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Increased Temperature and Entropy Production in the Earth's Atmosphere: Effect on Wind, Precipitation, Chemical Reactions, Freezing and Melting of Ice and Electrical Activity

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Abstract

Since the late nineteenth century, until the present time, there has been an increase in the earth's global mean surface temperature (GMST). This temperature increase has been calculated at 0.85˚C over the period 1880-2012. The causes of this temperature increase include increased levels of greenhouse gases (GHG's), variations in solar irradiance and changes in absorption and re-radiation of heat. Volcanic activity and orbital cycles work to cool the earth's surface. A thermodynamic analysis is presented of the earth's atmosphere. The analysis demonstrates an increase in entropy production as a result of increased GMST. An equation is derived expressing entropy production in the atmosphere based on atmospheric processes (wind, precipitation, chemical reactions, electrical activity and heat transfer). The effects of increased entropy production on wind, precipitation, freezing and melting of ice, chemical reactions and electrical activity are given showing an increase in the combination of the above phenomena.

Keywords

Temperature, Entropy, Earth's Atmosphere

1. Introduction

Since the late nineteenth century, until the present time, there has been an increase in the earth's global mean surface temperature (GMST) [1]. This temperature increase has been calculated at 0.85˚C over the period 1880-2012 [1]. The period 1880 to 2012 is arbitrary. Any period of time from the present (or near present) to a time in the recent past will suffice, provided there is an increase in GMST. ([1]—Chapter 2 provides detailed evidence for global warming). The causes of this temperature increase include increased levels of greenhouse gases (GHG's), variations in solar irradiance and changes in absorption and re-radiation of heat [1]. Volcanic activity and orbital cycles work to cool the earth's surface.

In this paper, a thermodynamic analysis is presented of the earth's atmosphere. This analysis consists of three parts: 1) Derivation of excess entropy produced in the atmosphere due to increased temperature; 2) Derivation of an equation expressing entropy production (in the atmosphere) based on atmospheric processes (wind, precipitation, lightning, chemical reactions and heat transfer); and 3) Proof that there must be an increase in a combination of these atmospheric processes due to increased temperature.

Thus, the aim of this paper is to gain an understanding of the production of entropy in the atmosphere by atmospheric processes, the effect of global warming on that entropy production and, in turn, the effect of global warming on those atmospheric processes.

2. Methods

The thermodynamic analysis of the earth's atmosphere developed in this paper uses theory from the following sources:

- The Clausius inequality ([2], p86)
- The equation for entropy changes $\mathrm{d}S$ as the sum of interior entropy change (d_iS) and external entropy change (d_eS) ([2], p88)
- The equation for local entropy production ([2], p336)
- The equation for entropy production in terms of heat conduction, electrical conduction and chemical reactions and the equation for entropy production in a bilinear form *. ([2], p346)
- The acceleration of a compressible fluid in an inertial frame—the Navier-Stokes equation ([3], pp 97-101)
- The acceleration of a compressible fluid in a rotating frame ([3], p104)
- The viscous force acting on rain (hail) ([3], p51)
- The Theorem of minimum entropy production ([2], p392)
- Air resistance to snow ([4])

**The entropy produced by rain* (*hail*) *or snow and wind is derived from the entropy production in a bilinear form* ([2], p346)

$$\sigma = \sum_{\alpha} \boldsymbol{F}_{\alpha} \boldsymbol{J}_{\alpha} \tag{1}$$

3. Results and Discussion

The higher GMST at the present time (T_2) compared to the late nineteenth century (T_1) is maintained by more heat from solar irradiance being retained in the atmosphere.

