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Technical Note: Estimation of global loss of freshwater based on sea level changes over geological time

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Abstract

Water vapour at the upper layer of the atmosphere undergoes light-dependent photolysis generating reactive hydrogen ions *in statu nascendi*t hat escape to space by different mechanisms. Besides hydrogen, other volatile gases such as methane molecules and helium atoms also escape to space in smaller quantities or traces such as oxygen. The escape of hydrogen through the planetary air leak cannot be reliably judged. Our estimation of global freshwater loss used another approach based on the sea level changes that continuously fluctuated over geological time. The most reliable evidence for eustatic sea level changes was provided by geologists estimating the shifts of shorelines generating sedimentary deposits. The sea level changes turned to volumetric data of a) radii of the Earth (r_1) to calculate the volume of the geoid Earth (V_1) comparing and validating them with available estimations, b) average sea depth (r_2) comparing volumetric values of the sea with best-fitting values (V_2). c) showing the correlation between geological changes (r_3) and corresponding sea volumes (V_3). These data,along with the sea volume of the infant Earth, allowed to plot a calibration curve to calculate the sea level belonging to the volume and *vice versa*. Geologic data indicate the shrinkage of freshwater pools during interglacial dilution periods and the remarkable long-term salination of the ocean.

Keywords

water vapour, photolysis of water, H escape, freshwater reserves, sea level rises, salination of sea

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1. Introduction

Water vapour at the upper layer of the atmosphere undergoes light-dependent photoionisation generating reactive hydrogen ions *in statu nascendi* that escape to space by different mechanisms. The escape velocity of hydrogen to the outer space is the highest among light gases followed by helium, ammonia and water vapour and is dependent on gravity, which in the inner planets of our solar system is lowest on Venus followed by Earth and Mars.The escape of gases, among others, is dependent on the temperature, rate of cooling, greenhouse effect. It was estimated that the Sun would be brighter and hotter in about 1 billion years and the global surface temperature could rise to about 47 ^{o}C. The Earth will be likely to lose its water (Schröder et al., 2008) similarly to what already happened to Venus.

Losses of light gases are unlikely to be inherent parts of the evolution, at least in the inner planets of our solar system. Vast losses of gases also came from the activity of the young Sun that blew light gases, primarily hydrogen and helium to the outer planets known as gas giants. An important factor related to the global loss of water is the polar wind that drives hydrogen and other ions to space seen as faint yellow area near the Earth's poles.

The shrinkage of freshwater reservoirs including atmospheric moisture (snow, rain, clouds) and ice (glaciers, polar ice, ice sheets, permanent snow) is contributed by the freshwater loss of global warming. The atmospheric escape of hydrogen on Earth is assumed to result in approximately 3kg/s loss of hydrogen and about 50 g/s loss of helium (Zahnle, 2006; Catling and Zahnle, 2009).The abundant CH_4 originating from methanogenesis could have supported the escape of hydrogen to space by orders of magnitude faster than today (Catling et al., 2001).Our own repeated calculations showed that under the conditions that exist today, the H escape could have resulted in only about 0.02% loss of the recent ocean volume. The explanation to this negligible loss could be that the escape of water: a) was much faster earlier, b) came from different sources that could sum up or c) was not significant during the evolution of Earth.

Regarding oxygen, only small quantities were found to escape to the Moon from the Earth (Terada et al., 2017). O_2 produced by photosynthesis absorbed in oceans and seabed rocks started to gas out about 1,850 Mya but was absorbed mainly by land surfaces. When the ocean saturated, oxygen began to accumulate in the atmosphere (Holland, 2006).

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An important warning signal of freshwater loss is the increasing gap between saltwater and freshwater, which is now 97 *versus* 3 %. The question is how this ratio could have changed from a dilute too salty and concentrate sea during evolution. The highest known sea level some 3,700-3,800 million years ago, suggested that the Infant Sea could have contained 26% more water than today (Pope et al., 2012; Rosing et al., 2010). Ice ages generated low sea levels particularly during the Proterozoic Snowball Earth period when Earth's surface became almost entirely frozen and covered by slush, snow and ice (Kirschwink, 1992; Allen and Etienne, 2008; Pu et al.,2016). The opposite tendency, namely the accumulation of substantial freshwater reservoirs was assumed to take place in the late Proterozoic aeon before the Cambrian period (541 Mya) and between the Ordovician and Silur epochs (Pu et al., 2016; Haq et al., 1988; Holland et al., 1986). Severe glaciations with low sea levels were followed by extreme high sea levels, *e.g.* during the Paleozoic era at the end of the Ordovician period (~450 Mya). Although the Ordovician lasted for only 45 million years and represented only ~1% of the age of the Earth, the life on Earth during this time diversified rapidly. The unprecedented radiation of species in Ordovician is accounted for by the dilute, yet optimal osmolarity (0.2 – 0.4 Osm) of the oxygenated ocean and the abundance of freshwater supply.

