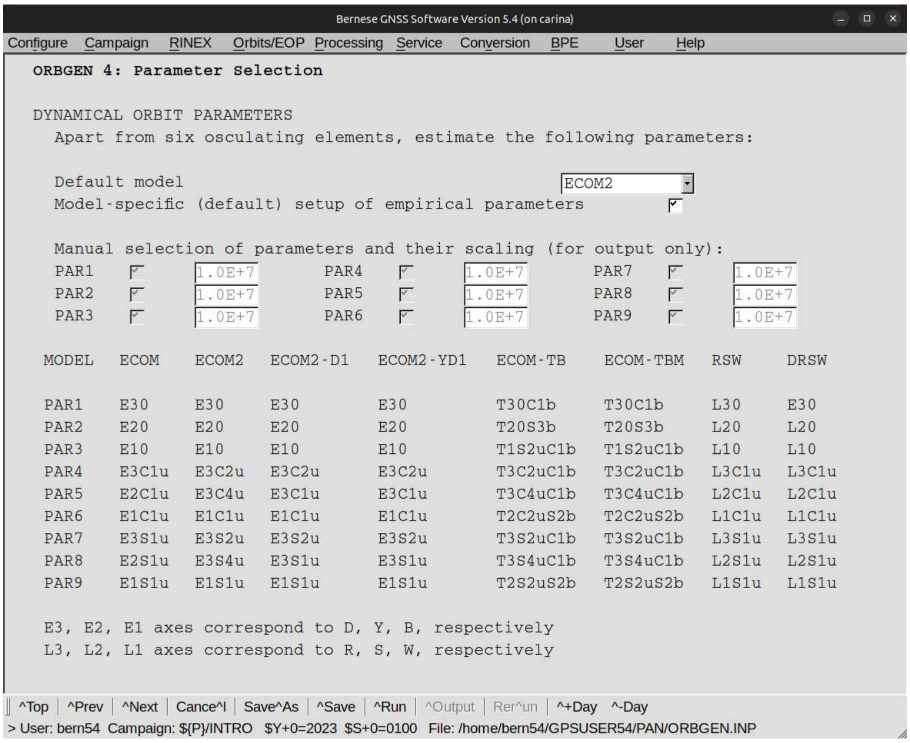

Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
ORBGEN 3.1: General Options
TITLE
EXAMPLE: Session $Y+0-$S+0: Standard orbit generation
TIME FRAME, POTENTIAL AND TIDAL CORRECTIONS
Time frame
GPS
Earth potential degree
12
Ocean tides max degree
8
Apply CMC correction
OTL:
ATL:
Apply antenna offset
SATELLITE SELECTION
ALL_SATELLITES
GPS
GLONASS
Galileo
SBAS
BeiDou
QZSS
The satellites in the following list will be
EXCLUDED
Satellite list
EXPERIMENTAL OPTIONS
True attitude modelling of satellites
Print beta angle and attitude switch info to STDOUT
Print Yaw angle to SYSOUT file
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/ORBGEN.INP


Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
ORBGEN 3.2: A priori Radiation Pressure Model
NON-CONSERVATIVE FORCES
Solar radiation pressure
SELECTED
GPS
GLONASS
Galileo
SBAS
BeiDou
QZSS
Apply partial shadow for LEO
Earth Radiation Pressure
Analytical
Reflected radiation
Emitted radiation
Numerical interpolation
Navigation Antenna Thrust
Thermal radiation
(defined by macromodel)
Rotation of solar panel
ATT
Only for Jason-2/3
Atmospheric force for LEO
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/ORBGEN.INP

For the options "EQUATION OF MOTION: Length of interval" and "VARIATIONAL EQUATIONS: Length of interval" interval lengths of 00 05 00 and 01 00 00 are sufficient when processing GNSS orbits. Note, that stochastic pulses can only be placed between the integration intervals. When activating the option "Setup of stochastic pulses" later in panel "ORBGEN 5: Stochastic Pulses and Satellite Accuracy Codes" to a specific value (e.g., Orbit midnight) the intervals should allow a realization of this selection.
Shorter intervals will increase of the program run time.

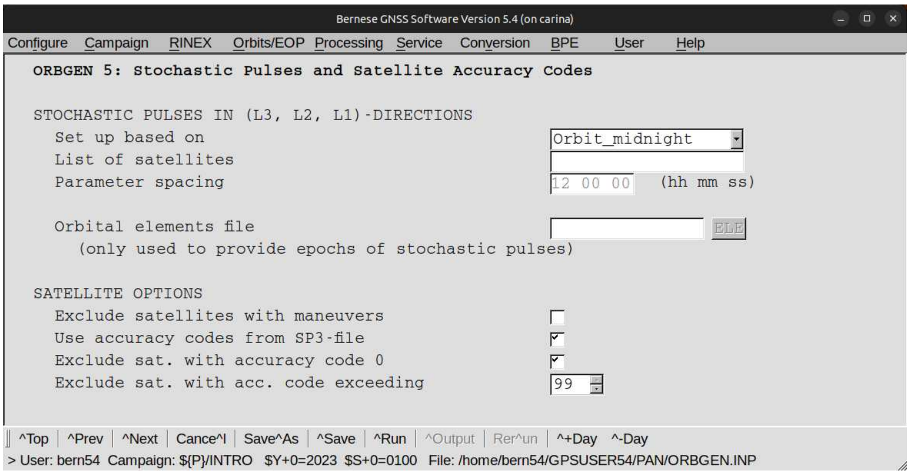


For the option "Number of iterations" 2 is sufficient for most of the cases. You may select a third iteration to check that the output does not change in the additional iteration.

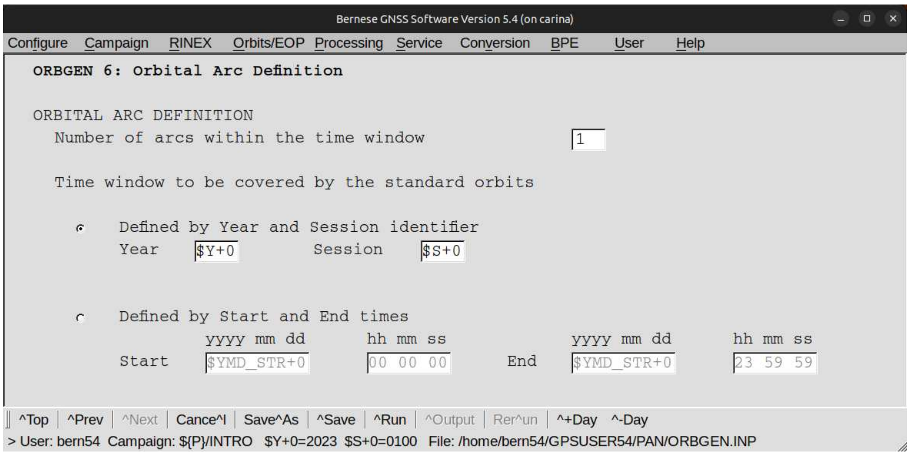


In this panel you see the available orbit models and which of the orbit parameters are used for which component in which coordinate system. We recommend to use the default setup as prepared in the `${CONFIG}/BOXWING.MAC` ("Satellite macro model" in "ORBGEN 1.1: Files for Force Modelling").

The stochastic pulses are set in the CODE operational final series – used during this exercise session – at Orbit midnight. For the operational final series from CODE this is the case since GPS week 2112, June 2020. For the other products from CODE or other sources we recommend to change the option "Setup of stochastic pulses" to Spacing with 12 00 00 for "Interval for stochastic pulses".



If you process precise orbits from CODE it is generally not necessary to remove bad satellites, because CODE orbit files contain the correct accuracy codes. It might become necessary for orbit products from other sources (e.g., from the IGS).



The program produces an output file `ORB_20230100.OUT` which should look like

```
...
****************************************************************************
COMPUTATION OF BERNESE STANDARD ORBITS FROM PRECISE ORBITS      13-JAN-25 17:21
****************************************************************************
...

----------------------------------------------------------------------------
LIST OF PRECISE FILES
----------------------------------------------------------------------------

FILE  PRECISE ORBIT FILENAME            RELATED POLE FILES
----  ------------------------------  --------------------------------

   1  ${P}/INTRO/ORB/COD_20230100.PRE   ${P}/INTRO/ORB/COD_20230100.ERP

...
```

Close to the end of the output file you can find the reporting on the orbit model used for each of the satellite according to the "Default model for empirical forces" setup. Most of the GNSS satellites will be represented by the ECOM2 orbit model. Below you find another table that is reporting the parametrization of the selected orbit model.

```
...
-------------------------------------------------------------------------------
USED EMPIRICAL MODELS
-------------------------------------------------------------------------------
     EMP MODEL            SATELLITES
     -------------------- --------------------------------------------------
EMP: ECOM2                  1    2    3    4    5    6    7    8    9   10
EMP: ECOM2                 11   12   13   14   15   16   17   18   19   20
EMP: ECOM2                 21   22   23   24   25   26   27   29   30   31
EMP: ECOM2                 32  101  102  103  104  105  107  108  109  111
EMP: ECOM2                112  113  114  115  116  117  118  119  120  121
EMP: ECOM2                124  201  202  203  204  205  207  208  209  210
EMP: ECOM2                211  212  213  215  219  221  224  225  226  227
EMP: ECOM2                230  231  233  234  236
EMP: ECOM2-YD1            214  218

-------------------------------------------------------------------------------


-------------------------------------------------------------------------------
DESCRIPTION OF EMPIRICAL MODELS
-------------------------------------------------------------------------------
             MODEL NAME       PAR IDX    PARAMETER LABEL   SHADOW  PAR_SETUP
        -------------------- ------- -------------------- ------ ---------
EMPPAR: ECOM2                      1 E30                       F         T
EMPPAR: ECOM2                      2 E20                       F         T
EMPPAR: ECOM2                      3 E10                       F         T
EMPPAR: ECOM2                      4 E3C2u                     F         T
EMPPAR: ECOM2                      5 E3C4u                     F         F
EMPPAR: ECOM2                      6 E1C1u                     F         T
EMPPAR: ECOM2                      7 E3S2u                     F         T
EMPPAR: ECOM2                      8 E3S4u                     F         F
EMPPAR: ECOM2                      9 E1S1u                     F         T

EMPPAR: ECOM2-YD1                  1 E30                       F         T
EMPPAR: ECOM2-YD1                  2 E20                       T         T
EMPPAR: ECOM2-YD1                  3 E10                       F         T
EMPPAR: ECOM2-YD1                  4 E3C2u                     F         T
EMPPAR: ECOM2-YD1                  5 E3C1u                     F         F
EMPPAR: ECOM2-YD1                  6 E1C1u                     F         T
EMPPAR: ECOM2-YD1                  7 E3S2u                     F         T
EMPPAR: ECOM2-YD1                  8 E3S1u                     T         T
EMPPAR: ECOM2-YD1                  9 E1S1u                     F         T

-------------------------------------------------------------------------------

...
```

Notice that for this day, the orbit model ECOM2-YD1 is used for two Galileo satellites, because their beta angles (elevation angle of the Sun above the orbital plane) are below the limit of 14 degrees. The related definition comes from the BOXWING.MAC file:

```
 ...
#PARAMETER         VALUE
#***************** ********************
MODEL IDENTIFIER   GALILEO-2
PARAMETER DEFAULT  ECOM2
PARAMETER BETA     ECOM2-YD1 14.0
 ...
```

The most important part of the program output is the quality of the orbit representation by the model defined for the current program run:

```
...
-------------------------------------------------------------------------------
RMS ERRORS AND MAX. RESIDUALS   ARC NUMBER:  1                    ITERATION:  2
-------------------------------------------------------------------------------

                          QUADRATIC MEAN OF O-C (M)         MAX. RESIDUALS (M)
SAT   #POS   RMS (M)     TOTAL   RADIAL  ALONG   OUT       RADIAL  ALONG   OUT
```

```
 ---   ----   -------     ----------------------------     --------------------

    1    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001
    2    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001
    3    288    0.001       0.001    0.000  0.001  0.000        0.001  0.002  0.001
    4    288    0.001       0.001    0.000  0.001  0.000        0.001  0.002  0.001
    5    288    0.001       0.001    0.000  0.001  0.000        0.002  0.002  0.001
    6    288    0.001       0.001    0.000  0.001  0.000        0.001  0.002  0.001
...
   31    288    0.001       0.001    0.000  0.001  0.000        0.001  0.002  0.001
   32    288    0.001       0.001    0.000  0.001  0.000        0.001  0.002  0.001
  101    288    0.001       0.001    0.001  0.001  0.000        0.003  0.002  0.001
  102    288    0.001       0.001    0.000  0.001  0.000        0.001  0.002  0.001
  103    288    0.000       0.001    0.000  0.001  0.000        0.001  0.002  0.001
...
  121    288    0.001       0.001    0.000  0.001  0.000        0.001  0.002  0.001
  124    288    0.001       0.001    0.000  0.001  0.000        0.002  0.002  0.001
  201    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001
  202    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001
...
  230    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001
  231    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001
  233    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001
  234    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001
  236    288    0.000       0.000    0.000  0.001  0.000        0.001  0.002  0.001

 --------------------------------------------------------------------------------
...
```

These should be 1 mm (for older orbits it may also be 3…5 mm) if precise orbits from CODE were used together with the consistent EOP information (the actual RMS errors depend on the quality of the precise orbits, on the pole file used for the transformation between IERS Terrestrial Reference Frame (ITRF) and International Celestial Reference Frame (ICRF), and on the orbit model used in ORBGEN).

The file ${P}/INTRO/OUT/ORB_20230100.LST summarizes the orbit fit RMS values in one table:

```
 EXAMPLE: Session 2023-0100: Standard orbit generation            13-JAN-25 17:21
 TIME FROM DAY : 2 GPS WEEK: 2244
      TO   DAY : 3 GPS WEEK: 2244
 -------------------------------------------------------------------------------------------
 ORBIT REPEATABILITY FROM A 1-DAY FIT THROUGH DAILY ORBIT SOLUTIONS (MM)
 # ECLIPSING SATELLITES:  18 E /   0 M (  0 EM)
 -------------------------------------------------------------------------------------------
 ECL   ..  ..  E.  ..  E.  .. ...  ..  ..  E.  E.  E. ...  ..  ..  ..  .. ...  ..  ..  ..  ..
 DOY    1   2   3   4   5   6 ...  31  32 101 102 103 ... 121 124 201 202 ... 231 233 234 236
 -------------------------------------------------------------------------------------------
 010    1   1   1   1   1   1 ...   1   1   1   1   1 ...   1   1   1   1 ...   1   1   1   1
 -------------------------------------------------------------------------------------------
 ALL    1   1   1   1   1   1 ...   1   1   1   1   1 ...   1   1   1   1 ...   1   1   1   1
 -------------------------------------------------------------------------------------------
```

The output shows that 18 satellites are in eclipse (indicated above the satellite number by E for Earth or M for Moon).

A similar file may be generated using the orbit products from IGS (including the EOP information). Using the same ORBGEN settings as for the CODE products, the following residuals will result:

```
 EXAMPLE: Session 2023-0100: Standard orbit generation (IGS)      15-JAN-25 07:52
 TIME FROM DAY : 2 GPS WEEK: 2244
      TO   DAY : 3 GPS WEEK: 2244
 -------------------------------------------------------------------------------------------
 ORBIT REPEATABILITY FROM A 1-DAY FIT THROUGH DAILY ORBIT SOLUTIONS (MM)
 # ECLIPSING SATELLITES:   9 E /   0 M (  0 EM)
 -------------------------------------------------------------------------------------------
 ECL   ..  ..  E.  ..  E.  ..  ..  E.  ..  E.  ..  .. ...  E.  ..  ..  ..  E.  E.  ..  ..  ..
 DOY    1   2   3   4   5   6   7   8   9  10  11  12 ...  23  24  25  26  27  29  30  31  32
 -------------------------------------------------------------------------------------------
 010    2   1   2   4   2   1   1   2   2   2   2   3 ...   3   2   3   3   2   2   1   1   3
 -------------------------------------------------------------------------------------------
 ALL    2   1   2   4   2   1   1   2   2   2   2   3 ...   3   2   3   3   2   2   1   1   3
 -------------------------------------------------------------------------------------------
```

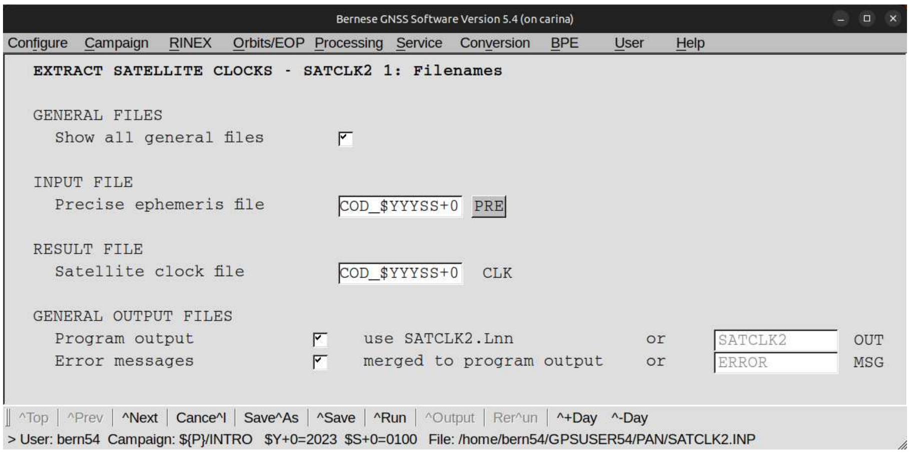
(Note the missing GLONASS and Galileo satellites in the IGS orbit product.)

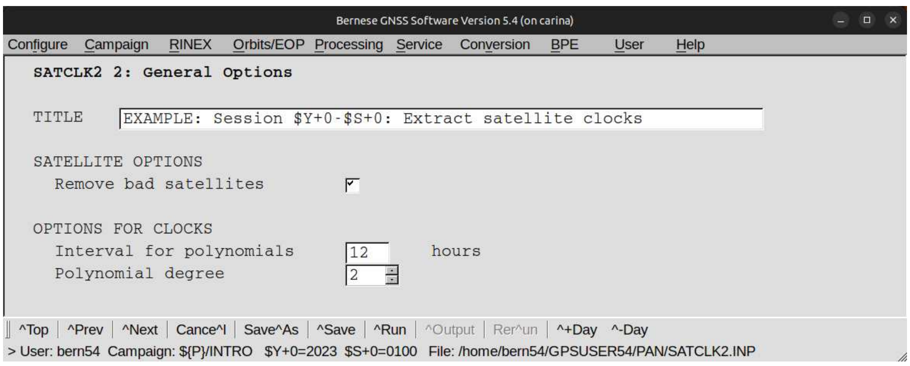
As you can notice the RMS errors are slightly larger. This does not mean that the orbits from CODE are better than the IGS orbits. The orbit model in ORBGEN is just more consistent with the orbit model used at CODE. Notice that, especially for a PPP, it is important to represent the orbit as accurately as possible, because inconsistencies between the orbits and clocks will degrade the results. For external orbits you can improve the fit (i.e., reduce the residuals) in ORBGEN, e.g., by setting up more frequent stochastic pulses.

In the example for day 011 of year 2023 a satellite 72 appears. The GPS–satellite 22 had a repositioning event at 11-Jan-2023 05:29:51 (see `${CONFIG}/SAT_2023.CRX`). The satellite is introduced in the processing with two independent arcs: one before (number 22) and one after (number 72) the event (you may verify this by the number of epochs available for each of these two satellite arcs).

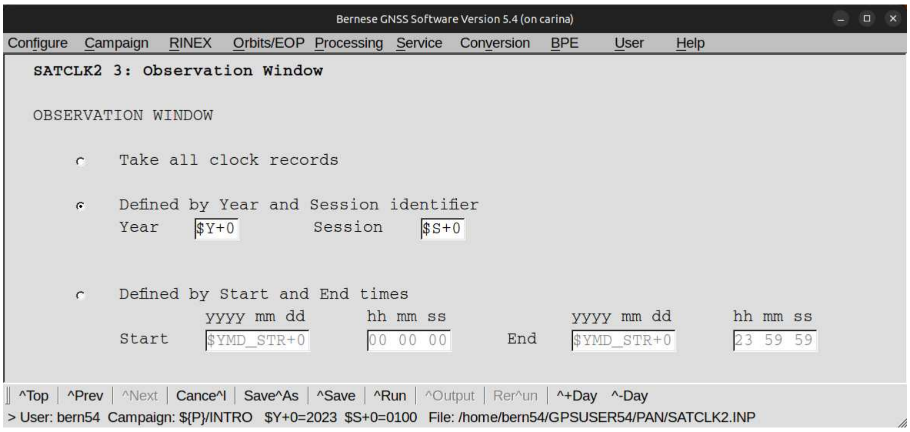
3.3 Extract satellite clock corrections

As the next step we run SATCLK2 from "Menu>Orbits/EOP>Import satellite clocks>From precise orbit files" in order to generate a satellite clock file (`CLK`) from the precise orbit file (`PRE`). The clock file will be needed, e.g., in program CODSPP (see Section 4.2.1, to be discussed in the Tuesday's lectures on pre-processing).





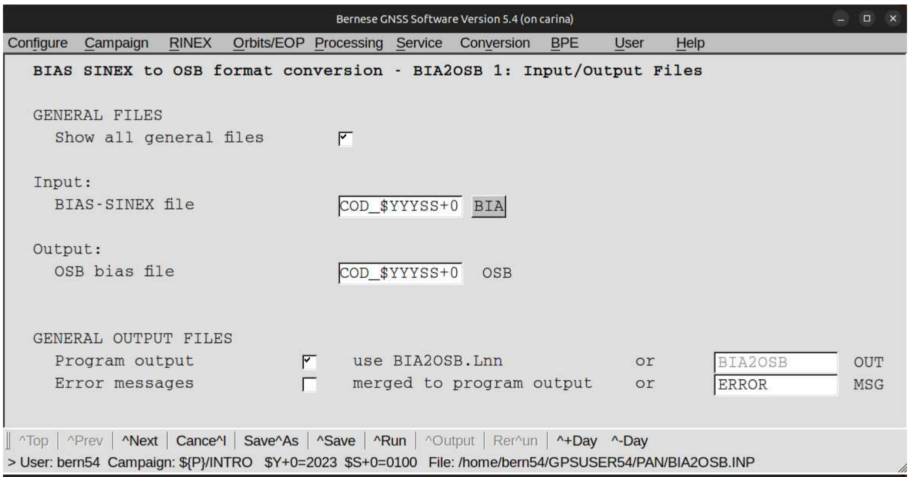
Panel "SATCLK2 2: General Options" contains the options for extracting the satellite clock information. The clock values in the precise orbit file are sampled to 15 min. We interpolate with a "Polynomial degree" of 2 with an "Interval for polynomials [h]" of 12 hours. This is good enough for the receiver clock synchronization in CODSPP.

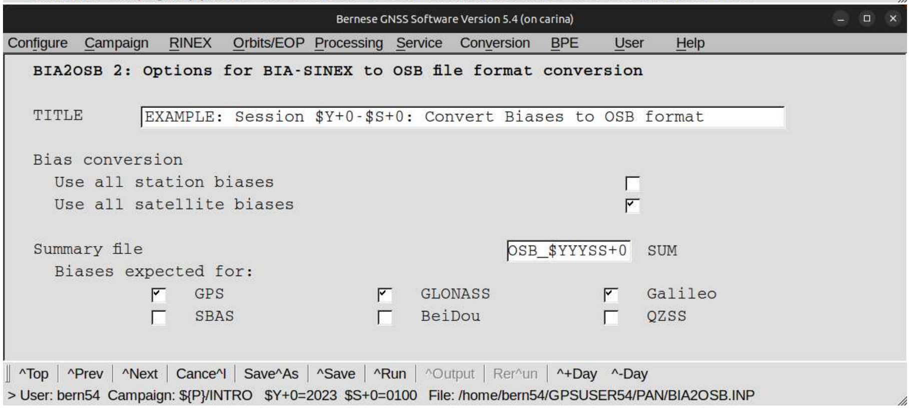


3.4 Convert Bias Corrections from Bias SINEX into Bernese bias Format

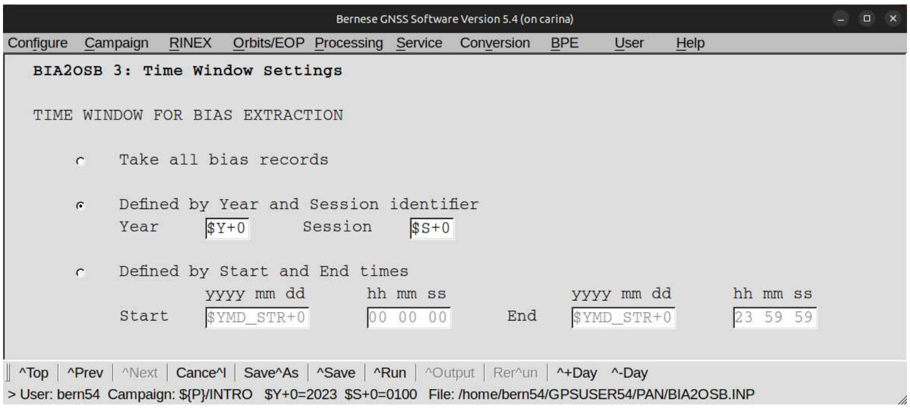
Ideally the clock corrections (either in a separate clock RINEX format or also in a precise orbit file) are provided together with a consistent set of code and potentially phase biases. Biases provided by a different source could potentially be less consistent.

In this context we run BIA2OSB from "Menu>Conversion>BIAS-SINEX to Bernese format" in order to extract biases from international Bias SINEX format file (BIA) into the Bernese formatted file with OSBs (OSB, both files are located in the ORB directory of the campaign).





We select the current session as the time window in order to extract the expected set of satellites if the input Bias SINEX file contains a longer interval than just the current session (like in our case) and within this interval a satellite change takes place:



If no bias information is provided we can use default code biases from the CODE processing (`http://www.aiub.unibe.ch/download/BSWUSER54/ORB`).

3.5 Session Goals

At the end of this session, you should have created the following files:

1. *Bernese pole file in the campaign's ORB directory:* `COD_20230100.ERP` ,
2. *Bernese standard orbit file in the ORB directory:* `COD_20230100.STD` ,
3. *Bernese satellite clock file in the ORB directory:* `COD_20230100.CLK` .
4. *Biases in Bernese format file in the ORB directory:* `COD_20230100.OSB` .

4 Terminal Session: Tuesday

Today's terminal session is to:

1. *import the observations from the RINEX format into the Bernese format using RXOBV3 (section 4.1).*
2. *preprocess the Bernese observation files:*
   - *receiver clock synchronization (CODSPP, section 4.2.1)*
   - *baseline generation (SNGDIF, section 4.2.2)*
   - *preprocess baselines (MAUPRP, section 4.2.3)*

4.1 Importing the Observations

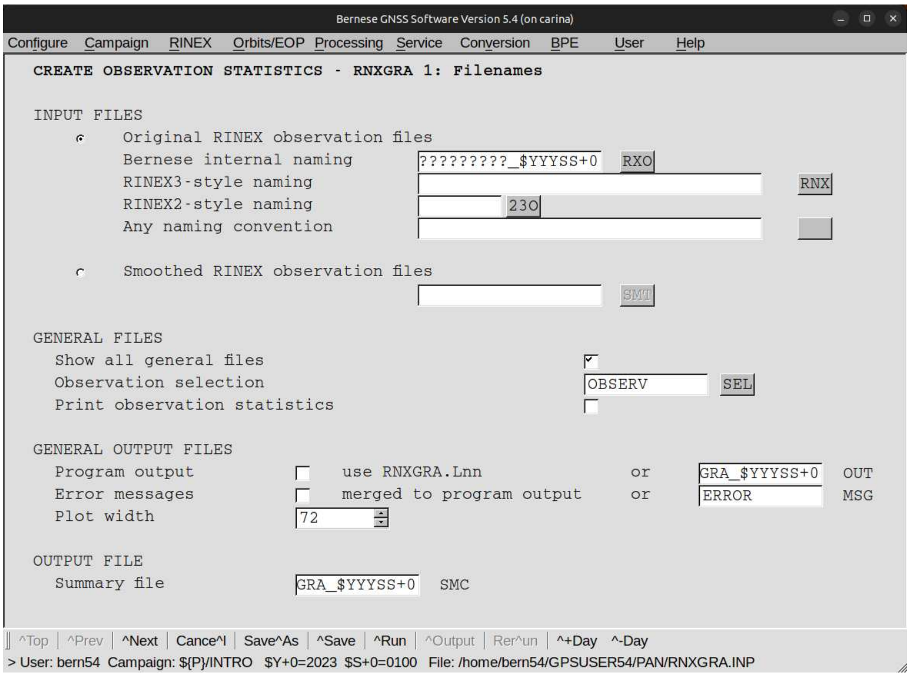
The campaign has been set up and all necessary files are available. The first part of processing consists of the transfer of the observations from RINEX to Bernese (binary) format.

4.1.1 Inventory of the input RINEX files

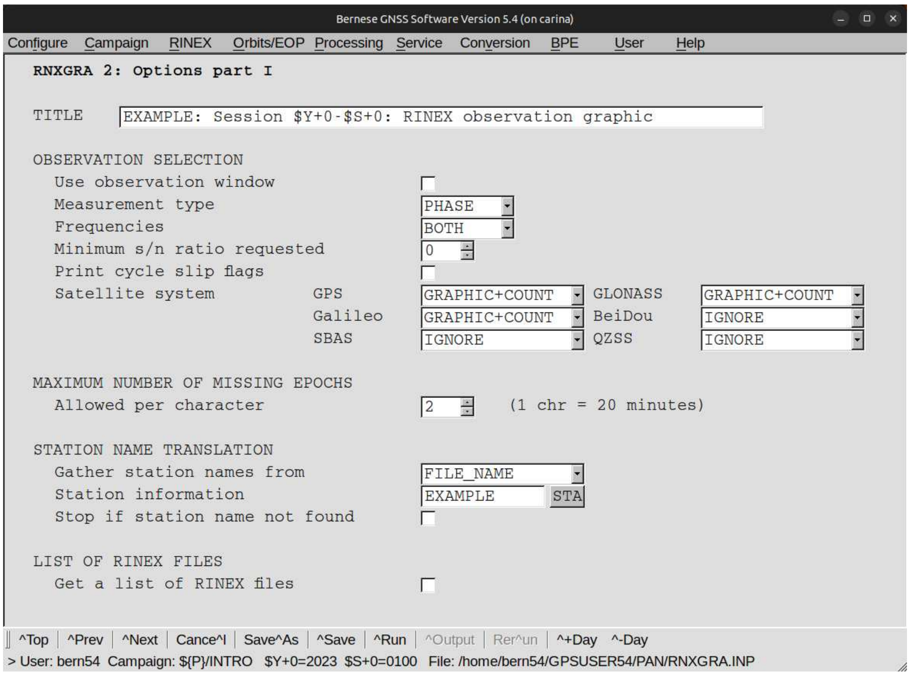
Before starting the data analysis, it is recommended to get an overview of the data availability, completeness, and a first impression on the data quality. For this purpose you may generate a pseudographic from the RINEX observation files using the program RNXGRA in "Menu>RINEX>RINEX utilities>Create observation statistics".

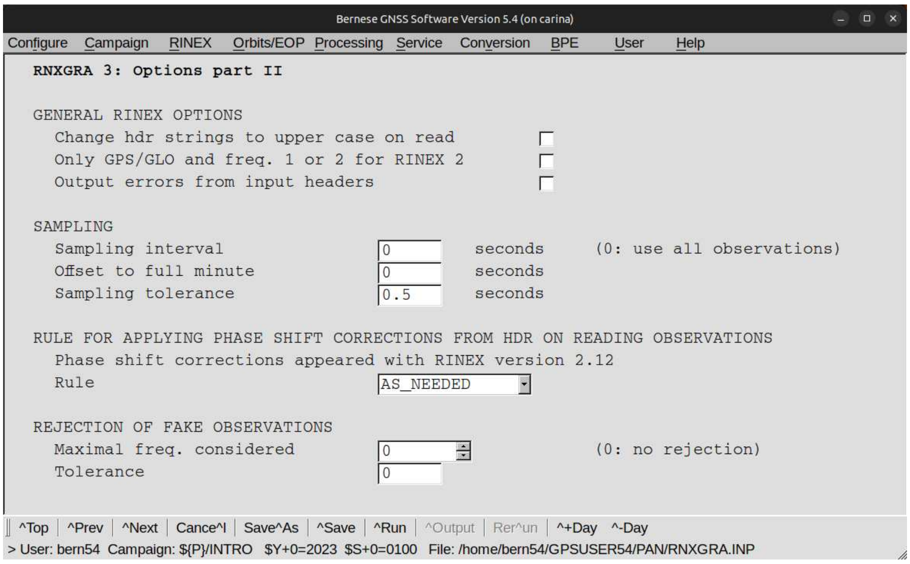
Note that this step is not mandatory and can also be skipped during the tutorial exercise.

You have to select the RINEX observation files for option "Original RINEX observation files". All three naming schemes of the files are supported by the user interface: "Bernese internal naming", "RINEX3-style naming", and "RINEX2-style naming". If there are files specified in more than one field, they are cumulated.

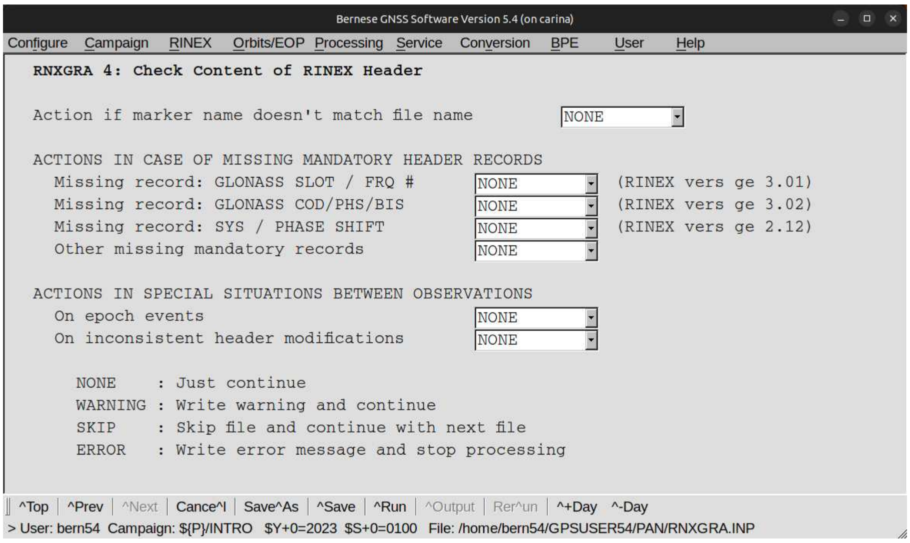


As only GPS, GLONASS, and Galileo satellite orbits are processed in this example, only those systems are selected





All validations are disabled in this step because they can also be carried out when importing the data by the program RXOBV3 described in Section 4.1.2 .



From the processing you get a summary in `${P}/INTRO/OUT/GRA_20230100.SMC`:

```
DATE : 2023-01-10

 PHASE OBSERVATIONS
 BOTH FREQUENCIES

    1 |**************3-                 -147873-                       -14*****
    2 |                  -3********731            -23****************621-
    3 |******************41-                     -2333-                    -17*
    4 |  -4******************711-                       -37**732-
    5 |                 -3***************41           -116*********8-
    6 |      -6***************4-           -129*********6-
    7 |          -19*****************811-                        14*****951-
    8 |******3-              -1489***72-                        -14************
    9 |     -16*******************21-                      -3332-
   10 |**941-                         -5********42-            -29*************
...
  231 |       -12276972-                              -15********************85-
  233 |                   -2*******9631-                -47********************
  234 |***************4-                -1389*******62-
  236 |********92-                    --237**962-
 -----+-----------------+-----------------+-----------------+-----------------+
      0                                  12                                  24
```

```
NUMBER OF SATELLITES INCLUDED IN DATA FILES:    82
```

The summary reports the number of stations tracking each satellite during a certain period of the day. If more than 9 stations are in view a *-character is written.

The second part shows how many satellites were observed by each station during the course of the day (again the *-character is indicating a number > 9). This part is shown separately for each selected satellite system.

```
DATE : 2023-01-10

PHASE OBSERVATIONS
BOTH FREQUENCIES

SATELLITE SYSTEM: GPS

BRST |*988**9**999*8999799****9**957*98*999**99889*9******99***9**8899**9*9*99
GANP |9**89*999**98*889*988**9***989*9989***8*89898****9***999*99****988889998
HERT |**88**9***988899999**9*9**999**98*999**999*9*9*999****9999*9*9***999999
JOZ2 |****9999***99*889*9*********8**89*******9999*****9****99*98*******989999
LAMA |998869889*8886767898*7889898886788899898677799999799*898788888887667888
MATE |8989*99799***898899899998998787989**898*7998999*****98899**98*7799978978
MIKL |*9*9*999*******88***89****9*9999*********9899*****9****************9988***
MORP |*9888889*98887776889*988*999888797998899757999998988799789879888*9878779
ONSA |**98*99*****989*****************99*******978***************9*******9*999*
ORID |99**99*99**9**9***989***9**8899*99**9*9***99*********99*****9*88**9*99*9
PTBB |**899898***89978******99****9*889*9**9*98889***999******999******9789899
TLSE |9*99******99*989*9*9***********99**9*9*9*************9*9*9***89***989*99
VILL |99899878998799799878799*99998999789899*9867899999**8788898887899987879*9
WSRT |**98**9*****9999******9*****************99****9**********99*********999*
WTZR |9*99**98***9**8****9***99*******89**9***99989**********99*9*9*******98*999
WTZZ |9*9-   -8***8**8***99***99******89**9***99989*-    -****98*9*9******989999
ZIM2 |9**8**99**99**87**9****9*****8989**999**9*99*9*******99**9**999**878*9*9
ZIMM |9988**99**989978**789**99*9*99989*9989**9799*9**8****9**99*99888*878*999
-----+-----------------+-----------------+-----------------+-----------------+
     0                                   12                                24
```

From this output it can be seen that station WTZZ has two short outages of up to one hour. This is typically caused by data management issues at the station (related to the extraction of the hourly RINEX files).

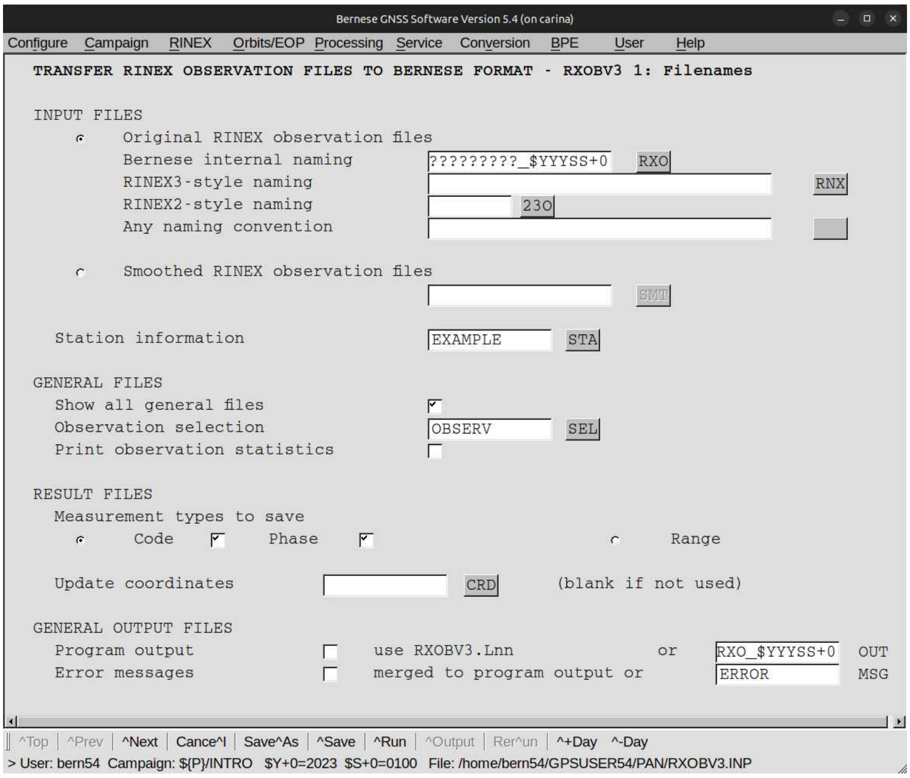
Similar tables for the other systems are available as well.

The program output file `${P}/INTRO/OUT/GRA_20230100.OUT` provides even more detailed information on each individual RINEX file.

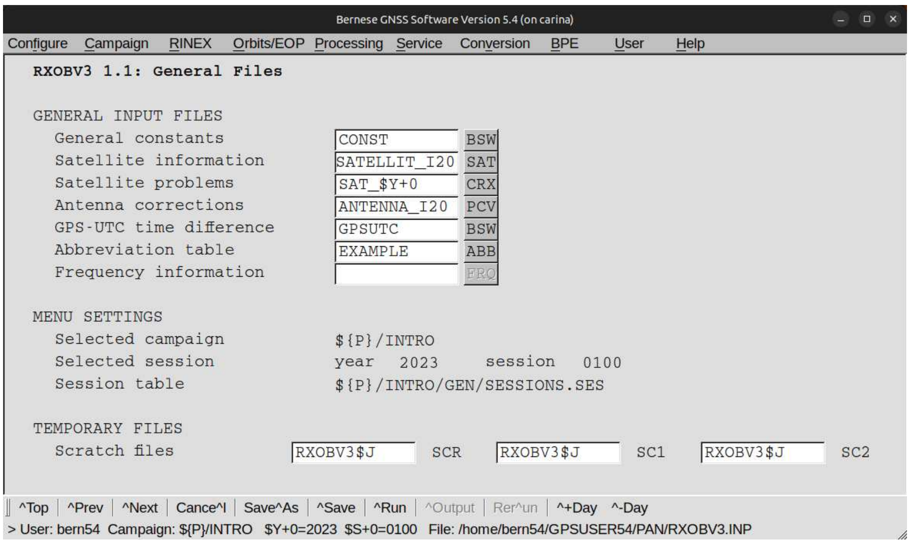
4.1.2 Converting the Observations from RINEX into Bernese format

Importing the RINEX observation files is the task of the program RXOBV3 in "Menu>RINEX >Import RINEX to Bernese format>Observation files" (we do not use the RINEX navigation files in this processing example).

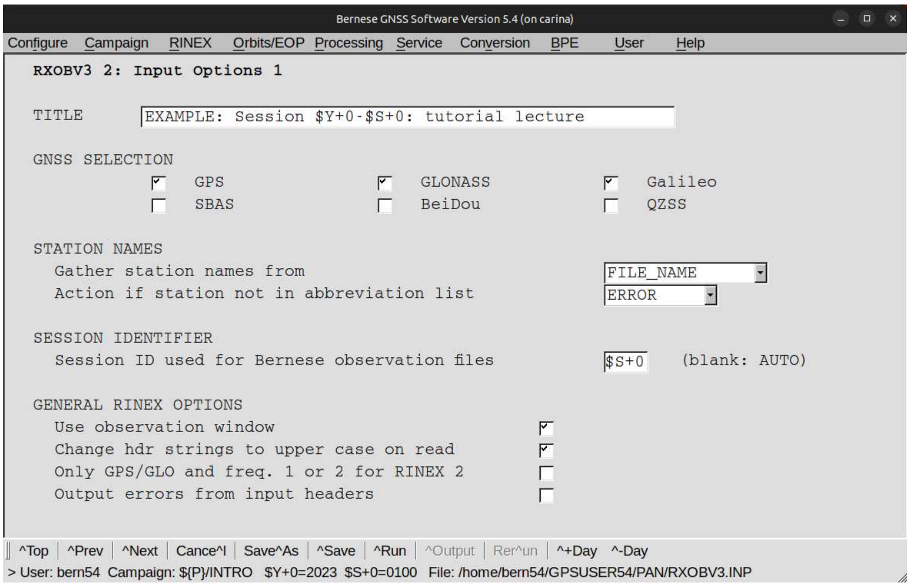
The principle of specifying the input RINEX files is the same as for all RINEX related programs (description see page 34):

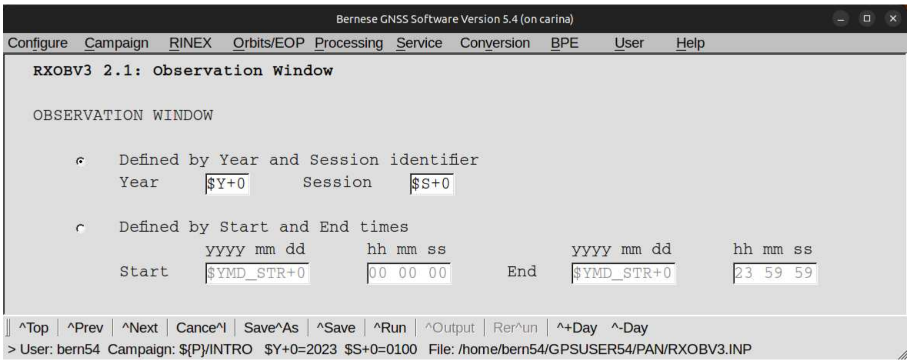


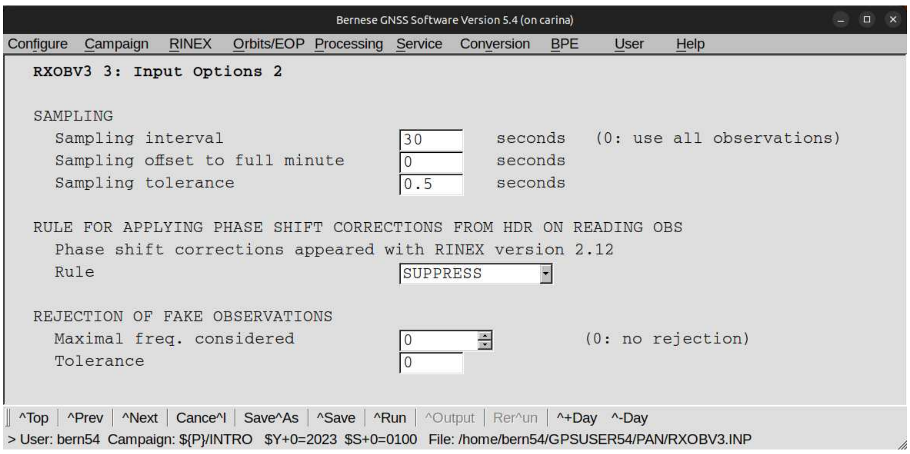
The next panel specifies the general input files. The "Satellite information" and "Antenna phase center corrections" files should consistently refer to the used reference frame even if the corrections themselfes are not yet needed for the import step.

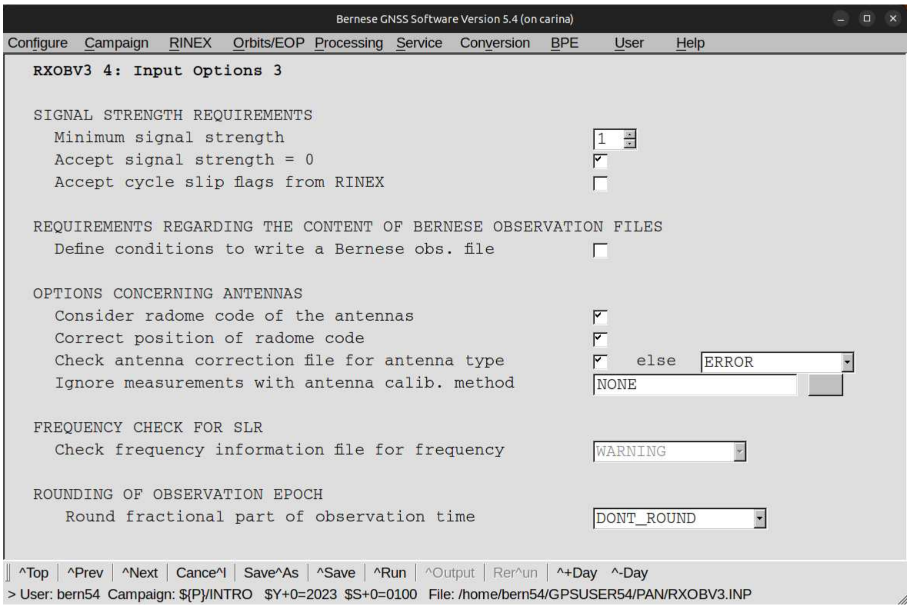


Other panels allow to select the data to be imported and to specify a few parameters for the Bernese observation header files.
Because the orbits contain only the GPS-, GLONASS, and Galileo-satellites, activate the related checkboxes in the option “GNSS SELECTION”.



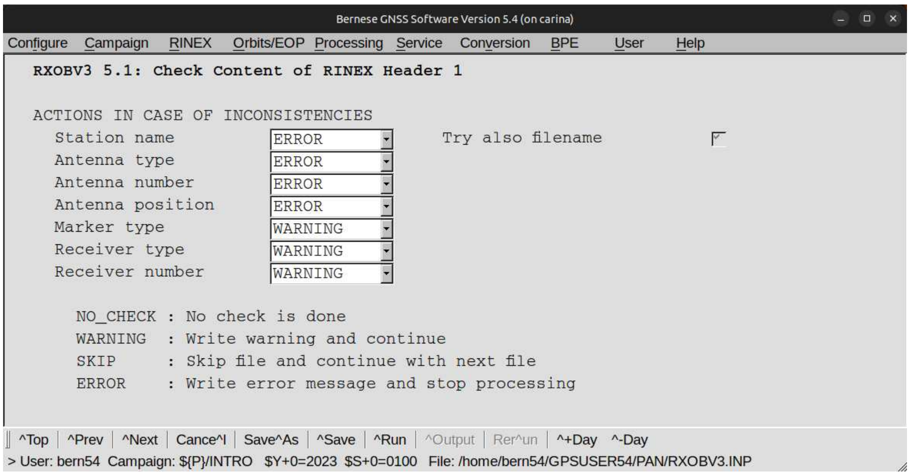


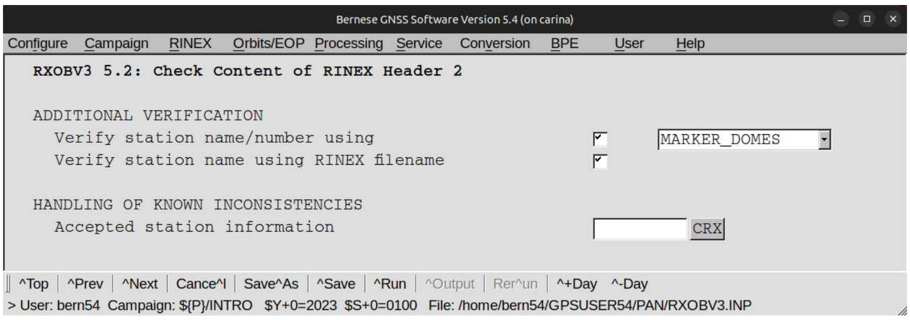




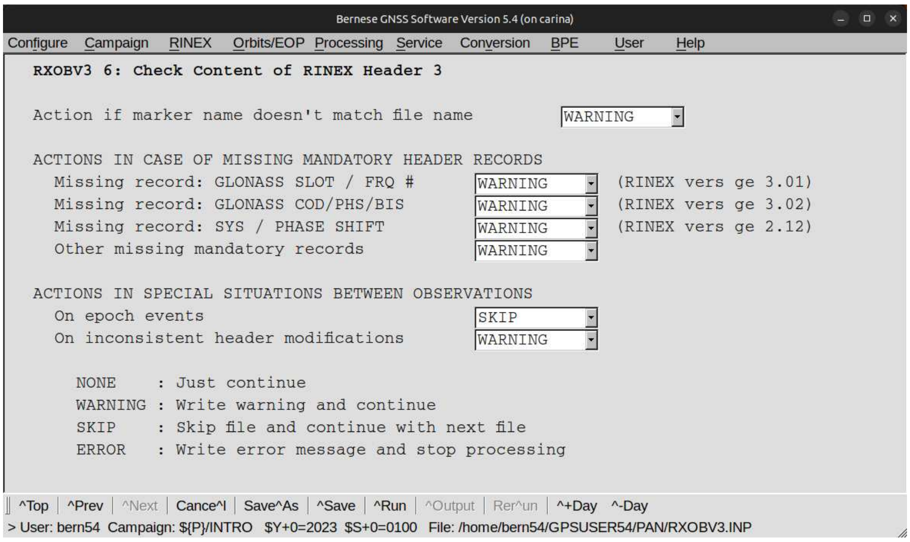
When switching for instance the option "Ignore measurements with antenna calib. method" to ADOPTED from GPS the observations from those GNSS are not imported where no antenna calibration is available for (see Table 1.2). It may also make sense to completely exclude stations where no calibration for the antenna with the specific radome is available (ADOPTED from NONE). In the case of the example dataset this would affect the station ONSA .

The next two panels are only displayed, if you specified a station information file in "RXOBV3 1: Filenames". They allow you to configure the RINEX header information verification:





The last panel allows for checking the compliance of the input RINEX file with the format definition.



Start the program with the `^Run`–button.

Various warning messages appear. In an automated processing they are sorted according to a priority and become better readable. In this case they are ordered just by the processing order. Most of them are not critical and just inform about assumptions made by the program RXOBV3 based on the RINEX format description:

```
### SR SAVMEA: Receiver clock offset in RINEX file found.
              It is assumed, that the observations in the
              RINEX file are not corrected by applying the
              receiver clock offset. Please check the
              keyword "RCV CLOCK OFFS APPL" in the RINEX file
              header!
              RINEX FILENAME: ...RO/RAW/BRST00FRA_20230100.RXO
```

The amount of these massages may be managed by the setting in panel “RXOBV3 6: Check Content of RINEX Header 3” .

More relevant are messages indicating observations were removed due to an entry in the “Satellite problems” file. In the example, stations BRST and VILL provide data for the five GLONASS satellites R06, R10, R22, R23 and R25, and the Galileo satellite E20[1] which are removed because of an entry in the “Satellite problems” file specified. in panel “RXOBV3 1.1: General Files”.

```
### SR SAVMEA: PROBLEM FOR SATELLITE:  123
              INDICATED IN SATCRUX : ${CONFIG}/SAT_2023.CRX
              PROBLEM              : BAD PHASE+CODE
              REQUESTED ACTION     : OBS. REMOVED
              TIME WINDOW          : 2020-11-25 06:00:00  2099-12-31 23:59:59
              IN RINEX FILE        : ...RO/RAW/BRST00FRA_20230100.RXO


### SR SAVMEA: PROBLEM FOR SATELLITE:  110
              INDICATED IN SATCRUX : ${CONFIG}/SAT_2023.CRX
              PROBLEM              : BAD PHASE+CODE
              REQUESTED ACTION     : OBS. REMOVED
              TIME WINDOW          : 2019-08-02 00:00:00  2099-12-31 23:59:59
              IN RINEX FILE        : ...RO/RAW/BRST00FRA_20230100.RXO
```

[1] GLONASS satellites carry the letter `R` in RINEX and satellite numbers between 100 and 199 within the *Bernese GNSS Software*. Galileo satellites have the RINEX letter `E` and satellite numbers between 200 and 299.

