International Conference on Space Optics—ICSO 2004

Toulouse, France

30 March–2 April 2004

Edited by Josiane Costeraste and Errico Armandillo

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International Conference on Space Optics — ICSO 2004, edited by Errico Armandillo,
Josiane Costeraste, Proc. of SPIE Vol. 10568, 105680G · © 2004 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2308028

POLDER 2 IN-FLIGHT RESULTS AND PARASOL PERSPECTIVES

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ABSTRACT

This paper presents a global approach of the POLDER 2 mission: from instrument design, pre-flight and in-flight calibrations till the first in-flight results. The POLDER 2 sensor has been developed by the Centre National d'Etudes Spatiales, the French space agency. It is part of the payload of the ADEOS II satellite developed by JAXA and launched in December 2002. POLDER 2 collected global data from April 2003, end of ADEOS II system check out phase, till the loss of the satellite on October 2003 due to a failure of the satellite power supply system.

The POLDER 2 sensor is designed to collect global and repetitive observations of the solar radiation reflected by the Earth-Atmosphere system for climate research.

The sensor is a wide field-of-view (2400 Km swath), low resolution (6x7 Km² at nadir) multi-spectral imaging radiometer / polarimeter. The instrument concept is based on a telecentric optics, a rotating wheel carrying 15 spectral filters and polarizers, and a bidimensionnal CCD detector array. The multi-disciplinary scientific objectives of POLDER 2 lead to severe radiometric and geometrical requirements, as well as a very accurate calibration of the sensor. These requirements are achieved through a stable instrument design, exhaustive pre-flight and original in-flight calibrations.

A derived model of POLDER 2 instrument will be flown on the payload of the CNES PARASOL micro satellite, the launch of which is planned end 2004. The PARASOL mission is part of the “Aqua train” i.e. the formation flying of 3 satellites following EOS-PM, so called “Aqua”.

ACRONYMS

ADEOS II	Advanced Earth Observation Satellite
ASAP	Ariane 5 Structure for Auxiliary Payload
BRDF	Bi-directional Reflectance Distribution Function
BPDF	Bi-directional Polarization Distribution Functions.
JAXA	Japan Aerospace Exploration Agency
PARASOL	Polarization and Anisotropy of Reflectance for Atmospheric Sciences coupled with Observations from a Lidar
POLDER 2	Polarization and Directionality of the Earth's Reflectance
TOA	Top Of the Atmosphere

1. INTRODUCTION

The regular increase in greenhouse gases due to anthropogenic emissions in the atmosphere may have a major impact on the Earth's climate in the forthcoming decades. In order to reduce the uncertainties in forecasting climatic changes, it is necessary to better understand the processes involved in interactions between aerosols, clouds, radiation and atmospheric circulation. Such interactions are poorly represented by current numerical models and there is a need to quantify their role in phenomena involved in the evolution of the climate system.

CNES, the French space agency, has therefore developed the POLDER 2 instrument as part of the payload of the ADEOS II satellite realized by JAXA the Japanese space agency. POLDER 2 on ADEOS II was successfully launched by a H2A rocket on December 14th, 2002 from the Tanegashima Space Center (Japan).

The POLDER 2 sensor has been acquiring continuous data from April 2003, beginning of the satellite operational phase, till the loss of ADEOS II on October 25th, 2003 due to a failure of the satellite power supply system.

POLDER 2 in flight calibration has been successfully performed by CNES from April 2003 till December 2003. The sensor calibration approach is based on a very stable design instrument (particularly during air/vacuum transitions), on an exhaustive pre-flight calibration and on many in-flight calibration methods using natural targets. This calibration approach provided satisfactory results and allowed to start in January 2004 the production and distribution of level 1 data and also the scientific products validation phase. The end of this validation phase is planned by mid 2004.

2. POLDER 2 INSTRUMENT CONCEPT

The POLDER 2 instrument concept is based on wide-field-of-view telecentric optics, a rotating wheel carrying spectral and polarizing filters and a charged coupled device (CCD) detector array. A schematic concept is given in Fig. 1.

