



Hungary
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GNSS Meteorology Products

User Manual

Hungary-Slovakia-Romania-Ukraine ENI Cross-border Cooperation Programme 2014-2020

GeoSES – Extension of the operational „Space Emergency System” towards monitoring of dangerous natural and man-made geo-processes in the HU-SK-RO-UA cross-border region

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1. Scope of the document

The Budapest University of Technology and Economics, Faculty of Civil Engineering, Department of Geodesy and Surveying developed a near-realtime GNSS processing facility for deriving atmospheric parameters using ground-based continuously operating GNSS stations (CORS).

The product line include the following atmospheric parameters:

- zenith total delays (ZTD);
- zenith wet delays (ZWD);
- zenith hydrostatic delays (ZHD);
- total refractivity profiles (GPSRF)
- water vapour density profiles (WVD)

The tropospheric delays (ZTD, ZHD and ZWD) are derived by a rigorous GNSS processing algorithm using the Bernese GNSS Software, while the GPSRF and WVD products are calculated using the tomographic algorithm developed in the frame of the GeoSES project.

This manual does not aim to discuss the methodology of the calculations. However, for the sake of completeness, we have attached the methodology description to the appendix of this manual.

To ease the use and visualization of our products, we have distinguished three level of users:

- general use: a web-based form is available to query the numerical values of the atmospheric parameters, including a graphical visualization for the atmospheric profiles;
- meteorologists/numerical weather modelling: the data can be downloaded in Little-R format that can be directly used by the open-source WRF (World Research Forecast) numerical weather model.
- GIS or NWM developers: the datasets are available in the widely used JSON format, that can be easily imported to programming languages like Python.

The user manual follows the aforementioned user levels and introduces the use of our products on various levels.

2. ,Principles in a nutshell

GNSS (Global Navigation Satellite Systems) are widely used for everyday navigational tasks as well as high accuracy positioning tasks in land surveying, precision farming, construction, autonomous driving, etc. To realize cm accurate satellite positioning, a ground-based augmentation system (GBAS) is used to provide additional signal corrections to the satellite signals. GBAS is usually organized on a national level, thus each HUSKROUA state has its own GBAS service (Hungary: GNSSNet.hu, CORRIGO; Slovakia: SKPOS, Romania: ROMPOS, Ukraine: ZAKPOS). The European Permanent Network (EPN) forms an overarching reference network for these national GBAS systems.

Since the coordinates of the GBAS reference stations are not only known but are continuously monitored, their observations can be used to estimate environmental parameters, such as the integrated water vapour (IWV) content of the atmosphere, since the propagation time of the satellite signal is affected by the atmospheric water vapour.

These signals delays – called the wet delays caused by the troposphere – are estimated by regularly processing GNSS signals observed by the GNSS reference stations. The basic products of this process are:

- The zenith wet delay (ZWD) representing the signal delay in the zenith direction caused by the atmospheric water vapour in the column above the GNSS station;
- The zenith total delay (ZTD) representing the total signal delay in the zenith direction caused by the total atmospheric masses in the column above the GNSS station (including both the dry and wet component of air masses);
- The zenith hydrostatic delay (ZHD) representing the signal delay in the zenith direction caused by the atmospheric masses in the hydrostatic equilibrium in the column above the GNSS stations (includes the effects of the dry and a part of the wet atmospheric masses).

In the frame of the GeoSES project a new tomographic reconstruction algorithm has been developed that enabled as to restore the spatial (3D) distribution of the refractivity field in the HUSKROUA region. The signal delays observed in the satellite directions are caused by the refractivity changes along the signal path. Since the slant tropospheric delays (SWD – slant wet delays) represents the integration of these refractivity changes, they can be used to reconstruct the 3D distribution of the atmospheric refractivity caused by the water vapour. Water vapour density is a direct function of the wet refractivity values and the temperature, thus WVDs can be estimated when not only the refractivities but also the temperature profiles are available.

The GNSS tomography approach enables us to provide additional products for the meteorology community to be able to refine the numerical weather prediction processes. The following products are available to the users:

- Atmospheric total refractivity profiles on a regular grid obtained from GNSS observations (GPSRF): atmospheric refractivity can be estimated directly from the GNSS signals without any additional meteorological observation and can be assimilated (included) in numerical weather models.
- Water vapour density profiles on a regular grid (WVD): WVD values cannot be calculated without the a priori knowledge of the vertical temperature profile in the atmosphere, thus these values contain some approximations, since temperature profiles are taken from the spatially and temporarily closest radiosonde profile. They should not be used in numerical weather modelling, since they might cause inconsistencies due to the different input data.

