Bernese GNSS Software Version 5.4

Tutorial

Processing Example
Introductory Course
Terminal Session

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Contents

1 Introduction to the Example Campaign

1.1 Stations in the Example Campaign

Data from seventeen 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 six days. Two days in year 2019 (day of year 044 and 045), two in 2020 (day of year 179 and 180), and two in 2021 (days 095 and 096). The observations are distributed in a mixture of RINEX 2 and RINEX 3 formats with related short and long filenames. 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 filenaming. The observation files contain also 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
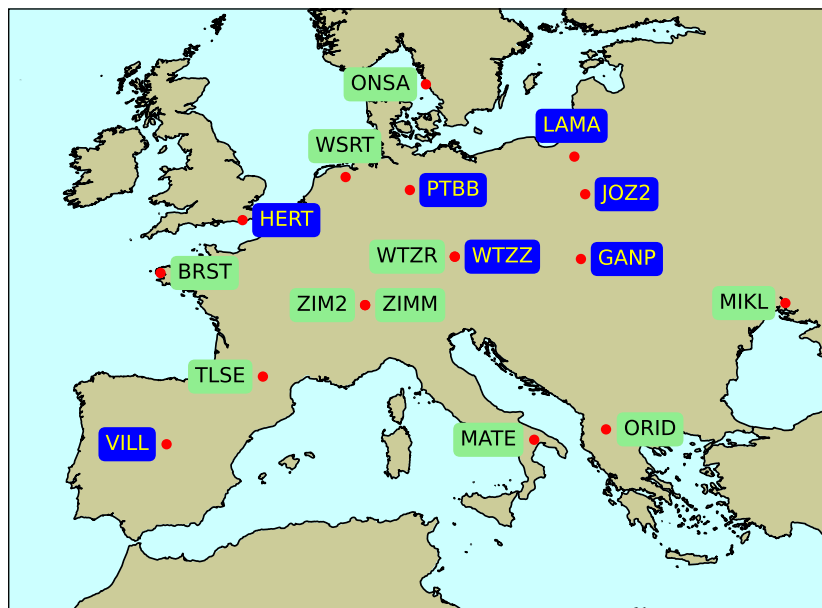
Figure 1.1: Stations used in example campaign (stations indicated by light boxes with coordinates given in the IGS 20 reference frame)

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		(GREC)
			TRM57971.00	NONE	2.0431 m
GANP00SVK 11515M001	Ganovce, Slovakia		TRIMBLE ALLOY		(GRECJI)
			TRM59800.00	SCIS	0.3830 m
HERT00GBR 13212M010	Hailsham, United Kingdom		LEICA GRX1200GGPRO		(GR)
			LEIAT504GG	NONE	0.0000 m
JOZ200POL 12204M002	Jozefoslaw, Poland	2019:	LEICA GRX1200GGPRO		(GRCJ)
			LEIAT504GG	NONE	0.0000 m
		2020/21:	TRIMBLE NETR9		(GRE)
			TRM59800.00	NONE	0.0000 m
LAMA00POL 12209M001	Olsztyn, Poland		LEICA GRX1200+GNSS		(GR)
			LEIAT504GG	LEIS	0.0600 m
MATE00ITA 12734M008	Matera, Italy		LEICA GR30		(GREC)
			LEIAR20	NONE	0.1010 m
MIKL00UKR 12335M001	Mykolaiv, Ukraine		LEICA GR10		(GRE)
			LEIAR10	NONE	0.0237 m
ONSA00SWE 10402M004	Onsala, Sweden	2019:	JAVAD TRE_G3TH DELTA		(GR)
			AOAD/M_B	OSOD	0.9950 m
		2020/21:	SEPT POLARX5TR		(GREC)
			AOAD/M_B	OSOD	0.9950 m
ORID00MKD 15601M001	Ohrid, Republic of North Macedonia	2019:	LEICA GRX1200GGPRO		(GR)
			LEIAT504GG	LEIS	0.0640 m
		2020/21:	LEICA GR30		(GREC)
			LEIAR25.R4	LEIT	0.0000 m
PTBB00DEU 14234M001	Braunschweig, Germany	2019:	ASHTECH Z-XII3T		(G)
			ASH700936E	SNOW	0.0562 m
		2020/21:	SEPT POLARX5TR		(GRECI)
			LEIAR25.R4	LEIT	0.0590 m
TLSE00FRA 10003M009	Toulouse, France		TRIMBLE NETR9		(GREC)
			TRM59800.00	NONE	1.0530 m
VILL00ESP 13406M001	Villafranca, Spain	2019:	SEPT POLARX4		(GRECI)
			SEPCHOKE_MC	NONE	0.0937 m
		2020/21:	SEPT POLARX5		(GRECI)
			SEPCHOKE_B3E6	NONE	0.0937 m
WSRT00NLD 13506M005	Westerbork, The Netherlands		SEPT POLARX5		(GRECJ)
			AOAD/M_T	DUTD	0.3888 m
WTZR00DEU 14201M010	Kötzting, Germany		LEICA GR50		(GRECI)
			LEIAR25.R3	LEIT	0.0710 m
WTZZ00DEU 14201M014	Kötzting, Germany		JAVAD TRE_3 DELTA		(GRECI)
			LEIAR25.R3	LEIT	0.2840 m
ZIM200CHE 14001M008	Zimmerwald, Switzerland		TRIMBLE NETR9		(GREC)
			TRM59800.00	NONE	0.0000 m
ZIMM00CHE 14001M004	Zimmerwald, Switzerland		TRIMBLE NETR9		(G)
			TRM29659.00	NONE	0.0000 m

In the terminal sessions you will analyze the data in order to obtain a velocity field based on products computed by Center for Orbit Determination in Europe (CODE) for the IGS repro3 campaign – the contribution to the ITRF 2020. For nine 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`). Even though the scale of the ITRF 2020 has slightly changed with respect to the repro3 series due to the combination with the other space-geodetic techniques, the orbit and Earth orientation parameters (EOP) products can be used together with the IGS 20 reference frame. For Precise Point Positioning (PPP) applications (in particular with the ambiguity resolution) this inconsistency will, however, degrade the results. A related update of the product series is under consideration.

Between the selected days in 2019 and 2020 the receiver in ONSA and the full equipment at stations JOZ2, ORID, PTBB, and VILL was changed. The receiver type, the antenna type, and the antenna height are provided in Table 1.1.

Ideally, consistent (`ROBOT`) calibrations for each GNSS that 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

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`	for GPS	`ONSA00SWE`
		`ADOPTED from GPS`	for other systems	
`AOAD/M_T`	`DUTD`	`ROBOT`	for GPS and GLO	`WSRT00NLD`
		`ADOPTED from GPS`	for other systems	
`ASH700936E`	`SNOW`	`ROBOT`	for GPS	`PTBB00DEU` (2019)
		`ADOPTED from GPS`	for other systems	
`LEIAR10`	`NONE`	`ROBOT`	for all systems	`MIKL00UKR`
`LEIAR20`	`NONE`	`ROBOT`	for all systems	`MATE00ITA`
`LEIAR25.R3`	`LEIT`	`ROBOT`	for all systems	`WTZR00DEU, WTZZ00DEU`
`LEIAR25.R4`	`LEIT`	`ROBOT`	for all systems	`ORID00MKD` (2020/21), `PTBB00DEU` (2020/21)
`LEIAT504GG`	`LEIS`	`ROBOT`	for GPS and GLO	`LAMA00POL,` `ORID00MKD` (2019)
		`ADOPTED from GPS`	for other systems	
`LEIAT504GG`	`NONE`	`ROBOT`	for all systems	`HERT00GBR,` `JOZ200POL` (2019)
`SEPCHOKE_B3E6`	`NONE`	`ROBOT`	for all systems	`VILL00ESP` (2020/21)
`SEPCHOKE_MC`	`NONE`	`ROBOT`	for GPS and GLO	`VILL00ESP` (2019)
		`ADOPTED from GPS`	for other systems	
`TRM29659.00`	`NONE`	`ROBOT`	for all systems	`ZIMM00CHE`
`TRM57971.00`	`NONE`	`ROBOT`	for all systems	`BRST00FRA`
`TRM59800.00`	`NONE`	`ROBOT`	for all systems	`JOZ200POL` (2020/21), `TLSE00FRA, ZIM200CHE`
`TRM59800.00`	`SCIS`	`ROBOT`	for all systems	`GANP00SVK`

no calibration is available. The values from the same antenna type without radome are used as a proxy.

The distances between occupied locations in the network are between 200 and 1000 km. 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, and PTBB are connected to H-Maser clocks, VILL to a Cesium clock. In 2020 and 2021 both receivers in Kötzting (WTZR and WTZZ) were connected to the same H–Maser (EFOS 18); in 2019 WTZZ is running on the internal receiver clock only.

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) format. The directory may contain observation (Hatanaka-compressed) and navigation files. The files in this area may even 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, 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, currently containing GPS and GLONASS.
>
> `COR` – CODE operational rapid solution, containing GPS, GLONASS and Galileo.
>
> `CODORO3FIN` – CODE contribution to IGS repro3, containing GPS, GLONASS, Galileo.
>
> `CODOMGXFIN` – CODE experimental Multi-GNSS Extension (MGEX) solution, containing GPS, GLONASS, Galileo, BeiDou, and QZSS.
>
> `IGS` – combined IGS products from the final series, containing only GPS. GLONASS may be added from separate files (named `IGL`)
>
> 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.

The IGS provides GPS and GLONASS orbits only in separate files (`IGS`/`IGL`-series from the final product line) stemming from independent combination procedures with different contributing analysis centers. Nevertheless, they are consistent enough to merge both files together as the first step of the processing. CODE as well as other analysis centers of the IGS (e.g., ESA or GFZ) contribute fully combined multi-GNSS solutions to the IGS final (and ultra-rapid) product line. The contributions of these groups are already combined GPS/GLONASS orbit 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. They are not used for the examples but it shall indicate that for other types of files other directories may be created.

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 17 stations selected for the example campaign are already in this `DATAPOOL`–area (`${D}`) after installing the *Bernese GNSS Software*. GNSS orbit information is available from CODE (legacy, rapid and MGEX) and IGS (directories `${D}/COD`, `${D}/COR`, `${D}/CODOMGXFIN` or `${D}/IGS`, 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_20190440.ION        HOI_20190450.ION        HOI_20201790.ION
                    HOI_20201800.ION        HOI_20210950.ION        HOI_20210960.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_20190440.GRD       VMF3_20190450.GRD       VMF3_20201790.GRD
                    VMF3_20201800.GRD       VMF3_20210950.GRD       VMF3_20210960.GRD

${P}/INTRO/OBS/

${P}/INTRO/ORB/     COD_20190440.PRE        COD_20190440.IEP
                    COD_20190450.PRE        COD_20190450.IEP
                    COD_20201790.PRE        COD_20201790.IEP        COD_20201790.BIA
                    COD_20201800.PRE        COD_20201800.IEP        COD_20201800.BIA
                    COD_20210950.PRE        COD_20210950.IEP        COD_20210950.BIA
                    COD_20210960.PRE        COD_20210960.IEP        COD_20210960.BIA
                    IGS_20190440.PRE        IGS_20190450.PRE        IGS_20201790.PRE
                    IGS_20201800.PRE        IGS_20210950.PRE        IGS_20210960.PRE
                    IGS_20190440.IEP        IGS_20190450.IEP        IGS_20201790.IEP
                    IGS_20201800.IEP        IGS_20210950.IEP        IGS_20210960.IEP
                    IGL_20190440.PRE        IGL_20190450.PRE        IGL_20201790.PRE
                    IGL_20201800.PRE        IGL_20210950.PRE        IGL_20210960.PRE
                    BIA_20190440.OSB        BIA_20190450.OSB        BIA_20201790.OSB
                    BIA_20201800.OSB        BIA_20210950.OSB        BIA_20210960.OSB

${P}/INTRO/ORX/

${P}/INTRO/OUT/     COD_20190440.CLK        COD_20190450.CLK        COD_20201790.CLK
                    COD_20201800.CLK        COD_20210950.CLK        COD_20210960.CLK
                    IGS_20190440.CLK        IGS_20190450.CLK        IGS_20201790.CLK
                    IGS_20201800.CLK        IGS_20210950.CLK        IGS_20210960.CLK


${P}/INTRO/RAW/     BRST00FRA_20190440.RXO  BRST00FRA_20190450.RXO  BRST00FRA_20201790.RXO
                    BRST00FRA_20201800.RXO  BRST00FRA_20210950.RXO  BRST00FRA_20210960.RXO
                    GANP00SVK_20190440.RXO  GANP00SVK_20190450.RXO  GANP00SVK_20201790.RXO
                    GANP00SVK_20201800.RXO  GANP00SVK_20210950.RXO  GANP00SVK_20210960.RXO
                    HERT00XYZ_20190440.RXO  HERT00XYZ_20190450.RXO  HERT00XYZ_20201790.RXO
                    HERT00XYZ_20201800.RXO  HERT00XYZ_20210950.RXO  HERT00XYZ_20210960.RXO
                    JOZ200XYZ_20190440.RXO  JOZ200XYZ_20190450.RXO  JOZ200POL_20201790.RXO
                    JOZ200POL_20201800.RXO  JOZ200POL_20210950.RXO  JOZ200POL_20210960.RXO
                    LAMA00XYZ_20190440.RXO  LAMA00XYZ_20190450.RXO  LAMA00XYZ_20201790.RXO
                    LAMA00XYZ_20201800.RXO  LAMA00XYZ_20210950.RXO  LAMA00XYZ_20210960.RXO
                    MATE00ITA_20190440.RXO  MATE00ITA_20190450.RXO  MATE00ITA_20201790.RXO
                    MATE00ITA_20201800.RXO  MATE00ITA_20210950.RXO  MATE00ITA_20210960.RXO
                    MIKL00UKR_20190440.RXO  MIKL00UKR_20190450.RXO  MIKL00UKR_20201790.RXO
                    MIKL00UKR_20201800.RXO  MIKL00UKR_20210950.RXO  MIKL00UKR_20210960.RXO
                    ONSA00XYZ_20190440.RXO  ONSA00XYZ_20190450.RXO  ONSA00SWE_20201790.RXO
                    ONSA00SWE_20201800.RXO  ONSA00SWE_20210950.RXO  ONSA00SWE_20210960.RXO
                    ORID00XYZ_20190440.RXO  ORID00XYZ_20190450.RXO  ORID00MKD_20201790.RXO
                    ORID00MKD_20201800.RXO  ORID00MKD_20210950.RXO  ORID00MKD_20210960.RXO
                    PTBB00XYZ_20190440.RXO  PTBB00XYZ_20190450.RXO  PTBB00DEU_20201790.RXO
                    PTBB00DEU_20201800.RXO  PTBB00DEU_20210950.RXO  PTBB00DEU_20210960.RXO
                    TLSE00FRA_20190440.RXO  TLSE00FRA_20190450.RXO  TLSE00FRA_20201790.RXO
                    TLSE00FRA_20201800.RXO  TLSE00FRA_20210950.RXO  TLSE00FRA_20210960.RXO
                    VILL00ESP_20190440.RXO  VILL00ESP_20190450.RXO  VILL00ESP_20201790.RXO
                    VILL00ESP_20201800.RXO  VILL00ESP_20210950.RXO  VILL00ESP_20210960.RXO
                    WSRT00NLD_20190440.RXO  WSRT00NLD_20190450.RXO  WSRT00NLD_20201790.RXO
                    WSRT00NLD_20201800.RXO  WSRT00NLD_20210950.RXO  WSRT00NLD_20210960.RXO
```

---

[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`.

```
                        WTZR00DEU_20190440.RXO    WTZR00DEU_20190450.RXO    WTZR00DEU_20201790.RXO
                        WTZR00DEU_20201800.RXO
                        WTZZ00DEU_20190440.RXO    WTZZ00DEU_20190450.RXO    WTZZ00DEU_20201790.RXO
                        WTZZ00DEU_20201800.RXO    WTZZ00DEU_20210950.RXO    WTZZ00DEU_20210960.RXO
                        ZIM200CHE_20190440.RXO    ZIM200CHE_20190450.RXO    ZIM200CHE_20201790.RXO
                        ZIM200CHE_20201800.RXO    ZIM200CHE_20210950.RXO    ZIM200CHE_20210960.RXO
                        ZIMM00CHE_20190440.RXO    ZIMM00CHE_20190450.RXO    ZIMM00CHE_20201790.RXO
                        ZIMM00CHE_20201800.RXO    ZIMM00CHE_20210950.RXO    ZIMM00CHE_20210960.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
                        IGB20_R.CRD          IGB20_R.VEL          IGB20.PSD
                        IGB20.FIX            IGB20.SIG
```

The directories `${P}/INTRO/MODEL/` and `${P}/INTRO/CONFIG/` contains 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 `${MDOEL}`- and `${CONFIG}`-directory to prevent potential interferences with your colleagues.

```
${P}/INTRO/MDOEL/   CONST.BSW            EGM2008_SMALL.GRV    IAU2000R06.NUT       IERS2010XY.SUB
                     OT_FES2004.TID       s1_s2_def_ce.dat     TIDE2000.TPO

${P}/INTRO/CONFIG/  BOXWING.MAC          DATUM.BSW            GPSUTC.BSW           POLOFF.POL
                     SAT_2019.CRX         SAT_2020.CRX         SAT_2021.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`	for PPP example
`SINEX.RNX2SNX`	for RNX2SNX example
`SINEX.IONDET`	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`	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 potentially 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. They do not contain orbits for the GLONASS satellites. The combined GLONASS satellite orbits from the IGS are available in `IGL`–files. Both precise orbit files need to be merged for a multi–GNSS analysis. The corresponding EOP are given in weekly 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 PPP using the example BPE (`PPP.PCF`) for day 044 of year 2019 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` .

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	—
`IERS2010XY.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

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`.

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`, `RNS2SNX`, `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 statusbar 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=2019, $S+0=0440). 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.

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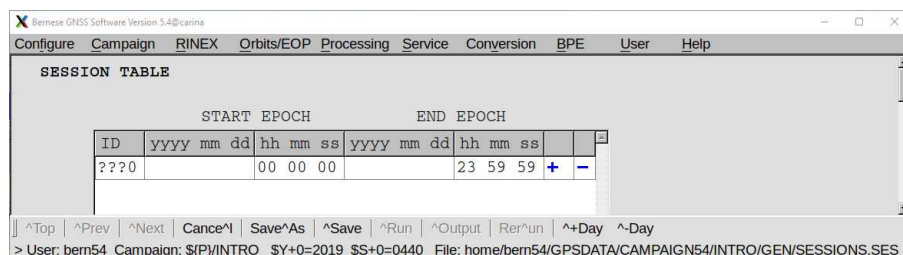
[1]At the exercise terminals the Bernese environment is loaded automatically during login. At home you have to source the file `${C}/LOADGPS.setvar` on UNIX–platforms either manually or during login.

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:

```
Date Selection Dialog@carina                              ×

   Year Month Day (YYYY MM DD)    2019 2 13       [      ]

   Modified Julian Date           58527          [      ]

   GPS Week, Day of Week (WWWW D) 2040 3          [      ]

   Year, Day of Year (YYYY DDD)   2019 44         [      ]

       [  +1  ]     [  -1  ]    [ Today ]   [ Compute ]

   Session Char                   0

   Session Table                  SESSIONS        [ SES ]

   Job ID                         [          ]

       [ Help ]    [ Set ]    [ Cancel ]    [ OK ]
```
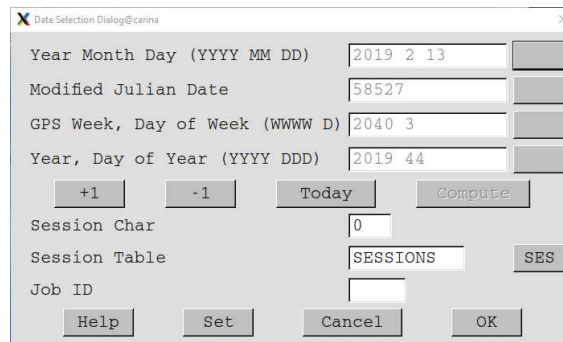
2.3 Campaign Setup

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*).
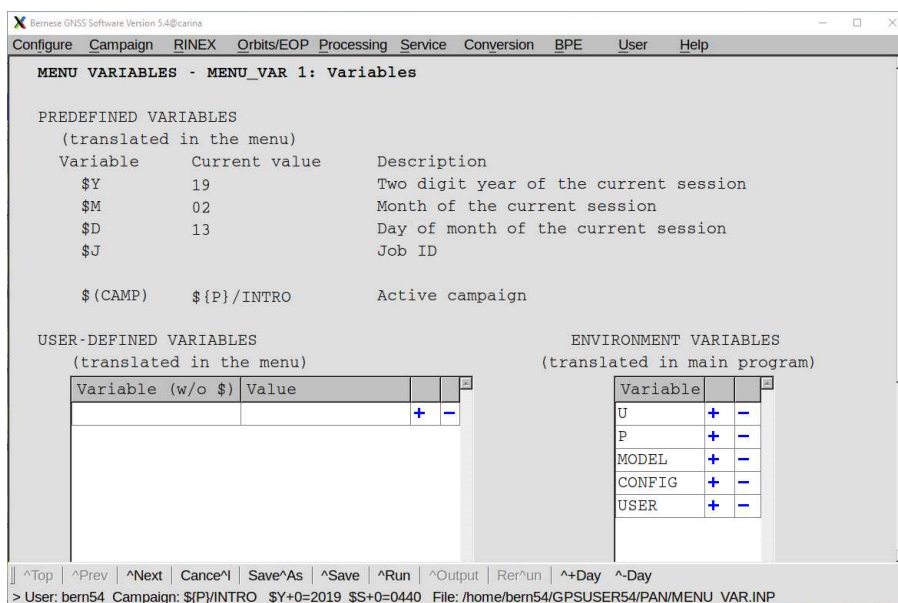
2.4 Menu Variables

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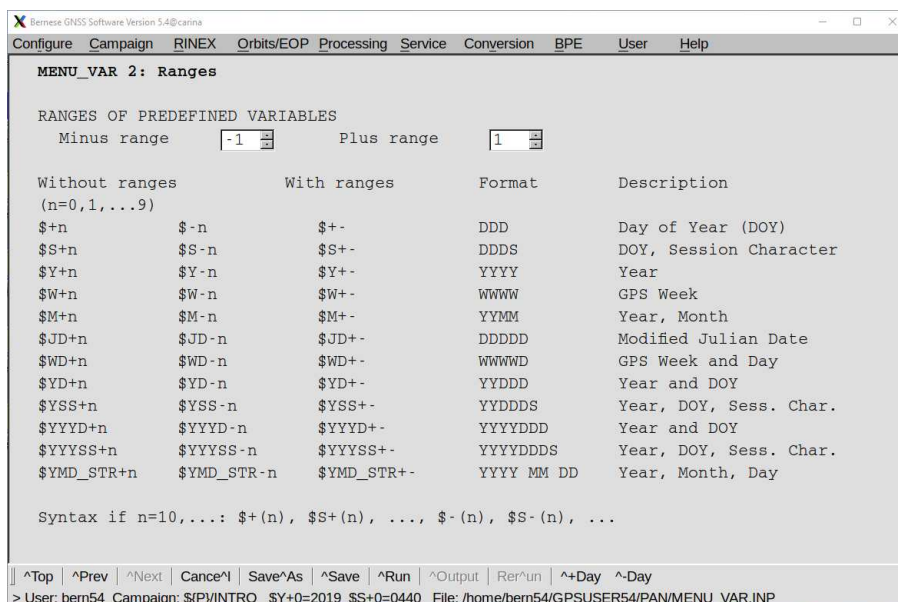
Be aware that the variable `$S+1` refers to the next *session*. Because we are using a session table for daily processing it also corresponds to the next day.

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":

```
X  Bernese GNSS Software Version 5.4@carina                                    —   □   ×

Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

    EXTRAPOLATE COORDINATES - COOVEL 1: Filenames

    GENERAL FILES
        Show all general files              ☑

    INPUT FILES
        Input coordinate file              EXAMPLE      CRD
        Input velocity file                EXAMPLE      VEL
        PSD correction (since ITRF14)      IGS20        PSD
        Annual/semiannual corrections                   TVC

    REFERENCE EPOCH                        yyyy mm dd       hh mm ss
                                           $YMD_STR+0       00 00 00

    RESULT FILE
        Output coordinate file             APR_$YYYSS+0    CRD
        Approx. velocities at ref. epoch                   VEL
        Stations without PSD corrections                   FIX

    GENERAL OUTPUT FILES
        Program output        ☑   use COOVEL.Lnn      or    COOVEL      OUT
        Error messages        ☐   merged to program output  or  ERROR   MSG

    TITLE     EXAMPLE: Session $Y+0-$S+0: Coordinate propagation

 ‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/COOVEL.INP
```

"Reference epoch: date"	$YMD_STR+0	→ 2019 02 13
"Output coordinate file"	APR_$YYYSS+0	→ APR_20190440
"Title line"	Session $Y+0-$S+0:	→ Session 2019-0440:

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: 0440 year 2019
Date         : 13-Jan-2024 15:36:36
User name    : bern54
================================================================================
```

```
EXAMPLE: Session 2019-0440: 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_20190440.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:     -4.1177275838466807



 ----------------------------------------------------------------
 >>> CPU/Real time for pgm "COOVEL": 0:00:00.134 / 0:00:00.134
 >>> 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_20190440.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 2019-0440: Coordinate propagation
-------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20               EPOCH: 2019-02-13 00:00:00

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

 43   BRST 10004M004    4231162.41765  -332746.42891  4745131.06968    IGS20
104   GANP 11515M001    3929181.30600  1455236.94546  4793653.99294    PPP
122   HERT 13212M010    4033460.75197    23538.05244  4924318.34740    PPP
143   JOZ2 12204M002    3664880.34767  1409190.82194  5009618.55508    PPP
166   LAMA 12209M001    3524522.69472  1329693.85317  5129846.42860    PPP
184   MATE 12734M008    4641949.29729  1393045.69364  4133287.66716    IGS20
198   MIKL 12335M001    3698553.70970  2308676.23252  4639769.62655    IGS20
235   ONSA 10402M004    3370658.33932   711877.34331  5349787.09062    IGS20
236   ORID 15601M001    4498451.47983  1708267.26377  4173591.98565    IGS20
264   PTBB 14234M001    3844059.76112   709661.55883  5023129.64494    PPP
329   TLSE 10003M009    4627851.66234   119640.28843  4372993.71461    IGS20
359   VILL 13406M001    4849833.60409  -335048.75055  4116015.05395    PPP
369   WSRT 13506M005    3828735.65242   443305.18368  5064884.85551    IGS20
370   WTZR 14201M010    4075580.32457   931854.03929  4801568.27077    IGS20
371   WTZZ 14201M014    4075579.21251   931853.36368  4801569.13639    PPP
383   ZIM2 14001M008    4331299.68387   567537.57591  4633133.88020    IGS20
385   ZIMM 14001M004    4331296.87301   567556.13266  4633134.09986    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.
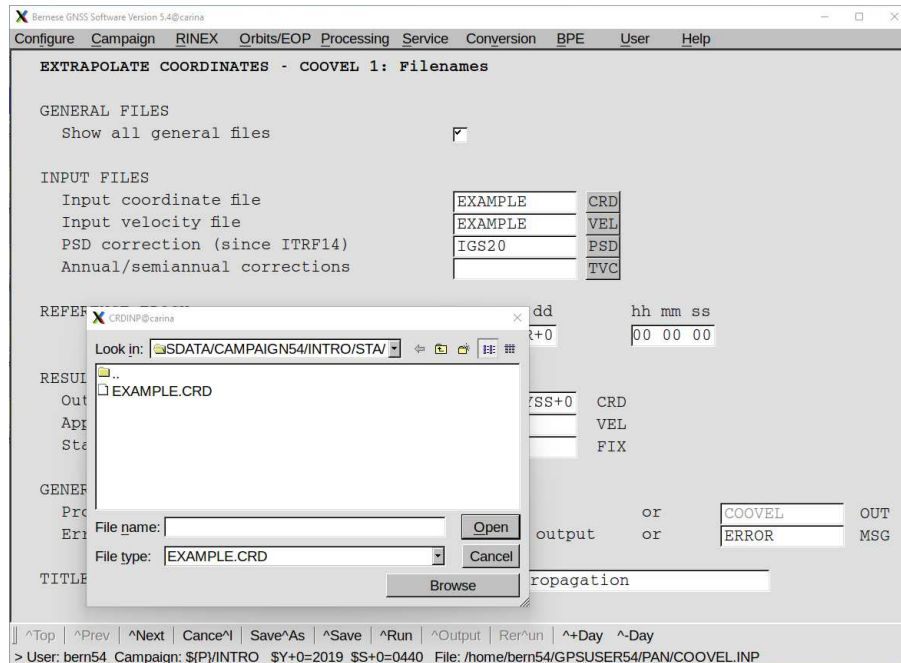
Here you can see the `LOCAL GEODETIC DATUM:` is set to `IGS20_0`. This difference is the indicator whether the PSD corrections have been applied or not. Coordinate files indicating that the PSD corrections have not been applied cannot be used for processing GNSS data. At the same time it is protecting 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 (044, year 2019) of the example dataset during the terminal sessions, you will need prepared coordinate files for all days later on Thursday. That's why, this step should be executed for all six days: 044 and 045 of year 2019, 179 and 180 of year 2020 as well as 095 and 096 of year 2021.

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 six sessions* `APR_20190440.CRD`, `APR_20190450.CRD`, `APR_20201790.CRD`, `APR_20201800.CRD`, `APR_20210950.CRD`, *and* `APR_20210960.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 or reprocessed products from CODE because they contain consistent orbits for GPS, GLONASS, and Galileo (at least the reprocessing series). Alternatively, the CODE rapid series contains the orbits from all 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.

You may alternatively use the products from the IGS. Separate product files for GPS and GLONASS orbits (no combination of Galileo products is executed so far) exist from independent combination procedures that first need to be merged for a multi-GNSS processing. For most of the applications, merging the precise orbit files is sufficient — a tutorial on the procedure is given in Section 7.1 of this book. On the other hand, the consistency of the orbits can not be as good as that of CODE (or other analysis centers) following the strategy of the rigorous combined processing of GPS and GLONASS measurements for orbit determination.

