

# ***INTRODUCTION TO THE SCIENCE OF CLIMATE CHANGE AND THE GREEN HOUSE EFFECT***

***INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH,  
KOLKATA***

***SUSTAINABILITY AND CHEMISTRY: A SYSTEMS APPROACH***

***CH 5106 – LECTURE 1***

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## ***WHY SUSTAINABILITY ?***

- Climate change : Impact on geosphere, atmosphere and hydrosphere
- Green House Gas Emissions
- Energy and material resources needed to drive human activity on Earth
  - Consumption
  - Depletion of natural resources
  - Waste generation and pollution
- Impact of human-made chemicals on the environment and human health (air, water and land)
- The humans-nature conflict ( e.g Zoonotic effect, exploitation of land resources, loss of biodiversity etc)
- The economy-ecology conflict

# ***LECTURE OUTLINE***

- Some key definitions: Weather, climate, climate change, global warming
- The Earth's energy budget and balance
- Nature of solar and terrestrial radiation
- The origin of the “Green House Effect”
- How and why does atmospheric warming vary in time and space and as a function of latitude and height?
- Why does “Green House Effect” cause warming of earth?  
How do Green House Gases trap heat?
- Why some gases contribute to “Green House Effect” and some do not?
- Anthropogenic GHG emissions : Origins and growth
- Measuring carbon dioxide concentration in the atmosphere

## ***LECTURE OUTLINE***

- Global carbon cycles and carbon exchange / redistribution
- Global warming and the impact on the “ocean systems”: Sea-level rise and ocean acidification
- The concept of “Climate Tipping Point”
- Consequences of climate change on the Earth’s systems
- Greenhouse effect, atmospheric concentration of CO<sub>2</sub> and climate change: The burden of proof
- The challenge of Net Zero? Why, how and by when?
- Can we pull the GHGs from the air or at the source of emission?
- How do we decarbonize the planet ? Which segment of the human activity and manufacturing industry emit the most?
- Science and technology challenges for mitigating climate change

## ***ADDRESS THE FOLLOWING QUESTIONS***

- ***What*** has been observed and what is projected?
- ***Why*** do these changes occur , or why are they expected?
- What is the ***timescale*** in which these changes operate?
- What are the ***uncertainty levels***, and ***sources of uncertainty*** ?

# ***WEATHER AND CLIMATE***

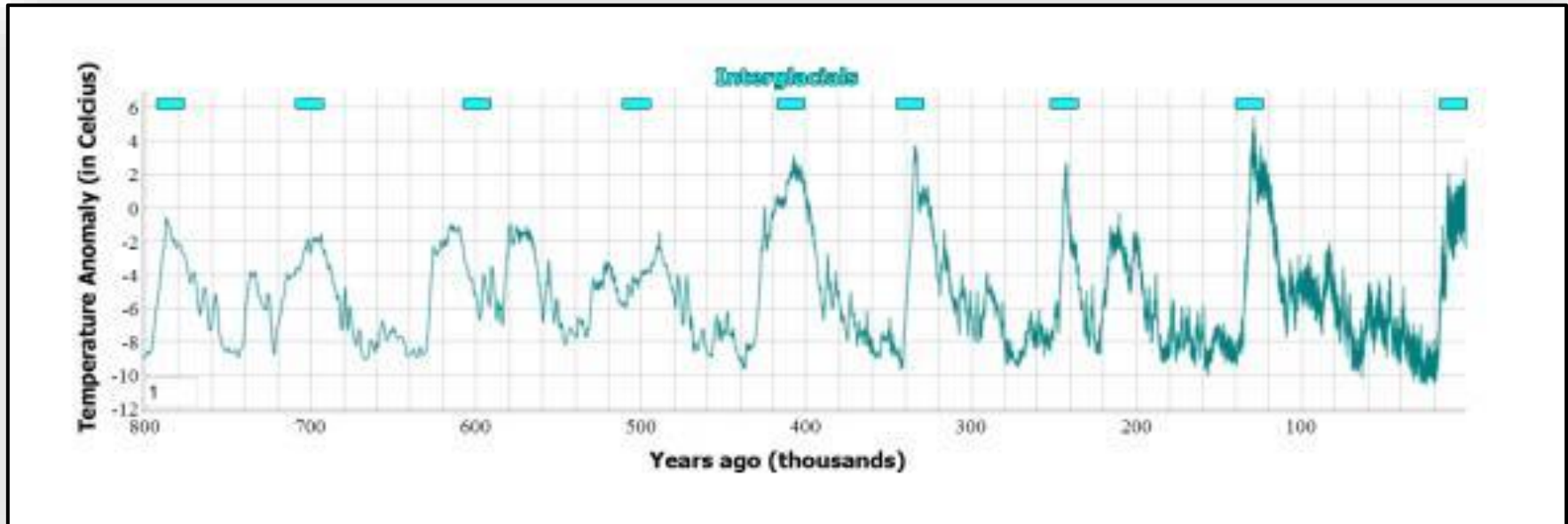
**WEATHER** the state of  
the  
atmosphere  
at some  
place and  
time

