Environment & Climate Change

BY

DR. UPAKUL MAHANTA,

Asst.Prof., Department of Physics,
Bajali College

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Chapter 1

Radiative Forcing

1.1 Introduction

Radiative forcing, a measure, as defined by the **Intergovernmental Panel on Climate Change (IPCC)**, of the influence a given climatic factor has on the amount of downward-directed radiant energy impinging upon Earths surface. Climatic factors are divided between those caused primarily by human activity (such as greenhouse gas emissions and aerosol emissions) and those caused by natural forces (such as solar irradiance). For each factor, so-called forcing values are calculated for the time period between 1750 and the present day. "Positive forcing" is exerted by climatic factors that contribute to the warming of Earths surface, whereas "negative forcing" is exerted by factors that cool Earths surface. In a more quantitative way, Radiative Forcing is defined, as the change in net downward radiative flux at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, while holding surface and tropospheric temperatures and state variables such as water vapor and cloud cover fixed at the undisturbed values. The prime agents for this kind of changes are mainly due to two effects at large. These are

• Insolation and • Albedo

1.1.1 Insolation

Insolation is the solar radiation that reaches the earth's surface. It is measured by the amount of solar energy received per square centimetre per minute.
Insolation affects temperature. The more the insolation, the higher the temperature. In any given day, the strongest insolation is received at noon.

• **Factors affect insolation (without the effect of the atmosphere):**
• Angle of the sun
• Distance between the sun and the earth
• Duration of daylight
The longer the duration of daylight, the more the insolation received per day. However insolation has the effect on earth's atmosphere in the difference scale of the amount of heat incident upon the earth and amount of heat reflected back into the space.

1.1.2 Albedo

Albedo can be defined as a way of quantifying how much radiation is reflected from the surface. It is a comparison between the reflection radiation from the surface to the amount of radiation that hits it. This term also refers to the quantity of radiation generated by electromagnetic rays which consequently reflects away. Mathematically

$$Albedo = \frac{Amount\,of\,heat\,reflected\,back}{Amount\,of\,heat\,incident\,upon} \tag{1.1}$$

Albedo helps us to know how well a surface reflects solar energy. It is measured on a scale of zero to one (0-1). Surfaces differ in absorbent ability but will always be in the range of between 0-1
Value "0" - If a score of zero is given, then the conclusion is that the surface is highly receptive to light, meaning that the surface takes in all the light that comes into contact with it. It is characterized by black surfaces. Value "1" score is evidence that the surface does not absorb incoming light. It is characterized by white surfaces.

1.2 Natural Radiative Forcing & Climate change

Basically there are two major natural radiative forcing are present. These are
• Solar Radiative Forcing and • Volcanic Radiative Forcing

1.2.1 Solar Radiative Forcing

Several natural drivers of climate change operate on multiple time scales. Solar variability takes place at many time scales that include centennial and millennial scales as the radiant energy output of the Sun changes. Also, variations in the astronomical alignment of the Sun and the Earth (Milankovitch cycles will be discussed in the next chapter) induce cyclical changes in radiative forcing, but this is substantial only at millennial and longer time scales. As the Earth is continually bathed in energy from the sun. A portion of the energy that arrives at Earth is reflected back into space, another portion is absorbed directly by the atmosphere, and the remainder moves through the atmosphere to the surface. Sunlight energy heats land and water at the surface, and in turn, they emit heat. This heat provides further warming of the atmosphere. The mix of gases in our atmosphere keeps some of the heat energy from escaping directly to space. This process is the naturally occurring greenhouse effect, and it keeps Earth warm enough to support life.
In accordance with the basic laws of thermodynamics, as Earth absorbs energy from the sun, it must eventually emit an equal amount of energy to space. The difference between incoming and outgoing radiation is known as a planets radiative forcing (RF). In the same way as applying a pushing force to a physical object will cause it to become unbalanced and move, a climate forcing factor will change the climate system. When forcings result in incoming energy being greater than outgoing energy, the planet will warm (positive RF). Conversely, if outgoing energy is greater than incoming energy, the planet will cool, a concept similar to insolation. Currently due to wavelength-albedo dependence, solar radi- ation-wavelength dependence and absorption within the stratosphere and the resulting stratospheric adjustment, the radiative forcing is reduced to about 78%. Thus solar irridance ie amount of sunlight received by the earth is going to alter radiative forcing. Then the major factor effecting the sun's energy throw towards depends upon the following factors.