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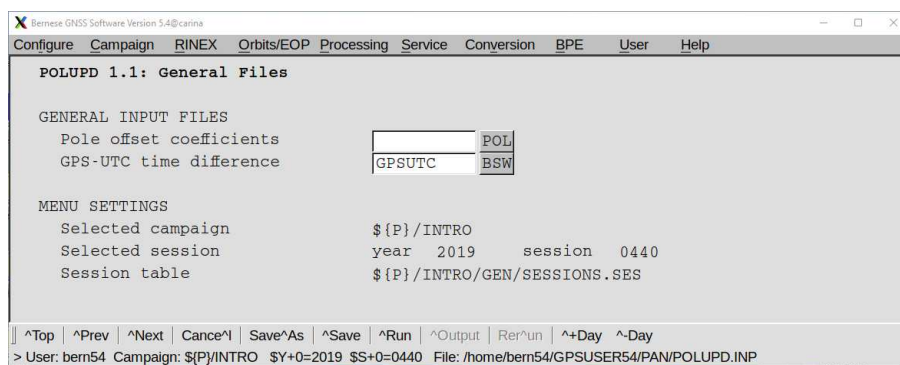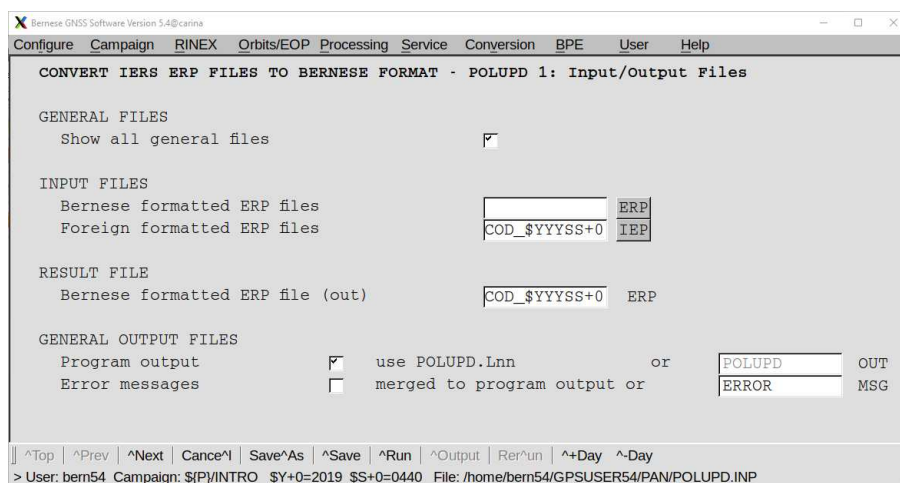
Together with the nutation and subdaily pole model also the meanpole model is specified in this panel. They are reported in the resulting Bernese formatted pole file in order to check the consistent use.

Take care on the option "Meanpole model". It has to be chosen consistently to the EOPs to be converted. The reprocessing series generated in preparation of ITRF 2020 use IERS2010_v1.2.0. As soon as the ITRF 2020 respective the IGS 20 will be introduced in the operational processing of the IGS this "Meanpole model" has to be used also for the operational products. 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).

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 reprocessing series – used during this exercise session – at Orbit midnight. For the operational final series from CODE this strategy is applied 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".

```
X Bernese GNSS Software Version 5.4@carina                              —  □  ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

   ORBGEN 5: Stochastic Pulses and Satellite Accuracy Codes

   STOCHASTIC PULSES IN (L3, L2, L1)-DIRECTIONS
      Set up based on                          Orbit_midnight      ▼
      List of satellites
      Parameter spacing                        12 00 00   (hh mm ss)

      Orbital elements file                                         ELE
         (only used to provide epochs of stochastic pulses)


   SATELLITE OPTIONS
      Exclude satellites with maneuvers           □
      Use accuracy codes from SP3-file            ☑
      Exclude sat. with accuracy code 0           ☑
      Exclude sat. with acc. code exceeding     99 ▪

‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/ORBGEN.INP
```

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).

```
X Bernese GNSS Software Version 5.4@carina                              —  □  ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

   ORBGEN 6: Orbital Arc Definition

   ORBITAL ARC DEFINITION
      Number of arcs within the time window          1

      Time window to be covered by the standard orbits

         ⦿   Defined by Year and Session identifier
             Year     $Y+0      Session      $S+0


         ○   Defined by Start and End times
                      yyyy mm dd      hh mm ss              yyyy mm dd     hh mm ss
             Start    $YMD_STR+0      00 00 00     End      $YMD_STR+0     23 59 59




‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/ORBGEN.INP
```

The program produces an output file ORB_2019044.OUT which should look like

```
...
*******************************************************************************
COMPUTATION OF BERNESE STANDARD ORBITS FROM PRECISE ORBITS     13-JAN-24 15:42
*******************************************************************************
...

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

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

   1   ${P}/INTRO/ORB/COD_20190440.PRE   ${P}/INTRO/ORB/COD_20190440.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   28   29   30
 EMP: ECOM2                  31   32  101  102  103  104  105  107  108  109
 EMP: ECOM2                 110  111  113  114  115  116  117  118  119  120
 EMP: ECOM2                 121  122  123  124  126  201  202  203  204  205
 EMP: ECOM2                 207  208  209  211  212  213  214  215  218  219
 EMP: ECOM2                 221  224  225  226  227  230  231  233  236


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



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


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

 ...
```

Inspecting for instance the program output for day 179 in the year 2020, you will find a series of Galileo satellites represented by the ECOM2-YD1 because of their beta angles (elevation angle of the Sun above the orbital plane) are below the limit 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    0.001    0.001   0.001   0.001   0.001    0.003   0.002   0.003
   2    288    0.001    0.001   0.001   0.001   0.001    0.002   0.002   0.003
   3    288    0.001    0.001   0.001   0.001   0.001    0.005   0.003   0.001
   4    288    0.000    0.000   0.000   0.001   0.000    0.001   0.002   0.001
   5    288    0.001    0.001   0.001   0.001   0.001    0.004   0.003   0.001
   6    288    0.001    0.001   0.001   0.001   0.001    0.003   0.002   0.003
 ...
  31    288    0.001    0.001   0.000   0.001   0.000    0.001   0.002   0.001
  32    288    0.001    0.001   0.001   0.001   0.001    0.002   0.002   0.003
```

```
 101     288     0.001      0.001      0.002  0.001  0.001      0.007  0.004  0.003
 102     288     0.001      0.002      0.002  0.001  0.001      0.006  0.004  0.003
 103     288     0.001      0.001      0.002  0.001  0.001      0.009  0.004  0.004
...
 124     288     0.001      0.001      0.001  0.001  0.001      0.002  0.002  0.004
 126     288     0.001      0.001      0.000  0.001  0.000      0.001  0.002  0.001
 201     288     0.001      0.001      0.001  0.001  0.001      0.004  0.003  0.004
 202     288     0.001      0.001      0.001  0.001  0.001      0.006  0.003  0.004
...
 124     288     0.001      0.001      0.001  0.001  0.001      0.002  0.002  0.004
 126     288     0.001      0.001      0.000  0.001  0.000      0.001  0.002  0.001
 201     288     0.001      0.001      0.001  0.001  0.001      0.004  0.003  0.004
 202     288     0.001      0.001      0.001  0.001  0.001      0.006  0.003  0.004


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

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). Comparing the RMS error from the third and the fourth iteration you will see that three iterations are sufficient to produce precise standard orbits for GNSS satellites.

The file ${P}/INTRO/OUT/ORB_20190440.LST summarizes the orbit fit RMS values in one table:

```
EXAMPLE: Session 2019-0440: Standard orbit generation           31-AUG-23 09:27
TIME FROM DAY : 3 GPS WEEK: 2040
     TO   DAY : 4 GPS WEEK: 2040
----------------------------------------------------------------------------
ORBIT REPEATABILITY FROM A 1-DAY FIT THROUGH DAILY ORBIT SOLUTIONS (MM)
# ECLIPSING SATELLITES:   8 E /   0 M (  0 EM)
------------------------------------------------- ... --------------- ... ---------------
ECL  ..  ..  E.  ..  E.                           ...                 ...
DOY  1   2   3   4   5   6 ...  31  32 101 102 103 ... 124 126 201 202 ... 230 231 233 236
------------------------------------------------- ... --------------- ... ---------------
044  1   1   1   1   1   1 ...   1   1   1   2   1 ...   1   1   1   1 ...   1   1   1   1
------------------------------------------------- ... --------------- ... ---------------
ALL  1   1   1   1   1   1 ...   1   1   1   2   1 ...   1   1   1   1 ...   1   1   1   1
------------------------------------------------- ... --------------- ... ---------------
```

The output shows that 8 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) following the procedure described in Section 7.1. As you can notice the RMS errors are slightly larger. It 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:

```
EXAMPLE: Session 2019-0440: Standard orbit generation           14-JAN-24 05:22
TIME FROM DAY : 3 GPS WEEK: 2040
     TO   DAY : 4 GPS WEEK: 2040
----------------------------------------------------------------------------
ORBIT REPEATABILITY FROM A 1-DAY FIT THROUGH DAILY ORBIT SOLUTIONS (MM)
# ECLIPSING SATELLITES:   8 E /   0 M (  0 EM)
------------------------------------------------- ... -----------------------------------
ECL  ..  ..  E.  ..  E.  ..  ..  ..  ..  E.  ..  E. ...  ..  ..  ..  ..  E.  ..  ..  ..  ..
DOY  1   2   3   4   5   6   7   8   9  10  11  12 ...  24  25  26  27  28  29  30  31  32
------------------------------------------------- ... -----------------------------------
044  2   2   3   3   3   2   2   3   2   3   2   4 ...   2   3   3   2   4   3   2   1   1
------------------------------------------------- ... -----------------------------------
ALL  2   2   3   3   3   2   2   3   2   3   2   4 ...   2   3   3   2   4   3   2   1   1
------------------------------------------------- ... -----------------------------------
```

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

In the example for day 045 of year 2019 a satellite 76 appears. The GPS–satellite 26 had a repositioning event at `14-Feb-2019 19:47:44` (see `${CONFIG}/SAT_2019.CRX`). The satellite is introduced in the processing with two independent arcs: one before (number 26) and one after (number 76) the event (you may verify this by the number of epochs available for each of these two satellite arcs).
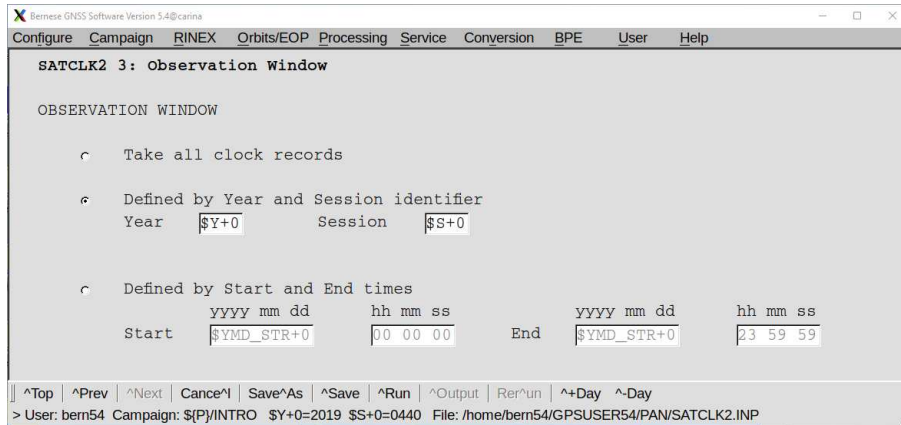
3.3 Extract satellite clock corrections

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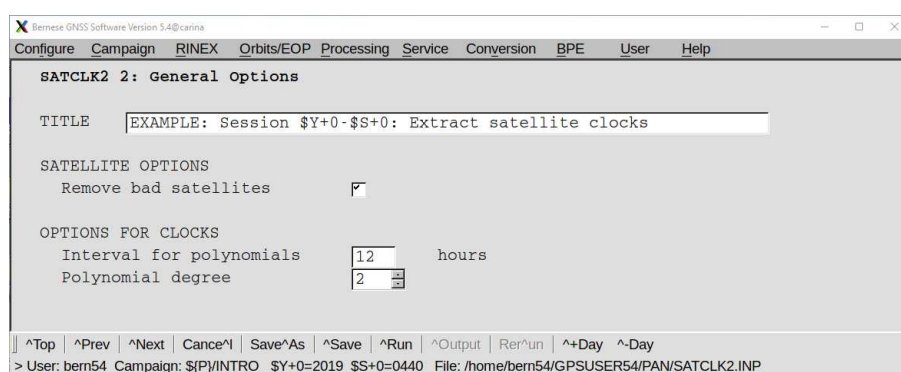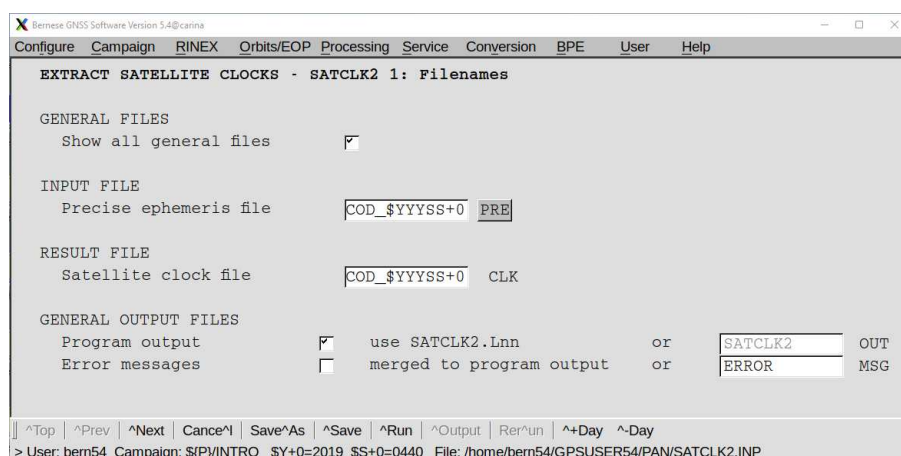
Panel "SATCLK2 2: General Options" contains the options for extracting the satellite clock information. The clock values in the precise orbit file are sampled to 15 min. We interpolate with a "Polynomial degree" of 2 with an "Interval for polynomials [h]" of 12 hours. This is good enough for the receiver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

```
X  Bernese GNSS Software Version 5.4@carina                                    −   □   ×

Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE    User    Help

   SATCLK2 3: Observation Window


   OBSERVATION WINDOW


         ⊙    Take all clock records


         ⊙    Defined by Year and Session identifier
              Year     $Y+0        Session     $S+0



         ⊙    Defined by Start and End times
                        yyyy mm dd      hh mm ss                yyyy mm dd      hh mm ss
              Start     $YMD_STR+0      00 00 00     End        $YMD_STR+0      23 59 59


 ^Top  | ^Prev | ^Next | Cance^l | Save^As | ^Save | ^Run | ^Output | Rer^un | ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/SATCLK2.INP
```

A message like this is expected:

```
 ### FN O_SATCLK2:chkSufficientNbClkValues, PG SATCLK2 (13-Jan-2024 15:46:23)
        Satellite clock correction values missing
        Minimal number  : 3
        Number in sample: 0
        Satellite       : R26
        File name       : ${P}/INTRO/ORB/COD_20190440.PRE


 ### FN O_SATCLK2:chkSufficientNbClkValues, PG SATCLK2 (13-Jan-2024 15:46:23)
        Satellite clock correction values missing
        Minimal number  : 3
        Number in sample: 0
        Satellite       : E01
        File name       : ${P}/INTRO/ORB/COD_20190440.PRE
 ...
```

It indicates that the precise orbit files do not contain clock corrections for Galileo satellites. Consequently they are not available for the synchronization of the receiver clocks in CODSPP. It does not matter because it is sufficient to do this process based on the GPS satellite clocks only.

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_20190440.ERP`,
2. *Bernese standard orbit file in the ORB directory:* `COD_20190440.STD`,
3. *Bernese satellite clock file in the ORB directory:* `COD_20190440.CLK`.
4. *Biases in Bernese format file in the ORB directory:* `COD_20190440.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

```
X Bernese GNSS Software Version 5.4@carina                           –  □  ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

   RNXGRA 3: Options part II

   GENERAL RINEX OPTIONS
      Change hdr strings to upper case on read        ☐
      Only GPS/GLO and freq. 1 or 2 for RINEX 2       ☐
      Output errors from input headers                ☐

   SAMPLING
      Sampling interval              [0       ]   seconds    (0: use all observations)
      Offset to full minute          [0       ]   seconds
      Sampling tolerance             [0.5     ]   seconds

   RULE FOR APPLYING PHASE SHIFT CORRECTIONS FROM HDR ON READING OBSERVATIONS
      Phase shift corrections appeared with RINEX version 2.12
      Rule                           [AS_NEEDED        ▾]

   REJECTION OF FAKE OBSERVATIONS
      Maximal freq. considered       [0      ▴▾]          (0: no rejection)
      Tolerance                      [0       ]

‖ ^Top │ ^Prev │ ^Next │ Cance^l │ Save^As │ ^Save │ ^Run │ ^Output │ Rer^un │ ^+Day  ^-Day
> User: bern54 Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/RNXGRA.INP
```

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 .

```
X Bernese GNSS Software Version 5.4@carina                           –  □  ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

   RNXGRA 4: Check Content of RINEX Header

   Action if marker name doesn't match file name        [NONE      ▾]

   ACTIONS IN CASE OF MISSING MANDATORY HEADER RECORDS
      Missing record: GLONASS SLOT / FRQ #     [NONE    ▾]   (RINEX vers ge 3.01)
      Missing record: GLONASS COD/PHS/BIS      [NONE    ▾]   (RINEX vers ge 3.02)
      Missing record: SYS / PHASE SHIFT        [NONE    ▾]   (RINEX vers ge 2.12)
      Other missing mandatory records          [NONE    ▾]

   ACTIONS IN SPECIAL SITUATIONS BETWEEN OBSERVATIONS
      On epoch events                          [NONE    ▾]
      On inconsistent header modifications     [NONE    ▾]

      NONE    : Just continue
      WARNING : Write warning and continue
      SKIP    : Skip file and continue with next file
      ERROR   : Write error message and stop processing

‖ ^Top │ ^Prev │ ^Next │ Cance^l │ Save^As │ ^Save │ ^Run │ ^Output │ Rer^un │ ^+Day  ^-Day
> User: bern54 Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/RNXGRA.INP
```

From the processing you get a summary in `${P}/INTRO/OUT/GRA_20190440.SMC`:

```
DATE : 2019-02-13


PHASE OBSERVATIONS
BOTH FREQUENCIES


    1 |******************82-               11237631-                        -1*
    2 |            -19************4-               -37************51-
    3 | -17******************41-                          -3221-
    4 |            -45555555577777777773-                          111-
    5 |            -3***************4-              -125********82-
    6 |       -19************82-              -138*********81-
    7 |1-          -3*****************41-                        -16******3
    8 |*********92-               -1249****83-                   -17*******
    9 |      -1******************821-                       -2221-
   10 |*******731-                      -5********41-              -3*********
...
  231 |-366776621-                   --368999****9999*******99871-
  233 |    -13577888999999998874--            -1189999999999998651-
  236 |            -3676632-                   -3789999*********
-----+----------------+----------------+----------------+----------------+
     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 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 : 2019-02-13


PHASE OBSERVATIONS
BOTH FREQUENCIES

SATELLITE SYSTEM: GPS

BRST |*****************9879889977788778988899999*9**99999999987798889889****
GANP |9**************9**9999**99989998878*9**9*88899**9*99997888788889999999
HERT |****************9*9*9**99*8878888887899999**9**99*999799*8888878*89*****
JOZ2 |****- **********9****9***98**9**997*9*******89*****99898899779899*******
LAMA |*9*******9*****9998888*998887679877887*9*99788899998867886776877899**89
MATE |****************99989889988888899898988889989*98888*9787778898898899*9
MIKL |***************9****99**9889*9*********9*9****99***988889889*****9***
ONSA |*****************9*****9*8*8******9*****9989*999*99889*9******
ORID |****************99*8889887877888**999899**99899*97887888*8888899**
PTBB |67*****9********88898789*9998786898678779998787899999888777777687578999*98
TLSE |****************99**988877796797789*9999*****9*9998999*7799888889****
VILL |9*********99****9***998887888887865687989999878989988899866668768799999
WSRT |---7-------------9-------6***999*9*****----*******889****9*9899*******
WTZR |*********- ****9****9**989978**88898***9***9****999998*99*7789898*9*****
WTZZ |****************9**89*98898***9***9****999998*9997779898*9*****
ZIM2 |****************9***9**899*897889*99*9*****9999989*998789889989****
ZIMM |9***************989**99*98898986889*9989989*99999989898777798878889***
-----+----------------+----------------+----------------+----------------+
     0                12               24
```

From this output it can be concluded that station WSRT seems to have some tracking problems in the first half of the day. It is therefore recommended to have a particular look at the results from this station in the different processing steps. In addition, the stations JOZ2 and WTZR show short outages of one hour. This 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_20190440.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 36):

```
X  Bernese GNSS Software Version 5.4@carina                              —  □  ×
 Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

    TRANSFER RINEX OBSERVATION FILES TO BERNESE FORMAT - RXOBV3 1: Filenames

    INPUT FILES
        ⦿    Original RINEX observation files
            Bernese internal naming       ?????????_$YYYSS+0      RXO
            RINEX3-style naming                                             RNX
            RINEX2-style naming                        19O
            Any naming convention

        ○    Smoothed RINEX observation files
                                                            SMT

      Station information              EXAMPLE      STA

    GENERAL FILES
        Show all general files               ☑
        Observation selection            OBSERV      SEL
        Print observation statistics         ☐

    RESULT FILES
        Measurement types to save
          ⦿     Code   ☑    Phase  ☑                   ○      Range

        Update coordinates         [          ]  CRD      (blank if not used)

    GENERAL OUTPUT FILES
        Program output          ☐    use RXOBV3.Lnn          or   RXO_$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=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/RXOBV3.INP
```

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 itself are not yet needed for the import step.

```
X  Bernese GNSS Software Version 5.4@carina                              —  □  ×
 Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help
    RXOBV3 1.1: General Files

    GENERAL INPUT FILES
        General constants          CONST         BSW
        Satellite information      SATELLIT_I20  SAT
        Satellite problems         SAT_$Y+0      CRX
        Antenna corrections        ANTENNA_I20   PCV
        GPS-UTC time difference     GPSUTC        BSW
        Abbreviation table          EXAMPLE       ABB
        Frequency information                     FRQ

    MENU SETTINGS
        Selected campaign          ${P}/INTRO
        Selected session           year   2019    session   0440
        Session table              ${P}/INTRO/GEN/SESSIONS.SES

    TEMPORARY FILES
        Scratch files              RXOBV3$J    SCR    RXOBV3$J    SC1    RXOBV3$J    SC2

 ‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/RXOBV3.INP
```

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.

```
X  Bernese GNSS Software Version 5.4@carina                                    –   □   ×

Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE     User     Help

   RXOBV3 6: Check Content of RINEX Header 3

   Action if marker name doesn't match file name        WARNING        ▼

   ACTIONS IN CASE OF MISSING MANDATORY HEADER RECORDS
      Missing record: GLONASS SLOT / FRQ #      WARNING      ▼  (RINEX vers ge 3.01)
      Missing record: GLONASS COD/PHS/BIS       WARNING      ▼  (RINEX vers ge 3.02)
      Missing record: SYS / PHASE SHIFT         WARNING      ▼  (RINEX vers ge 2.12)
      Other missing mandatory records           WARNING      ▼

   ACTIONS IN SPECIAL SITUATIONS BETWEEN OBSERVATIONS
      On epoch events                           SKIP         ▼
      On inconsistent header modifications      WARNING      ▼

      NONE    : Just continue
      WARNING : Write warning and continue
      SKIP    : Skip file and continue with next file
      ERROR   : Write error message and stop processing


 ‖ ^Top │ ^Prev │ ^Next │ Cance^l │ Save^As │ ^Save │ ^Run │ ^Output │ Rer^un │ ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019 $S+0=0440  File: /home/bern54/GPSUSER54/PAN/RXOBV3.INP
```

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 do 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_20190440.RXO
```

or actions taken on the observations that do not influence the processing results:

```
### SR SAVMEA: JUMP INTRODUCED INTO PHASES
              DUE TO FORMAT OVERFLOW
              RINEX FILE   : ...RO/RAW/HERT00XYZ_20190440.RXO
              FREQUENCY    : L1
              SATELLITE    :122
              JUMP (CYCLES):    579337875.0
              EPOCH        :2019-02-13 18:10:00
```

In some cases where there are several (inconsistent) header sequences in the RINEX files containing different information (e.g., related to the APPROX POSITION XYZ record):

```
### SR O_RNXBASE:wrtHdrEntryChkErrsToLfnErr, PG RXOBV3
    Inconsistency between the following two RINEX headers detected:
    Filename (header to update):
     ${P}/INTRO/RAW/JOZ200XYZ_20190440.RXO
    Filename (new header):
     ${P}/INTRO/RAW/JOZ200XYZ_20190440.RXO
    Geocentric approx. ant. marker pos.  (APPROX POSITION XYZ)
      in header to update: '(3.6648784825E+06,1.4091900878E+06,5.0096170459E+06)'
      in new header:       '(3.6648768963E+06,1.4091892139E+06,5.0096167523E+06)'
```

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, station ONSA provides data for the two GLONASS satellites R12 and R06 (satellite system `R` for GLONASS in RINEX whereas satellite numbers between 100 and 199 are in use within the *Bernese GNSS Software*) 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:  112
              INDICATED IN SATCRUX : ${CONFIG}/SAT_2019.CRX
              PROBLEM              : BAD PHASE+CODE
              REQUESTED ACTION     : OBS. REMOVED
              TIME WINDOW          : 2016-11-22 00:00:00  2019-06-19 23:59:59
              IN RINEX FILE        : ...RO/RAW/ONSA00XYZ_20190440.RXO

### SR SAVMEA: PROBLEM FOR SATELLITE:  106
              INDICATED IN SATCRUX : ${CONFIG}/SAT_2019.CRX
              PROBLEM              : BAD PHASE+CODE
              REQUESTED ACTION     : OBS. REMOVED
              TIME WINDOW          : 2018-04-08 00:00:00  2099-12-31 23:59:59
              IN RINEX FILE        : ...RO/RAW/ONSA00XYZ_20190440.RXO
```

The program produces an output file `RXO_20190440.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_20190440.RXO  ${P}/INTRO/OBS/BRST0440.CZH  2880  75780 74934   31   22   24
                                ${P}/INTRO/OBS/BRST0440.CZO
                                ${P}/INTRO/OBS/BRST0440.PZH  2880  75654 74864   31   22   24
                                ${P}/INTRO/OBS/BRST0440.PZO

  2  ...GANP00SVK_20190440.RXO  ${P}/INTRO/OBS/GANP0440.CZH  2880  77299 76553   32   22   24
                                ${P}/INTRO/OBS/GANP0440.CZO
                                ${P}/INTRO/OBS/GANP0440.PZH  2880  77040 76362   32   22   24
                                ${P}/INTRO/OBS/GANP0440.PZO

  3  ...HERT00XYZ_20190440.RXO  ${P}/INTRO/OBS/HERT0440.CZH  2880  52454 51981   31   22    0
                                ${P}/INTRO/OBS/HERT0440.CZO
                                ${P}/INTRO/OBS/HERT0440.PZH  2880  52454 51970   31   22    0
                                ${P}/INTRO/OBS/HERT0440.PZO

...

 16  ...ZIM200CHE_20190440.RXO  ${P}/INTRO/OBS/ZIM20440.CZH  2880  79238 78472   32   22   24
                                ${P}/INTRO/OBS/ZIM20440.CZO
                                ${P}/INTRO/OBS/ZIM20440.PZH  2880  78966 78274   32   22   24
                                ${P}/INTRO/OBS/ZIM20440.PZO

 17  ...ZIMM00CHE_20190440.RXO  ${P}/INTRO/OBS/ZIMM0440.CZH  2880  28964 28819   32    0    0
                                ${P}/INTRO/OBS/ZIMM0440.CZO
                                ${P}/INTRO/OBS/ZIMM0440.PZH  2880  28844 28729   32    0    0
                                ${P}/INTRO/OBS/ZIMM0440.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 February 2019 32 GPS, 22 GLONASS, and 24 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.

