# Geodetic Infrastructure for GNSS-Positioning-Services (GIPS)

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MOLDPOS

www.moldpos.eu

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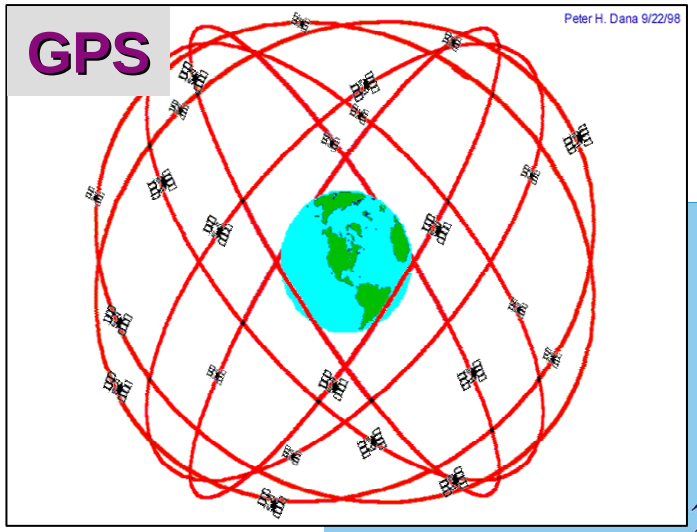
Hochschule Karlsruhe
Technik und Wirtschaft (HSKA)
IAF
Institut für Angewandte Forschung (IAF)

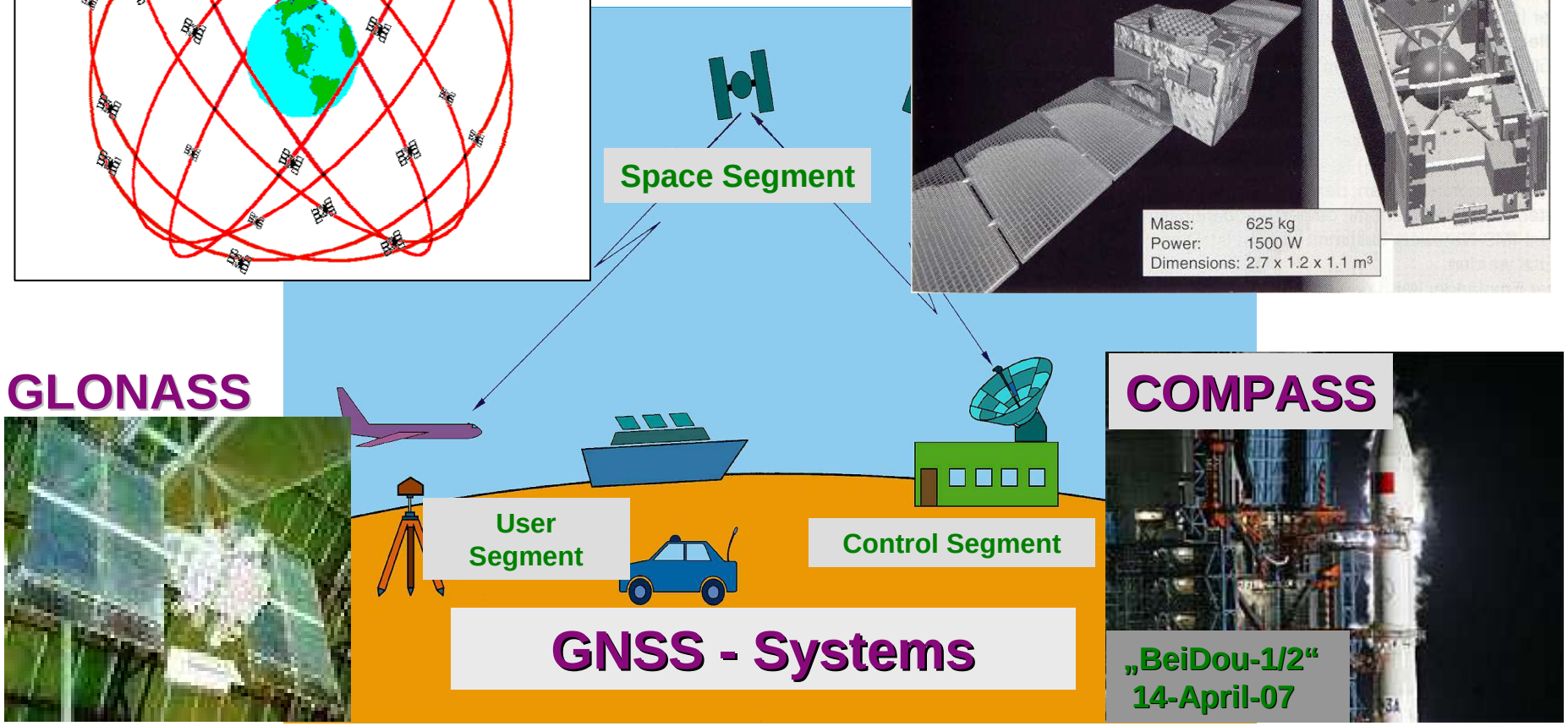
www.geozilla.de, www.galileo-bw.de

# GNSS for Global Positioning in ITRF/ECEF Frames




**< 50 (2010)**

**105! (2013)**




**GLONASS**

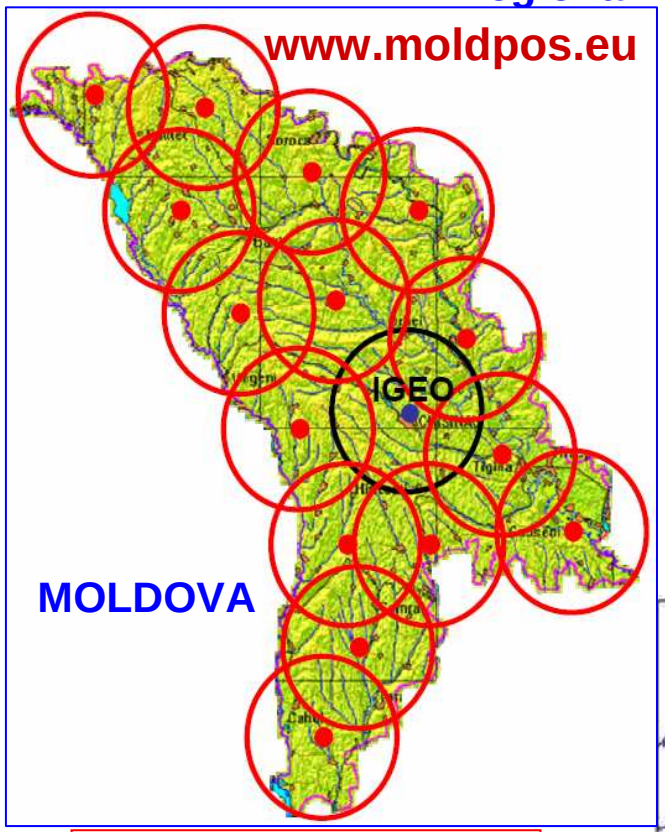
# GNSS-Positioning-Services

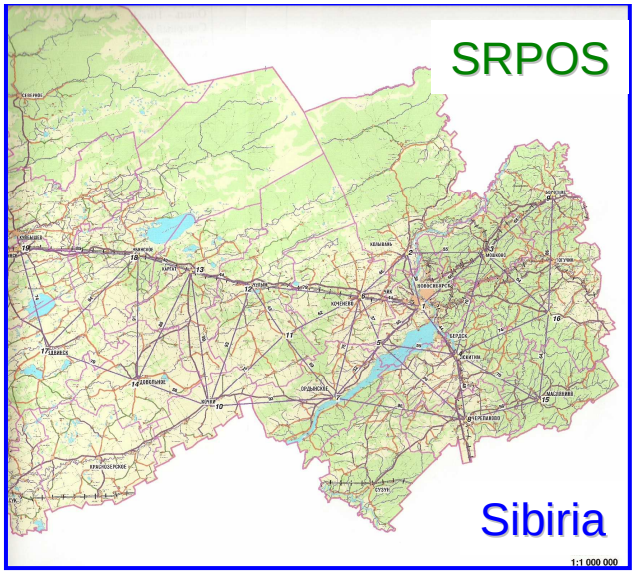
## www.euref.eu

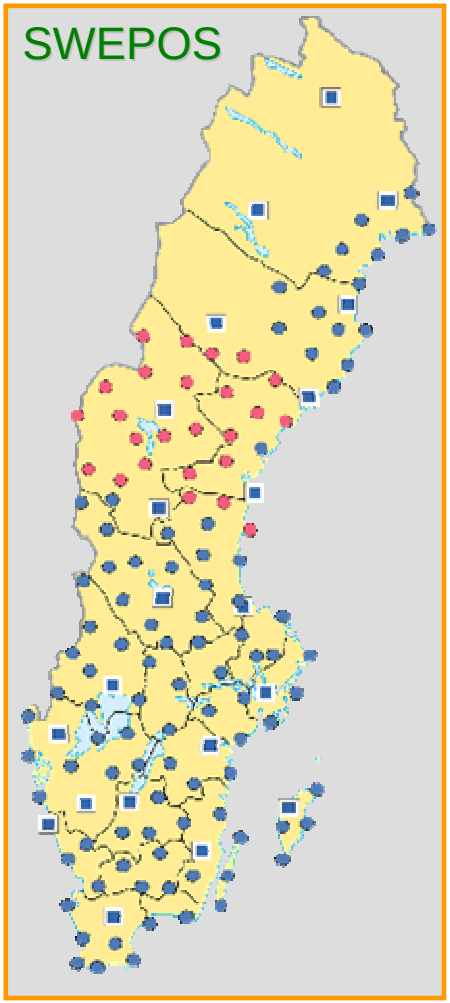
***GNSS-Networks in EURASIA: SAPOS®/Axio-Net/VRSNow® , SWIPOS®/SwissSat® … SwePos®, CzePos® ,LatPos®, CroPOS®, HePos® , … Hungary, Slowenia, Romania, Siberia (SRPOS), …Moldova (www.moldpos.eu)***

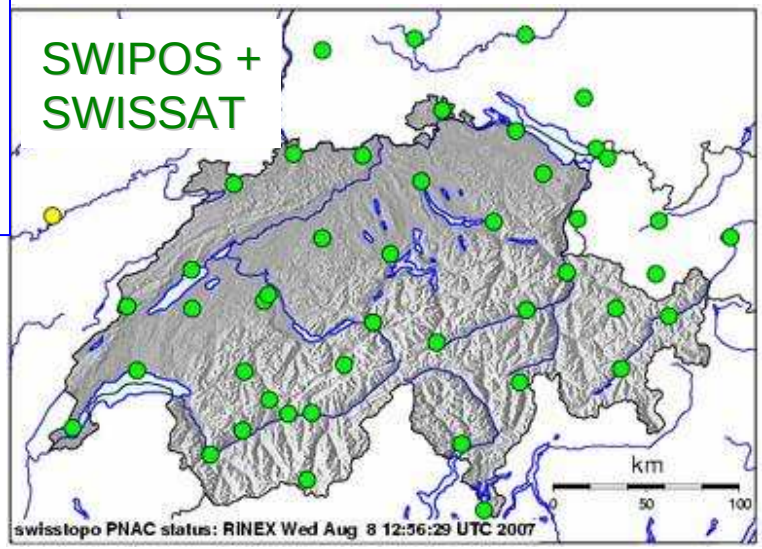
# Precise Differential ("cm") DGNSS

## Regional DGNSS-Services in and outside Europe




**"cm"**

**⇔**

**!Code- and Phase-Corrections !**

**RTCM 3.1**

# GNSS-Service and RTCM-based Positioning

Adresse http://www.rtcm.org/

RTCM

The Radio Technical Commission for Maritime Services

Overview | Publications | Annual Meeting | Membership | Calendar | Contact Us | Visit Us

## Welcome

What do you see when you step onto the bridge of a modern ship or well-equipped boat?

Chances are that RTCM standards and RTCM activities had a lot to do with the communication and navigation equipment there.

In the United States, the Federal Communications Commission and U.S. Coast Guard use RTCM standards to specify radar systems, Emergency Position Indicating Radio Beacons, and the basic version of Digital Selective Calling radios.

**RTCM Guides**

Guide to International Requirements for GMDSS Communication Equipment 1.1

Guide to International Ship Navigation Equipment Requirements Version 1.2

Personal Locator Beacons used on land in the U.S. are required to meet an RTCM standard.

RTCM standards are used internationally for Differential Global Navigation Satellite Systems and Electronic Chart Systems.

RTCM members also have the opportunity to monitor and participate in the development of international standards for maritime radiocommunication and electronic navigation systems.

# GNSS-Services and RTCM-based Positioning

## Basic GNSS-Data collected at the GNSS-Reference-Stations at a Time t-Δt

$$\nabla\rho(t-\Delta t)^{Sat}_{Ref} = \rho[(x,y,z)_{REF};(x,y,z)_{SAT,\Delta t}]_{true,Ref} - \rho(t-\Delta t)_{Observed,Ref}$$

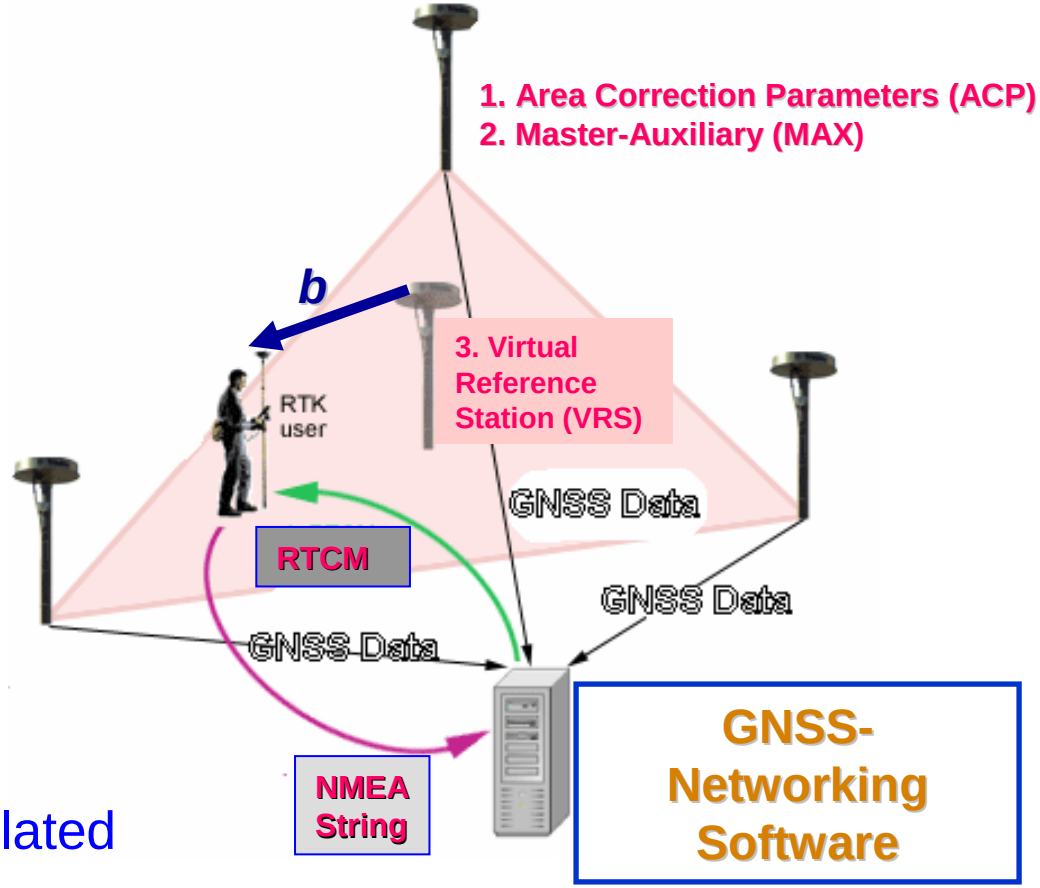
$$\nabla\lambda_R(t-\Delta t)^{Sat}_{Ref} = \lambda_R[(x,y,z)_{REF};(x,y,z)_{SAT,\Delta t}]_{true,Ref} - \lambda_R(t-\Delta t)_{Observed,Ref}$$

**RTCM 3.1**

**Observations-**

**Corrections**

$$\lambda_R(t)^{Sat}_{Rov,corrected} = \lambda_R(t)^{Sat}_{Rov,Observed} - \nabla\lambda_R(t-\Delta t)^{Sat}_{Ref}$$

