Preliminary Study on 3D Reference Frames for the Russian Federation

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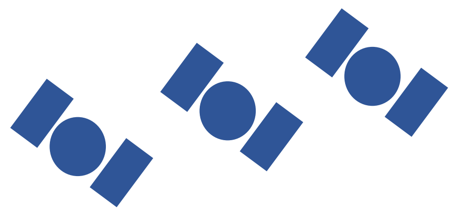
Content

- Overview of 3D reference frames in Russia
- Criteria of the perfect terrestrial reference frame
- Possible developments
- Suggestions for practical implementation

Geodetic Infrastructure in Russia

GNSS: GLONASS + GPS + ..



Government operated networks

Different CORS Networks

ITRF, WGS84, local datums

State Geodetic Network

2D: SC-42, SC-95, SC-63

3D: GSC-2011, PZ-90.11

State Levelling Network

BSV-77

State Gravimetry Network

Structure of the State Geodetic Network

Different CORS Networks

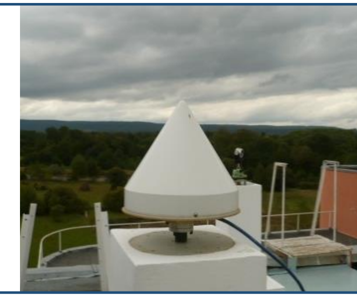
- Regional Authorities'
- Private Companies
- State owned companies

State Geodetic Network

- FAGS
- VGS
- SGS-1
- Old network 1-4 class

46 Continuously Operating Reference Stations (**CORS**) as of 2015

80 planned by 2020



Nearly **288 000 "passive" reference points** (landmarks, pillars)

2D and 3D Reference Frames. Ground Infrastructure

Reference frame: ITRF (different versions), SC-42, SC-95, local/regional datum

Different CORS Networks

- Regional authorities'
- Private companies
- State owned companies

State Geodetic Network

- FAGS
- VGS
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- Old network 1-4 class

3D reference frame: GSC2011

2D reference frames: SC-95, SC-42, SC-63, local/regional datum

3D Reference Frames: PZ-90.11, GSC-2011

- ✓ First introduced on Jan 28, 2012 (Gov. Decree N 1463)
- ✓ Centimeter-level agreement with ITRF2008
  - ✓ PZ-90.11 at epoch 2010.0
  - ✓ GSC-2011 at epoch 2011.0
- ✓ GSC-2011
  - ✓ surveying and mapping
- ✓ PZ-90.11
  - ✓ Space activities
  - ✓ Navigation
  - ✓ Geodetic works for military purposes

GSC-2011

- ✓ Implemented and maintained by the Federal Service of Registration, Cadaster, and Cartography- Rosreestr
- ✓ Centimeter-level agreement with ITRF2008 at epoch 2011.0
- ✓ NUVEL-1A tectonic plate motion model was used in adjustment
- ✓ Expected to replace legacy SC-42, SC-95 by 2021
- ✓ During the transition period is typically applied as static one for the reference epoch 2011.0.
- ✓ Guidelines on accounting for displacements and deformations are under development.

PZ-90.11

- ✓ Native reference frame for GLONASS ephemerides
- ✓ Implemented and maintained by the Russian Space Agency and Ministry of Defense
- ✓ Replaced previous version PZ-90.02 on 31st December 2013
- ✓ Practically accessible only via precise GLONASS ephemerides using Precise Point Positioning (PPP) provided by SVOEVI
- ✓ Described in:
  System of geodetic parameters "PARAMETRY ZEMLI 1990" (PZ-90.11) Reference Document. Moscow,2014 http://eng.mil.ru/files/PZ-90.11_final-v8.pdf
- ✓ Kinematic reference frame

Transformation Parameters

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_2 = (1+m) \begin{pmatrix} 1 & +\omega_Z & -\omega_Y \\ -\omega_Z & 1 & +\omega_X \\ +\omega_Y & -\omega_X & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_1 + \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix}$$

