VIENNA
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TECHNOLOGY

INSTITUTE OF
PHOTOGRAMMETRY
AND REMOTE SENSING

Google Summer of Code

Rigorous support of Vertical Datums within OGRSpatialReference

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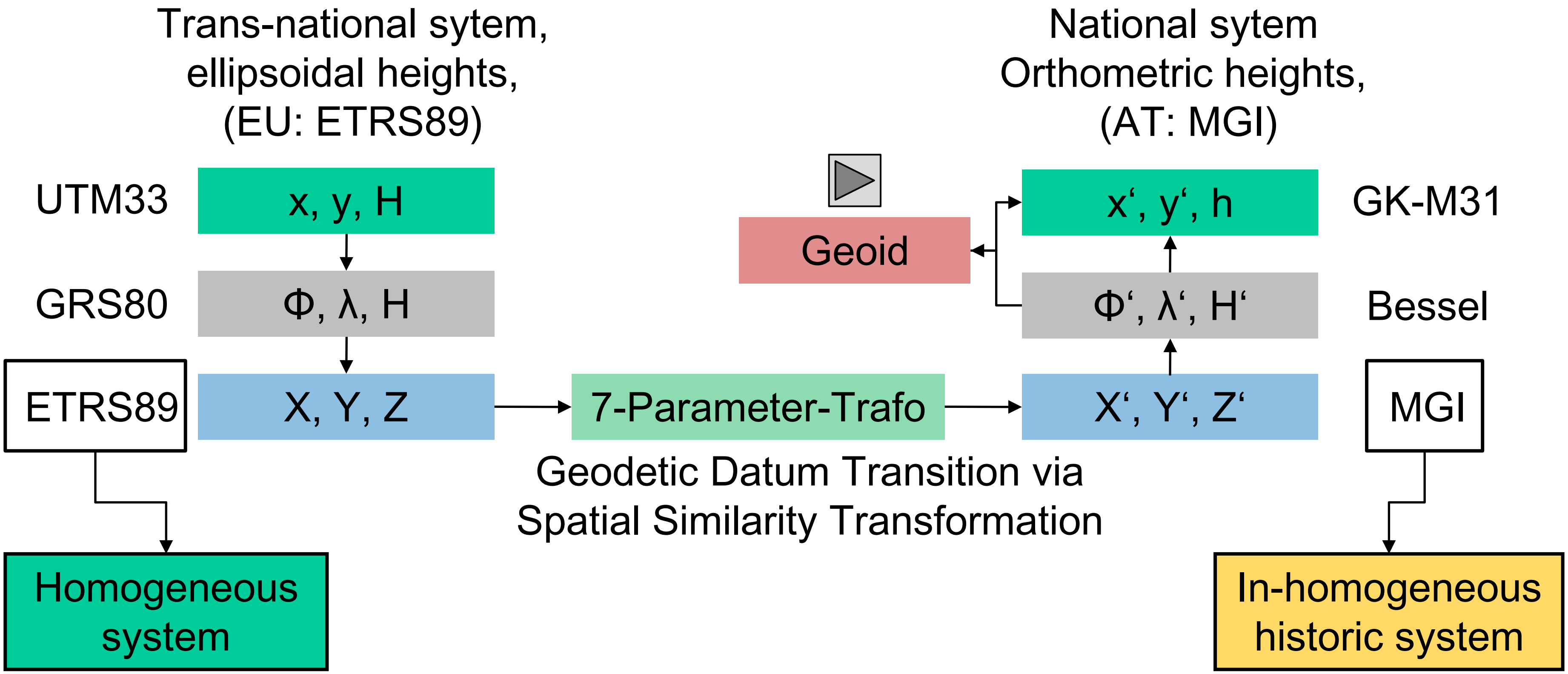
Spatial Referencing

- OpenGIS® Implementation Specification: **Coordinate Transformation Services**
- Available at: http://www.opengeospatial.org/standards/ct
- Generic description of spatial reference systems
  - Known Text (WKT) representation ▶
  - Horizontal systems (geographic and projected systems)
    - Reference spheroids (SPHERIOD)
    - Geodetic datum transformation (TOWGS84)
    - Map projections (PROJECTION)
  - Vertical systems
    - Vertical datum (VERT_DATUM)
  - Compound Systems (horizontal + vertical → 3D)
- Implementations available:
  - GDAL/OGR library: Spatial reference classes (built upon PROJ4 library)
- Existing problems
  - **No standards for vertical transformations available**
  - **Different approaches for transition: national → global reference systems**

