ABSTRACT

Reconstructions of global mean temperature show a quasi-periodic change in climate throughout Earth's geological history. This change usually consists of a rise and fall in temperature owing to small differences in the amount of solar radiation that reaches the Earth. However, the current period of warming remains of enormous significance and interest because of its unexpected rate of change. This sudden increase in temperatures across the planet has raised concerns that we may be at the peak of the Holocene extinction period (Sixth Great Mass Extinction). Studies have concluded that between 15 to 37% of endemic plants may become extinct by 2050. The impacts are not only significant but probably point to irreversible changes in the biodiversity of the planet.

This increased rate of temperature change is thought to be human induced. Such a conclusion is arrived at from consensus exhibited by a large number of climate models that show a significant agreement with observed changes in climate. The models point toward a greenhouse forcing modulated climate. However, uncertainties still exist within these models. The situation is further aggravated due to the non-linear interaction between different forcings in a climate model which makes the study of individual pathways a formidable task. The presence of these uncertainties hinders our ability to successfully predict future climate change and mitigate our response towards the same.

Existing climate models simulate non-linear effects of physical processes leading to fluctuations in global climate. Some of these more advanced models use observations to constrain various parameters involved. However, they tend to be very computationally expensive. Also, the exact physical processes that affect the climate variations have not been completely comprehended. Therefore, to obtain an insight into global climate, we have developed a physically motivated reduced climate model. The model utilizes a novel mathematical formulation involving a delay differential equation to study temperature fluctuations when subjected to imposed radiative forcing. We have further incorporated simplified equations to test the effect of diverse mechanisms of climate forcing and evaluated the extent of their influence. The findings are significant in our efforts to predict climate change and help in policy framing necessary to tackle it.

Though the global trends in the climate are driven by anthropogenic forcings, the primary driver of the climate on Earth is the Sun. This is because it is the only natural

source of energy for dynamics of the climate. However, current literature estimates the temperature response due to solar forcing to be very low. But this is only true when considering the primary effects of solar forcing. Therefore, in our study, we have reassessed the impact of solar forcing on our climate using both primary and secondary effects of solar activity. The primary effects are due to change in energy output by the Sun while the secondary effects are due to the Sun's influence in interplanetary space through modulation of Galactic Cosmic Ray (GCR) flux on Earth. These effects are expected to be pronounced over time scales relevant to the climate phenomena.

Using the computational model, we were able to identify signatures of the sun's secondary effects on global climate. The model points towards a higher forcing due to solar activity than previously estimated. A toy model that encodes the influence of Galactic Cosmic Rays on the climate has also been proposed. We were further able to model the effect of large-scale circulations using the delay term in our equations. The results point to a shift in our understanding of the Sun-Climate link that has been so far considered an area of low understanding.

The impact of the Sun on the interplanetary space that produces these secondary effects (GCR modulation) is determined by the magnetic field distribution at the source surface boundary (at $2.5R_{\odot}$). This distribution is in turn determined by the coronal dynamics of magnetic fields. Therefore it is important to reliably measure coronal magnetic fields. However, due to the low densities in the corona that results in a low photon flux, observations of magnetic field structures in the corona are not possible. In the second part of the thesis, we meet the need to study such dynamics by extrapolations of the photospheric (solar surface) magnetic field using theoretical models.

The simplest and most commonly utilized model used to study the corona is the Potential Field Source Surface (PFSS) extrapolation. The current free condition assumed while performing this extrapolation provides us the lowest energy state of the corona for a given photospheric magnetic field distribution. A current free condition implies a magnetic field devoid of twists and writhes. The extrapolations are calculated at discrete time intervals. Such a measure is reasonable due to high velocities of the Alven waves as compared to large scale motions in the photosphere. This allows the overlying flux systems to achieve equilibria over relatively shorter timescales than those involved in photospheric motions.

To study the coronal magnetic field structure and its evolution over a complete solar cycle, we have developed a PFSS model. The model has been developed on a finite difference grid. Though it lacks the fine structure resolution ability of a spherical harmonic solution, it is able to overcome issues of ‘ringing’ close to strong magnetic field structures. It is further useful in coupling with other finite difference codes.

Using the developed computational model, we have simulated the evolution of open flux at the source surface boundary. The photospheric magnetic field used for this study is the output from a Surface Flux Transport model which simulates the evolution of photospheric structures. A complete scientific analysis of these products will be conducted in further studies.

Finally, we look into the solar dynamo mechanism that leads to the formation of strong magnetic field structures at the photosphere. It is this mechanism that is responsible for the 11-year cycle of the Sun. Due to the impossibility of obtaining observations in the convection zone, theoretical calculations are used to model the dynamics. We then compare its simulated structures at the photosphere with observations. Currently, flux transport dynamo models employing the Babcock-Leighton mechanism have emerged as promising candidates in explaining different aspects of the solar cycle.

Differential rotation in the convective zone is expected to shear the existing poloidal magnetic field to create a toroidal component. This accumulated toroidal fields at the base of the convection zone erupt on reaching sufficient strength. Under the Babcock-Leighton (BL) mechanism, the erupted flux tubes are converted to poloidal fields at the surface. Varied physical processes such as diffusion, turbulent pumping and meridional circulation help in the transport of fields between the base of the convection zone and surface.

In order to study the dynamics of the convection zone, where the dynamo mechanism operates, we develop a three-dimensional dynamo code. The code is pivotal in our study of non-axisymmetric processes in the solar dynamo. We further gain an understanding of the magnetic flux tube eruption process and its impact on the Babcock-Leighton Mechanism. In our code, we have tested the self divergence cleaning ability of induction equation by not directly imposing the divergence free condition. Instead, the divergence is expected to dissipate as a direct consequence of the induction equation. Earlier codes have explicitly defined cleaning algorithms to remove accumulated divergence. We have further used coarser grids as we move towards the poles to overcome the difficulty of grid convergence.

We have independently developed and studied the above computational codes. However, they are linked through various physical processes as discussed above.