R.J.B November, 2018 Flat-Earth Paper... Supplementary file with BULK DENSITIES, SOM, CARBON and other sections too lengthy to include in main text.

Non-flat Earth Recalibrated for Terrain, Soil Surface Tortuosity and SOM Humus Microporosity

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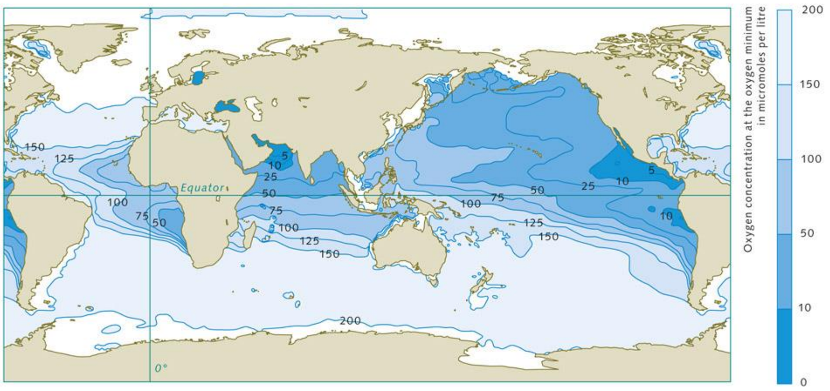
Oxygen and CO_2

In a seminal paper from 25 yrs ago, Duursma & Boisson (1994) stated: "*the atmosphere contains: 3.53 x 10^{19} mol O_2,... For the total world ocean, the oxygen reserve is then: 3.1 x 10^{17} mol O_2... Almost 120 times more O_2 is present in the atmosphere than in the oceans (Tab. 2)*." Oxygen deficiency limits life in the seas but much less so on land or in soil. Particularly insects have a system of tracheae restricts their size, but animals such as earthworms have capillaries combining a circulatory with a respiratory system that diffuses O_2 via the cuticle to haemoglobin thus allowing a larger size and the strength to construct extensive burrow systems thereby aerating soils for other organisms to survive therein.

Oxygen that is necessary for almost all living organisms to respire, is depleted by 99.2% at the air/water boundary yet it percolates throughout the soil to depth, as with rainwater, due mainly to the burrowing of earthworm and some other soil organisms themselves mostly dependent upon the earthworms' activities. Moreover, even the minor remaining 0.8% of this vital gas resource is soon depleted in the open sea (figure).



Oxygen deficiencies in the oceans (from: https://worldoceanreview.com/en/wor-1/ocean-chemistry/oxygen/ "after Keeling *et al*., 2010"; reproduced with permission from Dr Jan Lehmköster, Maribus gGmbH 22 Aug. 2018).

Duursma & Boisson, 1994 also estimated the total amount of CO_2 = CO_2 + HCO_3 + CO_3 in the entire ocean as 2.9 x 10^{18} mol CO_2, a factor 55 times higher than the CO_2 in the atmosphere. They noted that the oceans only contain 0.22% of the world's biomass and discussed issues of climate change claiming that "*the oceans have a very large interface with the atmosphere, amounting to 70 % of the earth's surface* **[sic]** *and a primary productivity which ranges from 30 to 300 g C/m2/yr (Berger et al., 1989)*". Yet the ocean's relative surface area is seriously questioned herein, as is its productivity due partly to lack of sufficient minerals such as iron or nitrogen, thus all productivity estimations are highly speculative and totals rather suspect (figure).

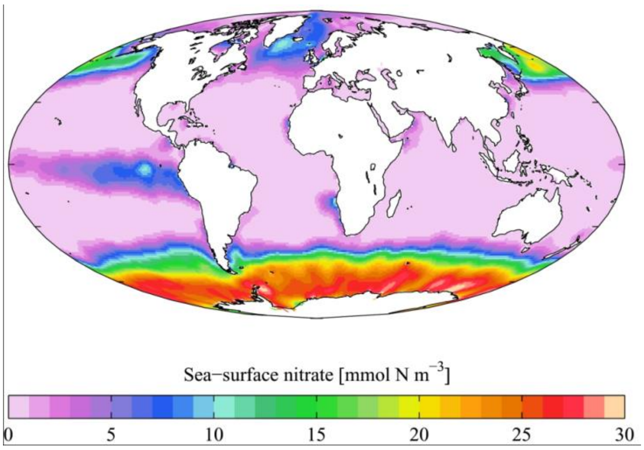
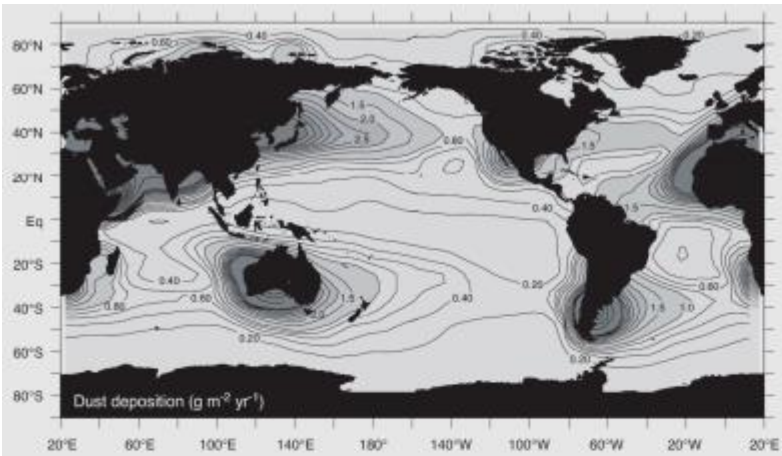


Figure of nitrogen nutrient deficiencies in oceans (https://commons.wikimedia.org/wiki/File:WOA05_sea-surf_NO3_AYool.png).

Even where N is available, other essential components such as Iron may be short as in equatorial Pacific (figure).



(https://en.wikipedia.org/wiki/World_Ocean_Atlas).

Figure of Iron deficiency in ocean, most iron and other minerals relate to wind and water eroded topsoils (https://en.wikipedia.org/wiki/High-nutrient,_low-chlorophyll_regions).

