SOLUTIONS FOR GEODETIC DATA INTERCONNECTION BETWEEN ROMANIA AND BULGARIA

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***Abstract**: This article aims to make a brief description of the work done to realize the interconnection for the coordinate and projection systems between Romania and Bulgaria. This has emerged as a necessity, because in the Danube basin, which belongs to Romanian sector, coexist more hydrometric systems, projection systems and reference ellipsoids. In order to ease the measurements, the determinations, the topo-geodetic maps and the hydrographical work is aimed to interconnect in a unitary system that meets the requirements of both countries. This study was conducted within the project "Set up of a support system for hydrographical works on the Danube in order to ensure minimal navigation depths (BORD)", whose beneficiary is AFDJ (Galati Lower Danube River Administration, A.A.).*

***Keywords:** coordinate transformation, reference system, permanent stations, projection, heights*

1. Introduction

Within the network of naval transport in the European Union, an important sector is the Romanian transport sector, especially the one secured by the the Danube river. The Danube river also asists with passenger transport, tourism development, and the trade and transport of goods between EU countries. All of this can experience a significant development if optimal conditions for navigation are provided. In order to modernize the transport sector the project *"Set up of a support system for hydrographical works on the Danube in order to ensure minimal navigation depths (BORD)"* was initiated, which, as the title suggests has the main objective to ensure and improve the navigation safety. Basically the system aims to provide support for performing hydrographic navigation maps and also supports for the fairway maintenance.

The support system consists of 144 sites distributed along the Danube river on the Romanian bank, each containing 3 marks named: witness mark, azimuth mark and reference mark. Because the Danube river is at the border of Romania with 4 other states, in the Danube basin belonging to Romanian sector coexist more hydrometric systems, projection systems and reference ellipsoids. For this reason an interconnection of all hydrographic works in a unitary system emerges as necessary. According to european transport requirements for *Corridor VII* within in the international standards *IHO S-44; S-57; 7008/1996* it is recommended the use of ETRS89 (European Terrestrial Reference System 89) for planimetric measurements and the use of Black Sea 1975 for heights.

This article aims to make a brief description of the work done to attain the interconnection for the coordinate and projection systems between Romania and Bulgaria. To do this, first, we will present some features for the national systems of both countries.

Romanian National Reference System features:

- National reference system: **S42 System**, based on **Krasovski** elipsoid and materialized through a network of triangulation;
- With a coordinate system defined in **1970 stereographic projection plan**;
- since 2009, Romania adopted **ETRS89** system, which is based on the **GRS80 ellipsoid**, and is used particulary for determining the coordinates of GNSS permanent stations and satellite measurements;
- for heights determination it is used the **Black Sea 1975** system.

BGS2005 (Bulgarian Geodetic System 2005) contains [2]:

- geodesic fundamental parameters under Geodetic Reference System 1980 (**GRS1980**);
- **ETRS89** geodetic coordinate system;
- altimetry system conducted by leveling points that belong to the Leveling National Network which is included in the **European United Network of Leveling (UELN)** and defined in **European Vertical Reference System (EVRS)**;
- geodetic projection - **Universal Transverse Mercator (UTM),** wich is a cylindrical projection, and a rectangulary coordinate system **CS2005**.

BGS2005 planimetric system network points are materialized on the ground with marks that belong to the National Network GPS and GNSS permanent stations defined in ETRS89 epoch 2005.0.

In Bulgaria there are two systems used for defining heights: The Baltic Sea Altimetry System (Kronsradt) and EVRS / EVRF2007 (Amsterdam).

Also, in Bulgaria operates there are more GNSS networks with permanent stations in the private sector: GEONET, BULiPOS, NAVITEQ, SMARTBUL. Among these, to achieve the interconnection stage, there were purchased and used data from the network of permanent stations GEONET.

For the coordinates transformation that belongs to a different system than the national system, Bulgaria uses the BGS Trans 4.2 software, which can be downloaded free of charge on the site http://www.cadastre.bg/en/content/programa-za-transformaciya-na-koordinati.

