Paper for Consideration by Data Quality Working Group

Data Quality – a shared interest between chart producer and user

Submitted by:	DQWG - Chair
Executive Summary:	Informative paper describing the need for positional data quality within the marine environment.
Related Documents:	DQWG ToR, Global Positioning System Standard Positioning Service Performance Standard (www.gps.gov), IERS Technical Note No.36, www.igs.org, S-52 Presentation Library Ed.4.0.2, correspondence from shipping industry, S-102 Ed.2.0.0, S-44 Ed 5.0.0, IMO Resolution A893.(21) Annex 25 Guidance for voyage planning, HSSC10/47
Related Projects:	S-97, Satellite derived bathymetry, Crowd sourced bathymetry, S-1xx standards, high density ENC's.

Introduction / Background

A principal aim of the IHO is to ensure that all the world's seas, oceans and navigable waters are surveyed and charted. The mission of the IHO is to create a global environment in which States provide adequate and timely hydrographic data, products and services and ensure their widest possible use. This paper will demonstrate the need for data quality, mainly focussed on positional accuracy, to achieve these goals.

Analysis/Discussion

Positional Accuracy is defined as the accuracy of the position of features within a spatial reference system. It consists of three data quality elements:

- absolute or external accuracy – closeness of reported coordinate values to values accepted as or being true;
- relative or internal accuracy – closeness of the relative positions of features in a dataset to their respective relative positions accepted as or being true;
- gridded data positional accuracy – closeness of gridded data spatial position values to values accepted as or being true.

1. ENC production

Hydrographic Offices produce and distribute Electronic Navigational Charts (ENC's). These are critical to the safety of navigation and life at sea, environmental protection, including the protection of vulnerable marine ecosystems, and the economics of the global shipping industry. ENC's provide data and information that can be used for sustainable fisheries activities and other sectoral uses of the marine environment, the delimitation of maritime boundaries and environmental protection. Under the International Convention for the Safety of Life at Sea, 1974, ships on international voyages are required to carry an electronic chart display and information system. So what positional accuracy levels have to be achieved to reach these goals?

2. End user perspective

From the end user perspective, the positional accuracy of the ENC has to be at least as good as the primary positioning, navigation and timing device used. Otherwise, a false sense of security will arise when its position is displayed on screen with a less accurate ENC. The US government has since 1978 provided a space-based radionavigation system owned by the US government and operated by the US Air Force. An unlimited number of users with a civil or military GPS receiver can determine accurate time and location, in any weather, day or night, anywhere in the world. The accuracy from satellite to end user (user range error) has improved over the years from 30m to 7m (95% confidence interval). The resulting horizontal positional uncertainty (95% CI) for the user position is now in the range from 30m to 5m depending on the type and age of the GPS receiver used. New systems like GLONASS, Galileo and Beidou may improve its position and/or redundancy.

3. **Coordinate Reference Systems (CRS)**:

A Terrestrial Reference System (TRS) is a spatial reference system co-rotating with the earth in its diurnal motion in space. In such a system, positions of points attached to the solid surface of the Earth have coordinates which undergo only small variations with time, due to geophysical effects (tectonic or tidal deformations). A Terrestrial Reference Frame (TRF) is defined as the realization of a TRS, through the realization of its origin, orientation axes and scale, and their time evolution. The International Earth Rotation and Reference System Service (IERS) is in charge of defining, realizing and promoting the International Terrestrial System (ITRS). Primary realizations of the ITRS are produced by the IERS ITRS Center (ITRS-PC) under the name International Terrestrial Reference Frame (ITRF). Since 1988, there have been 13 versions of the ITRF. ITRF14 (year 2014) is the latest realization. The ITRF2014 and WGS system are now aligned within cm level. The International GNSS Service (IGS) has many satellite tracking stations worldwide permanently monitoring satellites thus providing an absolute position on earth with a horizontal accuracy of 6 mm and a vertical accuracy of 12 mm (95%CI). This is the most accurate any position can be in a global system.

