



The Sun and its Role in Climate Change: a Record from the Horton Plains, Sri Lanka

Dr R. Premathilake



The climate system of the Earth is complex, and is represented by (1) atmosphere, (2) lithosphere (land), (3) hydrosphere (ocean and other water bodies), (4) cryosphere (ice and snow covered land and ocean), (5) biosphere (plant and animal life) and volcanos. The system outline is given in Figure 1, and it seems that all the main components of the system are interconnected. The sun is the major external source of energy for the system. The total power of the sun is about 3.86×10^{26} watts, which radiates out into space. Most of the radiation is in the visible and infrared part of the electromagnetic spectrum, with less amount of energy emitted into the radio, ultraviolet (UV) and X-ray bands. Solar radiation travels through the near vacuum of space from the sun to the earth. Terrestrial radiation is produced mainly as a result of

Understanding climate system

Earth is the only planet we know of that reinforce and allows the evolution of a large number of life forms, including macro and microorganisms, e.g. bacteria, algae, fish, elephants, plants and humans. This is ascribed to the rich abundance of water, which is part of the climate system of the earth, oxygen and carbon forming the basic ingredients of life. It is generally suggested that evolution of life started many million years ago, depending on the

relationship between environment, climate, and organization of each group of life. This formation is largely supported by the earth's surface 'temperature'. In addition, scientists argue that 'water' had played a unique role in establishing the equable climatic conditions, as compared to the existing atmospheric conditions of our neighboring planets, i.e., Mars and Venus. To understand the general climate and environmental situations of the earth, one has to first compare the main components of the Venus and Mass as shown in (Table 1).

Table 1: Explains the atmospheric conditions of Venus and Mass compared to the Earth.

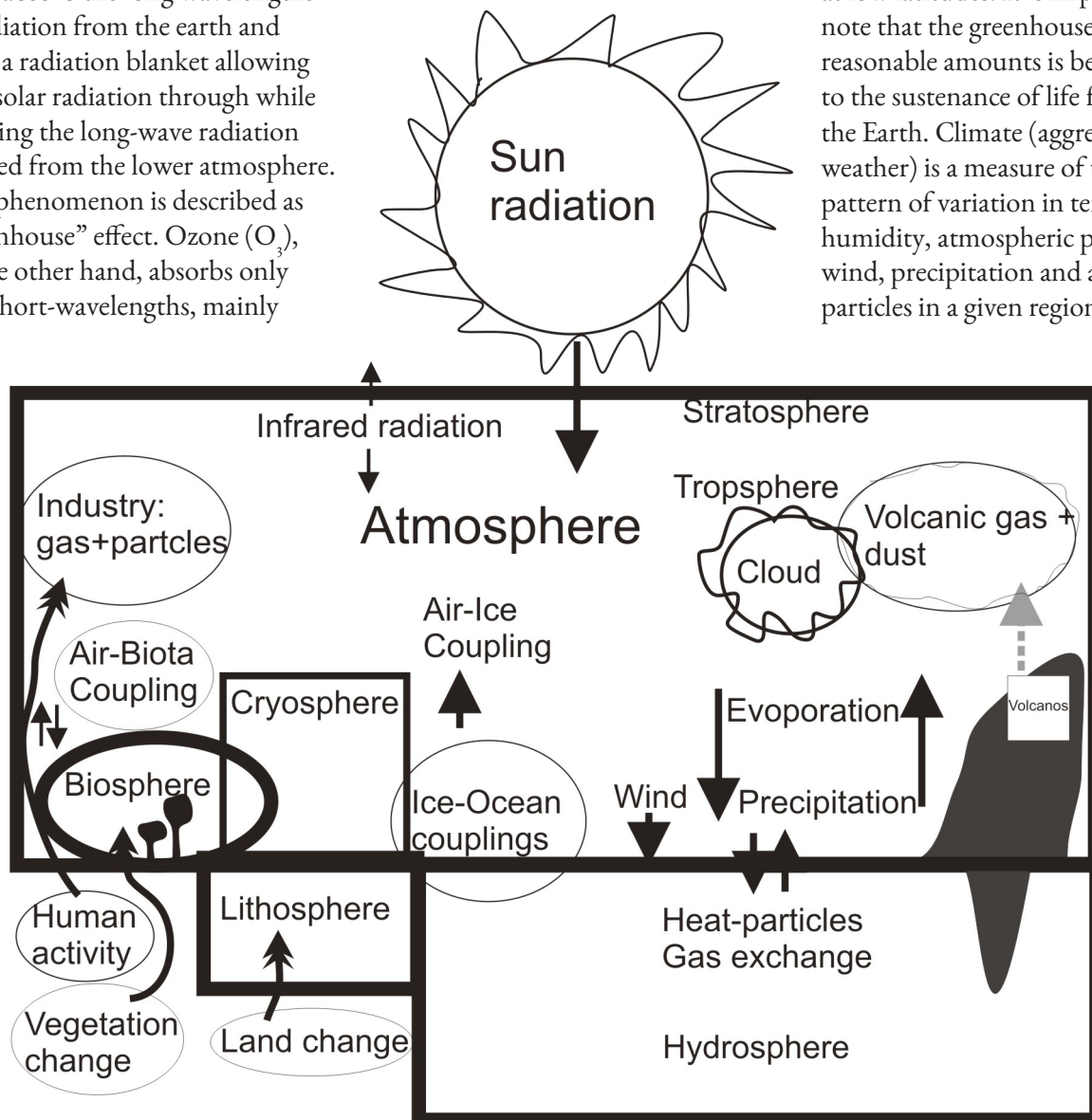
Planet	Mean surface temperature	Surface Pressure	Major constituents	Properties
Venus	476° C	90atm	CO ₂ > 90%	Very thick Co ₂ clouds cover
Earth	15° C	1atm	N ₂ = 78% O ₂ = 20% CO ₂ = 0.03%	Around 50% H ₂ O cloud cover
Mass	-33° C	0.007atm	Co ₂ > 80%	Scattered thin H ₂ O cover

