An overview of concepts in fusion of Earth data

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ABSTRACT: A definition of the data fusion is proposed, which allows to set up a conceptual approach to the fusion of Earth observation data by putting an emphasis on the framework and on the fundamentals in remote sensing underlying data fusion. Further definitions are given which describe the information intervening in any problem of data fusion. Fusion may be performed at different levels: at measurements level, at attribute level, and at rule or decision level. Several problems are to be solved prior to any process of fusion. They deal with either the selection of the representation space and the level of fusion, or with the processing to be applied onto the data. A formalism is discussed which sketches a fusion process. Several examples of fusion processes are given using this formalism.

1 INTRODUCTION

Data fusion is a subject becoming increasingly relevant as scientists try to extract more and more information from remotely sensed data using the concept of synergy. Data fusion is a very recent word. It means an approach to information extraction spontaneously adopted in several domains. An illustration is given by the human system which calls upon its different senses, its memory and its reasoning capabilities to perform deductions from the information it perceives. However the operation by itself is not new in remote sensing: classification procedures are performed for more than twenty years, and are obviously relevant to data fusion (see e.g., Mangolini 1994, Pohl 1996).

The quantity of information available to describe our environment increases rapidly. Archives are growing, as well as the number of space missions devoted to Earth observation. It is generally correct to assume that improvements in terms of classification error probability, rejection rate, and interpretation robustness, can only be achieved at the expenses of additional independent data delivered by more separate sensors. Sensor data fusion allows to formalise the combination of these measurements, as well as to monitor the quality of information in the course of the fusion process.

Data fusion means a very wide domain. It gathers a large number of methods and mathematical tools, ranging from spectral analysis to plausibility theory. Fusion is not specific to a theme or an application. On the contrary the tools used in a fusion process for a specific application may be tailored to that case.

A general definition of the fusion may be « set of methods, tools and means using data coming from various sources of different nature, in order to increase the quality (in a broad sense) of the requested information ». Information may be of various nature: it can be measurements as well as verbal reports. Some data cannot be quantified, their accuracy and reliability are difficult to assess.

Here, the domain is restricted to the fusion of sensor data. Data are quantitative measurements output from sensors, which can be precisely described. The present discussion is further restricted to the Earth observation.

2. DEFINITION

The above definition is too broad and is not very useful. A more precise definition is needed, which allows to set up a more conceptual approach to the fusion of Earth observation data.

I suggest the following definition: « data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different sources, and for the exploitation of their synergy in order to obtain information whose quality cannot be achieved otherwise ». This definition has at least two advantages. Firstly it is putting an emphasis on the framework and on the fundamentals in remote sensing underlying data fusion instead of on the tools and means themselves, as is done usually. The latter have obviously strong importance but they are only means not principles. Secondly it is putting also an emphasis on the quality. This is certainly the aspect missing in most of the literature about data fusion, but one of the most delicate.

3. FORMALISATION OF A FUSION PROCESS

There are several existing formalisms of a fusion process. They are usually adapted to the level of abstraction of the process. A fusion process can be decomposed into elementary fusion process. Each element is then represented by a fusion cell displayed in Figure 1 (after Houzelle, Giraudon 1994).

The fusion cell receives three types of information: sources data, auxiliary knowledge, and external knowledge. The back loop permits to describe iterative processes. Processing performed in the fusion cell can be anything: classification, conditional filtering, neural network, etc.

The information sources are the main inputs in the fusion cell. It can be the data provided by the sensors but also results from previous fusion processes, attributes, decisions (or rules). Examples are: one multispectral sensor (e.g., Landsat-TM, SPOT-XS, SSM/I), several monoband sensors (e.g., SPOT-PAN and ERS-SAR), or several multispectral and monoband sensors.

The auxiliary knowledge brings an additional information. This information is extracted from the same sources. The ancillary data related to the sensors and spacecraft are part of this auxiliary information: date and hour of acquisition, sensor calibration, etc. It may also stem from a processing of one of the source, or from another fusion process of all or part of the sources.

