Entropy budget of the earth, atmosphere and ocean system*

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Abstract The energy budget in the system of the earth, atmosphere and ocean conforms to the first law of thermodynamics, namely the law of conservation of energy, and it is balanced when the system is in a steady-state condition. However, the entropy budget following the second law of thermodynamics is unbalanced. In this paper, we deduce the expressions of entropy flux and re-estimate the earth, atmosphere and ocean annual mean entropy budget with the updated climatologically global mean energy budget and the climatologically air-sea flux data. The calculated results show that the earth system obtains a net influx of negative entropy ($-1179.3\,mWm^{-2}K^{-1}$) from its surroundings, and the atmosphere and the ocean systems obtain a net input of negative entropy at about $-537.4\,mWm^{-2}K^{-1}$ and $-555.6\,mWm^{-2}K^{-1}$, respectively. Calculations of the entropy budget can provide some guidance for further understanding the spatial-temporal change of the local entropy flux, and the entropy production resulting from all kinds of irreversible processes inside these systems.

Keywords: **system, thermodynamics, energy, entropy flux.**

The earth-atmosphere-ocean system consisting of the atmosphere, land and the ocean continuously exchanges energy and/or mass with its surroundings on the interface, and all these exchanging processes are irreversible. At the same time, there are many dissipative phenomena inside the system. From the viewpoint of non-equibrium thermodynamics, this system is open and dissipative. The two non-equibrium fluids, i.e. the atmosphere and seawater, play the role of work medium. The basic processes controlling the system are the absorption of the solar radiation and the emission of the infrared radiation. In equatorial regions, the system gains a net input of heat from the sun, but loses a net output of heat to the space in the polar regions. This inhomogeneous distribution of heat inevitably brings about all kinds of irreversible processes, and then increases the entropy of the system. In this case, the system would develop to the final equilibrium with complete randomness and disorder as time progresses. However, the system has not yet reached the equilibrium state and will become more and more complex and organized. The main reason for this is the influx of negative entropy, which is responsible for the "self-organization" of the system[1].

In order to understand more of the negative entropy flux and the orderly structure, the state variables of thermodynamics and their corresponding basic principles, including the principles of the mass, momentum, and energy conservation and the law of entropy increase should be employed[2]. The first three principles correspond to the continuity, motion, and energy equations, respectively. Most of the studies on atmospheric and oceanic physics use these three conservation equations as the foundational principles. The fourth principle is the second law of thermodynamics. It is hardly used because it relates to the systemic state variable, entropy, and the irreversible processes inside the system such as diffusion, heat radiation, heat production, chemical reactions, and energy dissipation, etc.

Although several studies have been carried out on the entropy change and entropy production of the global climate system[3~8], and some terse conclusions have also been given in the book of Peixoto and Oort[9], these studies focused more on the entropy of the atmosphere system, less on the ocean system. Therefore, it is necessary to study the thermodynamic characteristics of the atmosphere and ocean system as a global-scale open one which interacts with its surroundings.

In this paper, the background of the entropy for an open system is given. The general expression of the entropy flux density is deduced from the principle of equilibrium radiant in section 1, the calculations of the entropy fluxes using the new expression are pre-

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sented in section 2, and the final section of this paper is the conclusions.

1 Entropy change and negative entropy flux in an open system

Any macroscopic system in nature, living or non-living, is an open thermodynamic system exchanging energy and mass with its surroundings. According to the non-equilibrium thermodynamics[2], the time derivative of the total entropy (η) of the system may be written as the sum of two terms, i.e.

