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Availability of cloud-free Landsat images for operational projects. The analysis of cloud-cover figures over the countries of the European Community

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Abstract. The objective of the study is to obtain figures assessing the possibility of acquiring cloud-free images (Landsat TM and SPOT) throughout the countries of the European Community in the next campaign during a certain period of the year. Entry data transformation led to a very compact data set with an appropriate spatial and temporal resolution. Through a programme, estimations of the availability of good images can be easily obtained. It is shown that in areas of higher latitudes the disadvantage of bad weather can sometimes be compensated for by acquiring twice as many images, because of the bigger sidelap (over 50 per cent) of adjacent frames.

1. Introduction

In the beginning of 1987 the Joint Research Centre of the European Communities at Ispra (Italy) initiated a pilot project of remote sensing techniques applied to agricultural statistics. This project is divided into seven different actions. One of the main actions concerns crop area estimation using a combination of ground survey and remotely sensed data with a high resolution (Landsat Thematic Mapper and SPOT). The aim of this action is to produce agricultural statistics for the main crop types of different administrative regions throughout the countries belonging to the Community.

One of the main criteria of selecting these regions was, after the importance of crop production, the possibility of acquiring cloud-free images in the year 1988. Although there are statistical techniques to partly overcome the problems of non-responding areas due to clouds (Hanuschak 1976), the final estimation of crop acreage will generally be less reliable. Therefore one must try to obtain figures giving the probability in the next campaign for acquisition of cloud-free images in a certain period of the year. This study deals with this analysis. One acceptable source of information is the enormous amount of cloud cover (CC) figures recorded during the time Landsat-1 has been producing images. Dr J. Lichtenegger of the European Space Agency kindly provided us with a tape containing all the necessary data to make the analyses over the European Community up to the year 1986. In this tape the CC figures are recorded to each quarter scene.

To be able to integrate fully the data belonging to World Reference System (WRS) I (Landsat-1, -2, -3) and WRS II (Landsat-4, -5) we had to project the frame boundaries to one reference system, the ellipsoid coordinate system. The use of one reference system enabled us to use the information over all of the 15 years and for any region in the European Community. Furthermore, the projection of image limits to one reference system helped us to answer another question, namely 'Can increasing sidelap of images at higher latitudes compensate the generally worse CC figures by having twice as many images available?'. In other words, did we underestimate the availability of good images in the past by looking only at the figures of one scene at higher latitudes? We have tried to give an answer in our analysis. At the same time we have designed a general purpose programme which could serve the inquiry of good scenes and probabilities of geographically defined areas in Europe. This programme could be included as a module in an image acquisition catalogue. Although cloud coverage is recorded, one cannot derive information also about the meteorological conditions from this analysis, since we are dealing with transmission failures, availability of platforms, and all other obstacles between the sensor and the cloud cover estimation by man. As we are only interested, from a management (operational) point of view, in the availability of cloud-free images for the year 1988, the generalization which already lies at the basis of our definition of needs is justified. These figures could be related to other platforms in a relative way.

2. Data preparation

The source tape is a subset of all the catalogued Landsat MSS images. The subset parameters are longitude and latitude for the countries of the European Community and the most important period for crop production, namely April–September. However, after we applied a data check it seemed that some frames were estimated twice; once at the Kiruna receiving station and once at Frascati. Generally the figures from Italy were more optimistic than those from Sweden. Although this deviation was found more often in the higher estimates, the data had to be cleaned. After cleaning the data could be entered into a small data base. From this data base we could easily get a list of scenes corresponding to any combination of path, row, year, month, day, longitude, latitude and sensor. This facilitated the checking of the results of the analysis. The total number of images catalogued per year and per sensor is given in the table.

3. Definition of a good image

In the data we received, the cloud cover information is described by an integer in the range 0 to 9 for each quarter-scene MSS. We decided that for the purposes of the agriculture project, an image is good for sampling and for applying a regression estimate, if the cloud coverage is less than 10 per cent, which means a CC value of 0 in the entry data.

4. Availability and not probability

The principal aim of this study was, after elaboration of data of the previous 15 year period, to get information about the possibility of receiving a good image the next year, in a certain time period and inside the limits of a geographic area.

