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REPORT ON THE UNITED NATIONS/EUROPEAN SPACE AGENCY WORKSHOP ON GLOBAL CHANGE AND TRAINING COURSE ON MICROWAVE REMOTE SENSING APPLICATIONS

(Lima, 3-4 and 5-14 October 1994)

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INTRODUCTION

A. Background and objectives

1. At its thirty-seventh session, the General Assembly adopted resolution 37/90 of 10 December 1982, in which it endorsed the recommendation of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) that the United Nations Programme on Space Applications should, inter alia, promote the growth of indigenous nuclei and an autonomous technological base in space technology in developing countries, as well as promote greater cooperation in space science and technology between developed and developing countries as well as among developing countries.

2. The Committee on the Peaceful Uses of Outer Space (COPUOS), at its thirty-sixth session in June 1993, endorsed the activities of the United Nations Programme on Space Applications for 1994 as proposed by the Expert on Space Applications (A/AC.105/555) and as recommended by its Scientific and Technical Subcommittee at its thirtieth session. Subsequently, the General Assembly, in its resolution 48/39 of 10 December 1993, endorsed the activities of the Programme on Space Applications for 1994.

3. In response to Assembly resolution 48/39, and in accordance with the UNISPACE 82 recommendations, the Programme on Space Applications included, as part of its activities for 1994, the organization of a Workshop on Global Change and Training Course on Microwave Remote Sensing Applications. The Workshop and Course were organized for the benefit of participants from countries in the Latin American and the Caribbean region.

4. The United Nations/European Space Agency Workshop on Global Change and Training Course on Microwave Remote Sensing Applications were organized in cooperation with the Government of Peru for the benefit of participants from the region. These activities were co-sponsored by the European Space Agency and by the Comisión Nacional de Investigación y Desarrollo Aeroespacial (CONIDA). The Workshop and Course were held consecutively from 3 to 4 and from 5 to 14 October 1994, respectively, at the headquarters of CONIDA at Lima.

5. The objectives of the Workshop were (a) to familiarize participants with the scope of the International Geosphere-Biosphere Programme: a Study of Global Change (IGBP, also known as Global Change) and with the location, contents and conditions of access to its archives in the region and internationally; and (b) to discuss ways which would enable a broader cross-section of the scientific community to contribute to data collection efforts as well as to utilize data from the archives being integrated into countries in the region of Latin America and the Caribbean.

6. The objectives of the Course were to provide participants with education on the physical basis for radar (microwave) remote sensing as well as opportunities for hands-on training in specific applications of radar data. Through theoretical and practical exercises, the participants acquired knowledge regarding the information that can be derived from these data and how this information can contribute significantly to the knowledge of the natural resources of a country and assist in the formulation of sustainable development and management policies.

B. Organization and programme of the Training Course

7. The Workshop and Training Course were attended by 24 participants from the following countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Panama, Peru, Uruguay and Venezuela. Funds provided by the United Nations and the European Space Agency (ESA) were used to defray the costs of air travel as well as a daily subsistence allowance for 21 participants and instructors in the Workshop and the Course. The instructors for the Workshop and the Course came from Argentina,

Brazil, Canada, Costa Rica and Peru as well as from ESA and the United Nations (Office for Outer Space Affairs).

8. Through presentations at the Workshop, the participants became aware that Global Change aims at understanding the Earth as a complete system, in particular the interactions between land, ocean and atmosphere and the effects that changes in any of the biophysical or geophysical parameters can have on the system. Through round-table discussions, the participants and instructors identified international cooperative activities, including some in Latin America and the Caribbean, that are being conducted to establish global archives of data from satellite and land-based sources.

9. The Course provided participants with the physical theory on which remote sensing, both active and passive, is based. An overall view was presented of remote sensing in various intervals of the electromagnetic spectrum, including the visible, infrared and microwave regions and highlighted the multidisciplinary nature of the use of the data. The presentations included descriptions of the payloads of the European Remote Sensing Satellite (ERS-1) and RADARSAT satellites. Since the instrumentation on board both craft is mostly composed of active radar instrumentation, the Course emphasized active microwave remote sensing. The Course included the theory and concepts of Synthetic Aperture Radar (SAR) image formation as well as an introduction to digital image processing of radar data in agricultural, oceanographic, geologic, topographic and cartographic applications. The Course also provided the participants with examples of the applications of the data received from various of the instruments on board ERS-1 as well as with hands-on experience in digital processing of microwave image products. The presentations made by the lecturers included case-studies of programmes or projects conducted in Latin America.

10. The United Nations and ESA made use of the presence of individuals representing institutions from 12 countries in the region of Latin America and the Caribbean to further develop the concept of a programme proposal that could provide satellite data for institutions in developing countries. This concept had originated during a training course on microwave remote sensing held at Frascati in 1993 for African Francophone countries (A/AC.105/556 and Add.1) and had been further developed with participants in a similar course for the same region held at Frascati in 1994 (A/AC.105/594).

11. The present report, which covers the background, objectives and organization of the Course and of the Workshop as well as giving a summary of the technical presentations (see annex I and II for the programme of the Workshop and the Course respectively), has been prepared for COPUOS and its Scientific and Technical Subcommittee. The participants in the Course have reported on the knowledge acquired and on the work that they conducted during the Course to the appropriate authorities of the Government, universities and research institutions in their own countries.

I. POSSIBILITIES FOR THE ACQUISITION OF SATELLITE DATA

A. Background

12. During the Course held at Frascati in 1993, the participants indicated that two obstacles to their utilization of image products, such as those that they had learned to use at the Course, were the lack of access to them and a need for further education on the principles of their use along with hands-on training to develop experience in the mechanics of their analysis. The representatives of the Secretariat and ESA had indicated that they would explore ways and means through which at least a limited amount of data and further training could be provided for use in the ongoing activities of the participants.

