VEGETATION

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"VEGETATION" onboard SPOT 4

MISSION SPECIFICATIONS

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VERSIONS

(see Annex D for a list of modifications)

Version 0...	06/30/92.......	Initial specifications
Version 1...	01/12/93.......	Specifications discussed and proposed by the User's Committee meeting, Brussels 11/05/92 (Ref :CNES S4.CR.36-1566-CN 11/17/92)
Version 2...	04/15/93.......	Includes comments made during the User's Committee meeting, Brussels, 03/22/93
Version 3...	05/18/94.......	Includes recommandations from the System Concept Review, Toulouse, 04/21/94

CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. CONTEXT OF THE PROPOSAL

The concepts of an instrument dedicated to studies of the vegetation cover on a global basis was presented to CNES in 1985 as a candidate to complement the main SPOT 4 mission that is based on two high spatial resolution instruments. The overall objectives of "Vegetation" were to provide accurate and operational measurements of simple characteristics of vegetation canopies,

- either for scientific studies involving both regional and global scales experiments on long time periods (for example development of models of the biosphere dynamics interacting with the climate models),
- or for systems designed to monitor important vegetation productions, like crops, pastures and forests.

Since 1985, a large number of scientific and technical teams have been involved in the use of meteorological satellite data (such as NOAA-AVHRR or METEOSAT) for studies of vegetation characteristics, taking benefit of the repeatitivity of the system that allows an acquisition frequency adapted to the vegetation seasonal evolution rate, and of the possible global coverage with a spatial resolution varying from 1 to about 16km.

These studies provided much more knowledge of the possibilities of remote sensing to determine surface characteristics. They also played a key role in the development of global scale projects dedicated to the functioning of vegetation covers, their role in environmental and climate changes and their interaction with the atmosphere. Obviously, the relationships between remote sensing measurements and detailed parameters of biosphere processes are still to be established to reach the level of *in situ* studies, but it is also clear that even simple and robust estimates of main parameters —as reflectance of the solar energy or absorption of photosyntheticallly active radiation for example— can provide a much improved knowledge of the biosphere dynamics, both at regional and global scales. One key requirement for this simple data collection is that it is available for long periods of time (related to time response of the seasonal and climatic evolution), with a minimum and constant guaranteed accuracy or with complement measurements to allow some separation between target characteristics and disturbances due to its environment. Another important requirement is that the capability to migrate from local to regional then to global scales be provided, without the problems related to differences in time or environment conditions of the acquisition.

The "Vegetation" system, composed of an instrument onboard a satellite and of its associated ground segment, has the objectives to provide these long term simple measurements adapted to biosphere studies. Capabilities for scale integration are provided by the combination with the main SPOT instrument (HRVIR) which allows high spatial resolution for detailed modelling activities or multilevel sampling procedures. Availability of data to different types of users is permitted through the centralisation of reception and archiving global data, associated to quality monitoring. The launch date (around 1996) and duration of the system (about 5 years of estimated life time) is adapted to a systematic and extensive application of methodologies that are existing or will be developed in the next five years.

Evolution of the system.

Clearly this system will benefit from detailed studies based on other systems that are dedicated to specific studies of the characteristics of remote sensing measurements or to their relationships with surface or processes' parameters. It must be envisaged that the evolution of the mission specifications will have to take into account results of such studies to provide improved characterisation of the biosphere state and dynamics. Moreover, as many research activities and projects are being developped around the use of VEGETATION type data, new methodologies will certainly be validated to invert surface parameters from remote sensing measurements (for example estimation of absorption of photosynthetically active radiation): these methodologies must be taken into account in the evolution of the system, both during the time life of the ground segment associated to the initial onboard instrument and for following instruments that would continue the same type of mission.

B. PURPOSE OF THE MISSION SPECIFICATIONS

A detailed description of the domains that could benefit from this system is given in "A mission for Global monitoring of the continental biosphere" (Ref. 13). In this document, the mission objectives will be described and structured, to emphasise on the requirements of the system in terms of “data” characteristics, accuracy of their different aspects (radiometry, geometry) and constraints for operation of the system.

The particular data to which these quality specifications apply will be described. A strategy to define derived data products adapted to potential users will be outlined. The requirements for these derived data products should be defined by a User Committee, leading then to the definition of the part of the ground segment that must transform system products to users products.

Geometry and radiometry characteristics and their desired accuracy will be given. Particular attention will be given to the correlation to the high spatial resolution instrument characteristics to preserve one of the essential feature of the entire system.

Constraints for operation of the system, availability of data to users will be expressed.

II. MISSION OBJECTIVES

The domains for which that system is defined are described in Ref. 13, leading to a general description of the instrument characteristics. However, to precisely determine the specifications, the different uses that will be done of the data delivered by “Vegetation” have to be structured in order to give common constraints on all aspects of the measurements. This will show that a synthesis can be drawn, giving a minimum set of specifications for geometric and radiometric characteristics as well as for their accuracy.

A. RATIONALE FOR THE GENERAL DEFINITION OF THE SYSTEM

Mission based constraints

As mentioned above in the introduction, the objective is to provide simple and robust data adapted to biosphere studies : as the first order characteristics of land cover can be derived from a minimum set of remote sensing measurements, a number of goals relating to vegetation monitoring can be achieved if long term data sets are available to users with a minimum and guaranteed quality. The following discussion, referring to studies conducted in the last years, will summarise the concepts and justifications for that approach.

Wavelength domain	Measurement set for the next years	Improvements
Solar reflection : VIS/NIR/SWIR	• 3 spectral bands : VIS, NIR, SWIR • Additional bands for atmospheric corrections • Directional measurements (and/or polarisation)	• Active systems (lasers) • High spectral resolution • Polarisation On board preprocessing
Thermal infrared	• 1 to 3 spectral bands between 3.5 and 14 µm • Vertical sounder	• Active systems (?) • Spectroscopy
Active/ passive microwaves	• The largest wavelength with acceptable spatial resolution (passive microwaves)	• Enhancements of the spatial resolution (interferometry for passive microwaves)

Table 1 : Remote sensing measurement sets for biosphere studies

The rationale for the definition of general characteristics of the proposed system was developed in Ref. 9 (pp 65-75). Taking into account the different processes (exchanges between vegetation and soils, between vegetation and atmosphere, production mechanisms and ecosystems dynamics) and the scales —spatial as well as temporal scales— that have to be studied for a better understanding and then modelisation of the biosphere, different sets of measurements were detailed (table 1).

The “ideal” spatial systems that could contribute were outlined (table 2). They should be composed of two different satellites; each adapted to some specific measurements :

- a “mid morning” satellite for short wave measurements in the solar reflection domain, the reason for overpass hour being related to cloud cover which is statistically better at that time than in the afternoon when convection generally gives cumulus clouds in the tropical areas,
- an “afternoon” satellite for the studies of energy and water fluxes using mainly thermal infrared instruments.

