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Realization of a Global Unified Height System and its advances for Hydrographic Survey and for Coastal Mapping

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HYDRO 2010
Rostock-Warnemünde, 02.-05. November 2010

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Outline

I. Situation and Motivation
II. The IAG Inter-Commission Project 1.2 Vertical Reference Frames
III. Definition of a World Height System (WHS)
IV. Concepts for the Realization of a World Height System
V. WHS and Standards
VI. Resume, Recommendations

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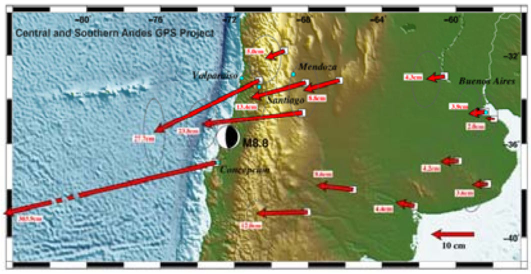
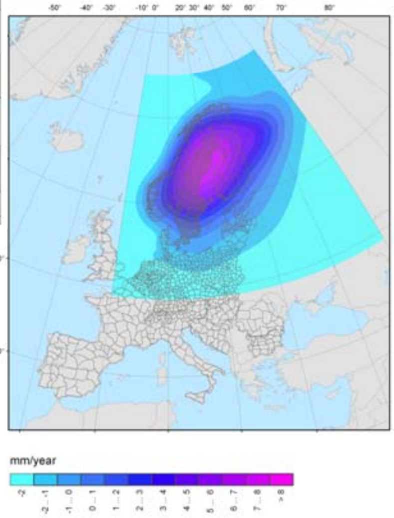
We are Living on the Changing Planet Earth



Fenoscandian land uplift model NKG2005LU (Ågren and Svensson)



Earth quake in Chile at 27-02-2010 6:34 UTC

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I. Situation and Motivation (1/4)

- **The vertical component plays a special role for the global monitoring of the topography of the Earth body**
  - **Sea level change**
  - **Change of the sea surface topography**
  - **Post glacial uplift**
  - **Ice melting etc**
- **Hydrography and Geodesy meets in costal zone areas**
- **Geometry X_P: The International Terrestrial Reference Frame (ITRF2008) is consistent within 10^{-8} to 10^{-9}**
- **Physical heights $-\Delta W_P = c_P = W_0 - W_P$ (Earth gravity field potential W(X)): Worldwide, there are some hundred physical height systems and chart datums, realized**
  - **by different tide gauges (inconsistencies in the range of 2 m due to sea surface topography)**
  - **by spirit levelling reduced by different theories (10^{-6})**
  - **at different epochs and as static systems**
- **Satellite gravity field missions GRACE, GOCE – 1 cm geoid globally with a spatial resolution of 100 km, gravity anomalies 1 mGal are expected**

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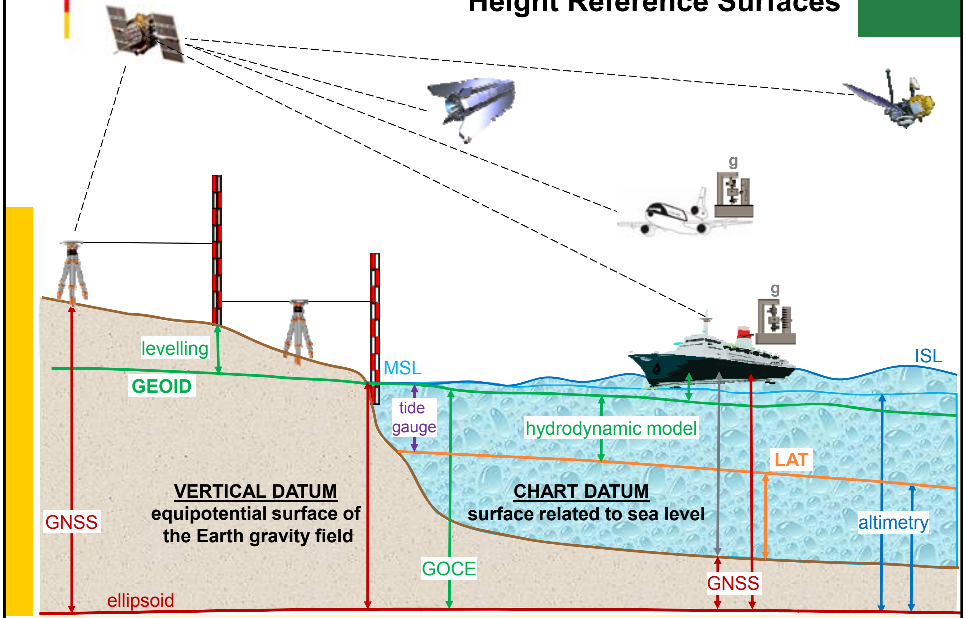
I. Situation and Motivation (2/4) Height Reference Surfaces



