DFHBF 5.0 - A New Integrated Geodesy Approach for Regional Gravity Field Modelling and Height Reference Surface Computation -

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Head of Institute of Geomatics and Projectleader at Institute for Applied Research (IAF)

RaD

www.dfhbf.de , www.goca.info, www.monika.ag, www.geozilla.de, www.moldpos.eu
www.navka.de, www.e-volo.com

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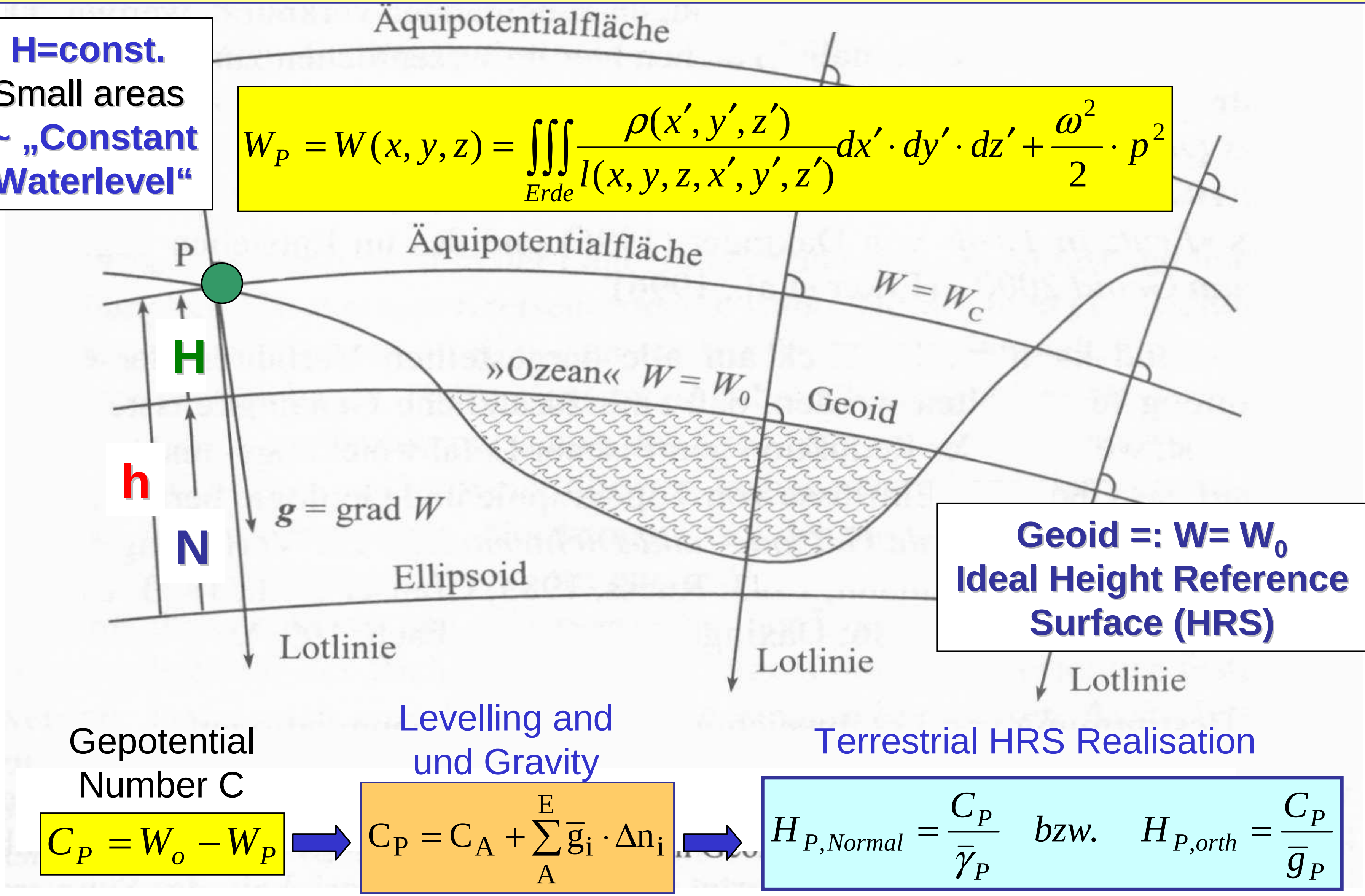
Study Programmes of the Faculty IMM with Contents related to Geodesy and Navigation (www.hs-karlsruhe.de) Research Oriented (BSc – MSc – PhD)

Height System and Height Reference Surface Types (QGeoid/Geoid)

Height System Types for Physical Heights H

H=const.
Small areas
~ „Constant Waterlevel“

$$W_P = W(x,y,z) = \iiint\limits_{Erde} \frac{\rho(x',y',z')}{l(x,y,z,x',y',z')} dx' \cdot dy' \cdot dz' + \frac{\omega^2}{2} \cdot p^2$$



Geoid =: W= W_0
Ideal Height Reference Surface (HRS)

Gepotential Number C

$$C_P = W_o - W_P$$

Levelling and und Gravity

$$C_P = C_A + \sum_A^E \bar{g}_i \cdot \Delta n_i$$

Terrestrial HRS Realisation

$$H_{P,Normal} = \frac{C_P}{\bar{\gamma}_P} \quad bzw. \quad H_{P,orth} = \frac{C_P}{\bar{g}_P}$$

EUROPE DHHN‘92

Height Reference System Types for Physical Heights H

Gravity Potential W of the Earth at Point P(r,λ, ϑ)

$$W = V + Z$$

Centrifugalpotenzial due to Eartrotation $Z = \frac{\omega^2}{2} \cdot r^2 \cdot \sin^2 \vartheta$

Gravitationpotential of Earth (Masses)

$$V = \frac{G \cdot M}{r} \cdot \left(1 + \sum_{n=2}^{\infty} \sum_{m=0}^{n} \left(\frac{a}{r}\right)^n \cdot (C_{nm} \cdot \cos m\lambda + S_{nm} \cdot \sin m\lambda) \cdot P_{nm}(\cos\vartheta)\right)$$

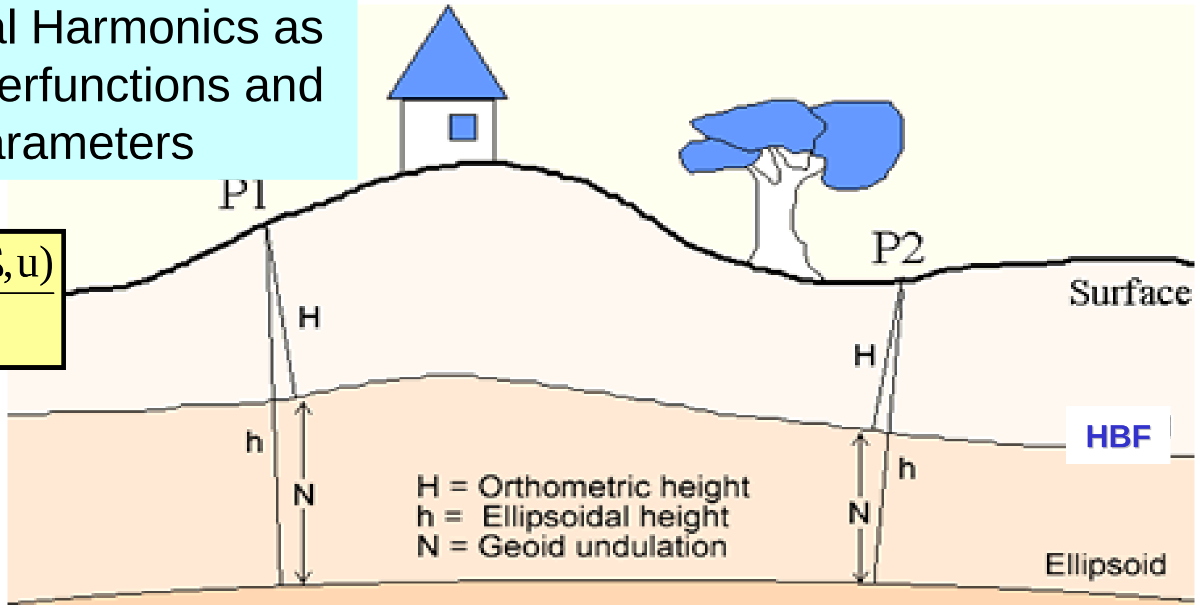
Spherical Harmonics as als Carrierfunctions and Parameters

Q-Geoid
- Normal Heights

$$N_{QG}(r,\lambda,\vartheta) = \frac{W(r,\lambda,\vartheta) - U_{GRS80}(\lambda,\text{ß},u)}{\gamma_Q}$$

Geoid ($W=W_o$)
- Orthometric Heights)

$$N_G = N_{QG} + \frac{\bar{g} - \bar{\gamma}}{\bar{\gamma}} \cdot H$$

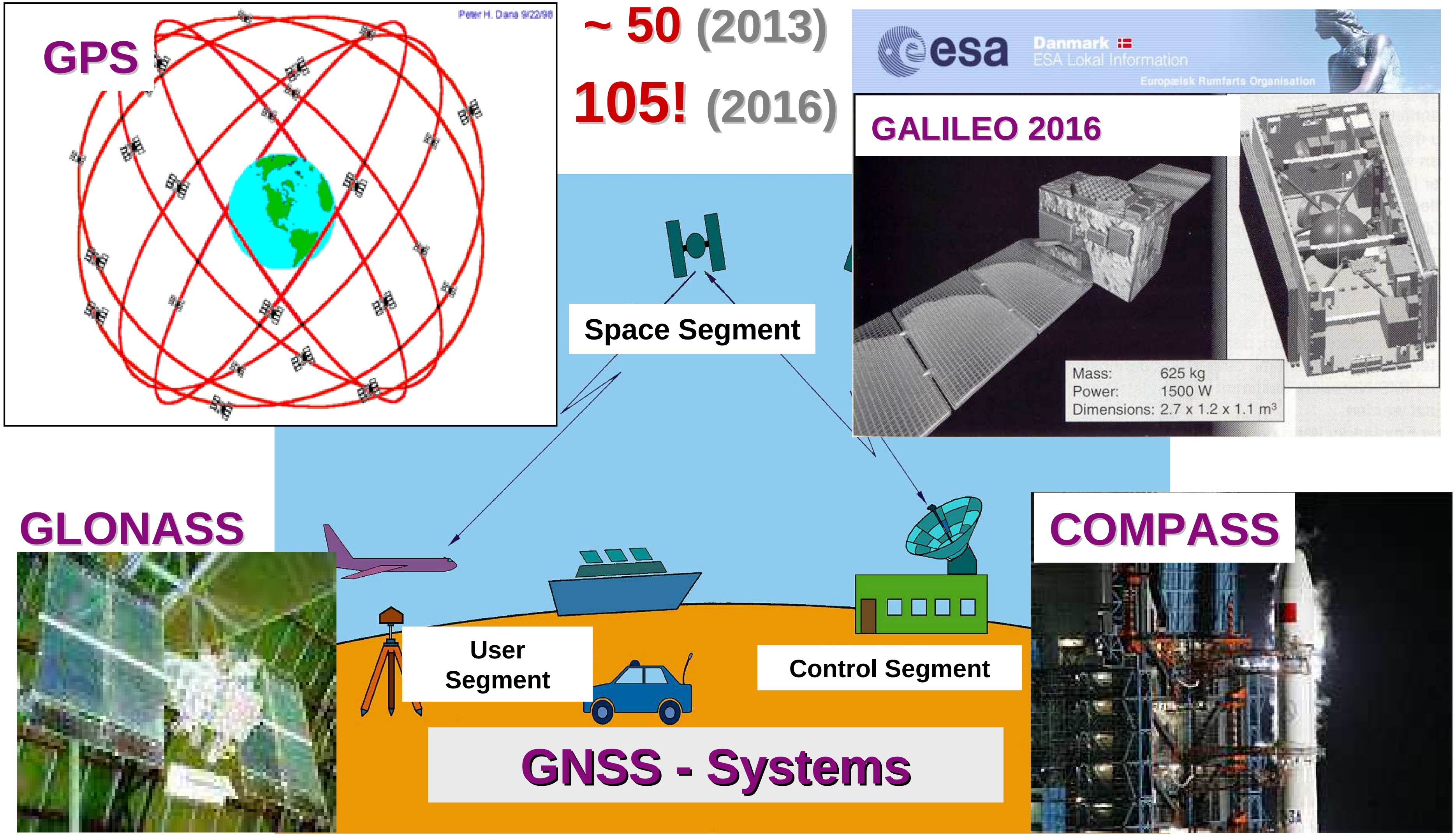


Precise
GNSS Positioning Services

Regional => Global
DGNSS => Absolute GNSS

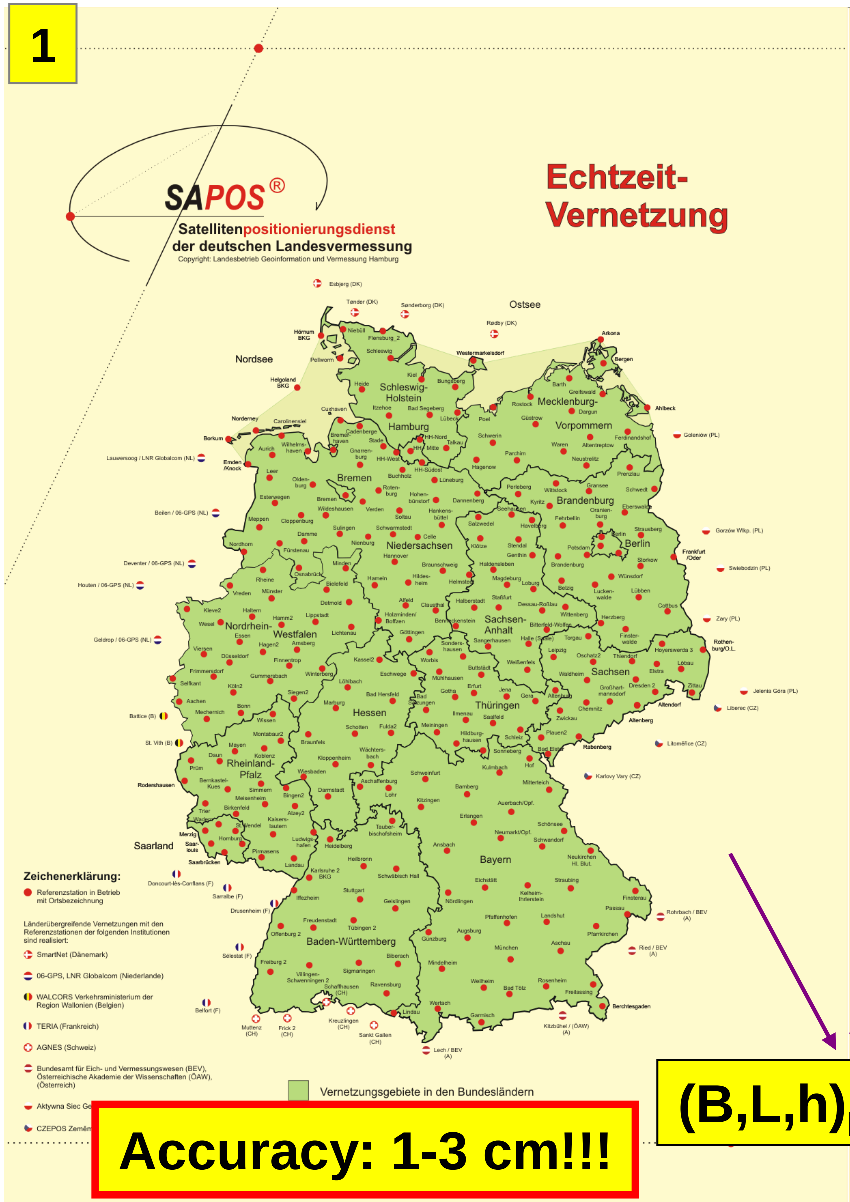
Paradigma Change: LowCost
Hardware – High Cost Algorithms

GNSS - Global Navigation Satellite Sytems



Regional Precise GNSS-Positioning Services e.g. Germany

1



2

SmartNet EUROPE powered by Leica Geosystems

3

AXIO-NET

4

TRIMBLE VRSNOW

Accuracy: 1-3 cm!!!

