THE NEW RTCM 3.1 TRANSFORMATION MESSAGES

Declaration, Generation from Reference Transformations and Implementation as a Server-Client-Concept for GNSS Services

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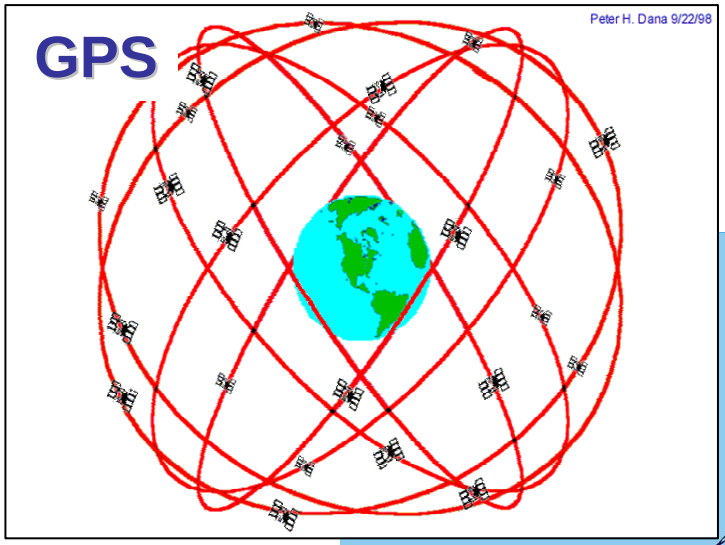
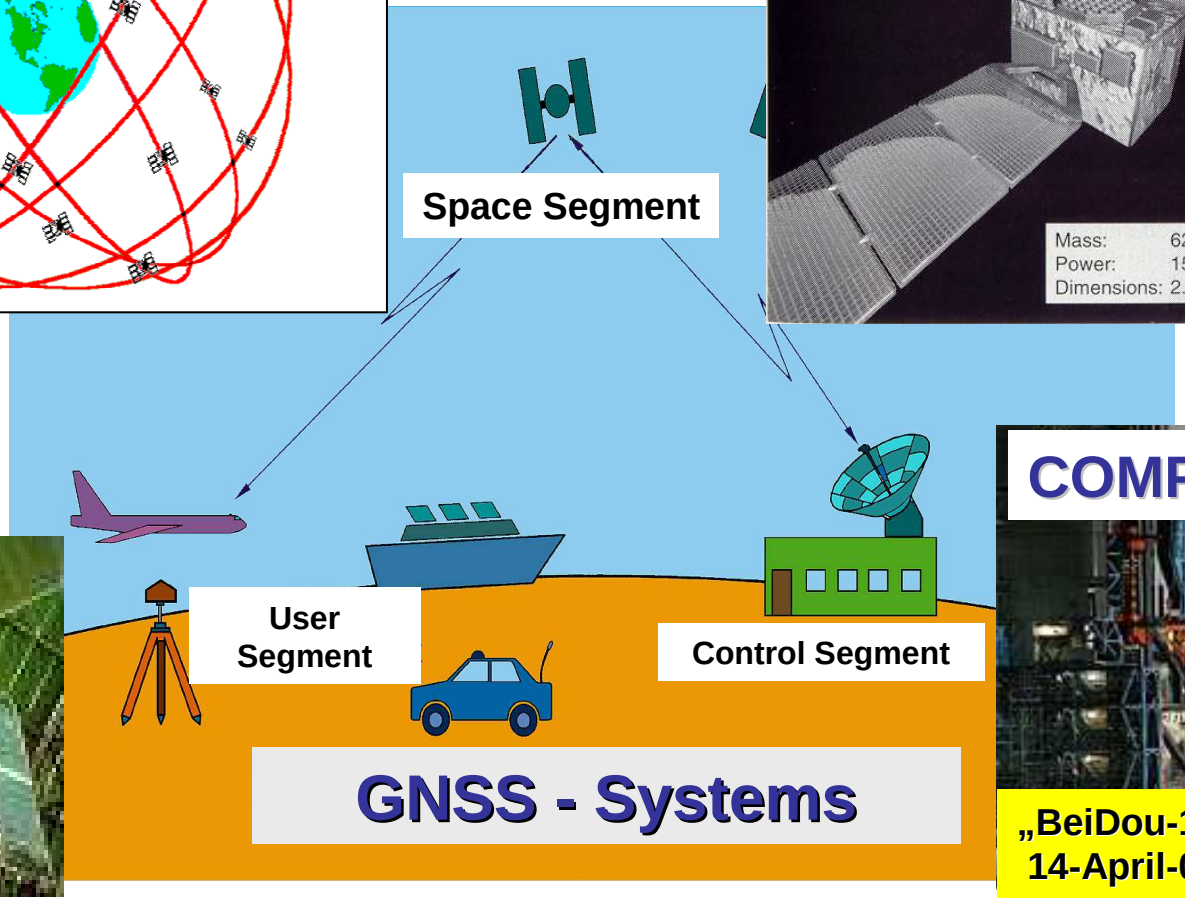
URL: www.dfhbf.de ; www.geozilla.de ; www.moldpos.eu; www.goca.info; www.monika.ag

GNSS for Global Positioning in ITRF/ECEF Frames



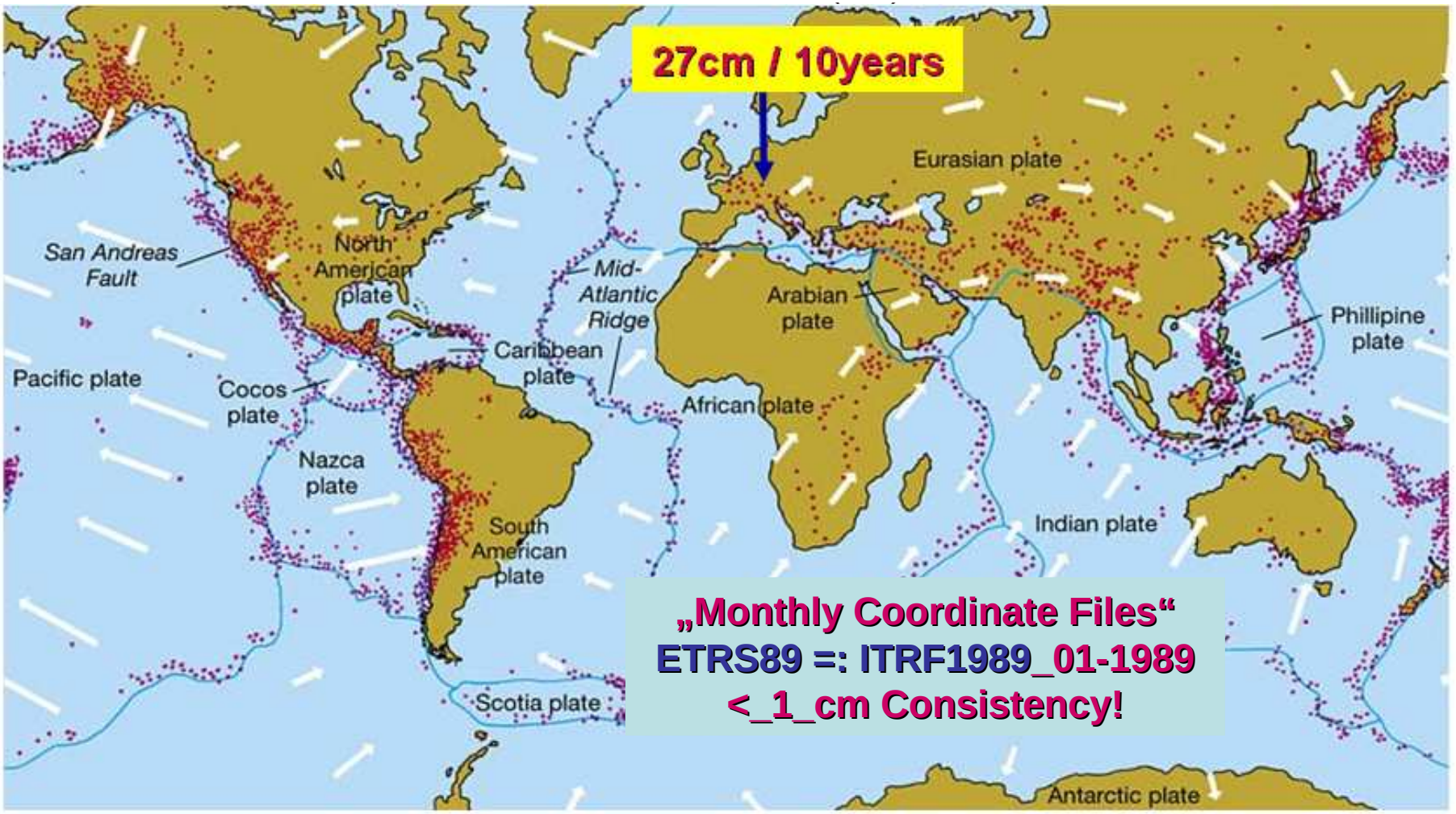


GLONASS

COMPASS

„BeiDou-1/2“
14-April-07

ITRF/ECEF - Datum <= International GNSS Service (IGS)



