Geodetic Infrastructures for GNSS-Positioning-Services (GIPS)

- The Motor for Prospective and Economy Relevant Developments in Public, RaD and Industry Sector at Brazil -

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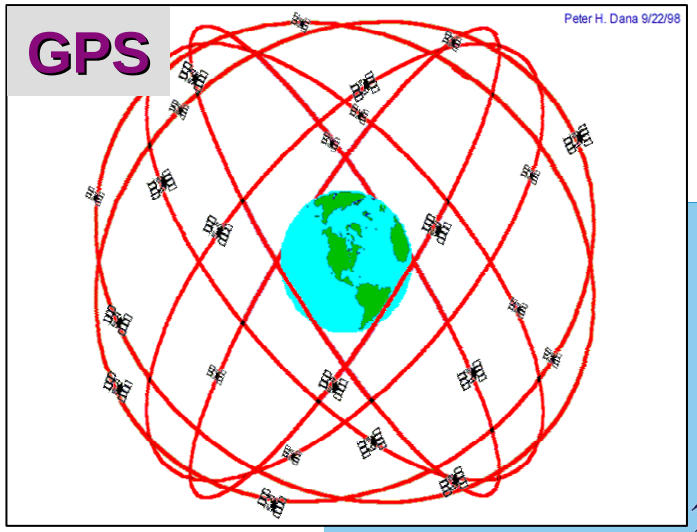
www.goca.info, www.monika.ag, www.dfhbf.de, www.moldpos.eu, www.geozilla.de, www.galileo-bw.de, www.navka.de

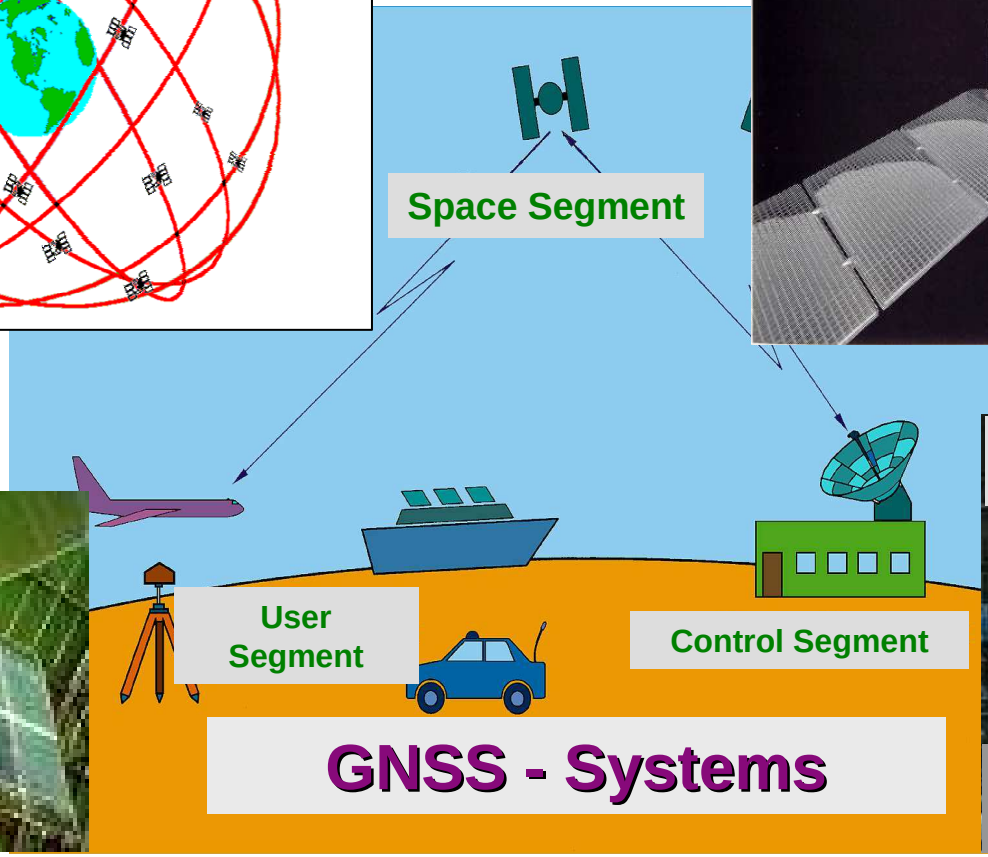
GNSS Positioning Services

GNSS for Global Positioning in ITRF/ECEF Frames

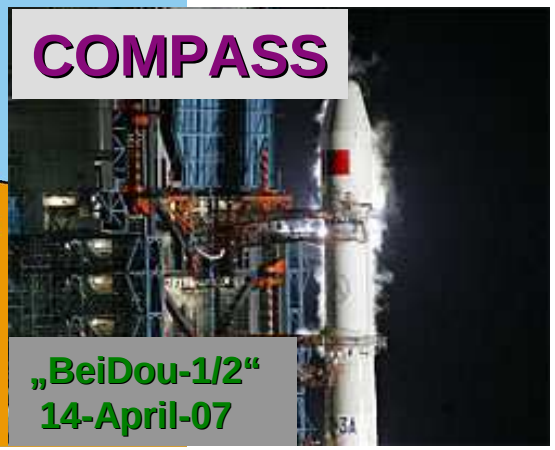


< 50 (2010)

105! (2014)



GLONASS

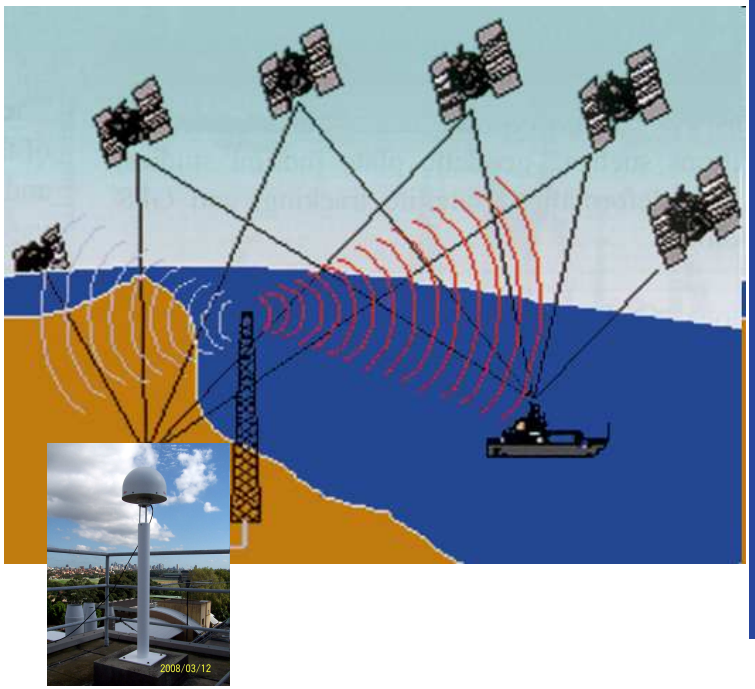


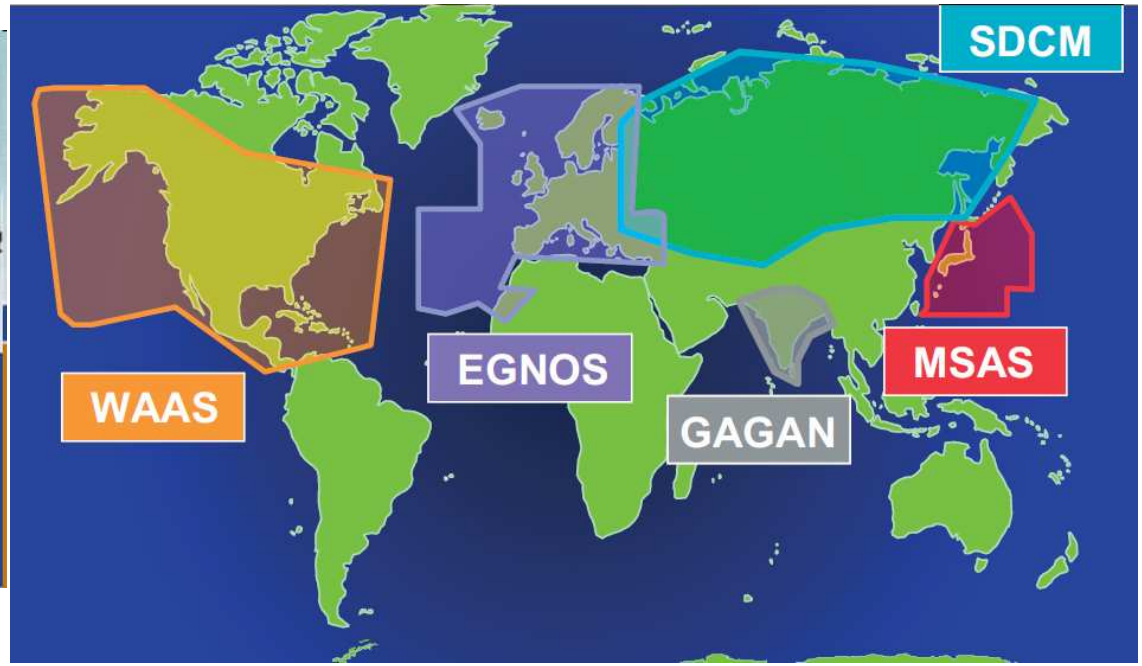
Space/Satellite Based Augmentation Systems (SBAS)

DNGSS-Corrections. Standard RTCA and RTCM

GNSS-Reference Stations
=> RTCM / RTCA Corrections
- Satellite Communication
- Internet Communication via GSM

Existing WAAS
Satellite or Mobile Internet (NTRIP)
RTCM or RTCA Corrections
Accuracy: 1 m

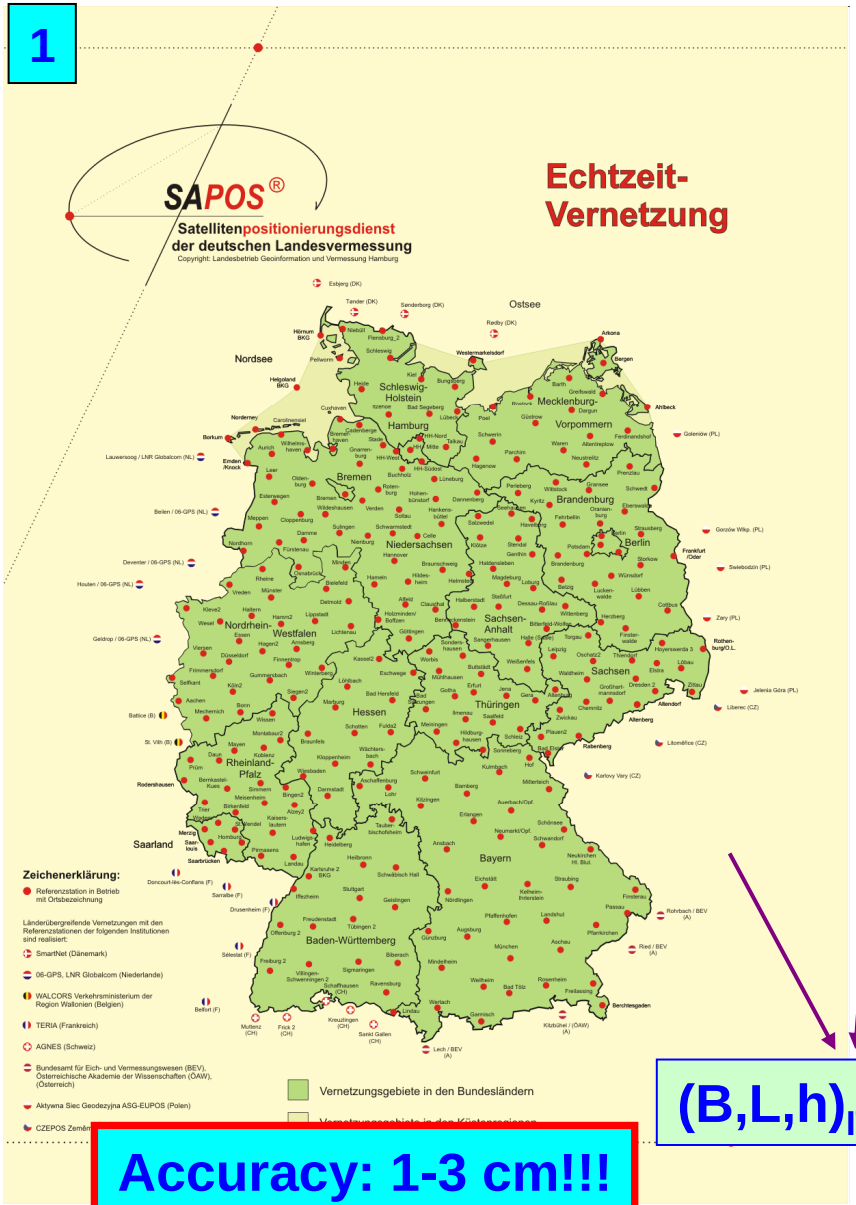




… WAAS (USA),CNSS (China),GAGAN/IRNSS (India),QZSS/MSAS (Japan),SDCM (Russia)

SITUATION in GERMANY

1



2

3

4

SmartNet EUROPE
powered by Leica Geosystems

AXNET

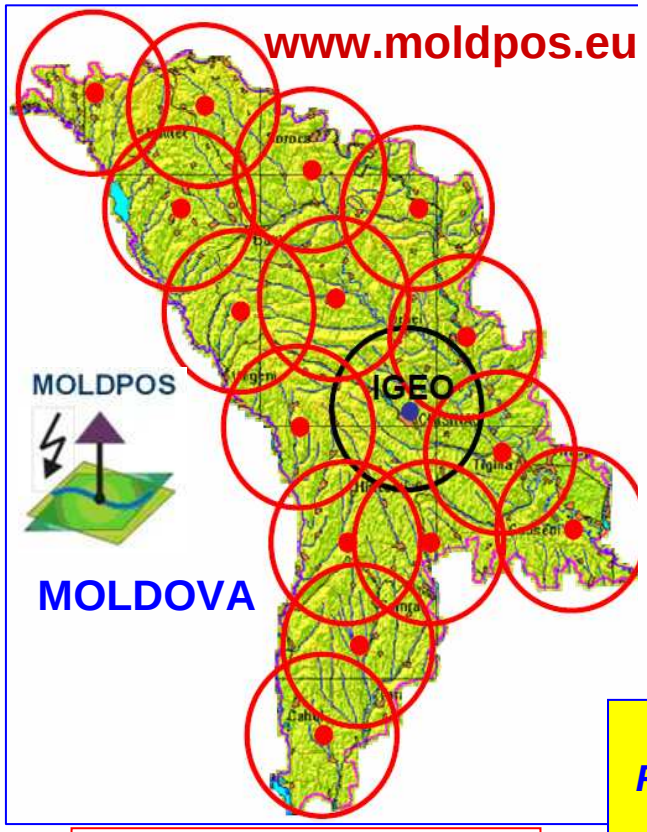
TRIMBLE
VRSNOW

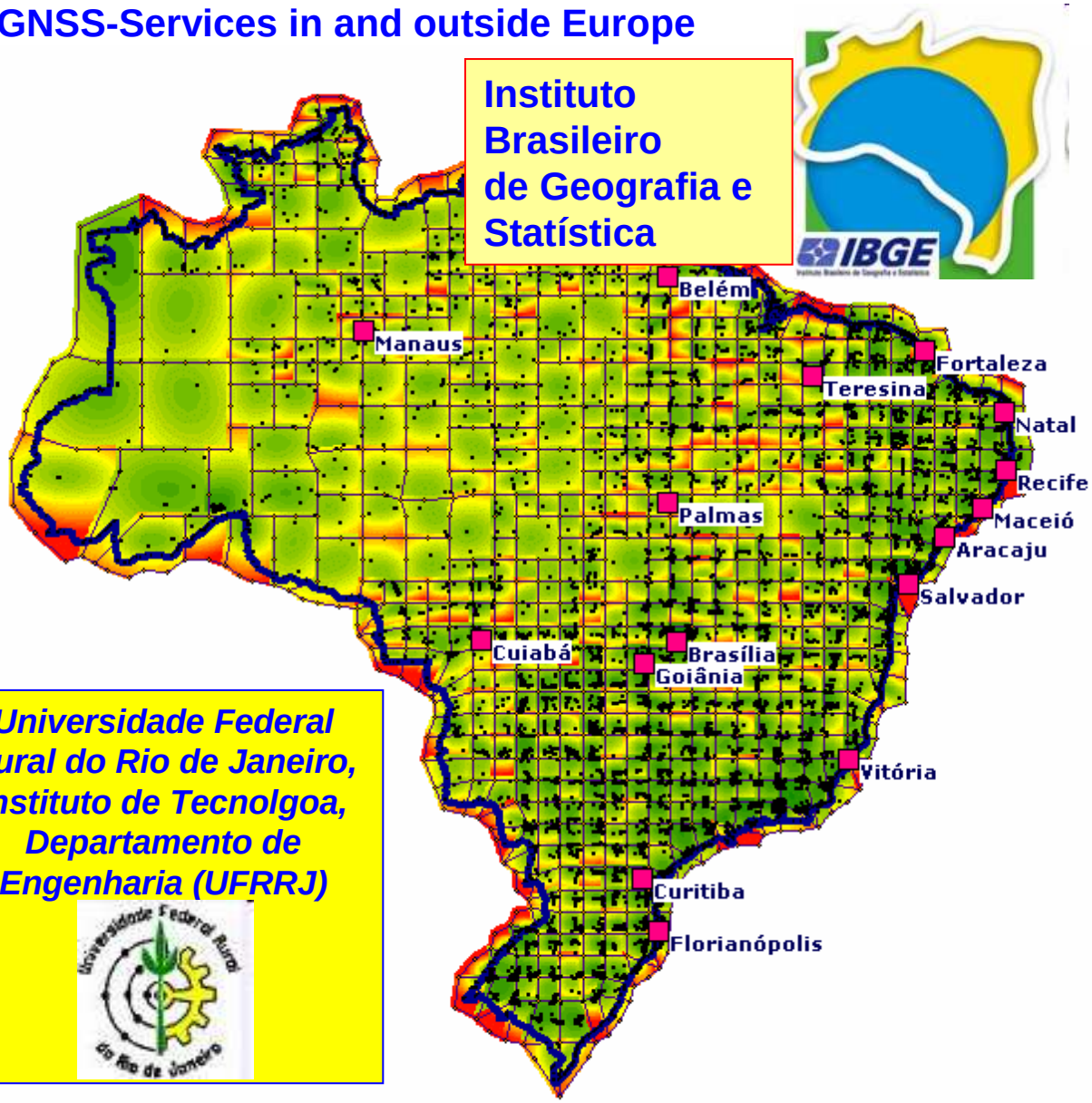
$(B,L,h)_{ITRF\text{-}related}$

Accuracy: 1-3 cm!!!

