

# 19th-century Canadian bang on when it came to oceans

## Matched state-of-the-art calculations on depth and volume of the seven seas

By RANDY BOSWELL, Canwest News Service May 21, 2010

It's one of the oldest and most vexing questions in science - and it pops up in kindergarten classes and love songs, too. How deep is the ocean?

And just for good measure, exactly how much water do the seven seas hold?

Researchers from two top U.S. marine-science centres - the Woods Hole Oceanographic Institute and the National Oceanic and Atmospheric Administration - set out last year to find the answers.

After employing the latest satellite technology, sophisticated computer-modelling tools and global bathymetric data sets compiled over the past 100 years, WHOI's Matthew Charette and NOAA's Walter Smith announced this week that the average depth of the world's oceans is 3,682 metres.

And they've concluded that the total volume of the Earth's sea water is 1.332 billion cubic kilometres.

But after completing their colossal calculations - aided by all of the high-tech measurement machinery the 21st century could muster - the U.S. scientists made another startling discovery: Their findings were virtually identical to those published 122 years ago by the pioneering 19th-century Canadian oceanographer John Murray.

After a series of scientific voyages in the 1870s and 1880s - including Britain's famous around-the-world Challenger Expedition from 1872 to 1876, which gave birth to the science of oceanography - Murray pegged the average ocean depth at 3,797 metres and total global sea water at 1.349 billion cubic kilometres.

"Remarkably, despite limited knowledge of sea floor topography and ocean area, Murray's ocean volume calculation is within 1.2 per cent of the value derived from this study," the U.S. experts acknowledge in an article published in the latest issue of the journal *Oceanography*.

Noting how the Cobourg, Ont.-born Murray "dangled lead weights from a rope off a ship" to derive his world-first estimates of ocean depth and volume, Charette and Smith marvel at "how accurate" the Canadian scientist's findings were despite the "cruder techniques" he used for the task.

Murray, born in 1841, left Canada at 17 to study in his parents' native Scotland, and the transatlantic voyage inspired his interest in ocean science.

By the time the British government approved the use of the HMS Challenger to map the world's oceans and conduct an unprecedented inventory of marine life, Murray had emerged as a leading expert in the field. The expedition's 10-day visit to Halifax in May 1873 helped ignite interest in marine science in Canada.

Murray's role as the chief investigator aboard the Challenger and the author of dozens of expedition studies earned him recognition as the father of oceanography, a name he coined and a discipline he shaped by writing many of its seminal texts.

Among them was his treatise *On the Height of the Land and the Depth of the Ocean*, a meticulously detailed profile of the Earth's marine and terrestrial features published in the *Scottish Geographical Magazine* in 1888.

The paper represented an attempt "to give numerical expression" to the shape of the land, the depth of the ocean and the profile of the sea

floor, Murray explained in his landmark study.

"It is at once evident that the data for any very accurate computation are not available, yet the records of travellers, of deep-sea expeditions, and the hydrographic surveys of various nations have of late years furnished much information," he stated. "The following results, although only approximate, will, however, do much to render our ideas more definite ... and the foundation may thus be laid for still more precise and accurate evaluations."

Murray, who is immortalized in the Latin name of the deep-sea octopus *Cirrothauma murrayi*, died in Scotland in 1914, a victim of one of the first car accidents in the British Isles.

A number of other scientists in subsequent decades repeated Murray's efforts to measure the oceans, some finding the Canadian's estimates too high and others finding them too low.

But the U.S. researchers found little to argue with in Murray's calculations, noting that the difference between their findings and his amounted only to about five times the volume of the Gulf of Mexico - a relative drop in the bucket, given the immensity of the Earth's saltwater reserves.

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# The Volume of Earth's Ocean

BY MATTHEW A. CHARETTE AND WALTER H.F. SMITH

**ABSTRACT.** Despite playing a significant role in the global water cycle, ocean volume has not been re-examined in over 25 years. The main uncertainty associated with ocean volume is the mean ocean depth. The earliest studies tended to overestimate ocean depth due to undersampling of seamounts and ocean ridges. The advent of the echosounder in the 1920s and subsequent ship-borne technologies rapidly increased aerial coverage of the ocean; hence, over time there has been a gradual decrease in calculated mean ocean depth. Today, however, in situ measurements span only ~ 10% of the ocean's surface area. Here, we use satellite altimetry data to estimate the ocean's volume, which is lower by a volume equivalent to 500 times the Great Lakes or five times the Gulf of Mexico when compared to the most recent published estimates.