The methodology of the derivation of the atmospheric products are explained in more detail in the following papers:

Rózsa Sz., Khaldi A., Ács Á., Turák B. Multi-GNSS Near Real-time Precipitable water vapour estimation for severe weather prediction. BULETIN STIINTIFIC AL UNIVERSITATII DE NORD BAIA MARE SERIA D EXPLOATARI MINIERE, PREPARAREA SUBSTANTELOR MINERALE UTILE, METALURGIE NEFEROASA, GEOLOGIE SI INGINERIA MEDIULUI 35 : 2 pp. 777-786. Paper: 15 , 10 p. (2021). URL: <https://www.proquest.com/docview/2616226699>

Further information is available on our website at: <http://gpsmet.agt.bme.hu>

3. How to use the products?

GNSS atmospheric products are being used by Meteorological Services for further improving the accuracies of the weathers predictions. Mile et al. (2019) has proved that the assimilation of GNSS ZTD products in numerical weather models significantly improve both the prediction of the temperature/dewpoint relative humidity up to 6 hours, and it also improved the forecast of 12h-precipitation sums. The following paper contains the detailed study:

Mile M., Benacek P., Rózsa Sz. The use of GNSS ZTDs in operational AROME 3D-Var over a CE domain. Atmos. Meas. Tech., 12, 1569–1579, 2019,

URL: <https://amt.copernicus.org/articles/12/1569/2019/amt-12-1569-2019.pdf>

We envisaged the following use cases for our GNSS meteorology products:

- visualization and numerical data collection;
- assimilation of the products in numerical weather models for weather prediction;
- data query for GIS systems and NWM software and other data warehouses.

Although our products are available in various formats to ease the use for the aforementioned applications, the product line is designed to especially support the assimilation of GNSS ZTDs and GPSRF values in numerical weather modelling, thus these geodetic products are available as a service for the meteorology community in the HUSKROUA region, including not only the national meteorology services, but also other NGOs and private companies providing weather predictions in the region.

All the products are available on the website of the GeoSES GNSS product website at <http://gpsmet.agt.bme.hu> under the Products menu.

In the next sections the data acquisition methods for the three use cases are introduced in more detail.

4. General use

The simplest way to retrieve the GNSS atmospheric products is to use the interactive tropospheric delay chart and the interactive refractivity and water vapour density profile charts. In the following subsections these tools are introduced.

4.1 The Interactive Tropospheric Delay Chart

The calculated zenith tropospheric delays above the permanent GNSS stations can be retrieved from the database using the **Interactive Tropospheric Delay Chart** product using a simple web form. The user can specify the type of the requested product (ZTD, ZWD or ZHD), the date and the station name, that can be selected from a list.

Epoch	ZWD [m]
2022-12-10-0-0-0	0.146
2022-12-10-1-0-0	0.146

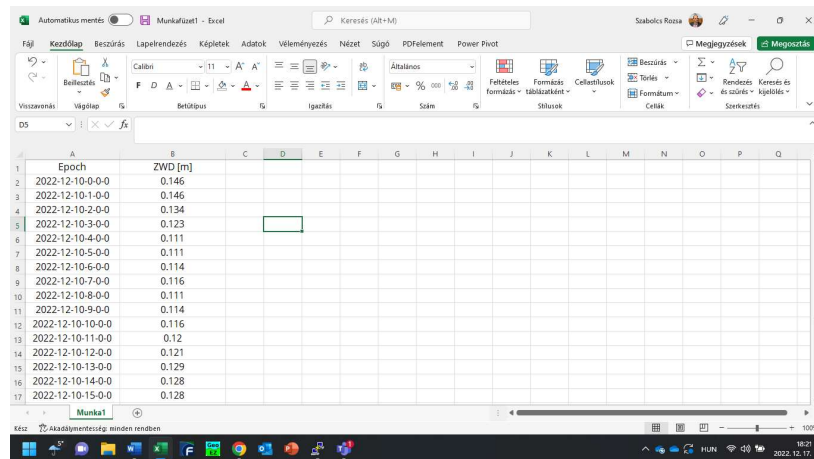
1. Figure: The interactive tropospheric delay chart tool

After submitting the query parameters the numerical values and the daily graph of the appropriate delay is displayed at the bottom of the page (see. Fig. 2.).



2. Figure: Results of the tropospheric delays

The graph can be saved as an image file by right-clicking on the item. The table containing the numerical values can be copied to any spreadsheet application, like MS Excel by selecting the full table and pressing CTRL+C and pasting the table to the chosen spreadsheet application (see Fig. 3.).

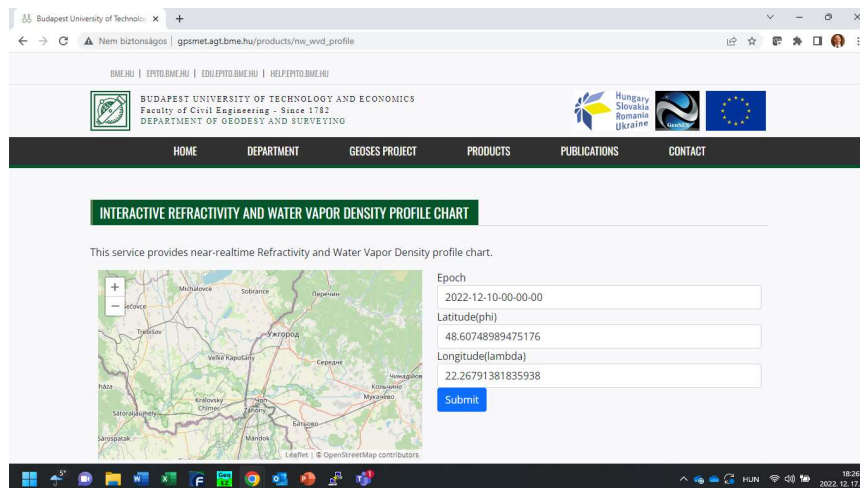


Epoch	ZWD [m]
2022-12-10-0-0-0	0.146
2022-12-10-1-0-0	0.146
2022-12-10-2-0-0	0.134
2022-12-10-3-0-0	0.123
2022-12-10-4-0-0	0.111
2022-12-10-5-0-0	0.111
2022-12-10-6-0-0	0.114
2022-12-10-7-0-0	0.116
2022-12-10-8-0-0	0.111
2022-12-10-9-0-0	0.114
2022-12-10-10-0-0	0.116
2022-12-10-11-0-0	0.12
2022-12-10-12-0-0	0.121
2022-12-10-13-0-0	0.129
2022-12-10-14-0-0	0.128
2022-12-10-15-0-0	0.128