The program produces an output file `RXO_20230100.OUT` in the directory `${P}/INTRO/OUT` (resp. corresponding filenames for the other sessions). This file may be browsed using the `^Output` button or with "Menu>Service>Browse program output" . After echoing the input options, the file provides an overview of the observation intervals), on the station information records in the RINEX observation file header and on the values that are used for the processing in the *Bernese GNSS Software*. In addition some observation statistics are available. In the last section you may check the completeness of the Bernese observation files by the available number of epochs:

```
 TABLE OF INPUT AND OUTPUT FILE NAMES:
 ------------------------------------
                                                                  #observ.      #satell.
 Num  Rinex file name              Bernese code  header  file   #epo #C1/P1   #P2  GPS  GLO  GAL
                                   Bernese code  observ. file
                                   Bernese phase header  file   #epo    #L1   #L2  GPS  GLO  GAL
                                   Bernese phase observ. file
 ---------------------------------------------------------------------------------------------

   1  ...BRST00FRA_20230100.RXO    ${P}/INTRO/OBS/BRST0100.CZH  2880  72794 72195   31   20   24
                                   ${P}/INTRO/OBS/BRST0100.CZO
                                   ${P}/INTRO/OBS/BRST0100.PZH  2880  72661 72123   31   20   24
                                   ${P}/INTRO/OBS/BRST0100.PZO

   2  ...GANP00SVK_20230100.RXO    ${P}/INTRO/OBS/GANP0100.CZH  2880  74837 73985   31   20   24
                                   ${P}/INTRO/OBS/GANP0100.CZO
                                   ${P}/INTRO/OBS/GANP0100.PZH  2880  74561 73779   31   20   24
                                   ${P}/INTRO/OBS/GANP0100.PZO

   3  ...HERT00GBR_20230100.RXO    ${P}/INTRO/OBS/HERT0100.CZH  2880  50249 50107   31   20    0
                                   ${P}/INTRO/OBS/HERT0100.CZO
                                   ${P}/INTRO/OBS/HERT0100.PZH  2880  50249 50104   31   20    0
                                   ${P}/INTRO/OBS/HERT0100.PZO
...

  17  ...ZIM200CHE_20230100.RXO    ${P}/INTRO/OBS/ZIM20100.CZH  2880  75859 75417   31   20   24
                                   ${P}/INTRO/OBS/ZIM20100.CZO
                                   ${P}/INTRO/OBS/ZIM20100.PZH  2880  75613 75241   31   20   24
                                   ${P}/INTRO/OBS/ZIM20100.PZO

  18  ...ZIMM00CHE_20230100.RXO    ${P}/INTRO/OBS/ZIMM0100.CZH  2880  28392 28227   31    0    0
                                   ${P}/INTRO/OBS/ZIMM0100.CZO
                                   ${P}/INTRO/OBS/ZIMM0100.PZH  2880  28284 28142   31    0    0
                                   ${P}/INTRO/OBS/ZIMM0100.PZO
```

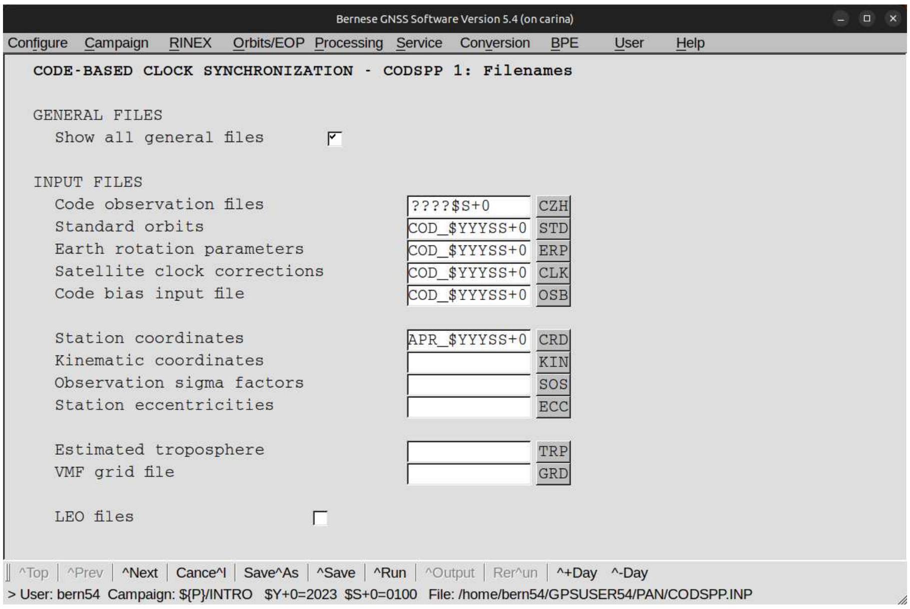
If epochs or satellites are missing for some RINEX files you may check this with the RINEX observation graphic from program RNXGRA ("Menu>RINEX>RINEX utilities>Create observation statistics"). In January 2023 31 GPS, 20 GLONASS, and 26 Galileo satellites were active.

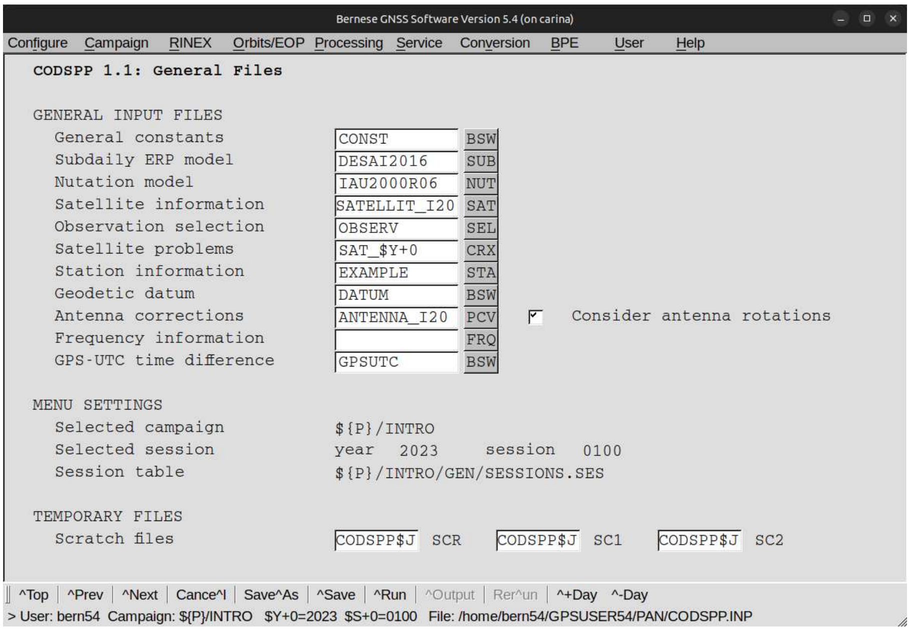
At the end of the RXOBV3 output there is a table of RINEX files rejected during the import for some reasons.

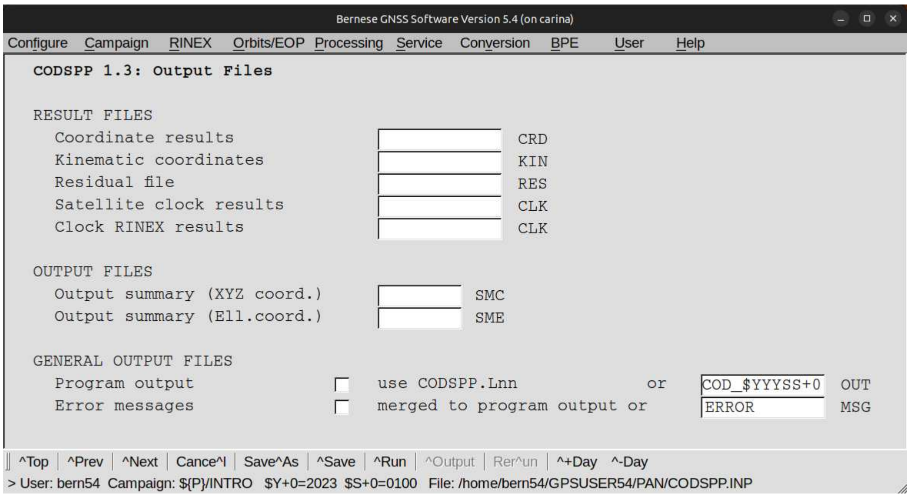
4.2 Data Preprocessing (I)

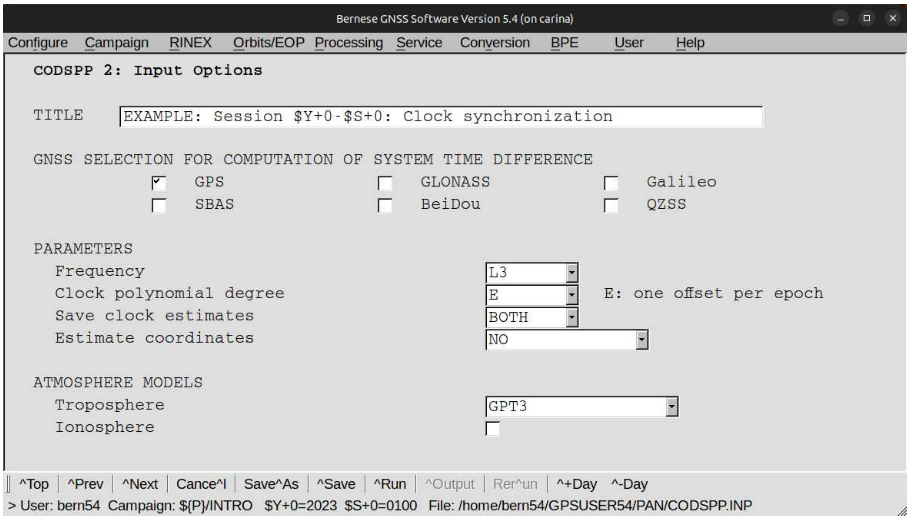
4.2.1 Receiver Clock Synchronization

Now we are ready to enter the processing part of the *Bernese GNSS Software*. We have to run three programs for this example. The first program is called CODSPP ("Menu>Processing >Code-based clock synchronization"). Its main task is to compute the receiver clock corrections with respect to the GPS system time.

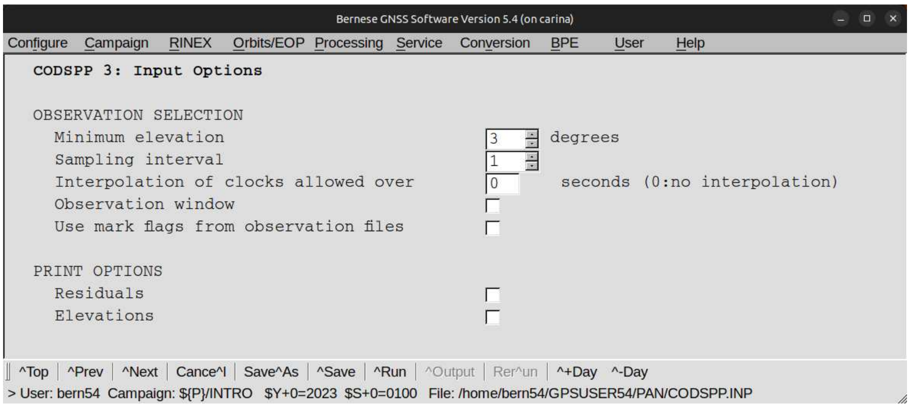

Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
CODE-BASED CLOCK SYNCHRONIZATION - CODSPP 1: Filenames
GENERAL FILES
Show all general files
INPUT FILES
Code observation files ????$S+0 CZH
Standard orbits COD_$YYYSS+0 STD
Earth rotation parameters COD_$YYYSS+0 ERP
Satellite clock corrections COD_$YYYSS+0 CLK
Code bias input file COD_$YYYSS+0 OSB
Station coordinates APR_$YYYSS+0 CRD
Kinematic coordinates KIN
Observation sigma factors SOS
Station eccentricities ECC
Estimated troposphere TRP
VMF grid file GRD
LEO files
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/CODSPP.INP

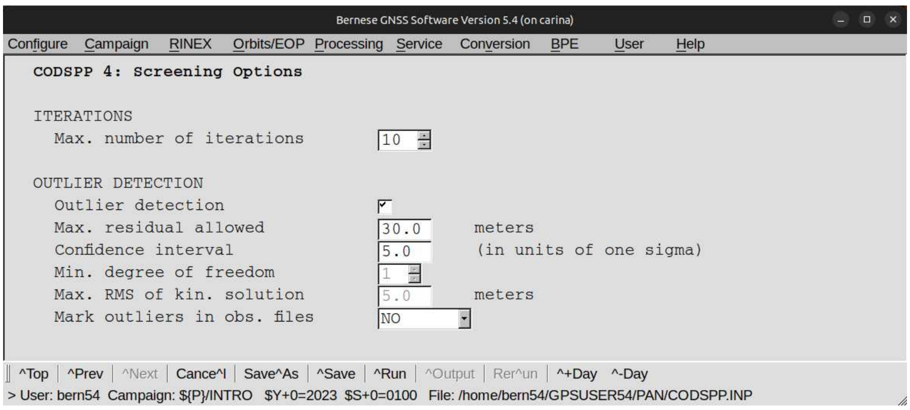

Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
CODSPP 1.1: General Files
GENERAL INPUT FILES
General constants CONST BSW
Subdaily ERP model DESAI2016 SUB
Nutation model IAU2000R06 NUT
Satellite information SATELLIT_I20 SAT
Observation selection OBSERV SEL
Satellite problems SAT_$Y+0 CRX
Station information EXAMPLE STA
Geodetic datum DATUM BSW
Antenna corrections ANTENNA_I20 PCV Consider antenna rotations
Frequency information FRQ
GPS-UTC time difference GPSUTC BSW
MENU SETTINGS
Selected campaign ${P}/INTRO
Selected session year 2023 session 0100
Session table ${P}/INTRO/GEN/SESSIONS.SES
TEMPORARY FILES
Scratch files CODSPP$J SCR CODSPP$J SC1 CODSPP$J SC2
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/CODSPP.INP


Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
CODSPP 1.3: Output Files
RESULT FILES
Coordinate results CRD
Kinematic coordinates KIN
Residual file RES
Satellite clock results CLK
Clock RINEX results CLK
OUTPUT FILES
Output summary (XYZ coord.) SMC
Output summary (Ell.coord.) SME
GENERAL OUTPUT FILES
Program output use CODSPP.Lnn or COD_$YYYSS+0 OUT
Error messages merged to program output or ERROR MSG
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/CODSPP.INP



We already have geocentric coordinates of good quality available for the sites from the PPP example BPE. Therefore, the option "Estimate coordinates" may be set to NO. The most important option in this CODSPP run is "Save clock estimates". It has to be set to BOTH in order to write the estimated receiver clock corrections into both, the code observation files and the phase observation files.





CODSPP produces the following output:

```
...
 STATION:  BRST 10004M004   FILE:  ${P}/INTRO/OBS/BRST0100.CZO      RECEIVER UNIT:    999999
 -------------------------------------------------------------------------------------------

 DAY OF YEAR         :   10
                                     FROM                           TO
 OBSERVATIONS        :       2023-01-10  00:00: 0.00       2023-01-10  23:59:30.00
 REQUESTED WINDOW    :                 --                           --

 MEASUREMENT INTERVAL:   30 SEC
 SAMPLING RATE       :    1
 PROCESSED FREQUENCY :   L3
 ELEVATION LIMIT     :    3 DEG

                              TROPOSPHERE                IONOSPHERE
 ATMOSPHERE MODELS   :        GPT3                       NONE


 STATISTICS FOR SATELLITE SYSTEM: GPS
 --------------------------------

 SATELLITE NUMBER    :     1     2     3     4     5     6     7     8     9    10 ...   TOTAL
 OBSERVATIONS IN FILE:   849  1049   812   939   958   968  1042   901   797  1082 ...   29012
 USED OBSERVATIONS   :   832  1029   807   939   939   959  1025   865   788  1058 ...   28572
 BAD OBSERVATIONS (%):   2.0   1.9   0.6   0.0   2.0   0.9   1.6   4.0   1.1   2.2 ...     1.5
 RMS ERROR (M)       :   1.1   1.0   1.0   1.3   1.2   1.0   1.1   1.5   1.0   1.1 ...     1.1


 RESULTS:
 --------

 OBSERVATIONS IN FILE:     29012
 USED OBSERVATIONS   :     28572
 BAD OBSERVATIONS    :         1.52 %
 RMS OF UNIT WEIGHT  :         1.20 M
 NUMBER OF ITERATIONS:         2


 STATION COORDINATES:
 --------------------

 LOCAL GEODETIC DATUM:  IGS20

                                  A PRIORI        NEW            NEW- A PRIORI   RMS ERROR
  BRST 10004M004    X            4231162.37      4231162.37           0.00         0.00
  (MARKER)          Y            -332746.36      -332746.36           0.00         0.00
                    Z            4745131.11      4745131.11           0.00         0.00

                    HEIGHT            65.82           65.82           0.00         0.00
                    LATITUDE      48 22 49.787    48 22 49.787     0  0  0.000        0.0000
                    LONGITUDE   -  4 29 47.726  -  4 29 47.726     0  0  0.000        0.0000



 CLOCK PARAMETERS:
 -----------------

 OFFSET FOR REFERENCE EPOCH:               -0.000000021  SEC


 CLOCK OFFSETS STORED IN CODE+PHASE OBSERVATION FILES

 RECEIVER UNIT       :  999999
 REFERENCE EPOCH     :       2023-01-10  00:00: 0.00
...
```

```
...
*******************************************************************************************
SUMMARY OF BAD OBSERVATIONS
*******************************************************************************************

MAXIMUM RESIDUAL DIFFERENCE ALLOWED  :     30.00 M
CONFIDENCE INTERVAL OF F*SIGMA WITH F:      5.00

NUMBER OF BAD OBSERVATION PIECES     :         8

NUMB FIL  STATION           TYP SAT        FROM                   TO            #EPO
-------------------------------------------------------------------------------------------

   1   6  MATE 12734M008    OUT   2  2023 01 10 08 54 00  2023 01 10 08 54 00      1

   2  13  VILL 13406M001    OUT  27  2023 01 10 00 46 00  2023 01 10 00 46 00      1
   3  13  VILL 13406M001    OUT  27  2023 01 10 00 47 30  2023 01 10 00 47 30      1
   4  13  VILL 13406M001    OUT   4  2023 01 10 00 49 00  2023 01 10 00 49 30      2
   5  13  VILL 13406M001    OUT  12  2023 01 10 10 58 00  2023 01 10 10 58 00      1
   6  13  VILL 13406M001    OUT  29  2023 01 10 13 36 00  2023 01 10 13 37 00      3
   7  13  VILL 13406M001    OUT  29  2023 01 10 13 38 30  2023 01 10 13 42 30      9

   8  16  WTZZ 14201M014    OUT  10  2023 01 10 10 51 00  2023 01 10 10 51 00      1

-------------------------------------------------------------------------------------------



------------------------------------------------------------------
>>> CPU/Real time for pgm "CODSPP": 0:01:16.883 / 0:01:16.889
>>> Program finished successfully
```

The most important message in the output file is CLOCK OFFSETS STORED IN CODE+PHASE OBSERVATION FILES. This indicates that the receiver clock corrections computed by CODSPP are stored in code and phase observation files.

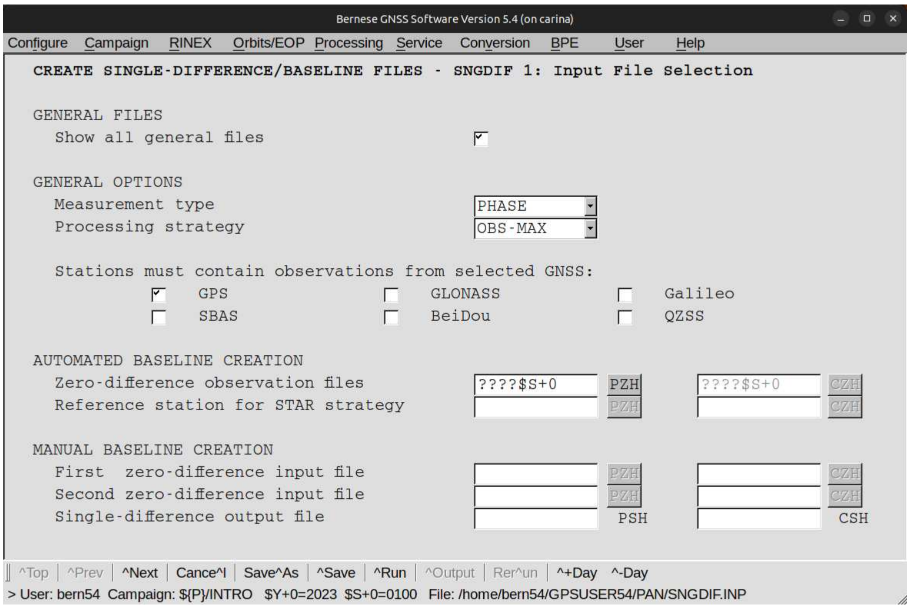
The a posteriori RMS error (for each zero difference file processed) should be checked in the CODSPP output file. A value of about 20–30 m is normal if Selective Availability (SA) — artificial degradation of the satellite clock accuracy — is on (before May 2000). Without SA a value of about 3 m is expected if P–code measurements are available (this is the case for the time interval of the processing example). However, even worse code measurements would still be sufficiently accurate to compute the receiver clock corrections with the necessary accuracy of 1 μs .

You may use the extraction program CODXTR ("Menu>Processing>Program output extraction>Code-based clock synchronization") to generate a short summary from the CODSPP program output:

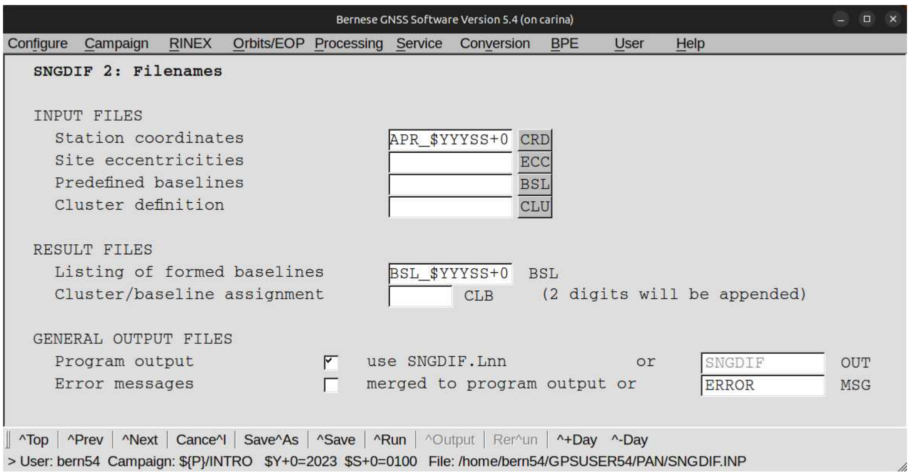
```
...
-------------------------------------------------------------------------------
File   Input files
-------------------------------------------------------------------------------
   1   ${P}/INTRO/OUT/COD_20230100.OUT
-------------------------------------------------------------------------------



 18 FILES, MAX. RMS:     4.48 M     FOR STATION: MORP 13299S001
           MAX. BAD:     4.63 %     FOR STATION: WSRT 13506M005
           MAX. OFF:    -0.40 MSEC  FOR STATION: WTZZ 14201M014


------------------------------------------------------------------
>>> CPU/Real time for pgm "CODXTR": 0:00:00.013 / 0:00:00.013
>>> Program finished successfully
```

4.2.2 Form Baselines

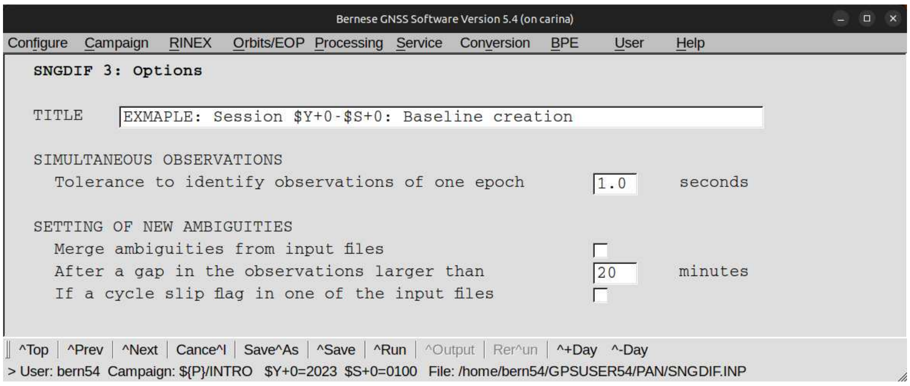
The second preprocessing program is called SNGDIF and may be activated in "Menu >Processing>Create baseline files". SNGDIF creates the single differences and stores them into single-difference observation files. We use the strategy OBS-MAX for PHASE observation files.

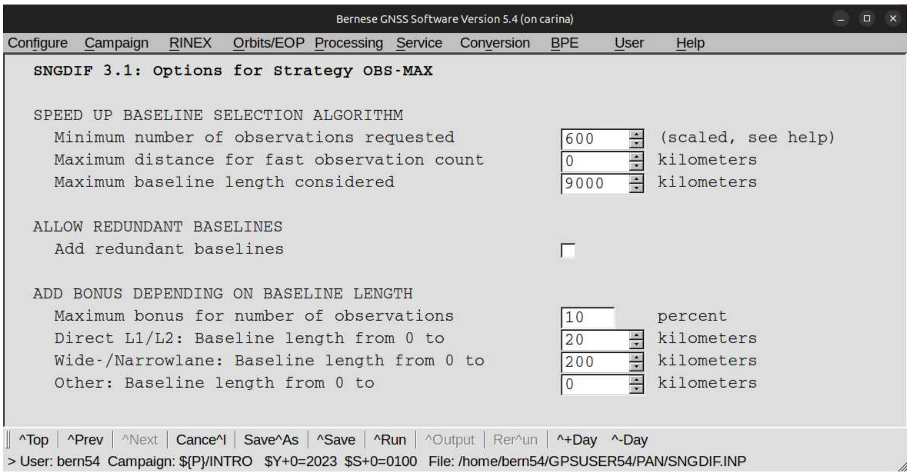


By activating the option "Stations must contain observ. from GPS" you demand that stations included in the baseline creation must contain at least GPS measurements. This option can be used to exclude those datasets containing no GPS observations.



The result file specified in option "Listing of formed baselines" stores the selected baseline configuration for further use.





The output of SNGDIF echoes the zero difference files used and the single difference files created. The first table confirms that all stations provide at least data from GPS. For that reason all stations are included in the baseline creation.

```
...

 NUM  HEADER FILE NAMES                     STATION NAME     #SAT  SYS    F  REMARK
------------------------------------------------------------------------------------
   1  ${P}/INTRO/OBS/BRST0100.PZH           BRST 10004M004    75   GRE    2  included
   2  ${P}/INTRO/OBS/GANP0100.PZH           GANP 11515M001    75   GRE    2  included
   3  ${P}/INTRO/OBS/HERT0100.PZH           HERT 13212M010    51   GR     2  included
   4  ${P}/INTRO/OBS/JOZ20100.PZH           JOZ2 12204M002    75   GRE    2  included
   5  ${P}/INTRO/OBS/LAMA0100.PZH           LAMA 12209M001    73   GRE    2  included
   6  ${P}/INTRO/OBS/MATE0100.PZH           MATE 12734M008    75   GRE    2  included
   7  ${P}/INTRO/OBS/MIKL0100.PZH           MIKL 12335M001    75   GRE    2  included
   8  ${P}/INTRO/OBS/MORP0100.PZH           MORP 13299S001    31   G      2  included
   9  ${P}/INTRO/OBS/ONSA0100.PZH           ONSA 10402M004    75   GRE    2  included
  10  ${P}/INTRO/OBS/ORID0100.PZH           ORID 15601M001    75   GRE    2  included
  11  ${P}/INTRO/OBS/PTBB0100.PZH           PTBB 14234M001    75   GRE    2  included
  12  ${P}/INTRO/OBS/TLSE0100.PZH           TLSE 10003M009    77   GRE    2  included
  13  ${P}/INTRO/OBS/VILL0100.PZH           VILL 13406M001    77   GRE    2  included
  14  ${P}/INTRO/OBS/WSRT0100.PZH           WSRT 13506M005    75   GRE    2  included
  15  ${P}/INTRO/OBS/WTZR0100.PZH           WTZR 14201M010    77   GRE    2  included
  16  ${P}/INTRO/OBS/WTZZ0100.PZH           WTZZ 14201M014    77   GRE    2  included
  17  ${P}/INTRO/OBS/ZIM20100.PZH           ZIM2 14001M008    75   GRE    2  included
  18  ${P}/INTRO/OBS/ZIMM0100.PZH           ZIMM 14001M004    31   G      2  included

...
```

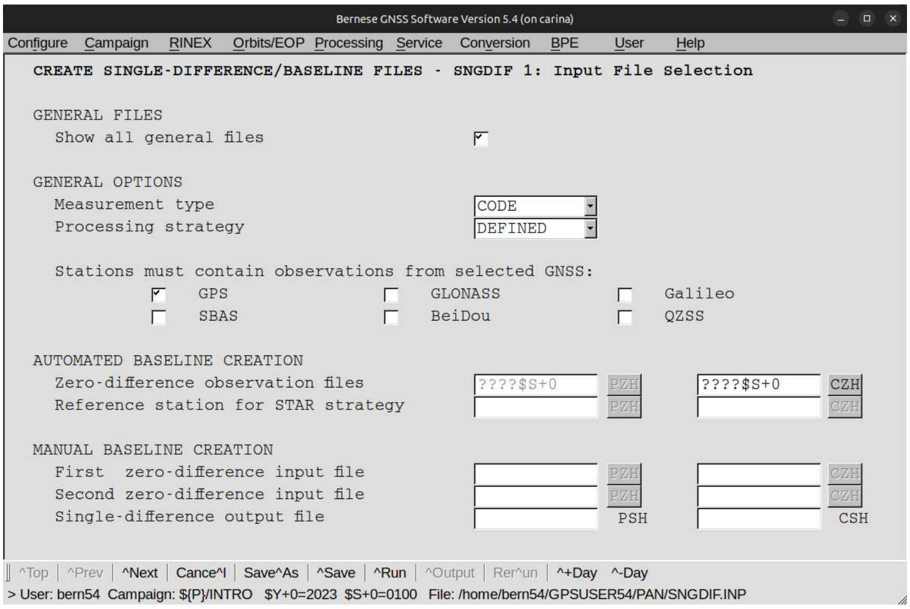
The creation of the following 17 baseline files from 18 zero difference observation files is reported:

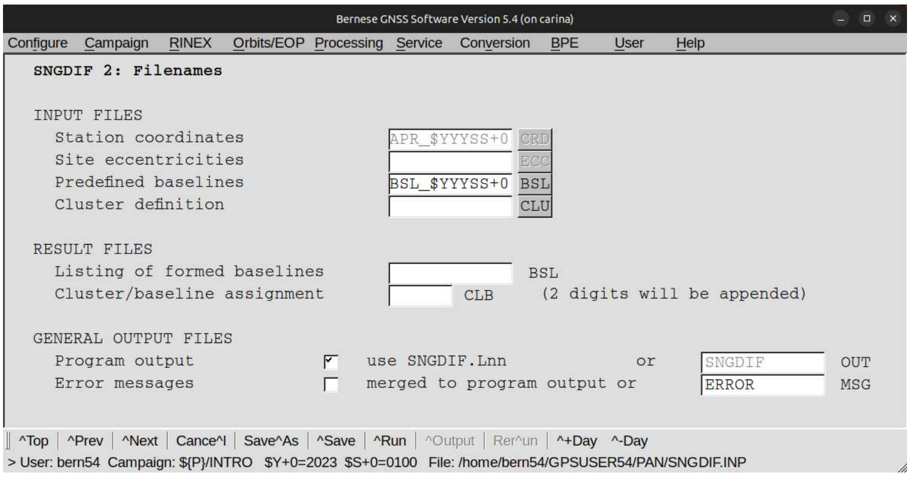
```
SNGDIF: INPUT AND OUTPUT OBSERVATION FILE NAMES
-----------------------------------------------
0-DIF. HEADER FILE NAMES (INPUT) 0-DIF. OBS. FILE NAMES (INPUT)   NUM
******************************** ******************************** ***

${P}/INTRO/OBS/BRST0100.PZH      ${P}/INTRO/OBS/BRST0100.PZO        1
${P}/INTRO/OBS/TLSE0100.PZH      ${P}/INTRO/OBS/TLSE0100.PZO        2
${P}/INTRO/OBS/GANP0100.PZH      ${P}/INTRO/OBS/GANP0100.PZO        3
${P}/INTRO/OBS/JOZ20100.PZH      ${P}/INTRO/OBS/JOZ20100.PZO        4
${P}/INTRO/OBS/HERT0100.PZH      ${P}/INTRO/OBS/HERT0100.PZO        5
${P}/INTRO/OBS/TLSE0100.PZH      ${P}/INTRO/OBS/TLSE0100.PZO        6
...

1-DIF. HEADER FILE NAMES (OUT)   1-DIF. OBS. FILE NAMES (OUT)     NR1 NR2 STAT.
******************************** ******************************** *** *** *****

${P}/INTRO/OBS/BRTL0100.PSH      ${P}/INTRO/OBS/BRTL0100.PSO        1   2   OK
${P}/INTRO/OBS/GAJO0100.PSH      ${P}/INTRO/OBS/GAJO0100.PSO        3   4   OK
${P}/INTRO/OBS/HETL0100.PSH      ${P}/INTRO/OBS/HETL0100.PSO        5   6   OK
${P}/INTRO/OBS/JOMI0100.PSH      ${P}/INTRO/OBS/JOMI0100.PSO        7   8   OK
${P}/INTRO/OBS/JOON0100.PSH      ${P}/INTRO/OBS/JOON0100.PSO        9  10   OK
${P}/INTRO/OBS/LAON0100.PSH      ${P}/INTRO/OBS/LAON0100.PSO       11  12   OK
${P}/INTRO/OBS/MAOR0100.PSH      ${P}/INTRO/OBS/MAOR0100.PSO       13  14   OK
${P}/INTRO/OBS/MOWS0100.PSH      ${P}/INTRO/OBS/MOWS0100.PSO       15  16   OK
${P}/INTRO/OBS/ONPT0100.PSH      ${P}/INTRO/OBS/ONPT0100.PSO       17  18   OK
${P}/INTRO/OBS/ONWS0100.PSH      ${P}/INTRO/OBS/ONWS0100.PSO       19  20   OK
${P}/INTRO/OBS/ONWT0100.PSH      ${P}/INTRO/OBS/ONWT0100.PSO       21  22   OK
${P}/INTRO/OBS/ORWT0100.PSH      ${P}/INTRO/OBS/ORWT0100.PSO       23  24   OK
${P}/INTRO/OBS/TLVI0100.PSH      ${P}/INTRO/OBS/TLVI0100.PSO       25  26   OK
${P}/INTRO/OBS/TLZI0100.PSH      ${P}/INTRO/OBS/TLZI0100.PSO       27  28   OK
${P}/INTRO/OBS/WTWZ0100.PSH      ${P}/INTRO/OBS/WTWZ0100.PSO       29  30   OK
${P}/INTRO/OBS/WTZI0100.PSH      ${P}/INTRO/OBS/WTZI0100.PSO       31  32   OK
${P}/INTRO/OBS/ZIZM0100.PSH      ${P}/INTRO/OBS/ZIZM0100.PSO       33  34   OK
...
```

If the strategy OBS-MAX was selected all possible pairs of zero difference files are listed with the corresponding criterion value. The baselines belonging to the created network configuration are labeled with OK.

```
        1 BRST 10004M004   - GANP 11515M001   #SAT:  75  CRIT.:   31100
        2 BRST 10004M004   - HERT 13212M010   #SAT:  51  CRIT.:   23376
        3 BRST 10004M004   - JOZ2 12204M002   #SAT:  75  CRIT.:   32336
        4 BRST 10004M004   - LAMA 12209M001   #SAT:  73  CRIT.:   22610
...
        9 BRST 10004M004   - ORID 15601M001   #SAT:  75  CRIT.:   30547
       10 BRST 10004M004   - PTBB 14234M001   #SAT:  75  CRIT.:   32910
       11 BRST 10004M004   - TLSE 10003M009   #SAT:  75  CRIT.:   34587  OK
       12 BRST 10004M004   - VILL 13406M001   #SAT:  75  CRIT.:   31232
...
      140 VILL 13406M001   - WTZR 14201M010   #SAT:  77  CRIT.:   31027
      141 VILL 13406M001   - WTZZ 14201M014   #SAT:  77  CRIT.:   28078
      142 VILL 13406M001   - ZIM2 14001M008   #SAT:  75  CRIT.:   31327
      143 VILL 13406M001   - ZIMM 14001M004   #SAT:  31  CRIT.:   12591
      144 WSRT 13506M005   - WTZR 14201M010   #SAT:  70  CRIT.:   32085
      145 WSRT 13506M005   - WTZZ 14201M014   #SAT:  70  CRIT.:   28660
      146 WSRT 13506M005   - ZIM2 14001M008   #SAT:  70  CRIT.:   31698
      147 WSRT 13506M005   - ZIMM 14001M004   #SAT:  31  CRIT.:   13581
      148 WTZR 14201M010   - WTZZ 14201M014   #SAT:  77  CRIT.:   40560  OK
      149 WTZR 14201M010   - ZIM2 14001M008   #SAT:  75  CRIT.:   36411  OK
      150 WTZR 14201M010   - ZIMM 14001M004   #SAT:  31  CRIT.:   13924
      151 WTZZ 14201M014   - ZIM2 14001M008   #SAT:  75  CRIT.:   32474
      152 WTZZ 14201M014   - ZIMM 14001M004   #SAT:  31  CRIT.:   12309
      153 ZIM2 14001M008   - ZIMM 14001M004   #SAT:  31  CRIT.:   16985  OK
```

The baseline file stored in option "Listing of formed baselines" can be used for various purposes, e.g., to create code single difference observation files for the same baselines as the corresponding phase files. One application is the ambiguity resolution using the Melbourne-Wübbena linear combination (e.g., in the tomorrows terminal session). For this purpose the file is introduced to option "Predefined baselines" when processing code measurements.

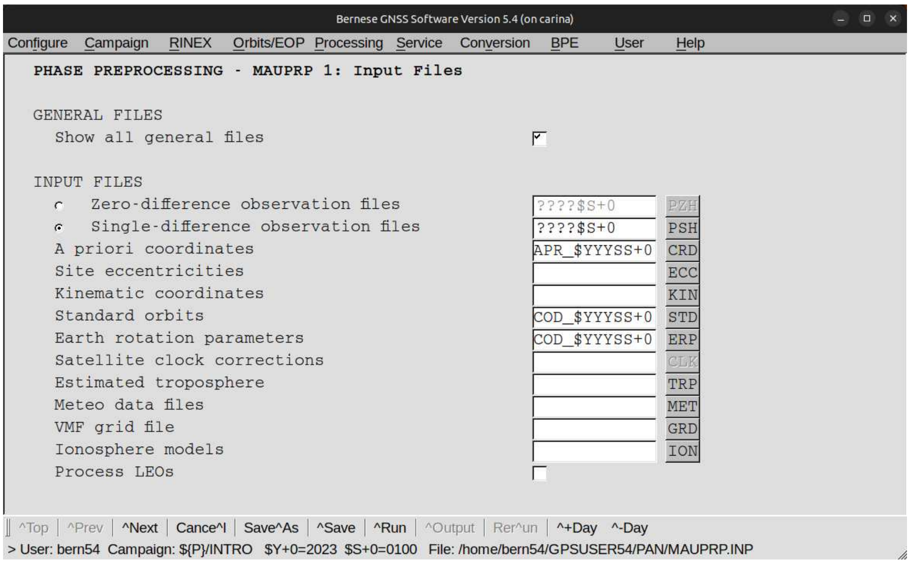


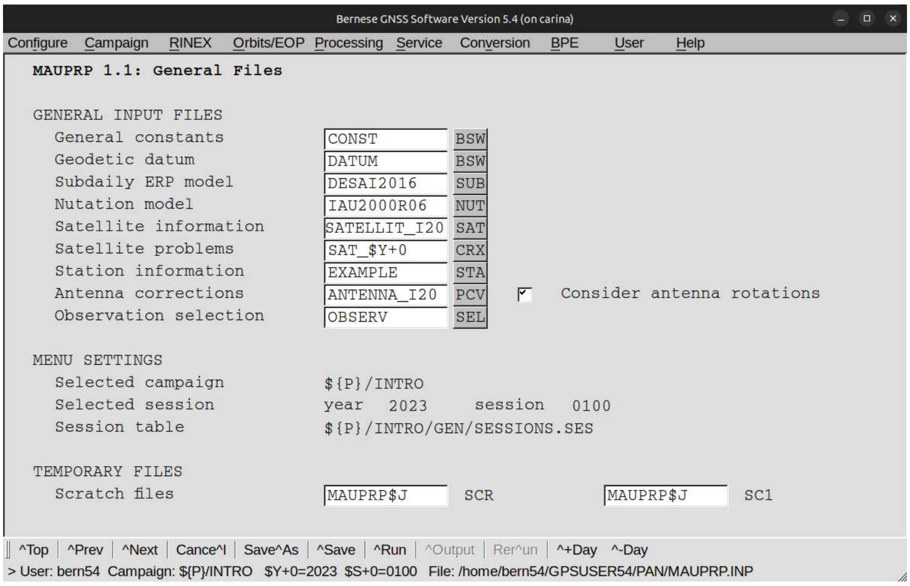


The other options do not matter because we use a predefined baseline configuration.

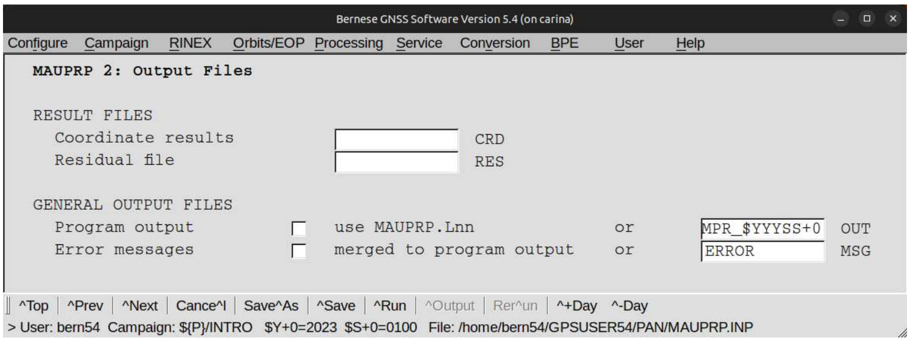
4.2.3 Preprocessing of the Phase Baseline Files

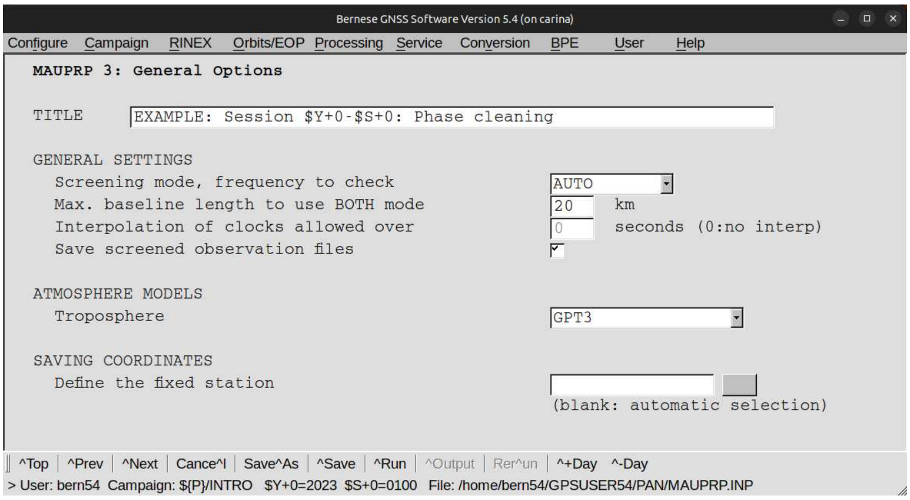
The main task of the program MAUPRP is the cycle–slip detection and correction. It is started using "Menu>Processing>Phase preprocessing".

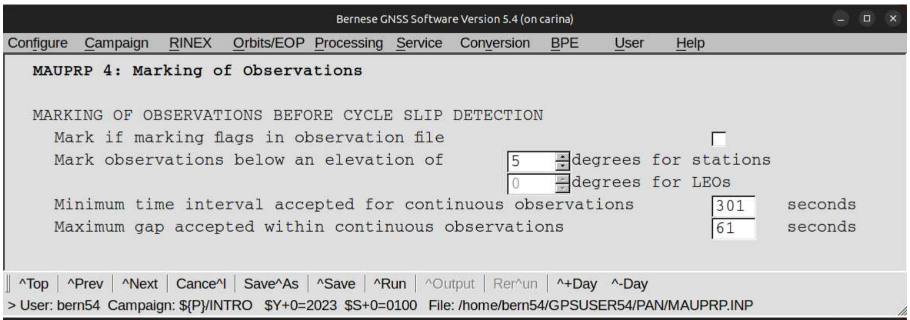


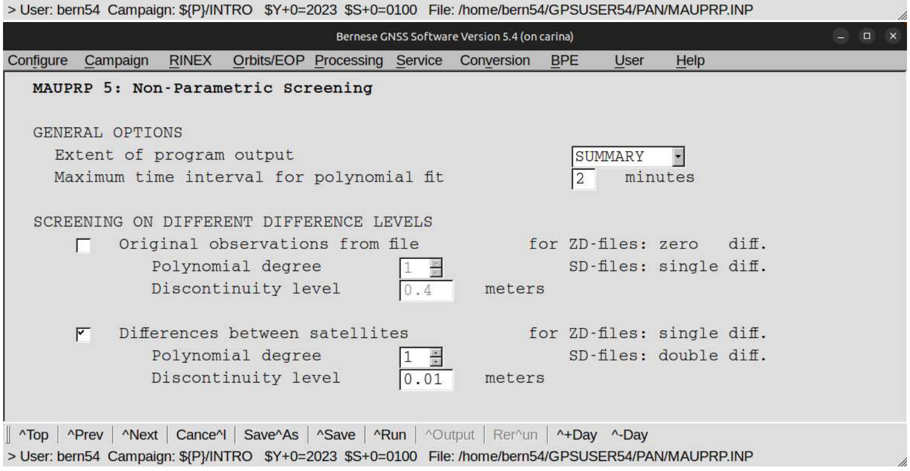


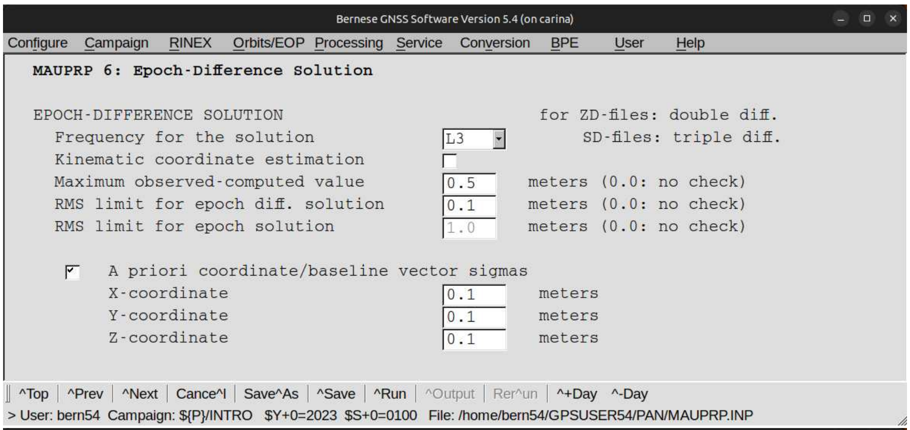
In the next input panel "MAUPRP 2: Output Files" you only need to specify the "Program output", e.g., to `MPR_$YYYSS+0` .

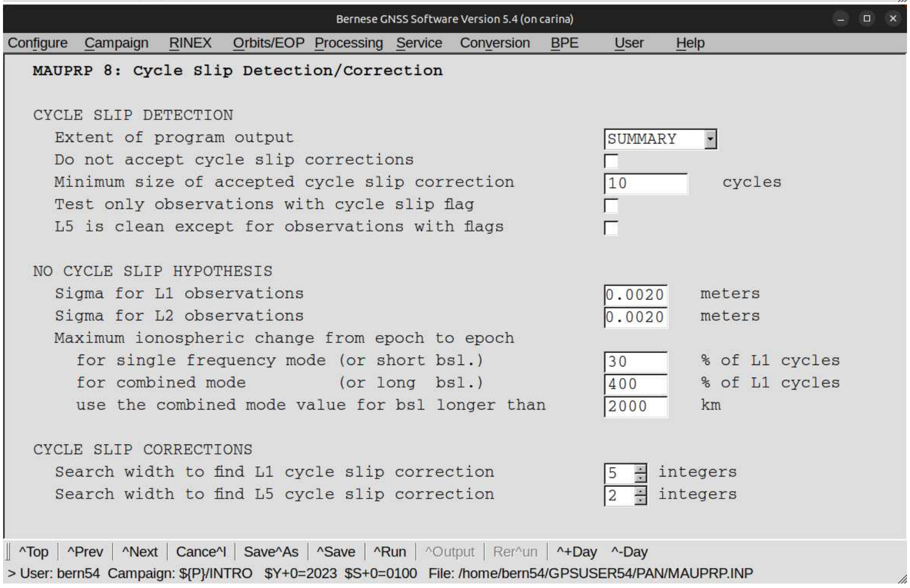


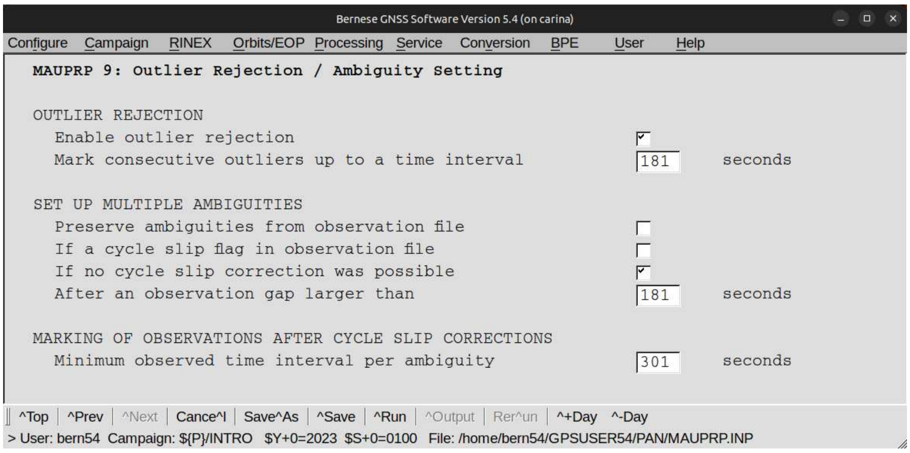

Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
MAUPRP 3: General Options
TITLE
EXAMPLE: Session $Y+0-$S+0: Phase cleaning
GENERAL SETTINGS
Screening mode, frequency to check
AUTO
Max. baseline length to use BOTH mode
20
km
Interpolation of clocks allowed over
0
seconds (0:no interp)
Save screened observation files
ATMOSPHERE MODELS
Troposphere
GPT3
SAVING COORDINATES
Define the fixed station
(blank: automatic selection)
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/MAUPRP.INP


Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
MAUPRP 4: Marking of Observations
MARKING OF OBSERVATIONS BEFORE CYCLE SLIP DETECTION
Mark if marking flags in observation file
Mark observations below an elevation of
5
degrees for stations
0
degrees for LEOs
Minimum time interval accepted for continuous observations
301
seconds
Maximum gap accepted within continuous observations
61
seconds
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/MAUPRP.INP


Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
MAUPRP 5: Non-Parametric Screening
GENERAL OPTIONS
Extent of program output
SUMMARY
Maximum time interval for polynomial fit
2
minutes
SCREENING ON DIFFERENT DIFFERENCE LEVELS
Original observations from file
for ZD-files: zero diff.
Polynomial degree
1
SD-files: single diff.
Discontinuity level
0.4
meters
Differences between satellites
for ZD-files: single diff.
Polynomial degree
1
SD-files: double diff.
Discontinuity level
0.01
meters
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/MAUPRP.INP







The output of the program MAUPRP is discussed in detail in the lecture session. The software manual contains a detailed description, too.

You can find here the results of the adjustment of the input parameters for the maximum accepted change of the ionosphere from one epoch to the next, which is computed according to the baseline length (AUTO in option "Screening mode, frequency to check", panel "MAUPRP 3: General Options").

```
...
STATION 1: BRST 10004M004          YEAR:  2023            SESSION:  0100
STATION 2: TLSE 10003M009          DAY :    10            FILE   :     0

REFERENCE EPOCH     : 2023-01-10 00:00:00
SAMPLING INTERVAL   :   30 SEC

BASELINE LENGTH (M) :    707461.880
OBSERVAT. FILE NAME : ${P}/INTRO/OBS/BRTL0100.PSH

BASELINE DEPENDENT OPTIONS:
--------------------------

CHECK FREQUENCIES (L1=1, L2=2, L1&L2=3, L1,L2=4) --> :      3
MAX. IONOS.DIFF. BETW. EPOCHS (o/o OF L1 CYCLES) --> :    161
...
```

The most important item to check is the epoch difference solution:

```
...
-----------------------------------------------------------------------
EPOCH DIFFERENCE SOLUTION
-----------------------------------------------------------------------

FREQUENCY OF EPOCH DIFF. SOLU.:           3
#OBS. USED FOR EPOCH DIFF. SOLU:      59576
RMS OF EPOCH DIFF. SOLUTION (M):      0.013

COORDINATES  NEW-A PRIORI X (M):     -0.026 +-       0.019
                          Y (M):      0.029 +-       0.020
                          Z (M):     -0.064 +-       0.013

-----------------------------------------------------------------------
...
```

The epoch difference solution is used as the reference for the data screening. For a successful phase preprocessing the RMS OF EPOCH DIFF. SOLUTION has to be below 2 cm. The estimates for the coordinates in the epoch difference solution are expected to be smaller than about 0.5 m.

It should be pointed out that it is not necessary to run the program MAUPRP more than once for each baseline. However, it is mandatory to run MAUPRP again if you (for whatever reason) have to re-create the baselines with program SNGDIF.

You might get some warning messages regarding too large $O - C$ (i.e., observed minus computed) values on certain baselines for certain epochs. The corresponding observations get flagged, and will not disturb the processing.

You can use the extraction program MPRXTR ("Menu>Processing>Program output extraction>Phase preprocessing") to generate a short summary of the MAUPRP output. The file you have specified in "MAUPRP station summary file" looks like this:

```
SUMMARY OF THE MAUPRP OUTPUT FILE
*********************************

SESS FIL OK?  ST1  ST2 L(KM)   #OBS.  RMS  DX   DY   DZ    #SL   #DL   #MA  MAXL3  SLIP
-------------------------------------------------------------------------------------------
0100   1 OK   BRST TLSE  707   59576   13  -26   29  -64     7  1169   117     29    12
0100   2 OK   GANP JOZ2  344   63915   12   23    6   40    11  1411   143     46    11
0100   3 OK   HERT TLSE  816   41056   11   14   12  -29    11   906    80     48    12
0100   4 OK   JOZ2 MIKL  973   61887   11 -125  -43 -158    21  1105   134     43    11
0100   5 OK   JOZ2 ONSA  830   64452   11 -134  -32 -164    14  1195   117     47    11
0100   6 OK   LAMA ONSA  674   44769    9  -27  -22  -50    32   410    88     48    11
0100   7 OK   MATE ORID  349   60120   12   62   22   52    70   606   112     47    11
0100   8 OK   MORP WSRT  599   22723    7   68   45   48     0   312    42      0     0
0100   9 OK   ONSA PTBB  575   66312    9   82   28  107     9   915   113     50    13
0100  10 OK   ONSA WSRT  603   54127    9   92   36  123     4   657    76     17    17
0100  11 OK   ONSA WTZR  920   64225   12   56    3   85     7   714    97     49    12
0100  12 OK   ORID WTZR 1084   60775   12   72   19   88    10   494    75     48    11
0100  13 OK   TLSE VILL  567   60701   11   -7    5  -33     8   650   109     34    12
0100  14 OK   TLSE ZIM2  597   60641   13 -113   23  -51    53  1363   125     42    11
0100  15 OK   WTZR WTZZ    0   60534   12    1    1  -12    11   427   122      0     0
```

```
0100   16 OK    WTZR ZIM2  476    62707    14    85    29    72     69  1454    114      50      11
0100   17 OK    ZIM2 ZIMM    0    23223    14   -41   -13   -23    229   372     49       0       0
---------------------------------------------------------------------------------------------------
Tot:   17                  595    66312    14  -134   -32  -164    229  1454    143      50       0
```

Note that in the bottom line the maximum values for each column are reported to show the "worst case".