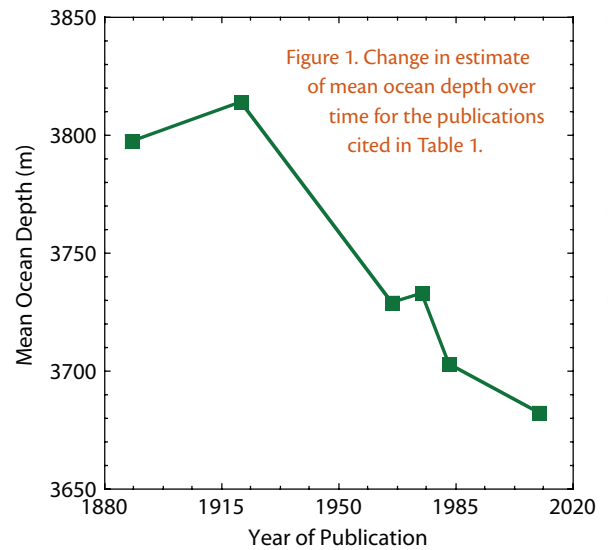
Approximately 97% of the world's water reserves exist in the ocean. In addition, 82% of water exchange occurs over the ocean, making it the major player in the world water balance (Baumgartner and Reichel, 1975). Geochemical budgets and climate models depend on accurate estimates of ocean volume. Despite having a significant role in the global water cycle, ocean volume has not been re-examined in over 25 years, and thus the most recent estimates are based on dated technology and databases for ocean area and, most importantly, depth.

Historically, ocean volume has been calculated as the product of ocean area and mean ocean depth. Most

early estimates were based on soundings with line or wire reported by various ships of opportunity (Murray, 1888; Kossinna, 1921). Data compilations based on such methods tended to overestimate ocean depth due to undersampling of seamounts and ocean ridges. Remarkably, Bache (1855), using tsunami-driven excursions in a tide gauge, estimated the mean depth of the Pacific Ocean between Shimoda, Japan, and San Francisco, California, to within 10%. The advent of the echosounder led to increased ocean bottom coverage and therefore greatly improved estimates. Since Kossinna (1921), the trend has been a gradual

decrease in estimated mean ocean depth (Figure 1; Table 1). Given that estimates of ocean area have generally varied by less than 0.25% over time, the main driver in ocean volume estimate deviation has been depth, which decreased ~ 3% between the Kossinna (1921) and Shiklomanov and Sokolov (1983) approximations. Surprisingly, this key component of the global water budget had not been recalculated using the latest satellite-derived ocean bathymetry.

How can satellite data be used to improve the accuracy of the ocean's volume? Despite great advances in ocean exploration over the past 50 years, less than 10% of the seafloor has been



mapped with ship-borne instrumentation. Smith and Sandwell (1997) combined satellite data, which determines ocean depth from gravity anomalies, with quality-controlled ship depth soundings to derive a high-resolution grid of seafloor topography. For this effort, we relied on the SRTM30PLUS V5 bathymetry database (Becker et al., 2009), which is derived following the method of Smith and Sandwell (1997), but includes the Arctic Ocean and incorporates retracked altimetry (Sandwell and Smith, 2009) and new single- and multi-beam echosounder data from US Navy, US National Geospatial Intelligence Agency, International Hydrographic Organization, US National Geophysical Data Center, and numerous other academic and industrial sources. This analysis resulted in a mean ocean depth value of 3682 m.

Remarkably, despite limited knowledge of seafloor topography and ocean area, Murray's ocean volume calculation is within ~ 1.2% of the value derived from this study. Compared with the most highly cited estimates of ocean volume (Baumgartner and Reichel, 1975; Shiklomanov and Sokolov, 1983; Menard and Smith, 1966), our estimate of  $1.332 \times 10^9 \text{ km}^3$  is  $6\text{--}18 \times 10^6 \text{ km}^3$  less (Table 1). This difference is primarily a result of a 21–51-m reduction in the mean ocean depth estimate. This difference, while only 0.45–1.4% of the total, represents a volume equivalent to 500 times the Great Lakes or five times the Gulf of Mexico. Although this reduction will not significantly affect, for example, oceanic geochemical budget

Table 1. Estimates of ocean depth, area, and volume.