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re-radiation of solar radiation. The energy is absorbed from the sun as the sun's spectrum but re-radiated from Earth at the much long-wavelengths (low energy radiation), associating with the temperature of Earth. Since the atmosphere is more absorptive to such long-wavelength terrestrial radiation, the atmosphere is largely heated. The atmosphere is the central component of the climate system of any planet. Water vapour, carbon dioxide and a number of other gas cover absorb the long wavelengths of radiation from the earth and act as a radiation blanket allowing little solar radiation through while trapping the long-wave radiation emitted from the lower atmosphere. This phenomenon is described as "greenhouse" effect. Ozone (O_3), on the other hand, absorbs only very short-wavelengths, mainly

in the ultraviolet range, and therefore forms a shield of sorts, absorbing much of the harmful ultraviolet radiation before it can reach the earth. Note that the trace gasses that contribute to the greenhouse effect in the Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), ozone (O_3), methane (CH_4), ammonia (NH_3), nitric acid (HNO_3), nitrous oxide (N_2O), sulphur dioxide (SO_2), chlorofluorocarbons (or more generally chlorocarbons e.g. CF_2Cl_2

- trade name Freon 12 and $CFCI_3$ - Freon 11), carbon monoxide (CO) and carbon tetrachloride (CCl_4) (IPCC list). Finally, a balance is maintained between incoming solar radiation and the amount of terrestrial radiation. This is referred to as the heat budget in the system. If this balance is disrupted, the Earth will become progressively colder (glacial/Ice Age condition) or warmer (interglacial/hot) at high latitudes, which corresponds to dry/arid or wet/humid conditions at low latitudes. It is important to note that the greenhouse effect in reasonable amounts is beneficial to the sustenance of life form on the Earth. Climate (aggregation of weather) is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation and atmospheric particles in a given region over



Source: Haris and Stone-house, 1991

Figure 1: Components of Earth's Climate System.

long periods of time. In this regards, overall climate condition is marked by the heat-level in responding to the complex relationship between atmosphere, hydrosphere, cryosphere and biosphere (Figure 1).

