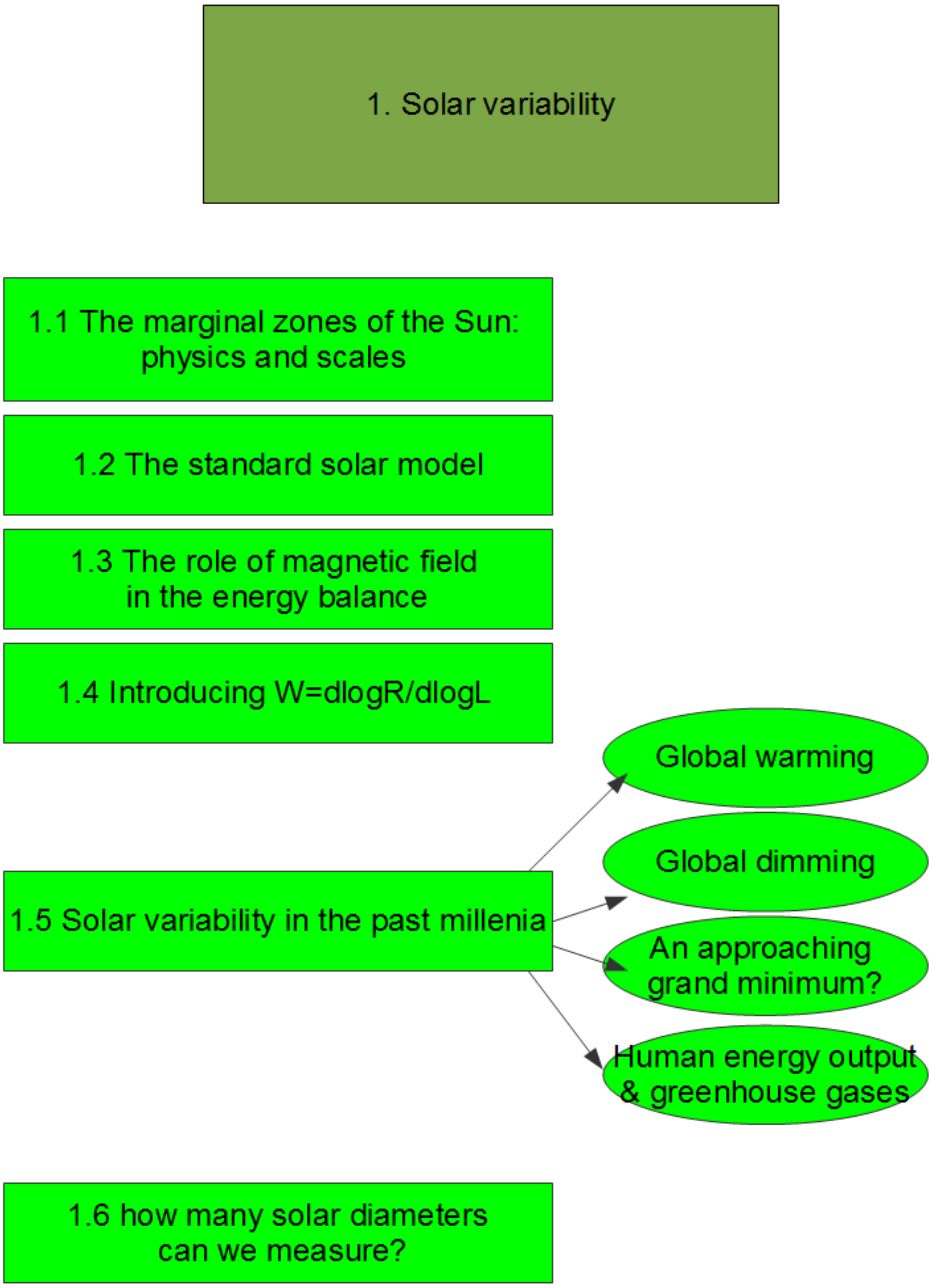
Chapter 1: Solar variability

The title is inspired by "The Sun as a Variable Star" the proceedings of the IAU colloquium n. 143.[1]



The variation of the luminosity L with radius R is described by a parameter W=dlogR/dlogL. The Picard mission is conceived to measure W accurately, and its value will be used to recover the past values of L_sun from historical measurements of R_sun in order to feed Earth's climate models.

[1] Pap, J. M., C. Fröhlich, H. S. Hudson & S. K. Solanki eds., The Sun as a Variable Star, Solar and Stellar Irradiance Variations, Cambridge University Press (1994).

1.1 The marginal zones of the Sun: physics and scale

This paragraph is dedicated to the marginal zones of the Sun, i.e. the solar surface and the atmosphere nearby when it is seen from a grazing view. Images, scales and physics are here summarized.

The marginal lines-emission region is the solar mesosphere.
In the following I will describe the reasons of this definition.

The flash spectrum (see fig. 1.1) has been obtained with a spectrograph during total eclipses, and the continuum of the spectrum corresponds to the light coming from the Baily's beads (the photosphere limb with Fraunhofer (F) lines seen in absorption). Also a myriad of faint emission lines are seen simultaneously superposed on this continuum, in the upper part of the figure. The thin layer associated with these faint emission lines between the photosphere (F-lines) and the low chromosphere, corresponds to the region which can be seen only during the internal contacts of a total eclipse.
This particular region has to be taken into account while defining the solar edge, and the continuum spectrum should be measured between these faint emission lines for accurately measuring the true solar diameter.
The spectrum of figure 1.1 has been obtained as the following. A moving plate spectrograph has been used in 1905 eclipse by W. W. Campbell [Campbell, 1906], then director of the Lick Observatory, in order to photograph the evolution of the spectrum with the reduction of the area of the visible Sun.
It is visible the transition between the absorption dark lines (photosphere with Fraunhofer spectrum) and the tiny emission lines. More up appear the lines of the chromosphere (few and brilliant), and finally the corona continuum (not well visible in the image, which has been scanned from the original).