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

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

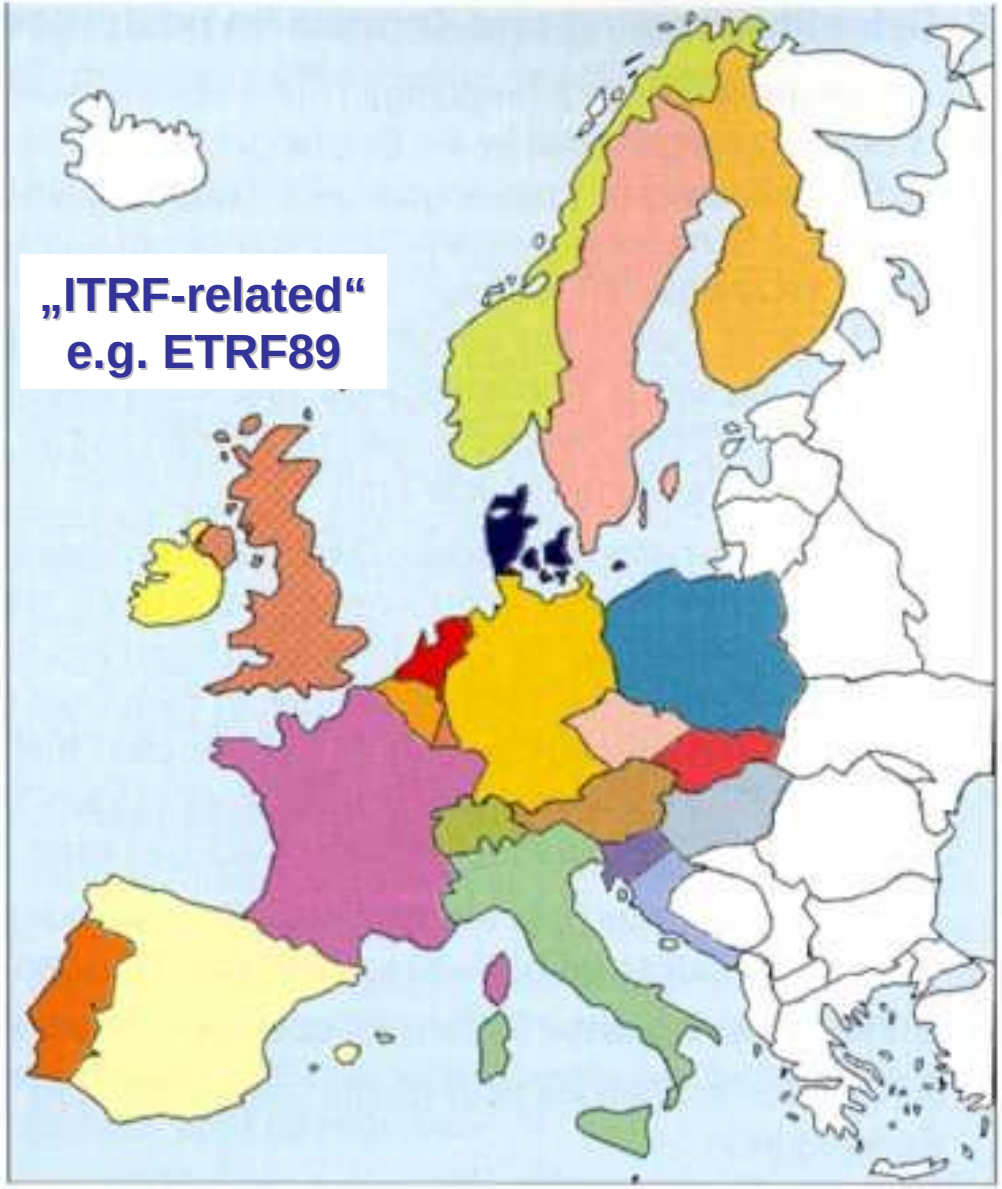
GNSS-Services and RTCM-based Positioning

RTCM-
Phase Corrections
⇒ cm -Solutions

- ***SAPOS®*** + ***ascos®***
SWIPOS® + ***SwissSat®***
:
SwePos®
CzePos®
LatPos®
ASG-EUPOS®
CroPOS®, HePos®
… Hungary, Slowenia, Romania, Moldavia,…

EUPOS® European Position Determination System **(East European States, Russia)**

- **...many others worldwide!**



GNSS-Services and RTCM-based Positioning

Adresse http://www.rtcm.org/

RTCM

The Radio Technical Commission for Maritime Services

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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

GNSS-Service – Network of Reference Stations
+ GNSS-Networking Software

GNSS-Services and RTCM-based Positioning

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

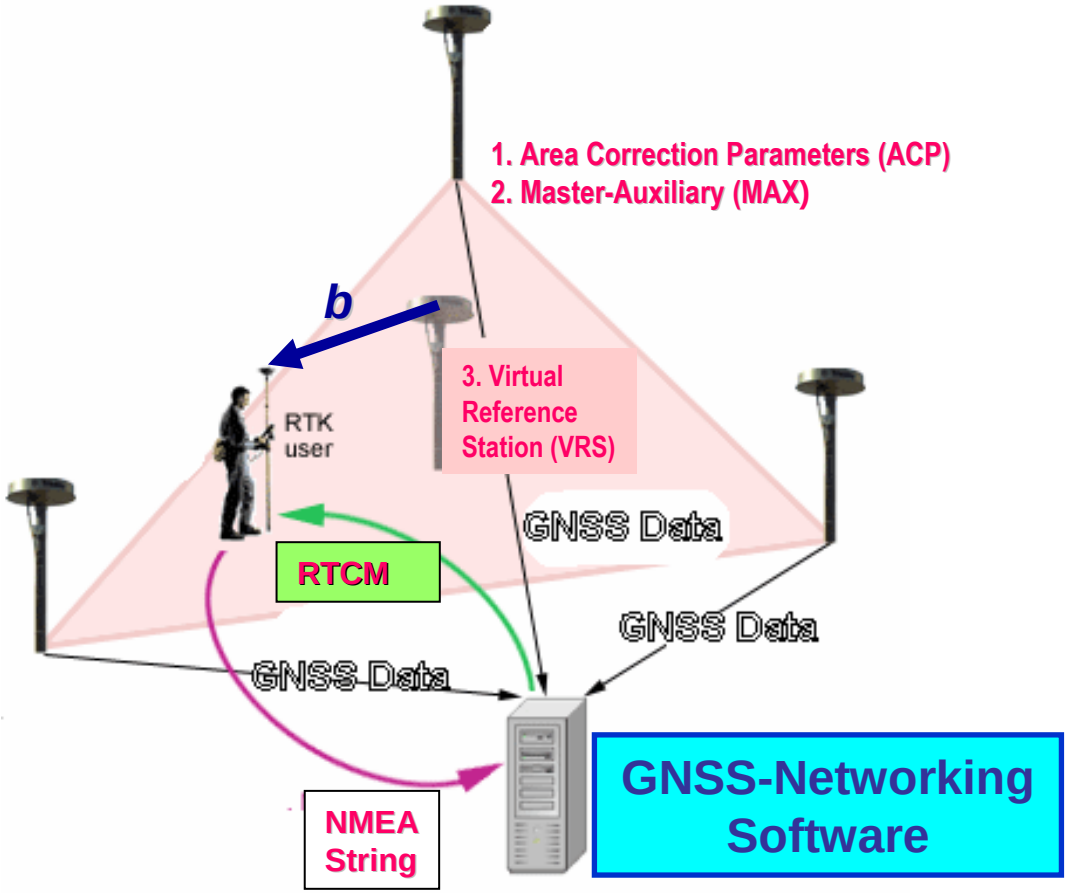
$$\nabla\rho(t-\Delta t)^{Sat}_{Ref} = \rho[(x,y,z)_{REF};(x,y,z)_{SAT,\Delta t}]_{true,Ref} - \rho(t-\Delta t)_{Observed,Ref}$$

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

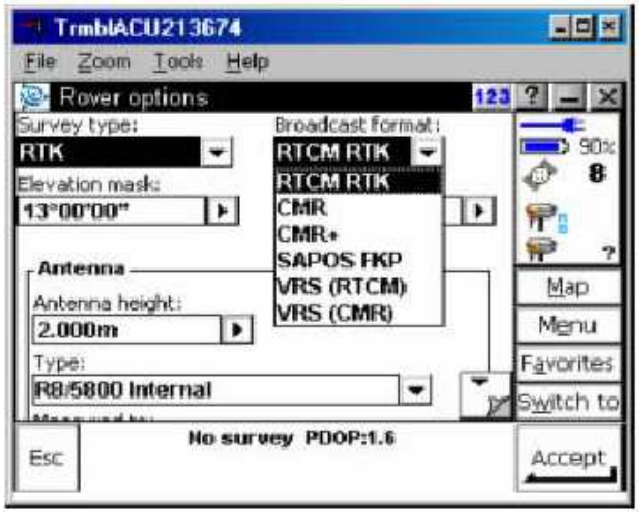
RTCM 3.1 Observations-Corrections

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

→ $(B,L,h)_{GNSS\text{-}Datum}$



GNSS-Services and RTCM-based Positioning



(TCP/IP-based, e.g. via Internet, GPRS – NTRIP)

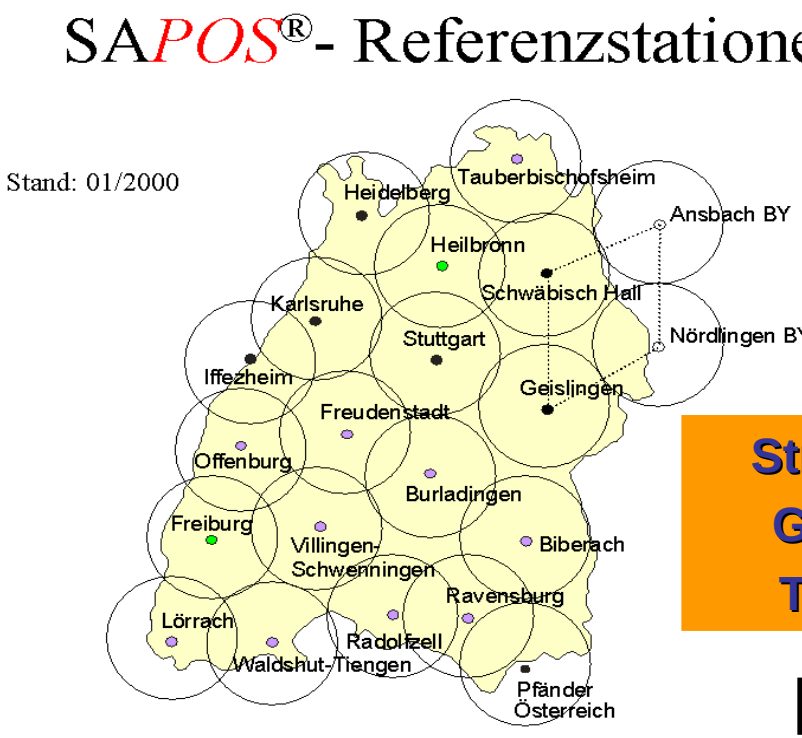
Trend at many new services
e.g. in
Poland
Slovenia