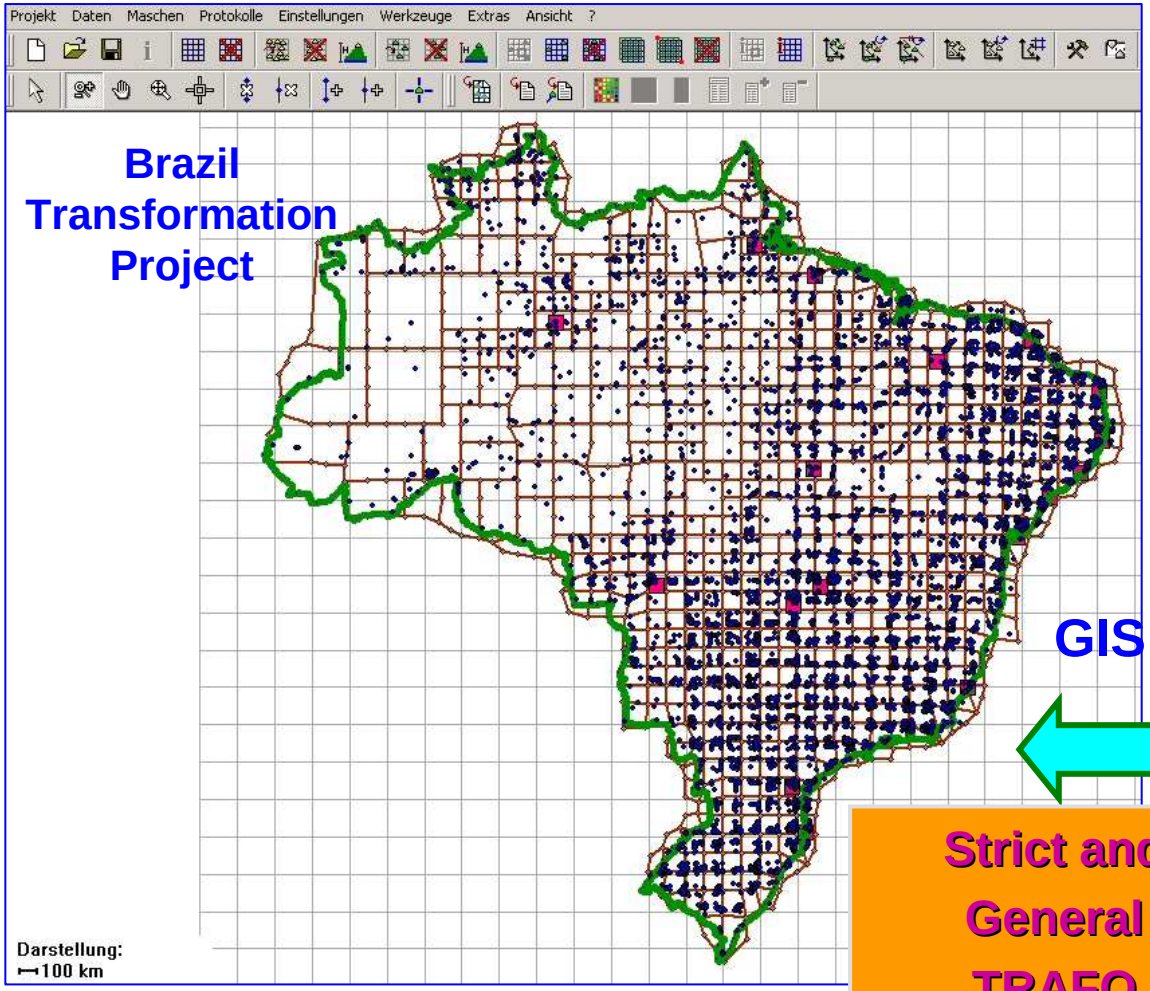



$(B,L,h)_{GNSS\text{-}Datum}$

**1 - 2 cm** ITRF-related

# Transformation Problems and Reference Transformations

## 1.) Horizontal Datum Transition from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$




GIS

**Strict and General TRAFO**

**ITRF / SIRGAS - Datum**

**GNSS-practice**

**Old Classical Systems**

# Transformation Problems and Reference Transformations

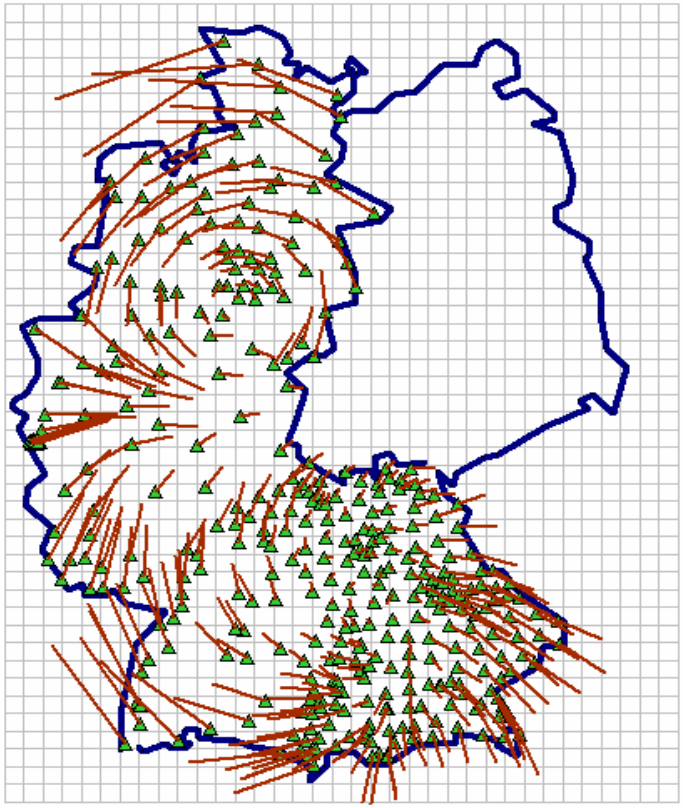
## 1.) Horizontal Datum Transition from (B,L) $_{GNSS,ITRF}$ to Classical Datum (B,L)$_{Classical}$

**ITRF / ETRF89 - Datum**

**GIS Transition to ITRFGNSS consistent frame**

**Strict and General TRAFO**

**GNSS-practice**

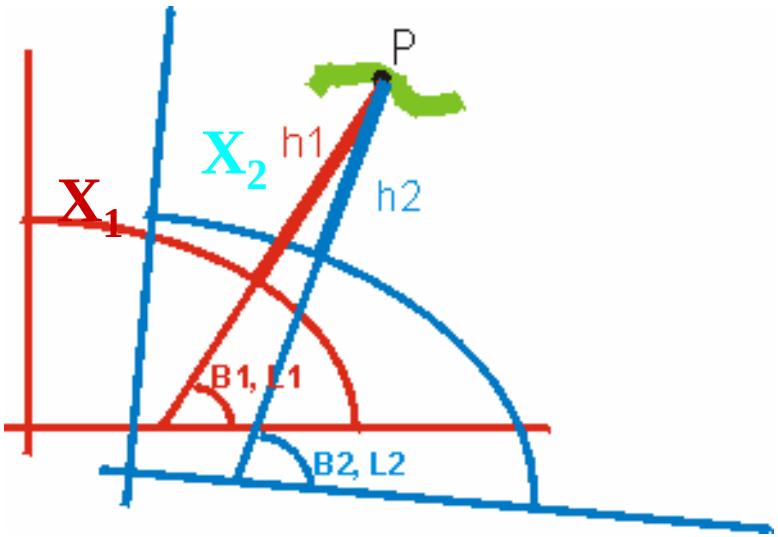



**Old Classical Systems**

# Transformation Problems and Reference Transformations

## 1.) Horizontal Datum Transition from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$

## „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**

**<u>Non-Linear</u> Realation (see above)**

# Transformation Problems and Reference Transformations

## 1.) Horizontal Datum Transition from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$

### 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

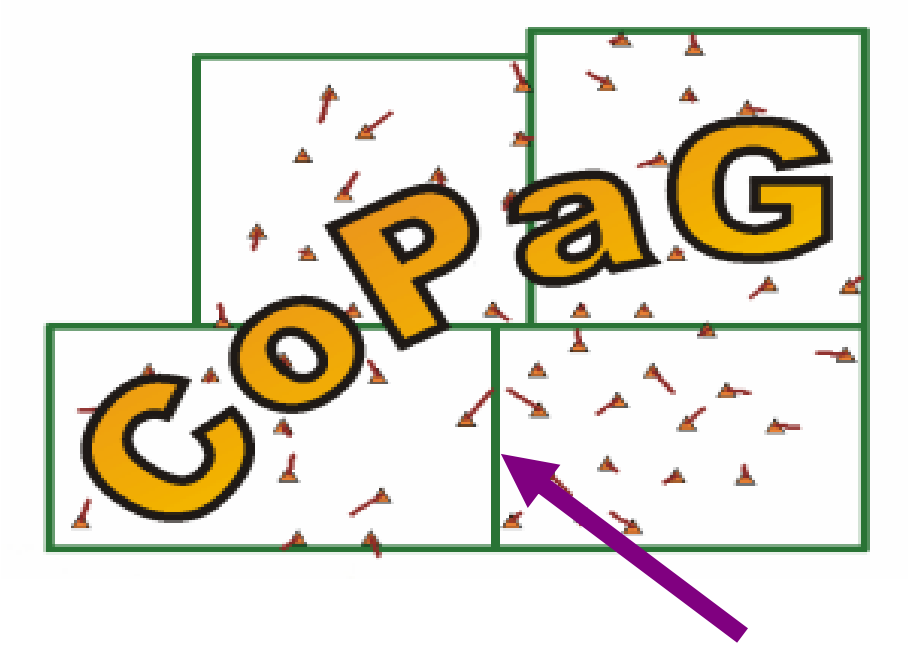
**WTRANS**

www.geozilla.de

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

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

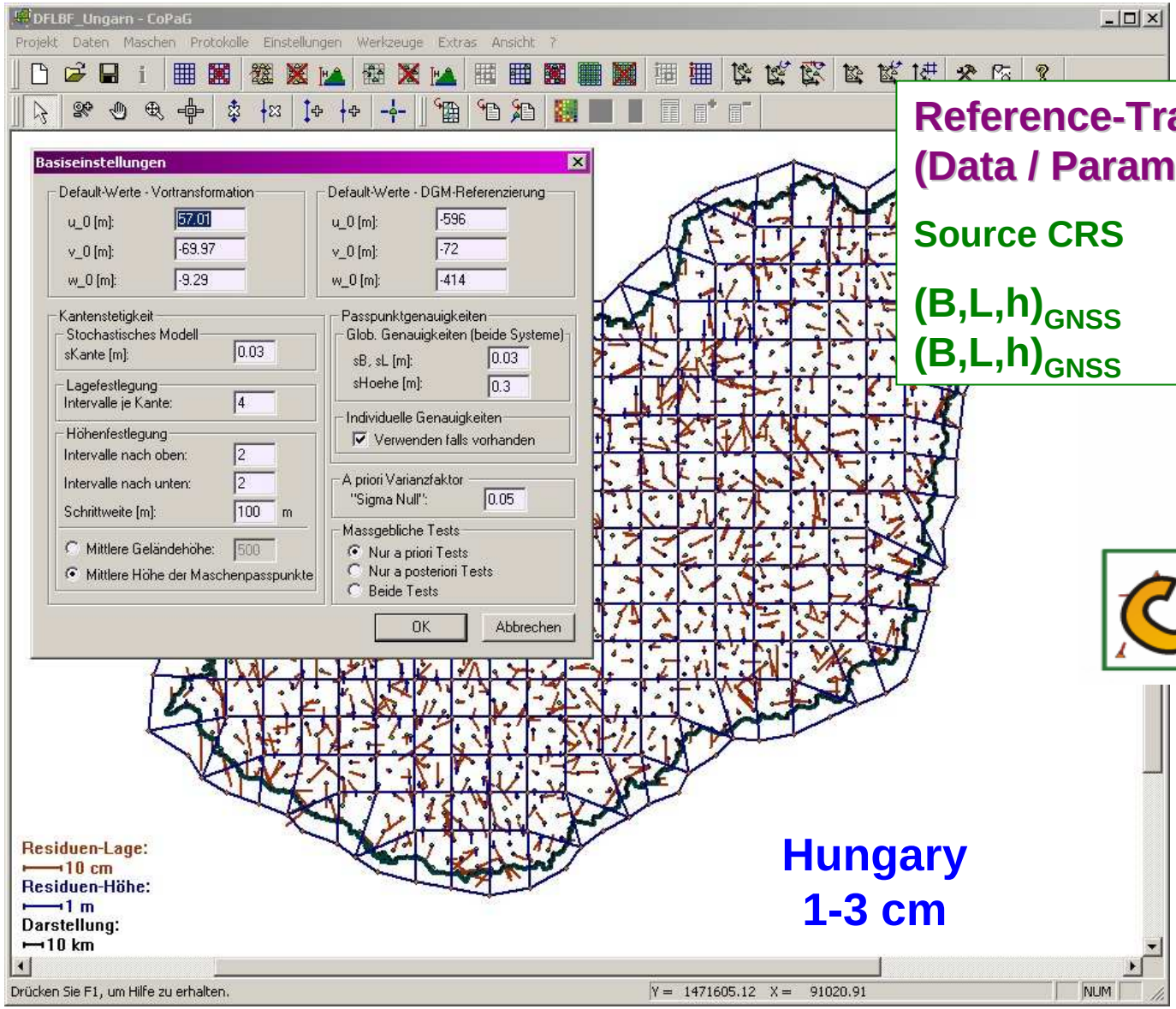
## COPAG = Continuously Patched Georeferencing




**Continuity along the Mesh Borders!**

# Transformation Problems and Reference Transformations

## 1.) Horizontal Datum Transition from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$




**Hungary**
**1-3 cm**

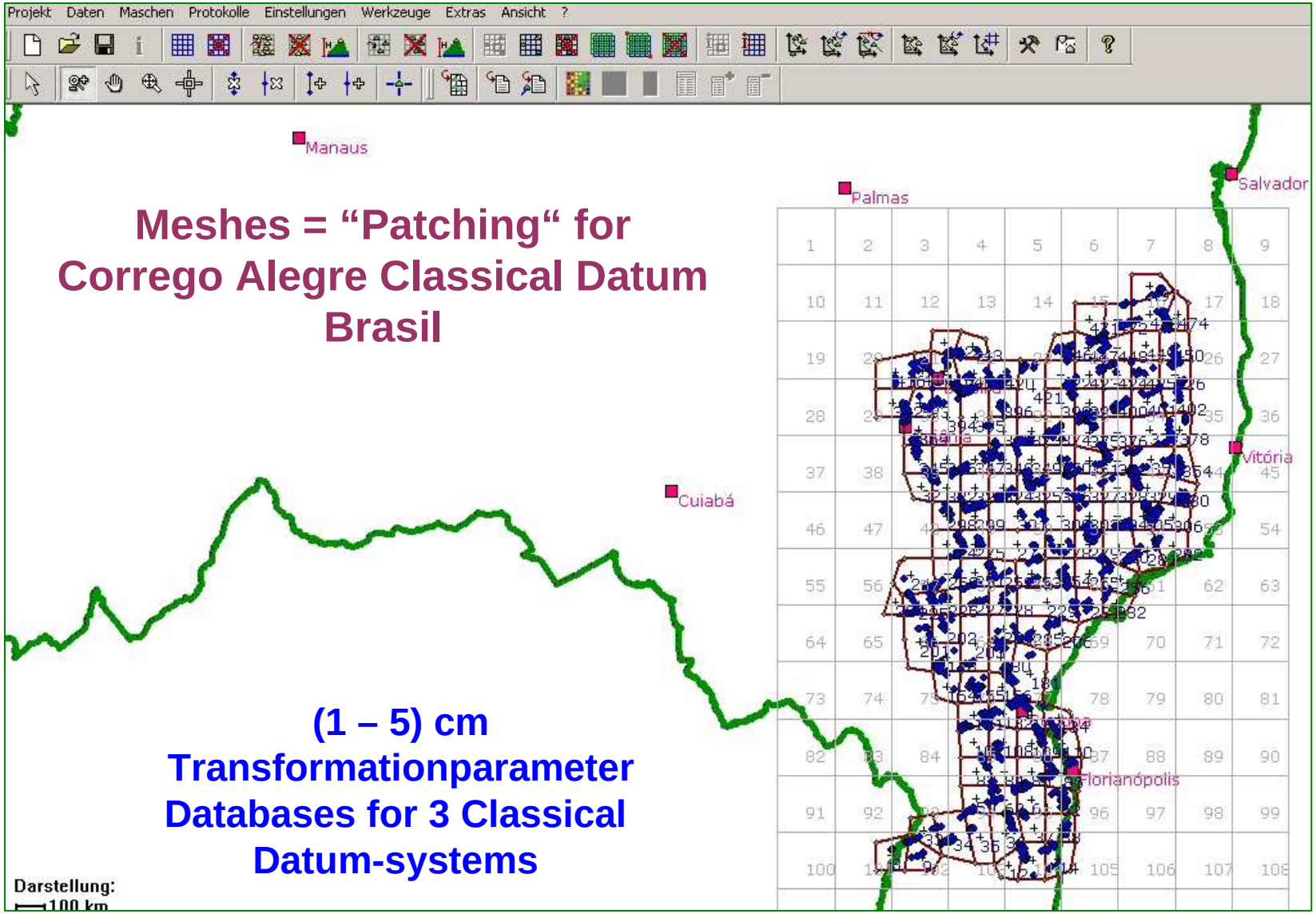
**Reference-Transformation**
**(Data / Parameters / Algorithms)**