$$d\eta = d_e\eta + d_i\eta, \tag{1}$$

where $d_e\eta$ is the entropy flux due to the interaction between the system and the surroundings, and $d_i\eta$ is the entropy produced by a source associated with irreversible processes or phenomena inside the system. According to the second law of thermodynamics, the generation inside the system is always positive, namely

$$d_i\eta \geqslant 0, \tag{2}$$

where the equality holds for a reversible or equilibrium system, and inequality holds for an irreversible or non-equilibrium process. With this expression, the thermodynamics of irreversible or reversible processes can be identified. For an isolated system having no interaction with its surroundings ($d_e\eta = 0$), the entropy increases with time and finally reaches its maximum when the system achieves an equilibrium state[10]. However, for an open system, because of the energy and mass transfers, when $d_e\eta/dt \leqslant -d_i\eta/dt$, there exists

$$d\eta = d_e\eta + d_i\eta \leqslant 0. \tag{3}$$

Equation (3) indicates that a decrease of entropy of a system means an increase in available energy and an evolution toward a state of greater order, i.e. nonlinear interactions frequently lead to order, dissipative structures through fluctuations[2].

Assuming an open system is in a steady state (namely $d\eta/dt = 0$), then Eq. (1) can be written as

$$d_i\eta/dt = -d_e\eta/dt. \tag{4}$$

Equation (4) indicates that the entropy flowing into the system across the boundaries is equal to that produced by irreversible processes inside the system. In other words, using Eq. (4), we can quantitatively calculate the entropy production by entropy flux indirectly, and understand more of the dissipative processes inside the system.

Although the system is not in equilibrium due to the exchange of mass and energy with the surroundings, we may assume that there exists a state of local equilibrium, so that we can accept the formal relations developed in equilibrium thermodynamics, namely the Gibbs relation

$$d\eta = \frac{dE}{T} + \frac{PdV}{T} - \frac{1}{T}\sum_i \mu_i dN_i, \tag{5}$$

where E, T, P, V, μ_i and dN_i are the internal energy, the temperature of blackbody radiant, pressure, volume, the chemical potential, and the total number of particles of the i-th component, respectively.

2 The entropy budget of the earth-atmosphere-ocean system

The openness characteristic of the earth-atmosphere-ocean system makes it continually exchange energy and mass with the surroundings to get more organisms. For example, in the atmosphere and the ocean systems, there are large- and meso-scale general circulations and global hydrologic cycle processes, etc. In the biosphere system, there is the "Pyramid of life", the highly-structured organic species. All these phenomena and processes depend on the negative entropy flux extracted from its surroundings. If the earth were an isolated system and did not exchange anything with its surroundings, it would inevitably develop to a complete equilibrium and uniform state without any difference with the increase of the entropy.

2.1 The entropy budget equation

The equation of the radiation entropy is still a challenge for many studies, and expressions for such equations are different from each other[5, 11, 12]. Hence, it is necessary for us to deduce the expressions. According to the thermal equilibrium theory[13], the radiant energy flux density (u_r) and the entropy flux density (η_r) of the thermal reservoir are

$$u_r = (\pi^2 T^4)/(15\hbar^3 c^3), \tag{6}$$

$$\eta_r = (4\pi^2/45)(T/\hbar c)^3, \tag{7}$$

where $\hbar$ is the Planck's constant, and c is the speed of light. By combining Eq. (6) with Eq. (7), the relationship between the radiant entropy flux density and the radiant energy flux is

$$\eta_r = \frac{4}{3}\frac{u_r}{T}, \tag{8a}$$

or

$$d\eta_r = \frac{4}{3}\frac{du_r}{T}. \tag{8b}$$

Considering the conservation of energy

$$\frac{\partial u_r}{\partial t} = -\nabla \cdot \boldsymbol{E}_r, \tag{9}$$

where $\boldsymbol{E}_r$ is the radiant energy flux density, substituting Eq. (9) into Eq. (8), the rate of the entropy change $\left(\left[\frac{d\eta}{dt}\right] = [\dot{\eta}]\right)$ of the system can be defined as

$$\left[\frac{d\eta}{dt}\right]_r = \frac{1}{\Sigma}\int\left[\frac{4}{3}\right]\left[\frac{1}{T}\right]\left(\frac{d\boldsymbol{u}_r}{dt}\right)\cdot \boldsymbol{n}\,d\Sigma$$
$$= -\frac{1}{\Sigma}\int \nabla \cdot \left[\frac{4}{3}\frac{\boldsymbol{E}_r}{T}\right] d\Sigma, \tag{10}$$

where the subscript "r" denotes the change of entropy due to radiant energy interactions, Σ, $d\Sigma$ are the surface area of the system and the cell, respectively, and $\boldsymbol{n}$ is the unit vector directed outward the boundaries of the system.