13. Between May 1993 and April 1994, representatives of the Office for Outer Space Affairs, Department of Development Support and Management Services (DDSMS) of the United Nations and ESA discussed the

issue and concluded that (a) for the courses to reach their objectives fully, it was essential that, on their return home, participants in the Course should have access to satellite data and to the necessary image processing software in order to strengthen their newly acquired skills; (b) institutions with ongoing projects would be the most likely to need and utilize the data; and (c) a programme proposal could be developed by the co-sponsors for capacity building and institution strengthening through which a limited amount of data, necessary software and further training could be provided to some institutions in the developing countries.

14. The development of the programme would include the following three phases: (a) needs assessment to determine the degree of interest of institutions in the regions participating in the programme and the quantities and types of data that are needed; (b) identification of ongoing projects in Africa and in the region of Latin America and the Caribbean that are using or could use satellite data; and (c) selection of projects on the basis of those remote sensing applications that were in greatest demand in the regions concerned. Subsequently, the programme would be presented by the co-sponsors, with the endorsement of the institutions and their Governments, to potential funding sources. The data that the programme would provide would not be limited to ERS-1 data but, on the basis of the requirements of the projects, could be from other satellites (e.g. Landsat, SPOT), or from a combination of them in order to take advantage of the complementary nature of satellite-obtained data.

B. Work conducted during the Workshop and the Course

15. The participants were informed that during the course of 1994, ESA, DDSMS and OOSA had entered into an agreement to conduct a survey of existing projects in Africa and in the region of Latin America and the Caribbean that could benefit from the use of satellite data. To this end, the co-sponsors would identify institutions conducting projects on remote sensing applications and invite them to indicate their interest in participating in the proposed programme by submitting brief profiles of the projects. The profiles would include the objectives and status of the project along with an indication of the number and type of images (data), software image processing module, possibly discrete hardware components and additional training that were required to use the data in the ongoing projects.

16. The co-sponsors would analyse the proposals and integrate a number of them into a programme proposal which would be presented to various funding sources. The proposed programme would have pragmatic goals that could produce results that could be quantified at intermediate stages to facilitate their monitoring. The participants in the Workshop and Course were also invited to follow-up on this initiative on their return to their home countries.

II. DISCUSSION AND RECOMMENDATIONS OF THE WORKSHOP

A. Background and discussion of the Workshop

17. Global Change is a multidisciplinary research programme under the auspices of the International Council of Scientific Unions (ICSU). Global Change cooperates closely with the World Climate Research Programme (WCRP) and with the Human Dimensions of Global Environmental Change (HDGEC) to decrease the uncertainties regarding global change phenomena and their consequences.

18. The objective of IGBP is to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in the system and the manner in which they are influenced by human activities.

19. To gain a predictive understanding of global change requires much more than a worldwide data-gathering exercise. Rigorous scientific research in many disciplines must be combined with a global-scale

vision, with working access to many data sets covering a wide range of variables over large geographic and temporal scales. No single country can aspire to achieve that level of integration on its own, carrying out all the studies that are needed and interpreting all the data that is acquired. For this purpose, an international effort is essential.

20. The initial task of Global Change was to define critical gaps in the understanding of the global bio-geo-chemical cycles and life-support processes in order that future research efforts could be focused. The identification of these gaps and their review by the international scientific community resulted in the formulation of six key research questions, each of which is now addressed by what are known as the Core Projects of IGBP that have an operational duration of approximately a decade. The Core Projects have been identified and described in the reports of IGBP. Two additional Core Projects are being developed for possible acceptance. Information on the Core Projects, IGBP Framework Activities and the National Committees and Regional Information Centres can be obtained from the IGBP secretariat, The Royal Swedish Academy of Sciences, box 50005, S-10405, Stockholm, Sweden.

B. Recommendations of the Workshop

21. The Workshop noted that, in general, there was a lack of awareness of the objectives and activities of IGBP, as well as of other international programmes related to Global Change, among institutions in Latin America and the Caribbean that could contribute to its goals or benefit from its findings. Thus, the Workshop concluded that additional efforts are necessary to bring such objectives and activities to the attention of decision makers of relevant institutions.

22. In particular, the Workshop noted that the need for a 1-km-resolution multitemporal data set of advanced very high resolution radiometer (AVHRR) images to provide global coverage of the land surface of the Earth has been identified by several international groups, including IGBP. To meet this need it would be necessary to coordinate the efforts of a number of ground receiving stations around the world to acquire, archive and distribute high resolution AVHRR data. Such efforts have recently been initiated by the National Oceanographic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) of the United States of America, and the United States Geological Survey (USGS) as well as by ESA, and should be followed and supported by institutions throughout Latin America and the Caribbean such as the recently established Inter-American Institute for Global Change Research.

23. At the national level it is necessary that the national committees, where they exist, or the scientific community should inform and promote access to information on activities related to Global Change and other relevant international programmes in order that some of the data gathered by existing projects or programmes could be used to verify the products generated by global and regional models. Towards this end, information on standards for data utilized by global models should be made available to the managers of those projects or programmes.

24. International and national organizations should make greater efforts to organize workshops and training courses on Global Change. These workshops and courses should be oriented to sensitizing and developing the capacity of (a) decision makers, (b) managers of relevant ongoing or planned projects or programmes, and (c) the scientific community.

25. Scientists and technical personnel involved in Global Change and related disciplines, within and outside the region of Latin America and Caribbean, should maintain and strengthen their contacts through modern and efficient communications media such as electronic mail.

III. SUMMARY OF PRESENTATIONS IN THE COURSE

A. Fundamentals of remote sensing

26. Electromagnetic radiation incident on an object on the surface of the Earth interacts at the atomic and molecular level with the object. As a result of this interaction, the portion of radiation that is reflected in the direction of a remotely placed sensor carries information that is intrinsic to the object. In remote sensing applications, the challenge is to identify the object including its characteristics and status given a measure of the relative amount of radiation that it has reflected. Discrimination between diverse types of objects becomes easier if measurements are done in several regions of the electromagnetic (EM) spectrum. The regions of the EM spectrum where these remote measurements are done are called "spectral bands" or simply "bands".

