COASTAL ZONES INVENTORY BY HIGH RESOLUTION SATELLITES

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ABSTRACT

The development of tools for assessing impacts on coastal environments is a reality. These impact assessments need both baseline and monitoring studies. Satellite remote-sensing data would be useful for coastal inventories (baselines) and monitoring if high spatial and temporal resolutions are yield compatible. An overview of the various sensors that could be used is presented. The constraints linked to the different resolutions are exposed. An example based on SPOT simulated data and trends are developed.

Keywords : high resolution, Coastal environment, Tidal range, Underwater mapping, Principal component analysis.

1. INTRODUCTION

Coastal zones are, all around the world, more and more subjected to demographic pressure such as tourism and industrial settlements. The exploitation of the natural ressources of these zones is peremptory for a lot of countries : (fisheries, aquaculture, seaweeds harvesting, sediments collecting...).

On the other hand, many of coastal ecosystems are essential for marine life because used as nurseries and spawning grounds (mangrove, salt-marshes, coral reefs). They are very sensible to pollution, mainly to oil pollution ; demonstrations were given by the last oil spills catastrophs.

The management of coastal environment is a must in this end of century. This management, which consists in a rational exploitation and/or protection, needs a good knowledge of the different components of the environment, such as a cartography, necessary for the inventory of these components.

"The coastal zone - the juncture between land and sea - is essentially linear and thus of finite areal extent. Although distinct in concept, it is difficult to define precisely because of the great variability that exists along and across it. This variability comes from contrasting characteristics associated with both the land and the sea, such as geologic structure, climate, biota, water chemistry, waves, currents and tides. All such elements have a bearing on the nature, distribution and availability of resources along the coast". (H.J. Walker, Ref. 1).

Three main characteristics of the coastal environment have to be underlined :

- the accessibility to the conventional investigation means is very often poor (marshes and mangroves, mud and reef flats, shallow waters...).

- the geographic scale needed for the study of the differents biotopes which compose this environment has to be sharp.

- the evolution with time is fast (tide, floods, winds,...).

Orbital remote sensing with satellite photography and imagery is an important tool in the development of coastal studies (ref. n°2)

According to the characteristics listed above high resolution satellite, may be considered as a good tool for coastal inventories and a good monitoring tool if they offer adequate repetitivity.

At the present time the needs facing coastal environment are not or unsatisfactory solved by conventional means. For example :

- in the occurence of an oil spill how to predict, in a short time the drift of the oil toward the coast ? How to assess the global impact of such a pollution ?

- what is the present surface of mangroves all around the world ? what are the evolutions of this surface ? what is the evolution of species composition with time ?

- how to measure, over a touristic coastal area the impact of tourism on the shores and on the inland uses?

- are the hydrographic charts exact and accurately revised in coastal zones of quick evolution (deltas, coral seas...)?

Remote sensing data may give some answers to these questions. After a quick overview of the performances of existing sensors and the spatial and temporal requirements facing coastal studies, the preliminary results based upon high resolution satellite

Sensor	Platform	Vegetation & Land Use	Biomass & Veg. Stress	Coastline Erosion	Coastal Geomorphology	Depth Profiles	Susp. Sediment Patterns	Susp. Sediment Concentration	Chlorophyll Concentration	Oil Slicks	Surface Temperature	Water Salinity	Current Circulation Patterns	Wave Spectra	Sea State	Surface Winds
Film Cameras	AC	3	1	3	3	2	2	1	1	2	0	0	2	2	2	1
	SC	2	1	2	2	1	2	1	1	1	0	0	2	2	2	1
Multispectral Scanners (Visible)	AC	3	2	3	3	2	3	2	2+	3	0	0	2	2	2	1
	SC	2	1	2	2	2	3	2	2	2	0	0	2	2	2	1
Thermal IR Scanners	AC	1	1	1	0	0	1	0	0	3	3	1	2	0	1	1
	SC	0	0	0	0	0	1	0	0	1	3	0	2	0	1	1
Laser Profilers	AC	0	0	1	1	3	1	0	0	1	0	0	0	3	3	1
	SC	0	0	1	1	2	0	0	0	0	0	0	0	2	2	0
Laser Fluorosensors	AC	1	0	1	0	1	1	2	3	3	1	1	1	0	0	0
	SC	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
Microwave Radiometers	AC	1	0	1	0	0	1	1	1	3	3	2	2	1	2	3
	SC	0	0	0	0	0	0	0	0	1	2	1	1	0	1	2
Imaging Radar (SAR or SLAR)	AC	2	1	3	3	1	1	0	0	3	1	1	2	3	3	2
	SC	1	0	2	2	1	0	0	0	2	0	0	1	2	2	1
Radar Altimeters	AC	1	0	1	1	0	0	0	0	1	1	1	2	2	2	1
	SC	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0

