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Research article

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Global Loss of Freshwater and Salination of Sea

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Abstract

The sea level has continuously fluctuated over geologic time. The best evidence for eustatic sea level changes was provided by geologists who studied the shifts of shorelines and recoveries resulting in sedimentary deposits also referred to as sequence stratification. Continuing global warming raised the question whether or not the melting of the glacial ice and snow reserves could result in earlier high sea levels. To answer the question the sea levels were turned to volumetric data. This was achieved by calculations i) using the radii of Earth, with and without the geometric radius of the geoid Earth, ii) selecting among data for an average sea depth, iii) comparing the volumetric values of best fitting values. Upon reliable data within 0.5% deviation were obtained, linear correlation was found between the volumes of sea that would be needed to achieve different sea levels. The calibration curve revealed that 80% (20 × 10^6 km^3) melting of the available fresh water reserves of polar glaciers, ice sheets and permanent snow (100%, ~25 × 10^6 km^3) would cause about 50 m sea level rise. These calculations prove that earlier high (200-300 m) sea level elevations will never be obtained due to the global loss of water to the outer space. In connection with the water deficiency, the osmotic gap between the osmotic concentration of land vertebrates (0.3 Osm) and that of sea (1.09 Osm) is reflecting the salination of ocean. Salinty changes were distinguished as short term dilution periods and a long-term salination process. Long-term salination contributed by human pollution of sea and fresh water will seriously impact future life on Earth.

Keywords Sea depth; Sea volume; Salination process; Dilution periods; Osmolarity; Escape of water vapour

Introduction

The best known and most accepted eustatic record known as the Exxon Curve, also referred to as the Vail or Haq graph [1-3] indicates, that the sea level today is near to its lowest level that ever occurred (Figure 1, oscillations in blue color). Eustatic changes affected not only the shape of oceanic basins, but also local changes took place by tectonic uplifts and prolapses. As a result the sea level fluctuated by hundreds of meters over geologic time. The most drastic growth and shrinkage of ice sheets in the last 500 million years (Mys) occurred primarily in the Northern hemisphere. The decreasing amount of fresh water could be counteracted at higher temperature by the increased evapouration of sea. Although, sea is the largets global equilibrium system, based on the law of dilute solutions its increasing salinity reduces evapouration [4,5].

It escaped attention that known eustatic sea level fluctuations and climatic changes, led to the salination of sea. This review proves by volumetric calculations that the melting of ice of glaciers and permanent snow could not elevate the sea to its earlier high levels as the freshwater reserves are close to exhaustion. It is concluded that the loss of water to space and the related salination of sea are more threatening life on Earth than the recent relatively short term interglacial dilution process of global warming contributed by man.

Sea level fluctuations

The sea level changes in Hallam's upper red curve (Figure 1) [6,7] show the tendency of gradual decrease of both the maximum (Figure 1, red line) and minimum (Figure 1, red dashed line) sea levels in the last 500 Mys. Althouh, less markedly than in the Hallam's curve, the declining tendency of Exxon sea levels also indicates the loss of seawater (Figure 1, blue lines).

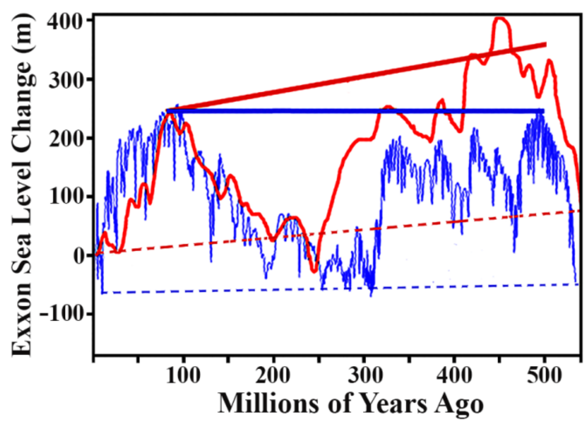

Figure 1: Exxon's (Haq's) and Hallam's sea level fluctuations in the past 500 million years.

