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VALIDATION ACTIVITIES PREPARATION FOR SMOS (*SOIL MOISTURE AND OCEAN SALINITY*) LAND PRODUCTS AT THE *VALENCIA ANCHOR STATION*

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Abstract

Since 2001, the *Valencia Anchor Station* is being used for validation activities in the context of low spatial resolution Earth Observation Missions such as CERES (*Clouds and the Earth's Radiant Energy System*), GERB (*Geostationary Earth Radiation Budget*), EPS (EUMETSAT Polar System), and is also being prepared for the SMOS (*Soil Moisture and Ocean Salinity*) Mission. All these missions have in common the low spatial resolution of their respective footprints (roughly of the order of 50 x 50 km^2) and the necessity to count on a well characterised and instrumented large scale area.

The *Valencia Anchor Station* has been selected as a primary validation site by the SMOS Mission. The reasonable homogeneous characteristics of the area make this site appropriate to undertake the validation of SMOS Level 2 land products (soil moisture content and vegetation water content) during the *Mission Commissioning Phase*, before attempting more complex areas. A control area of 10 x 10 km^2 has been chosen where a network of ground soil moisture measuring stations has being set up based on the definition of homogeneous physio-hydrological units attending to climatic, soil type, lithology, geology, elevation, slope and vegetation cover conditions. These stations are linked via a wireless communication system to a central post accessible via internet. The area soil moisture estimations to be obtained are presently being compared to modelling products both from ISBA – SURFEX and from HIRLAM.

INTRODUCTION

Several research studies within the fields of Soil Science, Meteorology, Climatology, Ecology and Agriculture, agree that for a better understanding of environmental processes it is necessary a good quantification of Soil Moisture (SM). That is, a number of quantities and parameters from these fields of study depend direct or indirectly on SM to provide a more representative hydrological budget and energy transfer budget, where water and energy fluxes are significantly affected. SM participates in these fluxes, as latent heat is determined by the surface water content, also influencing surface run-off. Through the improvements on these budgets, weather and climate predictions are expected to improve their forecasts and simulations.

L-band passive microwave radiometry is a very useful tool for SM monitoring because it allows nearly all weather observation, surface vegetation cover information, and brightness temperature, which is a direct SM related property. From the latter, SM retrieval is possible by using suitable algorithms which still today are continuously improving through the investigation of the dependence of the signal on

sensor configuration geometry (polarisation and incidence angle), interferometric aspects, types of vegetation cover, topography, heterogeneity within the same pixel, etc. Up to now, significant advances have already been achieved in these issues and the time is reaching now to validate these algorithms and those concerning the assimilation of these products into numerical models.

The SMOS Mission, which is a joint Earth observation mission between ESA, France, and Spain, is the second *Earth Explorer Opportunity Mission* developed as part of ESA's *Living Planet Program*. The *Microwave Imaging Radiometer with Aperture Synthesis* (MIRAS) radiometer, which is the main instrument onboard SMOS, is a 2-D Y-shaped interferometric radiometer made up of 69 antenna elements equally distributed on three 4.5-m arms. It will observe the emitted brightness temperature of the Earth at L-band (1.4–1.427 GHz) with a resolution of 40 km.

The VAS site is currently being used also for the validation of other low-resolution satellite remote sensing instruments such as GERB (*Geostationary Earth Radiation Budget*), CERES (*Clouds and the Earth's Radiant Energy System*) and EPS (*EUMETSAT Polar System*) (see http://www.uv.es/elopez), which are giving us a deep knowledge of the area. From the very beginning of SMOS, the VAS area is being thoroughly studied from different viewpoints through different field activities, many of them precisely related to the preparation for SMOS operations.

ESA accepted a proposal prepared by an international team of SMOS scientists coordinated by the *Climatology from Satellites Group* (GCS) to develop specific land product validation activities at the VAS*,* taking into account the special characteristics of this area with respect to its reasonable homogeneous conditions from different viewpoints (climate, topography, soil types, land uses, etc). The Project addresses the "*Validation of SMOS Products over Mediterranean Ecosystem Vegetation at the Valencia Anchor Station Reference Area*" (SMOS Cal/Val AO I.D. no. 3252). Its main objectives are (i) the development of the VAS site as a large reference area, sufficiently equipped with ground Soil Moisture (SM) probes and fully characterised, to contribute to SMOS land product validation, and (ii) the development of L-band emission models for typical Mediterranean ecosystem natural low-cover vegetation species and vineyards to be able estimate surface properties in the whole VAS area.