“Mid-morning” system	**“Afternoon” system**
Core instruments : wide FOV instrument (with 1 km spatial resolution) and high spatial resolution instrument (≈ 10-20m) with same spectral bands **Options** : thermal IR radiometer and spectrometer **Orbit** : sun-synchronous **Time** : 9h30 (solar) **Cycle** : global coverage each day	**Core instruments** : Thermal IR radiometer, IR spectrometer, atmospheric sounding **Options** : wide FOV VIS-SWIR microwave radiometer (10.7, 18.5, 37 GHz) imaging scatterometer (5.5 GHz) **Orbit** : sun-synchronous **Time** : 13h30 and 1h30 (solar) **Cycle** : global coverage

Table 2 : “Ideal” satellite system for biosphere studies

Different options were discussed, mainly about thermal infrared measurements : two types of information can be extracted from thermal infrared data : surface temperature and surface emissivity —with appropriate hypothesis for decoupling these two characteristics—.

- surface temperature is one of the keys to the determination of energy and water fluxes. However, it is certainly desirable to get thermal data at least on the

minimum or maximum values while a single measurement in the transition period (mid morning) might be difficult to interpret due to the variability of the factors that can cause different temperature elevation rates.
Then the best choices for thermal data would be either at the maximum temperature level (generally beginning of afternoon), or to use the geostationary meteorological satellites that provide adapted time sampling (about twice an hour) with spatial resolution that are in the range of about 5–10 km. Other needs of spatial resolution of about 30 m and several acquisition times during one day have still to be refined.

- surface emissivity might be one way to identify surface characteristics but it was considered that methodologies to extract useful information on emissivity had still to be validated. As in the solar radiation domain, the applications that could take advantage of emissivity estimations need a high spatial resolution. Existing technologies are still limited to provide such measurements in the near future.

Technological constraints

For the final specifications, limitations due to technology will impose strong correlation between different features, for example : getting a global coverage with a specified frequency of acquisition for a sun-synchronous satellite imposes a particular field of view of the instrument. For a desired spatial resolution, number of spectral bands and number of digitisation levels, this will determine the volume of data to be transmitted and the data rate, then the characteristics of the transmission systems that can be used (type of receiving station).

It was also considered that some choice had to be made to insure that measurements would be acquired as soon as possible. The opportunity to have such a mission onboard SPOT 4 was certainly one main factor for decision : some developments would not have been feasible in the time left for design and development before launch (thermal infrared for example), and limitations on weight, energy consumption and volume had to be taken into account.

Mission constraints were then traded against feasibility to insure availability of measurements as soon as 1996. Considering the operational and simple concepts which were retained for the general definition, while some simple characteristics (other spectral bands for example) had to be abandonned, the overall system keeps some coherence. It must be kept in mind that evolutions will have to be proposed and discussed as stated above, both on the ground segment of the first system and for the second instrument.

B. MAIN MISSIONS FOR THE VEGETATION SYSTEM

1. TYPICAL USES ON VEGETATION

From this rationale, and participating to the international development of studies of the biosphere, the needs for a vegetation mission were detailed, being consistent with the main recommendations also expressed in Ref. 16. Three typical uses could be outlined :

- **surface parameters mapping** : this is the basic need, especially for climate and meteorological studies where boundary conditions have to be prescribed for example to General Circulation Models or forecasting models. Factors such as surface roughness, albedo, heat exchanges —sensible and latent— are important variables for these models and they can be determined from "simple" identification of land cover. Their seasonal and long-term variations are related to vegetation dynamics and the capability to identify physical characteristics of land cover is a key to accurate prescription of these variables. Scales addressed in GCM or forecasting models (typically about 100 km) request that land cover and its variability must be determined with a sampling of about 8 to 10 km (Ref. 17) : the basic spatial resolution needed for identification of land cover and its variability is 1 km. The IGBP requirement introduces the need for *elementary zones* (blocks of about 10x10 km) on which radiometric properties should be specified for a more accurate analysis than on larger blocks (zones of about 1000x1000 km for example)
- **agricultural, pastoral and forest production** : since the beginning of the land surface satellite remote sensing era (1972), important projects (for example LACIE, AGRISTARS for USDA, MARS for CEC, TREES for ESA...) have been set up to develop methodologies and strategies to use remote sensing data either for mapping of land use in anthropogenized or natural ecosystems or for estimation of production potential. Their specific objective was to determine the evolution of productions. This objective had to be adapted for management of crop production for agricultural exporting countries, to monitoring of pastoral resources and their dependence from meteorological evolutions, to the evaluation of possible global impacts of deforestation and more generally to the needs of information related to political or social orientations and decisions. One strong model that should be used to infer specifications for the vegetation system is the MARS project, especially because of the structure of the project itself that is based on complementary approaches using ground surveys, high spatial resolution (SPOT and Landsat/TM data) as well as frequent observations (NOAA/AVHRR) and classical agrometeorological models.
- **terrestrial biosphere mechanisms monitoring and modelisation** : the contribution of the continental biosphere to the biogeochemical cycles (exchanges of carbon and other trace gases) and to water and energy exchanges is one of the objectives of the development of models. Interaction with human

activities is also one of the main points to be studied, because the effect of human pressure on the biosphere might be one of the means by which man is acting on climate on the long term. Biosphere processes and land cover characterisation are the basis for quantification : estimations of land cover variables as well as the dynamics of these variables have to be made for a good understanding leading then to modelisation. Predictions of impact of climate change on the biosphere and of interactions of the biosphere with the climate —either due to natural factors or to human pressure— can only be inferred from quantification and formalisation of the mechanisms by which vegetation cover and ecosystems are functioning. Multilevel series of models have to be developed and linked, ranging from ground studies, local parameterisation and models to regional or global dynamics and interaction models. Remote sensing of the vegetation as shown above offer a unique tool for these developments, providing the specification of the systems be adapted to each particular need.

2. Simultaneity with high spatial resolution acquisition

Beside the thematic nature of the mission as described above, one key feature of the system is that it should allow simultaneity between high spatial resolution and the Vegetation acquisition. This condition is important for the development and validation of models : as it is usually done, study or pilot sites are chosen for specific experiment, on which data related to the model that is to be developed or validated are collected. It is expected that the Vegetation-HRVIR system on board SPOT 4 will provide high spatial resolution but low temporal frequency together with low spatial resolution but high frequency acquisitions, especially for local or regional studies, allowing some “zooming” capability that is essential for the extrapolation or integration of processes at different scales : this should provide a unique capability for multiscale experiments, especially if they are complemented with ground and airborne acquisitions. This capability does not have to be systematic : a typical experimentation could need for example 4 or 5 high spatial resolution acquisitions during one vegetation cycle for a better determination of surface parameters and overall, identification of land cover and/or land use. Simultaneity is most important, especially because of disturbances due to the atmospheric conditions —either clouds or aerosol contents that are highly variable— and to reflectance variability due to directional effects related to sun azimuth and elevation angles. Coincidence between measurements will allow precise adjustments that are not possible with existing systems (midmorning high spatial resolution —Landsat TM or SPOT— and afternoon high frequency —NOAA/AVHRR—). The combination of spatial resolutions will be discussed later.