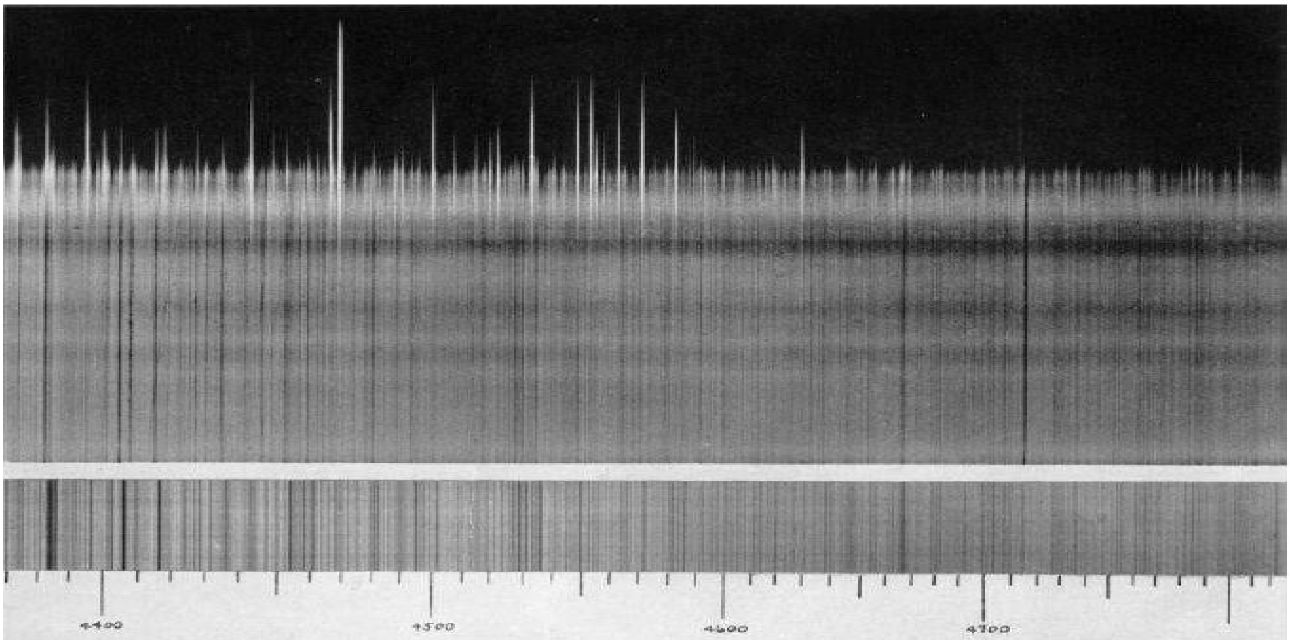


Fig. 1.1 Flash spectrum of 1905 total eclipse. The width of the slit was w =1.3mm and the plate moved of w each second. The lower part of the figure is the spectrum before the totality, where the continuous of the photosphere and a lot of absorption lines. In the upper part there are only the lines of chromosphere; their blend is 10^{-4} times the intensity of the continuum. After the beginnig of totaly only the continuum of the corona can be detected. The blend of the small emitting lines, just below the bright and few lines of the chromosphere, is perceived as white light and it is 10^{-3} times the intensity of the photosphere's continuum.

The blend of these tiny emission lines just above the solar limb is perceived as white light, and even if it is about 1000 times dimmer than the photosphere's brightness it can be confused with the photosphere itself, when the photosphere is seen through an area 1000 times smaller and without spectrograph, as it occurs during the last stages of a total eclipse. This successful 1905 eclipse expedition, sponsored by the billionaire Crocker, remained a cornerstone for the following decades.

Nowadays the definition of reversing layer, used in the original paper of Campbell[2] is no longer physically satisfying.

This region, in analogy with the situation in the Earth's atmosphere, can be defined as the **solar mesosphere**.

There the temperature has a local minimum of about 4500 K instead of 5800 K of the photosphere, after the temperature rises at the beginning of the chromosphere.
This region, over the photosphere, starts with a layer where the contrast of the granules changes.
The vertical magnetic field between granules and supergranules emerges and it spreads horizontally.
The propagating waves along the magnetic field become shock waves, and they release the energy in these layers.

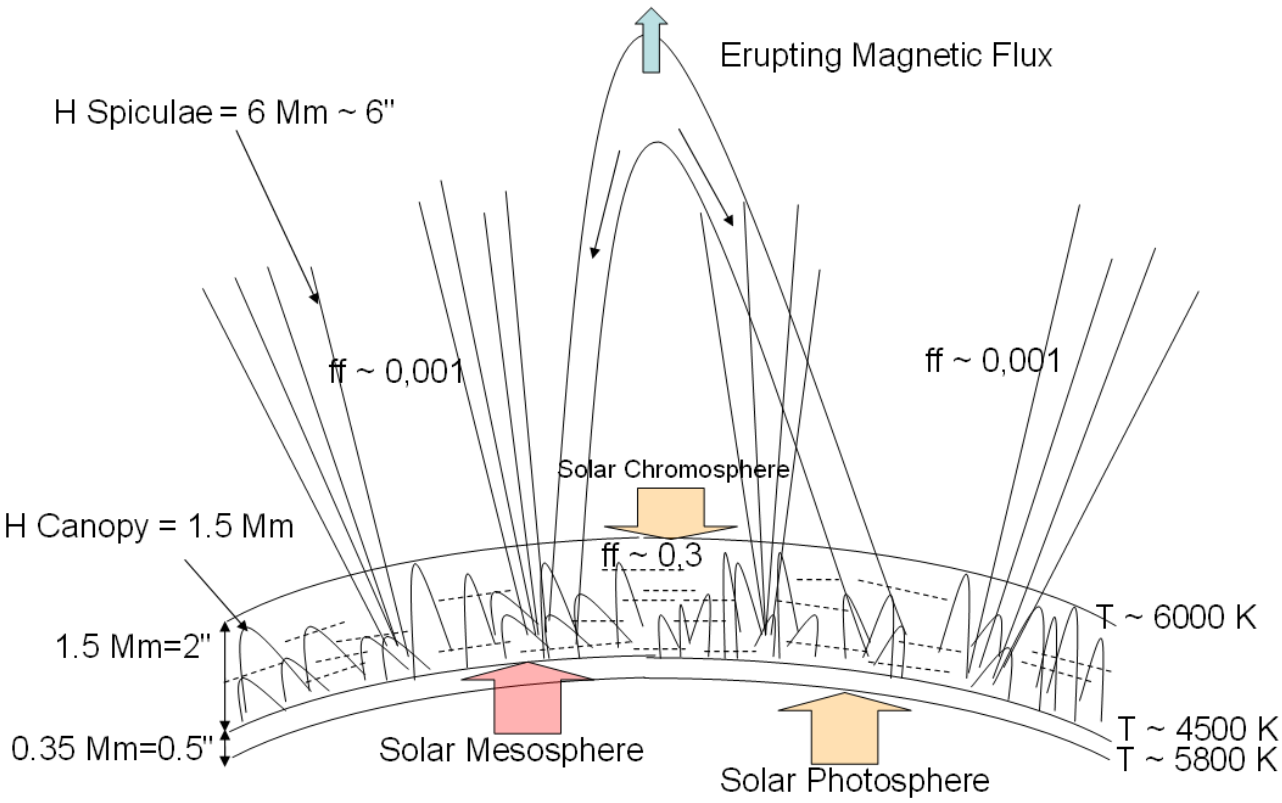


Fig. 1.2 Diagram of the Solar Mesosphere with length scales. The Filling Factor (ff) or heterogeneity factor, is the ratio between the volume occupied by the plasma over the total volume, because the plasma is magnetically confined. The inversion of the temperature occurs around 350 Km, or 0.50 arcsec above the photosphere.

[2] Campbell, W.W. and C. D. Perrine, Proc. Astron. Soc. Pacific **18** (1906) 13.

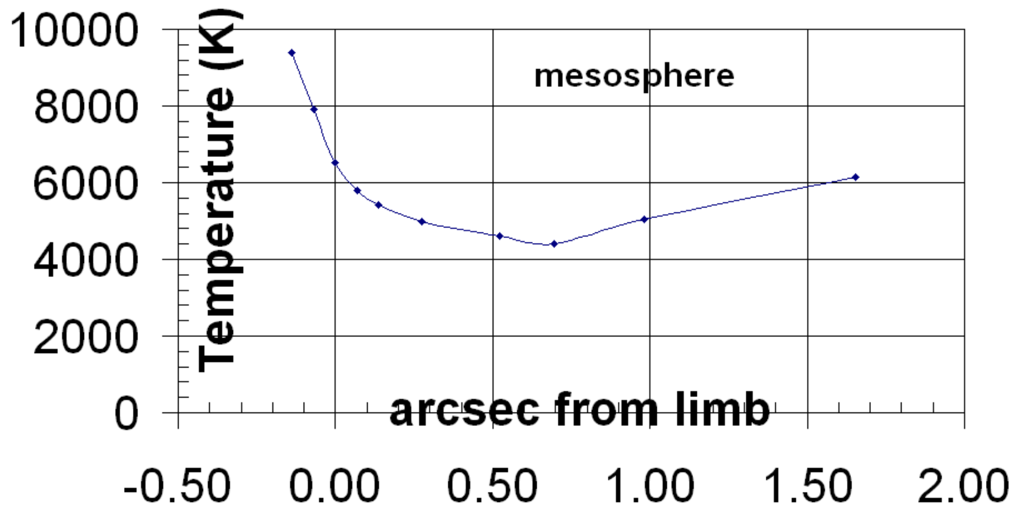


Fig. 1.3 The temperature's profile at the solar limb. In an hydrostatic one-dimensional model (data plotted from Foukal[3] tab. 5.2) the inversion of the temperature occurs around 350 Km, or 0.50 arcsec above the photosphere.

