Deformation Integrity Monitoring for GNSS-Positioning Services by the Karlsruhe Approach (MONIKA) - Concept, Realisation and Results -

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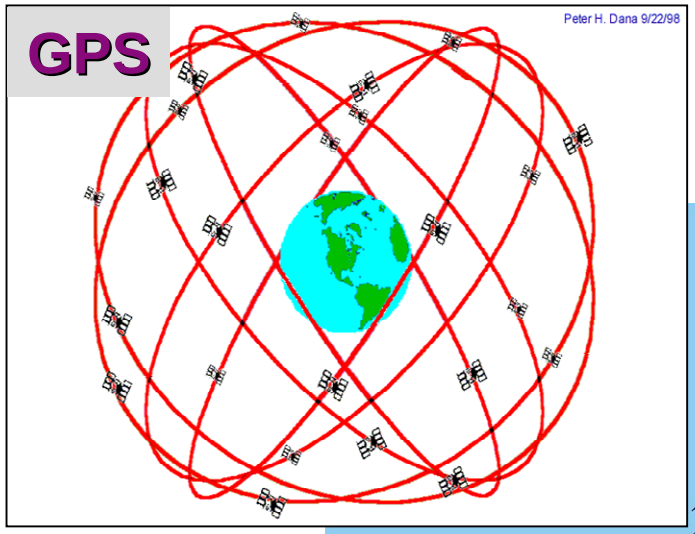
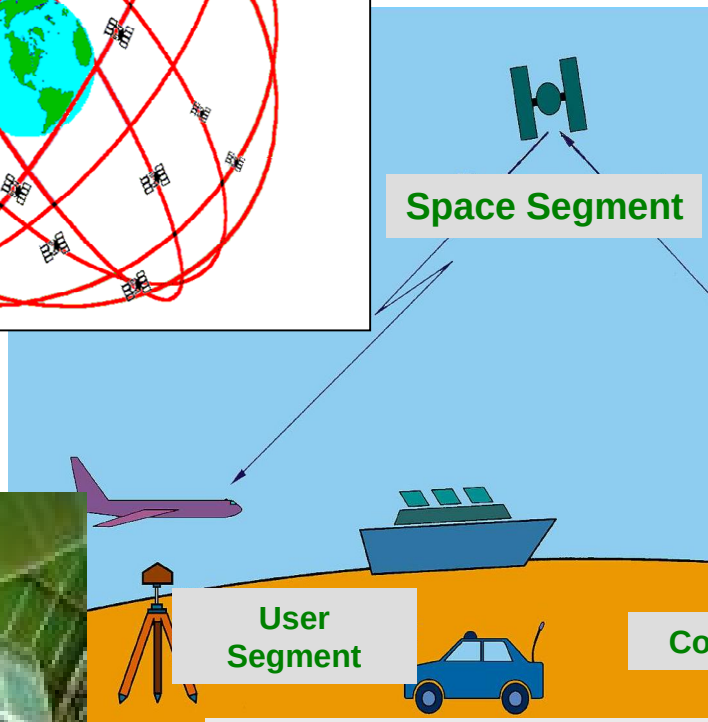
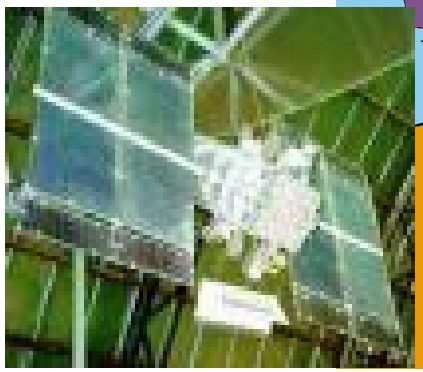
www.goca.info

GNSS for Global Positioning in ITRF/ECEF Frames







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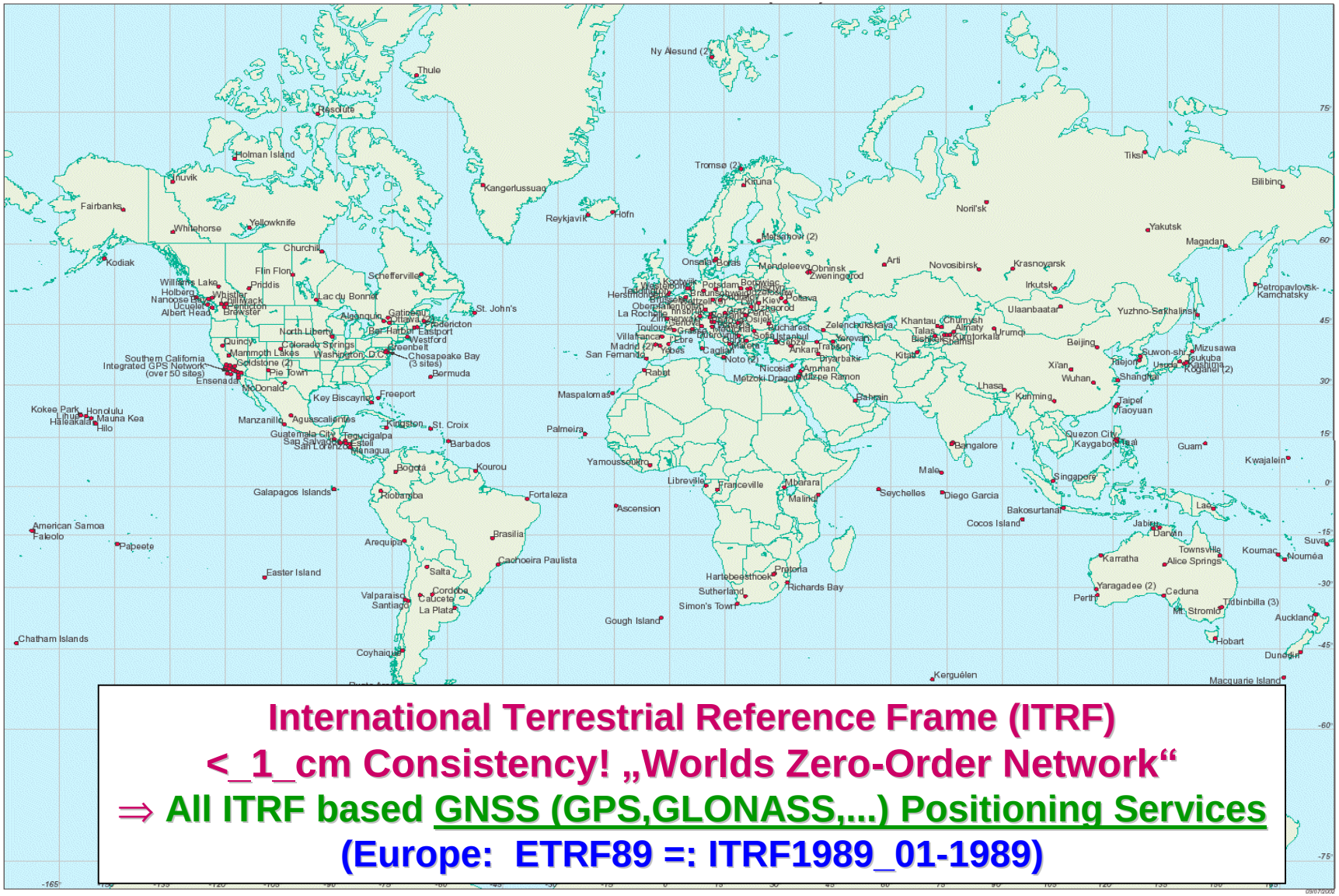
MONIKA GNSS - Reference- Station-MONItoring Karlsruhe

ITRF <= International GNSS Service (IGS)



International Terrestrial Reference Frame (ITRF)

<_1_cm Consistency! „Worlds Zero-Order Network“

⇒ All ITRF based GNSS (GPS,GLONASS,...) Positioning Services

(Europe: ETRF89 =: ITRF1989_01-1989)

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MONIKA GNSS - Reference- Station-MONItoring Karlsruhe

GNSS-Services and RTCM-based Positioning

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

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GNSS-Services and RTCM-based Positioning

RTCM 3.1 Observation Phase and Code Corrections => cm-Positioning

GNSS-Networks in EURASIA: SAPOS®/ascos® , SWIPOS®/SwissSat® …. SwePos®, CzePos® ,LatPos®, ASG-EUPOS® ,CroPOS®, HePos® , … Hungary, Slowenia, Romania, Moldavia, … SRPOS (Siberia)

... and many others worldwide!

International Symposium on GNSS, SBAS/GBAS and Applications, Berlin, 11.-14. November 2008

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GNSS-Services and RTCM-based Positioning

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

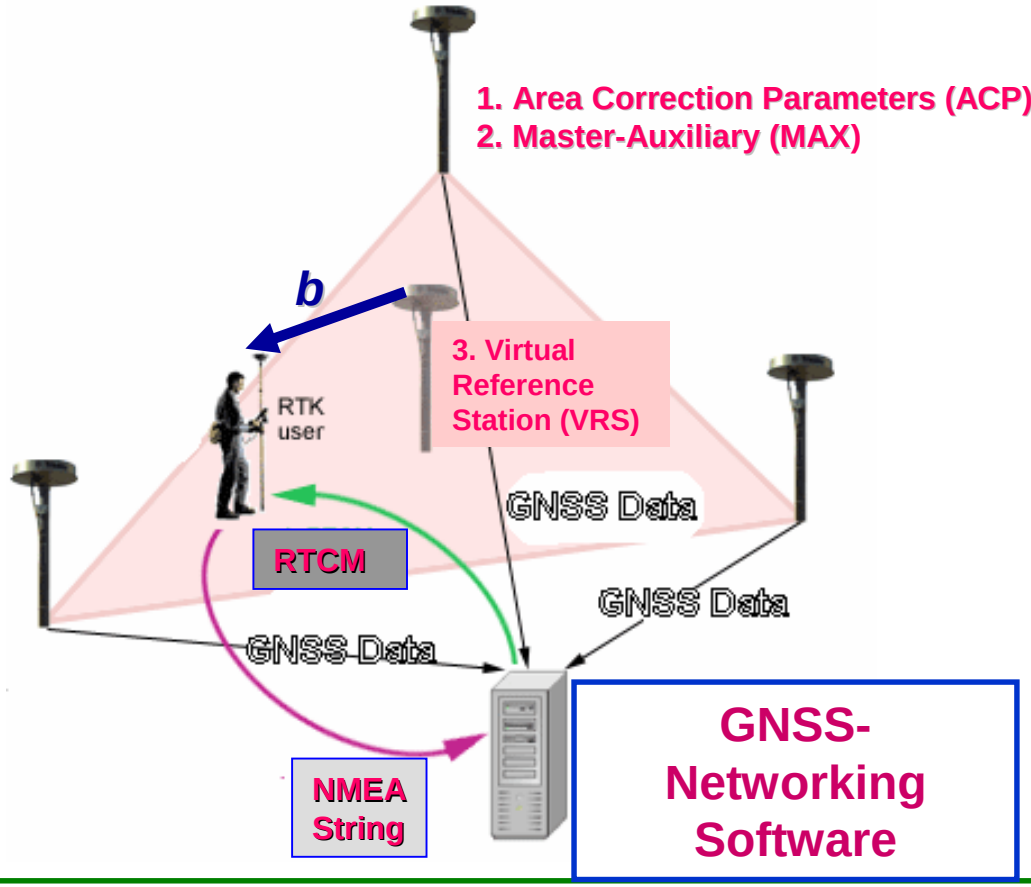
$$\nabla\rho(t-\Delta t)^{Sat}_{Ref} = \rho[(x,y,z)_{REF};(x,y,z)_{SAT,\Delta t}]_{true,Ref} - \rho(t-\Delta t)_{Observed,Ref}$$