4.3 Daily Goals

At the end of today's session, you should have created the following files:

1. *Bernese formatted zero difference observation files in your campaign's OBS directory:* `BRST0100.CZH`, `BRST0100.PZH`, `BRST0100.CZO`, `BRST0100.PZO`, *... (for all stations).*
2. *Single difference files (baseline files) in the OBS directory:* `BRTL0100.PSH`, `BRTL0100.PSO`, `GAJO0100.PSH`, `GAJO0100.PSO`,*... for all baselines,*
3. *you should also have verified the outputs of these programs:* ORBGEN, RXOBV3, CODSPP, SNGDIF, *and* MAUPRP

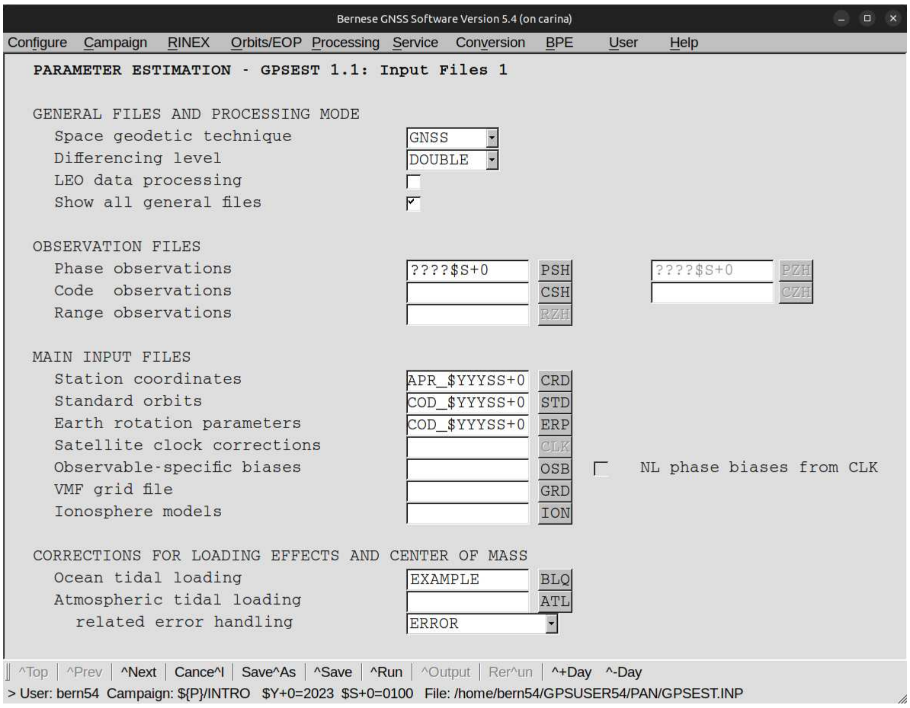
5 Terminal Session: Wednesday

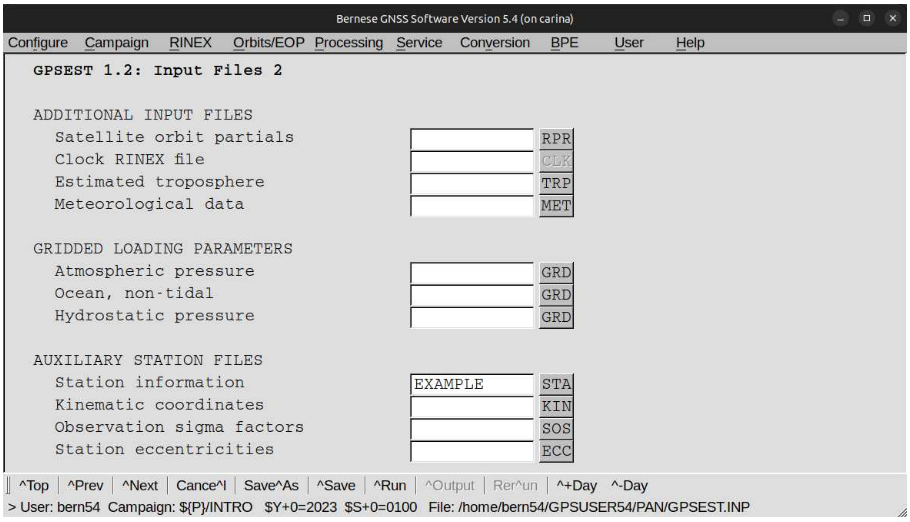
Today's terminal session is to:

1. *perform a residual screening (GPSEST, RESRMS, SATMRK),*
2. *generate a first estimation for coordinates and troposphere parameters (GPSEST),*
3. *resolve the double difference ambiguities (GPSEST).*

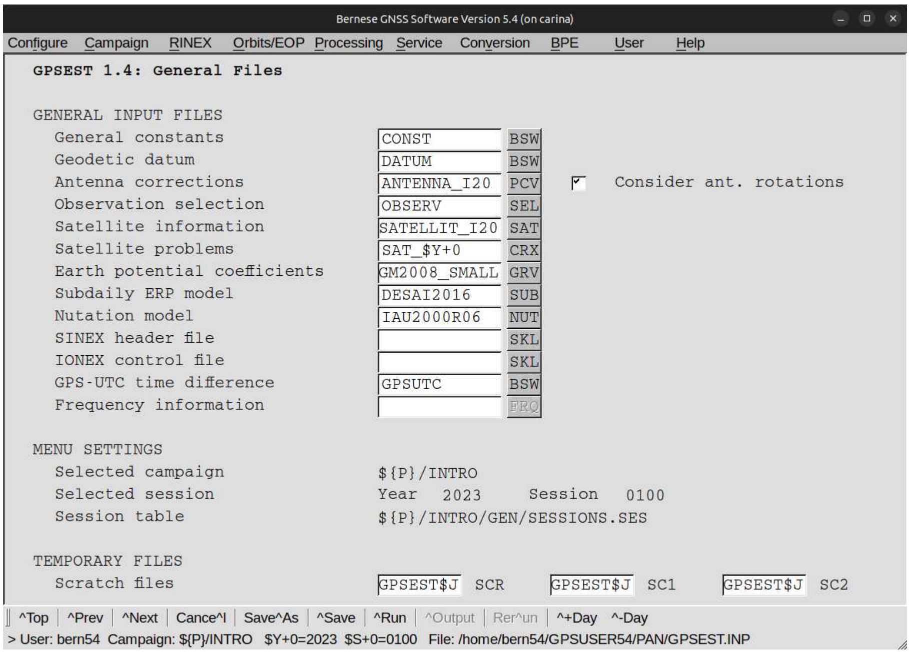
5.1 Data Preprocessing (II)

The main parameter estimation based on a least–squares adjustment is the task of program GPSEST. It is a good idea to start GPSEST first in the session mode and to produce an L_3 solution (ionosphere–free linear combination) with real–valued ambiguities. We do not expect any final results from this run but we want to check the quality of data and save the residuals after the least–squares adjustment. The program is available via "Menu>Processing >Parameter estimation". We use the following options:

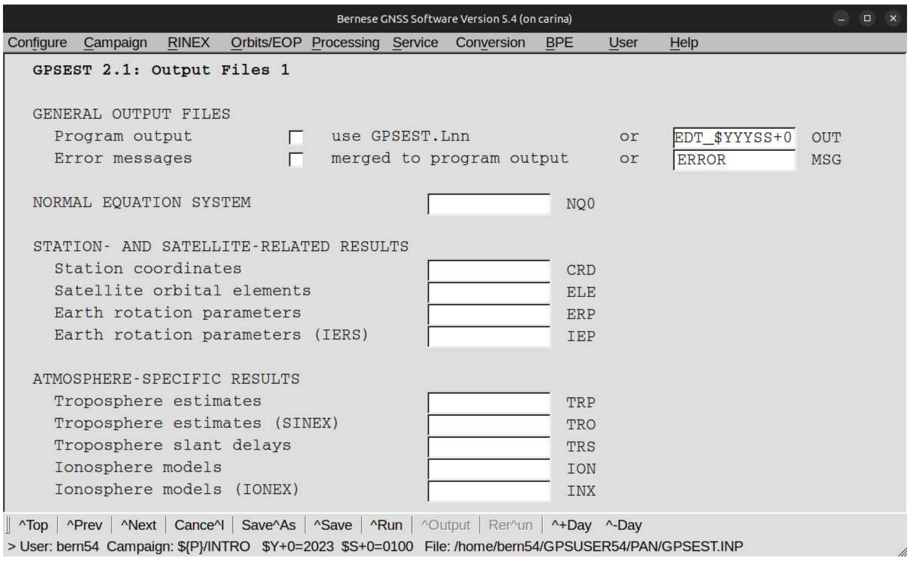


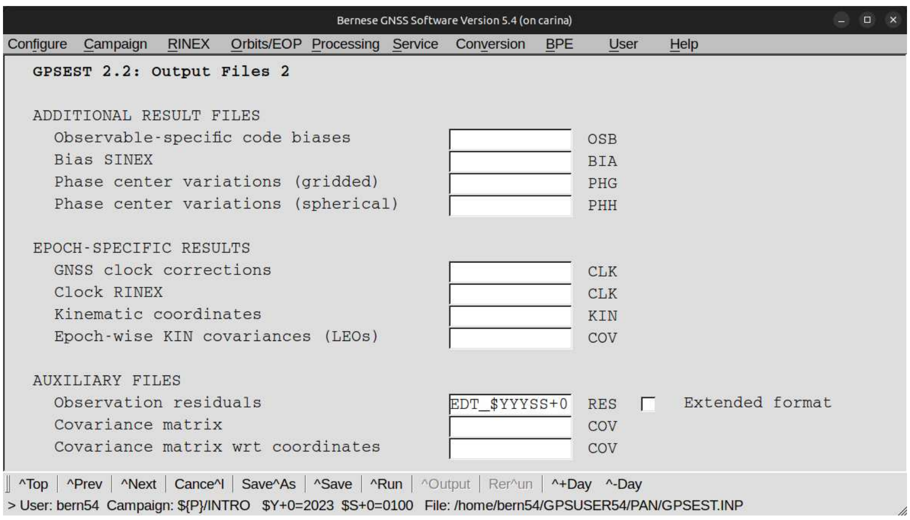


Verify the model and configuration files:

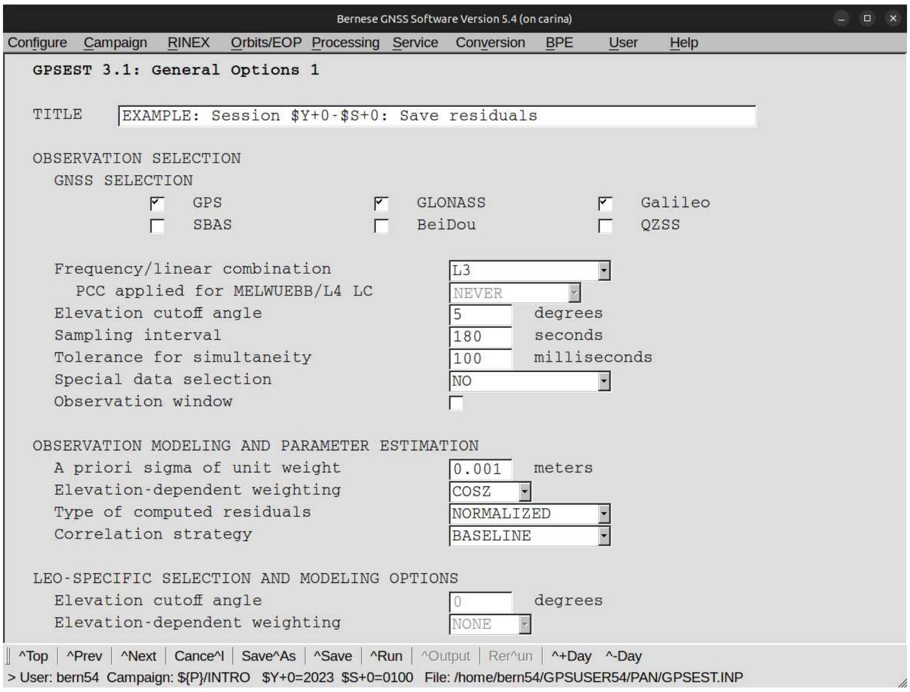


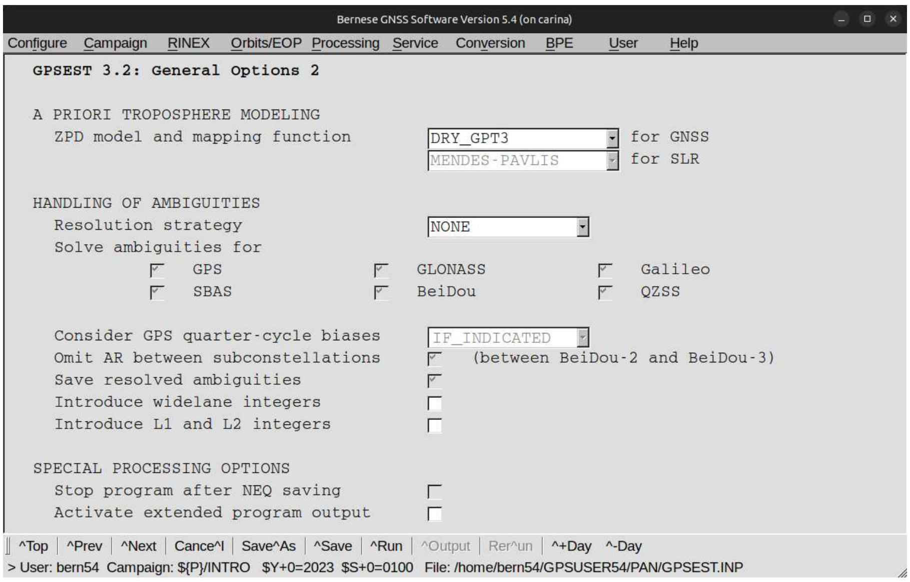
We recommend to select the following output files:



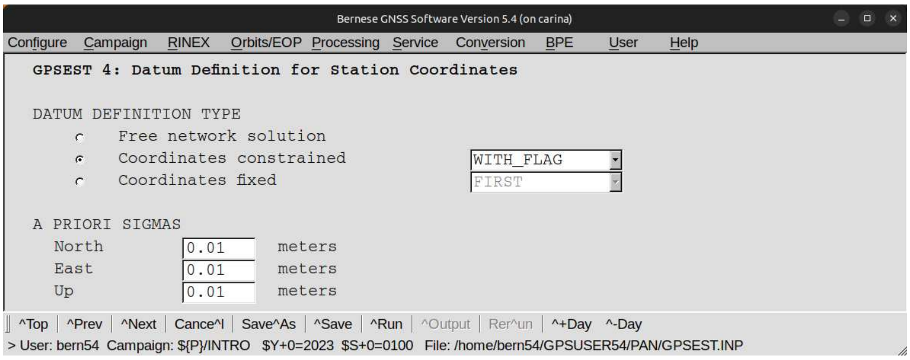


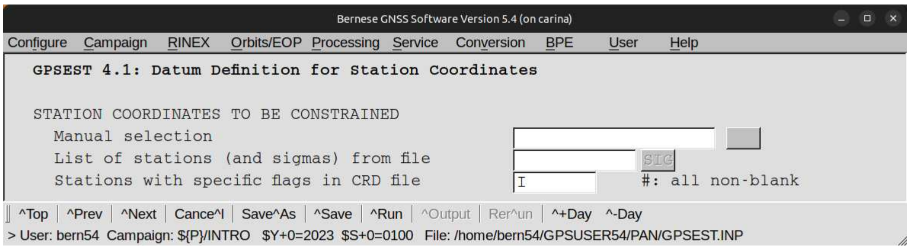
This run is intended to screen the post–fit residuals for outliers. Later on, for the ambiguity resolution, all observations are needed without down–sampling the data. To run the program GPSEST for the network with 18 stations and the observations to more than 75 satellites without reducing the data sampling rate takes easily 10 minutes or more. For that reason we are forced to sample the data, e.g., down to 3 minutes — we will see in the next step how to solve this discrepancy.



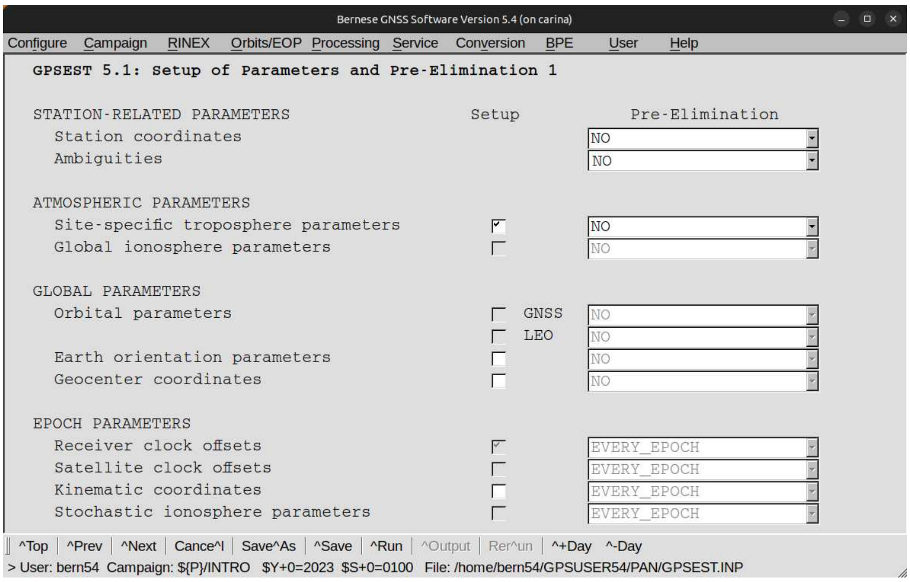


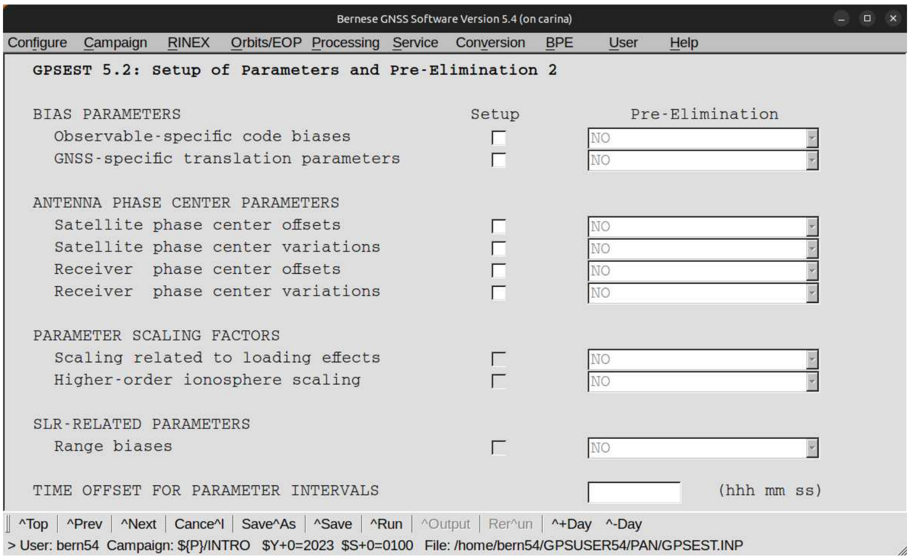
We want to put loose constraints on the station coordinates that are available from the IGS realization of ITRF 2020 reference frame (flag I like IGS20 in the coordinate file).



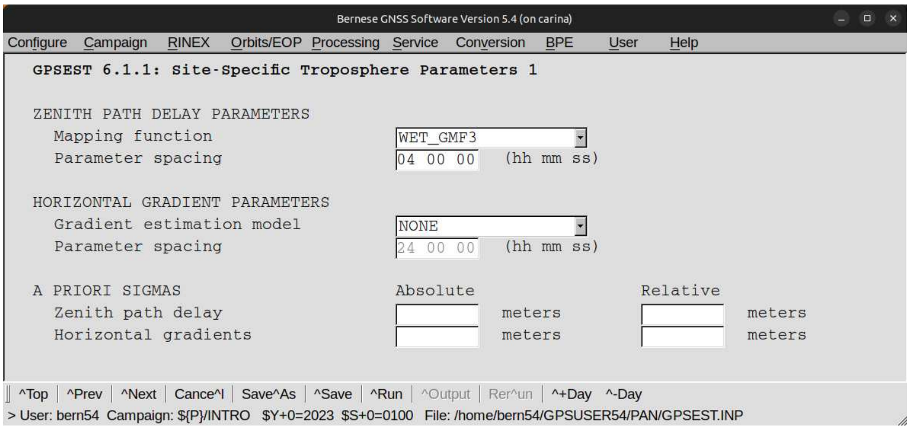


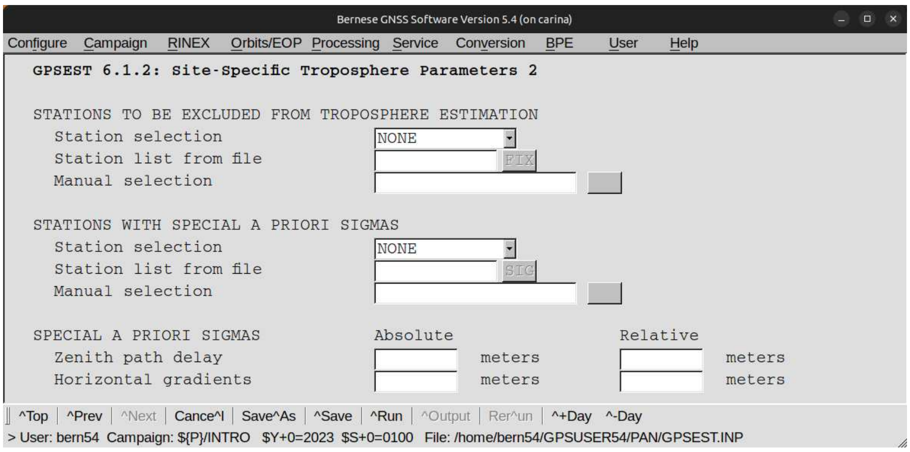
No parameters (not even ambiguity parameters) can be pre–eliminated if residuals should be written into the residual output file:





A 4 hour resolution in time for the troposphere parameters is sufficient for this purpose:





The program output of GPSEST summarizes all important input options, input data, and reports the estimated results. An important information in the output file is the a posteriori RMS error:

```
...
```

```
Statistics:
----------

Total number of authentic observations      156591
Total number of pseudo-observations             47

Total number of explicit parameters           2891
Total number of implicit parameters              0

Total number of observations                156638
Total number of adjusted parameters           2891
Degree of freedom (DOF)                     153747

A posteriori RMS of unit weight           0.001077 m
Chi**2/DOF                                    1.16

Total number of observation files               17
Total number of unobserved ambiguities         162
Total number of stations                        18

...
```

An a posteriori RMS error of about 1.0…1.5 mm is expected if elevation–dependent weighting is used. A significantly higher RMS error indicates that either your data stems from low–quality receivers, that the data was collected under extremely bad conditions, or that the preprocessing step (MAUPRP and CODSPP) was not successfully performed.

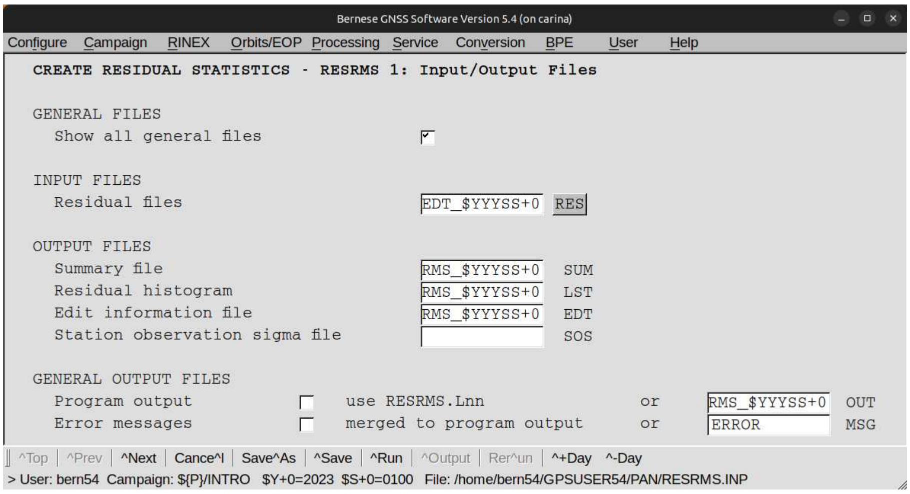
Below this part the program output reports the results of the parameter estimation in a standardized format for all parameter types:

```
...
Station coordinates and velocities:
----------------------------------

Sol Station name         Typ Correction  Estimated value  RMS error   A priori value ... Abb
---------------------------------------------------------------------------------------------
  1 BRST 10004M004         X    0.00306    4231162.37496    0.00315    4231162.37190 ... #CRD
  1 BRST 10004M004         Y    0.01128    -332746.34840    0.00300    -332746.35968 ... #CRD
  1 BRST 10004M004         Z   -0.00162    4745131.10986    0.00316    4745131.11148 ... #CRD
  1 TLSE 10003M009         X    0.00988    4627851.62550    0.00311    4627851.61562 ... #CRD
  1 TLSE 10003M009         Y    0.00952     119640.37315    0.00294     119640.36363 ... #CRD
  1 TLSE 10003M009         Z    0.00502    4372993.76503    0.00311    4372993.76001 ... #CRD
  1 GANP 11515M001         X    0.00831    3929181.23911    0.00319    3929181.23080 ... #CRD
  1 GANP 11515M001         Y    0.00898    1455237.02537    0.00300    1455237.01639 ... #CRD
  1 GANP 11515M001         Z    0.00340    4793654.07239    0.00320    4793654.06899 ... #CRD
  1 JOZ2 12204M002         X    0.00589    3664880.25578    0.00314    3664880.24989 ... #CRD
...

Site-specific troposphere parameters:
------------------------------------

Station name         Typ     Correction  Estimated value  RMS error   A priori value ... Abb
--------------------------------------------------------------------------------------------
BRST 10004M004        U         0.15198          2.46498    0.00106          2.31301 ... #TRP
BRST 10004M004        U         0.14020          2.45319    0.00064          2.31300 ... #TRP
BRST 10004M004        U         0.12765          2.44065    0.00062          2.31300 ... #TRP
BRST 10004M004        U         0.10715          2.42016    0.00064          2.31300 ... #TRP
BRST 10004M004        U         0.11315          2.42616    0.00062          2.31300 ... #TRP
BRST 10004M004        U         0.15931          2.47231    0.00065          2.31300 ... #TRP
BRST 10004M004        U         0.05468          2.36770    0.00096          2.31301 ... #TRP
GANP 11515M001        U         0.07272          2.19632    0.00099          2.12360 ... #TRP
GANP 11515M001        U         0.06538          2.18904    0.00067          2.12366 ... #TRP
GANP 11515M001        U         0.06212          2.18576    0.00067          2.12364 ... #TRP
...
```

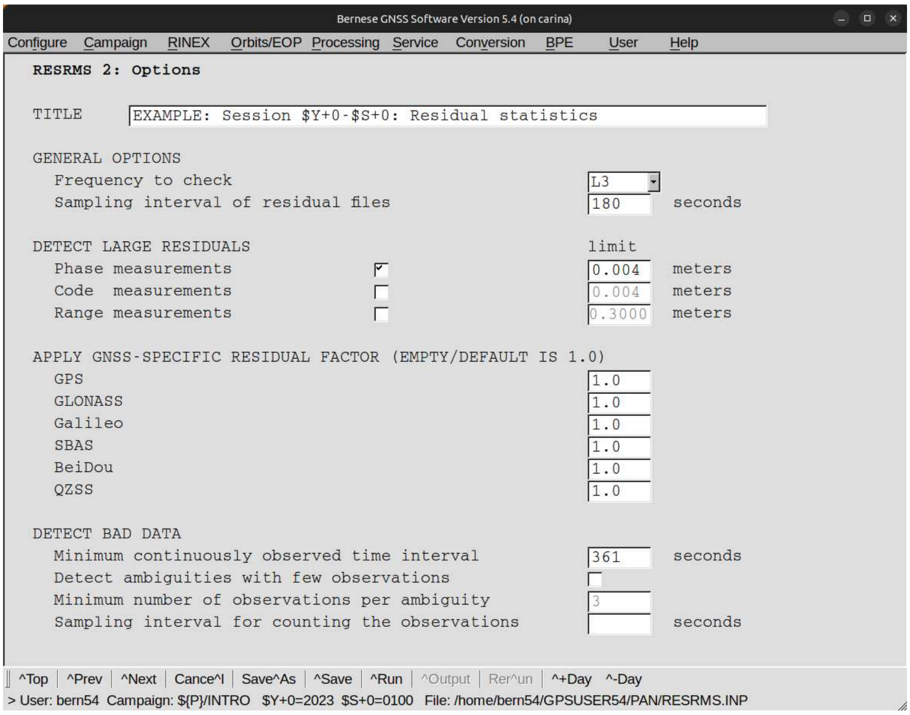
You should check the improvement for the a priori coordinates. If all stations get approximately the same improvement in the order of decimeters, very likely the datum definition failed. Check that you have really selected datum stations.

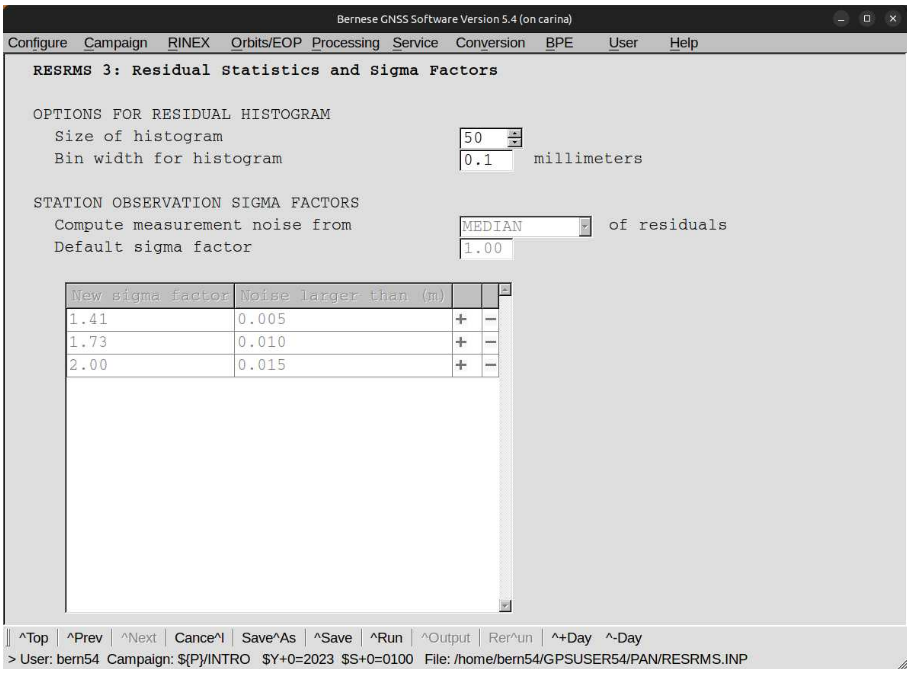
If the residuals have been stored in the binary residual file (specified in "GPSEST 2.2: Output Files 2") it is possible to have a look at the residuals (program REDISP, "Menu>Service>Residual files>Display residual file").

To screen the residuals automatically use the program RESRMS in "Menu>Service>Residual files >Create residual statistics".



The sampling interval you have previously introduced in option "Sampling interval" in program GPSEST has to be repeated here. RESRMS makes the assumption that the observations between two outliers in the sampled residual file are also bad.

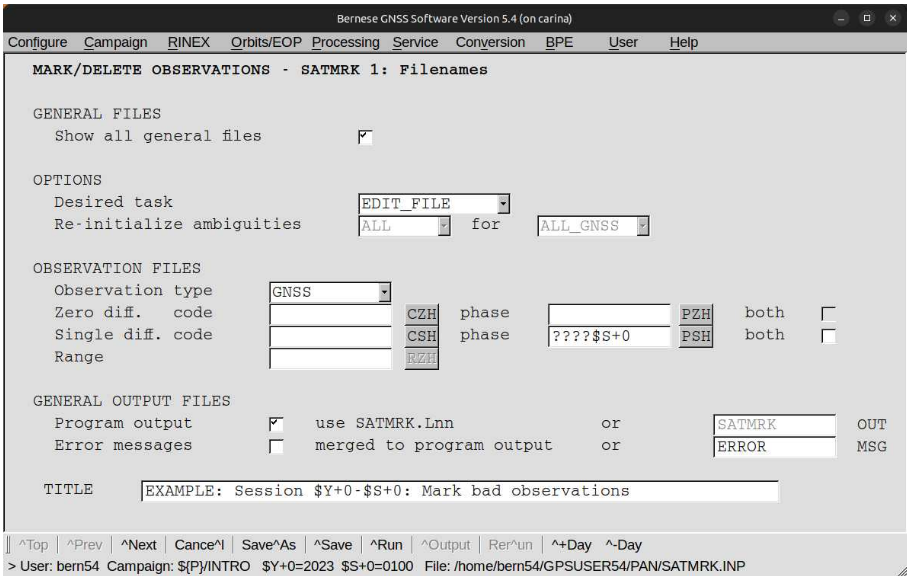


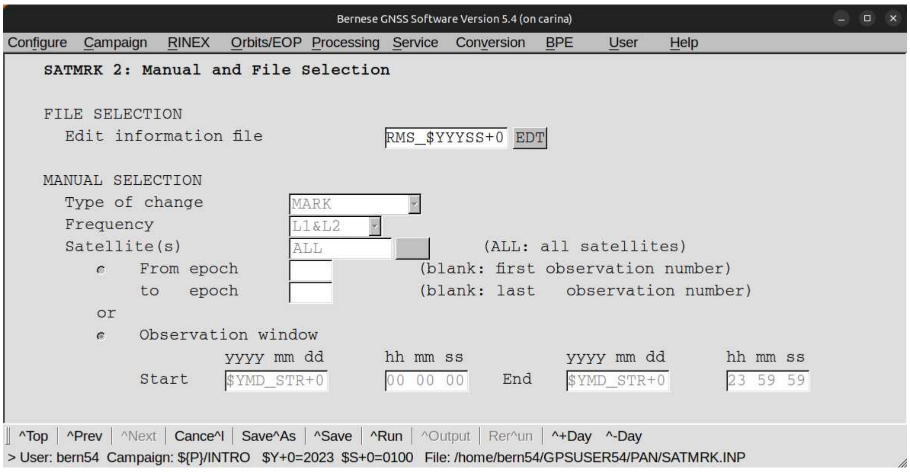


The program output of RESRMS (`${P}/INTRO/OUT/RMS_20230100.OUT`) provides a nice overview on the data quality.

```
...
FILE INFORMATION AND STATISTIC:
-----------------------------

Num   Station 1         Station 2        Total RMS  med.Resi  Sigma  numObs  nSat  nDel ...
------------------------------------------------------------------------------------- ...

  1   BRST 10004M004    TLSE 10003M009         1.5       0.8    1.2   10541    75    25 ...
  2   GANP 11515M001    JOZ2 12204M002         1.1       0.6    0.9   11227    75     2 ...
  3   HERT 13212M010    TLSE 10003M009         1.3       0.7    1.1    7374    51    11 ...
  4   JOZ2 12204M002    MIKL 12335M001         1.1       0.6    0.9   10855    75     0 ...
  5   JOZ2 12204M002    ONSA 10402M004         1.1       0.6    0.9   11337    75     2 ...
  6   LAMA 12209M001    ONSA 10402M004         1.0       0.6    0.8    7807    73     4 ...
  7   MATE 12734M008    ORID 15601M001         1.2       0.7    1.0   10474    75     6 ...
  8   MORP 13299S001    WSRT 13506M005         1.1       0.6    1.0    4248    31     1 ...
  9   ONSA 10402M004    PTBB 14234M001         1.2       0.6    0.9   11565    75     6 ...
...
-------------------------------------------------------------------------------------

NUMBER OF EDIT REQUESTS:   130
```

In addition, files containing a summary table (`${P}/INTRO/OUT/RMS_20230100.SUM`) and a histogram (`${P}/INTRO/OUT/RMS_20230100.LST`) of the residuals are available. The most important result file for the data screening is the "Edit information file" (`${P}/INTRO/OUT/RMS_20230100.EDT`), which may be used by the program SATMRK to mark outliers in the observation files ("Menu>Service>Bernese observation files>Mark/delete observations"):



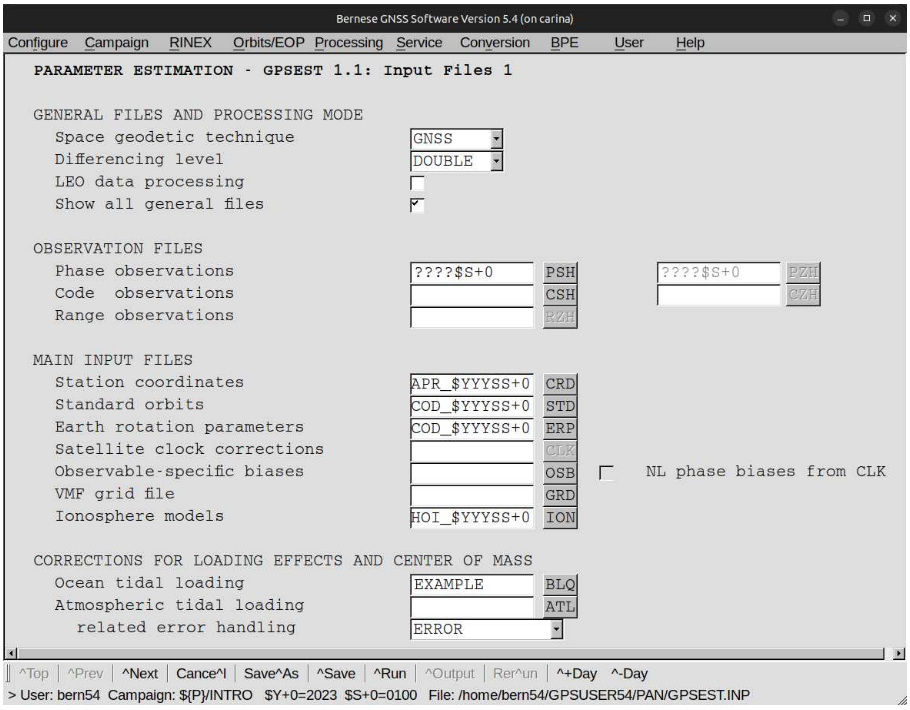


The program output of SATMRK reports the number of marked observations per baseline:

```
 ...
SUMMARY OF ACTION IN THE OBS. FILE(S):      ${P}/INTRO/OUT/RMS_20230100.EDT
-------------------------------------
                                            Mea-     Observations      ...
 Num  Station name 1        Station name 2   type    mark  unmark  delete ...
----------------------------------------------------------------------------- ...
   1  BRST 10004M004        TLSE 10003M009    P :     636       0       0 ...
   2  GANP 11515M001        JOZ2 12204M002    P :      38       0       0 ...
   3  HERT 13212M010        TLSE 10003M009    P :     326       0       0 ...
   4  JOZ2 12204M002        MIKL 12335M001    P :       0       0       0 ...
   5  JOZ2 12204M002        ONSA 10402M004    P :      44       0       0 ...
   6  LAMA 12209M001        ONSA 10402M004    P :      94       0       0 ...
   7  MATE 12734M008        ORID 15601M001    P :     112       0       0 ...
   8  MORP 13299S001        WSRT 13506M005    P :      22       0       0 ...
   9  ONSA 10402M004        PTBB 14234M001    P :     184       0       0 ...
 ...
----------------------------------------------------------------------------- ...
      Total:                                        3284       0       0 ...
----------------------------------------------------------------------------- ...
```

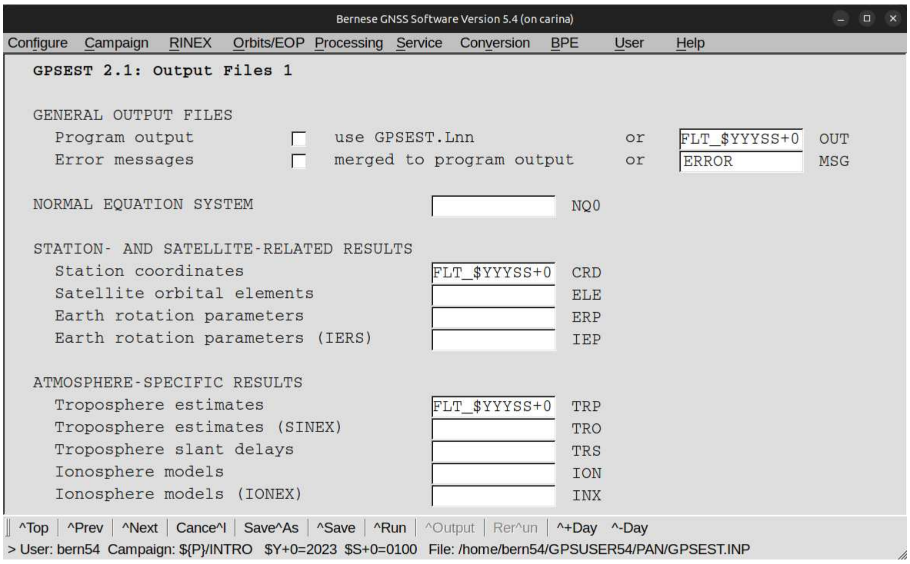
5.2 Produce a First Network Solution

After screening the observations for outliers we can generate an ionosphere–free (L_3) solution with unresolved ambiguities. A detailed discussion on the troposphere/ionosphere modeling will be given in a dedicated lecture tomorrow. The input options are very similar to the previous preprocessing step. There are only a few differences shown in the following panels:



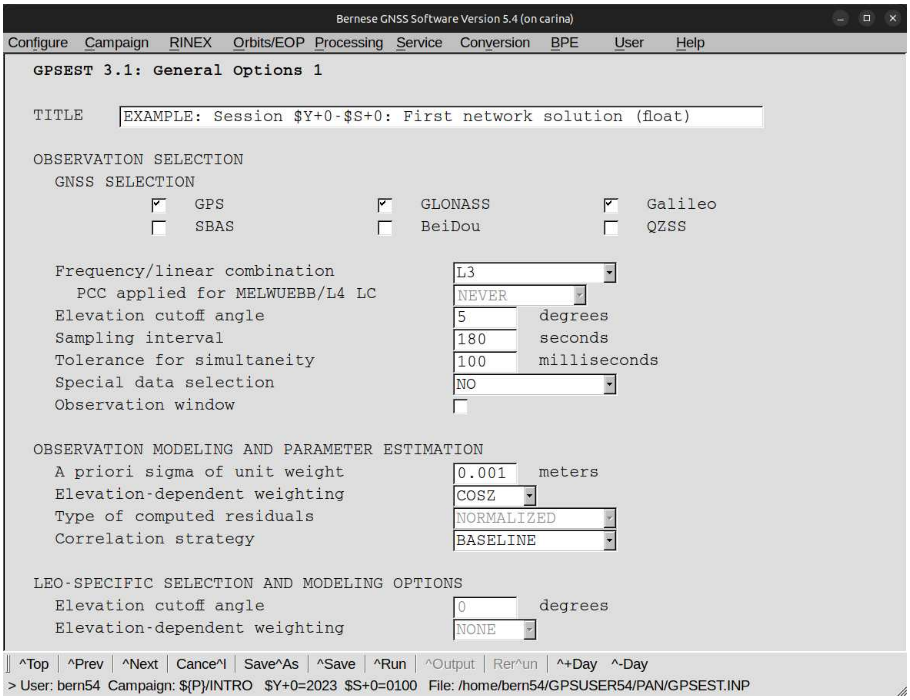
The file in the input field "Ionosphere models" enables the HOI–corrections, which are not canceled by the ionosphere-free linear combination.

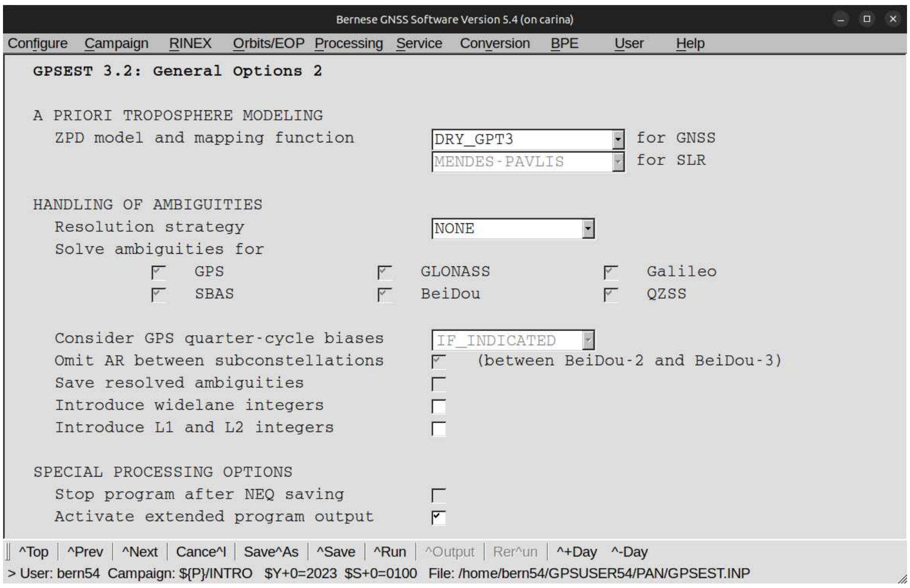
We store the coordinates and troposphere parameters into files to be re–introduced later:



In the subsequent panel you should remove the output filename for the "Residuals" because we do not need the residuals from this run.

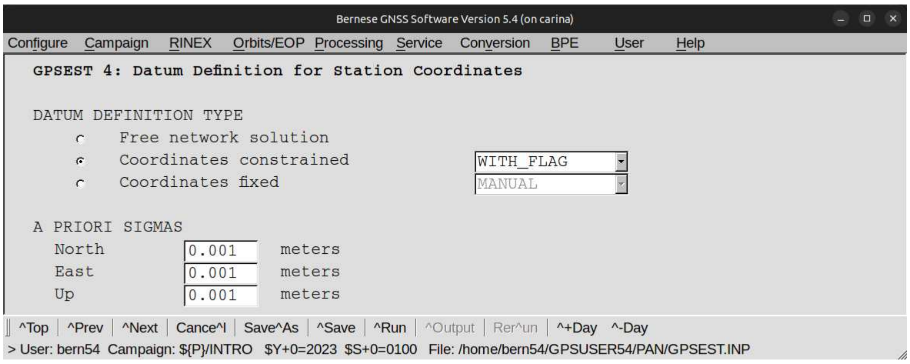
The next two panels with the general options for GPSEST remain untouched:

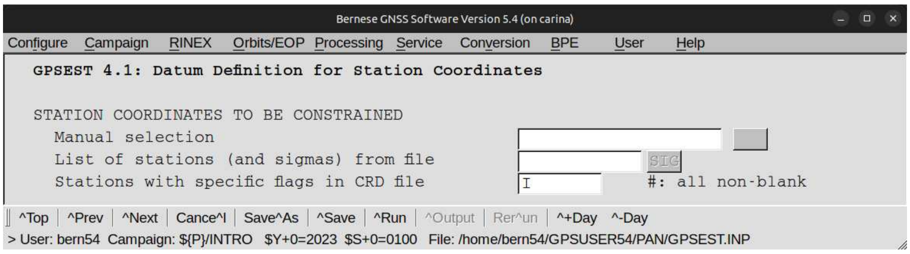




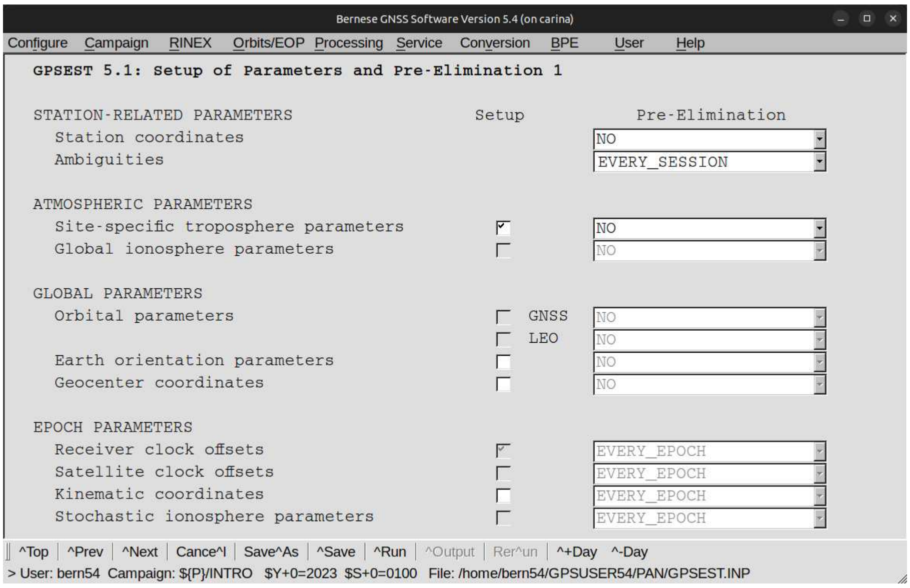
Nevertheless, it might be an interesting idea to enable the option "Activate extended program output". Two more panels appear where much more information on the data and results can be asked for. In this example we just enable the two options for "Printing: Extended summary concerning coordinates" and "Printing: Extended summary concerning troposphere". You are invited to discover these options further in order to adjust it to your needs.

To heavily constrain the coordinates of the IGS core sites is not the best way to realize the geodetic datum for a solution. The program ADDNEQ2 offers more sophisticated options (e.g., minimum constraint solution). Today we will follow this simple approach:

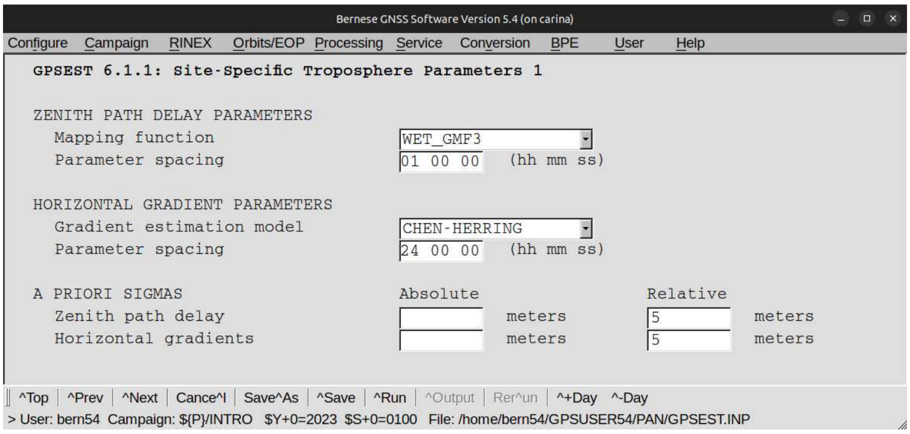




Since we do not store residual files in this run, ambiguity parameters may be pre–eliminated from the normal equation before the parameters are estimated:



The estimation of troposphere parameters is mandatory for a campaign of this type. We increase the number of estimated parameters (e.g., to 24 instead of 6 parameters per station and session). In addition, it is recommended to set up troposphere gradient parameters. In order to avoid a format overflow in the "Troposphere estimates" output file that may happen if a troposphere parameter is estimated based on very few observations concentrated at one end of the interval of parameter validity, a loose relative constraint (e.g., sigmas of 5 meter) may help.



In the first part of the output generated by program GPSEST, the selected options are echoed. The result part starts with some statistics on the parameters and the observations:

```
...

SUMMARY OF RESULTS
------------------

Number of parameters:
--------------------

Parameter type                          Adjusted   Expl.   Impl.  (elim)*  Del. Ref. Sing. No obs
-------------------------------------------------------------------------------------------------
Station coordinates / velocities              54      54       0              0    0     0      0
Ambiguities                                 2711       0    2711  (bfst)      0    0    19      0
Site-specific troposphere parameters         522     522       0              0    0     0      0
-------------------------------------------------------------------------------------------------
Total number                                3268     576    2692              0    0    19      0


*Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking (afst),
                                      epoch-wise (epow), after inversion (afin)
...
```

Then the a posteriori RMS error and the results of the initial least–squares adjustment are given

```
...
Statistics:
----------

Total number of authentic observations      156396
Total number of pseudo-observations             30

Total number of explicit parameters            576
Total number of implicit parameters           2692

Total number of observations                156426
Total number of adjusted parameters           3268
Degree of freedom (DOF)                     153158

A posteriori RMS of unit weight           0.000986 m
Chi**2/DOF                                    0.97
...
```

Below you find the extended output of the results for coordinates and troposphere parameters at the end of the file that we have asked for in panel "GPSEST 3.2.1.1: Extended Program Output Options":

```
...
Station coordinates and velocities:
-----------------------------------
Reference epoch: 2023-01-10 11:59:45

Station name          Typ   A priori value  Estimated value    Correction     RMS error  ...
------------------------------------------------------------------------------------------ ...
BRST 10004M004         X      4231162.37190    4231162.37224       0.00034       0.00063
                       Y      -332746.35968    -332746.35788       0.00180       0.00058
                       Z      4745131.11148    4745131.11043      -0.00105       0.00060

                       U           65.81675         65.81609      -0.00066       0.00076  ...
                       N         48.3804963       48.3804963      -0.00084       0.00043  ...
                       E         -4.4965905       -4.4965905       0.00182       0.00057  ...

TLSE 10003M009         X      4627851.61562    4627851.61790       0.00228       0.00052
                       Y       119640.36363     119640.36410       0.00047       0.00049
                       Z      4372993.76001    4372993.76217       0.00216       0.00051

                       U          207.18209        207.18523       0.00314       0.00062  ...
                       N         43.5606974       43.5606974      -0.00001       0.00038  ...
                       E          1.4808948        1.4808948       0.00041       0.00048  ...

GANP 11515M001         X      3929181.23080    3929181.23231       0.00151       0.00081
                       Y      1455237.01639    1455237.01926       0.00287       0.00071
                       Z      4793654.06899    4793654.07285       0.00386       0.00092

                       U          746.03194        746.03644       0.00450       0.00114  ...
                       N         49.0347157       49.0347157       0.00071       0.00048  ...
                       E         20.3229407       20.3229408       0.00216       0.00068  ...
...
```

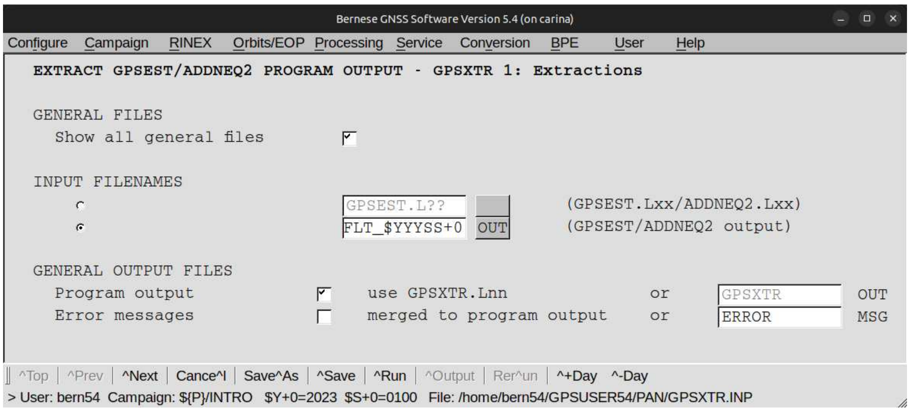
```
...
Troposphere parameters:
----------------------

Reference elevation angle of gradient terms :   45.0 degrees
Minimum elevation angle                     :      5 degrees
Mapping factor at minimum elevation angle   :   11.4

                        Corrections (m)              RMS errors (m)          ...
Station name        North     East    Zenith     North    East    Zenith    ...
----------------------------------------------------------------------     ...
BRST 10004M004     -0.00037 -0.00024  0.13467   0.00009  0.00011  0.00213  ...
BRST 10004M004     -0.00041 -0.00021  0.14806   0.00008  0.00010  0.00133  ...
BRST 10004M004     -0.00045 -0.00017  0.14802   0.00008  0.00010  0.00105  ...
BRST 10004M004     -0.00048 -0.00013  0.14387   0.00007  0.00009  0.00117  ...
BRST 10004M004     -0.00052 -0.00009  0.13338   0.00007  0.00008  0.00111  ...
...
BRST 10004M004     -0.00114  0.00055  0.12353   0.00007  0.00009  0.00112  ...
BRST 10004M004     -0.00118  0.00059  0.09643   0.00008  0.00010  0.00110  ...
BRST 10004M004     -0.00122  0.00063  0.07374   0.00008  0.00011  0.00109  ...
BRST 10004M004     -0.00125  0.00067  0.06851   0.00009  0.00011  0.00201  ...
GANP 11515M001     -0.00009  0.00013  0.06896   0.00009  0.00008  0.00179  ...
GANP 11515M001     -0.00009  0.00013  0.06915   0.00009  0.00008  0.00102  ...
GANP 11515M001     -0.00010  0.00013  0.06874   0.00008  0.00007  0.00117  ...
GANP 11515M001     -0.00011  0.00014  0.06698   0.00008  0.00007  0.00101  ...
GANP 11515M001     -0.00012  0.00014  0.06316   0.00007  0.00006  0.00104  ...
GANP 11515M001     -0.00013  0.00015  0.06070   0.00007  0.00006  0.00101  ...
...
```

Because outliers have been removed in the previous step, the obtained a posteriori RMS error should decrease (at least not increase). If this is not the case, it is likely that the observations and the heavily constrained a priori coordinates are inconsistent.

