The PICARD mission

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Abstract. The understanding of the physical processes taking place in the Sun allows construction of solar models. These models are validated by comparison between predictions and observations. Most of the observations are total and spectral solar irradiance, temperature, frequencies of oscillation, diameter, and asphericity, as well as their variations as a function of time. By 2006 and beyond, several missions dedicated to solar observations will be operated in particular PICARD and Solar Dynamics Observer which have complementary measurements and a strong scientific synergy for the study of the solar variability and its consequence for the Earth's climate.

Index Terms. PICARD, solar diameter, total solar irradiance.

1. Rationale of solar measurements

Solar measurements such as total solar irradiance, solar spectrum, temperature, frequencies of oscillation, diameter, are information which characterise our star in terms of energy and dynamics. Furthermore, these quantities have to be known as a function of time, and ideally known over some consecutive solar cycles as a given cycle does not look like the next. Some specific examples illustrate the scientific rationale of these measurements:

- helioseismology allows investigation of the solar interior providing in particular the rotation of the internal layers which are not accessible by direct observations.

- the solar spectrum measurement permits access to the solar atmosphere composition, and temperature of the photosphere, chromosphere and corona.

- the total solar irradiance (TSI) allows the determination of the solar luminosity, and the derivation of the temperature of the emissive layer.

Any change affecting these quantities will induce a change of solar diameter as well as the solar asphericity as resulting of temperature, composition (through opacity of the solar atmosphere), magnetic field and dynamics of the convective zone.

2. Measurements of the solar diameter

The diameter of all astrophysical bodies is a fundamental question and so the solar diameter. This is why its measurement was carried out since the Antiquity, however inaccurately given the technical means of that time. Ground based measurements were made with a precision of 0.5 to one arcsecond during the second half of the 17th century. Today, they are still performed with an increasing accuracy, and more recently from space.

Different methods and instruments are used for measuring the solar diameter such as the Mercury transits in front the Sun, solar eclipses, astrolabes, imaging telescopes. The results obtained by the ground-based observations show inconsistencies, consisting in either correlation or anti correlation with the solar activity, or none variation.

There are several sources of uncertainty affecting the results:

1. the turbulence of the local atmosphere which modifies the solar limb profile in case of ground based measurements,
2. the stability of the instruments point spread function,
3. the spectral domain of measurements which are not identical for all instruments making difficult comparison of their results
4. the spectral domain of measurements which contains more or less Fraunhofer lines able to gather photons from the upper solar atmosphere layers.
5. the data processing and filtering techniques for data analysis.

Discrepancies are likely due to a combination of the above causes, however difficult to analyse. This is why diameter determinations were carried out outside the atmosphere. The Michelson Doppler Imager is an instrument placed on board SoHO dedicated to helioseismology for studying the solar interior. Images in the photospheric continuum are also used to derive the solar diameter variation (Kuhn et al., 2004). A variation smaller than 15 milliarcseconds (mas) is found from minimum to maximum solar activity after significant corrections of thermal and ageing origin. Helioseismology also allows to determine the solar radius: using a solar model, the frequency of the f-modes can be predicted. By adjusting the solar radius, the difference observations/predictions is minimized and this allows to determine the solar radius. This radius is named "seismic radius" to avoid confusion with the radius measured in the photosphere. Indeed, the seismic radius corresponds to a deep layer 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 unclear variations with solar activity (Dziembowski et al., 1998, 2000, 2001; Antia et al., 2000; 2001, 2003).

Placed on a stratospheric balloon, the Solar Disk Sextant (SDS) flew four times from 1992 to 1996 (Sofia et al., 1994a, b) while the solar activity was decreasing. SDS is including an angular reference for diameter variation measurements. A diameter variation of 200 mas was measured in antiphase with the solar activity (Egidi et al., 2006), however only based on four flights. Consequently, from measurements, it is unclear to conclude about a relationship between the photosphere solar diameter and the solar activity. A detailed discussion of available diameter measurements is given in Thuillier et al. (2005).