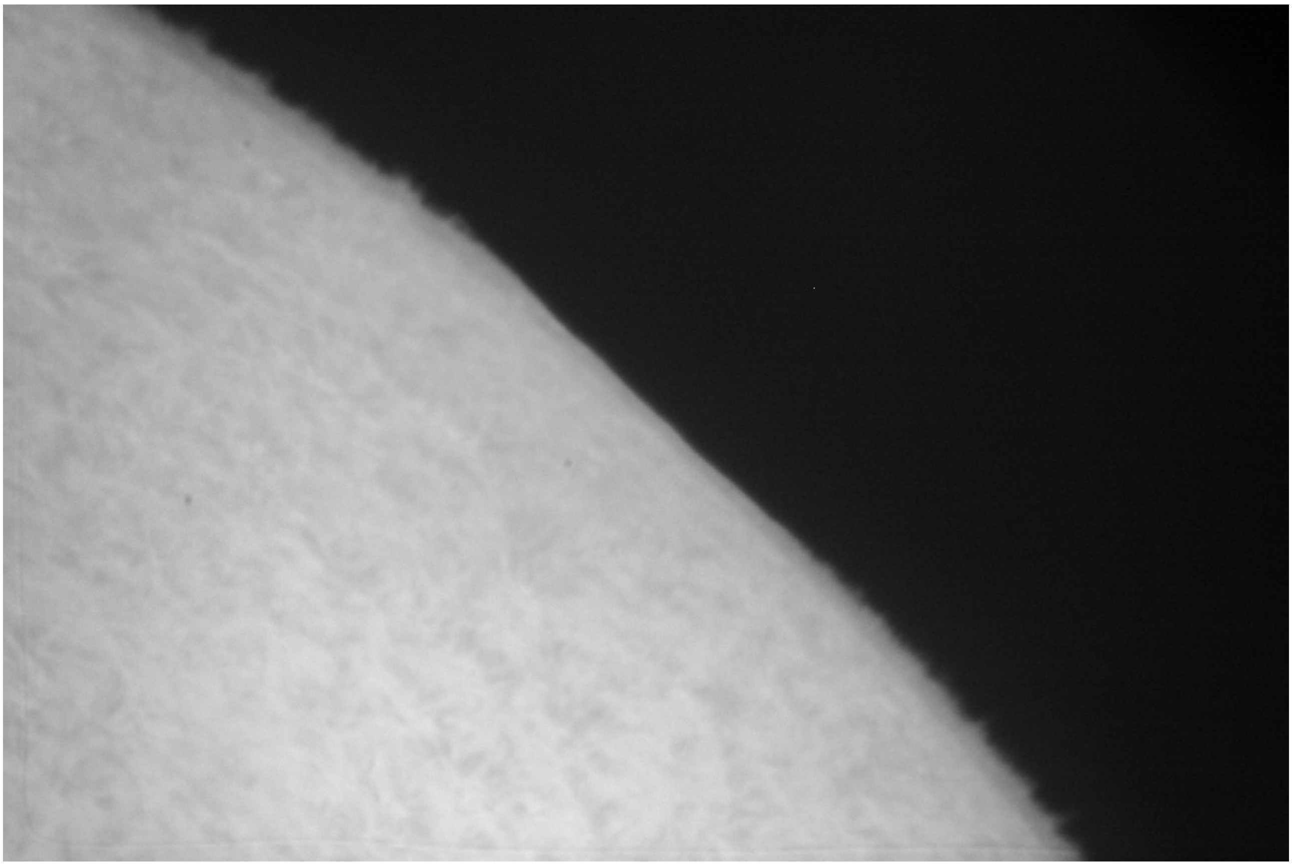


Fig. 1.4 The solar and the lunar limb: end of January 4th 2011 partial eclipse, in H alpha. The region under study is here imaged with the Bialkow Corograph (Poland) of 53 cm, the largest in the World, during the partial solar eclipse of January 4, 2011 at 10:57:01 UT in the red channel (H alpha).

The end of the eclipse has been calculated (with Occult 4 software) for a solar standard photospherical radius

[3] P. V. Foukal, Solar Astrophysics, (Wiley-WCH, Weinheim, 2004).

at 10:56:53 UT, which corresponds to the time in which the lunar limb is tangent to the solar limb.
In the following 15 seconds the Moon sweeped on the solar mesosphere and the spiculae.
The lunar limb is leaving the solar disk at a relative velocity of 0.343 arcsec/s, and it is visible in the central part of the figure, cutting partially the spiculae.
By the duration of the transit of the lunar limb (16 s) above the spicules their length is measured with an accuracy of ±1 s, i.e. ±0.3 arcsecs: 5.8±0.3 arcsecs, as presented in the figure 1.2, where 6 arcsec are indicated as the height of the spiculae.

1.2 The standard solar model

The standard solar model has two free parameters: the mixing length scale and the helium abundance, and after 4.52 billion year it should return the present radius of the Sun, its luminosity and the observed metal abundance. During the main sequence phase the solar diameter shrunk of 30%.[4]
The Sun is a star which is experiencing the main sequence phase of its evolution, therefore it is stable over a very long time span.

The standard solar model is used as a test case for the stellar evolution calculation because the luminosity, radius, age and composition of the Sun are well determined.[5]

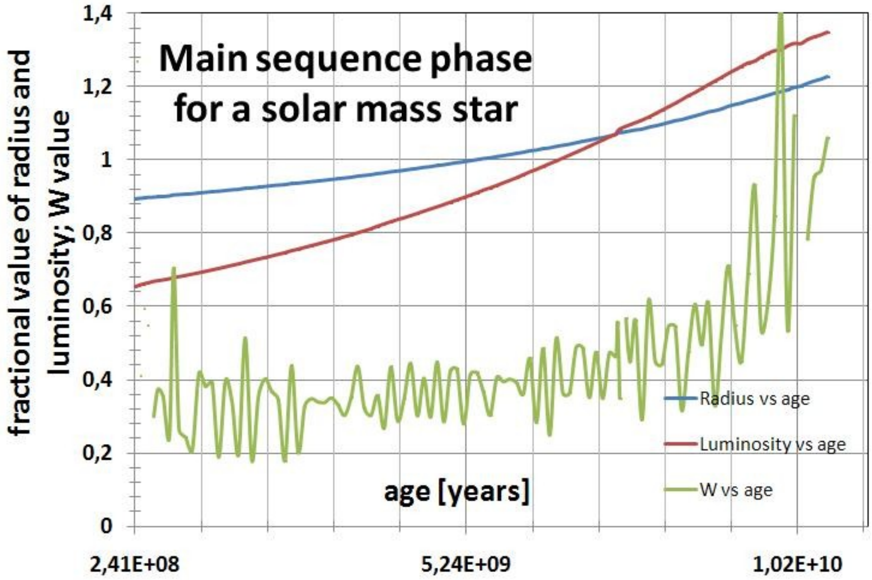


Fig. 1.5 A reference evolutionary model for a solar mass star calculated by L. Siess (1999) on his website of Liège University.[6] I have added the plot of W=dlogR/dlogL as computed from the same data.

Nevertheless certain properties of the Sun are observed to vary during the course of a sunspot cycle.

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4 The paradox of faint young Sun has been outilned firstly by Carl Sagan in 1972 is due to the fact that the solar luminosity grows up gradually during the main sequence phase. Early in the Earth's history, the Sun's output would have been only 70% as intense during that epoch as it is during the modern epoch. Different combinations of greenhouse effects have been claimed to solve this paradox. Moreover in the proterozoic epoch the Earth would have experienced periods of complete glaciation: the phenomenon is known as *Snowball Earth* at it is end with volcanic massive immission of carbon dioxyde, which led to an heavy greenhouse effect (A Neoproterozoic Snowball Earth, P. F. Hoffman, A. J. Kaufman, G. P. Halverson and D. P. Schrag, Science **281**, 1342, (1998)).