Precise Differential ("cm") DGNSS

Regional DGNSS-Services in and outside Europe





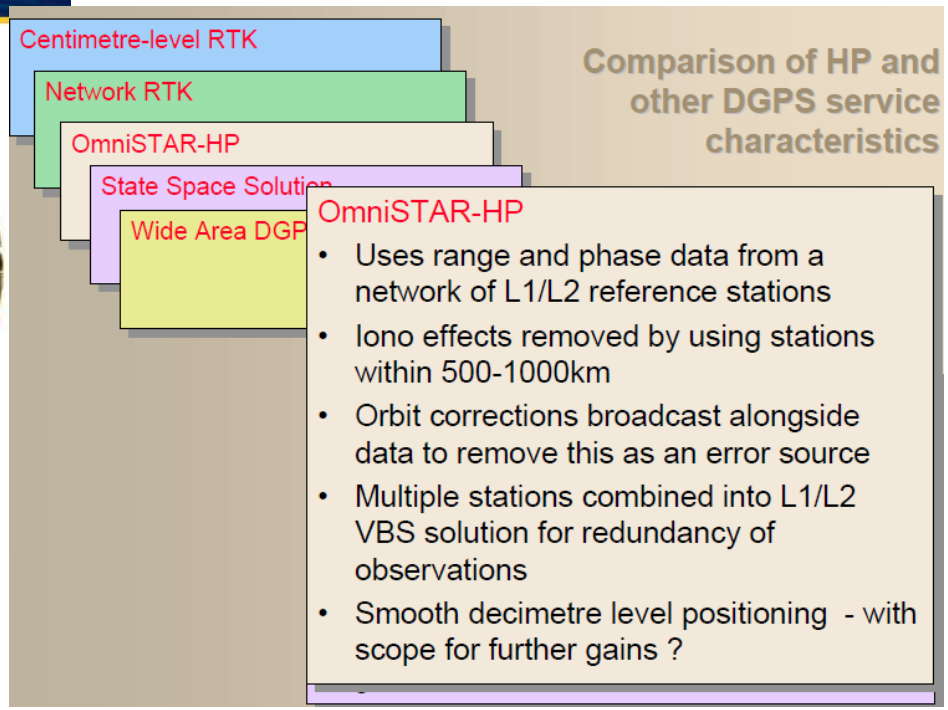
Instituto Brasileiro de Geografia e Statística

Universidade Federal Rural do Rio de Janeiro, Instituto de Tecnolgoa, Departamento de Engenharia (UFRRJ)

"cm"
⇔
!Code- and Phase-Corrections !
RTCM 3.1

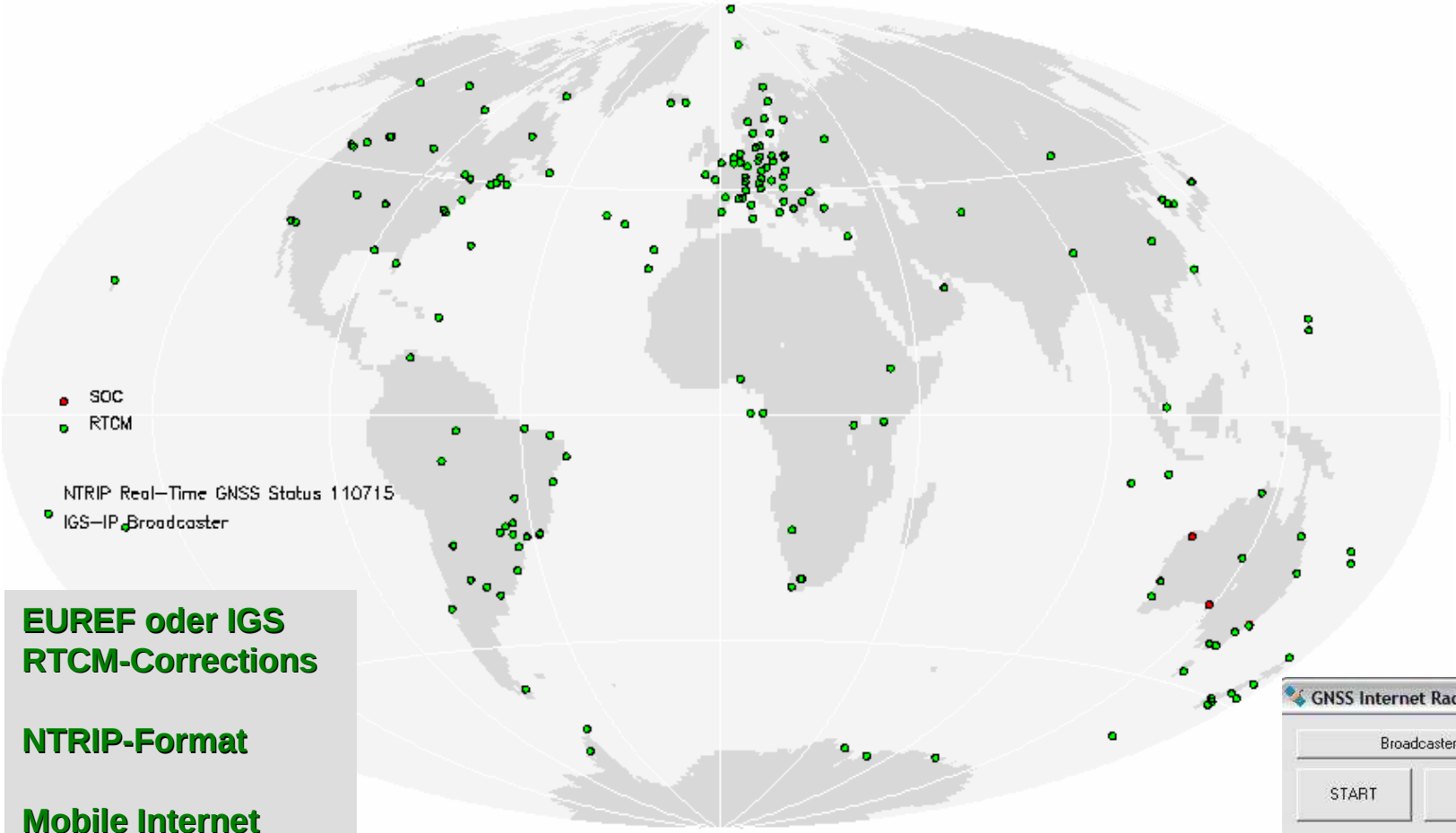
Augmentation Systems (SBAS, GSM/Internet-based)

.... with RTCM-Corrections for Precise Positioning and Navigation



- Networked RTCM Corrections
- Inhomogenously distributed GNSS-Reference Stations, like e.g. Brasil

Alternative to Commercial or State Regional GNSS-Services
EUREF-IP or IGS-IP and RTCM InterNet-Service (NTRIP)



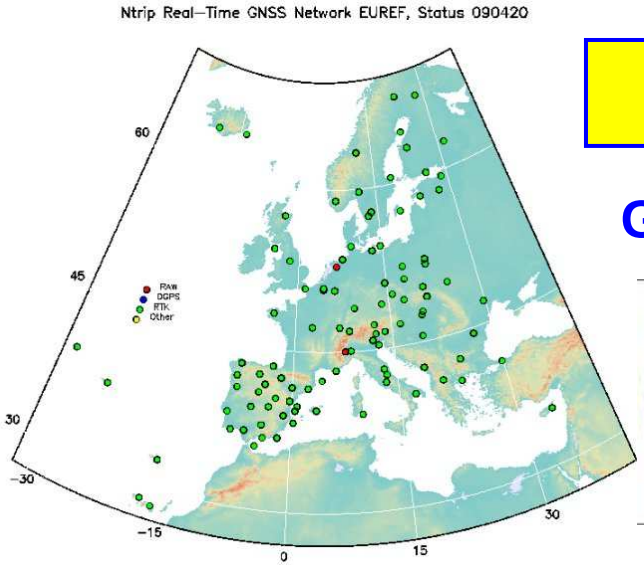
EUREF oder IGS RTCM-Corrections

NTRIP-Format

Mobile Internet (USB-Stick) and InterNet GNSS-Radio

GNSS-Internet Radio

EUREF-IP or IGS-IP InterNet-Service (NTRIP)



GNSS-Internet Radio

EUREF oder IGS RTCM-Corrections

NTRIP-Format

Mobile Internet (USB-Stick) and InterNet GNSS-Radio

JOHN DEERE

Hochschule Karlsruhe Technik und Wirtschaft
UNIVERSITY OF APPLIED SCIENCES

Ort	Basislinie [km]	Beobachtungsdauer [min]	EUREF IP		John Deere MRTK	
			Nord [m]	Ost [m]	Nord [m]	Ost [m]
Karlsruhe	ca. 20km	15 Minuten	0,0513	0,0604	0,0072	0,0055
Dresden	ca. 430km	15 Minuten	0,1657	0,2758	0,0088	0,0062
Warnemünde	ca. 610km	15 Minuten	0,1033	0,0742	0,0098	0,0054

Geodetic Infrastructures for GNSS Positioning Services (GIPS)

4 Components (GIPS 1,2,3,4)

- **GIPS 1,2 before Installation of a GNSS Service**
  - Infrastructure for Spatial Information (Basics)
  E.g. Europe: „INSPIRE (Infrastructure for Spatial Information in Europe)
  see inspire.jrc.ec.europa.eu
  Necessary for „daily GNSS-Positioning“ of the users of a GNSS-Positioning Service and for GIS purposes – Ready for Brasil!!!

- **GIPS 3,4 for running a GNSS Positioning Service (Provider and for special taks e.g. Geomonitoring)**

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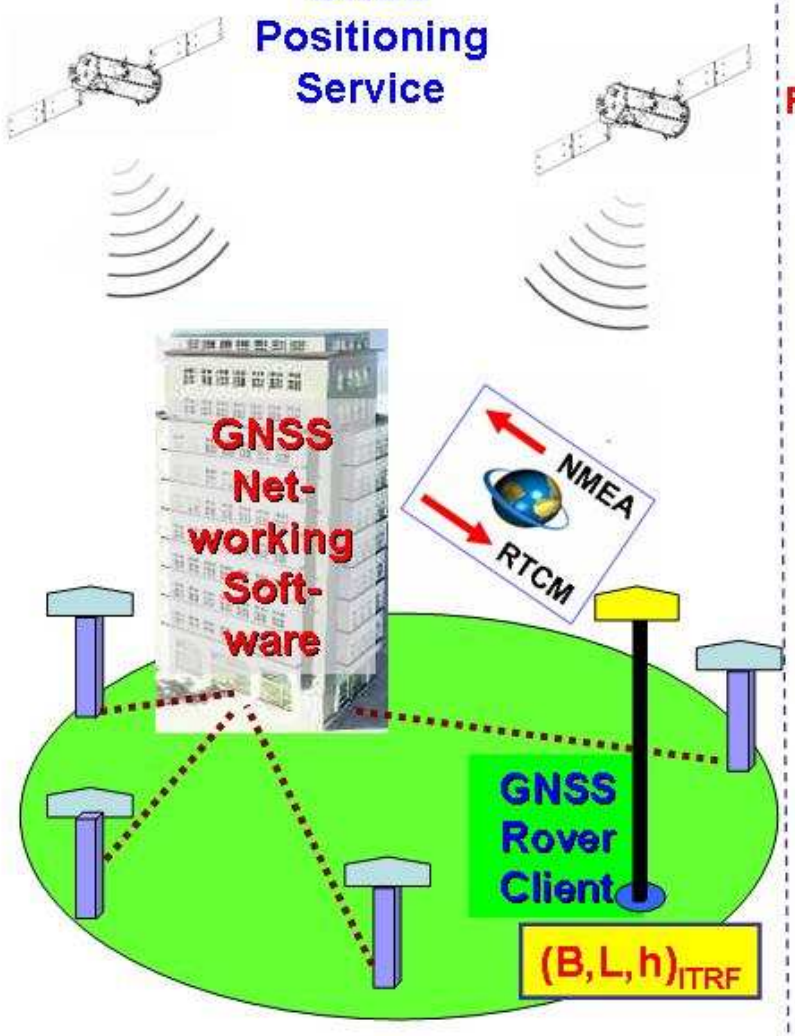
http://www.geozilla.de/files/Geodaetische_Infrastrukturen_fuer_GNSS-Dienste_%28GIPS%29.Jaeger..pdf

Geodetic Infrastructures for GNSS-Positioning Services (GIPS)

GNSS Positioning Service



e.g www.moldpos.eu

Geodetic Transformation Infrastructure

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

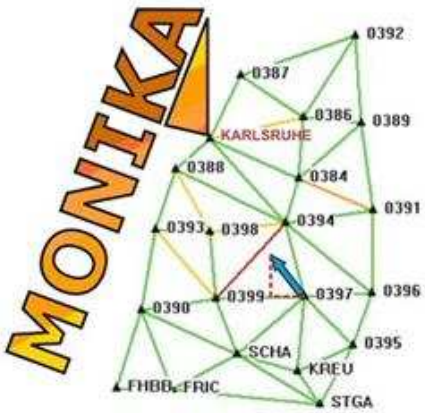
GIPS-2: Height Reference Surface and Transition (h→H). Trafo-3

www.dfhbf.de

www.geozilla.de

GIPS-3: RTCM Transformation Messages.Trafo-4

GIPS 4: Geomonitoring-Infrastructure



Coordinate-Integrity

www.monika.ag

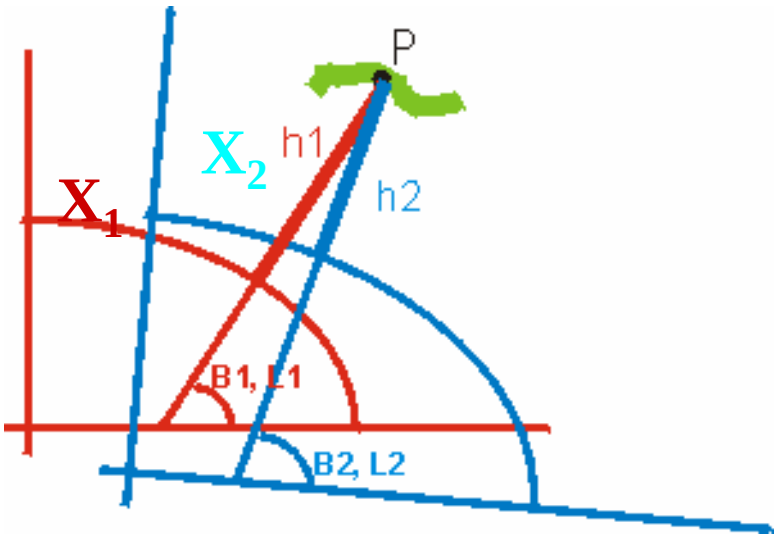
Georisk Mitigation

www.goca.info

GIPS-1
Horizontal Positioning

GIPS-1: Horizontal Datum-Trafo from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ - Karlsruhe Approach (COPAG) and Trafo-Database Computation

„All-over-the-World“ Problem



$$x = (N+h)\cdot\cos B\cdot\cos L$$

$$y = (N+h)\cdot\sin B\cdot\sin L$$

$$z = \left(\frac{b^2}{a^2}\cdot N + h\right)\cdot\sin B$$

mit $N(B) =$ Normalkrümmungshalbmesser

3D Similariy Transformation

$$X_2 = m\cdot R\cdot X_1 + t \;, \text{mit } X_1 = \begin{bmatrix} x_1(B_1,L_1,h_1) \\ y_1(B_1,L_1,h_1) \\ z_1(B_1,L_1,h_1) \end{bmatrix} \text{ und } X_2 = \begin{bmatrix} x_2(B_2,L_2,h_2) \\ y_2(B_2,L_2,h_2) \\ z_2(B_2,L_2,h_2) \end{bmatrix}$$

Rotation Matrix
3 Rotations

Non-Linear Realation (see above)

GIPS-1 Horizontal Datum Transition from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ – Karlsruhe Approach (COPAG) and Trafo-Database-Compution

Solution of the horizontal Transformation Problem

$$\left(\begin{bmatrix} B \\ L \\ h \end{bmatrix}_2 - \begin{bmatrix} \Delta B_{(a,b)_1,(a,b)_2} \\ \Delta L_{(a,b)_1,(a,b)_2} \\ \Delta h_{(a,b)_1,(a,b)_2} \end{bmatrix} - \begin{bmatrix} B \\ L \\ h \end{bmatrix}_1\right)_i + \begin{bmatrix} v_B \\ v_L \\ v_h \end{bmatrix}_i = [\text{Moldenski}]_{(B,L,h)_1,i} \cdot \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \Delta s \\ t_x \\ t_y \\ t_z \end{bmatrix}$$

3D Similarity ransformation Related to (B,L,h)

1D-,2D-,3D-

Identical Points

WTRANS
www.geozilla.de

$$\begin{bmatrix} -\sin(L)\cdot\frac{a\cdot W+h}{M+h} & \cos(L)\cdot\frac{a\cdot W+h}{M+h} & 0 & \frac{-\sin(B)\cdot\cos(B)\cdot N\cdot e^2}{M+h} & \frac{-\sin(B)\cdot\cos(L)}{M+h} & \frac{-\sin(B)\cdot\sin(L)}{M+h} & \frac{\cos(B)}{M+h} \\ \frac{\sin(B)\cdot\cos(L)\cdot(N\cdot(1-e^2)+h)}{(N+h)\cdot\cos(B)} & \frac{\sin(B)\cdot\sin(L)\cdot(N\cdot(1-e^2)+h)}{(N+h)\cdot\cos(B)} & -1 & 0 & \frac{-\sin(L)}{(N+h)\cdot\cos(B)} & \frac{\cos(L)}{(N+h)\cdot\cos(B)} & 0 \\ -N\cdot e^2\cdot\sin(B)\cdot\cos(B)\cdot\sin(L) & N\cdot e^2\cdot\sin(B)\cdot\cos(B)\cdot\cos(L) & 0 & h+a\cdot W & \cos(B)\cdot\cos(L) & \cos(B)\cdot\sin(L) & \sin(B) \end{bmatrix}$$

$$W = \frac{a}{N} = \sqrt{1-e^2\cdot\sin^2 B} \qquad e^2 = \frac{a^2-b^2}{a^2}$$

GIPS-1: Horizontal Datum-Trafo from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ - Karlsruhe Approach (COPAG) and Trafo-Database Computation