The interconnection stage objective for the project *"Set up of a support system for hydrographical works on the Danube in order to ensure minimal navigation depths (BORD)"* is to determine how to calculate the coordinates for the mutual points between Romania and Bulgaria. The planimetric coordinates also have to be calculated in the geodetic system ETRS89, at the 2005.0 epoch, and in the national projection system CS2005. The altimetric coordinates will be calculated in the Baltic Sea (Kronshtadt) orthometric system and altimetry system EVRS (EVRF 2007 network).

2. Coordinate determination in ETRS89

In Bulgaria the official reference system is ETRS89 (European Terrestrial Reference System 1989), and the coordinates of permanent stations are determined at the 2005.0 epoch. In Romania for determining the coordinates of permanent stations it is also used the ETRS89 reference system, with the ETRF 2005 network at 2005.0 epoch. As can be seen, the two geodetic networks (Romania and Bulgaria) are both using the ETRS89 reference system at 2005.0 epoch.

To have certainty on this issue, data was purchased from permanent stations belonging GEONET private network, stations located near the Bulgarian border with Romania.

Fig 1. GEONET bulgarian permanent station network map, placed on the border with Romania [4]

Their verification was done in several stages:

1. In the same period there have been RINEX data acquisition for permanent stations in Bulgaria, stations: VIDI, BELE, ORYA, SILI and RUSE, and permanent stations in Romania, stations BUCU, CALR, LEHL, SLTN, TAJO, DRTS and BAIS;

Tabel 1: GNSS sesion with permanent station from both countries [2]

Country	City	CODE	DATA	Local Time	
				START	STOP
BULGARIA	Ruse	RUSE	15.05.2015	09:00	14:00
	Belene	BELE	15.05.2015	09:00	14:00
	Oryahovo	ORYA	15.05.2015	09:00	14:00
	Vidin	VIDI	15.05.2015	09:00	14:00
	Silistra	SILI	15.05.2015	09:00	14:00
ROMÂNIA	Tătărăștii de Jos	TAJO	15.05.2015	09:00	14:00
	Lehliu	LEHL	15.05.2015	09:00	14:00
	Călărași	CALR	15.05.2015	09:00	14:00
	Slatina	SLTN	15.05.2015	09:00	14:00
	Drobeta Turnu Severin	DRTS	15.05.2015	09:00	14:00
	Băilești	BAIS	15.05.2015	09:00	14:00
	București	BUCU	15.05.2015	07:00	23:59

2. A network of permanent stations was established according to table 1;
3. The network was processed as constrained to the Bulgarian permanent stations, using the following steps::
   a. Processing vectors;
   b. Analysis of residual errors for each vector;
   c. Elimination of incorrect vectors;
   d. Setting parameters for compensation;
   e. The Network Compensation.

The data entered in compensation are only data records of permanent stations. For these were purchased records so as a measurement session should have at least 5 hours, and the measurement range for 5 seconds.