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

**DFLBF_DB**
**Transformation Parameters & Residuals**

# Transformation Problems and Reference Transformations

## 1.) Horizontal Datum Transition from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$

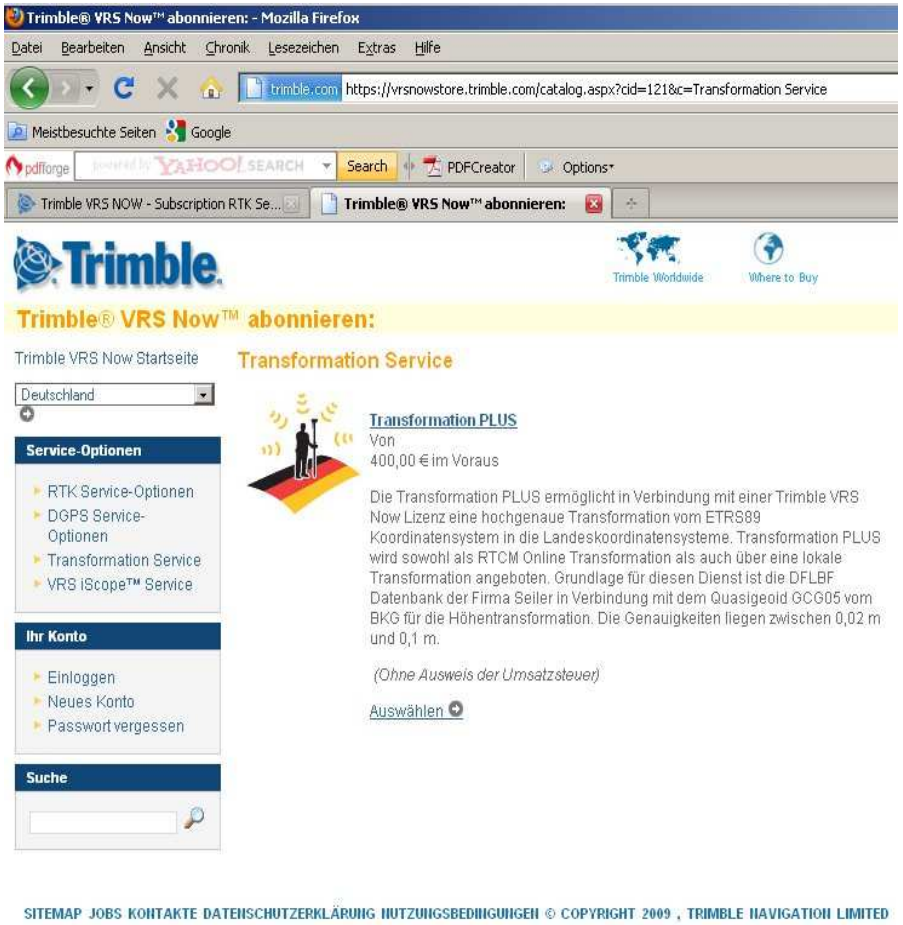



**Meshes = "Patching" for Corrego Alegre Classical Datum Brasil**

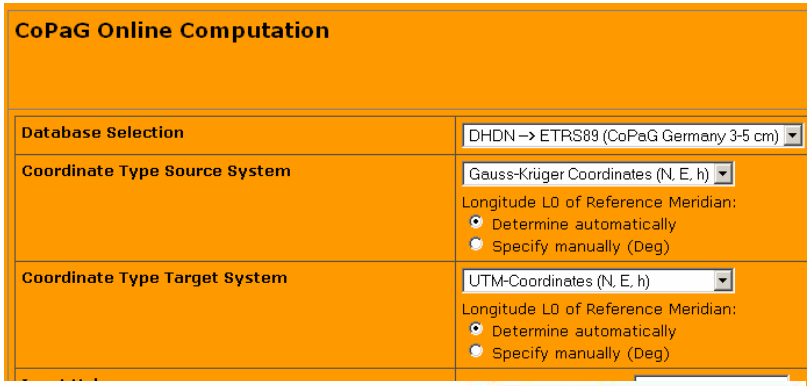
**(1 – 5) cm Transformationparameter Databases for 3 Classical Datum-systems**

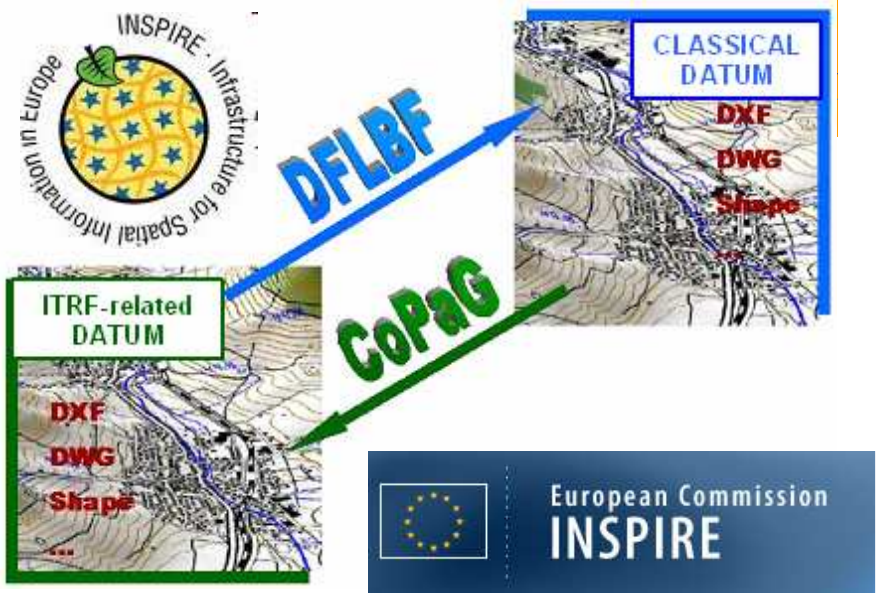
# Horizontal Transformation Problems and Reference Transformations

## 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 see www.geozilla.de

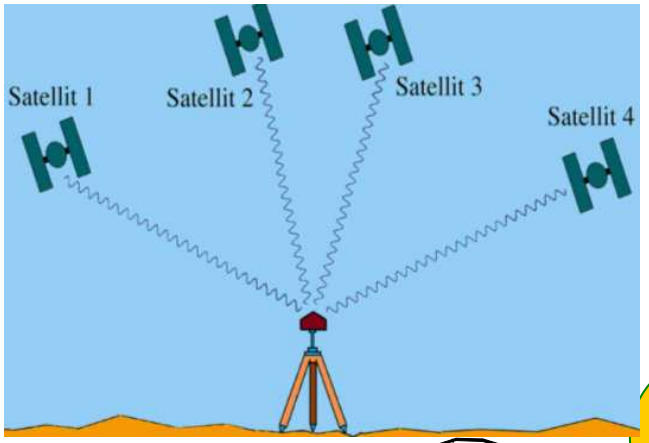


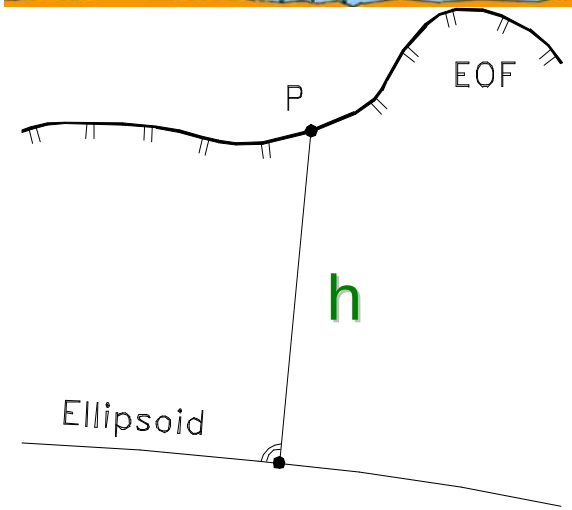

## 1.2 Horizontal Datum Transition from $(B,L)_{Classical}$ to $(B,L)_{GNSS,ITRF}$ COPAG-Databases for GIS see: www.geozilla.de



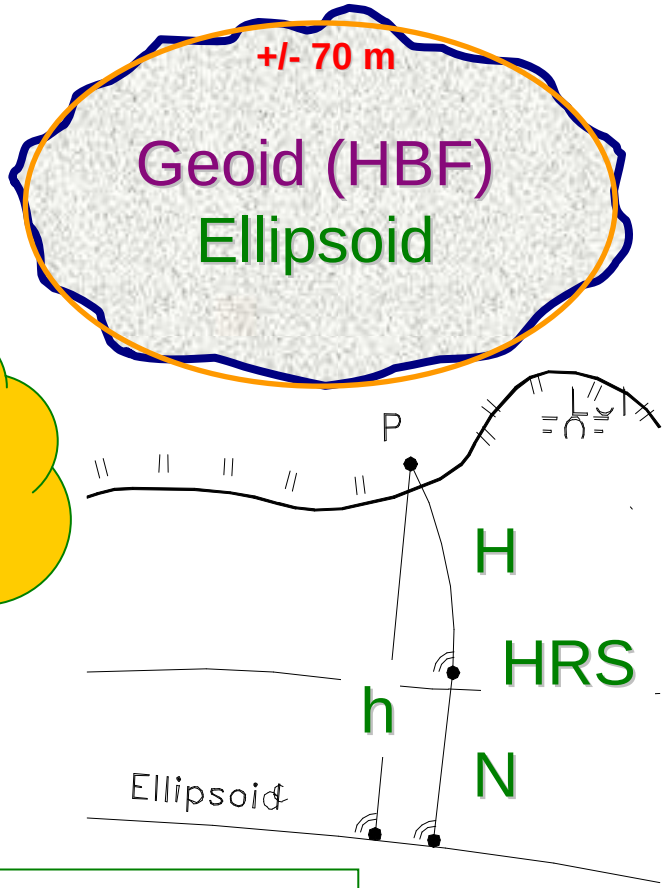



# 2. Height Problem / HRS Transition - Karlsruhe Reference Transformation




**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 |

# 2. Height Problem / HRS Transition - Karlsruhe Reference Transformation

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

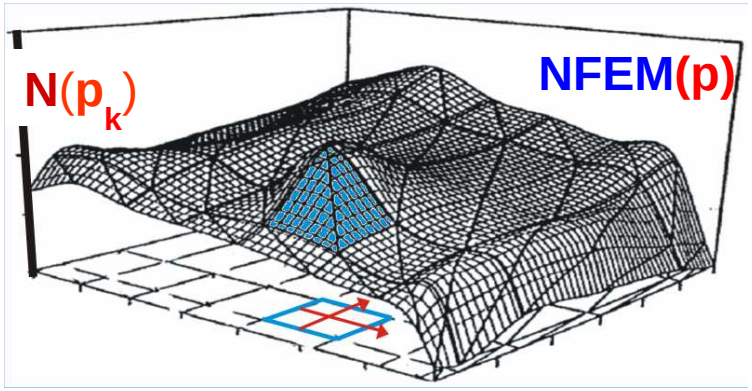
$$H + v = H$$

$$N_G{}'^{j} + v^{j} = \mathbf{f}^T \cdot \mathbf{p} + \partial N_G(\mathbf{d}^{j})$$

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

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

$$\frac{a}{4 \cdot \pi \cdot \gamma(B)} \iint_{\sigma} \Delta \mathbf{g} \cdot S(\psi) d\sigma + v = \mathbf{NFEM(p)} = \mathbf{f}^T \cdot \mathbf{p}$$




DFHBF DB

**Reference-Transformation**

**Source CRS** **Target CRS**

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

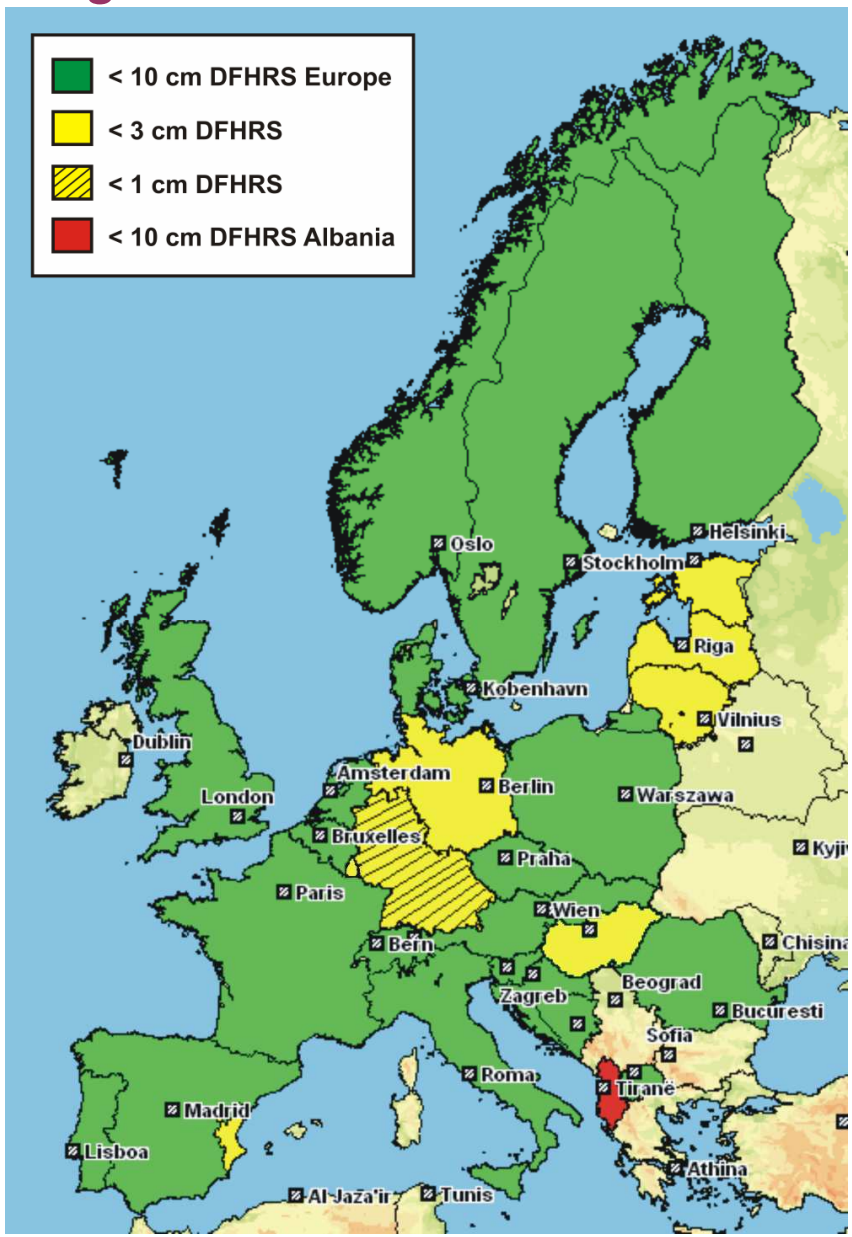
$$g^{LGV}_{grav\,r} + v = \sum_{k=0}^{\infty} \left(\frac{a}{r}\right)^{n(k)+1} \frac{(n(k)+1)}{r} \sum_{m=0}^{k} (\bar{C}'_{n(k)),m} \cdot \cos m\lambda' + \bar{S}'_{n(k),m} \cdot \sin m\lambda') \cdot P_{n(k),m}(\cos\theta') + dg(\mathbf{d})$$

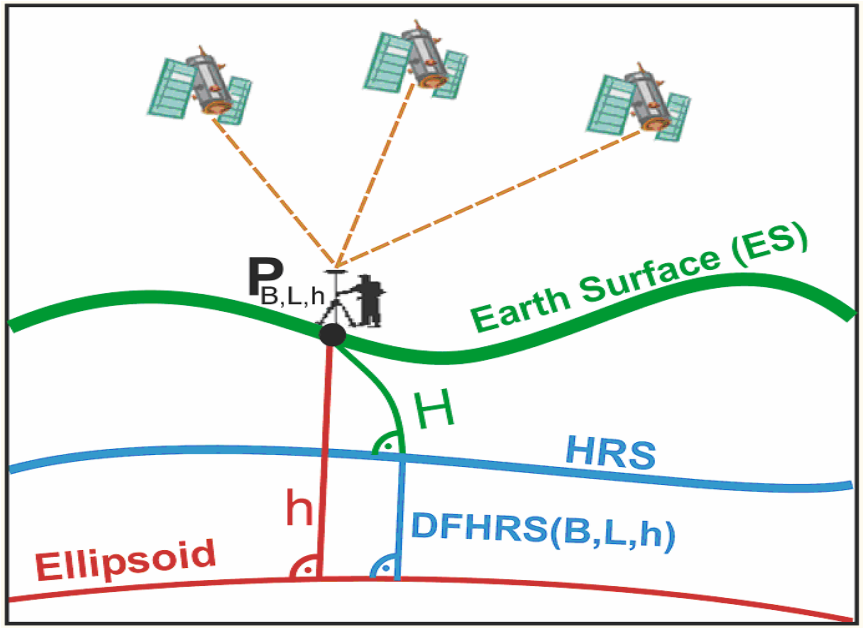
$$N^{j}_{GPM} + v = N(\bar{C}_{n(k),m}, \bar{S}_{n(k),m}) + \partial N(\mathbf{d}^{j})$$

$$= \frac{1}{\gamma_Q} \left( \sum_{k=0}^{\infty} \left(\frac{a}{r}\right)^{n(k)+1} \sum_{m=0}^{k} (\bar{C}'_{n(k),m} \cdot \cos m\lambda' + \bar{S}'_{n(k),m} \cdot \sin m\lambda') \cdot P_{n(k),m}(\cos\theta') - Vref \right) + \partial N(\mathbf{d}^{j})$$

