



ITRF and ETRF as a Reference Frame of Slovenian National Coordinate System

Oskar Sterle, Bojan Stopar, Sandi Berk, Klemen Medved and Polona Pavlovčič Prešeren



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REPUBLIKA SLOVENIJA MINISTRSTVO ZA OKOLJE IN PROSTOR GEODETSKA UPRAVA REPUBLIKE SLOVENIJE



- Establishment of modern national coordinate system of Slovenia EUREF GPS surveys 1994,-95,-96
- Permanent GNSS network SIGNAL
- Reprocessing of GNSS observations evaluation of coordinate system quality
- Activity towards high quality time dependent coordinate system of Slovenia
 - Combined geodetic net of 0th order
 - EUREF GNSS Survey 2016
 - Processing of permanent GNSS data on a daily basis
- To do's





EUREF GPS Surveys 1994,-95,-96

- GNSS survey on 49 geodetic points (passive net)
- Every geodetic point occupied for at least 72 hours
- Final set of 25 days (within 3 years) reference epoch 1995,55
- Geodetic datum: 6 IGS permanent stations
- Processing software: Bernese GPS Software, Version 4.2
- Global reference frame: ITRF96
- National coordinate system of Slovenia: ETRS89 for reference epoch 1995,55 denoted as D96/TM
- Time independent coordinate system
- Numerous rapid static surveys for determination of ~4000 geodetic points in new coordinate system
- Determination of transformation parameters between old (D48/GK) and new system





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Permanent GNSS network SIGNAL

- Motivation: limited/difficult access to D96/TM from passive net
- 2001: implementation of first station GSR1 (Ljubljana) 2001 (Private company Geoservis -Leica)
- 2004: additional 3 stations

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- 2006: consists of 15 stations (fully operational)
- Afterwords: minor changes / maintenance
- Currently: 16 stations operable (GPS+GLONASS)
- Connection to neighboring countries assuring full coverage for real-time products





Determining D96/TM coordinates to SIGNAL

- Mini EUREF 2007:
 - All SIGNAL stations (SLO + AUT)
 - 5 official EUREF geodetic points in Slovenia
- 72 hours of data
- Reference frame: ITRF05
- Geodetic datum for ITRF: 14 IGS stations
- Geodetic datum for D96/TM: SLO official EUREF geodetic points
- Bernese GPS Software, Version 5.0
- Reference epoch: 2007,26
- Differences in coordinates for EUREF points up to 4 cm (global/regional/local geodynamics!)
- Slovenia in ETRS89 NOT stable coordinates change in time
- Final results: alignment to D96/TM from epoch 1995,55 (EUREF stations)



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Reprocessing of all GNSS observations

Purpose/motivation:

- Significant differences between GNSS observations and coordinates of stations/points (displacements?)
- Coordinate system definition •
- Coordinate frame analysis/verification •
- Geo-kinematic model detection of • regional/local tectonic driven displacements

Data sources:

- Numerous repeated surveys on geodynamic points (75)
- Permanent stations in SLO, near SLO and allover EU
- Altogether: 138 geodetic points/stations •

Took us several years, finished in 2014!





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SIGNAL

APOS

EPN

IGS

Other

Passive

FReDNet





Reprocessing of all GNSS observations

Bernese GNSS Software, Version 5.0

- 11 reference IGS stations (geodetic datum in IGb08)
- GPS(+GLONASS if available)
- Processing on a daily basis coordinate time series in IGb08
- Reference coordinates + velocity vectors in 2010 in IGb08
- Velocity vectors in "local" frame (through ETRS)





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Reprocessing of all GNSS observations

gPPP - PPP based processing software

- Permanent GNSS stations only from 2000
- GPS, GPS+GLONASS ٠

euref

- 11 reference IGb08 stations ٠
- Geodetic datum with similarity transformation • of PPP on IGb08 coordinates :
 - 3-parameter (translations)
 - 4-parameter (translations + scale)
 - 6-parameter (translations + rotations)
 - 7-parameter (translations + rotations + scale)
- Results comparable to Bernese: •
 - mm and up to 5 mm level for Hz and V coordinates, respectively
 - mm/year level for velocities



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14°00'

14°30'

15°00'

15°30'

46°30'

46°00'

45°30'

13°30'

16°00'

16°30'



Evaluation of D96/TM reference frame

- Comparison between:
 - Official D96/TM coordinates of passive points and SIGNAL stations
 - Estimated coordinates from reprocessing considering their time dependency
- Comparison (transformation) done for epochs from 1989 up to 2010 (every 0,1 year)
- Coordinates of passive network 1995,55
- Coordinates of SIGNAL network 2007,26
- Evident tectonic activities on a (small) area of Slovenia
- D96/TM was outdated at that time
- Nonhomogeneous quality