Basically, the Project methodology consists of the development of a strategically designed ground-based SM measuring network defined over a reference control area and the use of different remote sensing techniques and reliable models to extrapolate these ground measurements to a reasonable homogeneous area of about the size of a SMOS pixel. The Project Team of scientists are strongly interested in developing and testing different approaches for SMOS data and product validation as well as in the development of L-band surface emission models, characteristic of the Mediterranean ecosystem types, which have not significantly been studied so far. The Project Team is thus organising a significant number of complex activities addressed to the objectives mentioned above. In this context, an SM measuring network is being deployed in an area of 10x10 km^2 which is fairly homogeneous and which will allow the independent elaboration of SM maps as reference for those that will be obtained from aircraft L-band radiometer data. Besides this, and in order to characterise shrubs and vineyards, in the framework of the *Mediterranean Ecosystem L-Band characterization Experiment* (MELBEX-1 and MELBEX-2), ground based L-band radiometry experiments have been developed earlier to fully account for all geometry observation conditions, different SM conditions and different vegetation growth development stages.

CHARACTERIZATION OF THE *VALENCIA ANCHOR STATION* REFERENCE AREA

The VAS Team will provide ground data specifically oriented to establish a detailed and tested SMOS validation approach. The site (39º34'15''N, 1º17'18''W [WGS84], 813 m above sea level) is a typical Mediterranean sparse vegetation ecosystem defined within the natural region of the *Utiel-Requena Plateau*, at about 80 km W of the city of Valencia, and represents a reasonably homogeneous area of about 50 x 50 km^2 with regard to its hydrological parameters. The main land use is vineyards (about 75% cover), with the presence of other typical Mediterranean ecosystem components (shrubs, oaks, pine, olive and almond trees, etc). Away from the vineyard growing season, the area remains mostly under bare soil conditions. The site is well instrumented and has already been the location of numerous field campaigns, as shown in Figure 1(a). Figure 1(b) shows the different sub-areas

defined, namely, the control area of 10x10 km^2, the SMOS pixel reference area of 50x50 km^2, and the 125 x 125 km^2 ECOCLIMAP grid size area. Around the VAS meteorological station, different areas of sizes 10 x 10, 50 x 50 and 125 x 125 km^2 have been defined to develop the validation methodology on a gradual basis. The sizes of these sub-areas are given in Table 1.
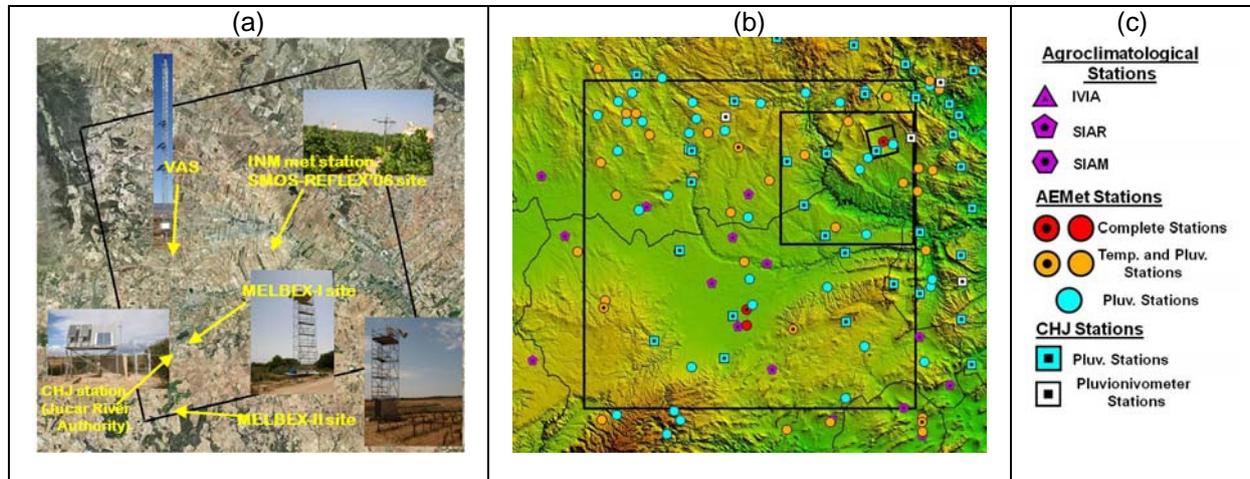
Figure 1: **(a)** *Valencia Anchor Station* **control area of 10x10 km^2: main instrumental sites related to SMOS validation activities. (b)** *Valencia Anchor Station* **sub-areas: control area of 10x10 km^2, SMOS pixel reference area of 50x50 km^2, and 125 x 125 km^2 ECOCLIMAP grid size area. The different dots inside refer to the different types of meteorological stations within the area. (c) A black dot means an automatic station. AEMet stands for** *Spanish Agency for Meteorology* **and CHJ stands for** *Jucar River Basin Authority*