3. Operational constraints for the main mission.

The typical uses described above all require long term monitoring, either for operational systems dedicated to weather forecast or agricultural production monitoring, or for scientific studies that require long time series for comparisons of several years and detection of regional or global changes. It should then be considered that the system must have a life time that should be not less than at least a decade, with possible changes in its characteristics that would ensure the continuity between successive instruments.

At shorter time scales, some days might be missed in some regions (for example in the winter season) because variations in vegetation covers are sometimes slow. However best efforts should be made so that data be available at a steady rate along the year, with no interruption in data availability that would be more than some days (to be refined depending of the time in the year and geographical location).

For the three typical uses described above, the following modes of operation of the system can be defined :

- for local studies, either in the context of modeling experiments or monitoring of special zones for example for agricultural or pastoral productions assessment, it is useful to have the capability to acquire the “Vegetation” data from local receiving stations that could provide better near real time access to raw data and possibly to adapted products,
- for other applications, when some entities have to monitor remote regions for which simple connections that would allow rapid transmission of locally received data cannot exist, it is desired to provide access to these data through a central archive. This particular capability will obviously need onboard recording and some capacity of high rate transmission and reception of telemetry. These facilities will have to be operated with the agreement of the system leading entities, as this operation mode requires some interaction with the satellite and particular transmission subsystems. Technical constraints and cost are the only limits to the number of facilities, no specification other than the need of that particular operation mode will be expressed.
- for the scientific applications related to global studies, the centralised archive is also necessary and a minimum number of receiving facilities adapted to reception of recorded data will have to be established to optimise the required volume of data that should be recorded onboard.

To perform these operation modes, it is likely that the system should be designed to provide

- a global mission for which a centralised archive would provide access of “Vegetation” data through a limited number of contacts,
- and a regional mission, for which users would get their data either through local receiving stations if their area of interest is located in the visibility circle of that station or through the centralised archive.

Besides the need for this type of operation, the system should be designed to allow "small" receiving stations to be operated by local entities. Some continuity with the existing scheme (AVHRR receiving stations) should be provided.

4. Background for specifications

The basis to determine the specifications is the existing knowledge of interpretation models as well as of correction of disturbing effects (atmosphere or directional effects). This knowledge was mostly obtained from studies using either ground investigations of radiometric properties of vegetation or soils, high spatial resolution satellites or NOAA-AVHRR data. Many references can be found in the literature (see for example refs. 12 and 13). It should also be taken into account that research activities will lead, before "Vegetation" launch date, to new methods that will probably allow to better correct for atmospheric effects or to include directional effects into interpretation models. But the strategy for defining the specifications must always be to design a system for operational use of satellite measurements into scientific or applicative projects and not for the development of new observation methodologies (improved atmospheric or directional effects corrections for example or new spectral bands for characterisation of other canopy parameters).

C. SECONDARY MISSION

As presented in Ref. 13, a secondary mission can be defined on observation of snow and ice. However, this secondary mission does not impose any other specification than those which are expressed for the main mission, except that ranges in reflectances should be extended for reflectances of up to 1.0 in the red and NIR bands if other specifications on radiometric resolution can still be obtained.

As areas covered by snow and ice on a large extent are generally near the poles, the conditions on sun zenith angle will not be always satisfied, then quality might be degraded on these areas.

Data collection should not be modified to record images related to that secondary mission on board, only local receiving stations would have to be used if necessary.

III. SPECIFICATIONS

A. FEATURES TO BE SPECIFIED

The main features that have to be defined for each typical use of the "Vegetation" mission are :

- the spectral properties : spectral bands , their location and bandwidth,
- the radiometric properties : resolution (expressed in terms of Noise Equivalent Difference of Reflectance : NE$\Delta\rho$) and accuracy (related to calibration capabilities)
- the temporal properties : frequency of data useful for a particular use, time and frequency of data acquisition,
- the geometric properties : spatial resolution, spatial coverage, viewing angles, accuracies for location and registration (between different bands, between different images)
- the coherence with high spatial resolution data,
- particular constraints on delivery, processing systems...

Application of the specifications :

As ancillary data could be used to improve the quality of measurements done by the instruments, some level of product must be defined : the following specifications apply to the first level of data that will be made available to users (Ref. 19). For this level, both system and ancillary informations are used to determine correction parameters. They include any knowledge that can be obtained from satellite sensors (attitude, orbit for example), from internal calibration systems as well as from calibration procedure that should be performed by the satellite operator. They also include informations that would be obtained from external data, especially for geometric processing where maps, digital elevation models or a database of ground control points could be used.

However, due to the lack of accuracy of some ancillary informations, the specifications might be difficult to meet or the quality of the data difficult to assess. This is particularly true for atmospheric corrections where the uncertainties on atmospheric properties might lead to uncertainies on ground reflectances that will be larger than the specifications. In that case, the quality will be expressed on the ground reflectance as specified but making the assumption that actual atmospheric effects are those which are computed using the atmospheric corrections procedure.

B. PROPOSED SPECIFICATIONS

1. The spectral properties

For each of the main missions, some specific parameters are important and have to be derived from remote sensing data. To keep the measurements as robust as possible, only wide spectral band measurements (≈ 50 nm) are considered and the objectives are to characterise the main features of plant canopies : absorption by chlorophyll, water contents and structural properties. The best and minimal set of spectral bands known to fulfil this need is composed of (see for example ref. 8)

- a red band centered on the absorption peak of the chlorophyll (0.665 µm),
- a near infrared band corresponding to the maximum vegetation spectral reflectance and principally related to the structural properties of the canopies and to percentage of soil covered by vegetation,
- a short wave infrared band centered around 1.65 µm where reflectance is related to water content of the canopy components and to its structure.

Considerations for atmospheric effects characterisation or correction should be added : among different possibilities that are under validation, both the use of adapted vegetation indices computed from red and near infrared reflectances (for example see ref. 18) and direct or indirect use of additional spectral bands in the blue region (see ref. 14) have to be retained. To provide capabilities of computing or characterising the atmospheric state (aerosols) an additional band can be proposed :

- a blue band (between .45 and .50 µm) where ground reflectance of vegetation cover is minimal and atmospheric aerosol diffusion effects are maximal.

The influence of atmospheric water vapour, which is most important in a wide near infrared band, can be severely decreased by limiting the upper portion of the near infrared band to avoid the .935 µm water vapour absorption band.

The spectral responses, as presented in annex A, will have to be as “similar” as possible to the high resolution instrument bands, at least for spectral bands that participate to the same mission : the red, near infrared and short wave infrared bands.