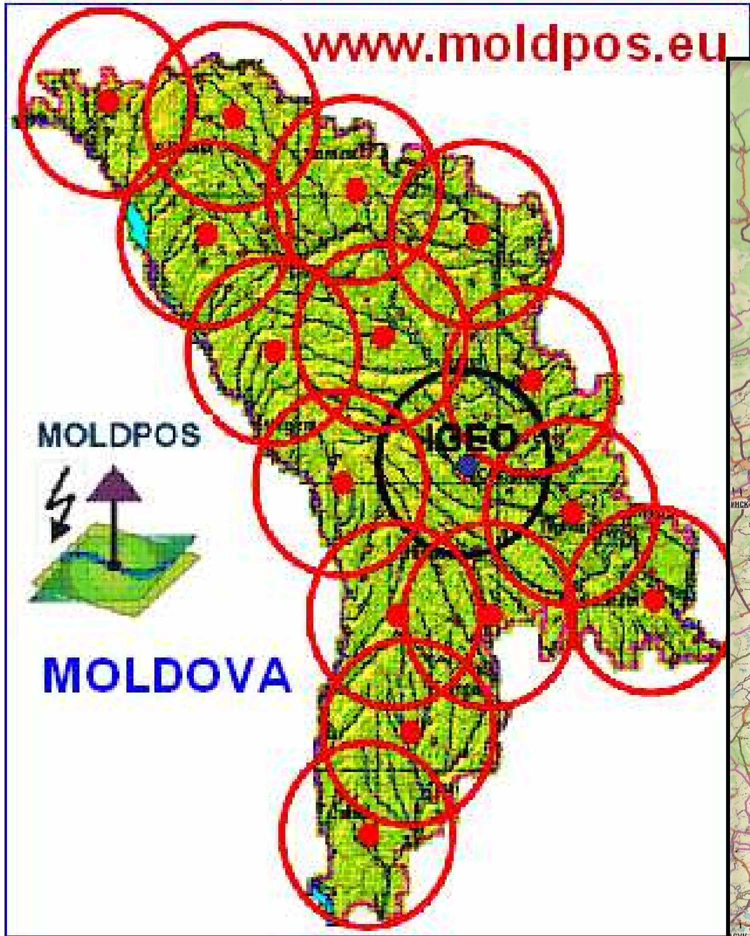
$(B,L,h)_{\text{ITRF-related}}$

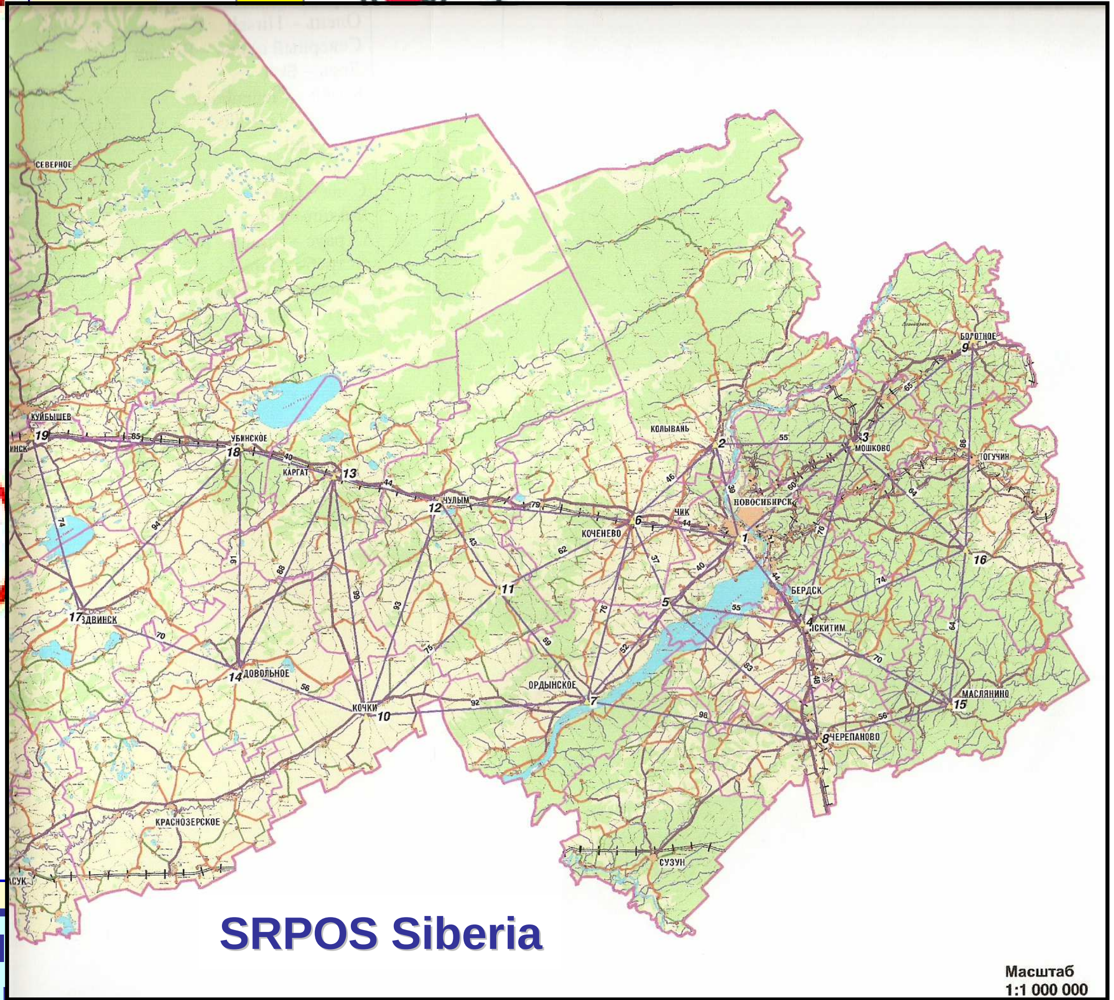
Regional Precise GNSS-Positioning Services - Worldwide

1

2

SmartNet





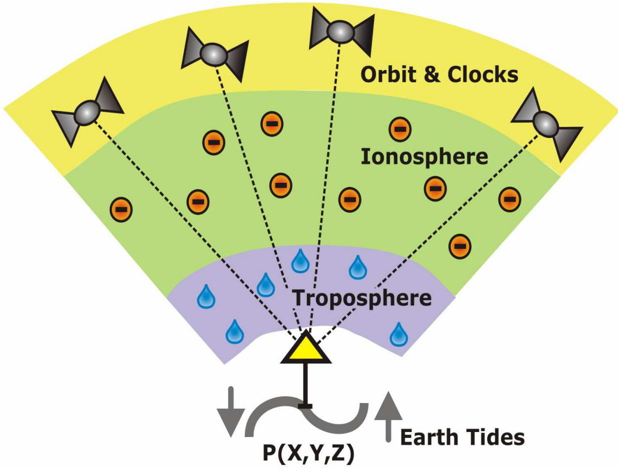
4 RTCM Services: 1-3 cm Horizontal

Geodetic Infrastructures for GNSS-Se

www.moldpos.eu

„Global G(lobal")NSS Precise Positioning Services - Worldwide

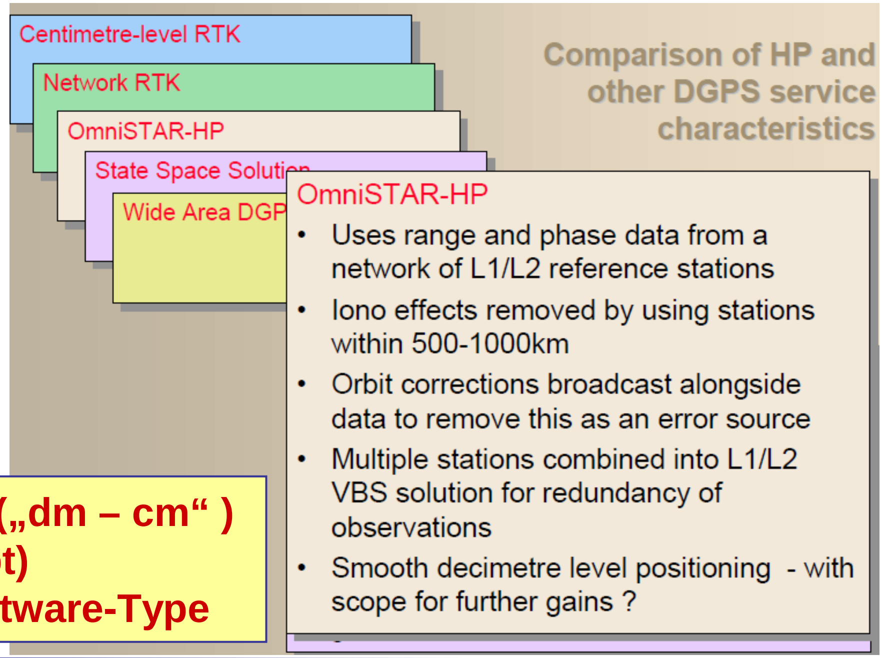
1



- SSR-based: Abs. Prec. OPPP
- Starfire™GPS-Corrections
- Starfire Receiver (left)
- Global Accuracy: „dm"

Abs. GNSS = „Non-DGNSS"
No Reference-Stations
But: NAVCOM Roverclients!

2



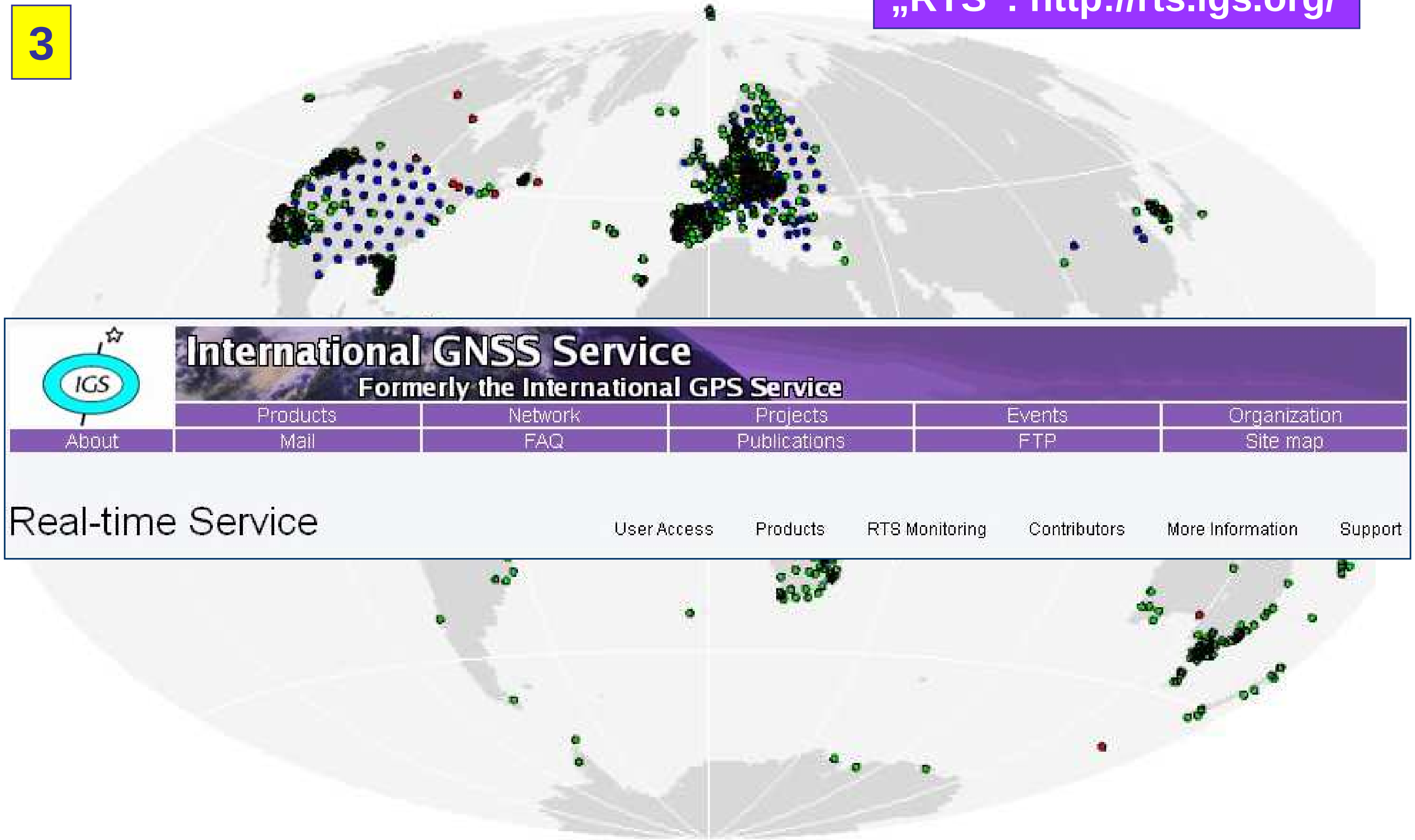
OSR (= Observation-)related: Networked, scalabe („dm – cm")
DGNSS RTCM Correction (VRS-Concept)
• RTCM-Standard =>Open for any Rover- and Software-Type

„Global G(lobal")NSS Precise Positioning Services - Worldwide

International GNSS-Service (IGS) - Online SSR Models, since April 2013

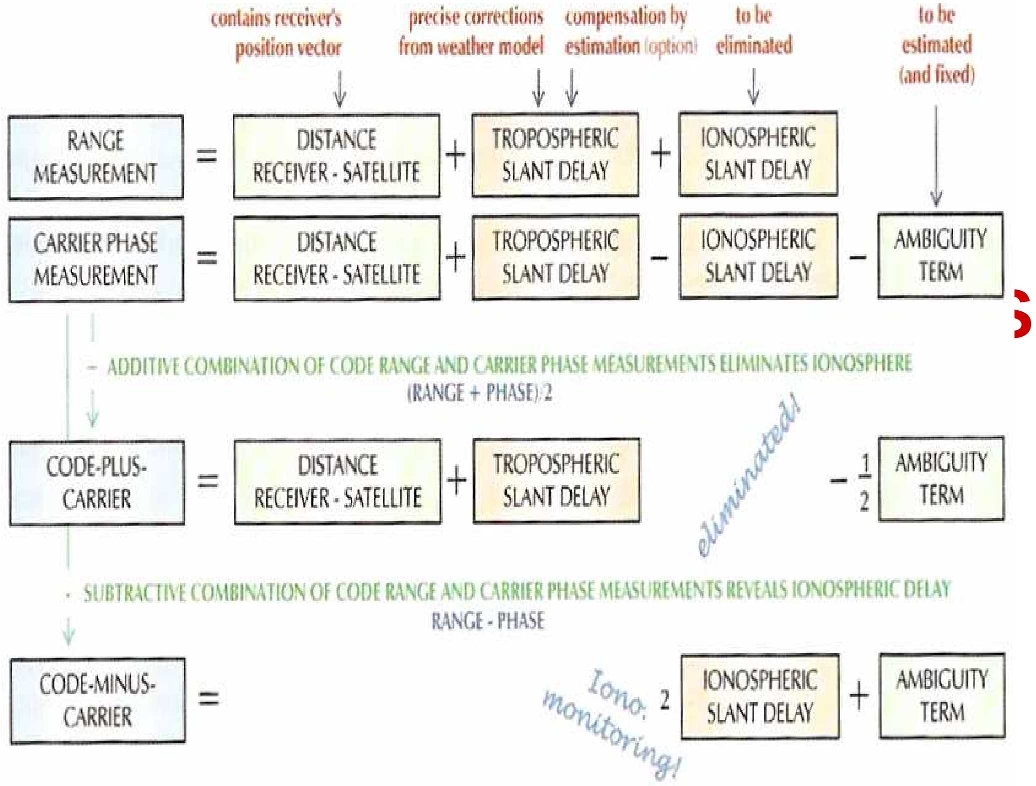
„RTS": http://rts.igs.org/

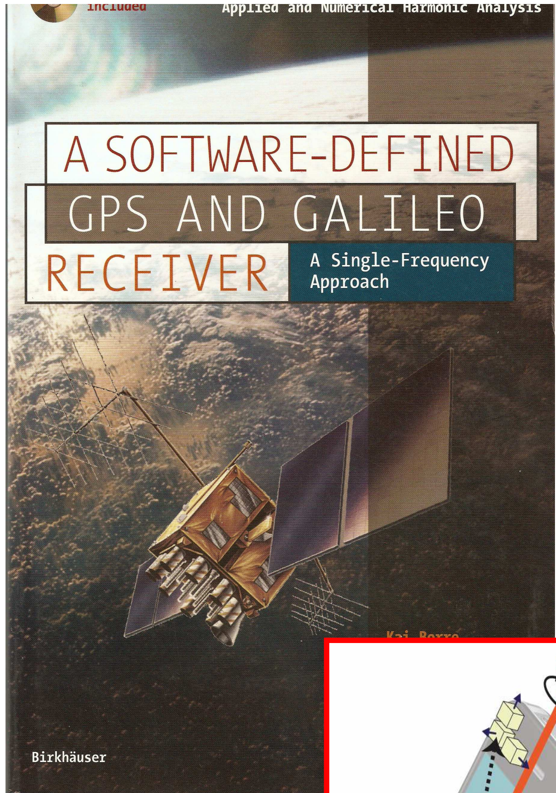
3



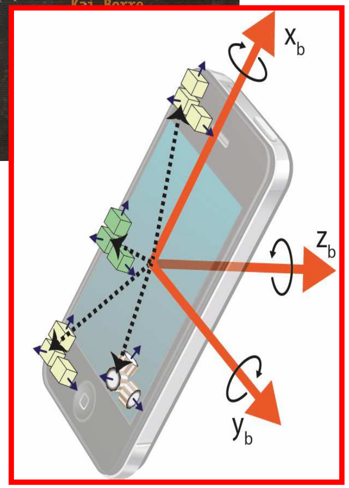
…. and Low-Cost GNSS-PositioningTrends

1.) „LowCost- High-Precise“ – „Software-Receiver“





2.) Online Precise Point Positioning (OPPP) „Absolute GNSS“



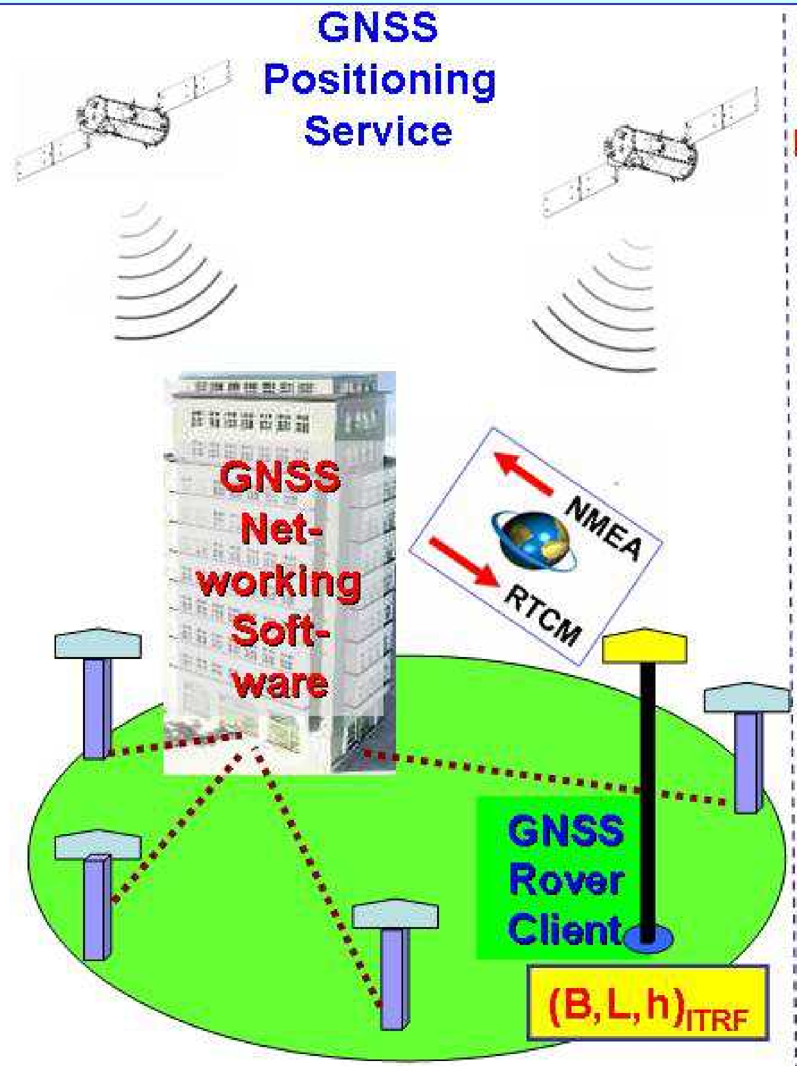
3.) RTKLIB Open Source …. *NAVKA-GNSS-Algorithms*

(www.navka.de)

=> GNSS + MEMS: „Multisensor – Platforms (NAVKA)“ *„Smartphone RTK“*

Geodetic Infrastructures
for
GNSS Positioning Services
(GIPS)