Usually expressed in terms of temperature, air pressure, humidity, wind speed and direction, precipitation, and cloudiness

**CLIMATE** the average  
of weather  
elements  
over a  
specified  
period of  
time

30 years according to the World Meteorological Organization)

# ***TEMPERATURE CHANGE IN THE ATMOSPHERE OVER THE PAST 800,000 YEARS***

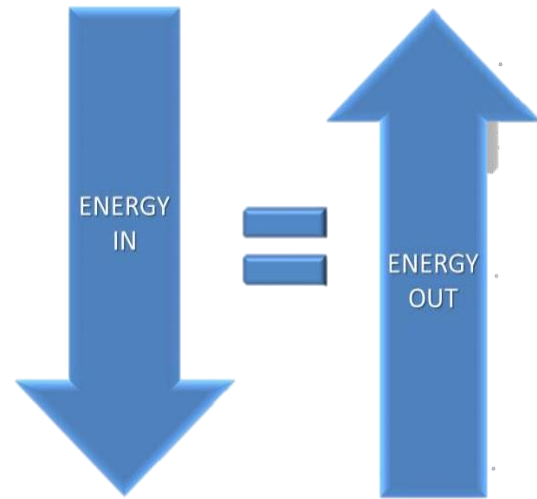


The planet's climate has changed many times over Earth's long geologic history. Over the past million years, Earth has experienced several glacial periods interspersed with interglacial (warmer) periods

The relatively constant and favorable interglacial period of climate experienced over the past 8,000 years has made human civilization's advancement possible

# ***RADIATIVE FORCINGS***

- The planet's global average temperature is determined by the balance of incoming and outgoing energy from Earth
- This incoming solar radiation may be scattered, reflected, or absorbed
- The energy balance may be altered in three ways
  - The sun's intensity may increase or decrease.
  - The reflection of solar radiation by clouds or ice may increase or decrease, causing either more or less radiation to be reflected to space rather than to Earth's surface.
  - The amount of infrared radiation from Earth's atmosphere to space may increase or decrease.



## **The Earth's Energy Budget**

When averaged over the course of a year, the incoming energy from the sun and outgoing energy from Earth are nearly in balance, keeping the average global temperature within the narrow range that supports and sustains life as we know it.