4. **Regional and local coordinate reference systems**

With the introduction of Global Navigation Satellite Systems (GNSS), the shape of the Earth can be determined at a certain point in time (epoch). Nations have, before the existence of GNSS, created a national wide geodetic network on land for various purposes, mostly rights, responsibilities and ownership of property. Usually a nationwide (local) geodetic network was based on the best fitting ellipsoid and using a chart projection with minimal distortion. These local systems are still being used today by national land administration offices. On a larger scale, in Europe for example, the continent was monitored using GNSS and a European realization of the ITRS was created. This is called ETRS89. It is using the same ellipsoid (GRS80) as the ITRF and WGS realizations, but its coordinates on land are by agreement fixed to the European plate. This means that coordinates of land administration offices do not change over time. The IGS tracking stations do monitor the movement of the tectonic plate and since 1989 the continent has moved approximately 70 cm in NE direction. Other tectonic plates are also moving, Australia's movement is much faster than the European one. Additionally in the vertical range, some landmasses are moving upwards due to postglacial effects.

5. **Chart producing perspective of a CRS**

The ENC's that are being produced by the Hydrographic Offices are using a so-called compound CRS. For the horizontal component of the CRS, geodetic coordinates (latitude and longitude) on WGS 84 is used. For the vertical component, the preferred option is Lowest Astronomical Tide (see IHO resolution 3/1919). If low water levels in a specific area frequently deviate from LAT, chart datum may be adapted accordingly. The horizontal positional accuracy can be no better than 0.006 m. The vertical accuracy of LAT is usually in the range of 0.15 m or less accurate (95%CI). This means no depth measurement in terms of absolute accuracy can be better than 0.15 m, unless a more accurate vertical component of a CRS is used as Chart Datum.

6. **Hydrographic Surveys, Satellite derived bathymetry, LIDAR surveys, crowd sourced bathymetry**

When producing an ENC, remote sensing has to be done to measure the depth of the seabed and any objects above the seabed in a CRS. This can be done from water (hydrographic survey vessel, regular vessels in transit), by air (airplane, helicopter, drone using LIDAR) or space (satellites in orbit). It is important to note the CRS used by the navigation system of the platform performing the remote sensing. If the platform receives its position in ITRF14 (or WGS 84) equivalent, the final dataset will remain in the same CRS. If however in the coastal zone, the platform is using the CRS used on land, there will most likely be a mismatch in both horizontal and vertical component of the CRS used. Land administration offices tend to use the local geoid as vertical reference and not LAT. Horizontally a local geodetic datum, based on a different ellipsoid than the one used by ITRF14 (or WGS 84) may be used.

Also their coordinates may be (adminstratively) fixed to the moving tectonic plate. When merging land and sea data together into a seamless chart, one common CRS is needed, which is WGS 84 and LAT from a maritime perspective. However, from a land administration point of view, the data at sea needs to be converted into the local horizontal and vertical CRS. An overview of the accuracy of local geoids is provided in Annex-B.

When using satellite-derived bathymetry, one must be careful when computing its result to the final Chart Datum used. The gravitational potential in the vicinity of the Earth, which is directly accessible to observation, is a combination of the tidal gravitational potential of external bodies (the Moon, the Sun, and the planets) and the Earth's own potential which is perturbed by the action of the tidal potential. The (external) tidal potential contains both time-independent (permanent) and time-dependent (periodic) parts, and so does the tide-induced part of the Earth's own potential. When removing the time dependant part, a "mean crust" remains. The mean tide geoid, for example, would correspond to the mean ocean surface in the absence of nongravitational disturbances (currents, winds). When removing the permanent part of the external potential from the mean tide potential results in the "zero tide." When removing the permanent part of the deformation-related contribution, the result is the "tide free" geopotential.[1]
To summarize:

- mean tide = mean ocean surface in absence of nongravitational disturbances;
- zero tide = mean tide without gravitational disturbances from other planets;
- free tide = all gravitational disturbances removed.

The GNSS community is using the free tide system. The oceanographic community is using the mean tide system. Systematic errors have to be accounted for when using satellite data as input for bathymetry in an ENC. When converting from ellipsoid (Ellipsoid Reference Surveying) to LAT, the difference is 0.00 at approximately 35 degrees latitude and increases towards the poles upto approx +15 cm (LAT - ellipsoid separation increases). At the equator the difference is approximately -10 cm.