The telecentric concept represents a major improvement over classical lenses, as it reduces the effect of the incidence angle on the entrance pupil area and provides near-perpendicular incidence of optical rays on the filters. In the case of POLDER 2, it has a focal length of 3.57 mm open to f: 4.6 and a field of view of ±43° along-track, ± 51° across-track and ± 57° in the diagonal. Its instantaneous field of view has a two-dimensional footprint on the Earth's surface which is partitioned into 242 x 274 pixels by the CCD matrix. From the ADEOS II orbit, this geometry produces a swath width of about 2400 km by 1800 km. And the arrangement of the photo-elements in the CCD matrix yields a quasi-constant horizontal resolution throughout the swath, only distorted by Earth curvature and equal to 6 x 7 km² at nadir.

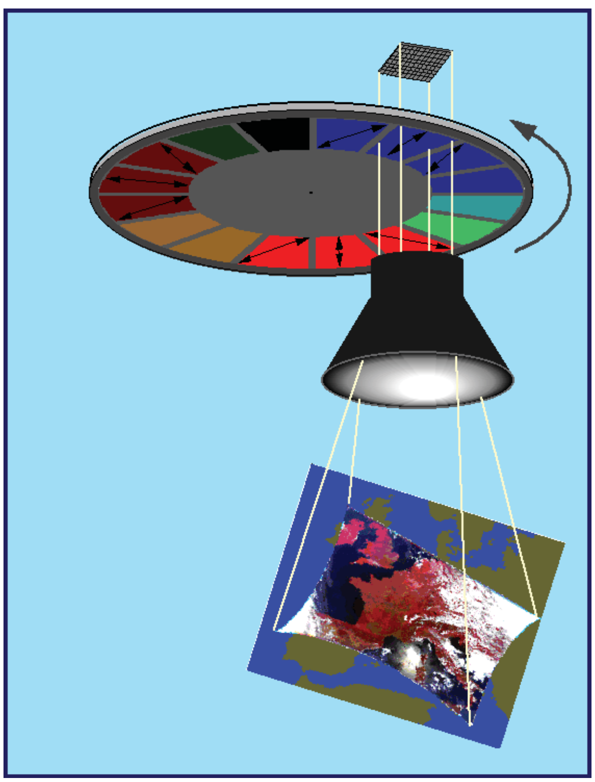

Fig. 1. Instrument concept

2.1 Multi-angle viewing capability

Fig. 2 illustrates the multi-angle viewing concept: it is achieved by the along-track migration at spacecraft velocity of the two-dimensional field of view. Thus over a single pass any target within the instrument swath can be observed quasi-simultaneously under up to 14 different viewing angles. The 4-day quasi-sub cycle of the ADEOS II orbit allows combining multi-pass observations obtained at short time intervals to get a more isotropic sampling of the BRDF and BPDF, the bi-directional reflectance and polarization distribution functions.

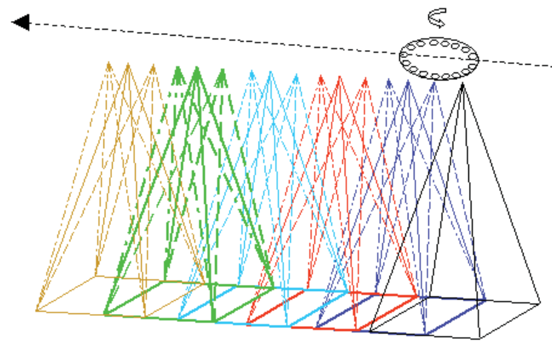

Fig. 2. Multi-angle viewing capability

2.2 Multi-polarization and multi-spectral capability

The multi-polarization and multi- spectral capability is produced by the rotation of the wheel equipped with sixteen slots hosting interference filters and polarizers. The wheel rotates steadily with a period of 4.9 s and the whole 16 channel observation/measurement sequence is activated every 19.6 s which corresponds to four rotations. The selection of the filters mounted on the wheel results in POLDER 2 capacity to observe reflectance's in eight narrow spectral bands of the visible and near infrared spectrum, namely 443, 490, 565, 670, 763, 765, 865 and 910 nm. Fig.3 presents the multi spectral instrument capability with the multi-disciplinary scientific objectives concerned by each spectral band. For three of these bands centred on 443, 670 and 865 nm respectively, measurements are made at three different polarization angles 60 degrees apart, using three different filters per band. For each of the three bands, three polarized channels are obtained by superimposing identical spectral filters with one polarizer, the axis of which turns by 60° from one channel to the next. The three polarization measurements are successive and have a total time lag of 0.6 s between the first and the third (last). In order to compensate for spacecraft motion during the lag and to co-register the three measurements, a small-angle, wedge prism is added to each polarizing assembly. As a consequence, the matrix image is translated in the focal

