Mapping Projects

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Organization

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- modern and official coordinate systems
- DB AG – DB_REF system
- local transformations/adjacency preserving transformation
- GNTRANS
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  - transformation model
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  - accuracy
  - module/patches
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Introduction

For all kind of applications a framework for spatial referencing is required. Geodetic network are installed by surveyors to create such framework. It is often necessary to transform the position of a point from one coordinate system into another. The concept of mapping includes such transformation of positions and is the basis of this presentation.

The progress in the surveying techniques, makes the establishing of improved coordinate systems necessary. Especially satellite surveying techniques require modern homogeneous geocentric coordinate systems to get the complete benefits of these techniques. Hence, the transition of the historically grown official networks with known distortions to modern homogeneous coordinates are a very important task today.

The DB AG has defined a homogeneous reference system DB_REF for their applications. The transformation of coordinates from the past, but still used official coordinate systems and coordinates derived from satellite surveying must be transformed into DB_REF and vis-versa. For this purposes, the transformation module GNTRANS has been developed

The present variety of coordinates in Germany is shown. The need of homogeneous, one-to-one transformation is investigated by analysing local transformation approaches. The general aspects, models, accuracy and applications of GNTRANS are finally discussed.

Introduction

- **satellite-based surveying techniques**
  - applications steadily increasing
  - accuracy range of: (mm) ... cm ... dm ... m
  - use of global cartesian coordinate systems
  - homogeneous coordinates
  - weather independent
  - no inter-station visibility
  - large distances

Modern Coordinate Systems

- **three-dimensional coordinate system**
  - geocentric, i.e. Earth's center-of-mass origin (in practice within a few cm)
  - Z-axis aligned with the Earth's axis of rotation (IERS Reference Pole)
  - X-axis IERS Reference Meridian
  - Y-axis completes right-handed coordinate system
- **why?**
  - satellite geodesy, ...
  - accuracy, consistency, internationally, globally, ...
- **e.g. WGS 84, ITRS xx, ETRS xx**

Official Coordinate Systems

- **historical development in Germany**
  - independent 2D and 1D networks
  - former West German states:
    - different surveying techniques
    - different computation techniques
    - combination of individual networks between 1870 and 1950
  - former East German states:
    - complete re-surveying of network starting in 1954

Official Coordinate Systems

- **datums**
- **projections**
- **height systems**

Rauenberg Potsdam

DHDN STN 42/83 PD 83

RD 83 ETRF 89

Krassowski Bessel GRS 80

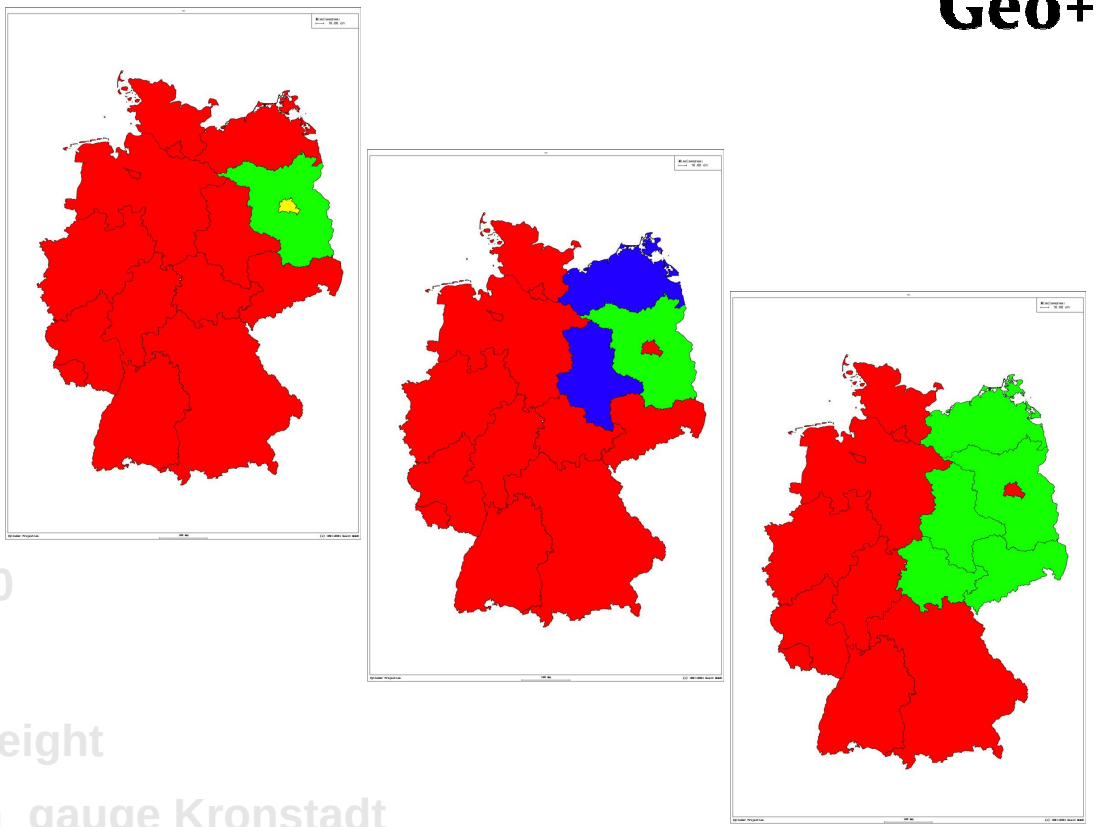
Gauß-Krüger Soldner UTM

orthometric height normal height

gauge Amsterdam gauge Kronstadt

DHHN 12 DHHN 85 HN 76 DHHN 92

coordinate status of states



- **even more variety through different state surveys**

Official Coordinate Systems

- **surveying in Germany is a task of the states**
  - different geodetic datums
  - different systems (horizontal, height)
  - different ellipsoids
  - different projections
  - different height systems
- **situation German-wide**
  - non-homogeneous coordinates for surveying and mapping applications
  - discontinuities/coordinate jumps at state boundaries

Official Coordinate Systems: Future

- **Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV)**
- **1991/1995 decision AdV – Plenum on horizontal control network**
  - German reunification and European integration demands for unified reference system
  - reference system identical to WGS 84, realization through ETRF 89
  - continuation of System 42/83 in former East German States until installation of reference system ETRF 89 (Sachsen and Thüringen introduce RD 83 and PD 83 as preliminary coordinates)

Official Coordinate Systems: Future

- **Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV)**
- **1993 decision AdV - Plenum on height control network**
  - normal height system
  - new computation of primary leveling network (DHHN 92)
  - DHHN 92 basic vertical control data for state survey authorities

Official Coordinate Systems: Future

- **Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV)**
- **1995 decision AdV – Plenum on horizontal control network**
  - ellipsoid GRS 80
  - Universal Transverse Mercator grid system (UTM)

DB AG - German-Wide Applications!

- **past**
  - positioning in official coordinate systems
- **goal**
  - one single homogeneous coordinate system German-wide
  - one single height system German-wide
- **task & consequence**
  - enable **homogeneous** transformations
  - enables rigorous use of modern surveying methods (e.g. GPS, GLONASS, Galileo)

Homogeneous Reference Systems

- **properties**
  - one transformation parameter set
  - one ellipsoid
  - one projection
- **homogeneous reference systems transform**
  - without accuracy loss
  - anytime
  - one-to-one

  into each other

DB AG – Considerations

- **features of a suitable reference system**
- **definition**
  - minor scale changes for existing data
  - systems capable to interact with industry and national systems
  - support of satellite-based surveying techniques
- **realization**
  - reference stations covering the complete area of applications
  - accuracy sufficient for all applications

DB AG – Definition of DB_REF

- **horizontal reference system**
  - geodetic datum
    - mean datum of official system of former West German states, Thüringen and Sachsen (7P- transformation)
  - ellipsoid
    - Bessel
  - projection
    - Gauß – Krüger
- **height reference system**
  - normal height system (DHHN 92)

DB_REF Realization

- **properties of horizontal reference system**
  - regional (D), homogeneous reference system
  - derived from ~ 1200 identical points from all state survey authorities (DREF 91, C-network)
    - ~ 900 points ETRF 89/DHDN
    - ~ 300 points ETRF 89/STN 42/83
  - ~ 3.5 m maximum difference to former/official systems
  - up to 10 ppm maximum scale change while transforming from former/official systems to DB_REF
  - simple coordinate transformation between ETRF 89 and DB_REF (7 Parameter)

DB_REF Realization

- **properties of height reference system**
  - regional (D), homogeneous reference system
  - orthometric heights
  - official height system (future nation-wide)
  - derived from ~ 340 identical points
    - DHHN 12, DHHN 85 and HN 76
    - DHHN 92 from nation-wide adjustment of German primary leveling network
  - simple computation from ellipsoidal DB_REF- heights (undulation)

Local Transformation

Satellite-based surveying techniques are frequently applied. Therefore it is useful to have a closer look at the currently applied strategies to relate the homogeneous coordinates derived from satellite surveys to the national coordinate system.

Generally, observations on at least one identical points, which is known in both coordinate systems must be performed. The coordinate system of the satellite positioning can be arbitrary, but close or well known in the homogeneous coordinate system, e.g. ETRF 89. Several such identical points are commonly used in surveying applications to get redundancy and reliability for the datum transition. Transformation parameters are estimated from the identical points, which can differ while the surveying area is changing.

The locally derived transformation parameter are depending on the arbitrary availability, access and selection of usable identical points. Hence, the coordinates resulting form different surveying areas will also differ. Individual distortions of the national system will propagate differently into the transformation parameter and finally into the estimated coordinates.

The use of local transformations can lead to significant discrepancies in the computed coordinates and will deteriorate the accuracy.

Local Transformation

A network of points has individual distortions associated to each individual point (see following graphics) due to the history of the network. In the example illustrated in the graphics, two different sets of transformation parameter are derived and used for two neighboring surveying areas- These are indicated by green and blue circles.

The different transformation parameter for the green and blue areas will result in different coordinates and therefore residuals for the new coordinates point (solid black circle). The different residuals are indicated by the corresponding colored vectors.

Depending on the discrepancies of the identical points and the used transformation parameter sets, a resulting coordinate difference is present (red vectors).

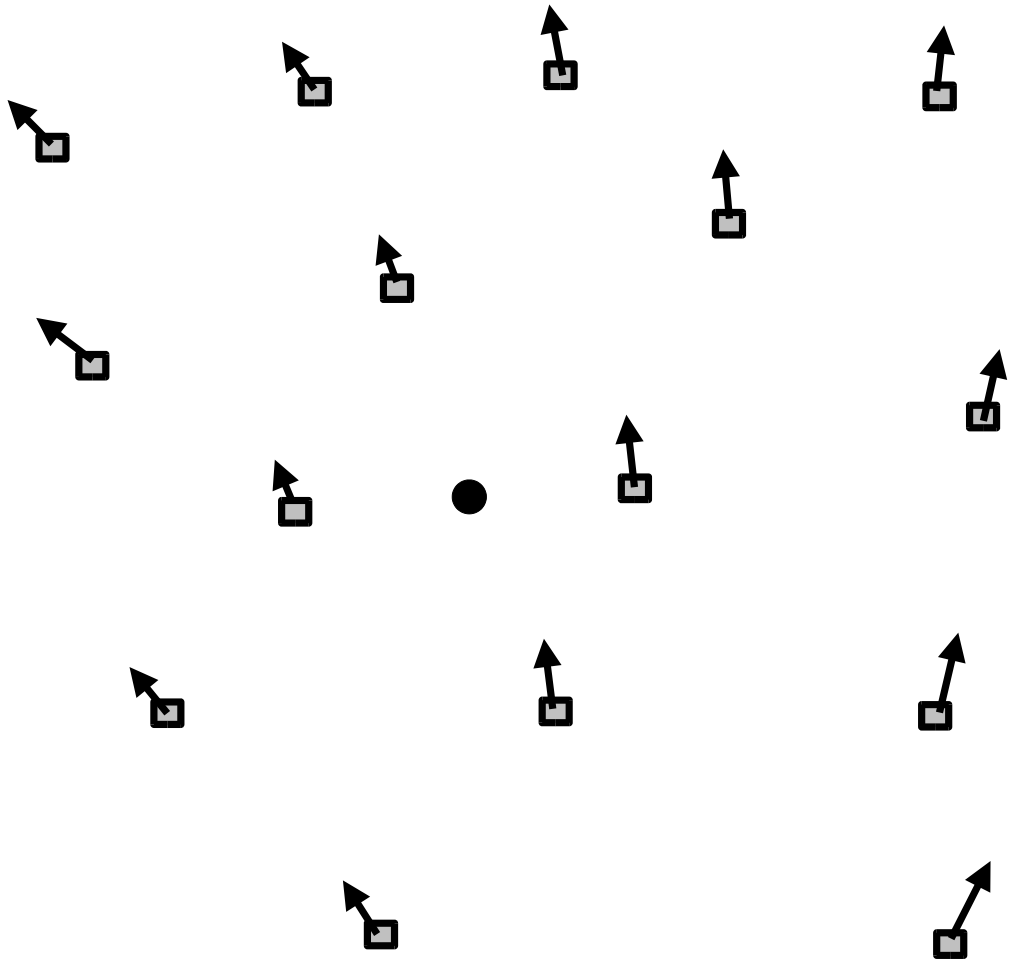
The above derived discrepancies are again depicted for a railway surveying application, which leads to differences in the combination of the coordinate results from the two processings.

Solution to the problem is a transformation module, which is independent from the individual characteristics of the individually selected identical points. GNTRANS is free of such effects, as it controls best all systematic distortions of the national/state coordinates system and even takes individual remaining distortions of the network into account.