2. The radiometric properties

Radiometric properties must be described in terms of :

- radiometric resolution which gives the smallest radiance or reflectance which should be detected : it will be expressed in terms of Noise Equivalent Difference of Reflectance (NE$\Delta\rho$) that should be detected within specified ranges of solar elevation angles and reflectances for each spectral bands,

- radiometric calibration : to insure that measurements taken in the same image, in different spectral bands or at different times are consistent. This will be specified in terms of

  1. intra-image consistency which could also be specified as an equivalent to a radiometric noise. Variations of calibration within short range (about 10x10km corresponding to the elementary zones) can be considered as high frequency radiometric noise and will be specified as part of the radiometric resolution. Low frequency variations of calibration could be specified either as radiometric noise (specifying values of NE$\Delta\rho$ for large areas and for the entire image) or as intra-image calibration,
  2. inter-band calibration accuracy and
  3. multitemporal calibration accuracy.

  Estimation of radiances or reflectances should also be comparable with other instruments : this should be insured by the absolute calibration accuracy.

Notes :

1. *Calibration accuracy figures will be given as relative accuracy of reflectances : $\Delta\rho/\rho$. For example, an absolute calibration accuracy of 10% means that a reflectance of 0.10 if known with an accuracy of .01.*
2. *As the final data that will be used are surface reflectances, the specifications must be given for surface reflectances. For the detailed specifications of the instrument itself, top of atmosphere (TOA) reflectances and radiances should be used. The transformation between surface and TOA reflectance or radiances can be performed using the 5S code (ref 10).*

Considering existing research work on the use of reflectance properties (Ref. 15) or derived indices (NDVI, SAVI, MSAVI, GEMI,...) and taking into account first optimisations done with system engineers, the following values can be proposed, for sun illuminations corresponding to a sun zenith angle of less than 60° :

- **ranges for surface reflectance** (allowing for saturation for some land covers as snow or bright soils in some conditions or spectral bands and for clouds) should be consistent with Ref. 3 :

  1. from 0.0 to 0.5 for the red band,
  2. from 0.0 to 0.7 for the NIR band and
  3. from 0.0 to 0.6 for the SWIR band.
  4. for the blue band, as it is only envisaged as an experimental band for possible corrections of atmospheric effects on soil and vegetation, typical values of surface reflectances on these two land covers are generally less than 0.5.

- **surface reflectance resolution** of the order of 0.001 to 0.003 should be an objective for the specification with some adjustments for the different bands :
    1. for the red band, as vegetation ground reflectances are low (generally less than 0.1) , a target specification of 0.001 for reflectances of up to 0.1 is desirable, at least for analysis on small blocks of pixels corresponding to areas of about 10x10km (see elementary zones in section II.B.1). The specified value for NEΔρ could increase linearly up to 0.003 for reflectances values of about 0.5.
    2. for the NIR and SWIR bands, reflectance differences of 0.003 must be detectable for the entire range of reflectances and either for small blocks or the entire image.
    3. for the blue band, as the variation of TOA reflectance for the extreme conditions of atmospheric conditions (from 5km to 23 km visibility) is about 0.035, differences of about 0.003 should be detectable.

Comment : from existing knowledge it can be assumed that, when atmospheric conditions and directional effects can be accurately estimated, variations of the surface NDVI values of about 0.03 can be related to variations of vegetation fraction cover, biomass or intercepted photosynthetically active radiation that are significant (refs 5, 12, 1). For conditions corresponding to the beginning of growth of vegetation, when red and NIR reflectances of 0.1 and 0.2 respectively can be encountered , this means that differences of about 0.0045 should be detected in the red and NIR bands. Taking into account the improvement that will occur in the interpretation schemes in the next three or four years, the above figures for noise specifications seems to be of the order of what should be useful for operational programmes using these types of data.

- **Intra-image consistency :** the calibration consistency within an entire image (large areas) should give a NEΔρ better than 0.005 for any reflectance value.
- **Calibration accuracy** should be comparable to the high resolution instrument specifications that are within a quality range consistent with existing studies and probable needs for the next ten years :
    1. interband and multitemporal calibration accuracy better than 3%,
    2. absolute accuracy better than 5%
- **Digitization** : digitization must be consistent with the radiometric resolution specification.

3. The time and frequency of data acquisition

It must be related to the evolution rate of the processes to be characterised, taking into account limitations due to observations from space in the solar energy domain, mainly atmospheric disturbances and cloud coverage. These two factors will force an over sampling in time so that accumulation of acquisitions and screening of cloudy measurements can lead to a “useful” acquisition frequency adapted for vegetation studies. The effect of these factors on acquisition reduction can only be known from statistics on cloud coverage and atmospheric optical thickness, which is varying during the day, with the season and with the geographical location.

To get a minimal cloud cover, the best acquisition time is midmorning as many of the sun synchronous satellite remote sensing systems devoted to land applications (Landsat, SPOT...).

Existing operational systems are delivering information on vegetation or meteorological conditions with a period ranging from 5 to 10 days. A mean interval between useful acquisitions to measure changes in vegetation growth can be considered to be about one week : high level products should then be generated to provide data with the usual frequency, the “Vegetation” system providing sufficient data to derive the final useful information. To achieve this goal, experience from existing systems shows that actual acquisition should be as much as possible with a frequency of one day, to ensure coverage of the entire land areas each day. Even with this strong constraint, cloud screening will, in some regions and for some periods in the year, significantly decrease the useful acquisition frequency (especially in the tropical regions during the rainy seasons). This is probably the greatest drawback of solar energy measurements and any possibility to keep to the one day interval should be reserved.

Frequency acquisition is strongly related to spatial resolution, number of pixels by line of image and field of view of the instrument. Consistent modifications of these parameters should be discussed with the users to provide the best compromise, current values for the specifications being the preferable combination that was accepted today.

4. The geometric properties

From an instrument point of view, geometric specifications should be expressed in terms of :

- sampling rate in two directions,
- Modulation Tranfer Function for the entire instrument (optical and electronic components),
- Field of view,
- accuracies of location and registration for each band relative to the others or to a reference image.

From the users’ point of view, specifications of spatial resolution, sampling rate and accuracies will define the main user’s characteristics of the system while other instrumental specifications will be adapted during the instrument design phase taking into account physical or technical constraints.

Spatial resolution and sampling

Two strategies can be used to define spatial resolution and sampling : either to consider the "Vegetation" instrument alone or to consider the association with the high spatial resolution instrument. A good number of criteria to make the choice of a particular spatial resolution have been defined (see for example ref. 6). Both the standard deviation of NDVI values at some particular dates and the standard deviation of time differences of NDVI on some selected sites were chosen and represented on the following figures (Figure 1 and Figure 2).