	10x10 km^2	50x50 km^2	125x125 km^2
NW	1.324047W 39.614397N	1.698423W 39.683639N	2.563715W 39.799068N
NE	1.209744W 39.634125N	1.115635W 39.675642N	1.104126W 39.784399N
SE	1.185856W 39.540461N	1.127737W 39.225365N	1.134179W 38.658662N
SW	1.300011W 39.520753N	1.706786W 39.233235N	2.570636W 38.672758N

Table 1: Valencia Anchor Station **coordinates of the different sub-areas defined: control area of 10x10 km^2, SMOS pixel reference area of 50x50 km^2, and 125 x 125 km^2 ECOCLIMAP grid size area**

Basically, the validation methodology consists on the definition of homogeneous environmental zones that permit the development of different sampling strategies according to the needs in every case. Given the large spatial variability of SM, the research group validation strategy has been to define a 10x10 km^2 control area, just in the center of the *Utiel-Requena Plateau* natural region, where a number of SM measuring probes have been installed for the continuous automatic measurement of SM at a number of the above mentioned units that correspond to the major land use types representative of other areas that could be defined over the same soil type. These units have been defined at characteristic spatial and temporal scales in relation to moisture variation in the soil. It is assumed that two or more of these units presenting the same environmental characteristics with respect to vegetation cover, soil type, geology and topography, will hold a certain degree of internal uniformity of the hydrological parameters, and therefore, a similar hydrological response (Figure 2). The final objective is to find *Hydrological* or *Physio-hydrological Response Units*, that are non-homogeneously structured entities presenting a certain degree of internal uniformity with respect to hydrological parameters and that are delimited by integrating areas with similar morphology, soil type, vegetation, draining patterns, geology, topography, etc. The main assumption for each Unit is that the dynamical variation of the hydrological parameters within a hydrological response unit should be a minimum as compared to other units dynamics. This methodology will hopefully provide a way of effective sampling design consisting of a reduced number of measuring points, sparsely distributed over the area, or alternatively, utilising SM validation networks where each sampling point is located at a point which is representative of the mean soil moisture of its complete area. Naturally, the methodology shown here is optimally been applied to the VAS area which contains a reduced number of land use and soil types, and is reasonably homogeneous and relatively flat, at the same time that is sufficiently large, already of about the size of a SMOS pixel.
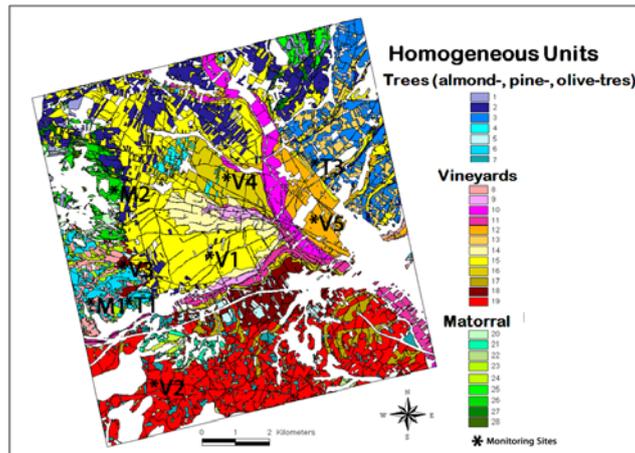
Figure 2: **Physio-hydrological units defined in the** *Valencia Anchor Station* **control area of 10x10 km^2**