That is:

$$\frac{\mathrm{d}Q_2}{\mathrm{d}t} > \frac{\mathrm{d}Q_1}{\mathrm{d}t} \tag{2}$$

Q_2 = Heat absorbed from solar irradiance at the present time

Q_1 = Heat absorbed from solar irradiance in the late 19th century

t = Time

Thus, excess heat production ($\frac{\mathrm{d}Q^*}{\mathrm{d}t}$) occurs at the present time compared to the late nineteenth century, and is given by

$$\frac{\mathrm{d}Q^*}{\mathrm{d}t} = \frac{\mathrm{d}Q_2}{\mathrm{d}t} - \frac{\mathrm{d}Q_1}{\mathrm{d}t} \tag{3}$$

The Clausius inequality states that

$$\mathrm{d}S \ge \frac{\mathrm{d}Q}{T} \tag{4}$$

S is entropy and T is temperature in Kelvins and, therefore,

$$\frac{\mathrm{d}S}{\mathrm{d}t} > \frac{\mathrm{d}Q/\mathrm{d}t}{T} \tag{5}$$

Thus: $\frac{\mathrm{d}S^*}{\mathrm{d}t}$ is the excess entropy produced in the atmosphere at the present time compared to the late nineteenth century.

The entropy produced in the atmosphere is given by

$$\sigma = \sum_{\alpha} \boldsymbol{F}_\alpha \boldsymbol{J}_\alpha \tag{1}$$

$$\frac{\mathrm{d}_i S}{\mathrm{d}t} = \int_v \sigma \mathrm{d}V = \int_v \sum_{\alpha} \boldsymbol{F}_\alpha \boldsymbol{J}_\alpha \mathrm{d}V \tag{6}$$

where:

$\sigma \equiv \frac{\mathrm{d}_i s}{\mathrm{d}t}$ = local entropy production [2]

$\boldsymbol{F}_\alpha$ = forces

$\boldsymbol{J}_\alpha$ = flows

$$\begin{aligned}\frac{\mathrm{d}_i S}{\mathrm{d}t} &= \int_V \left[\overbrace{\rho V}^{1} \overbrace{\left(-\frac{1}{\rho} \nabla p - g\boldsymbol{k} + \boldsymbol{F}_{visc} \right)}^{2} \overbrace{\frac{\rho V \boldsymbol{k}}{t}}^{3} \right] \mathrm{d}V \\ &+ \int_V \overbrace{\frac{m\boldsymbol{k}}{t}}^{4} \left[\overbrace{\left(mg\boldsymbol{k} - 6\pi\eta r\boldsymbol{v} \right)}^{5} + \overbrace{\rho V \left(-\frac{1}{\rho} \nabla p - g\boldsymbol{k} + \boldsymbol{F}_{visc} \right)}^{6} + \overbrace{\left(mg\boldsymbol{k} - \frac{1}{2} \rho C A \boldsymbol{v}^2 \right)}^{7} \right] \mathrm{d}V \\ &+ \int_V \left[\overbrace{\frac{\boldsymbol{I}_K \cdot \boldsymbol{E}}{T}}^{8} + \overbrace{\boldsymbol{J}_u \cdot \nabla \frac{1}{T}}^{9} + \overbrace{\sum_j \frac{A_{2j} v_{2j}}{T}}^{10} \right] \mathrm{d}V \end{aligned} \tag{7}$$

In Equation (7):

ρ is air density

p is air pressure

g is acceleration due to gravity

$\boldsymbol{k}$ is unit vector

$$\boldsymbol{F}_{visc} = \frac{\delta \boldsymbol{F}_{visc}}{\delta V} \tag{8}$$

and

$$\delta \boldsymbol{F}_{visc} = \delta V \eta \left[\nabla^2 \boldsymbol{u} + \frac{1}{3} \nabla \left(\nabla \cdot \boldsymbol{u} \right) \right] \tag{9}$$

$\boldsymbol{u}$ is air velocity

η is the dynamic viscosity of air

m is the mass of rain (hail) drops or snow

$\boldsymbol{v}$ is the rain (hail) or snow velocity

$\boldsymbol{E}$ is the Electric field Strength

$\boldsymbol{I}$ is the ion current density

$\boldsymbol{J}_u$ is the heat flow

T is the temperature in kelvins

A_{2j} is the affinity of the jth reaction

v_{2j} is the rate of the jth reaction

t is time

r is the radius of a rain (hail) drop

V is volume

C is the drag coefficient on snow

A is cross section of the snowflake

1 is the mass of air

2 is the acceleration of a blob of air—the Navier-Stokes Equation

3 is the flow of air

4 is the flow of rain (hail) or snow

5 is the force exerted on rain (hail)

