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Status of solar global properties measurements

PICARD mission

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Abstract. Global quantities such as total solar irradiance, temperature, solar spectrum, frequencies of oscillation, and their variations as a function of time, are characterizing the Sun properties that the solar models have to represent. This is why their simultaneous measurements are important for the understanding of the physical processes which take place in the solar machine. We review below the solar missions, which will be in space in 2006 and beyond. In particular, PICARD and Solar Dynamics Observer will be in operation together and will have complementary measurements and a strong scientific synergy for the study of the solar variability and its consequence for the Earth's climate.

Key words. Sun

1. Rationale for observing global solar measurements

Global solar measurements are high level information which characterise our star. Such as is the total solar irradiance (TSI) which allows recovering the solar luminosity, and consequently the temperature of the corresponding emissive layer. Observing the solar spectrum permits access to the solar atmosphere composition, and temperature of the different emitting regions making possible to distinguish emission from the photosphere, the chromosphere and the corona. Helioseismology is a powerful means of investigation of the solar interior allowing validation of the solar models by comparison between observations and predictions, and providing in particular the rotation of the internal layers which are not accessible by direct observations. Today most of the pressure modes (p-modes) have been detected with the SoHO instruments and analysed in term of physical processes. Existence of gravity modes (g-modes) are suggested by GOLF/SoHO and VIRGO/SoHO. Their detection would allow study of the dynamics of the nuclear solar core. These observations are relevant of the general problem of the stellar evolution. The solar diameter is a fundamental quantity as well as the diameter of all other astrophysical bodies. The solar diameter results of temperature, composition (through opacity of the solar atmosphere), magnetic field and dynamics of the convective zone. Any change affecting these quantities will result in a change of diameter as well as the solar asphericity. Differential rotation either determined by sunspots observations or by the helioseismology measurements, is information in relation with the magnetic field and dynamics of the solar interior. The sun being a variable star, the global properties of the sun have to be measured as a function of time, and simultaneously by more than one instrument, and in principle on a continuous basis as the successive solar cycles are not identical. Up to now this condition has been fulfilled for the total solar irradiance and solar spectrum.

2. Measurements of the solar diameter

The solar diameter has been observed for astrometry purposes since the Antiquity, however inaccurately given the technical means of that time. Measurements with a precision of 0.5 to one arcsecond began during the second half of 17th century from ground and were continued up to now with increasing accuracy, and more recently from space. Different techniques are used to measure the solar diameter such as the Mercury transits in front the Sun, solar eclipses, astrolabes, imaging telescopes. The results obtained by these ground-based observations are inconsistent, as showing either correlation or anti correlation with the solar activity, or none variation. The sources of these inconsistencies are likely: i) the turbulence of the local atmosphere which modifies the solar limb profile when it is observed from the ground, ii) the stability of the instruments point spread function, iii) the spectral domain of observation more or less free of Fraunhofer lines which are able to gather photons from the chromosphere and photosphere leading to an undefined altitude and in particular making ambiguous any variation with time, iv) the data processing and filtering techniques which have also a certain role as changing the observed solar limb shape, and consequently the corresponding diameter. However, all ground based measurements cannot be a priori rejected as nonsense as their quality depends of the site and data processing which may take into account to a certain extent the effect of the lower atmosphere. Given the difficulties and ambiguities of the ground based observations, diameter determinations were carried out outside the atmosphere. The MDI instrument on board SoHO is dedicated to helioseismology observations for the study of the solar interior. Images in the photospheric continuum were also used to derive the solar diameter (Kuhn et al. 2004). A variation smaller than 15 milliarcseconds (mas) is found from minimum to maximum solar activity. However, important corrections of thermal and ageing origin were made based on models. Helioseismologic results were also used to infer a solar radius as follows: given a solar model, it is possible to calculate the frequency distribution of the f-modes. By adjusting the solar radius, the difference between observations and predictions is minimized which determines the solar radius. To avoid confusion with the radius measured in the photospheric domain, helioseismology determines a radius that has to be named as seismic radius. Indeed, that radius cannot be identified with the photospheric radius as it corresponds to a deeper layer in the solar interior, located between 4000 and 8000 km below the photospheric diameter. Variations at that depth are found to be very small of the order of one or two mas, and present an annual effect likely due to the instrument thermal equilibrium and furthermore a change of diameter is observed after the temporary interruption of the SoHO operations in 1999. The seismic radius variation as a function of time is unclear showing either a correlation or an anti correlation or none variation with solar activity (Dziembowski et al. 1998, 2000, 2001; Antia et al. 2000; 2001, 2003). The Solar Disk Sextant (SDS) is an instrument design for diameter variation as including an angular reference made by a wedge. Placed on a stratospheric balloon, SDS (Sofia et al. 1984) flew four times from 1992 to 1996 taking advantage of the solar activity decrease during that period. A diameter variation of 200 mas was measured in antiphase with the solar activity (Sofia et al. 1992a, b; Egidi et al. 2005). A detailed discussion of available diameter measurements is made in Thuillier et al. (2005a). Consequently, the relation between the solar diameter variation and solar activity remains unclear at the experimental point of view. Several theoretical models provide predictions consisting in a very small diameter variation with solar activity. However, theses models do not simultaneously represent the variation of the p-mode frequency shift and the TSI variation both with solar activity. The Li et al. (2003) model which takes into account the turbulence in the convective zone has that capability. Running this model, the diameter at different depth is compared with the diameter at 5 Mm depth. Their ratio increases toward the surface allowing a much greater diameter variation in the photosphere than at the depth where the seismic diameter is determined by helioseismologic measurements. The corresponding figures are shown in the S. Sofia's presentation.