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/BRST0440.CZO      RECEIVER UNIT:    999999
--------------------------------------------------------------------------------------------

DAY OF YEAR        :    44
                                    FROM                              TO
OBSERVATIONS       :        2019-02-13  00:00: 0.00       2019-02-13  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     5     6     7     8     9    10    11 ...   TOTAL
OBSERVATIONS IN FILE:  857  1107   813   921   961  1045   937   768  1066   819 ...   29017
USED OBSERVATIONS   :  837  1085   805   903   959  1029   903   765  1047   804 ...   28520
BAD OBSERVATIONS (%):  2.3   2.0   1.0   2.0   0.2   1.5   3.6   0.4   1.8   1.8 ...     1.7
RMS ERROR (M)       :  1.1   1.1   0.9   1.0   1.2   1.0   1.2   1.0   1.0   1.1 ...     1.1

RESULTS:
--------

OBSERVATIONS IN FILE:     29017
USED OBSERVATIONS   :     28520
BAD OBSERVATIONS    :        1.71 %
RMS OF UNIT WEIGHT  :        1.17 M
NUMBER OF ITERATIONS:        2

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

LOCAL GEODETIC DATUM:  IGS20
                            A PRIORI            NEW           NEW- A PRIORI    RMS ERROR
 BRST 10004M004     X       4231162.42       4231162.42          0.00           0.00
 (MARKER)           Y       -332746.43       -332746.43          0.00           0.00
                    Z       4745131.07       4745131.07          0.00           0.00

                    HEIGHT        65.82            65.82          0.00           0.00
                    LATITUDE   48 22 49.784    48 22 49.784   0  0  0.000        0.0000
                    LONGITUDE  -  4 29 47.729  -  4 29 47.729  0  0  0.000        0.0000

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

OFFSET FOR REFERENCE EPOCH:             -0.000000019  SEC

CLOCK OFFSETS STORED IN CODE+PHASE OBSERVATION FILES

RECEIVER UNIT      :  999999
REFERENCE EPOCH    :        2019-02-13  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     :        28

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

   1    2   GANP 11515M001     OUT   4   2019 02 13 04 54 00   2019 02 13 04 54 30      2

   2    8   ONSA 10402M004     OUT  30   2019 02 13 00 16 30   2019 02 13 00 16 30      1
   3    8   ONSA 10402M004     OUT  15   2019 02 13 00 35 30   2019 02 13 00 35 30      1
   4    8   ONSA 10402M004     OUT  17   2019 02 13 01 49 00   2019 02 13 01 49 00      1
   5    8   ONSA 10402M004     OUT  12   2019 02 13 05 17 30   2019 02 13 05 17 30      1
   6    8   ONSA 10402M004     OUT  25   2019 02 13 06 02 00   2019 02 13 06 02 00      1
...
  18   13   WSRT 13506M005     OUT  23   2019 02 13 05 59 30   2019 02 13 05 59 30      1
  19   13   WSRT 13506M005     OUT   6   2019 02 13 06 13 30   2019 02 13 06 14 30      3
  20   13   WSRT 13506M005     OUT   9   2019 02 13 07 31 00   2019 02 13 07 32 00      3
  21   13   WSRT 13506M005     OUT   9   2019 02 13 07 35 30   2019 02 13 07 35 30      1
  22   13   WSRT 13506M005     OUT   9   2019 02 13 08 16 00   2019 02 13 08 16 00      1
  23   13   WSRT 13506M005     OUT  17   2019 02 13 14 14 00   2019 02 13 14 14 30      2
  24   13   WSRT 13506M005     OUT  12   2019 02 13 14 28 30   2019 02 13 14 32 00      8
  25   13   WSRT 13506M005     OUT  32   2019 02 13 14 28 30   2019 02 13 14 32 00      8
  26   13   WSRT 13506M005     OUT  24   2019 02 13 14 29 00   2019 02 13 14 32 00      7
  27   13   WSRT 13506M005     OUT   1   2019 02 13 14 29 00   2019 02 13 14 32 00      7
  28   13   WSRT 13506M005     OUT  24   2019 02 13 14 34 30   2019 02 13 14 35 30      3


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



------------------------------------------------------------------
>>> CPU/Real time for pgm "CODSPP": 0:01:13.209 / 0:01:13.232
>>> 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 $1\,\mu$s.

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_20190440.OUT
--------------------------------------------------------------------------------

 17 FILES, MAX. RMS:     3.15 M    FOR STATION: ONSA 10402M004
           MAX. BAD:     5.70 %    FOR STATION: MIKL 12335M001
           MAX. OFF:     0.25 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.

```
 X  Bernese GNSS Software Version 5.4@carina                              –   □   ✕

Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

   SNGDIF 3: Options


   TITLE       EXMAPLE: Session $Y+0-$S+0: Baseline creation


   SIMULTANEOUS OBSERVATIONS
       Tolerance to identify observations of one epoch        1.0       seconds


   SETTING OF NEW AMBIGUITIES
       Merge ambiguities from input files                  □
       After a gap in the observations larger than         20        minutes
       If a cycle slip flag in one of the input files      □


 ‖ ^Top | ^Prev | ^Next | Cance^l | Save^As | ^Save | ^Run | ^Output | Rer^un | ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019 $S+0=0440  File: /home/bern54/GPSUSER54/PAN/SNGDIF.INP
```

```
 X  Bernese GNSS Software Version 5.4@carina                              –   □   ✕

Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

   SNGDIF 3.1: Options for Strategy OBS-MAX


   SPEED UP BASELINE SELECTION ALGORITHM
       Minimum number of observations requested        600   ⬍  (scaled, see help)
       Maximum distance for fast observation count     0     ⬍  kilometers
       Maximum baseline length considered              9000  ⬍  kilometers


   ALLOW REDUNDANT BASELINES
       Add redundant baselines                         □


   ADD BONUS DEPENDING ON BASELINE LENGTH
       Maximum bonus for number of observations        10        percent
       Direct L1/L2: Baseline length from 0 to         20    ⬍  kilometers
       Wide-/Narrowlane: Baseline length from 0 to     200   ⬍  kilometers
       Other: Baseline length from 0 to                0     ⬍  kilometers


 ‖ ^Top | ^Prev | ^Next | Cance^l | Save^As | ^Save | ^Run | ^Output | Rer^un | ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019 $S+0=0440  File: /home/bern54/GPSUSER54/PAN/SNGDIF.INP
```

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    REMARK
 -------------------------------------------------------------------------------
   1 ${P}/INTRO/OBS/BRST0440.PZH         BRST 10004M004    77  GRE    included
   2 ${P}/INTRO/OBS/GANP0440.PZH         GANP 11515M001    78  GRE    included
   3 ${P}/INTRO/OBS/HERT0440.PZH         HERT 13212M010    53  GR     included
   4 ${P}/INTRO/OBS/JOZ20440.PZH         JOZ2 12204M002    53  GR     included
   5 ${P}/INTRO/OBS/LAMA0440.PZH         LAMA 12209M001    53  GR     included
   6 ${P}/INTRO/OBS/MATE0440.PZH         MATE 12734M008    75  GRE    included
   7 ${P}/INTRO/OBS/MIKL0440.PZH         MIKL 12335M001    75  GRE    included
   8 ${P}/INTRO/OBS/ONSA0440.PZH         ONSA 10402M004    54  GR     included
   9 ${P}/INTRO/OBS/ORID0440.PZH         ORID 15601M001    53  GR     included
  10 ${P}/INTRO/OBS/PTBB0440.PZH         PTBB 14234M001    32  G      included
  11 ${P}/INTRO/OBS/TLSE0440.PZH         TLSE 10003M009    77  GRE    included
  12 ${P}/INTRO/OBS/VILL0440.PZH         VILL 13406M001    79  GRE    included
  13 ${P}/INTRO/OBS/WSRT0440.PZH         WSRT 13506M005    74  GRE    included
  14 ${P}/INTRO/OBS/WTZR0440.PZH         WTZR 14201M010    77  GRE    included
  15 ${P}/INTRO/OBS/WTZZ0440.PZH         WTZZ 14201M014    79  GRE    included
  16 ${P}/INTRO/OBS/ZIM20440.PZH         ZIM2 14001M008    78  GRE    included
  17 ${P}/INTRO/OBS/ZIMM0440.PZH         ZIMM 14001M004    32  G      included
...
```

The creation of the following 16 baseline files from 17 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/BRST0440.PZH      ${P}/INTRO/OBS/BRST0440.PZO        1
${P}/INTRO/OBS/TLSE0440.PZH      ${P}/INTRO/OBS/TLSE0440.PZO        2
${P}/INTRO/OBS/GANP0440.PZH      ${P}/INTRO/OBS/GANP0440.PZO        3
${P}/INTRO/OBS/MIKL0440.PZH      ${P}/INTRO/OBS/MIKL0440.PZO        4
${P}/INTRO/OBS/GANP0440.PZH      ${P}/INTRO/OBS/GANP0440.PZO        5
${P}/INTRO/OBS/WTZZ0440.PZH      ${P}/INTRO/OBS/WTZZ0440.PZO        6
...


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

${P}/INTRO/OBS/BRTL0440.PSH      ${P}/INTRO/OBS/BRTL0440.PSO        1   2   OK
${P}/INTRO/OBS/GAMI0440.PSH      ${P}/INTRO/OBS/GAMI0440.PSO        3   4   OK
${P}/INTRO/OBS/GAWZ0440.PSH      ${P}/INTRO/OBS/GAWZ0440.PSO        5   6   OK
${P}/INTRO/OBS/HETL0440.PSH      ${P}/INTRO/OBS/HETL0440.PSO        7   8   OK
${P}/INTRO/OBS/JOON0440.PSH      ${P}/INTRO/OBS/JOON0440.PSO        9  10   OK
${P}/INTRO/OBS/LAON0440.PSH      ${P}/INTRO/OBS/LAON0440.PSO       11  12   OK
${P}/INTRO/OBS/MAOR0440.PSH      ${P}/INTRO/OBS/MAOR0440.PSO       13  14   OK
${P}/INTRO/OBS/MAZI0440.PSH      ${P}/INTRO/OBS/MAZI0440.PSO       15  16   OK
${P}/INTRO/OBS/ONPT0440.PSH      ${P}/INTRO/OBS/ONPT0440.PSO       17  18   OK
${P}/INTRO/OBS/ONWZ0440.PSH      ${P}/INTRO/OBS/ONWZ0440.PSO       19  20   OK
${P}/INTRO/OBS/TLZI0440.PSH      ${P}/INTRO/OBS/TLZI0440.PSO       21  22   OK
${P}/INTRO/OBS/VIWZ0440.PSH      ${P}/INTRO/OBS/VIWZ0440.PSO       23  24   OK
${P}/INTRO/OBS/WSWZ0440.PSH      ${P}/INTRO/OBS/WSWZ0440.PSO       25  26 WARNG
${P}/INTRO/OBS/WTWZ0440.PSH      ${P}/INTRO/OBS/WTWZ0440.PSO       27  28   OK
${P}/INTRO/OBS/WZZI0440.PSH      ${P}/INTRO/OBS/WZZI0440.PSO       29  30   OK
${P}/INTRO/OBS/ZIZM0440.PSH      ${P}/INTRO/OBS/ZIZM0440.PSO       31  32   OK
...
```

For the baseline WSWZ (WSRT-WTZZ) it is indicated that warning messages related to this baseline are issued that can be displayed via "Menu>$\underline{S}$ervice>Browse $\underline{e}$rror message":

```
 ### PG SNGDIF: JUMP INTRODUCED TO AVOID FORMAT OVERFLOW
               FREQUENCY    :    1
               SATELLITE    :    1
               EPOCH NUMBER :  299
               JUMP (CYCLES):     872366831.
               FILE         : ${P}/INTRO/OBS/WSWT0440.PSH
 ...
```

These jumps do not influence the obtained results.

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:  77   CRIT.:   32293
        2 BRST 10004M004   - HERT 13212M010   #SAT:  53   CRIT.:   24582
        3 BRST 10004M004   - JOZ2 12204M002   #SAT:  53   CRIT.:   22972
        4 BRST 10004M004   - LAMA 12209M001   #SAT:  53   CRIT.:   22225
...
        9 BRST 10004M004   - PTBB 14234M001   #SAT:  31   CRIT.:   11945
       10 BRST 10004M004   - TLSE 10003M009   #SAT:  77   CRIT.:   35538  OK
       11 BRST 10004M004   - VILL 13406M001   #SAT:  77   CRIT.:   31995
       12 BRST 10004M004   - WSRT 13506M005   #SAT:  73   CRIT.:   24936
...
      123 VILL 13406M001   - WTZR 14201M010   #SAT:  77   CRIT.:   30079
      124 VILL 13406M001   - WTZZ 14201M014   #SAT:  79   CRIT.:   32284  OK
      125 VILL 13406M001   - ZIM2 14001M008   #SAT:  78   CRIT.:   32108
      126 VILL 13406M001   - ZIMM 14001M004   #SAT:  32   CRIT.:   12797
      127 WSRT 13506M005   - WTZR 14201M010   #SAT:  73   CRIT.:   25785
      128 WSRT 13506M005   - WTZZ 14201M014   #SAT:  74   CRIT.:   26483  OK
      129 WSRT 13506M005   - ZIM2 14001M008   #SAT:  74   CRIT.:   26102
      130 WSRT 13506M005   - ZIMM 14001M004   #SAT:  32   CRIT.:   10829
      131 WTZR 14201M010   - WTZZ 14201M014   #SAT:  77   CRIT.:   45323  OK
      132 WTZR 14201M010   - ZIM2 14001M008   #SAT:  77   CRIT.:   36323
      133 WTZR 14201M010   - ZIMM 14001M004   #SAT:  31   CRIT.:   13183
      134 WTZZ 14201M014   - ZIM2 14001M008   #SAT:  78   CRIT.:   38261  OK
      135 WTZZ 14201M014   - ZIMM 14001M004   #SAT:  32   CRIT.:   14212
      136 ZIM2 14001M008   - ZIMM 14001M004   #SAT:  32   CRIT.:   17346  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 introduced to option "Predefined baselines" when processing code measurements.

```
X  Bernese GNSS Software Version 5.4@carina                                    —    □   ×
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE      User    Help

   CREATE SINGLE-DIFFERENCE/BASELINE FILES - SNGDIF 1: Input File Selection

   GENERAL FILES
      Show all general files                       ☑

   GENERAL OPTIONS
      Measurement type                          [ CODE        ▼]
      Processing strategy                       [ DEFINED     ▼]

      Stations must contain observations from selected GNSS:
            ☑    GPS               ☐   GLONASS          ☐   Galileo
            ☐    SBAS              ☐   BeiDou           ☐   QZSS

   AUTOMATED BASELINE CREATION
      Zero-difference observation files   [????$S+0   ] PZH   [????$S+0   ] CZH
      Reference station for STAR strategy [          ] PZH   [          ] CZH

   MANUAL BASELINE CREATION
      First  zero-difference input file   [          ] PZH   [          ] CZH
      Second zero-difference input file   [          ] PZH   [          ] CZH
      Single-difference output file       [          ] PSH   [          ] CSH

‖ ^Top │ ^Prev │ ^Next │ Cance^l │ Save^As │ ^Save │ ^Run │ ^Output │ Rer^un │ ^+Day │ ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/SNGDIF.INP
```

```
X  Bernese GNSS Software Version 5.4@carina                                    —    □   ×
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE      User    Help

   SNGDIF 2: Filenames

   INPUT FILES
      Station coordinates      [APR_$YYYSS+0] CRD
      Site eccentricities      [          ] ECC
      Predefined baselines     [BSL_$YYYSS+0] BSL
      Cluster definition       [          ] CLU

   RESULT FILES
      Listing of formed baselines   [          ]   BSL
      Cluster/baseline assignment   [      ] CLB    (2 digits will be appended)

   GENERAL OUTPUT FILES
      Program output      ☑   use SNGDIF.Lnn          or   [SNGDIF   ] 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=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/SNGDIF.INP
```

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` .

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
```

Bernese GNSS Software Version 5.4@carina

Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help

^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2019 $S+0=0440 File: /home/bern54/GPSUSER54/PAN/MAUPRP.INP

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

    [x]  Differences between satellites           for ZD-files: single diff.
            Polynomial degree        1                SD-files: double diff.
            Discontinuity level      0.01   meters
```

Bernese GNSS Software Version 5.4@carina

Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help

^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2019 $S+0=0440 File: /home/bern54/GPSUSER54/PAN/MAUPRP.INP

MAUPRP 6: Epoch-Difference Solution

```
EPOCH-DIFFERENCE SOLUTION                            for ZD-files: double diff.
    Frequency for the solution          L3              SD-files: triple diff.
    Kinematic coordinate estimation     [ ]
    Maximum observed-computed value     0.5    meters (0.0: no check)
    RMS limit for epoch diff. solution  0.1    meters (0.0: no check)
    RMS limit for epoch solution        1.0    meters (0.0: no check)

    [x]  A priori coordinate/baseline vector sigmas
            X-coordinate       0.1    meters
            Y-coordinate       0.1    meters
            Z-coordinate       0.1    meters
```

Bernese GNSS Software Version 5.4@carina

Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help

^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2019 $S+0=0440 File: /home/bern54/GPSUSER54/PAN/MAUPRP.INP

MAUPRP 8: Cycle Slip Detection/Correction

```
CYCLE SLIP DETECTION
    Extent of program output                      SUMMARY
    Do not accept cycle slip corrections          [ ]
    Minimum size of accepted cycle slip correction   10        cycles
    Test only observations with cycle slip flag      [ ]
    L5 is clean except for observations with flags   [ ]

NO CYCLE SLIP HYPOTHESIS
    Sigma for L1 observations                     0.0020   meters
    Sigma for L2 observations                     0.0020   meters
    Maximum ionospheric change from epoch to epoch
        for single frequency mode (or short bsl.)   30     % of L1 cycles
        for combined mode        (or long  bsl.)    400    % of L1 cycles
        use the combined mode value for bsl longer than  2000   km

CYCLE SLIP CORRECTIONS
    Search width to find L1 cycle slip correction    5      integers
    Search width to find L5 cycle slip correction    2      integers
```

Bernese GNSS Software Version 5.4@carina

Configure Campaign RINEX Orbits/EOP Processing Service Conversion BPE User Help

^Top ^Prev ^Next Cance^l Save^As ^Save ^Run ^Output Rer^un ^+Day ^-Day
> User: bern54 Campaign: ${P}/INTRO $Y+0=2019 $S+0=0440 File: /home/bern54/GPSUSER54/PAN/MAUPRP.INP

```
X  Bernese GNSS Software Version 5.4@carina                                    —    □    ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE   User   Help

   MAUPRP 9: Outlier Rejection / Ambiguity Setting


   OUTLIER REJECTION
      Enable outlier rejection                                    ☑
      Mark consecutive outliers up to a time interval            │181│      seconds


   SET UP MULTIPLE AMBIGUITIES
      Preserve ambiguities from observation file                 ☐
      If a cycle slip flag in observation file                   ☐
      If no cycle slip correction was possible                   ☑
      After an observation gap larger than                       │181│      seconds


   MARKING OF OBSERVATIONS AFTER CYCLE SLIP CORRECTIONS
      Minimum observed time interval per ambiguity               │301│      seconds


 ‖ ^Top │ ^Prev │ ^Next │ Cance^l │ Save^As │ ^Save │ ^Run │ ^Output │ Rer^un │ ^+Day │ ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  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:   2019          SESSION:  0440
STATION 2: TLSE 10003M009          DAY :    44           FILE   :     0

REFERENCE EPOCH      : 2019-02-13 00:00:00
SAMPLING INTERVAL    :   30 SEC

BASELINE LENGTH (M) :    707461.879
OBSERVAT. FILE NAME : ${P}/INTRO/OBS/BRTL0440.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:      60983
RMS OF EPOCH DIFF. SOLUTION (M):      0.013

COORDINATES  NEW-A PRIORI X (M):     -0.057 +-       0.018
                        Y (M):       0.020 +-       0.020
                        Z (M):      -0.062 +-       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
-------------------------------------------------------------------------------------
0440  1 OK   BRST TLSE  707   60983   13  -57   20  -62    9  1522   146    24     11
0440  2 OK   GANP MIKL  897   59647   11  -96  -31 -171   12   927   108    47     11
0440  3 OK   GANP WTZZ  544   65887   10  164    7  149    4   873   112    12     31
0440  4 OK   HERT TLSE  816   42085   12 -192   19 -282   11  1106   117    45     11
0440  5 OK   JOZ2 ONSA  830   43494   13  -19   25  -75    6  1049   129    34     13
0440  6 OK   LAMA ONSA  674   43514   12  -14   17  -83   35   809   135    42     11
0440  7 OK   MATE ORID  349   42135    9    2   17   22   29   735   103    44     11
0440  8 OK   MATE ZIM2 1014   57683   11  214   56  207   24  1390   136    44     11
0440  9 OK   ONSA PTBB  575   21952   13  120   35  164   63   265    38    50     13
0440 10 OK   ONSA WTZZ  920   44738   12  180   -3  214    3   717    83    25     11
0440 11 OK   TLSE ZIM2  597   62587   13  210  -28  203    6  1364   134    43     13
0440 12 OK   VILL WTZZ 1635   58894   10  237    4  250    5   712    73    16     17
0440 13 OK   WSRT WTZZ  607   40007   10  -14   24  -40    5  4134   404    49     12 <-- AMB
0440 14 OK   WTZR WTZZ    0   67195   11  -10  -17   39    4   563   116     0      0
0440 15 OK   WTZZ ZIM2  476   66640   12  -85   -3 -167    4  1406   105    30     11
0440 16 OK   ZIM2 ZIMM    0   24300   13   19   10   16    7   245    49     0      0
-------------------------------------------------------------------------------------
Tot: 16                665   67195   13  237    4  250   63  4134   404    50      0
                                                          +++++ +++++
```

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

The indicators show that there is a baseline with exceptionally many AMBiguities and marked observations. This is the baseline containing the station WSRT where data quality issues have already been detected in the RNXGRA summary output.

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:* BRST0440.CZH, BRST0440.PZH, BRST0440.CZO, BRST0440. PZO, *... (for all stations).*
>   2. *Single difference files (baseline files) in the OBS directory:* BRTL0440.PSH, BRTL0440.PSO, GAMI0440.PSH, GAMI0440.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 a 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:

No files are selected in the second input panel. Verify the model and configuration files:

```
X  Bernese GNSS Software Version 5.4@carina                                    —  □  ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

   GPSEST 1.4: General Files

   GENERAL INPUT FILES
      General constants              CONST          BSW
      Geodetic datum                 DATUM          BSW
      Antenna corrections            ANTENNA_I20    PCV    ☐   Consider ant. rotations
      Observation selection          OBSERV         SEL
      Satellite information          SATELLIT_I20   SAT
      Satellite problems             SAT_$Y+0       CRX
      Earth potential coefficients   GM2008_SMALL   GRV
      Subdaily ERP model             DESAI2016      SUB
      Nutation model                 IAU2000R06     NUT
      SINEX header file                             SKL
      IONEX control file                            SKL
      GPS-UTC time difference        GPSUTC         BSW
      Frequency information                         FRQ

   MENU SETTINGS
      Selected campaign              ${P}/INTRO
      Selected session               Year   2019     Session   0440
      Session table                  ${P}/INTRO/GEN/SESSIONS.SES

   TEMPORARY FILES
      Scratch files                  GPSEST$J   SCR    GPSEST$J   SC1    GPSEST$J   SC2

‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

We recommend to select the following output files:

```
X  Bernese GNSS Software Version 5.4@carina                                    —  □  ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

   GPSEST 2.1: Output Files 1

   GENERAL OUTPUT FILES
      Program output       ☐  use GPSEST.Lnn        or   EDT_$YYYSS+0  OUT
      Error messages       ☐  merged to program output  or   ERROR       MSG

   NORMAL EQUATION SYSTEM                          NQ0

   STATION- AND SATELLITE-RELATED RESULTS
      Station coordinates                          CRD
      Satellite orbital elements                   ELE
      Earth rotation parameters                    ERP
      Earth rotation parameters (IERS)             IEP

   ATMOSPHERE-SPECIFIC RESULTS
      Troposphere estimates                        TRP
      Troposphere estimates (SINEX)                TRO
      Troposphere slant delays                     TRS
      Ionosphere models                            ION
      Ionosphere models (IONEX)                    INX

‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

```
X  Bernese GNSS Software Version 5.4@carina                                    —  □  ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

   GPSEST 2.2: Output Files 2

   ADDITIONAL RESULT FILES
      Observable-specific code biases              OSB
      Bias SINEX                                   BIA
      Phase center variations (gridded)            PHG
      Phase center variations (spherical)          PHH

   EPOCH-SPECIFIC RESULTS
      GNSS clock corrections                       CLK
      Clock RINEX                                  CLK
      Kinematic coordinates                        KIN
      Epoch-wise KIN covariances (LEOs)            COV

   AUXILIARY FILES
      Observation residuals          EDT_$YYYSS+0  RES   ☐  Extended format
      Covariance matrix                            COV
      Covariance matrix wrt coordinates            COV

‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

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 17 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).

GPSEST 4: Datum Definition for Station Coordinates

DATUM DEFINITION TYPE
- Free network solution
- Coordinates constrained — WITH_FLAG
- Coordinates fixed — MANUAL

A PRIORI SIGMAS
North   0.01   meters
East   0.01   meters
Up   0.01   meters

GPSEST 4.1: Datum Definition for Station Coordinates

STATION COORDINATES TO BE CONSTRAINED
Manual selection
List of stations (and sigmas) from file   SIG
Stations with specific flags in CRD file   I   #: all non-blank

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

GPSEST 5.1: Setup of Parameters and Pre-Elimination 1

STATION-RELATED PARAMETERS	Setup	Pre-Elimination
Station coordinates		NO
Ambiguities		NO

ATMOSPHERIC PARAMETERS
Site-specific troposphere parameters	☑	NO
Global ionosphere parameters	☐	NO

GLOBAL PARAMETERS
Orbital parameters	☐ GNSS	NO
	☐ LEO	NO
Earth orientation parameters	☐	NO
Geocenter coordinates	☐	NO

EPOCH PARAMETERS
Receiver clock offsets	☑	EVERY_EPOCH
Satellite clock offsets	☐	EVERY_EPOCH
Kinematic coordinates	☐	EVERY_EPOCH
Stochastic ionosphere parameters	☐	EVERY_EPOCH

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       133349
Total number of pseudo-observations              46

Total number of explicit parameters            2909
Total number of implicit parameters               0

Total number of observations                  133395
Total number of adjusted parameters            2909
Degree of freedom (DOF)                       130486

A posteriori RMS of unit weight         0.001041 m
Chi**2/DOF                                      1.08

Total number of observation files                16
Total number of unobserved ambiguities          269
Total number of stations                         17

...
```

An a posteriori RMS error of about $1.0 \ldots 1.5$ mm is expected if elevation–dependent weighting is used. A significant 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     0.01152    4231162.42917    0.00303    4231162.41765  ... #CRD
  1 BRST 10004M004        Y    -0.00335    -332746.43226    0.00282    -332746.42891  ... #CRD
  1 BRST 10004M004        Z     0.00415    4745131.07383    0.00300    4745131.06968  ... #CRD
  1 TLSE 10003M009        X     0.00633    4627851.66867    0.00299    4627851.66234  ... #CRD
  1 TLSE 10003M009        Y    -0.00418     119640.28425    0.00276     119640.28843  ... #CRD
  1 TLSE 10003M009        Z    -0.00281    4372993.71180    0.00295    4372993.71461  ... #CRD
  1 GANP 11515M001        X    -0.00393    3929181.30207    0.00302    3929181.30600  ... #CRD
  1 GANP 11515M001        Y     0.00394    1455236.94940    0.00278    1455236.94546  ... #CRD
  1 GANP 11515M001        Z     0.03959    4793654.03253    0.00296    4793653.99294  ... #CRD
  1 MIKL 12335M001        X     0.00239    3698553.71209    0.00305    3698553.70970  ... #CRD

...


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

Station name        Typ     Correction  Estimated value  RMS error   A priori value   ... Abb
-------------------------------------------------------------------------------------- ... ---
BRST 10004M004        U       0.11019          2.42203    0.00081          2.31184  ... #TRP
BRST 10004M004        U       0.09745          2.40934    0.00061          2.31190  ... #TRP
BRST 10004M004        U       0.07787          2.38976    0.00063          2.31188  ... #TRP
BRST 10004M004        U       0.08644          2.39831    0.00063          2.31187  ... #TRP
BRST 10004M004        U       0.08075          2.39261    0.00061          2.31186  ... #TRP
BRST 10004M004        U       0.06701          2.37886    0.00067          2.31185  ... #TRP
BRST 10004M004        U       0.06765          2.37942    0.00098          2.31177  ... #TRP
GANP 11515M001        U       0.04676          2.16866    0.00067          2.12190  ... #TRP
GANP 11515M001        U       0.04605          2.16796    0.00048          2.12192  ... #TRP
GANP 11515M001        U       0.07752          2.19943    0.00045          2.12191  ... #TRP
GANP 11515M001        U       0.08049          2.20239    0.00047          2.12191  ... #TRP
GANP 11515M001        U       0.06357          2.18548    0.00045          2.12190  ... #TRP
GANP 11515M001        U       0.06543          2.18733    0.00049          2.12190  ... #TRP
GANP 11515M001        U       0.06934          2.19121    0.00069          2.12187  ... #TRP
HERT 13212M010        U       0.11227          2.41543    0.00084          2.30316  ... #TRP
HERT 13212M010        U       0.10498          2.40817    0.00066          2.30318  ... #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.

After running the program a warning message pops up indicating that the normalization of residuals based on the uncertainty of the estimated parameters (NORMALIZED in option "Type of computed residuals") fails. Some parameters related to the station WSRT (troposphere and ambiguities) show comparable high formal errors. In that case, no normalization of the residuals takes place. They ending as high residuals in the related result file and the related observations will be detected and removed in the subsequent steps.

```
### SR resout: Numerical  problems  with  normalization  detected
               for epoch 2019-02-13 01:33:00
               Number of effected observations:     1


### SR resout: Numerical  problems  with  normalization  detected
               for epoch 2019-02-13 23:58:00
               Number of effected observations:    12
...
### SR solcheck:   16 singular  element(s) found:
                   Num    Type
                   -----  -----
                   2117   S_
                   2206   S_
                   2225   S_
                   2239   S_
                   2255   S_
...
```

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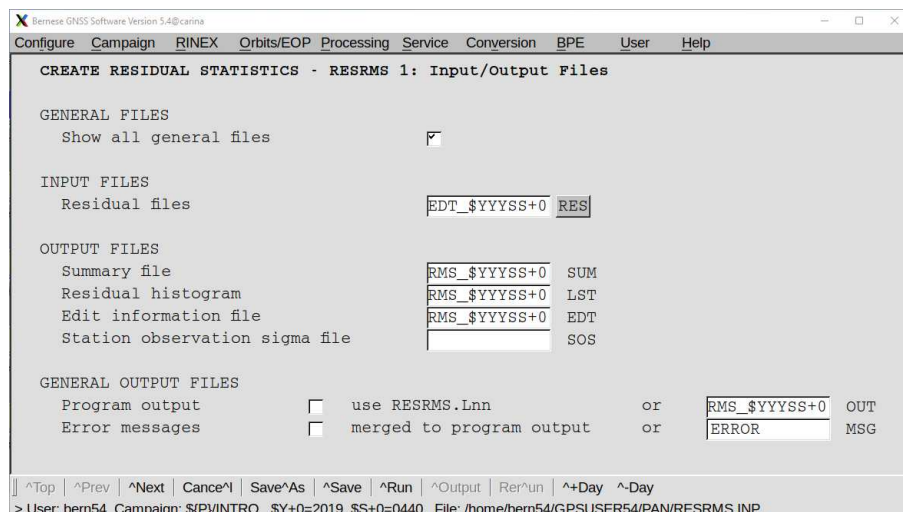
The sampling interval you have previously introduced in option "Sampling interval" in program GPSEST has to be repeated here. RESRMS makes the assumption that the observations between two outliers in the sampled residual file are also bad.

