

Springer Atmospheric Sciences

Indrani Roy

# Climate Variability and Sunspot Activity

Analysis of the Solar Influence on  
Climate

 Springer

**Springer Atmospheric Sciences**

More information about this series at <http://www.springer.com/series/10176>

Indrani Roy

# Climate Variability and Sunspot Activity

Analysis of the Solar Influence on Climate

 Springer

Indrani Roy  
Mathematics and Physical Sciences  
University of Exeter, College of Engineering  
Exeter, UK

ISSN 2194-5217                      ISSN 2194-5225 (electronic)  
Springer Atmospheric Sciences  
ISBN 978-3-319-77106-9              ISBN 978-3-319-77107-6 (eBook)  
<https://doi.org/10.1007/978-3-319-77107-6>

Library of Congress Control Number: 2018934396

© Springer International Publishing AG, part of Springer Nature 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature.

The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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

# Contents

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

<b>1</b>	<b>Climatology and General Circulation</b> .....	3
1.1	Climatology: SLP and SST .....	3
1.2	General Circulation .....	6
1.2.1	Meridional Circulation .....	6
1.2.2	Jet Formation: Thermal Wind Balance Relationship.....	8
1.2.3	Walker Circulation.....	9
<b>2</b>	<b>Major Modes of Variability</b> .....	11
2.1	Variability in the Troposphere.....	12
2.1.1	El Niño and Southern Oscillation (ENSO).....	12
2.1.2	North Atlantic Oscillation (NAO).....	14
2.1.3	Arctic Oscillation (AO) and Antarctic Oscillation (AAO) .....	15
2.1.4	Pacific Decadal Oscillation (PDO).....	17
2.1.5	Atlantic Multidecadal Oscillation (AMO).....	18
2.1.6	Indian Summer Monsoon (ISM) .....	19
2.1.7	Indian Ocean Dipole (IOD) .....	20
2.2	Variability in the Stratosphere .....	21
2.2.1	Quasi-Biennial Oscillation (QBO) .....	21
2.2.2	Stratospheric Sudden Warming (SSW) .....	24
	Referenes.....	26
<b>3</b>	<b>Stratosphere-Troposphere Coupling</b> .....	29
3.1	Background .....	29
3.2	Discussion with Schematic.....	30
3.3	Strength of Westerly: Solar Influence .....	31
3.4	Role of Zero Wind Line: QBO Influence .....	31
3.5	Sun, QBO and Polar Temperature in North Pole .....	32
3.6	Composites of Time Height Development of NAM.....	34

3.7	Annular Modes Pattern Similar .....	35
3.8	Solar Influence: Polar Vortex and Tropical Lower Stratosphere ...	35
3.9	Solar Influence: Tropical Lower Stratosphere to Troposphere.....	36
	References.....	37
<b>4</b>	<b>Teleconnection Among Various Modes.....</b>	<b>39</b>
4.1	Polar Vortex, QBO and ENSO.....	39
4.2	Polar Vortex and ENSO .....	40
4.3	ENSO and Polar Troposphere .....	40
4.4	ENSO, Polar Annular Modes and JET .....	41
4.5	ENSO Teleconnections.....	42
4.5.1	El Niño (Warm) and La Niña (Cold) Definition.....	42
4.5.2	El Niño or La Niña? .....	43
4.5.3	ENSO Seasonal Locking .....	44
4.5.4	Potential Problems with SST Data .....	44
4.5.5	Indian Summer Monsoon and Walker Circulation .....	45
4.5.6	Different Types of ENSO .....	47
4.5.7	Homogeneous Monsoon Region .....	48
4.5.8	ENSO ISM Correlation .....	48
4.5.9	SST Composites: EN vs. LN.....	49
4.5.10	ISM ENSO Teleconnection Compositing: EN vs. LN.....	50
4.5.11	Rainfall in South America ENSO (Different Types) Teleconnection .....	51
4.5.12	Summary: ENSO and Teleconnections .....	51
	References.....	52
<b>5</b>	<b>Solar Influence Around Various Places: Robust Solar Signal on Climate .....</b>	<b>53</b>
5.1	Signal on Sea Level Pressure (DJF) Using Multiple Linear Regression.....	53
5.1.1	Method of Multiple Regression Analysis .....	54
5.2	Solar Signal Around Aleutian Low (AL) and Pacific High (PH) .....	55
5.3	Solar Influence: Tropical Pacific SST .....	55
5.4	ENSO and Sun Phase Locking.....	56
5.5	Solar Signal in Tropical Pacific SST Using Compositing.....	58
5.5.1	Method of Solar Peak Year Compositing .....	58
5.6	Observation: Annual Mean Temperature.....	59
	References.....	61
<b>6</b>	<b>Total Solar Irradiance (TSI): Measurements and Reconstructions.....</b>	<b>63</b>
	References.....	66