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I. Situation and Motivation (3/4) Height Reference Surfaces

- **There is no vertical reference surface which is suitable for all applications and all users:**
  - **Hydrographical maps: chart datums – lowest astronomical tide (LAT)**
  - **Geo-topographic information on land: levelling networks TG MSL**
  - **Navigation: ellipsoidal heights (GRS80)**
  - **Oceanography: global geoid and ellipsoid.**
- **The choice of the vertical reference systems (VRS) depends on the properties of the corresponding heights (spatial and temporal variability), the possibility of its realization and the applicability for the user.**
- **Therefore, it is necessary to know the relations between the different VRS.**
  - **Geoidal models (EGM08, GRACE, GOCE)**
  - **Hydrodynamic models**
  - **Sea surface topography**
  - **Mean sea surface.**

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I. Situation and Motivation (4/4)
Geodetic Aspects

Disadvantages of the existing height systems

1. There are many reference levels (zero-height surfaces) as reference tide gauges (more than 100 world-wide), discrepancies of which can reach up to ± 2 m in a global frame
2. These discrepancies, together with the error propagation of spirit levelling with the distance from the tide gauge and the different gravity reductions applied, extend the uncertainty of these systems to the meter level, i.e., two to three orders of magnitude less than the accuracy of the geometric reference system (10^{-9})
3. They do not allow the data exchange in international projects and tasks, because they are only compatible with themselves
4. They do not support the reliable realization of $h = H + N$ in a world-wide scale

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II. The IAG Inter-Commission Project 1.2
Vertical Reference Frames (1/3)

Program of Activities of ICP1.2

- First term 2003 – 2007: Development of World Height system (WHS) conventions
- Study of information on regional vertical systems and of combination procedures of height data sets from different techniques
- Development of the basic relationships between WHS (gravity field) and ITRS (geometry) conventions, parameters, realization, models
- Preparation of a pilot project for the realization of a WHS
- At the Global Geodetic Observing System (GGOS) planning meeting in February 2010 the realization of a WHS was discussed as Theme 1.

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II. The IAG Inter-Commission Project 1.2 Vertical Reference Frames (2/3)

Main Objectives for a World Height System (WHS)

To define and to realize a global vertical reference system that

1. Supports geometrical (h) and physical heights (H), as well as their combination (h = H + N), world-wide with a centimetre precision (10^{-9}) in a global frame
2. Globally allows the unification of the existing physical height systems, i.e., all geopotential differences shall be referred to one and the same reference level (equipotential surface W_0)
3. Provides high-accuracy and long-term stability of the vertical/radial components (dh/dt, dH/dt, dN/dt) with an accuracy 10^{-9}

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II. The IAG Inter-Commission Project 1.2 Vertical Reference Frames (3/3)

Realization of a WHS – ICP1.2 Recommendations

- The WHS datum shall be realized by a conventional W_0 value
- The GGM for the WHS shall be conventional (CGGM)
- ITRF and CGGM have to be based on a set of consistent conventional numerical standards (IERS Conv., chapter 1.2)
- A global network of stations with geocentric coordinates in ITRS and geopotential numbers referred to a global gravity model (GGM), which has to be geocentric
- Changes of the vertical components can be observed with respect to the conventional WHS level by relevant observation techniques: GNSS, tide gauges, permanent (SG) and periodical (AG) gravity stations

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III. Definition of a World Height System (1/3)

- A World Height System (WHS) is a consistent model for geometry and geopotential of the Earth
- It is represented by a global geopotential model (GGM) as reference for physical heights – geopotental numbers
- The lowest order approximation of the GGM is the equipotential ellipsoid with 4 defining parameters: Geocentric gravitational constant GM, angular velocity of the Earth rotation ω, flattening f^{-1}, semi-major axis a – or the zero potential W_0
- The equipotential ellipsoid as mean Earth Ellipsoid is the zero level for geometric and physical heights
- At present for geometric and physical heights different reference ellipsoids are used
- Furthermore the data are reduced to different tidal systems

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III. Definition of a World Height System (2/3)

A World Height System (WHS) fulfils the following conventions:

1. The vertical datum is defined as the equipotential surface for which the Earth gravity field potential is constant:
   W_0 = const.