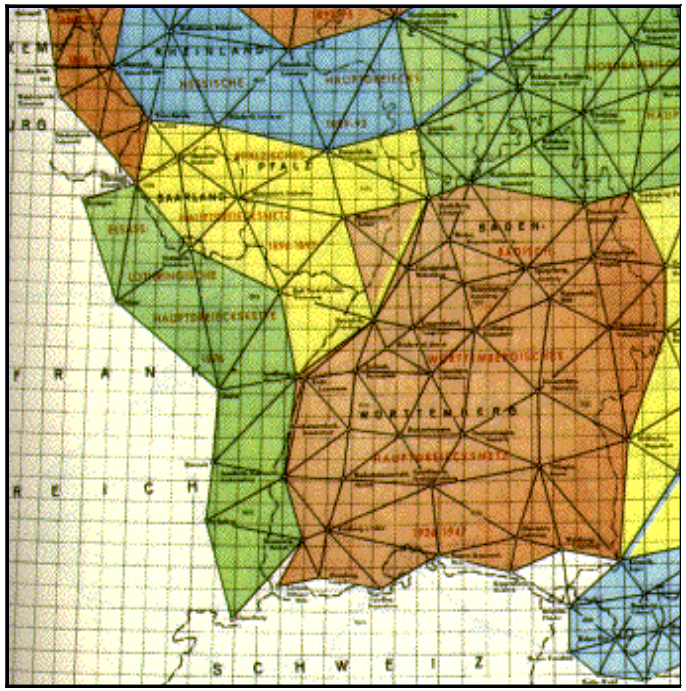
Many Commercial Hard- and Software with NTRIP-embedding see

http://igs.ifag.de/index_ntrip.htm

Transformation Problems and Reference Transformations

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





Strict and General TRAFO

ITRF / ETRF89 - Datum

(Enabled & GNSS-practice

Old Classical Systems

1. Plane Problem - Karlsruhe Reference Transformation

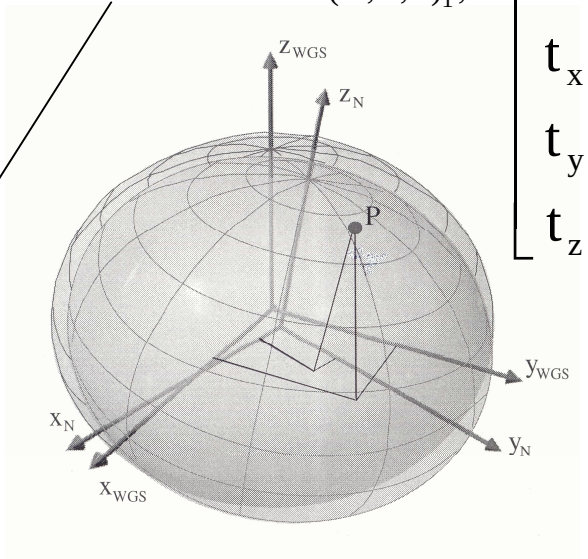
3D Similarity Transformation Related to (B,L,h)

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

Reference-Transformation
(Data / Parameters / Algorithms)

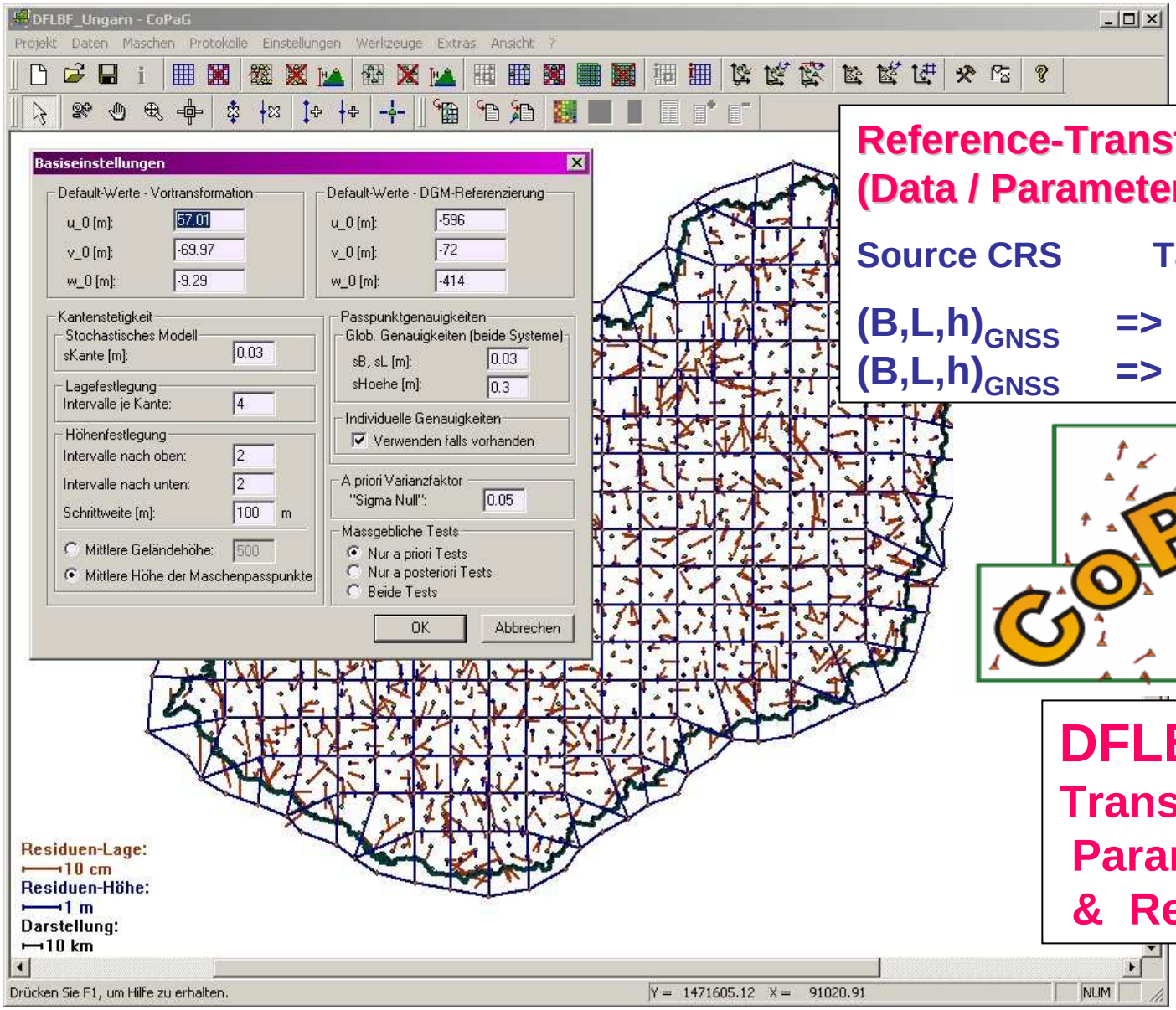
Source CRS **Target CRS**

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



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

1. Plane Problem - Karlsruhe Reference Transformation



Reference-Transformation (Data / Parameters / Algorithms)

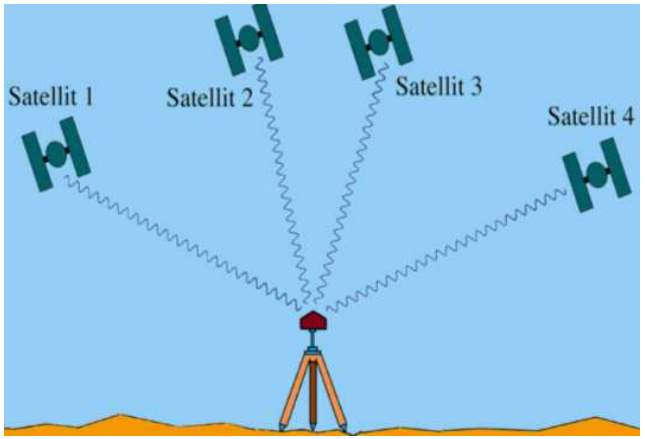
Source CRS **Target CRS**

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

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

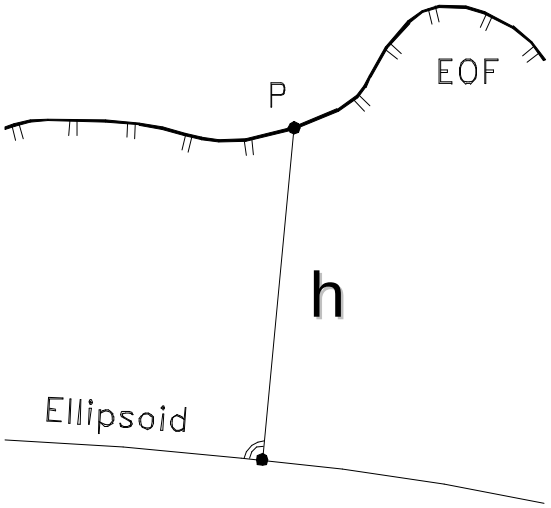
DFLBF_DB
Transformation Parameters & Residuals