**Part II Atmosphere-Ocean Coupling and Solar Variability**

**7 Ocean Coupling**..... 71

7.1 Shallow Overturning Circulation ..... 71

7.2 ENSO ..... 73

7.2.1 ENSO, Thermocline and Upper Ocean Heat Content .... 74

7.2.2 ENSO and Delayed Oscillator Theory ..... 75

7.2.3 ENSO and Shallow MOC in Tropical Pacific ..... 76

7.2.4 Pycnocline Convergence vs. SST ..... 77

7.2.5 Abrupt Rise in Temperature During 1977–1998 ..... 78

References..... 79

**8 The Sun and ENSO Connection–Contradictions and Reconciliations** ..... 81

8.1 Solar Signal and ENSO ..... 81

8.2 Contradiction (I): Solar Signal on Tropical Pacific SST-Active Solar Years and ENSO ..... 83

8.3 Contradiction (II): Solar Signal on Tropical Pacific SST-El Niño or La Niña ..... 86

8.4 Proposed Mechanism: Earlier Period ..... 92

8.5 Proposed Mechanism: Later Period ..... 94

8.6 Contradictions and Reconciliations..... 95

References..... 96

**9 A Debate: The Sun and the QBO** ..... 97

9.1 Data Analysis: Solar and QBO Separately ..... 98

9.2 Polar Temperature During JF with Respect to QBO (40 hPa) and F10.7 ..... 101

9.3 Polar Temperature During JF for QBO (30 hPa) and F10.7..... 103

9.4 Time Series of QBO at Different Height and EOF Analysis..... 104

9.5 Combined Effects: Solar with QBO..... 107

9.6 Summary ..... 109

References..... 110

**10 Solar Influence: ‘Top Down’ vs. ‘Bottom Up’**..... 111

10.1 Solar Influence: ‘Top Down’ ..... 111

10.1.1 Solar Influence: ‘Top-Down’ – via Polar Vortex and Lower Stratosphere ..... 111

10.1.2 Solar Influence: ‘Top-Down’ – via Lower Stratosphere to Troposphere..... 112

10.1.3 Solar Influence: ‘Top-Down’ – via Stratospheric Polar Vortex to Polar Troposphere..... 112

10.2 Solar Influence: ‘Bottom-Up’ ..... 112

References..... 114

<b>11</b>	<b>An Overview of Solar Influence on Climate</b> .....	117
11.1	Introduction .....	117
11.1.1	Methodology.....	119
11.2	Representative Results: Figure and Tables.....	121
11.3	Results Text .....	133
11.3.1	Atmosphere Only: Sun and QBO.....	133
11.3.2	Ocean (Only Pacific) and Atmosphere Coupling: Sun, QBO and ENSO .....	134
11.3.3	Atmosphere and Ocean (Only Pacific) Coupling: Sun, QBO, ENSO and Climate Change .....	134
11.4	Discussion .....	134
	References.....	138
<b>Part III Other Major Influences on Climate</b>		
<b>12</b>	<b>Sun: Atmosphere-Ocean Coupling – Possible Limitations</b> .....	143
12.1	Sun: Atmosphere-Ocean Coupling ‘Top-Down’ vs. ‘Bottom-Up’ Mechanism: a Case Study.....	143
12.2	Sun: Atmosphere-Ocean Coupling – Limitations of Peak Year Compositing .....	144
12.2.1	Solar Cycle Signals in Peak Year Compositing for SLP: a Case Study .....	144
12.2.2	Solar Cycle Signals in Peak Year Compositing for Indian Summer Monsoon: a Case Study.....	148