   The potential value W_0 shall be conventional

   Note: The vertical datum defines the relationship of the physical heights to the Earth body. W_0 shall be conventional and reproducible

2. The unit of length is the meter (SI) and the unit of time is the second (SI) (in agreement with IAU and IUGG (1991) resolutions, the scale being consistent with the TCG time)

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III. Definition of a World Height System (3/3)

3. The vertical coordinate of a point P is the difference

$$-\Delta W_P = c_P = W_0 - W_P$$

W_P … the Earth gravity potential at point P
W_0 … the WHS conventional zero level potential
$-\Delta W_P$ is also designated as geopotential number c_P, derived from spirit levelling

4. The WHS is a zero tidal system, in agreement with the IAG Resolution No 16 adopted in Hamburg in 1983

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IV. Concepts for the realization of a World Height System (1/7)

General possibilities for the realization

i. On continents:
by common adjustment of existing levelling networks (c_{P_k})

ii. Global:
general case for realization and unification - combination of GNSS or/and GNSS/levelling with GGM

iii. Over oceans:
using a model of mean sea surface topography and tide gauge observations

Combinations are useful

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IV. Concepts for the realization of a World Height System (2/7)

i. The classical approach (continental/levelling)

$W_p = W_0 - c_p$ (levelling)

from an adjustment of a levelling network (only on continents)

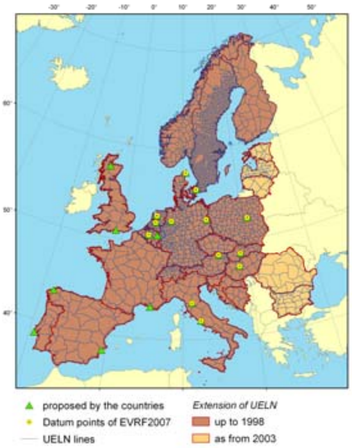
$$\boxed{H_n = \frac{c_P}{\bar{\gamma}}}$$

EVRF2007

- **27 European countries**
- **7939 nodal points**
- **10347 measurements**
- **s0 (1km): 1.11 kgal·mm**
- **geopotential numbers, normal heights**
- **Zero tidal system**

Datum of EVRF2007

- **13 points have been used fitting to the level of EVRF2000 by**



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IV. Concepts for the realization of a World Height System (3/7)

ii. The general approach (global/GBVP approach):

GNSS/Levelling with GGM

Wp = Up + Tp (GBVP)

from a GGM - in combination with

regional GM densification

$$\zeta = \frac{T_P}{\gamma_Q} = \frac{W_P - U_P}{\gamma_Q}$$

and GNSS heights h_p

$$\boxed{H_n = h_P - \zeta}$$

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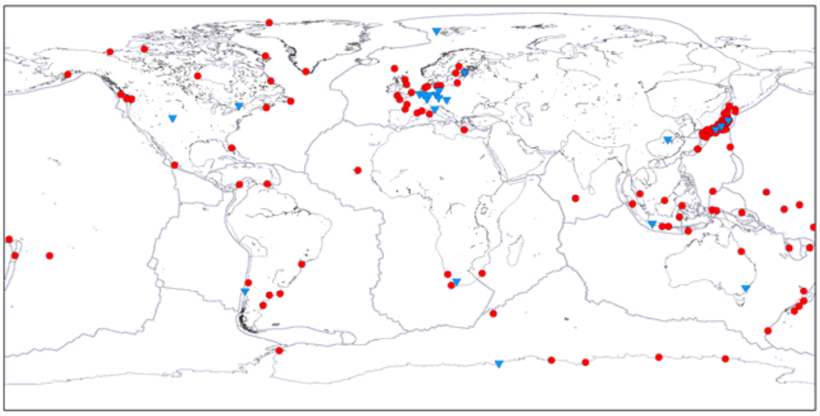
IV. Concepts for the realization of a World Height System (4/7)