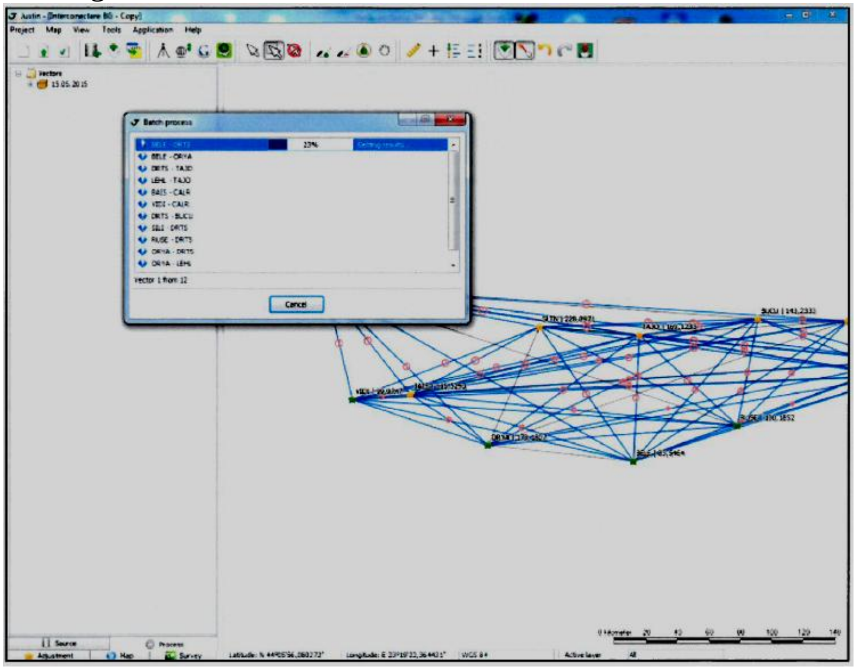

Fig. 2 Vector processing network of permanent stations [2]

Processing mode for observations is static. For each vector was made an analysis of residual errors. As a first goal of processing the observations was to eliminate gross errors of Blunders type. In order to eliminate this type of error, vectors that were removed were the ones with a few satellites in common, very long vectors and vectors with very large errors in their determination. This process is iterative, so after each vector was disabled, the compensation and the analysis of the results were remade for the entire network.

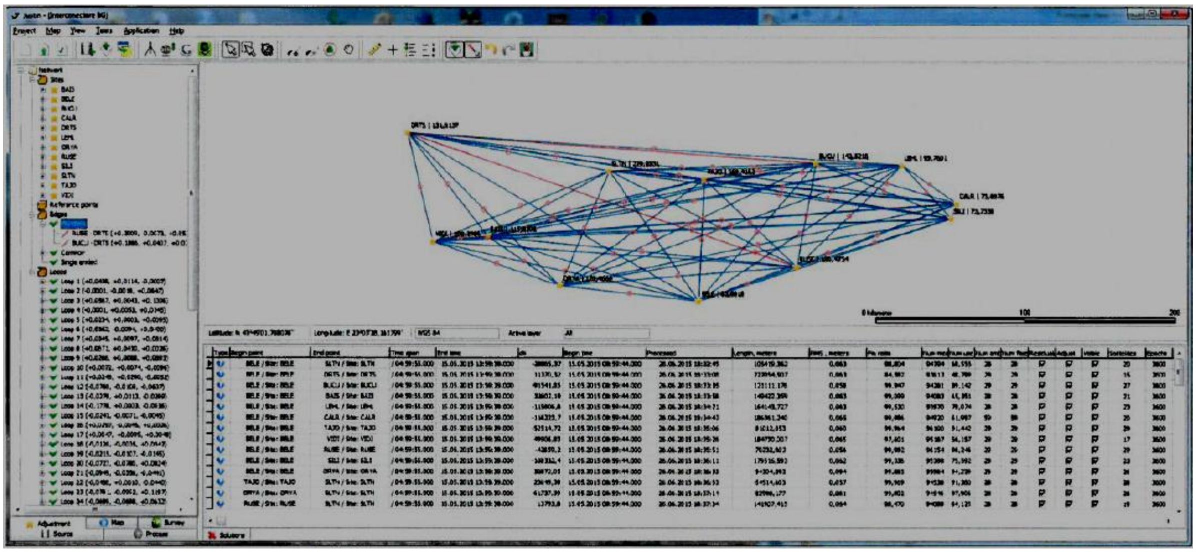

Fig. 3 Elimination of vectors with large errors [2]

After eliminating the Blunders type errors the Loops errors elimination was performed. This was also an iterative process and consisted in disabling by turn the vectors with large errors (long vectors, vectors that had no fixed ambiguities and vectors with RMS> 5 cm).