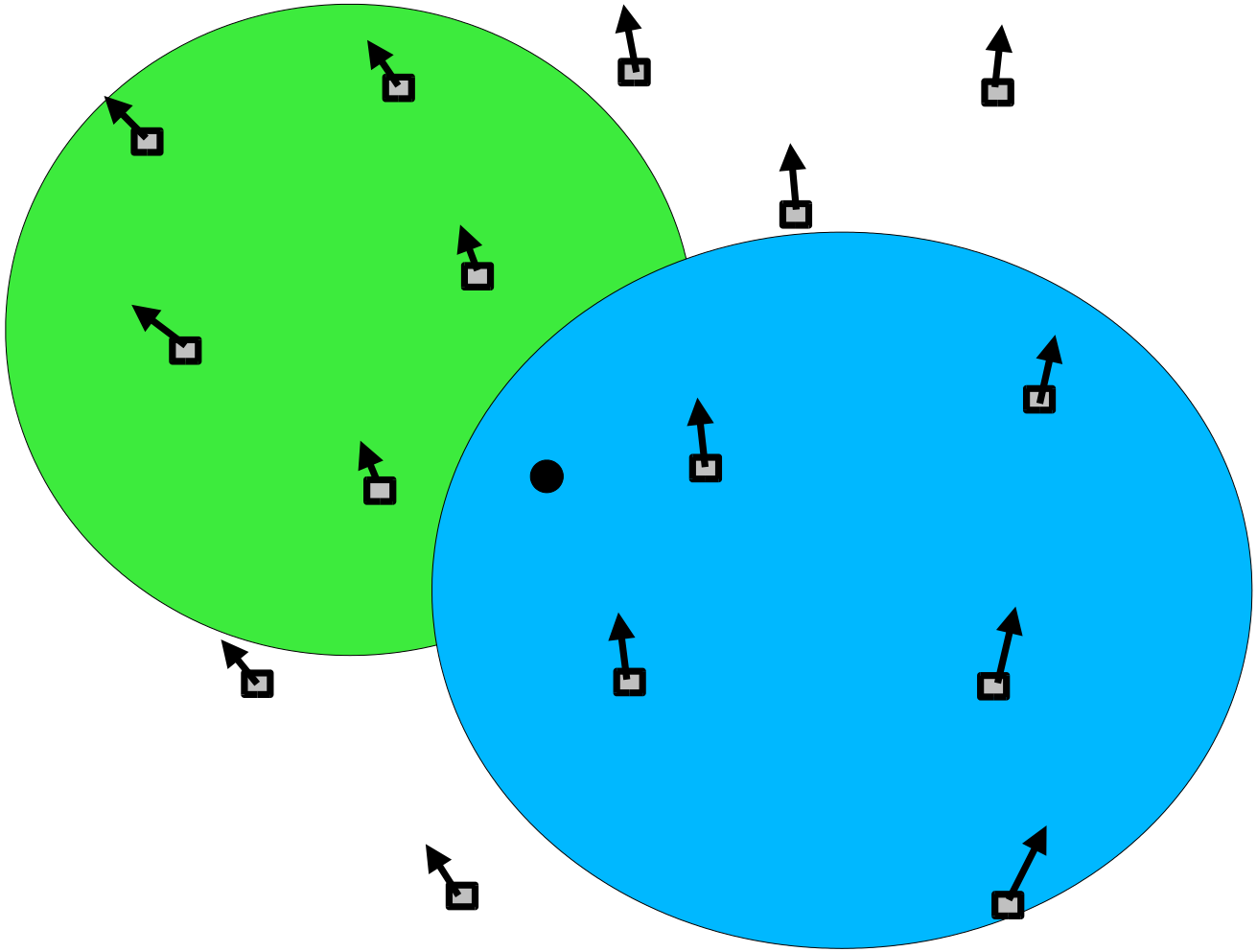
Local Transformation/ Adjaceny Preserving Transformation

- **problem: local transformation**
  - individual sets of identical points
  - individual sets of transformation parameters
  - distortions
- **solution: adjacency preserving transformation**
  - pre-requisite for general transformation module