The IHO standards for hydrographic surveys (S-44), are designed to provide a set of standards for the execution of hydrographic surveys for the collection of data, which will primarily be used to compile navigational charts. It uses amongst others Total Horizontal Uncertainty (THU) and Total Vertical Uncertainty (TVU) at a maximum allowable level to classify a survey to a certain standard. THU is a 2-dimensional quantity and it is assumed there is no correlation between errors in latitude and longitude. TVU is a 1-dimensional quantity. Both are using a-priori standard deviations of all observational inputs (CRS, vessel position, timing, motion, multibeam, instrument alignment, sound velocity, underwater acoustics, etc.) to compute the positional uncertainty.
When applying crowd sourced bathymetry (vessels in transit measuring depth), the accuracy of this measurement has to be available with the measurement. Most importantly if the depth measured was relative to sea surface (draught corrected) or to the keel. In the horizontal plane, the exact location of the echosounder can be out by as much as 100 meters due to positioning (30 m) and offset between GPS position and echosounder offset on the vessel. The measurement can however still be valid if no other and more accurate data already exists.

7. Gridded data

Gridded data sets are described in S-102 Edition 2.0.0. They are geo-rectified (linked to a CRS), simple uniform regular grids. The horizontal CRS is WGS 84 with possible projections None, UTM of UPS.
The possible uncertainty definitions in S-102 are:

- unknown
- Raw_Std_Dev
- CUBE_Std_Dev
- Product_Uncert
- Historical_Std_Dev

Raw_Std_Dev reflects the 68% CI. Multiplied by two it reflects the 95%CI.

[1] -Petit, G., & Luzum, B (2010) IERS Conventions (2010) (IERS Technical Note No.36), Bureau International des Poids et Mesures, US Naval Observatory, page 15.

When a gridded dataset is received from a third party, for example a port authority, and the dataset is delivered in another horizontal component of the CRS than WGS 84, a geodetic conversion has to be made. The ENC producer has to be aware that a simple uniform grid in a local CRS may not be the same simple uniform grid in WGS 84 with a projection. If coordinates are unchanged and no new gridding process is done, then the two dataset merge. If however a new gridding process is started, then some grid cells may contain two values and others may be left empty. Resampling to a higher horizontal resolution of the initial grid is then needed to maintain its horizontal accuracy after the conversion. Also note that the port authority may have the depth data in another vertical component of a CRS, usually the geoid. The geoid-LAT separation then also has to be taken into account.

8. High density ENC's

With the release of S-1xx product line, the historical 4Mb file size will also be lifted. This will enable the ENC producer to create more depth contour lines than the present mandatory ones. Depth contours are used to connect positions of equal depth. According to S-4, the standard series of depth contour lines to be charted is: 0 (where tides are appreciable), 2, 5, 10, 20, 30, 50, 100, 200, 300, 400, 500, 1000, 2000m etc. The 2 and 5 m contours may be omitted where they serve no useful purpose. Supplementary contours at: 3, 8, 15, 25, 40 and 75m and multiples of 10 or 100m may be shown, if the available data permit, to delineate particular bathymetric features where soundings would otherwise be the only depth information over a large area, or for the benefit of particular categories of shipping.

Now assume for high commercial marginal under keel clearance shipping the ENC producer wishes to create depth contour lines at 1m interval in the range of 10 to 30m. Using S-44 Special Order and Order 1a, we can calculate the TVU for each (gridded) depth position that is used to generate the contour line from. This gives the following results:

Depth	TVU (special order)	TVU (order 1a)
10 m	0.37 m	0.62 m
30 m	0.54 m	0.80 m

These numbers show that there is little point creating contour lines at a smaller interval than 1m, as the uncertainty at 30m depth is already 0.54m meaning that the adjacent contour line can be on almost the same location.

9. Portrayal of positional accuracy

There are three different types of geometry that can be displayed in an ENC: points, lines and areas. Each object has a horizontal positional uncertainty associated with it. (It also has a vertical positional uncertainty, but this cannot be displayed on a 2D screen). To display the uncertainty of a geometry the following proposals are made:

- for a point, a circle displaying the 95% CI.
- for a line, an area parallel to the line on either side displaying the 95%CI.
- for an area, same as for a line as the area is bounded by a line.

The condition to display is that the uncertainty has a clear relationship with the geometry that it represents (a parent-child relationship.) For a point, the circle has the same colour as the point but is transparent. For a black line, the area has for example a light grey transparency.