3. Figure. Numerical results pasted to MS Excel for further processing

4.2 The Interactive Refractivity and Water Vapour Density Profile Chart

The results of the tomographic reconstruction of the 3D distribution of atmospheric water vapour and wet refractivity can be visualized by the interactive profile maker form. One needs to choose the date and select any point on the map inside the study area denoted by the red rectangle or specify a defined latitude and longitude value. Please note that the specified geographical location must be in the area denoted by the red rectangle.



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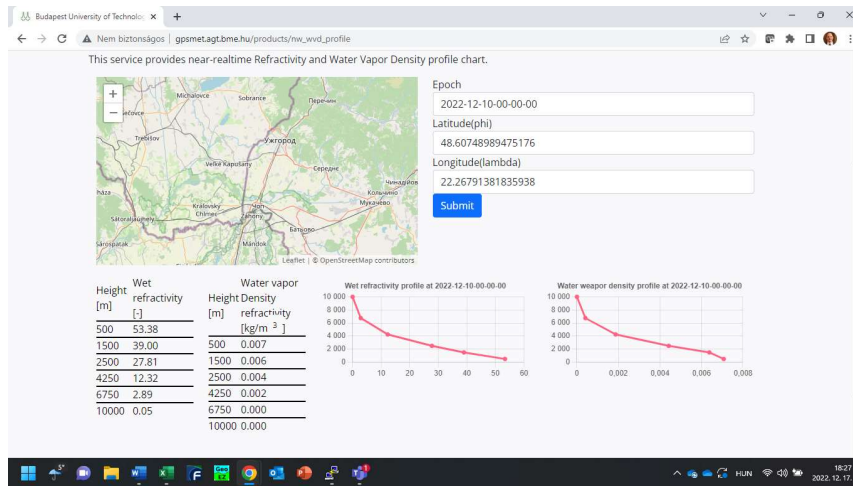
INTERACTIVE REFRACTIVITY AND WATER VAPOR DENSITY PROFILE CHART

This service provides near-realtime Refractivity and Water Vapor Density profile chart.

Epoch: 2022-12-10-00-00-00
Latitude(phi): 48.60748989475176
Longitude(lambda): 22.26791381835938
Submit

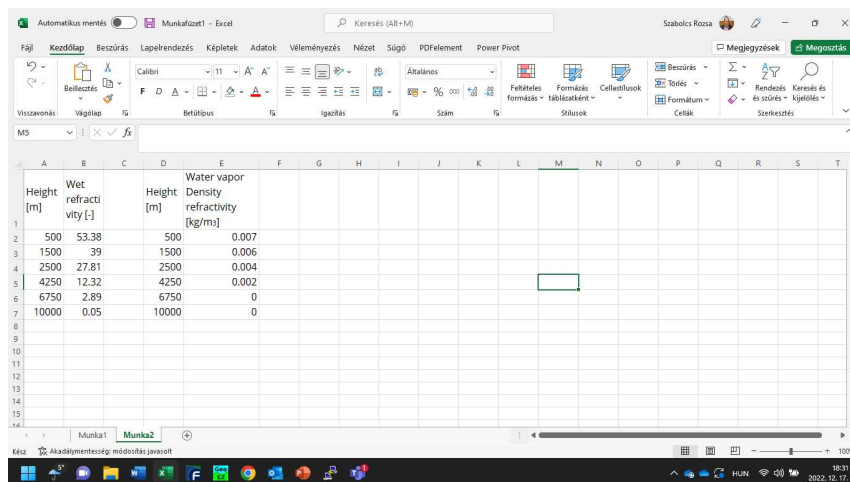
4. Figure. The interactive refractivity and water vapour density profile chart

After clicking on the 'Submit' button, the results are displayed at the bottom of the page. Please scroll down for the numerical values and the profiles.



5. Figure. Results of the wet refractivity and water vapour density retrieval.

Similarly to the delay results, the tables can be copied and pasted to any spreadsheets, while the graphs can be saved as image files from the webpage.