Geodetic Infrastructures for GNSS – Positioning Service (GIPS)



e.g www.moldpos.eu

Geodetic Transformation Infrastructure

GIPS-1: Horizontal Referencing $(B,L)_{blass}$ Trafo-1 and Trafo-2

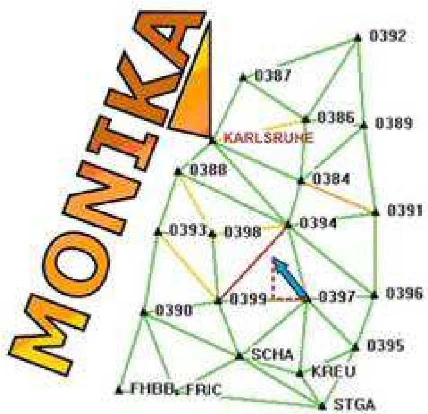
GIPS-2: Height Reference Surface and Transition ($h \rightarrow H$). Trafo-3

www.dfhbf.de

www.geozilla.de

GIPS-3: RTCM Transformation Messages. Trafo-4

GIPS 4: Geomonitoring-Infrastructure



Coordinate-Integrity

Georisk Mitigation

www.monika.ag

www.goca.info

GIPS-3- RTCM-Transformationmessages (2007) - Former use of Reference Transformations on GNSS - Controllers

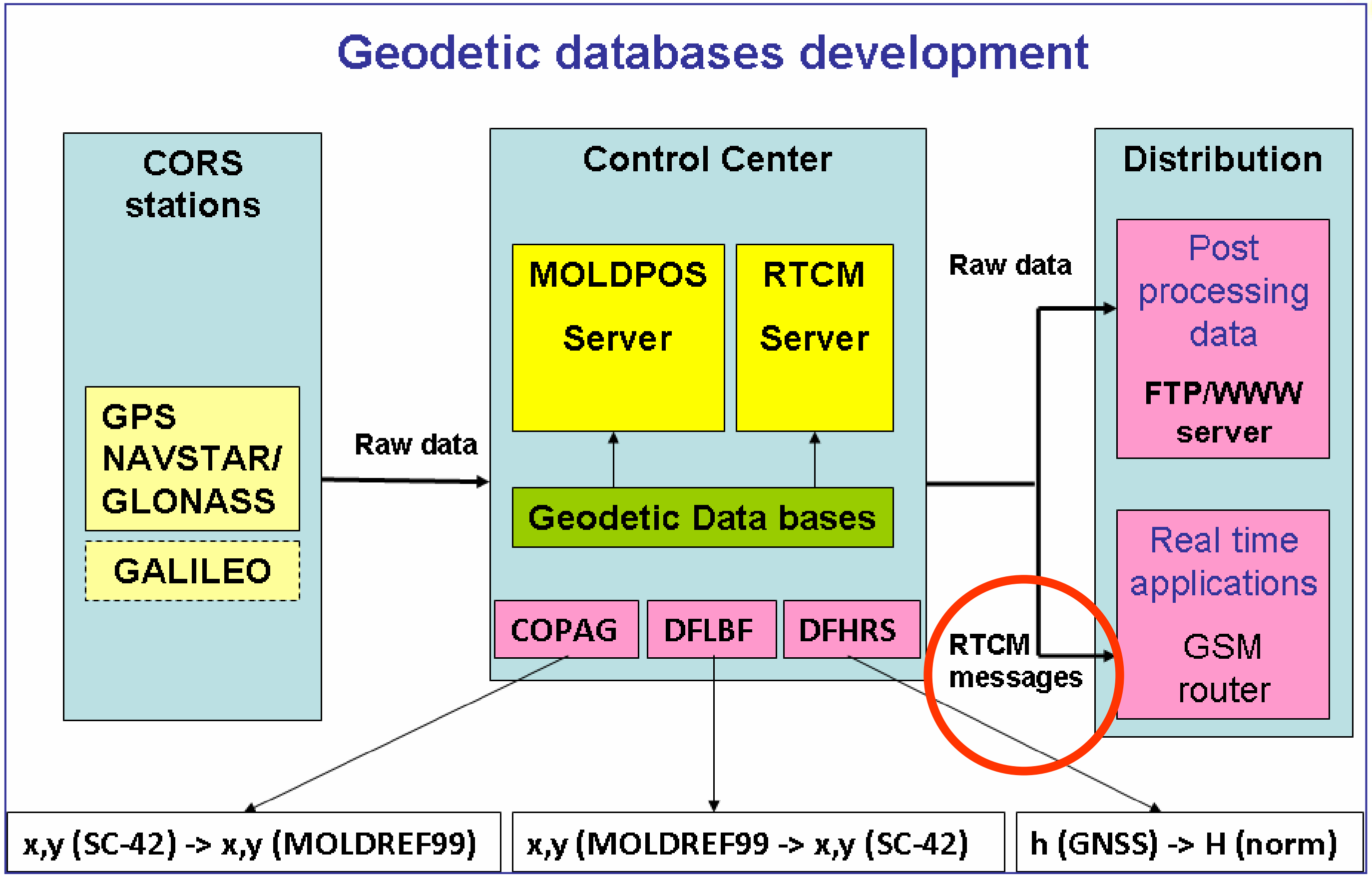
DFLBF / DFHBF

GIPS-3 - RTCM-Transformationmessages (2007) – Present use of Reference Transformations by GNSS Positioning Services Providers

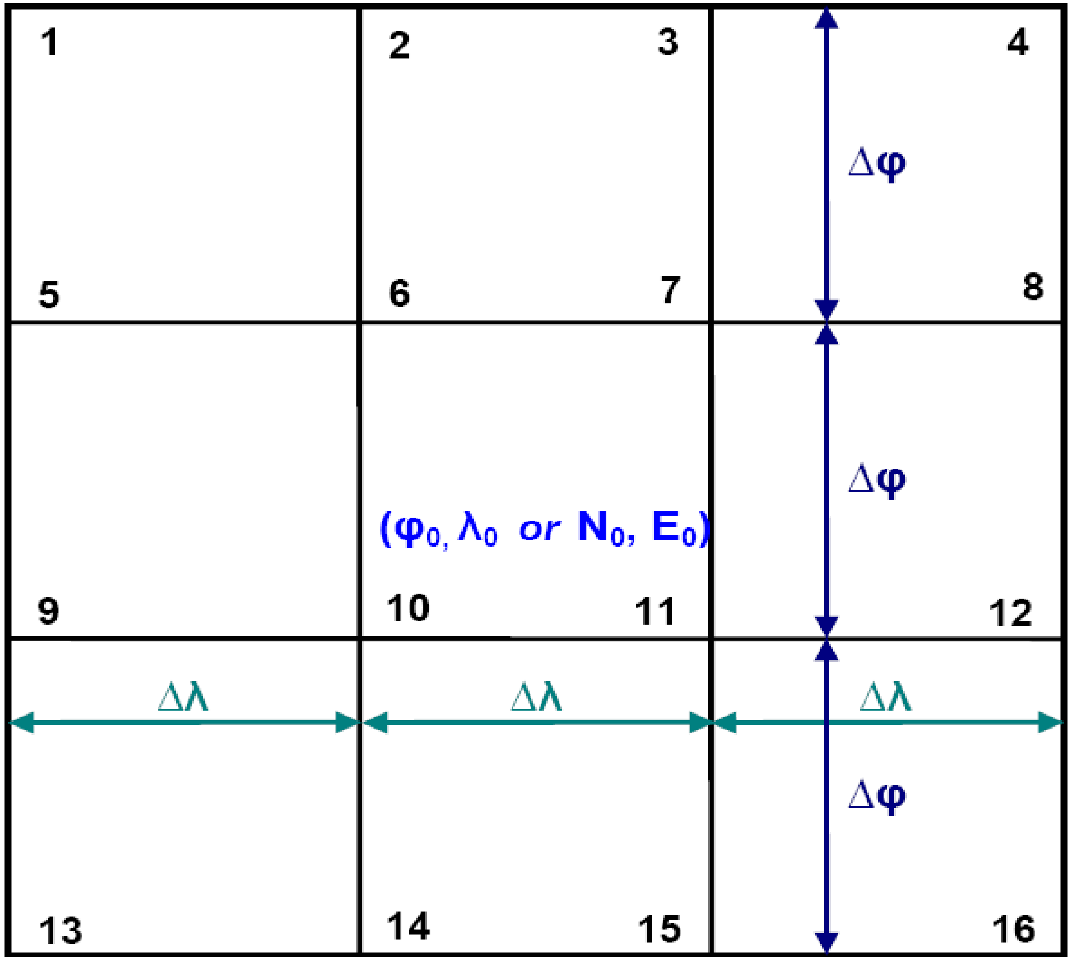
MOLDPOS- Project www.moldpos.eu

- Karlsruhe University of Applied Sciences (HSKA)
- Agency for Land Relations and Cadastre Moldova (ALRC)
- Technical University of Moldova (TUM)

Federal Ministry of Education and Research



GIPS-3 - RTCM-Transformationmessages (2007) – Present use of Reference Transformations by GNSS Positioning Services Providers



Area of validity for the 7PT Transformation (Origin,Extension and + 16 Gridpoints)

GIPS-3 - RTCM-Transformationmessages (2007) – Present use of Reference Transformations by GNSS Positioning Services Providers

RCTM-Messages 1021 or 1022

Data FIELD	DF NUMBER	Values	Remarks
Message Number	DF002	1021	
Source-Name Counter	DF+1	4	
Source-Name	DF+2	4258	ETRS89, Europa
Target-Name Counter	DF+3	7	
Target-Name	DF+4	31467	DHDN, GK-3
System identification number	DF+5	1	
Involved Transformation message	DF+6	0000000110	
Plate number	DF+7	7	
Computation Indicator	DF+8	1	
Height Indicator	DF+9	2	
ϕ_V	DF+10	49.0102	
λ_V	DF+11	8.3921	
$\Delta\phi_V$	DF+12	0.04	
$\Delta\lambda_V$	DF+13	0.06	
dX	DF+14	-617.880	
dY	DF+15	-253.456	
dZ	DF+16	-315.690	
R_1	DF+17	5.79748	
R_2	DF+18	-2.44443	
R_3	DF+19	-5.1534	
dS	DF+20	-13.51806	
add a_s	DF+24	8137.000	GRS80
add b_s	DF+25	6752.314	
add a_T	DF+26	7397.155	Bessel
add b_T	DF+27	6078.963	
Horizontal 7P Quality Indicator	DF+76	2	

Geoid-QGeoid Grid

Grid Location&Size

7 Parameters

Ellipsoid Parameters Source / Target

GIPS-3 - RTCM-Transformationmessages (2007) – Present use of Reference Transformations by GNSS Positioning Services Providers

Message 1023 or Message 1024

::

δN_{14} δE_{14} δh_{14}	Residuals P_{14}	DF+71 DF+72 DF+73	0.001 0.013 0.049	::
δN_{15} δE_{15} δh_{15}	Residuals P_{15}	DF+71 DF+72 DF+73	0.005 0.009 0.088	
δN_{16} δE_{16} δh_{16}	Residuals P_{16}	DF+71 DF+72 DF+73	0.006 -0.002 0.129	
Horizontal interpolation method indicator		DF+74	0	
Vertical interpolation method indicator		DF+75	0	
Horizontal Grid Quality Indicator		DF+78	1	
Vertical Grid Quality Indicator		DF+79	1	
Modified Julian Day (MJD) Number		DF+80	53570	

Height Indicator = 1 ➔ „dh_i„ = **Physical Heights‘ Residuals dH_i**

Height Indicator = 2 ➔ „dh_i„ = **Geoid / HRS Heights N_i (dN_i)**

GIPS-1

Continuous Datumtransformation Parameters between SG95 and SC42 for SRPOS GNSS Positioning Service (Novosibirsk Region)

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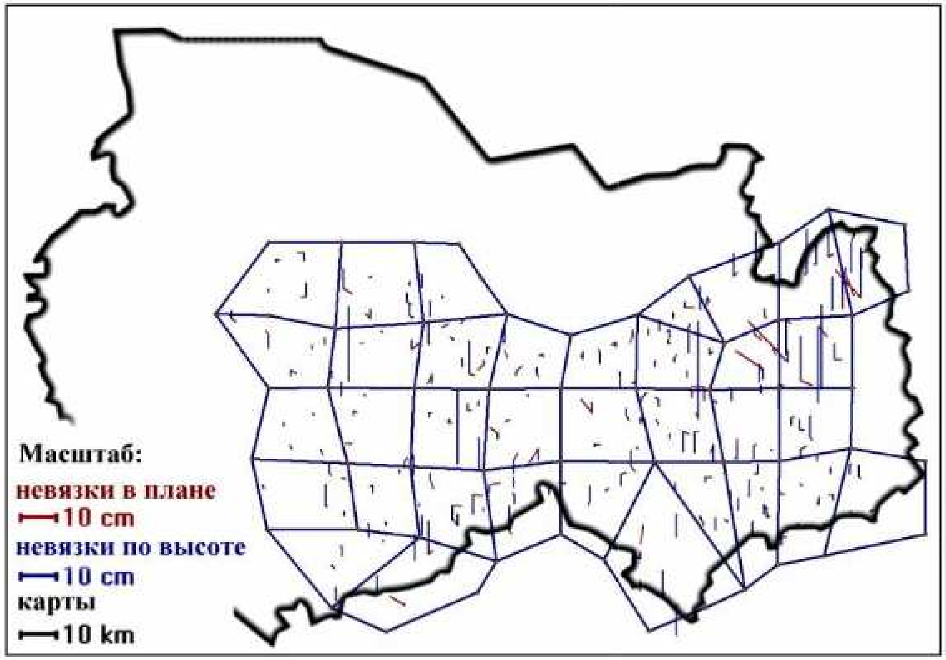
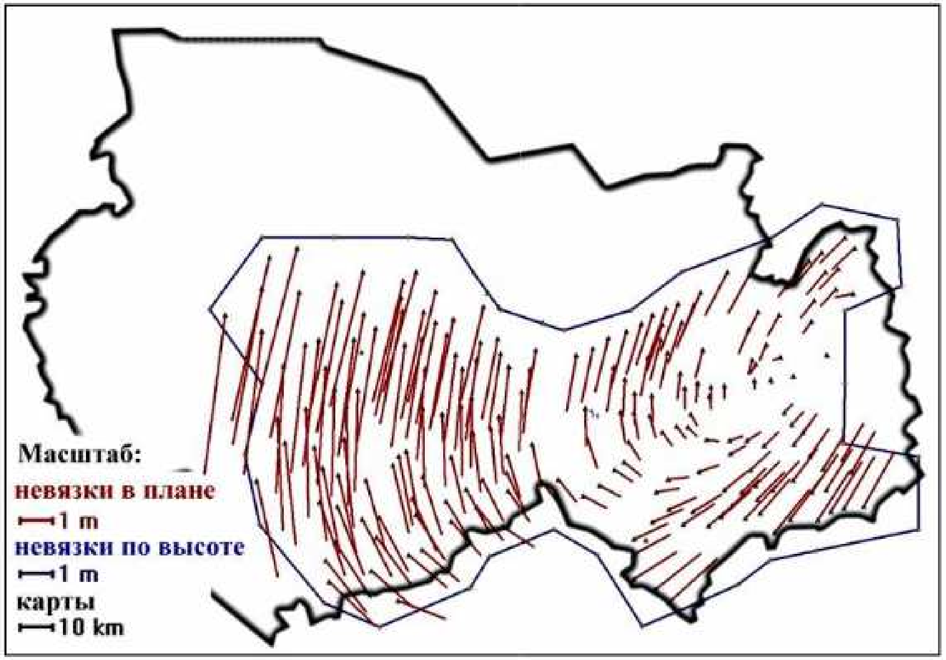
Reiner Jäger, Simone Kälber, Lagutina Elena and Tatyana Gorokhova (2012): "Determination of transformation parameters between international and state coordinate systems on the territory of the Novosibirsk region" ("ОПРЕДЕЛЕНИЕ ПАРАМЕТРОВ ПЕРЕХОДА ОТ ОБЩЕЗЕМНОЙ К ГОСУДАРСТ ВЕННОЙ СИСТЕМЕ КООРДИН АТ НАТЕРРИТОРИЮ НОВОСИ БИРСКОЙ ОБЛАСТИ"). Paper presented by Tatyana Gorokhova at the Interexpo Geosiberia 2012, Novosibirsk, Russia, 17.04.2012 - 19.04.2012.





