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Overview on METEOSAT Geometrical Image Data Processing

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ABSTRACT

Digital Images acquired from the geostationary METEOSAT satellites are processed and disseminated at ESA's European Space Operations Centre in Darmstadt, Germany. Their scientific value is mainly dependent on their radiometric quality and geometric stability. This paper will give an overview on the image processing activities performed at ESOC, concentrating on the geometrical restoration and quality evaluation. The performance of the rectification process for the various satellites over the past years will be presented and the impacts of external events as for instance the Pinatubo eruption in 1991 will be explained. Special developments both in hard- and software, necessary to cope with demanding tasks as new image resampling or to correct for spacecraft anomalies, are presented as well. The rotating lens of MET-5 causing severe geometrical image distortions is an example for the latter.

INTRODUCTION

The history of the METEOSAT system at ESA's European Space Operations Centre (ESOC) reaches back to the launch of the first satellite of the preoperational program in 1977. While this one was still of an experimental nature, its successor became fully operational in 1983 and was followed by four further satellites since then. MET-3, launched in 1988, is the last of the preoperational series and serves to date at 75°W for the Extended Atlantic Data Coverage (XADC) mission (de Waard, 1993) on behalf of the National Oceanic and Atmospheric Administration (NOAA). MET-4 to MET-6, positioned at 0° and 10°W, already belong to the operational program (Mason, 1987) and are operated on behalf of EUMETSAT.

An enormous wealth of data has been provided by the METEOSAT satellites, with the image data being the dominant source of information. The images acquired from METEOSAT, processed and disseminated at ESOC, are used by a wide research community as a mean to gain a better understanding of atmospheric processes. This, however, depends largely on the radiometric quality and geometric stability of the image data (Diekmann, 1994). Raw (unprocessed) images transmitted from the satellite are distorted due to its various movements during the image taking process. Since this prevents an accurate geographical identification of image pixels, an evaluation of the image distortions and a following resampling of the image pixels is a necessary step to reduce these geometric errors. This is achieved during the onground data handling by an image correction process called rectification. The principles of this geometrical correction scheme is described by Wolff (1985) and Bos et al. (1990) summarize the changes necessary in order to perform the rectifica-

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tion process in near real time. This paper gives a general overview on the various items related to the geometrical processing at ESOC.

METEOSAT IMAGE PROCESSING AT ESOC

The operational satellites of the METEOSAT series are spin-stabilized spacecrafts which scan the Earth once every half hour (a slot). The detector is a radiometer with a pointing direction stepping from south to north by rotating the telescope one step per image line. Four images are taken simultaneously in different frequency bands (infrared window, water vapour absorption band, two images in the visible spectral region), consisting of 8 bits per pixel and contain 2500*2500 pixels per image (2500*5000 for each of the VIS channels). Two of these data streams are currently processed in parallel at ESOC and a third one is possible for limited time periods (e.g. commissioning, anomaly investigations, etc.). A first preprocessing of the continuous raw image data stream consists predominantly of demultiplexing the data to form continuous pictures. The bulk of the following image data processing tasks is running operational on one of the two mainframe (MF) computers (COMPAREX 8/98). The second MF serves as backup and is normally used for other purposes. Both machines have undergone regular upgrades in order to cope with the growing need for computing power.

Figure 1 summarizes the main tasks and processes necessary to obtain rectified images and meteorological data as the final products to be provided to the user community.

After reception and preprocessing of the image and corresponding auxiliary data, the rectification of the images is the main and most time consuming task of the onground processing. This term refers to the fact that images of the Earth's surface and its atmosphere transmitted from the satellite are distorted due to its various movements during the image taking process. Since this makes a geographical identification of an image element (pixel) almost impossible, an evaluation of the image distortion and a corresponding resampling of the image pixel is a way of reducing these geometric errors.

The true image signal sensed by the METEOSAT radiometer is additionally altered and degraded by various radiometric noise sources originating from the satellite and the transmission (both Gaussian- and periodic noise), by the sampling and digitization process, and also through the introduction of spatial shift errors (during the attempt to geometrically correct the images). A variety of parameters is determined during the operational image processing for assessing the radiometric quality of the METEOSAT images (Diekmann and Amans, 1990; Diekmann, 1994).