The program output of RESRMS (`${P}/INTRO/OUT/RMS_2019044.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       1.4        0.7       1.1    10796    77     10 ...
   2    GANP 11515M001    MIKL 12335M001       1.4        0.7       1.1    10431    75     11 ...
   3    GANP 11515M001    WTZZ 14201M014       1.2        0.7       0.9    11525    78      1 ...
   4    HERT 13212M010    TLSE 10003M009       1.1        0.6       1.0     7536    53      7 ...
   5    JOZ2 12204M002    ONSA 10402M004       1.2        0.7       1.0     7778    53      6 ...
   6    LAMA 12209M001    ONSA 10402M004       1.1        0.6       1.0     7690    53      7 ...
   7    MATE 12734M008    ORID 15601M001       1.2        0.6       1.0     7441    53      5 ...
   8    MATE 12734M008    ZIM2 14001M008       1.3        0.7       1.1    10108    75     12 ...
   9    ONSA 10402M004    PTBB 14234M001       1.1        0.7       1.0     4163    32      2 ...
 ...

 -------------------------------------------------------------------------------------------- ...
  NUMBER OF EDIT REQUESTS:     85
```

In addition, files containing a summary table (`${P}/INTRO/OUT/RMS_20190440.SUM`) and a histogram (`${P}/INTRO/OUT/RMS_20190440.LST`) of the residuals are available. The most important result file for the data screening is the "Edit information file" (`${P}/INTRO/OUT/RMS_20190440.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 from SATMRK reports the number of marked observations per baseline:

```
...
SUMMARY OF ACTION IN THE OBS. FILE(S):      ${P}/INTRO/OUT/RMS_20190440.EDT
-----------------------------------
                                       Mea-       Observations        ...
                                       type     mark  unmark  delete  ...
  Num  Station name 1      Station name 2                              ...
-------------------------------------------------------------------------- ...
    1  BRST 10004M004      TLSE 10003M009    P :    238      0       0  ...
    2  GANP 11515M001      MIKL 12335M001    P :    238      0       0  ...
    3  GANP 11515M001      WTZZ 14201M014    P :     20      0       0  ...
    4  HERT 13212M010      TLSE 10003M009    P :    156      0       0  ...
    5  JOZ2 12204M002      ONSA 10402M004    P :    130      0       0  ...
    6  LAMA 12209M001      ONSA 10402M004    P :    160      0       0  ...
    7  MATE 12734M008      ORID 15601M001    P :     86      0       0  ...
    8  MATE 12734M008      ZIM2 14001M008    P :    262      0       0  ...
    9  ONSA 10402M004      PTBB 14234M001    P :     70      0       0  ...
  ...
-------------------------------------------------------------------------- ...
       Total:                                     1958      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:

```
X  Bernese GNSS Software Version 5.4@carina                                    −   □   ×

Configure   Campaign   RINEX   Orbits/EOP  Processing   Service   Conversion   BPE      User      Help

   PARAMETER ESTIMATION - GPSEST 1.1: Input Files 1


   GENERAL FILES AND PROCESSING MODE
      Space geodetic technique         GNSS      ▼
      Differencing level               DOUBLE    ▼
      LEO data processing              □
      Show all general files           ☑


   OBSERVATION FILES
      Phase observations               ????$S+0    PSH        ????$S+0    PZH
      Code  observations                           CSH                    CZH
      Range observations                           RZH

   MAIN INPUT FILES
      Station coordinates              APR_$YYYSS+0  CRD
      Standard orbits                  COD_$YYYSS+0  STD
      Earth rotation parameters        COD_$YYYSS+0  ERP
      Satellite clock corrections                   CLK
      Observable-specific biases                    OSB     □   NL phase biases from CLK
      VMF grid file                                 GRD
      Ionosphere models                HOI_$YYYSS+0  ION

   CORRECTIONS FOR LOADING EFFECTS AND CENTER OF MASS
      Ocean tidal loading              EXAMPLE       BLQ
      Atmospheric tidal loading                      ATL
         related error handling        ERROR         ▼

◄                                                                                    ►
‖ ^Top   ^Prev   ^Next   Cance^l   Save^As   ^Save   ^Run   ^Output   Rer^un   ^+Day   ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

The file in the input field "Ionosphere models" enables the HOI–corrections.

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

```
X  Bernese GNSS Software Version 5.4@carina                                    −   □   ×

Configure   Campaign   RINEX   Orbits/EOP  Processing   Service   Conversion   BPE      User      Help

   GPSEST 2.1: Output Files 1


   GENERAL OUTPUT FILES
      Program output          □   use GPSEST.Lnn             or   FLT_$YYYSS+0   OUT
      Error messages          □   merged to program output   or   ERROR          MSG

   NORMAL EQUATION SYSTEM                       NQ0

   STATION- AND SATELLITE-RELATED RESULTS
      Station coordinates              FLT_$YYYSS+0   CRD
      Satellite orbital elements                      ELE
      Earth rotation parameters                       ERP
      Earth rotation parameters (IERS)                IEP

   ATMOSPHERE-SPECIFIC RESULTS
      Troposphere estimates            FLT_$YYYSS+0   TRP
      Troposphere estimates (SINEX)                   TRO
      Troposphere slant delays                        TRS
      Ionosphere models                               ION
      Ionosphere models (IONEX)                       INX


‖ ^Top   ^Prev   ^Next   Cance^l   Save^As   ^Save   ^Run   ^Output   Rer^un   ^+Day   ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```
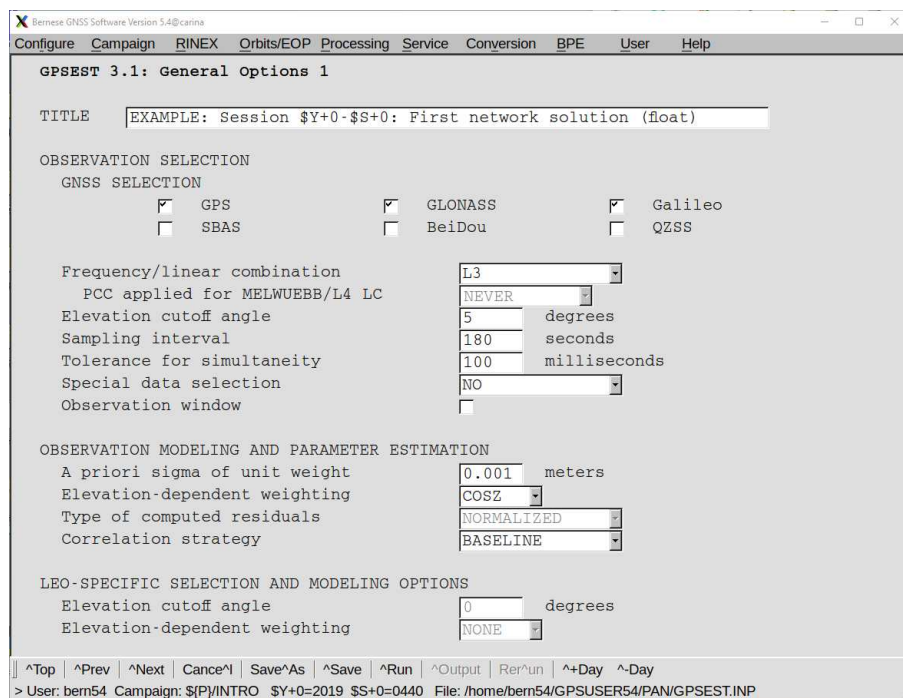
In the subsequent panel you should remove the output filename for the "Residuals" because we do not need the residuals from this run.

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.

```
Bernese GNSS Software Version 5.4@carina                              —  □  ×

Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE      User      Help

    GPSEST 6.1.1: Site-Specific Troposphere Parameters 1

    ZENITH PATH DELAY PARAMETERS
        Mapping function                  WET_GMF3              ▾
        Parameter spacing                 01 00 00    (hh mm ss)

    HORIZONTAL GRADIENT PARAMETERS
        Gradient estimation model         CHEN-HERRING          ▾
        Parameter spacing                 24 00 00    (hh mm ss)

    A PRIORI SIGMAS                       Absolute              Relative
        Zenith path delay                        meters        5         meters
        Horizontal gradients                     meters        5         meters


  ‖ ^Top │ ^Prev │ ^Next │ Cance^l │ Save^As │ ^Save │ ^Run │ ^Output │ Rer^un │ ^+Day  ^-Day
  > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

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          51         51       0              0    0    0     0
 Ambiguities                             2739          0    2739   (bfst)      0    0   40     0
 Site-specific troposphere parameters     493        493       0              0    0    0     0
 ---------------------------------------------------------------------------------------------
 Total number                            3243        544    2699              0    0   40     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      133235
Total number of pseudo-observations             30

Total number of explicit parameters            544
Total number of implicit parameters           2699

Total number of observations               133265
Total number of adjusted parameters           3243
Degree of freedom (DOF)                     130022

A posteriori RMS of unit weight         0.000987 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: 2019-02-13 11:59:45

Station name        Typ    A priori value   Estimated value    Correction       RMS error    ...
----------------------------------------------------------------------------------------------- ...
BRST 10004M004      X       4231162.41765    4231162.41830       0.00065          0.00063
                    Y       -332746.42891    -332746.42771       0.00120          0.00056
                    Z       4745131.06968    4745131.07283       0.00315          0.00060

                    U            65.81939         65.82211       0.00272          0.00076    ...
                    N         48.3804957       48.3804957        0.00168          0.00042    ...
                    E         -4.4965914       -4.4965914        0.00125          0.00056    ...

TLSE 10003M009      X       4627851.66234    4627851.66205      -0.00029          0.00051
                    Y        119640.28843     119640.28820      -0.00023          0.00046
                    Z       4372993.71461    4372993.71376      -0.00085          0.00051

                    U           207.18324        207.18244      -0.00080          0.00062    ...
                    N         43.5606968       43.5606968       -0.00041          0.00037    ...
                    E          1.4808939        1.4808938       -0.00022          0.00046    ...

GANP 11515M001      X       3929181.30600    3929181.29822      -0.00778          0.00061
                    Y       1455236.94546    1455236.95378       0.00832          0.00053
                    Z       4793653.99294    4793654.03586       0.04292          0.00063

                    U           746.00460        746.03412       0.02952          0.00078    ...
                    N         49.0347149       49.0347152        0.03144          0.00041    ...
                    E         20.3229395       20.3229396        0.01046          0.00051    ...

MIKL 12335M001      X       3698553.70970    3698553.70973       0.00003          0.00064
                    Y       2308676.23252    2308676.23206      -0.00046          0.00060
                    Z       4639769.62655    4639769.62475      -0.00180          0.00066

                    U            93.92954         93.92808      -0.00146          0.00081    ...
                    N         46.9727862       46.9727862       -0.00107          0.00045    ...
                    E         31.9728450       31.9728450       -0.00040          0.00059    ...

...
```

```
...
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      0.00044   0.00003  0.11297   0.00009   0.00011  0.00150   ...
BRST 10004M004      0.00043   0.00003  0.10486   0.00008   0.00010  0.00105   ...
BRST 10004M004      0.00043   0.00003  0.10191   0.00008   0.00009  0.00113   ...
BRST 10004M004      0.00043   0.00002  0.10370   0.00007   0.00009  0.00108   ...
BRST 10004M004      0.00042   0.00002  0.09834   0.00007   0.00008  0.00104   ...
...
BRST 10004M004      0.00034  -0.00007  0.06907   0.00007   0.00009  0.00106   ...
BRST 10004M004      0.00034  -0.00007  0.06841   0.00008   0.00010  0.00113   ...
BRST 10004M004      0.00034  -0.00008  0.07125   0.00008   0.00011  0.00116   ...
BRST 10004M004      0.00033  -0.00008  0.06842   0.00009   0.00011  0.00212   ...
GANP 11515M001     -0.00001  -0.00088  0.04855   0.00006   0.00006  0.00110   ...
GANP 11515M001     -0.00003  -0.00087  0.04251   0.00006   0.00006  0.00082   ...
GANP 11515M001     -0.00005  -0.00086  0.04326   0.00005   0.00006  0.00081   ...
GANP 11515M001     -0.00007  -0.00085  0.04354   0.00005   0.00005  0.00076   ...
GANP 11515M001     -0.00009  -0.00083  0.04544   0.00005   0.00005  0.00085   ...
GANP 11515M001     -0.00011  -0.00082  0.05617   0.00004   0.00005  0.00073   ...
...
```

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:
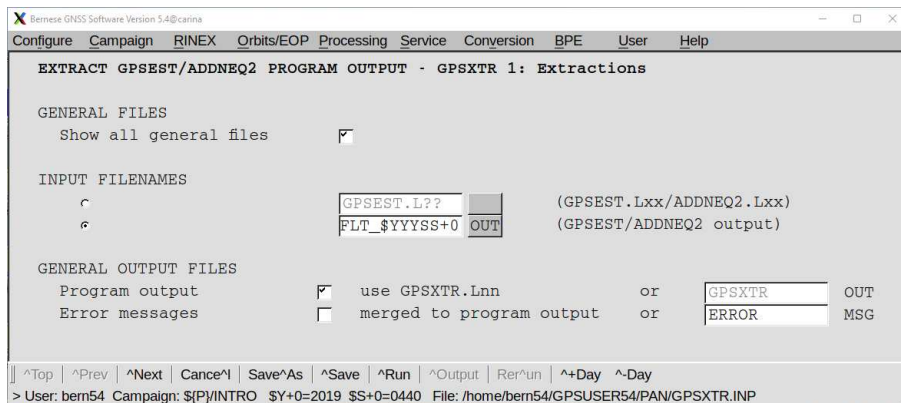
and select the name of the summary file
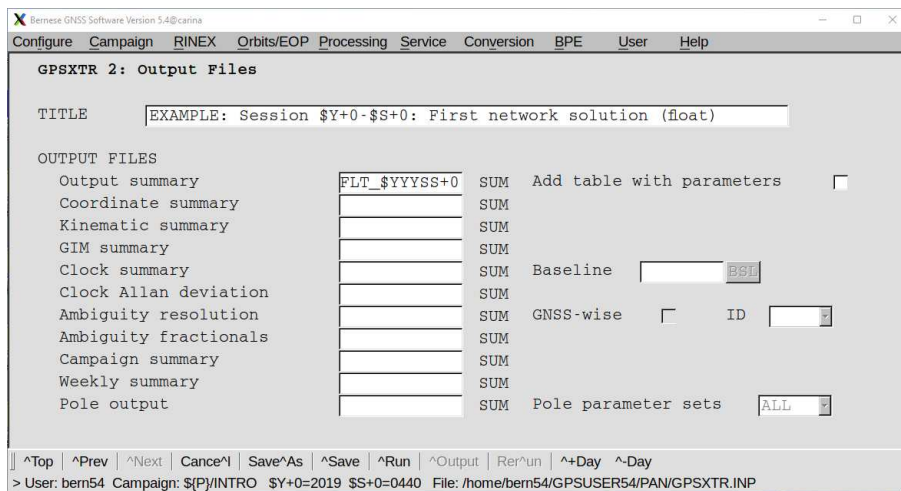
The short extraction from the full program output in `${P}/INTRO/OUT/FLT_20190440.OUT` reads like

```
FLT_20190440.OUT     Rms:  0.99 , # fil.:   16 , # obs.:   133265 , # par.:   3243
(DOY: 2019-044)
```

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 0440 of year 2019) can be generated by listing all phase single–difference header files in the campaign's observation directory of your campaign:

```
bern52@carina:~ > ls ${P}/INTRO/OBS/????0440.PSH
${P}/INTRO/OBS/BRTL0440.PSH
${P}/INTRO/OBS/GAMI0440.PSH
${P}/INTRO/OBS/GAWZ0440.PSH
${P}/INTRO/OBS/HETL0440.PSH
${P}/INTRO/OBS/JOON0440.PSH
${P}/INTRO/OBS/LAON0440.PSH
${P}/INTRO/OBS/MAOR0440.PSH
${P}/INTRO/OBS/MAZI0440.PSH
${P}/INTRO/OBS/ONPT0440.PSH
${P}/INTRO/OBS/ONWZ0440.PSH
${P}/INTRO/OBS/TLZI0440.PSH
${P}/INTRO/OBS/VIWZ0440.PSH
${P}/INTRO/OBS/WSWZ0440.PSH
${P}/INTRO/OBS/WTWZ0440.PSH
${P}/INTRO/OBS/WZZI0440.PSH
${P}/INTRO/OBS/ZIZM0440.PSH
```

The first baseline for this session is from BRST to TLSE with the observation filename `BRTL0440`. 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.
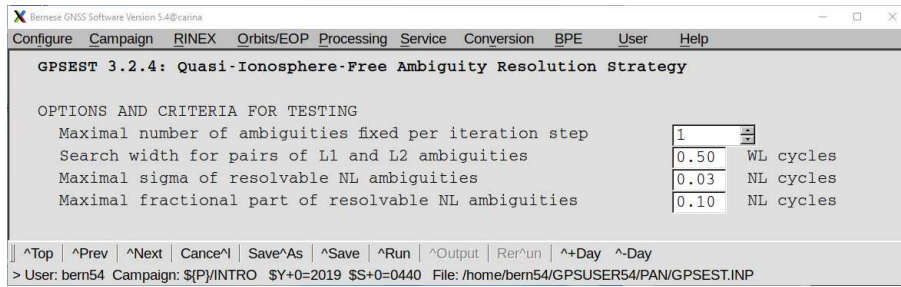
Even if we introduce the coordinate solution from the previous network solution from Section 5.2, we fix only the coordinates of the first station and estimate those from the second one with each iteration of ambiguity resolution. In this way, the geometry can react to the resolved ambiguities.
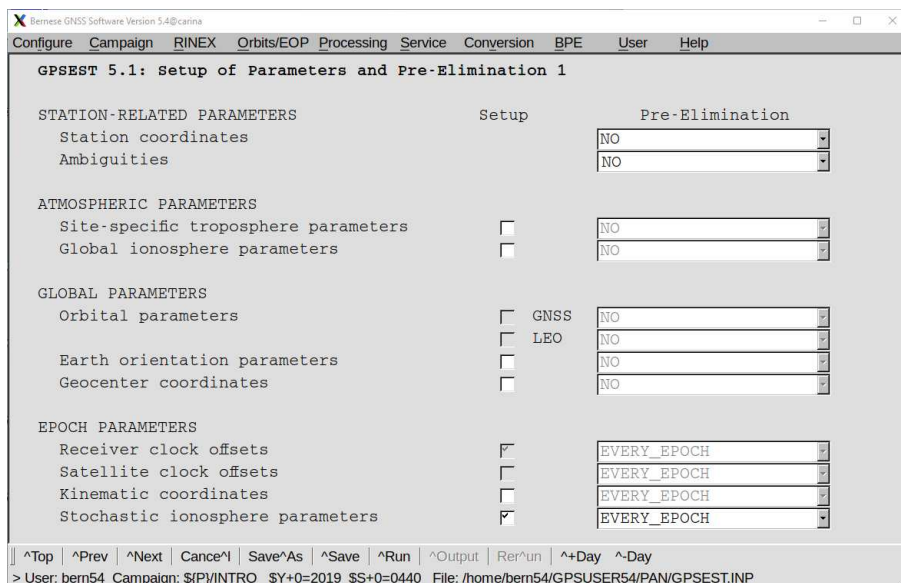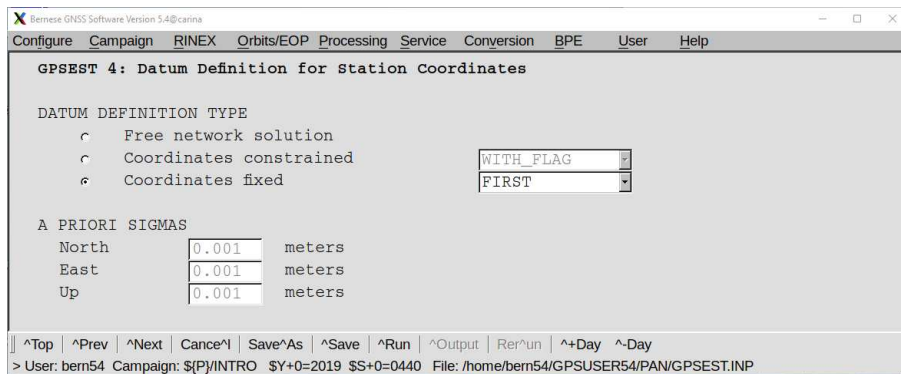
An additional panel with options specific to epoch–parameters is displayed now because the "Parameter Setup: stochastic ionosphere parameters" are pre-eliminated EVERY_EPOCH.
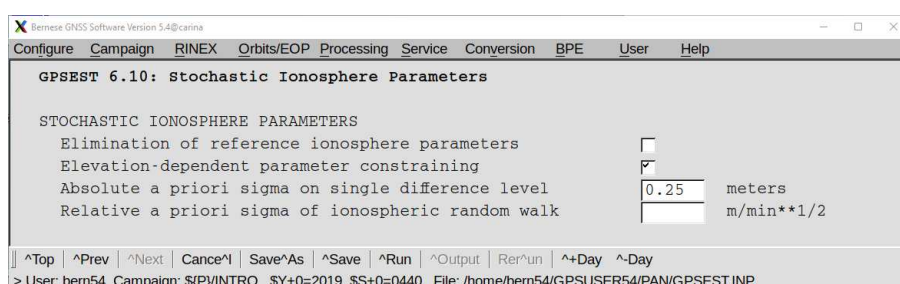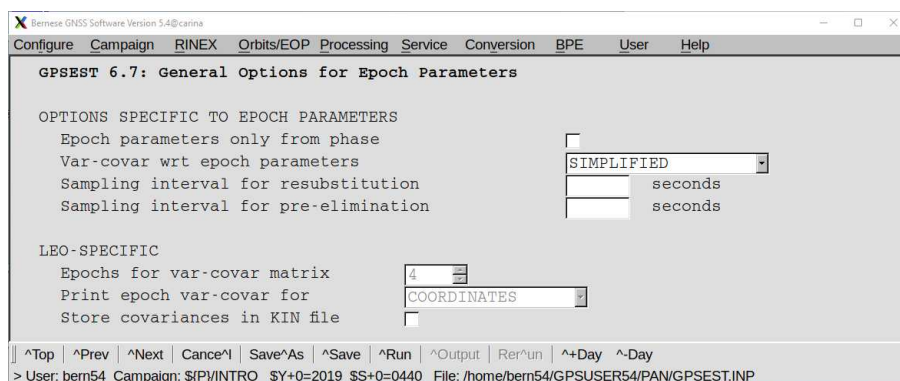
After reporting input options and input data for the current run of GPSEST, the results are presented in two parts. The first part refers to the solution where the ambiguities are estimated as real values whereas the second part reports the results after resolving the ambiguity parameters to integer 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                                 350       350        0               0    0    0     0
Stochastic ionosphere parameters          59105         0    59105   (epow)      0    0    0  5543
-------------------------------------------------------------------------------------------
Total number                              59458       353    59105               0    0    0  5543


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



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

Total number of authentic observations     112450
Total number of pseudo-observations             2
...

A posteriori RMS of unit weight          0.001254 m
Chi**2/DOF                                   1.57

...
```

```
...

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

Sol Station name          Typ Correction  Estimated value  RMS error   A priori value ... Abb
---------------------------------------------------------------------------------------- ... -----
  1 TLSE 10003M009          X   -0.00110    4627851.66095     0.00018    4627851.66205 ... #CRD
  1 TLSE 10003M009          Y    0.00010     119640.28830     0.00021     119640.28820 ... #CRD
  1 TLSE 10003M009          Z   -0.00092    4372993.71284     0.00016    4372993.71376 ... #CRD

...

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

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

    1      1    1      1     701   1   1    1  172  217        0.11   0.11    1432776.11
    2      1    1   2830    2880   1   1    2  172  217        3.50   0.85    1432629.50
    3      1    7    720    1326   1   1    4  172  217       -4.27   0.12    2614156.73
    4      1    7   2646    2825   1   1    5  172  217       -1.37   0.47    2614121.63
    5      1    8      1     401   1   1    7  172  217       -1.43   0.13    1201549.57
    6      1    8   2576    2581   1   1    8  172  217       -1.10   3.04    1201598.90
    7      1    8   2588    2880   1   1    9  172  217       -1.75   0.16    1201598.25
    8      1   10      1     240   1   1   10  172  217       -1.94   0.20    -940600.94
    9      1   10   1548    1718   1   1   11  172  217        1.94   0.35    -940558.06
   10      1   10   1725    1852   1   1   12  172  217        1.14   0.45    -940553.86
   11      1   10   2561    2825   1   1   14  172  217        5.07   0.18    -940673.93
   12      1   10   2832    2880   1   1   15  172  217        3.27   0.30    -940674.73
   13      1   11      1     606   1   1   16  172  217       -1.69   0.11    2346706.31
   14      1   11   2791    2825   1   1   18  172  217       -0.42   0.94    2346725.58
   15      1   11   2849    2880   1   1   19  172  217        3.13   0.64    2346724.13
   16      1   16      1      78   1   1   20  172  217       -1.69   0.51   -2504795.69
   17      1   16   2307    2842   1   1   22  172  217        0.19   0.12   -2504862.81
   18      1   16   2849    2880   1   1   23  172  217        3.85   0.55   -2504861.15
   19      1   18      1     561   1   1   24  172  217       -1.72   0.12    1349999.28
   20      1   18   2689    2842   1   1   25  172  217       -1.60   0.31    1349919.40
   21      1   18   2849    2880   1   1   26  172  217        3.24   0.42    1349919.24
   22      1   20      1     106   1   1   27  172  217       -1.43   0.45    -139284.43
   23      1   20   1424    1432   1   1   29  172  217       -2.66   2.41    -139505.66
   24      1   20   1439    1453   1   1   30  172  217        5.89   1.48    -139498.11
   25      1   20   1460    1779   1   1   31  172  217       -2.99   0.24    -139500.99
   26      1   20   2465    2842   1   1   32  172  217       -0.08   0.16    -139436.08
   27      1   20   2849    2880   1   1   33  172  217        3.58   0.56    -139435.42
   28      1   22     19     751   1   1   34  172  217        3.07   0.11   -1558169.93
   29      1   26   2167    2825   1   1   36  172  217       -3.61   0.11   -3210511.61
   30      1   27      1     272   1   1   38  172  217       -1.68   0.16    -899410.68
   31      1   27   2411    2825   1   1   39  172  217        1.20   0.13    -899408.80
   32      1   27   2832    2880   1   1   40  172  217        3.52   0.26    -899407.48
   33      1   30    836    1486   1   1   41  172  217       -1.23   0.12    3572427.77
...
```

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

   1 154 188    1 175 221    1   -4    0  -0.40    -0.54    0.138    0.007   0.003   211  225
```

```
-------------------------------------------------------------------------------
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  66  79   1  156 190   1    3    3   -0.28   -0.38   0.098   0.008   0.003  201  204


-------------------------------------------------------------------------------
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  79  96   1   93 113   1   -1    1    0.01    0.02  -0.011  -0.021   0.003  226  207


-------------------------------------------------------------------------------
...
-------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:    15
-------------------------------------------------------------------------------


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

   1   1   1   1   28  34   1   -3   -1    0.03    0.05  -0.015  -0.019   0.004    1   22


-------------------------------------------------------------------------------
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  28  34   2   98 118   1    4    3   -0.00   -0.00   0.001   0.000   0.003   22    3


-------------------------------------------------------------------------------
...
-------------------------------------------------------------------------------
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  51  62   1  113 136   1    8    5   -0.45   -0.58   0.130   0.004   0.005  114  110


-------------------------------------------------------------------------------
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  26  32   1  173 219  12   -8   -8   -0.79   -1.00   0.211  -0.044   0.005   20   25


-------------------------------------------------------------------------------
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  44  55   1  101 121   1    1    0    0.78    1.00  -0.217   0.021   0.005  107  103


-------------------------------------------------------------------------------
AMBIGUITY RESOLUTION ITERATION:    51
-------------------------------------------------------------------------------


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

   1  60  73   1  115 138   1   -3    0    0.22    0.27  -0.053   0.033   0.005  123  119
...
```

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: 48, 50 and 51 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: 65 or 76, 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     701   1   1    1    28  34          -3             1432773.       0.00000
    2     1    1   2830    2880   1   1    2   173 219          -4             1432622.       0.00000
    3     1    7    720    1326   1   1    4   126 157          -2             2614159.       0.00000
    4     1    7   2646    2825   1   1    5   173 219         -11             2614112.       0.00000
    5     1    8      1     401   1   1    7   125 155          -4             1201547.       0.00000
    6     1    8   2576    2581   1   1    8   172 217       -3.32   3.14      1201596.68
    7     1    8   2588    2880   1   1    9   173 219         -10             1201590.       0.00000
    8     1   10      1     240   1   1   10   141 174           2             -940597.       0.00000
    9     1   10   1548    1718   1   1   11   173 219          -7             -940567.       0.00000
   10     1   10   1725    1852   1   1   12   172 217       -1.17   0.46      -940556.17
   11     1   10   2561    2825   1   1   14   141 174           9             -940670.       0.00000
   12     1   10   2832    2880   1   1   15   173 219          -5             -940683.       0.00000
   13     1   11      1     606   1   1   16    19  24           0             2346708.       0.00000
   14     1   11   2791    2825   1   1   18   172 217       -2.67   0.97      2346723.33
   15     1   11   2849    2880   1   1   19   173 219          -5             2346716.       0.00000
   16     1   16      1      78   1   1   20   173 219         -11            -2504805.       0.00000
```

