THE EuroSTARRS-2001 AIRCRAFT CAMPAIGN OF THE EUROPEAN SPACE AGENCY IN SUPPORT OF THE SMOS MISSION

Ernesto LÓPEZ-BAEZA[1,2], Michael BERGER[3], Patrick WURSTEISEN[3], Jean-Christophe CALVET[4], Jacqueline ETCHETO[5], Jordi FONT[6], Yann KERR[7], Jerry MILLER[8], Jean-Pierre WIGNERON[9], Lester SIMMONDS[10], Carmen ANTOLÍN TOMÁS[2], J. Ferran FERRER[2], Kauzar SALEH CONTELL[1], Jacqueline BOUTIN[5], Thierry PELLARIN[4], Joel WESSON[8], and Bruce E. MAIN[10]

(1) Universitat de Valencia, Facultat de Física. Departament de Termodinámica Unidad de Investigación de Teledetección. Grupo de Climatología desde Satélites C/ Dr Moliner, 50. Burjassot. 46100 Valencia. Tel.: +34.96.3983118, Fax: +34.06.3983385, Ernesto.Lopez@uv.es
(2)Centro de Investigaciones sobre Desertificación (CIDE), Valencia, Spain
(3) ESTEC/ESA - Land Surfaces Unit, P.O. Box 299, 2200 AG Noordwijk, The Netherlands
(4) Météo France CNRM, 42 av G. Coriolis, 31057 Toulouse Cedex 1, France
(5) LODYC, UPMC, 4 Place Jussieu. 75252 Paris Cedex 05, France
(6) CMIMA-CSIC, Passeig Maritim, 37-39, 08003 Barcelona, Spain
(7) CESBIO, 18 Avenue Edouard Belin. 31401 TOULOUSE CEDEX 4, France
(8) NRL, Stennis Space Center, MS 39529. USA
(9) INRA Bioclimatologie, B.P. 81, 33883 Villenave d'Ornon CEDEX , France
(10) University of Reading. Department of Soil Science, United Kingdom

1. INTRODUCTION

The EuroSTARRS campaign of the European Space Agency (ESA) is an aircraft campaign designed to help scientists to prepare the SMOS (*Soil Moisture and Ocean Salinity*) Mission, which will be launched early in 2006 (Figure 1), to acquire global measurements of soil moisture and ocean salinity which are two parameters that play a key role in the determination of climate. Besides getting data of these two quantities, scientists will be able to incorporate these measurements in Numerical Prediction Models and Climate Models in order to significantly improve their analyses and predictions.

The EuroSTARRS-2001 campaign took place from 17 to 23 November 2001 implying a total number of six sites in Europe, between land surfaces of different nature and ocean surfaces. The objective of the campaign, as regards soil moisture estimation, was to investigate the effect of different vegetated covers on the L-band passive microwave signal received at the STARRS (*Salinity Temperature and Roughness Remote Scanner*) sensor (Figure 2) under different observation angles. As far as ocean measurements are concerned, the objective was to measure the influence of different meteorological parameters, among other wind speed, on the measurement of ocean salinity. The results of the campaign are of fundamental importance to finish the preparation of the algorithms that will permit the estimation of soil moisture content and ocean salinity from the microwave measurements acquired from space, before the satellite is actually launched.

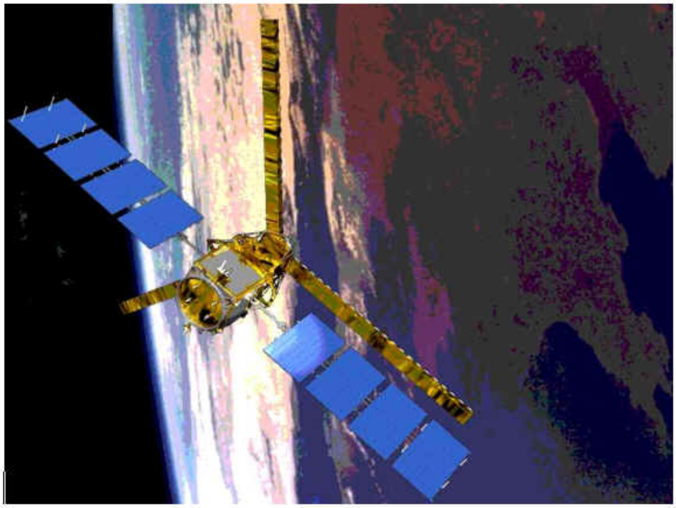

Figure 1: Artist vision of the SMOS Mission.