12.3	Difference in Winter Surface Climate Between Solar Minimum and Maximum .....	150
12.4	Sun (Using SSN) and NAO in Observation Using MLR Technique.....	151
12.4.1	Sun (Using SSN) and NAO in Two Different Time Periods (1856–1977) and (1878–1997).....	151
12.4.2	Sun (SSN) and NAO Longer Period (1870–2010).....	152
12.4.3	Sun (SSN) and NAO Lag Relationship .....	153
12.5	AMO and PDO Relationship.....	154
	References.....	155
<b>13</b>	<b>The Arctic and Antarctic Sea Ice</b> .....	157
13.1	Arctic Sea Ice: Last Few Years .....	158
13.2	Arctic Sea Ice: Change in 2014.....	158
13.3	Arctic Sea Ice and Solar Influence .....	160
13.4	Antarctic Sea Ice .....	162
	Reference .....	163
<b>14</b>	<b>CMIP5 Project and Some Results</b> .....	165
14.1	Global Climate Models (GCMs): Basic Equations .....	165
14.2	CMIP5 Project.....	166

- 14.3 Experiments: Historical and RCP (Representative Concentration Pathway) Scenarios..... 167
- 14.4 Some CMIP5 Models ..... 168
- 14.5 Temperature in CMIP5 and Observation..... 168
- 14.6 Indian Summer Monsoon (ISM) and ENSO in CMIP5 Models ... 170
  - 14.6.1 CMIP5 Models for ISM Are Performing Well ..... 170
  - 14.6.2 CMIP5 Models for ISM Not Performing Well ..... 171
  - 14.6.3 Models: CMIP5, AMIP5 and High Top, Low Top ..... 177
  - 14.6.4 Precipitation Composites- El Niño: (CMIP5 vs. AMIP5) ..... 179
  - 14.6.5 Changes in ENSO Variability 2050–2100 in CMIP3 Experiments ..... 181
  - 14.6.6 Stratospheric Features in CMIP5: Low and High Top Models ..... 181
  - 14.6.7 Simulated and Observed Stratospheric Temperature..... 181
- References..... 184
- 15 Green House Gas Warming..... 187**
  - 15.1 Laws of Radiation ..... 187
  - 15.2 Solar Radiation vs. Terrestrial Radiation..... 187
  - 15.3 Radiation Transmitted by the Atmosphere and Atmospheric Windows..... 188
  - 15.4 Absorption: Water Vapour and CO<sub>2</sub>..... 188
  - 15.5 CO<sub>2</sub> as a Greenhouse Gas..... 190
  - 15.6 Temperature and CO<sub>2</sub>: 400,000 Years ..... 190
  - 15.7 Earth’s Temperature Change in the Last 2000 Years ..... 190
  - 15.8 Radiative Forcing ..... 191
  - 15.9 Global Energy Balance..... 194
  - References..... 195
- 16 Volcanic Influences ..... 197**
  - 16.1 Volcano Cooling Effect ..... 197
  - 16.2 Influences of Volcanic Eruption ..... 198
  - 16.3 Effect of Large Eruptions on Weather and Climate ..... 199
  - 16.4 Polar Warming Associated with Large Eruptions..... 200
  - 16.5 Sun, Volcano and ENSO..... 201
  - References..... 202
- 17 Ozone Depletion in the Stratosphere..... 203**
  - 17.1 Ozone Hole and Montreal Protocol..... 203
  - 17.2 Ozone Hole Animation..... 204
  - 17.3 Greenhouse Gases and Ozone in Model..... 204
  - Reference ..... 205