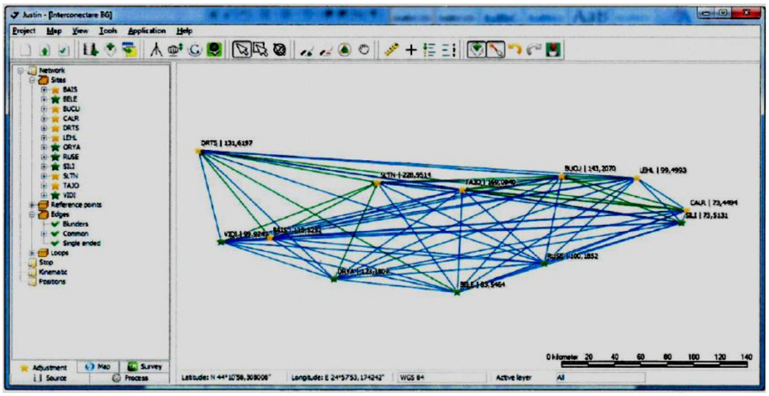

Fig. 4 The final network, resulted after the elimination of incorect vectors [2]

The elimination of incorect vectors was followed by the setting of the parameters for compensation and the final network compensation. To verify the accuracy of the internal network, the first network was compensated as free network. Only after checking the accuracy of the internal network it was compensated as a constrained network with the points that belong to the permanent stations in Bulgaria: VIDI, BELE, ORYA, SILI and RUSE. The final results were the determination of the coordinates for the points related to Romanian permanent stations (BUCU, CALR, LEHL, SLTN, TAJO, DRTS, BAIS) that were determined in ETRS89 system, at epoch 2005.0.

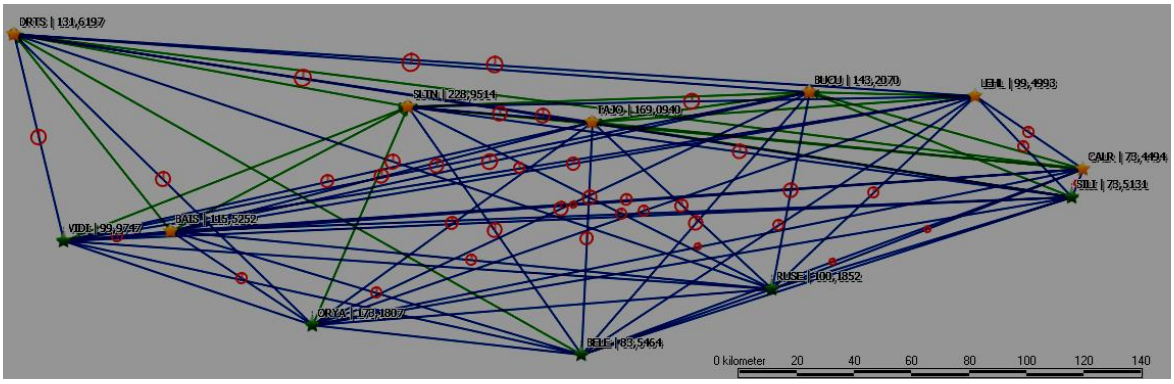

Fig. 5 Errors ellipse sketching [2]

Tabelul 2: Analysis of the results of Romanian and Bulgarian system [2]