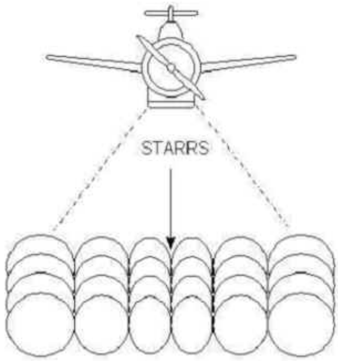

Figure 2: The STARRS sensor and a sketch of the measurement acquisition from the aircraft.

Different land surface sites were selected in Europe from Nezer Forest in Les Landes (France), to study coniferous forests, Agre Forest near Toulouse (France), to study deciduous forests, the city of Toulouse, to study urban environments, and an area of matorral and Mediterranean forests in the Requena area (Valencia, Spain) (Figure 3).

In the transit flight from France to Spain, the Dornier 228 aircraft from the *German Aerospace Centre* (DLR, Germany) (Figure 4) over flew an area of the Pyrenees to get some acquisitions to preliminary study the influence of topography on the brightness temperature.

Figure 3: Land surface study areas, (in red), and ocean sites (in green).

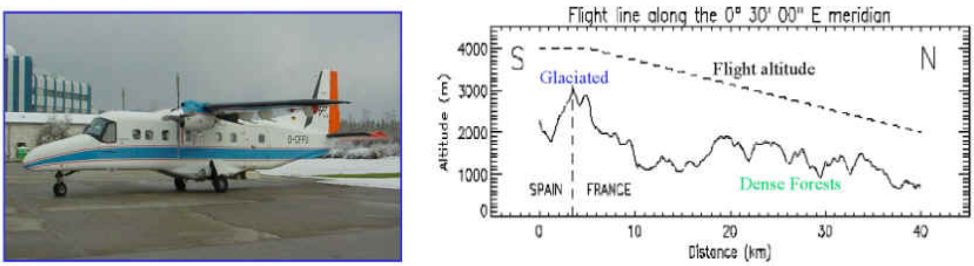

Figure 4: Dornier 228 aircraft from DLR holding the STARRS sensor (left), and detail of the transit flight across the Pyrenees (right).

The salinity sites were chosen, on the one hand, in the Bay of Biscay, around the French Gascogne buoy, to study the effect of strong changes in salinity from the coast to the inner part of the Atlantic Ocean, and on the other hand, around the Casablanca oil rig, near the end of the Ebro river (Tarragona), to mainly study the effect of wind speed on the salinity measurements and investigate azimuth dependence effects (Figure 3).

2. THE STARRS INSTRUMENT

The STARRS instrument was provided by the *Naval Research Laboratory* (NRL, USA) and installed onboard the Dornier aircraft. The radiometer measures the passive microwave radiation emitted by the land surface or the sea surface at a wavelength (L-band, 1,40-1,426 GHz) that enables scientists to estimate the respective soil moisture content or sea surface salinity. In its normal operation mode, the radiometer measures six crosstrack beams simultaneously (Figure 2) and builds a 2-D image as the aircraft moves along track In addition to the L-band radiometer, a nadir viewing C band radiometer (5-7 GHz) and a thermal infrared (TIR) 2-band radiometer can also acquire data at the same time. The antenna was mounted at right angles to the direction of flight and tilted by 12^o to acquire a wider range of incidence angles (Figure 5). This could simulate SMOS angular observations which will have a maximum incidence angle of 55^o. STARRS usually acquires six tracks of data along each flight track.

Figure 5: Situation of the STARRS radiometer under the Dornier 228 fuselage.

3. SCIENCE OBJECTIVES

The derivation of soil moisture (SM) and sea surface salinity (SSS) products from multi- angular STARRS data will support the development of retrieval algorithms for SMOS. In addition the EuroSTARRS-2001 Campaign will provide other main benefits, as follows:

- The campaign will be a valuable opportunity to obtain datasets from multiple sites with different surface characteristics. Subsequent analysis will help characterise the effects of look angle on brightness temperature.
- The data collected for SSS analysis will provide information relating to the effect of perturbing factors such as sea state and temperature.

More specific scientific objectives are summarised in Table 1.

Table 1: EuroSTARRS-2001 Scientific Objectives.