Red solid line, Hallam's high sea levels; red dotted line, Hallam's low sea levels. Blue solid line, Exxon's (Haq's) high sea levels; dotted blue line, Exxon's low sea levels. The figure was prepared by Robert A. Rohde from publicly available data [8].

Credit: https://en.wikipedia.org/wiki/Past_sea_level#/media/File:Phanerozoic_Sea_Level.png, share alike;

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http://www.universetoday.com/15055/diameter-of-earth; https://www.ngdc.noaa.gov/mgg/global/etopo1_ocean_volumes.html.

As far as the earlier imaginary geoid, ellipsoid, spheric shapes are concerned, there is a growing concensus that Earth is approximately spheric (Figure 2). To determine its exact shape, further measurements are under way. More importantly, the deviation between the radii of the polar minimum (6356.8 km) and equatorial maximum (6378 km) is only ~21 km (0.33 %), close enough to look at Earth as a sphere in many contexts, (http://www.universetoday.com/15055/diameter-of-earth), yielding a mean radius of 6,371 km (https://www.ngdc.noaa.gov/mgg/global/etopo1_ocean_volumes.html).

The formulae for applying approximations to the Earth's shape were analyzed by Alexander [9]. Ellipsoidal and geoid approximations coincided with that surface to which the oceans conform over the entire Earth. By finding the best fitting approximations of values of radii (Figure 2), the volumes of sea could be estimated within a relatively narrow range of error at different sea levels. These data served then as a basis for the discussion in relation to the salination of the ocean.

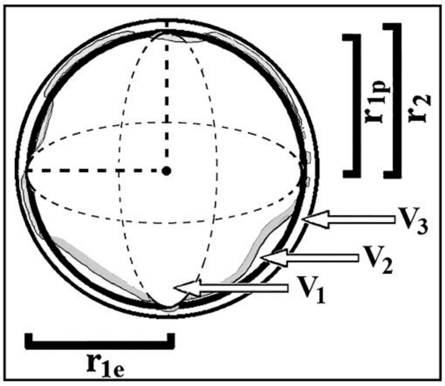

Figure 2: Demonstration of sea level change. Grey line indicates the geoid shape of Earth. Abbreviations: r_{1e}, equatorial radius; r_{1p}, polar radius; r_2, increased radius after sea level rise; V_1, volume of Earth; V_2, volume of sea; V_3, increased volume after sea level rise. Calculations were made using the sphere volume formula modified from [5].

Radii of Earth

The Earth's mean radius denoted R is the distance from the Earth's center to its surface, estimated to be 6,371.008 km [8,10]. R is also a unit length in astronomy and geology. The Earth mean radius (R) differs from the geometric radius (R), wich does not include the average depth of the sea (Figure 3A).

(https://en.wikipedia.org/wiki/past_sea_level#/media/file:phanerozoic_sea_level.png)

To assure that different approaches give the same results for the volume of the sea, two estimations and the mean value of recent sea volume obtained by others have been compared:

1) Geometric approach to sea volume (without land area 70.9 %): 1332.9 $\times 10^6$ km^3.

2) Sea volume based on ocean area x average sea depth: 361.9 $\times 10^6$ km^2 $\times$ 3.691 = 1335.7 $\times 10^6$ km^3. The deviation between these two calculations is 0.21 %.

3) Sea volume mean obtained from the estimations of others: 1335 $\times$ 10^6 km^3 (Figure 3B). Deviations of 3, relative to estimations of 1 and 2 were 0.15 % and 0.05 %, respectively.