Coordinate Transformation: Trans-national ←→ National via 7-P-Trafo



Trans-national sytem,
ellipsoidal heights,
(EU: ETRS89)

National sytem
Orthometric heights,
(AT: MGI)

UTM33 — x, y, H

GRS80 — Φ, λ, H

ETRS89 — X, Y, Z

7-Parameter-Trafo

Geoid

GK-M31 — x‘, y‘, h

Bessel — Φ‘, λ‘, H‘

MGI — X‘, Y‘, Z‘

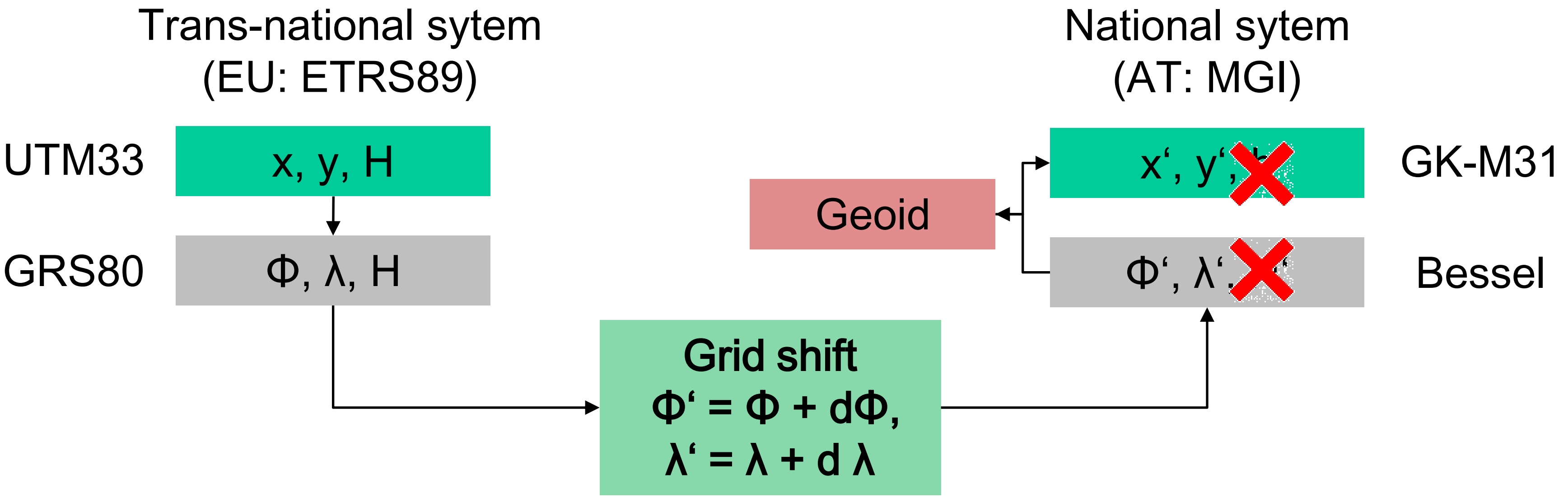
Geodetic Datum Transition via
Spatial Similarity Transformation

Homogeneous system

In-homogeneous historic system

x, y	Map coordinates
h, H	Orthometric/ellipsoidal height
Φ, λ	geographic coordinates
X, Y, Z	geocentric coordinates

Coordinate Transformation: Trans-national ←→ National via Grid Shifts



Trans-national sytem
(EU: ETRS89)

National sytem
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UTM33

x, y, H

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Φ, λ, H

Geoid

x‘, y‘,

GK-M31

Φ‘, λ‘,

Bessel

Grid shift
Φ‘ = Φ + dΦ,
λ‘ = λ + d λ

- **NTv2 (National Transformation v2) grid shifts**
  - Developed in Canada
  - Adopted for USA, Australia, Germany (BeTA2007), Austria (GIS-Grid), ...
  - Became quasi-standard

- Drawbacks
  - Not implemented as OGC Standard
    - Merges datum transition and inhomogeneities of national grids
      - Height information is lost
  - National height anomalies are not compensated (2D only)