The external knowledge is also an additional information whose goal is to constraint or guide the fusion process, by generally imposing *a priori* knowledge. Examples are given in the following.

4. PROPERTIES OF INFORMATION TO BE FUSED

Several problems are to be solved prior to any process of fusion (see e.g., Castagnas 1995, Pau 1988). The information entering a fusion cell should present several properties. They deal with either the selection of the representation space and the level of fusion, or with the processing to be applied onto the data.

A common co-ordinate system (e.g., geographical space and time) should be found in which the sources data can be represented. This is called alignment or conditioning. For example, geocoding the sources data is part of the alignment problem. This problem is difficult and according to some authors (see e.g., Thomopoulos, 1991, DSTO 1994), it differentiates data fusion from data concatenation. Although the latter can be accomplished easily and straightforward by state vector augmentation, data fusion requires conversion of the data into a common co-ordinate frame before concatenation Alignment should provide a general frame of referencing that can applied to homogeneous (commensurate) as well as heterogeneous (non-commensurate) data. The proposed formalism handles such cases (see e.g., example in Figure 6).

This concept is extended to a wider reference space (representation space) which also includes standardisation of units, calibration of sensors and atmospheric corrections, etc., if relevant.

Though having the same space reference, two sources may not refer to the same object (landscape). In the Meteosat case, the water vapour channel does not provide any information on the ground, while the visible and infrared channels do. Data to be fused need to be relevant to the objectives of fusion process. Then these data can be associated or concatenated into the state vector of the studied object (landscape).

The fusion process may apply at several levels. The first level is that of the data output from the sensors (often called signal or measurements). The second level is fusion of attributes, and the third one, fusion of decisions (or rules).

The result of a fusion process with signal as input is not necessarily attribute. This is true for classification for example, but other processes may result into another signal (e.g., arithmetical combination or filtering).

Our definition of data fusion is putting also an emphasis on the quality. This is certainly the aspect missing in most of the literature about data fusion. No processing step is explicitly devoted to that aspect. Though many papers are published about assessing the accuracy of a classification, I believe that there is a lack of techniques and protocols for assessing *a priori* or *a posteriori* the quality of a fusion product, that is answering the following questions: is it worth performing a fusion process ? Was it worth doing it ?

5. EXAMPLES OF FUSION PROCESS

Several examples are now given which illustrate the fusion formalism. Figure 2 depicts a supervised classification of a SPOT-XS scene. The XS data are entering the fusion cell as sources data. Spectral signatures enter the fusion cell as external knowledge. These spectral signatures may originate from the XS data themselves if ground truth is available and sufficient. They may also originate from a data base of spectral signatures. In that case, a special effort should be made on alignment, particularly on units, calibration and atmospheric correction of the XS data.

Figure 3a (after Mangolini, 1994) exhibits a fusion cell for classification. SPOT-XS, Landsat-TM and ERS data are entering the cell. An image of a texture parameter (e.g., the local variance) has been computed from a SPOT-PAN image. It enters the cell as auxiliary information since it does not stem directly from a source. The fusion process performs a classification, and provides also a confidence level. Such a scheme is called centralised architecture, since all sources enter the classifier. In Figure 3b, is presented a decentralised fusion process. Given the same sources, each of them enter a classifier, independently from the other sources. Each of the three classifier produces a classification and a confidence level. Then the three classifications enter a fusion cell. Confidence levels enter the cell as auxiliary information. A classifier performs the fusion of attributes, and the final classification is obtained.

For classification, centralised architecture provides better results, but when a source is 'noisy' as can be a SAR image. In that case, the SAR image pollutes the classification, and a decentralised scheme should be preferred. Mangolini (1994) has discussed several architectures for fusion process, including mixed which are half-way between centralised and decentralised architectures.