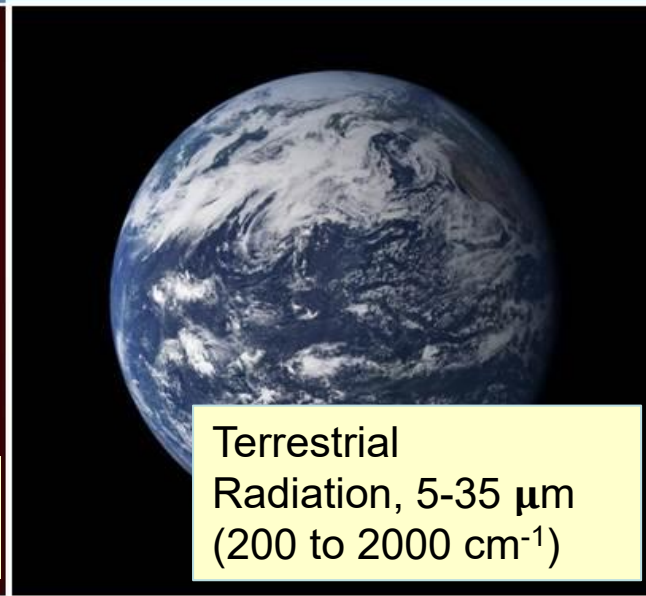
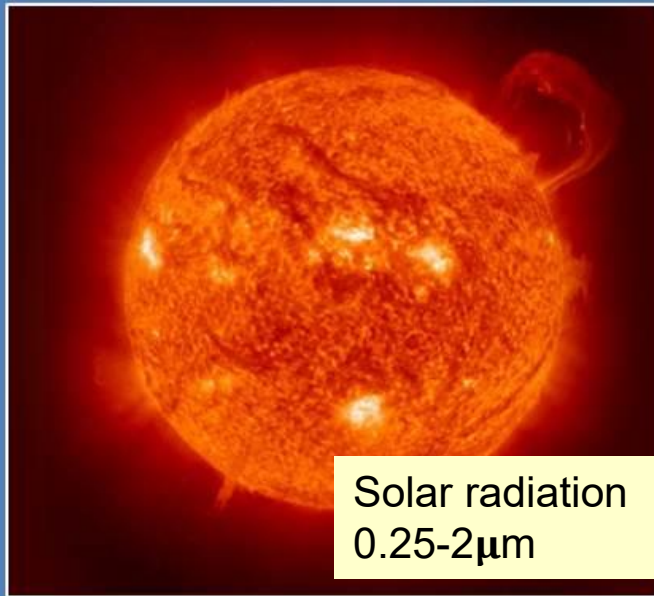
## **SOLAR FORCING**

- The total solar radiation distributed over the entire earth surface is equal to the incoming solar radiation flux per unit area at the top of the atmosphere and is given by the relationship:

**$S_0$  (W/m<sup>2</sup>) X  $\pi \cdot R_E^2$  ( m<sup>2</sup>), where  $R_E$  is the Earth's radius**

- This radiation is distributed over the entire earth surface area ( $4\pi \cdot R_E^2$  ) during one day due to the Earth rotation
- Radiation per unit area :  **$S_0 / 4$**
- The fraction of the solar radiation reflected by ice, clouds land etc. called *albedo*, is denoted by  **$\alpha \sim 0.3$**
- Both the Sun and the Earth emit radiation based on their surface temperature

# RADIATION OF THE SUN & THE EARTH



**SOLAR RADIATION**  
Shorter Wavelength  
(higher frequency) emits  
**MORE ENERGY**



**TERRESTRIAL RADIATION**  
Longer Wavelength  
(lower frequency) emits  
**LESS ENERGY**

Which laws of physics explain the differences in the nature of solar and terrestrial radiation?

## WIEN'S LAW

Wien's law explains the relationship between the object's temperature and the wavelength it emits.

$$\lambda_{\max} = \text{constant}/T$$

“**λ**” (**lambda**) – wavelength at which maximum radiation is emitted

**T** - object's temperature in Kelvin

**Constant** - 2,897 μm (micrometers).

The higher the object's temperature, the faster the molecules will vibrate and the shorter the wavelength will be.

Wein's law explains why the hot sun emits radiation at relatively shorter wavelengths, with the maximum emission in the visible region of the spectrum, and why the cool Earth emits almost all of its energy at longer wavelengths in the infrared region of the spectrum.