It is possible to explain that the high temperature of Venus can thus be attributed to the thick carbon dioxide (CO_2) cloud cover that encompasses the whole planet and acts as a radiation blanket (Table 1). In contrast to Venus, the planet Mars has a thin CO_2 cloud-cover and thus has a low surface temperature. The composition of the Earth's atmosphere given in Table 1 helps to explain the moderate mean temperature of the Earth. The present average earth surface temperature of 15.5°C (60°F) is considered to be close to the optimum for supporting life over the largest possible area on the globe.

Till the 19th century (pre-industrial times), the primary way through which humans contributed to global climatic change was by acquisition of forest lands (deforestation) for agricultural purposes, e.g., expanding of wetlands with rice agriculture from 5,000 BP onwards, for timber and firewood collection by prehistoric humans. This had some impact to global climate system, but it was apparently minimal, except for local changes. In this procedure, carbon dioxide (CO_2) and methane (CH_4) may have increased affecting the global climate system. However, scientific evidence indicates that climatic changes are induced by severe human activities such as, industrialization,



large scale land clearing/burning for agriculture purposes and mechanization of agriculture, which is defined as anthropogenic forcing in the climate system. On the other hand, global climate system is largely influenced by natural change, which is marked as natural forcing. Thus, climatic changes may take the form of increased/decreased global surface temperatures, substantial variation in precipitation patterns (arid or heavy rains), rise in sea-level, migration of fauna and desertification (increase aridity). Further, such climate changes will have significant impacts ecologically, economically and socially.

Causes of global climate change

Scientists argue that the number of causes for the changes can be identified in the geological past, covering the 250 million years, as follows.

Long-term natural forcing:

01. Effect of orbital parameter changes, as explained by

Milankovitch cycles

(1): 100,000 year-eccentricity cycle. This depends on the shape of the earth's orbit; either circular pattern or elliptical pattern. Shape of the orbit controls the amount of solar radiation reaching the earth in terms of energy flux integrated over all latitudes. This cycle is responsible for creating severe and large-scale ice ages.

(2): 40,000-year obliquity cycle. This depends on the angle between earth's rotation axis and the plane of the earth orbit. Today it is 23.5° away from a vertical drawn to the plane of the orbit. It normally changes from 22.5° to 24.5° within this periodicity. When the North Pole points away from the sun, the northern hemisphere experiences winter while when it is close to the sun, the northern hemisphere experiences summer time. Effect of the obliquity cycle forced the insolation changes (i.e., solar radiation reached per unit area on the earth surface) and it may largely contribute to changes in the climate conditions on the earth

surface. In general, the influence of the obliquity cycle is large at the poles and small at the equator making very significant climate change.

(3): 23,000-year precision cycle. Reason for this cycle is the overall effect of gravitational pull of the sun and moon on the equatorial belt of the earth. Owing to this effect, the earth's rotation axis wobbles and the North Pole describes a circle in space. Simultaneously, the elliptical orbit also rotates independently and more slowly. Scientists found that very significant peaks in the ice volume (Ice Ages) occurred at the periodicity of 23,000; 40,000 and 100,000 yrs.

02. Effect of changing pattern of the solar constant (i.e., power of the sun at the earth, is measured as watts per square meter: watts/m^2). It generally increases over the life of the Earth, but it varies by 1-3%, because of the Earth's slightly elliptical orbit around the sun. Scientists have suggested that the sun may have varied in its power output within this range. Recent investigations also suggest that this variation apparently has connection with sunspot cycles.

03. Effect of large-scale plate tectonic activities, land-uplifting, ocean circulation and isostatic sea level changes.

04. Effect of the occurrence of volcanic eruptions. This action release large amount of volcanic dust, named as aerosol (e.g., various particles, heavy minerals and silica) into atmosphere disrupting energy balance in the system.