plane to compensate for satellite motion and the three polarization measurements are obtained for the same fixed target. As multiple scattering/reflection processes induce elliptic polarization, the fourth component of the Stokes vector of the top of the atmosphere light is negligible compared with the others, as confirmed by radiative transfer simulations. As a result, the polarization is mostly linear for prevailing atmospheric conditions and the three POLDER 2 polarizers will be sufficient to determine the degree of linear polarization and the polarization direction of the linearly polarized Earth-reflected radiance.
A sixteenth, opaque filter is mounted on the wheel for frequent measurements of the CCD dark current and control of its stability.

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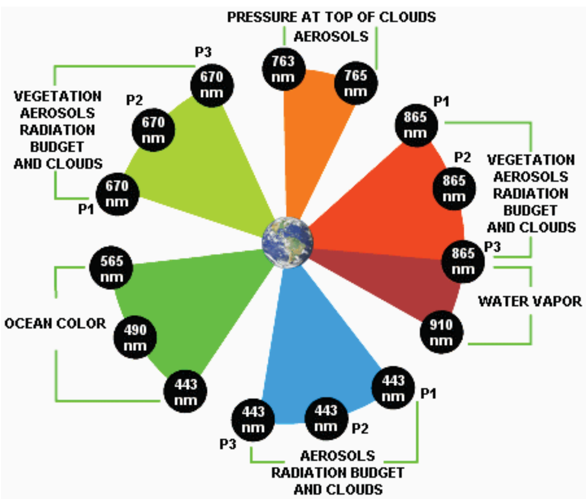

Fig. 3. Spectral and polarization channels with mission purposes.

3. PRE-FLIGHT CALIBRATION

The first aim of the radiometric calibration consists in determining the parameters of the radiometric model which characterises the response to a partially polarised light for each elementary detector and each spectral band. This model will be used by the level 1 processing in order to retrieve from raw data the intensity, polarisation rate and direction of the incident light which are the physical parameters to be measured by the instrument . The second aim of radiometric calibration is the determination of the relative spectral response of the instrument in each band for level 2 processing.

POLDER 2 pre-flight calibration gives rise to 2 main difficulties:

- the calibration of a bi-dimensional very wide field of view,
- the characterization of the polarization sensitivity in the whole field of view.

The accuracy of pre-flight calibrations relies on the following important testing hardware:

- two integrating spheres: a large integrating sphere for the calibration measurements of the whole field of view and a smaller transfer integrating sphere in order to check the air/vacuum stability of the absolute calibration, to determine the large integrating sphere low frequency non-uniformity, trough the instrument low frequency non-uniformity measurement,
- a polarizing system which enables the generation of different polarization rates and directions. It is made up of two parallel glass plates which can be oriented around two axes,
- a reference radiometer fitted with filters identical to POLDER 2 ones. The radiometer is used for absolute calibration and has been calibrated with each of the filters in a reference laboratory: the Laboratoire Central des Industries Electriques. This calibration has been operated against a spectrally calibrated source. The estimated accuracy of this calibration is: +/- 3.5%.
- a monochromator to measure the spectral response of the instrument; the rotation of the grating is synchronous with the instrument imaging cycle, and the emission stability of the lamp is checked all along the measurement. The stability of the response over several measurements is better than 1% and the variation of the center of the spectral profile is less than 0.3 nm.

The evaluated accuracy of the pre-flight absolute calibration is 5%. The relative calibration performances are divided in two parts: the high spatial frequency (inter-pixel calibration) is determined with 0.1% accuracy and the low frequency determined with 1 % accuracy. Inter-band calibration is better than 1 %.
The second par of pre-flight calibration is the geometrical calibration which consists in determining:

- the rotation matrix between the viewing geometry, defined by the optics and the CCD matrix, and the satellite reference frame
- for each spectral band the mathematical model linking each viewing direction within the instrument field of view to a pixel location in the focal plane. This model will be used by the level 1 processing in order to register and localise the data.