GIPS-1 Continuous Datumtransformation Parameters between SG95 and SC42 for SRPOS (Novosibirsk Region)

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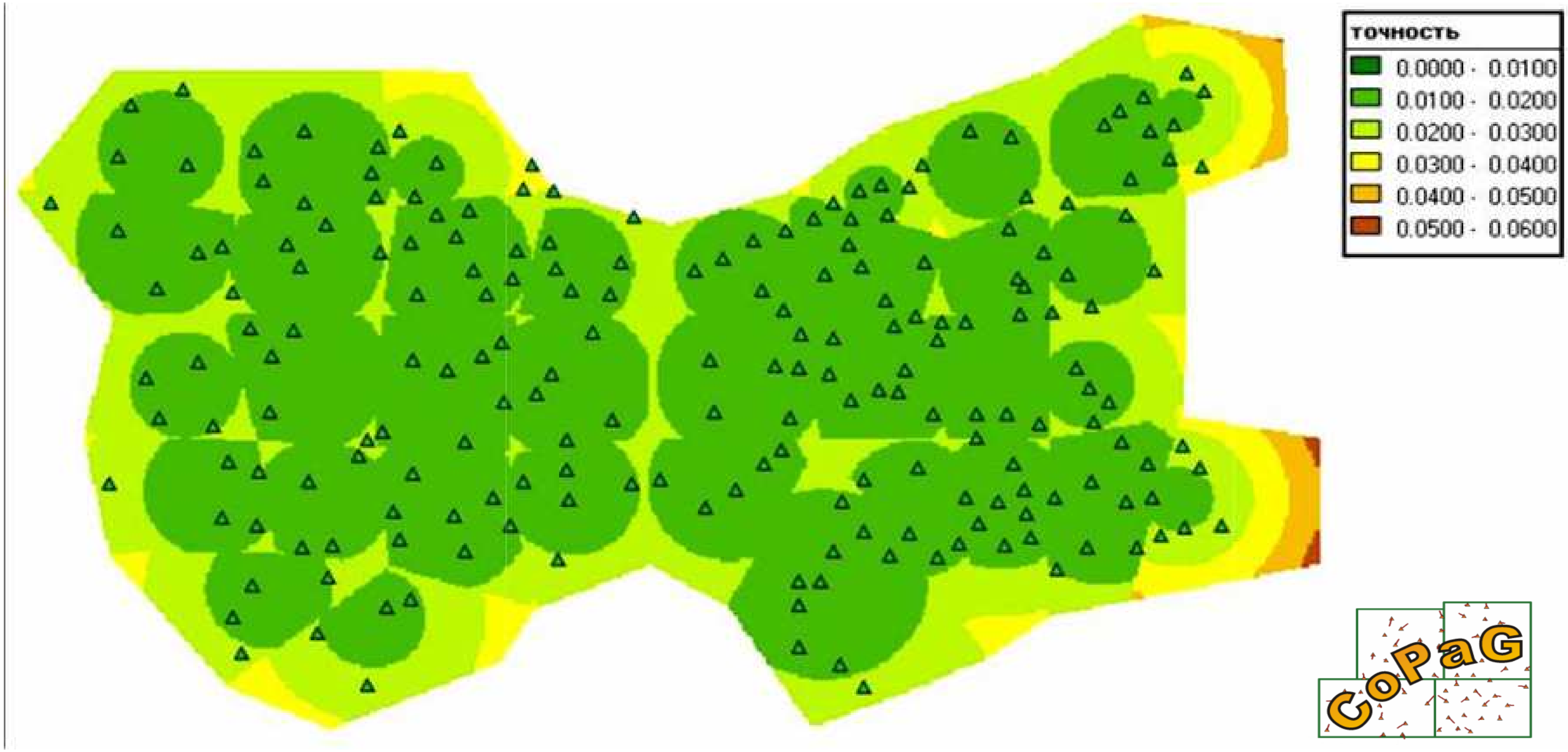
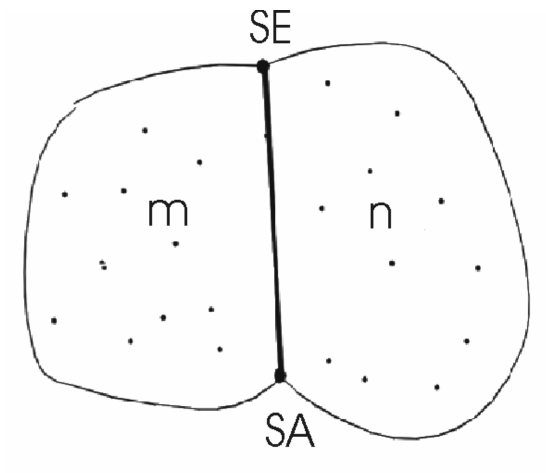


GIPS-2
Height Reference Surface
(QGeoid/Geoid)

DFHBF-Approach Version 4.0
Stage 1
„Geometrical Approach“

GIPS-2 DFHBF 4.0 - FEM Representation of HRS



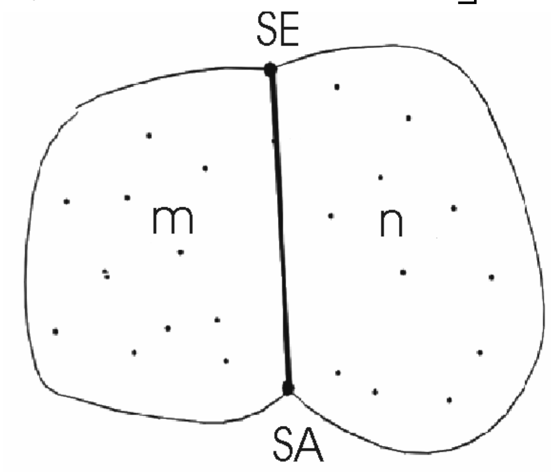
3D difference at any point P(x,y) along the border SA_SE of the meshes m and n has to vanish

$$\begin{bmatrix} \Delta x_{m,n} \\ \Delta y_{m,n} \\ \Delta N_{m,n}(y,x) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ N(\mathbf{p}_n, y, x) - N(\mathbf{p}_m, y, x) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \sum_{i=0}^{l} \sum_{j=0}^{l-i} \left(a_{ij,n} - a_{ij,m}\right) \cdot y^i \cdot x^j \end{bmatrix}$$

GIPS-2 DFHBF 4.0 - FEM Representation of HRS

$$\begin{bmatrix} \Delta x_{m,n} \\ \Delta y_{m,n} \\ \Delta N_{m,n}(y,x) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ N(\mathbf{p}_n, y, x) - N(\mathbf{p}_m, y, x) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \sum_{i=0}^{l}\sum_{j=0}^{l-i}\left(a_{ij,n} - a_{ij,m}\right)\cdot y^i \cdot x^j \end{bmatrix}$$

$$\begin{bmatrix} 0 \\ 0 \\ \Delta \mathrm{N}_{n,m} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \sum_{i=0}^{l}\sum_{j=0}^{l-i}\left(\mathrm{a}_{ij,n} - \mathrm{a}_{ij,m}\right)\cdot \mathrm{y}^i \cdot \mathrm{x}^j \end{bmatrix}$$



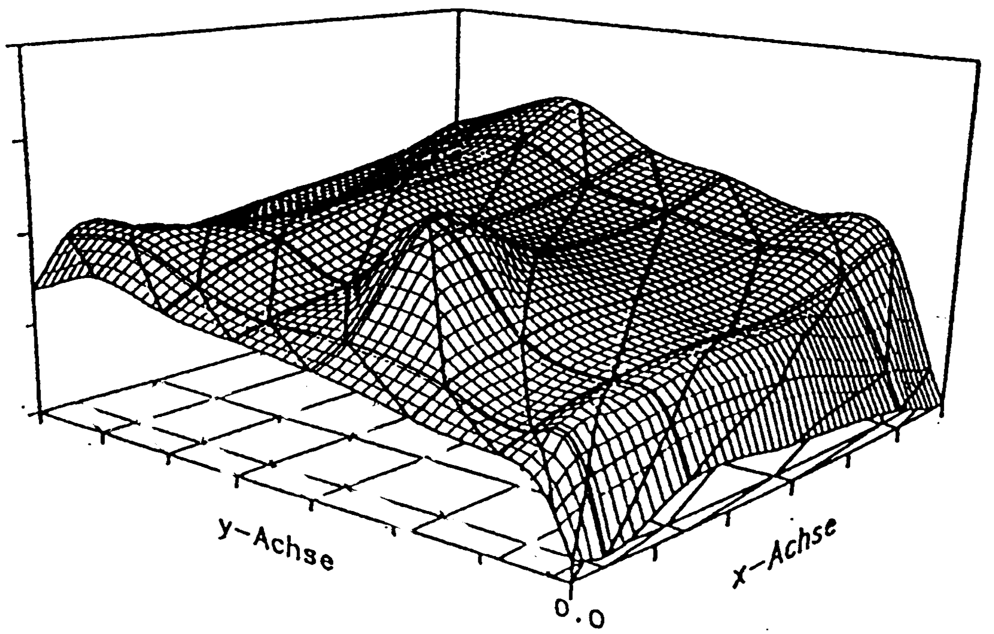
$$\sum_{i=0}^{l}\sum_{j=0}^{l-i}\left(a_{ij,n} - a_{ij,m}\right)\cdot\left(y_{sa} + t\cdot\left(y_{se} - y_{sa}\right)\right)^i \cdot \left(x_{sa} + t\cdot\left(x_{se} - x_{sa}\right)\right)^j = \Delta N_{m,n}(t) \equiv 0!$$

$$\Delta N_{m,n}(t) = c_0 + c_1 \cdot t + c_2 \cdot t^2 + \cdots + c_k \cdot t^k = \sum_{k=0}^{l} c_k \cdot t^k \equiv 0!$$

$$\Rightarrow \quad c_k(\mathbf{p_m}; \mathbf{p}_n; y_{sa}, x_{sa}; y_{se}, x_{se}) = 0, \quad k = 0, l$$

GIPS 2 - DFHBF 4.0 - FEM Representation of HRS

Result: Continuous Height Reference Surface: NFEM(p)



$$N_{FEM} = \left\{ \begin{array}{c} N(\mathbf{p}_k) = \sum_{i=0}^{l} \sum_{j=0}^{l-i} a_{ij,k} \cdot y^i x^j = \mathbf{f}^T \cdot \mathbf{p}_k \\ \\ C_{0,1,2}(\mathbf{p}_m ; \mathbf{p}_n) \end{array} \right\}$$

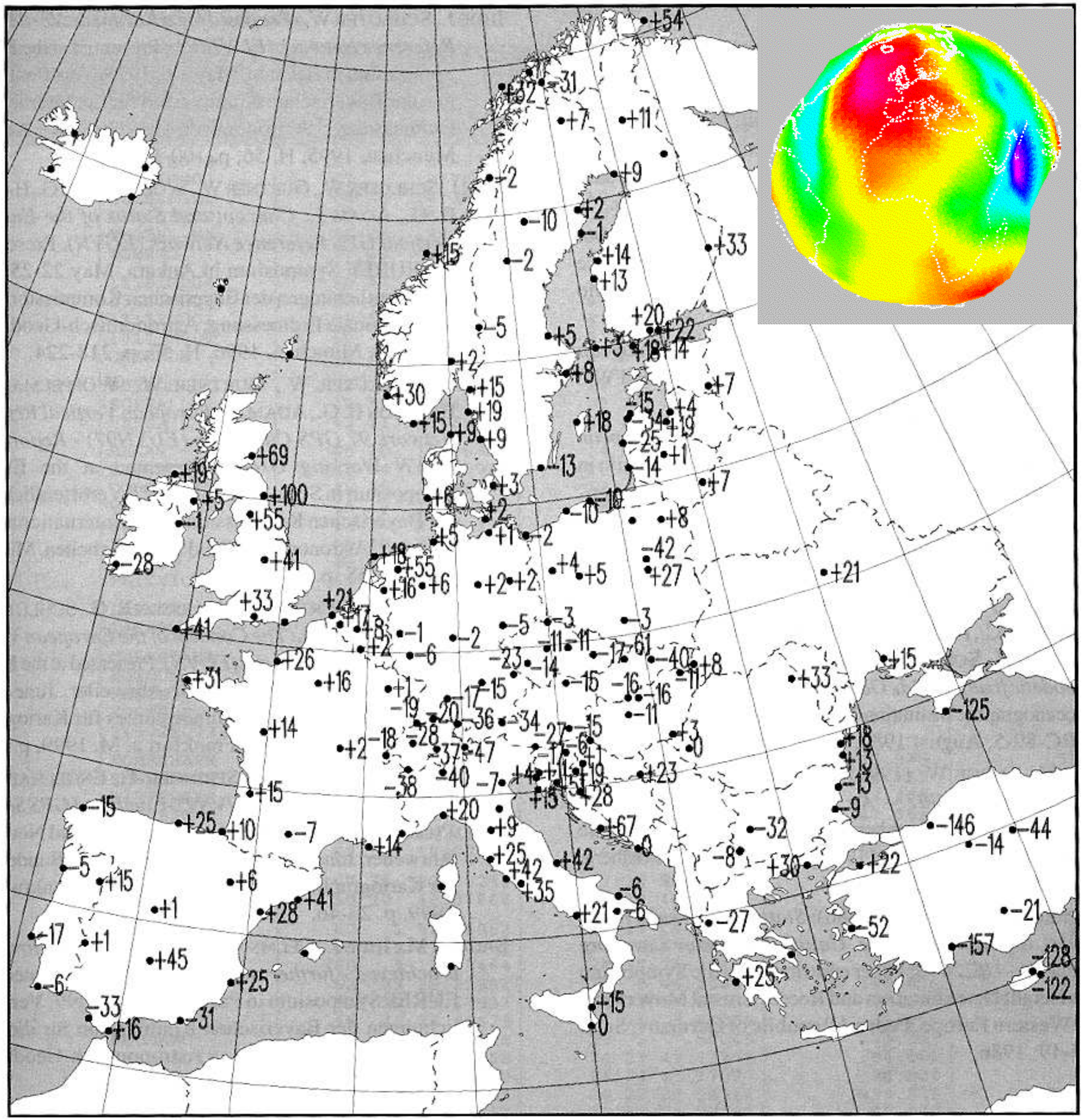
Weak-Shapes of Classical Gravimetric „Geoid“models

$$N = N_{\mathrm{Re}\,f} + \frac{a}{4\pi\gamma}\int_{\Psi=0}^{\psi_0}\int_{\alpha=0}^{2\pi}(\Delta g - \Delta g_{\mathrm{Re}\,f})\cdot S(\psi)\cdot d\psi\cdot d\alpha$$

EGG97 *European Gravimetric QGeoid 97 and others Non-fitted Stokes-based models*

Mean- up to lang-waved Errors

0.1 – 1.5 m !



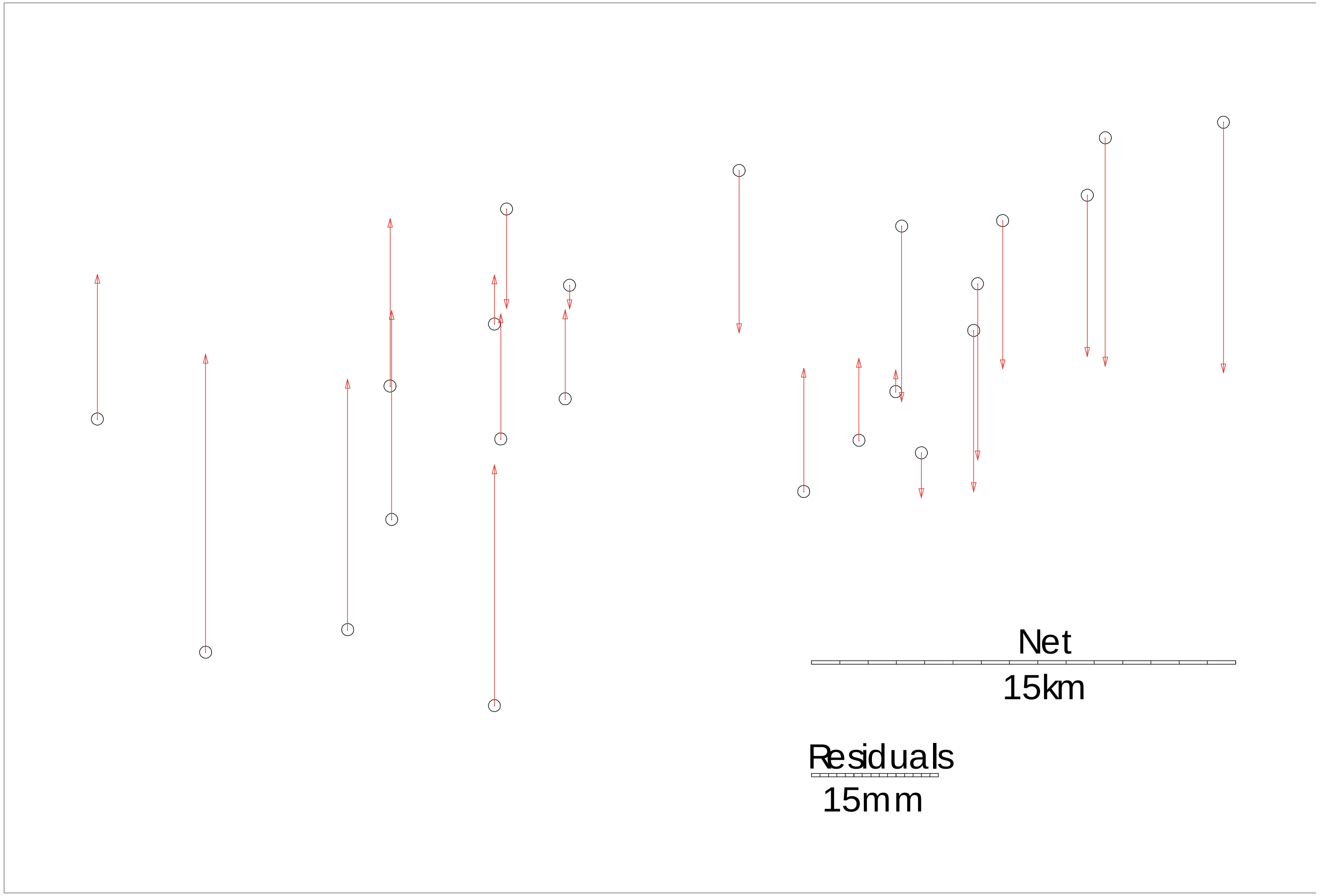
GIPS-2 - DFHBF 4.0 „Patching“ ∂N(d) using Identical Points

Tallinn Example

EGG97-QGeoid

without Datum ∂N(d)

+/- 3.5 cm „Tilt“



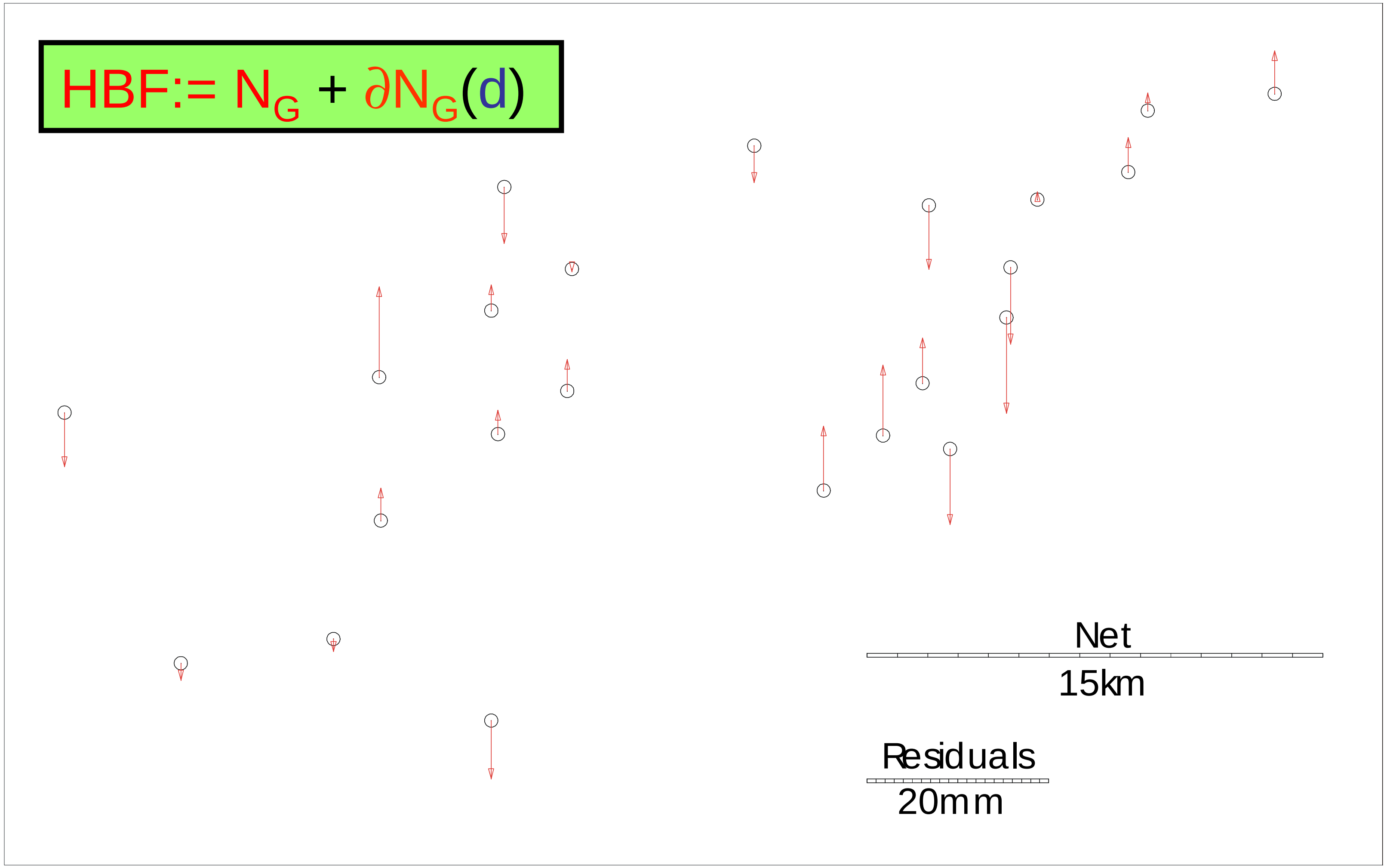
GIPS-2 DFHBF 4.0 „Patching“ ∂N(d) using Identical Points

Tallinn Example

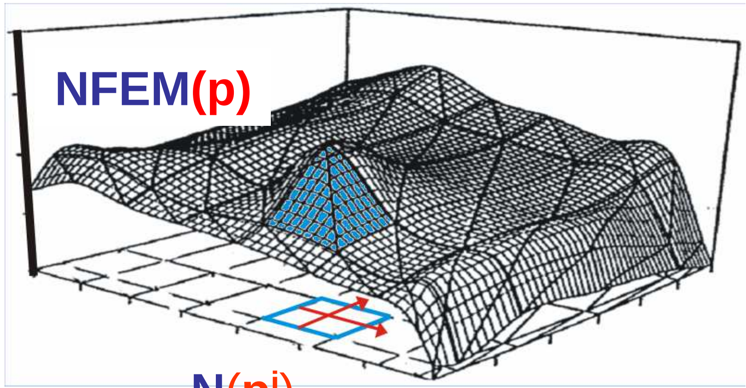
EGG97-QGeoid

With Datum ∂N(d)

+/- 4 mm



GIPS 2 DFHBF 4.0 - Approach FEM Representation of HRS



Complete New Computation of continuous HRS (p and Δ m)!