05. The complex interaction of atmosphere, the ocean and solar activities (e.g. sun-spots cycles), defined as El Nino and Southern Oscillation (ENSO) conditions.

Short-term anthropogenic forcing

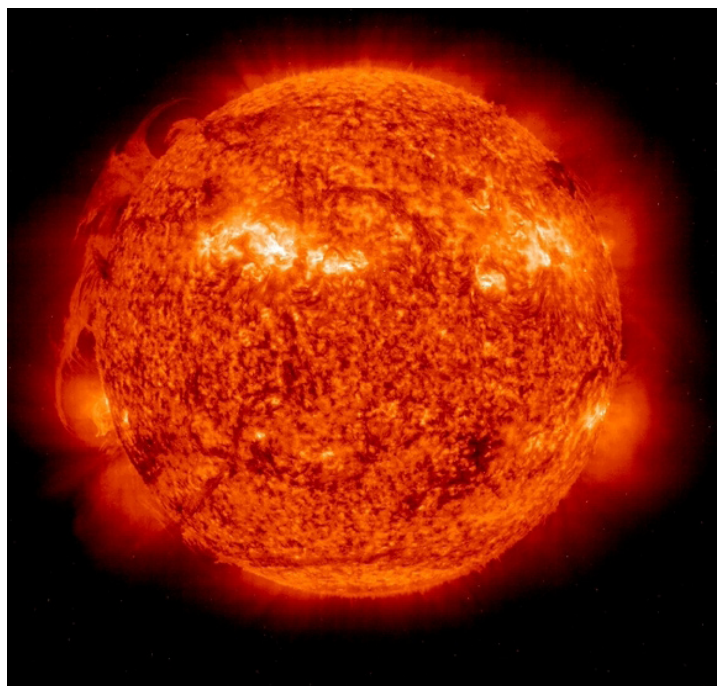
06. Greenhouse gas emission due to anthropogenic activities (e.g. CO_2 -fossil fuel burning) and other sources (e.g., CH_4 -wetland exposition).

07. Earth surface reflectivity (albedo) changes, with large-scale deforestation, land clearance and anthropogenic burning.

General context of the climate in South Asia

Global climate change has been attracting wide attention over the past two decades. Emphasis is now being placed on regionalization work, widely recognized to be an important step towards a better understanding of how the climate system varies naturally and also responds to changes in climate forcing. South Asia (e.g. Sri Lanka and India) is one of the most vulnerable regions to factors related to climate change. Billions of population

in South Asia are critically dependent on Asian summer monsoon rainfall for their annual water requirements. It is obvious that the understanding of climate and environmental change is a major challenge for a sustainable development in the region. Simultaneous occurrences of catastrophic floods and devastating droughts are common features of the climate in the region. Such climatic extremes (e.g. hydro-climatic variables) show much spatial and temporal variability on different time-scales, e.g. inter-annual, decadal and multi-decadal. During the last few decades, repeated natural hazards such as floods, droughts, landslides, meteorological depressions, cyclones and coastal erosion, have affected Sri Lanka. Recently, unexpected severe rainfall deluged the south-western part of the country, resulting in massive damage to towns, schools, homes, communication and other infrastructures. In the sector of agriculture, the suicides of several



farmers coincide with repeated crop failures due to seasonal and annual droughts. The impact of this type of crop failures seems to have increased during the last decade and has seriously affected about 200,000 families in Sri Lanka. In addition, the increasing dryness in all parts of the country coincides with the spread of weeds in paddy fields (e.g. weedy rice) having negative effects on high-yielding cultivated rice fields. The present crisis in the sectors of agriculture, health, environment and hydropower generation can partly be related to decisions taken by policy makers without proper consideration of long- and short-term predictions based on palaeo-climatological and hydrometeorological records on micro and macro time scales. Key uncertainties on micro and macro palaeoclimatic time scales remain to be solved in the tropics. It is said that knowledge on abrupt climate change, e.g. drought frequency, flood frequency, effect of ENSO conditions and ocean circulation in the tropics and the Southern Hemisphere is severely limited by lack of terrestrial palaeoclimatic records. Understanding these climatic extremes varied in the past related to proxy data, but the nature of the proxy and their statistical calibration are incomplete. Climatologists are refining general circulation models (GCM) and various other climate models to predict the impact of future climate trends. The GCM's and all other models require appropriate palaeoclimatic data to validate the climatic models in the region and global contexts, because direct observational series (instrumental data from meteorological stations/