According to IMO Resolution A893(21) Annex 25 – Guidelines for Voyage Planning:

The development of a plan for voyage or passage, as well as the close and continuous monitoring of the vessel's progress and position during the execution of such a plan, are of essential importance for safety of life at sea, safety and efficiency of navigation and protection of the marine environment. Voyage and passage planning includes appraisal, i.e. gathering all information relevant to the contemplated voyage or passage; detailed planning of the whole voyage or passage from berth to berth, including those areas necessitating the presence of a pilot; execution of the plan; and the monitoring of the progress of the vessel in the implementation of the plan. The following items are particular to note:

- appraisal: appropriate scale, accurate and up-to-date charts to be used for the intended voyage or passage, as well as any relevant permanent or temporary notices to mariners and existing radio navigational warnings;
- planning: the plotting of the intended route or track of the voyage or passage on appropriate scale charts;
- planning: safe speed, having regard to the proximity of navigational hazards along the intended route or track, the manoeuvring characteristics of the vessel and its draught in relation to the available water depth;
- execution: daytime versus night-time passing of danger points, and any effect this may have on position fixing accuracy;

When planning a voyage the CATZOC (Category Zone of Confidence) is available to the mariner. CATZOC is by definition an area displaying a certain quality standard (A1, A2, B, C, D or Unassessed) of underlying information. It is an aggregation of the quality of separate geometries (soundings, contour lines, completeness, and isolated dangers) that have to be taken into account when planning a safe voyage allowing enough under keel clearance (UKC) and cross track distance (XTD). This UKC and XTD can be considered a safety frame around the vessel. If isolated dangers (wrecks, shallow soundings etc.) can be shown in planning mode with a circle displaying its uncertainty, it will help the mariner to see if the planned route XTD is within the uncertainty range of isolated dangers. Calculation along the route should take the full circle or area into acount instead of using a “precise” point or line. Special care should be taken by the mariner when entering an Unassessed area and this should, if possible, be avoided. By definition an unassessed area is not accurate and should be considered as such during the appraisal phase.

Input from end users:
During the execution of a voyage, almost all users turn of the CATZOC symbol as it clutters the screen. Depth quality information is generally less important for international shipping below the 50m depth contour. Quality metadata could be used to allow display of two safety contours on ENCs (taking full advantage of the further granularity in depth contours supported by S-101) when an ECDIS is in planning mode. The first safety contour should be based on the bathymetric data portrayed on the chart. The second should be determined by the assessed worst case accuracy (position and depth) of the bathymetric data in that area of the chart and be default set to off during execution to avoid misunderstanding of the concept safety contour.

10. Methodology for the display of quality information

What is the relationship between portrayal of symbols, portrayal of the own-vessel symbol, CATZOC, UKC and chart scale? Depth contour lines have a line weight of 0.3 mm. This means that the separation to the next adjacent depth contour is at least 0.6 mm, otherwise the two lines would merge. Isolated dangers (obstruction, underwater rocks, wrecks) are symbolized as point with a (invisible) bounding box (see Appendix A). CATZOC is symbolized as an area.

Using various chart scales we see the area of the bounding box converted from mm to chart scale:

scale	DEPCNT	OBSTRN	UWTROC	SOUNDG	CATZOC
1:1000	0.6 m	4.1 m	4.0 m	3.5 m	17.0 m
1:2000	1.2 m	8.2 m	8.0 m	7.0 m	33.9 m
1:3000	1.8 m	12.3 m	12.1 m	10.5 m	50.9 m
1:4000	2.4 m	16.4 m	16.1 m	14.0 m	67.9 m
1:8000	4.8 m	32.8 m	32.2 m	28.0 m	135 m
1:12000	7.2 m	49.2 m	48.2 m	42.0 m	203 m
1:22000	13.2 m	90.2 m	88.4 m	77.0 m	373 m
1:45000	27.0 m	184 m	180 m	157 m	763 m
1:90000	54.0 m	369 m	361 m	315 m	1527 m
1:180000	108 m	738 m	723 m	630 m	3054 m
1:350000	210 m	1435 m	1407 m	1225 m	5939 m
1:700000	420 m	2870 m	2814 m	2450 m	11879 m

From the table above we see that the size of the symbol can be interpreted as the minimal uncertainty of the point object because when the object is displayed it covers a certain area (unless higher priority objects override this area).

The CATZOC position accuracy from S-57 is:

- A1 -> 5m + 5% depth
- A2 -> 20m
- B -> 50 m
- C -> 500 m
- D -> more than 500 m.