```
   17    1    16    2307   2842   1   1   22    31    39           -1           -2504864.        0.00000
   18    1    16    2849   2880   1   1   23   143   176            1           -2504864.        0.00000
   19    1    18       1    561   1   1   24    98   118           -1            1350000.        0.00000
   20    1    18    2689   2842   1   1   25    36    46           -1            1349920.        0.00000
   21    1    18    2849   2880   1   1   26   173   219           -5            1349911.        0.00000
   22    1    20       1    106   1   1   27   143   176           -3            -139286.        0.00000
   23    1    20    1424   1432   1   1   29   172   217        -4.97   2.49     -139507.97
   24    1    20    1439   1453   1   1   30   172   217         3.57   1.53     -139500.43
   25    1    20    1460   1779   1   1   31   173   219          -12            -139510.        0.00000
   26    1    20    2465   2842   1   1   32   173   219           -8            -139444.        0.00000
   27    1    20    2849   2880   1   1   33   143   176            2            -139437.        0.00000
   28    1    22      19    751   1   1   34    98   118            4           -1558169.        0.00000
   29    1    26    2167   2825   1   1   36   165   208          -10           -3210518.        0.00000
   30    1    27       1    272   1   1   38   141   174            2            -899407.        0.00000
   31    1    27    2411   2825   1   1   39   141   174            5            -899405.        0.00000
   32    1    27    2832   2880   1   1   40   143   176            1            -899410.        0.00000
   33    1    30     836   1486   1   1   41   173   219          -10            3572419.        0.00000
  ...
```

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                                  86       84       0                 0    2    0     0
 Stochastic ionosphere parameters          59105        0   59105   (epow)        0    0    0  5543
 --------------------------------------------------------------------------------------------
 Total number                              59194       87   59105                 0    0    0  5543


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


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

Total number of authentic observations     112450
Total number of pseudo-observations             2

Total number of explicit parameters            89
Total number of implicit parameters         59105

Total number of observations               112452
Total number of adjusted parameters         59194
Degree of freedom (DOF)                     53258

A posteriori RMS of unit weight          0.001298 m
Chi**2/DOF                                    1.68

Total number of observation files               1
Total number of unobserved ambiguities         92
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    -0.00063    4627851.66142    0.00014     4627851.66205 ... #CRD
  1 TLSE 10003M009         Y     0.00013     119640.28832    0.00007      119640.28819 ... #CRD
  1 TLSE 10003M009         Z    -0.00057    4372993.71319    0.00014     4372993.71376 ... #CRD
```

You may see from the output that from a total of 350 ambiguities 266 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 (WTWZ0440.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                             344      344        0           0    0    0     0
--------------------------------------------------------------------------------------
Total number                            347      347        0           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     118374
Total number of pseudo-observations             4

Total number of explicit parameters           347
Total number of implicit parameters             0

Total number of observations               118378
Total number of adjusted parameters           347
Degree of freedom (DOF)                    118031

A posteriori RMS of unit weight         0.001128 m
Chi**2/DOF                                   1.27

Total number of observation files               1
Total number of unobserved ambiguities         42
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                              56       52        0           0    4    0     0
--------------------------------------------------------------------------------------
Total number                             59       55        0           0    4    0     0


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

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

Total number of authentic observations     118374
Total number of pseudo-observations             4

Total number of explicit parameters            59
Total number of implicit parameters             0

Total number of observations               118378
Total number of adjusted parameters            61
Degree of freedom (DOF)                    118317

A posteriori RMS of unit weight         0.001326 m
Chi**2/DOF                                   1.76

Total number of observation files               1
Total number of unobserved ambiguities         42
Total number of stations                        1
...
```

From the number of ambiguity parameters it can be computed that 288 out of 344 ambiguities from GPS, GLONASS, and Galileo have been resolved to their integer numbers. Please remind, that at least 6 ambiguity parameters must remain real values because one reference ambiguity per GNSS and frequency are 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 sixteen 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 044 of year 2019) using "Menu>BPE>Start BPE processing":
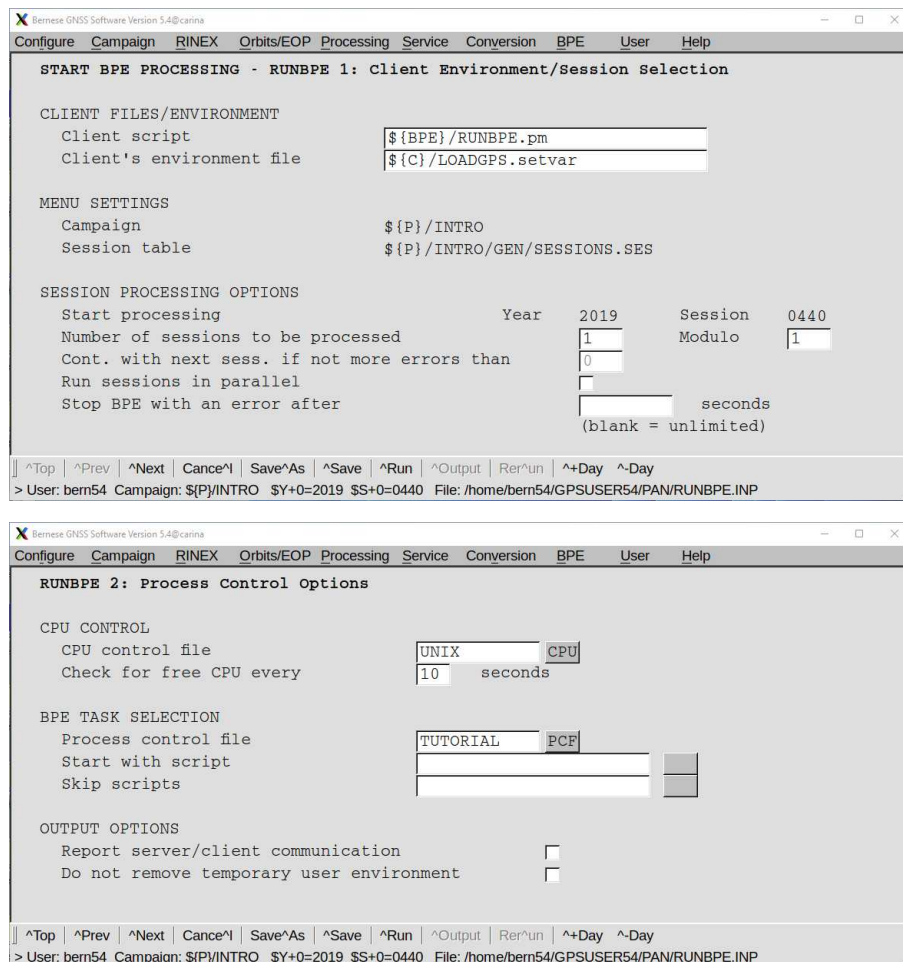
If you follow the tutorial outside from the environment of the *Bernese Introductory Course* you can select RNX2SNX in option "Process control file" and skip all scripts apart from the range between PID 401 SATMRK to PID 442 GNSL12_P (option "Skip scripts").
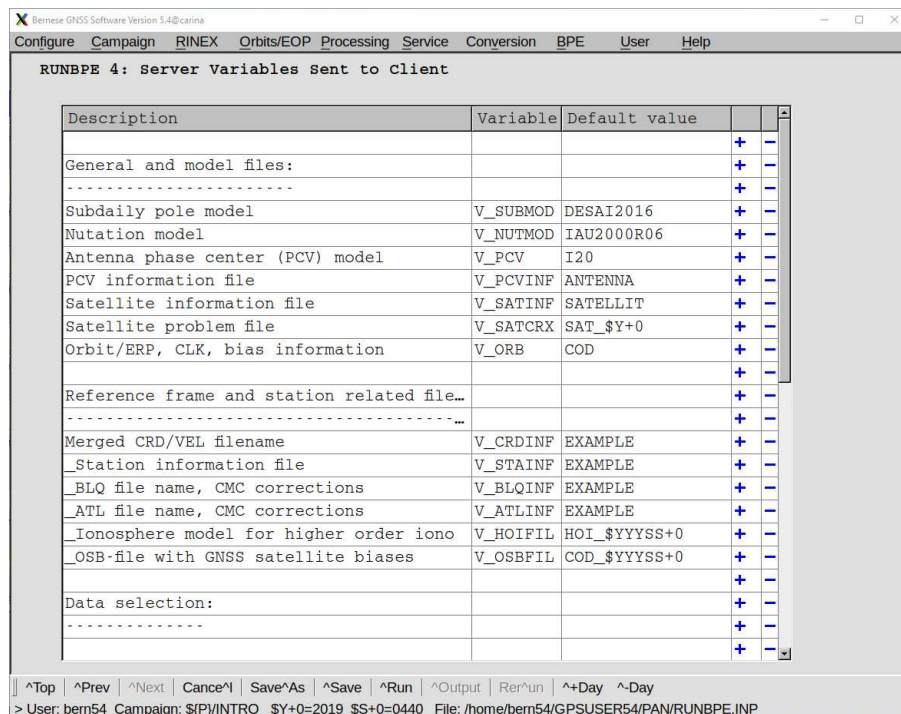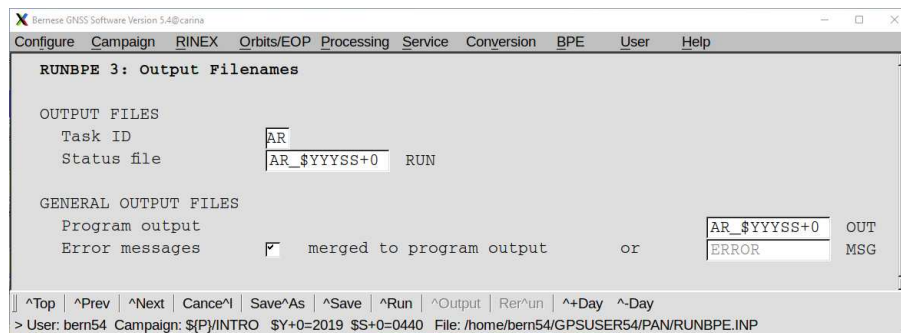
Run the BPE for the current session. If the BPE stops with an error you can inspect the files `${P}/INTRO/BPE/AR190440_...PRT` and `${P}/INTRO/BPE/AR190440_...LOG` belonging to your current session. These files report for instance if an input file is missing. This might be the case if you did not follow 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`):
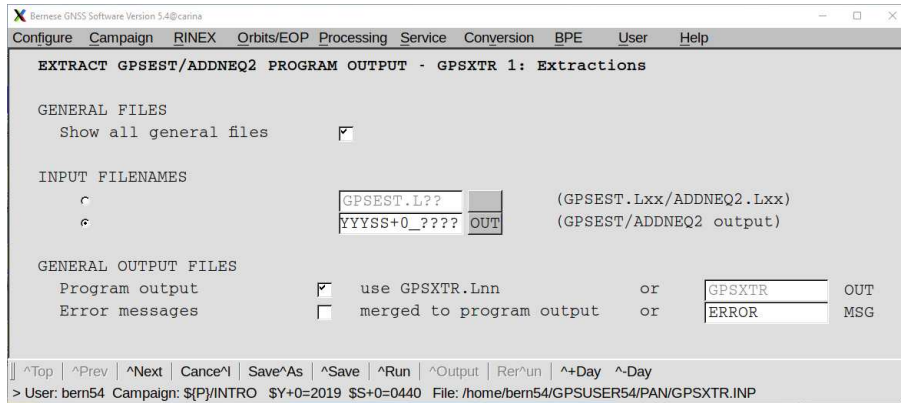
The entry for option "GPSEST/ADDNEQ output files" may be incomplete in the screenshot. It should be `L12_$YYYSS+0_????` (you may check with bottom right to the input field).

All program output files related to the `L12` ambiguity resolution method have been specified with program output filenames fitting in the shape `${P}/INTRO/OUT/L12_$YYYSS+0_????.OUT` and can, therefore, easily be selected in the input field "GPSEST/ADDNEQ output files".
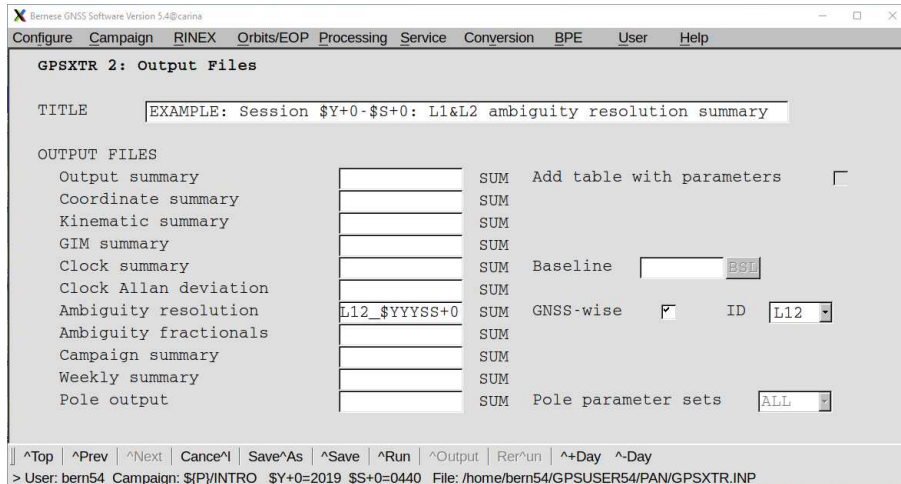
The resulting protocol in the file `${P}/INTRO/OUT/L12_20190440.SUM` looks like:

```
File       Sta1 Sta2     Length      Before       After     Res   Sys   ...
                         (km)     #Amb  (mm)    #Amb  (mm)   (%)         ...
          -------------------------------------------------------------...
WTWZ0440 WTZR WTZZ       0.002    130   1.1      2   1.3    98.5 G      ... #AR_L12
WTWZ0440 WTZR WTZZ       0.002    112   1.1     42   1.3    62.5  R     ... #AR_L12
WTWZ0440 WTZR WTZZ       0.002     90   1.1      0   1.3   100.0    E   ... #AR_L12
WTWZ0440 WTZR WTZZ       0.002    332   1.1     44   1.3    86.7 GRE    ... #AR_L12
ZIZM0440 ZIM2 ZIMM       0.019    112   1.2      4   1.3    96.4 G      ... #AR_L12
          -------------------------------------------------------------...
Tot:   2                 0.010    242   1.2      6   1.3    97.5 G      ... #AR_L12
Tot:   1                 0.002    112   1.1     42   1.3    62.5  R     ... #AR_L12
Tot:   1                 0.002     90   1.1      0   1.3   100.0    E   ... #AR_L12
Tot:   2                 0.010    444   1.2     48   1.3    89.2 GRE    ... #AR_L12


Legend:
 QTR   consider GPS quater cycle        : - (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`):

<div align="center">

Filenames from

	Manual processing	processed by the BPE
Strategy: direct L_1/L_2:	WTWZ20190441.OUT	L12_20190440_WTWZ.OUT

</div>

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_20190440.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)   (%)        ...
                   ---------------------------------------------------------...
BRTL0440  BRST TLSE   707.462    69   1.4     15  1.5   78.3 G    ... #AR_WL
BRTL0440  BRST TLSE   707.462    46   1.4     15  1.5   67.4    E ... #AR_WL
BRTL0440  BRST TLSE   707.462   115   1.4     30  1.5   73.9 G E  ... #AR_WL
GAMI0440  GANP MIKL   897.345    51   0.8      4  0.8   92.2 G    ... #AR_WL
GAMI0440  GANP MIKL   897.345    28   0.8      5  0.8   82.1    E ... #AR_WL
GAMI0440  GANP MIKL   897.345    79   0.8      9  0.8   88.6 G E  ... #AR_WL
GAWZ0440  GANP WTZZ   543.530    56   1.0      9  1.1   83.9 G    ... #AR_WL
GAWZ0440  GANP WTZZ   543.530    40   1.0      2  1.1   95.0    E ... #AR_WL
GAWZ0440  GANP WTZZ   543.530    96   1.0     11  1.1   88.5 G E  ... #AR_WL
...                                                          ...
WZZI0440  WTZZ ZIM2   475.909    54   1.1      6  1.2   88.9 G    ... #AR_WL
WZZI0440  WTZZ ZIM2   475.909    37   1.1      2  1.2   94.6    E ... #AR_WL
WZZI0440  WTZZ ZIM2   475.909    91   1.1      8  1.2   91.2 G E  ... #AR_WL
                   ---------------------------------------------------------...
Tot:  14             760.073   957   1.3    274  1.4   71.4 G    ... #AR_WL
Tot:   8             809.713   269   1.1     39  1.2   85.5    E ... #AR_WL
Tot:  14             760.073  1226   1.3    313  1.4   74.5 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)   (%)        ...
                   ---------------------------------------------------------...
BRTL0440  BRST TLSE   707.462    69   1.1     15  1.2   78.3 G    ... #AR_NL
BRTL0440  BRST TLSE   707.462    46   1.1     15  1.2   67.4    E ... #AR_NL
BRTL0440  BRST TLSE   707.462   115   1.1     30  1.2   73.9 G E  ... #AR_NL
GAMI0440  GANP MIKL   897.345    52   1.1      5  1.1   90.4 G    ... #AR_NL
GAMI0440  GANP MIKL   897.345    37   1.1     14  1.1   62.2    E ... #AR_NL
GAMI0440  GANP MIKL   897.345    89   1.1     19  1.1   78.7 G E  ... #AR_NL
GAWZ0440  GANP WTZZ   543.530    56   0.8     10  1.0   82.1 G    ... #AR_NL
GAWZ0440  GANP WTZZ   543.530    40   0.8      2  1.0   95.0    E ... #AR_NL
GAWZ0440  GANP WTZZ   543.530    96   0.8     12  1.0   87.5 G E  ... #AR_NL
...                                                          ...
WZZI0440  WTZZ ZIM2   475.909    54   0.9      6  1.1   88.9 G    ... #AR_NL
WZZI0440  WTZZ ZIM2   475.909    37   0.9      2  1.1   94.6    E ... #AR_NL
WZZI0440  WTZZ ZIM2   475.909    91   0.9      8  1.1   91.2 G E  ... #AR_NL
                   ---------------------------------------------------------...
Tot:  14             760.073   985   0.9    311  1.0   68.4 G    ... #AR_NL
Tot:   8             809.713   302   1.0     72  1.1   76.2    E ... #AR_NL
Tot:  14             760.073  1287   0.9    383  1.0   70.2 G E  ... #AR_NL

...
```

In particular for the Melbourne-Wübbena linear combination we observe a higher resolution rate for Galileo than for GPS. The reason is the lower noise level of code measurements obtained from the Galileo system. 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)   (%)        ...
-------------------------------------------------------------------...
BRTL0440  BRST TLSE    707.462   30  1.3    28  1.3    6.7  G     ... #AR_QIF
BRTL0440  BRST TLSE    707.462  114  1.3    36  1.3   68.4  R     ... #AR_QIF
BRTL0440  BRST TLSE    707.462   30  1.3    14  1.3   53.3    E   ... #AR_QIF
BRTL0440  BRST TLSE    707.462  174  1.3    78  1.3   55.2  GRE   ... #AR_QIF
GAMI0440  GANP MIKL    897.345   10  1.2     4  1.2   60.0  G     ... #AR_QIF
GAMI0440  GANP MIKL    897.345   96  1.2    38  1.2   60.4  R     ... #AR_QIF
GAMI0440  GANP MIKL    897.345   28  1.2     6  1.2   78.6    E   ... #AR_QIF
GAMI0440  GANP MIKL    897.345  134  1.2    48  1.2   64.2  GRE   ... #AR_QIF
GAWZ0440  GANP WTZZ    543.530   20  1.0    14  1.0   30.0  G     ... #AR_QIF
GAWZ0440  GANP WTZZ    543.530  100  1.0    34  1.0   66.0  R     ... #AR_QIF
GAWZ0440  GANP WTZZ    543.530    4  1.0     2  1.0   50.0    E   ... #AR_QIF
GAWZ0440  GANP WTZZ    543.530  124  1.0    50  1.0   59.7  GRE   ... #AR_QIF
...                                                               ...
WZZI0440  WTZZ ZIM2    475.909   12  1.1    10  1.2   16.7  G     ... #AR_QIF
WZZI0440  WTZZ ZIM2    475.909   94  1.1    28  1.2   70.2  R     ... #AR_QIF
WZZI0440  WTZZ ZIM2    475.909    4  1.1     4  1.2    0.0    E   ... #AR_QIF
WZZI0440  WTZZ ZIM2    475.909  110  1.1    42  1.2   61.8  GRE   ... #AR_QIF
-------------------------------------------------------------------...
Tot:  14              760.073   622  1.1   468  1.1   24.8  G     ... #AR_QIF
Tot:  13              774.297  1532  1.1   714  1.1   53.4  R     ... #AR_QIF
Tot:   8              809.713   148  1.1    56  1.2   62.2    E   ... #AR_QIF
Tot:  14              760.073  2302  1.1  1238  1.1   46.2  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_20190440.SUM` as well:

```
                                            numb.   ambiguity resolution statistics
     File     Station 1         Station 2       Sys  sat   total    L1          L2        ...
------------------------------------------------------------------------------------ ... ----
        1     BRST 10004M004    TLSE 10003M009  GPS   31      70    15  78.6%    15  78.6%  ... #AMB
        1     BRST 10004M004    TLSE 10003M009  GLO   22      58    19  67.2%    19  67.2%  ... #AMB
        1     BRST 10004M004    TLSE 10003M009  GAL   24      47     8  83.0%     8  83.0%  ... #AMB
        1     BRST 10004M004    TLSE 10003M009  tot   77     175    42  76.0%    42  76.0%  ... #AMB
        2     GANP 11515M001    MIKL 12335M001  GPS   31      53     3  94.3%     3  94.3%  ... #AMB
        2     GANP 11515M001    MIKL 12335M001  GLO   22      49    20  59.2%    20  59.2%  ... #AMB
        2     GANP 11515M001    MIKL 12335M001  GAL   22      38     4  89.5%     4  89.5%  ... #AMB
        2     GANP 11515M001    MIKL 12335M001  tot   75     140    27  80.7%    27  80.7%  ... #AMB
        3     GANP 11515M001    WTZZ 14201M014  GPS   32      57     8  86.0%     8  86.0%  ... #AMB
        3     GANP 11515M001    WTZZ 14201M014  GLO   22      51    18  64.7%    18  64.7%  ... #AMB
        3     GANP 11515M001    WTZZ 14201M014  GAL   24      41     2  95.1%     2  95.1%  ... #AMB
        3     GANP 11515M001    WTZZ 14201M014  tot   78     149    28  81.2%    28  81.2%  ... #AMB
      ...                                                                                   ...
       15     WTZZ 14201M014    ZIM2 14001M008  GPS   32      55     6  89.1%     6  89.1%  ... #AMB
       15     WTZZ 14201M014    ZIM2 14001M008  GLO   22      48    15  68.8%    15  68.8%  ... #AMB
       15     WTZZ 14201M014    ZIM2 14001M008  GAL   24      38     3  92.1%     3  92.1%  ... #AMB
       15     WTZZ 14201M014    ZIM2 14001M008  tot   78     141    24  83.0%    24  83.0%  ... #AMB
       16     ZIM2 14001M008    ZIMM 14001M004  GPS   32      57     3  94.7%     3  94.7%  ... #AMB
       16     ZIM2 14001M008    ZIMM 14001M004  tot   32      57     3  94.7%     3  94.7%  ... #AMB
 -----------------------------------------------------------------------------------...-.-----
       16     files  do  contain                GPS   32    1130   266  76.5%   266  76.5%  ,,,
       14     files  do  contain                GLO   23     846   403  52.4%   403  52.4%  ...
        9     files  do  contain                GAL   24     367    47  87.2%    47  87.2%  ...
       16     files  do  contain                tot   79    2343   716  69.4%   716  69.4%  ...


------------------------------------------------------------------
>>> CPU/Real time for pgm "OBSXTR": 0:00:00.023 / 0:00:00.023
>>> Program finished successfully


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


------------------------------------------------------------------
PRN |    Amb    |  L1 & L2 ambiguities  |   L5 ambiguities
    |   total   |  solved  #/clu   rel  |  solved  #/clu    rel
----+---------+----------------------+---------------------
  1 |       36  |     27     7.7   65.2 |     16     9.6    39.8
  2 |       41  |     36    12.2   80.6 |     29    15.8    66.3
  3 |       33  |     21     8.8   56.4 |     15    11.4    41.5
  4 |        6  |      0     0.0    0.0 |      0     0.0     0.0
  5 |       35  |     30    20.2   81.5 |     24    17.5    64.6
  6 |       44  |     34    14.3   71.9 |     28    16.3    59.7
  7 |       31  |     27    13.9   80.9 |     19    13.3    56.7
  8 |       49  |     42    12.6   78.9 |     34    12.7    63.9
 ...
 27 |       42  |     37    16.5   82.8 |     30    26.1    68.7
 28 |       40  |     32    18.5   75.7 |     26    15.0    60.7
 29 |       17  |     17    28.4   96.5 |     15    22.1    84.2
 30 |       18  |     18    18.4   94.6 |     16     9.3    79.4
 31 |       37  |     32    10.9   78.6 |     25     8.9    60.0
 32 |       55  |     43    18.8   74.0 |     34    13.6    57.3
```

```
101 |       50 |       41    3.8   60.3 |        0     0.0     0.0
102 |       55 |       45    3.2   56.4 |        0     0.0     0.0
103 |       36 |       22    3.4   43.1 |        0     0.0     0.0
104 |       30 |       17    4.1   42.9 |        0     0.0     0.0
105 |       28 |       16    3.9   42.3 |        0     0.0     0.0
107 |       30 |       25    3.3   58.3 |        0     0.0     0.0
...
122 |       24 |       18    3.3   52.3 |        0     0.0     0.0
123 |       39 |       28    3.8   52.7 |        0     0.0     0.0
124 |       45 |       30    4.0   49.9 |        0     0.0     0.0
126 |        2 |        2    2.0   50.0 |        0     0.0     0.0
201 |       21 |       18   18.2   81.0 |       14    16.0    62.5
202 |       12 |       12   26.9   96.3 |       10    20.3    79.2
203 |       16 |       15   15.7   87.8 |       11    17.5    64.8
204 |       17 |       17   29.0   96.5 |       15    16.4    82.9
...
230 |       17 |       16   36.3   91.5 |       12    17.6    66.6
231 |       16 |       13    9.0   72.2 |        8    11.0    45.5
233 |       21 |       20   14.3   88.6 |       13    18.1    58.5
236 |        9 |        9   24.7   95.9 |        8    18.8    84.2
----+---------+---------------------+----------------------
GPS |     1130 |      928   14.5   76.5 |      732    14.9    60.4
GLO |      846 |      616    3.6   52.4 |        0     0.0     0.0
GAL |      367 |      342   15.5   87.2 |      242    20.2    62.7
----+---------+---------------------+----------------------
```

Please note, that the program OBSXTR does only evaluate 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_20190440.OUT`, `EDT_20190440.RES` in your campaign's `OUT` directory,*
2. *screened the residual files from the above run using RESRMS: created files `RMS_20190440.SUM`, `RMS_20190440.LST`, `RMS_20190440.EDT`, and `RMS_20190440.OUT`,*
3. *used SATMRK to mark the identified outliers,*
4. *used GPSEST for a first coordinate and troposphere estimation, created files: `FLT_20190440.CRD` and `FLT_20190440.TRP`,*
5. *used GPSEST for QIF ambiguity resolution, created files: `BRTL2019044Q.OUT`,*
6. *used GPSEST for direct SIGMA ambiguity resolution, created files: `WTWZ20190441.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_20190440.SUM` and `L12_20190440.SUM`.*

6 Terminal Session: Thursday

> *Finish the work of yesterday by resolving the ambiguities for all baselines (day 044 year 2019) 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.
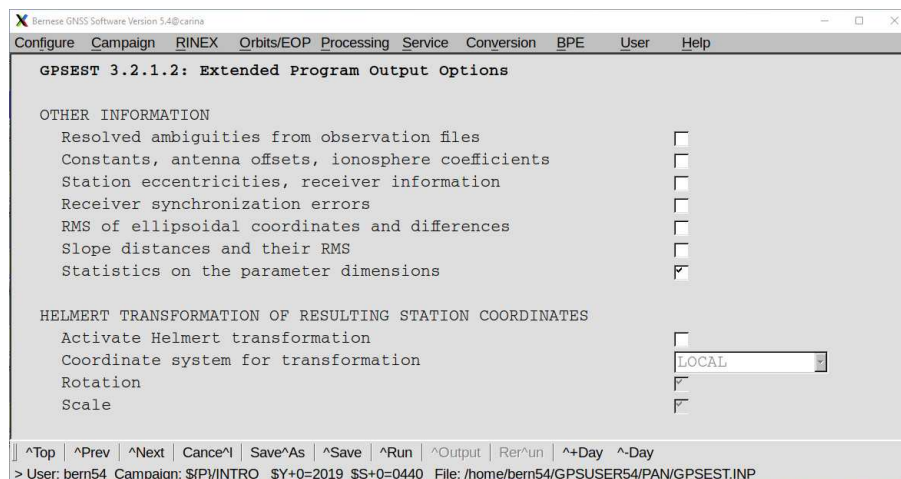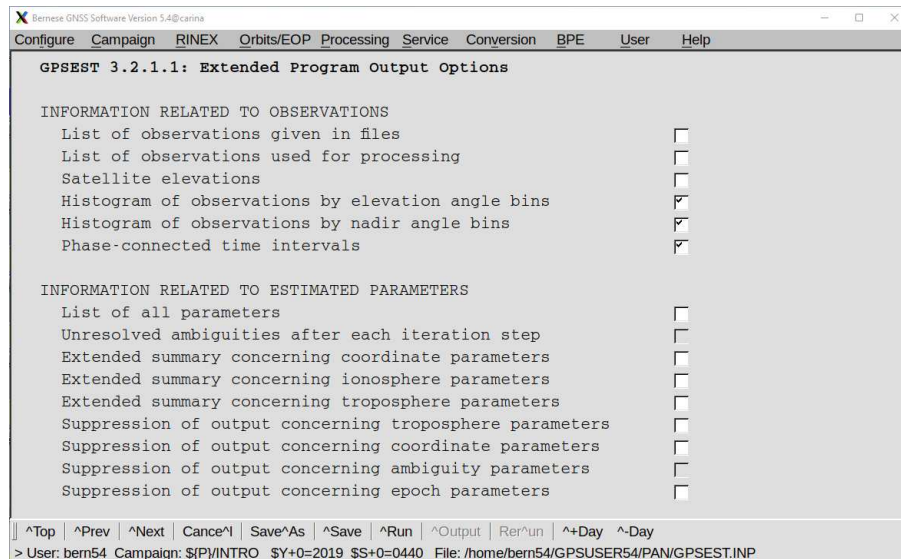
We do not fix any stations on their a priori position, i.e., the coordinates of all stations will be estimated. This retains the flexibility for later changes in the realization of the reference frame (station constraints) with program ADDNEQ2. Because no solution in GPSEST is computed you can select here all types of datum definition apart from "Coordinates fixed" (the normal equations are always stored without any constraints):
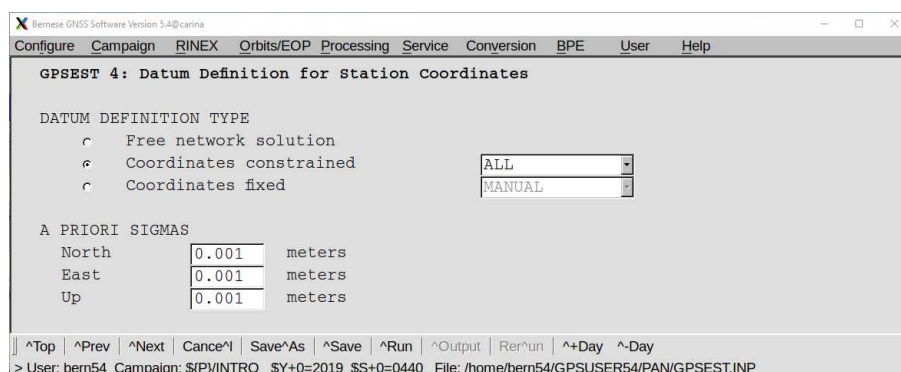
The remaining unresolved ambiguities are pre–eliminated. In addition we may set up additional parameters of interest.