Figure 4 deals with crop monitoring as it is done within the common agriculture policy of the European Union. Two images SPOT-XS and one SPOT-PAN, obtained at different dates (t1 to t3) enter the fusion cell. A geographical information system (GIS) provides an external knowledge on e.g., the cultivated areas. A classification is then performed.

Iterative processes can be represented. In Figure 5, a fusion process is performed for the prediction of the sugar beet crop (after Castagnas, 1995). Optical and/or radar data (depending upon their availability) enter the fusion cell as sources data. Meteorological data and *in situ* measurements (soil humidity) are external knowledge and inputs to a model for crop prediction. The model adjusts itself to the data as they are flowing in. There is a loop with an iteration on time, and the previous prediction enter the fusion cell as an auxiliary information to guide the analysis of the sources data.

In some cases, sources data are not always commensurate. That is that a metric does not exist for the union of the sources data (or of representations, Thomopoulos 1991). An example is given in Figure 6, which deals with the photo-interpretation of the brightest spots in a SAR image (Mangolini *et al.* 1993). This image is pretty noisy and it is very hard to distinguish objects. After superimposition onto a SPOT-PAN image, the small-scale transitions are extracted from the SAR image by means of a wavelet transform. The most intense transitions are kept and the corresponding pixels in the SPOT-PAN image are flagged. Thus the photo-interpretation is performed onto a more readable fused image. Since the processing of the SAR image produces attributes and not a signal, only the SPOT-PAN enters the fusion cell as sources data. The SAR derived information is an auxiliary information.

A last example is given in Figure 7, which shows that the formalism can be applied to Earth observation data not directly stemming from satellite sensor. Beyer *et al.* (1997) have derived maps of global solar radiation from Meteosat images. These maps have a poor accuracy. By merging them with a large set of *in situ* measurements, by means of co-kriging, they obtained more accurate maps. The *in situ* measurements enter the fusion cell as external knowledge in that case, since they constitute the truth towards which the maps are locally constrained. Have these measurements had the same reliability than the maps, they would have enter the fusion cell as auxiliary data.

6. CONCLUSION

A new definition of the data fusion has been proposed which emphasises the concepts and the fundamentals in remote sensing.

Properties of the information to be fused have been stated in plain text. Mathematical expressions of these properties exist which permit complex operations and proofs.

A concept has been proposed which allows to sketch out a fusion process. Several examples were shown, which demonstrate that most of the fusion processes used in remote sensing and Earth observation, if not all, can be represented by this formalism. Elaborated schemes can be sketched out in a simple way.

7. REFERENCES

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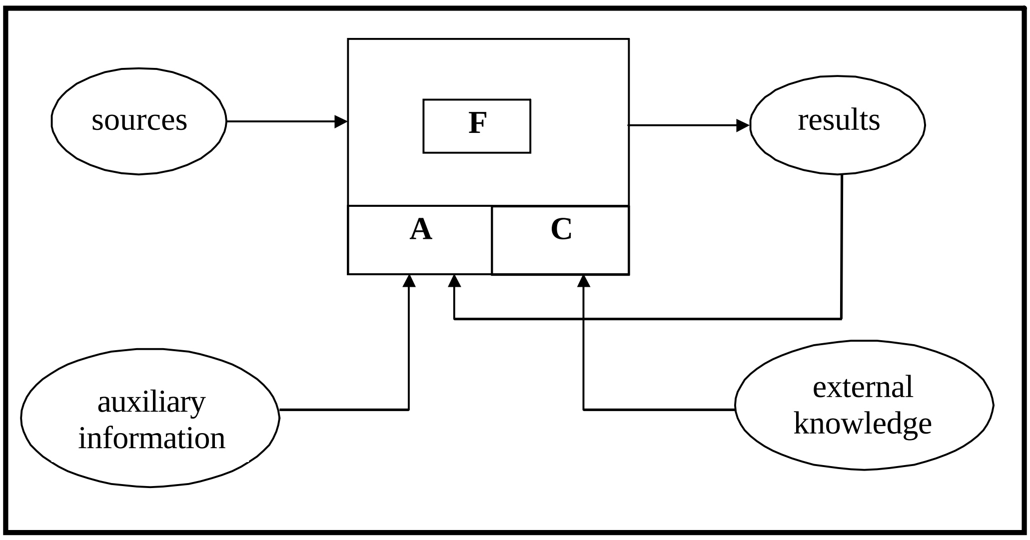

Figure 1. Formalisation of an elementary fusion process by a fusion cell (after Houzelle, Giraudon, 1994).