Net Primary Production (NPP)

Net primary production (NPP) is gross primary production (GPP) less respiration in plants, *i.e.*, an effective increase in biomass. Expressed as rate of carbon assimilation per square metre per year, conventional average annual productivity estimates are shown in the figure below and as per the table following:

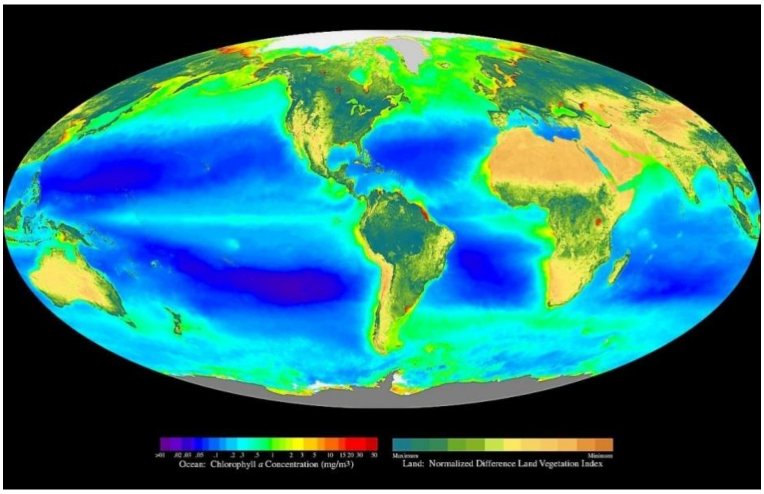


Figure of NPP (https://en.wikipedia.org/wiki/File:Seawifs_global_biosphere.jpg); note that much land is already degraded and that ocean (with a logarithmic scale) is only productive at the coast (due to soil and rock erosion) while even these high terrestrial contributions may be underestimations allowing for terrain undulations and the soil's tortuosity and relief; (see also https://archive.org/stream/ChemistryTheCentralScience/Campbell%20Biology%20-%2010th%20Edition%20%282013%29#page/n1283 figure 55.6 and especially www.napavalley.edu/people/acarranza/Documents/Ecosystems%20Production.pdf fig. 20.10).

Values in the table above were converted from Duursma & Boisson (1994: tab. 2) in mol to grammes by multiplying by atomic mass: for O_2 by x 32, C by x 12, and for C in CO_2 by x 0.273. Carbon total comes to 4.0 x 10^{15} mol or about 47.5 Gt carbon per year (or equivalent to 174 Gt CO_2 if all was burned or respired). Productivity values given by other authors (e.g. Whitman *et al*. 1998: tab. 6 taken from data of "Schlesinger, W. H. (1997) Biogeochemistry (Academic, NewYork), 2nd Ed.") are twice as high at 99 Gt total per year, whilst the satellite-derived Normalized Difference Vegetation Index (NDVI) Field *et al*. (1998) and Stiling (1996) (both quoted in Wikipedia https://en.wikipedia.org/wiki/Primary_production) have 105 Gt (54% from land) and 170 Gt per year (68% from land), respectively. Thus the precedence is to up the variables for terrestrial NPP. All these calculations, yet based upon a flat surface area of the land, are especially contested in the current work. Productivity totals are invariably based upon field surveys of biomes, multiplied by the (flat) area the biome is estimated to occupy. Such approximations are inevitably vague. The current thesis is that they also widely underestimate the terrestrial component due to omission of terrain considerations albeit the land is already proven much more productive that other biospheres (figure).

The data file attached has NPP recalculations for land and ocean of 110 vs. 55 Gt (67% vs. 33%) with just 4.6 Gt from water. Moreover, as noted above, Duursma & Boisson (1994: 135) reported oceanic primary productivity ranges from 30 to 300 g C/m^2/yr despite the oceans only containing 0.22% of the World's biomass. Much of their data is from Berger *et al.* (1989) who gave global ocean productivity at between 25 to 250 g C/m^2/yr to total about 30 Gt C *per annum* and a global respiration range of 4.0–4.3 x 10^{15} mol O_2/yr (= 133.8 Gt O_2/yr), which supports the supposition that respiration is in near equilibrium with the World's production of oxygen by photosynthesis as calculated in the table above at 131.9 Gt *per annum*. UNEP (2002: tab. 1.1) has Ocean vs. Land of 48.5–83 vs. 56.4–90 Pg C (totals 105–173 Gt C). It is noted below that NASA's

(2011) total GPP values are 215 Gt and a ratio of 60% soil to 40% sea rather than oft quoted 50 : 50 or even 40 : 60! NPP estimates are re-evaluated in the Results section.

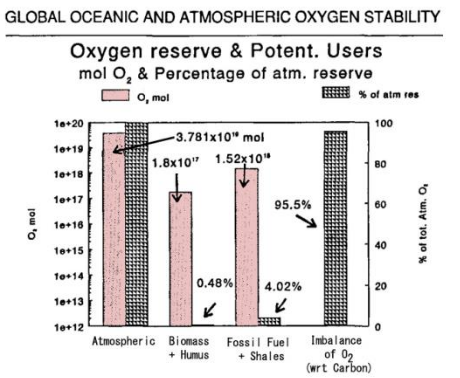
Photosynthesis and Respiration

There exists a 1-to-1 conversion (and *vice versa* by combustion or respiration) of O_2 to CO_2 on a molecular and vol % basis as in this photosynthesis formula showing six molecules of CO_2 producing six of O_2:

$$\underset{\text{Carbon Dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow{\text{Sunlight}} \underset{\text{Glucose (Energy)}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

Respiration in plants, animals, fungi and many microbes is the exact reverse formula, with mitochondria (or cell membrane in prokaryotes) harvesting energy in the form of ATP - adenosine triphosphate. This burns the stored carbohydrates and thus produces more CO_2.

Duursma & Boisson (1994: fig. 5) estimated a potential oxygen equivalent held in the world biomass and terrestrial humus (from Keeling *et al.*, 1993) at 1.8 x 10^{17} mol O_2 (180 x 10^{15} mol = 5,760 Gt or 0.48% of the total atmospheric oxygen mass; the biomass issue is further raised later. The reason for this oxygen detour is to comment on the related imbalance in the oxygen to carbon budget with surplus of >95.5% O_2 (Duursma & Boisson, 1994: fig. 7 – see figure).



World atmospheric oxygen reserves imbalance (95.5 %) is found by subtracting Biom and F.Fuel from Atm. Data (from Keeling et al. *1993).*

Figure of Oxygen imbalance (modified from Duursma & Boisson, 1994: fig. 7). Total global O_2 is about 1,209,920 Gt with its equivalent in CO_2 equal to about 330,308 Gt carbon, with C about (1,520 x 32 = 48,640 x 0.273 =) 13,278 Gt fossil fuels and about 1,586 Gt C in biomass and humus. However, the most likely bulk of the imbalance deficit is loss of ancient organic matter by tectonic subduction in sedimentary rocks (see Duursma & Boisson, 1994: fig. 10).