A

Earth radii	Radius (km)	Volume (x10^6 km^3)	Reference
r_{1p}	6,335.439	1064.95	[10]
r_{1e}	6,378.137	1086.5	[10]
r_m ($R_\oplus$) at sea level	6,371.008	1083.21	[10]
r_g ($R_\ominus$) only Earth	6,367.317	1081.37	Estimated

B

Depth of sea (m)	Area of sea 10^6 km^2	Volume of sea 10^6 km^3	Reference
3682.2	361.84	1332.4	[11]
3688		1335	[12]
		1335	[13]
3703	361.3	1338	[14]
3691		1332.9	Estimated
3691.05 Average	361.57	1334.7	

C

Volumes of sea and freshwater	Volume x 10^6 km^3	Reference
Water vapor (0.25 % of atmosphere)	1.2875	Estimated
Water photolysed to O_2	1.215	[15]
Present sea (total)	1,335	Table B
Freshwater (2.5% of sea)	38.14	*http (see below
Freshwater (total: 3%)	41.202	[13]
Ice and snow (2%, land and sea)	25.540	[13]
Freshwater (land: 1%)	15.662	[13]
Water on Earth (total)	1,376.242	[13]
	1,386	Table B
	1,375.64	Estimated
Highest sea level (500 Mys)	1,455	Estimated
Infant Earth (3,800 Mys)	1,682	Estimated

Figure 3: Volumes of Earth and Ocean.

A: Geometric radius (R): R - average sea depth: 6,371,008 m–3691 m=6,367,317 m.

V1 (geometric volume of Earth) from R : 1.08137 $\times$ 10^{21} m^3=1081.33 $\times$ 10^{12} km^3.

V2 (sea) from R minus R : 1083.21 $\times$ 10^{12}-1081.33 $\times$ 10^{12} km^3=1.88 $\times$ 10^9 km^3 (100%). V_2 (sea) without land area: 1.318 $\times$ 10^9 km^3=1332.9 $\times$ 10^6 km^3 (70.9 %).

B: Only the latest data (after 1980) have been included in the estimation of average depth of sea.

C: Differences between volumes of earlier high and recent sea levels:

500 Mys: 1,455 $\times$ 10^6 km^3–1,335$\times 10^6$ km^3=120 $\times$ 10^6 km^3.

3,800 Mys: 1,682 $\times$ 10^6 km^3–1,335$\times 10^6$ km^3=447 $\times$ 10^6 km^3.

Differences between the highest sea volumes and recent global water volumes:

500 Mys: 1,455 $\times$ 106 km^3–1,386 $\times$ 106 km^3=69 $\times$ 10^6 km^3.

3,800 Mys: 1,682 $\times$ 106 km^3–1,386 $\times$ 106 km^3=296 $\times$ 10^6 km^3.

http://water.usgs.gov/edu/earthhowmuch.html

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Estimations Mean Own Calculations

Conversion of sea levels to sea volumes

The comparison of freshwater reserves with sea level fluctuations showed that: The complete melting of available freshwater reserve (ice caps, glaciers and permanent snow) (~25 × 10^6 km^3) would cause ~65 m sea level rise taking into account that the presence of continental crust allows ~30% more elevation than the sea level rise without the land masses on Earth.

The total fresh water representing the fresh water reserve plus fresh water of land (~3 % of sea volume, ~40 × 10^6 km) would be sufficient to increase the sea level by about 110 m. Complete melting or complete loss of freshwater can be excluded in the foreseeable future.

The recent estimates of lowest (1332.4 × 10^6 km^3) [11-13] and highest (1338 × 10^9 km^3) [14] volumes of ocean show a 0.45 % deviation, confirming the validity of these data.

The calculations of Rosing's team [15,16] indicated that the ocean of the infant Earth about 3.7–3.8 billion years ago was up to 26% more voluminous. Data related to hypothetical volumetric increases and the sea levels belonging to them are given in Figure 4A. The calibration curve (Figure 4B) was extended (not shown) to estimate the volume of the infant Earth and revealed that this could have corresponded to an ~1680 × 10^6 km^3 volume and to an ~870 m higher sea level than today, assuming that the size of the Earth was nearly the same, and the land masses were higher than the sea level at that time. The data obtained from the calibration curve extended up to 870 m sea level correspond to ~335 × 10^6 km^3 (26.2% more) and a total of 1685 × 10^6 km^3 sewater. Rosing's group also argued that due to the lack of land masses, the early Earth was completely covered with water [17]. In the absence of continents the sea level rise could have been less, down from 870 to about 610 m.