5 Guenter, D., What is a solar model? http://www.ap.stmarys.ca/~guenther/evolution/what_is_ssm.html (2010)

6 http://www-astro.ulb.ac.be/~siess/MODELS/PMS/OV02/m1.0z02d02.hrd
it is the evolution of a solar mass star with z=0.02 and overshooting parameter d=2 pressure scale heights. The Sun has Z/X = 0.02497, and this explains why radius and luminosity do not cross each other at 1 value for present age (4.52 billion years).

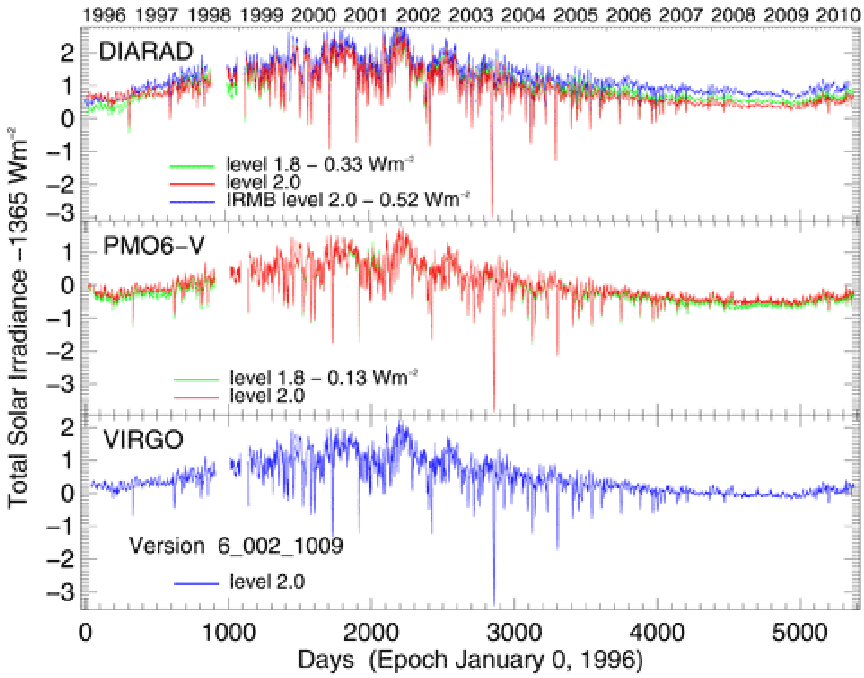

Fig. 1.6 The total solar irradiance measured in the last 14 years with the VIRGO experiment onboard of SOHO satellite.[7]

The daily averages of the solar irradiance have excursions between a minimum of 1362 W/m² and a maximum of 1368 W/m². The irradiance is affected by the occurrence of individual sunspots on the disk. Taking into account yearly averages, the peak to peak amplitudes of luminosity[8] are found to be about $\Delta L/L \approx 0.001$.

Moreover the variations of surface temperature are limited at 1.5 ± 0.2 K and they are in phase with other indicators of the cycle[9].
Using these constraints on the equation of Stefan-Boltzmann of a radiating sphere we can set an upper limit for the variations of the solar radius.

$$\Delta L/L=2\Delta R/R+4\Delta T/T \quad (1.0)$$

So with $\Delta L/L \leq 0.001$ and $4\Delta T/T \leq 0.001$, where T=5777 K for the photosphere, and L=1365 W/m². Assuming both L and T in phase, the amplitude of $2\Delta R/R$ is $\Delta R/R \ll 0.0001$ i.e. $\Delta R \ll \pm 0.1''$; while assuming them in anti-phase $\Delta R/R \approx 0.001$, and the maximum value for radius oscillation is $\Delta R = \pm 1''$where $R=959.26''$ at 1 AU of average distance.
We can consider these constraints on the possible variations of the diameter of astrophysical origin.

Nevertheless if the variation of the radius is due only to an outer layer, the whole variation can be larger, with a reasonable energy balance.

Variations of the order of 0.1 arcsec per solar cycle can be explained by various models, with different energy

[7] Source: http://www.ias.u-psud.fr/virgo/

[8] The difference between irradiance and luminosity is that the first can be affected by solar spots or active regions, while the second is independent on the local properties of the solar disk. Irradiance, hereinafter, is the instant value of the energetic output of the Sun while Luminosity is its reference, global, value.

[9] Gray, D. and W. Livingston, Monitoring the Solar Temperature: Spectroscopic Temperature Variations of the Sun, Astrophysical Journal v.474, p.802 (1997). Also a secular trend of 0.014 K per year was presented in that paper. No further mention of that trend in Livingston, W., Gray, D., Wallace, L., & White, O. R., Quiet Sun unaffected by Activity Cycle, Large-scale Structures and their Role in Solar Activity ASP Conference Series, Vol. 346, Proceedings of the Conference held 18-22 October, 2004 in Sunspot, New Mexico, USA. Edited by K. Sankarasubramanian, M. Penn, and A. Pevtsov, p.353- 355.

involved.
A variation of the solar radius implies a variation in the gravitational energy according to the following equation (1.1) where E is the accumulated energy, R is the variation of the solar radius, G the universal constant of gravitation and M the solar mass. A variation $\Delta R=0.1\%$ requires an energy variation 75 times larger than the energy irradiated.[10]

$$\Delta E=\Delta R\cdot(3GM^2/5R^2) \qquad (1.1)$$

Considering the radiant surface and the energy flux per unit area as constant, the radius variation produces a variation of the irradiance I according to the formula (1.2) where R is the solar radius

$$\Delta I=-\Delta R\cdot(2I/R) \qquad (1.2)$$

Therefore with a $\Delta R/R=0.1\%$ half of the variation of irradiance (the total is $\Delta I/I=0.1\%$) during a solar cycle is explained, the other half requires other explanations. If the radius variation is restricted only to the convective zone of the Sun, the observed variation of 0.1% requires a negligible gravitational energy of about 0.01% during a whole solar cycle.[11]

1.3 The role of the magnetic field

The energy stored in the magnetic field plays a fundamental role in the energy balance of the Sun, as well as the temperature of the photosphere and the diameter of the Sun.

Nevertheless the magnetic field is not taken into account in the standard solar model.
Moreover understanding the reasons of the cyclic variation of the total solar irradiance is one of the most challenging targets of modern astrophysics. These studies are essential also for climatologic issues, associated to the global warming discussion.
All attempts to determine the solar contribution to this phenomenon must include the effects of the magnetic field, whose strength and shape in the solar interior are far from being completely known.

Modelling the presence and the effects of a magnetic field requires a two-dimensional approach, since the assumption of radial symmetry is too limiting for this topic. A 2D evolution code has been introduced by Sabatino Sofia and his team at Yale University: rotation, magnetic field and turbulence are taken into account in such a model.[12]

There are other stars of colour index B-V close to the solar one B-V = 0.66, which show similar behavior in the chromospheric flux, with periodicities ranging from 7 to 16 years, very close to the solar cycle of 11 years.
The study of these stars will help to place the solar activity in a general perspective.

[10] Boscardin,S., A. Andrei, E. Reis Neto, J. Penna, V. d'Ávila, W. Duarte, P. Oliveira, XXXIII Reunião da SAB, resumo 362 (2007).

[11] Boscardin, S. C., UM CICLO DE MEDIDAS DO SEMIDIÂMETRO SOLAR COM ASTROLÁBIO, Ph D Thesis Observatorio Nacional, Rio de Janeiro, Brasil, 2011.

[12] Li, L., S. Sofia, P. Ventura, V. Penza, S. Bi, S. Basu and P. Demarque, Two-Dimensional Stellar Evolution Code Including Arbitrary Magnetic Fields. II. Precision Improvement and Inclusion of Turbulence and Rotation, ApJS **182** 584 (2009).