Gas escape theories did not provide reliable means to judge the global loss of water on Earth. Thus geological sea levels were turned into volumetric changes to give a reasonable explanation to the shrinkage of freshwater.

2. Assessing freshwater loss

2.1. Estimation of sea volume and turning sea levels to volumetric data

We used calculations of interconversions to turn sea levels and volumes into each other.The validity of the data obtained was tested by using:

i) Geometric radii of the geoid Earth and average radius
ii) Reliable estimates of average sea depth
iii) Comparison of volumetric estimates and selection among best-fitting values
iv) Testing whether volumetric changes belonging to sea levels can be used to construct a calibration curve

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v) Plotting the calibration curve to show the relationship between sea level rises and volumetric changes in sea volumes (Banfalvi, 2017).

2.2 Sea volumes

The extention of the calibration curve included the highest known sea level of the sea of the Infant Earth (~ 750 m) relative to the recent sea level (6,371,008 m). Compared to the average radius of the Globe (6367.3 km), the average depth of the sea (3682.2 m) is negligible thus the linearity of the calibration curve is not questionable (Fig. 1). Most of the data of the sea volumes were 30-40 years old, differed from each other and were significantly higher than the recent satellite measurements (https://www.livescience.com/6470-ocean-depth-volume-revealed.html). One could not explain the higher estimates of current sea volumes by recent changes. Rather, the amounts of undersea mountains, ocean ridges and other geographical features were not subtracted from the bulk of the ocean resulting in higher estimates. These structures under the sea level include *i)* the Globe itself, *ii)* continental shelves, slopes, rises, insular shelves that surround continents and islands, and *iii)* zones of the ocean floor (continental margins, deep-ocean basins, mid-ocean ridges, sediments) that are merged and referred to as undersea features.

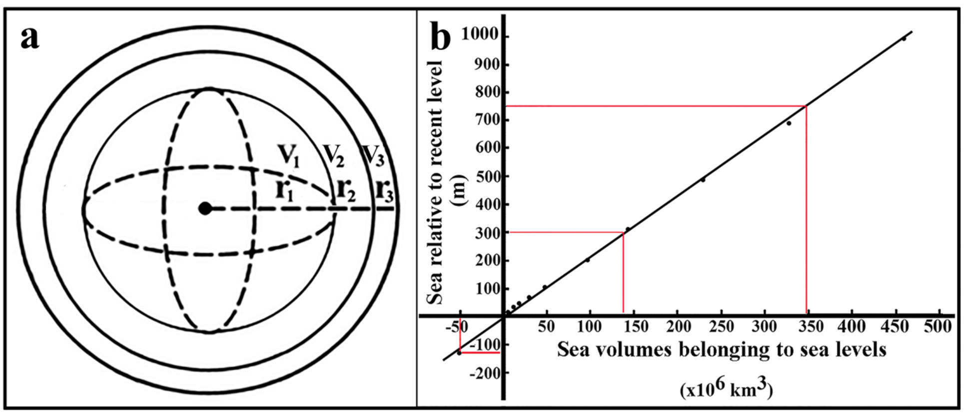

Figure 1. Demonstration of sea levels and volumes (a), plotting them into a calibration curve (b).

a) Data used for the calculation of underwater volumes of the continental shelf and other underwater features include: r_1 = average of equatorial and polar radii of geoid Earth (6367.3 km) (Banfalvi,

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2017). r_2 = radius of Earth + depth of sea (6,371,008 m) (Williams, 2012). V_1 = volume of Earth calculated from r_1 (1,081. 320 x10^9 km^3). V_2 = volume of sea (1332.9 x 10^6 km^3) (Banfalvi, 2017). V_3 = actual volume arising from sea level rise (0.09 m x 361.84 km^3 = 32.5 km^3). b) Relationship between sea level elevations and sea volumes relative to recent data. The data of abscissa represent eustatic sea level elevations and those of the ordinate the volumetric changes relative to recent data. Lowest sea level (-130 m) (~20,000 years ago), higher (~300 m) (~500 million years ago) and the highest sea level of the Infant Earth (3,700-3,800 million years ago). Modified with permission (Banfalvi, 2017).