**18 Influence of Various Other Solar Outputs**..... 207

    18.1 Mechanisms..... 208

    18.2 Other Influences, e.g. Galactic Cosmic Rays ..... 209

    18.3 Sunspot vs. Galactic Cosmic Ray (GCR)..... 209

    References..... 211

**Few Questions and Exercises for Students** ..... 213

**Further Reading**..... 215

**Index**..... 217

## Sources to Figures

- Fig. 1.1 Background maps generated via <http://cci-reanalyzer.org/>, using NCEP/NCAR Reanalyses v1 data, ClimateReanalyzer.org, University of Maine, Climate Change Institute
- Fig. 1.2 Plots generated using the data from NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their website at (<http://www.esrl.noaa.gov/psd/>)
- Fig. 1.3 Background map generated via <http://cci-reanalyzer.org/>, ClimateReanalyzer.org, University of Maine, Climate Change Institute
- Fig. 1.4 [http://www.cpc.noaa.gov/products/analysis\\_monitoring/ensocycle/meanrain.shtml](http://www.cpc.noaa.gov/products/analysis_monitoring/ensocycle/meanrain.shtml), link accessed on 10/12/2017, credit: National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center
- Fig. 2.2 [http://www.cpc.noaa.gov/products/analysis\\_monitoring/ensocycle/ensocycle.shtml](http://www.cpc.noaa.gov/products/analysis_monitoring/ensocycle/ensocycle.shtml), Credit: National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center
- Fig. 2.3 [https://pt.wikipedia.org/wiki/Gilbert\\_Walker](https://pt.wikipedia.org/wiki/Gilbert_Walker), link accessed on 10/12/2017
- Fig. 2.4 <http://www.ldeo.columbia.edu/NAO/>, link accessed on 10/12/2017, picture by Visbeck, M
- Fig. 2.5 [http://research.jisao.washington.edu/wallace/ncar\\_notes/](http://research.jisao.washington.edu/wallace/ncar_notes/), link accessed on 10/12/2017, credit J. Wallace, University of Washington
- Fig. 2.6 [http://nsidc.org/arcticmet/patterns/arctic\\_oscillation.html](http://nsidc.org/arcticmet/patterns/arctic_oscillation.html), link accessed on 10/12/2017, Image/photo courtesy of J. Wallace, University of Washington, supplied by the National Snow and Ice Data Center, University of Colorado, Boulder
- Fig. 2.7 <http://jisao.washington.edu/pdo/>, link accessed on 10/12/2017, credit: Nate Mantua, NOAA
- Fig. 2.8 [https://en.wikipedia.org/wiki/Atlantic\\_multidecadal\\_oscillation](https://en.wikipedia.org/wiki/Atlantic_multidecadal_oscillation), link accessed on 10/12/2017, credit: Giorgiognp2 under CC BY-SA 3.0
- Fig. 2.9 Background maps generated via <http://cci-reanalyzer.org/>, using NCEP/NCAR Reanalyses v1 data, ClimateReanalyzer.org, University of Maine, Climate Change Institute