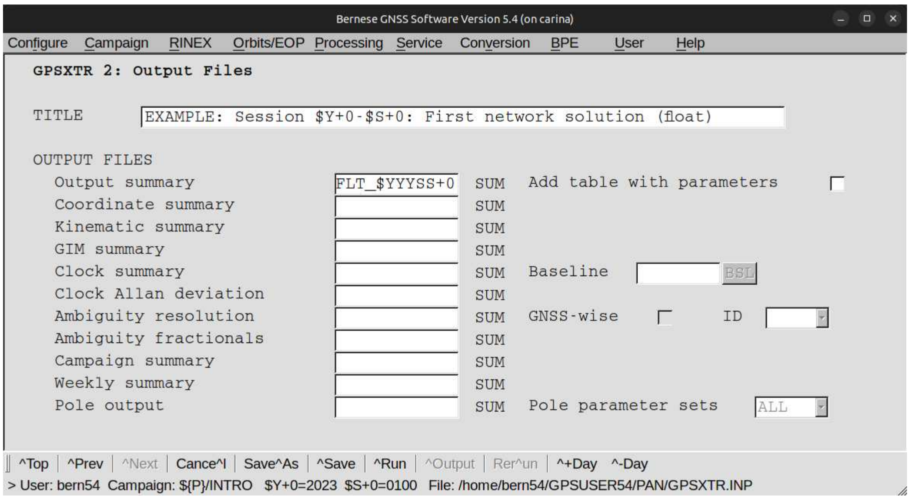
5.2.1 Program Output Extraction

The program output from the program GPSEST is quite long and contains many information that help to identify potential problems in the processing. On the other hand, it would be smart to extract the key parameters into a short summary that can for instance be included in a comprehensive processing protocol. The program GPSXTR (accessible via "Menu>Processing>Program output extraction>Parameter estimation/stacking") provides such a summary.

Select the program output(s) to be analyzed:



and select the name of the summary file



The short extraction of the full program output in ${P}/INTRO/OUT/FLT_20230100.SUM reads like

```
FLT_20230100.OUT    Rms:  0.99  , # fil.:  17  , # obs.:  156426  , # par.:  3268
(DOY: 2023-010)
```

Also other styles of output are available, check the online help for some examples. Please note, that some summaries only work on specific program output files containing the expected parameter types.

5.3 Ambiguity Resolution

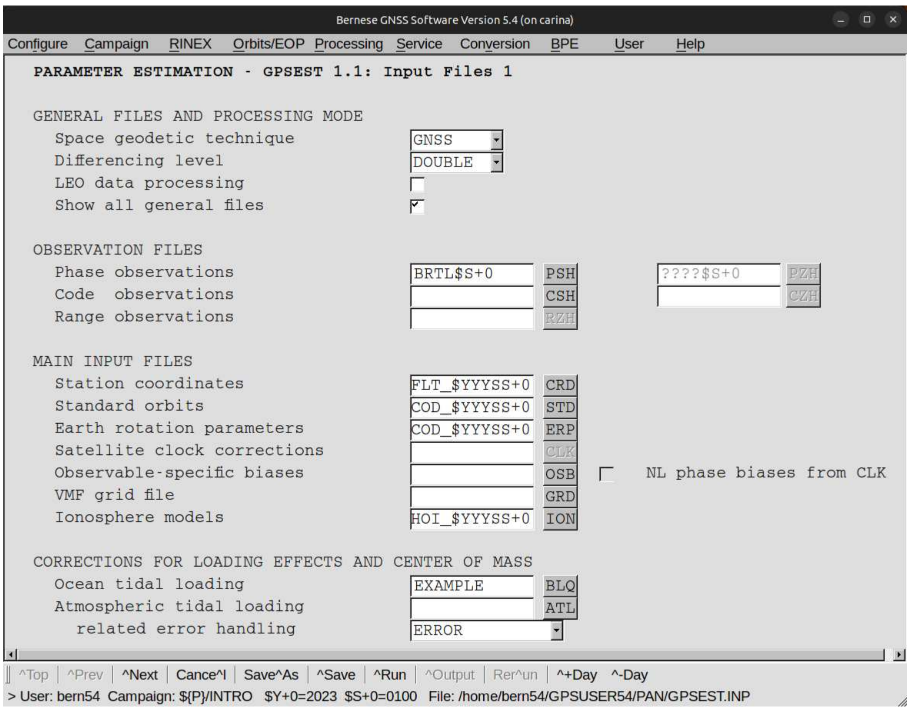
To resolve the ambiguities, we process the baselines separately one by one using the Quasi–Ionosphere–Free (QIF) strategy. This baseline processing mode is necessary because of the tremendous number of parameters. The attempt to resolve the ambiguities in a session solution might require too much CPU and memory to be feasible (several iterations with inversions of the full normal equation (NEQ) are necessary).

5.3.1 Ambiguity Resolution: Quasi–Ionosphere–Free (QIF)

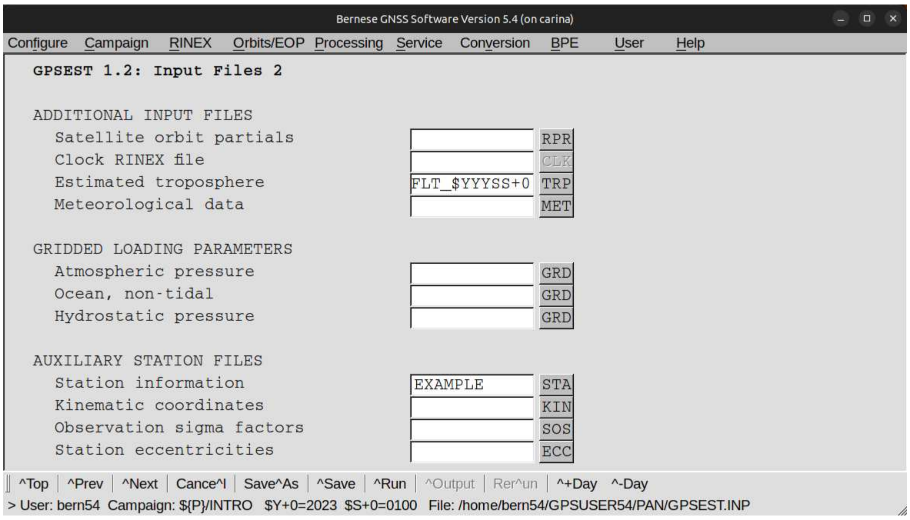
The complete list of baseline observation files of a session (e.g., session 0100 of year 2023) can be generated by listing all phase single–difference header files in the campaign's observation directory :

```
bern52@carina:~ > ls ${P}/INTRO/OBS/????0100.PSH
${P}/INTRO/OBS/BRTL0100.PSH
${P}/INTRO/OBS/GAJO0100.PSH
${P}/INTRO/OBS/HETL0100.PSH
${P}/INTRO/OBS/JOMI0100.PSH
${P}/INTRO/OBS/JOON0100.PSH
${P}/INTRO/OBS/LAON0100.PSH
${P}/INTRO/OBS/MAOR0100.PSH
${P}/INTRO/OBS/MOWS0100.PSH
${P}/INTRO/OBS/ONPT0100.PSH
${P}/INTRO/OBS/ONWS0100.PSH
${P}/INTRO/OBS/ONWT0100.PSH
${P}/INTRO/OBS/ORWT0100.PSH
${P}/INTRO/OBS/TLVI0100.PSH
${P}/INTRO/OBS/TLZI0100.PSH
${P}/INTRO/OBS/WTWZ0100.PSH
${P}/INTRO/OBS/WTZI0100.PSH
${P}/INTRO/OBS/ZIZM0100.PSH
```

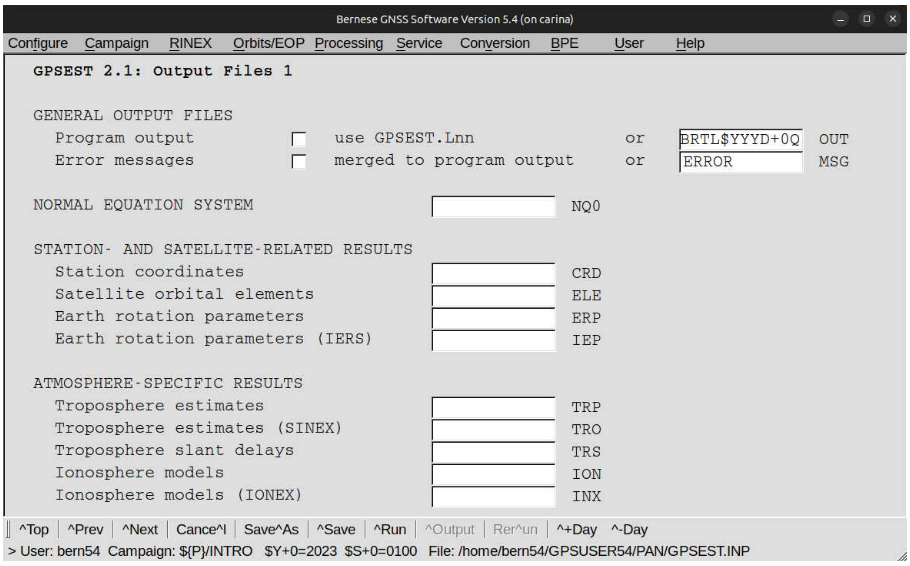
The first baseline for this session is from BRST to TLSE with the observation filename BRTL0100. Using the menu time variables this name is specified as BRTL$S+0. The following options are used for the ambiguity resolution step:



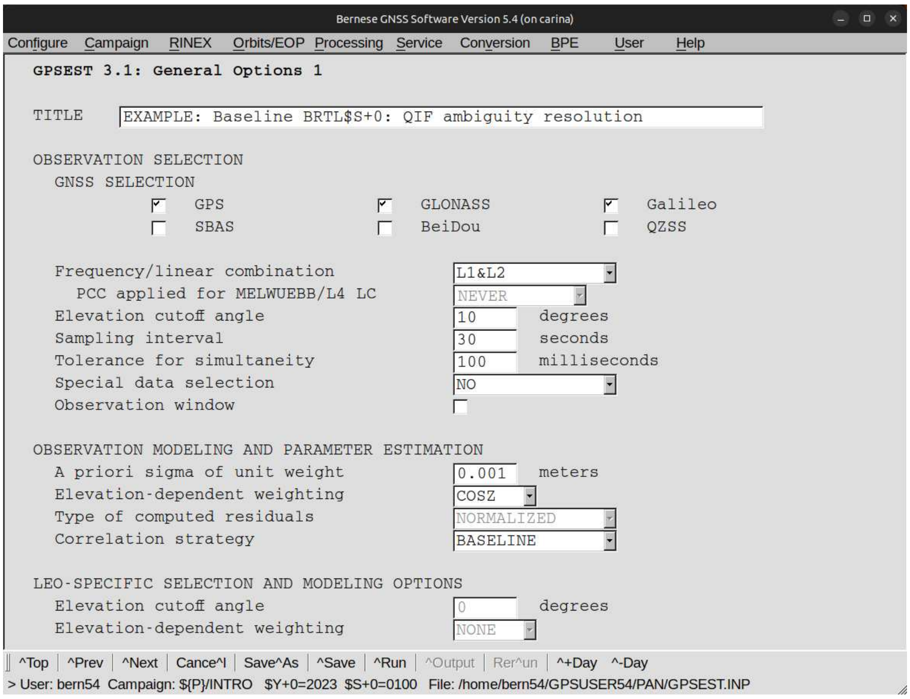
Only one baseline file is selected. Coordinates and troposphere estimates are introduced from the previous first network solution (Section 5.2).



Specify a baseline-specific output to prevent overwriting in subsequent runs: `BRTL$YYYD+0Q`. The `Q` at the end shall indicate that it is the output from the QIF–strategy.

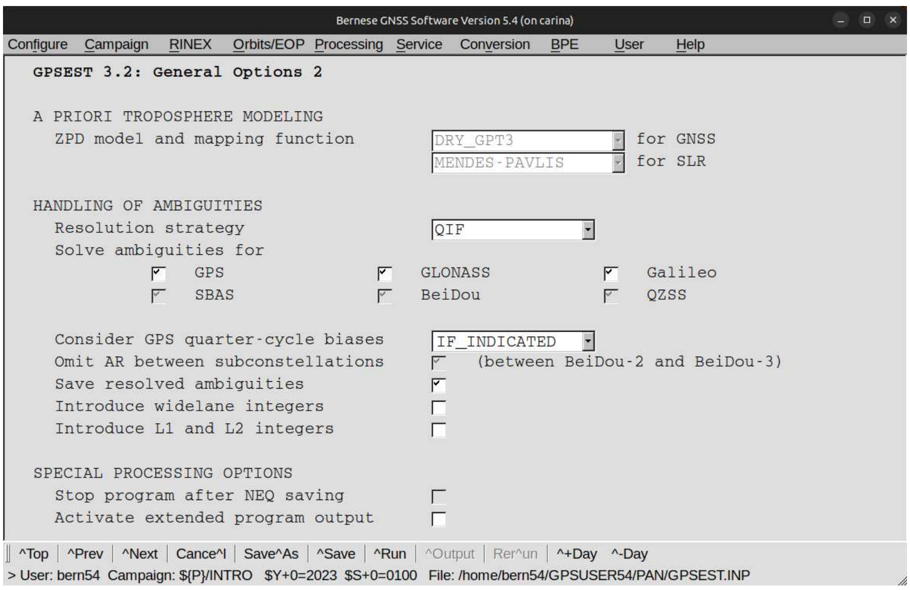


Because the QIF–ambiguity resolution strategy is very sensitive to the formal errors of the ambiguity parameters we have to include all measurements with the full sampling of 30 s into the processing.

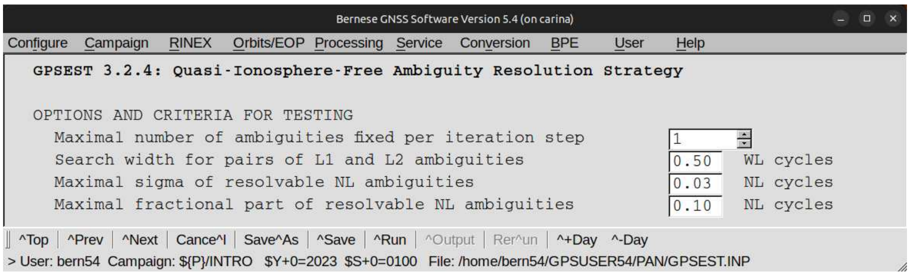


The selection of a "ZPD model and mapping function (GNSS)" is disabled because a troposphere file has been introduced in panel "GPSEST 1.2: Input Files 2". The program uses the troposphere model from this input file and allows no other selection for consistency reasons.

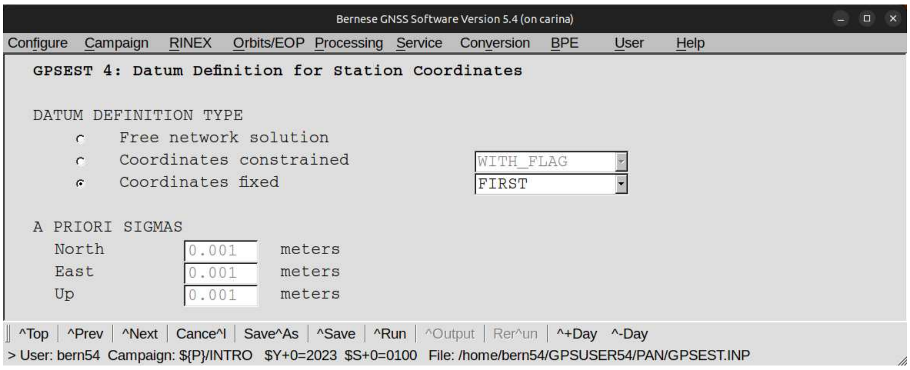
In the subsequent panel the "Resolution strategy" is chosen. Please, do not forget to store the resolved integer ambiguities in your observation file (mark checkbox "Save resolved ambiguities").

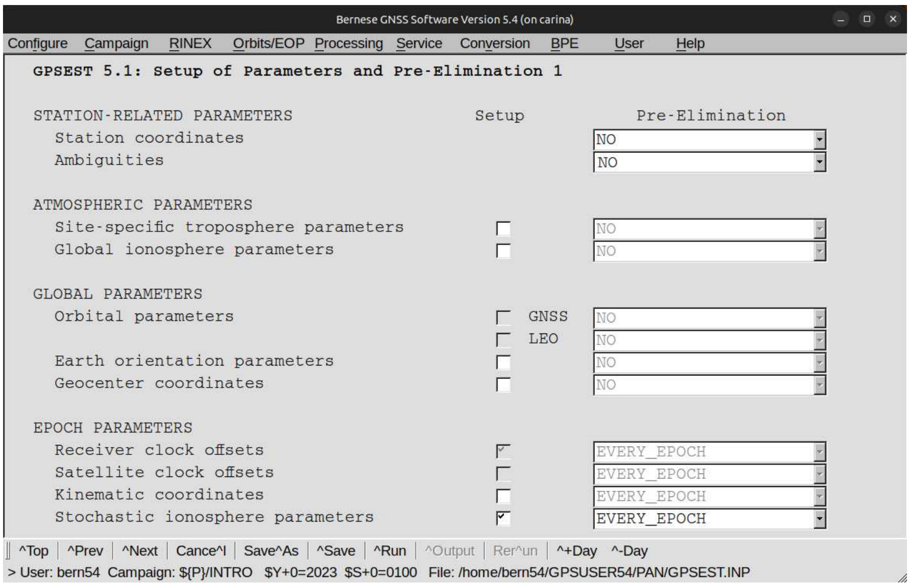


In case of ambiguity resolution including GLONASS, only one ambiguity per iteration can be resolved. The program will adjust the setting automatically issuing a warning message.

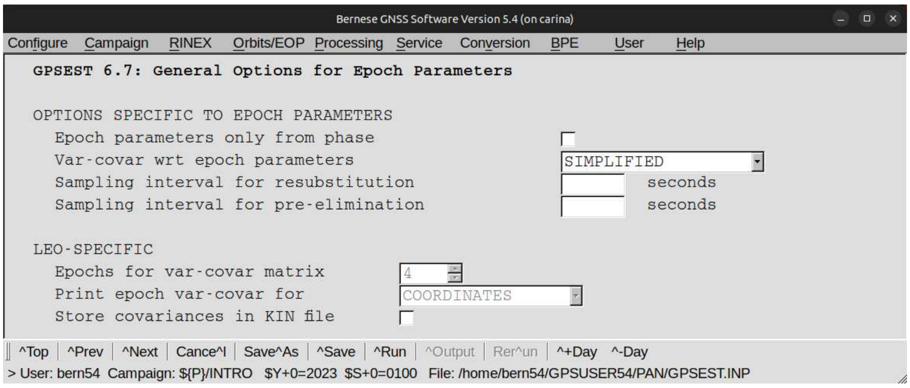


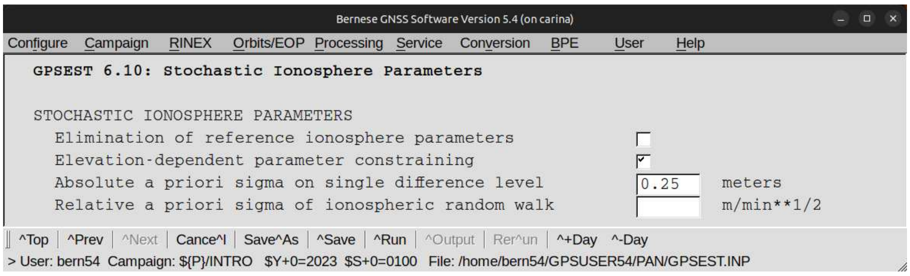
Even if we introduce the coordinate solution from the previous network solution from Section 5.2, we fix only the coordinates of the first station and estimate those from the second one with each iteration of ambiguity resolution. In this way, the geometry can react to the resolved ambiguities.





An additional panel with options specific to epoch–parameters is displayed now because the "Parameter Setup: stochastic ionosphere parameters" are pre-eliminated EVERY_EPOCH.





After reporting input options and input data for the current run of GPSEST, the results are presented in two parts. The first part refers to the solution where the ambiguities are estimated as real values whereas the second part reports the results after resolving the ambiguity parameters to integer values. The real–valued estimates for the ambiguities may be found below the Station coordinates and velocities section of the program output:

```
...

SUMMARY OF RESULTS
------------------

Number of parameters:
--------------------

Parameter type                        Adjusted   Expl.   Impl.  (elim)*  Del. Ref. Sing. No obs
-----------------------------------------------------------------------------------------------
Station coordinates / velocities             3       3       0              0    0     0      0
Ambiguities                                302     302       0              0    0     0      0
Stochastic ionosphere parameters         57405       0   57405  (epow)      0    0     0   5628
-----------------------------------------------------------------------------------------------
Total number                             57710     305   57405              0    0     0   5628


*Abbreviation pre-elimination (elim): before stacking (bfst), after stacking (afst),
                                      epoch-wise (epow), after inversion (afin)


Statistics:
----------

Total number of authentic observations      109050
Total number of pseudo-observations              2
...

A posteriori RMS of unit weight           0.001264 m
Chi**2/DOF                                    1.60

...
...
```

```
 Station coordinates and velocities:
 ----------------------------------

 Sol Station name         Typ Correction  Estimated value  RMS error   A priori value ... Abb
 ---------------------------------------------------------------------------------- ... ----
   1 TLSE 10003M009         X    -0.00028    4627851.61762    0.00019    4627851.61790 ... #CRD
   1 TLSE 10003M009         Y     0.00020     119640.36430    0.00021     119640.36410 ... #CRD
   1 TLSE 10003M009         Z    -0.00040    4372993.76177    0.00016    4372993.76217 ... #CRD

 ...

 AMBIGUITIES:
 -----------

                                            REFERENCE
 AMBI   FILE SAT. S_EPO   L_EPO FRQ WLF CLU   AMBI  CLU    AMBIGUITY    RMS    TOTAL AMBIGU.
 -------------------------------------------------------------------------------------

    1     1    1       1     509  1   1    1    75   90        -7.30   0.12     1864202.70
    2     1    1    2642    2880  1   1    2    75   90        -6.52   0.20     1864339.48
    3     1    3       1     659  1   1    3    75   90        -8.36   0.11     -750760.36
    4     1    3    2799    2880  1   1    4    75   90        -3.48   0.53     -750594.48
    5     1    8       1     204  1   1    5    75   90        -6.42   0.21    -1808333.42
    6     1    8    2377    2880  1   1    6    75   90       -10.01   0.12    -1808184.01
    7     1   10       1      52  1   1    7    75   90        -6.05   0.87      111000.95
    8     1   10    1354    1482  1   1    8    75   90        -6.05   0.41      110972.95
    9     1   10    1489    1668  1   1    9    75   90        -2.31   0.35      110974.69
   10     1   10    2372    2880  1   1   10    75   90        -2.21   0.14      110833.79
   11     1   14       1     234  1   1   11    75   90        -7.74   0.28     3165722.26
   12     1   14     924    1445  1   1   12    75   90       -12.73   0.14     3165405.27
   13     1   14    2757    2880  1   1   13    75   90        -3.09   0.41     3165802.91
   14     1   17      40     582  1   1   15    75   90        -5.58   0.14     3659546.42
   15     1   17    1273    1275  1   1   16    75   90        -0.20   4.31     3659483.80
   16     1   17    1282    1613  1   1   17    75   90         1.27   0.26     3659485.27
   17     1   21       1     417  1   1   18    75   90        -7.23   0.13      777312.77
   18     1   21    2506    2880  1   1   19    75   90         7.02   0.14      776999.02
   19     1   22       1     374  1   1   20    75   90        -7.91   0.18    -2981699.91
   20     1   22    1677    1714  1   1   21    75   90         1.44   0.94    -2981663.56
   21     1   22    1721    2128  1   1   22    75   90         1.08   0.18    -2981662.92
   22     1   22    2789    2880  1   1   23    75   90        -6.90   0.48    -2981854.90
   23     1   27       1      62  1   1   24    75   90        -6.85   0.62    -3336180.85
   24     1   27    2203    2880  1   1   25    75   90        -7.95   0.11    -3335862.95
   25     1   32       1     222  1   1   26    75   90        -7.92   0.27    -1527850.92
   26     1   32    1529    2016  1   1   27    75   90        -1.39   0.15    -1527880.39
   27     1   32    2023    2028  1   1   28    75   90        -5.44   3.48    -1527893.44
   28     1   32    2705    2880  1   1   29    75   90        -6.52   0.31    -1527834.52
   29     1  101       1     447  1   1   30    75   90        -8.63   0.13    -2619869.63
   30     1  101    1625    1951  1   1   31    75   90        -1.51   0.23    -2619820.51
   31     1  101    2630    2880  1   1   32    75   90        -5.05   0.18    -2619830.05
   32     1  107       1      42  1   1   33    75   90        -6.65   0.95     1191924.35
   33     1  107    1235    1736  1   1   34    75   90        -2.76   0.13     1191924.24
...
```

If GLONASS data are processed, single–difference (instead of double–difference) ambiguities are resolved and no — REFERENCE — as in case of, e.g., a GPS–only solution appears.

In the next part of the output the result of the QIF ambiguity resolution algorithm is given:

```
 ...

 AMBIGUITY RESOLUTION:
 --------------------

 STRATEGY :  QUASI-IONOSPHERE-FREE AMBIGUITY RESOLUTION (QIF)

 -------------------------------------------------------------------------------------------
 AMBIGUITY RESOLUTION ITERATION:     1
 -------------------------------------------------------------------------------------------

                                 BEST INT.    CORRECTIONS IN CYCLES
 FILE AM1 CL1 #AM1 AM2 CL2 #AM2    L1    L2     L1      L2      L5      L3    RMS(L3)  SA1  SA2
 -------------------------------------------------------------------------------------------

    1  57  64    1   70  81    1    -9    -8  -0.01   -0.01   0.005   0.007    0.003  215  203

 -------------------------------------------------------------------------------------------
 AMBIGUITY RESOLUTION ITERATION:     2
 -------------------------------------------------------------------------------------------
```

```
                                BEST INT.    CORRECTIONS IN CYCLES
FILE AM1 CL1 #AM1 AM2 CL2 #AM2   L1   L2    L1     L2     L5      L3    RMS(L3)  SA1  SA2
-----------------------------------------------------------------------------------------

   1 133 166   1  149 188   1    11   15  -0.76  -1.02   0.262   0.011   0.003  233  231

-----------------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:     3
-----------------------------------------------------------------------------------------

                                BEST INT.    CORRECTIONS IN CYCLES
FILE AM1 CL1 #AM1 AM2 CL2 #AM2   L1   L2    L1     L2     L5      L3    RMS(L3)  SA1  SA2
-----------------------------------------------------------------------------------------

   1  70  81   2   90 110   1     1   -2  -0.21  -0.28   0.074   0.012   0.003  203  208
...

-----------------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:    16
-----------------------------------------------------------------------------------------

                                BEST INT.    CORRECTIONS IN CYCLES
FILE AM1 CL1 #AM1 AM2 CL2 #AM2   L1   L2    L1     L2     L5      L3    RMS(L3)  SA1  SA2
-----------------------------------------------------------------------------------------

   1 146 185   1  147 186   1   -10  -11  -0.44  -0.57   0.130   0.023   0.004   12   25

-----------------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:    17
-----------------------------------------------------------------------------------------

                                BEST INT.    CORRECTIONS IN CYCLES
FILE AM1 CL1 #AM1 AM2 CL2 #AM2   L1   L2    L1     L2     L5      L3    RMS(L3)  SA1  SA2
-----------------------------------------------------------------------------------------

   1 140 177   1  147 186   2    -4   -6  -0.51  -0.65   0.136  -0.029   0.004   24   25
...

-----------------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:    47
-----------------------------------------------------------------------------------------

                                BEST INT.    CORRECTIONS IN CYCLES
FILE AM1 CL1 #AM1 AM2 CL2 #AM2   L1   L2    L1     L2     L5      L3    RMS(L3)  SA1  SA2
-----------------------------------------------------------------------------------------

   1  43  45   1   93 114   1     5    9  -0.63  -0.81   0.178  -0.012   0.005  115  111

-----------------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:    48
-----------------------------------------------------------------------------------------

                                BEST INT.    CORRECTIONS IN CYCLES
FILE AM1 CL1 #AM1 AM2 CL2 #AM2   L1   L2    L1     L2     L5      L3    RMS(L3)  SA1  SA2
-----------------------------------------------------------------------------------------

   1  52  59   1  150 189  21    -3   -9   0.38   0.52  -0.140  -0.030   0.005  204  212

-----------------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:    49
-----------------------------------------------------------------------------------------

                                BEST INT.    CORRECTIONS IN CYCLES
FILE AM1 CL1 #AM1 AM2 CL2 #AM2   L1   L2    L1     L2     L5      L3    RMS(L3)  SA1  SA2
-----------------------------------------------------------------------------------------

   1  68  79   1  105 126   1    -3   -1  -0.20  -0.26   0.054  -0.017   0.005  116  112

-----------------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:    50
-----------------------------------------------------------------------------------------

                                BEST INT.    CORRECTIONS IN CYCLES
FILE AM1 CL1 #AM1 AM2 CL2 #AM2   L1   L2    L1     L2     L5      L3    RMS(L3)  SA1  SA2
-----------------------------------------------------------------------------------------

   1  29  30   1  115 141   1    -3   -4  -0.81  -1.04   0.230  -0.010   0.005  101  105
 ...
```

The individual iteration steps are first described (we specified that only one ambiguity may be resolved within each iteration step — see panel "GPSEST 3.2.4: Quasi-Ionosphere-

Free Ambiguity Resolution Strategy"). The following information is listed for each resolved double–difference ambiguity:

`FILE` file number (1 in our case; we process one baseline only),

`AM1` first ambiguity number (single–difference level),

`CL1` corresponding ambiguity cluster,

`#AM1` number of ambiguities belonging to the same cluster,

`AM2, CL2, #AM2`
: similar information for the second ambiguity.

`BEST INT. L1, L2`
: are the integer corrections to the a priori values (a priori values are computed using the a priori coordinates and may be rather inaccurate).

`CORRECTIONS IN CYCLES`
: for carriers L1 and L2 gives the information about the fractional parts of the L_1 and L_2 ambiguities. The CORRECTIONS IN CYCLES L5 and L3 are of greater interest. The value L5 represents the ionosphere–induced bias expressed in L_5 cycles. These values may not be greater than the maximum value specified in panel "GPSEST 3.2.4: Quasi-Ionosphere-Free Ambiguity Resolution Strategy" (option "Search width for pairs of L1 and L2 ambiguities"). RMS(L3) is the criterion according to which the ambiguities are sorted. Ambiguities with L_3 RMS errors larger than the value specified in the program input panel (in our example 0.03) will not be resolved.

`SA1, SA2`
: first and second satellite number related to the ambiguities.
The first ambiguities are resolved for Galileo; with iteration AMBIGUITY RESOLUTION ITERATION: 15 the first GPS satellites follow. In ITERATION: 47, 49 and 50 there are examples for resolving pairs of ambiguities from the satellite using the same frequency. Later there are even examples for path–to–path ambiguity resolution, e.g., ITERATION: 52 or 66, indicated by the same satellite number for SA1 and SA2.

The following table summarizes the results of the ambiguity resolution:

```
...
                                              REFERENCE
AMBI   FILE SAT. S_EPO   L_EPO FRQ WLF CLU   AMBI  CLU    AMBIGUITY    RMS    TOTAL AMBIGU.    DL/L
------------------------------------------------------------------------------------------------------

   1     1    1      1     509  1   1    1     3     3            1              1864211.      0.000
   2     1    1   2642    2880  1   1    2   147   186          -11              1864335.      0.000
   3     1    3      1     659  1   1    3    74    87           -8              -750760.      0.000
   4     1    3   2799    2880  1   1    4    89   108           -4              -750595.      0.000
   5     1    8      1     204  1   1    5   147   186          -10             -1808337.      0.000
   6     1    8   2377    2880  1   1    6   126   158           -7             -1808181.      0.000
   7     1   10      1      52  1   1    7    89   108           -6               111001.      0.000
   8     1   10   1354    1482  1   1    8   147   186          -11               110968.      0.000
   9     1   10   1489    1668  1   1    9    26    27           -2               110975.      0.000
  10     1   10   2372    2880  1   1   10   126   158            2               110838.      0.000
  11     1   14      1     234  1   1   11   147   186          -11              3165719.      0.000
  12     1   14    924    1445  1   1   12   147   186          -16              3165402.      0.000
  13     1   14   2757    2880  1   1   13   147   186           -7              3165799.      0.000
  14     1   17     40     582  1   1   15    87   106            0              3659552.      0.000
  16     1   17   1282    1613  1   1   17   147   186           -1              3659483.      0.000
  17     1   21      1     417  1   1   18    87   106           -2               777318.      0.000
  18     1   21   2506    2880  1   1   19   139   175           10               777002.      0.000
  19     1   22      1     374  1   1   20   147   186          -10             -2981702.      0.000
  20     1   22   1677    1714  1   1   21    75    90         5.39   0.99    -2981659.61
  21     1   22   1721    2128  1   1   22    26    27            2             -2981662.      0.000
```

```
   22    1   22   2789   2880  1   1   23  147  186           -10           -2981858.       0.000
   23    1   27      1     62  1   1   24  147  186           -11           -3336185.       0.000
   24    1   27   2203   2880  1   1   25  126  158            -5           -3335860.       0.000
   25    1   32      1    222  1   1   26   89  108            -8           -1527851.       0.000
   26    1   32   1529   2016  1   1   27  120  148             1           -1527878.       0.000
   27    1   32   2023   2028  1   1   28   75   90         -1.48    3.67    -1527889.48
   28    1   32   2705   2880  1   1   29  147  186            -9           -1527837.       0.000
   29    1  101      1    447  1   1   30  115  141            -3           -2619864.       0.000
   30    1  101   1625   1951  1   1   31   75   90          2.51    0.23    -2619816.49
   31    1  101   2630   2880  1   1   32  115  141             0           -2619825.       0.000
   32    1  107      1     42  1   1   33   75   90         -2.71    1.00     1191928.29
   33    1  107   1235   1736  1   1   34   81   98            -4            1191923.       0.000
 ...
```

The ambiguities for which an RMS is specified could not be resolved (these ambiguities will be treated as real values by all subsequent program runs). In case of GLONASS, only ambiguities with the same channel number are resolved in Version 5.4 of *Bernese GNSS Software*.

Ambiguity resolution has an influence on other parameters. Therefore, the results of the ambiguity–fixed solution are given in Part 2 of the output:

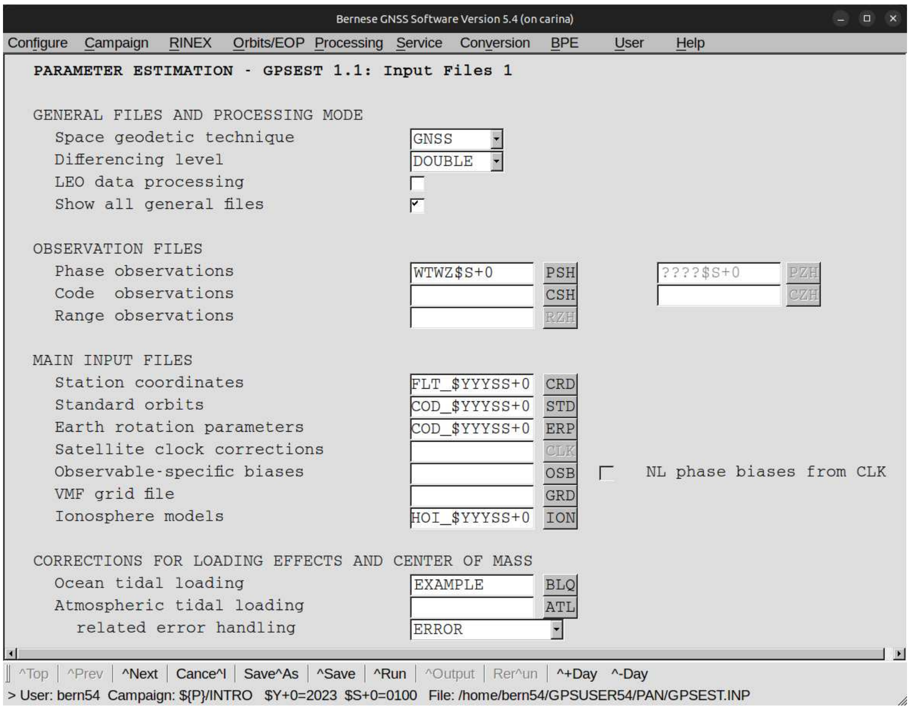
```
 ...
 SUMMARY OF RESULTS
 ------------------

 Number of parameters:
 --------------------

 Parameter type                        Adjusted    Expl.   Impl. (elim)*  Del. Ref. Sing. No obs
 -------------------------------------------------------------------------------------------------
 Station coordinates / velocities             3        3       0             0    0     0      0
 Ambiguities                                 78       76       0             0    2     0      0
 Stochastic ionosphere parameters         57405        0   57405   (epow)    0    0     0   5628
 -------------------------------------------------------------------------------------------------
 Total number                             57486       79   57405             0    2     0   5628


 *Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking (afst),
                                       epoch-wise (epow), after inversion (afin)


 Statistics:
 ----------

 Total number of authentic observations      109050
 Total number of pseudo-observations              2

 Total number of explicit parameters             81
 Total number of implicit parameters          57405

 Total number of observations                109052
 Total number of adjusted parameters          57486
 Degree of freedom (DOF)                      51566

 A posteriori RMS of unit weight           0.001337 m
 Chi**2/DOF                                    1.79

 Total number of observation files                1
 Total number of unobserved ambiguities          78
 Total number of stations                         1



 Station coordinates and velocities:
 ----------------------------------

 Sol Station name         Typ Correction  Estimated value  RMS error   A priori value ... Abb
 ---------------------------------------------------------------------------------- ... ----
   1 TLSE 10003M009        X    -0.00037    4627851.61753    0.00016    4627851.61790 ... #CRD
   1 TLSE 10003M009        Y     0.00138     119640.36548    0.00008     119640.36410 ... #CRD
   1 TLSE 10003M009        Z    -0.00081    4372993.76136    0.00015    4372993.76217 ... #CRD
```

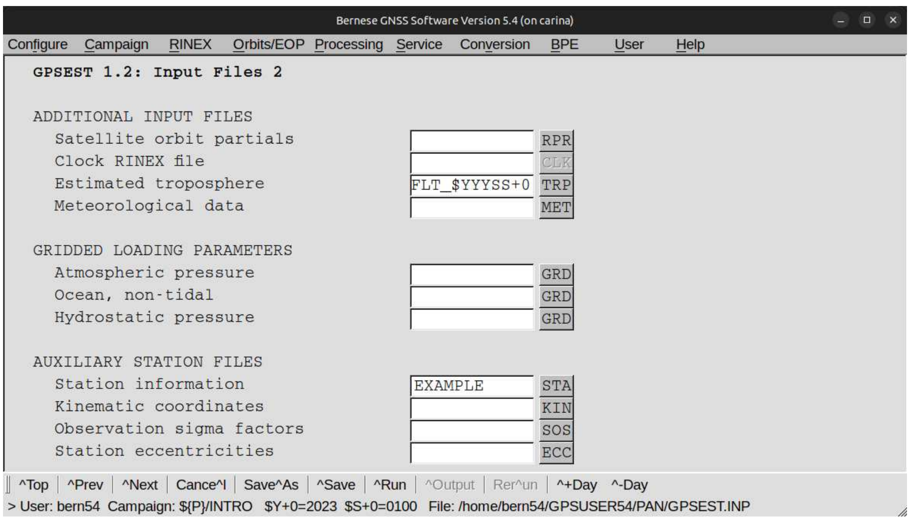
You may see from the output that from a total of 302 ambiguities 224 ambiguities could be resolved (compare part 1 AMBIGUITIES with part 2 AMBIGUITIES). Note that these numbers include reference ambiguities for each GNSS, GLONASS frequency number and frequency.

5.3.2 Ambiguity Resolution: Short Baselines

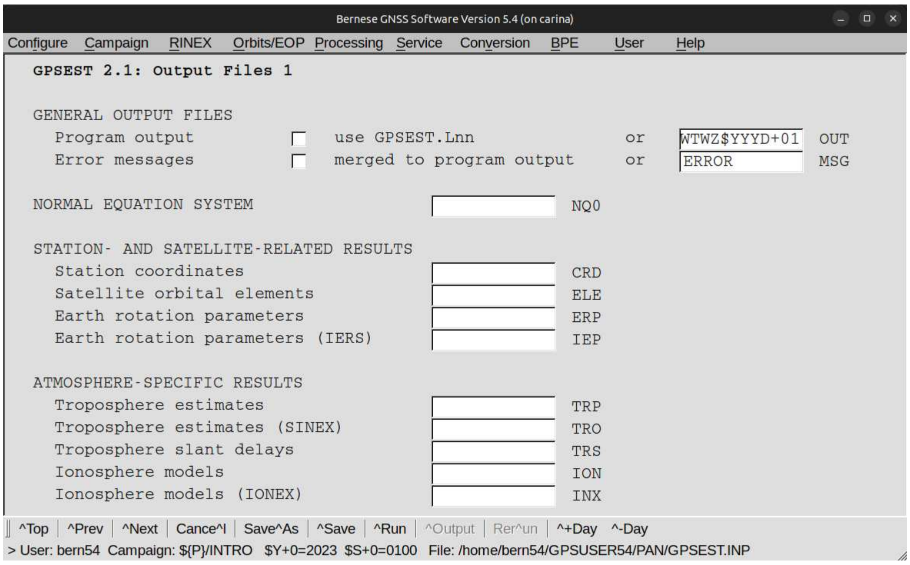
There are two very short baselines in the network where a direct ambiguity resolution for the L_1 and L_2 signal is possible applying the sigma–strategy.

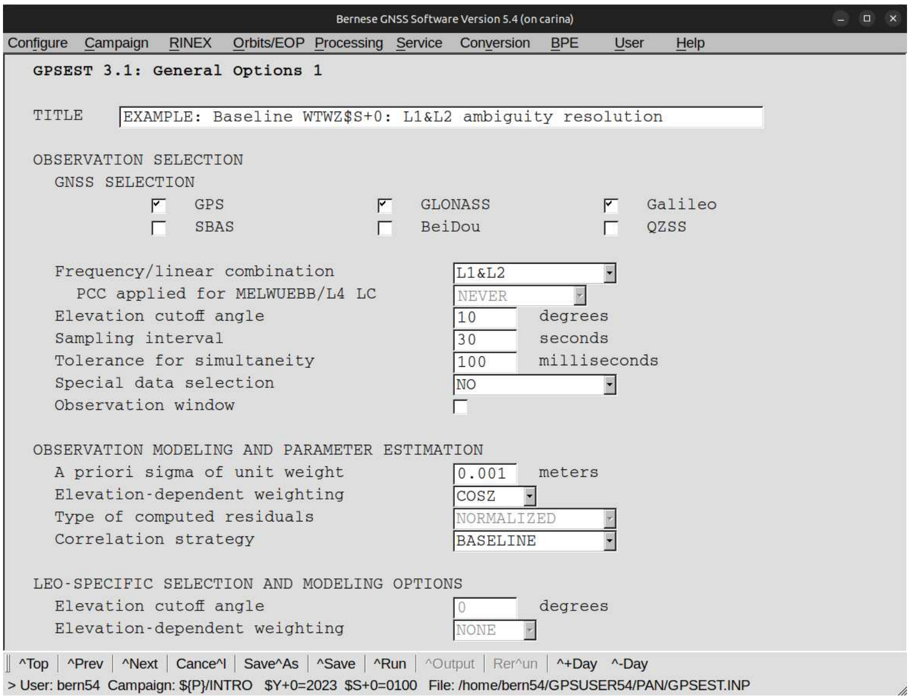
The ultra–short baseline in Kötzting is between WTZR and WTZZ (`WTWZ0100.PSH`). The `GPSEST` input panels should look like follows:

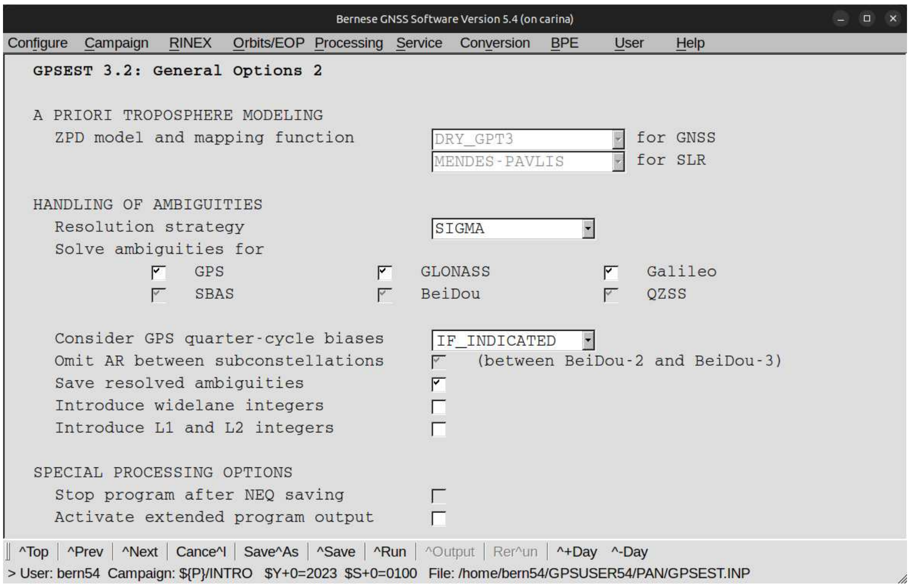


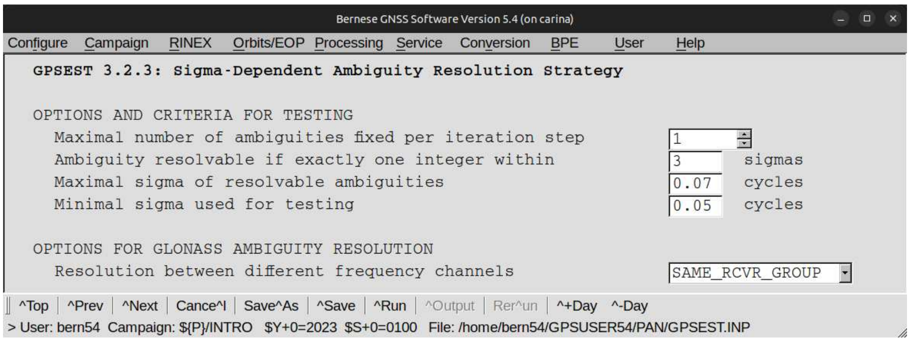


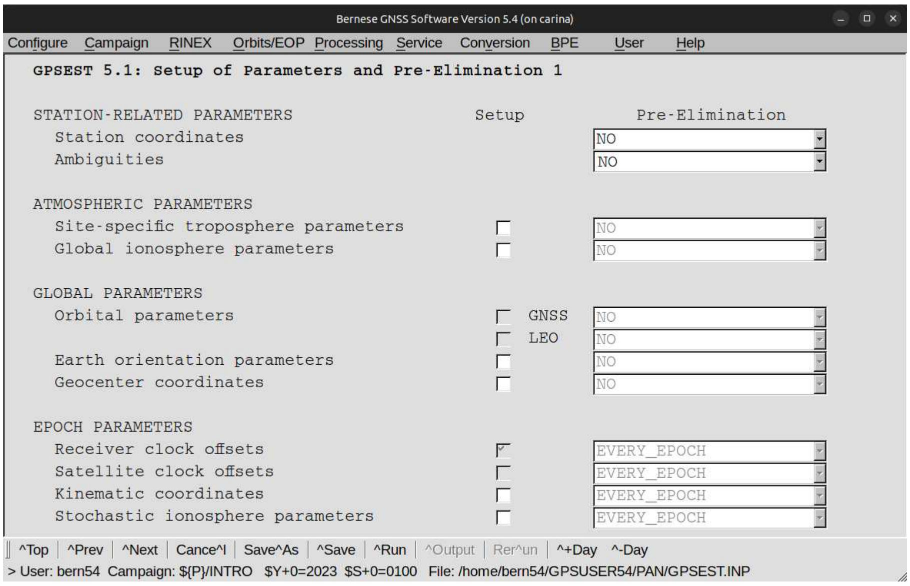
The program output name is again related to the name of the baseline but contains an identifier 1 at the end to distinguish the files from the output files of the QIF–strategy:











The structure of the program output is the same as it has extensively been described in the previous section for the QIF ambiguity resolution strategy. It starts with PART 1 for the solution before the ambiguity resolution. Here are the corresponding parameter statistics:

```
 ...
SUMMARY OF RESULTS
 ------------------

 Number of parameters:
 --------------------

 Parameter type                       Adjusted    Expl.   Impl. (elim)*  Del. Ref. Sing. No obs
 -----------------------------------------------------------------------------------------------
 Station coordinates / velocities            3        3       0             0    0     0      0
 Ambiguities                               364      364       0             0    0     2      0
 -----------------------------------------------------------------------------------------------
 Total number                              367      367       0             0    0     2      0


 *Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking (afst),
                                       epoch-wise (epow), after inversion (afin)


 Statistics:
 ----------

 Total number of authentic observations      107266
 Total number of pseudo-observations              4

 Total number of explicit parameters            367
 Total number of implicit parameters              0

 Total number of observations                107270
 Total number of adjusted parameters            367
 Degree of freedom (DOF)                     106903

 A posteriori RMS of unit weight           0.001139 m
 Chi**2/DOF                                    1.30

 Total number of observation files                1
 Total number of unobserved ambiguities          34
 Total number of stations                         1
 ...
```

After the ambiguity resolution the same statistics is provided in PART 2:

```
 ...
 SUMMARY OF RESULTS
 ------------------

 Number of parameters:
 --------------------

 Parameter type                       Adjusted    Expl.   Impl. (elim)*  Del. Ref. Sing. No obs
 -----------------------------------------------------------------------------------------------
 Station coordinates / velocities            3        3       0             0    0     0      0
 Ambiguities                                98       94       0             0    4     2      0
 -----------------------------------------------------------------------------------------------
 Total number                              101       97       0             0    4     2      0


 *Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking (afst),
                                       epoch-wise (epow), after inversion (afin)


 Statistics:
 ----------

 Total number of authentic observations      107266
 Total number of pseudo-observations              4

 Total number of explicit parameters            101
 Total number of implicit parameters              0

 Total number of observations                107270
 Total number of adjusted parameters            101
 Degree of freedom (DOF)                     107169

 A posteriori RMS of unit weight           0.001281 m
 Chi**2/DOF                                    1.64

 Total number of observation files                1
 Total number of unobserved ambiguities          34
 Total number of stations                         1
 ...
```

From the number of ambiguity parameters it can be computed that 266 out of 364 ambiguities from GPS, GLONASS, and Galileo have been resolved to their integer numbers. Please recall that at least 6 ambiguity parameters must remain real values because one reference ambiguity per GNSS and frequency is needed. For the Code Division Multiple Access (CDMA) systems GPS and Galileo they are reported as — Reference —. Because the two receivers belong to different groups regarding "GLONASS amb. resol. between different frequencies" only the ambiguities between the same frequency numbers have been resolved. In addition, depending on the receiver type, not all ambiguities for GPS are allowed to be resolved too, to prevent problems with the quarter–cycle bias between the P- and C-code signal (see option "Consider GPS quarter-cycle biases" in panel "GPSEST 3.2: General Options 2" and the lecture on ambiguity resolution).

5.3.3 Ambiguity Resolution: BPE

Admittedly, it is cumbersome to process the baselines "manually" one after the other — you have 17 baselines per session for this small example campaign. On Thursday you will have a lecture on automation of the data processing using the BPE.

In the example BPE `RNX2SNX.PCF` the sequence for the ambiguity resolution is included. For this tutorial lecture a small part of this BPE is extracted into a separate `TUTORIAL.PCF` BPE. The process control file (PCF) is located in the directory `${U}/PCF`. If you are not in the *Bernese Introductory Course* environment, you have to use the `RNX2SNX.PCF` instead of the `TUTORIAL.PCF` and skip the scripts that are not needed. You also need to adjust the variables in the lower section (a brief description is given in the panel description of the RUNBPE) program).

The `TUTORIAL.PCF` consists of two parts: the first part defines the scripts and the option directories where the program's input files are taken from. In addition the CPU specification and waiting conditions are defined to keep the correct order for the execution of the scripts. The keyword PARALLEL indicates a special execution mode for the scripts, e.g., `GNSAMB_P` with PID 412 or `GNSQIF_P` with PID 432. They may run in parallel for each individual baseline. The preparatory scripts, e.g., `GNSAMBAP` or `GNSQIFAP` define the list of baselines to be processed. The second part defines the so called BPE or PCF variables that can be used within the scripts or in the input fields of the menu. A detailed introduction to the BPE will be the topic of a lecture on Thursday.

The `TUTORIAL.PCF` is responsible for the following tasks:

`401 SATMRK` :
: All previously resolved ambiguities are re–initialized to start for all files from unresolved ambiguities (otherwise the interpretation of the statistic of resolved ambiguities may become difficult).

`411 GNSAMBAP` **and** `412 GNSAMB_P` :
: Applies the SIGMA ambiguity resolution strategy using the Melbourne-Wübbena linear combination to all baselines longer than 200 km of the example in a baseline–by–baseline mode, where several baselines may be processed at the same time in parallel.