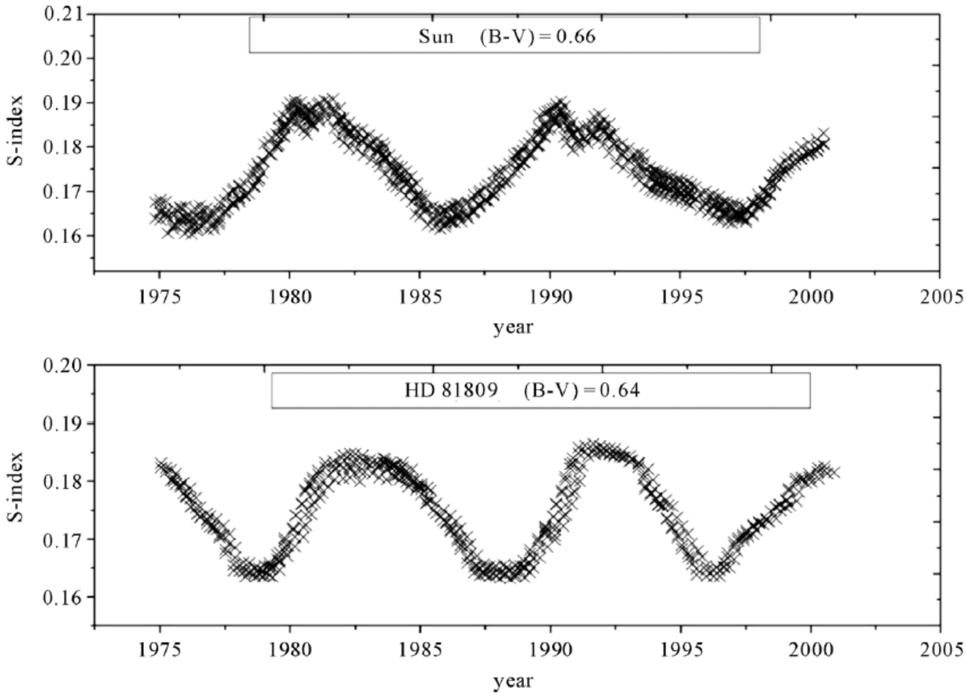

Fig. 1.7 The relative intensity of Ca II H (396.8 nm) and K (393.4 nm) emission lines for the Sun and the star HD 81809 (HR 3750) of Mv=5.4, Mount Wilson Observatory.[13]

1.4 Introducing W=dlogR/dlogL

The luminosity and the radius of the Sun are involved in the Stefan-Boltzmann equation, but their logarithmic derivative W is not ½ as for uncorrelated quantities, because of the magnetic field.

It is introduced the parameter W=dlogR/dlogL in order to describe the connection between luminosity and radius. For an isothermal Sun W=0.5.
From the model plotted in fig. 1.5 W ranges from 0.2 to 0.6 during the main sequence phase of a solar-type star, but it is from the Picard satellite mission that this parameter is expected to be determined observationally with an unprecedented accuracy.

The W parameter can be considered as a characteristic of the Sun during the present phase of its evolution, and it will help to know the solar luminosity in the past centuries, if some measurements of the diameter are available.

Data on the past solar diameter are expected to be obtained by total eclipses timing, with the required accuracy to feed opportune climate models. Eclipses are treated in chapter 3.

For a daily monitoring it is necessary a direct measurement or the timing of a transit on a meridian, an hourly circle or an almucantarat.
The methods based on timing are the other subject of this thesis in chapter 2.

[13] Bruevich, E. On chromospheric variations modeling for main-sequence stars of G and K spectral classes, Natural Science **3** 641 (2011).

1.5 Solar variability in the past millennia

The existence of ice ages either in the last million year and in the pre-cambrian age has been explained also with astronomical causes (Milankovitch cycles), but the periods of global warming and cooling in the past millennia have indeed a solar origin. Nowadays the global warming seems to be anthropogenic through the greenhouse effect. But this is still an open question with political, economical and social implications. Conversely there are emerging topics as the global dimming and the debate about the approaching new solar grand minimum.

The study of solar activity along centuries has permitted to identify a number of phenomena which are reliable indicators of the solar activity, as it is the solar spot number, available with continuity only since 1700.
These indicators, or proxies, show that the Sun undergoes some variability experiencing periods of grand maxima (10 to 15% of the time), normal activity and grand minima (15 to 20% of the time).[14]

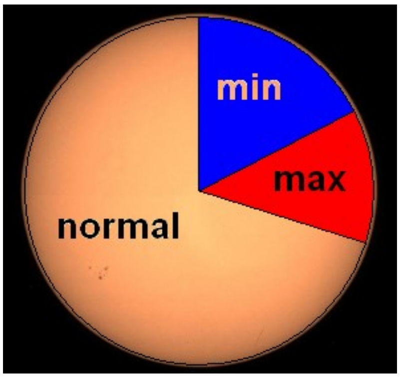

Fig. 1.8 The ratio between grand minina, grand maxima and normal activity.

The Maunder minimum, occurred between 1645 and 1715, is one of these period of grand minima, the only one witnessed in the telescope age; another relevant minimum has been named Dalton minimum and occurred around 1810.[15]
The Dalton minimum is the most similar to the recent exceptionally low solar minimum, occurring at the end of cycle XXIII and the rumor of an approaching grand minimum is gaining consensus in the science community.[16]

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[14] Usoskin, I., A History of solar activity over millennia http://cc.oulu.fi/~usoskin/personal/lrsp-2008-3Color.pdf

[15] Axel D. Wittmann, German astronomer and historian of science answered to my question about the names of solar minima in the following way. “If I remember correctly, some of the extended solar activity minima were named by John "Jack" Eddy in the 1970-ies after persons who investigated sunspot number records - in particular Wolf [Zürich], Spoerer [Potsdam], Maunder [Greenwich], and Gleissberg [Istanbul]. I knew Gleissberg in person, but I think the "Gleissberg cycle" is, like most other sunspot cycles except the 11-year cycle, a transient phenomenon which disappears after several hundred or thousand or hundred thousand years... I do not know much about the chemist and "atomic physicist" John Dalton (ca. 1766-1844) and his possible work in solar physics. But he flourished (lived) around the time of the "Dalton Minimum" (i.e. around 1810) which may be the reason for giving it his name. What remains is the Oort Minimum (around 1050) named after the Dutch astronomer Jan Hendrik Oort, who in 1927 investigated the rotation of the Milky Way (see "Oort's constants"). I am not aware of any "solar cycle research" by Oort, except that he was a member of the allied commission that investigated solar research in Germany after World War II. But more recently some evidence has accumulated that variations (fluctuations) of cosmic ray intensity - due to the motion of the Sun around the center of the galaxy - may cause climatic changes by influencing the formation of clouds in the Earth's atmosphere. In one of my publications (around 1980) I have tentatively suggested to name the most recent maximum (approx. around 1980/1990) "Eddy maximum" in honor of Jack Eddy's work on the solar cycle, but I do not know whether this has found a wider acceptance.”

[16] Lockwood, M., Solar change and climate: an update in the light of the current exceptional solar minimum, Proc. of the Royal Society A, **466**, 303-329 (2010).