Rating
3 = Reliable (Operational)
2 = Needs additional field testing
1 = Limited value (Future potential)
0 = Not applicable

Platform
AC = Aircraft (Medium or low altitude)
SC = Spacecraft (Satellite)

table 1. (from Klemas) Performances of aircraft and satellite remote sensors for coastal studies.

data will be exposed and some arguments for future remote sensing applications will be developed.

2. PERFORMANCE OF DIFFERENT AIRBORNE AND SPACEBORNE SENSORS FOR COASTAL STUDIES.

Table 1, from Klemas (ref.3) summarizes the performance of existing sensors providing data on coastal environment.

For vegetation and land use and biomass and vegetation stress both, film camera and multispectral scanners (now push broom devices) may be used as mapping tools for species condition and composition (ref. 4, 5, 6, 7, 8, 9, 10).

Aircraft photography and airborne multispectral data have been successfully used for coastal erosion and geomorphology which both need high resolution (ref.11, 12, 13).Imaging radar gives good promises (ref. 14).

For depth profiles only laser profilers (ref. 15) are operational devices. Anyway high resolution multispectral data with good wavelength positionning may be useful for mapping bottom features (ref. 16, 17, 18).

Multispectral data are used for the study of suspended sediment patterns, but ground truth is needed when suspended sediment concentrations have to be mapped (ref. 19, 20, 21). Chlorophyll concentrations can be determined using airborne lasers by the excitation of the fluorescence of chlorophyll pigments (ref. 22). The mapping of chlorophyll concentrations may be now realized using multispectral scanner such as CZCS and adequate athmospheric corrections (ref. 23, 24).

One of the first objectives of remote sensing was oil slick detection. Airborne thermal IR scanner and imaging radar are operational (ref. 25), lasers fluorosensors and microwave radiometers offer hope for measuring oil slick thickness and oil type and age (ref. 26-27).

Surface temperature is mapped with airborne or spaceborne thermal infrared scanners, for example with the AVHRR of TIROS N series satellite after geometric, radiometric and atmospheric corrections (ref. 28-29-30).

Water salinity is one of the most difficult oceanographical parameter to obtain by remote sensing. Only microwave radiometers from low altitude aircraft offer some results (ref. 31). This parameter will be very useful for coastal studies as the fishing of pelagic species, such as tuna, which move along thermal and/or salinity fronts.

Current circulation patterns may be detected by a lot of sensors but their study needs high repetitivity (ref. 14, 32, 33, 34).

Wave spectra and sea state which are very important oceanographical parameters for ship traffic, oil and gas offshore production etc. are obtained by using laser profilers, synthetic aperture radars and radar altimeters (ref. 14, 35, 36, 37). Wave spectra may be obtained from aerial photography (ref. 38) and from high resolution satellite data - a Spot simulation over Corsica shows a wave spectrum on the panchromatic channel (resolution 10 m).

Surface winds may be obtained with radar scatterometers (ref. 37).

Sea surface topography only obtained with radar altimeters is not reliable for coastal studies because of the precision required - about 1 cm over distances inferior to 50 km for tide circulation models.