DFHRS – Adjustment Approach State of the Art < 2005

$h_{GNSS} + v = H + NFEM(p) - h_{GPS} \cdot \Delta m$ <= GPS/Levelling Fitting Points

$H + v = H$

$N_G{}'^{j} + v^{j} = NFEM(p) + \partial N_G(d^{j})$ <= Any number Geoidmodels (Global, regional, local)

$\xi^{j} + v = -F_B / M(B) \cdot p + \partial \xi (d_{\xi,\eta})^{j}$ <= Sets of Deflections from Vertical

$\eta^{j} + v = -F_L/(N(B)\cdot\cos(B)) \cdot p + \partial \eta(d_{\xi,\eta})^{j}$ (Zenith Cameras or Geoidmodels)

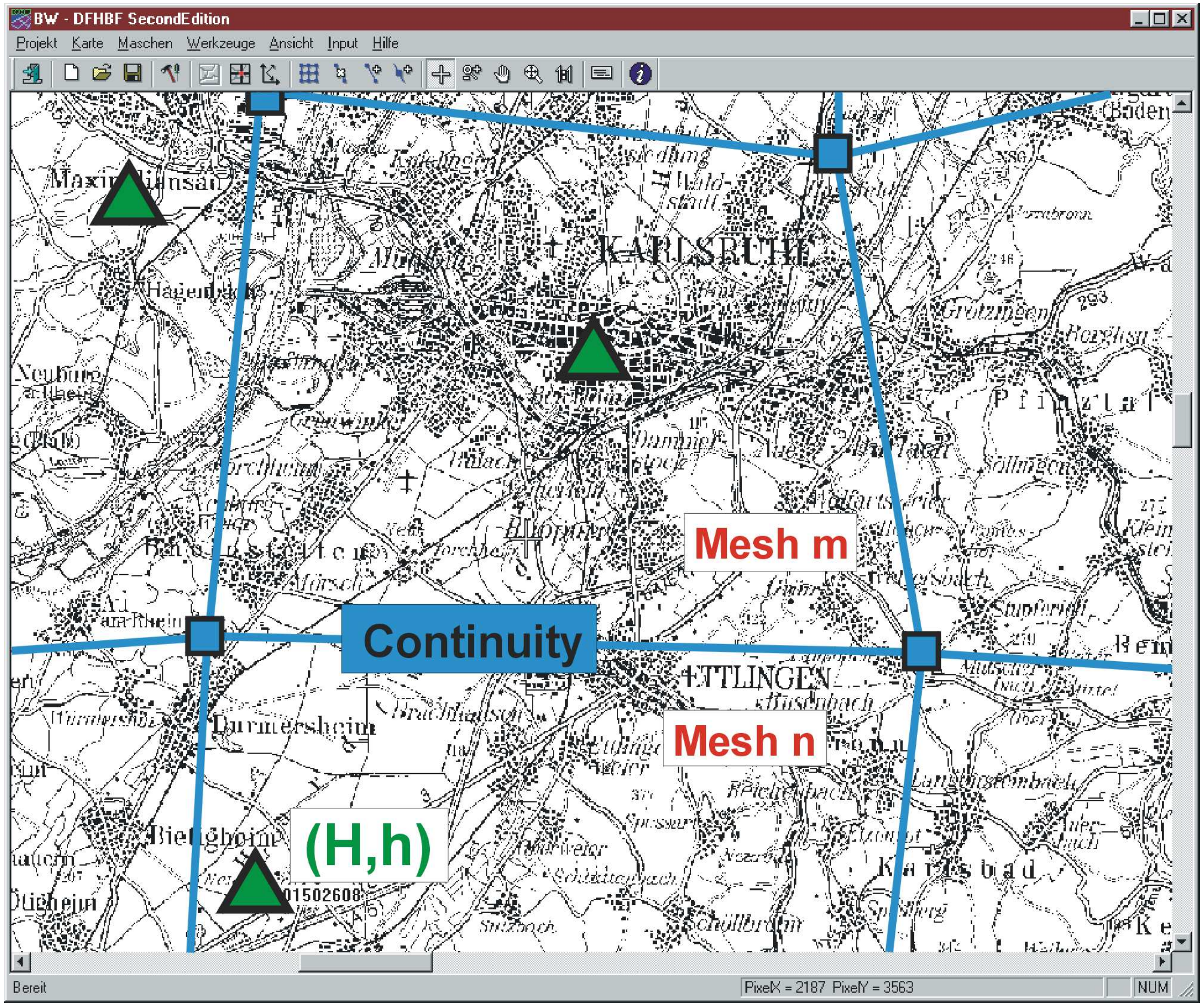
$\frac{a}{4\pi\cdot\gamma(B)}\iint_{\sigma}\Delta g\cdot S(\psi)d\sigma + v = NFEM(p)$ <= „Gravity“ by correlated Geoidmodels In the sense of an 2 step adjustment

GISP 2 DFHBF 4.0 – Based on FEM Representation of HRS

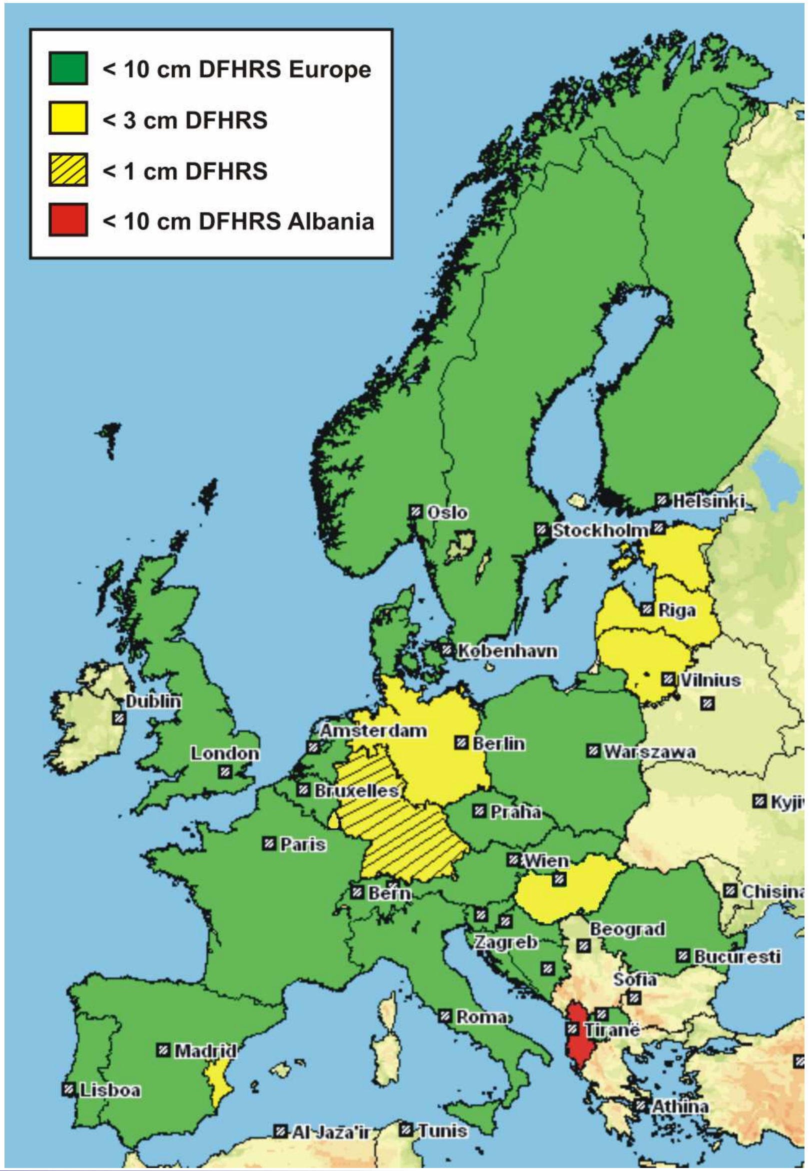
www.dfhbf.de

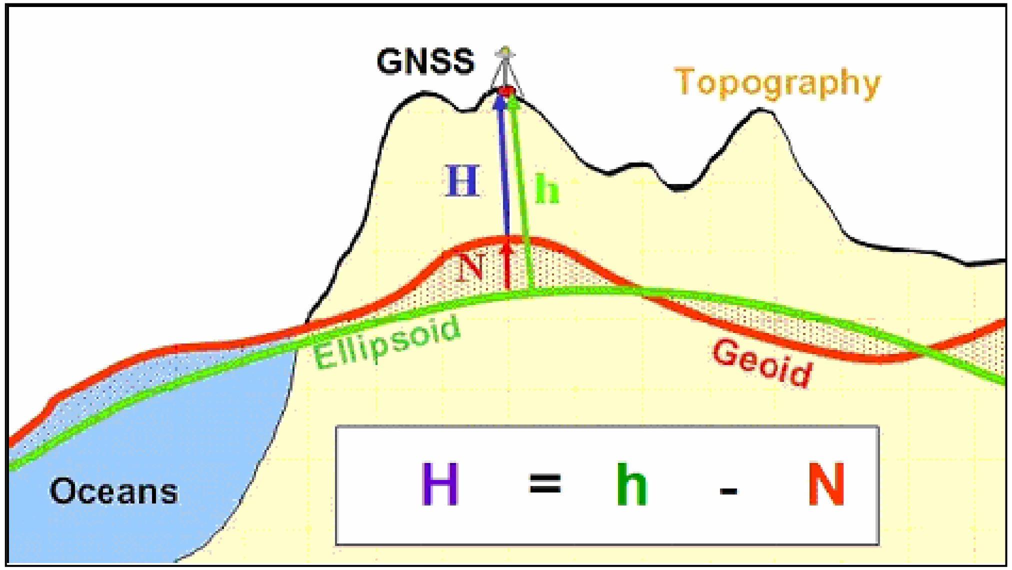
Software 4.2
Sreenshot

- Identical „Fitting“ Points (B,L,h;H)
- Meshes



GISP 2 DFHBF 4.0 – Based on FEM Representation of HRS





DFHBF - DataBases

$$N_G = N_{QG} + \frac{\bar{g} - \bar{\gamma}}{\bar{\gamma}} \cdot H$$

Quasi-Geoid N_{QG} **Quasi-Geoid N_G**

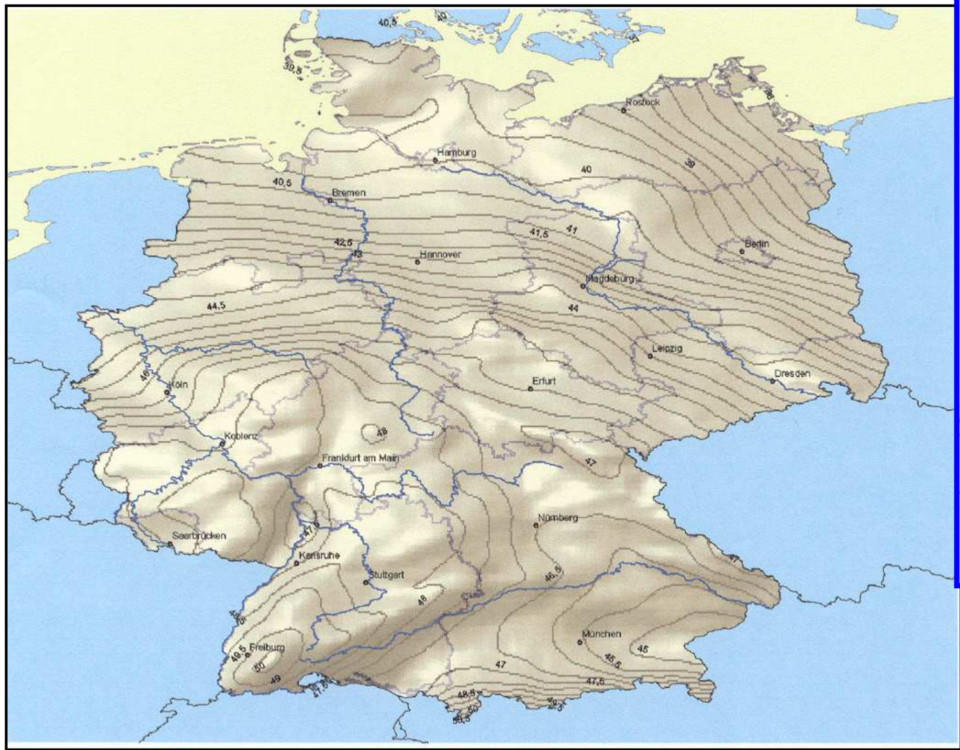
GIPS 2 DFHBF 4.0 – Based on FEM Representation of HRS

1-3 cm DFHBF_DB **NFEM(p)**

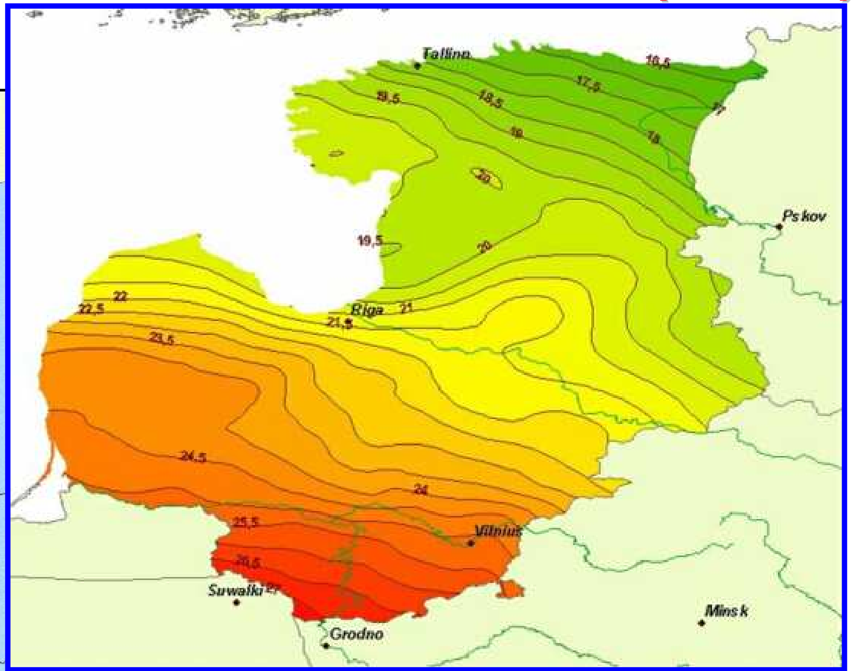
… Grmany

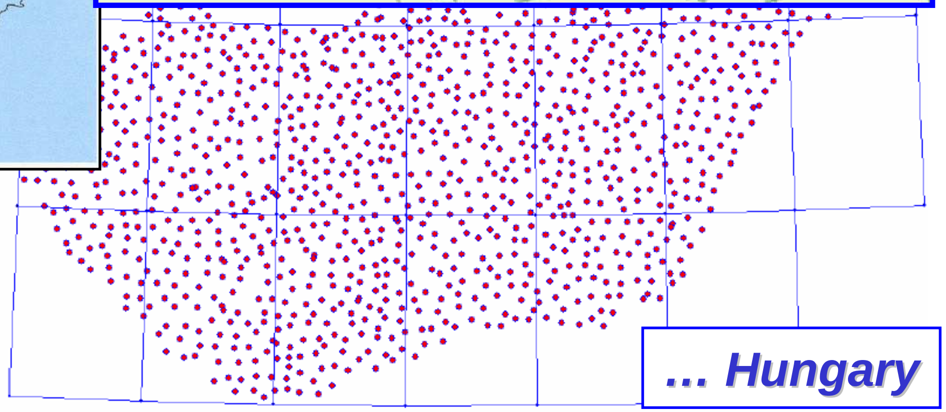
< 1 cm (Bayern, Ba-Wü, RLP, Saarland, Hessen)

1-3 cm DFHBF Databases



… Estonia, Latvia, Lithuania (2012/13)