These two figures clearly show that the information content decreases as spatial resolution increases but that the decrease in information content from Landsat MSS resolution to a resolution of more than 200 m is much more important than between 200m and 1km. Then, if the first strategy is considered, for one instrument that cannot have high resolution , some information at resolutions of about 200m has to be acquired : this is the MODIS case. In the second strategy and to extrapolate from biophysical models that are only established on "homogeneous" land cover, it is preferable to request some capability for sampling studies using spatial resolutions better than the Landsat MSS resolution and allow some flexibility for the low resolution system. As shown on Figure 1, to keep appropriate information on "Richmond" like zones that are very similar to classical European landscape, it seems desirable to specify a spatial resolution of about 1 km : this is coherent with studies on the European countries done for the MARS project where the AVHRR 1km resolution supplemented by high resolution imagery (Landsat TM or SPOT) proved to be satisfactory, with some problems due to lower resolution obtained for off nadir AVHRR pixels (ref. 15).

Then the requirement for spatial resolution and sampling interval is that it should be about 1 km, with preference for systems that would allow as constant as possible resolution in the entire field of view. The same spatial resolution and sampling specifications apply to all spectral bands.

Spatial resolution is also related to the shape of the MTF of the instrument that should be as high as possible up to Nyquist frequency; specifications usually retained for other instruments should be the objective : the MTF value must be no less than 0.3 up to a frequency corresponding to half the sampling frequency.

The field of view would have to be such that the entire globe can be imaged once each day, especially providing adjacent swath at the Equator. However, that requirement might lead to some problems :

- a complex design would have to be made to keep the radiometric quality within the specifications due to the high deviation from optical axis,
- spatial resolution might dramatically decrease due to earth curvature,
- directional effects due to high zenith observation angles might prevent any useful measurement. (For example , with an altitude of 800 km, an off nadir angle of 50° gives a zenith angle of observation of about 60° that represents a

maximum angle for which directional effects are becoming much variable and difficult to handle).

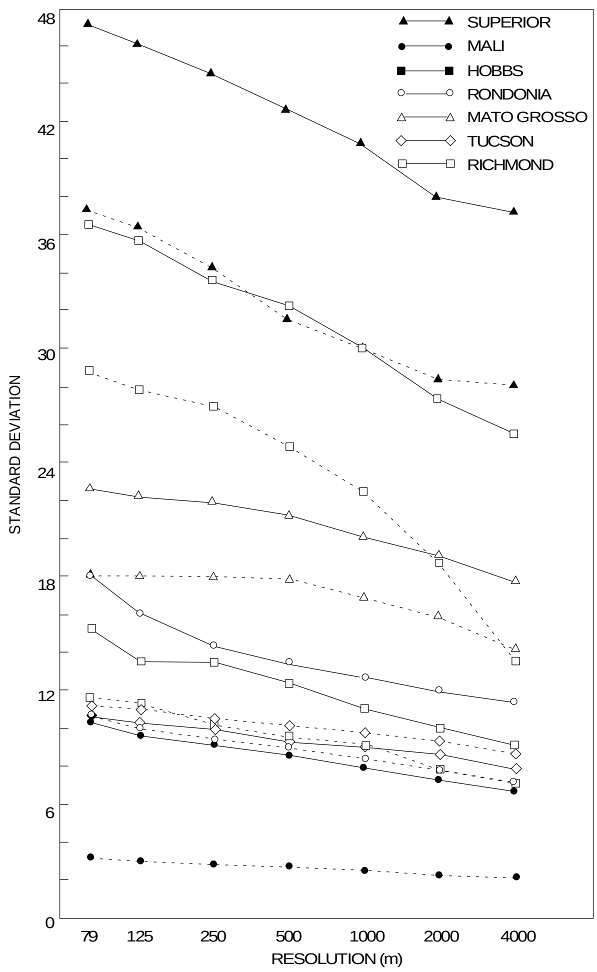

Figure 1: Standard deviation of NDVI on some selected sites for two different dates (solid and dotted lines) (from Ref. 6)

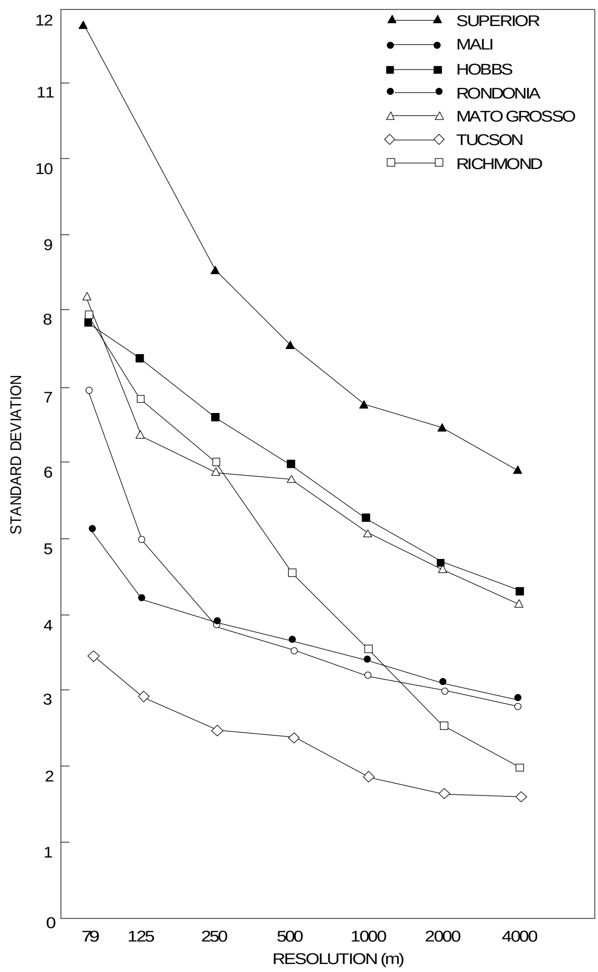

Figure 2: Standard deviation of differences between NDVI values at different dates for different spatial resolutions. (from Ref. 6)

Accuracies

Geometric quality must be expressed on the basis of the particular analyses that will be applied on the images : apart the local distorsion, some order of priority for specifications of the different accuracies can be given :

1. first, the highest priority should be put on the multispectral registration for spectral analyses or use of multispectral indices like the NDVI or new indices that could be generated using the SWIR or blue bands.
2. then comes the capability to correctly locate the High Resolution pixels acquired simultaneously, relatively to the VEGETATION pixels,

3. as the temporal evolution will be one of the most important feature analysed from the VEGETATION data, the multitemporal accuracy should be particularly good,
4. finally, the absolute location accuracy should allow adequate positionning of each time serie on other maps or geographical information.

Local distortion reflects the sampling accuracy within a small area and can be expressed as a quadratic mean of differences between the actual pixel position and a reference regular position. This characteristic should be consistent with the registration and multitemporal accuracies (see below) and such that the deviation for each spectral band be not more than 0.3 pixel,

Figure 3 represents the different types of errors that can be defined .