Global Carbon Cycle and the "Missing Sink" Dilemma

More directly relevant is the carbon "missing sink" imbalance in that, of 7–9 Gt human-induced, excess, annual CO_2 carbon emissions, about 3–4 Gt C per yr accumulates in the atmosphere and another 2 Gt in the oceans, another third (about 3–4 Gt C) is presumably captured on land but is supposedly accounted for neither in extra forest nor savannah growth (https://earthobservatory.nasa.gov/Features/CarbonCycle Sept. 2018; https://enviroliteracy.org/air-climate-weather/climate/the-missing-carbon-sink/). Surprisingly overlooked and underappreciated are the humus and soil biota factors underlying the grass or trees in the World's fertile soils which are the major store of carbon: much more so than superficial vegetation or surface ocean combined. Taking the upper ~4 Gt carbon in CO_2 terrestrial component. To "reverse engineer" the terrain issue, accounting for an extra 4 Gt carbon on land would require this to be added to Duursma & Boisson's estimate of primary production of 21.6 Gt C per annum from 15 Gha land (as noted in table above), *i.e.*, to be raised to 25.6 Gt C or by 18.5% overall. Thus at a fixed productivity rate the compromise terrain would need to be upped to 15 x 18.5% = 17.78 Gha. Three serious initial miscalculations with this are the actual flat land area of terrestrial productivity is a bit less, about 12 Gha, and so to achieve the same result would require a 23% terrain increase; secondly, the terrestrial productivity rates have since been greatly raised; and, thirdly, the on-the-ground measures often employ quadrats that also may underestimate by up to 55% (as was noted above).

Using NASA's alternative figures of 123 Gt C per annum on 15 Gha land, a 4 Gt surplus would require just 3.3% increase in either productivity or for land area to increase to 15.5 Gha. Nevertheless, as a basic terrain allowance on flat land, a 3–23% increment seems justifiable, as is discussed later.

NASA's current convention for carbon cycle is represented in the next figure:

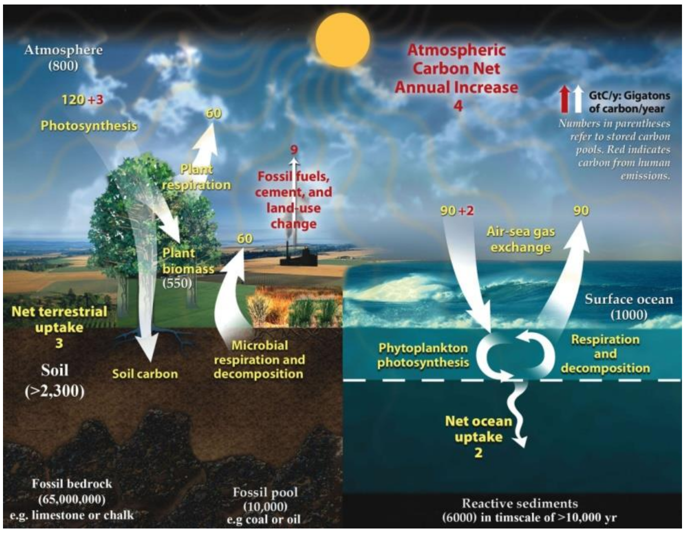


Figure of reactive carbon cycle relating to global warming; modified image from NASA (2011, from US DoE as per Blakemore, 2016a: fig. 4; https://public.ornl.gov/site/gallery/originals/BioComponents_Carbon.jpg) with bedrock component added; terrestrial components are questioned as likely underestimations due to surface undulation and sub-soil factors indicate that productivity is much higher on land.

Note NASA's figure above has annual gross primary productivity (GPP) in soil as 123 Gt vs sea's 92 Gt gas exchange (total 215 Gt), and a ratio of 60% soil to 40% sea; rather than oft quoted 50 : 50 overstating ocean's contribution. These figures show NPP (*i.e.*, GPP-respiration) is 63 Gt C/yr on land but unquantifiable from ocean on data provided. See Biotic C section below.

Relating to Greenhouse Gasses (GHG), the GWP table below shows carbon is the main issue (although these rates were later revised by IPCC):

Table of Global Warming Potential of Gasses from Duursma & Boisson (1994: tab. 3A)

Greenhouse gas GHG	Potentiality (Global Warming Potential)	Emission (1990) Gt	Relative contribution %
CO_2	1	26	61
CH_4	21	0.3	15
N_2O	290	0.06	4
CFCs	1,000s	0.007	9
HCFC	1,500	0.001	0.4
Others			10.6

Relating to carbonization of the atmosphere, the fossil fuel sources from are given by Lal (2008: fig. 1) as coal (3 Gt/yr) then oil (3 Gt/yr) and gas (1.5 Gt/yr). The only proven way to remove CO_2 from the atmosphere (Carbon-capture and Storage or CCS) is via photosynthesis on land and preservation in humus, and how to increase plant growth whilst sustaining yields and biodiversity (and without compromising the soil, the atmosphere or the water with pollutants) is by modern restoration of natural, organic farming (Blakemore, 2000, 2016a, b, 2018a). Permaculture too provides various and flexible means to rebuild soils for farm or forest sustainability whilst providing for all human needs (Mollison 1988).

Nutrients, Biomes and Carbon

Spontaneous generation has long been debunked and, similarly, it is not possible for any higher organism to exist without tangible resources as alluded to above: *viz*. gasses, sunlight, nutrients and habitat. Conventionally, soil nutrients are only considered in terms of simplistic chemicals N-P-K, whereas the proper plant requirements are complex and mainly carbon based, as shown in Permaculture's nutrient-pyramid charted below.

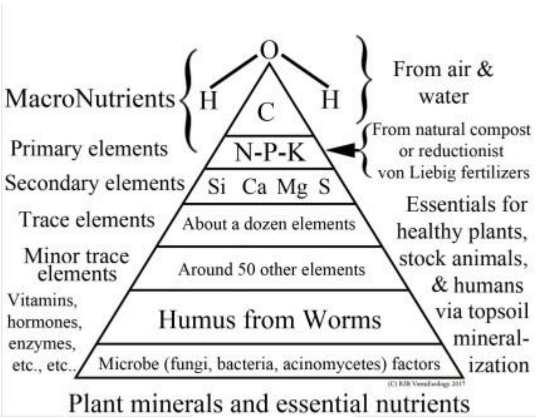


Figure of plant nutrient pyramid (from Blakemore, 2018c - https://vermecology.wordpress.com/2018/05/27/wormageddon-destruction-in-our-soils/); atmospheric N_2 is used by many nitrogen-fixing microbes and is also released by weathering from soils, the rates of which are substantially underestimated without terrain or relief.

Bulk Density (BD), SOC and Topsoil Loss

Total SOC to one metre was recalculated as just 1,061 Gt in a soil area of 12.58 Gha (Köchy *et al.* 2015; tab. 3). Although the argument is somewhat circular as these values are interdependent, yet if two median values – SOC of 1.3% and BD of 1.35 gcm^{-3} – are taken as representative, then this may be compared to global soil stock calculation in order to derive mass and volume (*i.e.*, the bulk density) of global topsoil. If 1,061 Gt represents 1.3% of topsoil mass, then mass of topsoil would total 81,615 Gt. This would give 81,615 Gt on 125,800 m^{-3} = 0.65 gcm^{-3} which is about half of the required soil BD. Thus, since the planimetric area is fixed, then the only way to increase the BD is to increase the terrain to increase the soil mass. An increase factor of at least 2.2 is need, *i.e.*, the surface area must more than double.