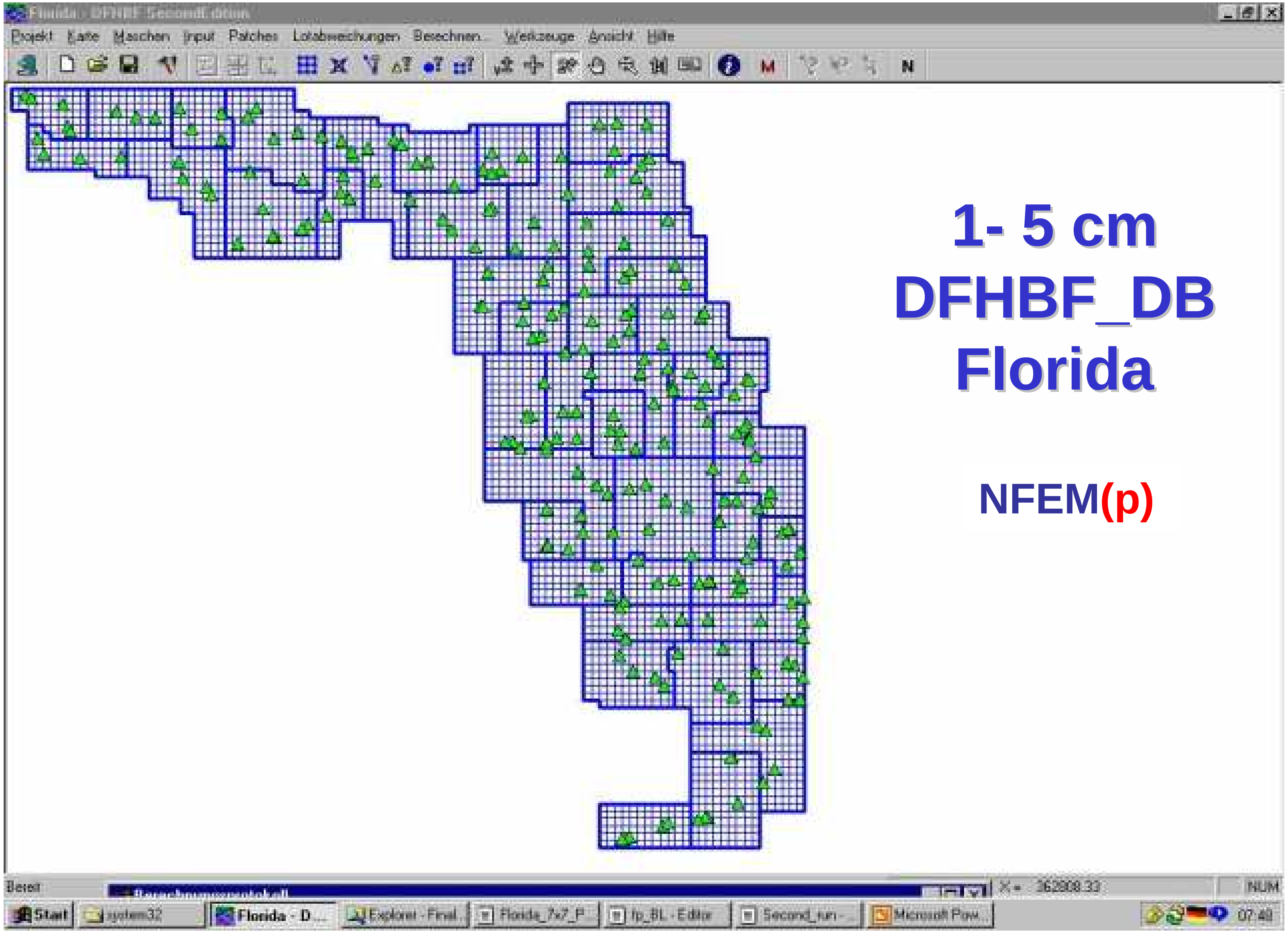


… Hungary

DFHBF-
Software

DFHBF-
-DLL/-Tools

GIPS 2 DFHBF 4.0 – Based on FEM Representation of HRS

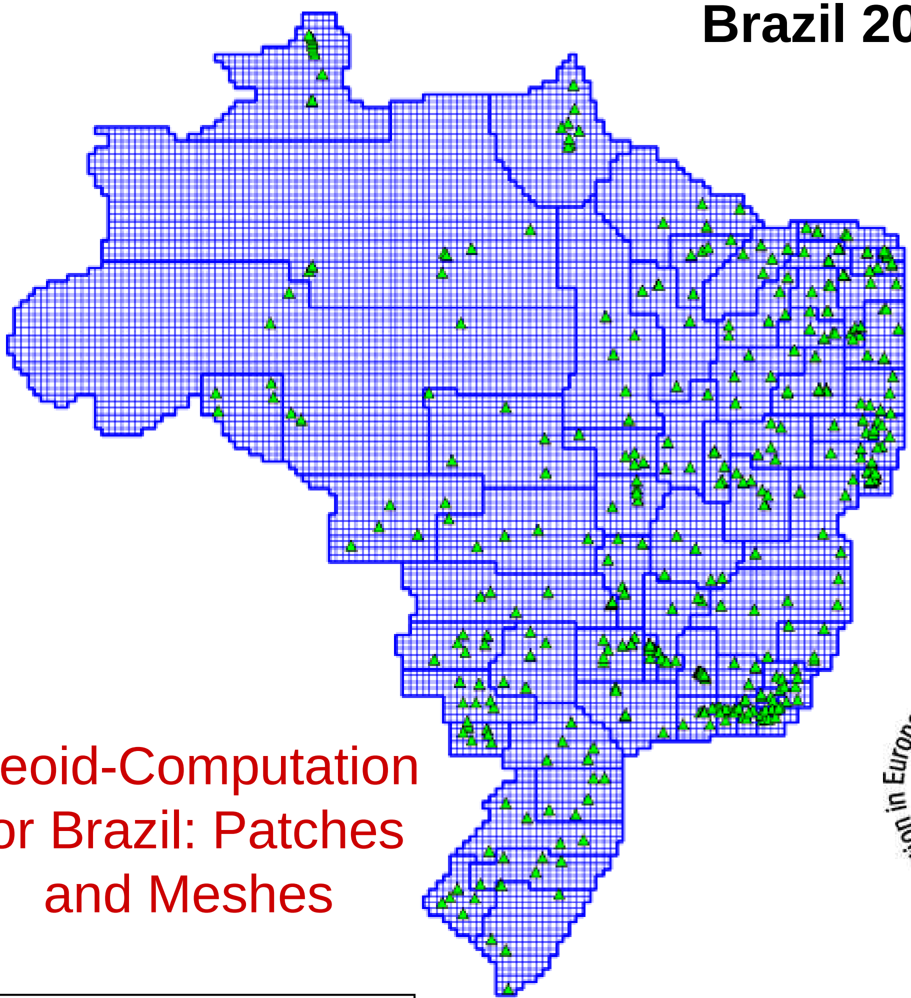


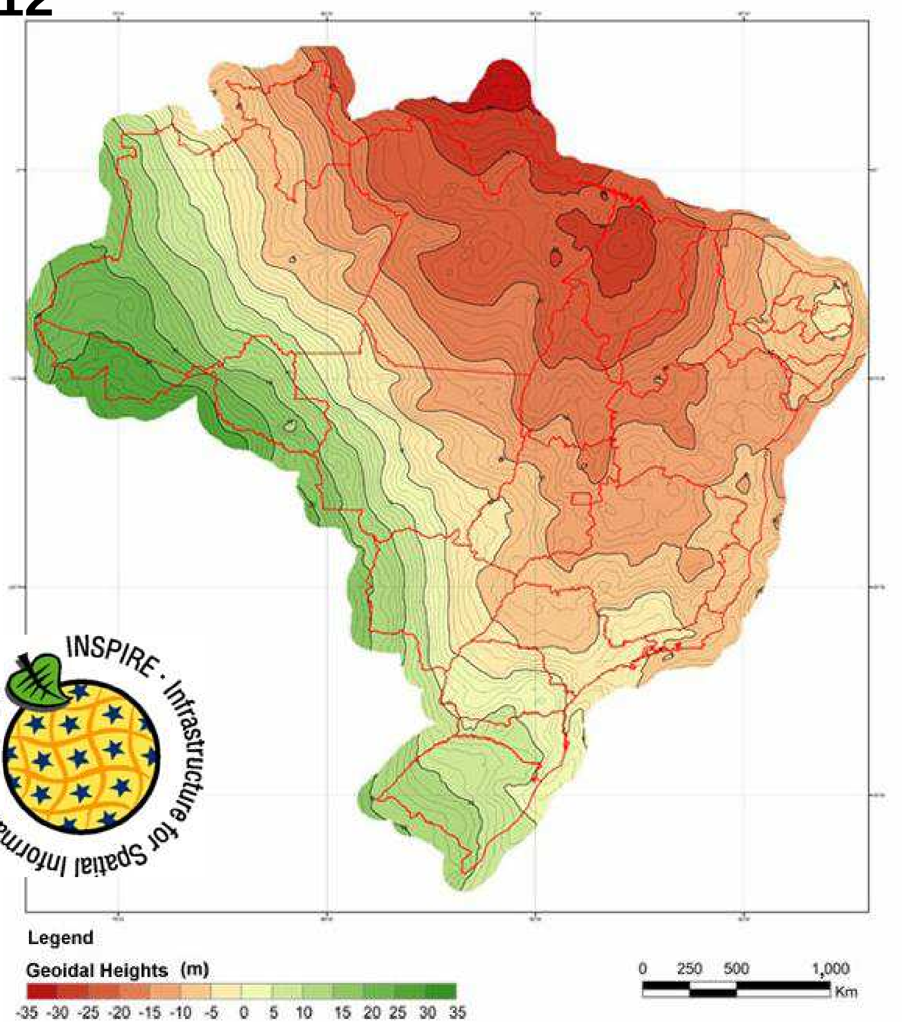
1- 5 cm
DFHBF_DB
Florida

NFEM(p)

GIPS 2 DFHBF 4.0 – Based on FEM Representation of HRS

Brazil 2012





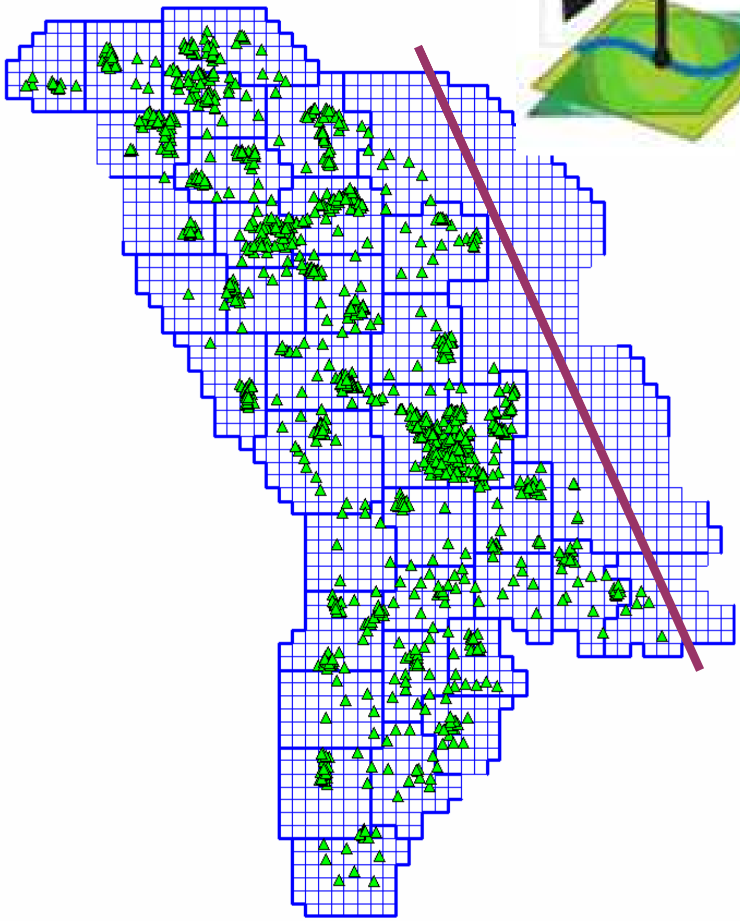
Geoid-Computation for Brazil: Patches and Meshes

www.dfhbf.de

GIPS 2 DFHBF 4.0 – Based on FEM Representation of HRS

www.moldpos.eu

MOLDPOS

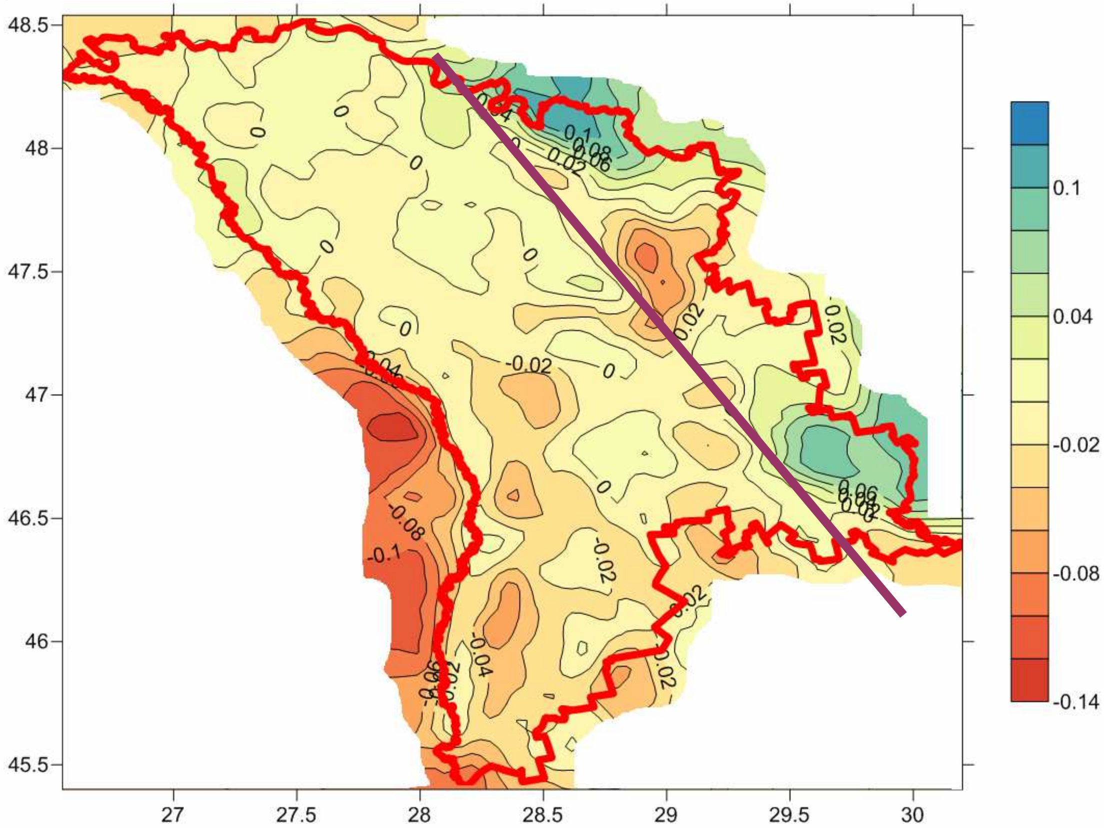


<u>1-3 cm Quasigeoid for Moldova (2011)</u>

„Patching“ of

EGG97 or EGM2008 GPM

nearly same results



GIPS 2 DFHBF 4.0 – Based on FEM Representation of HRS

Pktr	Höhe/Zielsys.	Verb. [
502	282.914	0.00832
547	466.421	-0.00113
1721	156.942	-0.00766
5121	1154.851	0.01081
5256	1773.778	0.03211
5332	348.495	-0.01315
6331	73.973	0.00021
6333	25.473	0.00546
6484	1143.221	0.00108
6583	974.753	0.00699
6585	944.169	-0.02735
7530	274.611	-0.01726
7532	23.566	-0.00566
7618	176.022	0.00680
7685	418.179	-0.02839
7693	732.667	-0.00159
7730	810.063	0.02328
7733	627.059	0.01427
7759	1102.272	0.00026
7783	934.590	-0.00485
7807	1385.507	-0.01562
8844	1150.900	0.00959
8851	111.850	-0.01132
10008	311.618	0.00216
10060	724.697	-0.00568
10066	105.636	-0.01091
10087	190.456	-0.01442
10093	312.034	0.01423
10119	1398.276	0.00175
10190	881.655	-0.00892
10195	1663.985	0.00434
10229	1124.945	-0.01924
11125	11.827	-0.00454

Geoid Computation for ALBPOS (Albania) 2013

er	Höhe/Zielsys.	Verb. [m]
11137	99.982	0.00330
11138	11.353	0.00539
11230	155.743	0.00623
11255	140.332	0.00792
11292	44.045	0.00634
11298	240.484	0.00805
11329	421.242	-0.00335
11463	940.048	0.00337
12339	15.261	-0.01416
12446	531.371	-0.01271
12475	381.966	0.00075
12486	374.872	0.01078
12492	621.275	0.02941
12583	1344.926	-0.03352
12608	952.015	0.00000
12643	926.835	-0.01037
12656	1224.130	0.01931
12687	1037.405	0.01431
13647	1448.707	-0.03311
13674	332.859	0.02693
13678	103.174	-0.00026
13758	310.588	-0.00993
13779	383.962	0.00097
13840	1053.998	0.03660
13844	848.199	-0.04238
65100	376.512	0.01078
124102	361.056	0.02017
440_1	177.386	0.00076
631	847.169	-0.00950
1103	810.053	0.01804
6399	9.201	0.01604
1176_1	228.362	-0.02767
1384_1	867.251	0.03291
641_1	1069.442	-0.02536

GIPS-2
Height Reference Surface
(QGeoid/Geoid)