In short : multispectral scanners (visible and thermal IR), laser profilers, laser fluorosensors and imaging radar overlay the big majority of coastal studies with very often operational potentiality. The aircraft appears the most reliable vector, but it should be noticed that the operational capability of the aircraft has to be tempered by three main constraints :

- cost when repetitivity is required,
- immobilization caused by weather,
- geometric distortions often difficult to correct.

Table 1 is only an estimate of the various sensors for measuring coastal properties. Considering the multispectral scanner (visible) on satellite, the performances indicated on table 1 refer to the use of Landsat MSS. With Landsat D Thematic Mapper and the Spot simulations program, noticeable advances are carried out, mainly in the fields of vegetation and land use, biomass and vegetation stress, coastal erosion, geomorphology and bathymetry. For these last studies, multispectral spaceborne sensors may be considered as operational.
All the performance of sensors indicated in this chapter are obviously conditioned, by their spatial and temporal resolution.

3. ADVANTAGES OF HIGH RESOLUTION AND HIGH REPETITIVITY FOR COASTAL ZONE INVENTORY AND MANAGEMENT.

According to the oceanographic objectives, the spatial and temporal resolution requirements are varying. Generally exists an opposition, for spaceborne remote sensing, beetween the spatial and the temporal constraints. For example, a high repetitivity is accompanied, for geostationnary satellites, whith low resolution (2,5 or 5 km per pixel with one image each 1/2 h for Meteosat). On the other hand, high resolution goes with low repetitivity. Solutions are partially offered by lateral views such as in the SPOT configuration (ref. 39) or by zoom devices set up upon a geostationnary satellite (ref. 40).

Fig. 1 from Klemas (ref.3) summarizes the spatial and temporal resolution requirements for coastal and deep ocean studies. Note that one moves further offshore, both the spatial and temporal resolution requirements become less stringent.

Geostationnary satellites, with spatial resolution varying from 1 to 5 km and temporal resolution around the hour, give access to clouds and weather studies, gross ocean circulation, streams and eddy monitoring.

Meteorological satellites (TIROS N type) give access to shelf circulation and coastal upwellings. They are interesting tools for great estuaries circulation studies (ref. 41) if performant geometric correction algorithms are developed.

Earth resources satellites such as Landsat 1, 2 and 3 allow gross coastal land use studies. They may give interesting informations upon shelf fronts, coastal upwellings, ice cover, eastuarine features but they are not operational tools for these last studies because of their low temporal resolution.

High resolution satellite programs such as Landsat D Thematic Mapper, SPOT, give access to seaweeds and marshes (mangroves) habitat mapping, coral reefs geomorphology,wetland biomass, siltation, hydrography, which are very important components of coastal use studies. The difference in temporal resolution beetween Landsat D Thematic Mapper (16 days) and SPOT (24 days) has no impact. On the other hand, the potential repetitivity of systems such as SPOT equiped with lateral views capabilities (access to the same frame each 2,5 days at a latitude of 45°) may be determinant for coastal studies such as ice cover mapping, storm damage assessment, ocean dumping, shelf fronts and pollutants, phytoplancton dynamics, upwellings, etc.

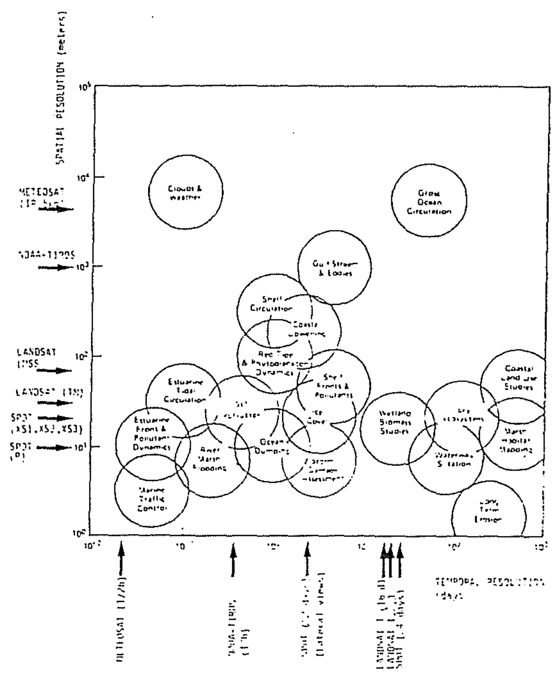


Fig.1 (from Klemas) Optimal spatial and temporal resolutions for oceanic and coastal investigations.