4. IN-FLIGHT CALIBRATION

POLDER 2 has no internal calibration source or device for in flight on board calibration. However, in order to ensure good in-flight radiometric performances, each calibration parameter of the radiometric model can be measured or monitored using various in-flight calibration methods based on acquisitions over wellknown natural Earth targets (Rayleigh, sunglint, clouds, deserts) and confronted to pre-flight measurements.

For instance, POLDER 2 absolute calibration is achieved through an absolute calibration of the shorter spectral bands (443nm Polarized , 443nm, 490nm, 565nm, and 670nm) based on the observation of the Rayleigh scattering over well-characterised oceanic sites. This absolute calibration is then transferred to the other longer wavelengths through inter-band calibration using the specular reflection of the sun over the ocean (sunglint). The absolute calibration derived through these two nominal methods has been validated using inter-band calibration over white convective clouds and cross-calibration with other space sensors over stable and well-characterised desert sites. Fig. 4 illustrates the in-flight absolute calibration of POLDER 2 results.
A light multi-temporal decrease of the radiometric sensitivity of about 0.1-0.2% per month (depending on the spectral band) has been also clearly detected and corrected into the data-processing.

λ	443P	443	490	565	670	763	765	865	910
ΔAk	0.929	0.938	0.970	0.990	0.995	0.987	0.987	0.980	0.980

Fig. 4. In-flight absolute calibration of POLDER 2 spectral bands (referring to the pre-flight coefficients)

Other radiometric parameters (multi-angular and in-polarisation characterisation) have been in-flight evaluated or monitored more or less precisely depending on the method, and some of them have been updated at the end of the commissioning phase when necessary.

The evaluated on-flight accuracies on the parameters of the radiometric model are :
- 2 to 3 % for absolute calibration;
- about 1 % for interband calibration;
- 0.1% for high frequency interpixel calibration ;
- 1 % for low frequency interpixel calibration;

Geometrical in-flight has been also performed : it consists in measuring by image correlation methods, the rotation matrix between the imaging frame defined by the optics and the CCD matrix, and the satellite reference frame on earth reference frame .

Considering the image quality performances achieved, the calibration review panel decided in December 2003 to authorise the start of POLDER 2 level 1 distribution to the users. The systematic processing and distribution of 7 months of data available started on January, 2004.

5. POLDER 2 FLIGHT RESULTS

5.1. First images acquired by POLDER 2 over Iberian Peninsula

Fig. 5 shows the first acquisition of POLDER 2 over the Iberian Peninsula on February 1st , 2003 in natural light (left image) and polarized light (right image).

Each image is a blue, green and red colour composite of POLDER 2 measurements at 443 nm, 670 nm and 865 nm. On the conventional image (left), we can clearly distinguish clouds (in white) sea in dark blue and different types of surfaces features : vegetation in red, bare soil in brown or yellow.

The polarized image (right) is more original. The blue colour prevails and the geographic contours can hardly be recognised. This is because the polarized light mainly results from scattering in the atmosphere which increases at shorter wavelengths (443nm). The ground surface has a very low contribution to the polarised signal which depends mainly on the atmosphere. This property of light is what allows us to see a rainbow, which is the result of the scattering of light by water droplets, and make it possible to tell whether cloud tops contain ice crystal or water droplets . Angular variations of the signal are also important, and this illustrates the valuable information obtained by combining polarisation and multidirectional capability of POLDER2 instrument.