6. Figure. Numerical values of wet refractivity profiles and water vapour densities copied to MS Excel

5. Products for Numerical Weather Modelling

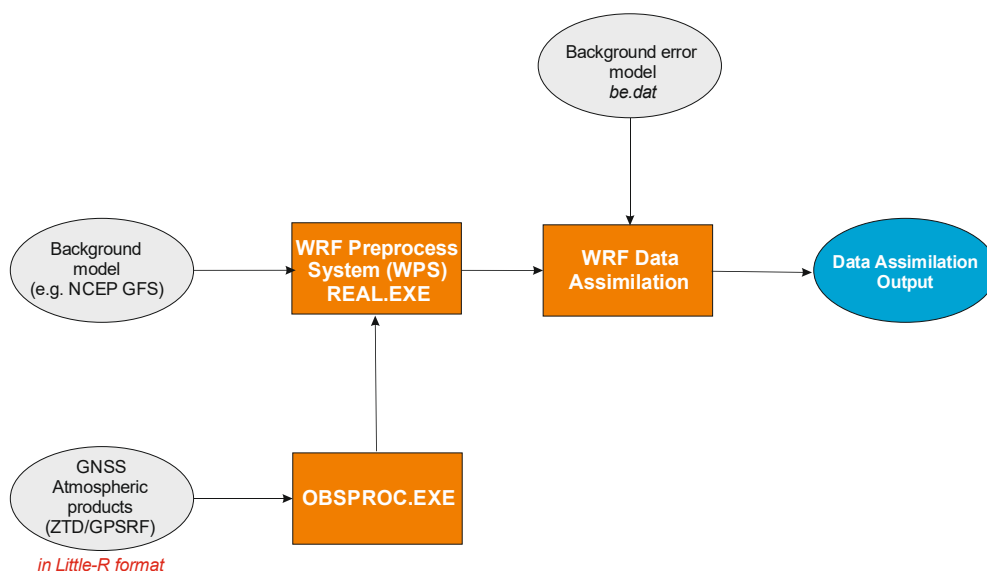
Apart from the previously introduced numerical and graphical reports, the meteorologist community is also served with tropospheric delays and total refractivity profiles in Little-R format. Little-R is a well-defined, standard input format of the open-source Weather Research and Forecasting (WRF) numerical model. This numerical model is widely used by meteorologists for numerical weather modelling and prediction. In order to use the following two products, one needs to download and install the WRF model. The model has an extensive documentation, users are directed to the following webpages for further information:

- Weather Research & Forecasting Model (WRF) webpage:
<https://www.mmm.ucar.edu/models/wrf>
- Online Installation Instructions and Tutorial:
<https://www2.mmm.ucar.edu/wrf/OnLineTutorial/>
- WRFDA Users' Page: <https://www2.mmm.ucar.edu/wrf/users/wrfda/index.html>

In order to fully exploit the information content of the GNSS atmospheric products, they should be assimilated in the numerical models. Therefore the WRFDA model must be installed.

The GNSS atmospheric products are encoded in the Little-R format. The format description is available at <https://www2.mmm.ucar.edu/wrf/users/wrfda/OnlineTutorial/Help/littler.html>.

As a general procedure in case of data assimilation one collects surface observations, atmospheric profiles, etc. and combines this information with a background atmospheric model, such as the Global Forecast System of the National Center for Environmental Prediction (NCEP). The flowchart of the data assimilation is depicted on Figure 7.

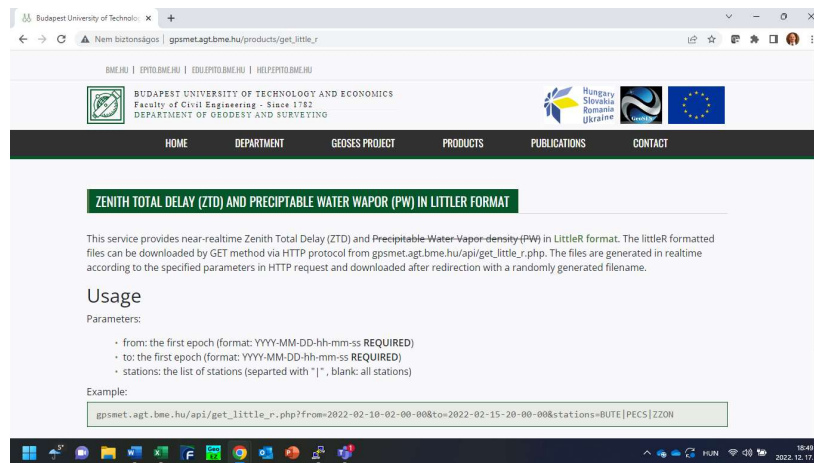


7. Figure. Flowchart of the data assimilation of GNSS atmospheric products

5.1 Zenith Total Delays in Little-R Format

Zenith total delays (ZTDs) are encoded as FM-114 messages (see the Little-R documentation for further details) in the header section of the files. The ZTD products can be downloaded using the API *get_little_r.php*. The API can be invoked from a web browser or from the command prompt using the *wget* application.

The API retrieves all the ZTD values between the starting epoch and the end epoch from the data warehouse for the selected GNSS stations. We recommend to retrieve all the available stations, since only those stations are used in the WRF model, which are located in the domain defined for the numerical weather modelling.



8. Figure The Zenith Total Delay retrieval in Little-R format for WRF users

To download the ZTDs for the date 2022-12-10 0:00:00, one needs to specify the following URL in the web browser:

[http://gpsmet.agt.bme.hu/api/get_little_r.php?from=2022-12-10-00-00-00-00&to=2022-12-10-00-00-00&stations=](http://gpsmet.agt.bme.hu/api/get_little_r.php?from=2022-12-10-00-00-00&to=2022-12-10-00-00-00&stations=)

Station	ZTD (m)	Message Format
BBYS	48.75180	FM-114 GE
BUTE	47.48094	FM-114 GE
GSR1	46.04813	FM-114 GE
KRA1	50.06611	FM-114 GE
MOP1	48.37272	FM-114 GE
SBG2	47.80342	FM-114 GE
TRF2	47.92796	FM-114 GE
TUBO	49.20589	FM-114 GE

9. Figure The dataset in Little-R format

One needs to scroll to the end of the rows to see the zenith total delays in cm units.