THE SMOS VALIDATION REHEARSAL CAMPAIGN

Over land, the main objectives of campaigns are the observations of the influence of the various vegetation canopies, their seasonal cycle, and the influence of surface roughness, dew, and frost using long-term ground-based observations (de Rosnay et al., 2006, Lopez-Baeza et al., 2006). The analysis of complex surfaces and the issue of mixed pixels are addressed with aircraft observations. Validation of the SM data products will be performed by combining the results from a number of different approaches. Field measurements will need to be scaled to SMOS scales (40 km) with the help of local SVAT models and meteorological networks. For the validation of SM, ESA focuses its effort on two key validation sites: the VAS, located in the east of Spain and the Upper Danube watershed located in the south of Germany (Delwart et al., 2008).

The general purpose of the *SMOS Validation Rehearsal Campaign* (SVRC) is to repeat the *Commissioning Phase* execution with all centers, all tools, all participants, all structures, all data available, assuming all tools and structures are ready and trying to produce as close as possible the post-launch conditions. The aim is to test the readiness, the ensemble coordination and the speed of operations, and to avoid as far as possible any unexpected deficiencies of the plan and procedure during the real *Commissioning Phase* campaigns (Bouzinac et al., 2008). A specific added-value objective of the VAS Team is to validate the ground sampling strategy defined for this campaign (10 x 10 km^2) by comparing the ground area-estimated products with the aircraft area-integrated measurements in order to be able to extend the methodology to the larger SMOS footprint representative area (50 x 50 km^2 and 125 x 125 km^2). The scientific framework in which context these objectives will be studied is monitoring of soil drying after a significant rainfall event takes place in the study area.

ACTIVITIES DURING THE SMOS VALIDATION REHEARSAL CAMPAIGN

Airborne Operations during the *SMOS Validation Rehearsal Campaign*

The aircraft measurements were performed using the *Helsinki University of Technology* (TKK) Short Skyvan research aircraft. The payload for the *SMOS Validation Rehearsal Campaign* consisted of the following instruments: (i) L-band radiometer EMIRAD provided by the *Technical University of Denmark* (TUD), (ii) HUT-2D L-band imaging interferometric radiometer provided by TKK (iii) PARIS GPS reflectrometry system provided by the *Institute for Space Studies of Catalonia* (IEEC), and (iv) IR sensor provided by the *Finnish Institute of Maritime Research* (FIMR). The campaign at the VAS Site started on 19th April 2008. The conditions for the flight were optimum because a rainfall event of a few days (30 mm accumulated precipitation) determined the first flight on the night of 22nd April. Then the following flights were performed on 24th, 28th April and 2nd May allowing for an optimum monitoring of the soil drying process. All the flights were performed before sunrise to avoid the influence of

evaporation. The area was crossed diagonally (NW to SE) and along 5 separate North/Southbound parallel lines displaced by 2 km relative to each other.

(a)	(b)	(c)
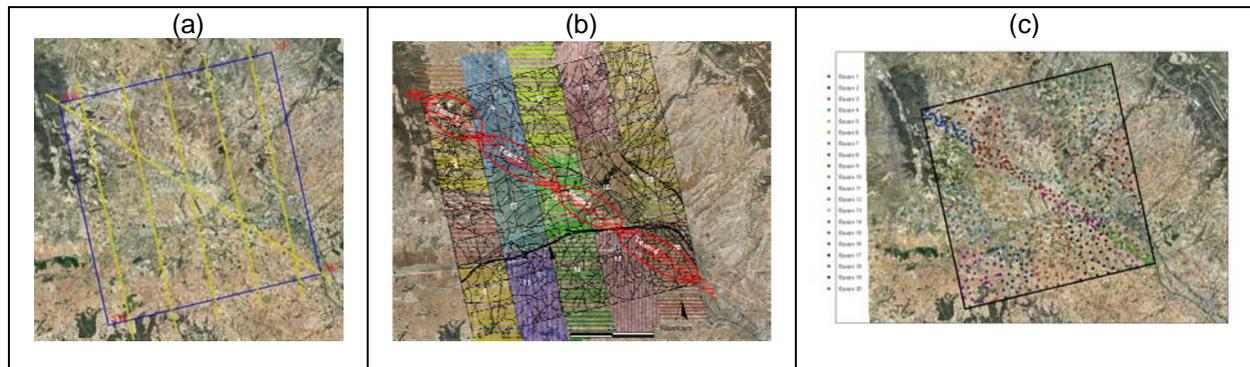
Figure 3(a): **Definition of the five flight lines and the diagonal flight line all geo-referenced over an orthophoto of the study area.** *Figure 3(b):* **Distribution of the 20 teams over the study area according to the aircraft operations.** *Figure 3(c):* **Sampling strategy**