3. PICARD Mission

Given the lack of consistency of the solar diameter variation obtained up to now, as well as disagreement among the theoretical models predictions, the PICARD mission will undertake measurements from space of several global parameters including the solar diameter with a metrological instrument. The PICARD mission was named after the French astronomer of the 17th century Jean Picard who achieved the first accurate measurements of the solar diameter. His measurements processed by Ribes et al. (1987) showed a diameter increase during the Maunder minimum with respect its value by 1710-1715 when the sunspots number was significantly greater than before. This has opened the discussion about the diameter variation and its relationship with the solar luminosity variation.

3.1. Scientific objectives of the PICARD mission

PICARD is a mission dedicated to the study of the Sun-Earth atmosphere relationship for which several specific objectives will be undertaken:

1. Determination of the variability of several global solar properties, such as TSI, UV irradiance, and the solar diameter by a dedicated instrument.
2. Modeling of the solar machine and study of the role of the magnetic fields on surface or deeper in the convective zone.
3. Contribution to solar luminosity reconstruction.
4. Long term trend study.
5. Understanding of the diameter variation as observed from ground.

The simultaneous measurement of TSI, solar diameter, and solar oscillations will introduce strong constraints in the solar models leading to improve the physical processes on which they are built. Asphericity and limb shape will complement this study. Solar luminosity being derived from TSI measurements, its relationship with the diameter variation (assuming it is observed), will be obtained in term of W = L/L/ R/R. Assuming a solar machine not fully chaotic as the solar cycles suggest, W determination will contribute to validate historical reconstruction of luminosity as follows: the most accurate solar diameter determination are obtained from eclipses timing (Sofia et al., 1984, 1985). Luminosity reconstructions based on different hypothesis agree for the recent period; however they disagree the most for the farthest. Around 1715, reconstructions differ by 2W/m2. For validating a climate model, the observed climate and its reconstruction are compared. A discrepancy may originate either from the model itself or from the energy input. Changing this input by an amount of 2 W/m2 will have a significant effect on the mean temperature. This is why validating solar luminosity reconstruction is an essential step in the climate modeling. For our society, climate prediction is of prime importance. Omitting the volcanic dusts, the two major inputs are the greenhouse gas concentration and the solar activity which both need to be anticipated. Given the industrial activity, the greenhouse gas concentration evolution may be estimated. There is a similar need at the scale of several tens of years for the Sun luminosity. Sun modeling is a first possibility based on improvements expected by simultaneous measurements of several solar global properties. An experimental way is also considered by using the solar diameter referred to stellar angular distances at the time of the mission. These measurements repeated during the next cycles using the same stars and after correction of their proper movements would provide information about the Sun secular activity trend. UV irradiance is the key input for ozone photochemistry which is considered as playing a significant role in the stratosphere/troposphere coupling. This is why the relevant spectral domain will be also observed during the PICARD mission.