Now, we consider the entropy budget equation for the earth system. Supposing the earth system only exchanges energy with its surroundings, and the surface radiates energy as a blackbody at temperature T_e, then Eq. (10) can be written as

$$\left[\frac{d\eta}{dt}\right]_r = -\left[\frac{4}{3}\right]\frac{1}{\Sigma}\int_\Sigma \nabla \cdot \left[\frac{\boldsymbol{E}_r}{T}\right] d\Sigma$$
$$= -\left[\frac{4}{3}\right]\frac{1}{\Sigma}\int_\Sigma \left[\frac{\boldsymbol{E}_{rs}}{T_s} + \frac{\boldsymbol{E}_{rl}}{T_e}\right]\cdot \boldsymbol{n}\,d\Sigma, \tag{11}$$

where $\boldsymbol{E}_{rs}$ is the short-wave radiant energy flux density, $\boldsymbol{E}_{rl}$ is the long-wave radiant energy flux density, and T_s is the blackbody radiation temperature of the sun's photosphere.

In fact, in a subsystem like the atmosphere or the ocean system, there is not only the radiant energy ($\boldsymbol{E}_{rs}$, $\boldsymbol{E}_{rl}$) exchange, but also the non-radiant energy ($\boldsymbol{E}_{sh}$, $\boldsymbol{E}_{lh}$) exchange with the surroundings. The rate of the entropy change due to energy exchange might be defined more appropriately as

$$\left[\frac{d\eta}{dt}\right]_h = -\frac{1}{\Sigma}\int_\Sigma\left\{\left[\frac{4}{3}\right]\cdot\left[\frac{\boldsymbol{E}_{rs}}{T_s} + \frac{\boldsymbol{E}_{rl}}{T_e}\right] + \left[\frac{\boldsymbol{E}_{sh} + \boldsymbol{E}_{lh}}{T_e}\right]\right\}\cdot \boldsymbol{n}\,d\Sigma, \tag{12}$$

where the subscript "h" denotes the rate of entropy change due to energy exchange including the radiant energy and the non-radiant energy.

There are two reasons for splitting the right-hand side of Eq. (12) into four terms (the short-wave radiation, long-wave radiation, latent heat and the sensible heat): One reason is associated with the transfer's mechanism of the energy, the difference of the radiate temperature. The other reason comes from the factor ("4/3"). As far as the mechanism of energy transfer is concerned, the transfer of the non-radiant energy, including the transfer of sensible heat flux and latent heat flux, is done mainly through fluid motions and/or microscopic particle collisions; while the radiant energy, i. e. the long-wave and short-wave energy, transfer via photons propagate. When the system is in the local equilibrium state, the fluid or the particles carry the local equilibrium temperature, but the photons promulgate in the air with the temperature of the blackbody radiation rather than that of the local equilibrium. Unfortunately, Paltridge did not note this difference and still treated them as the same in studying the entropy of the earth-atmosphere system[4~6]. Grassl pointed out that[14], if the incoming radiation is the solar short-wave radiation, the entropy that the earth system receives should be divided by the temperature of photosphere of the sun rather than that of the earth system. However, at that time, he did not pursue this reasoning in his calculations. Peixoto et al.[7,9] considered the difference in the radiation temperature in the estimate of the global mean entropy budget, but neglected the factor "4/3", the multiplier on the first term of the right-hand side of Eq. (12).

For the ocean system, which exchanges energy and mass with the surroundings, the calculation formulations of the rate of entropy change for the mass interaction can be written as

$$\left(\frac{d\eta}{dt}\right)_m = -\frac{1}{\Sigma}\int_\Sigma \sum_i \frac{\mu_i \boldsymbol{I}_i}{T}\cdot \boldsymbol{n}\,d\Sigma, \tag{13}$$

where the subscript "m" denotes the rate of entropy change due to the mass interactions, $\boldsymbol{I}_i$ is the mass flux of the i-th constituent across the boundaries of system (Σ), and T is the temperature of interface.