We mention that we did not compensate for the satellite system's failure during a certain period, which consequently provided us with a small number of images and less cloud-cover information. Moreover, some simplifications to our estimations led us to consider each quarter scene independently from its neighbours, which is not valid, because the weather conditions of the area presented in a quarter-scene are too much dependent on the climatic conditions over the whole of the geographic department or, in some cases of higher latitudes, over all the country. For the above reasons, the estimation of an exact probability for acquiring a good image, given by a precise statistical formula, was not possible. In other words, we proceeded by estimating an 'availability' of cloud-free images and not a 'probability' of receiving good images, estimations which seem to be close to one another. The way to compute this availability is presented in § 6.

Number of images catalogued by satellite and year (MSS only).

Year	Landsat MSS missions					
	Landsat-1	Landsat-2	Landsat-3	Landsat-4	Landsat-5	Total
1972	268	0	0	0	0	268
1973	171	0	0	0	0	171
1974	17	0	0	0	0	17
1975	1455	592	0	0	0	2047
1976	3826	82	0	0	0	3908
1977	7	4839	0	0	0	4846
1978	0	3773	738	0	0	4511
1979	0	4291	347	0	0	4638
1980	0	1786	3695	0	0	5481
1981	0	4810	593	0	0	5403
1982	0	0	0	777	0	777
1983	0	0	0	3783	0	3783
1984	0	0	0	3273	3743	7016
1985	0	0	0	2808	3691	6499
1986	0	0	0	40	3823	3863
Total	5744	20 173	5373	10681	11 257	53 228

5. Spatial and temporal resolution

Related to the spatial and time parameters referred to above is the concept of resolution. We decided that a spatial resolution of 0·1° in latitude and longitude, which corresponds to a $10\,000 \times 10\,000\,\mathrm{m}^2$ area, on the ground, and a temporal resolution of ten days, would be sufficient for the agricultural project's purposes.

6. Codification of the cloud-cover information

The data which ESA provided to us extended over the six months period, from April to September, for each of the 15 years 1972–1986. It covers the countries of the European Community from 32·54° to 64·85° latitude and from −9·20° to 31·25° longitude. A combination of the geographic distribution of the images and the sampling of these images in time could include the overlapping of all the path/row data and would provide us with more precise information over a certain area during a certain period. The codification we designed aimed for a very compact data set with a fast retrieval of the information wanted. It resulted in a 36 layer database where the geographical distribution is represented in the x and y axes and the temporal information is stored in the z axis (number of periods × the number of 8-bit layers necessary to store a yes or no for 15 years $= 18 \times 2 = 36$).

One layer has 321 rows and 471 columns with cell size of 0·1° on a side. The 36 layers have the following distribution in time. Every month (April to September) corresponds to six layers of cloud-cover information, each layer containing eight bits. Of these six layers the first, second and third pair contain information directly related to the first, second and third ten day period of a month. Finally every layer of these pairs is coded for an eight year period. The first layer of a pair is related to the first eight year block (1972–1979). The second one corresponds to the second eight year block (1980–1986), leaving one bit unused. Each bit corresponds to one of the 15 years and is set, if the cloud-covering figure is less than 10 per cent. Once the bit is set the year/period has a positive value and any other bit setting is neglected, as this already fulfils the requirements of the statement. The availability of cloud-free pixels during a certain time period is nothing more than the number of bits set over the 15 bits.

The appropriate software was developed for the needs of this data registration. In the beginning we created six images of six layers corresponding to each one of the six months. This was done by running through the ESA data file and picking up all the information related to the month, for all the catalogued frames of the two reference systems I and II. In a following step we patched them in order to create the 36 channel image. From this point on, the combined use of this 36 layer database with another routine which returns the limits of each quarter-scene was employed, in order to set the corresponding bits.

7. Mathematical model

The need for the simultaneous use of the cloud-cover information recorded by Landsat-1, -2, -3 (WRS I) and Landsat-4, -5 (WRS II) missions, throughout the 15 years, implied the location of the geographic area presented by a quarter-scene into a common reference system. The formula used to integrate the two different systems (WRS I and WRS II) into the ellipsoid reference system by calculating the latitude and longitude coordinates of each corner of the quarter-scene is a function of:

(1) the geographical coordinates of the nominal centre of the image,
(2) the geometry of the orbit and of the Earth,
(3) the orbit inclination at the height of the nominal centre, and
(4) the ground distances of a full Landsat MSS frame (approximately 185 km × 185 km).

