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Indrani Roy

Climate Variability and Sunspot Activity

Analysis of the Solar Influence on Climate

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Dedicated to my late parents
Sri Barin Kar
&
Smt Jyotsna Kar

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Introduction

The energy to drive the global atmospheric circulation originates from the Sun. During higher solar activity, the Earth is subjected to enhanced solar irradiance. However, the connection between the Sun and climate has been a puzzle. This is because during a typical 11-year cycle the solar energy output varies by only about 0.1% (Lean and Rind 2001). Based on energy considerations, such a change is too small to produce significant changes in surface conditions. The degree to which variation in solar output affects climate has been the topic of extensive research for a long time.

But nowadays, there is a common consensus that the variations in the UV part of the spectrum between solar maxima and minima (6–8%) leads to more ozone and warming during solar maxima in the upper stratosphere (Crooks and Gray 2005; Hood 2004 and Haigh 1994). Such modulations can impact tropospheric climate. The primary motivations for exploring the areas of solar 11-year cycle variability on climate are the following:

- The Sun is the principal source of energy in the earth; it causes day/night and seasons. There are reasons to believe that solar variability can influence the climate.
- As the Sun follows the 11-year cyclic variability, the knowledge about the Sun–climate relationship on that scale can be used for future climate prediction purpose.
- However, regarding energy output, there is only 0.1% change from solar minimum to maximum years of the 11-year variability, which is too negligible to influence the climate of the earth.
- Moreover, a significant signal is detected on some meteorological parameters, but most of the time that is regionally different. It can also vary with time periods. Unless there are mechanisms to support such behaviour, it may be a mere coincidence.

Other solar-related drivers are also found to influence the climate of earth, for example, geomagnetic activity, total solar irradiance (TSI) and solar cosmic or magnetospheric energetic particle precipitation, and are discussed briefly in the final chapter of the book. However, the current analysis mainly focuses on solar 11-year cyclic variability (as detected for Sunspot number (SSN)). It is because the knowledge about the Sun–climate relationship on that scale can be used for future projection purposes and hence has implications for improved climate prediction. Moreover, unlike other solar-related drivers, there is a very well-accepted mechanism for the SSN, based on solar UV-related variability.

This work is the collection of lecture notes as well as synthesised analyses of published papers on the described subjects. It is divided into three parts: Part I discusses general circulation, climate variability, stratosphere–troposphere coupling and various teleconnections. Part II mainly explores the area of different solar influences on climate and also discusses about ocean –atmosphere coupling. But without a prior knowledge of other important influences on the earth's climate, the understanding of the actual role of the Sun remains incomplete. Hence, Part III covers burning issues such as greenhouse gas warming, volcanic influences, ozone depletion in the stratosphere and Arctic and Antarctic sea ice. At the end of the book, there are few questions and exercises for students.

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Part I
Climatology, General Circulation, Climate Variability and Stratosphere-Troposphere Coupling

Abstract Part I initially focused on basic definitions of Climatology, General Circulation, Climate Variability and Stratosphere Troposphere Coupling. There was a discussion on Climatology of Sea Level Pressure (SLP) and Sea Surface Temperature (SST) which was followed by defining Hadley and Walker circulation. In the subsequent chapter, major modes of climate variability are included with their spatial characteristic and temporal behavior. It is then followed by an overview of Stratosphere-Troposphere coupling. Later on, there is a discussion based on teleconnection among various modes. Discussion on how robust solar influences around different places are detected is included afterwards. Finally, there is a discussion on Total Solar Irradiance (TSI) and how it is reconstructed.

Keywords Climatology · Modes of variability · Stratosphere-Troposphere Coupling · Total Solar Irradiance (TSI) · General circulation

Chapter 1
Climatology and General Circulation

Abstract This chapter focused on basic definitions of climatology and general circulation. There was a discussion on climatology of sea level pressure (SLP) and sea surface temperature (SST) which was followed by defining north-south Hadley and east-west Walker circulation. It also defined and described Ferrel cell, Polar cell and various jets. It explained thermal-wind balance relationship and its relevance to jet formation.