Vegetation	• Characterise the τ (vegetation optical depth) / look angle relationships for a range of vegetation types • Validate the proposed SMOS SM retrieval algorithms, especially in context with a wider range of vegetation types • Estimate specific multi-angular microwave signatures from low altitude flights over different land cover types with varying wetness conditions • Study the effect of topography on radiometric signal from homogeneous vegetation in areas of different topography • Validate the retrieval of mixed pixels through comparison of data acquired at low altitude with data acquired at high altitude • Provide data for a variety of forest types and variations within stands • Explore the implications of mixed pixels for retrieving SM within forested areas • Investigate the sensitivity of the retrieval algorithms to pixel size variation resulting from multi-angle observation • Acquire data from urban areas to investigate the emissions from different land use classes and determine the impact of RFI
Oceans	• Produce SSS gradients by operating STARRS from the coast out to sea • Investigate azimuth dependence effects

4. EUROSTARRS OPERATIONS

4.1. Calibration

The STARRS instrument is generally stable and relatively minor calibration activities are required to check the IR, L- and C-band sensors. A split window technique is employed to account for atmospheric variations.

Calibration is best carried out at the start and at the end of the campaign. Considering the required instrument integration time, the operating speed of the Dornier 228 and other factors, it was estimated that the size of calibration water bodies to be used need to be in the order of 2 km by 1 km.

Calibration flights were made primarily down the long dimension of a water body (small lake), with some flights at right angles to this axis. This latter case is to ensure that all tilted antenna components receive emissions from the water at the same time. *In situ* measurements of lake temperature and an estimate of wind strength was made at the same time of the overflight. It is important that temperature measurements are representative of the lake and this is why they were taken at a depth of 10cms. In order to avoid sun glint calibration flights were conducted during hours of darkness, however, early morning and late afternoon were also accepted. Three lakes were identified as being suitable for the calibration activities, namely:

- *Sanguinet-Cazaux lake* (near Nezer, Les Landes, site), N44 30.00 W1 10.00
- *Lac de Rieume* (near Toulouse), N43 25.02 E001 09.25
- *Contreras Reservoir* (near Valencia site), N39 33.560 W1 30.237

During the first test flight in Germany, calibration activities were also conducted over the lake 'Ammersee'. During the campaign, there was a calibration flight over the Lac de Rieume on 19 November and over the Contreras Reservoir on 21 November (Figure 6).

Figure 6: Sketch of the Dornier 228 flight lines over the Contreras Reservoir (Valencia Site) and detail of the calibration measurement over the lake surface.

4.2. Land Soil Moisture Data

Whilst the STARRS antenna was fixed so as to image in the along track direction, STARRS acquires six parallel beams of data quasi-simultaneously. Table 2 shows the potential for data acquisition over land from a single flight line with the configuration selected for this campaign (antenna with 12^{o} installation tilt relative to the horizontal).

Table 2: Viewing angles available due to 12° tilt of STARRS antenna.

STARRS Beam Identifier	**Incidence angle (with 12° shift)**
3L	-26.5°
2L	-9.0°
1L	+5.5°
1R	+13.0°
2R	+34.0°
3R	+50.5°

In order to construct multi-angle data sets of individual pixels, multiple passes of the test site were required.

Table 3 provides an example, based on the Valencia Site requirements, of the potential for acquiring multiple angle data from the STARRS instrument installed onboard the Dornier 228 (antenna with a 12° tilt). Note that pixels 6/7/8 are viewed in all possible angles at both altitudes.

Table 3: Availability of different viewing angles for land sites.

Pixel Line	1	2	3	4	5	6	7	8	9	10	11	12	13
Low altitude (300m pixel):													
1	26.5	9	5.5	19.5	34	50.5							
2		26.5	9	5.5	19.5	34	50.5						
3			26.5	9	5.5	19.5	34	50.5					
4				26.5	9	5.5	19.5	34	50.5				
5					26.5	9	5.5	19.5	34	50.5			
6						26.5	9	5.5	19.5	34	50.5		
7							26.5	9	5.5	19.5	34	50.5	
8								26.5	9	5.5	19.5	34	50.5
High altitude (900m pixel):													
1	...19.5			34			50.5						
2	...5.5			19.5			34			50.5			
3	9			5.5			19.5			34		50.5	
4	26.5			9			5.5			19.5		34	
5				26.5			9			5.5		19.5...	
6							26.5			9		5.5...	

Figure 7 shows the realization of Table 3 over the Valencia Site both for the low- and the high-altitude flights.

The specific objectives for the Valencia Site were:

- To acquire multi-angular observations over uniform vegetation covers within the observed pixel. The homogeneous vegetation types studied were matorral, vineyards (bare soil at the time of the campaign), pine trees, almond trees and olive trees.