4. AN EXAMPLE OF METHODOLOGY APPLIED TO COASTAL ZONE INVENTORY WITH HIGH RESOLUTION SATELLITE DATA (THIS EXAMPLE IS BASED UPON SPOT SIMULATED DATA) (Ref. 42) (fig.2 and 3)

Images intercepting coastal areas are characterized by strong variance. In fact there is a numerous set of different targets such as water, turbid or not, visible bottom types, sand and mud flats, rocks, marine vegetation (seaweeds, marshes mangroves), corals or ice formations, supratidal zones occupied or not by man (urban zones, forests, cultures, bare soils, ...). As a way to lower the variance of a system consists in stratifying this system, the methodology adopts the principle of distinguishing by single numerical algorithms the main facies included in the image. Strata will be thus extracted from original images and the pixels belonging to the identified strata will be considered for each stratum. According to the number of wavelengths, a classification may be thus performed on the clouds of pixels identified in each stratum. On these clouds, because of the reduction of variance expected, the application of statistical algorithms should be improved. This methodology uses the general image processing software (GIPSY) (ref. 44) developped at CNEXO/COB.

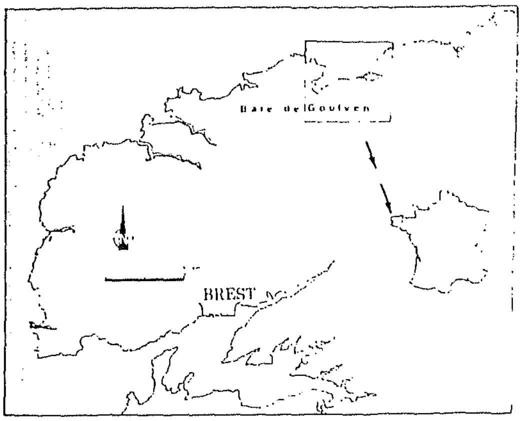


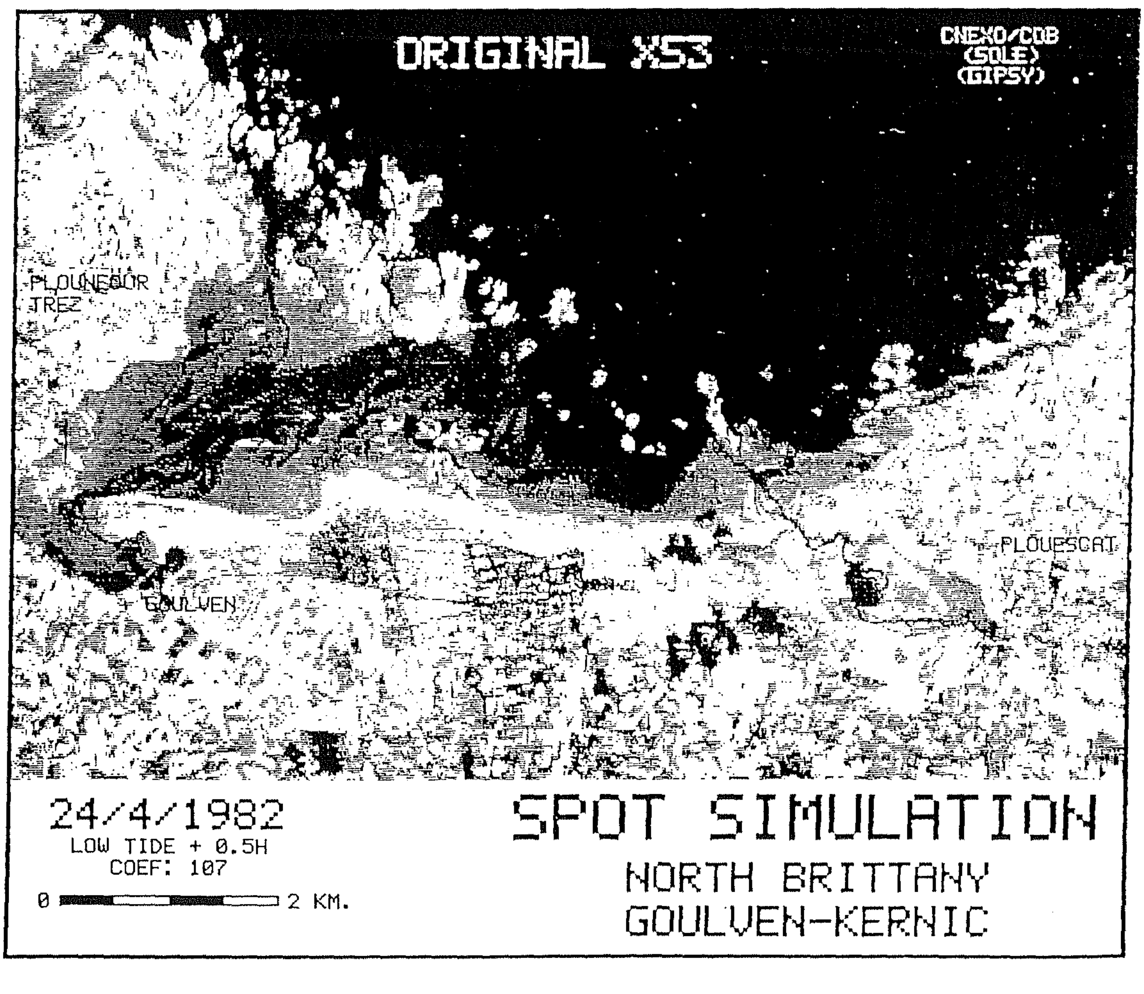
Fig. 2 - Localization of the studied area (Bay of Goulven).

4.1. Stratification - general inventory

Because of the high absorption of near infrared by water, the extraction of the aquatic stratum may be performed by simple thresholding on the near infrared channel. An automatic instantaneous coast line is obtained by the outline detection of the mask which corresponds to the water (ref.45).