`421 GNSL53AP` **and** `422 GNSL53_P` :
: Applies the SIGMA ambiguity resolution strategy using the wide- and narrow-lane

```
#
# ==========================================================================
# TUTORIAL.PCF
# ==========================================================================
#
# Purpose:
# Run the ambiguity resolution for one session in the <<Terminal Session>>
# of the Bernese Software Introductory Course
#
# --------------------------------------------------------------------------
#
# Author      :  R. Dach
# Created     :  27-Aug-2022
#
# Changes     :
#
# ==========================================================================
#
#

PID  SCRIPT    OPT_DIR   PARAMETERS
#
# Resolve phase ambiguities
# -------------------------
401  SATMRK    R2S_GEN   CPU=ANY
411  GNSAMBAP  R2S_AMB   CPU=ANY; WAIT=401
412  GNSAMB_P  R2S_AMB   CPU=ANY; WAIT=411;  PARALLEL=411
421  GNSL53AP  R2S_L53   CPU=ANY; WAIT=412
422  GNSL53_P  R2S_L53   CPU=ANY; WAIT=421;  PARALLEL=421
431  GNSQIFAP  R2S_QIF   CPU=ANY; WAIT=422
432  GNSQIF_P  R2S_QIF   CPU=ANY; WAIT=431;  PARALLEL=431
441  GNSL12AP  R2S_L12   CPU=ANY; WAIT=432
442  GNSL12_P  R2S_L12   CPU=ANY; WAIT=441;  PARALLEL=441
443  AMBXTR    R2S_AMB   CPU=ANY; WAIT=442
#
# End of BPE
# ----------
899  DUMMY     NO_OPT    CPU=ANY; WAIT=443
#
#

VARIABLE   DEFAULT         PARAMETERS
#
# General and model files:
# -----------------------
V_SUBMOD = DESAI2016;      DESCRIPTION=Subdaily pole model
V_NUTMOD = IAU2000R06;     DESCRIPTION=Nutation model
V_PCV    = I20;            DESCRIPTION=Antenna phase center (PCV) model
V_PCVINF = ANTENNA;        DESCRIPTION=PCV information file
V_SATINF = SATELLIT;       DESCRIPTION=Satellite information file
V_SATCRX = SAT_$Y+0;       DESCRIPTION=Satellite problem file
V_ORB    = COD;            DESCRIPTION=Orbit/ERP, CLK, bias information
#
# Reference frame and station related files:
# ------------------------------------------
V_CRDINF = EXAMPLE;        DESCRIPTION=Merged CRD/VEL filename
V_STAINF = EXAMPLE;        DESCRIPTION=_Station information file
V_BLQINF = EXAMPLE;        DESCRIPTION=_BLQ file name, CMC corrections
V_ATLINF = EXAMPLE;        DESCRIPTION=_ATL file name, CMC corrections
V_HOIFIL = HOI_$YYYSS+0;   DESCRIPTION=_Ionosphere model for higher order iono
V_OSBFIL = COD_$YYYSS+0;   DESCRIPTION=_OSB-file with GNSS satellite biases
#
# Data selection:
# --------------
#
# Data selection:
# --------------
V_OBSSEL = OBSERV;         DESCRIPTION=Observation selection file
V_SATSYS = GRE;            DESCRIPTION=Select the GNSS (max. supported: GRECJ)
#
# Ambiguity resolution:
# --------------------
V_GNSSAR = GRE;            DESCRIPTION=Select the GNSS for amb. resolu. (GECJ)
V_BL_AMB = 6000;           DESCRIPTION=Maximum baseline length for MW/L3 AR
V_BL_QIF = 2000;           DESCRIPTION=Maximum baseline length for QIF AR
V_BL_L53 = 200;            DESCRIPTION=Maximum baseline length for L5/L3 AR
V_BL_L12 = 20;             DESCRIPTION=Maximum baseline length for L1&L2 AR
#
# Other solution IDs used in the BPE:
# ----------------------------------
V_APR    = APR;            DESCRIPTION=A priori information
V_FLT    = FLT;            DESCRIPTION=Preliminary (ambiguity-float) results
#
# DO NOT USE V_D, V_J, V_M, V_Y VARIABLES!
# (they are used already by the menu)
#
```

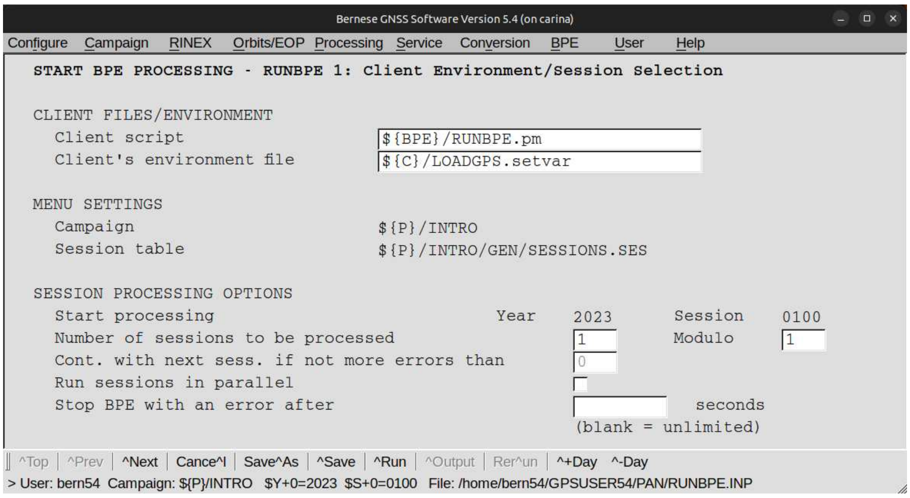
linear combinations to all baselines shorter than 200 km and longer than 20 km. In this example we don't have such a baseline, this section will be skipped automatically.

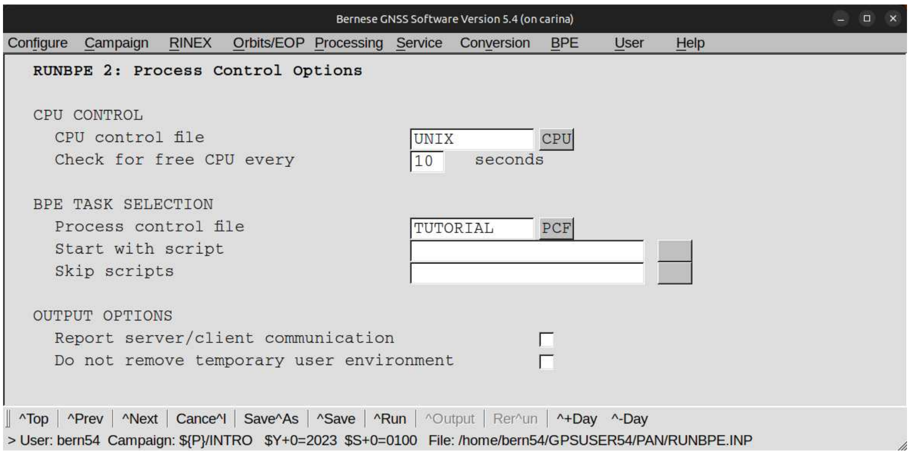
431 `GNSQIFAP` **and** 432 `GNSQIF_P` :
Applies the QIF ambiguity resolution strategy to all baselines of the example in a baseline–by–baseline mode, where several baselines may be processed at the same time in parallel. The resolved ambiguities from the previous steps are introduced and, consequently the algorithm only applies to the remaining unresolved ambiguities.

441 `GNSL12AP` **and** 442 `GNSL12_P` :
Applies the SIGMA ambiguity resolution strategy directly to the original observations on the L_1 and L_2 frequency for both short baselines in the example network: Kötzting (WTZR and WTZZ) and Zimmerwald (ZIM2 and ZIMM). These scripts also run in a baseline–by–baseline mode, allowing for a parallel processing.

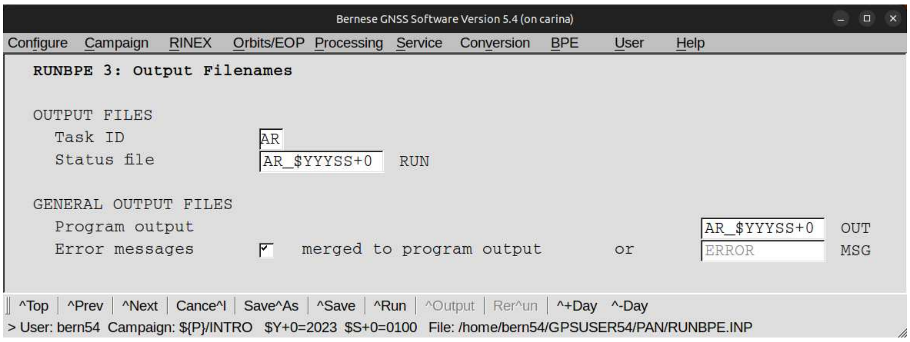
443 `AMBXTR` :
Creates a series of summary files on the success rate of the ambiguity resolution process in the various steps.

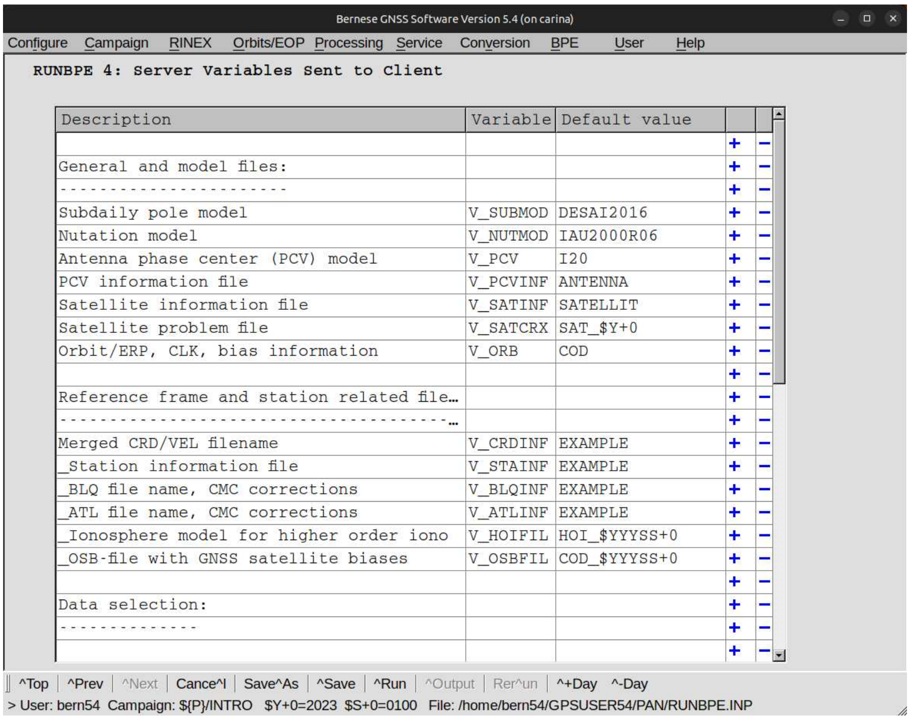
In the *Bernese Introductory Course* environment the `TUTORIAL.PCF` BPE can be started for one session (e.g., day 010 of year 2023) using "Menu>BPE>Start BPE processing":





If you follow the tutorial outside from the environment of the *Bernese Introductory Course* you can select RNX2SNX in option "Process control file" and skip all scripts apart from the range between `PID 401 SATMRK` to `PID 442 GNSL12_P` (option "Skip scripts").



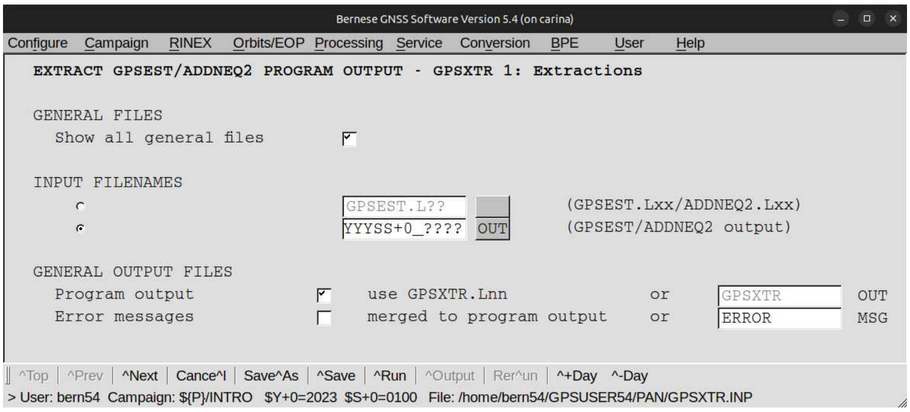


Run the BPE for the current session. If the BPE stops with an error you can inspect the files `${P}/INTRO/BPE/AR230100_...PRT` and `${P}/INTRO/BPE/AR230100_...LOG` belonging to your current session. These files report for instance if an input file is missing. This might be the case if you did not follow the naming convention proposed in the tutorial. In that case you have to copy the file from your naming to the expected one.

5.3.4 Ambiguity Resolution: Summary

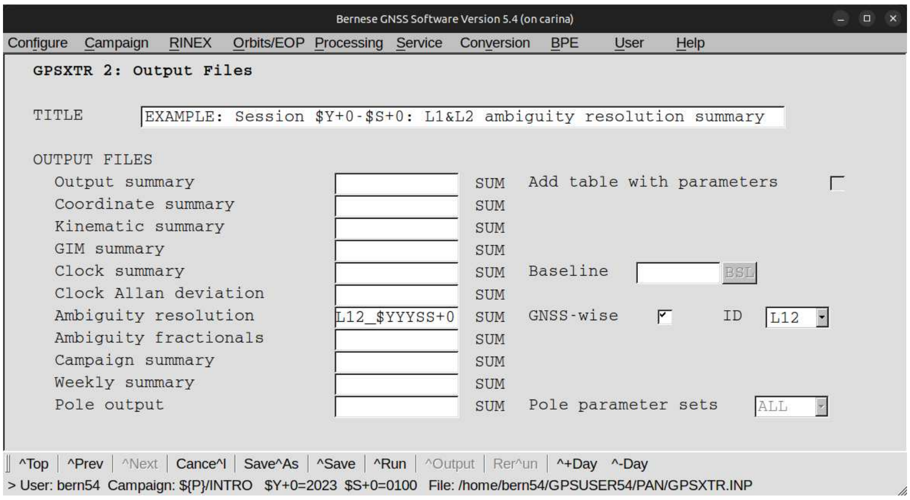
For each observation file a corresponding program output file is generated. To get an overview on the success rate of the various ambiguity resolution steps a one-line summary for each baseline (and optionally for each satellite system) is generated by the BPE in the last step (`443 AMBXTR`).

The program GPSXTR ("Menu>Processing>Program output extraction>Parameter estimation/stacking") was used in several configurations. Here we have a look at the extraction of the last step of the ambiguity resolution, direct use of the SIGMA-strategy on L_1 and L_2 frequencies (solution indicator `L12`):



The entry for option "GPSEST/ADDNEQ output files" may be incomplete in the screenshot. It should be L12_$YYYSS+0_????.

All program output files related to the L12 ambiguity resolution method have been specified with program output filenames fitting in the pattern ${P}/INTRO/OUT/L12_$YYYSS+0_????.OUT and can, therefore, easily be selected in the input field "GPSEST/ADDNEQ output files".



The resulting protocol in the file ${P}/INTRO/OUT/L12_20230100.SUM looks like:

```
 File      Sta1 Sta2     Length     Before       After      Res  Sys    ...
                          (km)    #Amb  (mm)   #Amb  (mm)   (%)         ...
 -----------------------------------------------------------------      ...
 WTWZ0100  WTZR WTZZ       0.002    146  1.1     20  1.3   86.3 G       ... #AR_L12
 WTWZ0100  WTZR WTZZ       0.002    108  1.1     56  1.3   48.1  R      ... #AR_L12
 WTWZ0100  WTZR WTZZ       0.002    106  1.1     14  1.3   86.8   E     ... #AR_L12
 WTWZ0100  WTZR WTZZ       0.002    360  1.1     90  1.3   75.0 GRE     ... #AR_L12
 ZIZM0100  ZIM2 ZIMM       0.019    120  1.3      1  1.3   99.2 G       ... #AR_L12
 -----------------------------------------------------------------      ...
 Tot:    2                 0.010    266  1.2     21  1.3   92.1 G       ... #AR_L12
 Tot:    1                 0.002    108  1.1     56  1.3   48.1  R      ... #AR_L12
 Tot:    1                 0.002    106  1.1     14  1.3   86.8   E     ... #AR_L12
 Tot:    2                 0.010    480  1.2     91  1.3   81.0 GRE     ... #AR_L12


Legend:
 QCB   consider GPS quarter-cycle bias  : - (not applicable) N (never) A (always)
                                          I (indicated) S (selected)
 FRQ   GLONASS resolution between freq.: - (not applicable) N (never) A (always)
                                          T (same rcvr. type) M (same rcvr. model)
```

If you compare the number of ambiguity parameters in the GPSEST program output with the number of ambiguities in the GPSXTR summary files, the number of reference ambiguities that need to be kept unresolved are considered.

The solution from the BPE are identical only to one of the manually processed solutions. You can compare the following two files in `${P}/INTRO/OUT` for each strategy (e.g., with `tkdiff`):

	Filenames from	
	Manual processing	processed by the BPE
Strategy: direct L_1/L_2:	`WTWZ20230101.OUT`	`L12_20230100_WTWZ.OUT`

The QIF-based ambiguity resolution in the automated processing started from the resolved ambiguities based on the Melbourne-Wübbena strategy whereas in the manual mode the QIF-strategy was applied to the plain files.

Let's have a look at the complete summary file generated by the script in the BPE available in `${P}/INTRO/OUT/AMB_20230100.SUM`. The first part is reporting about the wide-lane/narrow-lane ambiguity resolution starting from the Melbourne-Wübbena linear combination:

```
===============================================================================
 Code-Based Widelane (WL) Ambiguity Resolution (<6000 km)
===============================================================================

 File     Sta1 Sta2    Length     Before      After    Res  Sys   ...
                        (km)    #Amb (mm)  #Amb (mm)   (%)        ...
 ---------------------------------------------------------------  ...
 BRTL0100 BRST TLSE    707.462    66  1.3    11  1.3  83.3 G      ... #AR_WL
 BRTL0100 BRST TLSE    707.462    38  1.3     7  1.3  81.6   E    ... #AR_WL
 BRTL0100 BRST TLSE    707.462   104  1.3    18  1.3  82.7 G E    ... #AR_WL
 GAJO0100 GANP JOZ2    344.407    63  1.4     6  1.5  90.5 G      ... #AR_WL
 GAJO0100 GANP JOZ2    344.407    41  1.4     8  1.5  80.5   E    ... #AR_WL
 GAJO0100 GANP JOZ2    344.407   104  1.4    14  1.5  86.5 G E    ... #AR_WL
 HETL0100 HERT TLSE    816.392    59  0.9     8  1.0  86.4 G      ... #AR_WL
 JOMI0100 JOZ2 MIKL    973.137    60  1.4    20  1.5  66.7 G      ... #AR_WL
 JOMI0100 JOZ2 MIKL    973.137    40  1.4    20  1.5  50.0   E    ... #AR_WL
 ...
 TLZI0100 TLSE ZIM2    596.848    68  1.2    15  1.2  77.9 G      ... #AR_WL
 TLZI0100 TLSE ZIM2    596.848    36  1.2     6  1.2  83.3   E    ... #AR_WL
 TLZI0100 TLSE ZIM2    596.848   104  1.2    21  1.2  79.8 G E    ... #AR_WL
 WTZI0100 WTZR ZIM2    475.909    58  1.2    10  1.3  82.8 G      ... #AR_WL
 WTZI0100 WTZR ZIM2    475.909    39  1.2    12  1.3  69.2   E    ... #AR_WL
 WTZI0100 WTZR ZIM2    475.909    97  1.2    22  1.3  77.3 G E    ... #AR_WL
 ---------------------------------------------------------------  ...
 Tot:  15              674.331   910  1.1   174  1.2  80.9 G      ... #AR_WL
 Tot:  13              669.172   491  1.1   101  1.2  79.4   E    ... #AR_WL
 Tot:  15              674.331  1401  1.1   275  1.2  80.4 G E    ... #AR_WL
```

```
===============================================================================
 Code-Based Narrowlane (NL) Ambiguity Resolution (<6000 km)
===============================================================================

 File     Sta1 Sta2    Length     Before     After    Res  Sys   ...
                        (km)    #Amb (mm)  #Amb (mm)  (%)        ...
 ------------------------------------------------------------   ...
 BRTL0100 BRST TLSE    707.462    66  1.1    11  1.1  83.3 G     ... #AR_NL
 BRTL0100 BRST TLSE    707.462    38  1.1     7  1.1  81.6   E   ... #AR_NL
 BRTL0100 BRST TLSE    707.462   104  1.1    18  1.1  82.7 G E   ... #AR_NL
 GAJO0100 GANP JOZ2    344.407    64  0.8     6  0.8  90.6 G     ... #AR_NL
 GAJO0100 GANP JOZ2    344.407    40  0.8     7  0.8  82.5   E   ... #AR_NL
 GAJO0100 GANP JOZ2    344.407   104  0.8    13  0.8  87.5 G E   ... #AR_NL
 HETL0100 HERT TLSE    816.392    59  0.9    11  1.0  81.4 G     ... #AR_NL
 JOMI0100 JOZ2 MIKL    973.137    64  0.8    23  0.8  64.1 G     ... #AR_NL
 JOMI0100 JOZ2 MIKL    973.137    40  0.8    21  0.8  47.5   E   ... #AR_NL
 ...
 TLZI0100 TLSE ZIM2    596.848    68  1.0    15  1.1  77.9 G     ... #AR_NL
 TLZI0100 TLSE ZIM2    596.848    36  1.0     6  1.1  83.3   E   ... #AR_NL
 TLZI0100 TLSE ZIM2    596.848   104  1.0    21  1.1  79.8 G E   ... #AR_NL
 WTZI0100 WTZR ZIM2    475.909    59  1.2    10  1.2  83.1 G     ... #AR_NL
 WTZI0100 WTZR ZIM2    475.909    38  1.2    11  1.2  71.1   E   ... #AR_NL
 WTZI0100 WTZR ZIM2    475.909    97  1.2    21  1.2  78.4 G E   ... #AR_NL
 ------------------------------------------------------------   ...
 Tot:  15              674.331   923  0.9   192  1.0  79.2 G     ... #AR_NL
 Tot:  13              669.172   485  0.9   104  1.0  78.6   E   ... #AR_NL
 Tot:  15              674.331  1408  0.9   296  1.0  79.0 G E   ... #AR_NL
```

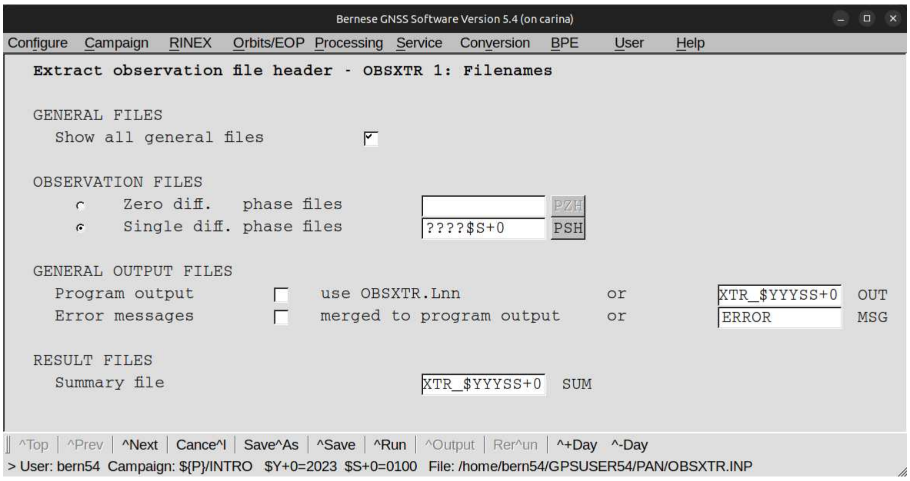
GLONASS is not included because it is not supported for the Melbourne-Wübbena linear combination with Version 5.4 of *Bernese GNSS Software*.

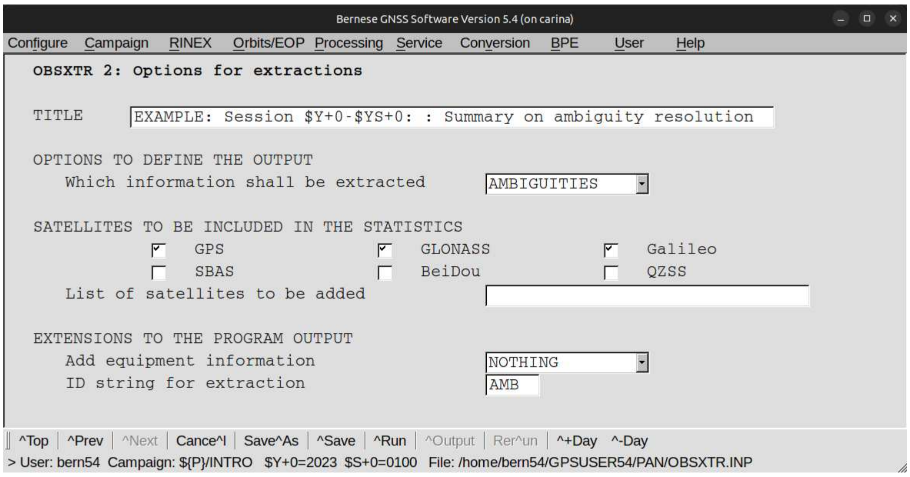
The next block of the ambiguity resolution summary is empty because no baselines for the related lengths are available in the example dataset. The next section is related to the QIF-strategy which is only applied to those ambiguities that are not resolved so far. For this reason the ambiguity resolution rate for GPS and Galileo are lower than it might be expected:

```
===============================================================================
 Quasi-Ionosphere-Free (QIF) Ambiguity Resolution (<2000 km)
===============================================================================

 File     Sta1 Sta2    Length     Before     After    Res  Sys   ...
                        (km)    #Amb (mm)  #Amb (mm)  (%)        ...
 ------------------------------------------------------------   ...
 BRTL0100 BRST TLSE    707.462    22  1.3    20  1.4   9.1 G     ... #AR_QIF
 BRTL0100 BRST TLSE    707.462    92  1.3    42  1.4  54.3  R    ... #AR_QIF
 BRTL0100 BRST TLSE    707.462    16  1.3    14  1.4  12.5   E   ... #AR_QIF
 BRTL0100 BRST TLSE    707.462   130  1.3    76  1.4  41.5 GRE   ... #AR_QIF
 GAJO0100 GANP JOZ2    344.407    12  1.0     8  1.0  33.3 G     ... #AR_QIF
 GAJO0100 GANP JOZ2    344.407    98  1.0    40  1.0  59.2  R    ... #AR_QIF
 GAJO0100 GANP JOZ2    344.407    16  1.0     8  1.0  50.0   E   ... #AR_QIF
 GAJO0100 GANP JOZ2    344.407   126  1.0    56  1.0  55.6 GRE   ... #AR_QIF
 HETL0100 HERT TLSE    816.392    22  1.1    14  1.2  36.4 G     ... #AR_QIF
 ...
 TLZI0100 TLSE ZIM2    596.848    14  1.2     6  1.2  57.1   E   ... #AR_QIF
 TLZI0100 TLSE ZIM2    596.848   134  1.2    70  1.2  47.8 GRE   ... #AR_QIF
 WTZI0100 WTZR ZIM2    475.909    20  1.4    14  1.4  30.0 G     ... #AR_QIF
 WTZI0100 WTZR ZIM2    475.909    90  1.4    32  1.4  64.4  R    ... #AR_QIF
 WTZI0100 WTZR ZIM2    475.909    24  1.4     6  1.4  75.0   E   ... #AR_QIF
 WTZI0100 WTZR ZIM2    475.909   134  1.4    52  1.4  61.2 GRE   ... #AR_QIF
 ------------------------------------------------------------   ...
 Tot:  15              674.331   372  1.1   244  1.2  34.4 G     ... #AR_QIF
 Tot:  14              679.688  1252  1.1   528  1.2  57.8  R    ... #AR_QIF
 Tot:  13              669.172   234  1.1   108  1.2  53.8   E   ... #AR_QIF
 Tot:  15              674.331  1858  1.1   880  1.2  52.6 GRE   ... #AR_QIF
```

The next section in the ambiguity resolution summary is related to the direct ambiguity resolution applying the SIGMA-strategy directly on the L_1 and L_2 observations for very short baselines. The same summary results as we have obtained above manually.

This multiple-step ambiguity resolution makes it difficult to get an overall overview on the success-rate of the ambiguity resolution. Such an overview can be provided by the program OBSXTR ("Menu>Service>Bernese observation files>Extract statistics from header file") that evaluates the header of the phase observation files on the relation of resolved ambiguities





The program output and a satellite-wise summary are attached to the ambiguity resolution summary `${P}/INTRO/OUT/AMB_20230100.SUM` as well:

```
                                                 numb.  ambiguity resolution statistics
 File   Station 1          Station 2          Sys  sat   total      L1            L2          ...
 ---------------------------------------------------------------------------------------------  ...  ----
    1   BRST 10004M004     TLSE 10003M009     GPS   31      66      11  83.3%     11  83.3%  ...  #AMB
    1   BRST 10004M004     TLSE 10003M009     GLO   20      46      21  54.3%     21  54.3%  ...  #AMB
    1   BRST 10004M004     TLSE 10003M009     GAL   24      39       7  82.1%      7  82.1%  ...  #AMB
    1   BRST 10004M004     TLSE 10003M009     tot   75     151      39  74.2%     39  74.2%  ...  #AMB
    2   GANP 11515M001     JOZ2 12204M002     GPS   31      64       5  92.2%      5  92.2%  ...  #AMB
    2   GANP 11515M001     JOZ2 12204M002     GLO   20      49      20  59.2%     20  59.2%  ...  #AMB
    2   GANP 11515M001     JOZ2 12204M002     GAL   24      41       4  90.2%      4  90.2%  ...  #AMB
    2   GANP 11515M001     JOZ2 12204M002     tot   75     154      29  81.2%     29  81.2%  ...  #AMB
    3   HERT 13212M010     TLSE 10003M009     GPS   31      60       8  86.7%      8  86.7%  ...  #AMB
 ...
   16   WTZR 14201M010     ZIM2 14001M008     GPS   31      59       8  86.4%      8  86.4%  ...  #AMB
   16   WTZR 14201M010     ZIM2 14001M008     GLO   20      45      16  64.4%     16  64.4%  ...  #AMB
   16   WTZR 14201M010     ZIM2 14001M008     GAL   24      39       3  92.3%      3  92.3%  ...  #AMB
   16   WTZR 14201M010     ZIM2 14001M008     tot   75     143      27  81.1%     27  81.1%  ...  #AMB
   17   ZIM2 14001M008     ZIMM 14001M004     GPS   31      61       1  98.4%      2  96.7%  ...  #AMB
   17   ZIM2 14001M008     ZIMM 14001M004     tot   31      61       1  98.4%      2  96.7%  ...  #AMB
 ---------------------------------------------------------------------------------------------  ...-----
   17   files do contain                      GPS   31    1059     148  86.0%    149  85.9%  ...
   15   files do contain                      GLO   20     680     294  56.8%    294  56.8%  ...
   14   files do contain                      GAL   26     553      68  87.7%     68  87.7%  ...
```

```
   17   files do contain                     tot   77    2292    510 77.7%   511 77.7% ...

-----------------------------------------------------------------
>>> CPU/Real time for pgm "OBSXTR": 0:00:00.019 / 0:00:00.019
>>> Program finished successfully


================================================================================
 Satellite-wise Ambiguity Resolution Statistics
================================================================================

-------------------------------------------------------------
PRN |    Amb    |  L1 & L2 ambiguities   |      L5 ambiguities
    |  total    |  solved  #/clu     rel |  solved  #/clu     rel
----+---------+-----------------------+----------------------
  1 |      39 |       33   35.0   82.2 |       26   35.1   64.8
  2 |      40 |       32   29.0   77.2 |       27   15.4   63.1
  3 |      33 |       25   34.7   73.6 |       20   34.3   58.8
  4 |      20 |       19   27.8   91.6 |       15   18.9   71.0
  5 |      35 |       34   28.4   93.7 |       29   21.2   79.0
  6 |      39 |       35   30.0   86.8 |       27   17.7   65.3
 ...
 27 |      38 |       32   18.8   79.7 |       24   19.0   59.8
 29 |      18 |       18   28.0   96.4 |       15   14.6   77.6
 30 |      17 |       17   34.8   97.1 |       14   25.3   79.1
 31 |      40 |       34   34.1   82.5 |       29   28.4   69.9
 32 |      54 |       50   27.4   89.2 |       41   17.7   71.6
101 |      47 |       41    3.6   63.1 |        0    0.0    0.0
102 |      42 |       39    2.6   57.1 |        0    0.0    0.0
103 |      21 |       20    3.0   63.1 |        0    0.0    0.0
104 |      24 |       16    3.6   47.9 |        0    0.0    0.0
105 |      23 |       16    3.4   49.3 |        0    0.0    0.0
107 |      45 |       35    3.1   52.8 |        0    0.0    0.0
 ...
121 |      27 |       24    3.4   63.1 |        0    0.0    0.0
124 |      40 |       34    3.5   60.4 |        0    0.0    0.0
201 |      15 |       15   31.3   96.8 |       13   27.0   83.5
202 |      19 |       14   33.1   71.5 |       11   13.0   53.4
203 |      16 |       16   23.8   95.8 |       12    8.9   66.5
204 |      37 |       25   26.7   65.0 |       17   14.1   42.7
...
230 |      27 |       26   27.9   92.8 |       19   14.4   65.5
231 |      17 |       15   32.3   85.5 |       12   27.2   68.0
233 |      25 |       24   32.9   93.1 |       21   27.9   81.0
234 |      25 |       24   33.7   93.2 |       18   29.4   69.6
236 |      21 |       19   34.0   87.8 |       13   28.0   59.7
----+---------+-----------------------+----------------------
GPS |    1059 |      945   27.8   86.0 |      770   21.4   69.3
GLO |     680 |      581    3.0   56.8 |        0    0.0    0.0
GAL |     553 |      502   29.5   87.7 |      403   22.4   69.6
----+---------+-----------------------+----------------------
```

Please note, that the program OBSXTR only evaluates the header of the observation files after the ambiguity resolution, whereas the program GPSXTR inspects the program output files from the specific GPSEST run, in which the ambiguity resolution is executed. Due to this the program GPSXTR has access to more information related to reference ambiguities due to user settings that are considered in the statistics. This detailed information is not available to OBSXTR. As a consequence the statistics provided by these two programs will slightly differ.

5.4 Daily Goals

At the end of today's session, you should have:

1. *used* GPSEST *for residual screening, created files:* `EDT_20230100.OUT`, `EDT_20230100.RES` *in your campaign's* `OUT` *directory,*
2. *screened the residual files from the above run using* RESRMS*: created files* `RMS_20230100.SUM`, `RMS_20230100.LST`, `RMS_20230100.EDT`, *and* `RMS_20230100.OUT`,
3. *used* SATMRK *to mark the identified outliers,*
4. *used* GPSEST *for a first coordinate and troposphere estimation, created files:* `FLT_20230100.CRD` *and* `FLT_20230100.TRP`,
5. *used* `GPSEST` *for QIF ambiguity resolution, created files:* `BRTL2023010Q.OUT`,
6. *used* `GPSEST` *for direct SIGMA ambiguity resolution, created files:* `WTWZ20230101.OUT`,
7. *apply the ambiguity resolution to all baselines running a BPE,*
8. *used* GPSXTR *to create a summary of the ambiguity resolution, created file:* `QIF_20230100.SUM` *and* `L12_20230100.SUM`.

6 Terminal Session: Thursday

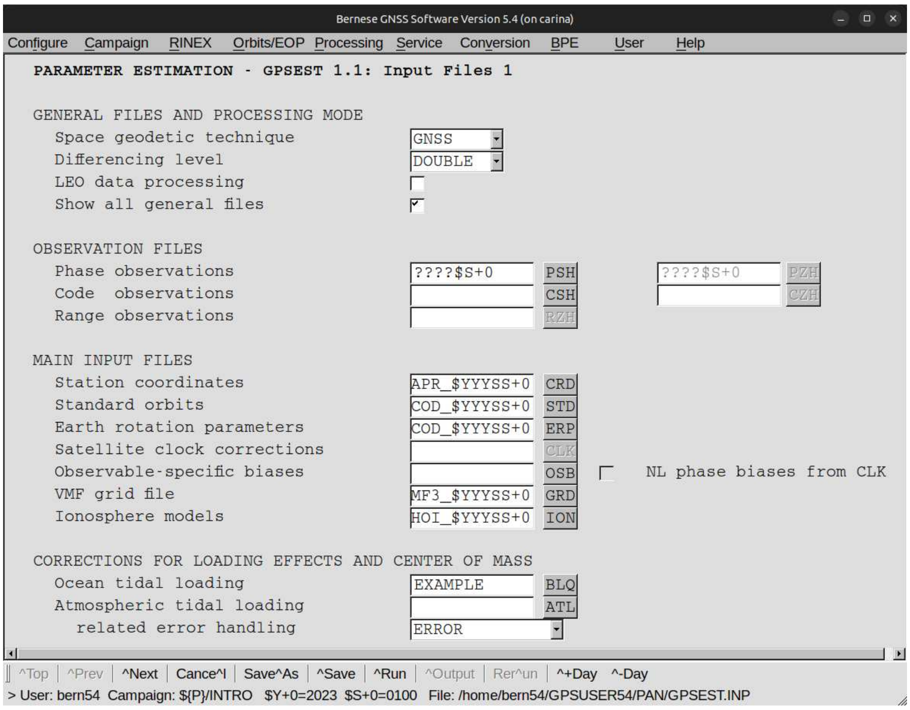
Finish the work of yesterday by resolving the ambiguities for all baselines (day 010 year 2023) if not yet done so far.
Today's terminal session is to:

1. *compute a final network solution of the day (GPSEST),*
2. *check the coordinates of the fiducial sites (ADDNEQ2, HELMR1),*
3. *check the daily repeatability (COMPAR2),*
4. *recompute the final solution and generate reduced size normal equation files (ADDNEQ2),*
5. *compute velocities (ADDNEQ2),*

for the current session. Compare the final coordinate results of the daily solutions (which are already processed and available).

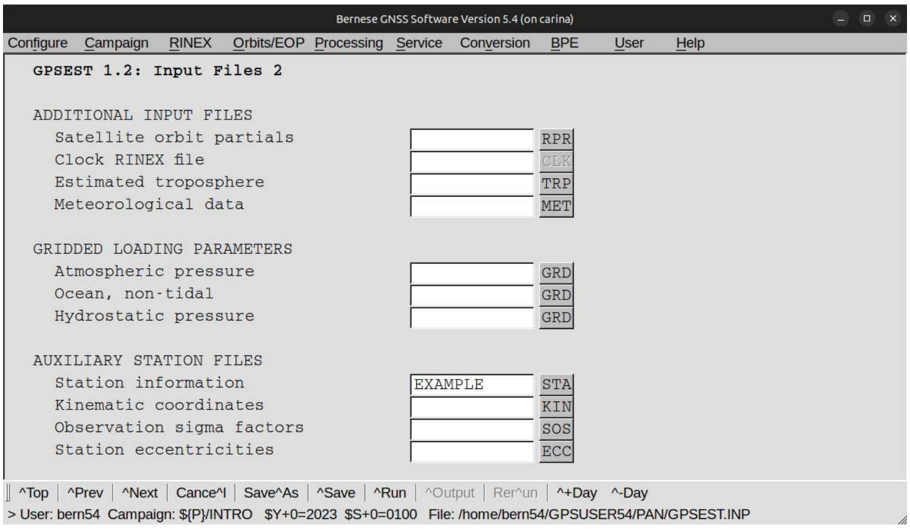
6.1 Final Network Solution

The resolved ambiguities may be introduced from the Bernese observation files into the final network solution. To start the program GPSEST in session mode you have to select all single difference files of the corresponding session. In panel "GPSEST 1.1: Input Files 1":

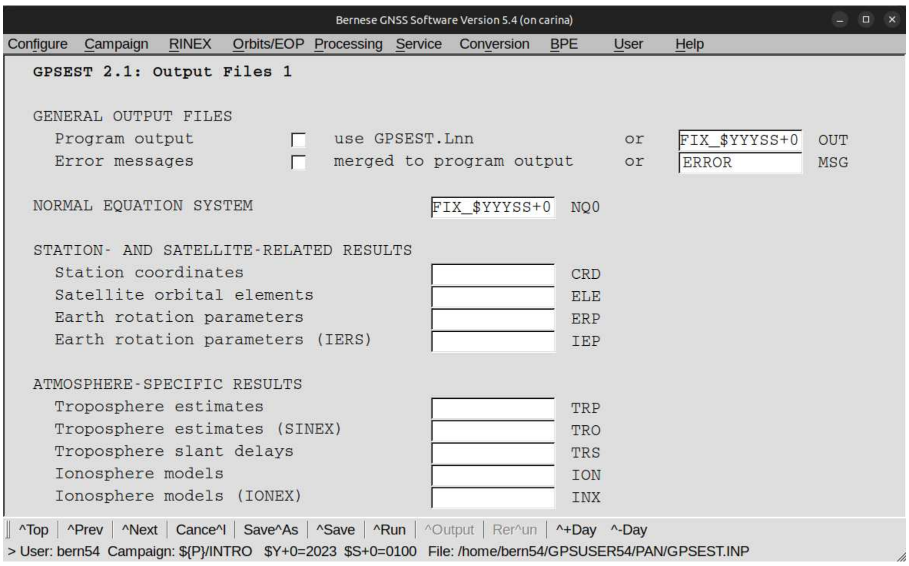


If the grid files for the coefficients of the VMF are available (downloaded from `https://vmf.geo.tuwien.ac.at/trop_products/GRID/1x1/VMF3/VMF3_OP/` and the five grid files of the day are concatenated), we can introduce VMF3_$YYYSS+0 into panel "GPSEST 1.1: Input Files 1".

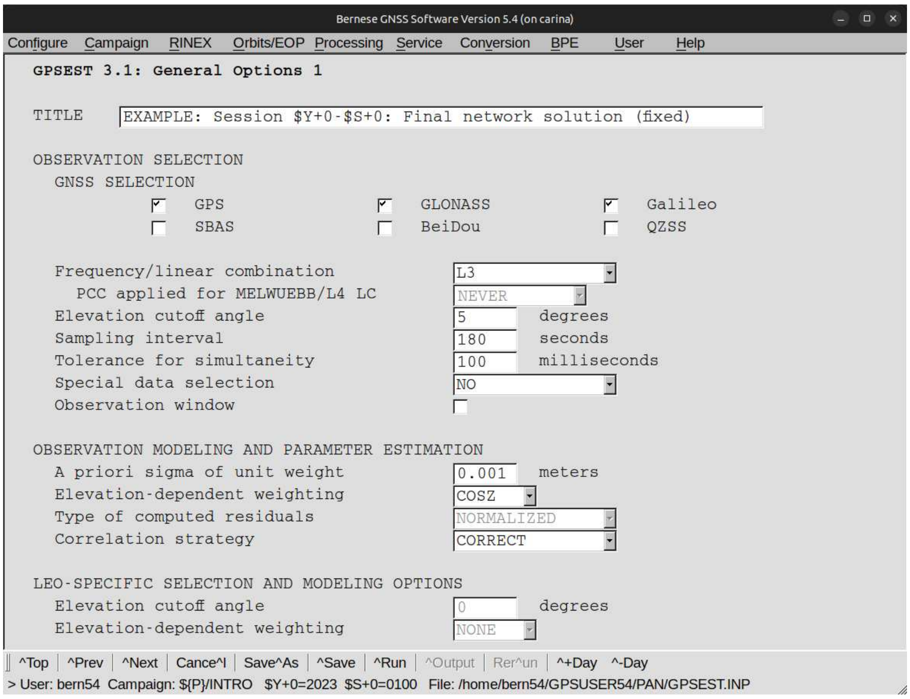
We do not introduce “Estimated troposphere” anymore from the previous solutions.



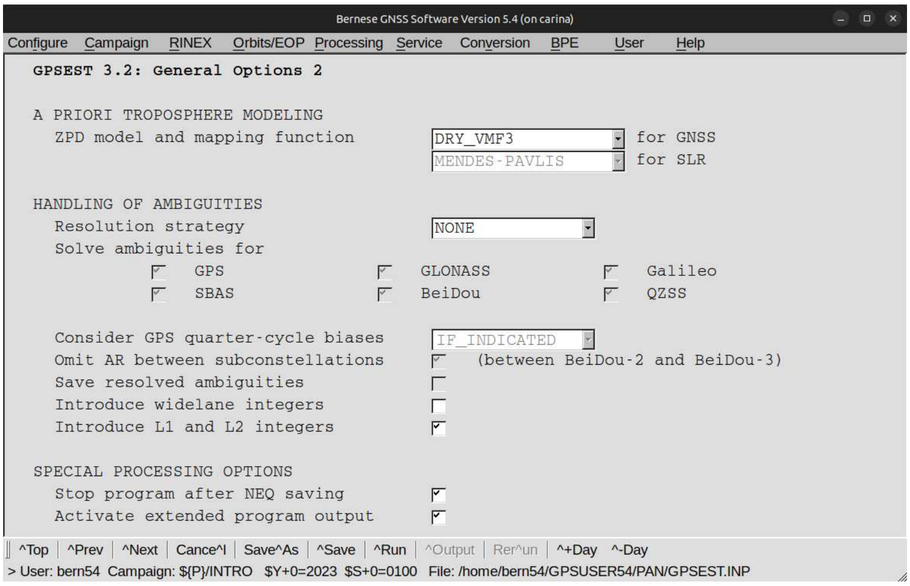
In panel “GPSEST 2.1: Output Files 1” we request the normal equation file as the only output file.



For the final run of GPSEST we consider the correlations between the observations correctly:

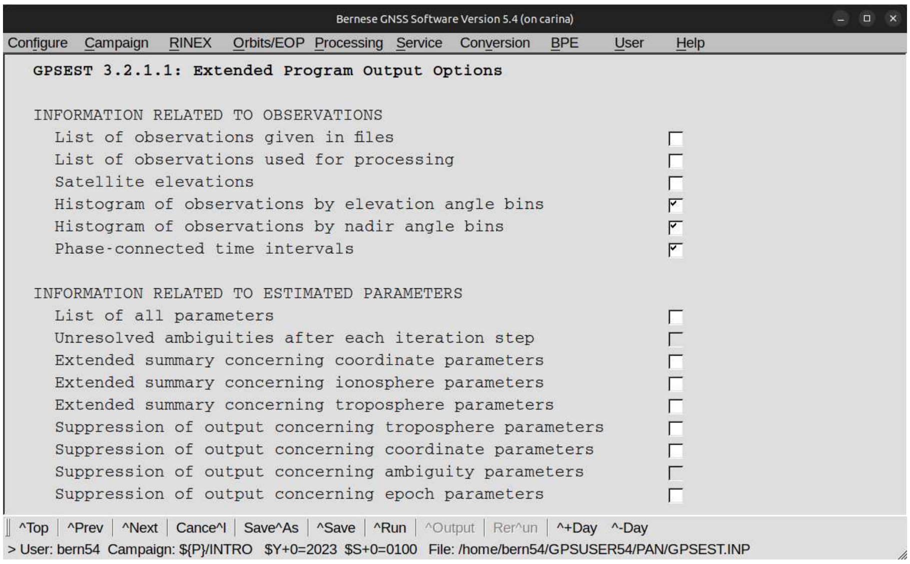


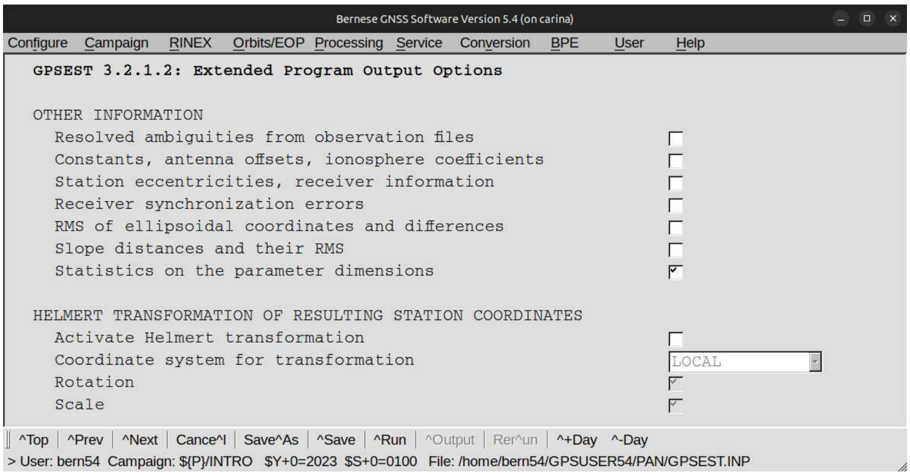
If the VMF grid files are available we can switch now from DRY_GPT3 to DRY_VMF3 to use the VMF instead of the Global Mapping Function (GMF). In the *Bernese Introductory Course* environment these files are available. Remember that you need to specify the grid files with the coefficients in the input field "VMF grid file" in panel "GPSEST 1.1: Input Files 1". Ambiguities which have been resolved in the previous runs of program GPSEST are introduced as known.



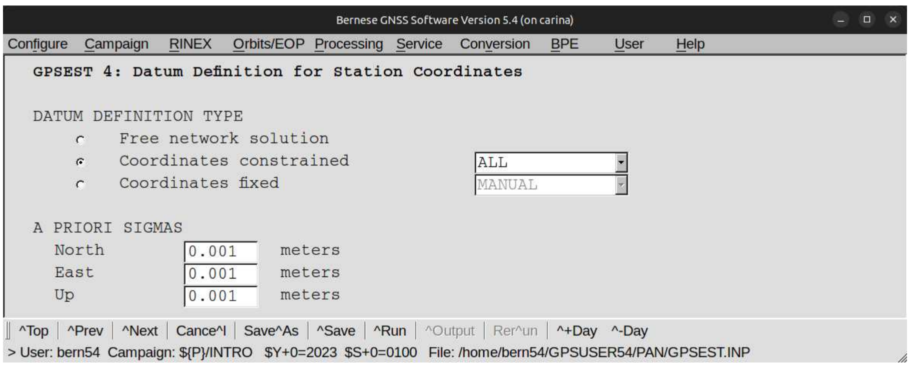
The checkbox in option "Stop program after NEQ saving" reduces the task of GPSEST to setting up the NEQ but not solving it. In particular in case of bigger networks this may save a lot of computing time because the solution for the session will be computed later on by ADDNEQ2 anyhow.

Since this is the final run of GPSEST, it is worthwhile to add some additional information about the observation files into the program output. This is useful if you archive the program output of this run together with the observation files and the resulting normal equation files.

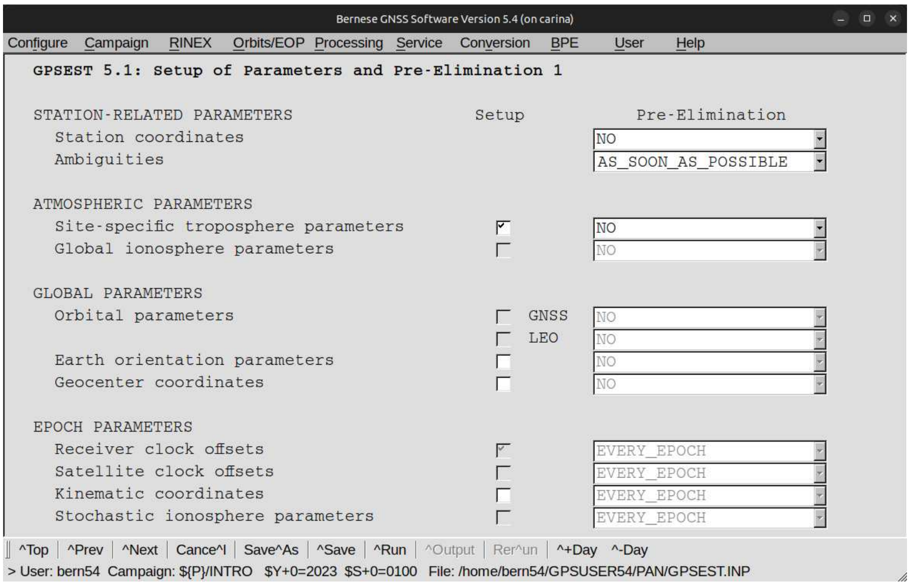




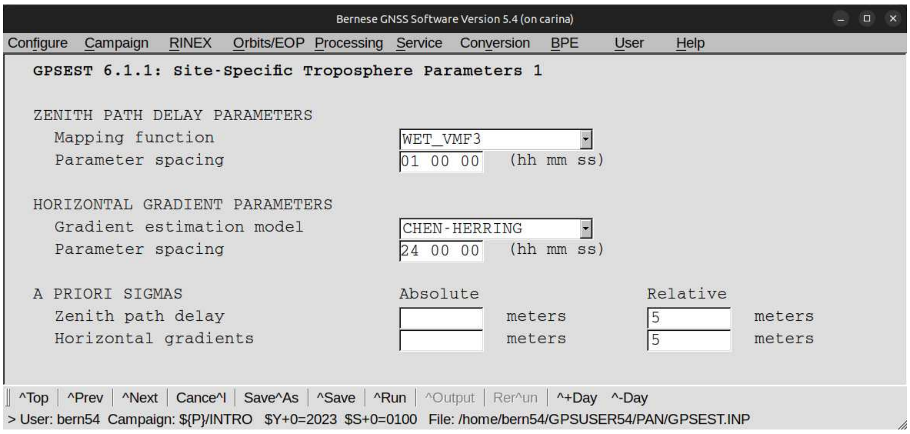
We do not fix any stations on their a priori position, i.e., the coordinates of all stations will be estimated. This retains the flexibility for later changes in the realization of the reference frame (station constraints) with program ADDNEQ2. Because no solution in GPSEST is computed you can select here all types of datum definition apart from "Coordinates fixed" (the normal equations are always stored without any constraints):



The remaining unresolved ambiguities are pre–eliminated. In addition we may set up additional parameters of interest.



The selection of the mapping function has to be consistent with the selection of the troposphere model in “ZPD model and mapping function (GNSS)” in panel “GPSEST 3.2: General Options 2”.



The output of GPSEST contains only the input parameter and ends with the parameter statistics:

```
SUMMARY OF RESULTS
------------------

Number of parameters:
--------------------

Parameter type                            Adjusted    Expl.   Impl. (elim)*  Del. Ref. Sing. No obs
-------------------------------------------------------------------------------------------------------
Station coordinates / velocities                54       54       0             0    0     0      0
Ambiguities                                    930        0     930  (bfst)     0    0    19      0
Site-specific troposphere parameters           522      522       0             0    0     0      0
-------------------------------------------------------------------------------------------------------
Total number                                  1487      576     911             0    0    19      0


*Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking (afst),
                                      epoch-wise (epow), after inversion (afin)


Statistics:
----------
```

```
 Total number of authentic observations      156396
 Total number of pseudo-observations              0
 Total number of observations                156396

 Total number of explicit parameters            576
 Total number of implicit parameters            911
 Total number of parameters                    1487


 Total number of observation files               17
 Total number of stations                        18
 Total number of satellites                       0


-----------------------------------------------------------------
>>> CPU/Real time for pgm "GPSEST": 0:02:12.438 / 0:02:12.455
>>> Program finished successfully
```

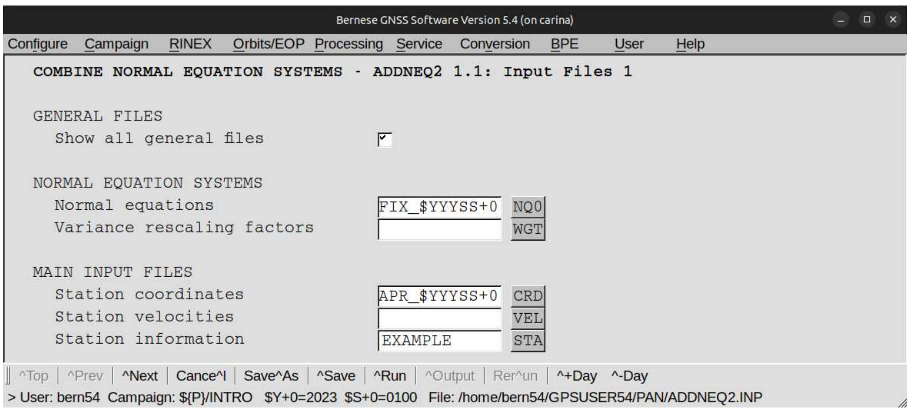
After running GPSEST in session mode the normal equation file `FIX_20230100.NQ0` should be available in the directory `${P}/INTRO/SOL`.

In the environment of the *Bernese Introductory Course* these files are provided for all four sessions in the archive `${S}/RNX2SNX/2023/SOL/` and `${S}/RNX2SNX/2024/SOL/`, respectively. Copy the files of the additional three days into your campaign. Following files should be now available in the directory `${P}/INTRO/SOL`

`FIX_20230100.NQ0`, `FIX_20230110.NQ0`,
`FIX_20242010.NQ0`, `FIX_20242020.NQ0`.