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

# 2. Height Problem / HRS Transition - Karlsruhe Reference Transformation



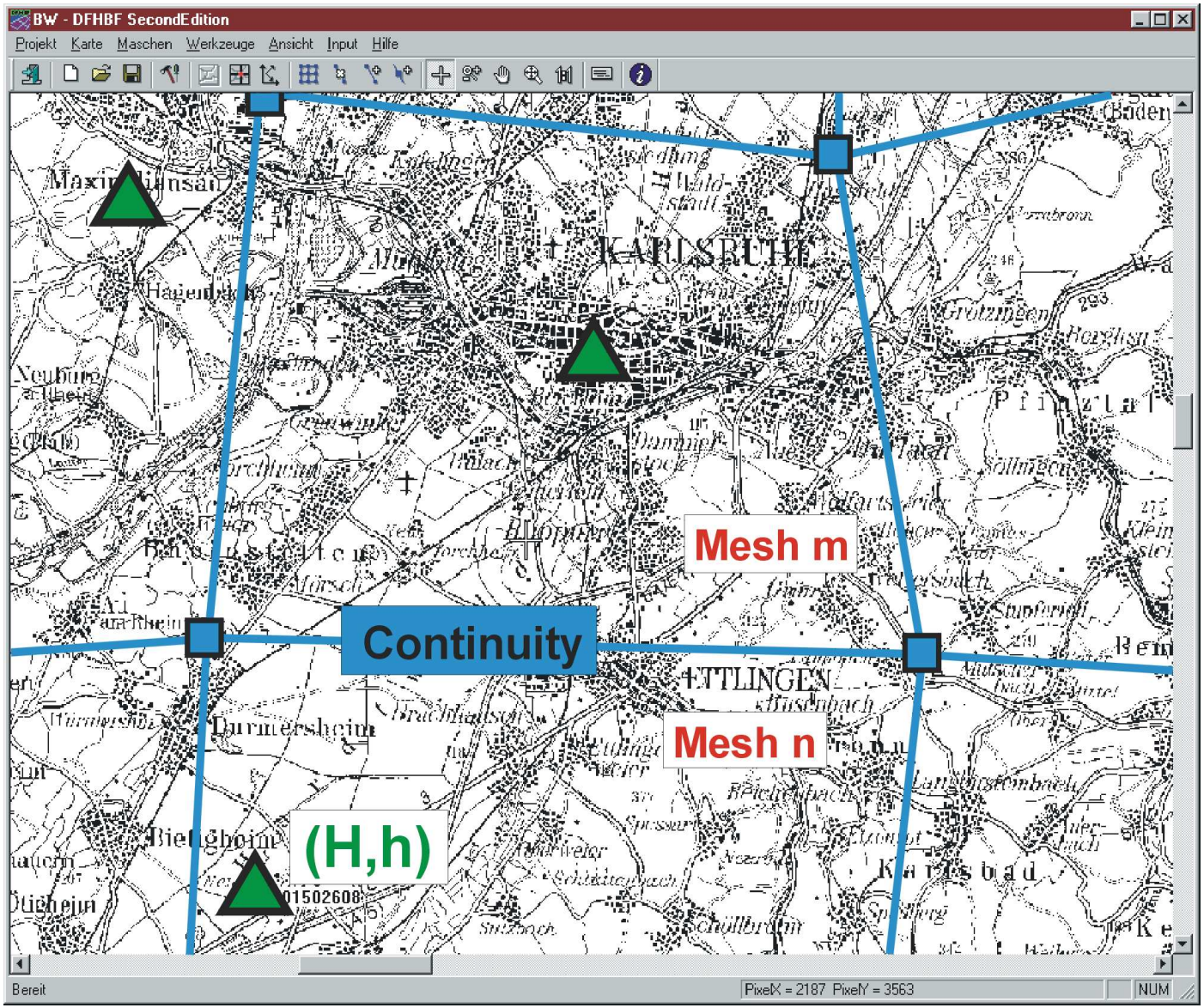



# 2. Height Problem / HRS Transition - Karlsruhe Reference Transformation

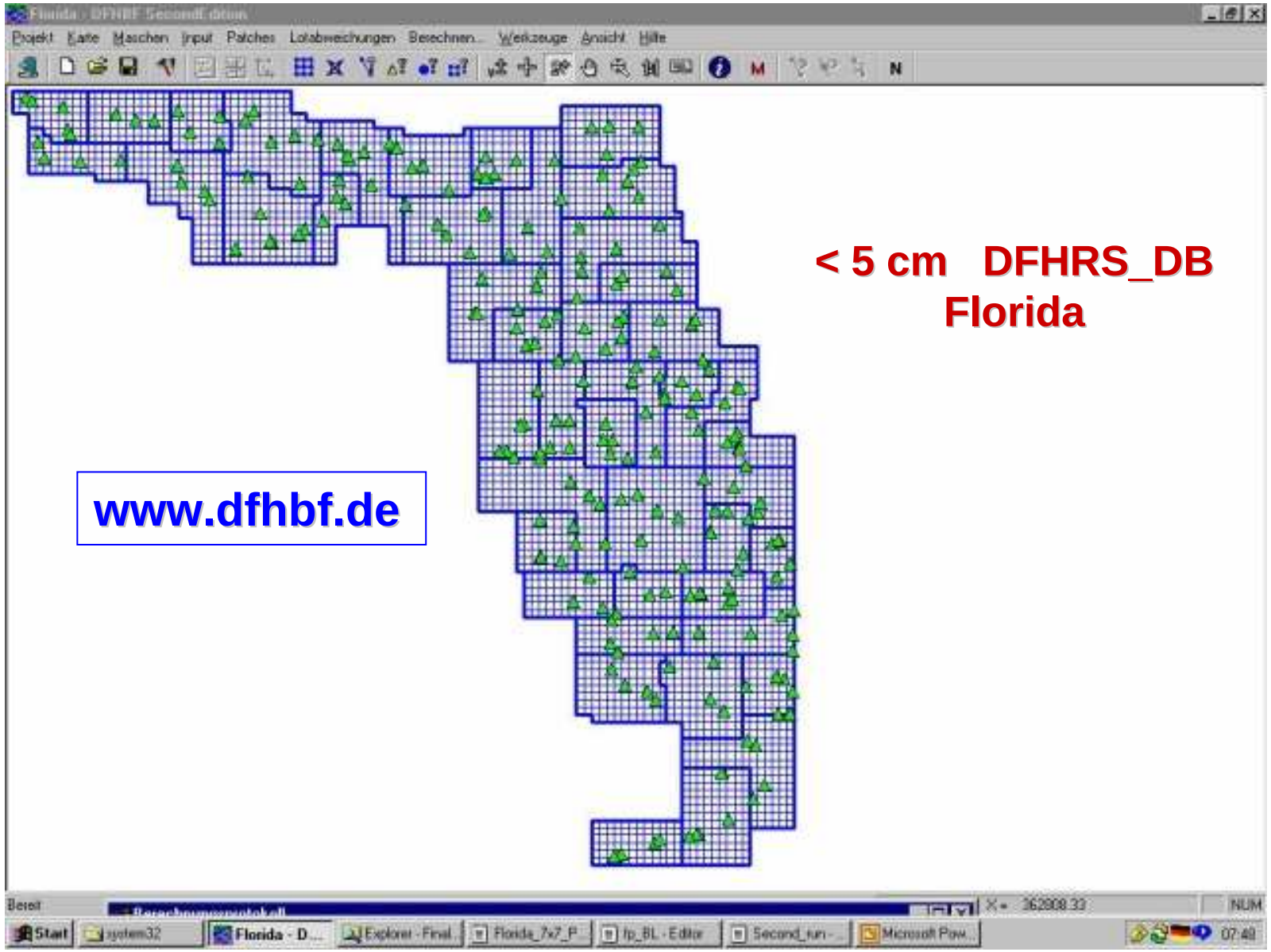
**www.dfhbf.de**

Software Sreenshot

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



# 2. Height Problem / HRS Transition - Karlsruhe Reference Transformation



# 2. Height Problem / HRS Transition - Karlsruhe Reference Transformation

**< 10cm DFHRS**
**Europe**
**„Fittingpoint-Design“**

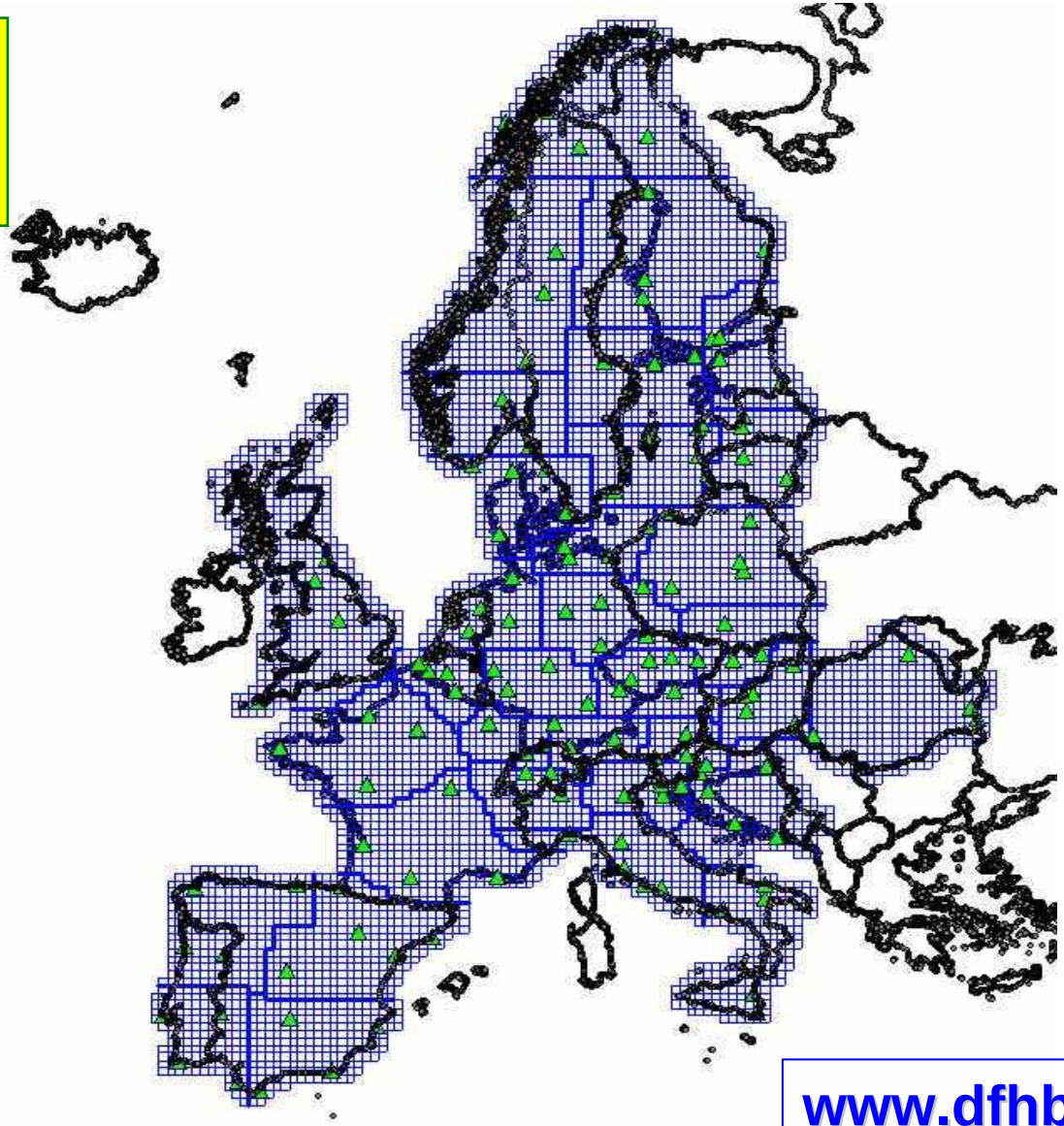
**ETRS89/EVRS**

**„GPS-/Levelling-Points of EVN“**

**Fitting Points**
**NFEM(p) =: h - H**

**Used for the**
**1st Version**
**< 10_cm DFHBFS**

**Europe**

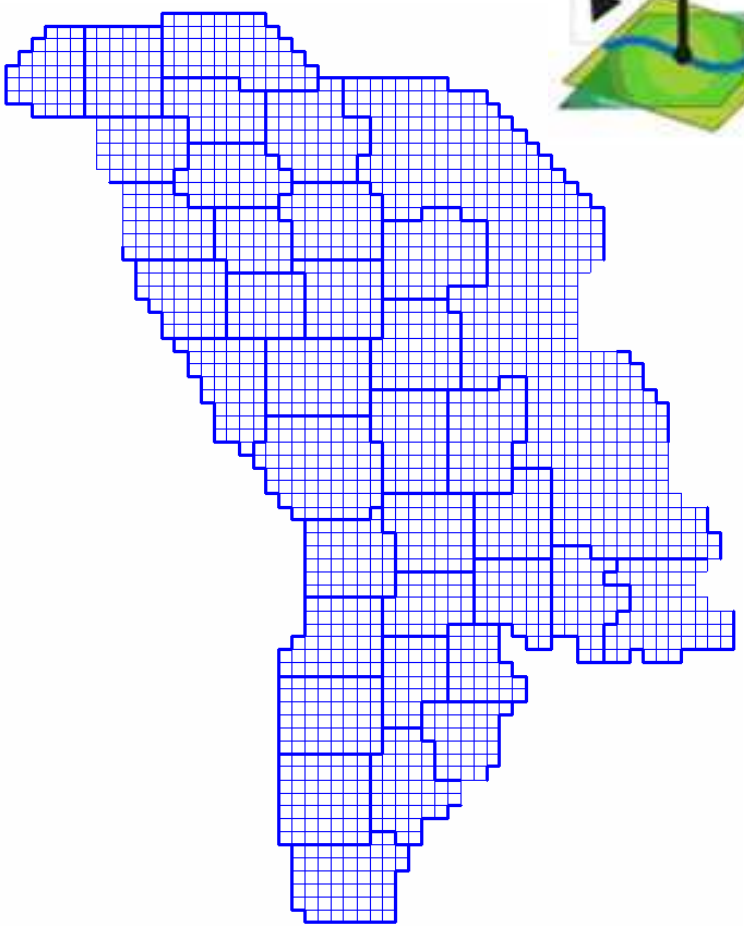


**www.dfhbf.de**

# 2. Height Problem / HRS Transition - Karlsruhe Reference Transformation

**www.moldpos.eu**

MOLDPOS



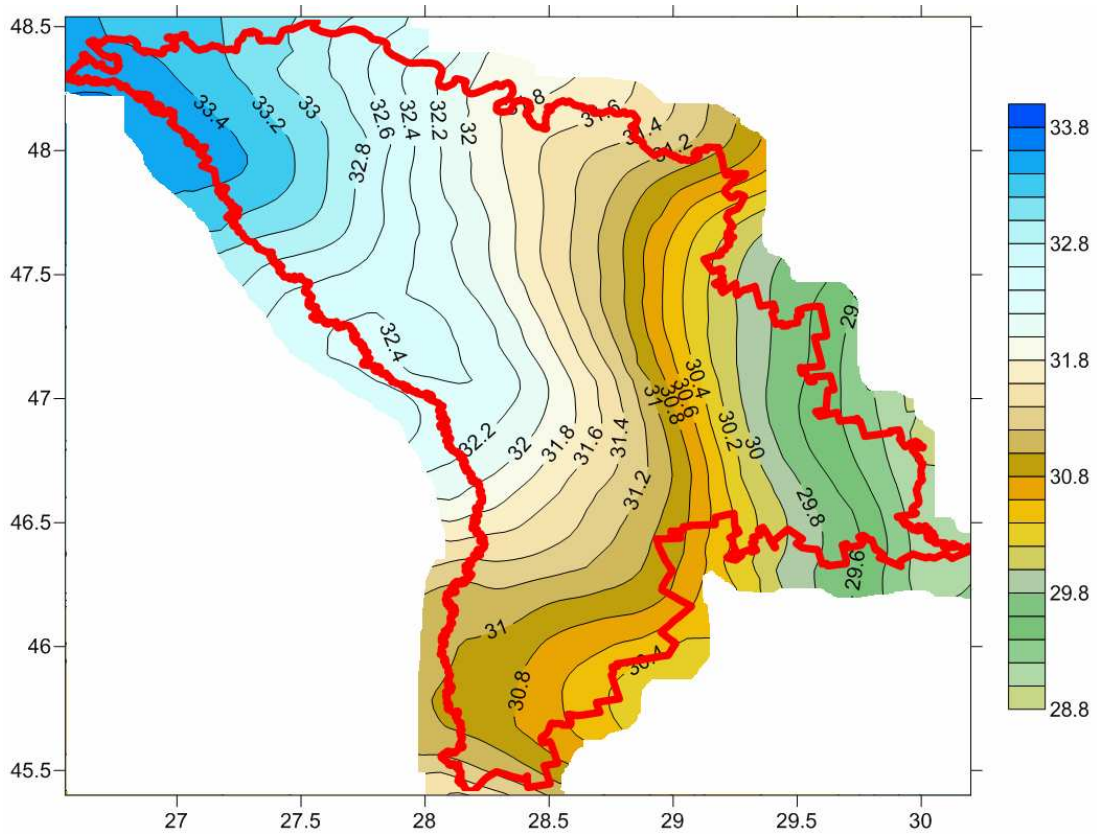
**www.dfhbf.de**

## 1-3 cm Quasigeoid for Moldova

Patching of

**EGG97 or EGM2008 GPM**

**Nearly same results**



# 2. Height Problem / HRS Transition - Karlsruhe Reference Transformation

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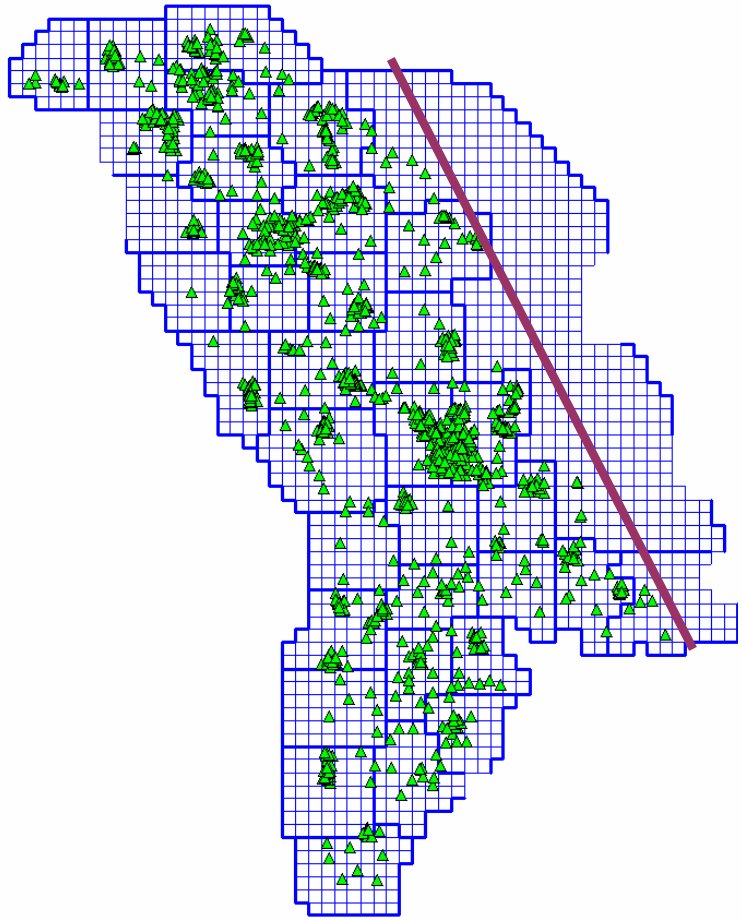
MOLDPOS