Ground Measurements during Aircraft Operations

The ground measurements were carried out by 20 teams of about 5 people each, distributed throughout the entire area, (4 teams for the detailed diagonal flight, 4 teams for the harder soil shrub area (left-hand side of Figure 3(b), teams 5, 6, 7, 8), and 3 teams for the rest of each flight line remaining. Depending on the soil properties and hardiness, each group took between 140-150 cylinder volumetric soil samples and an average of 250 (replicated three times) volumetric probe measurements every flight night. In summary, the SM measurements during the campaign were:

- 20 measuring teams with itineraries defined with 35-38 measuring plots (40 to 80 m^2 each), each team using a 4-wheel drive car
- Approximately 20 x 35 = 700 soil texture samples at each measuring plot obtained during the definition of the itineraries
- 4 volumetric SM cylinder samples at each measuring plot. Total number: 10.425 samples
- 7 Delta-T Theta Probe measurements at each measuring plot (with 3 repetitions each). Total approximate number of measurements:
  - 20 teams x 35 measuring sites x 7 measurements x 4 nights = 19.600 measurements (58.800 measurements considering the 3 repetitions of each measurement)

4 out of the 7 Theta probe measurements at each measuring plot were taken within < 50 cm distance of the volumetric SM cylinder sample to be able to correlate both SM measurements and for Delta-T Theta probe calibration purposes. All SM measurements were properly geo-referenced with GPS.

Together with the main objective of getting independent area integrated SM values to be compared with the aircraft measurements, the huge number of ground SM measurements were designed to:
(i) Measure SM of each significant and representative hydro-physiological unit to:
- compare different SM measurements within each unit
- compare different SM measurements in polygons within each
- compare SM measurements of similar units
- compare SM measurements of different units

(ii) Establish relationships to unify / fragment units or re-assign polygons in different units
(iii) Provide the approximate average for each unit and for all the units in total within the 10 x 10 km^2
(iv) Compare SM from the units to that of the total area
(v) Study the representativity of the automatic SM stations in the whole 10 x 10 km^2 area
(vi) Establish a quick and efficacious methodology to estimate SM of a large area out of a few measurements, as preparation for SMOS Cal/Val
(vii) Compare SM under humid and dry conditions; establish the spatial and temporal dynamics of SM

The information expected to be obtained from SVRC should be very rich regarding the VAS general characteristics. The selection of the automatic sampling measurements, necessarily reduced, is being done in a way that it is representative of the larger area, hoping to be able to extrapolate it to wider zones, *a posteriori*. This is an assumption that the team wants to test taking advantage of the aircraft

measurements and of the way the flight lines have been designed and programmed for the site. This is just what UVEG want to test, that with the defined network based on about 12 automatic measuring stations located over different physio-hydrological units, it will be sufficient to cover this study area of 10x10 km^2. The next step should be to extrapolate this methodology to the larger areas of 50 x 50 km^2 and 125 x 125 km^2 by using remote sensing techniques and modeling work.