- To acquire multi-angular observations over non-homogeneous pixels in order to be able to validate scaling algorithms (disaggregation). The area was very much appropriate to carry out multi-angular air observations from two different altitudes over non-homogeneous pixels (higher altitude pixels) resulting from the mixture of homogeneous vegetated surfaces corresponding to the lower altitude flights.

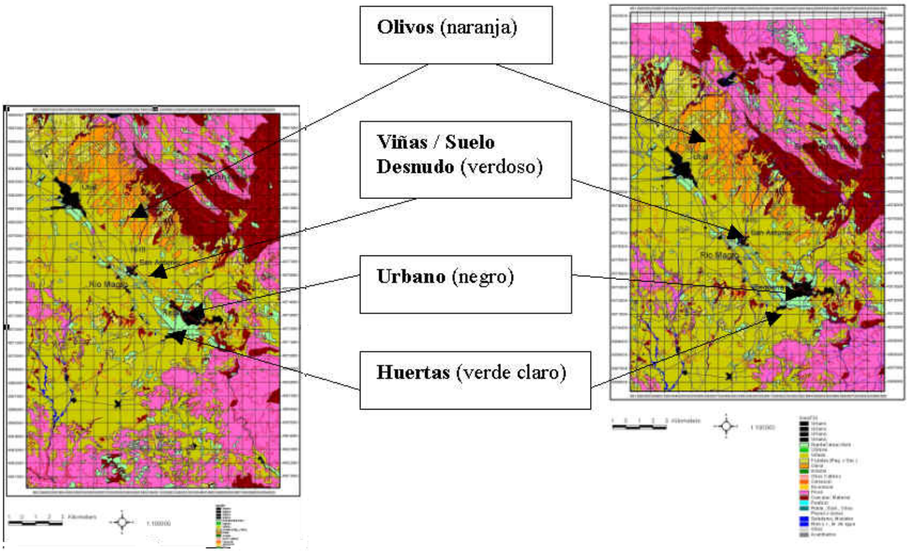

Figure 7: Low altitude flight lines (left) and high altitude flight lines (right) drawn over a land use map of the area at the scale 1:100,000.

Due to the mountains close to the study area (Sierra de Juan Navarro) and because of safety reasons, the low altitude flights (13 in total with a separation between them of 200m) could only be performed at an average altitude of about 600m, whereas the high altitude flights (4 in total with a separation between them of 500m) were performed at about 1800m (see Figure 7). The measurements were done near midday in order that the surface could change soil moisture content very little during the measuring time thus avoiding dew effect,

The main interest of the Valencia Site measurements was, on the one hand, the acquisitions for the first time over matorral and other Mediterranean ecosystem species, and to get to know the behaviour of the emitted microwave signal as a function of the observation geometry, assuming different soil moisture content degrees in the different surfaces observed. On the other hand, the different homogeneous land uses were chosen in such a way that a number of them could be grouped in a mixed larger pixel for the high altitude observations, so that, to be able to analyse and study the effects of scaling changes, specifically the disaggregation of the complex signal acquired over the mixed pixel into the simple acquisitions of the low altitude homogeneous pixels (Figure 8).