Table of current Soil Organic Carbon (SOC) deficit as revealed by bulk density (BD) shortfalls (assuming SOC is 1.3% of topsoil mass on flat surface area of 12 Gha).

SOC(1.3%)	Depth m (Authors)	Soil Gt	Volume Gm^3	Density tm^{-3}	*Cf.* 1.35tm^{-3}
1,500	1 (IPCC, 4p1000, etc.)	115,000	120,000	0.96	x 1.4
1,000	1 (Köchy et al.)	77,000	120,000	0.64	x 2.1
2,300	3 (NASA)	177,000	360,000	0.49	x 2.7
3,000	>3 (Köchy et al.)	>230,000	>360,000	0.64	x 2.1

Shortfall range 1.4–2.8 (both mean and median = x 2.1) shows a need to double land for terrain.

Erosion loss of 75 Gt per year (from Pimental & Burgess, as noted above) if from 166,000 Gt topsoil means that the upper 10 cm (which is where most biological activity occurs) would be eroded in about 200 yrs, the top 5 cm in 100 yrs and superficial 2.5 cm layer in just 50 yrs. In reality, as well as its exposure, the surface soil is less dense with lower bulk density than the subsoil, thus topsoil erosion would be most rapid.

In order to estimate the volume of topsoil and its humic SOM it is necessary to consider soil bulk densities. The Harmonized World Soil Database, for Bulk Density, says: "*The density of quartz is around 2.65g/cm³ but the bulk density of a mineral soil is normally about half that density, between 1.0 and 1.6g/cm³. Soils high in organics and some friable clay may have a bulk density well below 1g/cm³. Bulk density of soil is usually determined on core samples which are taken by driving a metal corer into the soil at the desired depth and horizon. The samples are then oven dried and weighed. Bulk density = mass of soil / volume as a whole.*"

A global average bulk density is thus almost impossible to determine as it is complicated by the exact proportions of soils with different densities that themselves vary spatially and temporally and in particular at depth. Bulk density of soil may range from 1.1 to 2.0 gcm^{-3} (Ref.: 383) and BD typical of mineral soils is given as example as between 1.2–1.8 gcm^{-3} (Köchy, 2015: 352 Ref.) giving a median value of about 1.5, and for highly organic soils (> 20% SOC) between 1.1-1.4 (Köchy *et al.*, 2015: 354) with median value 1.25 gcm^{-3}. However, examples from the Harmonized World Soils Database (HWSD, 2012) have 18 examples each from topsoil (they define as 0-30 cm) and subsoil (30-100 cm) with means here calculated as 1.323 and 1.305, respectively to give average mean of 1.31 gcm^{-3}. Shangguan *et al*. (2014: tab. 4) summarize all

SOC and BD data from HWSD (that they compare to their revision), but only for 0-30 cm topsoil, as shown in the following table.

SOC (%)	Range	<0.2	0.2–0.6	0.6–1.2	1.2–2.0	>2		**TOTAL**
	HWSD	0.3	16.2	41.3	24.8	17.3		99.9
BD (g/cm^3)	Range	<0.4	0.4–0.9	0.9–1.2	1.2–1.4	1.4–1.6	>1.6	
	HWSD	1.2	1.4	7.9	53.4	35.8	0.3	100

This gives approximate median values for SOC of 1.3% and BD of 1.4 gcm^{-3} (that would perhaps be slightly lower at 0-1 m depth). However, Shangguan *et al*. (2014: tab. 4) estimated SOC stock to depths of 2.3, 1, and 0.3 m as 1,922.7, 1,455.4, and 720.1 Gt, respectively, from an "aggregating after" approach. Thus, their total SOC to one metre depth is about twice the 0–30 cm depth value and this suggests doubling the 1.3% average to 2.6% SOC at 0-1 m depth. In contrast, Köchy, 2015: 52 Ref.) recalculated global SOC based upon corrected HWDS's BDs and for highly organic Histosols gave a median BD of 0.1 gcm^{-3} whilst providing the two median BD values given above of 1.5 and 1.25 that themselves have a mean value of 1.375 gcm^{-3}. Lee (1985: 195) assumes a bulk density of 1.4 gcm^{-3} and Whitman *et al*. (tab. 2) give all soils a mean value equivalent to 1.3 gcm^{-3}. Total SOC to one metre they recalculate as just 1,061 Gt globally in a soil area of 12.58 Gha (Köchy *et al.* (2015; tab. 3). Thus, 1.35 gcm^{-3} may be a reasonable global mean value.

Although the argument is somewhat circular as these values are interdependent, yet if two median values – SOC of 1.3% and BD of 1.4 gcm^{-3} – are taken as representative, then this may be compared to global soil stock calculation in order to derive approximate mass and volume (*i.e.*, the bulk density) of global topsoil.

1 ha = 10,000 m^2 thus, to one metre depth, 12.58 Gha is equivalent to 125,800 m^{-3} . Similarly, if 1,061 represents 1.3% of topsoil mass, then mass of topsoil would total 81,615 Gt. This would give 81,615 Gt on 125,800 m^{-3} = 0.65 BD which is about half of the required 1.4 BD, thus, since the planimetric area is fixed, then the only way to increase the BD is to increase the terrain to increase the soil mass. The increase factor is about 2.2, *i.e.*, the land area needs to more than double.

Global soil organic matter ranges from about 1% to 6% of the total topsoil mass for most upland soils. Soils whose upper horizons consist of less than 1% organic matter are mostly limited to desert areas, while the SOM content of soils in low-lying, wet areas can be as high as 90% but these are less extensive (Wikipedia). Possibly a reasonable median value is around 3.5%.

Comparison of HWSD with GSDE has approximately 83.4% of topsoils with SOC range 0.6-2.0 (median about 1.3% but this is for 0-0.3 m depth and should be doubled for 0-1 m depth to 2.6%). And 89.2% topsoils have bulk densities of 1.2-1.6 g/cm^3 with median about 1.4 g/cm^3

(Ref.: tab. 3). This GSDE also estimates global SOC stock to the depths of 2.3, 1, and 0.3 m as 1922.7, 1455.4, and 720.1 Gt, respectively.

The actual relationship between BD and SOC is much more complex (Ref.; figs. 8, 10) but the selected values appear to be within reasonable bounds. More finite resolution of BD and SOC is beyond the scope of the present work which uses these data for conceptual purposes rather than definitive proof. However, the conclusion is that work is yet required to resolve these issues and, unless some better reason is proposed, then terrain and topography may suffice. Indeed, the global calculations of the land contribution to the carbon cycle has long involved a conveniently ignored land discrepancy called the "missing sink" avoided by using only combined oceanic and atmospheric accumulations with the residual attributed to a land component. This will be discussed shortly.