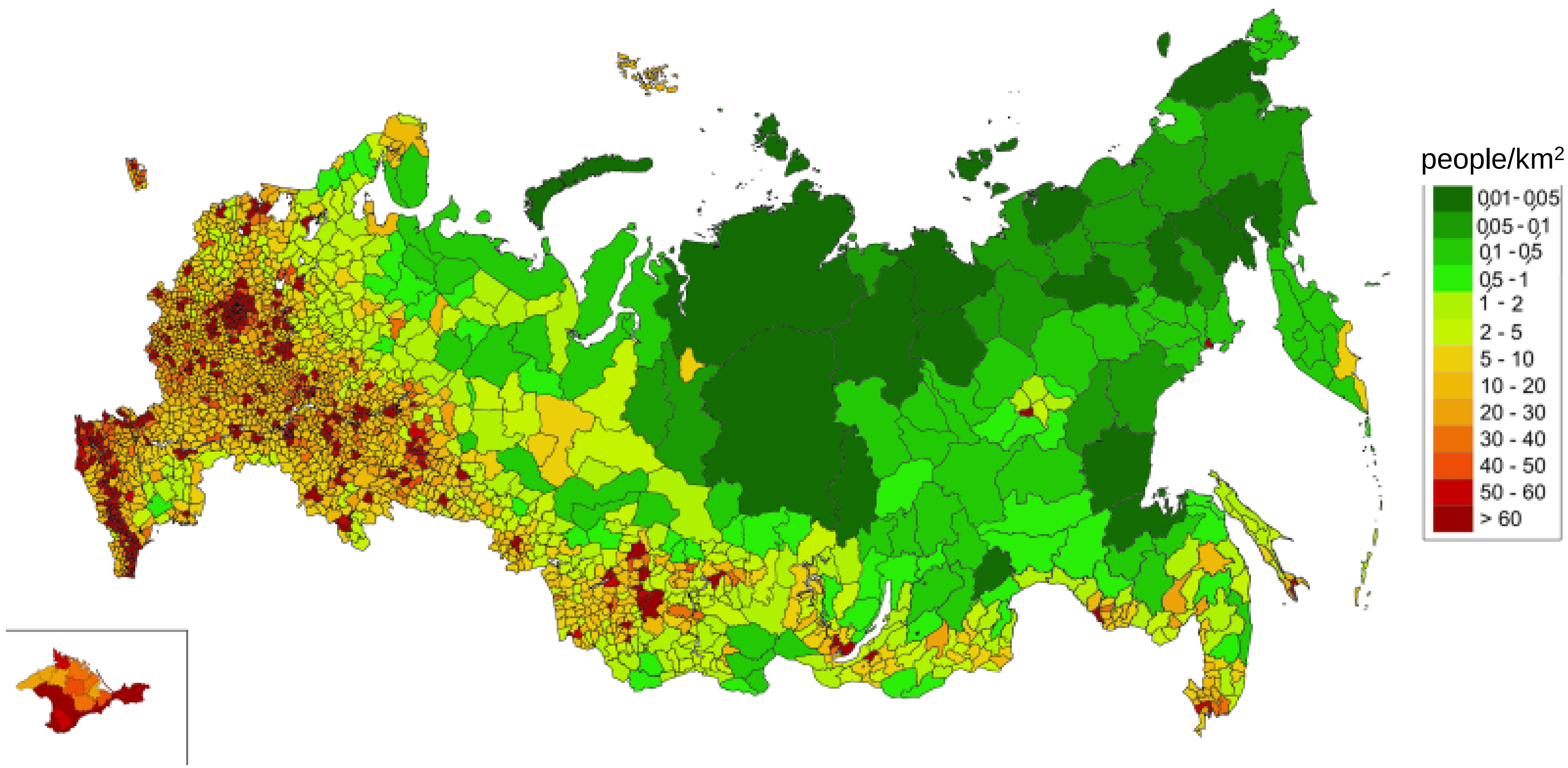
#	From system 1	To system 2	ΔX, m	ΔY, m	ΔZ, m	ω_X, 10^{-3}"	ω_Y, 10^{-3}"	ω_Z, 10^{-3}"	m, 10^{-6}	Epoche
1	SK-42	PZ-90	+25 ± 2	–141 ± 2	–80 ± 3	0 ± 100	–350 ±100	–660 ±100	0 ±0.250	–
2	SK-95	PZ-90	+25.90	–130.94	–81.76	0	0	0	0	–
3	PZ-90	PZ-90.02	–1.07 ±0.1	–0.03 ±0.1	+0.02 ±0.1	0	0	–130 ±10	–0.220 ±0.020	2002.0
4	WGS 84 (G1150)	PZ-90.02	+0.36 ±0.1	–0.08 ± 0.1	–0.18 ±0.1	0	0	0	0	2002.0
5	PZ-90.02	PZ-90.11	–0.373 ±0.027	+0.186 ±0.056	+0.202 ±0.033	–2.30 ±2.11	+3.54 ±0.87	–4.21 ±0.82	–0.008 ±0.004	2010.0
6	GSK-2011	PZ-90.11	0.000 ±0.008	+0.014 ±0.018	–0.008 ±0.011	–0.562 ±0.698	–0.019 ±0.259	+0.053 ±0.227	–0.0006 ±0.0010	2011.0
7	PZ-90.11	ITRF2008	–0.003 ±0.002	–0.001 ±0.002	0.000 ±0.002	+0.019 ±0.072	–0.042 ±0.073	+0.002 ±0.090	–0.000 ±0.0003	2010.0