For CATZOC = A1, the positional accuracy ranges from 5.0 at 0m depth to 7.5 m at 50m depth. We can now check if the size of the symbol represents a smaller area than the horizontal accuracy:
CATZOC = A1, only at chart scale 1:1000
CATZOC = A2, chart scales larger than 1:8000
CATZOC = B, chart scales larger than 1:22000
CATZOC = C, chart scales larger than 1:90000
CATZOC = D, chart scales larger than 1:180000

In the above cases, it makes sense to draw a circle of uncertainty around an isolated danger to be used in XTD analysis. In other cases, the size of the circle would be smaller than the size of the parent symbol. However for calculation of the planned route+UKC+XTD, the uncertainty should be taken into account by the ECDIS system.

The size of the CATZOC symbol is relatively large. It is suggested that CATZOC will be displayed in future as an area, bounded by a line with a transparency of the area. The type of symbology is still to be developed in liaison with the NCWG and ENCWG. The size of the area can be really small in theory, but a minimal area size (in mm) should be agreed upon as for the mariner it has no use to have a 1.0 x 1.0 mm area. Take into consideration that the fastest cruise line ship can sail at 32 knots and the largest container vessel has a length of 399 m. Most importantly, whatever symbology is chosen, the effect of good and poor quality should be visible to the mariner at a glance and at the same time not raise questions about already existing symbols and interpretations.

Conclusions
ENC's are primarily designed to be used for safety of navigation. Its strength is that it uses a global common geodetic reference system, thus enabling to depict 70% of the planet seamlessly. However, in the coastal zone when merging into the existing land administrations, conversion of data from land to sea and vice-versa needs to be done. As most land agencies are using a different horizontal and vertical datum than the ENC, a seamless integration cannot be achieved without some loss of accuracy.

When merging different surveys into a chart, the cartographer needs to be aware of the horizontal and vertical uncertainties of the data. A balance needs to be struck between data uncertainty and age of data.

Portrayal of uncertainty of data can be useful in a planning stage of a voyage, when the navigator is using UKC and XTD to plan a safe passage. The CATZOC symbology is to be changed and the minimal size of a CATZOC area should be agreed upon.

Recommendations
Other HSSC and IRCC workgroups should be made aware of the concept of horizontal and vertical uncertainty and the impact it has when merging data of different sources into an information product.

Justification and Impacts

None identified at this time.

Action Required of Data Quality Working Group
The DQWG is invited to:

a. note this report;
b. discuss it at its next meeting;
c. provide input papers to other WGs and PTs consideration if deemed necessary.

Appendix A: Table with symbols and size

Item	Width (mm)	Height (mm)
isolated danger beacon	2.22	5.44
isolated danger buoy	3.84	5.44
cable area	3.74	11.12
HO caution note	5.18	5.18
caution area	9.94	9.94
underwater hazard with a defined depth	8.00	6.32
underwater hazard with a depth greater than 20 meters	8.00	6.28
underwater hazard which covers and uncovers	8.00	6.32
transparant danger highlight for mariner's use	10.00	10.00
area where entry is prohibited or restricted or to be avoided	9.94	9.94
area where entry is prohibited or restricted or to be avoided, with other cautions	11.71	10.19
area where entry is prohibited or restricted or to be avoided, with other information	12.35	9.94
floating hazard to navigation	6.48	6.48
foul area of seabed safe for navigation but not for anchoring	3.91	3.00
fish trap, fish weir, tunny net	5.11	4.38
fish stakes	6.04	1.51
fishing ground	11.04	4.49
fish haven	9.84	6.16
area where fishing or trawling is prohibited or restriced	10.21	6.02
area where fishing or trawling is prohibited or restriced with other cautions	11.53	6.07
area where fishing or trawling is prohibited or restriced with other information	12.87	6.02
fishing harbour	5.84	5.84
hulk	4.88	2.66
area with minor restrictions or information notices	8.04	8.05
isolated danger of depth less than the safety contour	7.00	7.00
light vessel	7.45	3.64
land as a point at a small scale	2.06	2.06
point feature of area of low accuracy	11.29	12.35
fish farm	7.05	4.03
obstruction, depth not stated	4.10	4.10
obstruction which covers and uncovers	4.10	4.10
obstruction in the water which is always above water level	2.00	2.0
PSSA – centered symbol	12.70	5.00
position approximate	3.51	3.07
recommended track as an area	17.31	4.43
contour label	1.25	2.50
yacht harbour, marina	6.80	6.85
sand waves	11.79	1.79
deep soundings, greater than safety depth	1.25	2.50
swept sounding, used for deep soundings greater than safety depth	6.31	1.31
sounding of low accuracy	8.54	8.54
shallow soundings, less than or equal to the safety depth	1.25	2.50
drying height, used for shallow soundings, less than or equal to safety depth	2.05	0.01
swept sounding, used for shallow soundings less than or equal to safety depth	6.31	1.31
swept area	11.01	3.04
traffic crossing area	9.94	9.94
dangerous underwater rock of uncertain depth	4.02	4.02