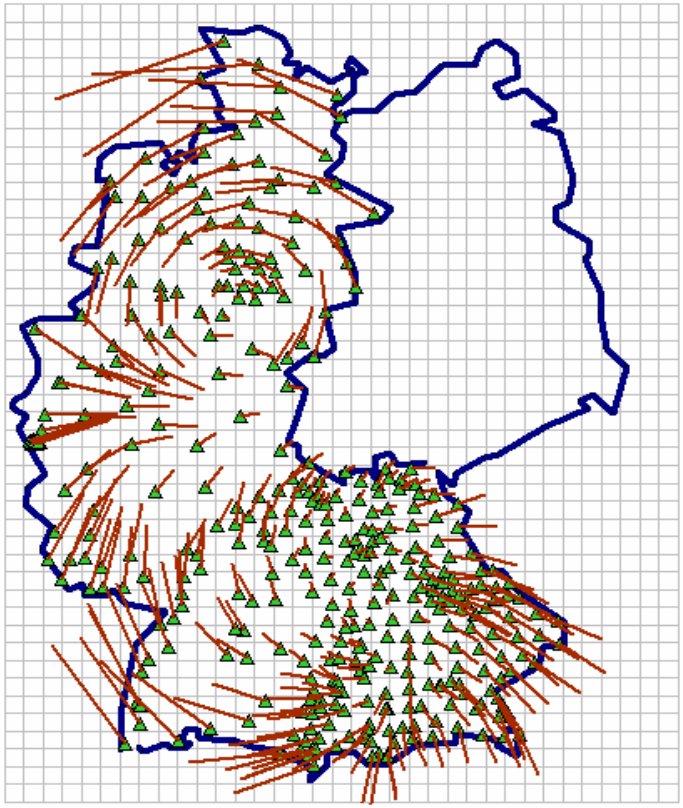
ITRF / ETRF89 - Datum

GIS Transition to ITRFGNSS consistent frame

Strict and General TRAFO

GNSS-practice

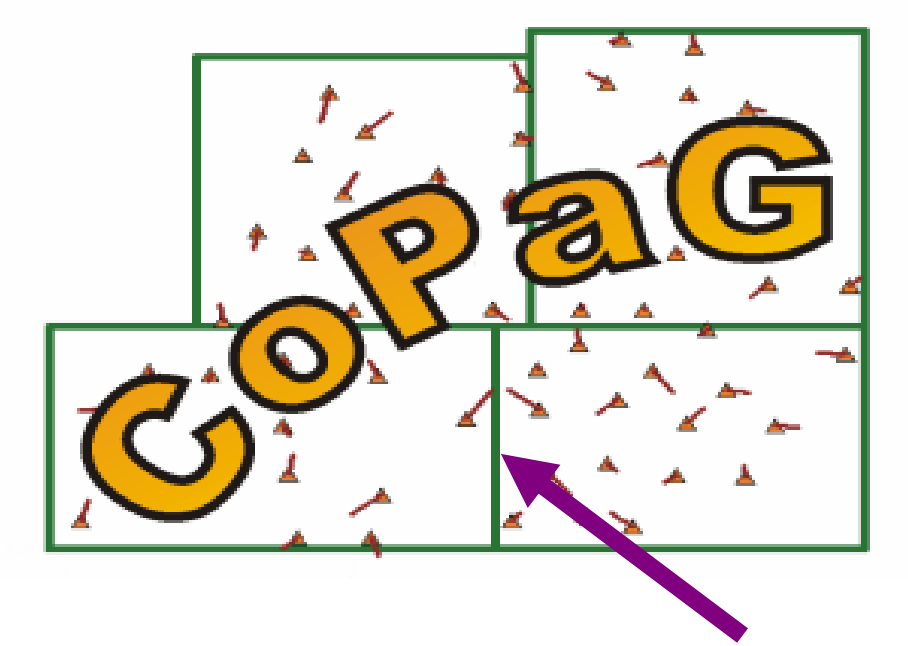
Long waved deflections - „Weak shapes“



Old Classical Systems

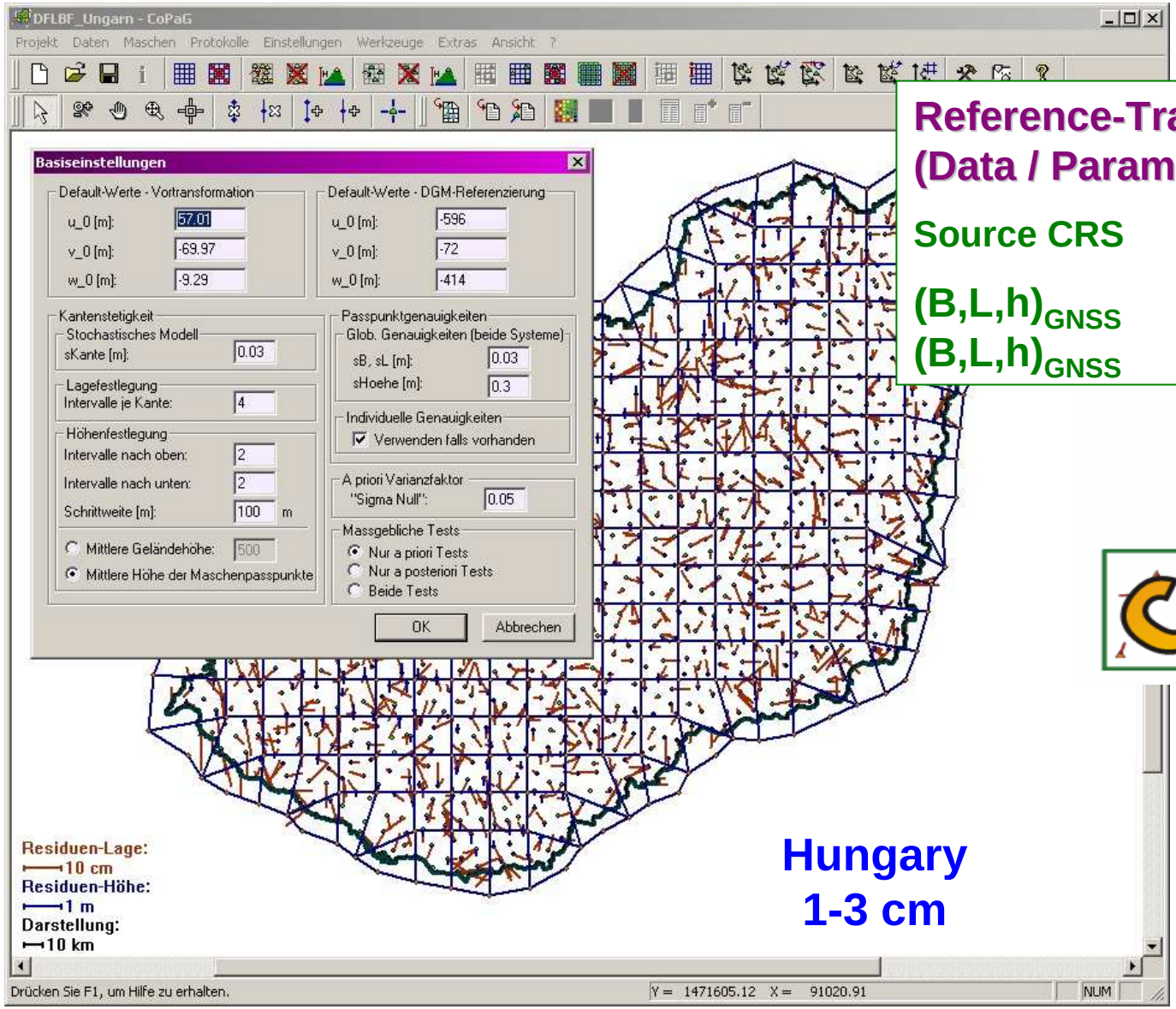
GIPS-1: Horizontal Datum-Trafo $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ Karlsruhe Approach (COPAG) and Database Computation

COPAG = Continuously Patched Georeferencing



Continuity along the Mesh Borders!

GIPS-1: Horizontal Datum-Trafo $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ Karlsruhe Approach (COPAG) and Database Computation



Hungary
1-3 cm

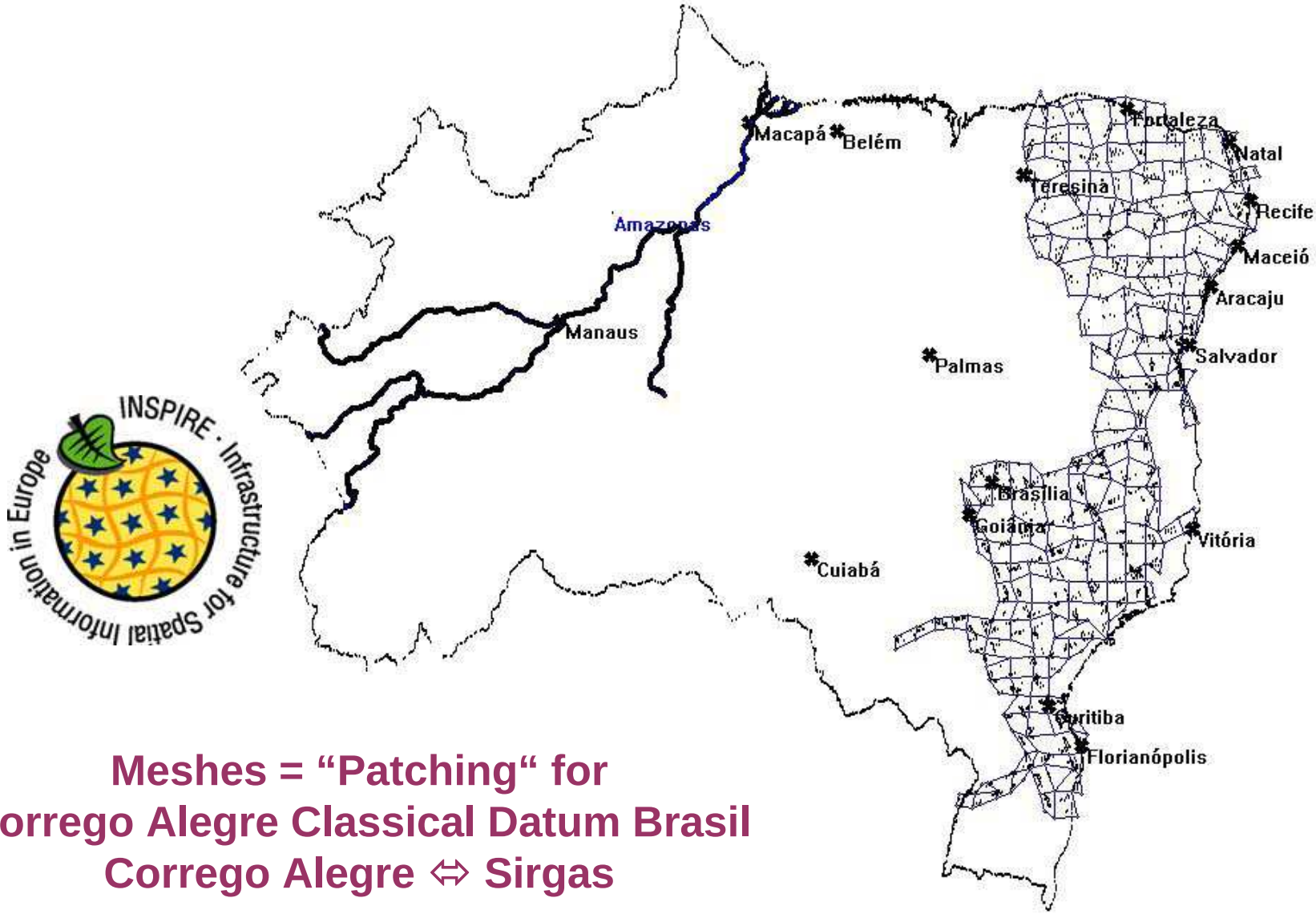
Reference-Transformation (Data / Parameters / Algorithms)

Source CRS		Target CRS
$(B,L,h)_{GNSS}$	=>	$(B,L)_{Classical}$
$(B,L,h)_{GNSS}$	=>	$(B,L,H)_{Classical}$

DFLBF_DB
Transformation Parameters & Residuals

GIPS-1: Horizontal Datum-Trafo $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ Karlsruhe Approach (COPAG) and Database Computation

Brasil

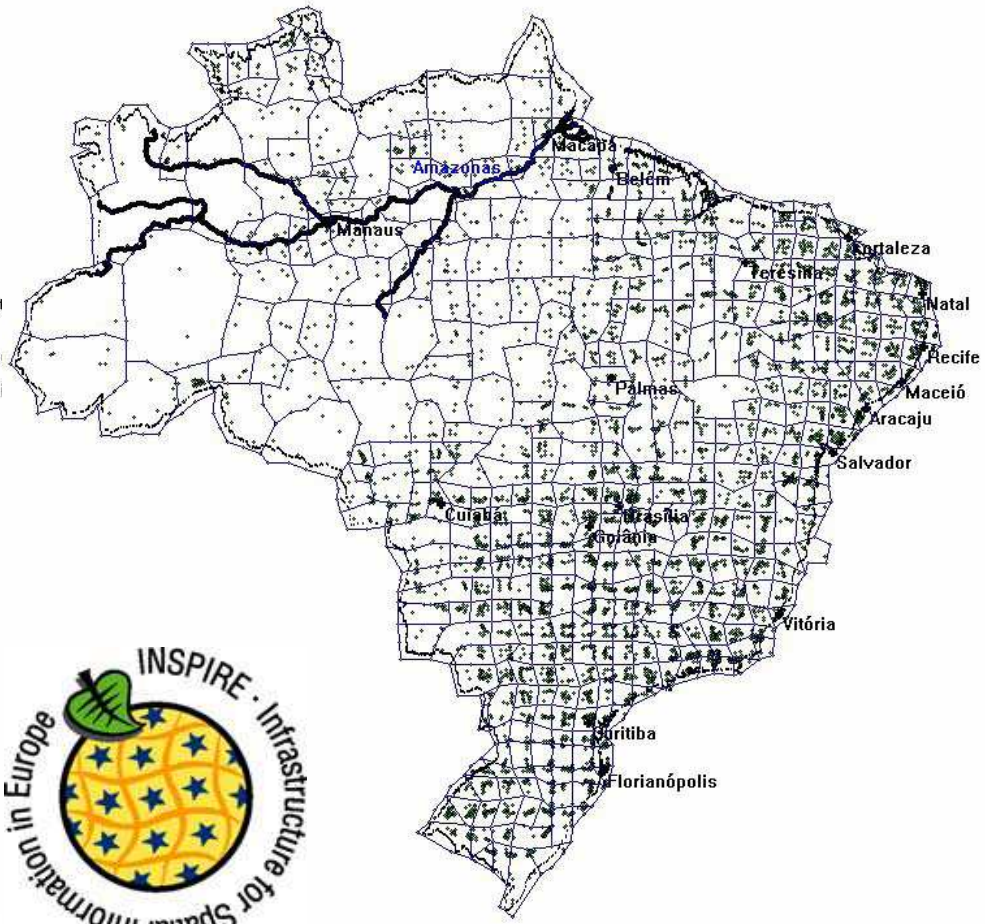


Meshes = "Patching" for
Corrego Alegre Classical Datum Brasil
Corrego Alegre ⇔ Sirgas

GIPS-1: Horizontal Datum-Trafo $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ Karlsruhe Approach (COPAG) and Database Computation

DFLBF/COPAG Databases for Brazil Meshes SAD69 ⇔ SIRGAS

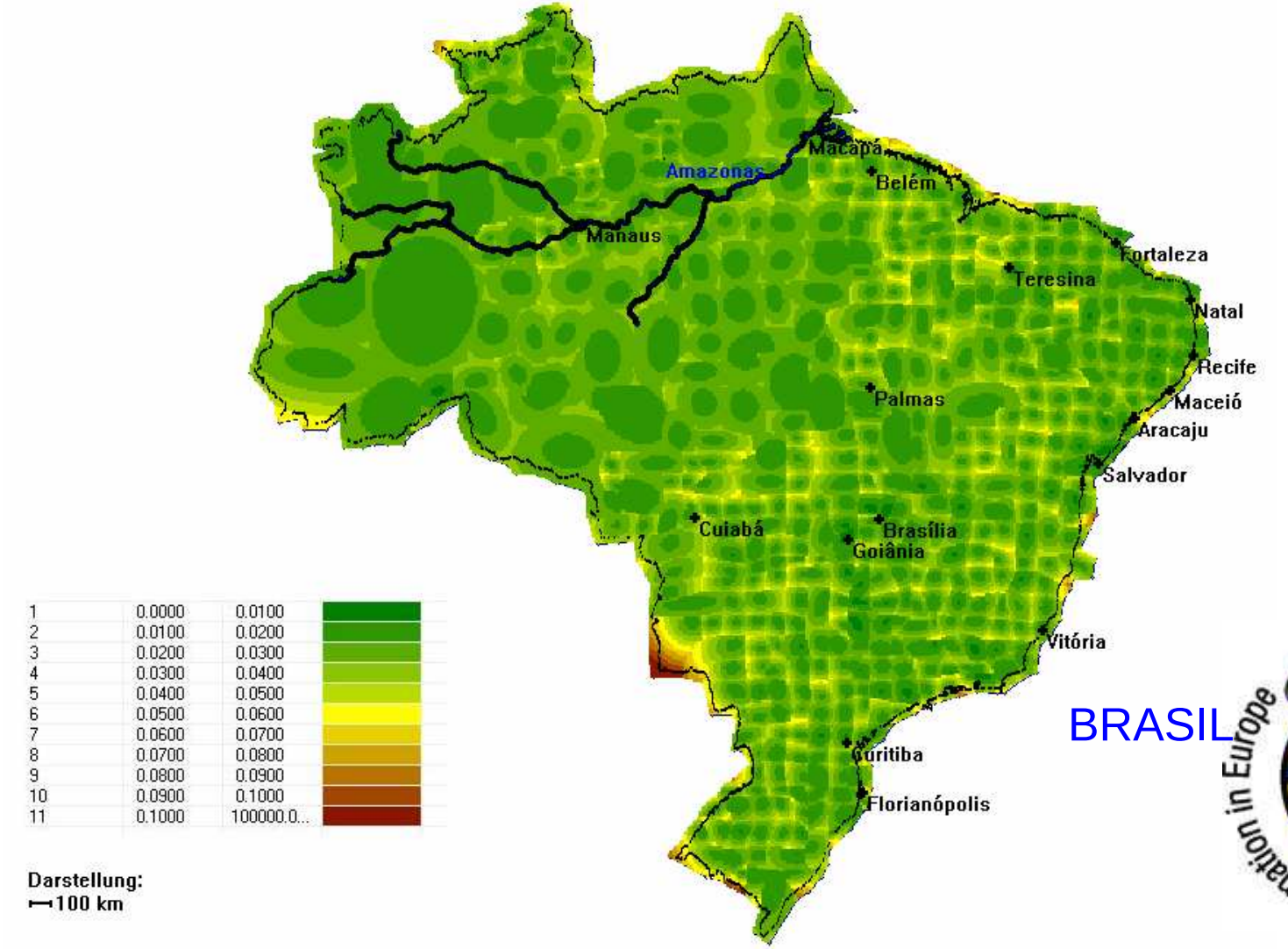
DFLBF/COPAG Databases for Brazil Meshes SAD96 ⇔ SIRGAS