Keywords Climatology · Sea Level Pressure (SLP) · Sea Surface Temperature (SST) · Hadley Cell · Ferrel Cell · Polar Cell · Walker Circulation · Subtropical Jet · Thermal Wind Balance · Aleutian Low · Icelandic Low · Azore High · Intertropical Convergence Zone (ITCZ)

To begin with, I start with the definition of weather and climate. Weather is the changing atmospheric conditions (as they affect people), such as precipitation, mist, fog, etc. or meteorological elements like temperature, humidity, winds, etc. On the other hand, the climate is weather averaged over an extended period (say, 30 years).

Below is a brief description about climatology (30 years average) of sea surface temperature (SST) and sea level pressure (SLP) followed by a description of the general circulation.

1.1 Climatology: SLP and SST

The climatology of SLP (Fig. 1.1) and SST (Fig. 1.2) is discussed during two different seasons, the boreal winter and summer. Boreal winter or summer means Northern Hemispheric (NH) winter or summer season. In contrast, austral winter or summer means Southern Hemispheric (SH) winter or summer.

The mean SLP during boreal winter (December-January-February, DJF) differed to that from boreal summer (June-July-August, JJA) and illustrated in Fig. 1.1a, b, respectively. The seasonal variations in SLP are most apparent in the NH. During winter the high-latitude oceans are characterised by low-pressure centres with the Aleutian Low (AL) and Icelandic Low centre in the northern margins of the Pacific

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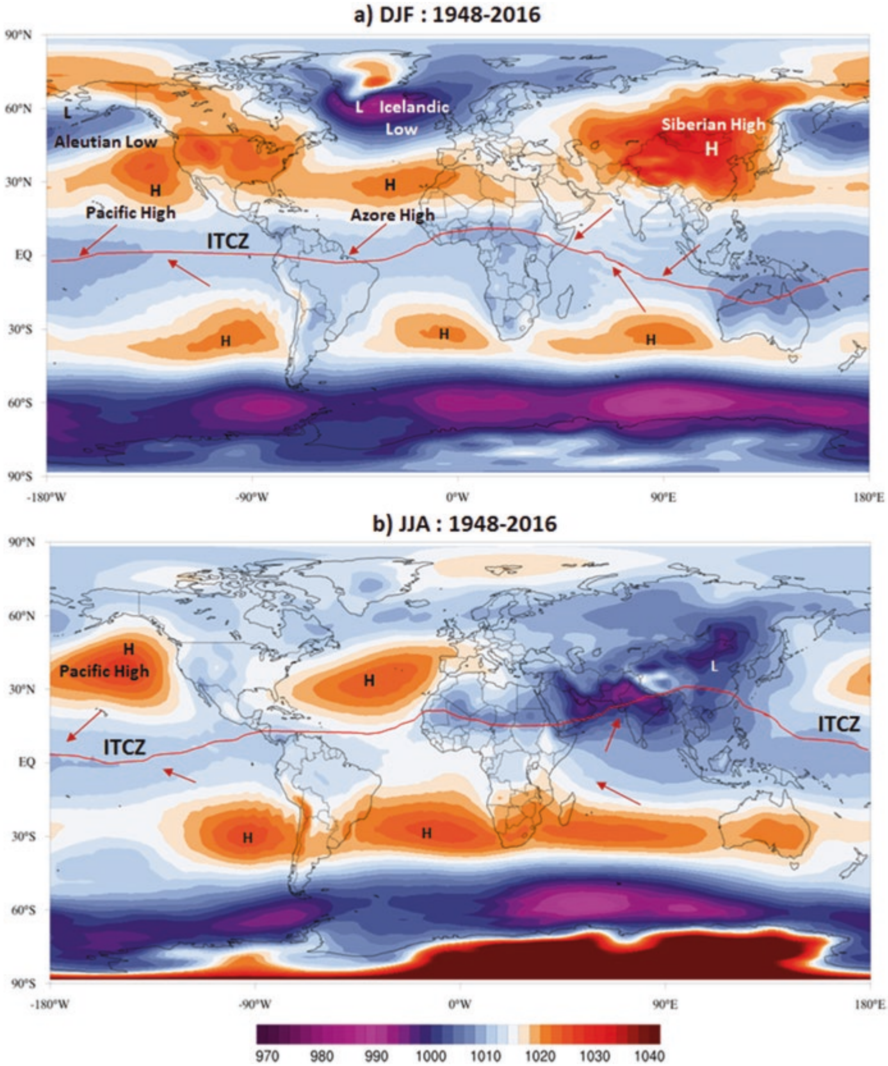