27. Photographic film is a sensor of electromagnetic radiation. It has been designed to represent objects approximately as they appear to the human eye in everyday situations. That is, photographic film is sensitive to radiation in the visible portion of the EM spectrum. The simplest and most inexpensive remote sensing product that can be obtained is a photographic representation of the image acquired by any type of sensor system. Such representations are generated for all sensor systems whose data have been acquired in any of a number of intervals of the EM spectrum.

28. A distinction has purposely been made in using the term "image" when referring to a representation of objects produced by a sensor which is not photographic film. Different types of sensors are used to extend detection capabilities to regions of the EM spectrum where photographic film does not respond. The type of sensors used in these regions are solid state detectors sensitive to EM radiation in specific wavelength intervals which may or may not include the visible region. In response to radiation received, detectors generate either a voltage or a current that is proportional to the amount of radiation received in their wavelength band of operation. The output signal is electronically sampled and converted to digital values that maintain a one-to-one correspondence to the original voltage or current value.

29. The digital values are stored on board the satellite for transmission to a ground receiving station. The digital data are corrected for geometric and radiometric distortions and arranged in matrix form, where each element of the matrix corresponds to the radiation received by the sensor from each resolution cell on the surface of the Earth. With the data in this form, it is possible to perform a computer-assisted analysis of the image. In order for the user to visualize the image, its range of digital values is first normalized to fall within the values from 0 to 255. A correspondence is then established between those digital values and a scale of grey tones going from black to white. This makes it possible for the image to be displayed, either on a screen monitor or on photographic film, in tones of grey.

30. Since an image is only a visual representation of the data obtained by the sensor system, its appearance can be arbitrarily modified. When data from only one band is displayed, it can be done in tones of grey or in hues of one of the primary colours (i.e. blue, green or red). If more than one band is to be displayed at the same time, each is assigned to hues of a primary colour (i.e. blue, green or red) and the user can select whether to display one, two or the three bands simultaneously. Objects on the surface of the Earth appear in colours which are a result of the superposition of the hues of the primary colours which in turn are a representation of the relative amount of EM radiation reflected by the objects in the intervals of the EM spectrum that correspond to the bands being displayed.

B. Digital image processing

31. The large potential that remote sensing from space offers is due to the following main characteristics: (a) the large surface area covered by each image; and (b) the high frequency with which data can be gathered

over the same area. Once acquired, the data are only useful after an analysis has been performed to extract information from them. That is, the features that are being studied must be identified and quantified. This process is called photointerpretation when performed through visual inspection of the image. The same process is called classification when performed with the aid of a computer. In both cases the objective is the same: to identify and discriminate among classes of objects that are of interest to the study from those that are not.

32. The use of computers can enhance and speed the process of extracting the information. The information contained in the images is originally in digital form to facilitate its display and analysis using a computer-based image processing system. However, excellent results can be obtained from the interpretation of photographic representations of the area being studied. A large number of examples of quality work using photointerpretation exist, particularly in applications such as forest management and geological mapping. At present it is possible to purchase high-quality photographic negatives or black and white/colour prints or transparencies of images at scales of up to 1:50,000. These photographic products are inexpensive and their interpretation requires simple equipment which is readily available in universities and survey and mapping institutions.

33. Digital image enhancement techniques improve the visual presentation of the information content of an image. These techniques assist in visual interpretation but do not create any new information. Common techniques include the following: contrast enhancement, spatial filtering, linear combinations of bands and principal component transformations. This step is usually done to allow the user to better identify a few areas or test fields in the image that can be used to "train" the computer during the classification process as well as to evaluate the results obtained from a classification.

34. Software programs which are used to discriminate the elements present in an image are called "classifiers" and fall into two broad categories which are defined by the degree of intervention necessary by the user. The most commonly used programs are the so-called "supervised classifiers". For these, the user identifies homogeneous test fields that are representative of the classes of objects in the image. For one of the bands, the classifier calculates the mean and standard deviation of the digital values of the picture elements (pixels) in each test field. This process is repeated for each of the spectral bands included by the user in the classification process.

35. The set of values of the mean and standard deviation of a class in each of the spectral bands used become the parameters that are used to identify the pixels that belong to a particular class. This set of numbers is also known as the "spectral signature" of the class. When the spectral signatures of all the important classes in the image have been obtained, the program classifies every pixel in the image as belonging to one of those classes. If the evaluation of the results is not satisfactory, the user must repeat the process by redefining the test fields and adding or removing classes. The process becomes iterative until the degree of accuracy is achieved.

36. Unsupervised classifiers require little interaction by the user and are based entirely on mathematical and statistical methods. While this approach makes the classification independent of specific knowledge of the area by the user, it is highly dependent on the mathematical and statistical skills of the user. In addition, unsupervised classifiers use very little of the general experience accumulated by the user in a specific field of application. Regardless of which method is used to classify satellite images, the information that is extracted is hardly ever used by itself but rather to complement or supplement information available from other sources as well as to reduce the amount of field work necessary to achieve the goals of a project.

C. Earth observation satellite systems

37. Earth observation satellites are classified as being "polar orbiting" or "geostationary orbiting" satellites. Together they form a family of satellites that cover practically all areas of the Earth (except for small regions around the poles), in a broad range of bands of the electromagnetic spectrum and with a diversity of spatial and spectral resolutions. Polar orbiting satellites are placed in low-Earth orbit a few degrees off of the poles and are Sun-synchronous (overhead passes at the same local solar time). These satellites have high spatial and spectral resolutions and long revisiting periods (on the order of days). Geostationary satellites are placed in high orbit (36,000 km) above the Earth's equator. In this particular orbit, called the geostationary orbit, the satellites rotate at the same angular velocity as the Earth so that they appear to remain stationary over the same area of the Earth. Geostationary satellites have a very high revisiting period (up to every half hour) but their sensors have low spatial and spectral resolutions.