Table 1 shows the recent volumetric data of water on Earth (Table 1). The continental margin is constituting about 28% of the oceanic area (Cook and Carleton, 2000). All the underwater features represent an estimated 29.5 % of sea volume and will be more precisely determined as the measurements will become eeven more accurate. The most reliable data obtained by satellite measurements of sea surface face some light reflection problems (Charette and Smith, 2010). The resolution of the sea depth needs further ”fine-tuning" by ship-based echo sonar and other methods. Satellite measurements show that the average ocean depth is 3,682.2 m. This value multiplied by the area of sea (361.84 x10^6 km^3) results in the volume of the ocean of 1,332.4 x10^6 km^3 (Charette and Smith, 2010). These measurements show a good match (±0.1%) with other values published within the last ten years (Table 1).

Table 1

Volumetric data of water on Earth

#	Volume of	Volume x 10^6km^3	Volume (%)	References
1	*Sea	1332.4	96.9	Charette and Smith, 2010
		1332.9	96.9	Banfalvi, 2017
		1335	97.1	Eakins and Sharman, 2010
		1335	97.1	Durack, 2015
2	**Sea (average)	1333.8	97.0	
3	†Freshwater in reservoirs	25.54	1.86	Durack, 2015
4	‡Freshwater in land	15.66	1.14	Durack, 2015
5	Freshwater total (#3 + #4)	41.20	3.00	Durack, 2015
6	Water on Earth (#2+#5)	1376.2	100	Durack, 2015
7	Sea (Infant Earth rel. to #2)	1681.1	126	Banfalvi, 2017
8	Global loss of water (#7-#6)	305	-22	This estimate

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*Sea volume, average of four estimates rounded up to 1335 x 10^6 km^3 (70.015%).

†Freshwater reservoirs: ice, glaciers, permanent snow.

‡Freshwater inland: lakes, artificial lakes, ponds, streams, wetland and groundwater.

Estimation of the global loss of water was obtained by subtracting the recent volume of the sea from the volume belonging to the highest sea level.

The largest volume represented by the volume of Earth + volume of the sea. Calculated from r_2: 6,371,008 m → 1,083.210 x10^9 km^3.

Volume of underwater features including continental shelf. Substraction of volumes calculated from r_2 and r_1: 1,083.210 x 10^9 km^3 - 1,081.320 x10^9 km^3 → 557 x 10^6 km^3 (29.5%)

Summary of volumes of sea 1332.9 x 10^6 km^3 (70.5%) plus underwater features and continental shelf: 557 x 10^6 km^3 (29.5%), total 1889.9 x 10^9 km^3 (100 %).

Calculation of continental shelf: land surface area of the World x average depth of ocean: 148.42 x10^6 km^2 x 3,6822 km = 548.42 x 10^6 km^3.

Volume of underwater features without continental shelf: 557 – 548.42 = 8.57 x 10^6 km^3 = 0.45%.

Our calculations showed that the volume of the underwater features excluding the continental shelf represents only 0.45 % of the size of the ocean, confirming that the average seabed (ocean floor) is a relatively flat surface. John Murray (1888) utilised a simple model and measured the depth of the ocean at several locations then calculated the ocean volume by only 1.2% higher than the current estimates of the amount of the world's oceans (Charette and Smith, 2010). Our data showed a close relationship between sea level rises and volumetric changes in the sea. These data were useful to create a calibration curve (Figure 1) (Banfalvi, 2017). The calibration curve was then extended to apply it to the highest sea levels. More importantly, the calibration curve served to estimate global water loss.

The elevations of sea level rises originate mainly from the melting of freshwater reservoirs and thermal expansion during interglacial periods. Predictions forecasted that the recent interglacial period could melt about 80% of the Earth'sice and snow reserves of ~50 x $10^6$$km^3$ (Berger and Loutre, 2002). Others judged that the freshwater reserve is only about half (24 x 10^6 km^3) of the earlier estimation (Shiklomanov,1995).The newest estimate of freshwater is somewhat higher (25.54 x 10^6 km^3) (Durack, 2015) but only about half of the maximum of the latest ice age some 120,000 years ago. By fitting sea level rises and volumes into the calibration curve (Fig. 2), sea levels can be turned into volumetric values and *vice versa.*

The highest reported sea level was at the period of the Infant Earth (Pope et al., 2012; Rosing et al., 2010). To estimate the global loss of freshwater, the highest sea level rise of the Infant Earth served as a basis. This sea level could have been by 750 m higher than it is today (Fig. 1b) with a sea volume of ~ 1,681 x 10^6 km^3. Volumetric data of sea and freshwater are summarised in Table 1. The calibration curve (Figure 1b) takes into consideration that in the presence of continental crust, the sea level is about 29.5 % higher than in its absence. Due to the lack of landmasses, the early Earth was assumed to be completely covered with water (Rosing et al., 2010). Thus the sea level of the Infant Earth could have been roughly 530 m higher than it is today.