The recent model (Li et al., 2003) allows to represent the variation of the p-mode frequency shift and the TSI variation both with solar activity. This model which takes into account the turbulence in the convective zone has been run at different depths. The ratio between the diameter at 5 Mm depth to its value in higher layers increases significantly allowing much greater variation in the photosphere than at 5 Mm where the seismic radius is measured. Furthermore, depending of the turbulence, a correlation or an anticorrelation may be predicted with solar activity (Sofia et al., 2005).

3. The PICARD mission

Given the inconsistencies of the solar diameter variation with solar activity observed up to now, as well as disagreement among the theoretical models predictions, the PICARD mission will undertake measurements from space of several solar parameters including the solar diameter with a metrological instrument. The PICARD mission is named after the French astronomer of the 17th century Jean Picard who achieved the first accurate measurements of the solar diameter.

3.1 Scientific objectives of the PICARD mission

PICARD is a mission dedicated to the study of the Sun-Earth atmosphere relationship with the following objectives:

1. Measurements of TSI, UV irradiance, and the solar diameter by metrological instrumentation and their variability.
2. Modelling 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.
5. Understanding of the diameter variation as observed from ground.

The simultaneous measurement of the total solar irradiance, solar diameter, and solar oscillations will introduce strong constraints in the solar models leading to improve the understanding of the physical processes on which they are built. Asphericity, irradiance in several spectral channels and solar limb shape will complement the above measurements. For climatology, excepting the volcanic dusts, the two major inputs are the greenhouse gas 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 evolution. Sun modelling 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 motion 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.

Solar Dynamics Observer (SDO) and PICARD will be launched around mid-2008. These two missions have deep relationship as their measurements strongly complement: 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.

3.2 Measurements of the PICARD mission and the instruments

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

1. the solar diameter, asphericity, and limb shape in the photospheric continuum,
2. the total solar irradiance
3. the solar oscillations to study the Sun internal structure,
4. the solar activity in the Ca II line,
5. the radiance/irradiance in UV and visible domains.
6. the solar diameter, asphericity, and limb shape in the photospheric continuum observed on the ground.

The above measurements will be achieved by the following instruments:

PREMOS, PREcision MOnitoring Sensor is made of four units: a set of 3 sunphotometers and the radiometer PMO6 as used on SoHO (Fröhlich et al., 1995) to measure the absolute 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 measure at 215, 268, 535, and 782 nm. PREMOS instrument is under the responsibility of the Physikalish-Meteorologisches Observatorium Davos and World Radiation Center (PMOD/WRC, Switzerland).

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 a 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. This strategy was used on board SoHO with the VIRGO experiment (Fröhlich et al., 1997; Fröhlich, 2003). Consequently, PICARD will ensure continuity with SoHO measurements series.

SODISM, SOlar Diameter Imager and Surface Mapper, is an imaging telescope measuring 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 and 782 nm) in the photospheric continuum as a function of the heliographic latitude. Images in the Ca II line (393 nm) 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, together with images in the 215nm wavelength.

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 ± 0.5°C and includes an angular reference.

Periodically, the instrument angular scale will be referred to star angular distances after orienting the spacecraft toward star doublets. The stellar reference will be reusable for future mission 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’Aéronomie (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. A detailed presentation of the instruments is made in Thuillier et al. (2006).

3.3 Main mission characteristics

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 sun synchronous 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.

The amount of telemetry to be downlinked will be around 2 GigaBits per day. A single S Band antenna, located near Toulouse, will be used.

3.4 International cooperation

PICARD is a cooperation between France, Belgium and Switzerland. In addition to the instrument SOVAP, Belgium will provide the Science Operation Center. This center will be implemented in Bruxelles, in the same premices as the SOC for Proba2.

A Guest Investigator programme will also be conducted, in order to allow scientists who are not part of the instrument teams to get some sets of data with the same rights as the PIs and Co'Is.

Finally, after a maximum period of two years after the end of the mission, all the scientific data will be publicly available.

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