Carbon is converted to SOM by applying a vanBemmelen correction of 2.0 (Ref.) that up until this paper had been unrealistically set at 1.724 (or in reverse its reciprocal of 0.58, now 0.5). Globally soil carbon is estimated at about 1,500 Gt in the top metre and about 2,344 Gt in the top three metres (Blakemore, 2016a, b). Jobbagy & Jackson (2000) give an average of 1,502 Gt in 1 m of topsoil, plus 491 and 351 in second and third metre depths, respectively (total 2,344 Gt). A most recent estimate is of 1,061 Gt SOC in the top 1 m soil (Ref.). Soils occupy 81% of land that is not yet extreme desert, rock, sand, ice, or waterlogged (19%) [Jackson *et al*. (1997: tab. 2)] or roughly 12.1 Gha.

These figures form the basis of a global soil bulk density assessment working from total SOC and presumed area of soil occupied land. The results show discrepancy in either SOC or land area. Since SOC has received much detailed assessment (on the assumption of "flat" area biomes), then the conclusion is that the land area data is inadequate. The most reasonable solution is to make allowance for undulating terrain to increase the actual soil surface area. All measurements of BD used fixed sample volumes and the mass of soil therein is also unchangeable thus the the only variable that can be modified (assuming SOC values are correct) is the surface area of land and the corresponding volume of soil (usually to 0.3 or from 1-3 m depth). Increasing the land area will require recalculation of SOC biome areas and thus increase the total soil volume. The data shows that correction factors of between 1.5 to 2.0 is required, this means increasing land area by between 50 to 100% to normalize the global soil bulk density.

Estimated by Köchy *et al.* (2015; tab. 3) is 1,061 Gt SOC in 1,258 Tm^3 (12.58 Gha) soil and, using their figures, a global soil bulk density is just 0.65 g/cm^3 which is unrealisticaly low.

When direct BD measures are missing, an estimate can be obtained from SOM. Kaur & Kumar (2002 https://www.thefreelibrary.com/A+pedo-transfer+function+(PTF)+for+estimating+soil+bulk+density+from...-a090681700) say: "*Although studies conducted by Saini (1966) and Jeffrey (1970) have shown that OM has a dominating effect on soil bulk density and that it can be used alone as a good predictor of soil bulk density, it has been observed (e.g. Alexander 1980; Huntington et al. 1989; Manrique and*

Jones 1991) that soil texture plays a major role in controlling bulk density where OM is a minor component." A case study from China discusses practical issues (Yi et al. 2016 - https://www.sciencedirect.com/science/article/pii/S1002016015600492).

SOM,BD and Soil Surface

A Fermi approximation for the total soil on Earth may be made based upon the bulk density (BD), given that both the global mass of soil carbon and the volume of topsoil are also provided. A bulk density value can be corrected only by adding mass as the measured volume is constant (**g/cm^3**). The only way to add mass for soil in the real world is by increasing its volume and the only way to do this (since soil sample masses are constant too) is to increase the terrestrial surface area from the current flat 12.1 Gha that topsoil occupies.

Excluding surface leaf litter, topsoils contain on average about 1-6% SOM (Ref.) globally, with median value about 3.5%. If 2,300 Gt SOC is doubled to 4,600 Gt by vanBemmelin factor to SOM, then dry mass of soil (100%) is about 131,000 Gt or 131 Tt. These figures on 12 Gha topsoil land to 3 m depth give bulk densities approximately 0.013 g/cm^3 for SOM and 0.36 g/cm^3 for total soil, respectively, that are much lower than expected mean values (0.1 for SOM and between 1.0-2.0 for most uncompacted soils, with median value about 1.5 g/cm^3 or less). It may therefore reasonably be assumed that the mass of soil on Earth may yet be quadrupled to around 524 Tt to give a BD value of around 1.5 g/cm^3. Although this too is likely an under-estimation given that porosity in productive, medium-textured soils has around 50% voids, thereby doubling the volume and halving the BD (Ref.). The question is: Where is this missing soil mass?

Possibly the simplest explanation is that it is missed from typical assessments that only consider flat-Earth values and that terrain actually greatly increased the volume thus mass. Although, as is noted, BD measurements only consider flat-core soil samples (volumes) thus the actual "on the ground" values are reliable references (unlike for superficial quadrats). It is the total land surface, the soil micro-relief and thus the area of each soil or vegetation type that are apparently widely under-represented in most studies.

Regarding real soil BD, given mean SOC of 1.3% then the old SOC of 3,000 Gt would give total soil mass of 230,769 Gt on 12 Gha to 3 metres depth = BD of just 0.6 gcm^{-3}, about half required 1.35 tm^{-3}; whereas a new SOC of 6,000 yields total soil of 461,538 Gt in same planimetric volume with true BD = 1.3 gcm^{-3} which tolerably matches the required field BD global mean of 1.35 gcm^{-3} (*Q.E.D.*). Conversely, the NASA (2011) figure of 2,300 Gt SOC contained in 12 Gha soil to 3 m depth gives a lower real SOM BD (4,600 Gt / 360,000 m^3) of 0.013 which indicates they underestimate terrestrial soil carbon mass by x 7.7, possibly due to several factors including terrain oversight and other unknown variables likely related to soil depth BD.

Microporosity

At the microporous scale, soil organic matter (SOM) and its colloids are reported to have adsorbic surface area for gaseous exchange of CO_2 of between 94–174 m^2g^{-1} (Ref.: tab. 2, Ref-pdf.) with a mean of **130 m^2g^{-1}**.

How many g in one tonne? (1 million) and times by 130 (130 million Mt^{-1}) but divide by 10,000 to give = 13,000 ha times by 4,600 Gt SOM = 59,800,000 Gha SOM surface area or ~**60 Tha**.

The ratio for mass is 1 t to 130 million m^2, and from bulk density, 1 t SOM has volume of 10 m^3 and apparent area of (31.6 m x 31.6 =) 1,000 m^2 with surface area 130,000,000 m^2 or **13,000 ha t^{-1}** and equivalent to 130,000 m^2 m^{-2} or **13.0 ha m^{-2}** – a difference of 1,000; or 130,000 ha ha^{-1} a difference of just 10.

Then 4,600 Gt SOM x 13,000 ha t^{-1} = 59,800,000 Gha or about **60 Tha**.

The ratio for porosity area is at least 130,000 m^2 m-^{2}or 130,000 ha ha^{-1}. Then, 12 Gha soil x 130,000 ha ha^{-1} = 1,560,000 Gha or about **1.56 Tha**. This is smaller than the mass calculation by a factor of about 38 times.