38. Very important geostationary satellites are the meteorological satellites (METEOSAT, GOES I and II, GMS and INSAT). These satellites are operated by a European consortium, EUMETSAT, by NOAA, by the Japan Meteorological Agency and by the Indian Space Research Organization, and are coordinated by the World Meteorological Organization. The primary function of these satellites is to provide data for studies of meteorological phenomena, to warn of catastrophic events and to forecast weather.

39. Meteorological satellites are also placed in polar orbit from where they provide north-south coverage of the Earth. These satellites have medium spatial and spectral resolutions; higher than satellites placed in the geostationary orbit but lower than satellites that are conventionally called Earth resources satellites. Polar orbiting satellites include the NOAA/TIROS-N series, the METEOR-2 and -3 series, operated by the Russian Federation, and the FENG YUN-1, operated by China. The primary function of these satellites is also meteorological. Operational products from these satellites include rainfall estimates, hurricane classification, tropical storm bulletins, cloud-top height and cloud-motion (winds) data. Data from these satellites are also being used for large scale agriculture, oceanography and water management.

40. However, increasingly, the data of polar orbiting meteorological satellites have been used for monitoring land phenomena such as the advance of desertification at regional and global scales. An instrument that has been extensively used in such studies is the NOAA Advanced Very High Resolution Radiometer (AVHRR). AVHRR is a five-spectral-band scanning radiometer which provides imagery (i.e. quantitative radiance data) at both 1 km and 4 km resolutions. The data are broadcast in real time to both Automatic Picture Transmission (low resolution) and High Resolution Picture Transmission (HRPT) users. Data from AVHRR can also be recorded on board for eventual transmission when the satellite is not within the line of sight of a ground receiving station.

41. The five spectral bands of the AVHRR sensor and the applications in which they are typically used are the following:

Band name	Micrometers	Application
Band 1	0.58-0.68	Daytime clouds, snow and ice mapping
Band 2	0.72-1.10	Surface water delineation, vegetation and agriculture assessment
Band 3	3.55-3.93	Night-time cloud mapping, sea surface temperature measurement, hot spot detection (e.g. forest fires)
Band 4	10.3-11.3	Day/night cloud mapping, sea/land surface temperature, soil moisture volcanic eruptions
Band 5	11.5-12.5	Sea surface temperature and soil moisture

A linear combination of bands 1 and 2 is commonly used for vegetation index studies, in particular to monitor the advance of deserts.

42. Earth resources satellites are placed in low, nearly polar orbit and provide high spatial resolution. This resolution is typically in the range of 10-30 m and is likely to improve to 1-2 m by the year 2000. Earth resources satellites have long revisit periods (of the order of weeks) and cover swaths of the order of 100 km in width. Operational satellite systems in this category include SPOT-2 and -3, Landsat-5 and IRS-1. Sensors on board these satellites operate in the visible and near infrared parts of the EM spectrum.

43. The data from the Earth resources satellites have been progressively used in many and diverse applications since the first Landsat satellite was launched in 1972. Since then, the data have been used with increasing success in the following main areas:

(a) Agriculture and forestry: discrimination of crop, timber and range vegetation types, determination of crop acreage by species, timber acreage and volume by species, range biomass, vegetation vigour and stress, determination of soil conditions and associations, and assessment of damage to grasslands and forests by fire;

(b) Land-use and land mapping: classification of land uses, cartographic mapping, categorization of land capability, separation of urban and rural areas, regional planning, and mapping of land/water boundaries and transportation networks;

(c) Geology: mapping of major geologic units, mapping of igneous intrusions and recent volcanic deposits, recognition of rock types, search for surface indications of mineralization and determination of regional structures;

(d) Water resources: determination of surface-water area and volume, mapping of floods and plains, determination of snow and ice areas and boundaries, sediment and turbidity patterns including water depth and delineation of irrigated fields;

(e) Oceanography and marine resources: detection of living marine organisms, of turbidity and circulation patterns, mapping of shorelines, shoals, shallow areas and their changes, mapping of ice for shipping routes and studies on global phenomena such as El Niño and La Niña;

(f) Environment: mapping and monitoring of land, air and water pollution, surface mining effects, determination of natural and man-made desertification, deforestation, eutrophication, and impact of urban and large infrastructure development.

44. Two other operational systems carry on board a combination of visible, infrared and microwave (radar) sensors. These two systems (ERS-1 and JERS-1) are operated by the European Space Agency and by the National Space Development Agency of Japan.

D. Concepts of radar remote sensing

45. Sensors that operate in the visible and infrared portions of the EM spectrum detect reflected sunlight or emitted thermal radiation and are not well suited to some types of Earth observation. This is particularly the case for tropical areas, which for large periods of time are not visible due to their cloud cover. In other situations, it may be necessary or desirable to view a region of the Earth as frequently as possible. For such cases it would be convenient to have the capability of observing the region of interest during periods in both the daytime and the night-time.

46. Microwave radiation, either emitted by the Earth due to its black body radiation characteristics or reflected from an external source such as the Sun, can penetrate cloud cover and even light rain and can also be measured during the night. There are two types of sensors that detect this radiation. These sensors are grouped into "passive" and "active" sensors depending on whether they detect radiation emitted or reflected from a natural source or whether they detect radiation that has been generated by the instrument itself.

47. Satellites that carry a radar sensor instrument on board (called radar satellites) provide their own "illuminating" source and are thus not dependent on sunlight. (The term "radar" stands for radio detection and ranging.) A radar instrument transmits short electromagnetic pulses that are backscattered by the surface of the Earth and that penetrate cloud cover with little or no attenuation. The backscattered radiation is received at the satellite and converted into an electrical signal that is suitable for recording and subsequent transmission to a ground receiving station. Radar satellites can have both imaging and ranging systems on board.