Various monitoring devices serve as indispensable tools for performance and quality controlling at the various stages of the image processing chain. Monitors connected to the front end processors display different raw image channels of the two operational satellites before any data processing. Different image display and processing devices allow an online control of raw and rectified images. In addition, a transputer augmented workstation (TAW) is available for fast monitoring and processing of images. They are transferred in real time via an FDDI interface from the mainframe computer, reduced to simple byte maps and stored on harddisks, which are each equipped with a dedicated transputer for fast I/O processing. This allows very fast and parallel zooming, scrolling and loops of up to 500 images in full resolution. A semi-automatic software system for quality controlling the image rectification (QCIR) is run on regular basis. The rectified images are finally subject to an advanced segmentation process, which is the basis for the

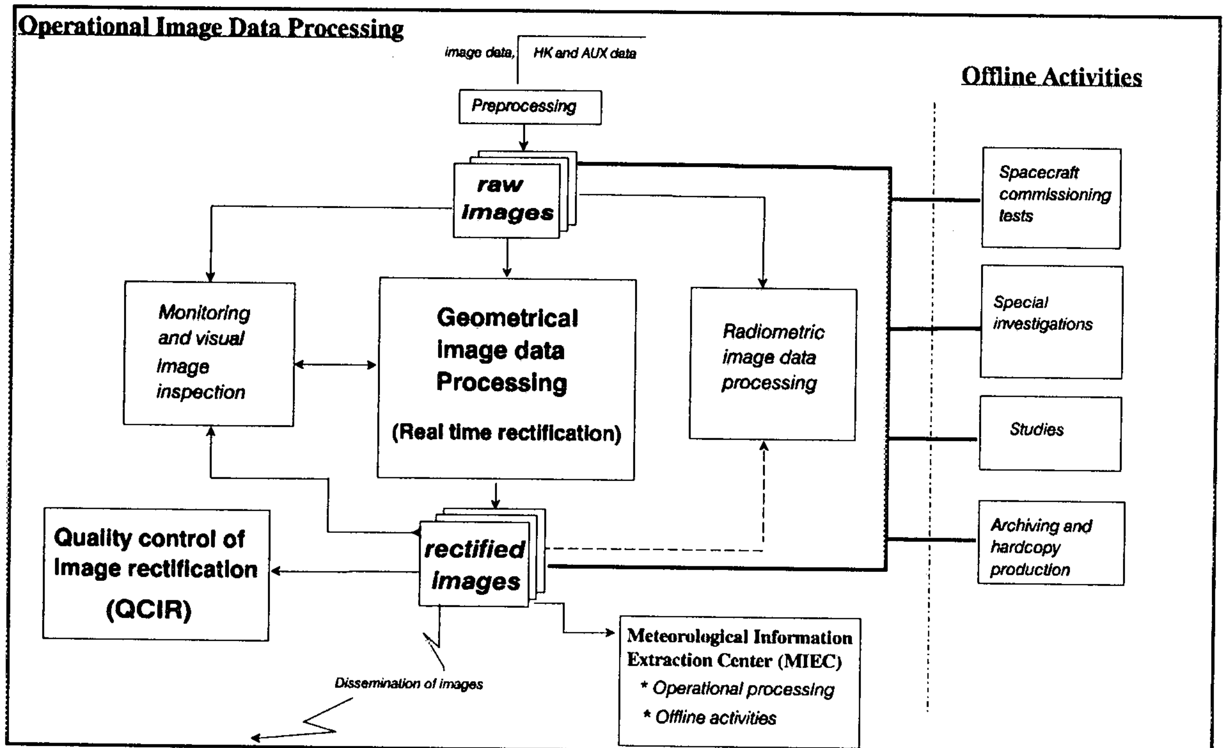

Figure 1 : METEOSAT image processing areas at ESOC

operational derivation of a number of meteorological parameters in the Meteorological Information Extraction Centre (MIEC).

Special software tools are finally developed for satellite commissioning operations and special investigations (e.g. satellite anomalies, end-of-life tests, measurement campaigns, etc.).

