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Computing the geobiosphere emergy baseline: A novel approach

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ABSTRACT

We demonstrate a new and novel approach to calculate Earth's geobiosphere emergy baseline (GEB). In this method we use gravitational potential energy dissipated in the generation of Earth's main renewable energy sources. From this gravitational perspective, we recognize three refinements to our understanding of Earths driving energies. First we acknowledge the recent literature suggests that Earth's geothermal energy is from two separate sources, decay of radioisotopes and primordial heat, thus warranting separate solar equivalence ratios (SERs). Second, tidal energy dissipation can be viewed as the loss of Earth's rotational kinetic energy (KE), due to gravitational interaction between Earth/Moon/Sun and frictional forces in Earth's oceans. Seen in this way we draw an equivalence between loss of Earth rotational KE and tidal energy dissipated. Third, Earth's rotational KE and primordial heat are coupled processes of the gravitationally induced accretion of Earth.

The four sources of available energy to the geobiosphere, solar radiation, tidal energy dissipation, primordial heat, and radiogenic heat, are expressed as a ratio of gravitational emergy needed to produce them. After all four sources are expressed by their gravitational transformities, solar equivalences are computed by dividing their gravitational transformity by the gravitational transformity of solar radiation, resulting in solar equivalent ratios. Using solar equivalences, we combine the four sources to express the emergy driving all planetary phenomena. The method yields four different baselines depending on the allocation procedure used to assign gravitational exergy of Earth's accretion to it is rotational KE and primordial heat. The GEBs ranged between 11.1E+24 sej J^{-1} and 13.8E+24 sej J^{-1}.

1. Introduction

In this paper we develop a new approach to computing solar equivalents for the driving energies of the geobiosphere (sunlight, tidal momentum and deep heat). The motivation for this new approach came from a sequence of realizations and questions regarding the present accounting for the GEB:

- First, it is inappropriate to label the ratio of solar exergy to tidal exergy, or solar exergy to geothermal exergy, as a *transformity*. This ratio of sej J^{-1} tidal or geothermal exergy is a 'solar equivalence ratio', rather than 'solar transformation ratio' (Raugei, 2013).
- There are, in the present GEB accounting, no nuclear UEVs (e.g. sej J^{-1} ^{238}U). While most elements and minerals are used for their chemical properties, some elements are used for their nuclear energies. Nuclear fuels are inappropriately characterized by chemical properties (e.g. concentration) if used as a nuclear fuel and therefore when used in this way, their UEVs should be based on their nuclear properties.
- Recognition that the Earth's primordial heat and radiogenic heat are derived from two different sources and have different transformities, calculated on the basis of their transformation of gravitational exergy into heat, as clarified below.
- Recognition that the interaction of gravitational potential of the Earth–Moon–Sun system with Earth's rotational kinetic energy is responsible for the tides. Specifically, Earth's rotation kinetic energy is directly dissipated via tidal friction.
- Finally, we postulated that it might be possible to express solar radiation, Earth's rotational kinetic energy, radiogenic heat and Earth's relic heat in a single quantity, the gravitational potential energy dissipated to produce them.

The new approach in this paper evaluates the gravitational potential energy dissipated in the production of each of the geobiosphere energy sources (sunlight, geothermal and tidal exergy) and then draws an equivalence to solar energy resulting in solar equivalent ratios (SERs) and solar equivalent exergy for each of the driving energies. A basic paradigm being challenged with this approach is that of backwards calculated equivalences

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(Raugei, 2013). Since solar energy in no way actually contributes to radiogenic heat, Earth's relic heat, or its rotational kinetic energy, it is apparent that these do not embody solar exergy and are inappropriately characterized as solar emergy. As is well understood, in the past, computations of Earth's deep heat and tidal energy input involved backwards calculation of equivalents to express each of these sources as solar *equivalent* energy. In this new approach we utilize forward calculation of the gravitational potential energy (GPE) that was dissipated in their production.

Forward computation of the geobiosphere emergy baseline (GEB) requires characterizing a common source of potential energy that generates each of the exergy sources to the geobiosphere. Gravitational potential energy can be shown to be the ultimate source of energy that generates sunlight (the intense pressure generated by the sun's gravity), radioisotopes (extreme temperatures and pressure resulting from gravity collapse of stars), Earth's primordial heat (heat left from the gravity induced Earth formation), and tidal energy (interaction of Earth–Moon–Sun gravitation with Earth's rotational energy). The objective of this approach is to calculate *gravitational transformities* (gej/J) for the geobiosphere sources. From the gravitational transformities (gej/J), solar equivalent energy ratios (seJ/J)[1] can be computed using the ratio of gej/J of sunlight to express each source in common solar energy based units. Once in a common unit (seJ) the sources may be added to express Earth's driving exergy sources as the GEB.