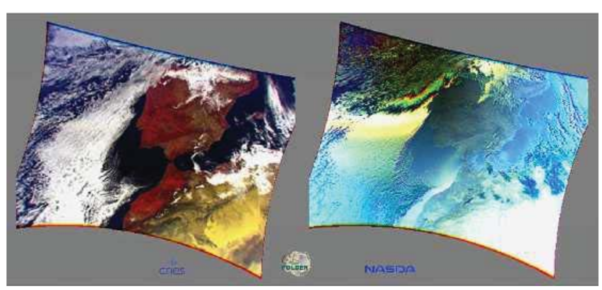

Fig. 5. First acquisition of POLDER 2 over the Iberian Peninsula on February 1st , 2003

5.2. First sequence of POLDER 2 images over Europe and North Africa

Fig. 6 shows the first sequence (top to bottom and left to right) of images taken by POLDER 2 on February 1st, 2003 over Western Europe and North Africa. Each image is a blue, green and red colour composite of POLDER 2 measurements at 443 nm, 670 nm and 865 nm. Marked differences appear between the clouds (in white) , sea in dark blue and different types of surfaces : vegetation in red, soil in brown and yellow.

An examination of the same area followed from one image to the other shows large variations in intensity. In the Mediterranean Sea a bright spot corresponding to sunglint appears south of Spain and moves southwards before disappearing over the Africa (images 1 to 3).
Owing to its wide field of view POLDER 2 can take images of a single target successively from different viewing angles (up to 14 times) . This unique capacity allows the directional properties of the radiation reflected by the Earth surface and atmosphere to be characterised and studied. This capability will lead to more accurate corrections for directional and atmospheric affects and better determination of target area properties.

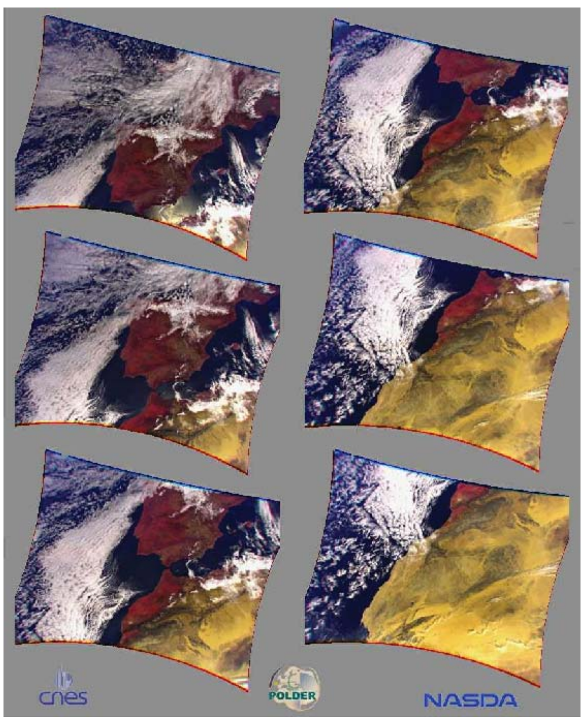

Fig. 6. First sequence of images taken by POLDER 2 over Western Europe and North Africa on February1st,2003

5.3. Global coverage

The instrument wide field of view provides a quasi daily global coverage . Fig. 7 shows one day of POLDER 2 acquisition on April 8th, 2003 with a blue, green and red colour composite of POLDER 2 measurements at 443 nm,670 nm and 865 nm.

Fig. 7. POLDER 2 Daily acquisitions

5.4. Scientific results

Different types of products from 3 geophysical processing lines will be available.

Level 2 products with following geophysical parameters computed by orbit segment and after atmospheric corrections will be provided :

- Ocean Colour & Marine Aerosols : marine directional radiances, water leaving radiances, pigment concentration, water type marine aerosols…etc
- Land Surfaces & Aerosols over Land: directional surface reflectance, aerosols & water vapour over land, optical thickness, Angstrom coefficient etc..
- Radiation Budget & Clouds: cloud cover, optical thickness, oxygen pressure, Raleigh pressure, cloud phase (water or ice), albedo..etc

Level 3 products i.e. temporal synthesis, computed every month or ten days, on POLDER 2 global grid from the level 2 geophysical parameters will also be provided.

Scientific validation phase is on going . So, these products, are not yet "scientifically" approved and not available. The end of validation phase is planned by mid 2004. More detailed information will be soon available on POLDER WEB site and User Desk at: http://polder-mission.cnes.fr

6. PARASOL PERSPECTIVE

A derived model of POLDER 2 instrument will be flown on the payload of the CNES micro satellite PARASOL. The PARASOL mission is part of the “AQUA train”. The “AQUA train” consists in the flying formation, shown in Fig. 8, of 3 satellites following EOS-PM, so called “AQUA” : CALIPSO, CLOUDSAT and PARASOL.