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

RTCM 3.1
Observations-
Corrections

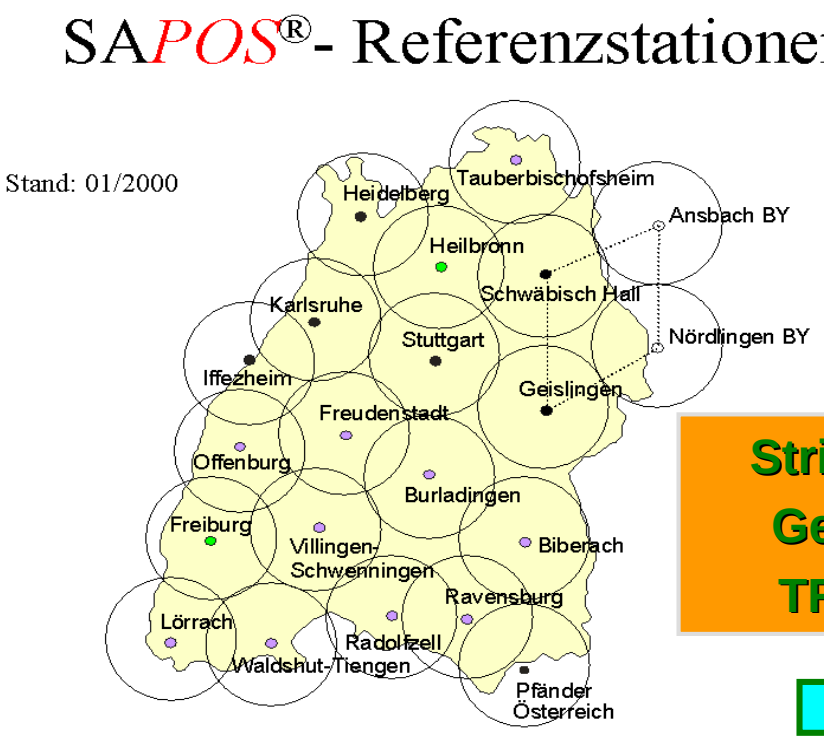
$$l_R(t)^{Sat}_{Rov,corrected} = l_R(t)^{Sat}_{Rov,Observed} - \nabla l_R(t-\Delta t)^{Sat}_{Ref}$$

→ $(B,L,h)_{GNSS\text{-}Datum}$

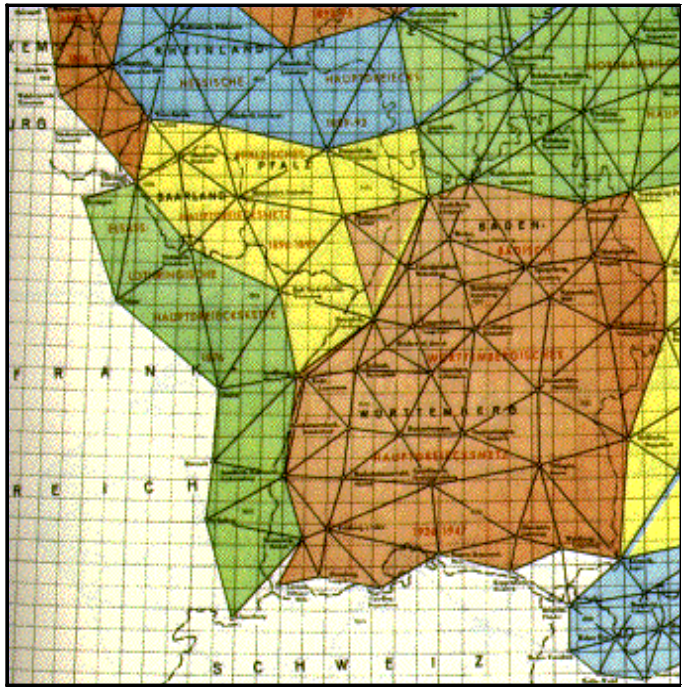


Transformation Problems and Reference Transformations

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



Strict and General TRAFO

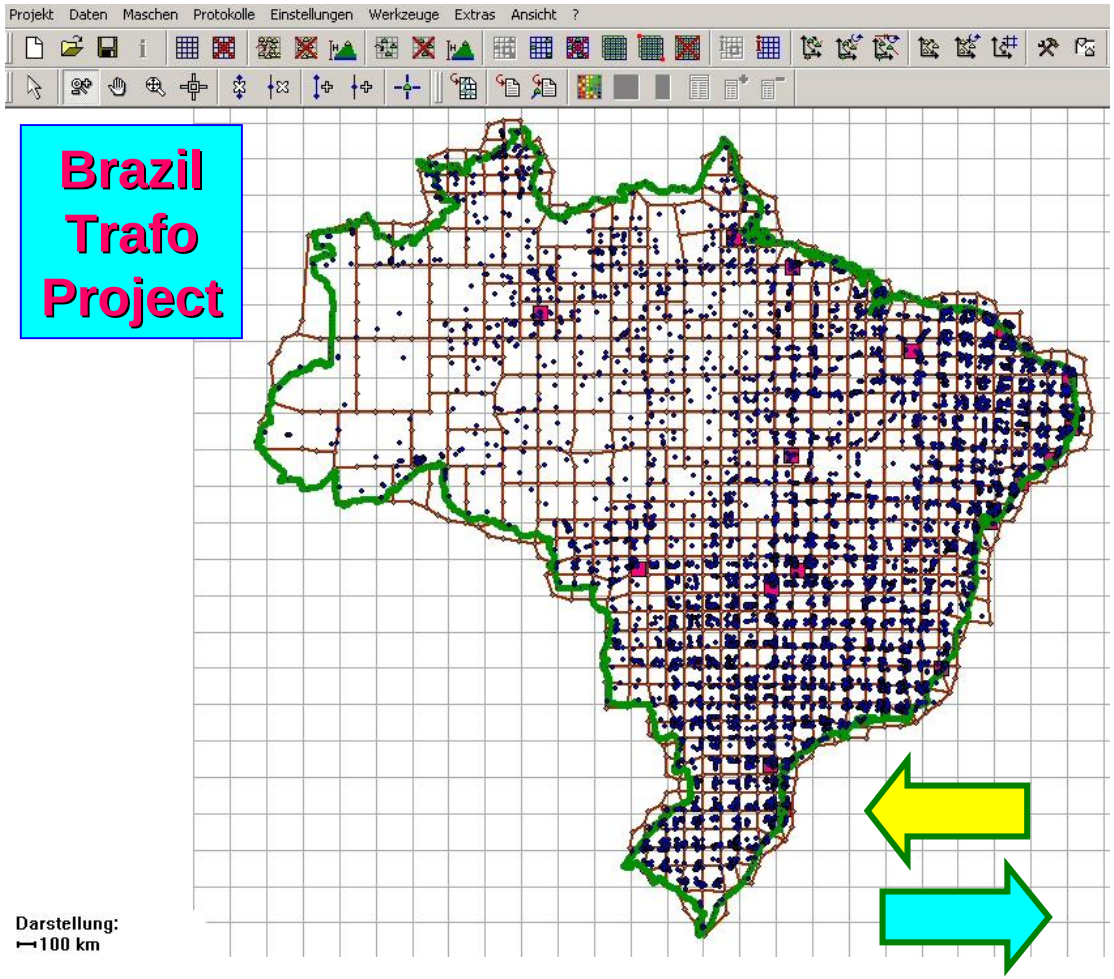


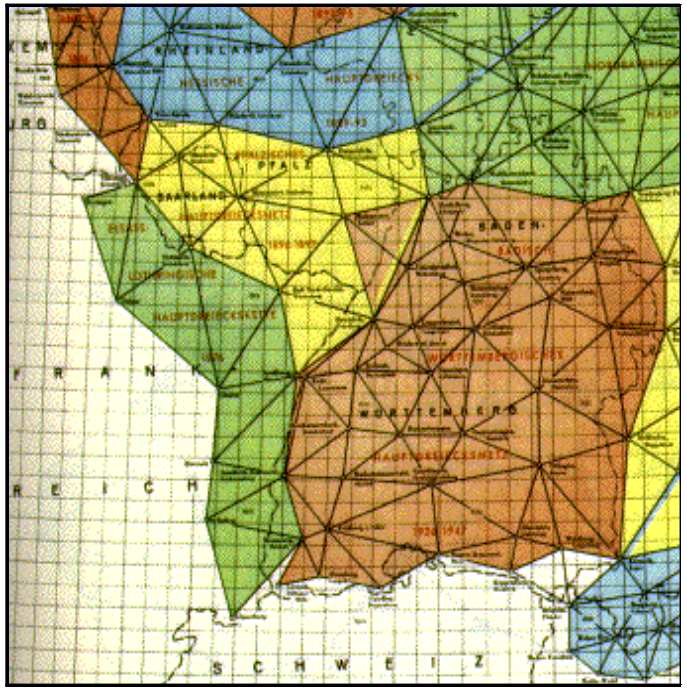
ITRF / ETRF89 - Datum

(Enabled & GNSS-practice

Old Classical Systems

Transformation Problems and Reference Transformations
1.) Horizontal Datum Transition from $(B,L)_{GNSS,ITRF}$ to Classical Datum $(B,L)_{Classical}$