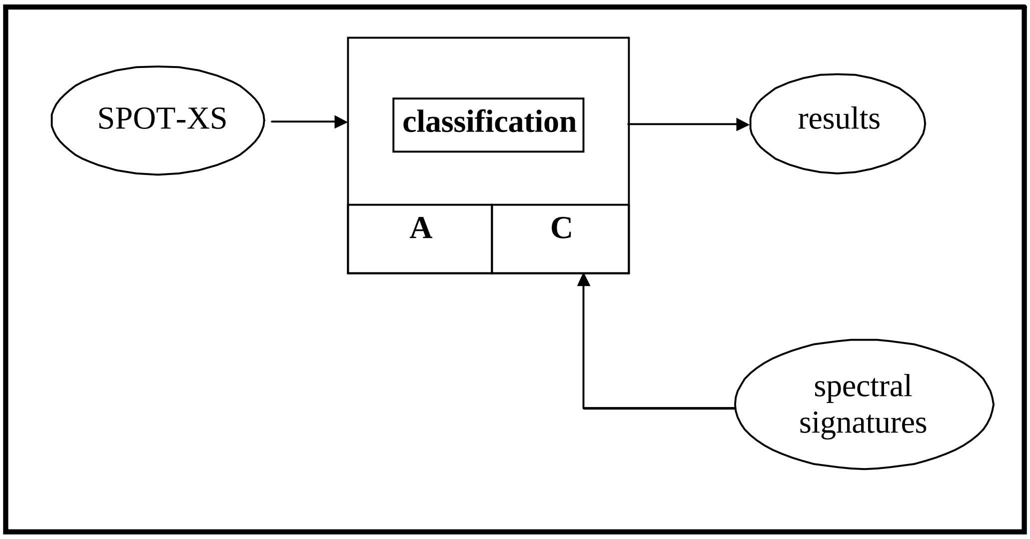

Figure 2. Formalisation of a supervised classification process by a fusion cell.