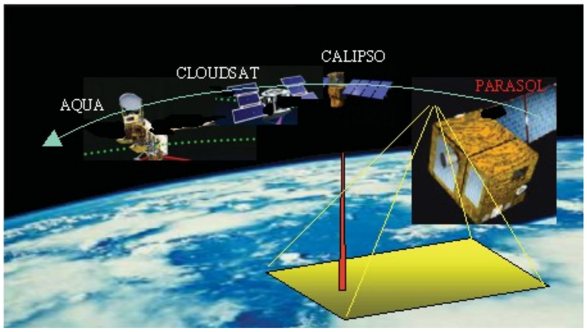

Fig. 8. AQUA train flying formation

To improve the knowledge of direct and indirect radiatives forcing of clouds and aerosols, it is necessary to better understand the interactions between liquid and solid particles in the atmosphere and the radiance, which are conditioned by the clouds and aerosols properties. The AQUA, CALIPSO, PARASOL and CLOUDSAT missions are intended to fulfil this purpose by collecting measures in different spectral domains (optical and microwave) accessible to spatial observation, and by combining measures covering larges fields of view with punctual measures.

Each instrument already enables to get some parameters, but the possibility to get, on the observed areas by CALIPSO LIDAR, the atmospheric reflectance's over a wide spectral domain from MODIS and CERES (AQUA instruments), and the multi-directionality as well as the polarization state of the reflectance's from PARASOL constitute an unique opportunity.

The synergy between the AQUA, CALIPSO, CLOUDSAT and PARASOL missions imply three major constraints on this mission, which are :

- the orbit characteristics that are set to : a 705 km altitude, a 98,21° declination (AQUA) or a 98,08° declination (CALIPSO),
- the equator time crossing which must be in concordance with the AQUA (13h30) and CALIPSO time crossing (set between 14h10 at the beginning of the mission and 12h50 at the end),
- the launch, which must take place during the activity phase of the constellation of other satellites.

The synergies are also reflected on the mission centres, for the orbit control as well as the scientific data processing.

A Science Segment with a level 1 science segment will be located in Toulouse in order to :

- prepare and sent the payload telecommand to the control center,
- follow-up the instruments performances,
- process the level 1 Data,

A thematic science segment located in Lille will :

- process the level 2 and 3 data,
- deliver the PARASOL products,

The launch of PARASOL is planned from Kourou in October 2004 as ARIANE 5 passenger on ASAP. The main passenger is HELIOS 2A, a French government observation satellite.

PARASOL satellite shown in Fig. 9 use the Myriade Micro-satellite product line developed by CNES. The first mission using this product line is DEMETER, which launch is planned by mid 2004.

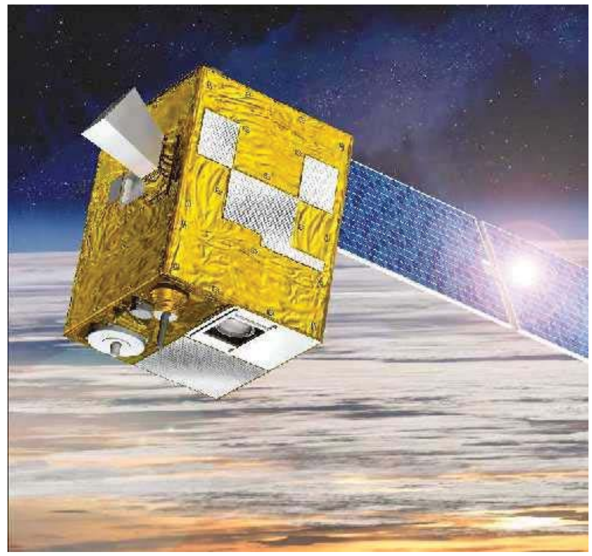

Fig 9 . PARASOL micro satellite

The PARASOL Payload, shown in Fig 10, developed, integrated and tested in CNES Toulouse facilities, is mainly set up of following constituents :

