Bioved, **30**(1) : 121–123, 2019 http://biovedjournal.org/

The greenhouse effect and earth's energy budget

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Received September 14, 2018 and Accepted December 28, 2018

ABSTRACT : The global energy budget is affected by external changes and internal climate variability as well as atmospheric composition, which mainly relies on the variability of the climate and anthropogenic activity, notably greenhouse gas emissions. More solar energy from sun has entered the top of the atmosphere than the amount of solar energy back in the form of infrared radiation since 1970. The energy imbalance increased over years and for a given energy imbalance, the oceans determine the climate response due to their huge heat capacity. Ocean warming accounts for about 93 per cent of the total excess energy, with the upper 700 metres accounting for 64 per cent of this. The associated temperature increase of the ocean has contributed about 40 per cent of the observed sea level rise since 1970. As a result of energy imbalance, the total mass loss from glaciers has increased significantly around 1970-2009. The loss of ice mass from the Antarctic Ice Sheets and Greenland has increased drastically over the period 2002-2011 compared to 1992-2001. Stabilisation of the energy imbalance would not immediately lead to a stabilisation of the warming. Full equilibrium would be reached in the deep ocean only after thousands of years.

Key Words: Energy budget, greenhouse gases, climate, energy imbalance, atmosphere.

The Earth has gone through intensive climatic alterations as a result of changes to the Earth's energy budget on geological periods. The energy budget is the amount of solar energy entering into the Earth minus the extent of energy leaving the Earth in the form of IR (infrared radiation). It was reported that about 59 per cent of the incoming solar energy is radiated back by atmosphere in the form of thermal infrared energy equivalent. The difference between incoming and outgoing radiation governs whether the planet cools, remains in balance or warms (Marshall and Plumb, 2008). The extent of solar energy absorbed by the system depends on the strength of the solar radiation, the changes in the Earth's orbit around the sun and amount of radiation reflected by the Earth's surface, aerosols and clouds. About 23 per cent of incoming solar energy is directly absorbed by ozone, clouds, aerosols and water vapour. The amount of total radiation which is reflected by earth's surface is called the Earth's albedo, which currently stands at around 30 per cent, but significantly higher albedo would have been observed in ice-house periods. Convection and Evaporation transfer 5 and 25 per cent of incoming solar radiation from the surface to the atmosphere. The outgoing IR emitted exactly balances the absorbed solar energy in case of equilibrium condition leading to an average earth's temperature of minus 18°C (NASA, 2012). Fortunately, the water vapour and other greenhouse gases (GHG's)in the atmosphere trap some of the IR emitted from the Earth's surface. The primary force responsible for the global warming is the greenhouse gases generated by anthropogenic activity, but not the changes in the solar activity (NASA, 2012). The atmosphere is also warmed by evaporation of water from the surface and convection, which therefore releases energy by condensation. As a result, the warmed atmosphere emanates IR both out to space, balancing the incoming solar radiation, and also to the Earth's surface, which warms further. These three processes transfer the equivalent of 53 per cent of the incoming solar energy to the atmosphere.

Effect on surface temperature

Most of the earth's radiation which escapes the atmosphere fall in the infrared band (8 to 11 microns) where the region of the spectrum is called the "atmospheric window". The natural greenhouse effect raises the Earth's surface temperature to about 15ºC on average due to greenhouse effect (Neelin and David, 2011). The back radiation is equivalent to 100 per cent of the incoming solar radiation. The amount of energy radiated from surface always increases faster than its temperature rises and surface radiated energy increases with the fourth power of temperature. As back radiation and solar heating from the atmosphere increases the surface temperature, the surface simultaneously exerts an increasing amount of heat energy which is equivalent to a 117 per cent of incoming solar energy. The net upward heat flow is equivalent to 17 per cent of incoming solar energy, where some amount of heat escapes directly to space, and the rest is transferred to higher levels of the atmosphere until the energy leaving the top of the atmosphere matches the amount of incoming solar energy (Fasullo and Kiehl, 2014).