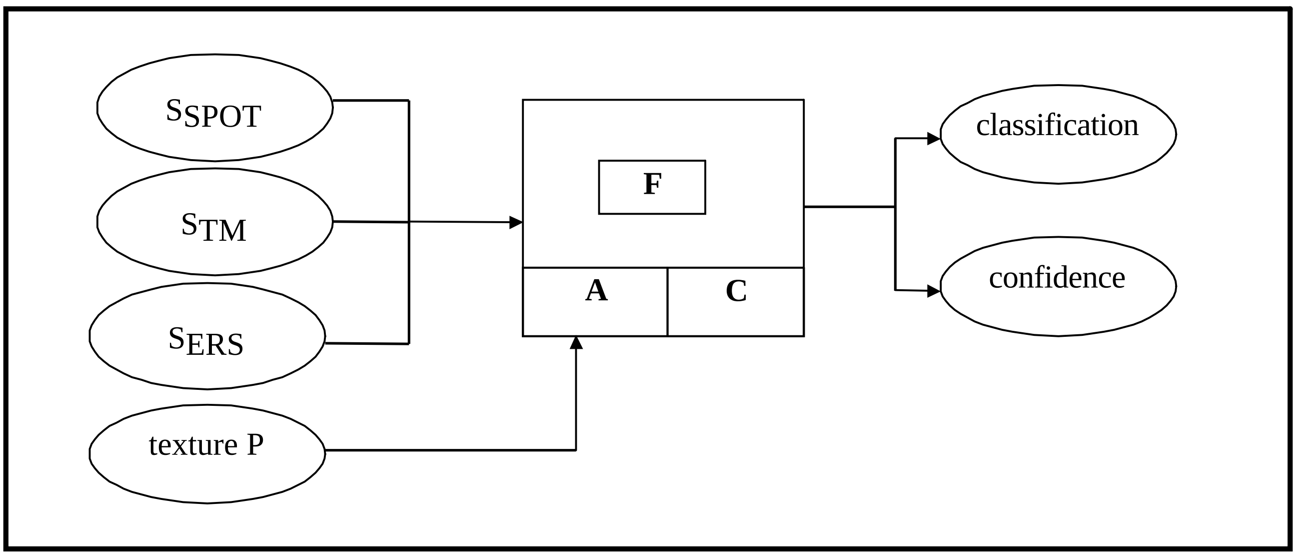

Figure 3a. Centralised architecture (after Mangolini, 1994).