THE REAL TIME RECTIFICATION PROCESS

The purpose of the METEOSAT raw image rectification is to remove the geometric image distortions caused by non-nominal spacecraft orbit, attitude, spin and other effects. It basically involves the modelling of the distortions and the transformation of the raw images according to this deformation model so as to obtain a rectified image centred on the nominal sub-satellite point (Wolff, 1985). Besides those already mentioned, a number of parameters (radiometer stepping parameters, vertical image centre positions, interchannel registrations, etc.) are used to calculate a pair of deformation matrices for the horizontal and vertical directions.

The calculation of some of the deformation model parameters is based on a continuous analysis of where the southern, northern, eastern and western horizons are located in the raw IR images. The polar horizon positions are necessary for determining parameters, such as the vertical image offset, the radiometer scanning parameters and for the determination of the refined spacecraft attitude. The equatorial horizons, on the other hand, are required for the calculation of the horizontal centring of the image, the sampling frequency and for general anomaly analysis. "Horizon" in this context is the point at which the IR sensor detects a change from space (count < 16) to atmosphere (count ≥ 16). This IR threshold corresponds to a temperature of approximately -90°C. It actually reflects a vertical atmosphere column integral and the temperature is the mean of this layer at the Earth's limb. Refined polar and equatorial horizons (in fractions of a pixel) are finally calculated by fitting a second order polynomial to a predefined number of lines containing (valid) horizons. A warming or cooling of the stratosphere consequently means a change of the determined horizon positions which in return degrades the rectification accuracy. This effect is observed during the normal seasonal temperature changes of the antarctic stratosphere, which allowed a modelling of this phenomenon, but also after a strong warming due to volcanic dust reaching the south polar stratosphere (Diekmann and Bowen, 1992).

Based on the two deformation matrices, the raw image is finally resampled to form the rectified image. This process is running since several years in near real time (Bos et al., 1990), with the old batch-system (starts the image rectification after reception of the whole image) providing a back-up. In the real-time rectification system some of the deformation parameters are predicted using a combination of information from previous IR images and measurements made in the first 350 image lines of the current IR image.

Another prerequisite was the use of the nearest neighbour resampling technique, because this fast and simple method was the only possible for the available data processing resources. After many years of experience with and improvements of the METEOSAT system, the residual geometrical errors in the image data are now mainly caused by the nearest neighbour resampling (Diekmann and de Waard, 1992). Since also the computer technologies have vastly stepped forward, the use of more sophisticated interpolation method within the METEOSAT rectification system has become possible. After a thorough study of various methods, the bicubic spline filter was selected for the image resampling. This CPU time consuming modification was first installed and tested on a dedicated hardware tool (see below) and 1993 installed on the operational mainframes, whose capacity had been more than doubled over the past three years.

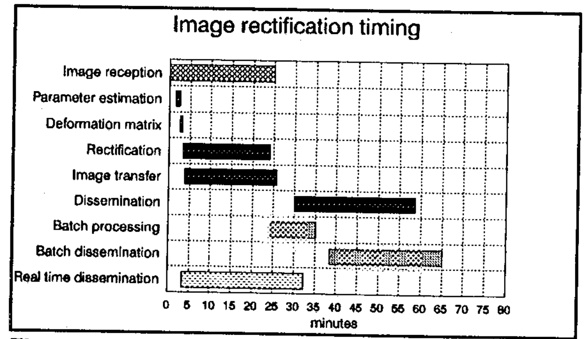

Figure 2 : Image rectification timing

The sequence of the main image rectification tasks is illustrated in Figure 2. The image is received within 25 minutes (5 minutes are needed for retrace and a standby period). Within the first ca. 4 minutes the deformation parameters are determined and the deformation matrices calculated. The resampling starts at that point and catches up with the incoming data stream fairly quickly. The processed image lines are transferred to the dissemination computer and divided into dissemination formats. The actual transmission of these formats starts with a small delay at the end of the slot. In the batch processing case this delay is at least eight minutes. A real time dissemination system with data compression and inclusion of other data products in the image data stream was developed and tested a few years ago, but not used in operations as it necessitates a change in the user reception equipment not covered by the present programme.