- a POLDER 2 camera
- a CCSDS mission data format device
- a flight software
- a 16 GBits solid state recorder
- a high rate X band telemetry (16.8 Mbit/s)

PARASOL payload main characteristics are :

Total mass	33 kg
Volume	0.5 x 0.5 x 0.3 m3
Max power consumption	77 W
Imaging data rate	880 Kbits/s

The PARASOL camera specification is otherwise identical to the POLDER 2, except for two points :

- the matrix orientation : the great axis has been set along the track to get a wider range of angles along the track,

- spectral wavelength modifications (justified by the fact that the PARASOL mission objectives are focused on aerosols and clouds) : a 1020 nm channel has been added and the 443 nm polarisation information suppressed and replaced by 490nm polarisation channel.

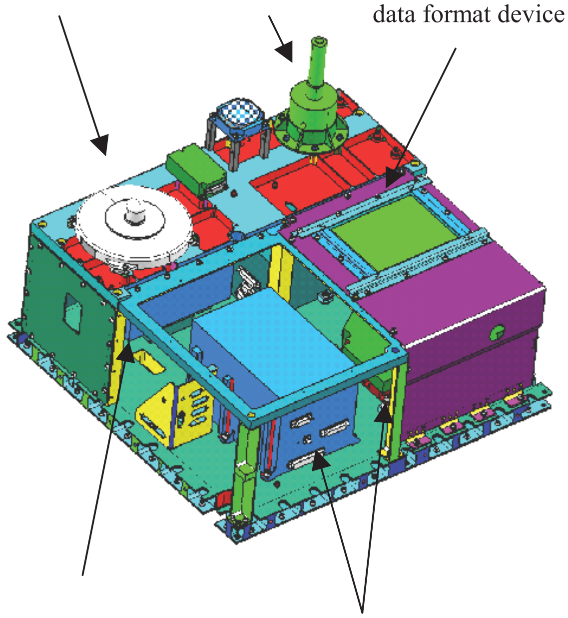

Fig.10 . PARASOL payload

7. CONCLUSION

POLDER 2 on ADEOS II was successfully launched by a H2A rocket on December 14th, 2002 from the Tanegashima Space Center (Japan). In spite of the loss of ADEOS II satellite, on October 2003 due to a failure of satellite power supply system, the POLDER 2 results are very encouraging.

The in-flight calibration has been successfully performed at CNES from April 2003 to December 2004. The calibration approach based on a very stable design instrument (particularly during air/vacuum transitions), on an exhaustive pre-flight calibration and on several in-flight calibration methods using natural targets provided satisfactory results. This in-flight calibration campaign achieved level 1 product validation. The distribution to general users started from January 2004. The high quality of these images extracted from level 1 shows that the POLDER 2 instrument, despite its rather simple design, will actually provide innovative and useful observations of the Earth system for climate and global change studies.

POLDER 2 scientific products are currently under validation phase. The end of this validation phase is planned by mid 2004 and will authorise the start of POLDER 2 level 2 and level 3 systematic processing and distribution to the users.

The additional information provided by original polarized measurements by combining polarisation and multi-directional measurements will allow a better characterisation of the atmospheric contribution to the signal measured at the top of the atmosphere and improvement in the determination of both surface and cloud parameters of interest. POLDER 2 will also permit investigation and refinement of important Earth remote sensing concepts, such as the differential absorption technique for retrieving water vapour amounts and the use of polarization measurements for making atmospheric corrections and retrieving aerosol characteristics. Despite the loss of ADEOS II, seven months of data have been acquired . These data added to the height months of data acquired from POLDER1 on ADEOS in 1996-1997, will allow achieving most of the scientific objectives of the POLDER 2 mission .

CNES also manufactured a derived model of POLDER 2 instrument. It will be flown on the payload of CNES PARASOL micro-satellite, the launch of which is planned end 2004 for a 2 years mission duration. The PARASOL mission is part of the “AQUA train” which consists in the flying formation of several satellites AQUA, CALIPSO, CLOUDSAT and PARASOL. The combined measurement, from the different spectral domains (optical and microwave) and by combining measures covering larges fields of view with punctual measure, will ensure a significantly improvement of clouds and aerosols properties understanding and provide suitable information for climate evolution researches .