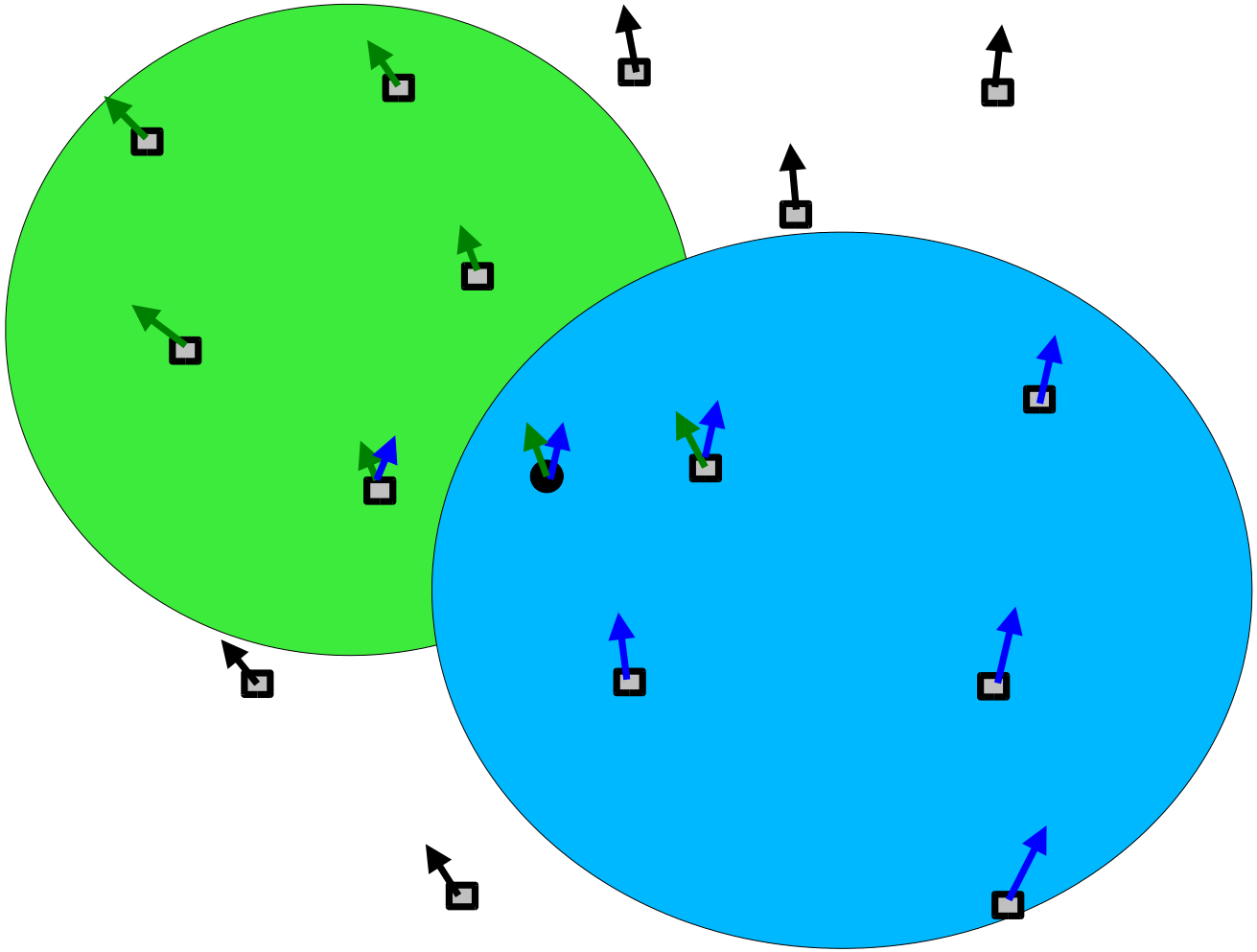
Local Transformation



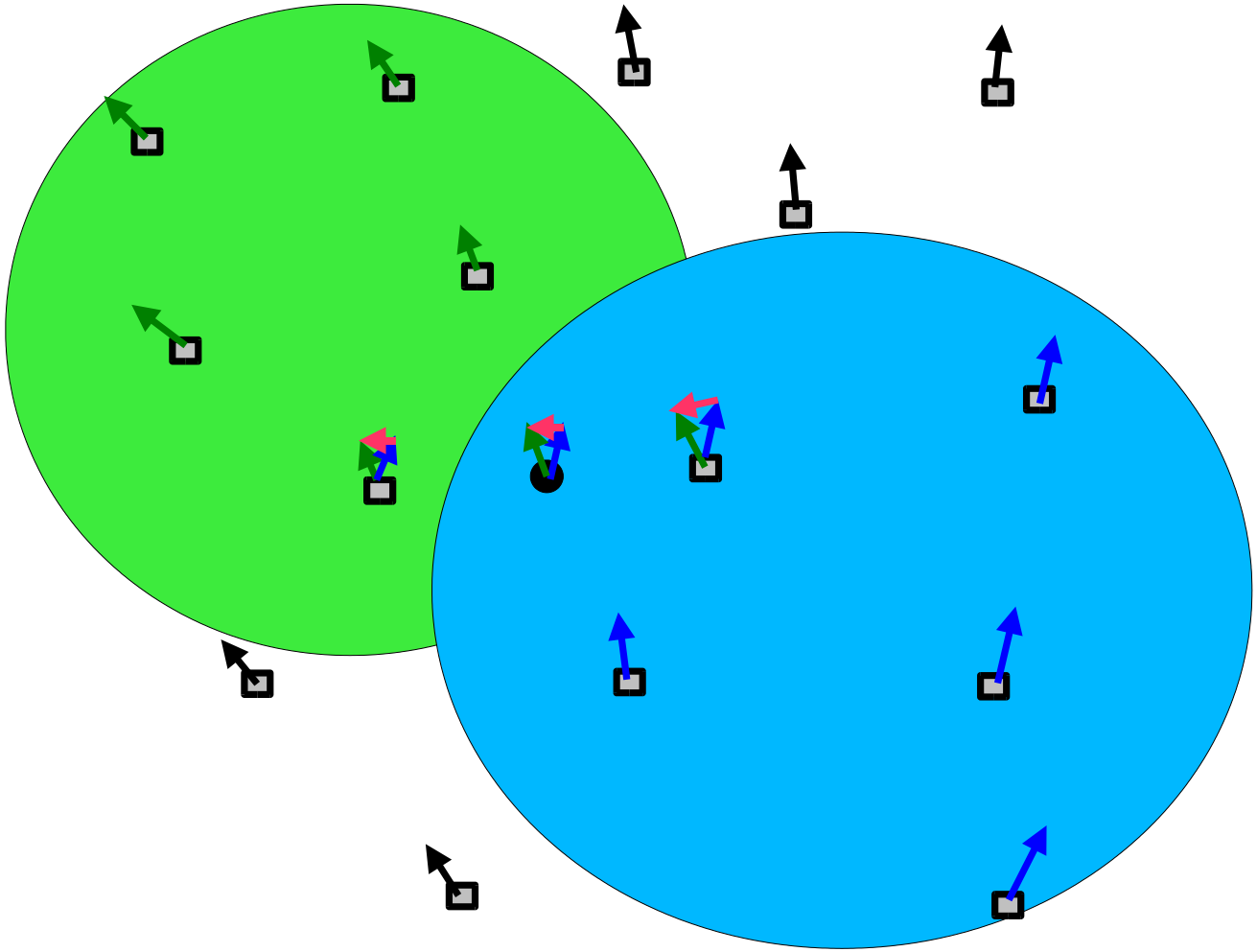
Local Transformation



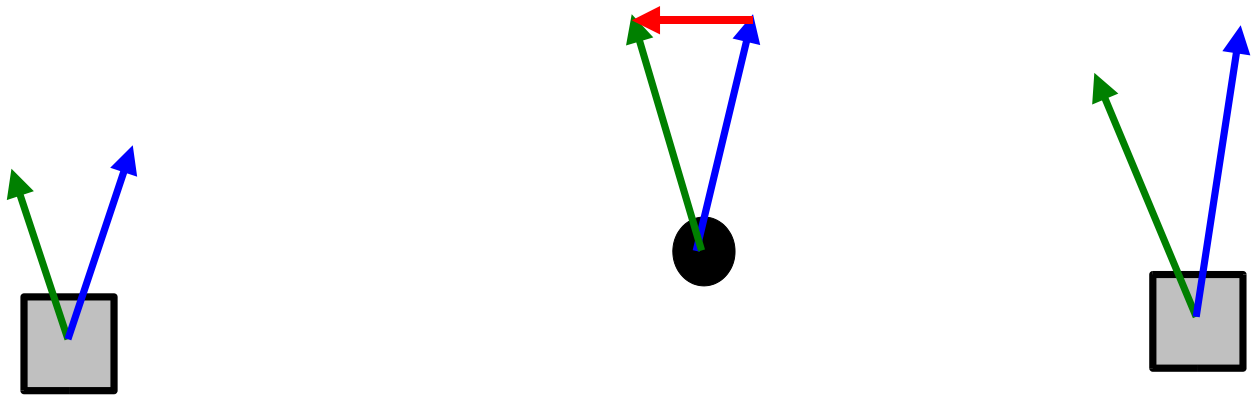
Local Transformation



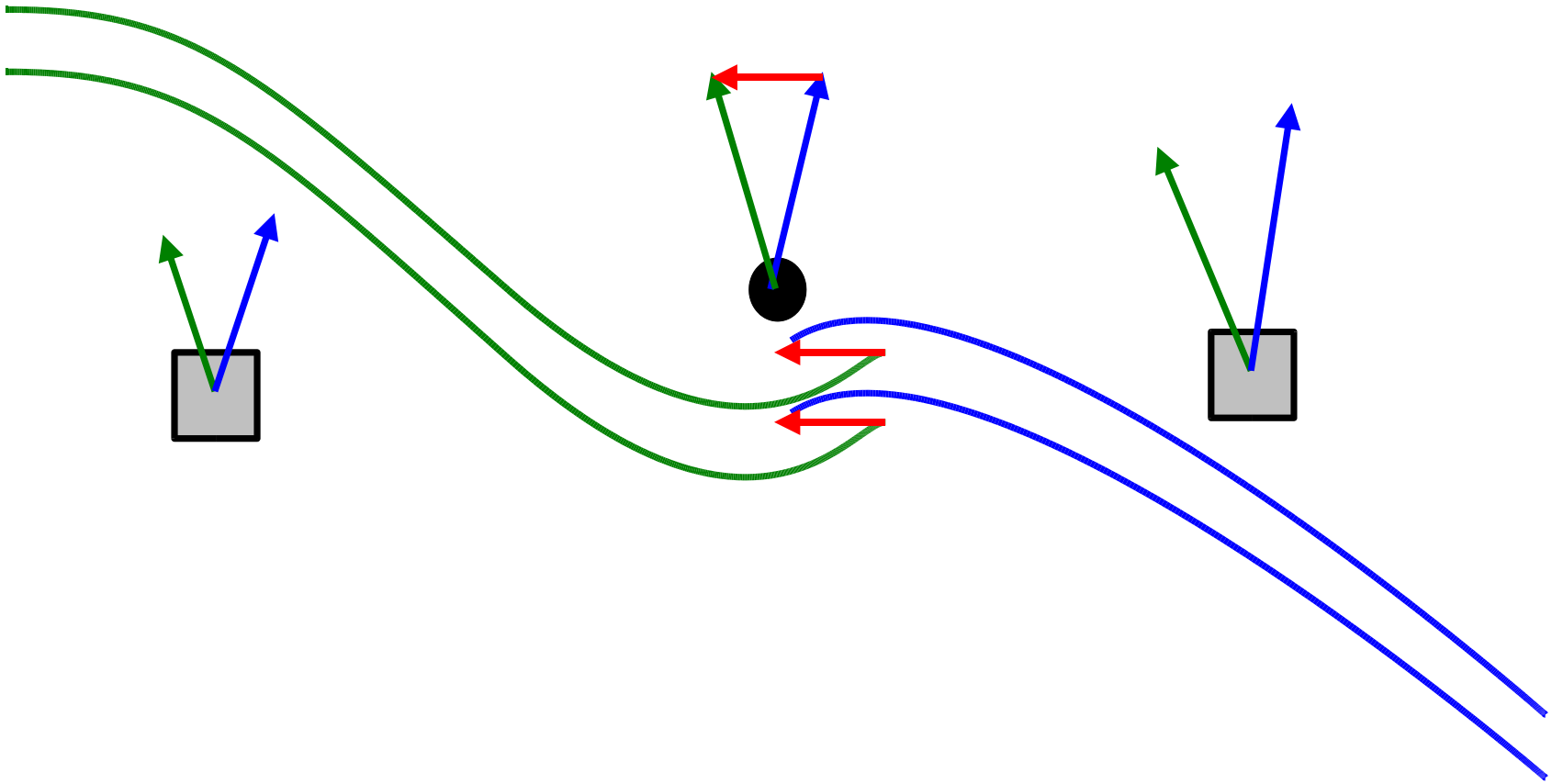
Local Transformation



Local Transformation



Local Transformation



Adjacency Preserving Projection

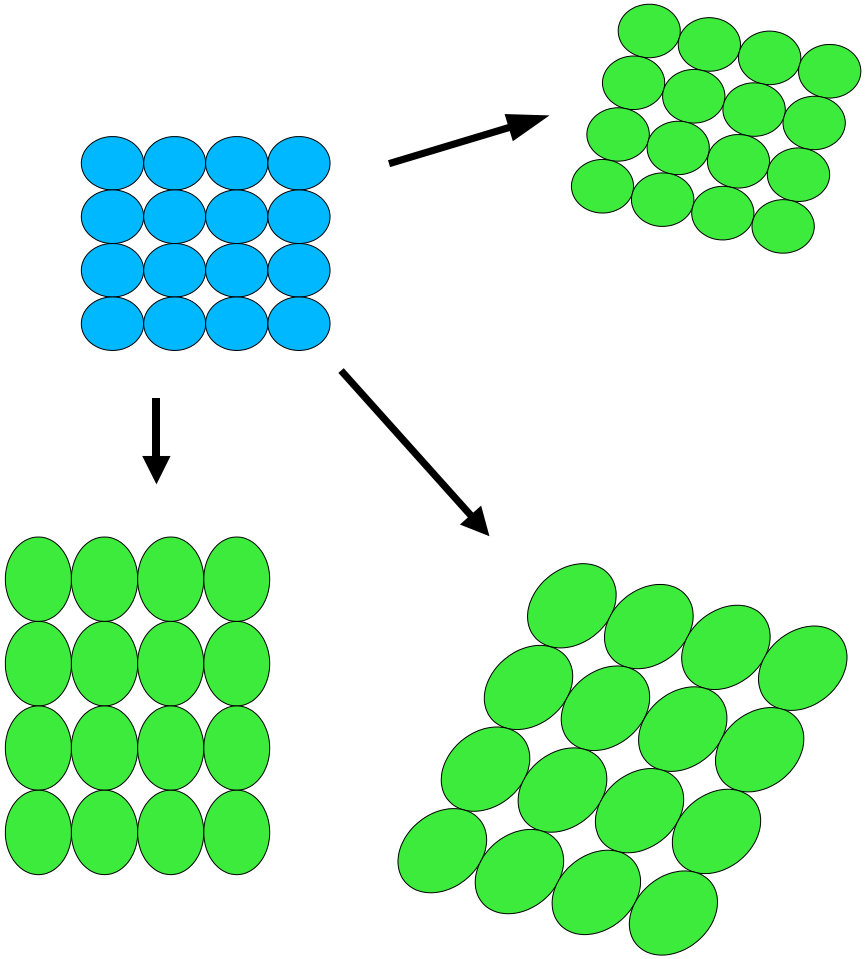
From the analysis of local transformation a generally characteristic of coordinate transformation can be derived.

It is important for a transformation to maintain the local relationships in the neighborhood or vicinity of the coordinates. This matter is shown in some following graphs. An essential feature of a transformation of coordinate system must therefore be, that the adjacent metric properties are preserved.

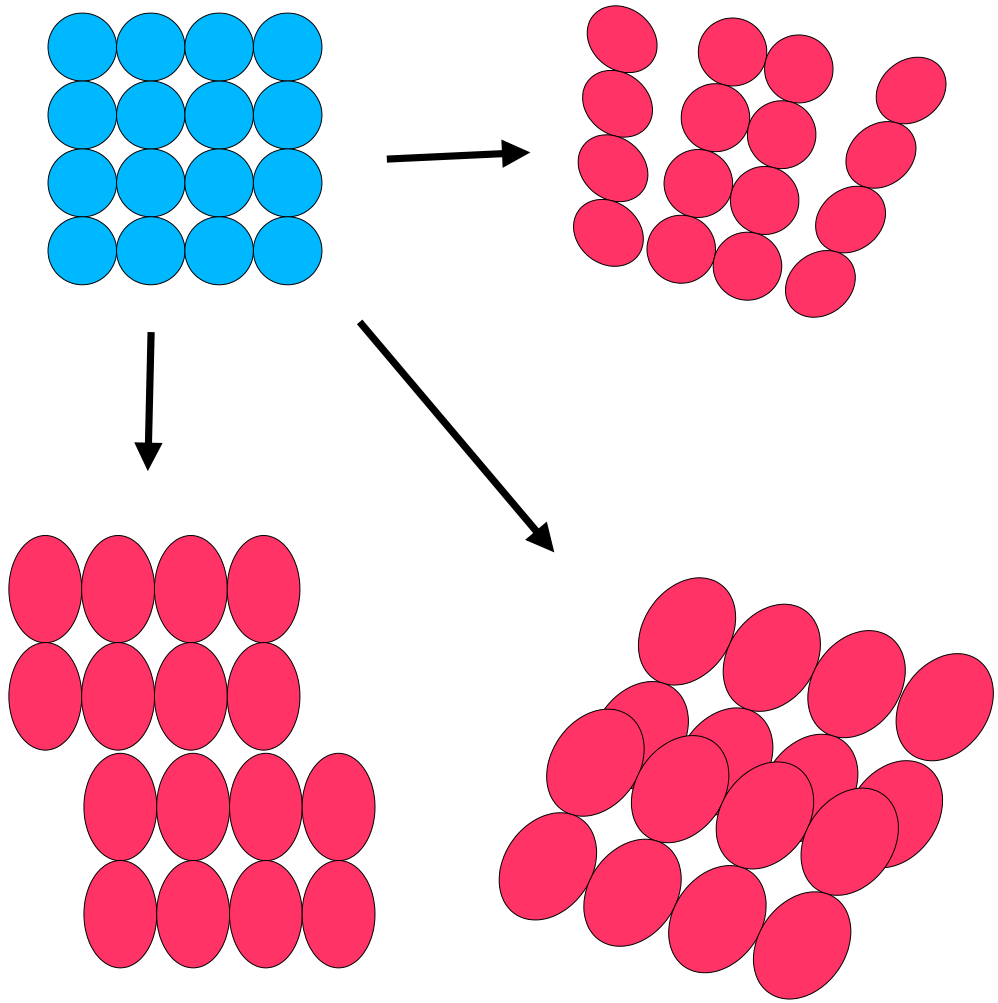
The adjacent metric properties can be changed while mapping the coordinates into another coordinate system. However, the relative information must be continuously and must be still maintained as it is shown in the first graphic (continuous).

In the non-continuous case, discontinuities or jumps occur. These situation must be especially considered in the development of homogeneous one-to-one transformations (see graphic non-continuous).

Adjacency Preserving Projection (continuous)

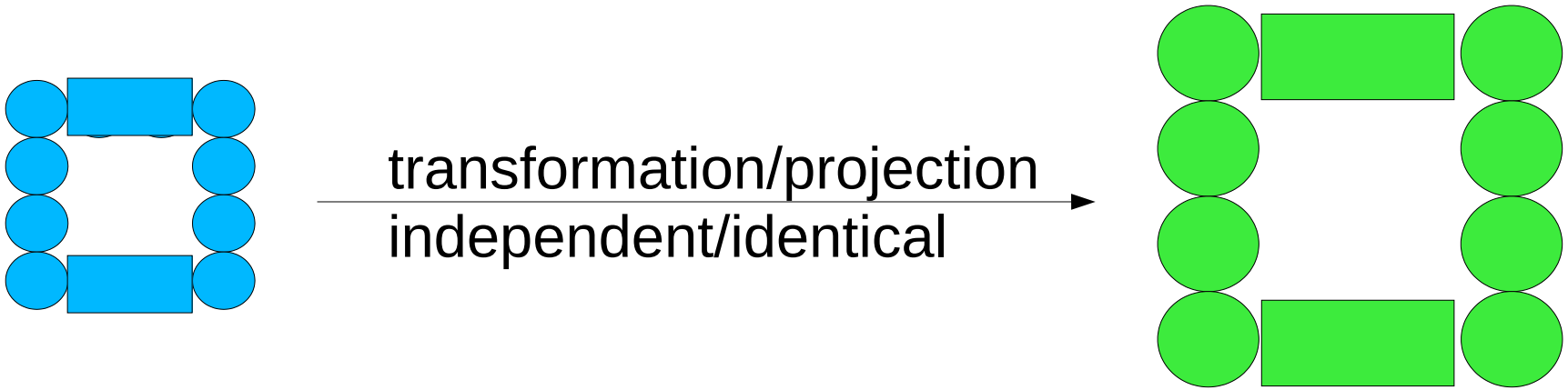


Disturbed Adjacency (non-continuous)



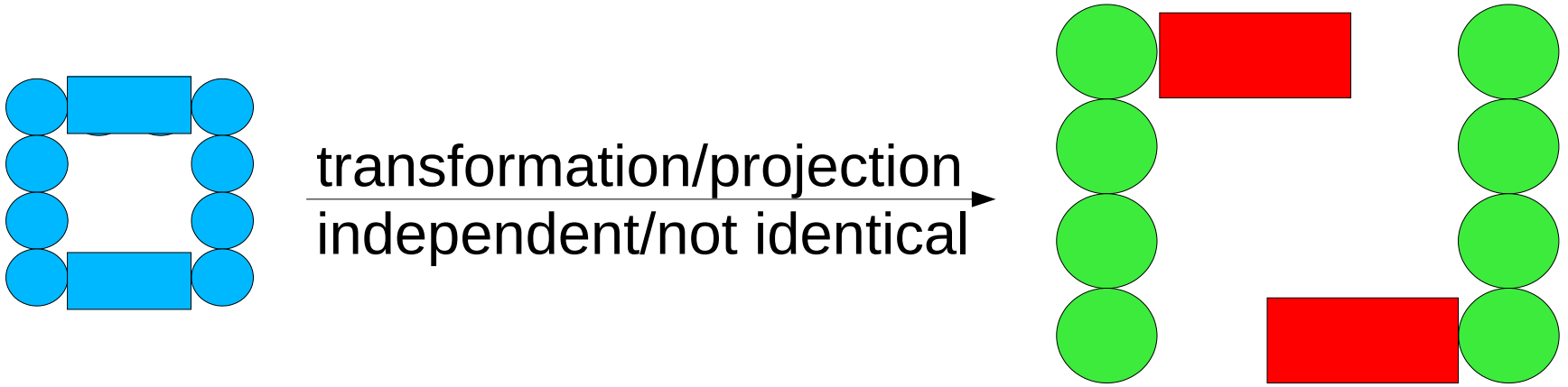
Adjacency Preserving Transformation

- **starting with**
  - consistency
- **resulting in**
  - consistency



Adjacency Preserving Transformation

- **starting with**
  - consistent projection
- **resulting in**
  - inconsistent projection