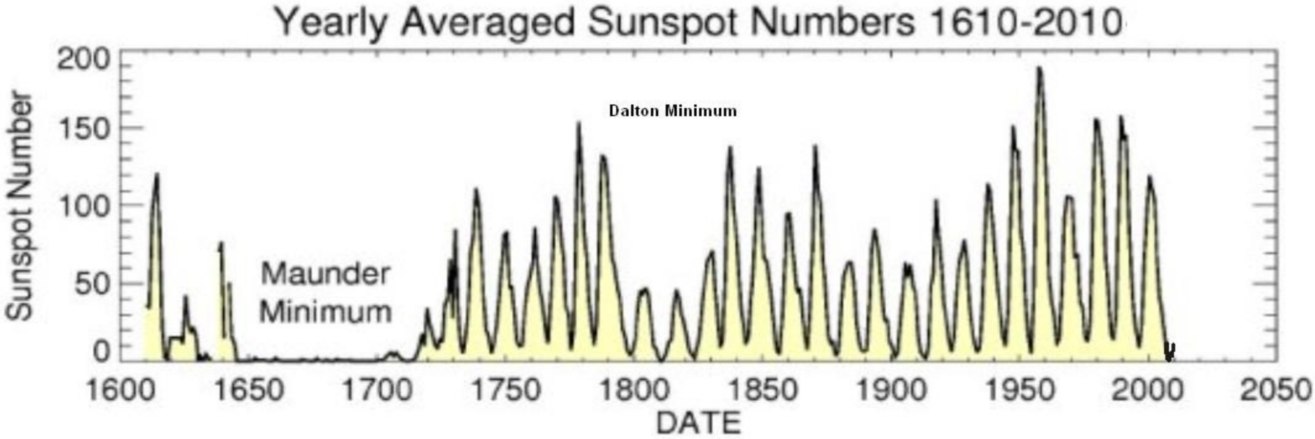

Fig. 1.9 The yearly averaged sunspot numbers from 1610 to 2010 from SIDC website.[17]

According to the observations from space of a large change in solar UV emission in the same phase of previous solar cycles there is evidence for centennial-scale change.[18]

Other confirmations come from the open solar magnetic flux derived from geomagnetic observations.[19]

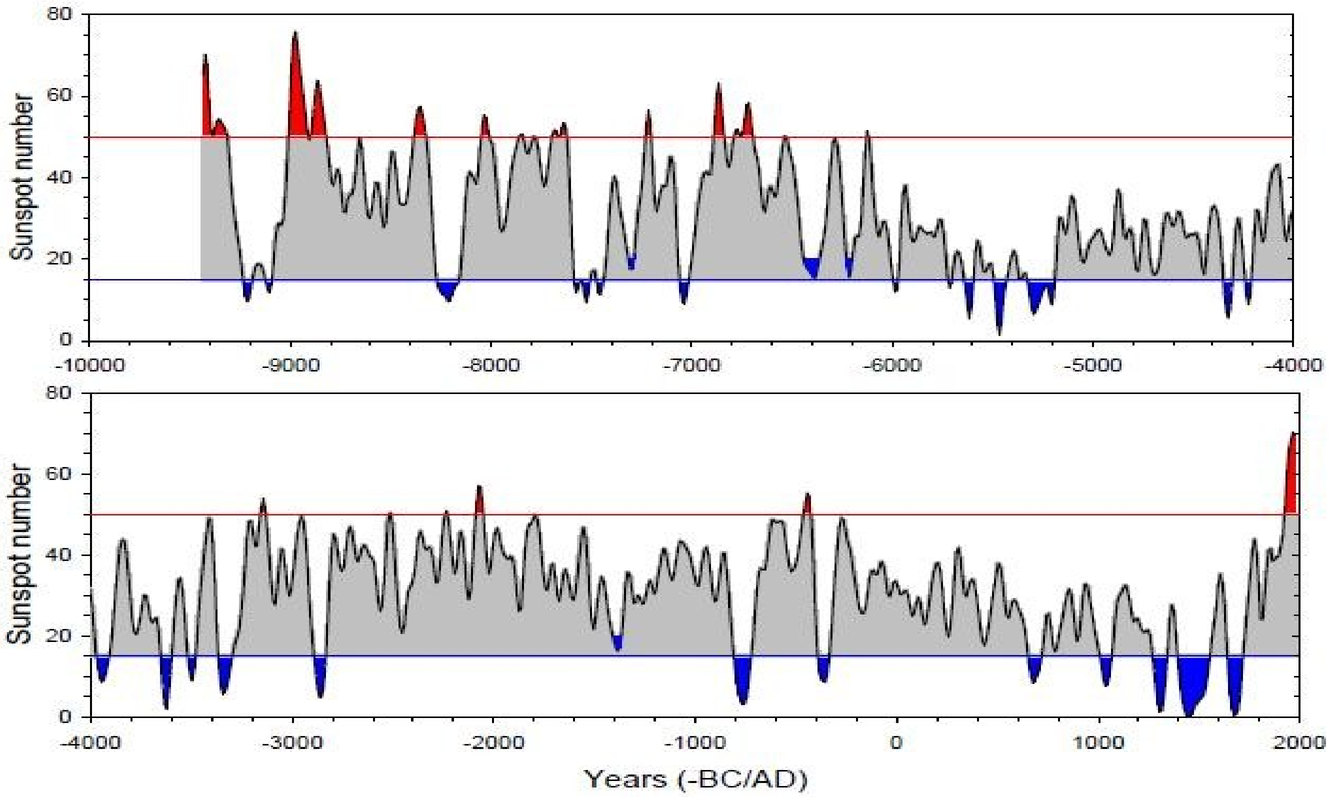

Fig. 1.10 The solar activity in the past millenia, with grand minina and grand maxima evidenced in blue and red (from Usoskin, 2008).[20]

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17 http://www.sidc.be/

18 Lockwood, M. , et al., Top-down solar modulation of climate: evidence for centennial-scale change, Environmental Research Letters **5** 034008 (9pp) 2010, IOP Publishing Ltd.

19 Lockwood, M. , et al., Are cold winters in Europe associated with low solar activity?, Environmental Research Letters **5** 024001 (7pp) 2010, IOP Publishing Ltd.

20 Usoskin, I., A History of solar activity over millennia http://cc.oulu.fi/~usoskin/personal/lrsp-2008-3Color.pdf

1.5.1 Global Warming

There is a long debate with this title, peaked with a Nobel Peace Prize assigned to a political personality.
The basic question is if this is anthropogenic, or if its origin is solar. Looking at the history of solar activity in the last few millennia, the role of mankind seems marginal.
Nevertheless the debate nowadays gained momentum because the anthropogenic energy on a yearly base corresponds to the % variation of the solar irradiance observed in the last three cycles.
In other terms the annual input of energy from human activities on the Earth system corresponds to one single hour of the solar input, i.e. $1/365/24=1.1\cdot10^{-4}$ of the total annual input.
The variations of the solar irradiance (see fig. 1.6) range up to 1 part over 1000, during a solar cycle, so the human component starts to be significant with respect to these solar variations.
Here is not the place where to present all the issues related to the Global Warming, there are two books written by solar physicist which I recommend: "The role of the Sun in climate change"[21] and "The Maunder minimum and the variable Sun-Earth connection".[22]
For the variability of the interpretations of data it is very interesting the website dedicated to the "infamous hockey stick"[23] which would have paved the way to that Nobel Prize...
What it is certain is that a global vision of the climate on the Earth is a very challenging task.
The dendrochronology helps to see locally the alternance between dry and wet years. Hot and cold seasons can be detected by the time of blossoms of some particular trees, but all these data can be valid in a restricted area. The lack of general information on the climate over the whole planet makes the interpretation of such data rather arbitrary.
Another example of problems in data analysis is the record of temperature.[24] The meteorological stations which in the XIX century were out of the cities now are included in the urban area. All cities behave like *heat islands*, storing the solar heat during the day and releasing it during the night.
Therefore the correctness of measurements on Global Warming on the Earth is a very delicate topic.
Moreover the models dealing with greenhouses gases are very delicate for what concern the servomechanism which would let the temperature exponentially grow once the raising started.
The fact that the atmosphere of the Earth contained more than 30 times the present amount of CO_2 during Jurassic,[25] or just before Cambrian, shows that the planet could bear such gaseous composition without losing its equilibrium, and also that the planet undergo greenhouse conditions without the contribution of mankind.
The influence of solar minima on the climate on Earth has been evidence by the authors above mentioned.
Frost fairs on the river Thames in London during 1814 at the end of the "Dalton minimum" is one example.
The "small ice age" during the Maunder minimum (1645-1715) has been represented by various artists.
Also the consequences of the explosion of Krakatoa volcano (1887) were represented by painters, and a study on the color of sunsets has been conducted in Greece. Sunsets appeared redder, caused by enhanced absorption. The paintings were analyzed with astronomical techniques as for looking for a color index. [26]

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[21] Hoyt, D.V. and Schatten, K.H., The role of the sun in climate change, New York Oxford, Oxford University Press, (1997).