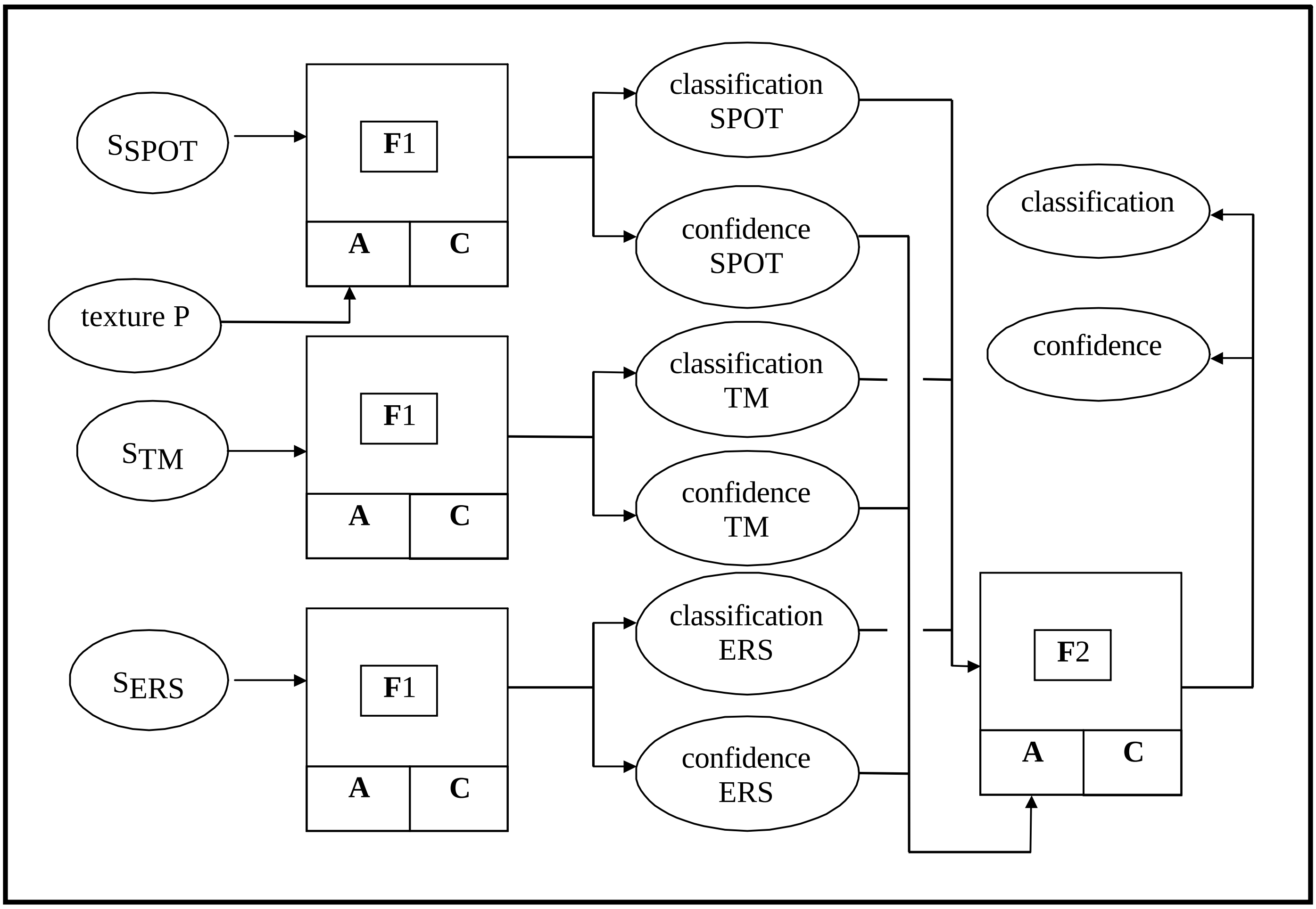

Figure 3b. Decentralised architecture using pixel confidence (after Mangolini, 1994).

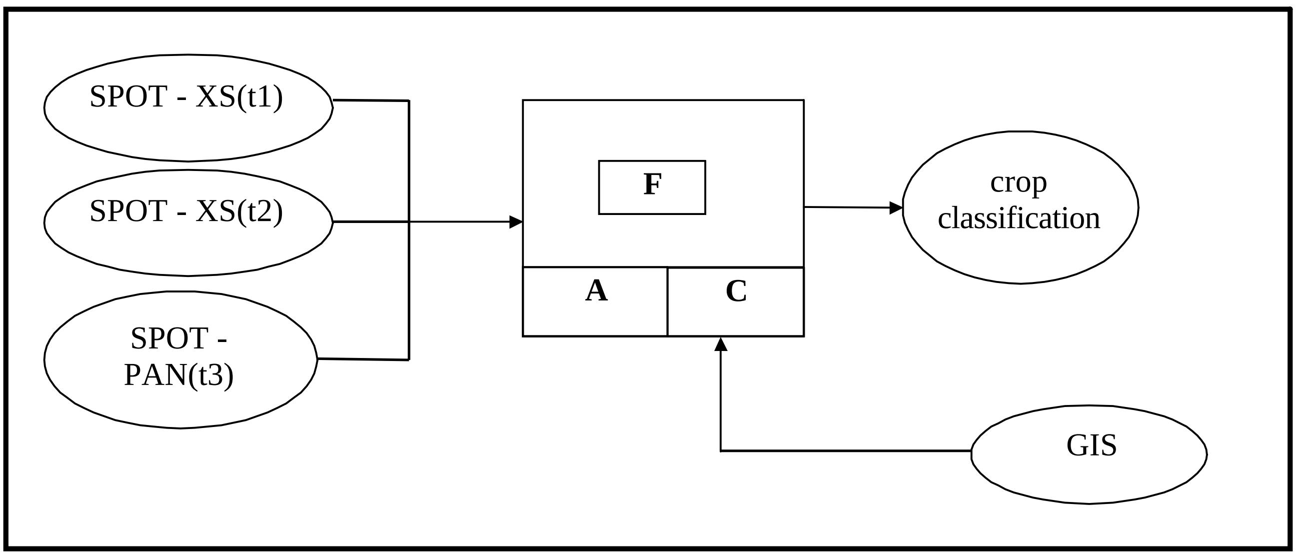

Figure 4. Crop monitoring.