GNTRANS

GNTRANS is a

- **transformation model for the transition of ETRF 89 coordinates and official state coordinates into a homogeneous coordinate system: DB_REF**

GNTRANS

- **motivation**
  - different applied coordinate systems nation-wide
    - non-homogeneous, inconsistent databases and documentation
  - network distortions in former systems
    - not adequate for modern surveying techniques
  - satellite-based techniques not easily integrated
    - no uniform transformation regulations
    - no uniform documentation regulations

GNTRANS – Model

- **multistage transformation (ETRF/national or state systems)**
  - 7P- transformation
  - continuous functional transformation
    - mathematical functional approach to describe remaining residuals after 7P- transformation
  - stochastic part
    - stochastic prediction of remaining discrepancies considering topological neighborhood (decorrelation along topology of discontinuity)

GNTRANS – Model

- **multistage transformation (ETRF/DB_REF)**
  - 7P- transformation
  - continuous functional transformation (for height component only)
  - stochastic part (for height component only)

GNTRANS – Principle of Transformation

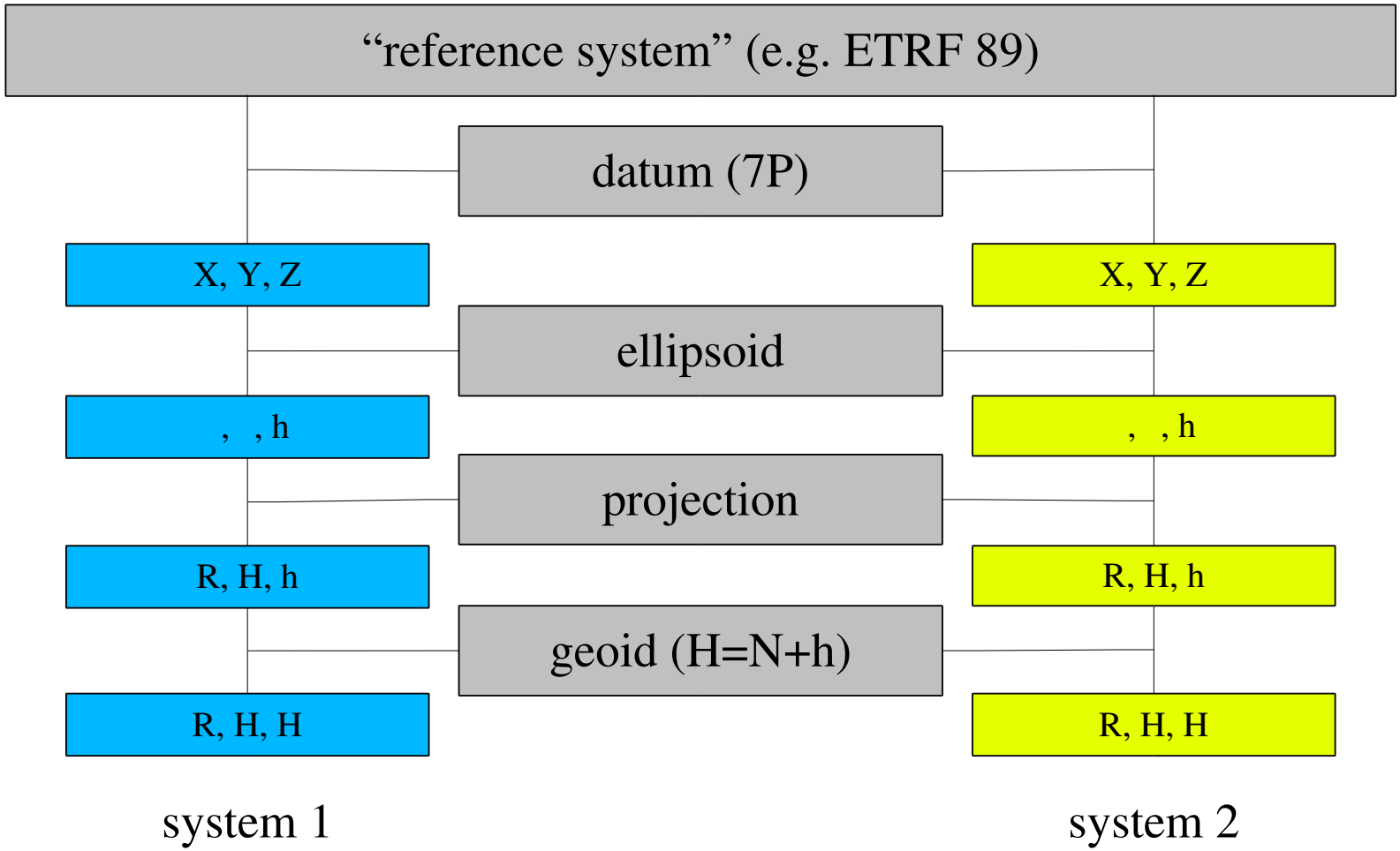
Some graphical examples have been selected to give some insight into the GNTRANS model.

The different handling of datum, coordinate system and projection is shown in the next graphs. Global cartesian coordinates are indicates by XYZ, ellipsoidal coordinates by φλh, and plane coordinates by RH and orthometric height by H. There are two branches, which perform the transformation from global cartesian coordinates down to a plane projection and a height component. Each branch represents one system. It is allowed to enter each system at any point and to leave the second system at any point. Internally, however, the complete transformations following the branches and the datum transformation in the global cartesian coordinates of the reference system ETRF 89 must be conducted.

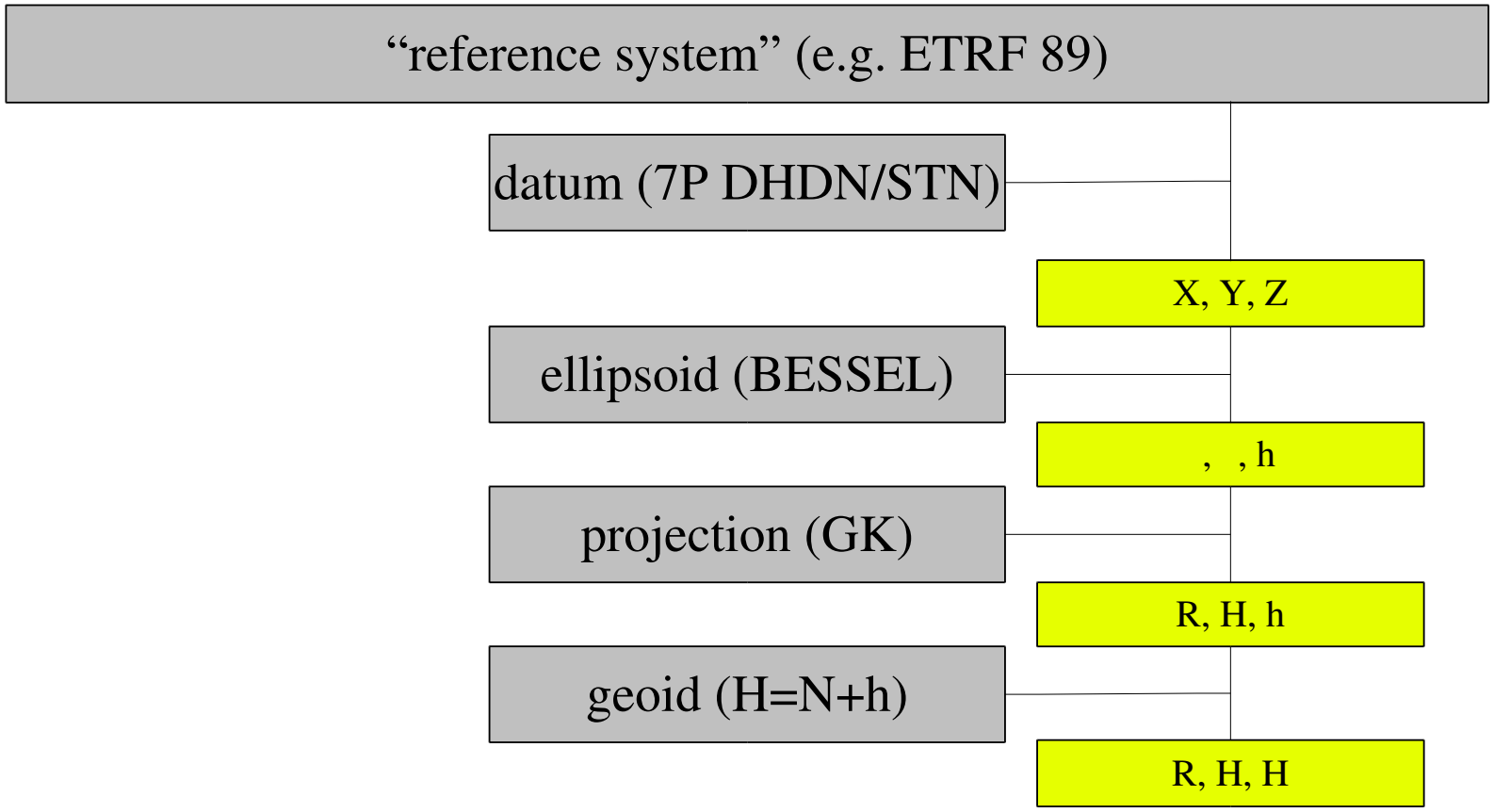
The special case of the transformation of ETRF 89 coordinates into national/state coordinates uses only transformation in one branch and ends at the reference system level. The second case shows only the transformation within an homogeneous coordinate system (e.g. ETRF 89 and change of height system).

The final two graphs show the parts, where a certain modeling of GNTRANS is necessary. These are the 7P- transformation, the modeling of undulations to perform the transition from ellipsoidal heights to orthometric height and the modeling of the network distortions of the official coordinate systems. For the homogeneous system DB_REF, exist no distortions in the network. Hence, this part of the transformation model is not required.

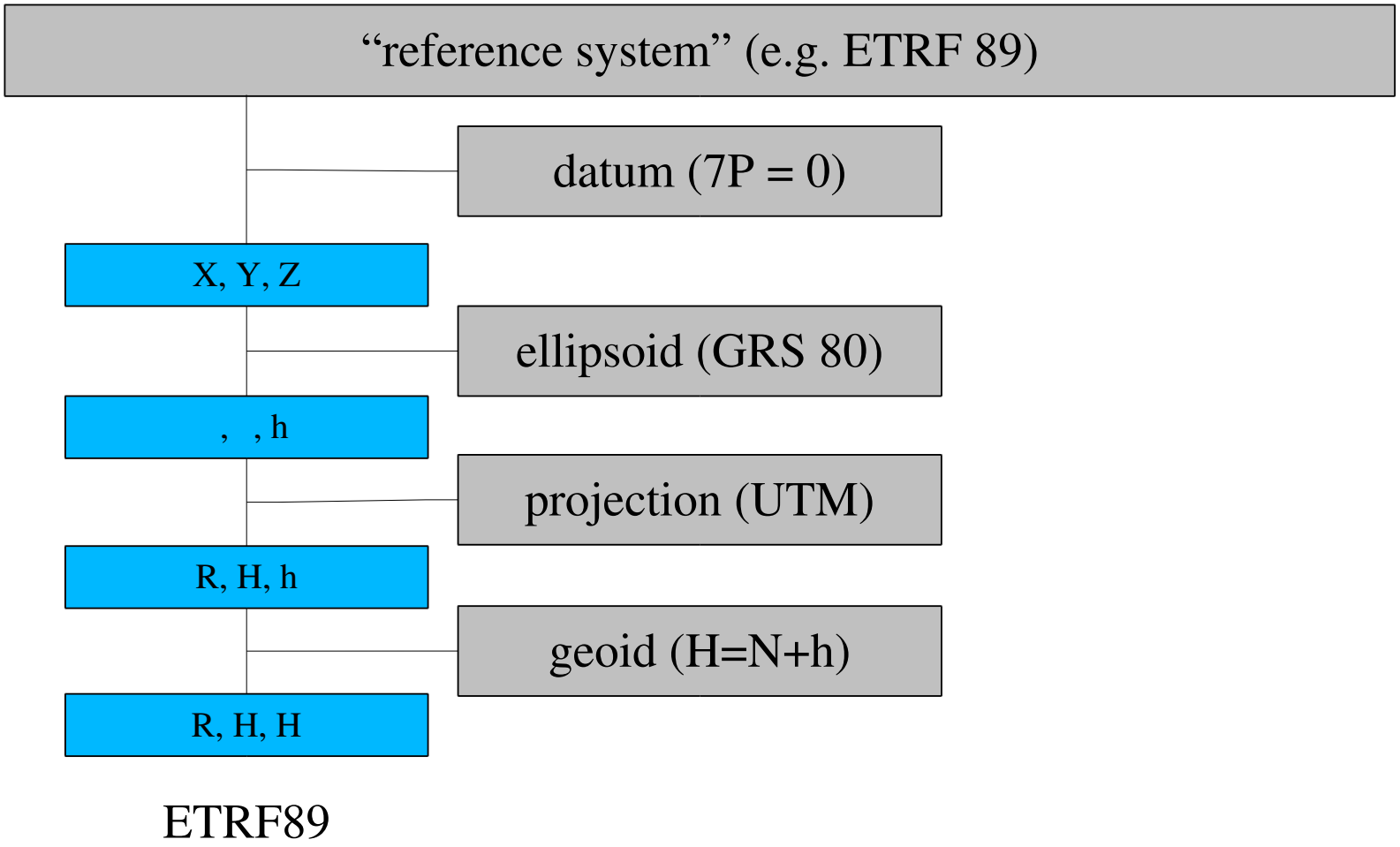
Principle of GNTRANS Transformation - Coordinate Systems