OGC: Coordinate Transformation Services – Well Known Text Representation (example)

```
PROJCS["OSGB 1936 / British National Grid",
       GEOGCS["OSGB 1936",
           DATUM["OSGB_1936",
               SPHEROID["Airy 1830",6377563.396,299.3249646,
                 AUTHORITY["EPSG","7001"]],
               TOWGS84[375,-111,431,0,0,0,0],
               AUTHORITY[["EPSG","6277"]],
           PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],
           UNIT["DMSH",0.0174532925199433,AUTHORITY["EPSG","9108"]],
           AXIS["Lat",NORTH],
           AXIS["Long",EAST],
           AUTHORITY[["EPSG","4277"]],
       PROJECTION["Transverse_Mercator"],
       PARAMETER["latitude_of_origin",49],
       PARAMETER["central_meridian",-2],
       PARAMETER["scale_factor",0.999601272],
       PARAMETER["false_easting",400000],
       PARAMETER["false_northing",-100000],
       UNIT["metre",1,AUTHORITY["EPSG","9001"]],
       AXIS["E",EAST],
       AXIS["N",NORTH],
       AUTHORITY[["EPSG","27700"]],
```

Quelle: http://www.opengeospatial.org/standards/ct

Height systems

$H_{ell} = H_{orth} + N = H_{norm} + \zeta$

H_{ell} ellipsoidische Höhe

H_{orth} orthometrische Höhe

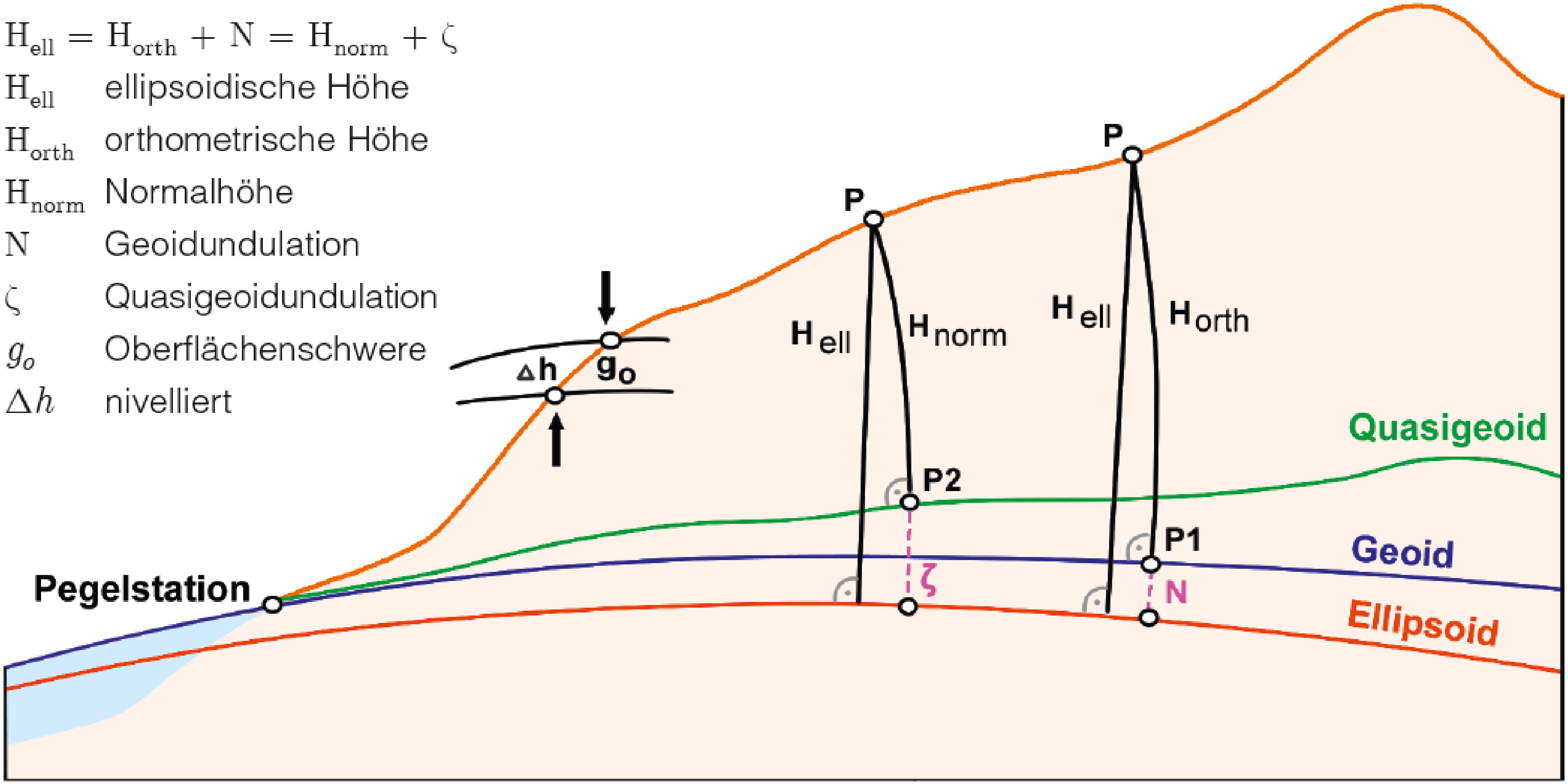
H_{norm} Normalhöhe

N Geoidundulation

ζ Quasigeoidundulation

g_o Oberflächenschwere

Δh nivelliert



Source: Briese et al., 2012: Transformation von GNSS-Höhen in österreichische Gebrauchshöhen mittels einer Transformationsfläche (Höhen-Grid)

Height systems

- Physical nature of heights (gravity field of the Earth)
- geoid = aequi-potential surface in mean sea level
- Height differences = potential difference
- Geo-potential cote:

$$C_p = \sum_{0}^{P} \Delta h . g_0$$

$$C_p = \text{geopotential cote in point P}$$

$$g_0 = \text{surface gravity along the levelling path}$$

$$\Delta h = \text{height difference (levelling)}$$

$$\Delta c = \text{potential difference}$$

Height systems

- Orthometric heights $H_{orth} = C / g*$
- Normal heights $H_{norm} = C / \gamma*$
- Dynamic heights $H_{dyn} = C / \gamma_G$

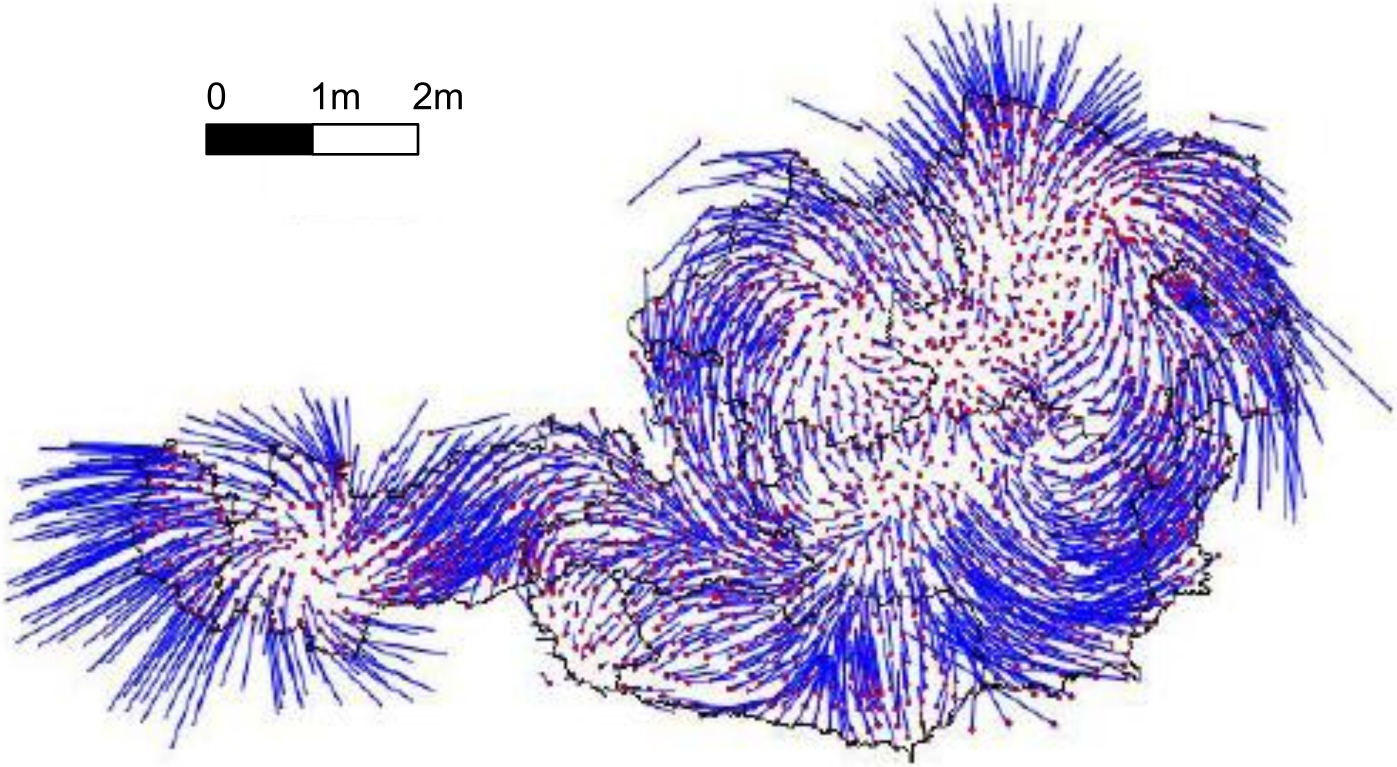
$g*$...integral gravity value in the mid between surface and geoid