A

a Radius (m)	b Volume ($x10^{12} km^3$)	c Volume increase ($x10^6 km^3$)	d Sea level rise (m)
6,371,008	1.08321	0	0
- 100	1.08315	- 50	-130
+ 20	1.08322	+10	26
+ 40	1.08323	+20	52
+ 60	1.08324	+30	78
+ 100	1.08326	+50	130
+ 200	1.08331	+100	260
+ 210	1.08332	+120	300
+ 300	1.08336	+150	390

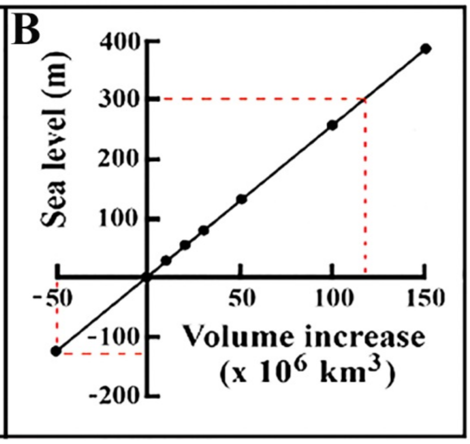

Figure 4: Freshwater reserves needed for hypothetical sea level elevations. A) Hypothetical increase of: a) radii relative to the sea level today in the absence of oceanic crust, b) volumes in the absence of oceanic crust, c) volumetric increase of sea levels in the presence of oceanic crust under the sea (+30%), d) sea level rises. B) Calibration curve: sea level rise versus sea volume increase. Data in red indicate the lowest (-130 m) (~20,000 years ago) and highest (~300 m) (~500 million years ago) sea levels.

Shrinkage of fresh water reservoir

Volumes of sea and freshwater are given in Figure 3C. By the end of the latest ice age the volume of the ice was ~50 × 10^6 km^3. A ~40 × 10^6 km^3 loss of all polar and glacial ice was predicted, corresponding to 80% loss of our freshwater reservoir [18]. According to Shiklomanov's estimation [19] the freshwater reserve (ice, glaciers, permanent snow) was only 24 × 10^6 km^3. An 80% loss (19.2 × 10^6 km^3) of this volume of fresh water could have caused an estimated 50 m sea level rise, disregarding the negligable thermal expansion of seawater as a consequence of global warming. A new estimate of the recent fresh water reserve (ice and snow) ~25.5 × 10^6 km^3 [13], could have corresponded 51% to that of the latest ice age some 20 Mys ago.

As far as thermal expansion is concerned, water expands between 4°C and 100°C, but contracts as it is warmed up from 0°C, and reaches maximum density at 4°C. The deep ocean water makes up about 90% of the volume of the oceans. The average deep sea temperature is 2°C, the average sea surface temperature 17°C. Assuming a 2°C increase in deep sea temperature (from 2 to 4°C) the volumetric contraction would still be negligible, if any.

Explanation to Figure 3: The continental crust contributes to about 30% higher sea level rise. Example: 20 m theoretical increase of the sea level (Earth radius, R), in the absence of continental crust would need 10 × 10^6 km^3 more water, but would in fact cause 30% higher, i.e. 26 m sea level elevation. Sea volume increase from the lowest (-130 m) to an earlier high (+300 m) sea level (total 430 m) would cause a volumetric increase of: 50 × 10^6+120 × 10^6 km^3=170 × 10^6 km^3 corresponding 12.73% volumetric fluctuation. Compared to the recent sea volume (1,335 × 10^6 km^3, 100 %) the volume at its earlier high (300 m) sea level could have been 1455 × 10^6 km^3 (109 %) and at its lowest level (-130 m) 1,295 × 10^6 km^3 (97%).