Assuming the seawater is composed of pure water and salt, and all the mass exchanging with the environment is only the freshwater, we obtain

$$\left(\frac{d\eta}{dt}\right)_m = \frac{1}{\Sigma}\int_\Sigma \frac{\mu I_0}{T} d\Sigma, \tag{14}$$

where μ is the relative chemical potential difference, and I_0 is the freshwater (precipitation- evaporation) diffused flux.

2.2 Entropy flux of the earth system

For the earth, the sun is the major source of energy, and the other source of nature energy is the geothermal energy. Assume that the geothermal energy is comparatively minor, and all the energy impinging on the earth from the sun is radiated back into space in the form of blackbody radiation. When the earth is in a steady state, the absorption of energy is equal to that of release, namely, the total energy that the earth obtains is zero. According to the Stefan-Boltzmann law of radiation, we obtain

$$F_{\mathrm{solar}} - F_{\mathrm{earth}} = 0, \tag{15}$$

$$F_{\mathrm{solar}} = \int (1-\alpha)\boldsymbol{E}_{\mathrm{sw}} \cdot \boldsymbol{n}\,\mathrm{d}\Sigma = S_0(1-\alpha)\pi R_{\mathrm{e}}^2, \tag{16}$$

$$F_{\mathrm{earth}} = \int \boldsymbol{E}_{\mathrm{lw}} \cdot \boldsymbol{n}\,\mathrm{d}\Sigma = 4\pi R_{\mathrm{e}}^2 \cdot \sigma T_{\mathrm{e}}^4, \tag{17}$$

where F_{solar} and F_{earth} represent the solar radiation of the earth absorbed and the long-wave radiation emitted to outer space from the earth system, respectively, $\boldsymbol{E}_{\mathrm{sw}}$ and $\boldsymbol{E}_{\mathrm{lw}}$ are the short-wave radiation flux density and the long-wave radiation flux density, $R_{\mathrm{e}} = 6.37 \times 10^6$ m is the average radius of the earth, $\alpha \approx 0.31$ is the planetary albedo of the earth, $S_0 = 1367\ \mathrm{Wm^{-2}}$ is the solar constant, $\sigma = 5.669 \times 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$ is the Stefan-Boltzmann constant, and T_{e} is the equivalent blackbody temperature of the earth. The solar radiation flux density and the equivalent blackbody temperature of the earth can be obtained from Eq. (15) through Eq. (17),

$$E_{\mathrm{s}} = (\pi R_{\mathrm{e}}^2 / 4\pi R_{\mathrm{e}}^2)(1-\alpha)S_0 = 235\ \mathrm{Wm^{-2}}, \tag{18}$$

$$T_{\mathrm{e}} = [(S_0/4\sigma)(1-\alpha)]^{1/4} = 254\ \mathrm{K}. \tag{19}$$

Furthermore, we can calculate the solar temperature (T_{s}) by employing the solar constant

$$T_{\mathrm{s}} = (4\pi D_0^2 S_0 / 4\pi R_{\mathrm{s}}^2 \sigma)^{1/4} = 5777\ \mathrm{K}, \tag{20}$$

where $R_{\mathrm{s}} = 6.96 \times 10^8$ m is the average radius of the photosphere, and $D_0 = 1.496 \times 10^{11}$ m is the mean distance from the earth to the sun. Therefore, using Eq. (11) and the radiation energy budget, along with the corresponding equivalent blackbody temperature, the entropy flux density of the earth system becomes

$$\Delta\eta_{\mathrm{earth}} = \eta_{\mathrm{in}} - \eta_{\mathrm{out}} = \frac{4}{3}\left(\frac{E_{\mathrm{s}}}{T_{\mathrm{s}}} - \frac{E_{\mathrm{e}}}{T_{\mathrm{e}}}\right) = -1179.3\ \mathrm{mWm^{-2}K^{-1}}. \tag{21}$$

