LEADLINE TO MULTIBEAM, SEXTANT TO GPS & CROW QUILL TO COMPUTER: BATHYMETRIC DATA COLLECTION, COMPILATION, ARCHIVING, AND DISTRIBUTION IN THE PAST CENTURY

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Abstract:
GEBCO has been publishing the bathymetry of the world's oceans for 100 years and, in that century, there have been revolutionary changes to defy even the retrospective imagination. From laborious sounding of the deep sea by lowering a weighted wire and positioning with celestial navigation with an accuracy of less than a nautical mile, the art and science of bathymetry has become orders of magnitude more accurate, more efficient, and more productive. Today's soundings are accurate to a few meters vertically and horizontally. Early progress was driven by engineering technology while later progress was detonated by computer technology, which has given us an exponentially growing capability, providing millions of times more computational power since the early 1970's. That capability has influenced all phases of bathymetric data management: collecting the soundings, compiling the data for analysis, archiving the data, and distributing the data and derived products. Our perception and model of the seafloor has likewise increased in accuracy and resolution in an exponential fashion, although even today, only of the order of 10% of the seafloor has been measured with direct echosounding. The task of GEBCO is to ride this growing wave of data, capability, and technology to continue producing the authoritative portrayal of the 70% of Earth's surface beneath the seas.

A – DATA COLLECTION

As with all endeavours of science, bathymetric data collection and processing has been driven by technology. This has become much more true since the early 1970’s when computers were enlisted in collection and processing, for, according to Moore's Law, computers double in their capacity to do work every 18 months. Thus, since 1973 we’ve seen a million-fold increase in computer power.

Sounding collection is the merging of two measurements, two different disciplines: 1) Depth measurement or Bathymetry and 2) Position measurement or Navigation. Even lead line measurements were driven by technology: Lowering a line until it touched the bottom benefited by the use of steam engines and piano wire to enable faster and deeper deep sea soundings.

The other side of the equation of sounding collection is navigation, knowing where the measured depth was located. Early navigation was primarily by celestial or celestial techniques such as the horizontal sextant, triangulating off fixed reference points on land.

Echo sounding (introduced in the 1930’s) was a first major step forward resulting in a spectacular increase in amount of data, recording traces of reflected sound on paper. These recordings also produced a myriad of artifacts and ambiguities that required expert interpretation in order to accurately assess the depth of the seafloor.

The collected soundings, recorded as a time series were later combined with the navigation, collected as a separate time series. Therefore, marine geologists are as concerned about navigation as the ship's bridge. Celestial navigation provided, at best, two positions per day: morning and evening stars. Radio navigation was highly dependent on environment and location for availability of signal. However, technology was likewise advancing the navigational arts. Celestial navigation was augmented with various forms of radio navigation including RADAR, LORAN, and OMEGA. Better timekeeping electronics benefited both navigation and echosounding. Finally, by the late 1960's the TRANSIT satellite Doppler navigation system became available, providing an order of magnitude more fixes than celestial methods.

During the mid-1960's computers began making an impact on sounding collection and processing. Initially they were used to digitize previously collected analog soundings, along with navigation, to produce digital sounding database. In January 1968 the first, shipboard-computer conference was held at the Scripps Institution of Oceanography, heralding the migration of computer technology onboard ships. While data were still collected in analog form and digitized, there was the glimmer of automatic processing in the future.

The early 1970's saw the beginning of many automated sounding systems including multibeam bathymetry using computer–aided technologies such as: 1) beamforming, interferometry, and raytracing all to address the spatial distribution of soundings across the ship's track, 2) measuring and monitoring the ship's attitude (pitch, heave, roll, and yaw) which is critical to positioning the soundings, and 3) bottom following algorithms to automatically record the soundings digitally. The final technological capstone to sounding collection was the introduction of Global Positioning Systems (GPS) whereby the position of the ship, within a few meters, can be determined every few seconds, using radio, travel-time differences of signals from a constellation of satellites to solve for the four unknowns: Latitude, Longitude, Elevation, and Time.

Today's technology permits a multibeam system navigated by GPS to automatically collect soundings, position them, and generate on-the-fly contour maps or color, shaded-relief maps of the seafloor. The quality of the data behind these maps is so good that the contours on independent tracks match and the process is known as mowing the lawn. That is how routine and how jaded we scientists have become.