1	10	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0	226.65700	0
2									
3									
4									
5	20	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0	238.58800	0
6									
7									
8									
9	30	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0	230.57200	0
10									
11									
12									
13	10	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0	233.92500	0
14									
15									
16									
17	20	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0	224.33300	0
18									
19									
20									
21	30	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0	201.60700	0
22									
23									
24									
25	10	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0	209.56000	0
26									
27									
28									
29	20	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0-888888.00000	0	230.16200	0
30									
31									

10. Figure. ZTD values in the Little-R file

The Little-R observation files can be directly imported to WRF using the OBSPROC.EXE program included in the WRFDA installation. To import the observations, one needs to save the Little-R file to the working directory of WRF. We recommend to use an easy-to-understand name, such as:

```
ztd_2022121000_2022121000.obs
```

We demonstrate the data import of the downloaded ZTD files in Little-R format to the WRF model in the next steps. To be able to import the data, one needs to adjust the filename and domain parameters (geographical coordinates of the domain boundaries) in the *namelist.obsproc* file. A sample *namelist.obsproc* file is available at our website for test purposes (<http://gpsmet.agt.bme.hu/sample/ztdlittler.zip>).

The following parameters has to be updated in order to import the ZTD observations:

Set the *obs_gts_filename* variable to the filename of the downloaded ZTD file in record1:

```
obs_gts_filename = 'ztd_2022121000_2022121000.obs',
```

Adjust the *time_window_min*, *time_analysis* and the *time_window_max* variables according to the time epoch of the downloaded file:

```
&record2
time_window_min = '2022-12-09_23:30:00',
time_analysis   = '2022-12-10_00:00:00',
time_window_max = '2022-12-10_00:30:00',
/
```

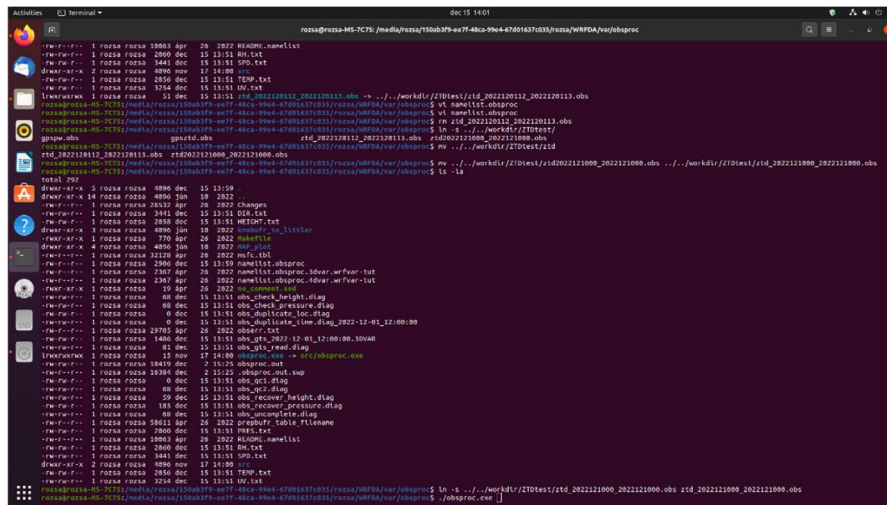
Set the projection variable in record7:

```
&record7
IPROJ = 1,
PHIC   = 47.50001,
XLONG  = 18.50,
TRUELAT1= 50.0,
TRUELAT2= 45.0,
MOAD_CEN_LAT = 47.50001,
STANDARD_LON = 18.50,
/
```

Check the output settings of the ZTD values in record9:

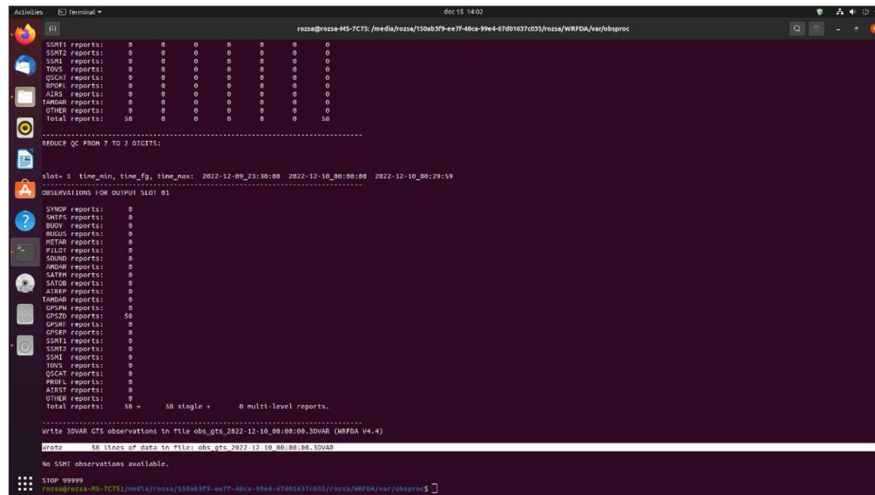
```
write_gpsztd= .true.,
```

Afterwards one needs to run the `obsproc.exe` program to import the Little-R file to WRF. The following figures show the appropriate steps in Linux environment.



11. Figure. Running the obsproc.exe program to import the GNSS atmospheric product to WRF model

After running the obsproc.exe program, one should see the following result:



12. Figure. OBSPROC.EXE results: 58 GPSZTD values are considered for the model domain

In our example the results were written to the *obs_gts_2022-12-10_00:00:00.3DVAR* file. The results are also available at <http://gpsmet.agt.bme.hu/sample/ztdlittler.zip> for reference.