$\gamma*$...normal gravity in the mid between surface and geoid

γ_G... mean gravity within a specific area

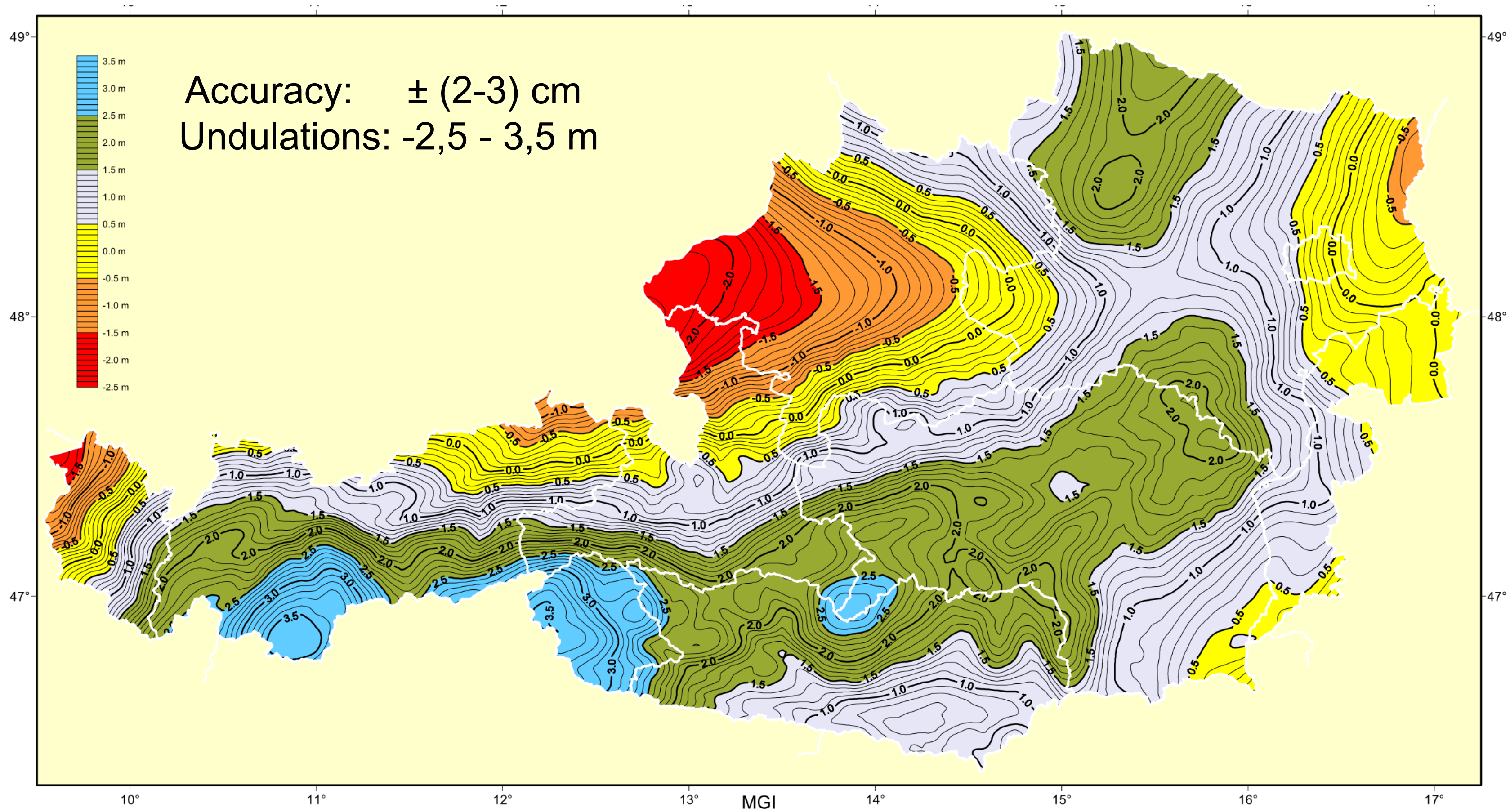
- Spherical heights
- “Heights in use” (historically grown height systems, often in homogeneous)