QUALITY CONTROL OF IMAGE RECTIFICATION

The method used to assess the rectification accuracy of METEOSAT images is described in detail by Adamson et al. (1988). The complex system called "Quality Control of Image Rectification" (QCIR) is based on about 120 reference landmarks (coastlines, islands, lakes) spread over the scanned Earth disk. They are extracted from rectified IR and VIS images and filtered by a simple automatic histogram and peak-identification process to extract those landmarks with less than ca. 10% cloudiness. These landmarks are later subject of another automatic test (based on landmark specific correlation coefficients) to delete the remaining cloud contaminated landmarks collected during about one week. The cloudfree landmarks passing both tests are correlated with an accurate digital reference landmark data set. The landmark displacement is defined to be the displacement of the maximum of the correlation surface from nominal. Results for each landmark are presented in terms of line and pixel deviations as well as in absolute and relative rms errors of the sum of both. This process runs on a weekly basis. For the relative errors the landmark position is compared with the results of the previous slot, which gives an indication of the rectification stability.

Constant biases determined with this method are usually attributed to a set of registration parameters describing the positions of the detectors onboard the satellite with respect to the detector optical axis. These important parameters are usually updated during the commissioning of a spacecraft and later optimized, if necessary.

Figure 3 summarizes the performance of the METEOSAT image rectification system since 1989. Large rms errors during the commissioning of MET-4 in 1989 were caused by imperfect detector registration values which could be corrected during the following weeks. The seasonal wave in the rectification errors can still be identified in 1990; a correction scheme based on a model of this oscillation was implemented in early 1991, resulting in a clear improvement of the quality. Volcanic dust in the lower stratosphere after the Pinatubo eruption in 1991 caused a warming of the east image horizons (July and August) and later of the antarctic stra-