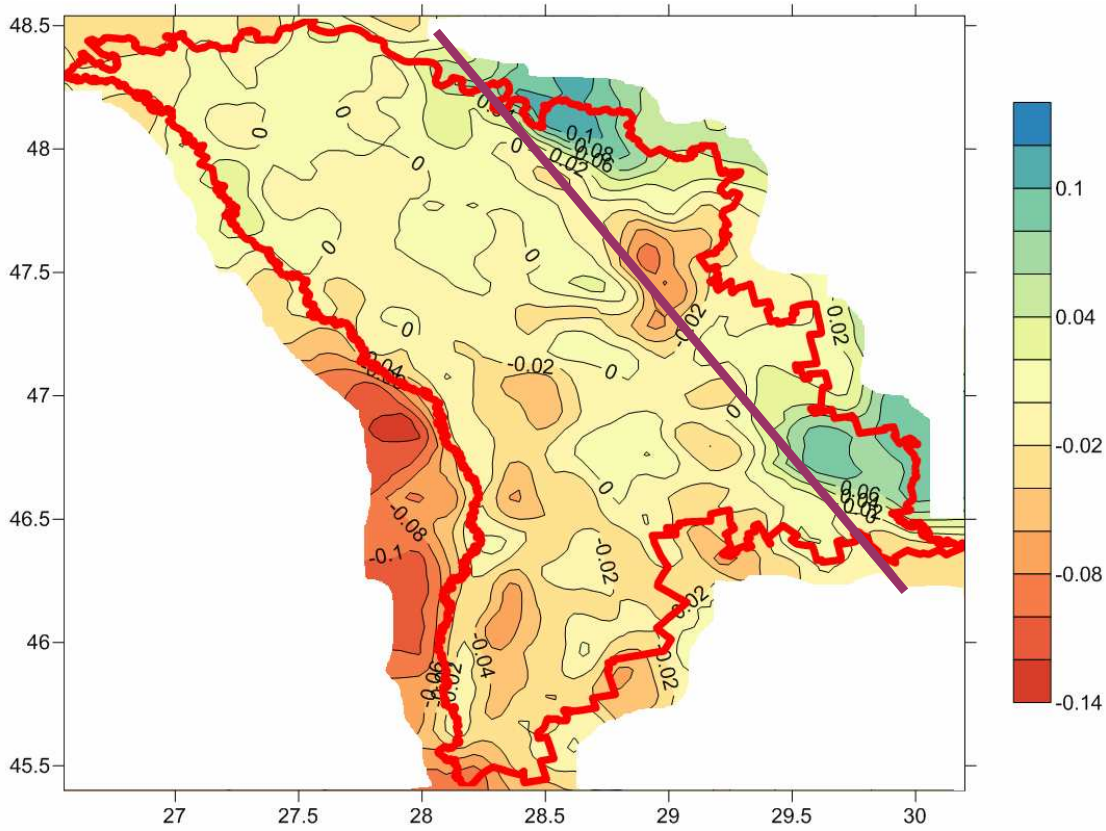
**1-3 cm Quasigeoid for Moldova**

Patching of

**EGG97 or EGM2008 GPM**

**Nearly same results**





# RTCM 3.1 Observations Corrections

# &

# „Seven RTCM Transformation Messages“

**(Scientific Member of International RTCM-Working Group 2004-2007)**

- **Transformation-Parameters (1021,1022)**
- **Residual-Grids and/or Geoid-Representations (1023,1024)**
- **Projection-Information (1025,1026,1027)**

**sent by GNSS-Positioning-Service**

**to**

**GNSS-Positioning-User**

**NMEA-based request to RTCM-Transformation Messages Server)**

# 3. Reference Transformations and RTCM Transformationmessages

## *Willkommen zur Intergeo 2004*

Trimble ist stolz darauf, auch in diesem Jahr ein offizieller Sponsor des Intergeo-Kongresses und Intergeo-Treffs zu sein.

Wir von Trimble haben es uns zum Ziel gesetzt, Ihnen die neueste Technologie bereitzustellen, die es Ihnen ermöglicht, die Vorteile lokalisierter, integrierter Vermessungslösungen zu nutzen und Ihre Effizienz, Produktivität und Ihren Gewinn zu erhöhen. Als Beweis unseres Engagements präsentieren wir in diesem Jahr eine Reihe von Lösungen, die speziell für unsere europäischen Kunden entwickelt wurden.

Durch die Akquisition der GeoNav GmbH sind wir in der Lage, Ihnen eine neue Feldsoftwarelösung, den Trimble Survey Manager, an die Hand zu geben. Die Software ist auf Anwendungen in der europäischen Vermessungsindustrie, und insbesondere auf Katastervermessungen, zugeschnitten. Des Weiteren haben wir unser GPS-Produktportfolio mit dem Trimble R8 um den „ultimativen VRS-Rover" ergänzt.

Der Trimble R8 ist eine Kombination aus einem leichten, kabellosen Rover ohne externes GSM-Modem und der L2C-fähigen GPS-Technologie für den Einsatz in europäischen VRS-Netzen. Anwendern von Robotic-Totalstationen bieten wir das lizenzfreie 2,4 GHz GeoRadio mit modernster Spread Spectrum-Technologie an, die Interferenzen von anderen Funkgeräten auf belebten Baustellen

## Neue Trimble Survey Manager Software

**Die fortschrittliche Trimble Feldlösung für präzise Echtzeit-Vermessungen.**

Trimble Survey Manager basiert auf der beliebten DCTools Software von Trimble GeoNav. Es ist eine flexible, einfach zu verwendende Oberfläche für Ihr Vermessungssystem. Trimble Survey Manager besteht aus Softwaremodulen für Feld und Büro und wurde speziell für die Datenerfassung, Datenverarbeitung und die Dokumentation präziser Echtzeit-Vermessungen entwickelt.

**ALLES UNTER KONTROLLE – MIT DEM TRIMBLE SURVEY MANAGER**

Das Trimble Survey Manager Feldmodul läuft unter Windows 9x, 2000, XP und Windows CE. Sie können Feldvermessungen auf der Plattform ausführen, die den Projektanforderungen am besten entspricht, einschließlich Notebooks, Tablet PCs oder unseren robusten und leistungsstarken Trimble Controllern: TSCe™, ACU oder Trimble Recon™. Trimble Survey Manager ist vollständig mit Trimble GPS- und Trimble Totalstationssystemen kompatibel und erlaubt die komplette Steuerung aller Instrumente und Messmethoden im Feld.

Die Trimble Survey Manager Software enthält die offiziellen Referenzkoordinaten des amtlichen Koordinatensystems, bietet volle SAPOS©- und ascos©-Unterstützung und die Implementierung von DFLBF und DFHBF. Sie gewährleistet die exakte Datenerfassung, -verarbeitung und Dokumentation nach amtlichen Vorgaben und wurde speziell für katasterspezifische Anforderungen in Deutschland optimiert.

## Bewährte GPS-Technologie in einer kostengünstigen L1-Lösung: das NEUE Trimble 5700 L1 GPS-System

**Der 5700 L1 GPS-Empfänger von Trimble ist ein bedienerfreundlicher GPS-Empfänger speziell für statische, L1-FastStatic und kinematische Vermessungen. Er ist eine flexible, kostengünstige Vermessungslösung mit bewährter Trimble GPS-Technologie.**

**UNTERNEHMEN**

Beginnen Sie mit einer preisgünstigen Trimble GPS-Einstiegslösung und rüsten Sie diese später für erhöhte Produktivität zu einem leistungsfähigen Zweifrequenz-System auf. Sie können Ihr System bei Bedarf sogar mit RTK nachrüsten.

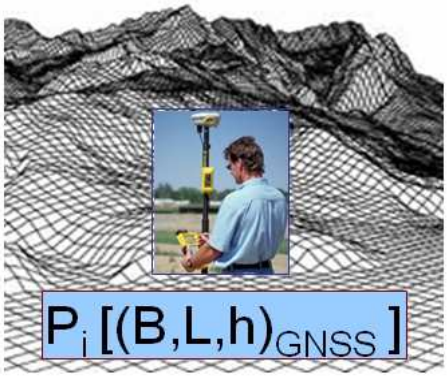
# 3. Reference Transformations and RTCM Transformationmessages

# 3. Reference Transformations and RTCM Transformationmessages

# 3. Reference Transformations and RTCM Transformationmessages

## „Gridding“ of Reference Transformations

**Source CRS - Grid**




Generated Grid of Local Virtual Fitting Points $P_i$

Any kind of individual

Reference Transformation

**Target CRS - Grid**

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

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

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

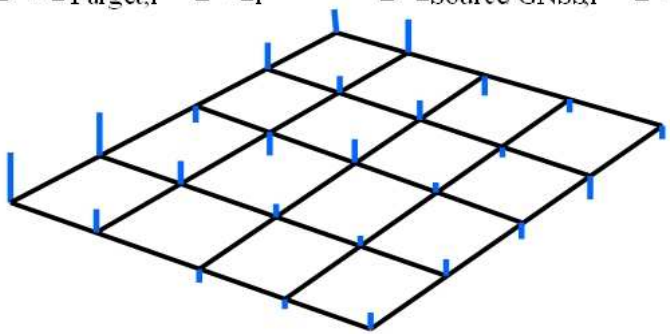
Resulting Local Virtual Fitting Points $P_i$

Gridding into 1.] and/or 2.]

1.] 7 Parameter Transformation

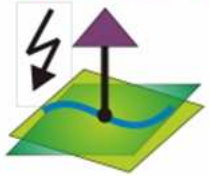
$$\begin{bmatrix} x_T \\ y_T \\ z_T \end{bmatrix}_{Target,i} + \begin{bmatrix} r_x \\ r_y \\ r_z \end{bmatrix}_i = s \cdot \mathbf{R} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{Source/GNSS,i} + \begin{bmatrix} t_x \\ t_x \\ t_z \end{bmatrix}$$

2.] Geoid/HRS Grid



7 Parameter Trend and 3D „Small“ Residual Grid

RTCM



Grid of $N_i$

## 3. Reference Transformations and RTCM Transformationmessages

# 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 | |
| $\phi_V$ | DF+10 | 49.0102 | |
| $\lambda_V$ | 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**

# 3. Reference Transformations and RTCM Transformationmessages

## Message 1023 or Message 1024

::

| | | | | |
|---|---|---|---|---|
| $\delta N_{14}$ | Residuals $P_{14}$ | DF+71 | 0.001 | :: |
| $\delta E_{14}$ | | DF+72 | 0.013 | |
| $\delta h_{14}$ | | DF+73 | 0.049 | |
| $\delta N_{15}$ | Residuals $P_{15}$ | DF+71 | 0.005 | |
| $\delta E_{15}$ | | DF+72 | 0.009 | |
| $\delta h_{15}$ | | DF+73 | 0.088 | |
| $\delta N_{16}$ | Residuals $P_{16}$ | DF+71 | 0.006 | |
| $\delta E_{16}$ | | DF+72 | -0.002 | |
| $\delta h_{16}$ | | 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 $N_i$ ($dN_i$)**

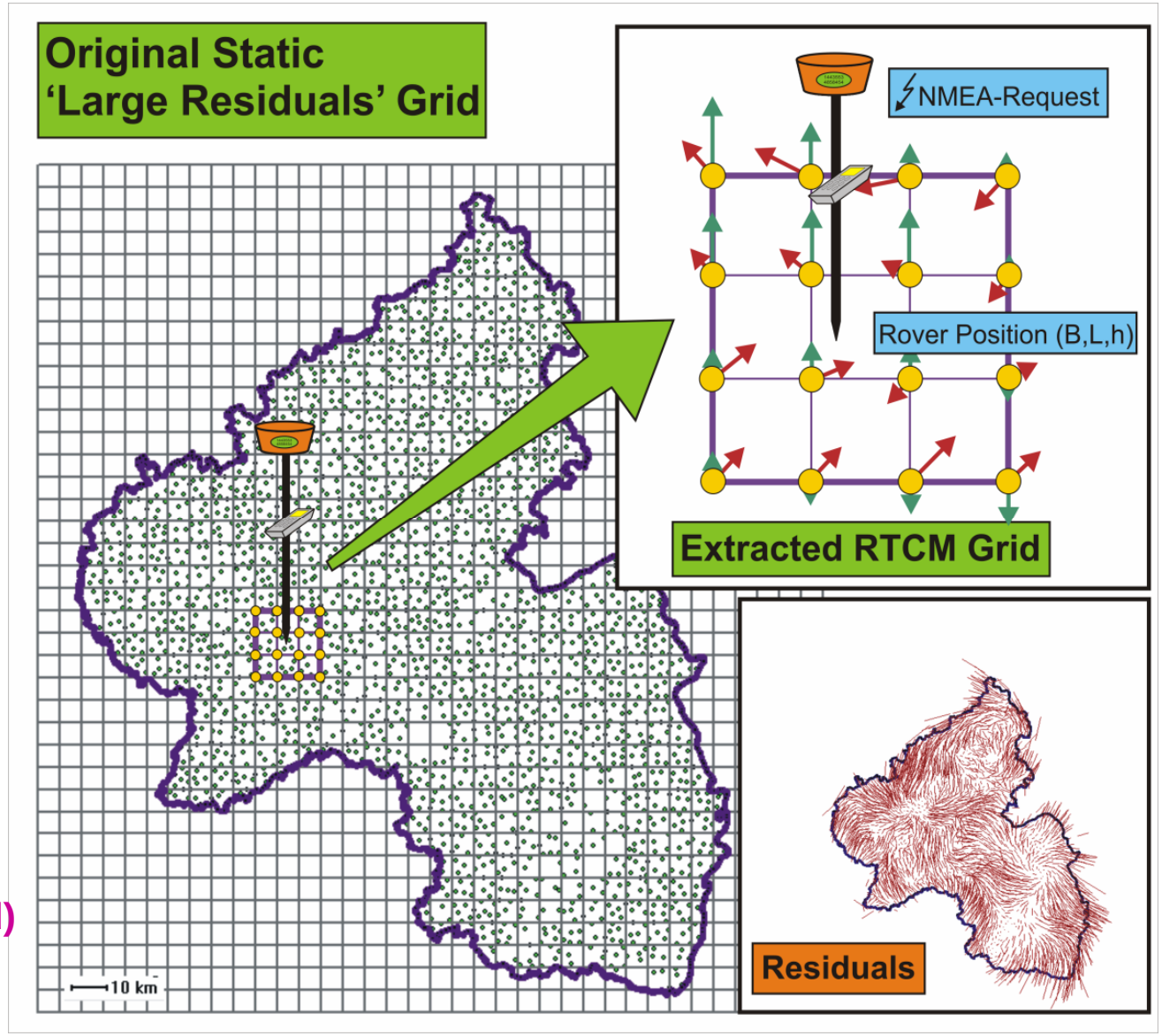
# 3. Reference Transformations and RTCM Transformationmessages