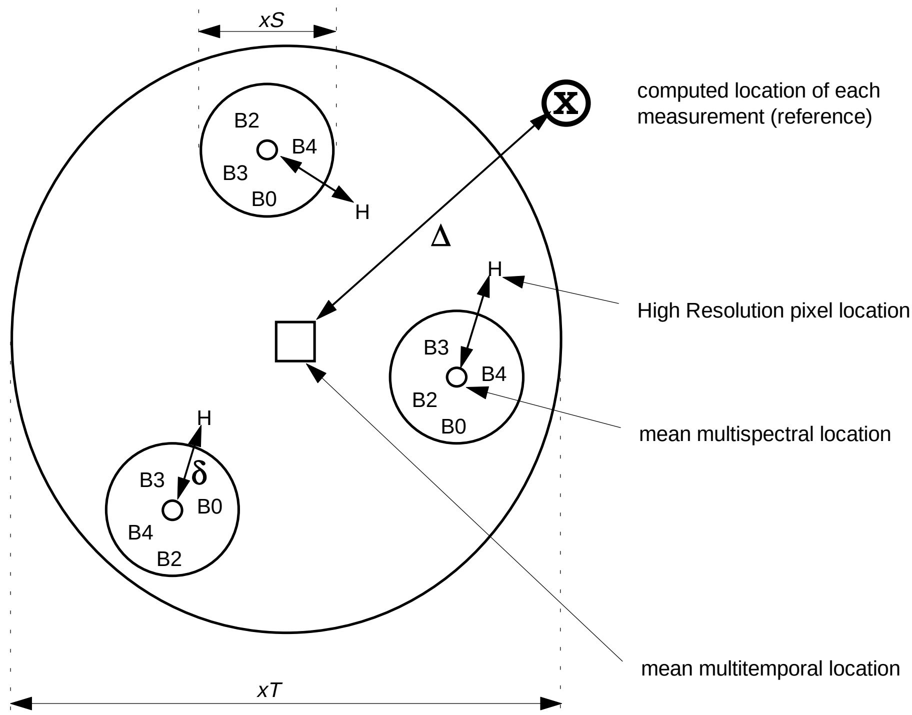

Figure 3: Diagram of errors to be considered for geometric specifications.

All measurements are represented by the position of their actual location relatively to the computed location represented by **X**.

Each individual spectral relative location for one date is represented by B0, B2, B3, B4 (blue, red, near infrared and short wave infrared spectral bands). The « mean multispectral relative location » is defined as the centre of the smallest circle including all spectral measurements relative locations. The multispectral registration error will be measured as the diameter of that circle : *xS*.

At one particular date, the corresponding High Resolution « multispectral pixel » will be located at H relatively to its computed location X. The colocation error is the distance between H and the mean multispectral relative location : δ.

At different dates, the mean multispectral relative locations will be located inside a smallest circle, the center of which is defined as the « mean multitemporal relative location ». The period that should be considered for the definition of that circle is one year. The multitemporal registration error will be measured as the diameter of that circle : *xT*.

Finally, the absolute location error will be defined as the distance between the mean multitemporal relative location and the computed location : Δ.

That particular scheme for definition of geometric errors puts a higher priority on the multitemporal registration than on absolute location of each multispectral pixel. However, the specification for the absolute location error of each multispectral measurement (one particular date) can be inferred from the specifications on *xT* and Δ.

The following specifications for the errors assume non biased errors and are given as the values of two standard deviations $\sigma_2()$ (corresponding approximately to a probability of 5% to have errors larger than the specified value in case of gaussian distribution) :

- multispectral registration specification : $\sigma_2(xS)$ should be significantly less than 0.3 km, with an objective value of 0.1 km,
- colocation specification : $\sigma_2(\delta)$ should be less than 0.3km,
- multitemporal registration : $\sigma_2(xT)$ should be less than 0.5 km with an objective value of 0.3km,
- absolute location specification : $\sigma_2(\Delta)$ should be less than 1 km with an objective value of 0.5 km.

For the blue band, as it should be used mostly for atmospheric corrections, at least for the first flight model of the instrument, the specifications for xS, δ, *xT*, and Δ can be relaxed to be of the order of 1km.

These specifications apply for the first level of products defined in the Product Definition document (Ref. 19).

5. Coherence with high spatial resolution data

As it is required that high spatial resolution data be used for specific studies together with the “Vegetation” data, some constraints have to be defined for the inter-instrument quality :

Collocation of pixels

See above.

Spectral bands consistency

The spectral bands of the two instruments should be as similar as possible, the relative difference between measurements on the same object being not more than 3%. This specification has to be insured on the typical spectral reflectance variations that can be found on bare soils and vegetation canopies.

6. Spatial coverage

Considering the importance of different areas of the globe both for scientific or applicative project, all the land areas should be imaged by the instrument at any time. Radiometric quality must be met as soon as the solar zenith angle is less than 60°. However, as described in the mission section, some areas could be excluded for the global mission : they are mainly areas covered by snow or ice (Antarctica and Greenland) for which the secondary mission could be performed using local receiving stations specifically installed for that purpose if there is no station dedicated to the vegetation mission itself.

To get daily coverage and then adjacent swath for the lowest possible latitudes, the system will be designed such that some overlap exist for high latitudes : geographical points at high latitudes might be imaged more than once a day but with different sun and viewing geometry. As this difference might give information on the directional properties of the surface, they should not be eliminated at any step of the acquisition-transmission-archiving chain.

7. Operation modes.

Central receiving system

The entire system should be designed to allow a centralised access to data over the entire globe. Users should find in a single facility :

- informations on all data acquired and processed to standard levels of processing, especially on their quality (cloud cover). Some information on High Resolution data acquired simultaneously to VEGETATION data should be made available.
- capability to process and deliver standard products,
- information related to the use of VEGETATION data sets.

See companion document on Products Specifications for a full description of the products (Ref. 19).

Local receiving stations

As described in the mission section, local receiving capacity should be possible with stations that are “affordable” to small organizations. Some continuity with the existing receiving stations should be provided, taking into account the new technical possibilities (changes in transmission bands, compression...).

As the quality of the data is strongly dependant from system informations on radiometry or geometry, these informations should be made available to the local stations for local processing up to the same data product as in the centralised archiving centre. It is also recommended that a standard preprocessing system be specified and provided for these stations.

Each local station will be responsible for other products processing and delivery as well as for their delivery time.

Degraded modes of operations

In case of failure of part of the system, every effort should be done to associate users through a structured entity similar to the International Users Committee and elaborate a new operating mode. Priorities should be established to provide as much compatible service as possible with the nominal mission. Some guidelines for priorities can already be given :

- the global coverage feature should be a high priority, leading for example to establish a network of local receiving stations in case of failure of one of the components of the system, allowing centralized access to the entire continental data set,
- data products similar to elaborate data sets already available from existing systems on the globe should be made avalaible, even if adaptability to particular needs cannot be achieved : for example synthetic data sets over periods of about a decade should be always available, possibly with only one sampling grid or on a predefined partition of the continents,
- the raw data, together with information on system parameters that should be used to process them, should **in any case** be archived because historical studies will have utmost importance for any analysis of changes at regional or global scales.