6 is the force exerted by wind on rain (hail) or snow

7 is the force exerted on snow

8 is the entropy produced by lightning

9 is the entropy produced by freezing or thawing of surface ice and precipitation

10 is the entropy produced by chemical reactions

In Equation (7) acceleration

$$a = -\frac{1}{\rho} \nabla p - g\boldsymbol{k} + \boldsymbol{F}_{visc} \tag{10}$$

gives the acceleration of wind in the inertial frame. To obtain acceleration in the rotating frame

$$a = -\frac{1}{\rho} \nabla p - 2\boldsymbol{\Omega} \times \boldsymbol{u}_R - \boldsymbol{\Omega} \times \left(\boldsymbol{\Omega} \times \boldsymbol{r} \right) - g\boldsymbol{k} + \boldsymbol{F}_{visc} \tag{11}$$

where

$$-2\boldsymbol{\Omega}\times\boldsymbol{u}_R$$

Is the Coriolis Force

and

$$-\boldsymbol{\Omega}\times\left(\boldsymbol{\Omega}\times\boldsymbol{r}\right)$$

Is the Centrifugal Force

where

$\boldsymbol{\Omega}$ is angular velocity of the rotating frame

u_R is velocity in the rotating frame

$\boldsymbol{r}$ is distance

And in Equation (7) the acceleration of wind [3] should be replaced by the right-hand side Equation (11).

Entropy produced at temperature T_2 and T_1 is

$$\left(\frac{\mathrm{d}_i S}{\mathrm{d}t}\right)_{T_2} \text{ and } \left(\frac{\mathrm{d}_i S}{\mathrm{d}t}\right)_{T_1} \text{ respectively.}$$

And the excess entropy produced due to increased temperature from T_1 to T_2 is

$$\frac{\mathrm{d}_i S^*}{\mathrm{d}t}=\left(\frac{\mathrm{d}_i S}{\mathrm{d}t}\right)_{T_2}-\left(\frac{\mathrm{d}_i S}{\mathrm{d}t}\right)_{T_1} \tag{12}$$

Using Equation (7)

The excess entropy production must be manifested by a combination of increased wind, precipitation, electrical activity, rates of chemical reactions and freezing and melting of ice. The more global mean surface temperature increases, the more there will be an increase in the combination of wind, precipitation, electrical activity, rates of chemical reactions and freezing and melting of surface ice.

Notes:

1) It is expected that an increase in GMST will result in:

a) Melting of surface ice to predominate over freezing of surface ice

b) Less freezing of precipitation

2) There is increased water holding capacity of air with increased temperature

3) In this paper no account is taken for wind of vorticity or wave motion

In the present work, entropy production (σ) for atmospheric processes are expressed in the bilinear form of forces ($\boldsymbol{F}_\alpha$) and flows ($\boldsymbol{J}_\alpha$)

$$\sigma=\sum_\alpha \boldsymbol{F}_\alpha \boldsymbol{J}_\alpha \tag{1}$$

As stated in the Methods Section, entropy production for heat conduction, electrical conduction and chemical reactions are given in Reference ([2], p346) of the Methods Section. In the case of wind and the effect of wind on rain (hail) or snow, the force acting on these processes is derived from the acceleration of a compressible fluid as given in References ([3], pp 97-101) & ([3], p104) of the Methods Section and the mass of fluid. The flow is given by the mass of fluid and the rate of flowing per time. The force acting on rain (hail) or snow is given by the acceleration due to gravity and the mass of rain (hail) or snow. The flow of rain (hail) or snow is the rate of falling of these substances.

The change of entropy may be expressed as the sum of two parts. $\mathrm{d}S = \mathrm{d}_i S + \mathrm{d}_e S$ (refer to Methods). Where $\mathrm{d}_e S$ is the entropy change, due to exchange of matter and energy with the exterior and $\mathrm{d}_i S$ is the entropy produced by irreversible processes in the interior of the earth's atmosphere. The production of entropy by electromagnetic radiation is not considered as this radiation originates from outside the atmosphere, only interior entropy production in the atmosphere is considered in this paper.