http://eng.mil.ru/files/PZ-90.11_final-v8.pdf

CORS Stations

>1600 stations

Population Density



Perfect Reference Frame: Accuracy, Stability, and Convenience

- **High accuracy over long term**
  Deformations are accounted to avoid accumulation of distortions.
- **Coordinates of ground-fixed points are constant**
  Locally immovable objects can be described in constant coordinates.
- **True coordinate geometry without transformation**
  Calculated distances, angles correspond to measured values accurately.
- **Ease of transformation**
  The models and procedures are standard, widely supported. It is better if they are simple and can be applied in the field without special software
- **Ease of introduction into practice**
  Minimum changes of existing practices.

Current Reference Frames

KINEMATIC GLOBAL
PZ-90.11 / ITRF

Native to GNSS, true geometry

Helmert transformation (7 parameters) at 2011.0
http://eng.mil.ru/files/PZ-90.11_final-v8.pdf

NATIONAL
GSC-2011 /ITRF

During the transition period GSC-2011 is being applied as static datum for the reference epoch 2011.0.

Constant deformation grids at 2011.0
(or 7 parameter Helmert)

STATIC
legacy SC-42 (Pulkovo), SC-95

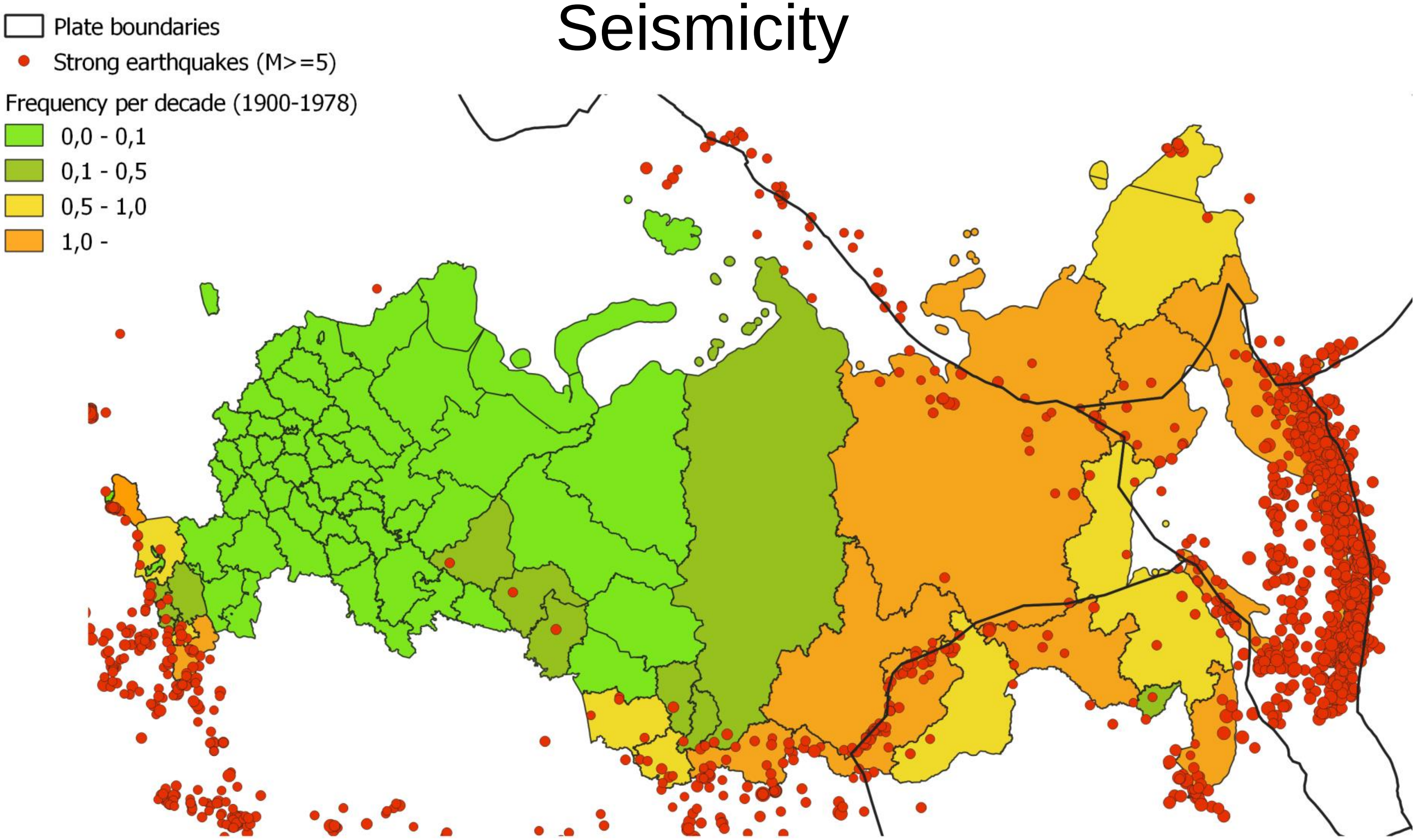
STATIC
regional/local datums

2D
Cadaster, city plans, etc.