2. Height Problem / HRS Transition - Karlsruhe Reference Transformation

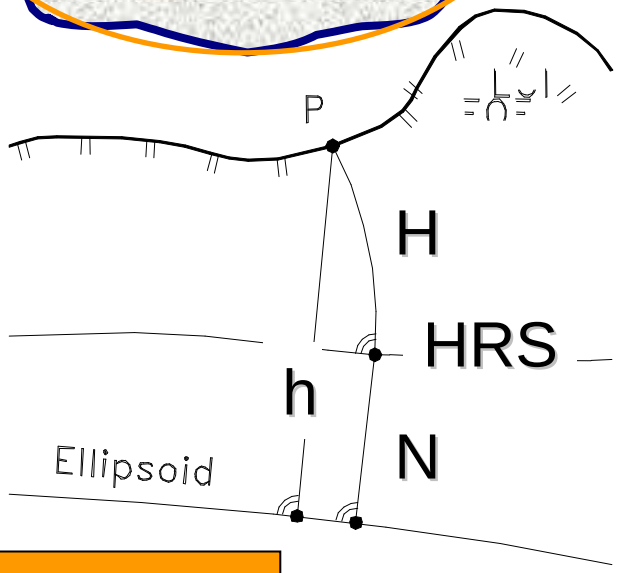


+/- 70 m

Geoid (HBF)
Ellipsoid



GNSS Heighting
„H from h- GNSS“



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

Reference-Transformation
Source CRS **Target CRS**
$(B,L,h)_{GNSS}$ => N

2. Height Problem / HRS Transition - Karlsruhe Reference Transformation

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

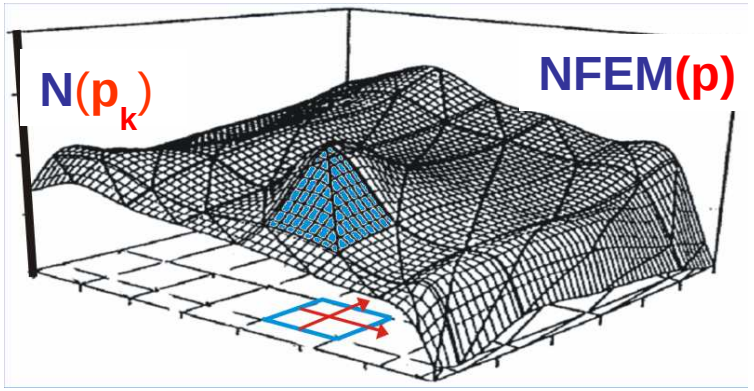
$$H + v = H$$

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

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

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

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



DFHBF DB

Reference-Transformation

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

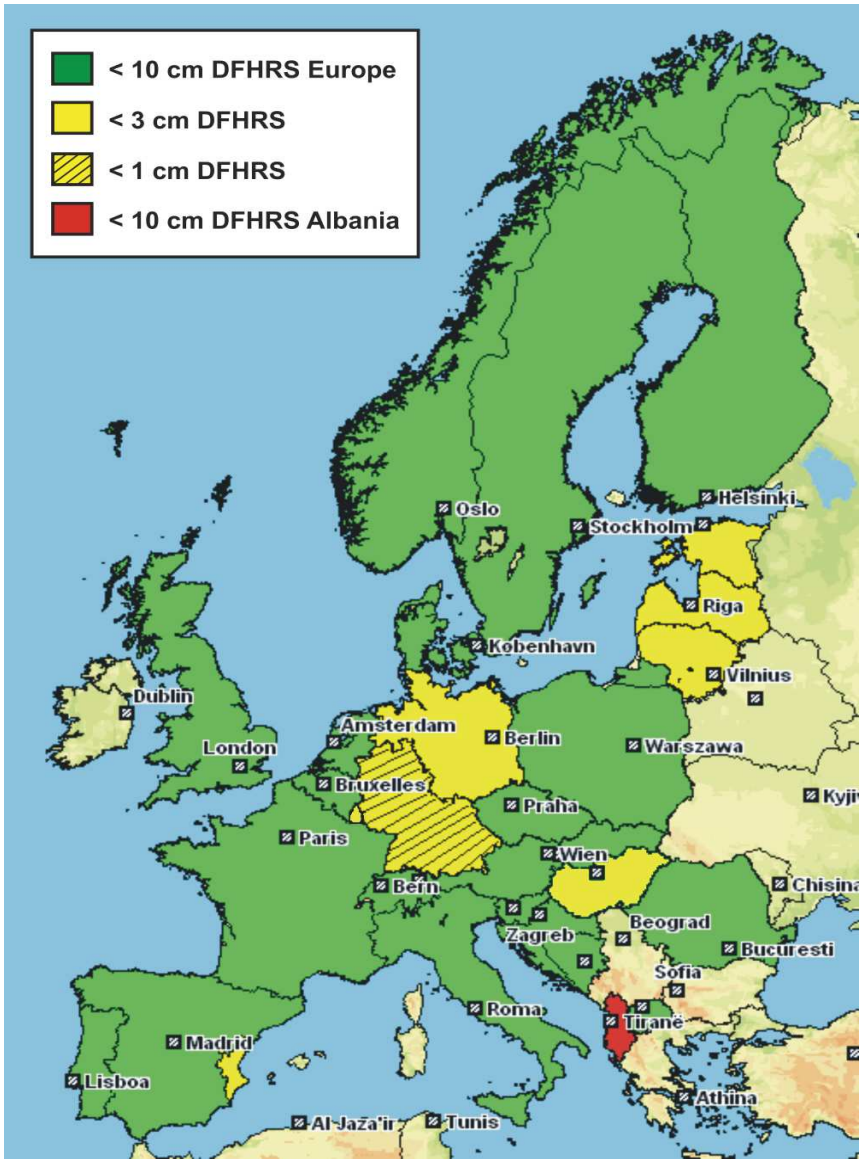
$$g^{LGV}_{grav\ r} + v = \sum_{k=0}^{\infty} \left(\frac{a}{r}\right)^{n(k)+1} \frac{(n(k)+1)}{r} \sum_{m=0}^{k} (\bar{C}'_{n(k)),m} \cdot \cos m\lambda' + \bar{S}'_{n(k),m} \cdot \sin m\lambda') \cdot P_{n(k),m}(\cos\theta') + dg(\mathbf{d})$$

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

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

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

2. Height Problem / HRS Transition - Karlsruhe Reference Transformation



Reference-Transformation

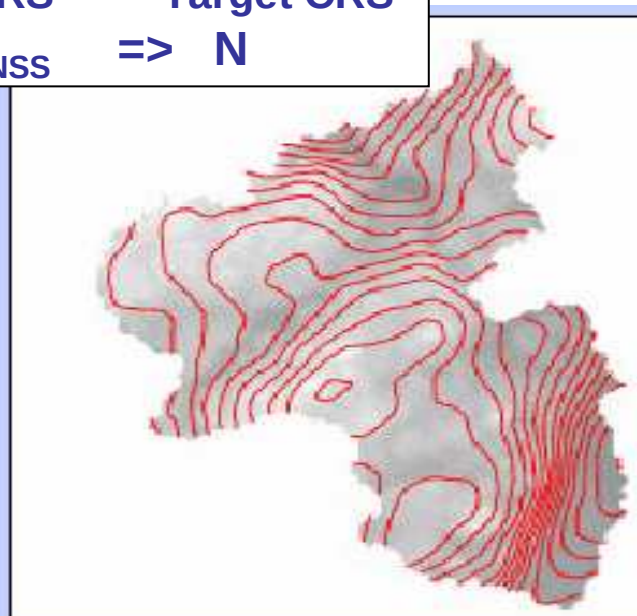
Source CRS Target CRS

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

Official State Databases

e.g.

in German Countries



DFHBF-DB

Herausgeber:

LVermGeo

Landesamt für Vermessung und Geobasisinformation Rheinland-Pfalz

Ferdinand-Sauerbruch-Straße 15
56073 Koblenz
http://www.lvermgeo.rlp.de

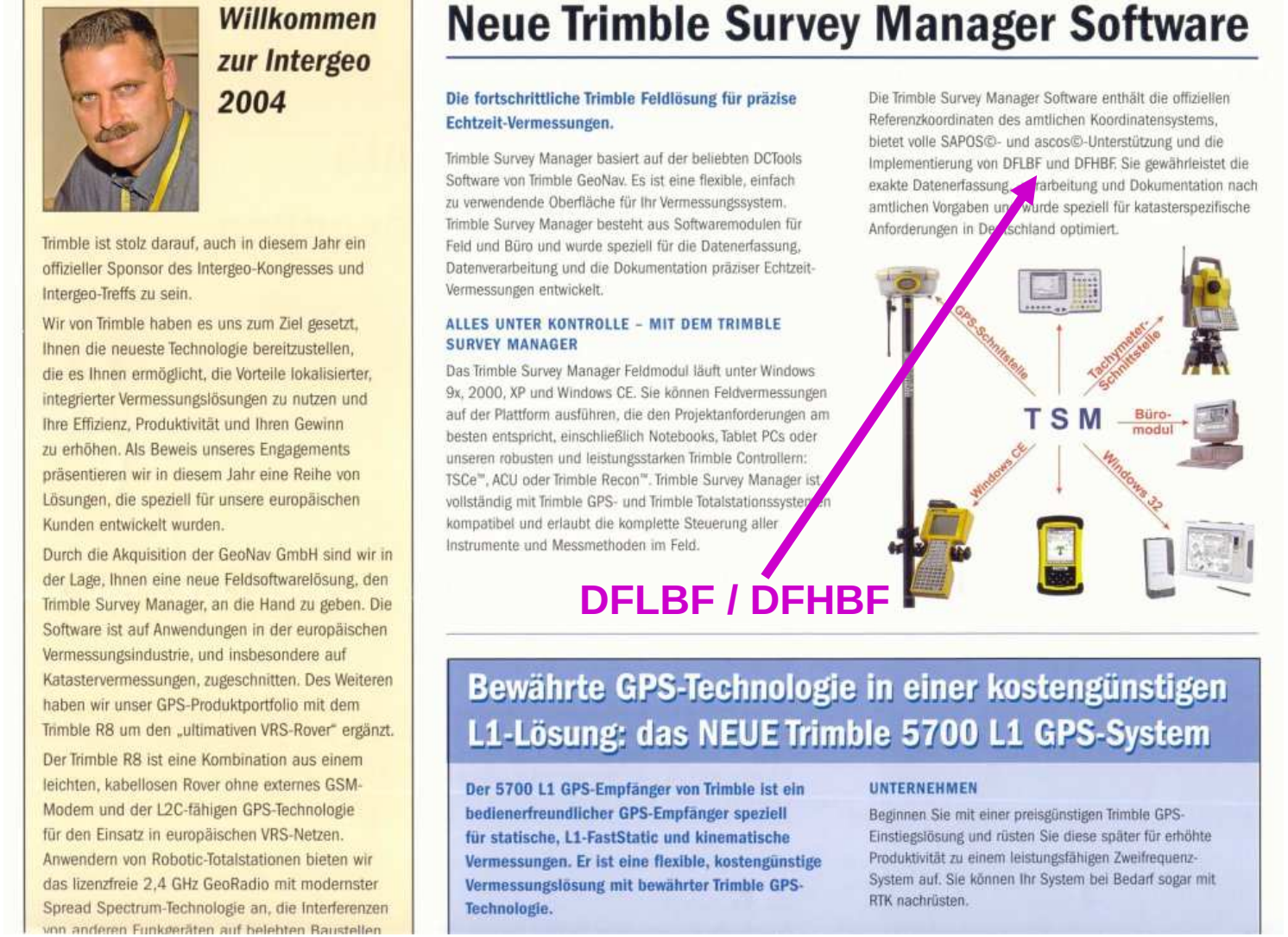
■ ■ ■

Present Use of Reference Transformations
Online on GNSS - Controllers

I. ITRF-based Source CRS	II. Refe-rence Trans-forma-tion Types	III. Targets and Direct Results		IV. Final Mathematical Model of Representation and Examples			V. GNSS-rover Data interface	
				„Grid only"	Parametric	Gridding Enabled	Parametric Representation	Grid
	⇒	$(B,L)_{Classical}$ and H	(1)	Most	DFLBF	All	DFLBF	All
$(B,L,h)_{GNSS}$	⇒	$(B,L)_{Classical}$	(2)	Most	DFLBF	All	DFLBF	All
	⇒	N with H = h_{GNSS} − N	(3)	BKG Quasi-Geoid; EGG97	EGM96 EIGEN DFHRS	All	EGM96 DFHRS	All

1. „Gridding" the Reference Transformation („Gridfactories")
2. Direct Access to Reference Transformation

Present Use of Reference Transformations on GNSS - Controllers



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.

DFLBF / DFHBF

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.

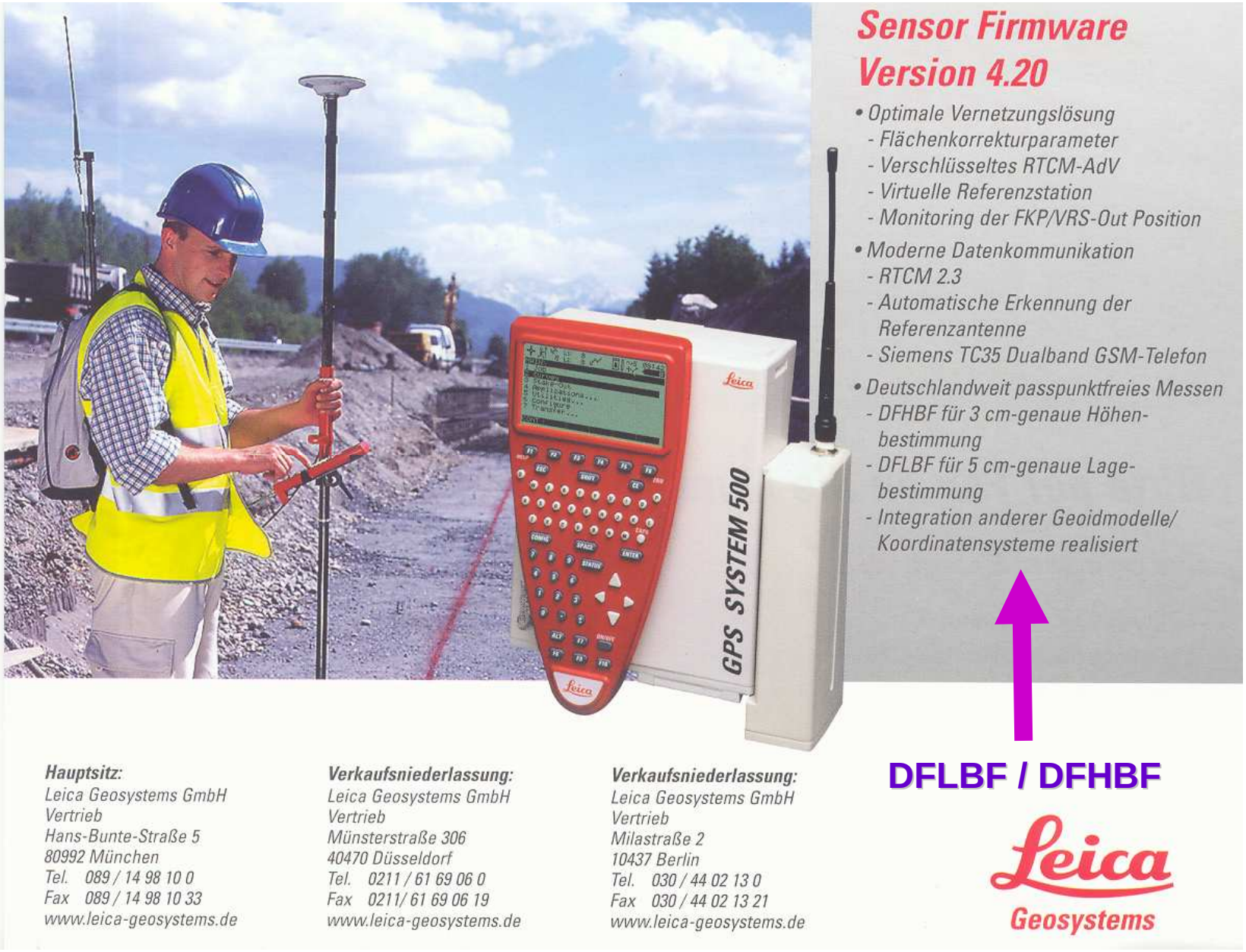
UNTERNEHMEN

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.

Present Use of Reference Transformations on GNSS - Controllers

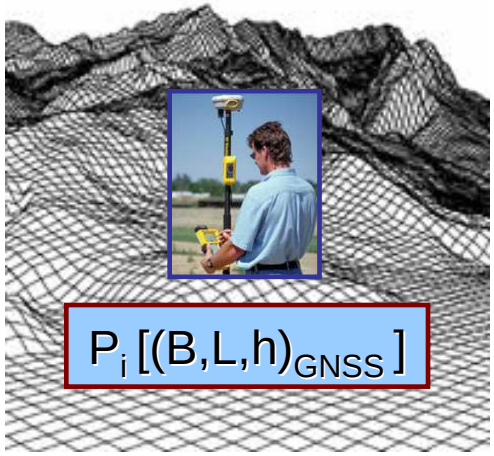
TOPCON

Present Use of Reference Transformations on GNSS - Controllers



Gridding of Reference Transformations

Source CRS - Grid



Reference

Transformations

Target CRS - Grid

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

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

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

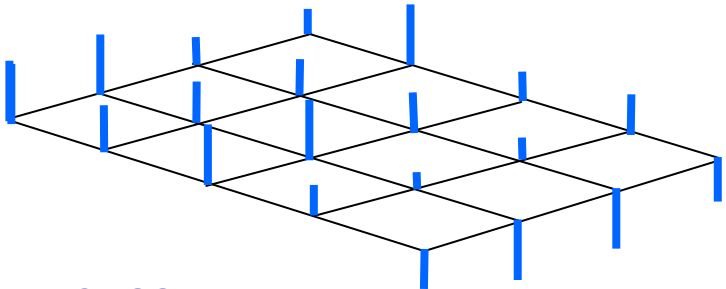
Virtual Fitting Points P_i — **Gridding** — **Virtual Fitting Points P_i**

1.] **7 Para meter Trafo**

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

7 Parameters
3 Residual Grid

2.] **Geoid/HRS Grid**



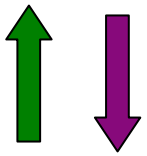
Grid of N_i

RTCM 3.1

RTCM 3.1 Observations Corrections
&
„7 RTCM Transformation Messages“

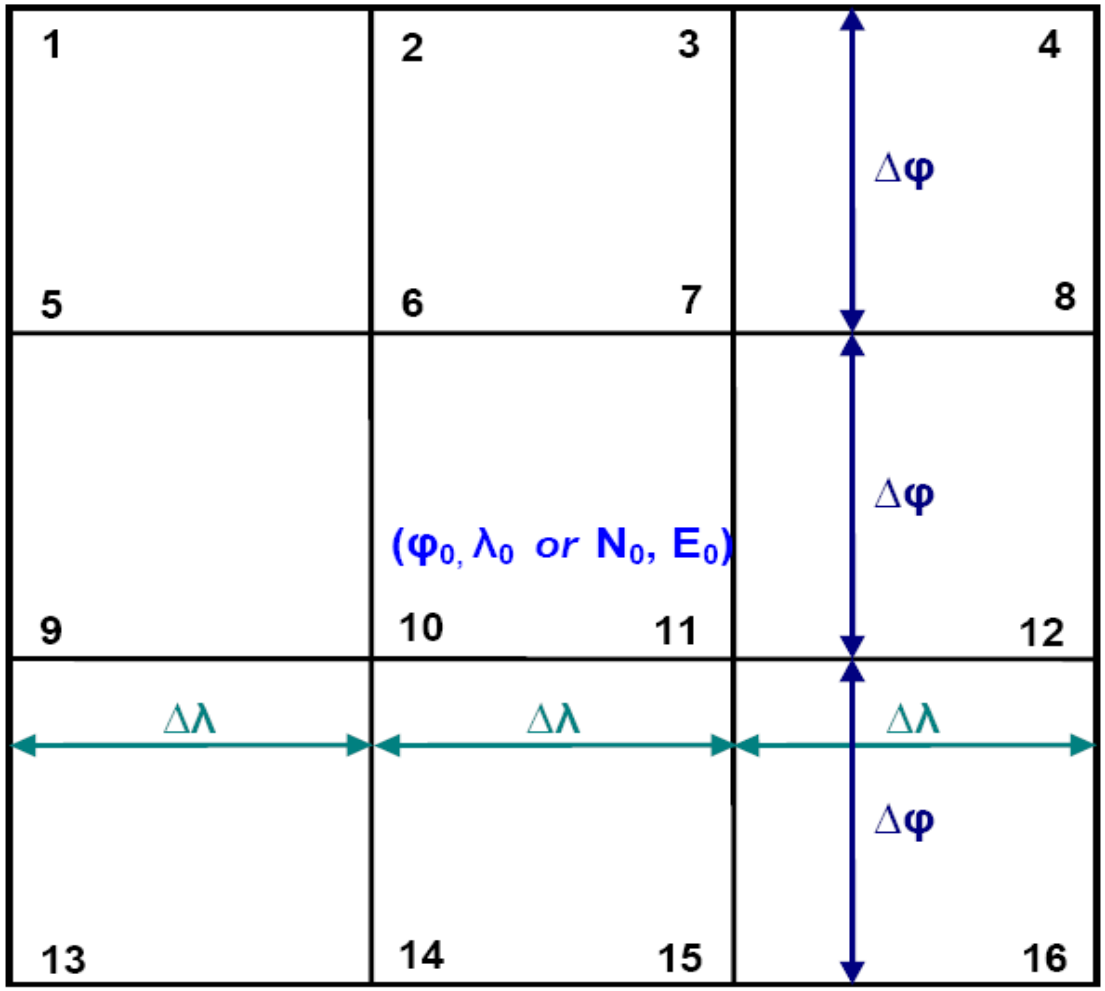
- Transformation-Parameters (1021,1022)
- Residual-Grids and/or Geoid-Representations (1023,1024)
- Projection-Information (1025,1026,1027)