Obviously, the earth absorbs energy (at temperature 5777 K) from the sun. In order to keep the energy balance, the earth releases energy (254 K) back to the universe. According to the Planck's blackbody radiation law, the wavelength of the energy released to the environment is longer than that of the absorbed. The difference of the radiation temperature and the wavelength ensures that the earth system can obtain a net input of negative entropy. With this negative flux, the earth system can select a new way to become more and more organized and complex. If the sun were replaced by another star with the same radiation energy flux density (the same solar constant) but with a much lower temperature, the wavelength of the emission peak of this hypothetic star would shift toward the infrared spectrum. That is to say, although the radiation energy absorbed by the earth from this hypothetic star is the same as that by the sun, the corresponding negative entropy is less for the hypothetical star. With the cooler star, many processes occurring in the system might develop in a different manner or can not develop at all. For example, it is impossible for plants to maintain the photosynthesis with infrared photons. Therefore, the biosphere (if it exists) in the earth system might be quite different from what it is now.

2.3 Atmosphere system

The atmosphere system (from the top of the mesosphere to the surface of the ocean and the land) is a subsystem of the earth. The exchange of energy and mass makes it more complicated than the earth system itself. As discussed in the previous section, though a number of studies and analyses have attempted to estimate the entropy budget of the atmosphere, the results are subject to considerable uncertainties. In order to give a more accurate calculation, the analysis method of Peixoto[7], together with the updated data given by Kiehl and Trenberth[15], will be used in the present calculation. The results are shown in Table 1.

Generally, the results of our calculations are similar to those of Peixoto et al.[7], but the order of magnitude is quite different, because we use the updated global energy budget data, and introduce the "4/3" multiplier, which they neglected, into the relation of the radiation (energy) flux density and the radiation entropy flux density. In addition, we add the latent heat term into the energy budget to avoid the unbalance of energy.

2.4 The ocean system

Like the atmosphere system, the global ocean system exchanges energy and mass (mainly the freshwater) with its surroundings at the air-sea interface. The entropy flux of the global ocean can be estimated by Eq. (12) and Eq. (14), together with the global air-sea energy and mass flux data from the Southampton Oceanography Center[16]. The energy and the corresponding entropy flux densities of the global ocean system are given in Table 2.

Table 1. Entropy budget of the global atmosphere estimated under the annual mean condition

	Solar radiation	From atmosphere	From cloud	From the earth's surface
Top of the mesosphere	↓ $T = 5777$ K, $E = 235$ Wm^{-2}	↑ $T = 252$ K, $E = -165$ Wm^{-2}	↑ $T = 259$ K, $E = -30$ Wm^{-2}	↑ $T = 288$ K, $E = -40$ Wm^{-2}
	$\dot{\eta} = 4E/3T = 54.2$	$\dot{\eta} = 4E/3T = -873.0$	$\dot{\eta} = 4E/3T = -154.4$	$\dot{\eta} = 4E/3T = -185.1$
	$\sum_i^{\text{Up}} \dot{\eta}_i + \sum_i^{\text{Bottom}} \dot{\eta}_i = -1158.3 + 620.9 = -537.4$ mWm^{-2}K^{-1}			
	Solar radiation	Terrestrial radiation	Sensible heat	Latent heat
The earth's surface	↓ $T = 5777$ K, $E = -168$ Wm^{-2}	↑ $T = 288$ K, $E = 66$ Wm^{-2}	↑ $T = 288$ K, $E = 24$ Wm^{-2}	↑ $T = 288$ K, $E = 78$ Wm^{-2}
	$\dot{\eta} = 4E/3T = -38.7$	$\dot{\eta} = 4E/3T = 305.5$	$\dot{\eta} = E/T = 83.3$	$\dot{\eta} = E/T = 270.8$

The data of the energy budget are from Kiehl and Trenberth[15]. The equivalent temperature T is in the unit of K, the energy flux E in Wm^{-2}, and the entropy flux ($\dot{\eta}$) in mWm^{-2}K^{-1} for each energy component at the top of the atmosphere and at the earth's surface. A positive (negative) sign represents the atmosphere gaining (losing) of the entropy.