48. The main quantities that are measured by a radar instrument are (a) the time delay of the reflected signal; and (b) the intensity of the reflected signal. The first of these quantities provides the direction and distance of an object to the radar while the latter provides the orientation, geometry, roughness and dielectric properties of the object. The roughness of an object is a characteristic that depends on the wavelength of the incident radiation. If the characteristic dimensions of the object are small compared to the wavelength of the incident radiation, the object is considered smooth. If the characteristic dimensions of the object are approximately the same as the wavelength of the incident radiation, the object is considered rough.

49. For remote sensing purposes, an imaging radar system is carried on board an aircraft or satellite. The system consists of a transmitter, a receiver, an antenna which transmits and receives EM radiation, and a signal processing and recording unit. The transmitter generates short microwave pulses of radiation with a duration of microseconds each. The pulse is transmitted by the antenna in a narrow beam into the range direction. For imaging radar systems, the geometric configuration is such that the beam is radiated from the side of the satellite at some angle of incidence to the surface of the Earth and perpendicular to the flight direction. This is called a side looking airborne radar (SLAR). More sophisticated versions of airborne radar have the same geometric configuration but utilize the concept of simulating a longer antenna by taking advantage of the motion of the satellite or aircraft and a complex sampling procedure of the returned signal. This type of instrument is called a synthetic aperture radar (SAR).

50. The reflected portion of the transmitted pulse is collected by the antenna and the instrument determines both the strength of the returned signal and the time delay with respect to the transmitted pulse in order to determine the range distance of the sensed object relative to the satellite. The radar beam is wide in the vertical direction and narrow in the horizontal or along-track direction. The motion of the satellite produces a two-dimensional image plane which results in a parallel and oblique view of strips of the surface of the Earth. This makes the scanning concept of an imaging radar very different from scanners that operate in the visible and infrared regions of the EM spectrum. The latter build an image of the surface of the Earth on a line-by-line basis, their viewing geometry is downward-looking and the spatial resolution of the resulting images depends on the angular resolution of the system's optics and on the altitude of the satellite or aircraft.

51. An imaging radar system has two spatial resolutions: one in the range or across-track direction and one in the along-track or azimuth direction. These resolutions depend, first on the electronic characteristics of the instrument and secondly on the geometry of the radiation incident on the surface. In the case of a SLAR, the azimuth resolution increases with increasing length of the antenna but decreases when objects are farther away from the antenna. The range resolution is determined by measuring the time delays along the slant path between reflected signals from the objects back to the antenna and increases as the time delay between transmitted and reflected pulses is shorter. For equal time delays (i.e. slant path resolution), ground resolution is better of objects farther away from the antenna.

52. For a SAR instrument, the limiting factor for its range resolution is being able to shorten the transmitted pulse while maintaining sufficient power to detect the reflected signal. A SAR system maintains the range resolution by transmitting more energy through a technique known as "chirping" whereby the transmitted pulse is modulated by a signal whose frequency increases (or decreases) linearly in time instead of through a sinusoidal modulation. Through a Doppler effect analysis of the reflected signals, the motion of the radar platform is used to improve the azimuth resolution and to make it independent of the distance of the object to the antenna and of the frequency of the incident radiation. This results in a constant resolution in the azimuth direction which is much better than in the case of a SLAR.

53. In radar image formation, the first return pulse corresponds to the object whose projected distance in the direction of the sensor system is the smallest. In general, this pulse corresponds to the object closest to the flight path. Because of the geometry of the incident pulse and the height of objects, the projected distance in the direction of the sensor system of the upper part of an object is smaller than the distance of its corresponding ground projection. This effect is known as foreshortening and makes terrain of high relief appear in the image as falling towards the radar. On the images, foreshortening causes the slopes to become extended and to appear darker. This effect can be corrected by reference to a digital terrain map.

54. The foreshortening effect can become very severe so that the top of a mountain appears to be closer to the flight path than the foot of the mountain. This effect is called layover and cannot be corrected. Other image degradations include speckle effect - which appears as noise on the image although strictly speaking it is not but is related to the frequency coherence of the system - as well as several effects due to the motion of the object with respect to the sensor or to other objects in the field of view of the radar.

55. The microwave spectrum is subdivided into various bands, each of which is referred to by a single letter and is determined by a range of frequencies as follows:

Band name	Band interval (GHz)	Band name	Band interval (GHz)
P-Band	0.225-0.390	K-Band	10.90-36.00
L-Band	0.390-1.550	Q-Band	36.00-46.00
S-Band	1.550-4.200	V-Band	46.00-56.00
C-Band	4.200-5.750	W-Band	56.00-100.0
X-Band	5.750-10.90		

For airborne radar missions, the most used bands have been the X-band, L-Band and K-Band. For the satellite radar systems, current and those to be launched by the turn of the century, the predominant frequency is C-Band.

E. Sources of satellite radar data

56. The European Remote Sensing Satellite-1 (ERS-1), was launched in July 1991 and carries several microwave sensors on board. Its primary instrument is the Active Microwave Instrument (AMI), which can provide high-resolution images (in C-band), wind speed through ocean wave spectra analyses and the length and direction of waves. While in an imaging mode, AMI covers a swath of 80-100 km, with a resolution of the order of 27 m in the range direction and 29 m in the azimuth direction.

57. Operating in the wind mode, AMI covers a swath of 400-500 km over the ocean with resolution cells of 50 km and measures wind speed in the range of from 4 to 24 m/s with an accuracy of from 0.5 m/s to 2 m/s. Wind speed and direction are determined by measuring the strength of the backscattered signal of each resolution element from three directions: obliquely ahead, to the side and obliquely behind the satellite path. The intensity of the three signals provides the wind speed, and the differences between them indicate

the wind direction with an accuracy of 20°. In wave mode operation, AMI determines the length and direction of ocean waves in 5 x 5 km cells for segments of 200-300 km along the satellite path. Ocean wavelengths of 100-1,000 m can be measured to an accuracy of 25 per cent.