In order to build a mathematical formula easily used and less computer-time consuming, we made the following assumptions:

(1) geometry of a spherical Earth with a radius of 6370 km,
(2) geometry of an absolutely circular orbit,
(3) stable altitude relationship between the satellite orbit and the nominal geoid, and
(4) a non-rotating Earth; the maximum error introduced in scanning direction by this assumption is expected to be $\simeq 200$ m for a 185 km scan ground length.

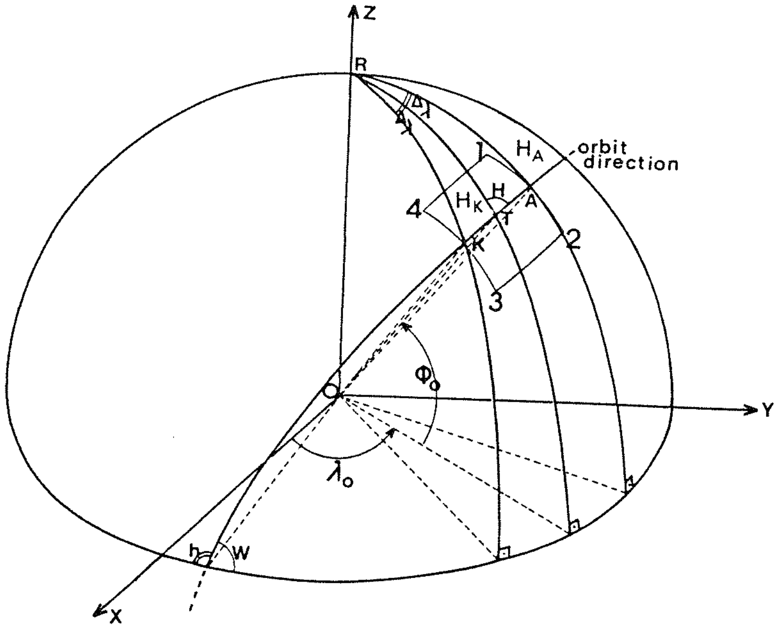
Figure 1 illustrates the Earth's and orbit's geometry as well as the formulae used.

In the entry data set, slight differences in (latitude, longitude) coordinates of the same nominal scene centre were found. So, mean coordinate values were calculated for each centre and afterwards were introduced into the formulae given in figure 1. Once the corner points were located in the (latitude, longitude) coordinate system they temporally projected in a 0·1° grid for cartographic purposes.

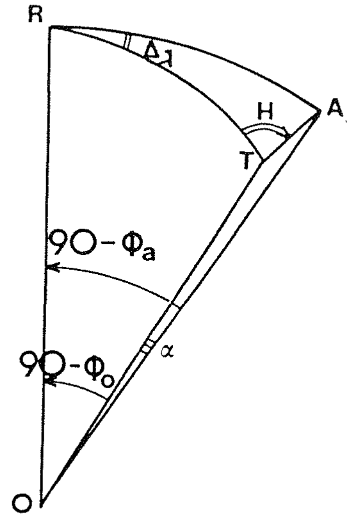
Figure 2, shows the projection of the frame network of Landsat-4, -5 missions over Greece and Great Britain. One can easily follow the changes in coverage side-laps of adjacent orbits.

8. Europe under the clouds

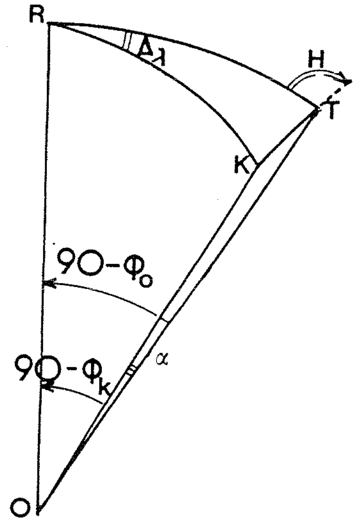
The period chosen to study the cloud-free pixel distribution for all the European Community was 15 July–15 September, when crop production is most important. The thematic map of figure 3 illustrates the results of this analysis.