non-dangerous wreck, depth unknown	5.00	3.00
dangerous wreck, depth unknown	5.90	4.10
submarine cable	30.30	5.00
boundary of an area with specific caution	30.30	5.18
boundary of an area to be navigated with caution	6.00	1.62
boundary of a deep water route	30.30	3.05
boundary of an area where entry is prohibited or restricted	27.29	5.78
fishing stakes	2.02	1.83
boundary of an area where trawling or fishing is restriced	27.29	3.93
safety contour of low accuracy in position	1.30	0.79
area of wreck or obstructions of low accuracy	1.30	0.79
oil, gas pipeline, submerged or on land	5.89	1.90
boundary of a precautionary area	30.30	5.03
area of depth less than the safety contour	22.50	43.13
CATZOC symbol (A1, A2, B, C, D)	16.97	11.84
CATZOC symbol (Unassessed)	16.04	4.30
dredged area	2.00	2.00
foul area, not safe for navigation	5.70	6.84
continuous pattern for an ice area (glacier, etc.)	14.34	13.31
area of no chart data	6.02	3.96
over scale part of a display containing data from more than one navigation purpose	9.00	4.00

Appendix B – accuracy of local geoids

Accuracy of (quasi-)geoid models (I)

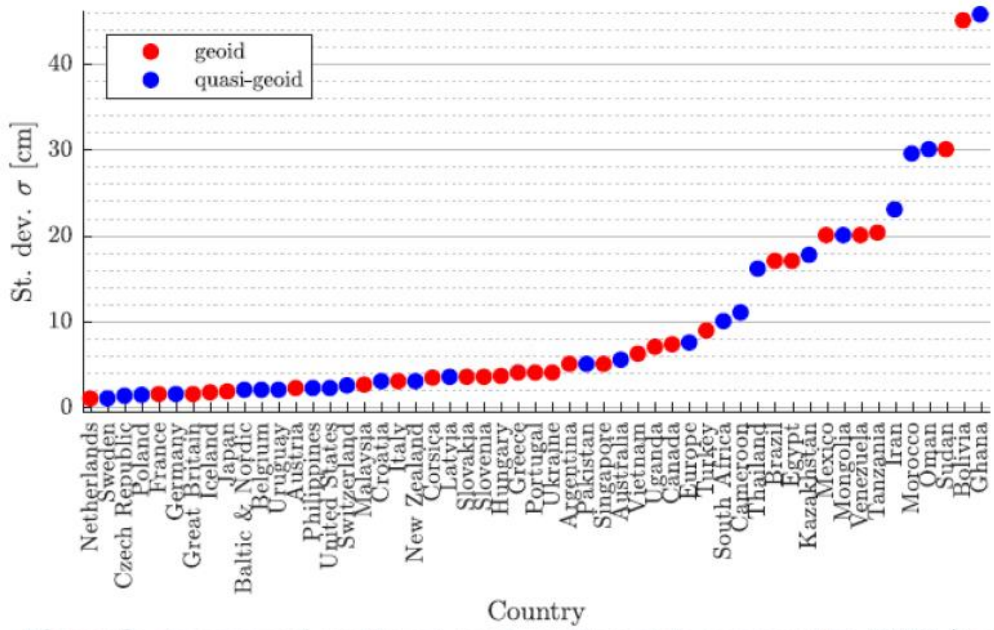

Figure 2: Accuracy of geoid and quasi-geoid models compared to GNSS/levelling for different countries

Courtesy of Technical University Delft (NL)