# STEFAN-BOLTZMANN LAW

All objects with temperatures above absolute zero (0K or  $-273^{\circ}\text{C}$ ) emit radiation at a rate proportional to the **fourth power** of their absolute temperature ( Black Body Radiation)

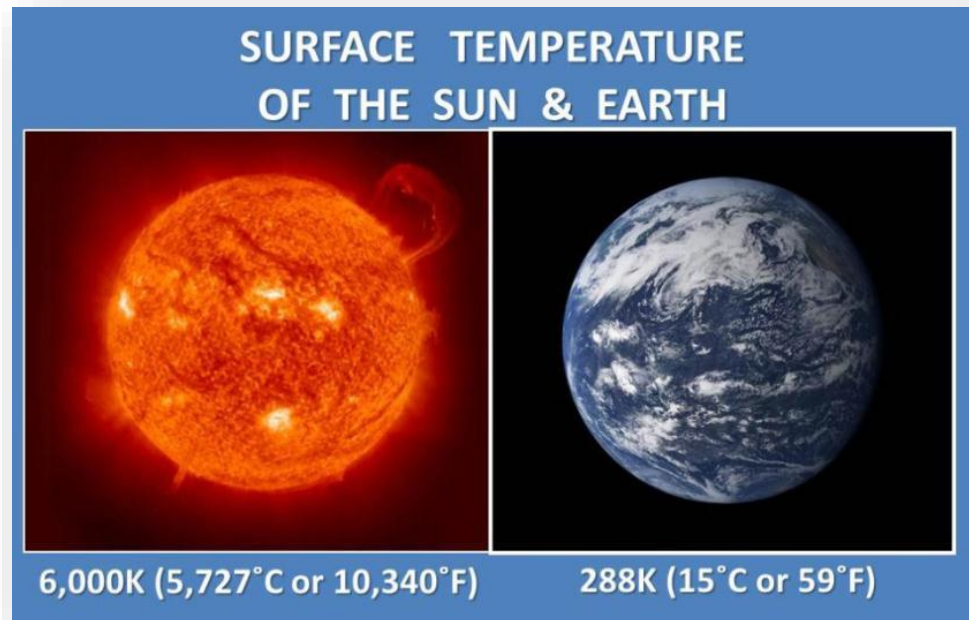
$$E = \sigma T^4$$

E - maximum rate of radiation (often referred to as energy flux) emitted by each square meter of the object's surface.

“ $\sigma$ ” (**sigma**) - the Stefan-Boltzmann constant ( $5.67 \times 10^{-8} \text{W/m}^2\text{K}^4$ )

**W (watt)** - unit used to express power (expressed in joules per second).

**T** - object's average surface temperature in Kelvin.



Assuming the earth to be in thermal equilibrium

$$S_0 / 4 (1 - \alpha) = \sigma T^4$$
$$T = -18^{\circ}\text{C}$$

Actual surface temperature of the earth is  $+14^{\circ}\text{C}$

**Missing Factor : The Greenhouse Effect**

# GLOBAL WARMING SCIENCE

A Quantitative Introduction to  
Climate Change and Its Consequences



ELI TZIPERMAN

Princeton University  
Press, 2022

# Dr. Swaminathan Sivaram

*Professor Emeritus and INSA Emeritus Scientist IISER, Pune and Kolkata  
Former Director, CSIR-NCL, Pune*



## Education & Experience

- ❑ B.Sc. in Chemistry – Madras Christian College, 1965
- ❑ M.Sc. in Chemistry – Indian Institute of Technology, Kanpur, 1967
- ❑ Ph.D. in Chemistry – Purdue University, USA, mentored by Nobel Laureate Prof. H.C. Brown, 1971
- ❑ Research Associate – Institute of Polymer Science, University of Akron, Akron, USA mentored by Prof. J.P. Kennedy, 1971-73
- ❑ Staff Scientist and Deputy General Manager, Research Centre, Indian Petrochemicals Corporation Limited, Vadodara, India, 1973-88
- ❑ Head, Polymer Chemistry Division, CSIR- National Chemical Laboratory, Pune, India, 1988-2002
- ❑ Director, CSIR- National Chemical Laboratory, Pune, India, 2002-10