**Using Reference Transformations**

**to compute a country-wide**

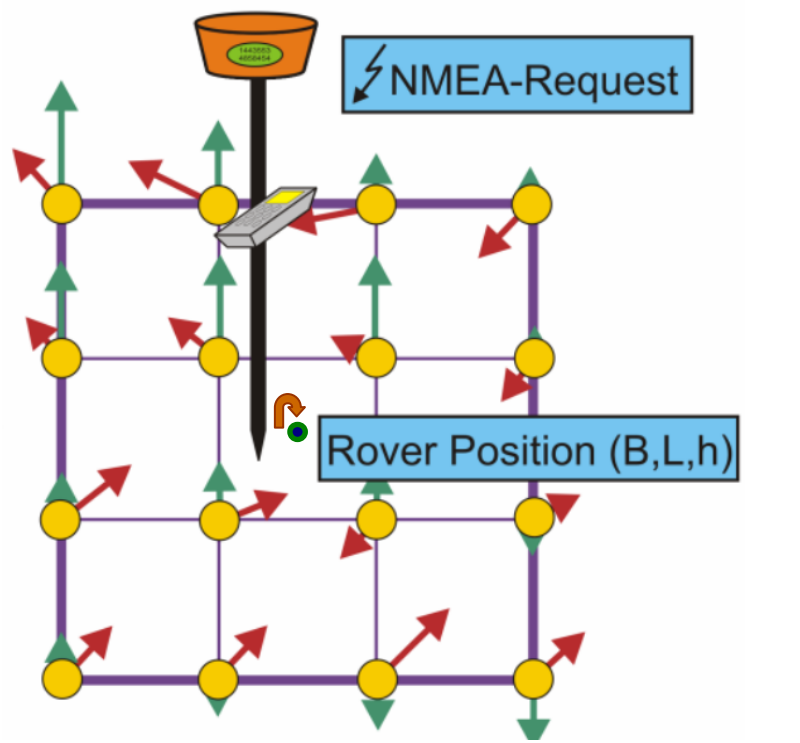
**1.) „STATIC GRID“**

**(„Large Residuals“ Grid)**



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

## 2.) „Dynamic Grid“




### Advantages

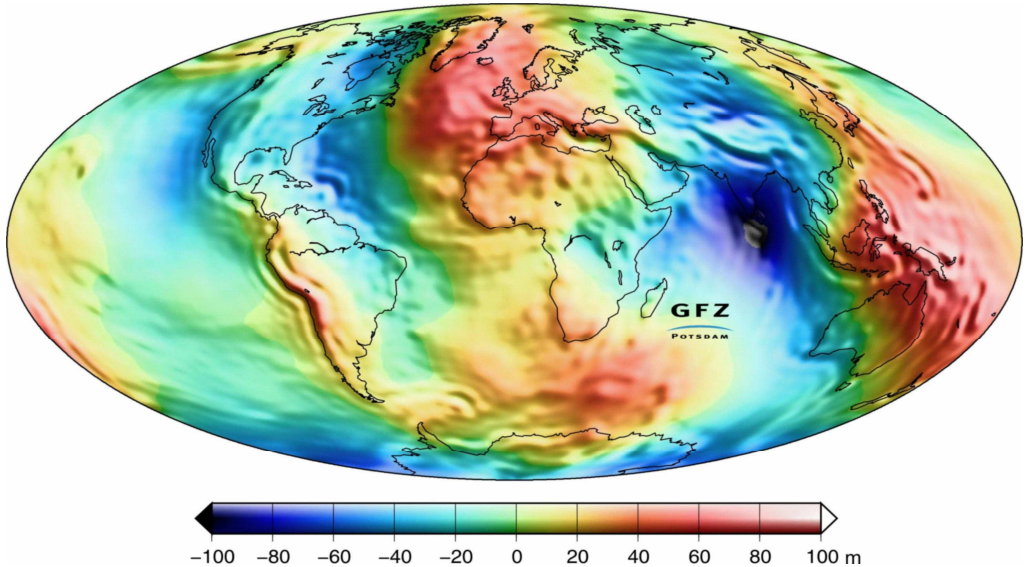
1.) No preceeding „Gridding“ Discretization Error
2.) Small Residuals - Small Interpolation error
3.) De facto - De facto independence of the residual interpolation method in the rover

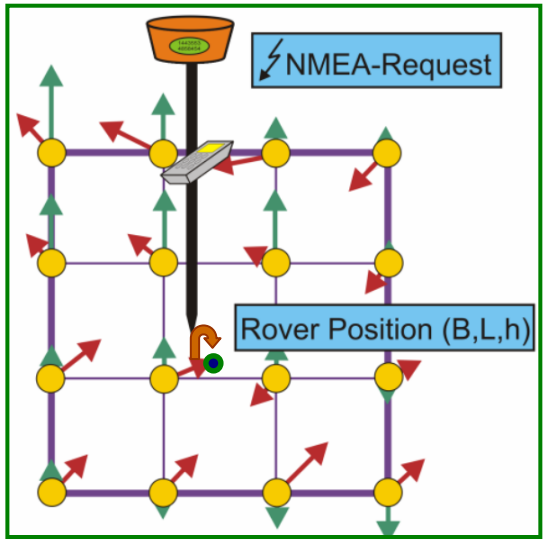
# 3. Reference Transformations and RTCM Transformationmessages

## Using Reference Tranformations to compute grids dynamically

## „Dynamic Grid“

### 4.) Direct use of Original Reference Transformations




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

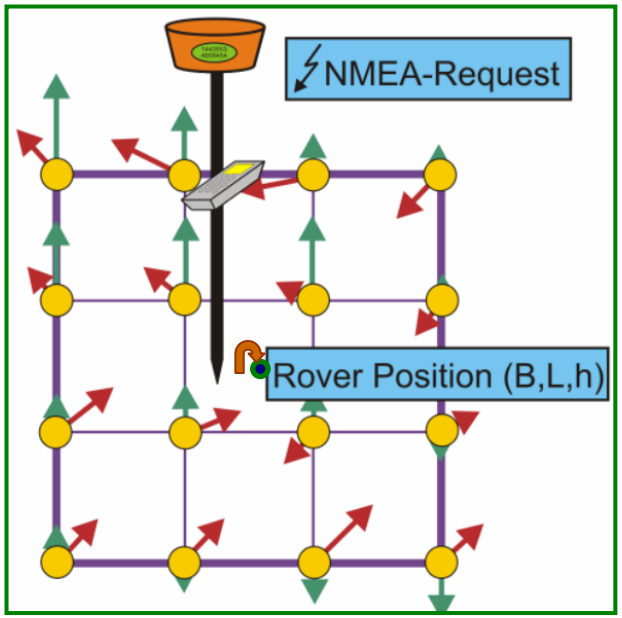
$$\begin{bmatrix}x\\y\\z\end{bmatrix}=\begin{bmatrix}u_i\cdot\sqrt{1+\varepsilon^2/u^2}\cdot\cos ß\cdot\cos\lambda\\ u_i\cdot\sqrt{1+\varepsilon^2/u^2}\cdot\cos\beta\cdot\sin\lambda\\ u\cdot\sin\beta\end{bmatrix}\qquad U=U(a,\varepsilon,\omega,M)_{REF}\,|\,(ß,\lambda,u))$$

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

# 3. Reference Transformations and RTCM Transformationmessages

## 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**

# 3. Reference Transformations and RTCM Transformationmessages

**General Configurable RTCM Transformation Messages Server**

***All kind of Reference Transformations in so called Transformation Modules***

**Dynamic & Combined & Static RCTM-Messages**

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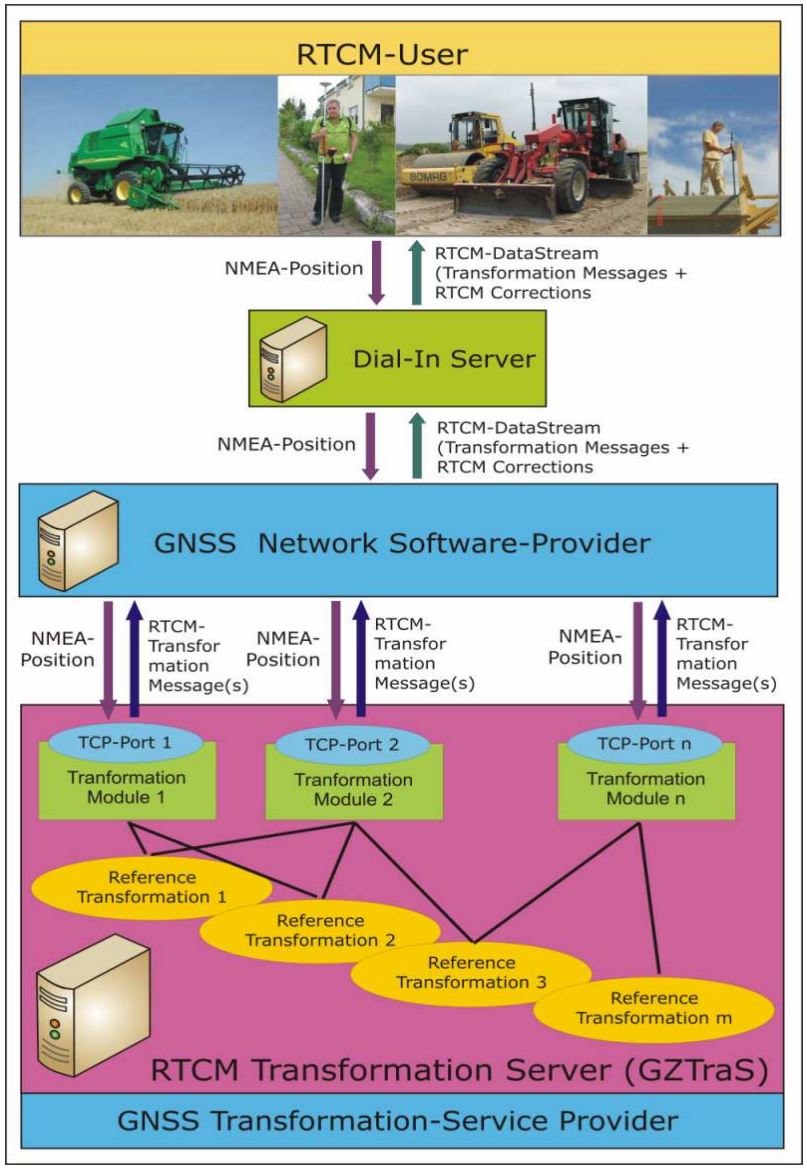
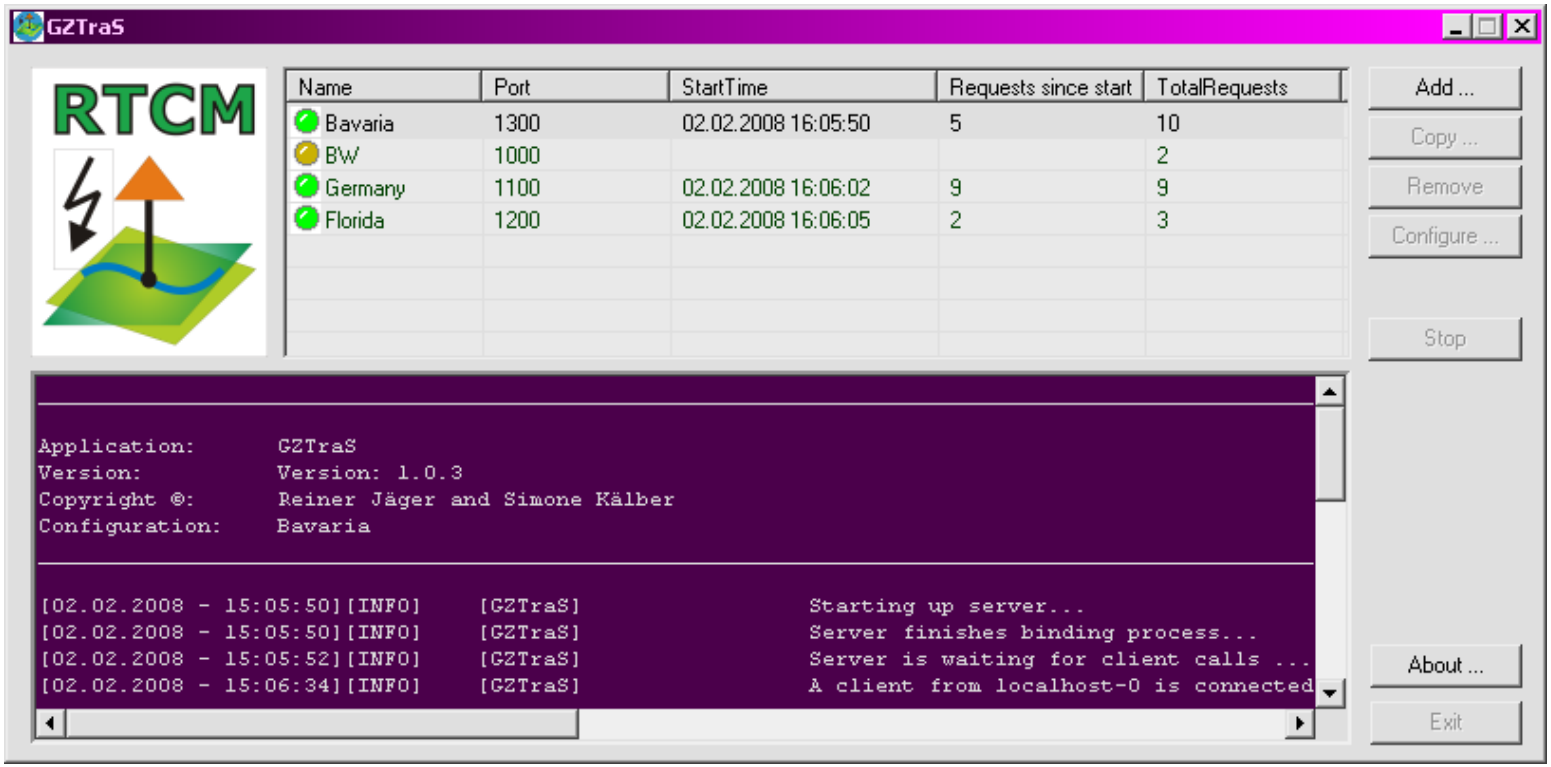
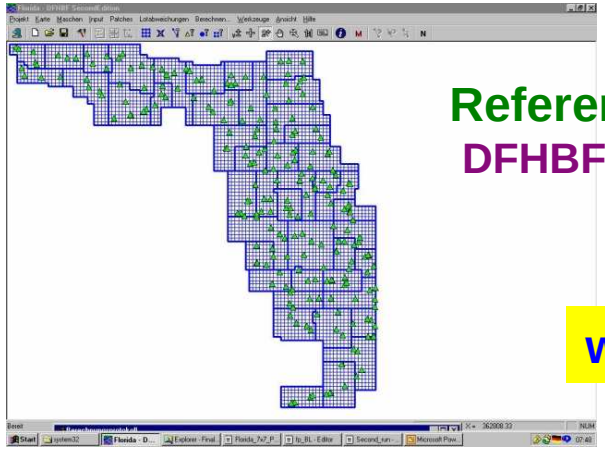
**Commuication Design in case of passing RTCM Transformation Messages through GNSS-Networking Software**