Table 2. Heat entropy budget of the ocean system

	Solar radiation	Surface radiation	Sensible heat	Latent heat
Air-sea interface	↓ $T = 5777$ K, $E = 154.72$ Wm^{-2}	↑ $T = 291.5$ K, $E = -53.07$ Wm^{-2}	↑ $T = 291.5$ K, $E = -8.35$ Wm^{-2}	↑ $T = 291.5$ K, $E = -93.30$ Wm^{-2}
	$\dot{\eta} = 4E/3T = 35.7$	$\dot{\eta} = 4E/3T = -242.7$	$\dot{\eta} = E/T = -28.6$	$\dot{\eta} = E/T = -320.0$
	$\sum_i \dot{\eta}_i = -555.6$ mWm^{-2}K^{-1}			

The energy budget and temperature distribution data are from the Southampton Oceanography Center. The units are the same as that in Table 1. The positive (negative) sign represents the ocean gaining (losing) of the entropy.

The results in Table 2 show that at the sea surface, the entropy flux density associated with the downward solar radiation is 35.7 mWm^{-2}K^{-1}, the entropy flux due to the upward long-wave radiation is -242.7 mWm^{-2}K^{-1}, and the entropy fluxes related to the release of the sensible heat and the latent heat are -28.6 mWm^{-2}K^{-1} and -320.0 mWm^{-2}K^{-1}, respectively. Adding all the values of these heat fluxes together, the total heat entropy flux equals -555.6 mWm^{-2}K^{-1}.

Moreover, the ocean system also relates to its surroundings through the mass flux. The sources of the mass are mainly the evaporation and the precipitation. The relationship between the global freshwater flux (E-P) and the sea surface salinity along the latitude can be seen in Fig. 1. From Fig. 1, we can see that in the subtropical regions, excess evaporation makes the ocean receive a net output freshwater flux (apparently a net input of salt flux) at the surface, while in the tropical and the polar regions, excess precipitation (rain or snow) results in a net freshwater input at the surface (apparently a net output of salt flux). The entropy flux related to the mass exchange can be calculated by Eq. (14). The correlative results are shown in Fig. 2.

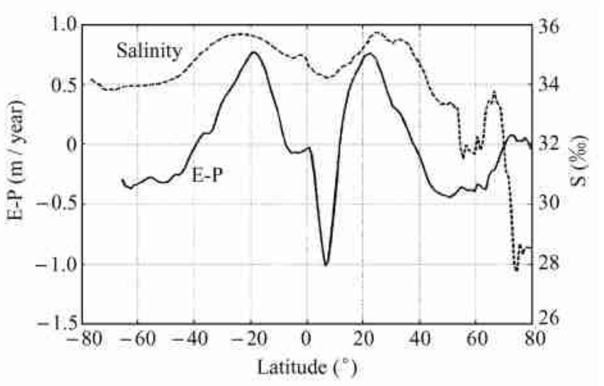

Fig. 1. Zonal averages of the E-P and the sea surface salinity. The energy flux and temperature come from the Southampton Oceanography Center.

From Fig. 2, we can see that the mass entropy flux varies with the evaporation and precipitation of the sea surface. In an excess evaporation region, there is a net negative entropy flux input into the

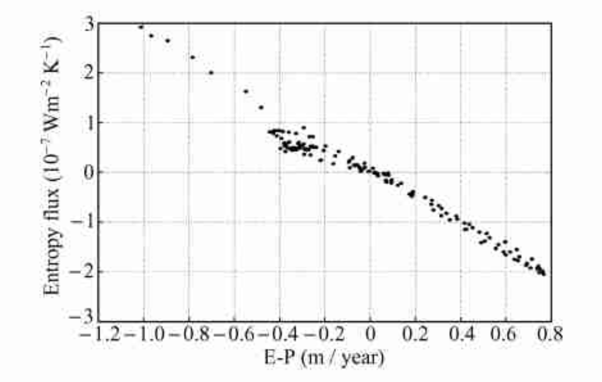

Fig. 2. Scatter diagram of the entropy flux versus the E-P associated with the mass exchange.