[END OF BD SECTION FIRST TRY... NOTE THESE FOLLOWING CALCULATIONS MAY BE MIXED>>>]

[BD of this SOM is then 4,600 Gt or 4.6 Tt / 60,000 Tha or 4,600 Gkg/Gha or 0.46 Gkg/Gm2. The authors estimate 1.1 g/cm3 for their samples. My estimate of global value is equivalent to 4600000 g / 59800 cm2 = 77 g/cm2 but x 3 metre depth or 300 cm = 17940000 thus 4600000 / 17940000 = 0.256 g/cm3 which is entirely reasonable for SOM].

[The ash-free samples' mean external surface area was 0.565 m^2 g^{-1} thus the ratio is about 130 m^2 g^{-1} / 0.556 m^2 g^{-1} gives a factor of 234 times for external to internal surface area. Given 12 Gha area to 3 m depth = 36 Gha x 230 factor = **8,424 Gha** surface area of SOM].

[The external ash-free basis surface area of the samples upon which these values are derived average about 0.0556 m^2 g^{-1} (Ref.: tab. 1) and the solid phase densities average about 1.1 g cm^{-3} (Ref.: tab. 2) that is about one million grammes per cubic metre (or 1 t m^{-3}). Thus the ratio is approximately (130 m^2 / 0.0556 m^2 =) 2,332 m^2 m^{-2} or **2,332 ha ha^{-1}** on sample ash-free surface area. Or, from SOM sample density per gramme, assuming one cm^3 has a base area of about 1 cm^2 and surface area of about 6 cm^2 or 0.0006 m^2 g^{-1} (whether square or cylindrical – Ref.) then 130 m^2 / 0.0006 m^2 = 216,666 m^2 m^{-2} or **216,666 ha ha^{-1}** on sample dry mass BD].

[An alternative calculation is possible from soil bulk density (BD). As the average BD of peaty SOM (as used for the surface area estimations) is around 0.1 g cm^{-3} (Ref.: 354), then one gramme of SOM with volume of 10 cm^3, if square, may have a side of 2.15 cm and a footprint (2.15 x 2.15 =) of ~4.6 cm^2; or if cylindrical an external surface area flat (3.16 x 3.16 cm) or circular (r = 1.78) an area of 10 cm^2. Thus the SOM surface area per flat m^2 is at least (10,000 cm^2 / 10 cm^2 x 130 m^2 =) 130,000 m^2 m-^{2}or 13.0 ha m^{-2} or **130,000 ha ha^{-1}** that is multiplied by 12 Gha soil "flat-Earth" area to give 1,560,000 Gha or **1.56 Pha**].

And because BD 0.1 g cm^{-3} is the same as 0.1 t m^{-3} (Ref.) then, because one tonne has 13,000 ha area, then one tenth of a tonne has 1,300 ha and, as a cubic metre has surface area of at least 1 m^2 x 130,000 m^2 m-^{2}= 130,000 m^2 or 13,000 ha, then one tenth is also 1,300 ha [QED].

Globally, about 81% of flat-Earth, or 12 Gha, supports topsoil the SOM of which may have a surface area of about (130,000 **ha ha^{-1}** x 12 Gha) = 1,560,000 Gha or **1.56 Pha**.]

It is also possible to extrapolate from NASA (2011) value of 2,300 Gt soil organic carbon (SOC) and, since SOM = 2 X SOC, thus there is about 4,600 Gt SOM. This value is for 0–3 m with earthworm burrows largely responsible for the porosity of the soil to such depth. If one gramme has area of 130 m^2, and as there are 1 million grammes in a tonne, then a tonne will potentially have surface area of 130 million m^2 or **13,000 ha t^{-1}** x 4,600 Gt = ~60 Pha [as above].

If internal surface area of each gramme is 130 m^2 then each tonne has 130 million m^2 or 13,000 ha t^{-1}. Thus (4,600 Gt x 13,000 ha t^{-1}) = ~**60.0 Pha** SOM surface area, even without four-fold increase for topographical relief and a recalculated global surface area of 100 Gha.

An alternative calculation is possible from soil bulk density (BD). As the average BD of peaty SOM (as used for the surface area estimations) is around 0.1 g cm^{-3} (Ref.: 354), then 0.1 gramme of SOM with volume of 1 cm^3, if square, has side of 1 x 1 cm = 1 cm^2; or if cylindrical a footprint of radius 0.565 cm and area of 1 cm^2; or if circular also a radius of 0.565 cm and area of 1 cm^2. Thus the SOM surface area per flat m^2 is at least (10,000 cm^2 / 10 cm^2 x 130 m^2 =) 130,000 m^2 m-^{2}or 13.0 ha m^{-2} or **130,000 ha ha^{-1}** that is multiplied by 12 Gha soil “flat-Earth” area to give 1,560,000 Gha or **1.56 Pha**.

This information allows much speculation on the true extent of the soils surface areas, making a four-fold increase seem even more reasonably acceptable compared to the over 200,000 times micro-surface area for SOM.

From earlier SOM estimates of 6,000 Gt, it appears valid to apply this to get a surface area in the order of 6,000 Gt x 13,000 **ha t^{-1}** = 78,000,000 Gha or **~78 Pha total soil surface area**.

Summary tables:

Table of current Soil Organic Carbon (SOC) deficit as revealed by bulk density (BD) shortfalls (assuming SOC is 1.3% of topsoil mass on flat surface area of 12 Gha).

SOC (1.3%)	Depth m (Auth.)	Soil Gt	Volume Gm^3	Density tm^{-3}	*Cf.* 1.35tm^{-3}
1,500	1 (e.g. IPCC, 4p1000)	115,000	120,000	0.96	x 1.4
1,000	1 (Köchy et al.)	77,000	120,000	0.64	x 2.1
2,300	3 (NASA)	177,000	360,000	0.49	x 2.7
3,000	>3 (Köchy et al.)	>230,000	>360,000	0.64	x 2.1

Shortfall range 1.4–2.8 (both mean & median = x 2.1) shows a need to double land for terrain.

Table summarizes the possible terrain scenarios for SOC at depth (assuming mean BD 1.35 gm^{-3} and SOC of 1.3%).

BD tm^{-3}	Area Gm^2	Factor	Soil Gt	Depth m	SOC @ 1.3%	*Cf.* 1,500 Gt
1.35	120,000	x 1	162,000	1	2,106	x 1.4
1.35	240,000	x 2	324,000	1	4,212	x 2.8
1.35	480,000	x 4	648,000	1	8,424	x 5.6
1.35	720,000	x 2	972,000	3	12,636	(x 4.2 *cf.* 3,000)

If soil weighs between 1.2- 1.7 tonnes per cubic m (https://www.reference.com/science/much-cubic						
tonnes per m3	area Gm3	tot mass Gt	bd	SOC @ 1.3%	For 1,500 Gt	
1.20	120,000	144,000	1.2	1,872	1.2	x
1.70	120,000	204,000	1.7	2,652	1.8	x
Or bcs bd is same as mass, then if BD is the required 1.35 get...						
1.35	**120,000**	**162,000**	**1.35**	**2,106**	**1.4**	**x**
					Q.E.D.	