2. Methods

Conceptually the idea is that gravitational potential energy (GPE) is the source for generation of higher quality energy like concentrated heat, sunlight, concentrations of matter, or rotational energy. For our purposes GPE is the lowest quality from which the others can be computed. In a paper on cosmology and emergy, Odum (in Brown et al., 2004) wrote:

> In the vast realm of space, stars and other units that self organize are *gravity produced*. . .. Under the pull of *gravity*, units of matter condense, storing energy and developing structure. The resulting increased *gravity* captures more material. The potential energy of mass falling inward together is concentrated and transformed into heat and energy of rotation. When the *gravity* and temperature are high enough, fusion reactions convert the mass of hydrogen into energy, turning such units into light emitting stars.[emphasis added]

Simply put, we compute gravitational transformities (gej/J) for each of the driving energies of Earth and then using the gravitational transformity of solar radiation, compute solar equivalent exergy (seJ) for the others. Table 1 shows the relationship between the gravitational transformity of sunlight to the gravitational transformity of the other sources τ_R/τ_S yielding solar equivalence ratios[2] (SER) for each source. The following paragraphs outline the methods and assumptions necessary for these equivalence calculations.

Table 1
Summary of proposed relationship between the gravitational transformity of and the SERs of the remaining exergy sources to the geobiosphere.

Geobiosphere energy source	Transformity symbol[a]	Units	SER (seJ J^{-1})
Sunlight	${}_g\tau_S$	gej/J	1
Radiogenic heat	${}_g\tau_R$	gej/J	${}_g\tau_R/{}_g\tau_S$
Primordial heat	${}_g\tau_Q$	gej/J	${}_g\tau_Q/{}_g\tau_S$
Tidal energy	${}_g\tau_K$	gej/J	${}_g\tau_K/{}_g\tau_S$

[a] We define a new gravitational transformity as the gravitational emergy per joule of exergy and use the symbol ${}_g\tau$ to differentiate it from solar transformity.

2.1. Redefinition of geothermal and tidal inputs

2.1.1. Deep heat

To accurately account for Earth's deep heat, primordial heat and heat generated by radionuclides should be accounted for separately. *Deep heat* was the term used in the past for the combined geothermal inputs to the geobiosphere that came from heat stored in the core of the Earth and heat from radiogenic sources. These are independent sources of heat exergy, which are generated from different processes and therefore should have different SERs. As a result, we have separated geothermal inputs to the geobiosphere into primordial heat and radiogenic heat, computing separate SERs for each.

2.1.2. Tidal energy

Gravitational attraction of the Earth–Moon–Sun system interacts with Earth's rotational kinetic energy to produce tides on Earth. Over the years the input of energy to the geobiosphere from this phenomena has been referred to as tidal input, tidal potential, tidal momentum, or tidal energy. The exergy input is relatively well known, about 1.17E+20 J yr^{-1} (Munk and Wunsch, 1998). Most of this exergy is dissipated in the oceans (about 96%) while a small fraction is dissipated in the land masses (4%).

The result of the gravitational "pull" by the Moon (and to a much lesser extent, the Sun), is that kinetic energy of the Earth's rotation is being dissipated, partly transformed into thermal energy and partly contributing to the orbital potential energy of the Moon. Earth's rotation is slowing down and the moon is moving farther away. The relationship between Earth's decreasing rotational KE and tidal exergy is direct. Thus if we compute a SER for Earth rotational kinetic energy, we can then apply this to the tides.

2.2. Gravity produces solar radiation

Siegel et al. (in this issue) developed a method to calculate a gravitational transformity of solar radiation based on the quantity of gravitational potential energy (GPE) that is dissipated in the generation of light. Essentially, the exergy content of solar heat was used to calculate translational kinetic energy of particles that fuse in the sun. Assuming kinetic energy is equal to GPE, only the reference frame changes (according to Einstein), this translational kinetic energy became the numerator in the ratio of gravitational transformity for sunlight. The denominator is the quantity of solar radiation output from the hydrogen fusion reactions responsible for our sun's light.

In large part, the sun's light is produced from what are known as the PPI and PPII fusion cycles (Table 2). The weighted average of the

[1] A note on units. We use different nomenclature for solar equivalent joule (seJ) and solar emjoule (sej). The units of solar equivalent exergy are solar equivalent Joules, abbreviated seJ (note the capital J). The abbreviation of the energy unit, Joule is always capitalized, thus solar equivalent joules are abbreviated using a capital J. A lower case 'j' in sej represents solar emjoules. An emjoule is not available energy, it is a record of available energy previously destroyed, thus we use the lower case "j". The GEB is expressed in seJs (solar equivalent joules) whereas subsequent geobiospheric resources (e.g. wind, rain, fossil fuels, etc.) are expressed in sej (solar emjoules). The distinction is not arbitrary as it clearly integrates the concepts put forth by Raugei (2013) that the independent energies driving the geo-biosphere (i.e. geothermal energy, Earth's tidal energy, or radionuclides) are in no way directly or indirectly a transformation of sunlight. Therefore they do not embody solar energy and are thus more appropriately characterized by equivalences.

[2] When describing the ratio of solar equivalent exergy to exergy the use of the term transformity is incorrect, since transformity is defined as the ratio of solar emergy to available energy (sej/J). Since the solar equivalents of tidal dissipation and geothermal heat are not emergy, it is more correct to refer to the ratio seJ/J as a solar equivalence ratio (SER).

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