ITRF / SIRGAS - Datum

(Enabled & GNSS-practice

Old Classical Systems

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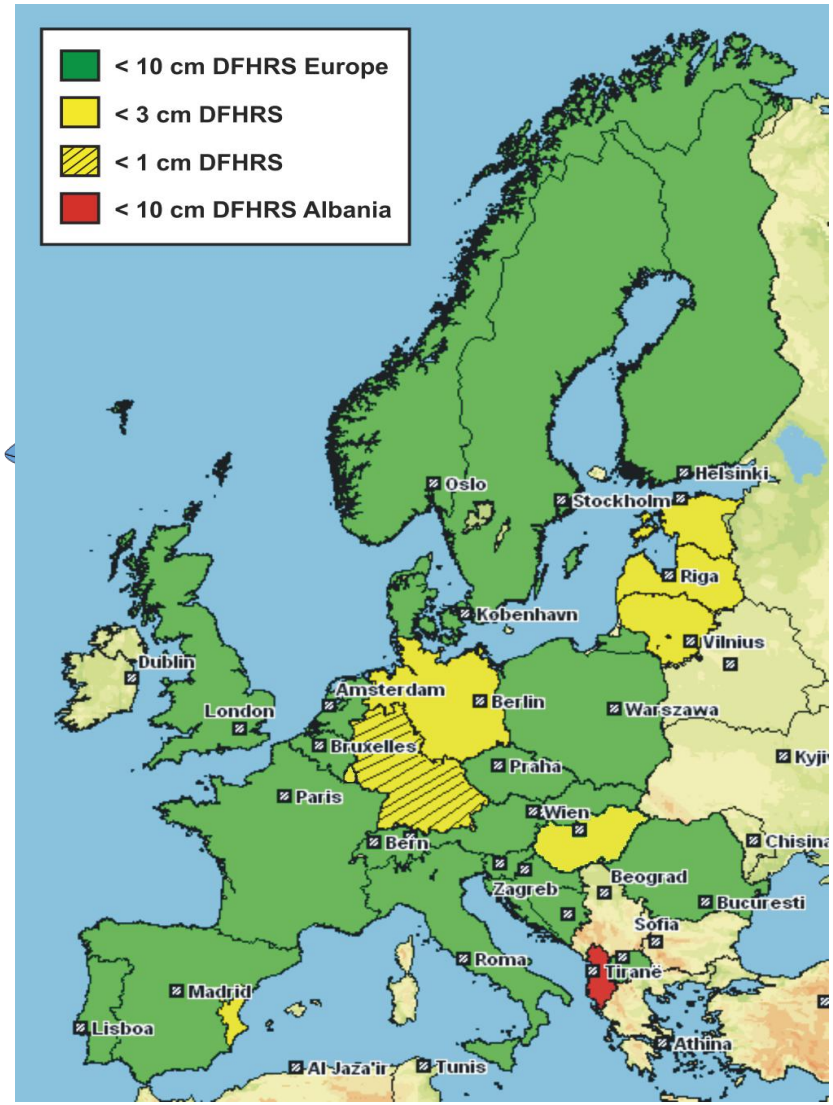
2. Height Problem / HRS Transition - Karlsruhe Reference Transformation



Reference-Transformation

Source CRS **Target CRS**

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

Official State Databases

e.g.

in German Countries

DFHBF-DB

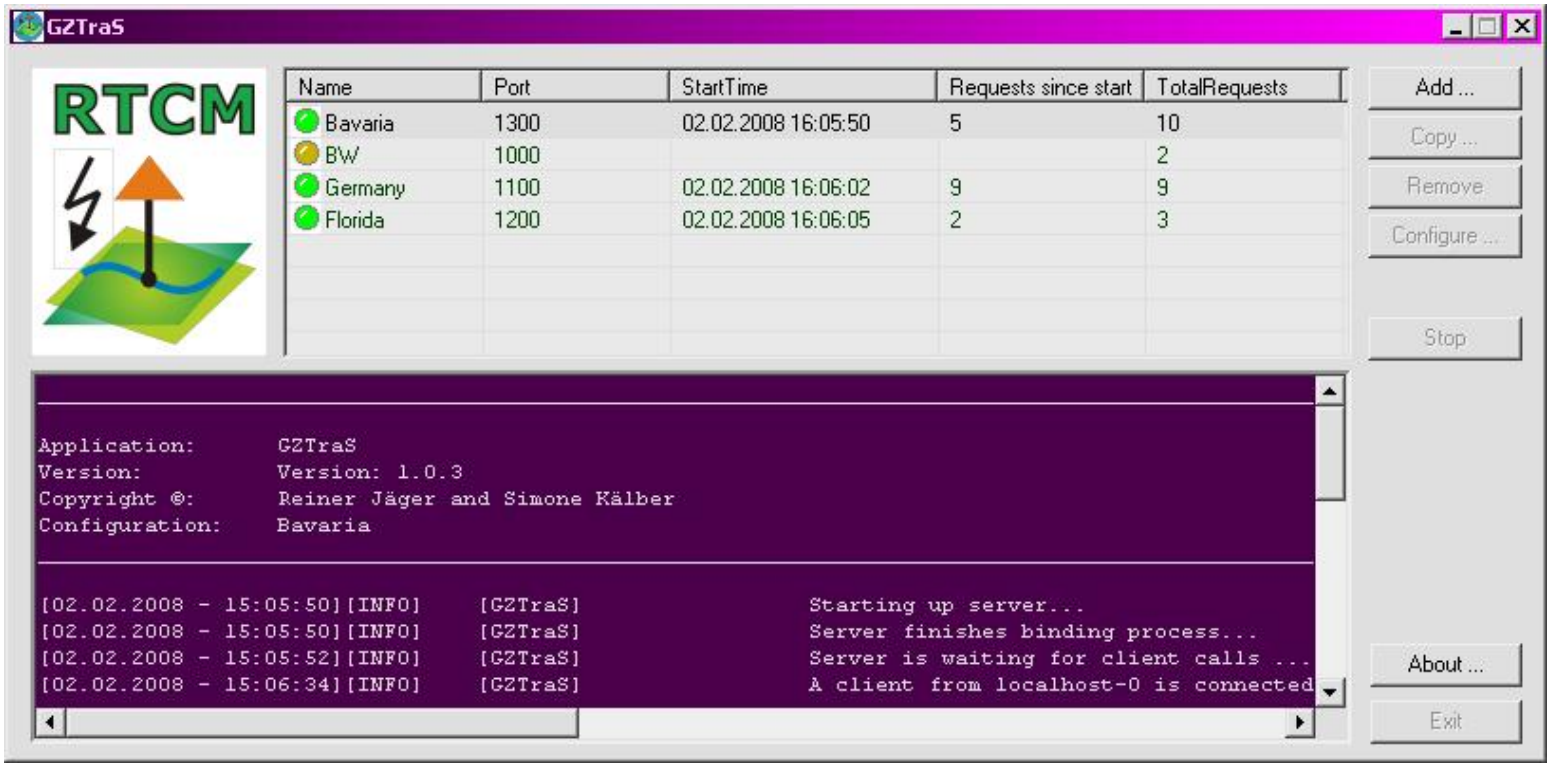
Herausgeber:

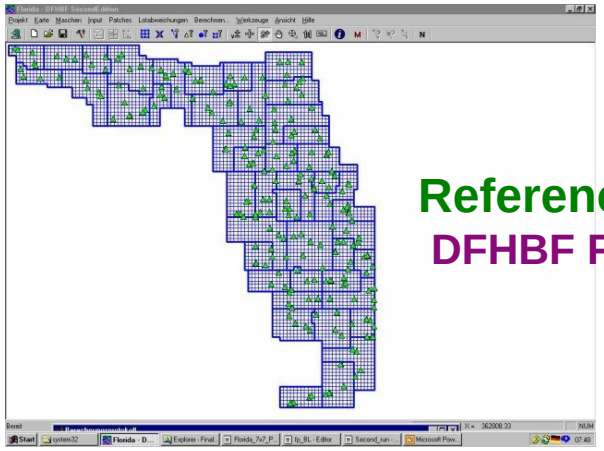
LVermGeo

Landesamt für Vermessung und Geobasisinformation Rheinland-Pfalz

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

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





Reference Transformations

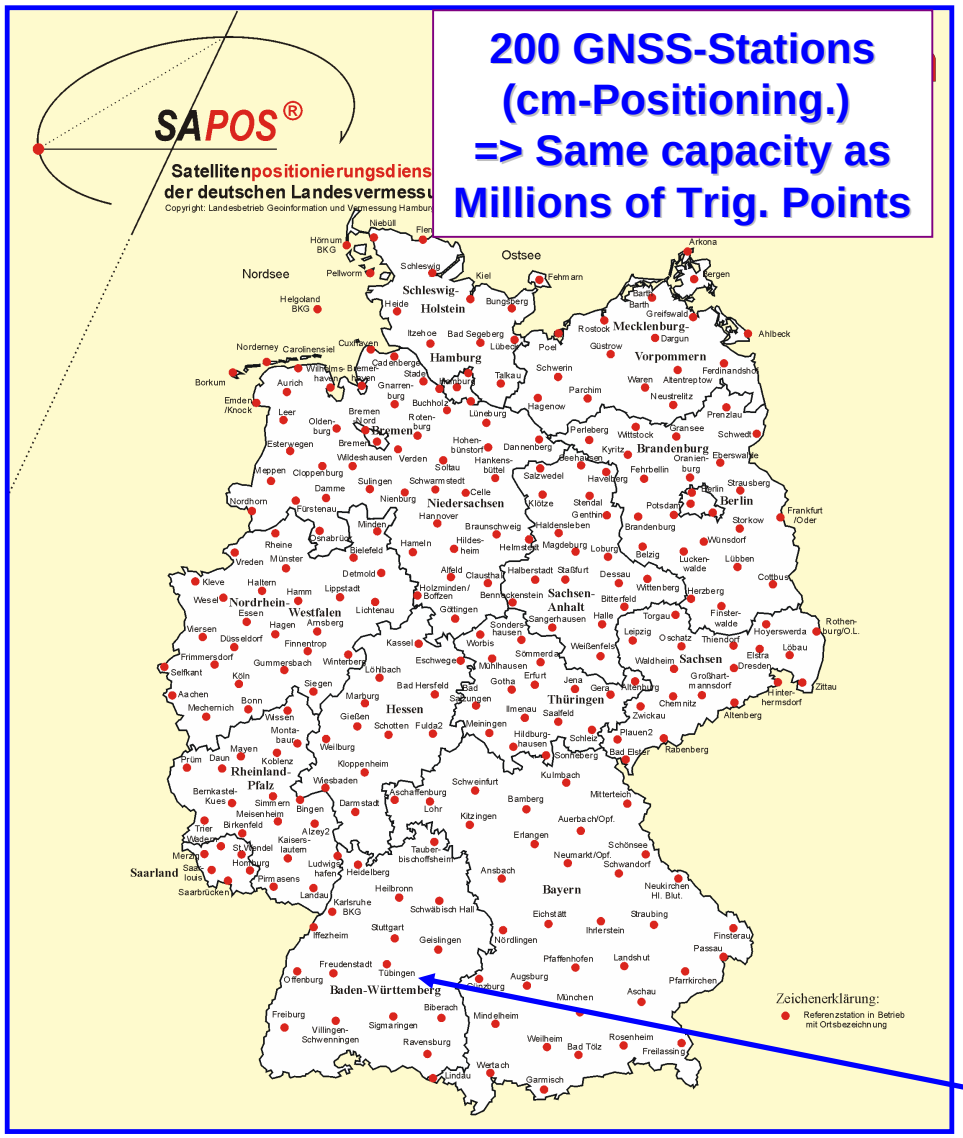
DFHBF Florida

DFHBF Bavaria

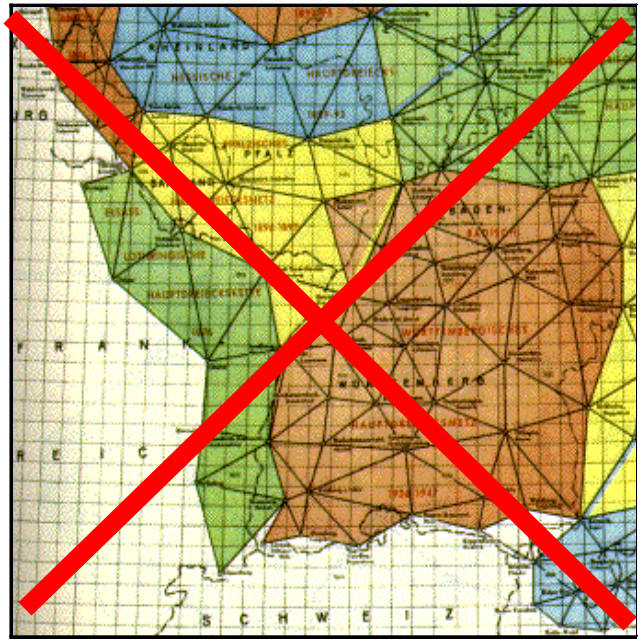
DFLBF Bavaria

www.geozilla.de

GNNS Reference Station Network - Monitoring



Old Classical Systems



Horizontal Positioning

ITRF-based datum => Direct access by GNSS (Old datum: GNSS online trafo)

Height

H(Physical) = h(GNSS) – N(Geoid)

~~(75% levelling points cancelled)~~

GNSS – Reference Stationscoordinate *MONI*toring *KA* Modell - *MONIKA*

Target

Permantent Control of Station-Positions

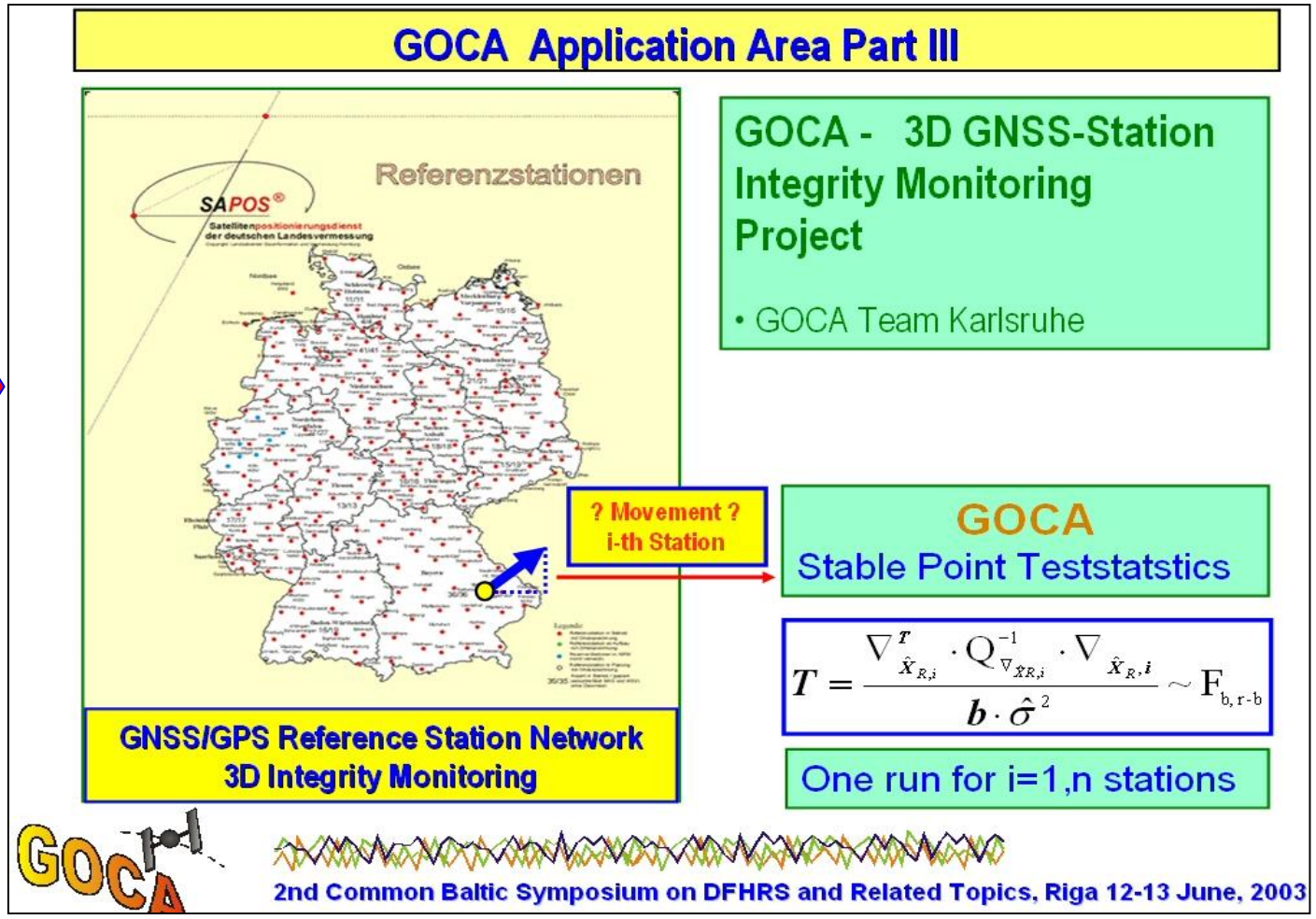
Forsight

Riga, 2003

Neccessity from the point of view of the GNSS-service-providers

AvD, 2006

(„officially“)



Consortium of the German Federal State Survey departements (AdV) (2006): Decision of the Plenum No. 118/6. Monitoring and supordinate reference frame for SAPOS®-Reference-stations. Agency of the AdV/Germany.

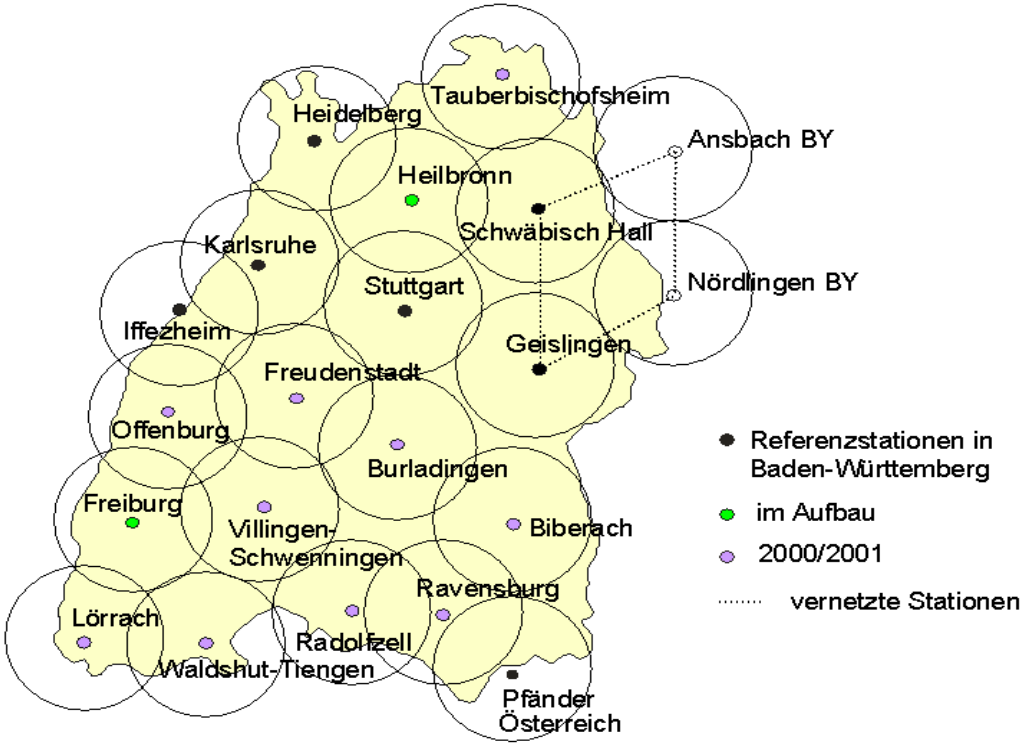
GNSS - Referenzstationskoordinaten *MONI*toring *KA* Modell - *MONIKA*

Cooperation Project

State Land Service (Landesvermessungsamt) Baden-Württemberg, Germany)

&

Karlsruhe University of Applied Sciences (HSKA)



GNSS – Reference-Stations-Coordinate - *MONI*toring According to the *KA*rlsruhe Approach (*MONIKA*)