35 30 25 20 $t_{min} = 2001.10$ RMS 10 t_{min}=2007.60 t_{min}=1996.20 5 • Skupaj Pasivno omrežje Omrežje SIGNAL 2000 2005 1990 1995 2010 t [leto]



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A certification towards high quality time dependent coordinate system of Slovenia

- Motivation:
 - Insufficient quality of D96/TM
 - Upgrading the definition of D96/TM time dependent coordinate system
- Activities, defined in 2016:
 - Combined geodetic net of 0th order backup/support of SIGNAL
 - EUREF GNSS Survey 2016 repeating EUREF GPS Surveys 1994,-95,-96
 - Processing of permanent GNSS data on a daily basis maintaining coordinate system
- Definition and realization national coordinate system on a basis of modern scientific principles
- Long term maintenance and analysis of national coordinate system





Combined geodetic net of 0th order

- Purpose/motivation backup in case of ... for • SIGNAL:
 - Land ownership of SMA(RS) •
 - Implementation guidelines for most precise geodynamic stations VLCH
- 6 locations in Slovenia •
- RMOG 10 permanent GNSS stations •
- GNSS Data available since mid 2016 • RUDI CO KDA



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DLBG

• CELJ

PZA

• SLOG

TRBN

CRNM ●

O DELN

VLKM

GSR1

O STA

RDVL

II IB

RIJE

IDRI

BOVC

NOVG

PORE

RCER







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EUREF GNSS Survey 2016

- From August until November 2016
- 72-hourly sessions on 48 passive geodetic points (92% repeatability compared to EUREF94,-95,-96)
- 37 permanent stations of SIGNAL and in neighboring countries
- 8 permanent stations of Combined geodetic net of 0th order
- 25 permanent stations of EPN

Altogether:

- 69 permanent GNSS stations and 48 passive points
- 80 consecutive days of complete data







EUREF GNSS Survey 2016 – processing of data

- Bernese GNSS Software, Version 5.2
- ITRF2008/IGb08
- Processing of data according to the "Guides for EUREF densification, Version 5"
- Results:
 - coordinates of all stations/points in reference epoch 2016,75 in IGb08
 - Coordinates of all stations/points in reference epoch 20167,75 in ERTF2005 - solution ETRS89/D17









80

70

30

20

10

-20 -30 -40 -50 -60

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EUREF GNSS Survey 2016 – evaluation of results

- Solution ETRS89/D17 differs to D96 (det. 1996)
- In case of passive geodetic points:
 - Up to 9 cm in N
 - Up to -5 cm in E
 - Sub 3 cm in h
- Smaller differences in case of SIGNAL (det. 2007)





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EUREF GNSS Survey 2016 – new realization of D96

- Denoted as D96-17
- "Optimal" solution with respect to passive as well as active network
- 60 Solution also verified by EUREF GB • 50 40 60 30 50 20 10 -10 -20 CAKO CELJ IDRI ILIB KARL KOPE LAN2 LEND MRBR NOVG PTUJ BODO FLDB **GSR1** KLA2 SLOG RUDI VLCH CRNM PORE RDVL RMOG -30 -10 -40 -20 -50 - 30 -40 -50



N

U



GNSS data processing on a daily basis

• Data from:

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- Permanent GNSS network SIGNAL, currently 27 stations (data from 2006)
- Permanent GNSS stations from Combined geodetic net of 0th order, currently 10 stations (data from 2016)
- Including:
 - 38 IGS stations in Europe
 - 25 EPN stations from neighboring countries of Slovenia
- Altogether ~100 permanent stations with daily GNSS data









GNSS data processing on a daily basis

- Bernese GNSS Software, Version 5.2, latest release:
 - GPS+GLONASSProcessing time:~3h per day (~21h per week)
- gPPP (PPP based processing tool):
 - GPS+GLONASS(+Galileo)
 - Processing time:~30min per day (~2h per week)
- Geodetic datum defined with known coordinates of ~30 IGS stations
- So far: approximately 3-4 years of data processed...



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Comparison of results Bernese/gPPP





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Comparison of results Bernese/gPPP

RMS of coordinate differences: 0.8 mm N, 1.6 mm E and 3.2 mm h







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To do's – instead of conclusions

- What we have:
 - A lot of high quality data
 - Superior processing tools
 - Old processing solutions
- To do:
 - Process all remaining data (several years from 2010)
 - Combine old and new solutions
 - Go to near real time processing





To do's – instead of conclusions

- However, more results open even more questions on:
 - Time series (biases of all kind, discontinuities, instrument changes, etc.)
 - Coordinate system definition time independent
 - Proper geodetic datum definition
 - Proper coordinate frame realization...
 - Automating processing procedure
 - Coping with more and more data

We are still at the beginning of the path...



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