Inhomogenities of Austrian National Reference System (MGI)



Austrian Federal Office of Metrology and Surveying (BEV) – Geoid model

Austrian Geoid 2008 – Reference Ellipsoid Bessel (MGI)



Accuracy: ± (2-3) cm
Undulations: -2,5 - 3,5 m

Geoidundulationen, bezogen auf Bessel Ellipsoid (MGI), berechnet aus gravimetrischen, astronomischen, GPS und Nivellement-Beobachtungen.

Stand: 2009 © BEV

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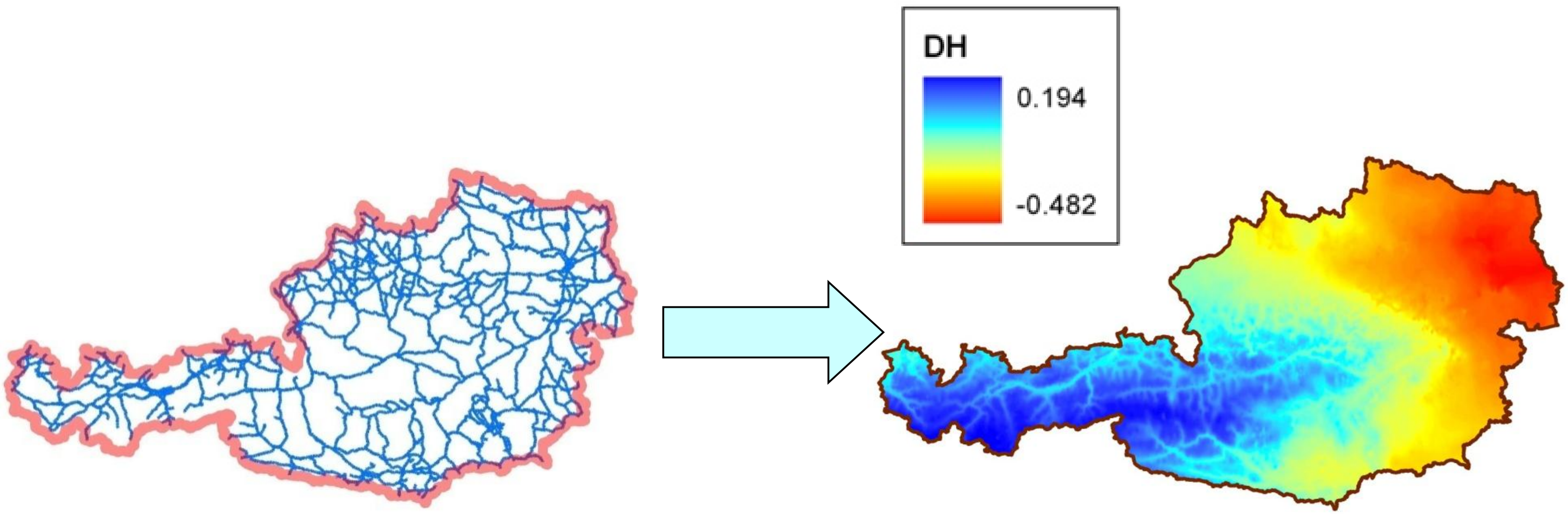
See you: www.bev.gv.at

Quelle: http://www.bev.gv.at

BEV - Height correction model

Vertical correction model compensating height anomalies in the Austrian national height system based on nivellement points
Transformation: „used heights (MGI) → orthometric heights (EVRS)