```
X  Bernese GNSS Software Version 5.4@carina                              –  □  ×
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

   GPSEST 5.1: Setup of Parameters and Pre-Elimination 1

   STATION-RELATED PARAMETERS                 Setup         Pre-Elimination
      Station coordinates                                   NO                      ▾
      Ambiguities                                           AS_SOON_AS_POSSIBLE     ▾

   ATMOSPHERIC PARAMETERS
      Site-specific troposphere parameters      ☑           NO                      ▾
      Global ionosphere parameters              ☐           NO                      ▾

   GLOBAL PARAMETERS
      Orbital parameters                        ☐  GNSS     NO                      ▾
                                                ☐  LEO      NO                      ▾
      Earth orientation parameters              ☐           NO                      ▾
      Geocenter coordinates                     ☐           NO                      ▾

   EPOCH PARAMETERS
      Receiver clock offsets                    ☑           EVERY_EPOCH             ▾
      Satellite clock offsets                   ☐           EVERY_EPOCH             ▾
      Kinematic coordinates                     ☐           EVERY_EPOCH             ▾
      Stochastic ionosphere parameters          ☐           EVERY_EPOCH             ▾

‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

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".

```
X  Bernese GNSS Software Version 5.4@carina                              –  □  ×
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

   GPSEST 6.1.1: Site-Specific Troposphere Parameters 1

   ZENITH PATH DELAY PARAMETERS
      Mapping function              WET_VMF3              ▾
      Parameter spacing             01 00 00    (hh mm ss)

   HORIZONTAL GRADIENT PARAMETERS
      Gradient estimation model     CHEN-HERRING          ▾
      Parameter spacing             24 00 00    (hh mm ss)

   A PRIORI SIGMAS               Absolute              Relative
      Zenith path delay                       meters    5          meters
      Horizontal gradients                    meters    5          meters

‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

The output of the 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        51       51       0              0    0    0     0
Ambiguities                           1105        0    1105  (bfst)      0    0   40     0
Site-specific troposphere parameters   493      493       0              0    0    0     0
-------------------------------------------------------------------------------------
Total number                          1609      544    1065              0    0   40     0


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

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

Total number of authentic observations        133235
Total number of pseudo-observations                 0
Total number of observations                   133235

Total number of explicit parameters               544
Total number of implicit parameters              1065
Total number of parameters                       1609


Total number of observation files                  16
Total number of stations                           17
Total number of satellites                          0



----------------------------------------------------------------
>>> CPU/Real time for pgm "GPSEST": 0:01:54.383 / 0:01:54.399
>>> Program finished successfully
```

After running GPSEST in session mode the normal equation file `FIX_20190440.NQ0` should be available in the directory `${P}/INTRO/SOL`.

In the environment of the *Bernese Introductory Course* these files are provided in the archive `${S}/RNX2SNX/2019/SOL/` `${S}/RNX2SNX/2020/SOL/`, and `${S}/RNX2SNX/2021/SOL/` respectively. Copy the files of the additional five days into your campaign. Following files should be now available in the directory `${P}/INTRO/SOL`

`FIX_20190440.NQ0`, `FIX_20190450.NQ0`,
`FIX_20201790.NQ0`, `FIX_20201800.NQ0`, and
`FIX_20210950.NQ0`, `FIX_20210960.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:
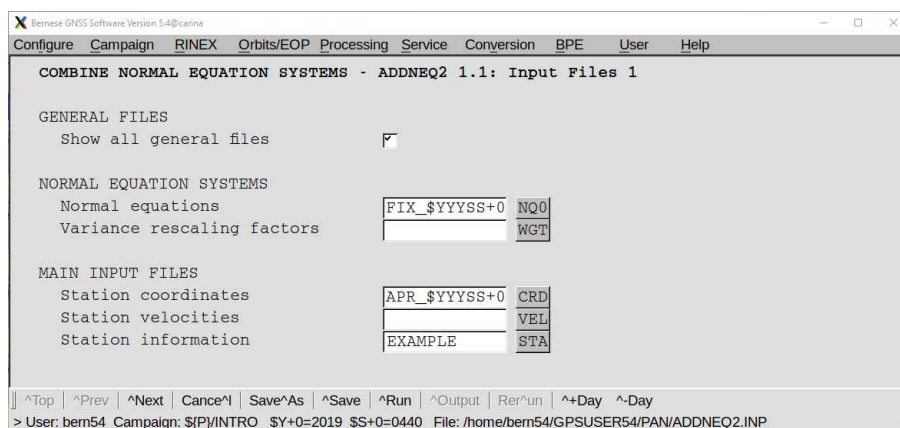
No further input files in the next panel are needed.

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.

```
ADDNEQ2 1.3: General Files

GENERAL INPUT FILES
    General constants              CONST        BSW
    Geodetic datum                 DATUM        BSW
    Antenna corrections            ANTENNA_I20  PCV
    Observation selection          OBSERV       SEL
    Satellite information          SATELLIT_I20 SAT
    Satellite problems             SAT_$Y+0     CRX
    Subdaily ERP model             DESAI2016    SUB
    Nutation model                 IAU2000R06   NUT
    SINEX header file              SINEX_INTRO  SKL
    IONEX control file                          SKL


MENU SETTINGS
    Selected campaign              ${P}/INTRO
    Selected session               Year  2019     Session   0440
    Session table                  ${P}/INTRO/GEN/SESSIONS.SES

TEMPORARY FILES
    Scratch file                   ADDNEQ2$J    SCR
```

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.

```
ADDNEQ2 2.1: Output Files 1

GENERAL OUTPUT FILES
    Program output        ☐   use ADDNEQ2.Lnn         or   FIN_$YYYSS+0  OUT
    Error messages        ☐   merged to program output or   ERROR         MSG

MAIN RESULT FILES
    Normal equations                    FIN_$YYYSS+0  NQ0
    SINEX with        NEQ  ▾                           SNX

STATION- AND SATELLITE-RELATED RESULTS
    Station coordinates                 FIN_$YYYSS+0  CRD
    Station velocities                                VEL
    Satellite orbital elements                        ELE
    Earth rotation parameters                         ERP
    Earth rotation parameters (IERS)                  IEP

ATMOSPHERE-SPECIFIC RESULTS
    Troposphere estimates               FIN_$YYYSS+0  TRP
    Troposphere estimates (SINEX)       FIN_$YYYSS+0  TRO
    Ionosphere models                                 ION
    Ionosphere models (IONEX)                         INX
```

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=2019 $S+0=0440 File: /home/bern54/GPSUSER54/PAN/ADDNEQ2.INP

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=2019 $S+0=0440 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            51       51        0           0    0    0     0
Site-specific troposphere parameters       493      493        0           0    0    0     0
----------------------------------------------------------------------------------------
Previously pre-eliminated parameters      1065              1065
----------------------------------------------------------------------------------------
Total number                              1609      544     1065           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      133235
Total number of pseudo-observations            445

Total number of explicit parameters            544
Total number of implicit parameters           1065

Total number of observations                133680
Total number of adjusted parameters           1609
Degree of freedom (DOF)                      132071

A posteriori RMS of unit weight          0.001089 m
Chi**2/DOF                                    1.19

Total number of observation files               16
Total number of stations                        17
...
```

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     0.00152    4231162.41917    0.00047    4231162.41765  ... #CRD
  1 BRST 10004M004          Y     0.00316    -332746.42575    0.00015    -332746.42891  ... #CRD
  1 BRST 10004M004          Z     0.00309    4745131.07277    0.00047    4745131.06968  ... #CRD
  1 GANP 11515M001          X    -0.00773    3929181.29827    0.00041    3929181.30600  ... #CRD
  1 GANP 11515M001          Y     0.00706    1455236.95252    0.00019    1455236.94546  ... #CRD
  1 GANP 11515M001          Z     0.04306    4793654.03600    0.00045    4793653.99294  ... #CRD
  1 HERT 13212M010          X    -0.01012    4033460.74185    0.00058    4033460.75197  ... #CRD

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

Station name          Typ     Correction  Estimated value  RMS error   A priori value  ... Abb
----------------------------------------------------------------------------------------------- ... -----
BRST 10004M004          N      0.00009         0.00009       0.00005          0.00000   ... #TRP
BRST 10004M004          E     -0.00001        -0.00001       0.00008          0.00000   ... #TRP
BRST 10004M004          U      0.07659         2.42832       0.00093          2.35173   ... #TRP
BRST 10004M004          U      0.07028         2.42138       0.00067          2.35111   ... #TRP
BRST 10004M004          U      0.06836         2.41885       0.00074          2.35049   ... #TRP
BRST 10004M004          U      0.07018         2.42005       0.00075          2.34987   ... #TRP
  ...
```

The coordinate solution for the session (`${P}/INTRO/STA/FIN_20190440.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: 0440 year 2019
Date           : 13-Jan-2024 18:31:56
User name      : bern54
================================================================================


EXAMPLE: Session 2019-0440: Check fiducial coordinates
--------------------------------------------------------------------------------


FILE 1: EXAMPLE.CRD: IGS20: coordinate list
FILE 2: FIN_20190440.CRD: EXAMPLE: Session 2019-0440: 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 |     -0.51      -2.80     -3.71 |  |
        |   6 | MATE 12734M008 | I W |     -0.35       1.26      0.67 |  |
        |   7 | MIKL 12335M001 | I W |      1.55       3.48     -0.79 |  |
        |   8 | ONSA 10402M004 | I W |      1.81       0.43     -9.50 |  |
        |   9 | ORID 15601M001 | I W |     -4.87       1.87     -8.85 |  |
        |  11 | TLSE 10003M009 | I W |     -0.29      -1.44      2.06 |  |
        |  13 | WSRT 13506M005 | I W |      3.56      -1.23      7.58 |  |
        |  14 | WTZR 14201M010 | I W |     -0.12       0.15      3.26 |  |
        |  16 | ZIM2 14001M008 | I W |     -0.57      -1.20      4.64 |  |
        |  17 | ZIMM 14001M004 | I W |     -0.21      -0.50      4.63 |  |
        |     |                |     |                                |  |
        ----------------------------------------------------------------
        |     | RMS / COMPONENT |    |      2.18       1.84      5.76 |  |
        |     | IQR             |    |      2.06       2.49      8.34 |  |
        |     | MEAN            |    |      0.00       0.00      0.00 |  |
        |     | MEDIAN          |    |     -0.25      -0.18      1.37 |  |
        |     | MIN             |    |     -4.87      -2.80     -9.50 |  |
        |     | MAX             |    |      3.56       3.48      7.58 |  |
        ----------------------------------------------------------------
              OVERALL RMS/IQR/MAX(3D)      3.71       3.07     10.27      ORID ...
        ----------------------------------------------------------------
        | ALL | RMS / COMPONENT |    |      2.18       1.84      5.76 |  |
        | ALL | IQR             |    |      2.06       2.49      8.34 |  |
        | ALL | MEAN            |    |      0.00       0.00      0.00 |  |
        | ALL | MEDIAN          |    |     -0.25      -0.18      1.37 |  |
        | ALL | MIN             |    |     -4.87      -2.80     -9.50 |  |
        | ALL | MAX             |    |      3.56       3.48      7.58 |  |
        ----------------------------------------------------------------
              OVERALL RMS/IQR/MAX(3D)      3.71       3.07     10.27      ORID ...

NUMBER OF PARAMETERS   :      3
NUMBER OF STATIONS     :     10
NUMBER OF COORDINATES  :     30
RMS OF TRANSFORMATION  :    3.71 MM

BARYCENTER COORDINATES:
LATITUDE               :     47 48 37.88
LONGITUDE              :     11 25 53.36
HEIGHT                 :          -64.817 KM

PARAMETERS:

TRANSLATION IN   N     :          0.02     +-   1.17     MM
TRANSLATION IN   E     :          0.03     +-   1.17     MM
TRANSLATION IN   U     :         -0.00     +-   1.17     MM

NUMBER OF ITERATIONS   :      1

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


----------------------------------------------------------------
>>> CPU/Real time for pgm "HELMR1": 0:00:00.135 / 0:00:00.135
>>> Program finished successfully
```
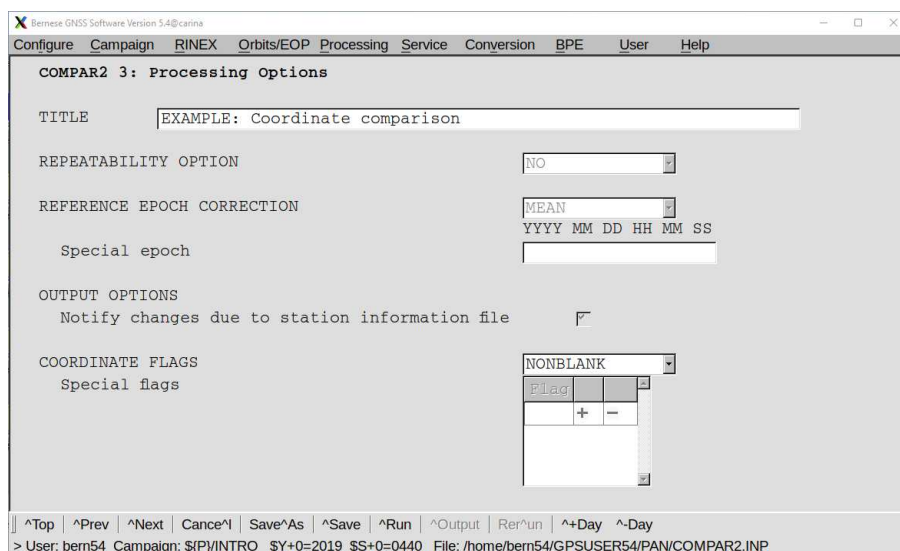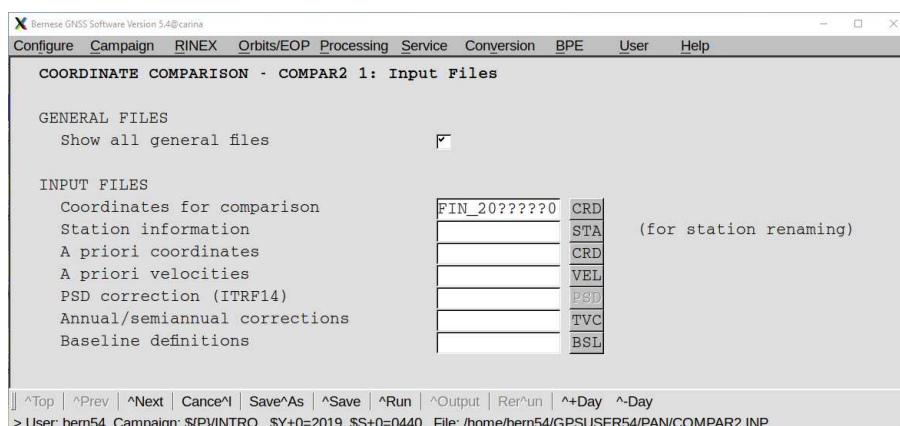
We can conclude that no problems concerning the stations used for the datum definition were detected.

If there were problems, the ADDNEQ2 run needs 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_20190440.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 six days (or make at least sure to have four days available), repeat the above steps for the remaining days.

6.3 Check the Daily Repeatability

If the minimum constraint solutions of the six 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.

```
X  Bernese GNSS Software Version 5.4@carina                                    —  □  ×
Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

     COMPAR2 4: Comparison of Individual Solutions


     NOTIFICATION OF POSSIBLE OUTLIERS
        Maximum tolerated residual              North  [15]   millimeters
                                                East   [15]   millimeters
                                                Up     [30]   millimeters

        Maximum tolerated root-mean-square error  North  [10]   millimeters
                                                  East   [10]   millimeters
                                                  Up     [20]   millimeters

        Minimum number of solutions for each station    [0]  ⬍

     LIST OF ACCEPTED MEAN COORDINATES/VELOCITIES       [          ]  FIX


‖ ^Top ∣ ^Prev ∣ ^Next ∣ Cance^l ∣ Save^As ∣ ^Save ∣ ^Run ∣ ^Output ∣ Rer^un ∣ ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/COMPAR2.INP
```

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    15.82    -18.89   -18.90    3.09    2.39   16.49   15.82
BRST 10004M004   E    14.91    -16.98   -17.54    1.23    1.30   15.85   16.15
BRST 10004M004   U     2.96      4.28     3.07   -0.83   -2.16   -2.97   -1.38

GANP 11515M001   N    12.89    -15.43   -15.25    3.04    1.20   13.32   13.13
GANP 11515M001   E    20.64    -25.62   -25.12    7.31    4.14   19.25   20.03
GANP 11515M001   U     2.41     -0.85    -2.46   -0.94   -1.64    3.78    2.11

HERT 13212M010   N    16.23    -19.80   -19.60    4.40    2.98   15.95   16.07
HERT 13212M010   E    15.93    -17.77   -18.15   -0.08    0.69   17.86   17.45
HERT 13212M010   U     3.04      1.09    -0.74    3.16    3.24   -2.60   -4.15

JOZ2 12204M002   N    13.92    -17.39   -16.58    4.37    2.55   13.55   13.49
JOZ2 12204M002   E    23.96    -29.98   -29.50    9.69    5.63   21.84   22.33
JOZ2 12204M002   U     1.61     -0.88     1.03    2.13    0.44   -0.21   -2.51

LAMA 12209M001   N    14.72    -18.18   -18.12    4.97    3.47   13.78   14.08
LAMA 12209M001   E    20.49    -24.67   -25.36    5.26    4.86   19.77   20.15
LAMA 12209M001   U     3.21     -4.52    -0.68   -1.70    0.72    5.11    1.08

MATE 12734M008   N    18.44    -22.42   -21.76    2.79    4.00   18.65   18.74
MATE 12734M008   E    23.06    -28.00   -27.43    4.78    4.14   23.36   23.16
MATE 12734M008   U     2.94     -2.20     3.30    1.30   -4.75    0.67    1.67

MIKL 12335M001   N    11.88    -14.43   -13.46    1.21    1.69   12.49   12.49
MIKL 12335M001   E    24.79    -30.39   -30.54    7.09    6.45   23.55   23.85
MIKL 12335M001   U     3.27     -3.64    -2.51   -1.61    5.22    1.95    0.59

ONSA 10402M004   N    15.83    -19.32   -19.47    4.89    3.40   15.27   15.24
ONSA 10402M004   E    16.26    -20.05   -19.07    3.30    3.11   15.88   16.83
ONSA 10402M004   U     3.06     -0.80    -3.41   -3.15    0.70    4.33    2.33

ORID 15601M001   N     8.56     -9.69    -9.64   -0.36    0.79    9.18    9.72
ORID 15601M001   E    25.27    -29.92   -31.42    5.09    6.42   24.31   25.52
ORID 15601M001   U     4.17      7.10     2.96   -2.93   -2.79   -3.10   -1.24

PTBB 14234M001   N    18.04    -22.12   -22.32    4.71    5.44   17.11   17.19
PTBB 14234M001   E    18.19    -21.78   -21.37    3.31    2.25   18.81   18.77
PTBB 14234M001   U     2.37     -0.88    -2.10   -2.53    2.73    3.00   -0.22

TLSE 10003M009   N    15.79    -18.79   -19.49    3.60    3.42   15.89   15.37
TLSE 10003M009   E    17.86    -21.38   -21.08    2.91    2.76   18.63   18.16
TLSE 10003M009   U     1.19     -0.16    -0.79   -0.73   -0.36   -0.33    2.37

VILL 13406M001   N    15.17    -18.25   -18.29    2.47    3.65   14.85   15.56
VILL 13406M001   E    16.41    -19.13   -19.53    2.04    2.28   17.03   17.31
VILL 13406M001   U     5.13      7.23     4.70   -4.54   -4.94    0.89   -3.35

WSRT 13506M005   N    16.92    -21.04   -20.57    4.38    4.98   16.95   15.30
WSRT 13506M005   E    16.56    -20.10   -19.77    3.01    3.62   15.75   17.50
WSRT 13506M005   U     5.60     -5.75    -3.93    8.59    5.05   -2.85   -1.10
```

```
WTZR 14201M010    N    12.14    -10.37   -10.65   11.09    9.93
WTZR 14201M010    E    15.86    -13.64   -13.83   14.29   13.18
WTZR 14201M010    U     2.71     -2.73    -1.54    3.36    0.91

WTZZ 14201M014    N    15.38    -18.60   -18.58    4.08    2.52   14.68   15.91
WTZZ 14201M014    E    19.81    -23.69   -23.77    4.39    2.85   19.86   20.36
WTZZ 14201M014    U     3.58     -4.46    -4.57    2.30    1.83    3.63    1.27

ZIM2 14001M008    N    15.20    -18.20   -18.03    2.60    2.49   14.69   16.46
ZIM2 14001M008    E    18.98    -23.00   -22.86    4.05    3.93   19.49   18.40
ZIM2 14001M008    U     1.87     -2.03    -2.07   -0.44    0.76    2.67    1.10

ZIMM 14001M004    N    15.74    -18.83   -19.01    3.20    2.94   15.27   16.44
ZIMM 14001M004    E    18.69    -23.03   -22.56    4.43    4.73   18.97   17.47
ZIMM 14001M004    U     2.35     -1.34    -2.58   -0.65   -0.11    4.32    0.37
```

In the section **Notification of detected outliers** all stations from the first (in 2019) and last (in 2021) pair of solutions get listed. While interpreting this output, keep in mind that the the six columns refer to different epochs. The difference between these epochs is about one year. 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:
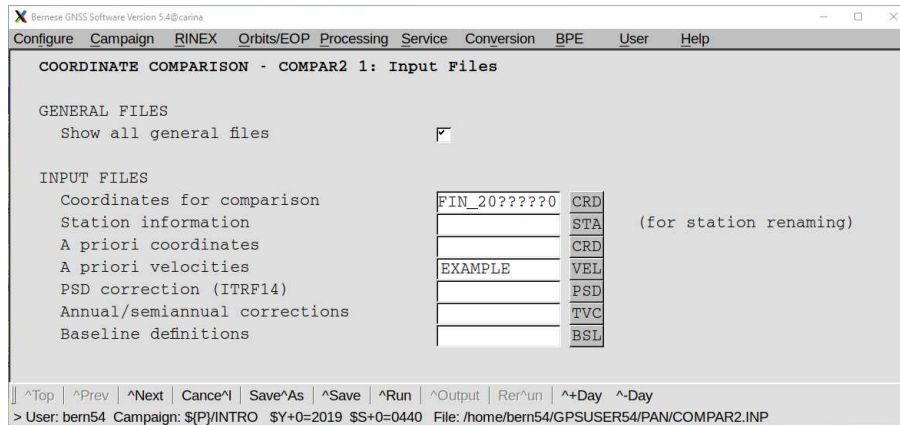
You may check the influence on the repeatability on your own. Please be reminded, that for the ITRF 2020 (IGS 20) reference frame the linear station velocities are not sufficient. You may see the effect of the PSD corrections in the repeatablity. This is not the case for this example because none of 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.
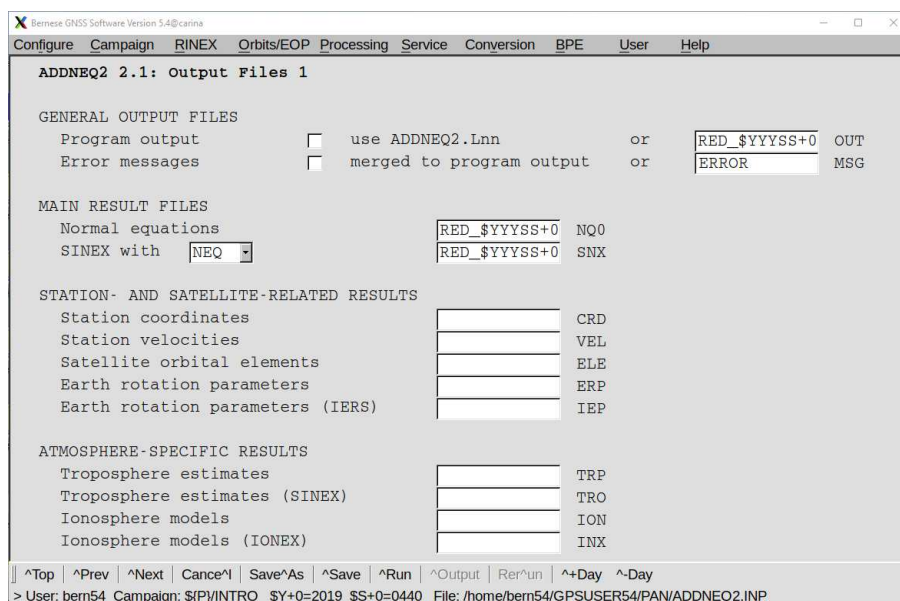
To generate these reduced `NQ0` files and the SINEX file, the execution of `ADDNEQ2` has to be repeated with the following changes in the input options:
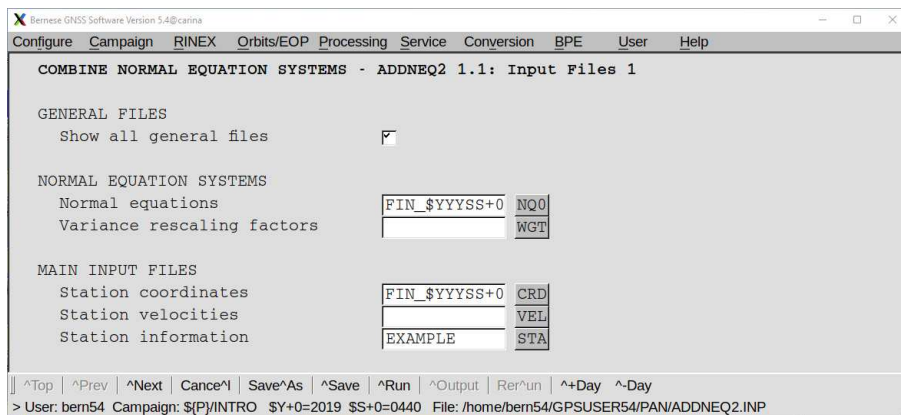
Please note that the output SINEX file includes again the skeleton from `${P}/INTRO/GEN/SINEX_INTRO` (Copied from `${D}/REF54` directory into the campaign) – the same file we used as skeleton for the troposphere SINEX generation.
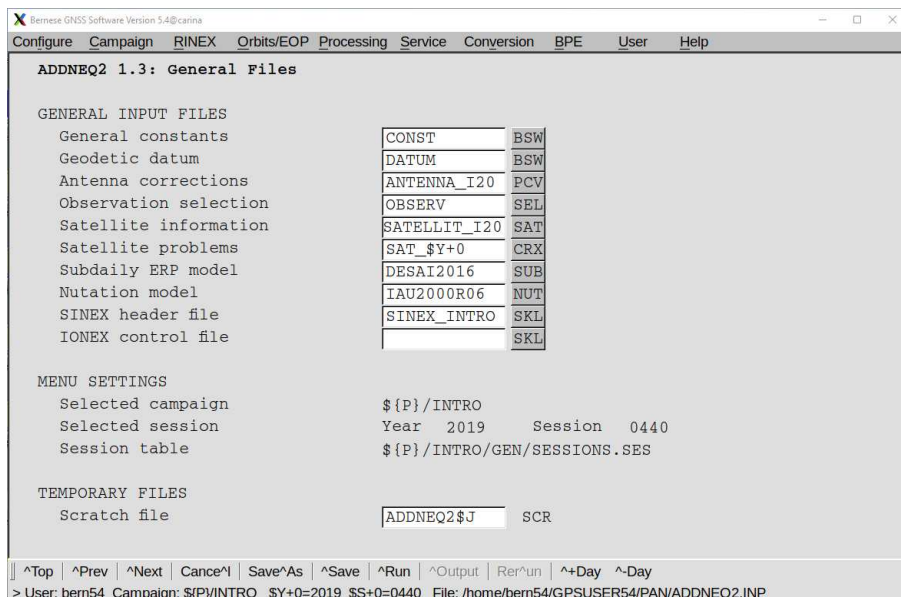
```
X  Bernese GNSS Software Version 5.4@carina                                    —   □   ✕
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

    ADDNEQ2 2.1: Output Files 1


    GENERAL OUTPUT FILES
        Program output        □    use ADDNEQ2.Lnn       or   RED_$YYYSS+0  OUT
        Error messages        □    merged to program output or  ERROR        MSG

    MAIN RESULT FILES
        Normal equations                    RED_$YYYSS+0  NQ0
        SINEX with    NEQ ▼                  RED_$YYYSS+0  SNX

    STATION- AND SATELLITE-RELATED RESULTS
        Station coordinates                              CRD
        Station velocities                               VEL
        Satellite orbital elements                       ELE
        Earth rotation parameters                        ERP
        Earth rotation parameters (IERS)                 IEP

    ATMOSPHERE-SPECIFIC RESULTS
        Troposphere estimates                            TRP
        Troposphere estimates (SINEX)                    TRO
        Ionosphere models                                ION
        Ionosphere models (IONEX)                        INX

 ‖ ^Top | ^Prev | ^Next | Cance^l | Save^As | ^Save | ^Run | ^Output | Rer^un | ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/ADDNEQ2.INP
```
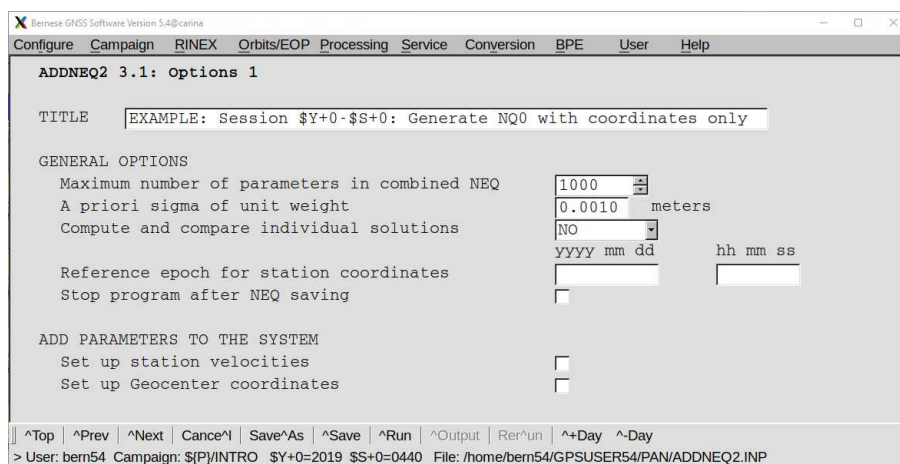
```
X  Bernese GNSS Software Version 5.4@carina                                    —   □   ✕
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

    ADDNEQ2 3.1: Options 1


    TITLE      EXAMPLE: Session $Y+0-$S+0: Generate NQ0 with coordinates only

    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=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/ADDNEQ2.INP
```
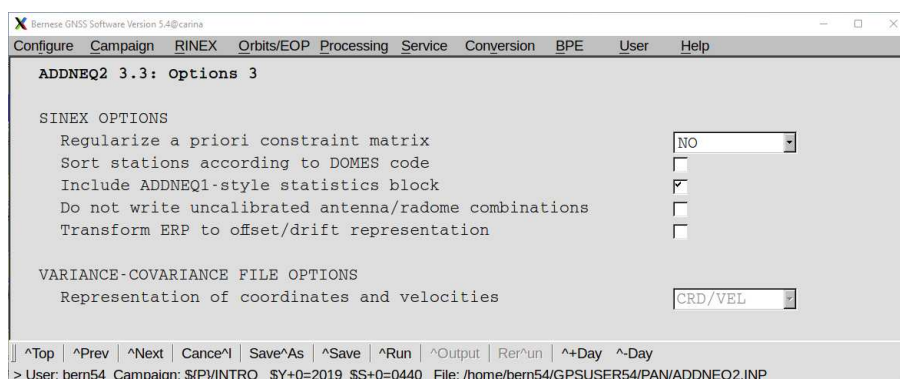
Because you are storing a SINEX file in NEQ representation (see option "Content of SINEX") no regularization is necessary.

```
X  Bernese GNSS Software Version 5.4@carina                                    —   □   ✕
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

    ADDNEQ2 3.3: Options 3


    SINEX OPTIONS
        Regularize a priori constraint matrix               NO ▼
        Sort stations according to DOMES code               □
        Include ADDNEQ1-style statistics block              ☑
        Do not write uncalibrated antenna/radome combinations □
        Transform ERP to offset/drift representation        □


    VARIANCE-COVARIANCE FILE OPTIONS
        Representation of coordinates and velocities        CRD/VEL ▼

 ‖ ^Top | ^Prev | ^Next | Cance^l | Save^As | ^Save | ^Run | ^Output | Rer^un | ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/ADDNEQ2.INP
```