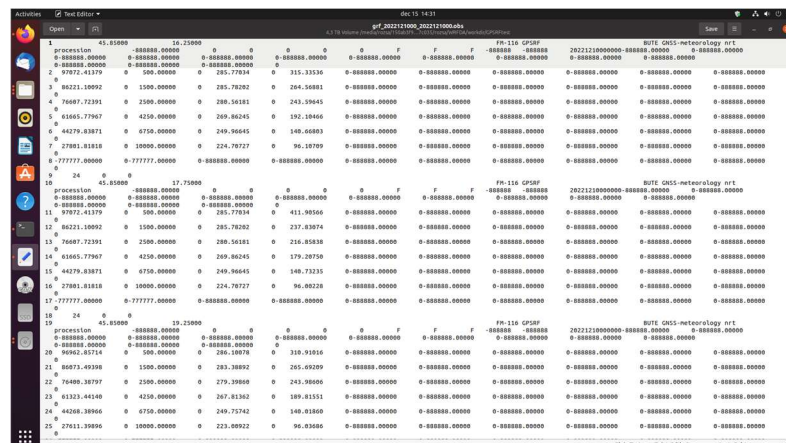
5.2 Total Refractivity Profiles in Little-R format

The tomographic reconstruction provides the 3D model of the wet refractivities in a predefined grid. However, WRF is able to assimilate total refractivities instead of the wet ones. To calculate total refractivities, the nearest radiosonde profile is used to calculate the hydrostatic refractivities and these are added to the wet refractivities stemming from the tomographic reconstruction.

The following API is used to retrieve the full total refractivity model for a specific epoch (use only full hours):

http://gpsmet.agt.bme.hu/api/get_little_r_refractivity.php?epoch=2022-12-10-00-0-0

The GPS refractivity values are encoded as FM-116 messages in the Little-R format. The first part of the downloaded Little-R file is depicted on Figure 13.



13. Figure. GPS refractivity values encoded in Little-R format

Similarly to the ZTD files, one needs to copy the downloaded file to the working directory of WRFDA. After updating the input filename in the *namelist.obsproc* file one can invoke the obsproc.exe program to import the refractivity observations.

The parameters of the *namelist.obsproc* file are identical to the ones introduced in section 5.1 except the input filename parameter in record1:

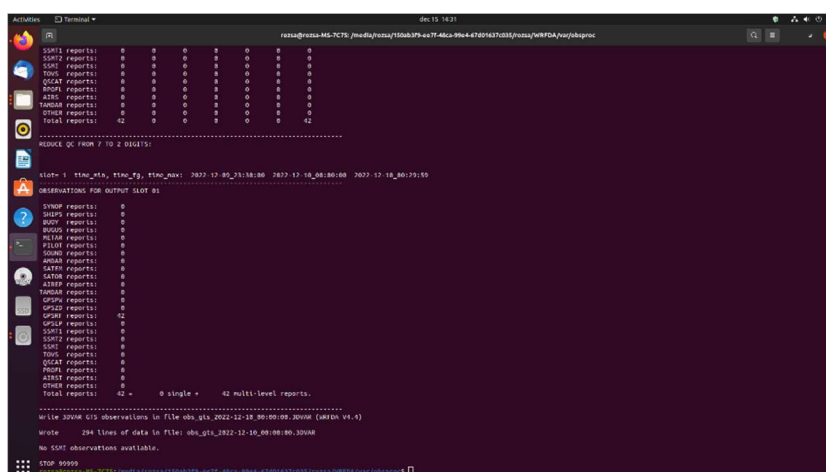
```
obs gts filename = 'grf 2022121000 2022121000.obs',
```

Please also check the setting of GPSREF observations in record9:

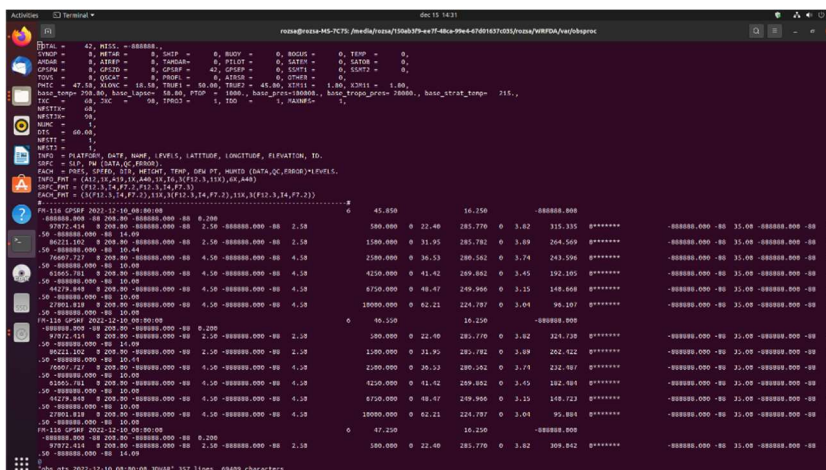
```
write gpsref= .true.,
```

Please note that a sample *namelist.obsproc* file is available at <http://gpsmet.agt.bme.hu/sample/gpsreflittler.zip>.