- Fig. 2.10 <http://www.whoi.edu/>, uploaded on 10/12/2017, credit E. Paul Oberlander, Woods Hole Oceanographic Institution. Copyright © Woods Hole Oceanographic Institution
- Fig. 2.12 <http://ugamp.nerc.ac.uk/hot/ajh/qbo.htm>, uploaded on 10/12/2017, after Plumb (1984)
- Fig. 2.13 Left: [http://lasp.colorado.edu/sorce/news/2004ScienceMeeting/SORCE%20WORKSHOP%202004/SESSION\\_2/2\\_4\\_McCormack.pdf](http://lasp.colorado.edu/sorce/news/2004ScienceMeeting/SORCE%20WORKSHOP%202004/SESSION_2/2_4_McCormack.pdf) Credit, John McCormack, US Naval Research Laboratory, Washington DC.; Right: <http://www.4college.co.uk/as/atm/air.php>, Link accessed on 10/12/2017
- Fig. 2.14 [http://lasp.colorado.edu/sorce/news/2004ScienceMeeting/SORCE%20WORKSHOP%202004/SESSION\\_2/2\\_5\\_Gray.pdf](http://lasp.colorado.edu/sorce/news/2004ScienceMeeting/SORCE%20WORKSHOP%202004/SESSION_2/2_5_Gray.pdf), link accessed on 10/12/2017, credit: Lesley Gray
- Fig. 2.15 <http://www.bu.edu/causes/documents/causes-news-v3-n2.pdf>, link accessed on 10/12/2017, Credit: K. Labitzke and M. Kunze
- Fig. 3.2 [http://lasp.colorado.edu/sorce/news/2004ScienceMeeting/SORCE%20WORKSHOP%202004/SESSION\\_2/2\\_4\\_McCormack.pdf](http://lasp.colorado.edu/sorce/news/2004ScienceMeeting/SORCE%20WORKSHOP%202004/SESSION_2/2_4_McCormack.pdf), picture (left); also after, CIRA climatology, Flemming et al., 1990
- Fig. 4.3 <https://climate.ncsu.edu/climate/patterns/ENSO.html>, link accessed on 10/12/2017, used from <http://www.srh.noaa.gov/jetstream/>, Credit: National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center
- Fig. 4.4 [http://www.cgd.ucar.edu/cas/catalog/climind/Nino\\_3\\_3.4\\_indices.html](http://www.cgd.ucar.edu/cas/catalog/climind/Nino_3_3.4_indices.html), link accessed on 11/12/2017; <http://www.esrl.noaa.gov/psd/map/clim/sst.anim.year.html>, link accessed on 11/12/2017
- Fig. 4.7 [https://www.climate.gov/sites/default/files/Walker\\_Neutral\\_large.jpg](https://www.climate.gov/sites/default/files/Walker_Neutral_large.jpg); [https://www.climate.gov/sites/default/files/Walker\\_LaNina\\_2colorSSTA\\_large.jpg](https://www.climate.gov/sites/default/files/Walker_LaNina_2colorSSTA_large.jpg); [https://www.climate.gov/sites/default/files/Walker\\_ElNino\\_2colorSSTA\\_large.jpg](https://www.climate.gov/sites/default/files/Walker_ElNino_2colorSSTA_large.jpg) Credit: National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center
- Fig. 4.9 [http://nihroorkee.gov.in/rbis/india\\_information/monsoon1.jpg](http://nihroorkee.gov.in/rbis/india_information/monsoon1.jpg), uploaded on 31/12/2017
- Fig. 6.1 <https://www.pmodwrc.ch/forschungentwicklung/solarphysik/tsi-composite/>, link accessed dt 2/4/18, credit Claus Fröhlich
- Fig. 7.1 <https://climatekids.nasa.gov/ocean/>, image accessed on 02/04/2018
- Fig. 7.2 <http://www4.ncsu.edu/~ceknowle/Envisions/chapter09copy/part1.html>, image accessed on 2/4/2018
- Fig. 7.3 [http://www.cpc.noaa.gov/products/analysis\\_monitoring/lanina/enso\\_evolution-status-fcsts-web.pdf](http://www.cpc.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf), link accessed on 2/4/18
- Fig. 7.4 after <http://www.ess.uci.edu/~yu/class/ess200a/lecture.7.climate.variations.pdf>, link accessed on 2/4/18