GNSS-RINEX-Data

Priority

„Relative“
deformation network“
= Congruency state

- Near-Online
- Multivariate
- Multi-epochal

Secondary

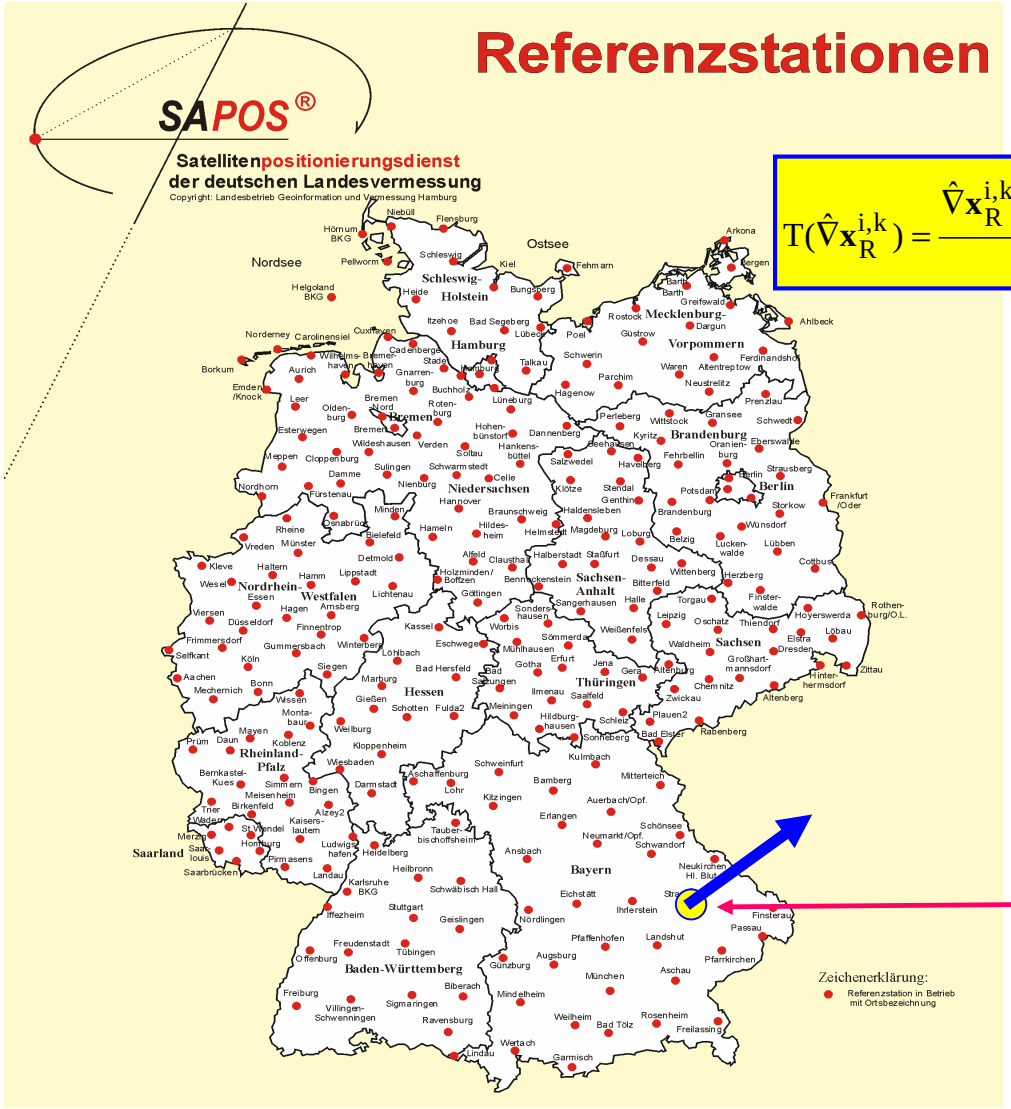
„Objectpoint Monitoring“

Coordinate related Deformation Analysis

= 2 adjustment steps
before deformation analysis. Both steps controlled in MONIKA

Concepts

- ITRF-based networks
- Free networks



GNSS – Reference-Stations-Coordinate - *MONI*toring According to the *KA*rlsruhe Approach (*MONIKA*)

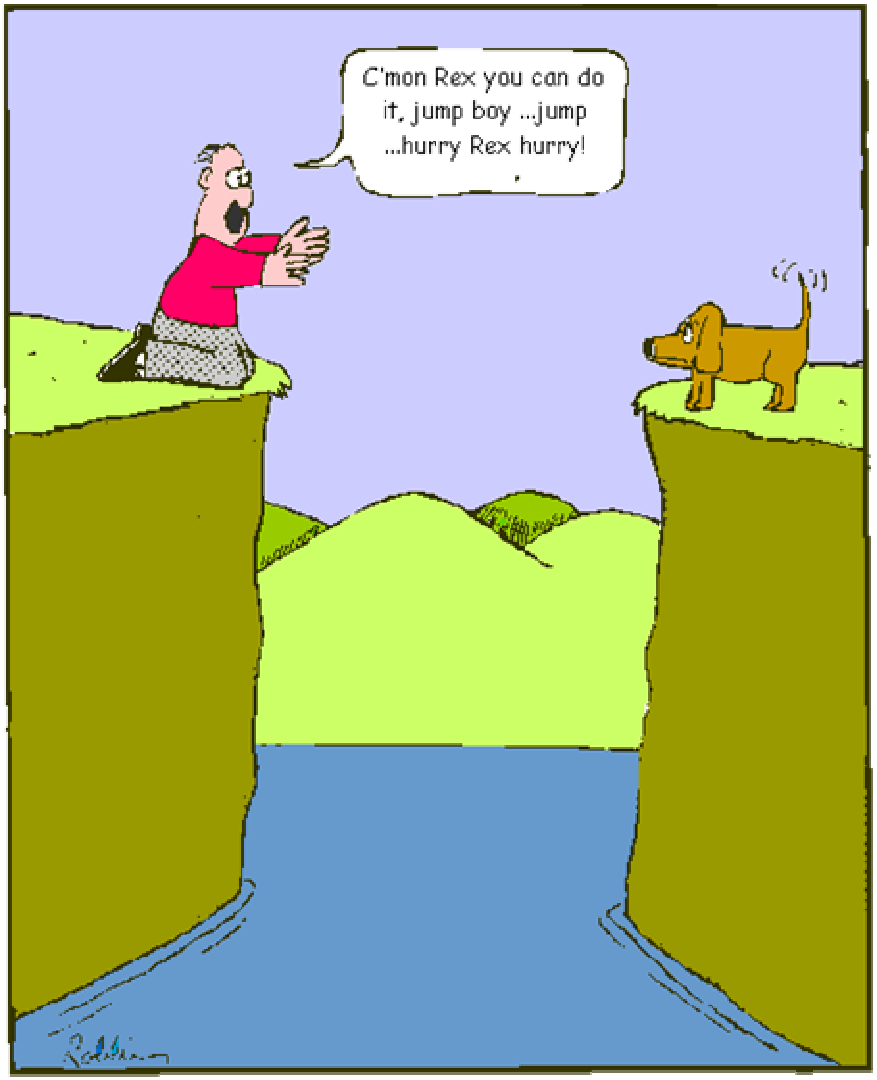
Scalable!