- Solar Flares
- Solar Prominences
- Coronal Mass Ejections (CME)
- Sunspots

Solar Flare

Sometimes a sudden, rapid, and intense variation in brightness is seen on the Sun. That is a solar flare. A solar flare occurs when magnetic energy that has built up in the solar atmosphere is suddenly released. The most powerful flares are barely detectable in the total solar irradiance. Solar flares affect all layers of the solar atmosphere as well as earth's atmosphere. X-rays and UV radiation emitted by solar flares can affect Earth's ionosphere and disrupt long-range radio communications.

Solar Prominence

A solar prominence (also known as a filament when viewed against the solar disk) is a large, bright feature extending outward from the Sun's surface. Prominences are anchored to the Sun's surface in the photosphere, and extend outwards into the Sun's hot outer atmosphere, called the corona. A prominence forms over timescales of about a day, and stable prominences may persist in the corona for several months, looping hundreds of thousands of miles into space.

Coronal Mass Ejections (CME)

A coronal mass ejection (CME) is a significant release of plasma and accompanying magnetic field from the solar corona. They often follow solar flares and are normally present during a solar prominence eruption. The plasma is released into the solar wind. When the ejection is directed towards Earth and reaches it as an interplanetary CME (ICME), the shock wave of traveling mass causes a geomagnetic storm that may disrupt Earth's magnetosphere, compressing it on the day side and extending the night-side magnetic tail. When the magnetosphere reconnects on the nightside, it releases a large amount of power on the order of terawatt scale, which is directed back toward Earth's upper atmosphere effecting it completely.

Sunspots

Sunspots form on the surface of the Sun due to strong magnetic field lines coming up from within the Sun trough the solar surface and appear visibly as dark spots compared to their surroundings. They are caused by interactions with the Sun's magnetic field which are not fully understood. But a sunspot is somewhat like the cap on a soda bottle: shake it up, and you can generate a big eruption. Sunspots occur over regions of intense magnetic activity, and when that energy is released, solar flares and big storms called coronal mass ejections erupt from sunspots.

All these four factor can significantly change insolation/albedo and solar irridance which can further effect the earth's atmosphere and climate change.

Chapter 2

Milankovitch Cycles

2.1 Introduction

The episodic nature of the Earth's glacial and interglacial periods within the present Ice Age (the last couple of million years) have been caused primarily by cyclical changes in the Earth's circumnavigation of the Sun. Variations in the Earth's eccentricity, Obliquity, and Precession comprise the three dominant cycles, collectively known as the Milankovitch Cycles for Milutin Milankovitch, the Serbian astronomer and mathematician who is generally credited with calculating their magnitude. Taken in unison, variations in these three cycles creates alterations in the seasonality of solar radiation reaching the Earth's surface. These times of increased or decreased solar radiation directly influence the Earth's climate system, thus impacting the advance and retreat of Earth's glaciers. It is of primary importance to explain that climate change, and subsequent periods of glaciation, resulting from the following three variables is not due to the total amount of solar energy reaching Earth. The three Milankovitch Cycles impact the seasonality and location of solar energy around the Earth, thus impacting contrasts between the seasons.

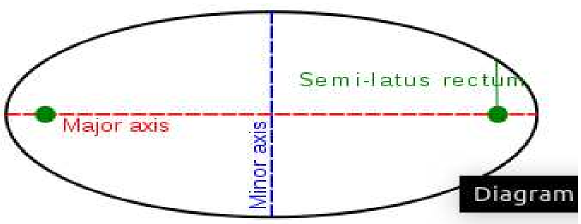
2.1.1 Eccentricity, The first Milankovitch cycle