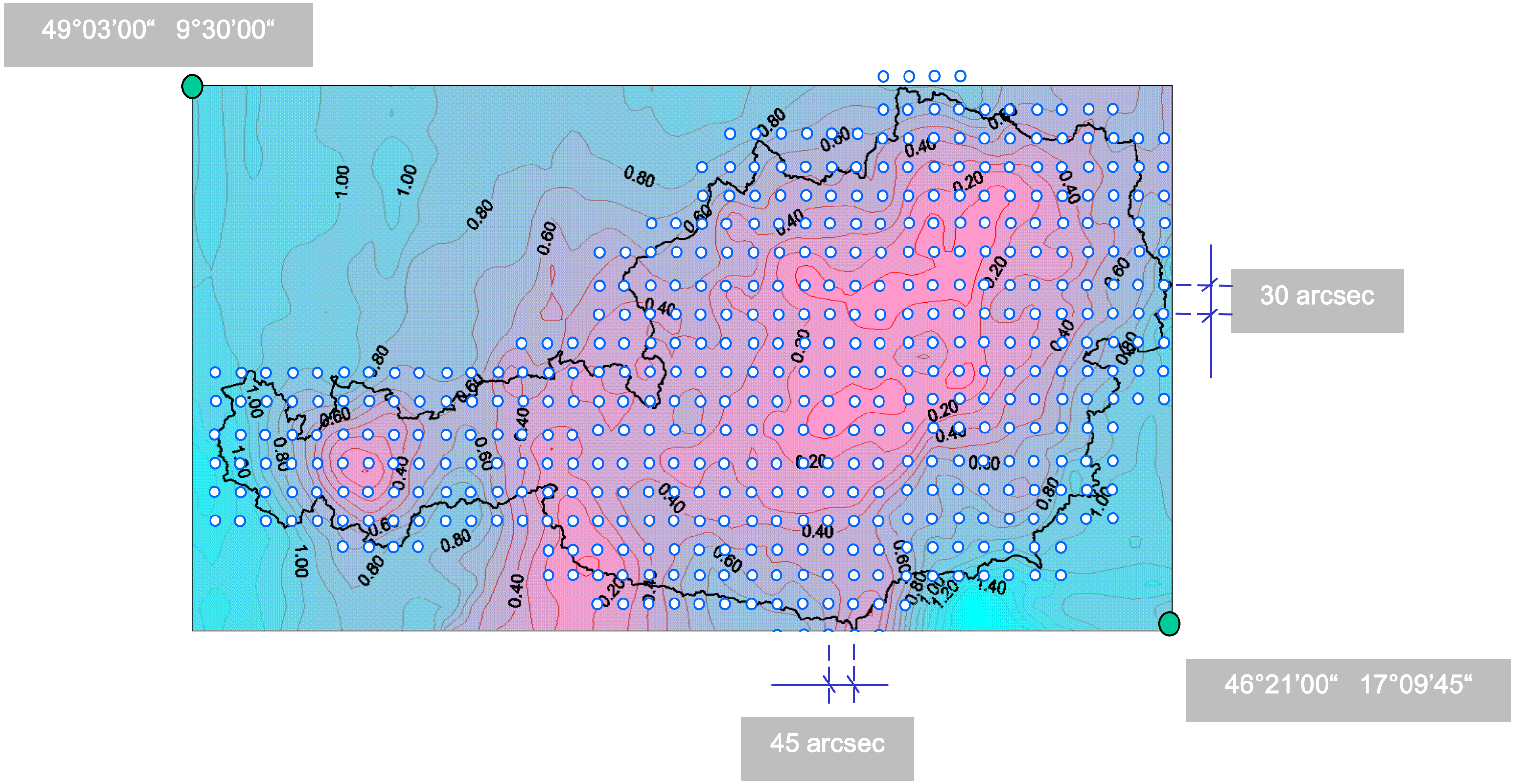
Modell NIV: aus Formel über Normalhöhe mit Verdichtung in die Fläche über Bougeranomalie



Source: http://www.bev.gv.at

BEV GIS-GRID (=Ntv2 grid for Austria)

GRID (Raster) in geographic coordinate system φ, λ ; grid width z.B. 30“x45“ (≈ 1x1 km)
Each grid post contains correction values dφ, dλ



Derived from 28.120 control points (coordinates available in both MGI und ETRS89 system); Transformation accuracy < 15 cm