Coordinate related Deformation Analysis

Time
Network-Size

Additional
- Transformations
„Reductions“
- Parametric Modelling

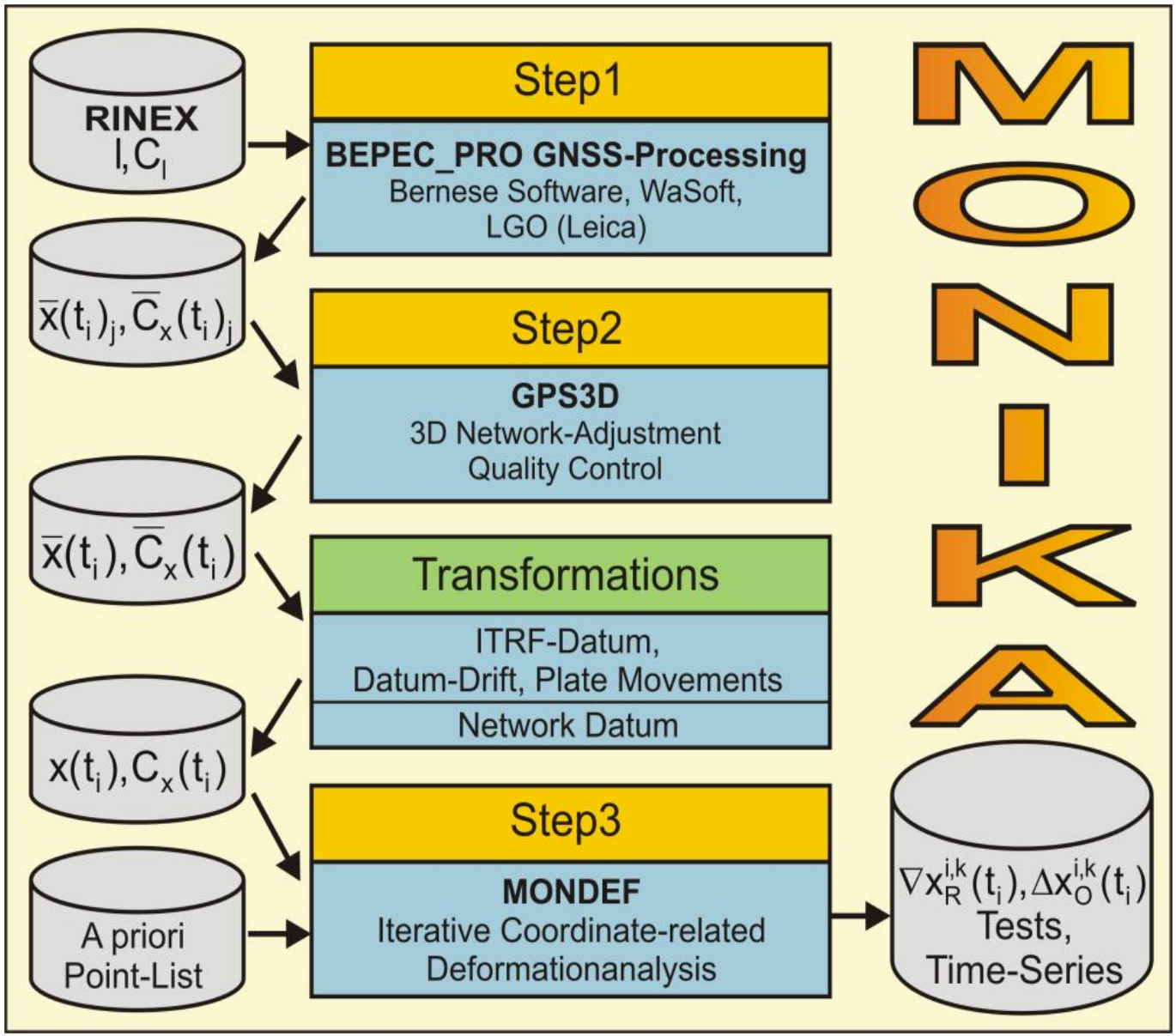
PLATE MOVEMENTS



GNSS – Reference-Stations Coordinate

- *MONI*toring According to the

***KA*rlsruher Approach (*MONIKA*)**



GNSS - Referenzstationskoordinaten *MONI*toring *KA* Modell - *MONIKA*

MONIKA Step 1

GNSS RINEX-Data $\mathbf{l}(t_i), \mathbf{C}_l(t_i)$

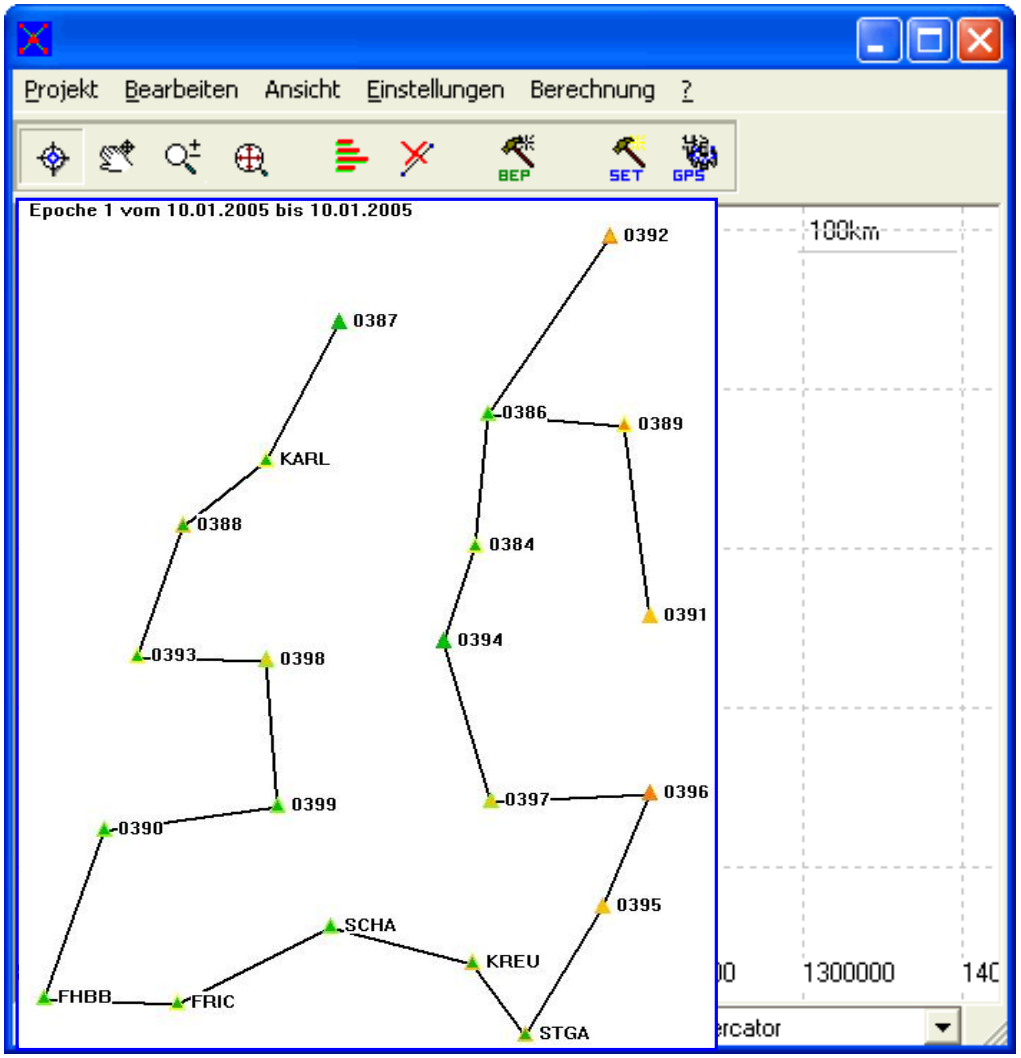
GNSS-Processing

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)
- Bernese GPS-Software 5.0

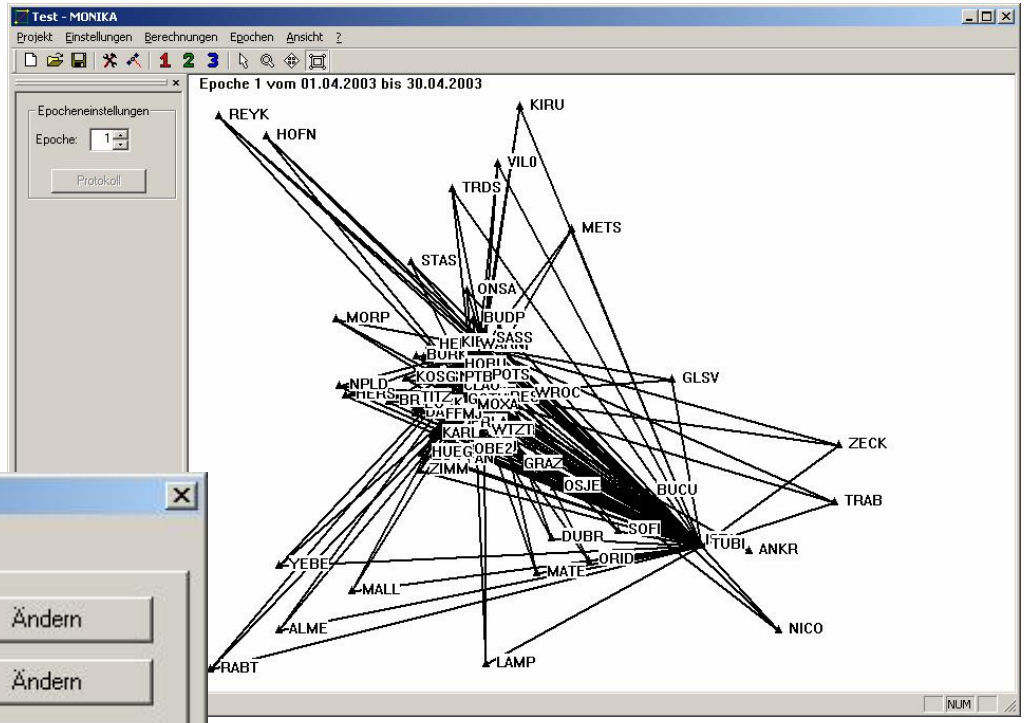


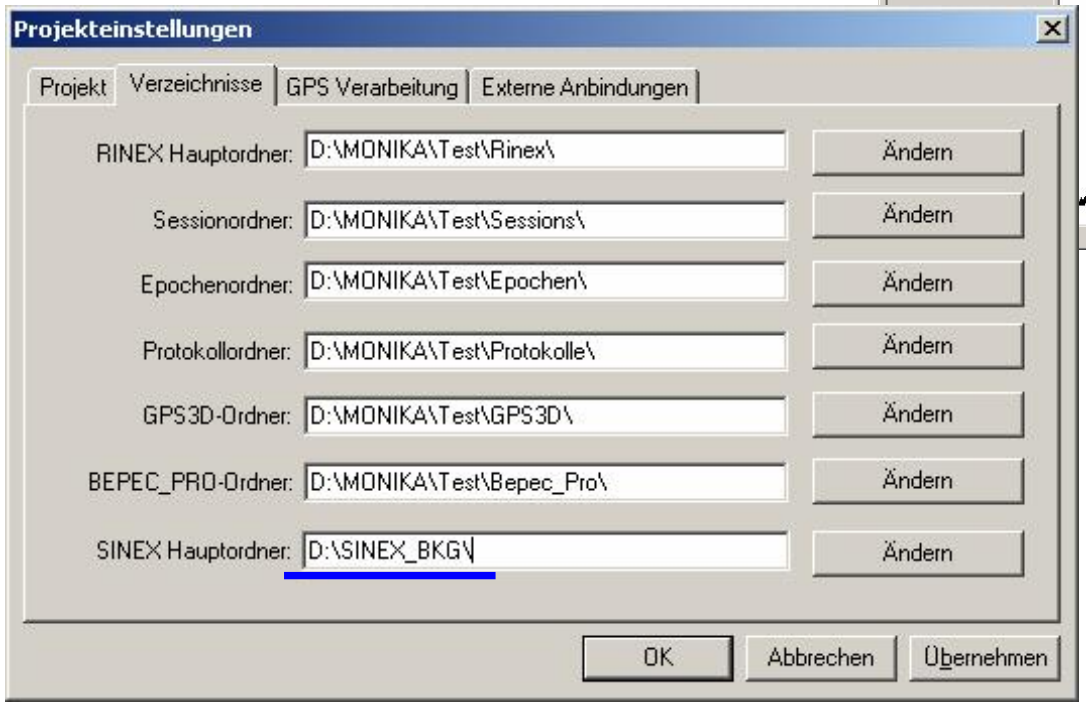
GNSS - Referenzstationskoordinaten *MONI*toring *KA* Modell - *MONIKA*

MONIKA Step 1

GNSS
SINEX-Data

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





GNSS – Reference- Station-Coordinate *MONI*toring *KA* Modell - *MONIKA*

MONIKA Step 2

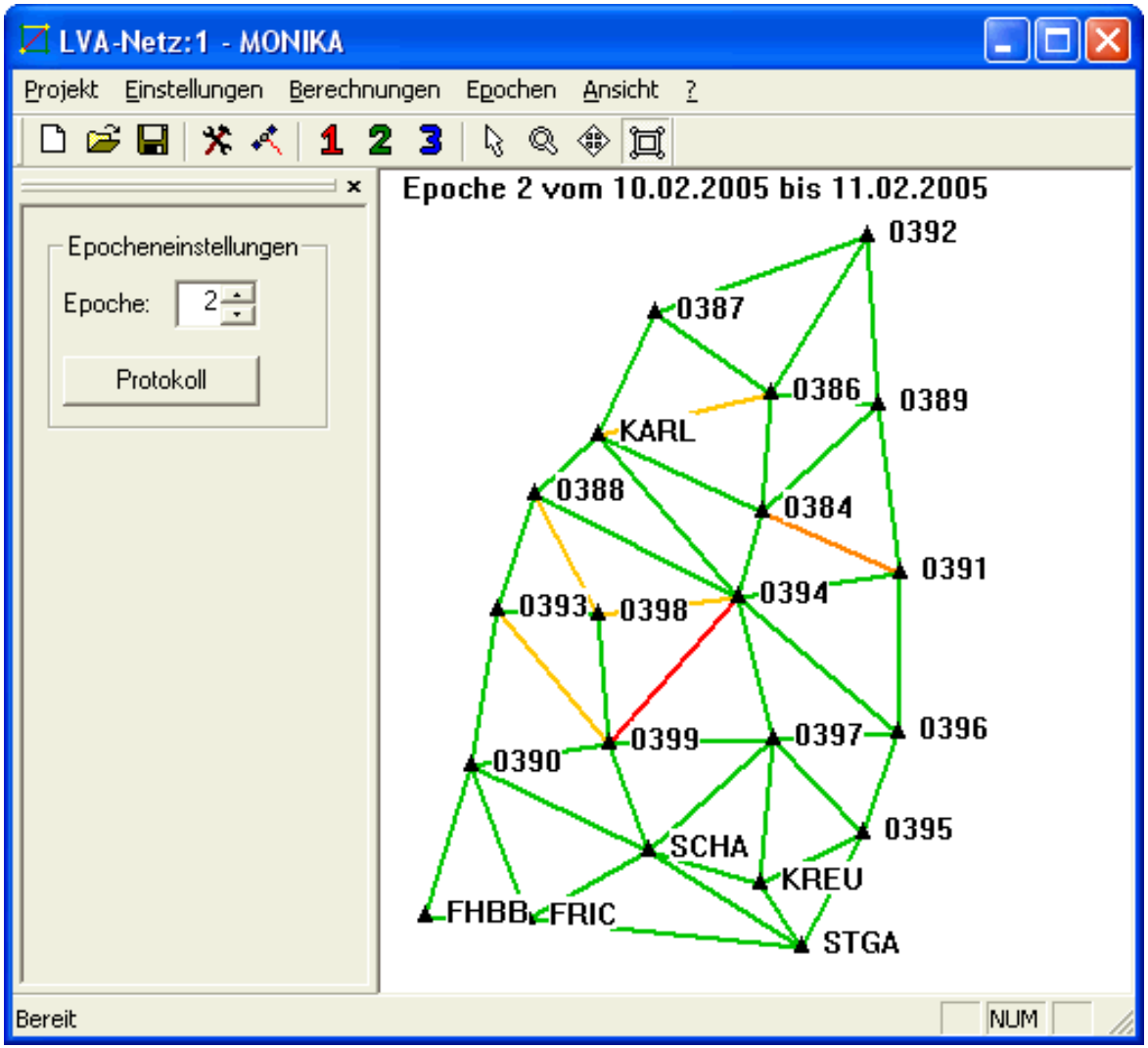
- Baselines
- Epoch Networks
- Partial Networks
- Daily Solutions