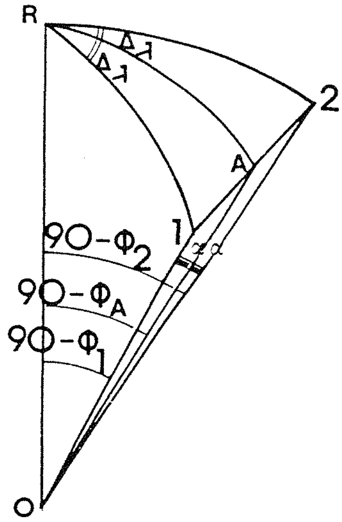
(a)



(b)



(c)



(d)

$$\cos H = \cos W / \cos \phi_0$$

ORTA::
$$\sin \phi_A = \cos \alpha \sin \phi_0 + \sin \alpha \cos \phi_0 \cos H$$
$$\cos \Delta\lambda_{TA} = (\cos \alpha - \sin \phi_0 \sin \phi_A) / \cos \phi_0 \cos \phi_A$$

ORKT::
$$\sin \phi_K = \sin \phi_0 \cos \alpha - \cos \phi_0 \sin \alpha \cos H$$
$$\cos \Delta\lambda_{0K} = (\cos \alpha - \sin \phi_0 \sin \phi_K) / \cos \phi_0 \cos \phi_K$$

OAR2::
$$\sin \phi_2 = \sin \phi_A \cos \alpha - \cos \phi_A \sin \alpha \sin H_A$$
$$\cos \Delta\lambda_{A2} = (\cos \alpha - \sin \phi_A \sin \phi_{A2}) / \cos \phi_A \cos \phi_{A2}$$

OAR1::
$$\sin \phi_1 = \sin \phi_A \cos \alpha + \cos \phi_A \sin \alpha \sin H_A$$
$$\cos \Delta\lambda_{A1} = (\cos \alpha - \sin \phi_A \sin \phi_{A1}) / \cos \phi_A \cos \phi_{A2}$$