Tectonic Plates

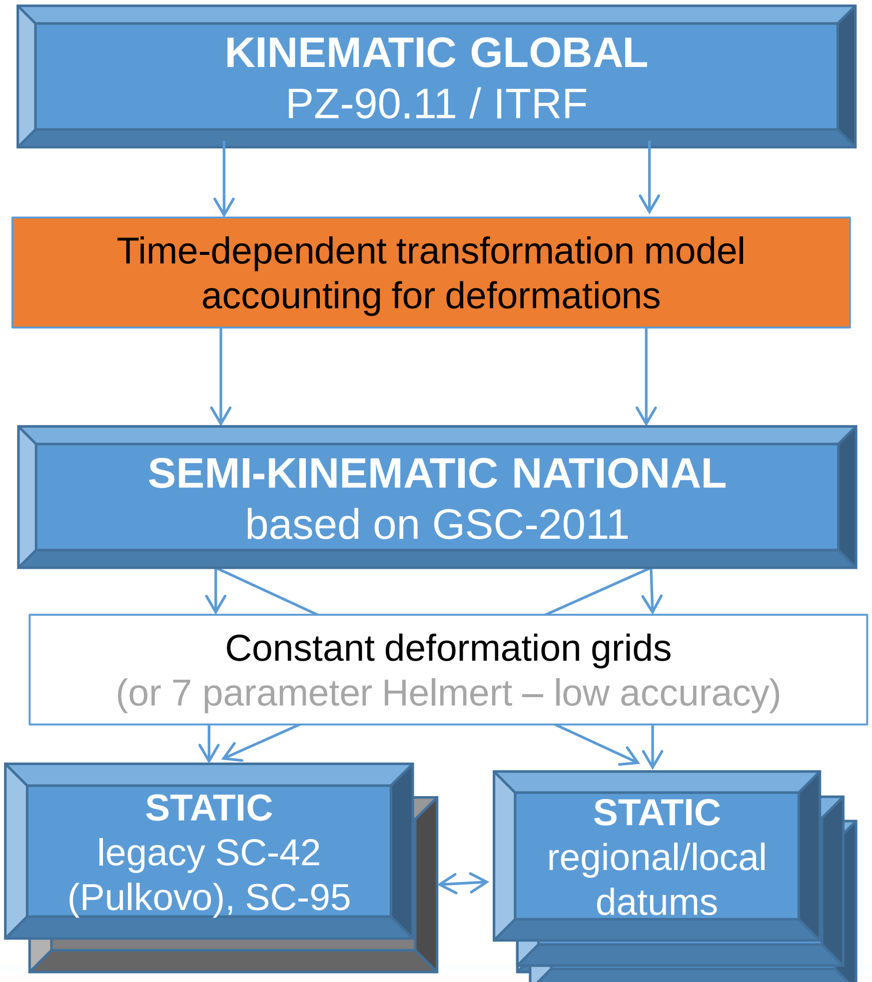
Plate Boundaries:
P. Bird, "An updated digital model of plate boundaries An updated digital model of plate boundaries", *Geochemistry Geophysics Geosystems*, vol. 4, no. 3, 2003. doi:10.1029/2001GC000252

Seismicity



Data from:
Kondorskaya N.V., Shebalin N.V. (eds.) New catalog of strong earthquakes in the USSR from ancient times through 1977. World Data Center A for Solid Earth Geophysics, Report SE-31, NOAA, Boulder, Colorado, USA, 1982, 608 p
http://www.wdcb.ru/sep/seismology/cat_strong_USSR.ru.html

General Solution



Native to GNSS,
true geometry

Catalogue at epoch 2011.0.

2D
Cadaster, city plans, etc.