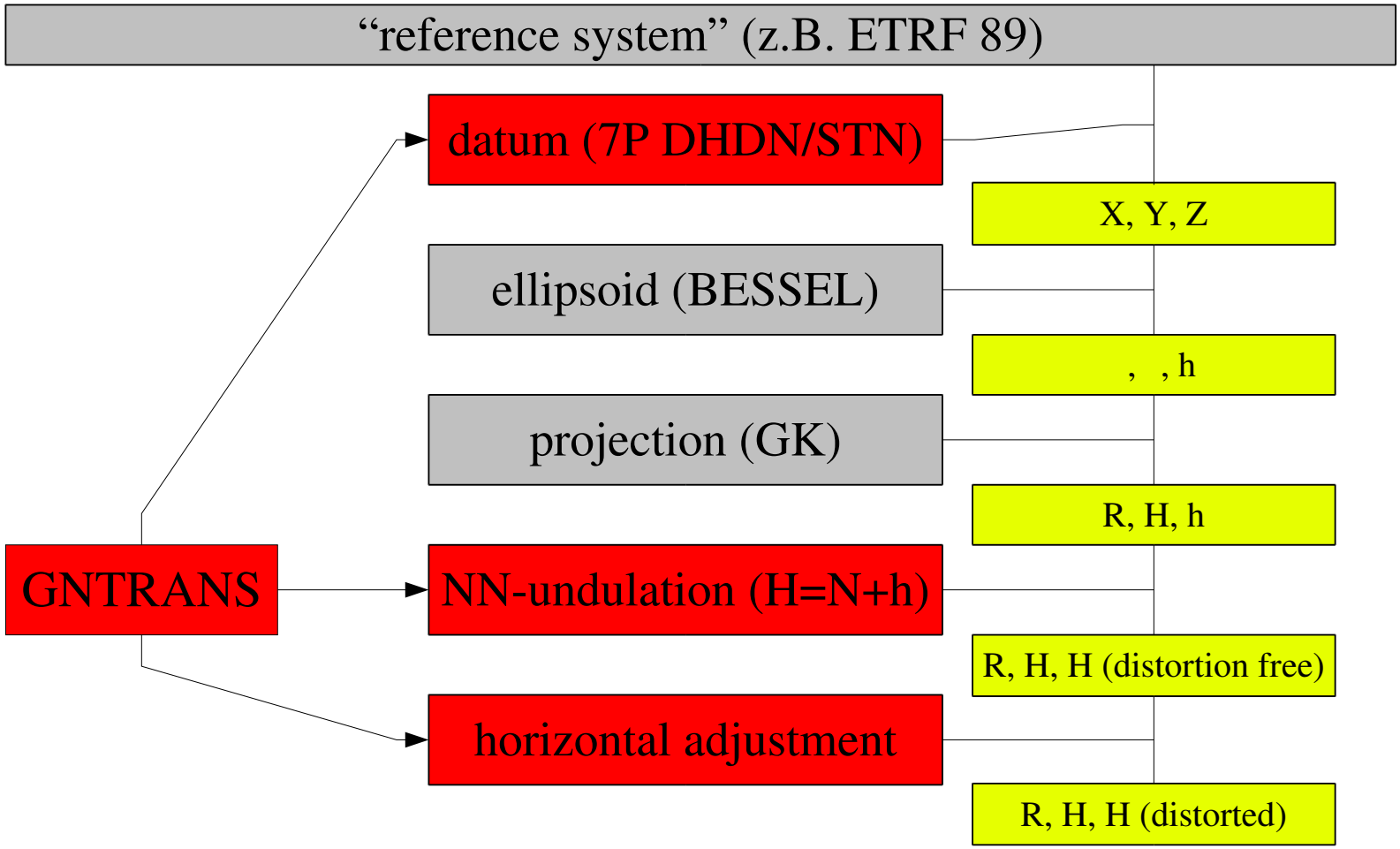
Principle of GNTRANS Transformation - National/State Systems - „Definition“



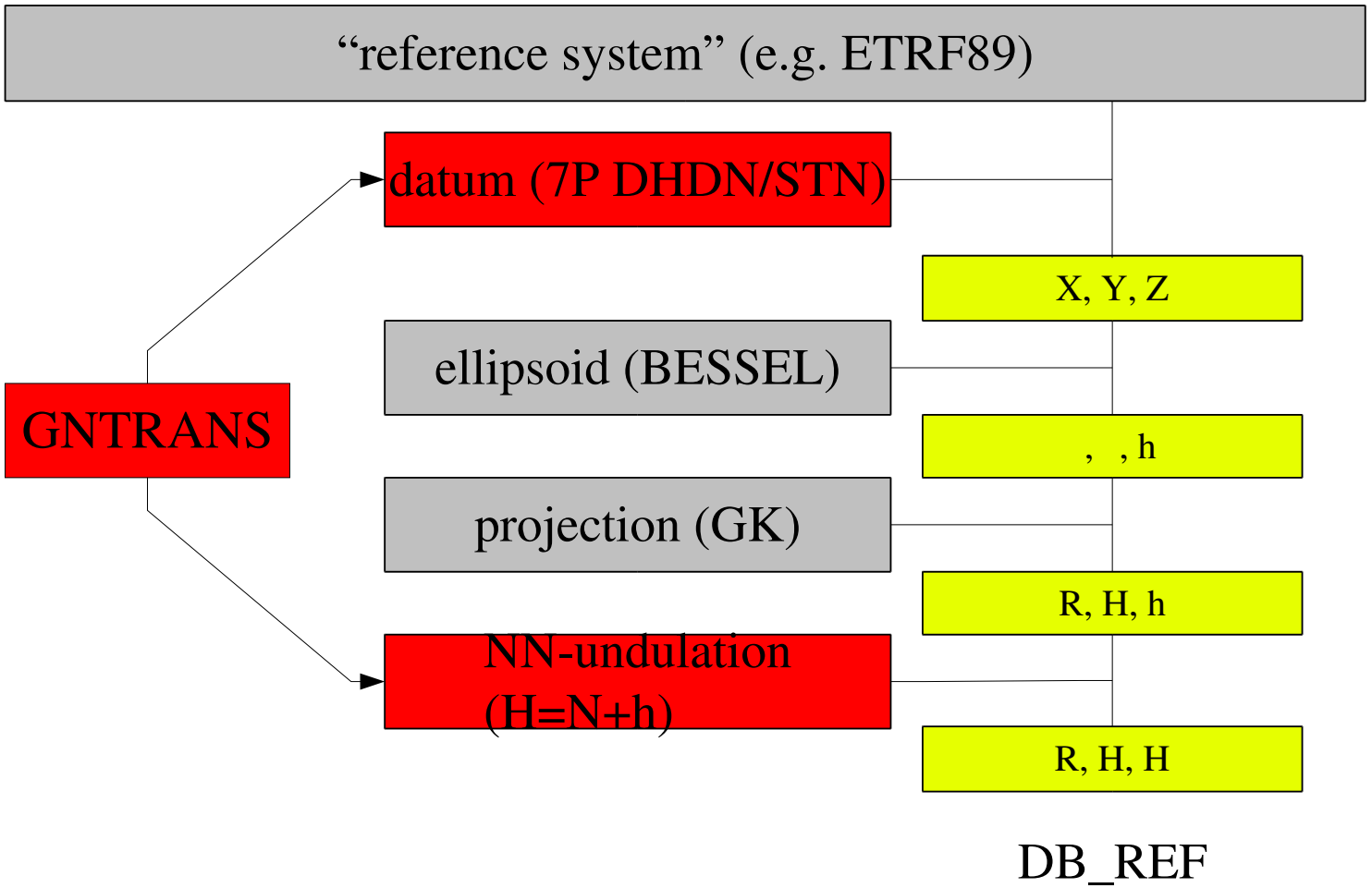
Principle of GNTRANS Transformation - Future National System ETRF 89



Principle of GNTRANS Transformation – National/State Systems



Principle of GNTRANS Transformation – DB_REF



GNTRANS – Model

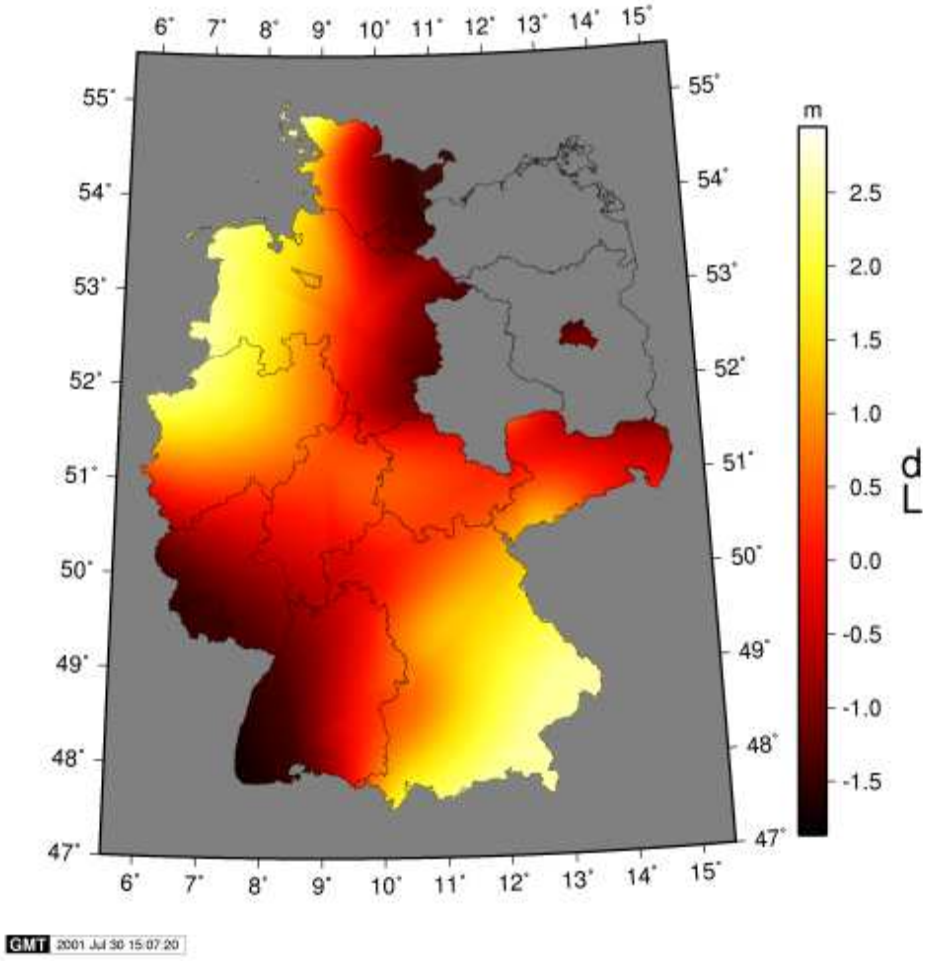
The functional part of the transformation is given in two graphics. The first one shows the east-west residuals of the official coordinate system of the former West German datum (DHDN). The maximum distortions amount to several meters (2-3 meter). The second graph gives the magnitude of the east-west residuals in the former East German states, which did not primarily converted their coordinates to the West German state datum. The range is much smaller and is in the order of +/- 0.5 m.

A residual plot of the horizontal coordinate residuals shows the complete information. The scale of the graph is different for the states using the former West German datum (1 m) and for the former East German states (0.1 m). The circular distortions are well visible, which are due to the historically development of the horizontal control network. A part of Bavaria is enlarged, which demonstrates the systematic behavior of the distortions in that area (plot scale 0.5 m).

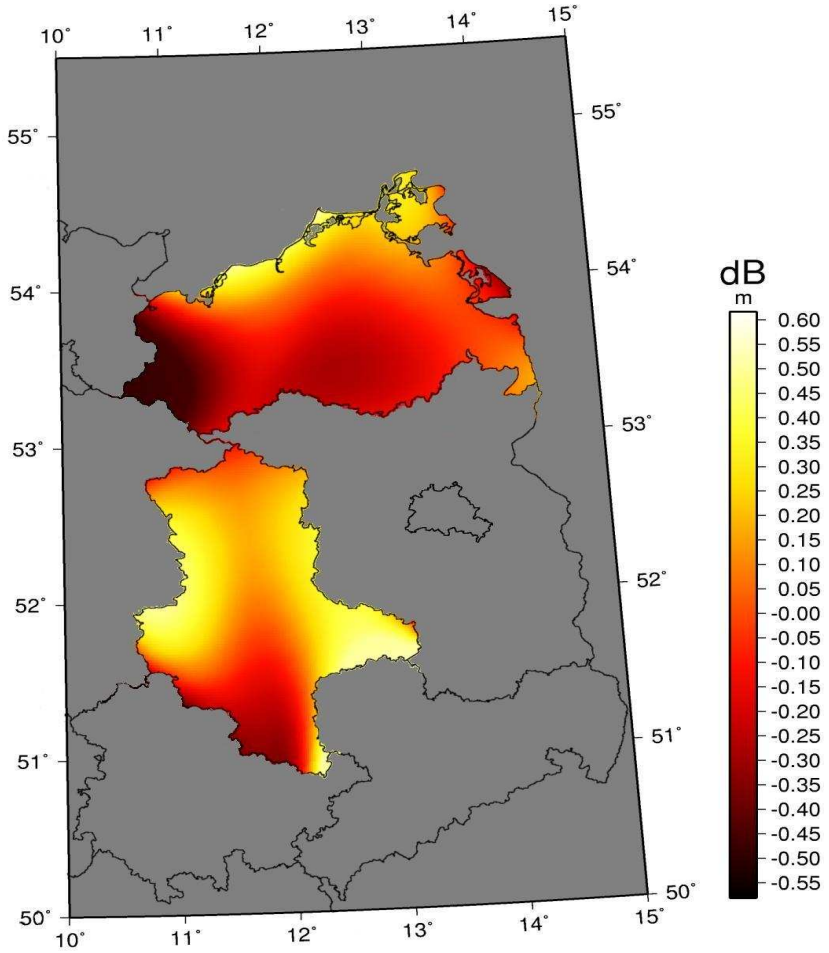
The same area is shown after applying GNTRANS and removing the systematic distortions. Individual non-systematic distortions remain, which represent the actual adjacent metric properties in the area.