Brazil

GIPS-1: Horizontal Datum-Trafo $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ Karlsruhe Approach (COPAG) and Database Computation

Accuracy of DFLBF/COPAG Databases for Brazil SAD99 ⇔ SIRGAS

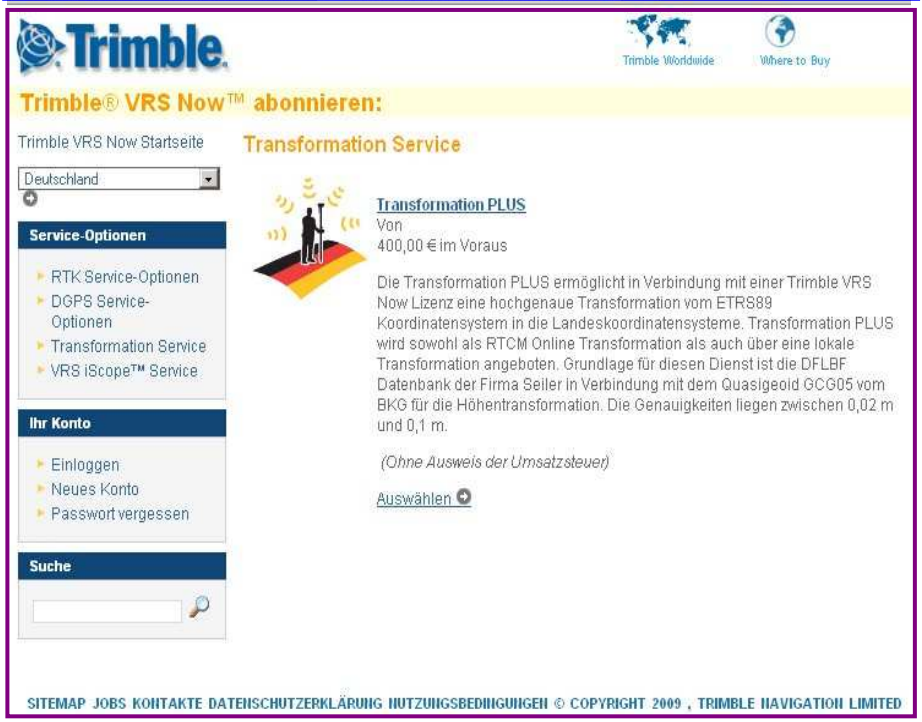


BRASIL

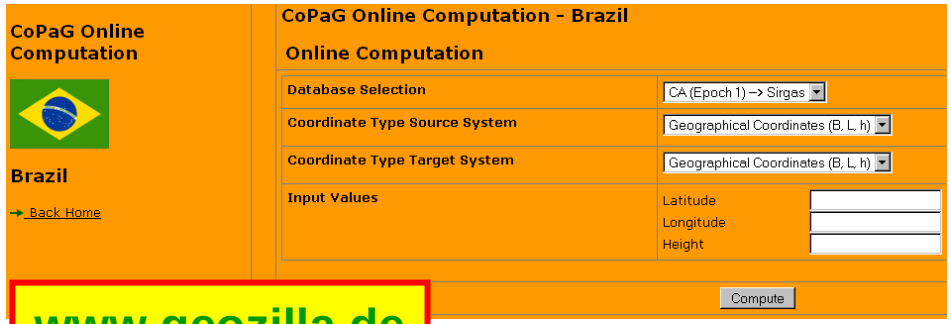
GIPS-1: Horizontal Datum-Trafo $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$ Karlsruhe Approach (COPAG) and Database Computation

GIPS-1.1: Horizontal Datum Transition from $(B,L)_{GNSS,ITRF}$ to $(B,L)_{Classical}$ *DFLBF-Databases.* Use in GNSS-Services on controllers and via RTCM

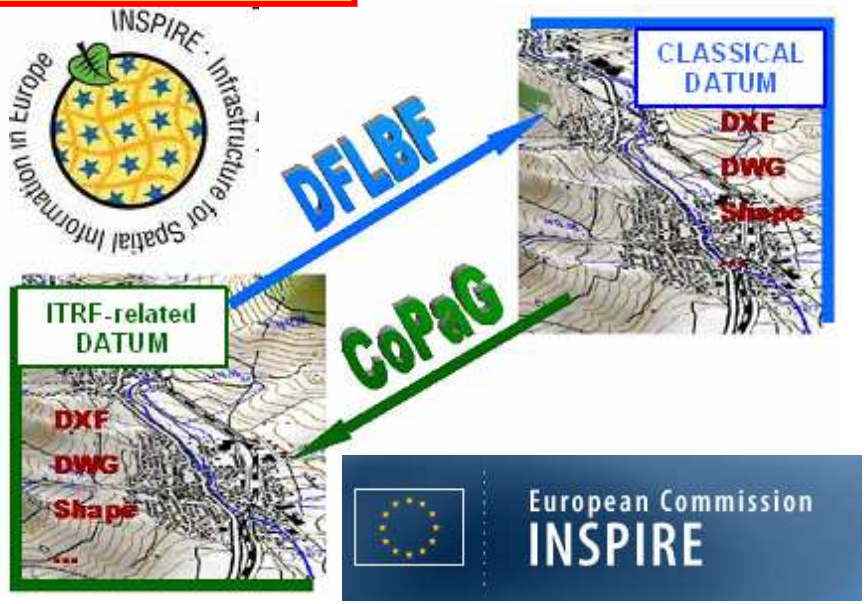
SmartNet EUROPE powered by Leica Geosystems



GIPS-1.2 :Horizontal Datum Transition from $(B,L)_{Classical}$ to $(B,L)_{GNSS,ITRF}$ *COPAG-Databases* for GIS

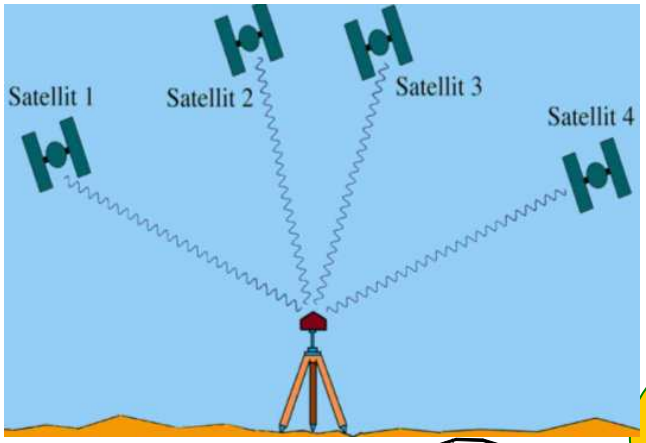


www.geozilla.de



GIPS-2
GNSS-Heighting

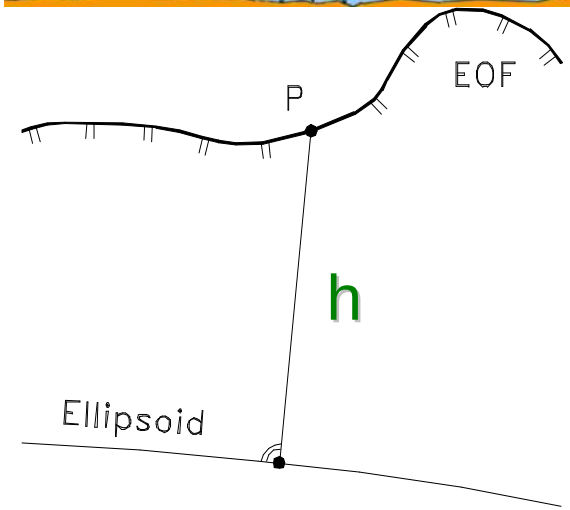
GIPS-2: Height Reference Surface (HRS) Qgeoid/Geoid (N) for Transition $h_{GNSS,ITRF}$ to Physical Heights H = h-N - Karlsruhe Approach (DFHBF) and DFHBF-DBComputation



+/- 70 m

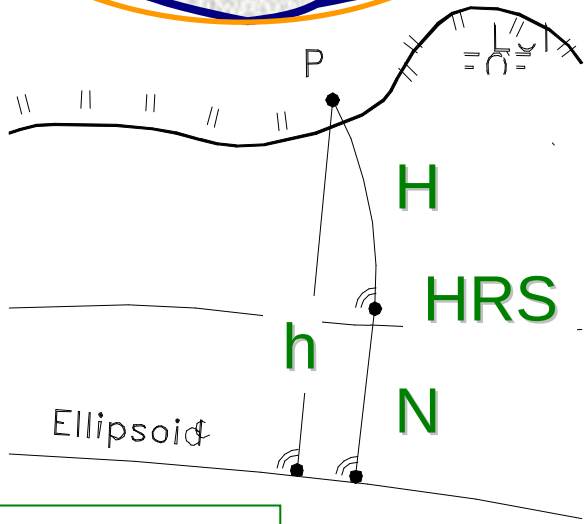
Geoid (HBF)

Ellipsoid



GNSS Heighting

„H from h- GNSS“



$$H = h - N(B,L,h)$$

www.dfhbf.de

Reference-Transformation

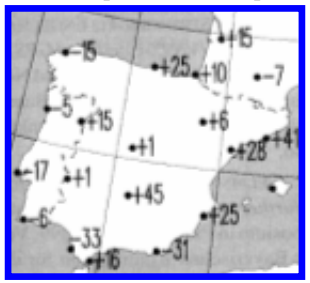
Source CRS Target CRS

$(B,L,h)_{GNSS}$ => N

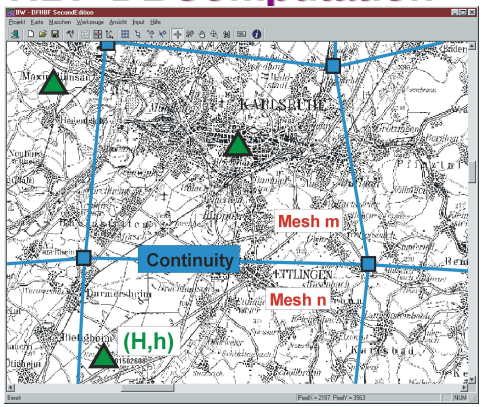
GIPS-2: Height Reference Surface (HRS) Qgeoid/Geoid (N) for Transition $h_{GNSS,ITRF}$ to Physical Heights H = h-N - Karlsruhe Approach (DFHBF) and DFHBF-DBComputation

$$h_{GNSS} + v = H + \mathbf{f}^T \cdot \mathbf{p} - h_{GPS} \cdot \Delta m$$

$$H + v = H$$



Identica Points



„Patching“

$$N_G{}^{j} + v^j = \mathbf{f}^T \cdot \mathbf{p} + \partial N_G(\mathbf{d}^j)$$

$$\frac{a}{4 \cdot \pi \cdot \gamma(B)} \iint_{\sigma} \Delta \mathbf{g} \cdot S(\psi) d\sigma$$

-Existing nonfitted Qgeoid
-/ Geoid GridsGrids

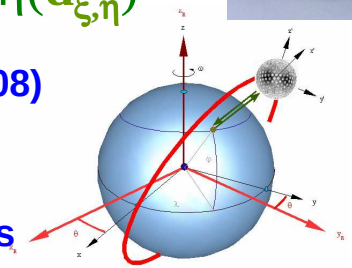
$$\xi^j + v = -\mathbf{f}_B{}^T / M(B) \cdot \mathbf{p} + \partial \xi (\mathbf{d}_{\xi,\eta})^j$$

$$\eta^j + v = -\mathbf{f}_L{}^T / (N(B) \cdot \cos(B)) \cdot \mathbf{p} + \partial \eta (\mathbf{d}_{\xi,\eta})^j$$

Deflections fo the Vertical from modern Zenith-Cameras or from Classical Geod- Astron. Campaigns

New: Global Geopotential Model (EIGEN,EGM2008) Coefficients (C_{nm},S_{nm}) => Mapped to Spherical Cap-Harmonic Coefficients (C'_{nm}, S'_{nm})

(C'_{nm}, S'_{nm}) => Introduced as direct observations



http://www.geozilla.de/files/Geodaetische_Infrastrukturen_fuer_GNSS-Dienste_%28GIPS%29.Jaeger..pdf

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

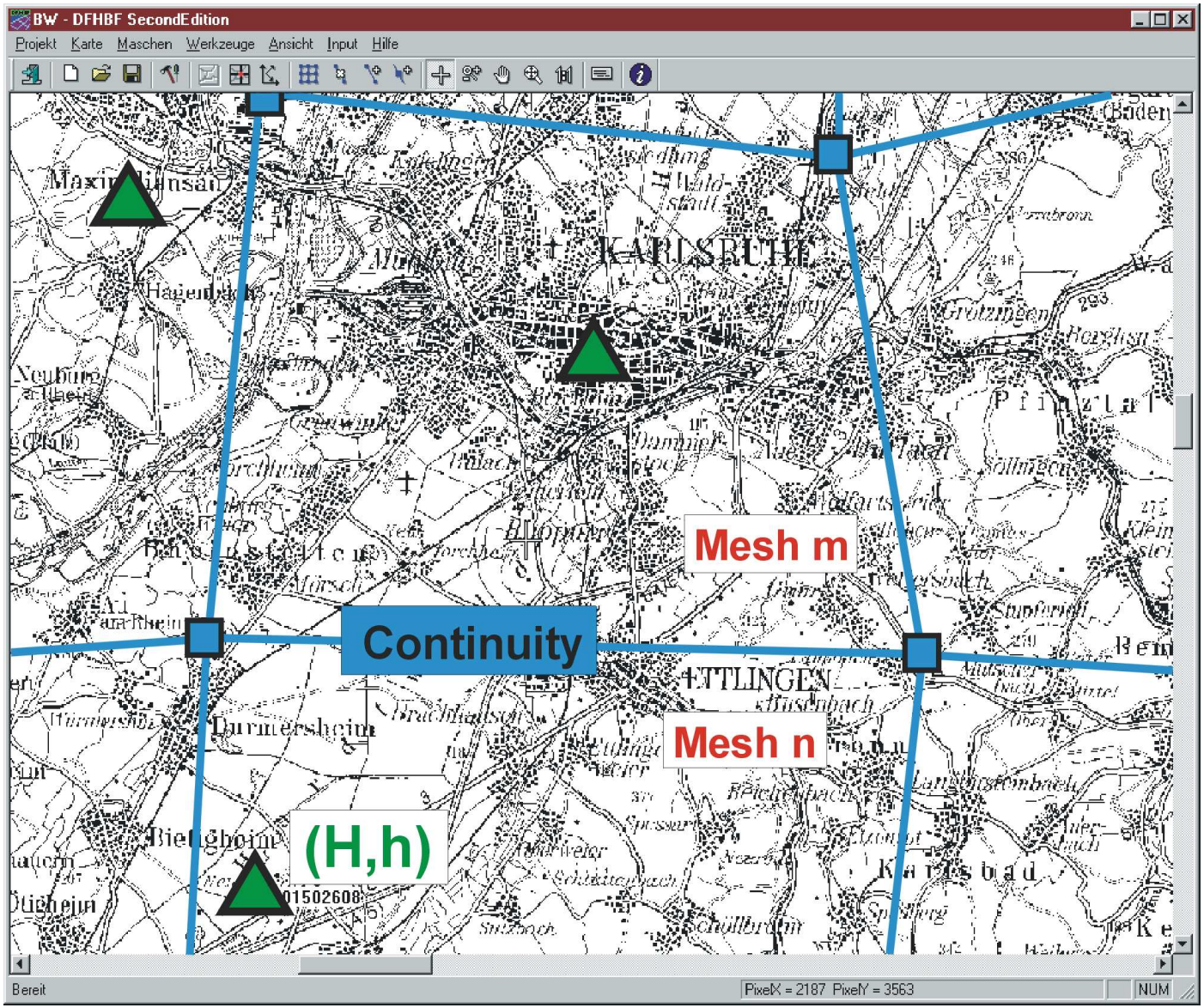
$$0 + v_{\Delta N} = N(\overline{C}'_{n(k),m}, \overline{S}'_{n(k),m}) - (\mathbf{f}^T \cdot \mathbf{p} + \Delta m \cdot h)$$

GIPS-2: Height Reference Surface (HRS) Qgeoid/Geoid (N) for Transition $h_{GNSS,ITRF}$ to Physical Heights H = h-N - Karlsruhe Approach (DFHBF) and DFHBF-DBComputation