Energy Imbalance

The magnitude of imbalance in earth's energy is responsible to climate science because it helps in the direct measure of state of climate. The Earth's energy budget can be disturbed by changes in solar energy reaching the top of the atmosphere or sulfate aerosols expelled into the high atmosphere by volcanic eruptions. The energy balance may also be affected by internal climate variability that changes the energy distribution among the components of the climate system, particularly the surface and deep Ocean (Neelin and David, 2011). The concentration of major GHG's in atmosphere such as CO_2 and CH_4 may have a strong influence on the Earth's energy balance. Increased levels of GHG's create a positive net inflow of energy by absorbing some of the outgoing IR emitted by the Earth. This then warms the climate system until the temperature increases necessarily to restore the outflow of IR. Sulphate aerosols produced from burning fossil fuels counterbalance this effect, while black carbon from partial combustion enhances the warming.

The rate at which the earth warms or cools is influenced by the way in which energy is disseminated amongst the various components of the climate system and their heat capacity. The oceans have greater heat capacity when compared to that of land surface and atmosphere, hence the heat flow into or out of the oceans determines the climate response to warming or cooling. The ocean occupies about 71 per cent of the Earth's surface with a total volume of 3.2 x 1017 cubic metres with an average depth of 3.7 km. The upper ocean absorbs more than 71 per cent of the excess energy and southern ocean absorbs to the tune of 12 per cent. The abyssal zone (3000-6000 meters) of the ocean below the surface, absorbs 5 per cent, whereas the ice and land absorbs 8 per cent and 4 per cent, respectively. The top most layer of the ocean (50-100 metres) is well mixed by surface cooling and winds, hence maintains uniform temperature profile in the vertical. Below the mixed layer is a thin layer of water where rapid changes in temperature and other properties prevail, except in high latitudes. As a result of climate change, mixed layer is heated up first and then slowly over many decades, the middle and deep Ocean gets heated up. The extent to which the surface temperature of sea changes depends on the net effect of the rate of energy flow from above and the rate at which heat is exchanged with the colder deep ocean.

Observed changes to the energy budget

As per fifth Assessment Report (AR5) of Intergovernmental Panel on Climate Change (2013), Earth gained considerable energy from 1971-2010, estimated at 274 x 1021 Joules, which is equivalent to the amount produced from more than two hundred thousand 1GW power stations. AR5 reported a projected increase in the Earth's energy (163 x 1021 Joules) from 1993-2010. (IPCC, 2013). Most of this additional energy is stored in the ocean as heat causing ocean warming which accounts for about 93 per cent of the total heating rate, with the upper 700 meters accounting for 64 per cent of this. The accompanying thermal expansion of the ocean has contributed about 40 percent of the observed sea level rise since 1970. Melting of ice is another indicator of this additional energy (Pierrehumbert and Raymond, 2010). Total mass loss from glaciers significantly increased from 226 Gt/year, 275 Gt/year, 301 Gt/year in the period 1971-2009, 1993-2009 and 2005-2009, respectively. The ice mass loss from the Greenland Ice Sheet had been increased by a factor of more than six (34 Gt/year over the period 1992-2001 to 215 Gt/year over the period 2002-2011), whereas average rate of ice loss from the Antarctic Ice Sheet also increased by a factor of five over the same period (IPCC, 2013)

Impact of projected changes in the energy budget

Four scenarios with widely differing GHGs pathways, reflecting varying levels of success in dealing climate change were analyzed by AR5. Among these Representative Concentration Pathways (RCP) scenarios, the lowest, RCP 2.6 is a very strong mitigation scenario, with CO_2 levels peaking by 2050 at ~443ppmv. The atmospheric CO_2 concentration levels at RCP 4.5, RCP 6.0 and RCP 8.5 were likely to reach ~538 ppmv, ~670 ppmv and ~936 ppmv. These RCP emissions scenarios are not predictions but they are plausible future scenarios which can be used as yardstick for scientific research and for policy deliberations (IPCC, 2013).

Climate change due to increased anthropogenic greenhouse gas emissions results in global energy imbalance. The inflow and outflow of energy within the atmosphere determine the state of our climate. The factors which are responsible for an increase in greenhouse gases may be regarded as causes of climate change. Absorption of radiation by the atmosphere's greenhouse gases, is the prime reason for the increasing global temperature and energy imbalance. The increased global temperature have a negative impacts such as increase in temperatures, changes in rainfall pattern, rising sea level, natural disasters, loss of biodiversity etc. To restore the energy budget to equilibrium, the carbon dioxide levels need to be reduced to about 350 ppm. Mitigation of excess greenhouse gases through various means by increasing carbon sinks e.g., through reforestation. The risks associated with human induced global warming can be substantially reduced by mitigation policies.

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