The difference between the DB_REF height system (DHDN 92) and the individual state height systems is shown in the last two residual plots. The differences are in the order of several centimeter up to a decimeter. After applying GNTRANS, the differences are well below one centimeter.

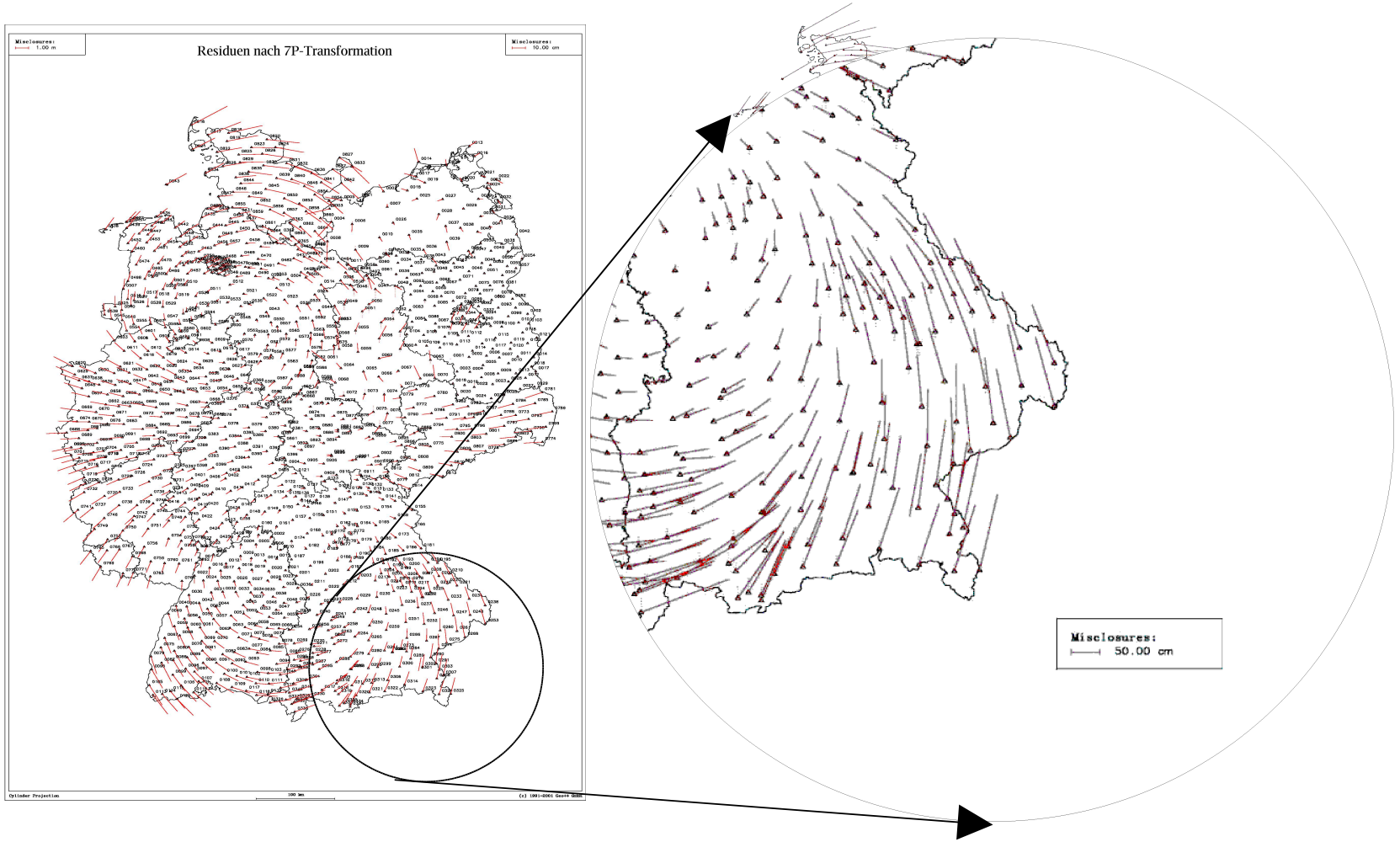
GNTRANS - Functional Part (East-West)
Former West German Datum



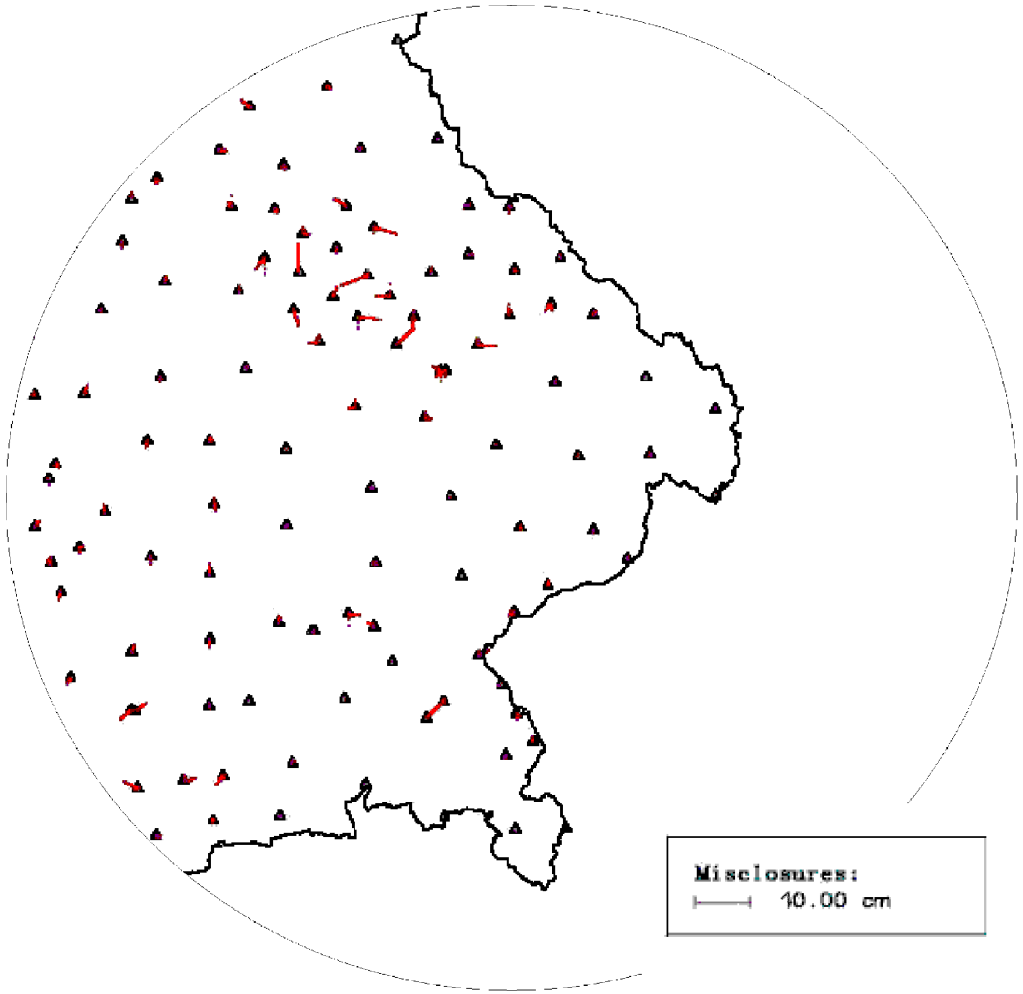
GNTRANS - Functional Part (North-South)
Former East German Datum



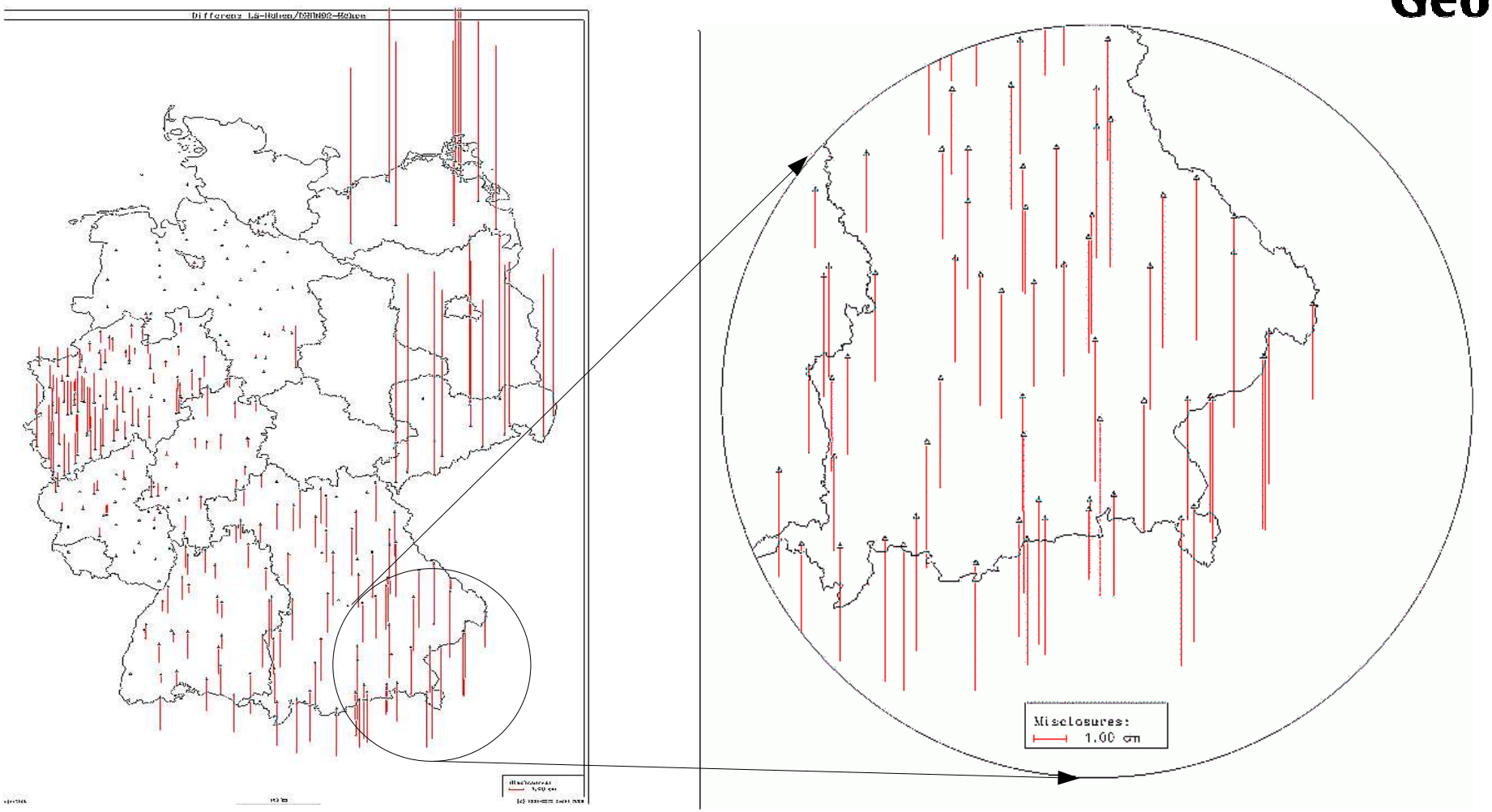
GNTRANS – Horizontal Residuals after 7P- Transformation



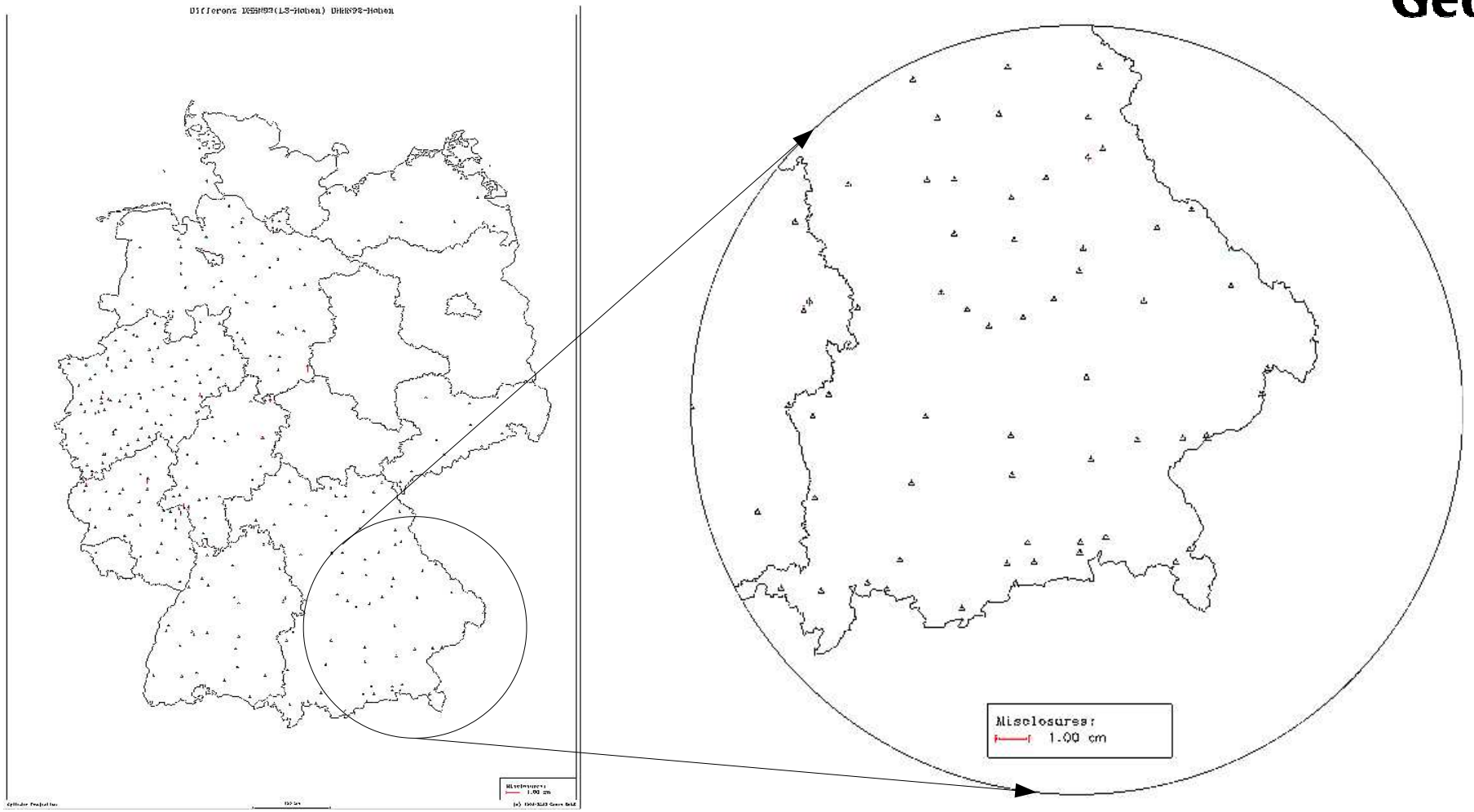
GNTRANS – Horizontal Residuals after Multistage Transformation



GNTRANS – Height Differences State Systems/DHHN 92 (DB)



GNTRANS – Height Residuals after Complete Transformation



General Aspect – Scale Factor

One major aspect of the definition of DB_REF is the scale. The transformation between the official coordinates systems used up to now and the DB_REF should cause small scale changes.