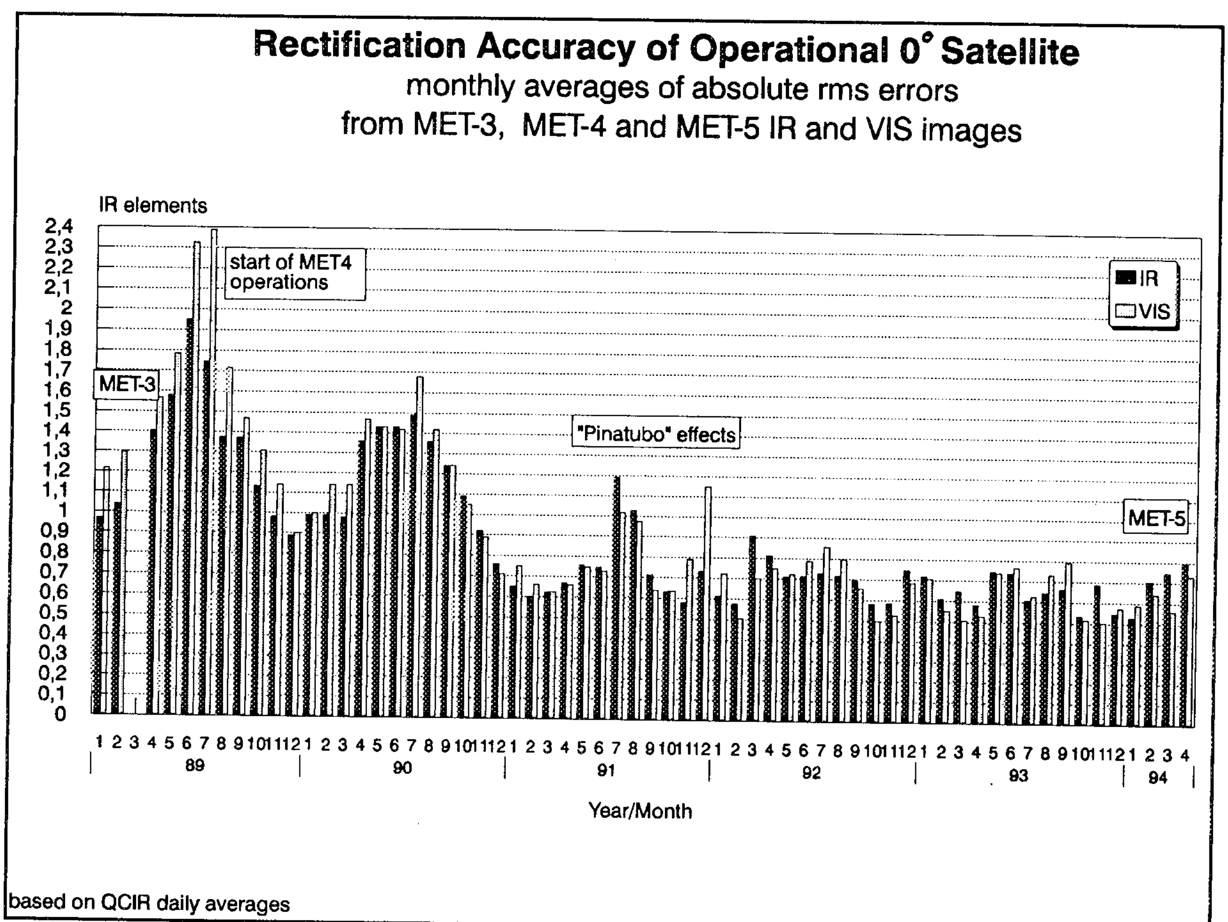

Figure 3 : Monthly means of absolute rms errors

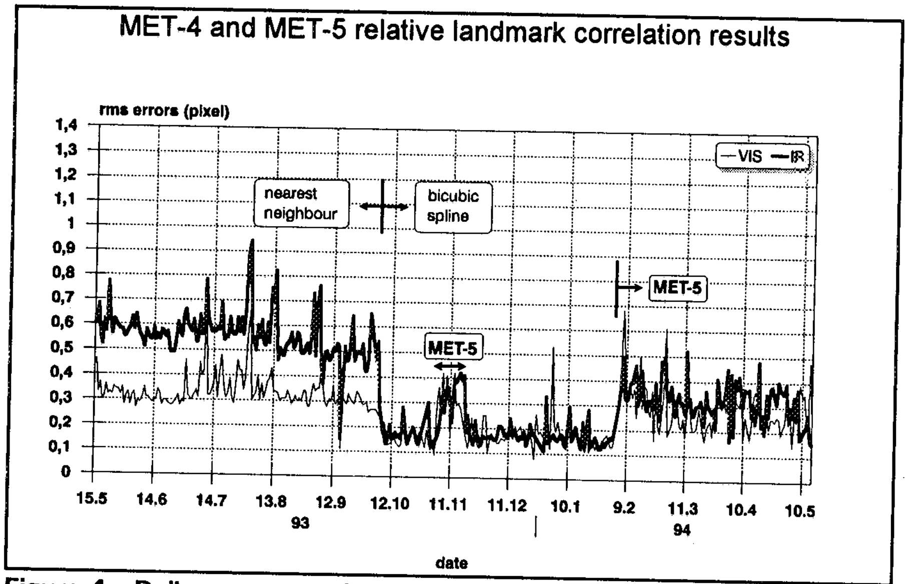

Figure 4 : Daily averages of relative rms errors, 1993 - 1994

tosphere. The resulting rectification degradations could be reduced by simple parametrizations of these temperature changes in the rectification software (Diekmann and Bowen, 1992). The remaining errors (around 0.6 IR elements rms) are predominantly inherent in the nearest neighbour resampling.

In addition to these rather predictable features, the rectification software had regularly to be extended in order to cope with unexpected anomalies originating from the spacecraft. For instance, the "fish" problem of MET-4 (electronic disturbances in all image channels, Baratelli et al., 1990), and the rotating lens of MET-5 (Olivier, 1991) had serious impacts on the radiometric and geometric image quality.

A significant improvement of the relative rectification was achieved in autumn 1993 with the initiation of the bicubic spline resampling technique in the operational rectification system. Figure 4 demonstrates this fact. The mean rms errors of landmark displacements from slot to slot (relative rms) was until October 1993 in the order of 0.6 IR pixels - approximately the statistical limit of the nearest neighbour technique. The results for the VIS channels were always slightly better because of the higher spatial resolution in horizontal direction. After start of the bicubic spline filter, the geometrical errors went down to values around 0.2 IR pixels for the MET-4 satellite - an improvement of a factor 3. A detailed study of the impact of the new method on the radiometric contents proved that no series degradations lowered the overall quality of the rectified images.