- Fig. 7.7 <http://data.giss.nasa.gov/gistemp/>
- Fig. 13.1 <http://www.climate4you.com/Polartemperatures.htm#Arctic> monthly surface air temperatures north of 70°N
- Fig. 13.2 [http://psc.apl.washington.edu/wordpress/wp-content/uploads/schweiger/ice\\_volume/BPIOMASIceVolumeAnomalyCurrentV2.1.png](http://psc.apl.washington.edu/wordpress/wp-content/uploads/schweiger/ice_volume/BPIOMASIceVolumeAnomalyCurrentV2.1.png)
- Fig. 13.3 <http://scitechdaily.com/images/Study-Shows-Volume-of-Arctic-Sea-Ice-Has-Increased.jpg>
- Fig. 13.4 EUMETSAT, OSI SAF (<http://osisaf.met.no>, graph plotted on 16/12/14.), also in <http://kaltesonne.de/wp-content/uploads/2014/12/arktis2.gif>
- Fig. 13.5 [http://www.7320.nrlssc.navy.mil/hycomARC/navo/arcticicen\\_nowcast\\_anim365d.gif](http://www.7320.nrlssc.navy.mil/hycomARC/navo/arcticicen_nowcast_anim365d.gif)
- Fig. 13.8 <http://www.vencoreweather.com/blog/2016/4/11/215-pm-global-sea-ice-makes-a-strong-comeback>, link on 11/4/16
- Fig. 13.9 [http://eoimages.gsfc.nasa.gov/images/imagerecords/8000/8239/antarctica\\_avhrr\\_81-07\\_lrg.pdf](http://eoimages.gsfc.nasa.gov/images/imagerecords/8000/8239/antarctica_avhrr_81-07_lrg.pdf), link accessed on 2/4/18
- Fig. 14.2 [https://ktwop.files.wordpress.com/2013/10/73-climate-models\\_reality.gif](https://ktwop.files.wordpress.com/2013/10/73-climate-models_reality.gif), uploaded on 30/12/2017. Credit: JR Christy, University of Alabama, Huntsville-model output from KNMI
- Fig. 14.3 <http://www.cato.org/blog/current-wisdom-record-global-temperature-conflicting-reports-contrasting-implications>. uploaded on 30/12/17, Cedit: © The Cato Institute 2014. Used by permission
- Fig. 15.1 [http://en.wikipedia.org/wiki/File:EM\\_spectrum.svg](http://en.wikipedia.org/wiki/File:EM_spectrum.svg), uploaded on 30/12/17
- Fig. 15.2 [https://commons.wikimedia.org/wiki/File:Atmospheric\\_Transmission.png](https://commons.wikimedia.org/wiki/File:Atmospheric_Transmission.png). CC BY-SA 3.0, image loaded on 30/12/2017
- Fig. 15.3 [earthobservatory.nasa.gov/Features/EnergyBalance/page7.php](http://earthobservatory.nasa.gov/Features/EnergyBalance/page7.php). uploaded on 30/12/2017, credit NASA's Earth Observatory
- Fig. 15.4 Carbon Connections. <http://carbonconnections.bsccs.org>. Copyright © BSCS. All rights reserved. Used with permission
- Fig. 15.5 <https://commons.wikimedia.org/w/index.php?curid=10684392>, loaded on 19/12/2017. (By Vostok-ice-core-petit.png; NOAA derivative work: Autopilot (Vostok-ice-core-petit.png) [CC-BY-SA-3.0 (<http://creativecommons.org/licenses/by-sa/3.0/>) or GFDL (<http://www.gnu.org/copyleft/fdl.html>)], via Wikimedia Commons.)
- Fig. 15.6 [https://www.frontiersin.org/files/Articles/317793/feart-05-00104-HTML/image\\_m/feart-05-00104-g002.jpg](https://www.frontiersin.org/files/Articles/317793/feart-05-00104-HTML/image_m/feart-05-00104-g002.jpg), uploaded on 19/12/2017, Copyright © 2017 Lüning and Vahrenholt
- Fig. 16.1 <http://www.carbonbrief.org/in-brief-how-much-do-volcanoes-influence-the-climate> uploaded on 30/12/17, used with permission
- Fig. 17.1 <http://www.environment.gov.au/protection/ozone/ozone-science/ozone-layer/antarctic-ozone-hole>, Animation link (dt 30/12/17)

- Fig. 18.2 <https://commons.wikimedia.org/wiki/File%3APIA16938-RadiationSources-InterplanetarySpace.jpg>, uploaded on 30/12/17, picture by NASA/JPL-Caltech/SwRI (<http://photojournal.jpl.nasa.gov/jpeg/PIA16938.jpg>) [Public domain], via Wikimedia Commons
- Fig. 18.3 <http://www.climate4you.com/Sun.htm#> Cosmic ray intensity and sunspot activity, uploaded on 30/12/2017, credit Germany Cosmic Ray Monitor in Kiel (GCRM) and NOAA's National Geophysical Data Center (NGDC)



# 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.

## References

- Lean J, Rind D (2001) Earth’s response to a variable Sun. *Science* 292(5515):234–236
- Hood LL (2004) Effects of solar UV variability on the stratosphere, solar variability and its effects on climate. *Geophys Monogr Amer Geophys Union* 141:283–303
- Crooks SA, Gray LJ (2005) Characterisation of the 11-year solar signal using a multiple regression analysis of the ERA-40 dataset. *J Clim* 18(7):996–1015. <https://doi.org/10.1175/JCLI-3308.1>
- Haigh JD (1994) The role of stratospheric ozone in modulating the solar radiative forcing of climate. *Nature* 370:544–546