The following two tables list the scale factor for several datum transformations for two different starting systems. The first table is based on the national/state system, while the second table is based on the DB_REF system.

The difference of the UTM projection compared to the Gauß - Krüger amounts to 400 mm/km. Hence, the scale introduced by the choice of the projection can have a significant impact. It it obvious, that the scale changes are small for the DB_REF system and most of the transformation. This is due to the fact, that DB_REF uses the Bessel ellipsoid and the Gauß – Krüger projection.

The scale changes were also investigated for the individual states in Germany. The scales are always below 10 mm/km.

Scale Factor – Relative to National/ State System

- **scale factor for different coordinate transformations starting from national/state system (DHDN)**

datum	*ellipsoid*	*projection*	*scale [mm/km] for distance from center meridian*		
			0 km	*50 km*	*100 km*
DHDN(LS)	BESSEL	GK	0	0	0
		UTM	-400	-400	-400
ETRF89	GRS80	GK	1	1	1
		UTM	-399	-399	-399
DB_REF	BESSEL	GK	±1 bis 10	±1 bis 10	±1 bis 10

*) DHDN is datum of former West German states

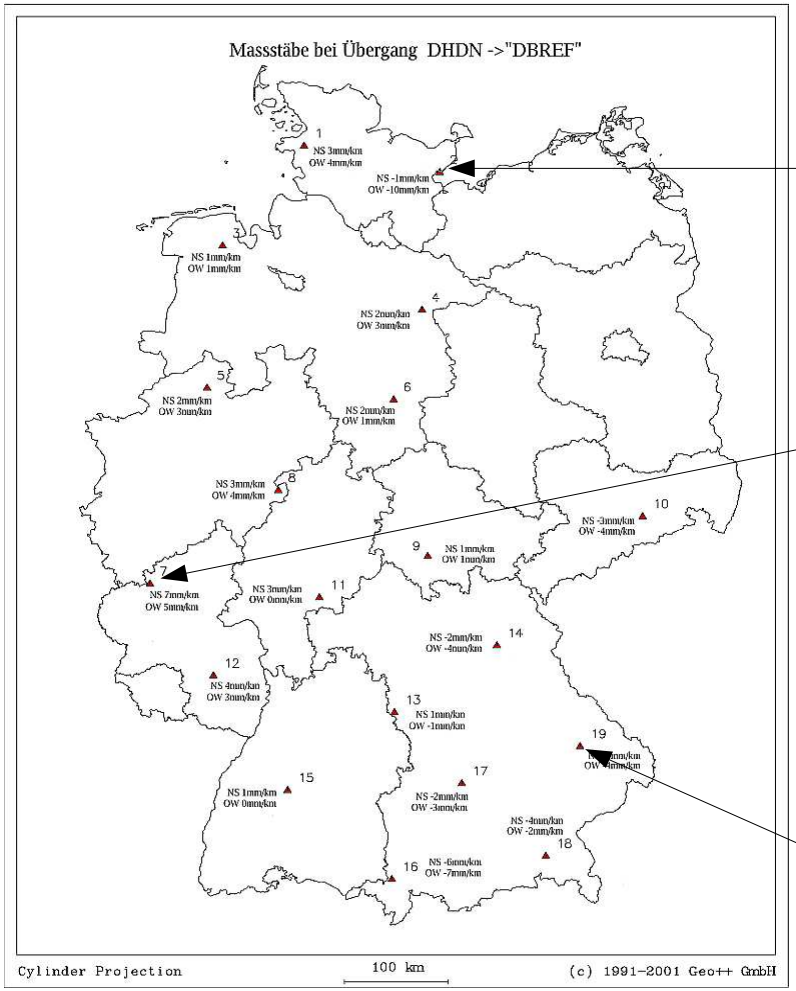
Scale Factor – Relative to DB_REF

- **scale factor for different coordinate transformations starting from DB_REF**

datum	*ellipsoid*	*projection*	*scale [mm/km] for distance from central meridian*		
			0 km	*50 km*	*100 km*
DB_REF	BESSEL	GK	0	0	0
STN42/83	KRASSOWSKI	GK	8	7	7
ETRF/BRAN	GRS80	UTM	-399	-399	-399

*) STN 42/83 is datum of former East German states
BRAN stands for Brandenburg

Scale Factor - National/State Systems
Vis-Versa DB_REF



point	NS	EW
	[mm/km]	[mm/km]
1	3	4
2	-1	-10
3	1	1
4	2	3
5	2	3
6	2	1
7	7	5
8	3	4
9	1	1
10	-3	-4
11	3	0
12	4	3
13	1	-1
14	-2	-4
15	1	0
16	-6	-7
17	-2	-3
18	-4	-2
19	-4	-4

GNTRANS - Accuracy of Transformation Module German-Wide

The accuracy of GNTRANS has been investigated using three different strategies

- internal accuracy
- external accuracy
- and comparisons from the field surveys.

The internal accuracy is a measure derived from the adjustment process of GNTRANS and is the formal standard deviation.

The external accuracy has been determined with a procedure, which eliminated every identical points individually and separately from the GNTRANS model. The GNTRANS model reduced by exactly one identical point is then used, to determine the eliminated point. The known coordinate can be compared with the transformed coordinates. From the differences a statistical value is computed, which represents an external accuracy measure. However, the accuracy measure is somehow pessimistic as the station density has been reduced significantly for exactly the area used for the evaluation of the external accuracy.

In between, several results from campaigns investigating the accuracy of GNTRANS in the field are known. The general accuracy measures have been verified and give even better agreements. From these experiences, local patches have successfully tested to improve the accuracy by adding locally or regionally additional identical points.

GNTRANS - Accuracy of Transformation Module German-Wide

- **internal accuracy**

area	*sx [m]*	*sy [m]*	*sz [m]*
DHDN	0.010	0.010	0.010
STN	0.001	0.002	0.001
BRAN	0.000	0.000	<0.010

- **external accuracy**

area	*sx [m]*	*sy [m]*	*sz [m]*
DHDN	0.047	0.046	0.027
STN	0.007	0.013	0.006
BRAN	0.000	0.000	0.010

GNTRANS – Model Properties

- **properties of transformation models**
  - preservation of adjacent metric properties
  - uniqueness/standardized
  - homogeneity
  - continuity
  - consideration of discontinuities
  - biuniqueness (one-to-one mapping)

Local Patches of GNTRANS

A local densification of GNTRANS has been conducted for the City of Düsseldorf. Additional identical points with coordinates given in ETRF 89 and official state system were used. The additional points were incorporated into GNTRANS in a so-called patch for the area of the City of Düsseldorf. The first view graph shows the horizontal performance of the German wide GNTRANS and the densified GNTRANS patch. The 3D difference are in the order of 2 cm and 0.5 cm, respectively. The second view graph shows the height components for the same two comparisons. The scale of the plots is always 2 cm.

Currently, the transformation of ellipsoidal heights derived from satellite-based surveying techniques to orthometric heights is discussed intensively in the state survey authorities in Germany. The state surveying authorities have installed RTK networks covering whole Germany (SA*POS*), which can be used for height determination.

For the investigation of the GNTRANS accuracy with SA*POS* (Satellite Positioning Service in Germany), a patch was generated for a well surveyed area in Niedersachsen called Verden. The height of the test area were precisely determined in ETRF 89 and the state height system DHHN 92. The ETRF 89 coordinates of several check points were positioned using a RTK GPS rover system and the SA*POS* RTK network of Niedersachsen.

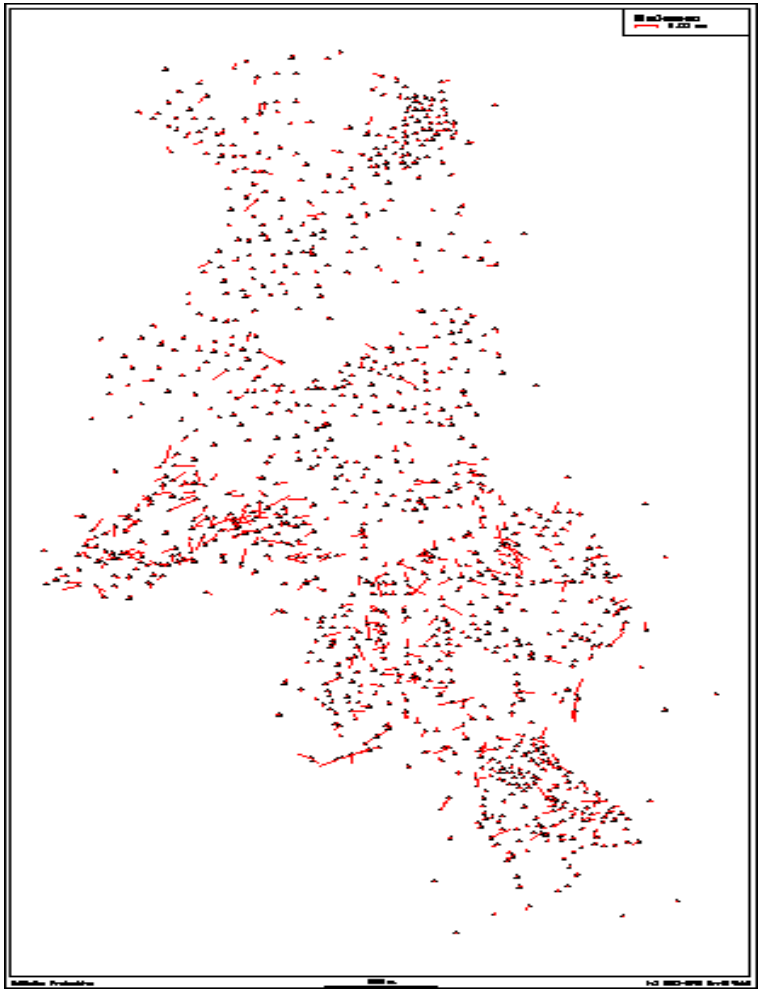
The comparison has been compueted in differently absolutely positioned networks. First a free network using only one datum defining station, secondly an official ETRF 89 datum was used.

GNTRANS – Modules/Patches

- **German-wide module**
  - developed and generated for DB AG
- **module/patches**
  - local accuracy improvement through densification of additional identical points
    - City of Düsseldorf
    - SA*POS* Test Verden, Niedersachsen
    - ...