58. ERS-1 also carries a Radar Altimeter (RA) that operates at a wavelength of 2 cm. This altimeter is used to measure average wave height and wind speed, and to determine meso-scale ocean topography. Data from this altimeter have been used successfully to determine ice type and topography as well as water/ice boundaries.

59. A third instrument on board ERS-1 is the Along Track Scanning Radiometer (ATSR) that operates in three bands in the thermal region of the EM spectrum. These bands are centred on 3.7, 11 and 12 micrometres. ATRS looks through the atmosphere at the surface of the ocean from two directions, downwards vertically and at an incidence angle of 50°. The difference between the oblique and vertical measures provides information on atmospheric absorption while the differences between measurements at the three wavelengths are used to determine atmospheric water vapour content.

60. The three instruments described above were designed primarily for ocean observations. Of the three, AMI, in its imaging mode, has been finding the greatest number of applications for land monitoring, surveying and exploration. In particular, its SAR images have been tested, with varying degrees of success, in agriculture, forestry, hydrology. cartography and geology, and for monitoring natural hazards such as floods and mud-flows. Near the coastline, SAR images have found applications to aquaculture, mangrove forestry and coastal monitoring (coastline, erosion, tidal flows and effects of dams).

61. Launched in 1992, the Japanese Earth Resources Satellite (JERS-1) is also equipped with a SAR sensor. However, this sensor system operates in the L-band (0.39-1.55 GHz). JERS also carries a visible and near infrared radiometer (VNIR) and a short wavelength infrared radiometer (SWIR); both instruments provide a spatial resolution of 18 m x 24 m. This satellite is equipped with an on-board recorder for transmission of gathered data when it comes within the line of sight of one of its ground receiving stations. The revisit period for this satellite is 44 days.

62. JERS-1 has been placed in Sun-synchronous orbit and its data is received by the Hatoyama Observation Center and by several other receiving stations around the world. This satellite conducts a variety of observations, not only for resources exploration but also for land survey; agriculture, forestry and fishery; sea-ice monitoring; environmental monitoring; disaster prevention; coastal monitoring; and other applications.

63. Canada's first remote sensing satellite, RADARSAT, will carry a SAR instrument that will operate in C-band with multi-mode single polarization. Its polarization will be horizontal-horizontal (HH) and refers to the orientation of the microwave energy transmitted and received by the satellite's antenna. Other possible polarizations include vertical transmission and vertical reception (VV) or vertical transmission and horizontal reception (VH) or horizontal transmission and vertical reception (HV). The polarization property of microwaves is very useful in differentiating objects on the ground, as surfaces reflect differently depending on the polarization of the incident energy.

64. RADARSAT will have the capability of imaging swaths from 50 to 500 km in width with associated resolutions of from 10 to 100 m. This instrument has been designed with capabilities for the following five operating modes: standard (25 x 28 m resolution, 100 km swath), wide swath (25 x 28 m resolution, 150 km swath), fine resolution (11 x 9 m resolution, 50 km swath), ScanSAR (50 x 50 m and 100 x 100 m resolutions, 300 and 500 km swaths) and extended (10-20° and 50-60° incidence angles, 25 x 28 m resolution).

65. The spacecraft has been designed for a five-year lifetime and is scheduled for launch during 1995. The satellite's orbit is planned at 800 km, it will be Sun-synchronous, dawn-to-dusk, with a 24-day revisit period and a three-day subcycle. The SAR antenna will point north but the spacecraft will be capable of rotating 180° about its yaw axis in order to obtain full coverage of the Antarctica. RADARSAT will operate with its antenna pointing south for a period of two weeks twice a year to allow full imaging of the Antarctica during its maximum and minimum coverage by ice.

66. RADARSAT products will be of the following three types: (a) geo-referenced products, i.e. standard images with systematic geometric corrections; (b) geo-coded products, i.e. images that have been re-sampled and rotated to conform to standard map projections; and (c) special products, e.g. unprocessed signal, single-look real or complex image files and analysis of external calibration files. The image products will generally be available in both photographic and digital forms.

67. Because it will carry on-board recorders, RADARSAT will be able to provide imagery of the entire globe. The RADARSAT instrument will be capable of collecting up to 28 minutes of SAR data during each of its 100.7-minute orbits. RADARSAT mission operations will be coordinated by a mission management office (MMO) which will serve as an interface between the user community, the mission control facility, and the ground receiving and processing facilities. MMO will monitor the entire data distribution, which will be carried out mainly by RADARSAT International, a private-sector corporation.

68. General information on past, current and future satellite SAR systems is presented below.

Past satellite SAR systems

	SEASAT	SIR-A	SIR-B	Kosmos1870
Country	USA	USA	USA	USSR
Agency	NASA	NASA	NASA	Glavkosmos
Platform	Seasat	Shuttle	Shuttle	Salyut
RADAR:				
Band	L	L	L	S
Polarization	HH	HH	HH	HH
Incidence angle (degree)	23	50	15-64	30-60
Range resolution (m)	25	40	25	30 approx.
Azimuth resolution (m)	25	40	58-17	30 approx.