# 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)

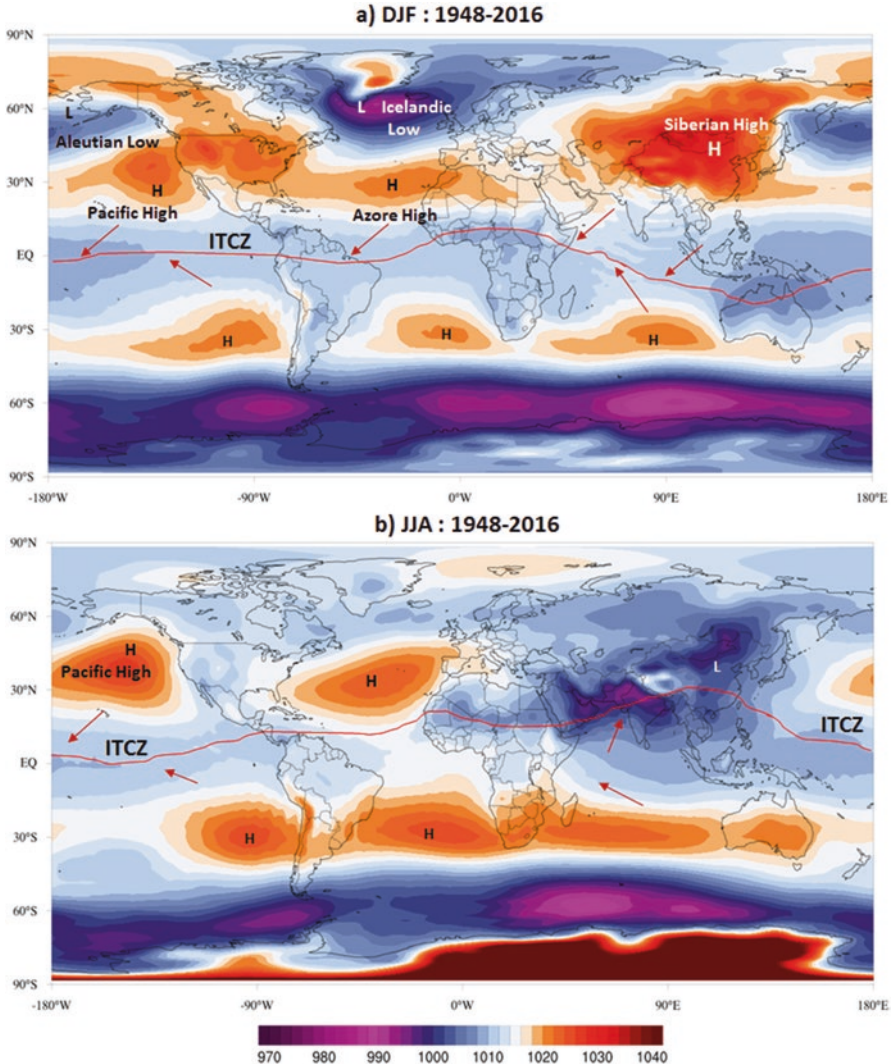
To begin with, I start with the definition of weather and climate. Weather is the changing atmospheric conditions (as they affect people), such as precipitation, mist, fog, etc. or meteorological elements like temperature, humidity, winds, etc. On the other hand, the climate is weather averaged over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



**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  $30^{\circ}\text{N}$  and associated with the Asian summer monsoon. Movement of the intertropical convergence zone (ITCZ), further north around the Indian Ocean