Currently the World Data Center for Marine Geology and Geophysics holds over 14 million trackline nautical miles of digital bathymetry. Historically this has been accumulating at about a 1/2 million nautical miles per year, since the initiation of digital data processing in the early 70's. Collection rates, in terms of soundings, continue to increase with higher and higher resolution surveys. The Center is anticipating three Terabytes of data / year from shallow water multibeam surveys in U.S. Coastal areas alone, as these systems begin providing data. The theoretical, full-coverage, global, sounding (data), frequency distribution is dominated by shallow depths due to small size of footprint and commensurate, high resolution. The sum off all soundings is about $4x10^{13}$ soundings, approximately the frequency of just shallow water soundings. Very high-resolution data, collected in coastal zones is the next big surge of bathymetric data to be handled. In the theoretical model of complete coverage of the seafloor, at maximum resolution, 95% of the soundings would be in the shallowest 20 meters of the ocean, 99% of the soundings in the uppermost 200 meters of seafloor.

B – COMPILATION

The First Edition GEBCO contained 18,400 discrete soundings but by 1952, some years after the introduction of the echo sounder, the Third Edition was nearing completion and, 358,700 mainly selected depths were shown on the printed bathymetric charts - about a 2000 % increase. From 1931, after the first of the 1:1 Million Plotting Sheet Series was introduced, IHB draughtsmen laboriously transferred depths onto 1,000 paper-plotting sheets extracted from 'Lists of Soundings' supplied by Member States.

But as the years passed there was scant interest in GEBCO; bedevilled by poor quality control, it failed to provide a true geomorphological picture of the deep sea floor, even to the extent that was then possible with the existing amount of data. By 1953, when GEBCO had reached the age of fifty - it was in very poor health. The growing demands on the project were spiralling out of control and, we might have been forgiven for thinking at that time, that this great international project was in terminal decline. Over the next twenty years numerous attempts were made to revive it, but not until 1973, following the SCOR Working Group 41 Report, was the GEBCO project finally revitalized. A Fifth Edition was planned and, to support it, a newly designed set of Plotting Sheets was introduced.

While the IHB continued to act as the ultimate data center for these new sheets, the Volunteering Hydrographic Offices undertook the task of maintaining them. There were two components to this task: The Track Sheet and the Sounding Sheet. The draughtsman's first task was to plot the ship's track, which he clearly marked with suitably timed intervals. Next, from the echo roll depths were selected from the raw data and extracted. These were plotted and meticulously drawn in a very small font onto the sounding sheet by aligning it with the plotted ship's track. Great dexterity was required to ensure that while thousands of depths may appear on a sheet, clarity was always preserved.

In order to fill numerous holes in its data collection, the UKHO, undertook a very an active role in promoting the collection of deep-sea soundings in areas of little or no data. The office collected details of ship movements and forged close links with captains and owners. Where possible, UK survey ships, grey navy ships and commercial vessels were regularly encouraged to run sounding lines across empty or recognised problem areas. This initiative proved most successful and large amounts of precious data was gathered this way.

Great care had also to be exercised in the interpretation of the raw data. Despite the best intentions, mistakes were made. In the late nineteenth century some HOs measured longitude from places other than Greenwich. If not detected this practice led inevitably to plotting errors where sometimes, unexpected seamounts appeared in deep water. Some of these errors remained on printed charts for nearly a century. As the years passed and the amount of collected data increased, it became necessary to generate several editions of each Plotting Sheet to record the massive number of soundings. It was clear that if data collection continued to grow at this rate, the new system, launched with such hope, was in danger of being submerged by its own success.

As the development of digital technology gathered momentum, serious questions were being raised about the viability and continued use of the GEBCO Plotting Sheet system, and the roles of the Volunteering Hydrographic Offices. Thus, in 1990, an IHO Working Group was set up to examine a number of critical questions. In 1991, The Working Group made 18 recommendations, which paved the way for the gradual introduction of a fully operative digital GEBCO system and for the gradual phasing out of the Plotting Sheets. All new analog sounding data was to be converted to digital form and programmes were made to retro-digitise the existing plotting sheets.

C - ARCHIVING

At the UKHO the archiving of the raw ships data and the thousands of Plotting Sheets was very carefully controlled. A comprehensive card record for each item of data and each individual sheet was used to register all the details of a particular cruise, including full details of origin, cross references to main archives and any relevant remarks. Dedicated staff could only handle the sheets themselves. Other Volunteering Hydrographic Offices ran very similar systems. Additionally, some countries, especially those with international chart series, opted to maintain a plotting sheet system incorporating sheets in areas outside of their own GEBCO area of responsibility.

One of the striking features of the GEBCO system, especially during the plotting sheet era, was the close co-operation between Member States in the international exchange of sounding data. Large containers comprising copies of plotting sheets or sometimes raw data were regularly sent or received from other HOs and a great deal of correspondence was generated. However, as digital archiving was slowly introduced in Oceanographic institutions and some HOs, it became imperative to face and adopt these changing techniques.