Perm. Stations.	**Coordinates calculation based on bulgarian permanent stations**				**ANCPI Coordinates**				**Differences between geodetic coordinate systems of Bulgaria and Romania**			
	Coordinate System BGS2005 (ETRS89 Epoch 2005.0) (BG)				**Coordinate System ETRS89 Epoch 2005 (RO)**							
	X [m]	**Y [m]**	**Z [m]**	**C. Elips. [m]**	**X [m]**	**Y [m]**	**Z [m]**	**C. Elips. [m]**	**dX [m]**	**dY [m]**	**dZ [m]**	**dH. El. [m]**
BAIS	4217905,212	1820054,956	4409956,398	115,525	4217905,209	1820054,940	4409956,413	115,529	-0,003	-0,016	0,015	0,004
BUCU	4093761,205	2007793,583	4445129,763	143,207	4093761,206	2007793,576	4445129,764	143,206	0,001	-0,007	0,001	-0,001
CALR	4069079,503	2101413,983	4424509,804	73,449	4069079,495	2101413,961	4424509,811	73,441	-0,009	-0,022	0,006	-0,008
DRTS	4196673,400	1749873,522	4458054,058	131,620	4196673,426	1749873,535	4458054,066	131,646	0,026	0,013	0,008	0,026
LEHL	4069496,338	2060206,177	4443376,095	99,499	4069496,330	2060206,169	4443376,081	99,482	-0,008	-0,007	-0,014	-0,017

SLTN	4156437,707	1882548,103	4441916,342	228,951	4156437,737	1882548,097	4441916,355	228,979	0,030	-0,006	0,014	0,028
TAJO	4132788,316	1942452,130	4438128,532	169,094	4132788,313	1942452,124	4438128,506	169,072	-0,003	-0,006	-0,026	-0,022

After obtaining the final results, an analysis of the differences between the two systems geodetic coordinate was made and the conclution was that the differences obtained are very small and they fit in a $\pm 3cm$ accuracy (according to the project). For this reason it was considered that the two coordinate systems are identical.

3. Transformation of geodetic coordinates in UTM projection system

The coordinates obtained in the ETRS89 system, epoch 2005.0, will be converted to UTM (Universal Transverse Mercator) using the software Trans BGS 4.2 (the official program of the *Agency for Cadastre, Geodesy and Cartography* from Bulgaria). The UTM coordinate transformation system will take into account that some of the points are in zone 34 and the other points are in zone 35.

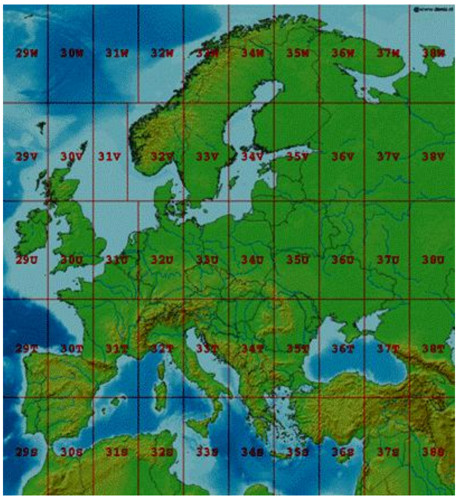

Fig. 6 Europe divided in UTM projection zones [5]

The transformation of the cartesian coordinates from the geocentric system ETRS89, epoch 2005.0 into UTM projection system was done also with the bulgarian software BGS Trans 4.2 and with the romanian software TransDatRo v4.04. The results obtained from the use of the two softwares were almost identical, the differences being under millimeter.