Classification of Regions

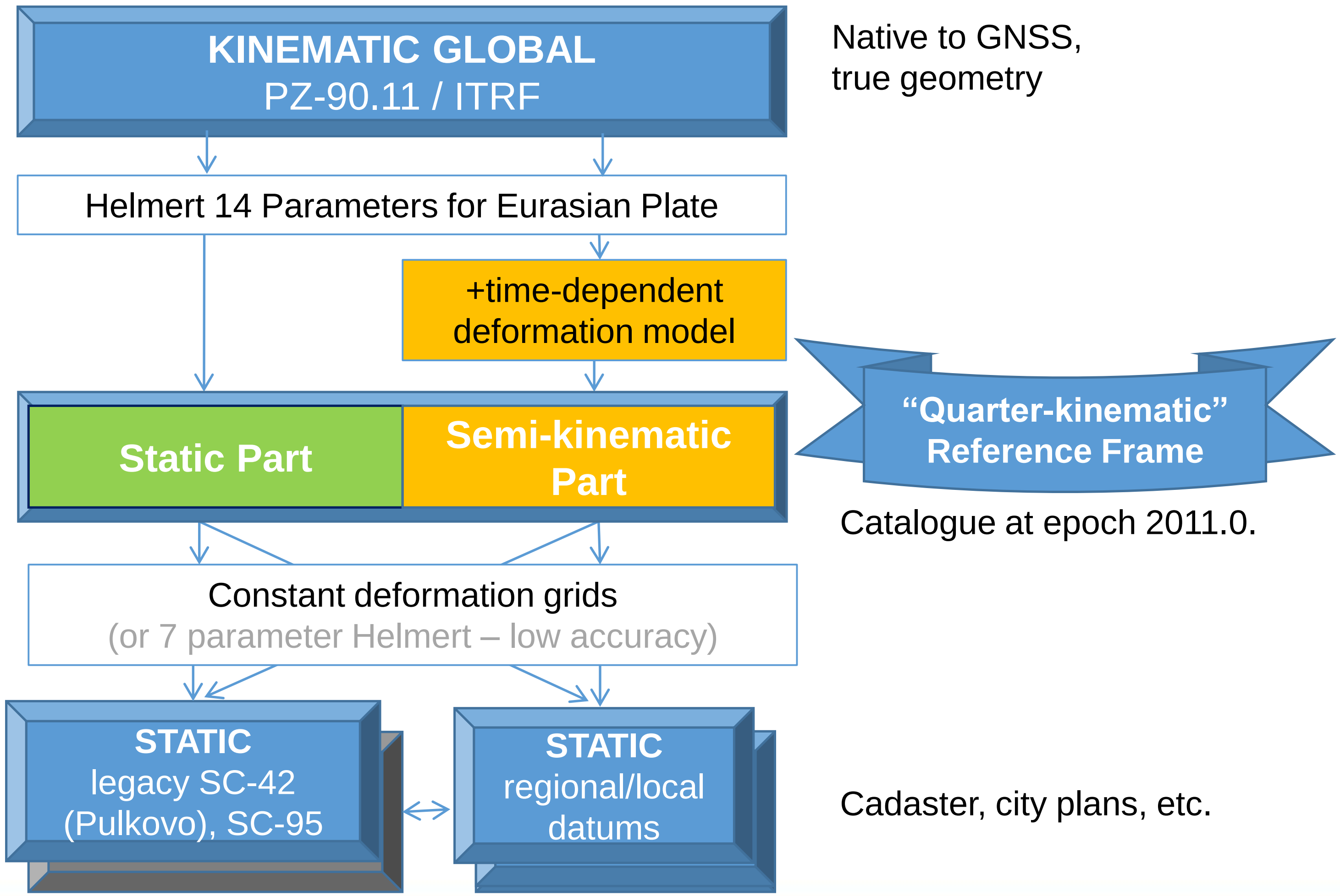
Regions	"RIGID"	"NONRIGID"
Number	59	26

Classification of Regions

Regions	“RIGID”	“NONRIGID”
Number	59	26
% of total roads length[1)]	75%	25%
% of cadaster parcels[2)]	78%	22%
% of total population[3)]	78%	22%

Data from:
Federal State Statistics Service, [1)]2017, [3)]2019.0 http://www.gks.ru
[2)]EGRP365 Cadaster Services, 2019 https://egrp365.ru/ratings/