Fig. 1.1 Mean SLP(mb) during (**a**) northern winter (DJF) and (**b**) northern summer (JJA). (Source: Background maps generated via http://cci-reanalyzer.org/, using NCEP/NCAR Reanalyses v1 data, ClimateReanalyzer.org, University of Maine, Climate Change Institute)

and Atlantic Oceans, respectively, whereas a high-pressure centre lies over Asia. During summer, the land-sea pressure contrast is reversed in midlatitudes, with the highest pressures over the oceans and the lowest pressures over the land areas. It is seen from that figure that most high-pressure regions persist throughout the year. Although, the Pacific High (PH) and Azore High are weaker in the winter than summer. The dominant low-pressure feature during NH summer is centred over Asia at about 30°N and associated with the Asian summer monsoon. Movement of the intertropical convergence zone (ITCZ), further north around the Indian Ocean

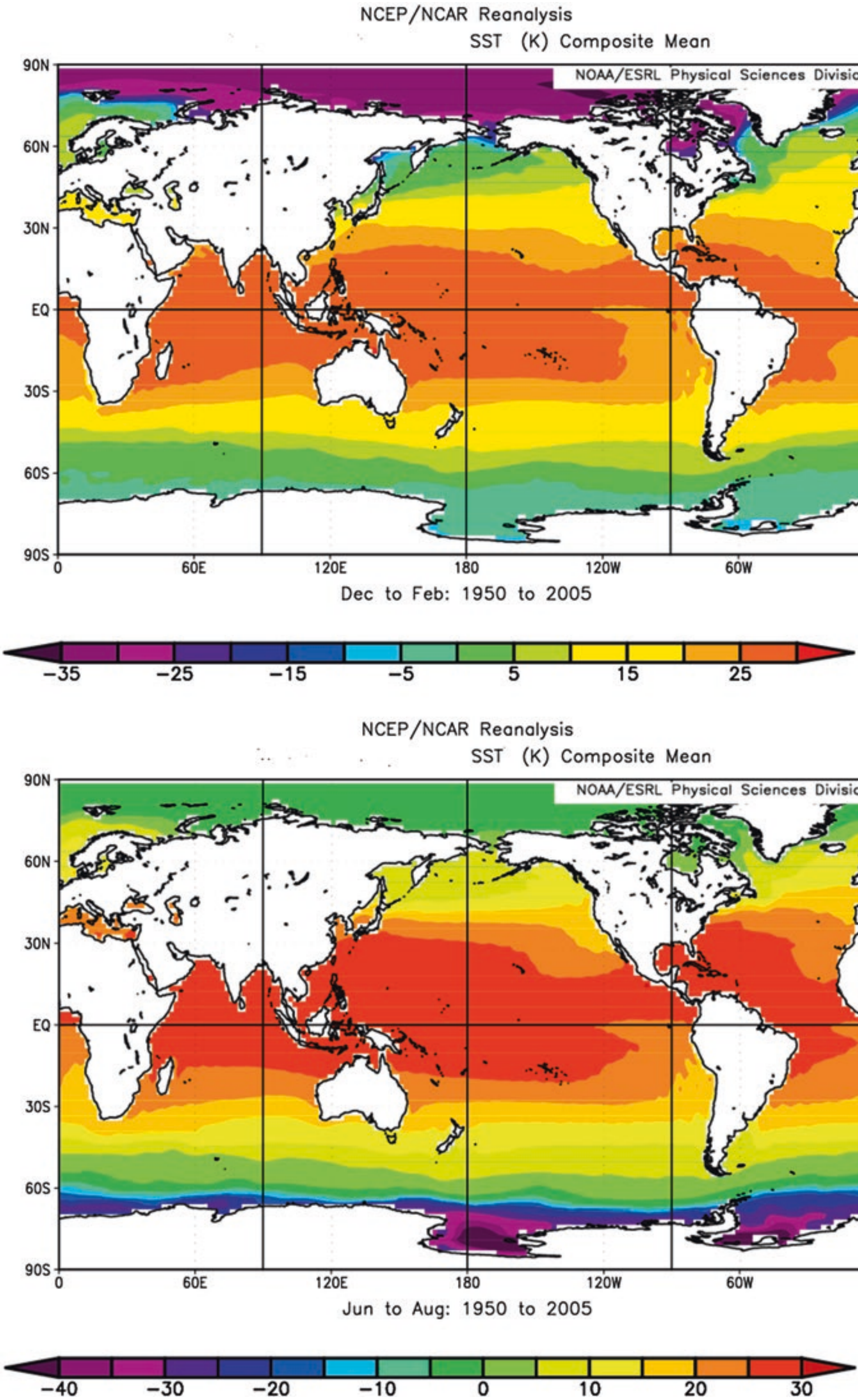

Fig. 1.2 NOAA extended SST (°C) composite mean. (Source: Plots generated using the data from NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their website at (http://www.esrl.noaa.gov/psd/))

region during summer, (shown in Fig. 1.1b compared to 1.1a) is clearly noticeable – which is responsible for monsoon around the Indian subcontinent region, causing heavy rainfall.

During winter (shown in Fig 1.1a), the AL and Icelandic Low are well developed. The AL extends from the Aleutian Islands into the Gulf of Alaska, and much stormy weather and precipitation in the Western USA are associated with its movement, whereas the strong circulation around the Icelandic Low produces northerly winds and cold weather in the eastern section of North America. Like the AL, ITCZ and PH are frequently in use in our subsequent discussion; we mention their mean position. The AL covers ~120°W–130°E, 35°N–70°N, whereas the PH centres between 20°N and 50°N, 100°W–140°E.