The determination of the supratidal stratum is performed by differenciation beetween two images, geometrically compatible, the first obtained when the tide is low, the second when the tide is up. If only a low tide image is available, the elimination of supratidal area may be performed by creating, with interactive process, a mask fitting with the limit of the higher tides. Eliminating water and "land", an intertidal stratum with determined surface for specified hour and tide coefficient may be isolated.

Over the intertidal stratum may be distinguished two substrata, one corresponding to vegetation the other to "no vegetation". This discrimination is realized by the use of a vegetation index (ref. 46-47) in the form of near infrared-red/near IR + red. The higher values of the histogram of this results correspond to vegetation, because vegetation presents spectral signatures very different in the red and near infra-red. The lower values correspond to the non vegetal areas. The vegetal



populations may be divided, in the case of temperate coastal environment, into subpopulations such as seaweeds and salt marshes, assuming that salt marshes use to grow over soft substrats where the hydrodynamism is weak when seaweeds grow over hard substrats (rocks) in most exposed zones.

When the penetration of light is sufficient over clear and shallow waters, the water stratum may be subdivided according to the existing bottom features. The methodology uses first the shorter wavelength band(MSS 4, TM band 1, SPOT XS1) with threshold, over high reflecting targets (sand) and low reflecting ones (rocks). Then is applied the principle of the ratio algorithm yet developped by POLCYN (ref. 18). The assumption is made that a pair of wavelength bands can be found such that the ratio of the bottom reflectances on these bands remains the same, whatever the bottom types, over a given scene, so :

$$\frac{rA1}{rA2} = \frac{rB1}{rB2} = R \qquad (1)$$

where rA, is the reflectance of the bottom type A in band 1.

