

Contents

Preface to the second edition	xi
Preface to the first edition	xiii
Acknowledgements to the second edition	xv
Acknowledgements to the first edition	xvii
List of figures	xix
List of tables	xxv
1 Introduction	1
1.1 The philosophy of this book	1
1.2 The layout	5
2 Solar observations	7
2.1 Synopsis	7
2.2 Instruments for observing the Sun	7
2.2.1 Measuring the total solar irradiance	8
2.2.2 There is more than total irradiance	8
2.2.3 Spectrography and polarisation	10
2.3 The history of solar observations	12
2.3.1 The importance of good observations	14
2.3.2 Criteria for good observations	14
2.4 Palaeo records of solar activity	17
2.4.1 Isotopic records	17
2.4.2 Geomagnetic field measurements	24
2.5 Space-borne solar observations	25

3	The physical properties of the Sun	29
3.1	Synopsis	29
3.2	The Sun as a star	29
3.2.1	Solar size and mass	29
3.2.2	The solar rotation	30
3.2.3	The solar material	31
3.2.4	The Sun's core	31
3.2.5	The photosphere	34
3.2.6	The chromosphere	38
3.2.7	The corona	38
3.2.8	The solar wind	39
3.3	The general solar magnetic field	40
3.3.1	The decay of magnetic fields	40
3.3.2	The geomagnetic-based solar model	41
4	Solar activity	45
4.1	Synopsis	45
4.2	The umbra	48
4.3	The penumbra	49
4.4	Sunspot groups	50
4.4.1	Sunspot brightness and temperature	53
4.5	Sunspot models	54
4.5.1	Dynamo action and magnetism	54
4.5.2	Convective and hydrodynamical sunspot models	58
4.5.3	Magnetic cooling models	58
4.6	Solar activity and preferred timescales	60
4.6.1	Solar activity and the sunspot cycle	60
4.6.2	Spectral analysis	62
4.6.3	Wavelet analysis	64
4.6.4	Comparison between preferred timescales	68
4.7	Sunspot groups and their magnetic field	69
4.7.1	Alternative measures of solar activity	70
4.7.2	Observed east-west asymmetry in sunspot statistics	70
4.8	The sunspot cycle and total radiance	72
4.8.1	Sunspots and the solar irradiation	74
4.8.2	Sunspot-irradiance models	75
4.8.3	Prediction of sunspots	83
4.9	Flares, prominences, faculae, and corpuscular clouds	86
4.9.1	Flares	86
4.9.2	Prominences	86
4.9.3	Faculae	86
4.9.4	Corpuscular clouds	87
4.9.5	Solar brightening, sunspots and faculae	87
5	Earth's climate	89
5.1	Synopsis	89

5.2	The observation of Earth's climate	91
5.2.1	Instrumental data	91
5.2.2	Upper air data	99
5.2.3	Earth-observing satellites and space-borne UV measurements.	99
5.2.4	Observation of planetary atmospheres.	106
5.2.5	Palaeo data – “proxy data”	106
5.2.6	Climate observations	109
5.3	Basic climate physics	110
5.3.1	Mass conservation.	110
5.3.2	Energy conservation	111
5.3.3	Momentum conservation	114
5.3.4	Effects of Earth's rotation	115
5.3.5	Charge conservation	116
5.4	Earth's energy budget.	117
5.4.1	Variations in solar output and terrestrial temperature.	117
5.4.2	Variation in insolation.	119
5.4.3	The natural greenhouse effect	120
5.5	The basic components of Earth's climate	122
5.5.1	The atmosphere	122
5.5.2	The oceans	130
5.5.3	The cryosphere.	135
5.5.4	The biosphere	139
5.6	Feedback mechanisms	140
5.6.1	Stefan–Boltzmann feedback.	141
5.6.2	Water vapour feedback	142
5.6.3	Ice- and snow-albedo feedback	143
5.6.4	Cloud feedback	144
5.6.5	Biochemical feedback.	145
5.7	The other planets in our solar system	145
5.7.1	The signature of solar variability from other planets	145
6	Solar activity and the stratosphere.	149
6.1	Synopsis	149
6.2	Solar activity and UV emission	150
6.3	The role of stratospheric ozone	151
6.3.1	Chemical reactions	151
6.4	The “ozone hole”	153
6.4.1	The theory of a link between solar activity and stratospheric ozone	153
6.5	The theory of a link between the QBO and solar activity	157
6.5.1	Introduction.	157
6.5.2	Sunspots and the QBO	157
6.6	The theory of a link between the AO and solar activity	159
6.6.1	Introduction.	159