ANNEX A : SPECTRAL BANDS SPECIFICATIONS

The following figures give the minimum and maximum value required for the spectral response of each of the principal bands (red, NIR and SWIR) and for the experimental blue band.

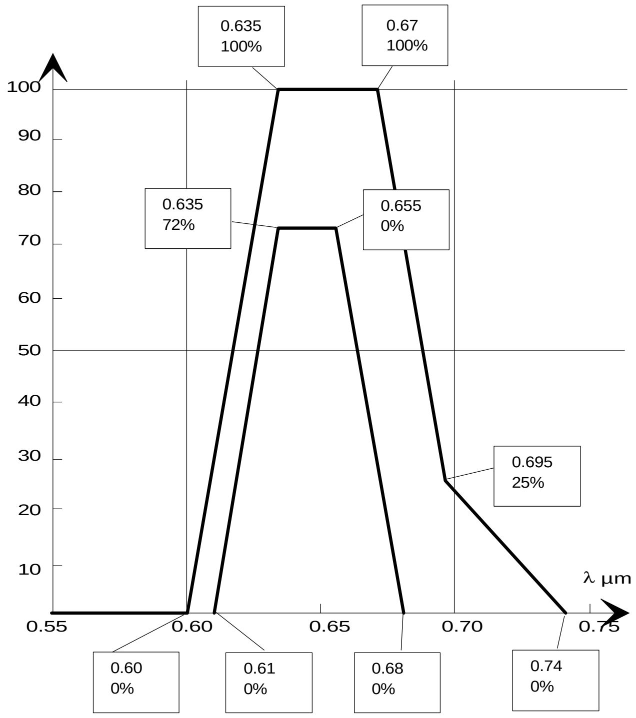

Figure 4: Red spectral response specification

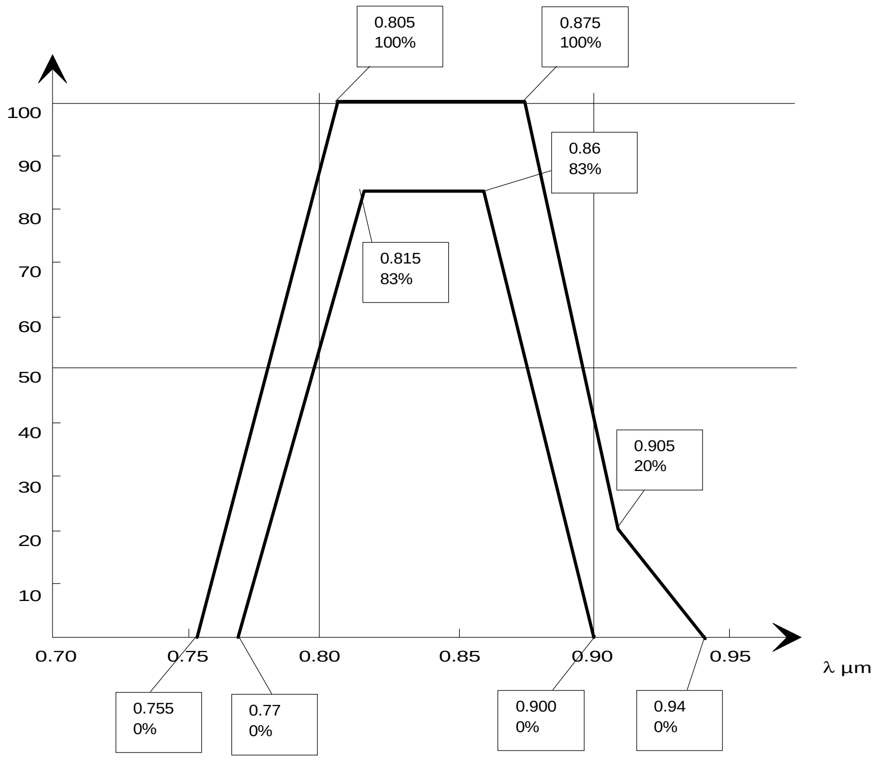

Figure 5 : NIR spectral response specification

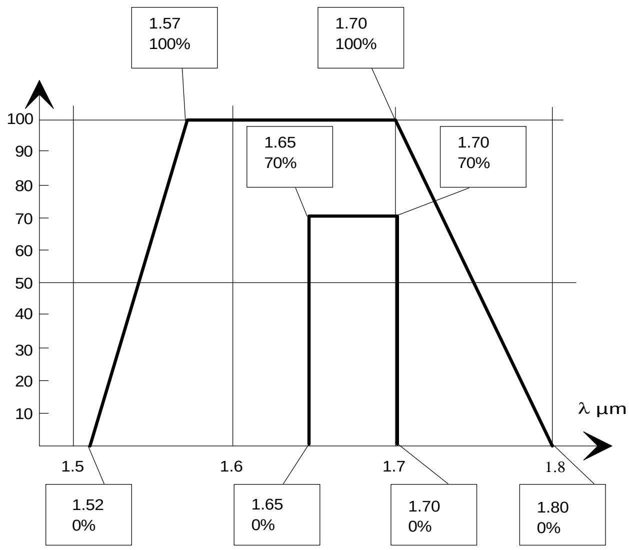

Figure 6 : SWIR spectral response specification

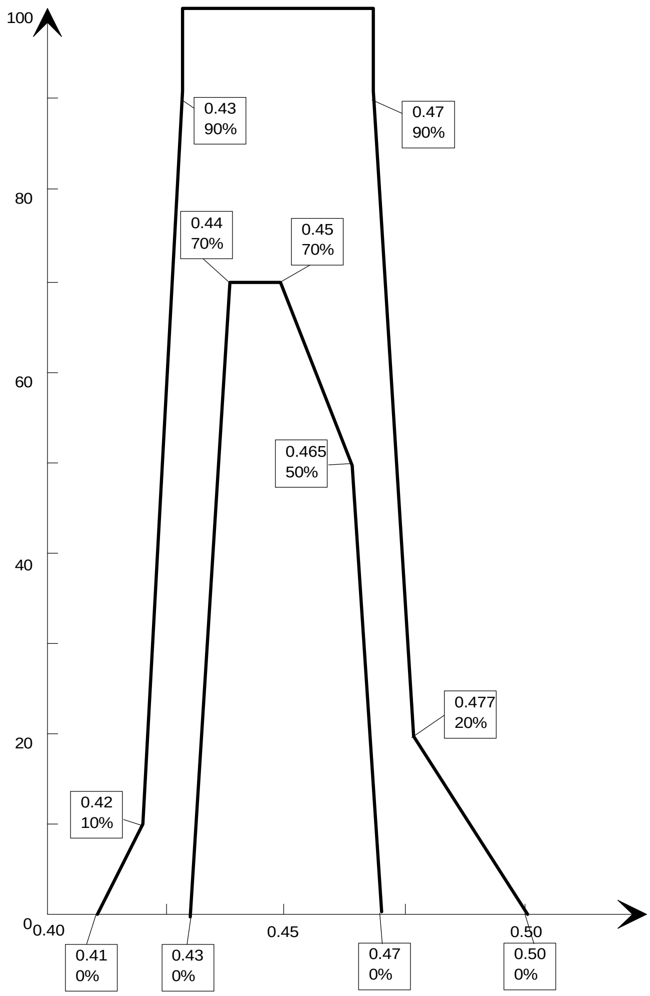

Figure 7 : Blue spectral response specification

ANNEX B : SUMMARY OF SPECIFICATIONS

Spectral bands

		Wavelength	Range for surface reflectance
Operational :	RED	0.61 - 0.68 µm	0.0 - 0.5
	NIR	0.78-0.89 µm	0.0 - 0.7
	SWIR	1.58-1.75 µm	0.0 - 0.6
Experimental :			
	BLUE	0.43-0.47 µm	0.0 - 0.5

Radiometric resolution (NEΔρ)

RED	0.001 up to reflectances of 0.10
	linear increase up to 0.003 for reflectances of 0.5
NIR, SWIR	0.003 for the entire range
BLUE	0.003 for the entire range

Intra-image consistency : within an entire image, corresponding to a NEΔρ of 0.005 for any reflectance value

Calibration accuracy :

interband and multitemporal : better than 3%

absolute : better than 5% .

Table 3 : Radiometric specifications

Spatial resolution : in both directions 1 km at nadir (±20%), minimum variations for off-nadir observations,

Field of view : maximum off-nadir observation angle of about 50°

Accuracies :

local distortion :	less than 0.3 pixel,
multispectral registration :	significantly better than 0.3 km (0.1 km objective)
multitemporal registration :	better than 0.5 km (0.3 km objective)
location accuracy :	better than 500m desired, 1000m specified
registration with HRVIR :	better than 0.3 km

Table 4 : Geometric specifications

ANNEX C : SPOT 4 CHARACTERISTICS

Satellite

SPOT 4 is a sun-synchronous satellite in the series which began with SPOT 1 which was launched in february 1986.

Its main characteristics are the following :

Expected launch date : 1996-1997

Mission duration : 4 yrs

Weight : 2680 kg

Payload : 1470 kg

Energy : 2200 w (after 4 yrs)

Orbit Period 101.46 mn

Inclination 98.72°

Excentricity $1.3\ 10^{-3}$

Number of revolutions per day 14 + 5/26

Cycle duration 26 days

Speed relative to ground 6.6 km/s

Equator crossing time (descending node) : 10:30 local solar time

	at the equator	at 45 ° latitudes
Distance between successive ground tracks[1]	2824 km	2000 km
Distance between adjacent ground tracks	108 km	76 km
Orbital altitude	822 km	832 km

Attitude control : pointing : < 0.15° (3σ)

rate : $< 8\ 10^{-4}$ °/s (3σ)

[1]With a field of view of ± 50.5 °, the ground swath width of VEGETATION is 2200 km.

High Spatial resolution payload : HRVIR

Swath	60 km at nadir,
Depointing	up to 27° from nadir
Spatial resolution	20 m in multispectral mode
	10 m in "panchromatic" mode
Spectral bands :	
Multispectral mode :	0.50 - 0.59 µm
	0.61 - 0.68 µm
	0.79 - 0.89 µm
	1.58 - 1.75 µm
"Panchromatic mode"	0.61-0.68 µm

ANNEX D : LIST OF SUCCESSIVE MODIFICATIONS

From version 0 to version 1

(page references are for version 1 document)

Modifications result from note CNES S4.CR.36-1566-CN (11/17/92) :

B0 resolution should be 1km in the global mode :