## Research Contributions

- ❑ Publications: ~260 papers in peer-reviewed journals
- ❑ Books: 2 edited books and 1 authored book
- ❑ Patents: Cited as an inventor in 52 US and European patents, 52 Indian patents
- ❑ Mentorship: Supervised ~45 Ph.D. theses and mentored over 15 postdoctoral fellows in a research career of over fifty years
- ❑ Research Interests: Polymer Chemistry, Sustainable Polymers and Sustainability, Decarbonization and Energy Transition issues and policies

## Selected Awards and Honours

- ❑ Padma Shri, Government of India (2006)
- ❑ Gold Medal, Chemical Research Society of India for lifetime achievement (2019)
- ❑ International Award for Distinguished Contributions to Polymer Science, Society of Polymer Science, Japan (2017)
- ❑ Doctor of Science (h.c.), Purdue University (2010)
- ❑ Distinguished Alumnus Award, IIT-Kanpur (1998)
- ❑ Life-time achievement award, Indian Chemical Society (2015), Indian Plastics Institute (2013), Indian Chemical Council (2009)
- ❑ The Vishwakarma Medal, Indian National Science Academy, New Delhi (2003)
- ❑ CSIR Technology Award in Chemical Sciences (2003)
- ❑ Chemical Research Society of India, Silver Medal, (2002)
- ❑ Shanti Swarup Bhatnagar Fellow, CSIR (2010–2015)
- ❑ J.C. Bose National Fellow, Department of Science and Technology (2006–2014)

## Academic Fellowships and Recognitions

- ❑ Elected Fellow of all the national science and engineering academies in India
- ❑ Fellow, The World Academy of Sciences (TWAS), Trieste, Italy
- ❑ Fellow, Royal Society of Chemistry (RSC), UK
- ❑ Fellow, International Union of Pure and Applied Chemistry (IUPAC)
- ❑ Professor of Eminence in Polymer Science, Somaiya Vidyavihar University, Mumbai; Distinguished Adjunct Professor, Institute of Chemical Technology, Mumbai, India
- ❑ Distinguished Visiting Professor, The King Abdullah University of Science and Technology, Thuwal, Saudi Arabia (2023, 2017); Harold A. Morton Distinguished Professor of Polymer Science, The University of Akron, Akron, Ohio, USA (2006); Elf ATOCHEM Visiting Professor, LCPO, University of Bordeaux, Bordeaux, France (1995)
- ❑ Vice President, Indian Academy of Sciences, Bangalore (2007 – 2012); Chemical Research Society of India (2005-08); Indian National Science Academy, New Delhi (2004-2006); Materials Research Society of India (2004-07); President and Founder, Society of Polymer Science, India (2009-15)
- ❑ Member of the Board of Directors, **Past:** Asian Paints Limited, Deepak Nitrite Limited, GMM Pfadler Limited, Apcotex Industries Limited, Supreme Petrochem Ltd; **Present:** Gharda Chemical Limited, Hitech Corporation Limited, 20 Microns Limited, Thriarr Polymers Limited
- ❑ Chairman, Technology Council, Apcotex Industries Limited, Mumbai; Scientific Advisor, Resil Ltd., Bangalore; Scientific Advisor, Praj Matrix R&D, PRAJ Industries, Pune; Chairman, Technology Council, Asian Paints Limited, Mumbai ;Scientific Advisor, Pashupati Group of Industries, Kashipur, Uttarakhand
- ❑ Consultant: Notark Limited, USA, Expanded Polymers Limited, Mumbai, Greenstone Fund Managers LLP, Mumbai, Atul Limited , Gujarat

# THANK YOU



***If you do not change direction,  
you may end up where we are  
heading: Lao Tzu***