3. Geochemical stability *versus* dynamic nature of global osmolyte system

Despite large sea level fluctuations, only small changes can be traced if at all, leading to the conclusion that in general, the rate of input and output in the sea was nearly equal in agreement with the long-term mean of its salt concentration (Pope et al., 2012). The idea of a general geochemical balance of the sea is related to the limited foreseeable future of man that is not longer than 100 years but provided a model to make such constancy plausible (Rubey, 1951; Railsbeck et al., 1989). The view of a dynamic osmolyte rather than a steady-state ocean system is gaining ground, by measuring short-term volumetric decreases during ice ages; sea level rises during interglacial periods and long-term salination of the ocean (Banfalvi, 1991; 2016; 2017).

The Unified Sea level Rise Projection (http://southeastfloridaclimatecompact.org/wp-content/uploads/2015/10/2015-Compact-Unified-Sea level-Rise-Projection.pdf) serves as a reasonable source of information to predict the sea level rise in the 21st-century relative to the 1992 mean sea level. The short-term rise envisaged 15-25 m by 2030. The medium-term sea level rise projected 25-66 m with a less likely possibility of reaching 86 m by 2060.The long-term projection predicted nearly 79-155 m sea level rise and a less likely extension to 206 m (Southeast Florida Regional Climate Change Compact, 2015). The melting of 20 x 10^6 km^3 ice and snow would correspond to about 80% loss of the available freshwater reservoir and would reduce the global freshwater volume to ~1.51% from 3% and cause a sea level rise of about 50 m (Figure 1). A higher sea level rise is less likely to occur than that predicted by 2060 in the Unified Sea level Rise Projection. Nevertheless, it may correspond to the forecast of the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment

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Report (ARS5) model projection (Nerem et al., 2018). It is unrealistic to assume the complete melting and loss of the freshwater reservoir during the recent interglacial period. A higher than 50 m sea level rise is unlikely to be reached simply because of the shortage of the freshwater reserve. The complete melting of the freshwater reservoir would be catastrophic, especially to the terrestrial vertebrates that are fully dependent on freshwater supply. Forced sea level rise patterns were predicted and could continue in the coming decades with elevated rates of rises (Fasullo and Nerem, 2018), but the rise may not be linear with time. The initial faster rate of sea level rise could slow down due to the shortage of freshwater reserve.

4. Conclusions

One explanation for the global freshwater loss is that water vapour at the upper atmosphere photohydrolysed to H and oxygen. H escaped to the outer space; oxygen formed the protective ozone layer. Calculations showed that the recent escape of hydrogen to space is low, but it could have been much higher at the earlier periods of global history. Calculations related to the hydrogen escape theory did not allow far-reaching conclusions regarding a significant water loss. Thus evolutionary changes of sea levels and their converted data to sea volumes were used to calculate the loss of water on Earth.

The consequence of gradual loss of water on Earth is that the salt concentration of sea increases. Based on Raoult's law applied to the sea as a global osmolyte system, the evaporation of water vapour decreases and results in less precipitation and freshwater.

Characteristic biological phenomena accompany the loss of freshwater. Although the recent sea level rise will not significantly reduce the salinity of the sea, due to the limited freshwater reserves, its effect will severely impact flat seashores impacting many large cities. The life of sea animals will be hardly affected, unlike land vertebrates, including man that are entirely dependent on freshwater. The migration of people driven by the shrinkage of available freshwater and the spread of deserts are continuing. Due to the freshwater shortage, the habitat of species is decreasing at an alarming rate, threatening with extinction many endangered freshwater species.

It is concluded that different sea levels with decreasing heights during evolution can be used to estimate the global loss of water. The sea level of the Infant Earth could have been by 26% more voluminous than it is today. The second-largest sea levelrise (~300 m) took place some 500 million years ago. Fluctuations indicate record-low sea level (-130 m) about 20,000 years ago. The basis of estimation of the global loss of freshwater is the subtraction of the recent volume of the sea from the amount belonging to the highest sea level. The substantial freshwater shrinkage contributed by man and the salination of sea demand counteractions to be taken or already in effect to protect life on Earth.

Data availability

The MS will be deposited into the institutional repository of DEA (Educational and Research Support) of the University of Debrecen and National Library.

Author contribution

All activities related to the preparation and publication of the manuscript were carried out by the single author.

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Conflict Of Interest Statement The author declares to have no conflict of interest.

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Ethical consideration The author has no ethical issues to be considered.

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