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_20190440.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       51       51       0                  0    0    0    0
Site-specific troposphere parameters  493        0     493  (bfst)          0    0    0    0
----------------------------------------------------------------------------------------------
Previously pre-eliminated parameters 1065              1065
----------------------------------------------------------------------------------------------
Total number                         1609       51    1558                  0    0    0    0
```

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

Total number of authentic observations      133235
Total number of pseudo-observations            493

Total number of explicit parameters             51
Total number of implicit parameters           1558

Total number of observations                133728
Total number of adjusted parameters           1609
Degree of freedom (DOF)                     132119

A posteriori RMS of unit weight        0.001089 m
Chi**2/DOF                                    1.19

Total number of observation files               16
Total number of stations                        17
...
```

You can also see that the number of explicit parameters in the NQ0 file was dramatically reduced (from 544 to 51). 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 (044/045 year 2019, 179/180 year 2020, and 095/096 year 2021) from `${S}/RNX2SNX/2019/SOL/RED_2019*NQ0`, `${S}/RNX2SNX/2020/SOL/RED_2020*NQ0`, and `${S}/RNX2SNX/2021/SOL/RED_2021*NQ0` into the `${P}/INTRO/SOL/` directory. The normal equation files have to cover a reasonable time interval to reliably estimate velocities (in this case about two 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      0.00109    132071     1.19      133677         3          51        1558          0
    2      0.00106    134591     1.13      136030         3          51        1391          0
    3      0.00148    147487     2.19      148986         3          51        1451          0
    4      0.00145    147425     2.09      148917         3          51        1444          0
    5      0.00110    138482     1.22      139733         3          48        1206          0
    6      0.00111    136210     1.23      137543         3          48        1288          0

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

BRST 10004M004   N   0.69    0.38    0.24   -0.67   -0.91    0.94    0.11
BRST 10004M004   E   1.34    0.84    0.26   -1.89   -1.51    0.87    1.26
BRST 10004M004   U   1.21    0.66   -0.44    0.17   -1.58   -1.04    1.77

GANP 11515M001   N   0.82    0.28    0.34   -0.06   -1.59    0.69    0.37
GANP 11515M001   E   1.41   -0.66   -0.27    2.75    0.12   -1.17   -0.71
GANP 11515M001   U   1.23    1.29   -0.23   -0.88   -1.88    1.11    0.62

HERT 13212M010   N   0.31   -0.03    0.03    0.52   -0.45   -0.00   -0.09
HERT 13212M010   E   2.28    1.21    0.78   -3.48   -2.35    1.95    1.55
HERT 13212M010   U   2.97   -0.47   -2.19    3.89    3.58   -2.20   -2.54

JOZ2 12204M002   N   0.57   -0.53    0.15    1.00   -0.49   -0.05   -0.30
JOZ2 12204M002   E   2.41   -1.58   -1.22    4.34    0.83   -1.73   -1.57
JOZ2 12204M002   U   1.64   -2.06   -0.05    2.51    0.57   -0.43   -1.56

LAMA 12209M001   N   0.78   -0.26   -0.34    1.45    0.28   -0.62   -0.54
LAMA 12209M001   E   0.66    0.09   -0.70    0.71    0.86   -0.52   -0.46
LAMA 12209M001   U   1.78   -1.52    2.40   -1.80    0.36    1.83   -1.04

MATE 12734M008   N   0.72    0.01    0.54   -1.38    0.12    0.37    0.48
MATE 12734M008   E   0.33   -0.10    0.35   -0.26   -0.40    0.42   -0.05
MATE 12734M008   U   2.99   -2.29    3.31    1.87   -4.54   -0.12    2.08

MIKL 12335M001   N   1.05    0.07    0.95   -1.59   -0.91    0.81    0.77
MIKL 12335M001   E   1.21   -0.36   -0.66    1.55    1.51   -0.91   -1.10
MIKL 12335M001   U   2.50   -1.21    0.01   -1.49    5.12   -0.69   -0.93

ONSA 10402M004   N   0.56   -0.09   -0.38    1.08    0.00   -0.15   -0.51
ONSA 10402M004   E   0.40   -0.35    0.55   -0.29   -0.00   -0.33    0.44
ONSA 10402M004   U   1.82    2.19   -0.34   -3.05    0.51    1.36    0.53

ORID 15601M001   N   1.50    0.91    0.88   -2.44   -1.00    0.84    1.42
ORID 15601M001   E   0.92    0.60   -1.02   -0.45    1.42   -0.76    0.13
ORID 15601M001   U   2.14    2.53   -1.50   -1.68   -1.85   -0.24    2.82

PTBB 14234M001   N   0.96   -0.71   -1.04    0.38    1.50   -0.49   -0.64
PTBB 14234M001   E   0.84    0.67    1.01   -0.55   -1.15    0.57    0.37
PTBB 14234M001   U   1.73    0.33   -0.81   -2.37    2.57    1.03   -1.01
```

```
TLSE 10003M009   N    0.32     0.45    -0.37   -0.14    0.08    0.24   -0.32
TLSE 10003M009   E    0.62     0.13     0.37   -0.89   -0.67    0.71    0.22
TLSE 10003M009   U    1.28     0.33    -0.19   -0.44   -0.51   -1.91    1.99

VILL 13406M001   N    0.60     0.23     0.07   -1.03    0.55   -0.09    0.63
VILL 13406M001   E    0.89     0.59     0.14   -1.34   -0.80    0.58    0.92
VILL 13406M001   U    3.11     2.49     0.09   -3.13   -4.01    3.93    0.91

WSRT 13506M005   N    0.98    -0.44    -0.11    0.35    1.38    0.34   -1.56
WSRT 13506M005   E    0.63    -0.12     0.16   -0.60    0.44   -0.83    0.83
WSRT 13506M005   U    5.48    -3.56    -1.65    8.66    4.79   -5.52   -2.56

WTZR 14201M010   N    0.37     0.27    -0.14    0.34   -0.46
WTZR 14201M010   E    0.29     0.11    -0.16    0.39   -0.24
WTZR 14201M010   U    1.91     0.01     1.29   -0.24   -3.04

WTZZ 14201M014   N    0.52     0.15     0.03    0.44   -0.75   -0.42    0.65
WTZZ 14201M014   E    0.51     0.24     0.08    0.08   -0.99    0.17    0.48
WTZZ 14201M014   U    1.39    -0.51    -0.52    2.14    1.32   -0.46   -1.63

ZIM2 14001M008   N    0.87     0.31     0.36   -1.00   -0.73   -0.27    1.39
ZIM2 14001M008   E    0.41    -0.08    -0.01   -0.02    0.29    0.57   -0.64
ZIM2 14001M008   U    0.30    -0.01     0.05   -0.27    0.54    0.11   -0.25

ZIMM 14001M004   N    0.50     0.32     0.00   -0.54   -0.42   -0.25    0.80
ZIMM 14001M004   E    0.83    -0.47    -0.07    0.44    1.17    0.38   -1.24
ZIMM 14001M004   U    1.01     0.81    -0.33   -0.44   -0.29    1.75   -0.98




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

Parameter type                    Component     Scaling factor wrt RMS /  variance      DOF
------------------------------------------------------------------------------------------
Station coordinates               N                             3.19946    10.23658      100
Station coordinates               E                             5.23596    27.41528      100
Station coordinates               U/vertical                    2.69179     7.24576      100
Station coordinates               Horizontal                    4.33889    18.82593      200
Station coordinates               All                           3.86857    14.96587      300
------------------------------------------------------------------------------------------
Total                                                           3.86857    14.96587      300
...
```

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, four stations are affected:

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


 ---------------------------------------------------------------------------------------..
 Station        First obs. epoch     Last obs. epoch      Receiver type          Antenna type ..
 ---------------------------------------------------------------------------------------..
 JOZ2 12204M002  2019-02-13 00:00:00  2019-02-14 23:59:30  LEICA GRX1200GGPRO    LEIAT504GG   ..
 JOZ2 12204M002  2020-06-27 00:00:00  2021-04-06 23:59:30  TRIMBLE NETR9         TRM59800.00  ..
                                                                                              ..
 ONSA 10402M004  2019-02-13 00:00:00  2019-02-14 23:59:30  JAVAD TRE_G3TH DELTA  AOAD/M_B     ..
 ONSA 10402M004  2020-06-27 00:00:00  2021-04-06 23:59:30  SEPT POLARX5TR        AOAD/M_B     ..
                                                                                              ..
 ORID 15601M001  2019-02-13 00:00:00  2019-02-14 23:59:30  LEICA GRX1200GGPRO    LEIAT504GG   ..
 ORID 15601M001  2020-06-27 00:00:00  2021-04-06 23:59:30  LEICA GR30            LEIAR25.R4   ..
                                                                                              ..
 PTBB 14234M001  2019-02-13 00:00:00  2019-02-14 23:59:30  ASHTECH Z-XII3T       ASH700936E   ..
 PTBB 14234M001  2020-06-27 00:00:00  2021-04-06 23:59:30  SEPT POLARX5TR        LEIAR25.R4   ..
                                                                                              ..
 VILL 13406M001  2019-02-13 00:00:00  2019-02-14 23:59:30  SEPT POLARX4          SEPCHOKE_MC  ..
 VILL 13406M001  2020-06-27 00:00:00  2021-04-06 23:59:30  SEPT POLARX5          SEPCHOKE_B3E6..
...
```

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        -0.01259         0.00334        0.00028
                      VY        0.01721         0.01765         0.00044        0.00012
                      VZ        0.01006         0.01349         0.00343        0.00031

                      VU       -0.00004         0.00475         0.00479        0.00040  ...
                      VN        0.01543         0.01514        -0.00029        0.00013  ...
                      VE        0.02033         0.02001        -0.00032        0.00010  ...
...
WTZZ 14201M014        VX       -0.01593        -0.01426         0.00167        0.00020
                      VY        0.01721         0.01772         0.00051        0.00009
                      VZ        0.01006         0.01273         0.00267        0.00022

                      VU       -0.00004         0.00312         0.00316        0.00029  ...
                      VN        0.01543         0.01585         0.00043        0.00009  ...
                      VE        0.02033         0.02045         0.00012        0.00007  ...

...

ZIM2 14001M008        VX       -0.01378        -0.01286         0.00092        0.00020
                      VY        0.01810         0.01806        -0.00004        0.00008
                      VZ        0.01164         0.01179         0.00015        0.00021

                      VU        0.00076         0.00150         0.00073        0.00027  ...
                      VN        0.01621         0.01565        -0.00056        0.00009  ...
                      VE        0.01974         0.01957        -0.00016        0.00007  ...
...
ZIMM 14001M004        VX       -0.01378        -0.01318         0.00060        0.00031
                      VY        0.01810         0.01769        -0.00041        0.00011
                      VZ        0.01164         0.01222         0.00058        0.00031

                      VU        0.00076         0.00156         0.00080        0.00042  ...
                      VN        0.01621         0.01621         0.00000        0.00014  ...
                      VE        0.01974         0.01925        -0.00048        0.00010  ...
...
```

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`:

```
...
370   WTZR 14201M010          -0.01593        0.01721        0.01006    IG20 EURA
371   WTZZ 14201M014          -0.01593        0.01721        0.01006    NNR  EURA
...
383   ZIM2 14001M008          -0.01378        0.01810        0.01164    IG20 EURA
385   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         -0.01371        0.00222        0.00016
                      VY          0.01721          0.01768        0.00047        0.00007
                      VZ          0.01006          0.01300        0.00294        0.00018

                      VU         -0.00004          0.00367        0.00371        0.00023   ...
                      VN          0.01543          0.01564        0.00021        0.00008   ...
                      VE          0.02033          0.02029       -0.00004        0.00006   ...
...
WTZZ 14201M014        VX         -0.01593         -0.01372        0.00221        0.00016
                      VY          0.01721          0.01768        0.00047        0.00007
                      VZ          0.01006          0.01301        0.00295        0.00018

                      VU         -0.00004          0.00367        0.00371        0.00023   ...
                      VN          0.01543          0.01564        0.00022        0.00007   ...
                      VE          0.02033          0.02029       -0.00004        0.00006   ...

...

ZIM2 14001M008        VX         -0.01378         -0.01283        0.00095        0.00016
                      VY          0.01810          0.01793       -0.00017        0.00006
                      VZ          0.01164          0.01198        0.00034        0.00016

                      VU          0.00076          0.00164        0.00088        0.00021   ...
                      VN          0.01621          0.01577       -0.00044        0.00007   ...
                      VE          0.01974          0.01945       -0.00029        0.00005   ...
...
ZIMM 14001M004        VX         -0.01378         -0.01283        0.00095        0.00016
                      VY          0.01810          0.01793       -0.00017        0.00006
                      VZ          0.01164          0.01198        0.00034        0.00016

                      VU          0.00076          0.00164        0.00088        0.00021   ...
                      VN          0.01621          0.01578       -0.00044        0.00007   ...
                      VE          0.01974          0.01945       -0.00029        0.00006   ...
...
```

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

```
EXAMPLE: Estimate final solution - coordinates and velocities    13-JAN-24 18:48
--------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20              EPOCH: 2015-01-01 00:00:00

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

 43    BRST 10004M004     4231162.47226  -332746.49379  4745131.03712   W    GRE
104    GANP 11515M001     3929181.36193  1455236.88350  4793653.99378   A    GRE
122    HERT 13212M010     4033460.79940    23537.97230  4924318.35818   A    GR
143    JOZ2 12204M002     3664880.40509  1409190.73252  5009618.56142   A    GRE
166    LAMA 12209M001     3524522.74510  1329693.77172  5129846.42519   A    GR
184    MATE 12734M008     4641949.37574  1393045.61381  4133287.60971   W    GRE
198    MIKL 12335M001     3698553.79492  2308676.15753  4639769.58706   W    GRE
235    ONSA 10402M004     3370658.41000   711877.28744  5349787.05070   W    GRE
236    ORID 15601M001     4498451.55310  1708267.17400  4173591.97666   W    GRE
264    PTBB 14234M001     3844059.81622   709661.47880  5023129.63889   A    GRE
329    TLSE 10003M009     4627851.70710   119640.21487  4372993.66294   W    GRE
359    VILL 13406M001     4849833.62039  -335048.82494  4116015.07867   A    GRE
369    WSRT 13506M005     3828735.71196   443305.12097  5064884.80160   W    GRE
370    WTZR 14201M010     4075580.37967   931853.96581  4801568.21514   W    GRE
371    WTZZ 14201M014     4075579.25914   931853.28128  4801569.12266   A    GRE
383    ZIM2 14001M008     4331299.73308   567537.50277  4633133.82755   W    GRE
385    ZIMM 14001M004     4331296.92165   567556.05878  4633134.04683   W    G
```

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

```
EXAMPLE: Estimate final solution - coordinates and velocities    13-JAN-24 18:48
--------------------------------------------------------------------------------
LOCAL GEODETIC DATUM: IGS20

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

 43    BRST 10004M004       -0.01300        0.01632        0.00849    W    EURA
104    GANP 11515M001       -0.01571        0.01686        0.00999    A    EURA
122    HERT 13212M010       -0.01396        0.01617        0.00944    A    EURA
143    JOZ2 12204M002       -0.01979        0.01848        0.00802    A    EURA
166    LAMA 12209M001       -0.01757        0.01594        0.01088    A    EURA
184    MATE 12734M008       -0.01881        0.01920        0.01427    W    EURA
198    MIKL 12335M001       -0.02005        0.01765        0.00970    W    EURA
235    ONSA 10402M004       -0.01568        0.01386        0.01069    W    EURA
236    ORID 15601M001       -0.01745        0.02122        0.00401    W    EURA
264    PTBB 14234M001       -0.01706        0.01620        0.01195    A    EURA
329    TLSE 10003M009       -0.01135        0.01810        0.01210    W    EURA
359    VILL 13406M001       -0.01205        0.01769        0.00916    A    EURA
369    WSRT 13506M005       -0.01473        0.01548        0.01192    W    EURA
370    WTZR 14201M010       -0.01371        0.01768        0.01300    W    EURA
371    WTZZ 14201M014       -0.01372        0.01768        0.01301    A    EURA
383    ZIM2 14001M008       -0.01283        0.01793        0.01198    W    EURA
385    ZIMM 14001M004       -0.01283        0.01793        0.01198    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_20190440.OUT`, `FIX_20190440.NQ0`,
> 2. *checked the coordinates of the fiducial sites using ADDNEQ2 and HELMR1, created files:* `FIN_20190440.CRD`, `FIN_20190440.TRP`, *optionally also* `FIN_20190440.TRO`, `FIN_20190440.OUT`, *and* `HLM_20190440.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_20190440.NQ0` *and* `RED_20190440.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:

7.1 Preparing Combined GPS and GLONASS legacy IGS–Orbits

In this section the differences to the standard procedure using CODE products containing GPS and GLONASS orbits with respect to IGS products are demonstrated. The IGS uses independent combination procedures for GPS and GLONASS orbits resulting in two sets of precise orbit files. That's why the orbits for the two GNSS first need to be merged.

In contrast, CODE (and other AC) uses a rigorous combined multi–GNSS processing scheme, hence producing a single precise orbit file.

7.1.1 Prepare Pole Information

For the IGS precise orbit files (`PRE`) the consistent EOP need to be available in the `ORB` directory (which is the case in the *Bernese Introductory Course* environment). As for the use of CODE products in Section 3.1, the EOP information has to be converted from the IERS/IGS standard format (file extension within the *Bernese GNSS Software* is `IEP`) to 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"). Simply specify IGS–related filenames.
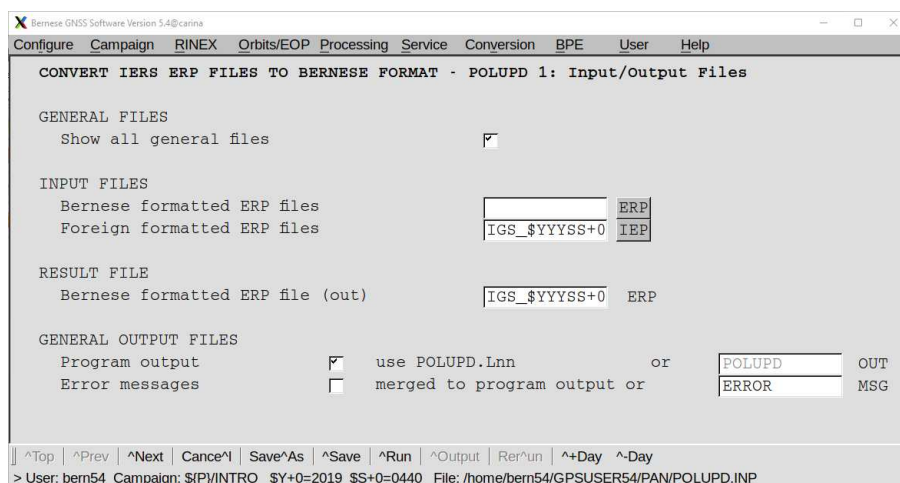
Because the input "Foreign formatted ERP files" is generated using the modelling of the operational processing within the IGS in that time for the "Subdaily ERP model" as well as the "Meanpole model" we have to switch it back to maintain the compatibility:

Because the IGS "Foreign formatted ERP files" contain only the noon epoch we have to enable the checkbox for option "Use ERP rates" in order to cover the full interval of the session in the resulting "Bernese formatted ERP file (out)".

The messages

```
### PG POLUPD: NUTATION MODEL NOT SPECIFIED IN INPUT ERP FILE
               USING NUTATION MODEL NAME : IAU2000R06

### PG POLUPD: SUBDAILY POLE MODEL NOT SPECIFIED IN INPUT ERP FILE
               USING SUBDAILY POLE MODEL NAME : IERS2010
```

just inform you that the nutation and subdaily pole models from the files in the input panel are written to the output file because no Bernese formatted ERP file was used as input. This is different to importing the EOP from CODE products because here the information on the nutation and sub daily pole model is also available in the international format (with the extension IEP).

7.1.2 Merging Precise Orbit Files

Before we can prepare the orbits from the IGS for a combined GPS+GLONASS processing we need to merge the two separate files IGS15941.PRE and IGL15941.PRE. This is the task of the program CCPREORB ("Menu>Orbits/EOP>Concatenate/merge precise orbit files"):
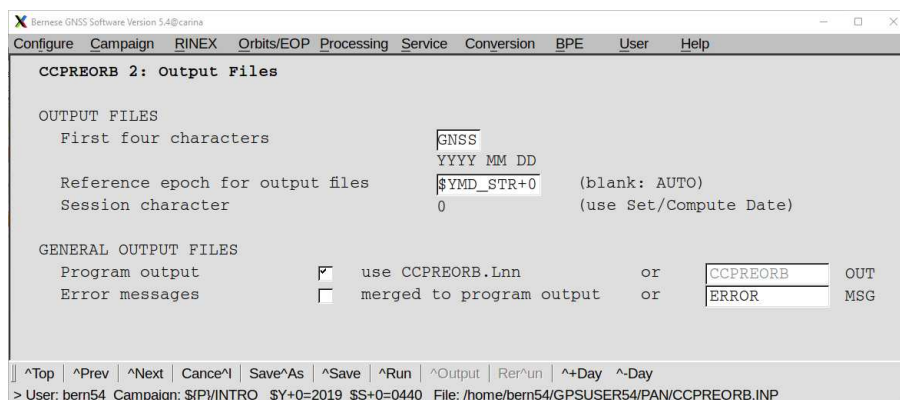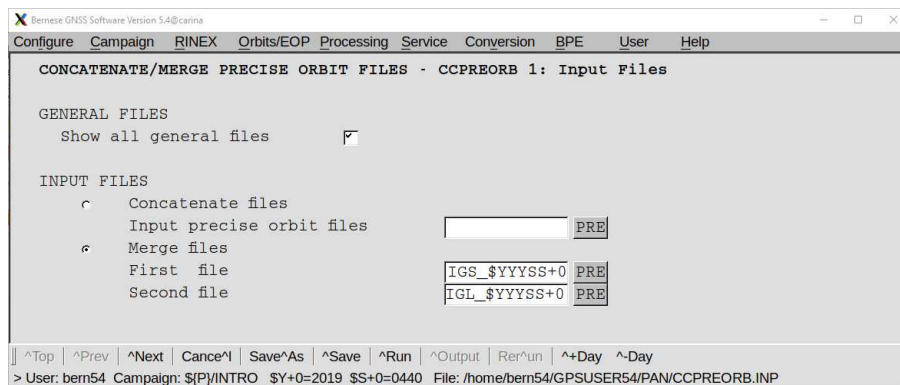
The resulting filename consists of the solution identifier ("First four characters") and the session of the first epoch (if "Reference epoch for output files" is empty). The reference epoch may also be specified by the user as the above example shows. Using the input options from above panel we expect the result file named as `${P}/INTO/ORB/GNSS0440.PRE`.
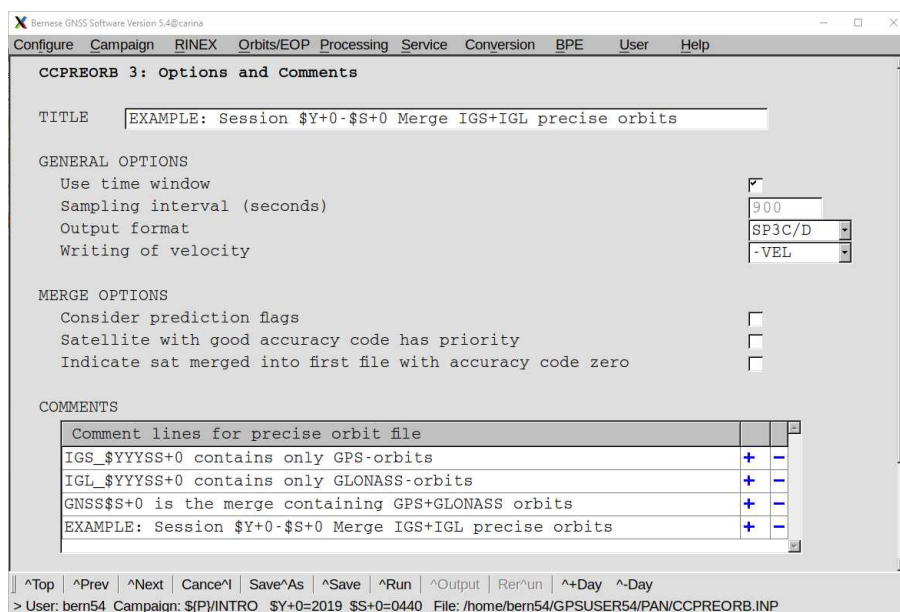
In the next panel you may specify the time window for which the satellite positions shall be included in the resulting precise orbit file.

7.1.3 Generating Standard Orbit Files

To generate the standard orbits (extension STD) from the merged precise orbits the program ORBGEN ("Menu>Orbits/EOP>Create/update standard orbits") has to be used. Introduce the merged IGS–related precise orbit file together with the consistent ERP file:

```
X  Bernese GNSS Software Version 5.4@carina                                      —  □  ×
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE      User      Help

   CREATE/UPDATE STANDARD ORBITS - ORBGEN 1: Input Files

   GENERAL FILES
      Show files for force modelling              ☑
      Show all general files                      ☑

   INPUT FILES
      ◉    Start with precise orbits          GNSS$S+0      PRE
           Use with general ERP file              ☑
      ○    Update standard orbit
              Orbital elements, file 1          [          ]  ELE
              Orbital elements, file 2          [          ]  ELE

      Earth rotation parameters              IGS_$YYYSS+0  ERP
      Ocean tidal loading                    EXAMPLE       BLQ   (for CMC)
      Atmospheric tidal loading              [          ]  ATL   (for CMC)


‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO   $Y+0=2019  $S+0=0440   File: /home/bern54/GPSUSER54/PAN/ORBGEN.INP
```

Adjust the entries for the "Satellite information" (including the correct antenna model based on IGS 14) and the "Subdaily ERP model" to be consistent to the introduced "Earth rotation parameters" file:

```
X  Bernese GNSS Software Version 5.4@carina                                      —  □  ×
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE      User      Help

   ORBGEN 1.2: General Files

   GENERAL INPUT FILES
      General constants           CONST         BSW
      Satellite problems          SAT_$Y+0      CRX
      Geodetic datum              DATUM         BSW
      Satellite information       SATELLIT_I14  SAT
                                  ☐  Error if not in satellite information file
      Subdaily ERP model          IERS2010XY    SUB
      Nutation model              IAU2000R06    NUT
      GPS-UTC time difference     GPSUTC        BSW
      F10.7 flux index            [          ]  FLX   ☐ Use defaults (FLX=120,AP=15)

   MENU SETTINGS
      Selected campaign           ${P}/INTRO
      Selected session            year  2019     session   0440
      Session table               ${P}/INTRO/GEN/SESSIONS.SES

   TEMPORARY FILES
      Scratch files               ORBGEN$J      SCR        ORBGEN$J    SC2


‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
> User: bern54  Campaign: ${P}/INTRO   $Y+0=2019  $S+0=0440   File: /home/bern54/GPSUSER54/PAN/ORBGEN.INP
```

The name of the resulting orbit file should also be related to IGS:

ORBGEN 2: Result and Output Files

RESULT FILES
Standard orbits   IGS_$YYYSS+0   STD
Radiation pressure coeff. [   ]   RPR
Residual file   [   ]   RES

OUTPUT FILES
Summary file   [   ]   LST
Summary file for IGS-ACC   IGS_$YYYSS+0   LST
Plot file of residuals   [   ]   PLT

GENERAL OUTPUT FILES
Program output   ☐ use ORBGEN.Lnn   or   IGS_$YYYSS+0 OUT
Error messages   ☐ merged to program output or   ERROR   MSG

In the general case it is preferable to setup the pulses just in an equidistant spacing by changing option "Setup of stochastic pulses" to Spacing. The interval in "Interval for stochastic pulses" is recommended to be relatively short in order to obtain a "reasonable" representation of the introduced positions in the precise orbit file. In case of IGS orbits one set of pulses at noon is sufficient.