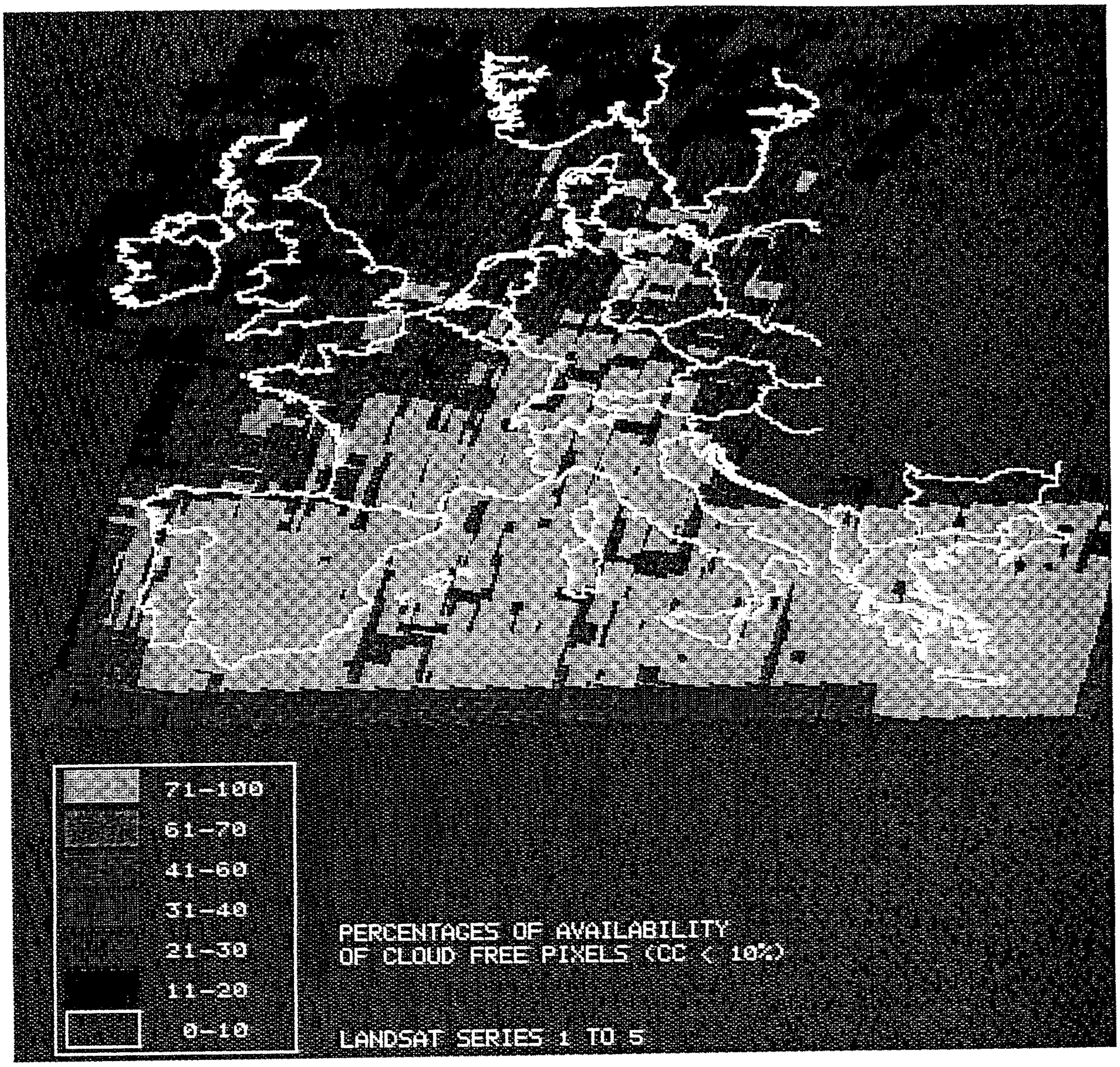
h:: equatorial orbit inclination

ϕ_0, λ_0:: latitude, longitude of the nominal center

1,2,3,4:: frame corner points

$\alpha^{(rad)}$ $= 92 \cdot 5/6370$

Figure 1. The geometry of the satellite orbit and the formulas used in order to calculate the (latitude, longitude) coordinates of the corner points of a Landsat MSS frame.