[End of Bulk Density section].

Arguments for Fisheries Depletion Flounder

More recently, Bar-On *et al.* (2018, Ref) estimated 0.7 Gt carbon in all marine fish. These data however are highly speculative and are at least double the earlier, more reasonable calculations of fish biomass: In essence a Wikipedia article (see https://en.wikipedia.org/wiki/Biomass_(ecology)) quotes global fish biomass sources of 0.8-2.0 Gt fresh weight that Bar-On *et al.* (2018: 34) initially accept, giving fish biomass as "≈***0.3 Gt C (2 Gt fresh weight)***" but they then speculate up to 0.5 mesopelagic fish + 0.15 other fish = 0.65 Gt C total (that they misreport as 0.7 Gt C). Fish wet weight would then be (0.65 x 6.7 =) 4.4 Gt, or more than double all previous calculations. Regarding global ocean fisheries, rates are given by UN's FAO at about 80 Mt per year or 0.08 Gt (just a tidy 10% of the lower total biomass estimate of 0.8 Gt). Another estimate is 95 Mt net yield including 40.4% bycatch (Davies *et al*. 2009: tab. 3) which, for a reasonable 2 Gt total, is about 4.75%. Taking the highest overestimation of fish (4.4 Gt), a total catch of 0.95 Gt is just 2% per annum making fish depletion near negligible. Regardless, marine fish contribution to total global nutrition is also most irrelevant providing less than 1% of total human food per year.

Total life may amount to (791 C x 2) = 1,582 Gt on land, plus (14.2 C x 2) = 28.4 in sea to give (1,582 + 28.4) = 1,610.4 Gt dry weight. As noted herein, the sub-surface biomass (fungi & roots) may double land proportion (1,582 x 2) = 3,164 and terrain may double it again (3,164 x 2) = to 6,328 Gt on land plus 28.4 in sea to give a total of about 6,356.4 Gt dry biomass. If water content is taken as 50% then this value is doubled again to about 12,712.8 Gt plus up to about 16 Gt worms and 2 Gt fish gives a substantial new total for Earth's living, respiring biomass of ~12,730.4 Gt.

Soil, Carbon and Climate Change

Why does soil and soil carbon matter? An immediate answer is that we rely on soil for 98-99.7% of our food, to filter and store water, and for 100% of our timber and natural fibres, so it would be useful to have a measure of just how much soil there is (Ref). This is important as topsoil erosion rates are 1,000-2,000 tonnes per second and soil is also depleted by agri-chemical pollution and urbanization (Ref.). We are rapidly losing this fundamentally vital resource that UN's FAO say may provide only another 50 years or so of harvests. So it may be in our best interests, and in the interests of remaining living organism, to get information straight about hills and soils. Earthworm populations and diversity are especially important for rebuilding healthy topsoils.

Pimental & Burgess (2013: 446) report that the Philippines, where more than 58% of the land has a slope greater than 11%, and in Jamaica where 52% of the land has a slope greater than 20%, soil erosion rates are as high as 400 t/ha/year.

The answer to "How much soil is there on Earth?" is still elusive. From NASA's 2,300 Gt SOC, Blakemore (2016a: 11) estimated 10,000 Gt topsoil SOM but this used the old van Bemmelen (1890) constant (itself recently revised upwards from x 1.724 to x 2.0 - Ref.), and even this is likely an underestimation allowing for glomalin, deep soil data and carbon in fungi, land algae plus living or dead roots (Jackson *et al*., 1997). Ideally, it is well above 10,000 Gt globally if loss from 10% of agricultural land is 75 Gt per year (Pimental & Burgess, 2013: 447), giving us (10,000 / 10 / 75) just 13 years!

Data above should be tempered with knowledge that land degradation due in no small measure to loss of natural soil fertility and excess synthetic Nitrogen (see Rockström *et al*., 2009) costs all of us up to $10.6 trillion each year, but, if sustainable land management was implemented (e.g. organic farming and Permaculture) then we could potentially benefit with $75.6 trillion added to global economy per year through jobs and increased agricultural output (UN's ELD, 2015).

About 2,350 years ago Aristotle told us the Earth was **not** flat and he also concurred with Plato in recognizing that soil erosion and loss of humus and earthworms (that he called the "*intestines of the earth*") is catastrophic to civilization (Ref.). Leonardo daVinci's observation 500 years ago that "*We know more about the movement of celestial bodies than about the soil underfoot*" seemingly still rings true. And NASA seems to be more distracted by Mars, Venus or on some other blue dot many light years away, so why worry about a bit of dirt on Earth?

Geomorphometry or geomorphometrics is a rapidly developing field. The challenge now is for professional geomorphometricists geographers or astronomers with the resources to provide more down-to-Earth topographic relief values, starting from sea-level up.

For background, see Blakemore (2010, 2012, 2015, 2016a, 2016b, 2016c, 2016d, 2017a, 2017b – and in prep) in peer-review and blog publications giving examples, rationale and references.

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Google Drive shared link (earlier version) - https://drive.google.com/file/d/0B1FEBK_Ori41NUltcXRjdDRKM2c/view?usp=sharing.

NEED to add all those data that i did find for terrain from China where mountains and hills account for 65% of the total (flat) land area, Bhutan and Switzerland,

Plus the soil tortuousity data.

The latest calculations by NOAA give an average height of land above MSL as 797 m (this also certainly an underestimation as their scale of calculation is 1 arc-minute digital representation (1 arc-min resolution corresponds to about 1.8 km postings according to Wikipedia - https://en.wikipedia.org/wiki/Global_Relief_Model, i.e., this scale is too coarse to realistically account for land topographical undulations) to accuracy of one meter altitude but with an error margin of no better than 10 metres that also "*does not resolve meter-level variations*" – https://ngdc.noaa.gov/mgg/global/etopo1_surface_histogram.html, figs. 1, 2). Moreover, NASA/NOAA only report a flat earth total surface area (e.g. Mt Fuji and all other Japanese mountains are counted as flat and only the 2-dimentional surface area is reported as the total land area for Japan). Presumably all flat areas are at mean sea level since their study states "*all originally referenced to sea level*" (https://ngdc.noaa.gov/mgg/global/relief/ETOPO1/docs/ETOPO1.pdf). The current study is only concerned with topography not bathymetry as most life, most productivity, and certainly most human requirements for survival come from the land which is almost entirely above sea level.