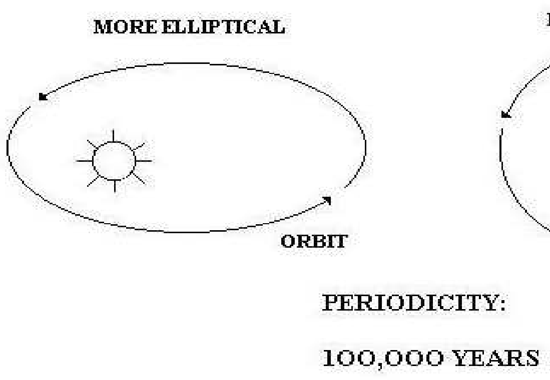
The Earth's orbit approximates an ellipse, ie the shape of the Earth's orbit around the Sun. It was first confirmed by Kepler upon the analysis of Tycho Brahe's data. Eccentricity measures the departure of this ellipse from circularity. The shape of the Earth's orbit varies between nearly circular (with the lowest eccentricity of 0.000055) and mildly elliptical (highest eccentricity of 0.0679).
The first of the three Milankovitch Cycles is the Earth's Eccentricity. The constantly fluctuating, orbital shape ranges between more and less elliptical (0 to 5% ellipticity) on a cycle of about 100,000 years. These oscillations, from more elliptic to less elliptic, are of prime importance to glaciation in that it alters the distance from the Earth to the Sun, thus changing the distance the Sun's short wave radiation must travel to reach Earth, subsequently reducing or increasing the amount of radiation received at the Earth's surface in different seasons.

Mathematically this ecentricity has the following expression.

$$e = \sqrt{1 - \frac{b^2}{a^2}}$$

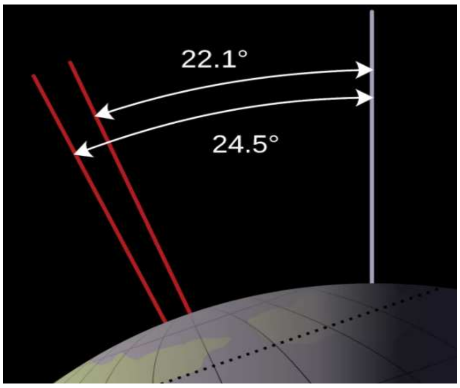
where b is minor axis and a is the major axis. Have a look at the diagram. If a and b are equal then the value of e is zero which means we have circle, otherwise an ellipse.

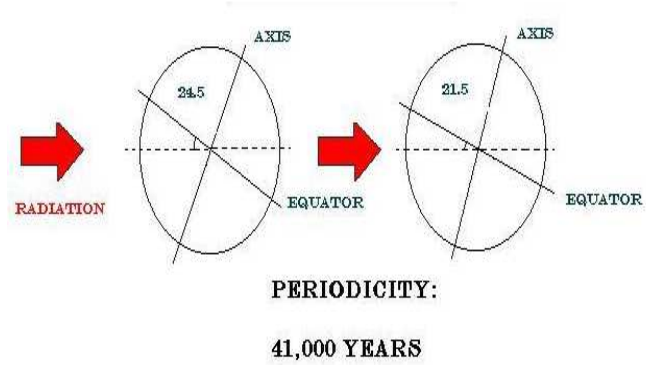




2.1.2 Obliquity, The second Milankovitch cycle

The obliquity or the axial tilt of the Earth's axis relative to the plane of its orbit around the Sun, is the reason that we experience seasons. Slight changes in the tilt changes the amount of solar radiation falling on certain locations of Earth. Over the course of about 41,000 years, the tilt of the Earth's axis,the obliquity, varies between 21.1 and 24.5 degrees. When the axis is at its minimal tilt, the amount of solar radiation doesn't change much between summer and winter for much of Earth's surface and therefore, seasons are less severe. This means that summer at the poles is cooler, which allows snow and ice to persist through summer and into winter, eventually building up into enormous ice sheets. Today the Earth's axial tilt is about 23.5 degrees.





2.1.3 Precision, The third Milankovitch cycle

Aside from the tilt, Precession is the Earth's slow wobble as it spins on axis. This wobbling of the Earth on its axis can be likened to a top running down, and beginning to wobble back and forth on its axis. A complete wobble cycle is more or less 23,000 years. This motion is caused by tidal forces from the Sun and Moon. Precession as well as tilting are the reasons why regions near and at the poles experience very long nights and very long days at certain times of the year. The precession of Earth wobbles from pointing at Polaris (North Star) to pointing at the star Vega. When this shift to the axis pointing at Vega occurs, Vega would then be considered the North Star. Due to this wobble a climatically significant alteration must take place. When the axis is tilted towards Vega the positions of the Northern Hemisphere winter and summer solstices will coincide with the aphelion and perihelion, respectively. This means that the Northern Hemisphere will experience winter when the Earth is furthest from the Sun and summer when the Earth is closest to the Sun. This coincidence will result in greater seasonal contrasts. At present, the Earth is at perihelion very close to the winter solstice.