The advantage is that the variance of the ratio is smaller indeed that the variance among the single band reflectances over several bottom types. The main drawback is that this method can be only applied to depths inferior than the penetration depth in the band n°2 considered, that is, for MSS 5 and SPOT XS2, a few meters.

The water depth, too, can be computed in the ratio method according to equation (2):

$$z = - \frac{1}{2\,(K2 - K1)} \ln \left| \frac{V2 - V2S}{V1 - V1S} \times \frac{V01}{V02} \right|$$

where

- Ki = the water attenuation coefficient (m^{-1}) in band i
- Vi = the signal value in band i
- ViS = the signal value in band i over deep water
- VOi = limiting signal as depth approaches zero

VOi may be obtained from theory or from ground truth. The signal value for band i can be written:

$$Vi = ViS + VOi\, e^{-2\, Ki\, z} \qquad (3)$$

Figure 4 summarises the results of the stratification of the SPOT simulated image of the Bay of Goulven (North Brittany), the original of which is shown in figure 3.

4.2. Classification

The radiometric value of each pixel in each wavelengh is considered for a determined stratum. A principal component analysis is applied, in the n dimension space corresponding to the original wavelengths, over the pixels cloud which corresponds to each stratum. Generally, the two first principal axes contain the big majority of the variance of the system so the spectral information adquired over n wavelengths may be reduced to a lower dimension (ref. 40). If, for a considered stratum, a wavelength is dominant compared to the others, (near infrared for example for vegetation) it may be advantageous to reduce the data before the computation of the eigeinvectors. This has the advantage to decrease the dependance beetween the first component and the dominant wavelength in the stratum.

Considering the three images obtained after projection of the data onto the 3 first principal axes, one may create a colour composite (ref. 49) with, for example first axis in red, second in green, third in blue. Also considering that the contributions of the two first components exceeds 90% of the total variance, a partition may be realized according to the density of pixels on the bidimentional histogram PC1 - PC2.

Results obtained upon intertidal zones show that the general structure of intertidal vegetation such as seaweeds and mangroves and a zonation of specific dominants may be obtained (ref. 8-43).

CONCLUSION

High resolution satellite data offer good promises for coastal environment quantification and monitoring. From Landsat D program, unfortunately stopped, and Spot one, will be carried out new concepts and new applications. In fact, because of the high spatial resolution the spectral analysis of image will be insufficient although necessary. High resolution data are very sensitive to luminance variations from pixel to pixel and to association of pixels. So the pixel must not be considered alone with its own radiometric counts but considered with respect to its environment. Texture analysis (Ref. 50, 51, 52) will obviously know new developments and applications with and because of high resolution data. Better stratifications and/or better discriminations into the strata may be obtained.

An other trend concerns the mixing of data obtained from different sources. For example mixing passive radiometric data (Landsat D, Spot simulated) with active ones such as SAR (SIR-B experiment). Improvements in relation with facies discrimination, facies structure, geomorphology, etc. should be expected.

Landsat D TM and SPOT payloads were not defined for coastal purposes; they are in the first place land-observation satellites. "Marine satellites" have existed (SEASAT) or are being developed: ERS-1 from ESA, an Ocean Color Imager on a future NOOA satellite, TOPEX (USA), POSEIDON (France), GEOSAT (USA), MOS-1 (Japan), NROSS (USA) etc. "Coastal satellites" as represented in Table 1 and Figure 1 are not so easy to conceive.

High spatial resolution satellites and the new concepts linked to their data will introduce new ways of considering coastal remote sensing. The mportant step for the future will be the introduction of high temporal resolution - a very necessary dimension - for the understanding of an essentially dynamic environment.