The following figure shows the result of importing process. Since the profiles are reconstructed in a 6×7 grid in the HUSKROUA region, altogether 42 profiles should be imported in all cases.



14. Figure. Altogether 42 atmospheric profiles are imported to WRFDA.



15. Figure. The output of the OBSPROC.EXE file showing the GPSREF profiles

The sample input and output files of the OBSPROC.EXE program are available for download on the <http://gpsmet.agt.bme.hu/sample/gpsreflittler.zip> website for reference.

Please note, that the data retrieval and preprocessing procedure can be easily automated using bash scripting. In this case we recommend to use the *wget* program for automatically downloading the observation files in Little-R format. The data can be downloaded using the following command in a Linux terminal:

```
wget  
http://gpsmet.agt.bme.hu/api/get_little_r_refractivity.php?epoch=202  
2-12-10-00-0-0 -O grf_2022121000_2022121000.obs
```


6. Data retrieval for programmers (GIS and NWM developers)

The GNSS atmospheric products are also available in the widely used JSON file format. JSON (JavaScript Object Notation) is a standard text-based format for representing structured data on JavaScript object syntax. This format can be easily used in the Python programming language. The exact structure of the JSON files depend on the represented data structure. The appropriate data structures are given in the respective product pages.

6.1 List of Stations in the database

The database contains different types of stations. GNSS stations are linked to their respective operator, such as:

GNSS Station Types:

- IGS;
- EUREF;
- HUNGAROCNTR
- GEODETANET
- ZAKPOS
- BME

Meteorological station types include:

- METAR: for station belonging to the METAR network
- SYNOP: synoptic stations providing SYNOP messages
- RAOB: radiosonde stations providing radiosonde profiles to the NOAA RAOBS database

The station list can be retrieved by the following API:

http://gpsmet.agt.bme.hu/api/get_stations.php

The structure of the resulting file is as follows according to the JavaScript notation:

```
{
  "data": #list of stations
  [
    {
      "id": "station ID (string)",
      "coords":
      [
        "latitude [degree] (WGS84) (float) ",
        "longitude [degree] (WGS84) (float)",
        "height [meter] (WGS84) (float)"
      ],
      "network": "network name (string), Possible values: IGS,
      EUREF, HUNGAROCNTR, GEODETANET, ZAKPOS, BME, METAR, RAOB,
      SYNOP "
    },
    {

```

```
"id": "station ID (string)",
"coords":
[
"latitude [degree] (WGS84)(float) ",
"longitude [degree] (WGS84)(float)",
"height [meter] (WGS84)(float)"
],
"network": "network name (string), Possible values: IGS,
EUREF, HUNGAROCNTR, GEODETANET, ZAKPOS, BME, METAR, RAOB,
SYNOP "
},
{
"id": "station ID (string)",
"coords":
[
"latitude [degree] (WGS84)(float) ",
"longitude [degree] (WGS84)(float)",
"height [meter] (WGS84)(float)"
],
"network": "network name (string), Possible values: IGS,
EUREF, HUNGAROCNTR, GEODETANET, ZAKPOS, BME, METAR, RAOB,
SYNOP "
},
...
],
"log":#program log
{
"error": "program error (string",
"warning": "program warning (string)",
"info": "program information (string)"
}
}
```

The top rows of the file contain some METAR station data:

```
{ "data": [
{"id": "LZIB", "coords": [48.1687, 17.2077, 133.0], "network":
"METAR"},
{"id": "LZTT", "coords": [49.0667, 20.25, 718.0], "network":
"METAR"},
{"id": "LZKZ", "coords": [48.6667, 21.2333, 230.0], "network":
"METAR"},...] }
```

The records include the ID of the station (LZIB), the coordinates of the station in a vector ([48.1687, 17.2077, 133.0]) and the network type (METAR).

6.2 Zenith Total Delay in JSON format

This service provides the same service as the 'Zenith Total Delay in Little-R format'. The data retrieval can be invoked using the following URL:

[http://gpsmet.agt.bme.hu/api/get_ztd.php?from=2022-12-10-00-00-00-00&to=2022-12-10-00-00-00&stations=BUTE](http://gpsmet.agt.bme.hu/api/get_ztd.php?from=2022-12-10-00-00-00&to=2022-12-10-00-00-00&stations=BUTE)

The result of the query is:

```
{ "data":
{ "BUTE": { "2022-12-10-0-0-0": 2.38588 } },
"log": { "error": [], "warning": [], "info": ["Zenith Total Delay
data from 2022-12-10 00:00:00.00 to 2022-12-10 00:00:00.00"] }
}
```

The data section contains the station ID (BUTE) and the ZTD values observed at the station (date+time, ZTD value). Please note that several dates can be retrieved at the same run. The data section ends with some logs that can be omitted in the further processing.

The structure of the file is as follows:

```
{
"data":#array of stations
{
"station ID":#array of epochs: ("epoch": "ZTD value
[meter] (float) ")
{
"2022-10-20-14-0-0": "ZTD value [meter] (float),
"2022-10-20-15-0-0": "ZTD value [meter] (float),
"2022-10-20-16-0-0": "ZTD value [meter] (float),
...
},
"ZZON":#array of epochs: ("epoch": "ZTD value [meter] (float) ")
{
"2022-10-20-14-0-0": "ZTD value [meter] (float),
"2022-10-20-15-0-0": "ZTD value [meter] (float),
"2022-10-20-16-0-0": "ZTD value [meter] (float),
...
},
"BME1":#array of epochs: ("epoch": "ZTD value [meter] (float) ")
{
"2022-10-20-14-0-0": "ZTD value [meter] (float),
"2022-10-20-15-0-0": "ZTD value [meter] (float),
"2022-10-20-16-0-0": "ZTD value [meter] (float),
...
}
```

```

},
...
},
"log": #program log
{
  "error": "program error (string)",
  "warning": "program warning (string)",
  "info": "program information (string)"
}
}

```

6.3 Zenith Wet Delay in JSON format

This product provides the calculated zenith wet delays at the GNSS stations. Its usage is identical to the use of the ZTD retrieval in JSON format.