The calibration curve (Figure 3B) shows that 80 % (20 × 10^6 km^3) of the somewhat higher (~25 × 10^6 km^3) freshwater reserve [13], could cause an ~50 m sea level rise. That the linearity of the calibration curve is far from being disrupted can be explained by the small fluctuations (from -130 to +870 m) of sea relative to the recent sea level with a radius of 6,371,008 m. Further estimations modified by seasonal variability bring us closer to the speed of glacier calving estimated to cause either less than 1m (0.5 to 1.4 m) [20] or higher (0.8–2 m) than 1 m/century sea level rise [21], by the end of 2100. The reason why scientist have almost doubled their sea level rise projections is related to the higher than expected levels of greenhouse gas emission. As observations regularly exceeded sea level rise projections, the latest prediction proposed that the ocean could rise to nearly 2 m by the end of the century. The relatively fast melting of Antarctica alone cause seas to rise more than 15 meters by 2500 [22]. Another pessimistic forecast predicted an even faster and a complete melting of ice sheets that could lead to a sea level rise of about 80 meters, and the disappearance of glaciers by 2200 [23].

Balance of Salination and Dilution Processes

Among the reasons of long-term (Mys) salination of sea the following processes have been mentioned: i) ice formation, ii) continental drift, iii) weathering and denudation, iv) hydrological cycle, v) sea level regression, vi) river pollution and ocean dumping of contaminated wastes, vii) disruption of themohaline circulation. The long-term salination and temporary sea dilution processes have been recently reviewed [5].

Salination and dilution processes of sea suggest that the salination outweighs the impact of the dilution processes, especially if we consider the gradual loss of water to the outer space. This does not concern the estimated 46 million m^3 "loss" of drinking water that disappers globally every day, but returns to the global system in virtually the same quantity (https://www.theguardian.com/sustainable-business/2015/mar/02/water-loss-eight-things-you-need-to-know-about-an-invisible-global-problem).

The real loss refers to the water that is never regained and causes the shrinkage of volumes of ocean and fresh water contributed by:

Small proportion of water that is photolysed generating molecular oxygen and hydrogen. The major source of oxygen is photosynthesis in land (1.65×10^{14} kg/y) and ocean (1.35×10^{14} kg/y) [15]. Molecular oxygen is dissolved in water (sea and fresh water) and present in the atmosphere.

In the process of cellular respiration (glycolysis, Krebs Cycle, electron transport chain) nutrients are oxidized and converted to CO_2 and useful energy in cells.

Oceans with higher salt content warm up faster, dissolve less oxygen, generate lower vapour pressure and rain, diminish the amount of fresh water, slow down the hydrological and glacial cycles.

An estimated 80% melting of the 24×10^6 km^3 [19] or 25.5×10^6 km^3 [13] ice and permanent snow reservoir could cause a sea level rise of 50–52 m. Higher sea level rises in the past (>200 m) undoubtedly prove that a significant portion of the freshwater reservoir has been lost and evapourated to space contributing to the salination of sea.

Ocean as a Semiclosed Osmolyte System

The Devonian salt concentration of ocean is believed to have corresponded to the concentration of blood electrolytes (0.3 Osm) at the time when land vertebrates left the sea [24-27]. The average osmolality of today's sea (1.09 Osm) is more than three times higher than the blood of land vertebrates (~0.3 Osm).

To explan this osmotic paradoxon the ocen dilution theory hypothesized that the salinity of ocean was 1.5 to 2 times the recent value and declined relatively late in the history of Earth. Based on this theory, salt deposition was the highest in the last 540 million years totaling about 12×10^{21} g, while halite deposits older than these probably were not more than 0.5×10^{21} g [28]. The ocean dilution theory assumed an initial high followed by a declining salt concentration of ocean and tried to explain why evolution of more complex life took so long. A 1.5–2 times higher salt content of ocean would mean 1.6–2.2 Osm concentration inexplicably widening the gap between the osmolarity of sea and land vertebrates. In sharp contrast to the ocean dilution theory the mineralogy of marine evapourites ruled out drastic changes in the composition of sea water during the last 900 Mys [29]. Alternatively, the oceans could have become saltier with time as sodium and chlorine were weathered out of continental rocks and carried to the sea, contributed by the global loss of water [16] and supporting the long-term salination theory of ocean [4,5].