Current satellite SAR systems

	Lacrosse	Almaz	ERS-1	J ERS-1
Country/organization	USA	Russian Federation	ESA	Japan
Agency	USAF	Glavkosmos	ESA	MITI/NASDA
Platform	Atlantis	Salyut	ERS-1	J ERS-1
Launch date	13.12.88	31.3.91	16.7.91	11.2.92

RADAR:				
Band	X	S	C	L
Polarization	HH	HH	VV	HH
Incidence angle (degree)	dirigible	30-60	23	38
Range resolution (m)	>1	15-30	26	18
Azimuth resolution (m)	>1	15	28	18

Planned satellite SAR systems

	SIR-C/X-SAR	ERS-2	RADARSAT
Country/organization	USA/ESA	ESA	Canada
Agency	NASA/DLR/DARA	ESA	CSA/USA
Platform	Shuttle	ERS-2	(TBD)
Launch date	1993, 1994, 1996	1994	1995
RADAR:			
Band	L, C, X	C	C
Polarization (band)	VH (L+C); VV (X)	VV	HH
Incidence angle (degree)	15-55	23	<20 to >50
Range resolution (m)	10-30	26	10-100
Azimuth resolution (m)	30	28	9-100

F. Radar applications to agriculture and forestry

69. The general objective of the use of remote sensing in soil, agriculture and forestry applications is to obtain information for resources inventory and management or for understanding environmental and global change phenomena. The use of radar images can complement existing information or that which might be acquired by other sensors including field data. In this sense, radar can make important contributions: (a) to identifying and mapping vegetation and soil types; (b) to determining phenological stages, deforestation, afforestation, regrowth and desertification; and (c) to extracting biophysical parameters such as biomass, vegetation density and height and soil moisture.

70. Microwave techniques for measuring soil moisture include the use of both passive and active sensors with each having distinct advantages. Passive microwave techniques have a large area coverage since the source of the radiation is emission from the Earth itself while active systems measure only radiation reflected from the swath within the beam that has been sent by their antenna. However, active systems provide more power to the signal and can achieve higher resolutions. In addition, the choice of incidence angle of the radiation, its wavelength and polarization allows for such possibilities as gathering information from the crown of a forest or for a far greater penetration of the vegetation canopy.

71. The theoretical basis for measuring soil moisture using either active or passive microwave sensors is based on the large contrast between the dielectric properties of water and dry soil. The dielectric constant for water is of the order of 80 while for dry soils it is between 3 and 5. As a result, as water is added to soil, the dielectric constant of the combination can change dramatically. The magnitude of both emitted and reflected microwave is dependent on the value and changes of the dielectric constant. Thus, changes in measured values in the microwave region of the EM spectrum can be directly related to degrees of soil moisture. In recent experimental results, radar backscatter responses extracted from ERS-1 SAR data have been strongly correlated to soil moisture content.

72. In contrast to water or soil/rock surfaces which have a continuous interface with air, vegetation has a discontinuous or not well defined interface (e.g. a surface covered by leaves and air spaces). The strength of the backscattered signal can result from surface scattering (continuous interface), volume scattering (i.e. from the entire canopy) or multiple surface-volume scattering interactions. Thus, the penetration of the incident radiation, the surface roughness of the vegetation and the dielectric properties of the volume all contribute to the net backscattered radiation detected by the SAR antenna. The effects of these parameters on the measured signal depend on the angle of incidence, polarization and frequency of the radiation, and a careful consideration (or selection) of their characteristics is necessary to arrive at an accurate analysis of SAR data.

73. Incident microwave radiation of lower frequencies (i.e. longer wavelengths) penetrates vegetation more and returns information on the structure of the canopy including the trunks/stalks and possibly the soil boundary. This information is best extracted through elaborate canopy modelling techniques that perform a mathematical treatment of the physical interaction of the radiation with each class of component (leaf, trunks/stalks, soil). However, simpler analyses leading to a determination of whether the dielectric constant of the area under observation is closer to the values expected for soil than for vegetation can serve to separate sparse vegetation (low plant density and height) from dense vegetation as would be the case for various growth stages of crops. If the microwave wavelength is chosen to interact with the leaf portion of the canopy, the vegetation volumetric water content will also serve to indicate an advanced growth stage. The same technique could be used to delineate flooded from non-flooded vegetation. In the latter case, the vegetation cover might be so dense that the effect of the underlying water does not appear in the visible or infrared bands.

74. The delineation of forest and non-forest areas is generally possible in SAR images. Good results have been obtained in identifying swamp forest stands. However, the discrimination of forest clearcut and regeneration sites has been generally poor when images from only a single date or taken in a single frequency band have been used. A significant improvement has been noted when either a multi-temporal or a multi-frequency approach has been used taking advantage of change detection information. Deciduous and coniferous stands can be differentiated by the use of multiple view angles.

G. Use of radar in geology

75. Radar images have been used by geologists for more than 20 years for lineament detection and mapping as well as for oil and mineral exploration. The use of SAR images in these fields has been natural because the interaction of the radiation is to a large degree with the object of interest. That is, the rock and terrain are often exposed and not obscured by vegetation or other matter that could mask their effect on the returned signal. In addition, radar images are particularly sensitive to topographic features, surface roughness and moisture content (or to the lack of it).

76. In the case of lineament studies, the interpretation of images is done in a similar manner to the procedure used with conventional air photographs. However, the interpreter should bear in mind that the shadows seen on the image are due to the oblique incidence angle of the microwave radiation and not to solar illumination. Thus, associated effects that need to be considered are foreshortening and layover; these effects have been described above. However, the use of images obtained at different view angles has been found to enhance the shadow effects with the end result that they facilitate the recognition of lineaments over mountainous regions.

77. Topography enhancement is also related to the incidence view angle selected and improved results have been obtained from the analysis of several images acquired with different viewing angles. Since in general, the drainage network appears clearly on SAR images, its combined use with the topography (also derived from the SAR image) allows for a satisfactory study of the geomorphology of the area. Because of the

penetrating capabilities of microwave radiation, there are examples where even subsurface structure which is part of a drainage network can be seen beneath sand-covered plains.

78. SAR data are also useful to study weathering characteristics and erosion processes over sedimentary, metamorphic and basic rocks as well as for studies related to quaternary deposits, relative dating of the cenozoic period, characterization of lava flows and discrimination of lithologies.