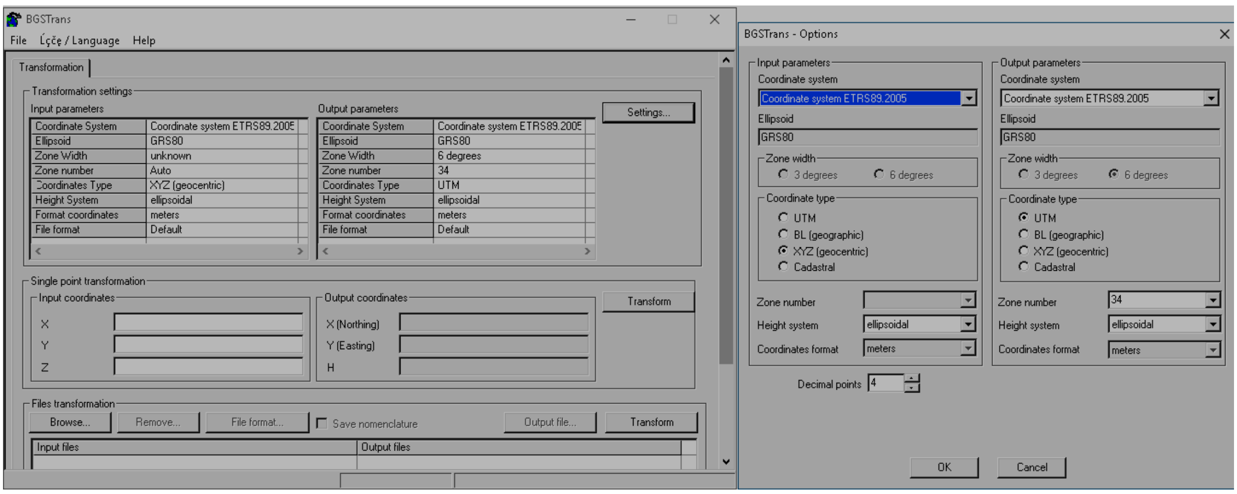

Fig. 7 The transformation of Cartesian coordinates in UTM projection

4. Transformation of geodetic coordinate into planimetric coordinate CS2005

Bulgaria, to determine points, besides using UTM projection system also uses the CS2005 system. Again, for this transformation it is used the BGS Trans 4.2 software.

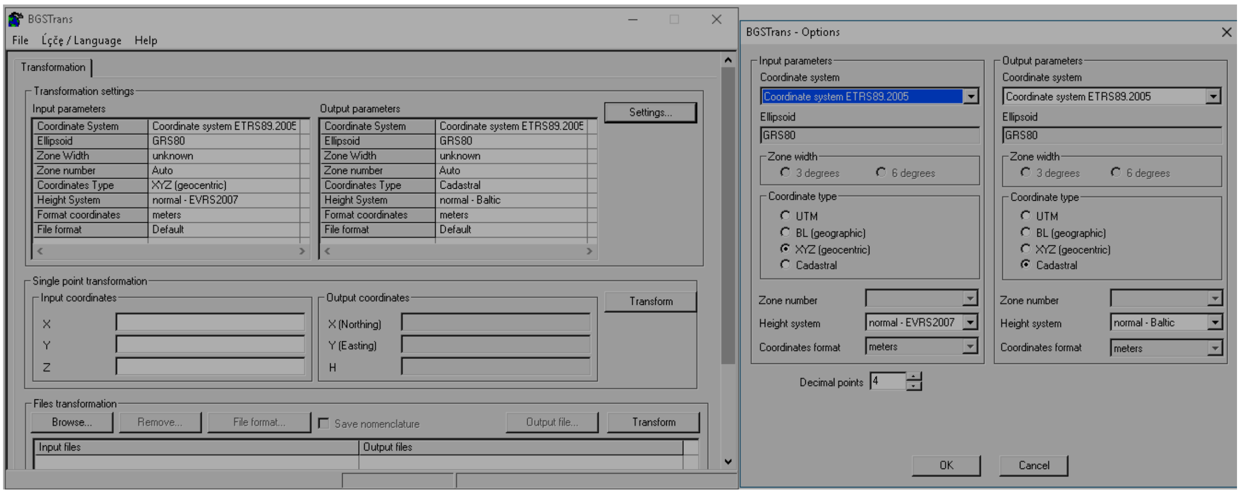

Fig. 8 Transformation of global cartesian coordinates into projection system CS2005

5. Determination of altimetry coordinates

For the heights determination Bulgaria uses the level system EVRF 2007 and the normal heights system Baltic Sea (Kronsradt). The level determination for the points that belongs to AFDJ Support System 2014 was achieved through geometric leveling measurements in the Black Sea 1975 level system. To achieve coordinates into the european altimetric system EVRS (network EVRF 2007) the romanian software for transformation TransDatRo v4.04 was used. Further, to achieve results in the Baltic Sea (Kronstadt) system it the bulgarian software for transformation BGS Trans 4.2.was used. Basically, the heights were determined by geometric leveling in the Romanian Black Sea 1975 system and to achieve results in EVRS systems (network EVRF 2007) and Baltic (Kronstadt) were used TransDatRo v4.04 and BGS Trans 4.2 softwares.