DFHBF-Approach Version 5.0
Stage 2
„Integrated Approach“

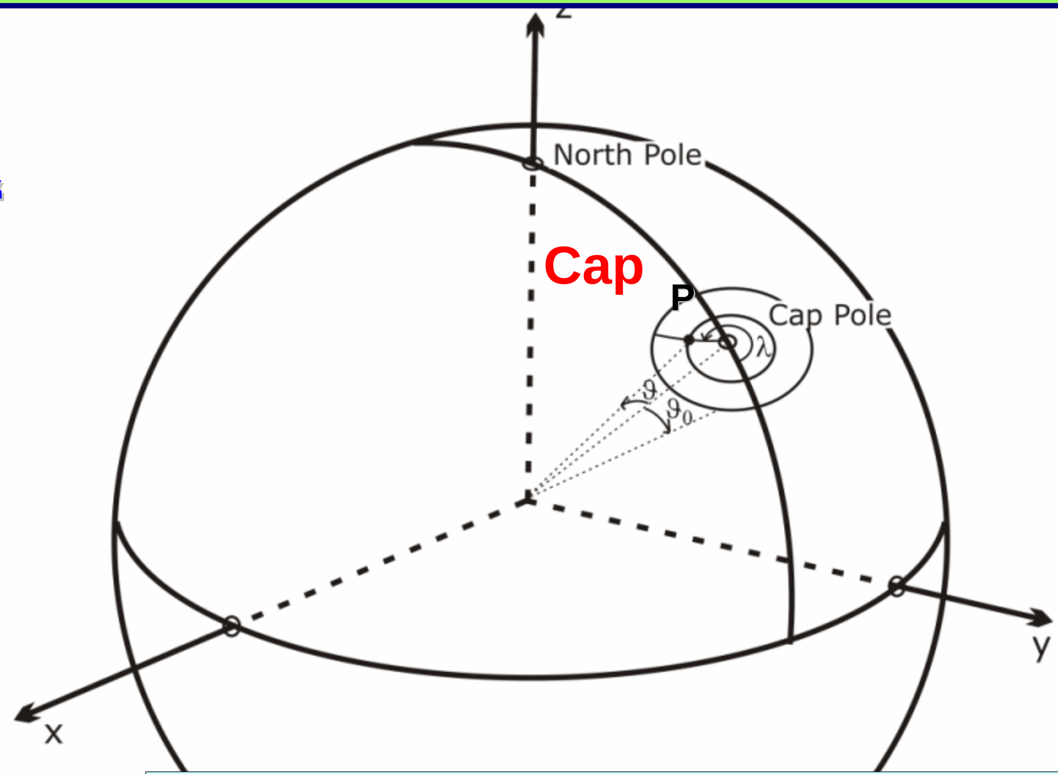
GIPS 2 DFHBF 5.0 – Based Spherical Cap Harmonics SCHA

DFHRS - Stage 2
Integrated „Approach“

Sperical Cap Harmonics (SCHA)

as

Carrier Functions of the Gravity Potential V



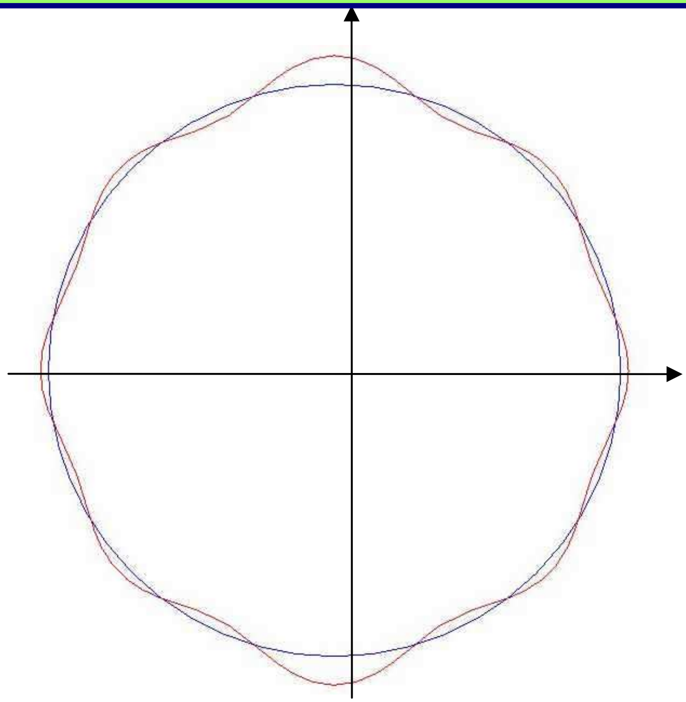
$$\tan\lambda' = \frac{\cos\varphi.\sin(\lambda-\lambda_0)}{\sin\varphi\cos\varphi_0 - \cos\varphi\sin\varphi_0\cos(\lambda-\lambda_0)}$$

$$\cos\theta' = \sin\varphi\sin\varphi_0 - \cos\varphi\cos\varphi_0\cos(\lambda-\lambda_0)$$

$$V(r,\lambda',\theta') = \frac{G\cdot M}{a}\sum_{k=0}^{k\,max}\left(\frac{a}{r}\right)^{n(k)+1}\sum_{m=0}^{k}(C'_{n(k),m}\cdot\cos m\lambda' + S'_{n(k),m}\cdot\sin m\lambda')\cdot P_{n(k)),m}(\cos\theta'))$$

GIPS 2 DFHBF 5.0 – Based Spherical Cap Harmonics SCHA

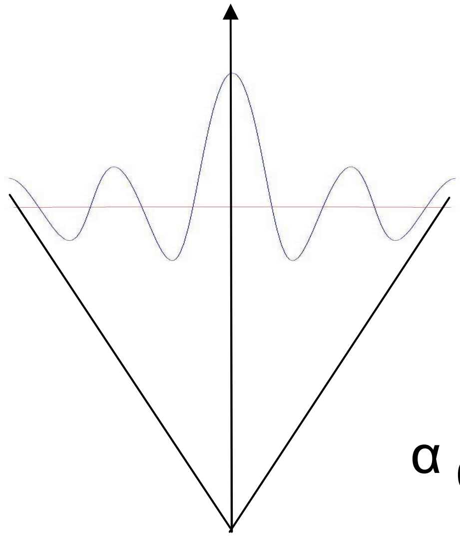
Global Spherical-Harmonics (SH)



$\alpha_0 = 90°$

SCHA „Resolution“ for „2mm QGeoid“
n=7200 and u =50.000.000 Coefficients

Spherical Cap Harmonics (SCHA)



α_0 = arbitrary

$$n_{SHA} = n(k) \approx \frac{90°}{\alpha} \cdot (k, \mathrm{SCHA} + 0.5) - 0.5$$

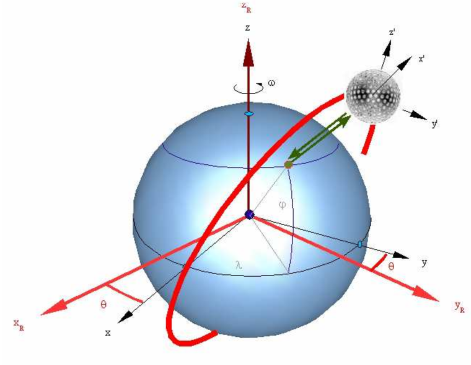
α = 1° (=110 km area) => k-SCHA = 80 and u = 6.400

α = 3° (=330 km area) => k-SCHA = 250 and u= 62.500

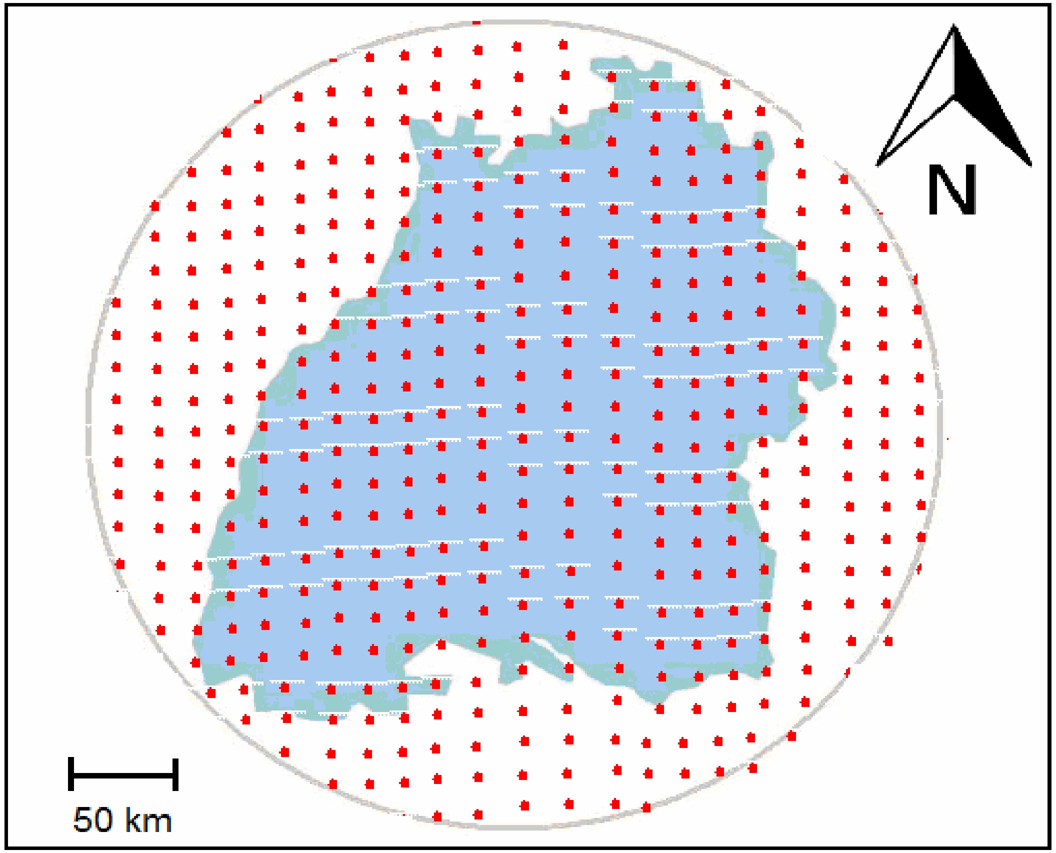
α = 25° (Europe) => k-SCHA = 2000 and u =4.000.000

GIPS 2 DFHBF 5.0 – Based Spherical Cap Harmonics SCHA

1. Treatment of Global Gravity Models – Example Baden-Württemberg



„Mapping" of Global SCH-Coefficients (e.g. EGM 2008) (C_{nm}, S_{nm}) to local SCHA-Coefficients (C_{nm}‘, S_{nm}‘)



1.1 3D-Grid Generation

$$V_{SCHA}(r,\theta',\lambda') = \frac{GM}{r}\sum_{k=0}^{k\,max}\left(\frac{R}{r}\right)^{n(k)+1}\sum_{m=0}^{k}\left(C'_{nm}\cos m\alpha' + S'_{nm}\sin m\alpha'\right)\bar{P}_{n,m}(\cos\theta') = V_{Global}(r,\theta,\lambda)$$

1.2 Computation of $(C_{nm},S_{nm})'$ from (C_{nm},S_{nm}) as Adjustment

$$\mathbf{l} = [V_1 \quad V_2 \quad V_3 \quad V_4 \quad \cdots\cdots \quad V_m]^T$$

$$\mathbf{A} = \begin{bmatrix} \frac{GM}{r_1} & \frac{GM}{r_1}\frac{R}{r_1}P_{10} & \frac{GM}{r_1}\frac{R}{r_1}\cos\alpha_1 P_{11} & \frac{GM}{r_1}\frac{R}{r_1}\sin\alpha_1 P_{10} & & \\ \frac{GM}{r_2} & \frac{GM}{r_2}\frac{R}{r_2}P_{10} & \frac{GM}{r_2}\frac{R}{r_2}\cos\alpha_2 P_{11} & \frac{GM}{r_2}\frac{R}{r_2}\sin\alpha_2 P_{10} & \cdots & \cdots \\ \frac{GM}{r_3} & \frac{GM}{r_3}\frac{R}{r_3}P_{10} & \frac{GM}{r_3}\frac{R}{r_3}\cos\alpha_3 P_{11} & \frac{GM}{r_3}\frac{R}{r_3}\sin\alpha_3 P_{10} & & \\ & \vdots & & & \ddots & \\ & \vdots & & & & \\ & \vdots & & & & \frac{GM}{r_m}\left(\frac{R}{r_m}\right)^n \sin m\alpha_m P_{nn} \end{bmatrix}$$

$$\hat{\mathbf{x}} = [C'_{00} \quad C'_{10} \quad C'_{11} \quad S'_{11} \quad C'_{20} \quad \cdots\cdots \quad S'_{nn}]^T$$

$$\hat{\mathbf{x}} = (\mathbf{A}^T \mathbf{C}_l^{-1} \mathbf{A})^{-1} \mathbf{A}^T \mathbf{C}_l^{-1} \mathbf{l}$$

DFHBF - Extension to SCHA

2. Treatment of Gravity Observations

$$\begin{pmatrix} 0 \\ 0 \\ -g \end{pmatrix} = \mathbf{g}^{LAV}$$

Sensor-Observation at Position P(x,y,z)

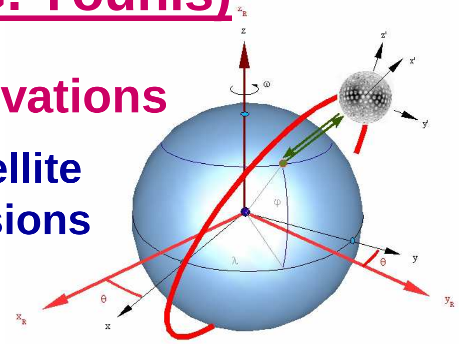
$$\begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix}^{ECF} = R(B,L,\eta,\xi)^{ECF}_{LAV} \cdot \begin{bmatrix} 0 \\ 0 \\ -g \end{bmatrix}^{LAV} \Rightarrow \begin{bmatrix} g_x' \\ g_y' \\ g_z' \end{bmatrix}^{ECF}_{grav} = \begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix}^{ECF} - \left[g^{ECF}_{centrifugal} \right]$$

$$\Rightarrow \begin{bmatrix} g_N \\ g_E \\ g_r \end{bmatrix}^{LGV}_{grav} = R(\varphi,\lambda)^{LGV}_{ECF} \cdot g'^{ECF}_{grav} \qquad \mathbf{g}^{LGV}_{grav} = \left[\frac{1}{r}\cdot\frac{\partial V}{\partial \theta'}, \frac{1}{r\cdot\sin\theta'}\cdot\frac{\partial V}{\partial \lambda}, \frac{\partial V}{\partial r}\right]^T$$

$$\boxed{g^{LGV}_{grav\ r} + v = \sum_{k=0}^{\infty}\left(\frac{a}{r}\right)^{n(k)+1}\frac{(n(k)+1)}{r}\sum_{m=0}^{k}(\bar{C}'_{n(k)),m}\cdot\cos m\lambda' + \bar{S}'_{n(k),m}\cdot\sin m\lambda')\cdot P_{n(k),m}(\cos\theta')}$$

GIPS 2 DFHBF 5.0 – Based Spherical Cap Harmonics SCHA

Observation Equations - DFHBF Version 5 (Dr.-Arbeit G. Younis)



1. SCHA-Coefficients computed from global SH as direct observations

$$C'_{n(k),m}(t) + v = \hat{C}'_{n(k),m} \quad \text{and} \quad S'_{n(k),m}(t) + v = \hat{S}'_{n(k),m}$$

Satellite Missions

2. Gravity Observations rotated to SCHA

$$g^{LGV}_{grav\ r} + v = \sum_{k=0}^{\infty} \left(\frac{a}{r}\right)^{n(k)+1} \frac{(n(k)+1)}{r} \sum_{m=0}^{k} (\bar{C}'_{n(k)),m} \cdot \cos m\lambda' + \bar{S}'_{n(k),m} \cdot \sin m\lambda') \cdot P_{n(k),m}(\cos\theta')$$

3. Vertical Deflections from Zenith Cameras (T = (V+Z) – U)

$$\xi = -\frac{\partial N_{QG}}{\partial B} \cdot \frac{\partial B}{\partial s_N} = -\frac{\partial B}{\partial s} \cdot \frac{\partial N_{QG}}{\partial B} = \frac{-1}{(M+h)} \cdot \frac{1}{\gamma_Q} \cdot \frac{\partial}{\partial B} T_p = \frac{-1}{\gamma_Q \cdot (M+h)} \cdot \left(\frac{\partial T}{\partial B}\right)_P$$

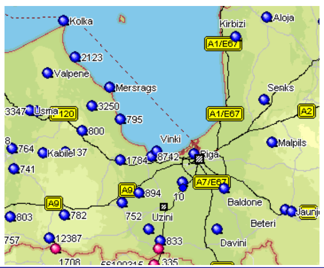
$$\eta = -\frac{\partial L}{\partial s} \cdot \frac{\partial N_{QG}}{\partial L} = \frac{-1}{(N+h) \cdot \cos B} \cdot \frac{1}{\gamma_Q} \cdot \frac{\partial}{\partial L} T_P = \frac{-1}{\gamma_Q \cdot (N+h) \cdot \cos B} \cdot \left(\frac{\partial T}{\partial L}\right)_P$$

Gravity-Meter

Vertical Deflections Zenith-Cameras

4. Fitting Points

$$h - N_{Normal} = N_{QG} = \frac{(V - V_{ref})_P}{\gamma_Q} = \frac{T_P}{\gamma_Q}$$



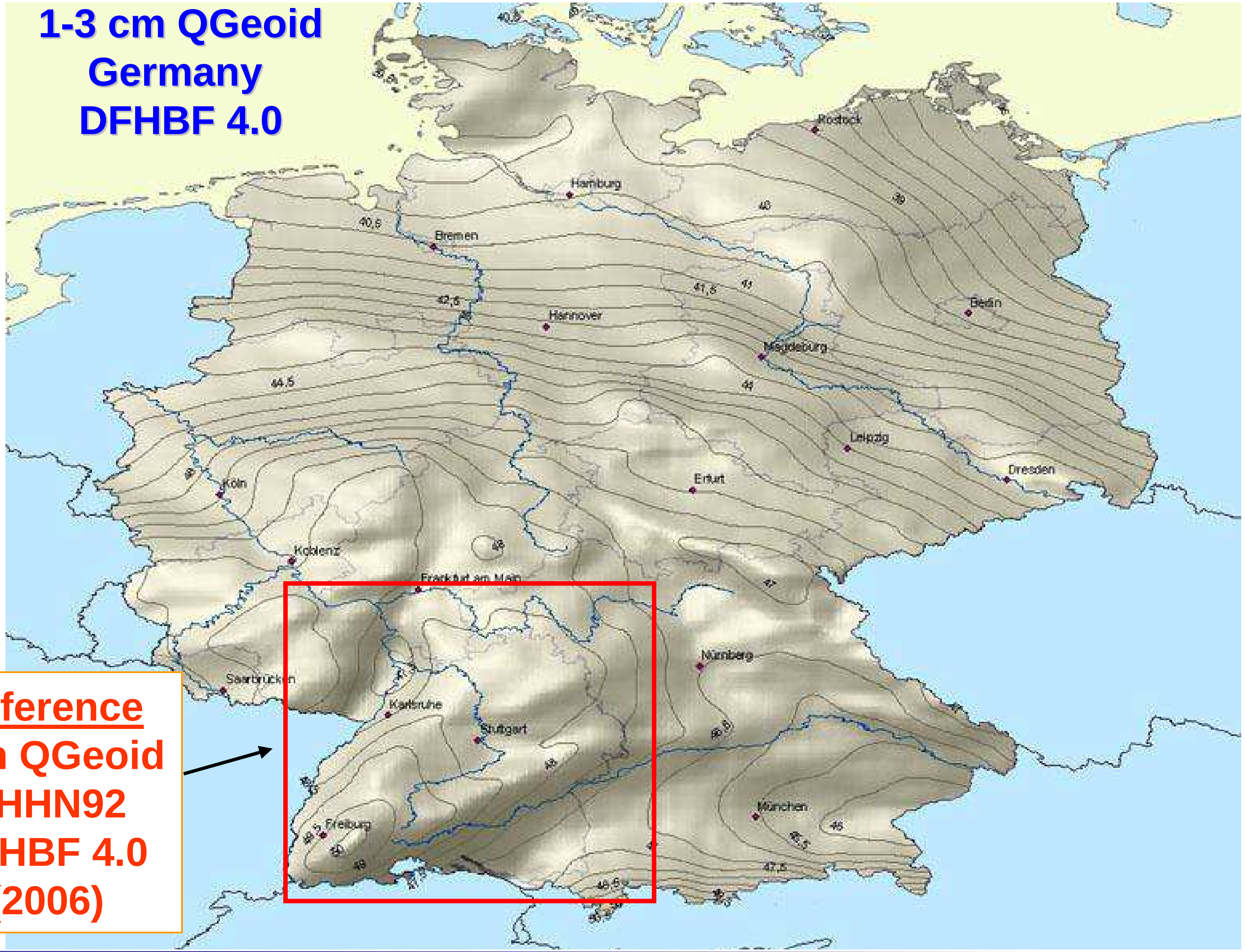
Fitting Points

www.dfhbf.de
www.moldpos.eu

GIPS-2
Height Reference Surface
(QGeoid/Geoid)