79. Experience with radar data has shown that the best bands to study soil and rock erosion are L and C while bands C and X are best for desertification studies as they are sensitive to sand dune movements. Both HH and VV polarizations are useful for structural studies; however, HH is better due to its sand, snow and ice penetration capability. Analysis has also shown that to obtain specific parts of the geological information, it is desirable to use images with at least two incidence angles of illumination.

H. Practical exercises

80. The participants in the Course had several sessions of hands-on training with images from ERS-1, LANDSAT and SPOT. These practical exercises were conducted primarily on PC-based digital image processing systems. Through these practical sessions, the participants became familiar with the type of software programs that are used to perform enhancement and filtering operations on digital images. They also acquired experience in interpreting SAR images for geological, oceanographic and agricultural applications.

81. The exercises included reading in SAR data into the computer's disk and applying to it a number of digital filters in order to compare their effect on the image. Other exercises covered data compression from 16 to 8 bits, reduction of image pixel size, enhancement and selective extraction of features that appear on the image as well as combining multi-date SAR images and SAR images with Landsat (Thematic Mapper) images.

IV. DISCUSSIONS AND CONCLUSIONS OF THE COURSE

82. During the concluding part of the Course, the participants expressed their commitment to follow-up on the work that they had conducted regarding the programme proposal that would be prepared by the United Nations and ESA. In this respect, the participants would inform the authorities of their institutions in order that a brief overview of the objectives and current status of their ongoing projects, including specific details of the type and quantity of satellite data that was needed, could be transmitted to the co-sponsors.

83. The participants expressed their appreciation of the technical quality of the training programme that was prepared and delivered to them. In addition, the participants expressed their appreciation for the fellowships received from the co-sponsors, which had made their participation in the Course possible, as well as for the cooperation and support that they had received from administrative and technical personnel of ESRIN.

Annex I

PROGRAMME OF THE WORKSHOP

Date/Time	Subject	Speaker
3 October 1994		
	Opening and introduction to the Workshop	
09.00-09.30	Registration for Workshop and Course	
09.30-10.00	Opening ceremony and welcome addresses	R. Poggi, CONIDA S. Camacho, United Nations M. Fea, ESA
10.30-11.00	Introduction of participants and support personnel	Co-sponsors
11.00-12.30	Introduction to Global Change and objectives of the Workshop	S. Camacho, United Nations
12.30-13.00	Visit to the facilities of CONIDA	R. Coloma, CONIDA
14.15-15.15	Global Change: objectives, activities and projects of IGBP	I. Velasco, University of Buenos Aires
15.15-15.45	Panel session	All lecturers
16.00-17.00	Introduction to Climate Change	J. Amador, University of Costa Rica
17.00-17.15	General discussion	All participants
4 October 1994		
	Global Change: national and regional activities	
09.00-10.00	Regional aspects of climate change	J. Amador, University of Costa Rica
10.00-10.45	Panel session and general discussion	All participants
11.15-12.15	Problems related to integrating information	J. Amador, University of Costa Rica
12.15-13.00	Panel session and general discussion	All participants
14.15-15.15	Global change activities in Argentina	I. Velasco, University of Buenos Aires
15.15-15.45	Panel session and general discussion	All participants
16.00-16.30	ELADA: a biodiversity Atlas	C. Hutton, CCRS
16.30-18.00	Summary and conclusions	All participants

Annex II

PROGRAMME OF THE COURSE

Date/Time	Subject	Speaker
5 October 1994		
	Introduction to remote sensing and Earth Observation satellite systems (EO)	
09.00-09.30	Introduction of participants and support personnel	United Nations/ESA
09.30-10.45	Principles of remote sensing	S. Camacho, United Nations
11.15-13.15	Visible, infrared and microwave remote sensing	S. Camacho, United Nations
14.15-15.30	Polar and geostationary satellites	M. Fea, ESA
15.45 17.15	Landsat and SPOT systems	M. Fea, ESA
6 October 1994		
	Introduction to microwave instruments	
09.00-10.45	Microwave instruments - active and passive	M. Fea, ESA
11.15-13.15	SAR theory and concepts	M. Fea, ESA
14.15-15.30	The ERS-1 system	M. Fea, ESA
16.00-16.30	The Envisat system	M. Fea, ESA
16.30-17.15	The RADARSAT system	C. Hutton, CCRS
7 October 1994		
	Introduction to digital image processing	
09.00-10.45	Introduction to image processing systems	C. Hutton, CCRS
11.15-13.15	Introduction to digital image processing	C. Hutton, CCRS
14.15-17.15	Practical exercises on PCs	C. Hutton/F. Quispe, CCRS/PERU
10 October 1994		
	Digital image processing	
09.00-10.45	Radar data processing (e.g. radiometric corrections calibration, filtering, 16 to 8-bit compression)	C. Hutton, CCRS

11.15-13.15	Radar data processing (multitemporal imaging, colour coding) and complementarity of EO Space Data	M. Fea, ESA
14.15-17.15	Practical exercises and PC workshop - optical and microwave image analysis	Hutton/Fea/Quispe, CCRS/ESA/PERU
11 October 1994		
	Applications to geology and mineral prospecting	
09.00-13.15	Theory and applications	U. Palme, INPE
14.15-16.45	Practical exercises	U. Palme, INPE
12 October 1994		
	Applications to agriculture and forestry (soil moisture, crop monitoring etc.)	
09.00-13.15	Theory and applications	U. Palme, INPE
14.15-16.45	Practical exercises	U. Palme, INPE
13 October 1994		
09.00-13.15	Theory and applications	U. Palme, INPE
14.15-16.45	Practical exercises	U. Palme, INPE
14 October 1994		
09.00-09.45	Distribution of ERS-1 data	M. Fea, ESA
09.45-10.45	General discussion	Co-sponsors
11.15-13.15	Discussion on possible projects as follow-up to the Workshop on Global Change and other areas within the UN/ESA framework	United Nations/ESA
	Certificates and closing	Co-sponsors