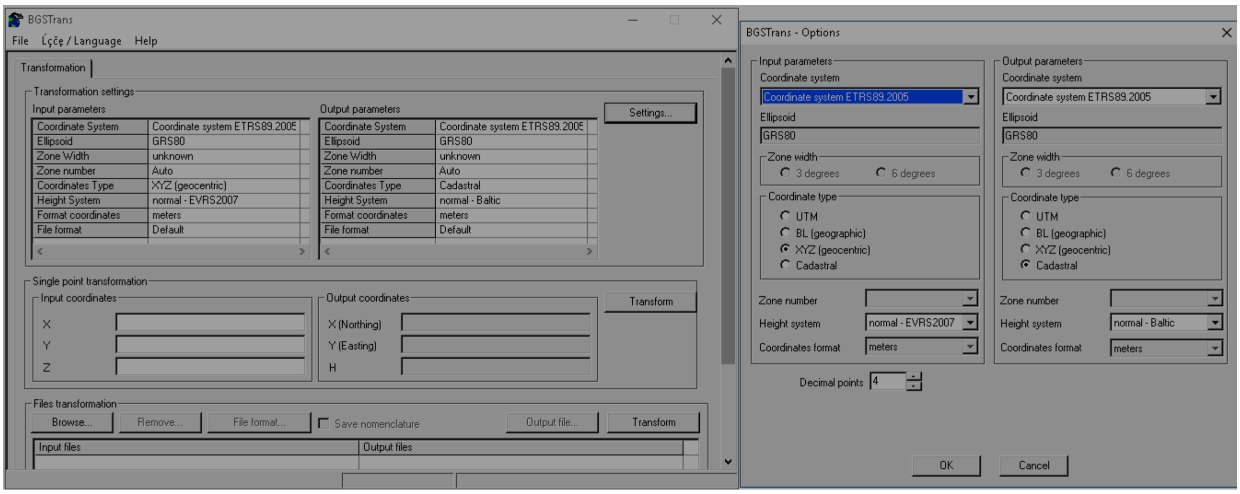

Fig. 9 Transforming heights from EVRS 2007 system into Baltic Sea (Kronstadt) system

6. Conclusions

- both countries use the ETRS89 geodetic system, at epoch 2005.0;
- in the points processing, placed near the border with Bulgaria, any romanian user can use the bulgarian permanent stations, as it provides differential corrections in the same system with the one used in Romania;
- the verification of this hypothesis was conducted by comparing the results obtained in the compensation of the permanent romanian stations, determined as new points and constrained to the bulgarian permanent stations, and the coordinates received from ANCPI;
- to bring the coordinates into a geodetic systems from Bulgaria the BGS Trans 4.2 software can be used (equivalent to romanian software TransDatRo v4.04);
- the coordinate transformation from ETRS89 system, epoch 2005.0, to UTM projection can be achieved with BGS Trans 4.2 software and with TransDatRo v.4.04 software;
- the results, obtained after the coordinate transformations from the ETRS89 system, epoch 2005.0, to UTM projection with both softwares (BGS Trans 4.2 and TransDatRo v.4.04), were considered equal, the differences being under the millimeter;
- the coordinate transformation from ETRS89 system, epoch 2005.0, to cadastral system CS2005 can be achieved with BGS Trans 4.2 software;
- the coordinate transformation from Black Sea 1975 level system to EVRF2007 can be achieved with TransDatRo v.4.04 software;
- the coordinate transformation from EVRF2007 to Baltic Sea (Kronsradt) level system can be achieved with BGS Trans 4.2 software.

7. References

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