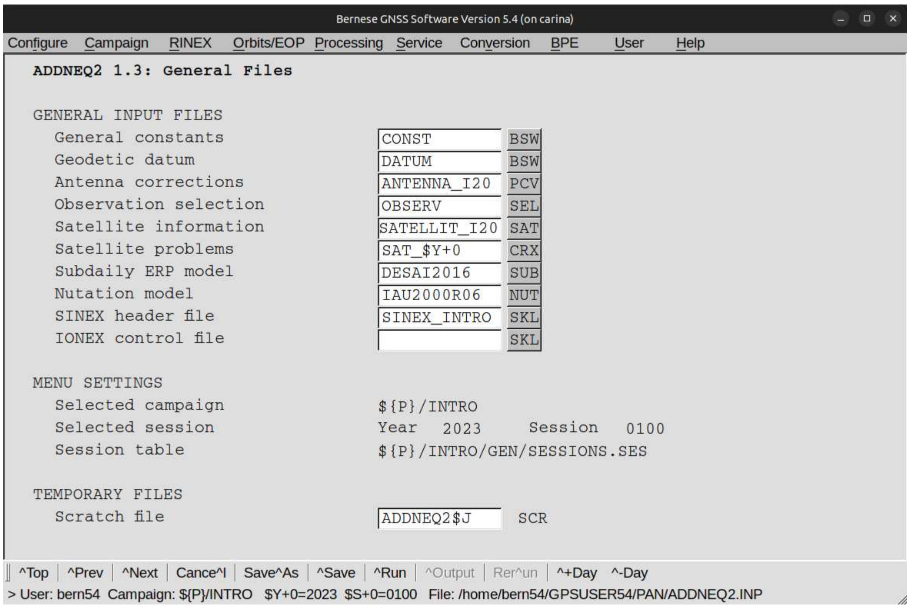
6.2 Check the Coordinates of the Fiducial Sites

To check the consistency of our network solution with respect to the coordinates available in the IGS 20 reference frame we generate a minimum constraint solution for the network using program ADDNEQ2 ("Menu>Processing>Combine normal equation systems") with the following options:

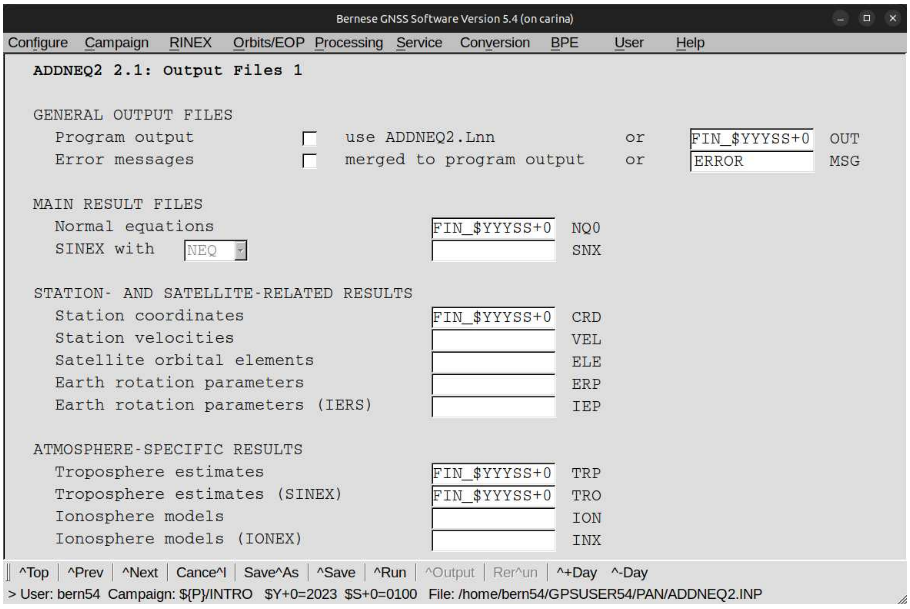


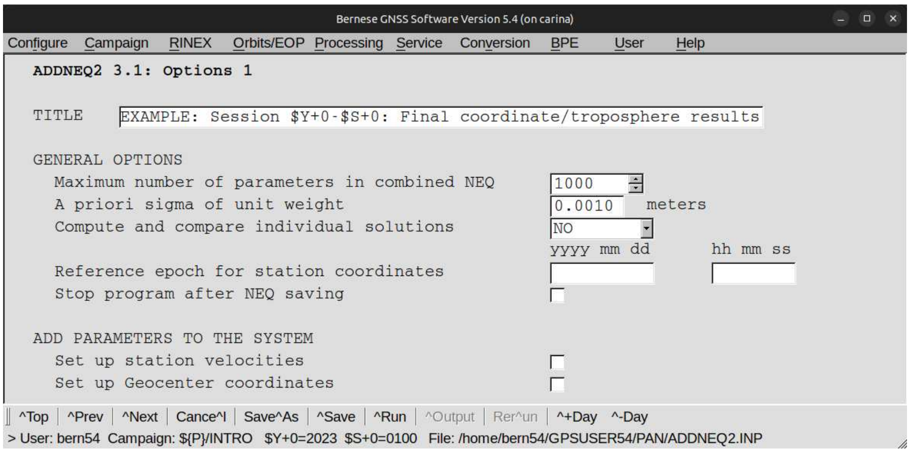
No further input files in the next panel are needed.

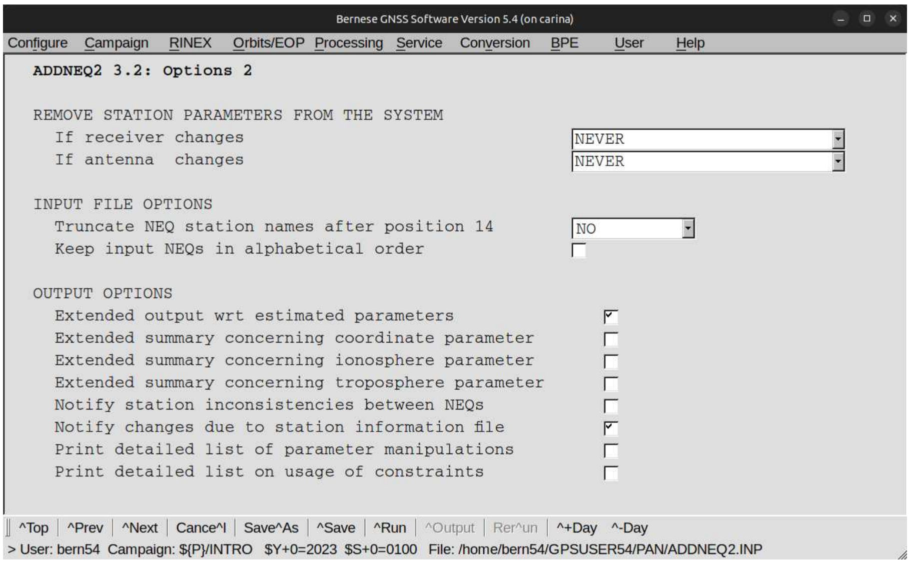
If we intend to store a troposphere Solution INdependent EXchange format (SINEX) file to make the troposphere estimates also available in the international format, we need to add the "SINEX header file". Please adjust the content (in particular the institution and authorship) of this file before using it for your applications.



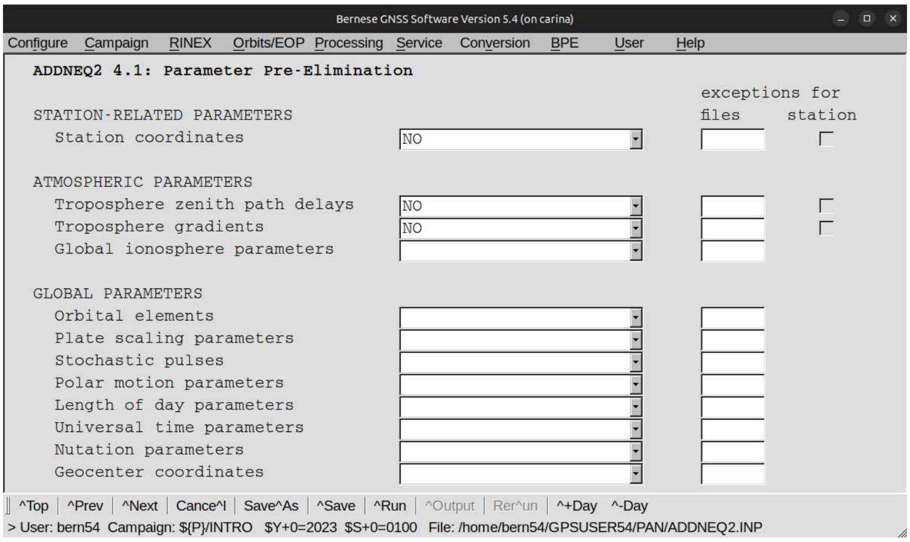
The troposphere estimates are now written in the Bernese internal (option "Troposphere estimates") and the international format (option "Troposphere estimates (SINEX)"). If there is no need to store both, you may also limit yourself to one of them or even to not store the troposphere results at all.



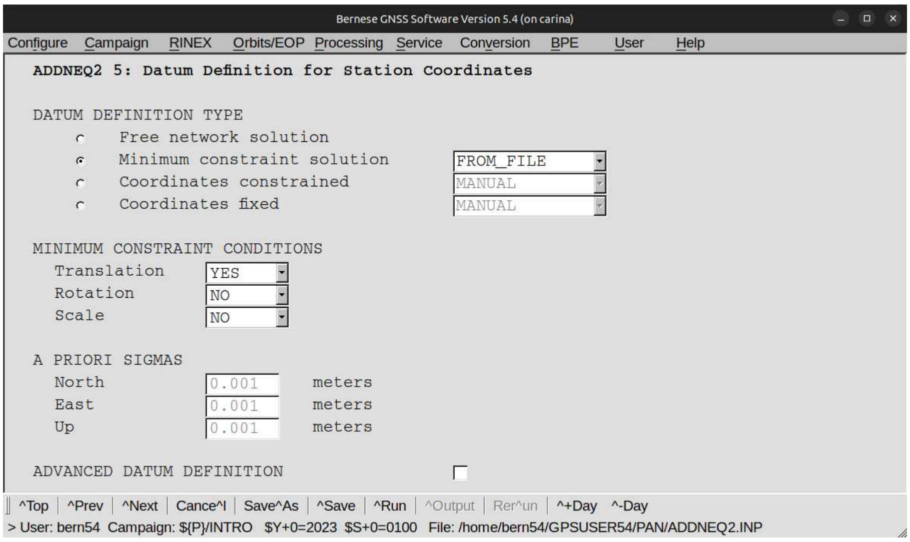

Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
ADDNEQ2 3.1: Options 1
TITLE
EXAMPLE: Session $Y+0-$S+0: Final coordinate/troposphere results
GENERAL OPTIONS
Maximum number of parameters in combined NEQ
1000
A priori sigma of unit weight
0.0010
meters
Compute and compare individual solutions
NO
yyyy mm dd
hh mm ss
Reference epoch for station coordinates
Stop program after NEQ saving
ADD PARAMETERS TO THE SYSTEM
Set up station velocities
Set up Geocenter coordinates
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/ADDNEQ2.INP

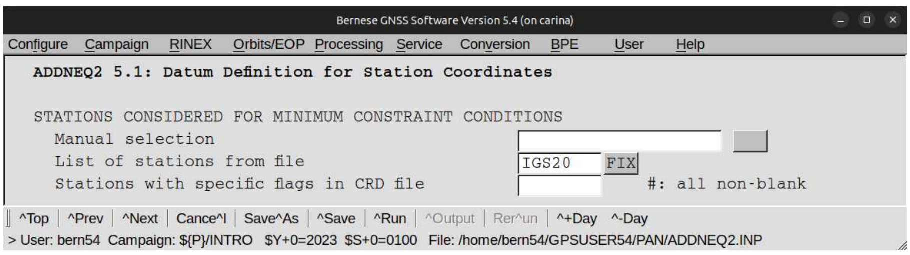

Bernese GNSS Software Version 5.4 (on carina)
Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help
ADDNEQ2 3.2: Options 2
REMOVE STATION PARAMETERS FROM THE SYSTEM
If receiver changes
NEVER
If antenna changes
NEVER
INPUT FILE OPTIONS
Truncate NEQ station names after position 14
NO
Keep input NEQs in alphabetical order
OUTPUT OPTIONS
Extended output wrt estimated parameters
Extended summary concerning coordinate parameter
Extended summary concerning ionosphere parameter
Extended summary concerning troposphere parameter
Notify station inconsistencies between NEQs
Notify changes due to station information file
Print detailed list of parameter manipulations
Print detailed list on usage of constraints
^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2023 $S+0=0100 File: /home/bern54/GPSUSER54/PAN/ADDNEQ2.INP

In the following three panels, all parameter types supported by ADDNEQ2 are listed. You may specify whether a parameter shall be pre-eliminated or not. An empty entry means that the parameter is not expected in the input NEQ files.
Please note that an automated preselection is not possible for technical reasons. If a parameter with an empty input field is detected in the input NEQ files, the program will stop with an error. In the opposite case, a warning message is issued.

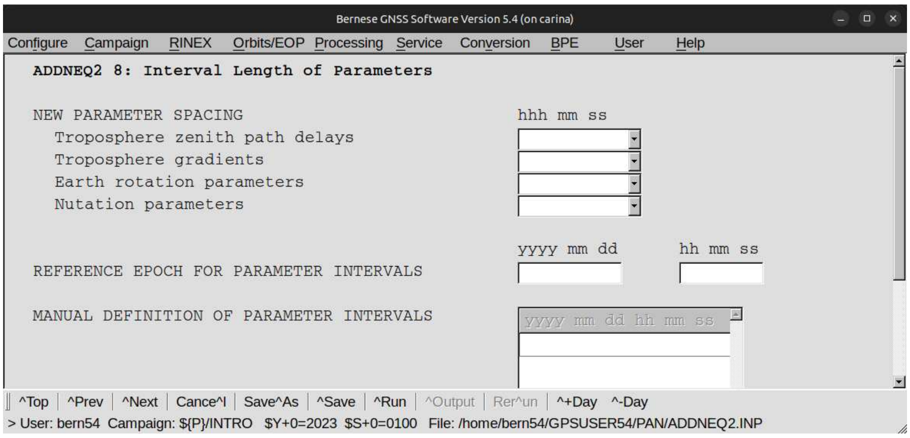


For the validation of the datum stations we choose the "Minimum constraint solution". Because it is a regional network, we only apply the no–translation condition. The other conditions are sufficiently defined by the satellite orbits.

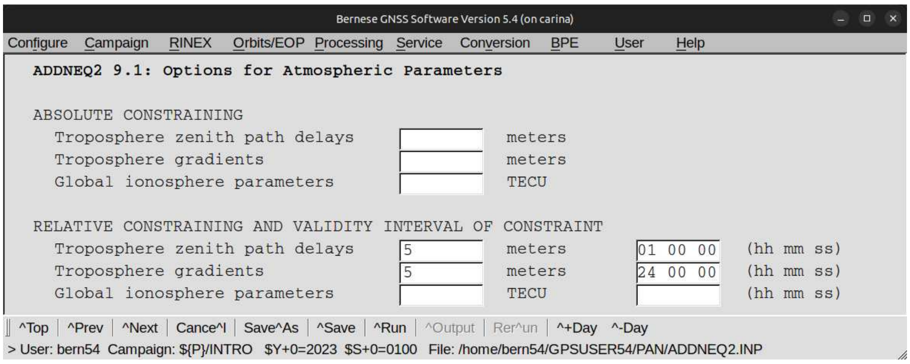




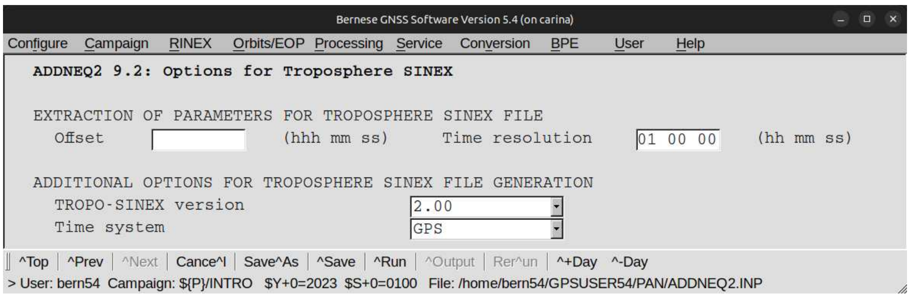
The following panel allows to change the parameter spacing. We do not need this feature at the moment and leave, therefore, all input fields empty.



The relative constraints applied to the vertical troposphere and gradient parameters are so loose that they do not affect the solution. As in GPSEST, they simply prevent a format overflow in the output troposphere file in case of very weakly observed parameters due to gaps in the observation scenario.



If you have selected troposphere output in SINEX format you may select the spacing of the sampling of the reported records. Please note that this has no impact on the parametrization of the troposphere parameters.
Furthermore you can decide whether the traditional (0.01) or the latest (2.0) version of the troposphere SINEX format shall be written. In the latter case the nine character station IDs are taken from the related column in PART II of the "Station information" file you have selected in panel "ADDNEQ2 1.1: Input Files 1". Please make sure that you provide for each station in your processing the related entry.



For option "Time system for TROPO-SINEX" we select GPS because the processing takes place in the GPS time system.

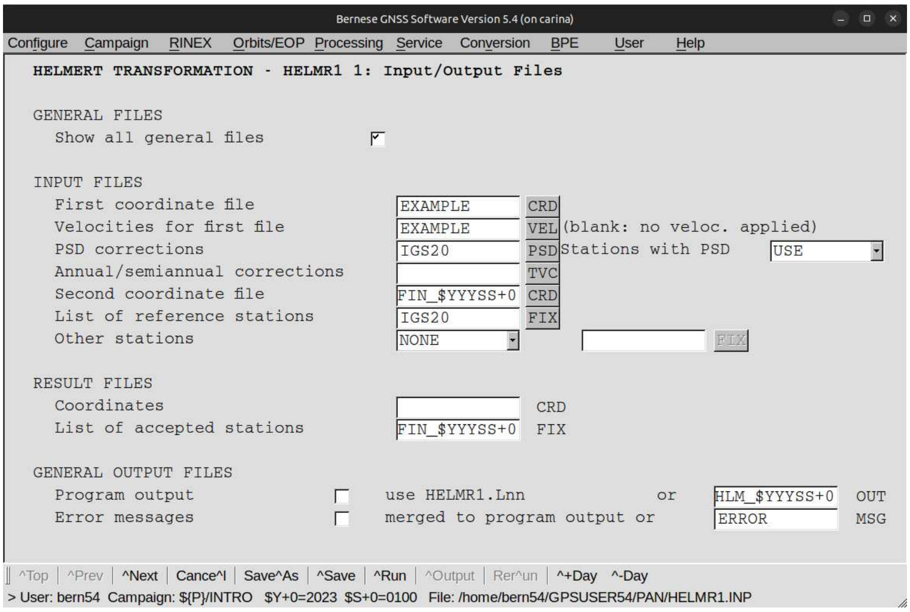
The ADDNEQ2 program output starts with some information about the parameters contained in the input `NQ0` file(s). The input options for the program run follow. An important part is the statistics for the current ADDNEQ2 solution with the same layout you know already from GPSEST:

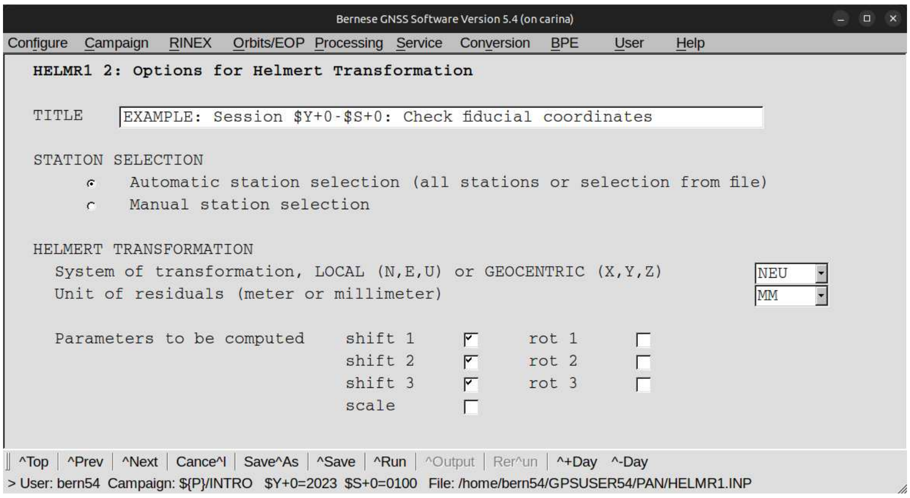
```
...

SUMMARY OF RESULTS
------------------

Number of parameters:
--------------------

Parameter type                        Adjusted    Expl.   Impl. (elim)*  Del. Ref. Sing. No obs
-----------------------------------------------------------------------------------------------
Station coordinates / velocities            54       54       0             0    0     0      0
Site-specific troposphere parameters       516      516       0             0    0     6      0
-----------------------------------------------------------------------------------------------
Previously pre-eliminated parameters       911              911
-----------------------------------------------------------------------------------------------
Total number                              1481      570     911             0    0     6      0


*Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking (afst),
                                      epoch-wise (epow), after inversion (afin)


Statistics:
----------

Total number of authentic observations      156396
Total number of pseudo-observations            465

Total number of explicit parameters            570
Total number of implicit parameters            911

Total number of observations                156861
Total number of adjusted parameters           1481
Degree of freedom (DOF)                     155380

A posteriori RMS of unit weight           0.001036 m
Chi**2/DOF                                    1.07

Total number of observation files               17
Total number of stations                        18
...
```

Below this part the program output reports the results of the parameter estimation in the same standardized format for all parameter types as in the program GPSEST:

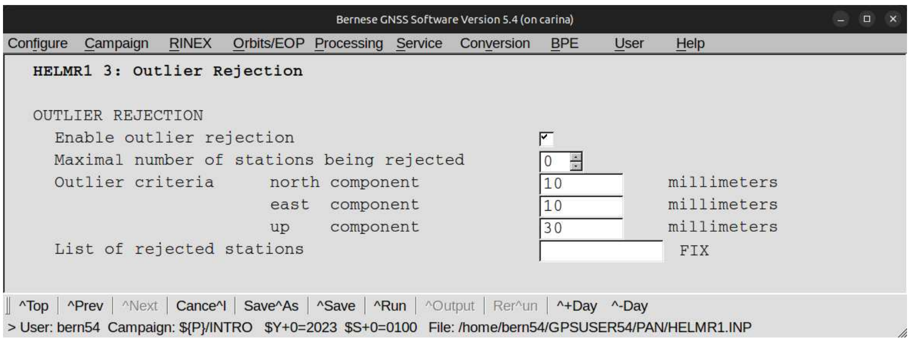
```
...
Station coordinates and velocities:
----------------------------------

Sol Station name         Typ Correction  Estimated value  RMS error   A priori value  ... Abb
------------------------------------------------------------------------------------  ... ----
  1 BRST 10004M004         X    0.00016    4231162.37206    0.00043    4231162.37190  ... #CRD
  1 BRST 10004M004         Y    0.00213    -332746.35755    0.00015    -332746.35968  ... #CRD
  1 BRST 10004M004         Z   -0.00115    4745131.11033    0.00043    4745131.11148  ... #CRD
  1 GANP 11515M001         X    0.00060    3929181.23140    0.00039    3929181.23080  ... #CRD
  1 GANP 11515M001         Y    0.00026    1455237.01665    0.00019    1455237.01639  ... #CRD
  1 GANP 11515M001         Z    0.00165    4793654.07064    0.00047    4793654.06899  ... #CRD
  1 HERT 13212M010         X    0.00110    4033460.69194    0.00055    4033460.69084  ... #CRD
...

Site-specific troposphere parameters:
------------------------------------

Station name         Typ     Correction  Estimated value  RMS error   A priori value  ... Abb
------------------------------------------------------------------------------------  ... ----
BRST 10004M004        N        -0.00049         -0.00049    0.00005          0.00000  ... #TRP
BRST 10004M004        E        -0.00035         -0.00035    0.00007          0.00000  ... #TRP
BRST 10004M004        U         0.13591          2.45465    0.00098          2.31874  ... #TRP
BRST 10004M004        U         0.14373          2.46063    0.00076          2.31690  ... #TRP
BRST 10004M004        U         0.15014          2.46520    0.00063          2.31506  ... #TRP
BRST 10004M004        U         0.14308          2.45630    0.00068          2.31322  ... #TRP
...
```

The coordinate solution for the session (`${P}/INTRO/STA/FIN_20230100.CRD`) may be compared with the a priori coordinates of the IGS core sites. The program HELMR1 ("Menu>Service>Coordinate tools>Helmert transformation") is used for this purpose:





The last panel allows even for an automated quality control and manages a potential update of the list of stations used for the datum definition (option "List of accepted stations" in panel "HELMR1 1: Input/Output Files"):



For our example we get the following output.

```
===============================================================================
Bernese GNSS Software, Version 5.4
-------------------------------------------------------------------------------
Program        : HELMR1
Purpose        : Helmert Transformation
-------------------------------------------------------------------------------
Campaign       : ${P}/INTRO
Default session: 0100 year 2023
Date           : 17-Jan-2025 08:22:27
User name      : bern54
===============================================================================


EXAMPLE: Session 2023-0100: Check fiducial coordinates
-------------------------------------------------------------------------------


FILE 1: EXAMPLE.CRD: IGS20: coordinate list
FILE 2: FIN_20230100.CRD: EXAMPLE: Session 2023-0100: Final coordinate/troposph

LOCAL GEODETIC DATUM: IGS20
RESIDUALS IN LOCAL SYSTEM (NORTH, EAST, UP)

LIST OF REMOVED STATIONS:
OUTLIER CRITERIA:                    10.00     10.00     30.00

---------------------------------------------------------------------
| NUM |      NAME        | FLG |     RESIDUALS IN MILLIMETERS   |   |
---------------------------------------------------------------------
|     |                  |     |                                |   |
|   1 | BRST 10004M004   | I W |       1.20      -2.06      0.47 |   |
|   6 | MATE 12734M008   | I W |      -2.32      -2.21     -1.93 |   |
|   7 | MIKL 12335M001   | I W |       4.00       8.85     10.19 |   |
|   9 | ONSA 10402M004   | I W |       1.06      -2.49      1.55 |   |
|  10 | ORID 15601M001   | I W |      -1.07       0.67     -2.30 |   |
|  12 | TLSE 10003M009   | I W |       0.11      -1.11     -1.91 |   |
|  14 | WSRT 13506M005   | I W |       0.32      -1.59     -0.00 |   |
|  15 | WTZR 14201M010   | I W |      -1.21      -1.22     -5.55 |   |
|  17 | ZIM2 14001M008   | I W |      -0.95      -0.88     -0.03 |   |
|  18 | ZIMM 14001M004   | I W |      -1.14       2.04     -0.48 |   |
|     |                  |     |                                |   |
---------------------------------------------------------------------
|     | RMS / COMPONENT  |     |       1.79       3.41      4.09 |   |
|     | IQR              |     |       2.20       2.73      2.39 |   |
|     | MEAN             |     |      -0.00      -0.00     -0.00 |   |
|     | MEDIAN           |     |      -0.42      -1.17     -0.26 |   |
|     | MIN              |     |      -2.32      -2.49     -5.55 |   |
|     | MAX              |     |       4.00       8.85     10.19 |   |
---------------------------------------------------------------------
        OVERALL RMS/IQR/MAX(3D)        3.24       2.58     14.08       MIKL ...
---------------------------------------------------------------------
| ALL | RMS / COMPONENT  |     |       1.79       3.41      4.09 |   |
| ALL | IQR              |     |       2.20       2.73      2.39 |   |
| ALL | MEAN             |     |      -0.00      -0.00     -0.00 |   |
| ALL | MEDIAN           |     |      -0.42      -1.17     -0.26 |   |
| ALL | MIN              |     |      -2.32      -2.49     -5.55 |   |
| ALL | MAX              |     |       4.00       8.85     10.19 |   |
---------------------------------------------------------------------
  ALL   OVERALL RMS/IQR/MAX(3D)        3.24       2.58     14.08       MIKL ...

NUMBER OF PARAMETERS  :     3
NUMBER OF STATIONS    :    10
NUMBER OF COORDINATES :    30
RMS OF TRANSFORMATION :    3.24 MM

BARYCENTER COORDINATES:

LATITUDE              :    47 48 37.88
LONGITUDE             :    11 25 53.37
HEIGHT                :         -64.817 KM

PARAMETERS:

TRANSLATION IN  N     :           0.02     +-  1.02    MM
TRANSLATION IN  E     :           0.03     +-  1.02    MM
TRANSLATION IN  U     :           0.00     +-  1.02    MM

NUMBER OF ITERATIONS  :     1

ACCEPTED STATIONS     :    10
REJECTED STATIONS     :     0
VERIFIED STATIONS     :     0

-----------------------------------------------------------------
>>> CPU/Real time for pgm "HELMR1": 0:00:00.122 / 0:00:00.122
>>> Program finished successfully
```

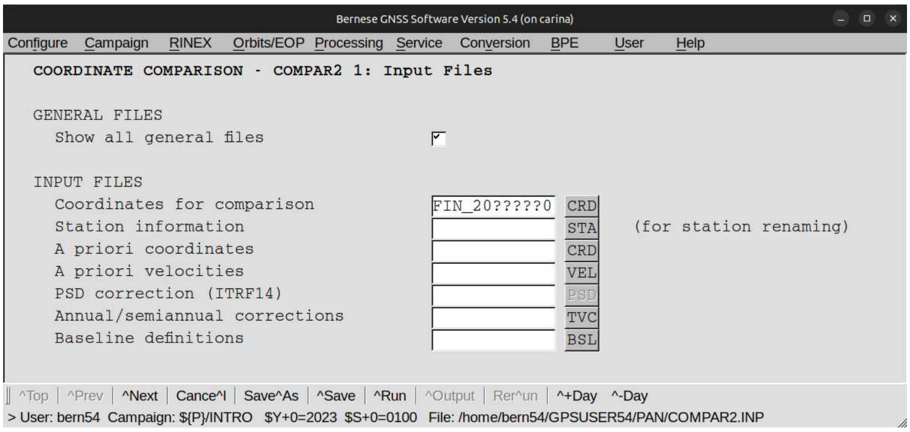
We can conclude that no problems concerning the stations used for the datum definition were detected.

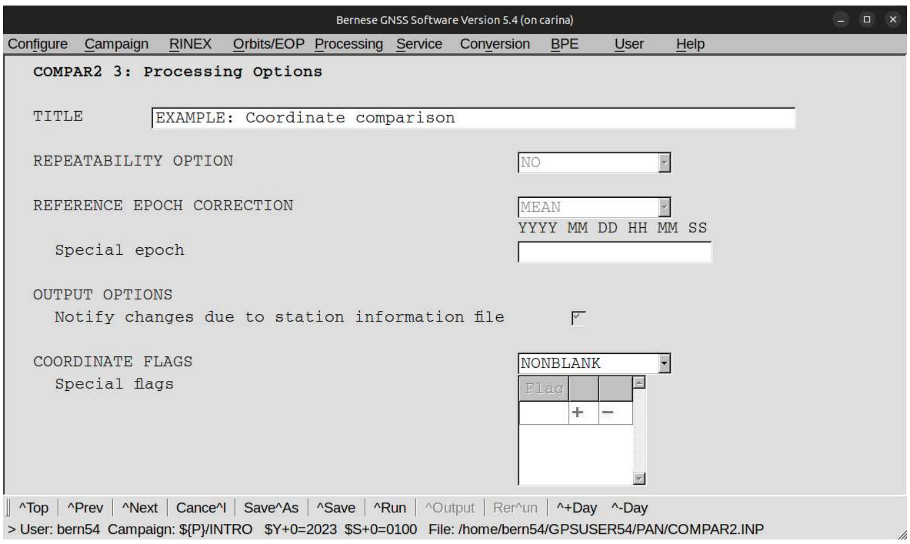
If there were problems, the ADDNEQ2 run would need to be repeated with the problematic station either removed from the file `${P}/INTRO/STA/IGS20.FIX` (e.g., by using the result file `${P}/INTRO/STA/FIN_20230100.FIX`) or with manual selection of the stations used for the datum definition in panel "ADDNEQ2 5.1: Datum Definition for Station Coordinates".

In order to check the repeatability of the coordinate solutions for all four days, repeat the above steps for the remaining days.

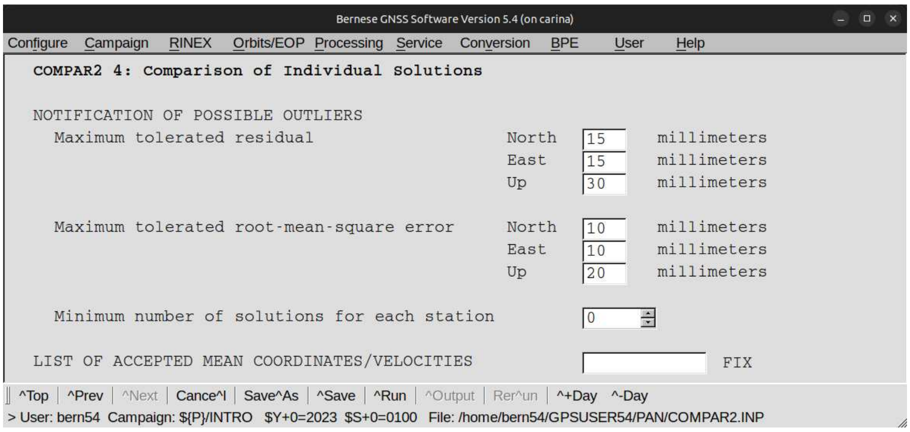
6.3 Check the Daily Repeatability

If the minimum constraint solutions of the four sessions are available, the repeatability of the coordinate solutions may be checked using the program COMPAR2 ("Menu>Service >Coordinate tools>Coordinate comparison").





In the last panel you can define thresholds for detecting stations with exceptionally poor coordinate repeatability.



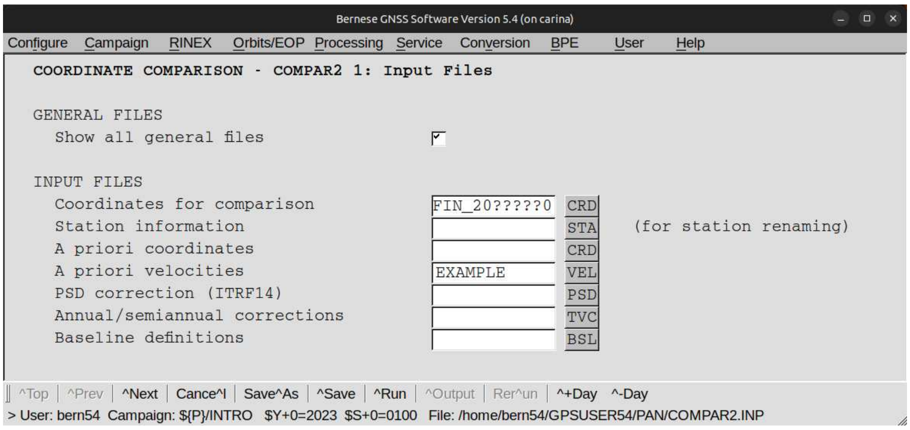
The program computes the arithmetic mean for all station coordinates. The difference of each individual coordinate set to this mean value and the overall RMS are reported in the following section of the program output:

```
Comparison of individual solutions:
-----------------------------------

BRST 10004M004   N   15.74     -14.05  -13.20   13.81   13.45
BRST 10004M004   E   12.91     -11.55  -10.78   12.10   10.22
BRST 10004M004   U    6.57       4.59    6.47   -3.87   -7.18

GANP 11515M001   N   12.86     -10.64  -11.63   11.29   10.98
GANP 11515M001   E   17.45     -15.36  -14.87   14.70   15.52
GANP 11515M001   U    1.07       0.26    0.97   -1.52    0.29

HERT 13212M010   N   14.68     -12.83  -12.30    9.83   15.30
HERT 13212M010   E   14.09     -11.92  -12.24   14.51    9.65
HERT 13212M010   U    6.44       3.33    6.20   -8.61   -0.92

JOZ2 12204M002   N   14.09     -11.60  -12.79   12.25   12.14
JOZ2 12204M002   E   18.73     -16.11  -16.29   15.14   17.27
JOZ2 12204M002   U    1.95       1.18    1.81   -2.55   -0.44

LAMA 12209M001   N   13.31     -10.64  -12.38   11.41   11.61
LAMA 12209M001   E   18.89     -16.36  -16.36   16.51   16.21
LAMA 12209M001   U    2.70       2.19    2.13   -3.42   -0.90

MATE 12734M008   N   16.54     -13.68  -14.95   14.47   14.16
MATE 12734M008   E   20.01     -17.00  -17.64   16.57   18.07
MATE 12734M008   U    2.84      -1.39   -3.27    2.88    1.78

MIKL 12335M001   N    9.90      -8.26   -8.87    8.72    8.42
MIKL 12335M001   E   21.45     -18.06  -19.09   18.84   18.30
MIKL 12335M001   U    6.64      -6.56   -4.71    4.32    6.96

MORP 13299S001   N   20.23     -17.14  -17.89   17.89   17.14
MORP 13299S001   E   14.23     -12.71  -11.92   12.83   11.80
MORP 13299S001   U   12.96      13.56    8.56  -12.16   -9.96

ONSA 10402M004   N   14.78     -12.82  -12.78   12.74   12.86
ONSA 10402M004   E   14.80     -12.47  -13.15   12.56   13.06
ONSA 10402M004   U    4.37      -5.38   -1.37    2.04    4.71

ORID 15601M001   N    9.44      -8.12   -8.23    8.52    7.83
ORID 15601M001   E   21.75     -18.61  -19.06   18.74   18.93
ORID 15601M001   U    3.94      -0.92   -2.55    5.81   -2.35

PTBB 14234M001   N   16.37     -13.66  -14.67   14.61   13.73
PTBB 14234M001   E   16.61     -14.00  -14.77   14.13   14.64
PTBB 14234M001   U    5.54       0.87    2.25   -7.94    4.82

TLSE 10003M009   N   15.17     -13.32  -12.95   13.26   13.01
TLSE 10003M009   E   15.95     -13.59  -14.03   14.05   13.57
TLSE 10003M009   U    1.09       1.18    0.66   -0.78   -1.06

VILL 13406M001   N   11.99     -10.18  -10.51   11.65    9.05
VILL 13406M001   E   16.05     -13.67  -14.13   13.96   13.84
VILL 13406M001   U    1.67       1.04    0.99    0.44   -2.47
```

```
WSRT 13506M005   N   11.61     -9.95  -10.15    9.54   10.56
WSRT 13506M005   E   16.19    -13.39  -14.64   14.02   14.00
WSRT 13506M005   U    1.79     -0.01   -1.06   -1.45    2.52

WTZR 14201M010   N   13.86    -12.13  -11.87   12.42   11.58
WTZR 14201M010   E   16.33    -14.06  -14.22   13.74   14.54
WTZR 14201M010   U    2.45      2.87    1.19   -1.93   -2.13

WTZZ 14201M014   N   14.12    -12.56  -11.87   12.90   11.54
WTZZ 14201M014   E   16.11    -13.54  -14.35   13.79   14.10
WTZZ 14201M014   U    2.44      2.31    1.19   -3.33   -0.17

ZIM2 14001M008   N   14.77    -12.97  -12.61   13.01   12.58
ZIM2 14001M008   E   17.52    -15.55  -14.80   15.25   15.10
ZIM2 14001M008   U    1.46      0.97    1.05   -2.09    0.07

ZIMM 14001M004   N   14.26    -12.48  -12.22   12.21   12.49
ZIMM 14001M004   E   17.41    -16.66  -13.41   14.73   15.34
ZIMM 14001M004   U    1.08      0.84   -0.50   -1.29    0.95
```

In the section Notification of detected outliers many stations from the different sessions are listed. While interpreting this output, keep in mind that the the four columns refer to different epochs. The difference between these epochs is about 1.5 years. Obviously, station velocities need to be estimated (this will be done in the next step described in Section 6.5).

If reliable velocities for all stations are available they can be introduced in program COMPAR2:



You may check the influence on the repeatability on your own. Please be reminded, that for the ITRF 2020 (IGS 20) reference frame the linear station velocities are not sufficient. You may see the effect of the PSD corrections in the repeatablity. This is not the case for this example because none of the stations is affected by an earthquake and, therefore, no PSD corrections have to be considered.

This output may be used for quality assessment. Stations with a problem in one or more sessions can be identified and excluded from the final ADDNEQ2 solution by adding them to section TYPE 003: STATION PROBLEMS in the station information file (`${P}/INTRO/STA/EXAMPLE.STA`). All parameters of these stations will be pre–eliminated before the normal equations are stacked and, therefore, also before the solution is computed.

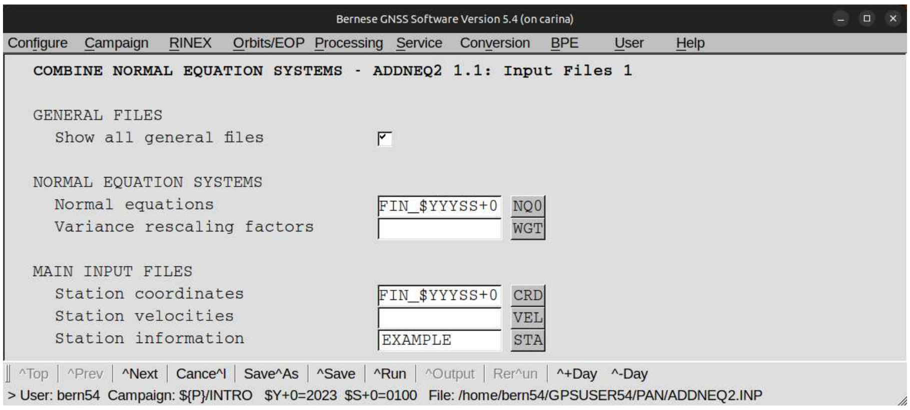
6.4 Compute the Reduced Solution of the Sessions

If one or more stations have to be excluded from the session solution or if the datum definition of the solution is still not acceptable, the final solution of the session has to be re–computed by repeating the ADDNEQ2 from Section 6.2. Finally, the result files for the final solution of the session are:

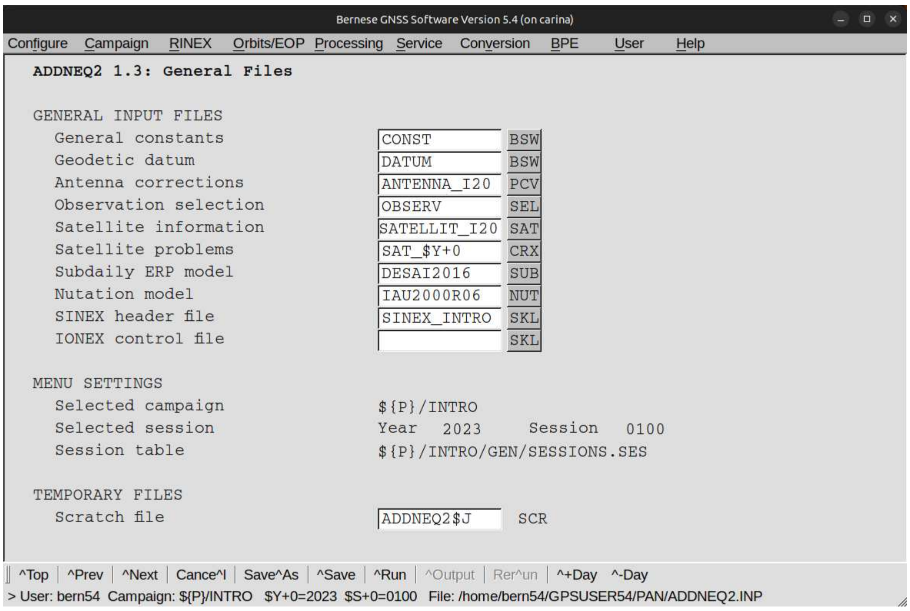
${P}/INTRO/SOL/FIN_$YYYSS+0.NQ0,
${P}/INTRO/STA/FIN_$YYYSS+0.CRD,
${P}/INTRO/ATM/FIN_$YYYSS+0.TRP, and potentially
${P}/INTRO/ATM/FIN_$YYYSS+0.TRO.

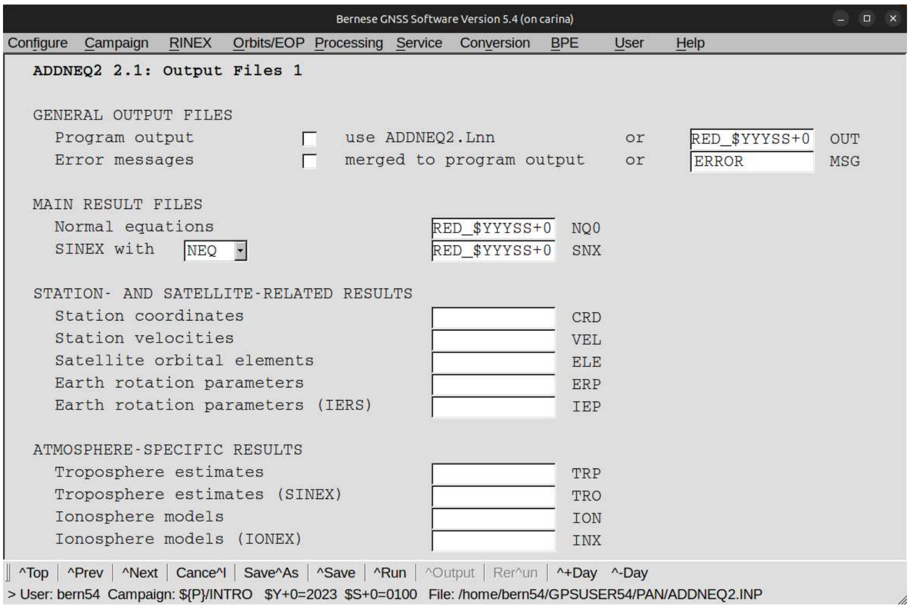
It is preferable for the velocity estimation to have smaller normal equation files containing only the coordinate parameters for each session. In addition, we generate a coordinate SINEX file (in NEQ representation) as the final solution of the day, so the troposphere parameters have to be pre–eliminated before the solution is computed. We introduce the station coordinates (${P}/INTRO/STA/FIN_$YYYSS+0.CRD) obtained with the minimum constraint solution in the previous run of ADDNEQ2 and constrain the solution to these coordinates.

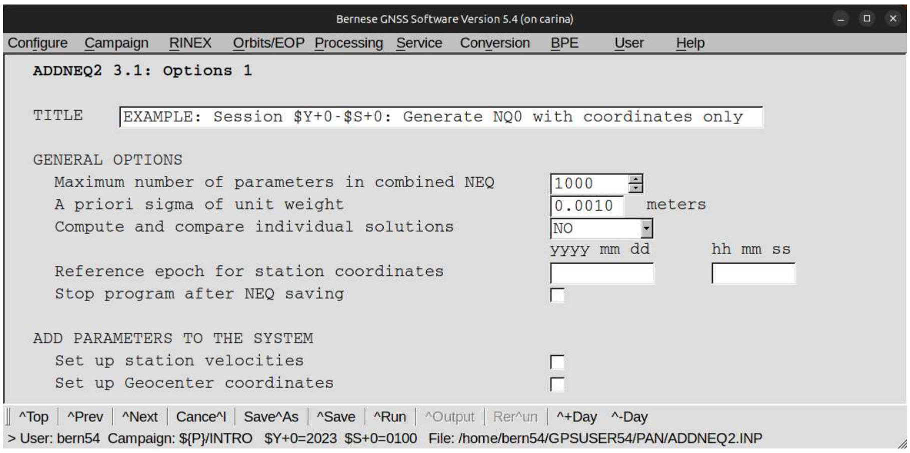
To generate these reduced NQ0 files and the SINEX file, the execution of ADDNEQ2 has to be repeated with the following changes in the input options:



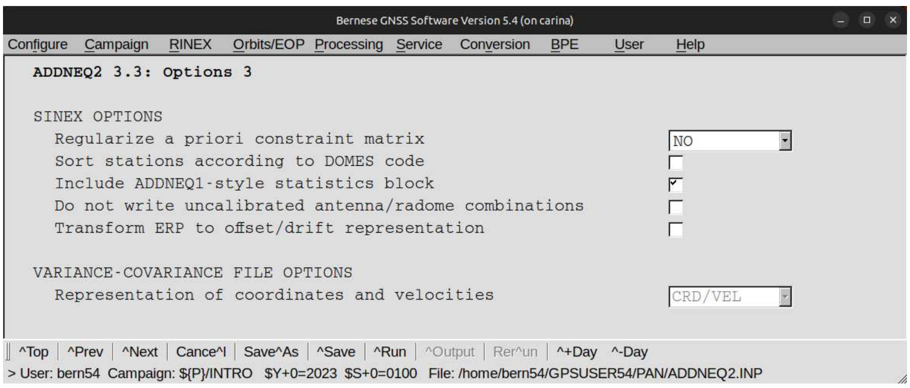
Please note that the output SINEX file includes again the skeleton from ${P}/INTRO/GEN/SINEX_INTRO.SKL (copied from ${D}/REF54 directory into the campaign) – the same file we used as skeleton for the troposphere SINEX generation.



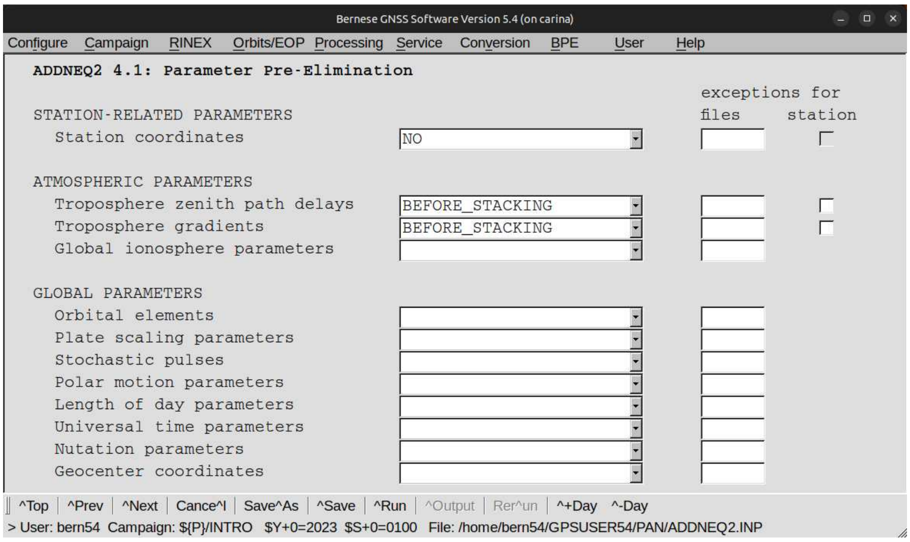




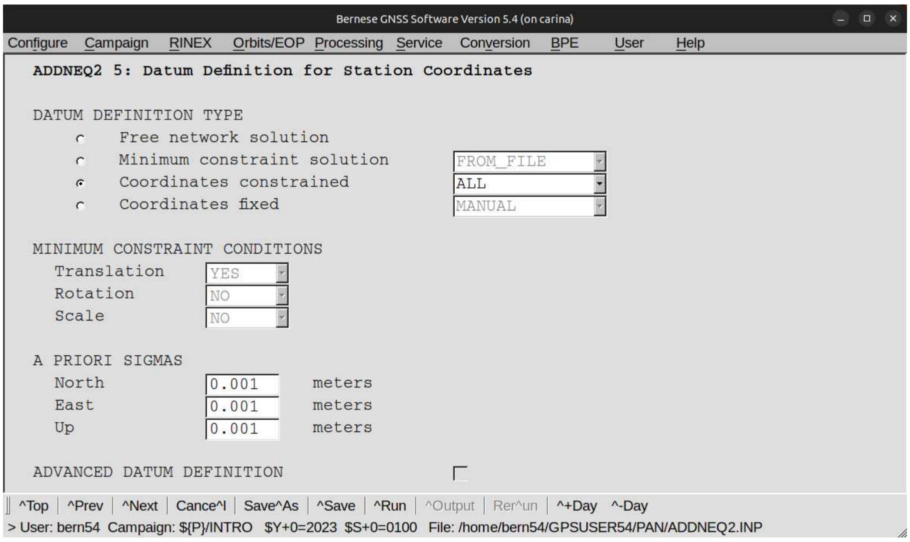
Because you are storing a SINEX file in NEQ representation (see option "Content of SINEX") no regularization is necessary.



The troposphere parameters are pre–eliminated:



To keep the a priori and estimated sets of coordinates in the resulting SINEX file consistent, we introduce the coordinate solution of the session in "Station coordinates" in "ADDNEQ2 1.1: Input Files 1" and constrain all coordinate parameters to these values.



The normal equation file (`${P}/INTRO/SOL/RED_20230100.NQ0`) contains only the station coordinate parameters. The following section of the program output documents the pre–elimination of the troposphere parameters:

```
...
SUMMARY OF RESULTS
------------------

Number of parameters:
--------------------

Parameter type                        Adjusted    Expl.    Impl. (elim)*  Del. Ref. Sing. No obs
------------------------------------------------------------------------------------------------
Station coordinates / velocities           54       54        0              0    0     0      0
Site-specific troposphere parameters      516        0      516  (bfst)      0    0     0      0
------------------------------------------------------------------------------------------------
Previously pre-eliminated parameters      911               911
------------------------------------------------------------------------------------------------
Total number                             1481       54     1427              0    0     0      0


*Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking (afst),
```

```
                                    epoch-wise (epow), after inversion (afin)


 Statistics:
 ----------

 Total number of authentic observations      156396
 Total number of pseudo-observations            516

 Total number of explicit parameters             54
 Total number of implicit parameters           1427

 Total number of observations                156912
 Total number of adjusted parameters           1481
 Degree of freedom (DOF)                     155431

 A posteriori RMS of unit weight           0.001036 m
 Chi**2/DOF                                    1.07

 Total number of observation files               17
 Total number of stations                        18
 ...
```

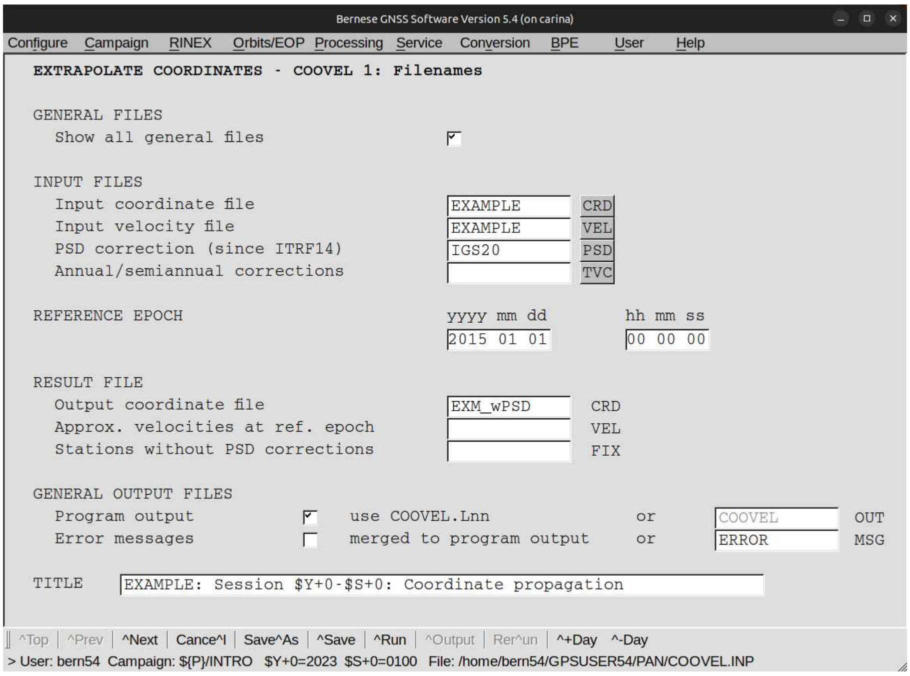
You can also see that the number of explicit parameters in the NQ0 file was dramatically reduced (from 570 to 54). This is an advantage for the combination of a big number of normal equation files for the estimation of station velocities.

6.5 Velocity Estimation

6.5.1 Preparation for ITRF 2020/IGS 20 Velocity Estimation

This section can be skipped if no ITRF 2020/IGS 20 reference frame is used as geodetic datum.