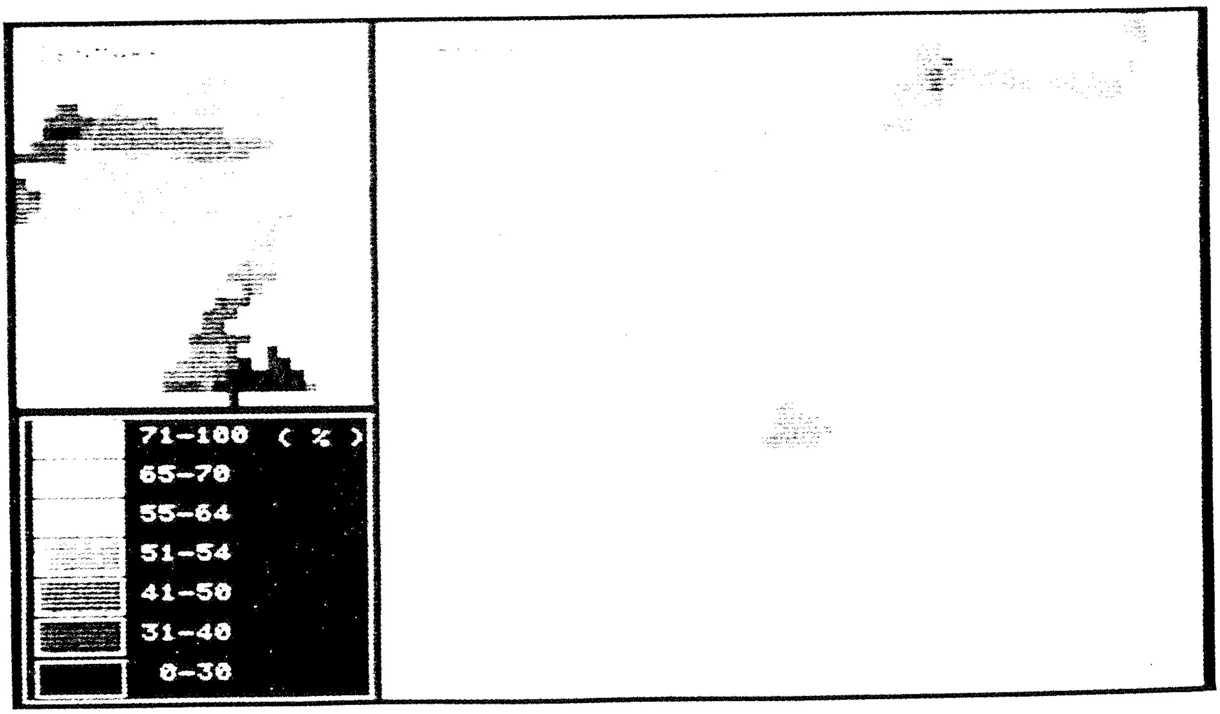
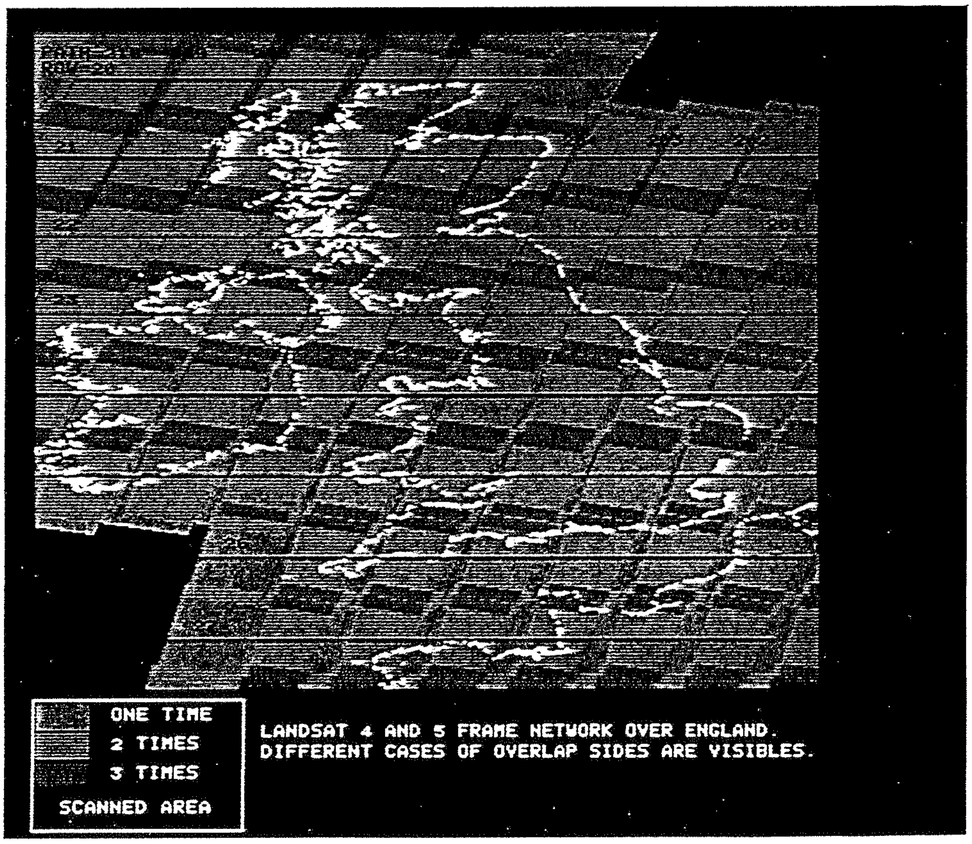


Figure 2. The projection of the WRS II (Landsat-4, -5) over Greece and Great Britain to a 0·1 (°) grid. Changes in coverage sidelaps of adjacent orbits are visible.

(*a*)



(*b*)

Figure 3. (*a*) Thematic map showing the availability of cloud free pixels (CC < 10 per cent) for the European Communities, during the period of 15 July–15 September. (*b*) Description of the same availability for Greece and Denmark.