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

Δt

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

- Epoch States



MONIKA Step 2

- Baselines
- Epoch Networks
- Partial Networks
- Daily Solutions

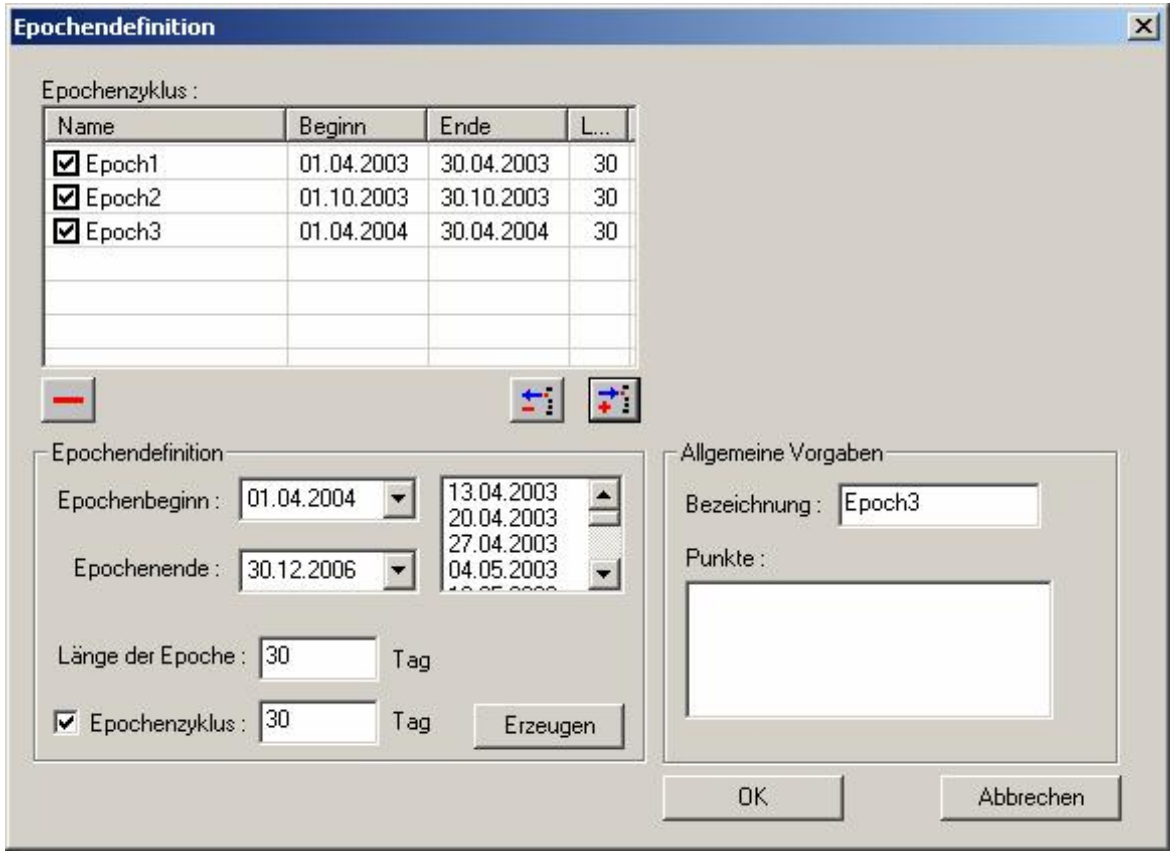
$$\bar{x}(t_i)_j, \bar{C}_x(t_i)_j$$

Δt

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

•Epoch States

Automatic Epoch Generation



GNSS – Reference- Stations-Coordinate *MONI*toring *KA* Modell - *MONIKA*

Considering Datum-drift and Plate-Movement Rates

Use

of

IERS

Parameters

Reference time

t_0

Epoch time

t_i

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

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

GNSS – Reference- Stations-Coordinate *MONI*toring *KA* Modell - *MONIKA*

Considering Datum-drift and Plate-Movement Rates

$$\left(\left(\mathbf{R}_{P(j)} \cdot \mathbf{x}(t_1)_{ITRFzz.t_1}\right)\right) \cdot (t_2 - t_1)$$

Cartesian rotation vector for each major plate using the NNR-NUVEL1A kinematic plate model (no net rotation). *mas* Milliarc second. Anticlockwise rotations of magnitude $|\vec{\Omega}|$ around each plate polar axis (defined by the vector $\vec{\Omega}$) are assumed positive

Plate name	Ω_x (mas/y)	Ω_y (mas/y)	Ω_z (mas/y)	$\lvert\vec{\Omega}\rvert$ (mas/y)
Africa	0.1837	−0.6392	0.8090	1.047283
Antarctica	−0.1693	−0.3508		
Arabia	1.3789	−0.1075		
Australia	1.6169	1.0569		
Caribbean	−0.0367	−0.6982		
Cocos	−2.1503	−4.4563		
Eurasia	−0.2023	−0.4940		
India	1.3758	0.0082		
Nazca	−0.3160	−1.7691		
North America	0.0532	−0.7423		
Pacific	−0.3115	0.9983		
South America	−0.2141	−0.3125		
Philippines	2.0812	−1.4768		

MONIKA Trafos 1 - Step 2

Use of IERS- and other Parameters for referencing the deformation analysis to a common reference-time t_2

Table 1

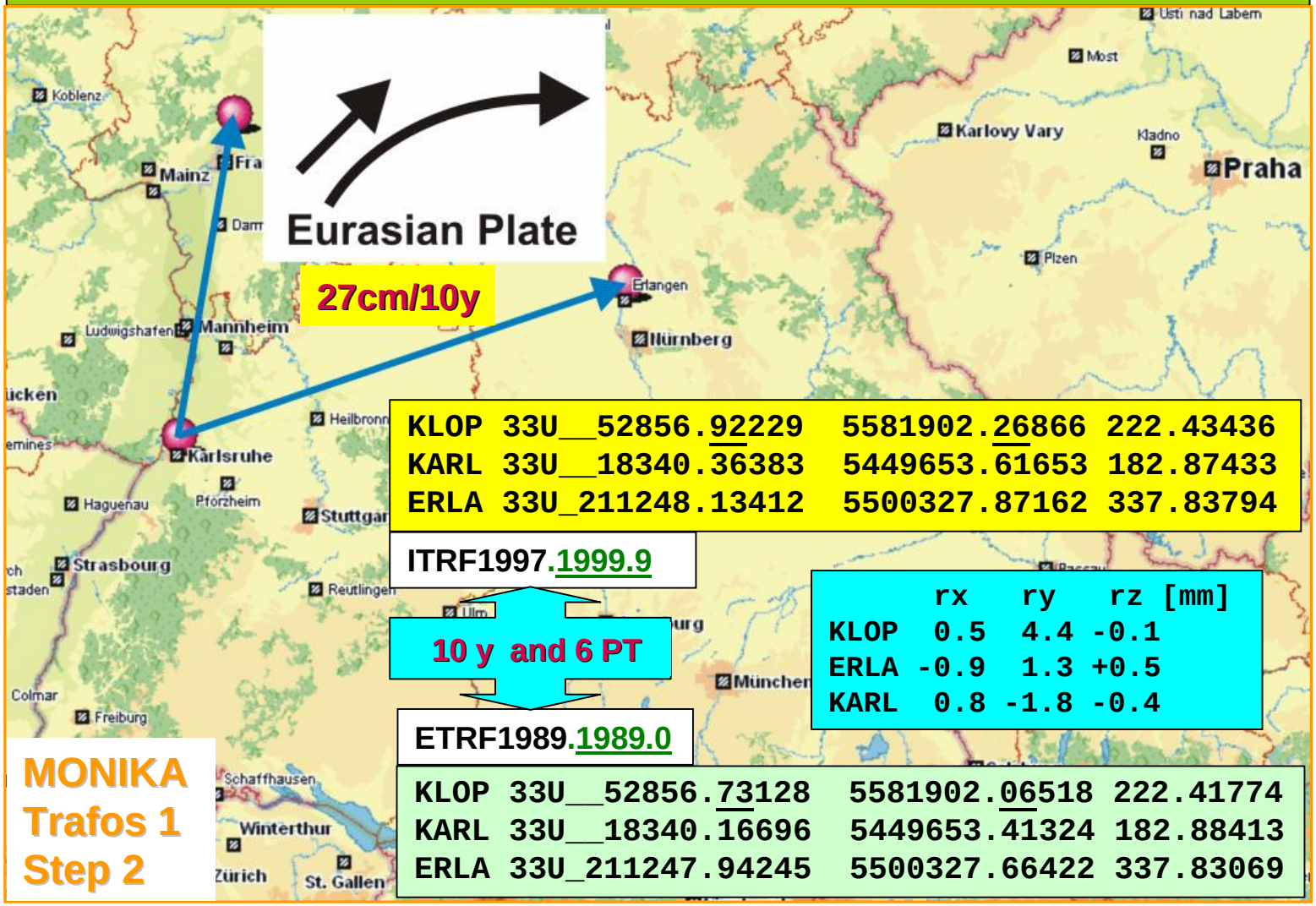
Most recent 14-transformation parameters between modern geocentric frames (Ferland 2002, p. 26). IGS(ITRF2000) → IGS(ITRF97) (epoch: t_k=2001.5). *mas* Milliarc second; *ppb* parts per billion =10^{-3} ppm. Anticlockwise rotations of amounts ϵ_x, ϵ_y, ϵ_z about the *x*, *y*, and *z* axes are assumed positive

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

T_x (m)	T_y (m)	T_z (m)	ϵ_x (mas)	ϵ_y (mas)	ϵ_z (mas)	s (ppb)
0.0047	0.0028	−0.0256	−0.030	−0.003	−0.140	1.48
±0.0005	±0.0006	±0.0008	±0.025	±0.021	±0.021	±0.09
$\dot{T}_x$(m/y)	$\dot{T}_y$(m/y)	$\dot{T}_z$(m/y)	$\dot{\epsilon}_x$(mas/y)	$\dot{\epsilon}_y$(mas/y)	$\dot{\epsilon}_z$(mas/y)	$\dot{s}$(ppb/y)
−0.0004	−0.0008	−0.0016	0.003	−0.001	−0.030	0.03
±0.0003	±0.0003	±0.0004	±0.012	±0.011	±0.011	±0.05