WHS integrated station network: Stations of International GNSS Service (IGS) Tide Gauge (TIGA)-PP



• GPS/tide gauge stations ▼ super-conducting gravimeter stations

For further consideration: Integration of worldwide GNSS Tsunami early warning system buoys for long term control of mean sea surface and connection to satellite altimeter observation

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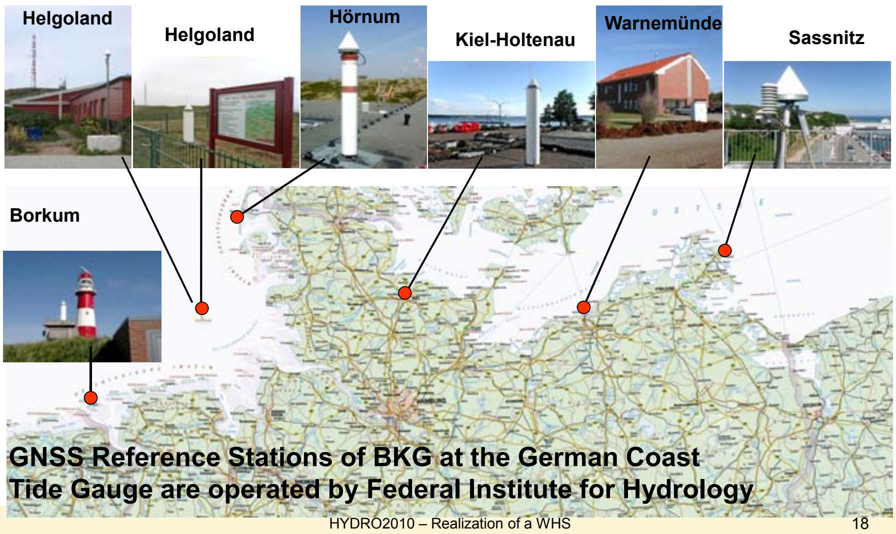
IV. Concepts for the realization of a World Height System (5/7)

GNSS RT reference stations of at the german coast part of global IGS networks and projects



GNSS Reference Stations of BKG at the German Coast
Tide Gauge are operated by Federal Institute for Hydrology

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IV. Concepts for the realization of a World Height System (6/7)

GREF GNSS Station Warnemünde (IGS TIGA Station)

Tide Gauge

GNSS RT Station

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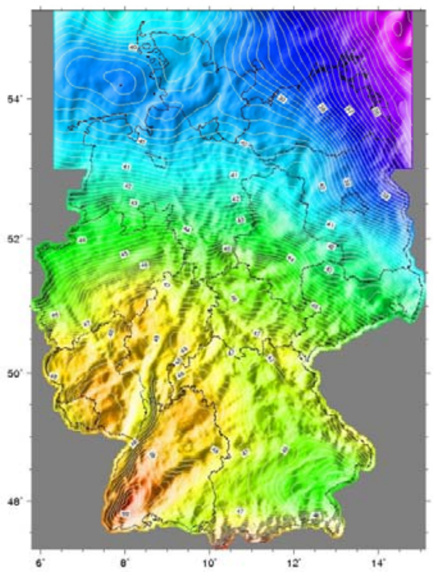
IV. Concepts for the realization of a World Height System (7/7)



2009 extended version of the GCG2005 (densified GRACE gravity model, GNSS/levelling heights, terr. gravity) based on:

1) gravity data from the airborne campaigns:
- **BalGRACE2006 and**
- **NorthGRACE 2007 / 2008**

2) altimetry data obtained from the
- **TU Dresden and the**
- **KMS2002 model**

3) an improved DTM (25m x 25m)

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V. WHS and Standards (1/3)

Geodetic Reference System 1980 (GRS80, mean Earth ellipsoid) defines major parameters for geodetic reference systems related to a level ellipsoid

- Agreed by IUGG, IAG and IAU.
- Recommended by IAG for the conversion of ITRF Cartesian coordinates to ellipsoidal coordinates.
- Worldwide use for many map projections and million of coordinates.
- At the IUGG General Assembly 1991 in Vienna new values for the geocentric gravitational constant GM and the semi-major axis a of the level ellipsoid were recommended.
- Since this time these parameters have been used in global gravity models e.g. EGM96 and EGM08