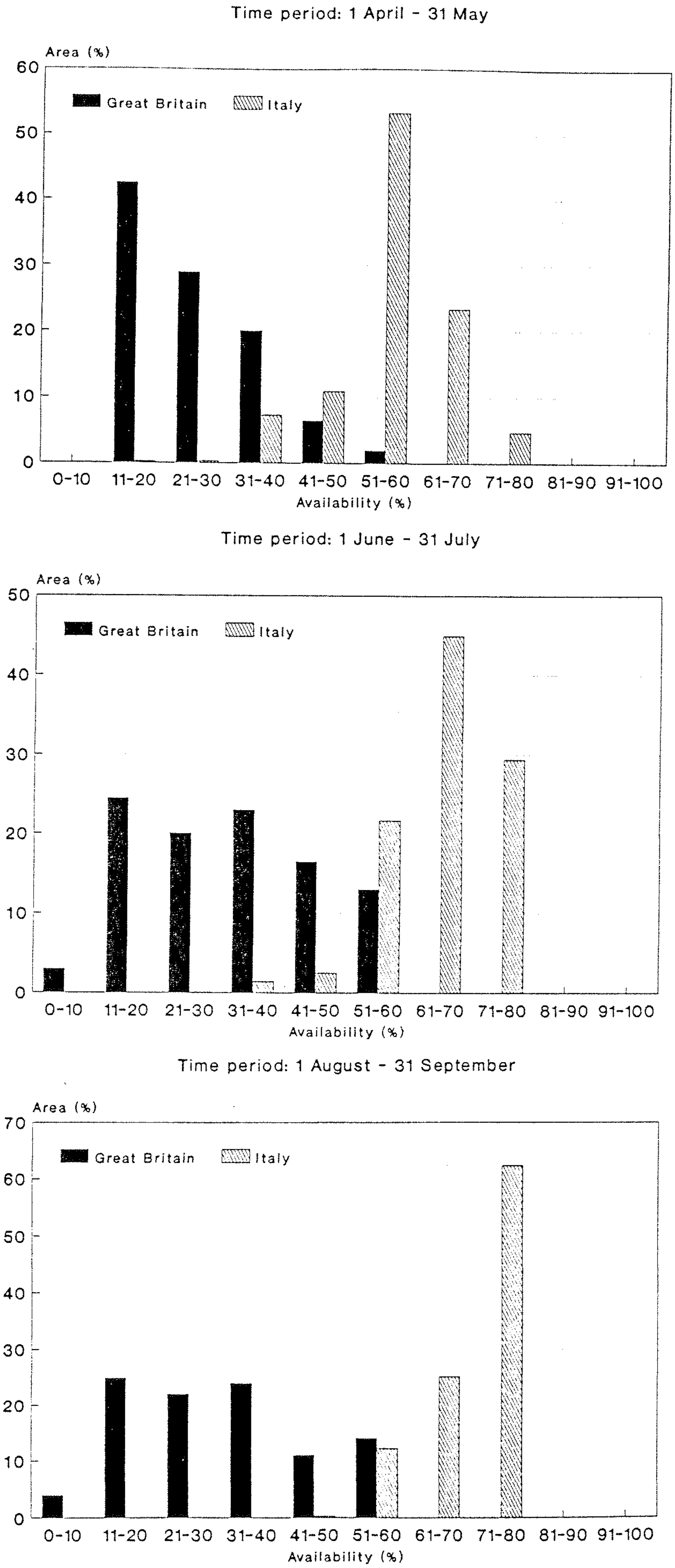


Figure 4. Histograms of availability of cloud free pixels versus area for Italy and Great Britain.