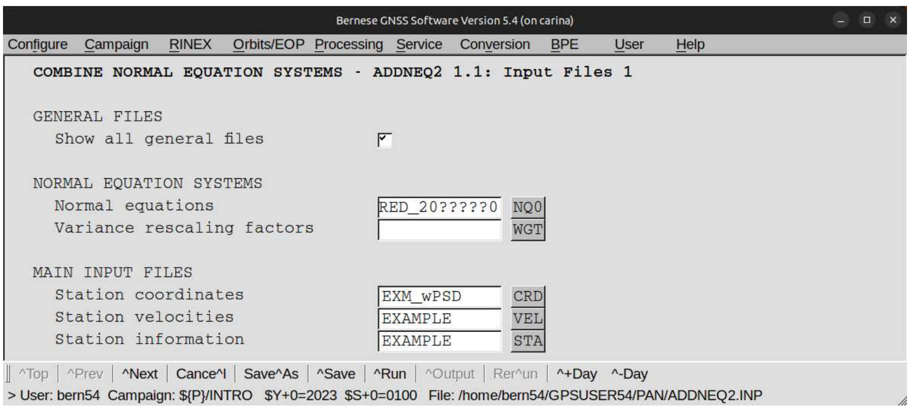
Because of the PSD corrections, the linear station velocity may not represent the actual station velocity and one has to prepare the station coordinate and velocity files before they can be used for the datum definition in the program ADDNEQ2. We have to compute the station coordinates at the reference epoch using the program COOVEL ("Menu>Service >Coordinate tools>Extrapolate coordinates"):

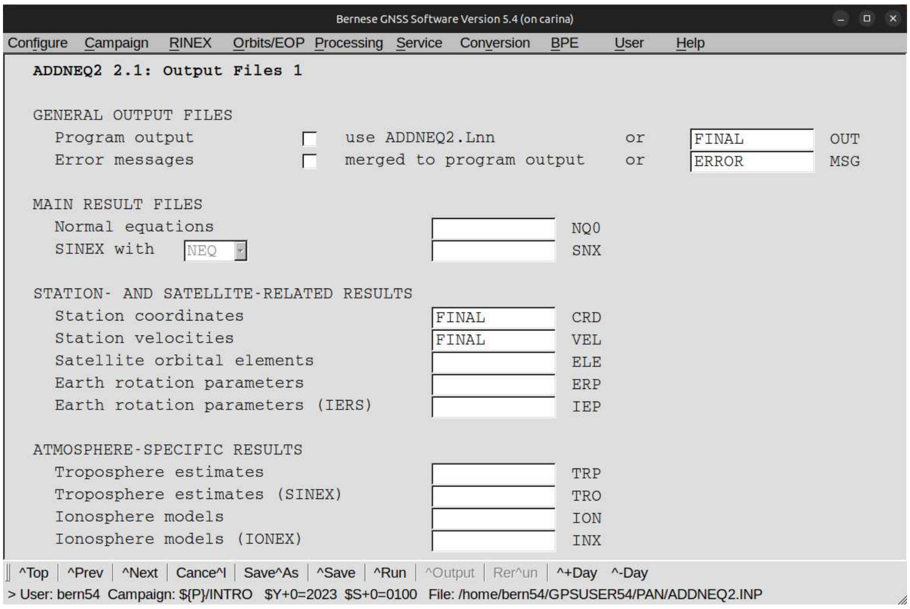


In our example none of the stations that shall be used for the datum definition is related to the PSD corrections. So, you can continue here. If you have another station selection where the PSD corrections become relevant the distributed BPE `${U}/PCF/ITRF.PCF` may be helpful. In the related `README` file you will find further instructions. It can be accessed via "Menu>Help>Readme" (Section Example BPE).

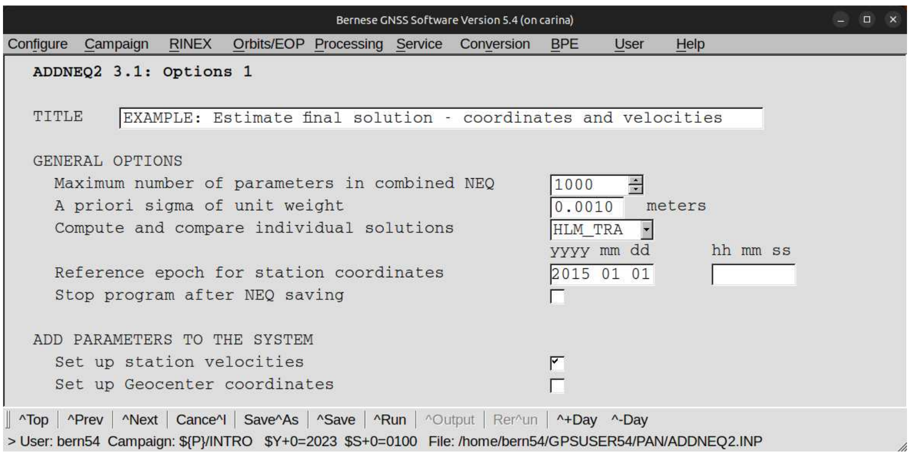
6.5.2 Velocity Estimation Based on NEQ Files

The velocity estimation in program ADDNEQ2 is easy. Introduce the normal equation files containing only the station coordinate parameters. Independent from your success in following the example so far, you may copy the prepared files for all days (010/011 of year 2023 and 201/202 of year 2024) from `${S}/RNX2SNX/2023/SOL/RED_2023*NQ0` and `${S}/RNX2SNX/2024/SOL/RED_2024*NQ0` into the `${P}/INTRO/SOL/` directory. The normal equation files have to cover a reasonable time interval to reliably estimate velocities (in this case about 1.5 years):



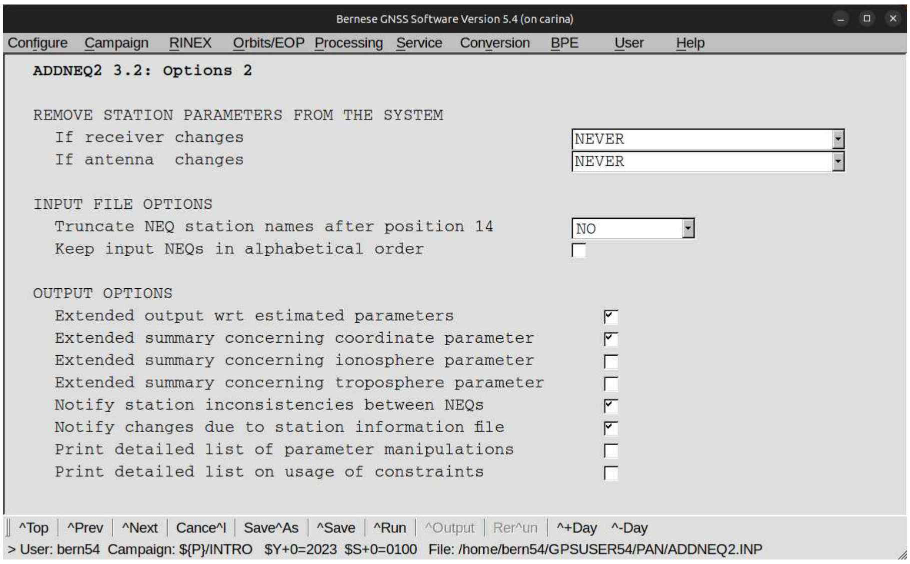


Station velocities are set up by marking the corresponding checkbox:

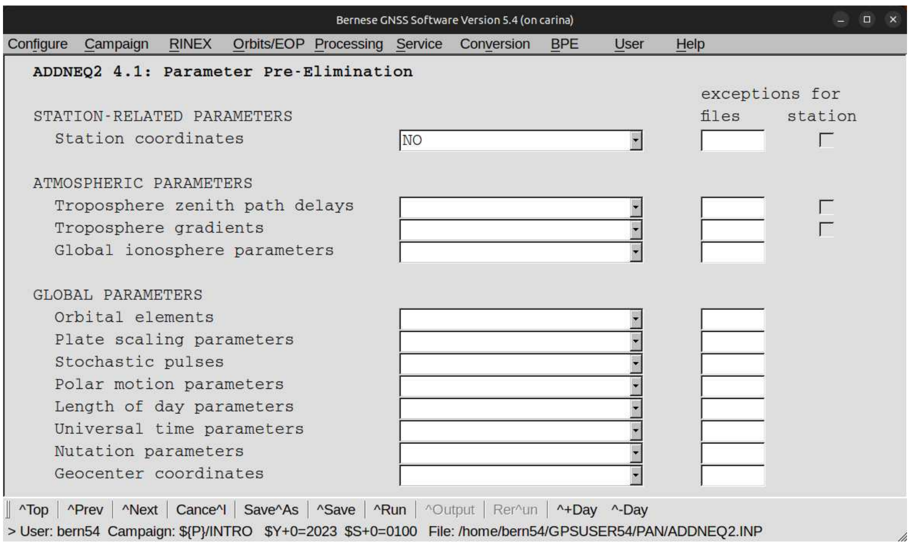


Furthermore, we check the repeatability of the daily solutions after the velocity estimation. The coordinates in the resulting file will refer to the epoch 2015 01 01.

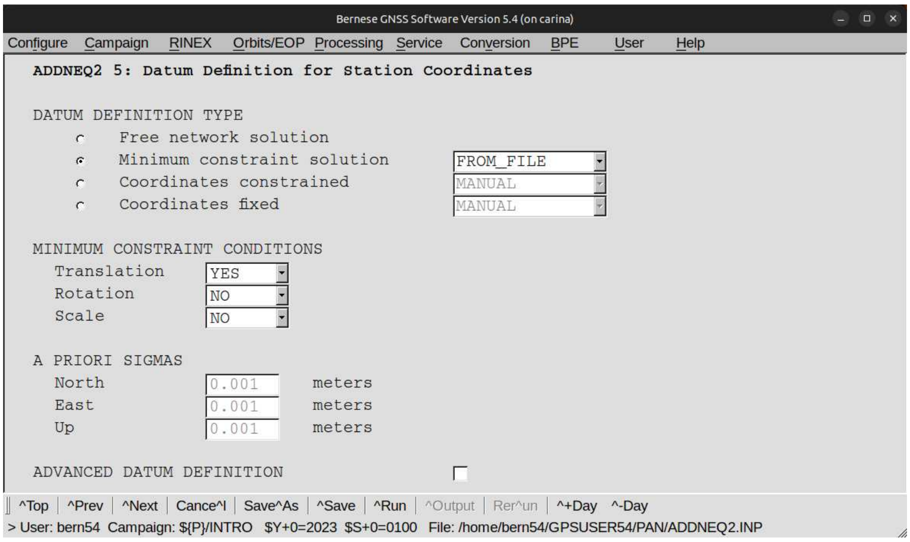
This panel is important for stations where an equipment change has taken place during the interval covered by this solution.

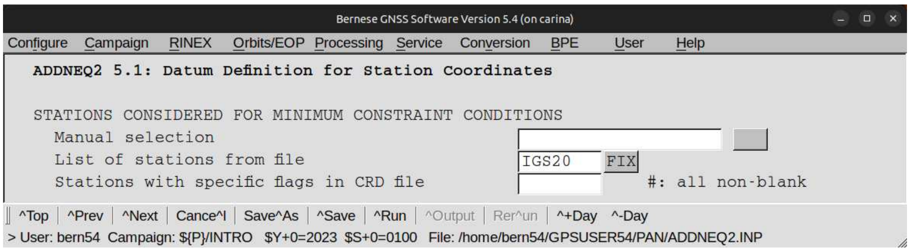


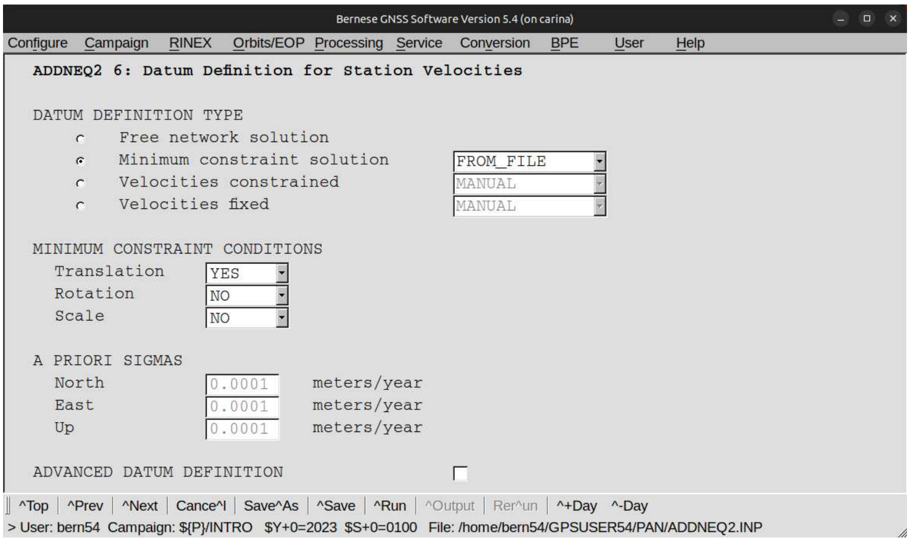
The input NEQ files only contain coordinates:

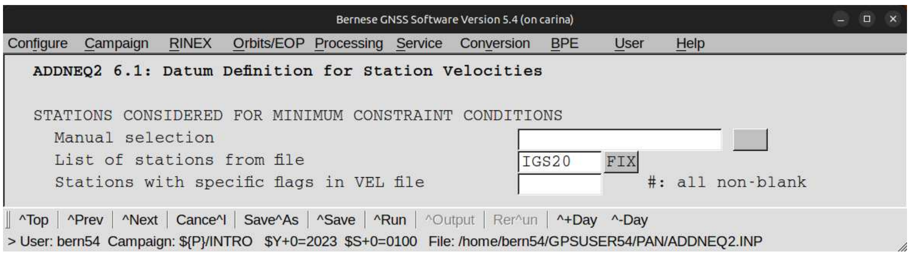


The realization of the geodetic datum is done separately for positions and velocities in the following panels:

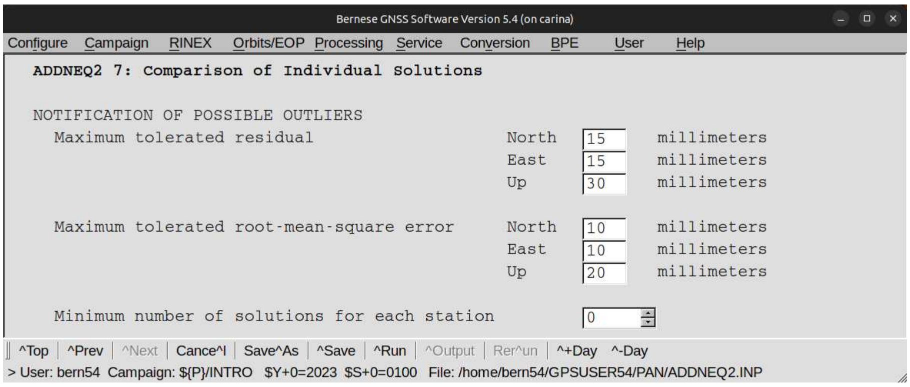








The following panel provides options to detect bad daily solutions based on the repeatability:



After the velocity estimation the repeatability of the coordinate solutions from the individual normal equations look like:

```
...

Statistics of individual solutions:
----------------------------------

                                               #Observations                  #Parameters
File      RMS (m)       DOF  Chi**2/DOF   authentic   / pseudo    explicit   / implicit / singular
-----------------------------------------------------------------------------------------------------
   1      0.00104    155380        1.07      156858          3          54         1427          0
   2      0.00109    156778        1.19      158238          3          54         1409          0
   3      0.00130    156819        1.70      158453          3          54         1583          0
   4      0.00136    159452        1.84      161004          3          54         1501          0



Comparison of individual solutions:
----------------------------------

BRST 10004M004   N    0.51     -0.56    0.55     0.27   -0.30
BRST 10004M004   E    0.88     -0.36    0.36     1.03   -1.00
BRST 10004M004   U    2.12     -0.97    0.93     2.37   -2.46

GANP 11515M001   N    0.37      0.36   -0.37     0.25   -0.28
GANP 11515M001   E    0.48     -0.26    0.27    -0.52    0.53
GANP 11515M001   U    0.32     -0.34    0.39    -0.16    0.14

HERT 13212M010   N    2.20     -0.39    0.39    -2.59    2.74
HERT 13212M010   E    2.02      0.18   -0.17     2.60   -2.34
HERT 13212M010   U    2.92     -1.46    1.46    -2.01    4.15

JOZ2 12204M002   N    0.40      0.47   -0.48     0.11   -0.14
JOZ2 12204M002   E    0.97      0.07   -0.08    -1.20    1.17
JOZ2 12204M002   U    0.36     -0.31    0.36    -0.29    0.30

LAMA 12209M001   N    0.62      0.86   -0.64    -0.05    0.06
LAMA 12209M001   E    0.04     -0.05   -0.01     0.03   -0.04
LAMA 12209M001   U    0.41      0.03    0.02    -0.53    0.46

MATE 12734M008   N    0.52      0.51   -0.51     0.34   -0.40
MATE 12734M008   E    0.73      0.32   -0.31    -0.83    0.84
MATE 12734M008   U    1.32      0.99   -0.93     1.33   -1.28

MIKL 12335M001   N    0.29      0.18   -0.19     0.32   -0.28
MIKL 12335M001   E    0.41      0.48   -0.50     0.18    0.02
MIKL 12335M001   U    0.92     -0.90    0.95    -0.83    0.33

MORP 13299S001   N    0.38      0.24   -0.27     0.38   -0.40
MORP 13299S001   E    0.55     -0.37    0.37     0.53   -0.61
MORP 13299S001   U    2.03      2.40   -2.51    -0.49    0.19

ONSA 10402M004   N    0.13     -0.16    0.12    -0.05    0.10
ONSA 10402M004   E    0.37      0.33   -0.34    -0.32    0.29
ONSA 10402M004   U    1.72     -2.01    2.04    -0.69    0.41

ORID 15601M001   N    0.45     -0.07    0.08     0.51   -0.58
ORID 15601M001   E    0.25      0.23   -0.21    -0.22    0.20
ORID 15601M001   U    4.00      0.78   -0.88     4.80   -4.84
```

```
 PTBB 14234M001   N    0.51      0.37   -0.40    0.52   -0.46
 PTBB 14234M001   E    0.39      0.37   -0.39   -0.29    0.30
 PTBB 14234M001   U    4.61     -0.69    0.74   -5.52    5.69

 TLSE 10003M009   N    0.35     -0.32    0.31    0.27   -0.31
 TLSE 10003M009   E    0.30      0.25   -0.23    0.28   -0.26
 TLSE 10003M009   U    0.77      0.26   -0.27    0.89   -0.93

 VILL 13406M001   N    1.23      0.03   -0.05    1.46   -1.54
 VILL 13406M001   E    0.24      0.26   -0.27    0.12   -0.15
 VILL 13406M001   U    1.81      0.01   -0.07    2.02   -2.41

 WSRT 13506M005   N    0.39     -0.04    0.03   -0.45    0.50
 WSRT 13506M005   E    0.52      0.63   -0.64   -0.03   -0.03
 WSRT 13506M005   U    1.07      0.51   -0.51   -1.28    1.13

 WTZR 14201M010   N    0.47     -0.26    0.26    0.50   -0.53
 WTZR 14201M010   E    0.39      0.08   -0.08   -0.47    0.47
 WTZR 14201M010   U    0.98      0.82   -0.83    0.83   -0.91

 WTZZ 14201M014   N    0.74     -0.49    0.45    0.77   -0.78
 WTZZ 14201M014   E    0.38      0.40   -0.41   -0.21    0.22
 WTZZ 14201M014   U    0.80      0.53   -0.56   -0.84    0.78

 ZIM2 14001M008   N    0.38     -0.31    0.31    0.32   -0.35
 ZIM2 14001M008   E    0.30     -0.36    0.36    0.06   -0.06
 ZIM2 14001M008   U    0.26     -0.04    0.06   -0.37    0.24

 ZIMM 14001M004   N    0.21     -0.25    0.26   -0.04    0.00
 ZIMM 14001M004   E    1.34     -1.57    1.65   -0.34    0.30
 ZIMM 14001M004   U    0.62      0.68   -0.66   -0.41    0.27


 Variance-covariance scaling factors:
 ----------------------------------

 Parameter type                       Component    Scaling factor wrt RMS /  variance      DOF
 -------------------------------------------------------------------------------------------
 Station coordinates                  N                              2.57282     6.61940       72
 Station coordinates                  E                              3.28118    10.76612       72
 Station coordinates                  U/vertical                     2.22879     4.96749       72
 Station coordinates                  Horizontal                     2.94835     8.69276      144
 Station coordinates                  All                            2.72965     7.45100      216
 -------------------------------------------------------------------------------------------
 Total                                                               2.72965     7.45100      216
...
```

Below this table, bad daily solutions according to the settings in panel "ADDNEQ2 7: Comparison of Individual Solutions" are summarized (if there are any). In this example we have no additional section and, therefore, no outliers.

Directly below the Solution Statistics potential changes of the equipment are reported that might influence the velocity estimation. In our example, one station is affected:

```
 Station inconsistencies:
 ----------------------

 ---------------------------------------------------------------------------------- ...
 Station         First obs. epoch     Last obs. epoch      Receiver type   Antenna type ...
 ---------------------------------------------------------------------------------- ...
 WSRT 13506M005  2023-01-10 00:00:00  2023-01-11 23:59:30  SEPT POLARX5    AOAD/M_T     ...
 WSRT 13506M005  2024-07-19 00:00:00  2024-07-20 23:59:30  SEPT POLARX5    LEIAR25.R4   ...
...
```

If you compare the velocities obtained for the two sites in Kötzting (WTZR and WTZZ) and Zimmerwald (ZIM2 and ZIMM) you will find small differences:

```
...
Station coordinates and velocities:
----------------------------------
Reference epoch: 2015-01-01 00:00:00

Station name          Typ   A priori value  Estimated value    Correction     RMS error  ...
------------------------------------------------------------------------------------------ ...
...
WTZR 14201M010        VX          -0.01593         -0.01749      -0.00156       0.00025
                      VY           0.01721          0.01506      -0.00215       0.00011
                      VZ           0.01006          0.00828      -0.00178       0.00028

                      VU          -0.00004         -0.00270      -0.00266       0.00036  ...
                      VN           0.01543          0.01577       0.00035       0.00012  ...
                      VE           0.02033          0.01858      -0.00175       0.00009  ...
...
WTZZ 14201M014        VX          -0.01593         -0.01740      -0.00147       0.00029
                      VY           0.01721          0.01481      -0.00240       0.00012
                      VZ           0.01006          0.00873      -0.00133       0.00032

                      VU          -0.00004         -0.00234      -0.00229       0.00042  ...
                      VN           0.01543          0.01604       0.00062       0.00013  ...
                      VE           0.02033          0.01831      -0.00202       0.00011  ...
...
ZIM2 14001M008        VX          -0.01378         -0.01566      -0.00188       0.00028
                      VY           0.01810          0.01805      -0.00005       0.00010
                      VZ           0.01164          0.01052      -0.00112       0.00029

                      VU           0.00076         -0.00133      -0.00210       0.00038  ...
                      VN           0.01621          0.01681       0.00060       0.00012  ...
                      VE           0.01974          0.01993       0.00020       0.00010  ...
...
ZIMM 14001M004        VX          -0.01378         -0.01448      -0.00070       0.00043
                      VY           0.01810          0.01806      -0.00004       0.00015
                      VZ           0.01164          0.01094      -0.00070       0.00044

                      VU           0.00076         -0.00022      -0.00099       0.00058  ...
                      VN           0.01621          0.01624       0.00003       0.00019  ...
                      VE           0.01974          0.01979       0.00005       0.00015  ...
...
```

You can constrain the velocity estimates for the pairs of receivers at one location in the station information file. Copy the original station information file `${P}/INTRO/STA/EXAMPLE.STA` and add the following lines to part TYPE 004: STATION COORDINATES AND VELOCITIES (ADDNEQ) of this copy.

```
TYPE 004: STATION COORDINATES AND VELOCITIES (ADDNEQ)
-----------------------------------------------------
                                          REL. CONSTR. POSITION     RELATIVE CONSTR. VELOCITY
STATION NAME 1        STATION NAME 2   ...  EAST       UP         NORTH      EAST       UP
****************      **************** ...  **.*****   **.*****   **.*****   **.*****   **.*****
WTZR 14201M010        WTZZ 14201M014   ...                         0.00001    0.00001    0.00001
ZIM2 14001M008        ZIMM 14001M004   ...                         0.00001    0.00001    0.00001
```

(Pay attention to the number of blank lines before the next section starts.)

When introducing this information, the program ADDNEQ2 will issue the following message:

```
### SR AOPTNET: You are going to use relative constraints for station
                coordinates/velocities from station info file.
                Please keep in mind that you will NOT constrain the
                estimated results but only the improvements of the
                apriori values.
```

If only the improvements (column Correction) for the velocities are constrained, you must make sure that also the a priori values (column A priori value) for the velocities are identical to obtain (column Estimated value) the same velocities for a group of stations.

You can verify this in the input velocity file ${P}/INTRO/STA/EXAMPLE.VEL:

```
...
326  WTZR 14201M010         -0.01593        0.01721        0.01006    IG20 EURA
327  WTZZ 14201M014         -0.01593        0.01721        0.01006    NNR  EURA
...
339  ZIM2 14001M008         -0.01378        0.01810        0.01164    IG20 EURA
340  ZIMM 14001M004         -0.01378        0.01810        0.01164    IG20 EURA
...
```

If this is not the case, you should unify the a priori values.

The relative constraining of the velocity estimates is confirmed in the section of the input parameters (below the a priori coordinates and velocities) of the ADDNEQ2–program output:

```
 ...

 Relative constraints between stations:
                                                ...  relative constraints for velocities
 Station names                                  ... N (m/year)    E (m/year)    U (m/year)
 ---------------------------------------------- ... -------------------------------------
 WTZR 14201M010        WTZZ 14201M014           ...  0.00001       0.00001       0.00001
 ZIM2 14001M008        ZIMM 14001M004           ...  0.00001       0.00001       0.00001
...
```

Introducing this modified station information file instead of the original one you will get the following estimates for the station velocities in Kötzting and Zimmerwald:

```
 ...

 Station coordinates and velocities:
 ----------------------------------
 Reference epoch: 2010-01-01 00:00:00

 Station name          Typ   A priori value  Estimated value    Correction     RMS error  ...
 ---------------------------------------------------------------------------------------- ...
 ...
 WTZR 14201M010        VX          -0.01593         -0.01739      -0.00146       0.00020
                       VY           0.01721          0.01495      -0.00226       0.00008
                       VZ           0.01006          0.00849      -0.00157       0.00022

                       VU          -0.00004         -0.00249      -0.00245       0.00029  ...
                       VN           0.01543          0.01586       0.00043       0.00009  ...
                       VE           0.02033          0.01845      -0.00187       0.00007  ...
 ...
 WTZZ 14201M014        VX          -0.01593         -0.01739      -0.00146       0.00020
                       VY           0.01721          0.01495      -0.00226       0.00008
                       VZ           0.01006          0.00849      -0.00157       0.00022

                       VU          -0.00004         -0.00249      -0.00245       0.00029  ...
                       VN           0.01543          0.01586       0.00043       0.00009  ...
                       VE           0.02033          0.01845      -0.00188       0.00007  ...
 ...
 ZIM2 14001M008        VX          -0.01378         -0.01529      -0.00151       0.00022
                       VY           0.01810          0.01807      -0.00003       0.00008
                       VZ           0.01164          0.01064      -0.00100       0.00023

                       VU           0.00076         -0.00100      -0.00176       0.00030  ...
                       VN           0.01621          0.01663       0.00041       0.00009  ...
                       VE           0.01974          0.01990       0.00016       0.00008  ...
 ...
 ZIMM 14001M004        VX          -0.01378         -0.01529      -0.00151       0.00022
                       VY           0.01810          0.01807      -0.00003       0.00008
                       VZ           0.01164          0.01064      -0.00100       0.00023

                       VU           0.00076         -0.00100      -0.00176       0.00030  ...
                       VN           0.01621          0.01662       0.00041       0.00009  ...
                       VE           0.01974          0.01990       0.00016       0.00008  ...
 ...
```

The final results are contained in the files ${P}/INTRO/STA/FINAL.CRD

```
EXAMPLE: Estimate final solution - coordinates and velocities    17-JAN-25 13:35
--------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20            EPOCH: 2015-01-01 00:00:00

NUM  STATION NAME           X (M)          Y (M)          Z (M)     FLAG
SYSTEM

 39  BRST 10004M004    4231162.50863  -332746.48595  4745131.05970    W    GRE
 95  GANP 11515M001    3929181.37404  1455236.89987  4793653.99867    A    GRE
108  HERT 13212M010    4033460.83097    23537.97846  4924318.40508    A    GR
127  JOZ2 12204M002    3664880.41443  1409190.75498  5009618.56011    A    GRE
148  LAMA 12209M001    3524522.77019  1329693.77702  5129846.45357    A    GRE
165  MATE 12734M008    4641949.35227  1393045.61764  4133287.59572    W    GRE
179  MIKL 12335M001    3698553.75676  2308676.13037  4639769.54771    W    GRE
184  MORP 13299S001    3645667.83124  -107277.09105  5215053.69898    A    G
213  ONSA 10402M004    3370658.40365   711877.28986  5349787.02751    W    GRE
214  ORID 15601M001    4498451.52962  1708267.17016  4173591.94488    W    GRE
237  PTBB 14234M001    3844059.83611   709661.48589  5023129.65195    A    GRE
294  TLSE 10003M009    4627851.72239   119640.22176  4372993.66786    W    GRE
316  VILL 13406M001    4849833.59475  -335048.83031  4116015.08468    A    GRE
325  WSRT 13506M005    3828735.68919   443305.10975  5064884.82387    W    GRE
326  WTZR 14201M010    4075580.40379   931853.98814  4801568.24617    W    GRE
327  WTZZ 14201M014    4075579.28334   931853.30360  4801569.15404    A    GRE
339  ZIM2 14001M008    4331299.75150   567537.50269  4633133.84102    W    GRE
340  ZIMM 14001M004    4331296.94166   567556.05776  4633134.06090    W    G
```

and ${P}/INTRO/STA/FINAL.VEL

```
XAMPLE: Estimate final solution - coordinates and velocities    17-JAN-25 13:35
--------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20

NUM  STATION NAME           VX (M/Y)       VY (M/Y)       VZ (M/Y)  FLAG   PLATE

 39  BRST 10004M004         -0.01698        0.01604        0.00643    W    EURA
 95  GANP 11515M001         -0.01772        0.01460        0.00896    A    EURA
108  HERT 13212M010         -0.01724        0.01569        0.00493    A    EURA
127  JOZ2 12204M002         -0.02054        0.01490        0.00827    A    EURA
148  LAMA 12209M001         -0.02058        0.01519        0.00665    A    EURA
165  MATE 12734M008         -0.01603        0.01894        0.01624    W    EURA
179  MIKL 12335M001         -0.01544        0.01903        0.01318    W    EURA
184  MORP 13299S001         -0.02667        0.01700        0.00119    A    EURA
213  ONSA 10402M004         -0.01490        0.01406        0.01282    W    EURA
214  ORID 15601M001         -0.01379        0.02124        0.00955    W    EURA
237  PTBB 14234M001         -0.01913        0.01568        0.00968    A    EURA
294  TLSE 10003M009         -0.01321        0.01782        0.01164    W    EURA
316  VILL 13406M001         -0.00846        0.01891        0.00952    A    EURA
325  WSRT 13506M005         -0.01210        0.01715        0.00850    W    EURA
326  WTZR 14201M010         -0.01739        0.01495        0.00849    W    EURA
327  WTZZ 14201M014         -0.01739        0.01495        0.00849    A    EURA
339  ZIM2 14001M008         -0.01529        0.01807        0.01064    W    EURA
340  ZIMM 14001M004         -0.01529        0.01807        0.01064    W    EURA
```

6.6 Daily Goals

At the end of today's session, you should have:

1. *used GPSEST to compute a final solution of the day, created files: FIX_20230100.OUT, FIX_20230100.NQ0,*
2. *checked the coordinates of the fiducial sites using ADDNEQ2 and HELMR1, created files: FIN_20230100.CRD, FIN_20230100.TRP, optionally also FIN_20230100.TRO, FIN_20230100.OUT, and HLM_20230100.OUT – these results should be available for all sessions,*
3. *used COMPAR2 to check the daily repeatabilities, created file: COMPAR.OUT,*
4. *used ADDNEQ2 to create a final session solution, and reduced size NEQs, created files: RED_20230100.NQ0 and RED_20230100.SNX,*
5. *if possible, used ADDNEQ2 for velocity estimation, created files: FINAL.CRD and FINAL.VEL.*

7 Additional Examples

In the previous terminal sessions you have estimated coordinates, velocities, and troposphere parameters. This is the standard application of the *Bernese GNSS Software* for most users.

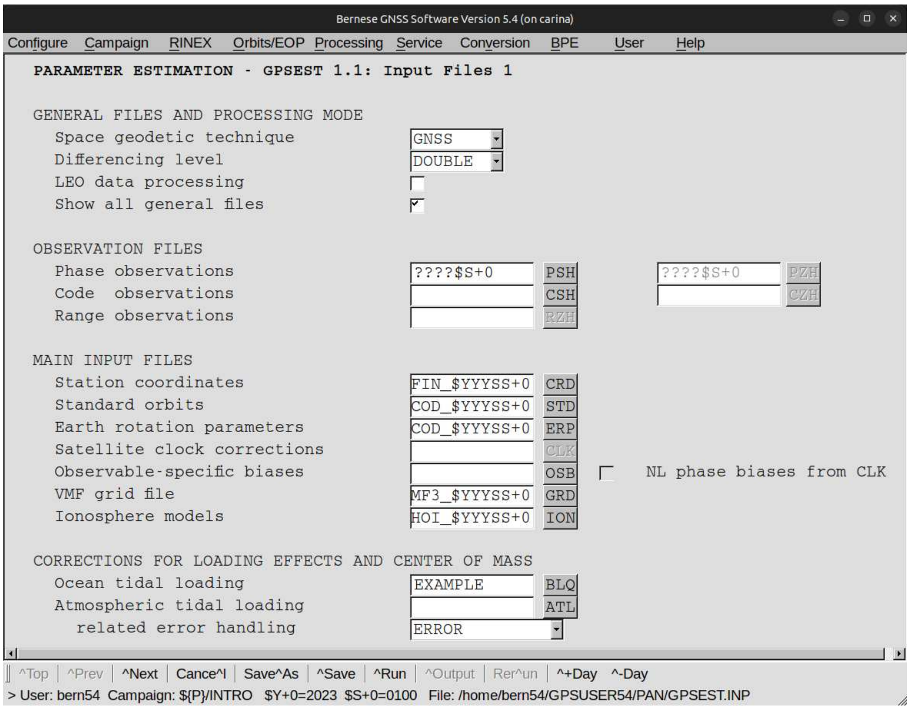
If you have finished this work or if you want to follow more examples at home, this section of the document provides some suggestions to practice:

- kinematic positioning for a station
  (see Section 7.1 on page 126), and
- simulation of GNSS observations
  (see Section 7.2 on page 132).

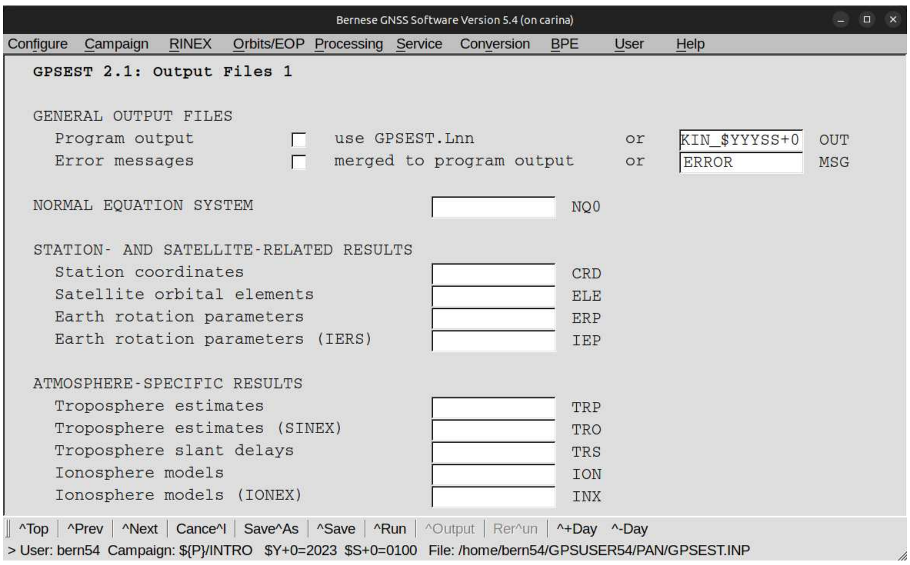
7.1 Kinematic Positioning

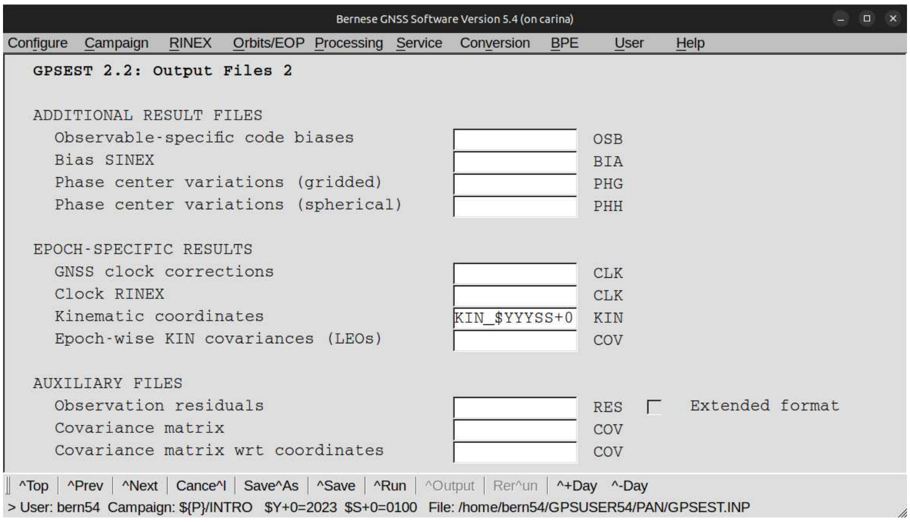
7.1.1 Estimating Kinematic Positions in a Double–Difference Solution

The example campaign contains no really roving stations. You can, however, define one of them to be kinematic (e.g., station GANP). Introduce the coordinates from the final solution (`${P}/INTRO/STA/FIN_20230100.CRD`) for all other sites.

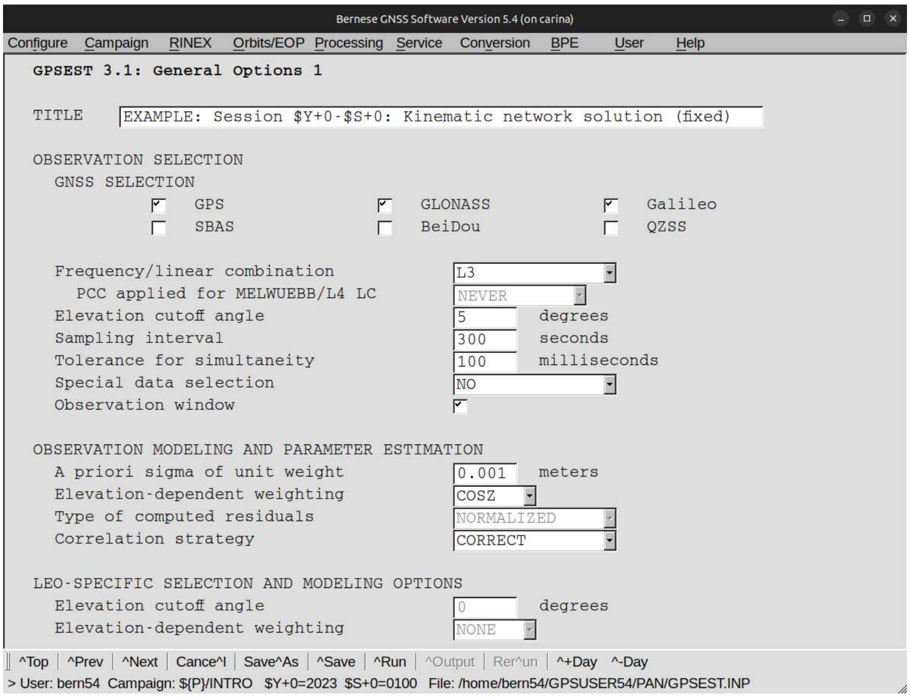


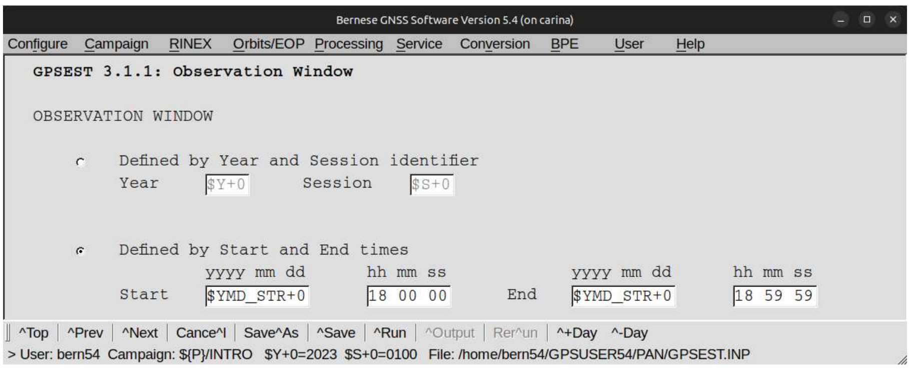
Remove the name of the resulting "Normal equations" file in panel "GPSEST 2.1: Output Files 1" if there is any entry in this input field. Store the kinematic coordinates in an output file ("Output kinematic coordinates" in panel "GPSEST 2.2: Output Files 2").



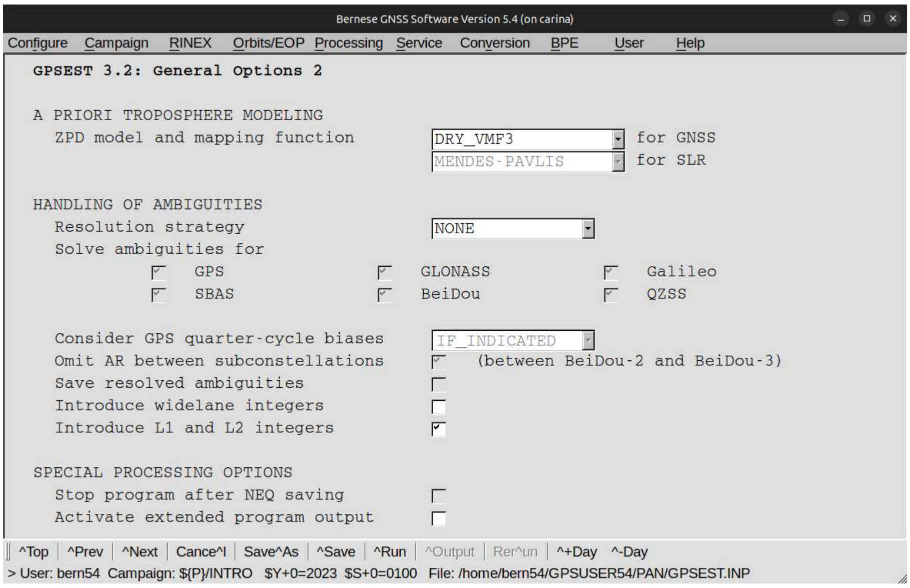


Because the number of parameters for the kinematic positioning may become very large, we select only a short data interval of one hour for this kinematic positioning:

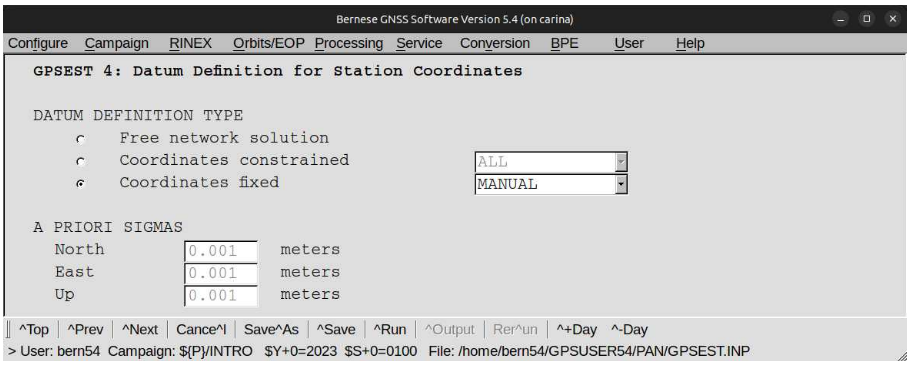


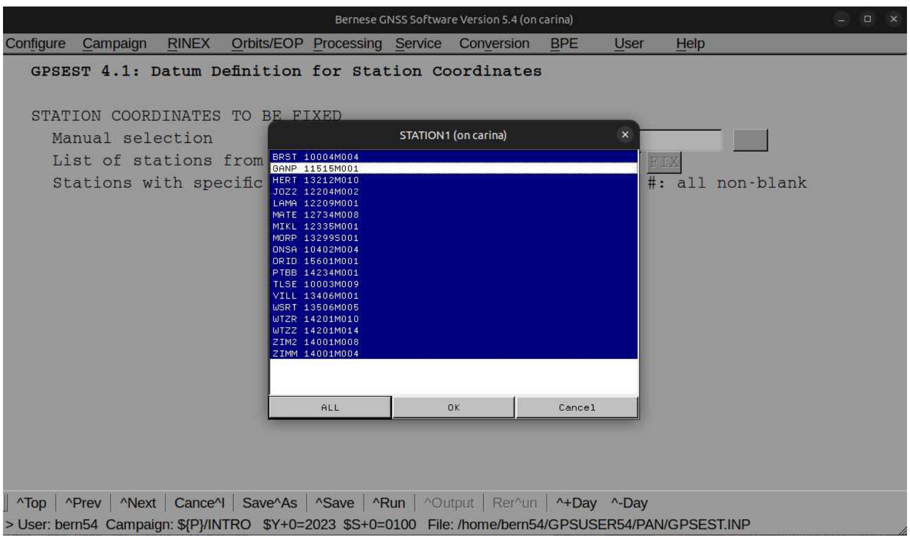


The option “Activate extended program output” may be disabled now:

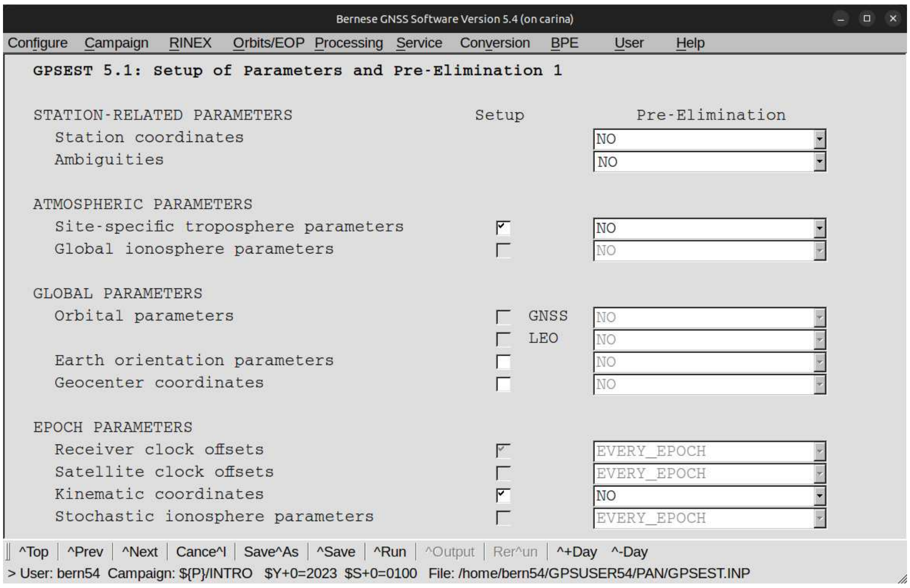


Fix all station coordinates apart from GANP in the panels “GPSEST 4: Datum Definition for Station Coordinates” (choose MANUAL in panel “GPSEST 4: Datum Definition for Station Coordinates” and select all stations except GANP in panel “GPSEST 4.2”).

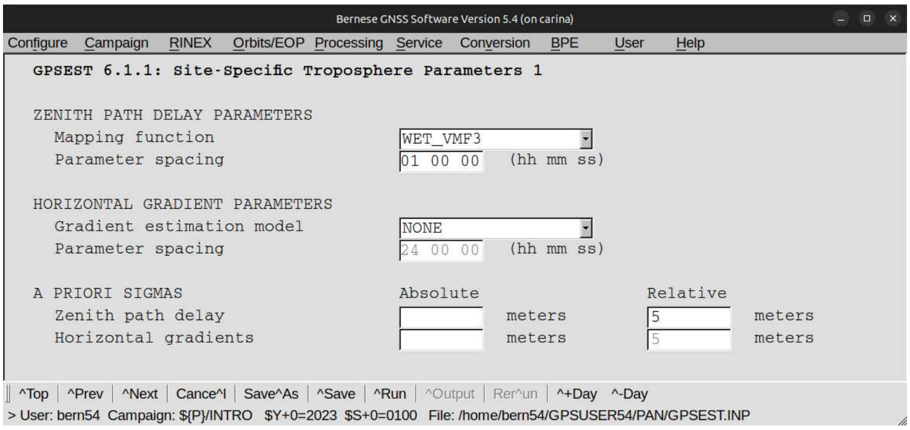




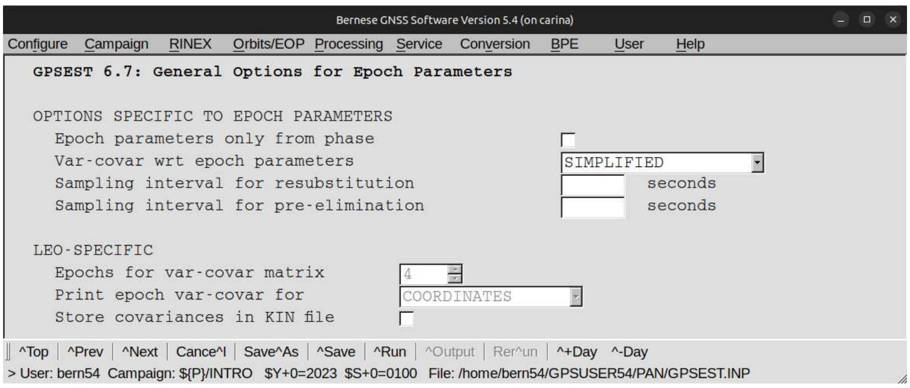
Enable the kinematic coordinates option without any pre–elimination in a first run:



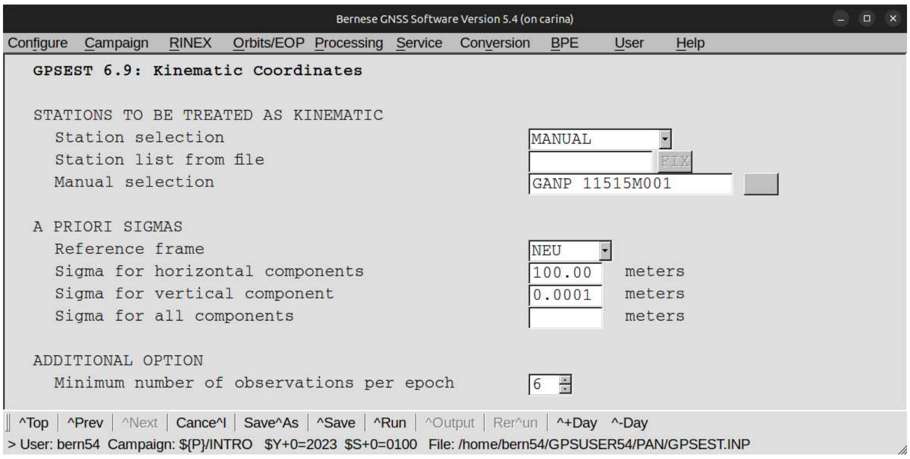
Because of the short analysis interval of only one hour we disable the estimation of troposphere gradients:



An additional panel for options related to epoch parameters is displayed where you can accept the default values:



Let us assume only horizontal movements for this site:

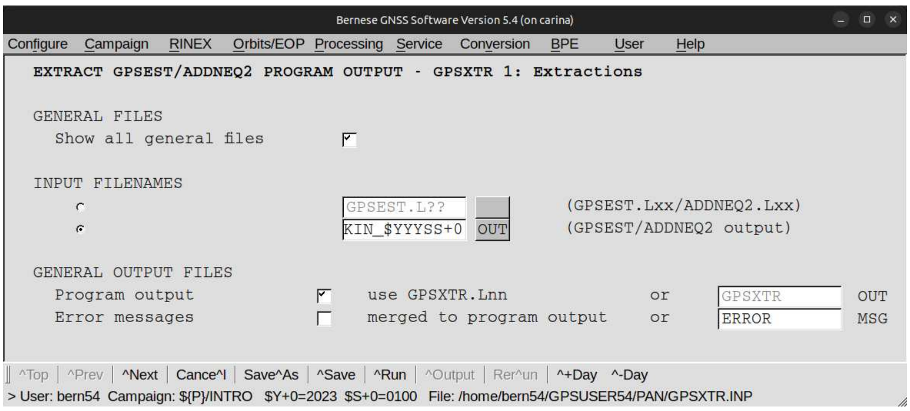


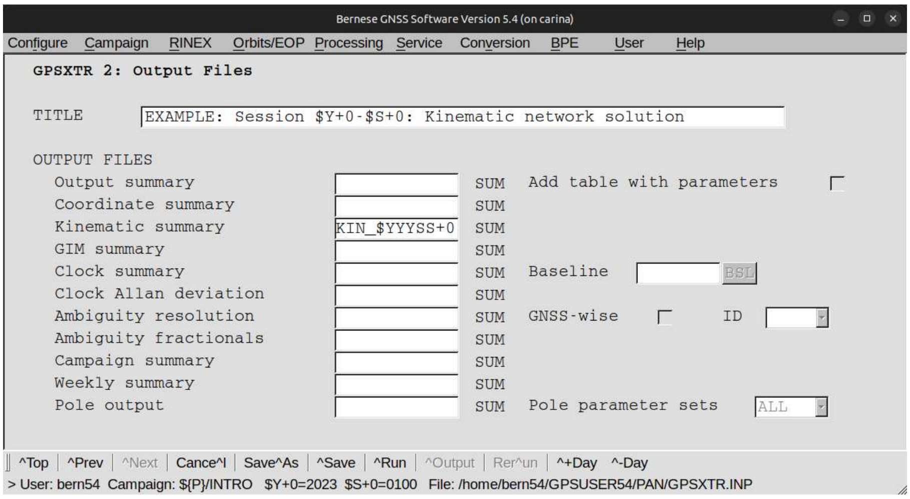
7.1.2 Extracting the Program Output from a Kinematic Positioning

As expected you will get only small estimates for the kinematic coordinates since GANP was not moving:

```
Kinematic coordinates:
---------------------

Station name    Typ Obs  Correction   Estimated value  RMS error ... From                 Num Abb
-------------------------------------------------------------- ... ---------------------------
GANP 11515M001   X   22    0.00309    3929181.23449    0.00216 ... 2023-01-10 18:00:00   37 #KIN
GANP 11515M001   Y   22   -0.00156    1455237.01509    0.00252 ... 2023-01-10 18:00:00   38 #KIN
GANP 11515M001   Z   22   -0.00204    4793654.06860    0.00178 ... 2023-01-10 18:00:00   39 #KIN
GANP 11515M001   X   21   -0.00069    3929181.23071    0.00211 ... 2023-01-10 18:05:00   40 #KIN
GANP 11515M001   Y   21    0.00041    1455237.01706    0.00253 ... 2023-01-10 18:05:00   41 #KIN
GANP 11515M001   Z   21    0.00044    4793654.07108    0.00176 ... 2023-01-10 18:05:00   42 #KIN
GANP 11515M001   X   21    0.00396    3929181.23536    0.00208 ... 2023-01-10 18:10:00   43 #KIN
GANP 11515M001   Y   21   -0.00359    1455237.01306    0.00254 ... 2023-01-10 18:10:00   44 #KIN
GANP 11515M001   Z   21   -0.00215    4793654.06849    0.00175 ... 2023-01-10 18:10:00   45 #KIN
GANP 11515M001   X   20    0.00175    3929181.23315    0.00206 ... 2023-01-10 18:15:00   46 #KIN
GANP 11515M001   Y   20   -0.00210    1455237.01455    0.00253 ... 2023-01-10 18:15:00   47 #KIN
GANP 11515M001   Z   20   -0.00079    4793654.06985    0.00175 ... 2023-01-10 18:15:00   48 #KIN
GANP 11515M001   X   21    0.00342    3929181.23482    0.00203 ... 2023-01-10 18:20:00   49 #KIN
GANP 11515M001   Y   21   -0.00056    1455237.01609    0.00253 ... 2023-01-10 18:20:00   50 #KIN
GANP 11515M001   Z   21   -0.00262    4793654.06802    0.00173 ... 2023-01-10 18:20:00   51 #KIN
GANP 11515M001   X   20    0.00046    3929181.23186    0.00203 ... 2023-01-10 18:25:00   52 #KIN
GANP 11515M001   Y   20   -0.00054    1455237.01611    0.00258 ... 2023-01-10 18:25:00   53 #KIN
GANP 11515M001   Z   20   -0.00021    4793654.07043    0.00177 ... 2023-01-10 18:25:00   54 #KIN
GANP 11515M001   X   20    0.00132    3929181.23272    0.00200 ... 2023-01-10 18:30:00   55 #KIN
GANP 11515M001   Y   20    0.00117    1455237.01782    0.00254 ... 2023-01-10 18:30:00   56 #KIN
GANP 11515M001   Z   20   -0.00143    4793654.06921    0.00175 ... 2023-01-10 18:30:00   57 #KIN
...
```

With the program GPSXTR ("Menu>Processing>Program output extraction>Parameter estimation/stacking") a comprehensive summary of the estimates for the kinematic solution can be extracted:





The resulting summary file looks like:

```
*STATION        GANP 11515M001
*XEPO        12
*INI          3929181.2314   1455237.0166   4793654.0706
*EST                0.0000         0.0000         0.0000
*DIFXYZ             0.0022        -0.0015        -0.0014
*DIFNEU            -0.0021        -0.0021        -0.0000
-------------------------------------------------------------------------------
  EPOCH              DN             DE             DU
59954.75000        -0.0031        -0.0025         0.0000
59954.75347         0.0007         0.0006         0.0000
59954.75694        -0.0033        -0.0047        -0.0000
59954.76042        -0.0012        -0.0026         0.0000
59954.76389        -0.0040        -0.0017        -0.0000
59954.76736        -0.0003        -0.0007         0.0000
59954.77083        -0.0022         0.0006        -0.0000
59954.77431        -0.0005        -0.0014        -0.0000
59954.77778        -0.0014        -0.0040         0.0000
59954.78125        -0.0030        -0.0051        -0.0000
59954.78472        -0.0018        -0.0056         0.0000
59954.78819        -0.0049         0.0015         0.0000
-------------------------------------------------------------------------------
*AVG               -0.0021        -0.0021        -0.0000
*SIG                0.0016         0.0024         0.0000
*RMS                0.0026         0.0031         0.0000
*RMSTC              0.0010
```

The different components of the summary are described in the online help.