Mean SSTs during boreal winter (represented here by December–January–February (DJF)) and summer (represented here by June–July–August (JJA)) are illustrated in Fig. 1.2a, b, respectively. During both the seasons, the equator is warmer than the pole. Such temperature gradient is responsible for driving the meridional heat transport through different circulation cells and is described below in the chapter on general circulation.

1.2 General Circulation

Earth's equatorial regions receive more heat than the areas nearer to the pole, which experiences a net deficit (also shown in Fig. 1.2). To prevent the equatorial region from getting warmer and the polar region getting cooler, there must be a transport of heat from the equatorial region towards the pole. Such transport of heat is associated with following meridional circulation cells (shown in Fig. 1.3).

1.2.1 Meridional Circulation

The north south meridional circulation comprises of three cells; Hadley cell, Ferrel Cell and Polar cell.

Hadley Cell Persistent surface heating around the equator results in a rising and poleward moving air at the equator; as this air moves poleward, it cools radiatively and sinks near 30° latitude; it finally returns towards the equator, at low levels. This meridional circulation cell is called the Hadley cell. It is a thermally direct circulation where heat from the sun is converted to motion that transports energy from warm to cold regions. The high-pressure bands around 30° latitude and the low pressure near the equator are signatures of the sinking and rising portion of this Hadley cell, respectively (shown in Fig. 1.3).

Ferrel Cell In midlatitudes the cell that circulates in the opposite direction to the Hadley cell is known as the Ferrel cell, and the overall movement of surface air in