QGeoid Computation
Baden-Württemberg
„Integrated Approach DFHBF 5.0“

GIPS – 2 DFHBF 5.0 Integrated Approach
– QGeoid Computation Baden-Württemberg-



Reference
1cm QGeoid
DHHN92
DFHBF 4.0
(2006)

GIPS 2 DFHBF 5.0 Integrated Geodesy Approach – QGeoid Computation Baden Württemberg-

Used Data - Input DFHBF 5.0

- 129 Fitting Points (B,L,h|H)

- 13671 Gravity Values (final)

- EGM2008 Global GPM mapped to SCH

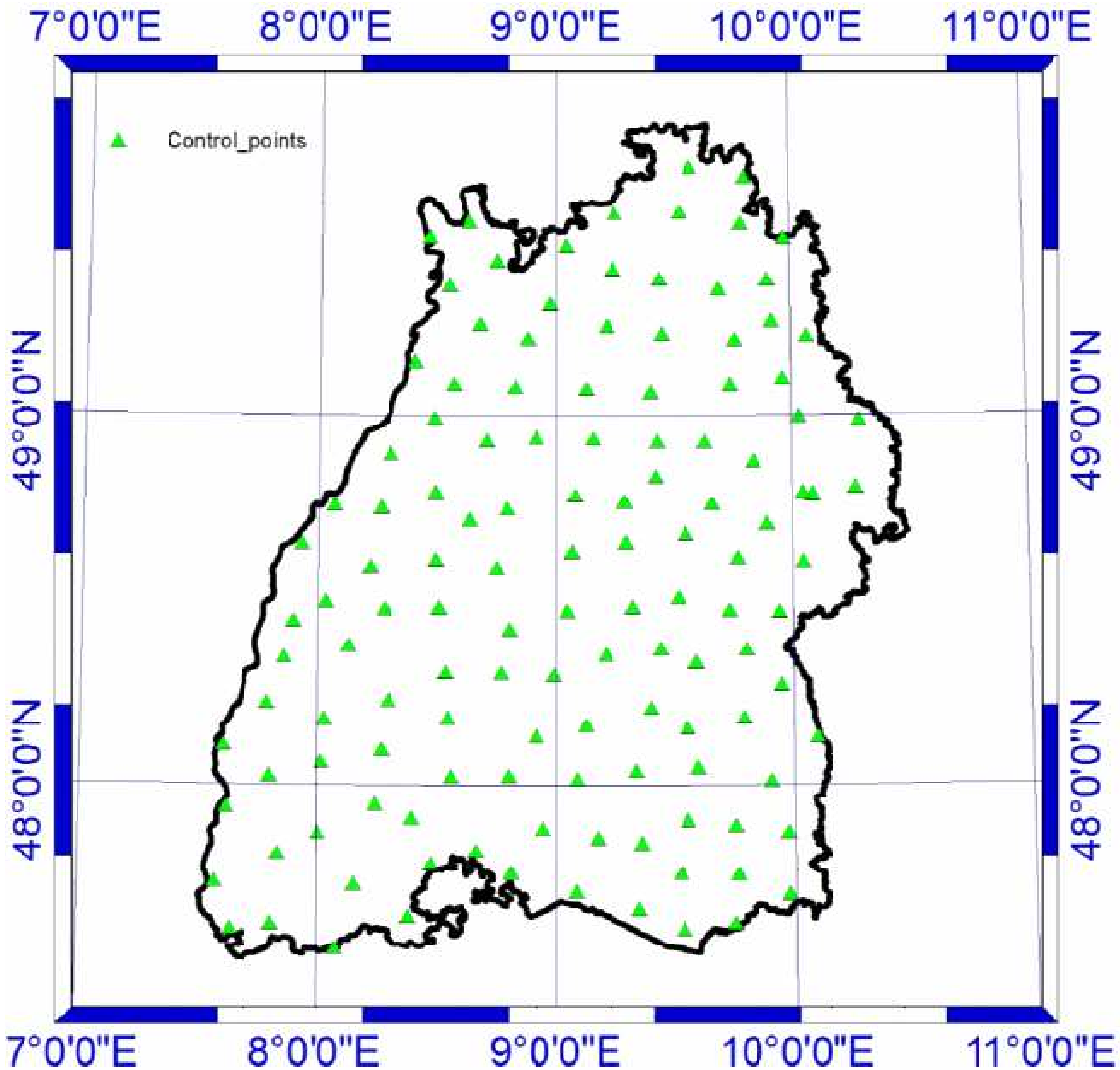
• SCH Degree (m,n(k)) = 300

1. Output DFHBF 5.0)

Fitting Points (h-H)

- Mean residual: 8 mm

- 1 blunder detected by Data-Snooping Test



GIPS 2 DFHBF 5.0 Integrated Geodesy Approach – QGeoid Computation Baden Württemberg-

Used Data - Input DFHBF 5.0

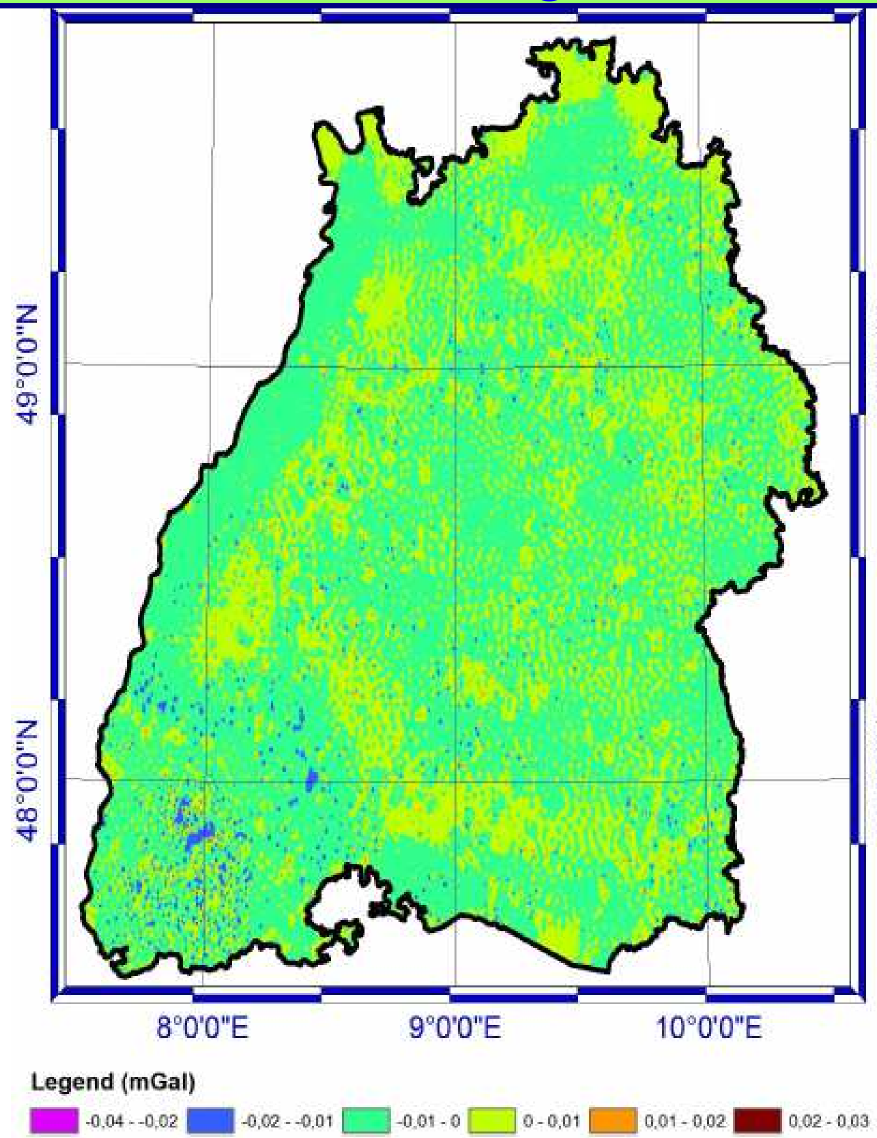
- 129 Fitting Points (B,L,h|H)
- 13671 Gravity Values (final)
- EGM2008 Global GPM mapped to SCH

• SCH Degree (m,n(k)) = 300

2. Output DFHBF 5.0)

Terrestrial Gravity Points g(B,L,h)

- Mean Residual: 0.0032 mGal
- 1031 gravity values eliminated in advance due to wrong georeferencing
- 269 blunders detected in DFHBF V. 5.0 adjustment by datasnooping



GIPS 2 DFHBF 5.0 Integrated Geodesy Approach – QGeoid Computation Baden Württemberg-

Used Data - Input DFHBF 5.0

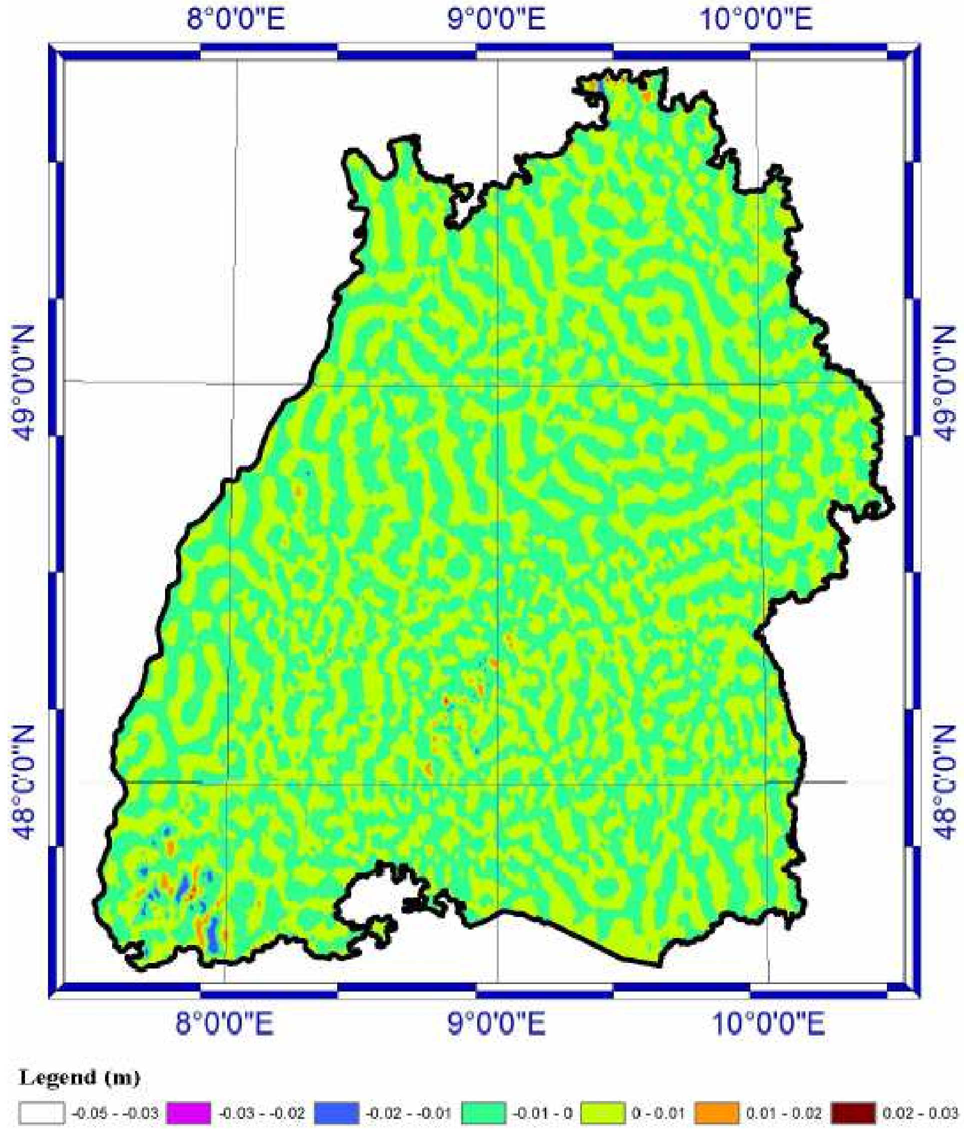
- 129 Fitting Points (B,L,h|H)
- 13671 Gravity Values
- EGM2008 Global GPM mapped to SCH

• SCH Degree (m,n(k)) = 300

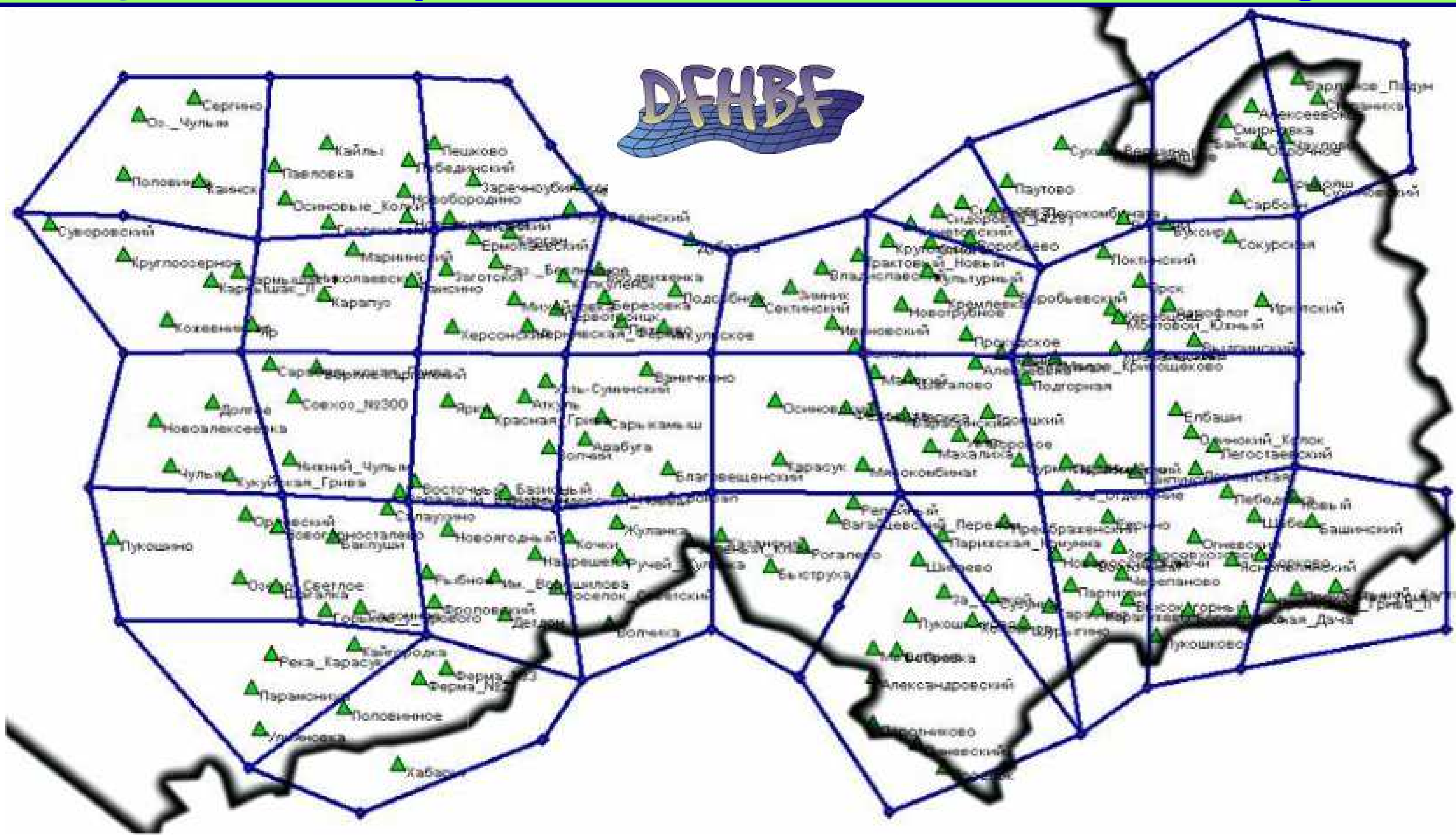
3. Independent Validation

Country-wide Comparison with 1 cm DFHBF 4.0 QGeoid of B.W.

=> Mean Residual: 1.3 cm



GIPS 2 DFHBF 5.0 Integrated Geodesy Approach – QGeoid Computation for SRPOS Novosibirsk Region-



DFHBF-Database QGeoid for SRPOS: DFHBF Version 4.0 or DFHBF Version 5.0

To be computed in 2013 at SSGA

Conclusions

Integrated DFHBF-Approach “DFHBF 5.0” based on Regional Spherical Cap Harmonics Coefficients (Cnm’,Snm’) integrate all relevant original observations
- Geometrical data
- Physcical data and
- Global GPM

DFHBF V 5.0 is worldwide unique and can be used
- QGeoid or Geoid Computation (GIPS-2)
- Gravity Field Modelling
- Integrated Geodetic Networks of all Types

Present results in PhD (12/2012) of MSc Ghadi Younis
DAAD funded PhD candidate in the DFHBF RaD project (www.dfhbf.de)

DFHBF 5.0 formulated as Gauss-Markov-Model (GMM)
- Stat.Testing of all origina observations, e.g. gravity!
  (... impossible in e.g. Stokes-based approaches)
- Open for Optimization
- Scalable to any Size of Area

Further Research
- Vertical Deflections from Zenith Cameras
- Optimum Design for the Use of Gravity and Zenith Camera Data


THANK
YOU
THANK