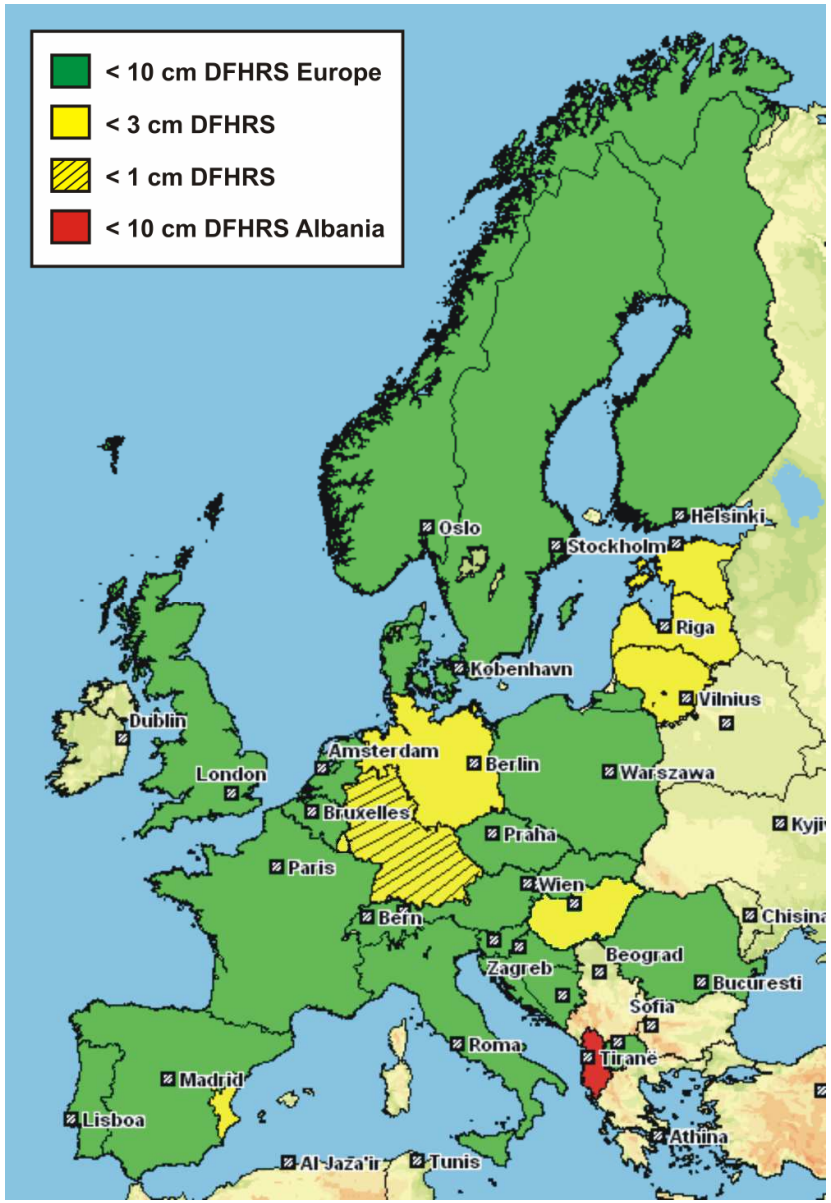
www.dfhbf.de

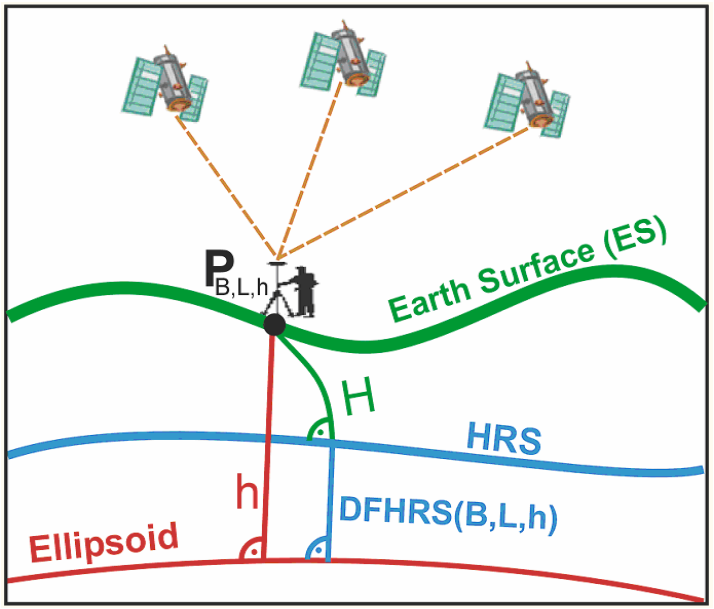
Software Sreenshot

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



GIPS-2: Height Reference Surface (HRS) Qgeoid/Geoid (N) for Transition $h_{GNSS,ITRF}$ to Physical Heights H = h-N - Karlsruhe Approach (DFHBF) and DFHBF-DBComputation





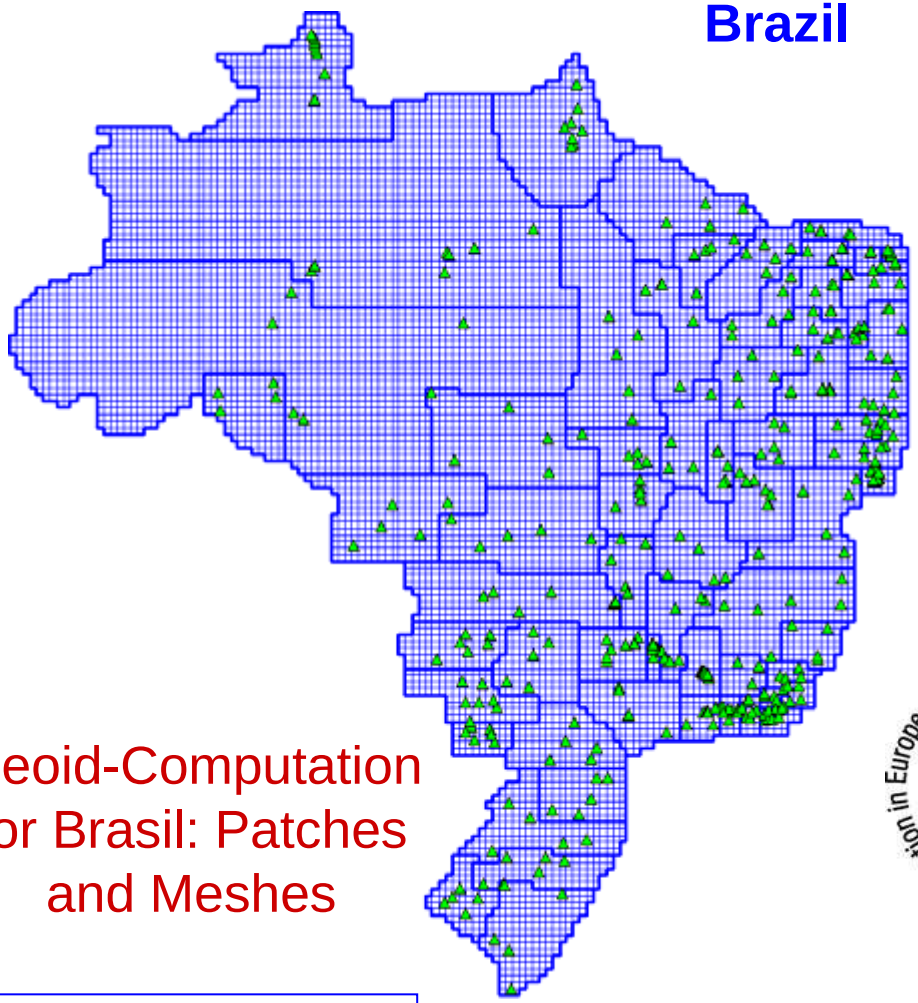
DFHBF - DataBase

Quasi-Geoid N_{QG} Quasi-Geoid N_G

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

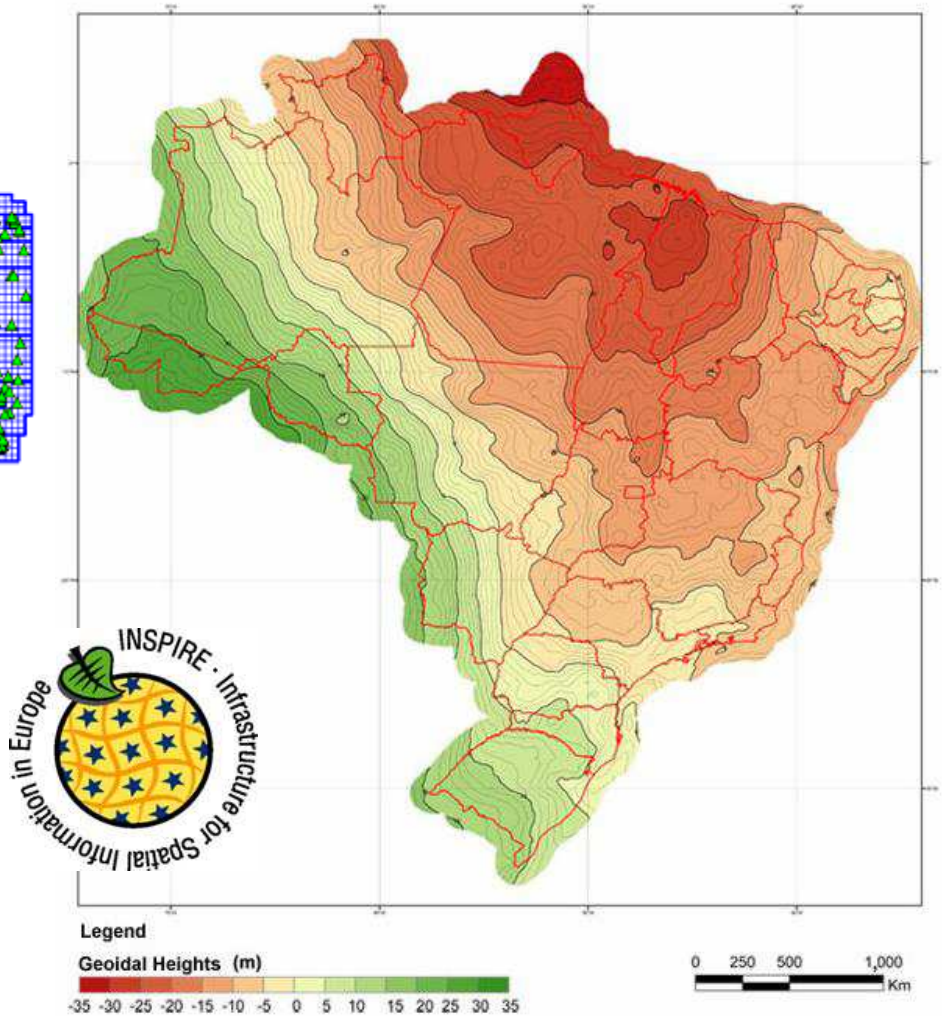
GIPS-2: Height Reference Surface (HRS) Qgeoid/Geoid (N) for Transition $h_{GNSS,ITRF}$ to Physical Heights H = h-N - Karlsruhe Approach (DFHBF) and DFHBF-DBComputation

Brazil



Geoid-Computation for Brasil: Patches and Meshes

www.dfhbf.de



GIPS-3
RTCM Transformation Messages Provision

Reiner Jäger, University of Applied Sciences (HSKA)
Goiania 10-15.Juli 2011

GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach

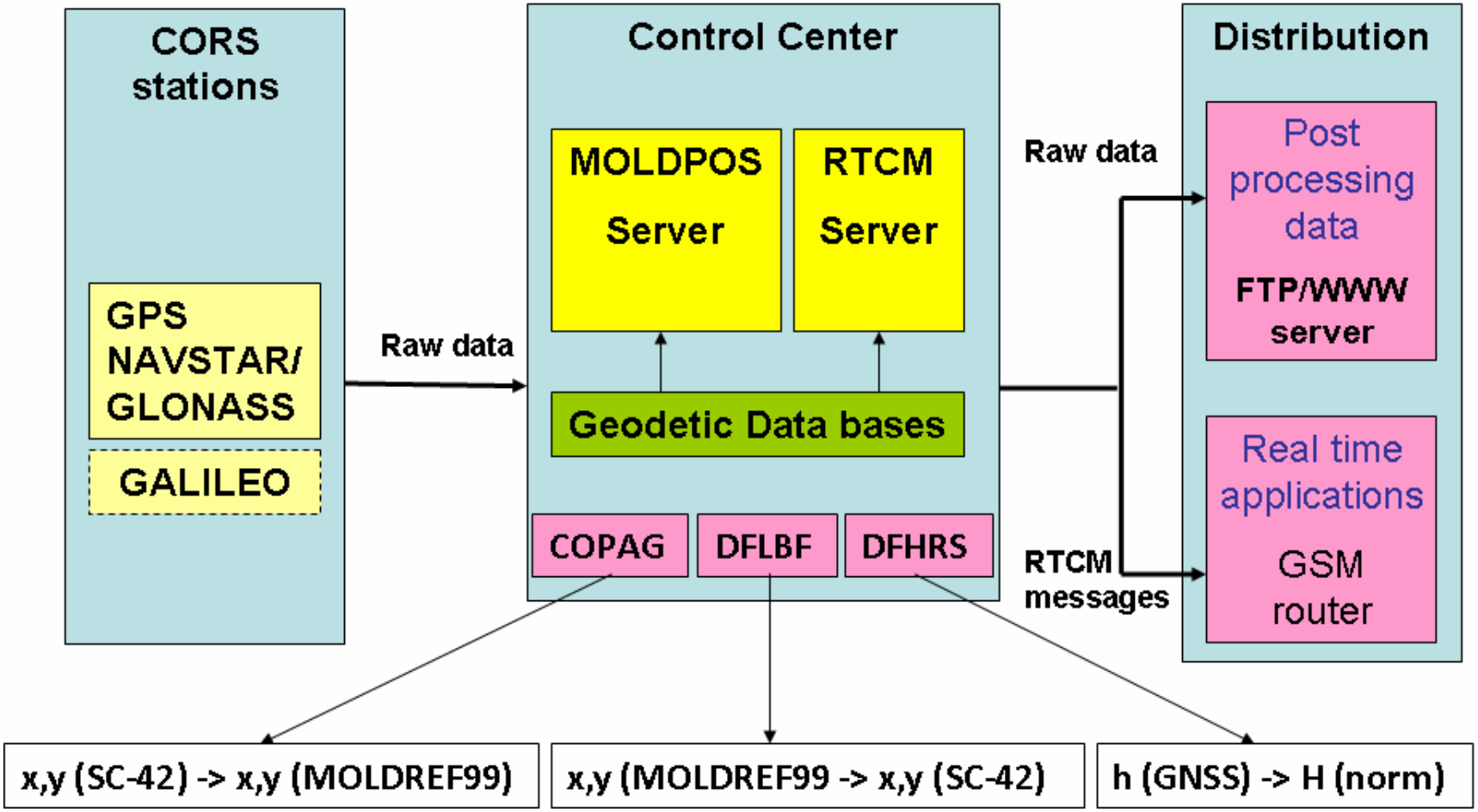
Present or „old“ standard:Trafo-Databases or„Grids“ in GNSS-controllers (Trimble, Leica-Geosystems, Topon, etc.)

New standard:RTCM-Transformation Parameters from GNSS-Positioning Service

HS Karlsruhe BMBF-Project 2010-2011: www.moldpos.eu

MOLDPOS

Geodetic databases development

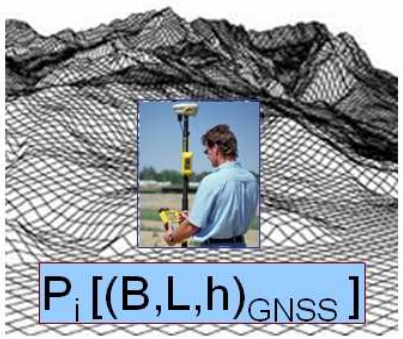


GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach

New standard:RTCM-Transformation Parameters from GNSS-Positioning Service

„Gridding“ of Reference Transformations by Virtual Fitting Points

Source CRS - Grid



Generated Grid of Local Virtual Fitting Points P_i

Any kind of individual

Reference Transformation

Target CRS - Grid

$P_i\,[(B,L)_{Class}]$

$P_i\,[(B,L,H)_{Class}]$

$P_i\,[N]$ $P_i\,[H=h_{GNSS} - N]$

Resulting Local Virtual Fitting Points P_i

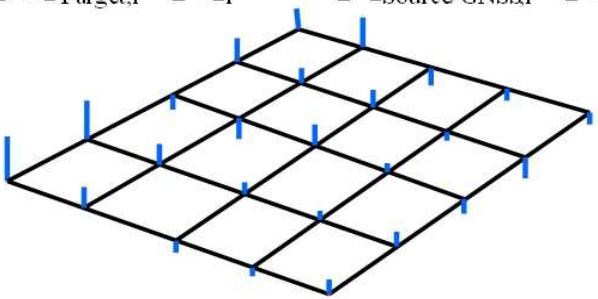
Gridding into 1.] and/or 2.]