ORBGEN 5: Stochastic Pulses and Satellite Accuracy Codes

STOCHASTIC PULSES IN (L3, L2, L1)-DIRECTIONS
Set up based on   Spacing
List of satellites
Parameter spacing   12 00 00   (hh mm ss)

Orbital elements file   [   ] ELE
   (only used to provide epochs of stochastic pulses)

SATELLITE OPTIONS
Exclude satellites with maneuvers   ☐
Use accuracy codes from SP3-file   ☑
Exclude sat. with accuracy code 0   ☑
Exclude sat. with acc. code exceeding   99

Now you should go back to panel "ORBGEN 3.3: Numerical Integration" and increase the values for options "EQUATION OF MOTION: Length of interval" and "VARIATIONAL EQUATIONS: Length of interval". We don't need to support the pulses at uneven epoch.

ORBGEN 3.3: Numerical Integration

PRINT RESIDUALS   NO
   In RSW Coordinates   ☐

NUMERICAL INTEGRATION
Number of iterations   2

EQUATION OF MOTION
Polynomial degree   10
Length of interval   01 00 00   (hh mm ss)

VARIATIONAL EQUATIONS
Polynomial degree   12
Length of interval   06 00 00   (hh mm ss)
Additional sets   0   (only relevant for LEO orbits)
Use extended RPR Format   ☐   (only intended for LEO orbits)

The other options can be used as given in Section 3.2. The resulting program output is expected to look like

```
 ...
 -------------------------------------------------------------------------------
 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    96     0.002     0.002   0.002   0.002   0.001    0.006   0.005   0.003
   2    96     0.002     0.002   0.002   0.002   0.001    0.008   0.005   0.004
   3    96     0.003     0.003   0.004   0.002   0.003    0.013   0.007   0.006
   4    96     0.004     0.003   0.005   0.003   0.002    0.011   0.007   0.009
   5    96     0.003     0.003   0.005   0.002   0.001    0.020   0.007   0.002
   6    96     0.002     0.002   0.002   0.002   0.002    0.005   0.004   0.004
   7    96     0.002     0.002   0.001   0.001   0.002    0.003   0.003   0.005
   8    96     0.003     0.003   0.003   0.003   0.002    0.006   0.007   0.004
   9    96     0.002     0.002   0.002   0.001   0.002    0.003   0.003   0.004
  10    96     0.003     0.003   0.004   0.002   0.002    0.015   0.006   0.005
  11    96     0.003     0.002   0.003   0.003   0.002    0.006   0.007   0.004
  12    96     0.004     0.004   0.005   0.003   0.002    0.018   0.007   0.005
  13    96     0.001     0.001   0.001   0.001   0.001    0.003   0.003   0.005
 ...
  28    96     0.005     0.004   0.007   0.003   0.002    0.031   0.007   0.007
  29    96     0.003     0.003   0.004   0.003   0.002    0.007   0.008   0.003
  30    96     0.002     0.002   0.003   0.002   0.002    0.005   0.004   0.004
  31    96     0.001     0.001   0.001   0.001   0.001    0.003   0.003   0.003
  32    96     0.001     0.001   0.001   0.001   0.001    0.003   0.004   0.003
 101    96     0.007     0.007   0.010   0.006   0.003    0.018   0.013   0.007
 102    96     0.003     0.003   0.004   0.002   0.002    0.019   0.006   0.009
 103    96     0.005     0.005   0.008   0.003   0.002    0.014   0.010   0.008
 104    96     0.006     0.006   0.009   0.004   0.003    0.015   0.019   0.006
 105    96     0.005     0.005   0.007   0.003   0.003    0.012   0.013   0.006
 107    96     0.006     0.006   0.009   0.004   0.003    0.017   0.016   0.006
 108    96     0.005     0.005   0.008   0.003   0.002    0.013   0.010   0.005
 109    96     0.004     0.004   0.006   0.003   0.003    0.012   0.012   0.009
 ...
 120    96     0.003     0.003   0.003   0.002   0.004    0.007   0.007   0.016
 121    96     0.004     0.004   0.005   0.002   0.003    0.009   0.008   0.009
 122    96     0.004     0.004   0.006   0.002   0.003    0.014   0.007   0.006
 123    96     0.004     0.004   0.005   0.002   0.003    0.010   0.005   0.009
 124    96     0.003     0.003   0.002   0.001   0.004    0.004   0.004   0.014
 126    96     0.007     0.006   0.007   0.006   0.007    0.013   0.011   0.013


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

The RMS error for the orbit fit for precise IGS orbits should be below 5 mm (for older orbits it may also achieve 10...15 mm).

The file `${P}/INTRO/OUT/IGS_2019044.LST` contains the same results as displayed on page 31 but contains also the GLONASS satellite orbits:

```
EXAMPLE: Session 2019-0440: Standard orbit generation          14-JAN-24 05:22
TIME FROM DAY : 3 GPS WEEK: 2040
     TO   DAY : 4 GPS WEEK: 2040
 -------------------------------------------------------------------------------
ORBIT REPEATABILITY FROM A 1-DAY FIT THROUGH DAILY ORBIT SOLUTIONS (MM)
# ECLIPSING SATELLITES:   8 E /   0 M (   0 EM)
 ----------------------------------- ... ----------------------------- ... ---------------
ECL  ..   ..   E.   ..   E.   ..   ..   .. ...  ..   ..   ..   ..   ..   ..   .. ...  ..   ..   ..   ..
DOY  1    2    3    4    5    6    7    8 ...  31   32  101  102  103  104  105  107 ... 122  123  124  126
 ----------------------------------- ... ----------------------------- ... ---------------
044  2    2    3    3    3    2    2    3 ...   1    1    7    3    5    6    5    6 ...   4    4    3    6
 ----------------------------------- ... ----------------------------- ... ---------------
ALL  2    2    3    3    3    2    2    3 ...   1    1    7    3    5    6    5    6 ...   4    4    3    6
 ----------------------------------- ... ----------------------------- ... ---------------
```

If you want to use these orbit files in the processing programs, you have to replace the CODE-related by the IGS-related filenames for the standard orbit and EOP files.

7.2 Kinematic Positioning

7.2.1 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_20190440.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:
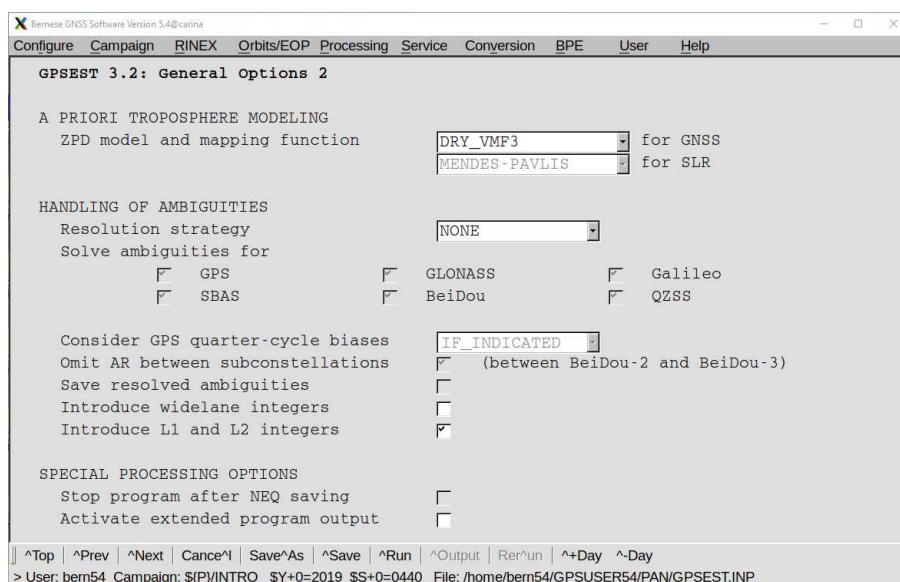
Fix all station coordinates apart from GANP in the panels "GPSEST 4: Datum Definition for Station Coordinates" (choose MANUAL in panel "GPSEST 4: Datum Definition for Station Coordinates" and select all stations except GANP in panel "GPSEST 4.2").
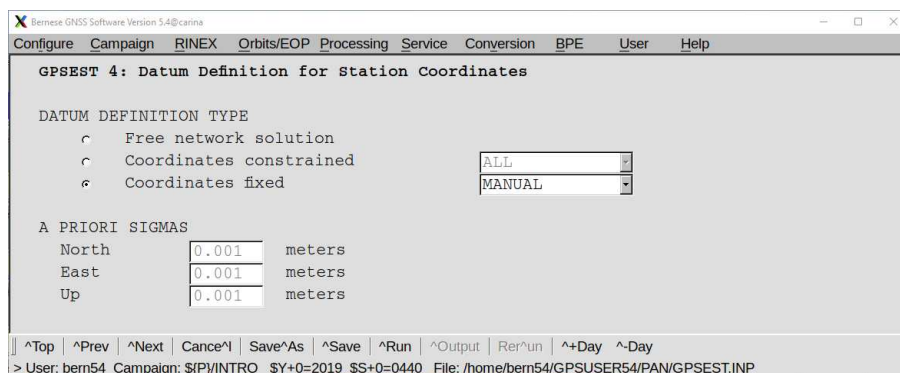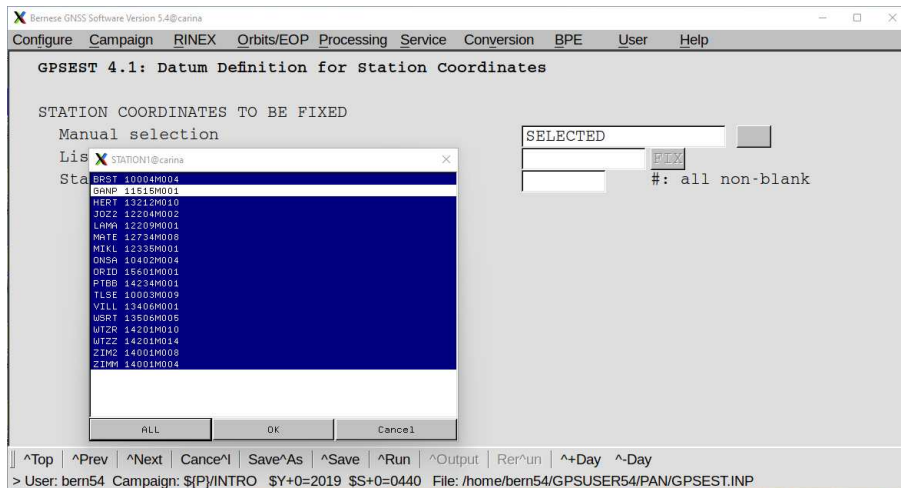
Enable the kinematic coordinates option without any pre–elimination in a first run:
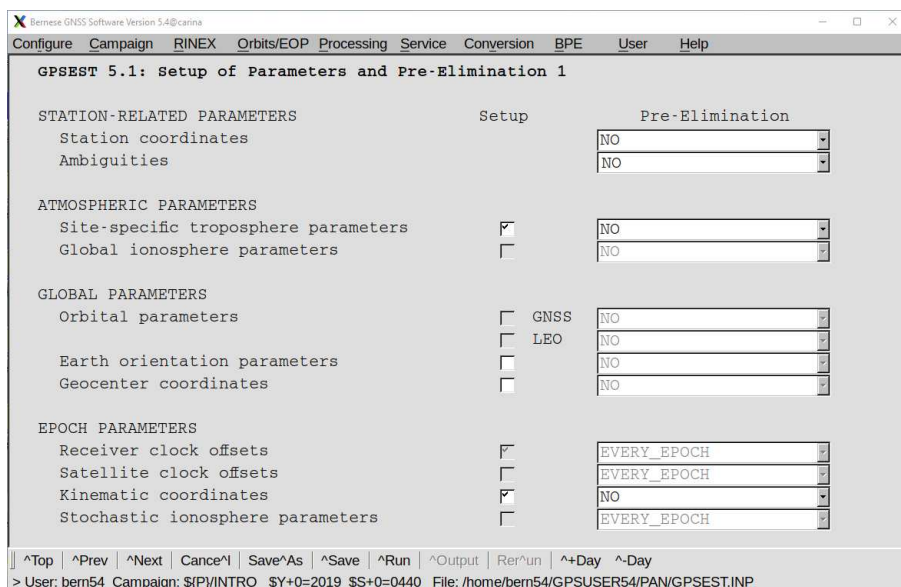
Because of the short analysis interval of only one hour we disable the estimation of troposphere gradients:
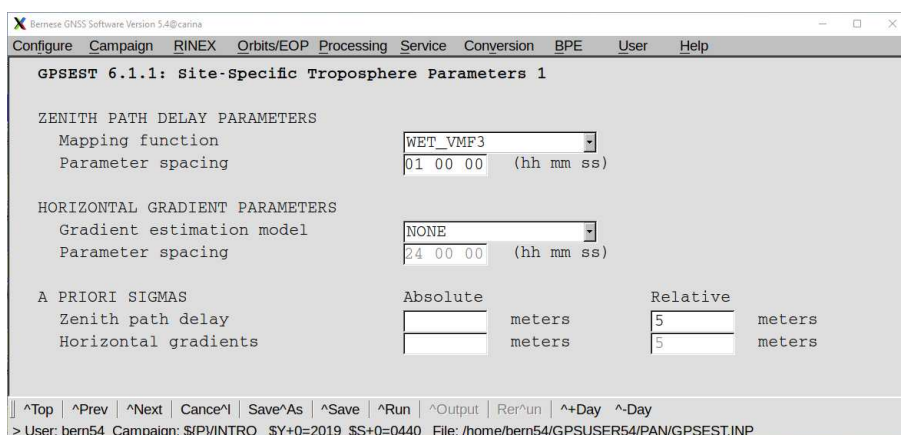
An additional panel for options related to epoch parameters is displayed where you can accept the default values:

```
X  Bernese GNSS Software Version 5.4@carina                                    —   ☐   ✕

Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE      User      Help

    GPSEST 6.7: General Options for Epoch Parameters


  OPTIONS SPECIFIC TO EPOCH PARAMETERS
     Epoch parameters only from phase              ☐
     Var-covar wrt epoch parameters                SIMPLIFIED              ▾
     Sampling interval for resubstitution                        seconds
     Sampling interval for pre-elimination                       seconds

  LEO-SPECIFIC
     Epochs for var-covar matrix         4      ⬍
     Print epoch var-covar for           COORDINATES            ▾
     Store covariances in KIN file       ☐

 ‖ ^Top   ^Prev   ^Next   Cance^l   Save^As   ^Save   ^Run   ^Output   Rer^un   ^+Day   ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019 $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

Let us assume only horizontal movements for this site:

```
X  Bernese GNSS Software Version 5.4@carina                                    —   ☐   ✕

Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE      User      Help

    GPSEST 6.9: Kinematic Coordinates


  STATIONS TO BE TREATED AS KINEMATIC
     Station selection                    MANUAL              ▾
     Station list from file                                 FIX
     Manual selection                     GANP 11515M001            ▭

  A PRIORI SIGMAS
     Reference frame                      NEU   ▾
     Sigma for horizontal components      100.00        meters
     Sigma for vertical component         0.0001        meters
     Sigma for all components                           meters

  ADDITIONAL OPTION
     Minimum number of observations per epoch   6   ⬍

 ‖ ^Top   ^Prev   ^Next   Cance^l   Save^As   ^Save   ^Run   ^Output   Rer^un   ^+Day   ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019 $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

7.2.2 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   41    0.00446    3929181.30273    0.00244  ...  2019-02-13 18:00:00    35 #KIN
GANP 11515M001   Y   41    0.00241    1455236.95493    0.00260  ...  2019-02-13 18:00:00    36 #KIN
GANP 11515M001   Z   41   -0.00436    4793654.03164    0.00211  ...  2019-02-13 18:00:00    37 #KIN
GANP 11515M001   X   40   -0.00286    3929181.29541    0.00243  ...  2019-02-13 18:05:00    38 #KIN
GANP 11515M001   Y   40    0.00213    1455236.95465    0.00260  ...  2019-02-13 18:05:00    39 #KIN
GANP 11515M001   Z   40    0.00169    4793654.03769    0.00209  ...  2019-02-13 18:05:00    40 #KIN
GANP 11515M001   X   40    0.00041    3929181.29868    0.00241  ...  2019-02-13 18:10:00    41 #KIN
GANP 11515M001   Y   40    0.00002    1455236.95254    0.00262  ...  2019-02-13 18:10:00    42 #KIN
GANP 11515M001   Z   40   -0.00034    4793654.03566    0.00206  ...  2019-02-13 18:10:00    43 #KIN
GANP 11515M001   X   39    0.00052    3929181.29879    0.00242  ...  2019-02-13 18:15:00    44 #KIN
GANP 11515M001   Y   39    0.00205    1455236.95457    0.00260  ...  2019-02-13 18:15:00    45 #KIN
GANP 11515M001   Z   39   -0.00104    4793654.03496    0.00206  ...  2019-02-13 18:15:00    46 #KIN
GANP 11515M001   X   40   -0.00091    3929181.29736    0.00240  ...  2019-02-13 18:20:00    47 #KIN
GANP 11515M001   Y   40    0.00061    1455236.95313    0.00260  ...  2019-02-13 18:20:00    48 #KIN
GANP 11515M001   Z   40    0.00056    4793654.03656    0.00204  ...  2019-02-13 18:20:00    49 #KIN
GANP 11515M001   X   39   -0.00237    3929181.29590    0.00241  ...  2019-02-13 18:25:00    50 #KIN
GANP 11515M001   Y   39    0.00097    1455236.95349    0.00263  ...  2019-02-13 18:25:00    51 #KIN
GANP 11515M001   Z   39    0.00164    4793654.03764    0.00203  ...  2019-02-13 18:25:00    52 #KIN
GANP 11515M001   X   38   -0.00241    3929181.29586    0.00241  ...  2019-02-13 18:30:00    53 #KIN
GANP 11515M001   Y   38   -0.00101    1455236.95151    0.00264  ...  2019-02-13 18:30:00    54 #KIN
GANP 11515M001   Z   38    0.00226    4793654.03826    0.00203  ...  2019-02-13 18:30:00    55 #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:

```
Bernese GNSS Software Version 5.4@carina                          —   □   ×
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

    EXTRACT GPSEST/ADDNEQ2 PROGRAM OUTPUT - GPSXTR 1: Extractions


    GENERAL FILES
        Show all general files        ☑

    INPUT FILENAMES
        ○                   GPSEST.L??        (GPSEST.Lxx/ADDNEQ2.Lxx)
        ◉                   KIN_$YYYSS+0 OUT  (GPSEST/ADDNEQ2 output)

    GENERAL OUTPUT FILES
        Program output      ☑   use GPSXTR.Lnn          or   GPSXTR   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=2019 $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSXTR.INP
```

```
Bernese GNSS Software Version 5.4@carina                          —   □   ×
Configure   Campaign   RINEX   Orbits/EOP   Processing   Service   Conversion   BPE   User   Help

    GPSXTR 2: Output Files


    TITLE          EXAMPLE: Session $Y+0-$S+0: Kinematic network solution

    OUTPUT FILES
        Output summary          [            ]  SUM   Add table with parameters   ☐
        Coordinate summary      [            ]  SUM
        Kinematic summary       [KIN_$YYYSS+0]  SUM
        GIM summary             [            ]  SUM
        Clock summary           [            ]  SUM   Baseline   [        ] BSL
        Clock Allan deviation   [            ]  SUM
        Ambiguity resolution    [            ]  SUM   GNSS-wise   ☐   ID  [   ▾]
        Ambiguity fractionals   [            ]  SUM
        Campaign summary        [            ]  SUM
        Weekly summary          [            ]  SUM
        Pole output             [            ]  SUM   Pole parameter sets  [ALL ▾]

  ‖ ^Top | ^Prev | ^Next | Cance^l | Save^As | ^Save | ^Run | ^Output | Rer^un | ^+Day | ^-Day
  > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019 $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSXTR.INP
```

The resulting summary file looks like:

```
*STATION        GANP 11515M001
*XEPO        12
*INI         3929181.2983    1455236.9525    4793654.0360
*EST               0.0000          0.0000          0.0000
*DIFXYZ            0.0006          0.0005         -0.0006
*DIFNEU           -0.0010          0.0002         -0.0000
-------------------------------------------------------------------------
  EPOCH           DN              DE              DU
58527.75000      -0.0066          0.0007         -0.0000
58527.75347       0.0026          0.0030          0.0000
58527.75694      -0.0005         -0.0001         -0.0000
58527.76042      -0.0016          0.0017          0.0000
58527.76389       0.0009          0.0009          0.0000
58527.76736       0.0025          0.0017          0.0000
58527.77083       0.0035         -0.0001         -0.0000
58527.77431      -0.0026          0.0014          0.0000
58527.77778      -0.0035         -0.0018         -0.0000
58527.78125      -0.0042          0.0032          0.0000
58527.78472      -0.0004         -0.0033         -0.0000
58527.78819      -0.0017         -0.0045         -0.0000
-------------------------------------------------------------------------
*AVG              -0.0010          0.0002         -0.0000
*SIG               0.0030          0.0024          0.0000
*RMS               0.0031          0.0023          0.0000
*RMSTC             0.0011
-------------------------------------------------------------------------
```

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

7.2.3 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").

7.3 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.

7.3.1 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/????0440.CZ?
bern54@carina:~ > rm ${P}/INTRO/OBS/????0440.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
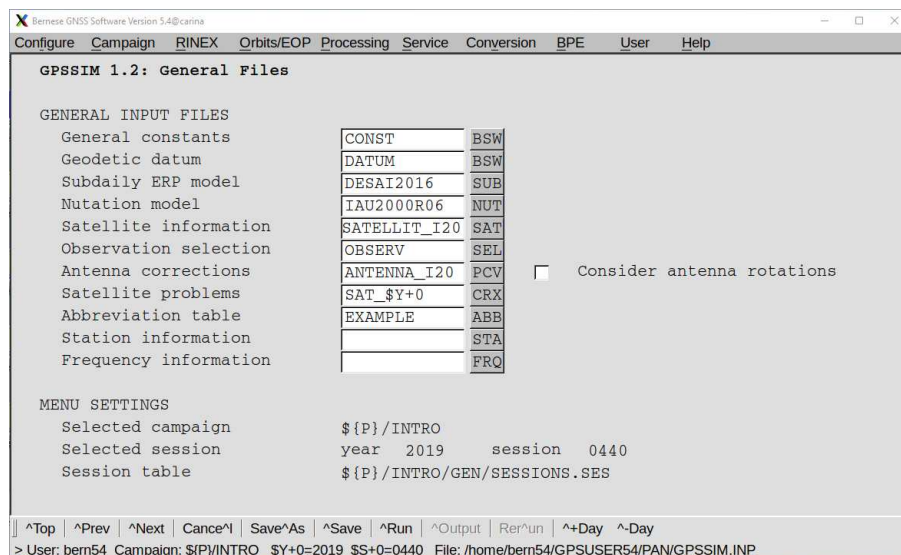
In the next panel, the interval for data simulation is defined and the list of stations selected from all sites in the input "Coordinate file":
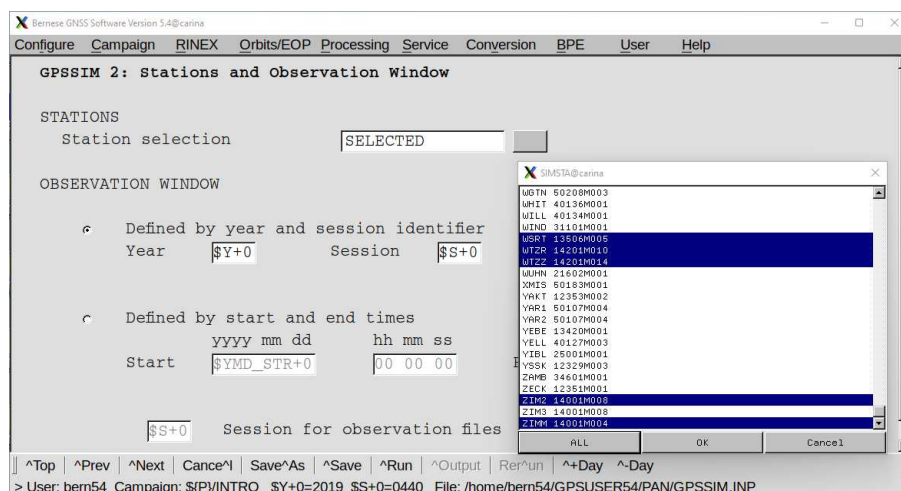
The meta data for each station is specified in this panel:

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.

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.

7.3.2 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        51      51       0               0    0    0    0
Ambiguities                           2925    2925       0               0    0    0    0
Epochwise receiver clocks             4896       0    4896  (epow)       0    0    0    0
Epochwise satellite clocks           10076       0   10076  (epow)       0    0    0    0
------------------------------------------------------------------------------------------
Total number                         17948    2976   14972               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    270132
Total number of pseudo-observations            0

Total number of explicit parameters         2976
Total number of implicit parameters        14972

Total number of observations              270132
Total number of adjusted parameters        17948
Degree of freedom (DOF)                    252184

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

Total number of observation files             34
Total number of stations                      17
...
```

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     4231162.41917    0.00000     4231162.41917 ... #CRD
  1 BRST 10004M004        Y    0.00000     -332746.42575    0.00000     -332746.42575 ... #CRD
  1 BRST 10004M004        Z   -0.00000     4745131.07277    0.00000     4745131.07277 ... #CRD
  1 GANP 11515M001        X   -0.00000     3929181.29827    0.00000     3929181.29827 ... #CRD
  1 GANP 11515M001        Y    0.00000     1455236.95252    0.00000     1455236.95252 ... #CRD
  1 GANP 11515M001        Z   -0.00000     4793654.03600    0.00000     4793654.03600 ... #CRD
  1 HERT 13212M010        X   -0.00000     4033460.74185    0.00000     4033460.74185 ... #CRD
  1 HERT 13212M010        Y    0.00000       23538.04010    0.00000       23538.04010 ... #CRD
```

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

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

Station name      #obs    Correction  Estimated value  RMS error ... From                      Abb
-------------------------------------------------------------------------- ... ------------------------
BRST 10004M004    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
GANP 11515M001    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
HERT 13212M010    60 R    -0.00000       -0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
JOZ2 12204M002    56 R    -0.00000       -0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
LAMA 12209M001    58 R    -0.00000       -0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
MATE 12734M008    60 R    -0.00000       -0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
MIKL 12335M001    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
ONSA 10402M004    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
ORID 15601M001    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
PTBB 14234M001    60 R    -0.00000       -0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
TLSE 10003M009    60 R    -0.00000       -0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
VILL 13406M001    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
WSRT 13506M005    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
WTZR 14201M010    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
WTZZ 14201M014    60 R    -0.00000       -0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
ZIM2 14001M008    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 00:00:00  #RCK
ZIMM 14001M004    60 R     0.00000        0.00000        0.00000 ... 2019-02-13 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 $1\,\mu$m level.

7.3.3 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/????0440.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, what is managed 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:

```
  X  Bernese GNSS Software Version 5.4@carina                              —   □   ×

 Configure  Campaign  RINEX  Orbits/EOP  Processing  Service  Conversion  BPE  User  Help

   GPSEST 5.1: Setup of Parameters and Pre-Elimination 1

      STATION-RELATED PARAMETERS              Setup        Pre-Elimination
         Station coordinates                            [NO                    ▼]
         Ambiguities                                    [NO                    ▼]

      ATMOSPHERIC PARAMETERS
         Site-specific troposphere parameters    □      [NO                    ▼]
         Global ionosphere parameters            □      [NO                    ▼]

      GLOBAL PARAMETERS
         Orbital parameters                      □ GNSS [NO                    ▼]
                                                 □ LEO  [NO                    ▼]
         Earth orientation parameters            □      [NO                    ▼]
         Geocenter coordinates                   □      [NO                    ▼]

      EPOCH PARAMETERS
         Receiver clock offsets                  ☑      [EVERY_EPOCH           ▼]
         Satellite clock offsets                 ☑      [EVERY_EPOCH           ▼]
         Kinematic coordinates                   □      [NO                    ▼]
         Stochastic ionosphere parameters        □      [EVERY_EPOCH           ▼]

 ‖ ^Top  ^Prev  ^Next  Cance^l  Save^As  ^Save  ^Run  ^Output  Rer^un  ^+Day  ^-Day
 > User: bern54  Campaign: ${P}/INTRO  $Y+0=2019  $S+0=0440  File: /home/bern54/GPSUSER54/PAN/GPSEST.INP
```

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

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

Total number of authentic observations      118515
Total number of pseudo-observations             16

Total number of explicit parameters           2763
Total number of implicit parameters              0

Total number of observations                118531
Total number of adjusted parameters           2763
Degree of freedom (DOF)                     115768

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

Total number of observation files               16
Total number of stations                        17
...
```

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.

7.3.4 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.