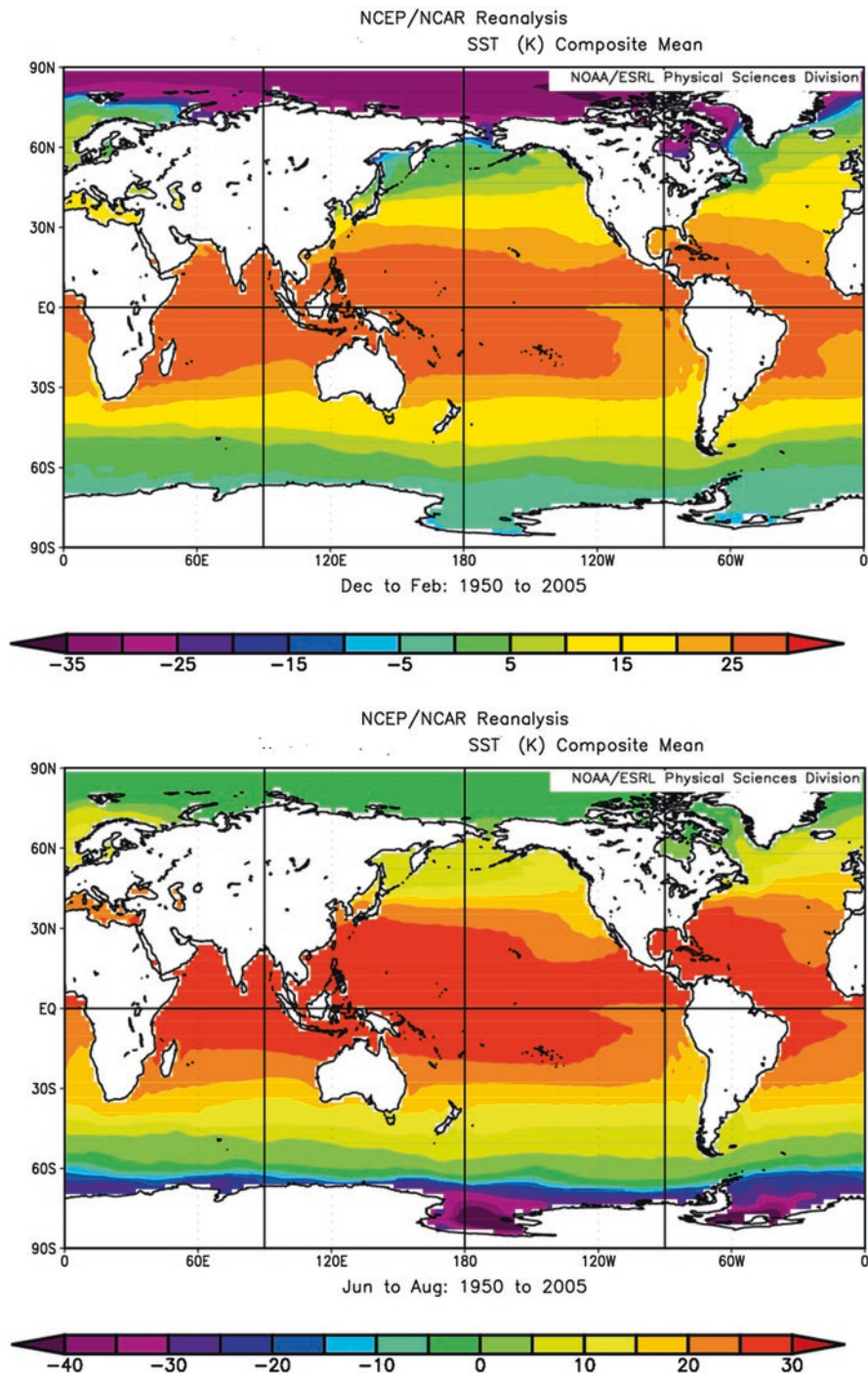


Fig. 1.2 NOAA extended SST (°C) composite mean. (Source: Plots generated using the data from NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their website at (<http://www.esrl.noaa.gov/psd/>))

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  $\sim 120^{\circ}\text{W}–130^{\circ}\text{E}$ ,  $35^{\circ}\text{N}–70^{\circ}\text{N}$ , whereas the PH centres between  $20^{\circ}\text{N}$  and  $50^{\circ}\text{N}$ ,  $100^{\circ}\text{W}–140^{\circ}\text{E}$ .

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  $30^{\circ}$  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  $30^{\circ}$  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