6.4 Zenith Hydrostatic Delay in JSON format

This product provides the calculated zenith wet delays at the GNSS stations. Its usage is identical to the use of the ZTD retrieval in JSON format.

6.5 Wet refractivity in JSON format

This service provides near-realtime Wet Refractivity (Nw) values computed by the tomographic reconstruction in JSON format for a given epoch. The values can be retrieved using the following API:

http://gpsmet.agt.bme.hu/api/get_nw.php?epoch=2022-12-10-00-00-00

The resulting file contains the 3D wet refractivity model including the coordinates of the center points of the voxels and the respective wet refractivity values.

```

{"data":
{"data":
  {"500.0":
    {"45.85":
      {"16.25": 55.2137, "17.75": 151.784, "19.25": 51.2,
       "20.75": 55.2137, "22.25": 52.9782,
       "23.75": 55.2137, "25.25": 55.2137},
    {"46.55":
      {"16.25": 64.608, "17.75": 49.7609, "19.25": 61.2046,
       "20.75": 60.7224, "22.25": 55.1037,
       "23.75": 55.2137, "25.25": 55.2137},

```

```

"47.25":
  {"16.25": 48.9199, "17.75": 49.7324, "19.25":
59.3124, "20.75": 49.935, "22.25": 54.0643,
"23.75": 55.2137, "25.25": 55.2137},
"47.95":
  {"16.25": 55.2137, "17.75": 27.5372, "19.25":
52.4923, "20.75": 96.8601, "22.25": 60.8913,
"23.75": 52.0553, "25.25": 55.2137},
"48.65":
  {"16.25": 55.2137, "17.75": 43.8617, "19.25":
49.1112, "20.75": 43.8011, "22.25": 52.8716,
"23.75": 55.2137, "25.25": 55.2137},
"49.35":
  {"16.25": 41.6416, "17.75": 55.2137, "19.25":
55.2137, "20.75": 34.9739, "22.25": 55.2137,
"23.75": 55.2137, "25.25": 55.2137}},
"1500.0":
  {"45.85":
    {"16.25": 32.1834, "17.75": 5.44533, "19.25":
32.2436, "20.75": 32.1834, "22.25": 30.4653,
"23.75": 32.1834, "25.25": 32.1834}, ...

```

The file lists the refractivity values in an increasing order with the height, geographic latitude and longitude. The file structure is given at the following URL:
http://gpsmet.agt.bme.hu/products/get_nw

6.6 Wet Refractivity (NW) profile in JSON format

This tool provides similar wet refractivity profiles as the Interactive Refractivity and Water Vapour Profile Chart tool. The only difference is that the query is invoked using a HTTP GET message and the output is given in JSON file format.

The data can be downloaded using the following URL:

http://gpsmet.agt.bme.hu/api/get_nw_profile.php?epoch=2022-12-10-00-00-00&phi=45.01457&lam=17.054754

The following parameters are used in the URL:

- epoch: the epoch of the Nw profile
- phi: geographic latitude of the profile
- lam: geographic longitude of the profile

The output of this query is:

```

{"data":
[

```

```
[500.0, 107.02392347079993],  
[1500.0, 17.838354143480014],  
[2500.0, 17.838354143480014],  
[4250.0, 8.14713926757334],  
[6750.0, 3.32224785152],  
[10000.0, 0.16689261900400004]  
],  
"log":  
{  
  "error": [],  
  "warning": [],  
  "info": ["Wet Refractivity(Nw) profile at 2022-12-10  
00:00:00.00"]  
}  
}
```

The output contains the array of the wet refractivities and the respective elevations for the specified geographical location.

The detailed structure of the file can be found on the product webpage.

6.7 Water vapour density profile in JSON format

This tool provides similar wet refractivity profiles as the Interactive Refractivity and Water Vapour Profile Chart tool. The only difference is that the query is invoked using a HTTP GET message and the output is given in JSON file format.

The data can be downloaded using the following URL:

http://gpsmet.agt.bme.hu/api/get_wvd_profile.php?epoch=2022-12-10-00-00-00&phi=45.01457&lam=17.054754

The output file is:

```
{"data":  
[  
[500.0, 0.01010672739705333],  
[1500.0, 0.0029051496303533365],  
[2500.0, 0.0028529534529826693],  
[4250.0, 0.001254091642968001],  
[6750.0, 0.0004742421674853333],  
[10000.0, 2.144777733133334e-05]  
],  
}
```

```
"log":  
  {  
    "error": [],  
    "warning": [],  
    "info": ["Wet Refractivity(Nw) profile at 2022-12-10  
00:00:00.00"]  
  }  
}
```

The output contains the array of the wet refractivities and the respective elevations for the specified geographical location.

The detailed structure of the file can be found on the product webpage.