3.2. Measurements of the PICARD mission and the instruments

PICARD will perform measurements of the following quantities and their variability (Table 1).
From space:

1. the solar diameter, asphericity, and limb shape in the photospheric continuum,
2. the differential rotation,
3. the solar oscillations to study the Sun internal structure,
4. the total solar irradiance,
5. the radiance/irradiance in UV and visible domains,

and from ground:

1. the solar diameter, asphericity, and limb shape in the photospheric continuum.

The PICARD payload is composed of the three instruments: PREMOS, SOVAP, SODISM. PREMOS, PREcision MOnitoring Sensor is made of four units: a set of 3 sunphotometers and the absolute radiometer PMO6 as used on SoHO (Frhlich et al. 1995) to measure the total solar irradiance. The sunphotometers will be used to study the ozone photochemistry, to perform helioseismologic observations, and to relate radiance/irradiance observations with the corresponding images recorded by the imaging telescope (SODISM) as described below. PREMOS will select the spectral domains of observations by using interference filters with central wavelengths at 215, 268, 535, and 782 nm. The experiment comprises three units in order to assess sensitivity changes likely to occur for the most frequently exposed UV filters. The other two radiometers will be less frequently used (once per week, once per month respectively). PREMOS will provide absolute calibration to the SODISM channels. PREMOS instrument is under the responsibility of the Physikalish-Meteorologisches Observatorium Davos and World Radiation Center (PMOD/WRC, CH).
The SOlar VAriability PICARD (SOVAP) instrument provided by the Royal Meteorological Institute of Belgium (RMIB) will measure the absolute total solar irradiance. This instrument is an absolute radiometer of DIARAD type used in previous space missions, SoHO (Dewitte et al. 2004) and SOLCON on the Space Shuttle in 1992, 1993, 1994, 1998 and 2003 (Dewitte et al. 2001) Improved confidence in the TSI measurements can be achieved by using two radiometers of different concept operated at the same time as allowing to discriminate between signal variations of instrumental or solar origin. In particular it allows a validation of the in-flight ageing correction, which is the most important element contributing to the long term repeatability of the TSI measurements. This strategy was implemented on board SoHO with the VIRGO experiment consisting in the two radiometers DIARAD and PMO6 (Frhlich et al. 1997; Frhlich 2003). Consequently, PICARD will ensure continuity with SoHO measurements series by using the same type of instruments.
SODISM, SOlar Diameter Imager and Surface Mapper, is an imaging telescope of 11 cm diameter of Cassegrain type associated to a 2048x2048 pixels CCD detector from E2V. It measures the solar diameter and limb shape with an accuracy of a few milliarcseconds per image, and performs helioseismologic observations to probe the solar interior. The solar diameter is measured at three wavelengths (535, 607 782 nm) in the photospheric continuum as a function of the heliographic latitude. Images in the Ca II line are used to detect active regions near the limb which may alter the diameter measurements. These images will also be used to measure the solar differential rotation as well as for Space Weather. Probing the Sun's deep layers by helioseismologic observations is made by measuring the photometric fluctuations of the solar limb at 535 nm and in 32x32 macropixels. The instrument is made of material of low expansion coefficients (Invar, Zerodur, carbon-carbon), and thermally control within 0.5C. Furthermore, an angular reference included in the instrument consists in four prisms. This system provides the

Table 1. Measurements carried out during the PICARD mission in orbit and on the ground. SODISM I: diameter measurement in orbit. SODISM II, on ground SOVAP and PREMOS: measurement of the absolute Total Solar Irradiance (TSI) PREMOS: measurement in 5 spectral domains. MISOLFA: measurement of the local atmosphere turbulence from the ground.

Themes	Measurements	Instruments
Solar Physics	Variability Diameter/Luminosity	SODISM I, SOVAP, PREMOS
	Asphericity, limb shape	SODISM I
	Differential rotation	SODISM I
	Diameter/stellar reference	SODISM I
	Helioseismology	SODISM I, PREMOS
Climate	Diameter/Luminosity	SODISM I, SOVAP, PREMOS
	Luminosity	SOVAP, PREMOS
	UV Variability	PREMOS, SODISM I
Atmospheric physics	Diameter and limb shape at ground.	Gound-based instruments:
	Ozone photochemistry	SODISM II, MISOLFA, PREMOS
Space Weather	Images @215 and 393 nm(Ca II)	SODISM I