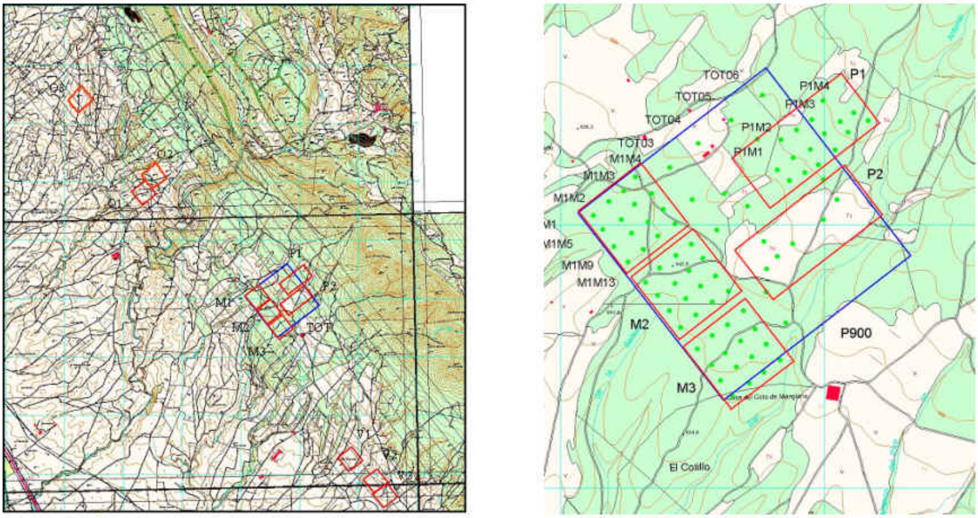

Figure 8: Left: Homogeneous pixels (in red, 300 x 300 m size) defined under the low altitude flight lines, and mixed pixel (in blue, 900 x 900 m size) defined under the high altitude flight lines. Right: Detail of the mixed pixel containing some of the homogeneous pixels. M1, M2, and M3 are the matorral pixels and P1 and P2 the pine tree pixels. The green dots indicate the exact position of the sampling points located by GPS.

Besides the aircraft acquisitions, the other important component of the campaign was the ground measurements performed over the different surface types, as reference for the STARRS measurements. Thus, in the land experiments, a complex deployment was displayed for the ground measurements of soil moisture content, vegetation parameters, radiative temperature (thermal) of the different surfaces, surface roughness, stone percent cover, soil texture, etc. (Figure 9).

4.3. Sea Surface Salinity Data

Given that the SMOS mission will be able to provide data with an up to 55° incidence angle, it was desirable to simulate this performance using STARRS. For the collection of SSS data the aircraft flew 10 circles of 1600 m radius, at an aircraft banking angle of 22°. This resulted in the acquisition of data with incidence angles from 0° up to 80°. These circular flights were performed near the buoys and the platform in order to maximize the benefit of the correlative measurements. To avoid problems associated with sun glint, flights collecting data over the sea took place after sunset. Sunset was defined as being 30 minutes after the Sun had gone beneath the horizon.

Over the Casablanca petrol platform and over the sea buoys placed near by, researchers from the Barcelona Institute of Oceanography measured wind velocity and sea surface temperature and salinity at the same time that the Dornier 228 was getting the STARRS acquisitions over the area (Figure 10).

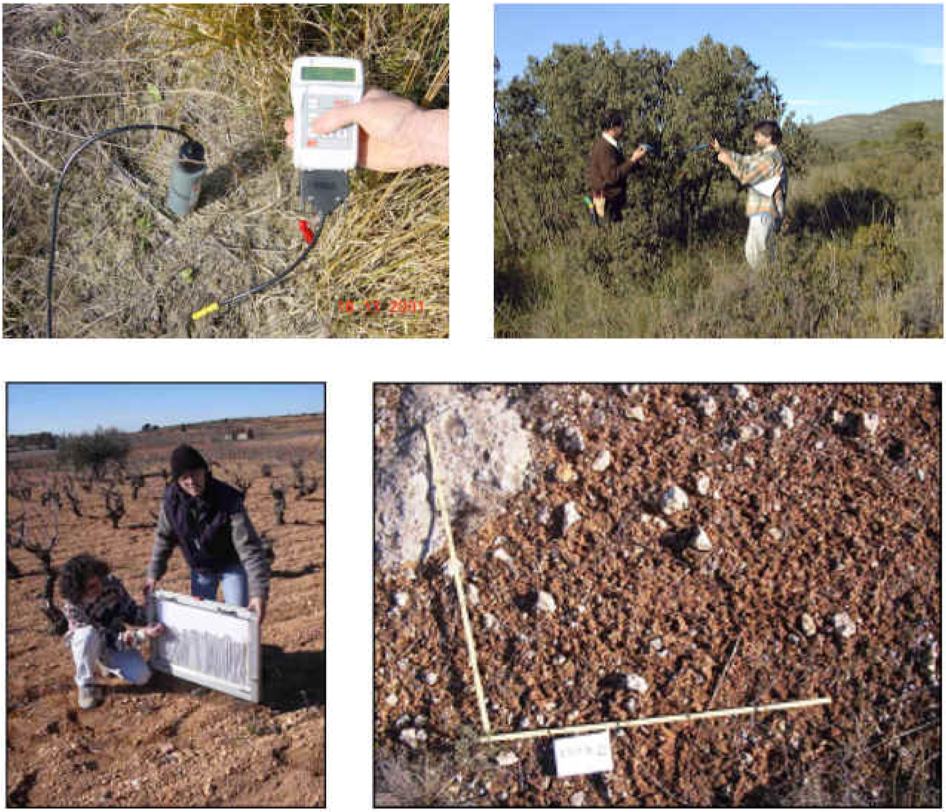

Figure 9: Soil moisture content, alometric vegetation parameters, roughness and percent cover of stones ground measurements (respectively, left to right and up to bottom).