GNSS – Reference- Stations-Coordinate *MONI*toring *KA* Modell - *MONIKA*

Considering Datum-drift and Plate-Movement Rates




```
KLOP 33U__52856.92229   5581902.26866 222.43436
KARL 33U__18340.36383   5449653.61653 182.87433
ERLA 33U_211248.13412   5500327.87162 337.83794
```

ITRF1997.1999.9

10 y and 6 PT

```
        rx    ry    rz [mm]
KLOP   0.5   4.4  -0.1
ERLA  -0.9   1.3  +0.5
KARL   0.8  -1.8  -0.4
```

ETRF1989.1989.0

```
KLOP 33U__52856.73128   5581902.06518 222.41774
KARL 33U__18340.16696   5449653.41324 182.88413
ERLA 33U_211247.94245   5500327.66422 337.83069
```

MONIKA Trafos 1 Step 2

Use of the geodynamic parameters as prior information for the Bayes estimation of Datum-Transition Datum Drift and Plate-Rotation

GNSS-Reference-Stations-Coordinate *MONI*toring *KA* Model *MONIKA*

MONIKA Step 2 – Coordinate related Referencepoint-Deformationanalysis

MONIKA
ITRF-embedded
Deformation
Analysis Concept

RINEX

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

SINEX

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

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

Epoch States
+ Geodyn. Trafo
MONIKA Step 2

MONIKA
Free GNSS-network
Deformation
Analysis Concept

Singular

Unknown Datum

GNSS-Reference-Stations-Coordinate *MONI*toring *KA* Model *MONIKA*

MONIKA Step 2 – Coordinate related Referencepoint-Deformationanalysis

MONIKA

Free GNSS-network

Deformation Analysis Concept

Original GNSS observations RINEX

$$\mathbf{l}(t)_i, C_l(t)_i$$

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

Epoch States + Geodyn. Trafo

MONIKA Step 2

Singular

x_0 ?

Unknown Datum

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

New x_0

Helmert-Transformation d=3

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

S-Transformation d=3

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

MONIKA Trafo 2 - Step 2

MONIKA Step 3 – Coordinate related Reference-Point-Deformationanalysis

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

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

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

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

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

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

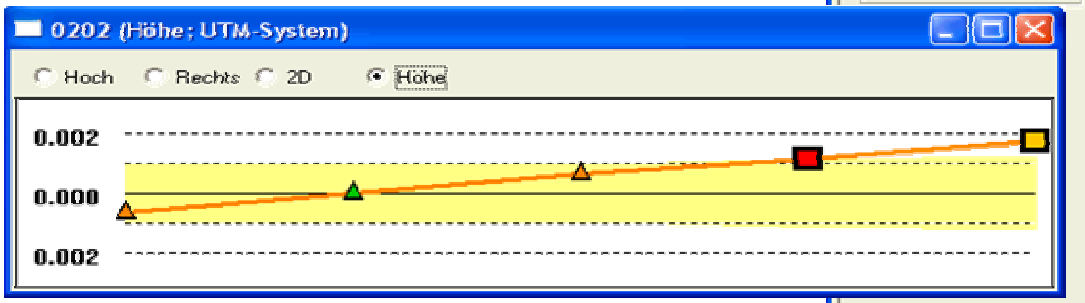
(= 1.0 accuracy , 1-α = 19.9 % error ellipsoid)

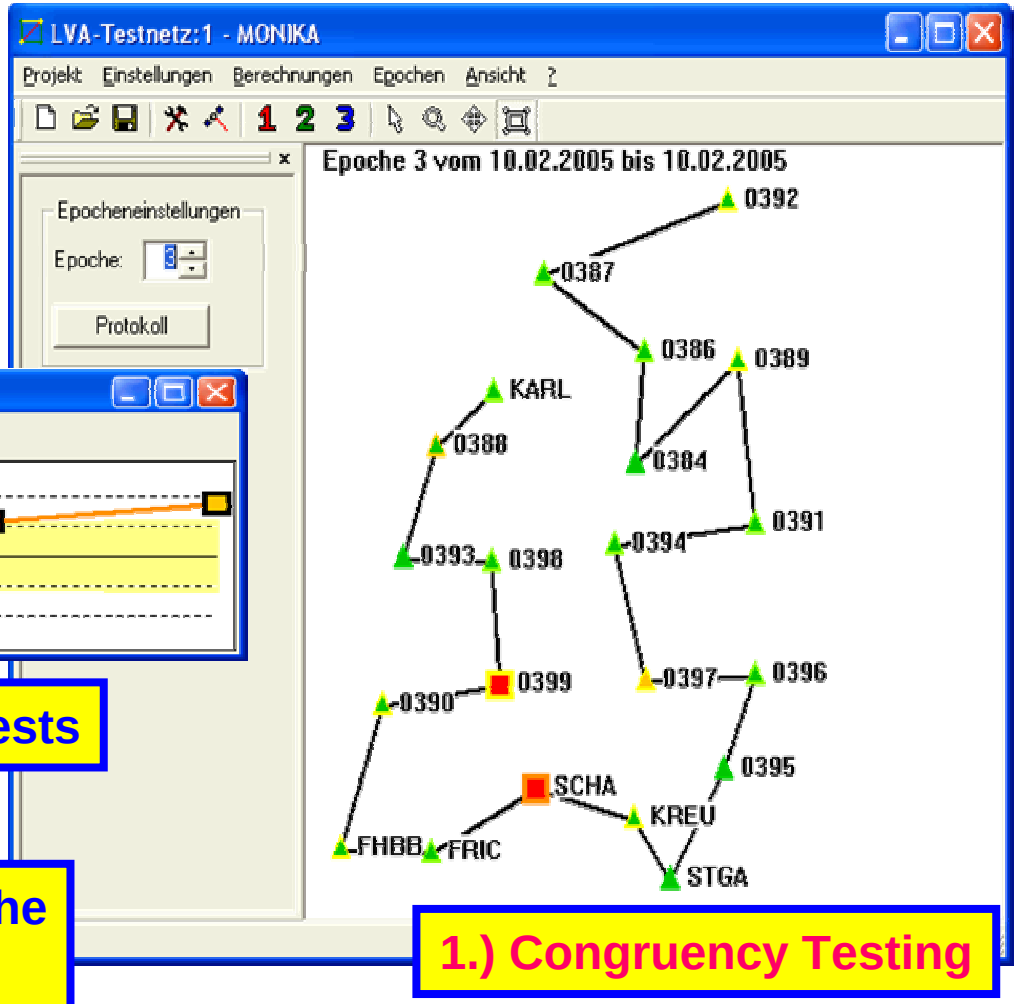
Detectability of GNSS Reference Station Deformations $\nabla \mathbf{x}_R^{i,k}$

GNSS – Reference-Stations-Coordinate *MONI*toring *KA* Model - *MONIKA*

MONIKA Step 3 –

Coordinate related Reference-Points Deformation Analysis





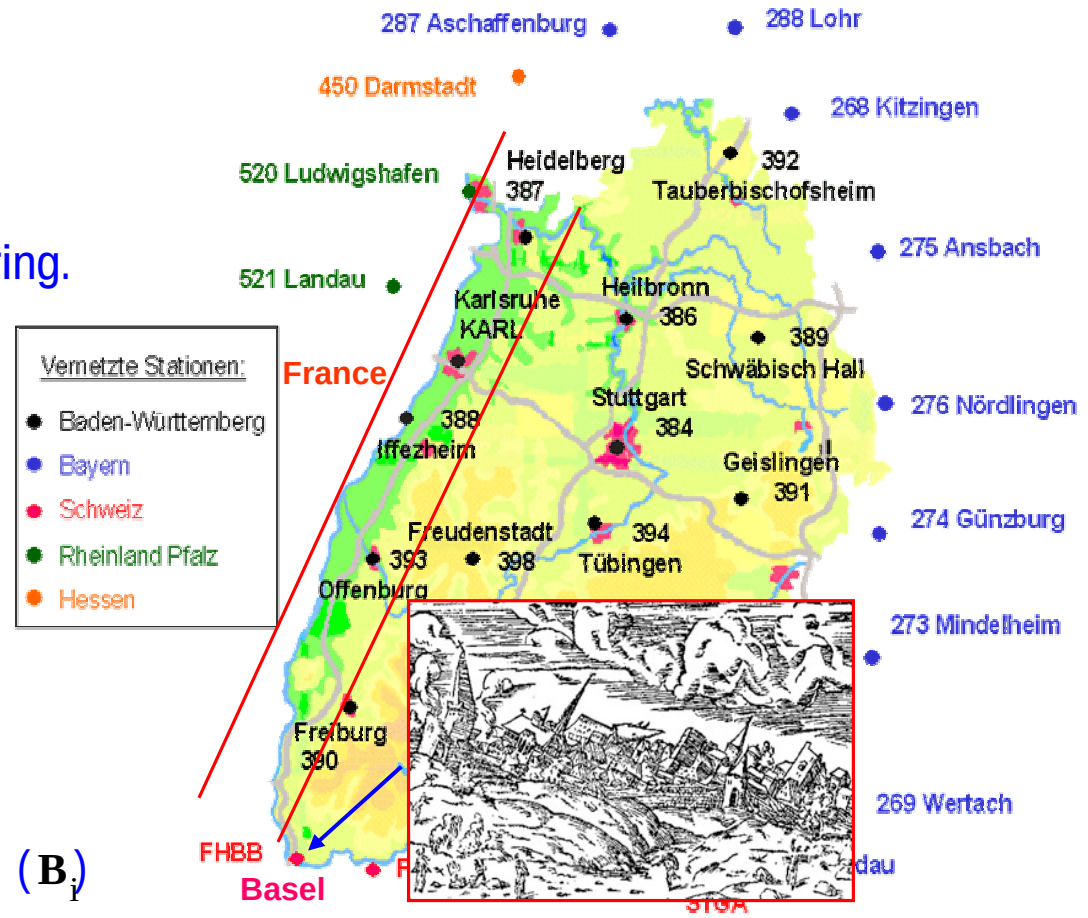
2.) Additionally: Object-Points + Tests

3.) Additionally: Full spectrum of the Deformationsanalysis Features of the GOCA-software (www.goca.info)

1.) Congruency Testing

Present results and Further Developments of GOCA_MONIKA

- Cooperation with State Service of Baden-Württemberg Ba-Wü
  - High need of MONIKA
    German AdV-Decision for GNSS-Monitoring.
    Worldwide Upcome von GNSS-Services
  - Accuracy of the displacements in 4 epochs and 24-hours-measurements
    1 - 2 mm Horizontal and
    3 - 4 mm Height
    => High Sensitivity
  - Longterm and large area monitoring, requires geodynamical standard trends
  - More Complex models e.g. point groups ($\mathbf{B}_i$)



- *Included:* GNSS-based Monitoring of Earthequake zones (e.g. Basel), Landslides, Mining, Constructions etc.
- *AGU 2007,Acapulco,G05: Large Scale Geodetic Networks for Science,Hazard Monitoring & Infrastructure*