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V. WHS and Standards (2/3)

Numerical Standard Conflict:

In IERS 2003 conventions (IUGG, IAG, IAU) there are two sets of parameters of a level ellipsoid in use: In chapter 1.2 numerical standards and in chapter 4 the GRS80

IAG ICP1.2 recommends:

- The IAG needs to remove this inconsistency in view of the development of integrated geodetic applications
- Investigations should be carried out to clarify if there is a need to change the W_0 value

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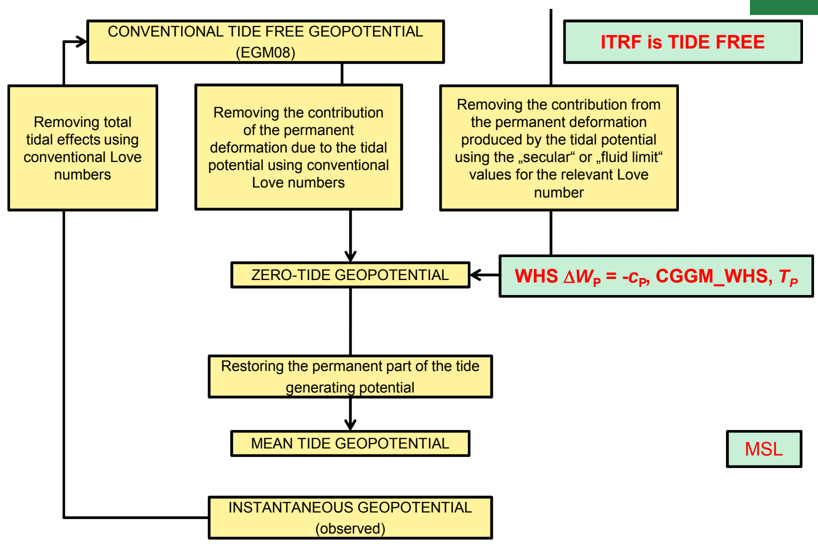
V. WHS and Standards (3/3)



Treatment of observations for tidal effects in the geopotential

VI. Resume, Recommendations

- For combination of geo data in costal areas different height reference surfaces (LAT, MSL, Geoid, Ellipsoid) has to be considered
- The gravity field related (physical/levelling) heights are used together with ellipsoidal (geometrical) heights for the determination of the topography of solid and fluid Earth surface
- The instantaneous sea surface should observe against a conventional W_0 value, which has been agreed as the zero level of a GVRS
- The satellite gravity missions GRACE and GOCE are the basis for the unification of different vertical reference systems
- Consistent models and standards for the integration of data to combine geometric positioning (GNSS, SLR, VLBI) with physical heights and other earth gravity field parameters at 1 cm-accuracy level are needed globally
- The inconsistencies in the IAG/IAU/IERS conventions shall be removed in view of the development of integrated geodetic/hydrographic products and applications

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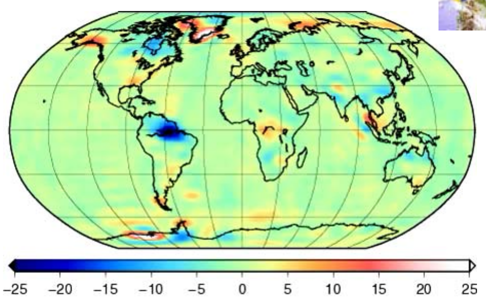
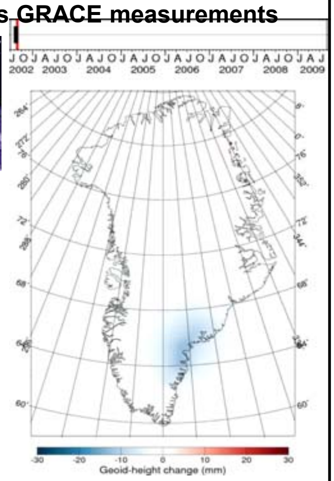
Our Living Planet Earth

Changes of the global continental water reservoir during the years 2006 and 2007 of the GRACE mission



IGG - Institut für Geodäsie und Geoinformation, Universität Bonn

Ice height changes in Greenland during six years GRACE measurements



GFZ RL04, August 2002 - August 2008,
GIA corrected
(Sasgen *et al.,* GFZ, Sek. 1.5)