sent by **GNSS-Positioning-Service**
to
GNSS-Positioning-User



NMEA-based request to RTCM-Transformation Messages Server)

RCTM 3.1 Transformation Messages – Defintion and Examples



Area of validity for 7P transformation (origin and extension)
+ 16 Grid-Points

RCTM 3.1 Transformation Messages – Defintion and Examples

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

RCTM 3.1 Transformation Messages – Defintion and Examples

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**

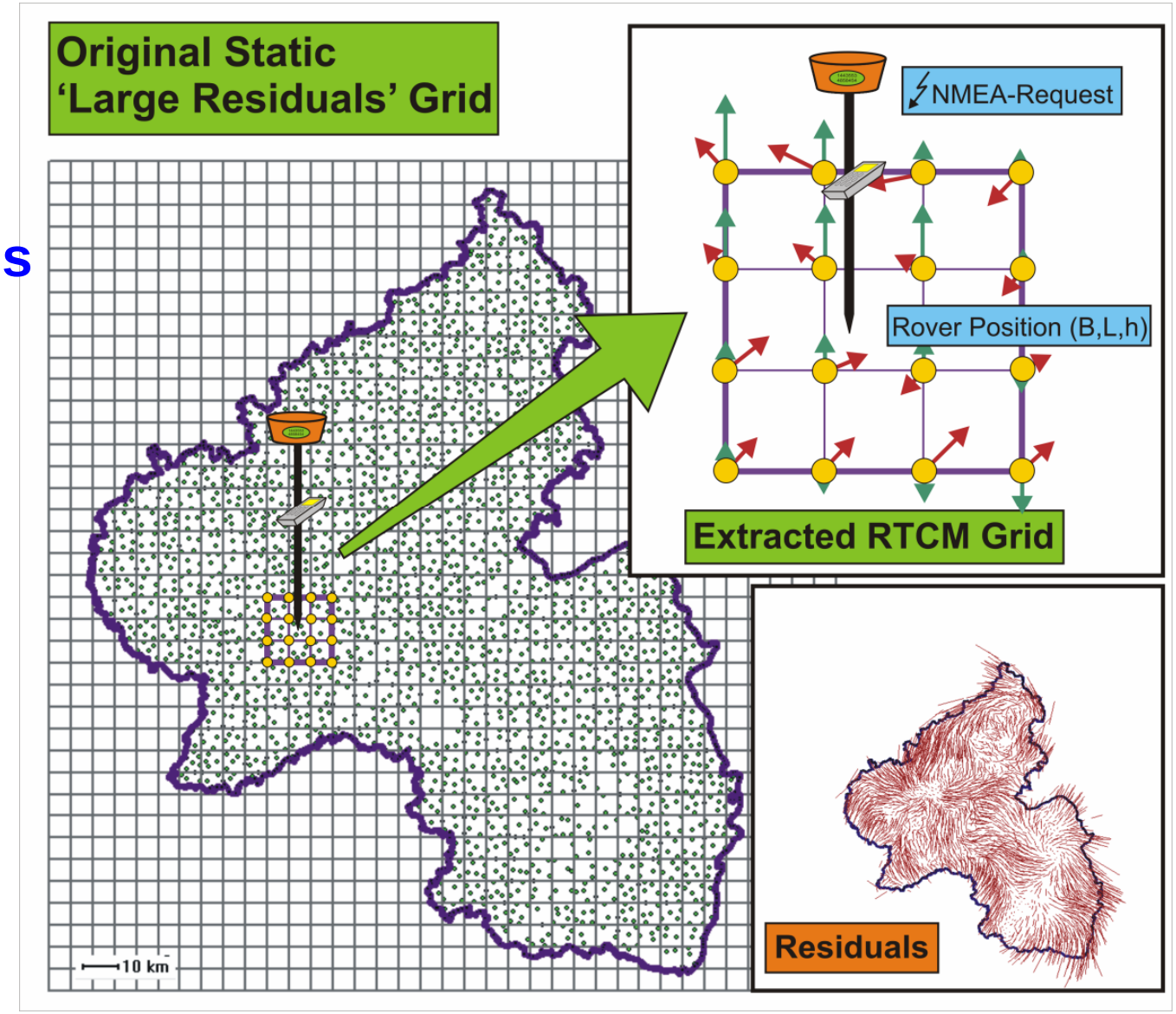
Height Indicator = 2 ⇨ **„dh_i„ = Geoid / HRS Heights N_i (dN_i)**

RCTM 3.1 Transformation Messages – Message Generation

Using Reference Transformations

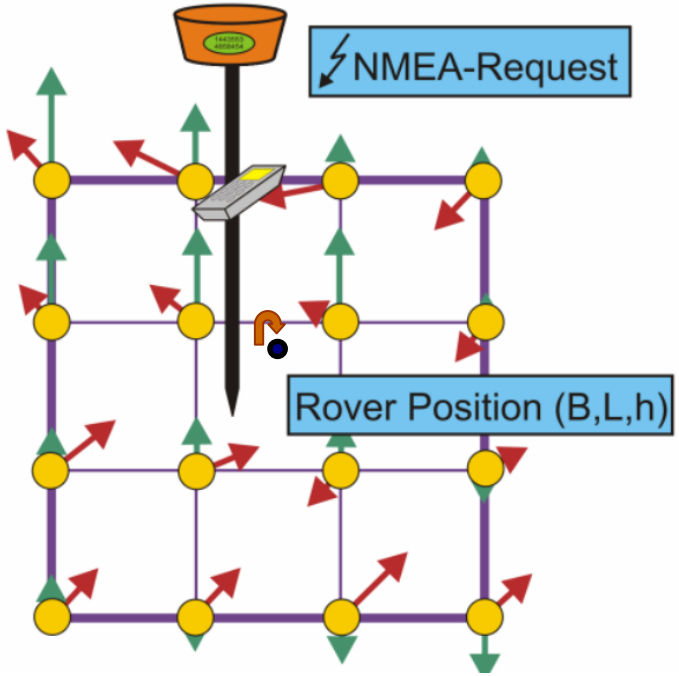
to compute a country-wide

„STATIC GRID“



RCTM 3.1 Transformation Messages – Message Generation

Using Reference Tranformations to compute grids dynamically online on NMEA-request by virtual fitting points „Dynamic Grid“



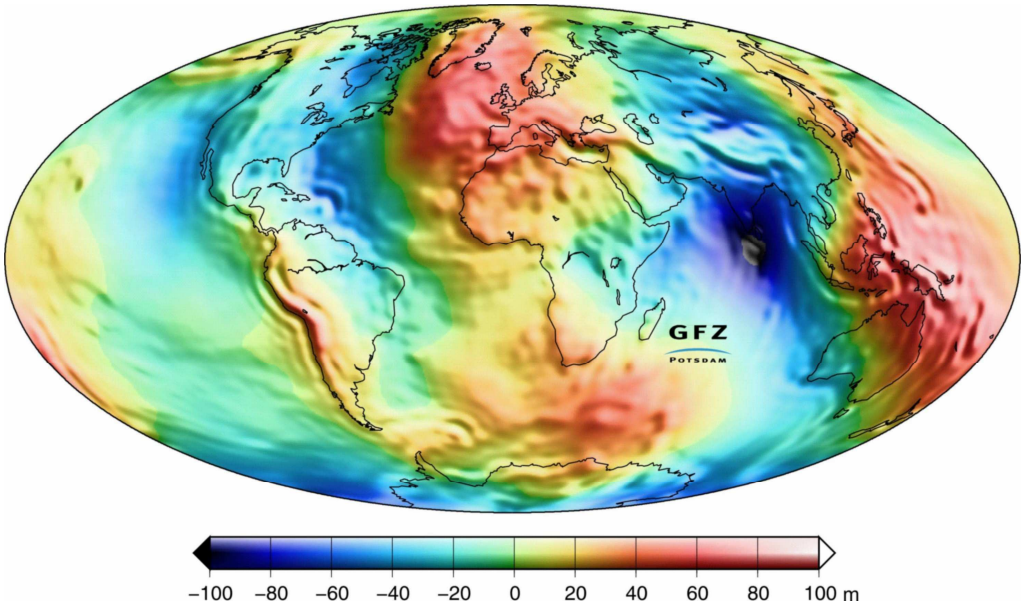
Advantages of „Dynamic Grid“

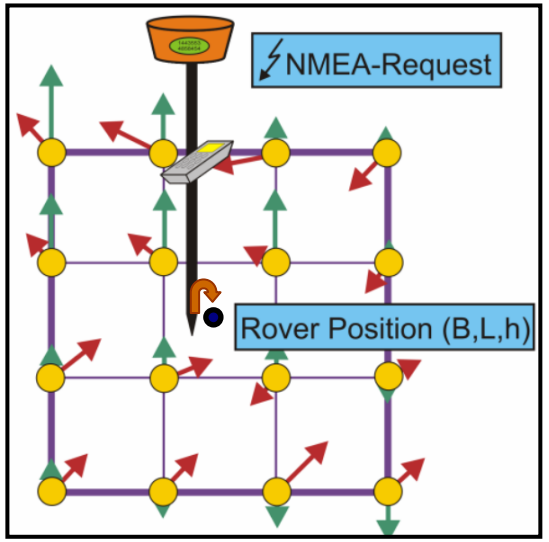
1.) No preceeding „Gridding“ Discetization Error
2.) Smaller Residuals - Smaller Interpolation errors
3.) “ “ - Interpolation method in GNSS-Rover not so relevant