[22] Wei-Hock Soon, W. and S. H. Yaskell, The Maunder minimum and the variable sun-earth connection, River Edge, NJ: World Scientific (2003).

[23] http://www.john-daly.com/hockey/hockey.htm (2004).
The author is J. L. Daly, he is not a professional scientist, but this field is now belonging to politcs, and all opinions have to be considered. Nevertheless even the Nobel Prize for peace are not necessarily chosen by a scientific board, and moreover he publishes books on the Global Warming sold in the science section of the libraries from US to South Korea, like Kyobo Bookstore in Seoul visited twice in 2005 and 2009 by me.

[24] On this topic there are the books of Leroy Ladurie, E., Histoire humaine et comparée du climat. Canicules et glaciers, XIIIe-XVIIIe siècles, Paris, Fayard (2004).
Alexandre, P., Le climat au Moyen Age, Paris, EHESS, 1987.
Titov, J., Evidence of Weather in the Account Rolls of the Bishopric of Winchester, 1209-1350, in Economic History Review, 1960

[25] That news is in a diorama exhibited in the Science Museum of Sydney, accessible to the kids, as well as the information that the oceans can absorb large amounts of CO_2.

[26] Zerefos., C., V. Gerogiannis, D. Balis, S. Zerefos, A. Kazantzidis, Atmospheric effects of volcanic eruptions as seen by famous artists and depicted in their paintings, Atmos. Chem. Phys., **7**, 4027-4042 (2007).

Another effect has been a more pronounced and prolonged twilight, similar to what is sometimes produced by high clouds in the stratosphere: polar stratospheric clouds (PSC's). In that case twilight might also be spread wider along the horizon than usual.[27]

Fig. 1.11 Frost fairs on the river Thames n 1814.

1.5.2 Global Dimming

The reversal of the Global Warming is also claimed. The condensation trails ("contrails") of the airplanes act like a filter for the solar radiation coming toward the Earth's surface.[28] The contrails reduce the daily temperature range.[29] During the period 11–14 September 2001, without commercial airplanes flying on the US it was registered an anomalous increase in the average diurnal temperature range (that is, the difference between the daytime maximum and night-time minimum temperatures) . Because persisting contrails can reduce the transfer of both incoming solar and outgoing infrared radiation, and so reduce the daily temperature range, at least a portion of this anomaly has been attributed to the absence of contrails over this period.

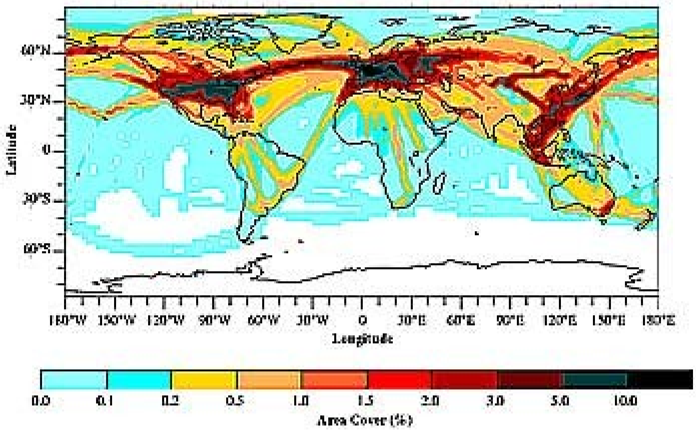

Fig. 1.12 Persistent contrail coverage (in % area cover) based on meteorological analysis data and on fuel emission database for 2050 (fuel consumption scenario for 2050), assuming linear dependence on fuel consumption and overall efficiency of propulsion h of 0.5; global mean cover is 0.5%.[30]

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[27] Van der Verfe, S. Private communication (2010), in the occasion of the volcanic eruption in Iceland, which blocked the fly in the northern europe for a few weeks in April 2010.

[28] http://www.ipcc.ch/ipccreports/sres/aviation/index.php?idp=40

[29] Travis, D. J., A.M. Carleton and R. G. Lauritsen, Nature **418** 601 (2002).

[30] Source: IPPC, Aviation and the Global Atmosphere, http://www.ipcc.ch/ipccreports/sres/aviation/index.php?idp=40 fig 3.23. According to these authors the increasement of the coverage by contrails will correspond to an increasement of the heat through greenhouse effect. Just the contrary of the previous article of Travis et al. on Nature. The IPPC Intergovernmental Panel on Climate Change is also the recipient of the aforesaid Nobel Peace

More in general also smog is a source for the Global Dimming, which would amount to 4% of solar radiation arrived to the Earth since 1960.[31]

1.5.3 An approaching Grand Minimum?

After an unusual period of no spot activity, the XXIV cycle of the Sun has started to resume a rather normal activity in the month of July 2011.[32] Groups of spots appeared on the solar surface, leading the international solar community to switch the theme of solar meetings from "Solar Astrometry and Grand Minima of Activity"[33] to "The Sun: from quiet to active – 2011".[34]
The long period of time with the Sun spotless, almost 3 years, has been compared with the "Dalton minimum" occurred in 1810-14.
The trend of diminution of surface magnetic field of the Sun, would led to zero within the present decade. Livingstone and Penn have observed spectroscopic changes in temperature sensitive molecular lines, in the magnetic splitting of an Fe I line, and in the continuum brightness of over 1000 sunspot umbrae from 1990-2005. All three measurements show consistent trends in which the darkest parts of the sunspot umbra have become warmer (45K per year) and their magnetic field strengths have decreased (77 Gauss per year), independently of the normal 11-year sunspot cycle. A linear extrapolation of these trends suggests that few sunspots will be visible after 2015.

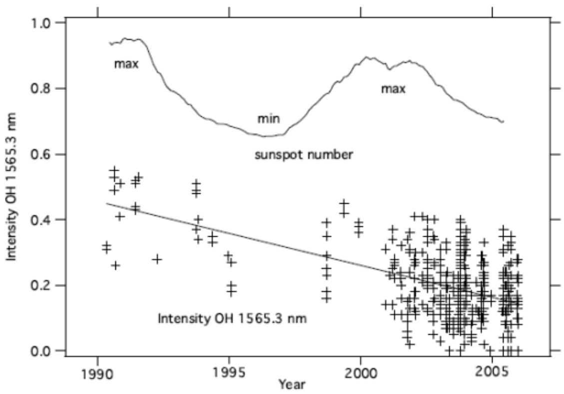

Fig. 1.13 The line depth of OH 1565.3 nm for individual spots. The upper trace is the smoothed sunspot number showing the past and current sunspot cycles; the OH line depth change seems to smoothly decrease independently of the sunspot cycle.[35]

Prize. Because of its scientific and intergovernmental nature, the IPCC embodies a unique opportunity to provide rigorous and balanced scientific information to decision makers. By endorsing the IPCC reports, governments acknowledge the authority of their scientific content. *The work of the organization is therefore policy-relevant and yet policy-neutral, never policy-prescriptive.* That Nobel Price recipient was indeed not neutral.

31 http://en.wikipedia.org/wiki/Global_dimming

32 http://www.sidc.be/products/quieta/

33 Galileo – Xu III meeting, Beijing, October 11-15, 2011, parallel session, conceived in March 2011.

34 International Workshop on Solar Physics, Lebedev Institute of the Russian Academy of Sciences, August 29 – September 02, 2011.