7.1.3 Further suggestions

- Introduce the result file with kinematic coordinates as an input file for another run of GPSEST. If the estimates become zero it is a confirmation that the file was correctly considered as the a priori kinematic positions for the station GANP.
- Use the pre–elimination EVERY_EPOCH for the "Kinematic coordinates" (they are back–substituted by the program in order to get a solution also for those parameters). Compare the results with the first solution.
- Switch the "Var-covar wrt epoch parameters" in panel "GPSEST 6.7: General Options for Epoch Parameters" from SIMPLIFIED to CORRECT. Compare the results again with the first solution.
- Compute kinematic coordinates for the full day using the epoch–wise pre–elimination and back–substitution algorithm. To save computing power we recommend to sample the data to 300 s.
- Repeat the kinematic solution considering only one of the GNSSs at the time in panel "GPSEST 3.1: General Options 1".

7.2 Simulation of GNSS Observations

The *Bernese GNSS Software* provides the simulation tool GPSSIM ("Menu>Service>Generate simulated observation data"). It generates synthetic GNSS (i.e., GPS, GLONASS, Galileo, BDS, and QZSS) observations for terrestrial static or kinematic stations as well as for LEOs. Code and phase zero difference observation files can be created based on an observation scenario defined by

- GNSS satellite geometry given by a standard orbit and
- a set of receivers with positions from a coordinate file, kinematic positions, or a LEO standard orbit file.

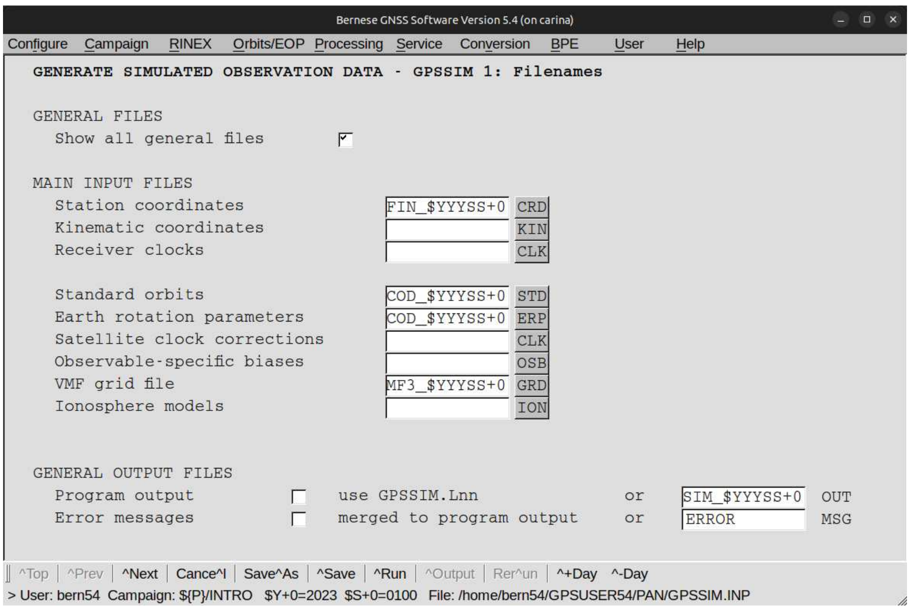
7.2.1 Simulation of GNSS Observations

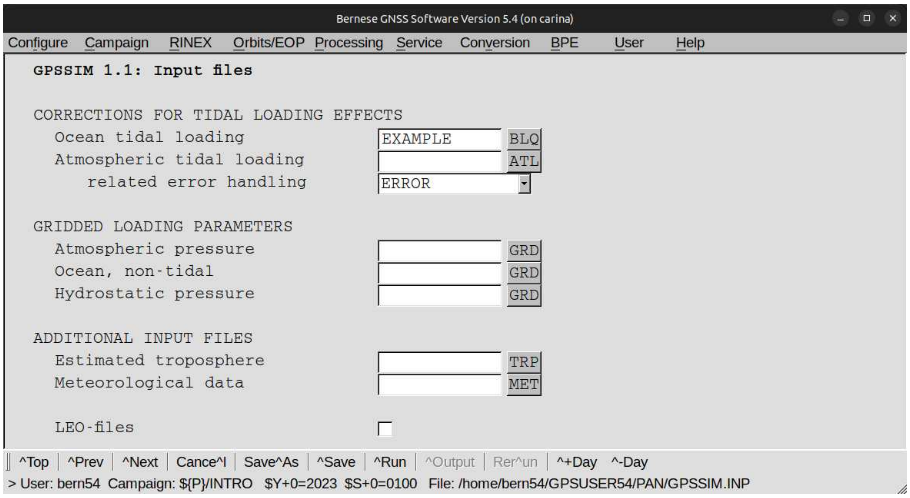
It is important that you remove all previously existing observation files for this session from the OBS directory of your campaign before you start to simulate observations. Otherwise you run into the danger of mixing your current set of simulated observations with other measurements:

```
bern54@carina:~ > rm ${P}/INTRO/OBS/????0100.CZ?
bern54@carina:~ > rm ${P}/INTRO/OBS/????0100.PZ?
```

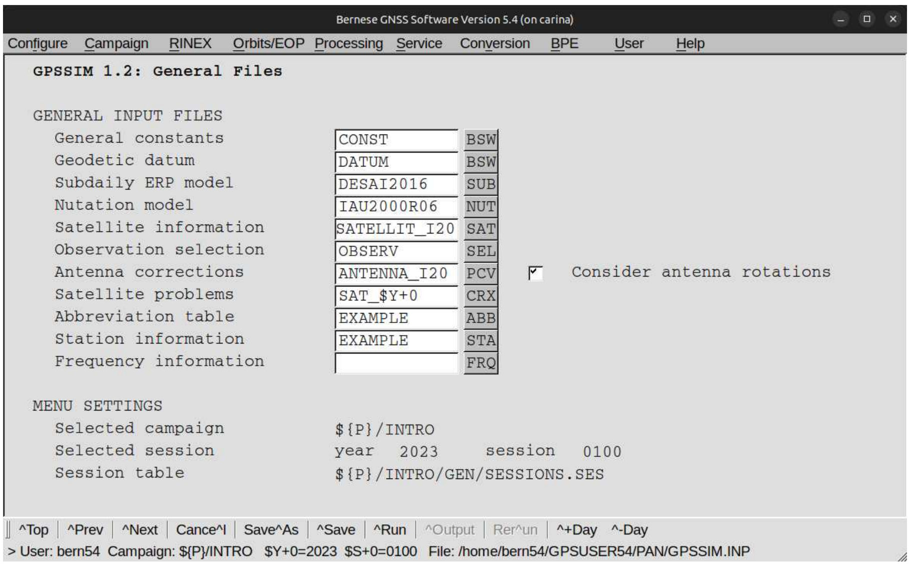
Please keep in mind that the observation files from your previous work in this campaign are lost due to this command. If you still need them, please copy them away.

The input files for the generation of synthetic GNSS observations with program GPSSIM ("Menu>Service>Generate simulated observation data") are defined in the first input panel:

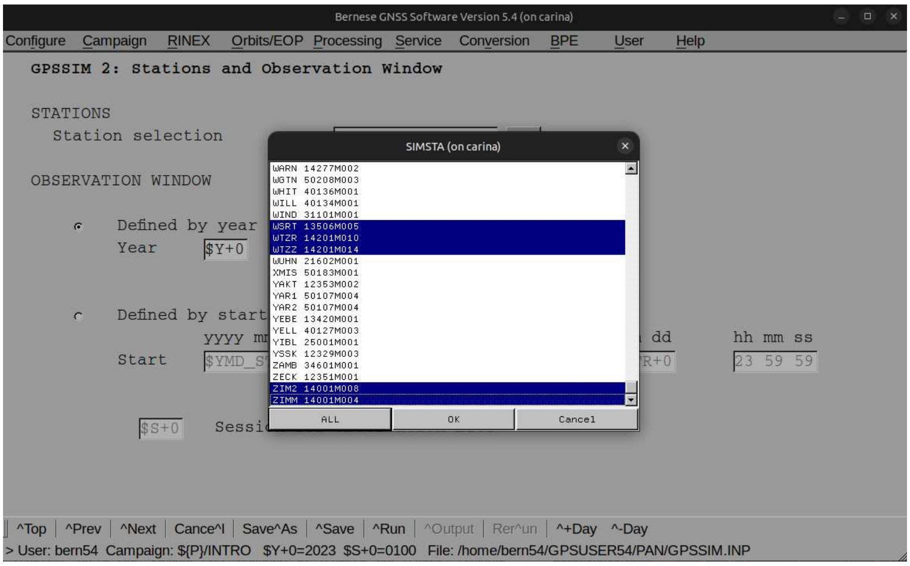




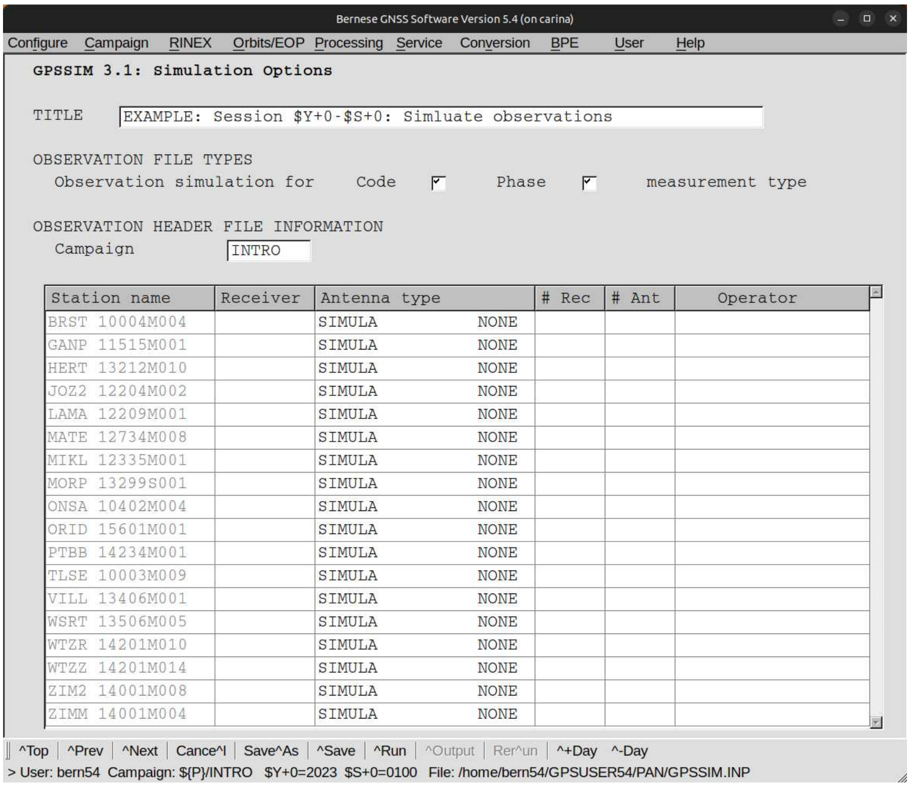
Select `EXAMPLE.ABB` in option “Abbreviation table”. Take care on the consistency for the other entries



In the next panel, the interval for data simulation is defined and the list of stations selected from all sites in the input "Coordinate file":



The meta data for each station is specified in this panel:



The "Receiver" for each station must start with SIMULA to indicate that this is a simulated station. In the input field you may only extend this string by a user input which is not done in this example. For simplicity it is also assumed that all stations are just using the same "Antenna type", namely SIMULA with radome ID NONE .

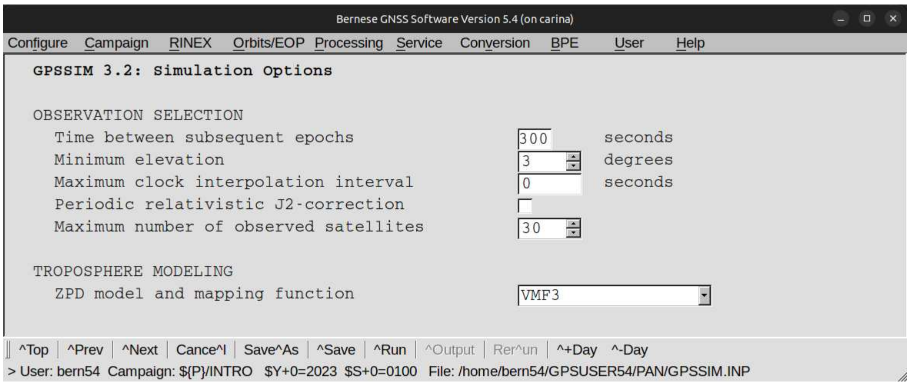
The selection of the systems for the simulation is given by the content of your standard orbit file. The signal types used for the two frequencies for each of these GNSS are given in the "Observation selection" file also defined in panel "GPSSIM 1.2: General Files":

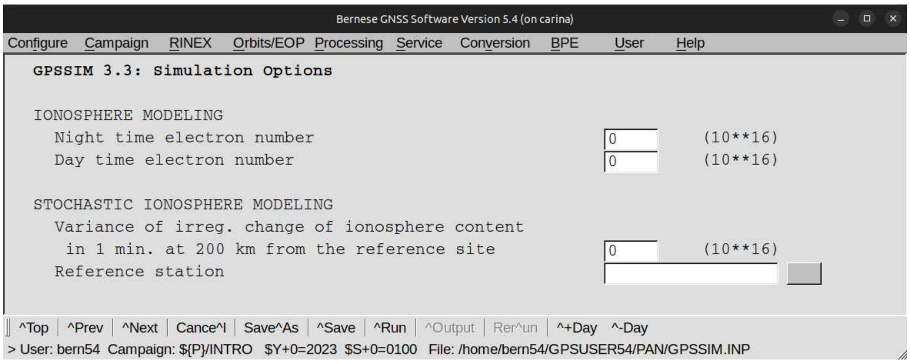
```
...

Receiver type          S/S  O/F  RINEX observation codes and their priority
********************   ***  ***  *** *** *** *** *** *** *** *** *** *** *** ***
...
SIMULA                 G    L1    1P
                       G    L2    2P
                       G    C1    1P
                       G    C2    2P
                       R    L1    1P
                       R    L2    2P
                       R    C1    1P
                       R    C2    2P
                       E    L1    1C
                       E    L2    5Q
                       E    C1    1C
                       E    C2    5Q
...
```

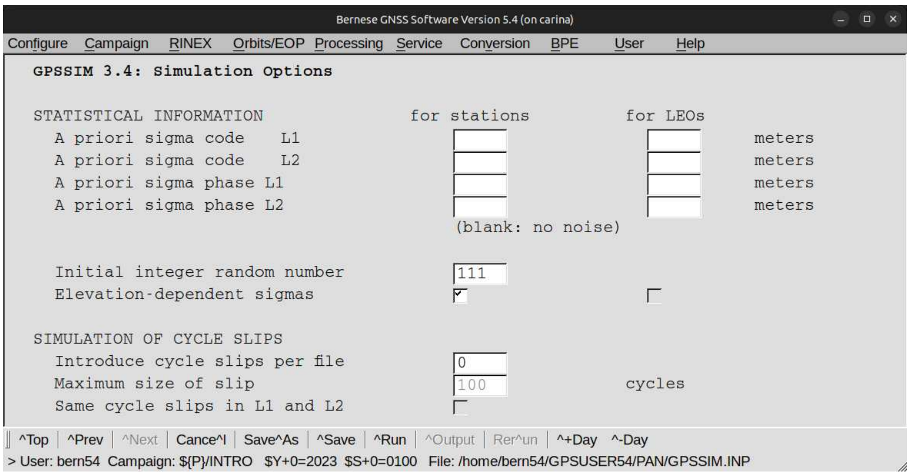
Note that each of these frequencies needs a corresponding antenna correction in the "Antenna corrections" file given in panel "GPSSIM 1.2: General Files". The simplest definition for this application is:

```
...

ANTENNA/RADOME TYPE  NUMBER SYS FRQ TYP D(O) D(Z) D(A) M(Z)  SINEX      ...
******************** ****** *    *** ***  ***  ***  ***  ***  ********** ...
SIMULA          NONE      0 G      2   0    0    0    0   90
                            R      2   0    0    0    0   90
                            E      2   0    0    0    0   90


      NORTH MM  EAST MM   UP MM   FACTOR
      *****.** *****.** *****.**  **********
G01 0     0.00     0.00     0.00   0.100E+01
G02 0     0.00     0.00     0.00   0.100E+01
R01 0     0.00     0.00     0.00   0.100E+01
R02 0     0.00     0.00     0.00   0.100E+01
E01 0     0.00     0.00     0.00   0.100E+01
E05 0     0.00     0.00     0.00   0.100E+01
...
```

In the subsequent panels some basic characteristics, assumptions on the ionospheric conditions, and the noise level are introduced. Even cycle slips may be simulated.



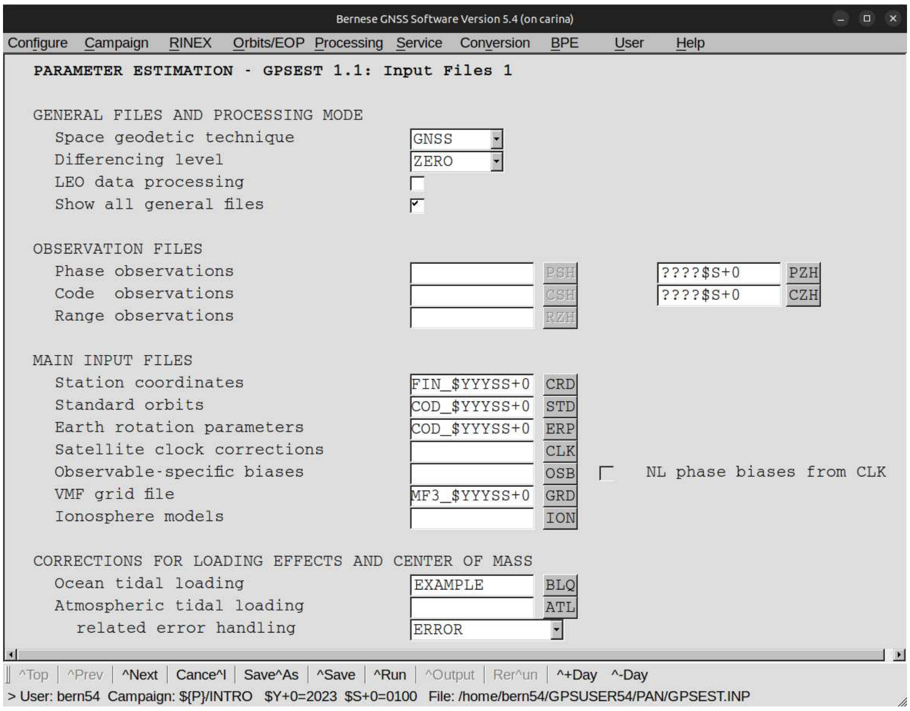


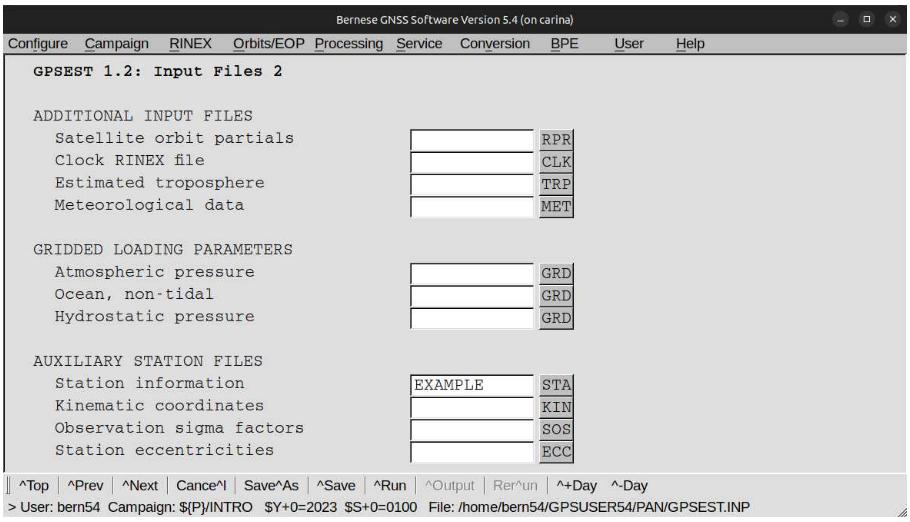


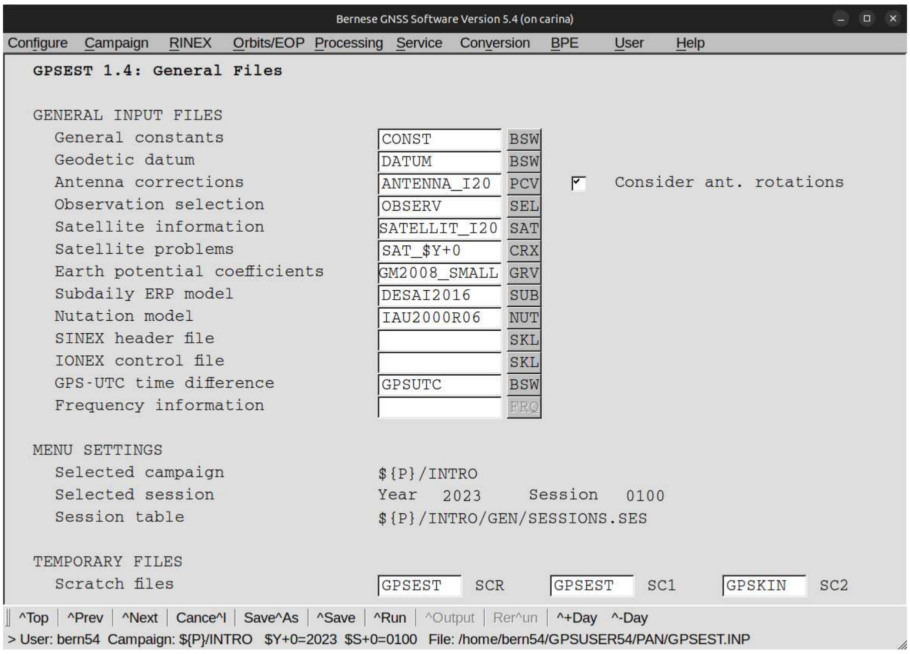
The observations are generated without noise to check the consistency with the processing program in the subsequent sections.

7.2.2 Zero Difference Solution from Simulated GNSS Observations

The simulated observations can directly be introduced in program GPSEST for an analysis on zero difference level (if you have not simulated cycle slips). Please pay attention to the consistency of all input files with respect to the simulation:

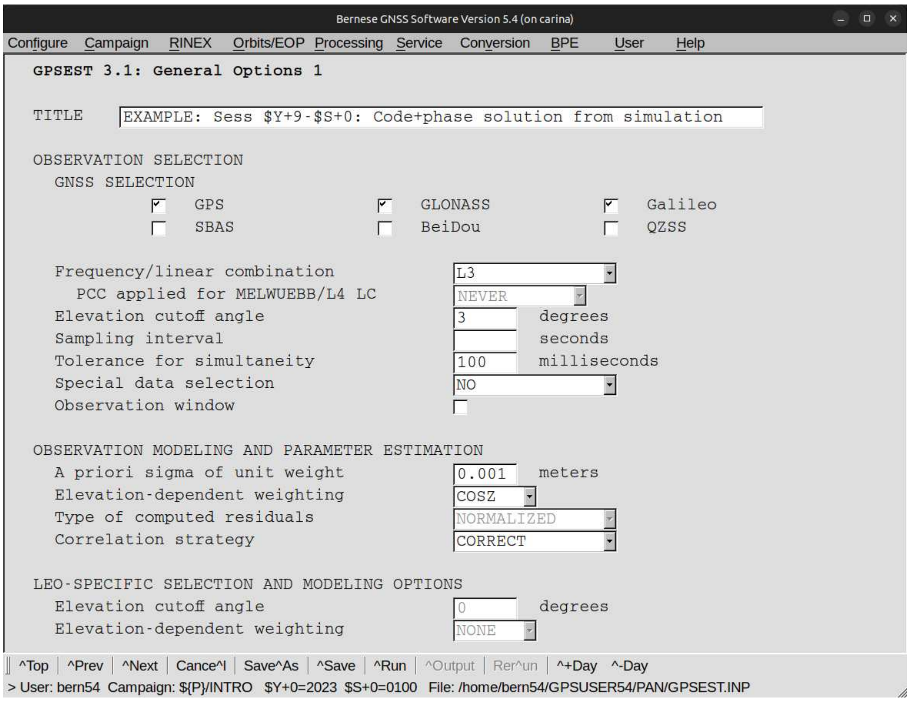


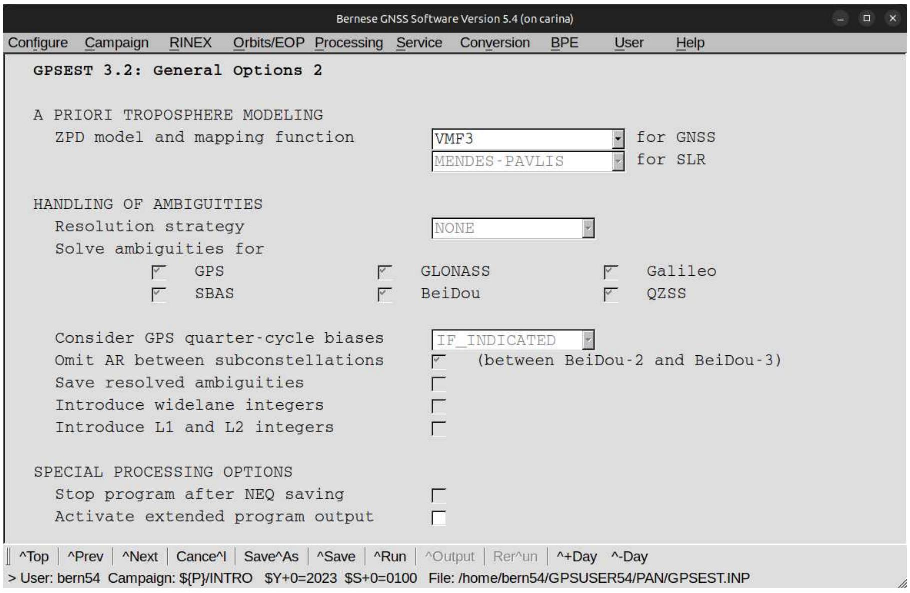




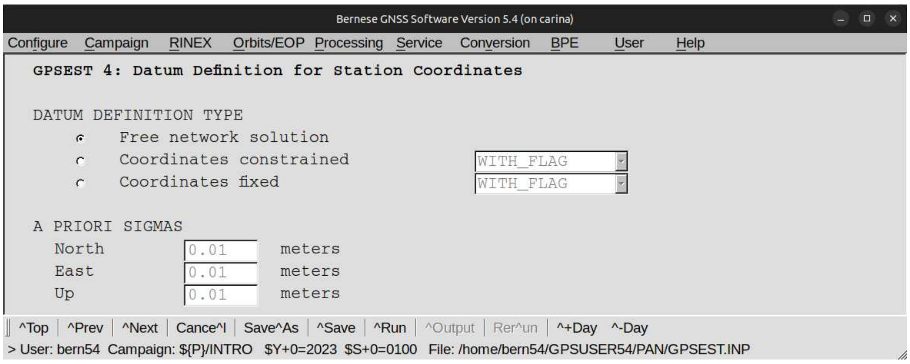
Result files can be specified to compare the results with the inputs for GPSSIM. A residual file might also be useful.

The processing models also have to be consistent with the simulation or to contain well defined differences which are the subject of your investigation:

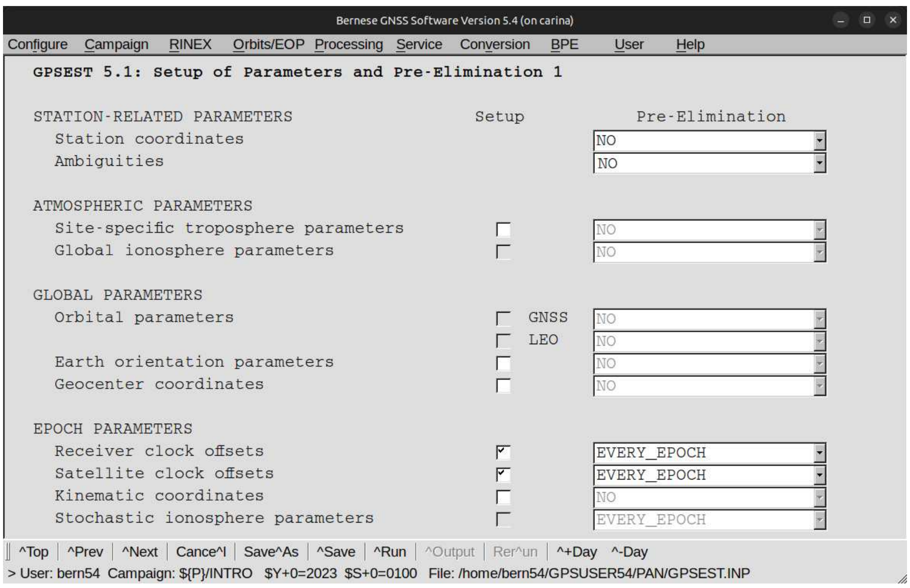


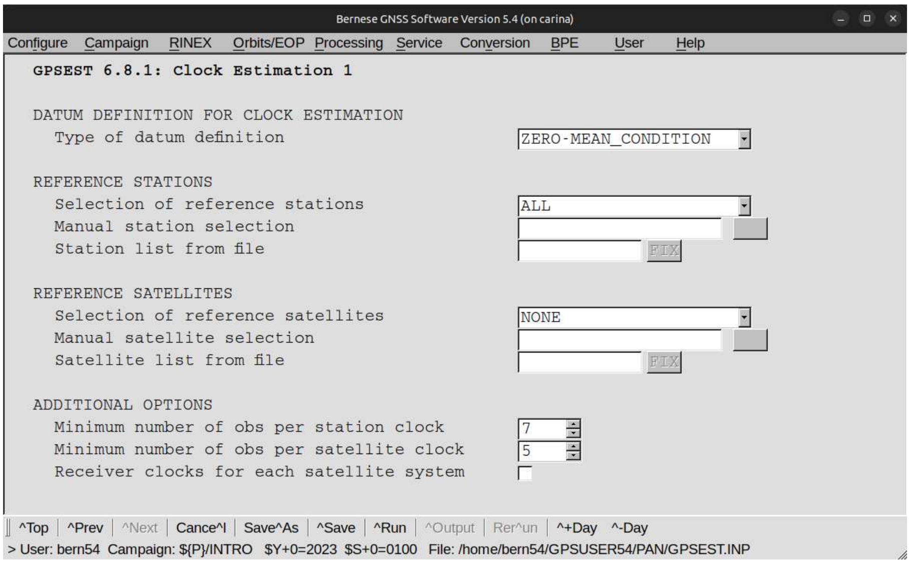


No constraints for datum definition are needed because these are noise–free simulated data:



Only the receiver and satellite clocks are estimated:





The resulting program output file looks like the usual output from GPSEST but with perfect observations without any noise:

```
...
SUMMARY OF RESULTS
------------------

Number of parameters:
--------------------

Parameter type                          Adjusted    Expl.    Impl.  (elim)*   Del.  Ref.  Sing.  No obs
--------------------------------------------------------------------------------------------------------
Station coordinates / velocities              54       54        0              0     0      0      0
Ambiguities                                 2979     2979        0              0     0      0      0
Epochwise receiver clocks                   5184        0     5184  (epow)      0     0      0      0
Epochwise satellite clocks                  9874        0     9874  (epow)      0     0      0      0
--------------------------------------------------------------------------------------------------------
Total number                               18091     3033    15058              0     0      0      0


*Abbreviation pre-elimination (elim): before stacking (bfst),  after stacking (afst),
                                      epoch-wise (epow), after inversion (afin)


Statistics:
----------

Total number of authentic observations      280282
Total number of pseudo-observations              0

Total number of explicit parameters           3033
Total number of implicit parameters          15058

Total number of observations                280282
Total number of adjusted parameters          18091
Degree of freedom (DOF)                     262191

A posteriori RMS of unit weight           0.000000 m
Chi**2/DOF                                    0.00

Total number of observation files               36
Total number of stations                        18
...
```

No improvements for the station coordinates and other parameters are expected:

```
...
Station coordinates and velocities:
----------------------------------

Sol Station name         Typ Correction  Estimated value  RMS error   A priori value ... Abb
------------------------------------------------------------------------------------ ... -----
  1 BRST 10004M004         X    -0.00000    4231162.37206    0.00000    4231162.37206 ... #CRD
  1 BRST 10004M004         Y     0.00000    -332746.35755    0.00000    -332746.35755 ... #CRD
  1 BRST 10004M004         Z    -0.00000    4745131.11033    0.00000    4745131.11033 ... #CRD
  1 GANP 11515M001         X    -0.00000    3929181.23140    0.00000    3929181.23140 ... #CRD
  1 GANP 11515M001         Y     0.00000    1455237.01665    0.00000    1455237.01665 ... #CRD
  1 GANP 11515M001         Z    -0.00000    4793654.07064    0.00000    4793654.07064 ... #CRD
  1 HERT 13212M010         X    -0.00000    4033460.69194    0.00000    4033460.69194 ... #CRD
  1 HERT 13212M010         Y     0.00000      23538.10452    0.00000      23538.10452 ... #CRD
...
```

The inter–system and inter–frequency biases have been assumed to be zero during the simulation (which is equivalent to any other constant number):

```
...
Epochwise station clocks:
------------------------

Station name      #obs   Correction  Estimated value  RMS error ... From                 Abb
---------------------------------------------------------------- ... ------------------------
BRST 10004M004      54 R    0.00000          0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
GANP 11515M001      56 R    0.00000          0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
HERT 13212M010      58 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
JOZ2 12204M002      56 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
LAMA 12209M001      56 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
MATE 12734M008      50 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
MIKL 12335M001      50 R    0.00000          0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
MORP 13299S001      60 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
ONSA 10402M004      60 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
ORID 15601M001      46 R    0.00000          0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
PTBB 14234M001      58 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
TLSE 10003M009      54 R    0.00000          0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
VILL 13406M001      54 R    0.00000          0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
WSRT 13506M005      60 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
WTZR 14201M010      54 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
WTZZ 14201M014      54 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
ZIM2 14001M008      52 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
ZIMM 14001M004      52 R   -0.00000         -0.00000    0.00000 ... 2023-01-10 00:00:00  #RCK
...
```

The same holds for the epoch–wise clocks.

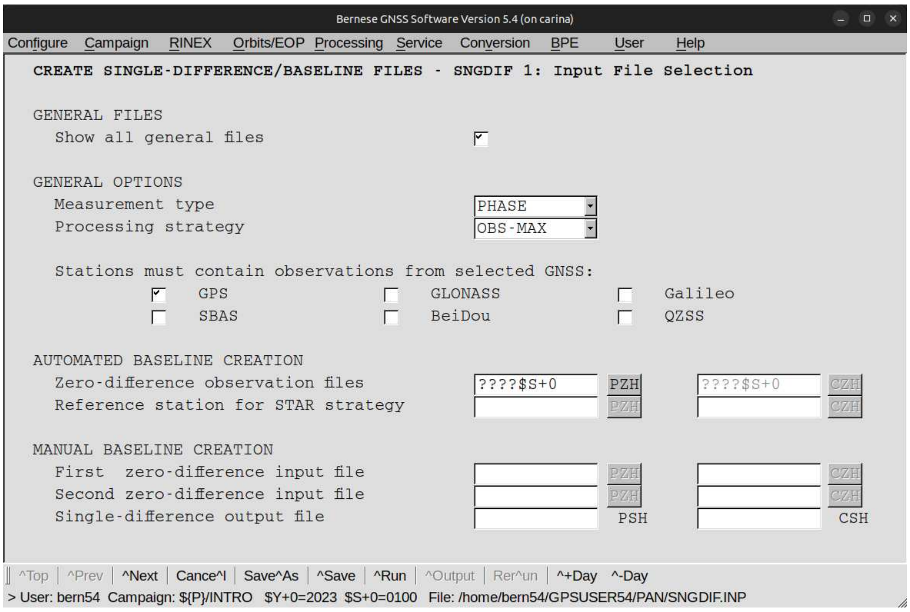
The residuals in the optional residual output file of such a dataset are well below the 1 μm level.

7.2.3 Double–Difference Solution from Simulated GNSS Observations

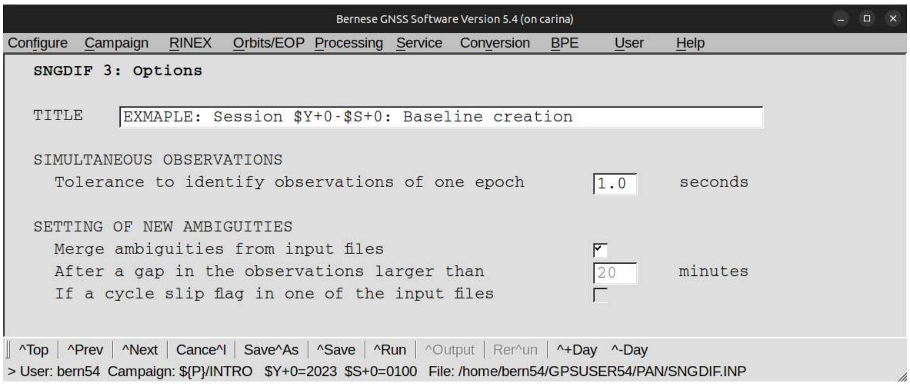
As in the beginning of the simulation, you should make sure that no other baseline observation files for the current session exist in the `OBS`-directory of your campaign to prevent any interferences and mixtures of simulated measurements with other ones.

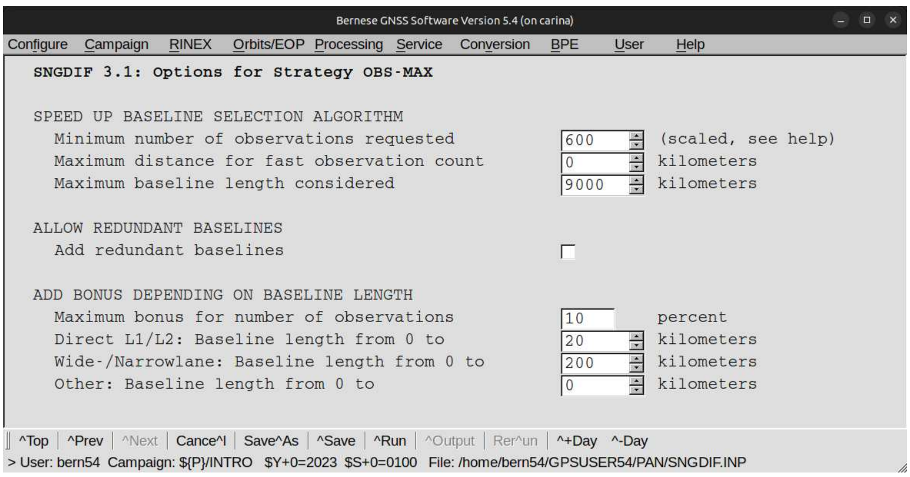
```
bern54@carina:~ > rm ${P}/INTRO/OBS/????0100.PS?
```

The simulated measurements can also be processed in the double-difference mode. In that case you have to start with forming baselines using the program SNGDIF ("Menu>Processing >Create baseline files") in nearly the same way as in Section 4.2.2 for real observations:

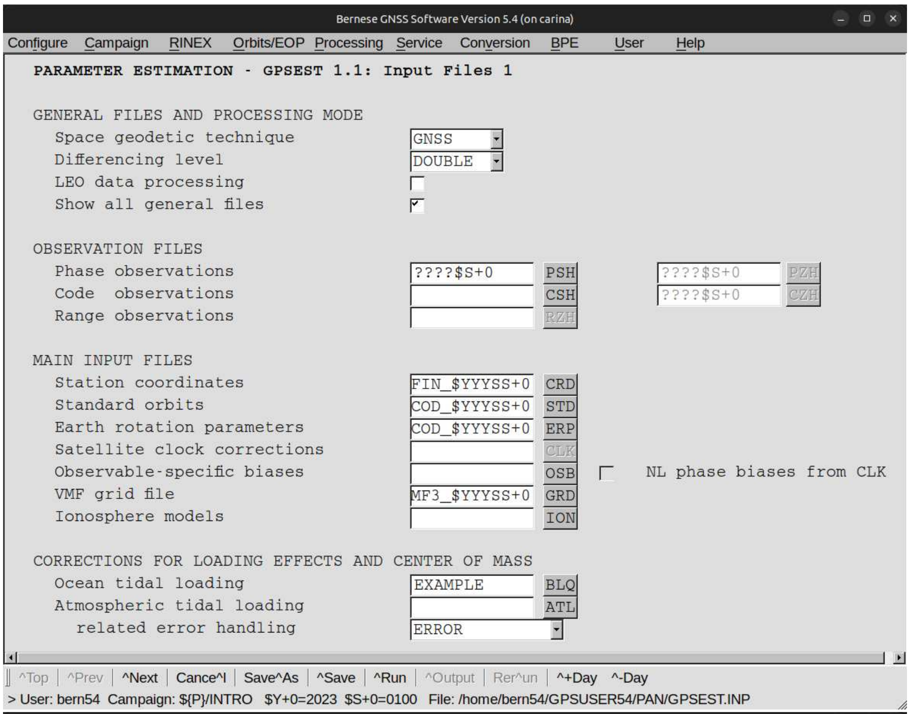


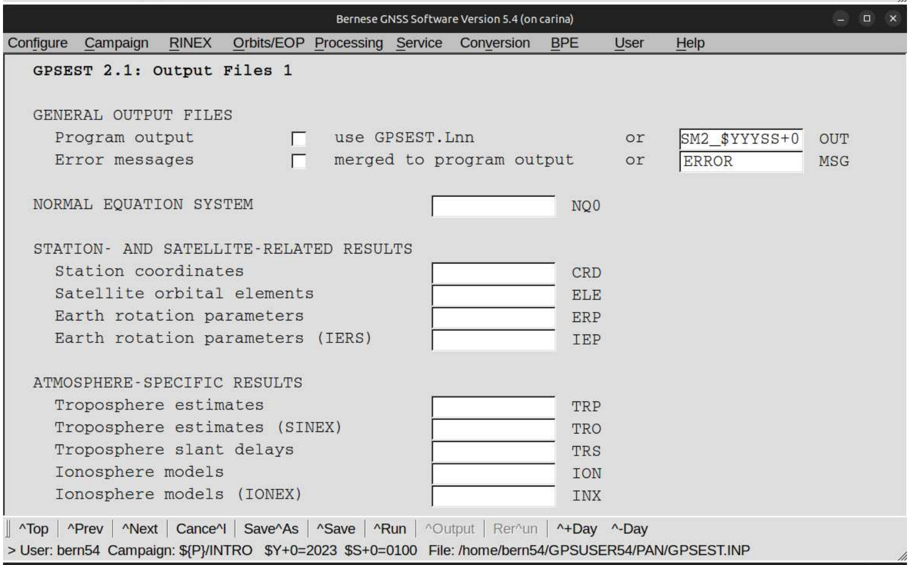
The main difference is that you should also keep all ambiguities from the zero difference in the baseline observation files, which is achieved by checking the box for option "Merge ambiguities from input files":

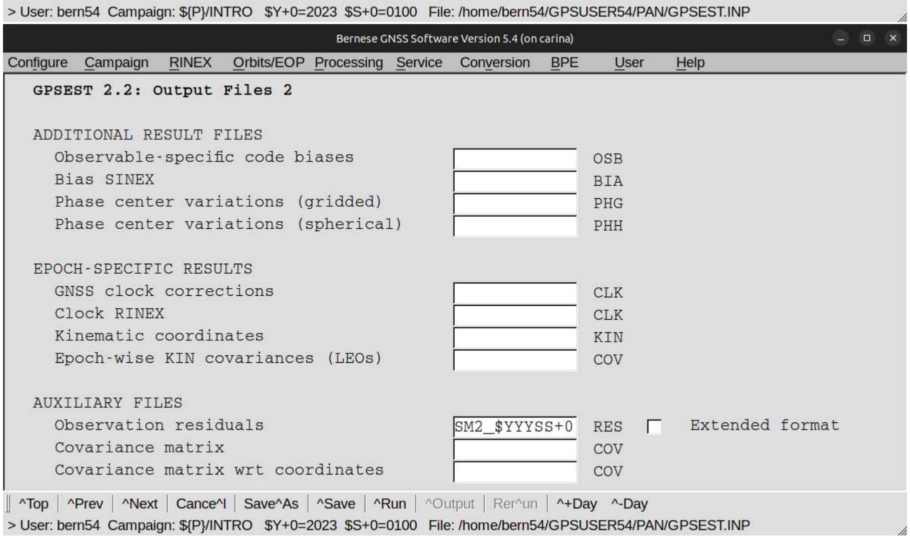




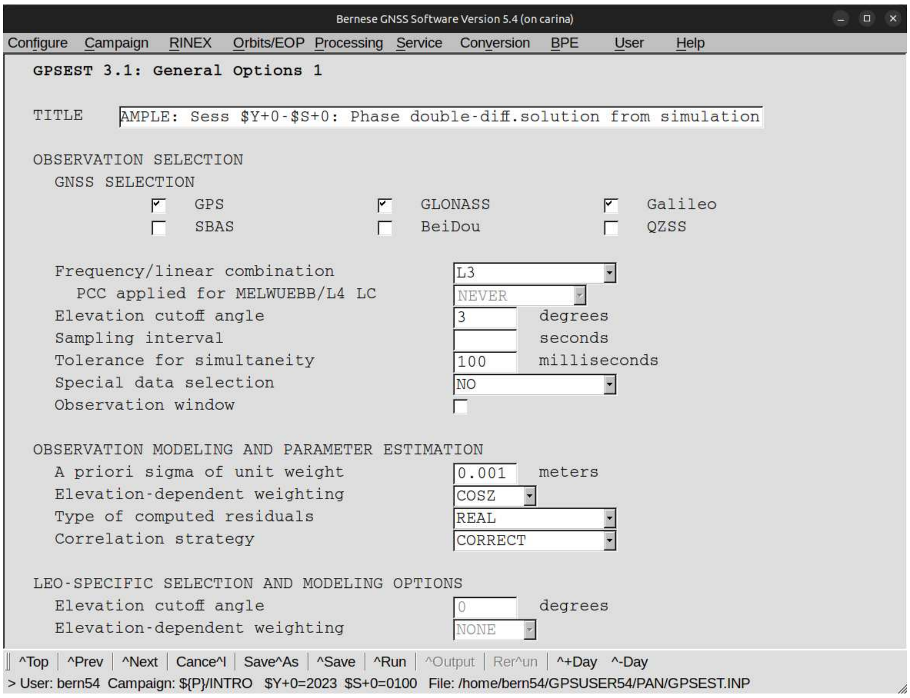
The resulting baseline files from simulated observations can now be analyzed with program GPSEST:

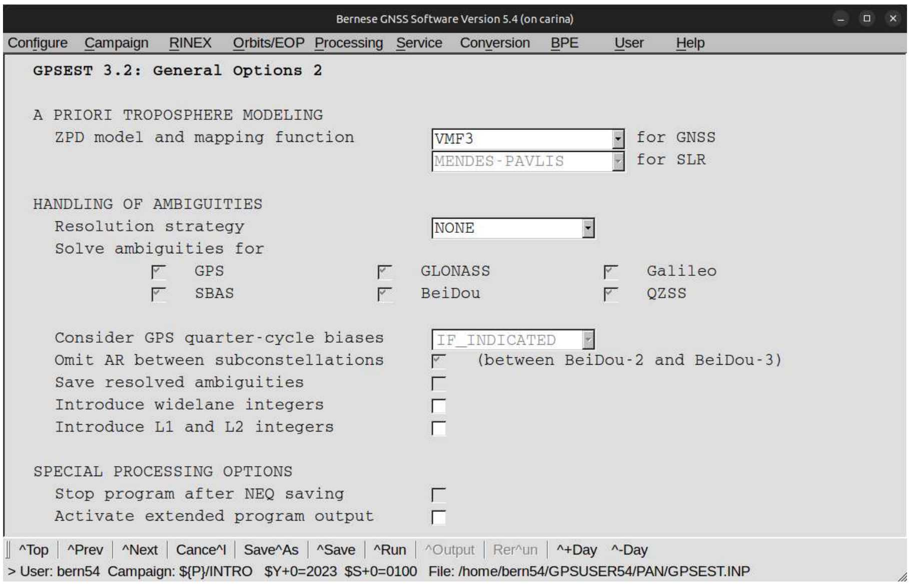




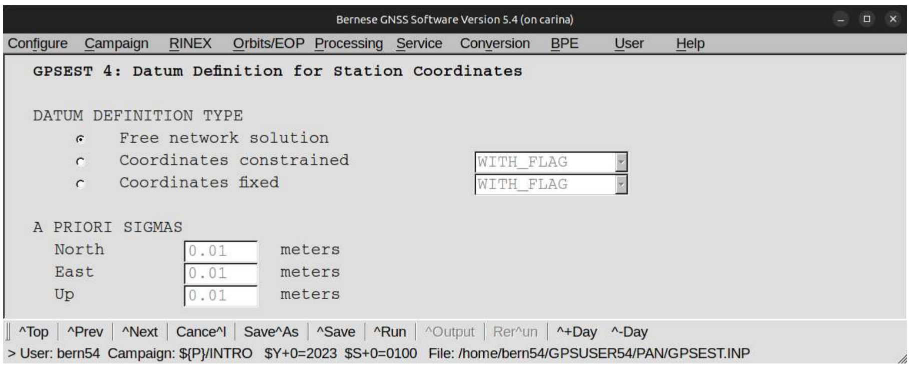


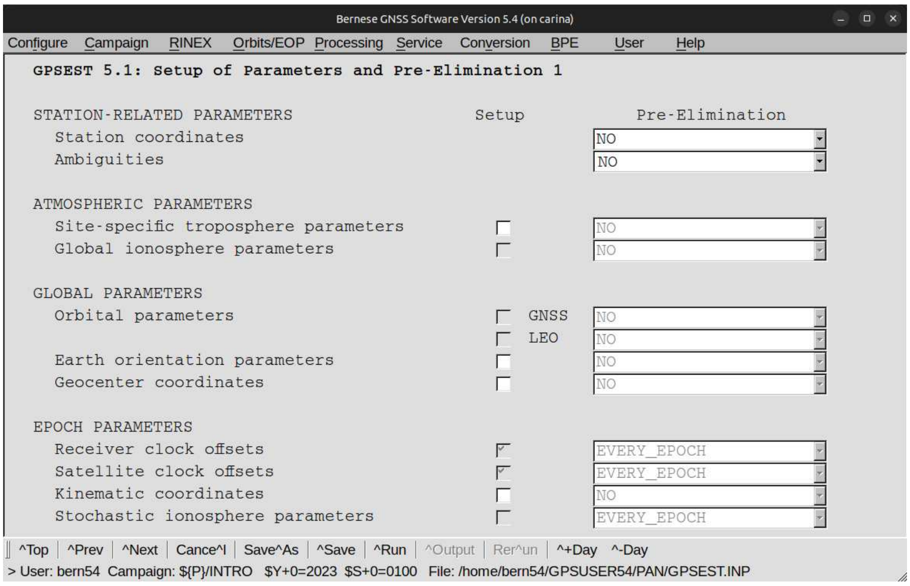
The models are selected to be fully consistent with the simulation:





No other parameters than station coordinates and ambiguities are estimated:





The results are analogue to the zero difference case previously described:

```
...
 Statistics:
----------

Total number of authentic observations      123468
Total number of pseudo-observations             17

Total number of explicit parameters           2846
Total number of implicit parameters              0

Total number of observations                123485
Total number of adjusted parameters           2846
Degree of freedom (DOF)                     120639

A posteriori RMS of unit weight           0.000000 m
Chi**2/DOF                                    0.00

Total number of observation files               17
Total number of stations                        18
...
```

The ambiguities are set up in a way that the correct resolution for all ambiguities is zero in any case. This is an easy way to verify ambiguity resolution strategies.

7.2.4 Final Remarks

There are many opportunities to use this simulation tool. It depends on your needs and the concrete target of the simulation study to define the experiment. As it was just demonstrated the full consistency between the processing and the simulation programs is guaranteed by the *Bernese GNSS Software*.

The big advantage of a simulation is that the correct solution is known a priori. On the other hand, you have to keep in mind that the simulated data can only contain effects included in the simulation model. If a receiver for instance introduces a significant variation of the inter–system bias between GPS and GLONASS data – an effect that is not considered in the simulation model – the influence of such an effect on the results cannot be evaluated by the simulation.