Proposed Solution

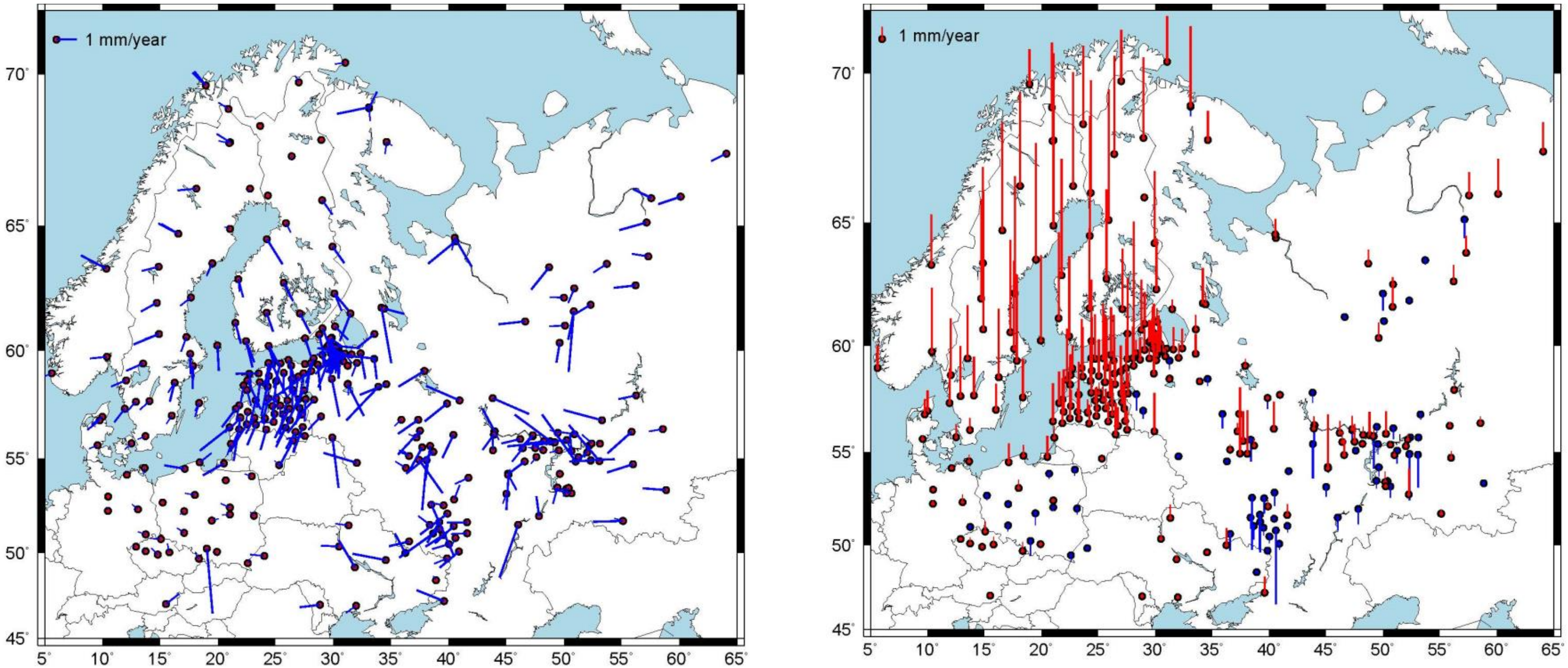


Benefits of "Quarter-kinematic" Approach

- ✓ Long-term coordinate accuracy and self-consistency for the whole country
- ✓ Constant coordinates *for the majority (¾)* of the ground-fixed objects
- ✓ *Appropriate* accuracy of coordinate geometry without transformation *in ¾ of the cases*
- ✓ Ease of coordinate transformations *for the majority of users and acceptable complexity for all*
- ✓ Ease of introduction*: minimum changes in respect to the existing procedures for static-mode GSC-2011*

Next Step

Accounting for a small intra-plate deformations, post-glacial rebound for the regions previously considered “rigid”



Figures from: Database of CORS coordinates and velocities (European Part). Pulkovo Central Astronomical Observatory. http://www.gaoran.ru/russian/database/station/databasev_rus.html

Conclusions

- ✓ "Quarter-kinematic" approach is to facilitate implementation of the sustainable national reference frame.
- ✓ The approach is to enable smooth transition of GSC-2011 from the static mode to a semi-kinematic reference frame at the first step.
- ✓ The next step is implementation of a time-dependent model and a procedure for accounting for smaller intra-plate deformations, post-glacial rebound for the whole territory.
- ✓ Implementation of a highly accurate reference frame will enable greater contribution to ITRF via either
  - ➢ establishing of the North East Eurasia Reference Frame NEEREF (Savinykh et al. 2014),
  - ➢ integration into both APREF and ETRF, building "bridge" between them.

Thank you for your attention!