Departments) are too short for these purposes.

Scientists are of the view that better understanding the sun and its role in climate changes is extremely important, but this is a difficult goal. It is important, because to properly assess the effect of human-induced climate change (anthropogenic forcing), an accurate quantification of the natural climate forcing (solar forcing) is urgently required. But, it is also a very difficult task, because,

- (1) natural forcing (solar forcing) records are generally not well quantified
- (2) the response of the climate system to various forcing is non-linear due to feed-back mechanisms
- (3) lack of validated climate models
- (4) some problem with proxy records used for climate reconstruction and their calibrations.

Thus, work for documenting and analysing solar forcing, past climate changes (palaeoclimate records), and climate modelling work in tropics are urgent task to be completed. For this purpose, scientific communities are largely required to formulate new research problems that address how past solar variation and many other anthropogenic variations have affected climate system and how this information can be used to construct solar-climate and anthropogenic-climate modelling. This modelling business may largely help for a better understanding of the complex processes that go on within the Earth/Climate system,

and ultimately, developing our nation's socio-cultural and economic vitality for future.

Records from the Horton Plains

Sri Lanka is ideally situated for investigating the impact of atmospheric/oceanic events on the Asian (Indian) summer monsoon regime. This is because, the central Highlands (2,100-2,600 m above mean sea level) act as a physiographic barrier to moisture-laden monsoon winds, and is a natural climatological observatory tower in the Indian Ocean. Radiocarbon dated multi-proxy records (pollen: Figure 2, spores, phytoliths, diatom, magnetics, carbon and nitrogen isotopes and *Sphagnum* spp macrofossil) indicated that one of the very interesting geo-physical (peat and sedimentary) archives, located in the Horton Plains, in central Sri Lanka, has captured a 24,000 year old palaeoclimatic record. In our studies, we wish to emphasize that the number of periods of monsoon weakening lasted much longer than the periods of monsoon intensification during the past 24,000 years. The generalized trends in our records indicate that there is high-risk for monsoon rains in our part of the world in the future. If the monsoon downturn is prolonged as indicated in our records, the threat to agriculture, irrigation, hydropower generation, forestry and so many other sectors in socio-economic context, would be significant. To mitigate climate change-induced damage as described above, it is now the time for policy makers, politicians, and economic authorities to consider the best strategies and