→ GIS - GRID

Source: http://www.bev.gv.at

Issues

- Transformation from ellipsoidal (geometric) to orthometric (physical) heights requires geoid model (quasi geoid for dynamic/normal heights)
- In-homogeneity of historical height systems can be corrected with additional height correction models:
  h_{ell} → [geoid] → h_{ortho} →[vertic. corr. model] → h_{used}
- Additional (optional) constant vertical offset (tidal diff., local heights, …)
- Additional (optional) z-scaling
- Geoid models are normally provided in geographic coordinates (GEOGCS; φ,λ). Thus, linkage between GEOGCS and VERT_CS would be necessary
- Geoids are normally provided as rasters. Thus, (bi-linear) interpolation at arbitrary positions is required.
- How to specify vertical CS (including geoids, height corr. models, height offsets) in OGC Coordinate Transformations (CT) Services spec.? This issue does not have to be tackled within the GSoC project
- Height correction should be performed on the GEOGCS (φ,λ) level

Implementation issues

- Available libraries
  - GDAL/OGR (Spatial Reference class)
  - Proj4 (currently doing most of the transformation job)
  - ... ...
- Class interface:
  - Based on OGR Spatial reference
  - Add members/functions for vertical component
    - SetGeoidModel(char* psz_geoidfile)
    - SetHeightCorrModel(char* psz_geoidfile)
    - SetHeightOffset(const double d_offset)
    - ....
- Allow vertical transformations for all systems based on GEOGCS

Implementation issues

- **Support of different GEOID File Format**
  - Using OGR different raster formats could easily be supported
- **Library dependency**
  - PROJ.4 is an independent library
  - OGR depends on PROJ.4
- **Technical solution for vertical transformation**
  - Inside PROJ.4 with GEOID interpolation calls to OGR
    - + Current transformation workflow is preserved
    - - PROJ.4 loses independence
  - Full transformation workflow inside OGR (favored by IPF)
    - + Transformation code at one place
    - - double transformation code in PROJ.4 and OGR (rewrite *pj_transform*)
- **Optional additional Libraries**
  - The GeographicLib could be usefull (parts or full library). http://geographiclib.sourceforge.net/html/index.html

Implementation issues

- **Current Transformation class (OGR)**
  - OGRProj4CT (derived from OGRCoordinateTransformation) wraps the transformation call to *pj_transform*

- **New Transformation Implemation**
  - A new class e.g. OGRProj4CT3D (also derived from OGRCoordinateTransformation) should be written. Containing the changed/improved *pj_transform* code

Generic Transformation Path (status quo)

- PROJ4 (pj_transform pseudo code):
  - projected coordinate (proj)
  - geographic coordinate
  - scale /meridian offset transformation
  - geoid transform
  - geographic to wgs84 :
  - -> grid shift
  - -> geographic to geocentric -> 3/7 parameter transform
  - wgs84 to geographic :
  - -> grid shift
  - -> geographic to geocentric -> three/seven parameter transform
  - geoid transform
  - scale /meridian offset transformation
  - geographic coordinate (inverse proj)
  - projected coordinate

Generic Transformation Path (3D add-ons)

- PROJ4 (pj_transform pseudo code):
  - projected coordinate (proj)
  - geographic coordinate
  - scale /meridian offset transformation
  - generic height transformation (geoid + height.corr. + z offset/scale)
  - geographic to wgs84 :
  - -> grid shift
  - -> geographic to geocentric -> three/seven parameter transform
  - wgs84 to geographic :
  - -> grid shift
  - -> geographic to geocentric -> three/seven parameter transform
  - generic height transformation (geoid + height.corr. + z offset/scale)
  - scale /meridian offset transformation
  - geographic coordinate (inverse proj)
  - projected coordinate

Additional ideas

- 3D grid shift
  - Current status: Ntv2 only 2D
  - 3D-extension desirable (not within GSoC project)
- De-coupling in-homogeneities of national systems from datum transformation
  - Status quo:
    - geographic coo. (datum 1) →
    - grid shift →
    - geographic coo. (datum2)
  - Desired (optional)
    - geographic coo. (datum 1) →
    - grid shift (national in-homogeneities only) →
    - Homogenized geographic coo. (datum 1) →
    - to wgs84
    - Three/seven parameter transformation
    - … … (back again)

Proposed way of preceeding

Spatial Reference Systems:

- Based on **OGRSpatialReference** class
- Derived class **OGRSpatialReference3D** (working title)
- Add members/functions for vertical transformation
  - Geoid model
  - Additional height correction model
  - z offset and scale

Transformations:

- Based on **OGRCreateCoordinateTransformation**
- Derived class **OGRCreateCoordinateTransformation3D**
- Make OGRCreateCoordinateTransformation ::transform function virtual
- Re-write OGRCreateCoordinateTransformation3D::transform (cf. Slide: Generic Transformation Path (3D add-ons))