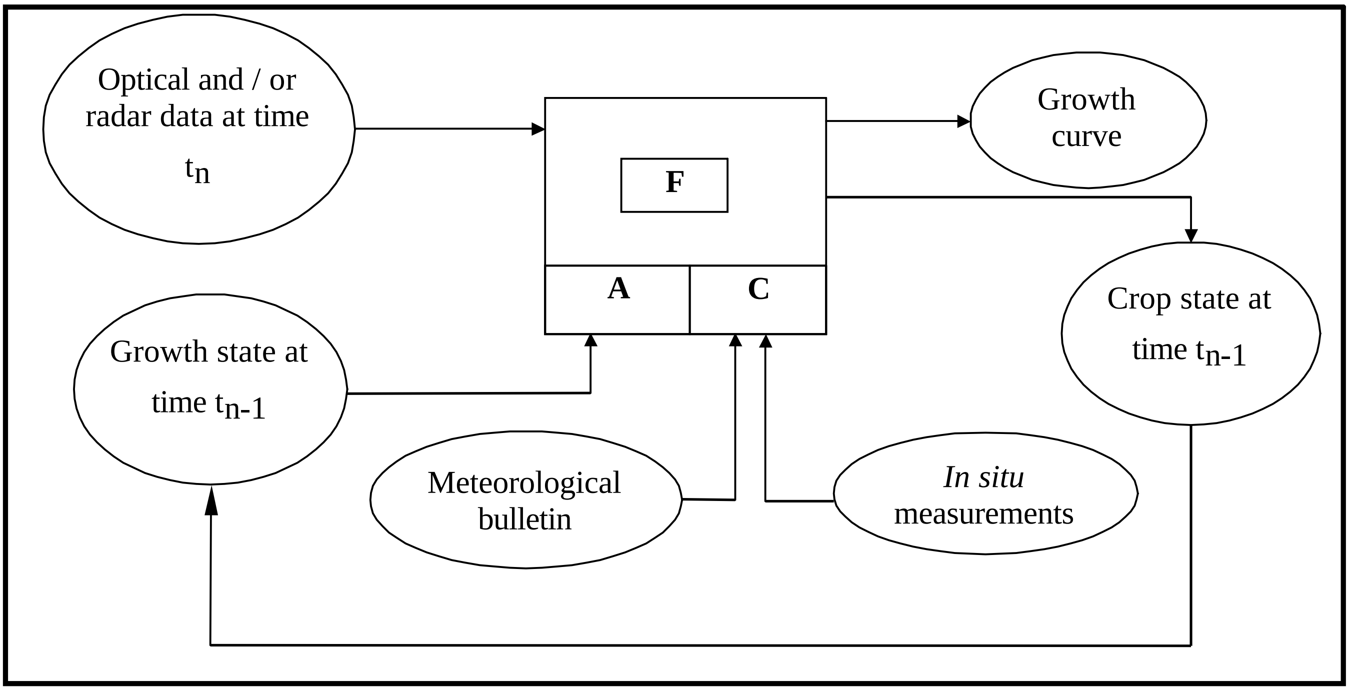

Figure 5. Sugar beet crop prediction (after Castagnas 1995)