Mean Depth (m)	Area ( $10^6 \text{ km}^2$ )	Volume ( $10^9 \text{ km}^3$ )	Reference
3797	355.3	1.349	Murray (1888)
3814	362.0	1.370	Kossinna (1921)
3729	362.0	1.350	Menard and Smith (1966)
3733	361.1	1.348	Baumgartner and Reichel (1975)
3703	361.3	1.338	Shiklomanov and Sokolov (1983)
3682.2	361.84	1.3324	This study

calculations, ocean volume is a key constant in Earth science that should be reported accurately with the most current, state-of-the-art ocean area and mean depth estimates.

Interestingly, technical improvements in seafloor mapping are mainly improving the spatial resolution, that is, adding detail at certain wavelengths in the topography spectrum, while making little or no change in the grand mean. For example, satellite altimetry, in part limited by geophysics (isostasy) and more certainly limited by the algorithms used, can add information to topography only over a limited band of wavelengths, and this cannot change the overall mean. Therefore, the mean depth of the ocean changes only as more of the ocean is mapped by ships, a process that is, at present, happening very slowly. The fact that to date only 10% of the seafloor has been mapped, and that the measured area is not a random sample given that the majority of the soundings have taken place in coastal areas, argues for continued ocean exploration as well as development of new approaches and technologies over the coming decades.

The new emphasis on ocean observing systems should provide an ideal opportunity to answer this call.

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## SUPPORTING MATERIAL

For the bathymetry analysis, we worked from the SRTM30PLUS V5 dataset of September 16, 2008. The “pinged” and “estimated” values in Table 2 refer to 30 arc second pixels in the gridded data set that are flagged as having been measured by one or more echosoundings (pinged), or that were estimated (we had no direct in situ data so we filled them in with estimates from our satellite altimetry technique).

It is important to note that the pinged mean depth is shallower, on average, than the estimated mean depth (Table 2). This is not entirely unexpected, as surveys are more common and dense in shallow coastal areas, while the deep ocean is relatively unexplored. Hence, our conclusion about the ocean volume rests mostly on unsurveyed (in a direct sense) areas. It is possible that the volume may change by 7% if all the unsurveyed areas were found to be so shallow that the unmeasured mean depth converged upon the measured one. In order to put a bound on potential uncertainty in the ocean depth measurement, suppose that eventually the entire ocean is mapped with multi-beam echosounders to the standards for hydrographic surveys of the International Hydrographic Organization S-44 (5th edition; [http://www.iho-ohi.net/iho\\_pubs/IHO\\_Download.htm](http://www.iho-ohi.net/iho_pubs/IHO_Download.htm)), and suppose further that the depths reported by the ships give mean values in 30 arc second boxes that exactly match the estimates in Sandwell and Smith (2009). Even with these additional data, the expected 1-sigma uncertainty in depth measurements will be 1.2%.

The uncertainty associated with the ocean area estimate was derived in the following way: when we make a 30 arc second grid point estimate, the output is an elevation or depth value. If the value is less than zero, it was recorded as a depth (*Note*: We did not try to mask

out land topography below sea level such as for Death Valley and the Dead Sea rift, which should make a negligible change in the results within the number of significant digits we report). Where a coastline crosses through a pixel and there is both land and sea within the box, the result ends up either land or sea but not both. We counted the number of times the land/sea state changed, and assumed that that many pixels could be ambiguous. The summed area of the “ambiguous” pixels is given as the possible error bar on ocean surface area. An additional complication not discussed here is the Antarctic ice shelves with open ocean water beneath them, and how they are represented in the grid. These are an inconsequential fraction of the ocean area and volume.

For the volumes, again, the measured volume is less than 10% of the total volume as it relies upon the new mean depth value, which is 90% estimated. Regardless, we conclude that the trend of a decrease in mean depth over time is real, and can be explained by better technology finding more shallow areas and seamounts. The uncertainty reported in Table 2 is propagated from the estimated depth and area uncertainties.

Table 2. Mean ocean depth, area, and volume derived for this study.

	Mean Depth (m)	Area (10 <sup>6</sup> km <sup>2</sup> )	Volume (10 <sup>9</sup> km <sup>3</sup> )
Mean or Total	3682.22	361.841	1.33238
Pinged	3504.49	32.4558	0.113741
Estimated	3699.73	329.385	1.21864
1-sigma Uncertainty (%)	1.2	0.14	1.2

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