Escape of Water Vapour to Outer Space

The atmospheric escape of volatile molecules to the space [16] is not to be confused with the sequestration of small gas molecules to our planet. Relevant examples of sequestration are the condensation of water vapour to rain, ice and snow, or the sequestration of carbon dioxide to the plants, coal or to the sedimentary rocks in ocean. The volatile, low molecular weight reductive gases of Earth's air, primarily hydrogen, biogenic methane and the atomic helium are trickling away into space, causing among others the irreversible oxidation of Earth's surface [30]. The atmospheric loss of gases to the outer space named Jeans escape, after Sir James Jeans [31], is an estimated 3 kg/s hydrogen and 50 g/s helium [32]. Most of the water is evapourated from the sea as water vapour that due to its lower molecular mass, relative to other more bulkier molecules of air (N_2, O_2, CO_2) can freely move up in the atmosphere as a gas. High in the atmosphere a small portion of water molecules of the water vapour gas is split to hydrogen and oxygen atoms by the incoming ultraviolet radiation from the Sun. Reactive hydrogen atoms of water origin being in nascent state (in statu nascendi) form immediately H_2 molecules, whereas nascent oxygen atoms may combine with oxygen molecules (O_2) to form ozone (O_3). The thin ozon layer shield protects our planet form UV-B light irradiation.

The loss of water was studied as follow-on to the Mars Express mission, optimised to the atmosphere of the Venus in the Venus Express satellite program of the European Space Agency (ESA). The Venus Express spacecraft mission started in 2006 and ended in 2014 (http://www.esa.int/Our_Activities/Space_Science/Venus_Express/Venus_Express_goes_gently_into_the_night; http://sci.esa.int/venus-express). The major discovery of the Venus Express project was that is has confirmed the loss of a large quantity of water into space over billions of years (http://sci.esa.int/venus-express/54068-7-water-loss). Although, the atmosphere of Earth is two orders of magnitude less dense than that of Venus at the surface, a similar mission could be adapted to the atmosphere of the Earth. The industrial team led by EADS Astrium (now Airbus Defence and Space) could confirm in a remarkably short period of time, that the water on Earth similarly Mars and Venus is constantly lost to space.

Conclusion

Solid evidence is provided that water on Earth is constantly lost. Evidence is based on the fact that the melting of fresh water reservoirs is unable to elevate sea to earlier high levels as reservoirs are close to exhaustion.

Fresh water is lost as water vapour to the outer space [16] and is assumed to contribute to the salination of sea.

Salination of sea is related to the melting and freezing cycles of polar ice and snow. Dilution of sea is regarded a temporary episode belonging to the ongoing interglacial period, speeded up by recent global warming.

Faster melting of ice and snow causes higher local dilution, storm intensification, and is masking the long-term global salination of sea.

Earth is not a sealed, only a "semi-closed" global osmolyte system. It turned from a dilute Devonian solution (0.3 Osm) to an osmolyte between dilute and concentrated (1.09 Osm) solutions.

Ongoing long-term salination, increases salt concentration of sea, generates lower vapour pressure, cloud and precipitate formation and causes the spread of deserts.

The loss of fresh water, the falling partial pressure of water vapour in air, endanger terrestrial life and will gradually restrict life to more osmotolerant species in an increasingly salty and dense soup of sea.

Finally, unless global, particularly fresh water pollution will be limited, the salination process contributed by man will be accelerated. Salination is regarded a more devastating process to life on Earth than the recent global warming episode, often misinterpreted as part of a naturally occurring interglacial dilution process.

Competing Interest

The author declares to have no competing interest

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