RCTM 3.1 Transformation Messages – Message Generation

Using Reference Tranformations to compute grids dynamically „Dynamic Grid“

4.) Direct use of Original Reference Transformations





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

$$\begin{bmatrix}x\\y\\z\end{bmatrix}=\begin{bmatrix}u_i\cdot\sqrt{1+\varepsilon^2/u^2}\cdot\cos ß\cdot\cos\lambda\\u_i\cdot\sqrt{1+\varepsilon^2/u^2}\cdot\cos\beta\cdot\sin\lambda\\u\cdot\sin\beta\end{bmatrix}$$

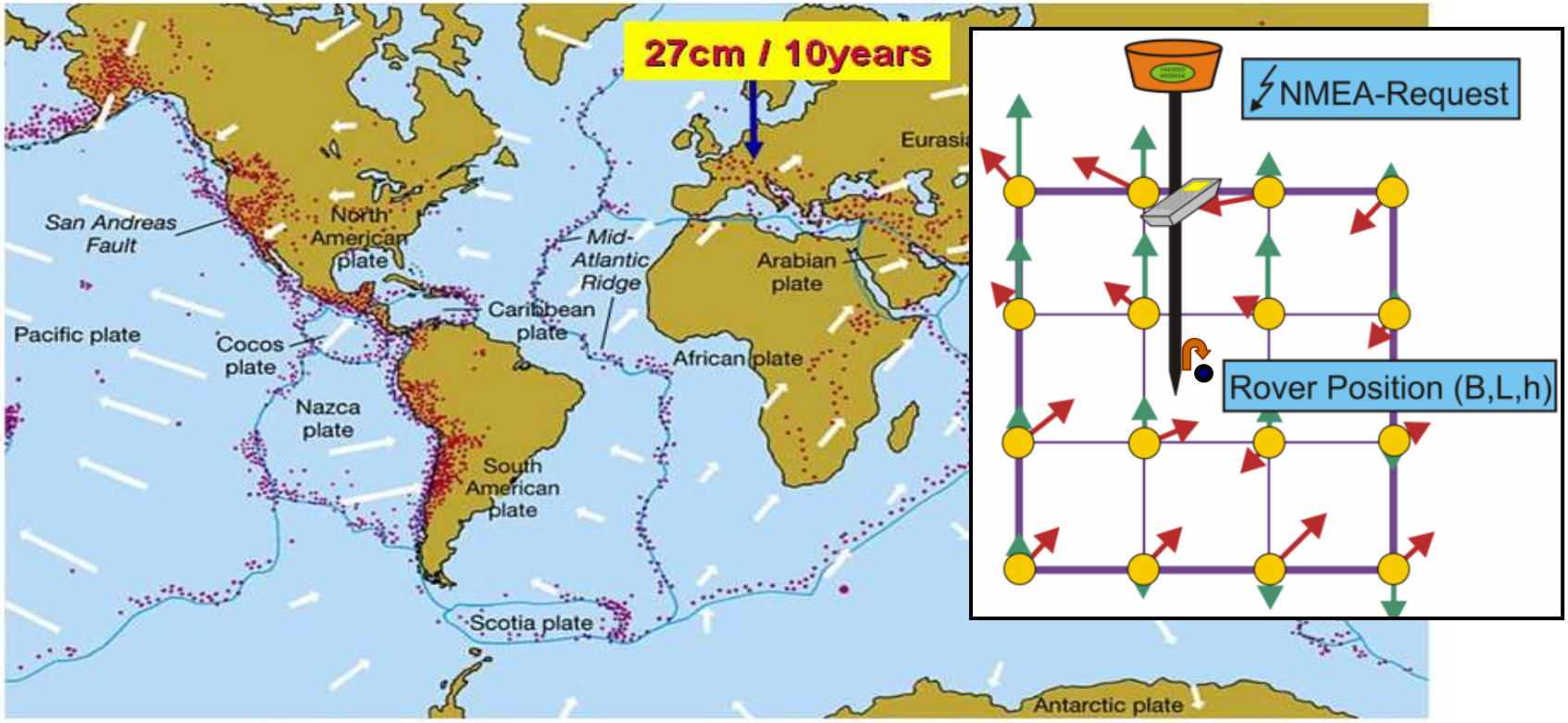
$$U=U(a,\varepsilon,\omega,M)_{REF}\mid(ß,\lambda,u))$$

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

RCTM 3.1 Transformation Messages – Message Generation

Using Reference Tranformations to compute grids dynamically „Dynamic Grid“

5.) „Combined Messages Generation“ in case of ITRF-Operation Mode



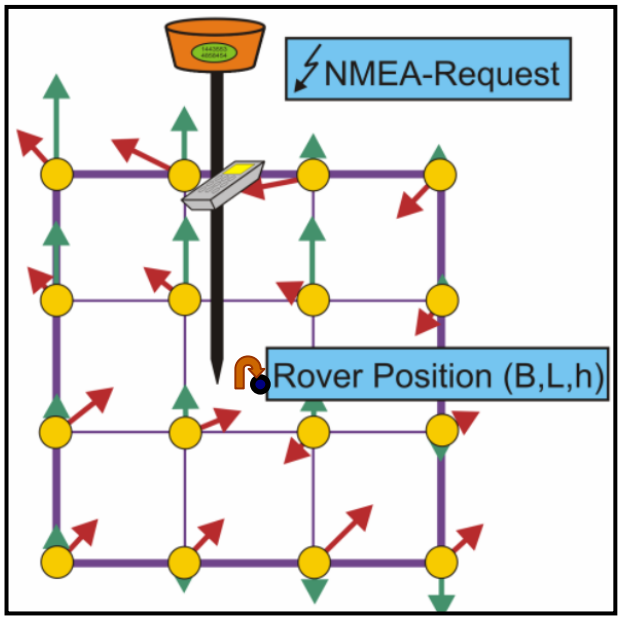
$$x(t_1)_{ITRFzz,t_1} = (1+\Delta m)\cdot \mathbf{R}(\varepsilon_x,\varepsilon_y,\varepsilon_z)\cdot \mathbf{x}(t_1)_{ITRFyy,t_1} + \mathbf{t}$$

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

RCTM 3.1 Transformation Messages – Message Generation

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

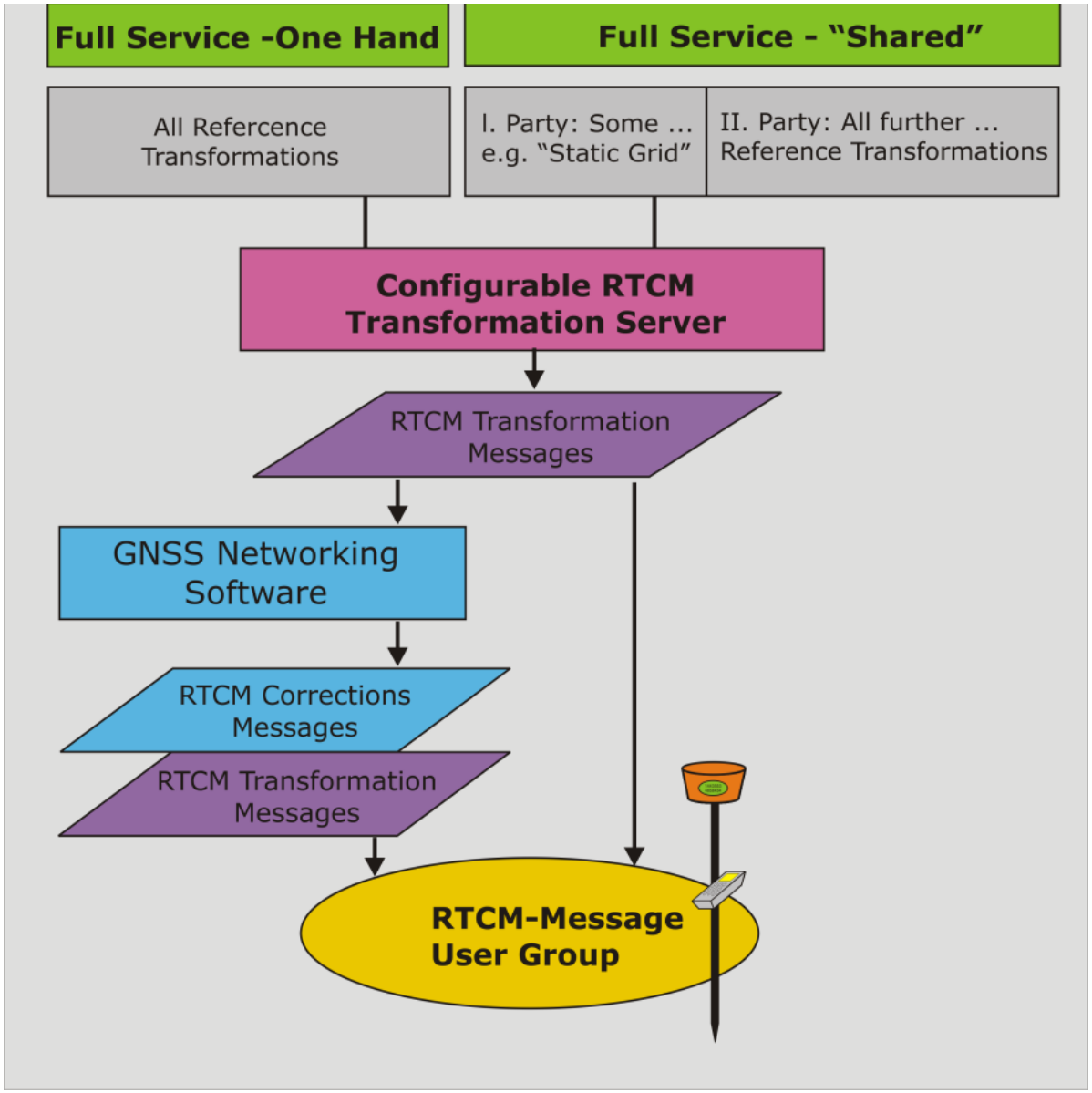
Part 2 - *Standard Reference Transformations*