1.] 7 Parameter Transformation

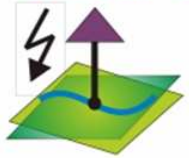
$$\begin{bmatrix} x_T \\ y_T \\ z_T \end{bmatrix}_{Target,i} + \begin{bmatrix} r_x \\ r_y \\ r_z \end{bmatrix}_i = s \cdot \mathbf{R} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{Source/GNSS,i} + \begin{bmatrix} t_x \\ t_x \\ t_z \end{bmatrix}$$

7 Parameter Trend and 3D „Small“ Residual Grid

2.] Geoid/HRS Grid



RTCM



Grid of N_i

GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach

Message 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-Grid or not

Grid Location&Size

7 Parameters

Ellipsoid Parameters Source / Target

GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach

Message 1023 or Message 1024

::

δN_{14}	Residuals P_{14}	DF+71	0.001	::
δE_{14}		DF+72	0.013	
δh_{14}		DF+73	0.049	
δN_{15}	Residuals P_{15}	DF+71	0.005	
δE_{15}		DF+72	0.009	
δh_{15}		DF+73	0.088	
δN_{16}	Residuals P_{16}	DF+71	0.006	
δE_{16}		DF+72	-0.002	
δh_{16}		DF+73	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)**

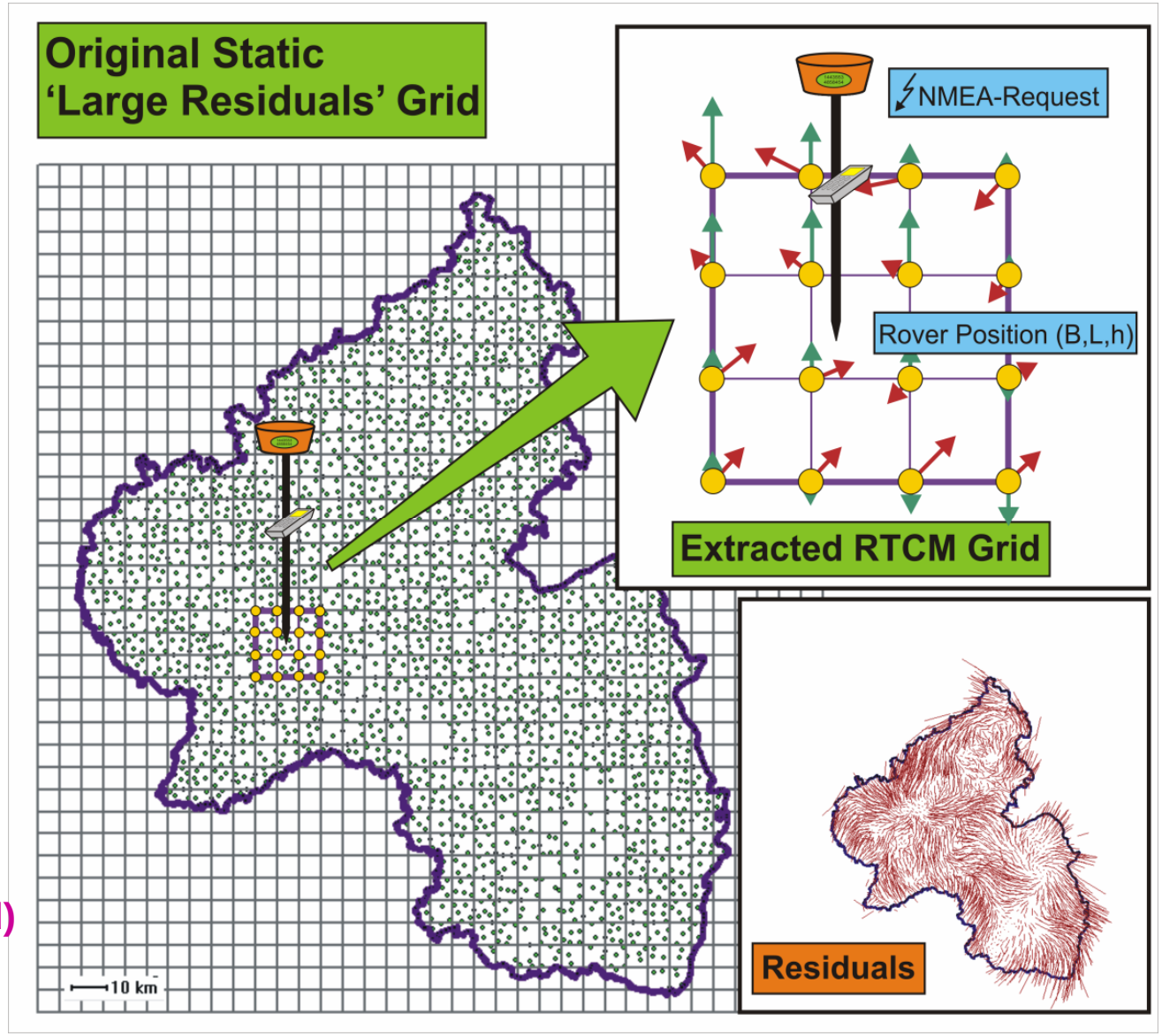
GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach

Using Reference Transformations

to compute a country-wide

1.) „STATIC GRID“

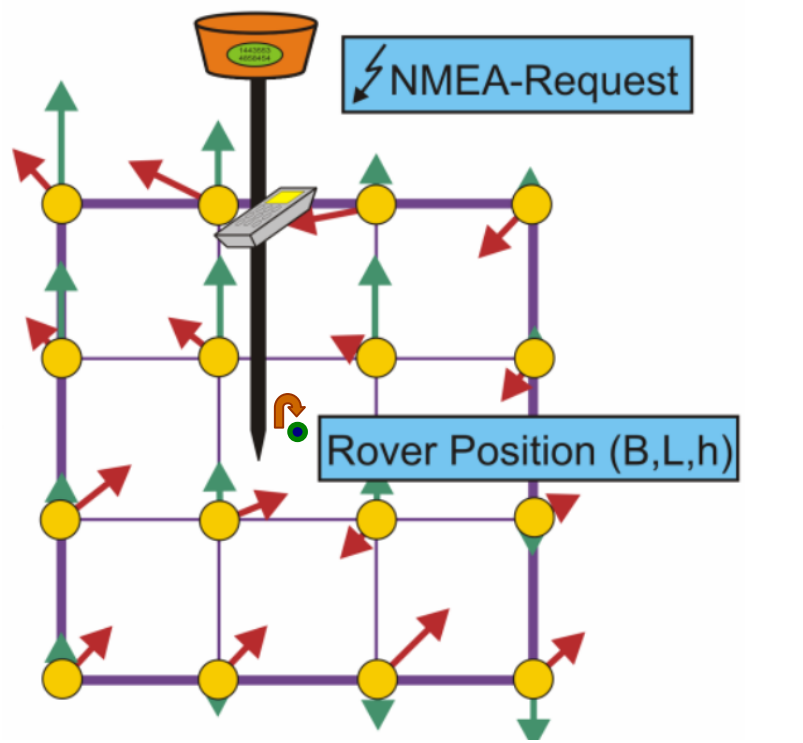
(„Large Residuals“ Grid)



GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach

Using Reference Transformations to compute country-wide grids dynamically online on NMEA-request by virtual fitting points

2.) „Dynamic Grid“



Advantages

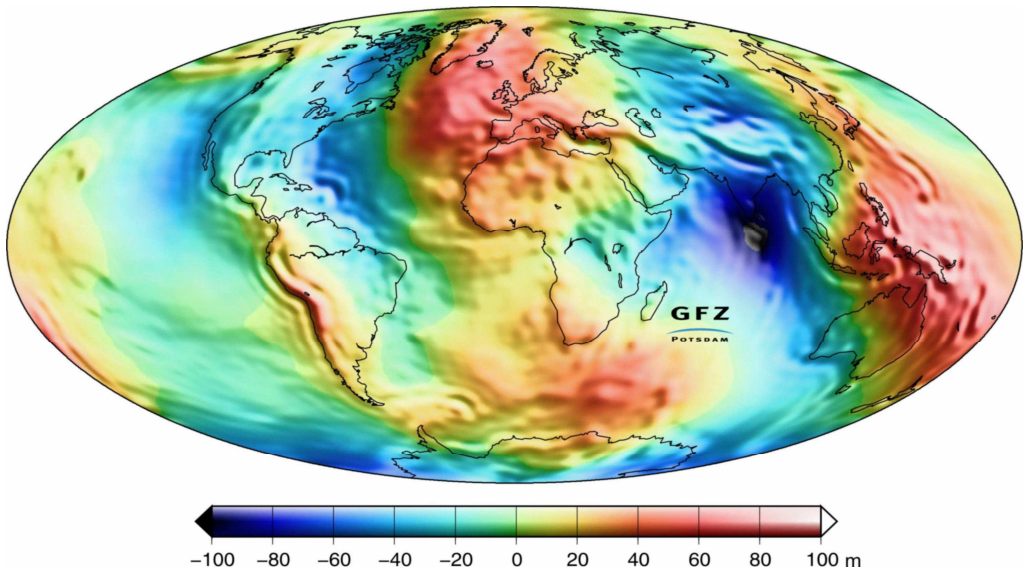
1.) No preceeding „Gridding“ Discretization Error
2.) Small Residuals - Small Interpolation error
3.) De facto - De facto independence of the residual interpolation method in the rover

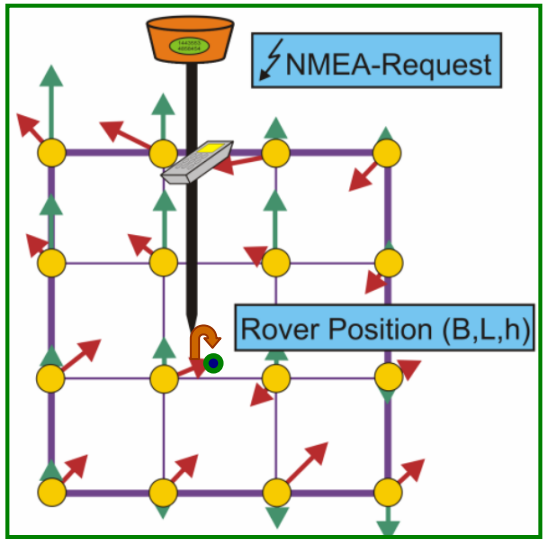
GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach

Using Reference Tranformations to compute grids dynamically

„Dynamic Grid“

4.) Direct use of Original Reference Transformations





$$W(r,\vartheta,\lambda)=\left\{\frac{GM}{r}\cdot\left(1+\sum_{n=2}^{\infty}\sum_{m=0}^{n}\left(\frac{a_{GRS80}}{r}\right)^{n}\cdot\left(C_{nm}\cos m\lambda+S_{nm}\sin m\lambda\right)\cdot P_{nm}(\cos\vartheta)\right)\right\}$$

$$\begin{bmatrix}x\\y\\z\end{bmatrix}=\begin{bmatrix}u_i\cdot\sqrt{1+\varepsilon^2/u^2}\cdot\cos ß\cdot\cos\lambda\\ u_i\cdot\sqrt{1+\varepsilon^2/u^2}\cdot\cos\beta\cdot\sin\lambda\\ u\cdot\sin\beta\end{bmatrix}\qquad U=U(a,\varepsilon,\omega,M)_{REF}\,|\,(ß,\lambda,u))$$

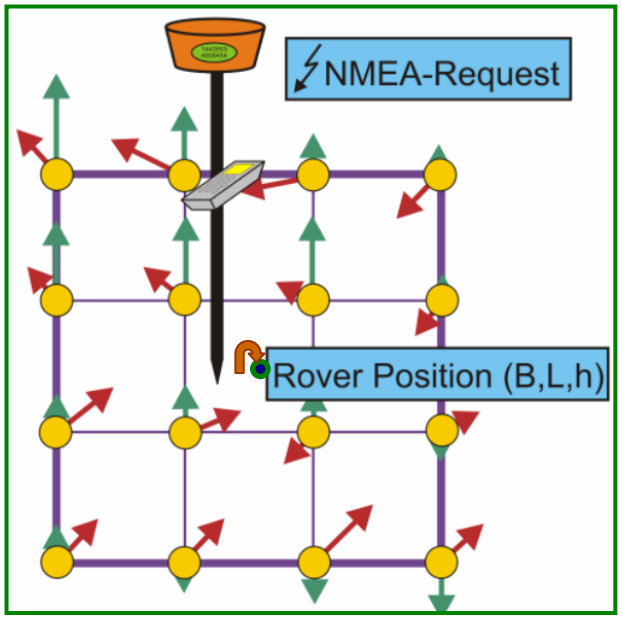
$$N((x,y,z)_{GNSS})=\frac{W-U}{\gamma_{h-N}}$$

GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach

Using Reference Tranformations to compute grids dynamically

„Dynamic Grid“

5.) „Combined Message Generation“



Part 1 - *Plate Models*

$[(B,L,h)_{ITRF\text{-}related}]_i \Rightarrow [(B,L,h)_{GNSS,ITRF}]_i$

Virtual Fitting-Points

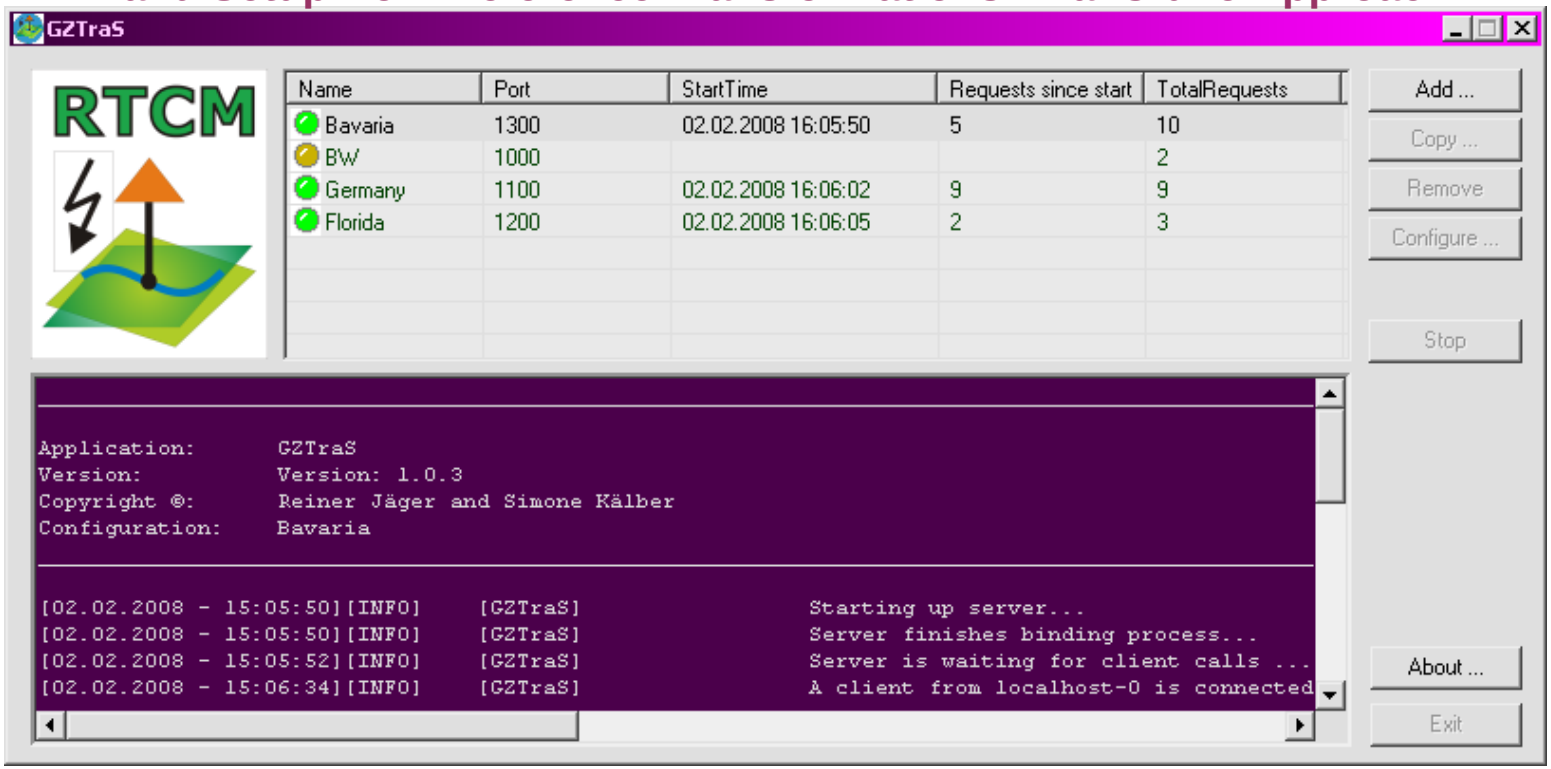
Part 2 - *Standard Reference Transformations*

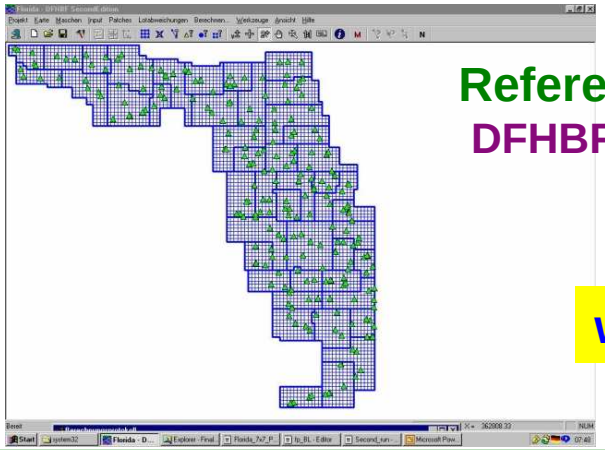
$[(B,L,h)_{ITRF\text{-}related}]_i \Rightarrow [(B,L)_T\ ,\ H_T \text{ or } N)]_i$

Virtual Fitting Points

Dynamic Message Set up by local 7PT Gridding

GIPS-3: RTCM Transformationmessages and Setup from Reference Transformations - Karlsruhe Approach





Reference Transformations

DFHBF Florida

DFHBF Bavaria

DFLBF Bavaria

www.geozilla.de

GIPS-4
Monitoroing of GNSS-Reference Stations including Geomonitoring

Reiner Jäger, University of Applied Sciences (HSKA)
Goiania 10-15.Juli 2011

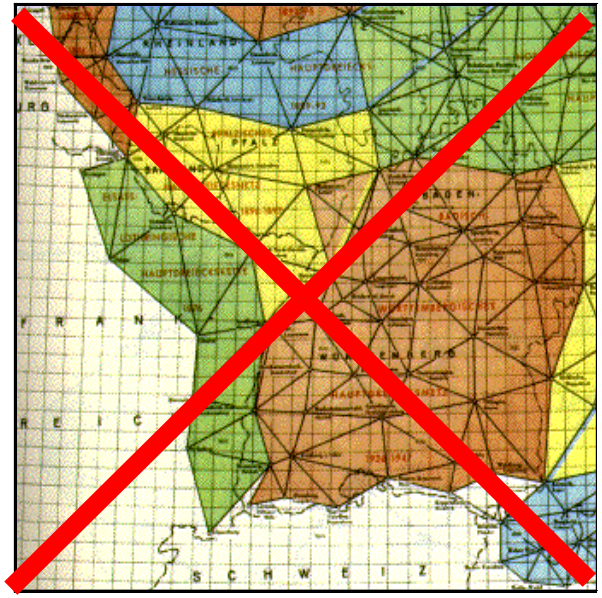
Hochschule Karlsruhe Technik und Wirtschaft (HSKA)
IAF Institut für Angewandte Forschung (IAF)