THE MET-5 ROTATING LENS ANOMALY

MET-5 was launched in March 1991 and was expected to become the prime operational satellite after its successful commissioning. However, it was discovered that the rectification accuracy, in particular the relative rectification performance, was significantly worse that the results of other satellites. The reason was an unexpected movement of the Earth's disk in the image frame in the order of one IR pixel. Indicator for this anomaly were the east/west and north/south horizons. Only the IR and WV channels were affected, but not the VIS channels.

After extensive investigations, the cause of the MET-5 image anomaly was identified as being caused by a rotating lens (L3) inside the radiometer cold assembly just in front of the passively cooled longwave detectors (Olivier, 1991). This lens is not held firmly enough to prevent a rotation. The amplitude of this rotation corresponds to geometrical distortion of the Earth image of about 1.1 IR pixels, with a frequency between 2 and more than 10 slots. Even interruptions of the lens rotation have been observed. The more or less constant amplitude can be explained if one assumes that the optical and geometric centre of the lens do not coincide. Such a constant lens rotation introduces a sinusoidal distortion into the IR and WV images (because L3 focuses the incoming radiation only in these detectors) in both horizontal and vertical direction.

As a consequence of this, the image rectification system has been extensively modified in two steps so as to enable it to minimize these geometrical distortions. The software version developed first was running in batch mode (after reception of the whole image) and separates the deformation modelling into two parts : the calculation of a base deformation that corresponds to the deformation model that would have been obtained in the absence of a lens rotation, and the evaluation of correction functions to compensate for the additional distortions (Hanson and Adamson, 1992). The latter is essentially achieved by an accurate determination of the horizontal Earth horizons and a representation of the east-west distortion curve by a sine wave model. This distortion curve is then translated into the corresponding south-north distortion curve using the assumption that the lens rotates uniformly during the course of a slot. This method gave satisfying results, which were, however, still somewhat worse than corresponding MET-4 results.

A real time correction independent on such assumptions developed under ESA contract is just being installed at ESOC. East and west horizons of each line delimit an Earth cord. Using datation data which are transmitted with each image line, the angle between the sun and the midpoint of each chord is measured and compared to a predicted value. This is based on a METEOSAT state vector model determined from observations over several days, such that the anomalous lens rotation effects are averaged out. When the lens motion displaces the line of sight in horizontal direction, the measured chord midpoint will be shifted with respect to the predicted midpoint, which allows a direct correction. When the lens rotation displaces the line-of-sight in vertical direction, the measured angular span of a chord will grow or shrink when compared with the predicted value based on the state vector. This also allows a correction in south-north direction. First results have shown that with this method a real time rectification is possible with a rectification accuracy similar to non disturbed satellites.

A TRANSPUTER AUGMENTED WORKSTATION

In spite of various attempts to minimize the remaining errors in the real time rectification, the nearest neighbour resampling imposed a non-reducible limit to the final results. A variety of methods were studied which could possibly be used instead. All were based on interpolation of weighted pixel counts surrounding the pixel in question. Radiometric changes introduced by the finally chosen bicubic spline method are well within the accuracy of the radiance figures themselves. They could even lead to an improvement by reducing the impact of the satellite's radiometer and associated equipment on the original image.

The initial technical realization of this very time consuming resampling process was part of the development of a transputer augmented workstation (TAW) funded by the Austrian Authorities under ESA contract. The scope was a computer prototype in hard- and software for real time resampling using advanced filter techniques, product extraction as well as rapid image display and processing. The design of the TAW supports interfaces to modules for further applictions. Besides the rectification module, a second component is connected for near real time water vapour wind vectors (WVWV) using an optimum pattern matching algorithm. Various automatic quality control tools are applied to the wind vectors, which were optimized for this special application beforehand (de Waard et al., 1994). Ad-ditional image processing tools are available on a connected workstation, which also allows the online calculation