5. CONCLUSIONS

This paper is intended to give a general overview of the EuroSTARRS-2001 campaign, its motivation, rationale and technical design. A description of the processing of the STARRS data acquired during this campaign, its analysis and preliminary results are given also in this book (SALEH *et al.*, 2002).

EuroSTARRS is one of the most complex campaigns ESA has ever organised. It was necessary to make sure that various European ground teams coordinate. The effort dedicated to the campaign clearly reflects the importance of the two quantities under consideration, that is, soil moisture and ocean salinity, which should be better known in order to be able to improve forecasts and predictions of the numerical meteorological and climate models.

On the one hand, soil moisture levels determine health and vigour status of vegetation and play an important role in the correct determination of evapotranspiration and run-off, thus influencing the amount of solar radiation that is absorbed in the land surface. On the other hand, ocean salinity is definitely responsible for the ocean currents, main drivers of the global climate.

The main scientific part of the work is presently being carried out, starting by the data processing and aiming at a deep analysis and interpretation of the results. The STARRS acquisitions are first quality data and their geo-referencing is highly accurate: viewing angles were obtained within 1 to 2 degrees, and the flight lines match almost perfectly to an accuracy of 5m. This should lead to a valuable data-base including several observation angles over the same pixels on the ground. It is envisaged to study the effect of the under story, litter and the influence of the percentage stone cover within the observed area.

The University of Valencia is collaborating with the *Institut National de Recherche Agronomique* (INRA) at Bordeaux and the *Centre National de la Recherche Meteorologique* (CNRM) at Toulouse for the analysis of the data set.

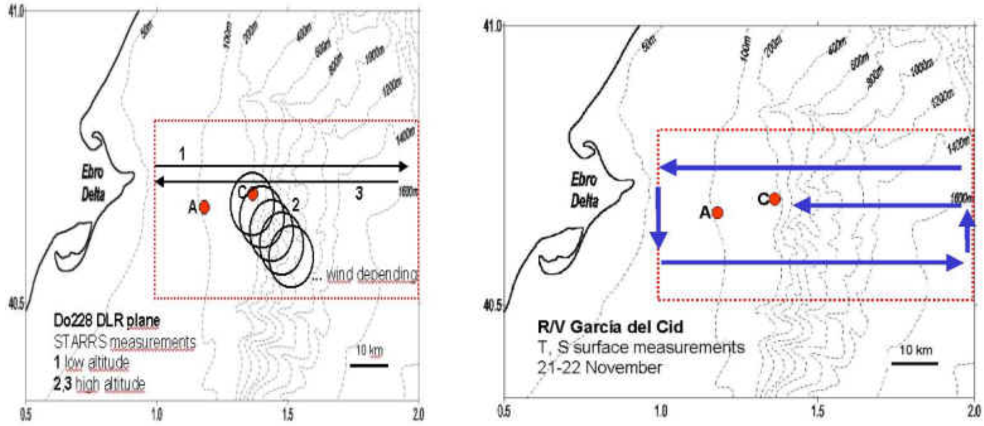

Figure 10: Casablanca data acquisition by EuroSTARRS aircraft (A = Actinia Platform, C = Casablanca Platform). Right Transect followed by the García del Cid research ship from the Spanish Research Council (CSIC) around the Casablanca and Actinia petrol platforms.

6. ACKNOWLEDGMENTS

The added complexity of the Valencia Site measurements required the material and human help from institutions that willingly and readily provided. The *Climatology from Satellites Group* and the CIDE from the University of Valencia sincerely acknowledge the collaboration provided by the Regional Ministry for Environment and VAERSA (Valenciana de Aprovechamiento Energético de Residuos S. A.), by the Environment Section of the Town Hall of Valencia and its Municipal Foundations of Parks and Gardens and of the School of Gardening and Landscape, the Jucar

Hydrological Council and the owners of the farms where most of the measurements took place (Coto Mangla.no). As far as the Valencia Site is concerned, this work was carried out in the framework of the ESA-ESTEC contract no: *15949/02/NL/SF, and the Spanish National Space Research Programme Project no: PNE-009/2001-C-03*.

7. REFERENCES

SALEH, K., CALVET, J.-C., WIGNERON, J.-P., PRIOR, J., and LÓPEZ-BAEZA, E. (2002): *Microwave Radiometry For Soil Moisture Monitoring: Preliminary Results From The Eurostarrs-2001 Campaign* (this book).