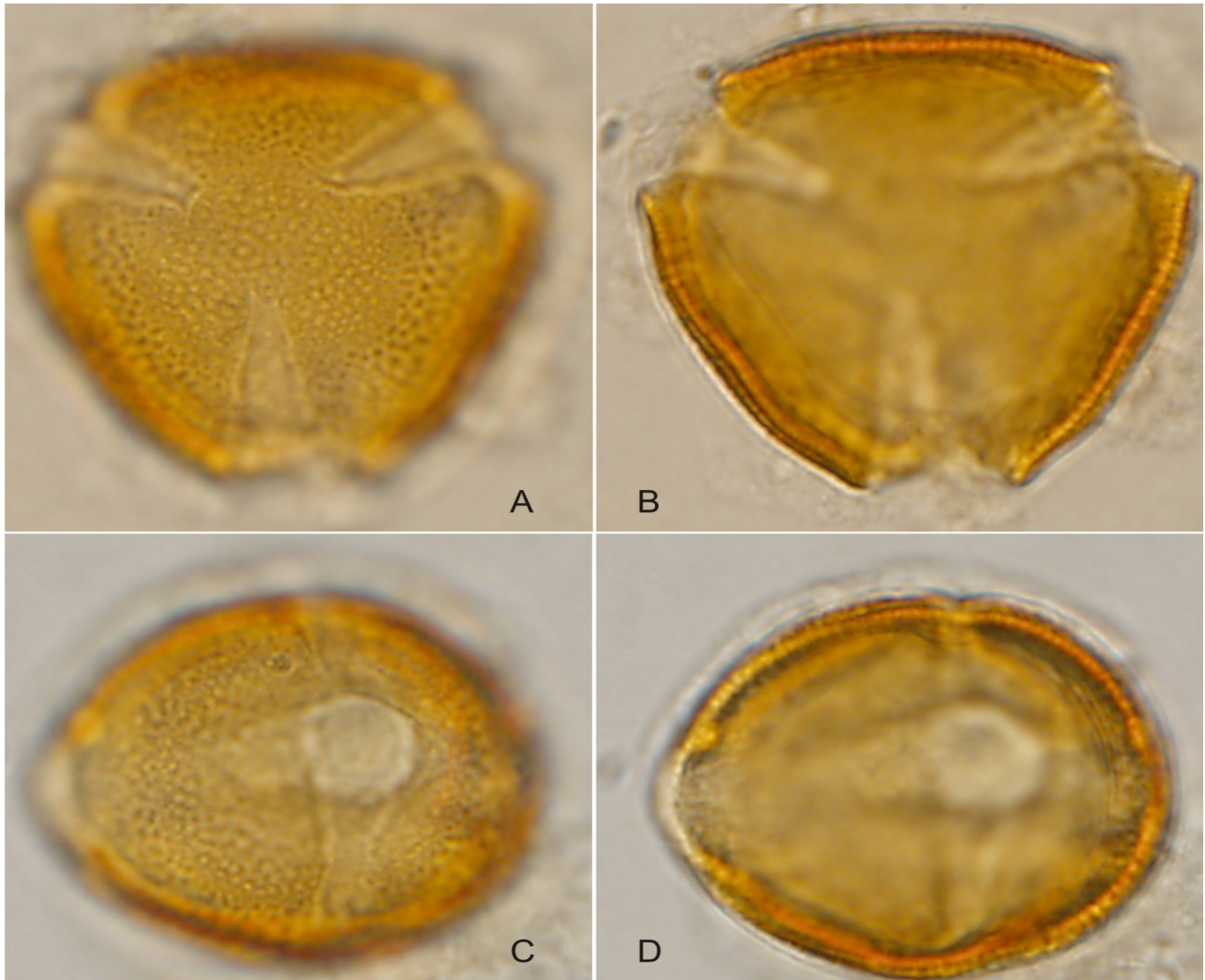


Figure 2: Radiocarbon dated pollen proxy of *Calophyllum* sp. found from the Horton Plains (15,000 years old fossil pollen records). A, B: $3CP$ -Polar views, C, D: $3CP$ -Equatorial views. Magnification: X1000.

practices for water management with sustainable development. For this purpose, understanding earth system science with the best knowledge relevant to climate science is essential.

Our palaeoclimate records will also throw some light into the pre-history of South Asia and the long term ecology of tropical ecosystems and their future trends. It is interesting that our records show that monsoon cyclicality

is a long-term phenomenon as suggested by other scholars in South Asia, and that cyclicality operates at different periodicities, associating with orbital/sub-orbital forcing (solar forcing). This means that solar forcing appears to have predominated, compared to anthropogenic forcing. Several repeated short-term wet and dry episodes found from the sequence are very significant for understanding behavior of climate system in our part of the world.

Reasons for these changes are still unclear. However, future research will allow us to understand the mechanism of these changes.

Dr R. Premathilake

Laboratory for Palaeoecology,
Postgraduate Institute of
Archaeology,
University of Kelaniya.
407, Bauddhaloka Mawatha,
Colombo7.