NOAA's figure is reproduced here (with permission 22 August, 2018):

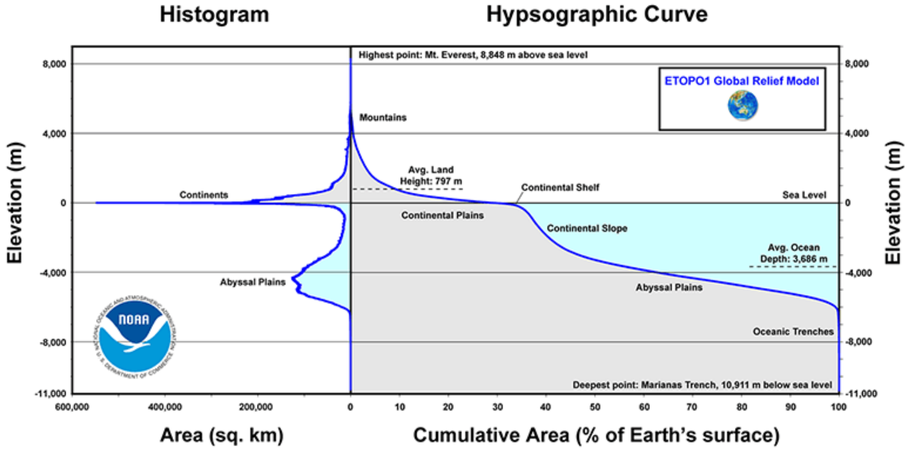

Figure 1: Global histogram and hypsographic curve of Earth's surface from [https://ngdc.noaa.gov/mgg/global/etopo1_surface_histogram.html fig. 1](https://ngdc.noaa.gov/mgg/global/etopo1_surface_histogram.html). (Modified, with permission, from Eakins, B.W. and G.F. Sharman. Hypsographic Curve of Earth's Surface from ETOPO1, NOAA National Geophysical Data Center, Boulder, CO, 2012). Note that the planet's largest habitat, the atmosphere, extends up to 100 km; the ocean is only productive in (at most) the top 100 m) and that the estimate of land area, and hence % or Earth's surface totally ignores topography, *i.e.*, that the land is hilly and thus more area is exposed to sunlight and gas exchange and provides more habitat.

Wikipedia says: The pedosphere is the outermost layer of Earth's continental surface and is composed of soil and subject to soil formation processes. The total arable land is 10.9% of the land surface, with 1.3% being permanent cropland.[132][133] Close to 40% of Earth's land surface is used for agriculture, or an estimated 16.7 million km2 (6.4 million sq mi) of cropland and 33.5 million km2 (12.9 million sq mi) of pastureland. See Our Wold in Data too....

Sun's energy is dissipated by the atmosphere but much more so by the hydrosphere. This study concerns the interface between the atmosphere and the land surface of the Earth that is the most exposed to sunlight.

Urban (including roads) and waterways each occupy less than 1-2% of total land surface, about the same area as occupied by flat lakes and waterways, and these are therefore rather minor considerations. Most habitable land is vegetated and has a Leaf Area Index.

As a simple example: Mt Fuji that I see from my home is 3.776 km high with mean basal diameter of 38 km (radius = 19 km) and circumference of 123 km giving it a 'footprint' of ca. 1,130 km^2. However, the actual surface area of this near-perfect cone-shaped volcano is 1,156 km^2, or just 1.9% larger than the flat surface area, larger when its curves are considered. Secondary undulations and micro-terrain could reasonably double this again to ~2,300 km^2. Japan is a particularly mountainous country, yet its area is claimed as just 377,900 km ^{2}including 3,091 km^2 inland water such as Lake Biwa to give a flat land area of 374,809 km^2. Were this also quadrupled (x 4) to account for terrain then the actual total undulating land surface is closer to ~1,500,000 km^2 although such a reasonable figure cannot be found elsewhere and Japan is yet classed as a "small" country.

Unflattening the Earth and worms.

It is a remarkable deficit that global estimates of total soil are unavailable since we rely upon it for 99.7% of our food (plus all our timber and fibres) and for filtering all our freshwater. Part of the difficulty is that the actual surface area of land is unavailable, all calculations being based upon 2-dimentional "flat earth" models whereas actual topographical terrain is hilly. The current paper estimates that actual surface area of land is at least double the flat area (ca. 15 Gha) at a macro scale (ca. 1 m resolution) and more than doubled again for the higher resolution (say 1 cm scale) to give a land area of at least 60 Gha. At finer resolutions, which are important for calculations of gaseous exchange and primary productivity, the actual land surface area is much higher. In addition to the topographical terrain of topsoil there is surface

Ecology is the scientific study of interrelationships between organisms (biology) and their environment (the biotic, both living and dead, and abiotic components). A first step to understanding an ecosystem is to catalogue an inventory of its natural biotic resources. Second steps are to report its abiotic reserves and to estimate primary productivity from energy flows. For Earth major resources are the atmosphere, water and soil. Yet while the composition of the first two are reasonably well determined it is surprising that estimates of the vital topsoil resource vary widely and a consensus is wanting. This paper will attempt an estimate of the global soil resource.

Soil covers the fertile surfaces of the planet in much the same way that clothes dress the body or paint covers buildings. A major oversight is that the undulating surface of land is often ignored as a factor when calculating ecosystem areas and most calculations are based upon flat two-dimensional values.

The most important nutrient flows relate, in order of importance, to water, carbon and nitrogen cycles. Applications of recent import are the assessment of global carbon and global biomass using only flat earth values for ecozones, similarly for the estimates of primary productivity for land vs. oceans and the newly reported discovery of natural nitrogen mineralization from rocks.

NOAA sources of topography are apparently only to 30 arc-seconds (~ 1 km2) https://www.ngdc.noaa.gov/mgg/global/etopo1sources.html; and the latest SRTM data at 30 m resolution is also uncompiled (https://www2.jpl.nasa.gov/srtm/). Nevertheless they report (https://www.ngdc.noaa.gov/mgg/global/etopo1_ocean_volumes.html) total surface of the Earth as 510,082,000 sq. km and the oceans cover ~70.9 thus land is 29.1% or 148,433,862 sq. km (14.8 Gha). NASA has land surface area as xxx. National Geographic has *148 million square kilometers*. IPCC has zzz. While the United Nations Statistical Division has total land area of 148,940,000 km2 or 14.9 Gha. (https://en.wikipedia.org/wiki/List_of_countries_and_dependencies_by_area).

CIA factbook – land surface 29.1% or 148.94 million km2 of total 510,072 millon km2- https://www.cia.gov/library/publications/the-world-factbook/geos/xx.html

Productivity image credit: http://www.pinsdaddy.com/primary-productivity-in-ecosystems / ; http://bio1151b.nicerweb.net/Locked/media/ch54/54_04NetPrimaryProduction.jpg

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