1. modification to III.B.2 "surface reflectance resolution" section page 22 : no more reference to 1x1 or 4x4 km modes,
2. deletion of III.B.4 "Particular case for the blue band" section page 26.

Absolute calibration specified to 5% : modification of III.B.2 section "Calibration accuracy" page 22.

Multispectral registration : should be significantly better than 0.3 (page 26)

Coverage of all land surface areas : modifications to III.B.6 page 27.

From version 1 to version 2

A paragraph was added in the introduction to emphasize the need for evolution of the system (page 10)

a paragraph was moved from section III.A to section II.A and adapted to recall constraints and background which were taken into account for definition of the system. (page 13)

an annex was added to give a short description of SPOT 4 (annex C)

From version 2 to version 3

The modifications were recommanded by he System Concept Review (april 94) :

- the geometric specifications were reviewed to give a priority order between the different aspects of geometric accuracy,
- operation modes and degraded modes were reviewed
- product description refers entirely to the companion document

LIST OF ACRONYMS AND ABBREVIATIONS

5S	Simulation of the Satellite Signal in the Solar Spectrum : computer code for atmospheric effects on radiometric measurements (Ref. 10)
AVHRR	Advanced Very High Resolution Radiometer (one of the instruments on the low earth orbit meteorological satellites of NOAA)
CEC	Commission for the European Community
CNES	Centre National d'Etudes Spatiales (France)
EOS	Earth Observing System : US ensemble of platforms dedicated to the global change studies.
ESA	European Space Agency
EUMETSAT	European Meteorological Satellites agency
FOV	Field Of View for an observation instrument
GCM	General Circulation Model : model of atmospheric circulation for climate studies or weather forecast
GEMI	Global Environment Monitoring Index (Ref 18)
HRVIR	Haute Résolution Visible et Proche InfraRouge : high resolution visible and near infrared instrument on board SPOT 4 which is an evolution of the HRV (Haute Résolution Visible) instrument on board SPOT 1 to 3
IFOV	Instantaneous Field Of View
IGBP	International Geosphere Biosphere Program
METEOSAT	geostationary meteorological satellite operated par EUMETSAT
MODIS	Moderate Resolution Imaging Spectrometer : to be on board some of the EOS platforms
MSAVI	Modified SAVI
MSS	MultiSpectral Sensor : one of the instruments on board the Landsat satellites
MTF	Modulation Transfer Function
NDVI	Normalized Difference Vegetation Index : computed from NIR and VIS reflectances, ratio of their difference over their sum.
NE$\Delta\rho$	Noise Equivalent Difference of Reflectance
NIR	Near InfraRed domain (wavelength between 0.7 and 1.0 μm)
NOAA	National Oceanographic and Atmospheric Administration (USA)
SAVI	Soil Adapted vegetation Index
SWIR	Short Wave InfraRed domain (wavelength between 1.0 and 2.5 μm)

TM	Themapic Mapper : an instrument on board the Landsat satellites
TOA	Top Of Atmosphere : for reflectances or radiances
USDA	United States Department of Agriculture
VIS	Visible domain (wavelength between 0.4 and 0.7 μm)

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