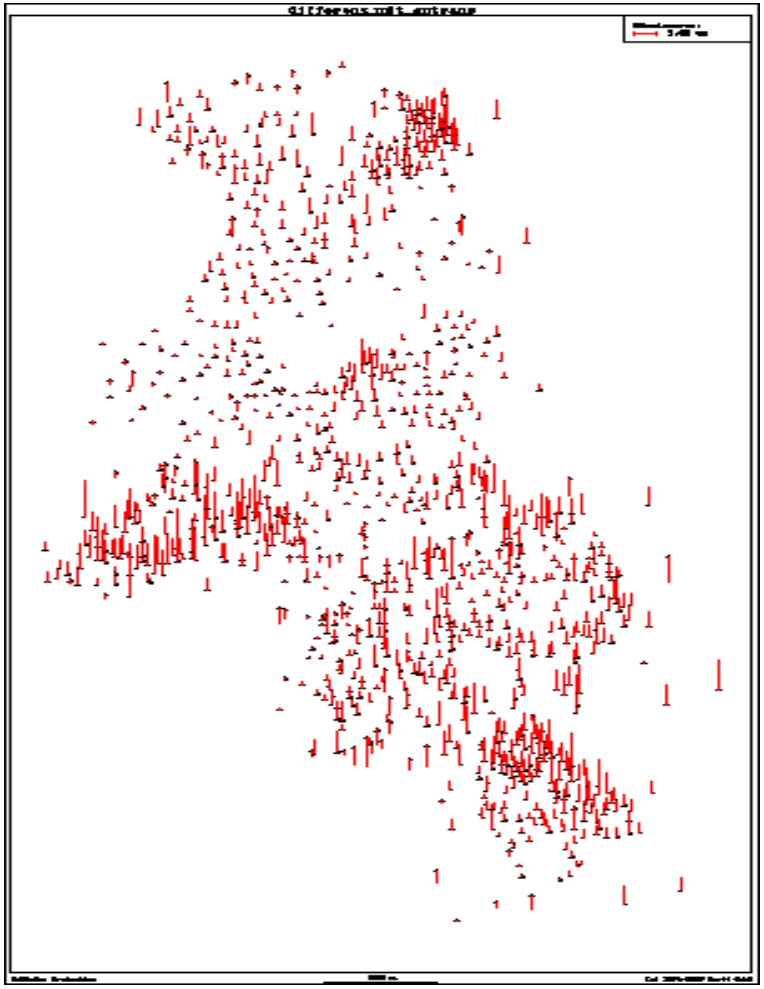
GNTRANS - Düsseldorf Patch
Horizontal Component

GNTRANS

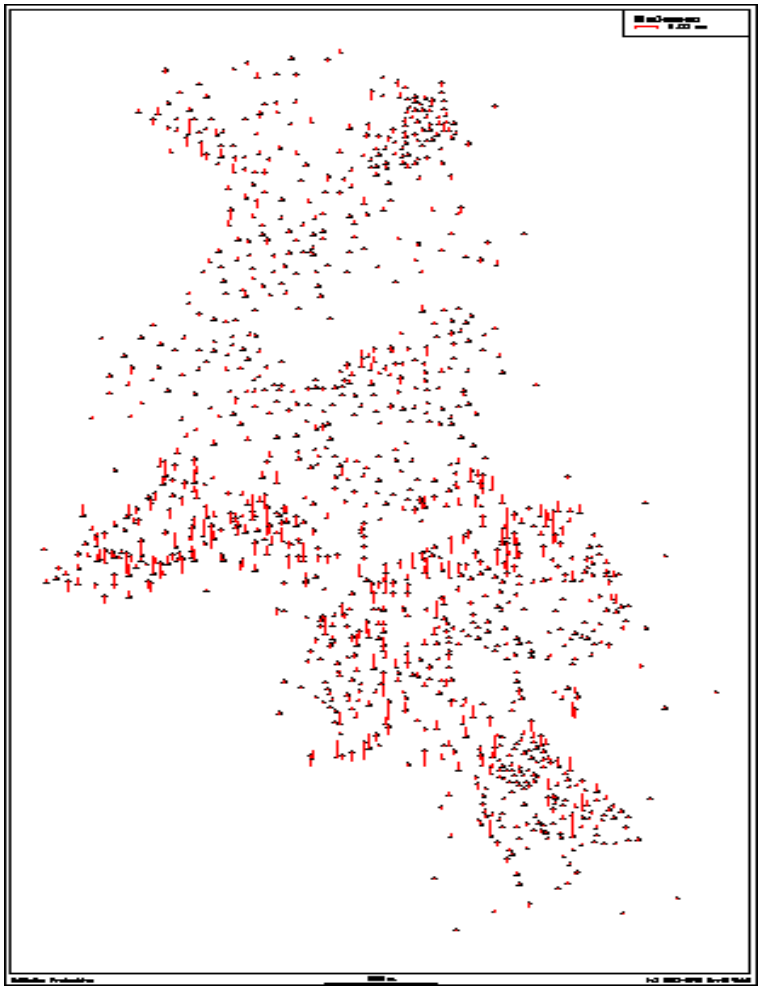


GNTRANS patch

GNTRANS - Düsseldorf Patch
Height Component



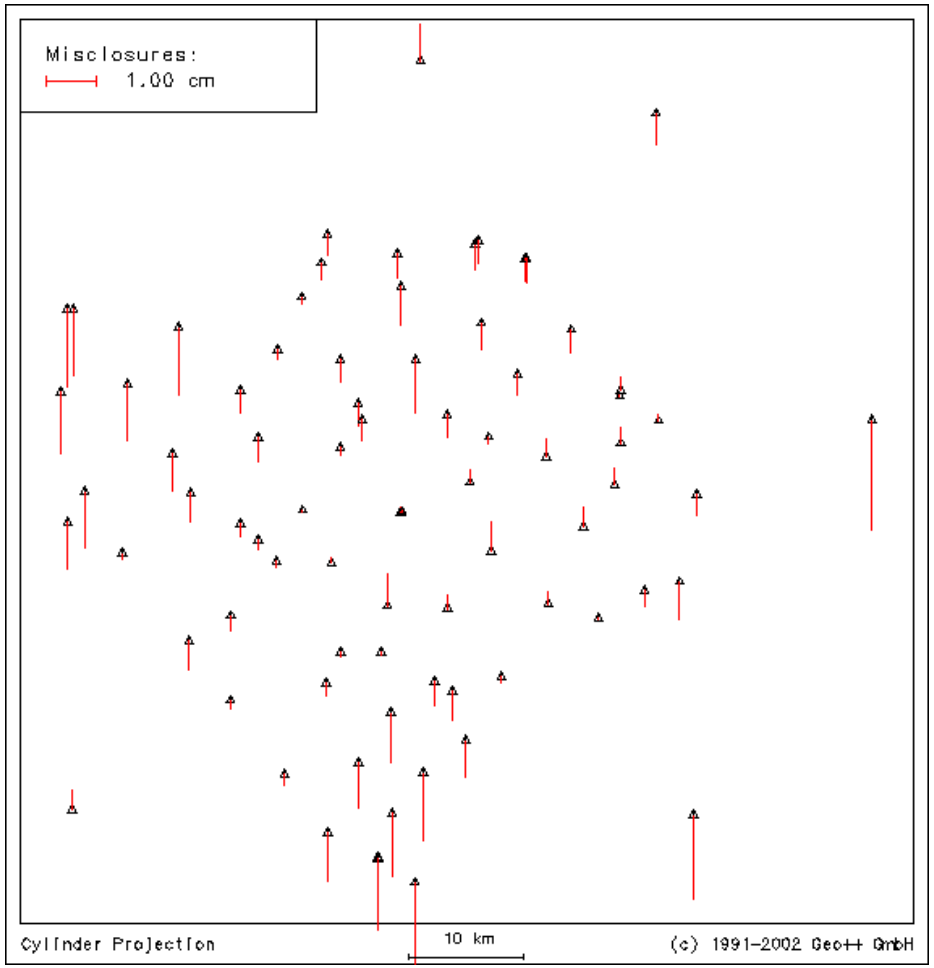
GNTRANS



GNTRANS patch

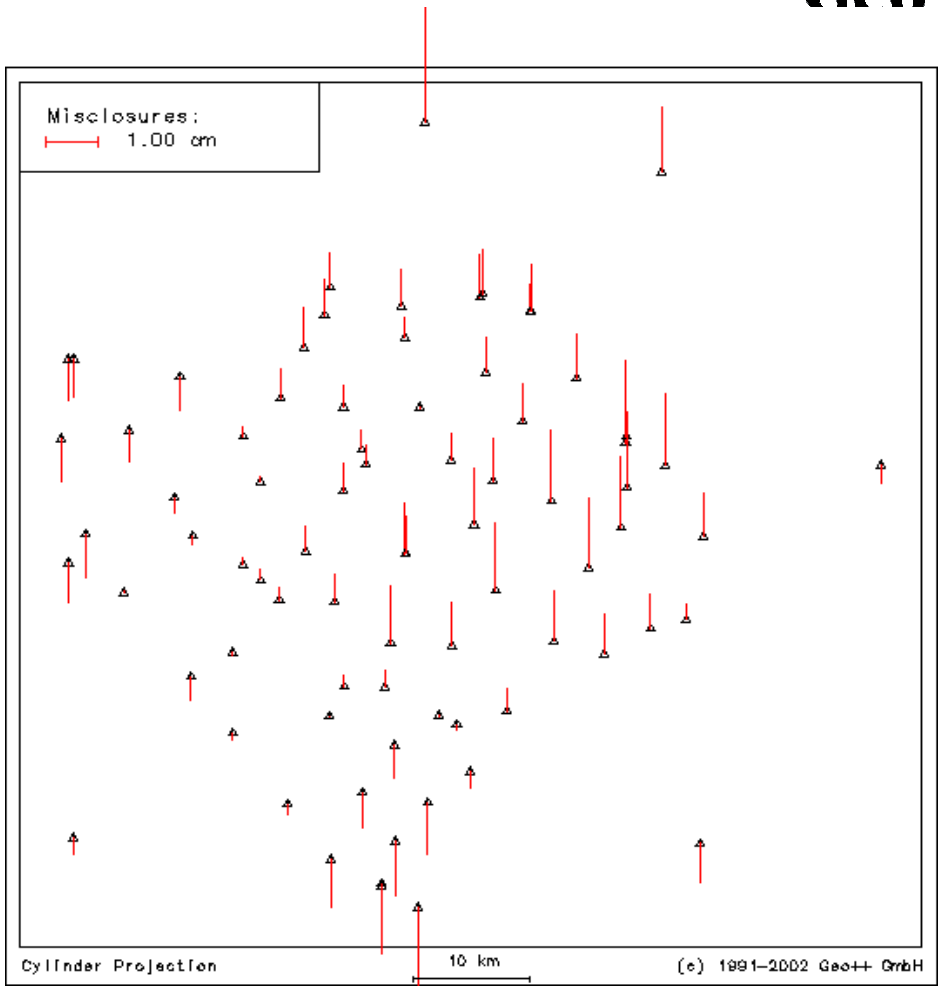
GNTRANS – SA*POS*® Patch Verden

- **GNTRANS patch**
  - free positioning of network
  - comparison with precise reference coordinates
  - mean height differences well below 1 cm



GNTRANS – SA*POS*® Patch Verden

- **GNTRANS patch**
  - constrained positioning of network
  - comparison with precise reference coordinates
  - mean height differences well below 1 cm

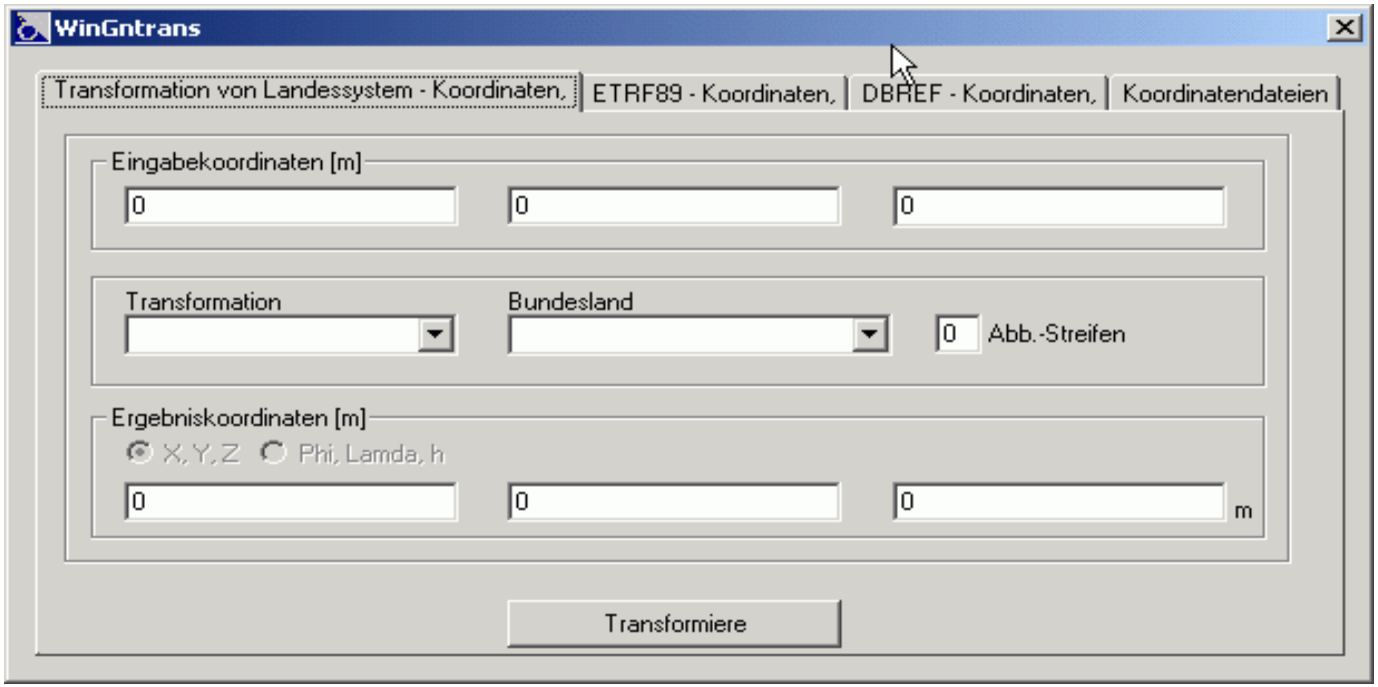


GNTRANS – Application

- **command line oriented**
  - professional use
  - simple handling in batch files
- **examples**
  - transformation ETRF 89 to DB_REF
    - gntrans -t ETDB < `input.dat` > `output.dat`
  - transformation state system to DB_REF
    - gntrans -t LSDB -l THUE < `in.dat` > `out.dat`

GNTRANS – Application

- **graphical user interface**
  - transformation with “a Mouse Click“



GNTRANS – Application

- **GNTRANS-DLL**
  - simple integration of GNTRANS-Module in any application software (e.g. TechNet VerMessen)

- **GNTRANSRT**
  - real time application in RTK-networks

Summary

- satellite-based applications demand for modern coordinate systems
- coordinate variety in Germany
- problems for German-wide applications
- homogeneous transformation
- GNTRANS model and performance
- transformation model for the transition of ETRF 89 coordinates and official state coordinates into a homogeneous coordinate system DB_REF