The first task was to devise a schedule for the huge effort of capturing all the UKHO plotting sheet data into digital form. Programmes were designed and written which would provide not only a data capture amenity but would also ensure a high-performance storage and manipulation facility. It has been suggested that one result of transferring from analog to digital compilation methods, was a hundred-fold increase in the rate at which sounding could be compiled. Although this claim may have been truer for the compilation of bathymetric, rather than Hydrographic charts, nevertheless, the other side of the equation had to be faced. In order to achieve this huge transition - everywhere in the ocean mapping community - there was an inevitable rise in the requirement for extra staff and financial resources. It was a hugely taxing time.

Today, the World Data Center for Marine Geology and the collocated IHO Data Center for Digital Bathymetry primarily manage digital data, hence we have a minimum of paper records, microfilms, etc. The management of digital data is both a blessing and a curse, as the bits and bytes are much easier to handle, but they are likewise much easier to lose. While technology has enabled much higher collection rates, it has also enabled us to handle, review, archive, and distribute digital data in those larger volumes and with greater ease.

Archiving in the digital world has several meanings. First is the security archive, the duplicating and storing the data exactly as it arrived. Following that is a cursory quality assessment, followed by reformatting and storing in a retrieval system by which the data can be accessed. Finally, there is the concern of migrating the archived data to media and technologies that will permit their continued access. Just as the digital media of paper, tapes and punch cards are no longer used and virtually impossible to read, we must constantly be ready to migrate our digital data to new technologies such as DVD (Digital Versatile/Video Disc) and LTO (Linear Tape-Open) in order to insure their survival.

A new dimension to archiving has arisen in the last few years, the concept of data stewardship. That is not only archiving the data, in the sense of putting on a shelf and allowing it to accumulate dust, but renewing it, reviewing it, improving it, and making it accessible to purposes for which it applies, though not conceived at the time of collection. This means annotating the data with metadata to describe it and make it useful to disciplines outside of its original purpose. This means adapting access systems that make the data more readily available. This means reformatting data into modern, more generally useful forms that articulate gracefully with data management systems, be they spreadsheets or relational databases.

D - DISTRIBUTION

The international exchange and distribution of sounding data, as recommended in the 1991 Working Group Report, has not been entirely achieved. For numerous reasons Hydrographic Offices have chosen to protect their raw data and thus operate different regimes in respect to the provision of information to the IHO DCDB. These choices range from full compliance to a policy of withholding access to raw depth data completely. It must be concluded that the exchange of data as envisaged by the Working Group has not materialised.

In mitigation, it was not foreseen that rapid advances in technology would allow the construction of high quality gridded data sets in so short a time. The combination of this advance and the growing reluctance of some HOs to release raw data meant that one of the original aims of the Working Group was not fully achieved. However, although some HOs have concentrated on building their own databases, without passing raw depth data to the IHO DCDB, they have all made gridded versions of such data freely available, Initially bathymetric data were distributed digitally on punch card. Subsequently magnetic tape became the medium of preference, a mode still used today, although the formats and structure of today's magnetic tape are a far cry from those of the mid 1970's. Oddly enough, a collaborative exchange format designed in 1977 for Marine Geophysical Data (MGD77) is still in use because of its simplicity. However, for the much more complex and voluminous multibeam bathymetry, there is a multitude of formats, most managed by a multibeam software system, "mbsystem."

Beginning in 1991, the World Data Center for Marine Geology and Geophysics, Boulder, began distributing the complete collection of world trackline geophysical data, including bathymetry, along with search and access software, on a CD-ROM set. The software was designed to run on desktop personal computers and made the database accessible anywhere in the world. The database has been updated numerous times. Currently the CD-ROMs are used in conjunction with World Wide Web, whereby the most recent data and software can be accessed until the next updated CD-ROM is issued. Volumes of data have continued to grow and DVD technology is the next, obvious step. Ultimately as Web access and bandwidth increase beyond the necessary threshold, network distribution of the data and software will become the mode.

Using gridded data, we've generated earth models since the mid 60's. GEBCO has used contours to describe that same type of earth model. Most recently, GEBCO has also adapted the gridded model, especially for portraying detail in the coastal regions of the world, above the first GEBCO contour of 200 meters. With increasingly more powerful computer techniques, the ability to incorporate new data and modify the current, best, map or model of the earth in a timely fashion has grown to where updates are virtually instantaneous. However, even today, only about 10% of the seafloor has actually been accurately mapped. The challenge to GEBCO is to continue to push that elusive frontier of accurate, high-resolution, and complete global mapping.