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

Virtual Fitting Points

Dynamic Message Set up by local 7PT Gridding

RCTM 3.1 Transformation Messages – „Full Service“ GNSS-Transformation Services



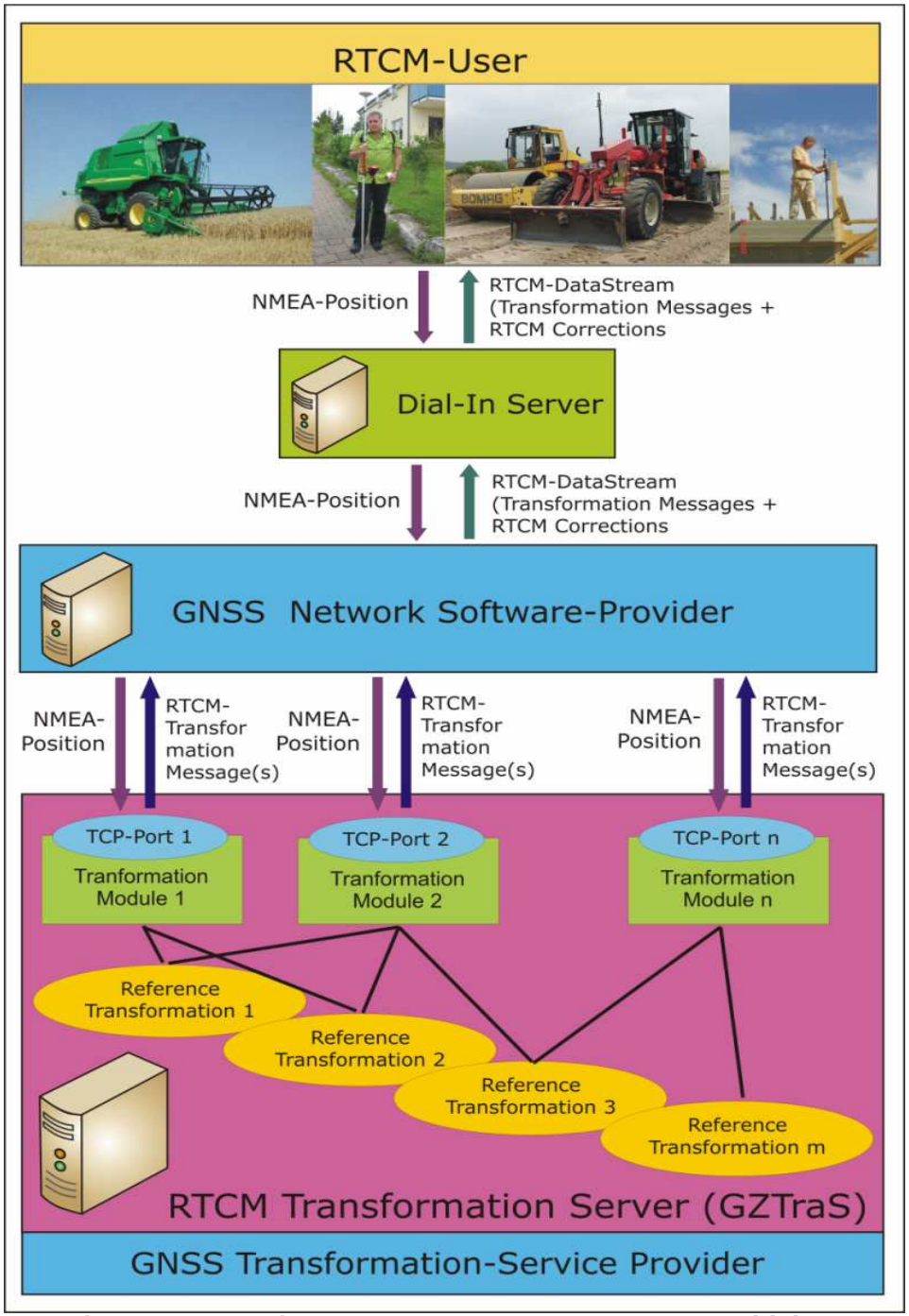
RCTM 3.1 Transformation Messages

General Configurable RTCM Transformation Messages Server

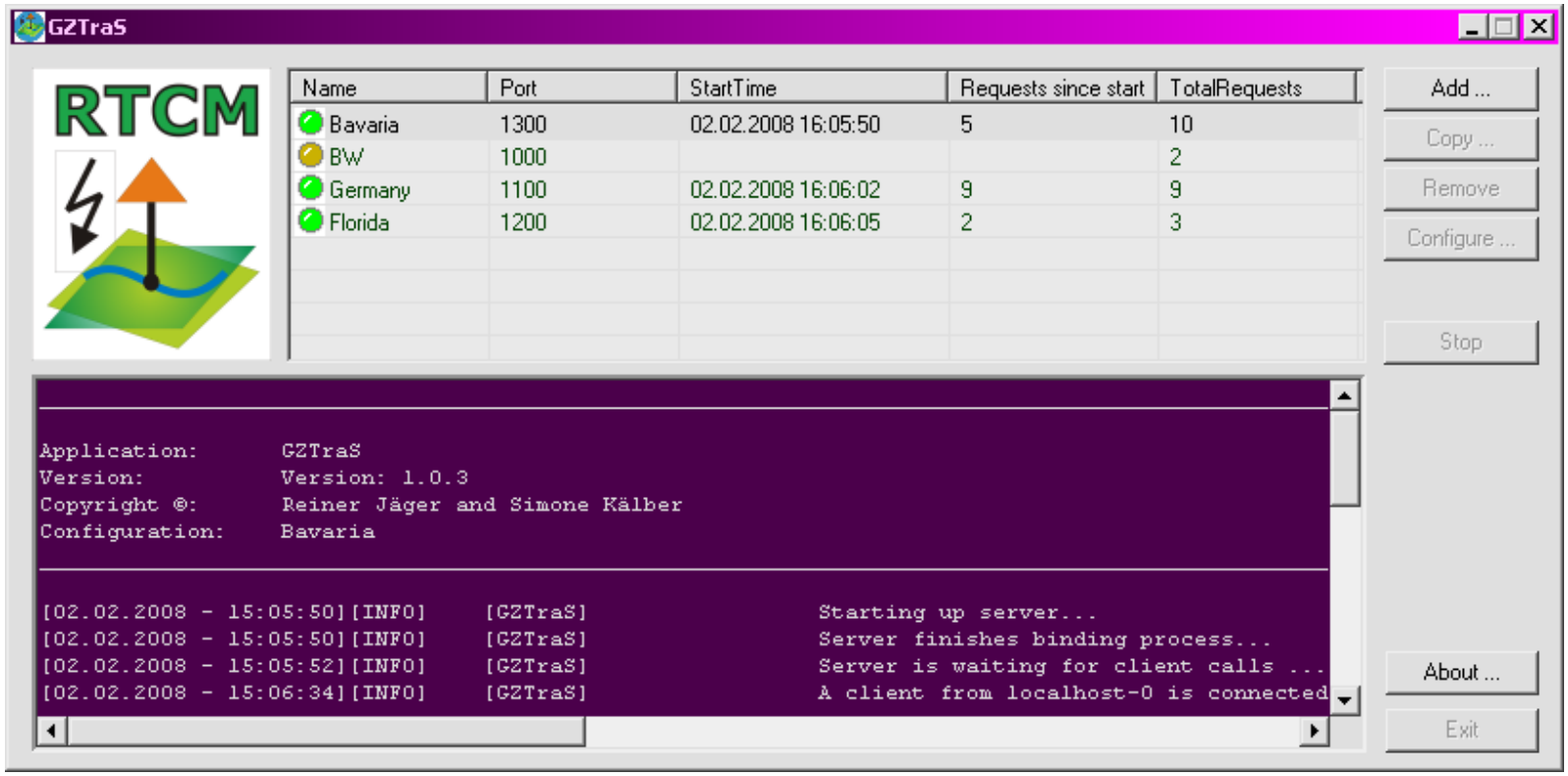
All kind of Reference Transformations in so called Transformation Modules

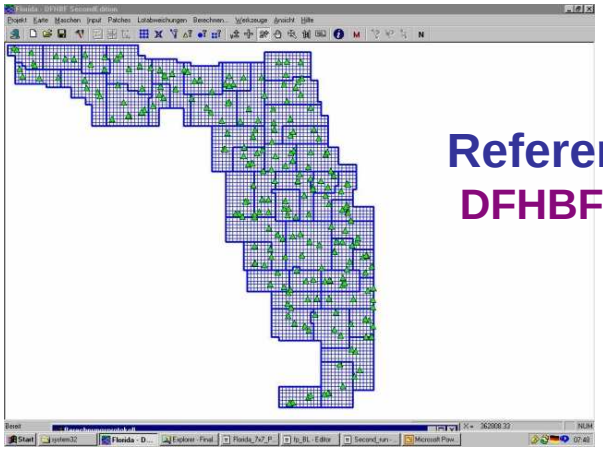
Dynamic & Combined & Static Messages

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



RCTM 3.1 Transformation Messages – GZTra-Server and GZTra-Client





Reference Transformations

DFHBF Florida

DFHBF Bavaria

DFLBF Bavaria

www.geozilla.de