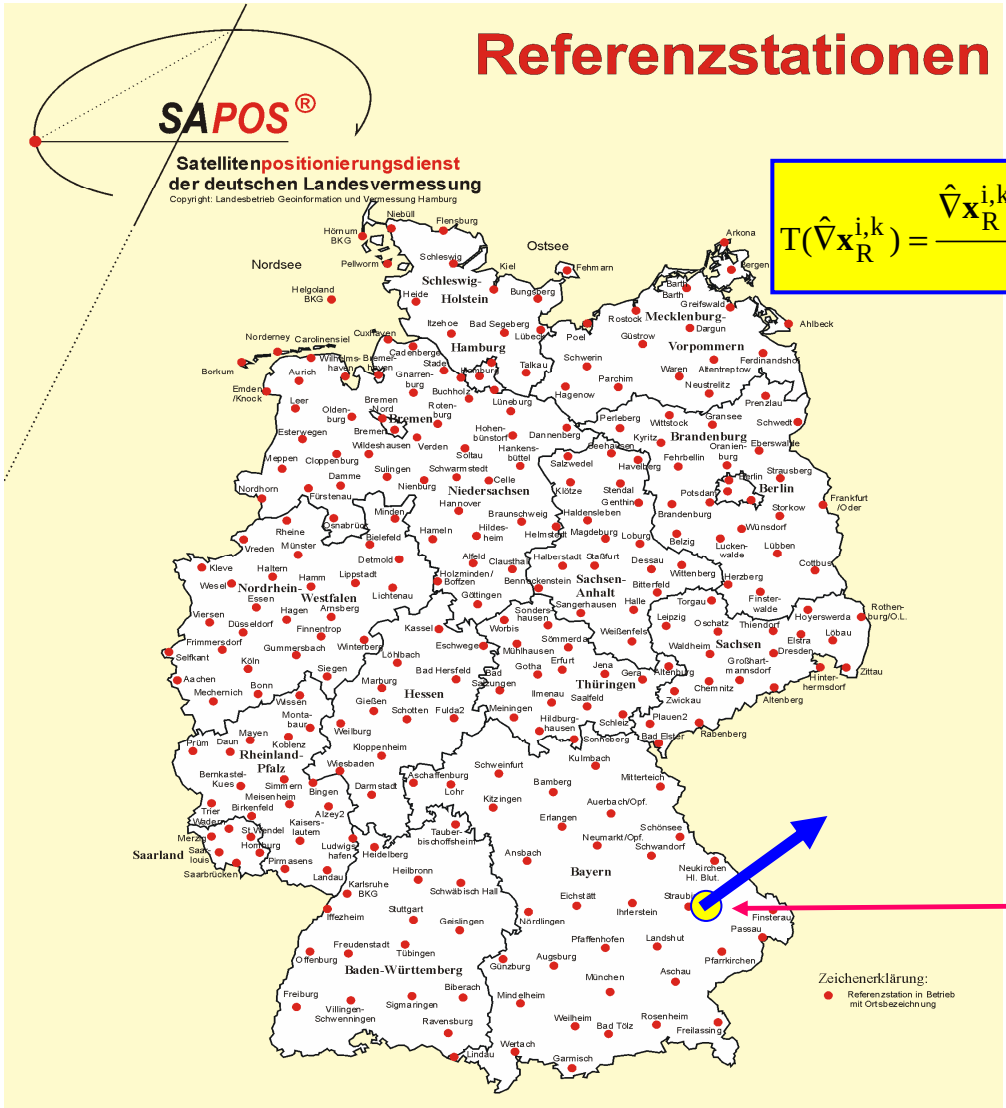
GIPS-4: GNSS-Reference Station Monitoring and Use as Geosensor-Networks for Geomonitoring and Hazard Mitigation – Karlsruhe Approach (MONIKA)

GNSS Reference Station
MONItoring
by the **KA**rlsruhe
approach and software
(**MONIKA**)

www.monika.ag

Old Classical Systems



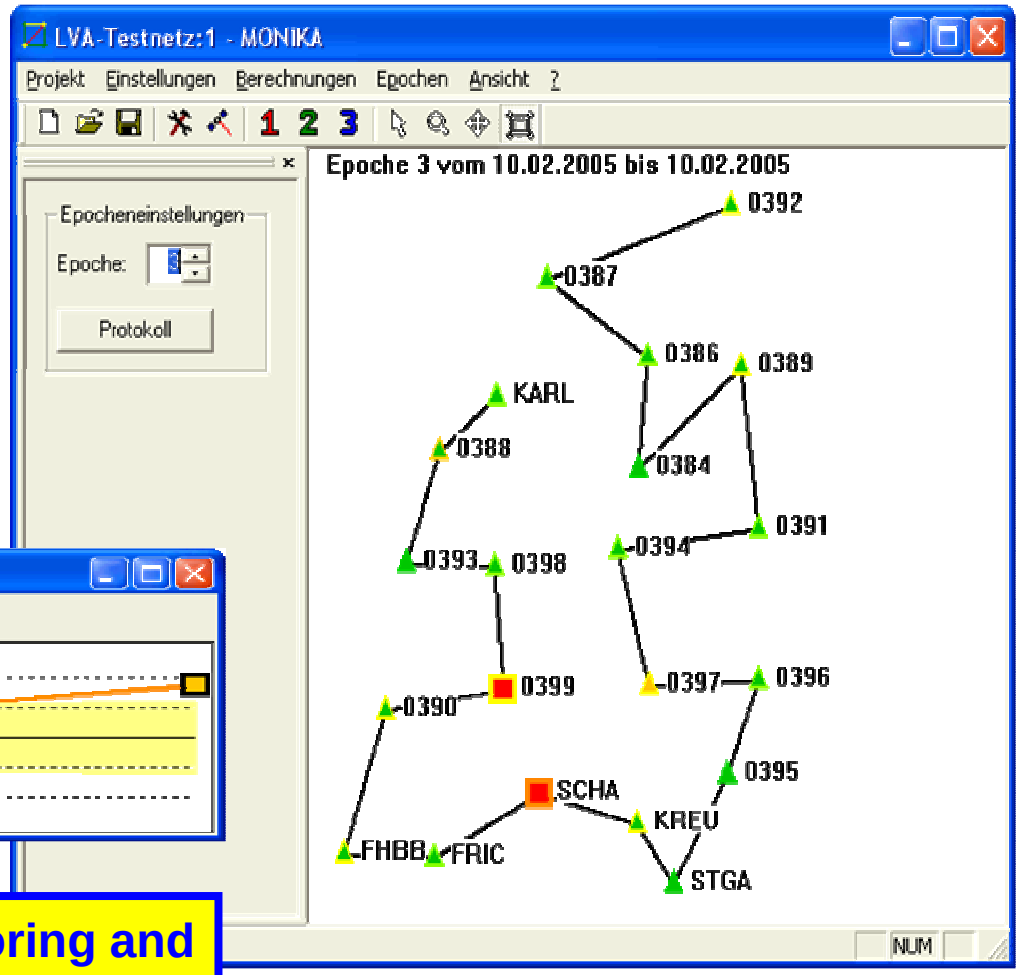


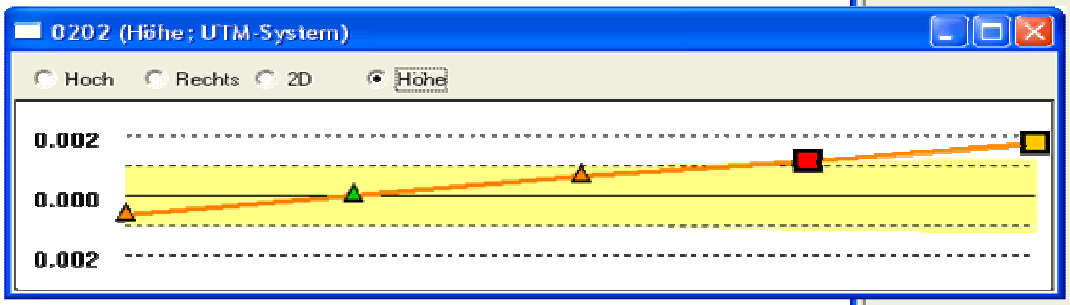
$$T(\hat{\nabla}\mathbf{x}_R^{i,k}) = \frac{\hat{\nabla}\mathbf{x}_R^{i,k\,T}\,(\mathbf{Q}_{\hat{\nabla}\hat{\nabla}_R}^{i,k})^{-1}\,\hat{\nabla}\mathbf{x}_R^{i,k}}{3\cdot\hat{\bar{\sigma}}^2}$$

GIPS-4: GNSS-Reference Station Monitoring and Use as Geosensor-Networks for Geomonitoring and Hazard Mitigation – Karlsruhe Approach (MONIKA)

MONIKA
Coordinate related Reference-Points Deformation Analysis

Multivariate and Multi-Epoch Congruency Testing





Additionally: Local Object – Monitoring and Deformation Analysis

www.monika.ag

GIPS-4: GNSS-Reference Station Monitoring and Use as Geosensor-Networks for Geomonitoring and Hazard Mitigation – Karlsruhe Approach (MONIKA)

MONIKA Step 1

I. GNSS RINEX

$$\mathbf{l}(t_i), \mathbf{C}_l(t_i)$$

GNSSControl-Software

1. Data Communication
2. Processing

Processing Engines

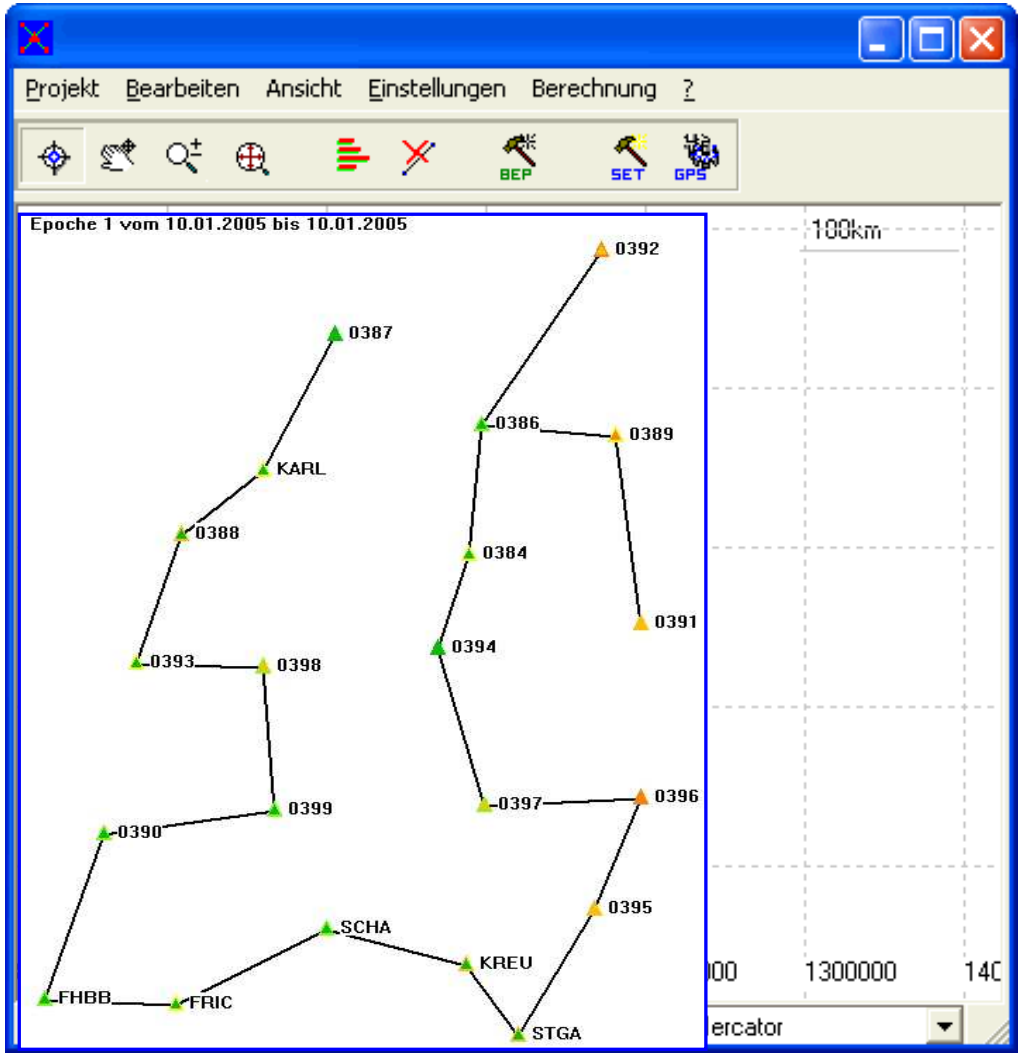
- WA1 (Wanninger Software)
- Berner GNSS-Software 5.0
- RTKLIB - based

$$\overline{x}(t_i)_j, \overline{C}_x(t_i)_j$$

II. GNSS SINEX

Import

$$\overline{x}(t_i)_j, \overline{C}_x(t_i)_j$$



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GIPS-4: GNSS-Reference Station Monitoring and Use as Geosensor-Networks for Geomonitoring and Hazard Mitigation – Karlsruhe Approach (MONIKA)

MONIKA Step 2

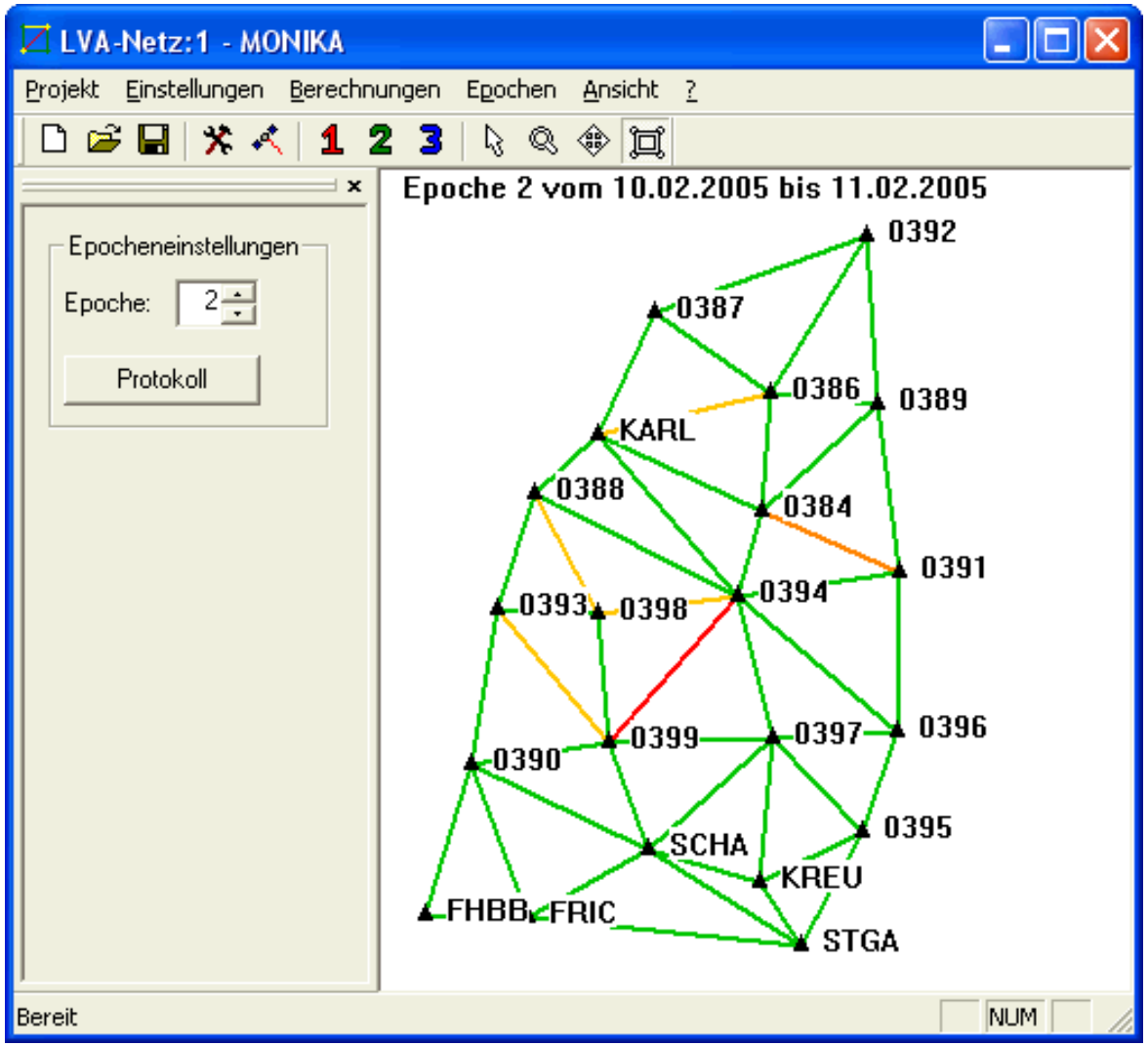
- Baselines
- Epoch Networks
- Partial networks
- Daily Solutions

$$\bar{x}(t_i)_j, \bar{C}_x(t_i)_j$$

Δt

$$\bar{x}(t_i), \bar{C}_x(t_i)$$

- Epoch States



MONIKA Step 2 – Coordinate related Referencepoint-Deformationanalysis

MONIKA

Free GNSS-network

Deformation Analysis Concept

Original GNSS observations

RINEX

$$\mathbf{l}(t)_i, \mathbf{C}_l(t)_i$$

SINEX

$$\bar{x}(t_i), \bar{C}_x(t_i)$$

Epoch States

MONIKA Step 2

Singular

x_0 ?