Estimation of Soil and Vegetation Parameters

Soil Texture

Previously to the SVRC, soil samples were obtained in the area to analyze soil texture in each unit that a priori may present significant internal differences, attending to variations in soil type, physiographic characteristics, vegetation use or natural vegetation and, above all, lithology, since these are the parameters that can change its variability. The type of soil shows very little variability (Haplic and Petric Calcisols or Calcaric Cambisols), physiographic characteristics are mostly flat and soil uses are perfectly differentiated, being five uses or vegetation types (namely vineyards, almond-, olive-, pine-trees and shrubs) those covering the area. In the VAS area the soil texture is therefore a parameter that depends mainly on "*parent material*" o lithology, over which the soil has been formed or made up, because the mineral composition of the "*parent material*" determines its weathering and conditions the resultant granular consistency, since the remaining factors that form the soil are similar.

Fractional Vegetation Cover (FVC), Leaf Area Index (LAI) and Vegetation Water Content (VWC)

The three stages planned to achieve these parameters are:
  (i)   High resolution characterization of vegetated cover (FVC, LAI, VWC) from *in situ* measurements and satellite images
  - In situ estimation of vegetation parameters (FVC, LAI, VWC) over areas representative of the existing variability in the study area during the phenological cycle of vegetation
  - Spatial extension to the complete area by using high resolution and *in situ* information
  (ii) Development of a methodology for the estimation of biophysical parameters (FVC, LAI, VWC) at medium resolution (250 - 500 m) (MERIS/MODIS data)
  - Geometric and atmospheric correction of MERIS images
  - Development of prototype algorithms from MERIS/MODIS data
  - Algorithm validation by using high resolution maps and algorithm selection
  (iii) Spatial and temporal characterization of the vegetated cover. Working scale of 250 m
  - Determination of the annual temporal dynamics for the principal vegetation classes existing in the study area
  - Analysis of the interannual temporal dynamics (2008-2009-2010) and its relationship with climatological parameters (air temperature, relative humidity, precipitation,…)

Vegetation Measurements

Vegetation over the 10 x 10 km^2 area shows a scarce diversity of vegetation species. Within the area, the major vegetation uses are vineyard, almond- and olive-trees, coniferous forests, matorral shrubs (*Thymus vulgaris*, *Rosmarinus officinalis*, *Quercus coccifera*, *Genista scorpius, Ulex parviflorus, Ramnus licioides, Stipa tenacissima, Juniperus communis*), and very scarce areas of cereals (*Zea mays* and *Avena sativa*). Vegetation parameter sampling was not needed to be too intensive. However, accurate estimation of vegetation stage was meant to be achieved through simple measurements over well chosen areas:
  - Vegetation height
  - Phenologic stage (number of leaves in vineyards/plant, etc) in some fields
  - Digital photographs giving general information on the phenology (in orchards)
  - LAI measurements in shrubs and matorral areas
  - Alometric parameter sampling in tree areas to relate plant dimensions to vegetation characteristics which are required as inputs for the retrieval models.
  - Vegetation water content sampling

For each of the dominant vegetation types, the sampling performed consisted of: branches and leaves of almond, olive, *Holm Oak* and pine trees, and complete individuals of shrubs. In these samples, all the dimensional parameters were measured together laboratory analysis to estimate biomass.

Sea Surface Measurements for Calibration Purposes

Sea surface measurements (temperature, salinity and wind speed) were performed by OCEANSNELL, for calibration purposes of the radiometers onboard the research aircraft. The area of measurements was chosen such that there was no RFI present.

Modeling

There are two components for modeling:
(i)   At CESBIO, modeling work is currently carried out in order to simulate passive microwave brightness temperatures. Firstly, Surfex, a SVAT (*Soil-Vegetation-Atmosphere Transfer*) model from Météo France, is used to characterize the surface according to ground and meteorological data from the VAS site. Then, outputs from this surface modeling are used in the L-MEB (*L-band Microwave Emission of the Biosphere*, Wigneron et al., 2007) model to simulate the surface emission (brightness temperatures) at L-band. These simulations, spatialized at the SMOS pixel, will be compared in a further step with SMOS measurements during the *Commissioning Phase*.
(ii)   HIRLAM is currently being applied to the area and will be compared with the SM network, in collaboration with AEMet. All the HIRLAM analyses during SVRC are currently available.