6.6.2	A connection between solar activity and the AO	159
6.7	Criticism of solar-stratosphere hypotheses	160
6.8	Volcanoes	161
7	Solar magnetism and Earth's climate	165
7.1	Synopsis	165
7.2	Northern lights and the solar cycle	166
7.2.1	Introduction.	166
7.3	Earth's magnetic and electric fields	166
7.3.1	Geomagnetic storms	166
7.3.2	The geomagnetic field and solar wind	167
7.3.3	The magnetic field of other planets.	168
7.3.4	The Van Allen belts	168
7.4	Charging mechanisms.	168
7.4.1	Lightning	168
7.4.2	The atmospheric electric field	168
7.4.3	Cosmic rays.	169
7.4.4	Interaction between cosmic rays and the air	169
7.5	Airglow, sprites and elves	170
7.6	A historical note on the aurora: theory and observations	171
7.6.1	Early scientific documentation	171
7.6.2	The aurora and geomagnetic disturbances	171
7.6.3	The discovery of day-side and night-side auroras.	172
7.6.4	Charged particles and the aurora	172
7.6.5	The northern lights and the weather	172
7.6.6	The interplanetary magnetic field and the solar cycle	172
7.7	The aurora and solar activity.	173
7.7.1	The theory of day-side auroras	173
7.7.2	The theory of night-side auroras	173
7.7.3	The aurora and the geomagnetic field	173
7.7.4	Aurora activity.	175
7.8	Historical climate information from aurora observations	176
7.8.1	Aurora and the Maunder minimum	176
7.8.2	The "Little Ice Age" and aurora activity.	176
7.8.3	The magnitude and extent of the "Little Ice Age".	177
7.9	The Maunder minimum and the quiet-Sun theory	177
7.10	Magnetic fields, cosmic rays and cloud cover	179
7.10.1	The cosmic ray and sulphate hypothesis	179
7.10.2	The electro-freezing hypothesis.	179
7.10.3	The galactic cosmic rays and the climate	180
7.10.4	Low and high clouds.	180
7.10.5	The hypothesis on cosmic rays and cloud droplet formation	182
7.10.6	Criticism of Svensmark's hypothesis	186
7.11	The Maunder minimum	191

7.11.1	The weakness of comparisons with “Sun-like” stars	193
7.12	The influence of corpuscular clouds	194
7.12.1	Solar activity and lightning	195
7.12.2	The geomagnetic field and oceanic currents	196
7.12.3	The geomagnetic field and sea level pressure	196
8	A review of solar–terrestrial studies	197
8.1	Synopsis	197
8.2	A brief historical note on solar–terrestrial links	199
8.2.1	Historical account of sunspots and hypothesised links with Earth’s climate	199
8.3	Recent statistics on solar–terrestrial links	208
8.3.1	A renaissance for solar–terrestrial links	208
8.4	Recent work and hypotheses	209
8.4.1	Basic statistical concepts	209
8.4.2	Linear trends	212
8.4.3	Correlation	213
8.4.4	Correlation and de-trending the data	215
8.4.5	Correlation and filtering the data	216
8.4.6	Autocorrelation and lag-correlation	220
8.4.7	Monte Carlo simulations	223
8.4.8	The solar cycle length and terrestrial temperature	226
8.4.9	Considerations on solar cycle lengths	230
8.4.10	Correlation studies and pitfalls	232
8.5	Validation of predictions	234
8.6	Total solar irradiance studies	240
8.6.1	The “Little Ice Age” and TSI	240
8.7	Comparisons with stellar studies	245
8.7.1	The life cycle of a star	245
8.7.2	Inferring the solar evolution from stellar studies	246
8.7.3	The “snowball Earth” effect	247
8.8	Is there a relation between sunspots and rainfall?	248
8.9	Requirements of solar–terrestrial hypotheses	248
9	Solar activity and regional climate variations	251
9.1	Synopsis	251
9.2	El Niño Southern Oscillation and solar activity	252
9.2.1	How solar activity may physically affect ENSO	260
9.3	The role of solar activity in the south Asian monsoon system	265
9.3.1	The monsoon	265
9.3.2	Relation to sunspots	266
9.4	The North Atlantic Oscillation and sunspots	266
9.4.1	How may the NAO be affected by solar activity?	267
9.5	The Gulf Stream and sunspots	269
9.6	Pacific Decadal Oscillation and solar activity	271
9.7	Land–sea contrasts	273

9.8	Other external climate forcings	274
9.8.1	The anthropogenic perturbation to the natural balance. .	274
9.8.2	Orbital parameters	275
9.8.3	The Moon.	276
9.8.4	Meteorite impacts	276
10	Synthesis	277
11	Appendix	281
	Bibliography	285
	Exercises.	299
	Index	309