Unknown Datum

$$\bar{x}(t_i), \bar{C}_x(t_i)$$

New x_0

Helmert-Transformation d=3

$$x(t_i) =: \bar{x}(t_i) \,\big|\, x_0$$

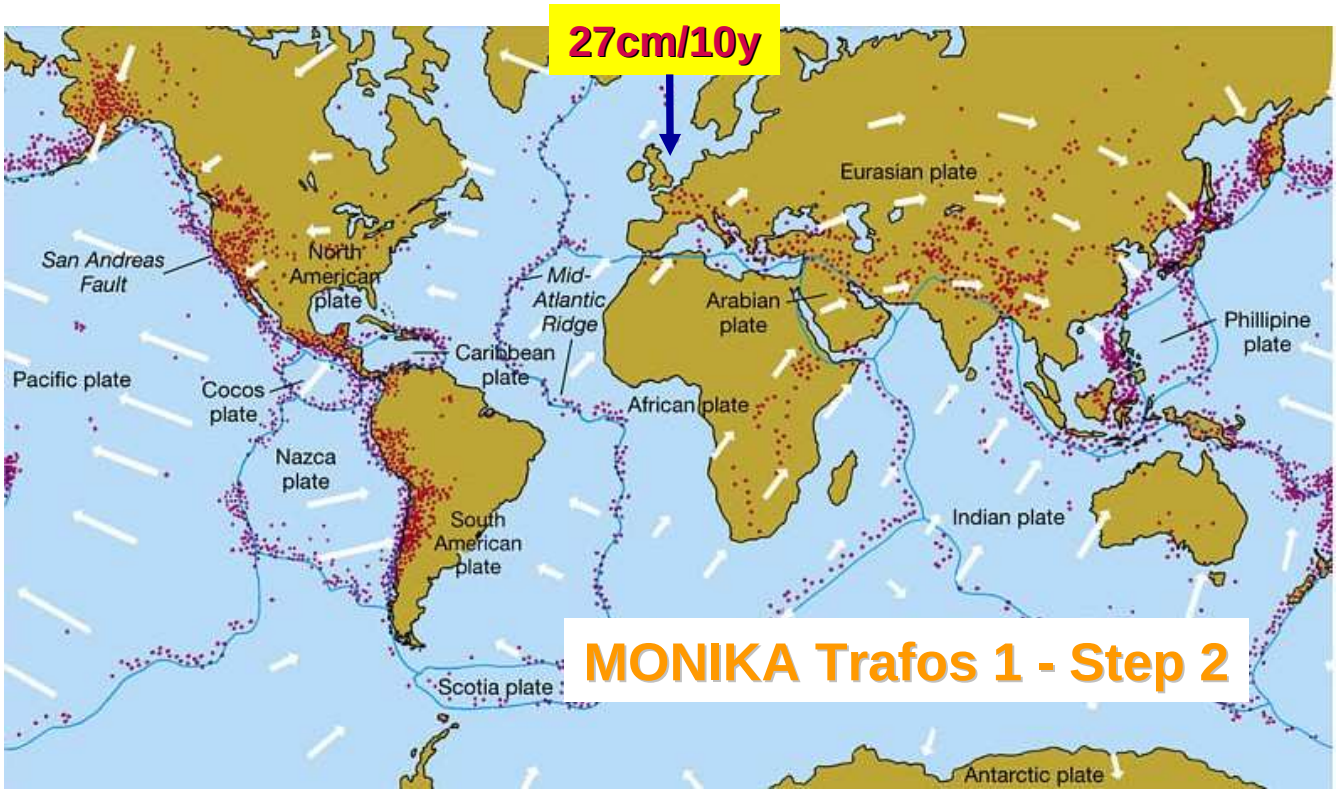
S-Transformation d=3

$$C_x(t_i) = S \cdot \bar{C}_x(t_i) \cdot S^T$$

MONIKA Trafo 2 - Step 2

www.monika.ag

MONIKA Step 2 – Coordinate related Referencepoint-Deformationanalysis



Use of IERS Parameters

Reference time t_0

Epoch time t_i

Consideration of Datum-drift and Plate-Movement Rates

$$x(t_1)_{ITRF_{zz},t_1} = (1+\Delta m)\cdot \mathbf{R}(\varepsilon_x,\varepsilon_y,\varepsilon_z)\cdot \mathbf{x}(t_1)_{ITRFyy,t_1} + \mathbf{t}$$

$$\mathbf{x}(t_2)_{ITRFzz.t_2} = \mathbf{x}(t_1)_{ITRFzz.t_1} + \left(\left((\dot{\mathbf{R}}+\Delta\dot{m})\cdot \mathbf{x}(t_1)_{ITRFzz.t_1} + \dot{\mathbf{t}}\right) + \left(\dot{\mathbf{R}}_{P(j)}\cdot \mathbf{x}(t_1)_{ITRFzz.t_1}\right)\right)\cdot(t_2-t_1)$$

MONIKA Step 3 – Coordinate related Reference-Point-Deformationanalysis

$$(\mathbf{x}(t_i) - \mathbf{x}_0^i) + \mathbf{v}_{x(t_i)} = \mathbf{D}_R^i \cdot d\hat{\mathbf{x}}_R^i + \mathbf{D}_O^i \cdot d\hat{\mathbf{x}}_O^i \quad \text{and} \quad \mathbf{C}_x(t_i)$$

ΔT

$$(\mathbf{x}(t_i) - \mathbf{x}_0^i) + \mathbf{v}'_{x(t_i)} = \mathbf{D}_R^i \cdot d\hat{\mathbf{x}}'^i_R + \mathbf{D}_O^i \cdot d\hat{\mathbf{x}}'^i_O + \mathbf{B}_i^k \cdot \hat{\nabla}\mathbf{x}_R^{i,k}(t_i)$$

$$\mathbf{B}_i^k \cdot \hat{\nabla}\mathbf{x}_R^{i,k}(t_i) = \left[\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \ldots \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \ldots \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}\right]^T \cdot \hat{\nabla}\mathbf{x}_R^{i,k}(t_i)$$

$$\hat{\nabla}\mathbf{x}_R^{i,k}(t_i) = -(\mathbf{B}_i^{k\,T}\mathbf{P}^i\mathbf{Q}_{vv}^i\mathbf{P}_i\mathbf{B}_i^k)^{-1} \cdot \mathbf{B}_i^{k\,T}\mathbf{P}^i \cdot \mathbf{v}_{x(t_i)} \quad \text{and} \quad \mathbf{Q}_{\hat{\nabla}\hat{\nabla}_R}^{i,k}(t_i) = (\mathbf{B}_i^{k\,T}\mathbf{P}^i\mathbf{Q}_{vv}^i\mathbf{P}_i\mathbf{B}_i^k)^{-1}$$

MONIKA Step 3 – Coordinate related Referencepoint-Deformationanalysis

3D a-posteriori Teststatistics – Significance of $\nabla \mathbf{x}_R^{i,k}$

$$T(\hat{\nabla}\mathbf{x}_R^{i,k}) = \frac{\hat{\nabla}\mathbf{x}_R^{i,k\,T} \cdot (\mathbf{Q}_{\hat{\nabla}\hat{\nabla}_R}^{i,k})^{-1} \cdot \hat{\nabla}\mathbf{x}_R^{i,k}}{3 \cdot \hat{\bar{\sigma}}^2} = \frac{\hat{\nabla}\mathbf{x}_R^{i,k\,T} \cdot (\mathbf{B}_i^{k\,T}\mathbf{P}^i\mathbf{Q}_{vv}^i\mathbf{P}_i\mathbf{B}_i^k) \cdot \hat{\nabla}\mathbf{x}_R^{i,k}}{3 \cdot \hat{\bar{\sigma}}^2} \sim F_{3,r-3}$$

$$\hat{\bar{\sigma}}^2 = \frac{\mathbf{v}^T\mathbf{P}\mathbf{v} - \hat{\nabla}\mathbf{x}_R^{i,k\,T} \cdot (\mathbf{Q}_{\hat{\nabla}\hat{\nabla}_R}^{i,k})^{-1} \cdot \hat{\nabla}\mathbf{x}_R^{i,k}}{r-3}$$

Test related to 1-α, e.g = 95% Confidence ellipsoid

Sensitivity ellipsoid
α = 5 %, ß=95%

$$\hat{\nabla}\mathbf{x}_R^{i,k\,T} \cdot (\mathbf{Q}_{\hat{\nabla}\hat{\nabla}_R}^{i,k})^{-1} \cdot \hat{\nabla}\mathbf{x}_R^{i,k} = \lambda(F'_{3,r-3}, \alpha, \beta) = 17.3$$

ß%-Sensitivity

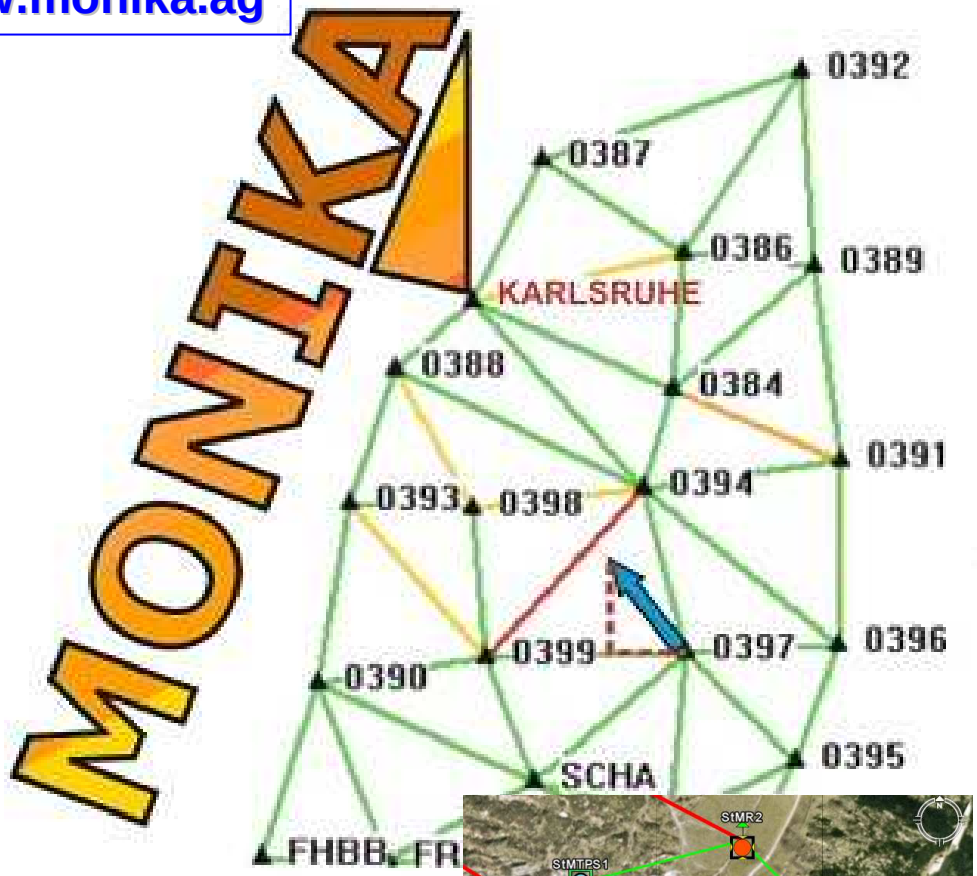
$$f = \sqrt{17.3} = 4.2$$

(= 1.0 accuracy , 1-α = 19.9 % error ellipsoid)

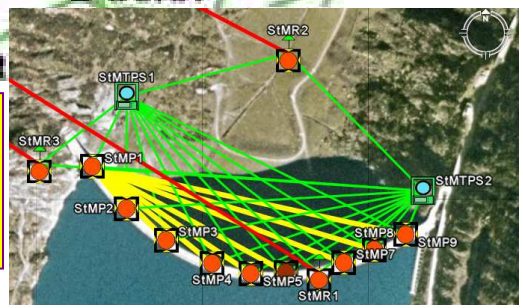
Detectability of GNSS Reference Station Deformations $\nabla \mathbf{x}_R^{i,k}$

GNSS-Reference Station Monitoring and Use as Geosensor-Networks for Geomonitoring and Hazard Mitigation – Karlsruhe Approach (MONIKA) -

www.monika.ag



GNSS-Positioning-Service of Rheinland-Pfalz (SAPOS) - Volcano Monitoring -



GNSS-Positioning-Service Geomonitoring of Local Objects

GNSS-Positioning-Service Geomonitoring of Natur Hazard Zones

GNSS Positioning Services
+
GIPS

Motor for New Developments
e.g.
Precise Multisensor Navigation

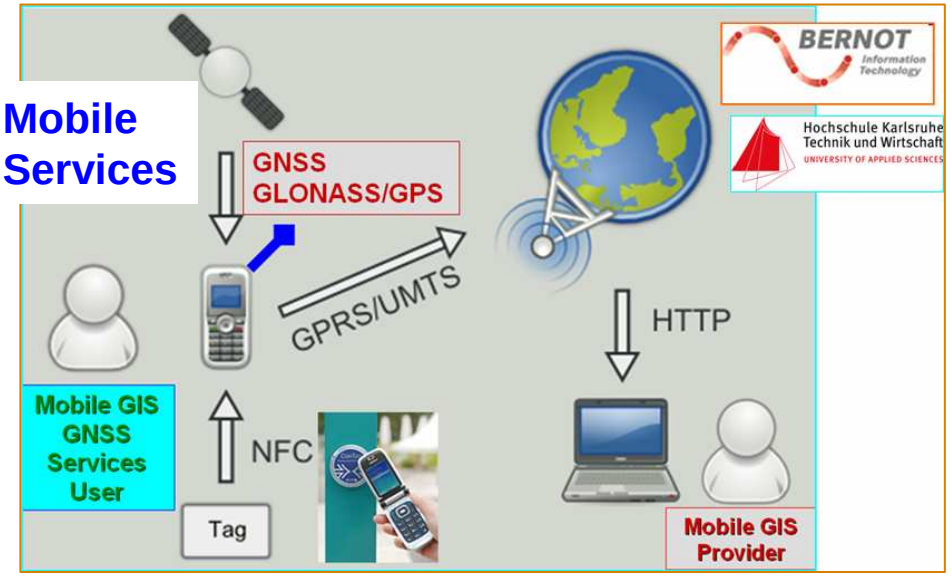
! Geodetic Know How questioned !

GNSS-Positioning Services – Precise Positioning/Geodata Acquisition/Navigation

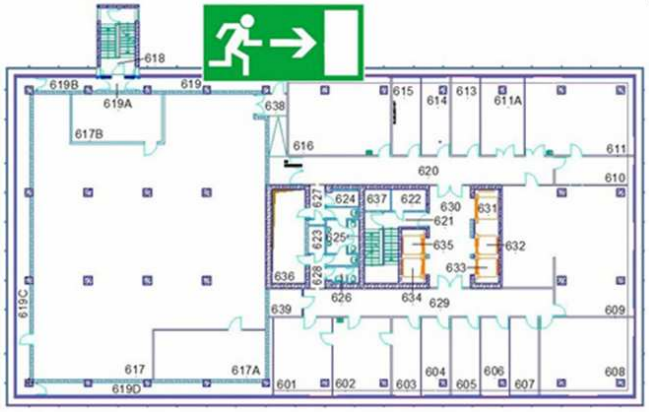
Mobile GIS

Augmented Reality and Mobile Data-Acquisition

Mobile Services



Seamless Outdoor/Indoor Navigation Multisensor-Systems



GNSS-Positioning Services – Precise Positioning/Geodata Acquisition/Navigation

Algorithms for Precise Multisensor-Multi-Purpose Navigation-Platforms

www.navka.de

Joint Research Project 2011 - 2013

GNSS

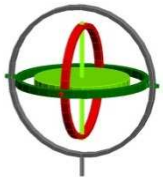
+

Autonomous Sensors (MEMS)

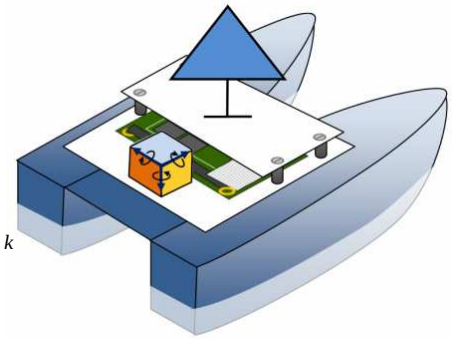
- **Gyroscopes**
- **Accelerometers, etc.**

Field Robots

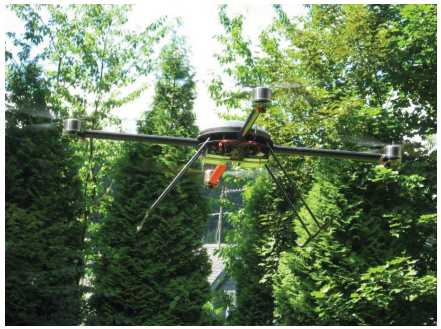
$$\begin{bmatrix} N \\ E \\ v \\ \dot{v} \\ y \\ \dot{y} \end{bmatrix}_{k+1} = \begin{bmatrix} N_k + [v_k \cdot \sin(y_k)] \cdot \Delta t + \frac{1}{2}[\dot{v}_k \sin(y_k) + v_k \cos(y_k)\dot{y}] \cdot \Delta t^2 \\ E_k + [v_k \cdot \cos(y_k)] \cdot \Delta t + \frac{1}{2}[\dot{v}_k \cos(y_k) - v_k \sin(y_k)\dot{y}] \cdot \Delta t^2 \\ v_k + \dot{v}_k \cdot \Delta t \\ \dot{v}_k \\ y_k + \dot{y}_k \cdot \Delta t \\ \dot{y}_k \end{bmatrix}_k$$



$$\dot{y} = \boldsymbol{\omega}_{np}^{p}(3) = [\boldsymbol{\omega}_{ip}^{p}(3) - [\mathbf{R}_{n}^{p}(r \approx 0, p \approx 0, y)](t) \cdot \boldsymbol{\omega}_{in}^{n}](3)]$$



Water-Drones



Air-Drones

GNSS-Positioning Services – Precise Positioning/Geodata Acquisition/Navigation

Algorithms for Precise Multisensor-Multi-Purpose Navigation-Platforms

Hochschule Karlsruhe
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Joint Research
Project 2011,2012,2013

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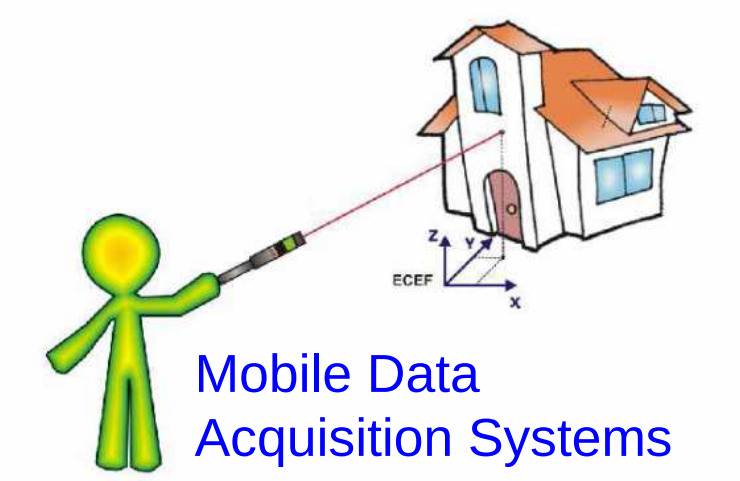
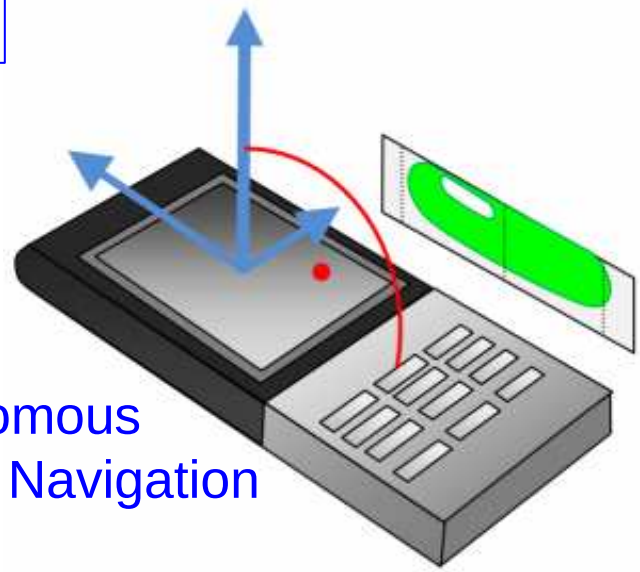


Mobile Data
Acquisition Systems



Autonomous
Indoor Navigation

SIEMENS
BOSCH
IFN
Integrierte Informationssysteme
MESA
BERNOT
teXXmo
BES


THANK
YOU
THANK