ocean, while there is a net output of the negative entropy flux in the region where the precipitation is larger than the evaporation. In general, the total entropy flux associated with the mass exchange on the air-sea interface is about 0.51 mWm^{-2}K^{-1}, which is further smaller than that of the entropy flux due to the energy exchange with the surroundings. Thus, it can be neglected on the entropy budget in the global ocean system.

Finally, a summary of the energy and entropy fluxes for the earth, atmosphere and ocean system is shown in Table 3.

Table 3. Annual mean energy flux and entropy flux budget in the earth-atmosphere-ocean system

System/ interface		Solar radiation	Terrestrial radiation	Atmosphere radiation	Cloud radiation	Sensible heat	Latent heat	Total value
Earth system	Energy flux	235.0	−235.0					0.0
(Above the atmosphere)	Entropy flux	54.2	−1233.5					−1179.3
Atmosphere system	Energy flux	235.0	−40.0	−165.0	−30.0			0.0
(Above the mesosphere)	Entropy flux	54.2	−185.1	−873.0	−154.4			−1158.3
	Energy flux	−168.0	66.0			24.0	78.0	0.0
(At the earth surface)	Entropy flux	−38.7	305.5			83.3	270.8	620.9
Ocean system	Energy flux	154.72	−53.07			−8.35	−93.30	0.0
(At air-sea interface)	Entropy flux	35.7	−242.7			−28.6	−320.0	−555.6

The units are the same as that in Table 1. The positive (negative) sign represents the gaining (losing) entropy for the system.

In general, the earth-atmosphere-ocean system does not accumulate energy, but accumulate negative entropy when it is in a steady state. From the calculations of this paper, the influx of the negative entropy into the earth system is −1179.3 mWm^{-2}K^{-1}, and the negative entropy input into the atmosphere and the ocean systems are −537.4 mWm^{-2}K^{-1} and −555.6 mWm^{-2}K^{-1}, respectively. From the thermodynamic point of view, the negative entropy input offsets the increase of the entropy production for the system to evolve or maintain all kinds of the irreversible processes and phenomena.

3 Conclusions

We have introduced the entropy, the concept of negative entropy flux, and the ability of the system to effectively extract entropy from its surroundings. It is generally accepted that the total energy budget of the system is zero, namely, the system does not accumulate energy when it is in a steady state. However, the difference between the absorbed and released entropy makes the system accumulate negative entropy flux. As a magic "self-organizing force", the influx of the negative entropy (information) is responsible for the creation and organization of all kinds of striking phenomena and processes on the earth.

One of the challenges encountered in the estimate of the entropy flux lies in the definition of the entropy change associated with the energy radiation. In this paper, we correct the relationship between the radiation energy flux and the corresponding entropy flux by considering the difference of the blackbody radiation temperature. At the same time, based on the equilibrium radiation theory, we introduce the "4/3" factor on the right-hand side of the relation, and present the relevant calculations for the earth, atmosphere and ocean systems. The results show that the earth, atmosphere and ocean systems gain a great deal of negative entropy flux, and decrease its entropy by "manipulation" from the environments with the mass and energy exchange. The characteristic of the negative entropy flux driving structure of the system makes it serve as a measure to analyze the formation and evolvement of the dissipative structures inside the system.

It should be noted that the estimates of the entropy budgets in this paper are for the earth, atmosphere and the ocean systems, and the entropy flux of the local region and the entropy production are beyond the scope of the present paper, which we will study further. We consider the study of the entropy flux in the earth, atmosphere and ocean system will play a very important role in a better understanding of the thermodynamic-dynamical mechanisms of many kinds of ordered structures, such as the atmospheric general circulation, the oceanic general circulation, especially the thermohaline circulation inside the system.

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