The present study defines entropy production in the atmosphere in terms of atmospheric processes, namely wind, rain, heat transfer, lightning and chemical reactions.

There have been many studies of entropy production in the atmosphere. Nicolis and Nicolis [5] show that decreasing and increasing values of entropy production are possible in the earth's atmosphere. Paillard and Herbert [6] suggest the maximum entropy production principle, generally assumed to be applicable only for stationary systems, could be extended to time-varying climatic problems, provided the internal time scales are small compared to the speed of external changes**.

Paltridge [7] discusses that small-scale convective heat transfer processes (where the preferred steady state mode is one of maximum entropy production) may be applied to the larger earth atmospheric system**. A system of minimum entropy exchange can accurately predict meridional distribution of temperature, cloud cover and energy flux [8]. Other studies postulate maximum entropy production in the atmosphere [9]. There is much debate on the application of maximum entropy production to the earth's atmosphere. [10] [11]. Bannon [12] discusses entropy production and climate efficiency using two representations of climate efficiency. Kleidon, [13] reviews the earth's atmospheric operating far from thermodynamic equilibrium and considers three different case of maximum entropy production. Liu *et al.* [14] have reviewed the concept of entropy and the principle of maximum entropy production in meteorology. Sura [15] considers the earth's atmosphere far from equilibrium, maximum entropy production and non-Gaussian variability about the mean of meridional heat flux and meridional temperature gradient. Marini-Bettolo [16] has described chemical reactions in the atmosphere.

***Minimum entropy production would occur if the atmosphere was in a stationary state*. ([2], p392).

In the current study, heat conduction includes formation of ice, thawing of ice and formation of hail from rain droplets. Also included in heat conduction is heat generated by forest fires, and the burning of fossil fuels and geothermal and volcanic activity.

The present study postulates neither minimum nor maximum entropy production. Rather it calculates entropy production based on atmospheric processes using the bilinear relation.

$$\sigma = \sum_{\alpha} \boldsymbol{F}_{\alpha} \boldsymbol{J}_{\alpha} \tag{1}$$

However, it does postulate increased entropy production as a result of increased global mean surface temperature.

The study undertaken here is analogous to a thermodynamic study of cancer [17]. In that study cancerous tumours are hotter than surrounding normal tissue. Because of the increased temperature of cancerous tumours, there is an increase in entropy production in the cancer, compared to surrounding normal tissue. In the thermodynamic study of cancer [17] the increased temperature and entropy production in cancer are spatial compared to surrounding normal tissue. In the present atmosphere study, the increased temperature and entropy production are temporal.

This paper breaks new ground by deriving expressions for entropy production by wind and rain (hail) or snow based on the bilinear relation:

$$\sigma = \sum_{\alpha} \boldsymbol{F}_{\alpha} \boldsymbol{J}_{\alpha} \tag{1}$$

It also proves that global warming must result in a combination of more severe weather patterns.

The increases in atmospheric processes, postulated in this paper, have been confirmed by observations of more severe weather patterns at present compared with past years [1].

4. Conclusions

In this paper the following theories are developed:

1) The concept of excess entropy production in the atmosphere $\frac{\mathrm{d}_i S^*}{\mathrm{d}t}$ due to temperature increases over a period of time.

2) An equation (Equation (7)) is developed describing entropy production in the atmosphere $\frac{\mathrm{d}_i S}{\mathrm{d}t}$ due to wind, precipitation and the effect of wind on precipitation, lightning, heat transfer and chemical reactions.

3) Proof that, as a consequence of excess entropy production, there must be an increase in a combination of wind, precipitation, lightning, chemical reactions and heat transfer.

A comparison of the increased entropy production of the earth's atmosphere is made with increased entropy production in cancer [17].

Conflicts of Interest

The author, Dr Michael A Pitt, states that there is no actual, potential or perceived conflict of interest in regard to the manuscript submitted for review.

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