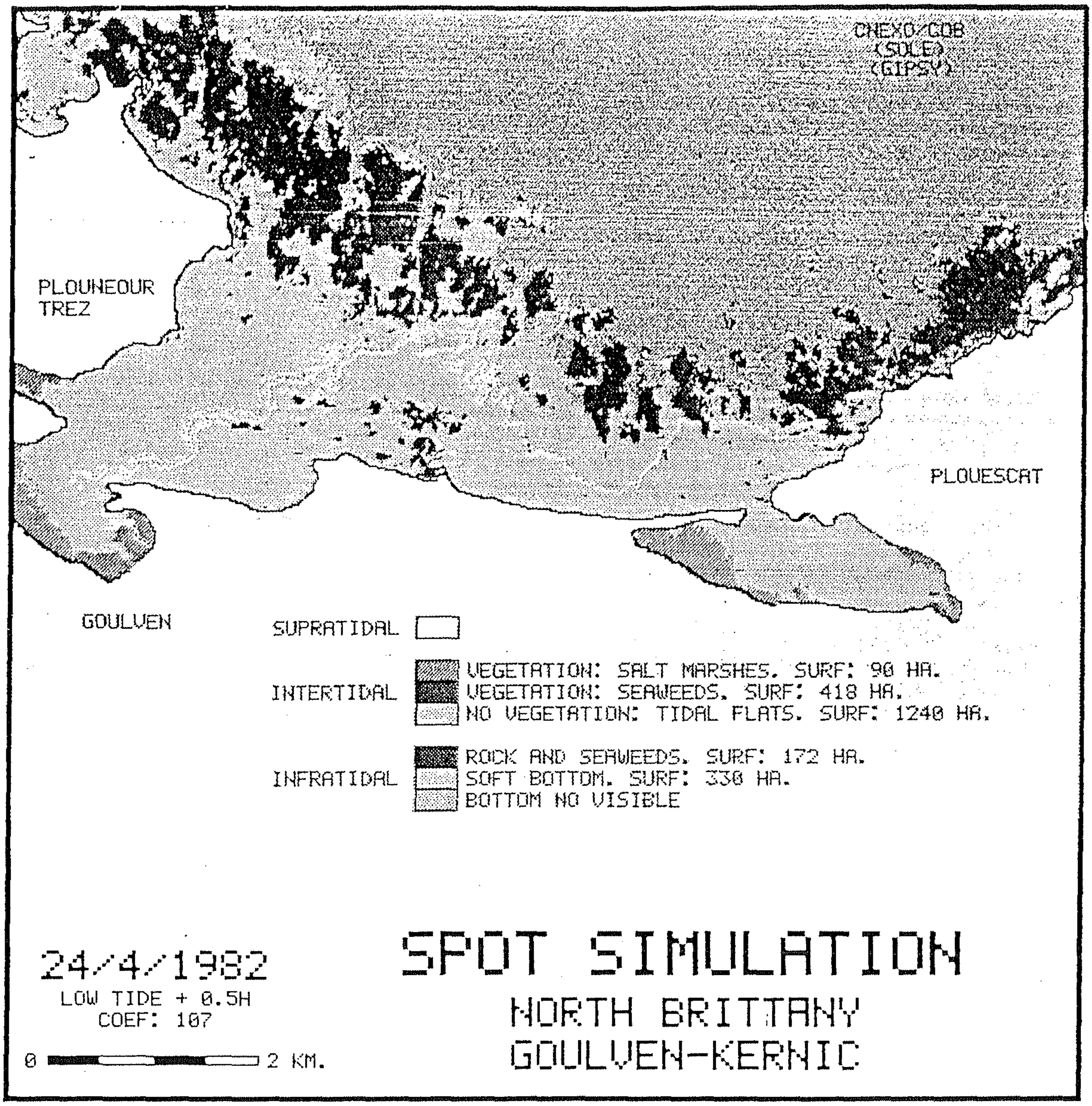


Fig. 4 - Bay of Goulven : SPOT simulated data stratification.

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