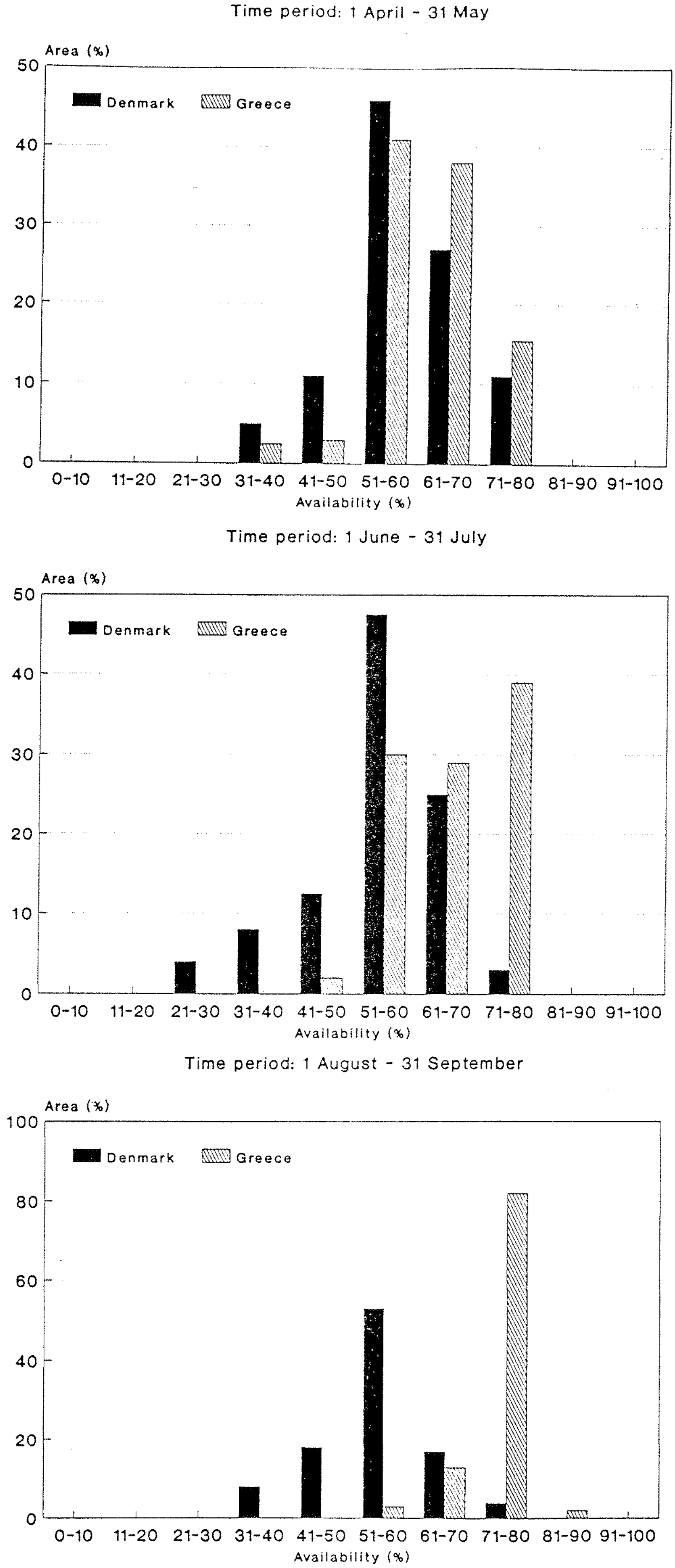


Figure 5. Histograms of availability of cloud free pixels versus area for Greece and Denmark.

9. Comparison of four areas

9.1. *Great Britain and Italy*

We analysed the cloud-free pixel distribution for Great Britain and Italy (see figure 4) during the same period. We examined these two countries because they present big differences in latitudes and thus different cases of coverage sidelaps of adjacent frames. Looking at the histograms of figure 4, one can easily see that the cloud-free pixel distribution over the two countries is extremely different during the three periods of April–May, June–July and August–September. In Great Britain, availabilities over 50 per cent are negligible for all of the three periods. On the contrary, in Italy the majority of the values is between 60 and 90 per cent. A study of the histograms shows that the best period to receive good images in Great Britain is June-July. For Italy the ideal period is July–September.

9.2. *Greece and Denmark*

Although Greece has generally better (CC) figures for each path/row scene, the two countries present similar availability against area distributions during the two periods April–May and June–July (see figure 5). Indeed, the fact of having, for Denmark, twice as many images available as for Greece, compensates for the disadvantage of the bad weather. Slight differences start to appear during the period of August–September when the weather becomes worse in Denmark.

10. Conclusion

Projecting the Landsat MSS frames of the two World Reference Systems into one LAT–LON grid gives precise information of the availability of cloud-free images from the Landsat MSS instrument. The figures obtained include every type of failure which can occur between the sensor on the platform and the user of the images. The information retrieval system that we built is user friendly and spatial and temporal resolution are sufficient to be used for image acquisition periods based on cloud-cover information. Starting an operational project without having the slightest idea of the availability of images or relying on information which is incomplete or not precise, quickly leads to excuses concerning the weather. At least with this data set one has the opportunity to avoid problems right from the start.

As the comparison between Greece and Denmark has shown, one can conclude that the availability of cloud-free images in areas of northern latitudes is higher if one regards the overlapping of frames than if calculated from one track frame only. The example of Great Britain versus Italy shows that bad weather cannot always be compensated by a greater overlap.

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