# 3. Reference Transformations and RTCM Transformationmessages



**Reference Transformations**

**DFHBF Florida**

**DFHBF Bavaria**

**DFLBF Bavaria**

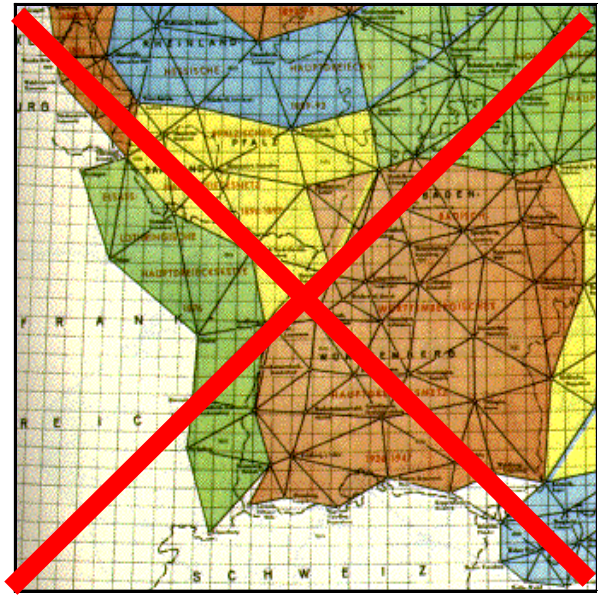
**www.geozilla.de**

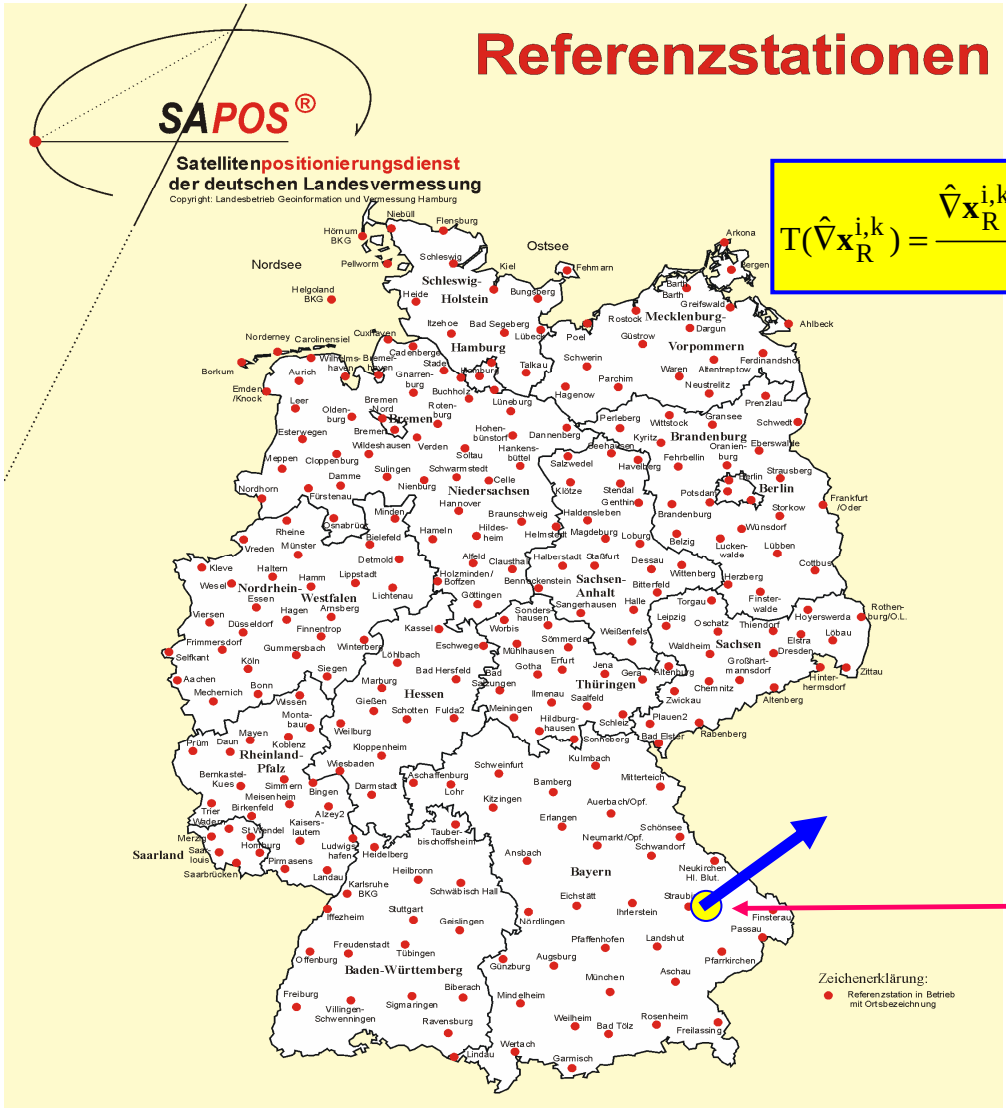
# 4. GNSS-Reference Station Monitoring

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

**www.monika.ag**

**Old Classical Systems**



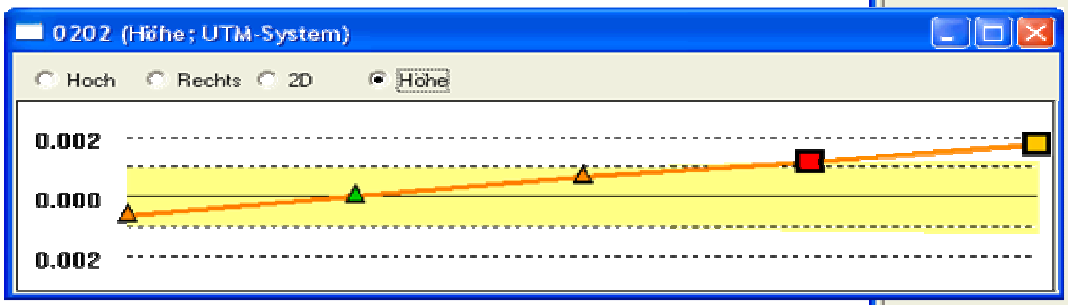


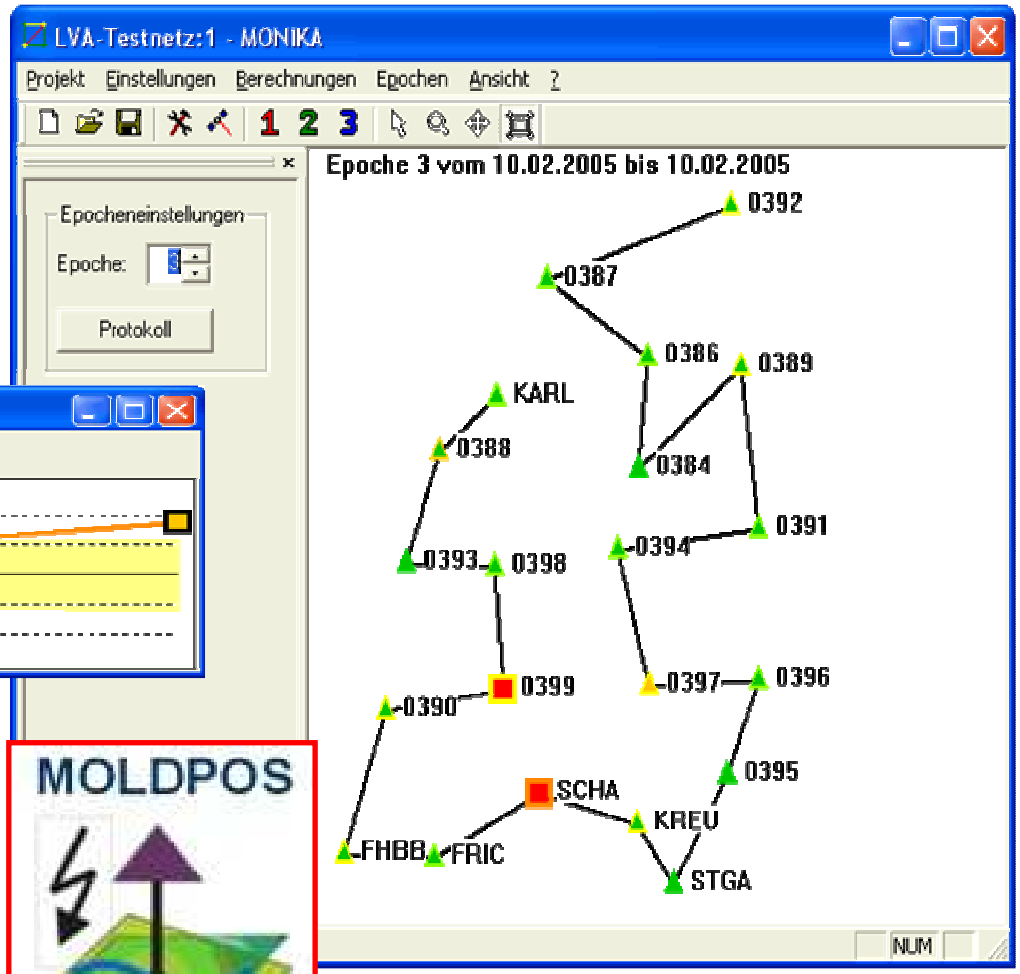

$$T(\hat{\nabla}\mathbf{x}_R^{i,k}) = \frac{\hat{\nabla}\mathbf{x}_R^{i,k\,T}\,(\mathbf{Q}_{\hat{\nabla}\hat{\nabla}_R}^{\;i,k})^{-1}\,\hat{\nabla}\mathbf{x}_R^{i,k}}{3\cdot\hat{\bar{\sigma}}^2}$$

# 4. GNSS-Reference Station Monitoring

**MONIKA**
**Coordinate related Reference-Points Deformation Analysis**

**Multivariate and Multi-Epoch Congruency Testing**




**Additionally: Object-Points + Tests**

**Additionally: Full spectrum of the Deformationsanalysis Features of GOCA**

MOLDPOS

**www.monika.ag**

# 4. GNSS-Reference Station Monitoring

## MONIKA Step 1

**GNSS RINEX-Data**

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

**GNSS-Processing**

→

**GOCA_BEPC_PRO**

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

**To be controlled by BPEC_PRO**

- LGO, Leica GeoOffice
- WA1 (Wanninger Software)
- Berner GPS-Software 5.0

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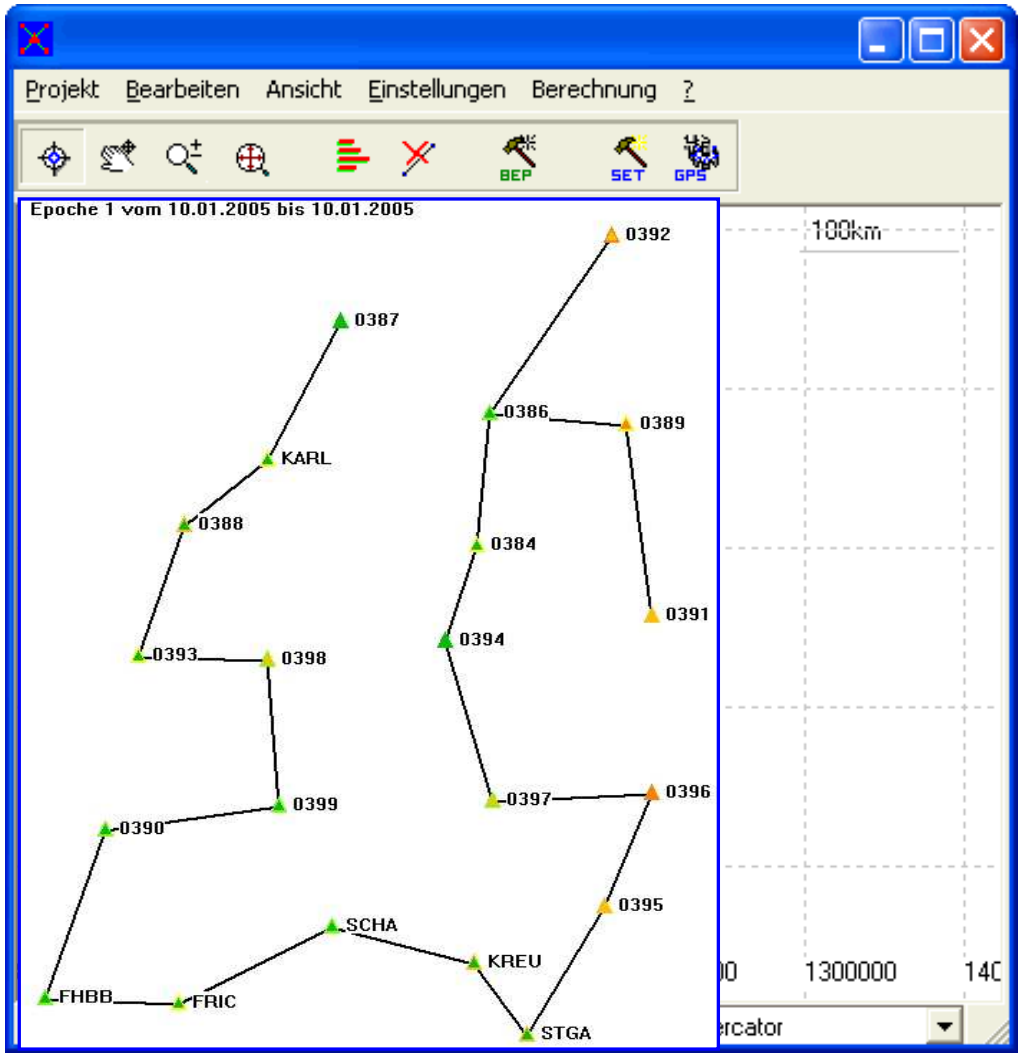


# 4. GNSS-Reference Station Monitoring

## MONIKA Step 2

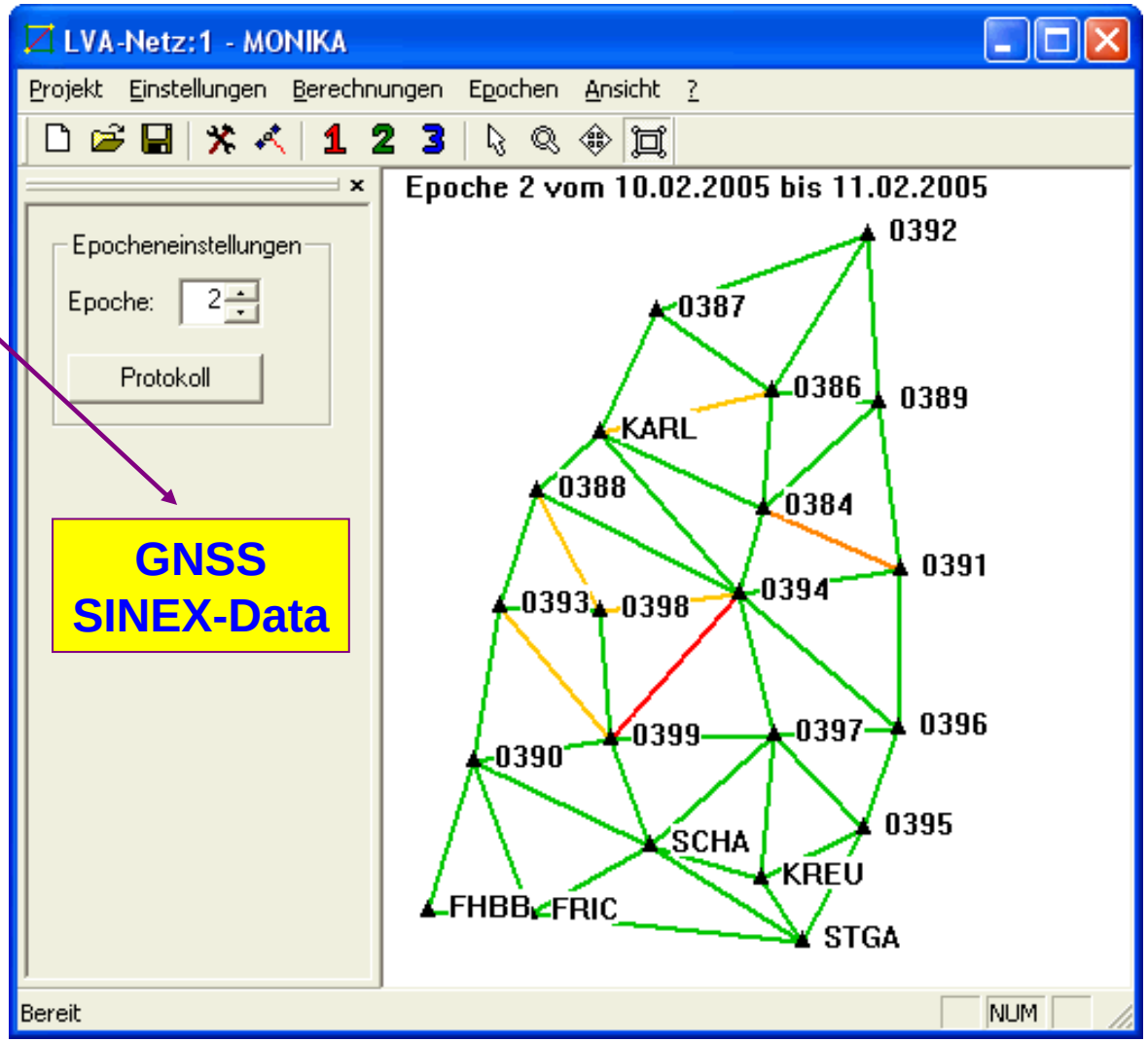
- Baselines
- Epoch Networks
- Partial networks
- Daily Solutions

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

$\Delta t$

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

- 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**

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

**S-Transformation d=3**

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

**MONIKA Trafo 2 - Step 2**

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# 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