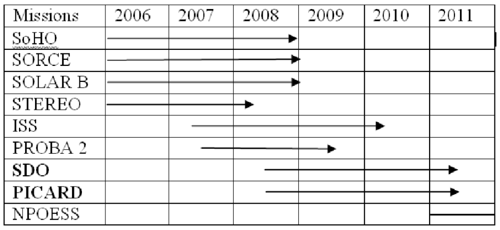

Fig. 1. This chart shows the space missions related to solar measurements from 2006 to 2011. SOHO: TSI, images in visible, UV and EUV, magnetograms, helioseismology. SORCE: TSI and solar spectrum from 12 to 2500 nm. SOLAR B: X-Rays-X and EUV. STEREO: CME. SOLAR/ISS: TSI and solar spectrum from 17 to 3000 nm. PROBA 2: EUV images, EUV spectral irradiance. SDO: EUV, magnetograms, helioseismology, images @ several wavelengths. PICARD: TSI, diameter, asphericity, solar limb,shape helioseismology, UV irradiance. NPOESS: TSI and minor components concentration measurements.

relationship (named internal scale) between a given point on the Sun and its corresponding image position in pixel on the CCD. Periodically, this scale will be referred to star angular distances after orienting the spacecraft toward doublets or triplets of stars selected as a function of the Earth's position around the Sun. The stellar scale being independent of the instrument, will be reusable in the future for estimating the secular change of the solar diameter, after taking into account the stars proper movement. This instrument is under the responsibility of Service d'Aronomie (CNRS, France). On the ground, a duplicate of SODISM will be running as well as an instrument to measure the local turbulence for the study of the difference between the solar shape and diameter measured at ground and in space. This study includes relationship with the PSPT program.
A detailed presentation of the instruments is made in Thuillier et al. (2005b).

The PICARD payload will be placed on board a microsatellite of a total mass of 160 kg. The launch of the spacecraft is foreseen by mid 2008. A heliosynchroneous orbit has been chosen for keeping as stable as possible the thermal environment of the instruments and for ensuring the longest time for helioseismology observations. Centre National d'Etudes Spatiales is the French space agency responsible of the mission.

4. Solar missions and synergy

Figure 1 shows the missions which are scheduled by the Space Agencies in a next future. By 2006 two new missions SOLAR B and STEREO will be dedicated to the study of the external sun layers by observations of short wavelengths emissions (X-rays and EUV) with particular attention to CME's. Two missions will be still in operation SoHO and SORCE

(Woods et al. 2000), both measuring the TSI, and the solar spectrum from 12 to 2000 nm for the latter. A successor to SORCE is expected. On board the International Space Station (ISS), three instruments should be in operation by spring 2007. They are presently in their integration phase on board their dedicated solar pointing system. The measurements consist in TSI and solar spectral irradiance performed by two instruments in the spectral range 17 to 3000 nm (Schmidtke et al. 2005). It is expected to run this payload during three years with retrieval to laboratory for a post flight calibration. Below 220 nm, the measurements will be referred to the absolute scale by a new technique based on absorption of the solar radiation by specific gases. This will bring important comparison with usual methods using synchrotron or blackbody radiation for determination of the instruments absolute scale. PROBA 2 also launched around the same time is dedicated to solar corona studies and Space Weather activity. By a fortunate coincidence Solar Dynamics Observer (SDO) and PICARD will be launched around mid-2008. These two missions have deep relationship as their measurements strongly complement. SDO carries three experiments: HMI is dedicated to the study of the solar magnetic activity and dynamics of the solar interior through helioseismology measurements; EVE will measure solar EUV irradiance with high rate sampling and spectral resolution, and AIA will image the transition region and corona. Consequently, SDO and PICARD will measure simultaneous several solar global properties (diameter, asphericity, total solar irradiance, magnetic fields, dynamics of the solar interior, and spectral irradiance), and solar magnetic activity allowing to study the sun from the interior to the exterior layers. Depending of SORCE mission extension (or its successor) and the ISS program, we may have between seven radiometers at the beginning of the SDO-PICARD missions, and two radiometers provided by PICARD by the end based on today approved missions. Finally, the synergy between SDO and PICARD will contribute to the Living With a Star science objectives for the understanding of solar variability and its effect on climate and for space weather.

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