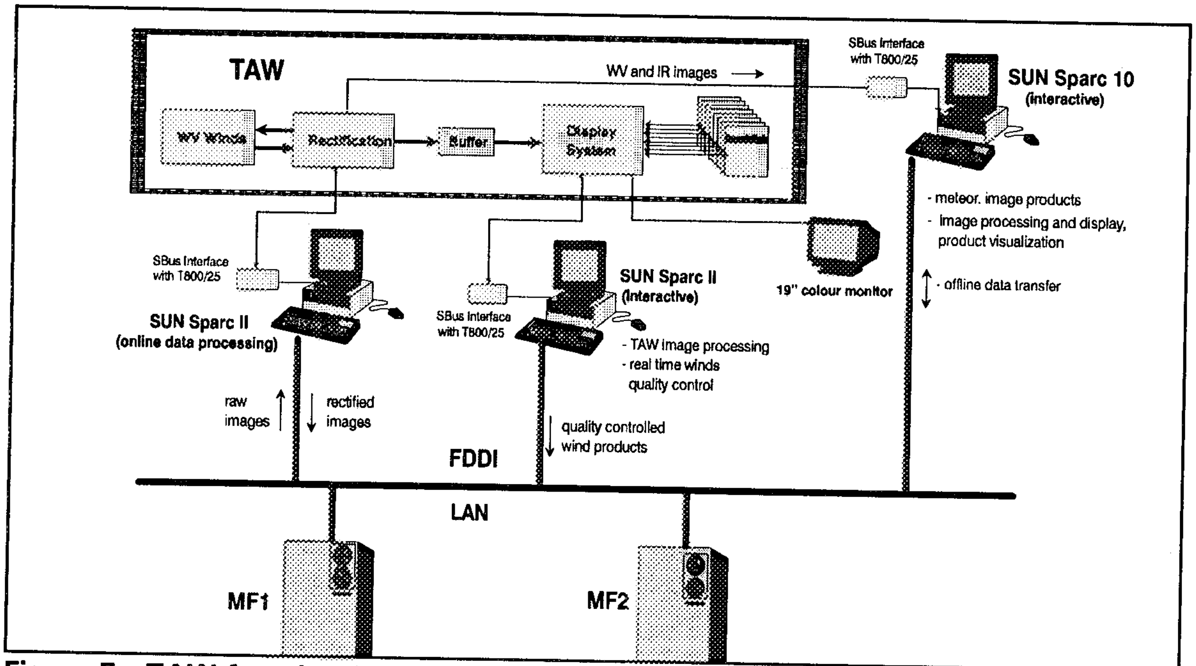

Figure 5 : TAW functional set-up

and display of various meteorological products.

The TAW is equipped with a total of 23 CPUs distributed over four different modules as sketched in Figure 5 and serves as a powerful state-of-the-art development and study environment. The capacity of this workstation is highlighted by its processing power which achieves a performance of almost 200 Mflops with the implemented applications (Scheiber, 1994).

The main components of the TAW are the resampling and WVWV modules, which both consist of T800 transputers and INTEL i860 processors. These functions are controlled via a Sun Sparc host computer, which also performs the image data transfer from and to the ESOC mainframes via an FDDI interface in real time mode. Raw and resampled images are also automatically transferred via a buffer module to the display system of the TAW. Eight harddisks with a total of 3.2 Gbyte, each equipped with a dedicated transputer for fast I/O processing, are available to store these images on a cyclic file system. This allows fast and parallel zooming, scrolling and loops of up to 500 IR images on a high resolution monitor. Additional functions of this module are pixel inspection, window extraction and grey value statistics, classifications and Fourier transformations, overlays and others.

SUMMARY

Digital images in three to four channels of two METEOSAT satellites (even three under certain circumstances) are received and processed at ESOC every half an hour - a maximum of 528 images per day. Before disseminated to the users, these images are geometrically corrected in near real time. The quality of this rectification process has constantly been ímproved over the past years due to better modelling of system inherent effects, anomaly handling and hardware upgrades. Monthly performance figures for perfectly processed and disseminated images of in most cases well above 98% and high quality cloud motion wind vectors deduced from METEOSAT images are good indications for a stable and reliable on-ground processing. Further developments are now coming to an end, since EUMETSAT is going to take over the whole operations in December 1995.

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