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

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

# 4. GNSS-Reference Station Monitoring

## MONIKA Step 3 – Coordinate related Reference-Point-Deformationanalysis

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

$\Delta T$

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

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

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

# 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** $\nabla \mathbf{x}_R^{i,k}$

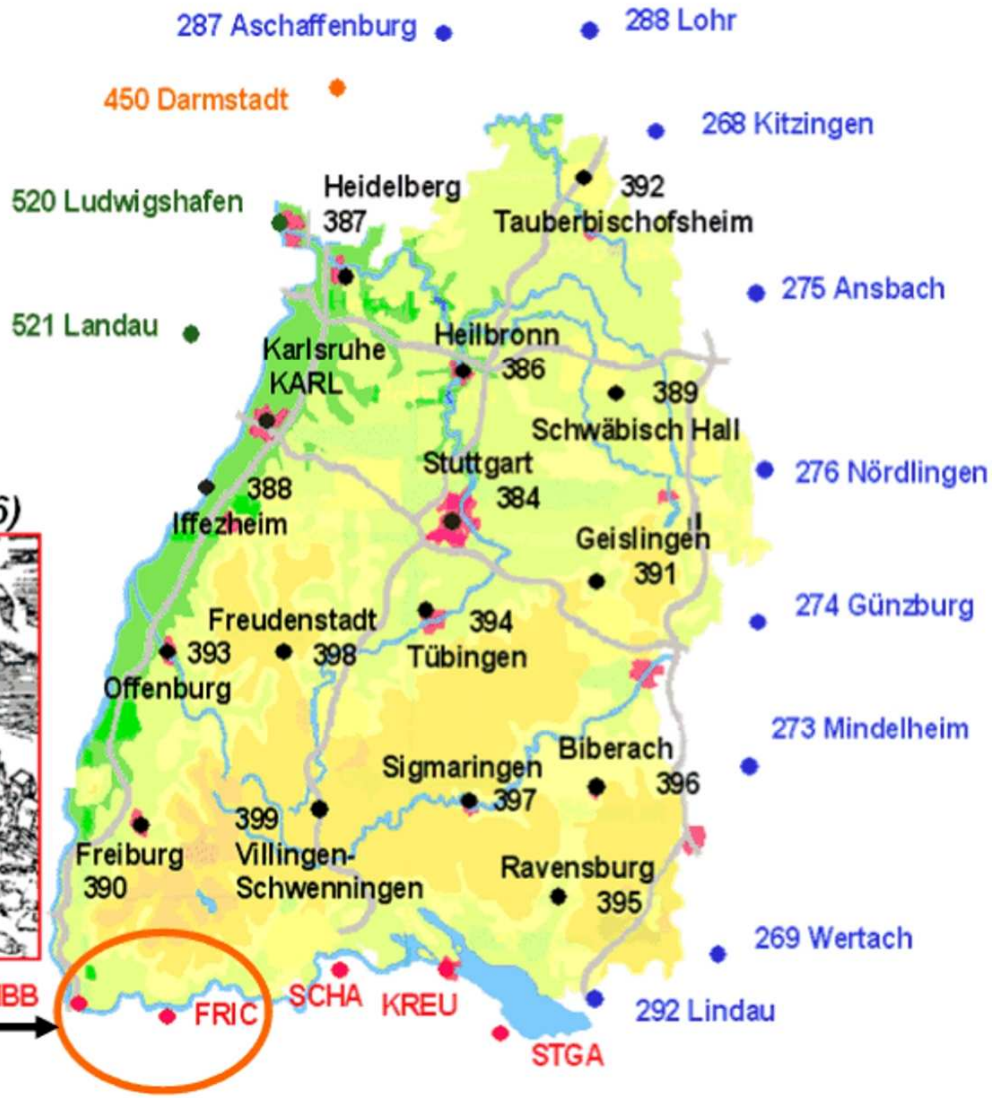
# 4. GNSS-Reference Station Monitoring

## SAPOS® Network Baden-Württemberg

GNSS-reference-stations and links to surrounding countries

Earthquake-zone North Switzerland

*Basel Earthquake 1356 (2006)*




**GNSS-Positioning-Service of Baden-Württemberg (SAPOS) - Rheingraben**

# 4. GNSS-Reference Station Monitoring

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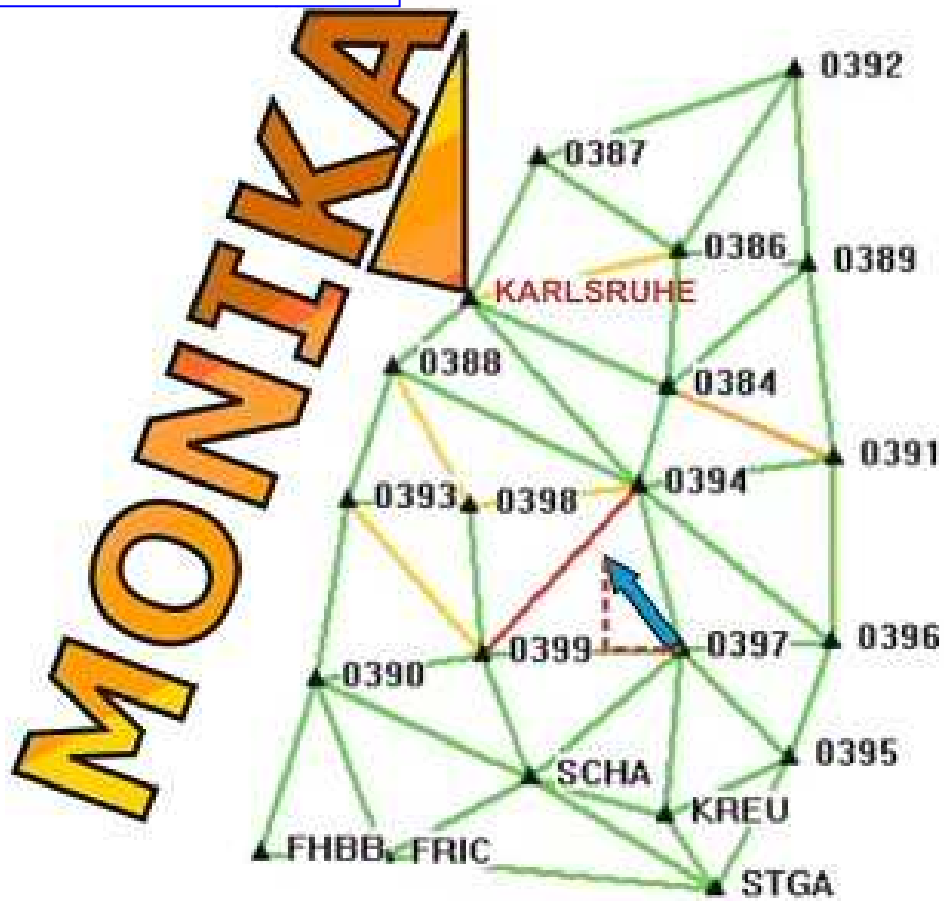
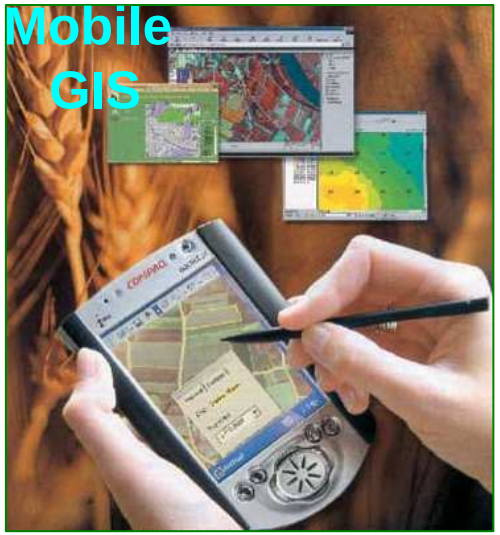
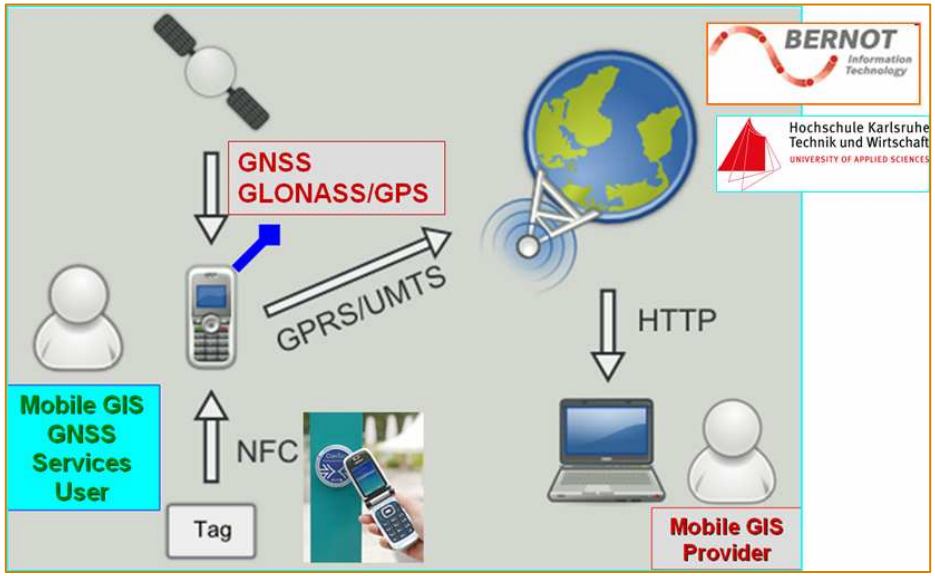


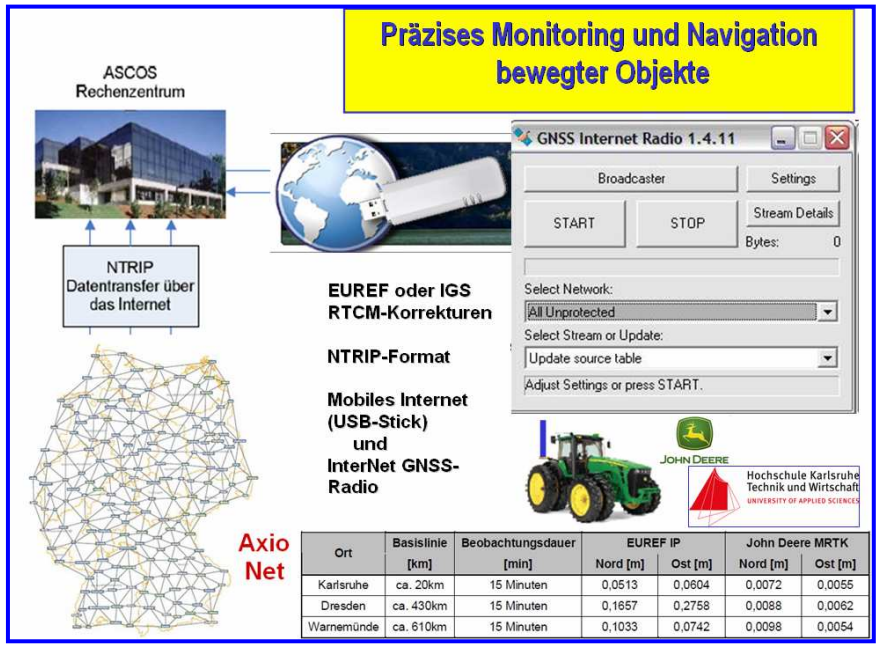
**GNSS-Positioning-Service of Rheinland-Pfalz (SAPOS) – Volcano Monitoring**

# 5. GNSS-Positioning Services – User-Groups





# 5. GNSS-Positioning Services – User-Groups



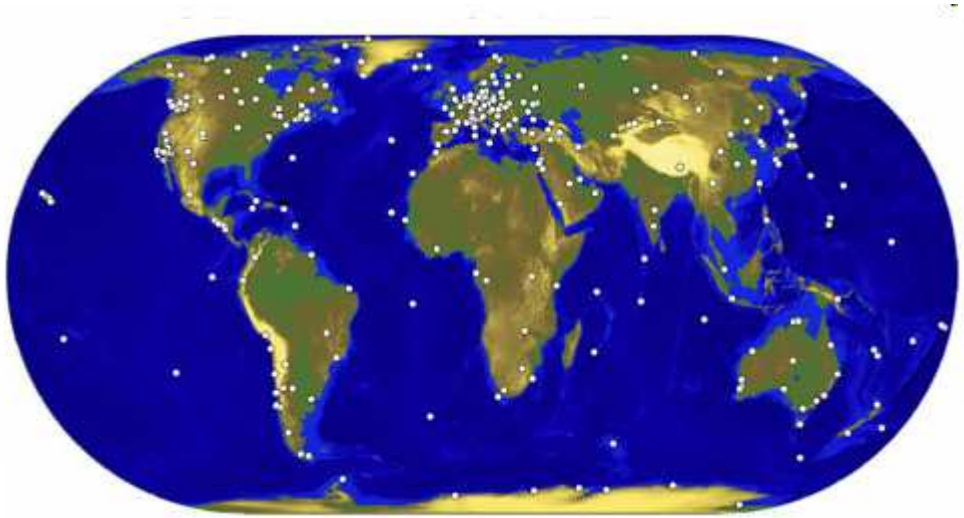

| Ort | Basislinie [km] | Beobachtungsdauer [min] | EUREF IP | | John Deere MRTK | |
|---|---|---|---|---|---|---|
| | | | Nord [m] | Ost [m] | Nord [m] | Ost [m] |
| Karlsruhe | ca. 20km | 15 Minuten | 0,0513 | 0,0604 | 0,0072 | 0,0055 |
| Dresden | ca. 430km | 15 Minuten | 0,1657 | 0,2758 | 0,0088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

## 6. Changes in GNSS-Positioning Services Network &Processing-Design

### Precise Point Positioning (PPP) = Absolute GNSS-Positioning

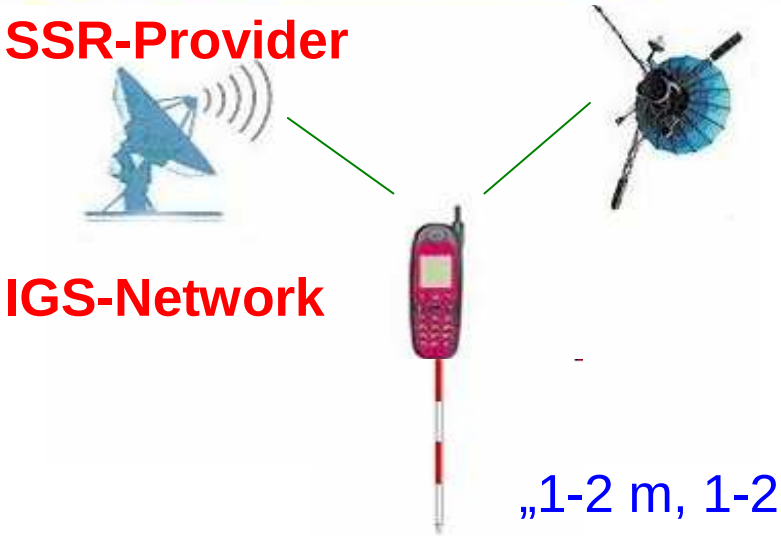
*? Breaking the Monopole of present DGNSS / Reference Station Services ?*

**Static Absolute (Non-D)GNSS** √
**Upload of Data for Processing**



**Dynamic Absolute GNSS**
**Online PPP („OPPP“) RTK**

- Server-Client for SSR?
- cm-RTK?
- LowCost-Sensors




„1-2 m, 1-2 dm , 1-2 cm“

# 6. Changes in GNSS-Positioning Services Network &Processing-Design

University of Applied Sciences

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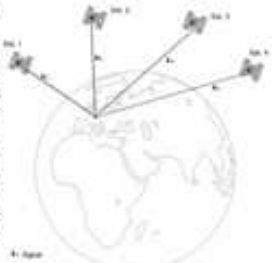
Technik und Wirtschaft
UNIVERSITY OF APPLIED SCIENCES

BOSCH
Technik fürs Leben

## Online Precise Point Positioning (OPPP) im Server-Client-Konzept mit IGS-Produkten

### Absolute GNSS-Positionierung (PPP)

Die nicht-differentielle „absolute" GNSS-Positionierung erfordert standardmäßig zur Berechnung der Position (ECEF-Koordinaten [$X_{Empfänger}$, $Y_{Empfänger}$, $Z_{Empfänger}$]) und des Empfängeruhrfehlers $\delta t_{Empfänger}$ mindestens vier Pseudoranges. Je nach GNSS-Sensorik können zudem auch Phasen- und/oder Dopplermessungen als Beobachtungen mit in das mathematische Modell dieses sog. „Precise Point Positioning (PPP)" mit einbezogen werden.



$$PSR_{Empfänger} = \rho + (\delta t_{Empfänger} - \delta t_{Satellit}) \cdot c + \delta_{Iono} + \delta_{Troposphäre} + \delta_{Geometrie} + \delta_{Rauschen}$$

mit

$$\rho = \sqrt{(X_{Erde} - X_{Empfänger}) + (Y_{Erde} - Y_{Empfänger}) + (Z_{Erde} - Z_{Empfänger})}$$

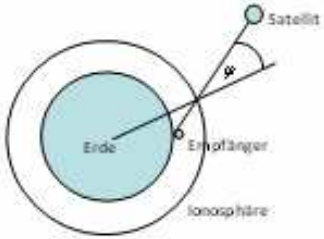
Die Fehlerkomponenten haben folgende Größenordnung

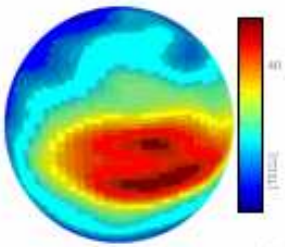
| Fehlerbudget | mit Broadcast-Message | mit IGS Daten |
|---|---|---|
| Satellitenposition | 1 - 3 m | 0.03 – 0.15 m |
| Satellitenuhrenfehler | 1.5 m | 0.03 – 0.9 m |
| Ionosphäre | 3 - 10 m | 0.2 – 1.3 m |
| Troposphäre | 0.7 m | 0.05 - 0.7 m |
| Erdgezeiten | 0.6 m (Höhe) | 0.6 m (Höhe) |
| Multipath | 1.0 m | 1.0 m |
| Antennenrauschen (Noise) | 0.5 m | 0.5 m |

Standardmäßig wird mit Low-Cost-Sensorik und Broadcast-Information online eine absolute Positionierungsgenauigkeit von ca. 5 - 10 m erreicht. Ziel der Entwicklungen war ein verbessertes absolutes, also ein Precise-Point-Positioning (PPP), welches basierend auf Codemessungen mit Low-Cost-Sensorik und -Antennen in der ersten Entwicklungsphase eine absolute GNSS-Genauigkeit besser als 2 m Meter liefern sollte. Das entwickelte Real-Time-

### Korrektur der ionosphärischen Wegverzögerung

Die Ionosphäremodellierung erfolgt im Standard des Single-Layer Modells. Der Winkel φ am ionosphärischen Punkt lässt sich aus dem Zenitwinkel am Boden berechnen, der Vertical Total Electron Content (VTEC)-Wert wird aus der vom IGS bereitgestellten TEC Map bilinear interpoliert.



Ionosphärische TEC Map

$$\Delta Iono\,[m] = \frac{1}{\cos\varphi} \cdot \frac{40.3}{f^2} \cdot VTEC$$

$VTEC$ = Vertical Total Electron Content

Einheit: $\left[\frac{10^{16}\ \text{Elektronen}}{m^2}\right]$

### Mathematische Modellbildung des OPPP

Das realisierte mathematische Modell des OPPP-Ausgleichungsalgorithmus basiert, neben dem im Hintergrund z.B. im Tageszyklus erfolgenden Download der o.g. IGS-Daten, auf den Messungen (Code-, Phasen- und Doppler) eines Low-Cost GPS-Systems. Der entwickelte OPPP-Algorithmus setzt prinzipiell keine Filterung aus Bewegung voraus und basiert Genauigkeits- und Zuverlässigkeitssteigernd auf eine robuste M-Schätzung. Die nachfolgende Tab. zeigt die mittlere Lageabweichung aus der Auswertung von 30480 OPPP-Positionierungen mit unterschiedlichen Orbitdaten.

| Broadcast Ephemeriden | IGS ultra-rapid | IGS final |
|---|---|---|
| 2.69 m | 2.16 m | 1.97 m |

THANK
YOU
THANK