35 Penn, M.J. and Livingston, W., ApJ (Letters), **649**, L45 (2006).

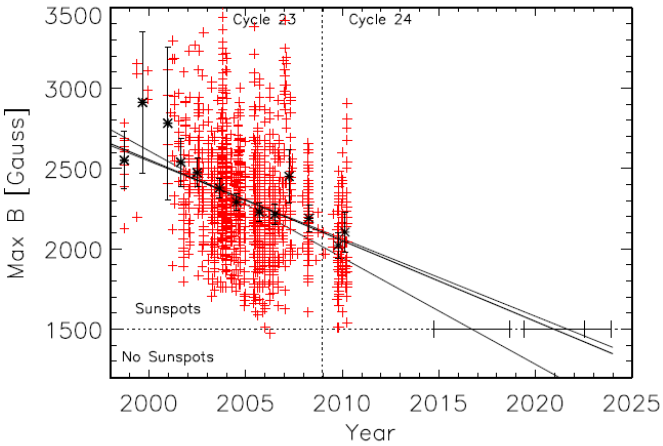

Fig. 1.14 Measurements of the total magnetic field strength at the darkest location in umbrae and pores as a function of time. The crosses show the individual measurements, the asterisks show annual bins. Three linear fits are shown: the bottom fit line fits data from 1998-2006 as done in our 2006 paper. The top line fits all the data from Cycle 23, and the middle line fits all of the data.[36]

The absence of spot would mean a new grand minimum, like the minimum of Maunder.

1.6 Several solar radii

There is a different radius for each wavelength, also for radio. There is also the seismic radius. How accurate are these values, and how big are their variations?

The solar diameter is defined as the position of the inflexion point of the limb darkening function. This function is the intensity variation of the Sun a
long its radius.

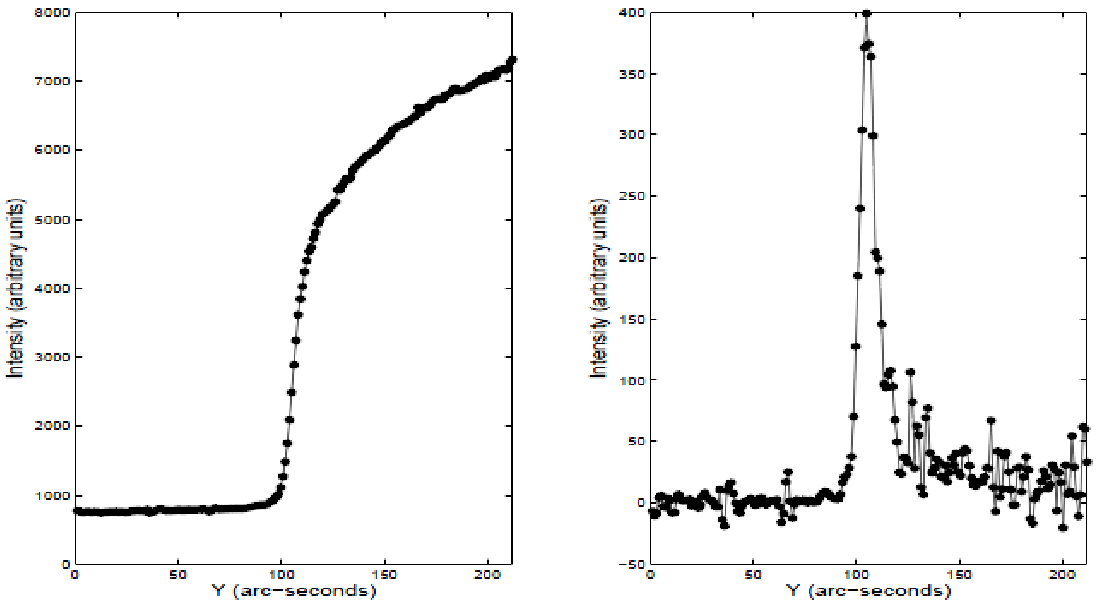

Fig. 1.15 Solar limb profile and its derivative of the image of the Sun at 535.75 nm made with SODISM II on August 11, 2011.[37]

[36] Penn, M.J. and Livingston,W. http://arxiv.org/abs/1009.0784 (2011).

[37] Irbah, A., M. Meftah , T. Corbard, R. Ikhlef, F. Morand, P. Assus, M. Fodil, M. Lin, E. Ducourt, P. Lesueur, G. Poiet, C. Renaud and M. Rouze, Ground-based solar astrometric measurements during the PICARD mission, submitted to SPIE (2011), fig. 12.

The different solar diameter measured at different wavebands is due to the differet height sampled within different wavebands.
Neckel and Slabs[38] have published accurate measurements of the solar diameter at the Kitt Peak observatory around the visible range of wavelengths, from 303 to 1099 nm.
These measurements still remain a fundamental reference for all models of solar emission.
The recent measurements made with the instruments of Picard-Sol show very well the difference between the wawelenghts.

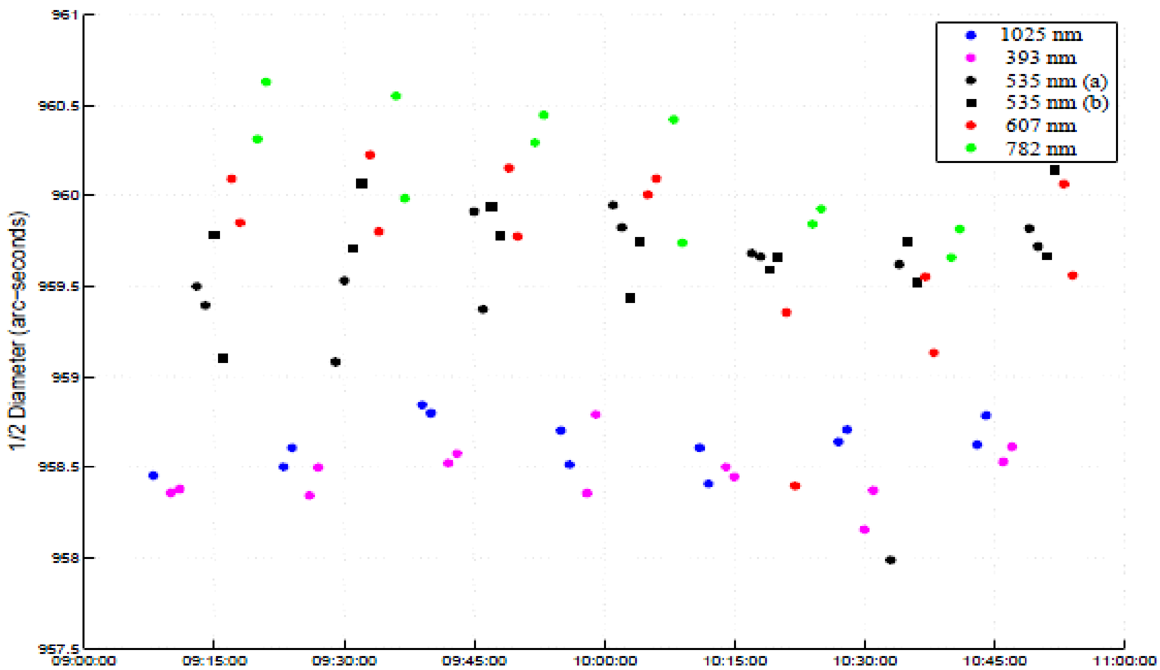

Fig. 1.16 The diameters measured with SODISM II on August 11, 2011 in different wavebands. SODISM (Solar Diameter Imager and Surface Mapper) is an 11-cm diameter Cassegrain telescope associated with a 2048x2048 pixels CCD detector where the whole SUN is formed. Wavelengths are selected by mean of interference filters placed on 2 wheels. Wavelength domains have been chosen free of Fraunhofer lines (535.75, 607.1 and 782.2 nm). Active regions are detected in the 215 nm domain and the CaII (393.37 nm) line. Helioseismologic observations are performed at 535.75 nm. From Irbah et al. (2011).[39]

38 Neckel H. and D. Slabs, Solar Phys. 153 (1994) 91.

39 Irbah, A., M. Meftah , T. Corbard, R. Ikhlef, F. Morand, P. Assus, M. Fodil, M. Lin, E. Ducourt, P. Lesueur, G. Poiet, C. Renaud and M. Rouze, Ground-based solar astrometric measurements during the PICARD mission, submitted to SPIE (2011), fig. 13.