PRELIMINARY RESULTS

Figure 4 shows a sample of the preliminary results corresponding to the ground SM measurements along the diagonal flight line. It represents the evolution along the four flight days of the measurements acquired in all the measuring plots of each of those ground teams. The distribution of all measurements for different land uses is given in Figure 5 from the first to the last flight.

Figure 4: Ground SM measurements along the diagonal flight line

Figure 5: **Distribution of all measurements for different land uses from the first to the last flight**
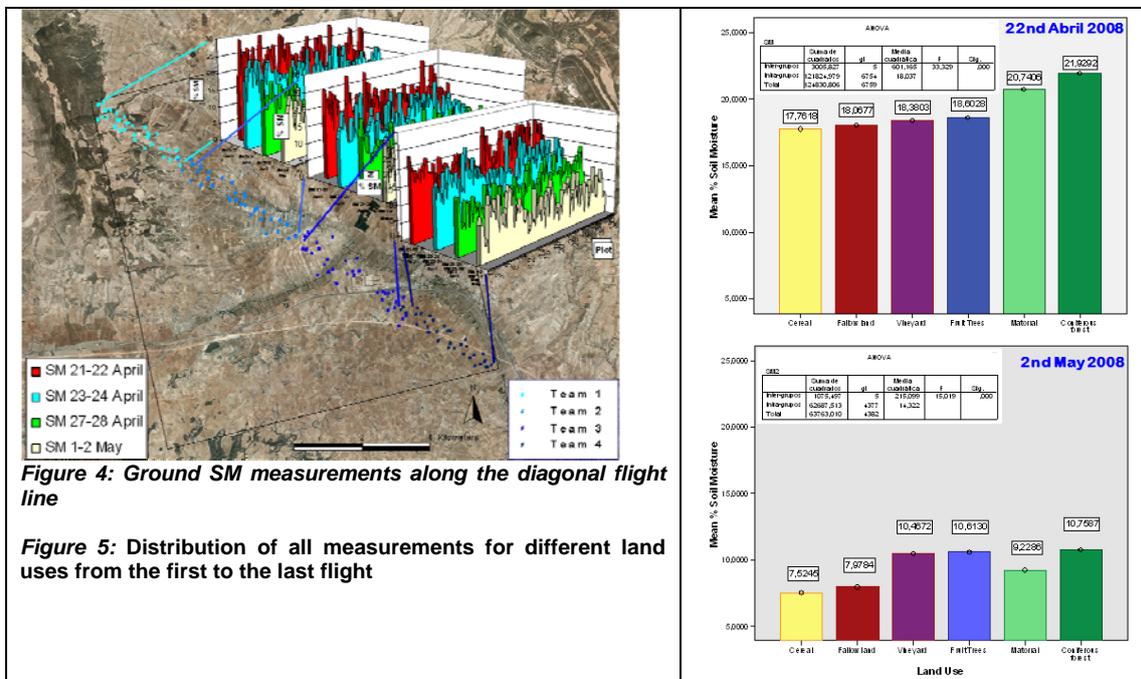
Figure 6 shows preliminary results from the EMIRAD system onboard the aircraft. The images show brightness temperatures from the nadir EMIRAD antenna for the flight lines of the different aircraft operations. The change from wet (22nd April) to drier (2nd May) conditions is clearly noticeable.
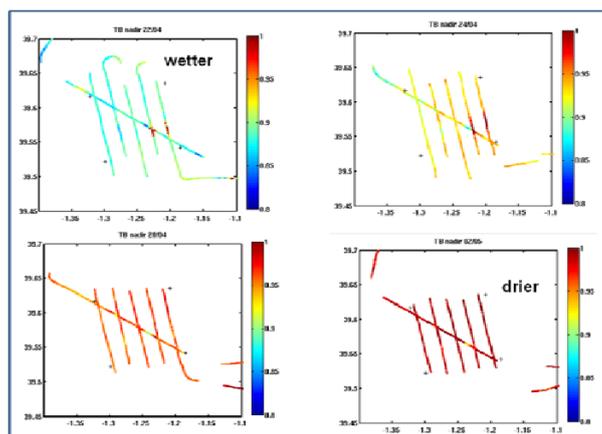
Figure 6: Brightness temperatures from the nadir EMIRAD antenna for the flight lines of the different aircraft operations

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