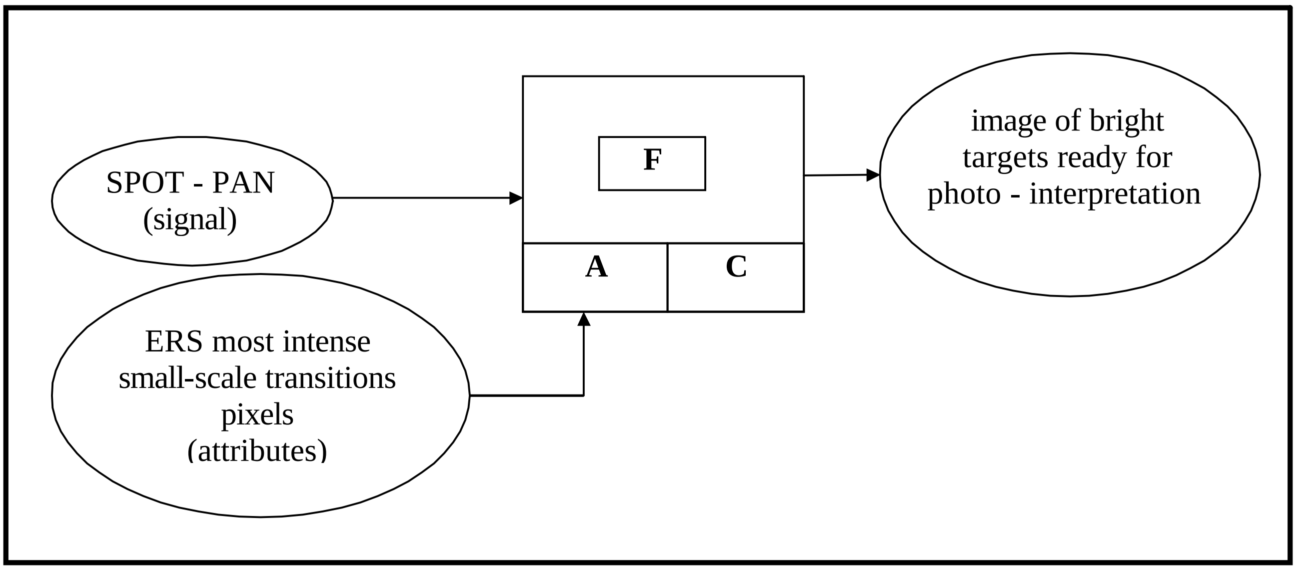

Figure 6. Example of heterogeneous fusion (after Mangolini *et al.*, 1993).

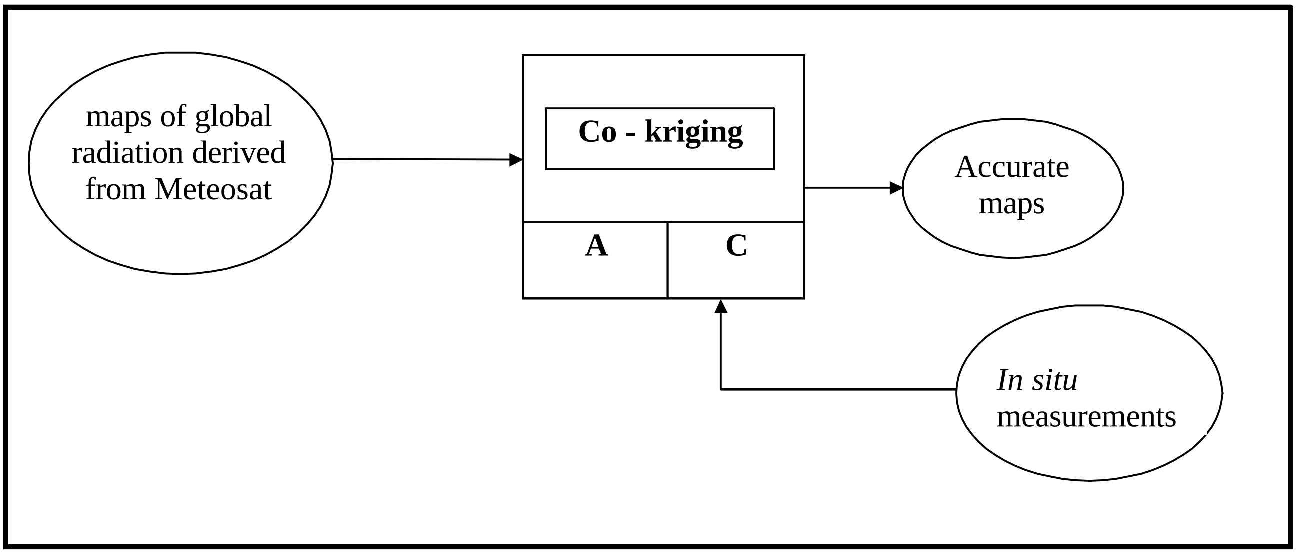

Figure 7. Merging maps and ground measurements (Beyer et *al.*, 1997).